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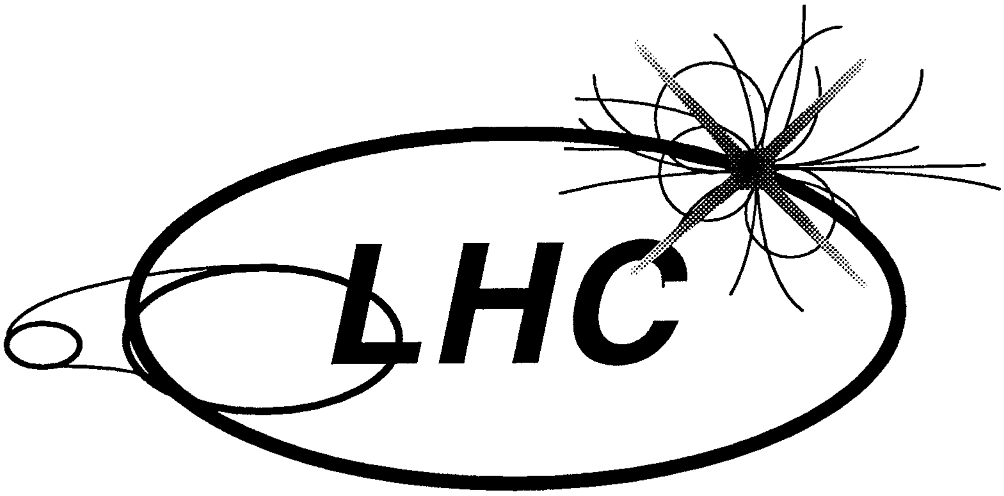
Towards the LHC Experimental Programme

5-8 March 1992
Evian-les-Bains, France



Proceedings
of the General Meeting
on LHC Physics & Detectors

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Chairman's Foreword

On behalf of the Organizing Committee, the Chairman would like to thank all the speakers, the groups who helped preparing the Expressions of Interest, the Chairmen of the sessions and the participants for their superb co-operation which made this meeting a success.

We would also like to acknowledge the enthusiastic support of many members of CERN staff in providing us with support during the meeting. We are especially indebted to Monique Budel, Pepi Dockheer, Janet Grant, Nick Grant and Susan Maio for their superb running of the Conference office, and to Daniel Boileau, Patrick Gilbert de Vautibault and Pierre Vannier for their competent audio-visual assistance.

Isabelle Klöckner and the staff of the Evian Tourist office and the Conference Centre deserve particular credit for their kindness and perfect help.

Last but not least, I want to express my warmest gratitude and appreciation to Seamus Hegarty for his excellent running of the meeting.

Günter Flügge

In Memory of Prince K. Malhotra

During the afternoon session on Saturday 7 March 1992, the participants at the meeting received the sad news that their colleague Prince K. Malhotra had succumbed to a heart attack which had struck him in the Conference Centre lobby.

Prince K. Malhotra, Head of the Experimental High Energy Physics Group at the Tata Institute of Fundamental Research in Bombay, was a member of the L3 collaboration. He was an active member of the High Energy Physics community both at Fermilab and CERN for many decades. With him the physics community has lost one of its eminent characters and many of us have lost a very good friend.

The meeting observed a minute's silence in his memory.

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Renton, Peter	University of Oxford	United Kingdom
Repellin, Jean-Paul	Laboratoire de l'Accélérateur linéaire	France
Revol, Jean-Pierre	CERN	
Riccati, Lodovico	INFN – Torino	Italy
Richter, Robert	Max-Planck-Institut für Physik, München	Germany
Richter, Wolfgang	CERN	
Rimmer, Peggie	CERN	
Rimoldi, Adele	Università di Pavia	Italy
Rodrigo, Teresa	Fermilab	USA
Rohrbach, François	CERN	
Roinishvili, Vladimir N.	Institute of Physics, Tbilisi, Georgia	CIS
Roncagliolo, Isabella	INFN – Sezione di Genova	Italy
Rosselet, Philippe	Institut de Physique nucléaire, Lausanne	Switzerland
Rossi, Leo	INFN – Sezione di Genova	Italy
Rosso, Ettore	CERN	
Rubbia, André	Massachusetts Institute of Technology	USA
Rubbia, Carlo	CERN	
Ruckstuhl, Werner	NIKHEF	The Netherlands
Ruggiero, Francesco	CERN	
Ruhlmann, Vanina	CEN Saclay	France
Runge, Kay	University of Freiburg	Germany
Sabaiduc, Vasile	Institute of Atomic Physics	Rumania
Safarik, Karel	Collège de France	France

Samm, Doris	RWTH Aachen	Germany
Sándor, Ladislav	Slovak Academy of Sciences, Kosice	Czechoslovakia
Santacesaria, Roberta	Università di Roma 'La Sapienza'	Italy
Santonico, Rinaldo	Università di Roma 'Tor Vergata'	Italy
Satz, Helmut	CERN	
Sauli, Fabio	CERN	
Sauvage, Gilles	LAPP Annecy	France
Saxon, David H.	University of Glasgow	United Kingdom
Scandale, Walter	CERN	
Schacher, Jürg	University of Bern	Switzerland
Schacht, Peter	Max Planck Institut für Physik	Germany
Schaffer, Arthur	Laboratoire de l'Accélérateur linéaire	France
Schegelsky, Valery	St Petersburg Nuclear Physics Institute	CIS
Schlatter, Dieter	CERN	
Schlein, Peter	UCLA	USA
Schlenstedt, Stefan	DESY	Germany
Schmidt-Parzefall, Walter	II. Institut für Experimentalphysik, Hamburg	Germany
Schmitt, Manfred	CERN	
Schmitz, Detlef	RWTH Aachen	Germany
Schmitz, Jurriaan	NIKHEF	The Netherlands
Schneegans, Marc	LAPP Annecy	France
Schönbacher, Helmut	CERN	
Schubert, Klaus	Universität Karlsruhe	Germany
Schukraft, Jürgen	CERN	
Schuler, Gerhard A.	CERN	
Schulte, Reiner	RWTH Aachen	Germany
Schultze, Klaus	RWTH Aachen	Germany
Schwarthoff, Hubert	RWTH Aachen	Germany
Sciacca, Crisostomo	Università di Napoli	Italy
Sciamanna, Marco	Università di Milano	Italy
Scribano, Angelo	INFN Pisa	Italy
Seez, Chris	Imperial College, London	United Kingdom
Sefkow, Felix	CERN	
Seiler, Paul G.	PSI Villigen	Switzerland
Seller, Paul	Rutherford-Appleton Laboratory	United Kingdom
Sendall, Mike	CERN	
Seyboth, Peter	Max-Planck-Institut für Physik, München	Germany
Shen, Benjamin	University of California at Riverside	USA
Shumeiko, Nikolay	Institute for Nuclear Problems, Minsk	CIS
Simak, Vladislav	Institute of Physics of CSAV	Czechoslovakia
Sjöstrand, Torbjörn	CERN	
Skaali, Bernhard	University of Oslo	Norway
Sloan, Terry	University of Lancaster	United Kingdom
Smernitsky, A.	ITEP Moscow	CIS
Smith, Alasdair	CERN	
Smith, Kenway	University of Glasgow	United Kingdom

Spillantini, Piero	Istituto di Fisica Nucleare, Firenze	Italy
Spiriti, Eleuterio	INFN Sezione Sanità	Italy
Spiro, Michel	CEN Saclay	France
St. Denis, Richard	Max-Planck-Institut München	Germany
Stapnes, Steinar	University of Oslo	Norway
Staude, Arnold	University of Munich	Germany
Stavrianakou, Maria	CERN National Technical University of Athens,	 Greece
Stefanini, Giorgio	CERN	
Stefanski, Ray	SSC Laboratory	USA
Stevenson, Graham	CERN	
Stiegler, Ulrich	Max-Planck-Institut München	Germany
Stierlin, Ulrich	CERN MPI Munich,	 Germany
Stimpfl-Abele, Georg	Laboratoire de Physique corpusculaire	France
Straumann, Ulrich	University of Zurich	Switzerland
Strong, John	Royal Holloway & Bedford New College	United Kingdom
Subbi, Johann	Institute of Chemistry & Physics, Tallinn	Estonia
Suzuki, Seiji	Hamamatsu Photonique France	France
Szoncsó, Fritz	Institut für Hochenergiephysik (ÖAW)	Austria
Takeuchi, Junichi	Hamamatsu Photonique France	France
Tanaka, Reisaburo	Ecole polytechnique de Palaiseau	France
Tang, Xiao-Wei	Institute of High Energy Physics – Beijing	China
Tauscher, Ludwig	University of Basle	Switzerland
Taylor, Thomas	CERN	
Ten Have, Ingrid	University of Glasgow	United Kingdom
Thome, Zieli	Federal University of Rio de Janeiro	Brazil
Thompson, Lee	University of Sheffield	United Kingdom
Thresher, John	CERN	
Ting, Samuel	Masachussetts Institute of Technology	USA
Tisserant, Sylvain	CPPM, Marseille	France
Tittel, Klaus	Universität Heidelberg	Germany
Tolsma, Hoite	NIKHEF	The Netherlands
Toriyama, Naofumi	Hamamatsu Photonique France	France
Toth, Jozsef	CERN	
Tran, Minh-Tam	Institut de Physique nucléaire, Lausanne	Switzerland
Triantis, Frixos	University of Ioannina	Greece
Tuchscherer, Hans	RWTH Aachen	Germany
Tuominiemi, Jorma	University of Helsinki	Finland
Turala, Michala	Institute of Nuclear Physics	Poland
Turlay, René	CE Saclay	France
Tuuva, Tuure	Research Institute for High Energy Physics SEFT	Finland
Uggerhøj, Erik	University of Aarhus	Denmark
Unal, Guillaume	Laboratoire de l'Accélérateur linéaire	France
Valdata-Nappi, Marisa	INFN / Università della Calabria	Italy
van der Graaf, Harry	NIKHEF	The Netherlands
van Doninck, Walter	Vrije Universiteit Brussel	Belgium

Vannucci, François	LPNHE – Université de Paris	France
Vanuxem, Jean-Pierre	CERN	
Varela, João	LIP	Portugal
Vazeille, François	Laboratoire de Physique corpusculaire	France
Vercesi, Valerio	INFN – Sezione di Pavia	Italy
Verdier, André	CERN	
Verweij, Henk	CERN	
Vialle, Jean-Pierre	LAPP Annecy	France
Viertel, Gert	ETH Zürich	Switzerland
Vignon, Bernard	ISN, Grenoble	France
Virchaux, Marc	CEN Saclay	France
Virdee, Tejinder	Imperial College, London	United Kingdom
Vodopianov, Alexandre	JINR Dubna	
Vorobyov, A.	St Petersburg	CIS
Voss, Rüdiger	CERN	
Wachsmuth, Horst	CERN	
Wagner, Albrecht	DESY	Germany
Wagner, Armin	Universität Mainz	Germany
Wagner, Victor	Vereinigte Schmiedewerke GmBH	Germany
Walker, Alan	University of Edinburgh	United Kingdom
Wallraff, Wolfgang	RWTH Aachen	Germany
Walter, Hans-Christian	PSI Villigen	Switzerland
Weidberg, Tony	University of Oxford	United Kingdom
Weisz, Sylvain	LPNHE Ecole polytechnique	France
Wenninger, Horst	CERN	
Werlen, Monique	University of Lausanne	Switzerland
Williams, David O.	CERN	
Windmolders, Roland	University of Mons	Belgium
Winter, Klaus	CERN Humboldt University, Berlin,	 Germany
Wittgenstein, François	CERN	
Witzeling, Werner	CERN	
Wolf, Günter	DESY	Germany
Womersley, John	Florida State University	USA
Wormser, Guy	Laboratoire de l'Accélérateur linéaire	France
Wotschack, Jörg	CERN	
Wu, Xin	University of Geneva	Switzerland
Wulz, Claudia-Elisabeth	Institut für Hochenergiephysik (ÖAW)	Austria
Yagil, Avi	Fermilab	USA
Zaganidis, Nicolas	CERN	
Zaitsev, Alexandre	IHEP Protvino	CIS
Zeyrek, Mehmet	METU – Ankara	Turkey
Zitoun, Robert	Université Paris VI	France
Zolnierowski, Yves	LAPP Annecy	France
Zotto, Pierluigi	University & INFN, Padova	Italy
Zweizig, John	UCLA	USA

Programme of the Meeting

Thursday 5 March

Chairman : R. Cashmore (Oxford)

09.00	Opening	G. Flügge (Aachen)
09.10	Physics with proton beams	C. Llewellyn Smith (Oxford) A. De Rújula (CERN)
11.00	*Coffee*	
11.30	Heavy ion physics	U. Heinz (Regensburg)
12.15	Electron-proton physics	G. Wolf (DESY)
13.00	*Lunch*	

Chairman : P. Darriulat (CERN)

14.30	Expression of Interest & Discussion (EoI) The ASCOT detector at the LHC	P. Norton (Rutherford Lab.)
16.00	*Tea*	
16.30	EoI : CMS – a compact solenoidal detector for LHC	M. Della Negra (CERN) H. Desportes (Saclay)
18.30	Drink at the Conference Centre offered by the Mayor of Evian-les-Bains	

Friday 6 March

Chairman : A. Astbury (Victoria)

09.00	EoI : EAGLE – Experiment for Accurate Gamma, Lepton and Energy measurements	P. Jenni (CERN)
10.30	*Coffee*	
11.00	EoI : To upgrade the L3 detector for LHC	S.C.C. Ting (MIT) F. Pauss (ETH, Zürich)
12.30	*Lunch*	

Chairman : J. Haïssinski (Paris)

14.00	EoI : An LHC collider beauty experiment for CP-violation measurements	P. Schlein (UCLA)
14.45	EoI : Measurement of CP-violation in B-decays using an LHC extracted beam	G. Carboni (Pisa)
15.30	*Tea*	
16.00	EoI : A study of CP-violation in B-meson decays using a gas jet at LHC	T. Nakada (PSI)
16.45	EoI : Neutrino physics at LHC	K. Winter (CERN)
17.15	EoI : A neutrino experiment at LHC	F. Vannucci (Paris)
17.45	End of Session	

Saturday 7 March

Chairman : L. Mandelli (Milan)

09.00	EoI : A dedicated heavy ion experiment at the LHC	J. Schukraft (CERN)
10.15	EoI : A feasibility study of using DELPHI as a detector for heavy ion collisions at LHC	G. Jarlskog (Lund)
10.30	*Coffee*	
11.00	EoI : A heavy ion experiment with CMS at LHC	L. Ramello (Turin)
11.30	The RHIC experimental programme	T. Ludlam (Brookhaven)
12.10	HERA news	A. Wagner (DESY)
12.30	*Lunch*	

Chairman : W. Hoogland (CERN)

14.00	Status of detector R&D	E. Iarocci (Frascati)
15.00	Triggering & data acquisition	S. Cittolin (CERN)
15.45	*Tea*	
16.15	Computing & networking	P.G. Innocenti (CERN)
17.00	The SSC experimental programme	R. Stefanski (SSC Laboratory)
17.45	End of Session	
19.30	Dinner at the Conference Centre	

Sunday 8 March

Chairman : G. Flügge (Aachen)

09.00	The LHC Machine	G. Brianti (CERN)
09.45	Experimental areas + scenarios	K. Eggert (CERN)
10.30	*Coffee*	
11.00	Closing Remarks	C. Rubbia (CERN)
12.00	End of Meeting	

Opening Talk

G. Flügge (Aachen), Chairman of the Meeting

4 March 1992

Opening Talk by the Chairman
G. Flügge, RWTH Aachen

Dear Colleagues,

I am pleased to welcome you today in the Evian Conference Centre to our "General Meeting on LHC Physics and Detectors" which we have called

Towards the LHC Experimental Programme.

This meeting will indeed be one of the most important steps to shape the experimental programme at the LHC.

The meeting was initiated jointly by CERN and ECFA, as was the Lausanne Workshop in 1984 where the first ideas of building a pp collider in the LEP tunnel were discussed (even before it existed). In 1987, in La Thuile, under the auspices of the Long-Range Planning Committee chaired by Carlo Rubbia, these ideas took shape in the LHC design, a 16 TeV pp collider which was then compared with the SSC and the CLIC e^+e^- collider.

With the machine design going ahead, it was clear that a particular effort would have to be put into detector R&D to cope with the challenges of a high luminosity pp collider. These problems were tackled in detail in the Barcelona Workshop in 1989 where a comprehensive survey of physics interest and detector R&D for the LHC was achieved.

In 1991, both SPC and ECFA vigorously supported the plan to build the LHC and discussed the possible shape of an experimental programme that would exploit the LHC physics opportunities to their fullest extent. This meeting is an offspring of these discussions and is an important step to this end.

The Evian Meeting is intended to provide a forum for in-depth discussions of experimental ideas taking shape now in many groups and proto-collaborations. Accordingly most of the meeting will be devoted to presentations and discussions of Expressions of Interest on a broad spectrum of experimental ideas including general purpose pp detectors, general purpose heavy ion detectors and more specialized experiments on beauty and neutrino physics.

These discussions will be introduced in this morning's session with summaries and updates of physics ideas at the LHC and will be complemented by talks on the LHC machine and its competitors and various summary talks on infrastructure, technical aspects, and R&D. The meeting will conclude on Sunday morning with a summary talk to be given by Carlo Rubbia.

Let me conclude my brief opening remarks by stressing again the chief intention of this meeting: that physicists interested in LHC experiments have an early opportunity for broad information and discussion.

These discussions should also be stimulated between the various groups that have already formed to compare detector concepts, discover advantages, disadvantages and maybe in many cases also similarities which may encourage engagements or even marriage!

This should help prepare the next important step in which collaborations take shape to formulate Letters of Intent.

I wish you a successful meeting.

Physics with proton beams I

C. Llewellyn Smith (Oxford)

Physics with Proton Beams I

Outline

- Progress since Lausanne
- Possible discoveries pre LHC
- Arguments ⇒ physics beyond std. model
- Constraints from LEP
- The problem of mass
- Phenomenology
  - Higgs < standard
    minimal SUSY
  - Strong $V_L V_L$ scattering?
  - SUSY
  - Top
- Conclusions

Omitted

- b, ν, new quarks, compositeness, W', Z', baryon # violation ......
  ↳ De Rujula (II)
- Full Acceptance Physics

Bjorken : 2 × 20 TeV spectrometers for SSC
↳ 2 × 1.2 kms
↳ 2 × 460 m at 15.4 TeV
but only 545 m available

Since Lausanne (1984)

- Unchanged
  - Status of big issues – mass
    – flavour
    – CP
    – unification
  - case for new physics $\lesssim$ 1 TeV
- Decreased
  - scope for discoveries pre-LHC
    – but only slightly - - - →
- Increased
  - Confidence in SM
  - Understanding of phenomenology*

* See Aachen Proceedings

– basic ref. for much of talk

Some Pos. Discoveries Pre LHC

- top - FNAL, or LEP if non-std. decays
- SUSY - FNAL
  LEP eg $\bar{e}e \to \chi_1^0 \chi_2^0$
  $\hookrightarrow \chi_1^0 f \bar{f}$
- leptoquark - HERA
- right handed current - HERA
- Higgs - H^0, $H^\pm$ LEP
  $t \to H^+ b$ FNAL
- $m_\nu \neq 0 <$ 17 keV
  oscillations < solar
  lab
- failure of std. model to fit precision LEP data

⋮

Evidence for Physics Beyond Std Model:

—

Hints of Physics beyond SM:

Expt: Solar ν, ν_{17}, $B_{\text{universe}} \neq 0$, dark matter, Centauros etc.........

Theory:

Need for q. theory of gravity

Complexity, arbitrariness of SM

Caution: some fashionable non-std. ideas may be right, but do not trust details

Bjorken "One thing for sure is that almost all the words in the Higgs Hunter's Guide on how to find a non-standard Higgs are wrong"

but valuable ⇒ stretch detector requirements

LEP ⇒ SU(2) x U(1) = theory ~~model~~

W, Z are gauge bosons ⟵ params of non-std. gauge ints. should respect this

De Rujula et al

- Mt quite tightly constrained

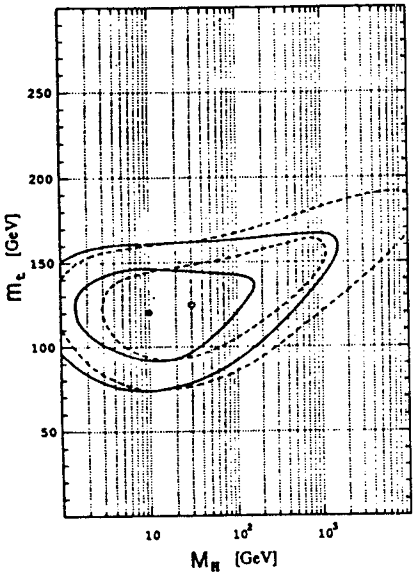
  Mt outside LEP range ⟶ major surprise

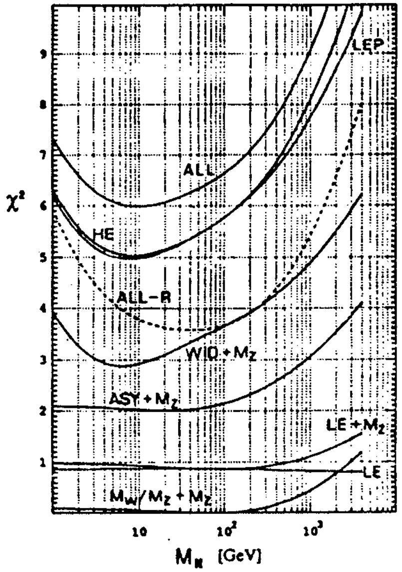
- $m_H \lesssim$ few TeV

figs ⟶

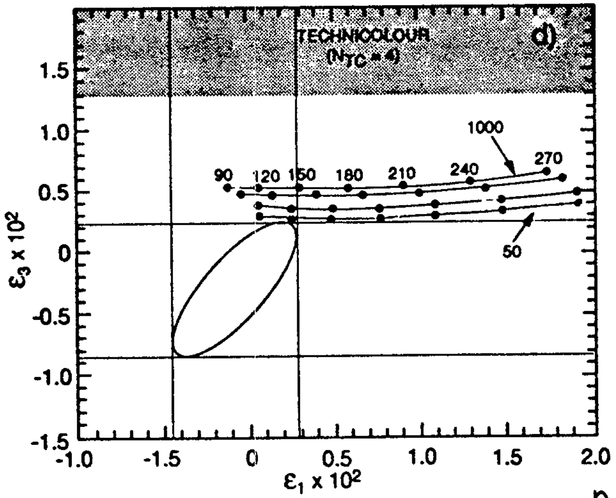
- data ⟶ challenge for technicolour
- minimalistic GUTs excluded

– data like SUSY GUTs with scale in predicted region but cannot fix scale < errors / GUT thresholds





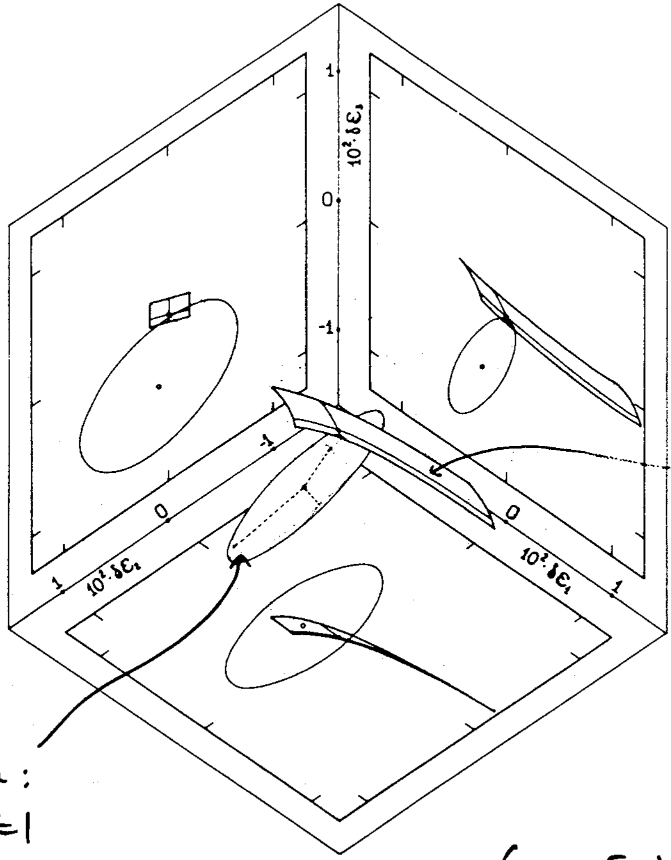
Ellis Fogli & Lisi



Altarelli Barbieri & Jadach

"Model-Independent" analysis in 3 dimensions

$$S = \frac{4\sin^2\Theta_W}{\alpha}\epsilon_3 \ , \ T = \frac{1}{\alpha}\epsilon_1 \ , \ U = -\frac{4\sin^2\Theta_W}{\alpha}\epsilon_2$$

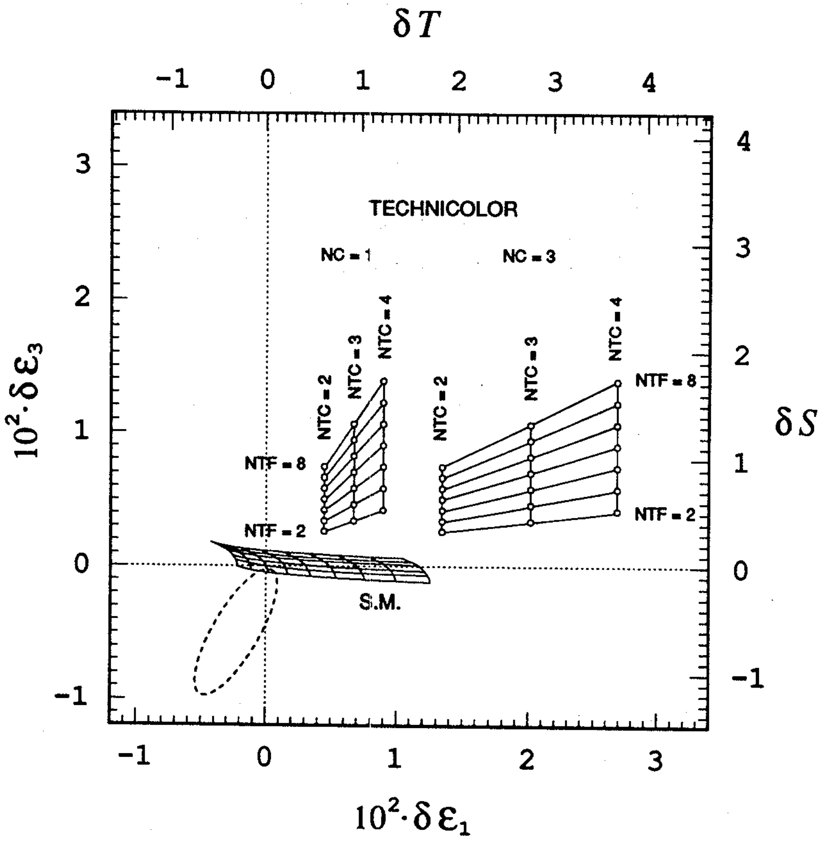


Standard Model

data: $\Delta\chi^2=1$

(J.E.llis + Fogli + Lisi)'

Confrontation with Technicolour Models



N_C = # colours of technifermions
N_{TC} = # technicolours
N_{TF} = # techniflavours

(J.E.llis + Fogli + Lisi)'

The Problem of Mass

What happens if:

$\mathcal{L}_{SM} \to \mathcal{L}_{SM} - \mathcal{L}_{Higgs}$ + mass terms for W, Z, q, ℓ + cut-off Λ?

- **Empirically**: LEP Obs. $= (LO)_0 (1 + \delta^{rad})$

$$\delta^{rad}_{1\,loop} \Rightarrow \underset{\nwarrow\ \alpha_W (a + b \ln(M_H/M_Z))}{\delta^{rad}_{SM}} - \alpha_W (c + b \ln(M_H/\Lambda))$$

LEP $\Rightarrow$ cut off / new phys. associated with $M_{W,Z} \lesssim$ few TeV

Physics of quark masses could be at higher scale (Higgs contribs $\sim \alpha_W m_{light}/M_W \ln(\,)$, $\alpha_W^2 m_t/M_W \ln(\,)$)

- **Theoretically**: in perturbation th.:-

$A(f\bar{f} \to W_L W_L) \sim \frac{g^2 s}{M_W^2}$ violates unitarity at $O(1\,\text{TeV})$

$\sim \frac{g^2 m_f \sqrt{s}}{M_W^2}$ violates unitarity at $O(20\,\text{TeV})$ for $m_t = 150$ GeV

Given: LEP $\Rightarrow W, Z$ = gauge bosons $\xrightarrow{?}$ massless!

Need Goldstone bosons $\Rightarrow W^\pm_L, Z_L, M_\gamma \neq$

They are <u>either</u> <u>elementary</u>:

eg MSM: $\begin{pmatrix} H^+ \\ H^0 \end{pmatrix} + cc$ $\quad H^\pm, \text{Im} H^0 \to W^\pm_L, Z_L$

Re $H^0 \to$ Physical Higgs: $M_H^2 \propto \underset{\nearrow\ \text{Higgs self int. coupling}}{\lambda}(\langle H \rangle) \langle H \rangle^2$

$\lambda(E, \lambda(\langle H \rangle)) \Uparrow$ as $E \Uparrow$ $\quad \xrightarrow[\text{Landau pole: nonsense (?)}]{E \to \Lambda} \lambda \to \infty$

$\Rightarrow$ New physics for $E \gtrsim \Lambda$

$M_H(\Lambda, \langle H \rangle) \lesssim 200$ GeV for $\Lambda \sim M_{Planck}$

$M_H \Uparrow$ as $\Lambda \Downarrow$ $\quad M_H \approx \Lambda$ for $\Lambda \approx 650$ GeV

either ↗ $M_H < 650$ GeV; pert. th. OK to Λ but need fine tuning or SUSY if $M_H \ll \Lambda$

or ↘ $M_H \gtrsim 650$ GeV – strong Higgs interactions / new physics $E \gtrsim 650$ GeV

<u>or</u> <u>composite</u>:

eg $\quad V_L = (Q\underset{\llcorner\leftarrow\ \text{techniquarks}}{\bar{Q}})^{0^-}$

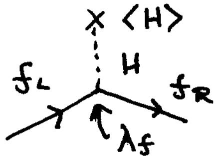
'Scale ~ 1 TeV $\leftarrow$ see compositeness

$\to (\bar{Q}Q)^{1^-}$ etc ~ 1 TeV

Both poss. fine for $M_{W,Z}$ but ....

Fermion Masses:

- **Higgs**



$\longrightarrow m_f = \lambda_f \langle H \rangle$

this works **but** all by hand, $\lambda_t > 2\times10^5 \lambda_e$!

no theory

[best ansatz: 7 params $\rightarrow$ 13 masses, mixings

$m_t = 176-190$ GeV, $\frac{V_{ub}}{V_{cb}} \approx 0{\cdot}05$: expt $0{\cdot}09 \pm {\cdot}05$

... Dimopoulos, Hall, Raby]

- **Technicolour**

need: "extended TC" $\longrightarrow m_f \neq 0$ - complex

"walking ETC" $\longrightarrow$ realistic m_f^{light} + no FCNC - v. complex

"strong walking ETC" $\longrightarrow m_t$ - byzantine + no viable models

variants: $\langle \bar{t} t \rangle$ plays role of $\langle H \rangle$

Special case of Composite Higgs models

$\nearrow$ from new dynamics at Λ

$\xrightarrow{\Lambda \to \text{large}}$ standard model, but needs fine tuning

- **Fermion mass generation ugly / unbelievable(?) in both cases**
  - **need new idea?**
  - **Should not rule out simple TC for $M_{W,Z}$?**

Standard Higgs

Aachen + $t\bar{t}H$, WH, jet tagging

- **LEP2**

assume $\bar{e}e \to ZH \Longrightarrow$

$\hookrightarrow b\bar{b}$

$\hookrightarrow L^+L^-$

discover / exclude for

$$M_H \lesssim \sqrt{s} - M_Z - 15 \text{ GeV}$$

need μ-vertex $\Rightarrow b\bar{b}$

$\Rightarrow$ suppress $\bar{e}e \to ZZ \to q\bar{q}$

$\hookrightarrow L^+L^-$

otherwise limit ~ 80 GeV

- **LHC/SSC**

- $g_{Hx\bar{x}} \propto M_x \Longrightarrow$ **H produced from / decays to heavy particles**

- **Hadronic channels not viable**

Need eg

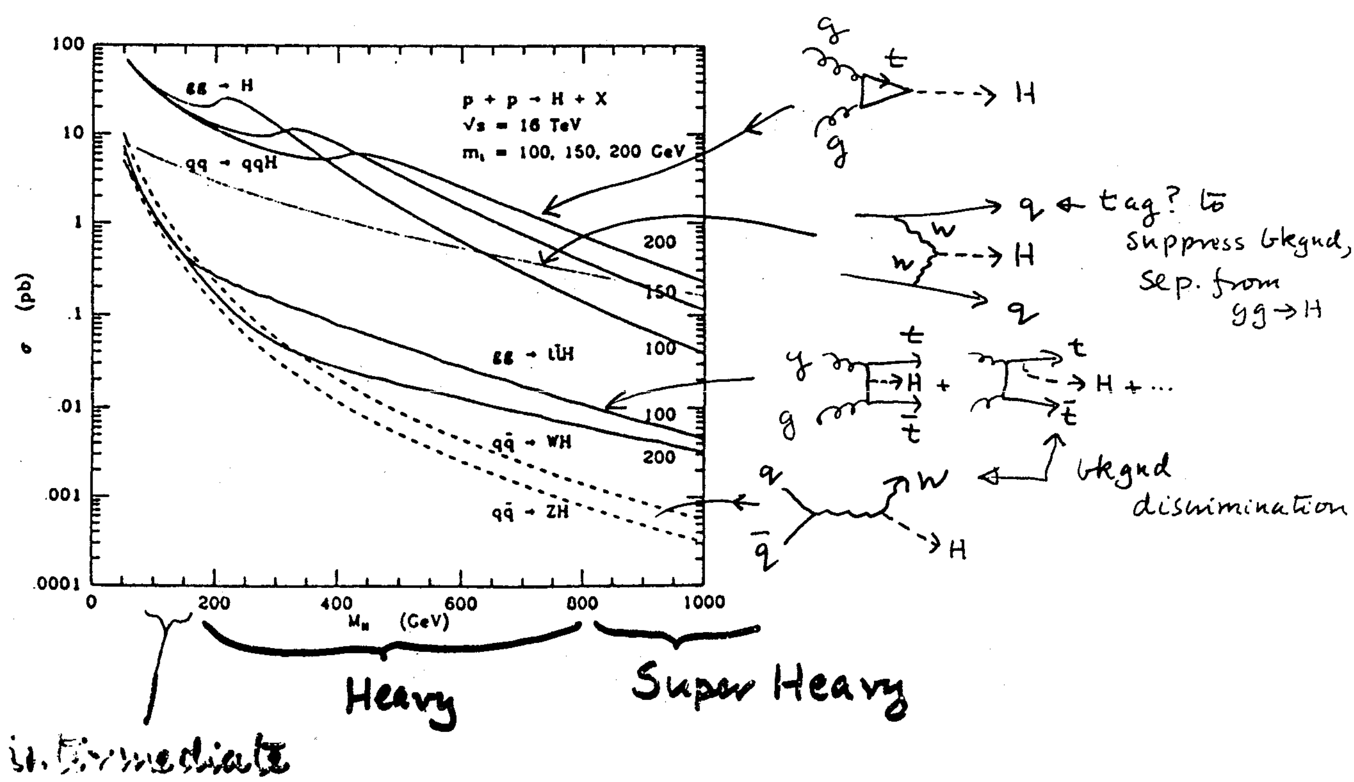
$H \to ZZ \to \mu^+\mu^-\mu^+\mu^-$ $\sim 5\times10^{-4}$

$\hookrightarrow Z^{(*)}Z \to \mu^+\mu^-\mu^+\mu^-$ $< 5\times10^{-4}$

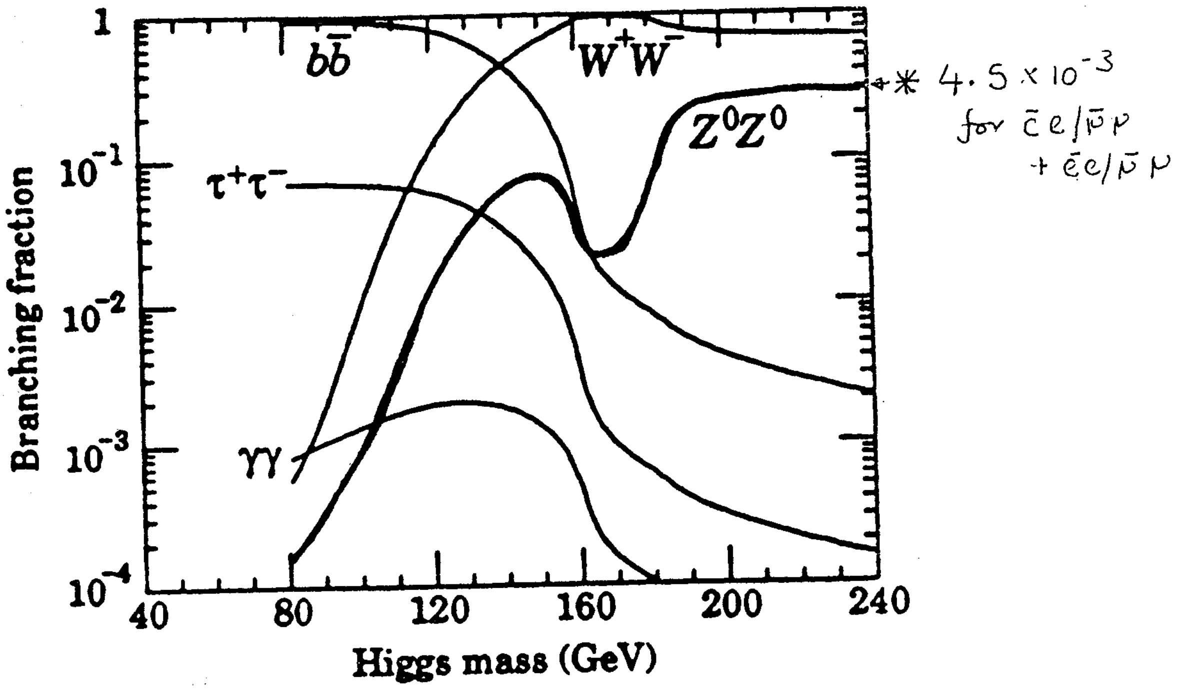
$\to \gamma\gamma$ $\lesssim 10^{-3}$

fig $\rightarrow$

- **Production** $\Rightarrow$ fig.



Kunsztr Stirling.



Intermediate Higgs

- $gg \to H \hookrightarrow \gamma\gamma$

  Rate OK ~~for~~ $M_H \lesssim 150$ but need $\xrightarrow{\text{fig}}$

  - γ/jet rejection 10^{-4}
  - $\Delta M_{\gamma\gamma}/M_{\gamma\gamma} \lesssim 1\%$

    to beat $q\bar{q}, gg \to \gamma\gamma$ bkgnd

- $gg \to t\bar{t}\,H \hookrightarrow \gamma\gamma$

  $\hookrightarrow$ isolated lepton

  $q\bar{q} \to WH \hookrightarrow \gamma\gamma$

Looks OK upto $M_H \lesssim 150$ $\xrightarrow{\text{figs}}$
with suitable cuts and high $\mathcal{L}$

Heavy Higgs

"Gold plated channel"

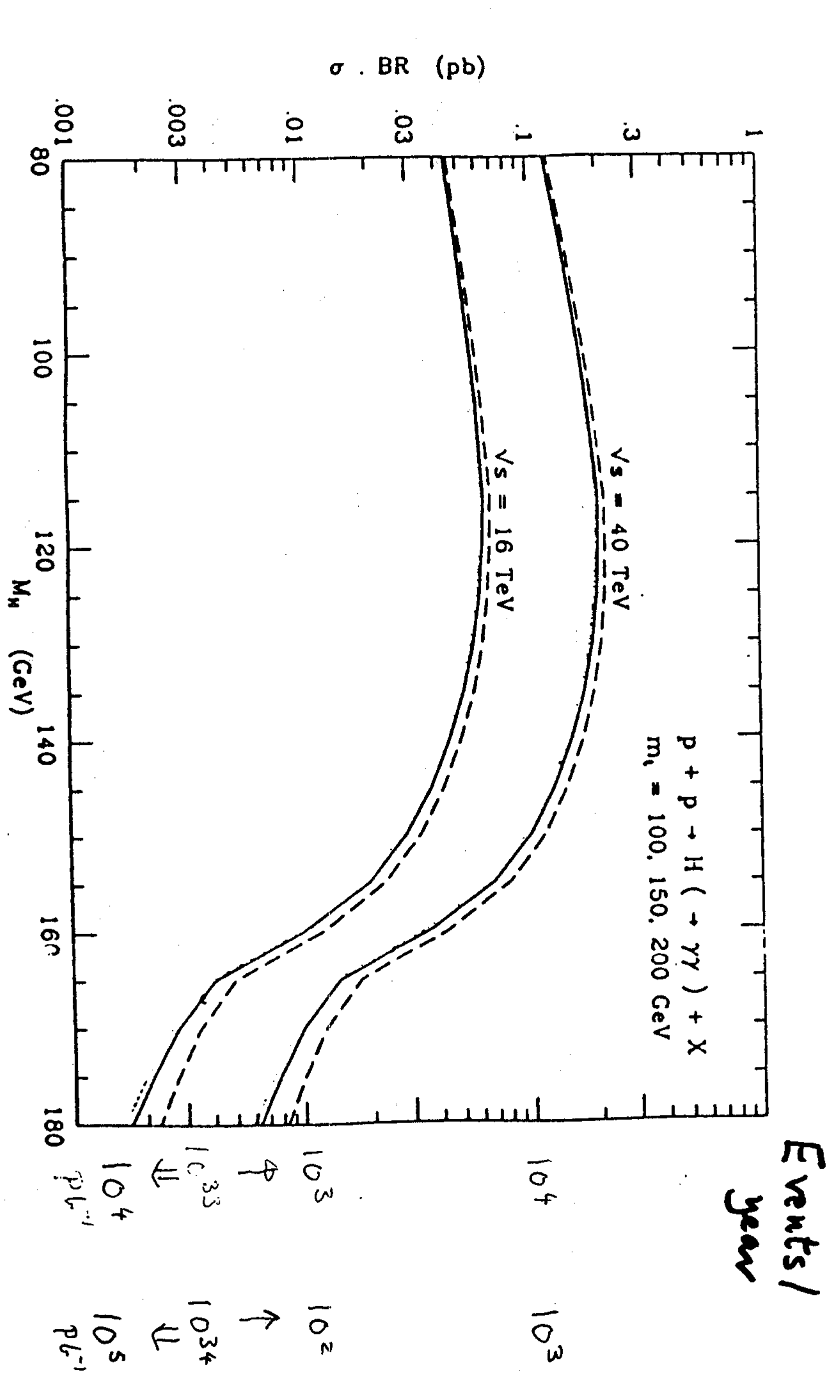
$pp \to H \ldots \hookrightarrow ZZ \to \ell^+\ell^-\hat{\ell}^+\hat{\ell}^-$

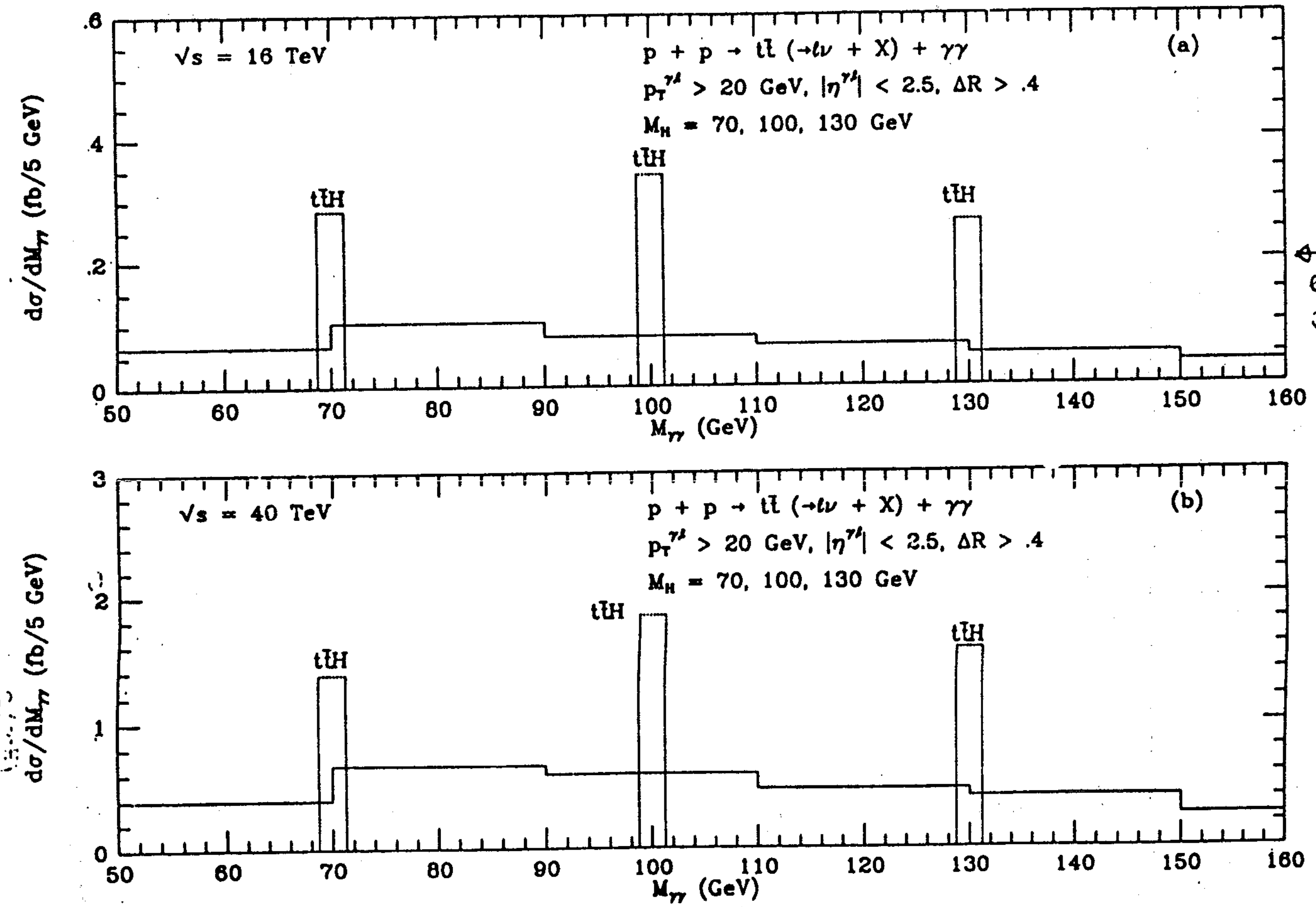
Looks OK for

$$\begin{matrix} 2M_Z\ (10^4 pb^{-1}) \\ 130\,GeV\ (10^5 pb^{-1}) \end{matrix} < M_Z < \begin{matrix} 500\,GeV\ (10^4 pb^{-1}) \\ 800\,GeV\ (10^5 pb^{-1}) \end{matrix}$$

$\xrightarrow{\text{figs}}$

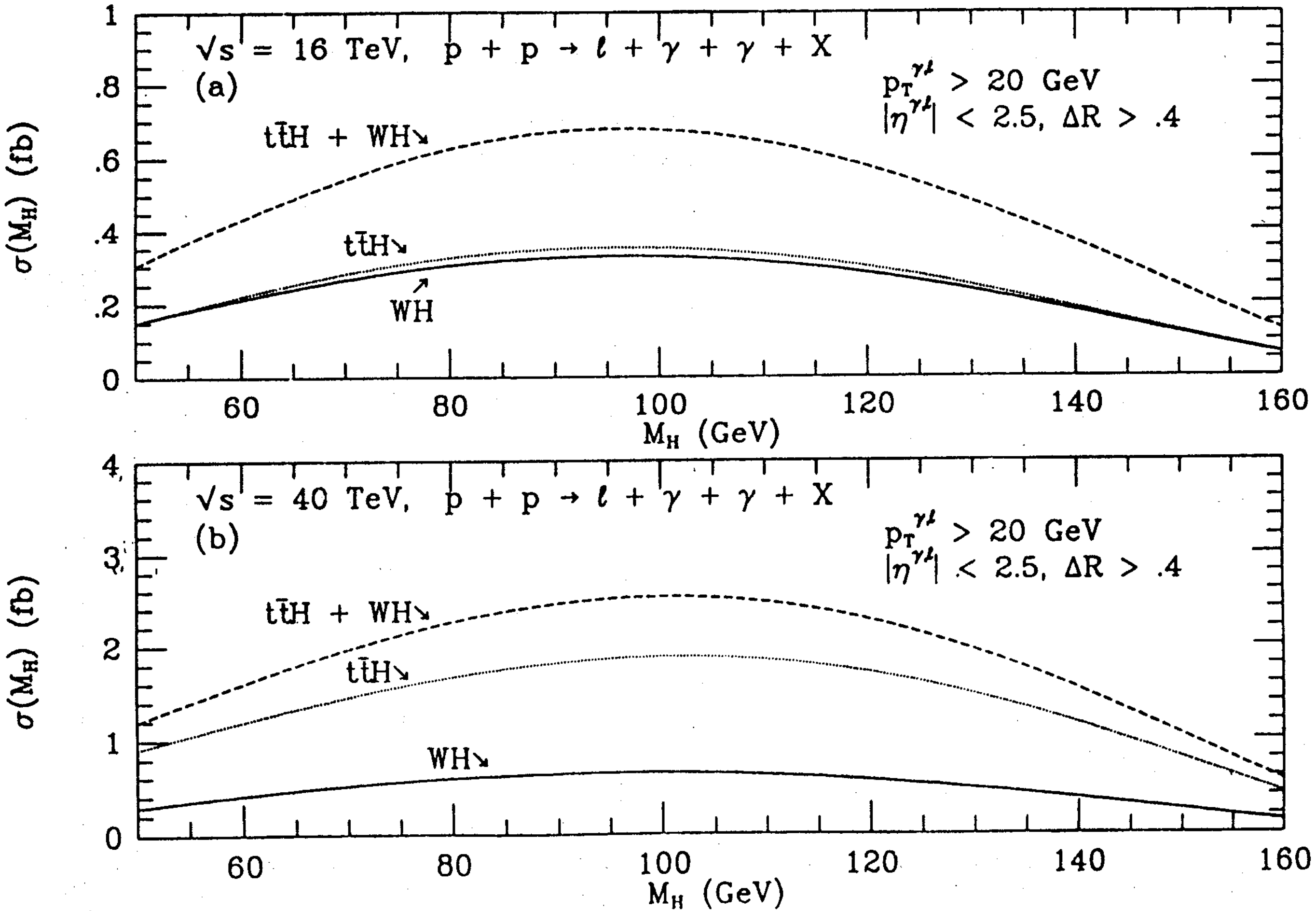
Kunsztr Stirling





← 20 events for 10^5 pb^{-1}

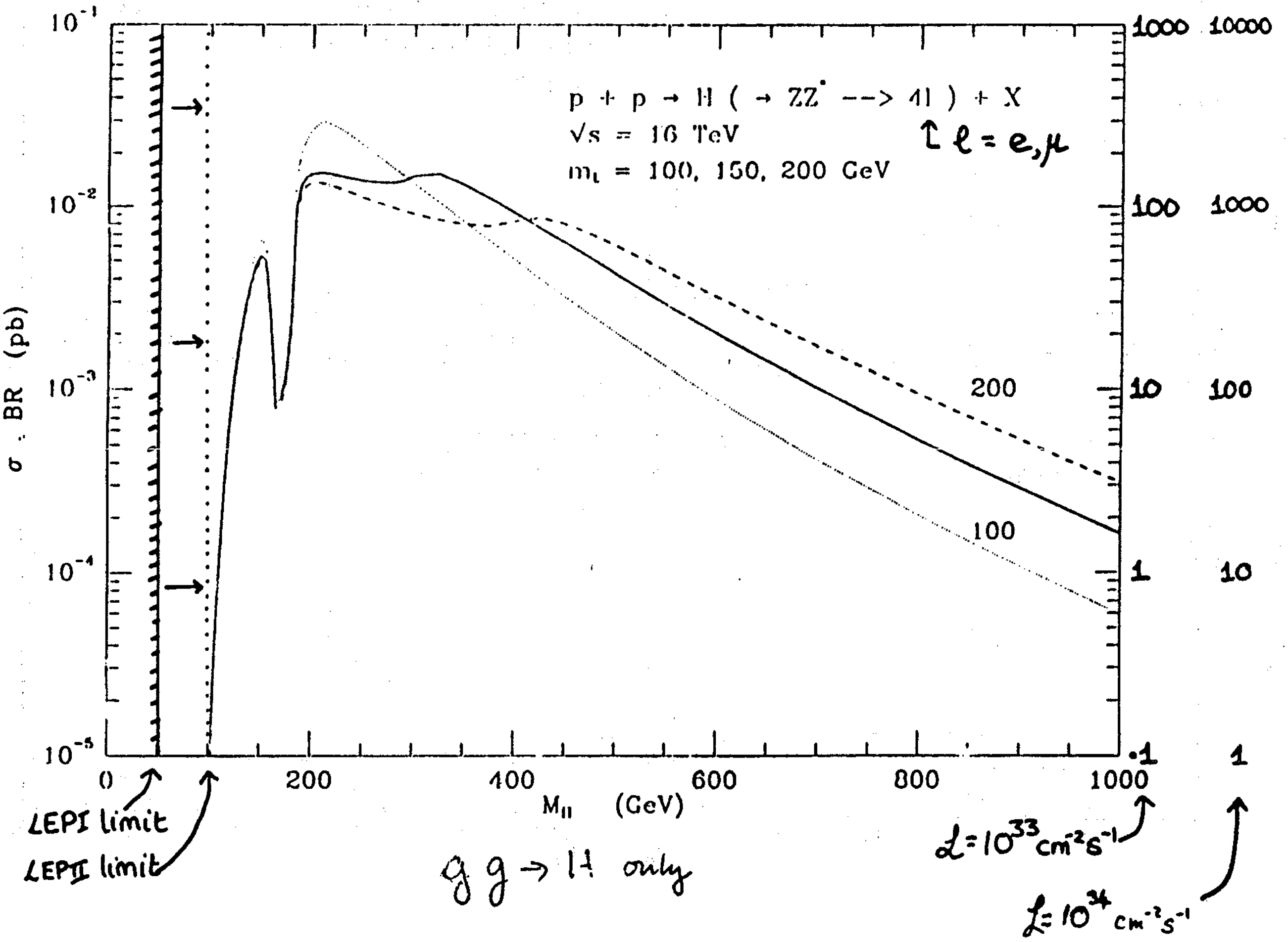
KST

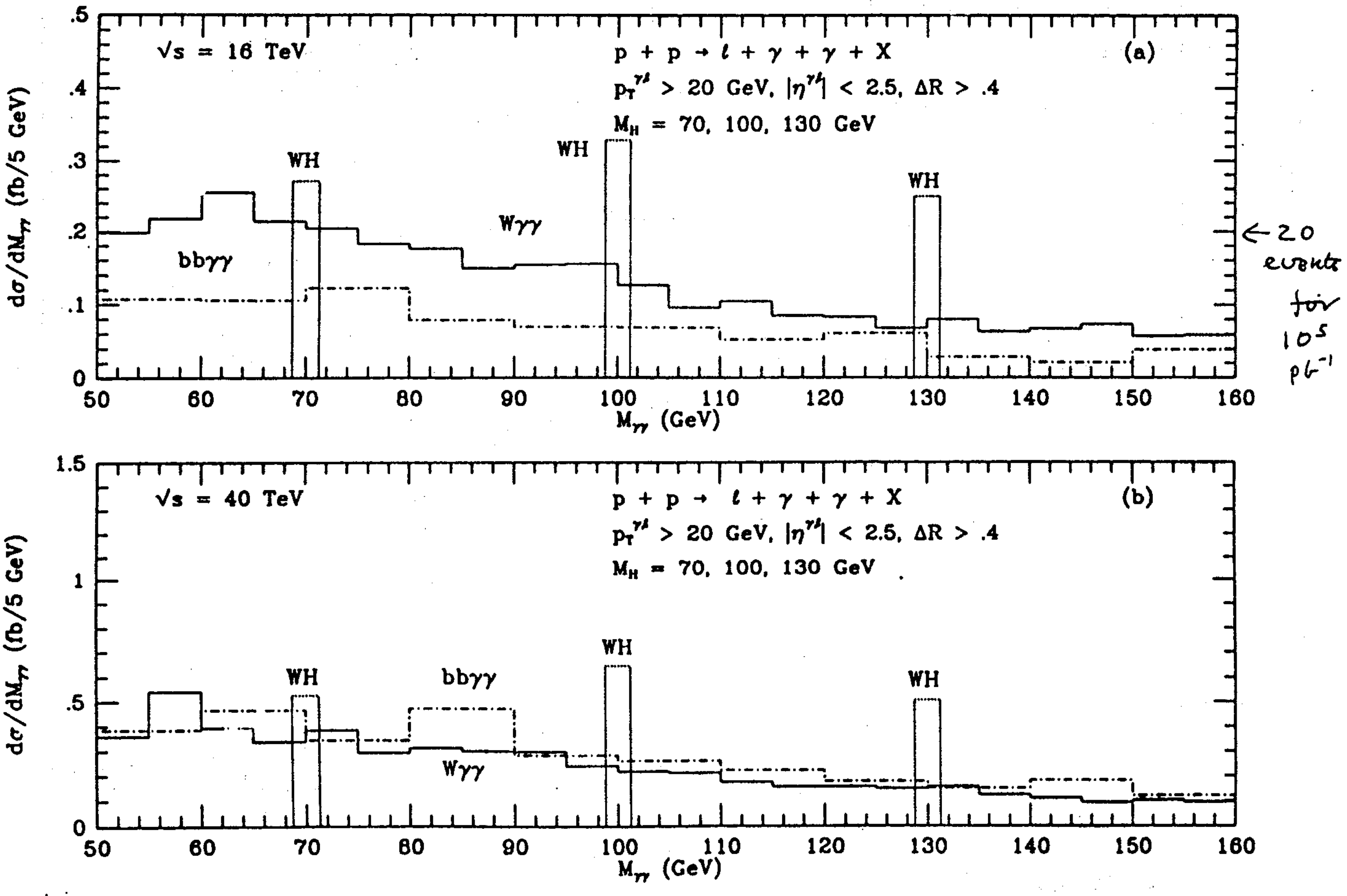


Knasgt Stirling r T...

Higgs at LHC

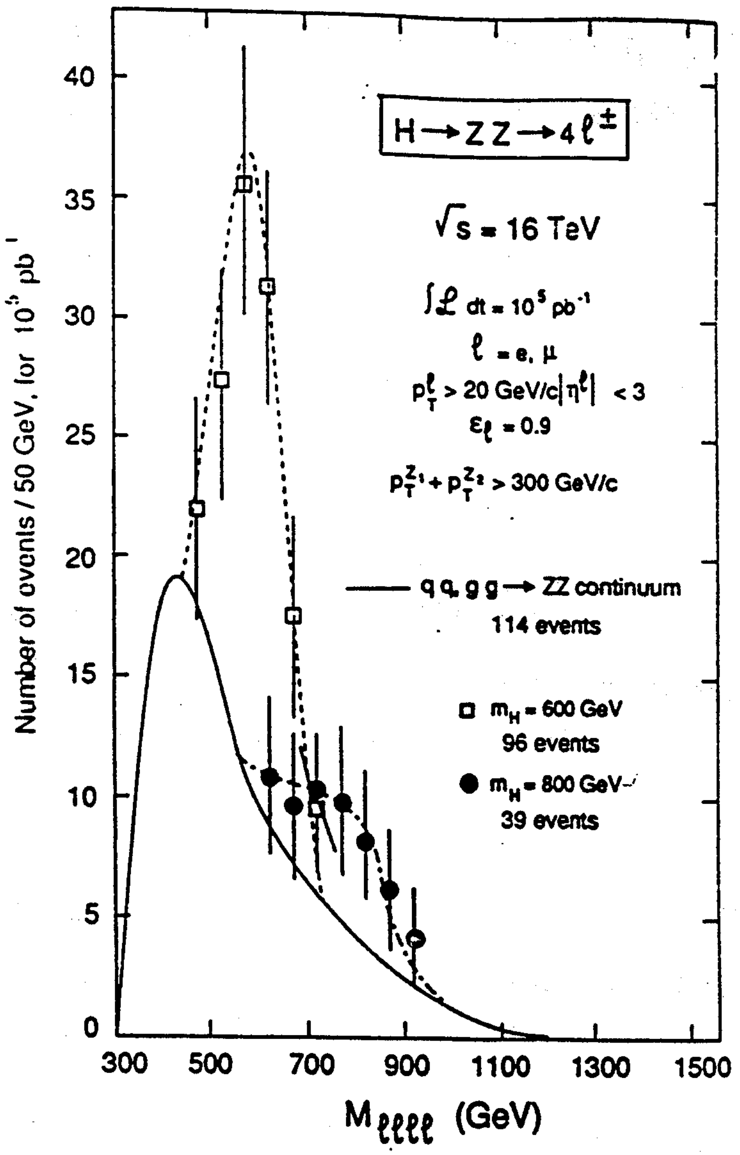
(Kunszt WJS 1990)





KST

-(Della Negra et al)



Super Heavy Higgs

v broad $\Gamma_H \approx 500 \left(\frac{M_H}{1\,TeV}\right)^3$ GeV

- $H \to ZZ \to \ell^+\ell^-\nu\bar{\nu}$

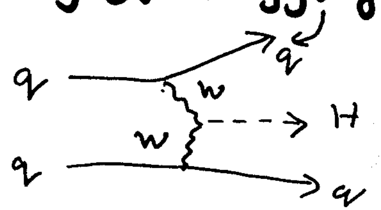
  rate $= 6 * 4\ell^{\pm}$

requires very hermetic detector

- $H \to WW \to \ell\nu$ jet jet

v. difficult - huge W + 2 jet ($M_{jj} \approx M_W$) bkgnd

Jet tagging? → beat → bkgnd ? → separate $WW \to H$, $gg \to H$



Looks promising at parton level but Monte Carlo (SDC) ⟹

Acceptance	WW/ZZ fusion	gg fusion	W+2j bkgnd	$t\bar{t}$ bkgnd
Single tag ⊛	0.23	0.08	0.11	0.035
Double tag ⊛⊛	0.052	0.007	0.005	0.002

$$\underbrace{\qquad\qquad\qquad}_{40\,TeV:\ P^T_{jet} > 50\,GeV}$$

⊛ One jet E > 3 TeV

⊛ ⊛ Two op. rapidity jets E > 1.5 TeV

Minimal Supersymm. Std. Mod. Higgs

$H_1 = \begin{pmatrix} H_1^+ \\ H_1^0 \end{pmatrix} \to \langle H_1^0 \rangle = V_1$ $\hookrightarrow m_{-1/3}, m_e$

$H_2 = \begin{pmatrix} H_2^0 \\ H_2^- \end{pmatrix} \to \langle H_2^0 \rangle = V_2$ $\hookrightarrow m_{2/3}$

2 params: $\tan\beta = V_2/V_1$: $1 < \tan\beta \lesssim \frac{m_t}{m_b}$?

M_A

- **Physical states:**

$H^\pm = -H_1^\pm \cos\beta + H_2^\pm \sin\beta$ → see disc. of t

$A = \cos\beta \, \mathrm{Im}\, H_2^0 + \sin\beta \, \mathrm{Im}\, H_1^0$ CP = -1

$\mathrm{Re}\, H_1^0 \to H^0 \cos\alpha - h^0 \sin\alpha$

$\mathrm{Re}\, H_2^0 \to H^0 \sin\alpha + h^0 \cos\alpha$

NB $M_h(M_A, \beta), \alpha(M_A, \beta)$ v. sensitive to quantum corrections $\xrightarrow{fig}$

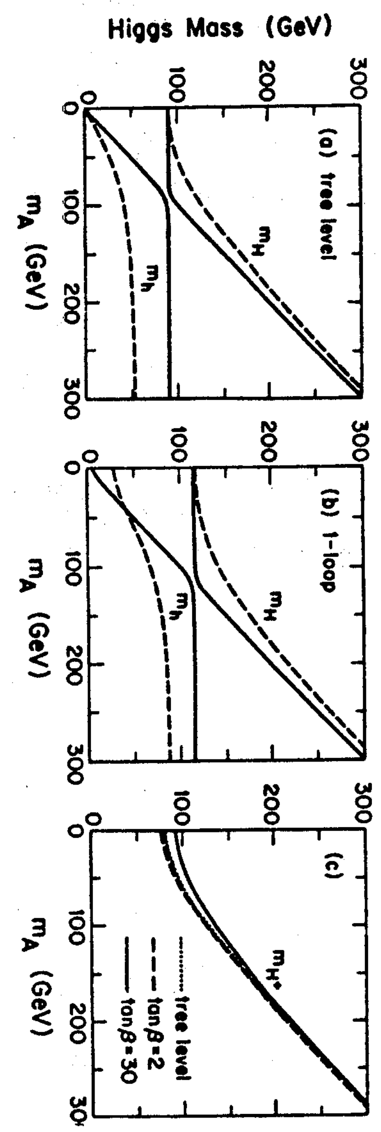
- **Tree level/std. couplings:**

	$b\bar{b}/\tau\bar{\tau}$	$t\bar{t}$	VV
h	$-\frac{\sin\alpha}{\cos\beta}$	$\frac{\cos\alpha}{\sin\beta}$	$\sin(\beta-\alpha)$
H	$\frac{\cos\alpha}{\cos\beta}$	$\frac{\sin\alpha}{\sin\beta}$	$\cos(\beta-\alpha)$
A	$\underbrace{-i\gamma_5\tan\beta}$	$\underbrace{i\gamma_5\cot\beta}$	0
$\tan\beta>1$:	>1	<1	

NB · As $M_A \to \infty$: $M_{H^0, H^\pm} \to \infty$

$g_{HVV} \to 0$, $h \to$ standard Higgs

· As $M_A^{tree} \to 0$: $g_{Hf\bar{f}}^{tree} \to$ std. Higgs



Barger, Berger, Stange, Phillips

Discovery of MSSM Higgs

- **Assume:** $H \to$ standard particles.
- **Calcs with radiative corrns:**

  Baer et al, Barger et al, Gunion et al, Kunszt & Zwirner

Optimists: can find something for most M_A, $\tan\beta$

Pessimists: only find one particle in many regions + hole where find none

LEP: $e^+e^- \to Zh, Ah$

As for Std Higgs $\Rightarrow$ $M \lesssim \sqrt{s} - M_{Z,A} - 15$ GeV.

Decays

- $\Gamma(\to b\bar{b}, \tau\bar{\tau}) >$ **standard unless $\tan\beta$ small**

  $\Rightarrow BR(\to\gamma\gamma) <$ **standard**

- $g_{AVV} = 0$, $g_{HVV} \xrightarrow{M_H \to \infty} 0$

  $\Rightarrow 4\ell^\pm$ **channel no good for A, only for H in limited region**

  $\Rightarrow \Gamma \lesssim$ **GeV even for $M \simeq 500$ GeV**

Production

- $g_{b\bar{b}A} > g_{b\bar{b}H/h} >$ **standard**

but not enough to overcompensate small $BR(\to\gamma\gamma)$ unless $\tan\beta$ huge

(or M_h very small $\to$ find at LEP)

- **Small $\bar{t}t$, VV couplings**

  $\Rightarrow \sigma_{\to t\bar{t}H,h,A}, \sigma_{\to WH,h} <$ standard

Discovery?

- **$\gamma\gamma$ mode**

  h - only if M_h close to max need v. close to max to tag $\xrightarrow{\text{fig}}$

  H - only if M_H close to min v. close to tag $\xrightarrow{\text{fig}}$

  A - hopeless $\xrightarrow{\text{fig}}$

- **Gold plated $4\ell^\pm$ mode**

  h, A - obviously not

  H - OK for $2M_Z < M_H < 2m_t$ $\tan\beta$ not too large $\xrightarrow[\text{fig}]{}$

- $\tau^+\tau^-$

  h, H, A - Some poss. for all if $\tan\beta$ large; H, A not too heavy $\xrightarrow[\text{fig.}]{}$

h→γγ

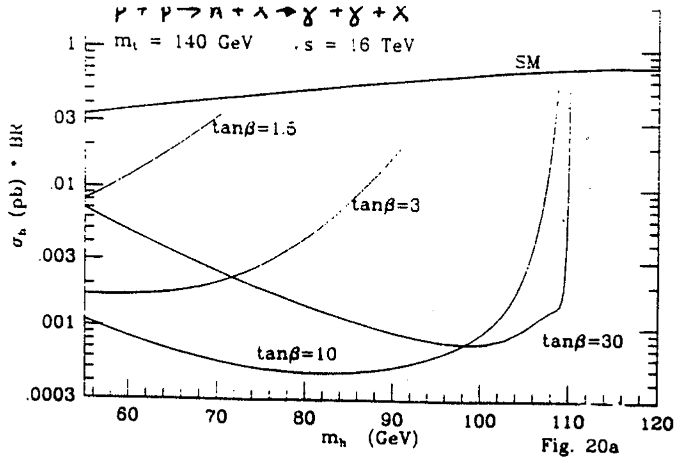

p + p → h + X → γ + γ + X
m_t = 140 GeV   √s = 16 TeV

Fig. 20a

+W

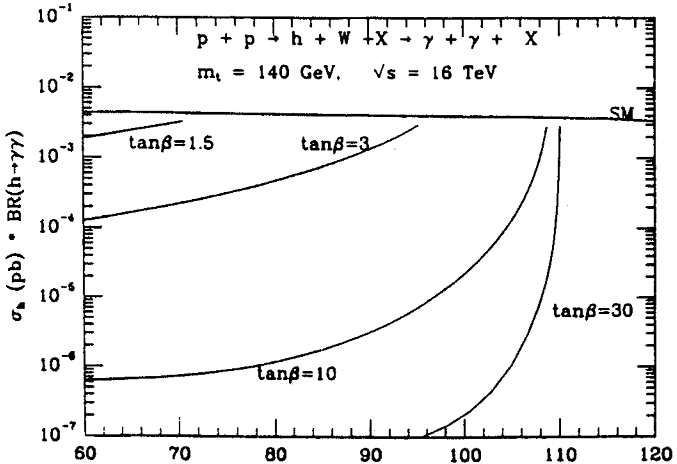
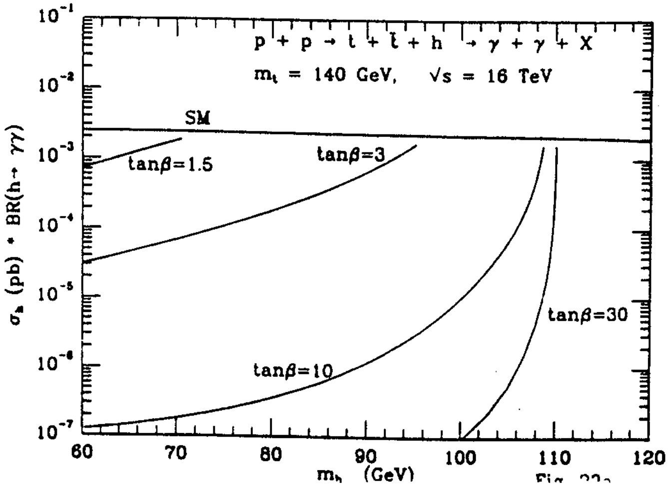

p + p → h + W + X → γ + γ + X
m_t = 140 GeV,   √s = 16 TeV

Fig. 22a

+tt̄


p + p → t + t̄ + h → γ + γ + X
m_t = 140 GeV,   √s = 16 TeV

Kunszt
& Zwirner

H→γγ

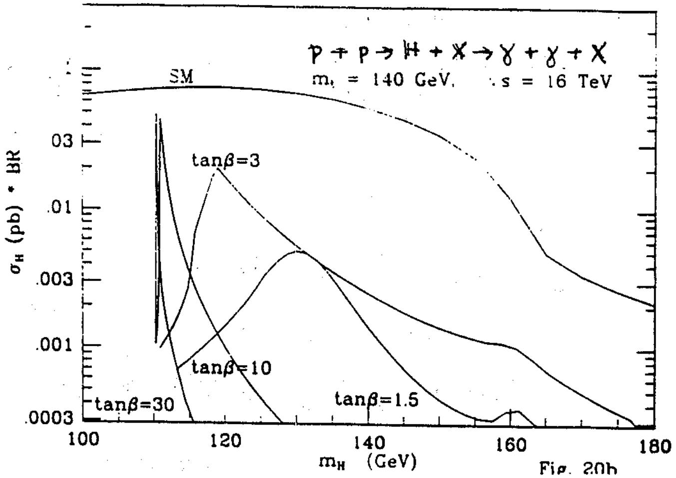

p + p → H + X → γ + γ + X
m_t = 140 GeV,   √s = 16 TeV

Fig. 20b

+W

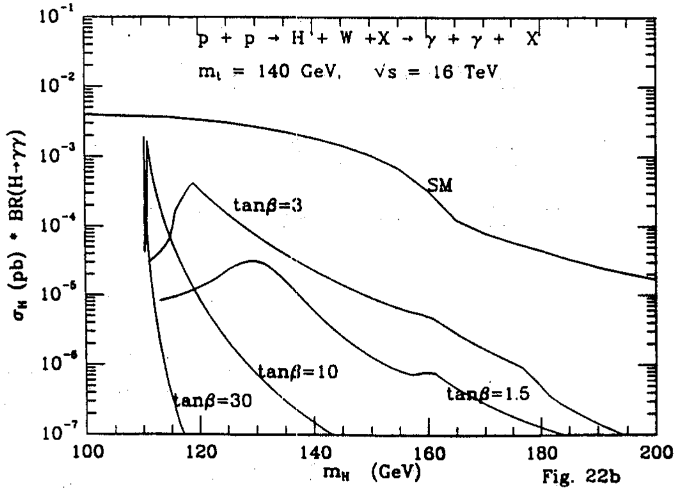
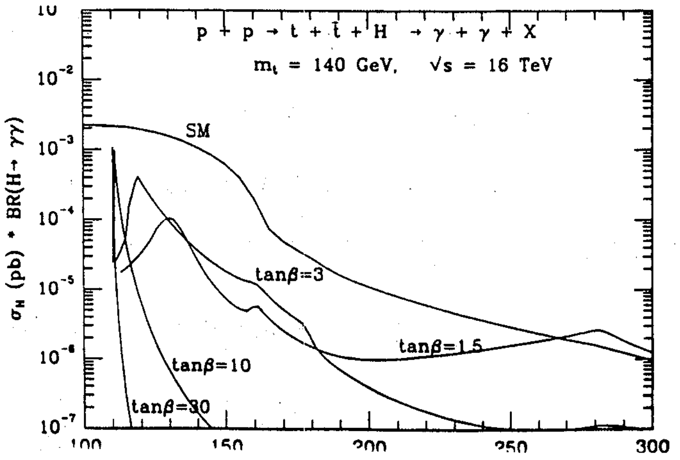

p + p → H + W + X → γ + γ + X
m_t = 140 GeV,   √s = 16 TeV

Fig. 22b

+tt̄


p + p → t + t̄ + H → γ + γ + X
m_t = 140 GeV,   √s = 16 TeV

← γZ

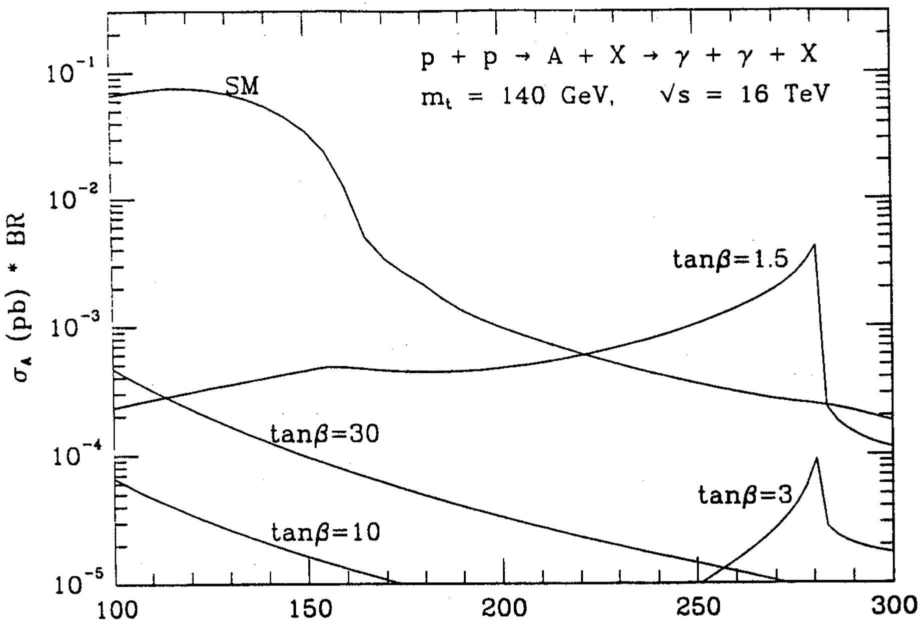


Fig. 20c

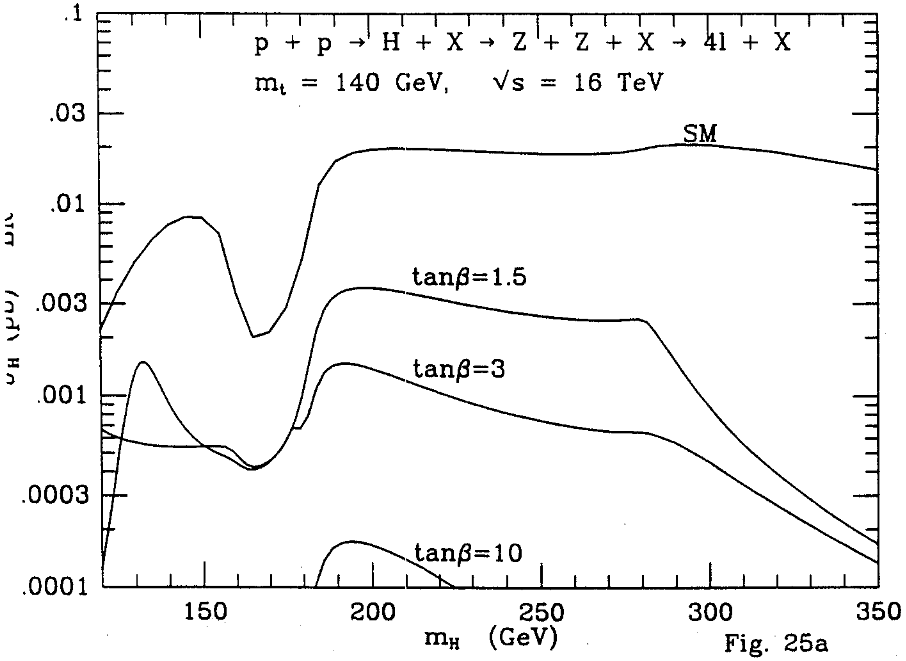


Fig. 25a

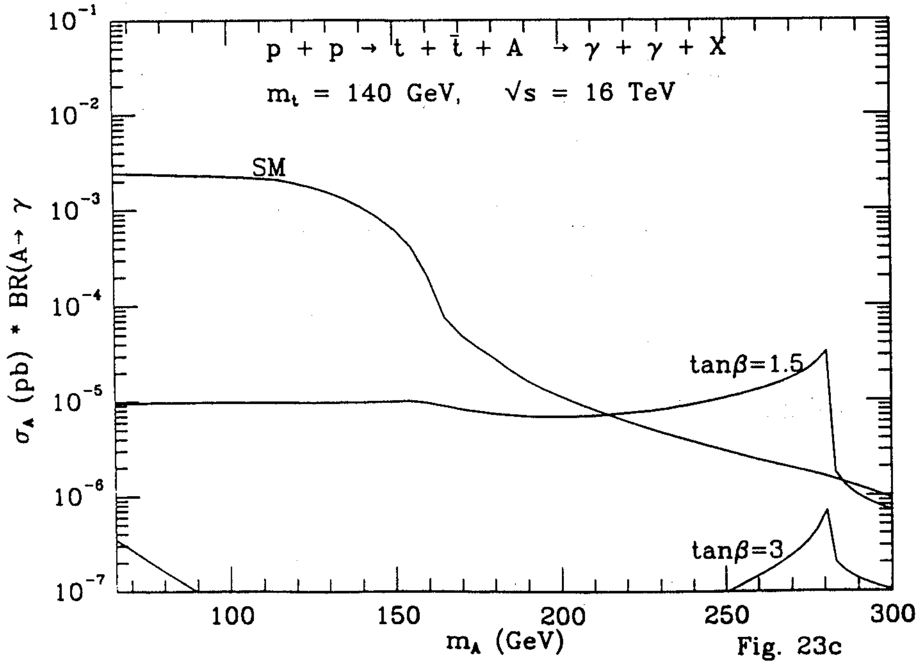


Fig. 23c

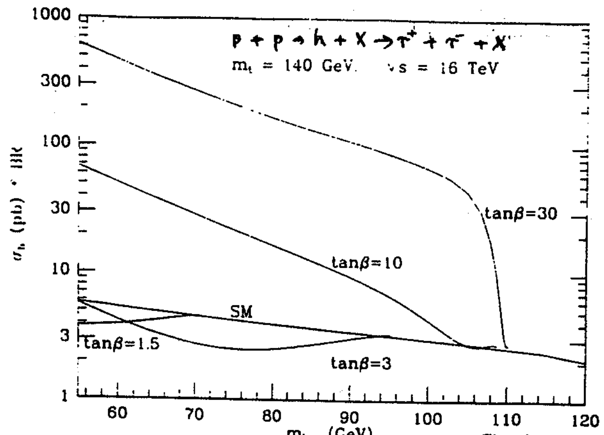


Fig. 27a

$h \to \tau^+\tau^-$

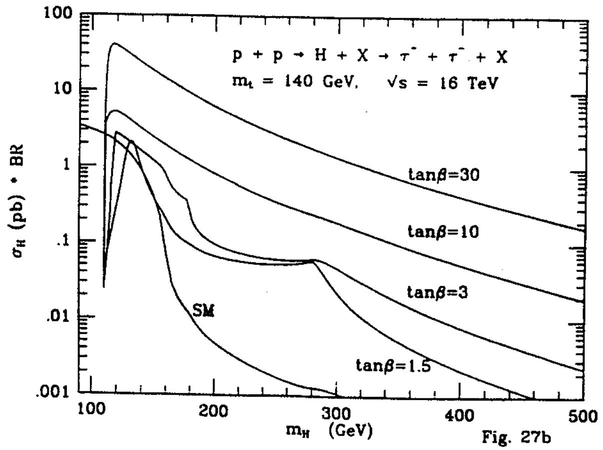


Fig. 27b

$H \to \tau^+\tau^-$

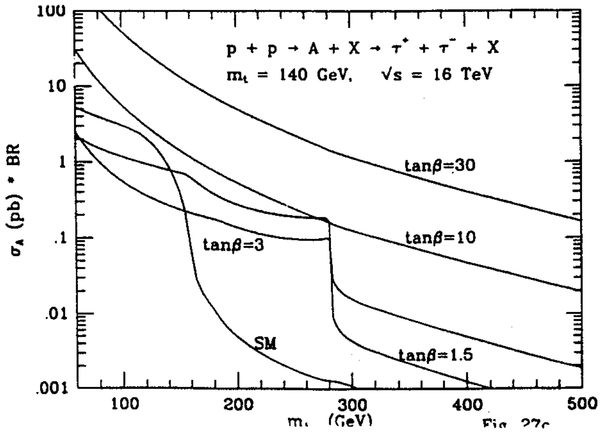


Fig. 27c

$A \to \tau^+\tau^-$

Conclusions on Neutral Higgs

- Standard H can be found from 0-1 TeV
- In MSSM
  - There are discovery regions for h, H and A – but also large inaccessible regions

    $(2 \lesssim \tan\beta \lesssim 20, \; 90 < M_A < 200)$

$\Rightarrow$ Challenge to phenomenologists & experiments!

$V_L V_L$ Scattering at $E \approx 1$ TeV

either one or more light H found

$\Rightarrow$ Study $\sigma_{V_L V_L} \Rightarrow$ Scattering weak?

or light H not found

essential $\sigma_{V_L V_L}$ → Heavy H … Strong int ? Higgs bootstrap TC ….
→ Weak! invisible (MSSM?) light H

- **$W^\pm Z \to \ell^\pm \nu \ell^+ \ell^-$**

might see resonance (ρ_{TC}) up to ~ 2 TeV

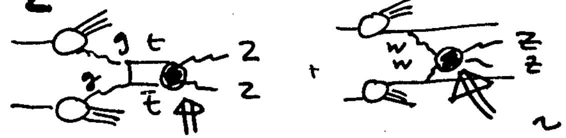
- **$W^+ W^+$** ← bkgnd rel. small

Chanowitz and Berger → various models of strong $V_L V_L$ scatt. and cuts:

eg $\dfrac{\text{Signal}}{\text{Bkgnd}} = \dfrac{31 \text{ events}}{6 \text{ events}}$ for $10^4\, pb^{-1}$ at SSC

Typically for same $\int \mathcal{L}\, dt$: $S_{LHC} \approx S_{SSC}/10 \quad B_{LHC} \approx B_{SSC}/4$

- **Z Z**



~ t and V mass gen ~ V mass gen

Ck γB: $\dfrac{S_{gg} + S_{WW}}{B} = \dfrac{10+17}{30}$ SSC, $10^4\, pb^{-1}$

$= \dfrac{1.7+1.8}{9}$ LHC, $10^4\, pb^{-1}$

Top

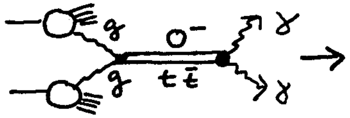
LHC ⇒ measure mass, study decays

- **Mass** $\sigma \sim 2 \times 10^3\, pb$ for $m_t = 150$ GeV

Aachen: • $\sigma_{\to t\bar{t}} \longrightarrow \delta m = \pm 15$ GeV

• $t\bar{t} \to W\bar{b}$, $\hookrightarrow e\bar{\nu}$ } → ± 5 GeV
$\hookrightarrow \bar{W} b$, $\hookrightarrow$ jet jet } → ± 8 GeV

Pancheri, Revol, Rubbia:



→ Xal ball

$\dfrac{\Delta E}{E} = \dfrac{2\%}{\sqrt{E}} \oplus 0.5\%$ fig →

→ ± 30 MeV(!) for $m_t = 100$ GeV

- **Decays:** $t \to H^+ b$?
  - MSSM → $\tau^+ \nu$, $\tan\beta \gtrsim 1$ fig →
  - → $c\bar{s}$, $\tan\beta \lesssim 1$

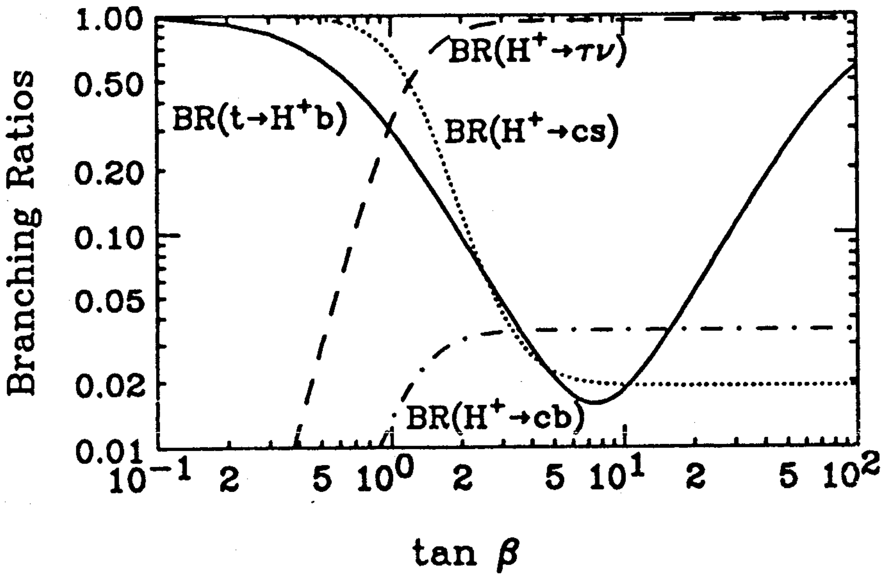
• $\dfrac{1 \text{ isolated } \mu}{2 \ \text{"} \ \ \mu s} \longrightarrow BR(t \to Wb)$

± 5% $10^4\, pb$ Aachen
± 7% $10^5\, pb$

• $gg \to \bar{t} \to \bar{b}\bar{\nu}\ell$ ← isolated + tag bs with μ-vertex
$\quad t \to Hb$
→ $\tau^+ \nu$
$\hookrightarrow \pi^+ \nu$ isolated π^+ - higher p_t than π from $W \to \tau\bar{\nu}$, $\hookrightarrow \pi\nu$ (helicity)
→ $c\bar{s}$ reconstruct M_{jj}

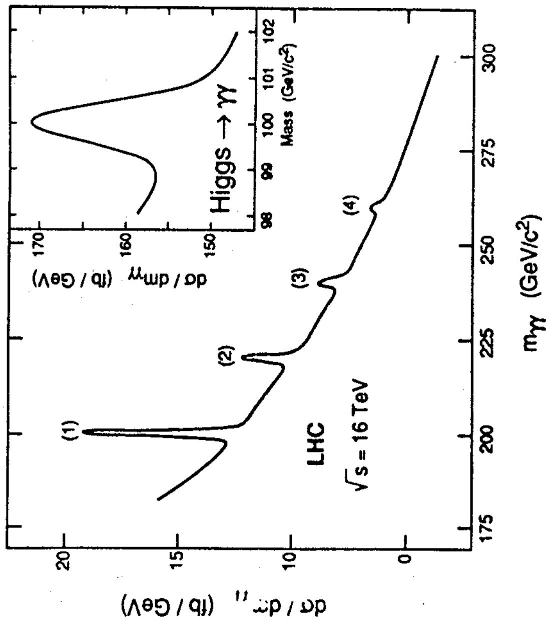
eg SDC 30% b tag efficiency $p_t > 30$ GeV

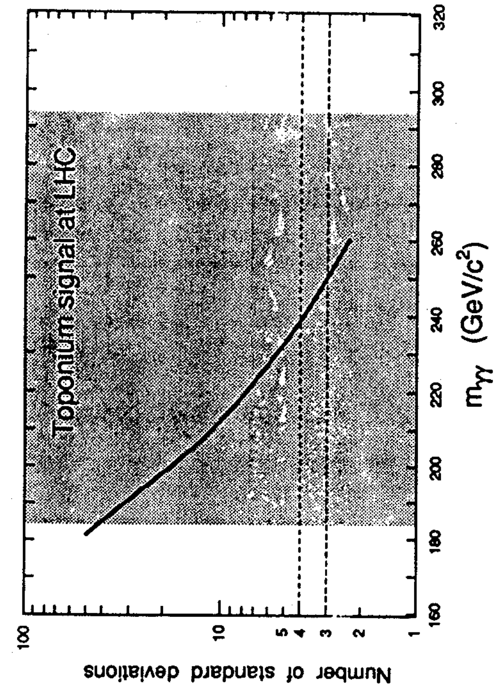
→ See $H^+(125)$ with $t(150)$: $\tau\nu$ - $\tan\beta \gtrsim 0.5$, $\bar{c}s$ - $\tan\beta \lesssim 0.$



$M_t = 1{\cdot}67\ M_{H^+}$

$H^+ \to W^+h$ kinematically forbidden





SUSY

Conventional: **R conserved**

→ Pair production

→ Decays → stable LSP

See Aachen: $\tilde{g}, \tilde{q} < 1.5$ TeV

NB complexity eg $M_{\tilde{g}} = 750$ GeV + certain MSSM params:

$\tilde{g} \to \tilde{\chi}^{\pm}_1 \bar{q} q'$ 30%

$\to \tilde{\chi}^{\pm}_2 \bar{q} q'$ 30%

$\to \tilde{\chi}^{0}_1 \bar{q} q$ 10%

$\to \tilde{\chi}^{0}_2 \bar{q} q$ 17%

$\to \tilde{\chi}^{0}_4 \bar{q} q$ 13%

$\tilde{\chi}^{\pm}_1 \to \tilde{\chi}^{0}_1 \bar{q} q'$ 67%

$\to \tilde{\chi}^{0}_1 \ell \nu$ 33%

$\tilde{\chi}^{\pm}_2 \to \tilde{\chi}^{\pm}_1 Z_0$ 40%

$\to \tilde{\chi}^{\pm}_1 h$ 5%

$\to \tilde{\chi}^{0}_1 W^{\pm}$ 10%

$\to \tilde{\chi}^{0}_2 W^{\pm}$ 30%

$\to \tilde{\chi}^{0}_3 W^{\pm}$ 15%

$\tilde{\chi}^{0}_{i>1} \to$ ....

- - -

$\Bigg\}$

large missing energy + jets

leptons + jets

leptons + jets + $\not{E}$

Z's + jets

Z's + jets + $\not{E}$

......

- - - -

$\chi^0_1 = $ LSP

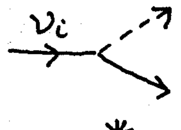
called $\tilde{\gamma}$ below

R Parity Broken

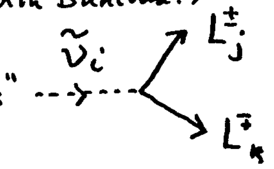
General renormalizable $\mathcal{L}_{MSSM} \supset \not{R}, \not{L}, \not{B}$

$\Rightarrow$ must take seriously (but trouble with Buninx?)

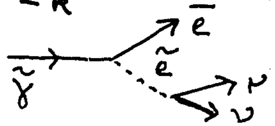
i) $[LL\bar{E}]$



+ "permutations"



LSP unstable*:

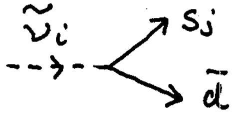


.....

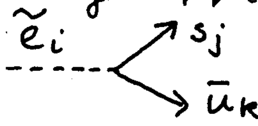
Poss. decays $\tilde{e} \to e\tilde{\gamma}, \mu\nu$ $\tilde{q} \to q\tilde{\gamma}$

$\tilde{g} \to q\bar{q}\tilde{\gamma}$

ii)* $[LQ\bar{D}]$



+



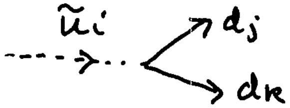
+ "perms."

$\tilde{\gamma}^* \to \bar{L} q \bar{q}', L \bar{q} q'$

$\tilde{e} \to e\tilde{\gamma}, q\bar{q}'$ $\tilde{q} \to q'\ell, q\tilde{\gamma}$ $\tilde{g} \to q\,\bar{\tilde{q}}^{(*)}$

$\to \bar{q}\,\tilde{q}^{(*)}$

iii)* $[\bar{U}\bar{D}\bar{D}]$



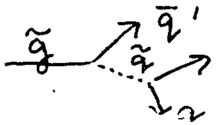
+ "perms."

$\tilde{\gamma}^* \to q q' q'', \bar{q}\bar{q}'\bar{q}''$ $\tilde{q} \to \bar{q}\bar{q}', \tilde{g}^{(*)} q$

$\tilde{g} \to q\,\bar{\tilde{q}}^{(*)}, \bar{q}\,\tilde{q}^{(*)}$

*** ☠ both at once ⟶ p decay**

* Will also have cascade decays:

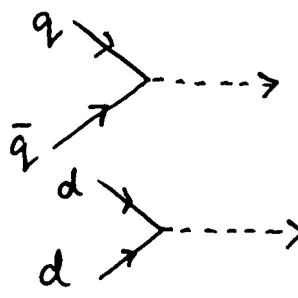


$\chi^{\pm,0} \to W^{(*)}/H^{(*)}/Z^{(*)}\,\hat{\chi} \cdots\cdots \to \tilde{\gamma}$

$\hookrightarrow \ldots$

- Single Production

Model dep. and generally (?) small except



$\tilde{L} \xrightarrow{eg} L\tilde{\gamma}$

$\hookrightarrow L'q\bar{q}$

$\tilde{\bar{u}} \xrightarrow{eg} \bar{q}\tilde{\gamma}$

$\hookrightarrow$ cascade → leptons

} good signatures

- Associated / strong production

$\to \tilde{g}\tilde{g} \to 2q2\bar{q}2\tilde{\gamma}$

$\xrightarrow{i)}$ $2q\bar{q} + \not{E}_T +$ 4 leptons

$\xrightarrow{ii)}$ $2q\bar{q} +$ 2 leptons + 2 jets

$\xrightarrow{iii)}$ 6 jets ×

$\xrightarrow{ii)}$ 2 leptons + 4 jets

$\xrightarrow{iii)}$ 4 jets

$\xrightarrow{iii)}$ $2q\bar{q} + 2V +$ Cascade productions

Cascade

$\to \tilde{q}\tilde{\bar{q}} \to$ Similar collection of good signatures

Conclusions

- The case for LHC/SSC is as strong as ever
- Emphasis on mass problem / Higgs ← brief from organizers ← benchmark process

Other items (SUSY, W', Z', compositeness..) potentially equally important / interesting

- Small prob. of any particular non-std scenario but models ⇒ stretch detector requirements

?↳ better for unknown

- New Physics ⇒ Std particles $\overset{?}{+}$ new (quasi) stable

⇑ See if charged? Stable neutrals interacting?

↳ Like good combination (or Selection if prepared to back hunch) of :

e, μ, τ, γ, W, Z, jets, $\not{E}_T$, b tagging

Physics with proton beams II

A. De Rújula (CERN)

SCENE I :
ORGANIZING KOMMITTEE [OK]

OK : 1ST SPKR : EVERYTHING THAT
MANY PEOPLE WANT TO HEAR
[ONCE MORE !]

YO : HUMM

OK : 3RD SPKR : EVERYTHING THAT
SOME PEOPLE DO NOT WANT
TO HEAR ONCE MORE

YO : HUMMUM

OK : 2ND SPKR (YOU) EVERYTHING
ELSE !

YO (AND NO DOUBT MANY BEFORE ME)

NEIN!

SO, HERE I AM

WHERE TO START
"EVERYTHING
ELSE" ?

E G.R. !

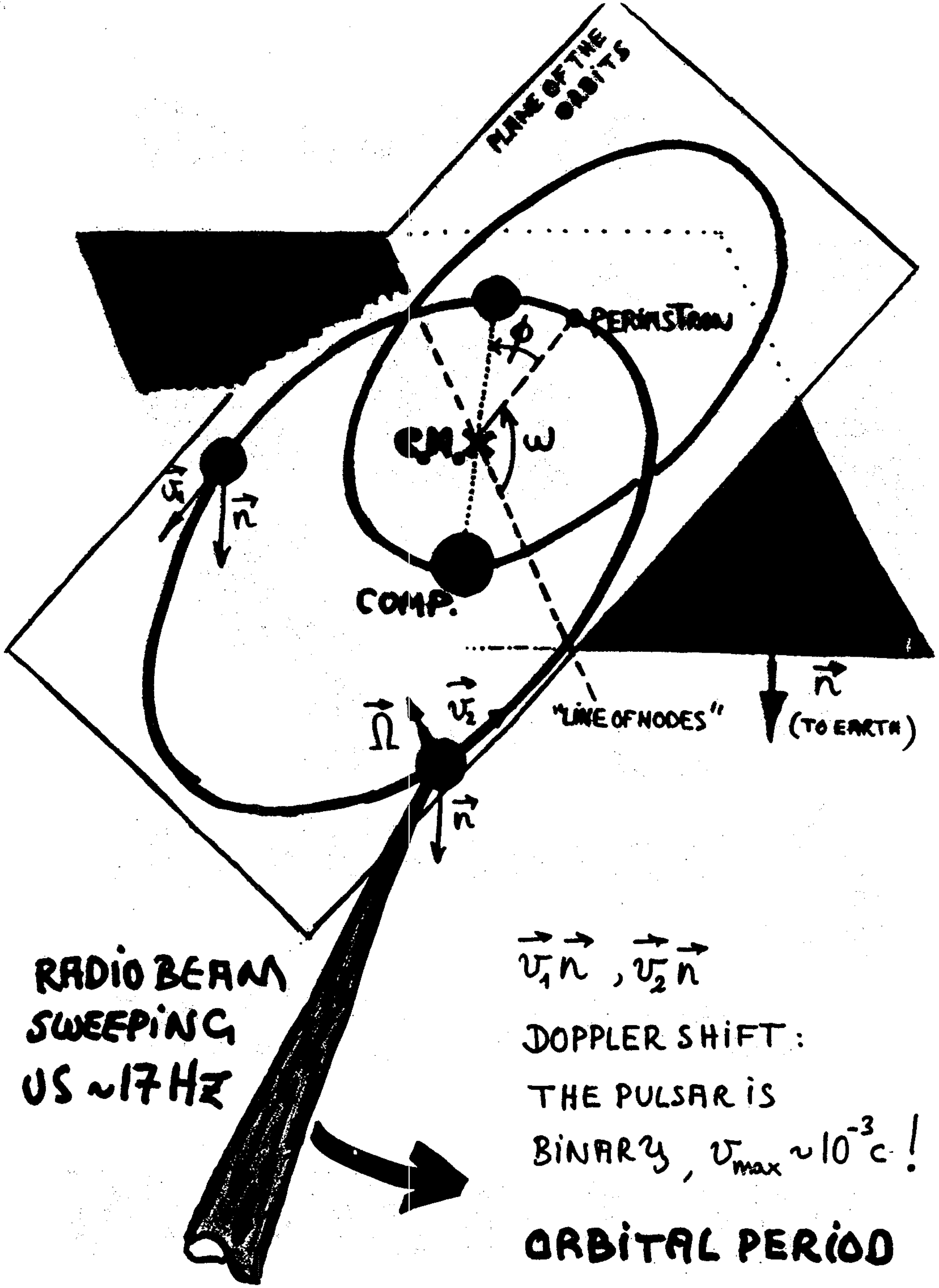
OF COURSE

GR AND iTS PPN NORDUEDT
PPK ESPOSiTO FARESE
DAMOUR
~~PPK~~ VEiLLET
RIEEI

NEiGHBOURiNG THEORiES

GR PASSES iTS NON-NULL
TESTS WiTH FLYiNG COLOURS

- PERiHELiON/ASTRON PRECESSiON
- LiGHT DEFLECTiON
- G-TiME DELAY
- LUNAR LASER RANGiNG
- SOLAR SYSTEM MODEL
- GW EMiSSiON BY PSR 1913+16



$\vec{v}_1 \vec{n}$, $\vec{v}_2 \vec{n}$

DOPPLER SHiFT:
THE PULSAR iS
BiNARY, $v_{max} \sim 10^{-3} c$!

ORBiTAL PERiOD

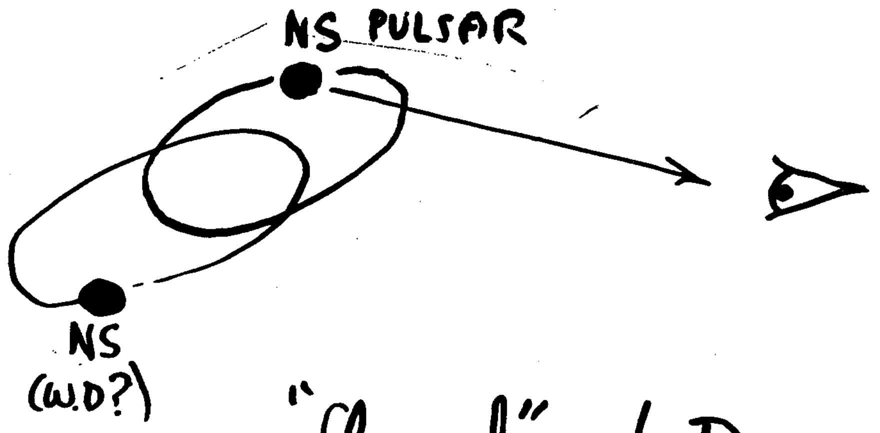
THE LEAST-WELL TESTED
PREDICTION OF GENERAL
RELATIVITY AGREES WITH
THEORY
TO BETTER THAN ½ %

➡ THE [NON QUANTUM]
THEORY OF G.R. IS "RIGHT"
TO A LEVEL SUPERIOR TO
THAT OF THE STANDARD
GAUGE THEORY OF PARTICLE
PHYSICS.

EINSTEIN
vs

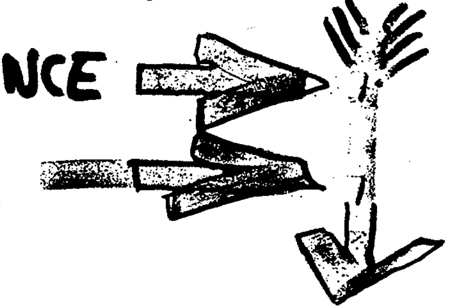
E
KN
HIGGS
BL W
BE R
LR A
ET L
Nik and BROUT

[redacted] [HULSE-TAYLOR BINARY PULSAR]



"Classical" imputs $P, e, a \sin i$

{ PERIASTRON ADVANCE
{ GR TIME DELAY



PERIOD'S SPEED-UP ◀◀ $M_{1,2} \simeq 1.4 M_\odot$

$$\frac{\dot{P}(\text{OBS})}{\dot{P}(\text{GW})} = \begin{cases} 1.008 \pm 0.008 \ (\text{DAMOUR/TAYLOR}) \ [\text{JANUARY 90}] \\ 1/2\,\% \ (\text{JANUARY 1992}) \end{cases}$$

↓

GR IS ESTABLISHED

EINSTEIN FRIEDMAN LEMAÎTRE
MODEL OF OUR EXPANDING UNIV.

EMPIRICAL SUCCESS :

$[G_N, H^{-1}] \rightarrow T_{MWBR} \sim 3°K$

N-SYNTH : ABUNDANCES OF PRIMORDIAL ELEMENTS

EMPIRICAL FAILURES

① UNIFORMITY OF MWBR : REQUIRES DIVINE INTERVENTION [ACAUSAL TUNING OF INITIAL CONDITIONS]

② $\Omega \sim O(1)$ (FLATNESS) : A MYSTERY

③ $\Lambda \sim 0$ COSMOCONSTANT (VACUUM ρ_E) AN ACT OF DIVINE TERRORISM

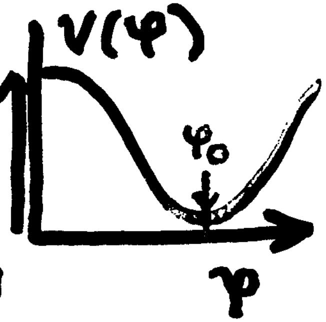
SO WHAT ?!

SO, WE ARE ABOUT TO GET OURSELVES INTO REAL TROUBLE

INFLATION SOLVES ① AND ②

BUT BRINGS ③ CENTERSTAGE

PRAYER : ONCE UPON
A TIME, THE UNIVERSE
HAD A VACUUM ENERGY ~
DENSITY SUPERIOR TO
THAT OF MATTER / RADIATION



⇨ IT EXPANDED $R \propto e^{\sqrt{\Lambda/3}\, t}$

$$\Lambda = 2\pi G V(0)$$

① MWBR COMES FROM CAUSAL DOMAIN

② THE PRIMORDIAL POTATO IS
IRONED FLAT FLAT FLAT

③ WHY IS $\Lambda_{NOW} = V(\varphi_0)$
"ZERO"

EQUIVALENCE
PRINCIPLE

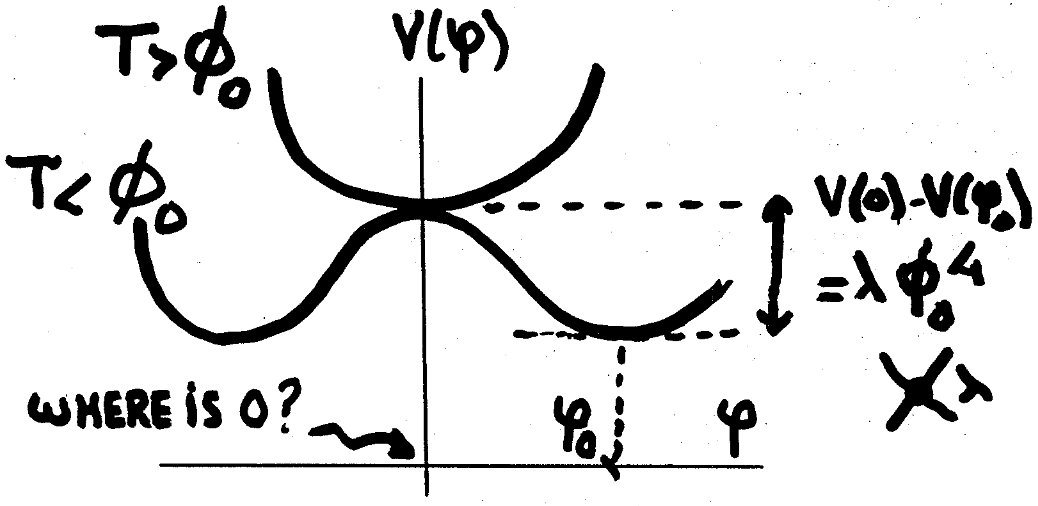
↓

GRAVITY COUPLES TO
THE EN/MOM TENSOR OF
EVERYTHING
IN PARTICULAR
(TO THE MASS-ENERGY
DENSITY OF EVERYTHING)
(NOT MOVING OR FLOWING)

(MATTER, RADIATION BATH
\+
VACUUM ENERGY DENSITY)

HERE IS WHERE PARTICLE PHYSICS HAS A SAY

WEAK PHASE TRANSITION $T > \phi_0$ (246 GeV) $\hookrightarrow T < \phi_0$

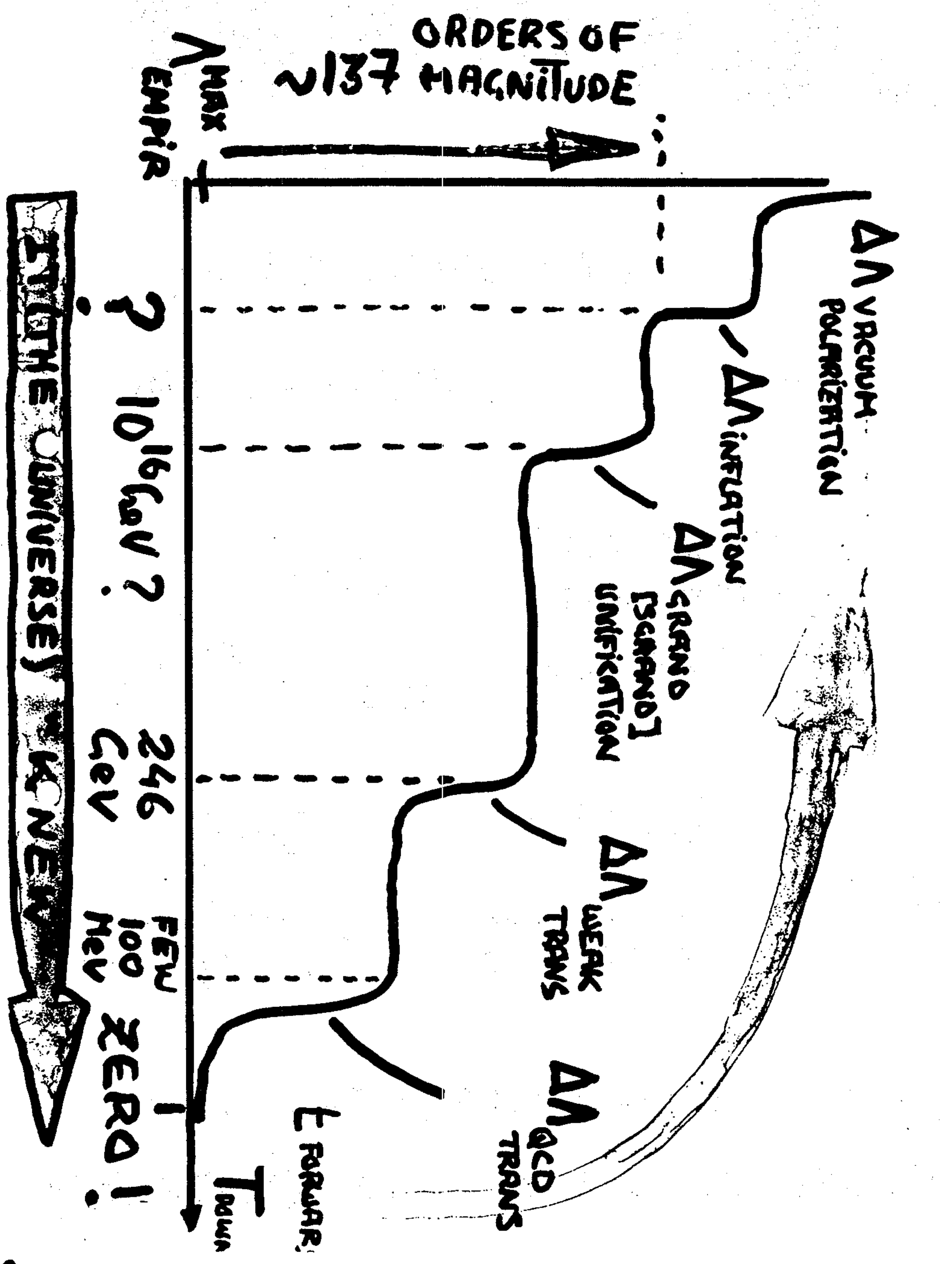


$$\Lambda_{EMPIR} \lesssim 9\frac{H_0^2}{c^2} \sim 3.10^{-83}\,GeV^2$$

$$\Delta\Lambda\begin{bmatrix}WEAK\\TRANS.\end{bmatrix} = 2\pi\lambda G_N\phi_0^4 = 2\pi\lambda\,\underbrace{3.10^{-29}\,GeV^2}$$

OBSERVABLE SPACE CURVATURE OVER ~20 cm

$$\Delta\Lambda_{WEAK} \sim 10^{54}\,\Lambda^{MAX}_{EMPIR.}$$



➡ ONLY IN THE DEPTHS
OF LEP CAVERNS

[BUT NOT IF YOU SURFACE
AND LOOK AT THE STARS]

CAN YOU [WITH A POKER FACE]

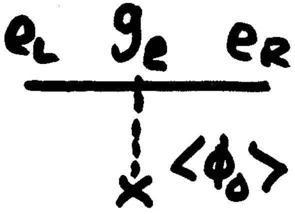
SAY : WE UNDERSTAND THE
SPONTANEOUS BREAKDOWN
OF GAUGE SYMMETRIES

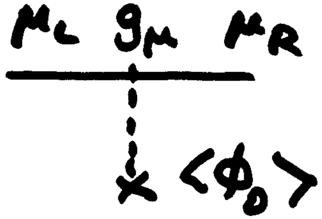
TEMPORARY CONCL/ALTERNATIVES

① QUANTUM GRAVITY WILL MIRACULOUSL
SAVE US ALL, EVEN AT "LONG" DISTANCE
SCALES WHERE IT SHOULD NOT MATTER

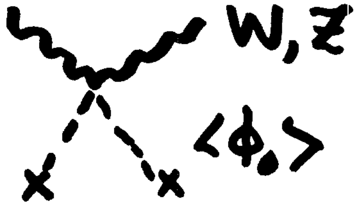
② SOMETHING IS FISHY IN THE
KINGDOM OF SCOTLAND

EXERCISE : GO EXPLAIN TO NON-EXPERTS
WHAT THE ORIGIN OF MASS IS IN SM





ETC



" FRICTION " OF
PARTICLES WITH
THE ETHER

LIKELY OUTCOME : (OWN EXPERIENCE)

YOU WILL BE TAKEN
FOR AN

IDIOT

MORAL:

THE JOB OF EXPERIMENTALISTS IS TO LOOK FOR TROUBLE

THEIR UTMOST JOY IS TO FIND IT

WHAT DO I CARE?

- GO FIND NOTHING BUT AN ELEMENTARY SCALAR WITH THE EXPECTED PROPERTIES
- FOOL THEORISTS/COSMOLOGISTS ALIKE
- DEEPEN THE MYSTERY OF THE NATURE AND "GRAVITY" OF THE VACUUM

BUT, BEWARE! IF YOU DISCOVER "THE HIGGS"

THIS COULD CONCEIVABLY STOP ALL PROGRESS TILL THE DAY

Ⓘ THEORISTS FIGURE OUT QUANTUM GRAVITY

Ⓘⓘ EXPERIMENTS REACH $\sqrt{s} \sim G_N^{-1/2} \sim 10^{19}$ GeV

(WHICHEVER COMES FIRST)

WHAT DO YOU CARE?

(YOU'LL ALL BE RETIRED)

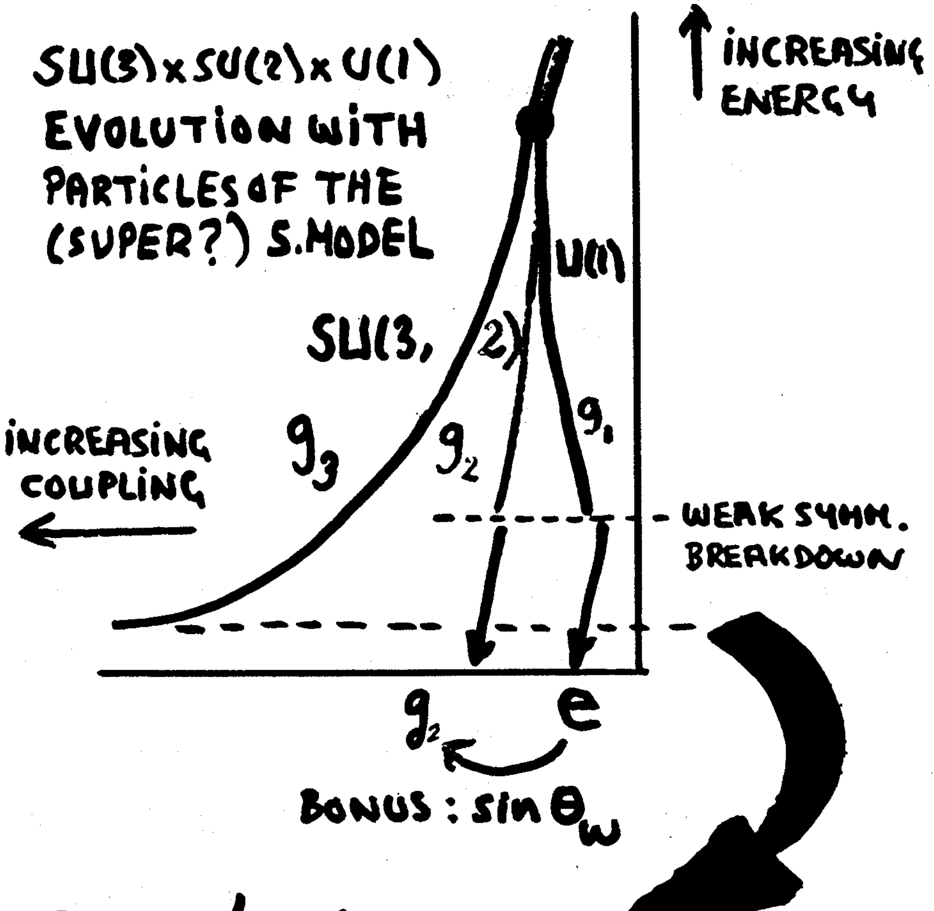
META-

[STANDARD]

PHY-

SICS

REMINDER THE GQW UNIF. GRAND PLOT



BONUS' : α_s BLOWS UP

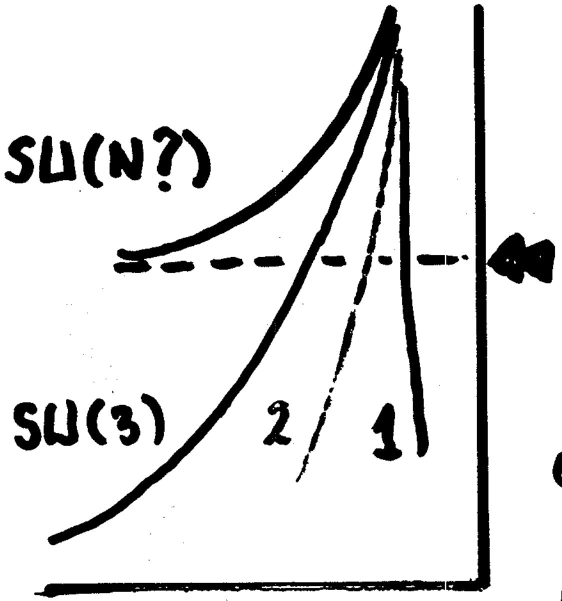
AT $\Lambda_{QCD} \sim 150\,MeV \sim R_H^{-1}$

$m_q \ll \Lambda$ $m_p \sim 2/R_H$ $m_p \sim 3/R_H$

G-UNIF : WE UNDERSTAND QCD SCALE

TECHNICLORE : A NSt ALTERNATIVE
[ELEGANT, SIMPLE]
(AND PROBABLY FALSE)

SUSSKIND...



TECHNI-HADRONS GALORE

"BUILD LHC/SSC AND REENACT YOUR CHILDHOOD"

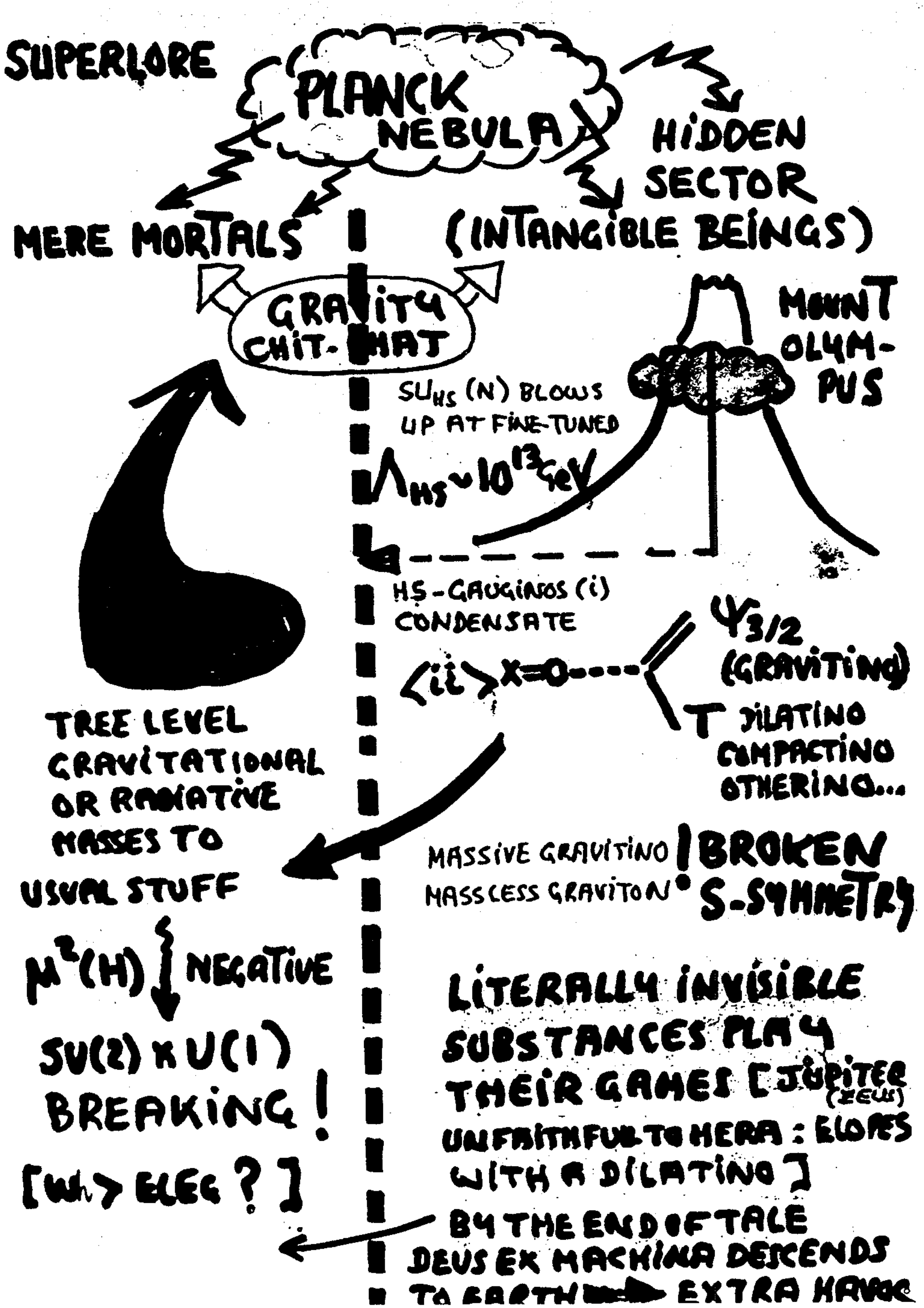
e.g : TECHNI-π'S

$[\pi_T^+, \pi_T^-, \pi_T^0]$

π_T'S JUST RIGHT TO BE [INEVITABLY] SPOUSED TO W, Z AND MAKE THEM MASSIVE

NO ELEMENTARY SCALARS

TROUBLE : MUST TUNE N, AND ALSO MAKE THE RUNNING COUPLING "WALK" (TO AVOID S.C. NEUT. CURRS



CONCLUSIONS (OPTIONAL, PICK YOUR OWN)

- ~~HOW MANY ANGELINOS~~ FIT ON THE TOP OF A SPIN?
- "IF PHYSICS DOES THIS TO ME, I RESIGN MY Ph.D."

- THS' IMAGINATION IS UNBOUNDED
- NATURE CAN EASILY VIOLATE THIS BOUND IF SHE HAS CHOSEN TC or SS, IT IS NO DOUBT IN AN ELEGANT WAY THAT WE HAVE NOT FOUND QUITE YET

EDITOR'S NOTE

THIS AND PREVIOUS TRANSPARS. WILL BE EXCISED FROM THE PROCEEDINGS, FOR FEAR OF THE INQUISITION, AN INEVITABLE CONSEQUENCE OF ALL FUNDAMENTALISMS.

CONCLUSIONS (COMPULSORY)

WE REMAIN IN DARKNESS:

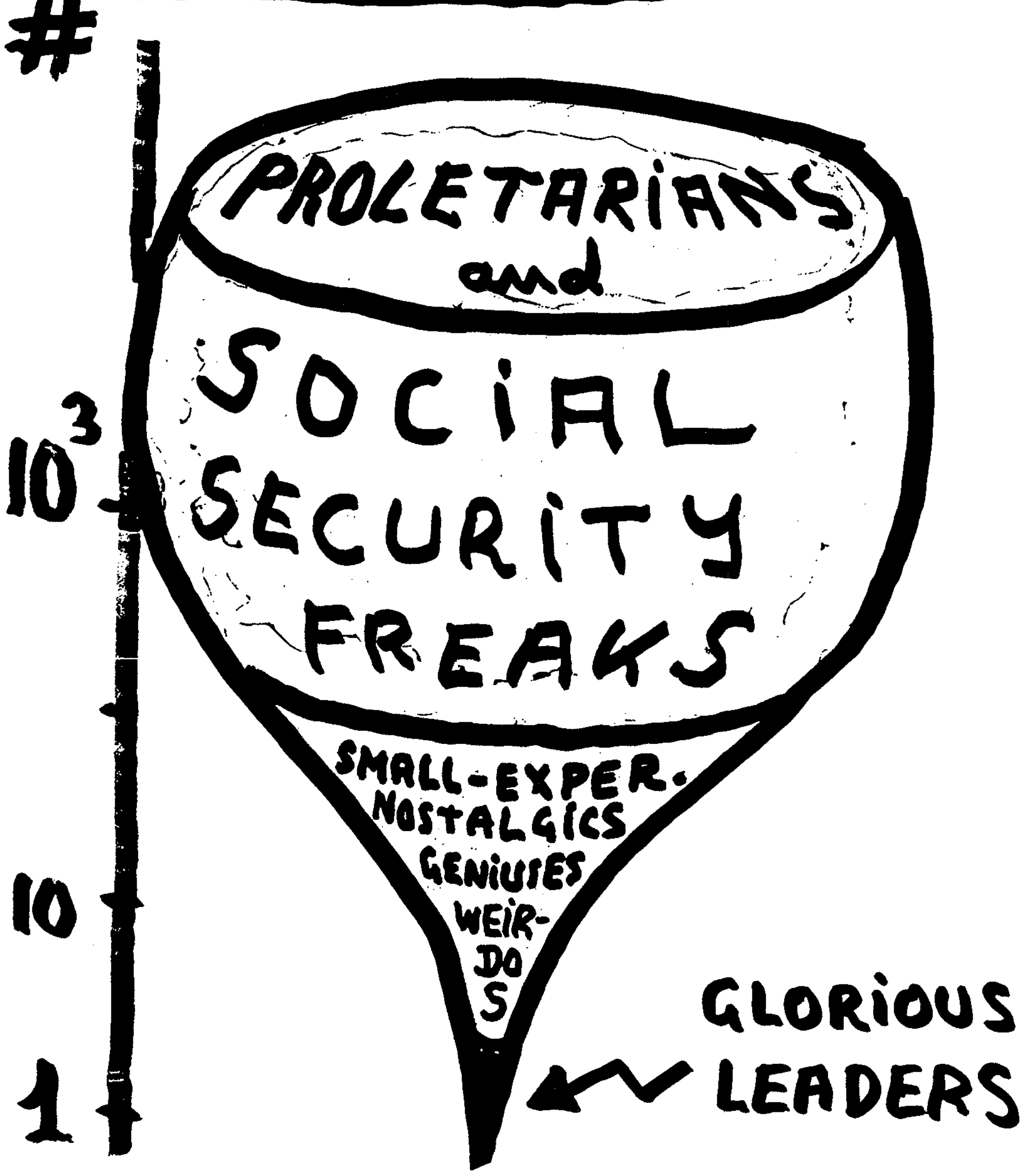
- GAUGE SYMMETRY BREAKING
- THE NATURE OF THE VACUUM
- MASS GENERATION
- THE GRAVITY OF EMPTY SPACE
- COSMO-PARTICLE INTERPLAY

BE PREPARED FOR:

NONE OF THE ABOVE
(Ho
TC
SS)

"UNFASHIONABLE"
META-THEORIES
and
DEMO-PHOBIC
EXPERIMENTS

LHC/SSC DEMOGRAPHICS



"SUBSTRUCTURE"

● EVERY TIME WE AGREE ON THE FUNDAMENTAL CONSTITUENTS NATURE PROVES US WRONG

■ WITH MOLECULES, ATOMS, NUCLEI

LIFE WAS SIMPLE $B, R^{-1} \ll M$

■ WITH HADRONS, TOUGHER $R^{-1} \sim M$

■ FOR q's and ℓ's $R \lesssim 1\,\text{TeV}^{-1}$!

$M \ll 1/R^{-1}$ $\text{ANTI-}\overset{\text{QUANTUM}}{\text{INTUITIVE}}$

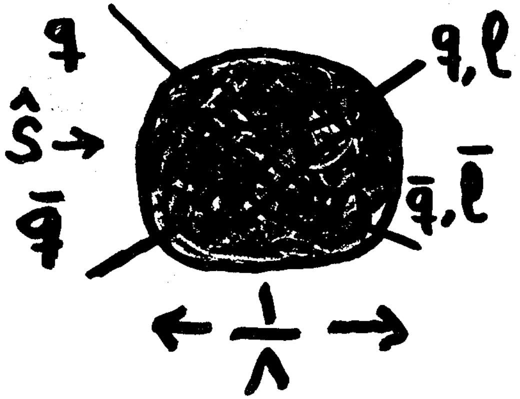
SHORTER WAVE
HIGHER ENERGY

THOUGH WE KNOW HOW TO "PROTECT" A SMALL MASS BY IMPOSING A "CHIRAL" SYMMETRY NO COMPELLING OR EXPLICIT PREON MODEL ∃

FERMI (1932):

UNKNOWNFUTURE ϕ CAN BE FULLY CHARACTERIZED BELOW ITS "TRESHOLD Λ" by A TAYLOR EXPANSION IN S/Λ^2 OF ITS EFFECT ON THE COUPLINGS BETWEEN THE KNOW PARTICLES

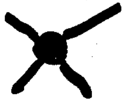
$$\mathcal{L}_F = G_F\, \bar{p} n \bar{e} \nu$$



EHLQ

$$\frac{1}{\Lambda^2}\, \bar{q} q \bar{\mu} \mu$$

$$\frac{1}{\Lambda^2}\, \bar{q} q \bar{q} q$$



DEVIATIONS FROM EXPECTED

$$\frac{d\sigma}{dE^T_{JET}} \qquad \frac{d\sigma}{dM(\mu\mu)}$$

[YOU'LL BE LOOKING FOR Z's ANYWAY]

eg $d\sigma/dE_T$:

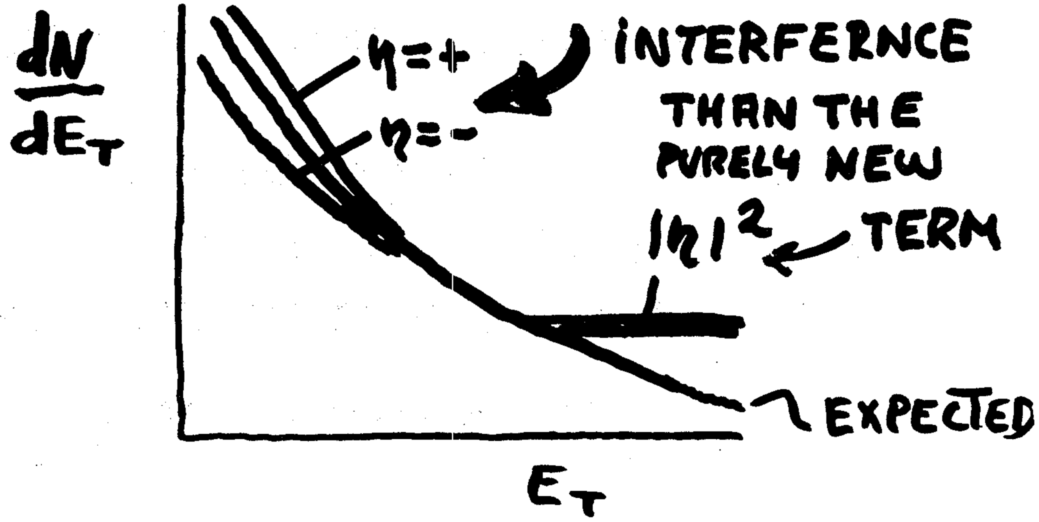
$$\sigma = \frac{\alpha_s^2}{\hat{s}} \longrightarrow \frac{1}{\hat{s}} \left| \alpha_s + \overset{\pm 1}{\eta} \frac{\hat{s}}{\Lambda^2} \right|^2$$

FOR RELATIVELY LARGE Λ^2

[COMPARED TO YOUR REACH]

OR RELATIVELY SMALL STAT.

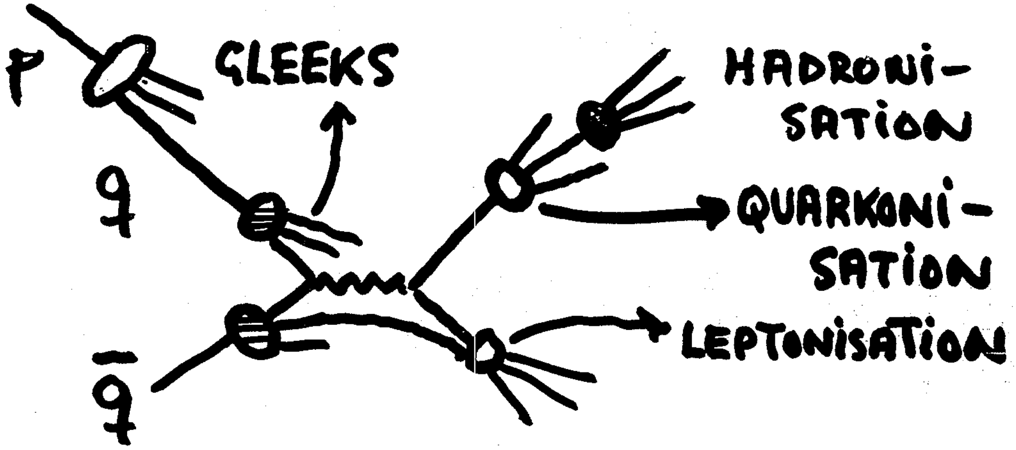
(AT LARGE E_T) IT IS MORE DIFF. TO SEE THE INTERFERNCE THAN THE PURELY NEW $|\eta|^2$ TERM



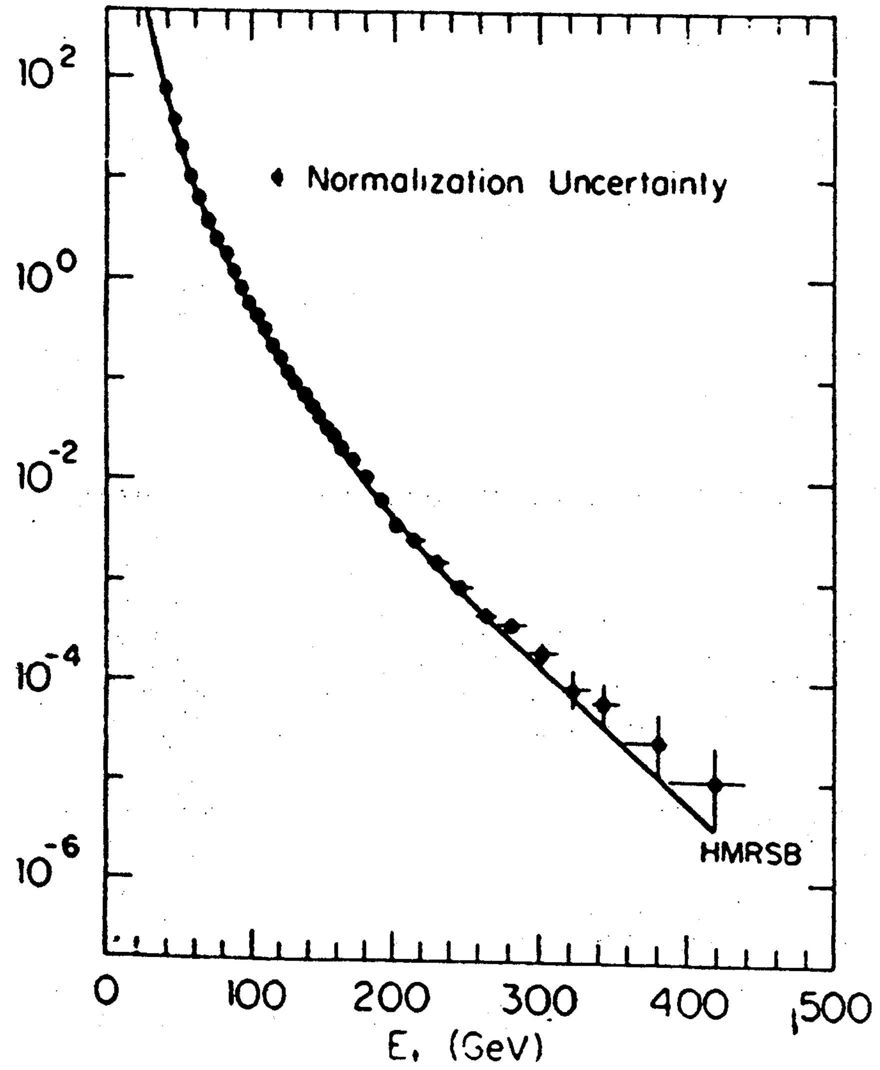
$\Lambda \sim 1$ TeV

AT $\hat{s} \sim \Lambda^2$ YOU HOPE TO SEE NEW RESONANCES.

AT $\hat{s} > \Lambda^2$ YOU SEE GLINTS...



"EXPLOSIVE" EVENTS WITH LARGE MULTIPLICITY AND TRANSVERSE MOMENTAE



$\Lambda \leq$ 1.4 TeV (90%)

THE POSSIBILITY THAT THE
STANDARD MODEL
DIRECTLY PROVIDE GLINTS
IS A SUBJECT OF CURRENT INTEREST

EFFECTIVELY-POINTLIKE BARYON-NUMBER-VIOLATING ANOMALOUS 'INSTANTON' AMPLITUDE

BUT, CALCULATIONS EMPLOY APPROXIMATIONS NOT OBVIOUSLY VALID IN THE REGIME THEY ARE USED

THE FLY
IN THE
STANDARD OINTMENT
–
CP VIOLATION

[redacted]

- U(1) PROBLEM : η' SHOULD BE THE 9TH GOLDSTONE BOSON $m(\eta') < \sqrt{3}\, m_\pi$ (WEINBERG)
- SOLUTION ('t HOOFT) : QCD VACUUM IS NONTRIVIAL $A_\mu(\eta')$ NOT CONSERVED
- DISASTER : THE QCD P, C & T THEOREM (THE QCD LAGRANGIAN IS SO DARNED SIMPLE THAT IT AUTOMATICALLY, SEPARATELY CONSERVES C, P, T) NO LONGER TRUE
- OTHERWISE : WHY IS CP (TO CHOOSE THE MOST CONSERV.) NOT VIOLATED AT THE STRONG LEVEL ?
- NATURAL SOLUTION (PECCEI-QUINN) ENDOW PARTICLES OF S.M. WITH WELL CHOSEN VALUES OF AN EXTRA CHARGE (INTRODUCE NEW GLOBAL U(1), ORIGINALLY and MOST ECONOMICALLY BROKEN AS ~~$U(1) \times SU(2)$~~)
- PRIZE (WEINBERG-WILCZEK) $\exists$ GOLDSTONE : AXION WITH PROPERTIES DETERMINED UP TO ~ 1 PARAMETER (WEAK COUPS, $m \sim$ MeV)
- FIASCO : IT DOES NOT EXIST

THE AXION SCALE f_a $\left(m_a \sim m_\pi^2/f_a\right)$ CONSTRAINED TO NARROW DOMAIN ABOVE WEAK SCALE, BELOW [S]GUT.

f_a STANDS THERE ALL BY ITSELF

CONCLUDE :

- IMPORTANT TO CONTINUE "OPEN-MINDED" AXION SEARCH
- WE HAVE NOT UNDERSTOOD ¡NOT UNDERSTOOD¡ THE STANDARD CP VIOLATION

A COSMOHINT : FOR NON STANDARD $\cancel{CP}$

- WHEN UNIVERSE WAS AT $T > m_e$ THERE WERE AS MANY e^+e^- PAIRS AS PHOTONS.
- A FRACTION ($\sim 10^{-9}$) OF e's (AND BARYONS) SURVIVED.
- THE STANDARD MODEL HAS ALL THE INGREEDIENTS TO GIVE SUCH A "BARYON EXCESS" SPONTANEOUSLY
- BUT ONE OF THEM ($\cancel{CP}$) IS ORDERS OF MAGNITUDE TOO WEAK TO EXPLAIN THE **OBSERVED EXCESS**

ON TOP OF ALL THIS :

WE ONLY HAVE 1½ EMPIRICAL CP NUMBERS (ϵ, ϵ')

⬇

PUT YOUR MONEY ON CP-SHARES

[THE STANDARD EDIFICE IS LIKELY TO CRUMBLE OVER ITS WEAKEST FOOT]

⬇

ATTEMPTS TO OBSERVE $\cancel{CP}$ IN B'S [LHC/SSC/BFACS] ARE SIMPLY **MANDATORY**

[redacted]

u YES [RUTHERFORD : NUCLEUS)

d YES [CHADWICK : NEUTRON]

s NO

c YEAH [$c\bar{c}$ PAIRS]

b NO

t ? UNLIKELY, UNLESS IT IS PECULIAR

e, μ, τ : SWEDES HATE ℓ^-

ν_e NO

ν_μ YES

ν_τ ? UNLIKELY, UNLESS IT IS PECULIAR

— TOP INTERLUDE —

"LEP-YEAR" $\sim 10^7$ secs

A GOOD

"TEVATRON-YEAR" $\sim 10^5$ secs

↓

INCREASINGLY PLAUSIBLE THAT THE TOP WILL BE FOUND AT LHC/SSC

(WHICHEVER COMES FIRST)

THINGS YOU ARE NOT READY FOR

MASSIVE LONG-LIVED PARTICLES

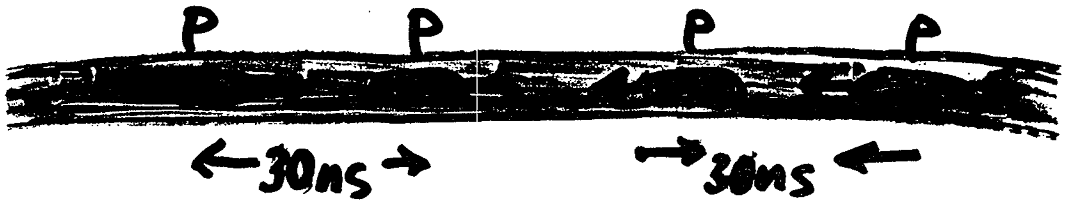
[IF YOU TRY TO MAKE THEM STABLE AND BE THE DARK MATTER OF OUR GALAXY AND THE UNIVERSE (eg: CHAMPS, NEUTRACHAMPS) THEN THEY ARE ALMOST EXCLUDED $\neq f(m)$]

OTHERWISE: WE KNOW LITTLE

eg: A QUIX [A COLOURED $\underline{6}$] WOULD BE STABLE AND BIND TO QUARKS [$\bar{3}$'s] TO MAKE

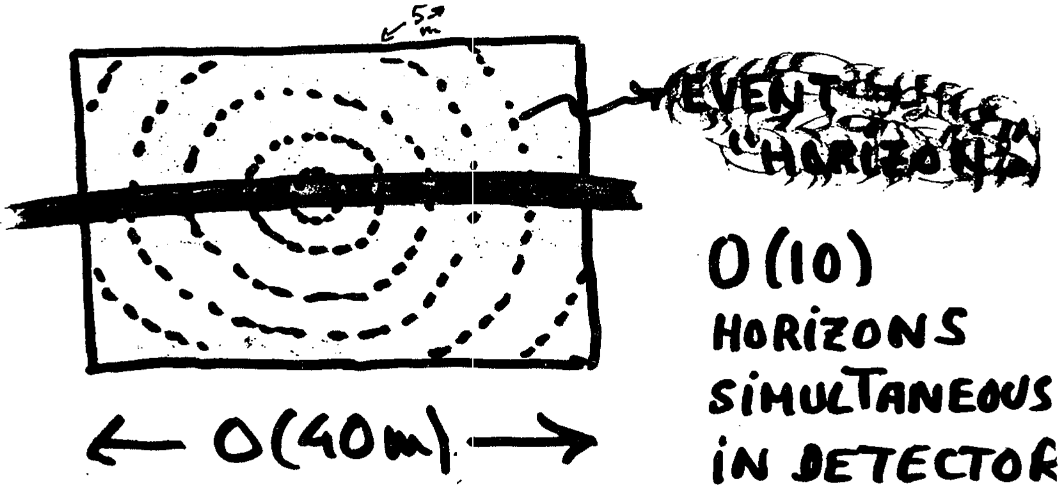
HEAVY HADRONS

SEARCH FOR MASSIVE STABLE PARTICLES AT, e.g. LHC



$c = 1$ (in hardware units $\sim$ 1 foot/nanosec.)

ONE BUNCH CROSSING / 15 nanosecs
LIGHT TRAVELS 5m in that TIME
$n_{CH} \sim 500$/INTER $n_{INTS} \sim 15$ ($\mathcal{L}=10^{3}\,\mathrm{cm}^{-2}\mathrm{s}^{-1}$



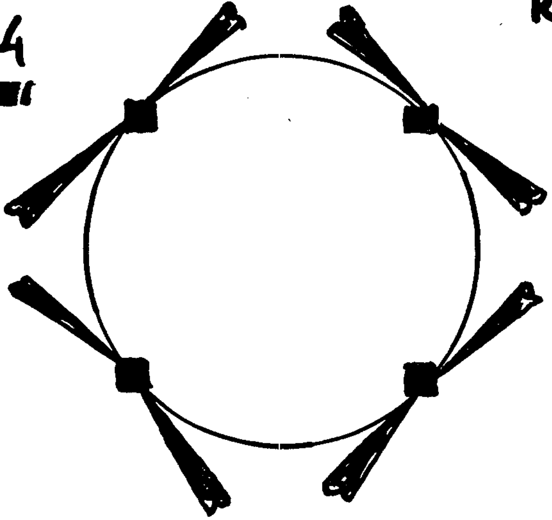
O(10) HORIZONS SIMULTANEOUS IN DETECTOR

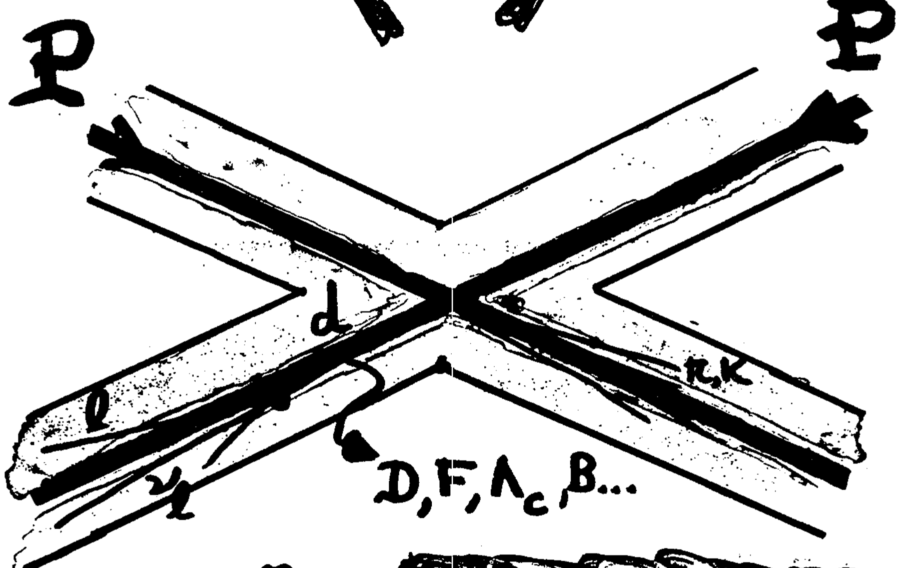
THINGS YOU CAN DO FOR FREE

N = # INT. REGIONS → [redacted]

RUCKL ET AL

e.g. N=4





$\frac{1}{x_F}(1-x_F)^{n\sim5}$

[redacted]

"BEAM-BEAM DUMP" PROMPT DECAYS

ν_τ FACTORIES SSC LHC

- SO MANY $\nu_{e,\mu}$ (μ)

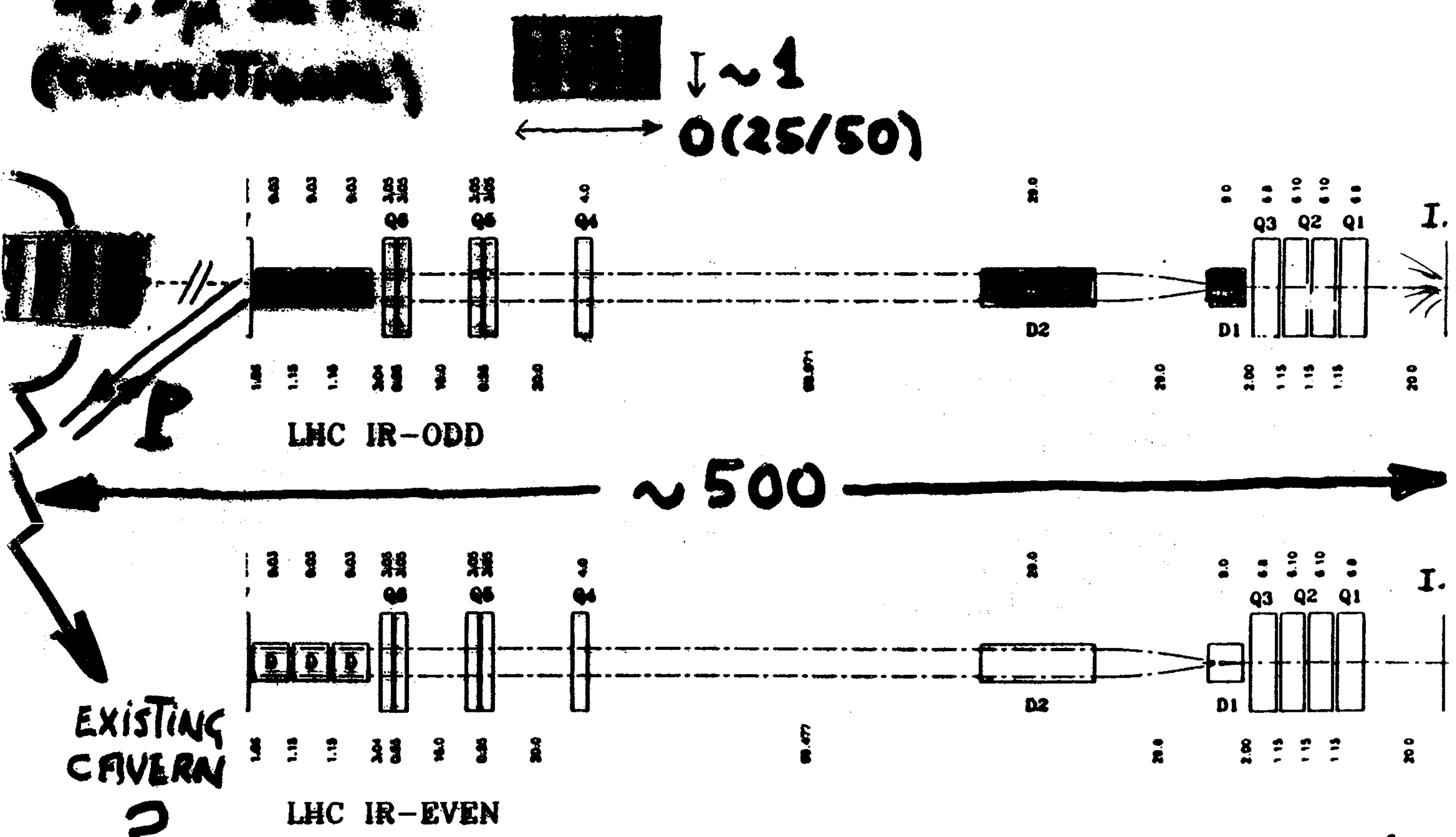
  SO ENERGETIC, COLLIMATED

  ▶▶ DO HIGH-E PHYSICS WITH TENS TO HUNDREDS OF THOUSANDS EVS/YEAR IN "TYPICAL" NEUTRINO DETECTOR (100's ON e^--TARGET)

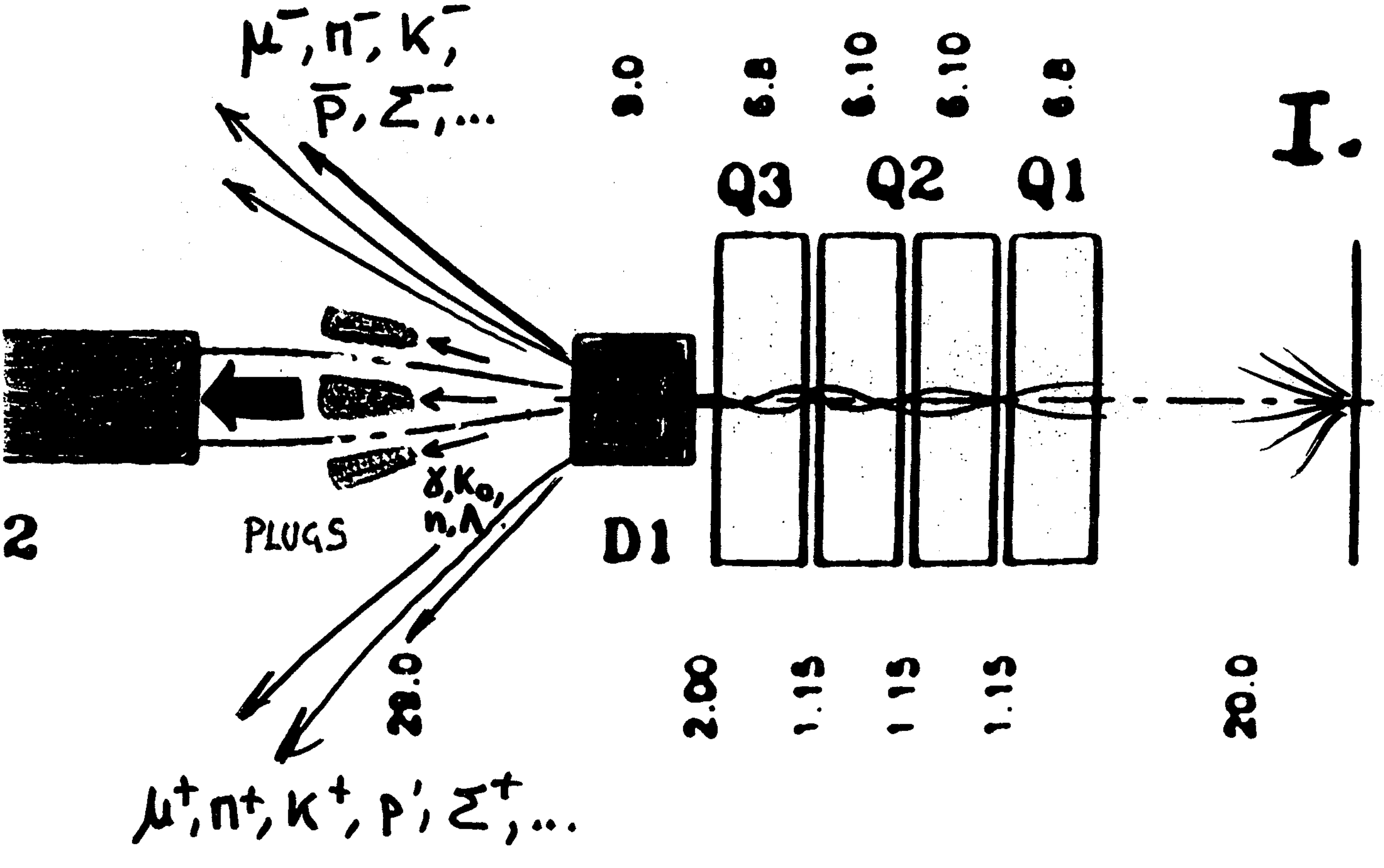
- SUFFICIENTLY MANY ν_τ's TO DISCOVER 'EM

  $\nu_\tau \to \tau + \ldots$

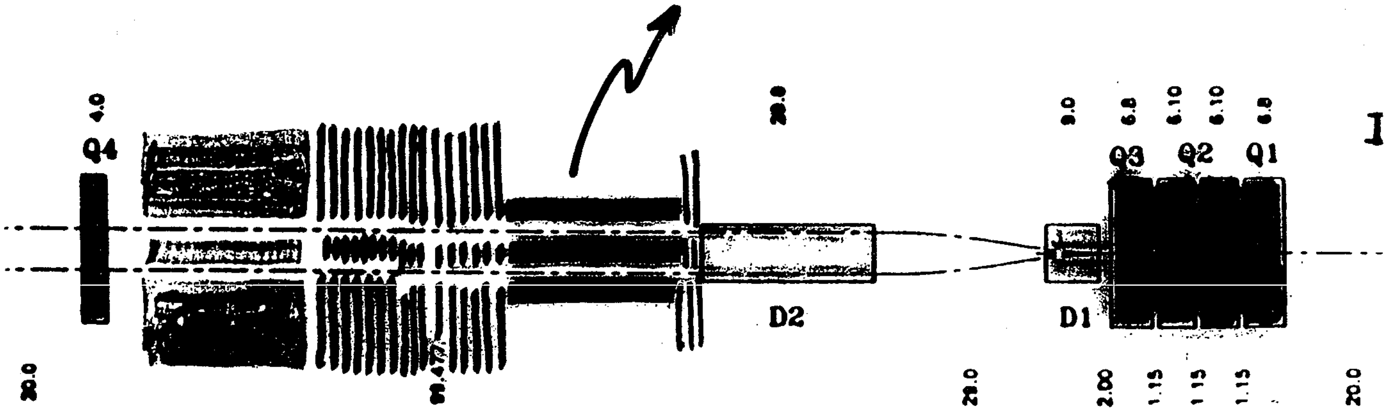
ν_e, ν_μ DETR. (CONVENTIONAL)



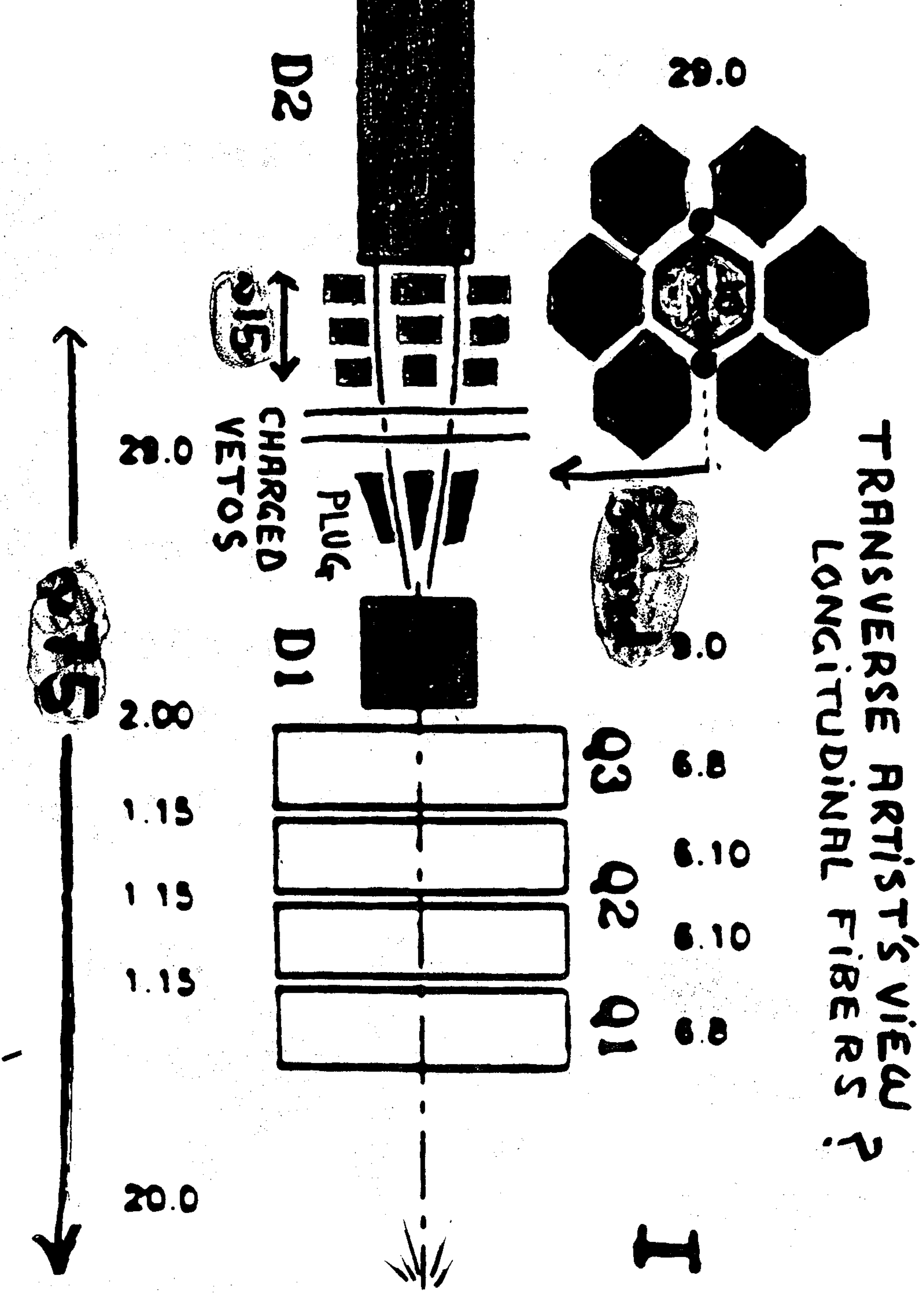
(ON TANGENT TO HIGH-LUMINOSITY INTERSECTION)



ν_τ ACTIVE TARGET



$$E_\nu(\theta)\frac{d\Phi_\nu}{d\cos\theta} \sim e^{-\theta/10^{-3}}$$



DETAILED MODELING

OF $\nu_{e,\tau,\mu}$ BEAMS

(E. FERNANDEZ, J.J GOMEZ-CADENAS et Al)

① EXPS ON CHARM PRODUCTION
> SOMEWHAT IMPROVED > 84

② INMORALLY SUCCESFUL TH
OF MULTIPARTICLE PROD.
(KAIDALOV et al.)

③ BETTER UNDERSTANDING
(AND "PESSIMISATION")
OF $\langle P_T [m_{\pi,K,p,D}, \sqrt{s}] \rangle$
(HAGEDORN - INSPIRED)

KAIDALOV et al.

pp
πp
pN
πN

$\Rightarrow$

$\pi^{\pm}+\ldots$
$p(\bar{p})\ldots$
$K,\bar{K},\Lambda,\bar{\Lambda}$
$D,\bar{D},\Lambda_c\ldots$ $\Leftarrow$ US (D_s)

$\sigma,\ \frac{d\sigma}{dx(y)}$
USEFUL TO

K: "QUARK-GLUON STRING MODEL"

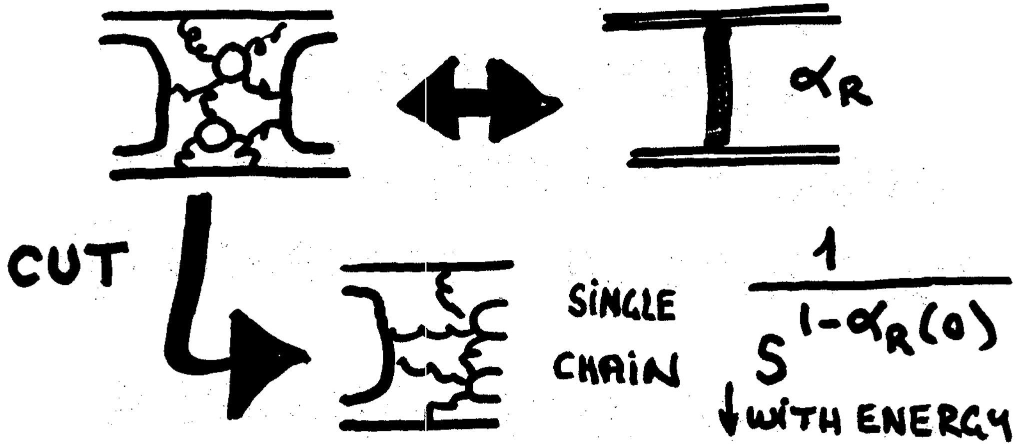
● $\left(\frac{1}{N[\text{LIGHT FLAVORS}]}\right)^2$ ⇒ TOPOL. CLASSIF OF QCD DIAGRS.

● ANALITICITY + UNITARITY ⇒ "REGGEON" CALCULUS

MULTIPLICITIES
MULTIPLIC. DISTRIBUTIONS
DEVIATIONS / KNO SCALING
$d\sigma/dt$ ELASTIC
$\rho = ReT/ImT\,|_{t=0}$
RESOLUTION OF SOME "PUZZLES"

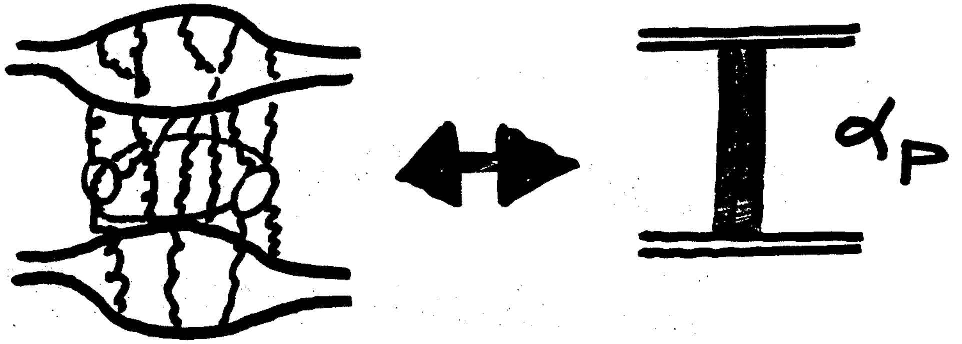
⇑ IN TERMS OF ② PARAMETERS PER PRODUCED FLAVOUR-TYPE

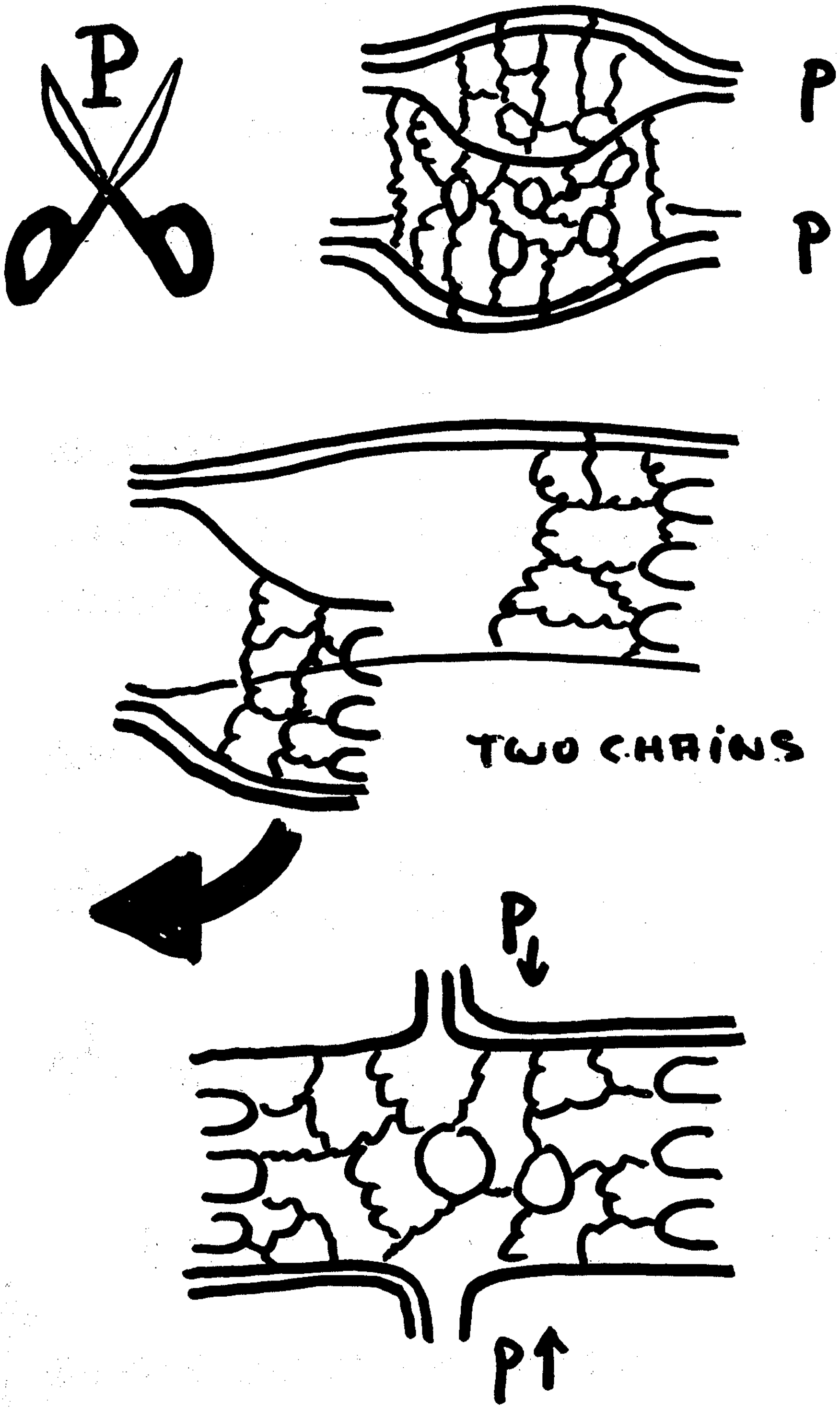
$\sigma(s_0),\ \alpha_R(0)$



$\frac{1}{s^{1-\alpha_R(0)}}$
↓ WITH ENERGY

POMERON ↑ WITH ENERGY





pp → h + ...

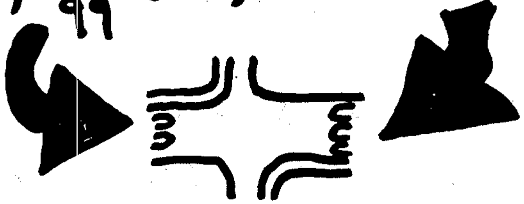
- $$\frac{d\sigma^h}{dx} = \sum_n \sigma_n(s)\, \varphi_n^h(s,x)$$

  ↓

  n cut Pomerons [GRIBOV calculus in - QUASI-EIKONAL approx.

- $$\varphi_1^h = F_q^h(x_+)\, F_{qq}^h(x_-) + (+\leftrightarrow -)$$

F = STRUCT. F. ⊗ FRAG. F.



- $$x_\pm = \frac{1}{2}\left(\sqrt{x^2 + x_\perp^2} \pm x\right)$$

$$x = \frac{2p_{\parallel}^h}{\sqrt{s}}$$

$$x_\perp = \frac{2\sqrt{m^2 + p_T^2}}{\sqrt{s}}$$

CORRECT KYNEMATICS ABSOLUT.
ESSENTIAL, AS IN DEEP INEL.
SCATTERING [ξ-SCALING]

(TRIVIALLY RESOLVED CONUNDRUM

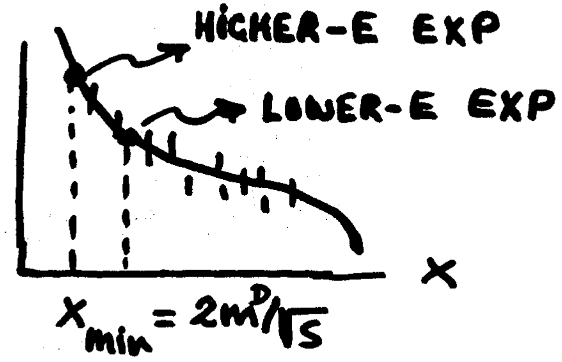
$pp \rightarrow D + \ldots$ FIXED TARGET

$$E_p = 400\,\mathrm{GeV} \quad \frac{d\sigma}{dx} \sim (1-x)^{4.9 \pm 0.5}$$

$$E_p = 800\,\mathrm{GeV} \quad \frac{d\sigma}{dx} \sim (1-x)^{11.2 \pm 0.9}$$

ROUGH TH. $\frac{d\sigma}{dx} \sim \boxed{\frac{1}{x}} (1-x)^m$

THRESHOLD EFFECTS NOT NEGLIGIBLE



$m(400) \sim 3.5 \pm 1.0 \quad m(800) \sim 6.0 \pm 1.5$

NON-ROUGH THEORY GETS RID OF DISCREPANCY)

$(x_+ x_-)$ STRING $\blacktriangleright$ $h + \ldots$

$$\varphi_1 = F(x_+)F(x_-) + (+ \leftrightarrow -)$$

$$F_u^h(x) = \int_x^1 dx' f^u(x')\, G^h\left(\frac{x}{x'}\right)$$

(LOW-Q^2 "STRUCT. FUNCT.") (LOW-Q^2 "FRAGM. FUNCT.)

f, G AT $\begin{matrix} x \rightarrow 0 \\ x \rightarrow 1 \end{matrix}$ DETERMINED BY REGGE POLE ARGUMENTS

e.g $f(x \rightarrow 0) \sim x^{-\alpha_M(0)}$

$f(x \rightarrow 1) \sim (1-x)^{\alpha_M - 2\alpha_N}$

ANSATZ $f(x) = f(x \rightarrow 0) \times f(x \rightarrow 1)$

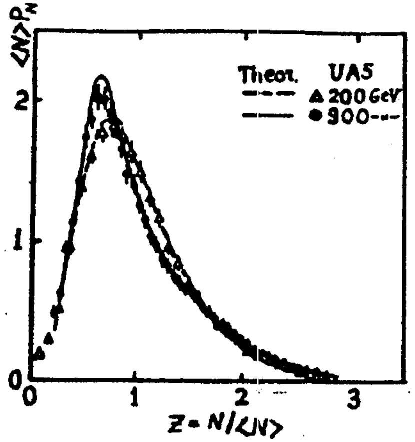


Fig. 14. b) full curve $\sqrt{s}$ = 900 GeV, dashed one $\sqrt{s}$ = 200 GeV

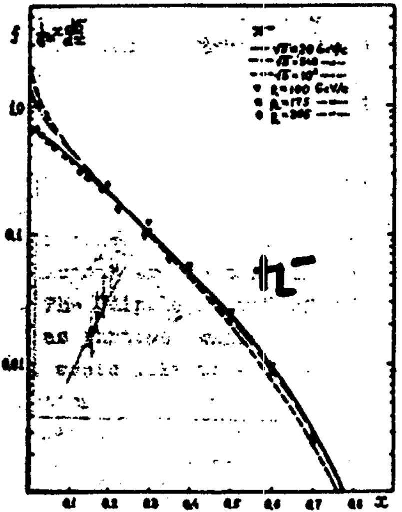


Fig. 15. π^--spectra in pp-interactions

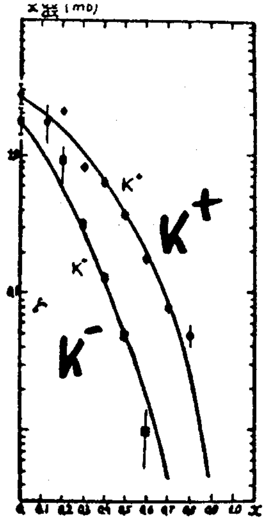


Fig. 16. K^+ and K^- spectra at p_L = 175 GeV

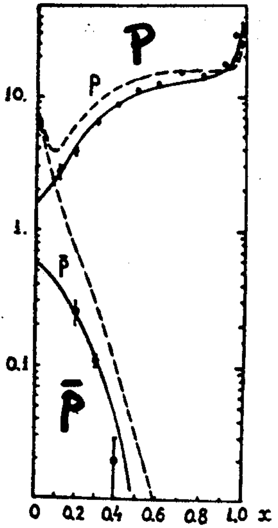


Fig.17. p and $\bar{p}$ -spectra. Experimental points for p_L = 175 GeV. Full curve for $\sqrt{s}$ = 20 GeV, the dashed one for $\sqrt{s}$ = 540 GeV.

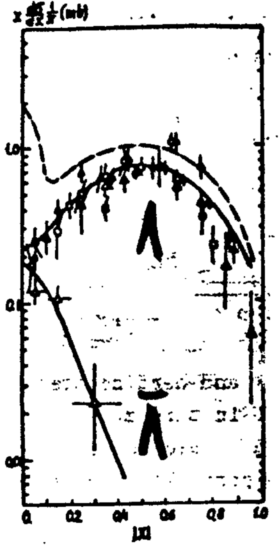


Fig.18. Spectra of Λ and $\bar{\Lambda}$ hyperons. Theoretical curves for $\sqrt{s}$ = 27.5 GeV/c (full curve) and $\sqrt{s}$ = 540 GeV/c (dashed one)

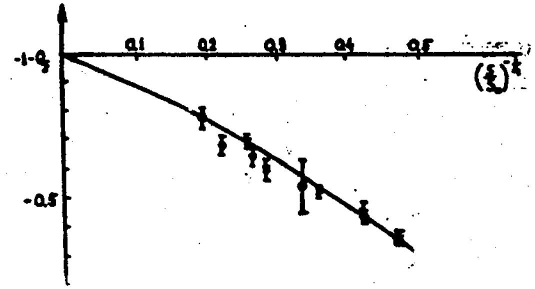


Fig.20. Energy dependence of $1-Q_\xi$ in $\pi^- p$ -interactions

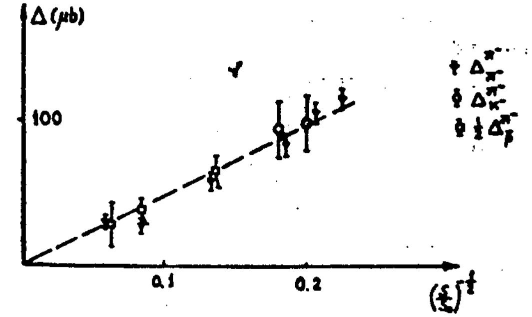


Fig.21. Comparison of the relation $\Delta_{\pi^-}^{\pi^-} = \Delta_{K^-}^{\pi^-} = \frac{1}{2}\Delta_{\bar{p}}^{\pi^-}$ with experiment

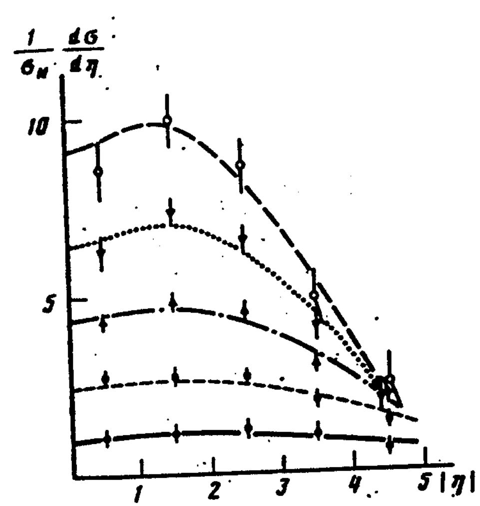


FIG. 9. Description of the data of the UA5 group[3] on the multiplicity dependence of the rapidity distributions. The continuous curves (dark circles) is for $2<N_{ch}<17$, the broken curve (squares) is for $18<N_{ch}<31$, the chain curve (triangles) is for $32<N_{ch}<45$, the dotted curve (inverted triangles) is for $46<N_{ch}<60$, and the curve with long dashes (open circles) is for $60<N_{ch}<90$.

$pp \rightarrow \pi^+$

$pp \rightarrow \pi^-$

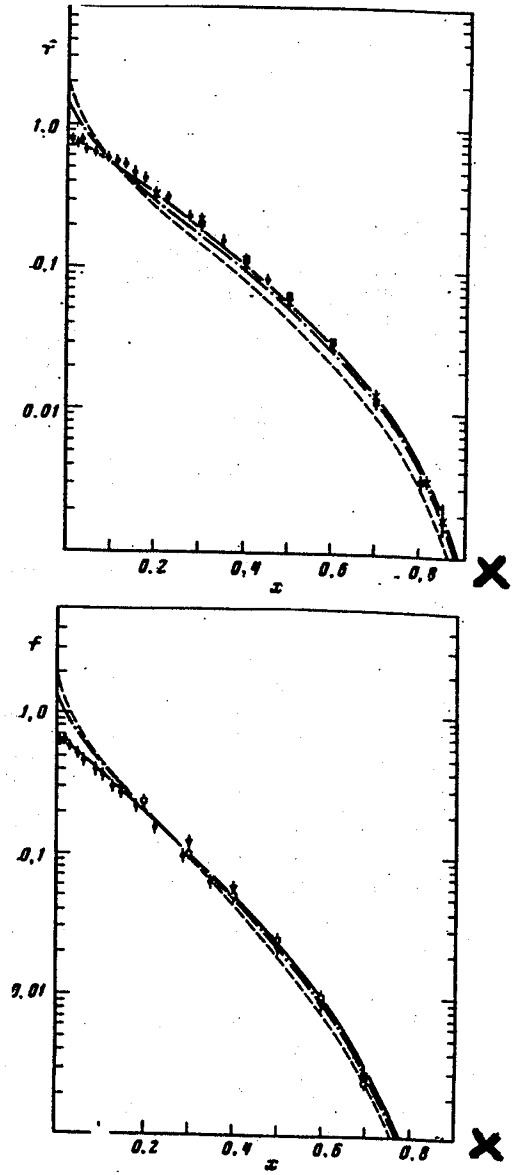


FIG. 10. Inclusive cross section f for π^+ mesons (a) and π^- mesons (b) at various energies. The data at $\sqrt{s} \approx 20$ GeV (Ref. 5) are shown. The continuous curve is for $\sqrt{s} = 20$, the chain curve for $\sqrt{s} = 540$, and the broken curve for $\sqrt{s} = 10^4$ GeV. Points for π^+: the crosses are for $p_{lab} = 100$, the dark squares for 175, and the dark circles for 205 GeV/c; for π^-: the inverted triangles are for $p_{lab} = 100$, the open squares for 175, and the open circles for 205 GeV/c.

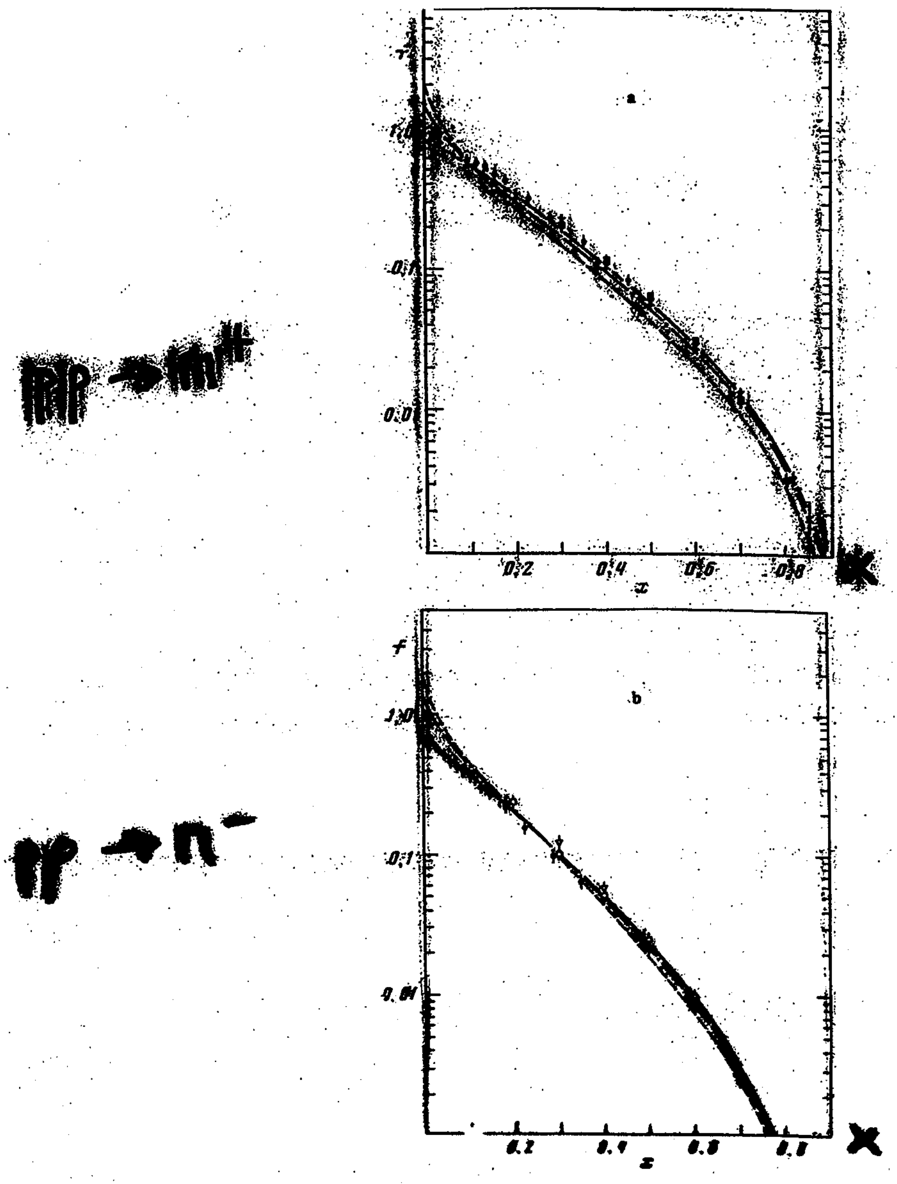


FIG. 10. Inclusive cross section f for π^+ mesons (a) and π^- mesons (b) at various energies. The data at $\sqrt{s} \approx 20$ GeV (Ref. 5) are shown. The continuous curve is for $\sqrt{s} = 20$, the chain curve for $\sqrt{s} = 540$, and the broken curve for $\sqrt{s} = 10^6$ GeV. Points for π^+: the crosses are for $p_{lab} = 100$, the dark squares for 175, and the dark circles for 205 GeV/c; for π^-: the inverted triangles are for $p_{lab} = 100$, the open squares for 175, and the open circles for 205 GeV/c.

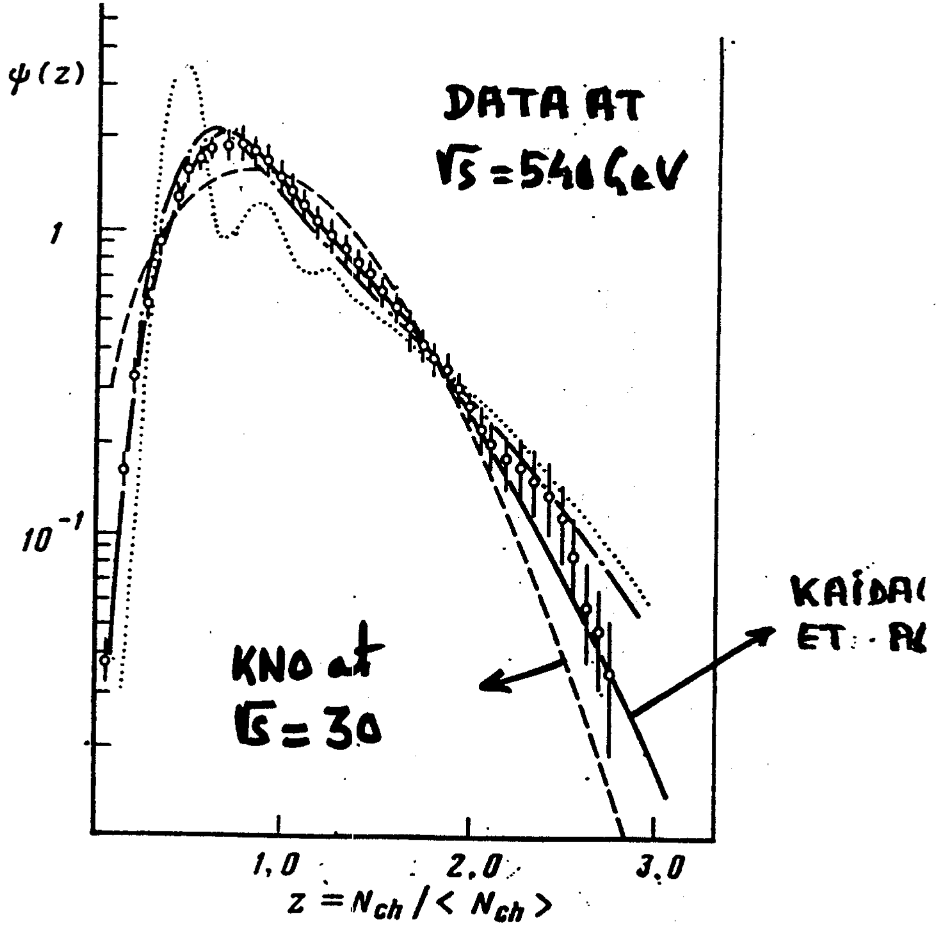


FIG. 6. The KNO function $\psi(z,\xi) = \bar{N}_{ch}\sigma_{N_{ch}}/\sigma^{in}$ as a function of $z = N_{ch}/\bar{N}_{ch}$ at $\sqrt{s} = 540$ GeV.[4] The continuous curve is the predicton of the model (variant 1 of Ref. 1), the broken curve is the KNO curve at $\sqrt{s} \sim 30$ GeV, the chain curve is the prediction of the model (variant 2), and the dotted curve is the prediction of the theory for the distribution at $\sqrt{s} = 10^5$ GeV.

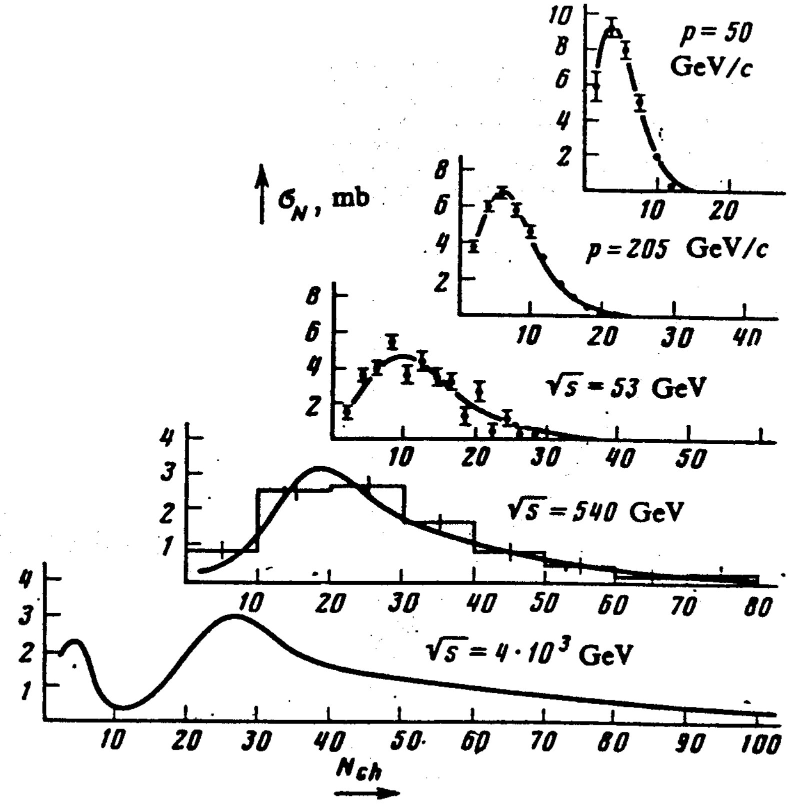


FIG. 4. Predictions of the model and their comparison with experimental data on the multiplicity distributions of charged particles in pp and $\bar{p}p$ interactions[3,5] (at $\sqrt{s} = 540$ GeV, the absolute values of the cross sections are obtained by multiplying $(\sigma_{N_{ch}}/\sigma^{in})_{exp}$ by σ^{in}_{theor}). The theoretical curve at $\sqrt{s} = 540$ GeV, like the experimental data, contains no contribution from single diffracton dissociation (at the other energies, this contribution is included).

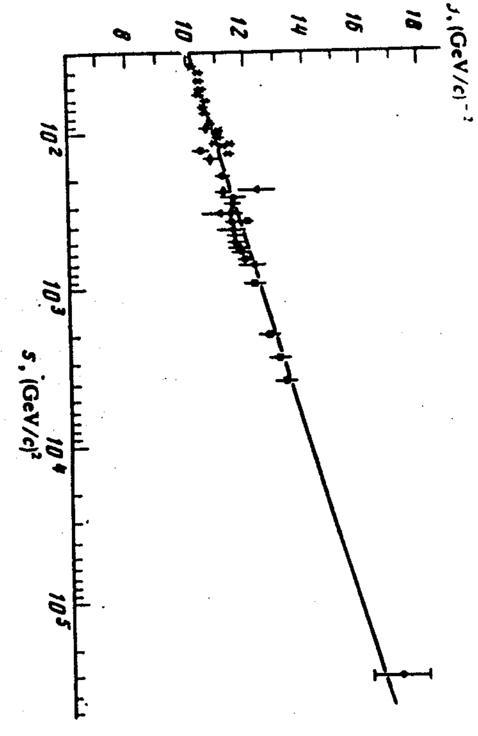
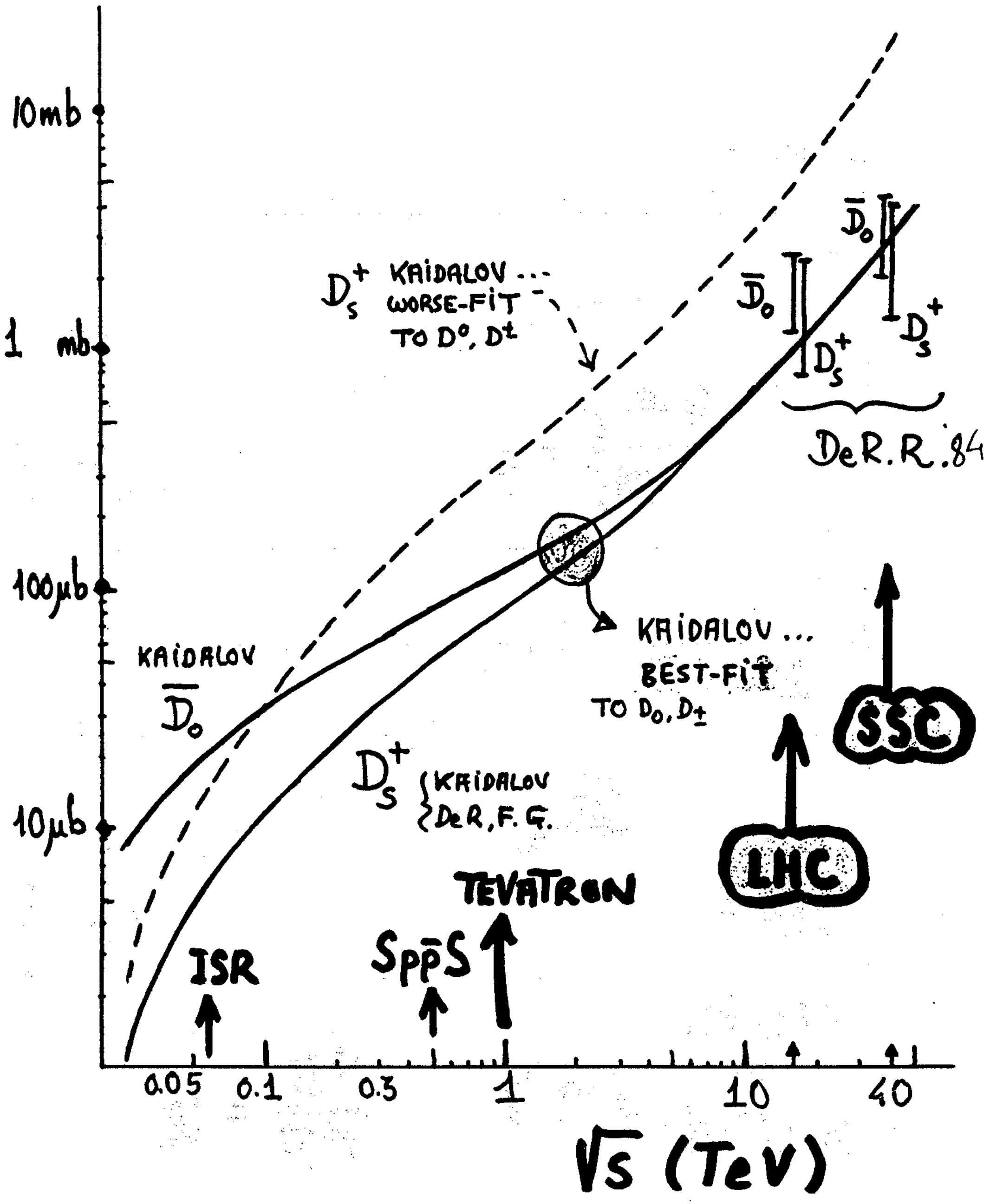
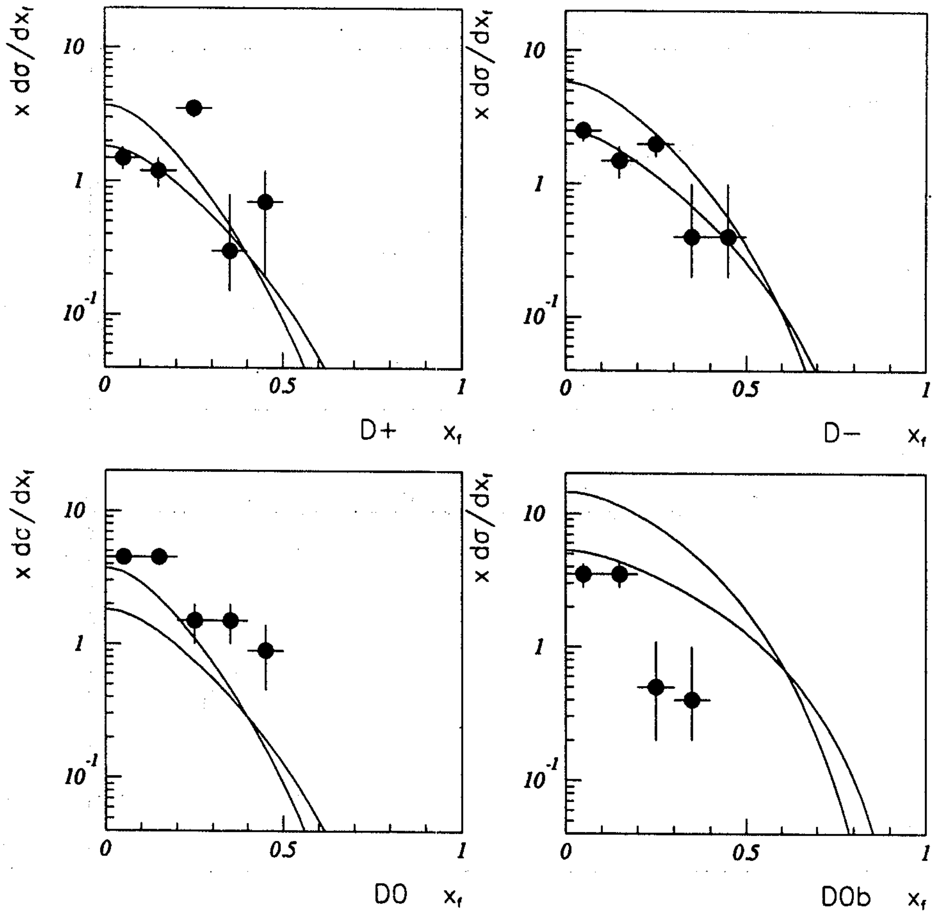
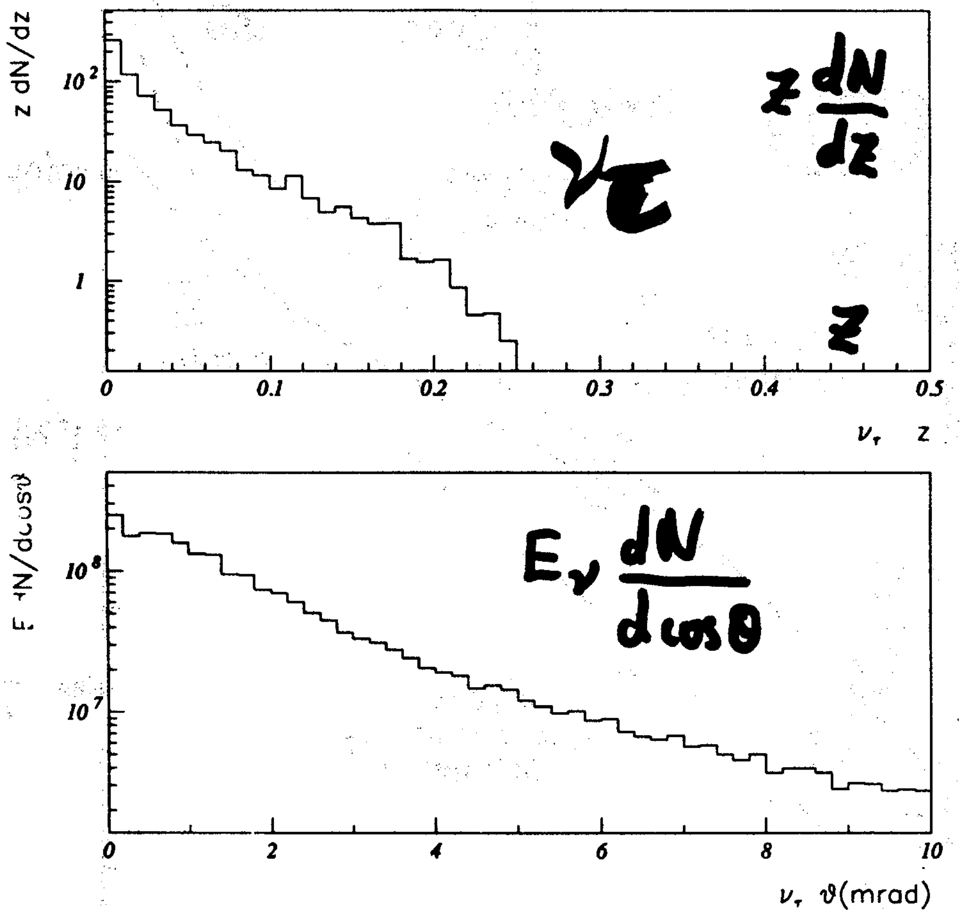


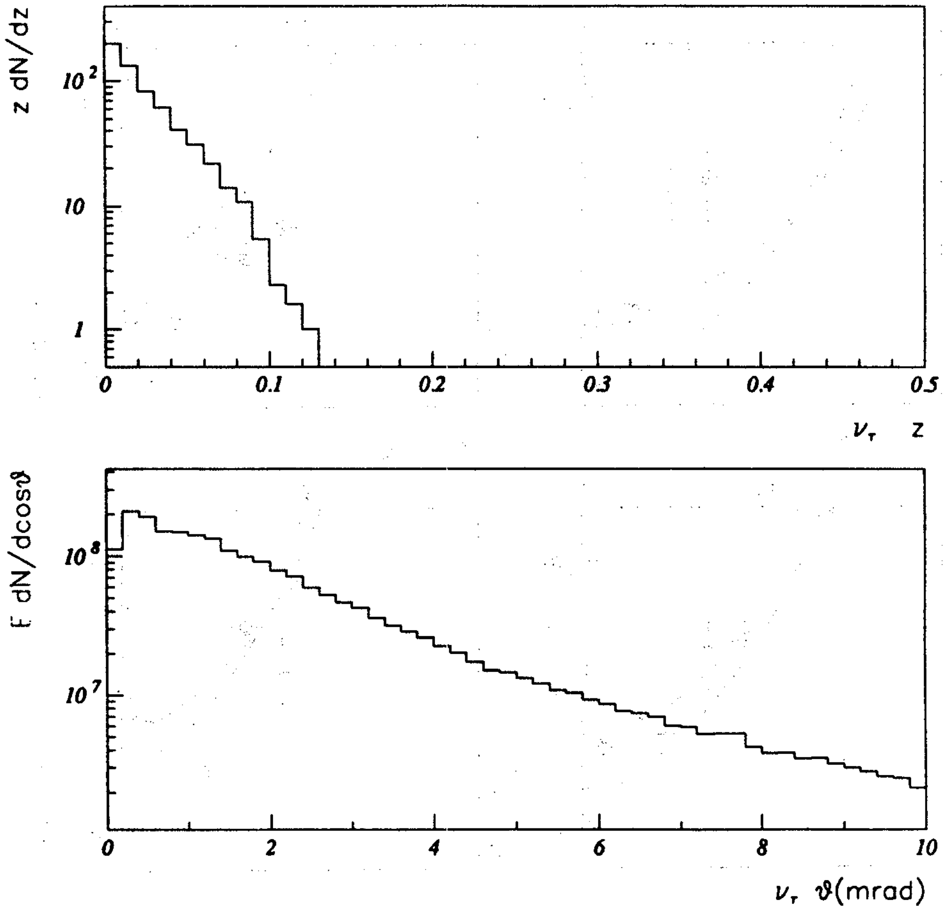
FIG. 2. Prediction of the model of a supercritical Pomeron (Re of Ref. 1) for the slope of the diffraction peak, $B(\xi)$ ($|t| \lesssim 0.1$ G
and its comparison with experiment.


10mb
1 mb
100μb
10μb
D_s^+ KAIDALOV ... WORSE-FIT TO $D^0, D^\pm$
$\overline{D}_0$
$\overline{D}_0$
D_s^+
D_s^+
DeR.R.84
KAIDALOV $\overline{D}_0$
KAIDALOV ... BEST-FIT TO $D_0, D_\pm$
D_s^+ {KAIDALOV DeR, F.G.
TEVATRON
ISR
$Sp\bar{p}S$
LHC
SSC
0.05
0.1
0.3
1
10
40
√s (TeV)


x dσ/dx_f
10
1
10^-1
0
0.5
1
D+
x_f
D−
DO
DOb

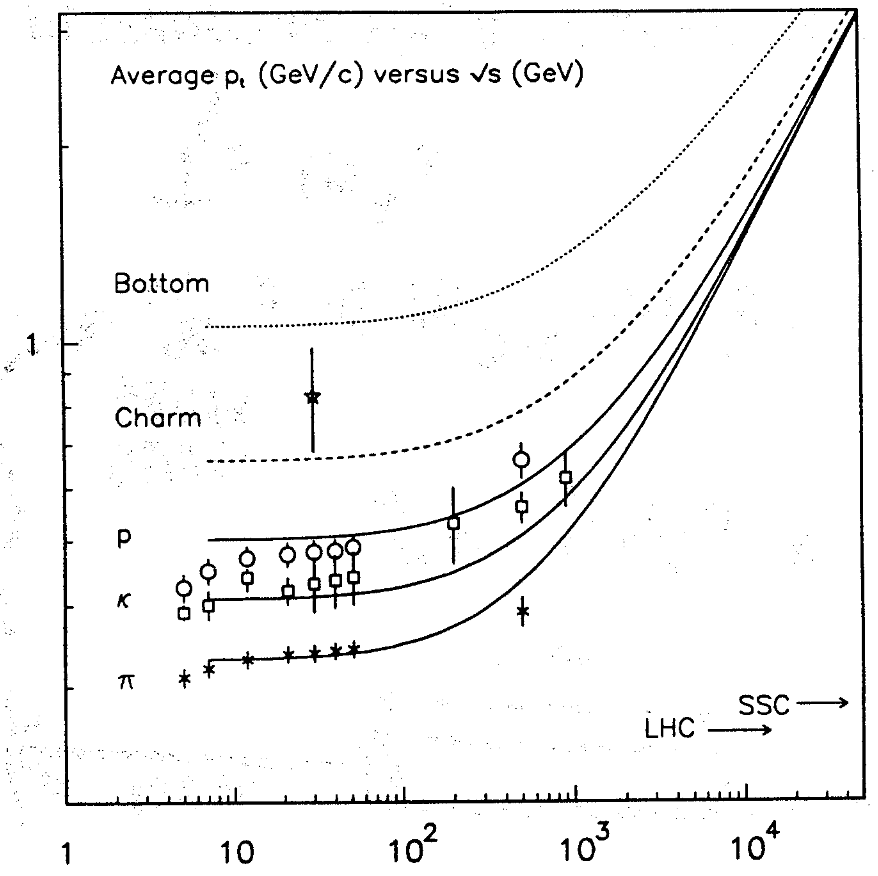
$z = \frac{E_\nu}{E_p}$ LHC BEAM * BEAM

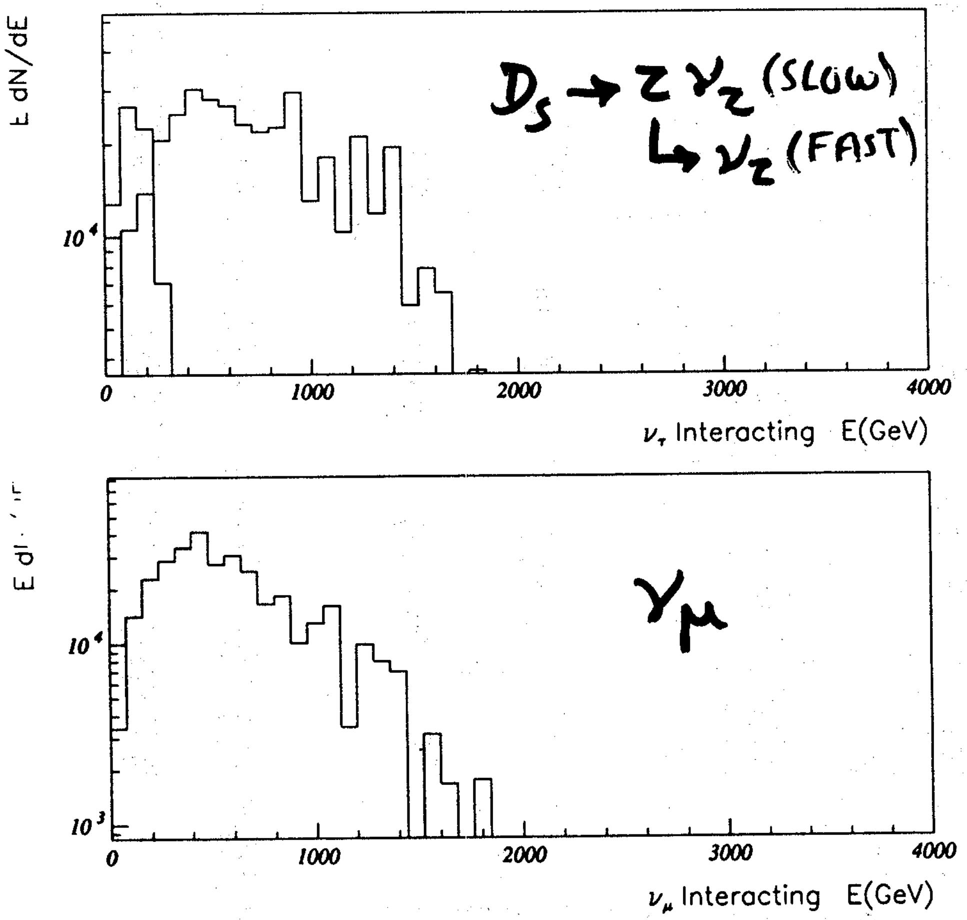




LHC
FIXED TARGET

INTERACTING ν's





	$\sqrt{s}$ TeV	P_T GeV	σ_{D_s} μb	$\#\nu_\mu$	$\#\nu_\tau$	MODEL
LHC B*B	16	2	4000	80000	9000	OPT
			1000	30000	3000	PESS
LHC B*T	.123	1	45	60000	6000	OPT
			15	30000	3000	PESS

COMPARABLE, BUT BEAM * BEAM PARASITIC
BEAM * (SCRAPER, DUMP) DEDICATED

ν_τ "VERTEX" DETECTOR

[FINE GRANED] FIBERS
Si-SANDWITCHES
ICARUS-chambers

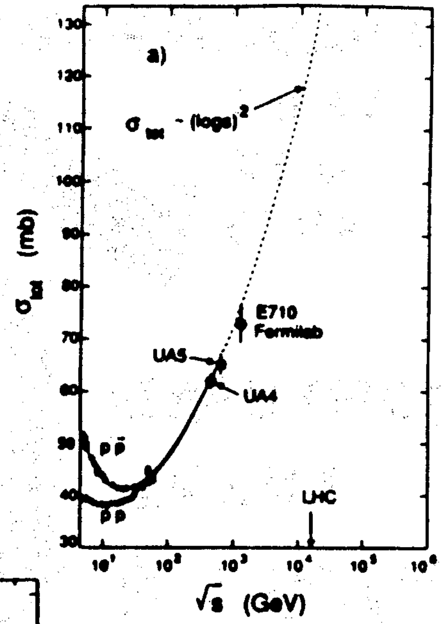
$\rho = 2\ gr/cm^3$

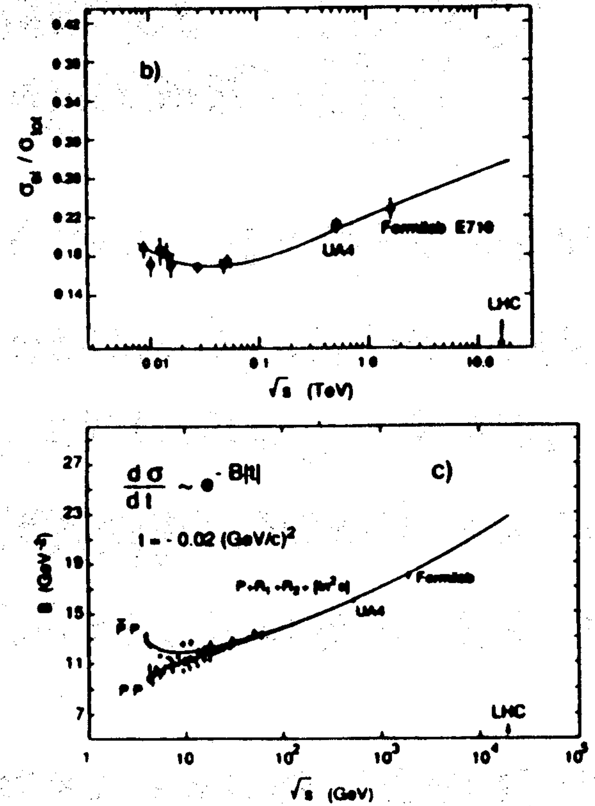
BEAM-BEAM $\mathcal{L} = 4\ 10^{34}\ cm^{-2}s^{-1}$

$T_y = 10^7 s$

ALTERNATIVE FIXED-TARGET SOURCE
BEAM SCRAPER SCRAPING ALL p's
THAT YOU CAN [DEDICATEDLY] ACCELERAT
($\sim 5\ 10^{17}/y$: SCANDALE)

Fig. 2 a) Total cross-sections, b) ratio of elastic to total cross-sections, and c) forward elastic slope, with extrapolations to the LHC





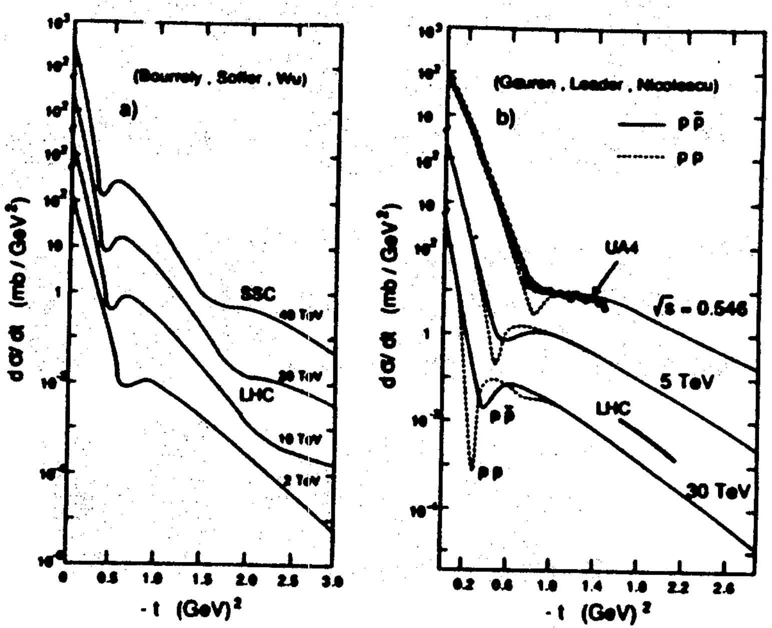


Fig. 3 Elastic differential cross-sections in the large-t range.

WE UNDERSTAND

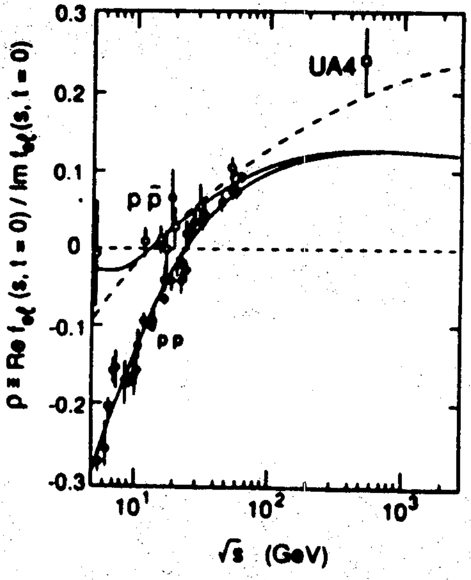
σ_{TOT}, $d\sigma/dt$ [t(]

FOR PP, $P\bar{P}$

ON MIGHTY

GENERAL

GROUNDS



ρ : IS "THE SURPRISE" WHERE WE EXPECT IT LEAST ?

Fig. 4 Compilation of data on ρ; the dashed line is the 'odderon model' prediction, solid line is the standard prediction.

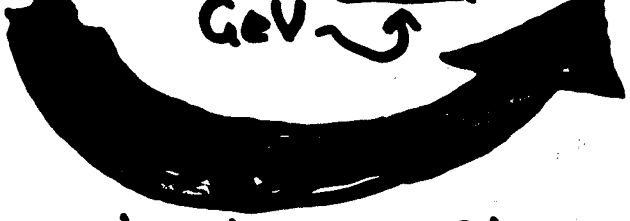
LESS THAN SUBLIMINAL MESSAGE

CONTRARY TO VARIOUS (ORTHOGONAL) THEORETICAL "FAITHS" WE KNOW NOTHING ABOUT ∅ ABOVE THE STUMBLING WALL: [redacted]

INTOLERABLY PRECISE UNDERSTANDING

PHYSICS ≥ 1 TeV = TOTAL IGNORANCE

250 GeV



GOOD OLD DAYS

PHYSICS IS EXPERIMENTATION RESULTS ARE SURPRISES

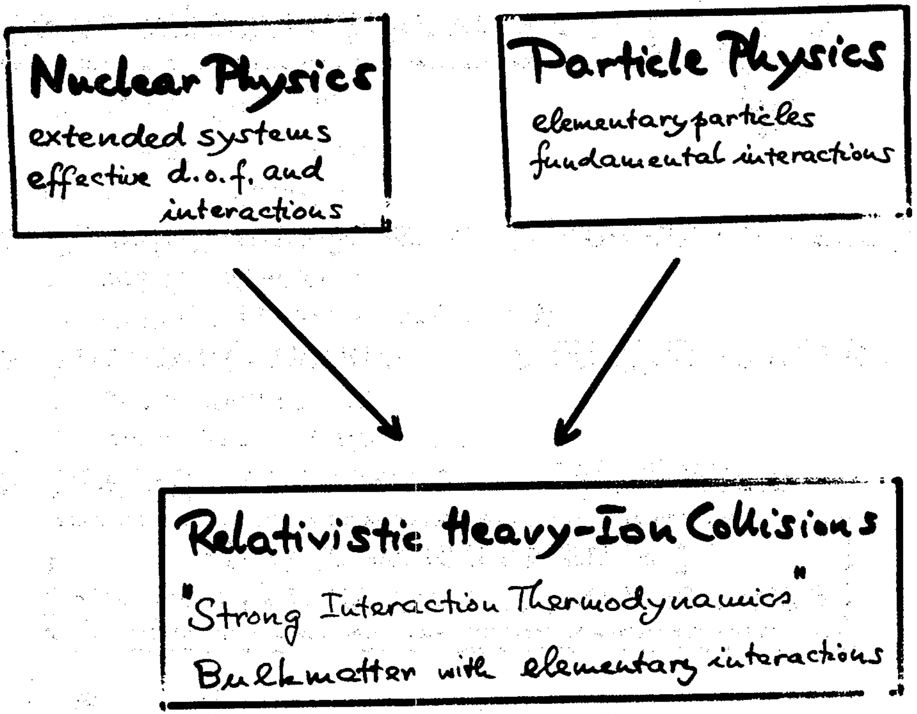
THAT (I THINK) IS WHY WE ARE HERE TODAY

Heavy ion physics at the LHC

U. Heinz (Regensburg)

Heavy Ion Physics
at the
LHC

1. Aims
2. Global Features
3. Initial Conditions
4. Space - Time Evolution
5. Experimental Probes



Nuclear Physics
extended systems
effective d.o.f. and interactions

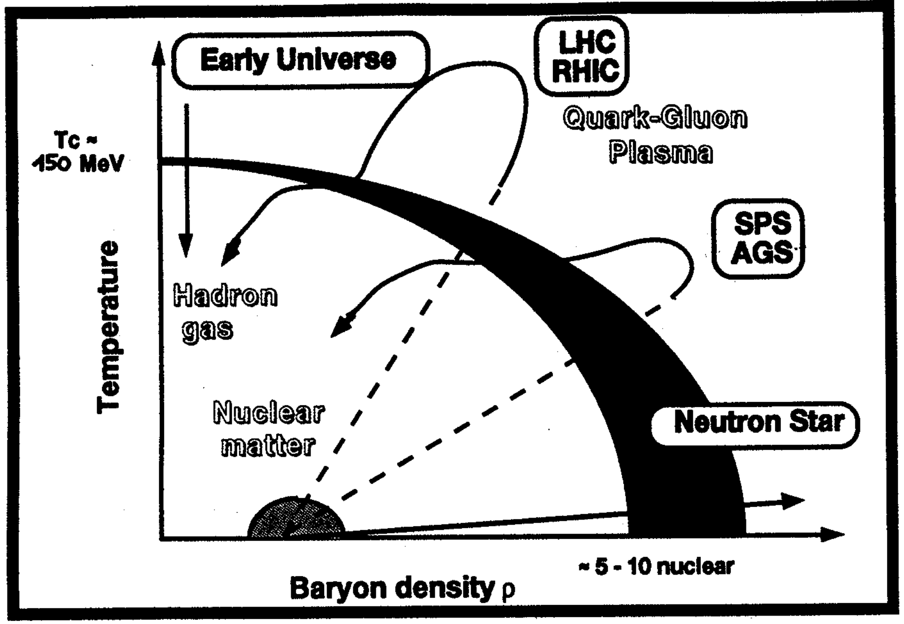
Particle Physics
elementary particles
fundamental interactions

Relativistic Heavy-Ion Collisions
"Strong Interaction Thermodynamics"
Bulkmatter with elementary interactions

Scale: $E \sim m_\pi \sim \Lambda_{QCD}$

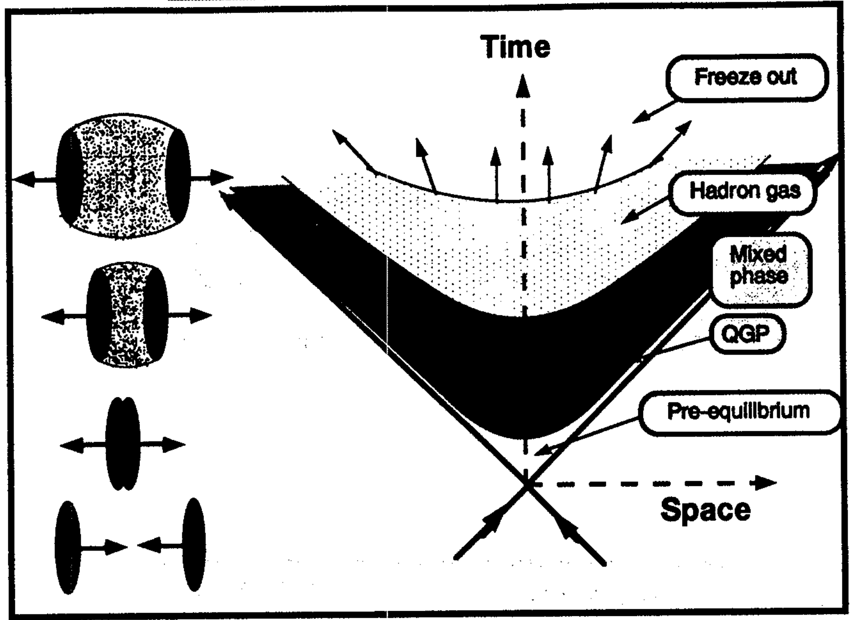
$\boxed{\text{SOFT PHYSICS !}}$

Phase Diagram of Matter



- **Cosmology** $t \approx 10^{-5}$ s, T ≈ 200 MeV
  density fluctuations during QCD phase transition
  - ⇨ nucleo-synthesis
  - ⇨ dark matter
  - ⇨ large scale structure of universe
- **Astrophysics** compressibility of matter
  - ⇨ stability of neutron stars
  - ⇨ dynamics of supernova explosions
- **High energy physics**
  - ⇨ symmetry breaking mechanisms
  - ⇨ origin of (constituent) masses
- **Nuclear physics**
  - ⇨ equation of state of matter
  - ⇨ collective phenomena (hydrodynamics)
  - ⇨ in medium effects (collective potentials)

Space-Time Evolution



Are heavy ions the right tool to study QCD-thermodynamics ?

- **Statistical concepts** => 'big' systems
  - ⇨ many particles, Nch > > 1
  - ⇨ dimensions >> 1 fm

A

- **Thermodynamics** => equilibrium system
  - ⇨ lifetime > relaxation time > 1fm/c
  - ⇨ collisions/particle > 1

$\sqrt{s}$

- **Quark-Gluon-Plasma** =>large energy density
  - ⇨ $\varepsilon_c \approx 1$ GeV/fm^3
  - ⇨ $T_c \approx 150$ MeV
  - ⇨ $\rho_c \approx 5 - 10\ \rho_{(nucleus)}$

To be experimentally verified !

Global Conditions

Multiplicity Densities (central region)

(A) $\overset{(-)}{p}p$ collisions:

Total multiplicity ($\frac{3}{2} \times N_{ch}$), minimum bias:

$$\boxed{\begin{aligned}\left.\frac{dN}{dy}\right|_{pp}^{\text{min. bias}} &= \frac{3}{2} \times 0.876 \times \left(0.023 \ln^2 s - 0.25 \ln s + 2.5\right) \\ &\approx 0.9 \ln \frac{\sqrt{s}}{2 m_p}\end{aligned}} \quad (s \text{ in GeV}^2)$$

CDF coll., Abe et al.
PR $\underline{D41}$ (1990) 2330

(fits data from ISR to Tevatron, $20\,\text{GeV} \leq \sqrt{s} \leq 1800\,\text{GeV}$)

$\sqrt{s}$ (GeV)	SPS(17)	LHB(77)	RHic(200)	LHC(6250)	LHC(16000)
$\left.\frac{dN}{dy}\right\|_{pp}^{\text{min. bias}}$	2.4	2.7	3.2	6.8	8.3

Note: SPS → LHC $\hat{=}$ ~factor 3 !

Tails of multiplicity distribution → 5-6 times minimum bias (CDF, PRL $\underline{64}$ (1990) 991)
(does not work for AA!)

$$\left.\frac{dN}{dy}\right|_{pp}^{\text{"central"}} (\sqrt{s} = 6250) \rightarrow 35 - 40$$

$\Rightarrow \varepsilon \sim 4.5\,\text{GeV/fm}^3$ (see later), but only over small volume!

$\Rightarrow$ pp run useful and important check on finite volume effects!

(B) Nucleus-Nucleus collisions

Extrapolation to large A:

$$\boxed{\left.\frac{dN}{dy}\right|_{AA}^{\text{central collision}} = A^{1+\alpha}\left.\frac{dN}{dy}\right|_{pp}^{\text{min. bias}}}$$

α parametrizes "rescattering" or "cascading"

$\alpha(A,\sqrt{s})$ hard to estimate → large uncertainties in extrapolation

Limits on α:

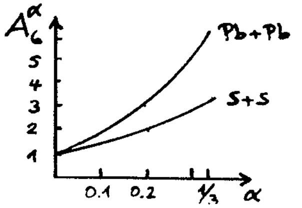
Empirical: at SPS, S+S vs p+p (NA35): $0 \leq \alpha \leq 0.05$
Pb+Pb expect $\alpha \simeq 0.1$
due to "rescattering"

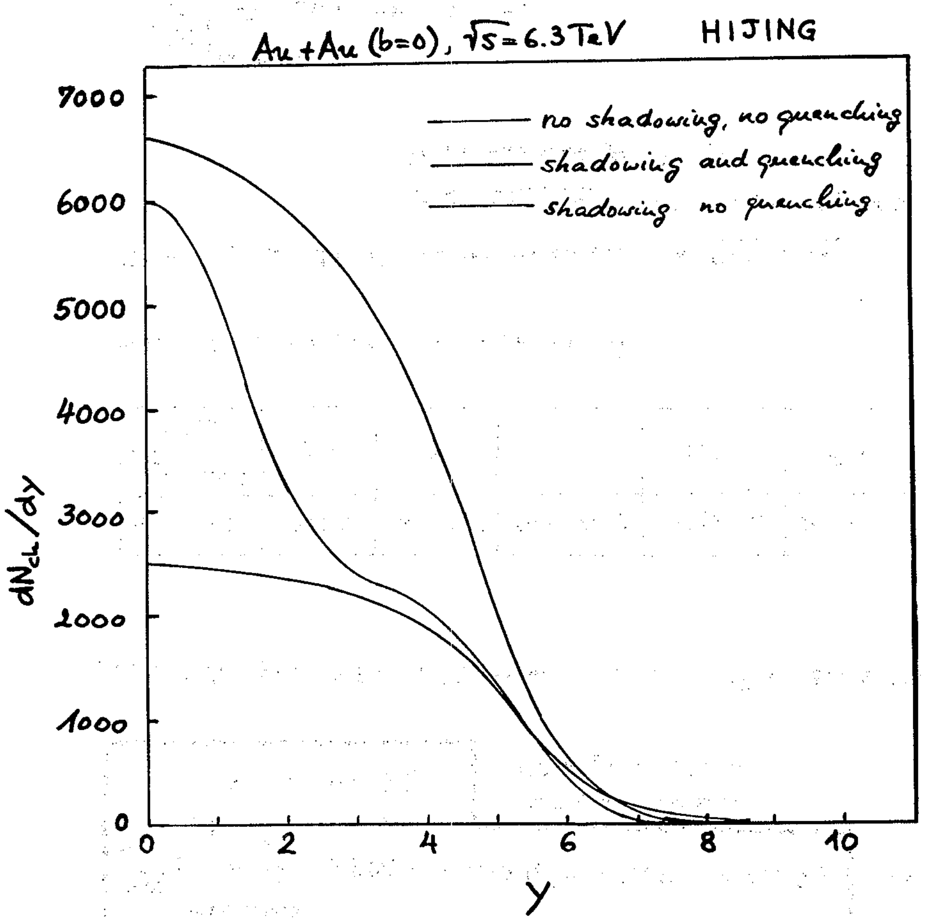
Theoretical: at high energies, expect semihard phenomena ("minijets") to dominate particle production
scales with $A^{4/3}\left(=\frac{A^2}{A^{2/3}}\right) \longrightarrow \alpha \to 1/3$

Thus expect α_{Pb+Pb} to grow from 0.1 to 0.33
as $\sqrt{s}$ grows from 20GeV to ∞.

$\sqrt{s}$(GeV)	SPS(17)	LHB(77)	RHIC(200)	LHC(6250)
$\left.\frac{dN}{dy}\right\|_{PbPb}^{central}$	500-800	560-1000	670-2000	1400-8000
α(assumed)	0.0-0.1	0.0-0.1	0.0-0.2	0.0 - 0.33

Note: Important to measure A-dependence of multiplicity density
pp, SS, CuCu, PbPb





Initial Conditions

Energy and entropy densities (central region)

Issue: estimate initial parameters by extrapolating observed final phase-space density back in time

Uncertainties: How far back in time? (Formation and Equilibration time scales)

"Naive" approach: Longitudinal boost-invariance:

(i) Free streaming longitudinal expansion, no work done by pressure: (Bjorken, PR D27 (1983) 140)

$$\boxed{\varepsilon_0 = \frac{1}{V_0} \langle m_\perp \rangle \frac{dN}{dy} = \frac{\langle m_\perp \rangle}{\pi (1.2\,fm)^2 \tau_0} A^{-2/3} \frac{dN}{dy}}$$

Factor $\langle m_\perp \rangle$ allows for collective transverse flow

$$\left.\begin{array}{ll} \tau_0 \approx 1\,fm/c & \text{"formation time"} \\ \langle m_\perp \rangle \approx 0.5\,GeV & \text{(from Tevatron data)} \end{array}\right\} \text{"conservative"}$$

(ii) Isentropic hydrodynamic expansion with longitudinal boost invariance (Hwa + Kajantie, PR D32 (1985) 1109)

$$\boxed{S_0 = \frac{1}{V_0} \underset{\substack{\uparrow \\ \text{pions}}}{3.6} \frac{dN}{dy} = \frac{3.6}{\pi (1.2\,fm)^2 \underset{\substack{\uparrow \\ \text{"thermalization time"}}}{\tau_0}} A^{-2/3} \frac{dN}{dy}}$$

Note: For same τ_0, (ii) leads to larger ε, T than (i) above SPS energies

However, (ii) does not correct for entropy produced by resonance decays → overestimate of S_0

If τ_0 does not depend on A → $s, \varepsilon \sim A^{\alpha + 1/3}$ (factor 6-35 for A=200:

→ Large A better than going into tails of pp!

Caution: Event generators which give large α also give larger τ_0!

How to vary the initial energy density?

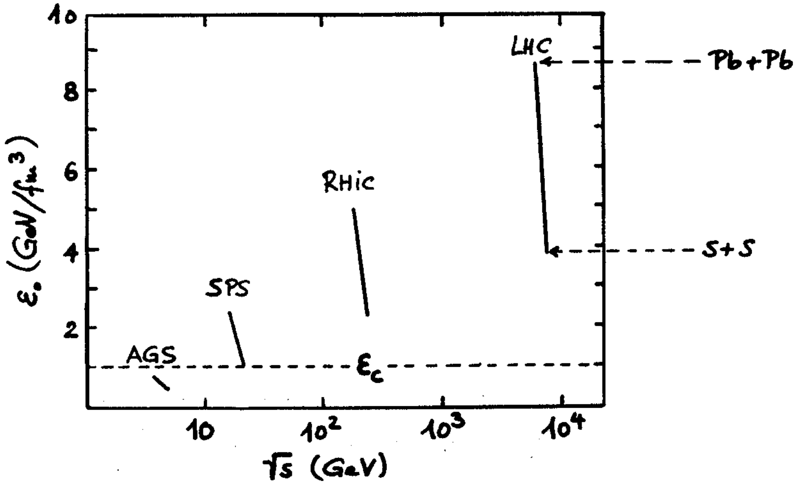
- vary $\sqrt{s}$ → very ineffective, since $\varepsilon_0 \sim \ln\sqrt{s}$

- vary A (pp, SS, CuCu, PbPb)
  - → changes ε_0 and V_0 simultaneously

- vary impact parameter at fixed (large) A (e.g. via E_T)
  - → changes only V_0 but leaves ε_0 essentially unchanged (Karsch + Satz, ZP C51 (91) 209)

Initial energy density at $y = 0$
(Bjorken estimate)

for $\tau_0 = 1\,\text{fm}/c$
$\alpha = 0.1$ independent of $\sqrt{s}$



Handy formulae for Pb + Pb:

$$\boxed{\begin{aligned} \varepsilon_0 &= \mathbf{3.5}\left(\frac{1\,\text{fm}/c}{\tau_0}\right)\left(\frac{\langle m_\perp\rangle}{0.4\,\text{GeV}/c^2}\right)(208)^\alpha\ \text{GeV}/\text{fm}^3 \\ s_0 &= \mathbf{32}\left(\frac{1\,\text{fm}/c}{\tau_0}\right)(208)^\alpha\ \text{fm}^{-3} \end{aligned}}$$

Initial temperature (central region)

Use EOS of ideal quark-gluon gas, 3 massless flavors. $\mu_B = 0$ (see later)

(i) $\varepsilon = \frac{\pi^2}{30}\left(2\times 8 + \frac{7}{8}\times 2\times 3\times 3\times 2\right)T^4 + B$

$$\Rightarrow \boxed{T_{Bj} = \left(\frac{\varepsilon - B}{1953}\right)^{1/4} \text{GeV}} \qquad (\varepsilon \text{ in GeV/fm}^3)$$

(ii) $s = \frac{2\pi^2}{45}\left(16 + \frac{7}{8}\times 36\right)T^3$

$$\Rightarrow \boxed{T_{HK} = \left(\frac{s}{2605}\right)^{1/3} \text{GeV}} \qquad (s \text{ in fm}^{-3})$$

$\sqrt{s}$ (GeV)	SPS(17)	LHB(77)	RHIC(200)	LHC(6250)
T_{Bj} (MeV)	157-185	164-193	172-234	213-335
T_{HK} (MeV)	162-194	171-207	179-259	231-410

Note: These are average values;
T may be up to 20% higher in center of firetube.

$\mu \neq 0$ will somewhat reduce T.

$$\boxed{T_i \sim 2T_c}$$

Baryon density (central region)

Energy loss of high energy protons through Pb target: $\delta y = 2 - 2.5$

Additional energy loss in Pb-Pb collisions via cascading.

Event generators (RQMD, VENUS, DTUNUC): $\delta y = 3.5$ (?)

→ figure

Schematic model (→ figure)

$$\frac{dN_B}{dy}(y=0) = \begin{cases} \frac{2A}{y_p} & y_{proj} < \delta y \\ \frac{2A}{\delta y}\left(2 - \frac{y_p}{\delta y}\right) & \delta y < y_p < 2\delta y \\ 0 & y_p > 2\delta y \end{cases}$$

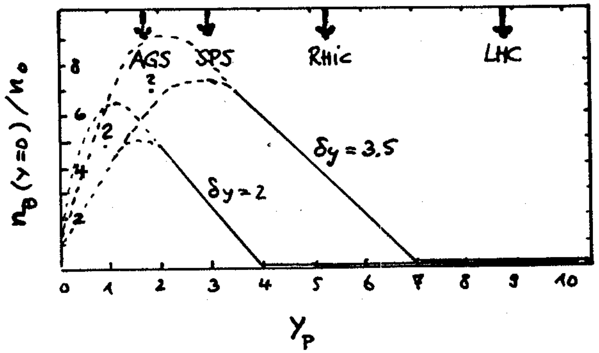
For $y_p \gtrsim \delta y$ onset of transparency

→ baryon density at $y=0$ begins to drop

Bjorken scaling expansion near $y=0$:

$$\frac{n_B(y=0)}{n_0} = \frac{1}{n_0}\,\frac{1}{\pi(1.2\,\text{fm})^2\tau_0}\,A^{-2/3}\frac{dN_B}{dy}(y=0)$$

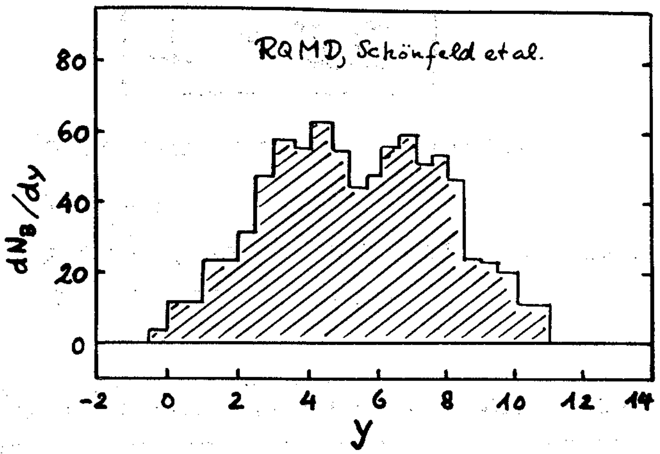
Baryon density at $y=0$:



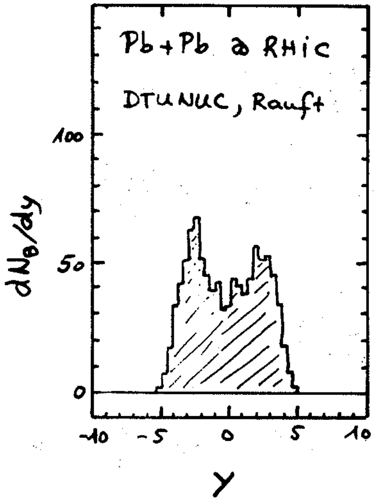
Note: Baryon density in fragmentation regions may be much higher!

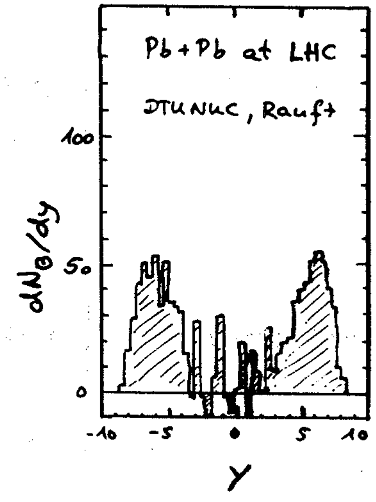
Pb + Pb at RHIC

net
baryon
density



net
baryon
density



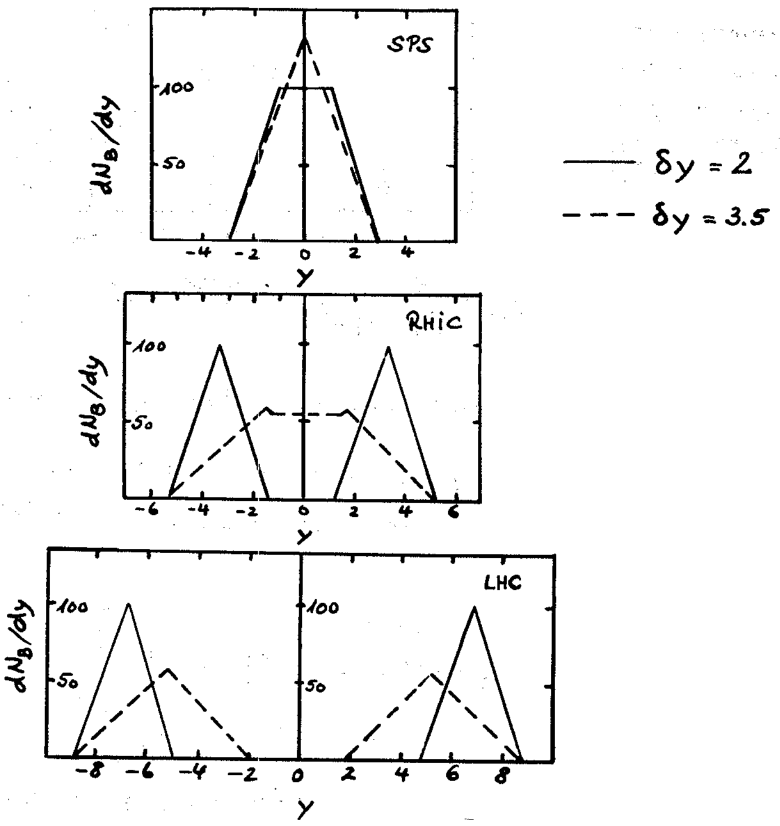


↑

large fluctuations
due to strong B-$\bar{B}$
production

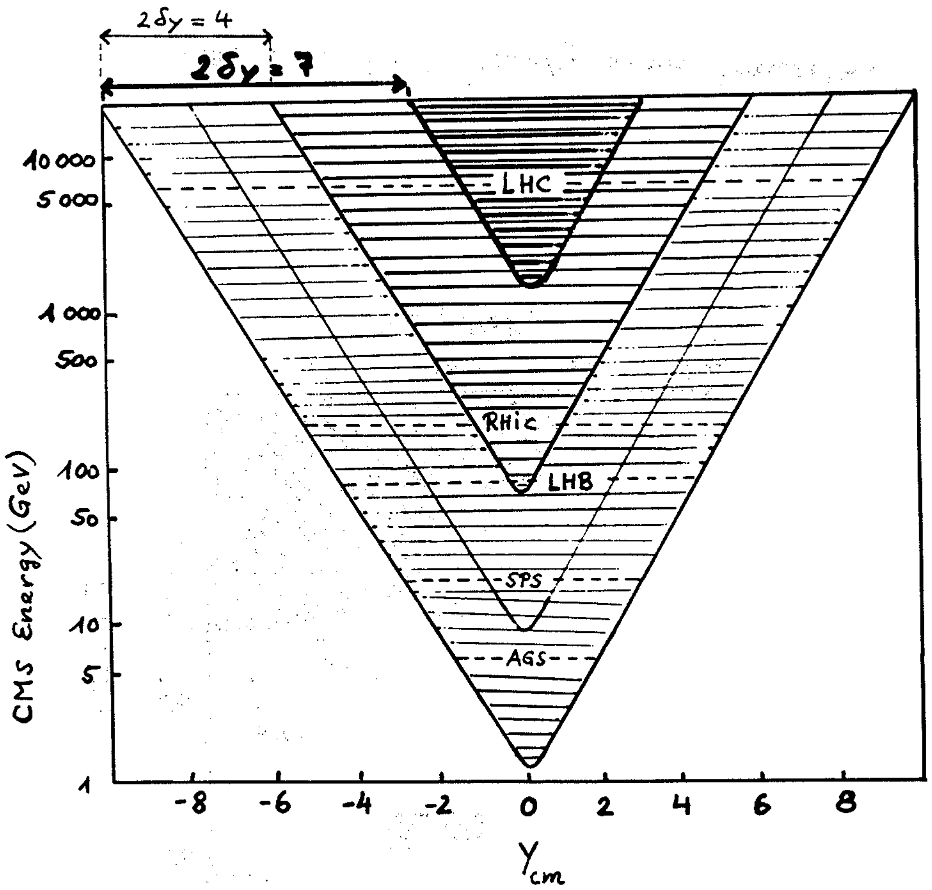
Event generators

Net baryon density (schematic)



(H. Satz, CERN-TH 6216/91)

Central rapidity gap



$\Longrightarrow$ Expect: Physics $\approx$ const. in $y \in [-2, 2]$

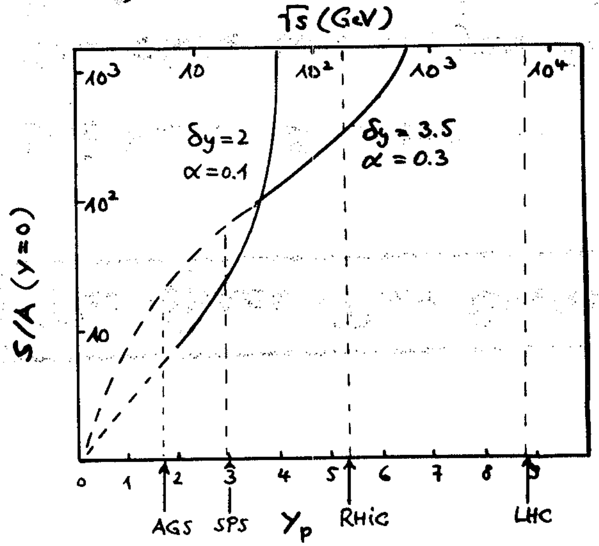
But: To check picture, measure $\frac{dN}{dy}$ (no particle id.) in larger region (-5 to +5 ?) (plateau ? Gaussian ?)

How well can we reproduce the Early Universe in the laboratory?

Specific entropy: $\left(\frac{S}{A}\right)_{\text{Early Universe}} = 10^{9\pm1}$

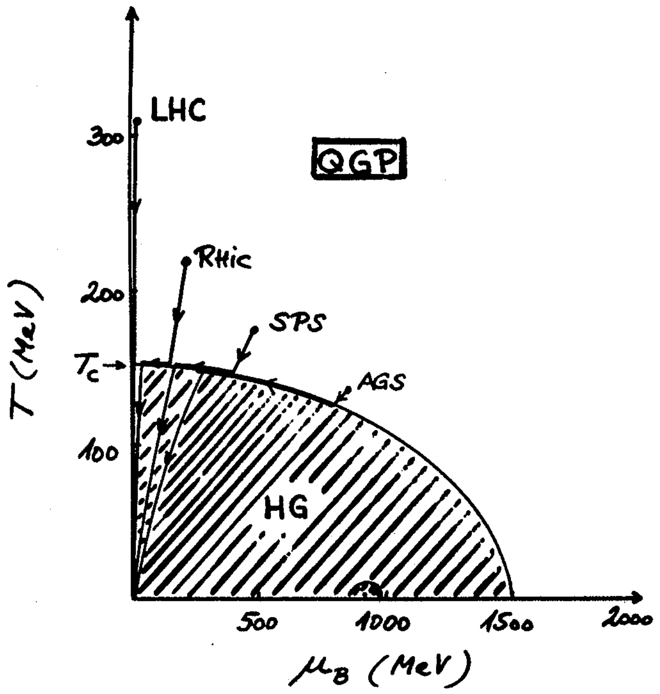
Nuclear collisions at $y=0$:

$$\frac{S}{A} \approx \frac{3.6 \frac{dN}{dy}}{\frac{dN_B}{dy}}$$



Even if $\frac{dN_B}{dy}$ = flat (??), we have at LHC $S/A\,(y=0) \sim 10^3$, i.e. about 5 times as usual as at RHic and more than 30 times as usual as at SPS.

Phase diagram with
expansion trajectories for
matter produced at $y \approx 0$
in various accelerators



Only with LHC "safely" above transition!

The Space-Time Evolution

Lifetimes & Sizes –

How close can we get to
the thermodynamic limit?

Lifetimes

Plasma lifetime:

- determined by entropy conservation:

$$s(\tau)\, V(\tau) \geq s_0 V_0$$

- initially only longitudinal expansion:

$$V(\tau) \sim \tau$$

→ upper limit: $s_0 \tau_0 \leq s_{had} \tau_{had}$ (no mixed phase)

$$\rightarrow \tau_{had} \geq \frac{s_0}{s_{had}} \tau_0 = \frac{d_{QGP} T_i^3}{d^{eff}_{HG} T_c^3} \tau_0 \approx \underset{\uparrow}{8} \left(\frac{T_i}{T_c}\right)^3 \tau_0 \sim \ln\sqrt{s}$$

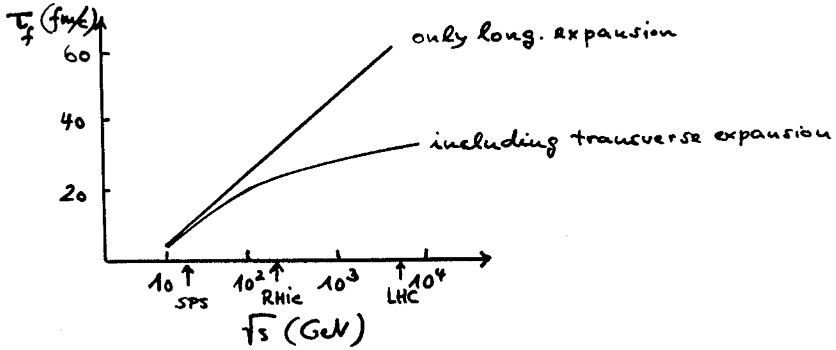
including 3 flavors + resonances

- transverse rarefaction shock cuts plasma life short

$$\tau_T = \frac{R_A}{s_{shock}} \sim (3-4) R_A \sim 20 - 30 \text{ fm/c for Pb}$$

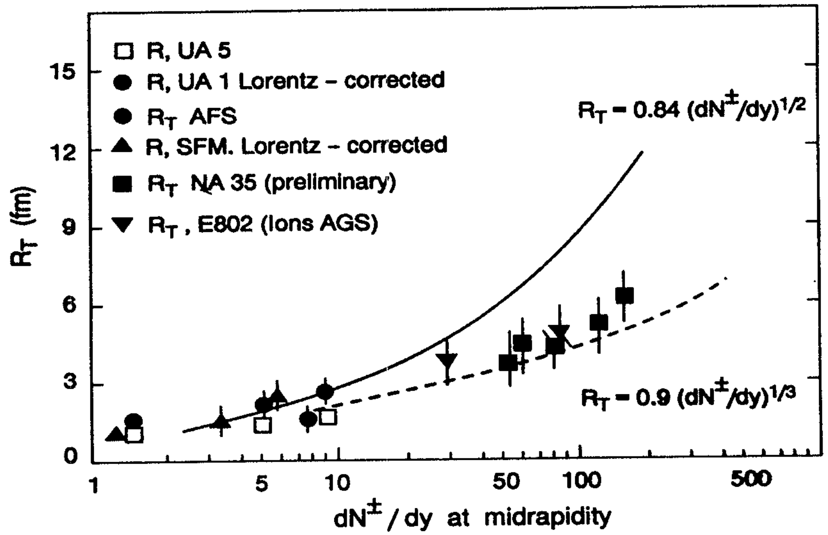
- after hadronization → 3-d expansion
  → very rapid decoupling

⇒ at high energies: total lifetime dominated by plasma phase ?



Size at freeze-out

2-pion HBT interferometry data:



Simple model to "explain" this:

Freeze-out at fixed τ_f, determined by transition temperature T_c

- $V_f = \pi R_f^2 \tau_f = \frac{V_0 s_0}{s_f} = \frac{1}{s_f}\, 3.6 \frac{dN}{dy} \xrightarrow[\frac{dN}{dy} = 2000 - 8000]{T_c = 150\,MeV} \underline{(0.8 - 3.4) \times 10^4 \text{ fm}^3}$!
- Since $\tau_f \sim R_f \Rightarrow R_f \sim \left(\frac{dN}{dy}\right)^{1/3}$

Consequences:

For $\frac{dN}{dy}(LHC) = 2000 - 8000 \Rightarrow R_f(LHC) = 10 - 20$ fm $= \underline{(1.5 - 3) \times R_{Pb}}$

[For $\frac{dN}{dy}(RHIC) = 700 - 2000 \Rightarrow R_f(RHIC) = 8 - 10$ fm $= \underline{(1 - 1.5) \times R_{Pb}}$]

Two words of caution:

1) Due to rapid longitudinal expansion volume elements which are separated in y by more than 1 unit are causally disconnected

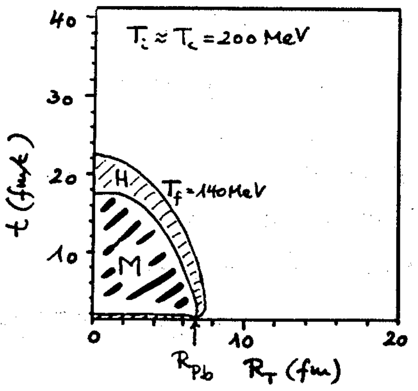
→ Causally connected volume at freeze-out is about factor 20 smaller

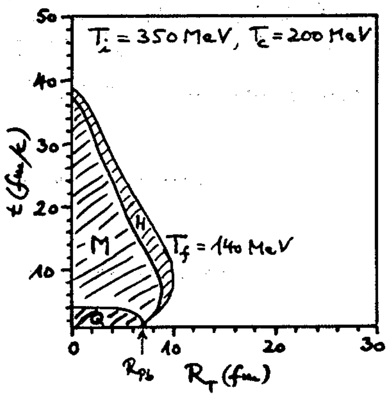
2) Freeze-out does not occur instantaneously at $\tau_f = \text{const.}$

→ volume decreases by sequential freeze-out

Example: 2+1 dim. hydrodynamics, v. Gersdorff, Kataja, Ruuskanen, McLerran 1987

Freeze-out surface:

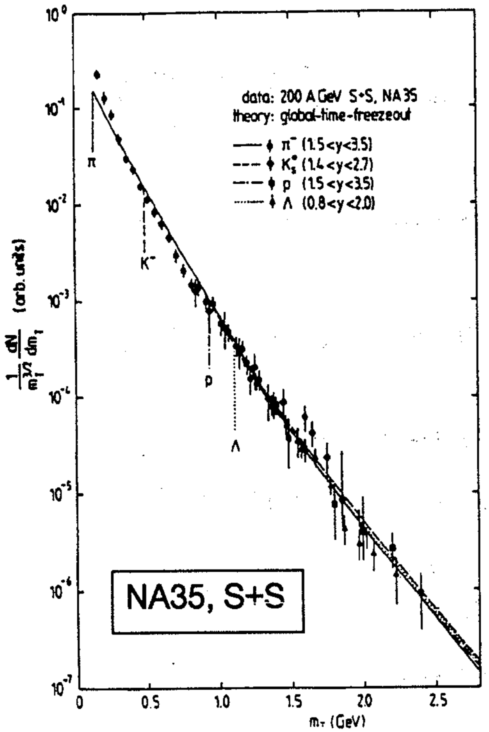


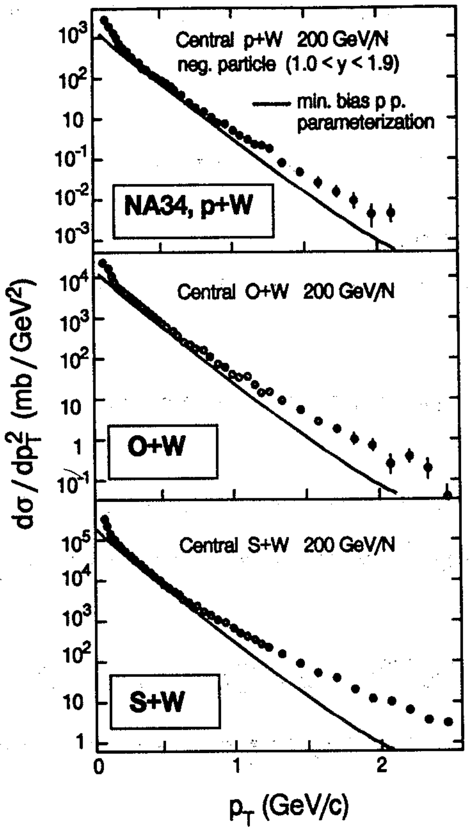


→ NA35 result $R_T(S+S) \approx 2 \times R_S$ very surprising!

Experimental Probes

Global features of P_t Spectra

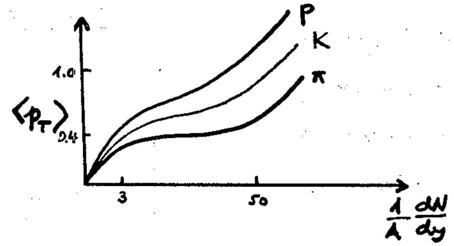




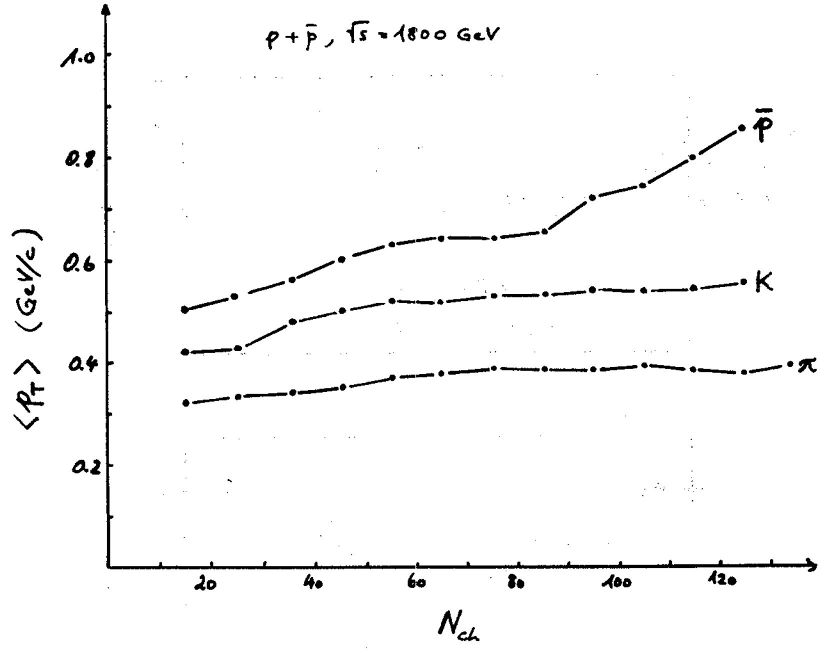
- **identified particles (π,K,Λ):**
  - ⇨ universal slope (m_t-scaling), T≈ 200 MeV (pp: T ≈150 MeV)
  - ⇨ consistent with thermalization (+ collective flow) ?
    - AGS (E802) $p_t(p) > p_t(K^+) > p_t(K^-) \approx p_t(\pi)$
    - CERN (NA34) $p_t(K^+) > p_t(K^-)$ at $y \approx y_{target}$
- **neg. particles(π):** (good statistics, large range in p_t)
  - ⇨ big enhancement from p-p -> p-W
    - at low pt < 250 MeV (resonance decays, Δ, ρ, ω ...)
    - at high pt > 1 GeV **CRONIN** effect, FNAL ('75)
    - (increases with centrality and with A_P, A_T) rescattering, flow

p_T - Spectra:

- 1^{st} order phase transition ⟷ characteristic "saddle point" in $\langle p_T \rangle$ vs. $\frac{dN}{dy}$ plot → Fig.
- Transverse flow → flattening of p_T-spectra + curvature → Fig.
  - → larger $\langle p_T \rangle$ for heavier hadrons



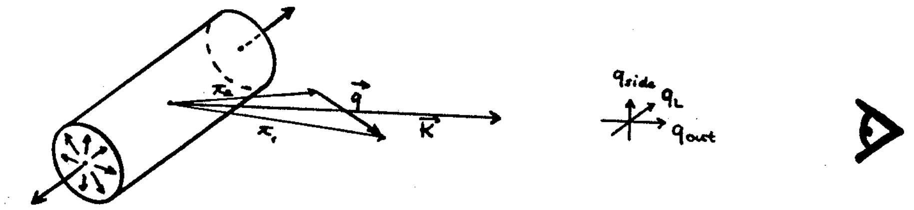
(Kataja et al.)



E735 (FNAL) (T. Alexopoulos et al. PRL 64 (90) 991)

Geometry & Dynamics at Freeze-Out

→ HBT Interferometry



Parametrize 2-particle-correlation function as

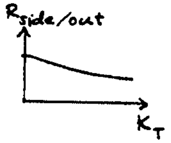
$$C(\vec{q},\vec{K}) = 1 \pm \lambda e^{-q_L^2 R_L^2(\vec{K}) - q_{side}^2 R_{side}^2(\vec{K}) - q_{out}^2 R_{out}^2(\vec{K})}$$

The parameters $R_i(\vec{K})$ ($i = L, side, out$) contain the following information (schematically): (Pratt, Sinyukov, Hama, Gyulassy...)

$R_{side}(K_T \to 0)$ ⟶ transverse size at freezeout R_T^f

$R_{out} - R_{side}$ ⟶ duration of particle emission $\Delta\tau_f$

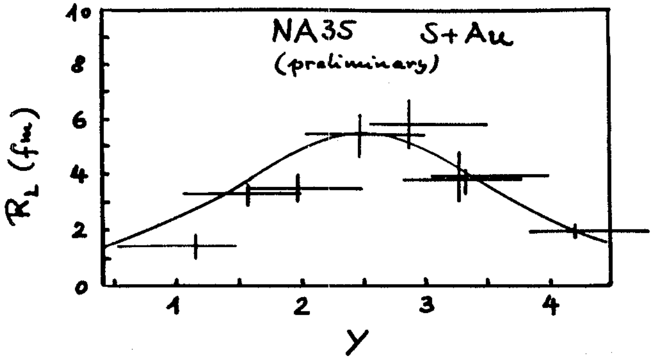
$\left.\begin{array}{l} R_{side}(K_T) \\ R_{out}(K_T) \end{array}\right\}$ ⟶ transverse expansion:

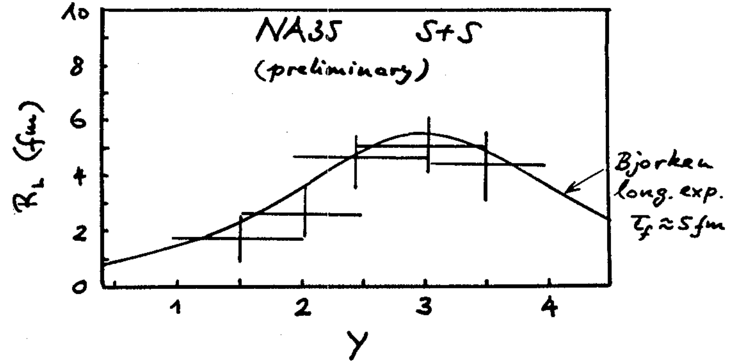


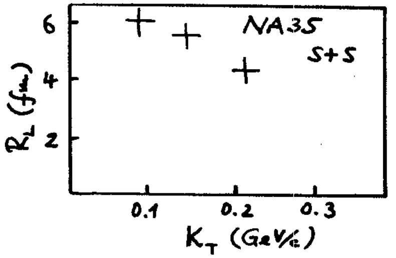
$$R_L = \sqrt{\frac{2T_f}{m_T}} \frac{1}{\frac{du_z}{dz}}$$ ⟶ longitudinal expansion and decoupling time τ_f

in local rest frame

$\sim \sqrt{2T_f}$ (τ_f) (for Bjorken expansion)







K_T-dependence of R_L supports longitudinal flow (Salzburg, preliminary)

- $R_{out} \approx R_{side}$ → $\Delta\tau_f \lesssim 2$ fm/c rapid freeze-out
- No positive sign of transverse flow yet due to small statistics at large K_T

Strangeness Production – Approach to Chemical Equilibrium

UA5 – Compilation
+ AA data

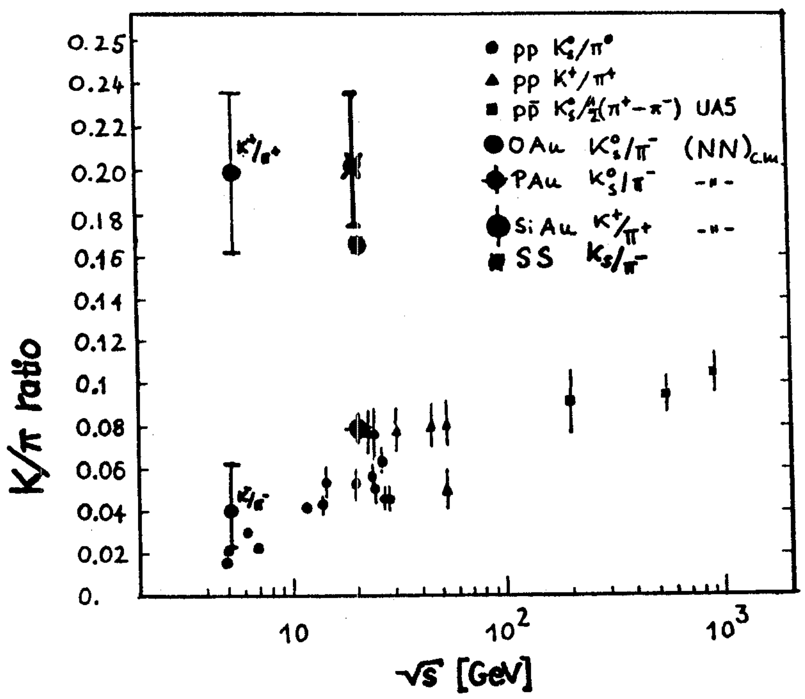
Need:
- $\frac{K^\pm}{\pi^\pm}$, $\frac{\phi}{\rho^0}$, ...
- $\frac{\Lambda}{p}$, $\frac{\Xi}{\Lambda}$, $\frac{\Omega}{\Xi}$, $\frac{\bar\Lambda}{\bar p}$, $\frac{\bar\Xi}{\bar\Lambda}$, $\frac{\bar\Omega}{\bar\Xi}$, ...
- Systematics with $p_\perp (m_\perp)$, Y , A_p , A_T !
  + centrality

to sort out mechanisms:

- hadronic rescattering (e.g. associated production $N + \pi \to KY$)
- hadronization of QGP (topological hadronization mechanism for $B - \bar B$ production ?)
- chemical vs. thermal freeze-out

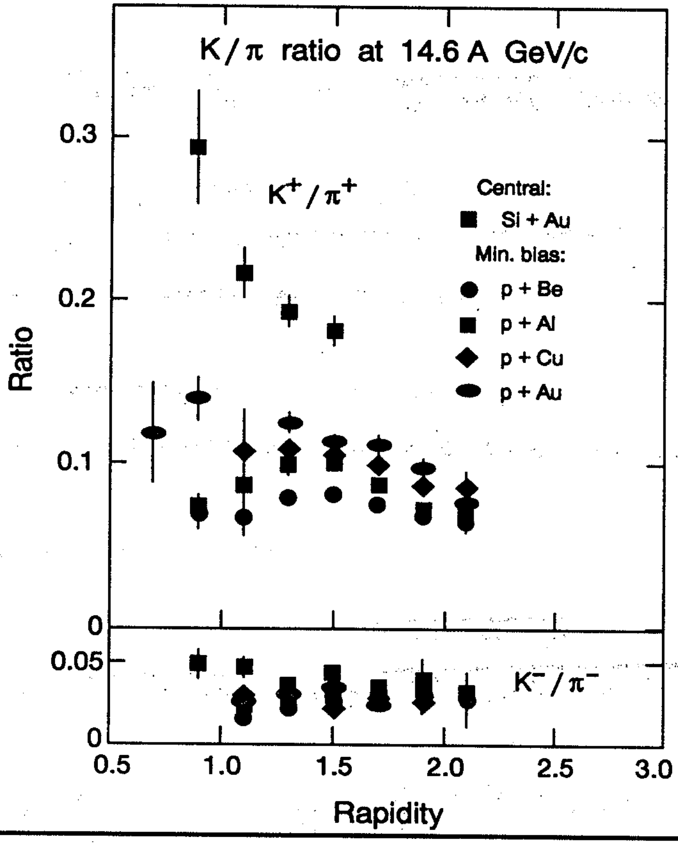
different equilibration time scales!

K/π -ratio (Experiment)



Kaons

E802 14.5 GeV/n Si+Au $K^+/\pi^+ \approx 20\%$ $K^-/\pi^- \approx 3\%$
pp $K^+/\pi^+ \approx 6\%$ $K^-/\pi^- \approx 3\%$

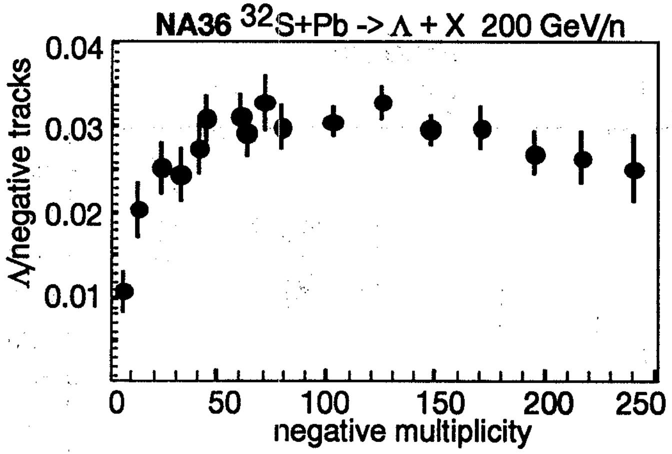


NA34 200 GeV/n O+W $K^+/\pi^+ \approx 20\%$ $K^-/\pi^- \approx 5\%$
(target fragmentation region)
NA35 200 GeV/n S+S $K_0 \approx$ 2-3 times larger than in pp
(midrapidity) increasing with centrality

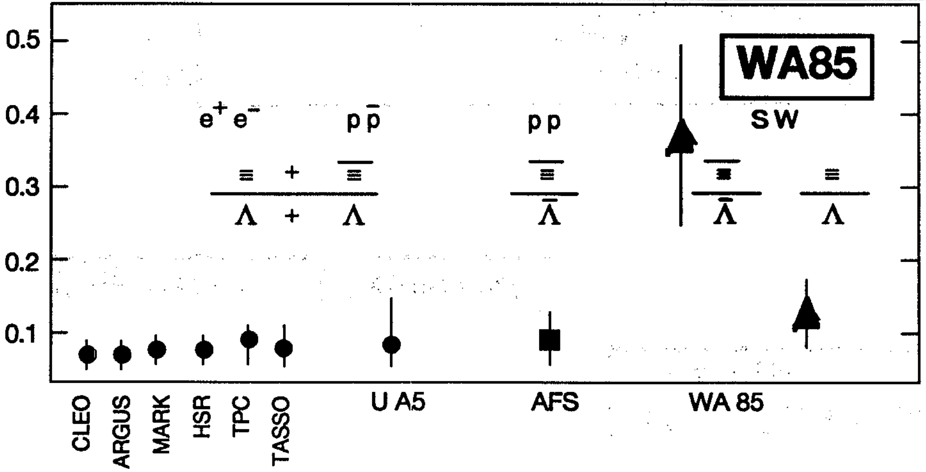
- **Strong Kaon enhancement ≈ equilibrium !**
  - ⇨ evolves gradually from p-p -> p-A -> A-A
  - ⇨ strongest in baryon dense region

Hyperons

NA35 O+Au ● Λ increase 2-3, no sign. effect in K_0^s, $\bar{\Lambda}$
S+S ● $\Lambda, \bar{\Lambda}, K_0^s$ increase ≈ 2-3 compared to pp
● y distrib: $\bar{\Lambda}, K_0$central, Λ fragment. region
NA36 S+Pb ● $\Lambda, \bar{\Lambda}$ increase ≈ 2-3 compared with centrality



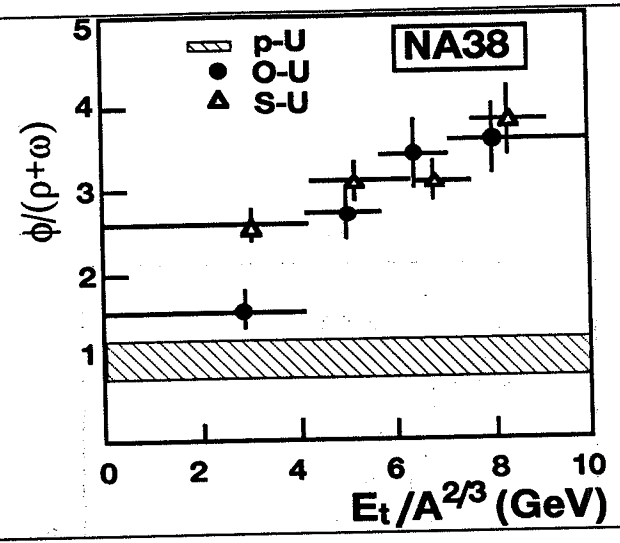
WA85 anti-Hyperons at $p_t > 1$ GeV, $y_{cm} \approx 0$
S+W/p+W ● 70% increase in Λ and $\bar{\Lambda}$
● factor >5 in $\bar{\Xi}/\bar{\Lambda}$, but low statistics



Phi Enhancement

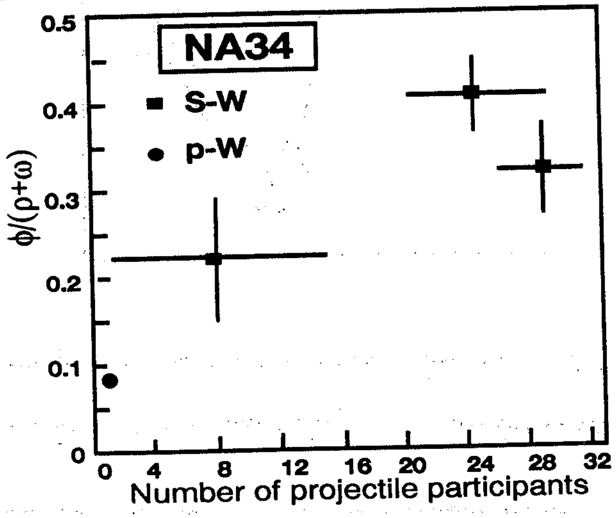
NA38 $\phi \to \mu\bar{\mu}$ high $p_t > 1.3$ GeV, $y_{cm} \approx 0.6$

● factor 3 enhancement with E_t in $\phi/(\rho+\omega)$



NA34 $\phi \to \mu\mu$ $p_t \approx 0.4 - 1.2$ GeV, $y_{cm} \approx 0.6$

● $\phi/(\rho+\omega)$ enhanced also at low p_t

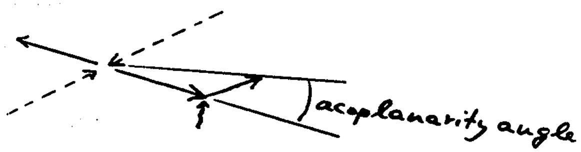


Jet quenching
& Jet acoplanarity

- Jets = hard probes, which measure properties of fireball medium via their modification through soft final state interactions

Jet quenching → energy loss of leading jet partons travelling through medium (Bjorken, Thoma+Gyulassy, ...)

Jet acoplanarity → widening of out-of-plane angular distribution via rescattering (Appel, Blaizot+McLerran, Rammerstorfer+Heinz)



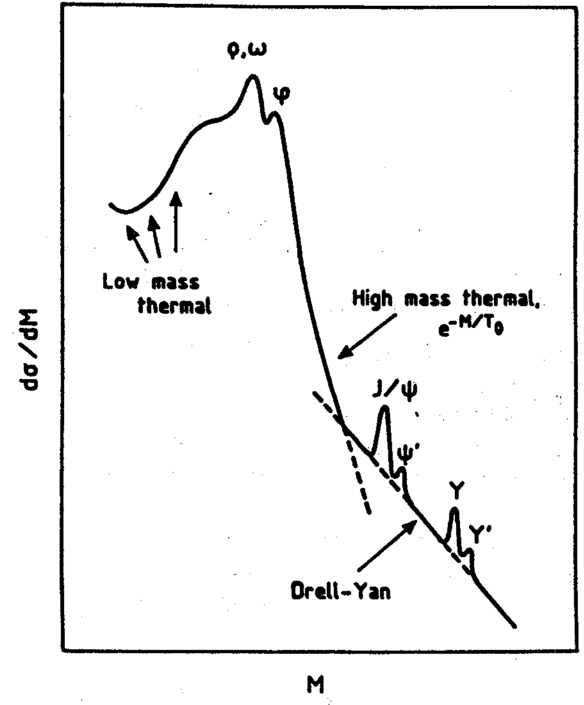
Important: Jets with $E_T \leq 40$ GeV hard to identify by calorimetry, due to enormous soft background in nucleus-nucleus collisions

→ identify by leading particles.

Use narrow correlation between direction of jet axis and of leading parton.

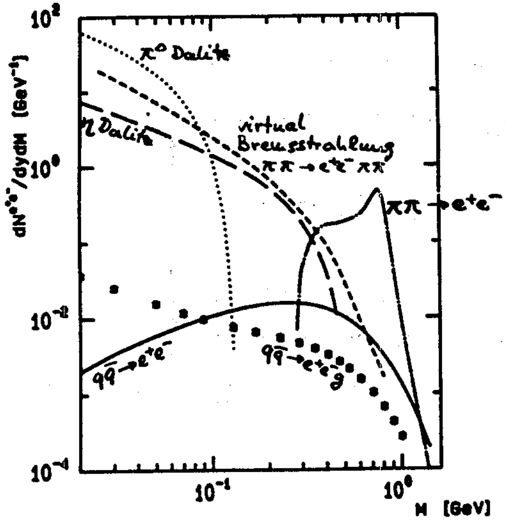
Dileptons & Photons

Decouple immediately → information on complete space-time history of collision!



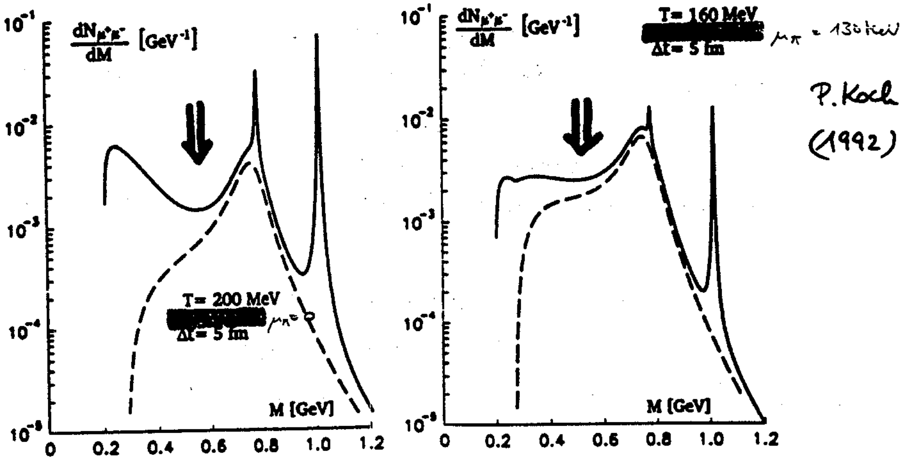
Continuum below $2m_\pi$:

Cleymans, Redlich, Satz 1991



Low mass thermal dileptons from QGP → hopeless

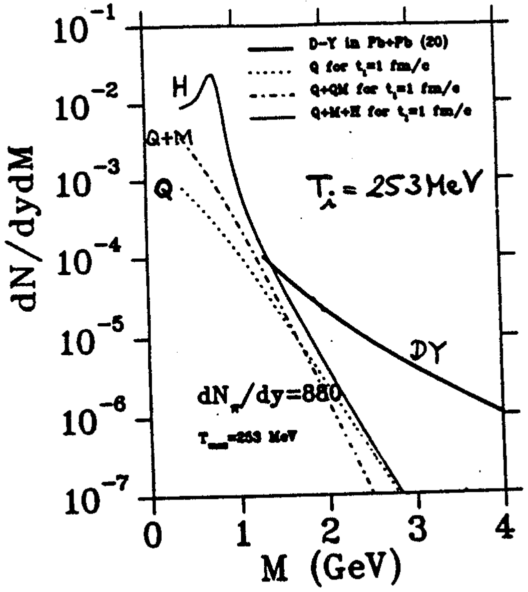
$2m_\pi < M_{\mu^+\mu^-} < m_\rho$:



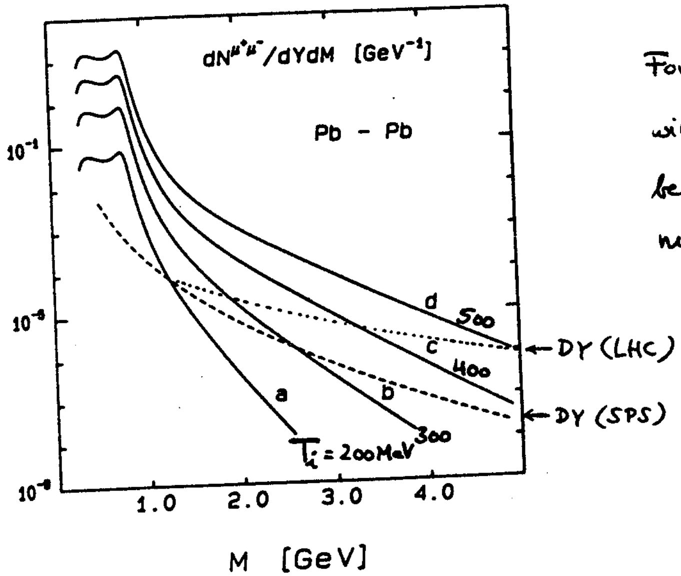
P. Koch (1992)

Region between $2m_\pi$ and m_ρ sensitive to $\mu_\pi \neq 0$!

High mass thermal dileptons:



For $T_i \leq 300$ MeV thermal QGP dileptons buried under DY and HG background.



For $T_i = 350 - 400$ MeV window for QGP between 1.5 GeV and $m_{J/\psi}$.

Difficult, but not hopeless!

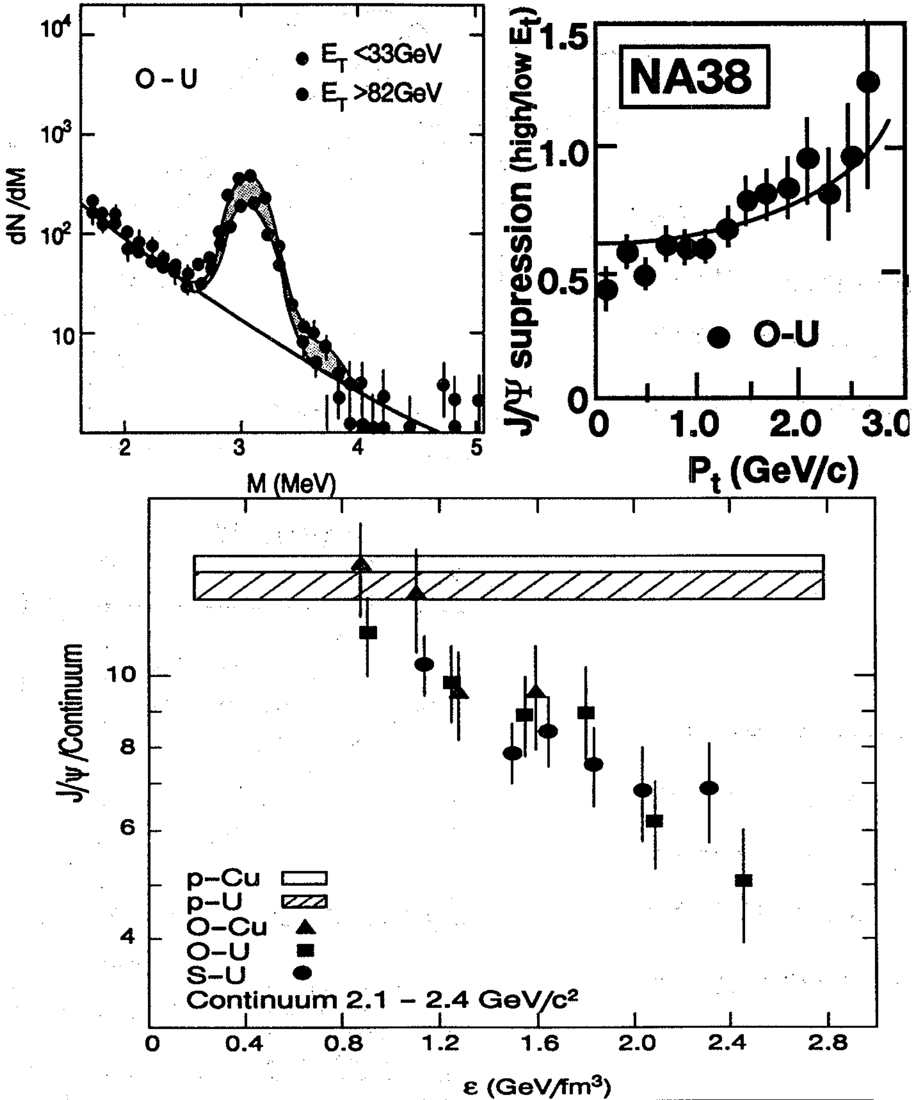
Vector Mesons:

A: Heavy Quarkonia $J/\psi, \psi', \ldots, \Upsilon, \Upsilon', \Upsilon'' \ldots$

- Early production by hard parton-parton scattering
  - → sensitive to nuclear modifications of structure functions (EMC, shadowing...)
  - → simultaneous study of DY necessary to separate initial state from final state effects
    Study A-dependence (<u>pp</u>, SS, PbPb!)
- Multiple initial state scattering before parton fusion into $c\bar{c}$, $b\bar{b}$
  - → changes $p_\perp$-spectrum of initial $c\bar{c}$, $b\bar{b}$ pair
  - → study $p_\perp$-dependence of Quarkonium and DY production
  - → Need good acceptance at $\boxed{\text{low } p_\perp \approx 0}$, where these effects are strongest, but also at large $p_\perp$
    Note: at large $p_\perp$ problematic background from B decays expected
- Final state absorption effects by soft processes in dense medium:
  - "melting" of bound states by color screening
  - collision dissociation by scattering with partons or hadrons in dense medium
  - → study systematics in E_T, $p_\perp$, need separation of $J/\psi, \psi', \ldots, \Upsilon, \Upsilon', \Upsilon''$ to study dependence on binding energy and system size → need good mass resolution $\lesssim 100-150$ MeV!

J/Ψ Suppression

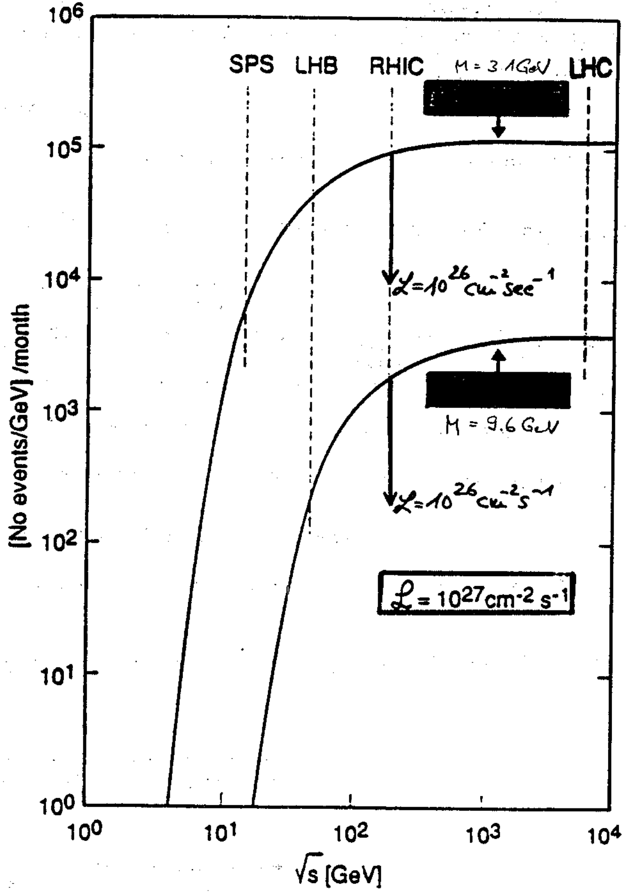
NA38 J/Ψ ->μμ relative to continuum (DY)



Strong E_t & p_t dependent suppression !

Important: Good statistics on DY spectrum between $c\bar{c}$ and $b\bar{b}$ resonance region to separate initial state from final state affects.

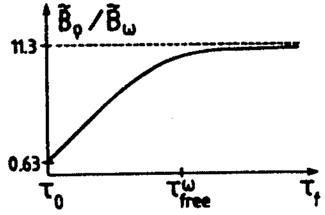
Drell-Yan rates at M_ψ and M_Υ

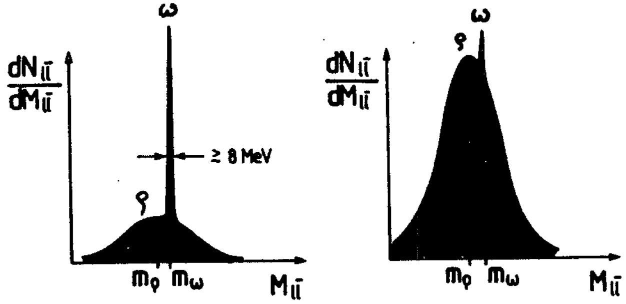


B: Low-Mass Vector Mesons ρ^0, ω, ϕ

- → information on space-time history of hadronic stage of collision (after hadronization)

- "ρ-clock":





$\tau_f - \tau_0$ small

$\tau_f - \tau_0$ large

- medium modifications of V-meson masses and widths (Shuryak...) → need $\tau(\text{hadronic phase}) \gtrsim \tau_V$
  e.g. $\frac{\phi \to l\bar{l}}{\phi \to K\bar{K}}$ as function of E_T (or ε)

- ϕ/ρ^0 or ϕ/ω → strangeness enhancement.

Important: $p_\perp$ - spectrum, $0 \le p_\perp^{Vector} \lesssim 1\text{-}2$ GeV

SUMMARY

What LHC can do better than RHIC:

- Higher initial energy density
  $\varepsilon_0 \gtrsim 10\, \varepsilon_c$
- Higher initial temperature
  $T_i \gtrsim 2\, T_c$

$\Big\}$ Only here QGP ≈ ideal plasma

- Higher specific entropy
  $S/A \gtrsim 10^3$ → closer to Early Universe

- Larger lifetimes and freeze-out volumes
  - → better thermalization and equilibration
  - → collective flow more prominent
  - → only here QGP begins to dominate space-time evolution

- Thermal dileptons from QGP (only possible if $T_i \gtrsim 350-400$ MeV)

- DY up to m_Υ
- Full study of $c\bar{c}$ and $b\bar{b}$ spectrum

$\Big\}$ if $\mathcal{L} \gtrsim 10^{27}\,\text{cm}^{-2}\text{s}^{-1}$

- Effects of dense matter on jets

Electron-proton physics

G. Wolf (DESY)

G. Wolf
6/3/92

LEP × LHC = LLHC

$$\underrightarrow{60 \text{ GeV } e} \qquad \underleftarrow{8000 \text{ GeV } p}$$

$$s^{1/2} = (4E_e E_p)^{1/2} = 1.4 \text{ TeV}$$

equivalent to fixed target xpt

$\underrightarrow{1040 \text{ TeV electron}}$

Luminosity $\mathcal{L} \sim 10^{32} \text{ cm}^{-2} \text{s}^{-1}$

$\rightarrow$ 500 pb^{-1} / year

take for structure fction measurements

4 years : $L = 2000 \text{ pb}^{-1}$

for particle searches

1 year : $L = 500 \text{ pb}^{-1}$

e × p	$\sqrt{s}$	dedicated $\mathcal{L}$	L/year	parasitic $\mathcal{L}$	L/year
60 × 8000	1.4 TeV	$1.3 \cdot 10^{32}$	800 pb^{-1}	$6 \cdot 10^{31}$	300 pb^{-1}
100 · × 8000	1.8	$2 \cdot 10^{31}$	100	10^{31}	50

what about pA ? → C Llewellyn Smith

Topics

- measure structure of q, g, e, ..
- new currents
- compositeness of e, q
- break down of standard model
  FCNC , FCCC
- production of heavy quarks
- search for new particles

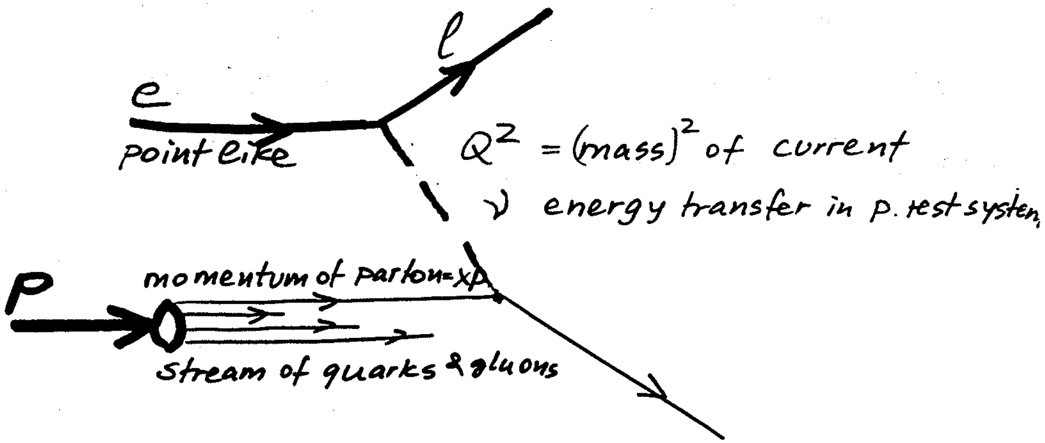
For details see

LHC workshop Aachen 1990

HERA workshops 1991, 1987

La Thuile 1987

60 GeV e → ← 8000 GeV p



$Q^2 = (\text{mass})^2$ of current

ν energy transfer in p. rest system

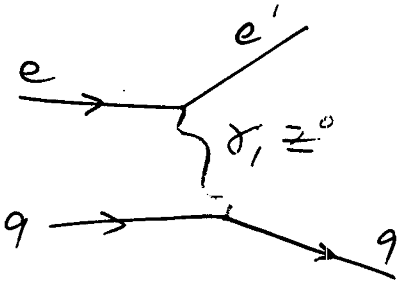
$x = \frac{Q^2}{2m\nu}$ $y = \nu/\nu_{max}$ $Q^2 = xys$

$Q^2_{max} = s = 2 \cdot 10^6$ GeV²

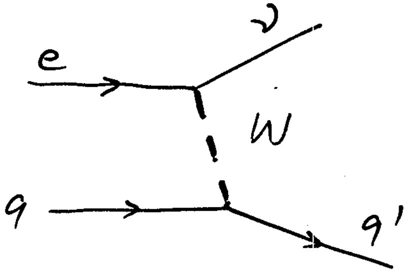
resolving power: $\Delta \approx \hbar/Q$ size of object that can be resolved

Q^2	Δ	
1 GeV²	$2 \cdot 10^{-14}$ cm	⇝ proton is extended object $r_p = 0.8$ f
~10	$7 \cdot 10^{-15}$	⇝ scaling ⇝ discover quarks
~100	$2 \cdot 10^{-15}$	⇝ scale breaking ⇝ QCD
$4 \cdot 10^4$	$1 \cdot 10^{-16}$	HERA ⇝ wait & see
$4 \cdot 10^5$	$3 \cdot 10^{-17}$	LLHC ⇝

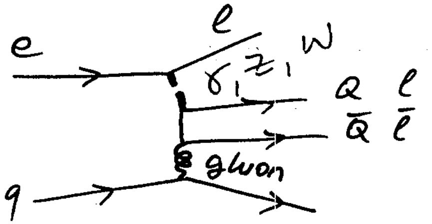
Note: in specific models resolving power can be a factor ~30 better



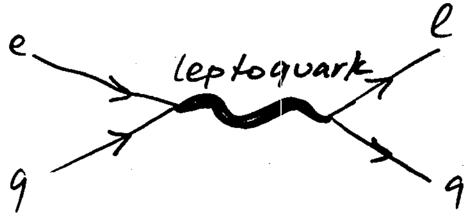
NC



CC

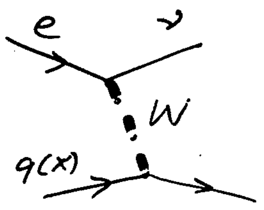


current-gluon fusion



s-channel resonance production

$e^- p \rightarrow \nu X$



$$\frac{d^2\sigma}{dx\,dy} \approx \frac{G^2 s}{2\pi} \frac{1}{(1+Q^2/M_W^2)^2} \left\{ \left(1-y+\frac{y^2}{2}\right) F_2(x,Q^2) + \left(y-\frac{y^2}{2}\right) xF_3(x,Q^2) \right\}$$

structure functions

$$F_2(x,Q^2) = \sum x\{q(x)+\bar{q}(x)\}$$

$$xF_3(x,Q^2) = \sum x\{q(x)-\bar{q}(x)\}$$

quark distribution functions

$$q(x) = u(x) + c(x)$$

$$\bar{q}(x) = \cos^2\theta_c\,\bar{d}(x) + \sin^2\theta_c\,\bar{s}(x)$$

given F_i at x, Q_0^2

→ QCD + Altarelli - Parisi evolution

predict $F_i(x,Q^2)$ $(x > x_0)$

provided QCD is correct

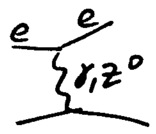
LLHC

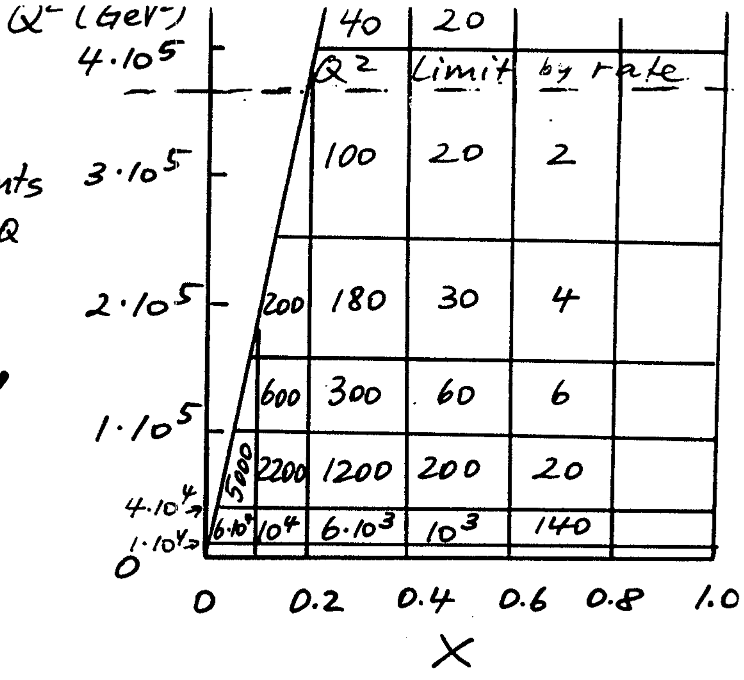
$\mathcal{L} = 2000\,pb^{-1}$

Number of events

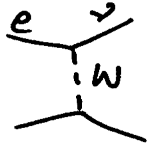
LUND LEPTO+ EHLQ

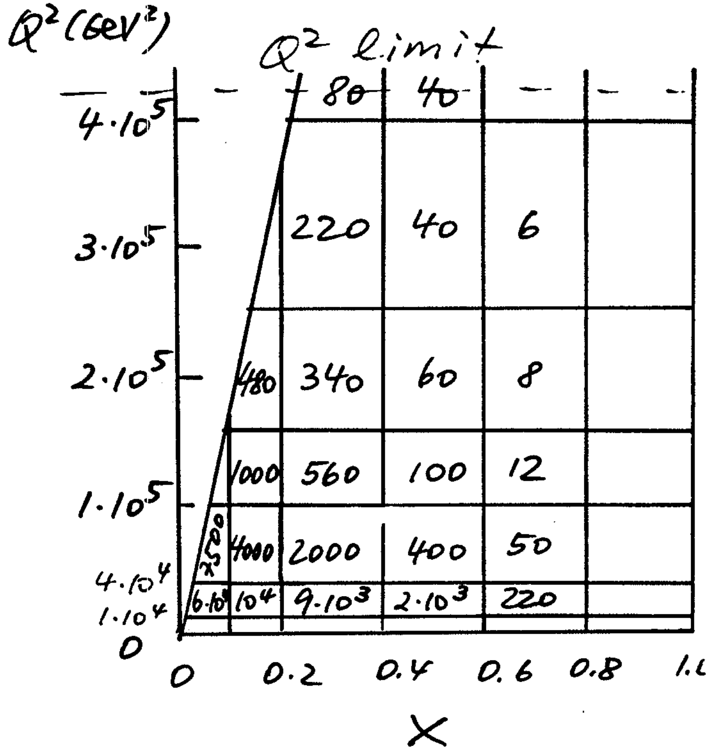
a) ep → eX



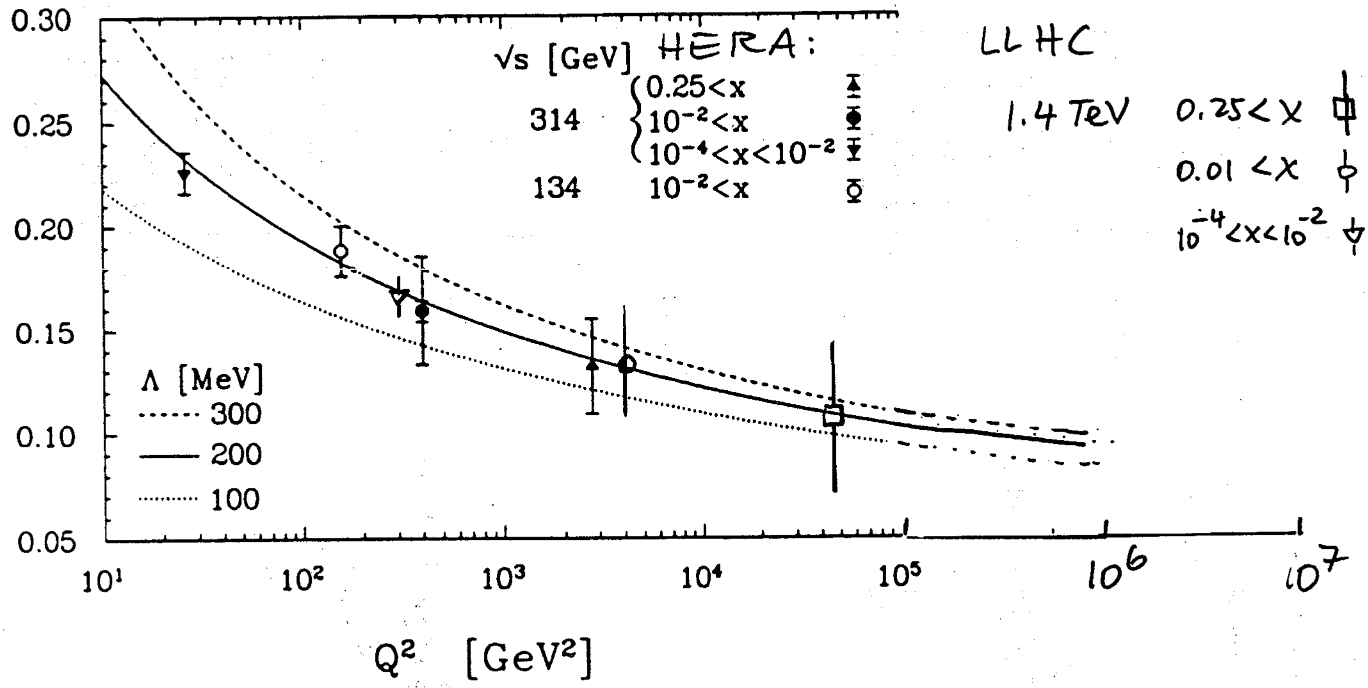


b) ep → νX



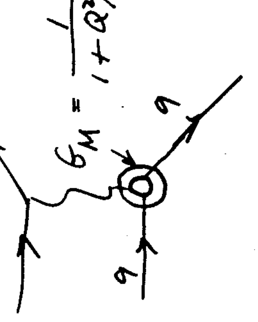


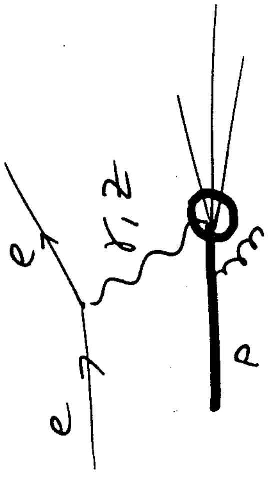
Blümlein
Klein
Ingelman
Rückl



Zerwas 124

$\sigma_M = \frac{1}{1+Q^2/M_q^2}$

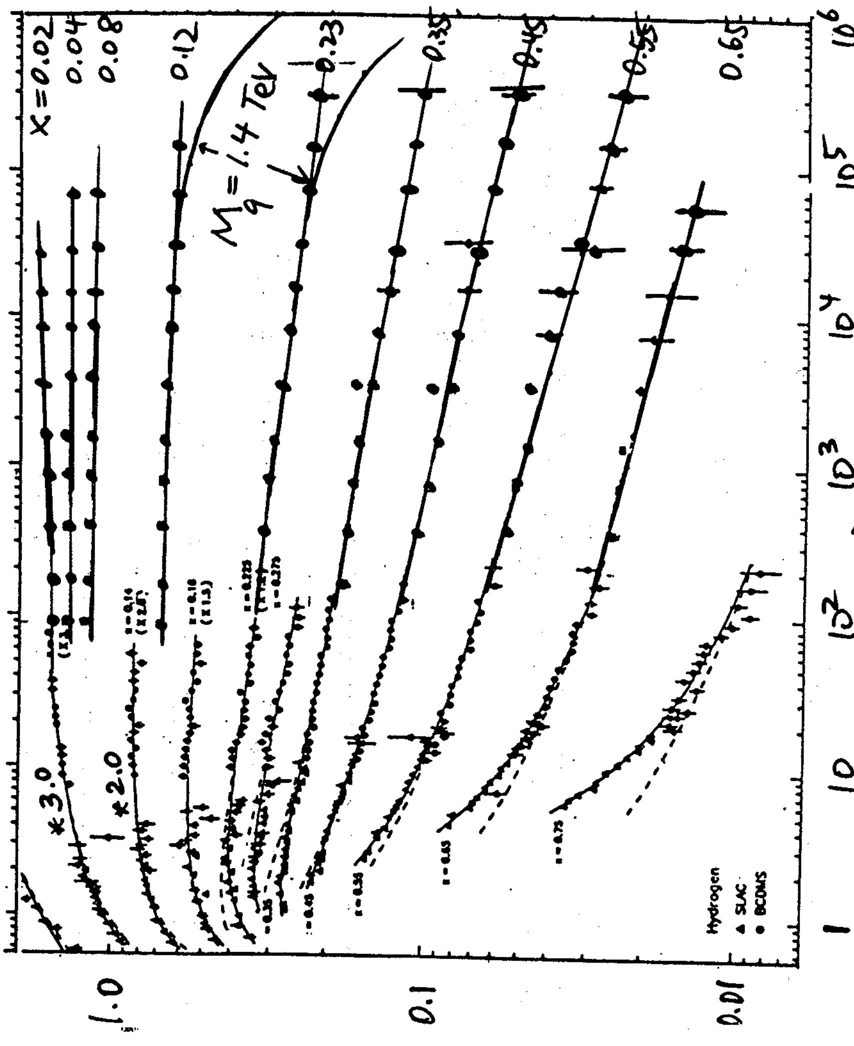




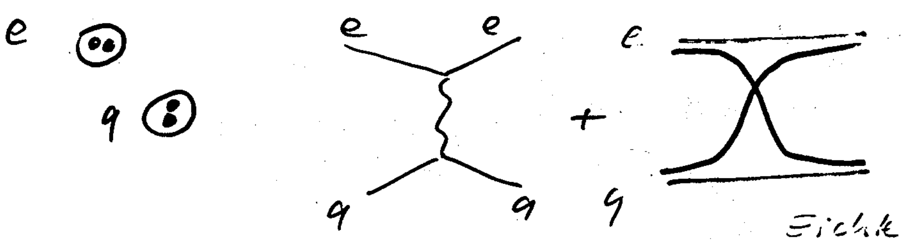
LHC limit $M \gtrsim 2$ TeV

HERA
10 GeV x 300 GeV $\mathcal{L}=100\,pb^{-1}$
30 x 820 $500\,pb^{-1}$

LLHC
60 x 8000
$\mathcal{L}=2000\,pb^{-1}$



electron + quark substructure



Eichten et al.
Rückl!

$$\mathcal{L} = \mathcal{L}_{SM} + \frac{g^2}{2\Lambda_H^2} \sum \eta_{\alpha\beta}\, \bar{e}_\alpha \gamma^\mu e_\alpha\, \bar{q}_\beta \gamma^\mu q_\beta$$

$$\alpha, \beta = L, R$$

assume $g^2/4\pi = 1$

$\to \Lambda_H$ sets mass scale

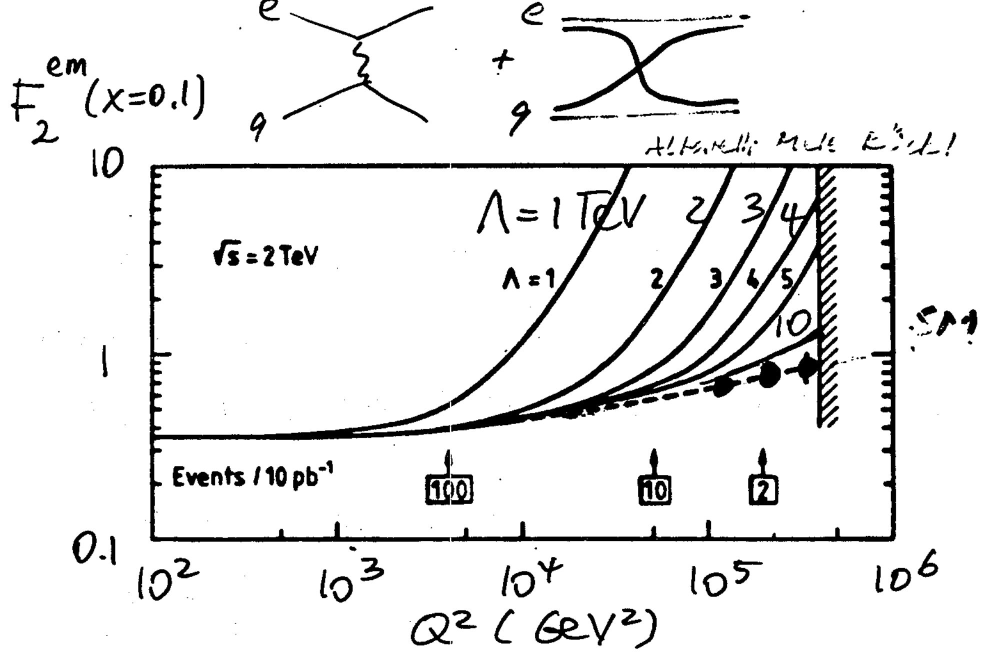
LHC: cross section measurements

$\to \Lambda_H \sim 7 - 19$ TeV

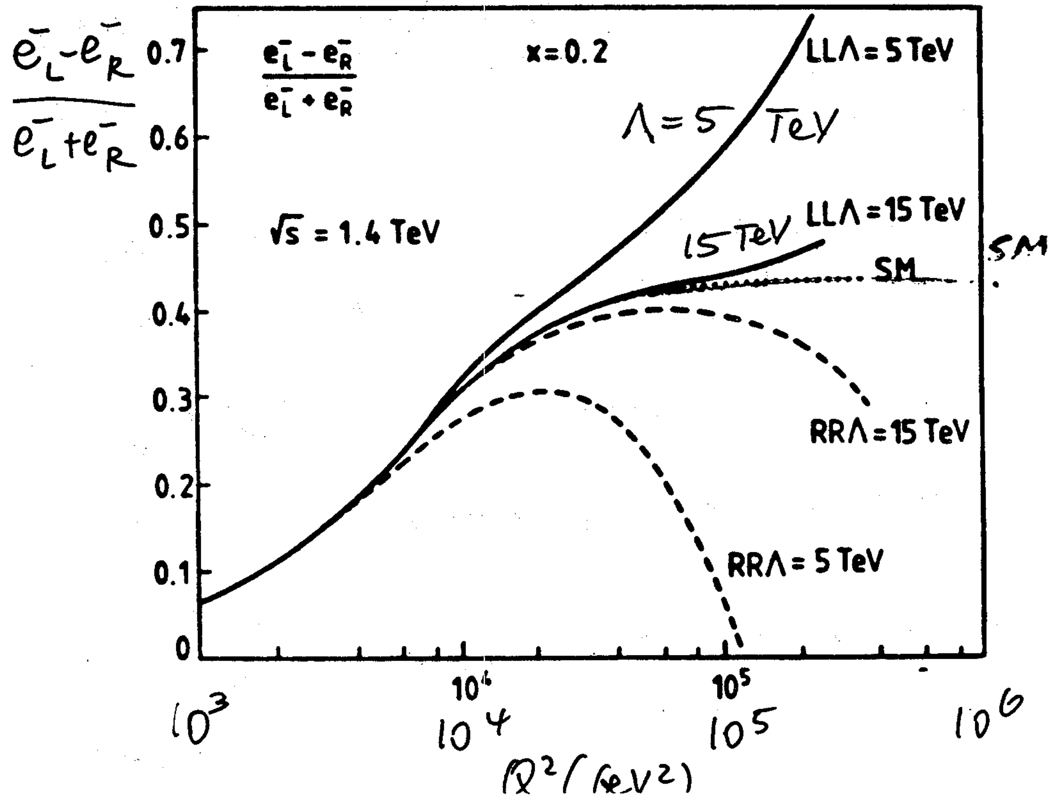
$\hookrightarrow 1 \cdot 10^{-18}$ cm!

asymmetry measurements

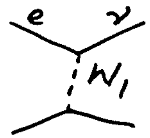
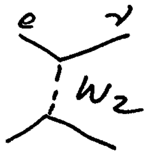
$\Lambda_H \sim 9 - 21$ TeV



Cornet & Martin
Doncheski



Search for new currents

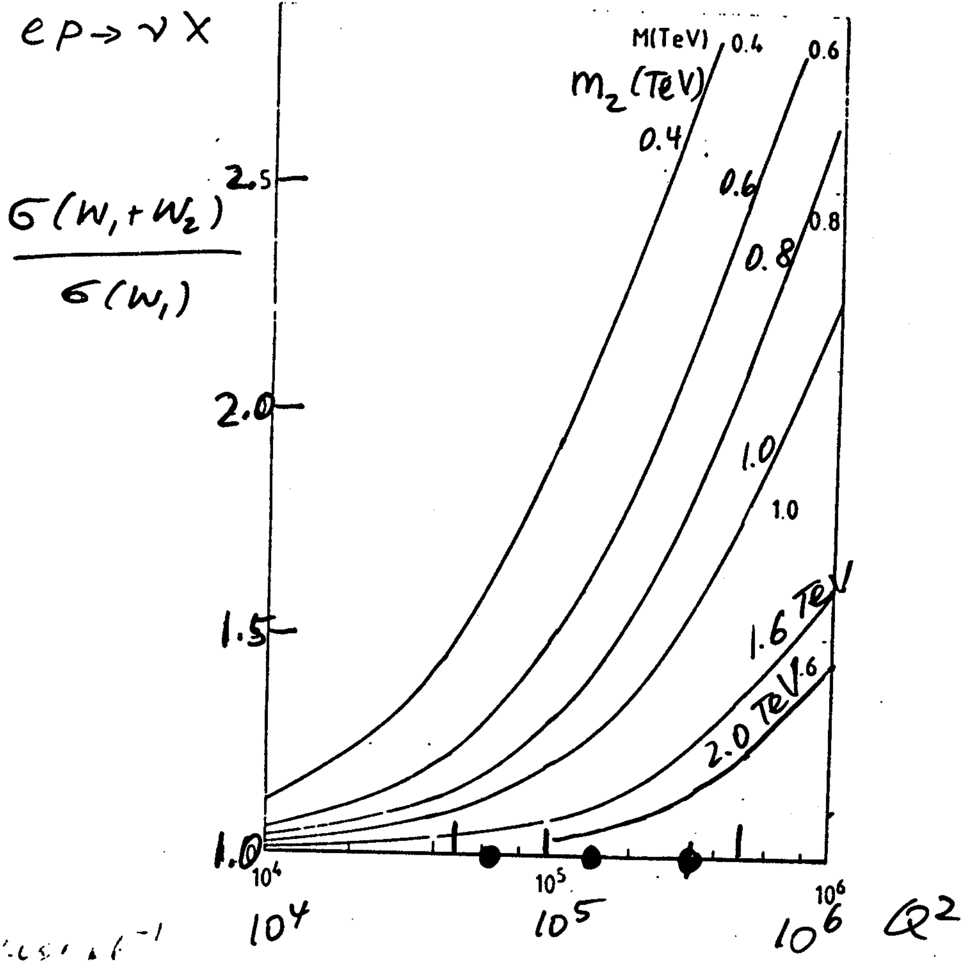
e.g. heavy W  + 

$$A_{1+2}(Q^2) \sim \frac{g_1^2}{Q^2+m_1} + \frac{g_2^2}{Q^2+m_2^2}$$

assume $G_F = \frac{g_1^2}{m_1^2} + \frac{g_2^2}{m_2^2}$ ⇐ Keep low energy behavior

Altarelli et al

ep → νX



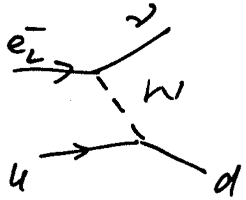
[illegible] $^{-1}$

→ Sensitive up to [illegible]

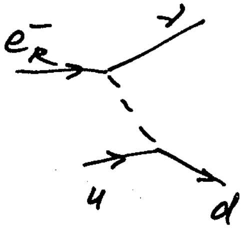
Chirality

Only left handed q, ℓ couple to charged weak current
right $\bar{q}, \bar{\ell}$

note ν right handed $\bar{\nu}$ left handed



Cross section ≠ 0



Cross section = 0

$$\frac{d^2\sigma}{dxdy}\begin{Bmatrix} e_L^- P \\ e_R^+ P \\ e_R^- P \\ e_L^+ P \end{Bmatrix} = \frac{\pi\alpha^2}{8\sin^4\theta_W}\frac{sx}{(Q^2+M_W^2)^2}\begin{cases} 4(u+c)+4(\bar{d}+\bar{s})(1-y)^2 \\ 4(d+s)+4(\bar{u}+\bar{c})(1-y)^2 \\ 0 \\ 0 \end{cases}$$

Non zero $\sigma(e_R^- P)$, $\sigma(e_L^+ P)$ signal new physics

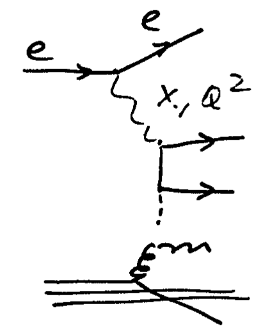
Polarized $e^\pm$ beams would give a powerful handle on chirality

Cornet & Martyn

$g = g'$ $P_e = 80\%$ → sensitive up to $m_{W_R} \approx 770$ GeV

Small x physics

Phys Rep 100
A.H. Mueller + ...



require: $Q^2 > Q_0^2 = 10 \text{ GeV}^2$

$\to \alpha_s$ small

How small can x be?

$$x = \frac{Q^2}{ys} \approx \frac{Q^2}{s} \text{ near } y=1$$

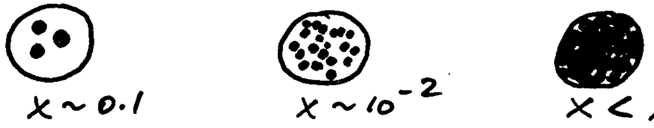
for fixed $Q^2 > Q_0^2$ need large s for small x:

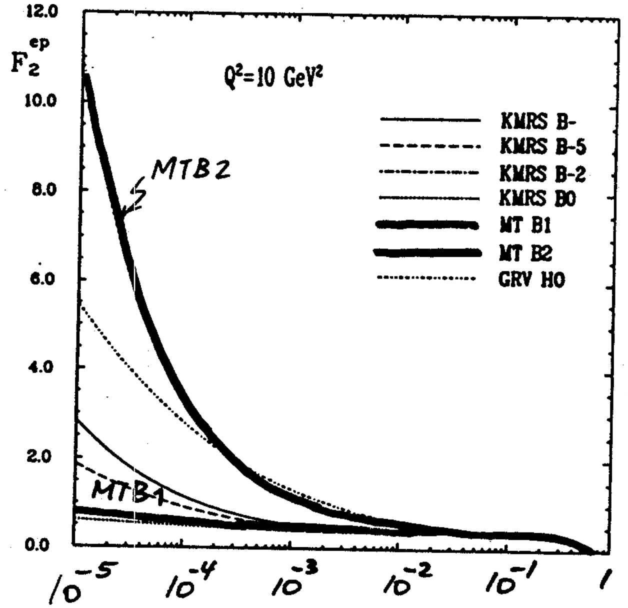
present expts	HERA	LHC
$s = 10^3 \text{ GeV}^2$	10^5	$2\cdot10^6$
$Q^2 > 10 \sim x_{min} = 10^{-2}$	10^{-4}	$2\cdot10^{-6}$ acc.$\to 10^{-5}$

As. $x \to 0$ for $Q^2 > Q_0^2$:

- number of gluons, seaquarks in protons grow $\to \infty$
  e.g. Regge: $G(x) \sim \frac{1}{x^{3/2}}$ number of gluons in $x, x+dx$
- transverse size of partons is fixed $\sim \frac{1}{Q}$
- partons confined in proton $\to$ overlap at some $x < x_{crit}$

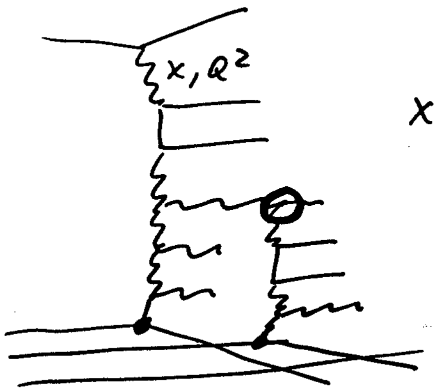
proton



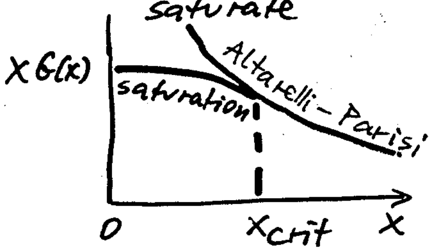


Consequences

I. partons interact;

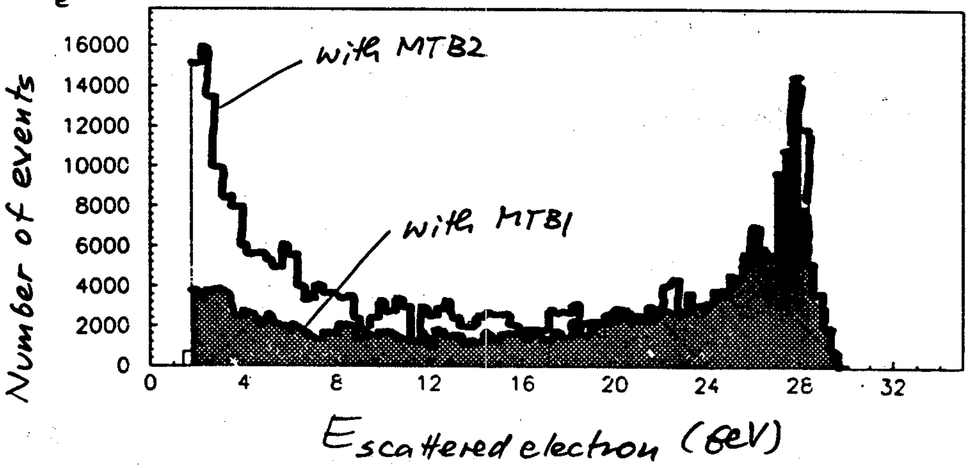


II. structure functions saturate

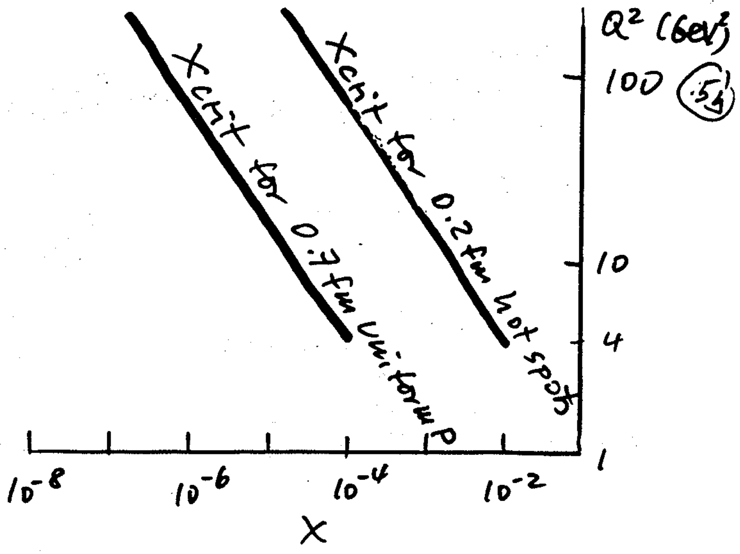


III. Parton overlap
= hot spots
→ produce minijets

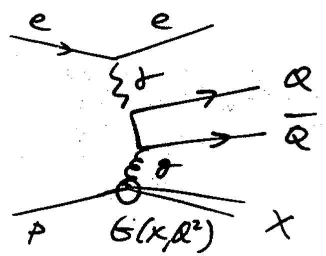
HERA 30×820 100pb^{-1}
$\theta_e = 140° - 155°$

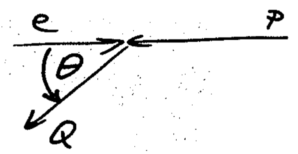


Kim & Ryskin



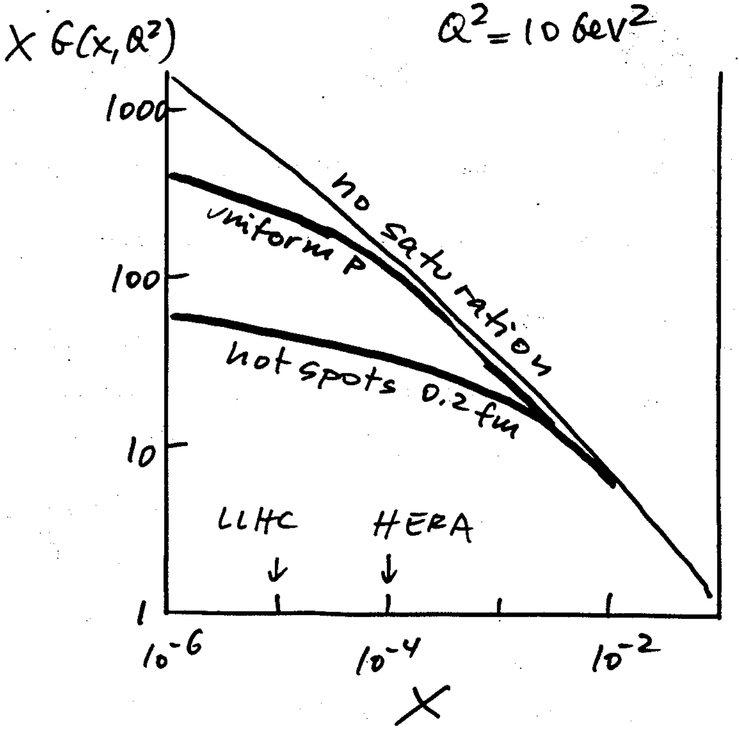
photon – gluon fusion of $c\bar{c}$, $b\bar{b}$

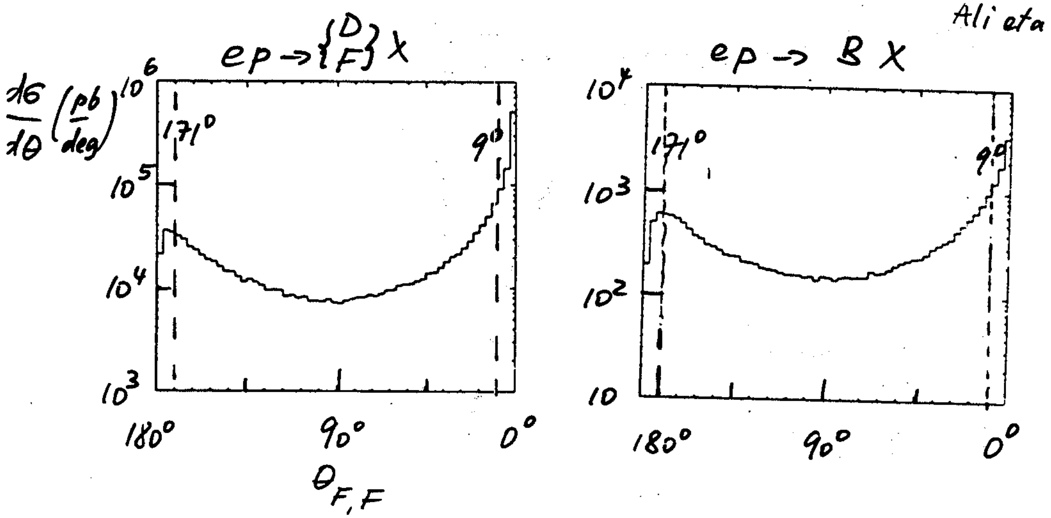




$\mathcal{L} = 1 fb^{-1}$

	$\sigma_{Q\bar{Q}}$	σ_Q $(9° < \theta_Q < 171°)$	N_Q $(9°–171°)$
$ep \to c\bar{c}X$	2.8 μb	3.2 μb	$3 \cdot 10^9$
$\to b\bar{b}X$	40 nb	57 nb	$6 \cdot 10^7$



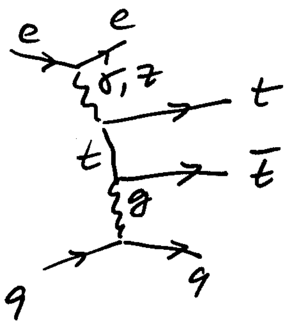


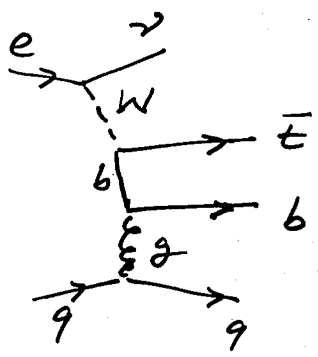
Ali et al

→ measure – $B_s^0 \bar{B}_s^0$ mixing

– $x\,G(x,Q^2)$ down to $x_g = 6 \cdot 10^{-5}$

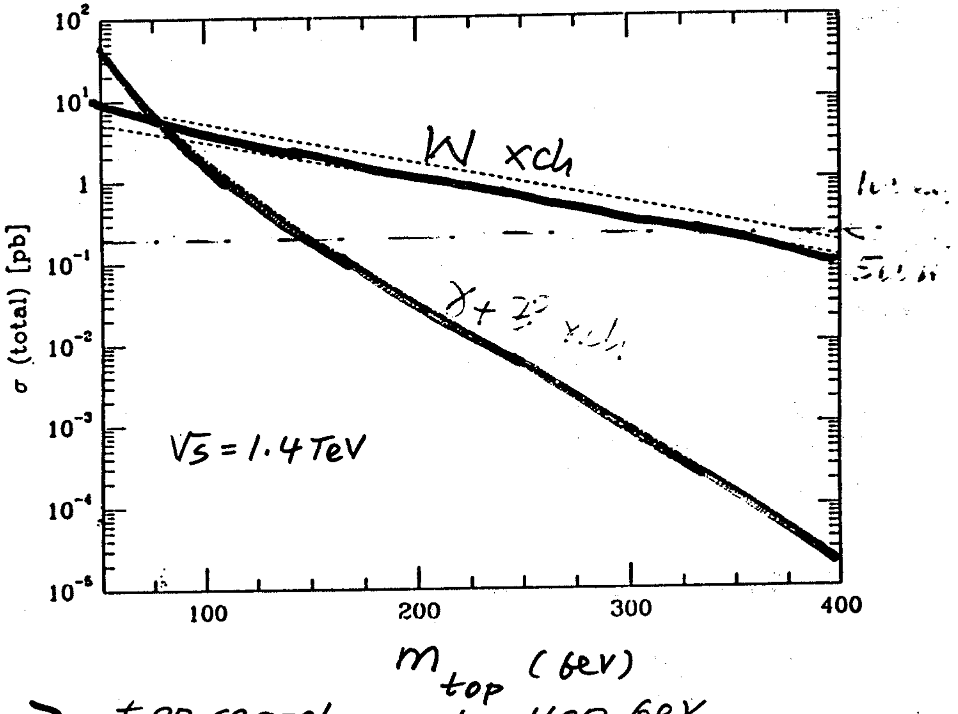
top quark production





$\sigma(ep \to tX)$

Schuler
Ali et al
Baer
vander Bij



→ top search up to 400 GeV

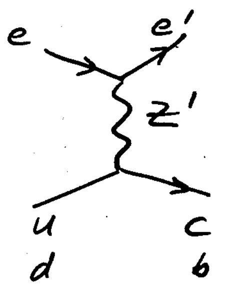
For $M_{top} = 150$ GeV, $\mathcal{L} = 500 pb^{-1}$: 1000 events

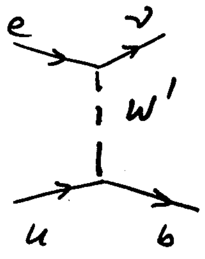
Search for breakdown of Standard Model

→ generation changing currents by new Z', W'

1st generation	d	u	e	ν_e
2nd	s	c	μ	ν_μ
3rd	b	t	τ	ν_τ

- quarks: search for:





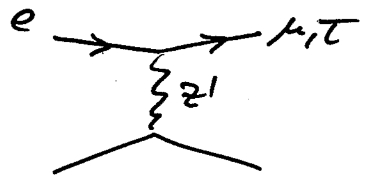
CKM
$\sim 2 \cdot 10^{-5}$

select - Large Q^2 to be sensitive to Z', W'
- $x > 0.2$ to avoid sea quark contrib

For $g_{ucZ'} = g_{uuZ}$ $\quad g_{ubW'} = g_{udW}$

sensitivity up to $M_{Z'}$ ≈ 0.8 - 1 TeV
$ W'$

- leptons: search for:

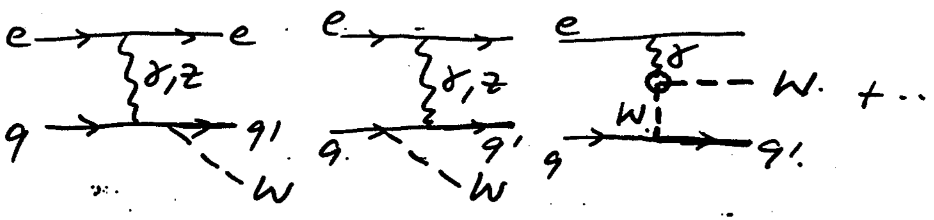


e.g. C.A. Heusch
Moriond '84

sensitivity up to $M_{Z'}$ ≈ 1.4 TeV

W, Z production

isolate from resolved γ to



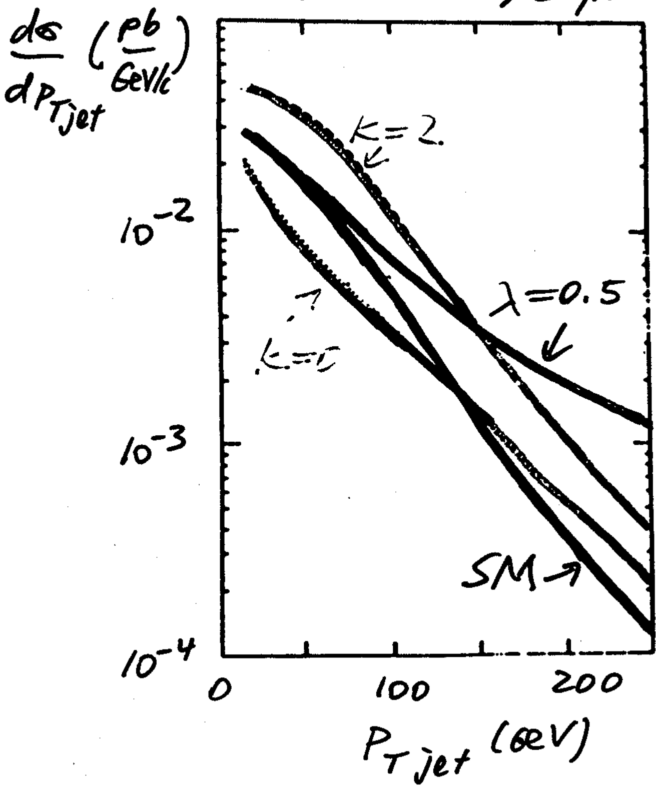
$$\mu_W = \frac{e}{2M_W}(1+K+\lambda) \qquad Q_W = \frac{e}{M_W^2}(\lambda - k)$$

SM:
$K=1$
$\lambda=0$

SM: $\sigma(e^-p \to W x) = 16\,pb$ ([illegible])

$e^-p \to e^- W_{\hookrightarrow e\nu, \mu\nu} + jet$

Baur, Kniel,
Vermaseren
Zeppenfeld
Helbig, Spiesber.



cuts
$|\eta_{e,jet}| < 4$
$P_{Te} > 10\,GeV/c$
$\not{P}_T > 10$
$\Delta R_{e jet} > 0.5$

$L = 2000\,pb^{-1}$:
~ 3200 events

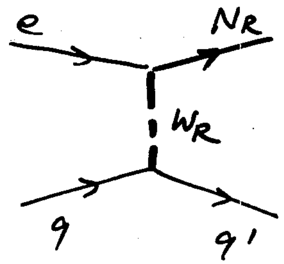
$\boxed{\Delta\lambda = \pm 0.1 \quad \Delta k = \pm 0.2}$

cf. LEP II

Δλ [illegible]

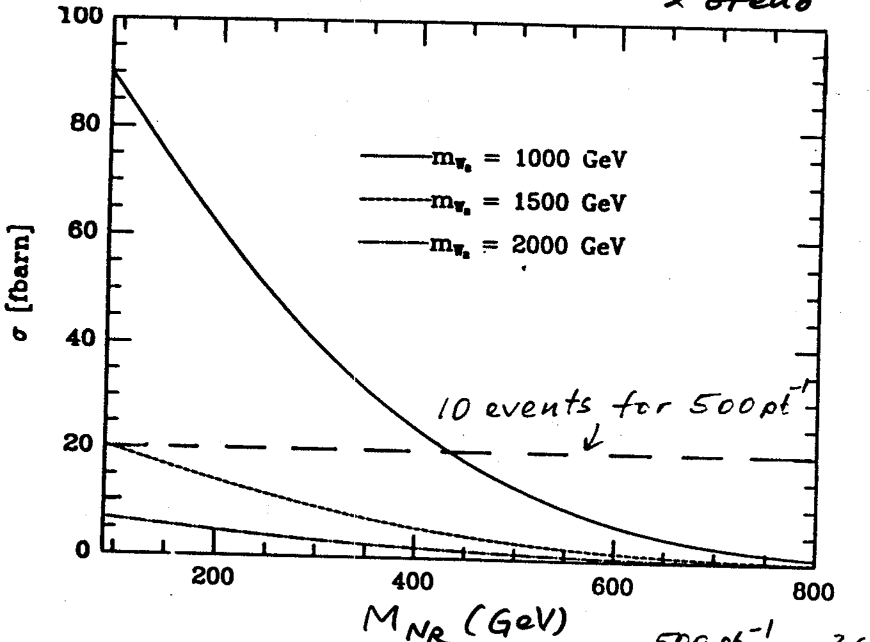
Note: measures <u>γWW</u> vertex; ZWW contribution is smal

Right handed W_R, N_R



$\sqrt{s} = 1.3\,TeV$

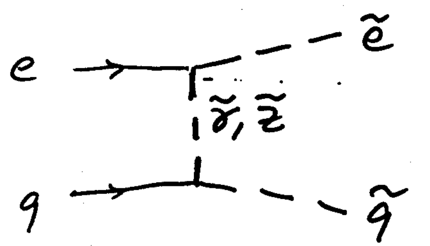
Buchmüller
& Greub



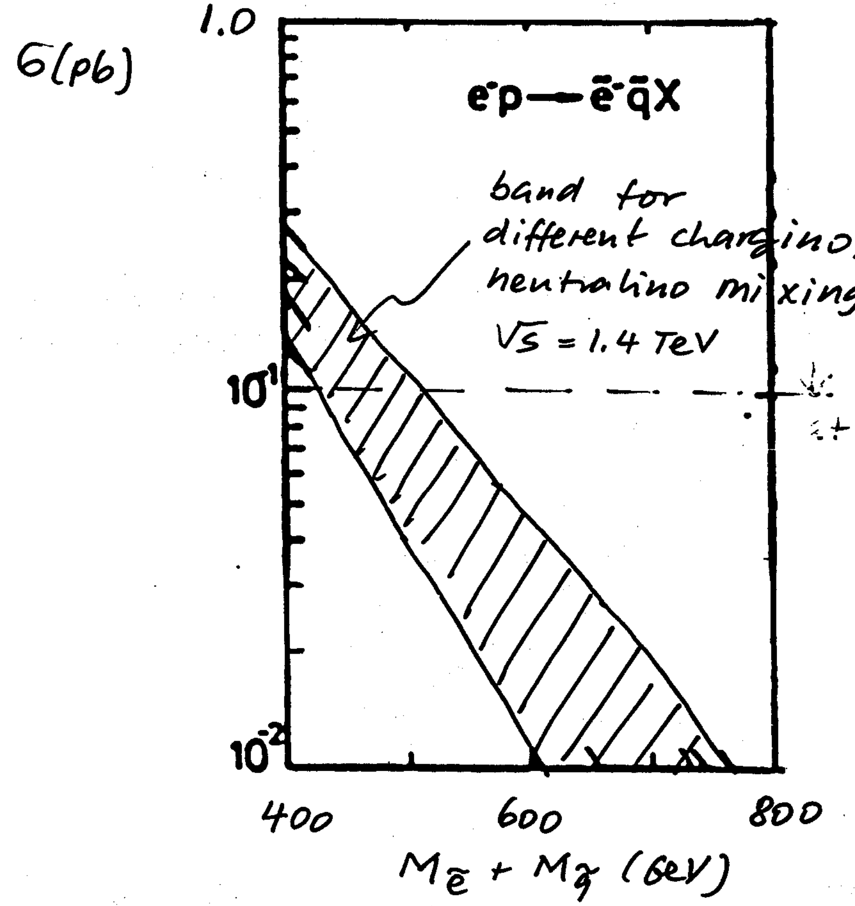
Sensitive up to

	$500\,pb^{-1}$	2000 pb
m_{W_R} =	1000 GeV	1500
m_{N_R} =	400 GeV	400

SUSY $eq \to \tilde{e}\tilde{q}$ $eq \to \tilde{\nu}\tilde{q}$



Komatsu
Rückl

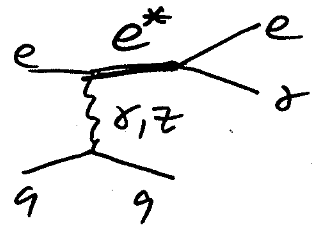


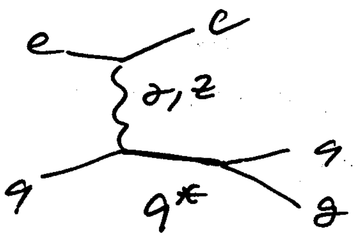
[illegible]

Excited electrons and quarks

If e, q are composites expect excited

e^*, q^*



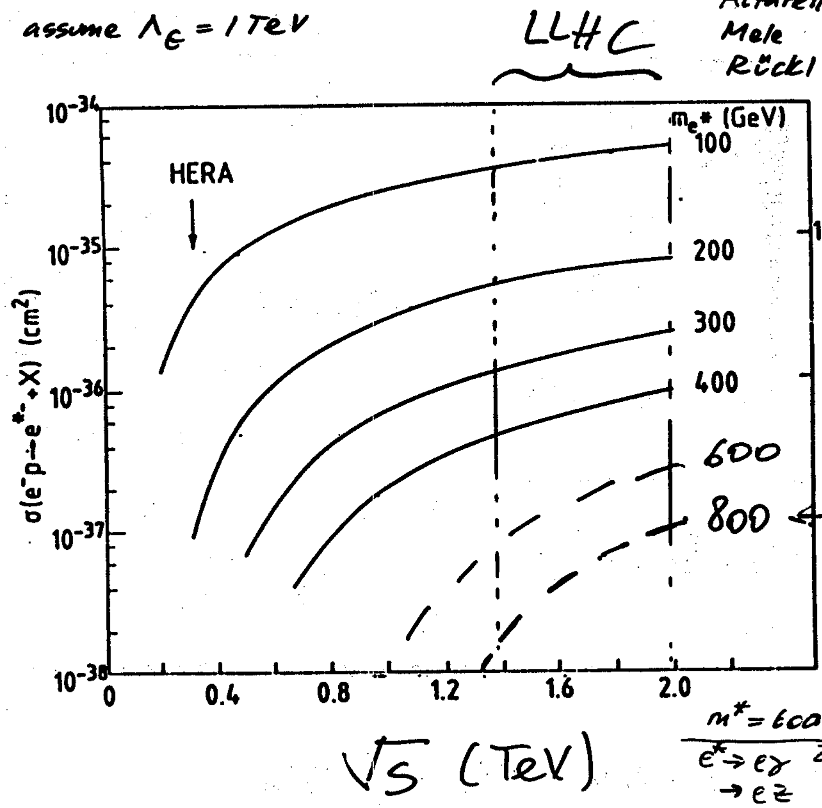


model

$$\mathcal{L}_G = \sum \frac{e}{4\Lambda_G} \bar{f}^* \sigma_{\mu\nu}(1-\gamma_5) f V_{\mu\nu} + h.c.$$

assume $\Lambda_G = 1$ TeV

Altarelli
Mele
Rückl



[illegible] at [illegible]

Berger et al

$m^* = 600$ GeV $\Lambda_F = m$

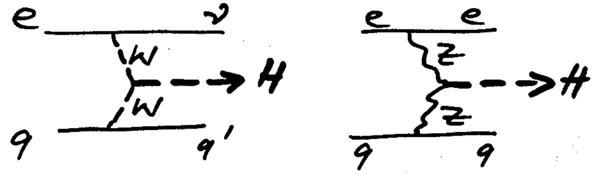
$e^* \to e\gamma$ 28%

$\to eZ$ 11%

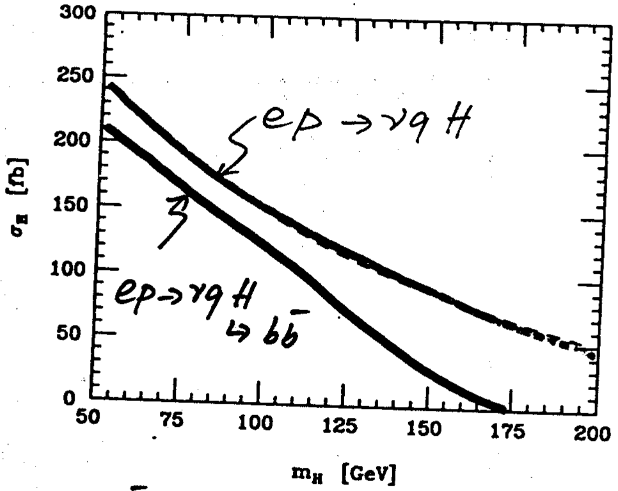
$\to \nu W$ 61%

[illegible]

Higgs production

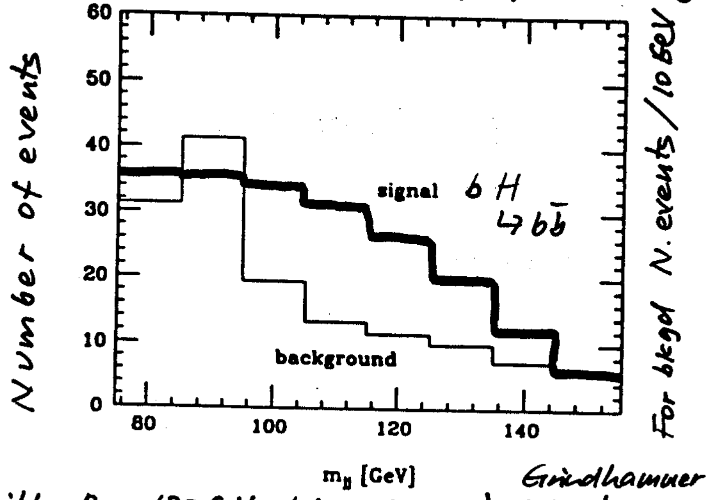


dominant decay
in intermediate regio
$H \to b\bar{b}$



Can one isolate $H \to b\bar{b}$ for $80 < M_H < 140$ GeV ?
→ 3jet events $P_{Tj} > 20$ GeV/c $|\eta_j| < 4.5$ $\Delta R_{jj} > 1$ $E_T > 100$ GeV
P_T miss > 20 GeV/c + b decay by vertexing

$\mathcal{L} = 1000\ pb^{-1}$

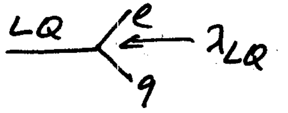


Grindhammer et al

conclusion:
with $1000\ pb^{-1}$ feasible 80 - 120 GeV
$\sim 2000\ pb^{-1}$ " - 140 GeV

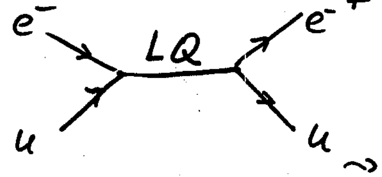
Leptoquarks LQ

Production mechanism depends on



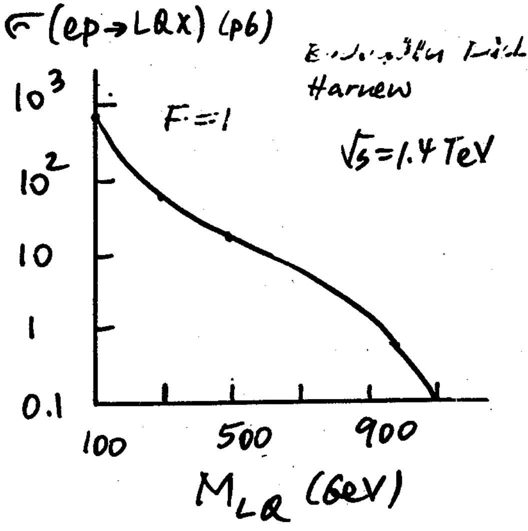
define $F = \dfrac{\lambda^2/4\pi}{\alpha_{em}}$

① λ_{LQ} independent of m_f e.g. → vector composit…
→ E6 models



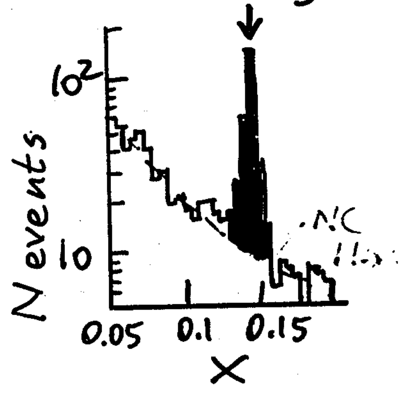
$$M^2_{LQ} = 4 E_e x E_p = x \cdot s$$

~> resonance in x distrib.



[illegible] Harnew

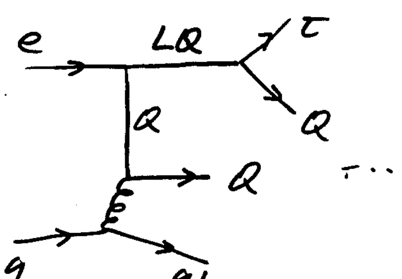
$M = 500$ GeV: $x = \dfrac{M^2_{LQ}}{s}$



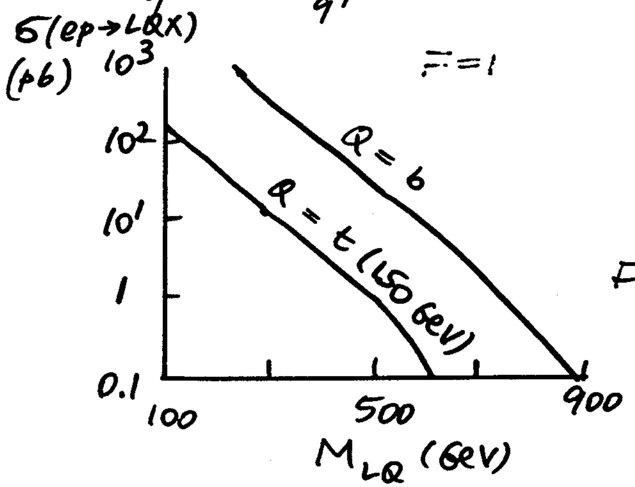
$\sqrt{s} = 1.4$ TeV
$L = 500\ pb^{-1}$ } ⤳ discovery limit on M_{LQ}

$F = 1$ $M = 1100$ GeV
$= 10^{-2}$ $= 700$
$= 10^{-3}$ $= 300$

② $\lambda_{LQ} \sim m_f$ c.f. — scalar [illegible]



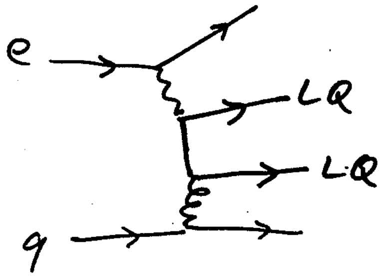
$Q = b, t$ ...



$\sqrt{s} = 1.4$ TeV
500 pb^{-1}
require 100 evts

		Q=b	Q=t
F=1:	M_{LQ}	800	600 GeV
10^{-2}		500	250

③ LQ pair production ⤳ indep of λ_{LQ}



$\sqrt{s} = 1.4$ TeV 500 pb^{-1}
> 100 events for $M_{LQ} \leq 140$ GeV (guess!)

physics at LLHC

- pointlike particle (e) probes quark, gluons, ..
- unique way to explore charged currents: $\sqrt{Q^2} \approx 700$ GeV

		HERA	LLHC	LHC_{pp}
$\sqrt{s}$		314 GeV	1400 GeV	
structure	Q^2_{max}	$4 \cdot 10^4$	$4 \cdot 10^5$ GeV²	
	x_{min}	10^{-4}	10^{-5}	
compositeness Λ		4-8 TeV	10-20 TeV	13
→ new W', Z'		700	1500-2000 GeV	4-500C
flavor C.C.	e→μ u→c	300-400	800-1000 GeV	
→ WWγ	$\Delta\lambda_\gamma$		± 0.1	± 0.1
	ΔK		± 0.2	
top quark		90	400 GeV	1000
Higgs			80-120 GeV	80-130? 130-800
→ LQ		280	1100 GeV	2000
$\tilde{e}, \tilde{q}$ ass $M_{\tilde{e}} = M_{\tilde{q}}$		90	300 GeV	1500
→ e^*, q^*		220	600 GeV	
W_R		400	1000 GeV	2800
N_R		150	400	

ep at $\sqrt{s} = 2$ TeV vs pp at $\sqrt{s} = 16$ TeV

where are the virtues of ep?

- discovery of new particles with final state electrons of a few hundred GeV

  e.g. $\tilde{e}$, N_R and $e \to L_e$ heavy electron
- search for flavor changing currents

  → clean environment
- composite scale
- structure studies

→ start with a point like probe = electron

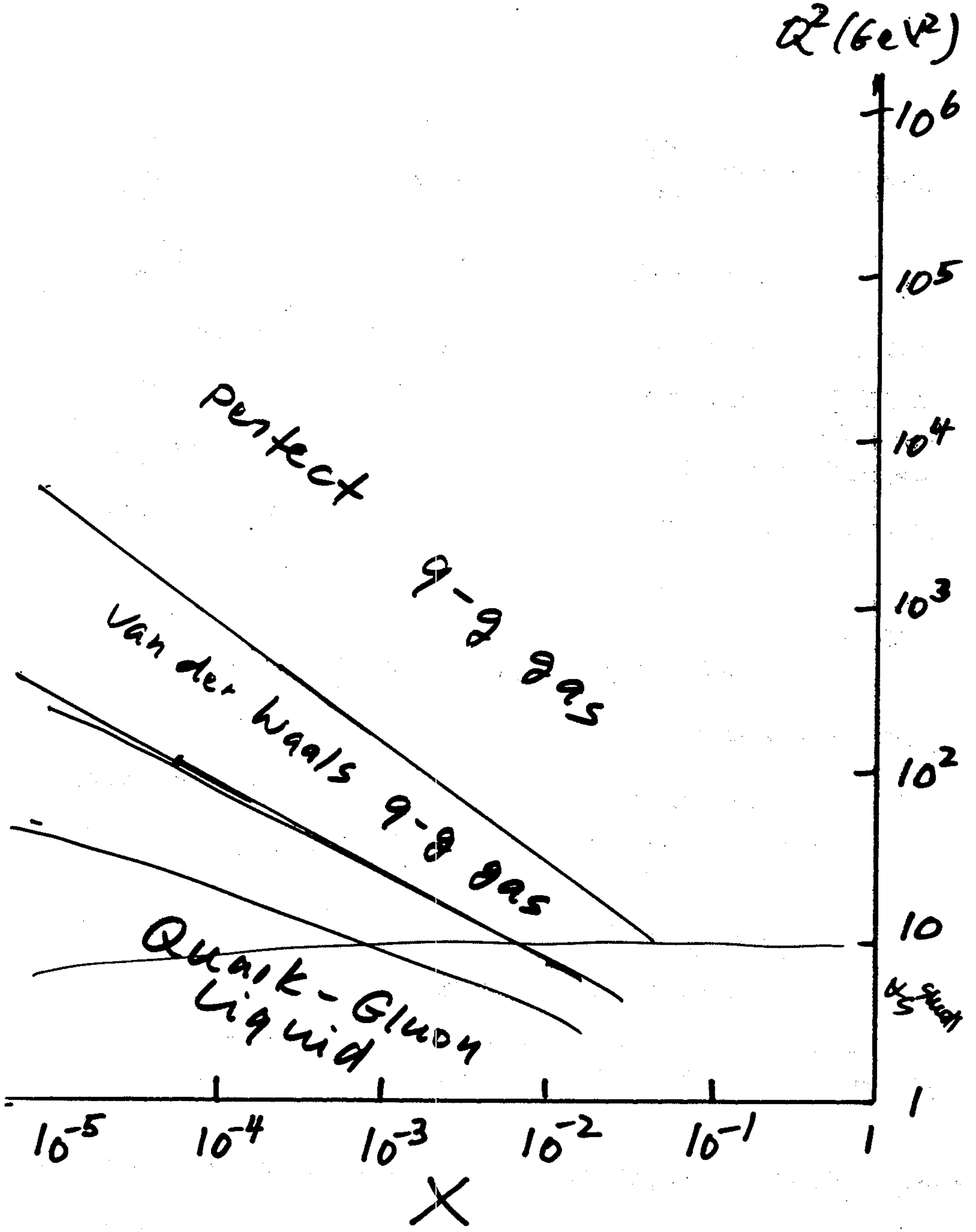
→ unique way to explore charged currents

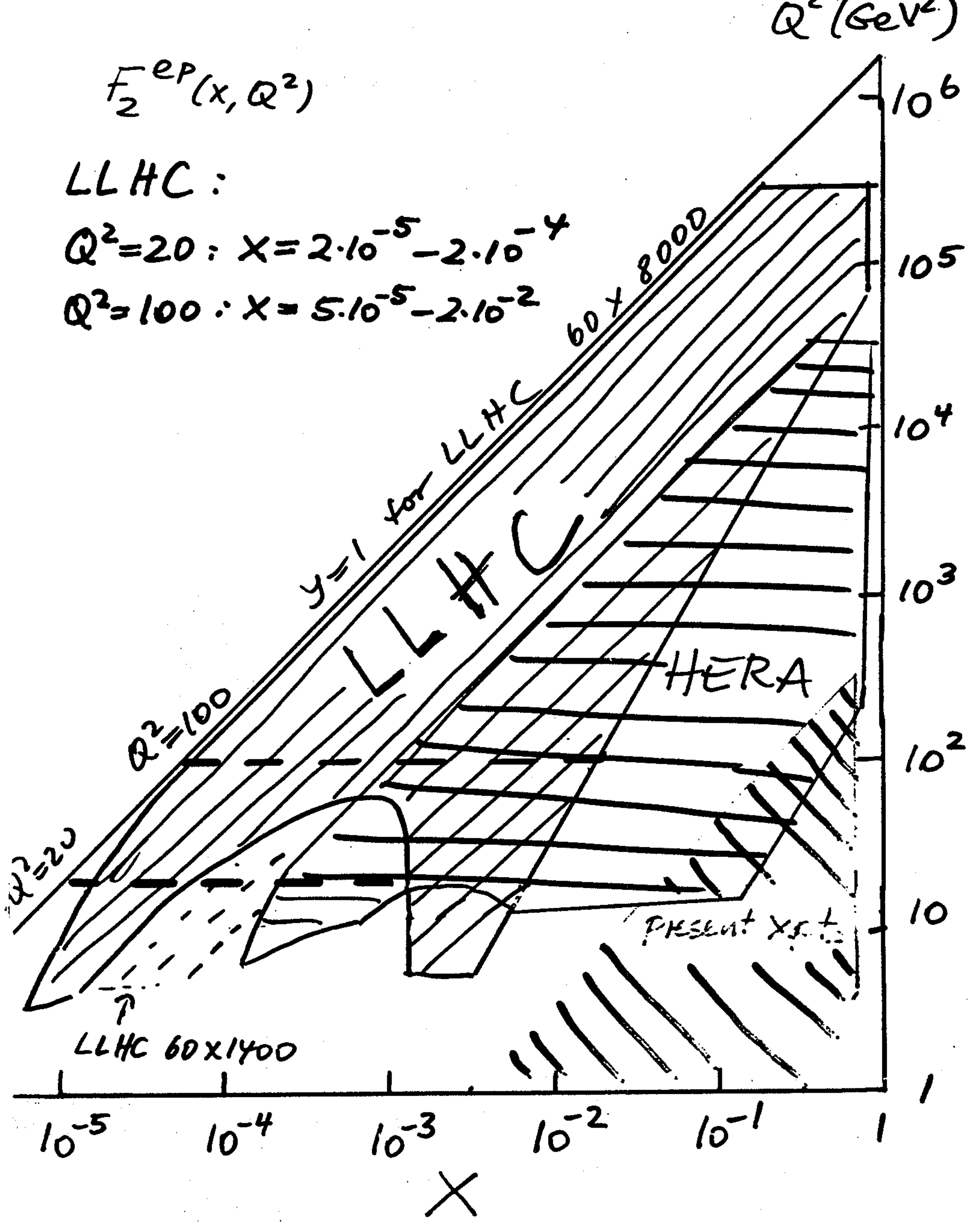
→ can increase Q^2_{max} by × 10 over HERA

→ extend x range down to 10^{-5}

? get near confinement

note: most optimistic guess Kim & Ryskin





$F_2^{ep}(x,Q^2)$

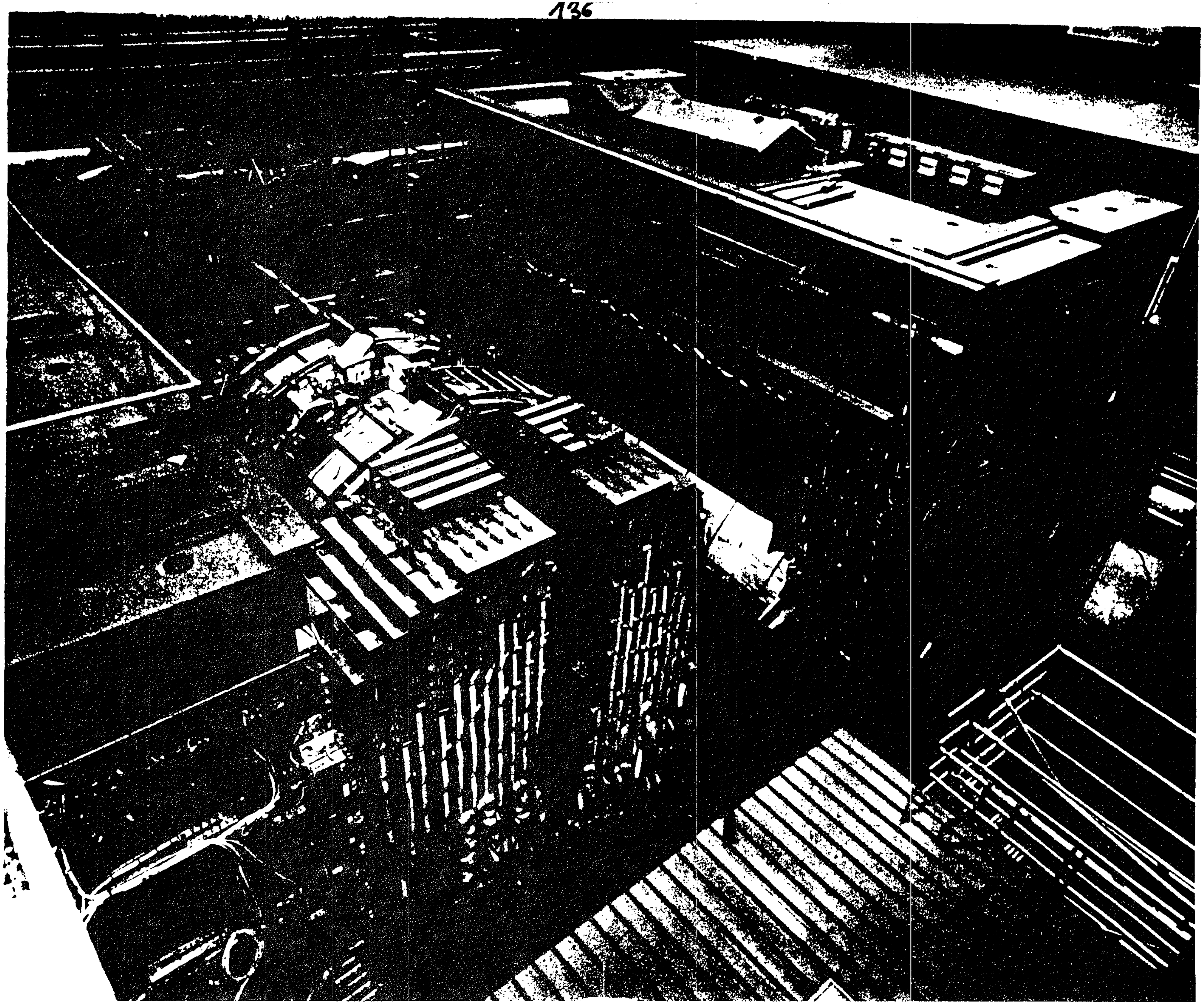
LLHC :

$Q^2=20 : X=2\cdot10^{-5}-2\cdot10^{-4}$

$Q^2=100 : X=5\cdot10^{-5}-2\cdot10^{-2}$

H1

ZEUS



Expression of Interest

The Ascot detector at the LHC

P. Norton (Rutherford-Appleton Laboratory)

ASCOT

Evian
5 March 92

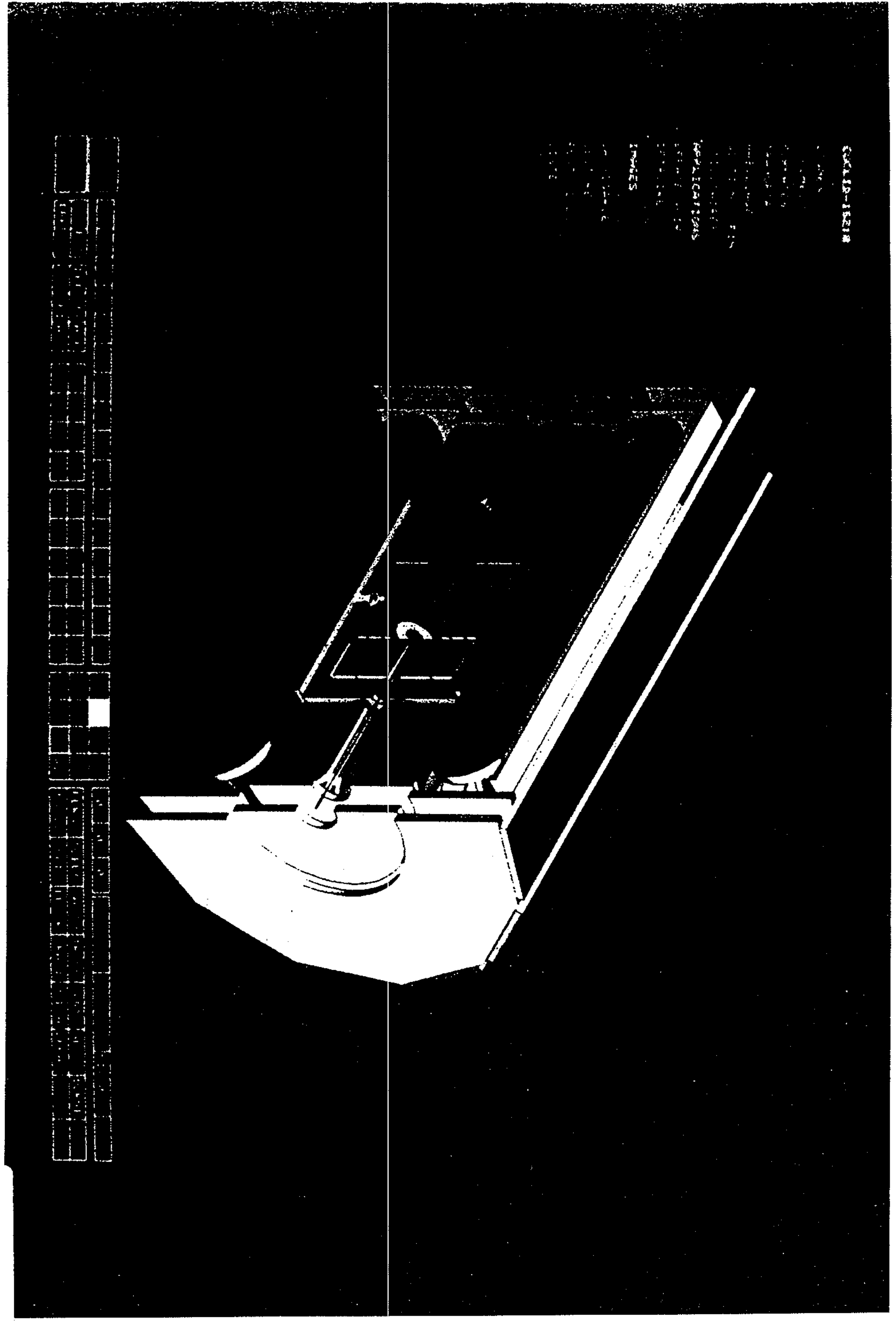
P.R. Norton
RAL

Participating Institutions

CERN
Edinburgh University
[Heidelberg University]
IHEP Protvino
JINR Dubna
Lebedev Institute of Physics, Moscow
LITMO Institute, St. Petersburg
[Mainz University]
Moscow State University
MPI Munich
Munich University
Nuclear Physics Institute, St. Petersburg
Rutherford Appleton Laboratory
Saclay
[Siegen University]
Tel Aviv University
Warsaw University
Wuppertal University

140

Apparatus with
Super
C
Onducting
Toroids



Ex60-2-92/1

LHC physics requires the detection and identification of

- Leptons — e, μ, (and τ)
- Photons
- Jets, $E_T{}^{miss}$

The most interesting processes have very small cross sections, so running at the highest possible luminosity is essential.

⇒ Very hostile environment in which to do physics

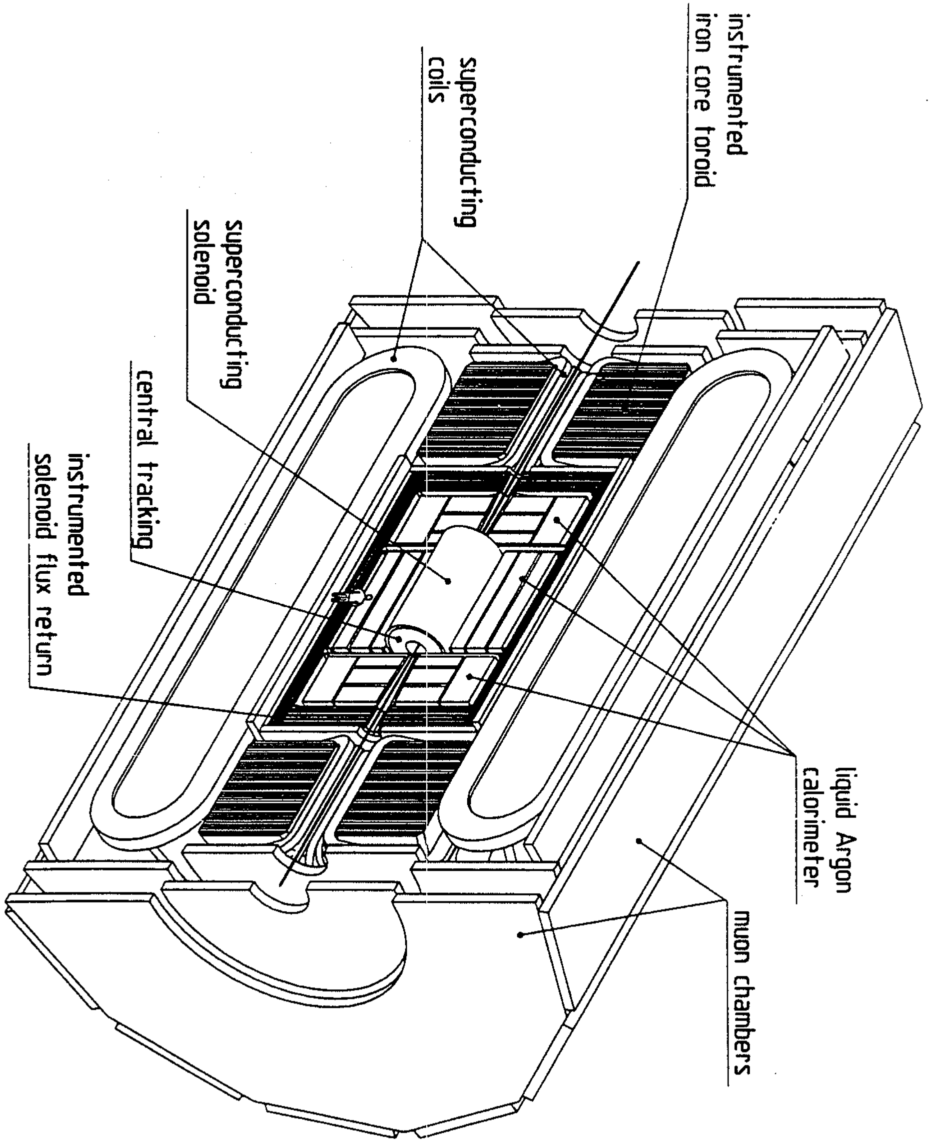
ASCOT Priorities

LHC physics requires the detection and identification of

1. Muons
   - Measure in TOROIDS outside the calorimeter with high precision
   - NO use of inner tracking necessary
   - Totally safe measurement at ANY luminosity
2. Electromagnetic Calorimetry
   - Uniformity
   - Stability
   - Granularity
3. Central Solenoid with inner tracking
   - Sign of $e^{\pm}$ up to 500 GeV
4. Minimize number of subdetectors (keep it simple)

Detector Overview

- Toroids & muon system: $|\eta| \leq 3$
  - – Barrel: s/c air core toroid – $< B > \sim 0.6$ T
  - – End-cap: s/c Fe core toroid – $< B > \sim 3$ T
  - – NO use of inner tracking necessary
- Calorimetry: $|\eta| \leq 3.5$
  - – Lead/LAr and Steel/LAr
  - – Hermetic
  - – 12 λ_{abs} at $\eta = 0$ and 14 λ_{abs} at $\eta = 3$
  - – Forward calorimeter: $|\eta| \leq 3.5 - 5.0$
- Solenoid
  - – $B = 1.5$ T
  - – Tracker: $|\eta| < 2.5$
- Overall
  - – length: 30 m
  - – radius: 11 m
  - – weight: 10,500 t

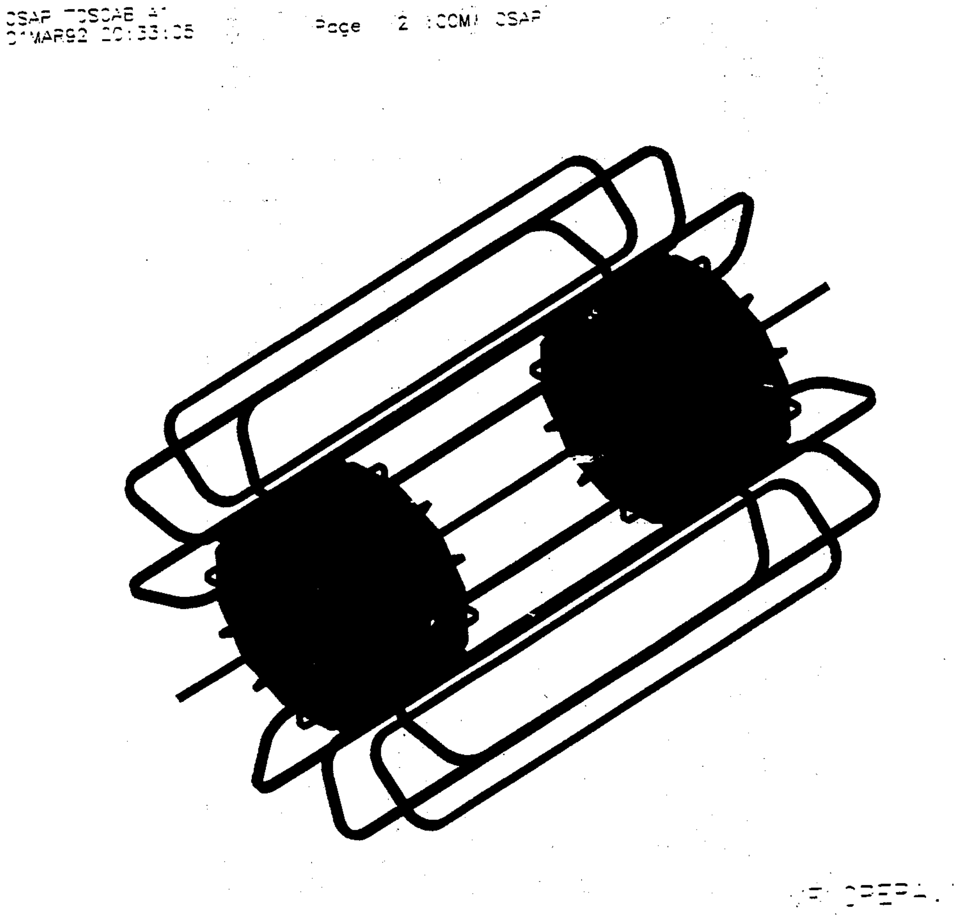


Why Toroids ?

- Field always perpendicular to particle direction
- Barrel
  - $\int Bdl \sim 1/sin\theta$
  - $< BL^2 > \sim 1/sin^2\theta$
  - Improved Δp/p as η grows (unlike solenoid)
- End-caps
  - Need a bigger $\int Bdl$ to match bending power to average muon momentum

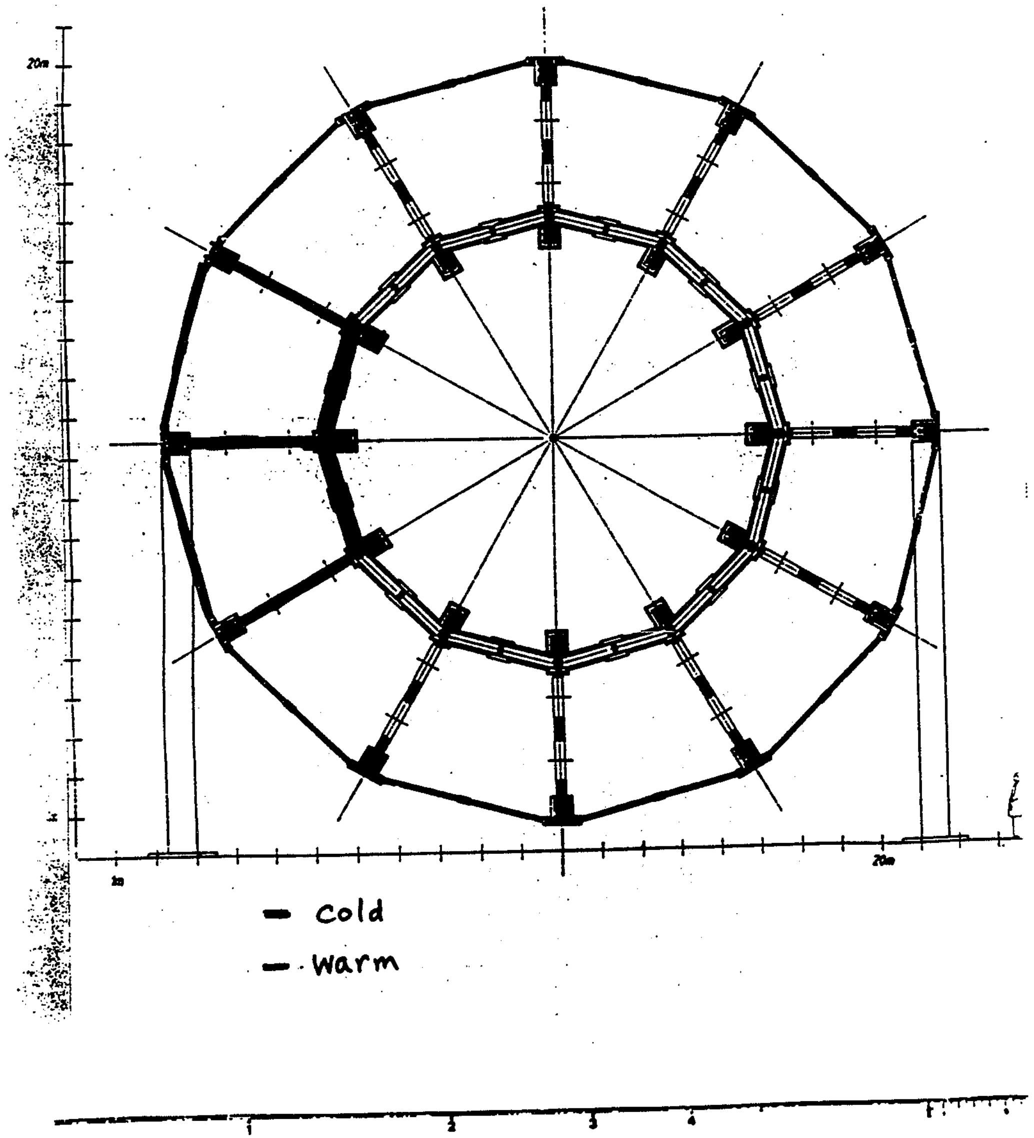
Table 1: *Dimensions and weights of the ASCOT detector components*

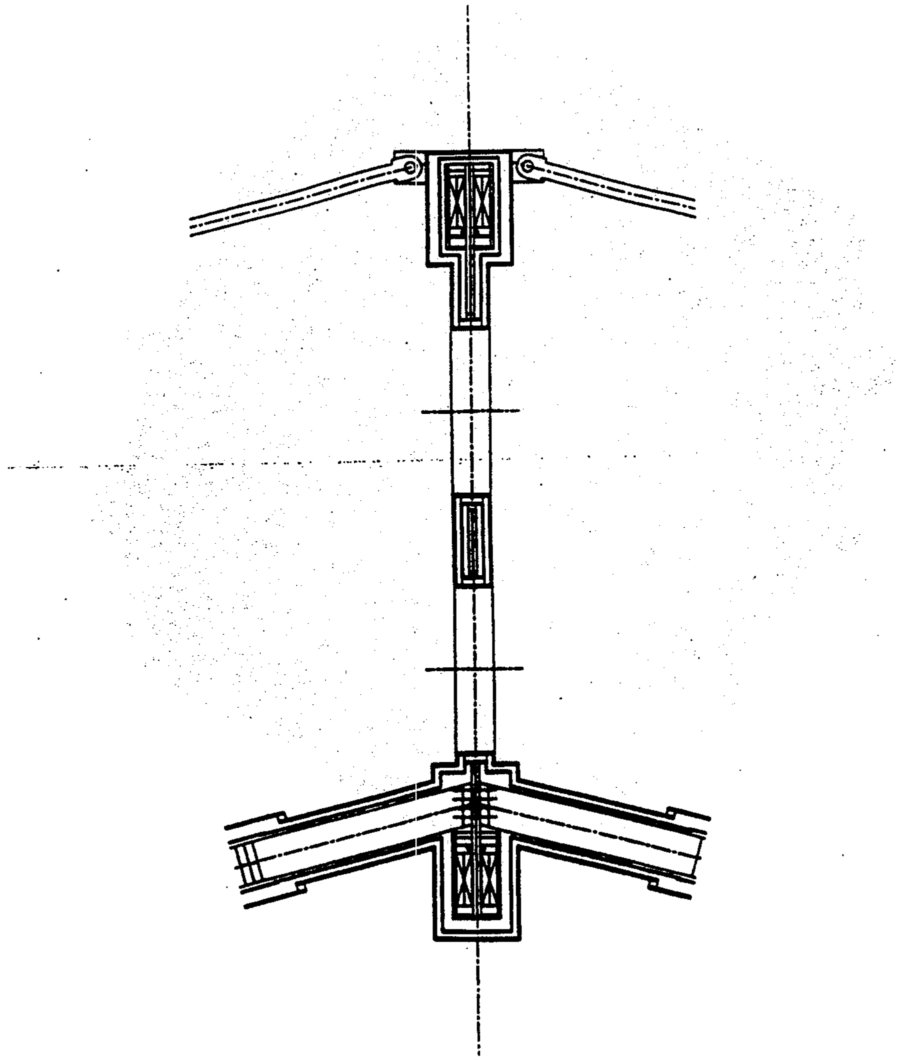
Detector Component	length (m)	radius (m)	weight (t)
Barrel Toroid	26	5.0 - 9.9	720
End-cap Toroids	5.6	0.2 - 5.2	2 × 2000
Barrel Muon Chambers	13, 26, 30	5, 7.5, 11	430
End-cap Muon Chambers		0.5 - 11	2 × 65
Barrel Calorimeter	5.0	1.4 - 4.7	1700
End-cap Calorimeters	3.8	0.2 - 4.7	2 × 1500
Forward Calorimeters	4.0	0.2 - 1.4	2 × 150
Solenoid	5.0	1.15 - 1.4	20
Inner Tracking Detector	5.0	0.4 - 1.15	< 1
T O T A L	30	11	10,500



Solution

- Barrel region ⇒ Air cored toroid of large size
  - Excellent muon-momentum resolution
  - Very low background
- End-cap region ⇒ Iron cored toroid with superconducting coils
  - High bending power because of 'free' 2.1 T from iron
  - Good momentum resolution, multiple scattering limited up to almost 1 TeV
  - Iron instrumented with streamer tubes to identify 'catastrophic' muon energy loss
  - 'Soft' decay muons from b, c, K, π range out in iron — reduce fluxes in muon detection system


20m
1m
20m
Cold
Warm
1
2
3
4



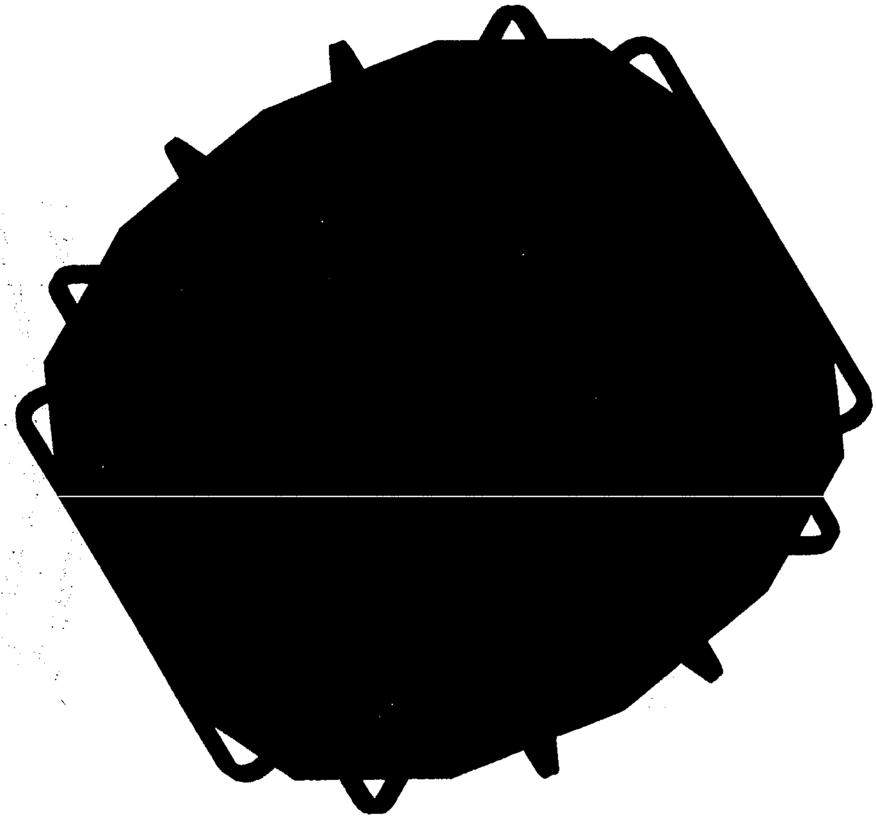
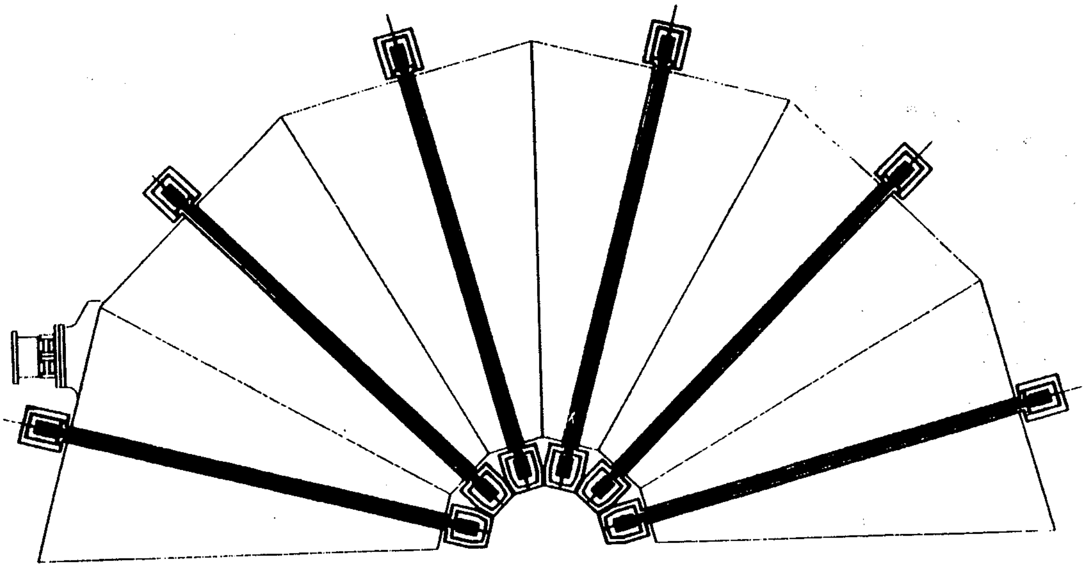


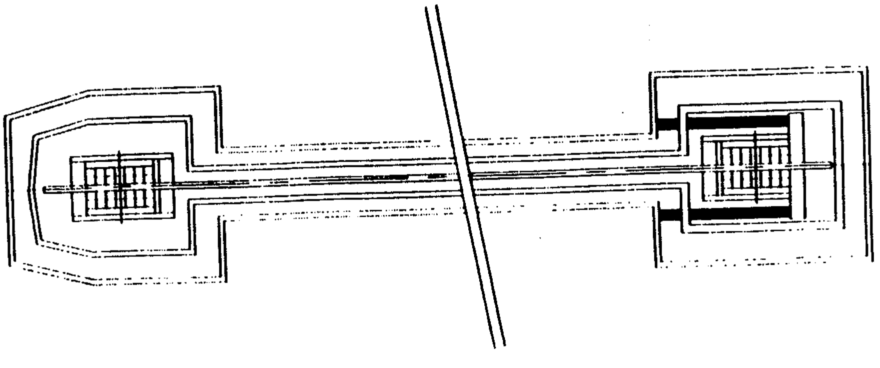
Table 2: *Air-core Toroid Parameters*

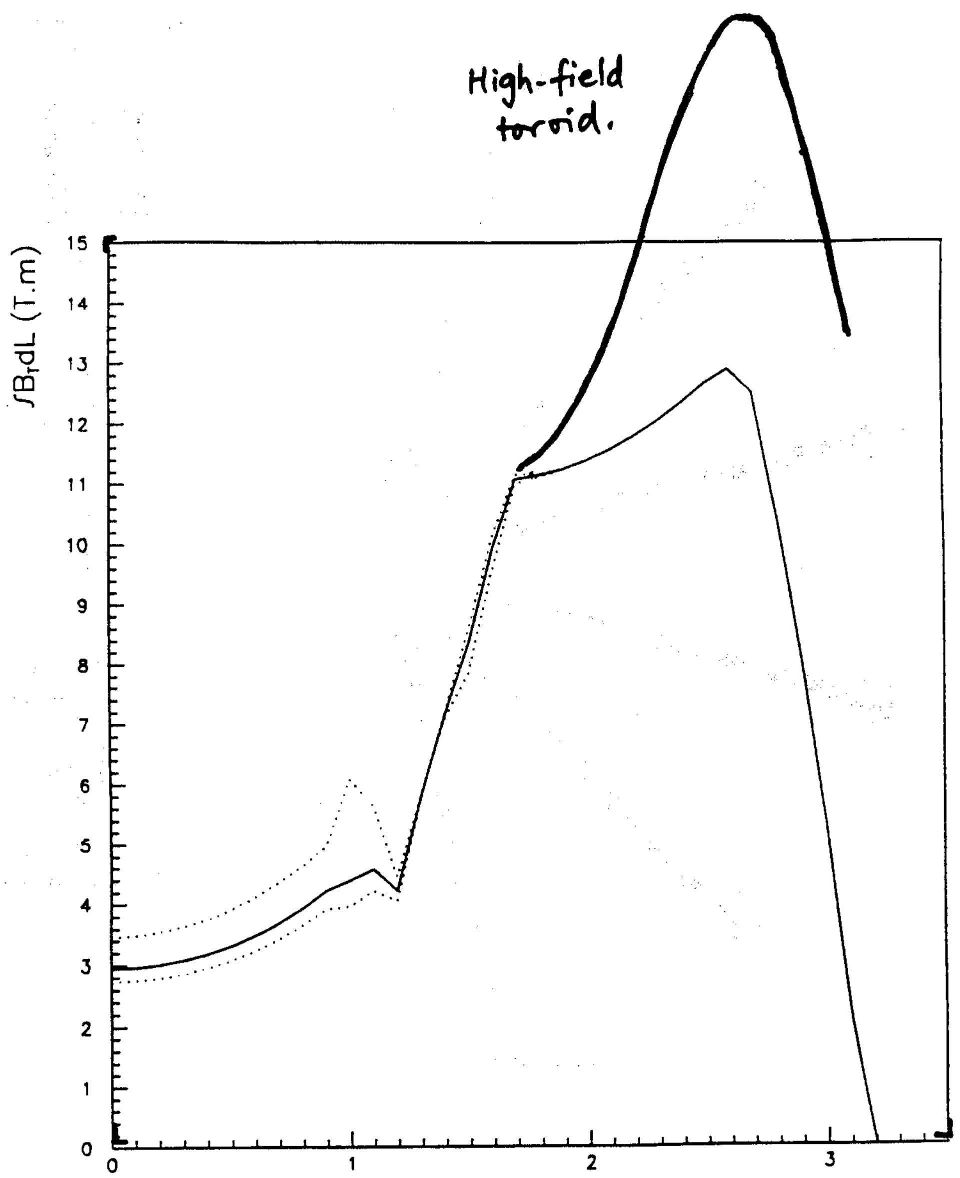
Inner free radius of toroid	5	m
Outer radius	9.9	m
Number of coils	12	
Individual coil overall dimensions	26 × 5	m^2
∫BdL at η=0	3	T·m
Total Ampere turns	26×10^6	A turns
Stored energy	~ 1	GJ
Peak field at the conductor	3.5	T
Radial force on inner leg	- 97	t/m
Radial force on outer leg	60	t/m
Operating current	20	kA
Conductor cross section	55 × 11	mm^2
Conductor total length	70	km
Weight of a coil	60	t
Refrigeration power at 4.5 K	1	kW

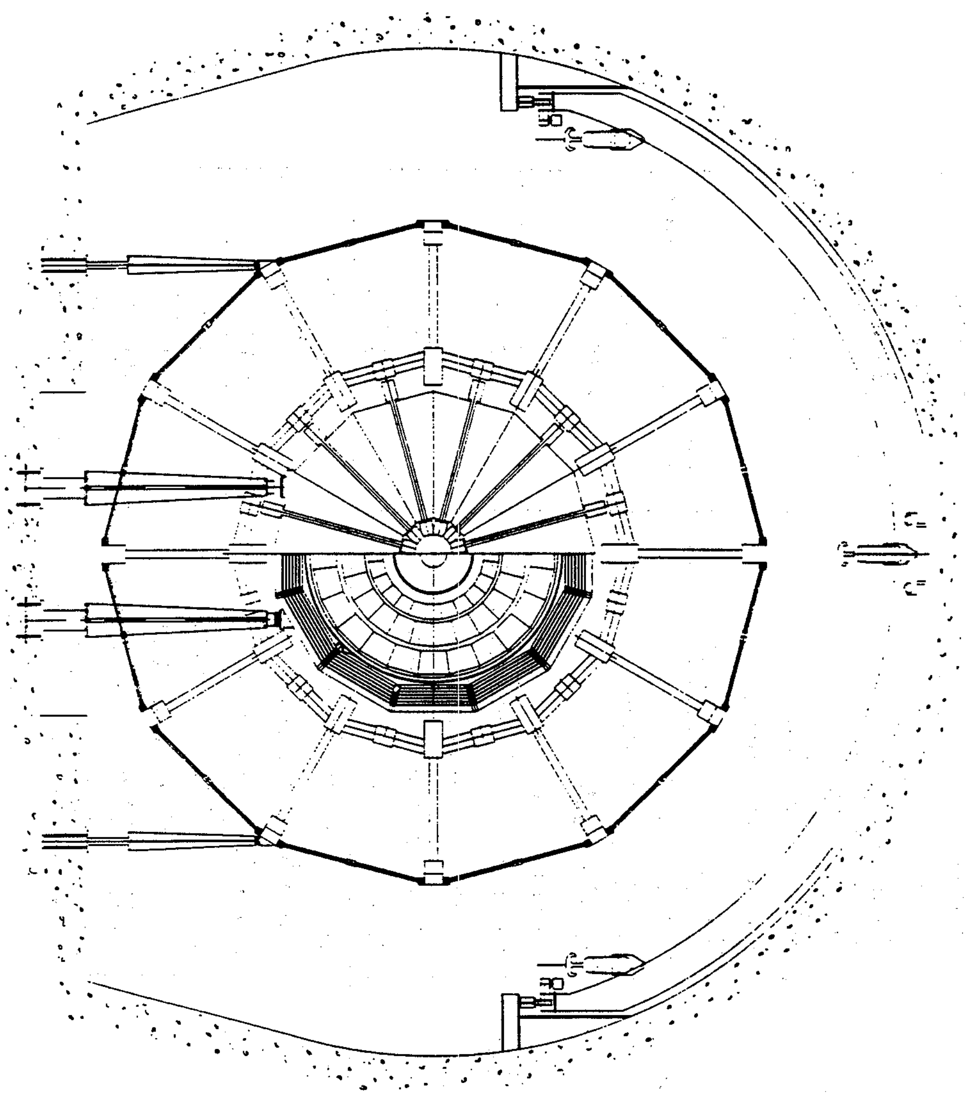
Table 3: *Parameters of the iron-core toroid; all figures refer to a single end-cap*

Iron-core	Radius	1.0 - 4.65 m
	Length	4.8 m
	Total weight	2000 t
Windings	No. of coils	12
	coil cross-section	0.128 m×0.064 m
	No. of layers per coil	4
	No. of turns per layer	7
Conductor	Cross-section	18.4 mm × 16.1 mm
	Length per half-coil	0.26 km
	Total length	6.35 km
	Operating current	23.8 kA
Magnetic field	At surface of inner conductor	1.93 T
	At inner radius of iron	3.72 T
	At outer radius of iron	2.45 T
	Stored energy	190 MJ
Magnetic forces	Total force on inner leg	- 335 t
	Total force on outer leg	186 t
	Force taken on iron	- 149 t
Thermal loads	4.2 K - 80 K Conduction	45 W
	4.2 K - 80 K Radiation	180 W
	80 K - 300 K Conduction	420 W
	80 K - 300 K Radiation	1190 W



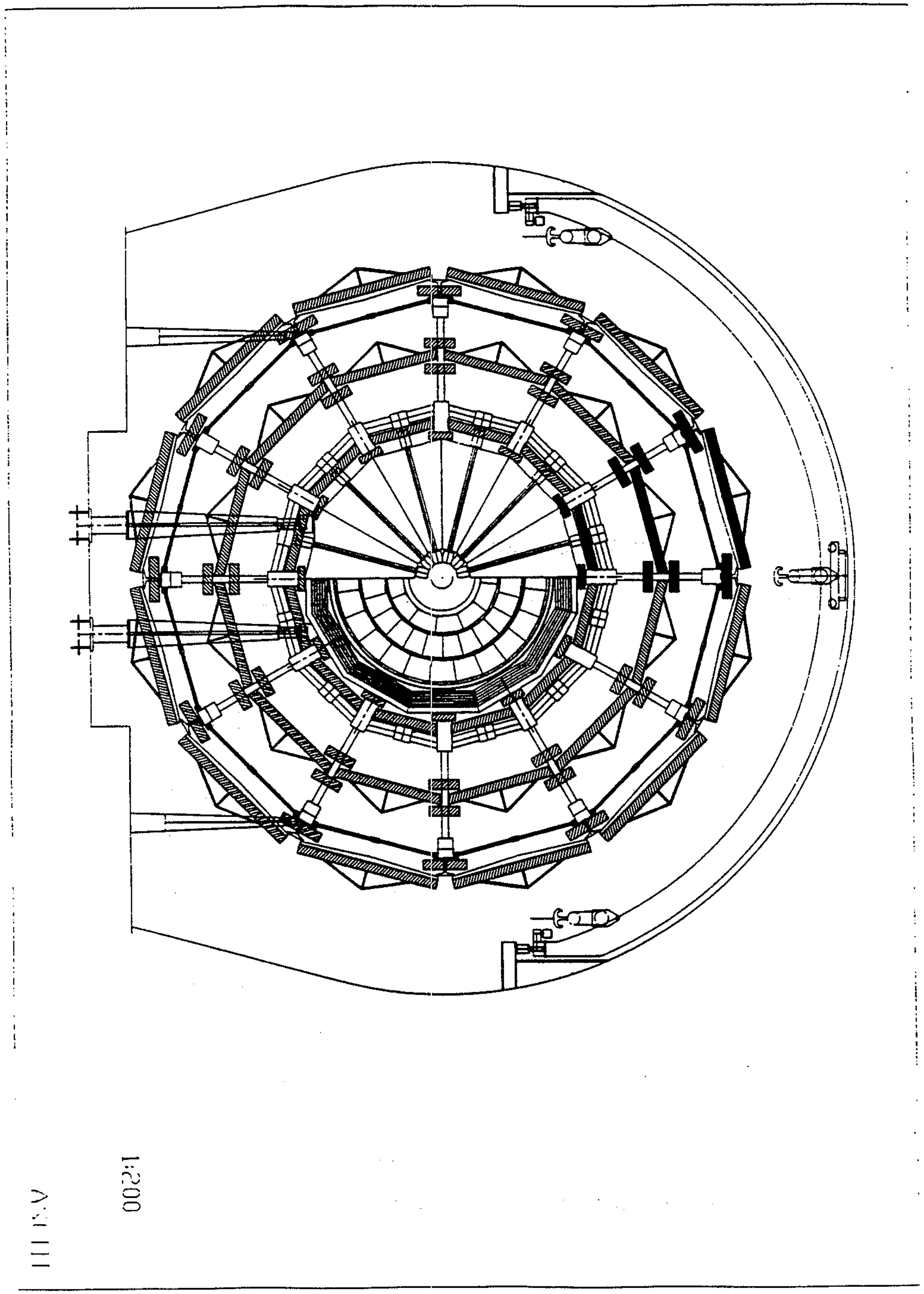



High-field toroid.
∫B_rdL (T.m)
15
14
13
12
11
10
9
8
7
6
5
4
3
2
1
0
0
1
2
3

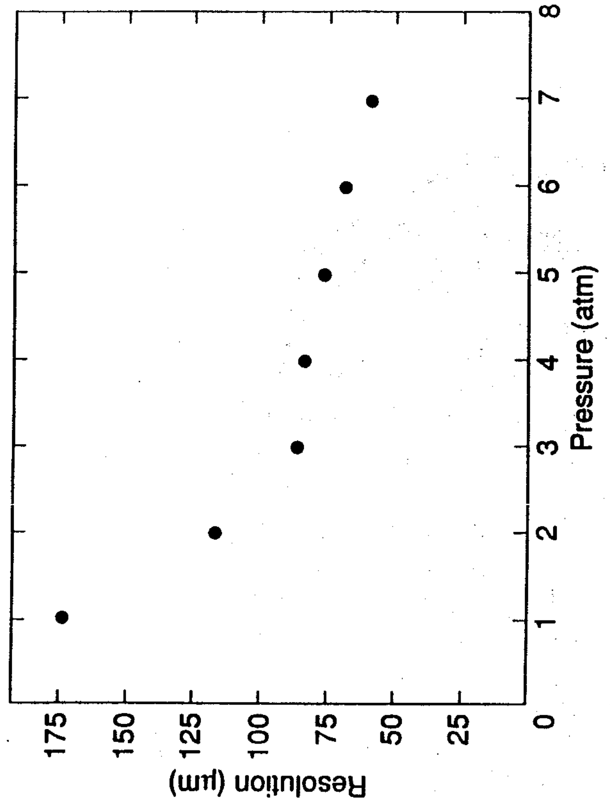


Muon Chambers

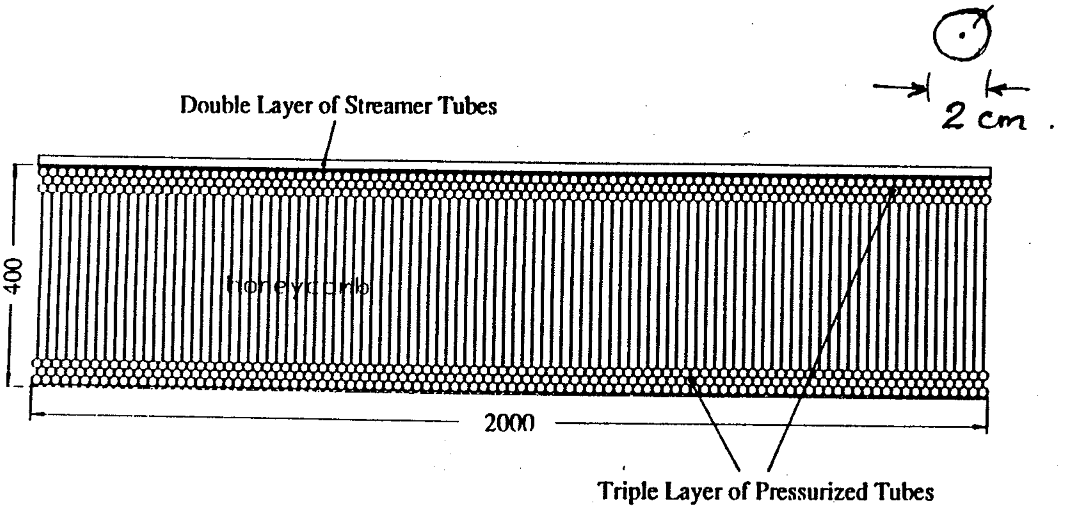
- Need accurate z coordinate !
- Strip readout will not do !!
  - Angles coarsen resolution because of fluctuation in ionisation
- Prefer tubes orthogonal to z
  - best resolution with $p > 1$ atm
  - $\leq 100\ \mu$m
- Trigger can use 'Iarocci' tubes
- Work in progress on survey mechanism



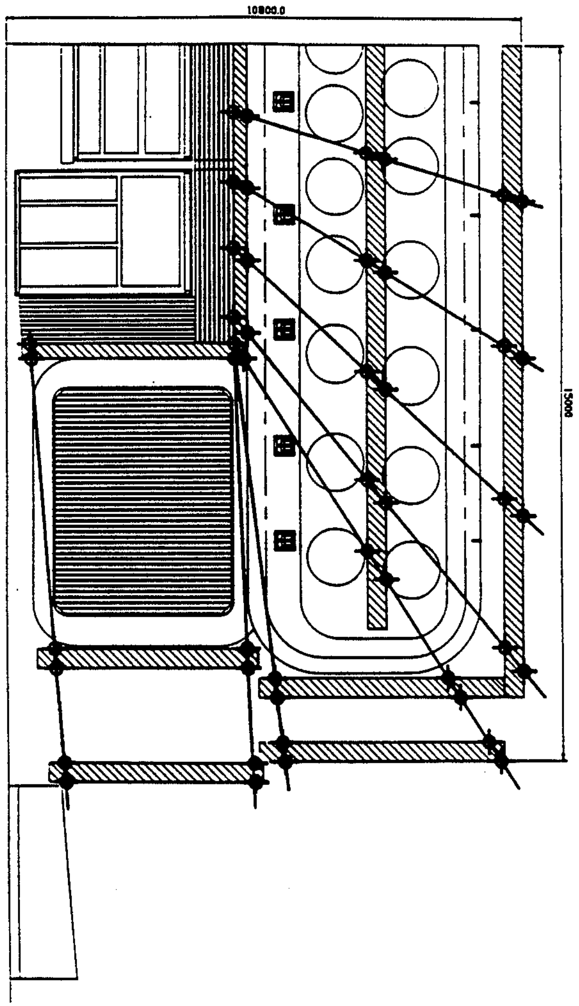
Variation of resolution with gas pressure.



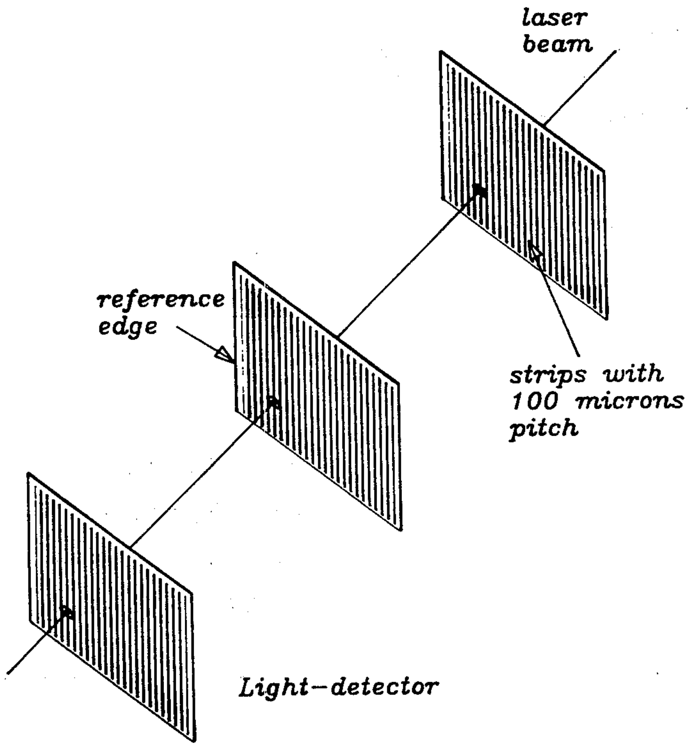
p = 3 bar

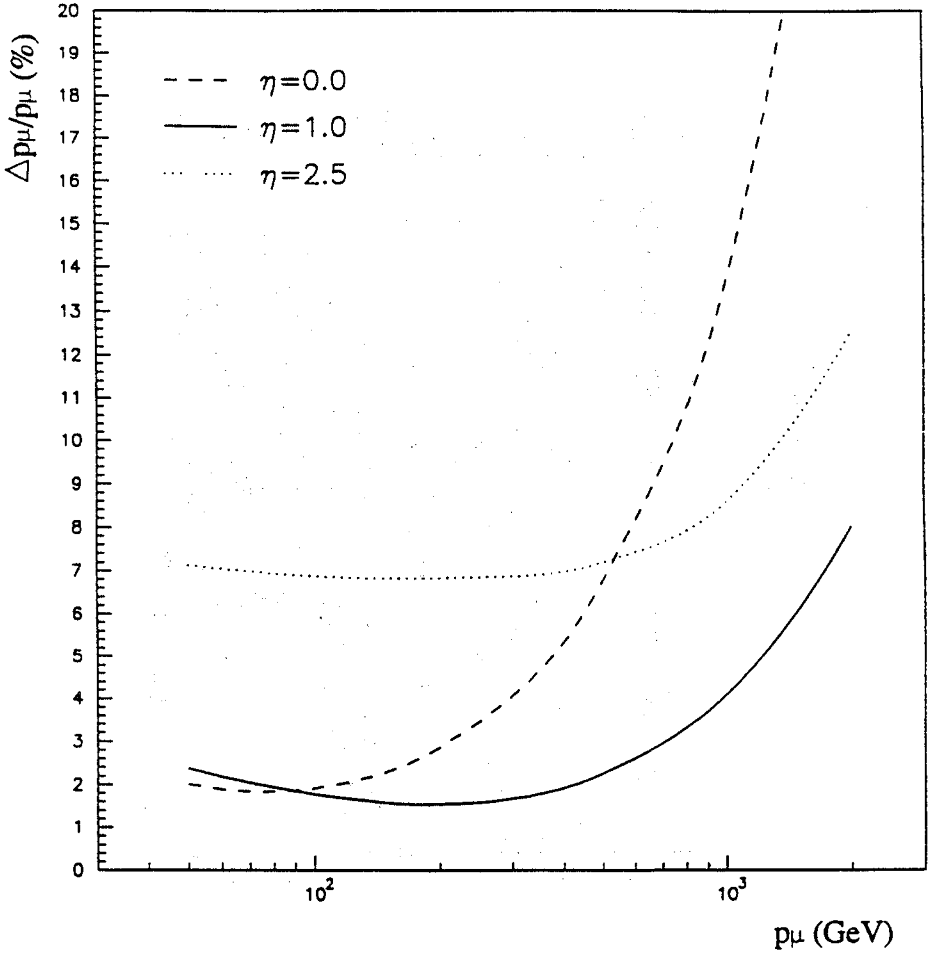


Alignment

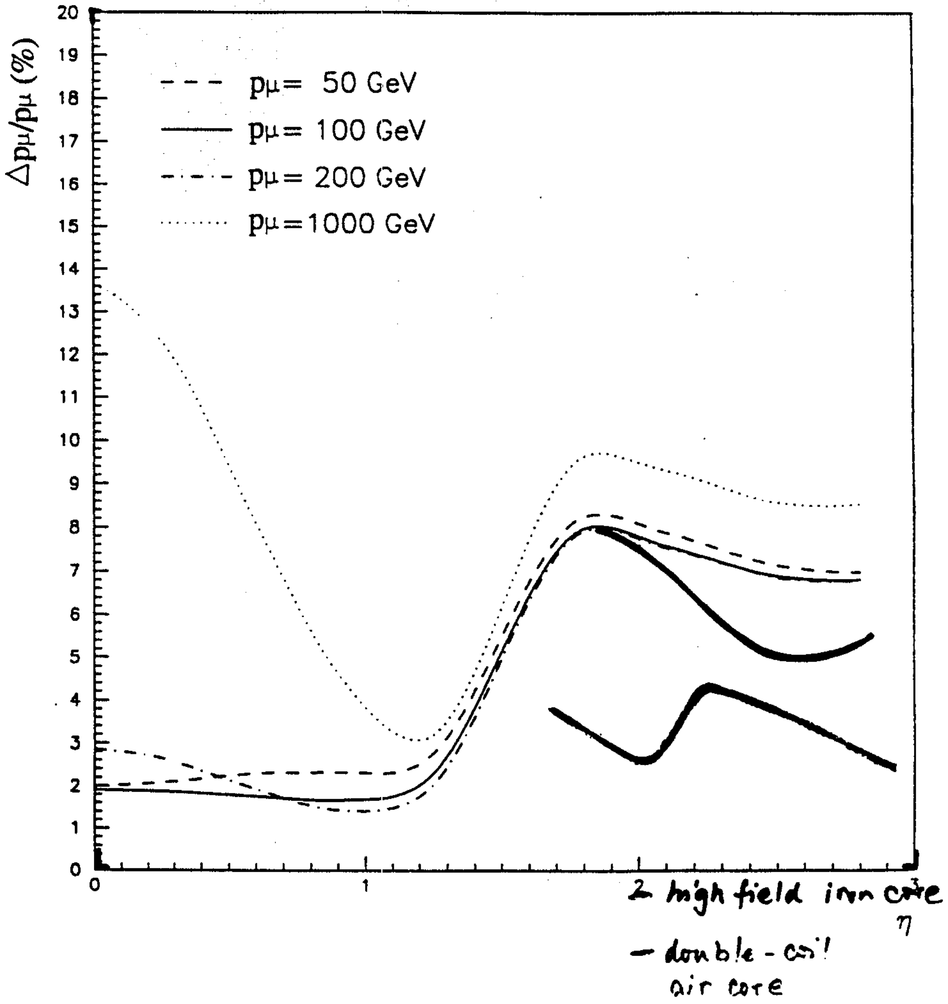


Principle of parallax-free laser alignment



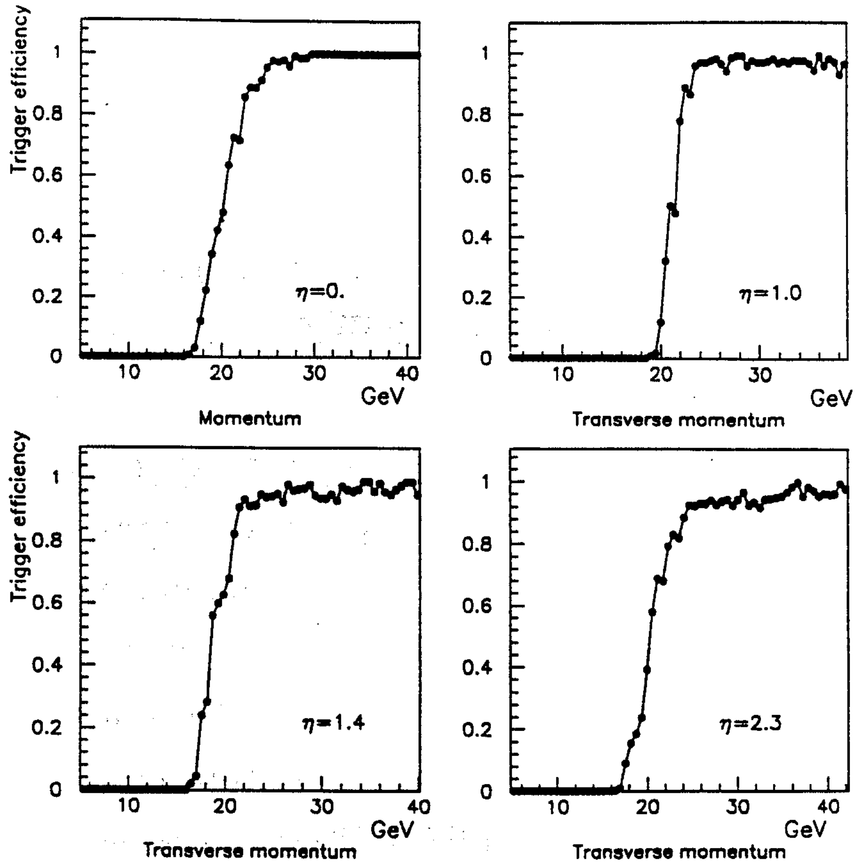


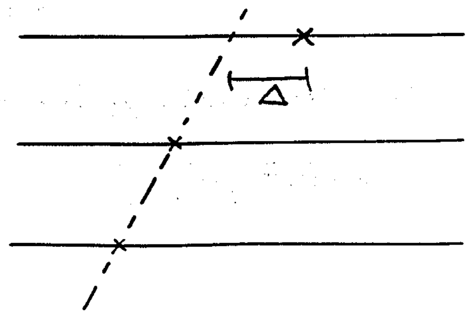
Δpμ/pμ (%)
20
19
18
17
16
15
14
13
12
11
10
9
8
7
6
5
4
3
2
1
0
η=0.0
η=1.0
η=2.5
10^2
10^3
pμ (GeV)



Δpμ/pμ (%)
20
19
18
17
16
15
14
13
12
11
10
9
8
7
6
5
4
3
2
1
0
pμ= 50 GeV
pμ= 100 GeV
pμ= 200 GeV
pμ=1000 GeV
0
1
2
3
η
high field iron core
— double-coil air core

Trigger





$\Delta \sim 18$ strips

$\bar{w} \sim 1cm$

TRIGGER EFFICIENCY $\eta = 1.0$, $\varphi = 10^{\circ}$

cuts in number of strips (1cm):

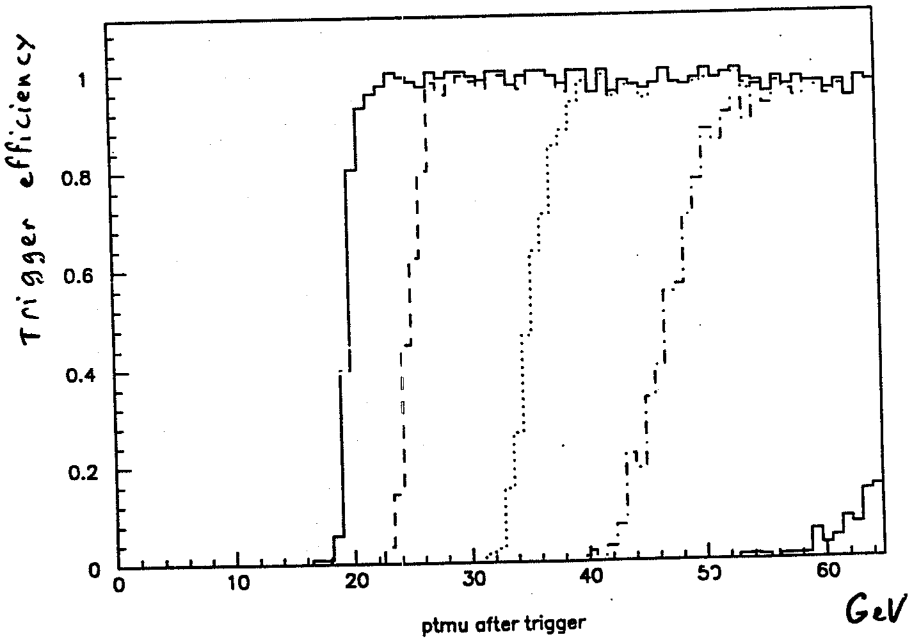
——— $\Delta = 18$

- - - - $\Delta = 14$

•••••••• $\Delta = 9$

—·—·— $\Delta = 6$

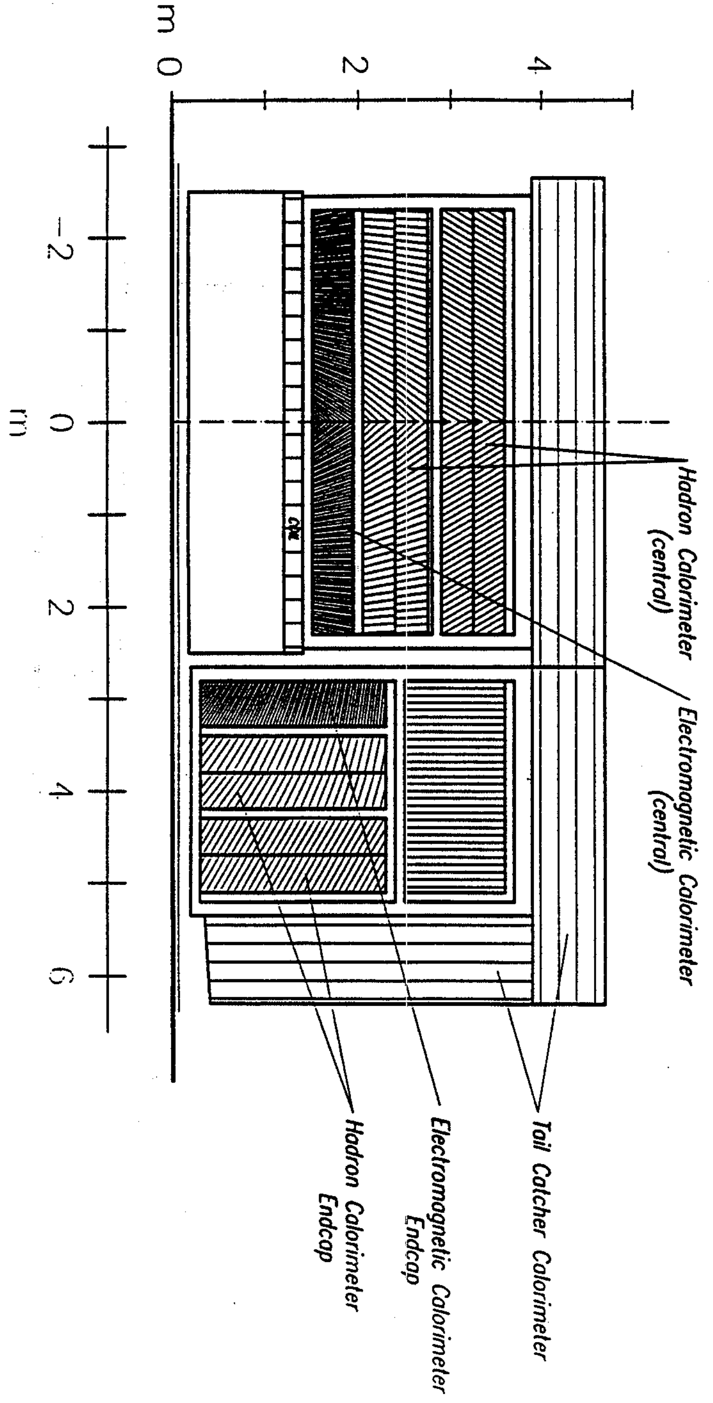
—— $\Delta = 4$



Calorimetry

Choose liquid argon ionisation

- because
  - stable & reproducible
  - transferable
  - uniform
  - linear
  - granular
  - radiation hard
  - OK in B-field
- but
  - must take signal out fast
    ⇒ narrow gaps



ASCOT Calorimeters

'Thin Gap' LAr Calorimeter

- Small LAr gaps 2×0.4 mm
- Preamps – VLSI chip on pad board
- Absorber plates and readout boards always at 45° to path of particle

Advantages of 'Thin Gap' calorimeter

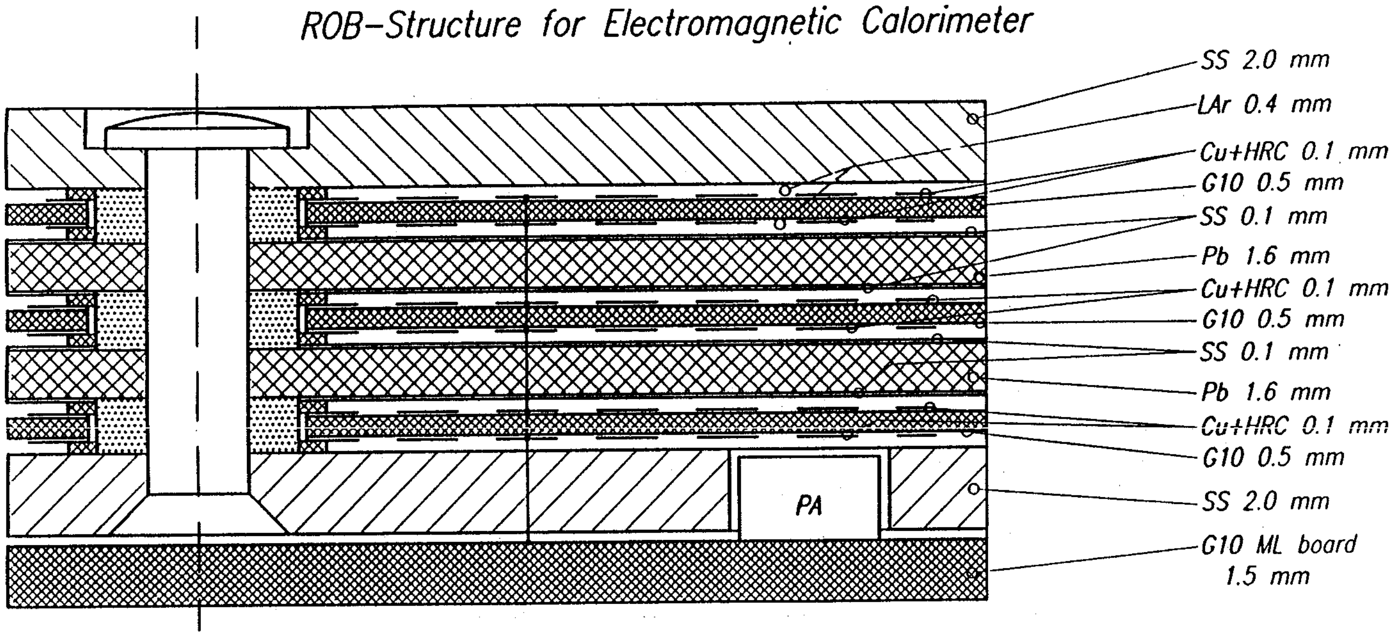
- Simple mechanical structure
- Very flexible pad segmentation (logitudinal and transverse)
- Energy response, resoln indept of η
- Short charge collection time
  - $\Rightarrow$ smaller pileup probabililty
- Operates at 300 V (not > 1 KV)
  - safer operation
  - smaller dead guard zone

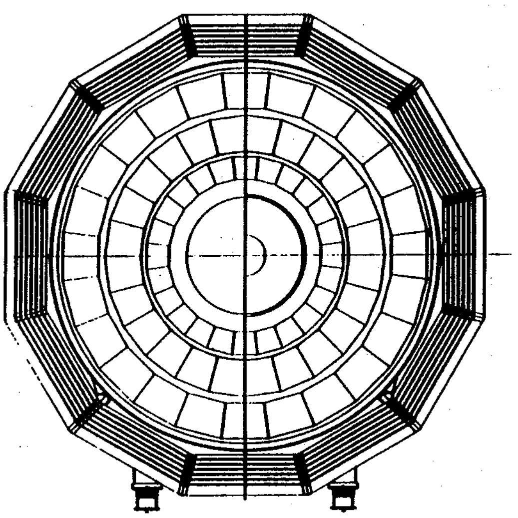
Table 5: *Characteristics of the ASCOT calorimetry*

	electromagnetic	hadronic
energy accuracy $\frac{\Delta E}{E}$	$\gamma: \sim \frac{9.5\%}{\sqrt{E}} \oplus 0.5\%$ e : $\sim \frac{11.0\%}{\sqrt{E}} \oplus 0.5\%$	$\sim \frac{50\%}{\sqrt{E}} \oplus 2.0\%$
acceptance	$\|\eta\| < 3.0$	$\|\eta\| < 5.0$
angular resolution	< 5 mrad	< 20 mrad
granularity $\Delta\eta$ x $\Delta\varphi$	0.02 x 0.02	0.08 x 0.08
uniformity of signal response	±0.5 %	±2 %
e/π separation	$> 10^3$	
calorimeter thickness	$26X_0$	12 λ_{abs} central 14 λ_{abs} forward

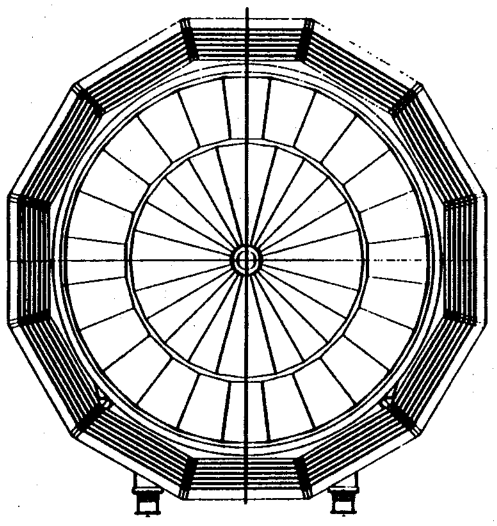
ASCOT

ROB–Structure for Electromagnetic Calorimeter





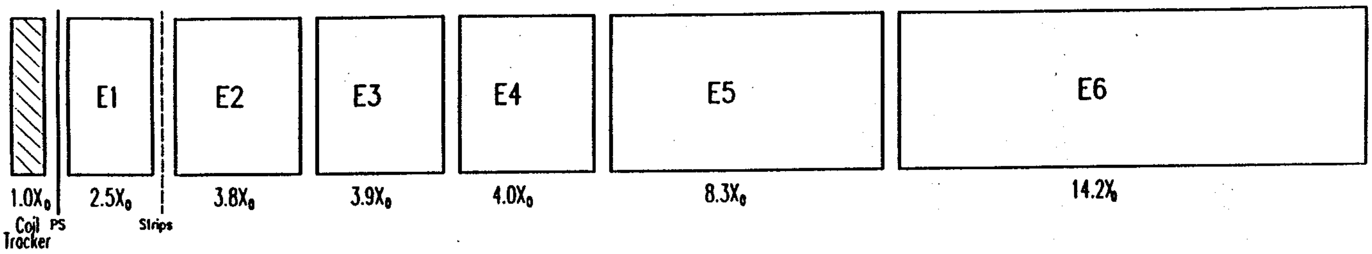
Barrel



End-cap

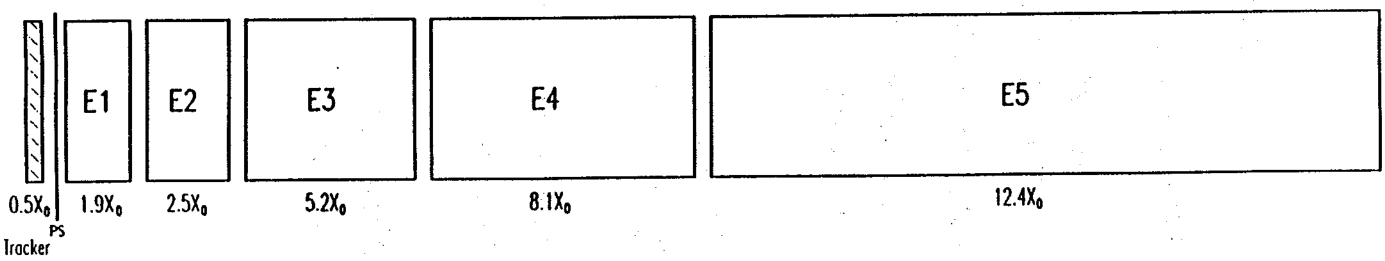
Longitudinal Segmentation (e.m. Calorimeter)

example: a, ECC, $\Theta=45^\circ$



PS Presampler
E1 ... E5 $\Delta\eta \times \Delta\Phi = 0.019 \times 0.022$
E6 $\Delta\eta \times \Delta\Phi = 0.038 \times 0.044$

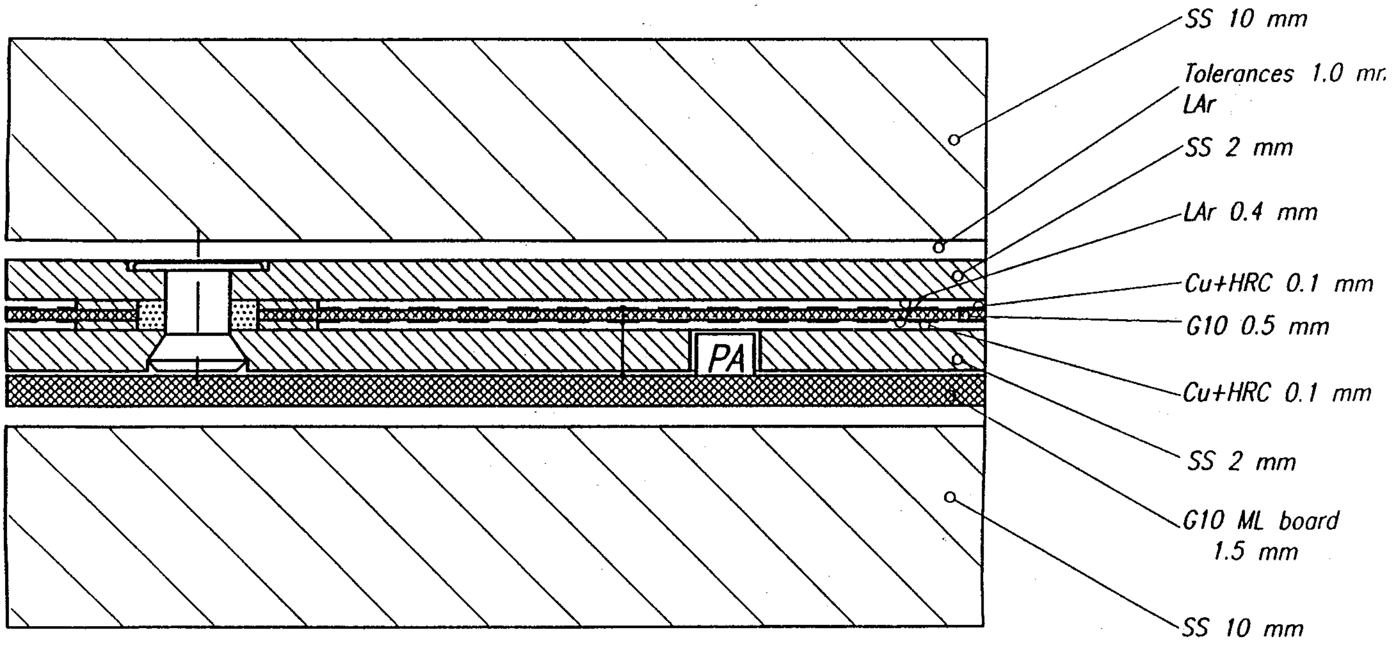
b, ECF, $\Theta=30^\circ$



PS
E1 ... E4 $\Delta\eta \times \Delta\Phi = 0.015 \times 0.022$
E5 $\Delta\eta \times \Delta\Phi = 0.030 \times 0.044$

ASCOT

ROB-Structure for Hadronic Calorimeter



Forward Calorimeter

- $|\eta|$ range 3.5 – 5.0
- Necessary for
  - $E_T{}^{miss}$ measurement
  - tagging of forward jets
- High radiation environment
- Ideas at present centre on
  - high pressure ($\sim$ 30 atm) gas ionisation tubes, diam. 6 mm, with 2 mm central electrode, embedded in lead or concrete
  - 4 longitudinal segments
  - $\sim$ 20,000 channels

Inner Tracking

Our demands are modest !

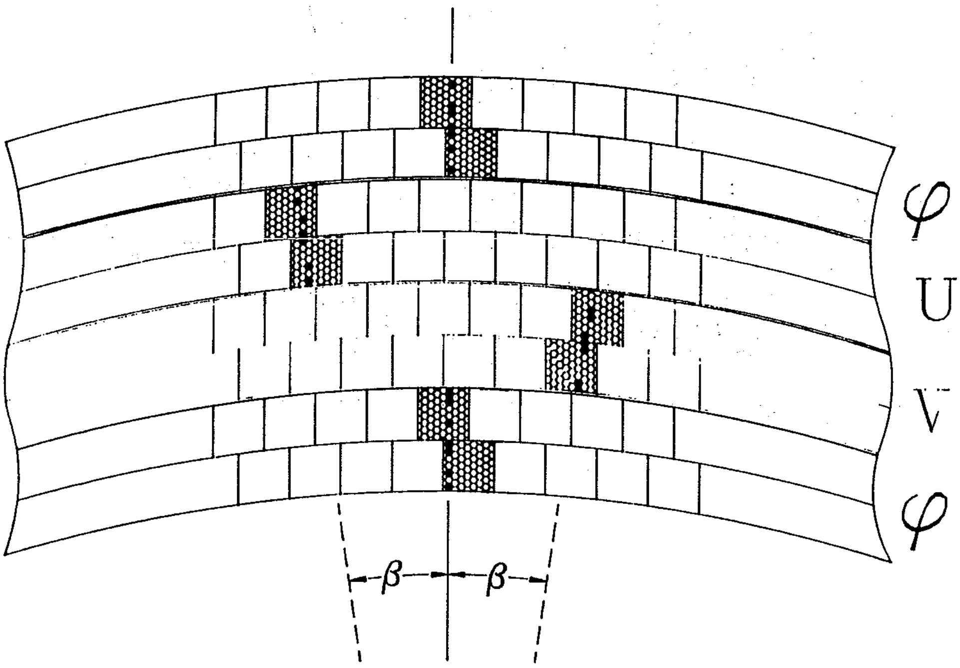
- **Measure sign of $e^{\pm}$ for momenta up to 500 GeV for $|\eta| \leq 2$** – Solenoid $B = 1.5$ T
- **Improve electron identification**
- **Consistency check on calorimeter calibration**

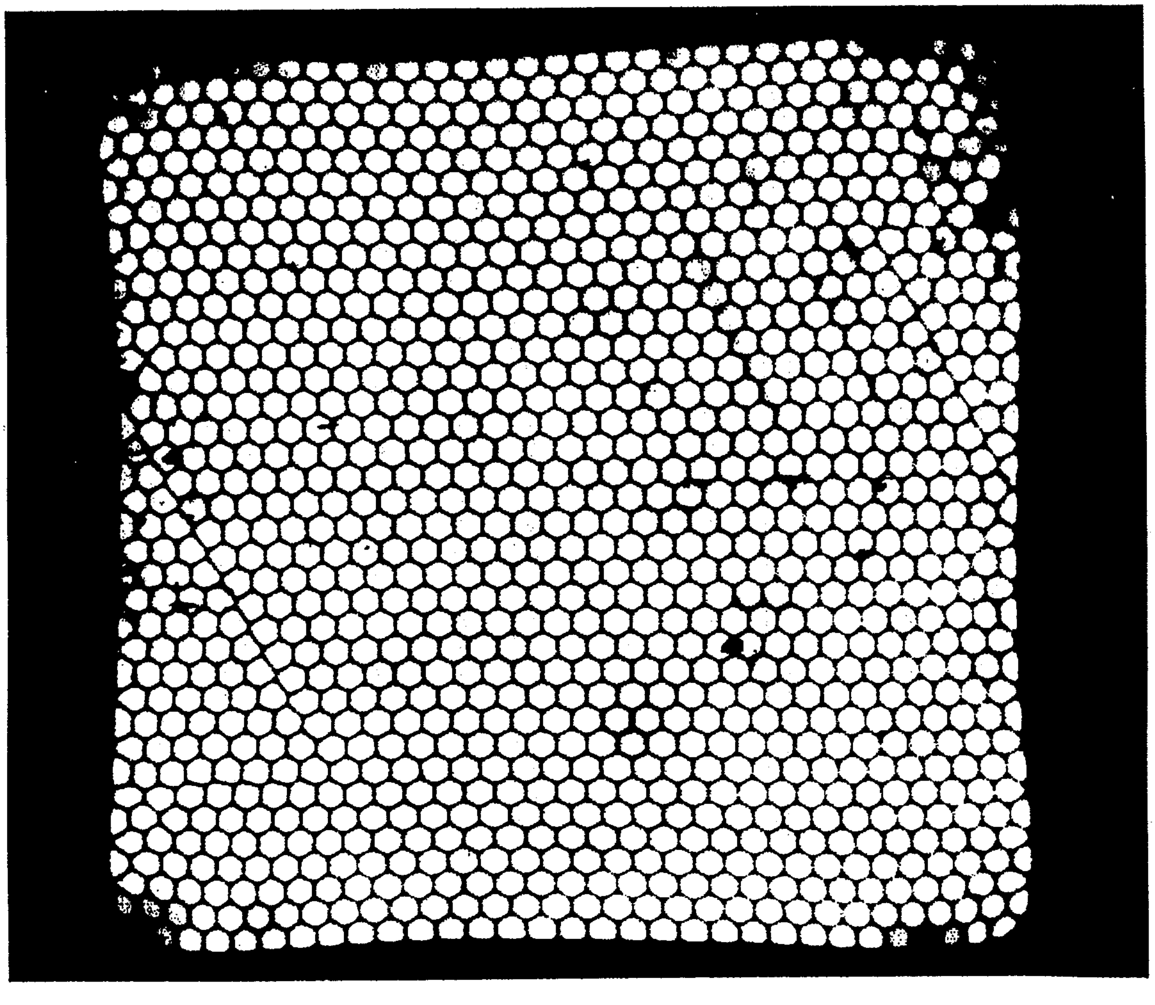
At lower luminosity, can hope to identify hadronic τ decays.

Tracking starts at the calorimeter or muon-station ⇒ narrow roads defined

No attempt made to reconstruct all tracks in the event

MULTIBUNDLES ARRANGED IN A CYLINDRICAL TRACKER SHELL





Fibre diameter 30 µm

1 mm

Photograph taken after 1 m fibre length.

Tracking elements

Scintillating fibres. $|\eta| \leq 1.4$

60μ diam. in bundles ~ 1×1 mm

$\phi u v \phi$ layers per station (6° stere.

radius 50 cm, 110 cm.

Gas microstrip chambers $1.4 < |\eta| \leq 2.5$

60 μm resolution requested.

2 stations of 4 layers each

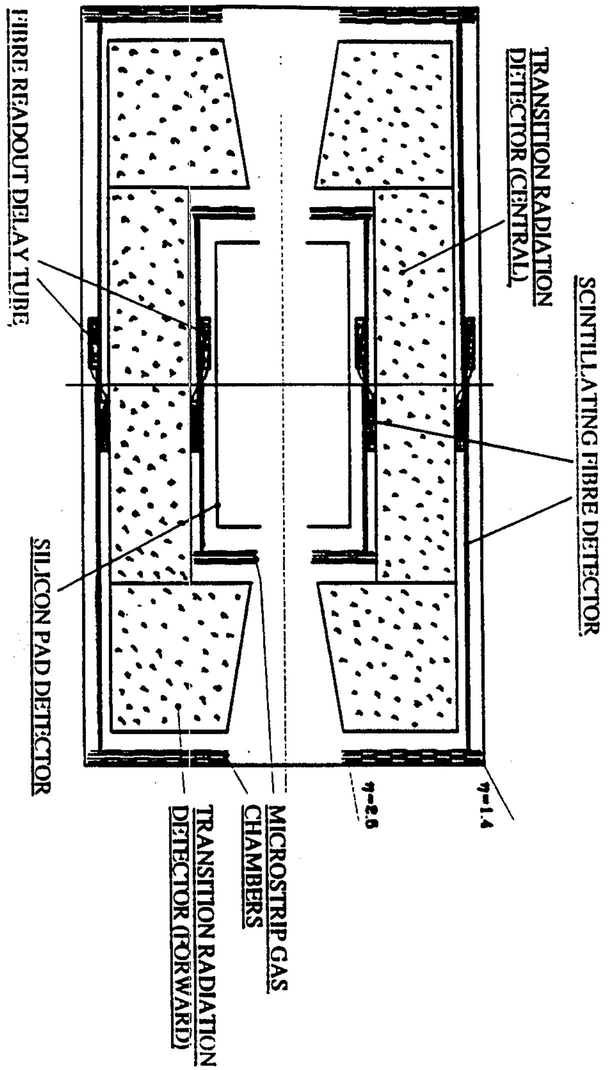
Semiconductor pad detector $|\eta| \leq 2.5$

Closest detector to beam crossing

Pad size ~ 3×3 mm²

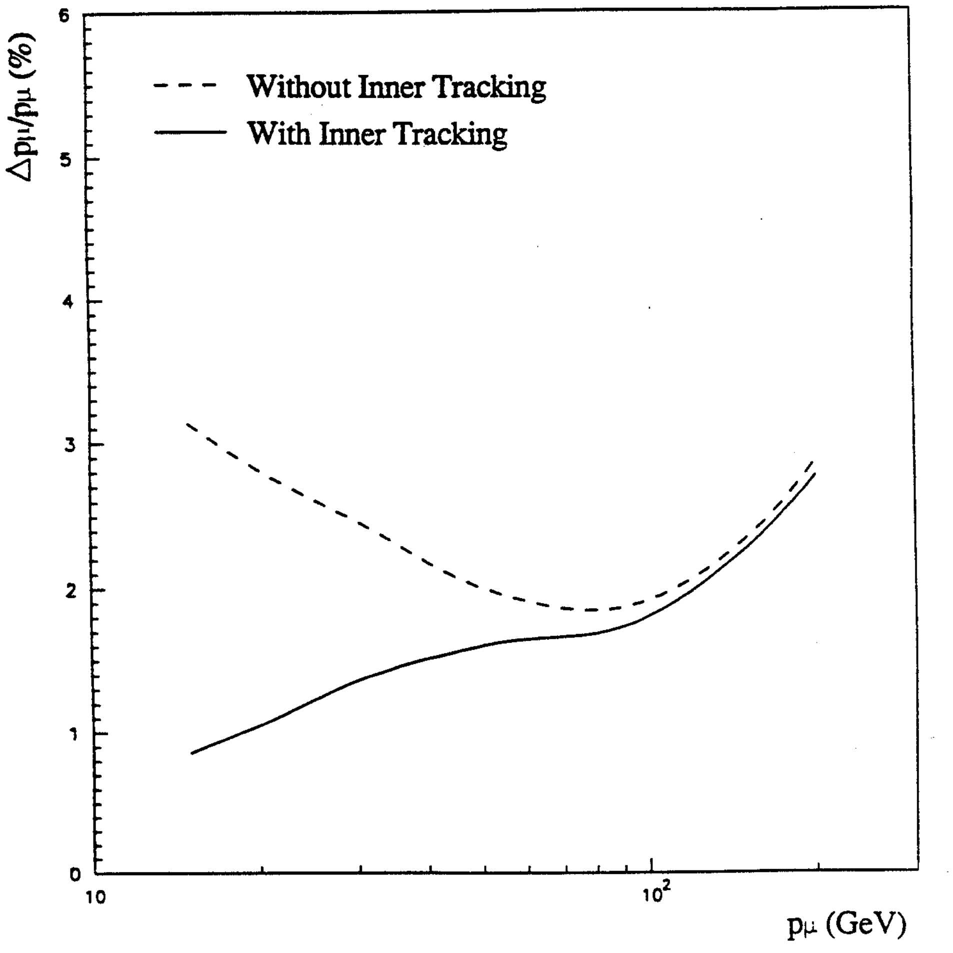
TRD tracker $|\eta| \leq 2.5$?

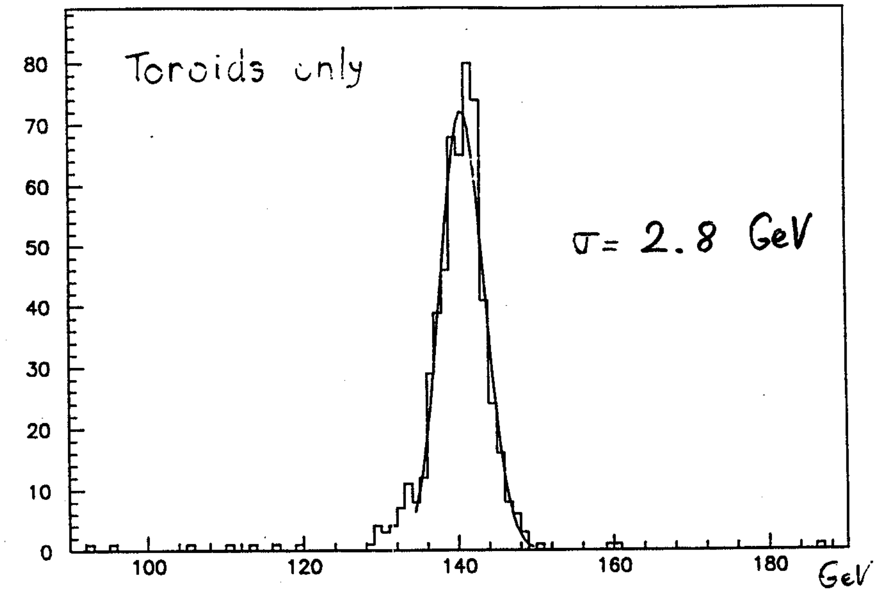
e.g. straw tube TRD considered by RD6.



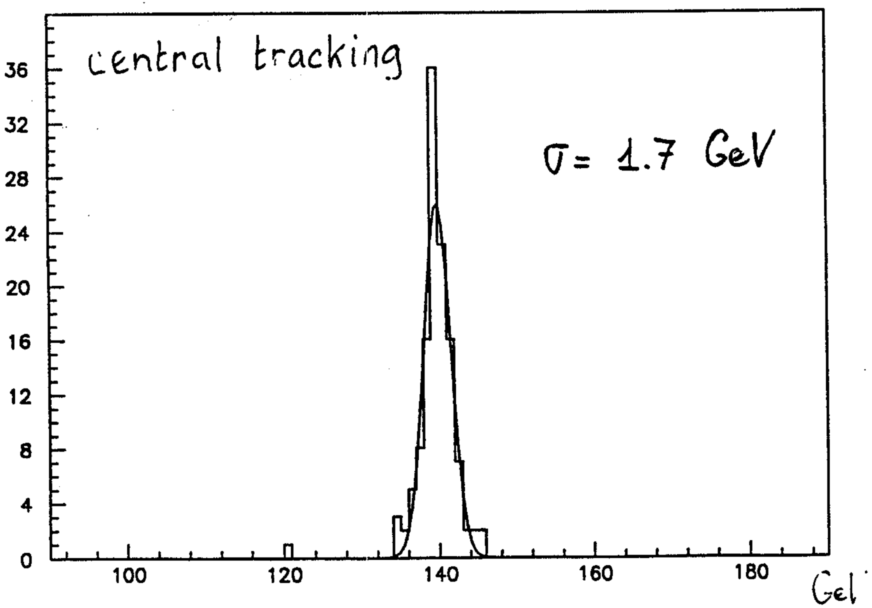
Standard Higgs (M= 140 GeV)

$H \to 4\mu$





4 muons mass, without inner tracking



4 muons mass, inner track., all eta lt 1.2

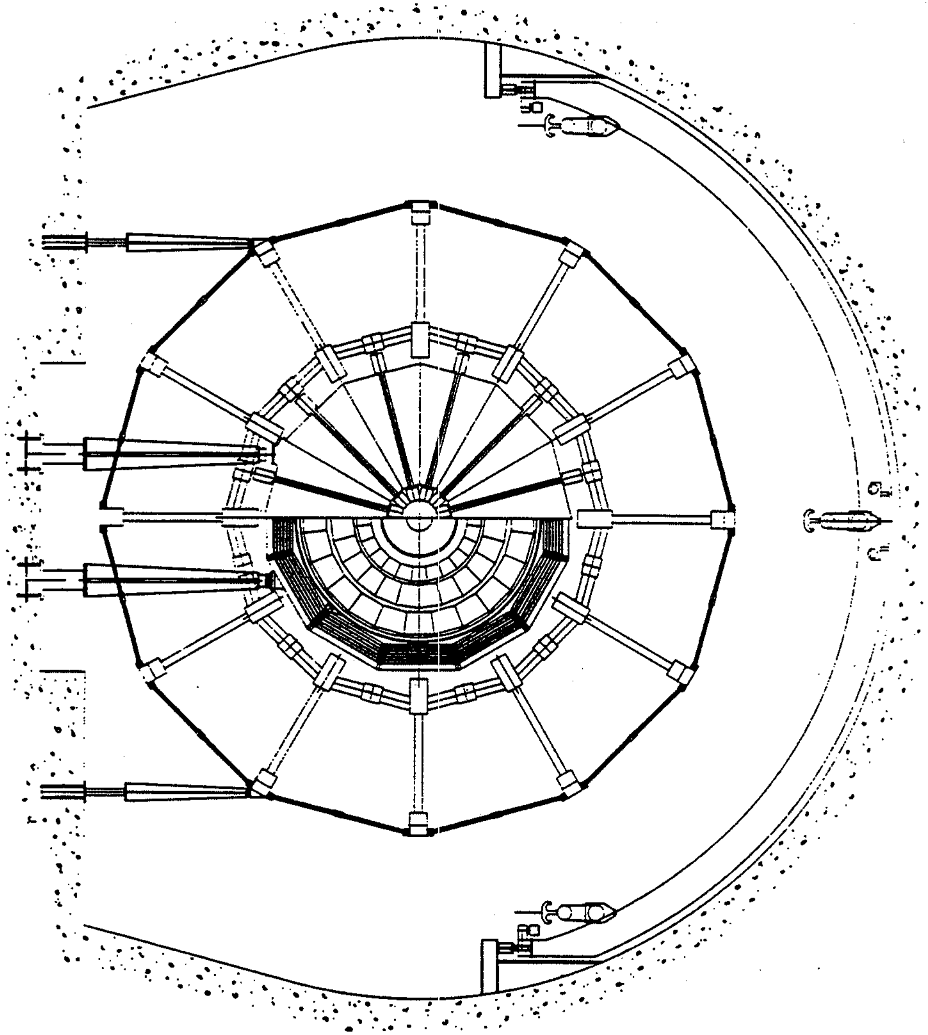
Assembly of detector.

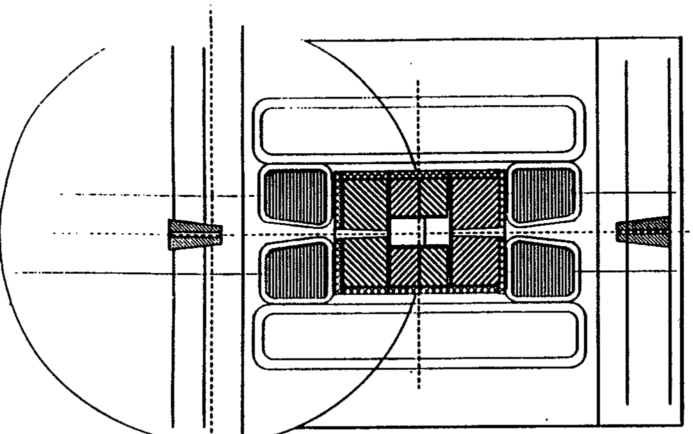
Guiding principles.

- keep individual piece-weights below $\boxed{500\ t}$ (crane capacity.
- preassembly of components in surface buildings.
- ease of assembly and movement to garage positions

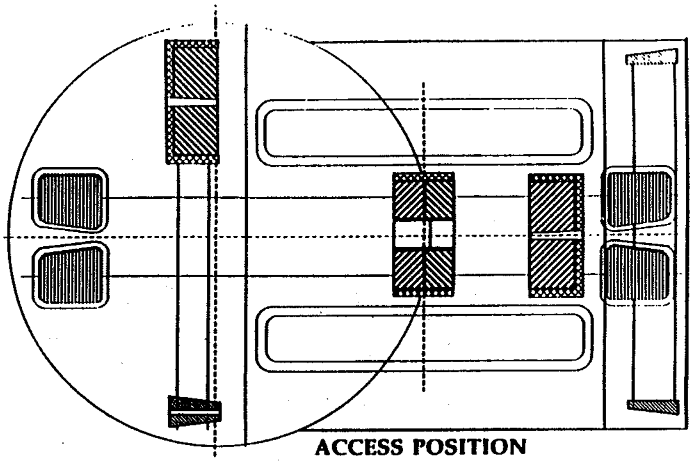
Large rail system carries all elements except air-core toroid which is free standing.

Installation schedule $\boxed{18\text{ months}}$ preceded by 2 yr. surface assembly.

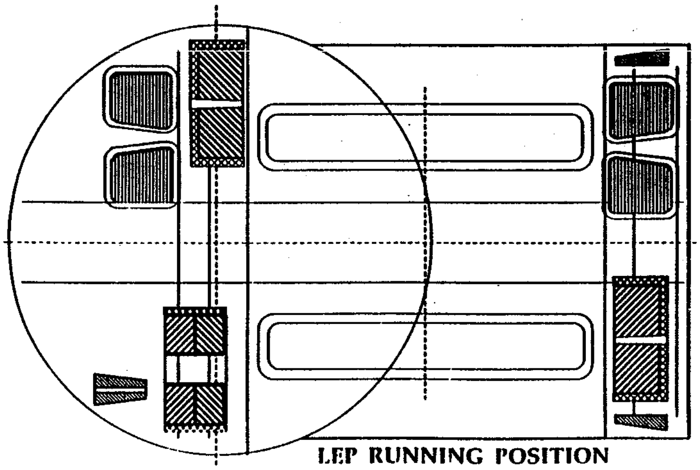




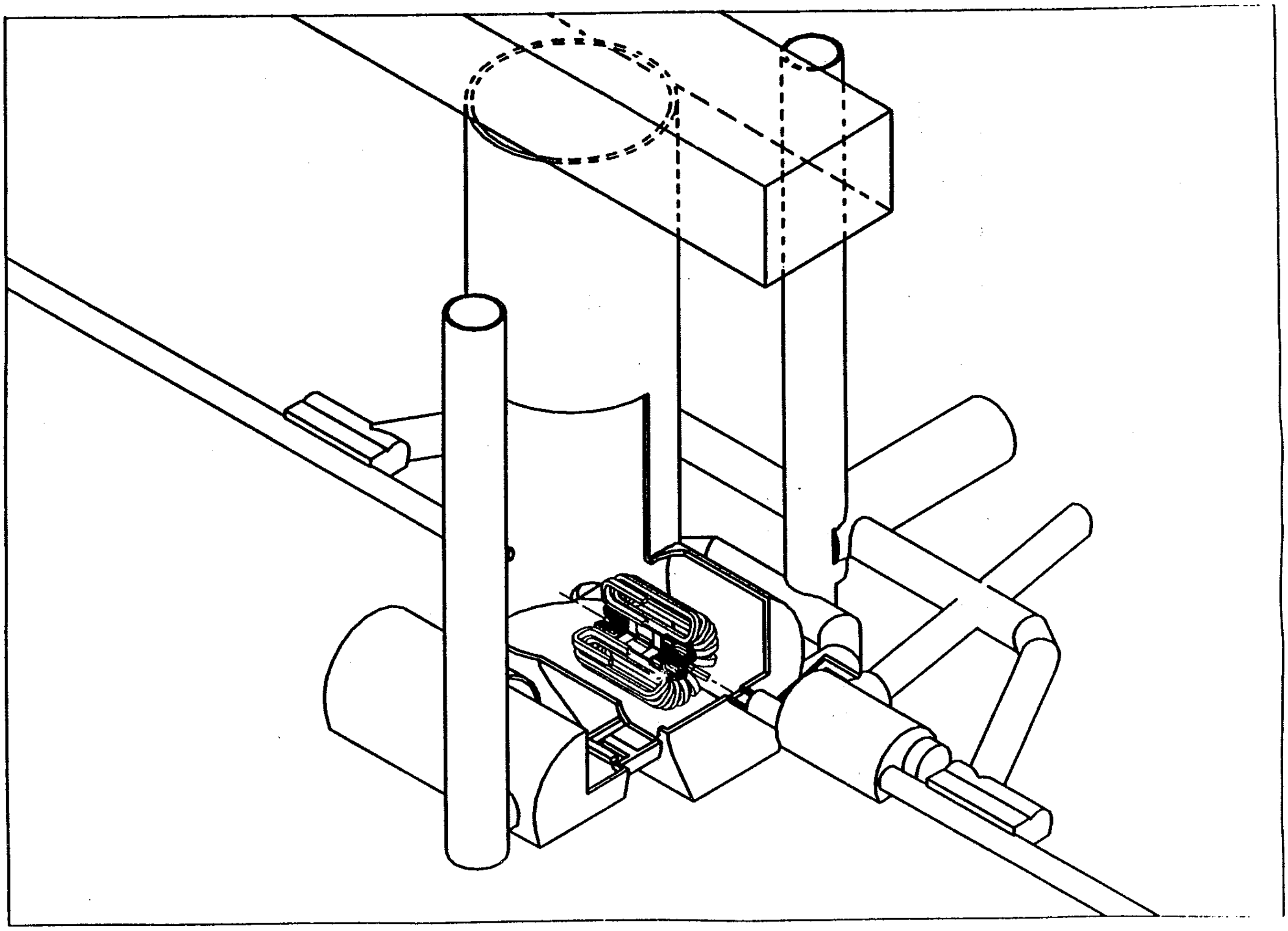
RUNNING POSITION



ACCESS POSITION



LEP RUNNING POSITION



Cost of ASCOT

Detector component	MSfr
Toroid magnets	130
Muon chambers	50
Calorimeters	120
Solenoid	10
Scintillating fibres	10
Microstrip gas chambers	5
TRD tracker	15
Silicon pad detector	5
Trigger	10
DAQ	20
Infrastructure	20
Total	395

Ongoing R & D Projects

Participation in RD-6 (Construction and beam test of a TRD Tracker)

Development of a high-precision muon tracking system (JINR Dubna, MPI Munich, Munich University)

Development of a 'Thin-Gap' Liquid-Argon calorimeter (Aachen University, CERN, Heidelberg University, MPI Munich)

Tests of Scintillating Fibres (Wuppertal)

Development of a Fast Pixel Readout for Scintillating Fibres (MPI Munich)

Expression of Interest

CMS : a compact solenoidal detector for LHC

M. Della Negra (CERN)
H. Desportes (Saclay)

C M S

COMPACT MUON SOLENOID

PRECISE MUON
ELECTRON
PHOTON DETECTOR

FOR L H C

M. DELLA NEGRA / CERN

EVIAN, 5 March 1992

OUTLINE :
MUONS
MAGNET CHOICE
TRACKING
CALORIMETRY
INSTALLATION

MORE TALKS ON CMS :

- 4 TESLA Superconducting Coil
  H. DESPORTES / Saclay (Next talk)
- Heavy Ions in CMS (E.O.I)
  L. RAMELLO / TURIN (Sat. 7 March 92)

MUONS

CMS DESIGN PRINCIPLE:

OPTIMIZE FIRST MUON DETECTION

- Muon identification easy at $L > 10^{34}$
- Unlike electrons muons can be identified inside JETS :
  - $b \rightarrow \mu$
  - control efficiency of isolation cuts
- Muons can be identified down to very low transverse momenta:

  Acceptance for $H \rightarrow ZZ^* \rightarrow 4\mu$
  $P_T{}^{\mu} \sim 5$ GeV

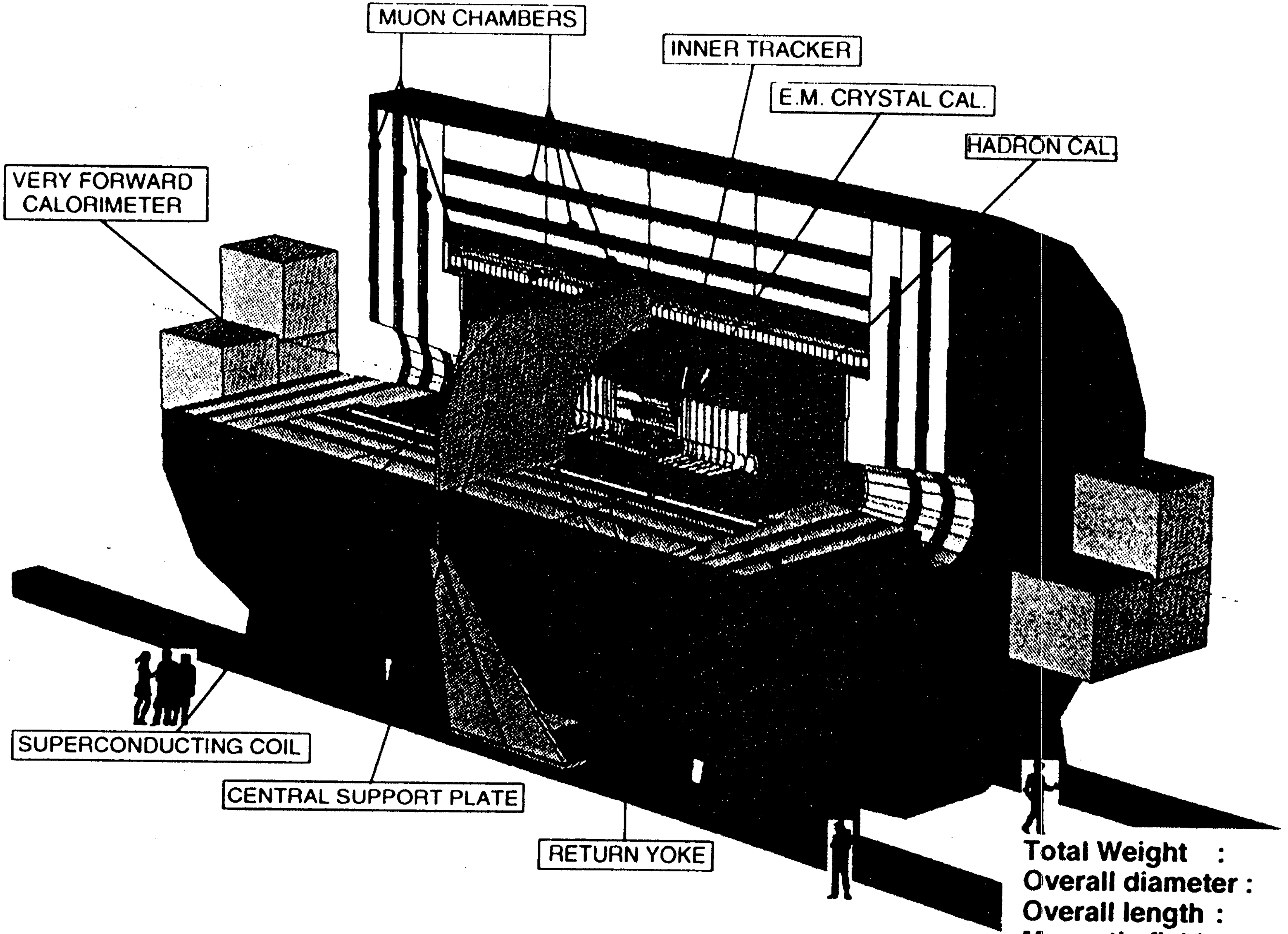
- The design of the muon magnet will influence the rest of the detector design:

CHOOSE FIRST WHICH MAGNET

CMS :	LONG SOLENOID	$L = 15$ m
	LARGE RADIUS	$R_{inside} = 2.9$ m
	STRONG FIELD	$B = 4$ Tesla

C.M.S.

A Compact Solenoidal Detector for L.H.C.



Total Weight :	**12.000 t.**
Overall diameter :	**14.00 m**
Overall length :	**20.00 m**
Magnetic field :	**4 Tesla**

ADVANTAGES OF STRONG MAGNETIC FIELD

B = 4 TESLA

- COMPACT DESIGN :

  Ø = 14 m, L = 20 m, Total Weight = 12000 t.

  COST : Detector surface
  Experimental Hall
  Installation time

- GOOD MUON MOMENTUM RESOLUTION

  Without strong demands on chamber space resolution

- FACILITATES TASK OF MUON TRIGGER

  P_T cut, level 1 trigger

- INNER TRACKING: (SOLENOID ONLY)

  helps pattern recognition at large radius (R > 1m)
  Good momentum resolution on charged particles

PHYSICS REQUIREMENTS ON MUONS

RAPIDITY COVERAGE: $|\eta| < 2.5$

MOMENTUM RANGE :

Minimum P_T: 5 GeV $H \to ZZ^* \to 4\mu$
Maximum P_T : 3 TeV $Z' \to \mu\mu$

GOOD RESOLUTION WANTED:

- At low momenta $\Delta p/p < 1\%$ $P_T < 50$ GeV

  $H \to ZZ^* \to 4\mu$ narrow signal

- At high momenta $\Delta p/p < 10\%$ $P_T \sim 3$ TeV

  Discover $Z' \to \mu\mu$ $m(Z') = 6$ TeV
  Forward /Backward asymmetry needs lepton charge

- Rejection of Non Z background :

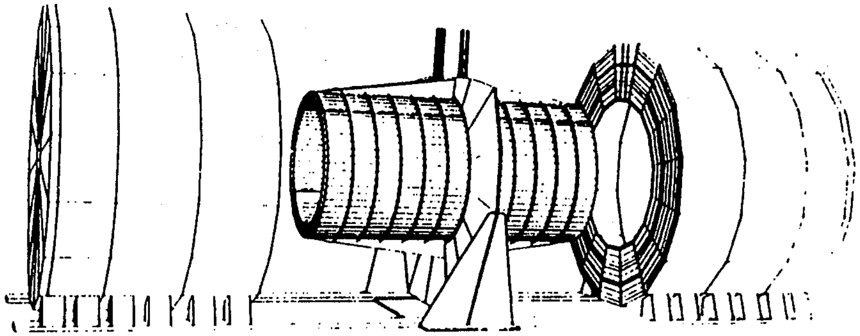
  e.g. top background:
  Resolution should match Z natural width of 1%

- SUSY Higgs :

  $H \to 4\mu$ narrow at all masses

- Unknown physics

4 TESLA SUPERCONDUCTING SOLENOID



STORED ENERGY	2.85 GJ
RADIAL PRESSURE	64 ATM
AXIAL FORCE	9900 tons
THICKNESS	70 cm (1.1 λ)
Ø MANDREL	6.8 m (Transport)
INNER RADIUS	2.95 m

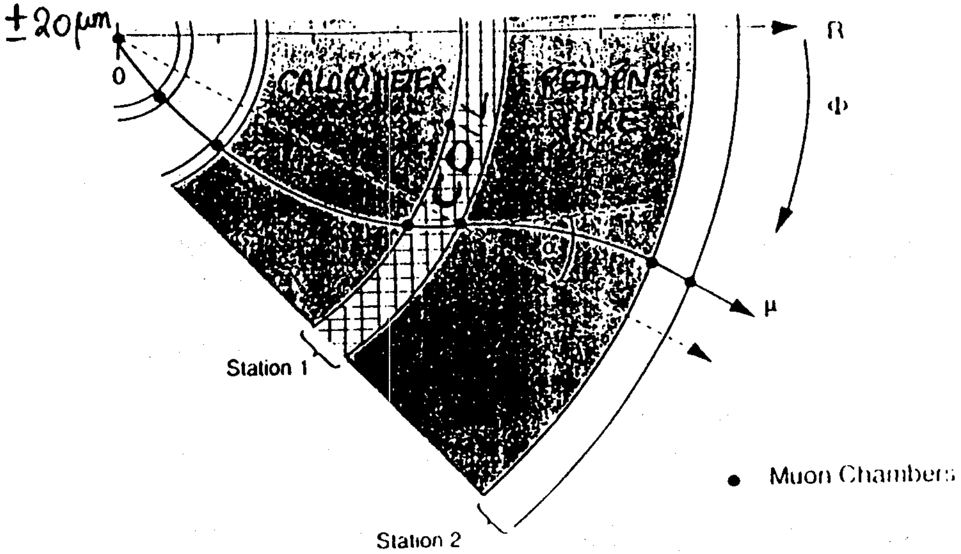
DESIGN BY SACLAY (J.C. LOTTIN, H. DESPORTES)

NEXT ~~TALK BY H. DESPORTES~~ suppressed

COST ESTIMATE : 75 MSF

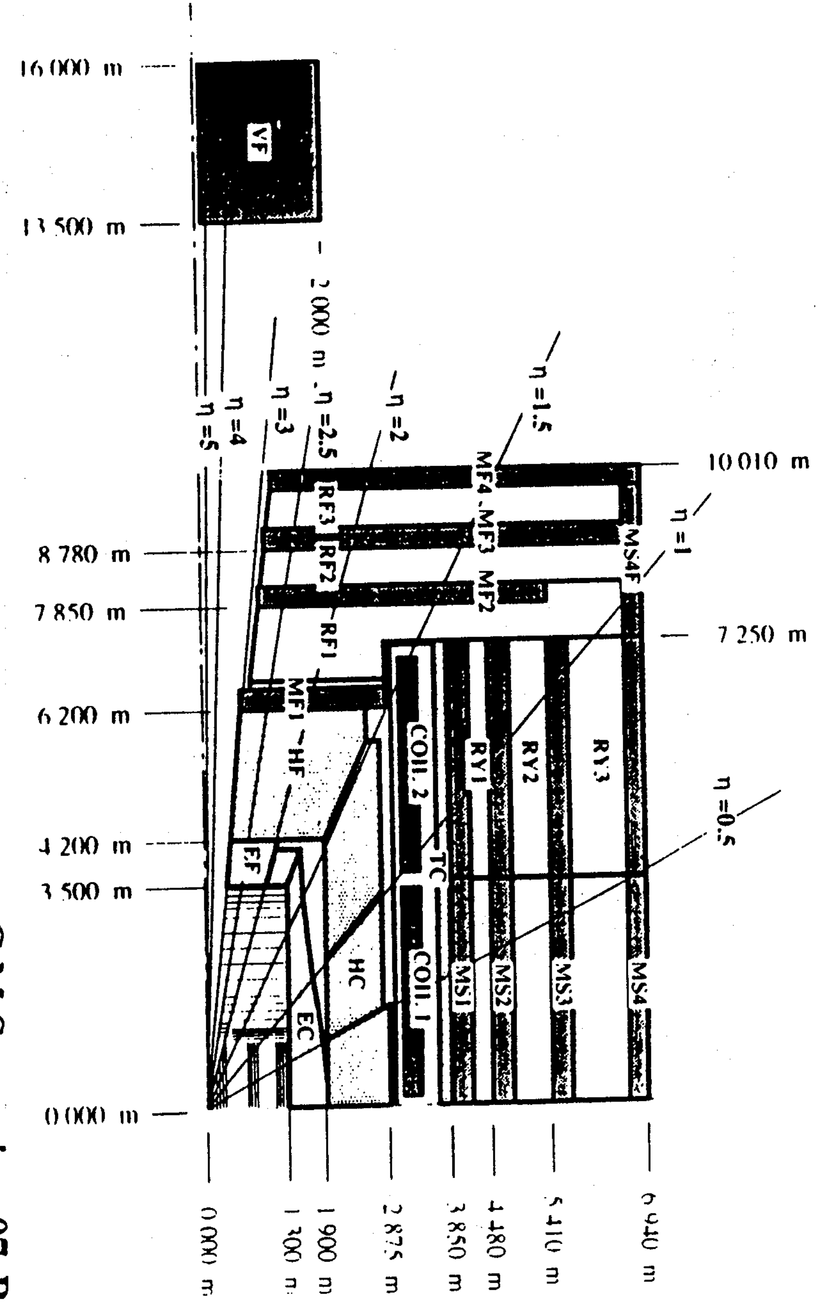
See DAPNIA report
DAPNIA/STCM 92-01

PREFER SOLENOID OVER TOROID



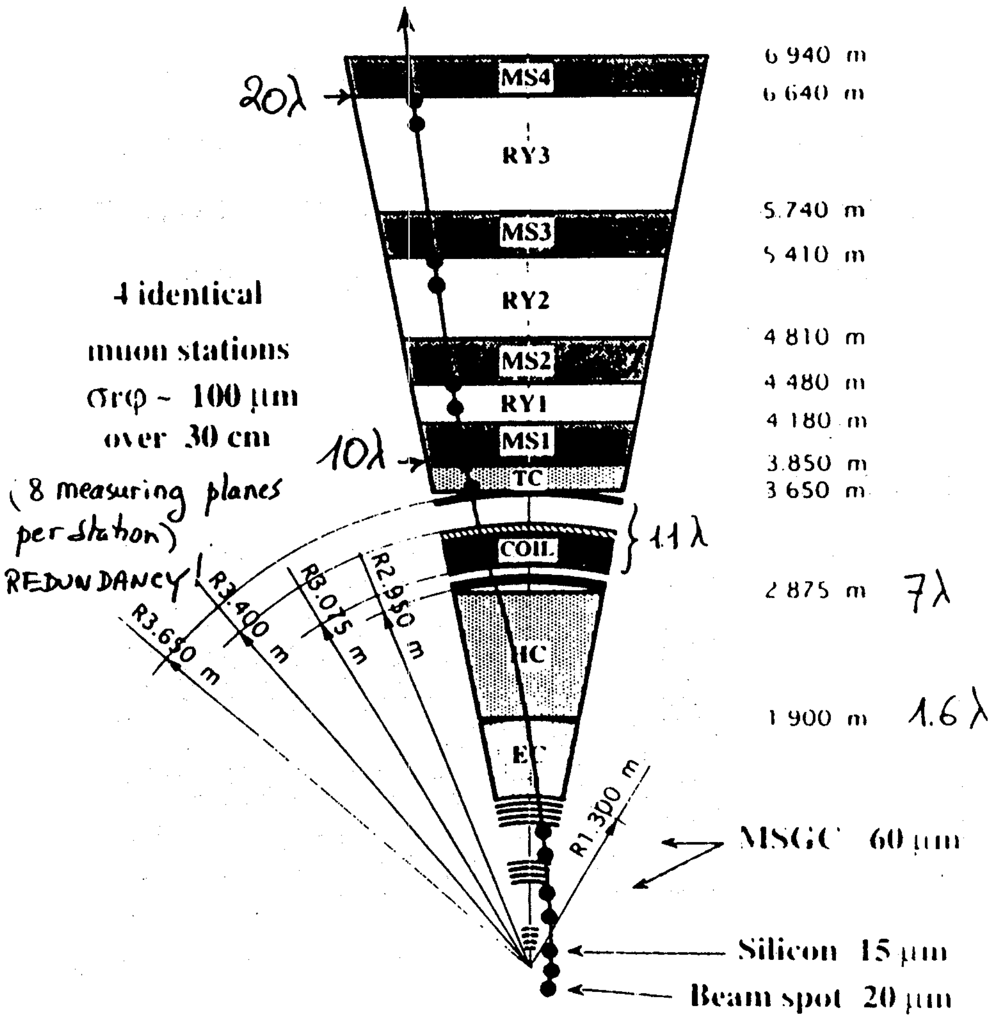
- Field parallel to beam : vertex ± 20 μm for free
- Magnet easier to build
- Large ∫Bdl for modest size
- Easy trigger : Track pointing to vertex
- 3 independent momentum measurements
  - in air, before absorber : low momentum μ's
  - after coil
  - after return yoke

Question :	forward coverage ?
Answer :	Long Solenoid rather than forward Toroid



C.M.S. version 07-B
CERN PPE 16-12-91
jl bénichou

C.M.S. Version 07-B



CERN PPE
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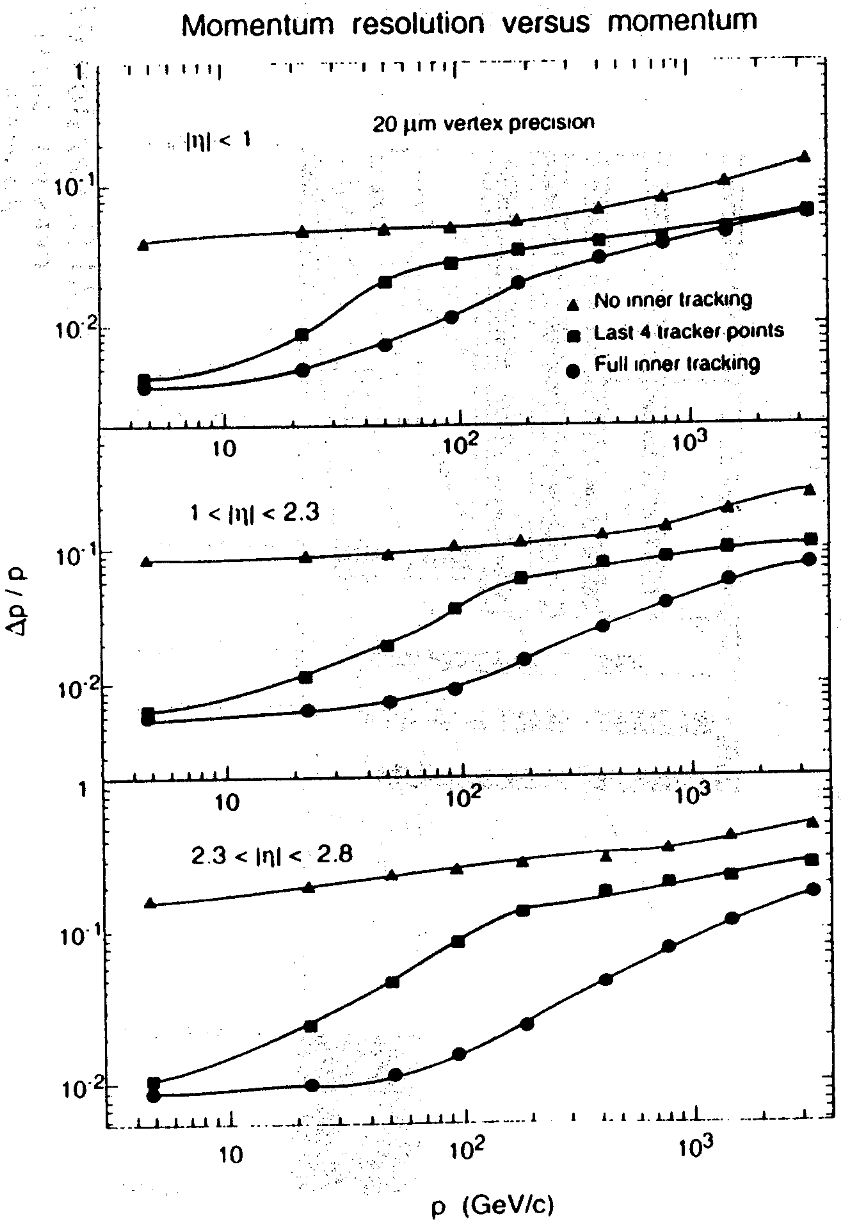
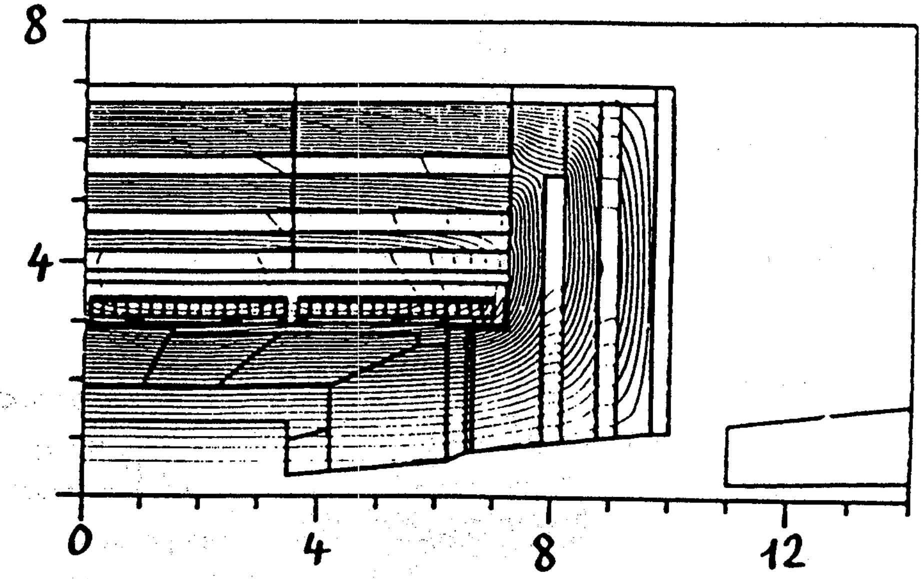
CMS-TN/92-12



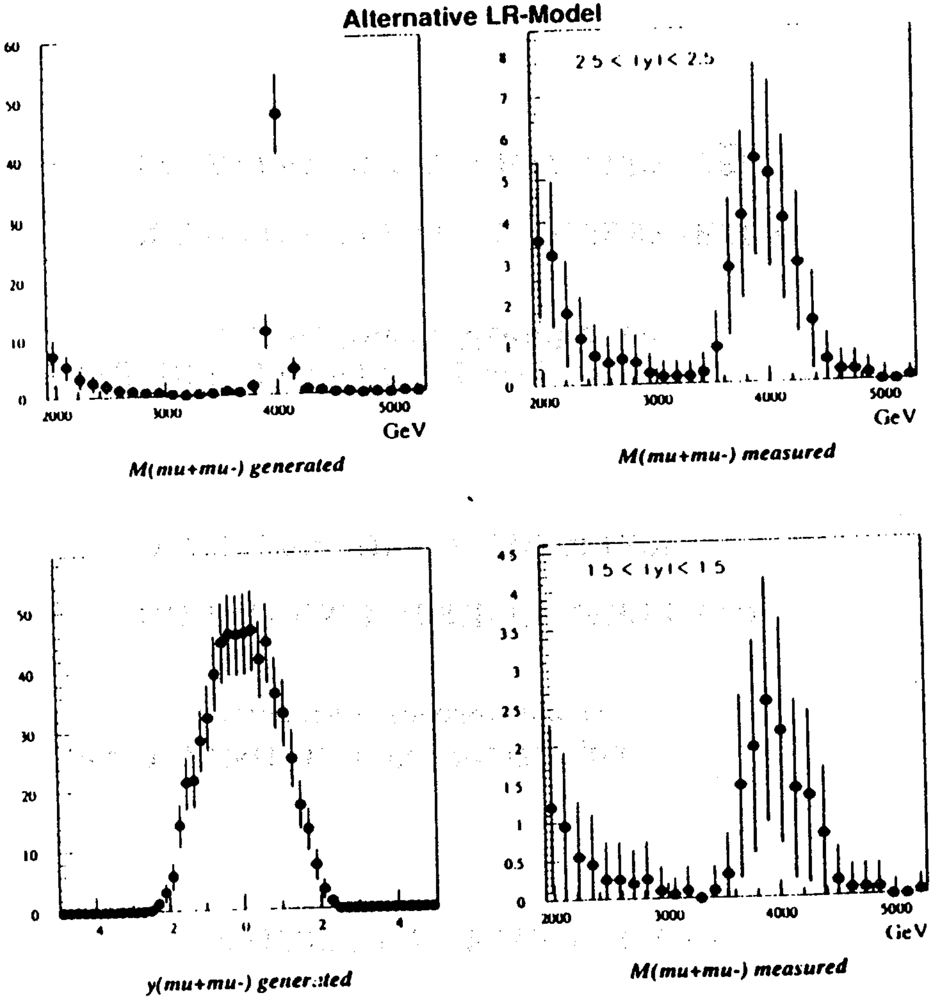
MAGNETIC FIELD MAP

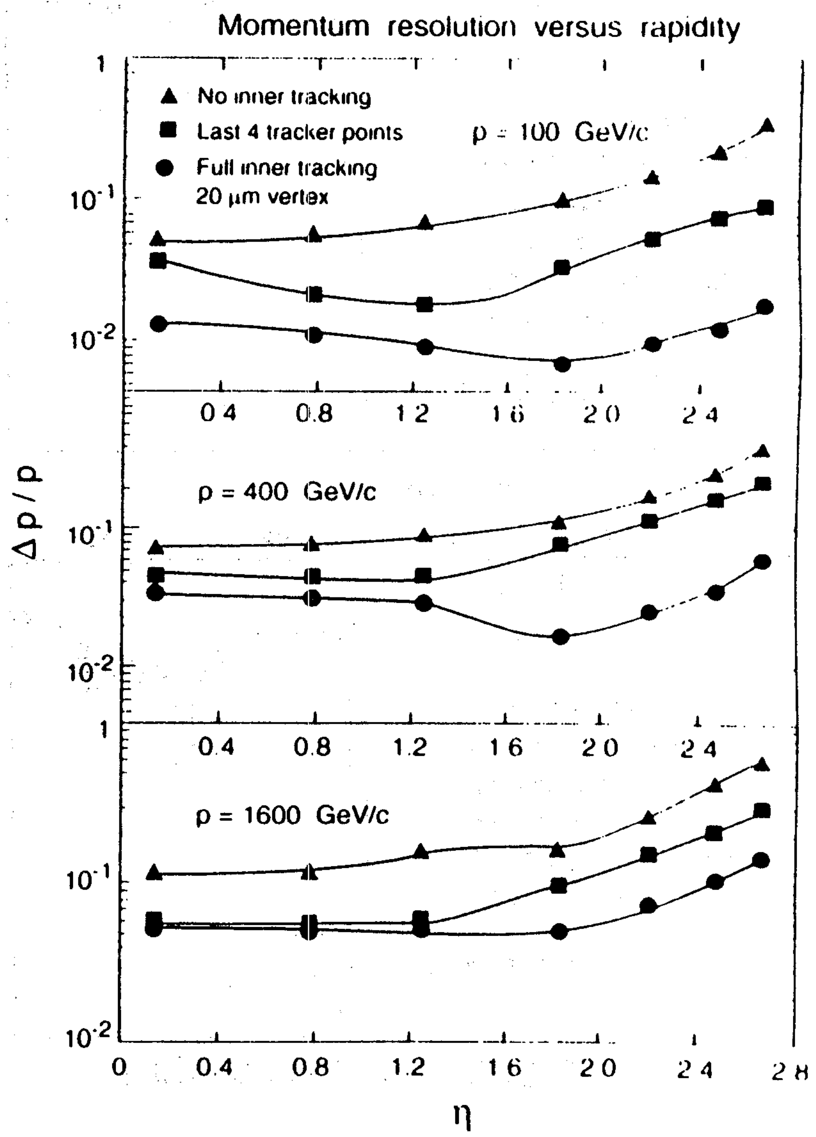


- NON MAGNETIC CALORIMETRY INSIDE COIL
- UNIFORM FIELD (4T) INSIDE TRACKING VOLUME
- RETURN YOKE: 1.8 m Fe SATURATED (1.8 T)
- FULL FIELD MAP INCLUDED INTO GEANT

$Z' \rightarrow \mu^+\mu^-$ $m(Z') = 4$ TeV

ALR - MODEL





CMS TN 92-05

CANDIDATE TECHNOLOGIES FOR MUON DETECTION IN CMS

PRESENTLY TESTED IN RD5:

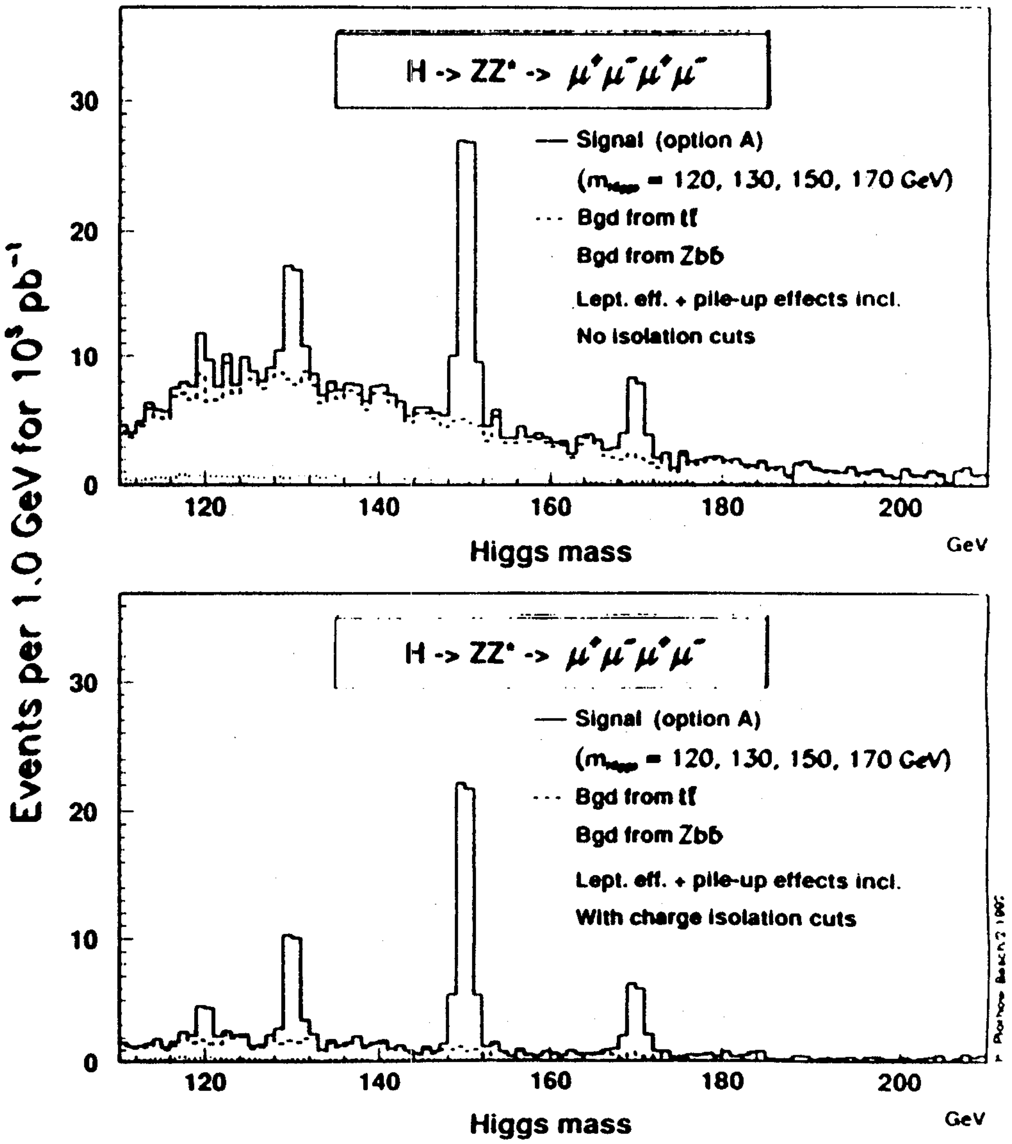
SPACE RESOLUTION 100-200 μm
(Momentum measurement)

- HONEYCOMB STRIP CHAMBERS (HSC's)
- WALL-LESS DRIFT CHAMBERS

TIME RESOLUTION < 5 nsec
(Trigger, Bunch identifier, t_0)

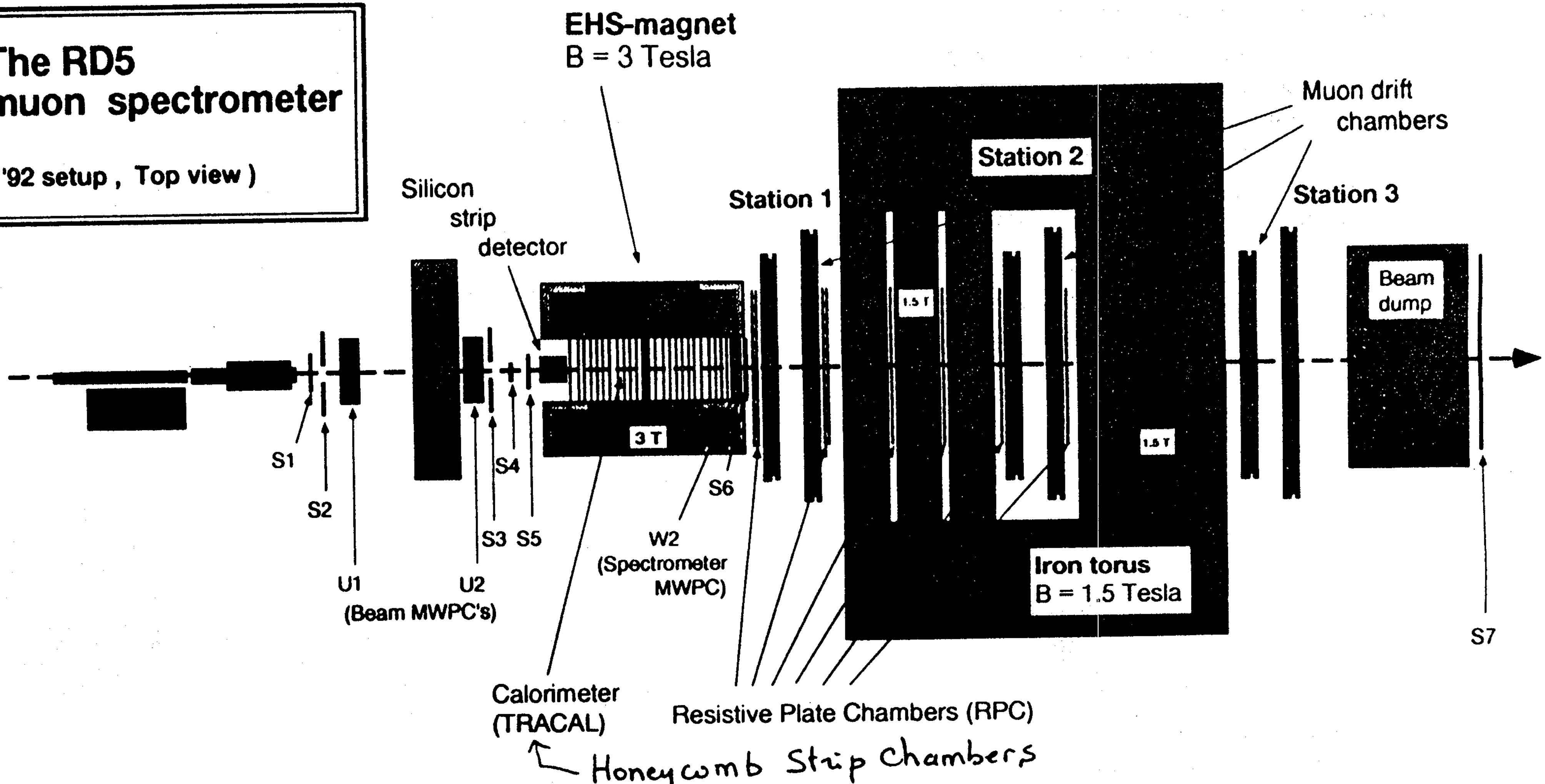
- RESISTIVE PLATE CHAMBERS (RPC's)
- PARALLEL PLATE CHAMBERS (PPC's)

Physics with the CMS Detector



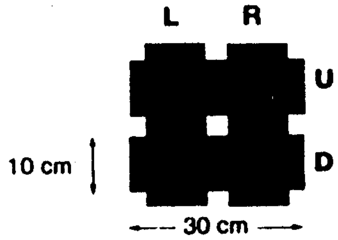
The RD5 muon spectrometer

('92 setup , Top view)



← Honeycomb Strip Chambers

S2, S3 - counters



Scintillation counters

S1: 10 cm x 15 cm
S5: 15 cm x 15 cm
S4: 4 cm x 4 cm
S6: 70 cm x 100 cm
S7: 100 cm x 250 cm

Trigger

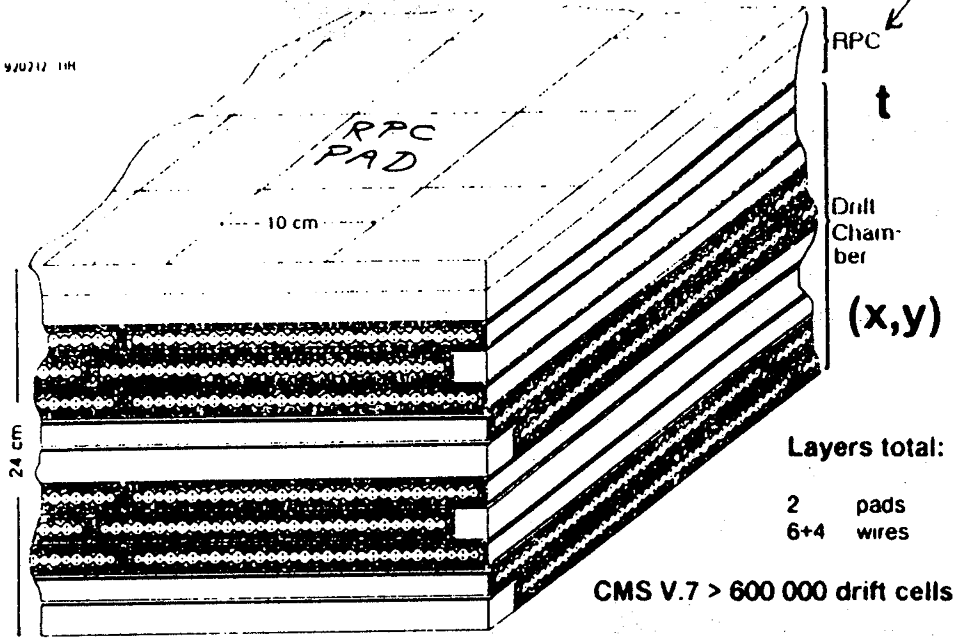
π (minimum bias)	: **S1 x S4 x S5**
π (punch through > 10 λ)	: **S1 x S4 x S5 x S6**
μ (muons)	: **S1 x (S4) x S5 x S6**

Hans Tuchscherer / PPE
RWTH Aachen

CMS-TN/92-02

MUON CHAMBER:

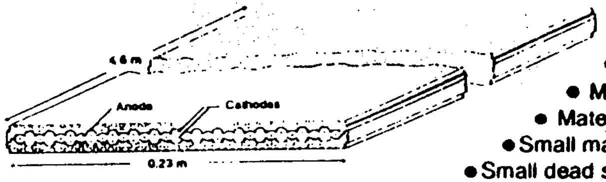
WALL- LESS DRIFT CHAMBER WITH LOCAL REFERENCE TIME



Layers total:

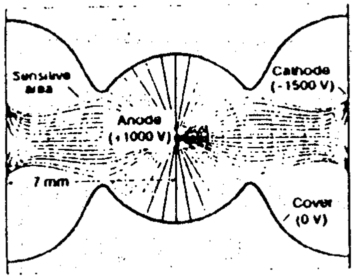
2 pads
6+4 wires

CMS V.7 > 600 000 drift cells



Multicell Unit:

- 16 wall-less drift cells
- Modular construction
- Material: Al or foam
- Small max. drift time (150 - 250 ns)
- Small dead space at wire ends



E-field in sensitive area of one 14 mm drift cell
Single hit ε = 96.3%, σ, ≤ 250 μm

Track Segment in One Module:

- Resolution ≈ 100 μm, ≤ 3 mr
- Efficiency > 99.2 %
- 4-6 hits in bending plane, 3-4 hits in other plane
- Bunch crossing number measured locally by RPC

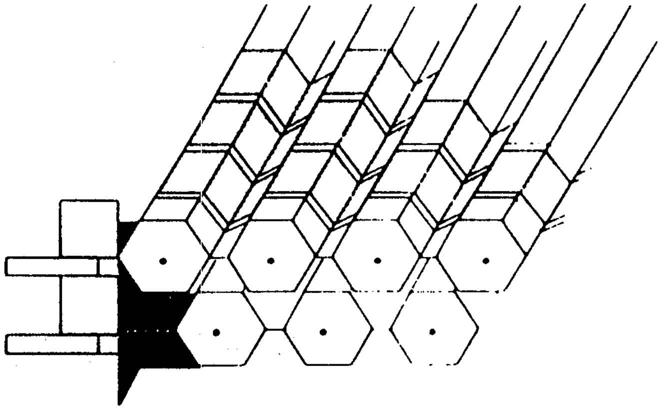
Groups involved:

- Aachen (drift chamber)
- Rome (resistive plate chamber RPC)

Next: Test combined prototype at RD5

CMS-TN/92-04
H. v.d. Graaf /Nikhef
A. König /Nijmegen

HONEYCOMB STRIP CHAMBERS

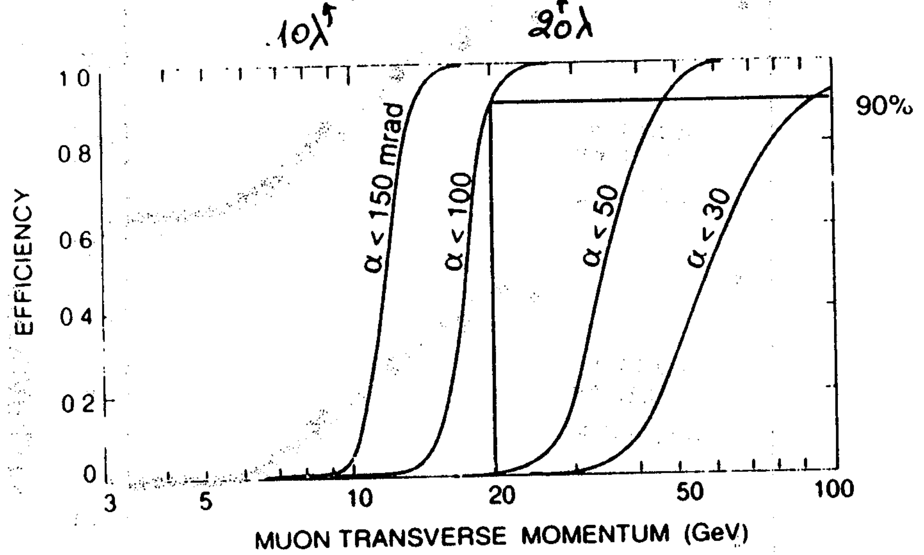


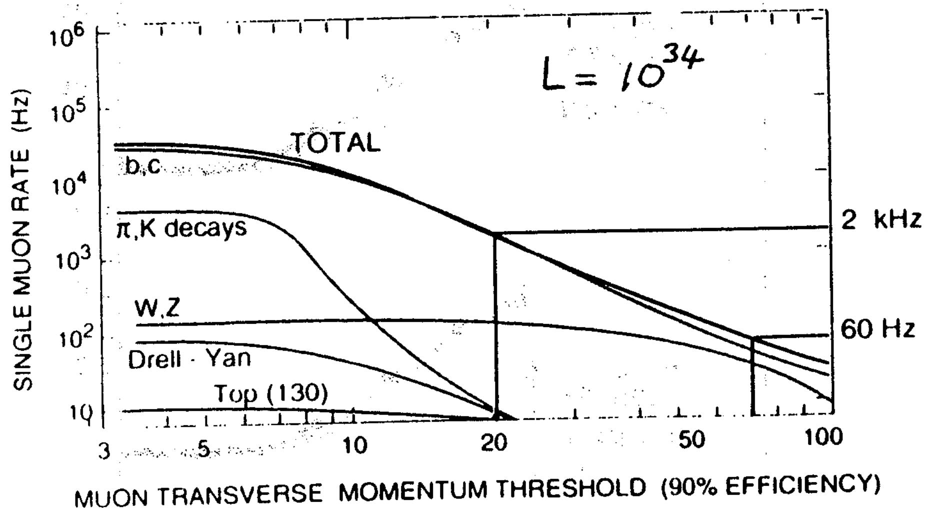
- **Folded mylar foil with copper strips** (low price!)
- **Central gold plated tungsten wire (20 μm)**
- **2 coordinates from the same detector**

  Wire pitch: 13 mm
  Strip pitch: 5 mm
- **2 – track separation 15 mm (strips)**
  13 mm (wires)
- **CMS muon station : 8 planes**
  efficiency of a muon station inside absorber to be measured in RD5 (dirty measurements due to radiated soft electrons)
- **Strip resolution 80 μm at normal incidence (measured in RD5)**

MUON TRIGGER $|\eta| < 1.5$

4 TRIGGER PLANES, 20mm ϕ -STRIPS
R = 3.8, 4.8, 5.6, 6.8 m





MUON CHAMBER

WALL -LESS DRIFT CHAMBER WITH LOCAL REFERENCE TIME

COMBINED DRIFT CHAMBER + RPC

- t_0 for drift time:

  By RPC $t_0 \leq 7$ ns (locally, to about 1 m 2)
  → identifies the beam crossing
  → time reference to 1 ns.
  Fast (hardware; no algorithm involved).

- Position & angle: By drift chamber.

- Resolve spatial ambiguities:

  Space points from projections (≥ 2 tracks in chamber)
  → ambiguities resolved by pads.

- Resolve temporal ambiguities:

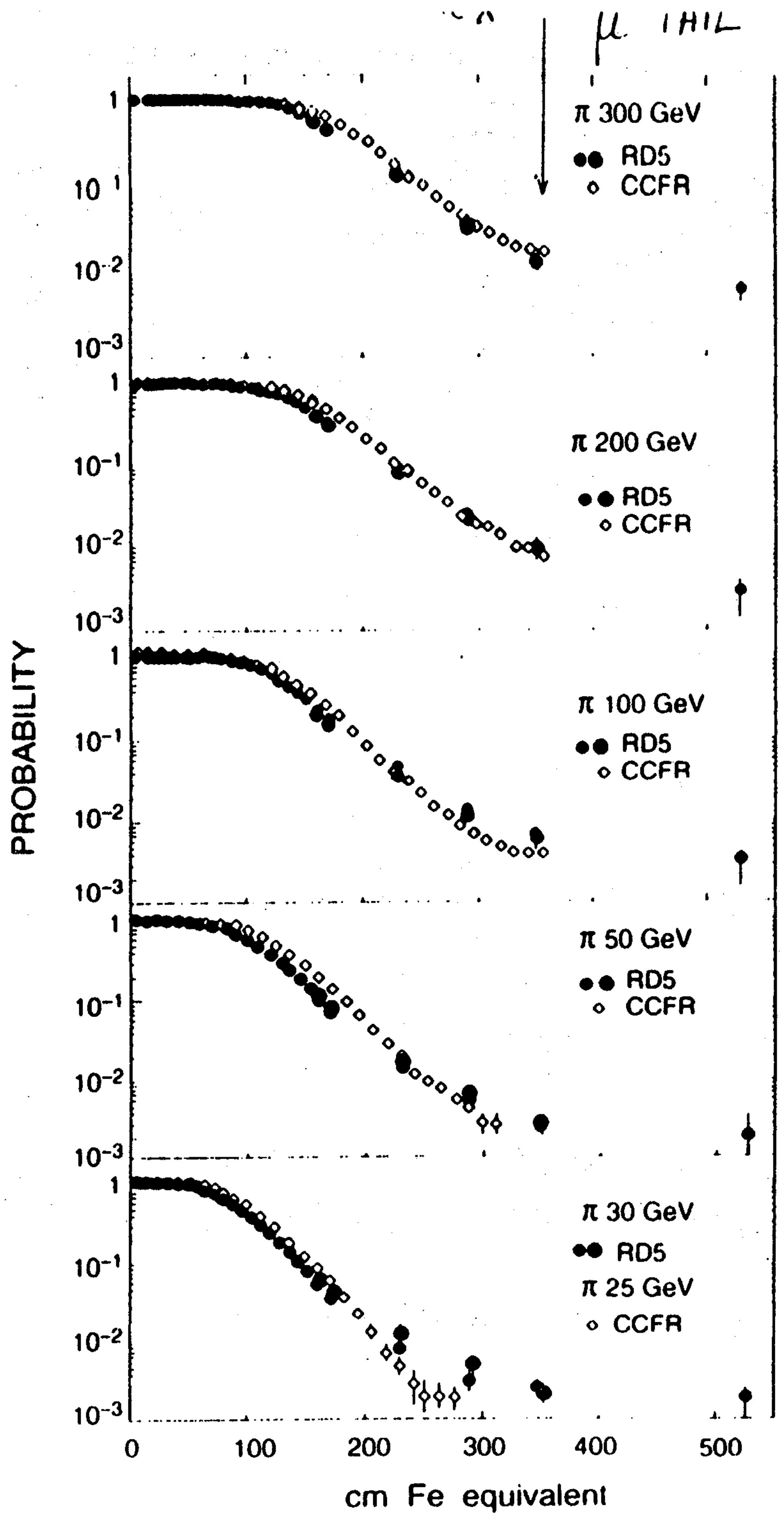
  Precise beam crossing label on track segment
  → avoids erroneous association of tracks from different beam crossings to one event.

- Fast & redundant:

  Here: fast and local timing measurement;
  Later: cross check with the track reconstruction
  → redundancy.

- Readout & trigger:

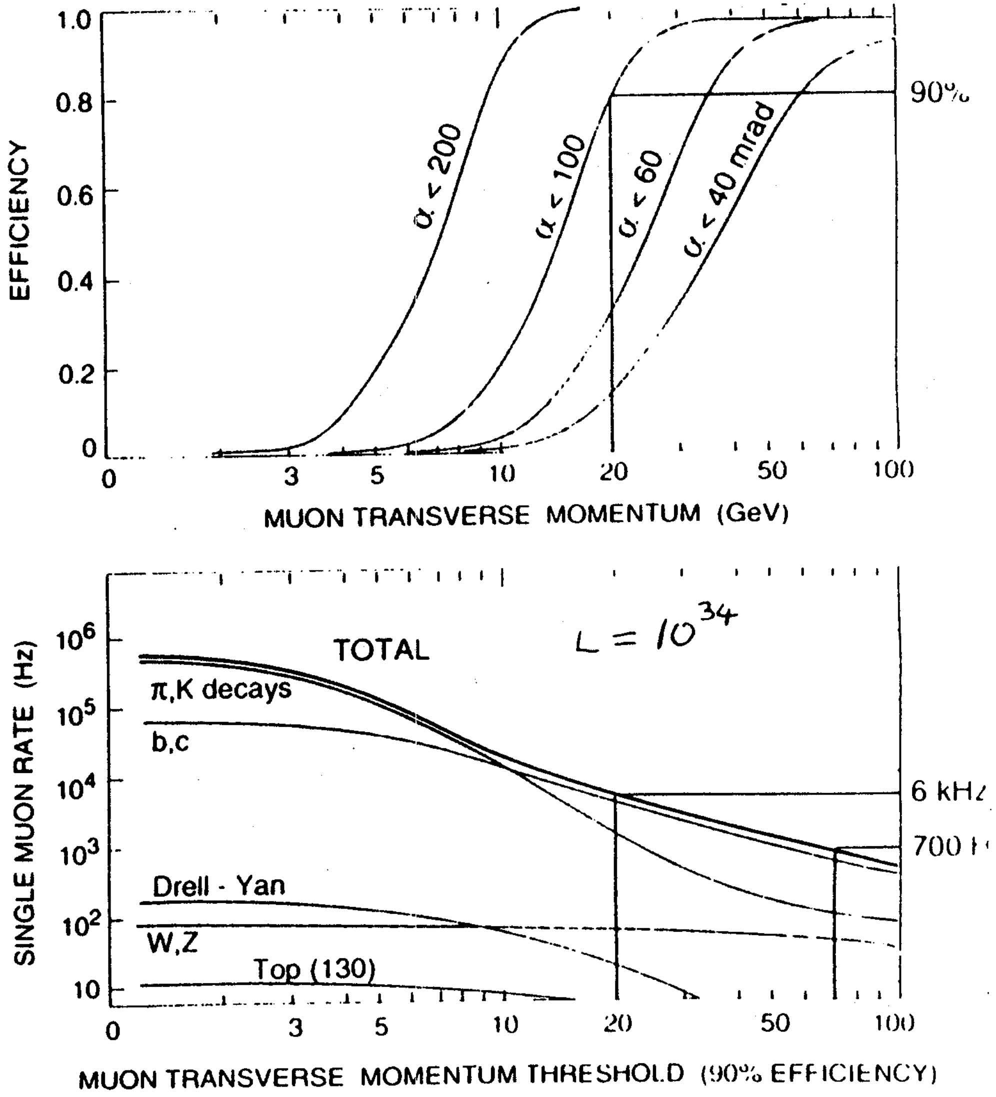
  Autotriggering (each module)
  → outputs track segment (hits) + event number
  → minimal data traffic.



FORWARD MUON TRIGGER $1.5 < |\eta| < 2.5$

3 TRIGGER PLANES, 30mm x 30mm PADS

Z = 6, 10, 11m



RD5

π^- 20 GeV

B=1

run 768

event 1130

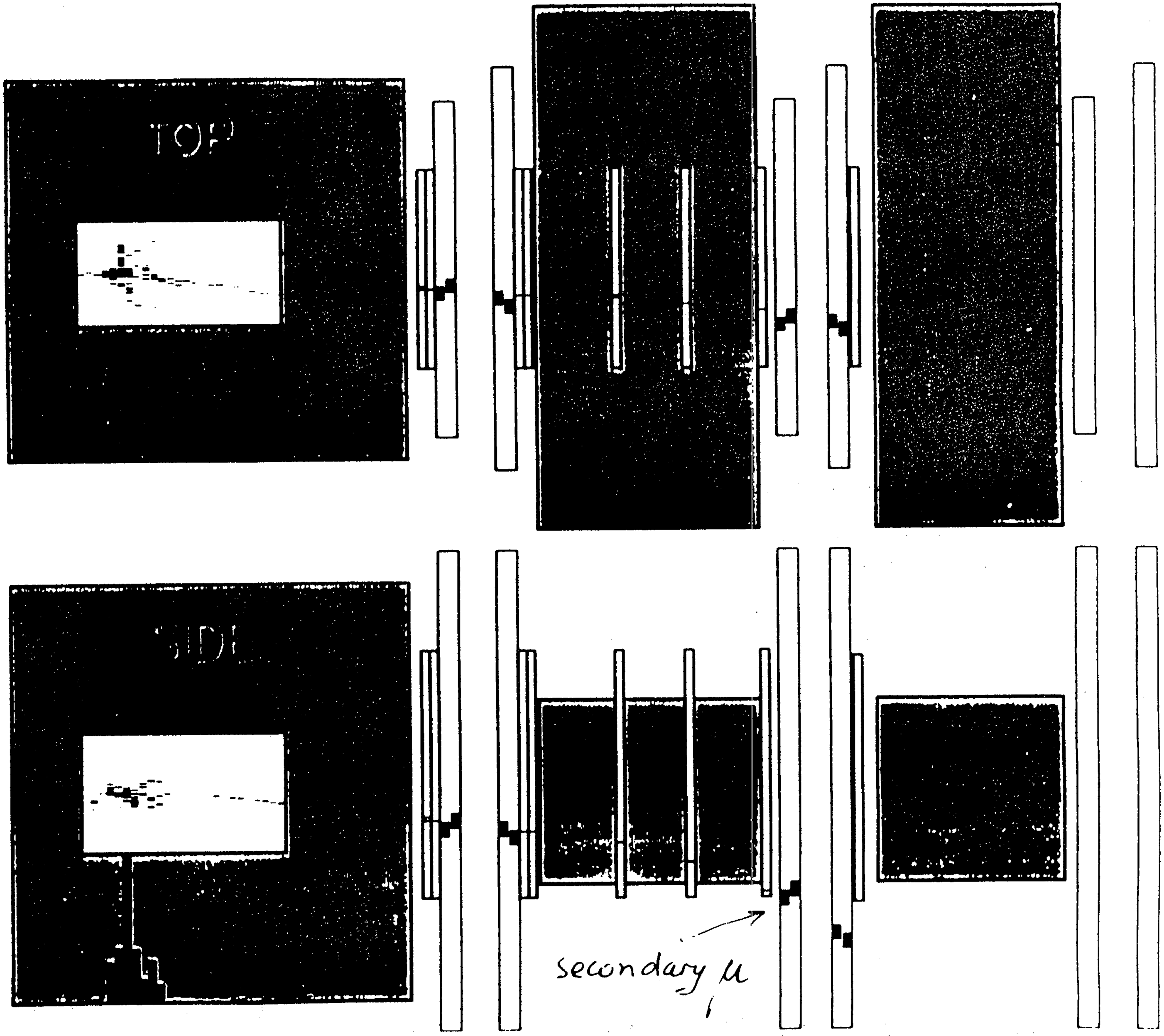
91.09.01 5:21

TRIGGER –

– physics mode

defined/meas.

S1	■	■
S2	□	□
S3	□	■
S4	■	■
S5	■	■
S6	■	■
S7	□	□
TRACAL		■
2ndpart.(S6)		□



CANDIDATE TECHNOLOGIES FOR MAGNETIC TRACKING IN CMS

- SILICON MICROSTRIPS (RD20) CMS-TN/92-10

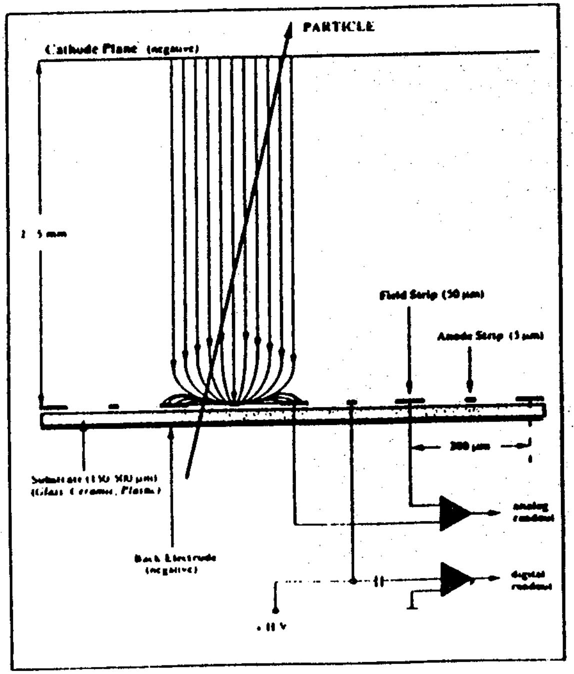
  50 μm pitch

- MICROSTRIP GAS COUNTERS (NIKHEF, RD10) MSGC's CMS-TN/92-11

  200 μm pitch

- SMALL DIAMETER SCINTILLATING FIBRES (RD7, LAA) CMS-TN/92-09

  Ø 60 μm



THE MICRO-STRIP GAS CHAMBER

TRACKING IN STRONG FIELD

($B = 4$ Tesla)

- **TRACKING CAVITY:**

  $R < 1.3$ m

  $|z| \leq 3.5$ m

- **GOAL:** $\Delta P_T/P_T = 0.1\ P_T$ [TeV] Eq. 2
- **PATTERN RECOGNITION:**

  -large P_T leptons
  muons (isolated or in jets),
  isolated electrons

  -but also large P_T tracks ($P_T > 2$ GeV)
  around lepton

RECOGNIZE ALL LARGE P_T TRACKS WITH $P_T > 2$ GeV

- **STRONG FIELD HELPS AT LARGE RADIUS:**

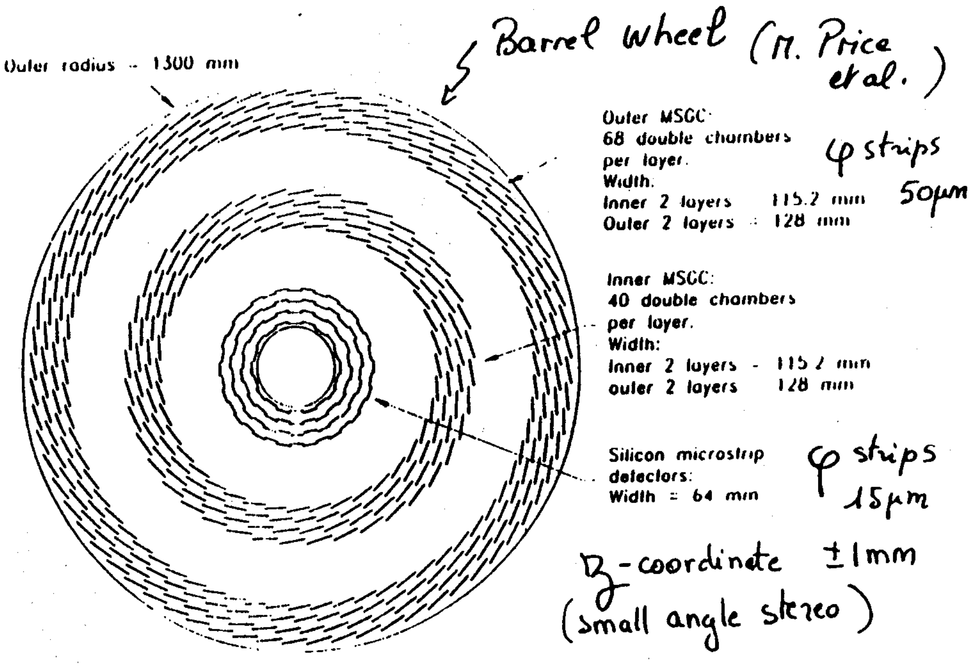
  P_T cut ~ 0.8 GeV at R ~1.3 m

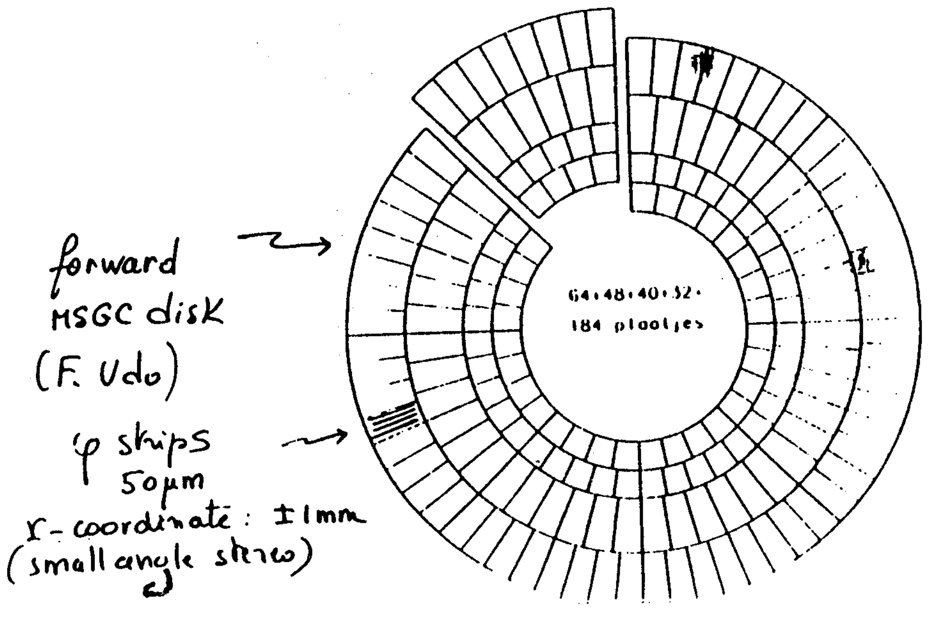
- **SMALL CELL SIZES:**

  necessary to maintain occupancies < 1%

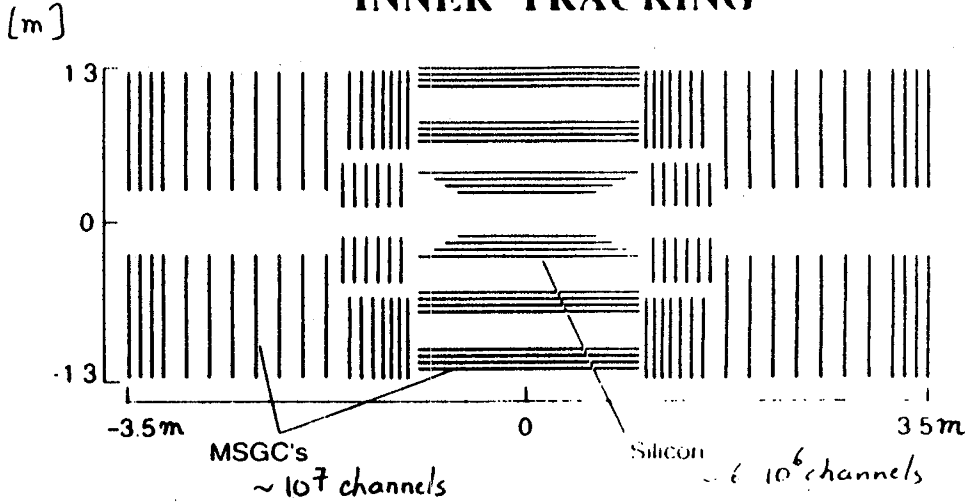
LARGE NUMBER OF CHANNELS: ~10^7

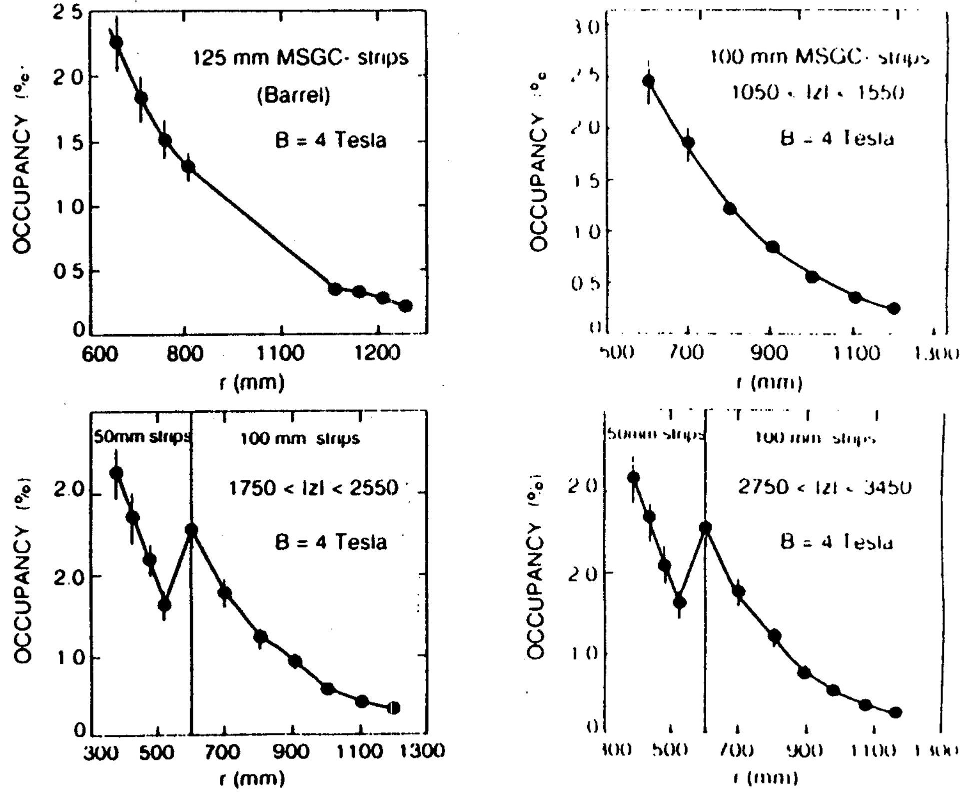
FIRST STUDIES ON MECHANICAL DESIGN





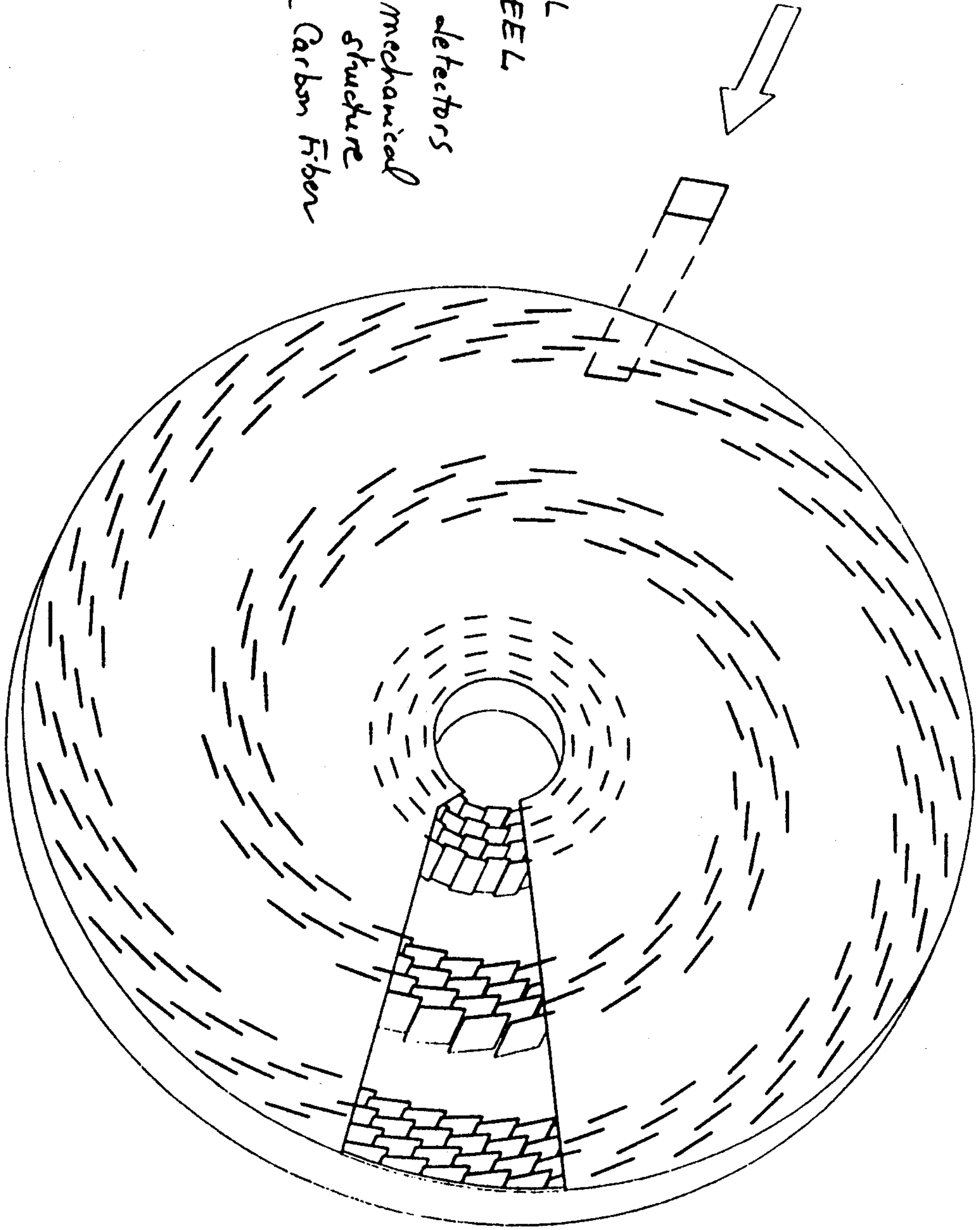
INNER TRACKING

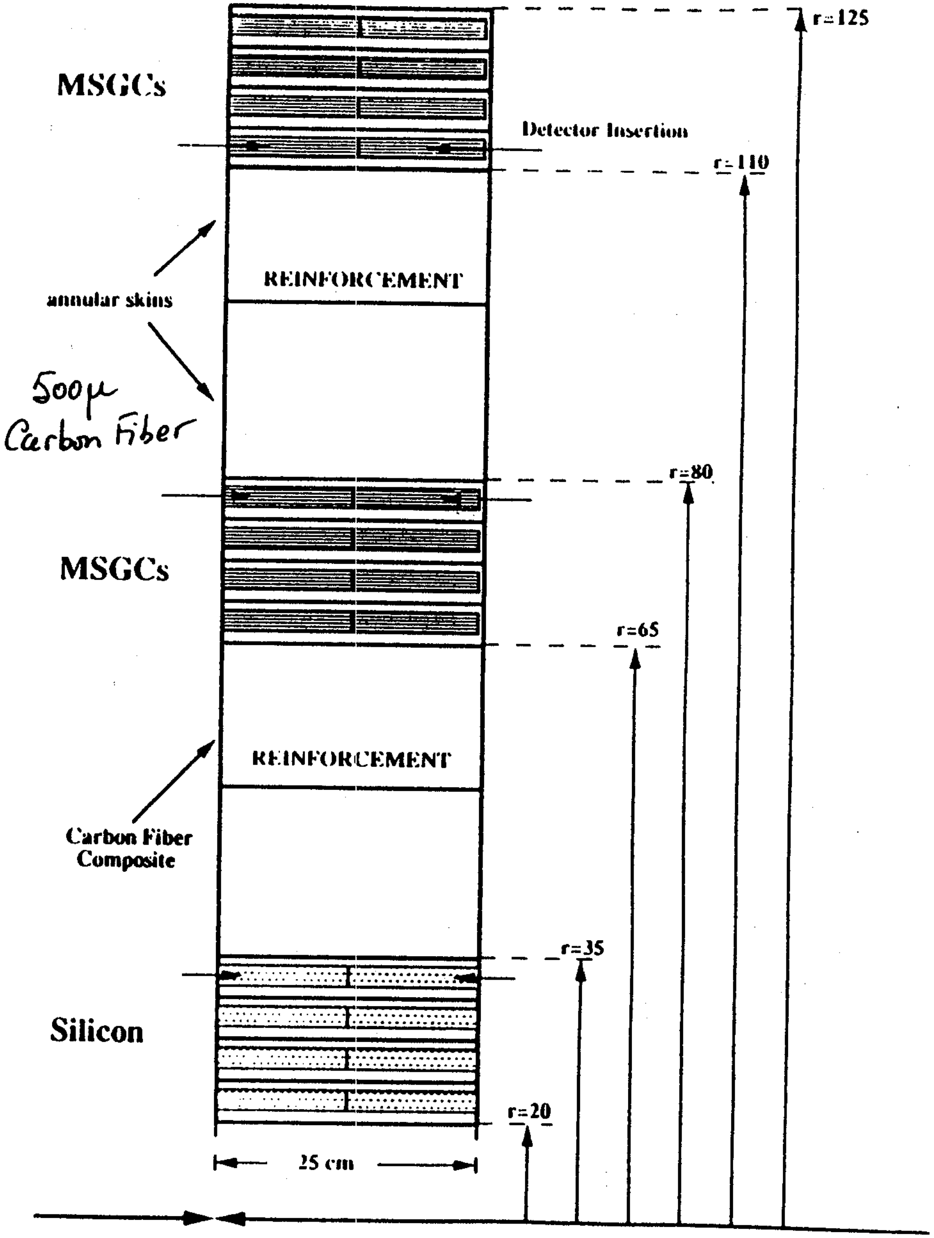




BARREL
WHEEL

5% r.l. detectors
5% r.l. mechanical structure
500μ Carbon Fiber

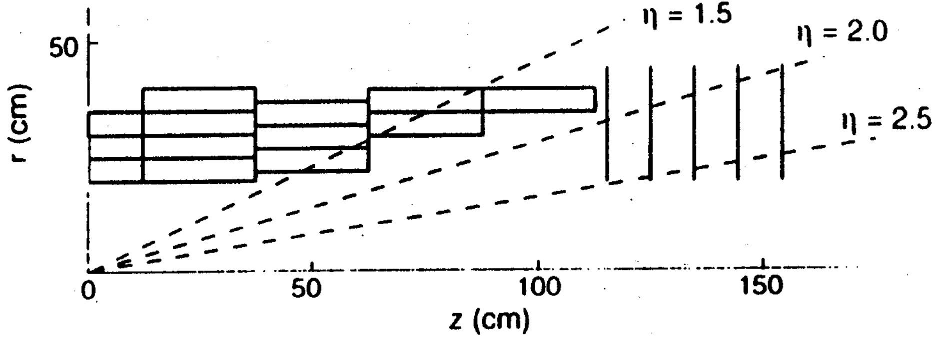


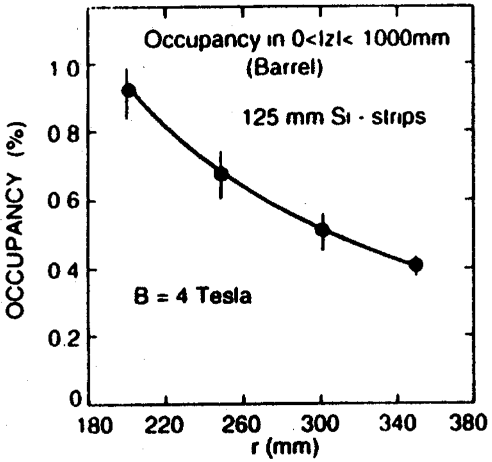


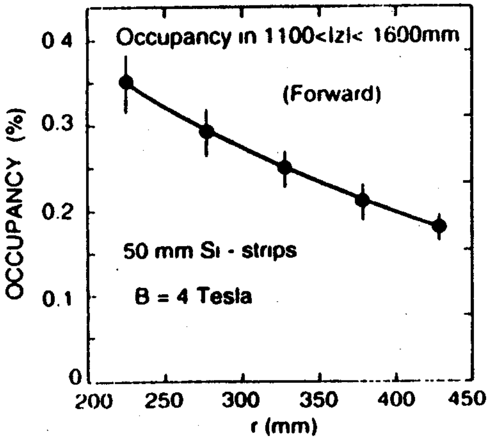
CMS Tracker 'Wheel'

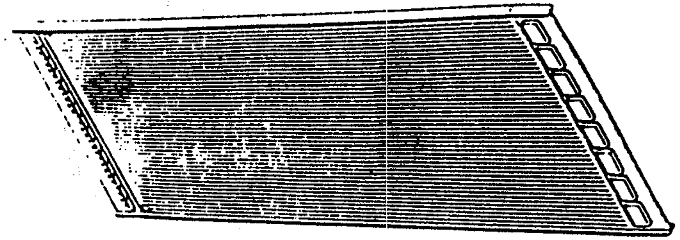
~6 10^6 channels

SILICON TRACKER

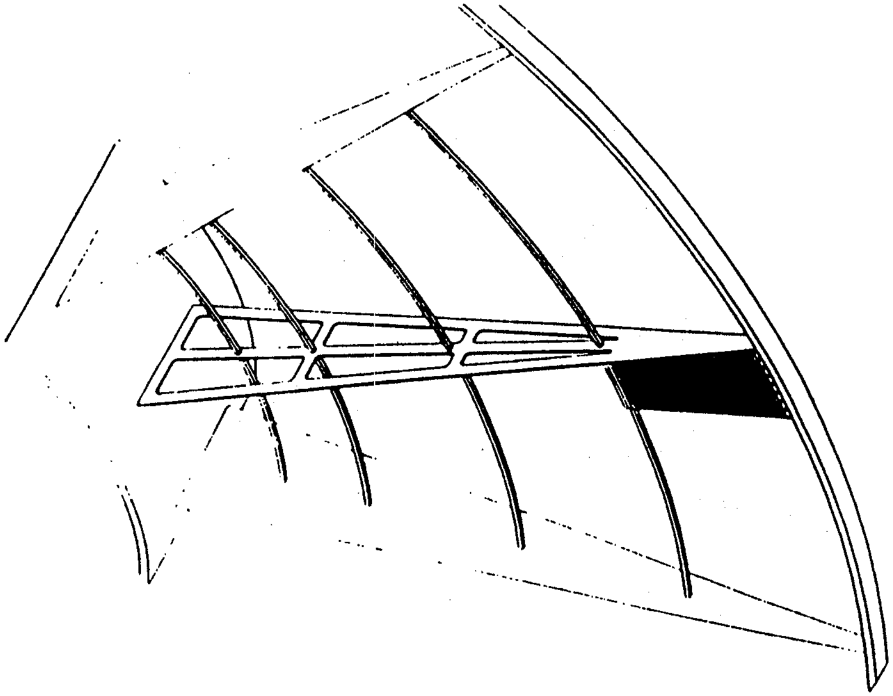


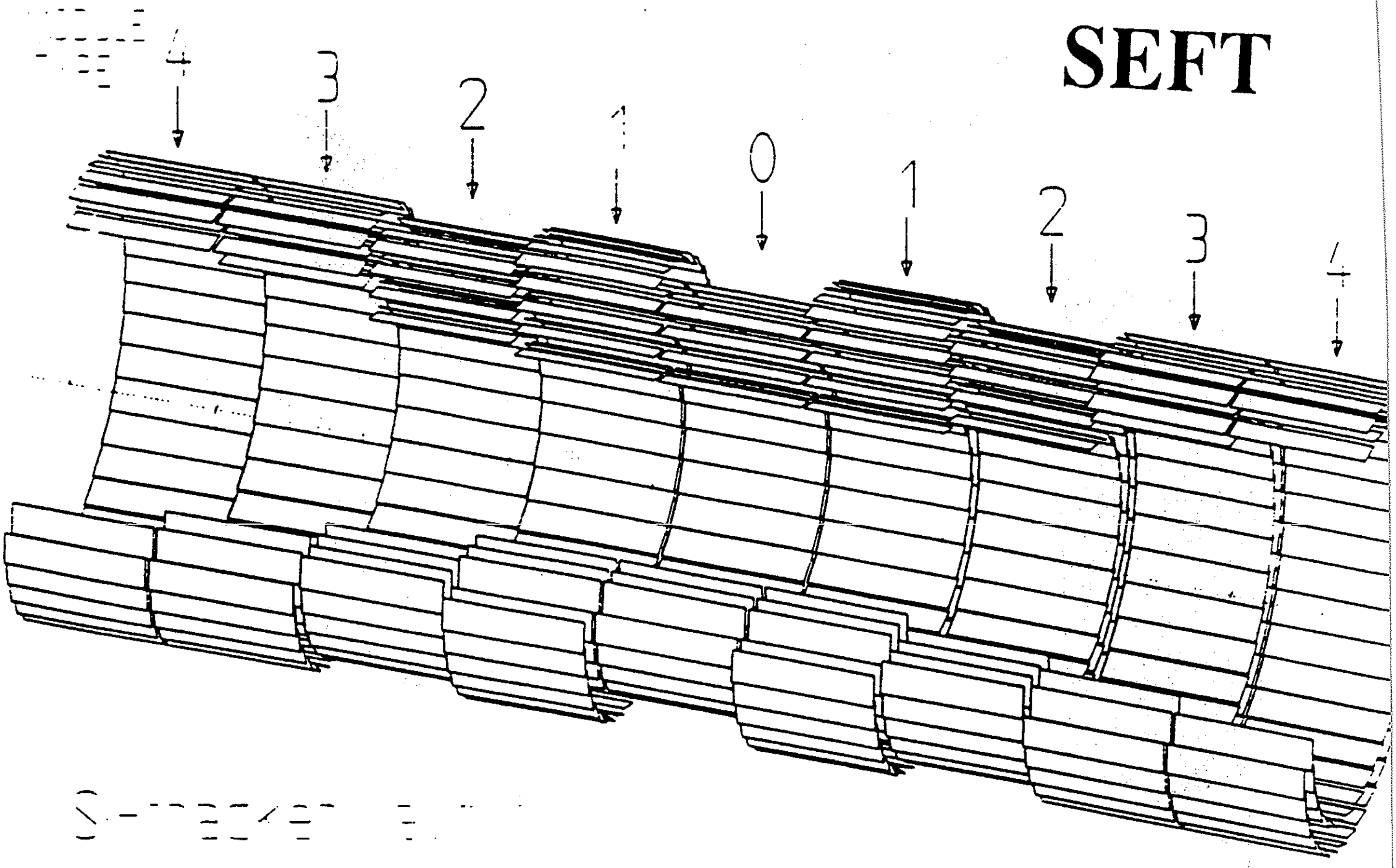






FORWARD MSGC DISK
F. Udo / Nikhef.

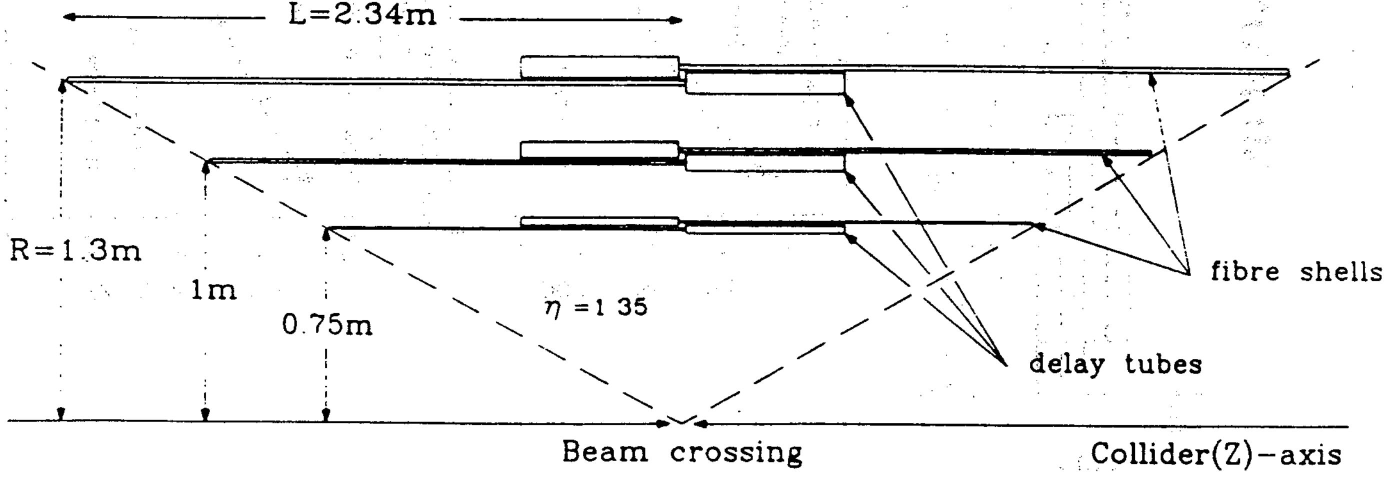




CENTRAL TRACKING WITH SCINTILLATING FIBRES (LAA,RD7)

30 to 60 points per track
r,φ,z – coordinates are measured
~160 millions fibres are readout by ~400 tubes
also provide pipeline for first level trigger

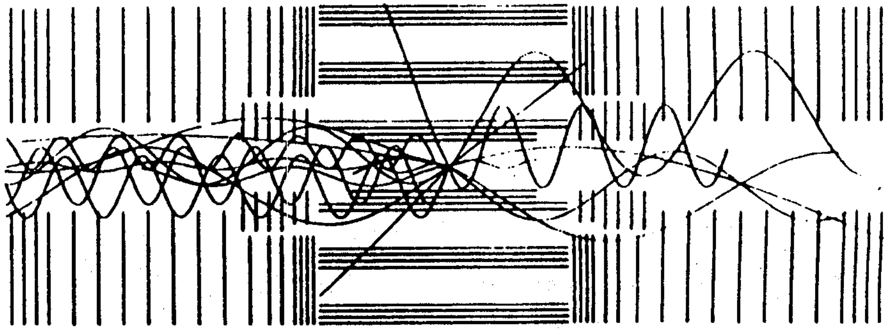
Polar – (R,Z) – plane



TRACKING SIMULATIONS

- FULL GEANT SIMULATION
  - 10 - 20 % r.l. (1% r.l. / plane)
  - Conversions
  - Curling tracks

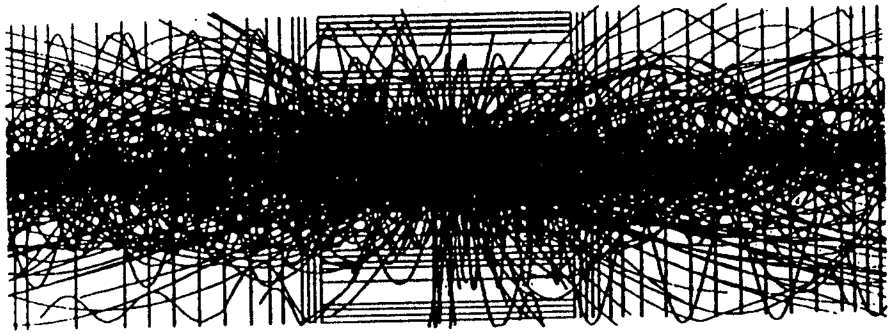
1. Min. Bias event
↓



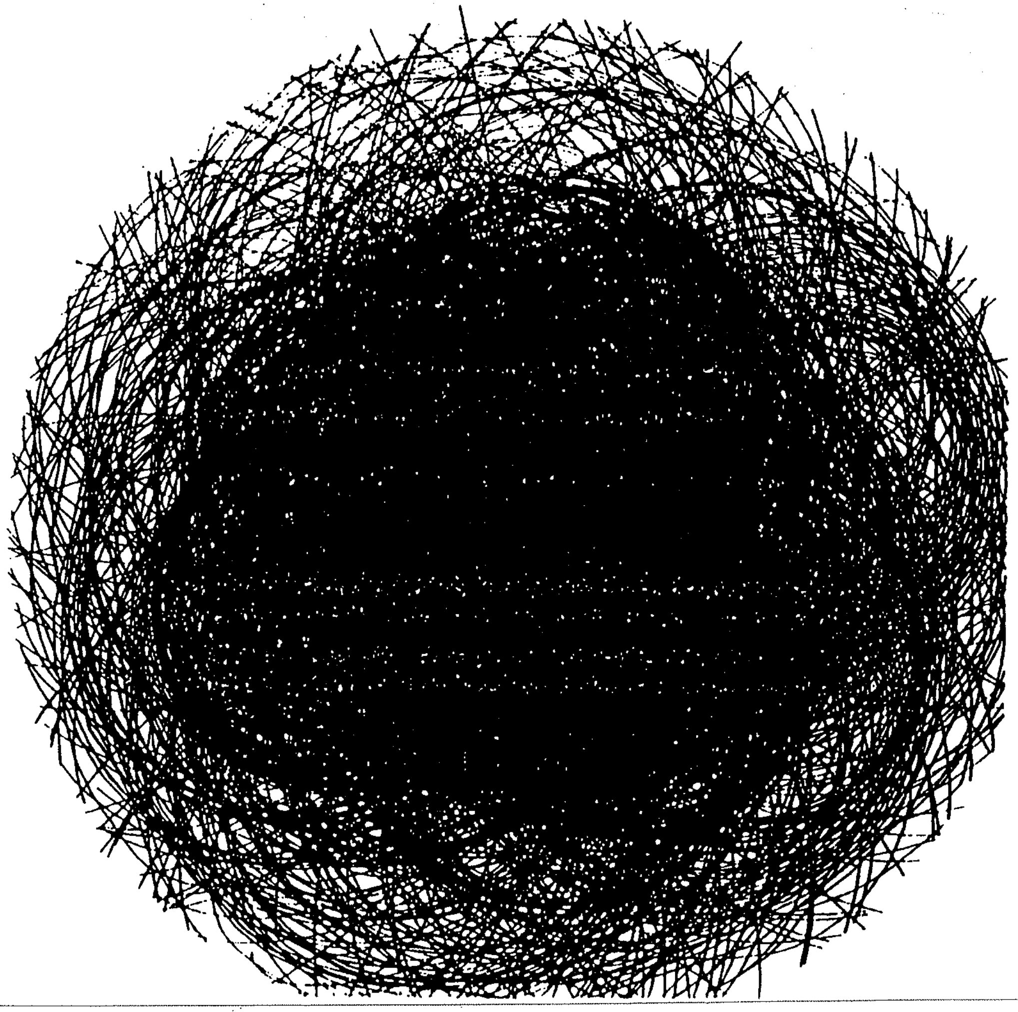
Tracking Cavity
$|z| \leq 3.5$ m
$R \leq 1.3$ m

1 CROSSING AT 10^{34}:

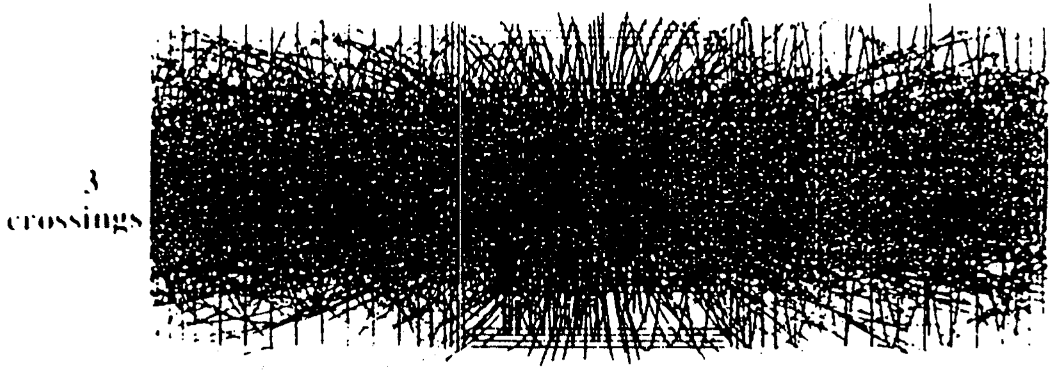
15 Min. Bias !



$L = 1.8 \ 10^{34}$
3 crossings (MSGC 50ns)
7m in Z



$L = 1.8 \ 10^{34}$
3 crossings (MSGC 50ns)



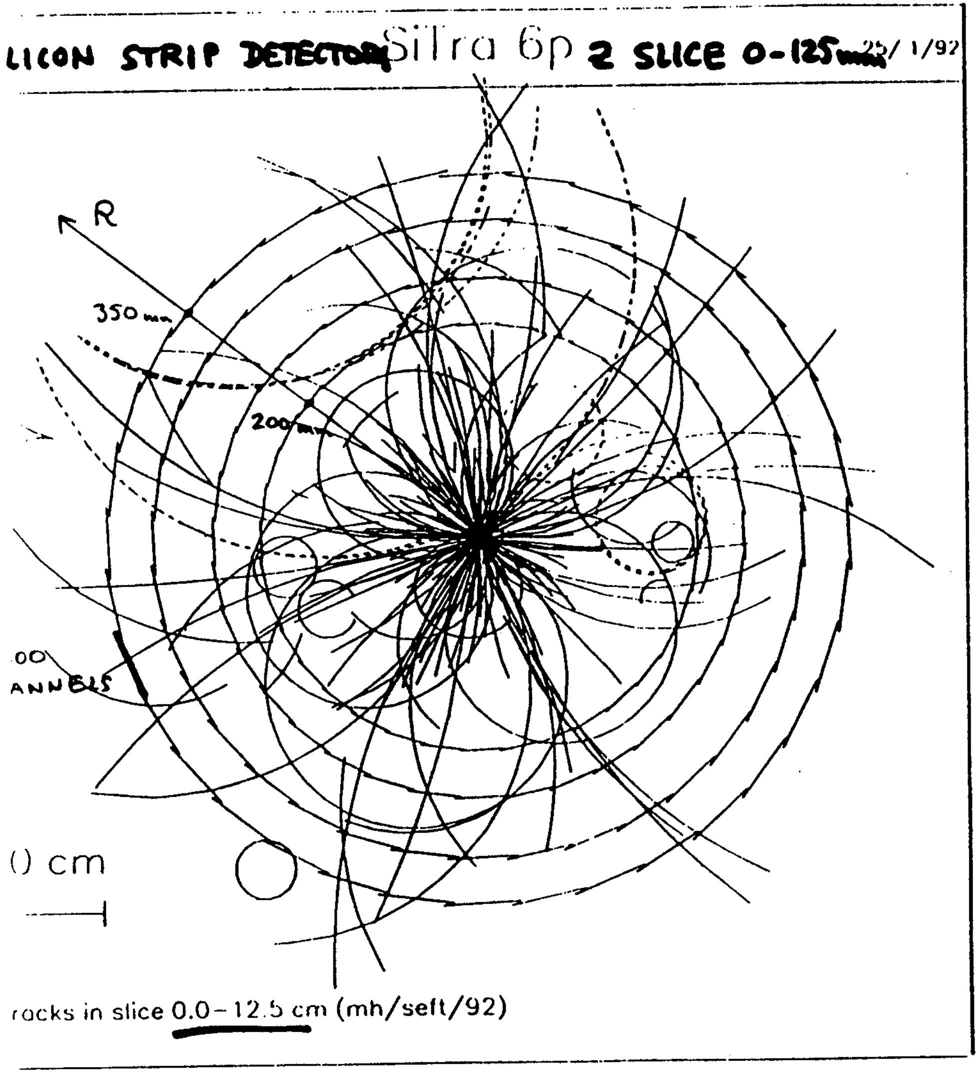
GMS TRACKING - SILICON

$\mathcal{L} = 1.8 \cdot 10^{34}$

15ns INTEGRATION

~15 MIN BIAS EVENTS

M. PIMIÄ
29 II 1992
SEFT-HELSINKI



LICON STRIP ~~DETECTOR~~ SiTra 6p Z SLICE 0-125mm 25/1/92

racks in slice 0.0-12.5 cm (mh/seft/92)

CMS TRACKING

M PIMIÄ
27 II 1992
SEFT-HELSINKI

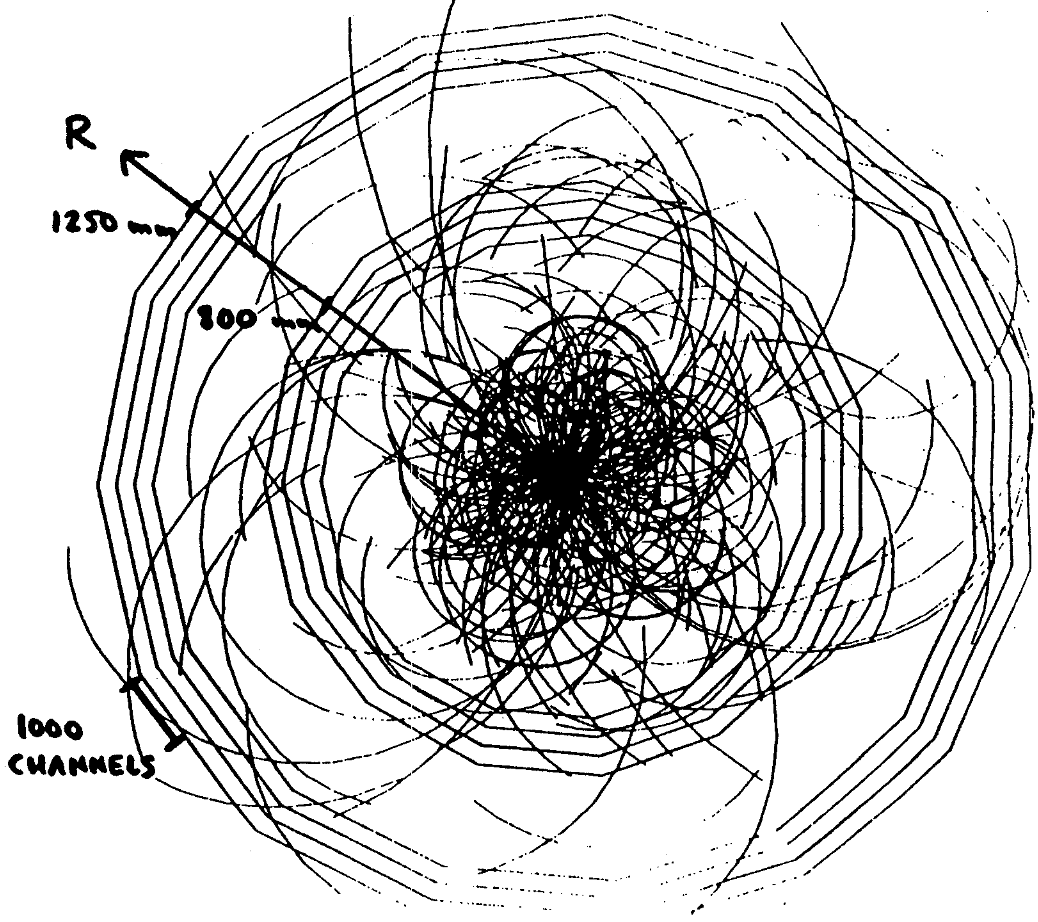
$\mathcal{L} = 1.8 \times 10^{34}$

3 CROSSINGS (MSGC 50 ns)

~ 50 MIN. BIAS EVENTS

Z - SLICE 0 — 125 mm

MICROSTRIP GAS CHAMBERS (MSGC)



THE BENEFIT OF MAGNETIC TRACKING

- ELECTRON IDENTIFICATION

  - Isolation cuts on charged tracks
  - matching calo / tracking:

    •*in position* : Position detector inside calorimeter after 5 r.l.
    •*in energy* : E/P cut

  known (CDF, UA1) to give jet rejection factors of order 10^6 .

  TRD NOT NECESSARY !

- ELECTRON CHARGE

  up to $P_T \sim 3$ TeV ($Z' \rightarrow e^+e^-$)

- PHOTON IDENTIFICATION

  - Isolation cuts on charged tracks

- CALORIMETER CALIBRATION

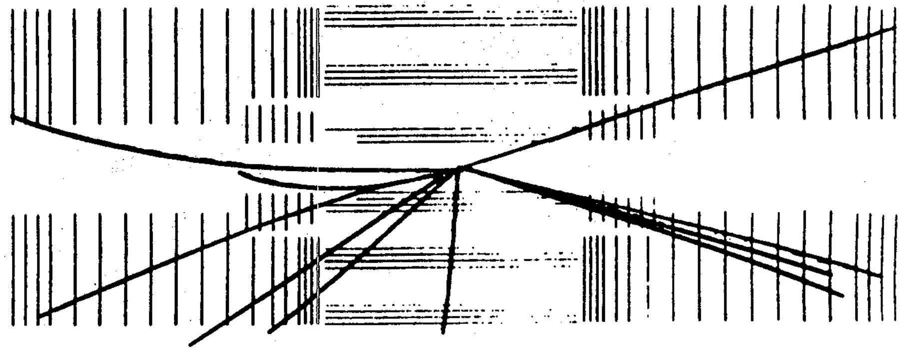
  - use isolated electrons from W, Z

  $\Delta P / P \sim 1$ %

- $\tau^\pm$, $h^\pm$ AT LARGE P_T

PATTERN RECOGNITION

- Full Geant with background
- $L = 1.8 \times 10^{34}$, integration time : 50 ns MSGC, 15 ns Silicon
- Full simulation of digitizations
- Apply additionnal inefficiency : 10% MSGC, 5% Silicon
- Add random noise channels : 0.1 % of channels (15000 hits)



isolated tracks $P_T > 2$

TRACK FINDING EFFICIENCY

η	0.0-0.5	0.5-1.0	1.0-1.5	1.5-2.0	2.0-2.5	Tota
P_T>5 GeV	99%	97%	98%	99%	98%	98%
P_T>2 GeV	99%	98%	97%	99%	98%	98%
errors	± 1%	± 1%	± 1%	± 1%	± 1%	± 1

NUMBER OF FAKE (GHOST) TRACKS / 3 CROSSINGS

(for 100 tracks with P_T>2 GeV)

η	0.0-0.5	0.5-1.0	1.0-1.5	1.5-2.0	2.0-2.5	Tota
P_T>5 GeV	0	0.2	0	0	0	0.2
P_T>2 GeV	0	0.4	0	0	0	0.4
errors	±0.2	±0.3	±0.2	±0.2	±0.2	±0.

e / γ CALORIMETER

- Discovery of the SM Higgs in mass range $80 \leq M_H \leq 135$ GeV requires detection of H -> γ γ decay mode.
- Large area of Minimal SUSY parameter space is covered by same mode but generally with a lower σ.B than in SM.
- Possibly important for Toponium -> γ γ

Natural width very small $\Gamma_H \sim 10^{-5}\ M_H$ $(M_H \leq 150\ \mathrm{GeV})$

S/B LIMITED by γ γ MASS RESOLUTION

Aim for best feasible energy (mass) resolution
Both stochastic and constant terms must be kept small.

Aim for $\frac{\sigma}{E} \approx \frac{2\%}{\sqrt{E}} \oplus 0.5\ \%$ Choose Crystals

CMS Natural place for such a calorimeter

High magnetic field and high performance tracking :

1) To maintain constant term < 0.5 % requires in situ calibration. We intend to use isolated electrons from W and Z decays. BUT simultaneous measurement of BOTH momentum and energy with accuracy of ≤ 1% is necessary.

2) Pileup from soft charged hadrons is much reduced by the strong field ($P_T^{cut} \approx 800$ MeV/c)

BACKUP Standard Energy Resolution $\frac{\sigma}{E} \approx \frac{10\%}{\sqrt{E}} \oplus 1.0\ \%$

ELECTRON IDENTIFICATION

CONVERSION BACKGROUND WITH 4 TESLA?

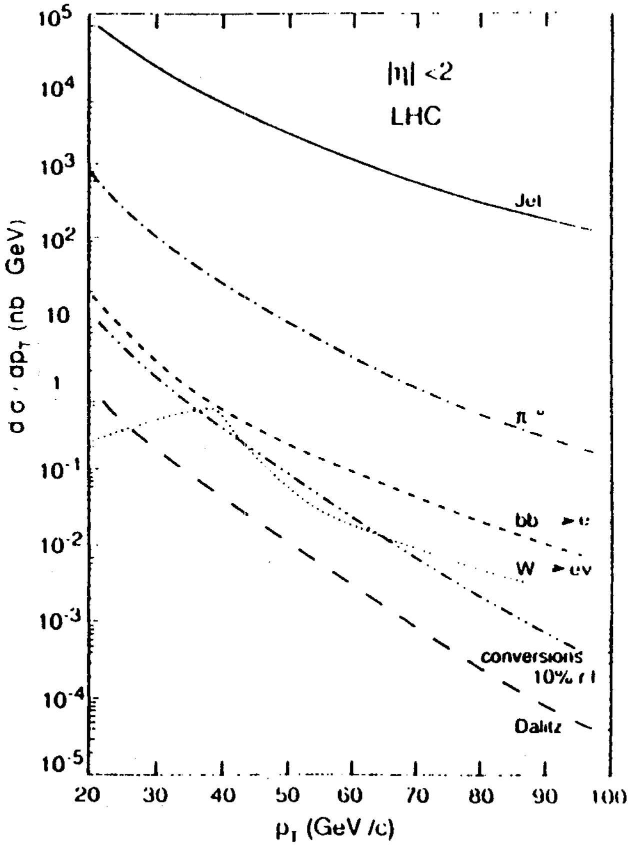
HIT IN 1ST PLANE AFTER BEAM TUBE (1% R.L.)

ISOLATION CUTS

CMS - TN/92-06

E/P CUT

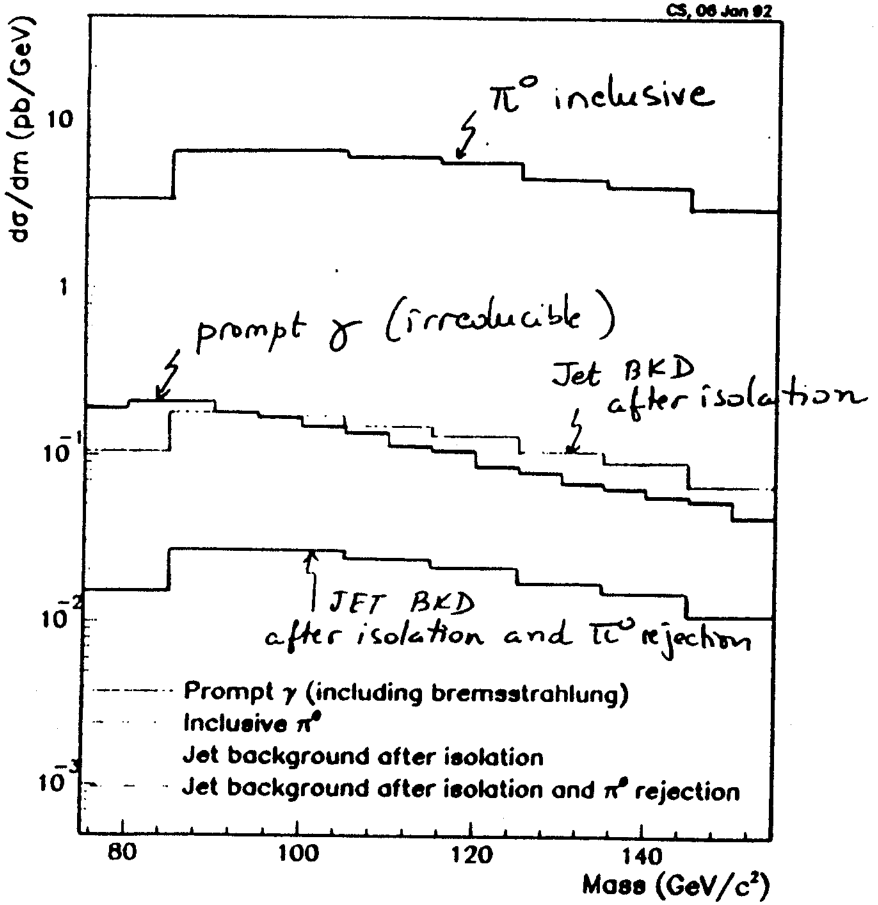
RAW RATES FOR SINGLE ELECTRONS (NO CUTS)



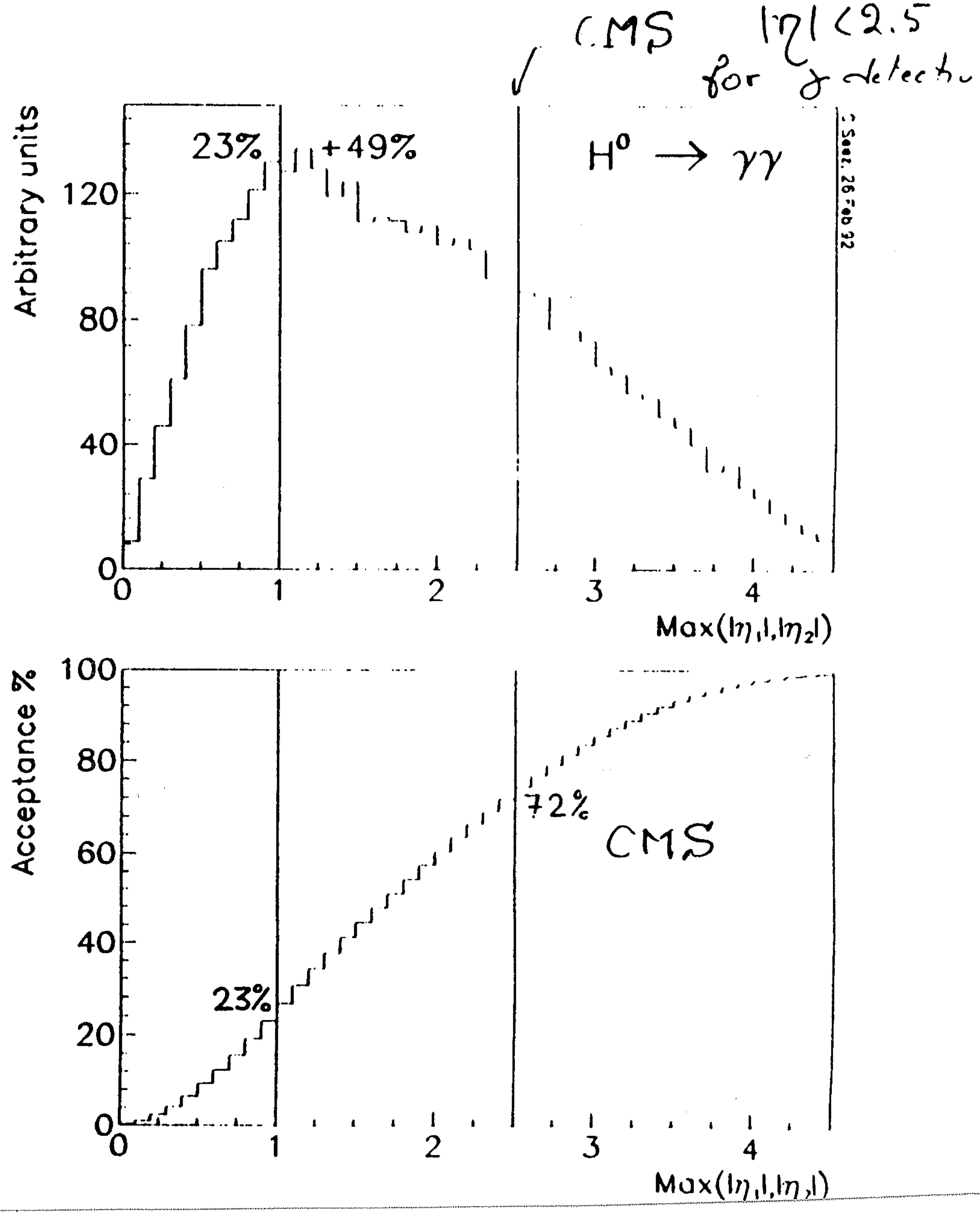
BACKGROUNDS TO H → γγ

- Irreducible $\bar{q}q$, gg → γγ
- reducible Jet → "γ"

NEED POSITION DETECTOR 2 mm STRIPS TO REJECT $\pi^0 \to \gamma\gamma$

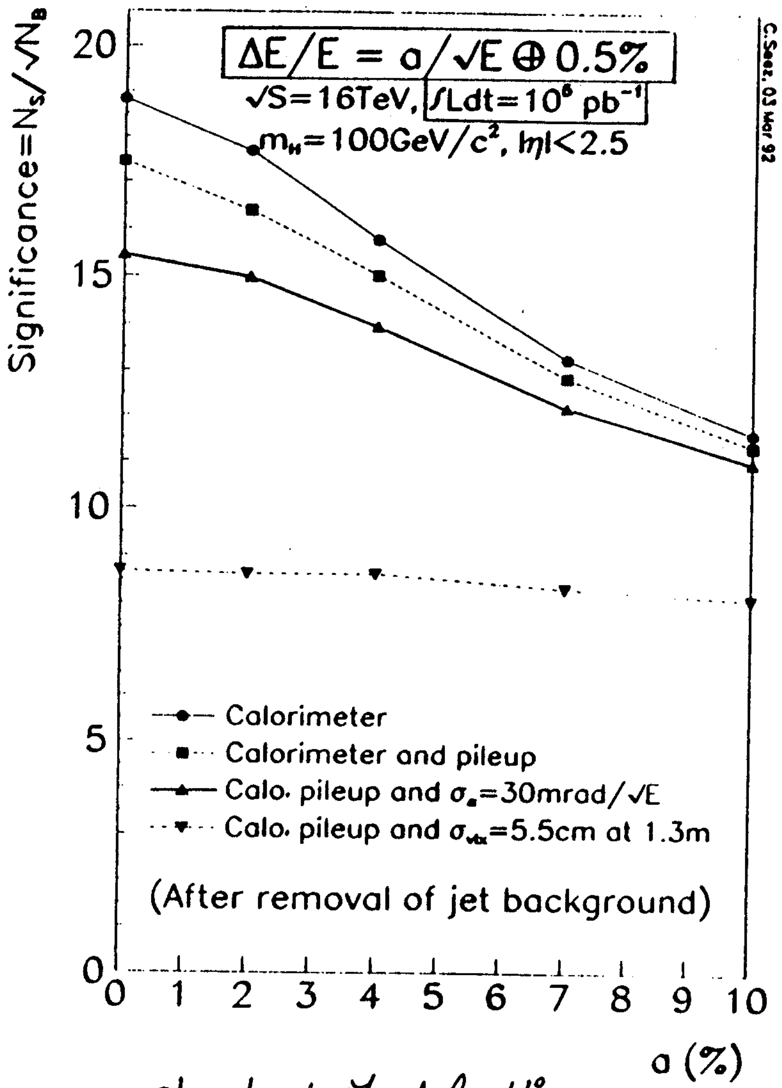


ACCEPTANCE V/S RAPIDTY COVERAGE



SIGNIFICANCE OF $H \to \gamma\gamma$ SIGNAL
$m_H = 100$ GeV, $\sigma B = 78.9$ fb

Djouadi, Spira, Zerwas PL B264 (1991) 440
(K-factor 1.5, $gg \to H$)



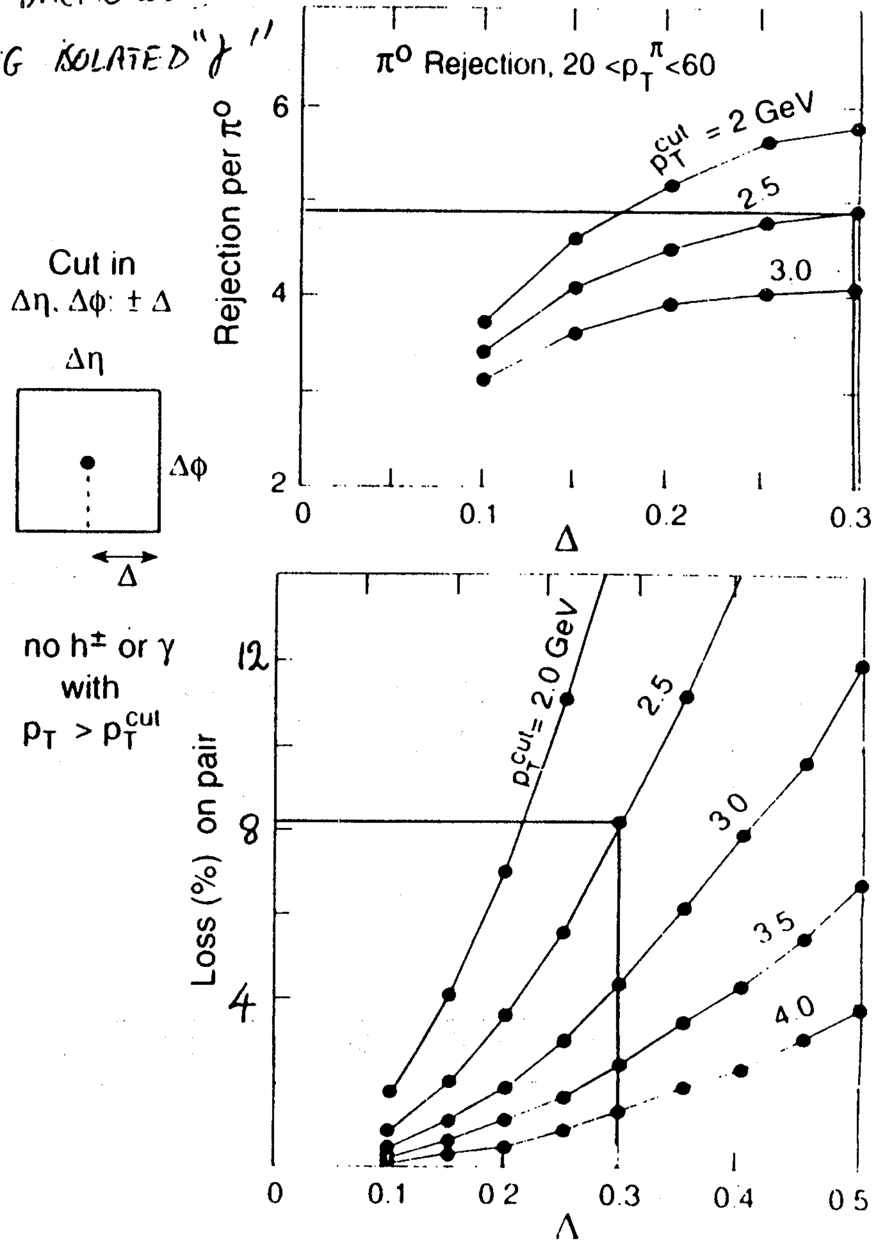
$\varepsilon_\gamma = 85\%$ each γ

Standard Model $H^0 \to \gamma\gamma$

CMS-TN/92-03

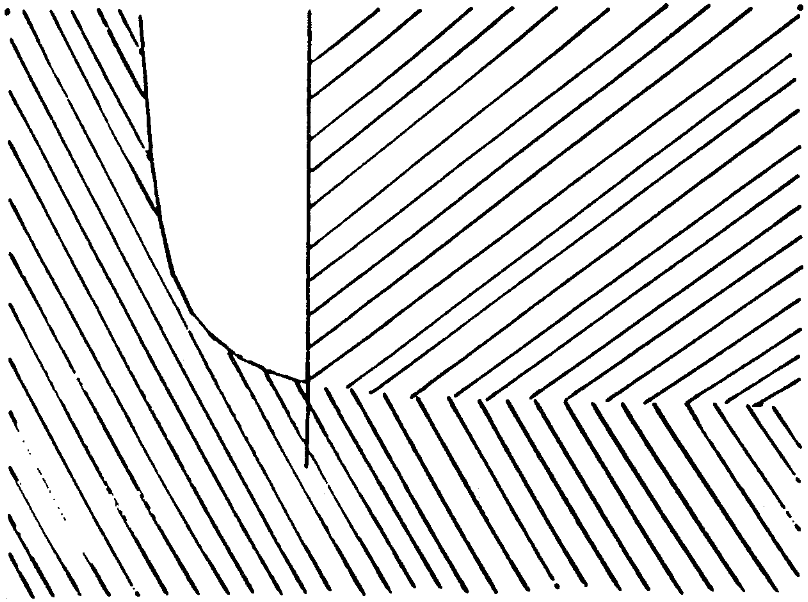
REJECTION, EFFICIENCY OF ISOLATION CUTS (L = 10^{34})

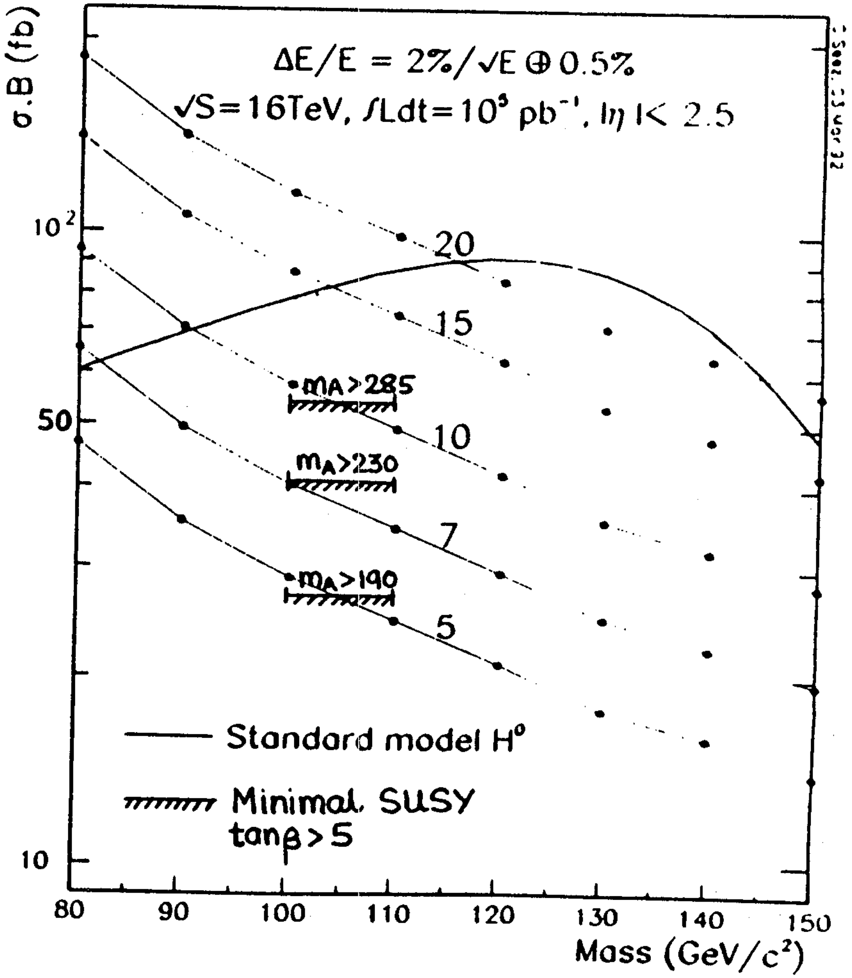
π^0 BACKGROUND FAKING ISOLATED "γ"



MS-TN/92-05

H→γγ DISCOVERY RANGE IN CMS





Ce F3 PROPERTIES

P. Lecoq, RD18

Best candidate of all crystals : CeF_3

$\rho = 6.16$ g/cm^3, $X_0 = 1.63$ cm, $R_M = 2.6$ cm

- Light output 50% of BGO
- Temperature dependence < 0.1% /° C
- 2 peaks : 310 nm (80%) 5, 20 nsec.
  340 nm (20%) 25 nsec.
- Can be read by standard Si PD in 4 TESLA

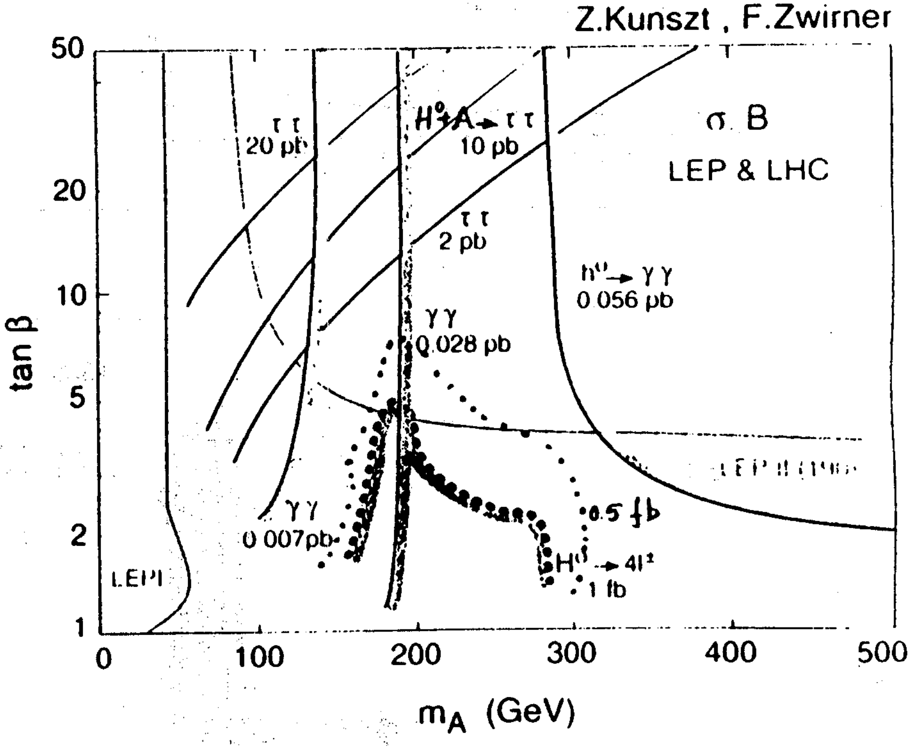
  Ongoing R&D to select optimal readout scheme
- Radiation hard (RD 18 measurements)
- Good mechanical properties

  → high production yield
- Target price (in collaboration with industry)

  ~ 2 \$ / cm^3

CAN WE EXCLUDE MSSM ?

EXCLUDED REGIONS IN SUSY PARAMETER SPACE



CeF$_3$ Radiation Test : 0·1 Mrad in 4 hours

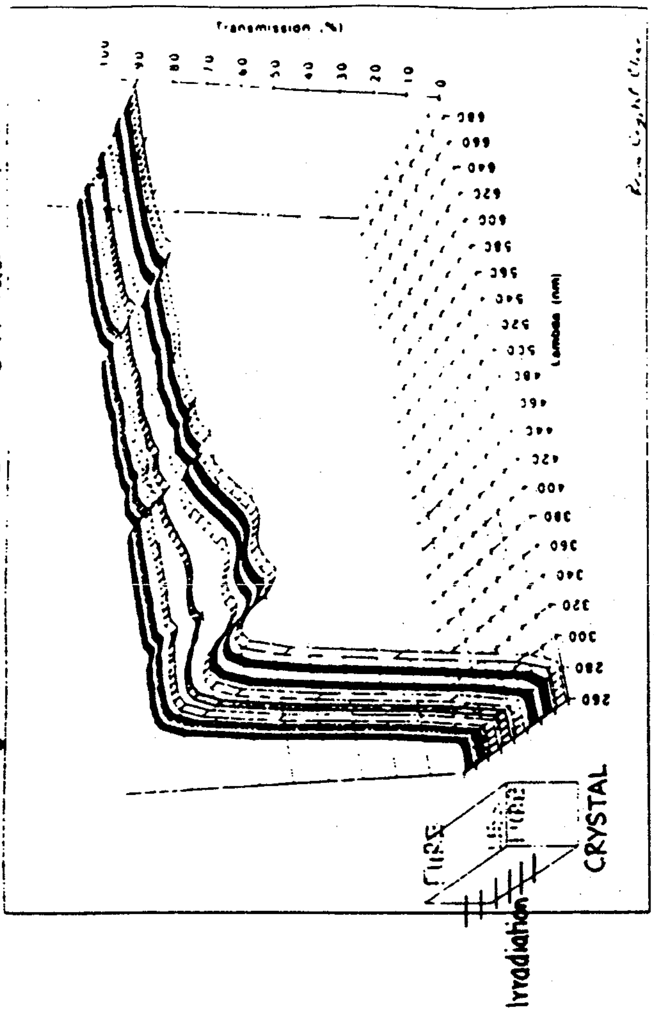


Fig 2 Transmission of CeF3 after 1000 Gy [illegible] crystal

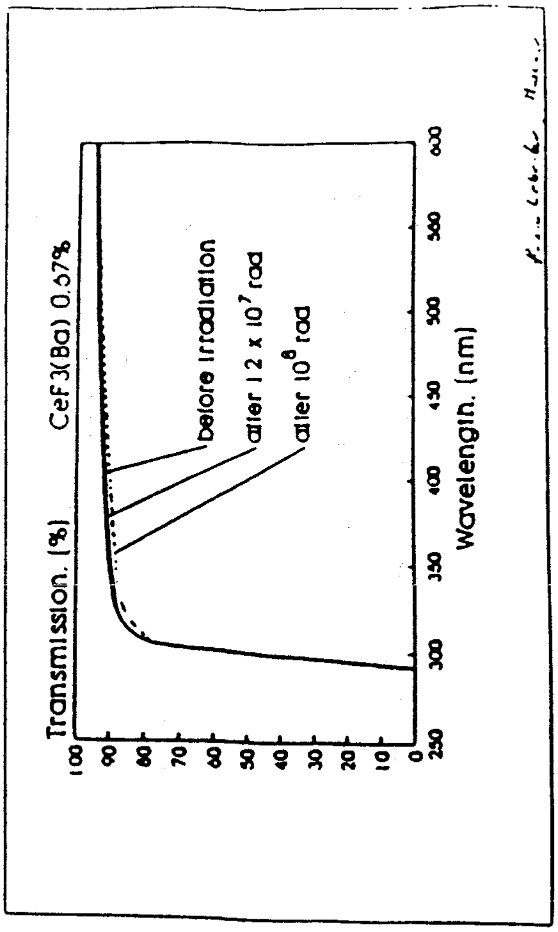
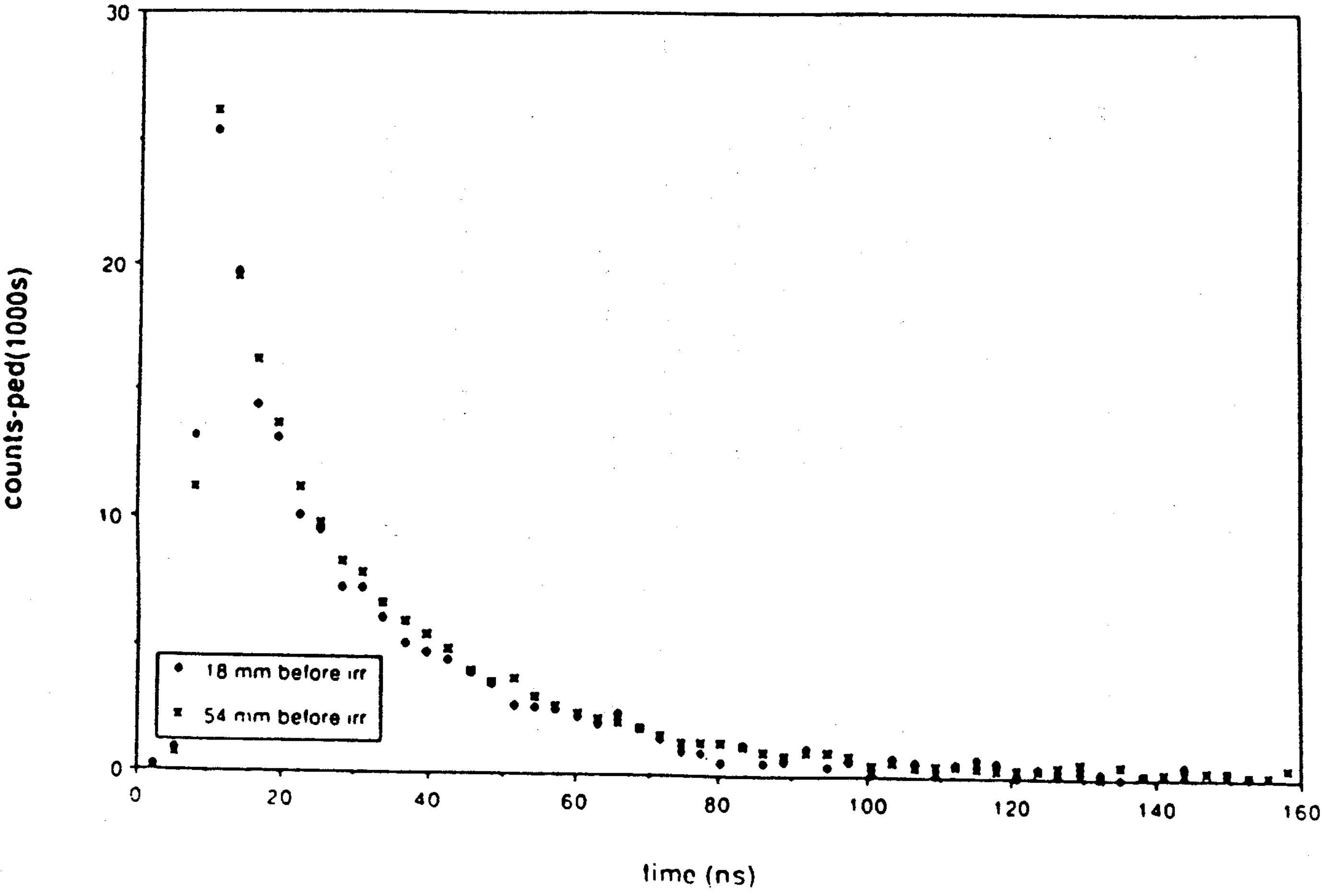


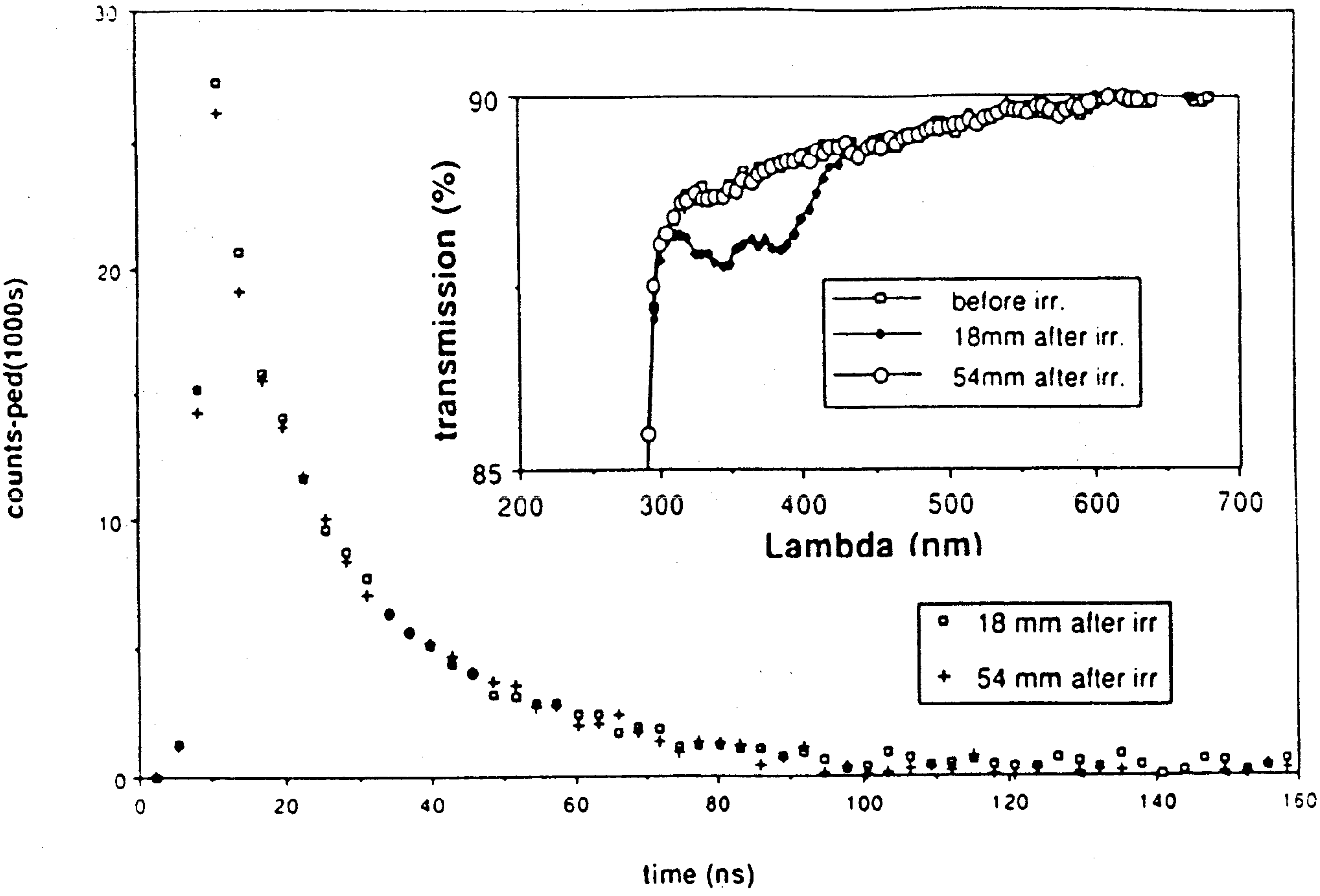
Fig 3: Effect of doping on CeF3 radiation hardness

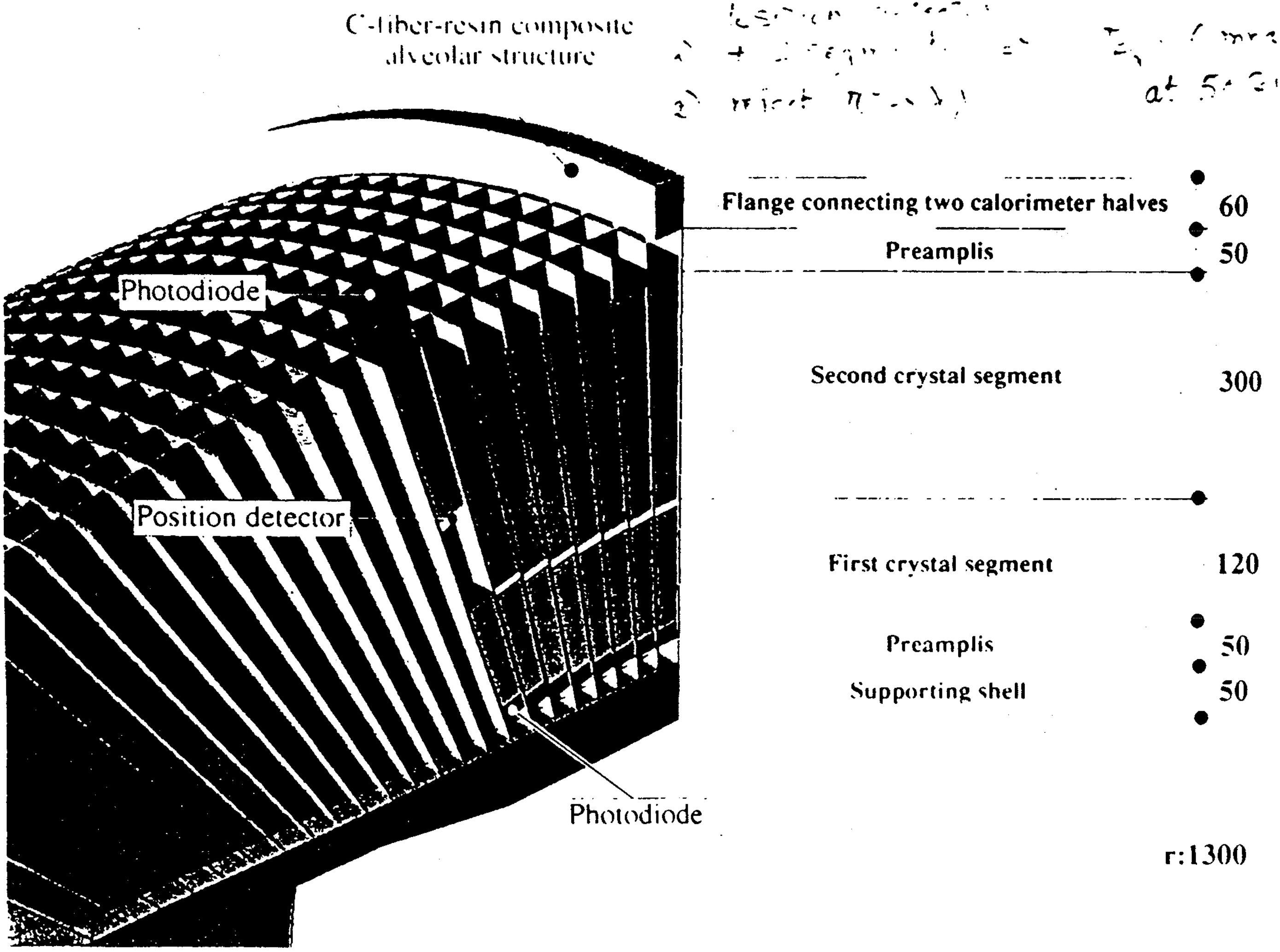
CeF3 (nr.33) 1.3 mm thick sample
decay before 1000 Gy Co-60 (0.1 Mrad)



CeF3 (nr.33) 1.3 mm thick sample
decay after 1000 Gy Co-60

Scintillation properties
not affected (yield, tim





[illegible]
1) + [illegible]
2) [illegible] at 5·[illegible]

Tower to Tower Inter-calibration using $Z^0 \to e^+ e^-$ pairs

$\sigma.B(Z^0 \to e^+ e^-) \approx 1$ nb $|\eta| \leq 2.0$
10 Hz at $L = 10^{34}$ cm^{-2}s^{-1}

Measurement Accuracy

(Tracking + Calorimetry + Bremsstrahlung)

$\sigma(\frac{E}{p}) \approx 0.9\ \%$ at $p_T = 50$ GeV/c $|\eta| = 0$

$\approx 1.2\ \%$ at $p_T = 50$ GeV/c $|\eta| = 1.5$

Efficiencies

Effective running time	0.7	
Trigger/DAQ	0.85	
Electron reconstruction	0.9	
Useful electrons	**0.7**	(Little or no bremstrahlung)
Geometric (Fiducial)	0.5	(Central hit)
Product	0.19	

Running time required for a new set of calibration constants

$\sigma_{intercalibration} = 0.3\ \% = \frac{1.2\%}{\sqrt{n_e}} \Rightarrow n_e = 16$ / tower

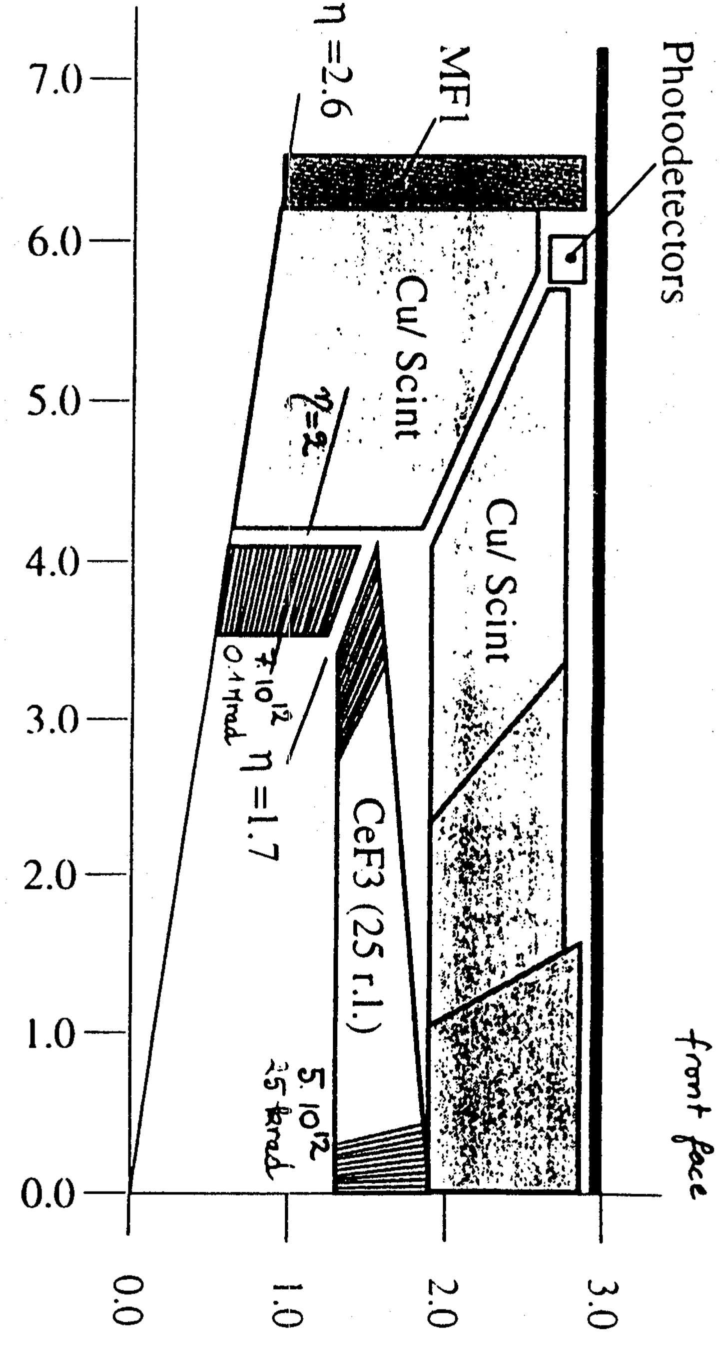
Total $N_e == \frac{4.5.10^4\ 16}{0.19} \approx 3.8\ 10^6$ electrons produced

2.2 days

C.M.S. Calorimetry inside Coil

elm: CeF3 26m3
Had: Cu/ Scintillator

~ 45,000 Crystals
~ 3.5cm x 3.5cm front face



ECAL : Pb / Scintillator Plates

Readout with WLS Fibres running perpendicularly to plates.

Sampling : 72 x 2 mm Pb / 4mm Scint
26 Xo : 44 cm.

Energy Resolution $\frac{\sigma}{E} \approx \frac{8.5\%}{\sqrt{E}} \oplus 1\%$

No. of Photons : 15000 γ / GeV
Si Photodiodes readout possible ?

Lateral Granularity $\Delta\eta \times \Delta\phi = 0.04 \times 0.04$
50 WLS Fibres of $\phi = 1$ mm in each tower

Position Detector

Insert Si Pad Detector at 4 – 5 Xo

Performance in Test Beam (INR + IHEP Russia)

26 Xo Sampling : 60 x 2.4 mm Pb / 3mm Scint

- Energy Resolution $\frac{\sigma}{E} \approx \frac{10\%}{\sqrt{E}}$

No. of Photelectrons : 1200 p.e. / GeV

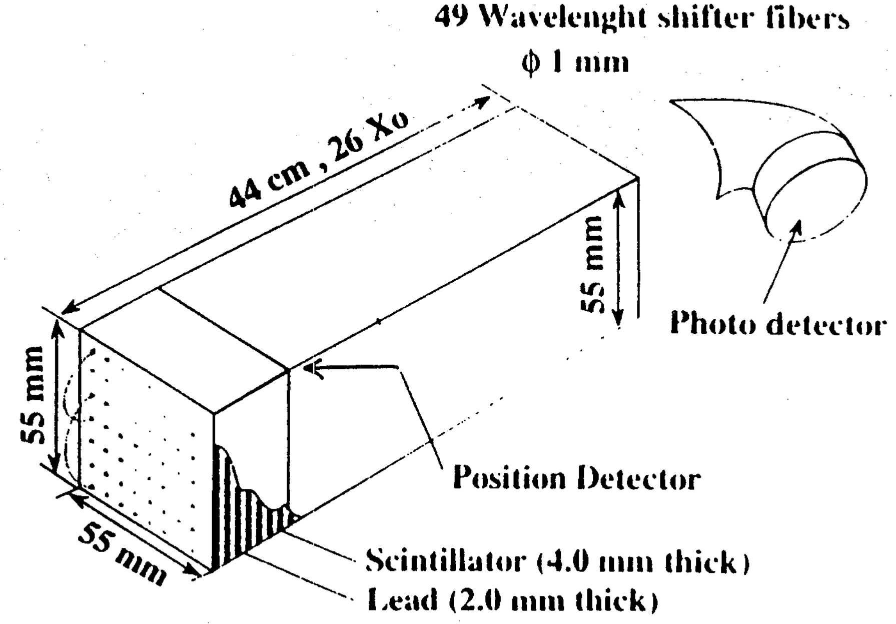
- Spatial Uniformity

Better than 1 % except near edges where it is ≈ 3%

- Position Resolution: $\sigma \approx 2$ mm at 12 GeV.

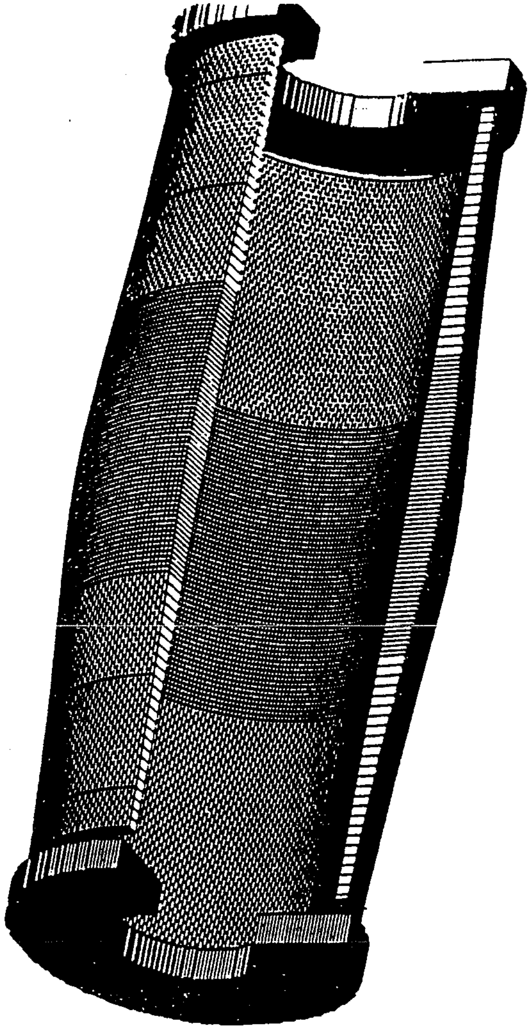
ECAL : Pb / SCINTILLATOR PLATES OPTION

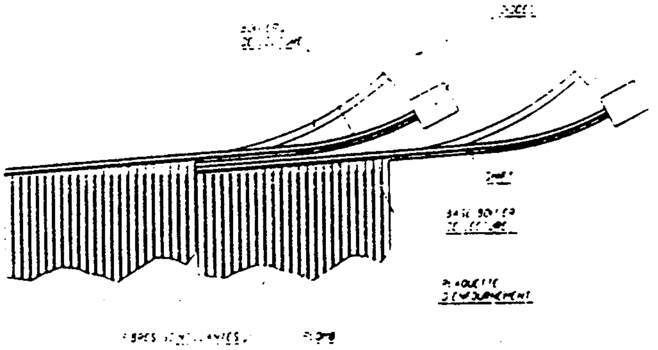
INR MOSCOW
IHEP PROTVINO



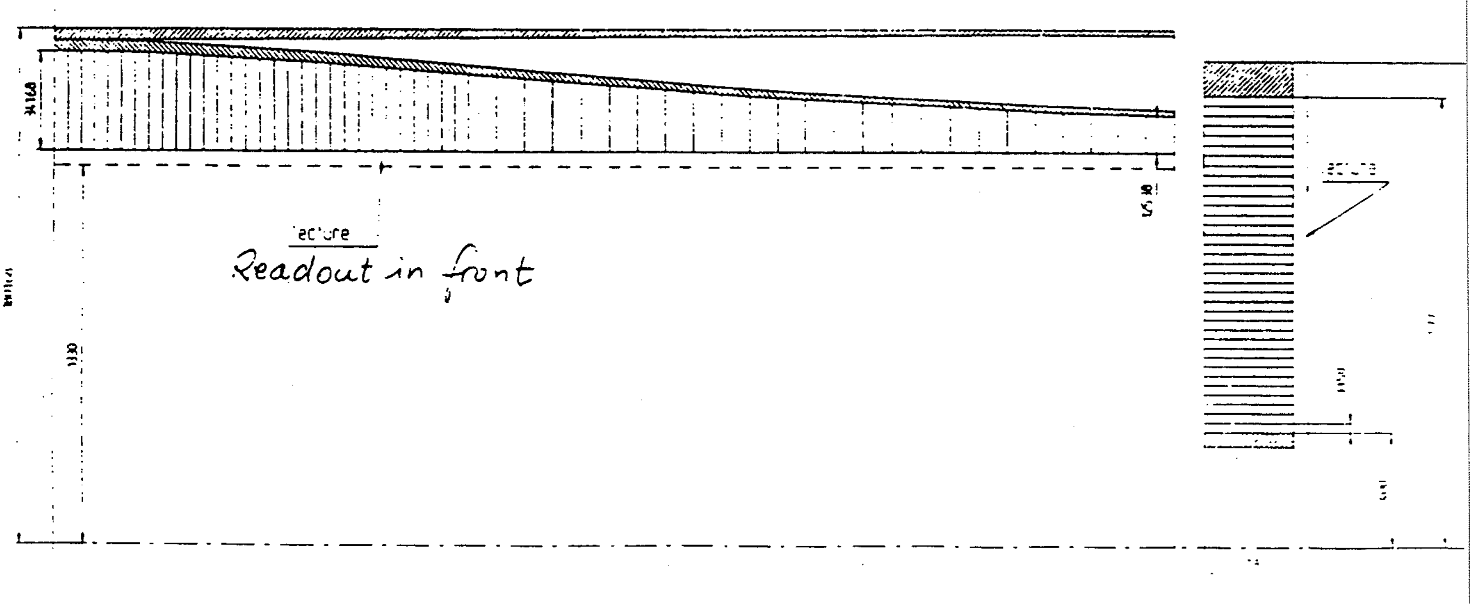
ECAL: Pb/SCINT. FIBRES OPTION

(Ec. Polytechnique, CMS-TN 92-13)





Readout in 4 Tesla?
WLS Plates ⊥ fibres
Photodetector? Pin diode
APD



Readout in front

R&D ON PHOTODETECTORS WORKING IN MAGNETIC FIELD

INTERESTING CANDIDATES (J-M Gaillard, RD1):

- PROXIMITY FOCUSSING HYBRID PM (DEP)

Photocathode + 10 kV gap → Silicon, Gain ~ 3000
Tests reported by LAA

- AVALANCHE PHOTODIODE (APD's, Advanced Photonics, Inc)

Q.E. ~ 100%
insensitive to magnetic fields
rugged, compact, low power consumption

Voltage 2.5 kV, Gain ~ 1000

Required Voltage Stability	~ few volts
Required Temperature Stability	< 1° C
Resolution	50% @ 100 photons 10% @ 1000 photons

ECAL: Pb/SCINT. FIBRES

(Ec. Polytechnique, CMS-TN 92-13)

Readout with WLS plates perpendicular to fibres

- **Sampling:**

1.5 mm fibres, Scint./Pb = 0.75, 30 rad. length

- **Energy Resolution:**

$\sigma/E \leq 10\ \%/\sqrt{E} \oplus 1\ \%$

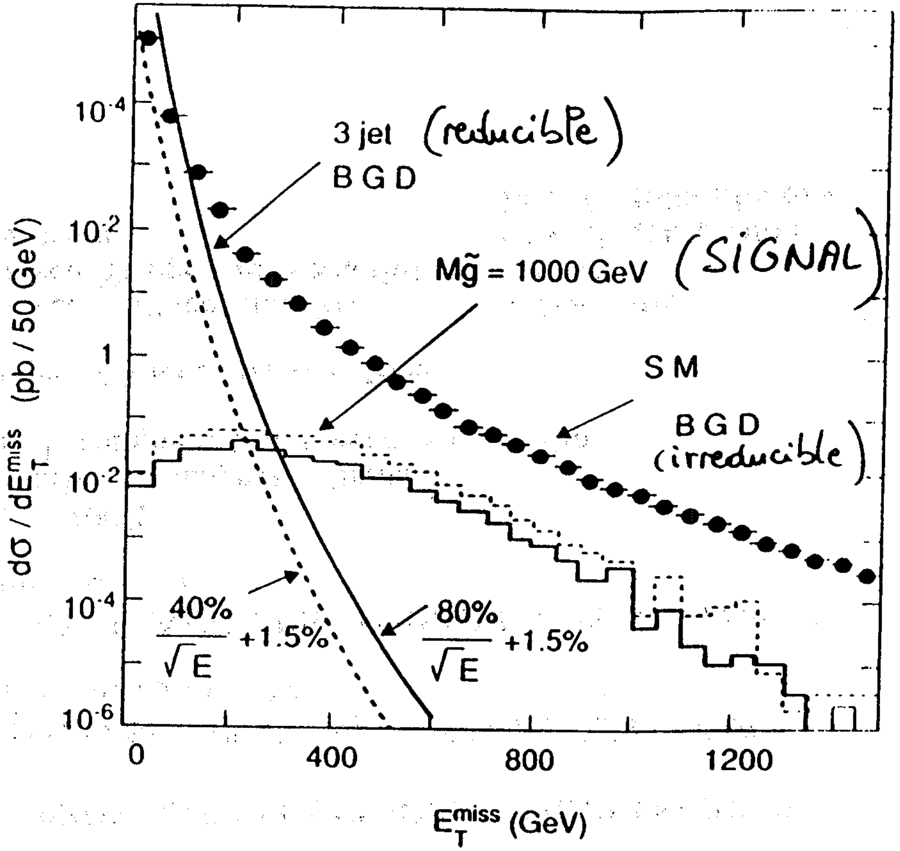
No of Photoelectrons: 1000 p.e./ GeV

- **Lateral Segmentation:**

33x48 mm2 $|\eta| < 0.92$
33x98 mm2 $0.92 < |\eta| < 1.77$

at $\eta = 0$ $\Delta\eta = 0.037$
$\Delta\phi = 0.025$
Projective in ϕ, non projective in η

SUSY GLUINOS $(m_{\tilde{g}} = 1 \text{TeV})$



HADRONIC CALORIMETER

PHYSICS REQUIREMENTS ?

JET ENERGY RESOLUTION

- **limited by Jet Algorithm, fragmentation, magnetic field (specific to CMS)**
- **pile-up at high luminosity:**

$\sigma \sim 4 - 8$ GeV in $\Delta R = 0.4$

- **W, Z → 2 jets reconstruction ?**
  H → ll jet jet ?
  H → lν jet jet ?
- **no point asking ultimate resolution**

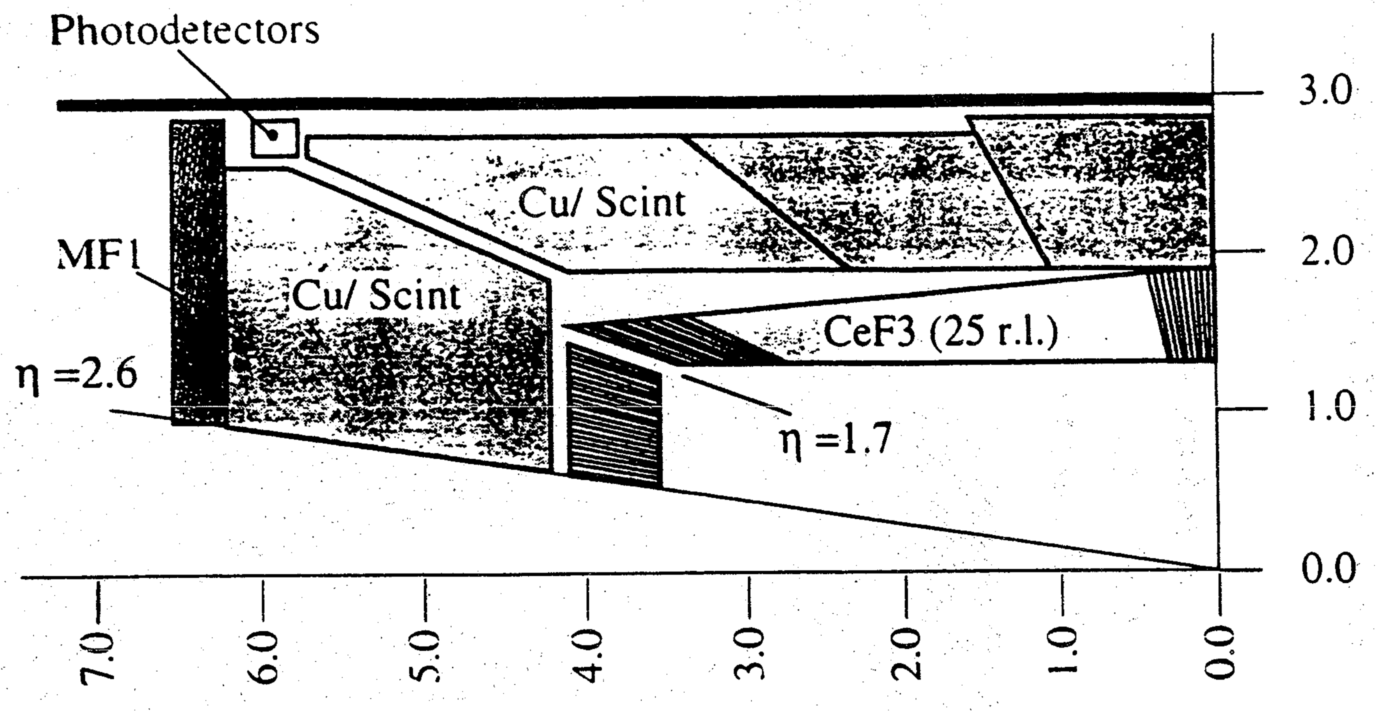
MISSING E_T ← CMS priority

- **hermeticity**
- **forward coverage η max = 4 to 5**
- **80 % / $\sqrt{E}$ good enough**

$t\bar{t}$ → lν jets
gluinos, squarks → jets + E_T miss
H → ll νν

C.M.S. Calorimetry inside Coil

elm: CeF3 26m3
Had: Cu/ Scintillator



HADRONIC CALORIMETER

COPPER/SCINTILLATOR

31mm Cu/4mm Scintillator Plates
+ Embedded WLS Fibres (Ø = 1mm)

BARREL:

η = 0   7.0 λ   (1.6 λ CeF3)   25 Scint layers

η = 1   9.2 λ   30 Scint layers

η = 1.5   10 λ   40 Scint layers

Δη x Δφ = 0.075 x 0.075 (3.5 k pointing towers)

Longitudinal segmentation   3 - fold

ENDCAP:

12λ   (1.6 λ CeF3)   50 Scint layers

Δη x Δφ = 0.0056   (3.5 k pointing towers)

Longitudinal segmentation   3 - 4 fold

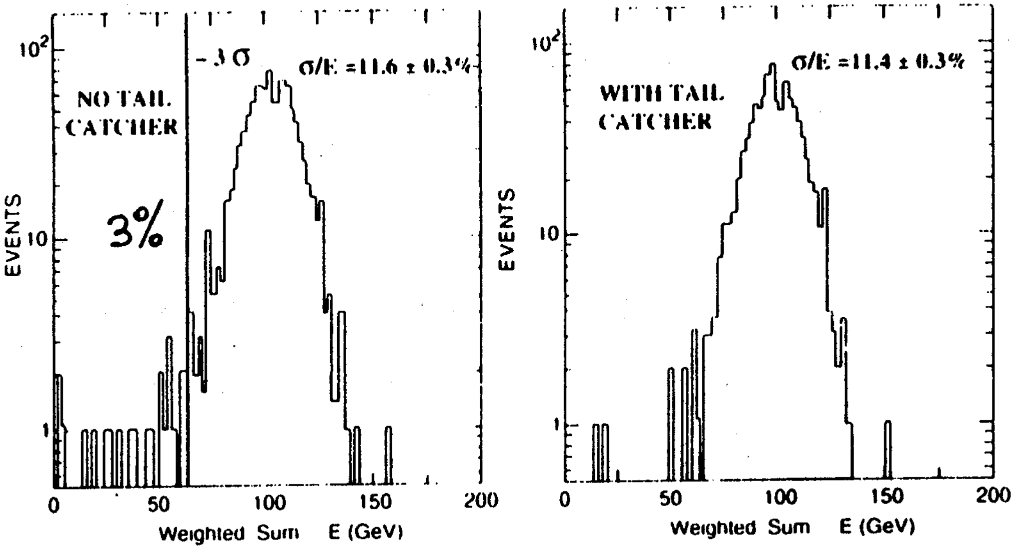
No of Towers   3.5 k

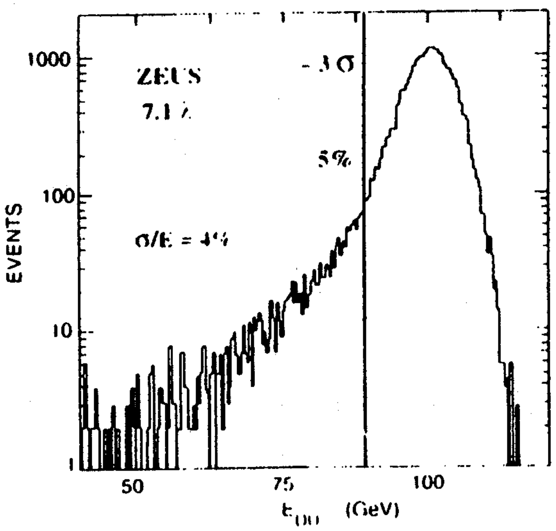
ENERGY RESOLUTION (INCLUDING CeF3):

20 %	at 10 GeV
11 %	at 100 GeV
8.8 %	at 500 GeV

RESOLUTION, CONTAINMENT (100 GeV π^-)

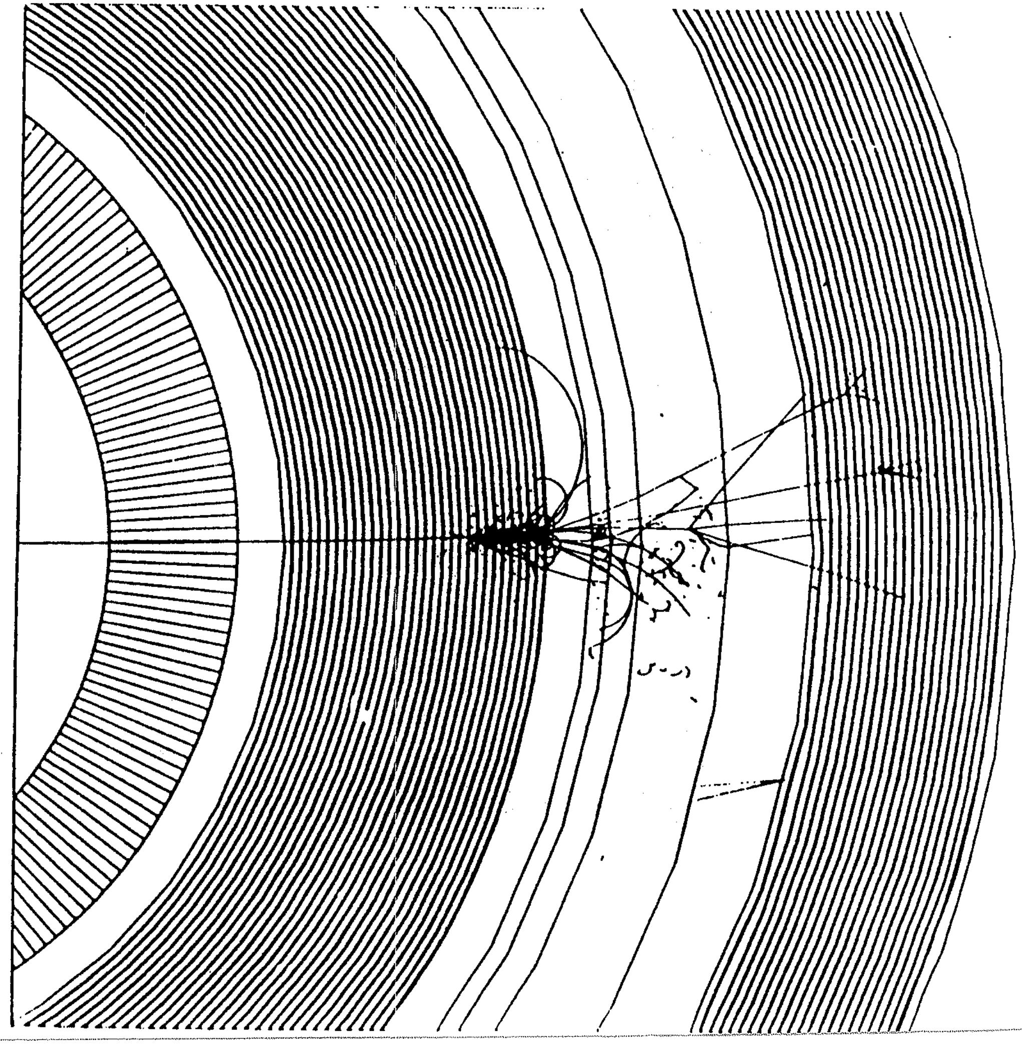
CMS 7 λ AT $\eta = 0$





IS A TAIL CATCHER NECESSARY FOR $|\eta| < 1$?

7 λ before coil (1.6 λ CeF3)
Coil : 1.1 λ
Tail catcher : 1.9 λ



HADRONIC CALORIMETER

COPPER / SILICON

ADVANTAGES OF SILICON

- works in magnetic field
- leads to fast and compact calorimeter
- Radiation hard up to 10^{14} n/cm2
- MIP detection capability
- very high granularity:

  2 cm x 2 cm detector
  longitudinal segmentation

→ TRACKING calorimeter (muons)

DISADVANTAGE :

Large area required ~ 2 000 m2

COST

→ low cost silicon pad production

DUBNA / ELMA (RUSSIA)

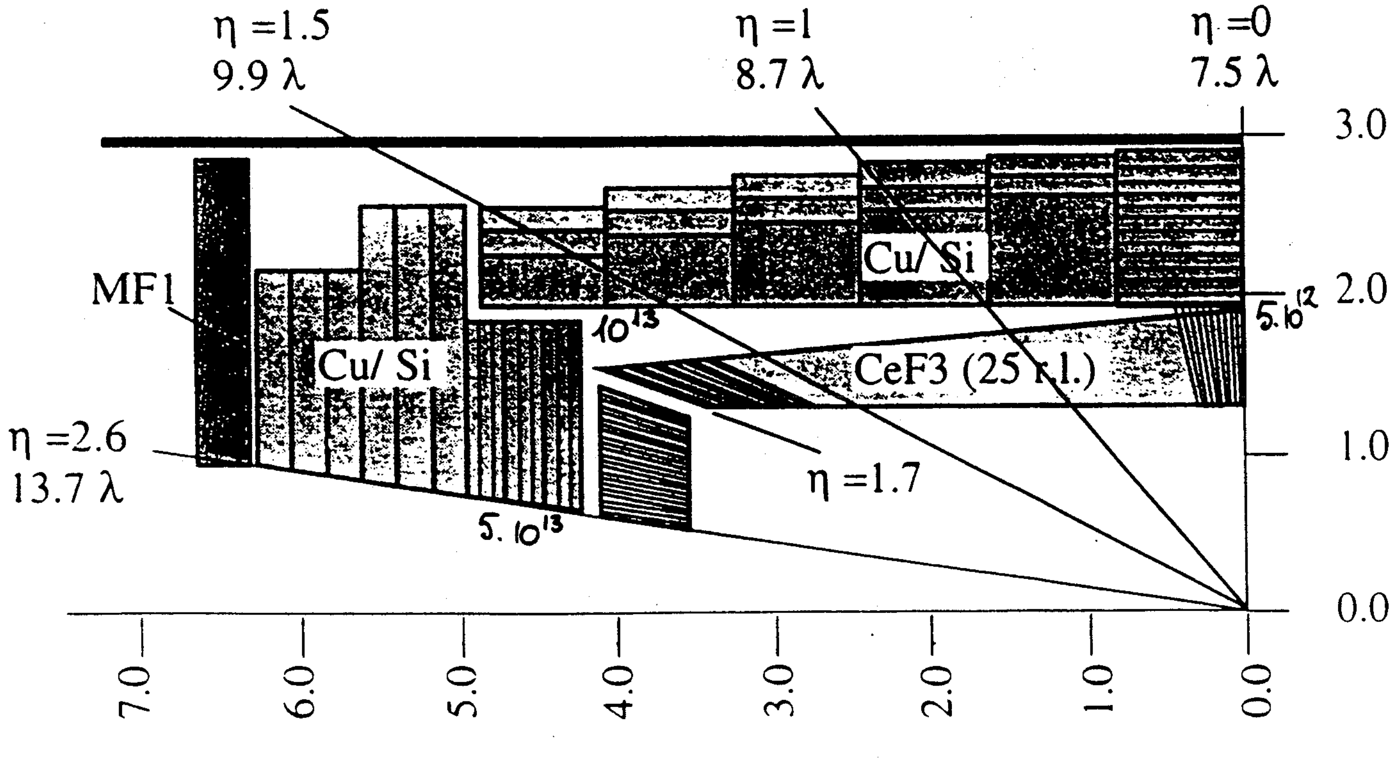
1.2 SF/cm2 0.6 SF/cm2 raw silicon
0.6 SF/cm2 processing

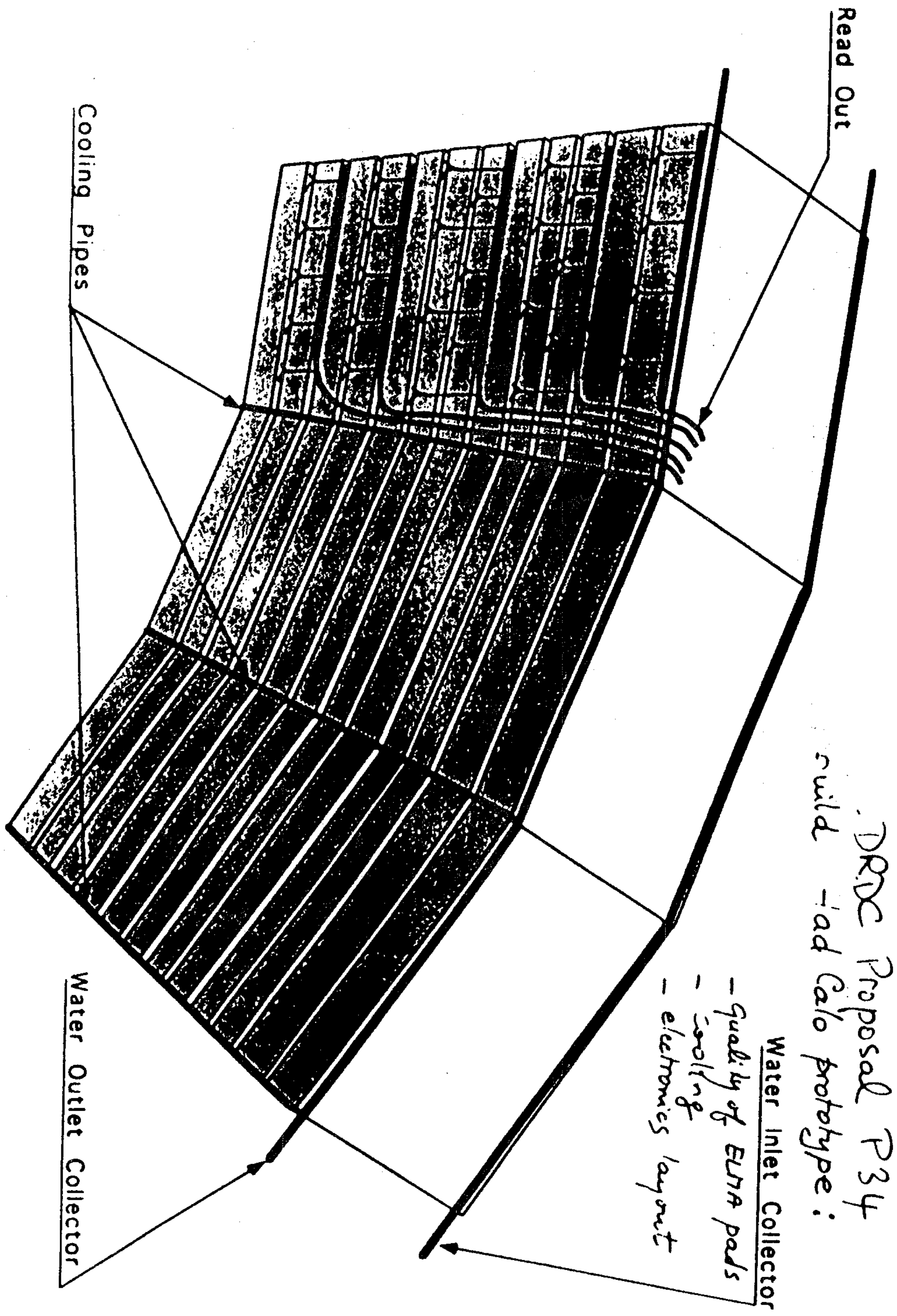
x 10

C.M.S. Calorimetry inside Coil

elm: CeF3 26m3
Had: Cu/ Silicon

2000 m² Silicon pads





. DRDC Proposal P34
build Had Calo prototype:
- quality of ELMA pads
- cooling
- electronics layout

HADRONIC CALORIMETER
COPPER/SILICON

BARREL (1600 m^2 Silicon):

10 layers 69mm Cu/0.4mm Silicon pads 2x2 cm^2
2 layers 100mm Cu/0.4mm Silicon pads 2x2 cm^2
4 pads drive 1 preamplifier

$\eta = 0$ 7.5 λ (1.6 λ CeF3)
$\eta = 1$ 8.7 λ
$\eta = 1.5$ 9.9 λ

Longitudinal segmentation 5 - fold
Total number of preamplifiers : 1M

ENDCAP (400 m^2 Silicon):

9 layers 69mm Cu/0.4mm Silicon pads 2x2 cm^2
6 layers 200mm Cu/0.4mm Silicon pads 2x2 cm^2

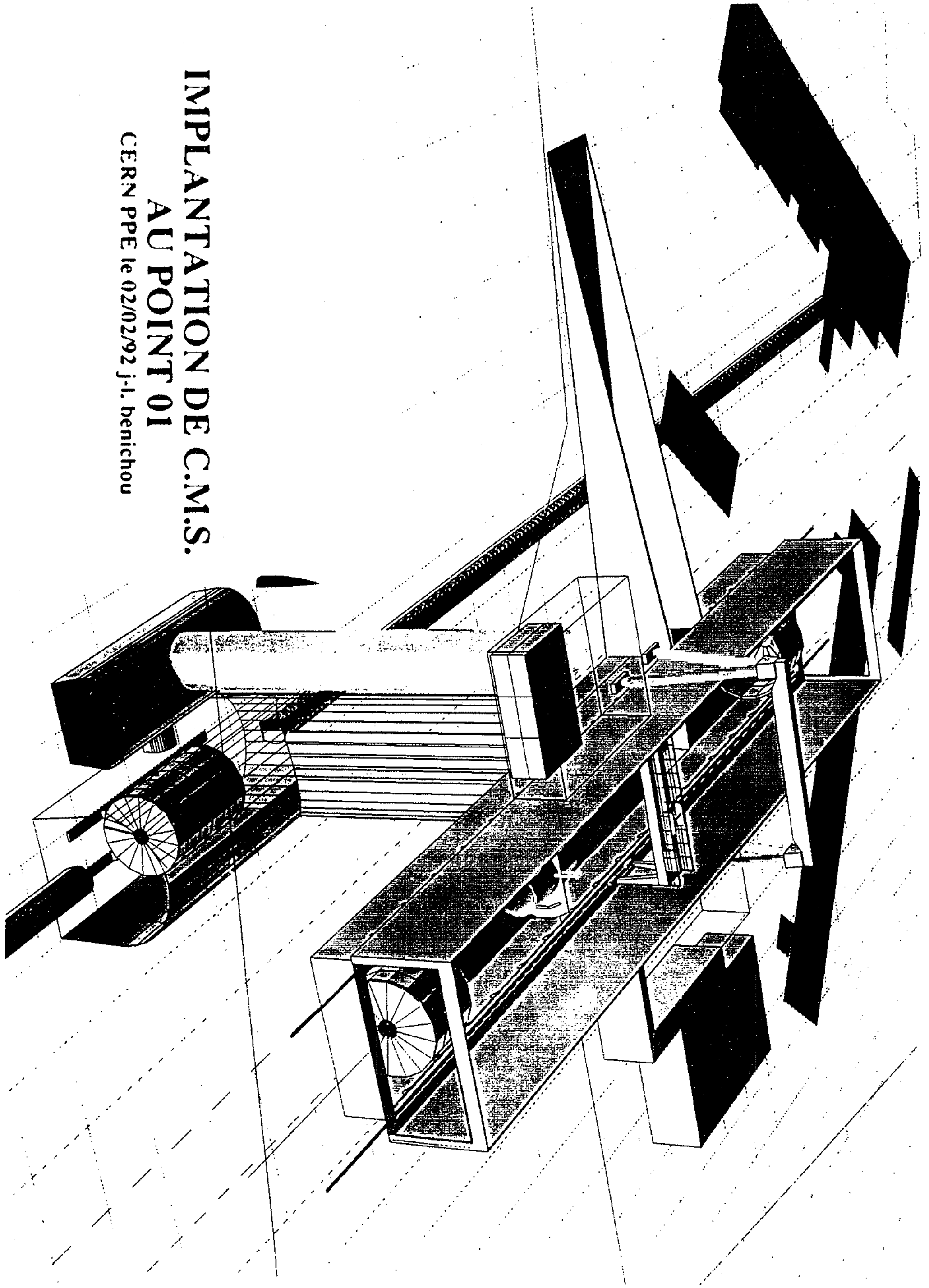
13.7λ (1.6 λ CeF3)

Longitudinal segmentation 9 - fold

Number of readout pads (2x2 cm^2) for μ tracking (6 planes):	0.3M
Total number of preamplifiers:	0.4M

ENERGY RESOLUTION (INCLUDING CeF3):

22.4 %	at 20 GeV
14.5 %	at 100 GeV
10.5 %	at 300 GeV



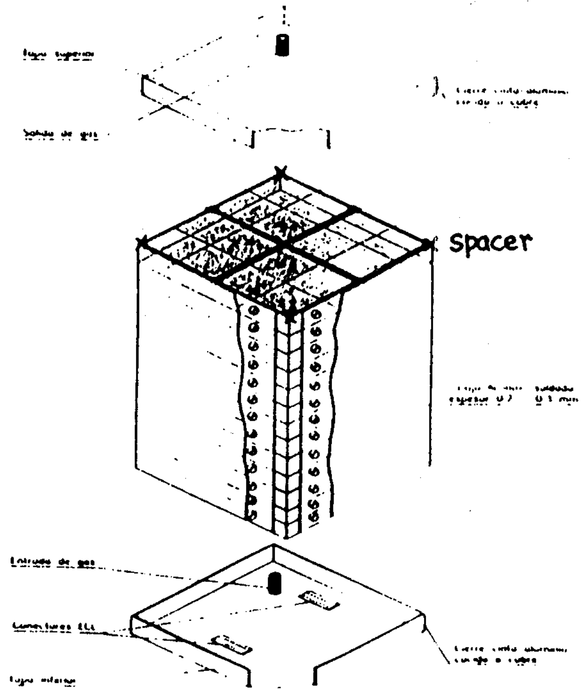
IMPLANTATION DE C.M.S.
AU POINT 01
CERN PPE le 02/02/92 j-l. benichou

VERY FORWARD CALORIMETER

- Fe - Gas sampling calorimeter using PPC's under stud
  (ITEP Moscow, CIEMAT Mad
- Rapidity Coverage $2.6 \leq \eta \leq 5$
- $12 - 14\lambda$ 17 mm Fe / 1mm Gas gap

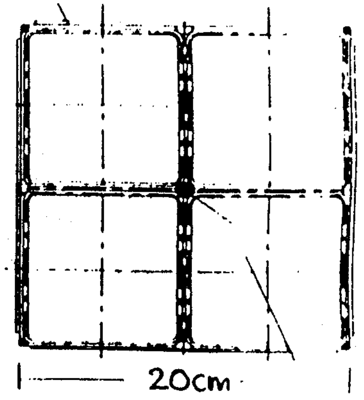
  Exact transverse and longitudinal granularity - under study
- Expected Resolution $\left.\frac{\sigma}{E}\right|_{em} \sim \frac{30\%}{\sqrt{E}}$ $\left.\frac{\sigma}{E}\right|_{Had} \sim \frac{100\%}{\sqrt{E}}$
- Modular construction

  Construct calorimeter by stacking "Bricks"



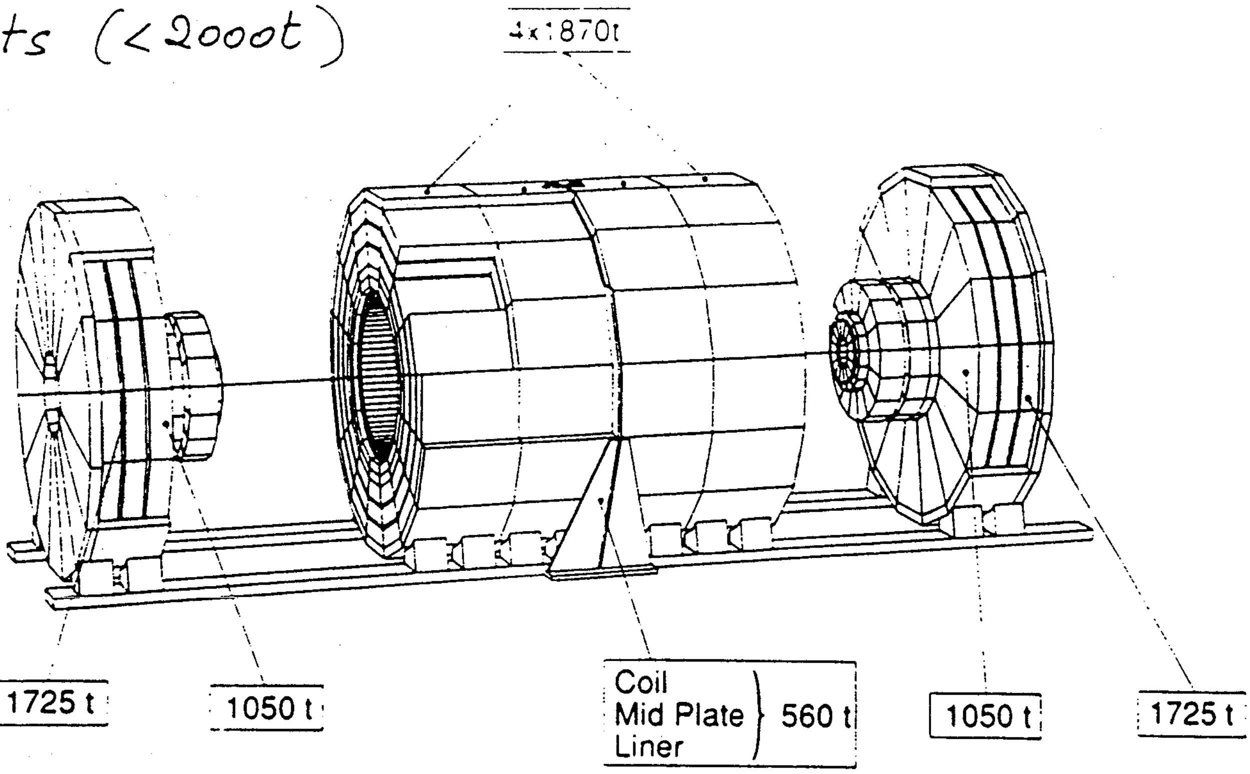
1 Module or "Brick"

Milled Fe Plate covered with chrome plated ceramic



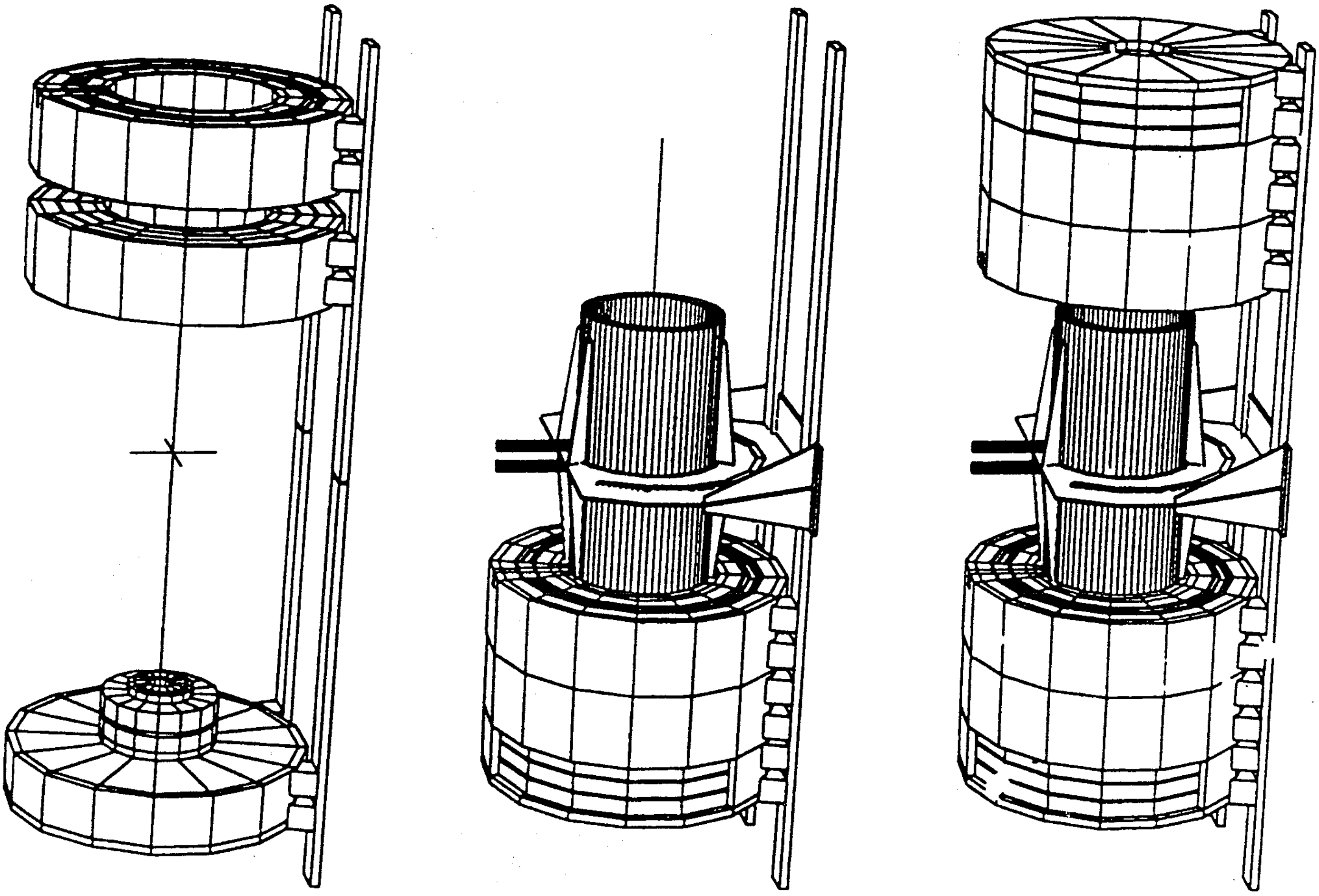
eg. 10x10 cm^2 Towers

9 parts (< 2000t)

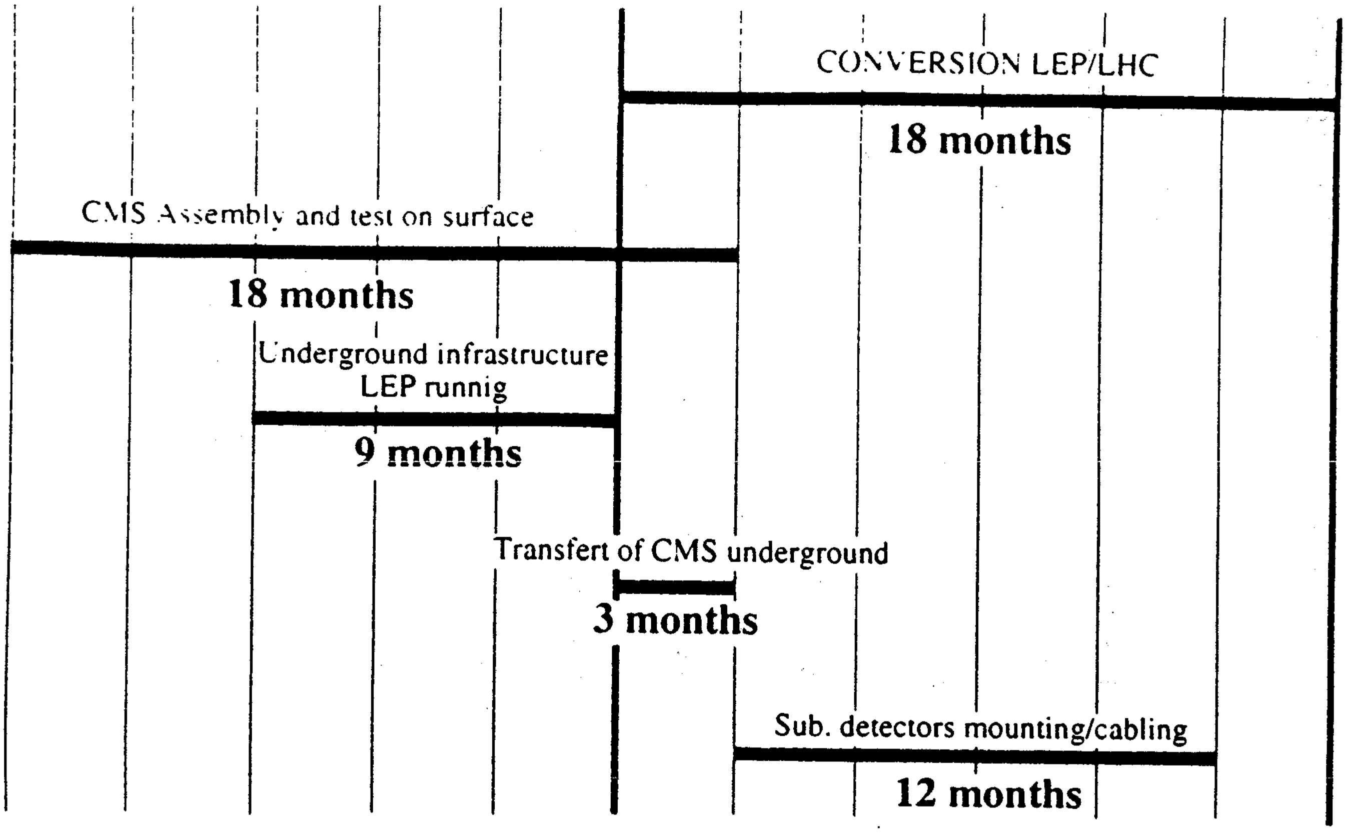


C.M.S. WEIGHT OF MOBILE PARTS

CERN PPE 18-10-91
j-l. bénichou



C.M.S. INSTALLATION PLANNING



CMS COST

Zeroth order estimates :

	(MSF)
Coil	75
Fe yoke	45
ECAL*)	100
HCAL **)	45
TRACKING	50
MUONS	30
DAQ	50
TOTAL	**395**

***) Ecal options.**

Crystals	**100**
Spaghetti	**30**
Scint. + WLS fibres	**20**

****) Hcal options**

Cu/Scint.	**32.5**
Cu/Silicon	**45**

CMS PHYSICS POTENTIALS

- HIGH LUMINOSITY

  VERY PRECISE μ, γ, e DETECTOR
  important to be prepared for SURPRISES!
  HERMETIC HADRON CALORIMETER
  FOR JETS AND MISSING TRANSVERSE ENERGY

- LOW LUMINOSITY

  SI TRACKER MODULAR $\rightarrow \mu$ - VERTEX

  TOP, BEAUTY, TAU'S , CP?

- HEAVY IONS (TALK BY L. RAMELLO)

  DIMUONS J/Ψ, Y, Y', Y"
  LOW P_T MUONS
  - TRIGGER
  - RECONSTRUCTION Δ M < 100 MEV

R&D: BUILD COMPLETE CMS SECTOR $2\pi/16$
AROUND 3 T EHS MAGNET IN H2 BEAM

TEST TRACKING, CALORIMETRY, MUONS
WITH 3 TESLA

CMS WORKING GROUPS

	CONVENORS
MUONS	E. Radermacher
COIL	J.C. Lottin H Desportes
MAGNET, INSTALLATION	A. Hervé
TRACKING	T. Meyer, M. Pimia
CALORIMETRY	T. Virdee
HEAVY IONS	L. Ramello
PHYSICS SIMULATIONS	H. Plothow-Besch D. Denegri
OFFLINE SOFTWARE	M. Pimia V. Karimaki
DAQ, TRIGGER	F. Szoncso S. Centro

AVAILABLE ON DISPLAY :

- Transparencies CMS Meetings 1 to 7
- CMS Technical notes
- Most important Plots

EVIAN, 5 March 1992

CMS

A Compact Solenoidal Detector for LHC

Expression of Interest

Institut für Hochenergiephysik der Österreichischen Akademie der Wissenschaften, *Vienna*, AUSTRIA
Université Libre, *Brussels*, BELGIUM
Vrije Univ., *Brussels*, BELGIUM
Université Catholique de Louvain, *Louvain-la-Neuve*, BELGIUM
Univ. Instelling Antwerpen, *Wilrijk*, BELGIUM
Univ. de l'Etat Mons, *Mons*, BELGIUM
Inst. of Physics, Acad. Sci. Byelorussia, *Minsk*, BYELORUSSIA
Research Institute for Nuclear Problems, Byelorussian State University, *Minsk*, BYELORUSSIA
Institute of Nuclear Research & Nuclear Energy, *Sofia*, BULGARIA
University of Sofia, *Sofia*, BULGARIA
Institute of Nuclear Physics, Czechoslovak Acad. Sci., Rez, *Praha*, CZECHOSLOVAKIA
Inst. of Chemistry and Physics, *Tallinn*, ESTONIA
Research Institute for High Energy Physics (SEFT), Univ. of Helsinki, *Helsinki*, FINLAND
Physics Department, Univ. of Helsinki, *Helsinki*, FINLAND
Univ. of Technology, *Helsinki*, FINLAND
Univ. of Technology, *Tampere*, FINLAND
Physics Department, Åbo Akademi, *Turku*, FINLAND
Laboratoire de Physique des Particules (LAPP), *Annecy-le-Vieux*, FRANCE
Institut de Physique Nucléaire, *Lyon*, FRANCE
Ecole Polytechnique, *Palaiseau*, FRANCE
DAPNIA, Centre d'etudes nucléaires, *Saclay*, FRANCE
Institute of Physics Academy of Science, *Tbilisi*, GEORGIA
Institute of High Energy Physics, Tbilisi State University, *Tbilisi*, GEORGIA
Universität Aachen, *Aachen*, GERMANY
Universität Kiel, *Kiel*, GERMANY
University of Ioannina, *Ioannina*, GREECE
Nucl. Research Center Demokritos, Attiki, *Athens*, GREECE
University of Athens, *Athens*, GREECE
Central Research Institute for Physics, Hung. Acad. Sci., *Budapest*, HUNGARY
Dipartimento di Fisica dell'Università and Sezione dell'INFN, *Padova*, ITALY
Dipartimento di Fisica and INFN, Università de L'Aquila, *Coppito (AQ)*, ITALY
Dipartimento di Fisica dell'Università and Sezione dell'INFN, *Genova*, ITALY
Inst. of Experimental Physics, University of Warsaw, *Warszawa*, POLAND
Institute for Nuclear Studies, *Warszawa*, POLAND
LIP, *Lisbon*, PORTUGAL
JINR, *Dubna*, RUSSIA
ITEP, *Moscow*, RUSSIA
INR, *Moscow*, RUSSIA
MSU, *Moscow*, RUSSIA
Lebedev Phusics Institue, *Moscow*, RUSSIA
IHEP, *Protvino*, RUSSIA
CIEMAT, *Madrid*, SPAIN
CERN, *Geneva*, SWITZERLAND
Imperial College, *London*, UK
Rutherford Appleton Laboratory, *Didcot*, UK
Univ. of California, *Davis*, USA
Univ. of California, *Riverside*, USA
Univ. of California, *Los Angeles*, USA
Institute of Nuclear Physics, *Taskhent*, UZBEKISTAN

49 institutions
including 20 from non member states

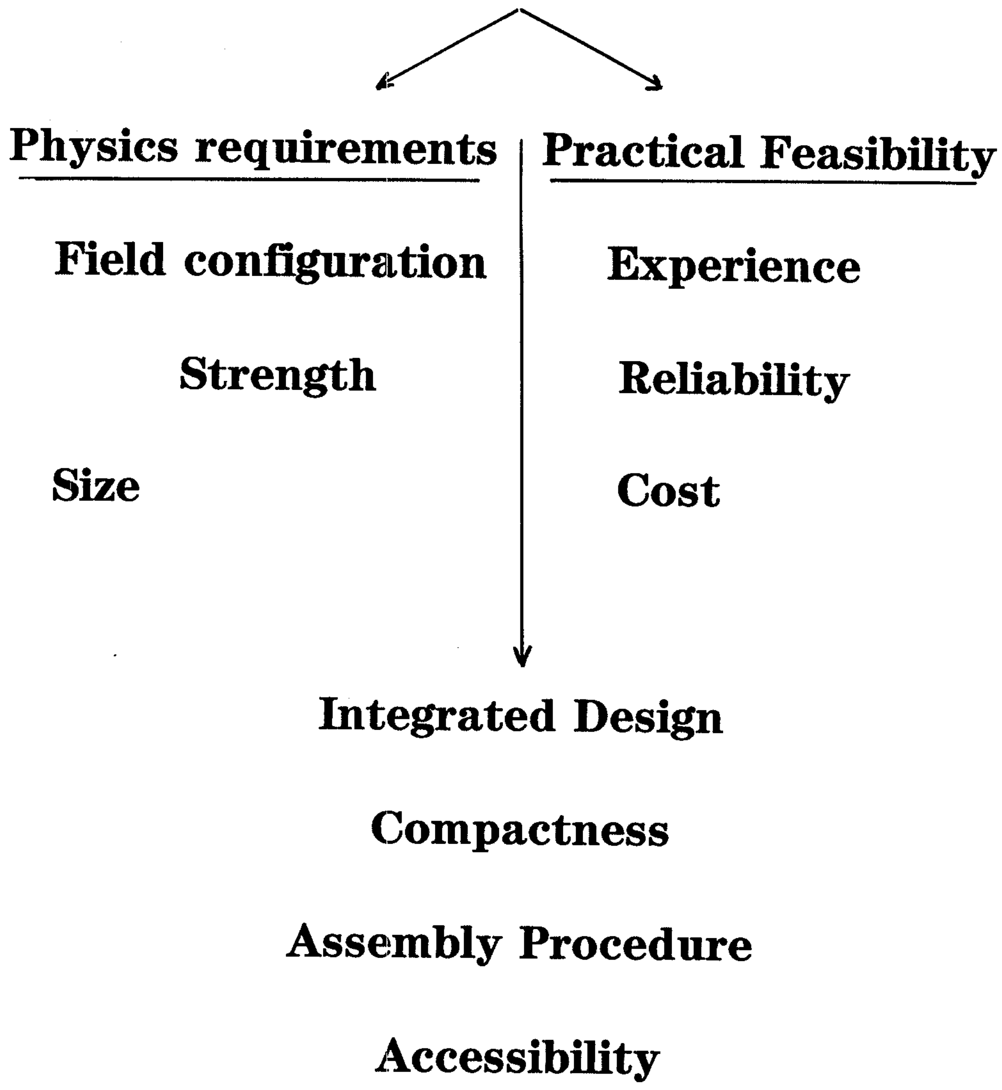
CONCEPTUAL DESIGN OF THE CMS
4 TESLA SOLENOID

----------oooooOOooooo----------

J.M. BAZE, H. DESPORTES, R. DUTHIL, C. LESMOND,
J.C. LOTTIN, Y. PABOT

CEA - Saclay - DAPNIA / STCM

DESIGN APPROACH



Physics requirements

Field configuration

Strength

Size

Practical Feasibility

Experience

Reliability

Cost

Integrated Design

Compactness

Assembly Procedure

Accessibility

BASIC PARAMETERS

<u>Solenoidal</u> Field
- Physics choice
- Good experience

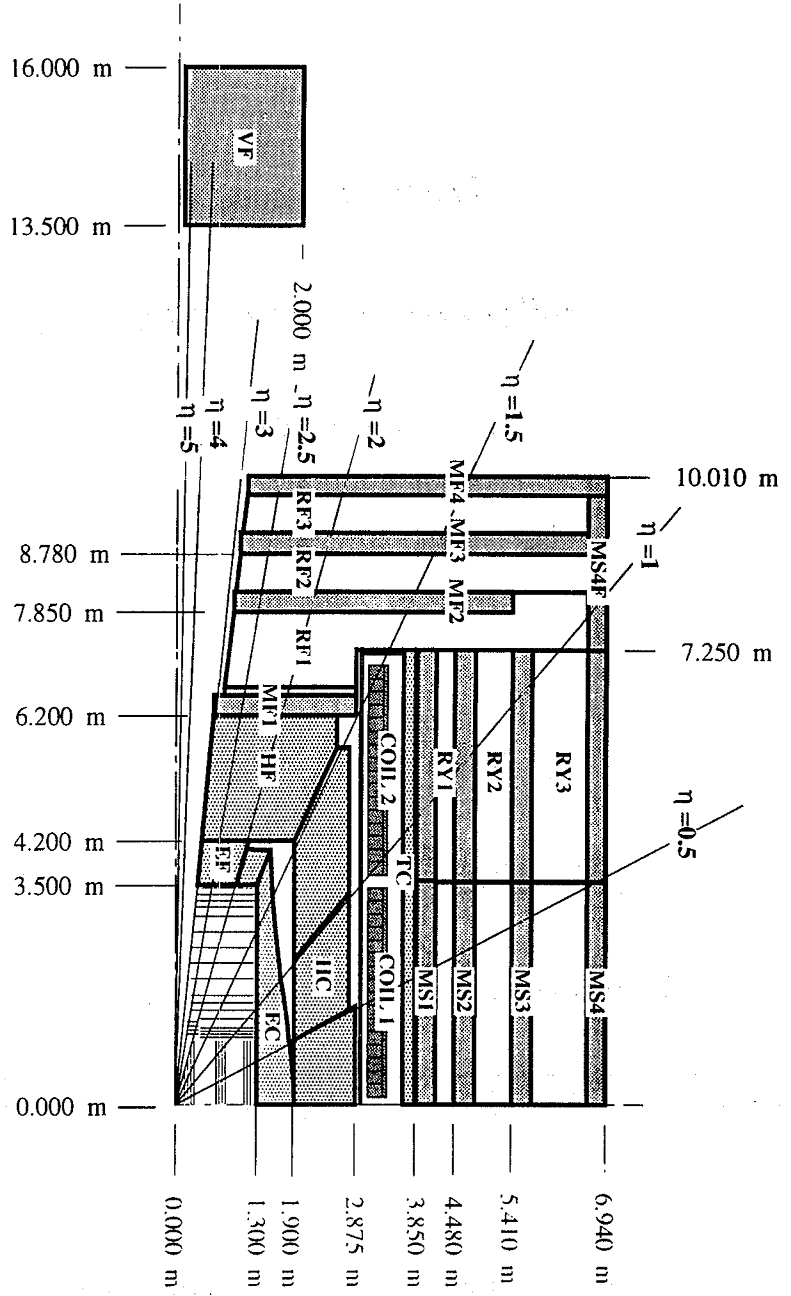
Central field → <u>4 T</u>
- High BdL
- Flux to saturate the Yoke (1.9 T)

Free Bore → <u>5.9 m</u>
- Transport limitation

Length → <u>14.4 m</u>

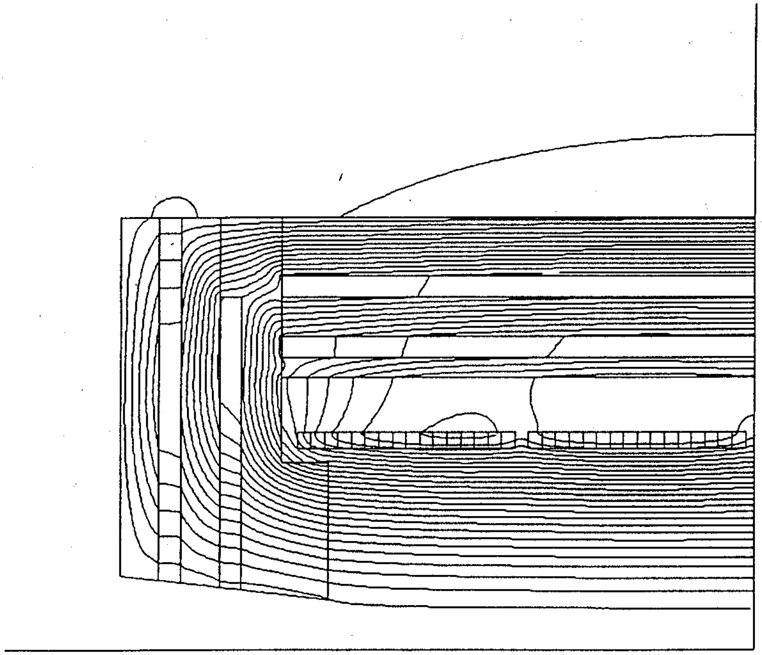
Radial thickness → <u>0.7 m</u>

<u>Central plate</u> supporting structure



C.M.S. version 07-B
CERN PPE 16-12-91
jl bénichou

CONCEPT GUIDELINES



Use available experience :

ALEPH/DELPHI Concepts

- **Alu-stabilized conductor**
- **Indirect cooling**
- **Inner winding (1 layer)**

But increased parameters

Stored energy	**x 20**
Forces	**x 10**
AT/length	**x 3**

- **Increase operating current**
- **Reduce overall current density**
- **Increase the number of layers**
- **Use a re-inforced conductor**
- **Special care**
  electrical insulation
  conductor fabrication (control)
  winding and impregnation
  mechanical design → stability

COIL CHARACTERISTICS

	CMS	ALEPH
Central field (T)	4	1.5
Magnetic length (M)	14	7
Free Bore (M)	5.9	5
Amp x turns (10^6)	46.5	9.5
Stored energy (MJ)	2 800	136
Axial force (t)	7 400	640
Radial pressure (Atm)	64	9
Total weight (t)	450	65
Operating current (A)	20 000	5 000
Number of sections	4	2
N layers per section	4	1
Conductor size (mm^2)	61 x 22.3	35 x 3.6
Type	Reinforced	Soft
Current density (A/mm^2)	14.7	40.
Dump time constant (s)	285	110
Static heat load at 4.5K (W)	400	100

CONDUCTOR DESIGN

Rated current 20 000 A

Peak field 4.6 T

COMPOSITION	*Content*
- Sc cable (NbTi)	4.5%
21 strands ϕ 1.9 mm	
Cu/Sc 1.4	
- Pure Alu (RRR = 200)	30%
- Alu-Alloy	65%

DESIGN GOALS

- Stability margin
  - $J/Jc = 30\%$ at 4.6 T
  - $Tc = 6.5$ K $\Delta H = 2500$ J/m^3
- Protection
  - Hot spot temperature 90 K
- Mechanical reinforcement
  - strain < 0.15%
  - Shear stress < 0.5 Kg/mm^2

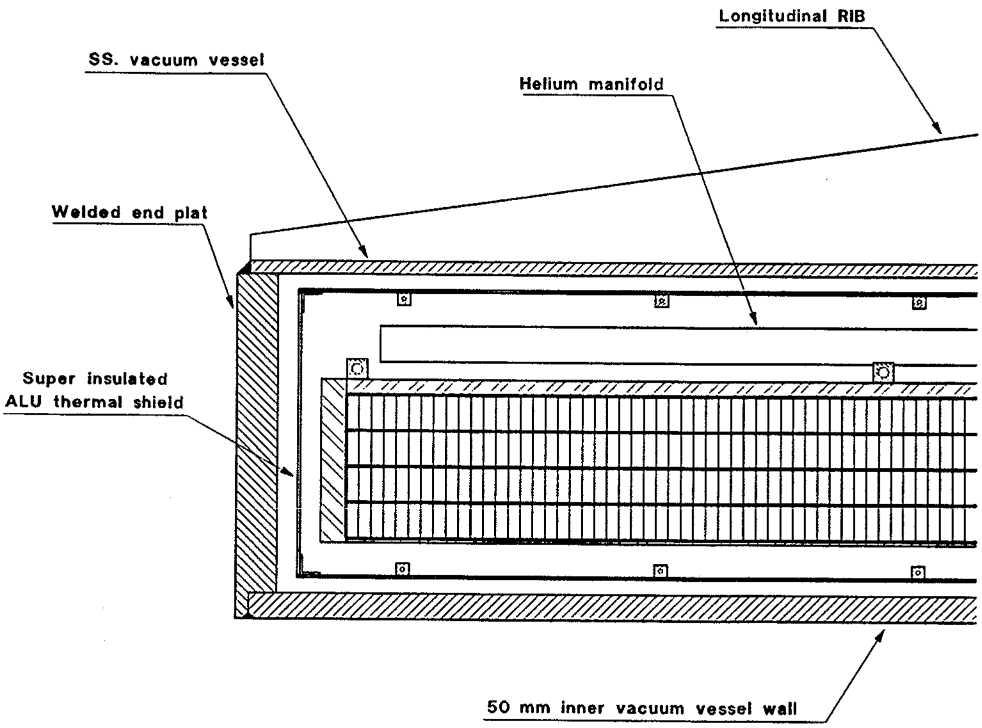
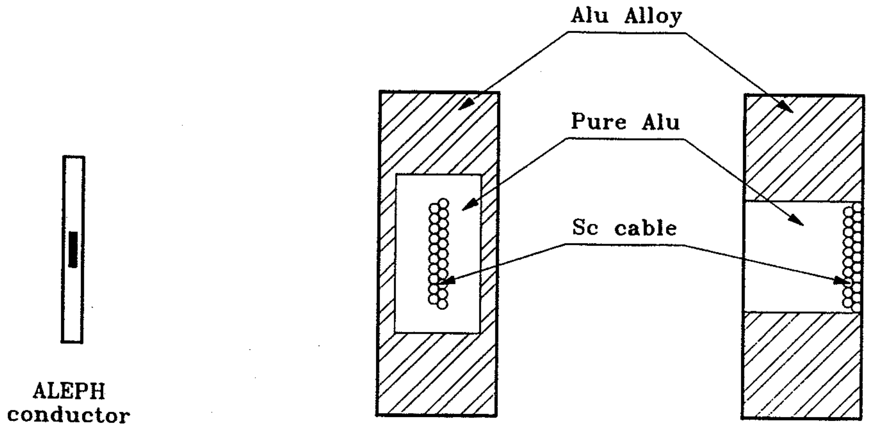


Fig.4 Coil end cross section

CMS CONDUCTOR



ALEPH conductor

Possible schemes
for CMS conductor

Assembly by double co-extrusion
or soft soldering

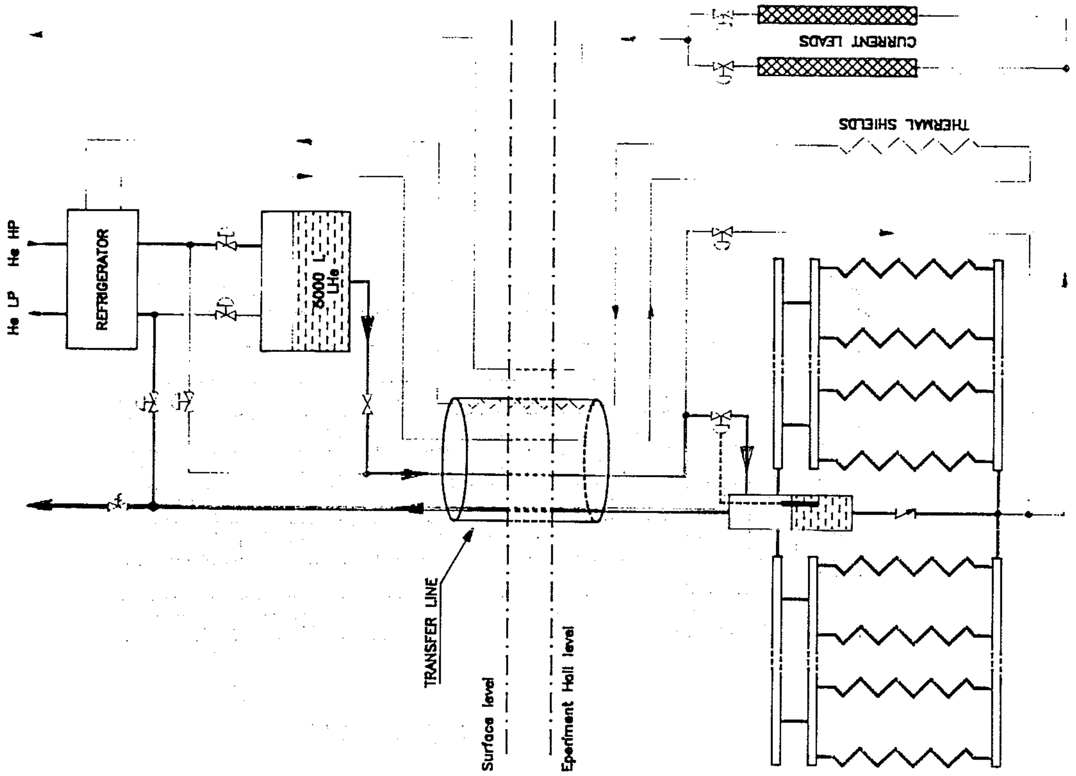


Fig. 9 Refrigeration Helium flow chart

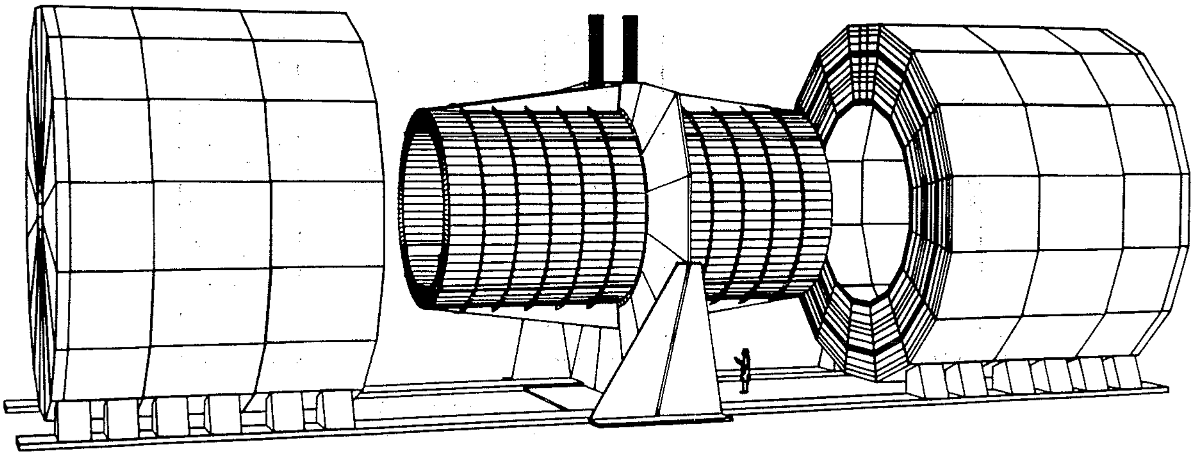


Fig. 3 CMS Detector with barrels in open position

PARTICULAR DESIGN ASPECTS

- Protection - Dump resistor scheme
  - Quench evolution dominated by
    - Quench back effect
    - Hot spot → 90 K
    - E/M = 13.3 kJ/kg

- Stability
  - Enthalpy margin
  - 3.3 Joule per meter length
  - (0.5 for ALEPH)
  - + Heat diffusion
  - Small mechanical disturbances

- Stress analysis
  - 3D finite element code CASTEM 2000

- Winding and fabrication techniques
  - Based on experience
  - Engineering development

CONCLUSIONS

Conceptual design

Based on existing experience

No hazardous extrapolation

Feasibility well understood

Required development

- Conductor industrial fabrication

- Stability complete analysis
  experimental back up

- Winding / Impregnation techniques
  Modelling

LHC

Expression of Interest

EAGLE : Experiment for Accurate Gamma, Lepton and Energy measurements

P. Jenni (CERN)

EAGLE

Experiment for Accurate Gamma, Lepton and Energy Measurements

Introduction

Global detector concept

Calorimetry

Inner detector

Muon measurement

Trigger and DAQ

Muon toroid and installation

Physics performance

Evian 6 March 1992

EXPERIMENT FOR ACCURATE GAMMA,
LEPTON AND ENERGY MEASUREMENTS

EAGLE

The EAGLE Collaboration proposes a detector concept aiming to exploit the full discovery potential of LHC right from its start up. The detector optimization is guided by physics issues such as sensitivity to the largest possible Higgs mass range, detailed studies of top quark decays, Supersymmetry searches, and sensitivity to large compositeness scales. The ability to cope with a broad variety of physics examples also demonstrates the detector's potential for unexpected new physics.

The primary goal of the experiment is to operate at the nominal high pp luminosity of 1.7 10^{34} $cm^{-2}s^{-1}$ with a balanced approach to electron, gamma, muon, jet and missing transverse energy signatures so that different final states will be used to corroborate possible new physics signals. In addition, during initial lower luminosity running, and to as high a luminosity as practicable, the experiment will address more complex signatures including tau detection and heavy flavour tags. These studies will allow measurements such as an accurate determination of the top quark mass, searches for charged Higgs to tau decays and pseudoscalar SUSY Higgs decays to tau pairs.

The main elements of the EAGLE detector concept are:

- a powerful inner detector in a 2T central superconducting solenoidal field which will provide accurate momentum measurements over a large rapidity span ($-2.5 < \eta < 2.5$) for isolated leptons, and enhance efficiently the electron identification,
- high quality electromagnetic sampling calorimetry combined with fine granularity preshower detection for electron and photon measurements,
- good and hermetic hadron calorimetry for jet and missing transverse energy measurements ($-5 < \eta < 5$),
- a warm iron toroid muon spectrometer with large acceptance ($-3 < \eta < 3$) for muon identification and stand-alone momentum measurement capability,
- a high precision vertex detector for (initial) lower luminosity operation,
- a modular and flexible trigger, data acquisition and analysis architecture.

The leading options for different regions of the inner detector include combinations of silicon micro strip and pad detectors, micro strip gas counters and transition radiation tracking. Scintillating fibres and GaAs micro strip detectors are also being considered. Both liquid argon (LAr Accordion) and scintillating fibre electromagnetic calorimetry are under study, followed by LAr or scintillator hadron calorimetry (fibres or tiles). Liquid scintillator or high pressure gas calorimeters are foreseen to cover the very forward regions. The following muon detectors are under evaluation: drift and cathode readout chambers for precision measurements and resistive plate chambers for triggering.

The final choice of the technologies for the various detector components will only be made when the outcome of a broad range of R+D projects, simulation studies and conceptual engineering designs is known. These efforts are presently being vigorously pursued.

EAGLE Collaboration

Alberta, Alma Ata, LAPP Annecy, Athens,
NTU Athens, Bern, Birmingham, Bratislava,
British Columbia, Cambridge, CERN,
Clermont-Ferrand, NBI Copenhagen,
Cosenza, INP Cracow, NCSR Demokritos,
Dortmund, Frascati, Geneva, Glasgow,
ISN Grenoble, Hamburg, Helsinki, Kosice,
Lancaster, Lisbon, Liverpool, QMW London,
RHBNC London, UC London, Lund,
Manchester, CPPM Marseille, Melbourne,
Milano, Montreal, ITEP Moscow,
Lebedev Moscow, MPEI Moscow, Naples,
Nijmegen, NIKHEF (Amsterdam, Nijmegen),
LAL Orsay, Oslo, Oxford, Paris VI, Pavia,
Pisa, Prague, CSAV Prague, IHEP Protvino,
COPPE Rio de Janeiro, Rome I and II,
Rutherford Appleton Laboratory, Saclay,
NPI St. Petersburg, Stockholm,
MSI Stockholm, Technion Haifa, Uppsala,
Victoria, Vienna, Weizmann Rehovot

Also participating but not yet committed:

IPNT Cracow, ATOMKI Debrecen,
Heidelberg, Siegen, Sydney

EAGLE presentation Evian 6-3-1992

Physics goals

Exploratory pp physics to cover the full discovery potential of the LHC

examples:

- ***sensitivity to the largest possible Higgs mass range***
- ***detailed studies of top quark mass and decays***
- ***Standard Model studies (gauge boson couplings)***
- ***Supersymmetry searches***
- ***sensitivity to large compositeness scales***

Search for unexpected new physics

Ready to do physics right from the start-up of LHC at one of its nominal high luminosity regions
($1.7\ 10^{34}$ cm^{-2}s^{-1})

Examples of physics signatures

Higgs searches:

$H \to \gamma\gamma$ (possibly $H \to \gamma Z$, $Z \to l^+l^-$ with $l^\pm = e^\pm$ or $\mu^\pm$)
from $pp \to H+X$ or $t\bar{t}H$, WH, ZH with e or μ tags

$H \to ZZ^* \to eeee$ or $ee\mu\mu$ or $\mu\mu\mu\mu$
$H \to ZZ \to$ as above
$\to ee\nu\bar{\nu}$ or $\mu\mu\nu\bar{\nu}$
$\to$ ee jet+jet or $\mu\mu$ jet+jet

$H \to WW \to l^+\nu l^-\nu$ or $l^\pm\nu$ jet+jet with forward jet tag

Top quark physics:

$t\bar{t} \to WbWb \to e\nu e\nu$ or $e\nu\mu\nu$ or $\mu\nu\mu\nu$ (plus $b\bar{b}$ tags)
$\to e\nu$ or $\mu\nu$ + $m_{3\text{-jets}}$ (plus b tag)
$\to$ 3-$l^\pm$ final states
$t\bar{t} \to H^\pm bWb \to \tau\nu$ plus $l^\pm$ tags (plus b tag)

Supersymmetry:

Main signatures for squark and gluinos are missing p_T plus jet topologies (direct decays) plus W or Z (cascade decays)

Compositeness:

Deviations in the jet cross section from the QCD expectation for very high p_T jets

Sensitivity to a variety of final state signatures is needed

Detector goals

Primary goal:

Balanced approach to electron, gamma, muon, jet and missing transverse energy measurements at high luminosity

balanced:

- *different final states to corroborate possible new physics signals*
- *detector not compromised in cost and layout on the basis of one particular component*

Additional goals:

During initial lower luminosity, and to as high a luminosity as practicable, more complex signatures including tau detection and heavy flavour tags

Large acceptance in rapidity and transverse momentum thresholds

Homogeneous detector layout with only the essential components

Design within realistic cost constraints

EAGLE approach to reach these goals

A wide-spread effort is going on with the aim to optimize a detector concept for LHC

Strong involvement in detector R&D projects

Broad physics and detector performance simulation activities

Major engineering studies

Every attempt is made to avoid premature choices on the basis of non-scientific arguments ...

R&D Collaborations in which EAGLE groups are involved

RD1 Scintillating fibre calorimetry

Cagliari, CERN, Clermont-Ferrand, Lisbon, Marseille, Naples, Palaiseau, Paris VI, Pavia, Rio de Janeiro, San Diego, Weizmann

RD2 Silicon tracking and preshower detector

Cambridge, CERN, Dortmund, Geneva, Hamburg, Melbourne, Oslo, Oxford, Perugia, RAL, Saclay, Sydney

RD3 Liquid Argon calorimetry

Annecy, BNL, CERN, Grenoble ISN, Stockholm MSI, Milano, Orsay LAL, Saclay, Victoria

RD4 Liquid Argon dopants

CERN, Stockholm MSI

RD5 Muon triggers and momentum reconstruction

Aachen III, Budapest KFKI, CERN, Helsinki, Madrid CIEMAT, NIKHEF, Nijmegen, Padua, Rome I and II, UCLA, UC Riverside, Vienna, Warsaw

RD6 Transition radiation tracking detector

BNL, Cracow INP, Dubna JINR, Glasgow, Lund, Moscow MPEI, Moscow Lebedev, Munich MPI, St. Petersburg NPI, RAL

RD8 GaAs detectors

Bolognia, CERN, Florence, Glasgow, Lancaster, RAL, Sheffield, Modena

RD11 2nd level trigger (EAST)

Amsterdam NIKHEF, Budapest, CERN, Cracow, Bucharest, Mannheim, Palaiseau, Rome I, RHBNC London, Utrecht, Zeuthen

RD12 Readout system test benches

Annecy LAPP, CERN, Helsinki, Padua, Pavia, Tampere

RD13 Scalable DAQ system

CERN, CEA Saclay, Frascati, Marseille, Pavia, Rome I

RD16 Digital front end electronics (FERMI)

CERN, Linkoping, MSI Stockholm, Stockholm, Milano, Pavia

RD19 Silicon pixel detectors

CERN, Bolognia, Genoa, EPFL, SSiS Lausanne, Leuven, Marseille CPPM, Milano, College de France, Pisa, ETHZ

RD20 Silicon strip detectors

CERN, Cracow INP, Helsinki, Liverpool, IC London, Marseille CPPM, Oslo, RAL, Strasbourg, Turin, Uppsala, PSI, Yale

RD23 Optoelectronic analog signal transfer

Birmingham, CERN, EPFL, Marconi Defence System, IC London, Lund, Oxford, RAL

Other R&D activities (not through DRDC)

Micro strip gas counters:

NIKHEF, Liverpool and other UK, Bratislava

Scintillating fibre tracking:

Frascati, Pisa

1^{st} level triggering:

Birmingham, QMW London, RAL
Stockholm

DRDC proposal in preparation

2^{nd} level triggering:

NBI Copenhagen

Radiation-hard very forward calorimetry

Liquid scintillator in capillary tubes:

Naples and ITEP Moscow

High pressure gas tubes:

IHEP Protvino

Global detector concept

Powerful inner detector in a 2 T central solenoid for accurate momentum measurement of isolated leptons over a large rapidity span ($-2.5 < \eta < 2.5$) and electron identification

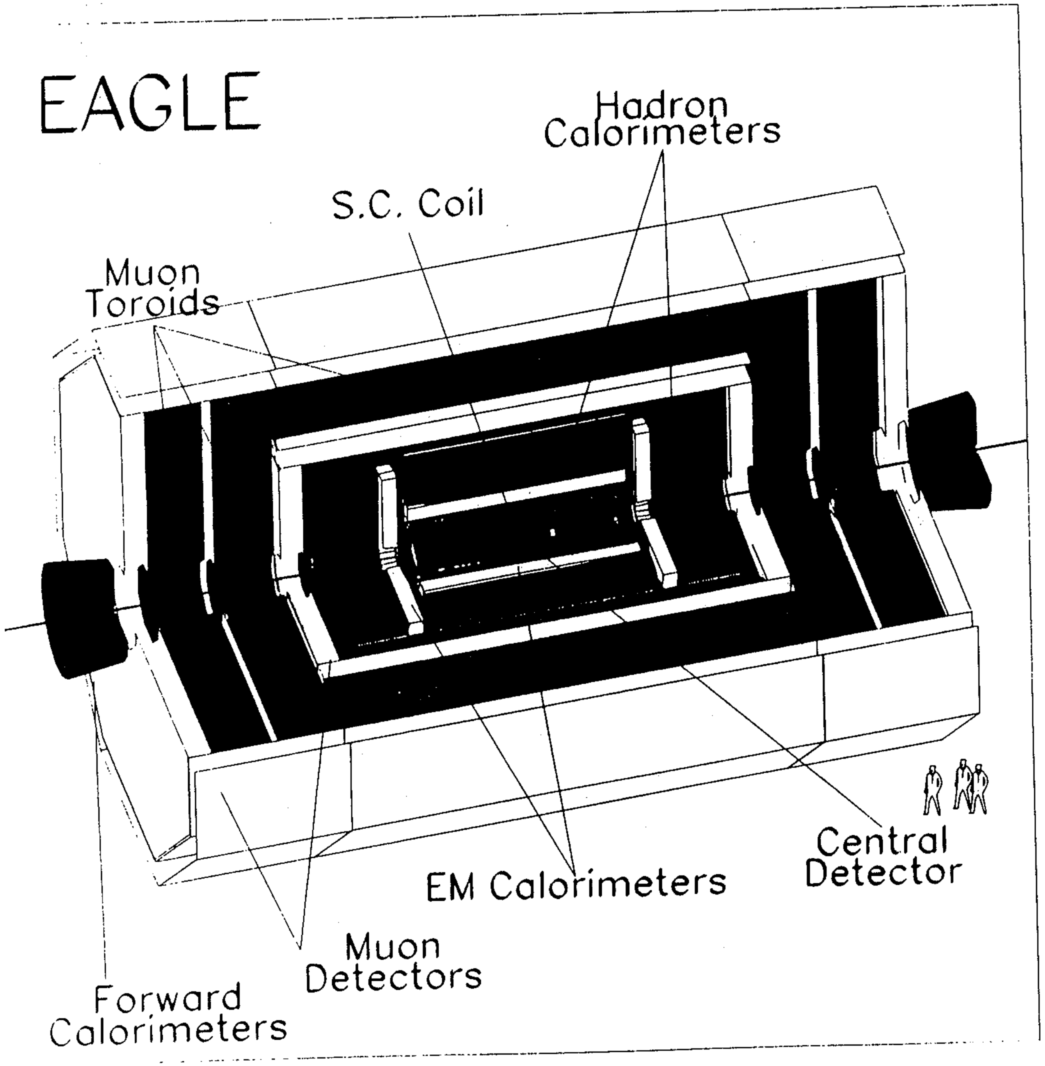
High quality EM sampling calorimetry combined with fine granularity preshower detection for electron and gamma detection

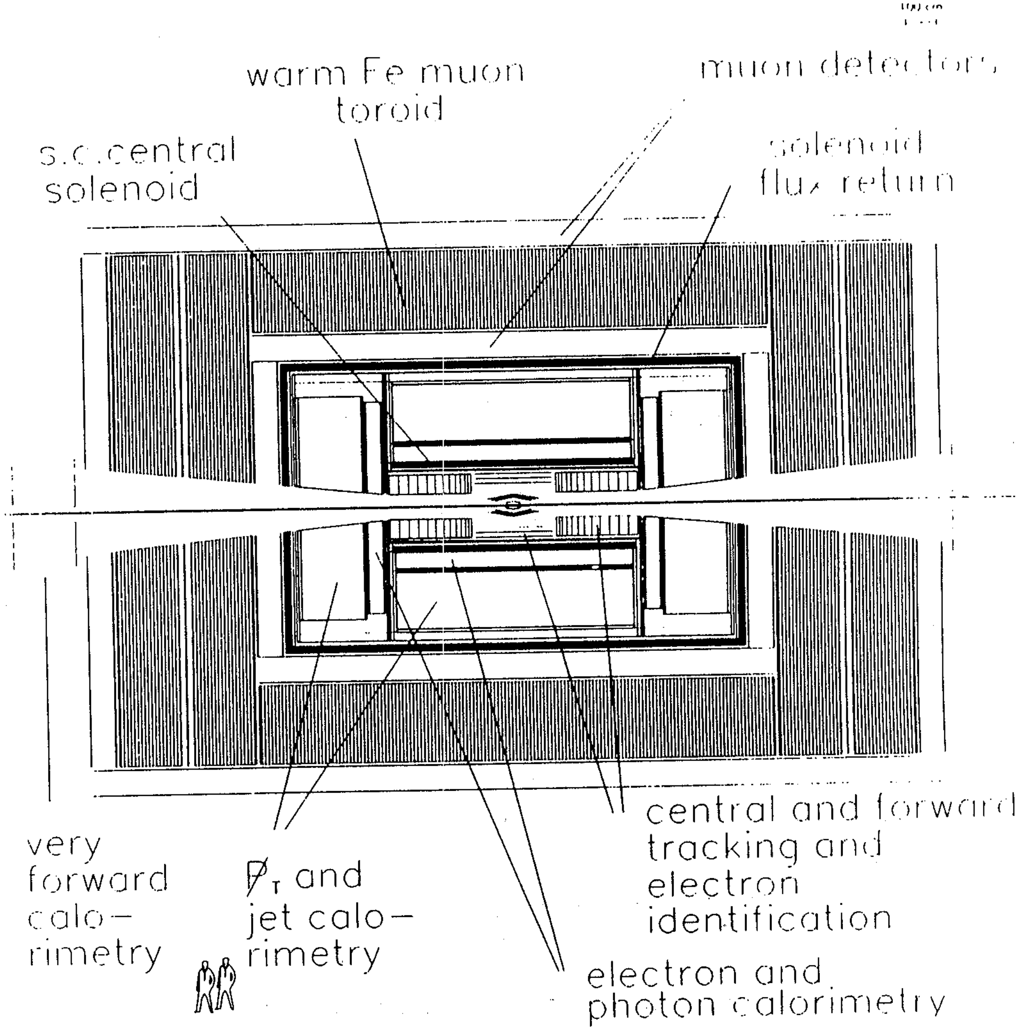
Hermetic hadron calorimetry for jet and missing transverse energy measurements ($-5 < \eta < 5$)

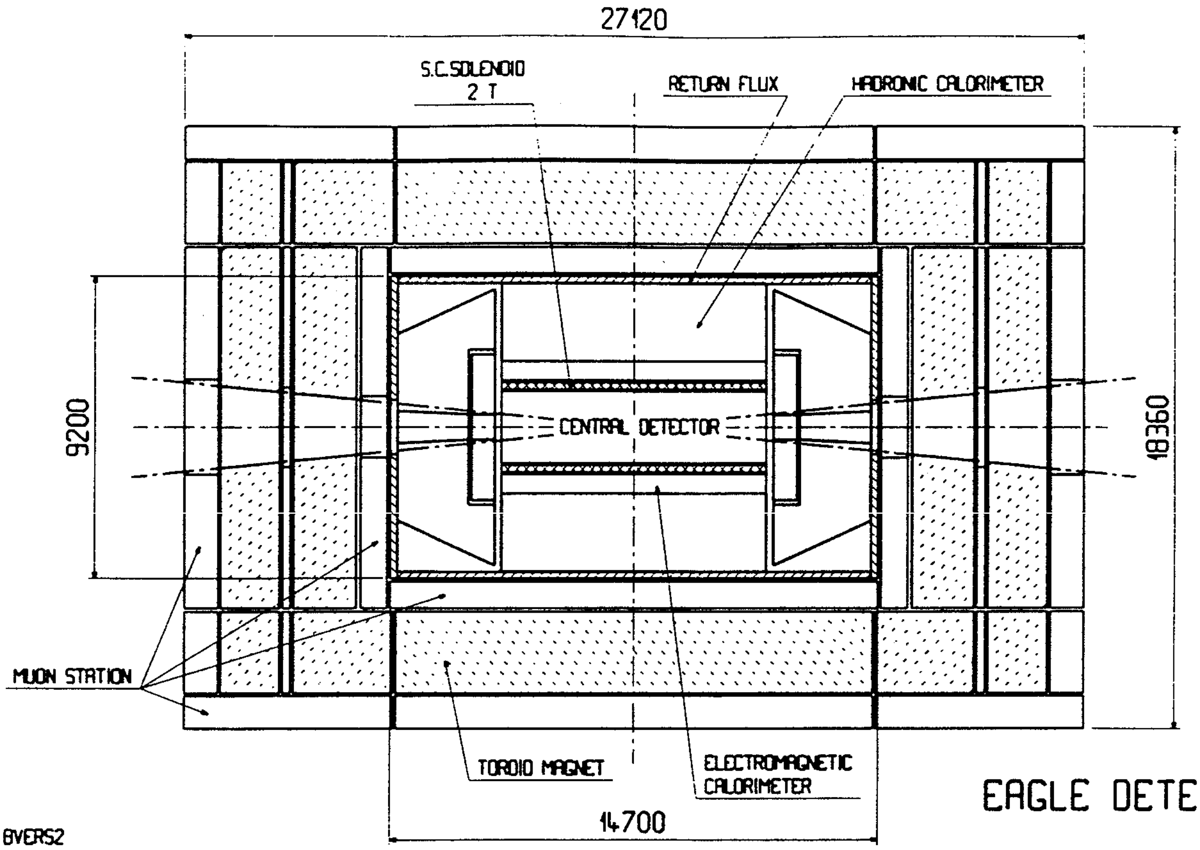
Iron toroid muon spectrometer with large acceptance ($-3 < \eta < 3$) and stand-alone momentum measurement capability

High precision vertex detector for (initial) lower luminosity operation

Modular and flexible trigger, DAQ and analysis architecture

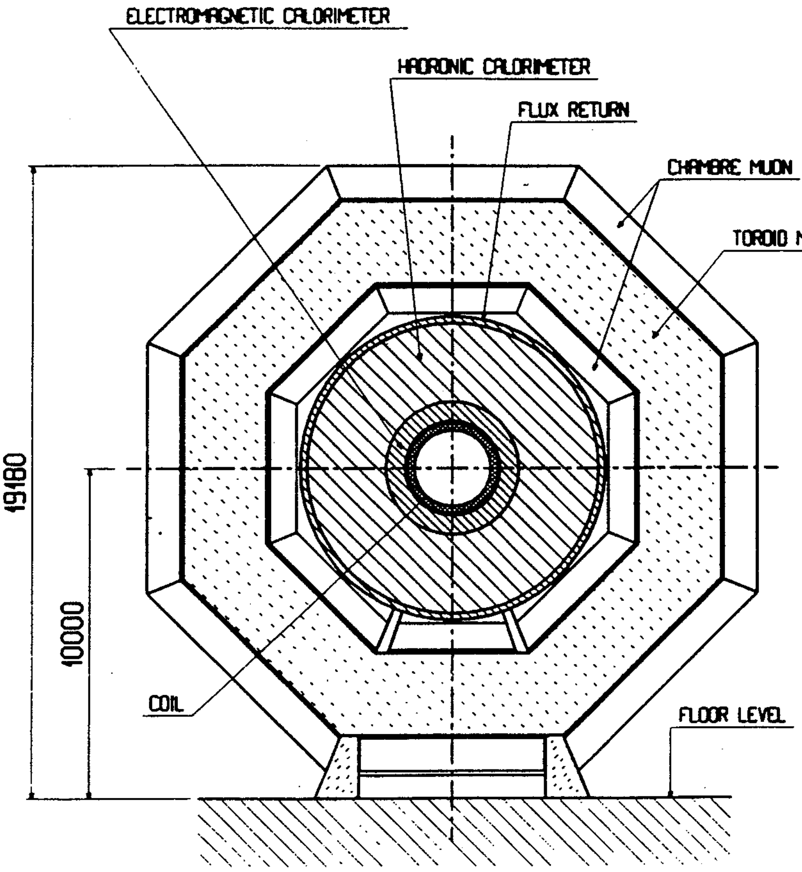

EAGLE
Hadron Calorimeters
S.C. Coil
Muon Toroids
Central Detector
EM Calorimeters
Muon Detectors
Forward Calorimeters


warm Fe muon toroid
muon detectors
s.c.central solenoid
solenoid flux return
very forward calo-rimetry
$\not{E}_T$ and jet calo-rimetry
central and forward tracking and electron identification
electron and photon calorimetry



EAGLE DETECTOR

BVERS2
26-02-1992



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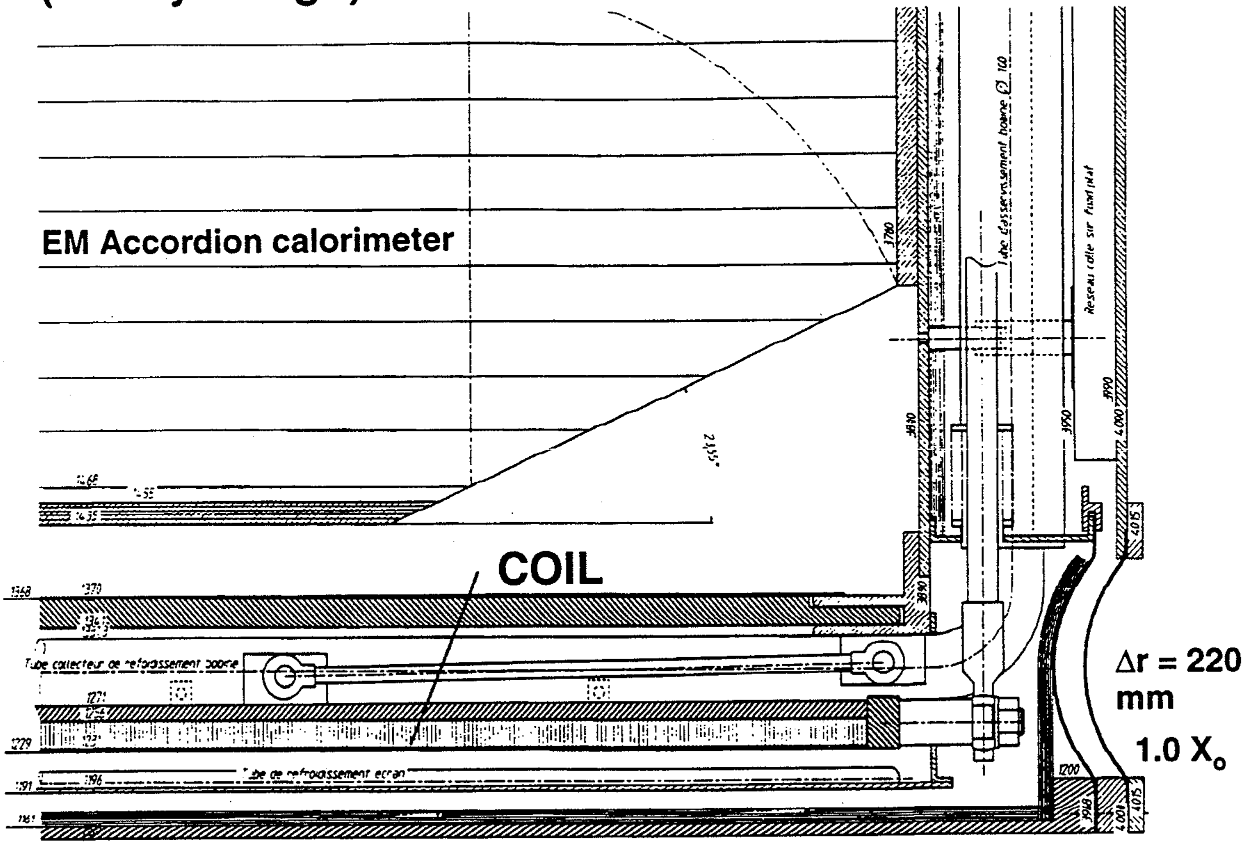
EAGLE DETECTOR

Superconducting coil integrated into LAr cryostat (Saclay design)



Central s.c. solenoid

The EAGLE concept includes a uniform 2 Tesla solenoidal magnetic field over the volume of the central inner detector (r = 1.1 m l = 8 m)

technical concepts considered:

- *integrated coil in a common cryostat with a liquid Argon calorimeter*
- *thin separate coil*

Engineering studies of thin superconducting solenoid coils are made in RAL and Saclay

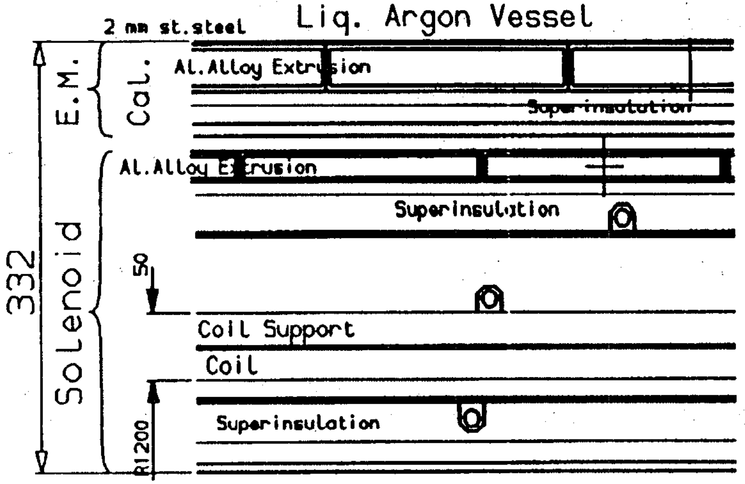
Coil positions in front or behind the EM calorimeter are under intensive studies

main arguments:

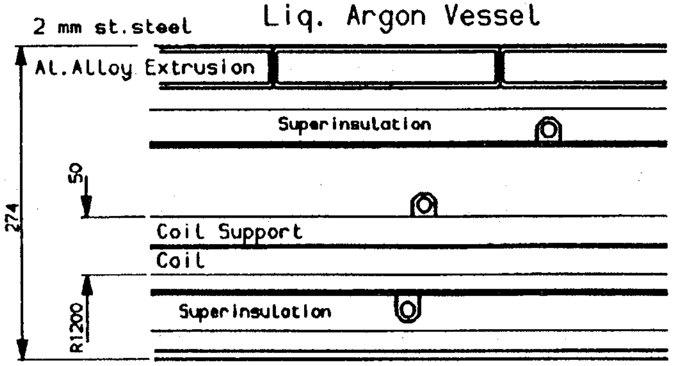
- *field homogeneity for inner detector*
- *material and field influence on EM calorimeter and preshower detector as well as on jet resolution*
- *muon resolution in combined inner and outer measurements*
- *costs*

Superconducting coil designs (RAL)

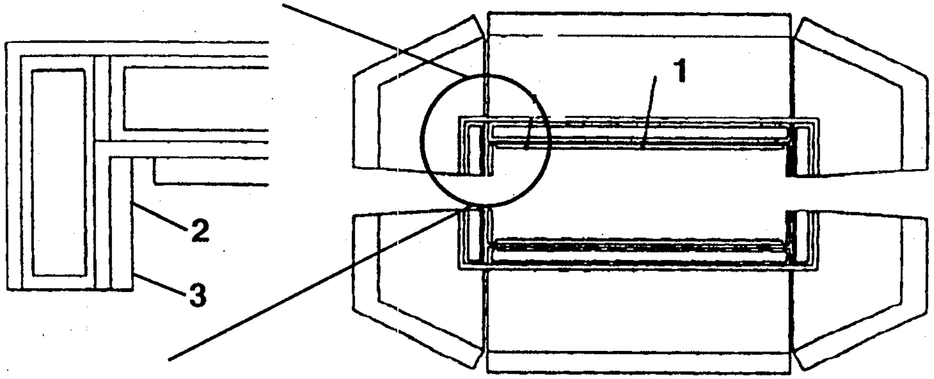
separate coil (Δr = 332 mm 1.1 X_o coil plus cryostat)



integrated coil (Δr = 274 mm 0.92 Xo coil plus cryostat)



Radiation levels in EAGLE



Neutron flux (10^{13} n $cm^{-2}y^{-1}$ with $E_n > 100$ keV)

($10^{34}cm^{-2}s^{-1}$ x 10^7s, Pb-LAr EM and Fe-LAr had calorimeter, 2 T magnetic field)

position	nothing	10 cm moderator all EM faces	TRD plus 10 cm mod. EC EM face
1	1.7	0.2	0.4
2	3.2	0.3	0.7
3	6.0	1.6	2.3

--> ***EAGLE plans to use neutron moderation***

Dose rates at cascade max. of EM showers (kGy per y)

η - range	0 - 1.5	1.5 - 2	2 - 2.5	2.5 - 3	3.5 - 4
dose rate	0.4	0.9	4	12	90

Dose rates for inner detector

40 kGy per y at r = 10 cm 4 kGy per y at r = 30 cm

Detector components

At this stage a few, typically two, options are still considered for many of the major detector components

The final choices of the technologies will only be made when the outcome of a broad range of R&D projects, simulation studies and conceptual engineering designs is known

Inner detector

Tracking:

- Silicon micro strip and pad detectors
- micro strip gas counters

(GaAs micro strip, Silicon pixel, and scintillating fibre detectors are also considered)

Electron (gamma) identification:

- transition radiation detection (TRD tracker)
- early shower detection (Silicon tracking and preshower or Silicon tracking plus cold LAr preshower)

both do also have a tracking role

Calorimetry (I η I < 3)

Electromagnetic with Pb absorber:

- fast liquid Argon (LAr Accordion)
- scintillating fibres

Hadronic with Fe absorber:

- fast liquid Argon (LAr Accordion)
- scintillating fibres
- scintillator tiles

Very forward calorimetry (3 < I η I < 5)

- liquid scintillator in capillary tubes
- high pressure gas tube

Muon measurements

- drift chambers with mini-drift cells
- honeycomb strip chambers
- thin proportional strip chambers
- resistive plate chambers (RPC) for triggering

Calorimetry

LHC requirements

Main considerations:

- exploratory LHC physics demands high luminosities which cause pile-up effects
- physics performances in most cases more strongly driven by electron and gamma signatures and resolution than by ultimate hadron measurements
- however, hadronic rapidiy coverage is important

Design goals

- high quality EM calorimetry, able to include the Higgs -> $\gamma + \gamma$ channel

$$\sigma_{EM} / E \sim 10\% / sqrt(E) \oplus 0.5\%$$

- good jet calorimetry within the high luminosity environment

$$\sigma_{jet} / E \sim 50\% / sqrt(E) + 2\%$$

- hermetic forward calorimetry to at least $| \eta | \sim 4.5$

EM requirements specific to H --> $\gamma\gamma$

Energy resolution

- sampling term has to be about 10% / sqrt(E) or better
- most important is the constant term which has to be kept below 1%

Directional resolution

- the H --> $\gamma\gamma$ mass resolution depends on the directional resolution for the γ's; to match the above energy resolution one has to reach at least

$$\sigma(\omega) \sim 100 \text{ mrad} / sqrt(E)$$

Rejection of π^0 background from QCD jets

- detailed simulations have demonstrated that a rejection of at least 10^4 is needed against the π^0 from QCD jets

These requirements can be met with

- ***high quality EM sampling calorimetry with good granularity***
- ***combined with fine granularity preshower detection for e, γ and π^0 identification***

Calorimeter options central region

Barrel and end caps covering $|\eta| < 3$

EM depth 25 - 30 X_o , total depth 10 - 12 λ

Technologies under study are:

Scintillating fibre calorimetry (based on RD1)

Pb absorber for electromagnetic part
Fe absorber for hadronic part (magnetic flux return)

Liquid Argon calorimetry (based on RD3 Accordion)

Pb absorber for electromagnetic part
Fe absorber for hadronic part (non-magnetic)

Integrated preshower detector

Scintillator tiles for hadronic part (conceptual design)

Fe absorber and scintillator tiles read out by wave length shifting fibres

Combined technologies as economically attractive solutions are also being considered

---

Scintillating fibre calorimeter design

EM calorimeter:

Pb : fibre ratio 1.8 : 1 with 1 mm diameter fibres

Stacked with extruded Pb profiles and soldered with low melting point alloy

Quasi-projectivity with $\Delta\eta x \Delta\phi \sim 0.02x0.02$ (with 6° tilt) obtained by 'staircase' geometry, about 70000 cells total

Expected resolution (MC simulations)

$$\sigma/E = 8\%/sqrt(E) + 0.2\%$$

Hadronic calorimeter:

Fe : fibre ratio 5 - 20 : 1 with 2 mm diameter fibres

Machined Fe plates, allowing magnetic flux return

Projective cells with $\Delta\eta x \Delta\phi \sim 0.05x0.05$ obtained by 'staircase' geometry, about 14000 cells total

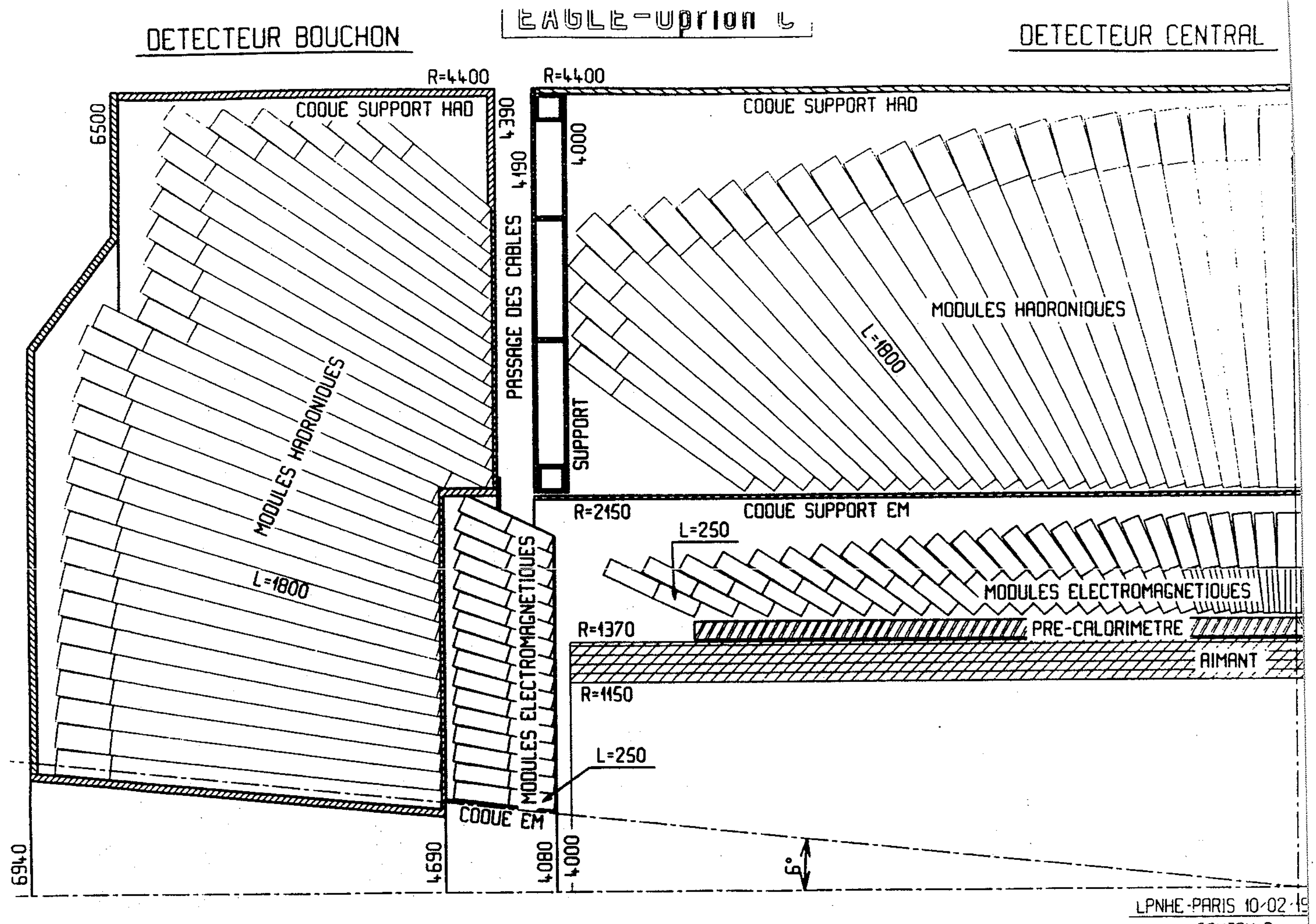
Expected jet resolution (combined with fibre EM calorimeter, MC simulation)

$$\sigma/E = 38\%/sqrt(E) + 1\%$$

Various light detectors under study (PMT's, proximity focussing diodes, avalanche photo diodes)

Modular construction in wheels supported separately in shells for the EM and hadronic part

EAGLE-Option C



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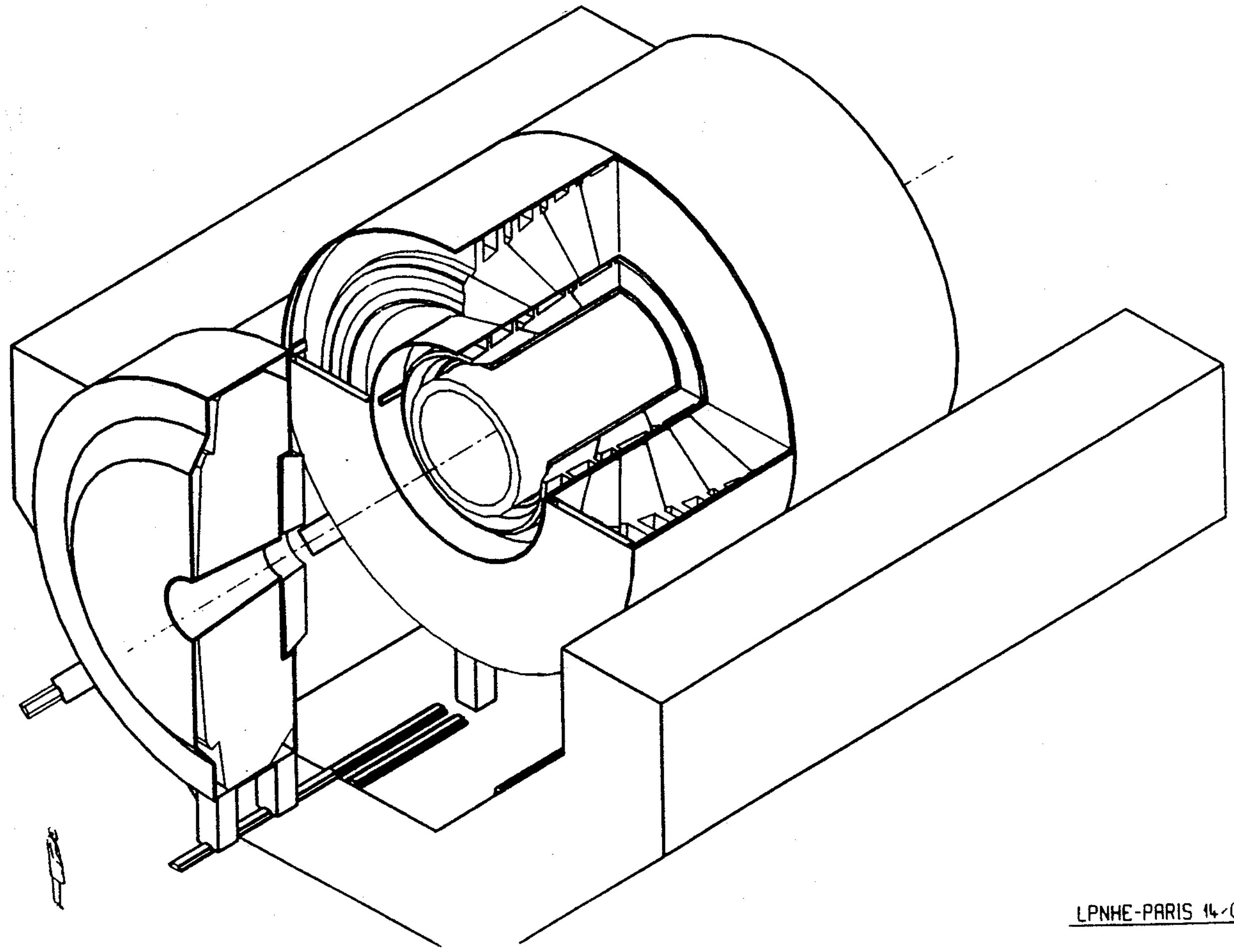
EAGLE-Option C



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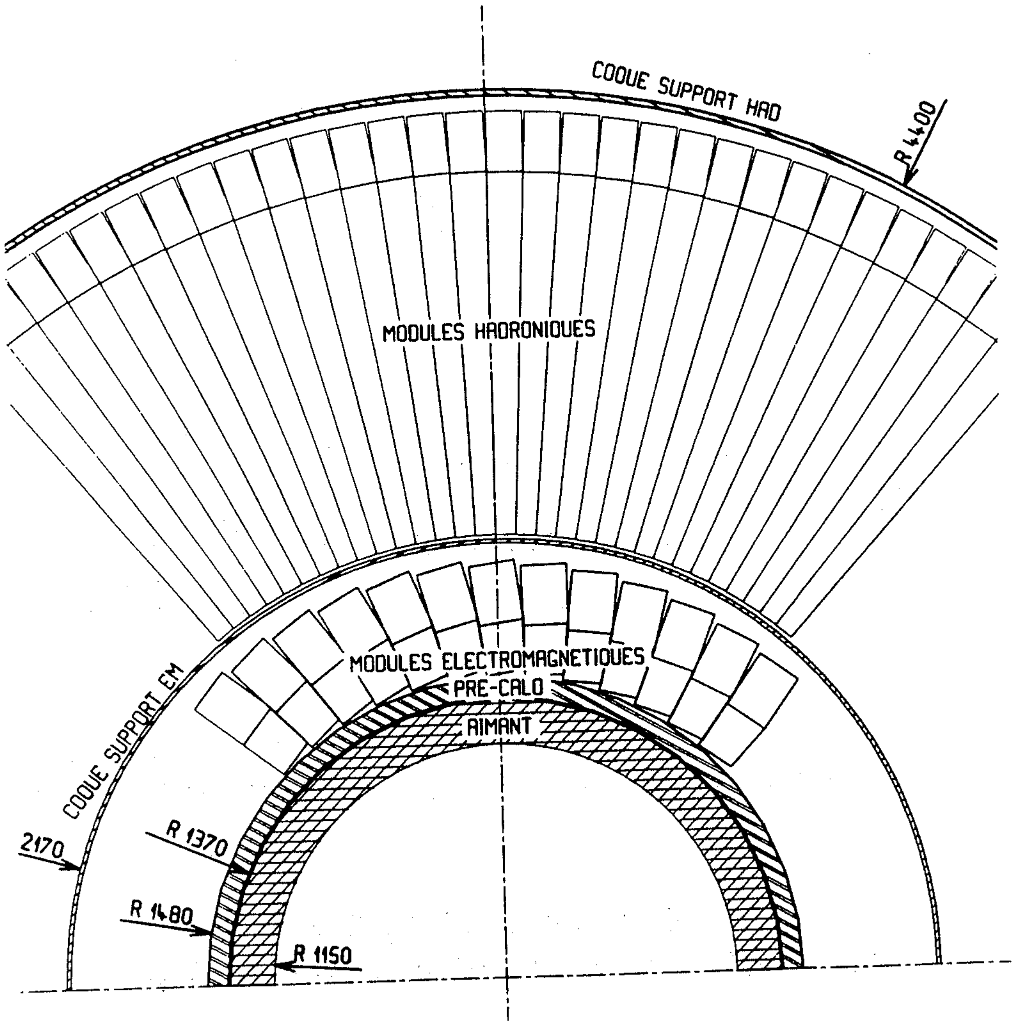
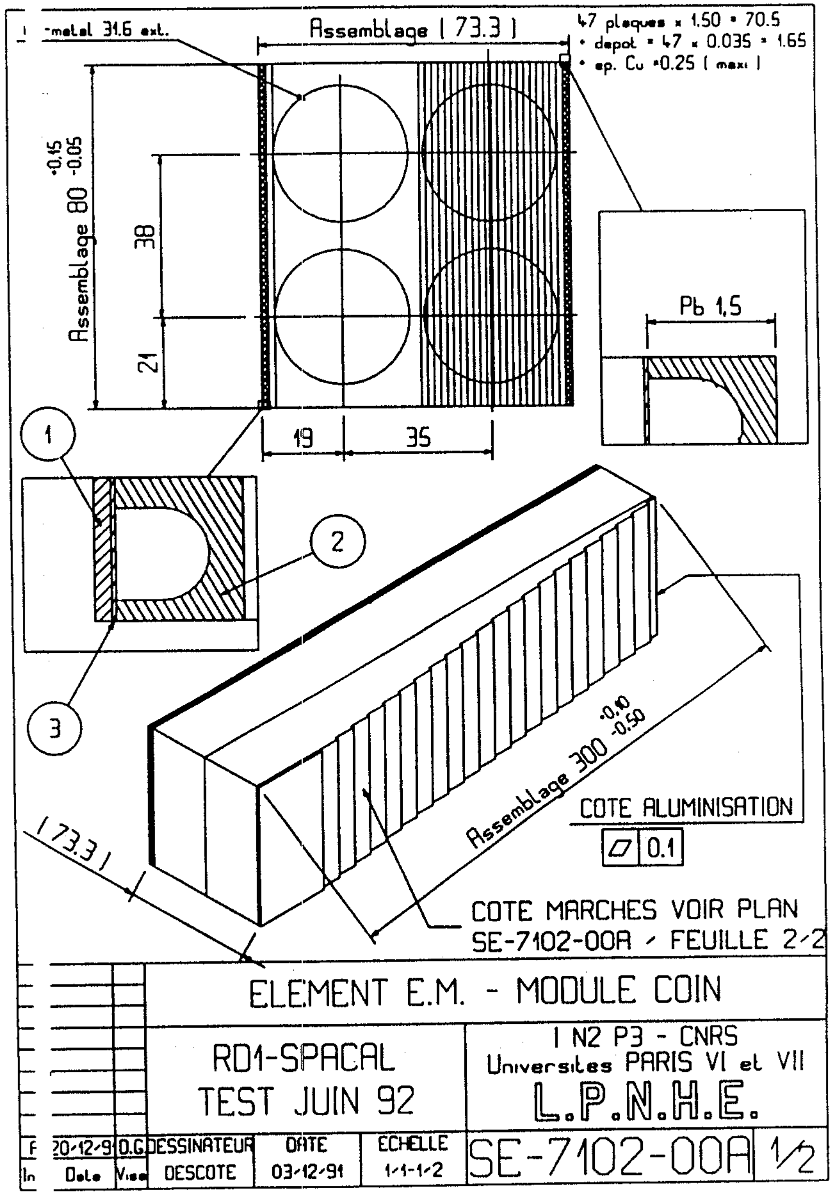
EAGLE-Option C

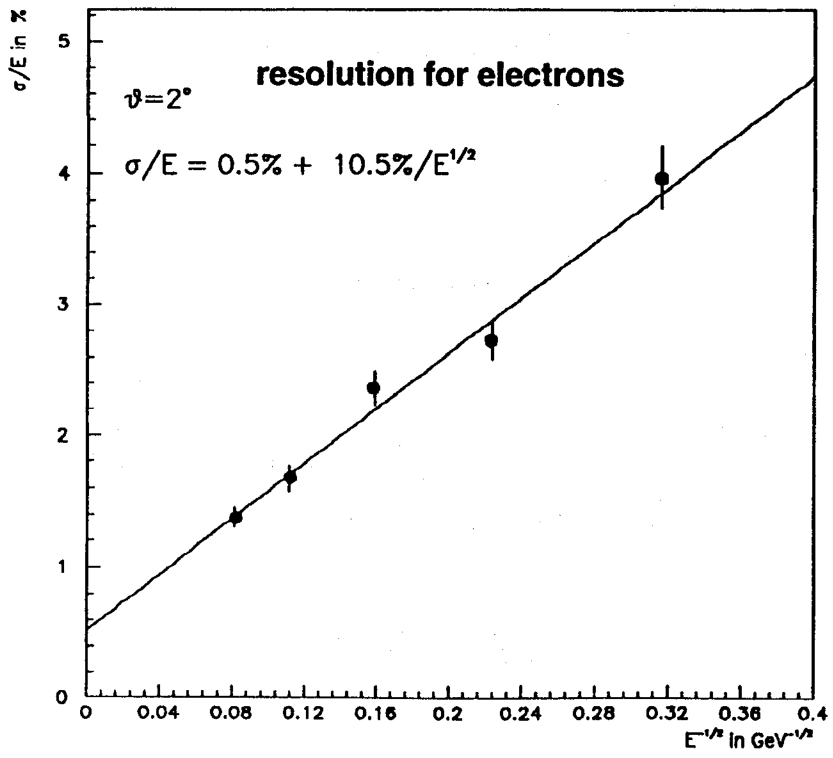
DETECTEUR CENTRAL





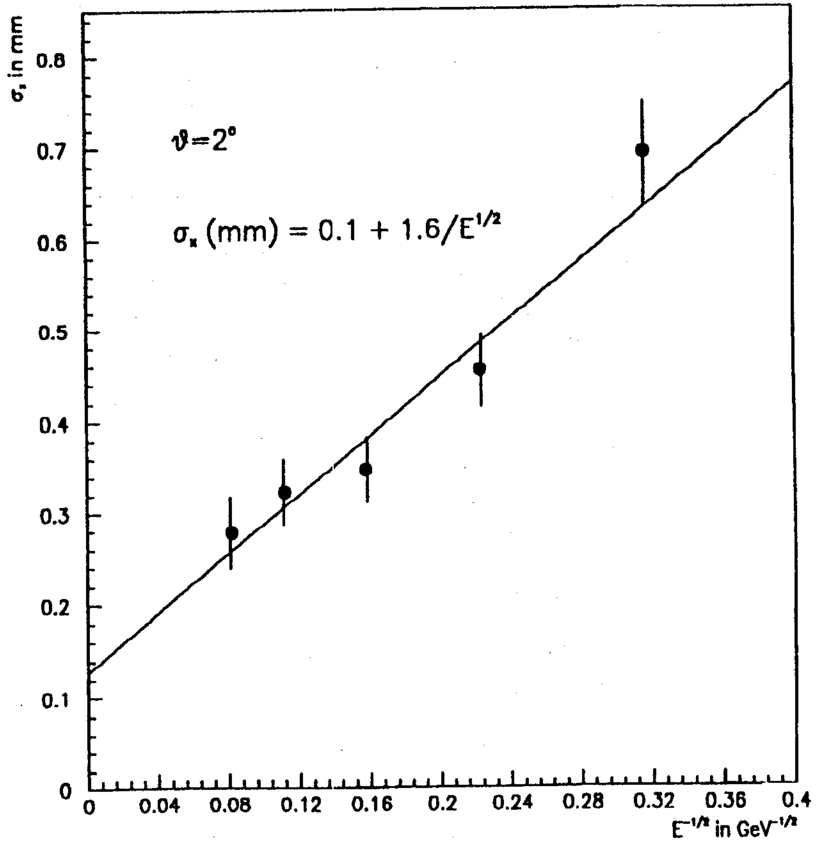
Test beam performance of an EM fibre calorimeter module

4 - cell test module with 500 μm diameter fibres and a Pb : fibre ratio of 4 : 1

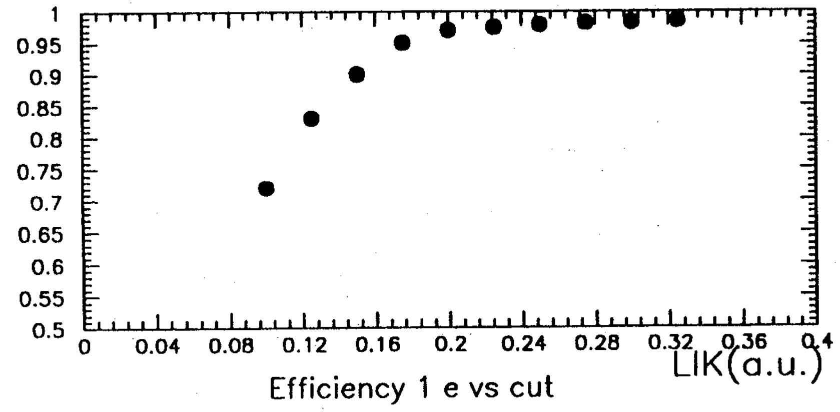


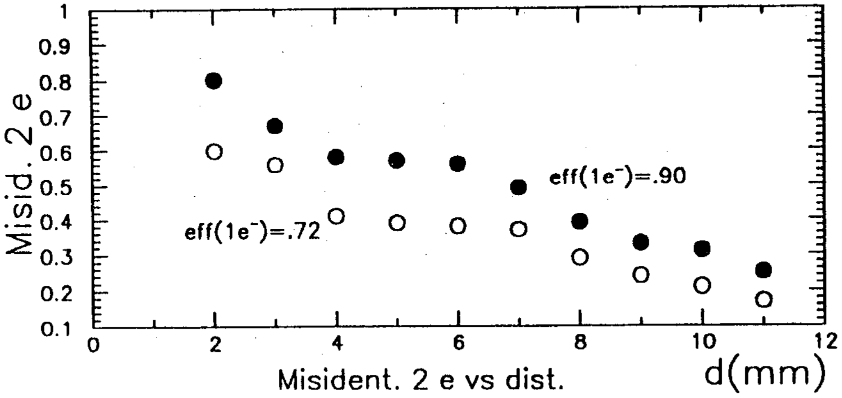
Electron position resolution near the centre of the four cells

(about 3 times worse at the centre of a single cell)



Simulated 2 - shower separation power (40 + 40 GeV) using single electron data


separation criteria 80 GeV electron data


simulated separation power 40 + 40 GeV

Liquid Argon calorimeter design

EM calorimeter:

Accordion structure for absorber (1.8 mm Pb clad with steel) and electrodes (Kapton multilayer boards)
- cable connections are eliminated to make towers
--> read-out speed, hermeticity, granularity

Projective cells with $\Delta\eta x \Delta\phi$ ~ 0.02x0.02 with 3 longitudinal samples (last one less granular), 230000 readout channels

Resolutions (from prototypes, fast $t_p(\delta)$ = 20ns shaping)

$\sigma(E)/E = 10\%/\mathrm{sqrt}(E) \oplus 0.6\% \oplus 0.32/E$ (incl. 3.3 X_o p.s. det.)

$\sigma_x = 3.7$ mm/sqrt(E) , $\sigma(\omega) = 48/\mathrm{sqrt}(E) + 365/E$ (mrad)

Hadronic calorimeter:

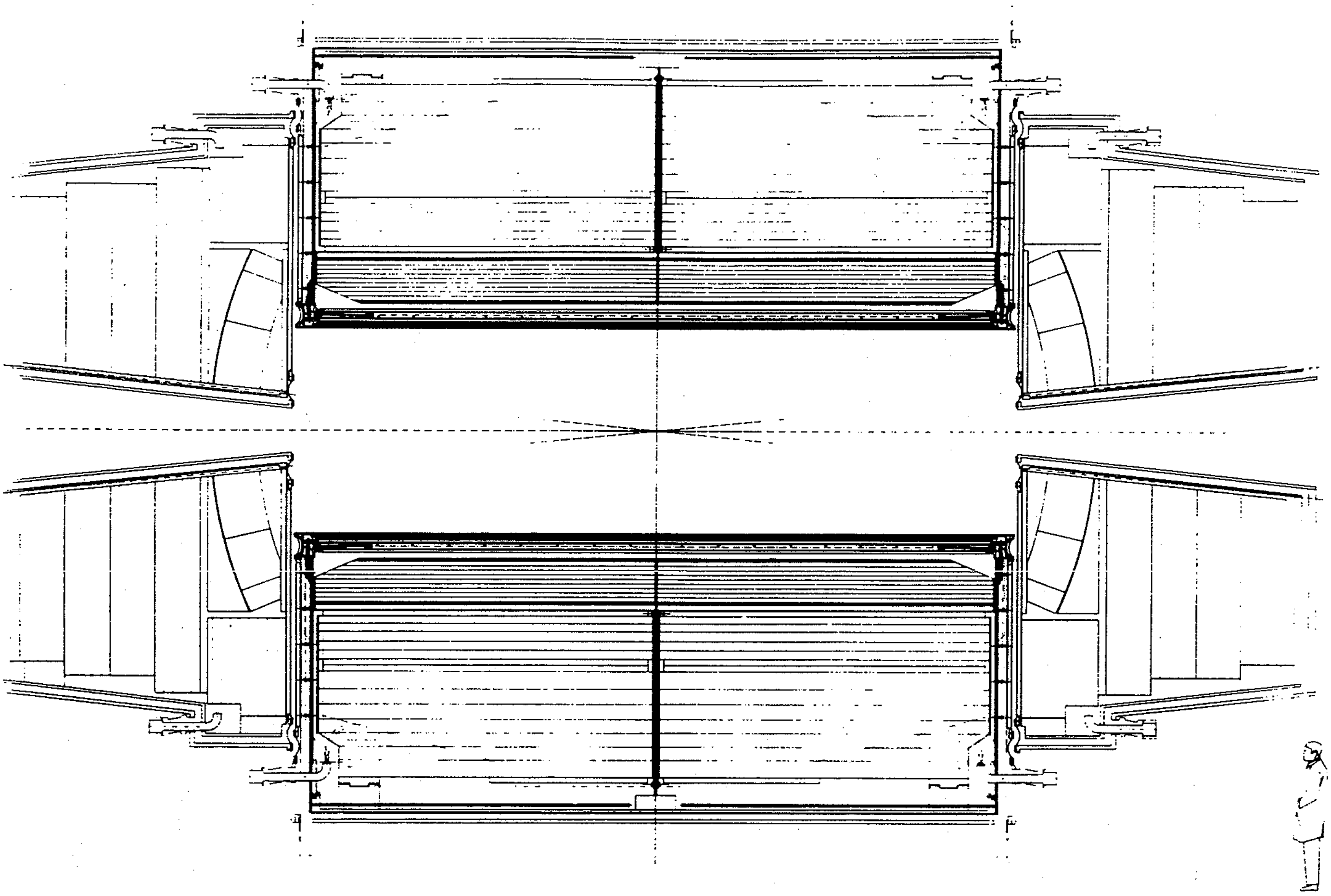
Steel absorbers (1 to 1.5 cm), cold shaped to Accordion structure, cut-isolated-assembled to allow EST readout

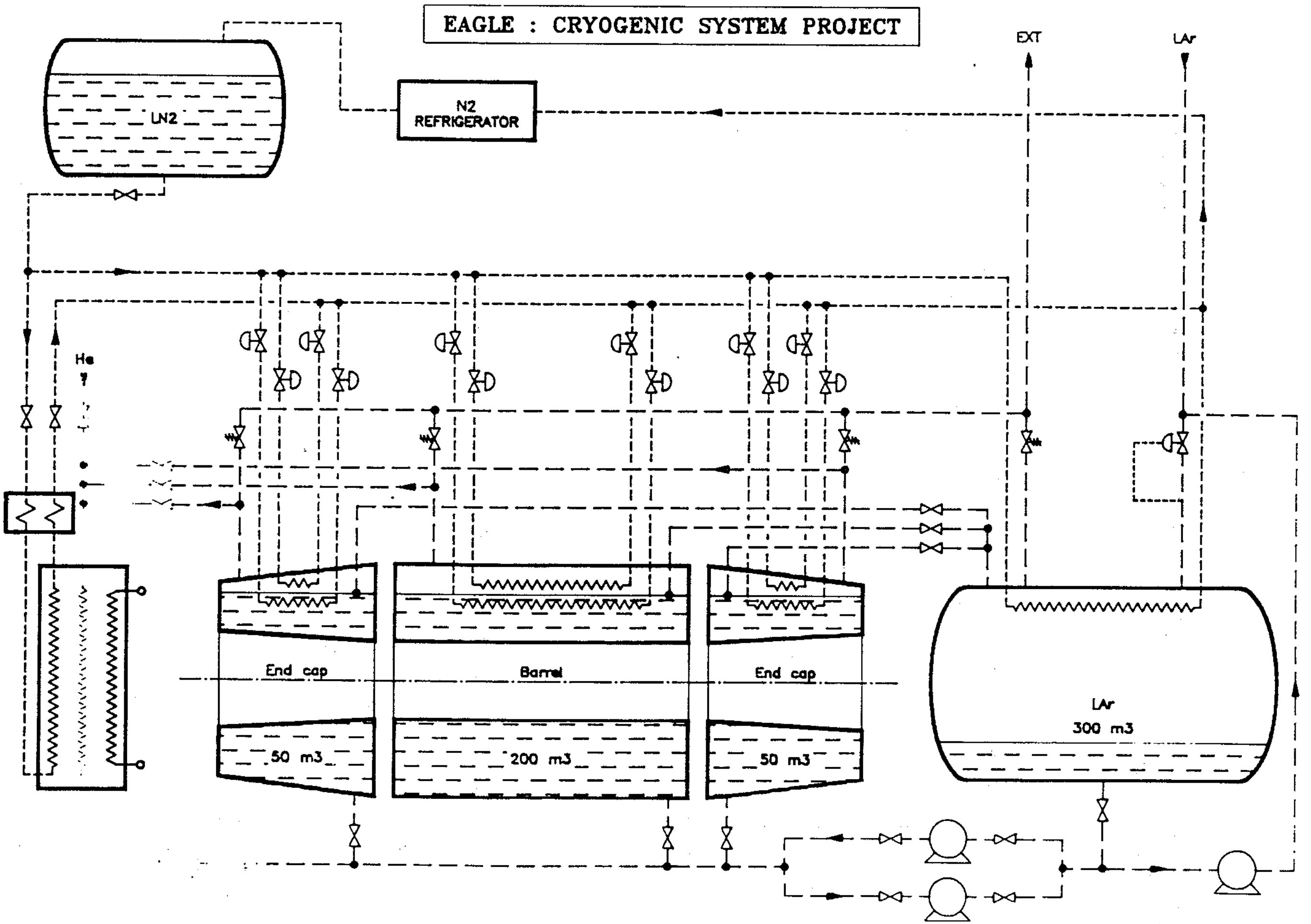
Projective towers with $\Delta\eta x \Delta\phi$ ~ 0.05x0.05 and 4 longitudinal samples, 60000 readout channels total

Expected jet resolution combined with LAr accordion EM calorimeter (MC simulation)

$$\sigma(E)/E = 60\%/\mathrm{sqrt}(E) + 3\%$$

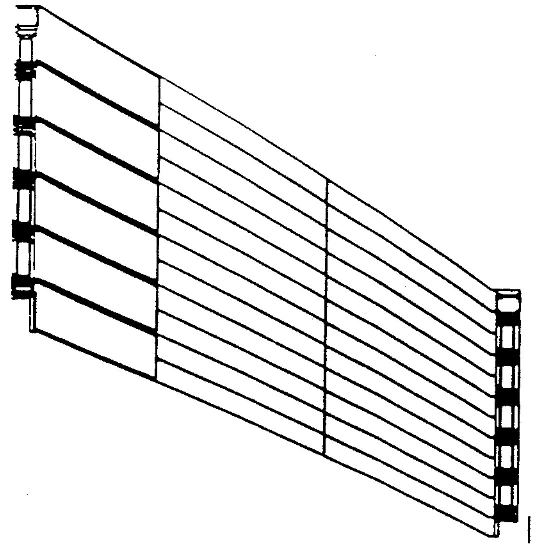
$\sigma(E)/E = 40\%/\mathrm{sqrt}(E) + 2.2\%$ with longitudinal weighting





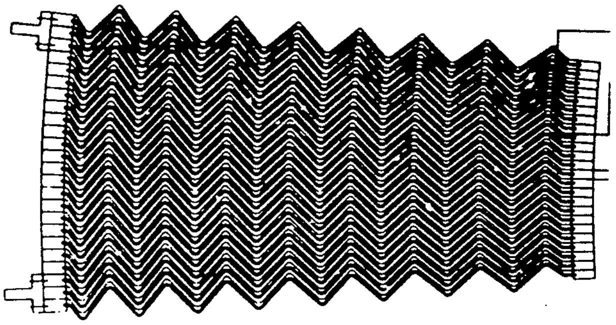
EAGLE : CRYOGENIC SYSTEM PROJECT

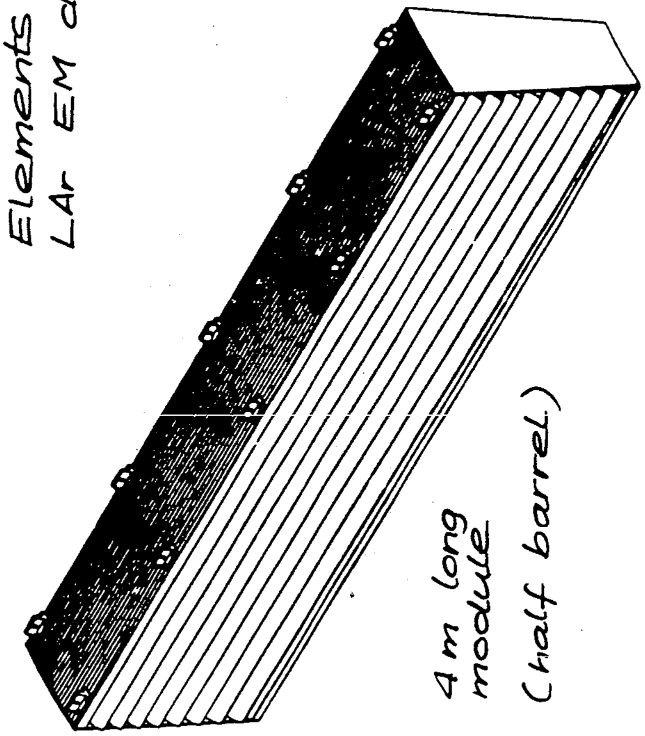
SACLAY / STCM 17/02/92



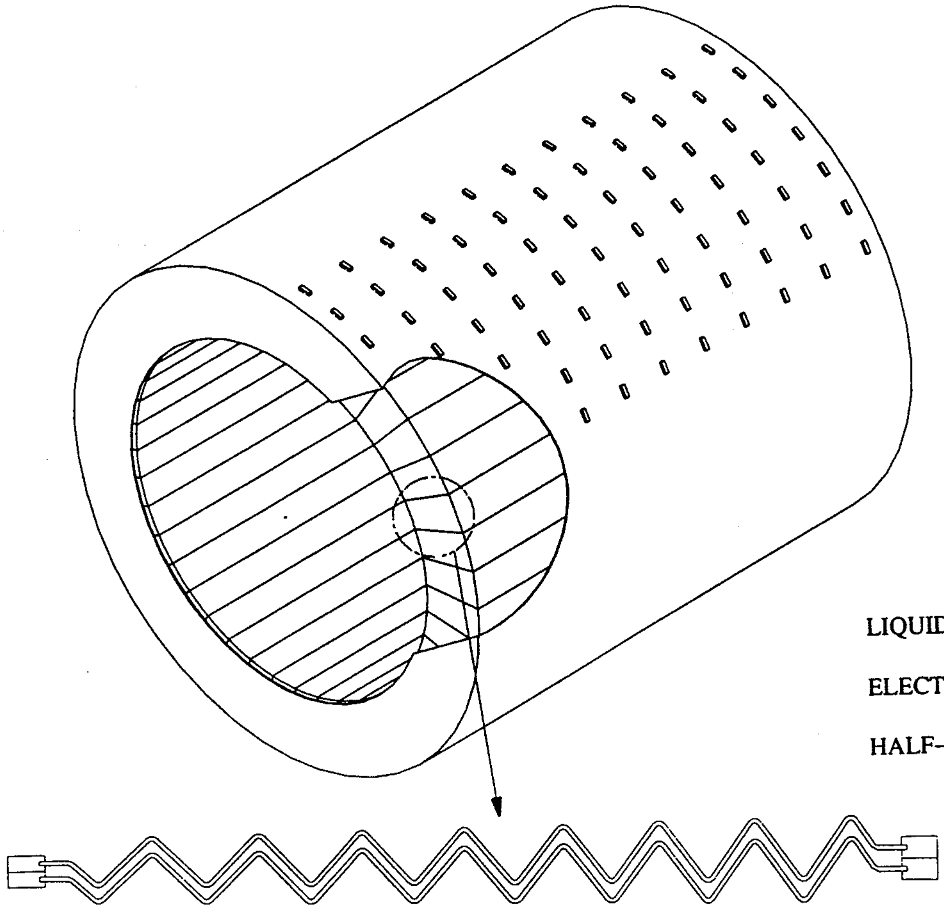
η projectivity and granularity (read-out kapton)

Elements of LAr EM design





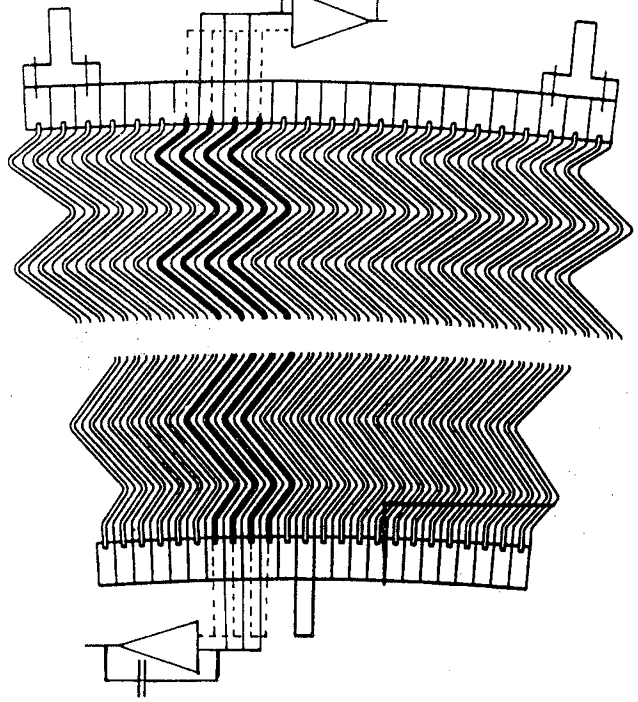
4 m long module (half barrel)

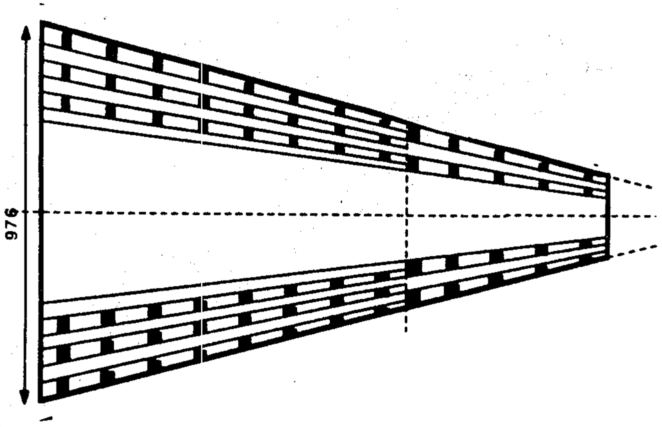


LIQUID ARGON

ELECTROMAGNETIC

HALF–BARREL

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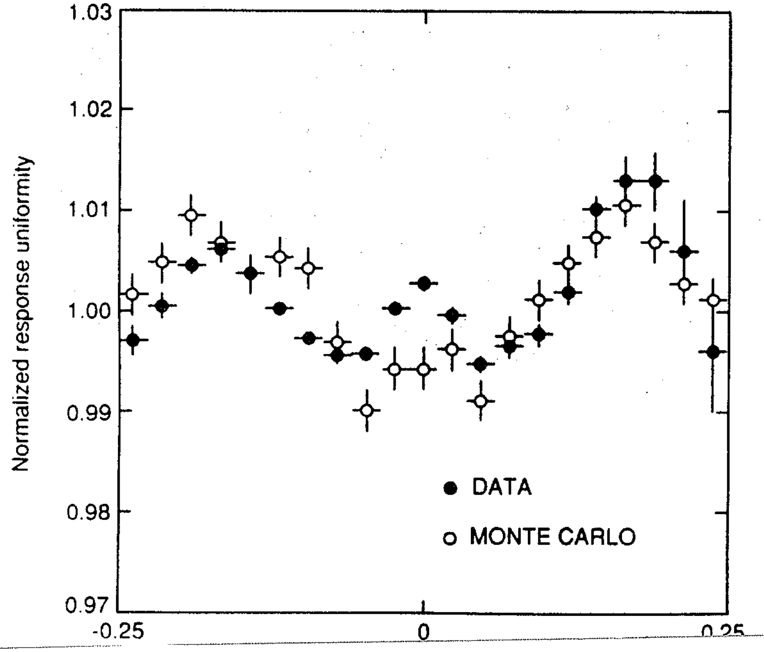
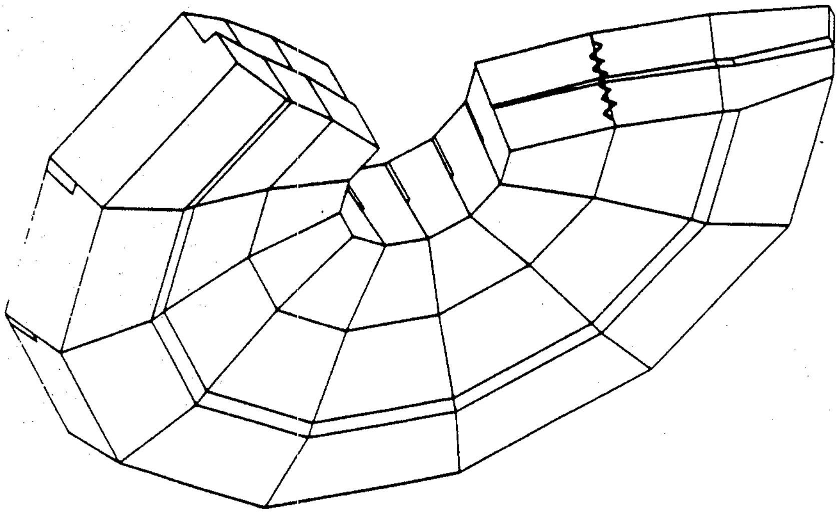
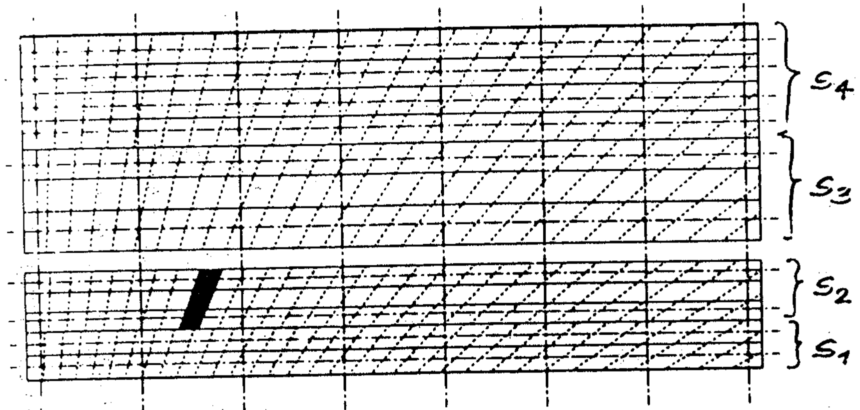
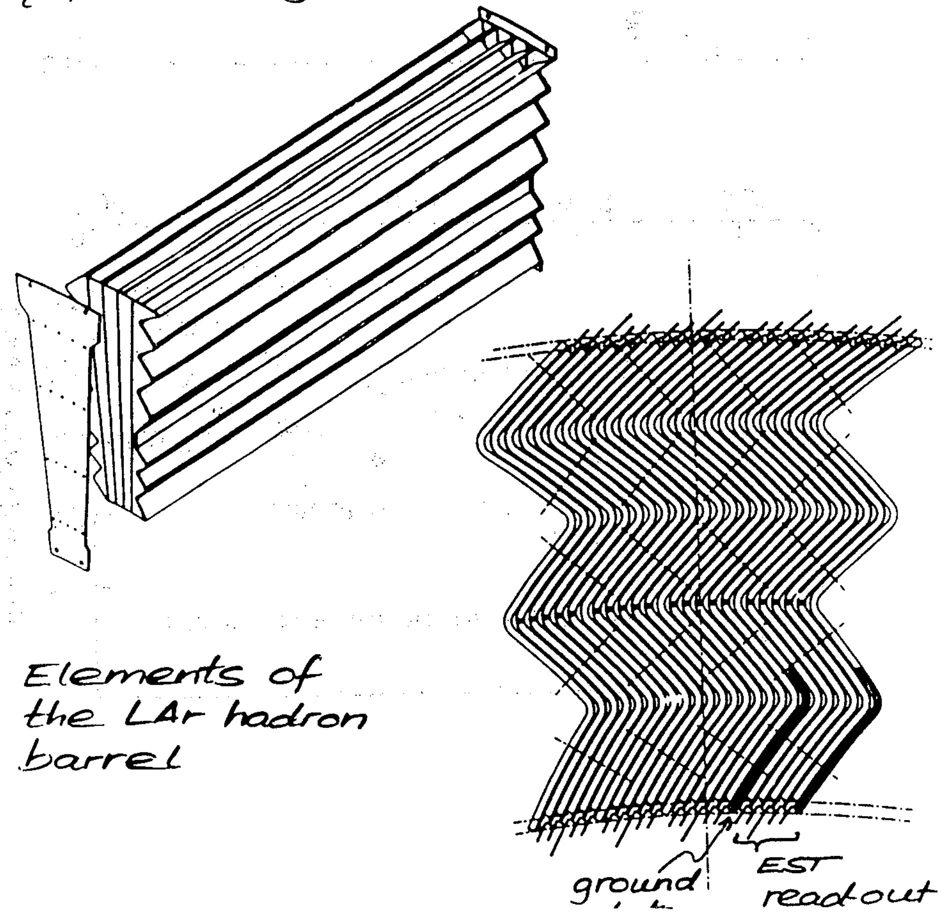

Normalized response uniformity
1.03
1.02
1.01
1.00
0.99
0.98
0.97
-0.25
0
0.25
● DATA
○ MONTE CARLO



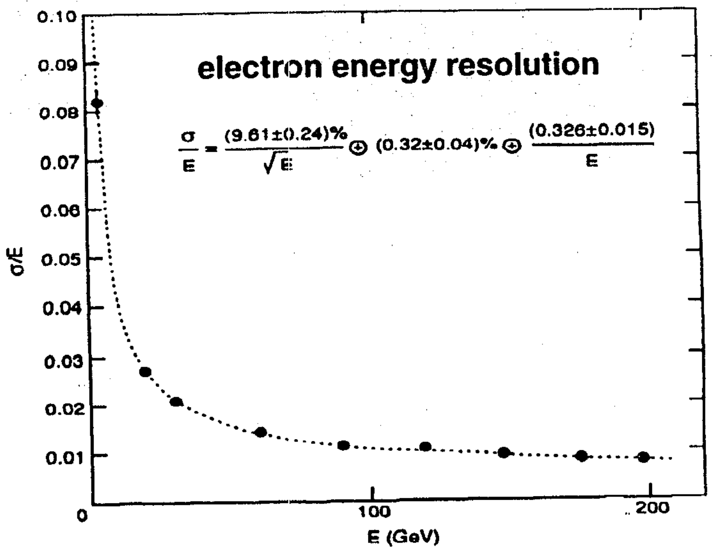


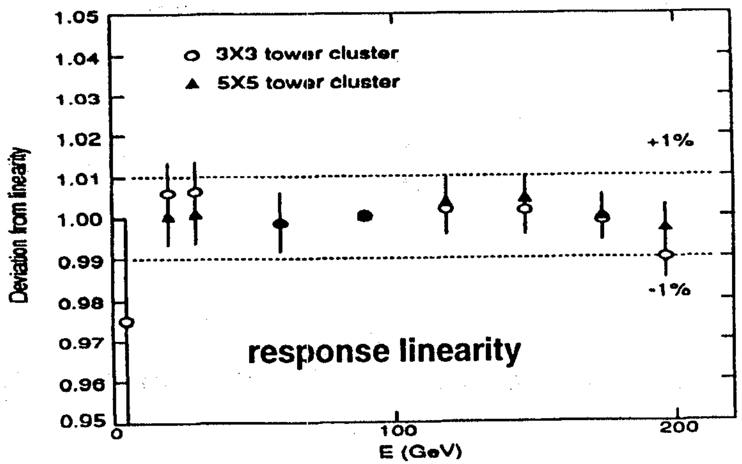
η projectivity and granularity



Elements of the LAr hadron barrel

Test beam performance of an EM LAr Accordion prototype module





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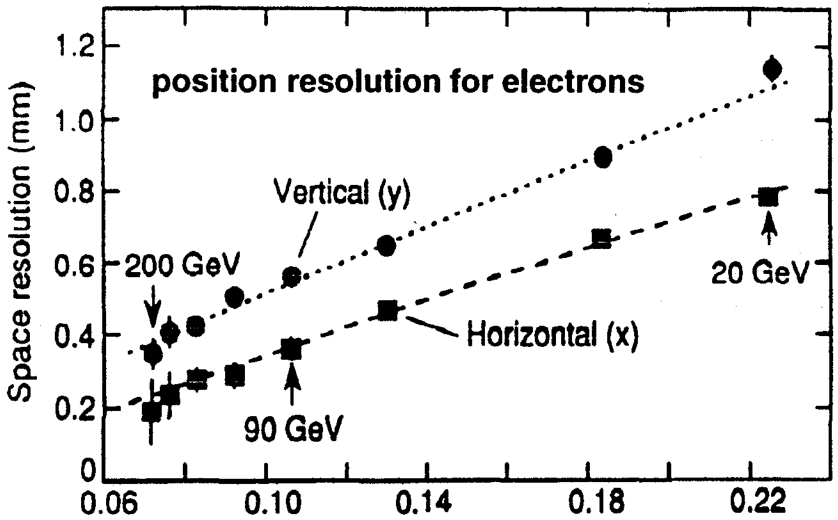
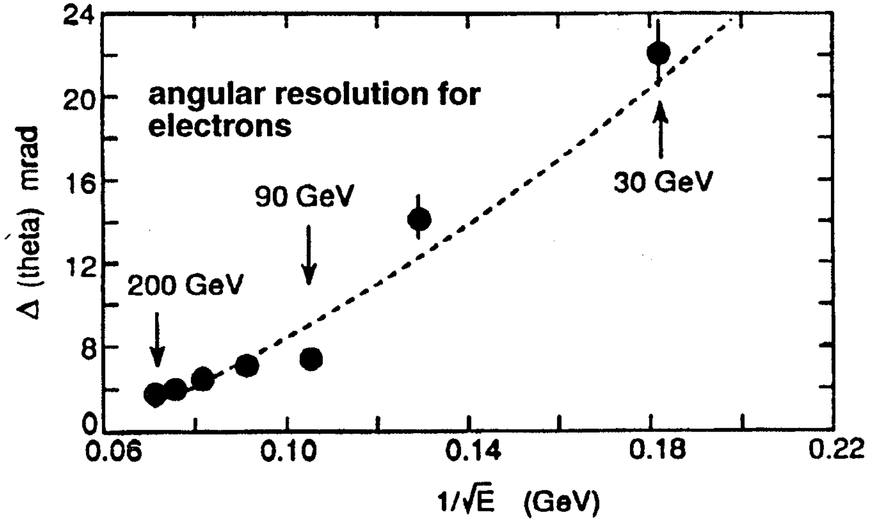
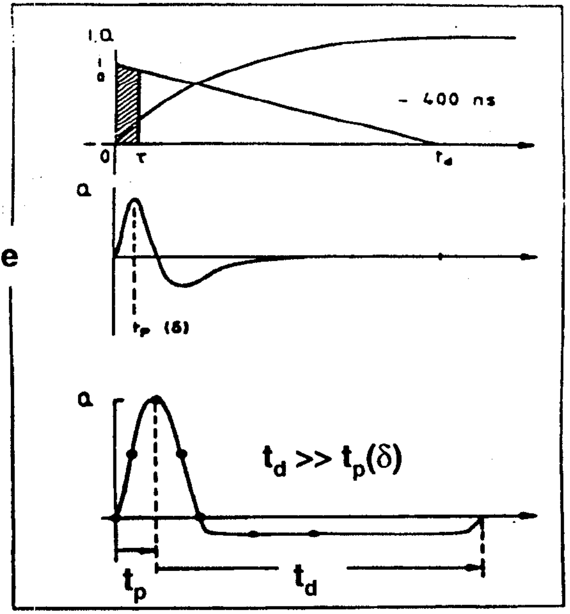




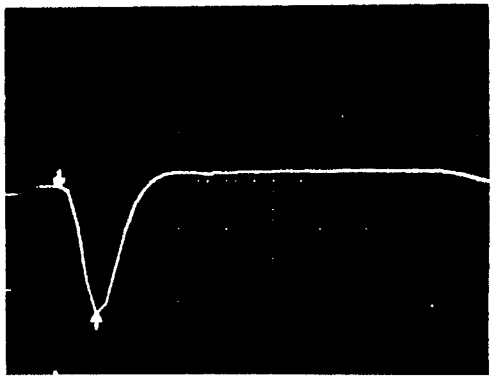
LAr Accordion time response for fast shaping



typical LAr response

bipolar shaping δ-pulse

bipolar shaping LAr pulse



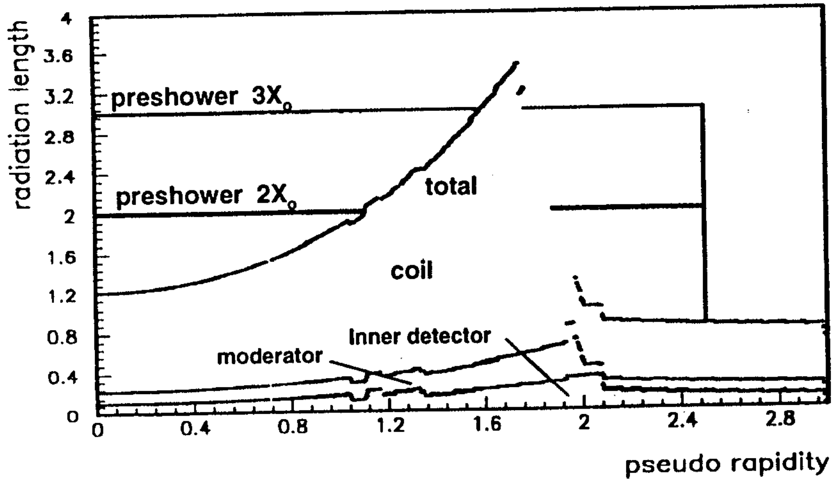
60 GeV electron signal with

$t_p(\delta)$ = 20 ns
t_p(LAr current) = 38 ns

Liquid Argon preshower detector design

Required for:
- energy correction because of the cryostat and coil material in front
- electron identification
- rejection of $\pi^0 \to \gamma\gamma$ background in the $H \to \gamma\gamma$ search

Material in front of EM calorimeter



Two layers of orthogonal strips preceeding the EM with granularities $\Delta\eta x \Delta\phi$ ~ 0.002x0.08 and $\Delta\eta x \Delta\phi$ ~ 0.08x0.002

300000 channels total, dynamic range (1/4 to < 300 MIP)

1 cm LAr traversed gives MIP / noise ~ 7

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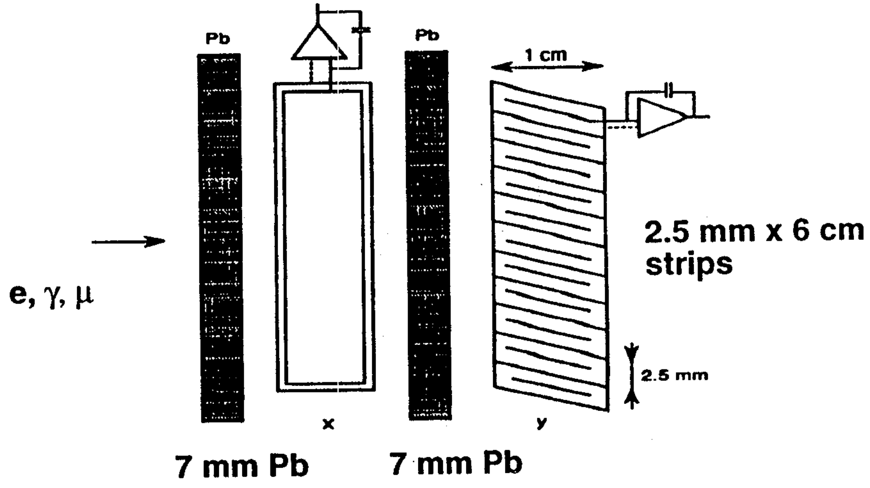
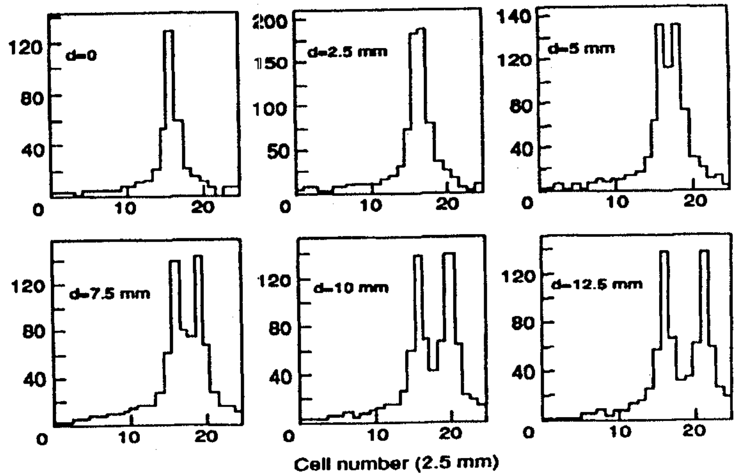
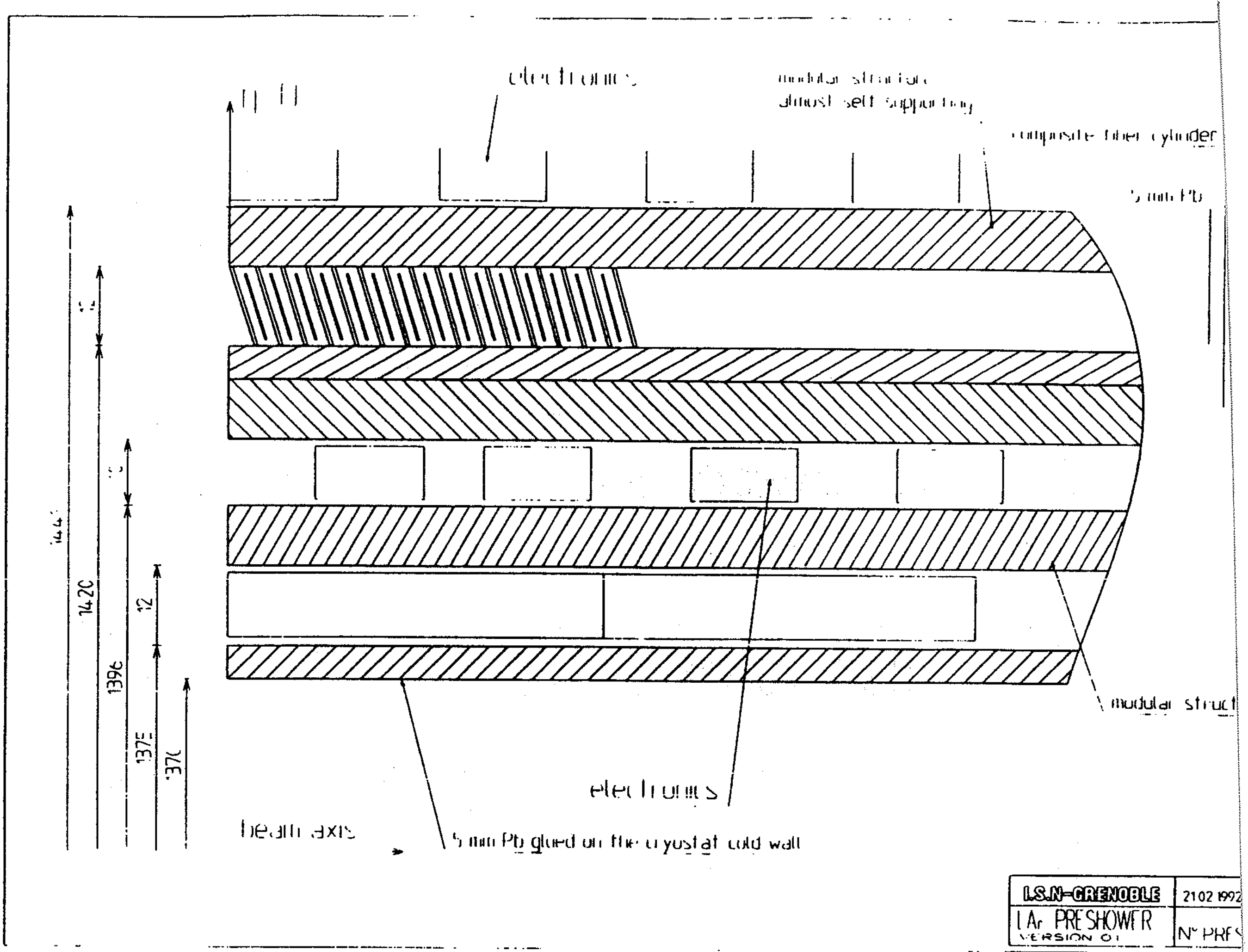
LAr preshower test beam module in front of EM Accordion calorimeter

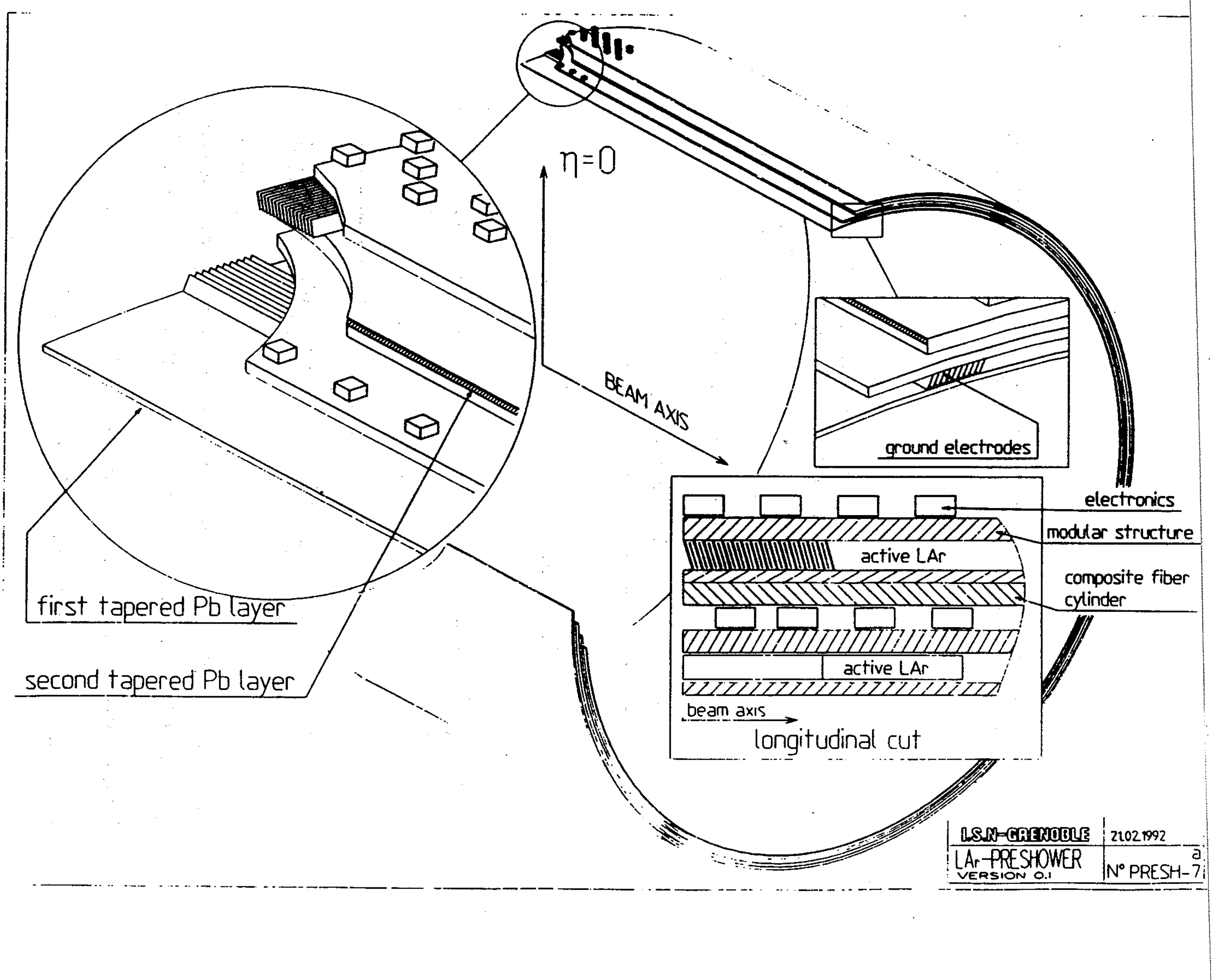


Separation capability for overlapped γ (averages)





I.S.N.-GRENOBLE 21.02.1992
LAr PRESHOWER
VERSION 0.1
N° PRES

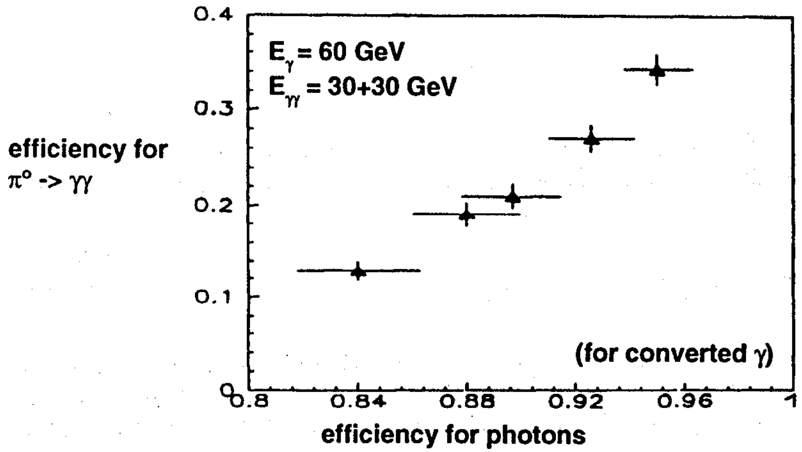


I.S.N.-GRENOBLE 21.02.1992
LAr-PRESHOWER
VERSION 0.1
N° PRESH-7

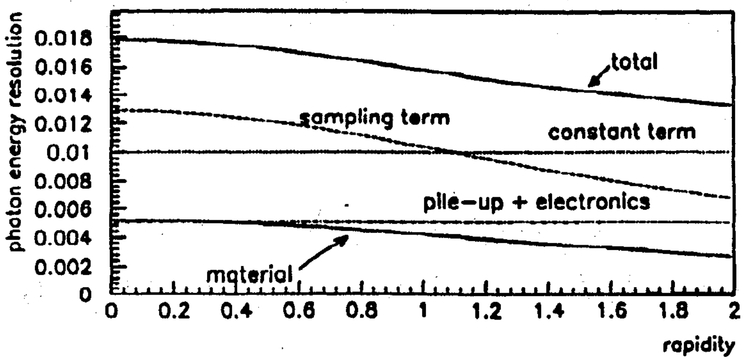
H -> $\gamma\gamma$ simulation using measured test beam performances of LAr preshower and EM calorimeter

π^0 -> $\gamma\gamma$ backgrounds constructed by overlapping single γ data from tagged γ beam

Simulated rejection power of preshower detector



Contributions to the γ energy resolution (m_H = 100 GeV)



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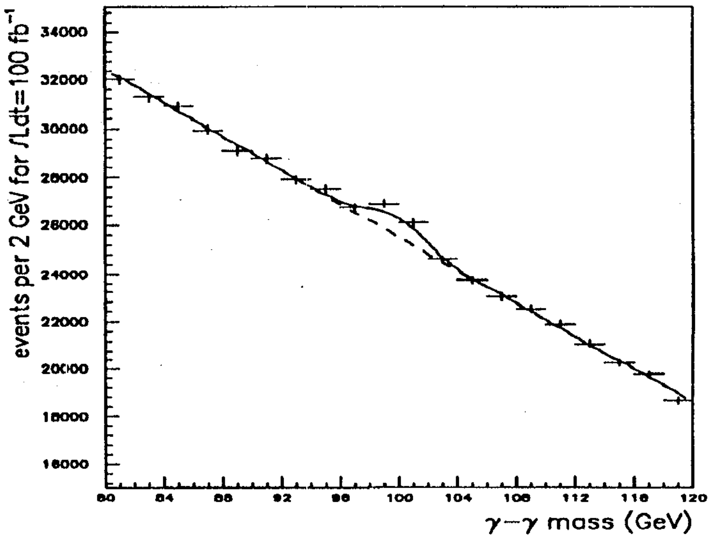
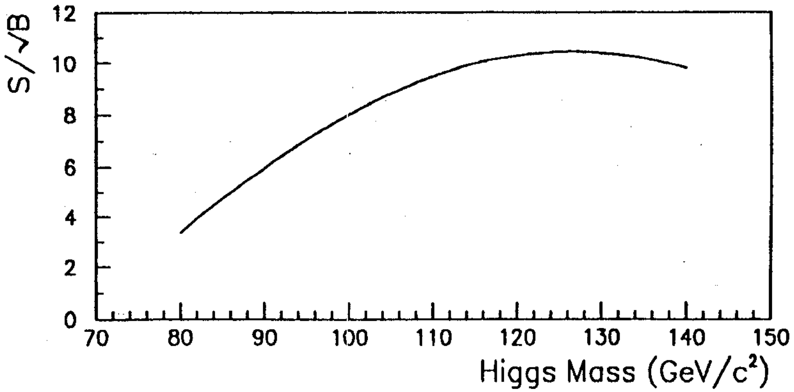
100 GeV H --> $\gamma\gamma$ simulation using LAr preshower and EM Accordion calorimeter performances from test beam

Simulation of QCD jet and π^0 background included



Significance as a function of m_H for 10^5 pb^{-1}



Scintillator tile hadron calorimeter conceptual design

Novel concept for a simple and economic hadronic scintillator calorimeter with Fe absorber and possibly integrated magnetic field return

Vertical scintillator plates (w.r.t. barrel axis) read out with straight wave length shifting fibers at two edges (light collection experimentally checked)

Granularity $\Delta\eta x \Delta\phi \sim 0.1x0.1$ with 4 longitudinal samples, 15000 channels total

η-projectivity by grouping WLS readout fibers of the longitudinal samples to form approximatively pointing towers

Expected jet resolution (MC simulation assuming a 25 X_o Pb - LAr EM calorimeter in front)

$$\sigma(E)/E = 41\%/E + 2\%$$

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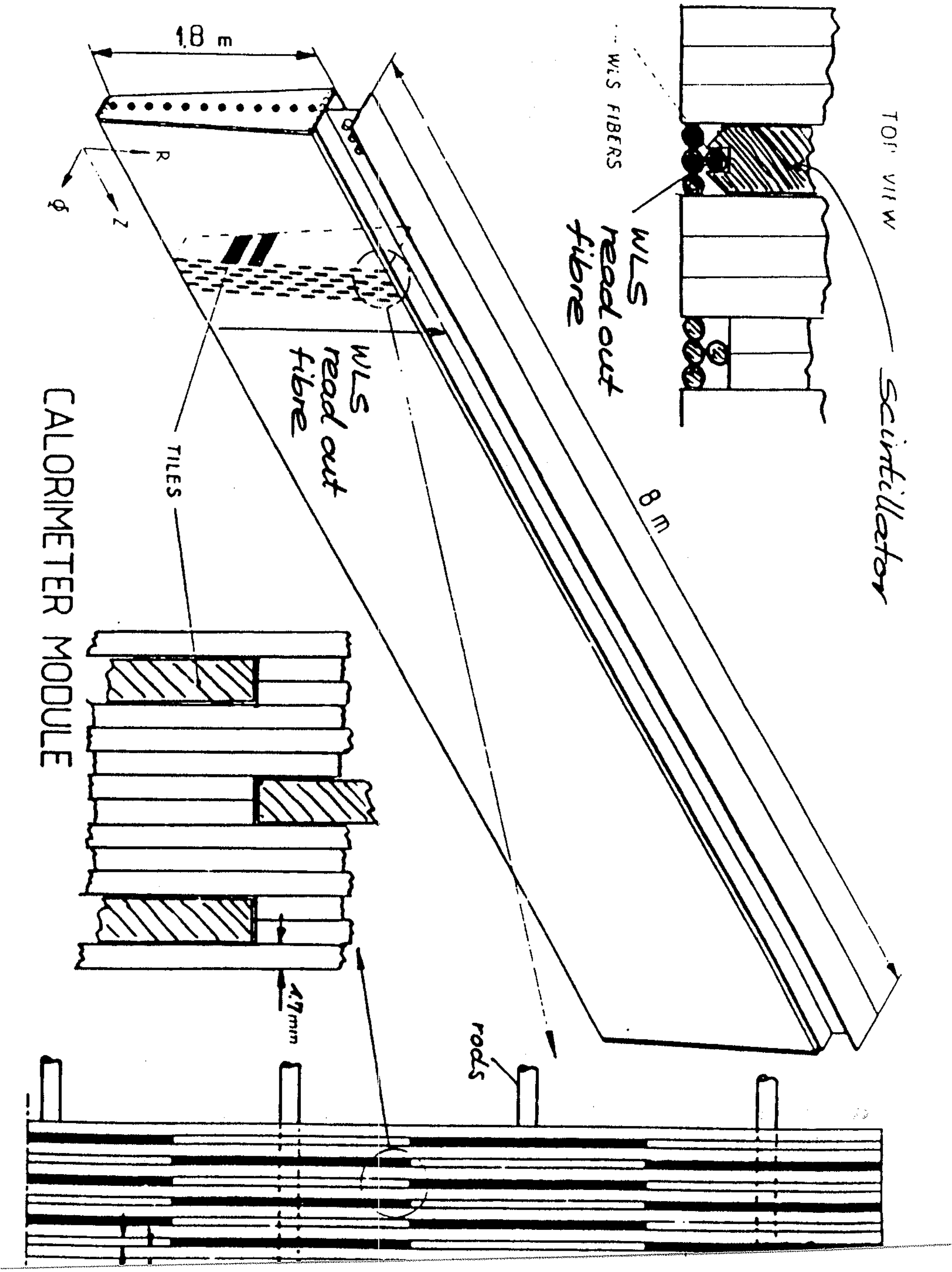
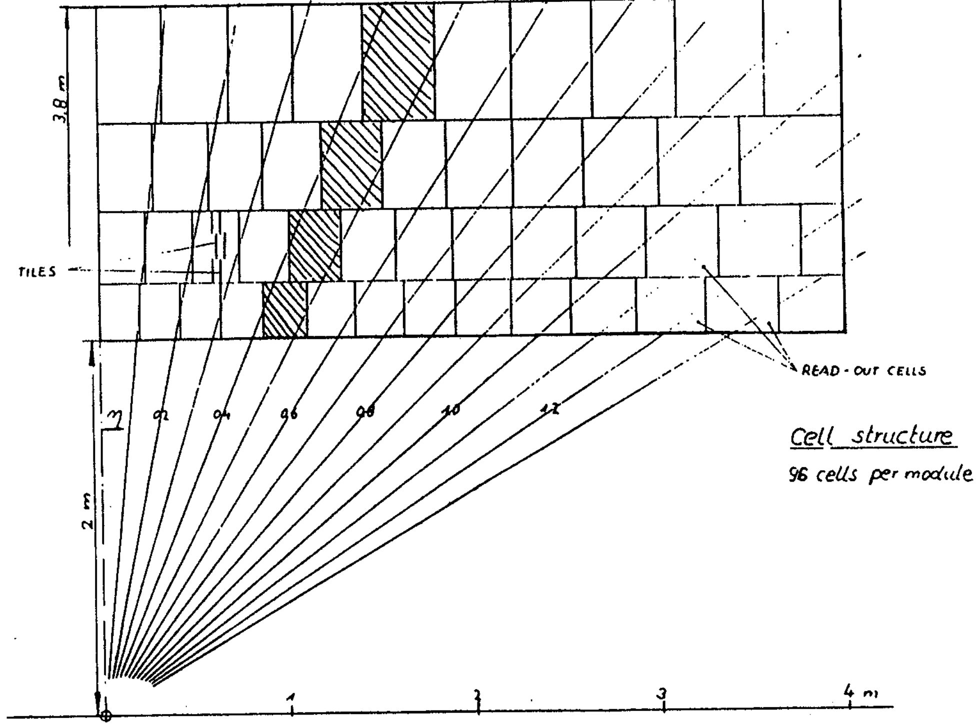
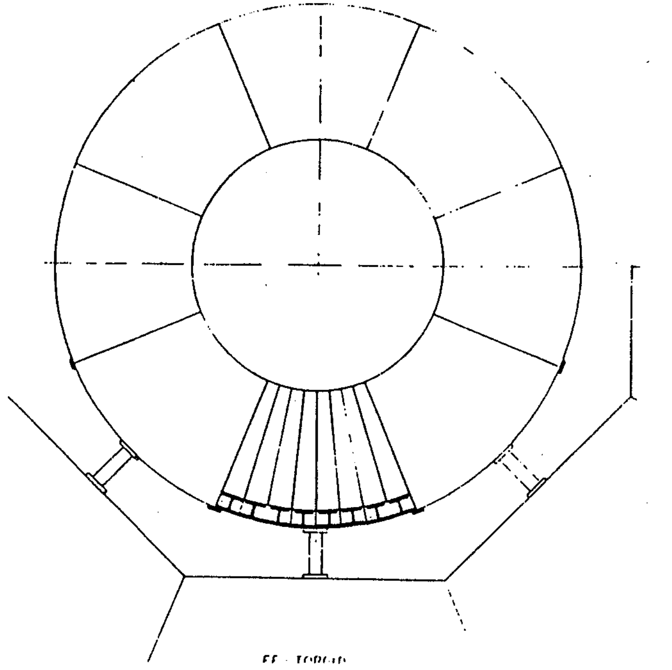




Cell structure
96 cells per module



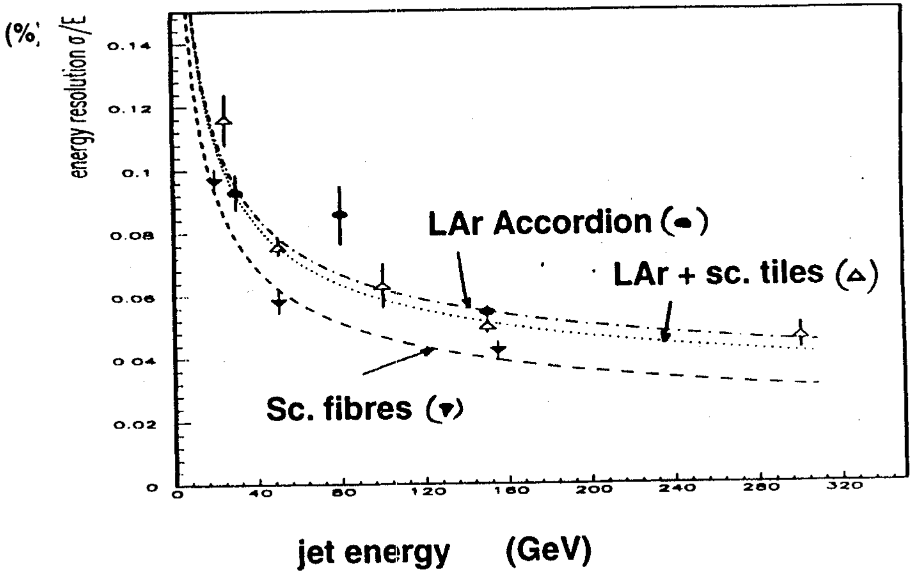
Simulated jet energy resolutions

Summary of the options considered:

scintillating fibres $\sigma(E)/E = 38\%/\mathrm{sqrt}(E) + 0.9\%$

LAr Accordion $\sigma(E)/E = 40\%/\mathrm{sqrt}(E) + 2.2\%$
(with longitudinal weighting)

LAr EM combined with scintillator tiles hadronic
$\sigma(E)/E = 41\%/\mathrm{sqrt}(E) + 1.8\%$



Detailed simulation studies investigate non-Gaussian tails, non-linearities .... for very high p_T jets, whereas pile-up effects are an important limitation at lower p_T jets (below typically 100 GeV).
Coil material and magnetic field effects are also studied.

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Very forward calorimetry

Separate detectors covering the very forward regions

($3 < |\eta| < 5$)

Required:
- complement missing E_T measurements (top quark physics, SUSY searches, $H \to ZZ \to l^+l^- \nu\bar{\nu}$ search ...)
- jet tagging for heavy H search

Technologies actively studied in EAGLE

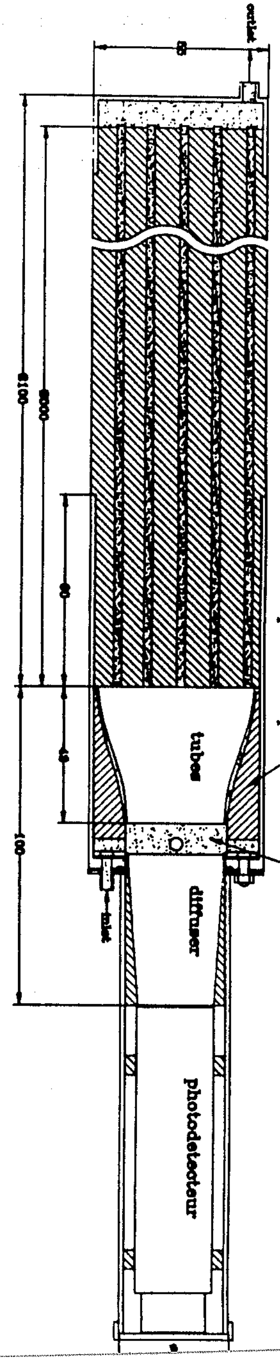
- *liquid scintillator in capillary tubes (ITEP)*
- *high pressure gas tubes (IHEP)*

Conceptual design

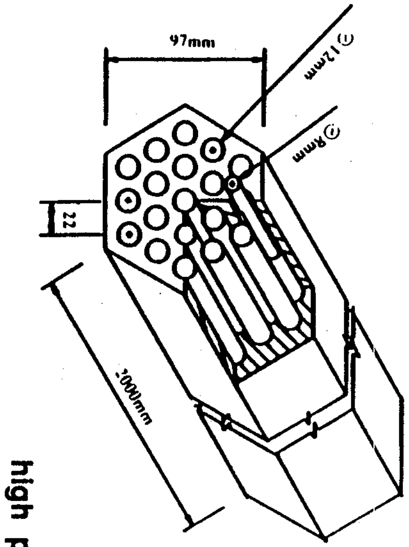
- quasi-projective geometry (direct E_T measurement), typical cell size 6x6 cm^2, 1000 - 3000 cells per side
- replaceable active media (hard radiation environment), liquid scintillator or gas (90% Ar/Xe + 10% CF_4 at 20 - 30 atm)
- adequate resolution and time response ($\sigma(E)/E < 100\%/\mathrm{sqrt}(E) + 5\%$, < 30 ns)
- rectractable, about 200 t per side

EAGLE presentation Evian 6-3-1992

VERY FORWARD CALORIMETER MODULE



liquid scintillator option

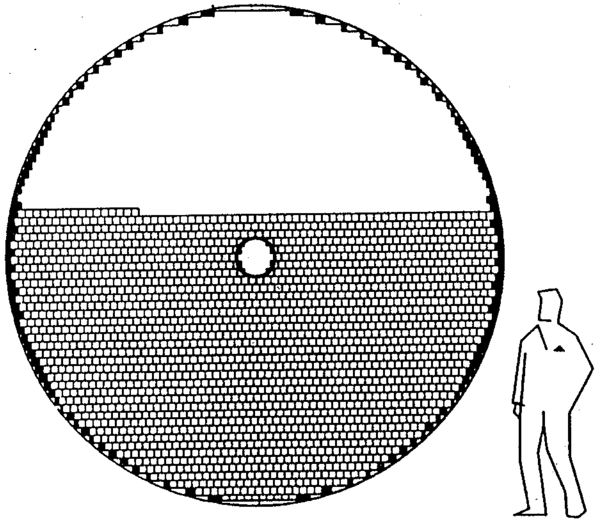


high pressure gas option

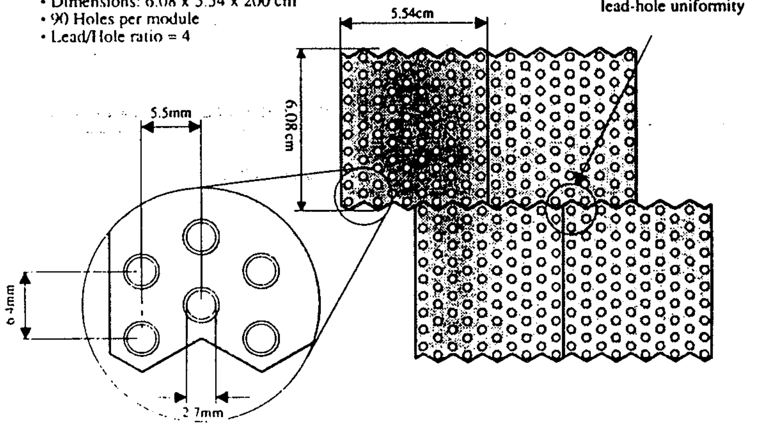
Very forward calorimeter assembly

number of modules 3126
gross weight 200 t

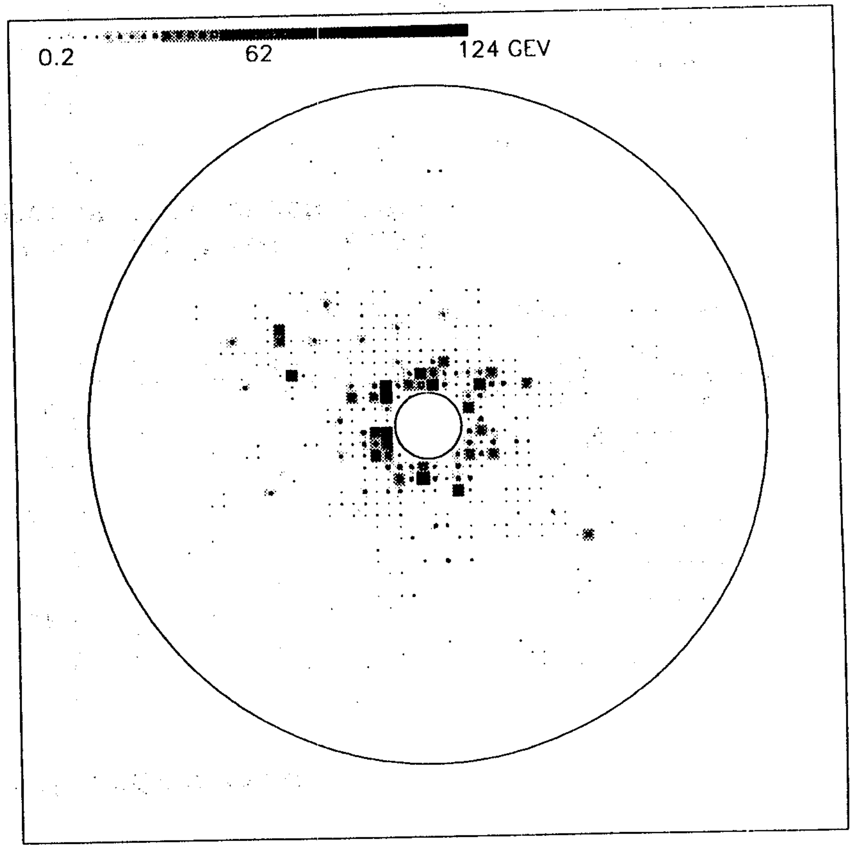
Sensitive area $20 < R,\mathrm{cm} < 180$
or $2.8 < |\eta| < 5.0$, at 15 m



- Dimensions: $6.08 \times 5.54 \times 200\ \mathrm{cm}^3$
- 90 Holes per module
- Lead/Hole ratio = 4

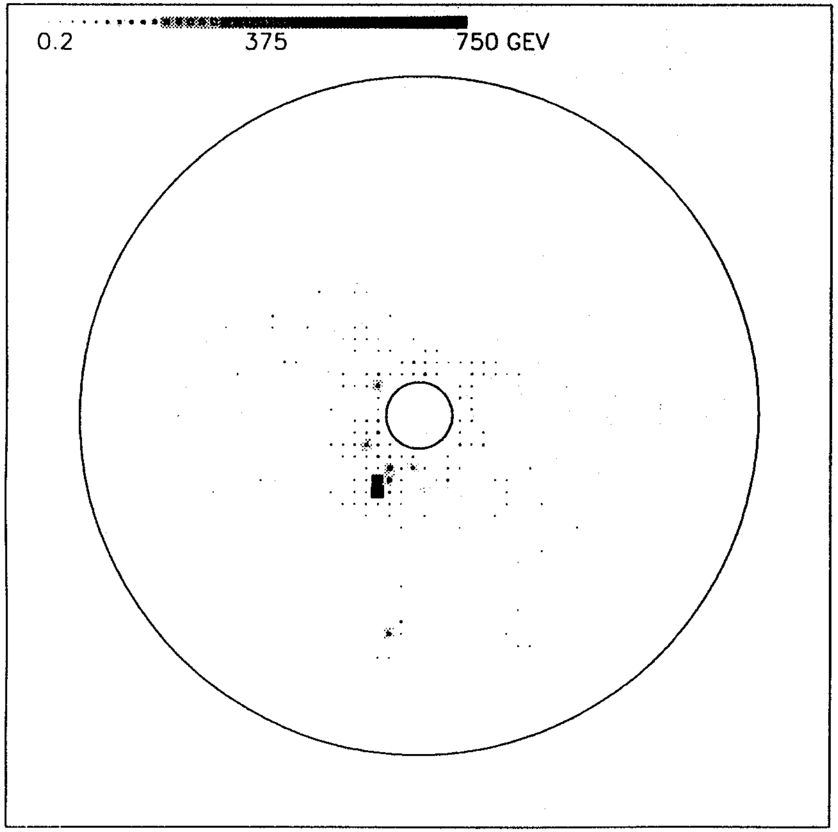


FORWARD REGION DETECTOR



20 MINIMUM BIAS EVENTS, OVERLAYED

FORWARD REGION DETECTOR

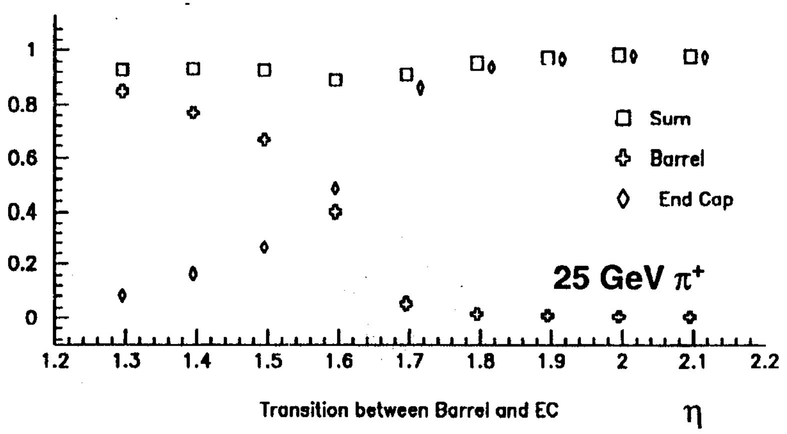


WW FUSION + 20 MINIMUM BIAS

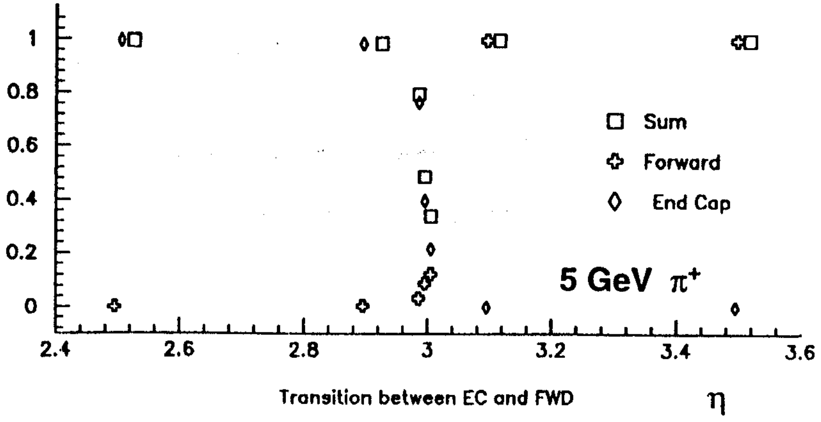
Calorimeter hermeticity

examples of hadron response studies over detector boundaries

barrel - end cap region

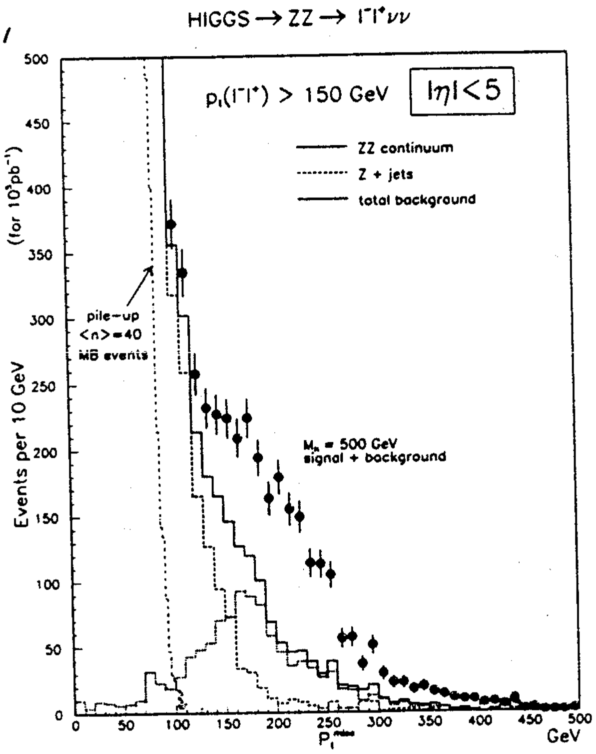


end cap - very forward region (geometry not yet optimized)



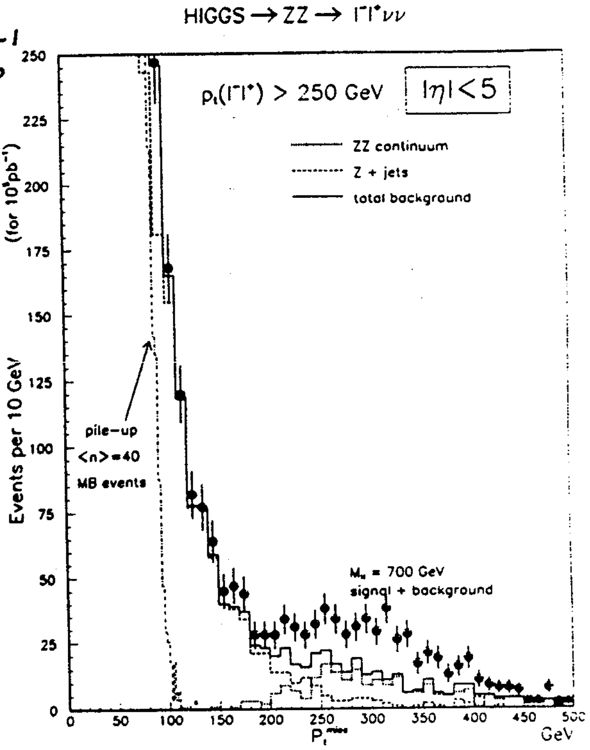
$m_H = 500$ GeV

$10^5 pb^{-1}$

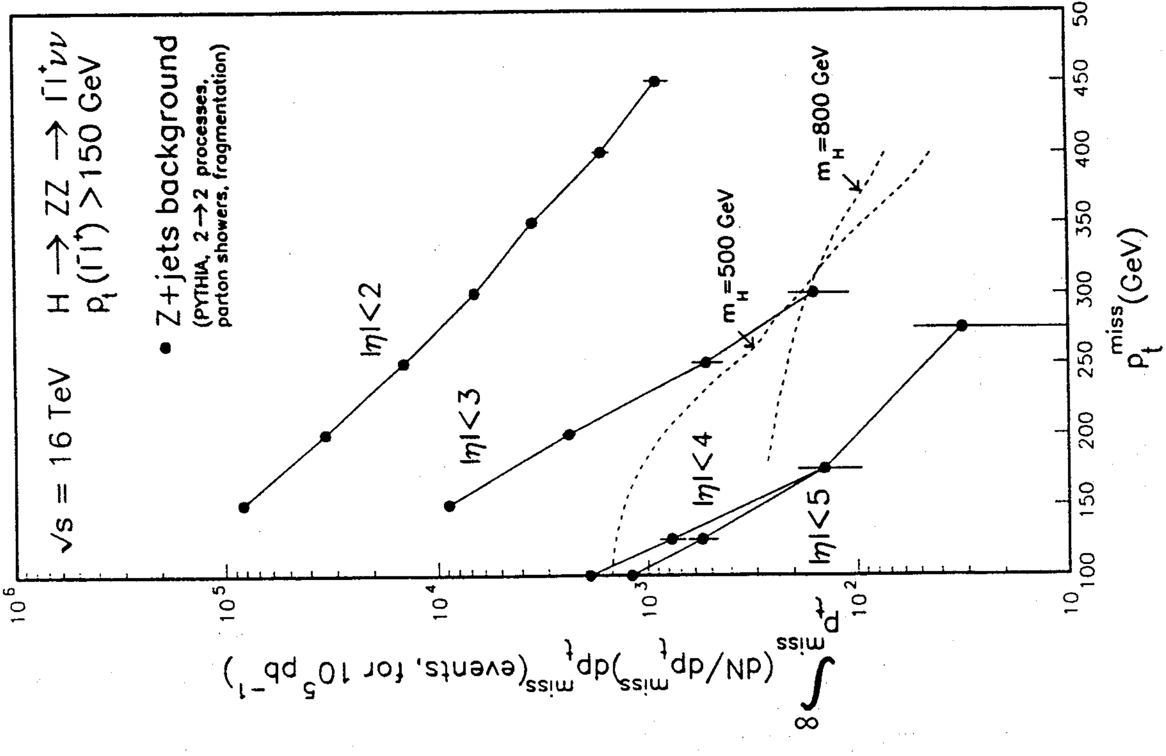


$m_H = 700$ GeV

$10^5 pb^{-1}$



Effect of calorimeter coverage



Inner detector

Role of the inner detectors in the EAGLE concept

primary goals:

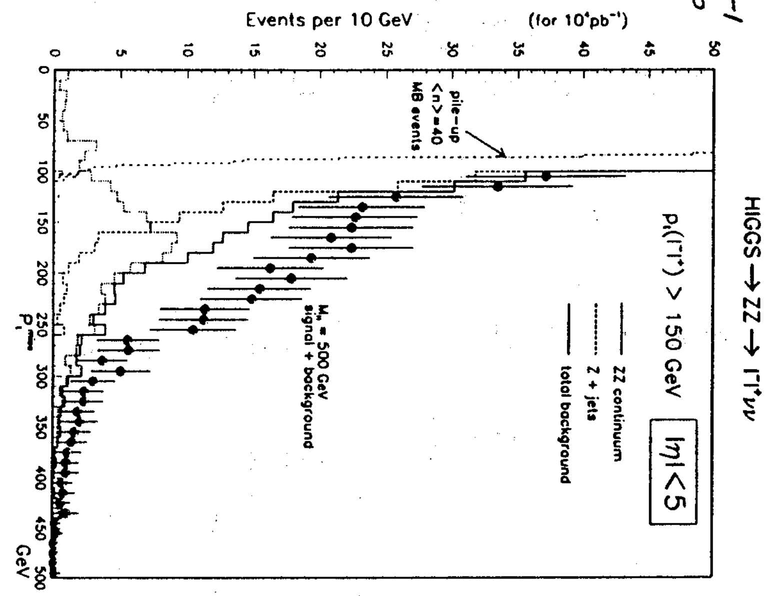
- **tracking and precision momentum measurement in the 2 T solenoidal field for isolated leptons ($e^{\pm}$ and $\mu^{\pm}$) over large pseudorapidity**
- **enhance electron identification (required in addition to the calorimeter)**

additional capabilities:
(at initial lower luminosities, and to as high a luminosity as practicable)

- **heavy flavour tagging with (removable) vertex detector**
- **τ-lepton identification (together with calorimeter)**

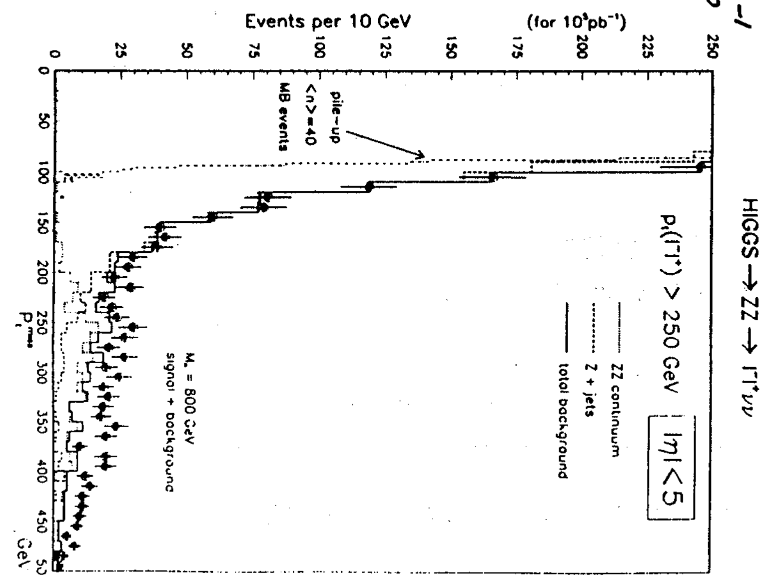
$m_H = 500$ GeV

$10^4 pb^{-1}$



$m_H = 800$ GeV

$10^5 pb^{-1}$

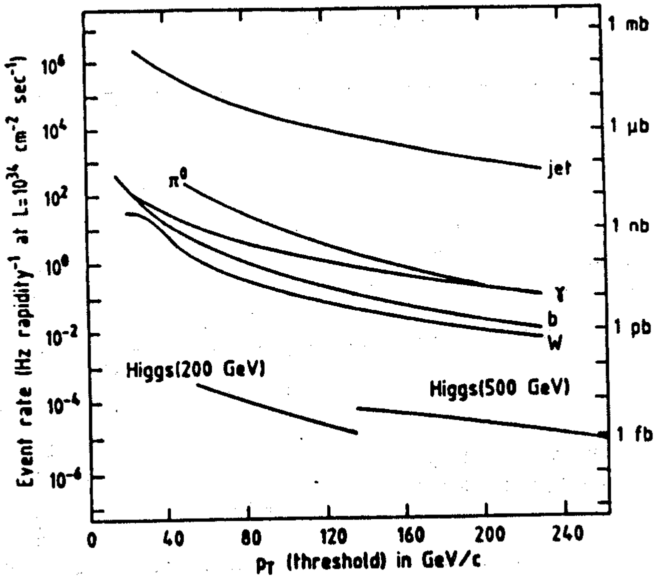


Electron identification and tracking

Large rejections are needed at LHC against backgrounds from jets, π^0 and γ:

10^5 - 10^6 against jets
10^2 - 10^3 against π^0 and γ

to reach the level of real electrons from heavy flavour and W decays

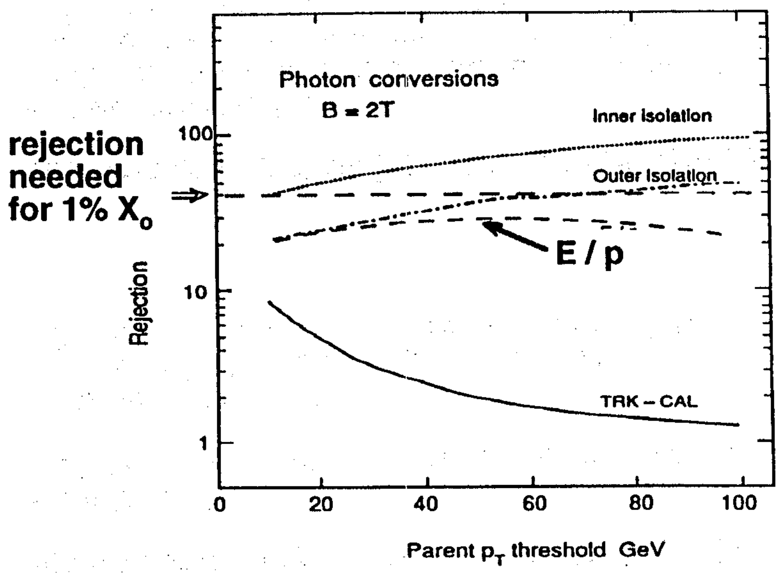


Calorimetric selection criteria provide only jet rejections at the level of 10^3

Remaining backgrounds:
- e^+e^- pairs (γ conversions, Dalitz decays) dominant
- hadrons or hadron + γ overlaps (expected to be ~ 10^{-6})

Strategy for electron identification in the inner detector:

-> E_{calo} and p_{track} matching

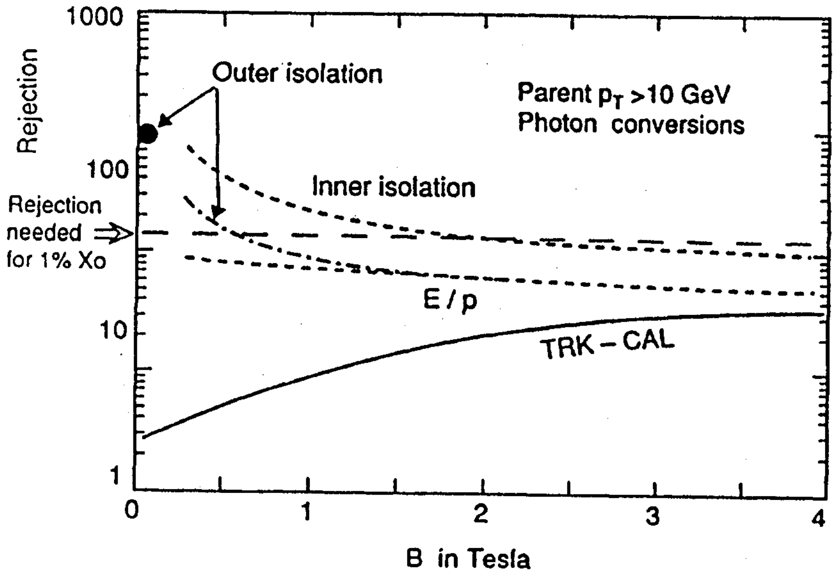


-> Further rejection comes from recognizing

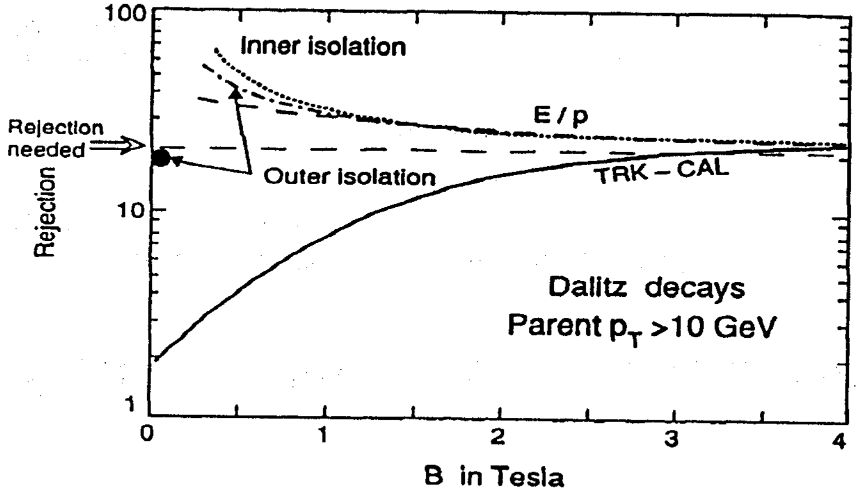
- conversions inside tracker volume (efficient 1st layer)
- Dalitz and early conversions: pattern recognition and identification of pair partner at very low p_T (>0.5 GeV) (TRD simulation: additional rejection is ~ 15)

Detailed simulations lead to background estimates of < 10% of the real electron rate for p_T > 20 GeV at high luminosity

Rejection of electron pairs from photon conversions



Rejection against Dalitz decays



Inner detector components under study

<u>Innermost tracker and vertex detector (r < 35 cm)</u>

- ***basic design:***
  Silicon micro strip counters (based on RD20)

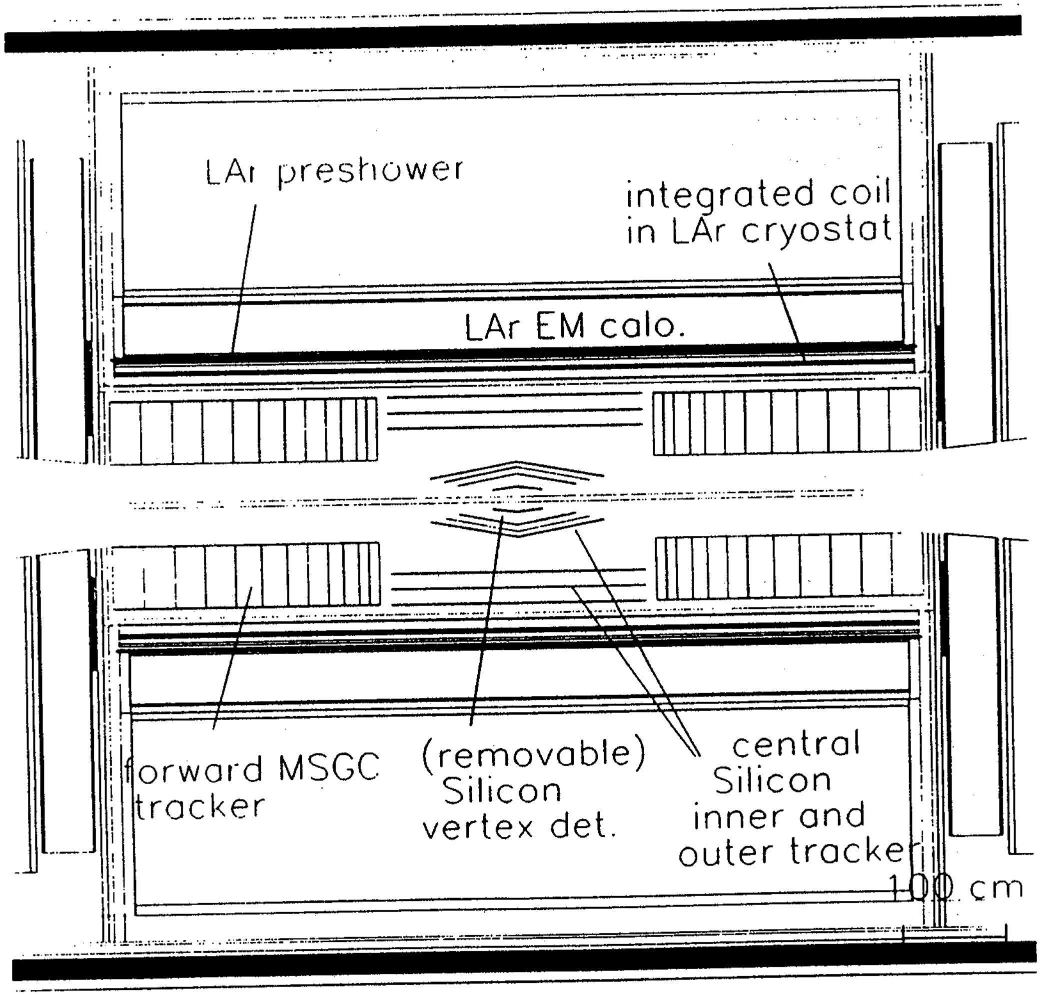
- ***enhancement options:***
  Silicon pixel detectors (based on RD19)
  GaAs micro strip counters (based on RD8)

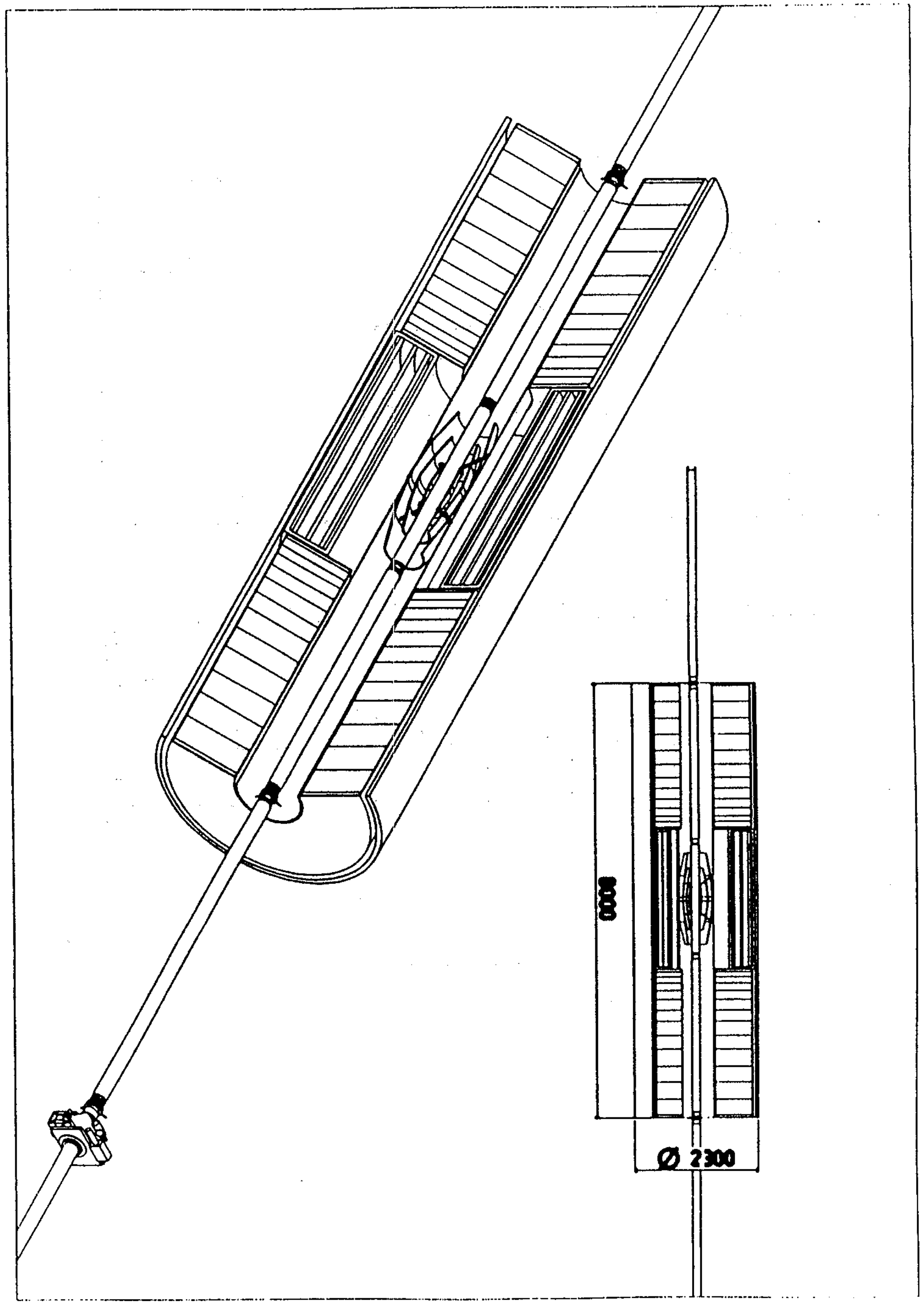
<u>Tracking and electron identification detectors at r > 35 cm</u>

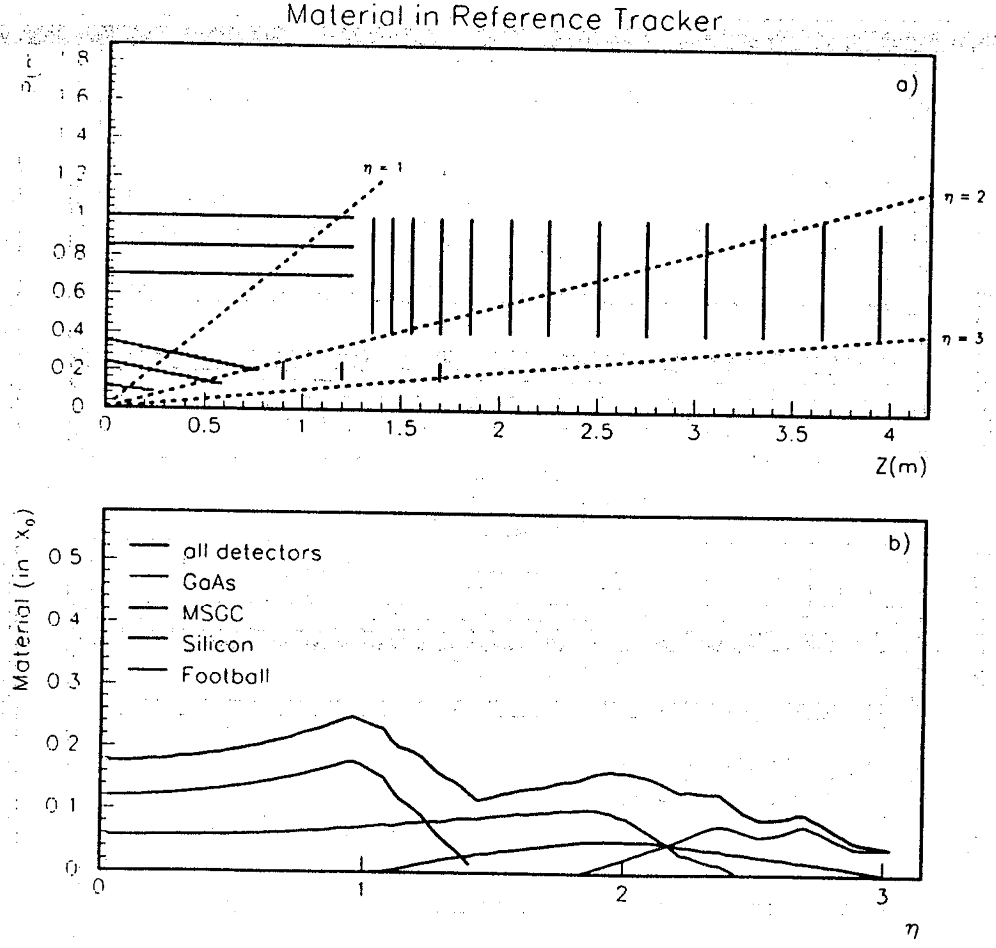
- ***basic designs include:***
  Silicon strip and pad detectors (based on RD2)
  Micro strip gas counters (based on R&D work of NIKHEF, Liverpool and other labs)
  Transition radiation tracking (based on RD6)

- ***in addition also investigated:***
  Scintillating fibre tracking (based on R&D work of Frascati and Pisa)

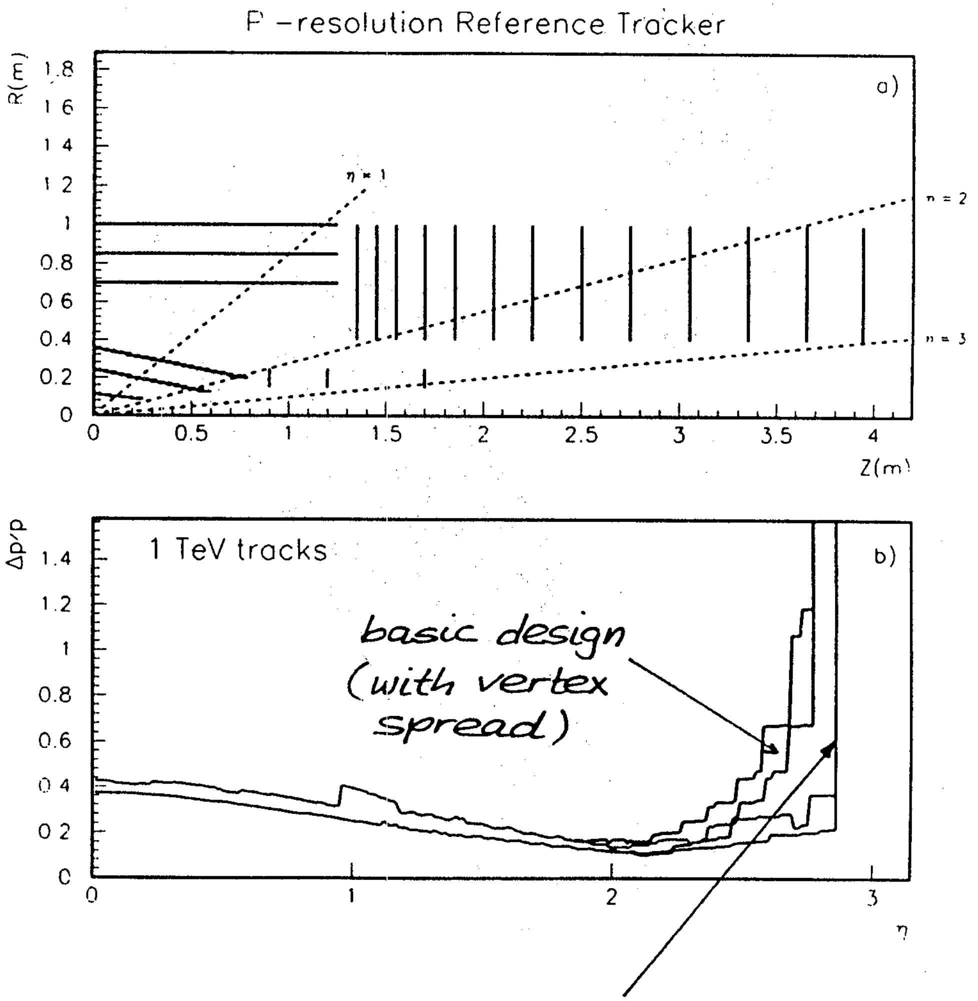
Inner detector version A







Material in Reference Tracker

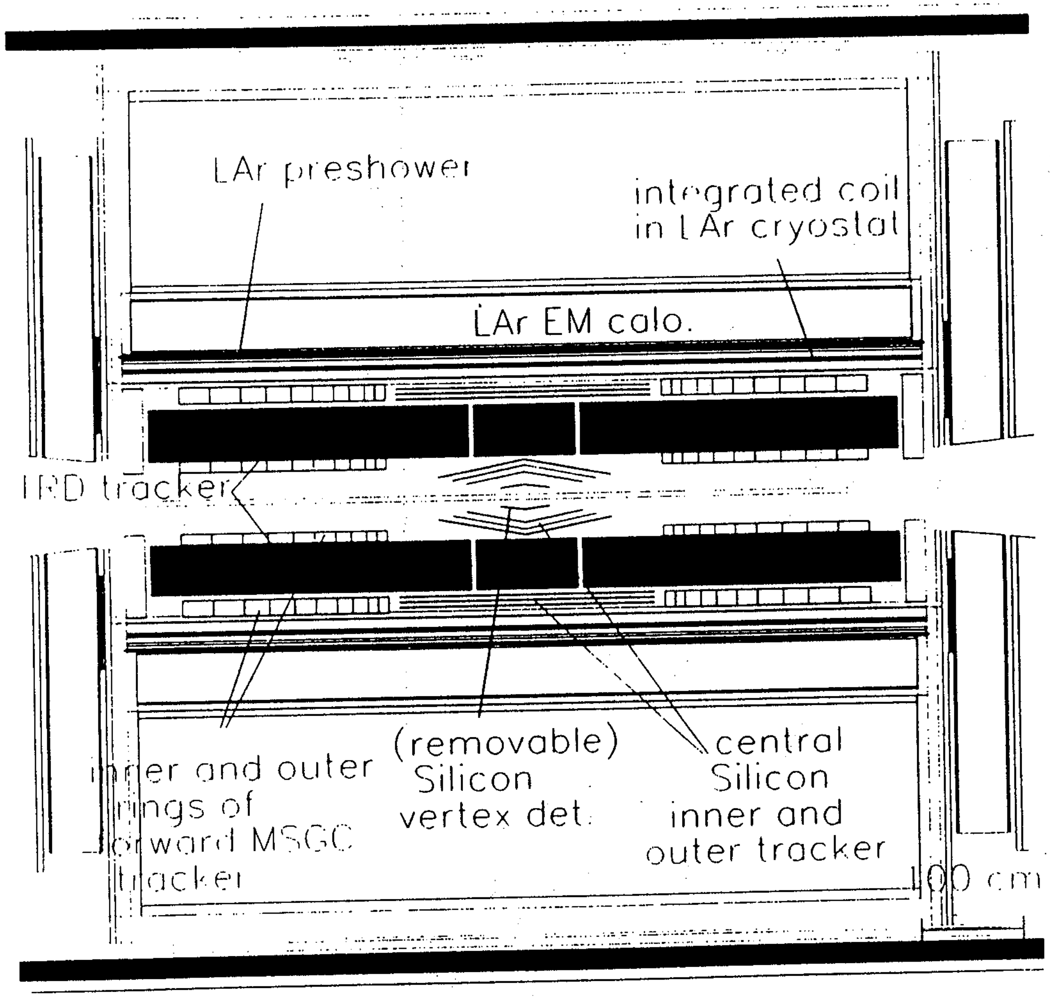


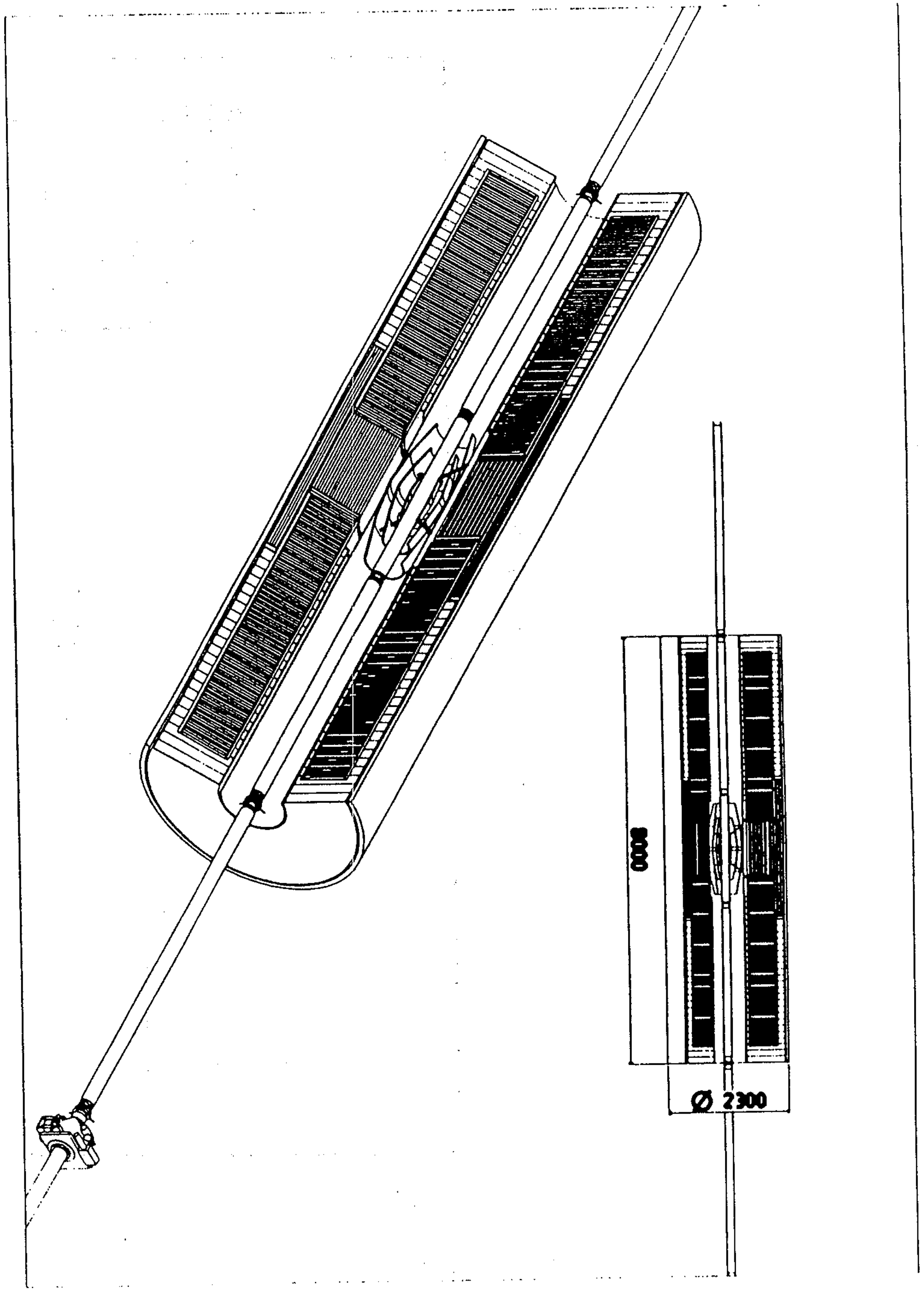
P -resolution Reference Tracker

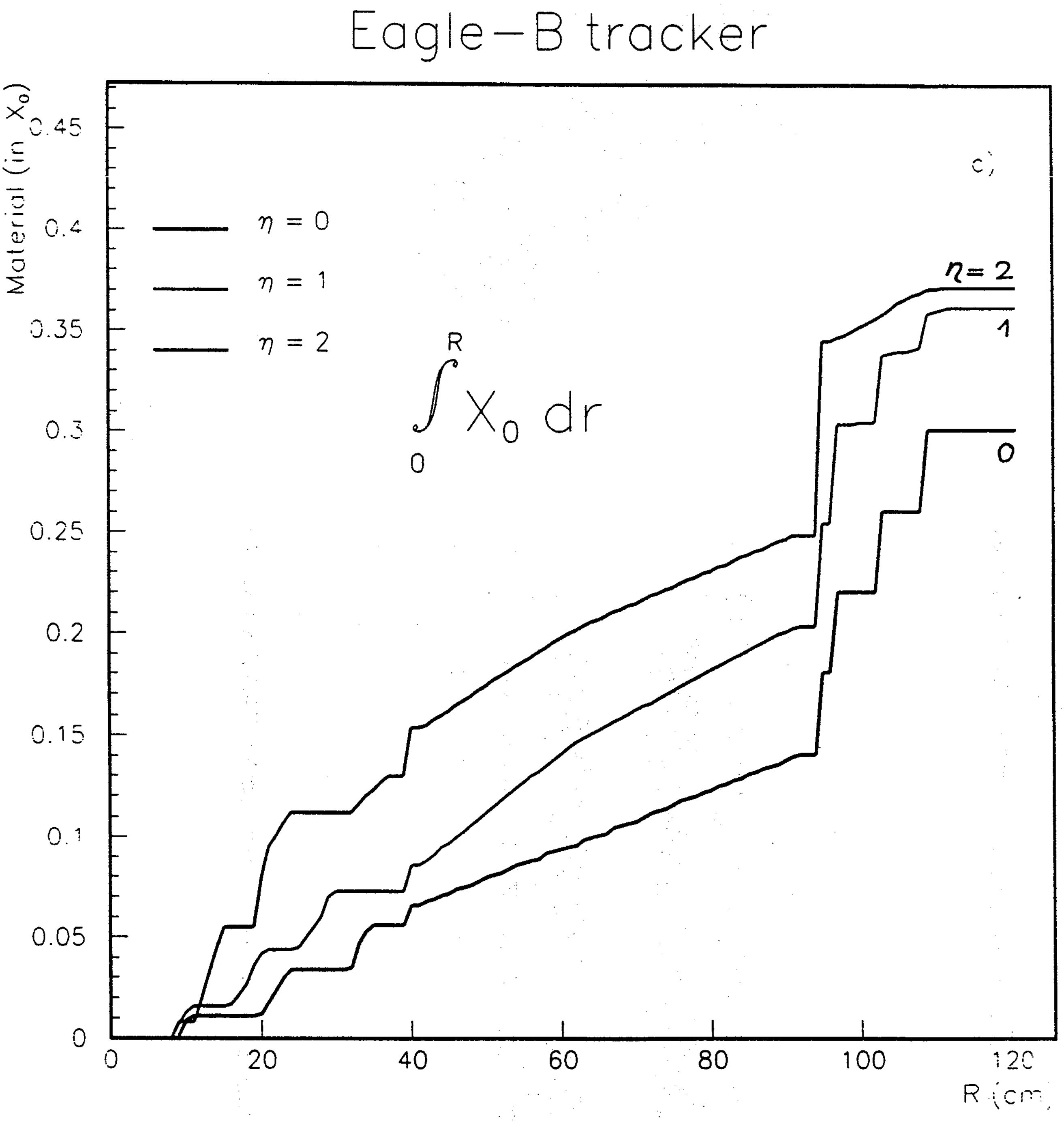
basic design (with vertex spread)

including forward GaAs wheels

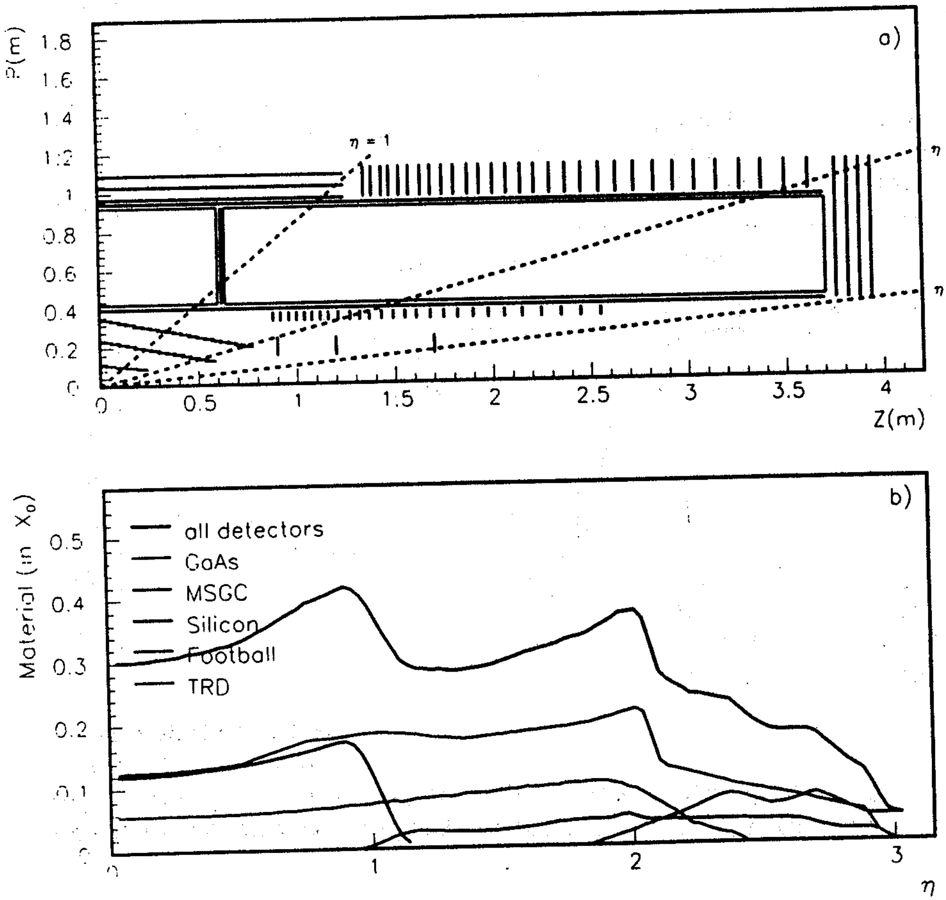
Inner detector version B



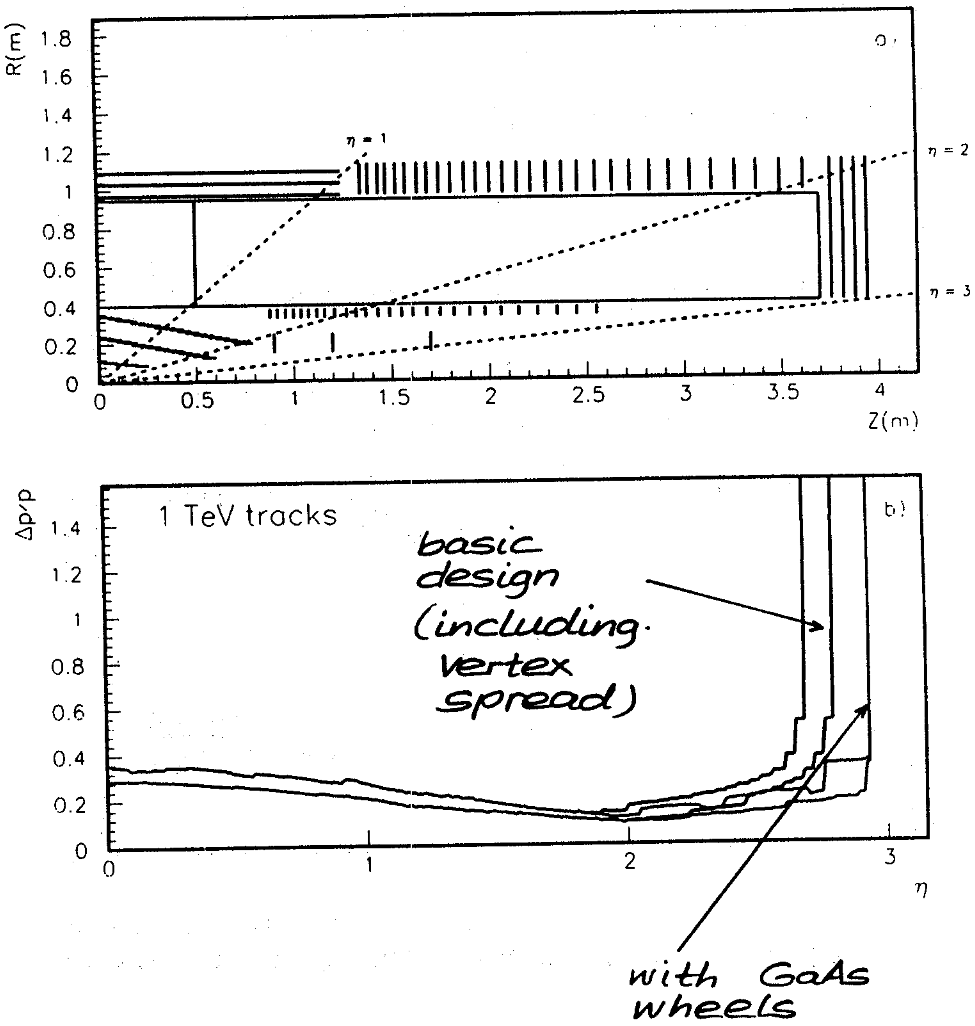



Eagle-B tracker
Material (in X$_0$)
0
0.05
0.1
0.15
0.2
0.25
0.3
0.35
0.4
0.45
c)
η = 0
η = 1
η = 2
$\int_0^R X_0\, dr$
η= 2
1
0
0
20
40
60
80
100
120
R (cm)

Momentum resolution for 1 TeV tracks



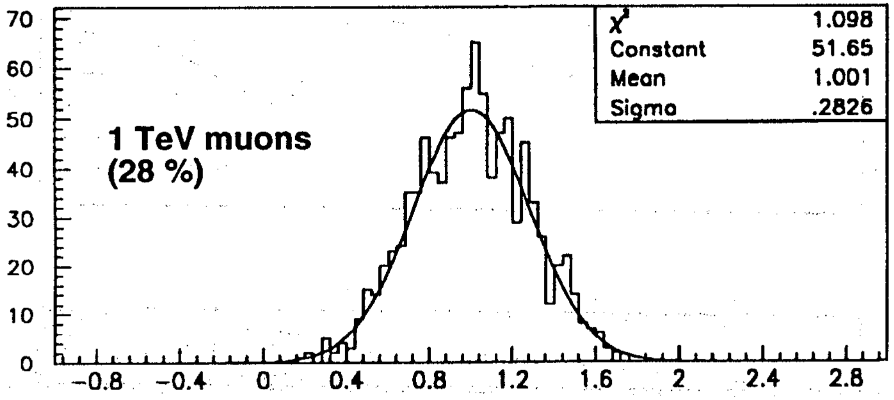
Material in EAGLEB Tracker



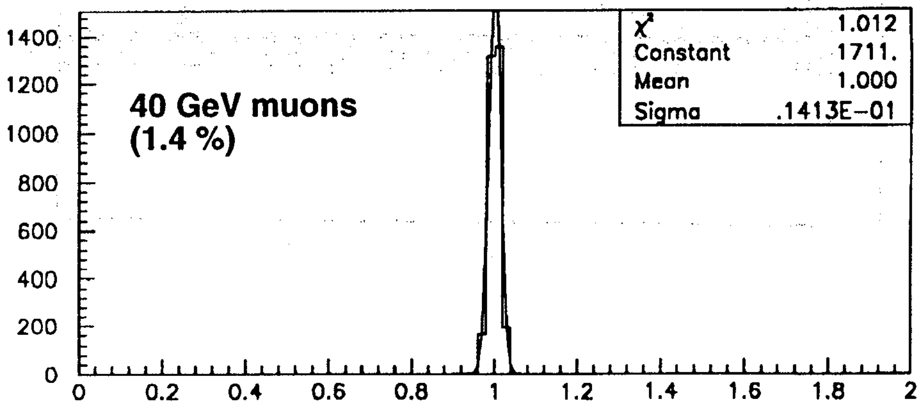
P -resolution EAGLEB Tracker

Pattern recognition and momentum resolution simulations

- define roads from calorimeter and muon detector
- demand 3 out of 4 hits in inner tracker and 5 out of 6 in outer tracker
- 5 parameter helix fit

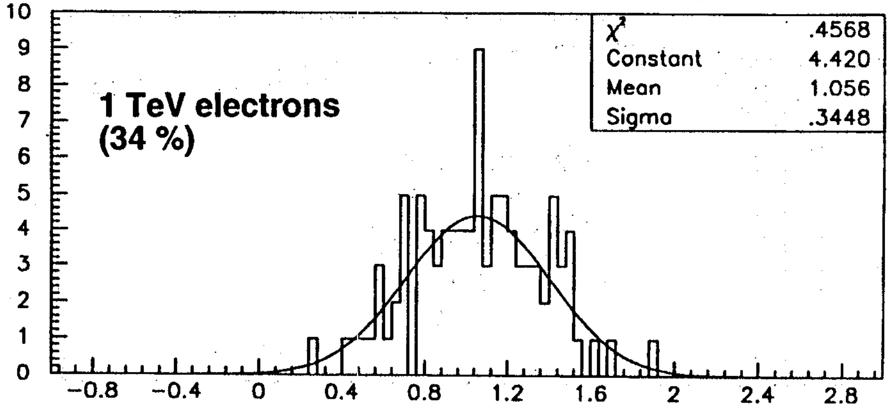


trackfit 1/Pt (TeV) for 1 TeV muons at eta=0.

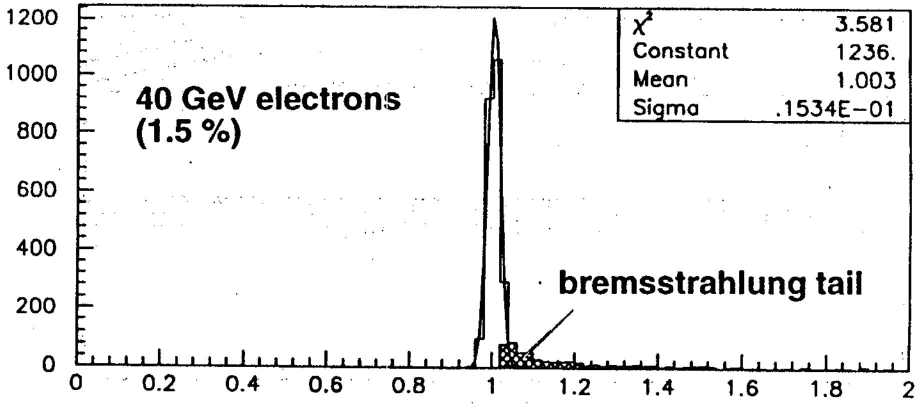


trackfit 1/Pt (GeV) for 40 GeV muons at eta=0.

For electrons the bremsstrahlung effects due to the tracker material are important



trackfit 1/Pt (TeV) for 1 TeV electrons at eta=0.



trackfit 1/Pt (GeV) for 40 GeV electrons

TRD tracking is expected to recover events in the bremsstrahlung tail which would fail E vs p selection

Simulated electron tracking efficiencies

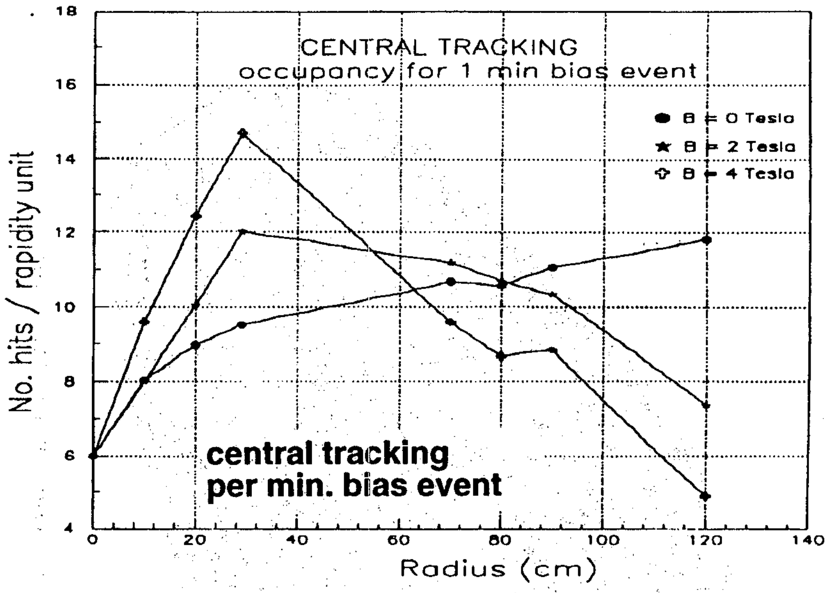
electron tracking efficiencies, including

- pattern recognition
- E vs p criteria (cut at 1.2)
- calorimeter selection (radius cut < 1 cell unit and cluster energy within 3σ)

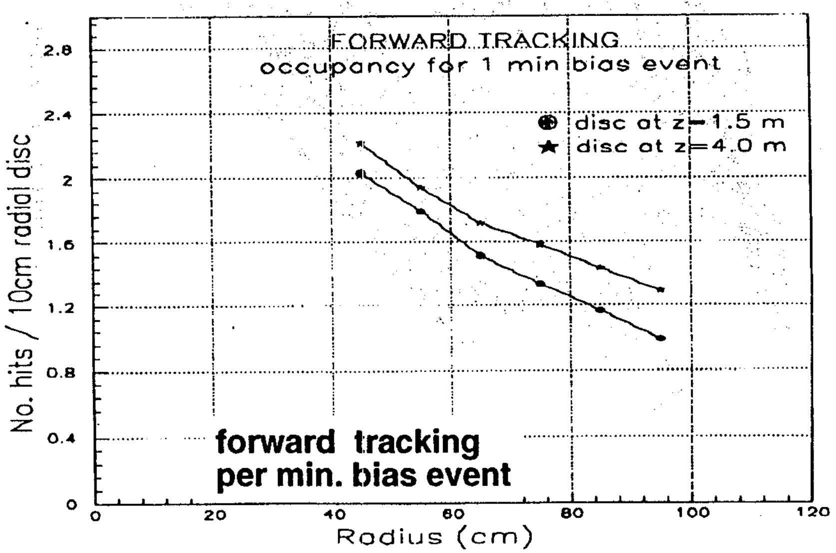
η	configuration	10 GeV	20 GeV	40 GeV
0	no TRD, no pile-up	0.93	0.97	0.98
1.2	no TRD, no pile-up	0.87	0.94	0.97
1.2	with TRD and pile-up	0.92	0.96	0.98

note: - rejection against em jets is under study

Occupancy studies for the inner detector



central tracking per min. bias event



forward tracking per min. bias event

Inner Silicon tracker and vertex detector (SITV)

Conceptual design with 3 super-layers, each consisting of 2 layers of wafers

- middle and outer super-layers are mainly for momentum measurements ($| \eta | < 2$)
  resolution 20 - 30 μm per point
- inner super-layer with independent mechanical support is mainly for vertexing ($| \eta | < 1.5$)
  resolution < 20 μm per point

Detectors
- single or preferentially double-sided Silicon strip detectors, pitch 50 - 100 μm, 13 m^2 all
- inner super-layer could be of the next generation of solid state detectors, in particular Silicon pixels

Number of channels: 4 - 5 10^6

Cooling
- about 7 kW power dissipated (for 1.5 mW/ch)
- various schemes considered, for example He gas flow at 7 ms^{-1} through the whole detector for operation at < 0°

Total material: 4 - 9 % X_o depending on η

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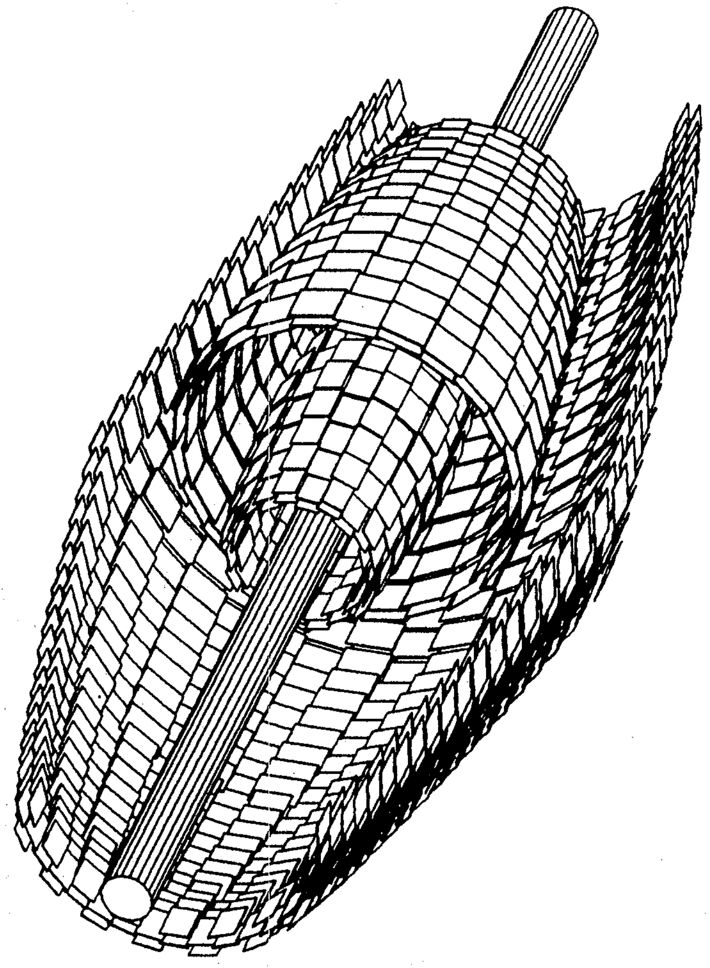
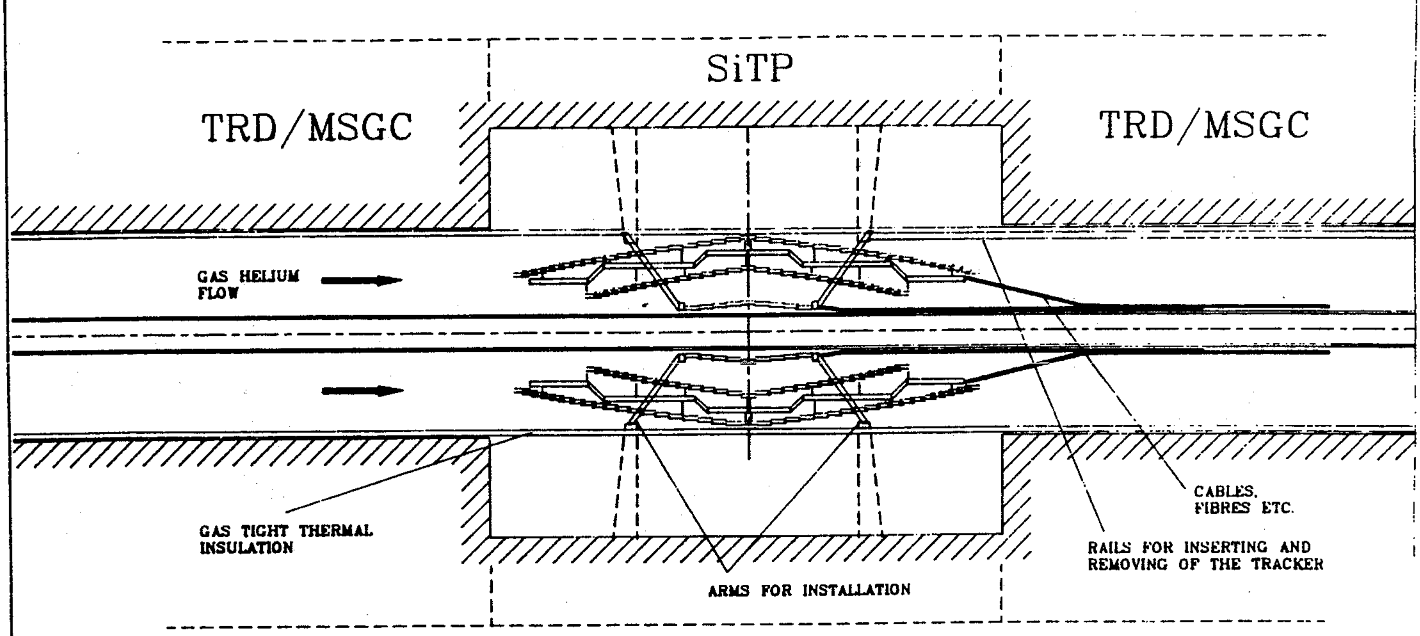


Si-detector wafers in the vertex/tracker



Si–vertex/tracker inside a spectrometer

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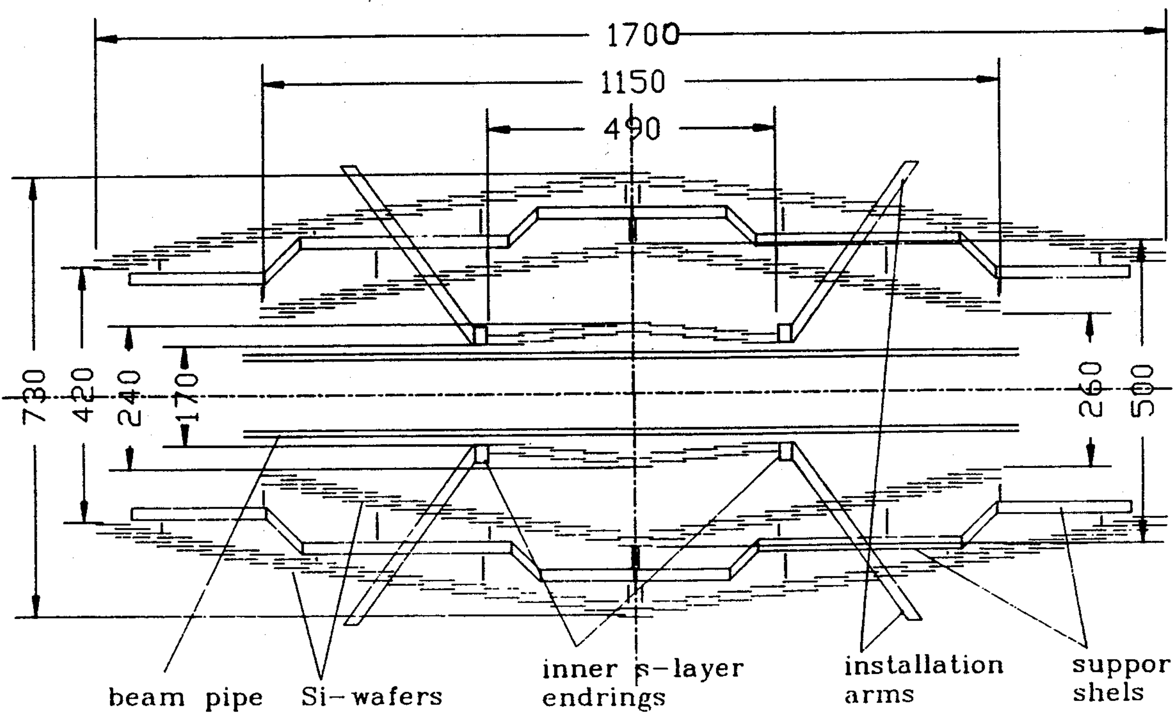

Si–vertex/tracker geomerty

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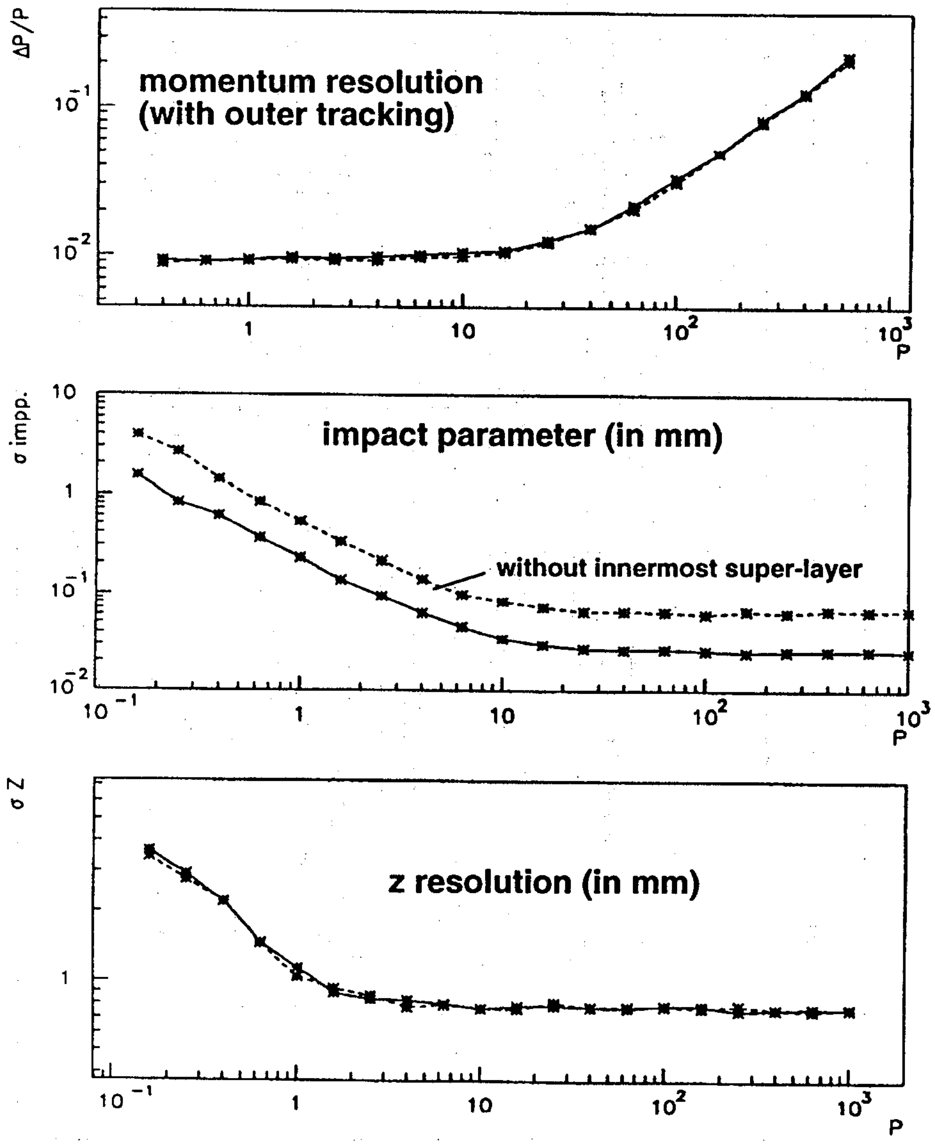
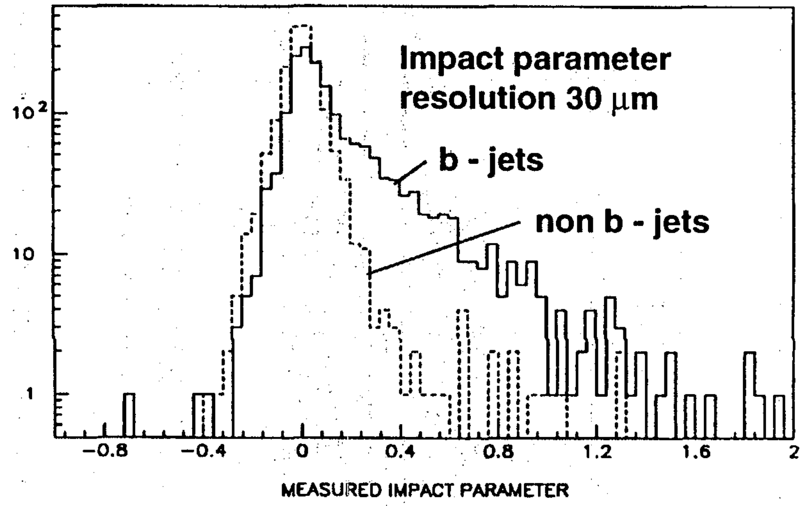
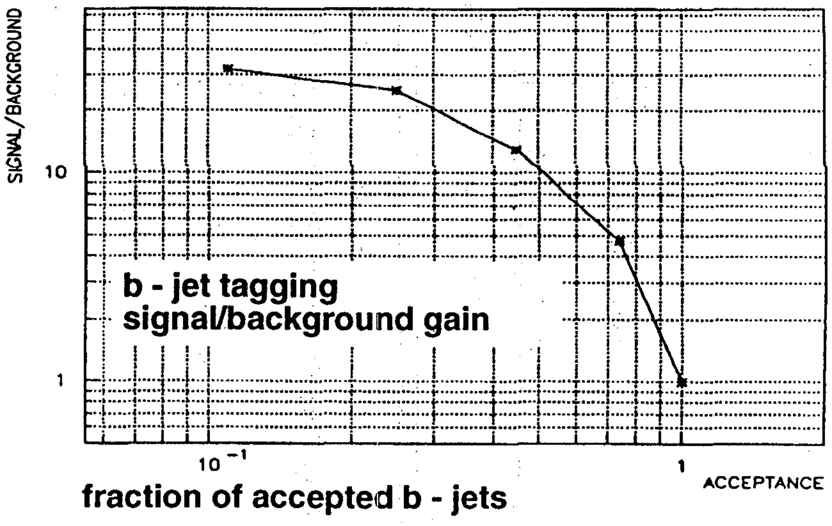
Simulated SITV resolutions at $\eta = 0$ as a function of p (in GeV)



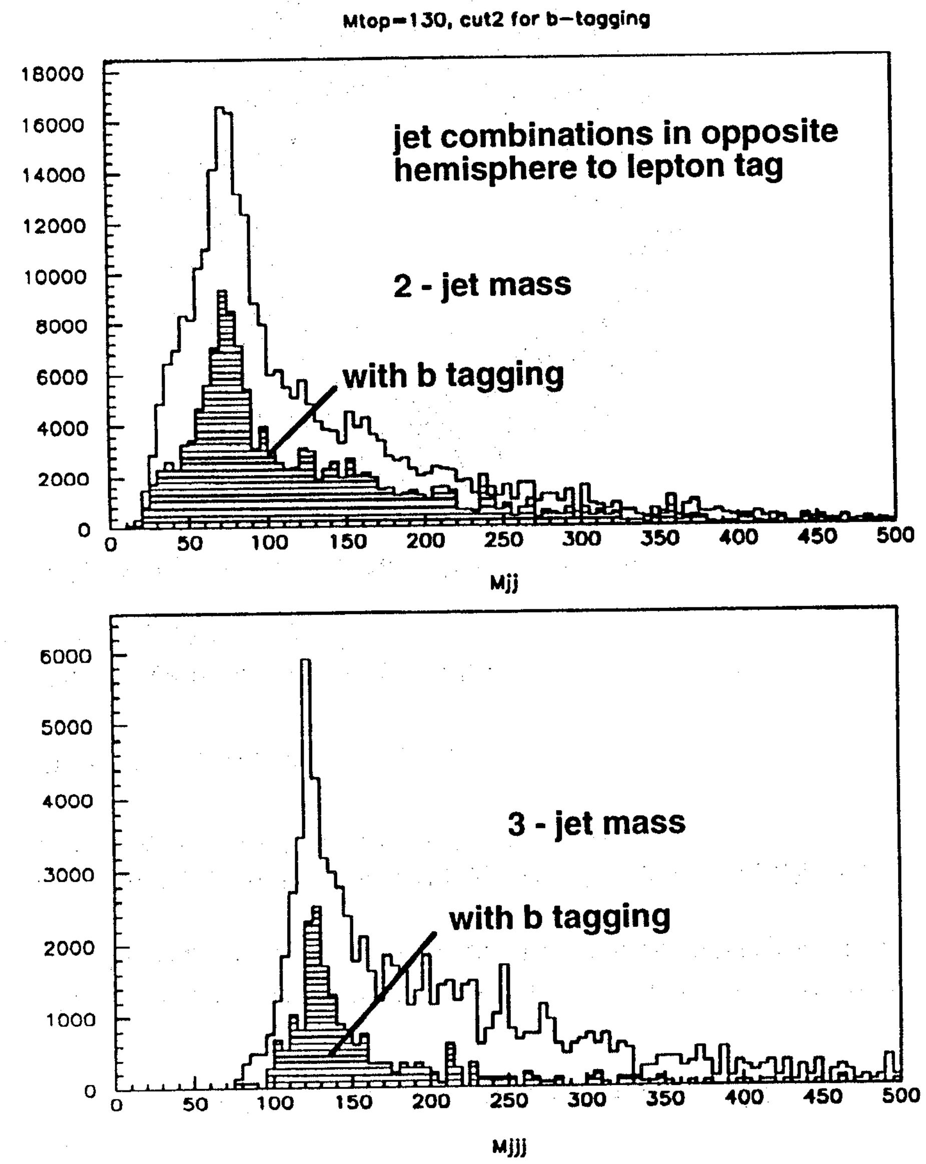
Simulated SITV performance

tt events with t -> Wb, one W -> lν (l = e or μ with $p_T > 40$ GeV) as tag, look at jets and tracks in the opposite hemisphere, p_T-jet > 40 GeV and p_T-tracks > 2 GeV

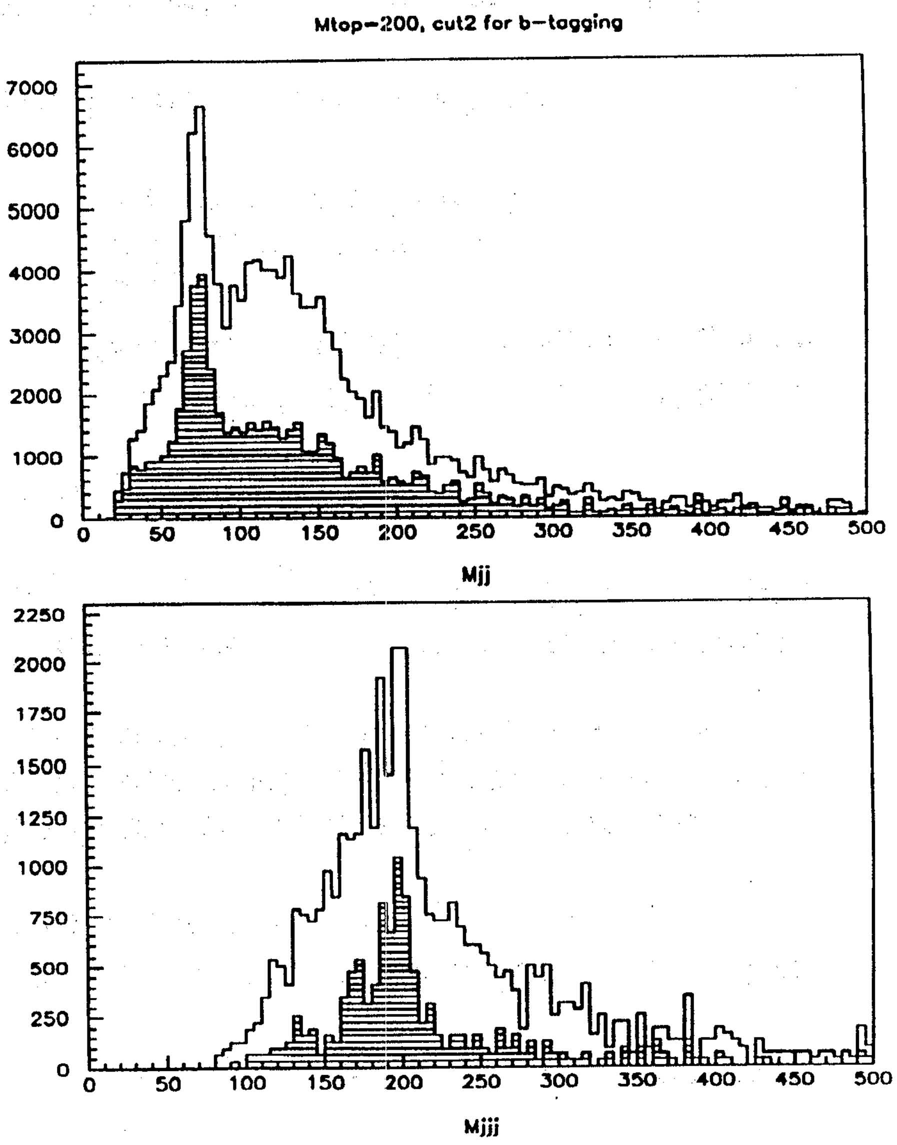




b - tagging effect for m_{top} = 130 GeV (normalized to 10^3 pb^{-1})



same for m_{top} = 200 GeV



GaAs micro strip counters

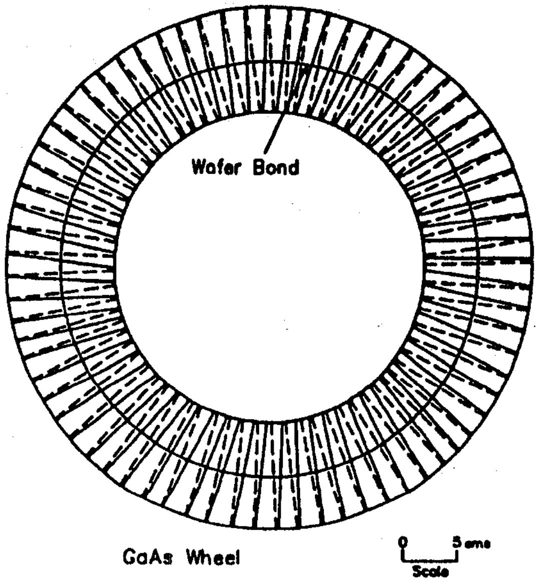
GaAs micro strip detectors offer the potential to extend tracking and momentum measurements to very large η

Conceptual design with three wheels on each side, two layers per wheel (small angle stereo)

Radial extension $15 < r < 25$ cm

GaAs counters 200 μm thick with 60 μm strips
10^6 channels total

Advantage of GaAs: radiation hardness



Outer silicon tracker (SITP)

The conceptual design consists of three super-layers covering $-1 < \eta < 1$

Each super-layer has two layers of counters, each layer provides hermetic coverage by overlapping counters

Stand-alone momentum measurement capability: $\sigma_{p_T} / p_T \sim 1.5\ 10^{-3}\ p_T$ (GeV)

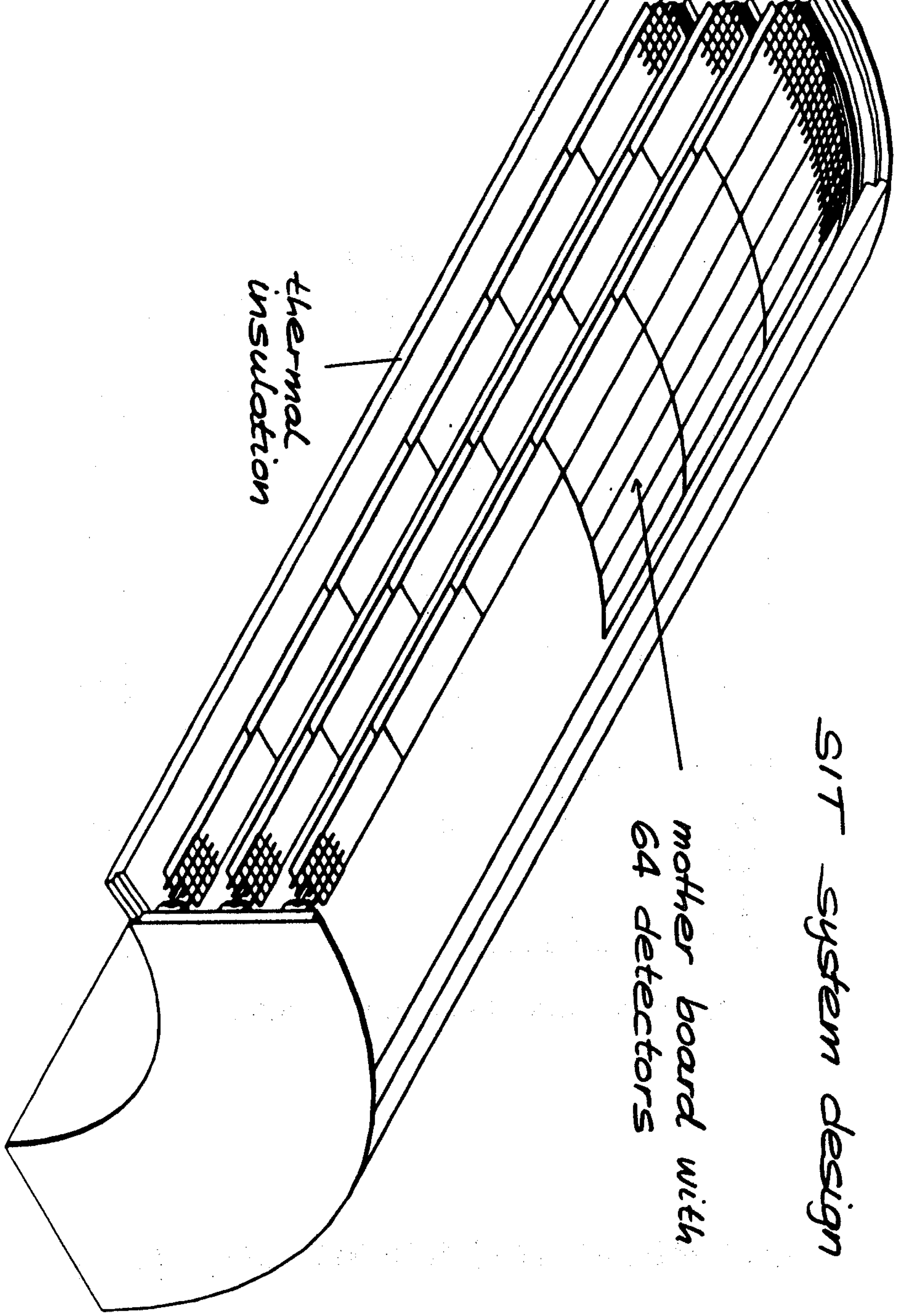
Two types of detectors:

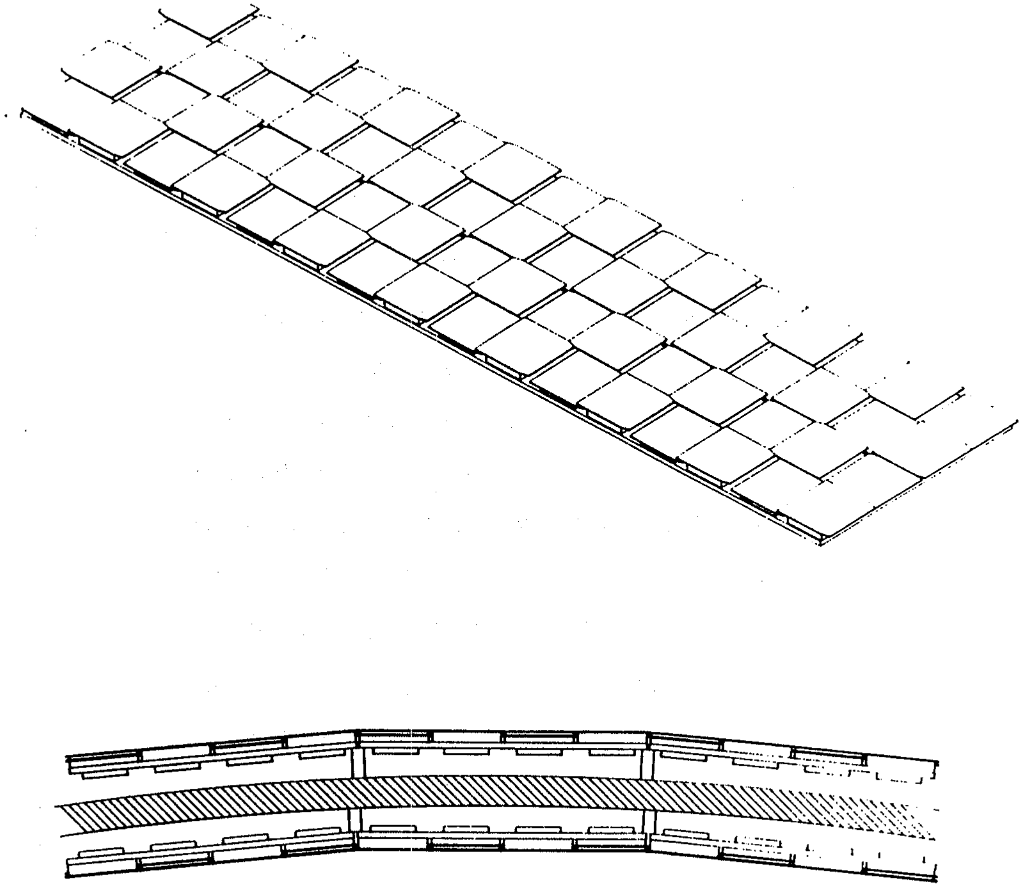
- strips with 375 μm pitch and 2.4 cm long, or with 200 μm pitch and 5 cm long
- pads with 3 mm x 3 mm (1 mm z - resolution)

Total Silicon area: ~ 80 m^2

Total number of channels: ~ 9 10^6

Material: 4% X_o per super-layer in total

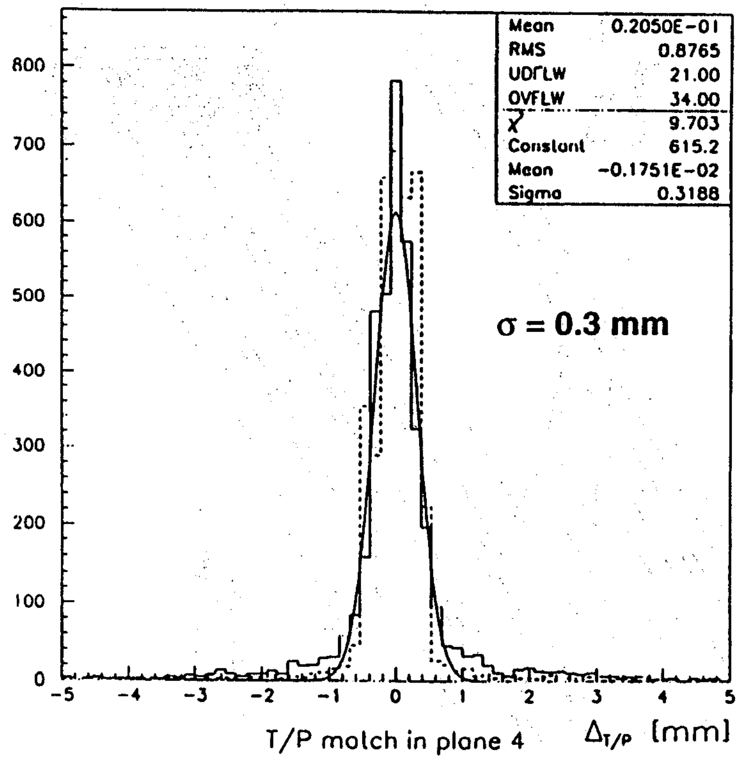




6. Layout of counters on an SITP module, showing the tile structure and the arrangement of SITP modules on the support structure.

SITP test beam performance

40 GeV electron track - preshower match



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Micro Strip Gas Counters

(EAGLE-B version)

- *number of channels : ~ 3 million*
- *occupancy : ~ 0.5 % @ 2 x 10^{34}*
- *precision : ~ 45 micron (with digital readout)*
- *speed : 20-30 nsec (gas dependent)*
- *radiation hardness : no degradation of the strips measured after a dose equivalent to two years of running @ 2 x $10^{34}$and @ 40 cm*

  lower gain due to deposit on the substrate
- *readout : binary (yes / no)*

  digital readout is cheap (~ 2 Sfr / channel)

  signals transmitted by optical fibers

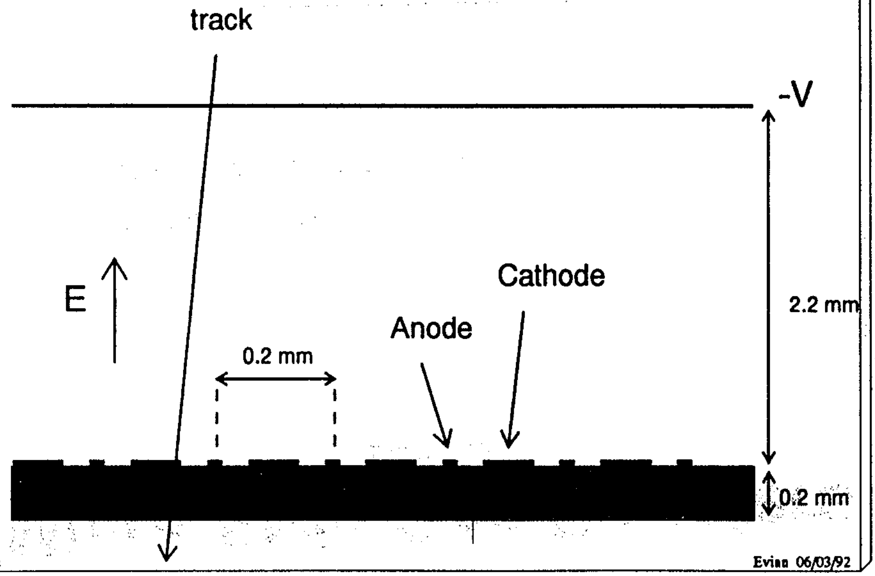
Eagle

Evian 06/03/92

Micro Strip Gas Counters

system layout

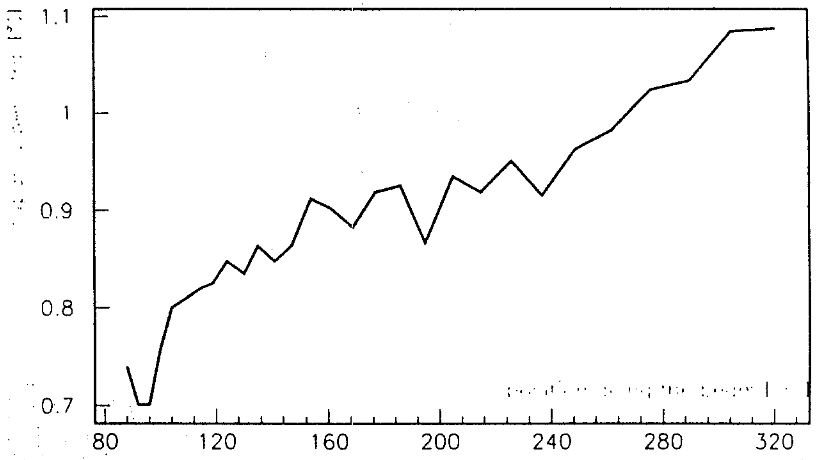
- *substrate : Pyrex glass (borosilicate)*
- *strips : ~ 1 micron Al*
- *gas : DME / CO2 (60% / 40%)*
- *V(Anode) - V(Cathode) = ~ 700 V*
- *V(drift) = ~ 8 kV / cm*

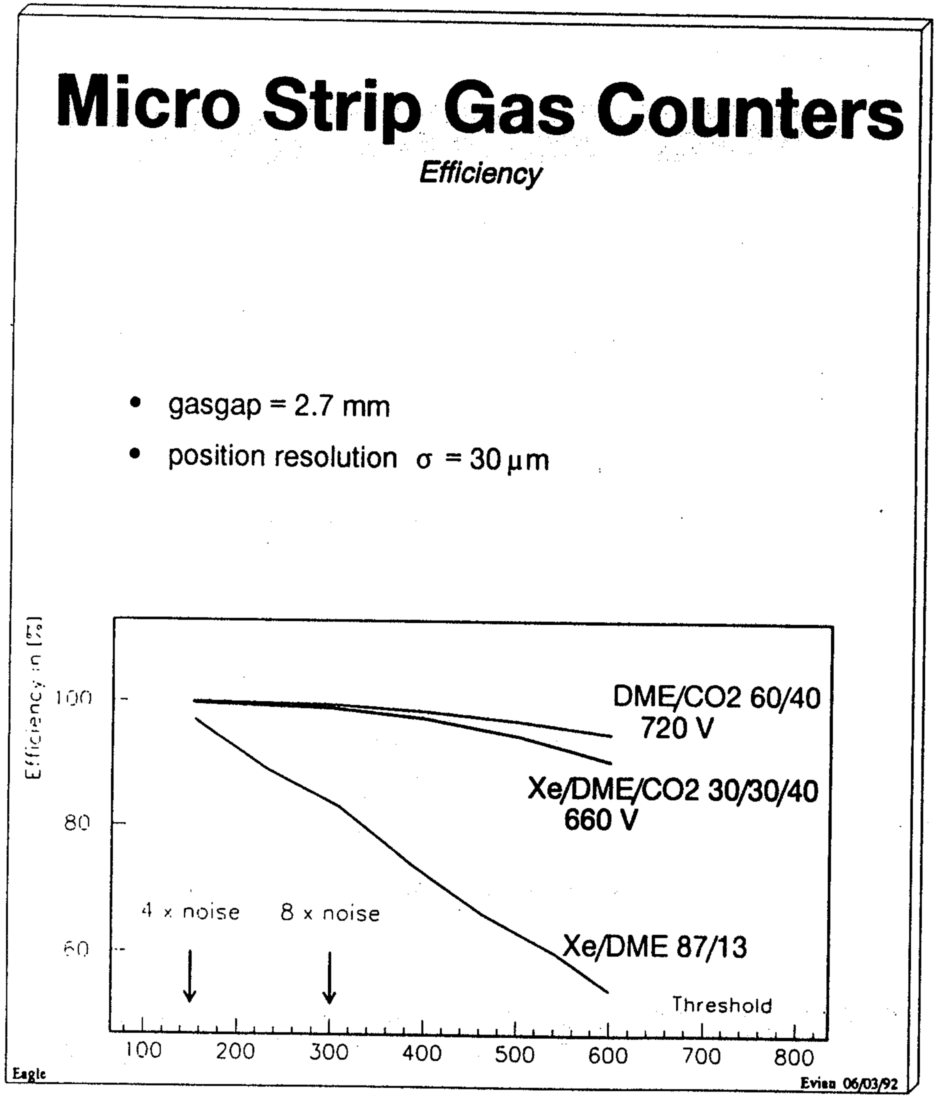


Micro Strip Gas Counters

occupancies

- *~ 20 minimum bias events / beam Xing*
- *min. bias from PYTHIA (Ref. Aachen Proc. Vol II pag. 155)*
- *MSGCs from r=40 cm to r=50 cm*
- *on average 2 strips hit per traversing particle*
- *factor 2 for 30 nsec gate included*
- *deviations from a smooth curve represent poor statistics in the Monte Carlo simulation*

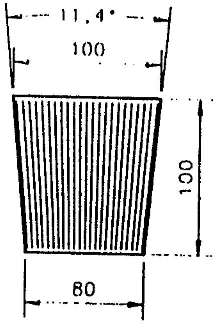


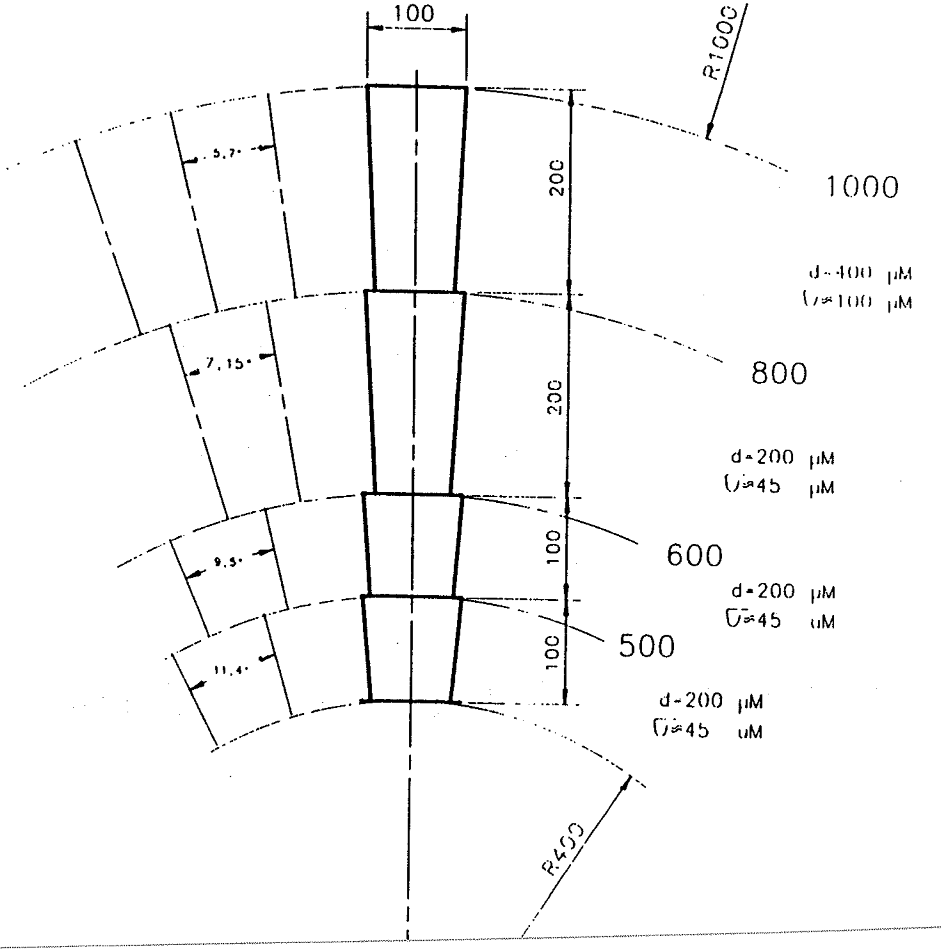


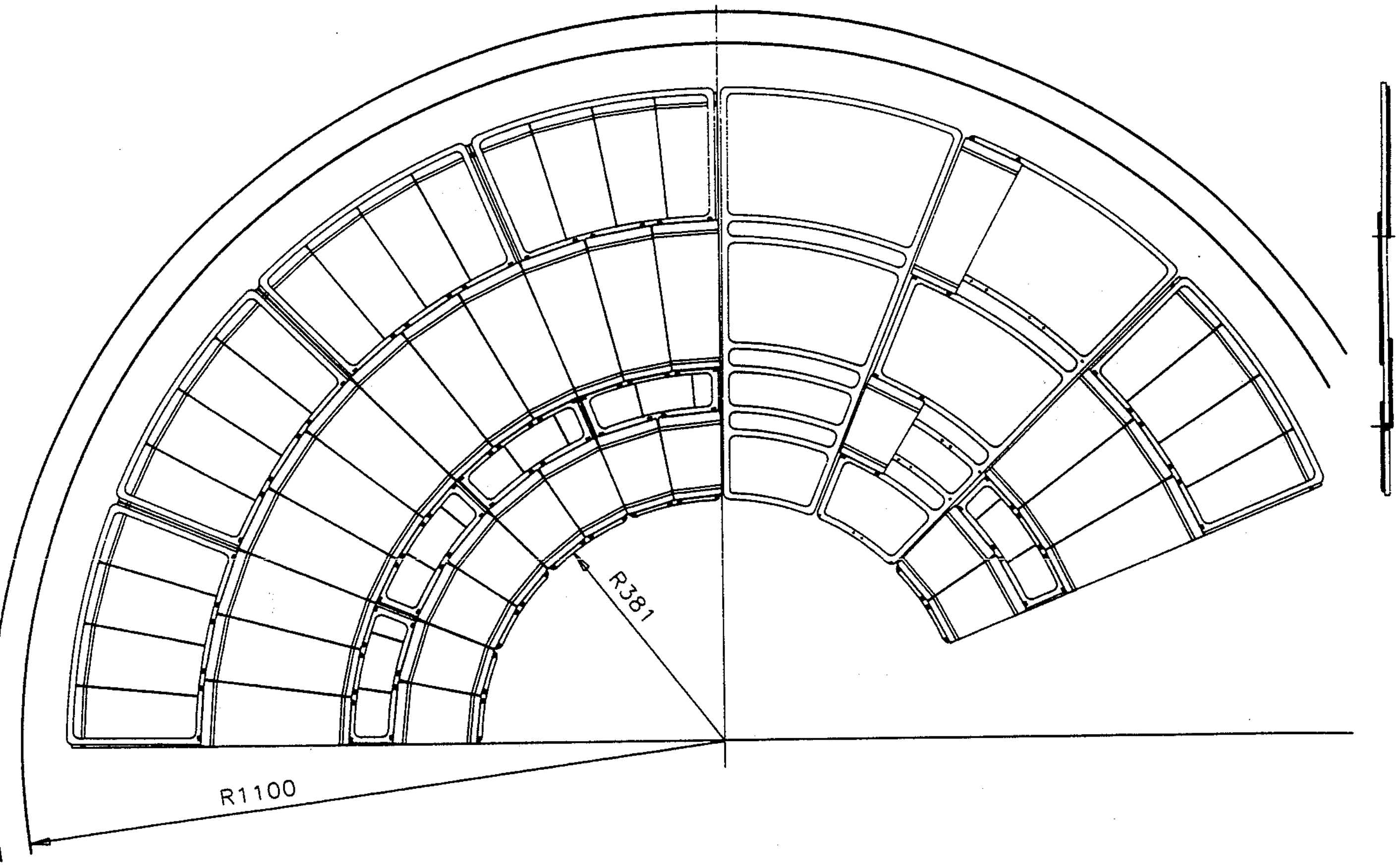
Micro Strip Gas Counters

Efficiency

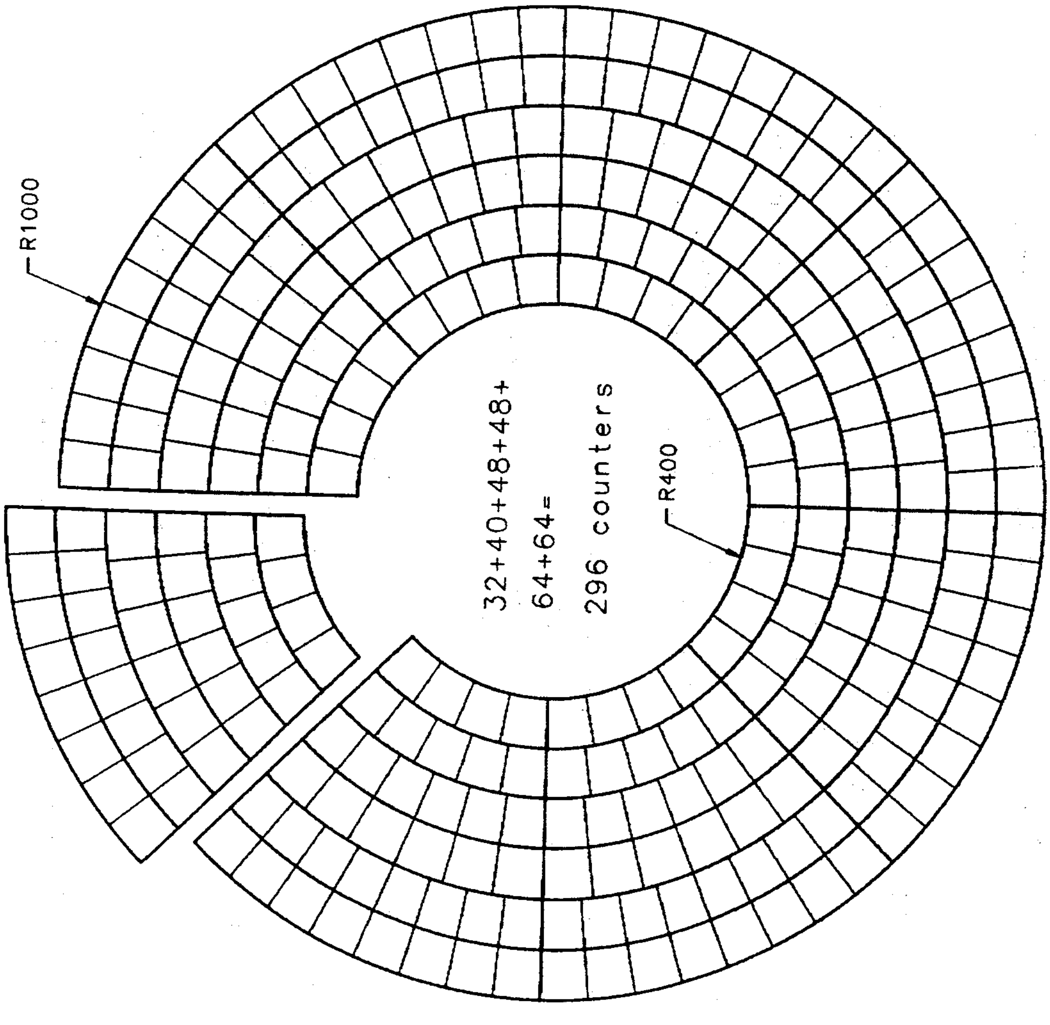
- gasgap = 2.7 mm
- position resolution σ = 30 µm







ONT



Transition radiation tracker

Main goals - high quality pattern recognition over $|\eta| < 2.5$ with 40 points per track
- good electron identification (only 3% occupancy for TR hits at high lum.)

System design with 300000 straw tubes with $Xe/CF_4/CO_2$ gas and polypropylene foil radiator, overall thickness ~ 10% X_o

Two-threshold readout for each straw
- 0.2 keV for tracking of all particles
- 5 keV (TR hit) for identification of electrons (E > 0.5 GeV) and pions/muons (E > 100 GeV)

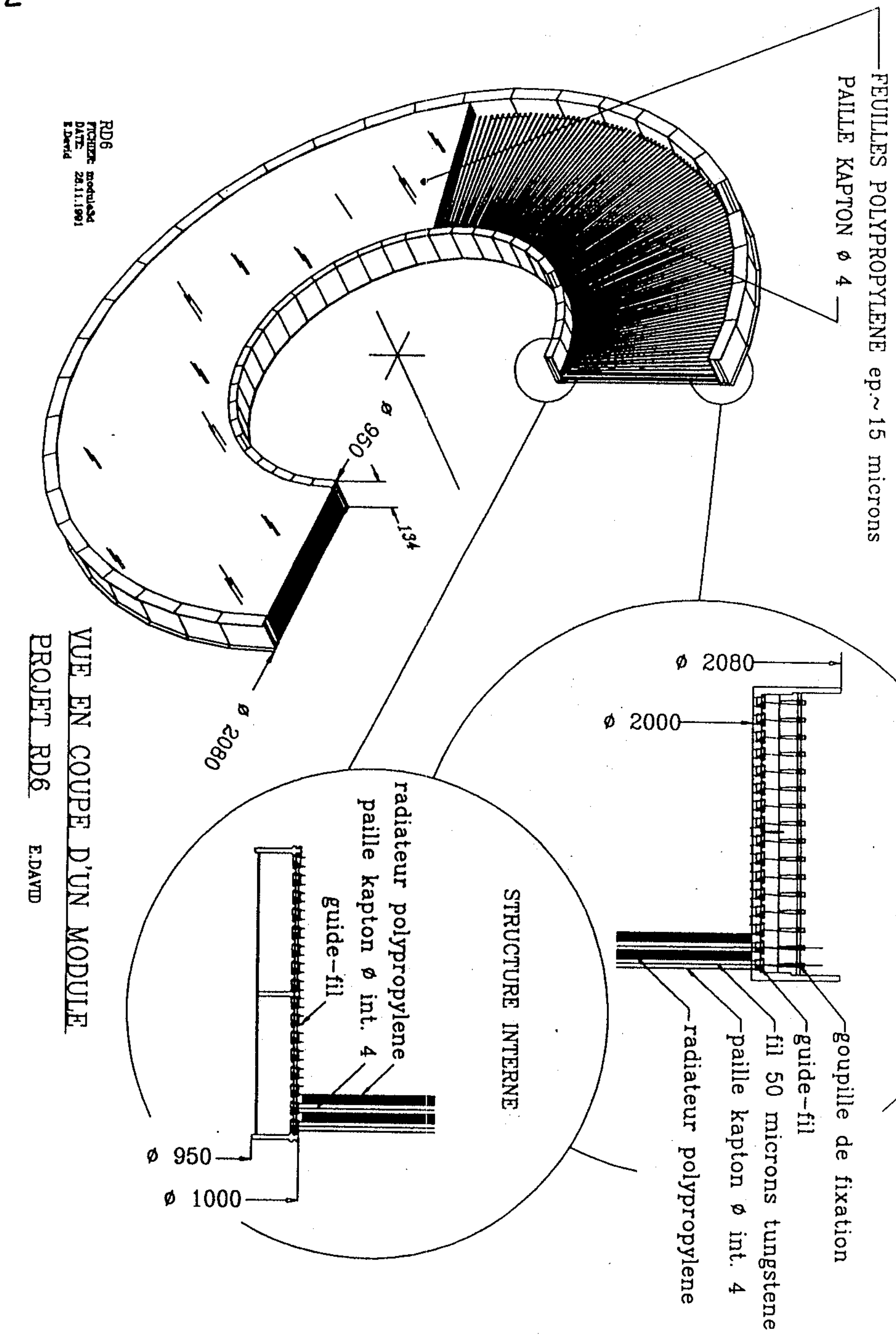
Performance evaluation (RD6 test beam plus simulations)

- space resolution 150 μm per straw (drift measurement) leading to $\delta p_T/p_T$ ~ 8% at 100 GeV with good pattern recognition

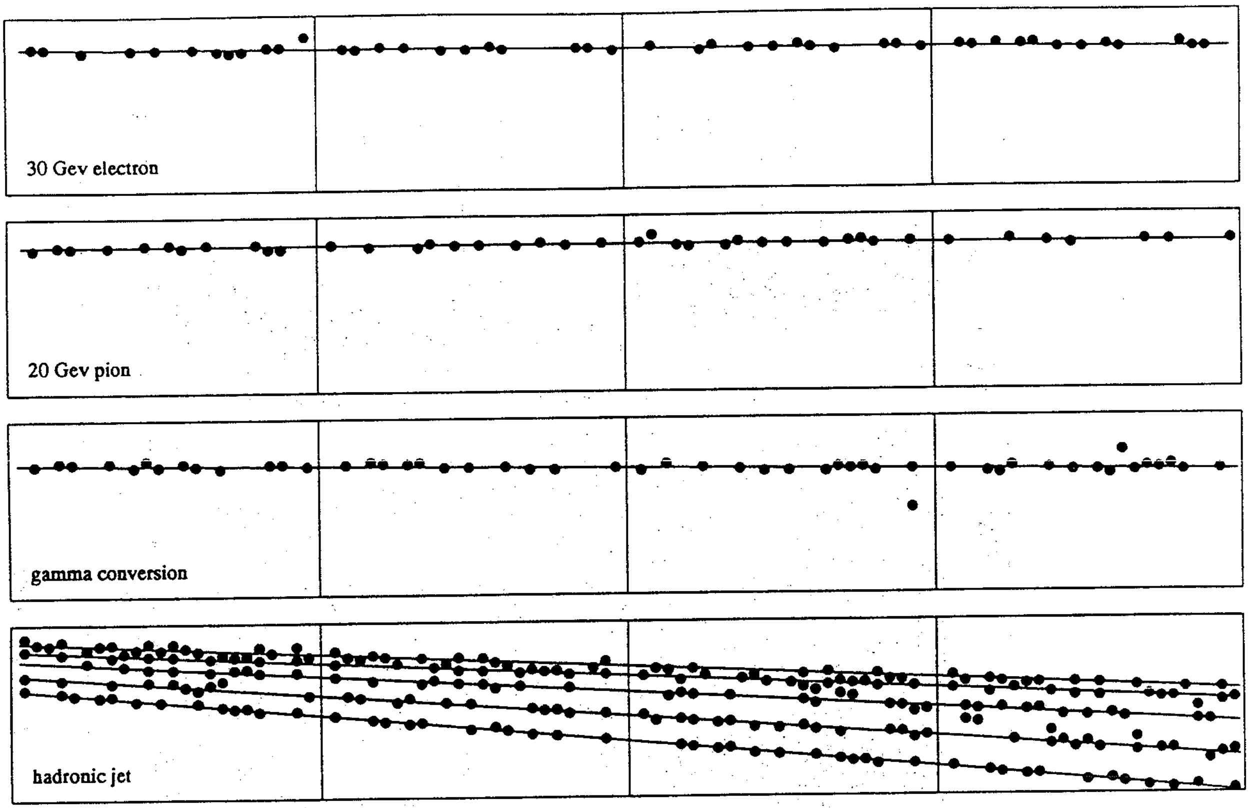
- rejection of backgrounds to isolated electrons ($\varepsilon_e = 95\%$)

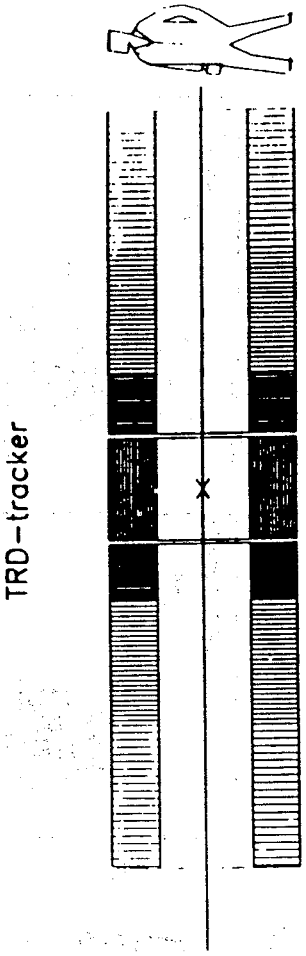
hadrons	30
electron pairs from conversions/Dalitz	50

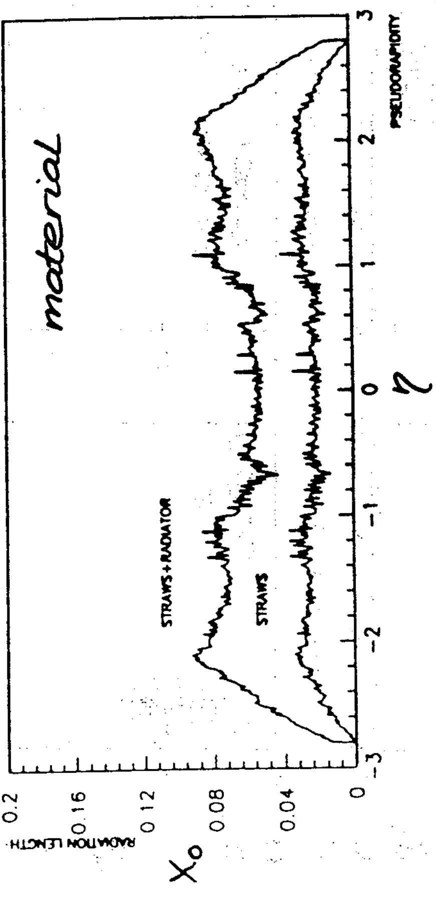
- simple and efficient 2^{nd}- level trigger on high p_T $e^\pm$
- sturdy detector in terms of radiation hardness and ageing

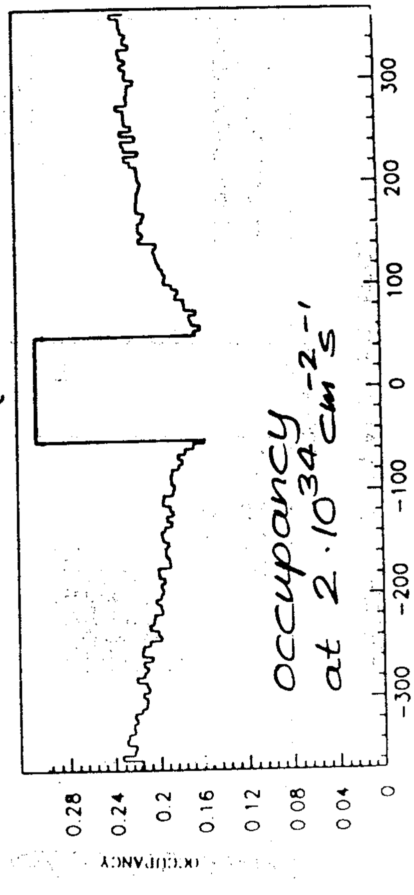


TRD Event Display

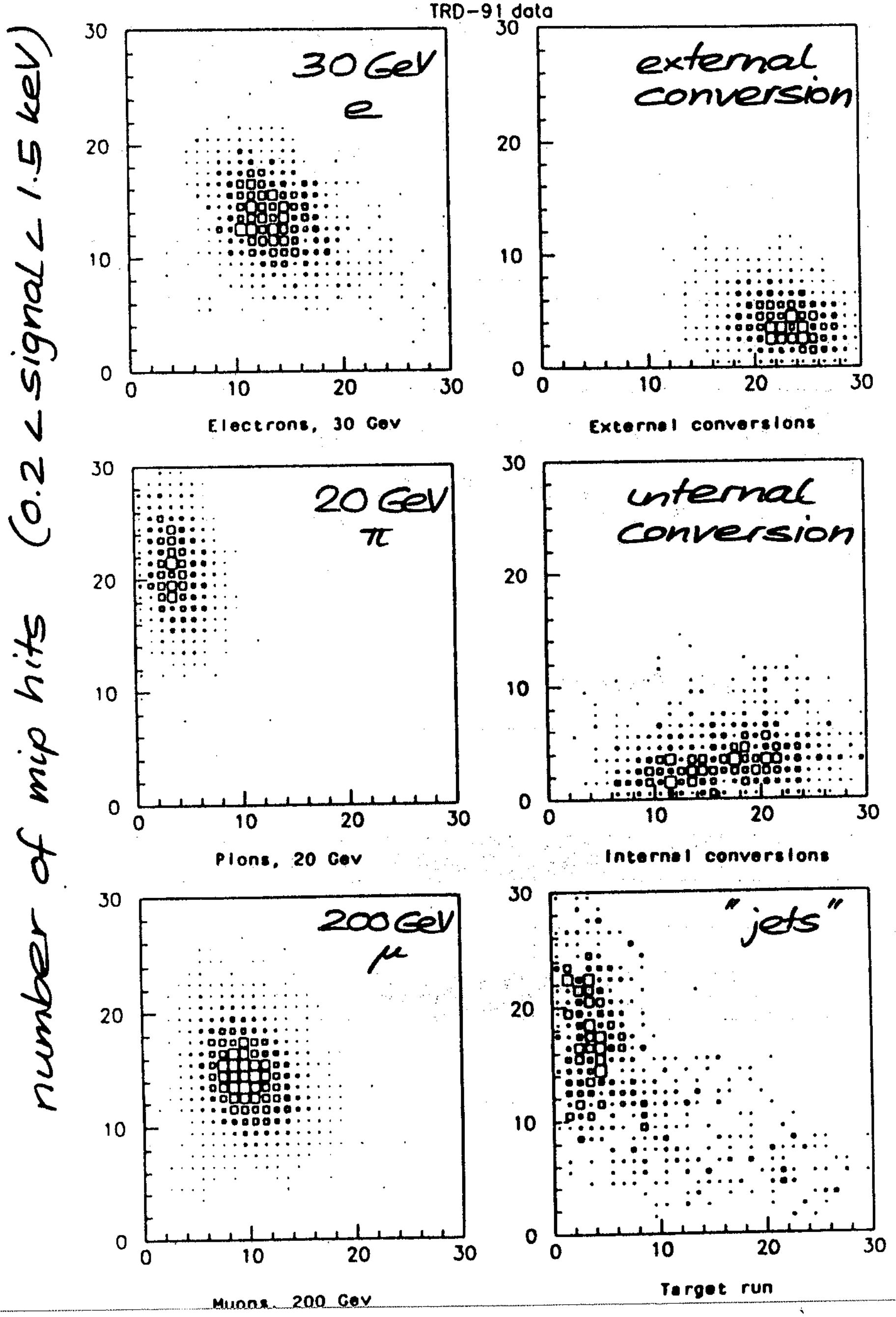


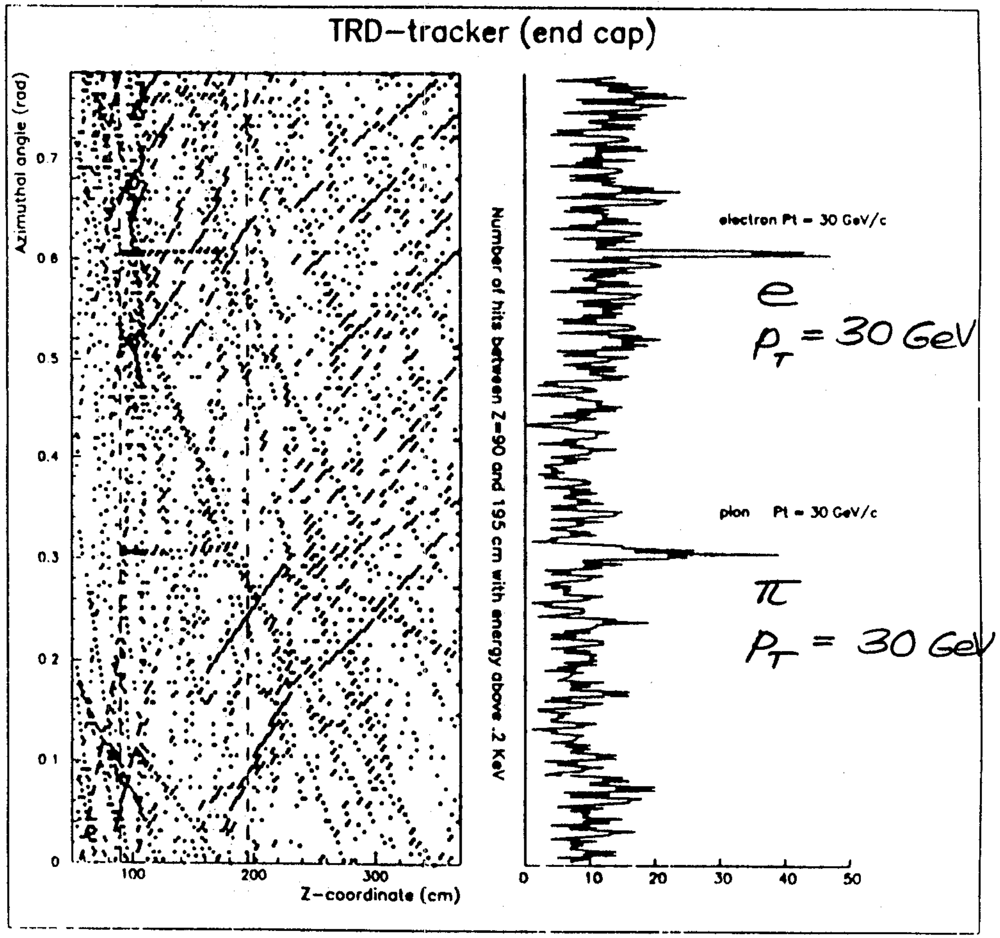






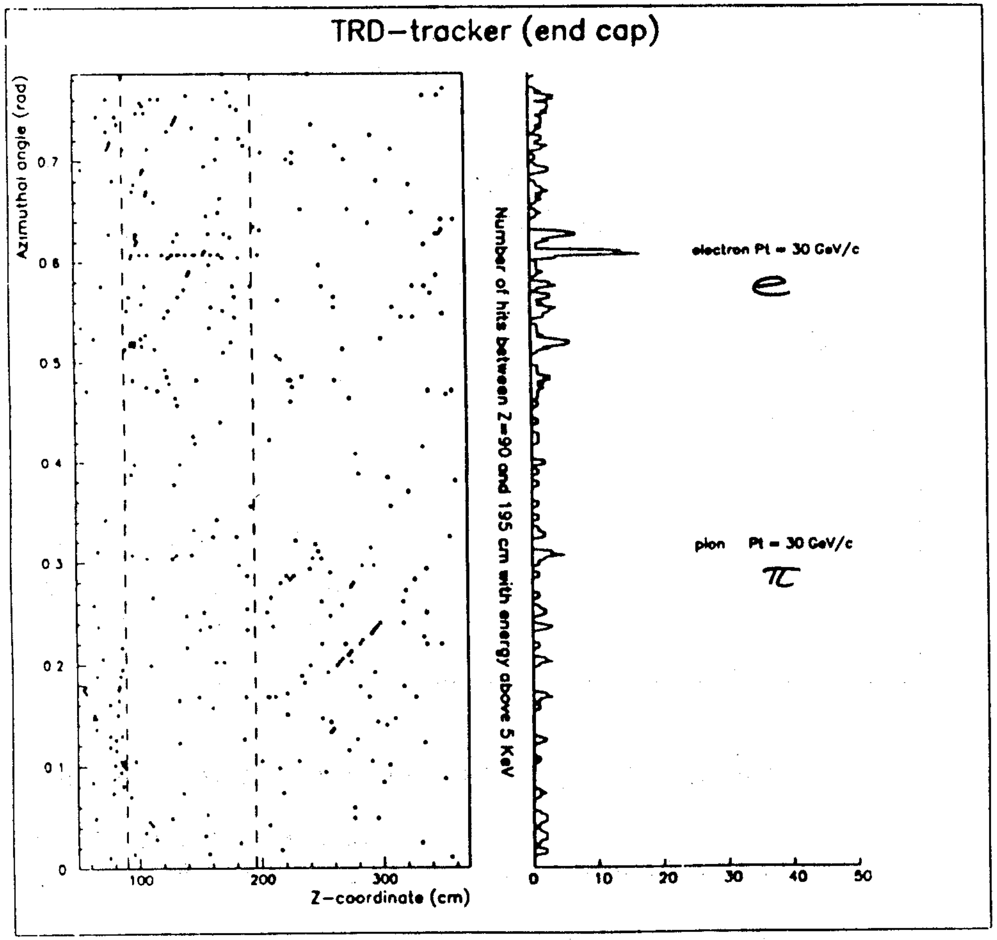
test beam data





all hits
30 min. bias overlaps

Muon measurements



TR hits only
30 min. bias overlaps

Muon measurements in EAGLE are based on a combined system of a warm iron toroid spectrometer with the inner detector

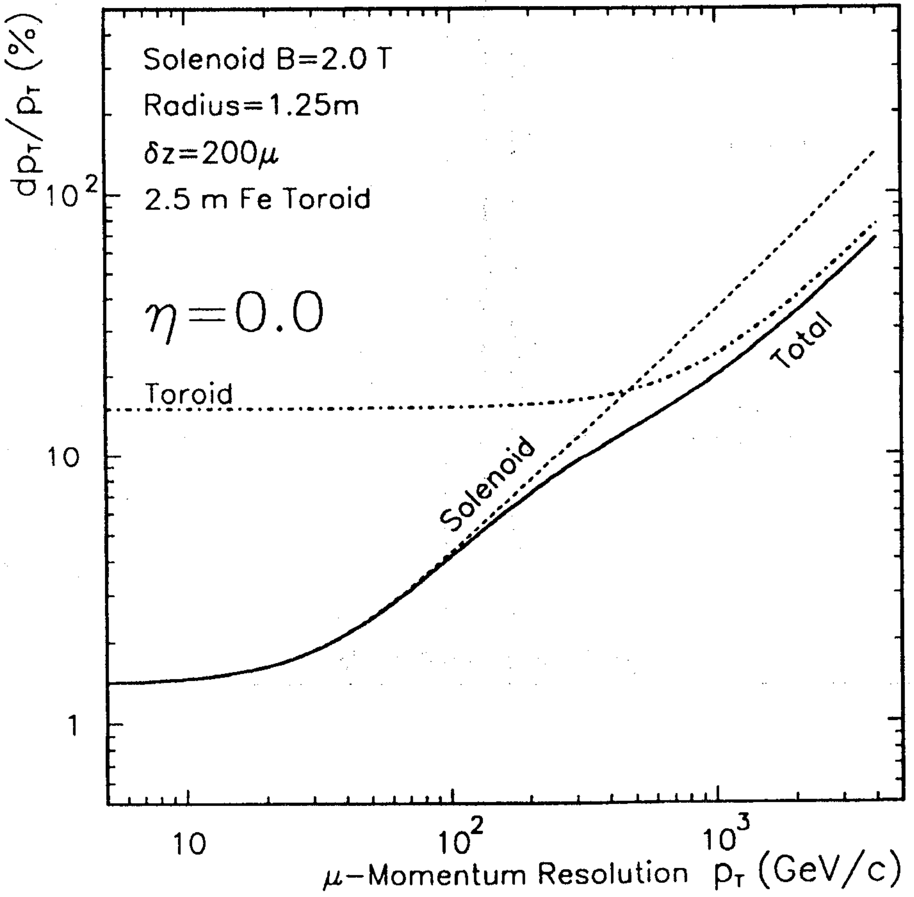
Advantages:

- *good momentum resolution, fully adequate for all expected LHC physics*
- *two fully independent momentum measurements*
- *large rapidity coverage*
- *safe very high luminosity capability*
- *excellent trigger performance*
- *reasonable costs and low risks*

Muon momentum resolution at η = 0

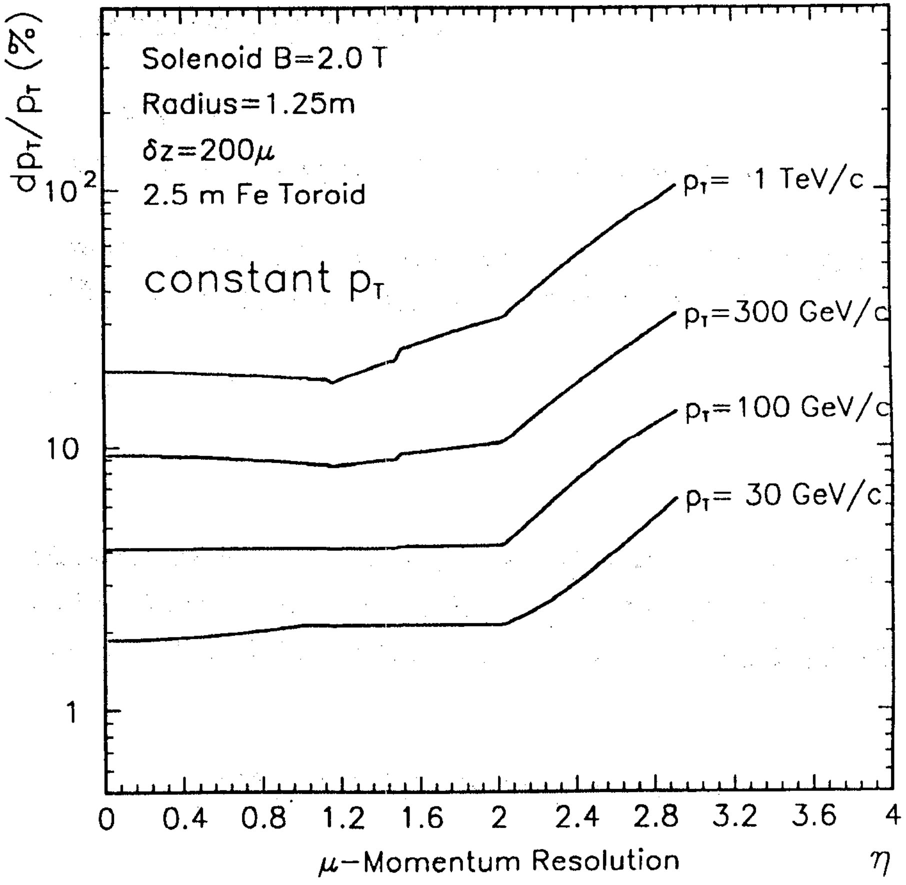
Toroid measurement based on difference between incident and exit angles

Independent measurement in the inner detector



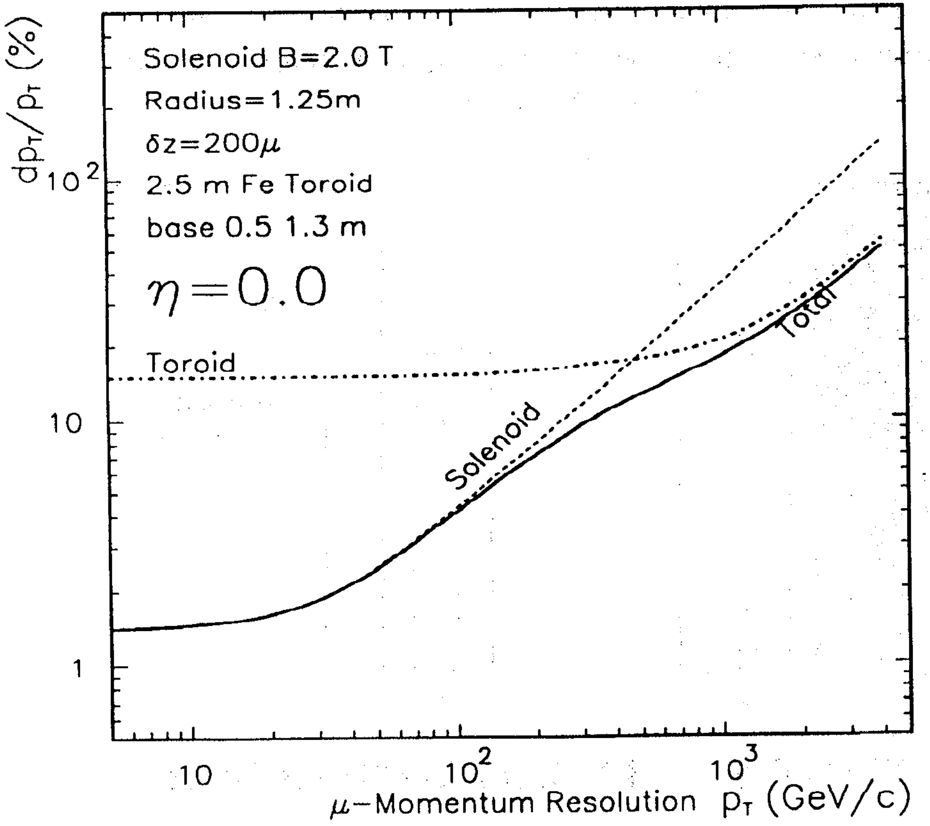
Muon momentum resolution as a function of η for constant p_T

Resolution combining the independent measurements in the toroid and the inner detector



Muon momentum resolution for a combined inner detector and muon system measurement

Using a z - measurement with δz = 0.5 mm in the last layer of the inner detector one can improve the toroid resolution for very high muon momenta by increasing the lever arm

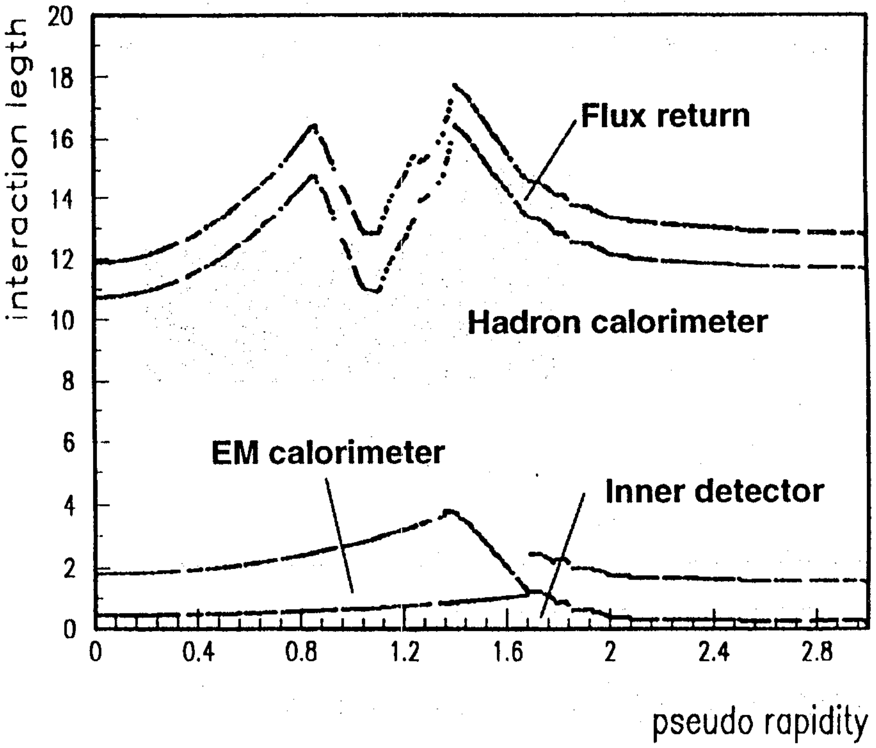


EAGLE presentation Evian 6-3-1992

Interaction lengths in front of first muon detectors

A minimum of 12 λ precede the first muon stations

very low punch through backgrounds are expected



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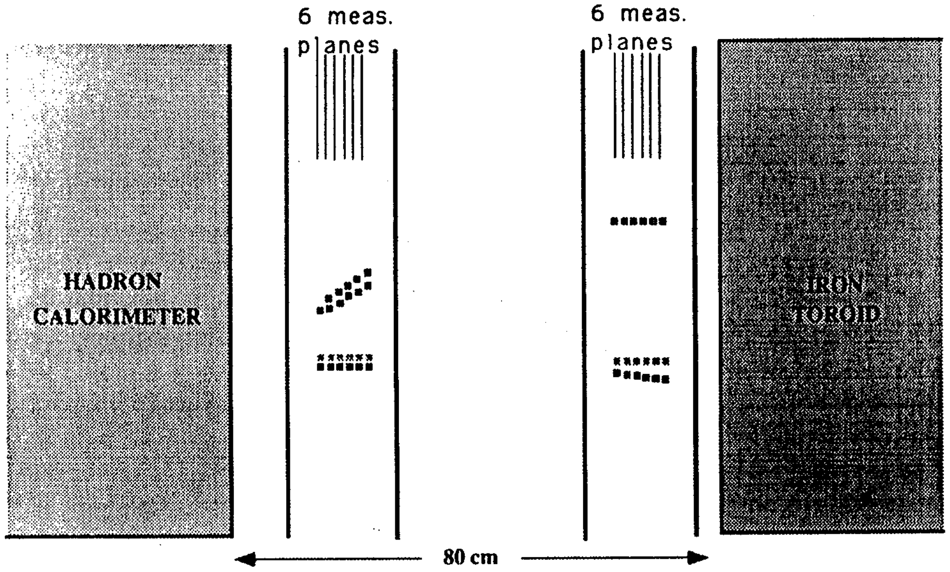
HIGH ENERGY MUON E.M. SHOWERING

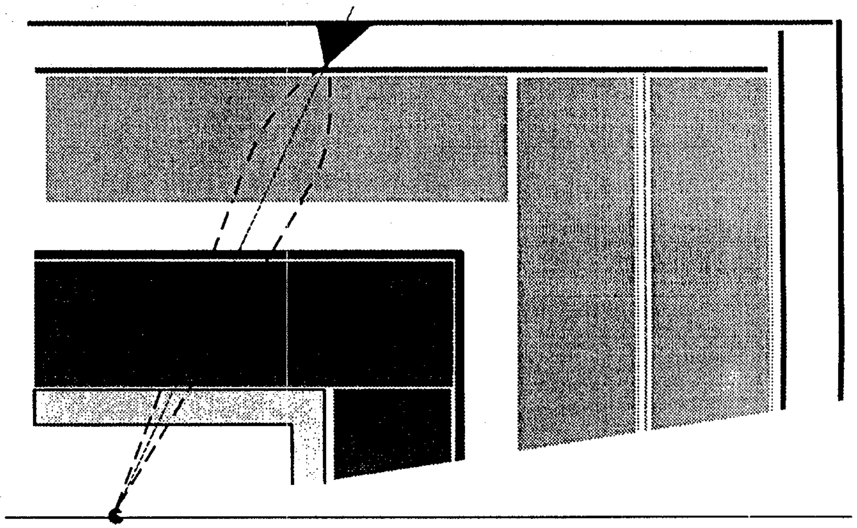


- 20% of 100 GeV μs have ≥ 1 electron track (GEANT simulation, in good agreement with NA4 measurements)
- Muon-electron separation and identification: need detectors with good single and double hit resolution (2 to 4 mm) & redundancy
- Full GEANT simulation of the muon stations 1 and 2
  - *Drift chamber 2x6 wire planes 15 mm spaced*
  - *σ (single hit) = 200 μm*
  - *σ (double hit) = 2 mm*
- Results:

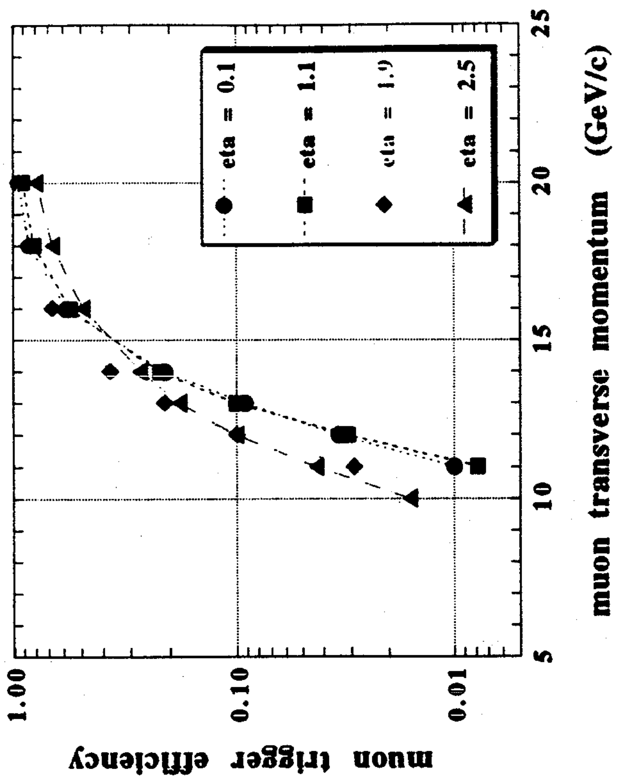
Muon energy, GeV	*Fraction of correctly reconstructed μ, %*
100	98
300	95
500	93

(Muon momenta can also be measured in the central solenoid)

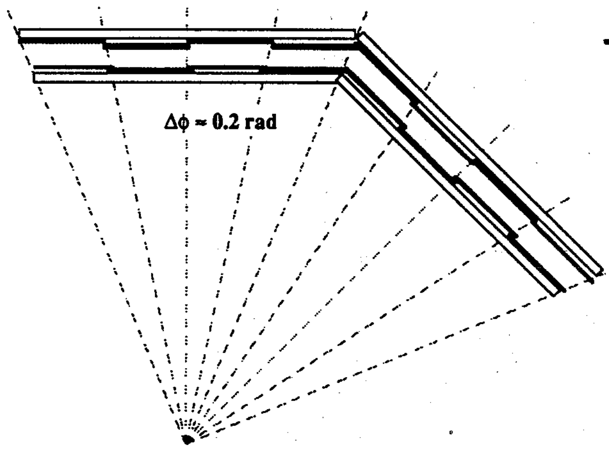
FIRST LEVEL MUON TRIGGER

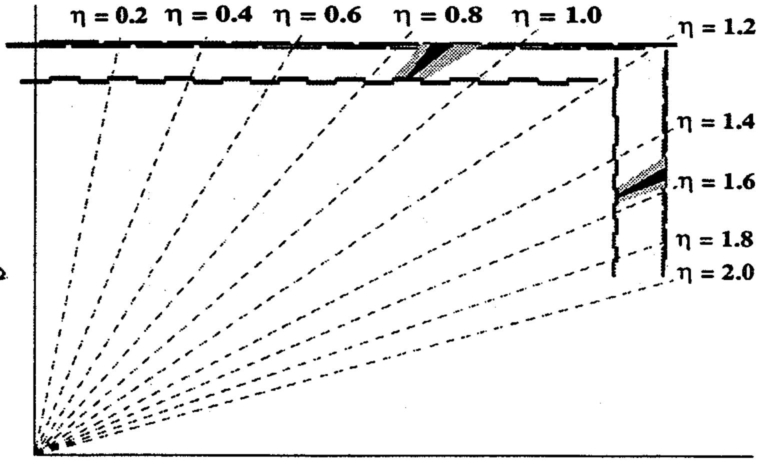


- TWO PLANES OUTSIDE THE IRON TOROID
- POINTING TO THE VERTEX ; ANGULAR RESOLUTION ~ 30 MRAD
- SHARP THRESHOLD IN TRANSVERSE MOMENTUM
- VERY GOOD TIME RESOLUTION < BUNCH CROSSING PERIOD
- VERY FAST RESPONSE < 10 BUNCH CROSSINGS
- SENSITIVE TO COSMIC RAYS POINTING TO VERTEX (~ 300 HZ)

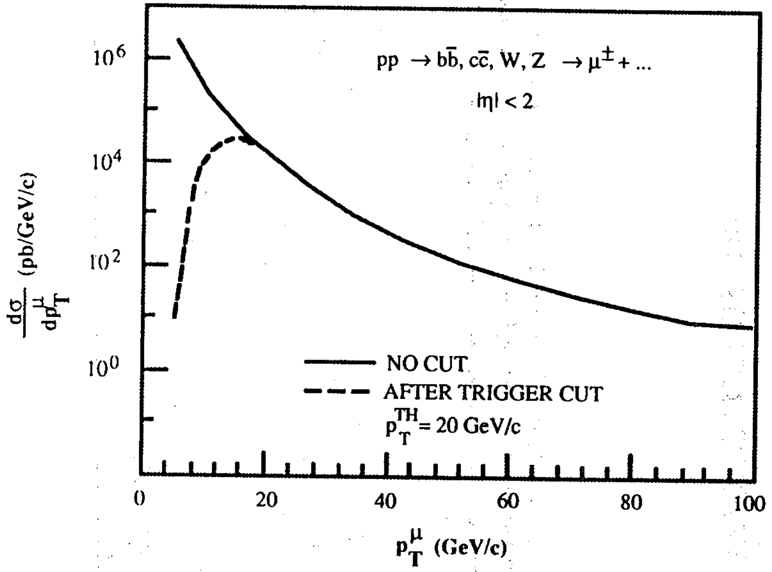


FIRST LEVEL MUON TRIGGER HODOSCOPE





TRIGGER RATES



$p_T^{\mu} > 20$ GeV/c $|\eta| < 2$ $L = 10^{34}$ cm^{-2} s^{-1}

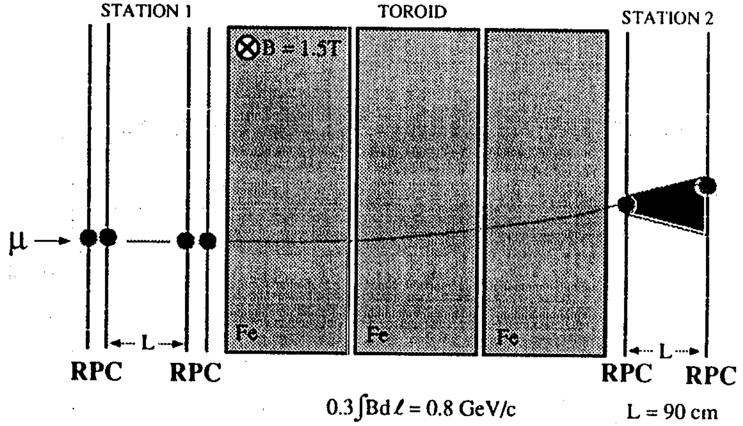
INCLUSIVE MUON TRIGGER

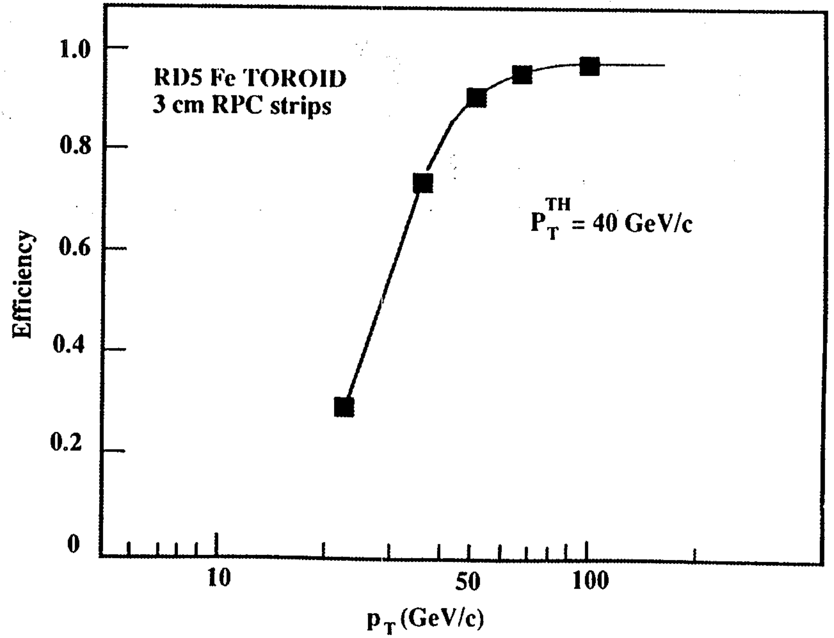
$pp \to b\bar{b}, c\bar{c}, W, Z \to \mu + ...$ ≈ 4000 Hz

$$\left.\begin{array}{l}\pi, K \to \mu \text{ DECAYS} \\ \text{HADRON SHOWERS PUNCH THROUGH} \\ \text{COSMIC RAYS}\end{array}\right\} \approx 400 \text{ Hz}$$

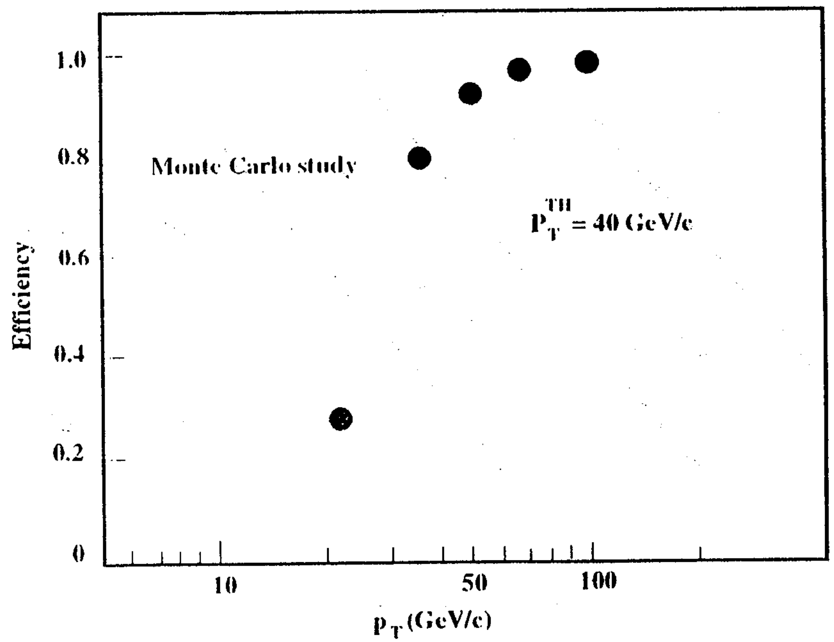
DIMUON TRIGGER ≈ 30 Hz

MUON TRIGGER STUDY IN RD5

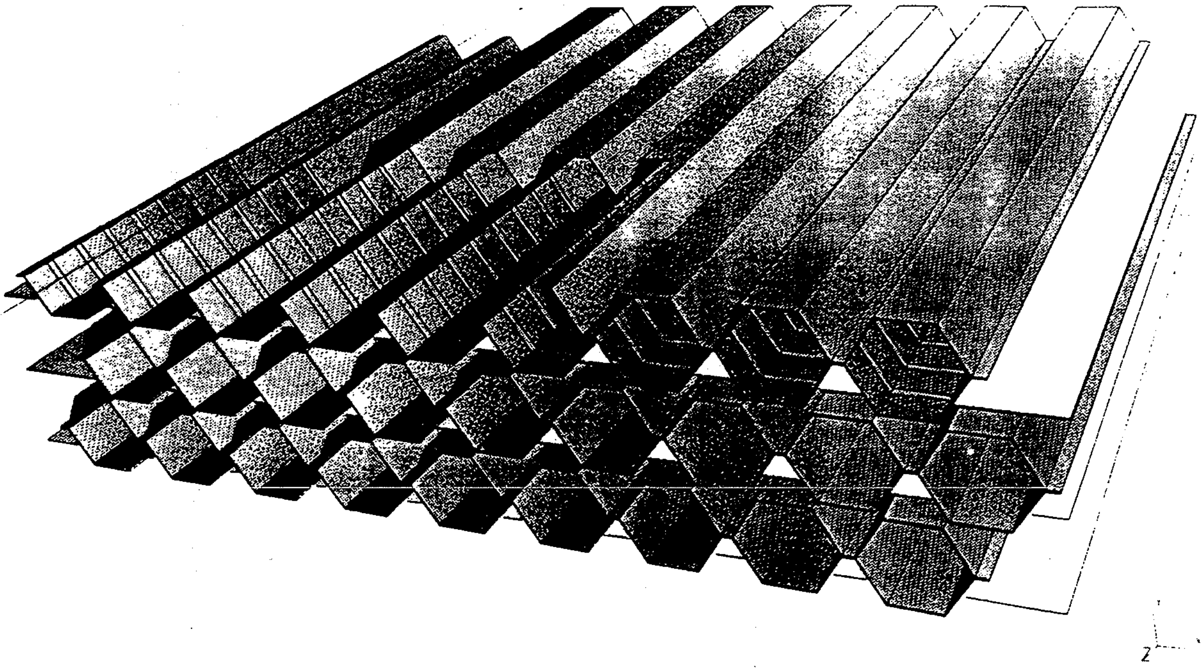




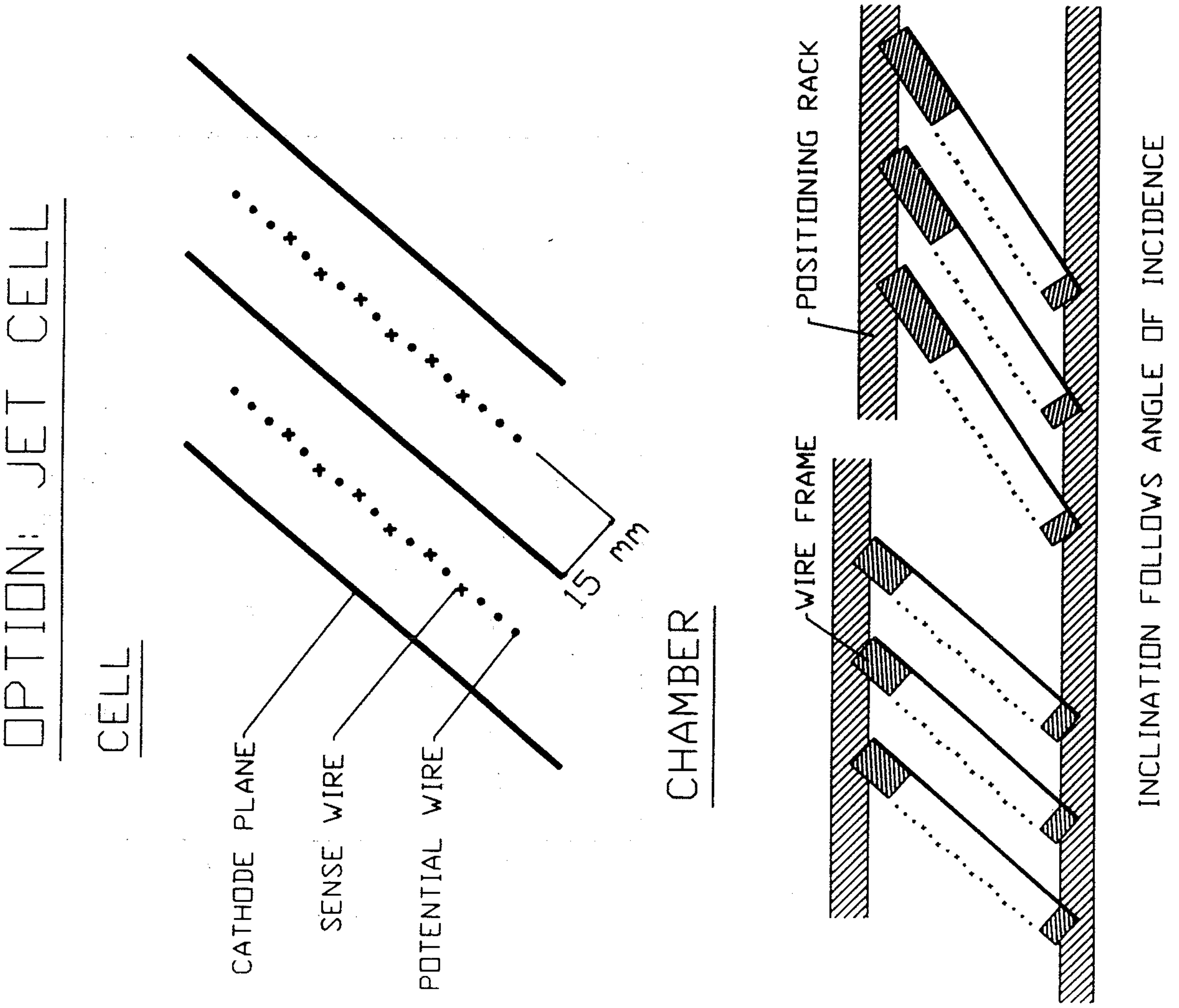
Muon chamber options



Specification	**Options**
space resolution ($\sigma_z < 200\ \mu m$)	- drift measurement - cathode strip interpolation
two - track separation ($\Delta < 3$ mm)	- drift chamber with field shaping - small diameter straws or honeycomb - very small cathode strips
trigger level - 1	- from external detectors (RPC) - from drift time (< 200 ns) - from strip number
orthogonal coordinate	- RPC or strips
event time (bunch number)	- fast detector (RPC) - drift cells with half cell off-set



- folded mylar foil with copper strips
- Cu-Be wire in axis of each hexagonal cell
- two coordinates from the same detector
- wire pitch 12.7 mm $\sigma < 200\ \mu m$ 900 k wires
- strip pitch 5 mm $\sigma < 100\ \mu m$ 800 k strips



EAGLE-MUONS-PPE.TA2
7100013-JR
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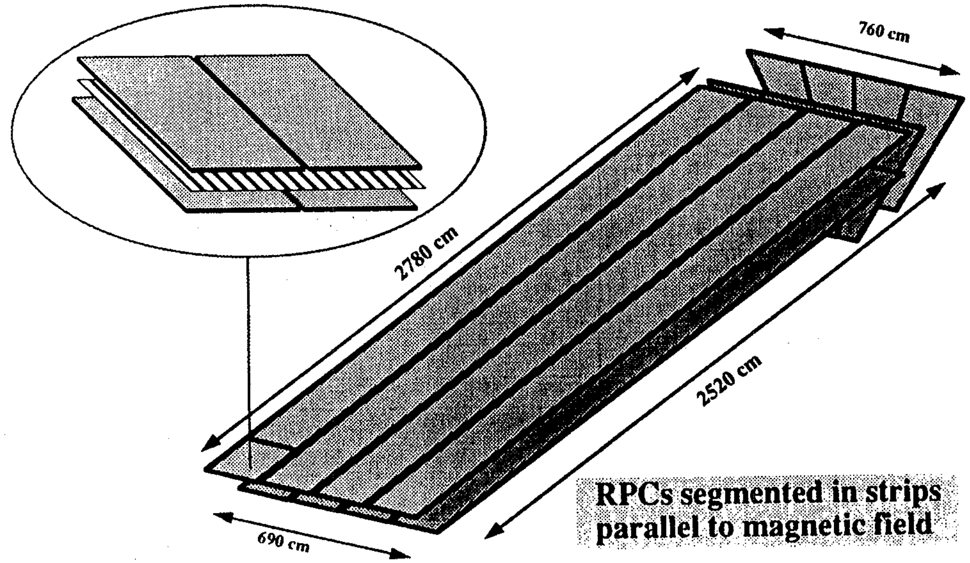
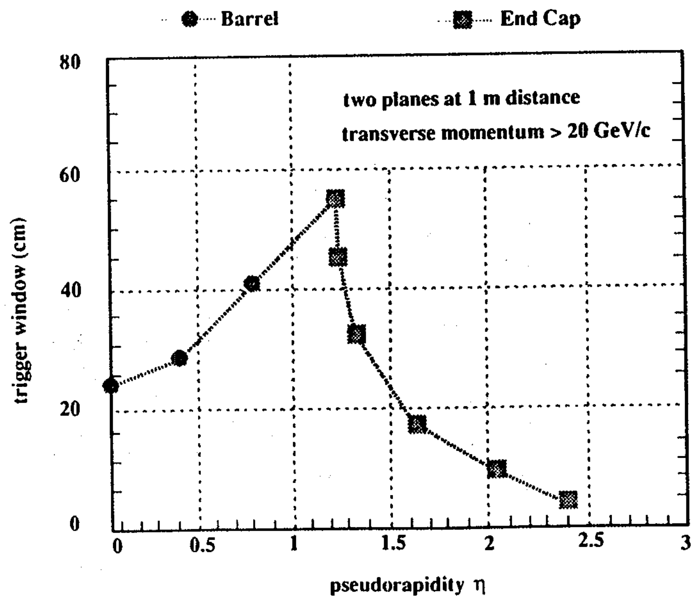
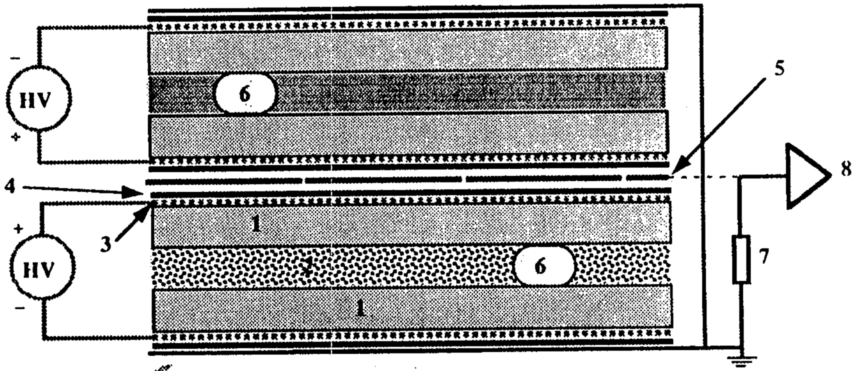
RESISTIVE PLATE CHAMBER TRIGGER PLANES



RPCs segmented in strips parallel to magnetic field



DOUBLE RPC LAYER



1 bakelite plate
2 gas
3 graphite coating
4 pvc insulating foil
5 aluminum strips
6 pvc spacer
7 line termination
8 front end electronics

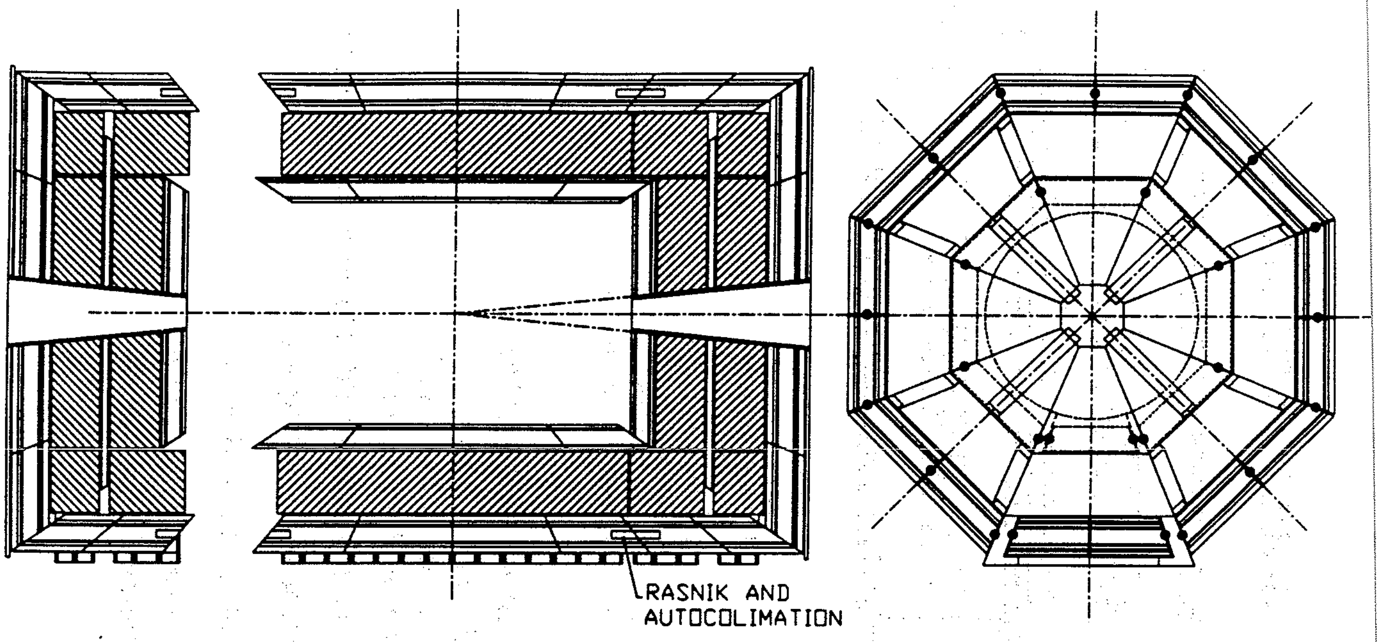
CHAMBER PROPERTIES

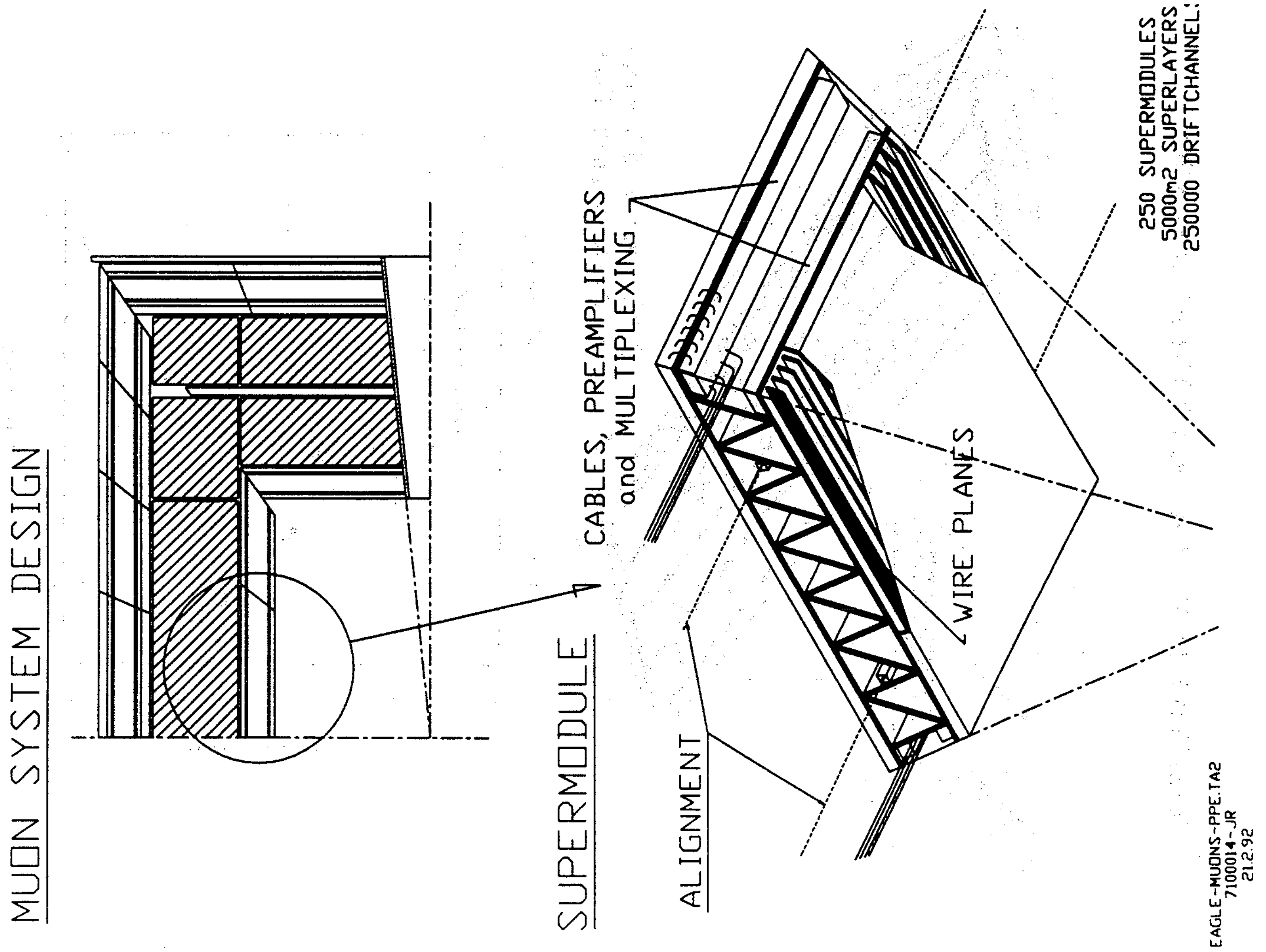
- Efficiency $> 99\%$
- Noise rate $\approx 2\ \mathrm{kHz/m}^2$
- Time resolution ≈ 1 ns
- Possibility to add a third layer with orthogonal strips

TRIGGER HODOSCOPES

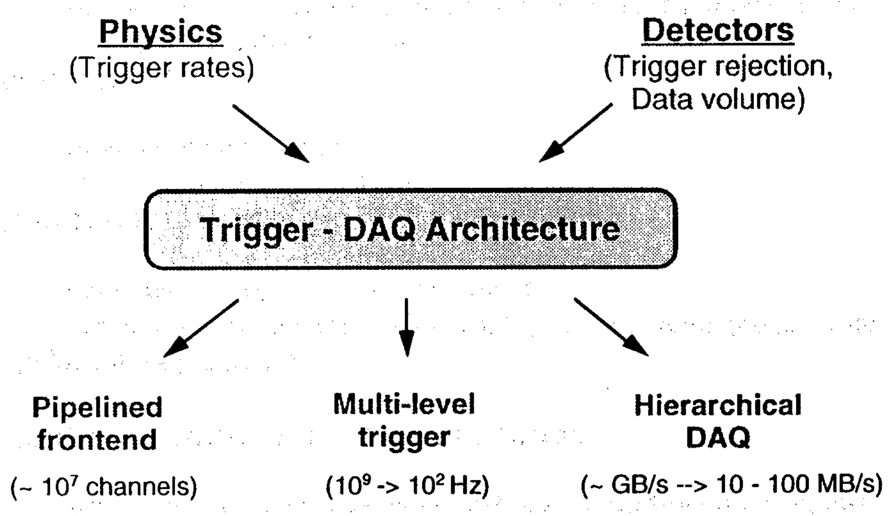
- Total surface $\approx 4000\ \mathrm{m}^2$
- Total gas volume $\approx 16\ \mathrm{m}^3$
- Flammable gas ≈ 10 kg

MUON SYSTEM: OVERVIEW AND ALIGNMENT





Trigger, Data Acquisition and Front-End Electronics



Physics
(Trigger rates)

Detectors
(Trigger rejection, Data volume)

Trigger - DAQ Architecture

Pipelined frontend
(~ 10^7 channels)

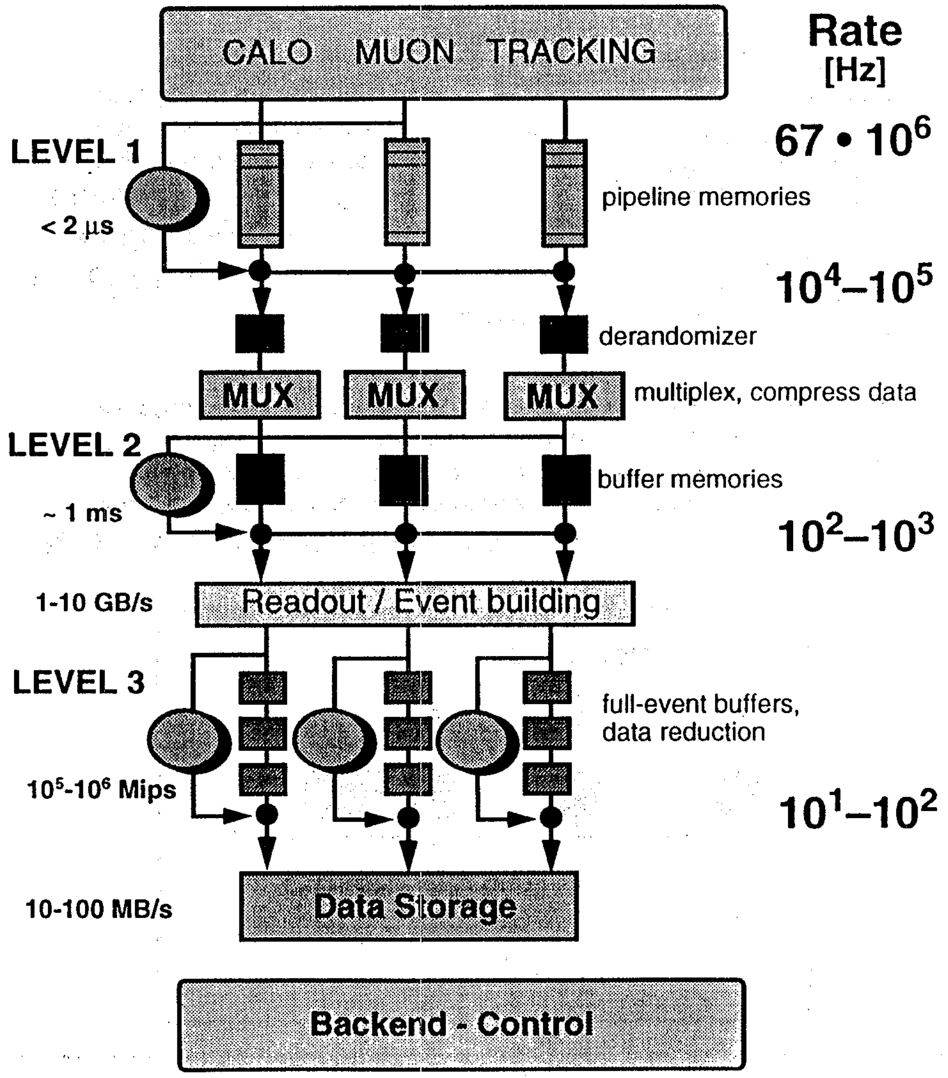
Multi-level trigger
(10^9 -> 10^2 Hz)

Hierarchical DAQ
(~ GB/s --> 10 - 100 MB/s)

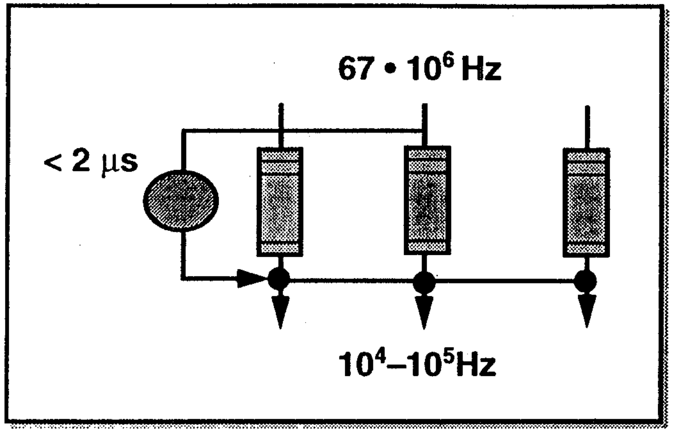
EAGLE groups participate to the following activities:

- Overall trigger/DAQ system
  - Behavioural simulation studies
- Frontend electronics (pipelined readout, etc)
  - R&D projects (RD2, RD6, RD16, RD20, RD23, etc)
- Physics input (rates, etc)
  - Physics simulation studies
- Level–1 triggers
  - Muon trigger (RD5)
  - Calorimeter trigger (UK, Stockholm)
- Level–2 triggers
  - Various architectures under study (RD11, NBI)
- Level–3 triggers, event building and backend
  - Switching networks for event building (RD11-13)
  - Software environment, full-system integration (RD13)

Trigger/DAQ Architecture



Level–1 trigger



Flexible and powerful trigger
Respond to new physics and unexpected background conditions

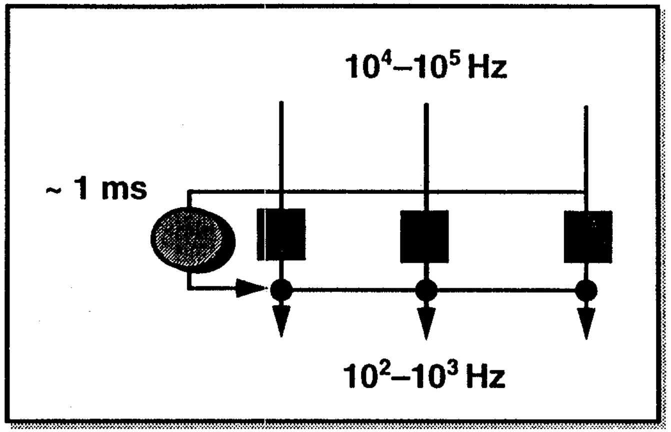
Unique bunch-crossing identification

Physics selections
muon, electron, photon, jet, missing E_T, high-p_T track (under study)
combinations of one or more of above

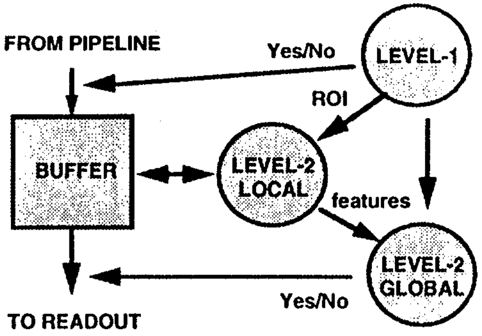
Calorimeter trigger
Granularity $\Delta\eta \times \Delta\phi \approx 0.1 \times 0.1$
Digital trigger processor

Muon trigger
Based on RPC detectors for $|\eta| < 2$
High-p_T muons = tracks beyond toroid pointing to interaction vtx
Resolution of p_T cut dominated by multiple scattering

Level–2 trigger



Refine physics selections of level–1
Full detector granularity and precision (calorimetry / muon tracking)
Use detectors not available at level–1 (TRD - Preshower - Tracking)
Sharper thresholds / Improved rejection of background
Additional requirements (e.g. muon isolation) / Physics selections



Level-1 trigger identifies regions of interest for level-2
e.g. calorimeter cluster
and muon track define
road in inner tracking

Several architectures under study
Programmable processors and high-performance data network
General-purpose or special-purpose processors

System aspects

- **System partitioning**
  Experiment --> Detectors --> Subsystems (System Units)
  System Unit = functionally is a piece of apparatus controlled by one readout processor, one clock line (internal timing is local), one L1 accept/reject line, one BC identifier line
- **Timing**
  clock distribution and system synchronisation
- **Gate logic and deadtime handling**
- **Error handling**
  global detection and fault tolerance
- **Calibration, control and monitoring**
- **Detector (local) requirements and local/global interface**
  - BC identifier
  - local error handling (wrong BC, buffers full, deadtime setting, ...)
  - interface to trigger system (communication/synchronisation)
  - data access

Modelling

Expertise developed with tools (Verilog, Modsim, Artifex) for
- behavioural simulation
- timing and statistical analysis.

- ***synchronous*** (clocked from BC to L1): FE interfaces, communication
- ***asynchronous*** (from L1 to EB): architecture, protocols, algorithms
- **event building**

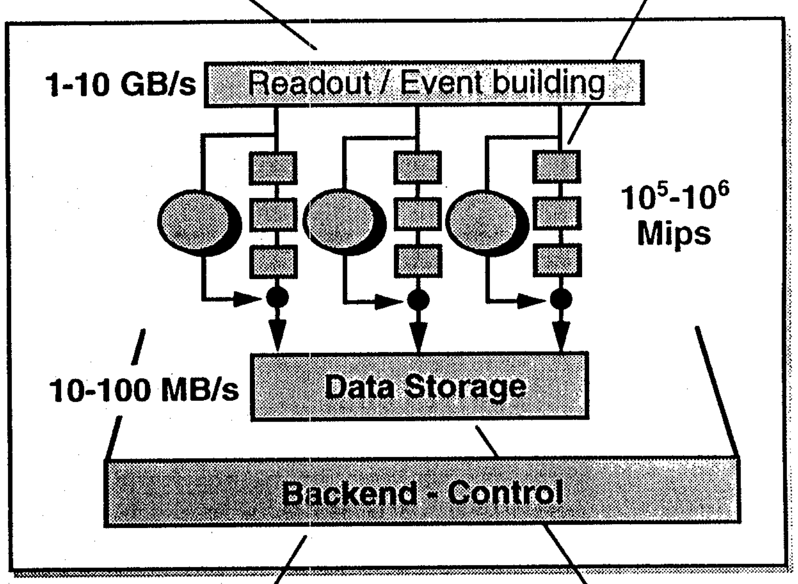
Hardware

development of adequate components for **timing and control signal distribution**

Level–3 trigger and Backend

bottleneck:
need a few Gbyte/s bandwidth

EAGLE event reconstruction:
a few x 10^2 Mips • s



Software development not to be underestimated:
Standard Operating System
Software Engineering
Architecture modelling

Up to 100 Mbyte/s:
might need parallel writing

Muon magnet and installation

Conceptual design studies for the toroid muon magnet
are made at CERN and at IHEP
(with broad-spread industrial input to optimize costs)

A 'large hole geometry' is preferred for the installation

- optimize civil engineering costs
- large scale prefabrication of heavy detector units in surface hall optimizes installation time

Installation scenario:

1 lower part of barrel toroid
2 barrel calorimeter
3 top part of barrel toroid
4 barrel muon chamber
5 inner detector
6 end cap calorimeters
(very forward calorimeters between 3 and 6)
7 end toroids
8 end toroid muon chambers

Horizontal movements of the end toroids by ~ 5.5 m and of the end cap calorimeters by ~ 4.5 m

EAGLE MAGNET TOROID PARAMETERS

26/02/92

BARREL TOROID

MAmpereturns	0.64	
Current	20	kA
Dissipated power	1.3	MW
Iron weight	14000	ton
Coil weight	50	ton

END TOROIDS

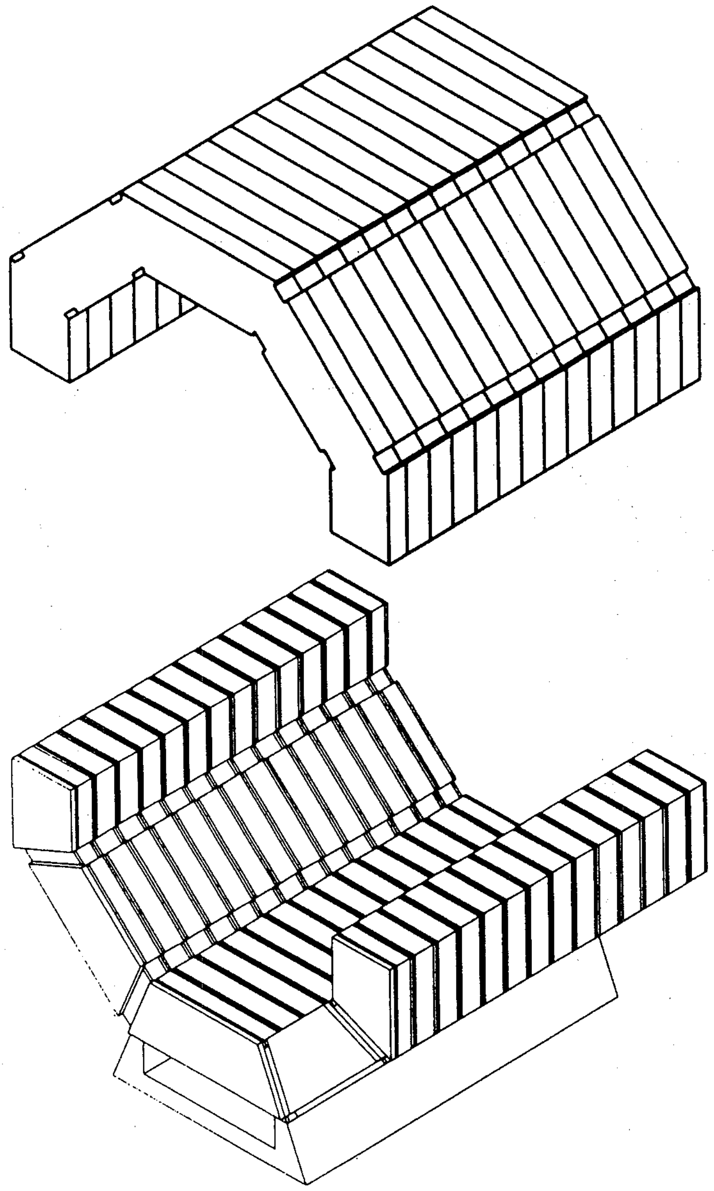
MAmpereturns	2.64	
Current	16/12.5	kA
Dissipated power	1.3	MW
Iron weight	13000	ton
Coil weight	96	ton

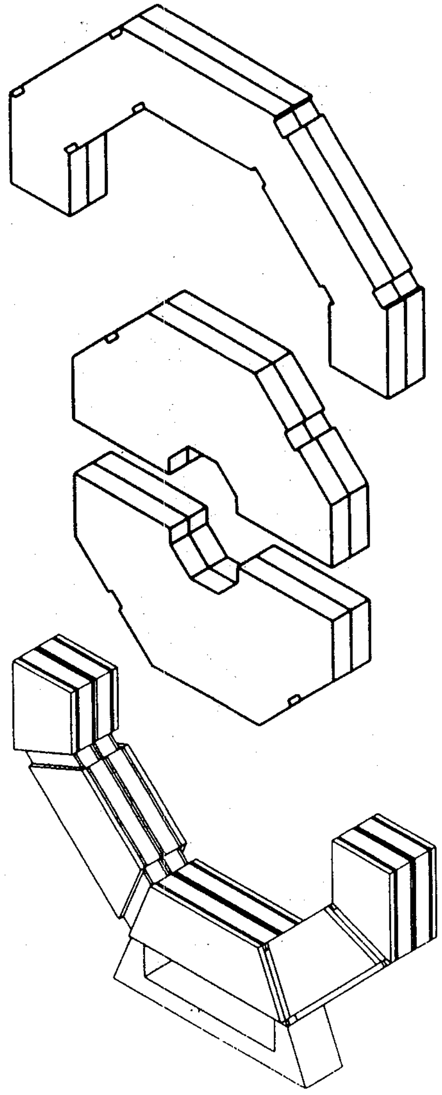
BUS BARS

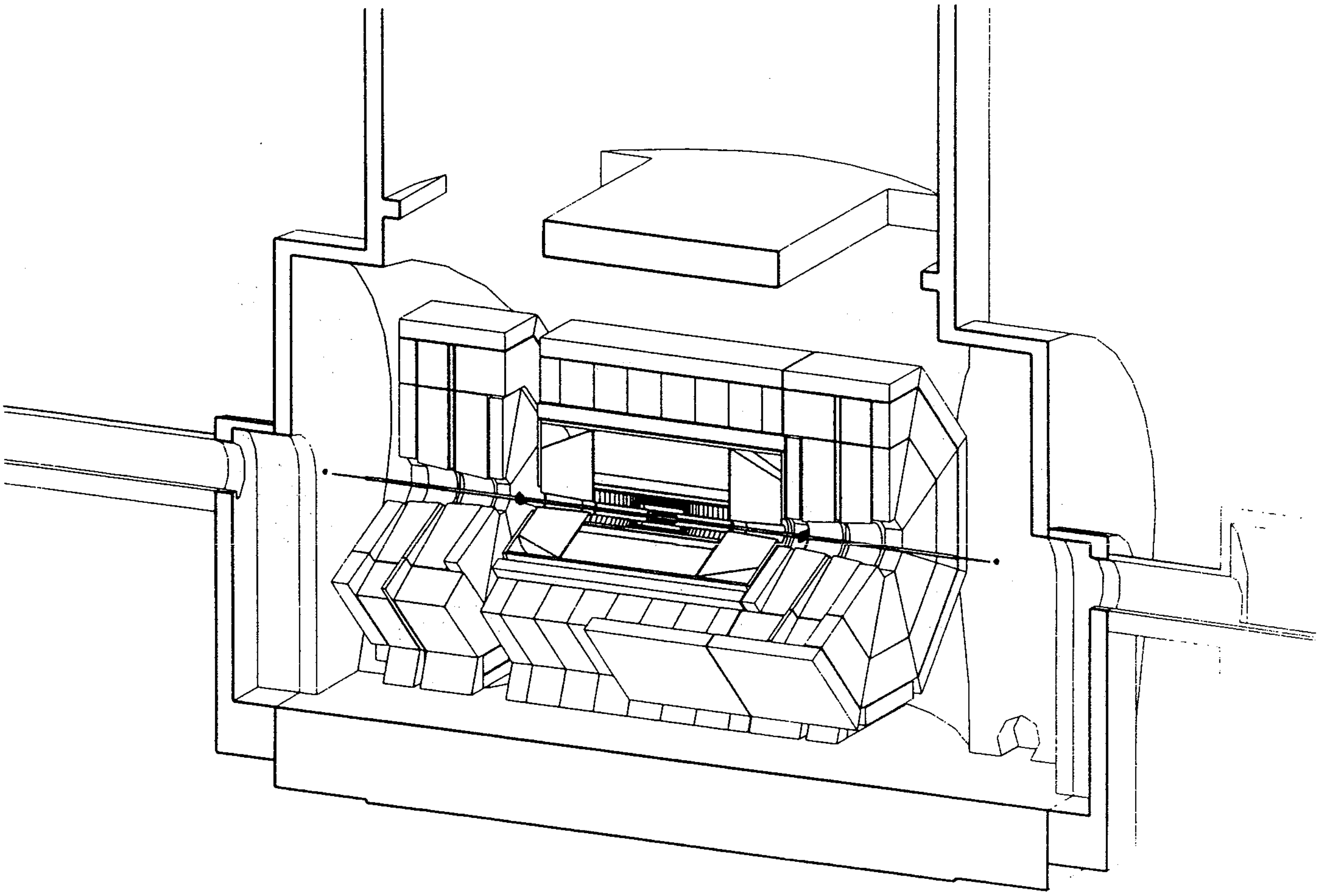
Conductor weight [Al]	34	ton
Dissipated power	0.4	MW

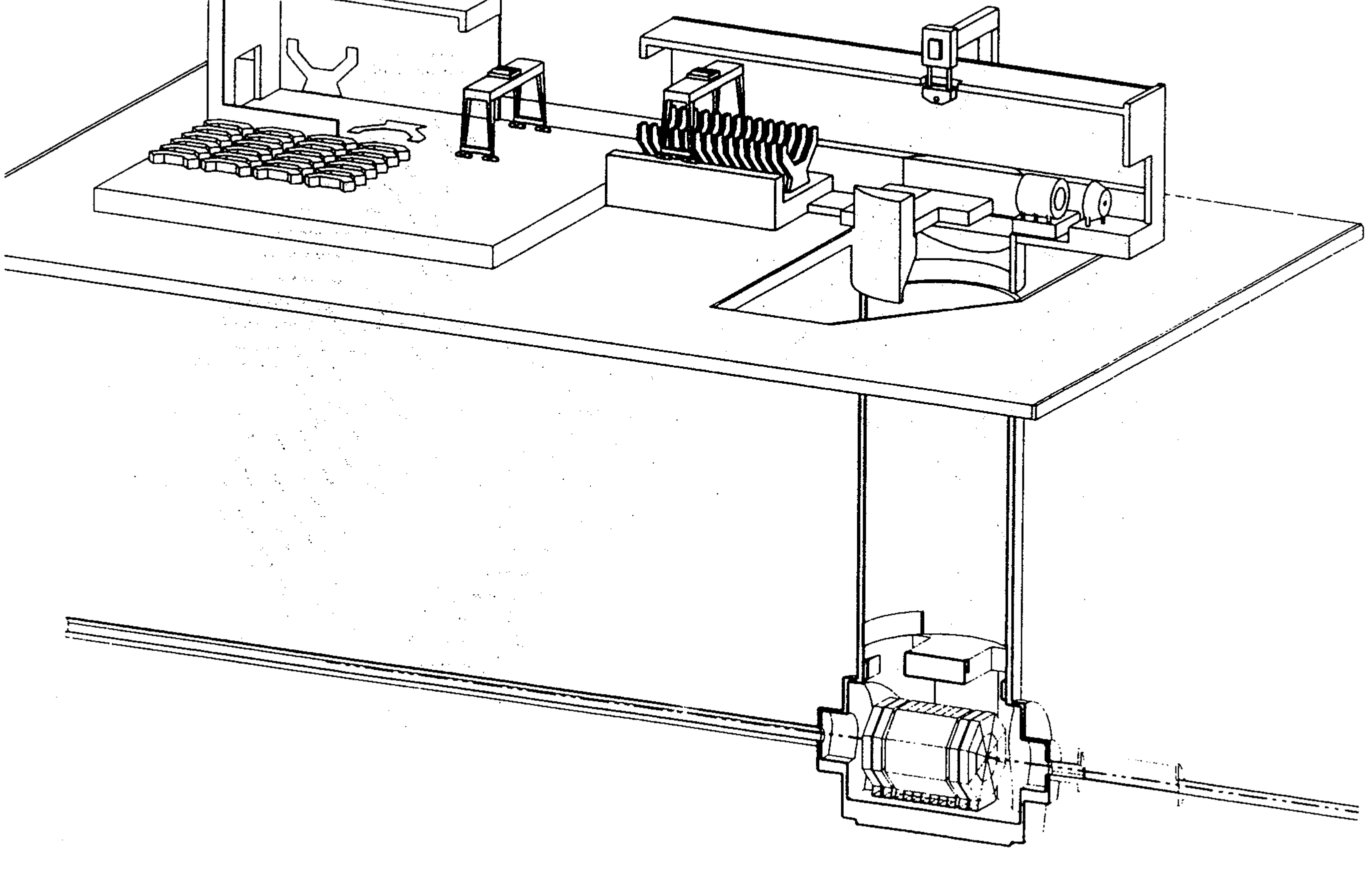
TOTAL

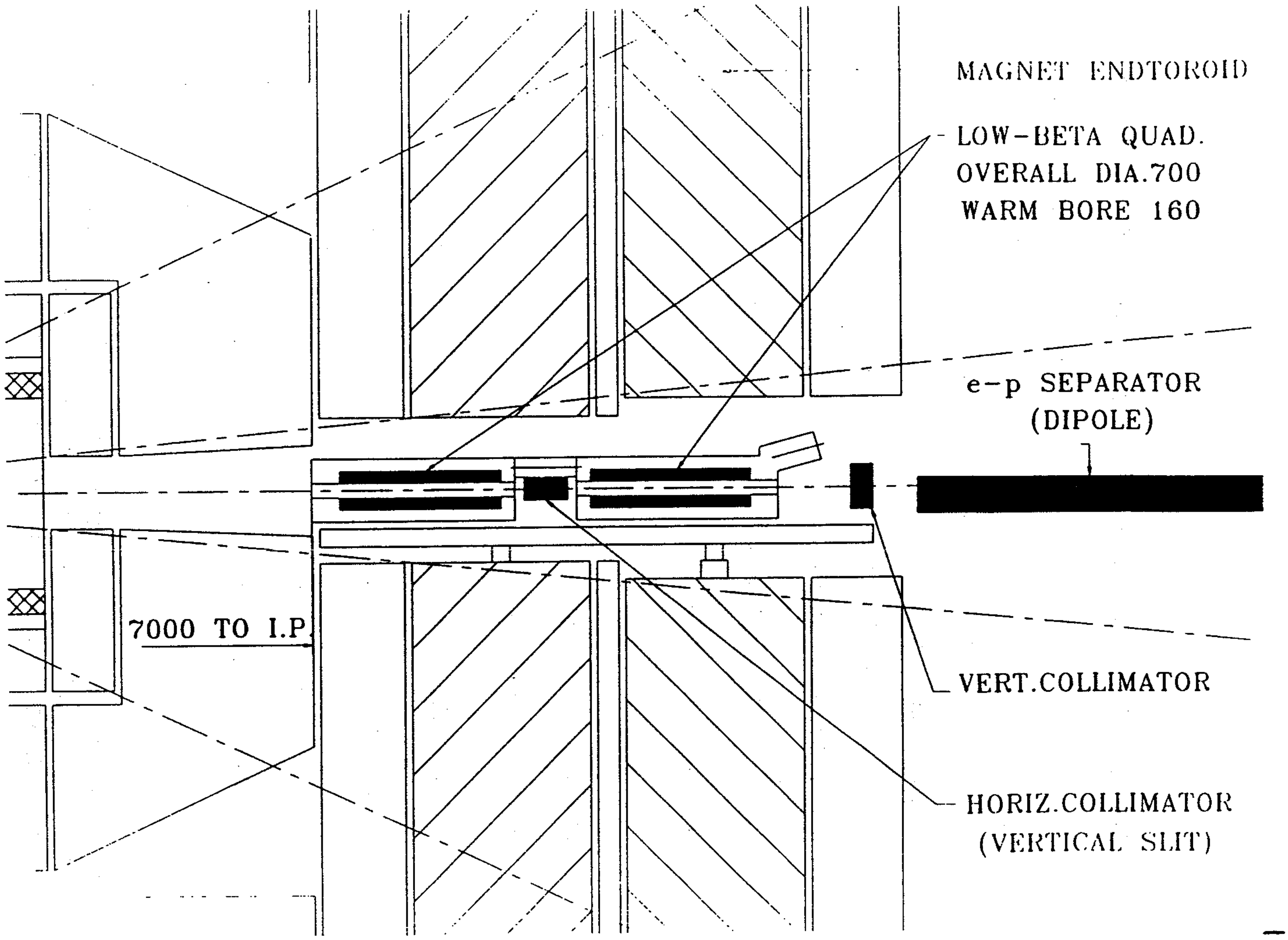
Dissipated Power	3.0	MW
Iron weight	27000	ton
Coil weight [Al]	180	ton
Cooling circuit	140	m3/h

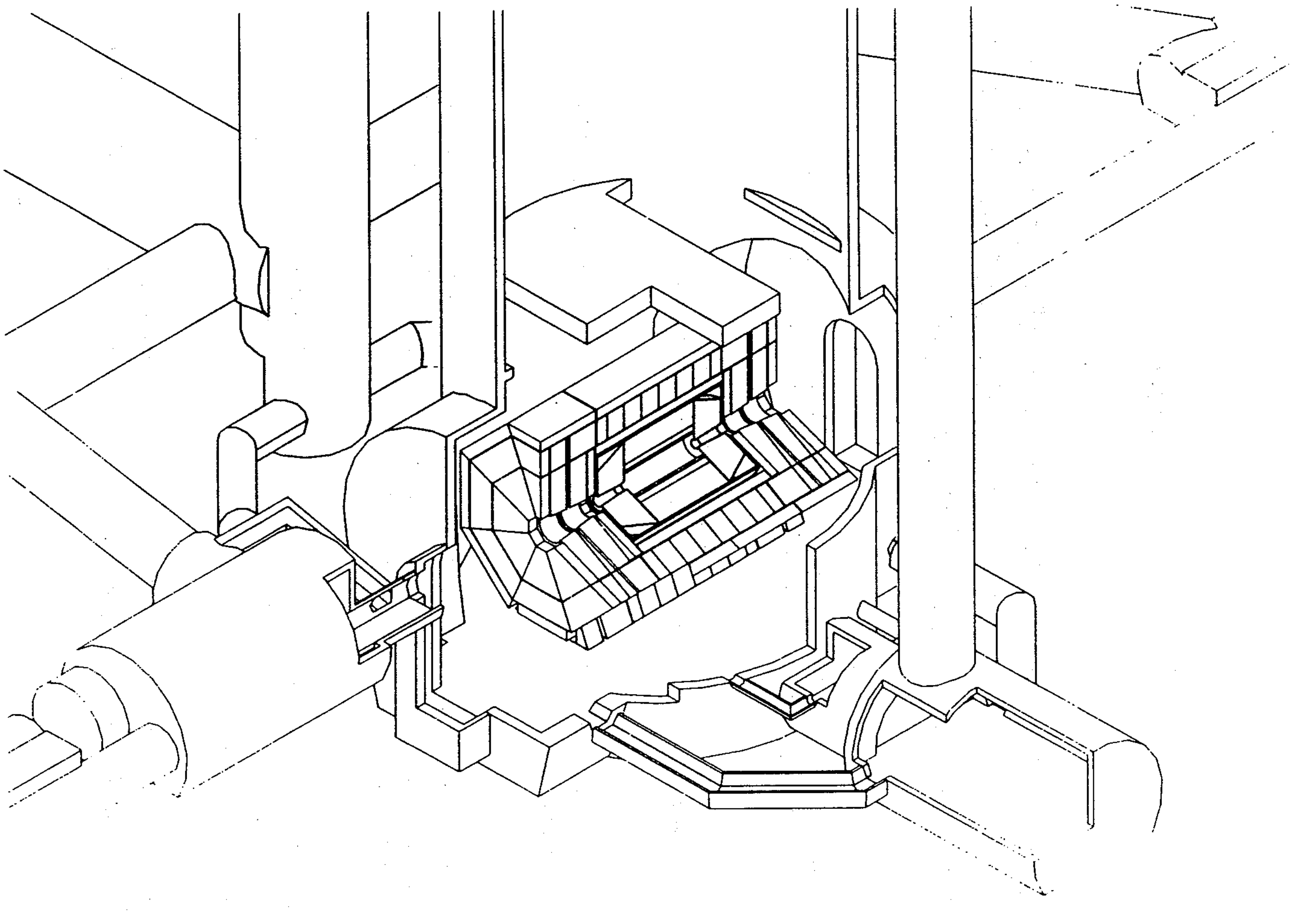









MAGNET ENDTOROID
LOW-BETA QUAD.
OVERALL DIA.700
WARM BORE 160
e-p SEPARATOR
(DIPOLE)
7000 TO I.P.
VERT.COLLIMATOR
HORIZ.COLLIMATOR
(VERTICAL SLIT)



Cost estimates

Costs for LHC detectors are of very serious concern, and much in-depth work is needed before reaching solid estimates

EAGLE is in a very early stage of cost estimates and detector optimization with respect to costs

Presently engineering and industrial cost estimates are only available for part of the components of the detector

Whenever possible experience from R&D projects has been used

At this early stage several subdetectors are designed to have stand-alone capabilities which in the final integrated lay-out can likely be reduced

It is particularly difficult to estimate FE electronics and DAQ costs as necessary solutions are not yet known in some cases

FE electronics costs for radiation exposed detectors have been increased by typically a factor two over normal costs

---

EAGLE costs - first rough estimate (MCHF)

		depending on options	
Inner detector		73 - 89	
inner Silicon tracker and vertex	24		
outer Silicon tracker	33 - 39		
transition radiation tracker	7 - 15		
micro strip gas counters	11 - 16		
Central solenoid (if separate)		12 - 18	165 (integr. LAr)
Preshower detector		20	
EM calorimeter		60	
Hadronic calorimeter		55	
Fe toroid and supports		90	
Muon chambers		34 - 44	
Very forward calorimetry		10 - 15	
DAQ, trigger, slow controls		60	
Primary infrastructure		33	
		450 - 500	

Installation costs are included on the large items, however not all manpower on the detector components, assuming a very strong involvement of the lab staff

Expected physics performance of EAGLE

Physics processes are being simulated with performance characteristics of EAGLE including pile-up effects when relevant

- resolutions EM $10\%/\text{sqrt}(E) \oplus 1\% \oplus$ noise
  jets $50\%/\text{sqrt}(E) + 2\%$
  muons as shown

- η-acceptances (trigger and analysis)
- efficiencies for leptons and b tag as shown

Examples:

<u>Top quark physics</u>
- top search and 3-jet mass (shown in SITV part)
- top decays and search for H^+

<u>Heavy Z' physics</u>
- l^+l^- and jet+jet channels

<u>Standard Model H physics</u>
- H --> $\gamma\gamma$ (partially shown in LAr part)
- H --> 4 charged leptons
- H --> ZZ --> $l^+l^- \nu\bar{\nu}$ (shown in forward calo. part)

<u>SUSY H</u>

<u>Technicolour $W_L Z_L$ and $Z\gamma$ resonances</u>

EAGLE presentation Evian 6-3-1992

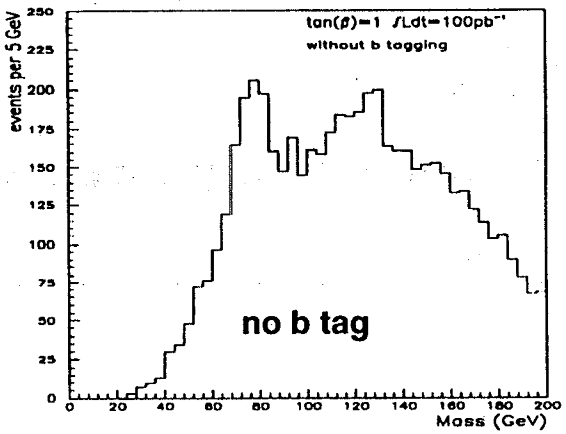
Search for $H^+ \dashrightarrow c\bar{s}$

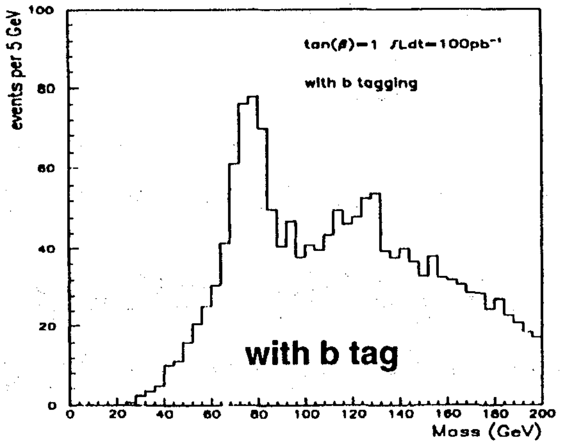
$t\bar{t}$ --> Wb H^+b, W --> e or μ tag (at 10^{33} cm^{-2}s^{-1})

2-jet mass in hemisphere opposite to lepton tag with p_T lepton > 40 GeV and p_T jets > 50 GeV, both $|\eta| < 2$

background: W + jets

m_{top} = 200 GeV m_{H+} = 130 GeV 100 pb^{-1}





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Search for H^+ --> $\tau\nu$

$t\bar{t}$ --> Wb H^+b, W --> e or μ tag, search for excess τ events (at 10^{33} $cm^{-2}s^{-1}$)

main τ-selection criteria: single isolated hadron (τ --> hν) track with $p_T > 30$ GeV, $|\eta| < 2$, identified in tracking and calorimeter

backgrounds: - fake τ's from $t\bar{t}$, W+jets, $b\bar{b}$
- real τ's from W --> τ --> h

b tag included to reduce non-top backgrounds

overall systematic error estimated to be 3% of observed total number of τ candidates

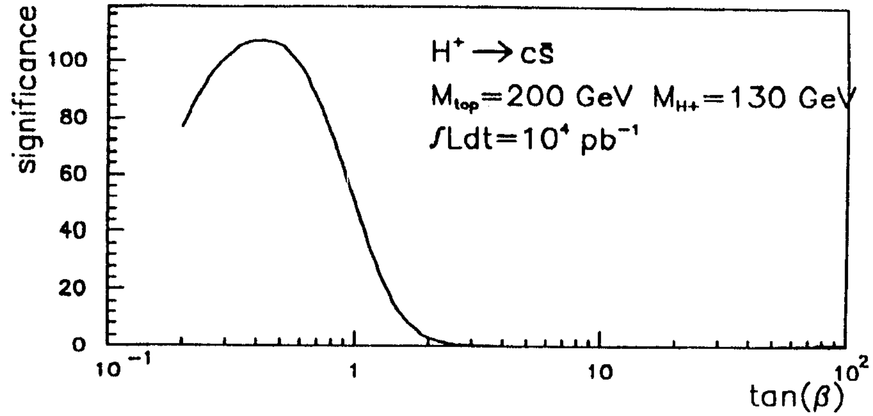
example: - m(top) = 140 GeV, m(H^+) = 100 GeV, 10^4 pb^{-1} and tanβ = 6 (lowest BR for t --> H^+b ~ 2.6%)

- N_τ observed = 775 (50% from W --> $\tau\nu$ and 50% from H^+ --> $\tau\nu$) + 917 fake τ from $t\bar{t}$ events

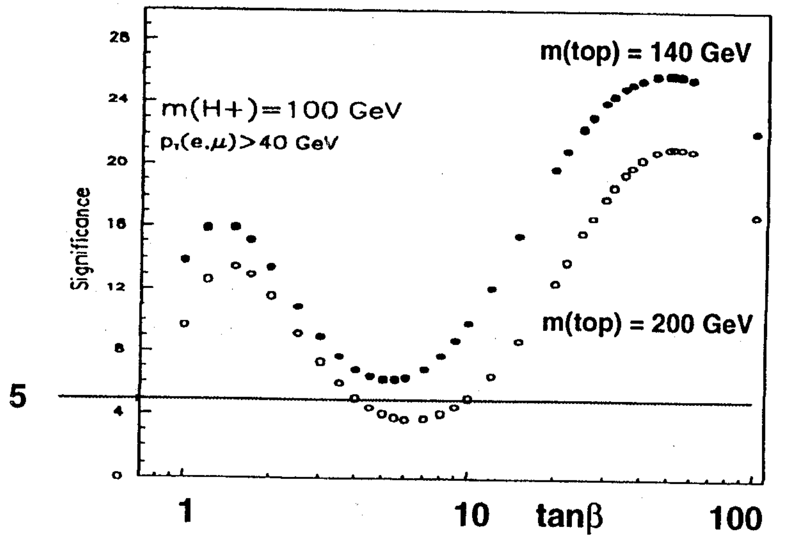
- statistical error on τ excess ~ 40
systematic error on τ excess ~ 50

EAGLE sensitivity to detect a charged Higgs (10^4 pb^{-1})

H^+ --> $c\bar{s}$ channel covers low values of tanβ

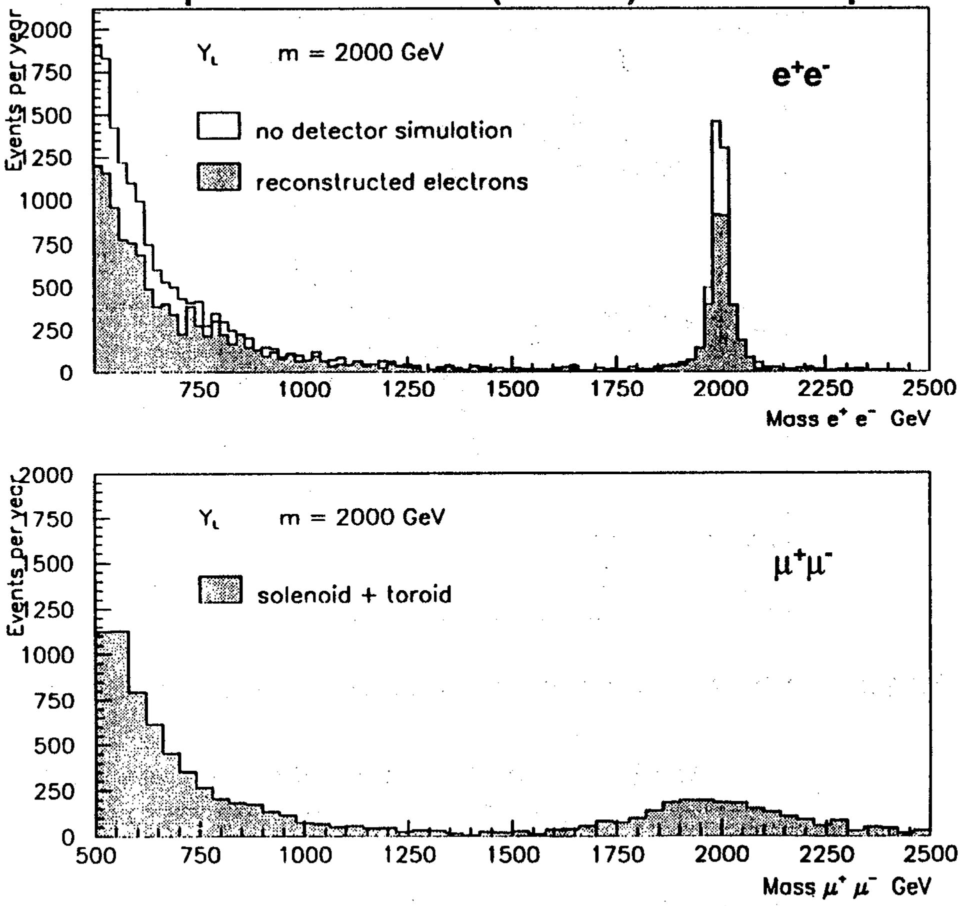


H^+ --> $\tau\nu$ channel covers large values of tanβ



Heavy Z' --> e^+e^- or $\mu^+\mu^-$

simulations using a specific model (Y_L with $\lambda_Y^2 = 0.2, 0.68$)
example m = 2 TeV BR ($Z' \to l^+l^-$) = 12% 10^5 pb^{-1}



- **mass and width measurements from e^+e^- channel**
- **discovery range typically 5 TeV from e^+e^- and 4 TeV from $\mu^+\mu^-$ (depends on model)**

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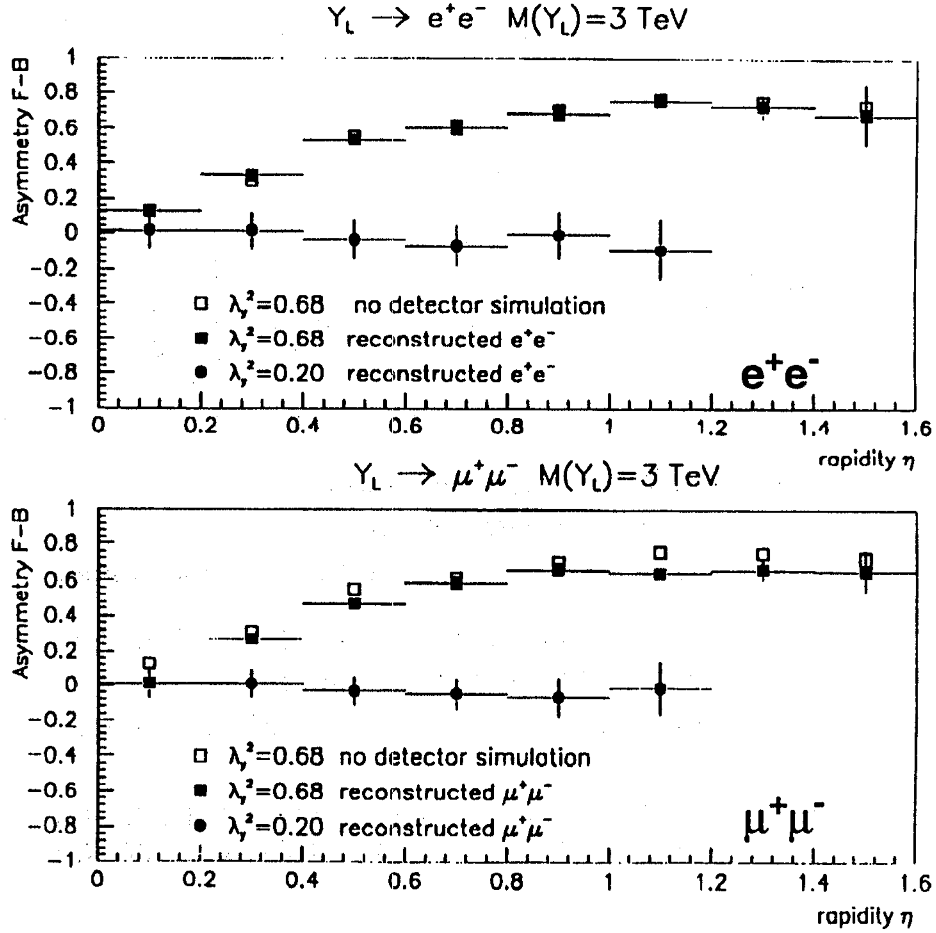
F - B charge asymmetry measurement

simulation with m = 3 TeV assuming 10^5 pb^{-1}



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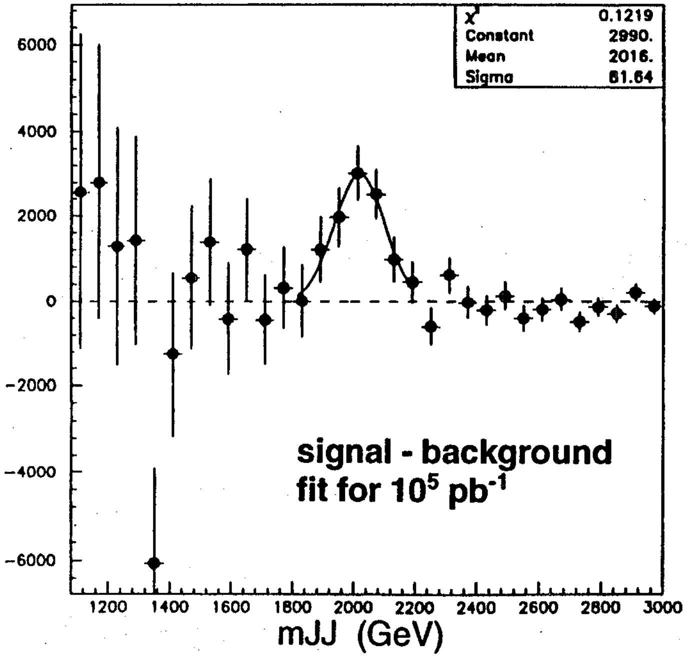
Heavy Z' --> jet + jet

example of jet spectroscopy at LHC

2 - jet selection: p_T - jet > 300 GeV and $|\eta| < 1$
(unbiased m_{JJ} distribution for $m_{JJ} > 1$ TeV)

simulation of QCD jets and Z' with m = 2 TeV and $\Gamma = 63$ GeV



pile-up effects are small but constant term of hadronic calorimeter plays a role

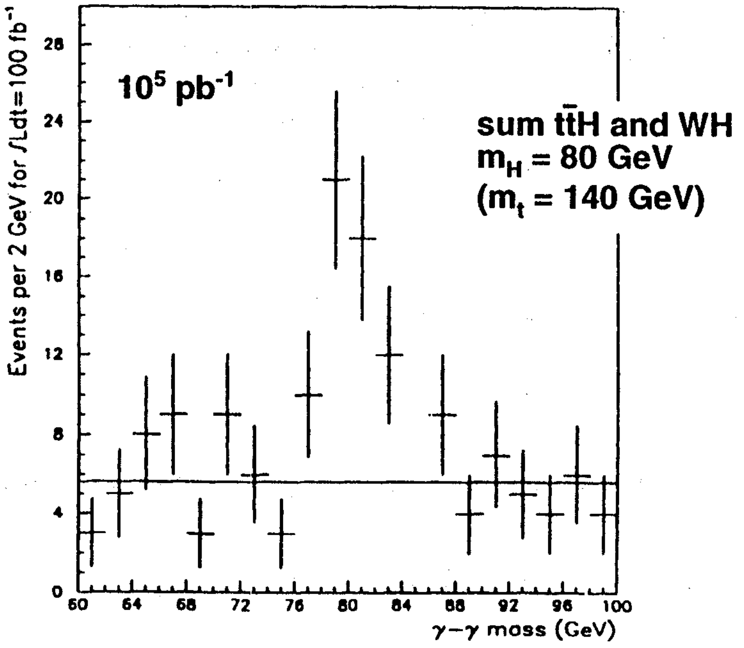
significant signals are obtained only at high luminosity, up to about m = 3 TeV

Associated Higgs production

WH and $t\bar{t}H$ channels cover the lowest part of the intermediate Higgs mass range ($80 < m_H < 130$ GeV)

simulated signature: e or μ tag ($p_T > 25$ GeV, $|\eta| < 2$) and H --> $\gamma\gamma$ with the same assumptions as for the direct search ($p_T > 25$ GeV, $|\eta| < 2$ for the γ)

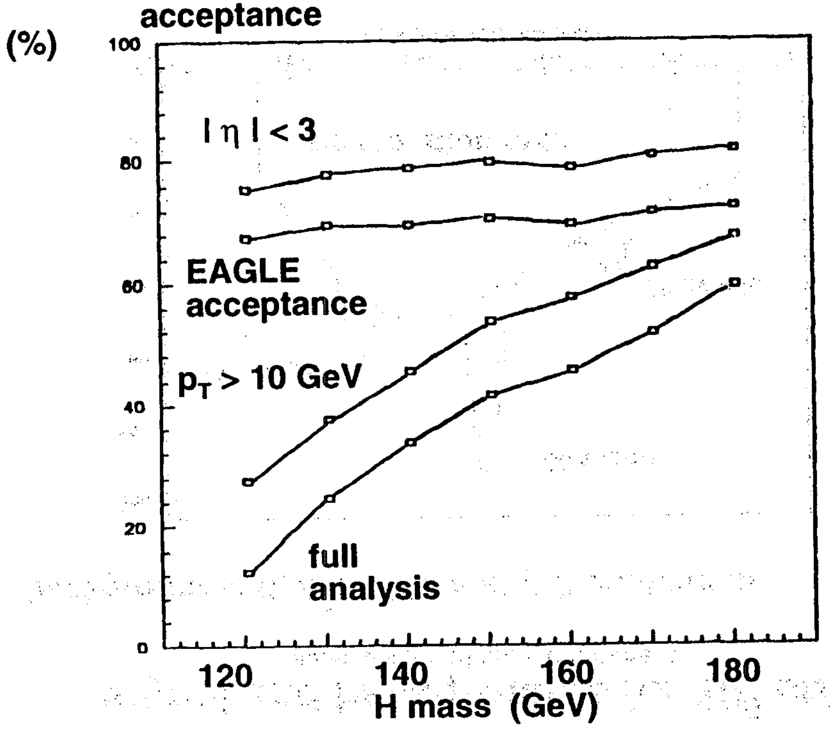
backgrounds: - irreducible from $W\gamma\gamma$ or $t\bar{t}\gamma\gamma$
- reducible from $b\bar{b}\gamma\gamma$, and many QCD processes with fake leptons or γ's



Intermediate mass H --> 4 charged leptons

Simulation of eeee, $ee\mu\mu$ and $\mu\mu\mu\mu$ final states

trigger thresholds: $p_T > 20$ GeV for the two highest P_T leptons
analysis thresholds: all lepton $p_T > 10$ GeV



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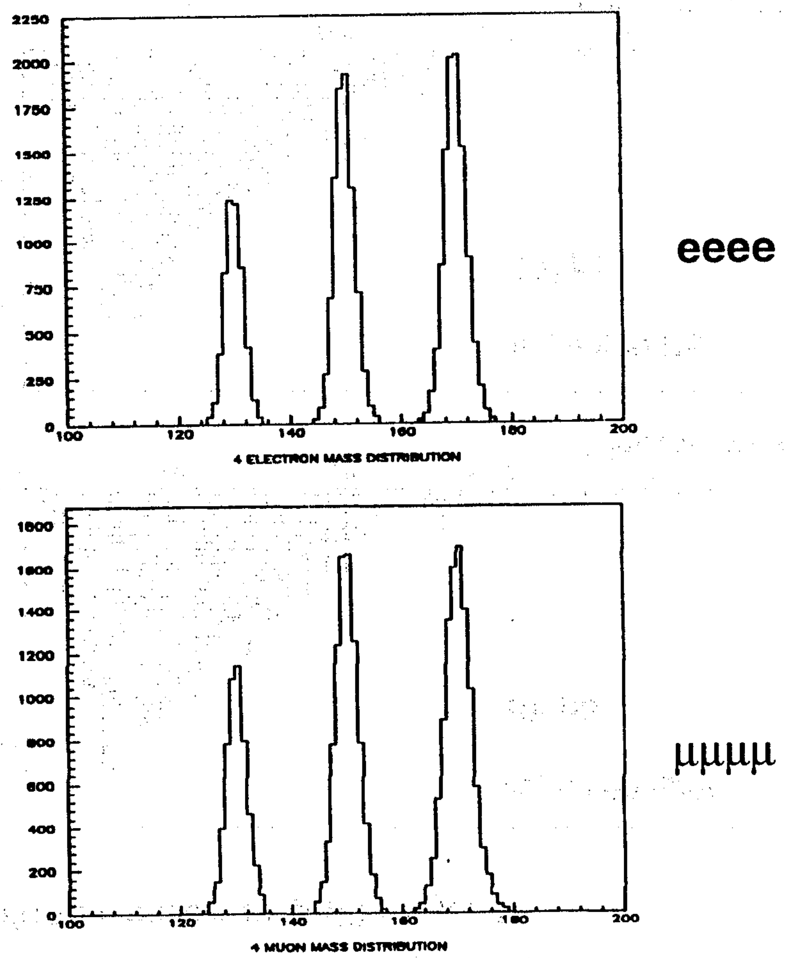
H mass resolution (4 charged leptons)



Higgs mass (GeV)	120	140	160	180
eeee resolution (GeV)	1.5	1.7	1.9	2.2
$\mu\mu\mu\mu$ resolution (GeV)	1.8	2.0	2.3	2.7

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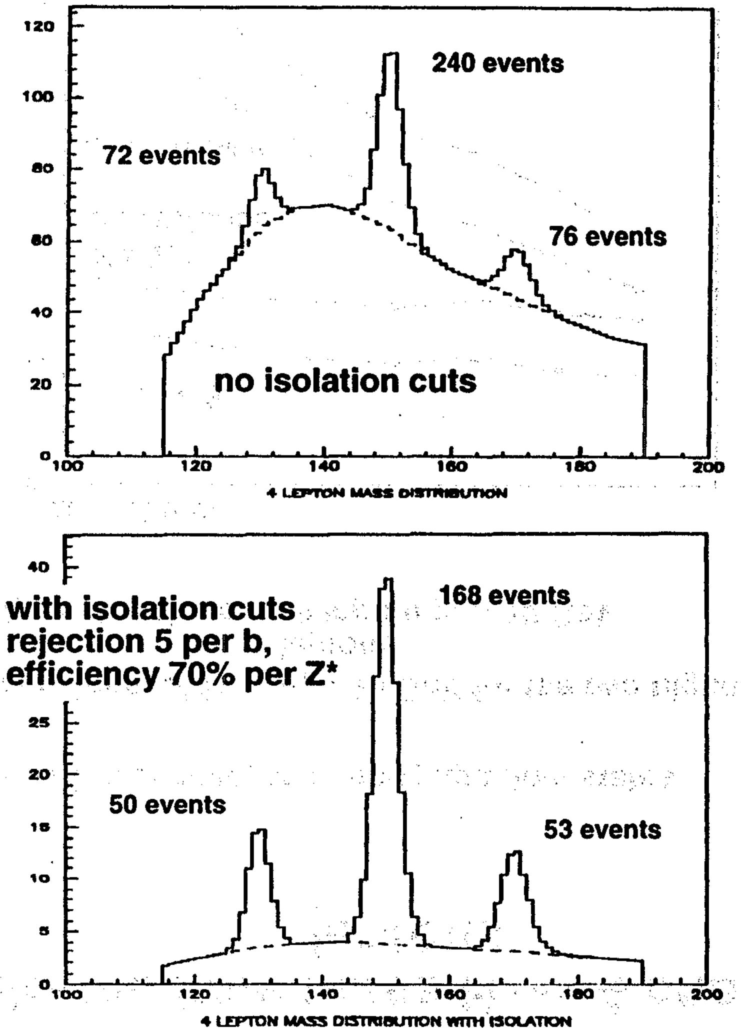
signal and backgrounds for 10^5 pb^{-1}

(eeee, eeμμ and μμμμ combined)

backgrounds: $\bar{t}t$, $Zb\bar{b}$, Z^*Z^* and γ^*Z^* continuum

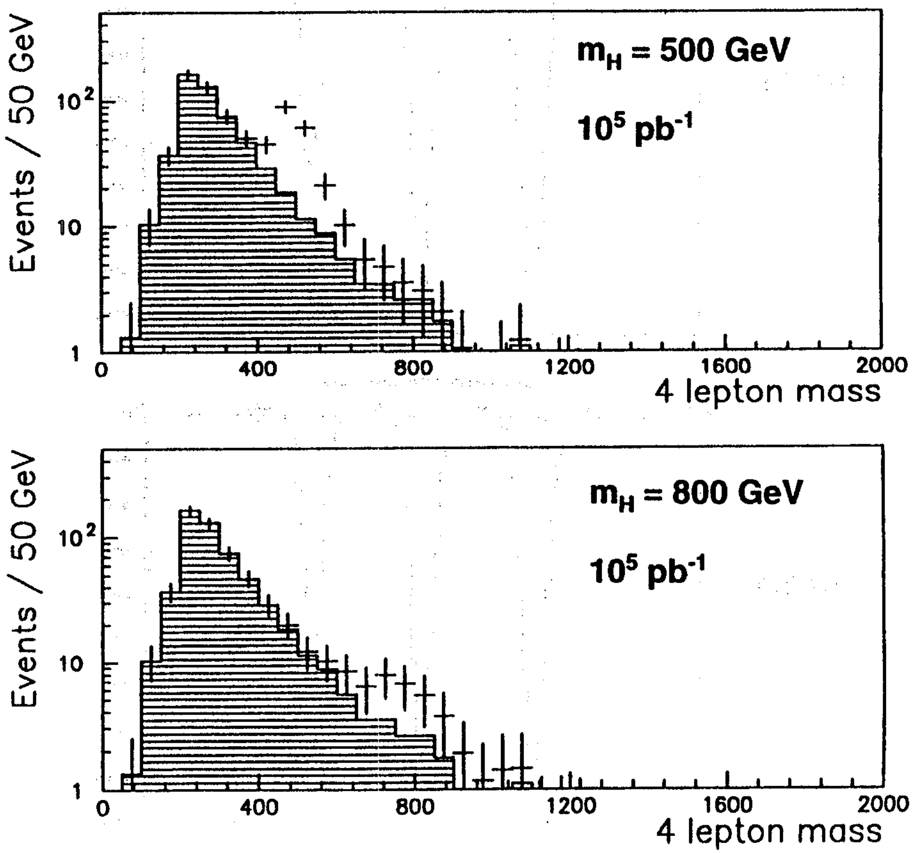


High mass H --> ZZ --> 4 charged leptons

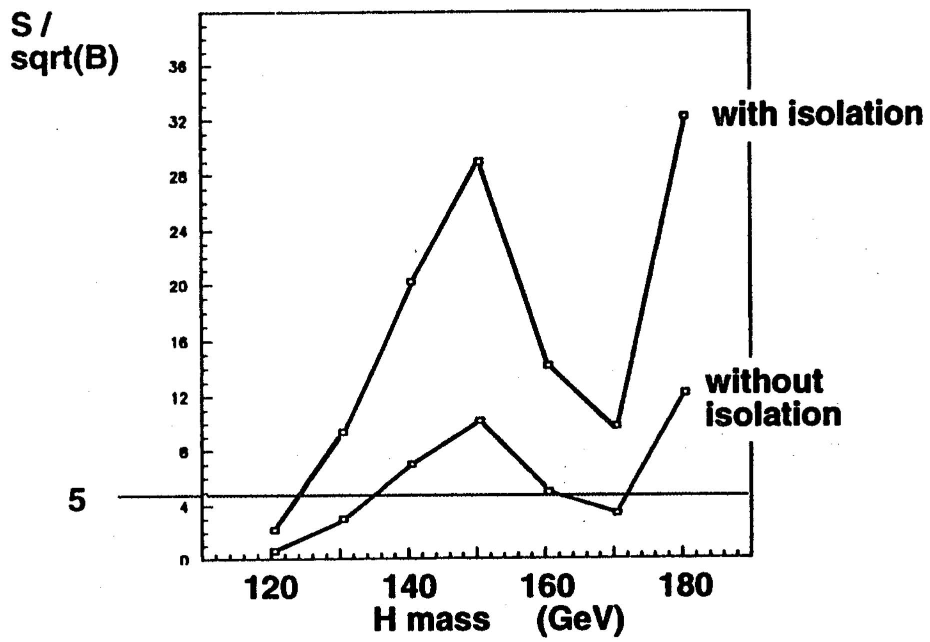
simulation for eeee, eeμμ and μμμμ final states
(using most recent calculations of Baur et al.)

background: - ZZ continuum
- ($Zb\bar{b}$ and $t\bar{t}$ negligible)

main kinematic cut: $p_T(Z) > m_{ZZ} / 4$



sensitivity for the 4 charged lepton final state (10^5 pb^{-1})



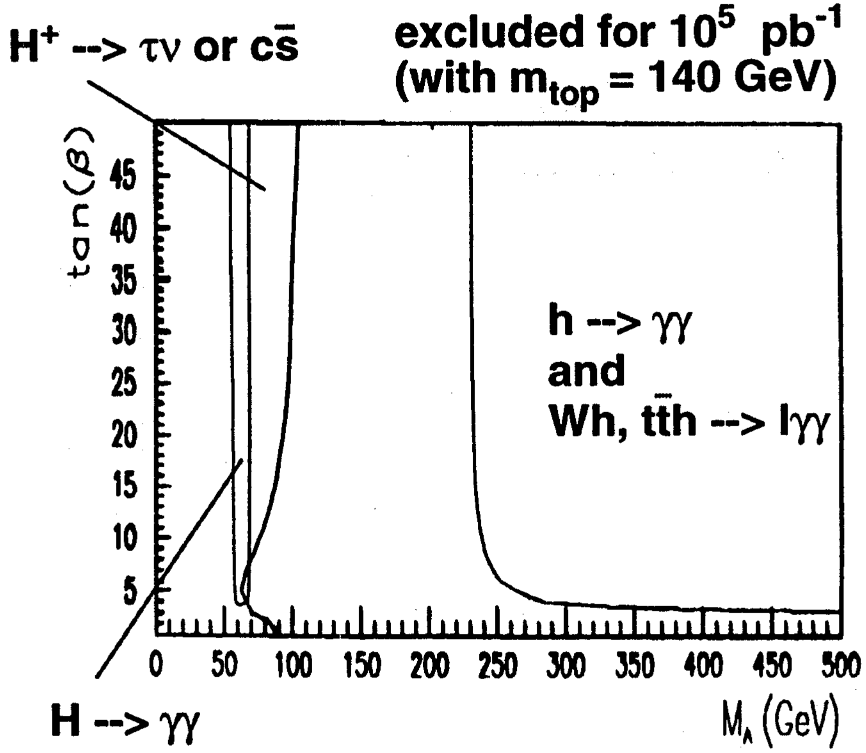
EAGLE Higgs search sensitivity summary

mass range (GeV)	channels
80 - 130	WH and $t\bar{t}H$ followed by H --> $\gamma\gamma$
90 - 150	H --> $\gamma\gamma$
125 - 180	H --> Z*Z* --> 4 charged leptons
high mass (< 800)	H --> ZZ --> 4 charged leptons --> $ee\nu\bar{\nu}$ or $\mu\mu\nu\bar{\nu}$
very high masses (> 500)	qq --> qqH through WW or ZZ fusion with tagging of forward quarks and H --> WW --> $l\nu$ jj

---

Sensitivity regions for Higgses of the MSSM

model has:
- H^o, h^o, A^o, H^+ and H^-
- two free parameters, for example m_A and $\tan\beta$
- masses are affected by radiative corrections for large m_{top}



A --> $\tau^+\tau^-$ --> eμ + ν's expected to exclude large $\tan\beta$

H --> 4 charged leptons expected to cover an additional region for low $\tan\beta$

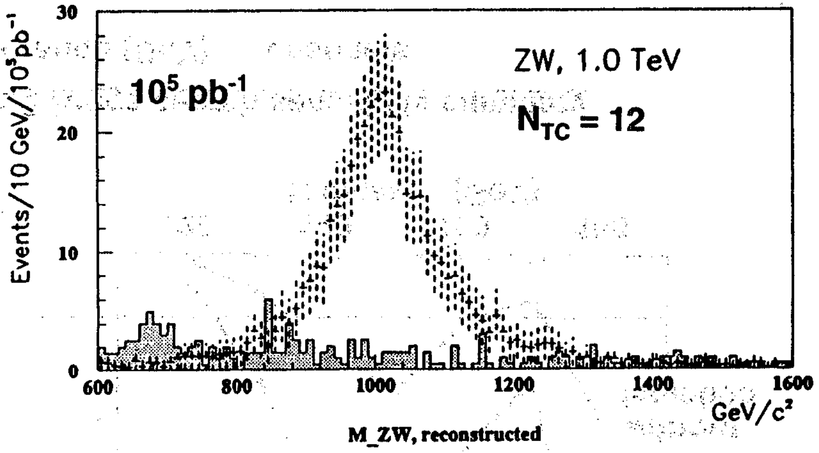
If m_{top} = 200 GeV larger regions are covered

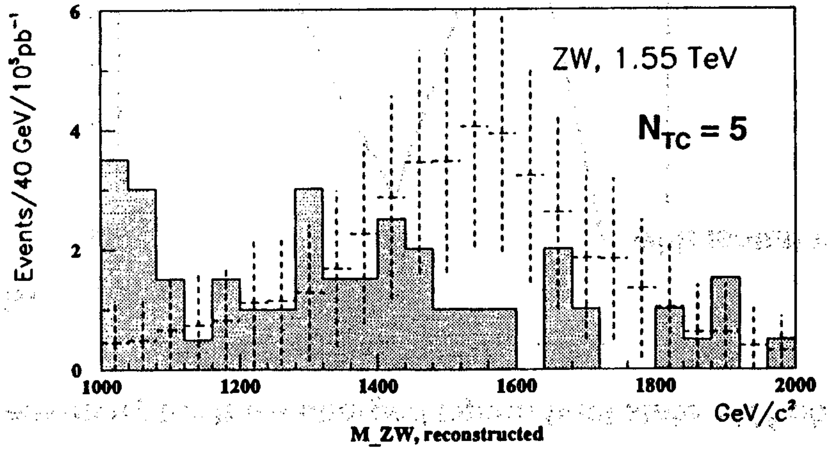
$W_L Z_L$ and $Z\gamma$ resonances

$V_L V_L$ scattering (if no H is found), example technicolour models with resonance production of VV pairs

WZ resonance (ρ_{TC}) with 3 charged leptons in the final state (e or μ), neutrino 4-momentum reconstructed using missing transverse energy and kinematical constraints

backgrounds: WZ from Standard Model, $t\bar{t}$ production

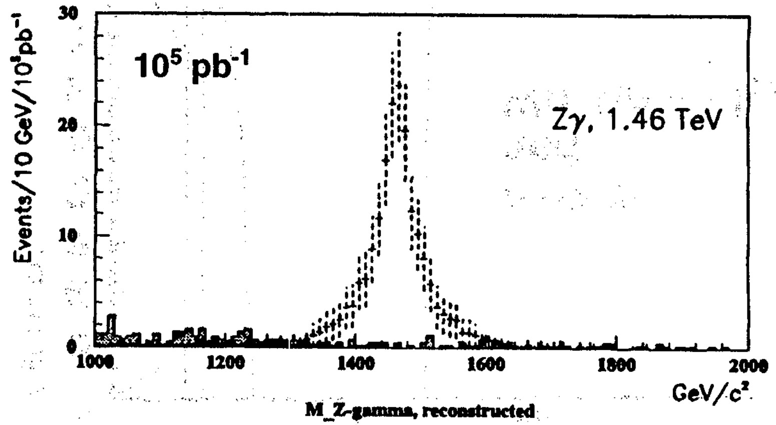


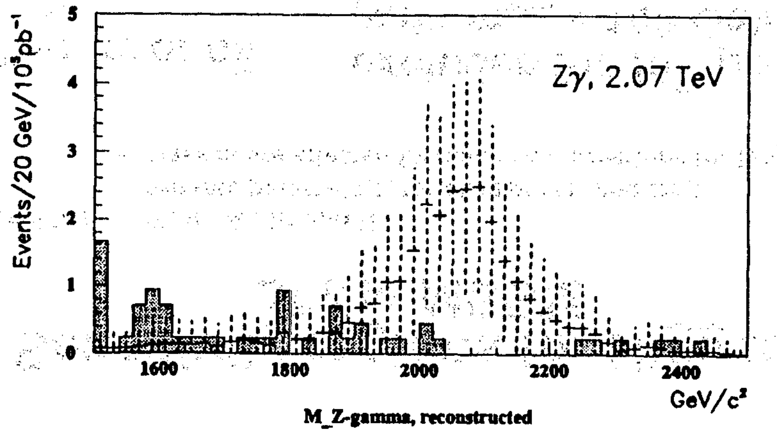


γZ resonance (ω_{TC}) with γee or $\gamma\mu\mu$ final state

simulated cases: $N_{TC} = 3$ with m = 2.07 TeV , Γ = 120 GeV
$N_{TC} = 6$ 1.46 TeV 31 GeV

backgrounds: γZ from Standard Model
Z+jet with fake γ from jet





Outlook

The EAGLE collaboration is working on a balanced detector concept which will cover

- *the expected broad discovery potential*
- *as well as possible new physics*

at LHC right from the start-up of the machine

Exciting physics is ahead of us, but there s a long way to go!

EAGLE is very open to new collaborators and invites all interested groups to take their share of the LHC detector challenge

The ambitious goals of EAGLE can only be met if there is strong enthusiasm for LHC experiments in the whole community

- *guidelines and timely calendar for Letters of Intent*
- *continued strong support for R&D*
- *continued and strongly increasing support for engineering studies*

Expression of Interest

L3 detector upgrade for LHC : The Extended L3 Collaboration

S.C.C. Ting (MIT)
F. Pauss (ETH, Zürich)

Evian

General Meeting on LHC Program

March 5-8, 1992

Expression of Interest

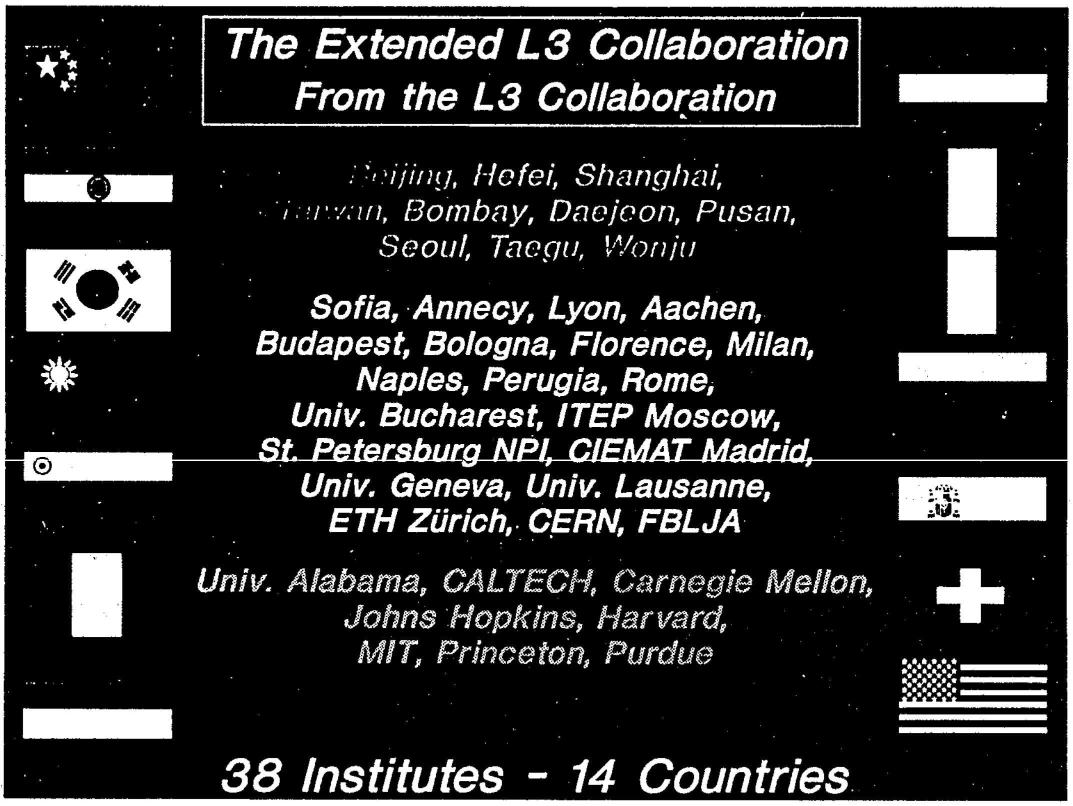
To upgrade the L3 detector for LHC

by

The Extended L3 Collaboration

Samuel C.C. Ting

Evian, March 6, 1992



The Extended L3 Collaboration
From the L3 Collaboration

Beijing, Hefei, Shanghai,
Taiwan, Bombay, Daejeon, Pusan,
Seoul, Taegu, Wonju

Sofia, Annecy, Lyon, Aachen,
Budapest, Bologna, Florence, Milan,
Naples, Perugia, Rome,
Univ. Bucharest, ITEP Moscow,
St. Petersburg NPI, CIEMAT Madrid,
Univ. Geneva, Univ. Lausanne,
ETH Zürich, CERN, FBLJA

Univ. Alabama, CALTECH, Carnegie Mellon,
Johns Hopkins, Harvard,
MIT, Princeton, Purdue

38 Institutes - 14 Countries

Dr. F. PAUSS
ETH Zürich

will report
on physics examples

Extended L3 Collaboration

Member States authors : 311

Non-Member States authors : 163

47 /lb

The Extended L3 Collaboration
New Members

Fudan, Jiatung, Shandong,
Tsinghua, Zhejiang

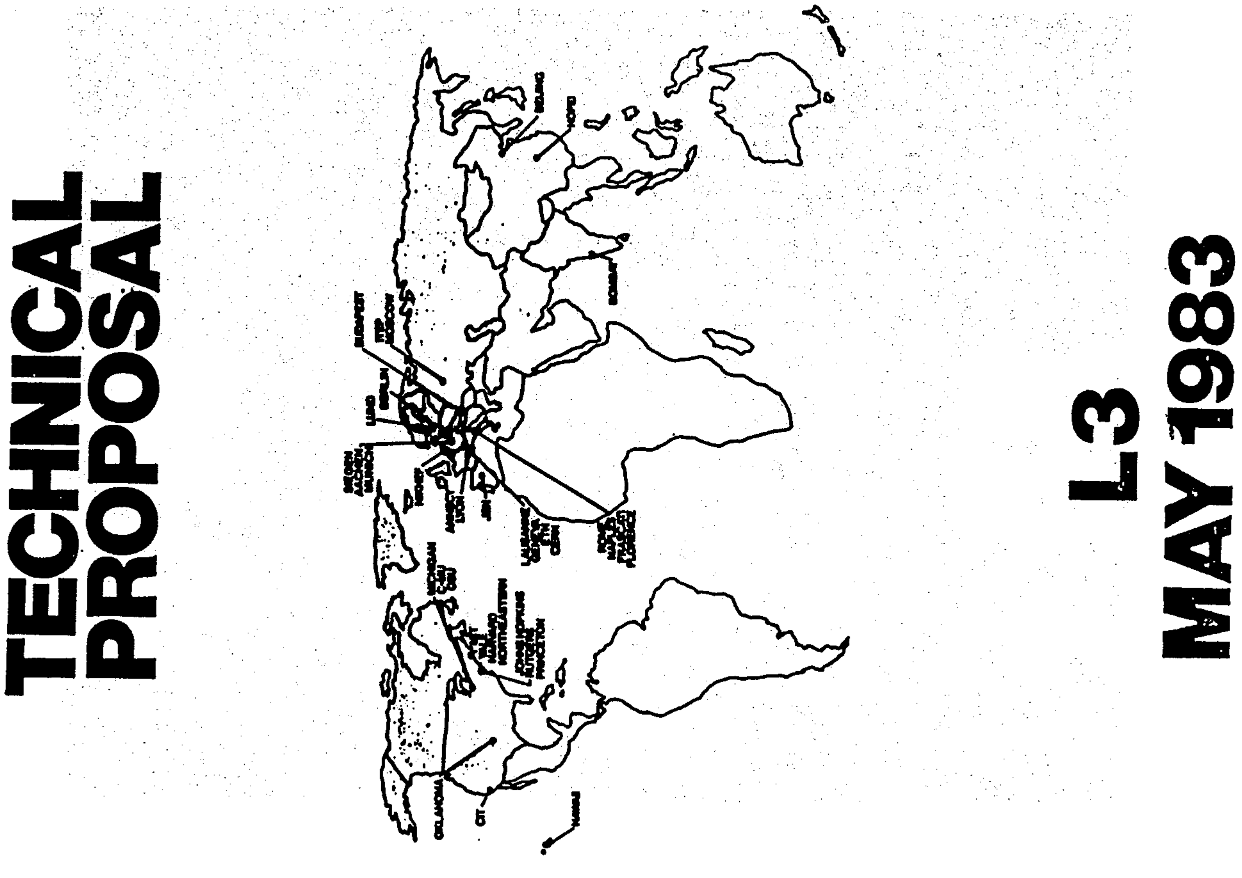
Inst. Cabling Industry Erevan,
Univ. Nicosia, Univ, Siegen,
Ust Kamenogorsk, Chernogolovka,
JINR Dubna, Kurchatov Moscow,
Zhukovsky Moscow,
Inst. Anorganic Materials Moscow,
Inst. Cabling Industry Moscow,
Inst. Mounting Technology Moscow,
Novosibirsk, Efremov St. Petersburg,
Inst. Structural Materials St. Petersburg

Univ. Alabama System:
Birmingham, Huntsville, Mobil

22 Institutes - 7 Countries

As stated in Chapter II (Physics Goals) of the L3 Technical Proposal of May 1983, some of the unique features are :

1. **Measurement of photons, electrons and muons with a resolution of $\Delta p/p \approx 1\%$.**
2. **The large magnetic hall with a $BL^2 = 160$ kG-m^2 and the fact that the central part of the detector can be easily modified or removed, making this experiment readily adaptable for future phases of LEP.**



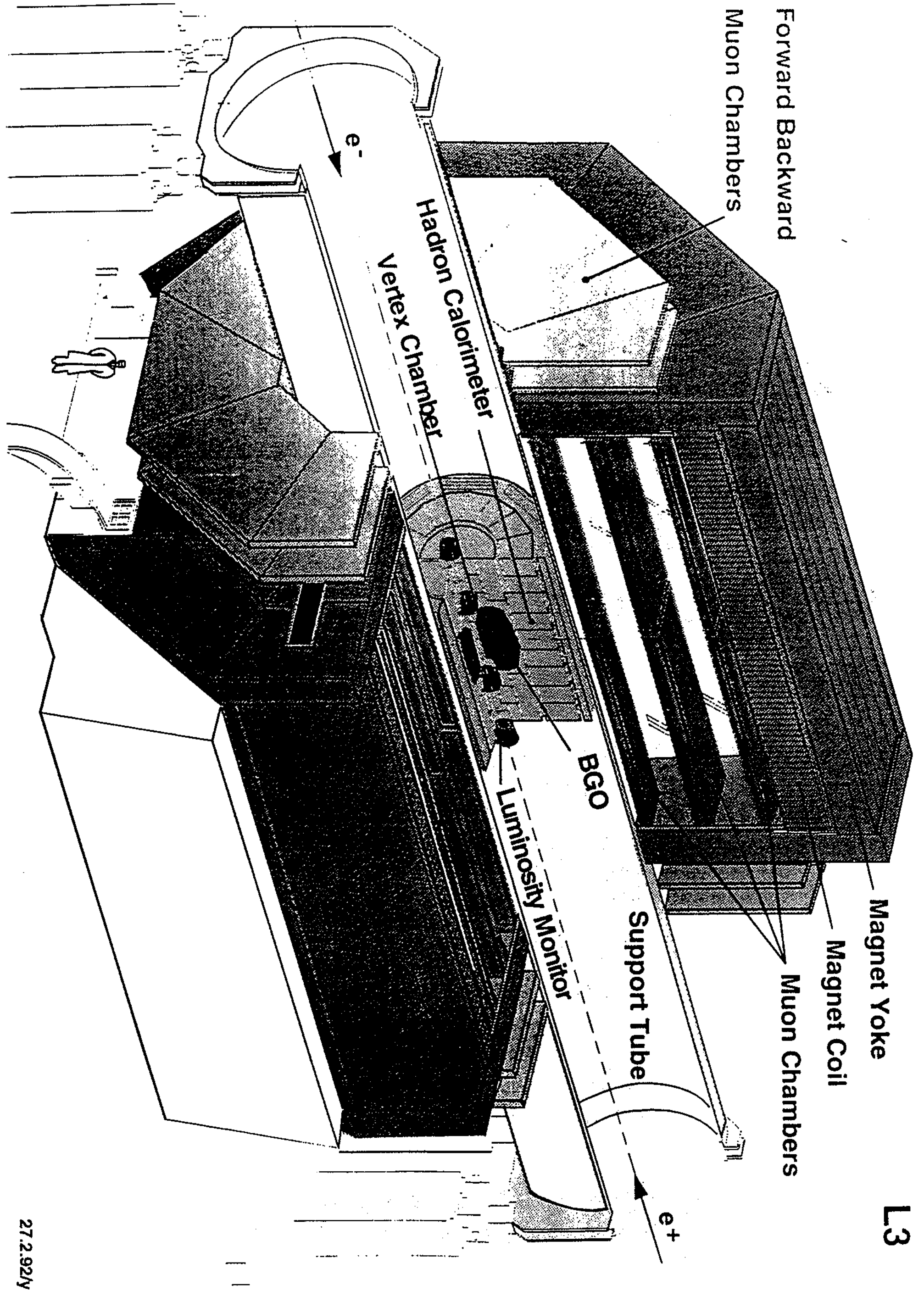
TECHNICAL
PROPOSAL

L3
MAY 1983

L3 is optimized for precise measurement of

Muons: $\left(\frac{\Delta m}{m}\right)_{\mu\mu} < 1.4\%$ at the Z^0

Photons:
Electrons: $\left.\right\}$ $\frac{\Delta E}{E} <$ 1% above 2 GeV
5% at 0.1 GeV



27.2.92/yt

Magnet

made by

U.S.A.
U.S.S.R.
Switzerland

Volume : 16m x 16m x 16m
Weight : ≈ 10,000 tons

The largest magnet

A. Hervé
H. Hofer
F. Wittgenstein

Design Consideration

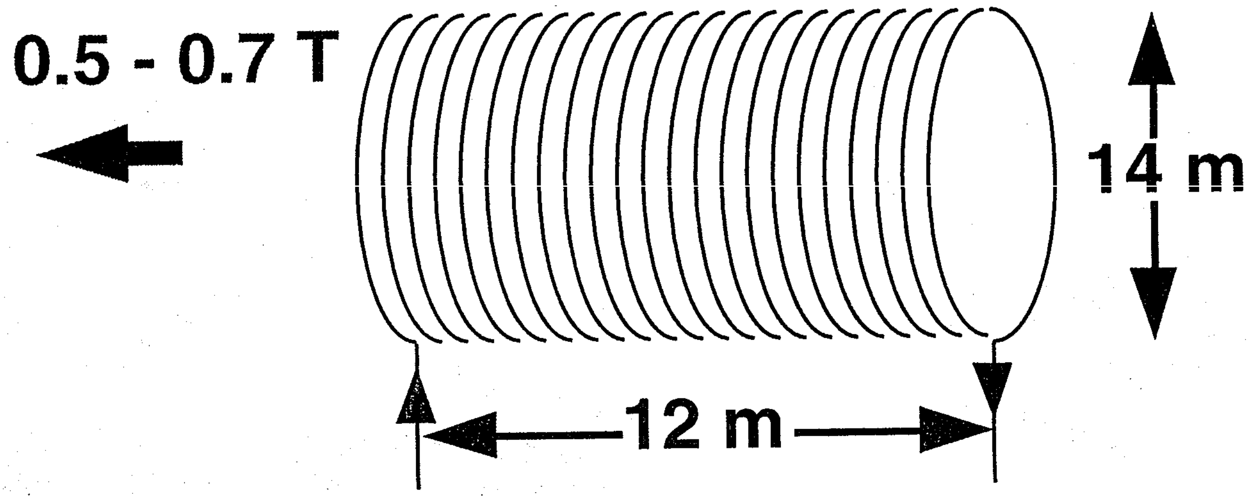
Since

$$\frac{\Delta p}{p} \sim \frac{1}{BL^2}$$

Good muon resolution is best achieved with a relatively low field in a Very Large Conventional magnet, all detectors being inside the coil

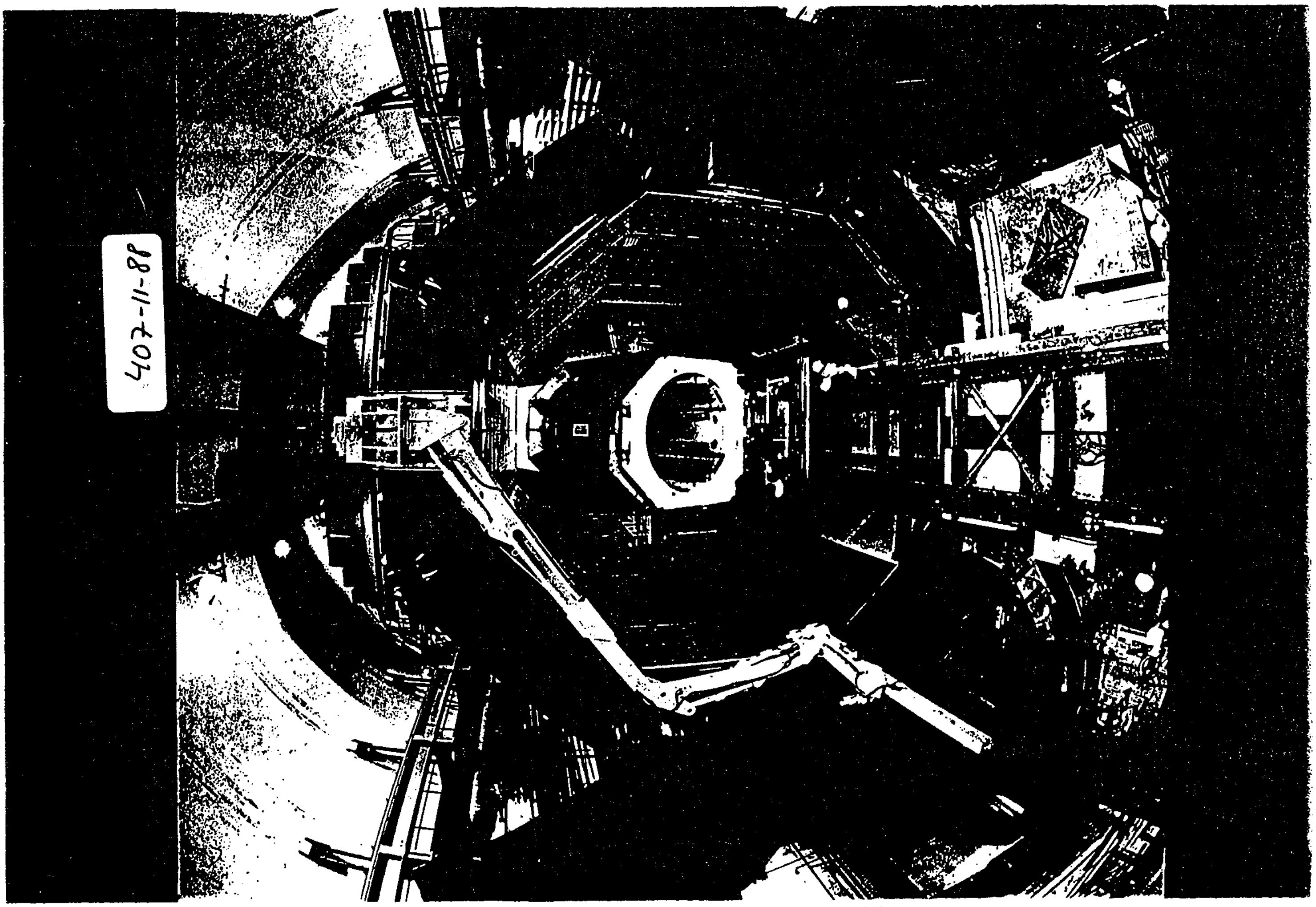
L3 Magnet

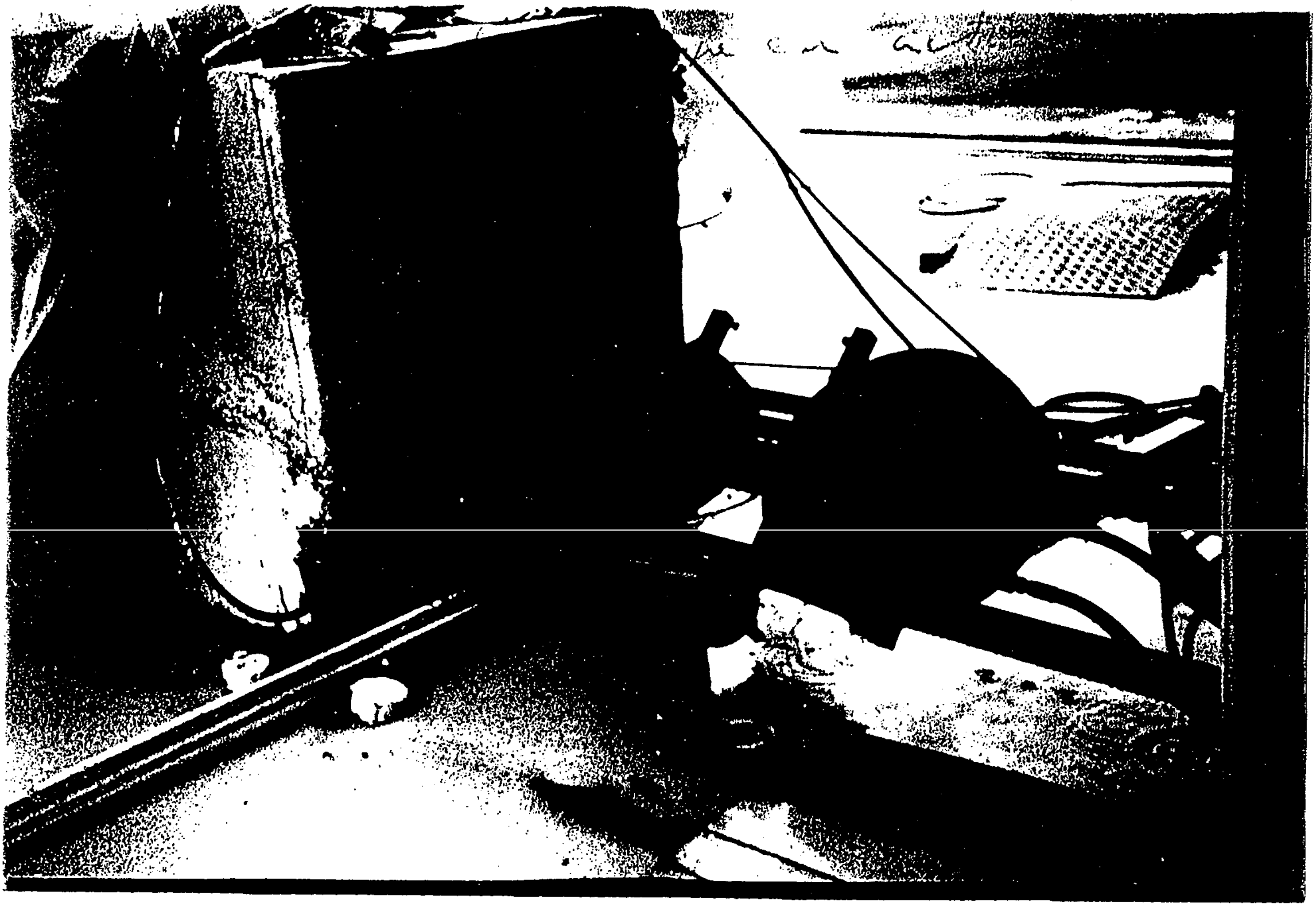
168 Turns



Power 4 - 7 MW

153/1.3 92





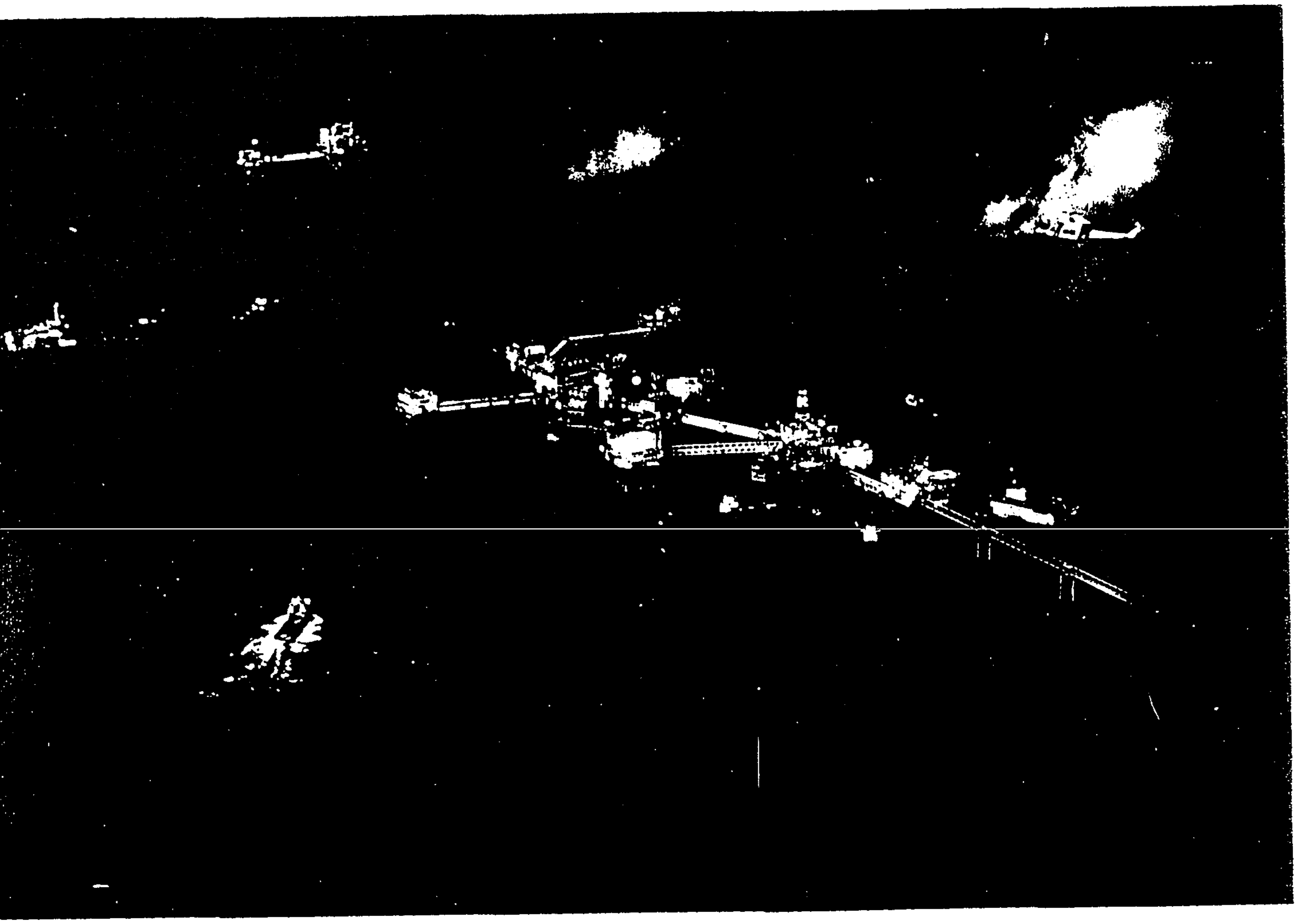
To lift L3 Magnet by ≈ 1 meter

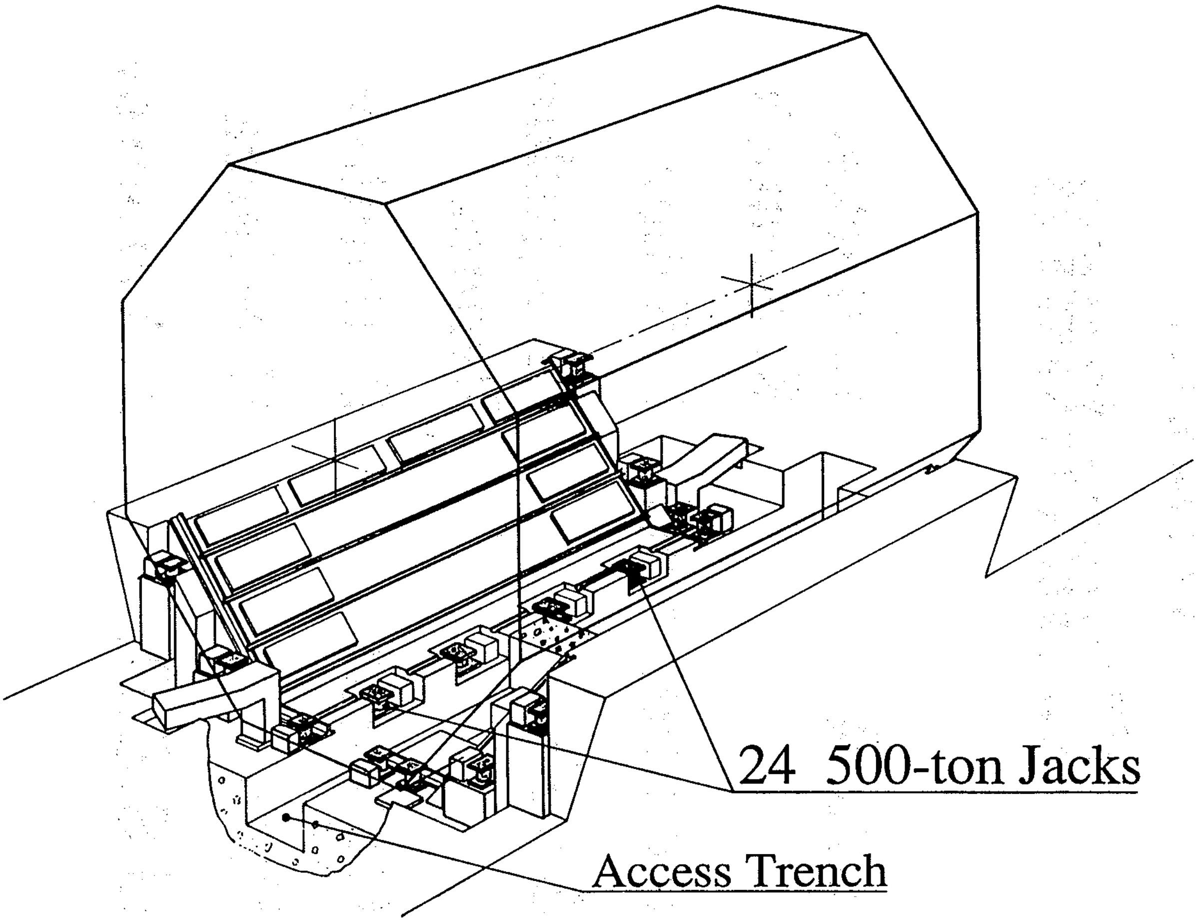
Supported by

ETH and INFN-Roma Since 1989

We now have detailed planning and price by the same company which lifted the Ekofisk Platform by 8 m in the North Sea with the same exacting precision.

165/5.3.92/yb



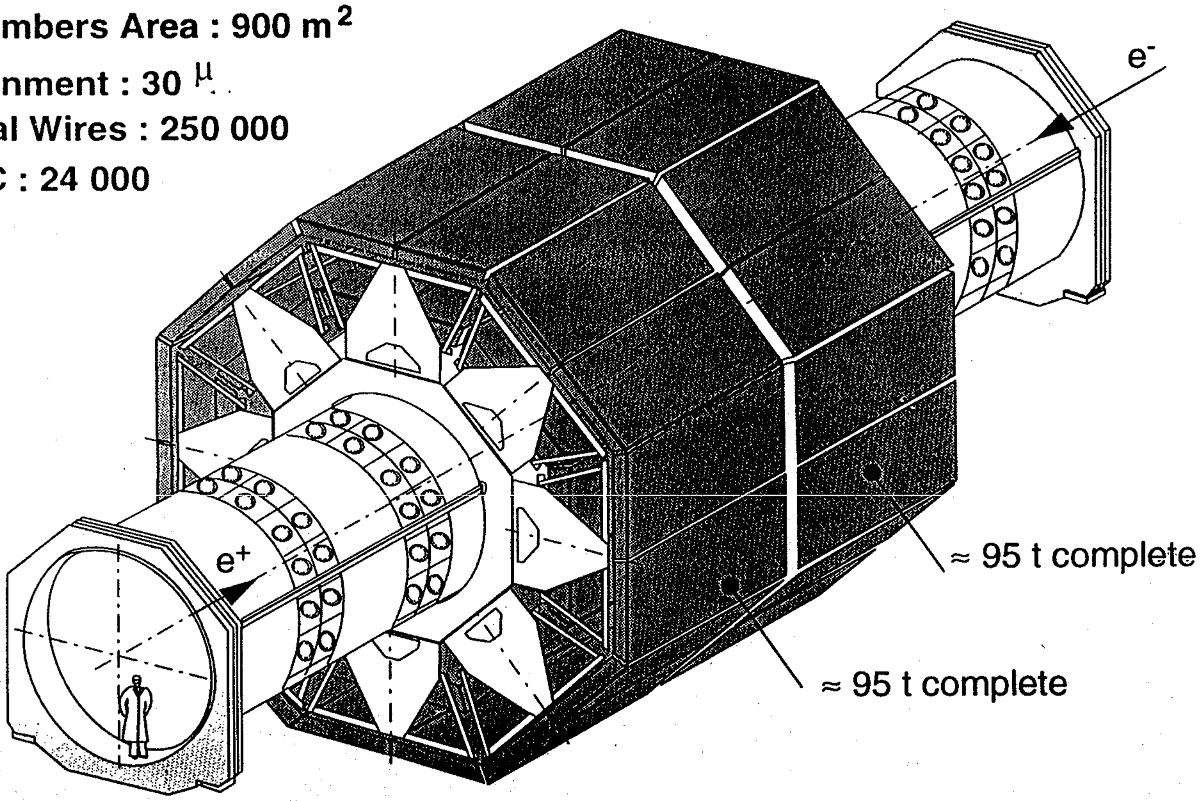

24 500-ton Jacks
Access Trench

Chambers Area : 900 m^2

Alignment : 30 μ

Total Wires : 250 000

TDC : 24 000



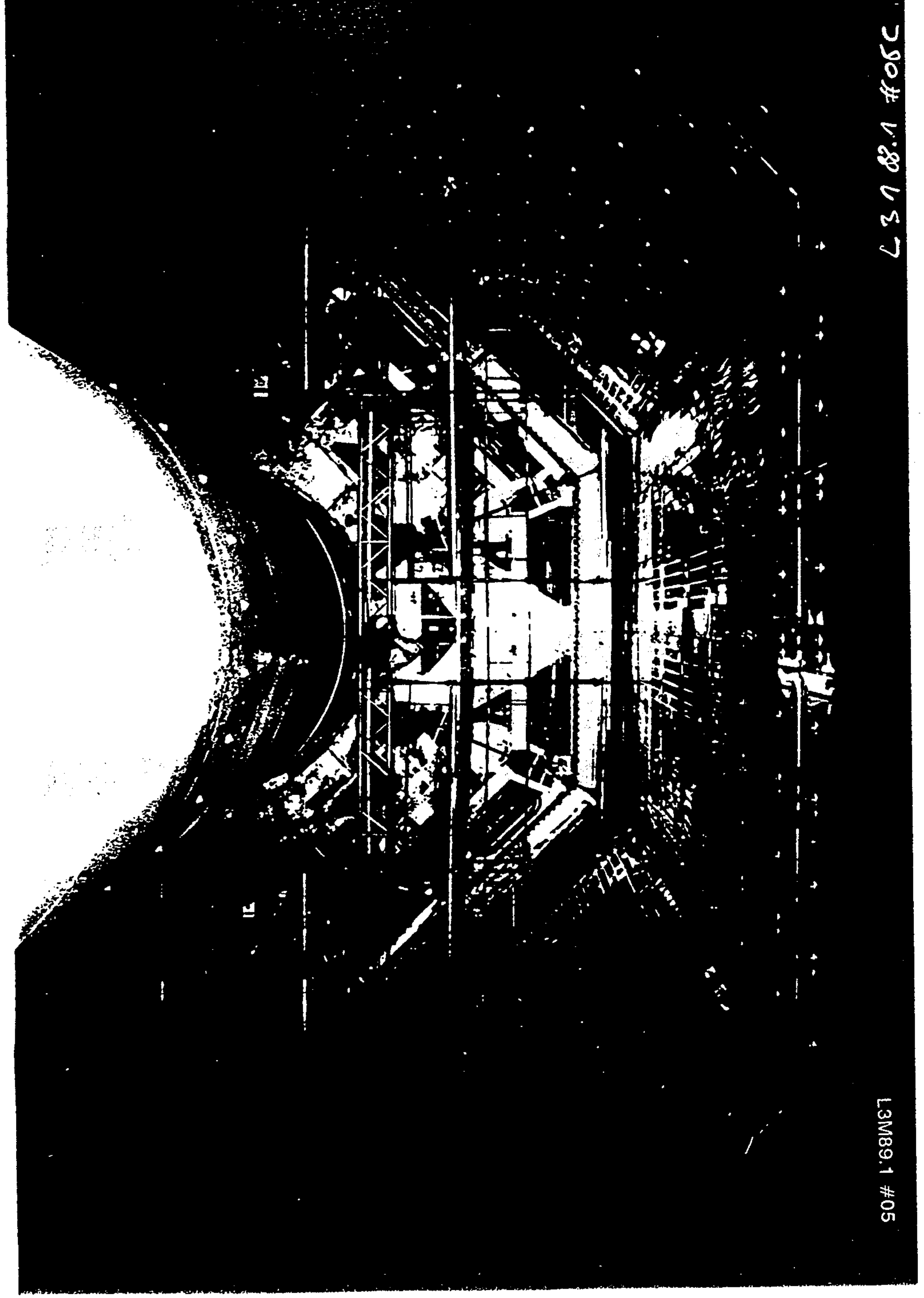
Muon Chamber Parameters

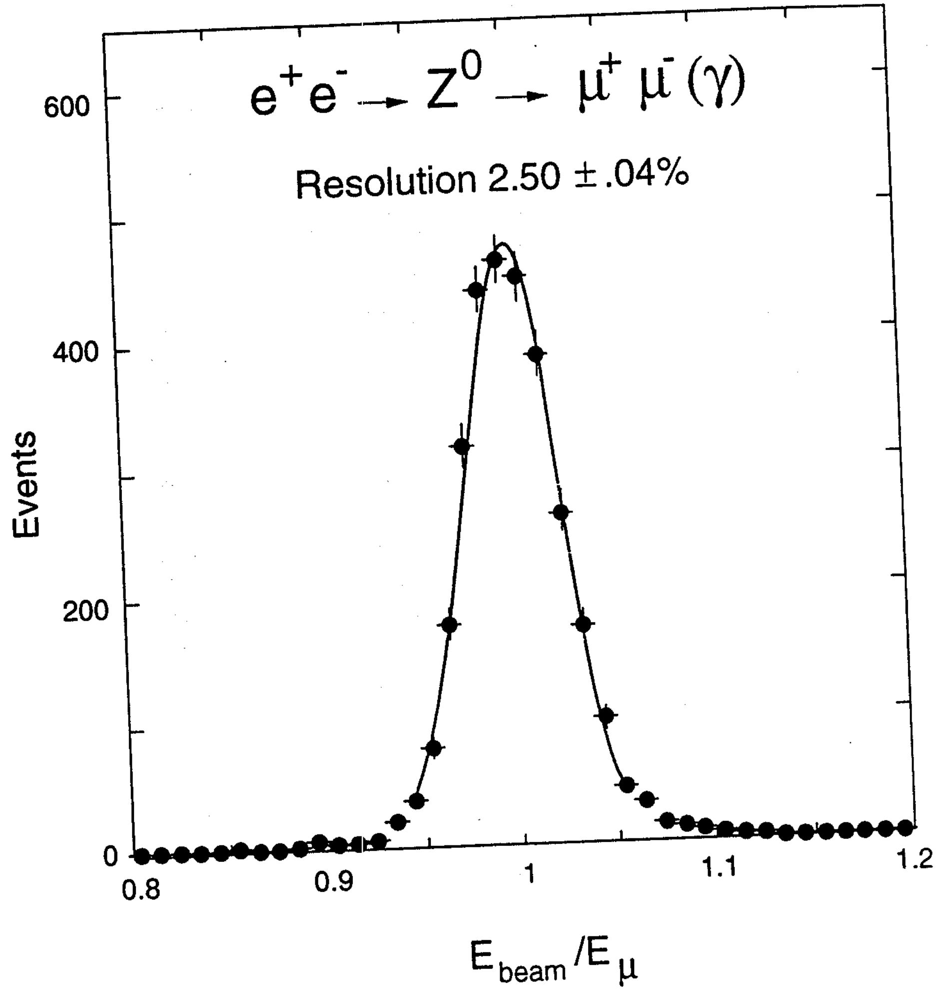
16 Dec. 91

LEP212 XP1 0015 4

Muon Chambers

U.S.A.	**U. Becker** **K. Strauch**
Switzerland	**P. Seiler**
Spain	**M. Aguilar-Benitez**
Holland	**P. Duinker**
Italy	**C. Sciacca**
U.S.S.R.	**A. Vorobyov**


L3M89.1 #05C
L3M89.1 #05


$e^+e^- \rightarrow Z^0 \rightarrow \mu^+\mu^-(\gamma)$
Resolution 2.50 ± .04%
Events
600
400
200
0
0.8
0.9
1
1.1
1.2
E_{beam}/E_μ

For LHC

$\sigma\mu = 250\ \mu$ / wire ⇨ $\sim 170\ \mu$ / wire

Different gas

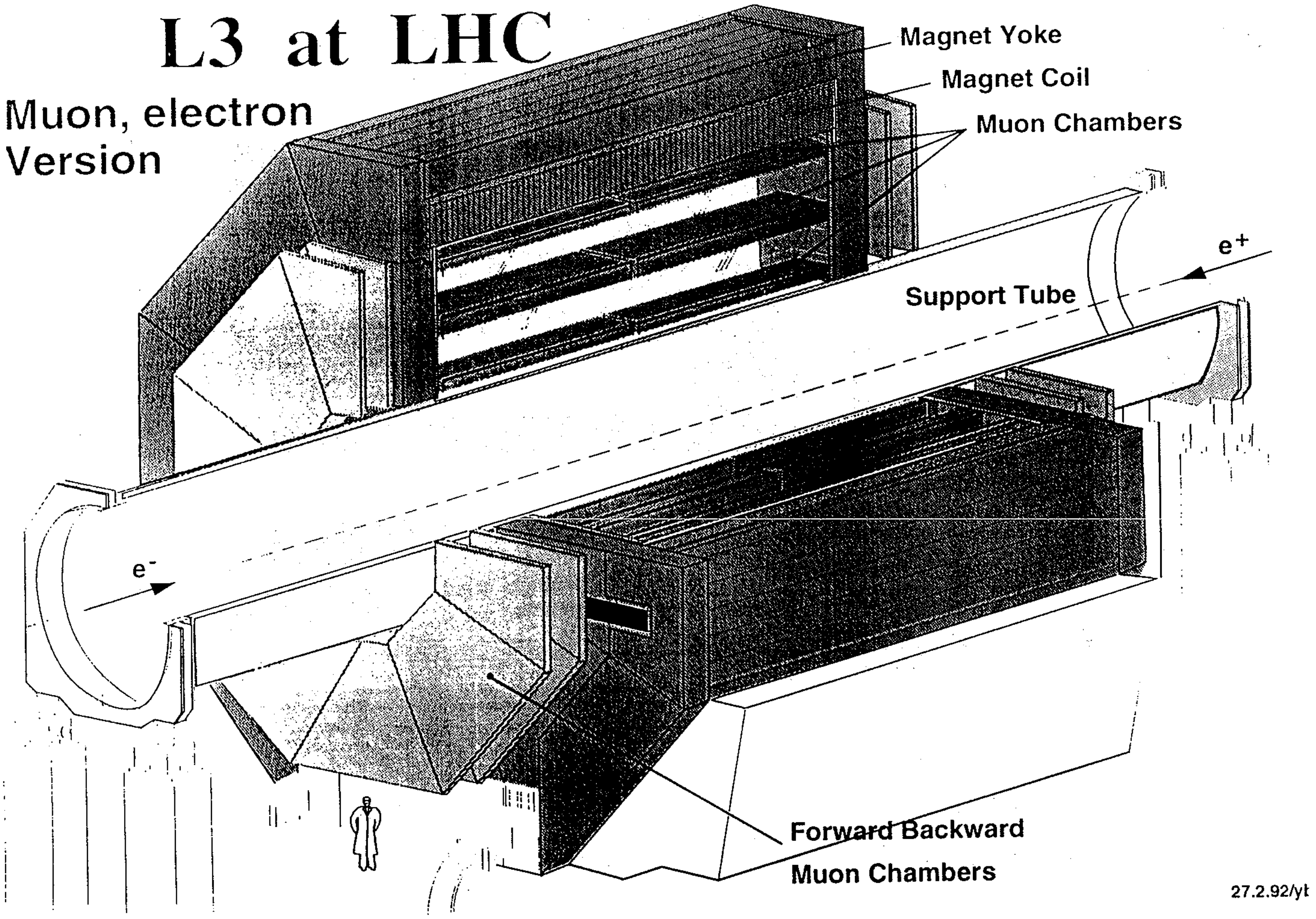
$B = 0.5$ T ⇨ 0.7 T

L3 Trigger

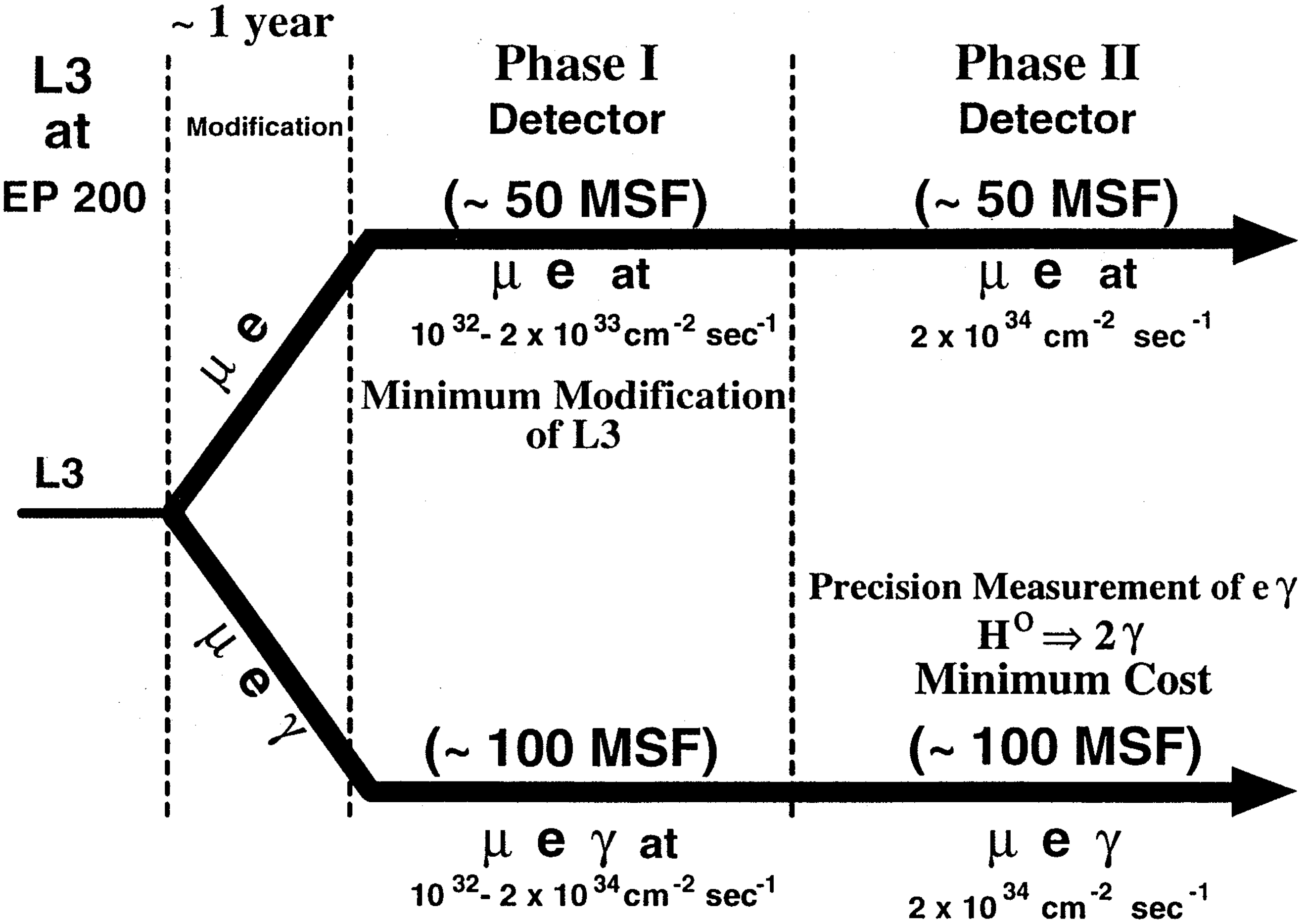
USA	M. Fukushima M. Capell
France	JJ. Blaising R. Morand A. Degre
Italy	R. Bizzarri S. Gentile C. Dionisi
World Lab.	S.X. Wu X. Cai

L3 at LHC

Muon, electron
Version



27.2.92/yt



Phase I
Detector

(~ 50 MSF)

μ e at
10^{32}- 2 x 10^{33} cm^{-2} sec^{-1}

Minimum Modification
of L3

(~ 100 MSF)

μ e γ at
10^{32}- 2 x 10^{34} cm^{-2} sec^{-1}

Phase II
Detector

(~ 50 MSF)

μ e at
2 x 10^{34} cm^{-2} sec^{-1}

Precision Measurement of e γ
$H^{O} \Rightarrow 2\gamma$
Minimum Cost

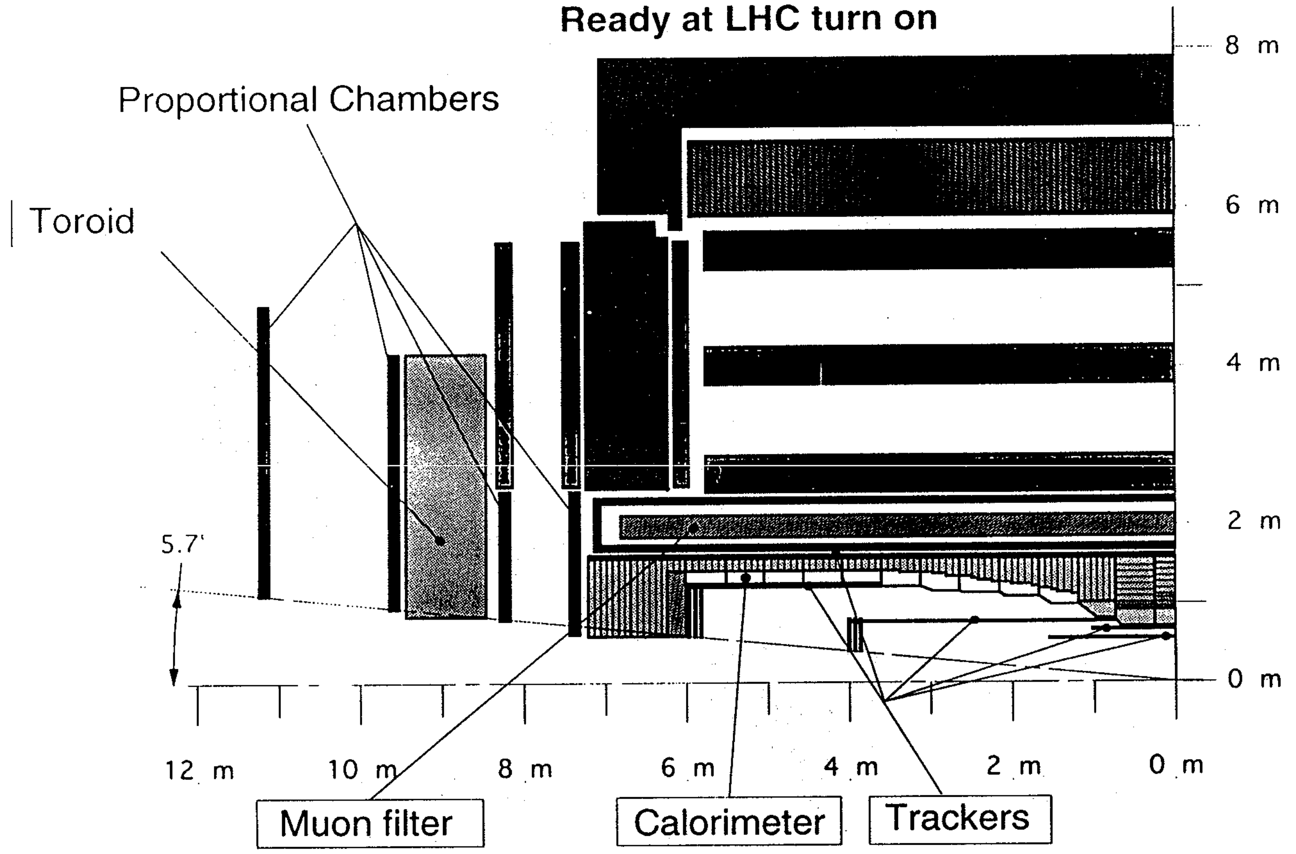
(~ 100 MSF)

μ e γ
2 x 10^{34} cm^{-2} sec^{-1}

158/5.392/r

PHASE 1

$L = 10^{32} - 2x10^{33}$ cm^{-2}sec^{-1}
Minimum Modification of L3
Ready at LHC turn on



L3 at LHC

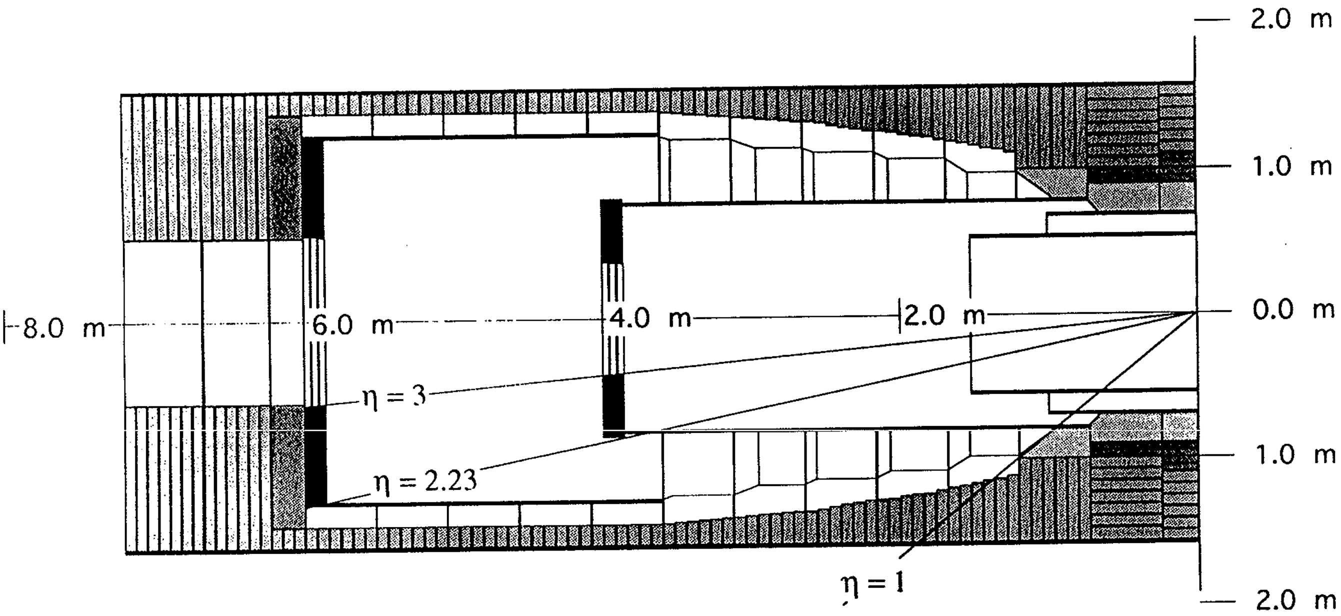
μ, e, Version

Minimum modification of L3
Phase I (~ 50 MSF)

Measuring μ, e: $10^{32} - 2 \times 10^{33}$ cm^{-2} sec^{-1}

Replace L3 vertex chamber and calorimeter

Calorimeter



Instrumented Thickness: 6-7 λ

Filtering Thickness (including SC coil and support stucture): > 9 λ

L3 at LHC
(μ,e version)

Phase I

New Calorimeter System

12/L3-LHC/rd

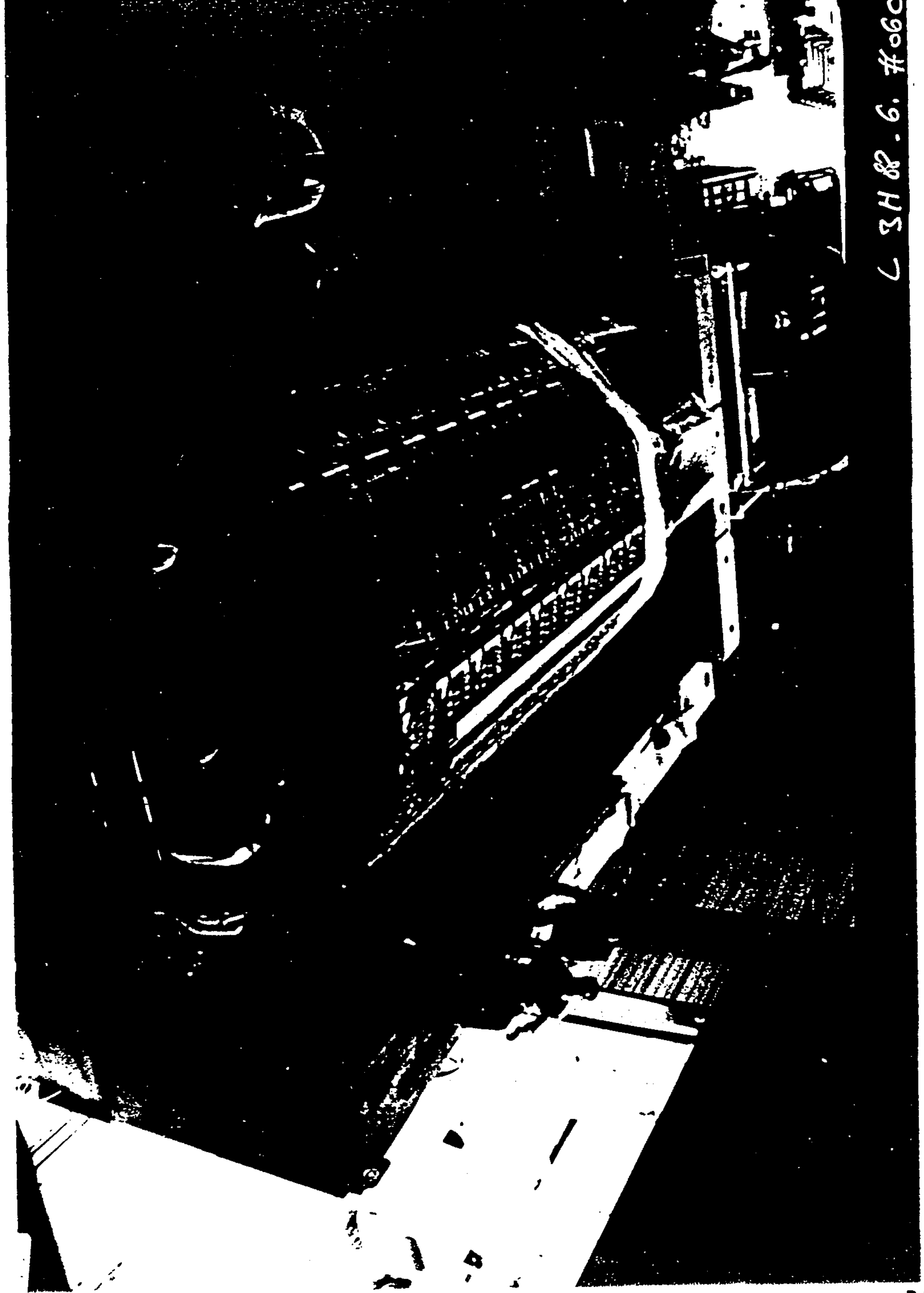
R & D
on

Hadron Calorimeter
and
Choice of Hadron Calorimeter

1. All Gas : L3 design
2. All Silicon
3. Front : Silicon
   Back : Gas

L3 Hadron Calorimeter

U.S.S.R.	Y.Galaktionov
Switzerland	H. Hofer W. Böhlen
Germany	K. Lübelsmeyer
India	P. Malhotra
Italy	P. Spillantini
China	H.W. Tang
U.S.A.	B. Roe
World Lab	A. Zichichi



L3 Vertex Detector

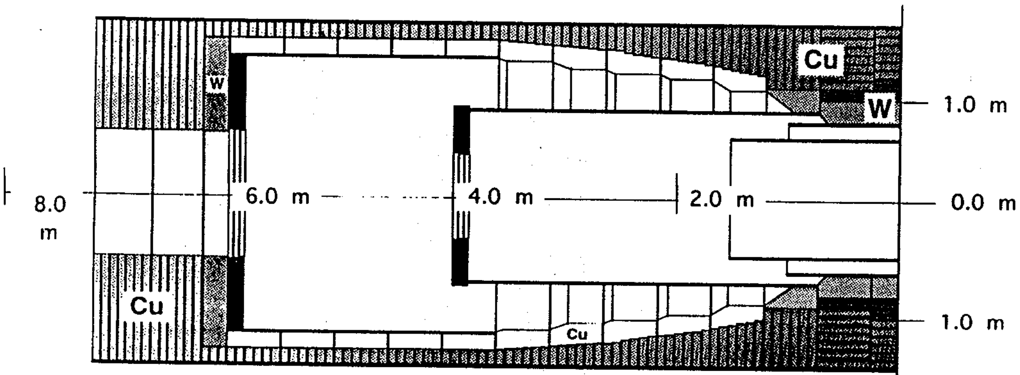
Switzerland	M. Bourquin H. Hofer
Germany	A. Böhm W. Lohmann
U.S.A.	A. Pevsner

and

L3 S.M.D.

Italy	R. Battiston
U.S.A.	D. DiBitonto
Taiwan	A. Chen

Gas Sampling Calorimeter
L3 like design



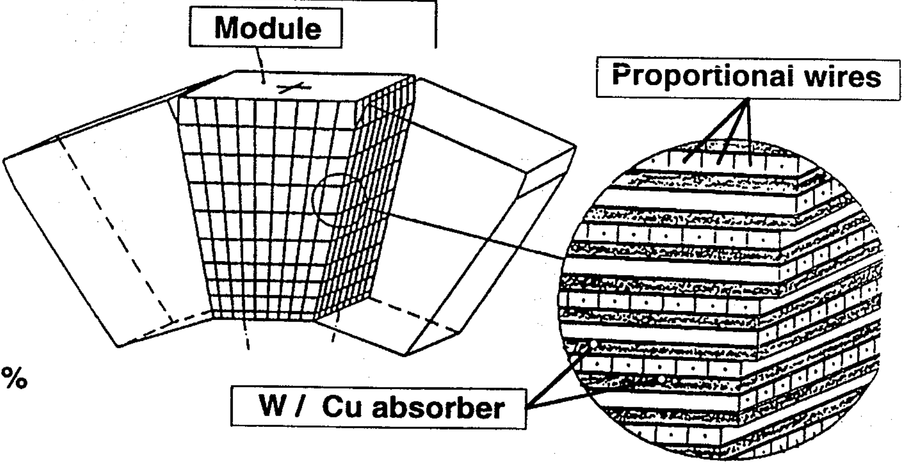
25 θ rings

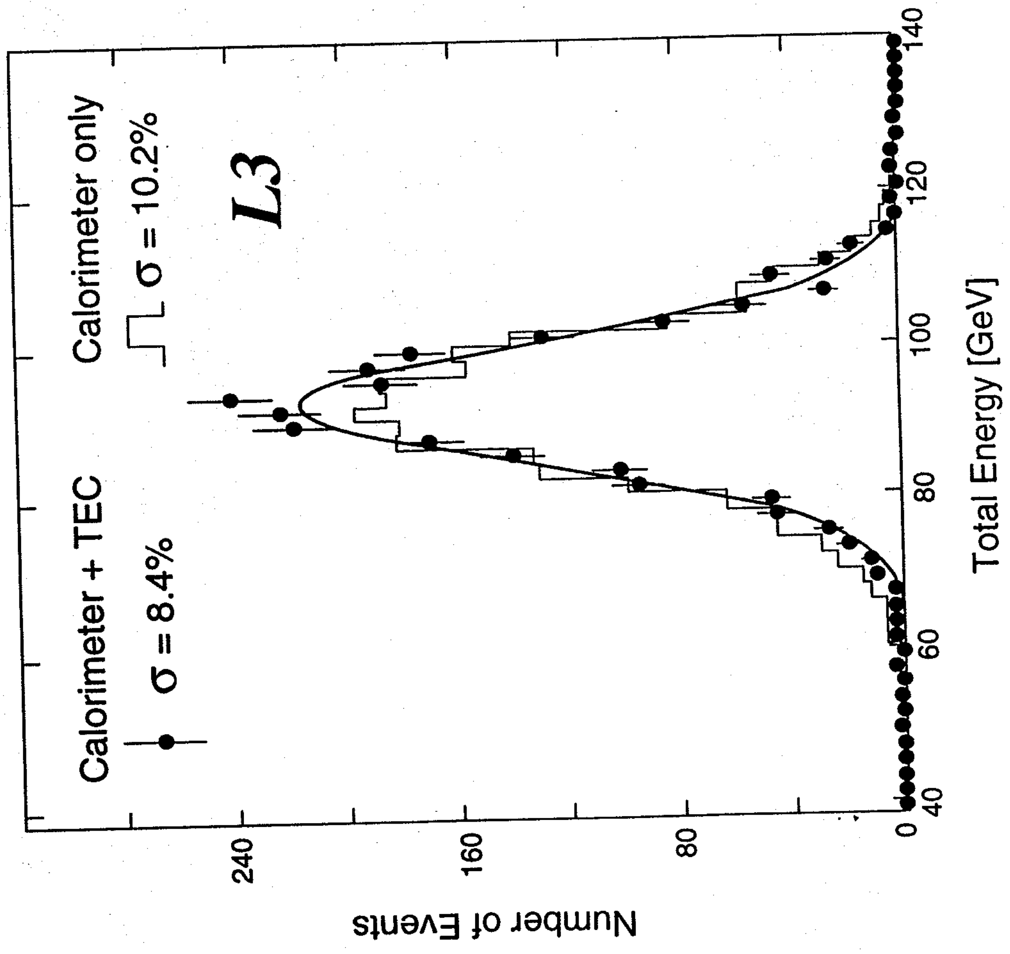
16 φ modules each

Total instrumented thickness 6-7 λ

Readout:
L3: wire readout
L3 upgrade: cathode pad readout

Jet energy resolution ≈ 10% above 100 Gev





EUROPEAN ORGANISATION FOR NUCLEAR RESEARCH

CERN/DRDC/91-54
DRDC/P34
January 13th, 1992

A Silicon Hadron Calorimeter module operated in a strong magnetic field with VLSI read out for LHC

F. Carminati, M. Della Negra, S. Giani, M. Glaser, A. Hervé,
J. M. Le Goff, F. Lemeilleur, M. Pimiä, E. Radermacher** and H. Verweij.
CERN, Geneva, Switzerland

M. Baturitsky[2], V. Chalyshev, A. Cheremukhin, B. Eidelman[3], V. Eremin[4], S. Golubykh,
I. Golutvin*, L. Ivanjutin[1], V. Izhevsky[1], V. Kalagin, V. Kharlamov[3], Y. Kozlov[1],
P. Kuchinsky[2], V. Lomako[2], S. Losanu, I. Lukyanov, S. Makarov[1], I. Merkin,
M. Milvidsky[1], V. Minashkin, D. Peshekhonov,V. Petrov[2], A. Rashevsky, I. Savin,
S. Sergeev, N. Shumeiko[2], A. Sidorov[1], N. Susova, A. Vasilesku, E. Verbitskaya[4],
A. Yaremchuk[3], V. Yavid[2], N. Zamyatin, V. Zhiltsov, V. Zubarev and V. Zverolovlev[3]
Joint Institute for Nuclear Research (JINR), Dubna, RSFSR

A. Baldini, M. Bocciolini, E. Borchi, A. Cartacci, C. Civinini, R. D'Alessandro, E. Gallo,
M. Meschini, M. Pieri and P. Spillantini
Dipartimento di Fisica dell'Università and INFN Sezione di Firenze, Italy

M. Acciarri, P. G. Avanzini[5], A. Baschirotto, S. Benetti, G. Cai[5], R. Castello, C. Furetta,
A. Gola[6], P. Menniti[6], R. Paludetto, S. Pensotti, S. Pizzini, P. G. Rancoita, M. Rattaggi and
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INFN Sezione di Milano, Italy

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* Joint Spokesmen
** Contact person
- Collaborators from industry (Ansaldo, ELMA, SGS-THOMSON, SIAPS) are listed under collaborating institutes

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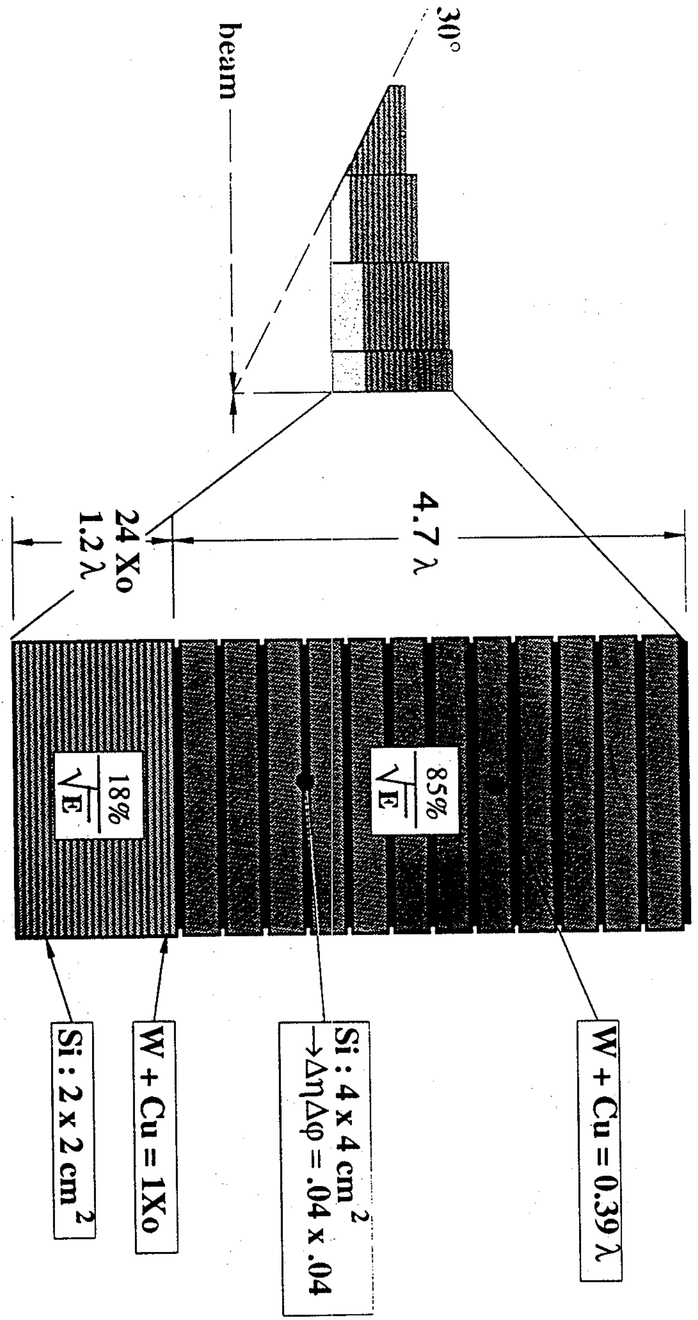
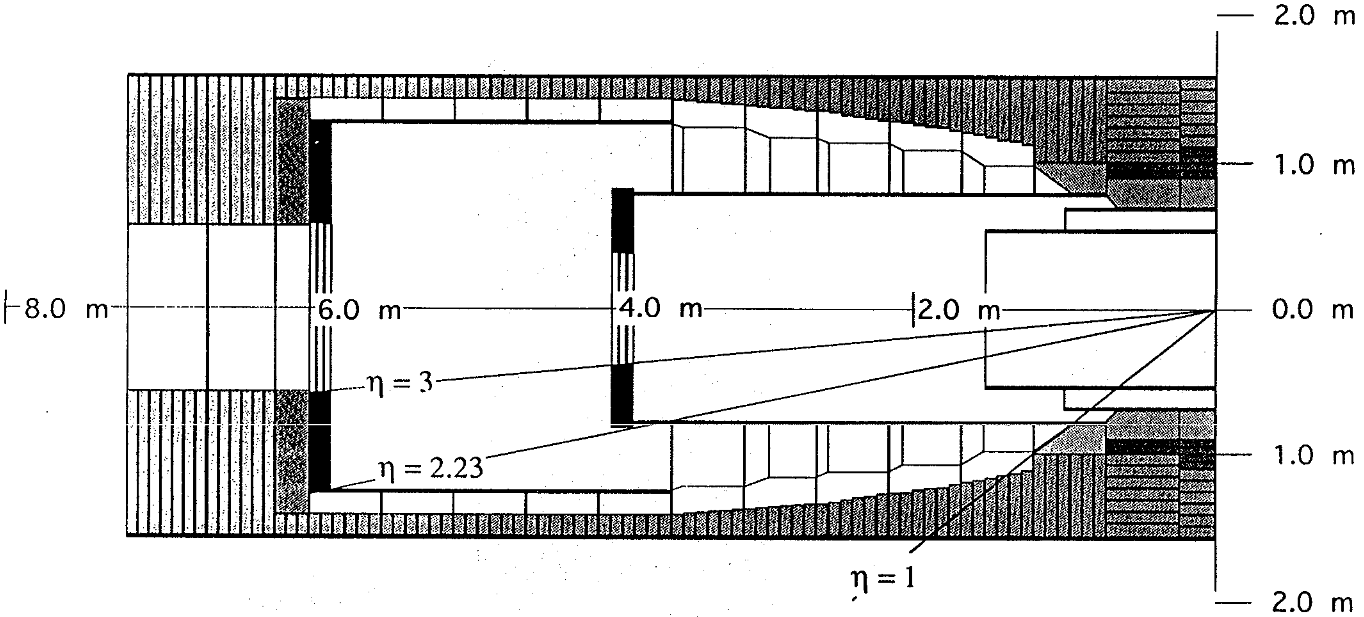
[2] Byelorussian State University, Minsk, Byelorussia.
[3] Research and Production Company SIAPS, Zelenograd, RSFSR.
[4] Joffe Physical-Technical Institute, St. Petersburg, RSFSR
[5] Ansaldo Ricerche spa, Genoa, Italy.
[6] SGS-THOMSON, Castelletto (Milan), Italy.

Calorimeter composition



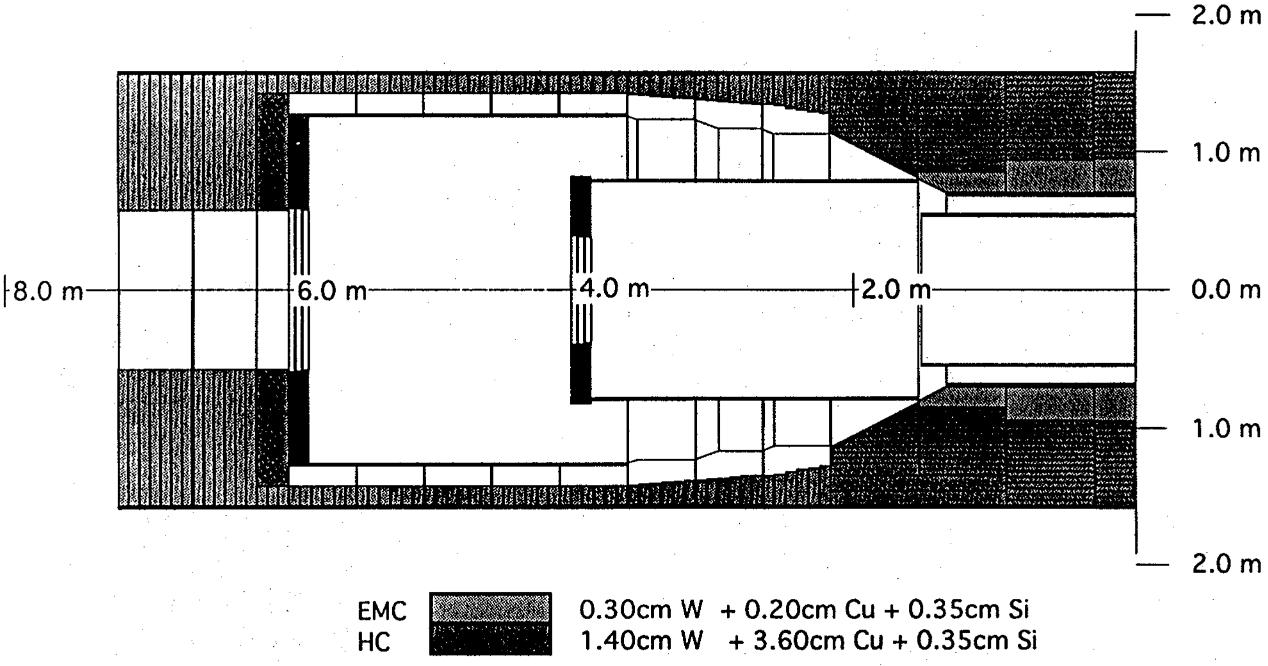
Calorimeter



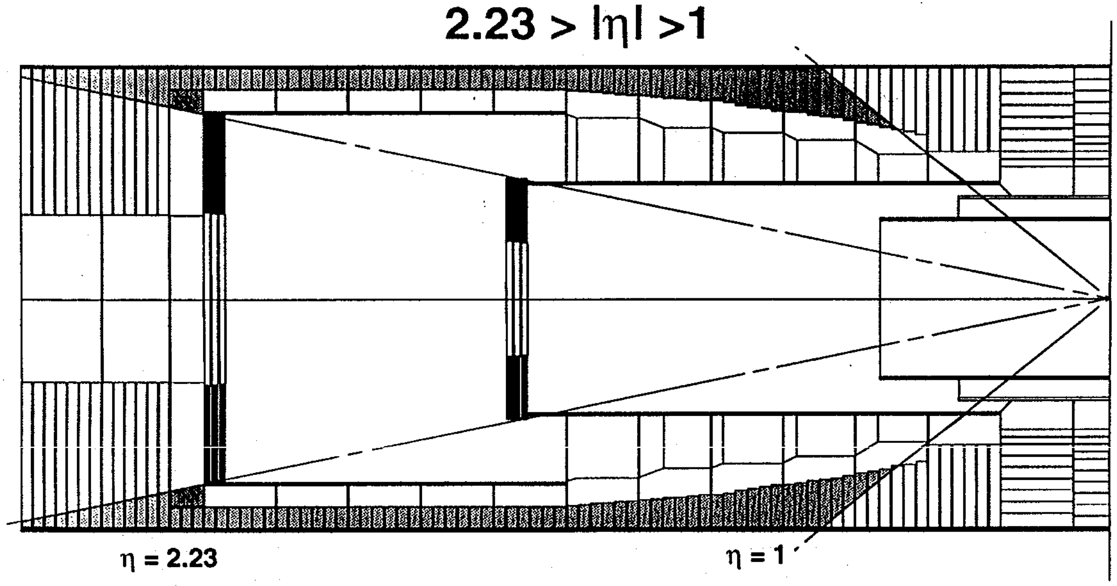
Instrumented Thickness: 6-7 λ

Filtering Thickness (including SC coil and support stucture): > 9 λ

Silicon Calorimeter



Calorimeter
$2.23 > |\eta| > 1$



0.5 Xo Cu + 5mm Gas
22.7 K ($4 \times 4 cm^2$)

0.5 λ Cu + 5mm Gas
4.5 K ($8 \times 8 cm^2$)

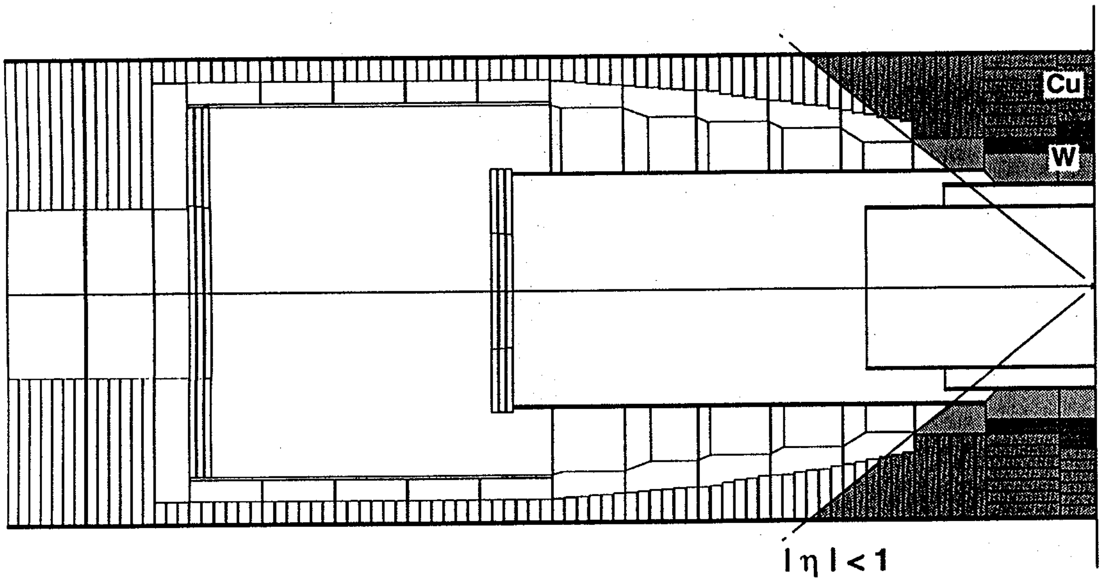
$\sigma / p = 0.27 / \sqrt{E} + 0.01$
$\Delta\eta \times \Delta\phi = 0.035 \times 0.07$

Pile up :
π° energy per tower per bunch : 17 Mev
Mean E_e from H (140Gev) => 4e : 90 Gev

Thickness e.m. = 22Xo(2.2λ)

Total thickness 6 λ

Calorimeter
$|\eta| < 1$



0.5 λ (W,Cu) + 5mm Gas
2.5K x ($8 \times 8 cm^2$)

0.5 Xo W + 2.5 mm Si
23 K x ($2 \times 2 cm^2$)

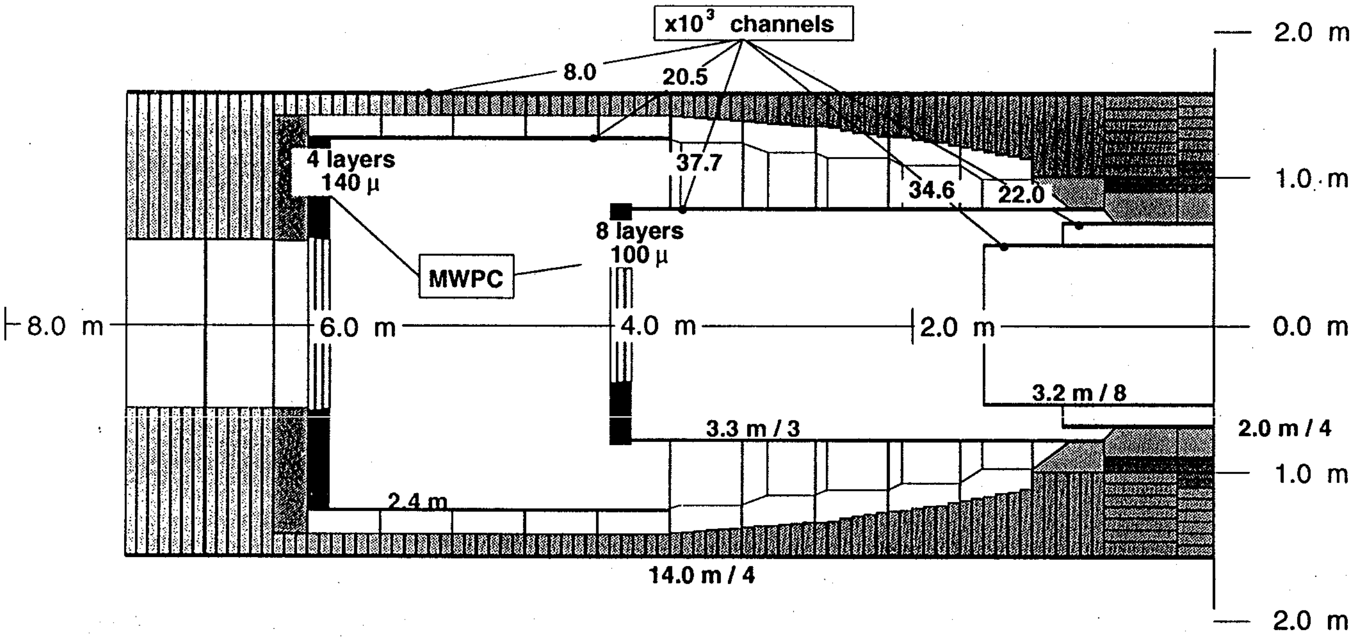
$\sigma / p = 0.12 / \sqrt{E} + 0.01$
$\Delta\eta \times \Delta\phi = 0.025 \times 0.029$

Pile up :
π° energy per tower per bunch : 6 Mev
Mean E_e from H (140Gev) => 4e : 35 Gev

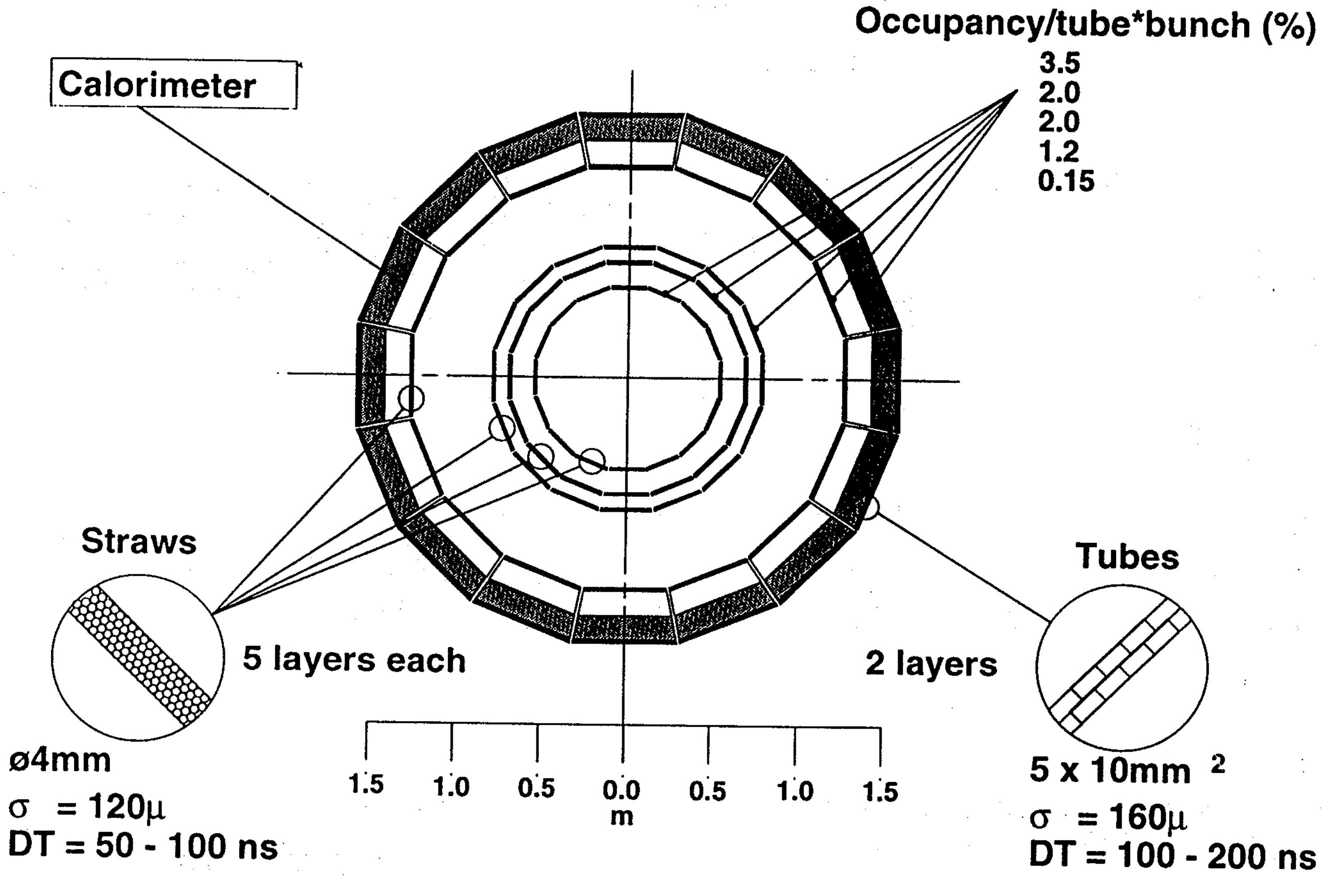
Thickness e.m. = 25Xo(1λ)

Total thickness 6 λ

Trackers



Trackers



L3 at LHC

(μ,e version)

Phase I

New Central Tracker

11/L3-LHC/rd

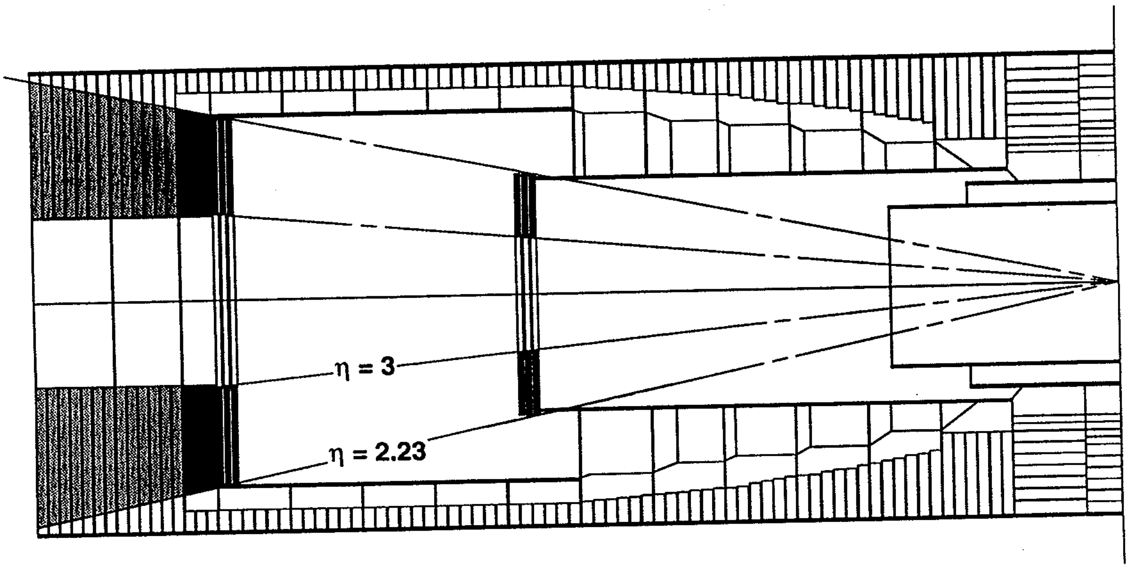
Calorimeter

$2.23 < |\eta| < 3.0$

1.0 XoW + 5mm Gas
20.9 K (2x2cm²)

0.5 λ Cu + 5mm Gas
2.6K (8x8cm²)

$\sigma / p = 0.24 / \sqrt{E} + 0.01$
$\Delta\eta \times \Delta\phi = 0.03 \times 0.033$



Pile up :
π° energy per tower per bunch : 26 Mev
Mean E_e from H (140Gev) => 4e : 160 Gev

Thickness e.m. = 25Xo(1λ)
<u>Total thickness 7λ</u>

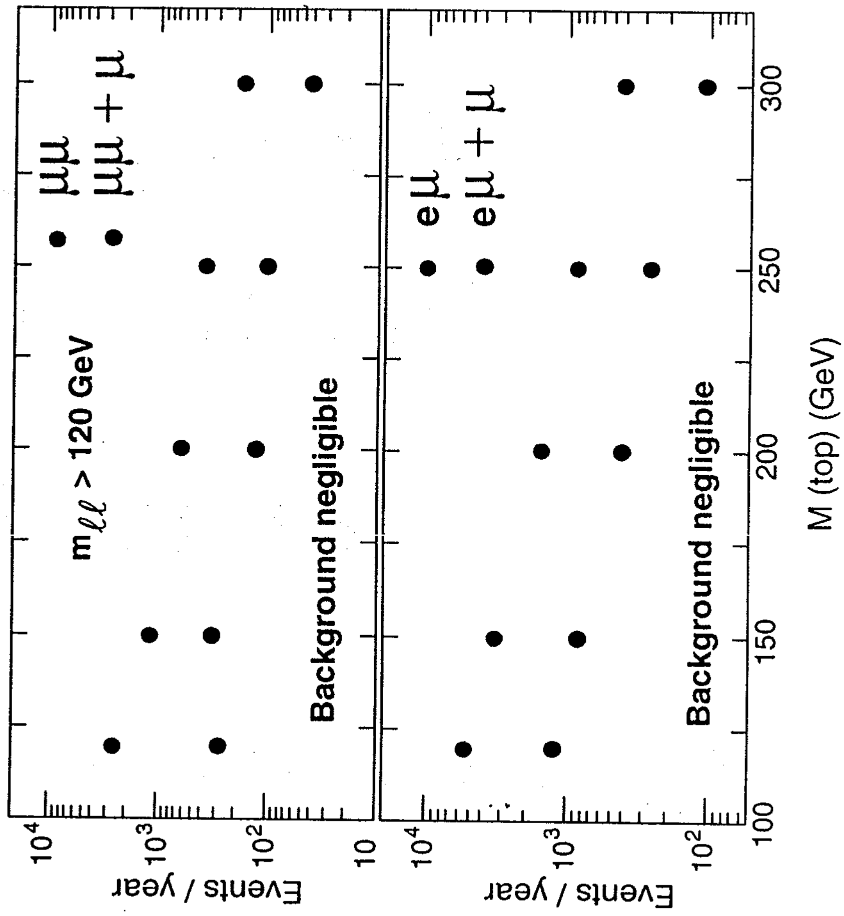
Physics of Phase I   Muon Detector

$\mathcal{L} = 10^{32}\ \mathrm{cm}^{-2}\ \mathrm{sec}^{-1}$

Search for New Quark

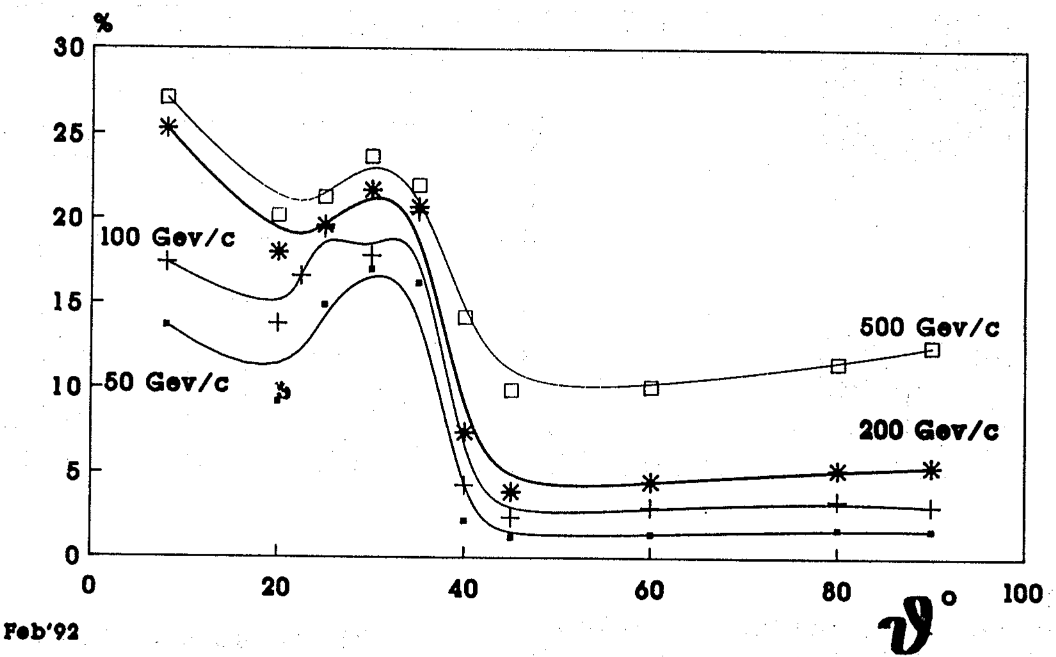
$$pp \rightarrow t\bar{t} \quad \begin{matrix} \ulcorner W\,b \; \ell\,\nu \\ W\,b \\ \llcorner \; \ell\,\nu \end{matrix}$$

$\eta < 1.6$
pt > 50 GeV
Ecal (R = 0.4) < 5 GeV
$\Delta(\varphi)$ z 20, 160



L3 Upgrade Phase 1

Muon Resolution without SC coil

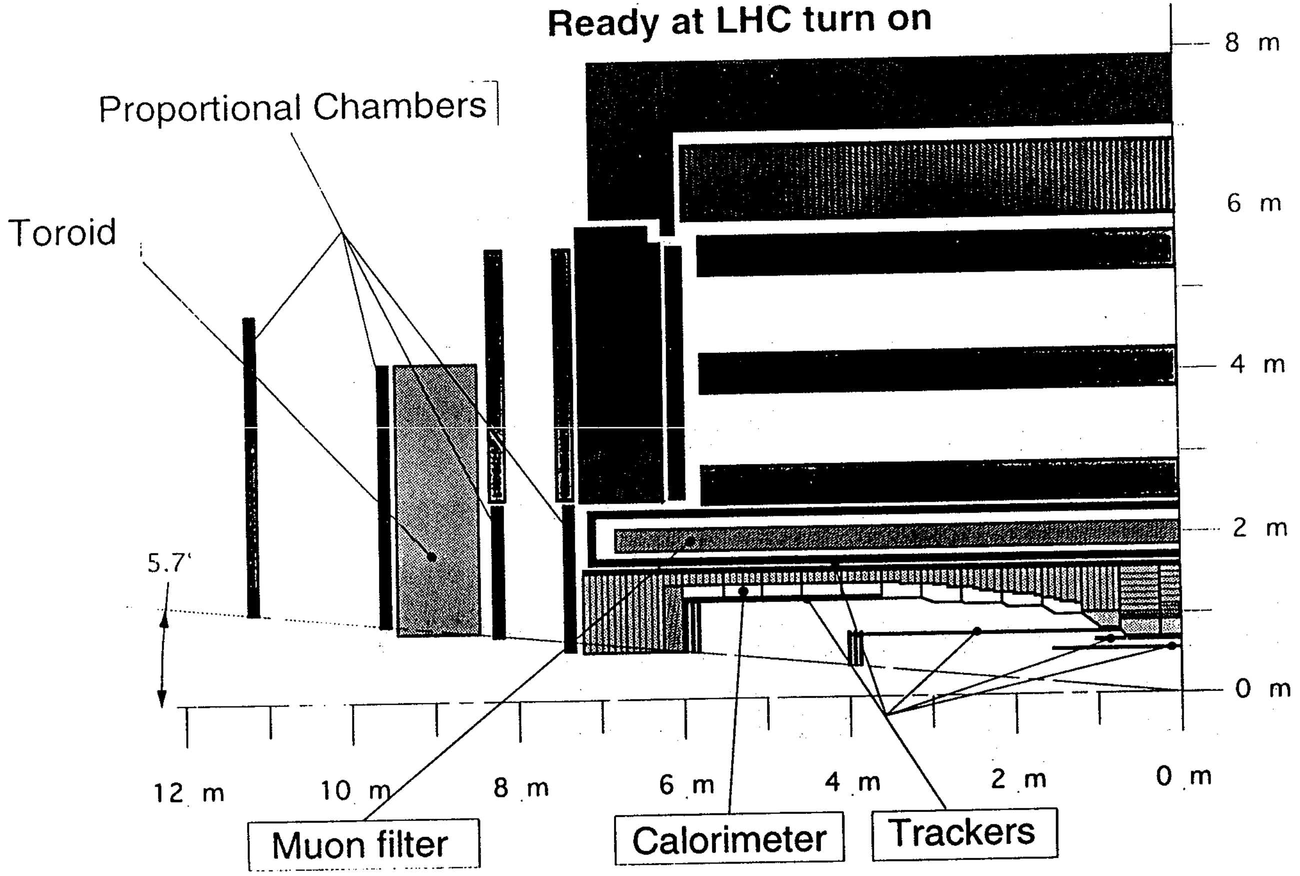


Feb'92

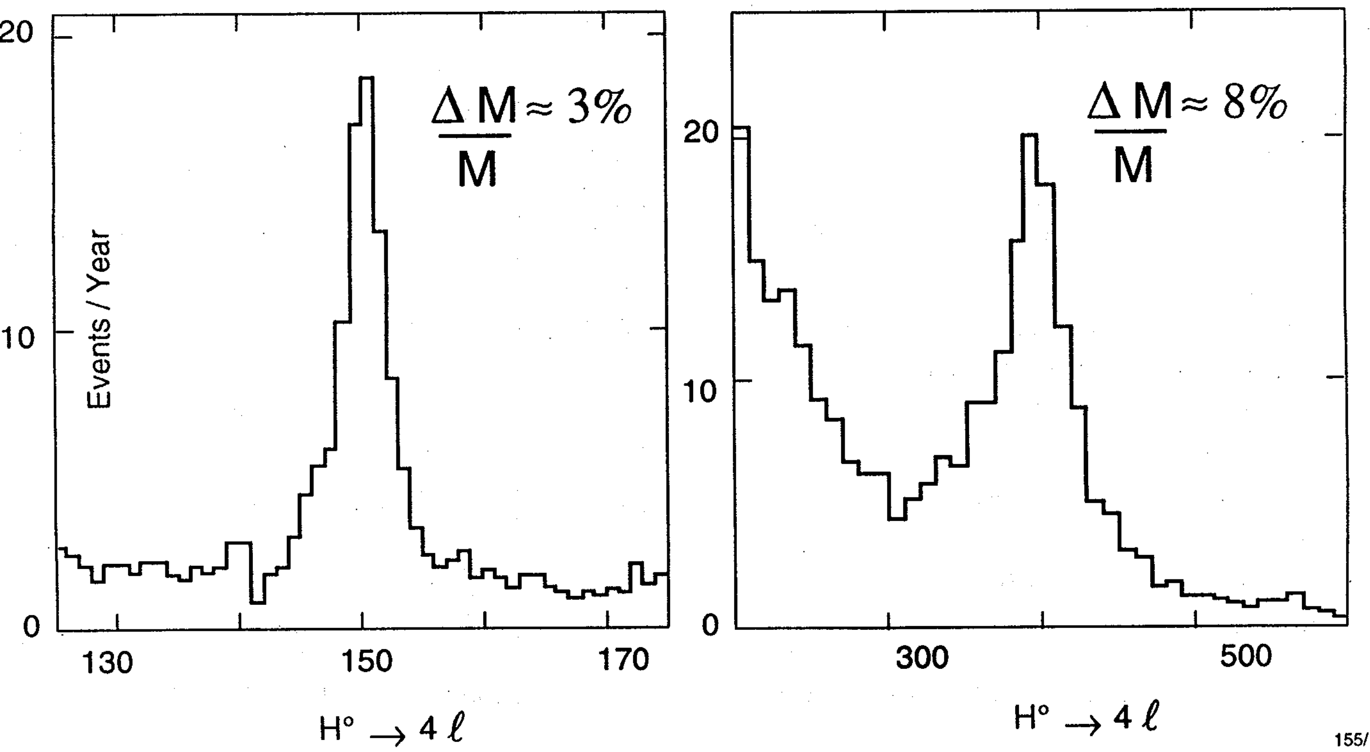
PHASE 1

$L = 10^{32} - 2x10^{33}\ cm^{-2}sec^{-1}$

Minimum Modification of L3
Ready at LHC turn on



Phase I: $\mathcal{L} = 1.65 \times 10^{33}\ cm^{-2}\ sec^{-1}$



155/1.3.9

Experimental Area and Infrastructure

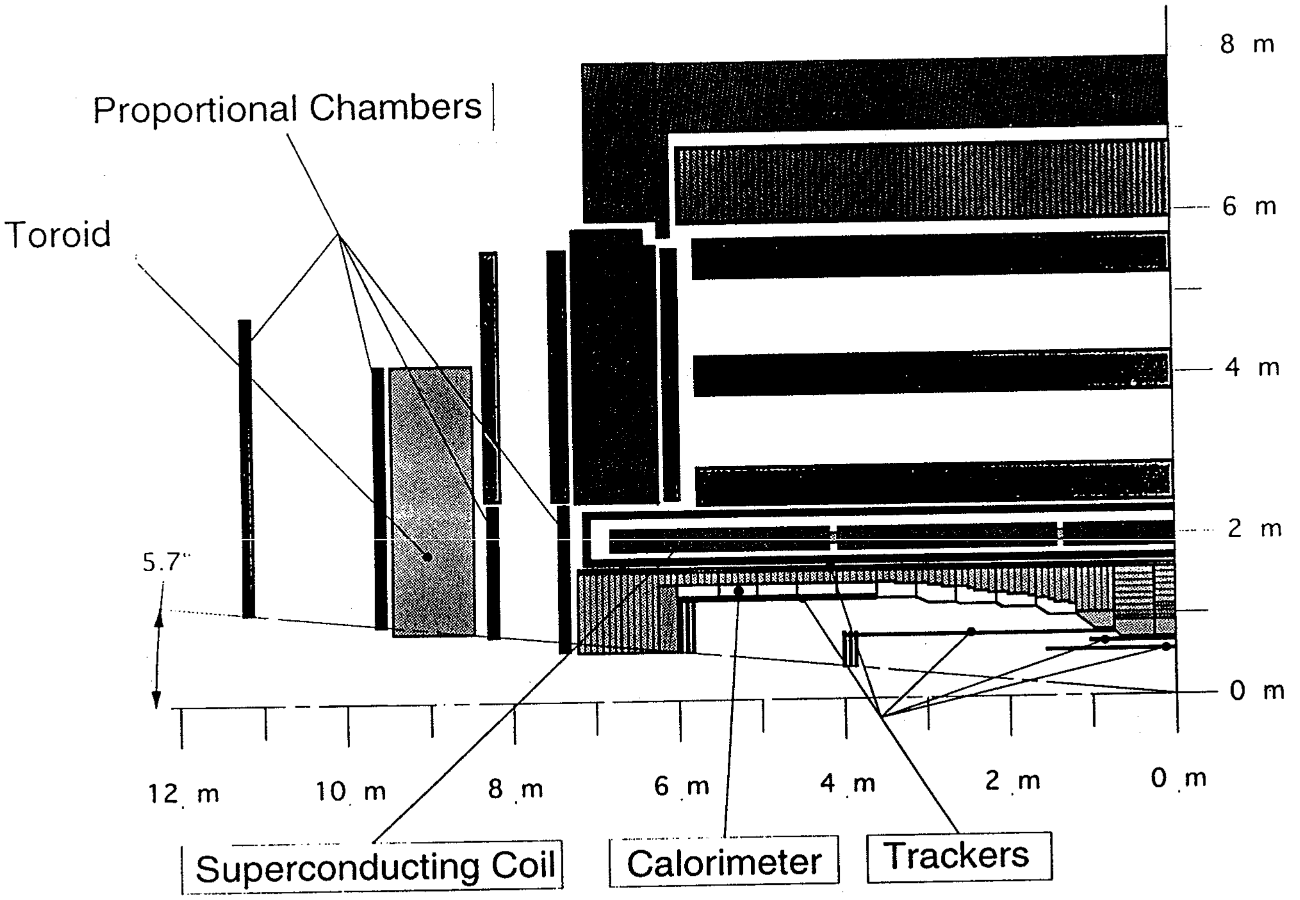
- **Underground Hall in P2 specially designed for L3 at LEP and future use of L3 at LHC**
- **Infrastructure and Surface Buildings available**

Cost of Specialized Muon Detector

(in 1992 KSF)

Elements	Total Cost Detector Phase I + Phase II	Existing from L3	Additional Cost Phase I	Additional Cost Phase II
Magnet (including Installation)	65'000	65'000	-	-
Magnet lifting	-	-	7'000	-
Detector specific infrastructure	34'000	34'000	-	-
Outer Toroid	4'000	-	4'000	-
Support Tube & Absorber	3'000	-	3'000	-
or 6 Tesla Coil (including Support &Installation)	46'500	-	-	46'500*
Installation (without Muon Detector)	4'000	-	4'000	-
Muon Detector (to 22°, including Installation)	66'000	66'000	-	-
Extension of F/B Muon Detector	4'450	-	4'450	-
Electromagnetic & Hadron Calorimeter	19'680	-	19'680	-
Inner Tracker	7'208	-	7'208	-
Racks + cooling & Counting room installation	2'700	1'700	1'000	-
On- and Off-line computers	26'800	26'800	-	-
Total Cost	283'338	193'500	50'338	46'500

* Superconducting Coil produced at the Kurchatov Institute of Atomic Energy



L3 at LHC

μ, e, Version

Phase II
(Additional 50 MSFr.)

Measuring Electrons & Muons
(1.65 x 10^{34} cm^{-2} sec^{-1})

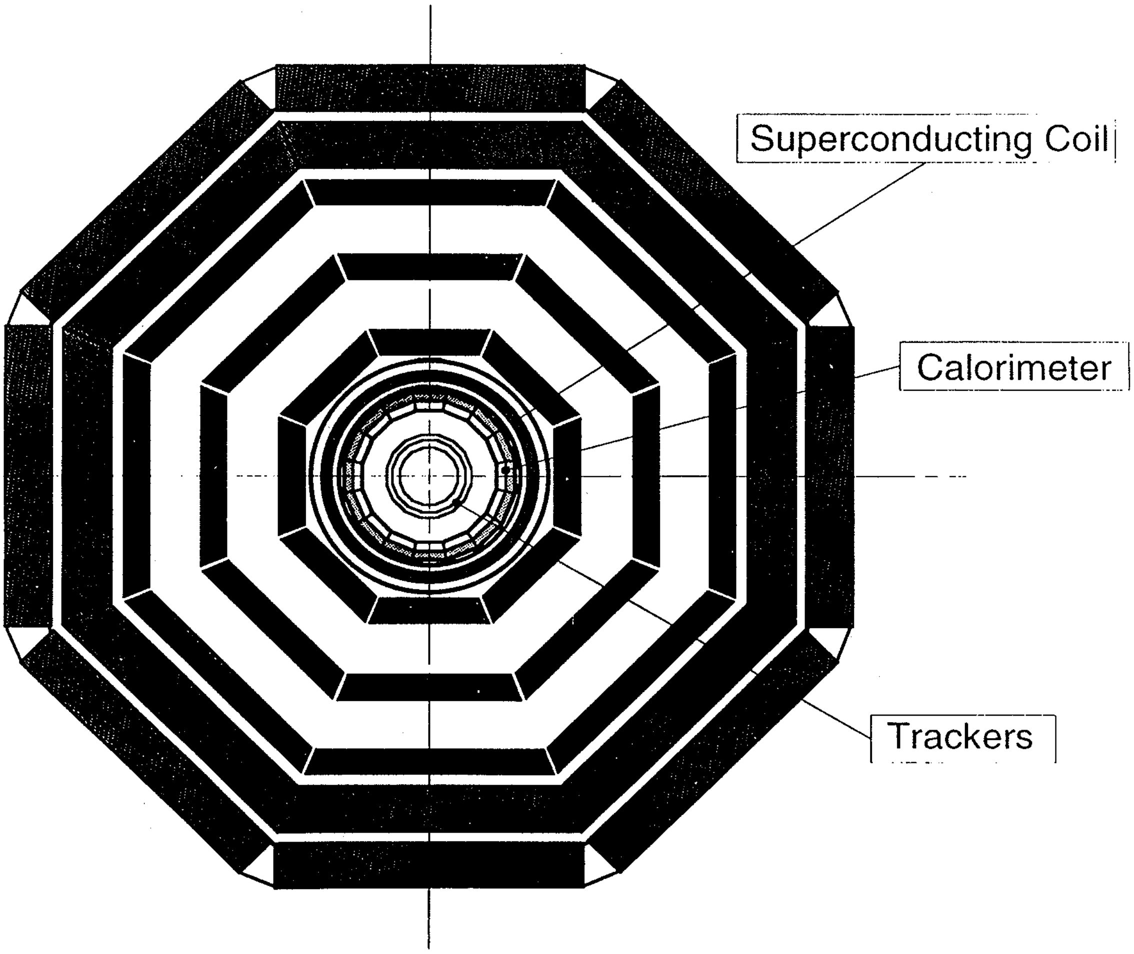
Replace support tube
with 6 T. Superconducting Coil

L3 at LHC

Phase II

Insertion of 6 T Superconducting Coil

10/L3-LHC/rd



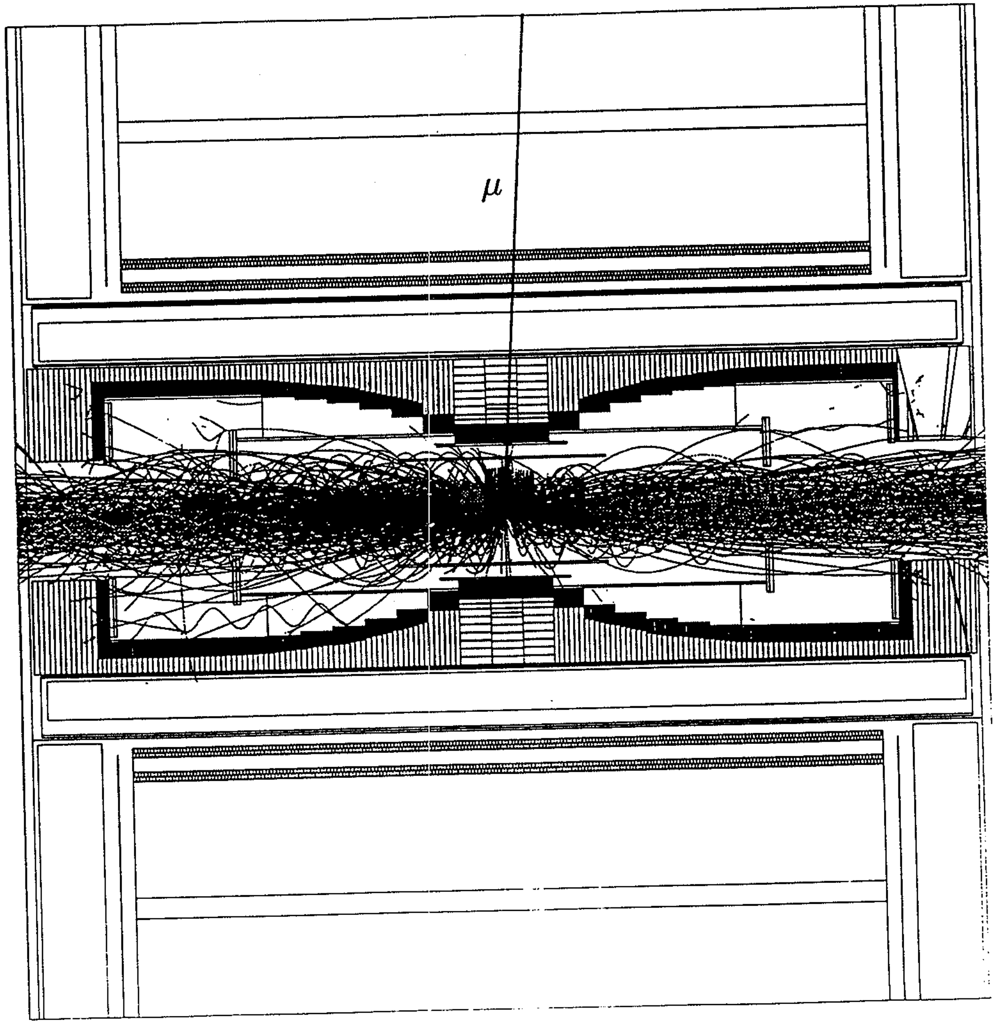
Strong Magnetic Field

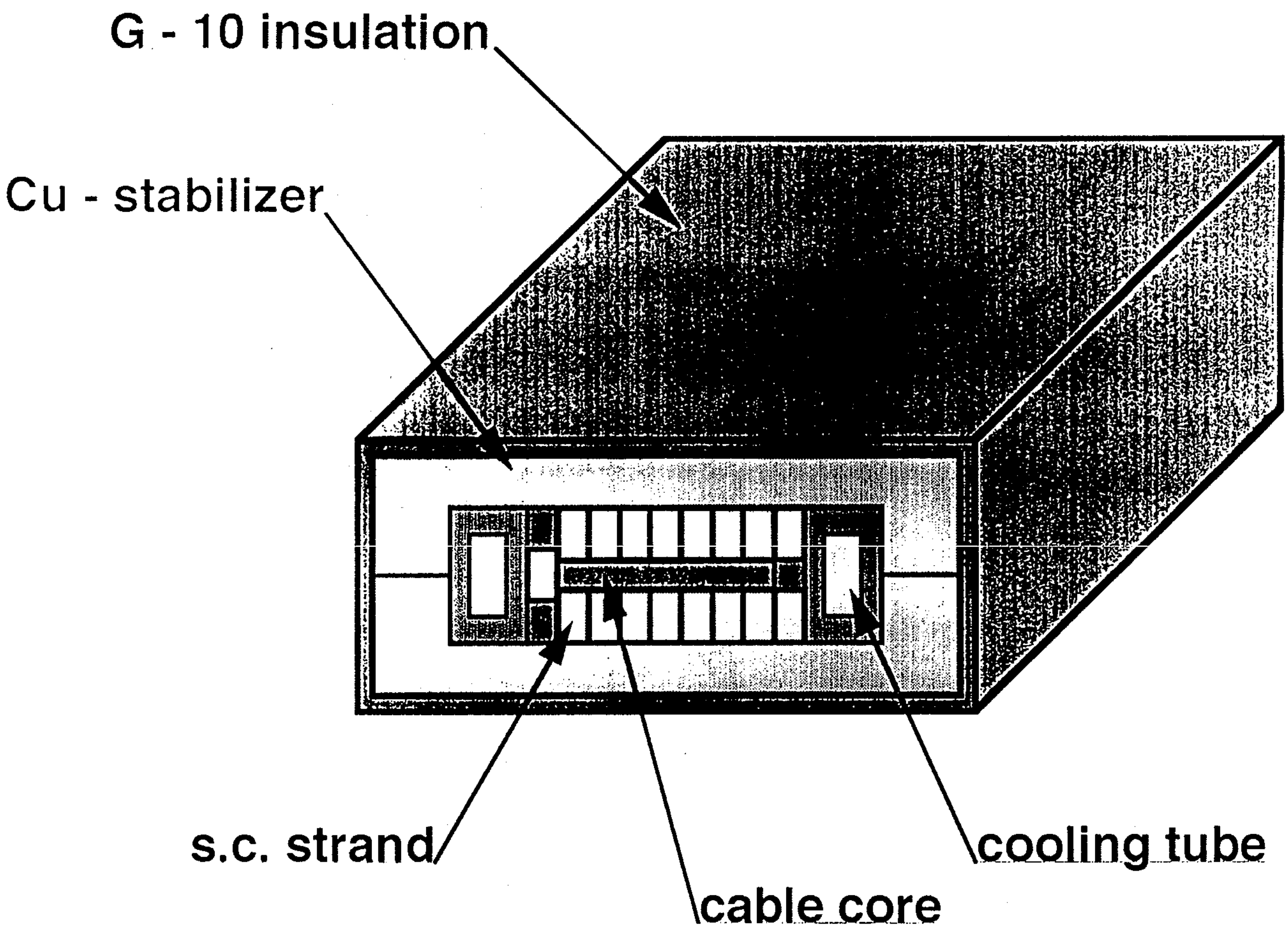
Improves muon resolution at high energy

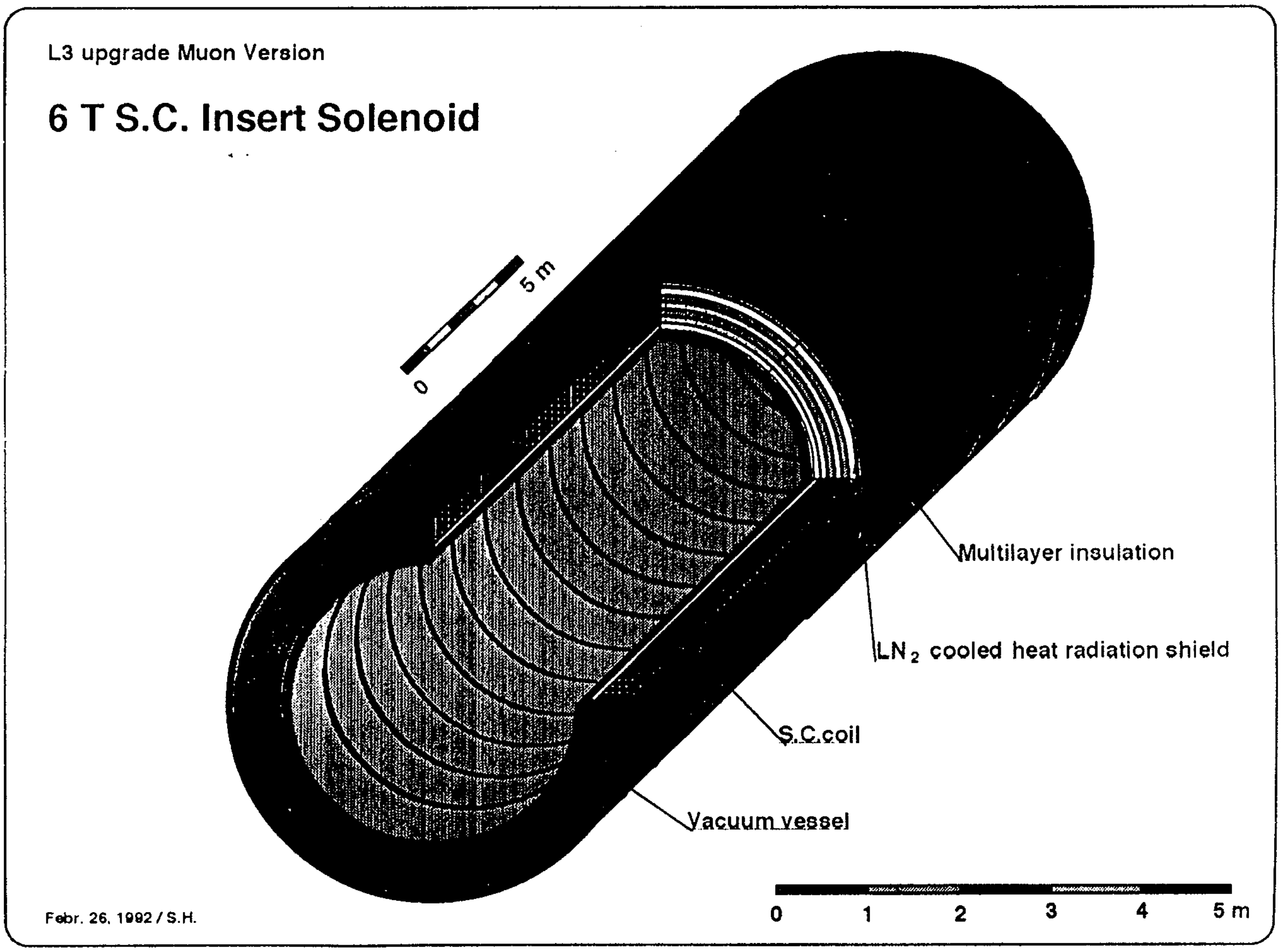
Removes low P_T background from inner trackers

The Effect of 6 Tesla Field

500 Gev Muon overlapped with 20 minimum bias events



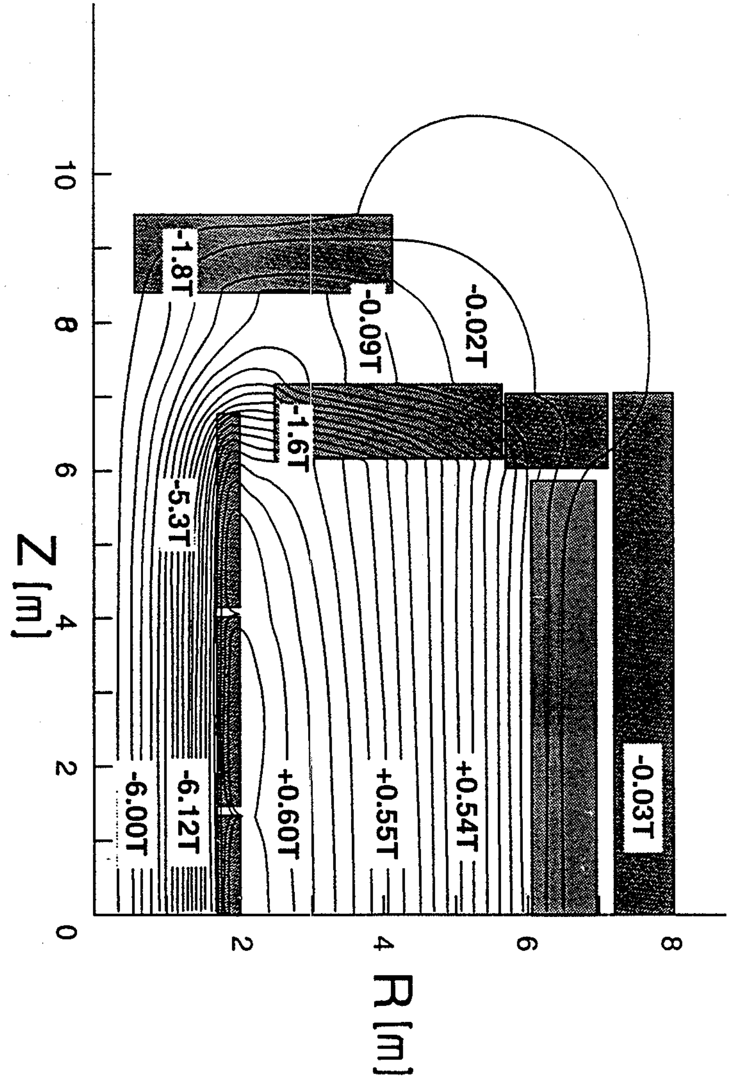

G - 10 insulation
Cu - stabilizer
s.c. strand
cable core
cooling tube


L3 upgrade Muon Version
6 T S.C. Insert Solenoid
0
5 m
Multilayer insulation
LN₂ cooled heat radiation shield
S.C.coil
Vacuum vessel
Febr. 26. 1992 / S.H.
0
1
2
3
4
5 m

Main Parameters
of 6 T insert Solenoid

PARAMETER	
Operation Field,T	**6.0=(6.5-0.5)**
Stored Energy, Gj	**2.3**
Operation current, kA	**20**
Inductance, H	**11.5**
Conductor length, km	**44.0**
Ampere turns, MA	**72.9**
Dumping voltage, V	**500**
Cold mass, t	**330**
Total mass, t	**400**
Length of the magnet, m	**14.20**
Magnet thickness, m	**0.625**
Free inner bore radius, m	**1.60**
Outer radius of the magnet, m	**2.225**

Flux Lines in the Magnet System



ref. 1/21 2.9

USSR 123182 Moscow

KURCHATOV IAE

Kurchatov Institute
For Atomic Energy

Superconductivity & Solid State Physics Division

Tel.: 7 095 196 59 73
FAX: 7 [illegible]
Telex: 411 594 SHUGA USSR
E-mail: RAU•KIAE.SU

Outgoing Facsimile Cover Sheet

To: Professor SCC Ting Fax 41 22 782 8923 CERN
From: Prof. N.A. Chernoplekov
Date: 03 march
No. of pages 2 + cover

To: Professor S.C.C. Ting

From: N.A.Chernoplekov

Dear Sam,

I'd like to inform you that we are continuing working on the L3 upgrade insert superconducting solenoid. As you know, we proposed conceptual design for 7.5 T version and made some analyses on the possibilities of installation of this solenoid inside the L3 detector. All this time we had fruitful discussions with people from the L3 collaboration and made substantial progress in our work, got more data for understanding of technical problems of this project and I think, we have found ways how to solve some of them.

We had many discussions with our Institutions and enterprises which could be involved in the implementation of this challenging work and met high interest in participation.

As before we consider the L3 upgrade experiment as a very promising project and the insert solenoid with such a huge stored energy as a challenging and responsible part of the detector.

Me and my colleagues discussed our possibilities on the realization of the insert solenoid for 6 T. We think we can do most of work here using our good relations with our collaborators in Russia and other members of the CIS.

It is clear that due to large dimensions and weight we can not deliver to CERN the fully assembled device ready for installation. This means that substantial part of the final assembly, tests and installation should be done on site.

The cost estimate which we carried out in the last fall at CERN in 1990 $ units, based on the world market price, resulted in cost for 7 T version of about 30 M$ and about 26 M$ for 6 T version. About forty percent of the total cost was cost for a conductor. Some estimates made by other experts showed even higher cost.

We tried to figure out the cost for the magnet as if we would manufactured here as much as possible and after that delivered it to CERN for final assembly.

Our work here we estimated to be about 13 M$, including 6.3 M$ for a conductor. This number is based on nowday prices for superconductor, copper and stainless steel. We feel that cryogenics (estimated as 3 M$ including nitrogen distribution) should be bought somewhere in Europe (for instance, Sultzer)

Transport expenses we can estimate only approximately, a best guess estimate - 1M$.

All this, including 2 M$ for final assembly, installation and test gives 19 M$.

This estimate doesn't take into account a support from our government which we can not foresee now.

I think we still shall try to find the support for our work from our government because we expect to meet understanding that the participation in such a forefront projects is very important for our country from many standpoints: physics, technology, cooperation, education etc. True, that the objective difficulties in economy may postpone or reduce this support. But even without it we feel that our estimate promises to reduce the cost for a magnet substantially as if it has been done completely in Europe.

Also, we shall discuss other ways of cooperation if some considerations would arise for more effective solutions in building this magnet.

Let me close that brief letter by expressing a hope that we'll have a chance to meet each other in the nearest future to discuss issues of the mutual interest in more details.

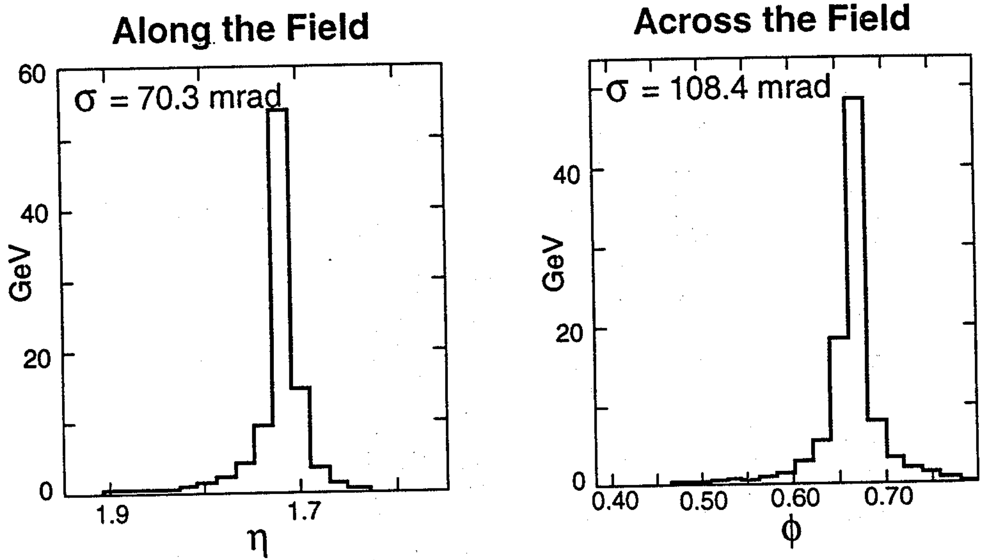
Sincerely yours,

N. Chernoplekov

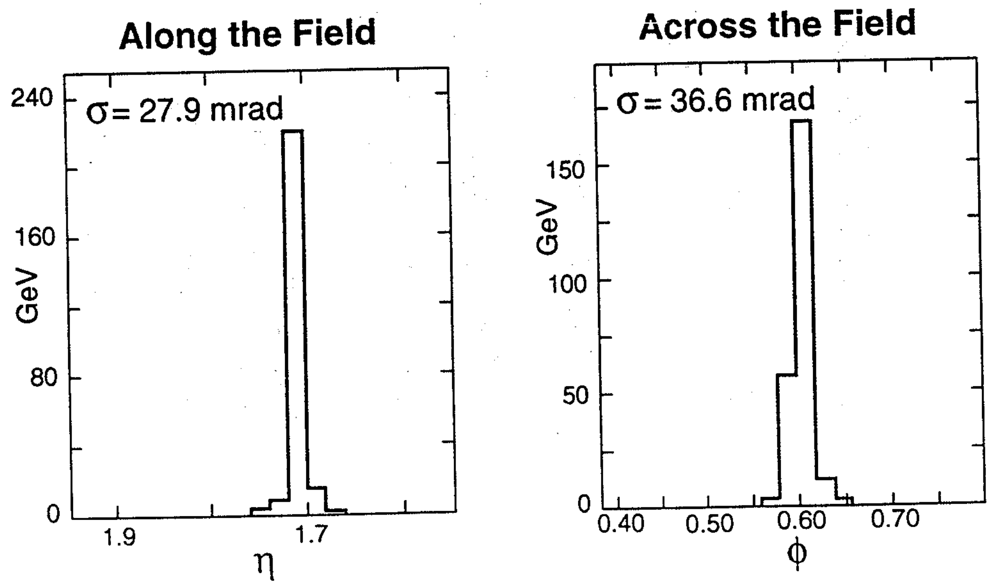
N.Chernoplekov

Shower Profiles in 6 Tesla Field

$E_{\pi} = 100$ GeV $\theta = 20°$



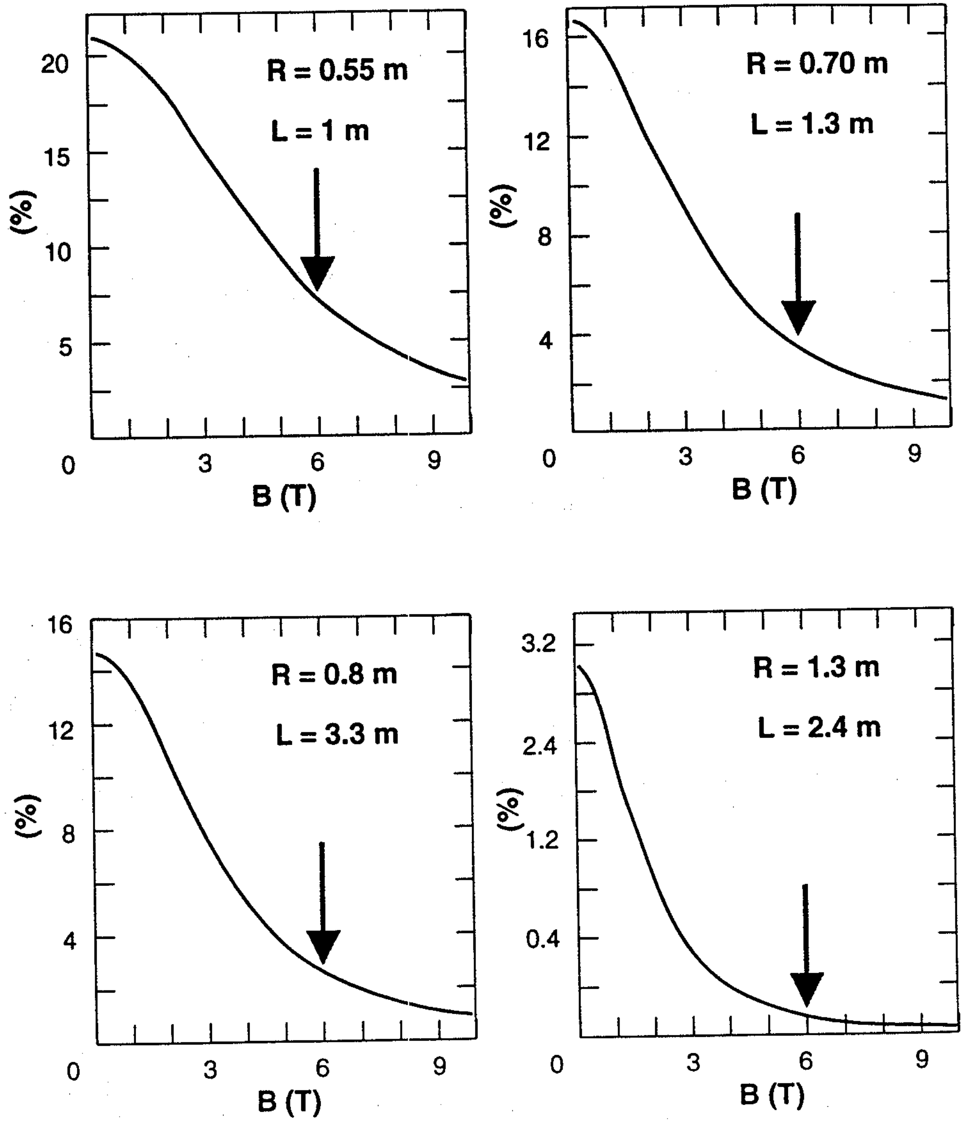
$E_{e} = 250$ GeV $\theta = 20°$



Occupancy in Different Trackers Versus Magnetic Field

(no albedo)

20 min. bias events



System Redundancy

Muons

Precision L3 muon detector : P_1
Trackers in strong field : P_2
Reject background : $P_1 = P_2$

Electrons

Electromagnetic calorimeter : E
Inner trackers : P
Reject background : P = E

Hadron Calorimetry

Lepton isolation & filtering

Occupancies of inner trackers

Full Monte Carlo simulation:
PYTHIA/GEANT/GHEISHA

Luminosity $1.6x10^{34}$ cm^{-2} sec^{-1}

Magnetic field: 6 Tesla

Occupancies/ 1m of straw/ 20 min.bias events with and without calorimeter albedo:

Radius of tracker/cm/	55	70	80	130
No albedo	.078	.032	.013	.0004
Albedo in	.087	.040	.018	.005

Muon Detector

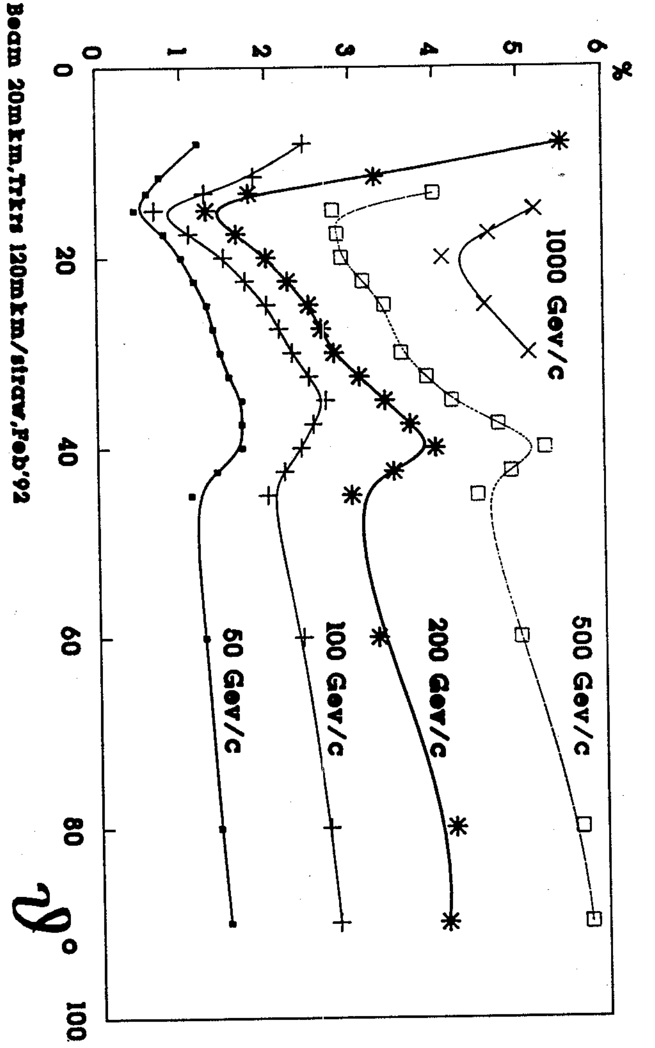
Outer L3 muon detector
and
forward proportional chambers
ensure precision momentum
measurement below 200 GeV

Outer L3 muon detector
also serves for
track finding in trackers

Trackers in 6 Tesla field provide
accurate measurement
above 200 GeV

L3 Upgrade

Muon Resolution for complete detector



Beam 20mkm,Trkrs 120mkm/straw,Feb'92

Study of Particle rates in Muon Chambers

100 000 events generated by (PYTHIA) Monte-Carlo with full shower simulation (GEANT/GHEISHA)

59 tracks were detected

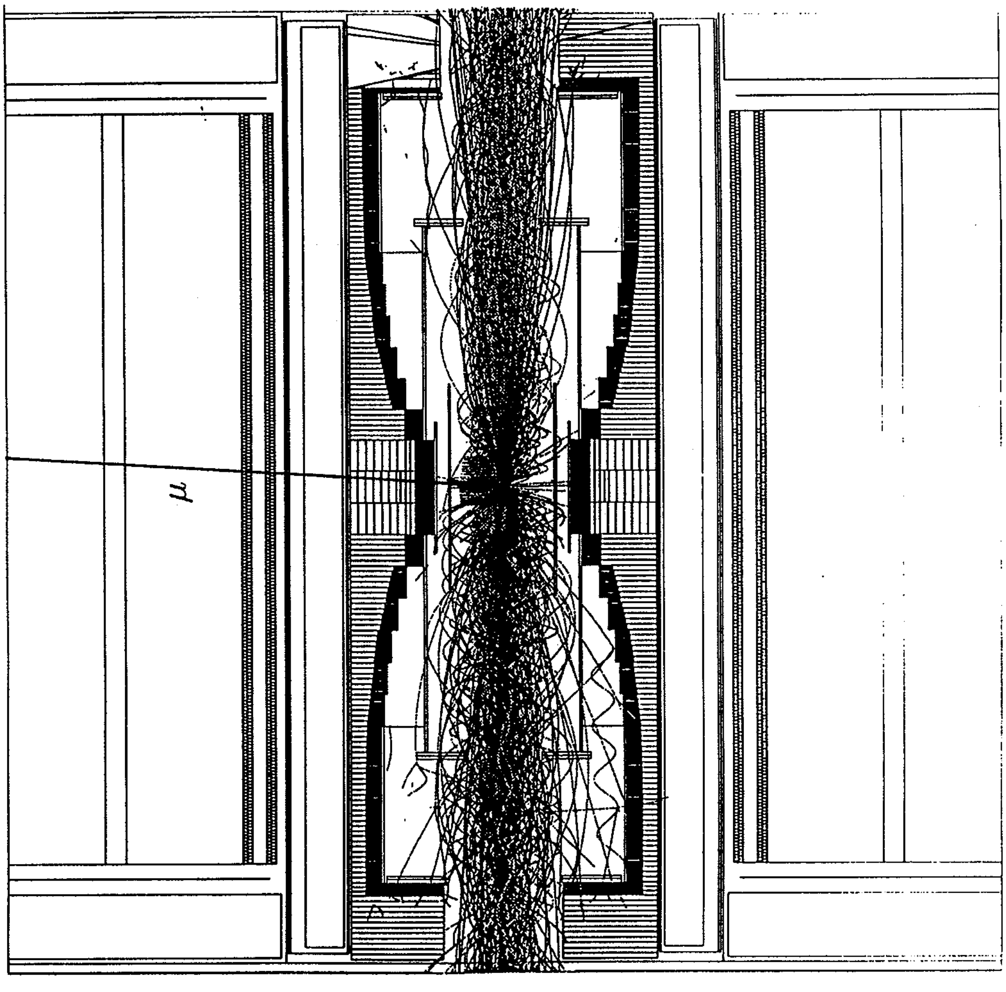
Counting rate in the barrel :
16 x 10^{34} x 160 mb x 59/100 000 = 1.5 MHZ

Counting rate in chamber :
1.5 MHZ / 16 = 94 KHZ

Rate in a cell :
94 KHZ / 20 = 4.7 KHZ

Muon Trigger

500 Gev Muon overlapped with 20 minimum bias events



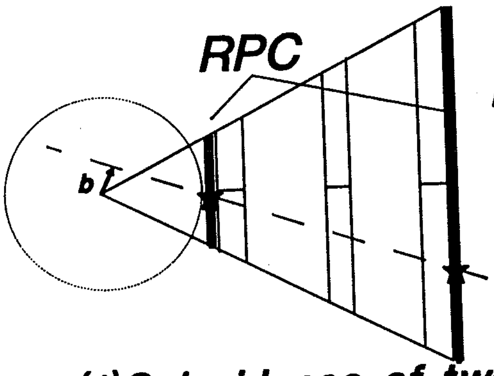
Pattern Recognition

Muons

Extrapolate isolated tracks from outer muon detector

Make χ^2 fit with the nearest hits in inner trackers.

Muon Trigger



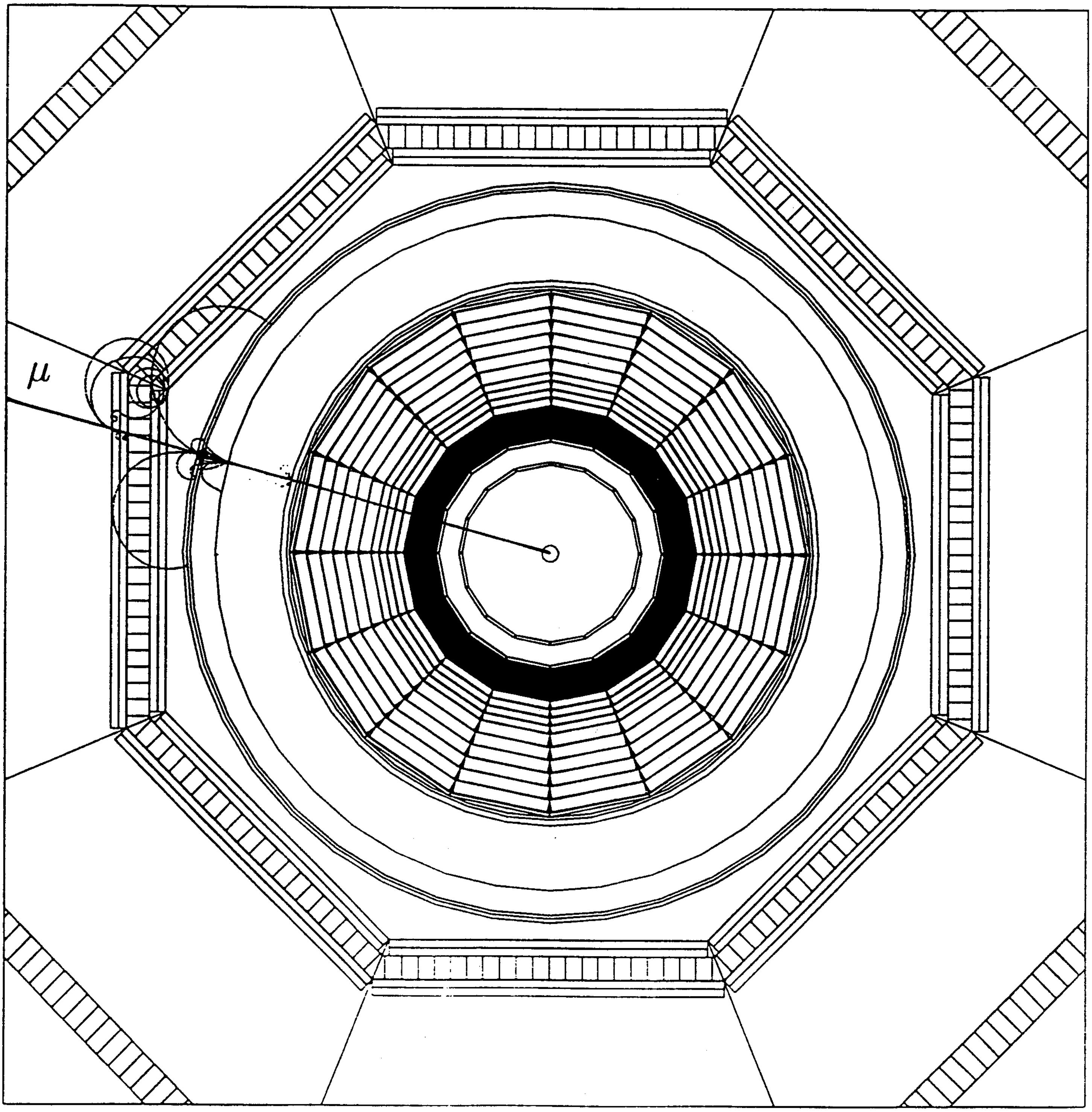
Measurement of impact parameter b with RPC trigger counters.

Requirement:

(1)Coincidence of two RPC hits in one octant
($\Delta t < 15$ nsec)
(2)Impact parameter $b < b_{cut}$
e.g. $p = 10$ Gev/c ➡ $b = 225 \pm 20$ mm

Dimuon trigger rate: ≈200Hz
for $p > 10$ Gev/c and $\eta < 3$

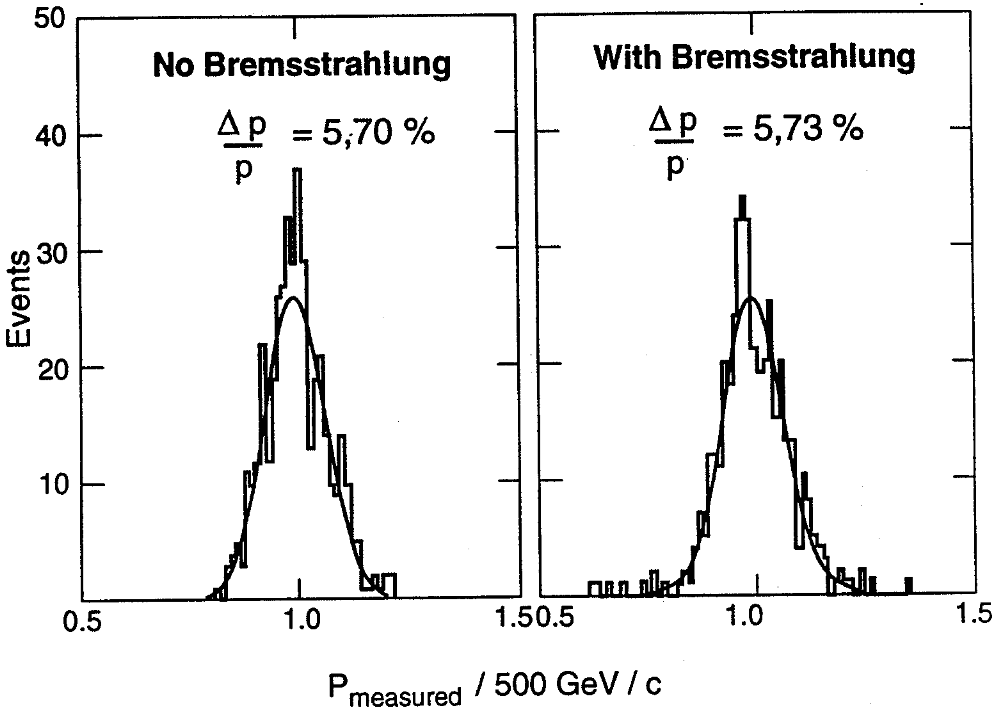
Pattern recognition with Bremsstrahlung



500 Gev muon

Influence of Muon Bremsstrahlung on Muon Momentum resolution for high Energy Muons

E_{μ} 500 GeV $\theta_{\mu} = 85°$

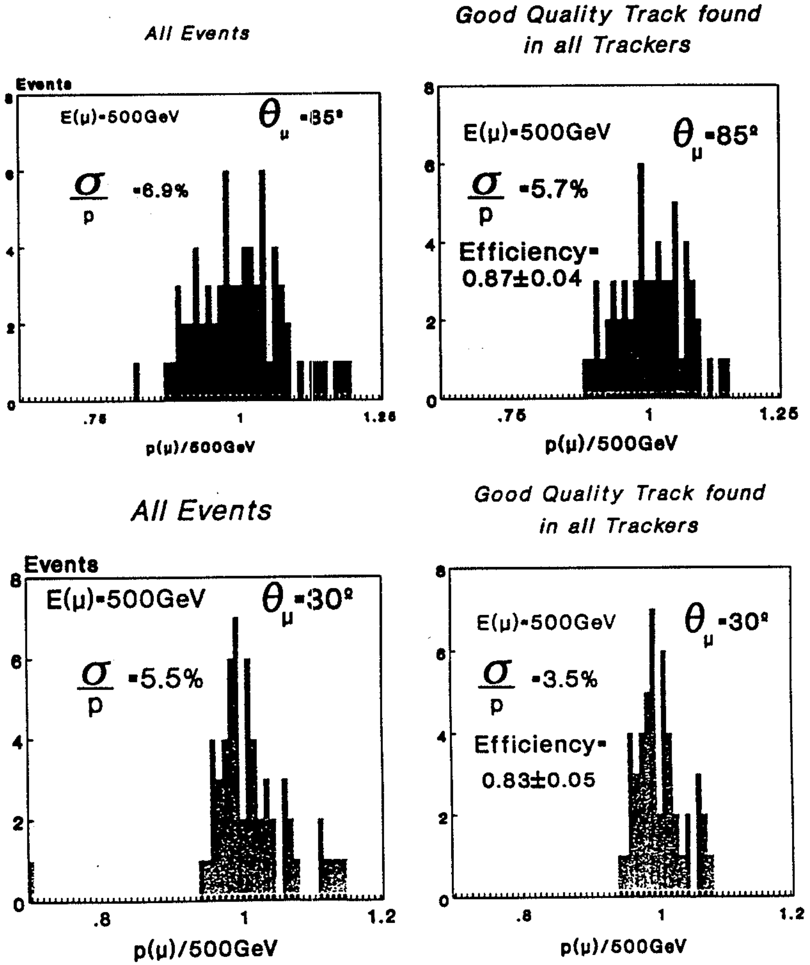


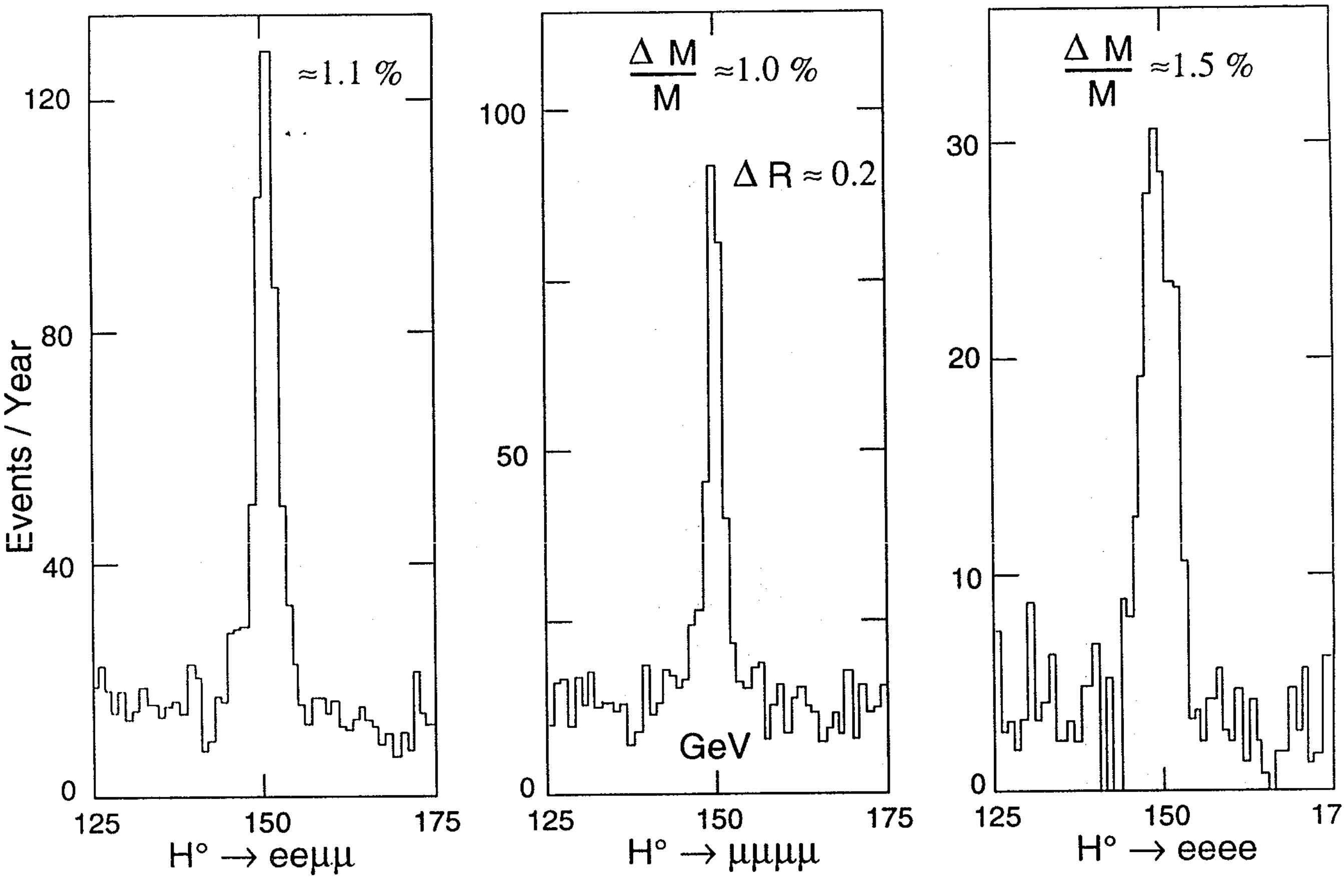
Probability of Bremsstrahlung

500 GeV / c	19 %
200 GeV / c	6 %

Muon Momentum Measurement

μ overlapped by 80 min. bias events





$H^\circ \rightarrow Z^\circ Z^\circ \rightarrow \ell^+ \ell^- \ \ell'^+ \ell'^-$ + background + 80 min. bias

---

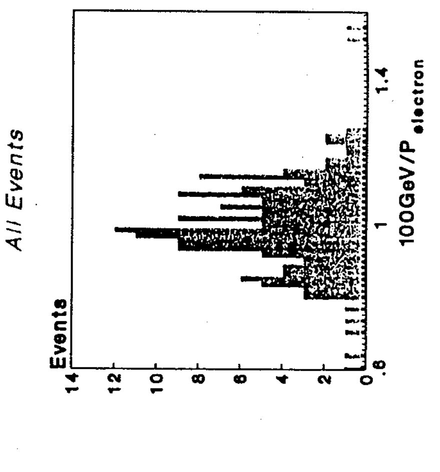
Pattern Recognition of Isolated Electrons

Full PYTHIA/GEANT simulation with 80 minimum bias events and albedo from calorimeter

1) Electrons found by isolation in calorimeter with almost 100% efficiency for p_t > 20GeV

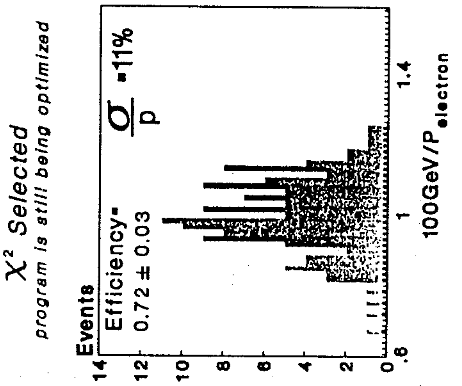
2) To find the charge, calorimetric energy is used to make χ^2 fit through interaction point and nearest hits of tracker

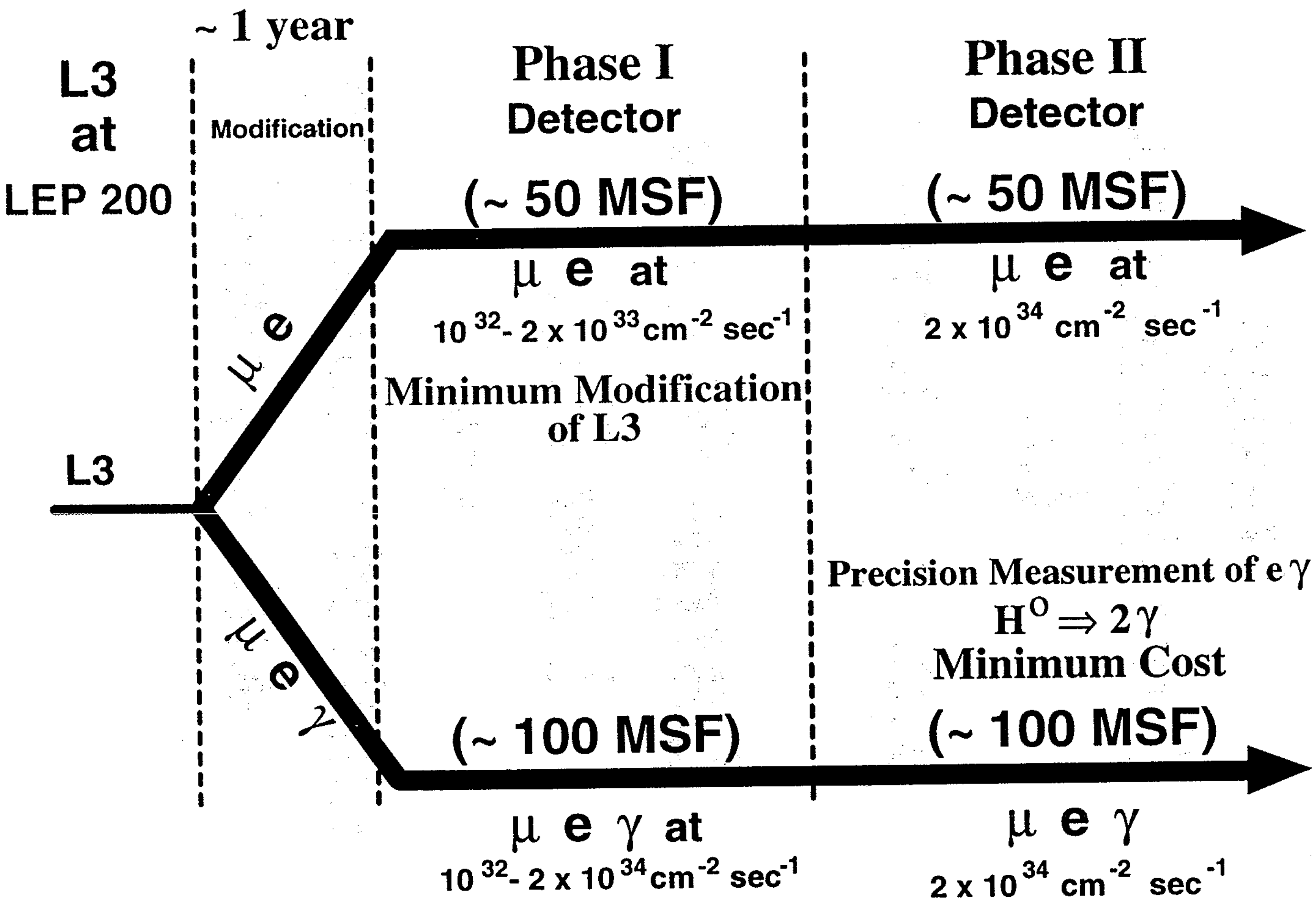
All Events



χ^2 *Selected*

program is still being optimized





L3 at LEP 200

~ 1 year

Modification

Phase I Detector

(~ 50 MSF)

μ e at

10^{32}- 2 x 10^{33} cm^{-2} sec^{-1}

Minimum Modification of L3

(~ 100 MSF)

μ e γ at

10^{32}- 2 x 10^{34} cm^{-2} sec^{-1}

Phase II Detector

(~ 50 MSF)

μ e at

2 x 10^{34} cm^{-2} sec^{-1}

Precision Measurement of e γ

$H^0 \Rightarrow 2\gamma$

Minimum Cost

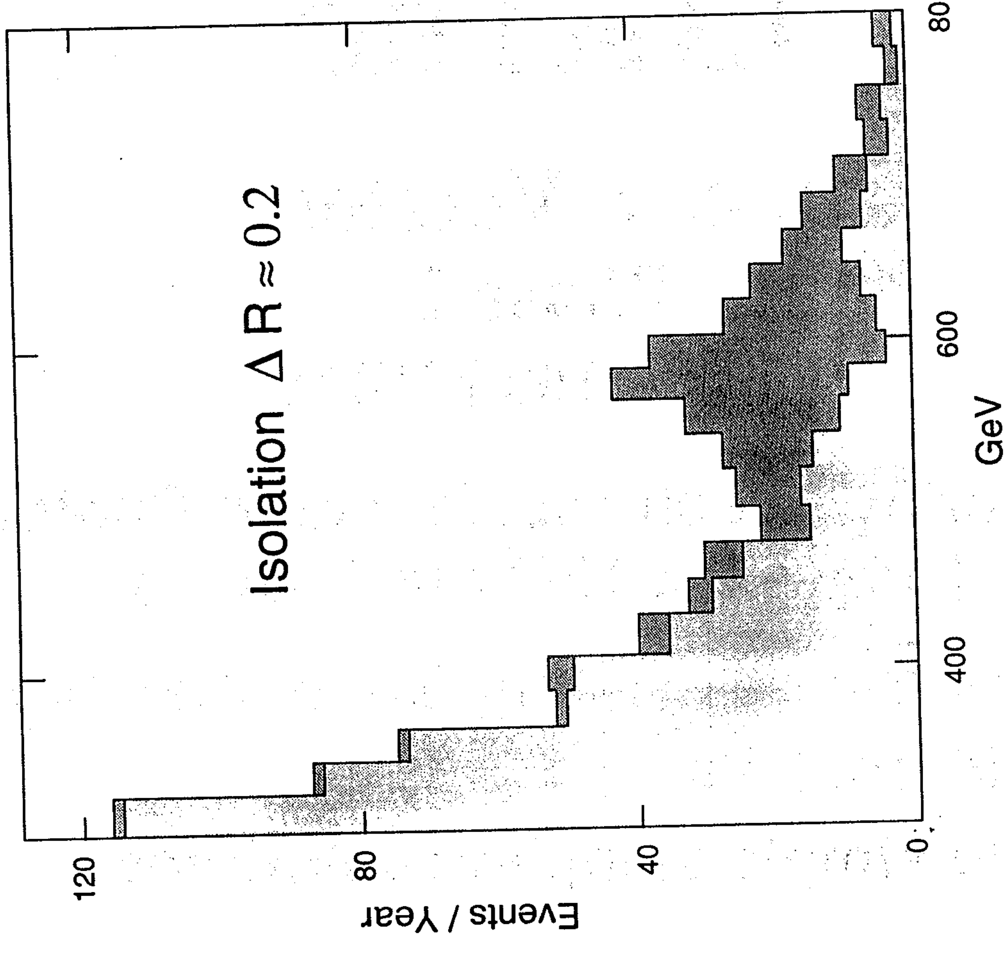
(~ 100 MSF)

μ e γ

2 x 10^{34} cm^{-2} sec^{-1}

158/5.392/r

Higgs Signal: M_H = 600 GeV



$H^\circ \rightarrow Z^\circ Z^\circ \rightarrow \ell^+\ell^- \ell'^+\ell'^-$, $\ell, \ell' = e, \mu$

+ background + 80 min. bias

Design Considerations for μ,e, γ detectors

Large Radius
Low Field
and
Limited η coverage
with crystals

L3 at LHC

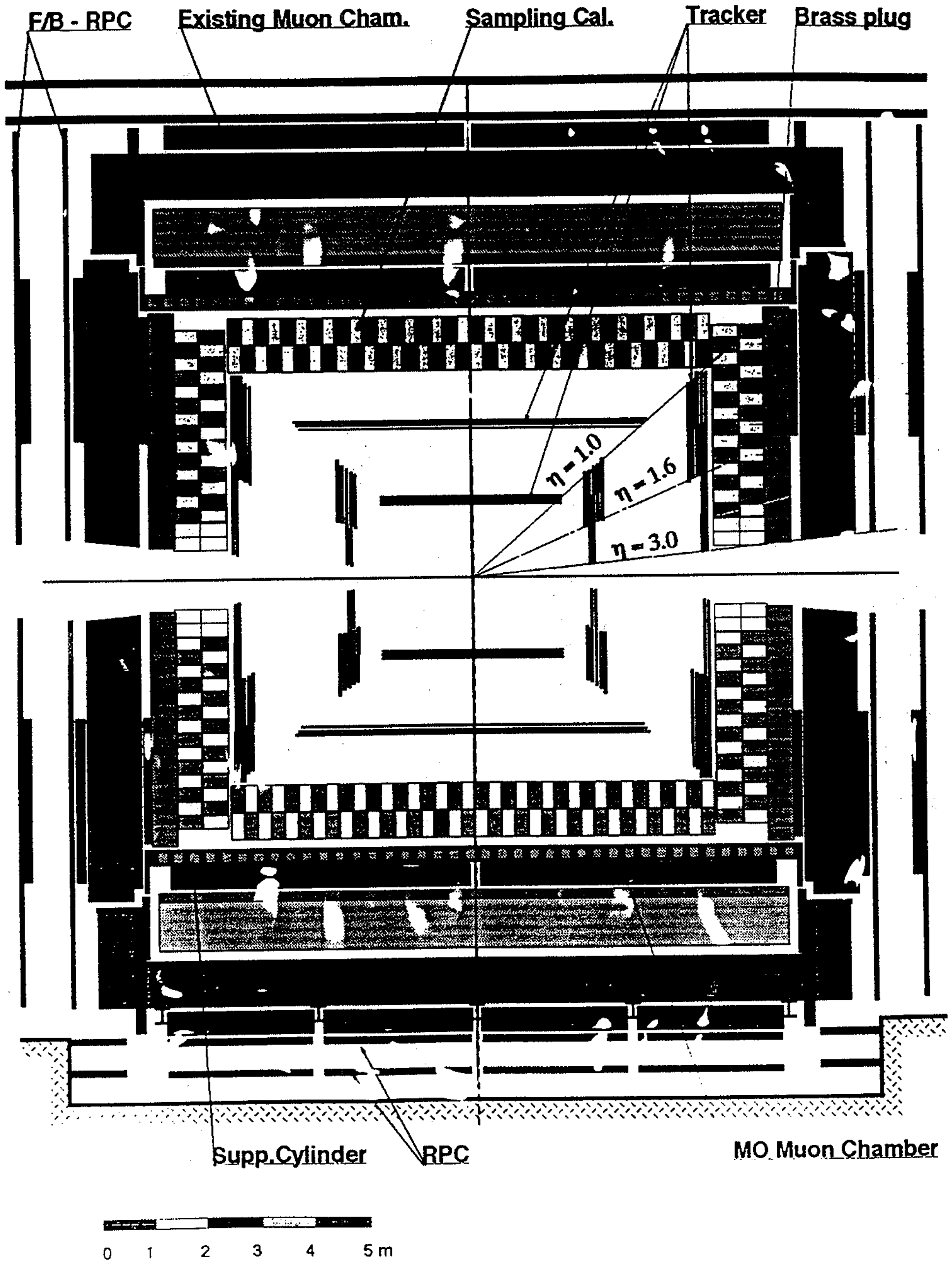
μ, e, γ Version
Phase I
(Cost ≈ 100 MSFr.)

Measuring Electrons, Muons & Photons
(10^{32} - 2 x 10^{34} cm^{-2} sec^{-1})

1. Re-arrange existing Muon chambers
2. Add trackers
3. Add simple sampling calorimeter

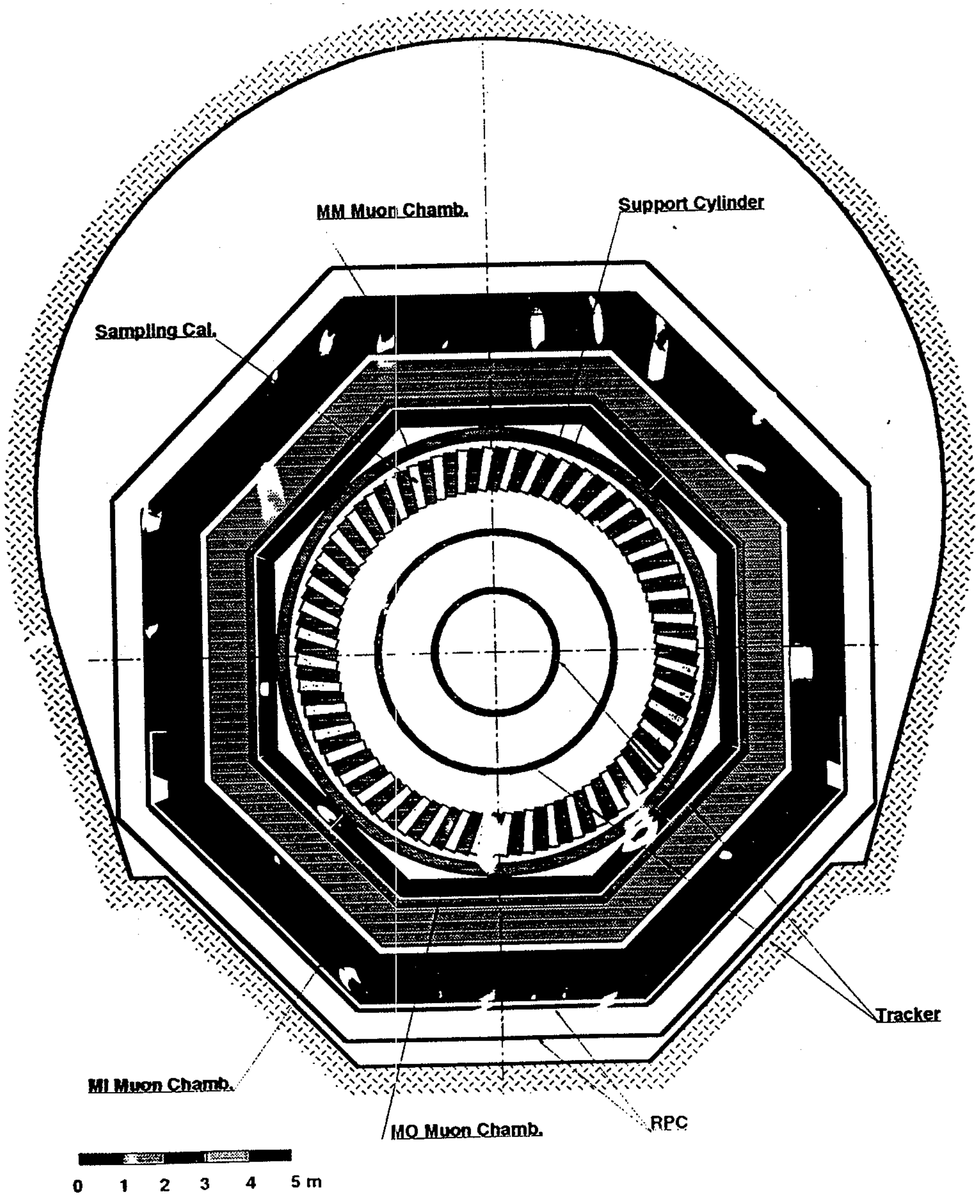
μ - e - γ - Detector Version for LHC

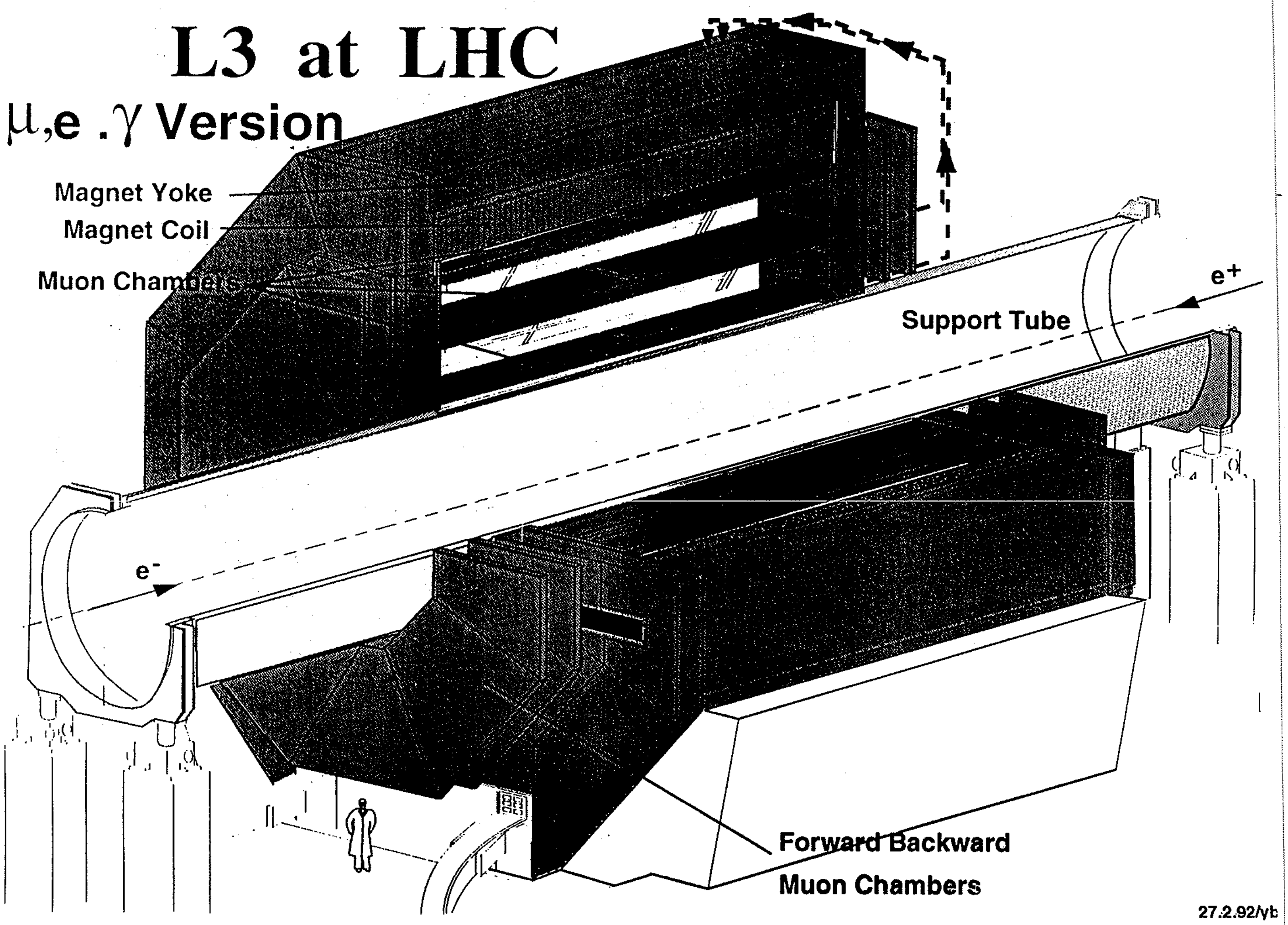
Phase 1



μ - e - γ - Detector Version for LHC

Phase 1





L3 at LHC

μ, e, γ Version

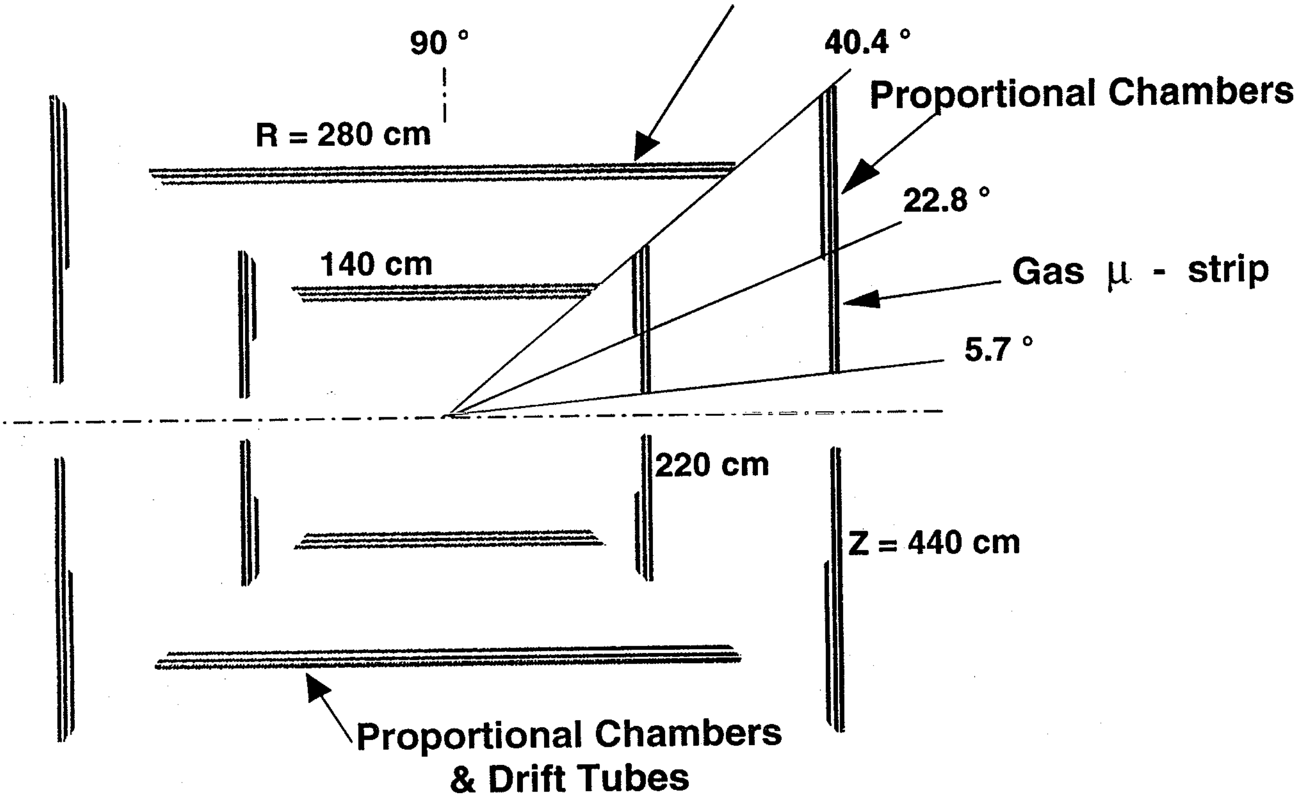
Phase I

Measuring Electrons, Muons & Photons

(10^{32} - 2 x 10^{34} cm^{-2} sec^{-1})

1. Re-arrange existing Muon chambers

Trackers



Total Material < 2 % X_0

B.05/4.3.92

L3 at LHC

μ, e, γ Version

Phase I

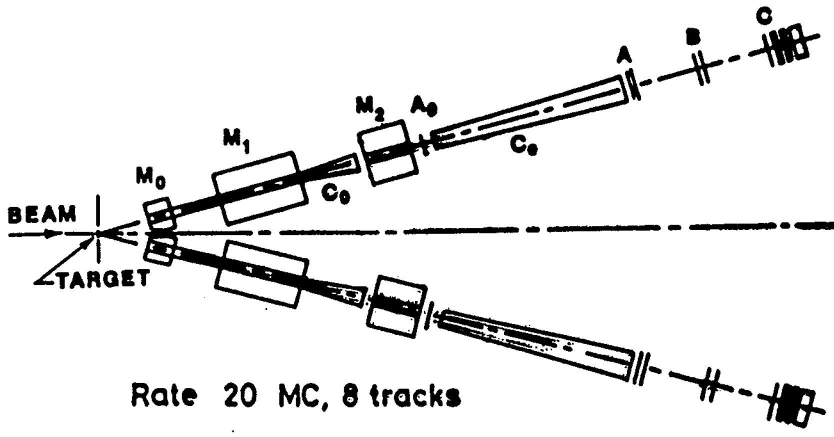
Measuring Electrons, Muons & Photons
(10^{32} - 2 x 10^{34} cm^{-2} sec^{-1})

2. Add Trackers

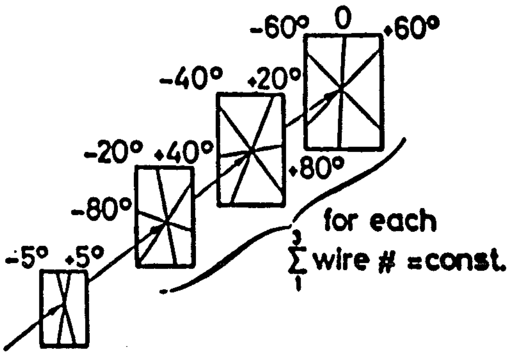
SPS CERN (NA10)

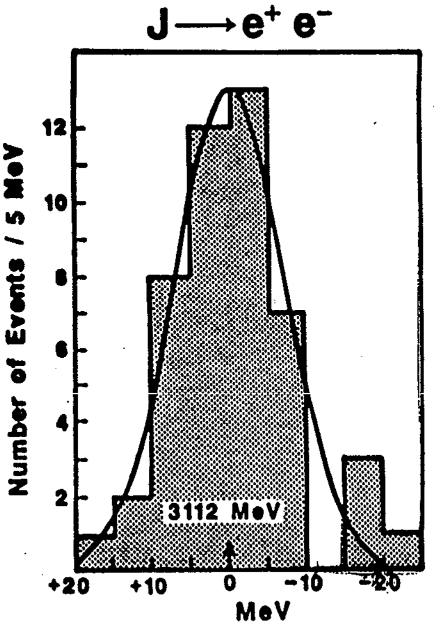
BNL 1974

p + Be ⟶ e^+e^- + X



Rate 20 MC, 8 tracks

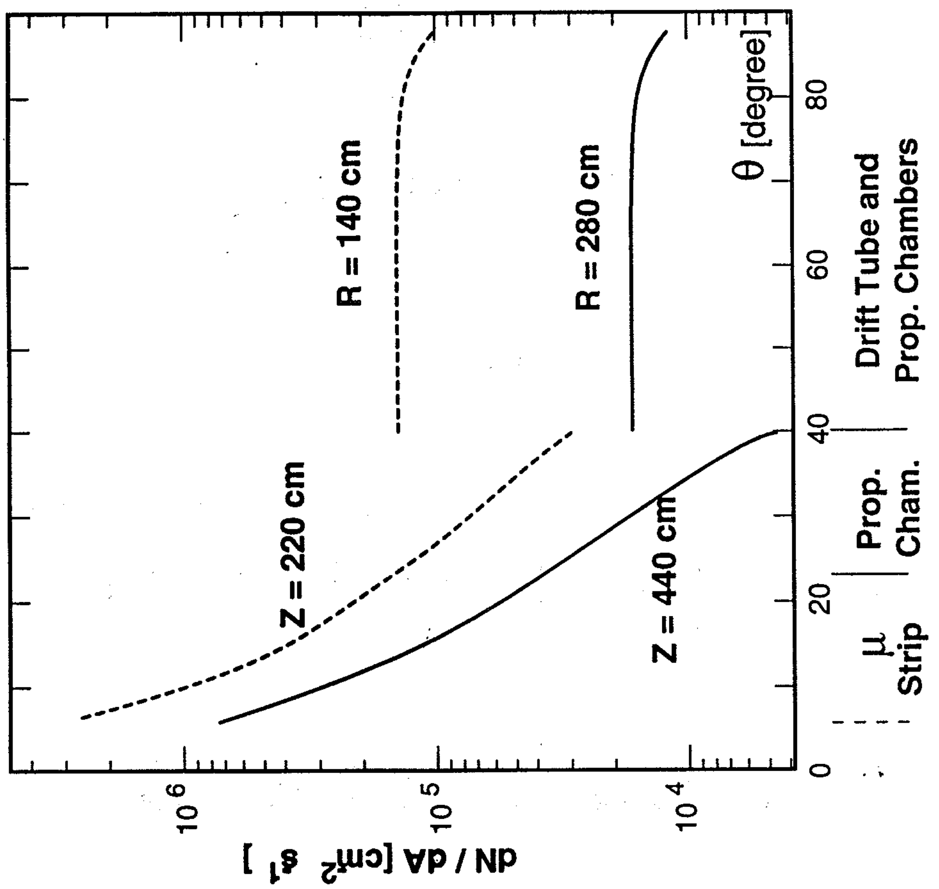




$\Delta m/m \sim 1/1000$

$\mathcal{L} = 10^{36}\ cm^{-2}\ sec^{-1}$

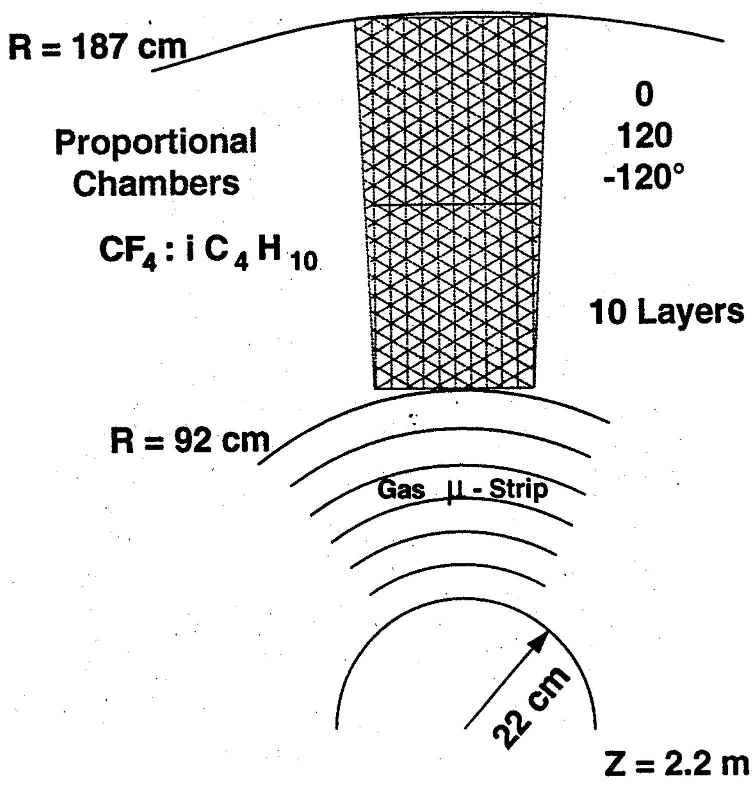
$L = 1.6 \cdot 10^{34} cm^{-2}s^{-1}, \sigma_{in.} = 81$ mb, B = 0.7 T



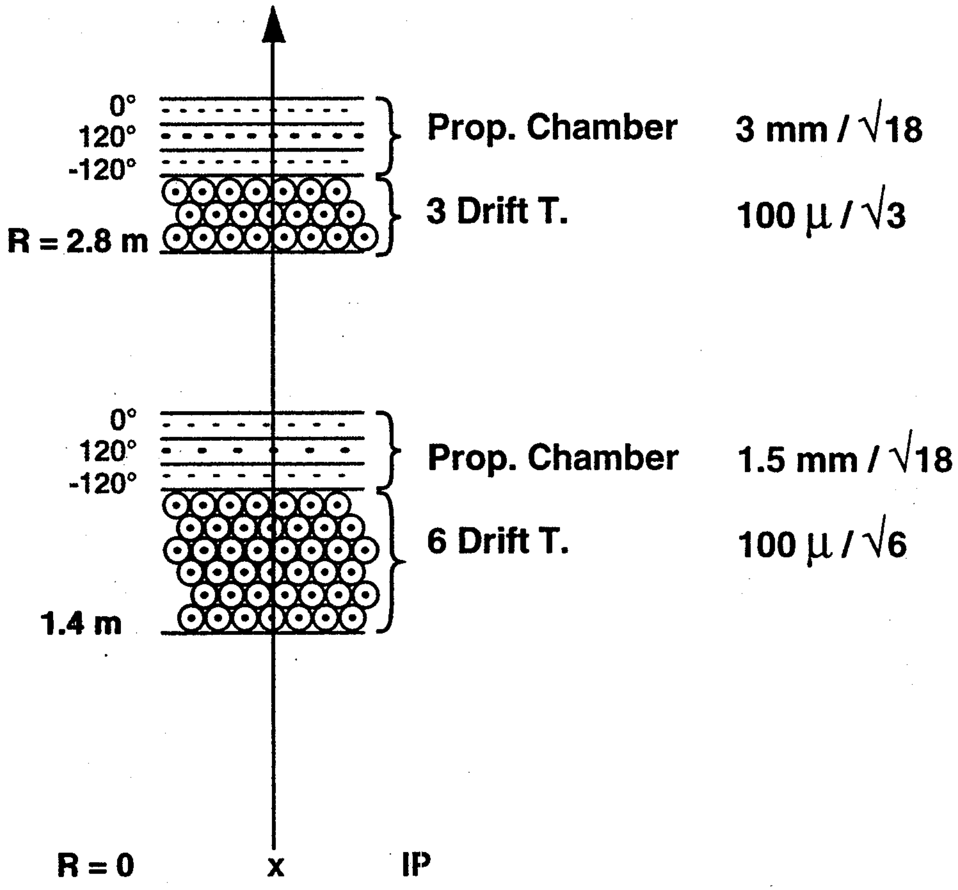
Element Areas matched for < 2% Occupancy

B.+F.ref.07/28.2.92

Forward 40.4 → 22.8°



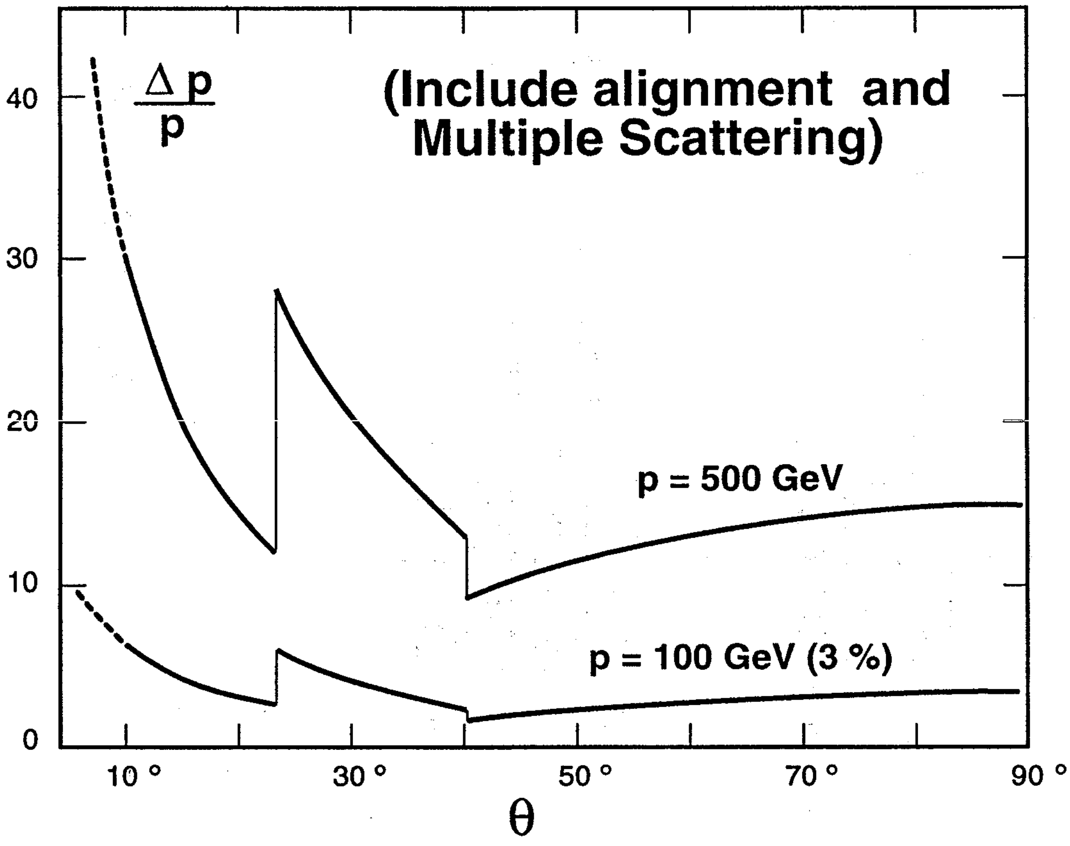
Barrel 90 ° - 40.4 °



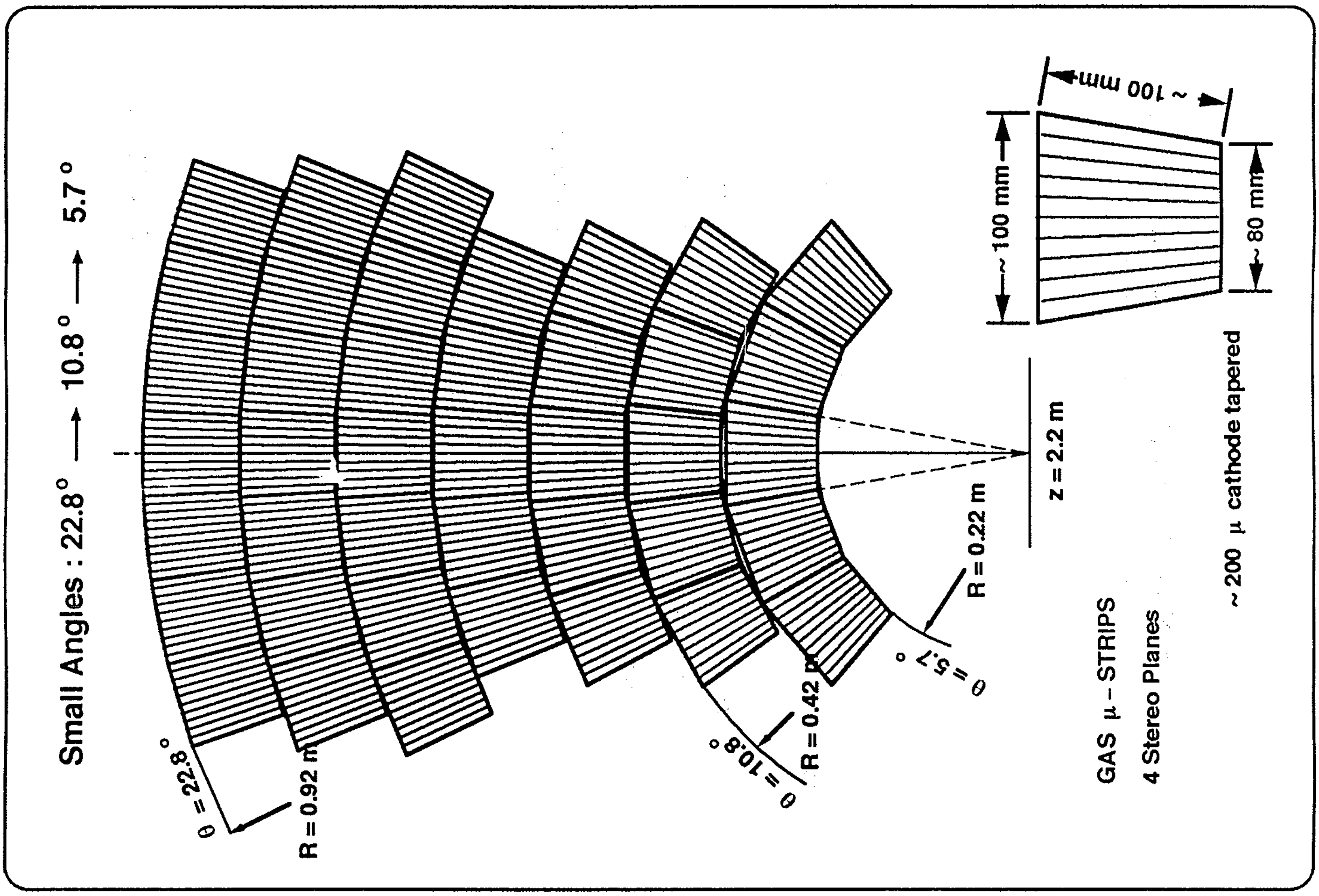
Total: 2 % Xo

ref.1/28.2.92

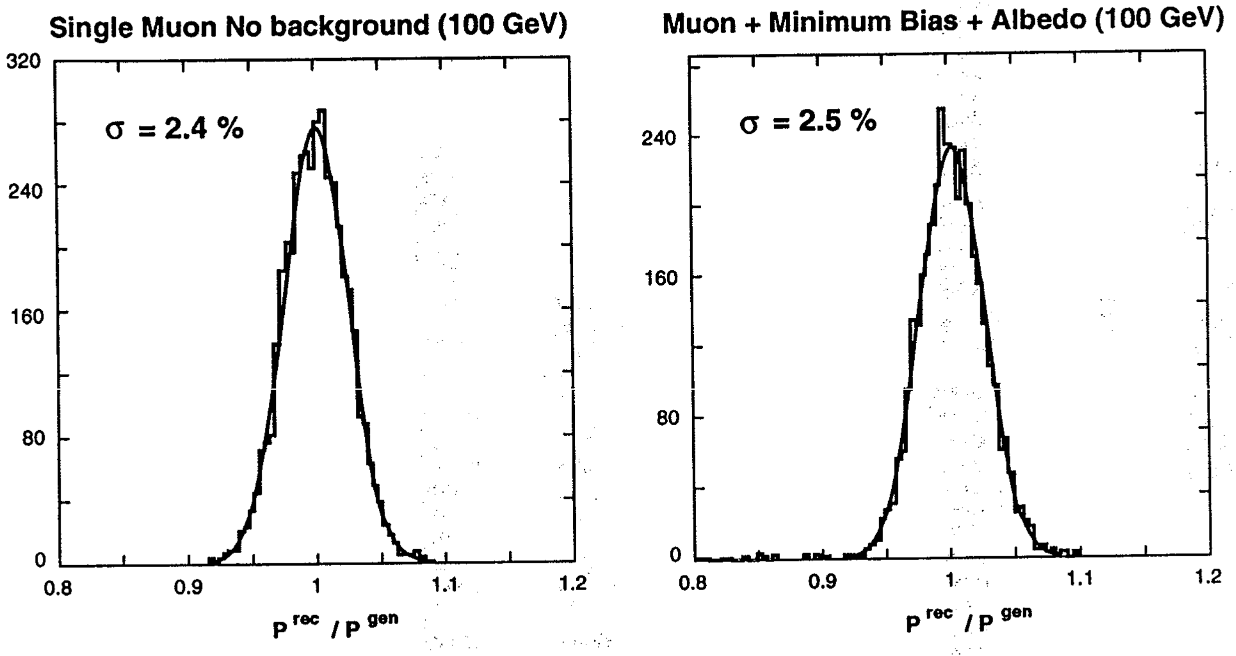
Resolution



.02/4.3.92



Pattern Recognition Efficiency is 98 % with χ^2 cut

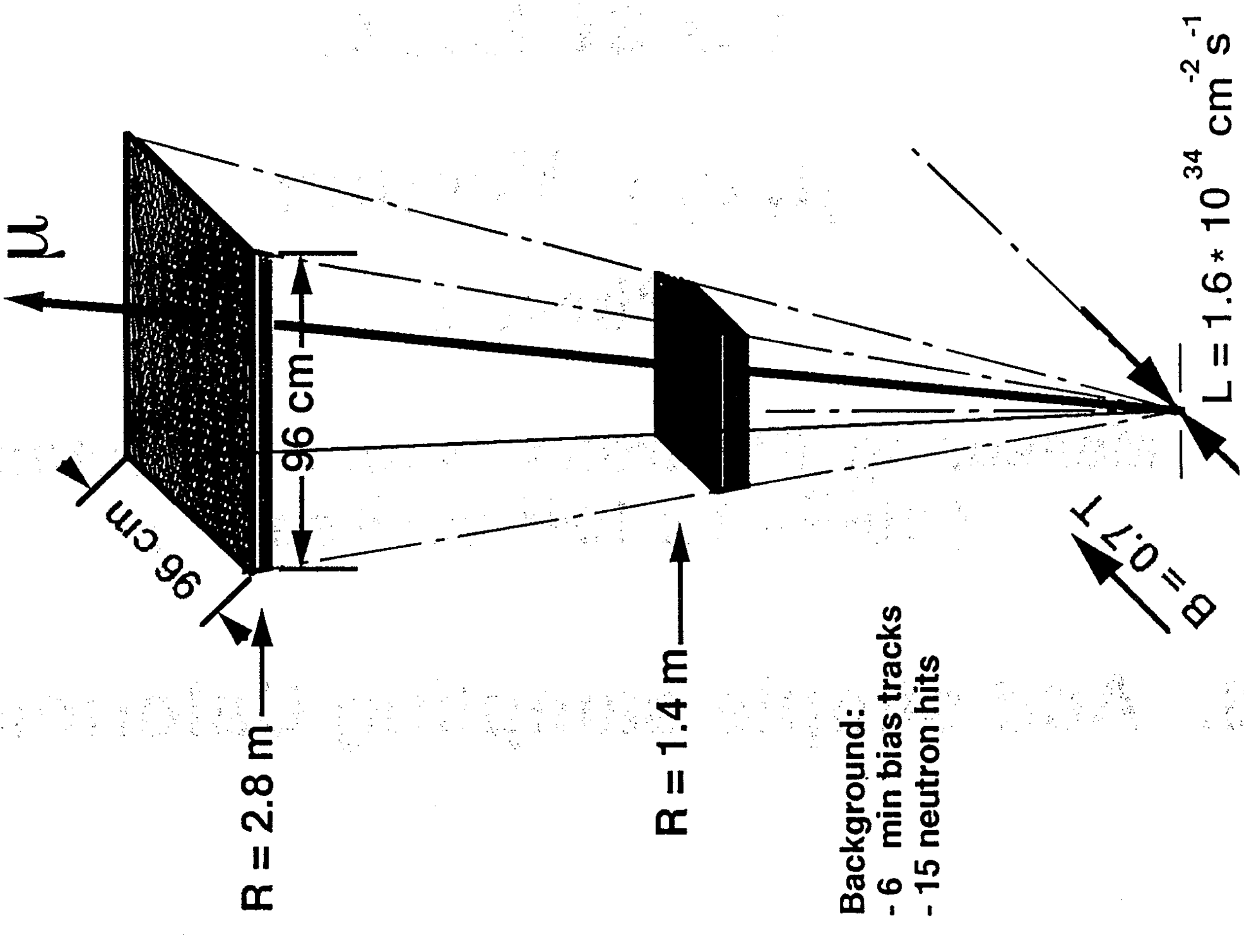


Full resolution calculation (including multiple scattering + alignment) yields

$$\frac{\Delta p}{p} = 3.0 \% \text{ at } 100 \text{ GeV}, 90^\circ$$

162-163/4.3.9

Pattern Recognition



Background:
- 6 min bias tracks
- 15 neutron hits

L3 at LHC

μ, e, γ Version

Phase I

Measuring Electrons, Muons & Photons
(10^{32} - 2 x 10^{34} cm^{-2} sec^{-1})

3. Add simple sampling Calorimeter

R & D

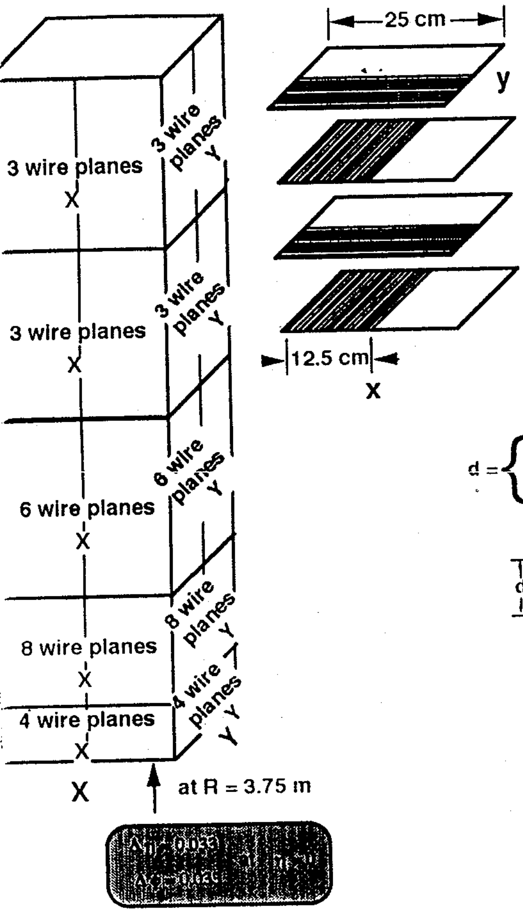
on

Sampling Calorimeter

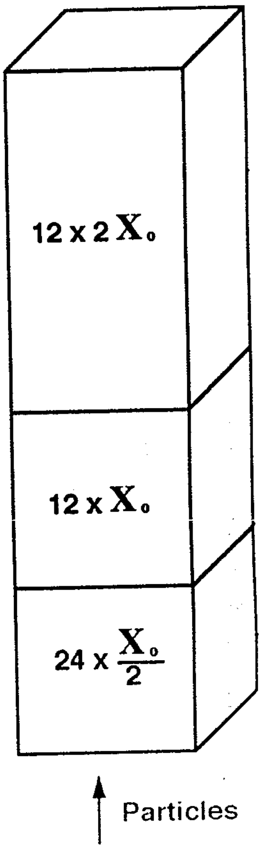
1. L3 design
2. Liquid Argon

Read - out segmentation (like L3)

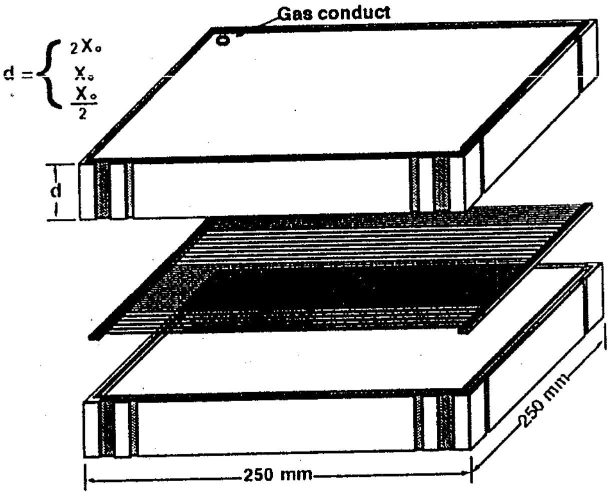
(finer segmentations in forward region)



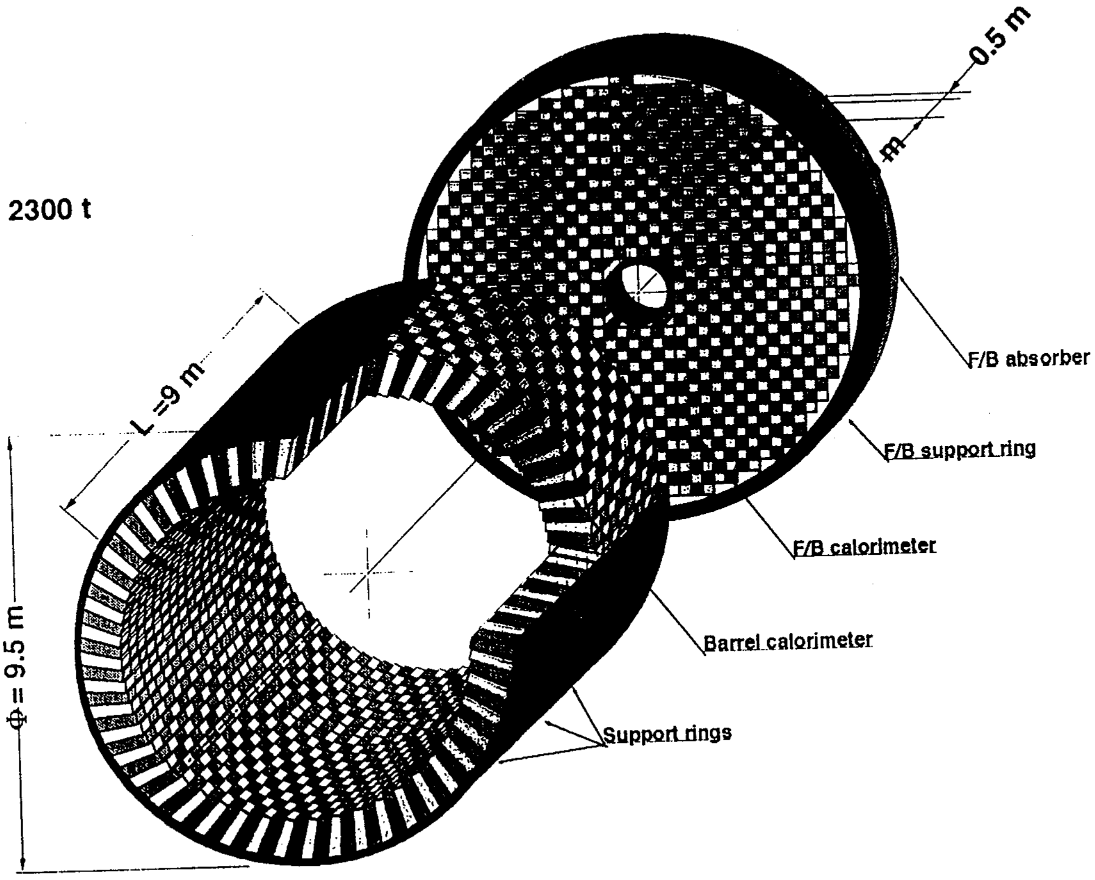
Sampling (like L3)



Sintered brass elements and wire plan



Weight: 2300 t



Sampling Calorimeter

Overall Dimensions	**Inner Radius: 3.75 m** **Outer Radius: 4.75 m** **Length: 11 m** **Weight: 2 300 t**
Number of "bricks"	**5 500**
Readout channels	**120 000**
Absorber	**Brass**
Depth	$50\ X_0$ $4.8\ \lambda$ ($+ 1.7\ \lambda$ with crystals)
Detector	Thin Gap Wire Chambers CF_4 (+Isobutan) 3 mm Gap 2 mm Wire Spacing
Energy Resolution electromagnetic	$\sim \frac{25\ \%}{\sqrt{E}} + < 3\%$
hadronic	~ 13% at 100 GeV (without Crystals)

German HEP Institutions Request
to the
BMFT

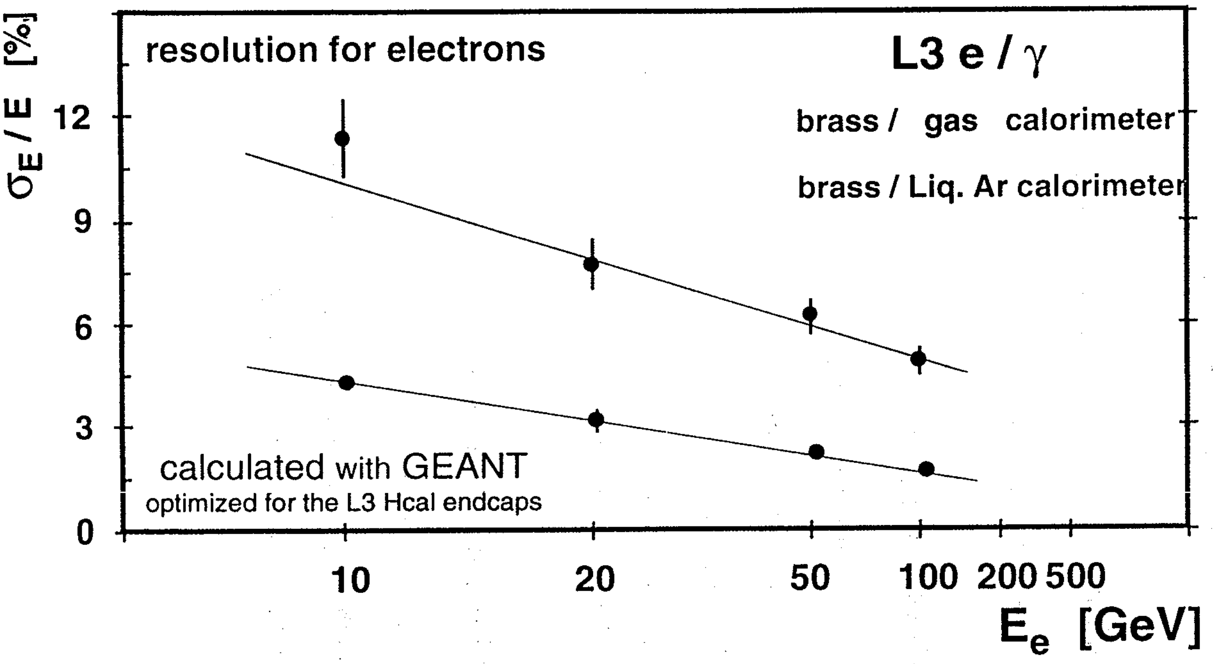
Thin-Gap Flüssig-Argon Kalorimeter

Vorhabenbeschreibung:

Gesamtziel des Vorhabens ist Entwicklung , Bau und Test des Prototyps (elektromagnetischer Teil) und des kompletten Kalibrationsmoduls (elektromagnetischer und hadronischer Teil) eines Flüssig-Argon Kalorimeters mit extrem dünnen Detektorgap (0.4mm) und in den kalten Detektor integrierter ´front-end´ Elektronik.

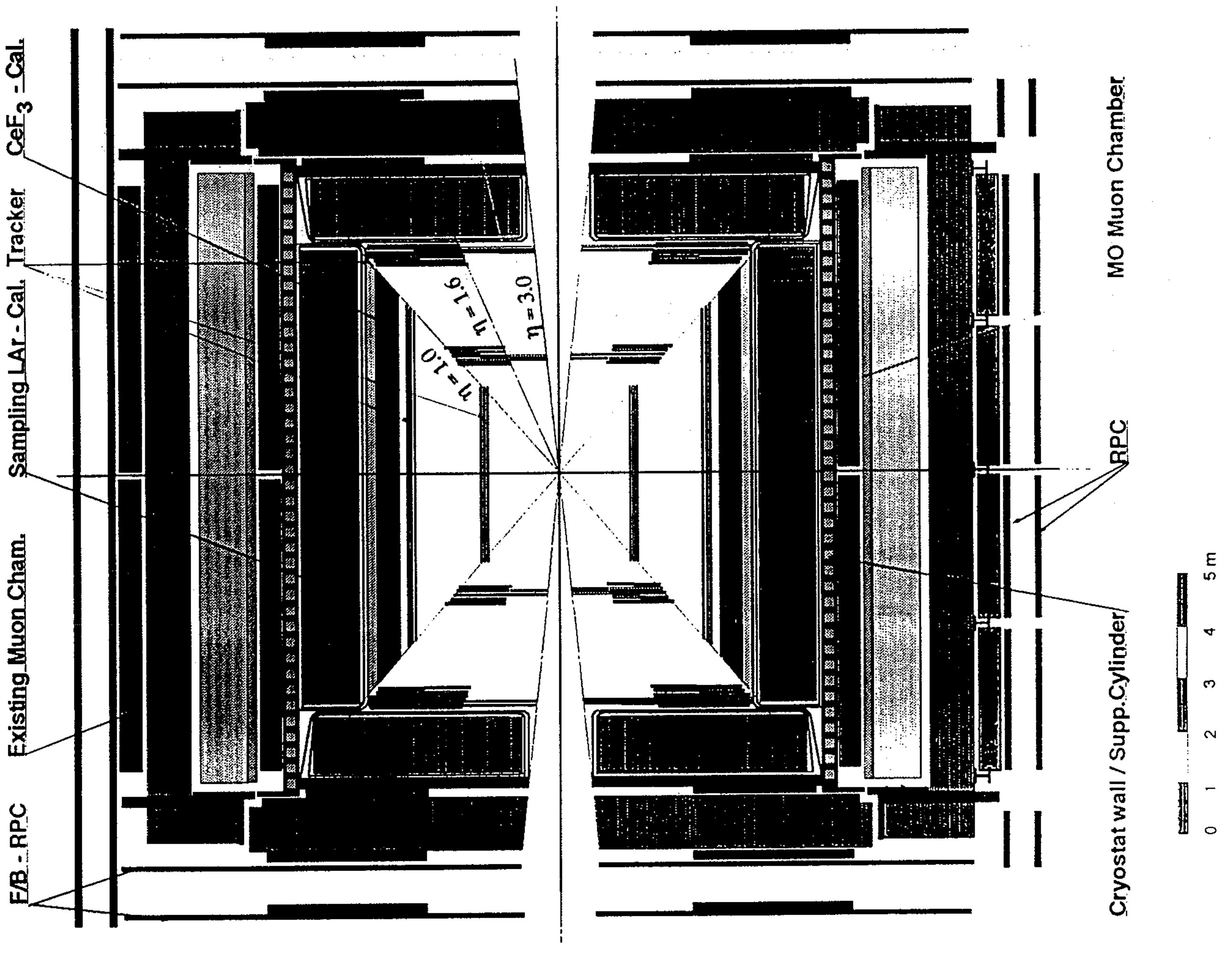
Zur Zeit sind an diesem Projekt folgende Hochenergiephysik Institute beteiligt:

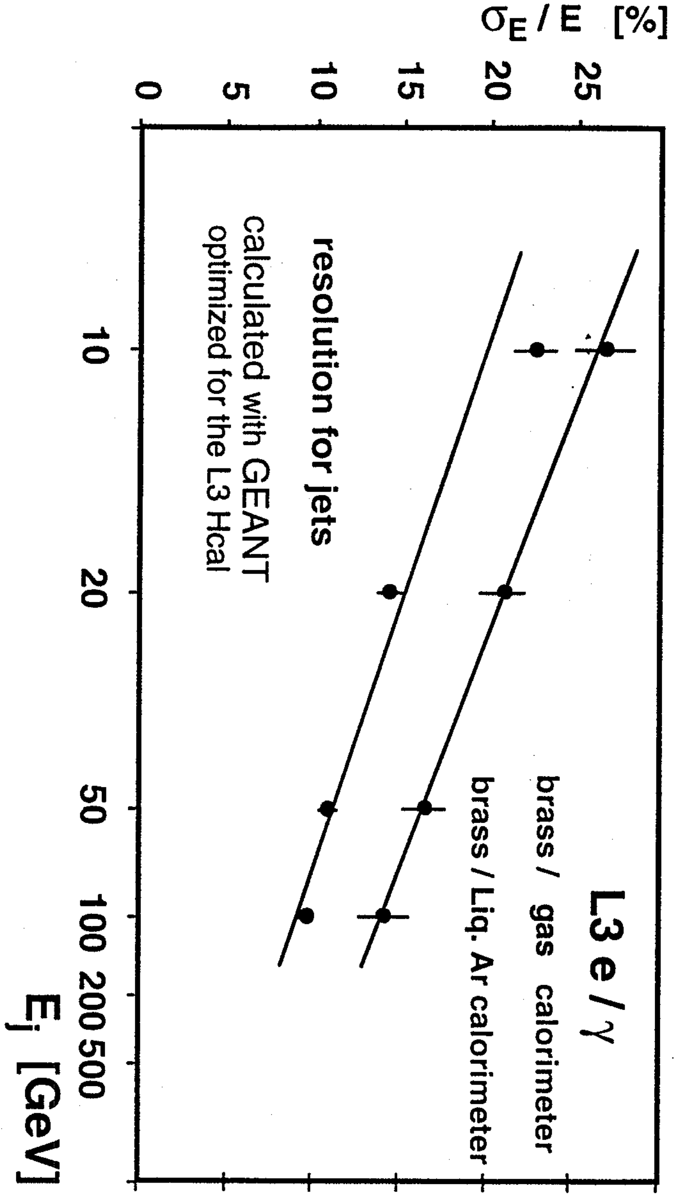
- I. Physikalisches Institut der RWTH Aachen
  (*Ch . Berger, W. Braunschweig, K. Lübelsmeyer, W. Wallraff*)
- Max Planck Institut für Physik und Astrophysik München
- Institut für Hochenergiephysik der Universität Heidelberg



μ - e - γ - Detector Version for LHC

LAr Option Phase 2





Muon System

Clean identification of muons over rapidity range $|\eta| < 3$.

It consists of two types of detectors:

1. L3 Muon Chambers

- position resolution = 30 µm.
- angular resolution 1.8 mrad.
- drift time ≈ 1 µsec.
- one layer inside the solenoid, a second layer outside of the magnet return yoke.

2. Resistive Plate Chambers

- Pulse rise time few nsec.
- Two double layers outside the magnet return yoke.
- Used in the L3 upgrade for LEP200.

Performance of the Muon System

Muon Trigger:

- Level-1:
  Di-muon trigger requires two reconstructed RPC tracks.
- Level-2:
  Improved muon p_T measurement using the L3 muon chambers.

Muon Reconstruction:

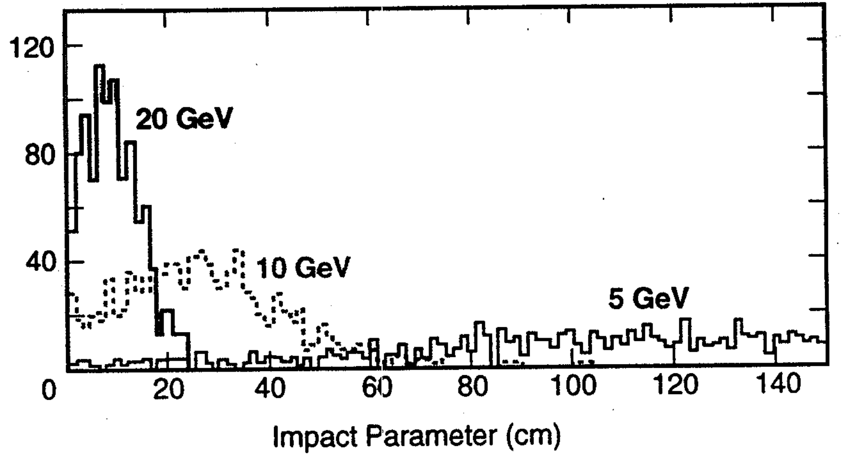
- Outer muon system: Clean identification of muons after 15 λ.
- The inner tracker: precise momentum measurement ($\Delta p_T / p_T = 3.0\%$ at $p_T = 100$ GeV)
- The outer system provides an independent momentum measurement ($\Delta\ p/p \approx 30\%$). Important to reject decay and punch through background.

Trigger Efficiency

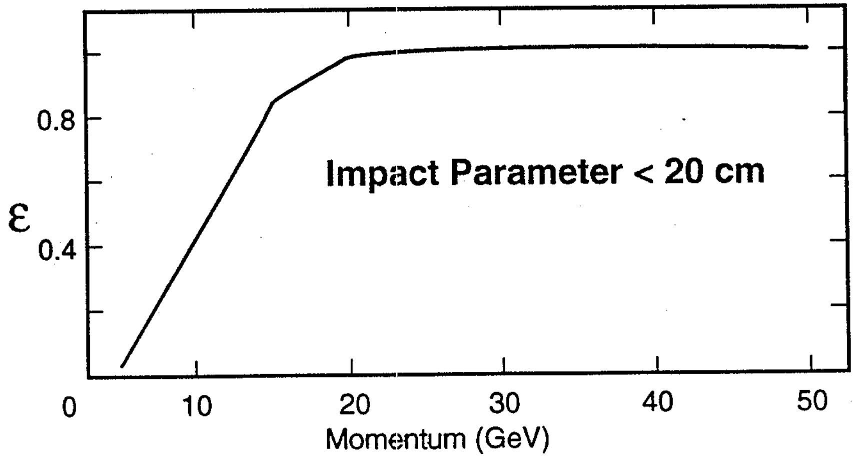
The level-1 trigger requires two RPC tracks pointing to the interraction region.

Measurement of Impact parameter → p_T measurement

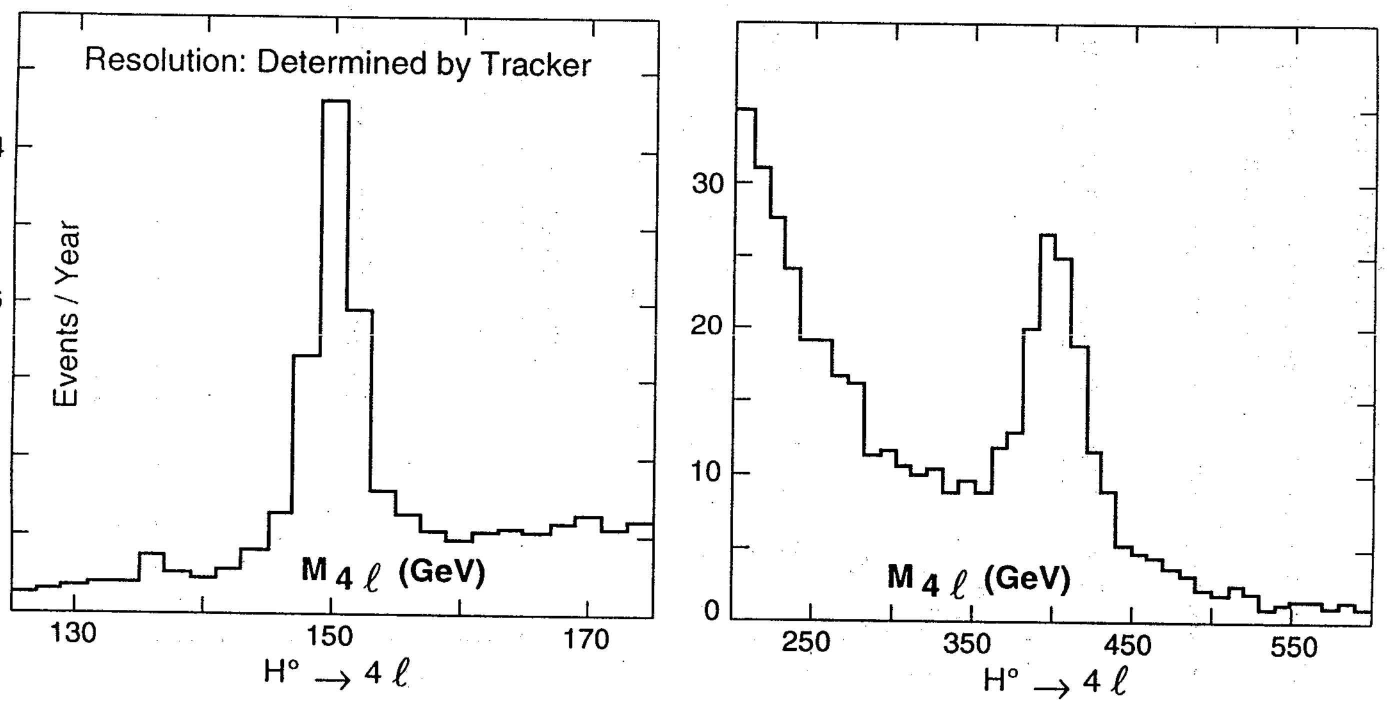
Reconstructed Impact Parameter from RPC



Trigger efficiency



Phase I: $\mathcal{L} = 1.65 \times 10^{33}$ cm^{-2} sec^{-1}



154/1.3.92

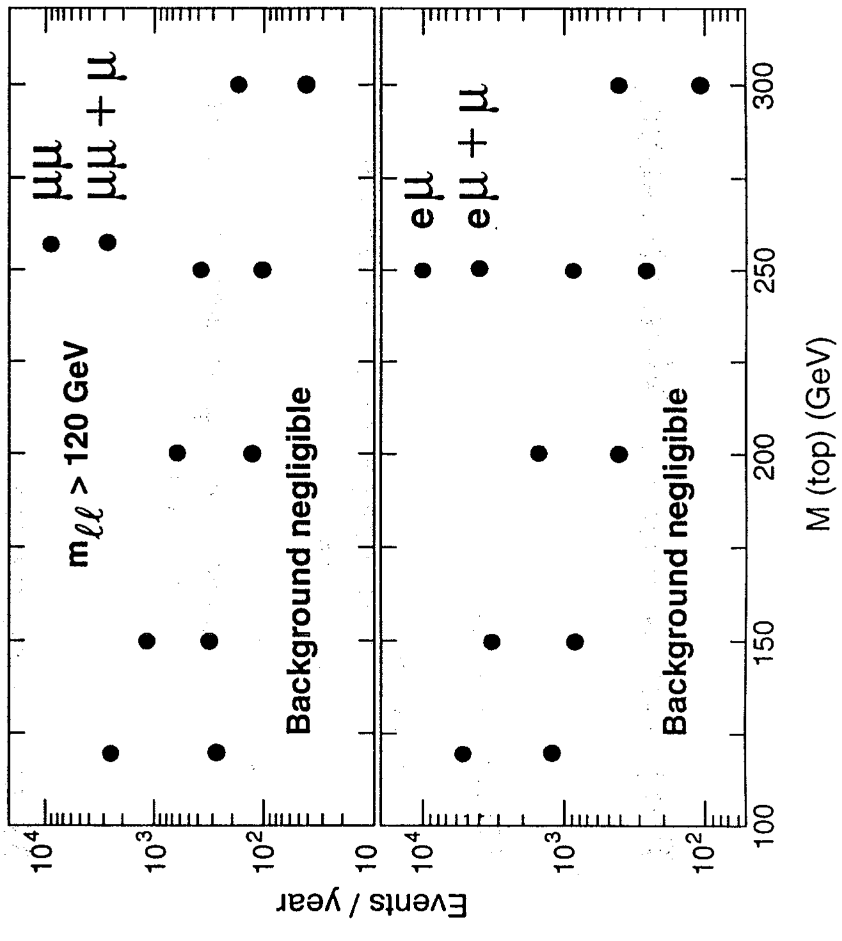
Physics of Phase I e, γ Detector

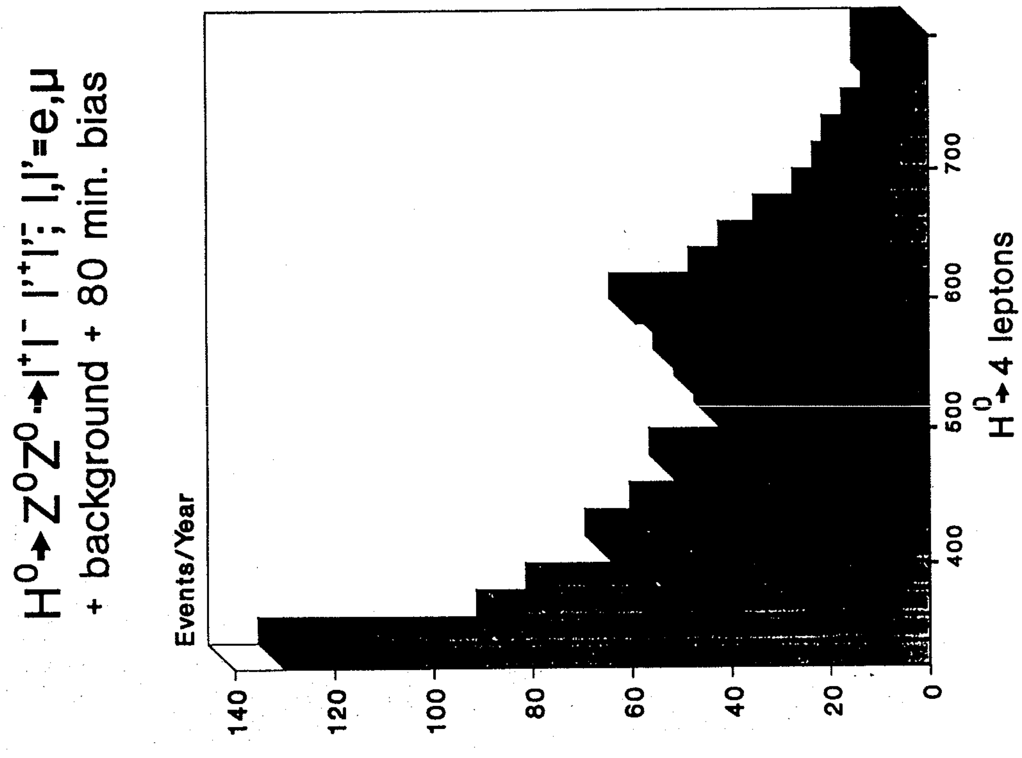
$\mathcal{L} = 10^{32}$ cm^{-2} sec^{-1}

Search for New Quark

$pp \rightarrow t\bar{t}$ W b → ℓν, W b → ℓν

η < 1.6
pt > 50 GeV
Ecal (R = 0.4) < 5 GeV
Δ (φ) ≈ 20, 160



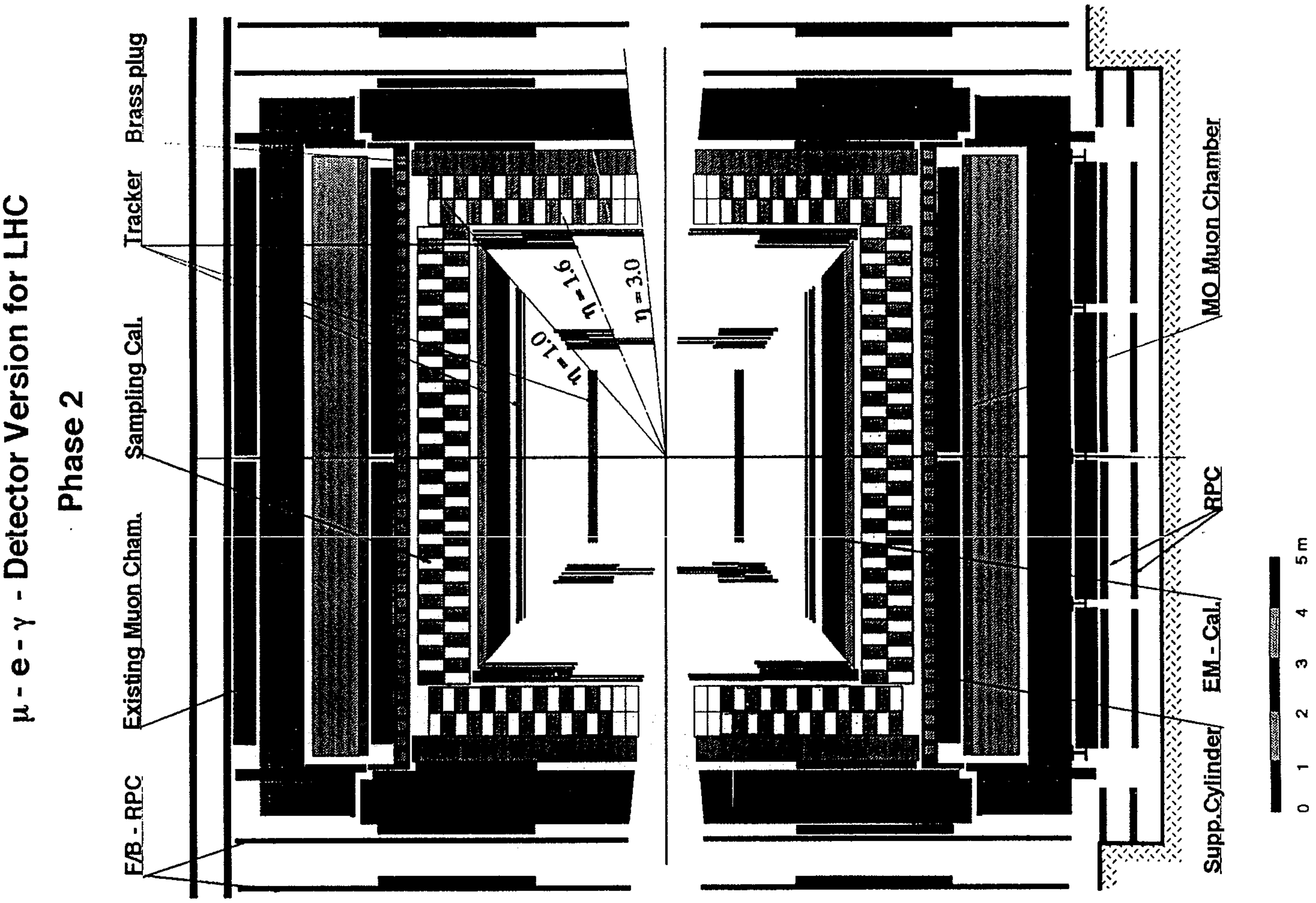


L3 at LHC

μ, e, γ Version

Phase I

$H^O \Rightarrow 4\ \ell$ at 1.65×10^{34} cm $^{-2}$ sec $^{-1}$



L3 at LHC

μ, e, γ Version
Phase II

(Cost ≈ 100 MSFr.)

at 1.65 x 10^{34} cm^{-2} sec^{-1}

Add Crystals in $|\eta| < 1.0$

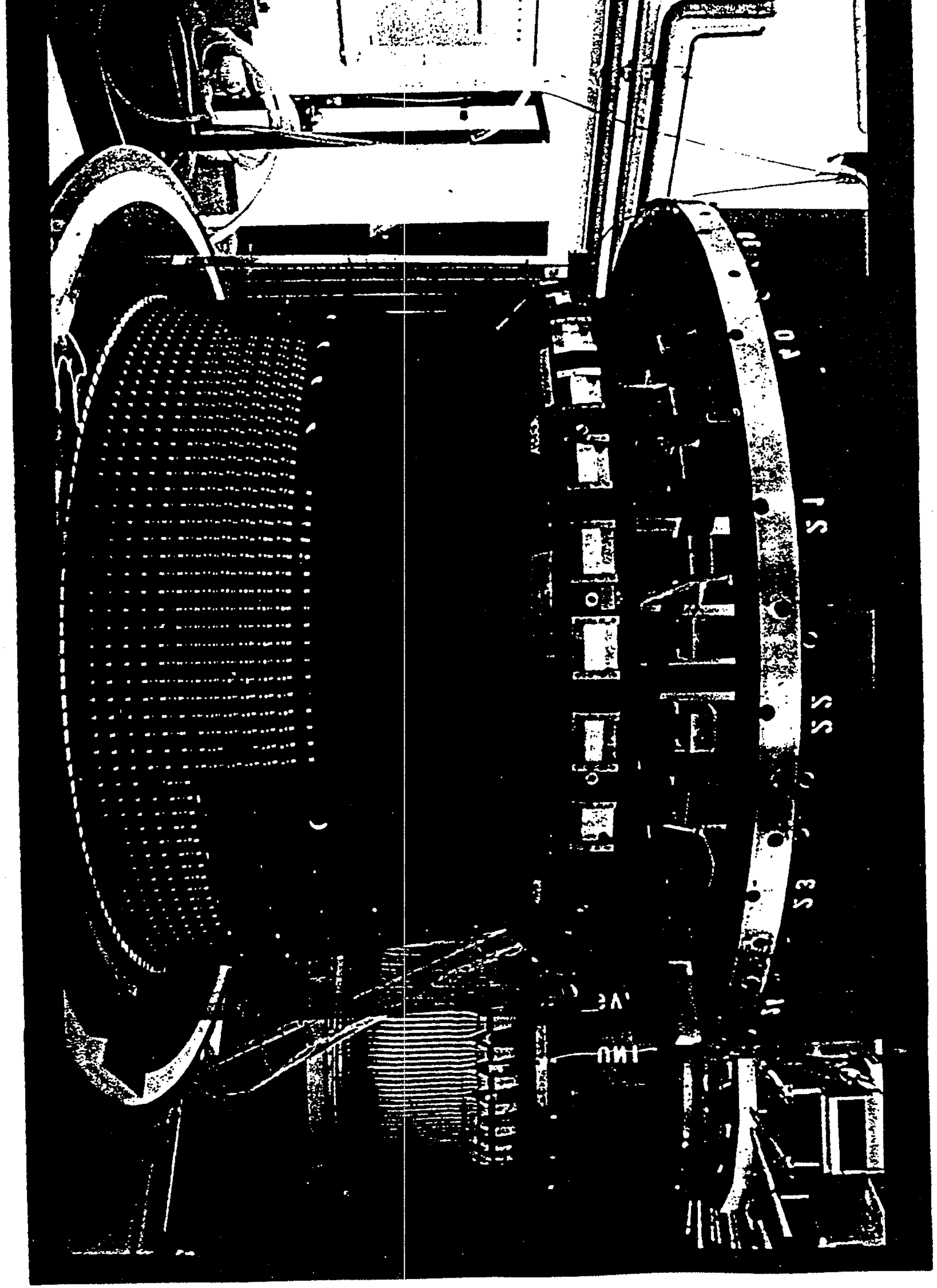
Measure e, γ precisely

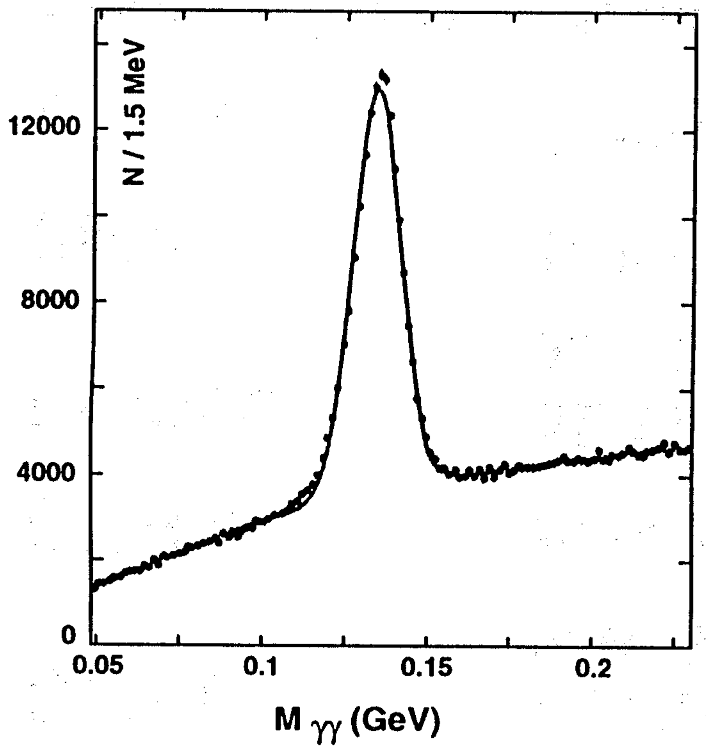
$H_0 \rightarrow \gamma\gamma$

BGO

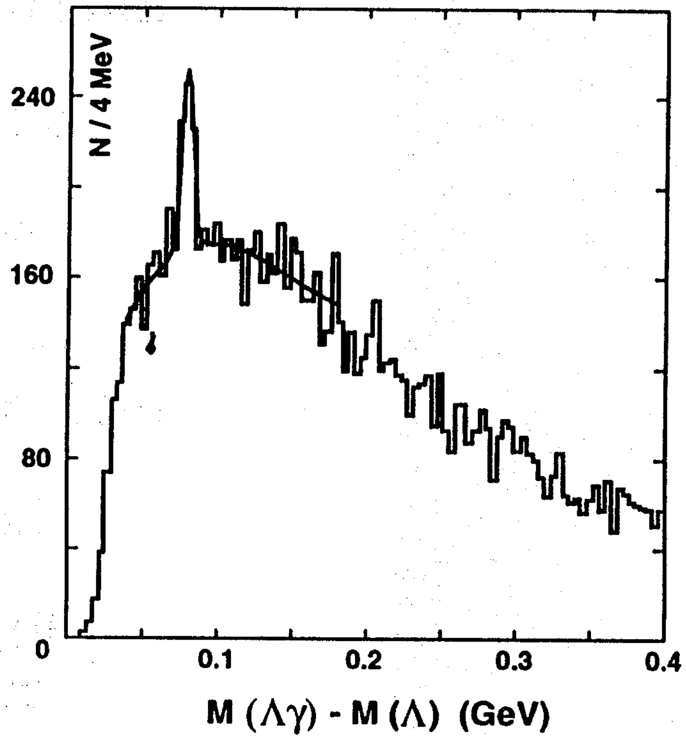
Electromagnetic Calorimeter

China	D.S. Yan Z.W. Yin
CERN	P. Lecoq
France	M. Vivargent J.P. Burq
Italy	B. Borgia
U.S.A.	P. Piroue
Switzerland	M. Bourquin R. Weill
Germany	D. Schmitz
Holland	R. Van de Walle

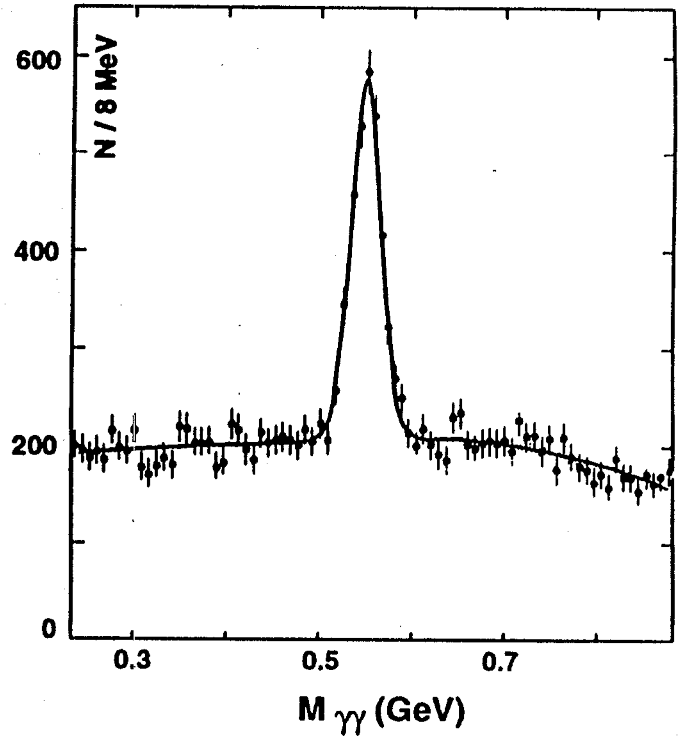




π°, $\sigma = 7$ MeV



Σ°; $\sigma = 4$ MeV



η, $\sigma = 16$ MeV

R & D

To produce high quality dense radiation resistant crystals for Hadron Colliders at the lowest price

1. **At the Shanghai Institute of Ceramics (SIC) in collaboration with E.T.H.**
2. **At the Institute of Solid State Physics (Chernogolovka), in collaboration with M.I.T.**
3. **In 20 crystallographic firms in the world, coordinated by the Crystal Clear Collaboration :**

   13 Institutes (5 from L3) with *P. Lecoq, M.Schneegans, J.P. Burq, D. Schmitz , B. Borgia and others.*

Crystals from China

At present, CeF_3 crystals are fulfilling the physics specifications for the e/γ electromagnetic spectrometer

The present price for CeF_3 crystals is of the order of 10 US\$/cm^3

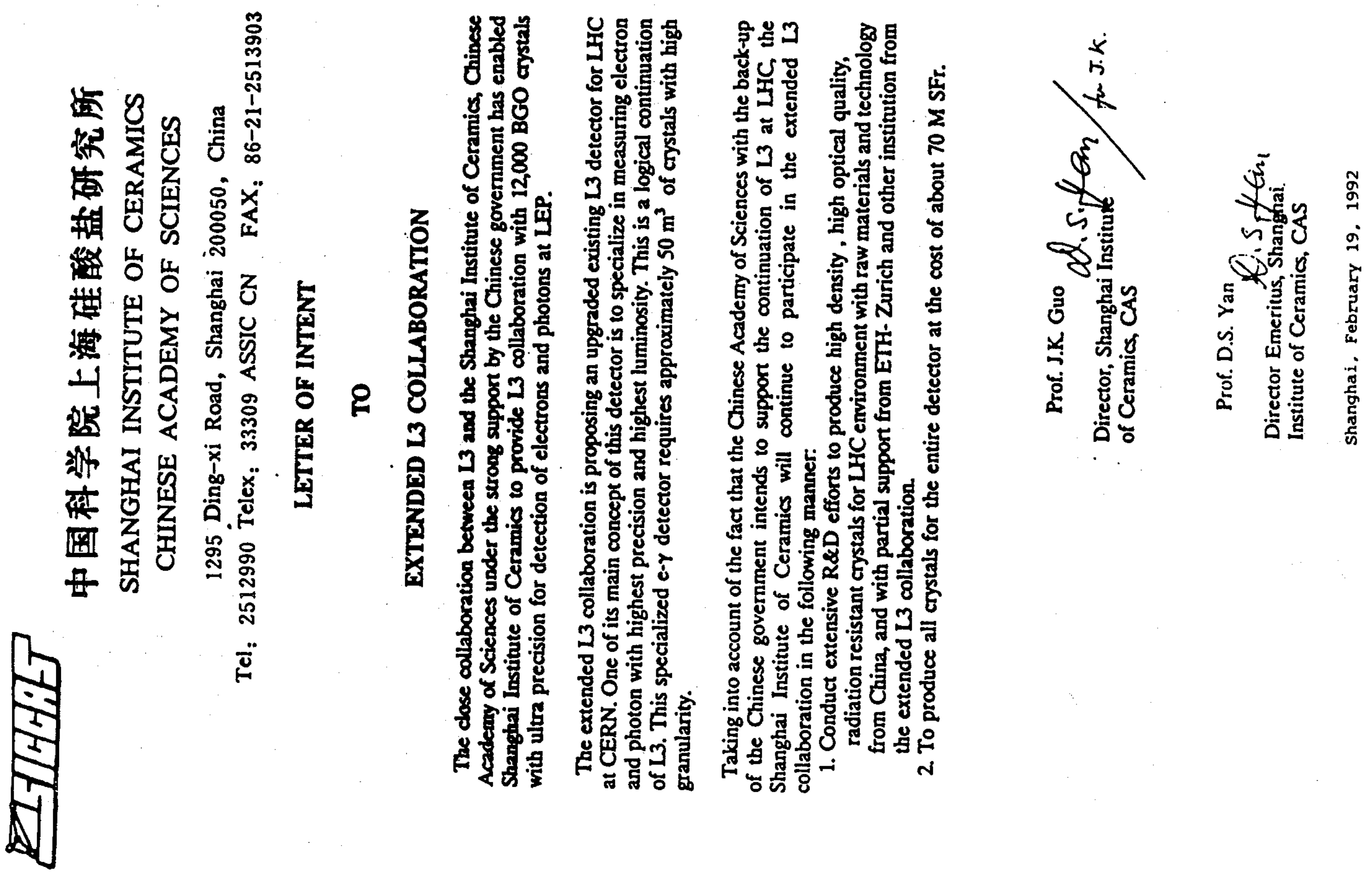
The following progress allows the Shanghai Institute of Ceramics (SIC), together with the other institutions with the strong support of the Chinese Government, to produce 50m^3 of crystals for the entire electromagnetic calorimeter e/γ detector for a total price of 70 MSfr.

1. L3 agreements with the following Chinese institutions to carry out research programs to develop new crystals :
   - Institute of Crystal Materials, Shandong University, Jinan
   - Department of Materials Science and Engineering, Zhejiang University, Hangzhou
   - Shanghai Institute of Ceramics, Shanghai,
2. Infrastructure and experience to produce large amounts of crystals already available at SIC (partially from mass production of L3 BGO)
3. China is the world first producer of Cerium oxide and other rare earth materials

Example of
Crystals for μ, e, γ Detector

CeF_3 used for simulation and Mechanical Design

	CeF_3	BGO	Units
Density	6.2	7.1	g/cm^3
Radiation Length	1.6	1.1	cm
Moliere Radius	2.6	2.7	cm
Decay Time Constant of Light	20-30	340.	ns
Total Light *(relative)*	≈ 0.5	1	
Temperature Dependance *(at 20° C)*	< 0.1	-1.4	%/°C



SICCAS
中国科学院上海硅酸盐研究所
SHANGHAI INSTITUTE OF CERAMICS
CHINESE ACADEMY OF SCIENCES
1295 Ding-xi Road, Shanghai 200050, China
Tel: 2512990 Telex: 33309 ASSIC CN FAX: 86-21-2513903

LETTER OF INTENT
TO
EXTENDED L3 COLLABORATION

The close collaboration between L3 and the Shanghai Institute of Ceramics, Chinese Academy of Sciences under the strong support by the Chinese government has enabled Shanghai Institute of Ceramics to provide L3 collaboration with 12,000 BGO crystals with ultra precision for detection of electrons and photons at LEP.

The extended L3 collaboration is proposing an upgraded existing L3 detector for LHC at CERN. One of its main concept of this detector is to specialize in measuring electron and photon with highest precision and highest luminosity. This is a logical continuation of L3. This specialized e-γ detector requires approximately 50 m^3 of crystals with high granularity.

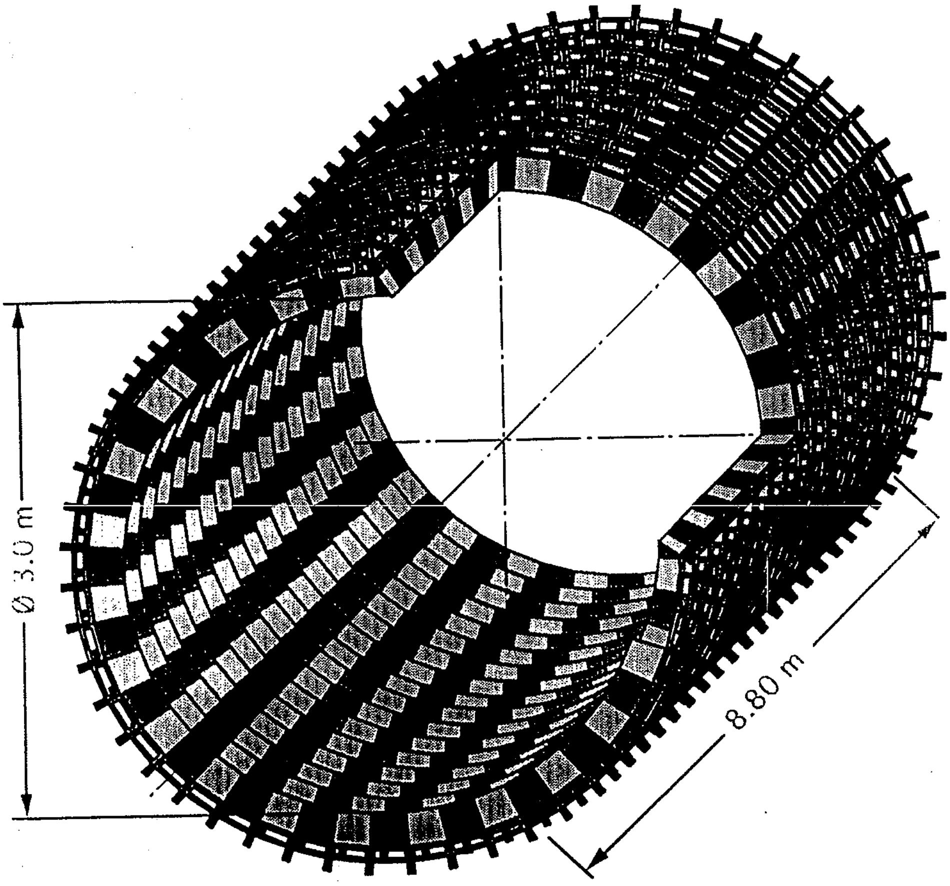
Taking into account of the fact that the Chinese Academy of Sciences with the back-up of the Chinese government intends to support the continuation of L3 at LHC, the Shanghai Institute of Ceramics will continue to participate in the extended L3 collaboration in the following manner:

1. Conduct extensive R&D efforts to produce high density, high optical quality, radiation resistant crystals for LHC environment with raw materials and technology from China, and with partial support from ETH- Zurich and other institution from the extended L3 collaboration.
2. To produce all crystals for the entire detector at the cost of about 70 M SFr.

Prof. J.K. Guo D.S. Yan for J.K.
Director, Shanghai Institute
of Ceramics, CAS

Prof. D.S. Yan D.S. Yan
Director Emeritus, Shanghai
Institute of Ceramics, CAS

Shanghai, February 19, 1992



CeF$_3$ Features

Good mechanical properties → No cleaving
Easy to machine
High production yield

Emission in visible region → No UV reflectors needed
No special windows

Almost no temperature dependance

Good radiation resistance

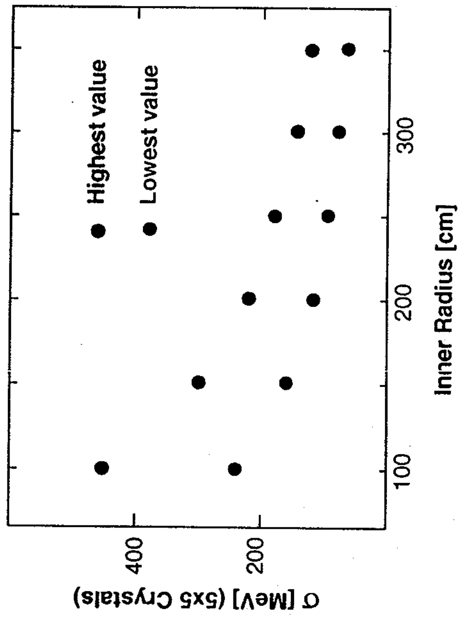
Advantages of Large Radius (I)

Less sensitive to background

Average pile-up energy $\propto 1/R^2$

RMS of pile-up energy $\propto 1/R$

Crystals are 1 Molière Radius



Contribution to mass resolution due to pile-up

$$\delta m/m = 1/2\ \sigma_{PU} \sqrt{(1/E_1^2 + 1/E_2^2)}$$

where E_1 is the energy of the most energetic photon
and E_2 is the energy of the least energetic photon.

For M_H = 100 GeV :

$\delta m/m$ = 0.17% for $\sigma_{PU} \approx$ 100 MeV at R = 3m

Resolution of CeF$_3$ Calorimeter

$$\frac{\sigma}{E} = \underbrace{\left(\frac{0.94\ \%}{\sqrt{E}} \oplus 0.14\ \% \oplus 0.025\ \%\ \text{x}\,E^{\,0.34}\right)}_{\text{Intrinsic to CeF}_3\text{ for 25 }X_0\text{, No walls}} \oplus \underbrace{\underbrace{\frac{100\ \text{MeV}}{E}}_{\text{Noise}} \oplus \underbrace{\frac{100\ \text{MeV}\,\text{x}\ f}{E}}_{\text{Pile up}} \oplus \underbrace{0.5\ \%}_{\text{Calibration}}}_{\text{Specific to e}/\gamma\text{ Detector Design}}$$

To reduce Noise : Need low capacitance readout: (phototriode → 20 MeV/Crystal)

→ low magnetic field

To reduce Pile up : Average pile up £ $\frac{1}{R^2}$

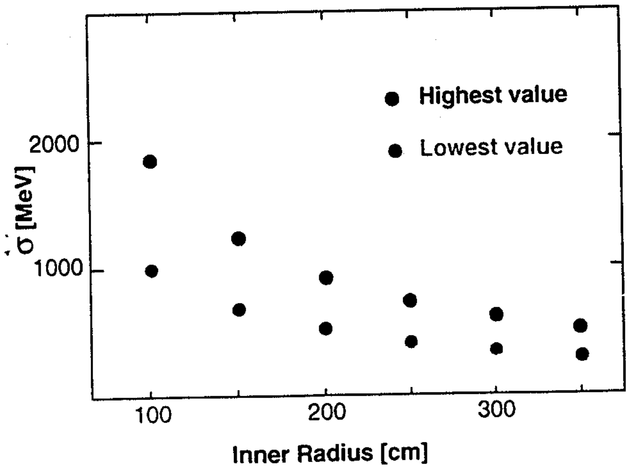
→ Place Crystals far away from Vertex

Advantages of Large Radius (II)

Each crystal covers very small solid angle

Cleaner isolation cuts
Better π° rejection

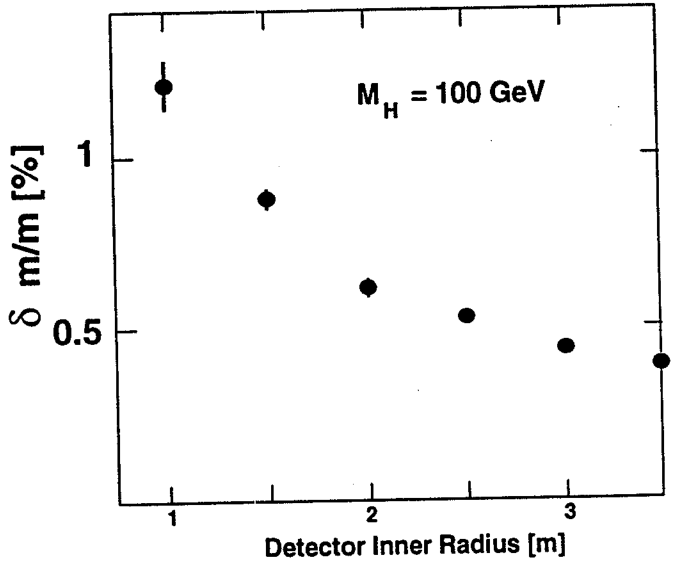
Pile up in crystal
and
sampling calorimeter in 8 Molière Radii



Advantages of Large Radius (III)

Photon pointing not needed

δM/M for 100 GeV Higgs
due to 5.7 cm Vertex uncertainty



Therefore position detector not necessary at R = 3m,

$$\frac{\delta m}{m} = 0.5\%$$

Advantages of Large Radius (IV)

Reduce raw trigger rate
Easier isolation cuts

Trigger Summary

Detector at large radius → Lower background rates

Jet Trigger Rates

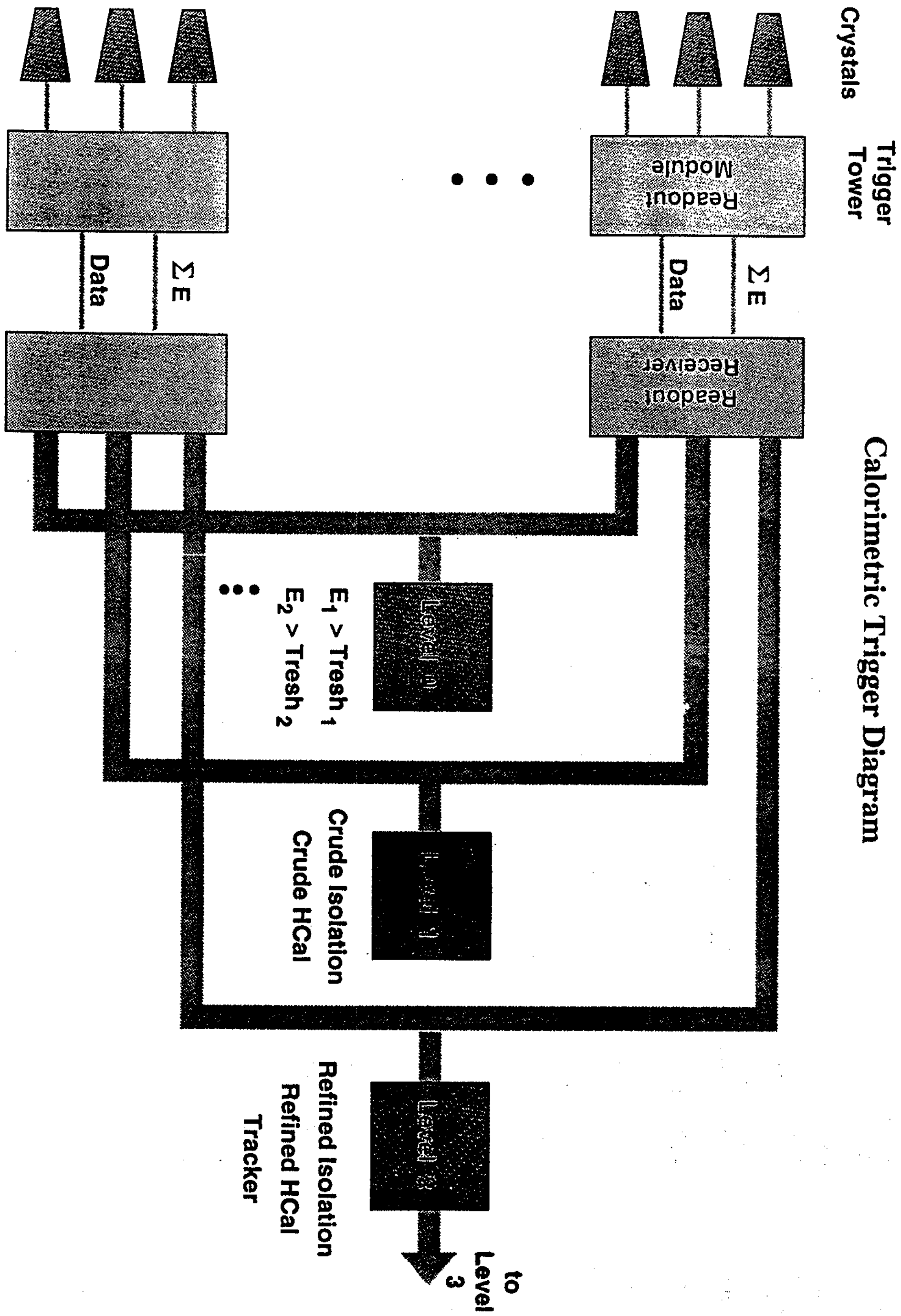
	Level 0	Level 0 + 1	Level 0 + 1 + 2
≥ 1 Hit > 10	100 000 Hz	50 000 Hz	6 000 Hz
≥ 2 Hit > 10	3 500 Hz	400 Hz	< 1 Hz
≥ 1 Hit > 20	15 000 Hz	3 000 Hz	600 Hz
≥ 2 Hit > 20	200 Hz	4 Hz	≈ 0 Hz
≥ 1 Hit > 30 *	3 000 Hz	700 Hz	250 Hz
1 Hit > 20 & 1 Hit > 30	100 Hz	3 Hz	≈ 0 Hz

* For in-situ electron calibration

Higgs Trigger Efficiencies

	Level 0	Level 0 + 1	Level 0 + 1 + 2
+ 19 Min Bias	97.5%	96.5%	94.0%
+ 38 Min Bias	98.1%	94.8%	90.4%

Calorimetric Trigger Diagram



In Situ Calibration

For a calibration error of ε (%) the number of events needed at energy E is

$$\varepsilon^2 = [\, (\sigma_{EM}/E)^2 + (\delta\, p/p)^2 + (\sigma_{PU}/E)^2\,] / N$$

where σ_{EM}/E is the resolution in the crystals,

δ p/p is the momentum resolution of the tracker

σ_{PU}/E is the contribution from pile up

Crystals : $\sigma_{EM}/E = 1\%$ for Σ_9 and $\sigma_{EM}/E = 0.5\%$for Σ_{25}

Tracker : δ p/p = 3% at 100 GeV

Thus, to calibrate with an accuracy of ε = 0.3% at 50 GeV requires about 40 events/crystal (Σ9) and about 30 events/crystal (Σ25)

Advantages of Low Field

Low capacitance readout ⇒ Low Noise

BGO : All charge integrated in << 1 bunch crossing

Si photodiode read-out ⇒ ≈ 1 MeV Noise

(agrees with theoretical limit)

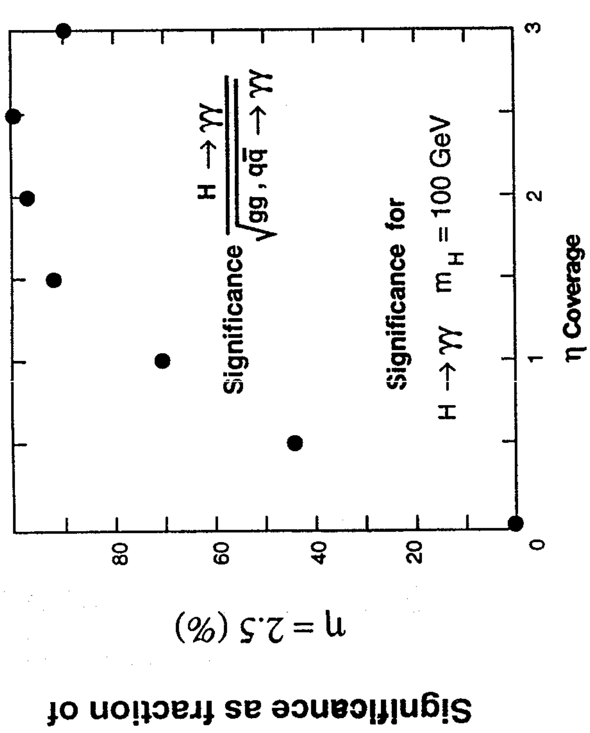
CeF3 : Cannot integrate all charge in 1 bunch crossing

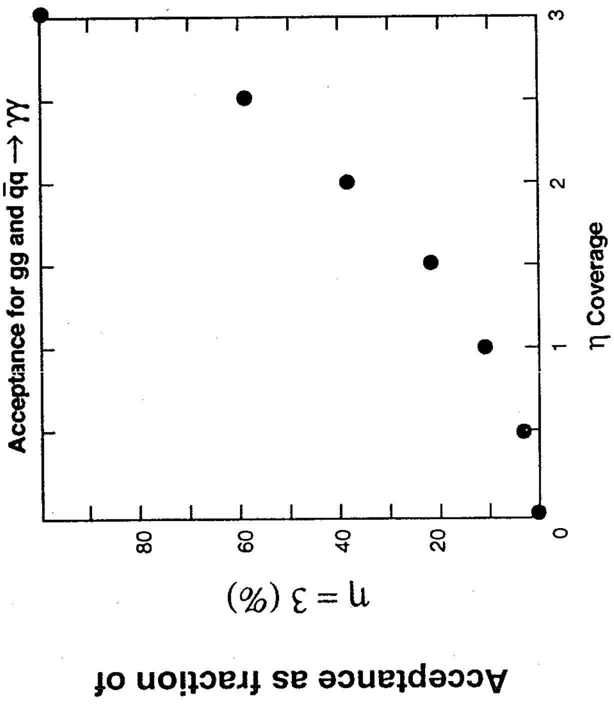
Si Photodiode read-out ⇒	80 - 340 MeV Noise
Vacuum Photodiode ⇒	5 - 20 MeV Noise
Vacuum Phototriode ⇒	2 - 15 MeV Noise

Low Field ⇒ Vacuum photodetector possible

- We assume 20 MeV of 100% uncorrelated noise for calculations (because we expect <20 MeV of uncorrelated noise, but some correlated noise)

Choice of Crystal η Coverage (I)





In Situ Calibration

The cross-section for isolated $e^{\pm}$ from W,Z → $e^{\pm}$ + X in $|\eta| < 1$ is

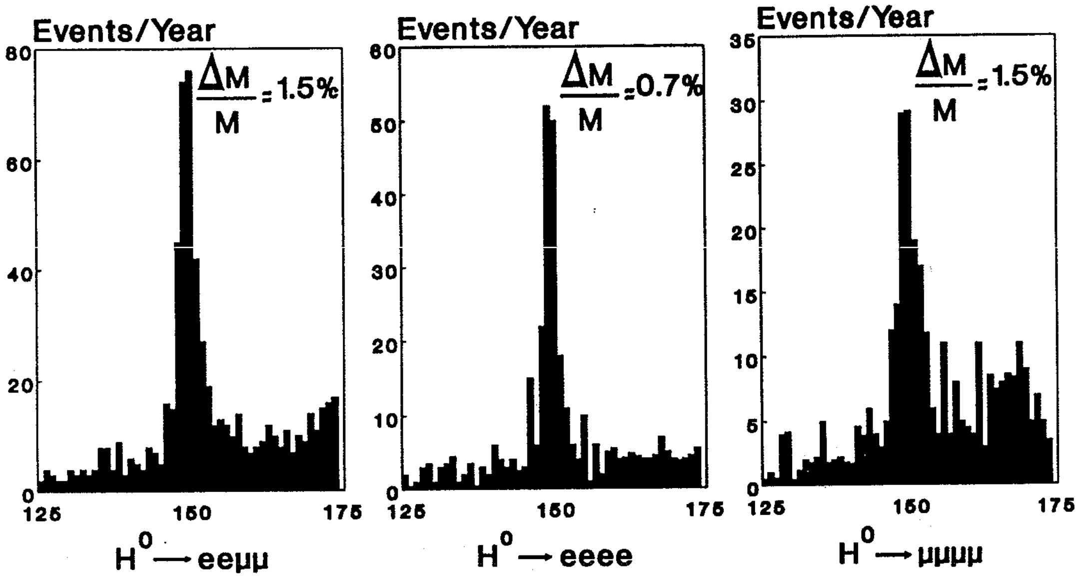
5 nb for $p_T > 30$ GeV
600 pb for $p_T = 50 \pm 6$ GeV

Calibration monitoring to an accuracy of
$\varepsilon = 0.3\%$ at $E = 50 \pm 6$ GeV
can therefore be performed on the entire detector

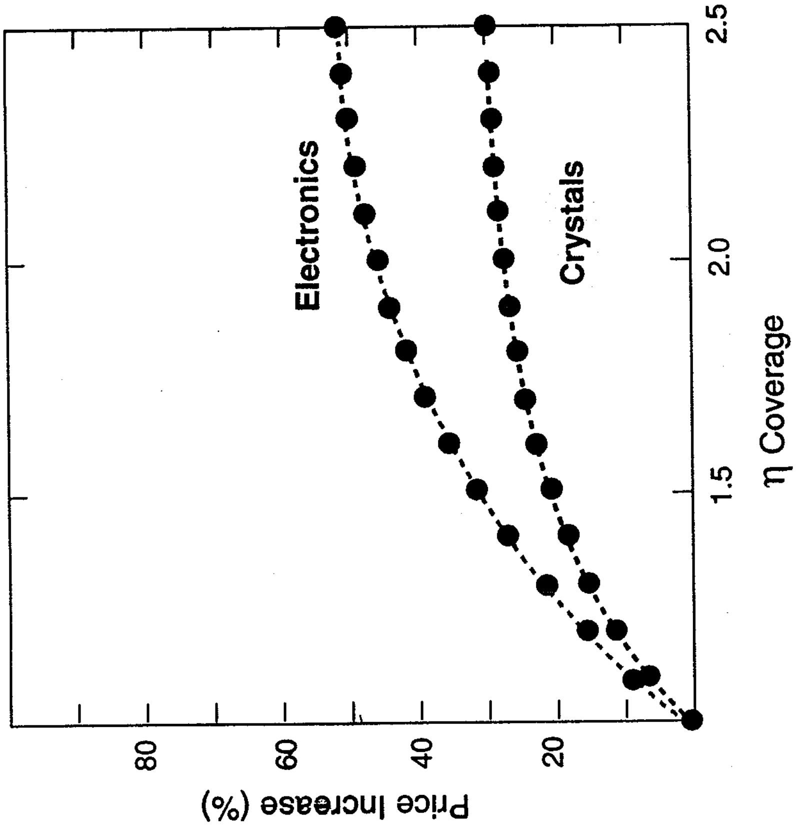
1-2 times per year (10^7 s) at $L = 10^{33}$
30 times per year at $L = 2 \times 10^{34}$

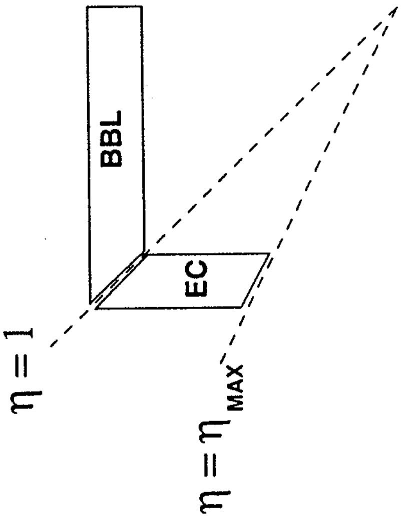
$H^0 \rightarrow Z^0 Z^0 \rightarrow l^+ l^- l'^+ l'^-$

+ background + 80 Minimum Bias



Choice of η Coverage (II)





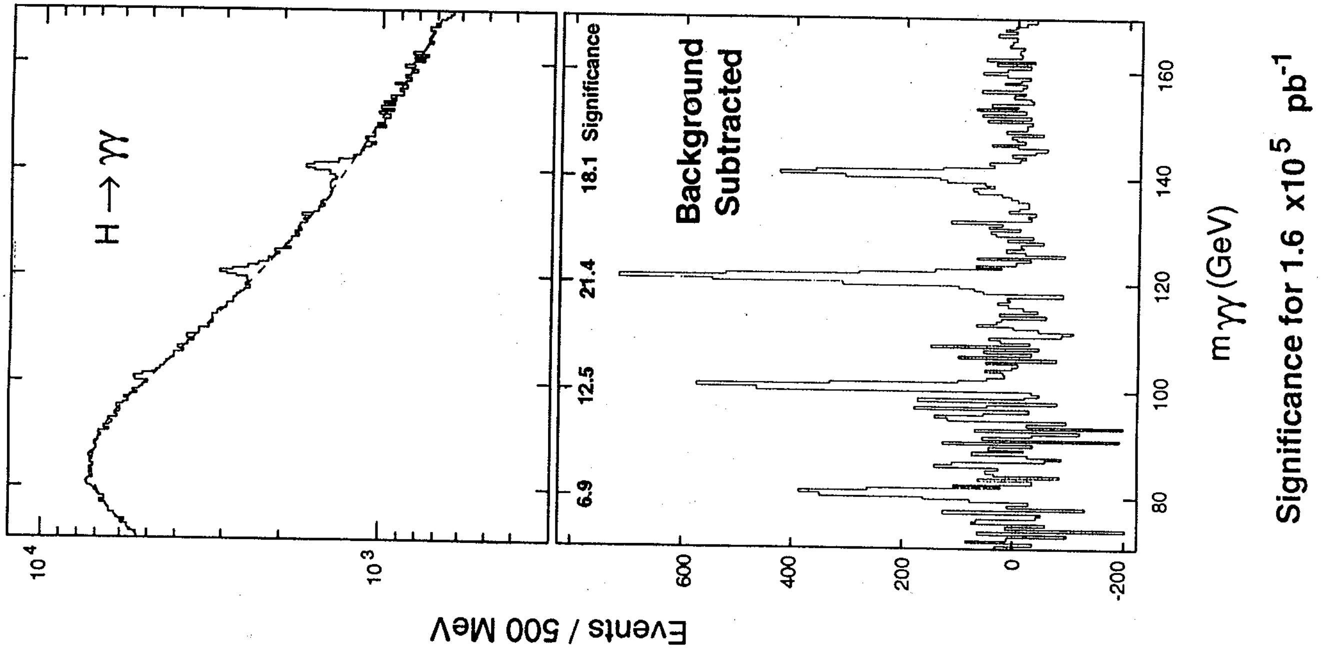
143/29.2.92

Cost of Specialized Electron/Gamma Detector

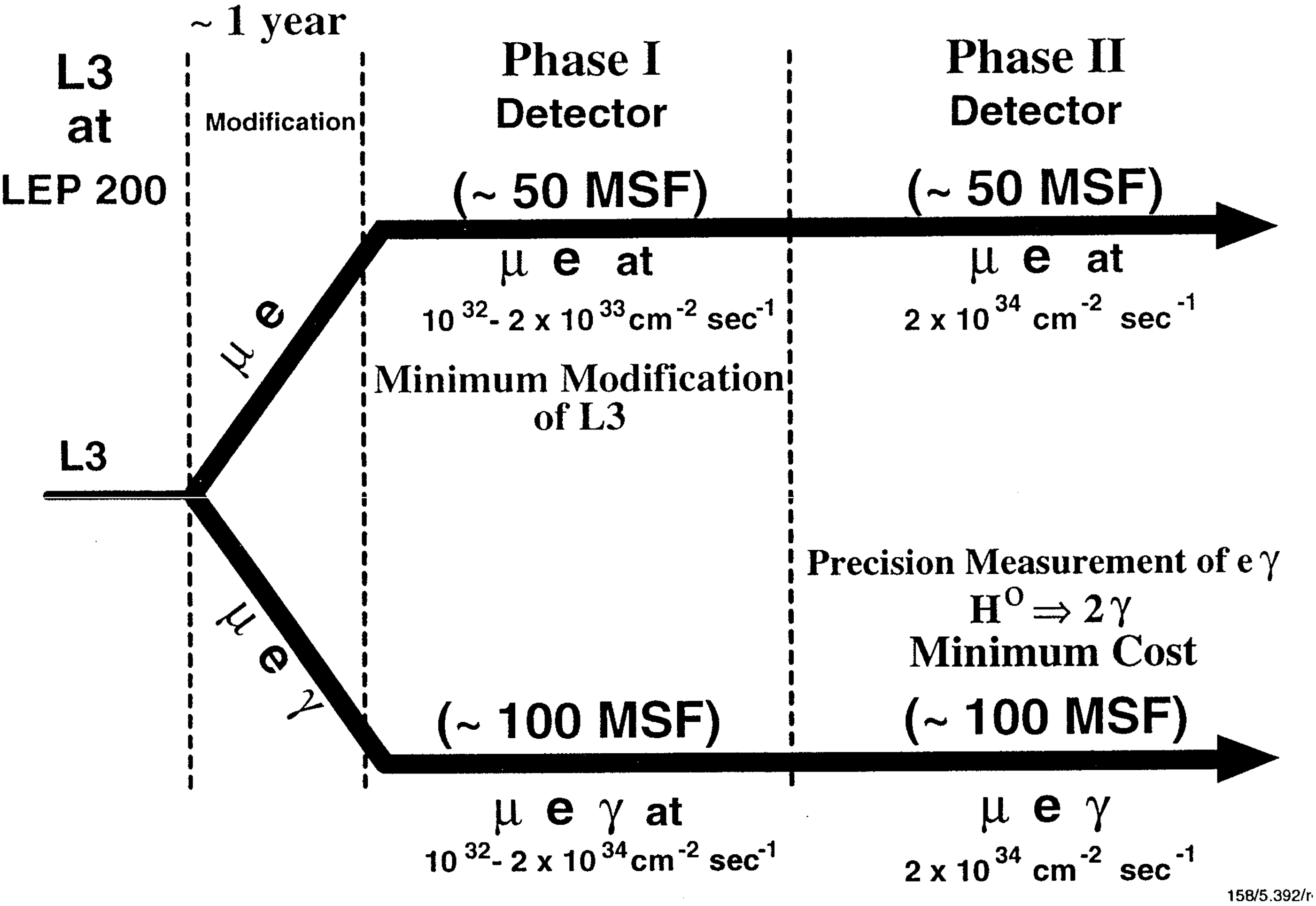
(in 1992 KSF)

Elements	Total Cost Detector Phase I + Phase II	Existing from L3	Additional Cost Phase I	Additional Cost Phase II
Magnet (including Installation)	65'000	65'000	-	-
Magnet lifting	-	-	7'000	-
Detector specific infrastructure	34'000	34'000	-	-
Installation without Electromagnetic calorimeter	4'500	-	4'500	-
Installation with Electromagnetic calorimeter	+ 1'500	-	-	1'500
Muon Detector (→ 22°) including support & installation	66'000	65'000	1'000	-
Sampling Calorimeter	34'000	-	34'000	-
RPC Chambers & support	3'400	-	3'400	-
Support tube	5'000	-	5'000	-
Electromagnetic Calorimeter	99'500	-	-	99'500*
Tracker	56'500	-	56'500	-
Racks + cooling & Counting room installation	2'700	1'700	800	200
On- and Off-line computers	26'800	26'800	-	-
Total Cost	398'900	192'500	112'200	101'200

* Crystals from China



Pauss26-27/2.3.92



~ 1 year

L3
at
LEP 200

Modification

Phase I
Detector

Phase II
Detector

(~ 50 MSF)

(~ 50 MSF)

μ e at
10^{32}- 2 x 10^{33} cm^{-2} sec^{-1}

μ e at
2 x 10^{34} cm^{-2} sec^{-1}

μ e

Minimum Modification of L3

L3

Precision Measurement of e γ
$H^{O} \Rightarrow 2\gamma$
Minimum Cost

μ e γ

(~ 100 MSF)

(~ 100 MSF)

μ e γ at
10^{32}- 2 x 10^{34} cm^{-2} sec^{-1}

μ e γ
2 x 10^{34} cm^{-2} sec^{-1}

158/5.392/r

We are now planning to perform specialized and precise LHC experiments

after the completion of the full LEP 200 program and of the future LEP upgrades.

We intend to use much of the existing L3 detector, electronics & infrastructure

together with new additions based on the results of our R&D efforts.

The spirit of these upgrades is that they should be simple enough so that they can be quickly implemented in L3

and be ready at LHC turn on with moderate additional resources.

The designs emphasize running at the highest LHC luminosities.

F. Pauss

PHYSICS SIMULATIONS

Results for both Detector Concepts

EXAMPLES OF PHYSICS TOPICS

- Top: $t\bar{t} \rightarrow 2\ell + X,\ 3\ell + X$
- Standard Model Higgs: $H \rightarrow 4\ell$
  $H \rightarrow \gamma\gamma$
- $Z' \rightarrow \ell^+\ell^-$
- Supersymmetry: $h^0 \rightarrow \gamma\gamma$
- Toponium: $O^{-+} \rightarrow \gamma\gamma$

Illustrate particular strong points for two detector concepts:

μe-Detector:

$$H \rightarrow 4leptons:\ m_H = 150 GeV$$
$$Z' \rightarrow \mu^+\mu^- :\ m_z = 4 TeV$$

$\mu e\gamma$ Detector: $H \rightarrow \gamma\gamma$

DETECTOR SIMULATION

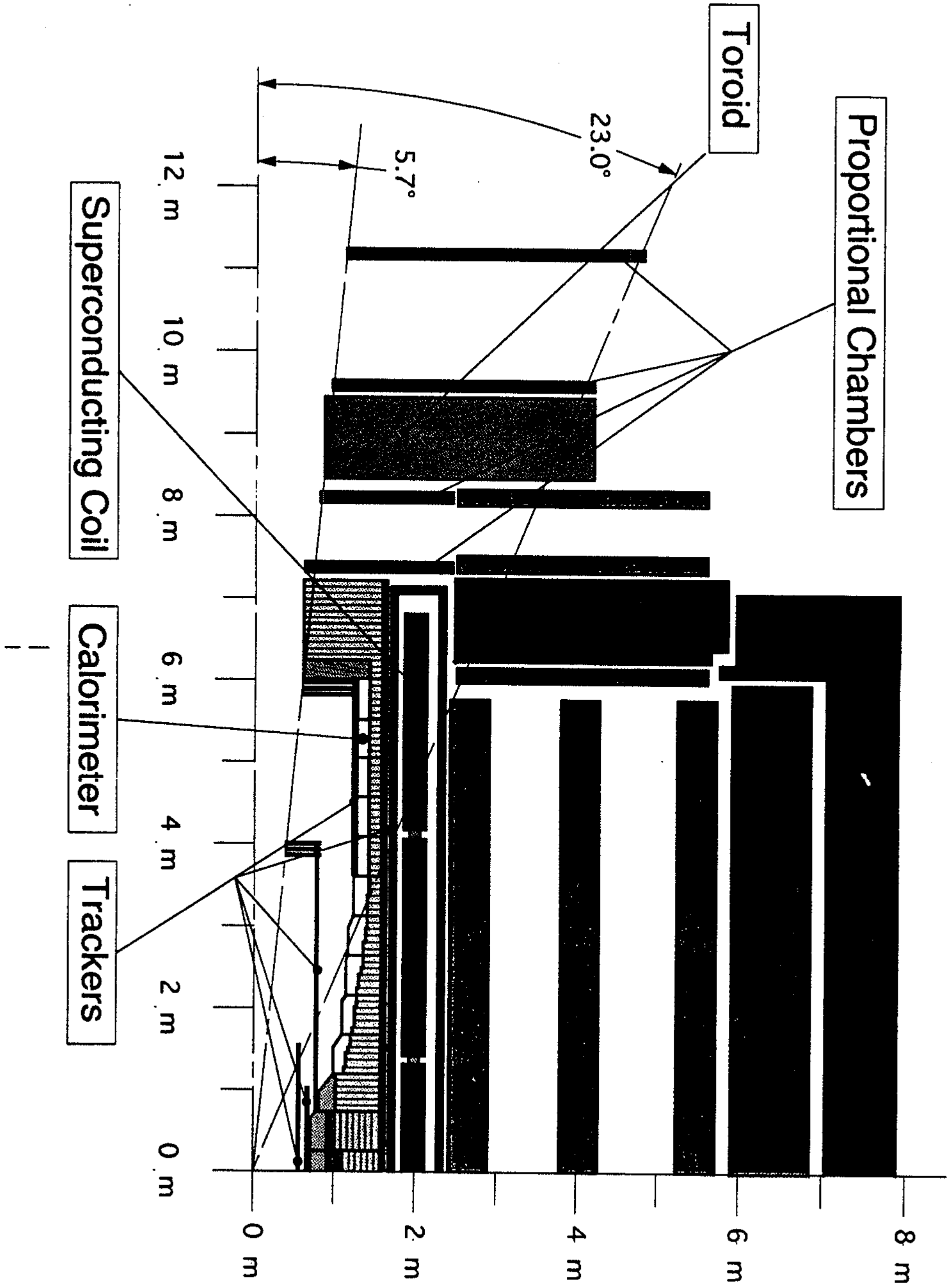
GEANT/GHEISHA

- Energy and momentum resolution
- Effects of B-Field
- Effects of pileup
- Reconstruction efficiencies
- Occupancies
- Particle identification

FAST SIMULATION

- π, k decay in flight
- Parametrization of punchthrough probabilities (obtained from GHEISHA)
- For μe-detector: Fast shower simulation for e,γ,hadrons
  - Longitudinal and transverse shower spread based on L3 test beam data (NIM A288, 1990, 364)
  - Magnetic field effects are taken into account

PHYSICS GENERATOR: PYTHIA (5.5)



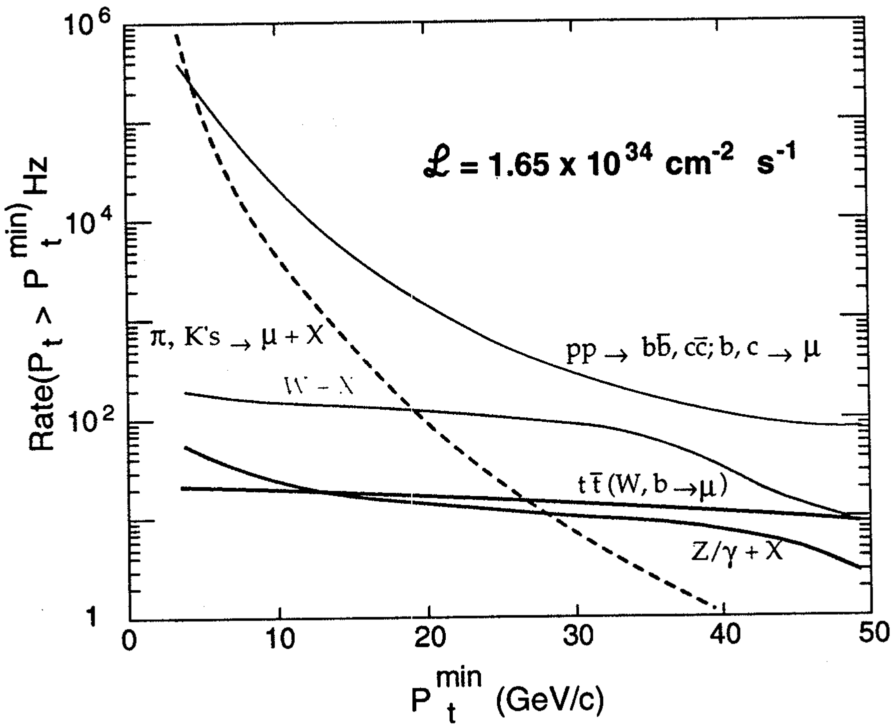
Single Muon Rates

Prompt Muons: pp → $t\bar{t}$ X, $b\bar{b}$ X, $c\bar{c}$ X
pp → Z X, W X, ZZ, WW

Background: π, K decay
punchthrough

Integral Single Muon Rates

For $P_t > P_t^{cut}$ $|\eta| < 3$



Pauss 24/3.3.92

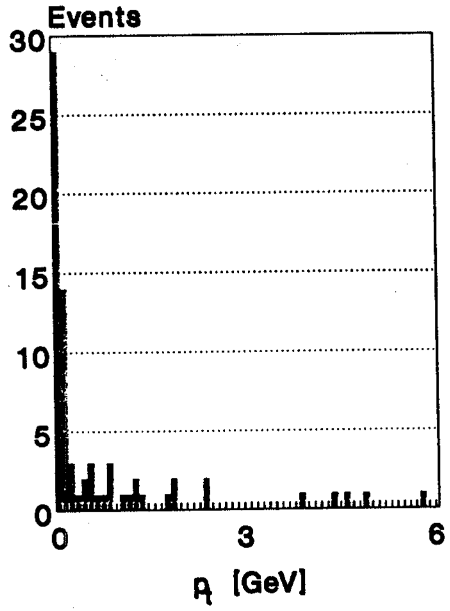
Punch Through Calculation

- 100k PYTHIA events (all processes included)
- **Full GEANT/GHEISHA simulation**
- 73 tracks in the muon chamber barrel, mainly at low p_t

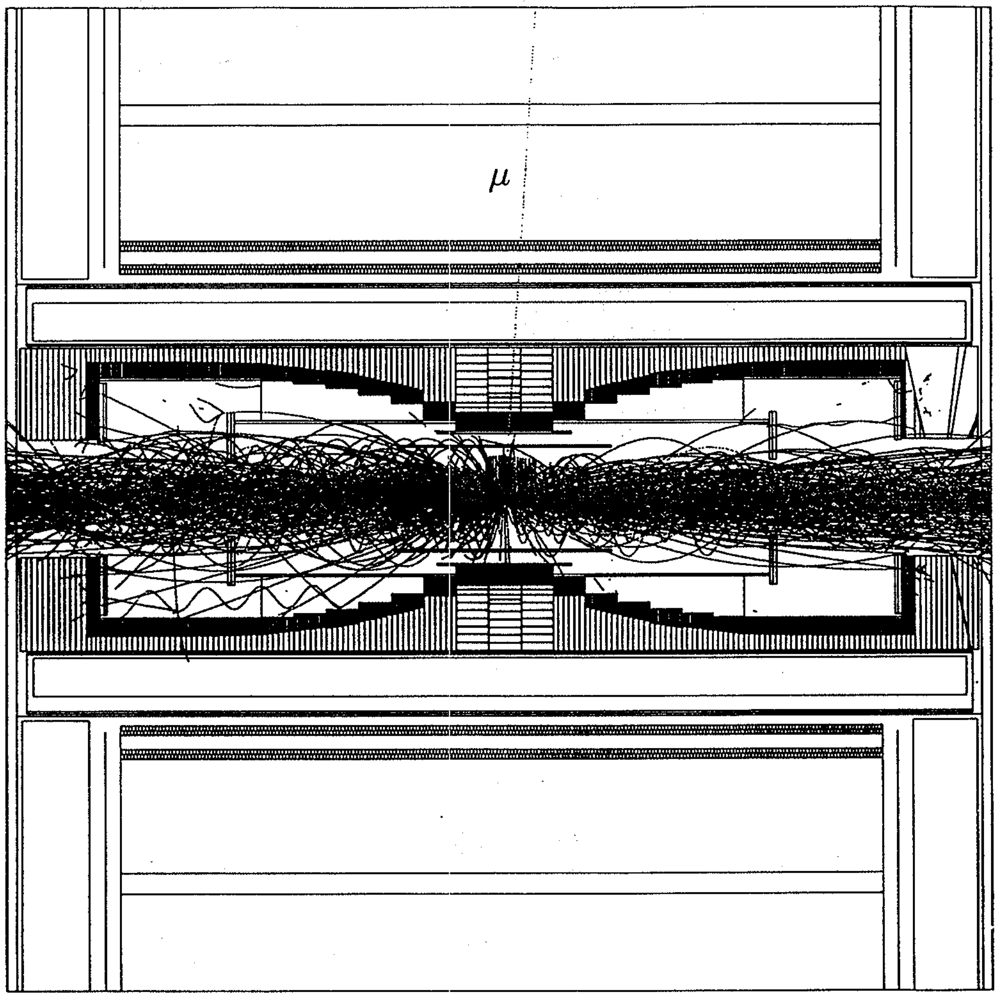
➡ **Total Rate 1.8MHz**

➡ **Total Rate 120kHz for p_t › 3GeV**

Muon p_t after Absorber

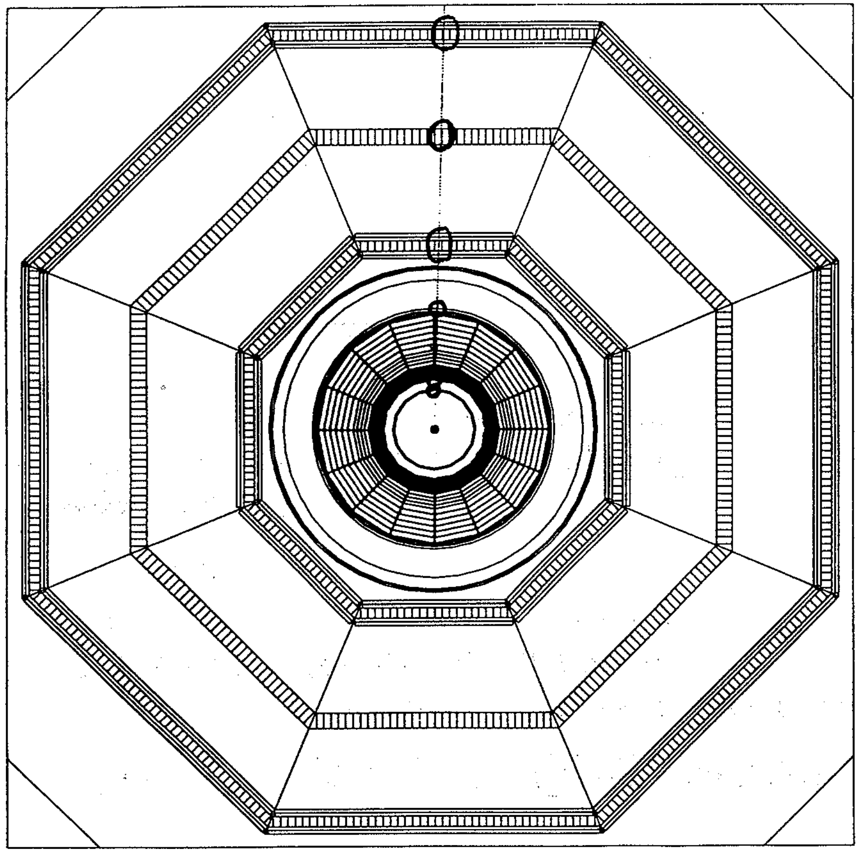


500 Gev Muon overlapped with 20 minimum bias events



Pattern recognition of muons

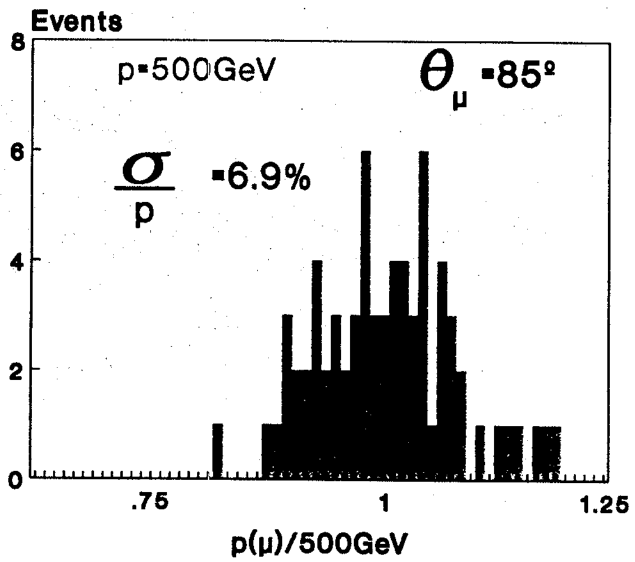
1. muon track found in outer chambers is extrapolated into inner trackers.
2. hits in the trackers are searched for in the road of ±5 σ_{ms}.
3. for each superlayer 4 tubes out of 5 are required.
4. assumed double track resolution 40 nsec.



Momentum Resolution at p=500GeV

without min.bias: $\Delta p/p=5.7\%$

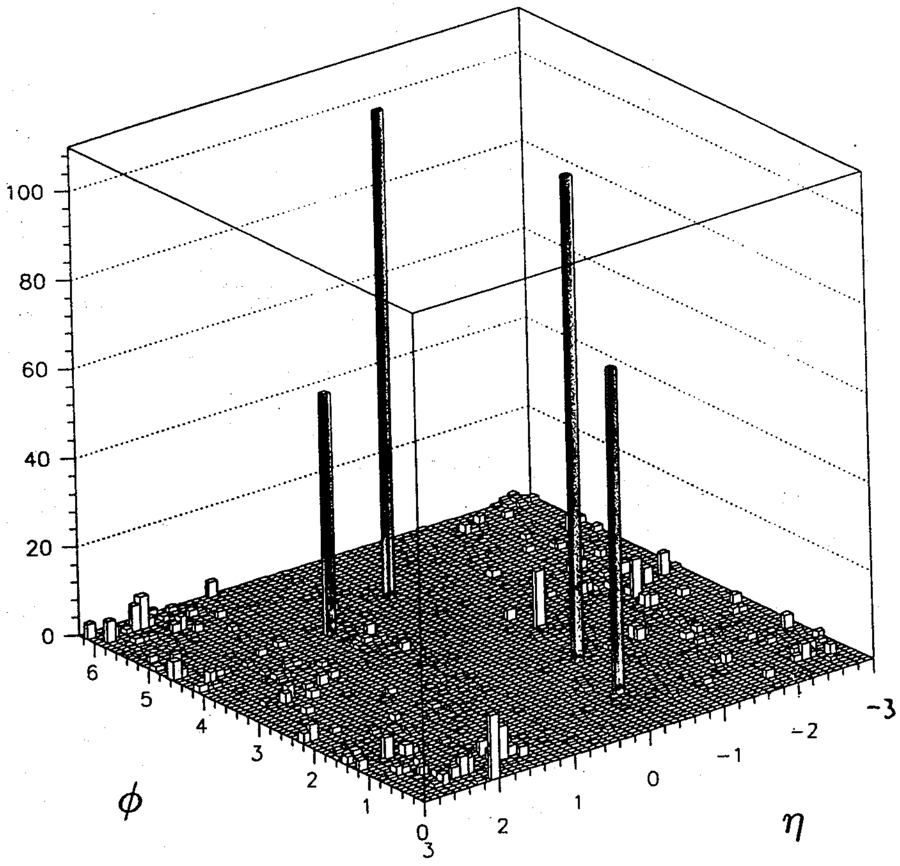
with 80 min.bias: $\Delta p/p=6.9\%$


All Events

Due to min.bias, 13% of tracks contain earlier hits in the inner tracker ➡ Small effect on momentum resolution

$H^0 \rightarrow Z^0 Z^0 \rightarrow e^+e^-\ \ e^+e^- \quad (M_H = 400\ \text{GeV})$

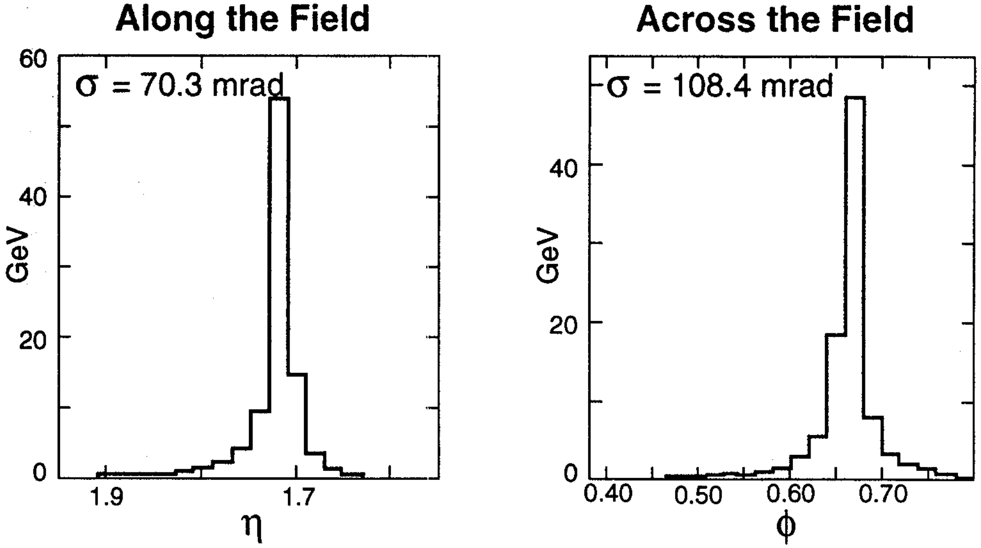
- 20 minimum bias events overlayed.
- Calorimeter segmentation $\Delta\phi \times \Delta\eta \approx 0.03 \times 0.03$.



Plot for $\Delta\eta \times \Delta\phi = 0.1 \times 0.1$

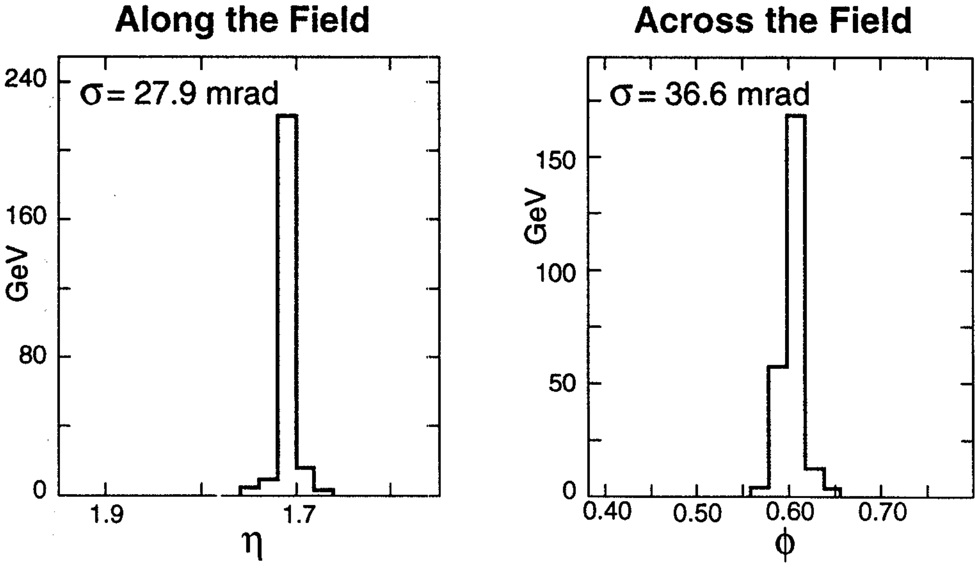
Shower Profiles in 6 Tesla Field

E_π = 100 GeV θ = 20°

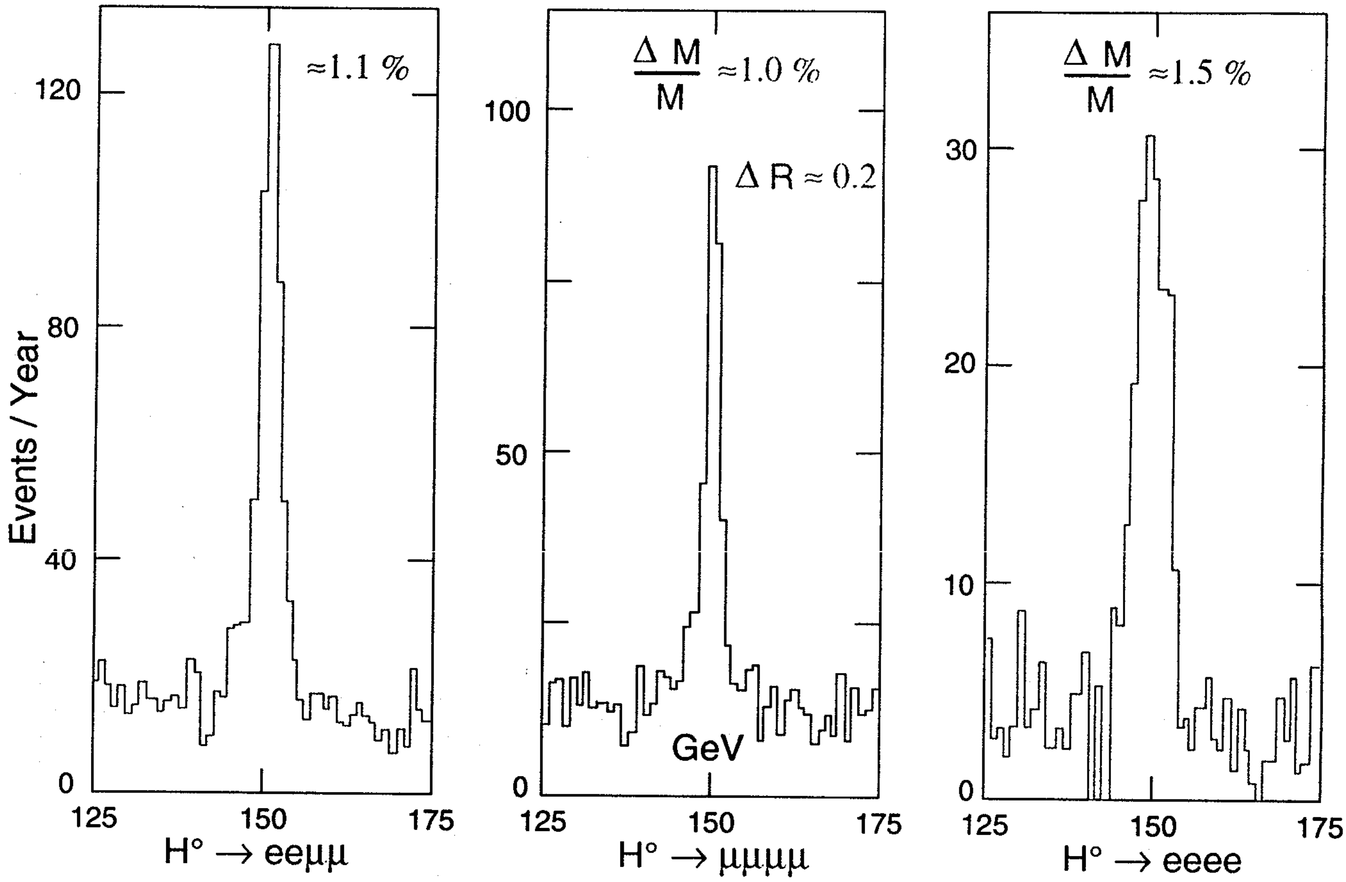

Along the Field

Across the Field

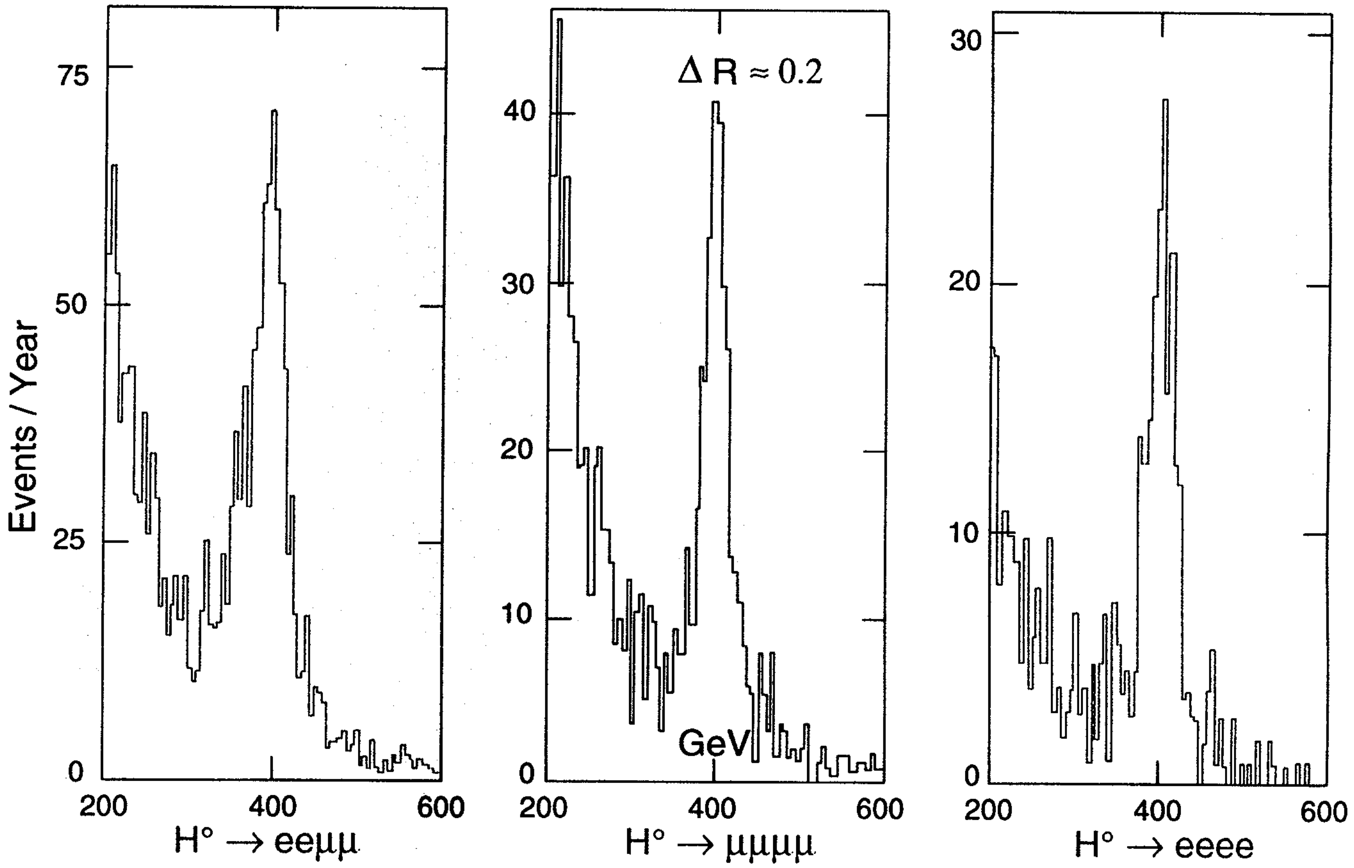
E_e = 250 GeV θ = 20°


Along the Field

Across the Field



H° → Z° Z° → $\ell^+ \ell^- \ \ \ell^+ \ell^-$ + background + 80 min. bias



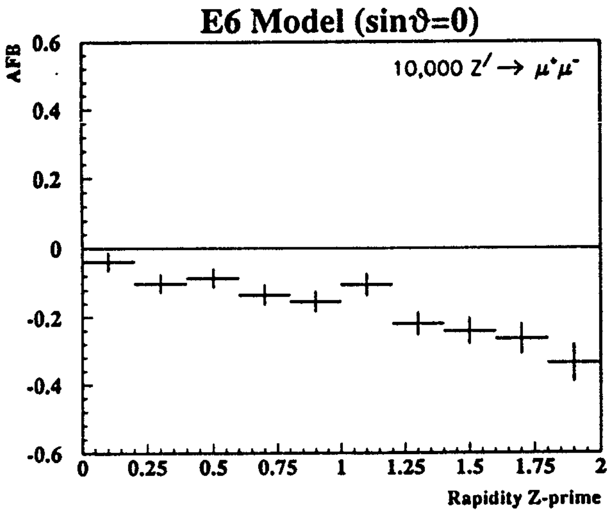
H° → Z° Z° → $\ell^+ \ell^- \ \ \ell^+ \ell^-$ + background + 80 min. bia

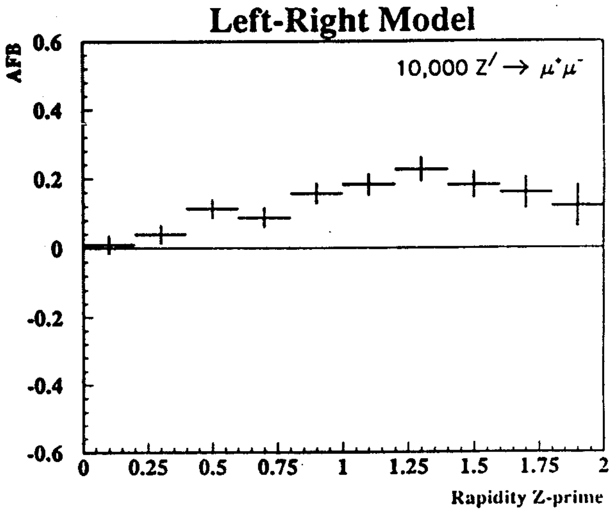
157/3.3.9

Z' Forward-Backward Asymmetry

$M_{Z'} = 1\ TeV, \qquad \int \mathcal{L}dt = 1.6 \times 10^5 pb^{-1}$

⟶ E6 Model ($\sin\theta$=0): 58,000 $Z' \to \mu^+\mu^-$
⟶ Left-Right Model: 66,000 $Z' \to \mu^+\mu^-$



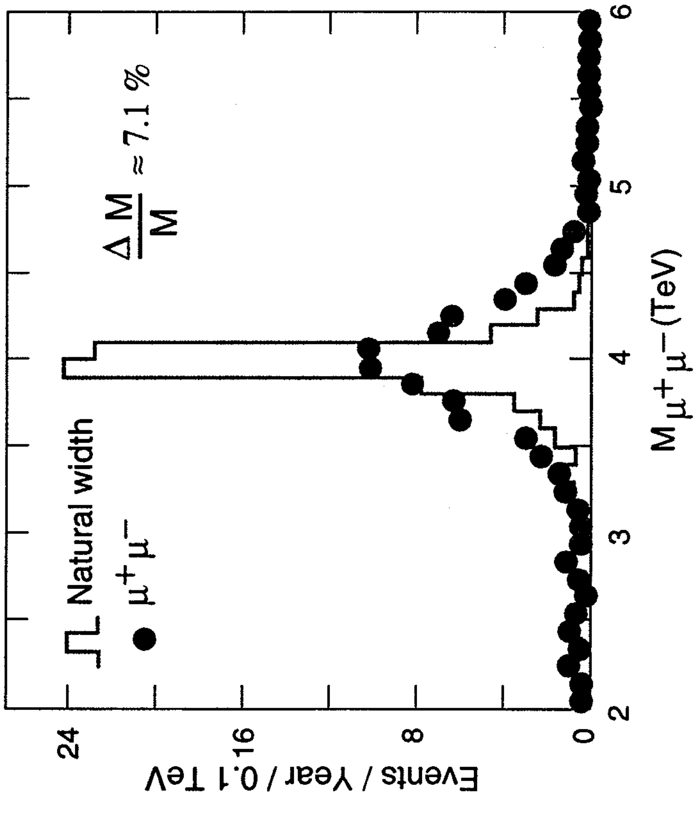


$Z' \to \mu^+\mu^-$, $M_{Z'} = 4$ TeV

Integrated Luminosity = $1.6 \times 10^5\ pb^{-1}$

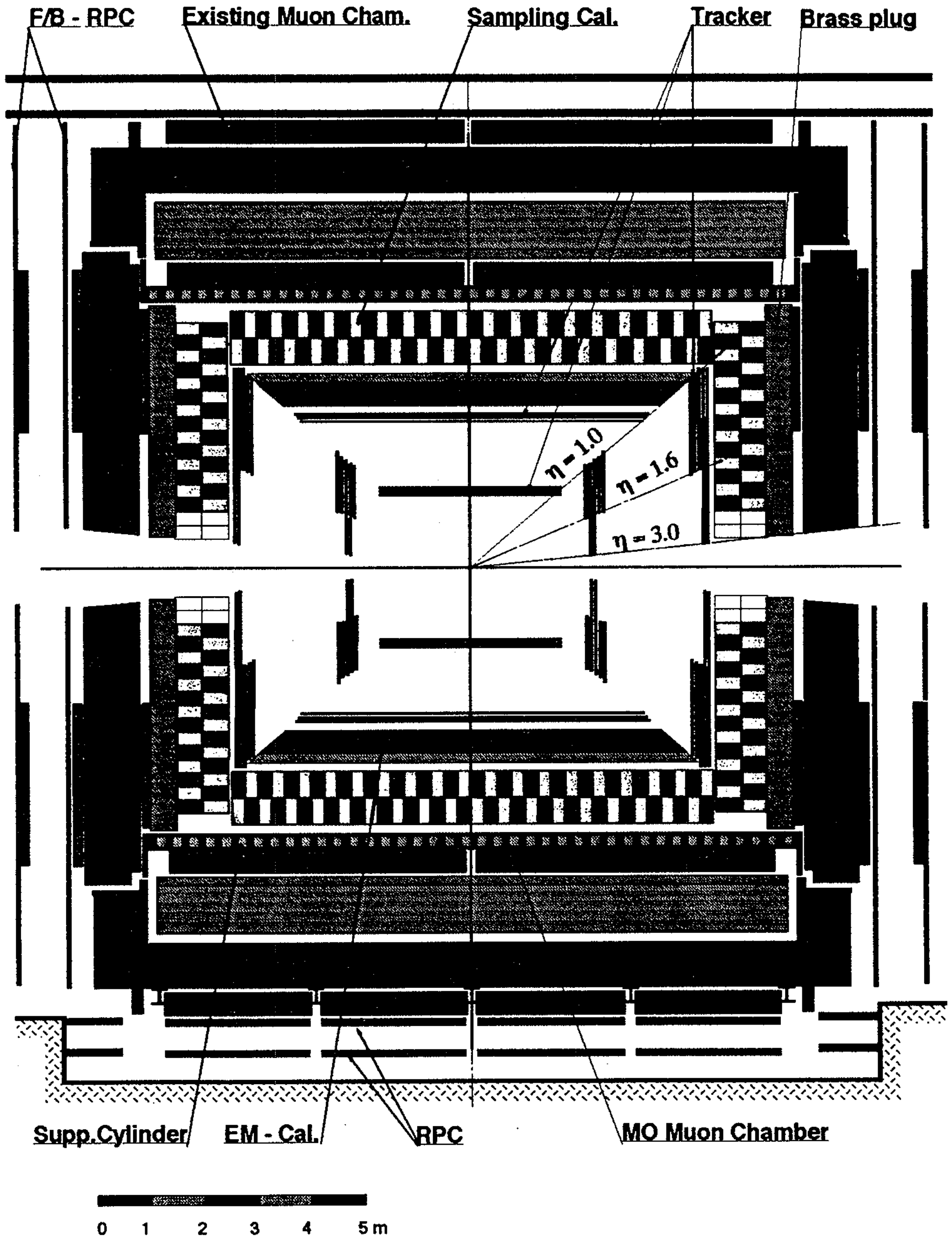
Cuts: $|\eta| < 3$, $p_T(\mu) > 50$ GeV

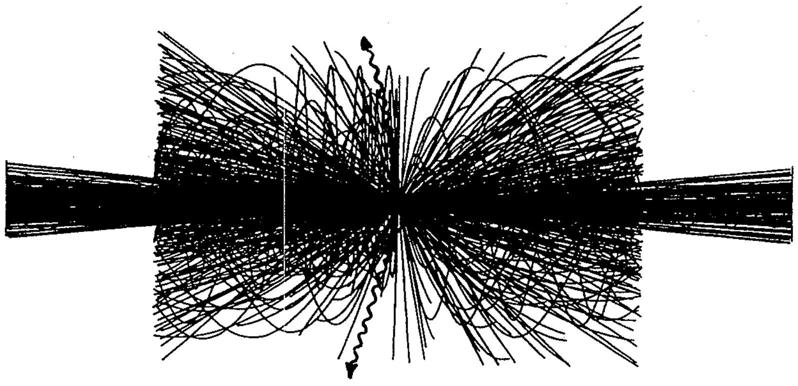
Extended Gauge Model: 90 $Z' \to \mu^+\mu^-$ events



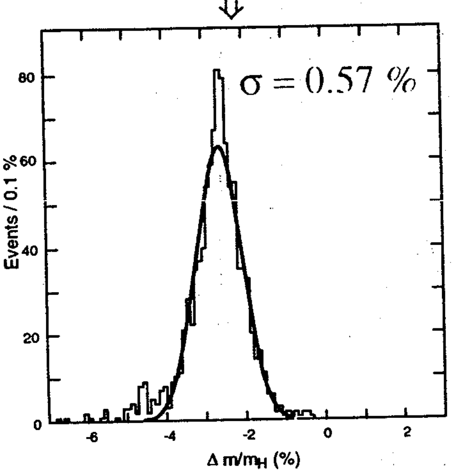
μ - e - γ - Detector Version for LHC

Phase 2

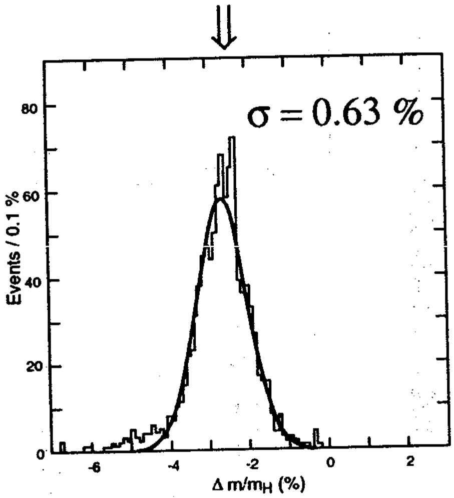




Pile Up + Vertex smearing
+ Noise : 20 MeV/Crystal



Pile Up + Vertex smearing
+ Noise : 20 MeV/Crystal
+ Calibration : 0.5 %



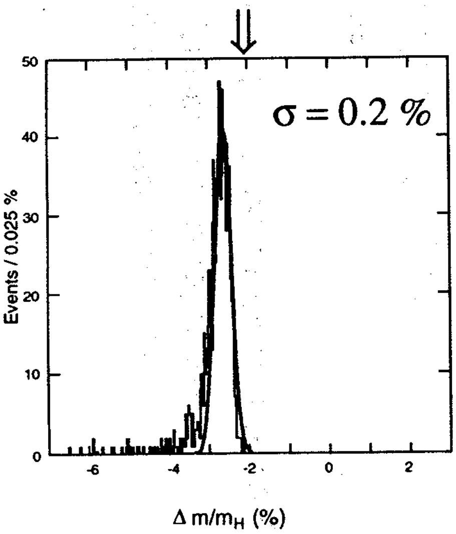
$H \rightarrow \gamma\gamma : m_H = 100$ GeV

Influence of pile up and vertex smearing ($\sigma_z = 5.7$ cm) in 5x5 cells and $25X_0$

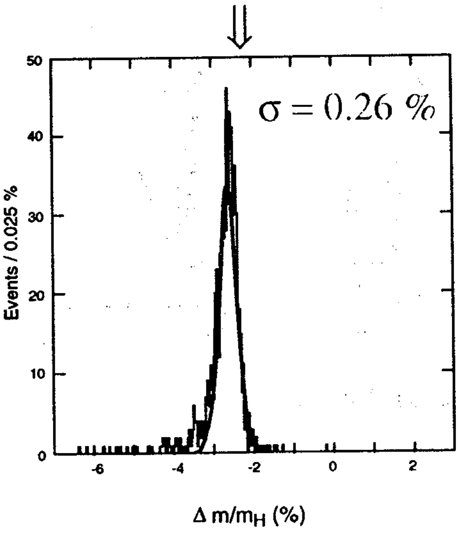
CeF_3 - Calorimeter at R = 3 m and B = 0.7 T

Granularity: $\Delta\eta \times \Delta\varphi = 0.01 \times 0.01$

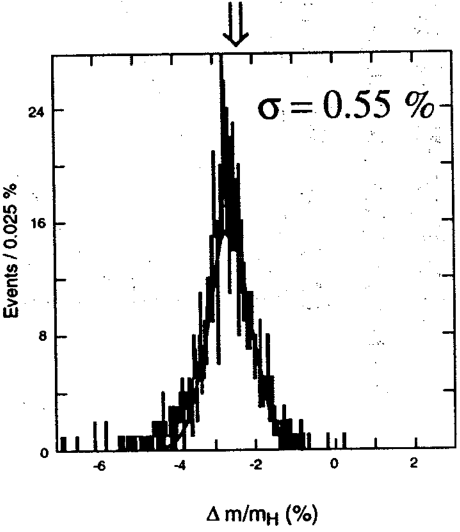
Intrinsic



Pile Up



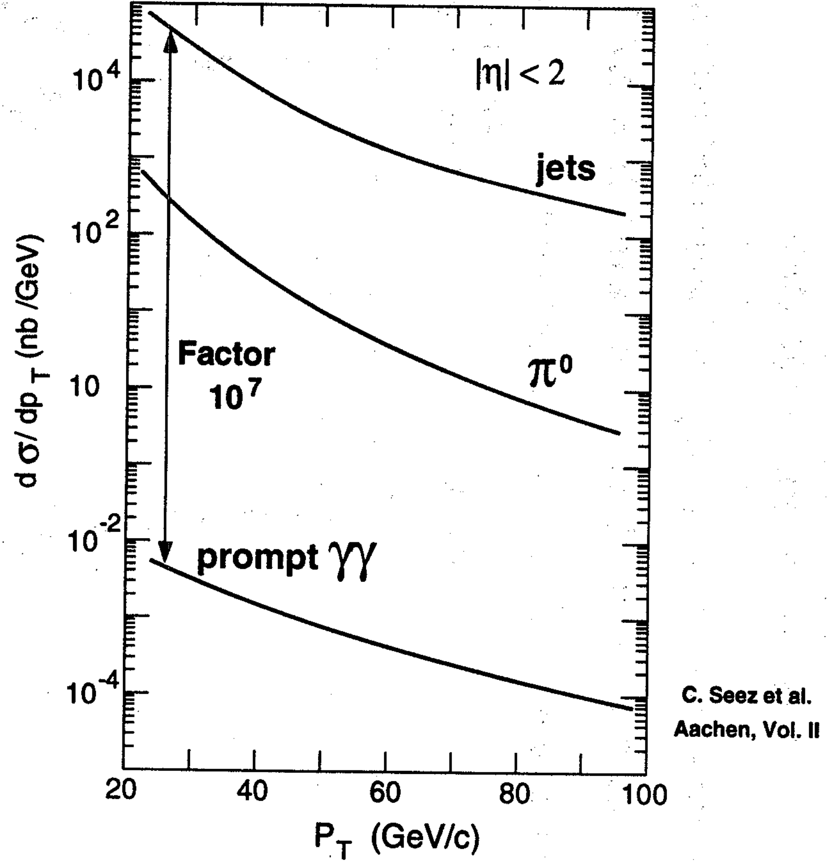
Pile Up and
Vertex smearing



Background to H → $\gamma\gamma$

Problem: QCD jets faking isolated photons

jets → π^0 → isolated photons

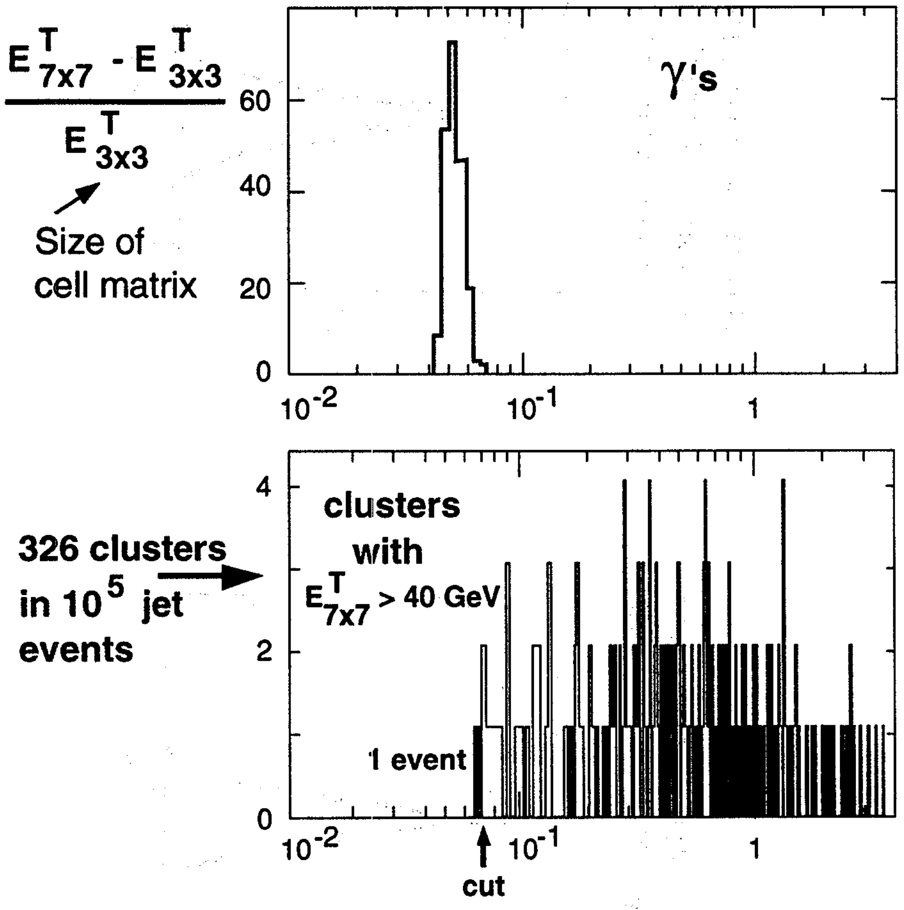


C. Seez et al.
Aachen, Vol. II

Need: rejection factor of ≈ 10^8, to reduce the QCD-jet background below the irreducible $\gamma\gamma$ background

Jet background rejection using GEANT ($P_T^{jet} > 40$ GeV)

Jet → Cluster → Isolated γ



Suppression Factor for $pp \Rightarrow$ jets $\Rightarrow$ Isolated π^0

$E^H_T > 40\text{GeV}, E^L_T > 25\text{GeV}$

① **Shower Shape** $S^H_1 = 330, S^L_1 = 80$

for events not rejected by ①

② **Hadronic Leakage**

Charged Track veto $\Big\}$ $S^H_2 \approx S^L_2 \approx 3.3$

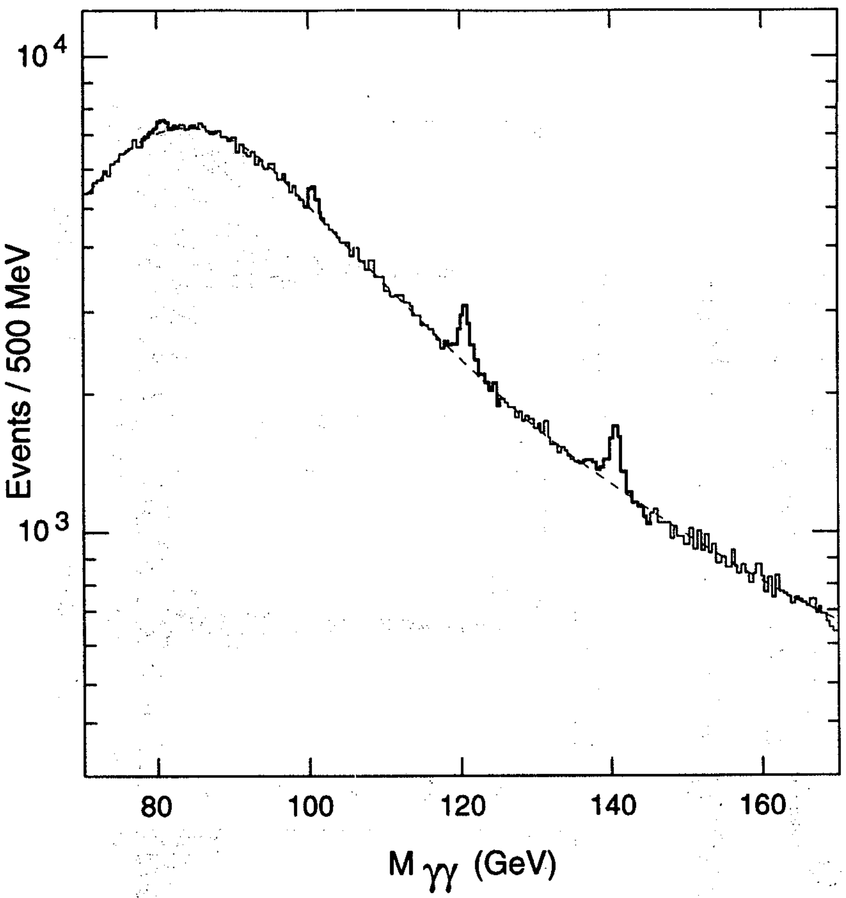
$$\mathcal{S} = \frac{1}{P}\,[S^H_1 \times S^L_1 \times S^H_2 \times S^L_2] \approx 1\,.1\times10^8$$

$P = 2.6\times10^{-3}$ = Probability of E^H_T>40GeV, E^L_T>25GeV in the same event.

$\Longrightarrow$ **Advantage of small granularity:** only from crystals (Size≈1R_M) at R=3m we obtain sufficient π^0 rejection

REMARK: Additional suppression possible from detailed shower analysis

H → $\gamma\gamma$ and irreducible $\gamma\gamma$ Background



H → $\gamma\gamma$ Signal includes:

Kunszt and Stirling (Aachen)

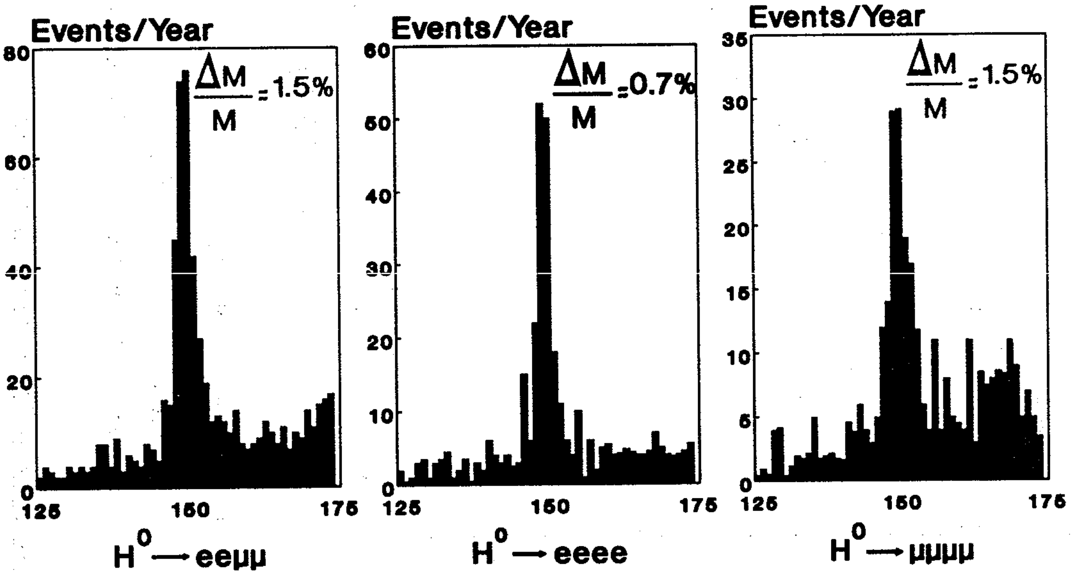
Djouadi, Spira and Zerwas (Phys.Lett.B264, 440 (1991)

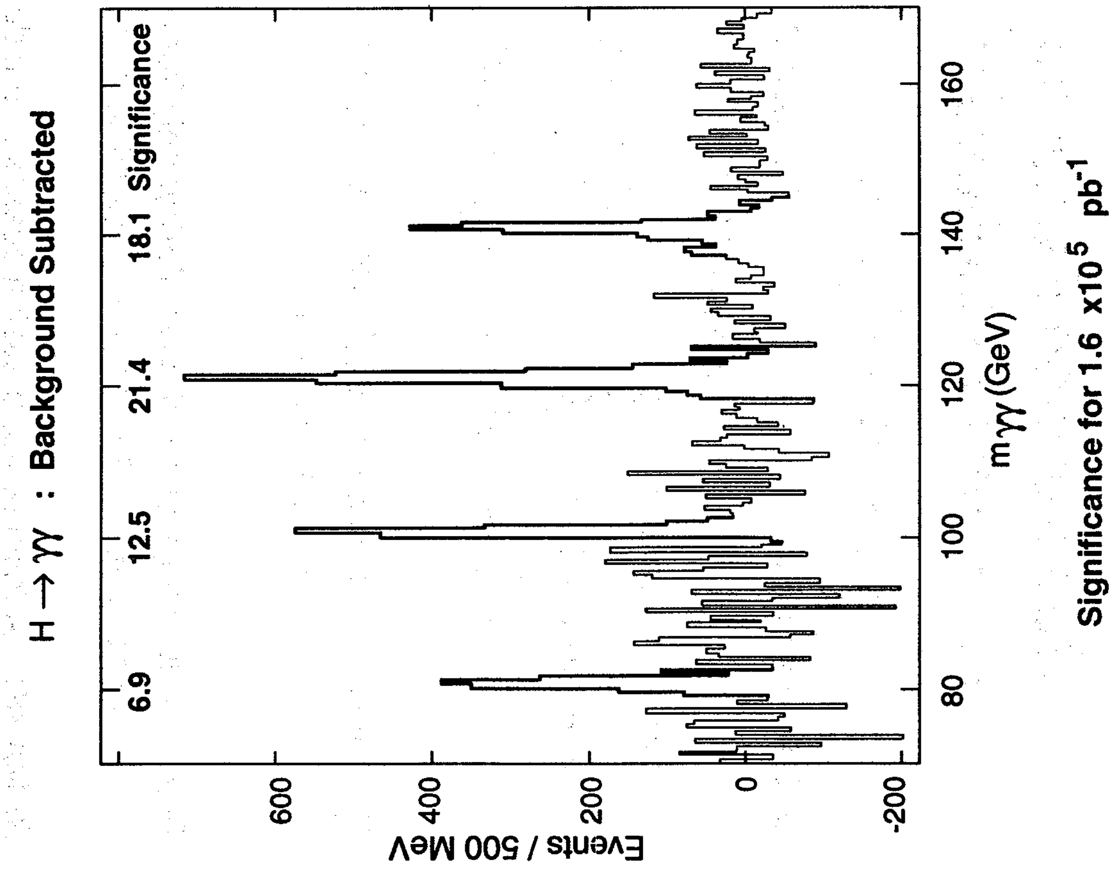
Irreducible Background includes:

$q\bar{q} \rightarrow \gamma\gamma$, $gg \rightarrow \gamma\gamma$, and Bremsstrahlung

$H^0 \rightarrow Z^0 Z^0 \rightarrow l^+ l^- l^+ l^-$

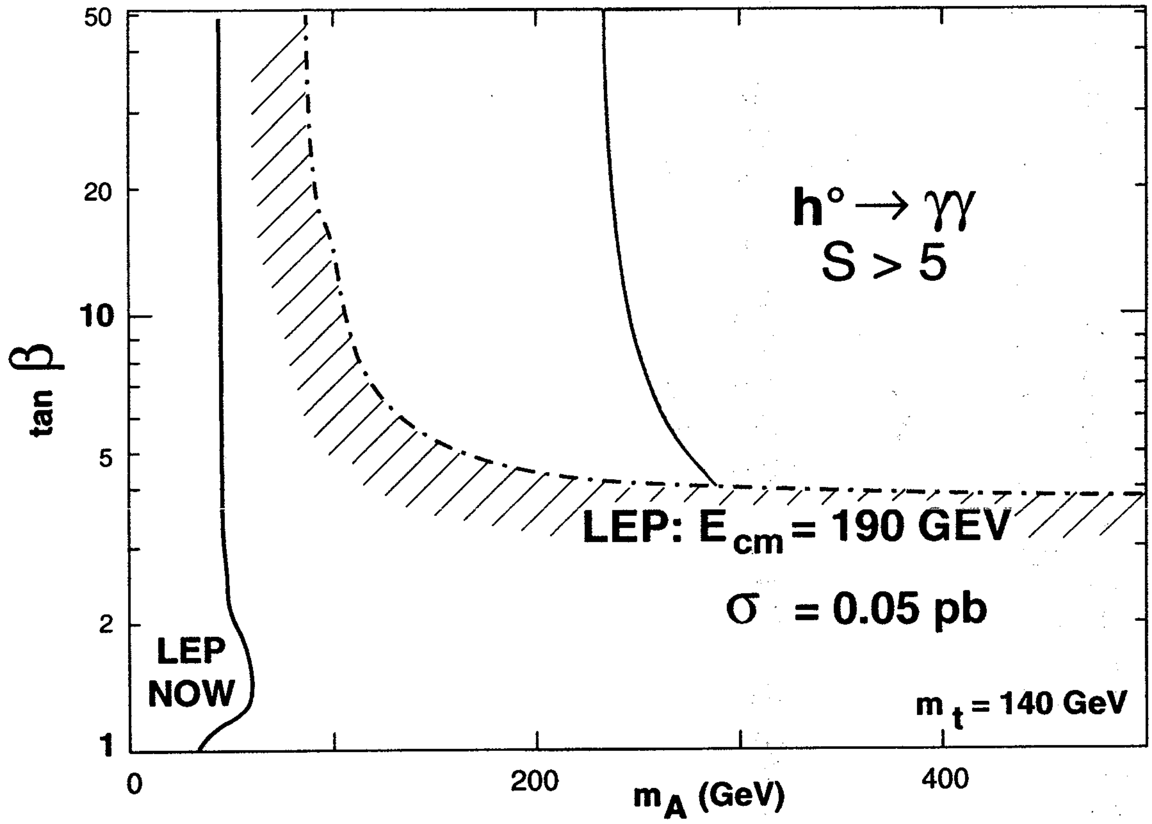
+ Background + Minimum Bias





Significance for 1.6 x10^5 pb^{-1}

Supersymmetry: h° → $\gamma\gamma$



Kunszt, Zwirner
CERN-TH.6150/91
ETH - TH/91-7

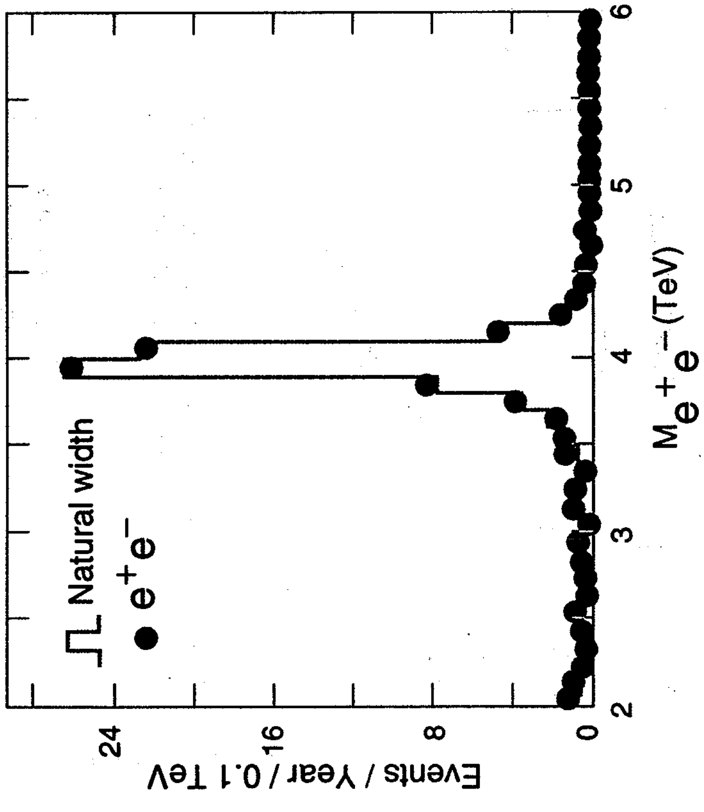
For $S = \frac{N_s}{\sqrt{N_B}}$ only gg Fusion contribution

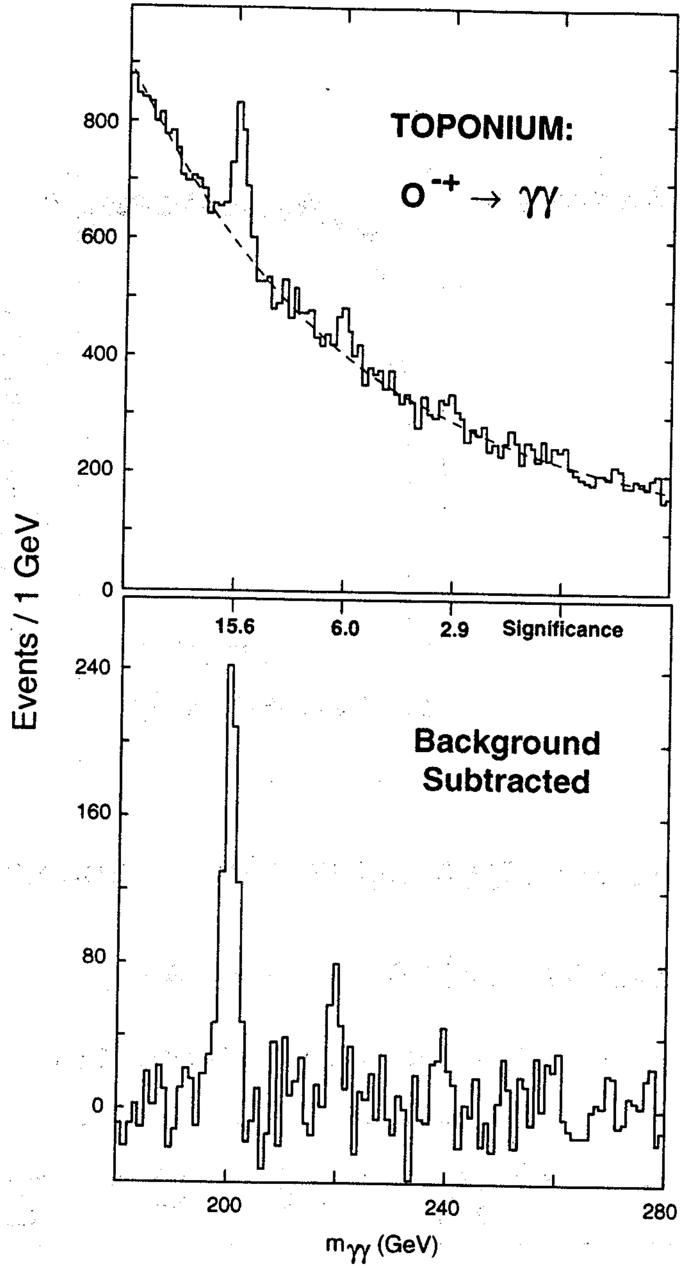
$Z' \to e^+e^-$, $M_{Z'} = 4$ TeV

Integrated Luminosity = 1.6×10^5 pb^{-1}

Cuts: $|\eta| < 3$, $p_T(e) > 50$ GeV

Extended Gauge Model: 90 $Z' \to e^+e^-$ events





G. Pancheri
J.P. Revol
C. Rubbia
CERN-PPE/92-001

CONCLUSION

Both detector concepts can operate at the highest LHC Luminosity

and

have an excellent physics potential

Expression of Interest

An LHC collider Beauty experiment for CP-violation measurements

P. Schlein (UCLA)

EOI
Evian
5-8 March, 1992

An LHC Collider Beauty Experiment for CP-Violation Measurements

J. Ellett, S. Erhan, D. Lynn, M. Medinnis, P. Schlein,
M. Spencer, J. Zweizig
University of California, Los Angeles, U.S.A.

J. Seguinot, T. Ypsilantis
Collège de France, Paris, France

A. Kaschuk, V. Samsonov, V. Sarantzev, E. Spiridenkov, A. Vorobyov
Institute for Nuclear Physics, Gatchina, St. Petersburg, Russia

C. Joseph, J.P. Perroud, M.T. Tran
University of Lausanne, Lausanne, Switzerland

M. Kreisler
University of Massachusetts, Amherst, MA, U.S.A.

W. Hofmann, K.T. Knöpfle
Max Planck Institut für Kernphysik, Heidelberg, Germany

T.Y. Chen, D. Xi, N.G. Yao
Nanjing University, Nanjing, P.R.C.

P. Bogunovic, G. Paic, D. Rendic, D. Vranic
Rudjer Boskovic Institute, Zagreb, Croatia

R. Dzhelyadin, Y. Guz, V. Kubic, V. Obraztsov, A. Ostankov
IHEP-Serpukhov, Protvino, Russia

R. Harr, P. Karchin
Yale University, New Haven, Connecticut, U.S.A.

Spokesman: P. Schlein [SCHLEIN @ UCLAHEP]

CP- VIOLATION HAS ONLY BEEN OBSERVED IN K-DECAY. IF IT IS DUE TO THE FAMILIAR WEAK INTERACTION, A PATTERN OF LARGE CP-VIOLATING EFFECTS IS EXPECTED IN B-DECAY

HOWEVER, IF CP-VIOLATION HAS ITS ORIGIN IN SOME NON-STANDARD MODEL PHYSICS AT A HIGH MASS SCALE, CP-VIOLATING EFFECTS IN B-DECAY COULD BE AS SMALL AS THEY ARE IN K-DECAY (10^{-3})

TO DISTINGUISH THESE TWO POSSIBILITIES, IT IS CRUCIAL TO STUDY CP-VIOLATION EFFECTS IN B-DECAY IN ALL POSSIBLE WAYS AND TO TEST ALL EXPECTED REDUNDANCIES

MEASURE:
Non-exponential decay time distributions FOR CP-EIGENSTATES and associated rate asymmetries

WE NEED: LARGE EVENT SAMPLES
CLEAN RECONSTRUCTED MASS PEAKS
Separate: B_d, B_s, B_c, etc
GOOD PROPER TIME RESOLUTION
INITIAL FLAVOR TAGGING

CP-VIOLATION

$$N(B \rightarrow J/\psi\, K) = A(t)\, e^{-t}\, [1 - \sin(2\beta)\sin(x't)]$$

$$\overline{N}(\overline{B} \rightarrow J/\psi\, K) = \underset{\text{ACCEPTANCE, TRIGGER, RECONSTRUCTION}}{A(t)}\, e^{-t}\, [1 + \sin(2\beta)\sin(x't)]$$

Ideally → 2 Distinct Data Samples

In practice → Incorrectly flavor tagged events appear in wrong sample

→ALL DATA SAMPLES ARE LINEAR SUPERPOSITIONS OF 2 EQUATIONS

2 sources of mistagging:

- Flavor oscillation of tag-providing B

  Probability (non-oscillation) $= \frac{1}{2}(2+x^2)/(1+x^2)$

  Probability (oscillation) $= \frac{1}{2}x^2/(1+x^2)$

$$\rightarrow N(B) = A(t)\, e^{-t}\, [1 \pm \frac{1}{1+x^2} \sin(2\beta)\sin(x't)]$$

- Bad tag from extraneous source

  g = good tag, b = bad tag

$$D = \left\langle \left(\frac{g-b}{g+b}\right) \cdot \left(\frac{1}{1+x^2}\right) \right\rangle$$

$$N(B) = A(t)\, e^{-t} \left[1 \pm \underbrace{D \sin(2\beta)}_{\text{MEASURE}} \sin(x't) \right]$$

Error in sin(2β)

$$\delta[\, D \sin(2\beta)\,]^2 = 1/(I_0\, N)$$

$\overset{\text{MC}}{I_0} = 0.56$ is a statistical factor from fitting time dependence with our acceptance function

$$N = N(B) + \overline{N}(\overline{B})$$

$\overset{\text{MC}}{D} = 0.37$ (averaged over B_u, B_d, B_s etc.)

$$\boxed{\delta[\, \sin(2\beta)\,]^2 = 1/(I_0\, \underbrace{D^2}_{D'^2} N)}$$

VALUES GIVEN LATER IN TALK

IT IS ESSENTIAL TO INCLUDE ALL DILUTION + STATISTICAL EFFECTS IN ANY ESTIMATES OF "CP-REACH" OF AN EXPERIMENT

COMPARE LHC COLLIDER B-FACTORY WITH e^+e^- B-FACTORY

e^+e^-: Small $\sigma_{b\bar{b}}$ (Larger Efficiences)

Need expensive new type facility; untested

Can't do B_s, B_c or B-baryons physics

Most likely a luminosity dead end at 10^{34}

LHC: Large $\sigma_{b\bar{b}}$ (Smaller Efficiences)

B_s, B_c, B-baryons are accessible

There is considerable experience at the ISR with the type of spectrometer we propose (see below). In addition, the associated silicon micro vertex detector configuration has recently been tested successfully at the SPS -Collider (P238 - see below).

WHY LHC-COLLIDER MODE?

COMPARE $\sigma_{b\bar{b}}$ TO σ_{TOTAL} (Approx.)

	$\sqrt{s}$	$\sigma_{b\bar{b}}$	$\sigma_{b\bar{b}}/\sigma_{tot}$
LHC F.T.	.12	1	1/50,000
SPS-Collider	.63	15	1/ 4000
Tevatron	1.8	50	1/ 1400
LHC-Collider	16	300	1/ 300

The $\sigma_{b\bar{b}}/\sigma_{tot}$ ratio is clearly much more favorable in the collider mode than in Fixed Target (even with the use of a nuclear target).

Larger $\sigma_{b\bar{b}}$ is in itself a considerable advantage and avoids having to run F.T. at high interaction rate.

NEED OPTIMIZED DEDICATED COLLIDER B- DETECTOR

ISSUES RELEVANT TO ITS DESIGN:

- ACCEPTANCE
- TRIGGERING R+D: P238, RD21
- RECONSTRUCTION
    - particle id - RICH R+D { YPSILANTIS, SEGUINOT
    - mass resolution($\sigma \approx$ 10 MeV)
    - $\delta t / t$ resolution (≤ 6 %)
- FLAVOR TAGGING

Extensive MC simulation has been done to reliably estimate the detector performance on each issue

---

Acceptance

Far above threshold, B production is forward-backward peaked due to interaction of unequal energy partons.

→ Instrument 2 forward arms
600 mrad aperture open geometry

EXAMPLE: $B^0 \rightarrow J/\psi K^0_s \rightarrow l^+ l^- \pi^+ \pi^-$

LHC: 55% fully contained (Same for $\bar{B}^0$)
SPS: 23% " "

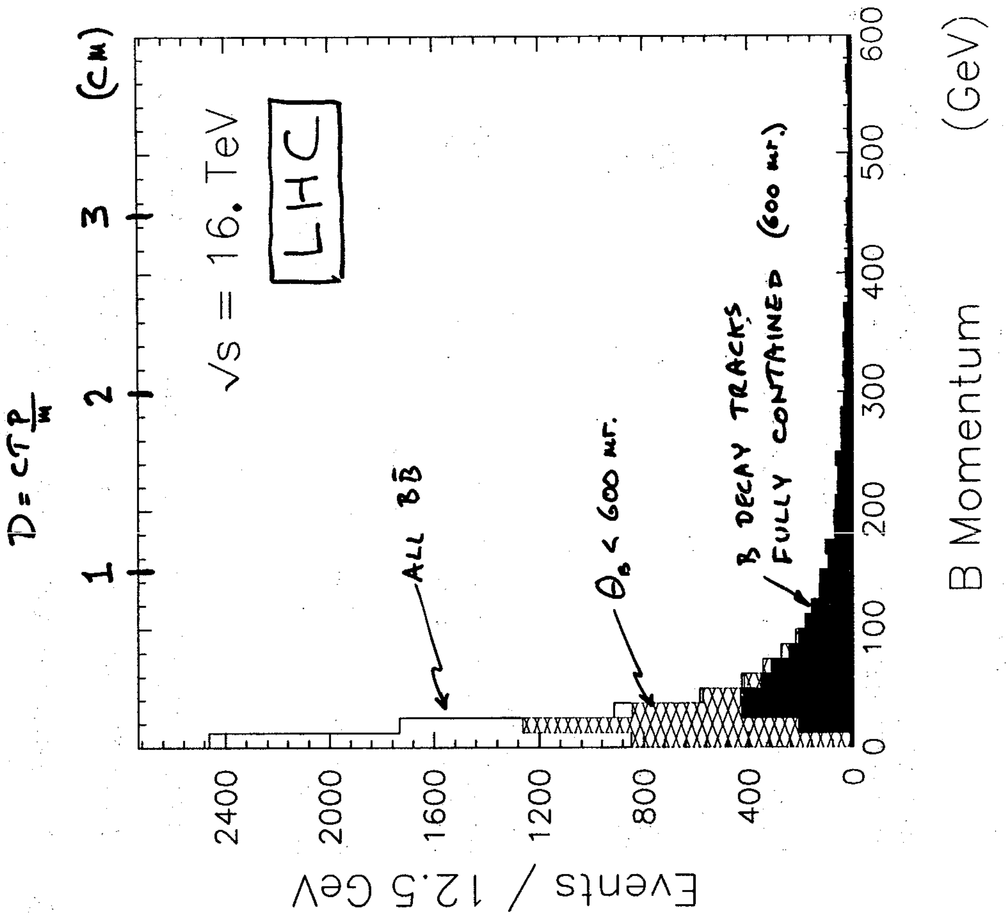
Observation:

$P_B \geq 20$ GeV ⇒ B decay tracks contained

→ $<P_B>$ ~ 45 GeV SPS
~100 GeV LHC (BECAUSE OF TAIL !)
D ~ 1 mm / 15 GeV

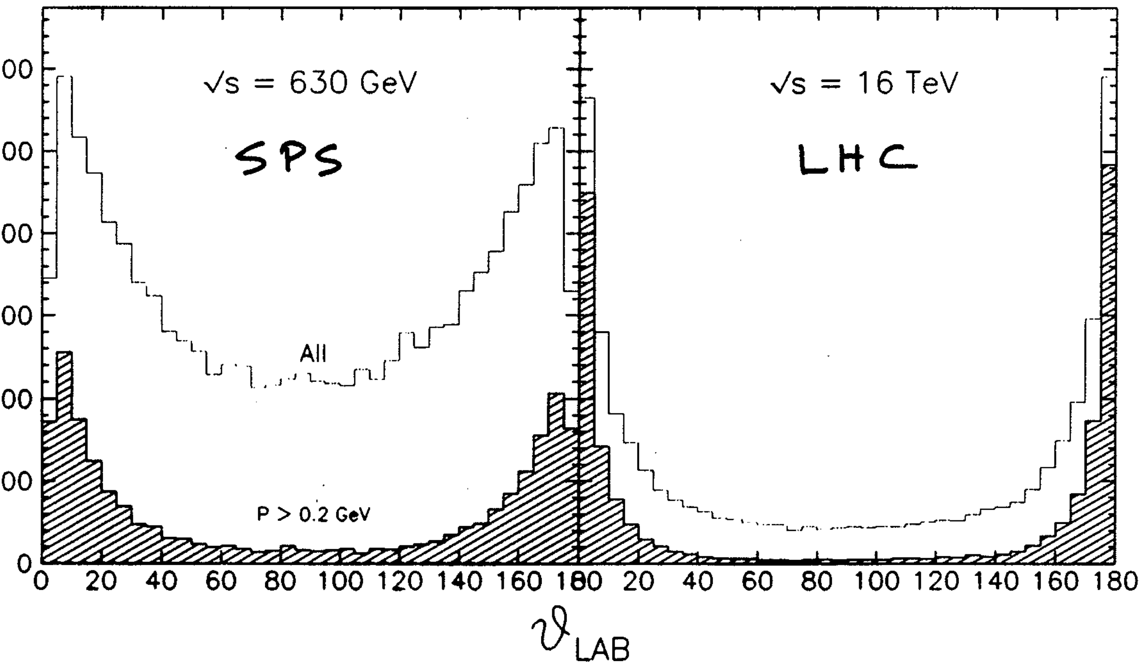
20 GeV corresponds to smaller X_F at larger $\sqrt{s}$.
∴ Larger fraction of σ is accepted.

PYTHIA



B Decay tracks

PYTHIA



Spectrometers

	No. 1	No. 2
Maximum aperture (mrad)	600	100
Minimum aperture (mrad)	100	4
Magnet type	quad.	dipole(s.c.)
Integrated field (Tm)	2.4(max)	5.0
RICH momentum for 3σ π/K separation:		
C_5F_{12} liquid (GeV)	7	7
C_5F_{12} gas "	46	72
CF_4 gas "	–	90
3×3 mm PADS (YPSILANTIS)		
Chambers		
spatial resolution / plane (µm)	100	100
time resolution (nsec)	≈50	≈50
Electromagnetic calorimetry required energy resolution	< 4%/√E	

Installation of 2nd arm is optional (doubles statistics)

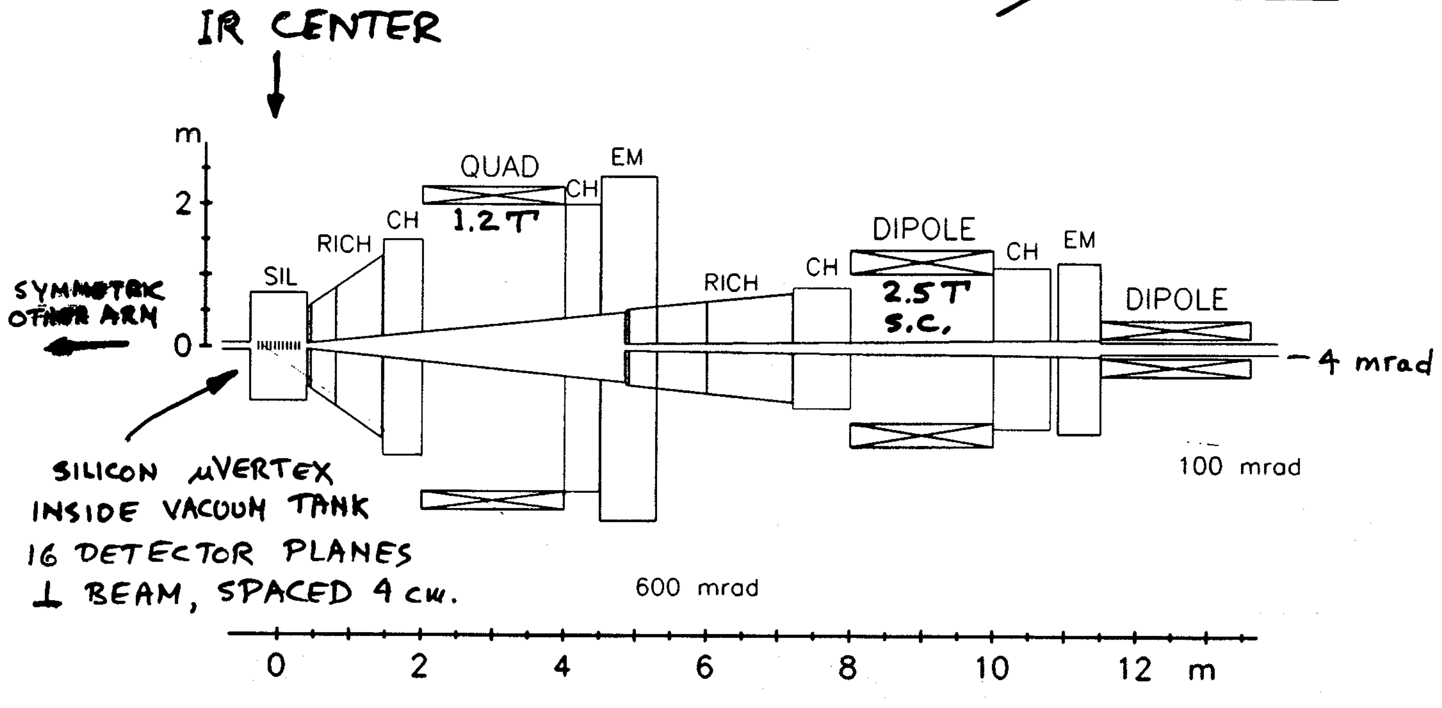
Muon filter may be useful (under study)

⊛ Cost/arm ≈ 15 MSF + e.m. calorimetry

COST IS LOW BECAUSE DEVICE IS ESSENTIALLY A LOW-ENERGY FIXED-~~TARGET~~ TARGET SPECTROMETER.

FORWARD SPECTROMETER SYSTEM

~~P238~~ LHC



SPS-COLLIDER
1990

TOPOLOGY TRIGGER

Real-time calculations on silicon-strip detector planes perpendicular to beams

⇒Fixed target geometry

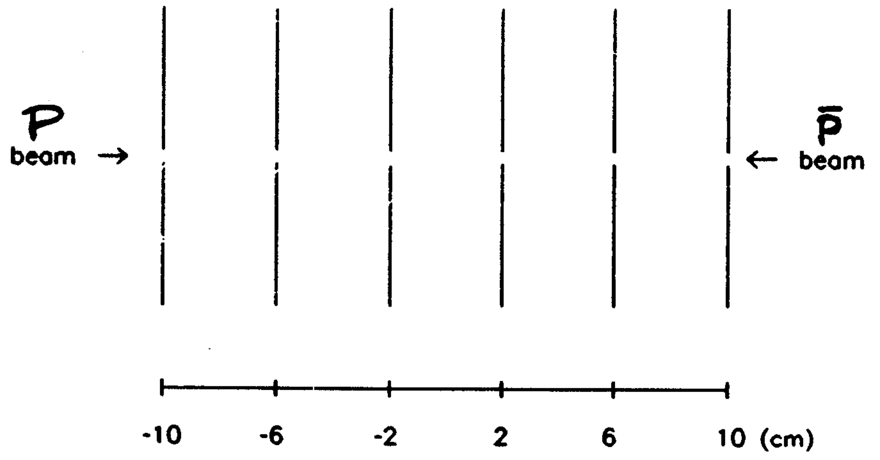
Planes distributed throughout source region with only a few cm longitudinal spacing: Minimize extrapolation distance

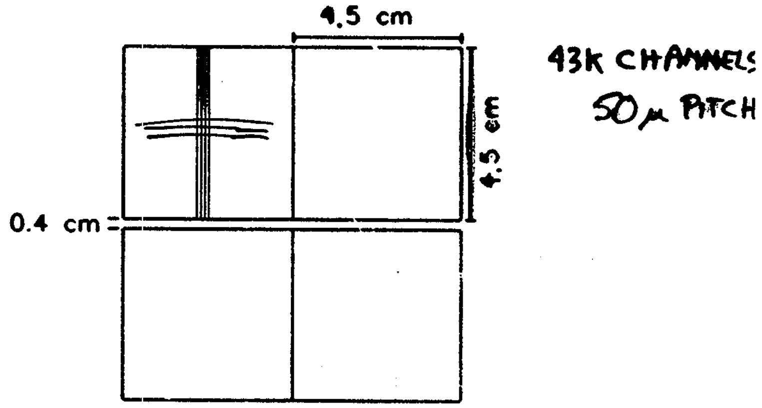
→ **STRATEGY:** Veto events which are consistent with a single vertex

R+D: P238 Si Run, SPS-COLLIDER (1990)
RD21 Interface Si to Data-Driven Processor (1992)

P238 SILICON DETECTOR

✱ CENTERED ON INTERACTION REGION LSS5



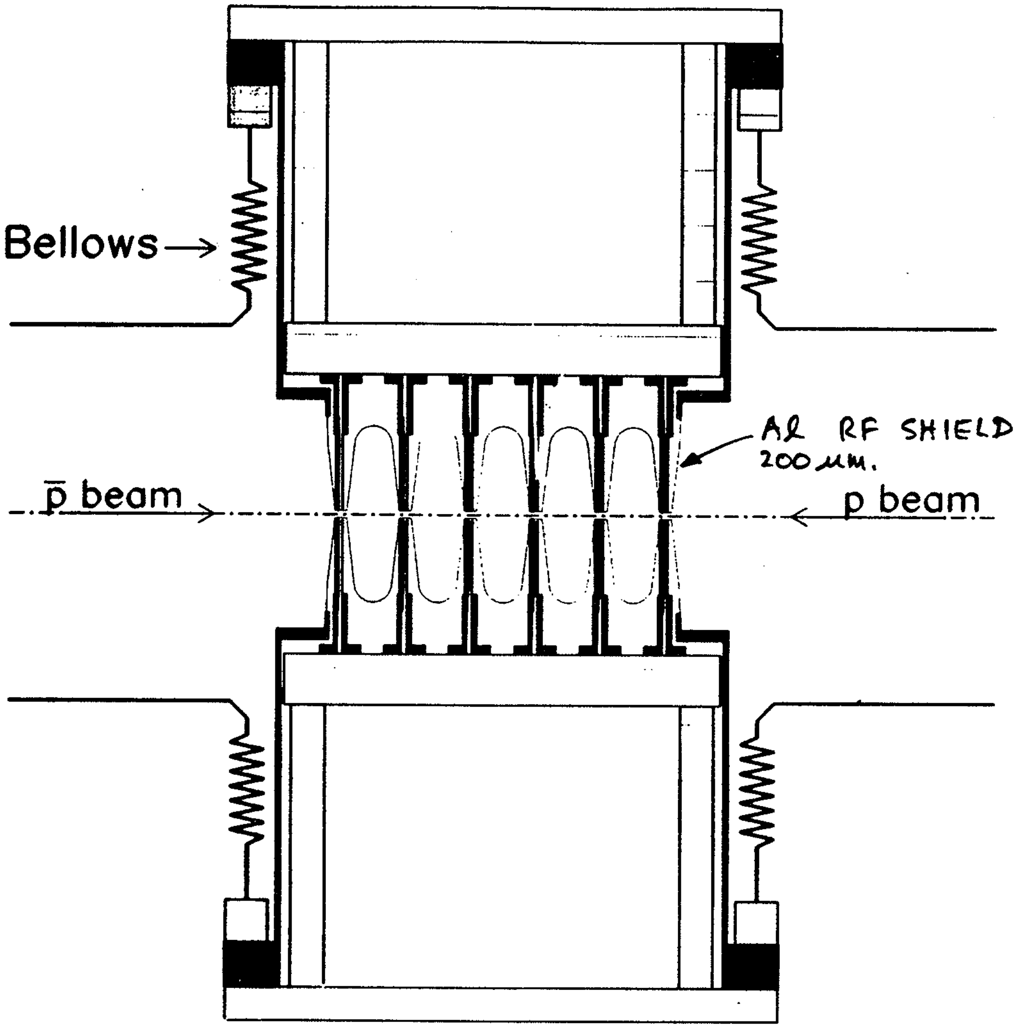


LHC EXPERIMENT REQUIRES 16 PLANES

P238

POSITIONED AT CENTER 400 OF LSS5 (SEPT-DEC 1990)

SEPT-DEC 1990
LSS5



P238 Silicon Micro-vertex Detector

Operational Summary

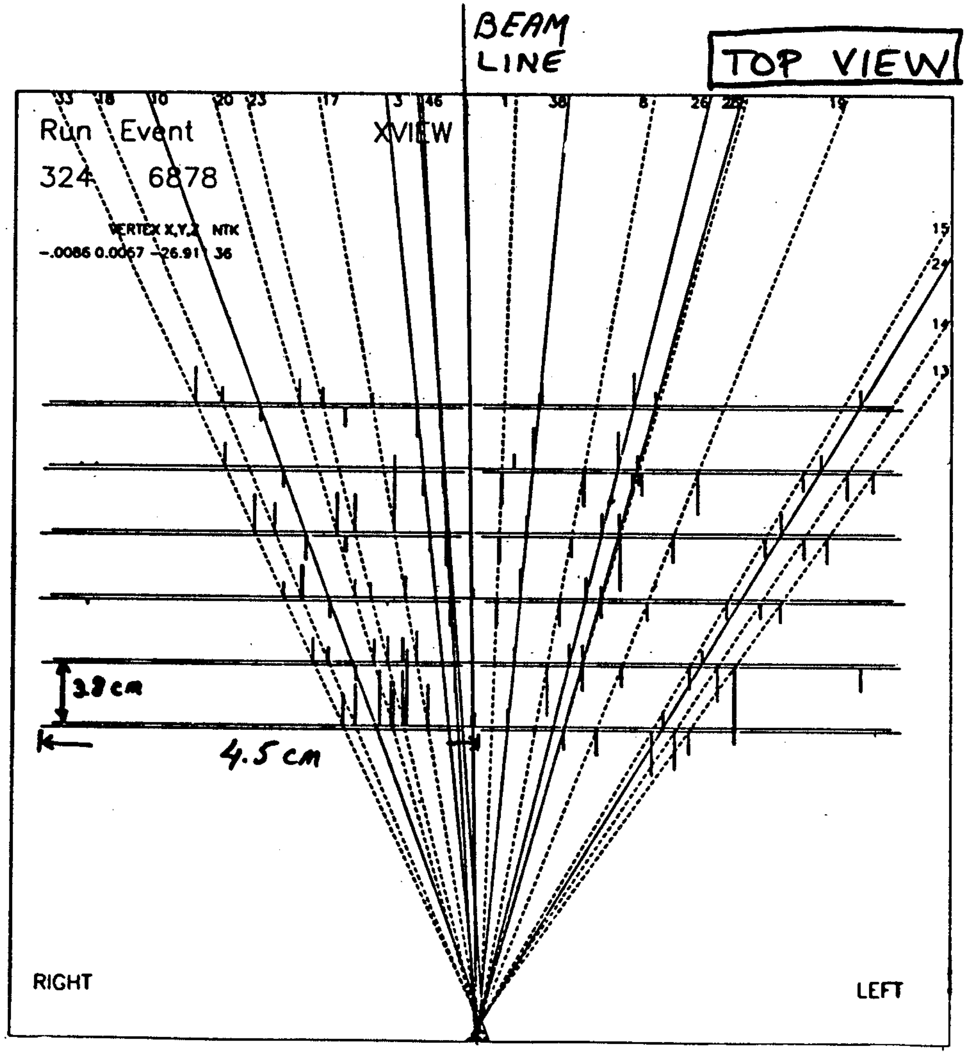
- The detector was routinely run at a distance of ± 1.5 mm from the collider beam
  - RF pick-up from passing beams was not a problem
  - no increase in interaction rates was observed as detectors were brought into position
  - beam positions were stable
- Detectors worked well in vacuum
  - signal/noise ~ 25
  - point resolution 4-8 microns
- Events were clean:
  - **few** halo tracks
  - **hit and** track distribution as expected from **the** Monte Carlo (VALIDATES OUR SIMULATION WORK)

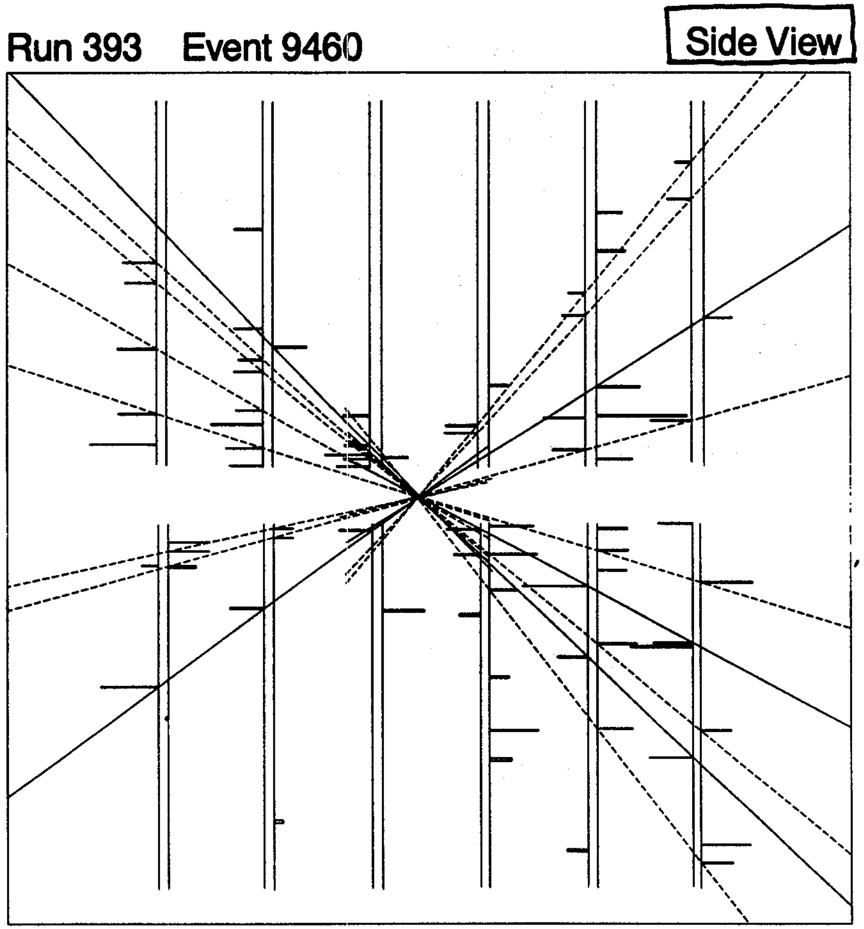
IN PRESS - NIM

P238
1990

REAL
DATA

P238 TYPICAL EVENT





BOTH HEMISPHERES CONTRIBUTE
PRIMARY VERTEX INFORMATION

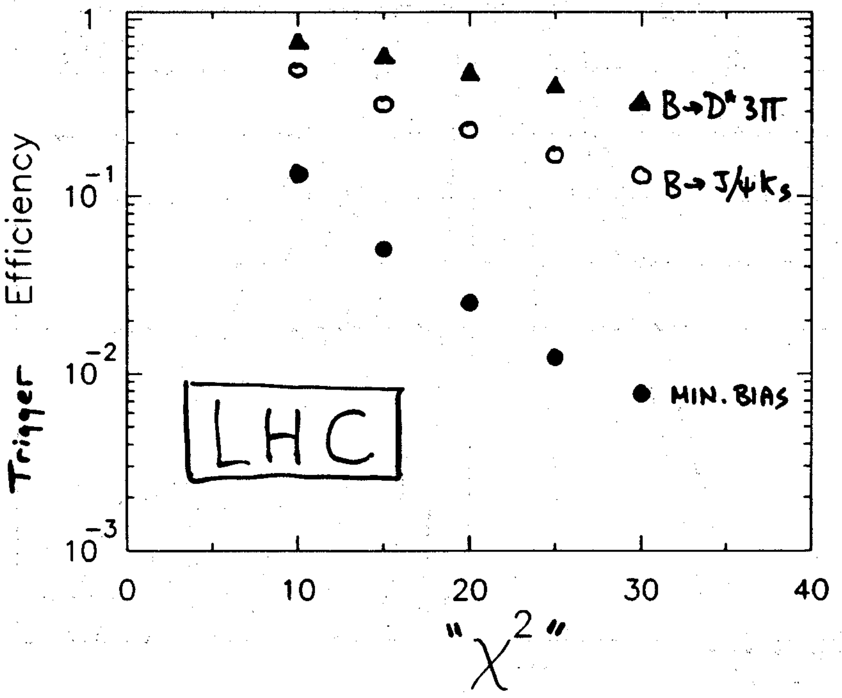
$$P238 \left\{ \begin{array}{l} \sigma_z = 350 \ \mu m \\ \sigma_{x,y} = 38 \ \mu m \end{array} \right\} \longrightarrow$$

FULL Si DETECTOR
MATCHED TRACKS
MOMENTUM MEASUREMENT
YIELD $\sigma(\Delta z_B) \sim 180 \ \mu m$.

$\sigma(\tau)/\tau \sim 6\%$

TRIGGER EFFICIENCY

PYTHIA- GEANT SIMULATION



SUPPRESS MIN BIAS $\frac{1}{100}$

" $B\bar{B}$ $\sim \frac{1}{7} - \frac{1}{2}$ MULTIPLICITY DEPENDENT

RELATIVE SUPPRESSION
(ENHANCEMENT FACTOR) 15-50

Machine Interface

- Maximum luminosity ≈ 4 x 10^{31}
  - pileup
  - radiation damage
  - data rate (particularly front end)

⇒ (Keith Potter) $\beta^* \approx 200$ m

$\sigma_{beam} \approx 300\ \mu m$

closest distance of approach of vertex detector to beam ≈ 3 mm

→ ALL OUR LHC M.C. ASSUME THIS VALUE

from study by F. Ruggiero:

- Power loss of beam due to RF shield is negligible (≈ 1 watt), but requires a smooth transition from shield to beam pipe

- Under study:
  - coherent tune shifts
  - (possible) multi-bunch instabilities
  - transverse impedence

RD-21:

SILICON + DATA-DRIVEN PROCESSOR

GOAL: Develop and verify the techniques necessary for a topology-triggered B experiment at the LHC.

Builds on P238 run which demonstrated that a planar geometry silicon strip detector runs background-free in the SPS collider environment.

NEXT STEP: interface silicon system to data-driven trigger processor for real-time calculations.

Processor and high-speed silicon readout system interface is under construction.

Fixed-target test run anticipated: Dec. 1992

EVENT RECONSTRUCTION SIMULATION

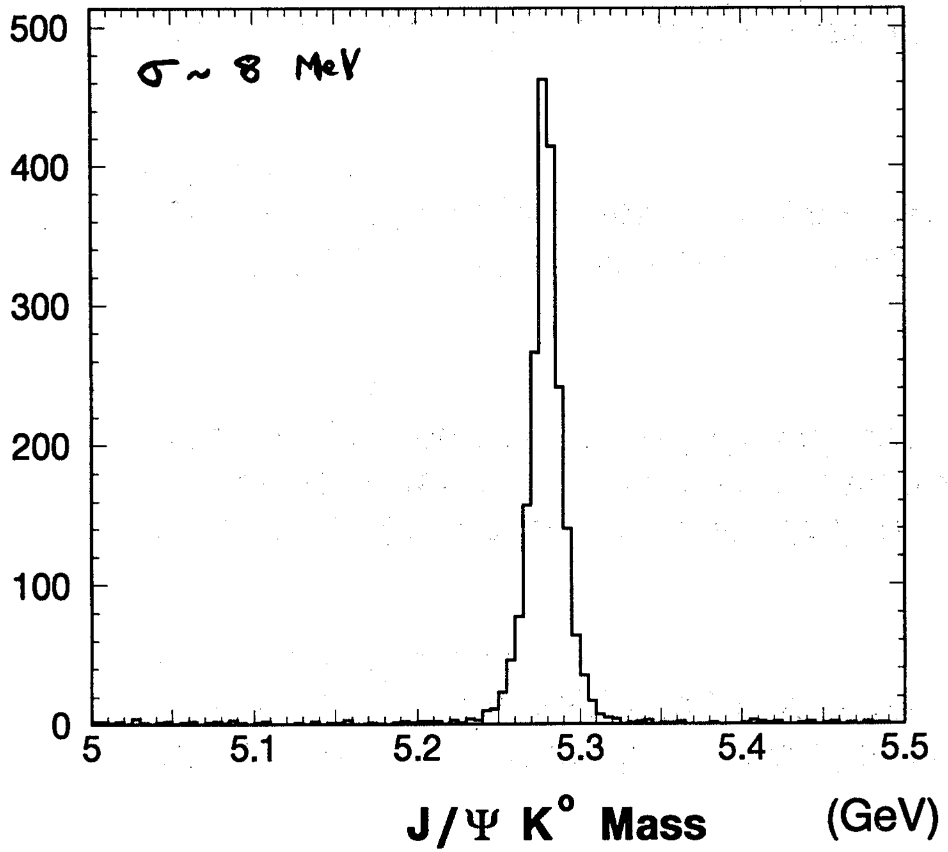
Full Multi-Vertex Reconstruction requires:

$z_B - z_{primary} > 0.5$ mm

Transverse momentum balance at B, and sometimes D, vertices

Reconstruction software written for many different final states and run on Monte-Carlo data samples to find efficiency

Same software packages also run on MIN. BIAS AND inclusive $b\bar{b}$ Monte-Carlo sample to determine the combinatoric background

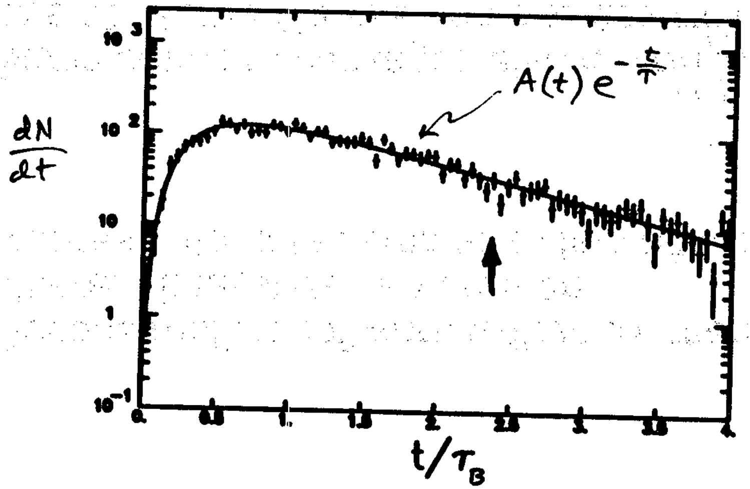


$B_d \longrightarrow J/\psi \ K_s \rightarrow \ell^+\ell^-\pi^+\pi^-$

NO EVIDENCE FOR SIGNIFICANT BACKGROUND IN THIS CHANNEL.

$B \rightarrow \pi^+\pi^-$ UNDER STUDY ($\sigma \sim 20$ MeV WITHOUT SUPERCONDUCTING QUAD)

PROPER TIME DISTRIBUTION ACCEPTED, TRIGGERED, RECONSTRUCTED B-MESONS – SIMULATION



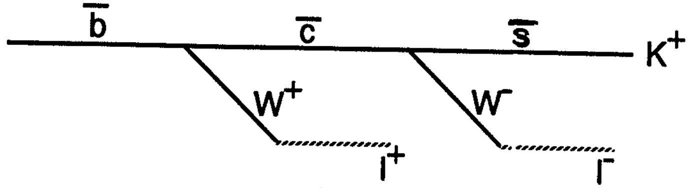
→ DISTORTION OCCURS FOR $t < 1$ MEAN LIFE.

MAXIMUM CP-VIOLATION DIFFERENCES IN $B_d, \bar{B}_d$ DECAYS OCCURS WHEN $\sin(xt) = \sin\left(\frac{\Delta M}{\Gamma}\frac{t}{\tau}\right) = 1$

$\frac{\Delta M}{\Gamma}\frac{t}{\tau} = \frac{\pi}{2} \longrightarrow \frac{t}{\tau} = 2.4$

$\frac{\Delta M}{\Gamma} \leftarrow 0.7$

FLAVOR TAGGING



CUT ON P_t OF ℓ TO SUPPRESS SOFTER ℓ^- (low yield)

Use PYTHIA (depend on its hadronization scheme) to study effectiveness. Oscillation included in generation.

Consider as tags, all reconstructed spectrometer tracks :

High transverse momentum leptons (> 1.2 GeV) - no vertex requirement

$K^{\pm}$ not coming from primary vertex (> 3σ) - using SVX information (~2/3 OF TAGS)

Form event tag as "majority vote" of all tagging particles (usually only 1 voter)

⇒ tagging efficiency = 35.5%
D = 0.37

COMPARATIVE CP - REACH FOR
$B^0_d \rightarrow J/\psi K^0_s$

	LHC Collider	e^+e^- (e.g. SLAC)
Peak Luminosity	$4 \cdot 10^{31}$	$3 \cdot 10^{33}$
$\sigma_{b\bar{b}}$	$3 \cdot 10^{-28}$	$1.2 \cdot 10^{-33}$
2-Arm Geom. Accept.	.55	1.0
Trigger Efficiency	.20	1.0
Reconstruction Eff.	.20	.58
Tagging Efficiency	.36	.45
$D'^2 = I_0 D^2$	.077	.25
Rate = D'^2N (Hz)	$35 \cdot 10^{-5}$	$1.4 \cdot 10^{-5}$
$\boxed{\delta[\sin(2\beta)]}$ $t=2 \cdot 10^7$	$\boxed{0.012}$ (800 pb^{-1})	$\boxed{0.060}$ (60 fb^{-1})

D'^2N also contains BR=$6 \cdot 10^{-5}$ ($B_d \rightarrow \ell^+\ell^- \pi^+\pi^-$), 2x for B and $\bar{B}$ and 0.4 for hadronization probability (0.5 for e^+e^-)

↑

THE "BOTTOM LINE" → { $2{,}4 \times 10^{11}$ $b\bar{b}$ PRODUCED } THE REQUIRED NUMBER FOR ANY HADRON EXP

Expression of Interest

Measurement of CP-violation in B-decays using an LHC extracted beam : The LHB Collaboration

G. Carboni, Pisa

Measurement of CP-violation in B-decays using an LHC extracted beam: an Expression of Interest

The LHB Collaboration

Aarhus [1]- Bologna [2] - CERN [3] - Dubna [4]- Frascati [5] - Genova [6]
Karlsruhe [7]- Lecce [8]- London [9] - Mons [10] - Moscow [11]
Pisa [12] - Roma [13] - Strasbourg [14]
Stuttgart [15] - Torino [16]

Presented by G. Carboni, Pisa

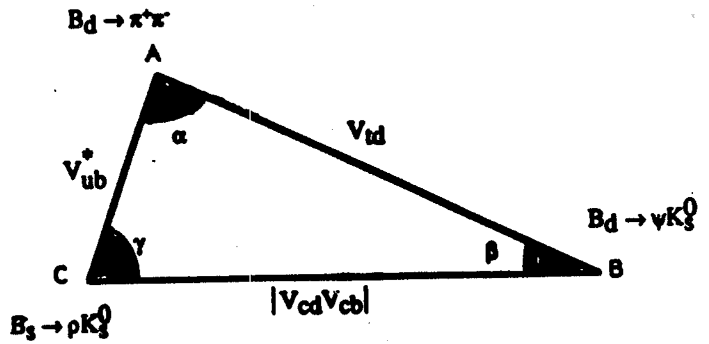
1 ISA, University of Aarhus, Aarhus, Denmark
2 Università di Bologna and INFN, Bologna, Italy
3 CERN, Geneva, Switzerland
4 JINR, Dubna, USSR
5 Laboratori Nazionali di Frascati, Frascati, Italy
6 Università di Genova and INFN, Genova, Italy
7 Institut für Experimentelle Kernphysik, Universität Karlsruhe, Germany
8 Università di Lecce and INFN, Lecce, Italy
9 Imperial College, London, United Kingdom
10 Université de Mons-Hainaut, Mons, Belgium
11 Lebedev Physical Institute, Moscow, USSR
12 Università di Pisa and INFN, Pisa, Italy
13 Università 'La Sapienza' and INFN, Roma, Italy
14 Centre de Recherches Nucléaires, Strasbourg, France
15 Max-Planck Institut für Metallforschung, Stuttgart, Germany
16 Università di Torino and INFN, Torino, Italy

CP violation in B-decays

after >25 years from the discovery of CP-violation no clear-cut evidence for the validity of the SM predictions:

[redacted] = $(2.3 \pm 0.7) \times 10^{-3}$ NA31
$(6.0 \pm 6.9) \times 10^{-4}$ E731 (EPS,1991)

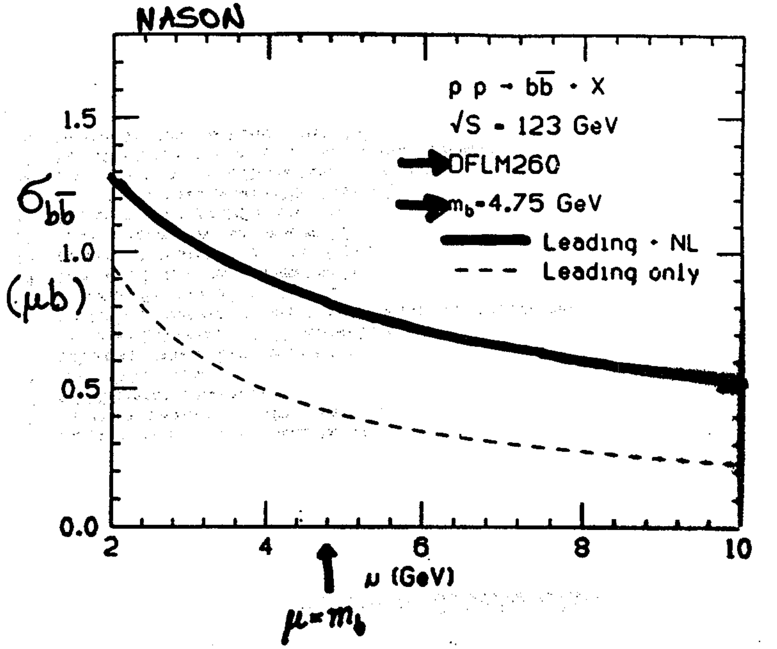
- B experiments are crucial
  - ● complementary information to K^o
  - ● fewer theoretical uncertainties
  - ● large effects, less dependent on m_{top}



☞ direct access to CKM matrix angles/phases.
CP asymmetries are potentially large:

$$A = \sin(2\phi),\ \phi \in \{\alpha,\beta,\gamma\}$$

But: small B.Ratios, need for large ($>10^8$) number of $b\bar{b}$.



$\sigma_{b\bar{b}} = 0.5 - 1\ \mu b$ at $\sqrt{s} = 123$ GeV

- On nuclear target $\sigma_{b\bar{b}} \propto A$, $\sigma_{b\bar{b}}/\sigma_T \propto A^{1/3}$
- 10^{10} $b\bar{b}$/year possible with 2×10^8 p/s beam on a nuclear target 5% λ_{int}

Cu = 7.5 mm
W = 5 mm.
$< m_{ch} > \simeq 20$ (M.BIAS)
$\dot{N}_{int} = 10$ MHz

THE **LHB** PROGRAM

→ Use of the LHC extracted beam, in conjunction with a powerful detector of large acceptance, to collect a large sample of B.pairs (10^{10} in 1-2 years)

→ Precise measurement of the **CP** asymmetries of several B decays, thus overconstraining the CKM matrix → stringent test of the Standard Model

→ Precision studies of

lifetimes
B_s^0 oscillations
rare decays
B- baryons
$B_c^\pm$

THE ADVANTAGES OF THE LHB APPROACH:

- Large Lorentz boost of B's
  (λ_B several cm.)
- Large particle momenta mean less multiple scattering and easier trigger
- Primary vertex Known "a priori"
  (thin target)
- In contrast to jet target or collider-type experiments, full detector optimization possible WITHOUT COMPROMISE

THE **LHB** DETECTOR CONCEPT

- Fully parasitic beam extraction based on channeling in a bent Si XTAL (RD22 experiment on the SPS)
- Angular coverage to virtually zero degrees. Radiation-safe μVTX
- Possible 'visual' observation of **decays** inside a μVTX detector close to the target à la WA92.

TRIGGER : multi-level based on large-P_T leptons & hadrons, + sec. vertex/i.p. trigger

B-TAGGING : based primarily on large-P_T leptons, Other possibilities (e.g. $K^\pm$) under study.

DESIGN NOT YET "FROZEN"

Optimization → simulated response
→ experience from other expts.

The LHB beam extraction

Why conventional extraction cannot be used for LHC ?

- interference with collider operation
- straight sections are probably too short for electrostatic septa

☛ use channeling in a bent crystal , placing crystal in beam natural halo : halo is populated by beam-beam and beam-gas collisions .

$I_{halo} = 4 \times 10^{9}$ protons/s

☛ >10 % bending efficiency (CERN H8 beam test)

$I_{ext} = 4 \times 10^{8}$ protons/s

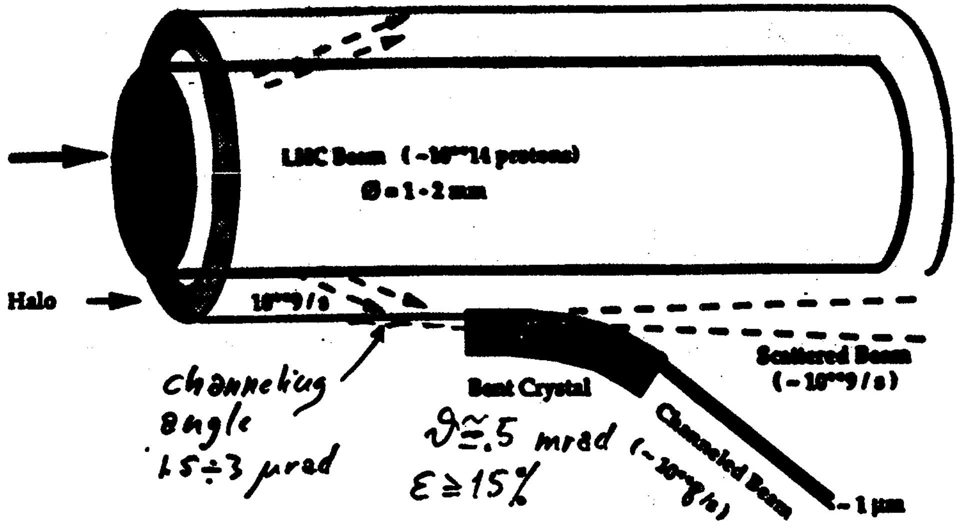


Figure 2: *A schematic view of how a crystal could be used to extract beam from the LHC. Note that only a very small fraction of the thickness of the crystal (typically 1 μm out of a mm) contributes to the bending process. Hence the need for good surface quality and very good alignment of the crystal lattice planes with the edge of the crystal.*

CERN/DRDC 91-25
DRDC/P29
15 July 1991

A proposal to test beam extraction by crystal channeling at the SPS: a first step towards a LHC extracted beam

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ISA, University of Aarhus, Aarhus, Denmark

K. Elsener, G. Fidecaro, M. Fidecaro
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D. Websdale
Imperial College, London, United Kingdom

R. Bellazzini, A. Brez, G. Carboni (*), F. Costantini, S. Lami,
M.M. Massai, M.R. Torquati
Università di Pisa and INFN, Pisa, Italy

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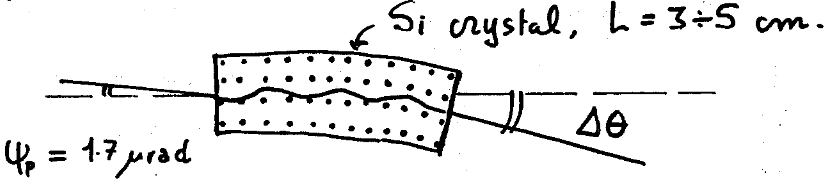
L. Lanceri, P. Poropat
Università di Trieste and INFN, Trieste, Italy

(*) Spokesperson

Approved as RD22

BENDING EFFICIENCY =
ACCEPTANCE ⊗ (1-DECHANNELING)

- ACCEPTANCE



- $|\Psi/\Psi_p| < 1$ OK for LHC/SSC
- "Surface" acceptance ≈ 50% - 80%

- DECHANNELING LOSSES

- Multiple scattering ∝ L_{XTAL} / p
- Bending dechanneling: F(p/R)

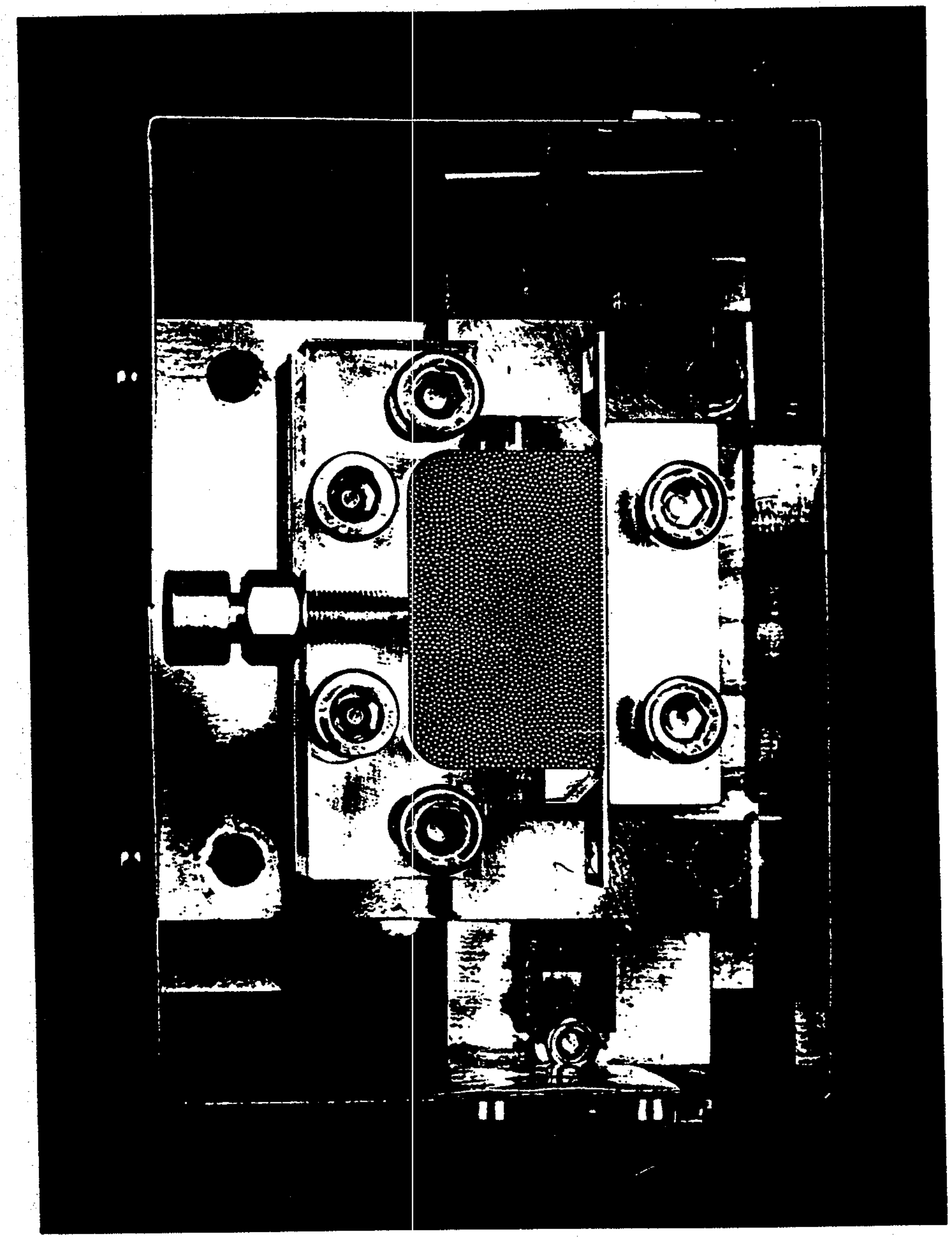
CERN TESTS (S.P. Moller et al., PL B256, 91 (1991)) on H8 micro-beam (divergence ± 3 μrad)

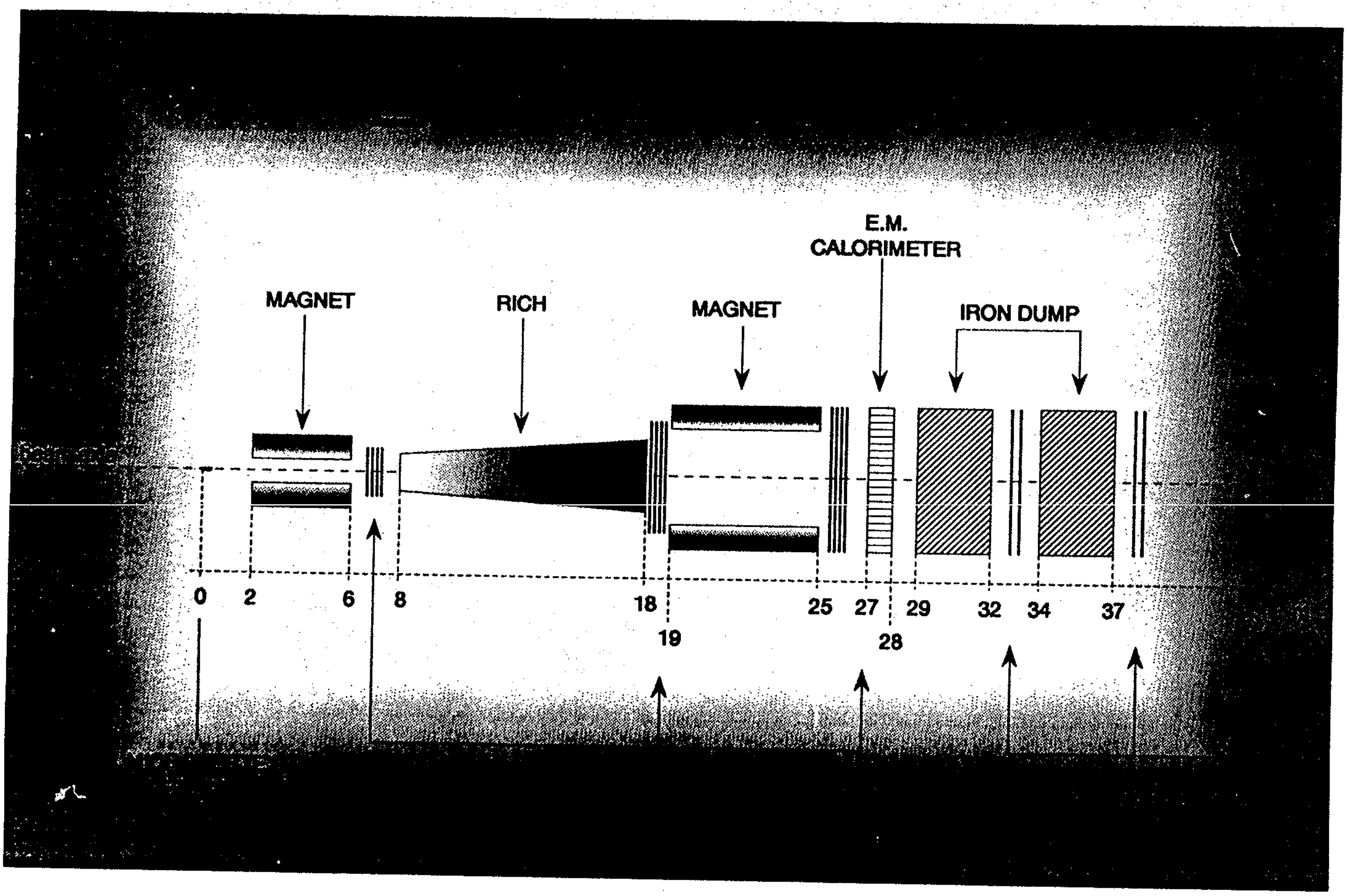
→ $\varepsilon_{bending}$ > 10%, θ = 7 mrad

Good agreement with theory.

RD22 EXPERIMENT BEING INSTALLED NOW ON THE SPS:

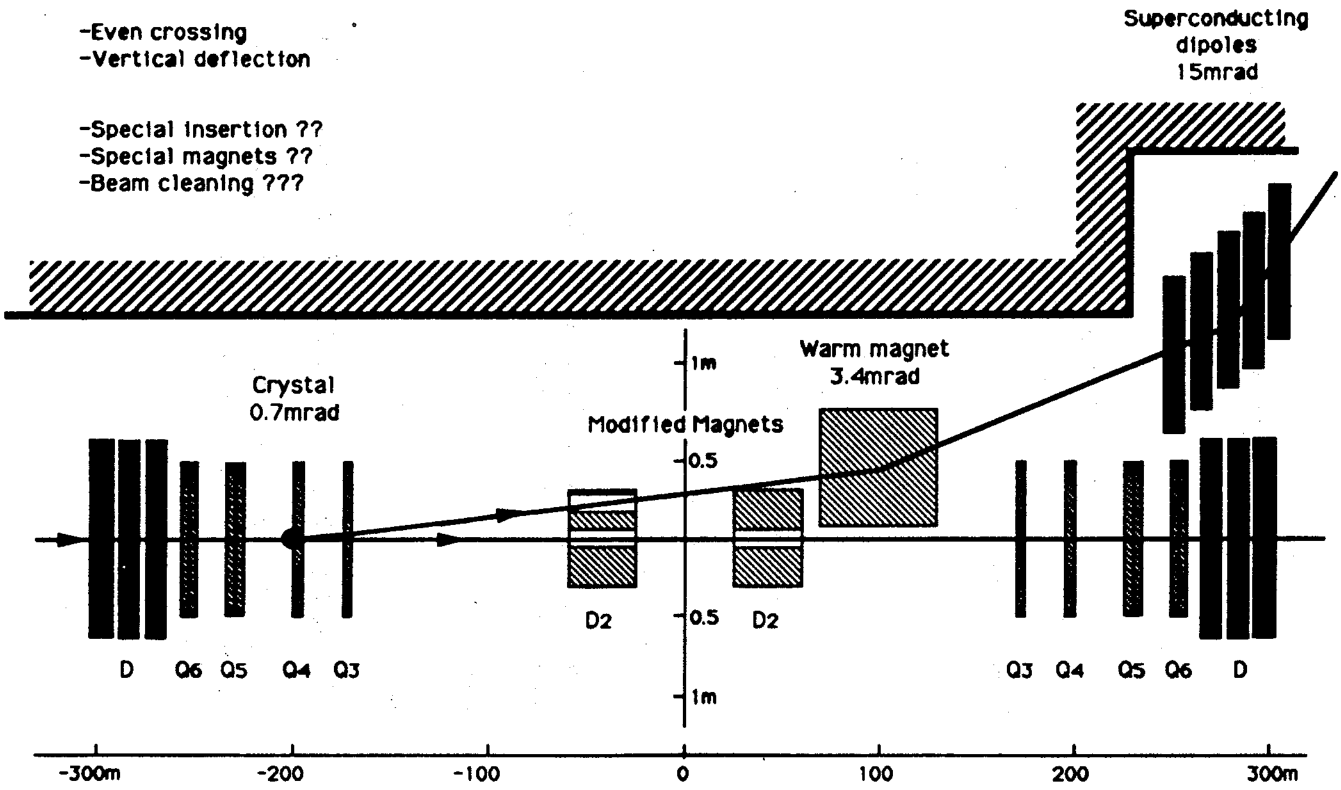
use the SPS to demonstrate that high-efficiency extraction is possible using a bent crystal, with beam conditions similar to LHC ones.





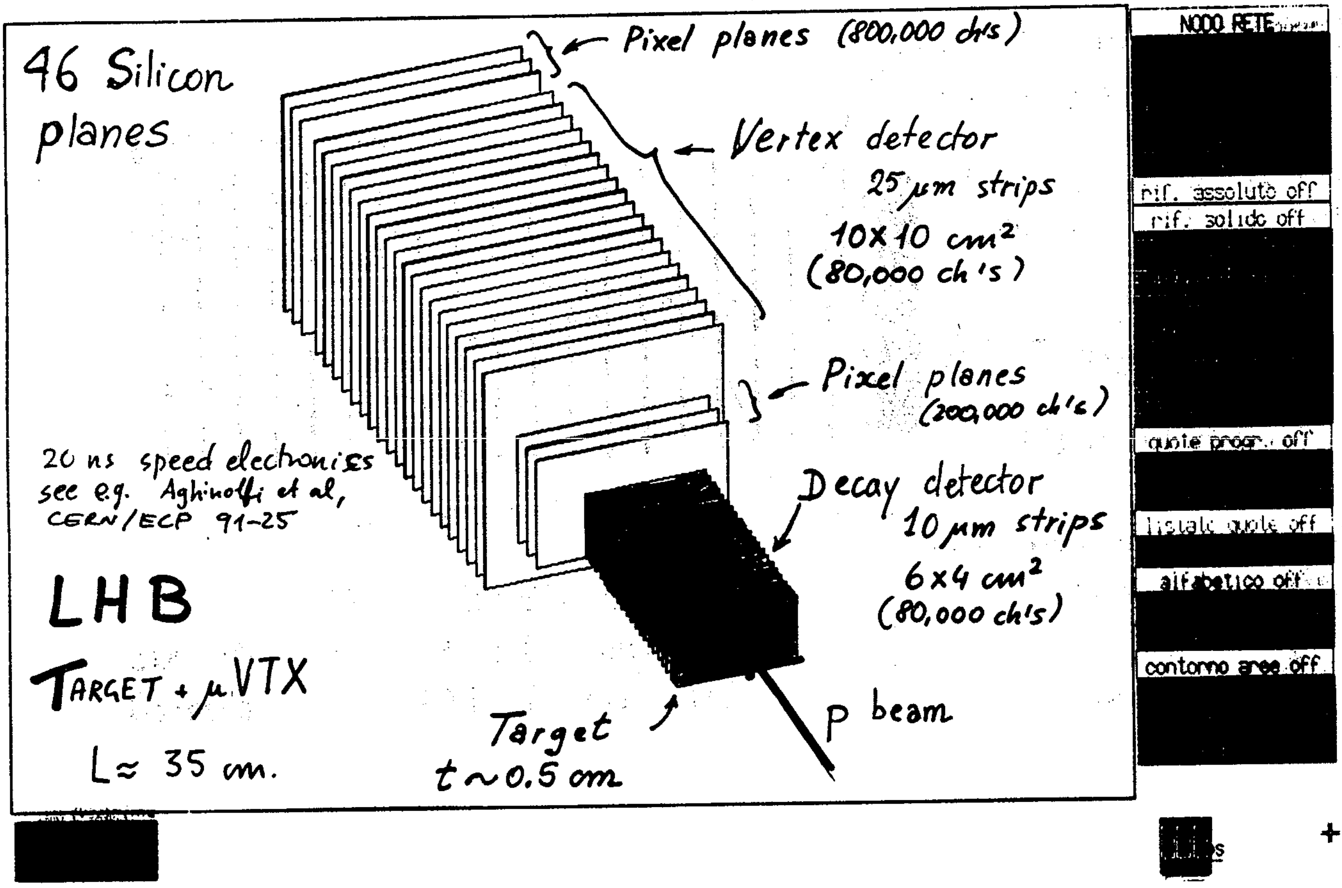
K. M. Potter

Schematic Layout of Halo Extraction using Crystal Channeling



-Even crossing
-Vertical deflection

-Special insertion ??
-Special magnets ??
-Beam cleaning ???



TRACKING IN LHB

$0 < \theta \leq 75$ mrad $\quad > 60\%$ of B's

- 2-Magnet solution looks promising:

  $\int B dl = \pm 7$ Tm $\rightarrow \frac{\delta P}{P} \leq 10^{-4} P \oplus 0.003$

Main advantage: compactness

- High precision tracking built around 1st magnet → small size

  upstream: μ VTX detector

  downstream: 1 m² precise detectors

  Many options →
  - * Si MSD
  - * MS Gas Chambers
  - * Scintillating Fibers

- 2ND Magnet tracking → mostly K_s ($\lambda_{K_s} = 8$m)

  Larger area but resolution less demanding

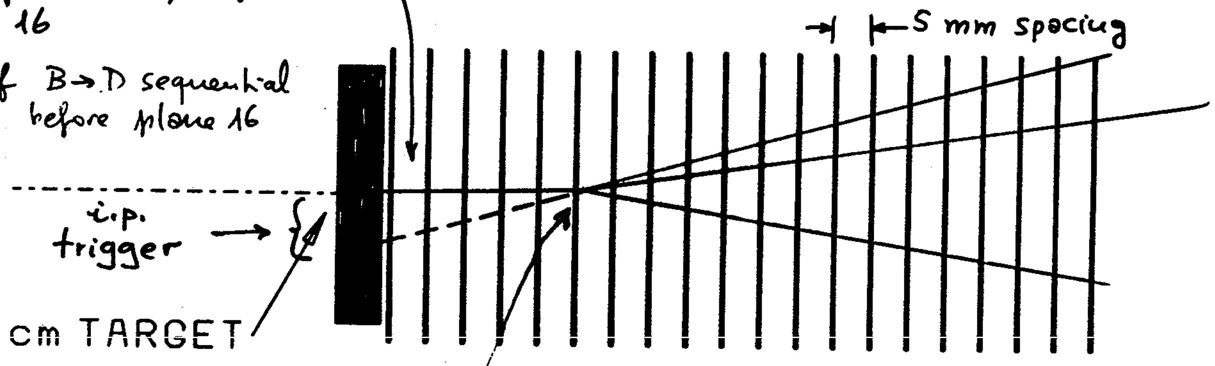
- Space between magnets used for the particle identifier (RICH, TRD?) and for K_s decays

ALSO:
simple P_T trigger scheme

R.Hurst, L.Rossi

LHB Decay Detector

B decay length 2.5 cm
→ 97% of B's decay before plane 16
→ 86% of B→D sequential decays before plane 16

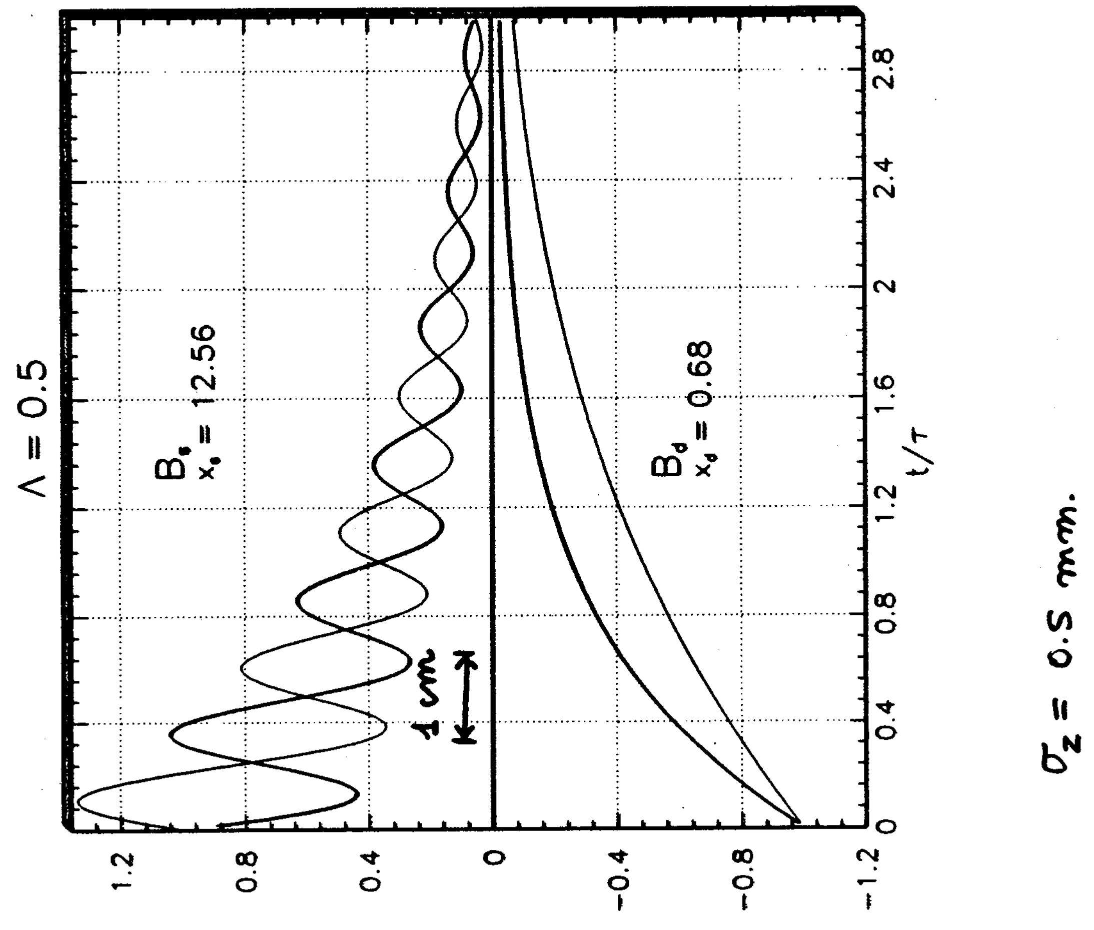


all Z planes

Decay vertices determined with accuracy of
$\sigma_\perp \sim 1 \mu m$
$\sigma_z \sim 0.5$ mm.

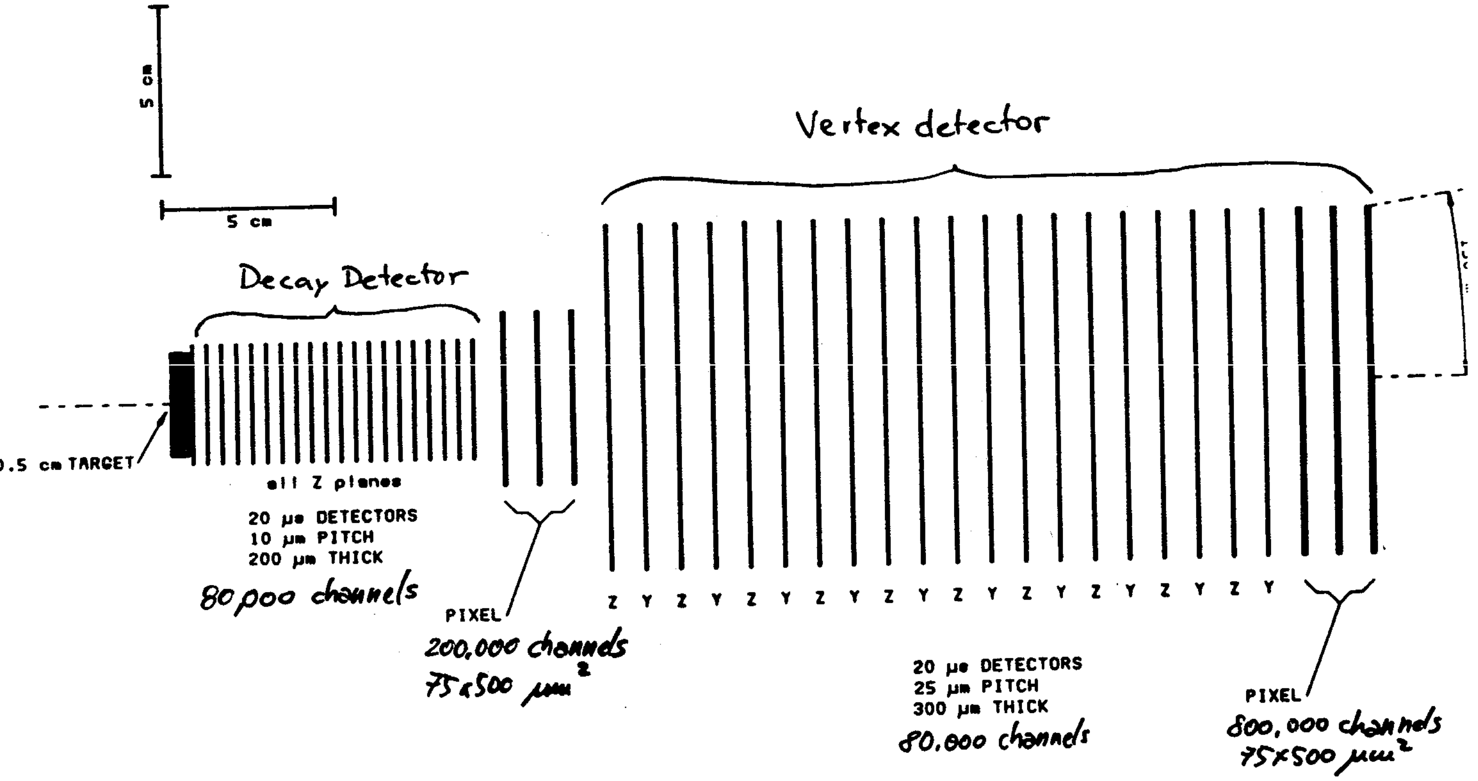
20 μs DETECTORS
10 μm PITCH
200 μm THICK

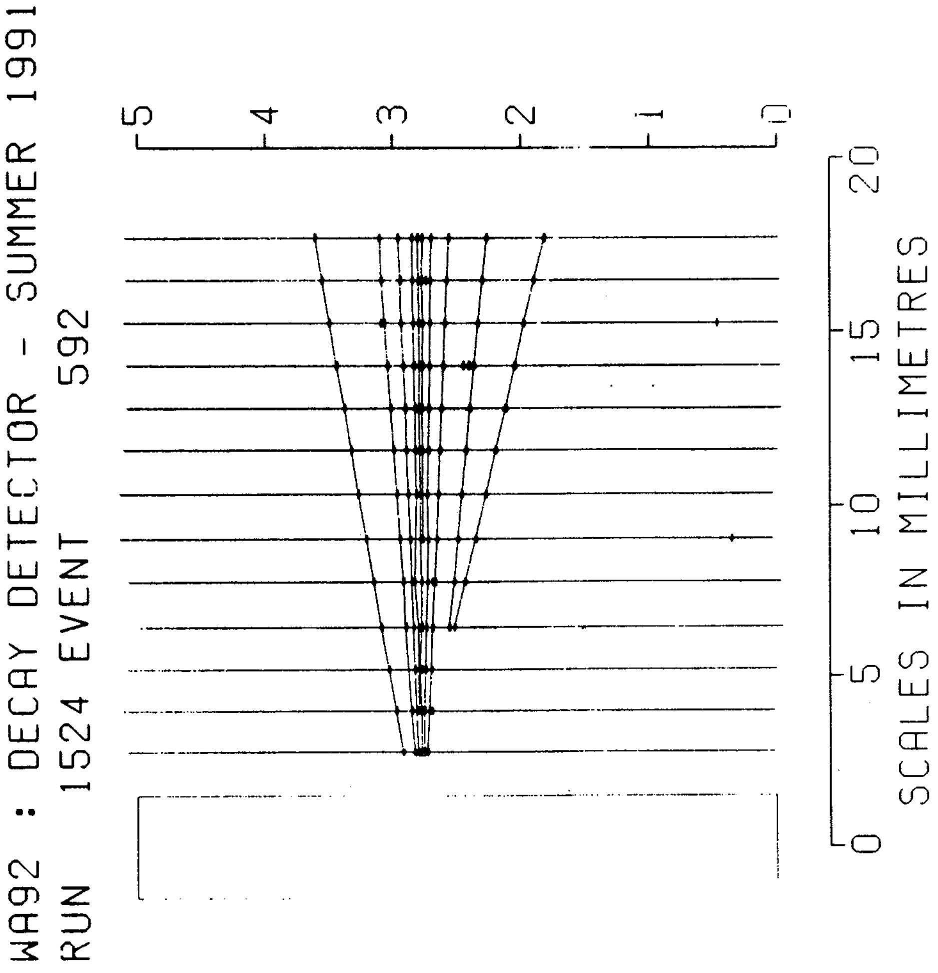
80,000 channels



R.Hurst, L.Rossi

LHB VERTEX DETECTOR



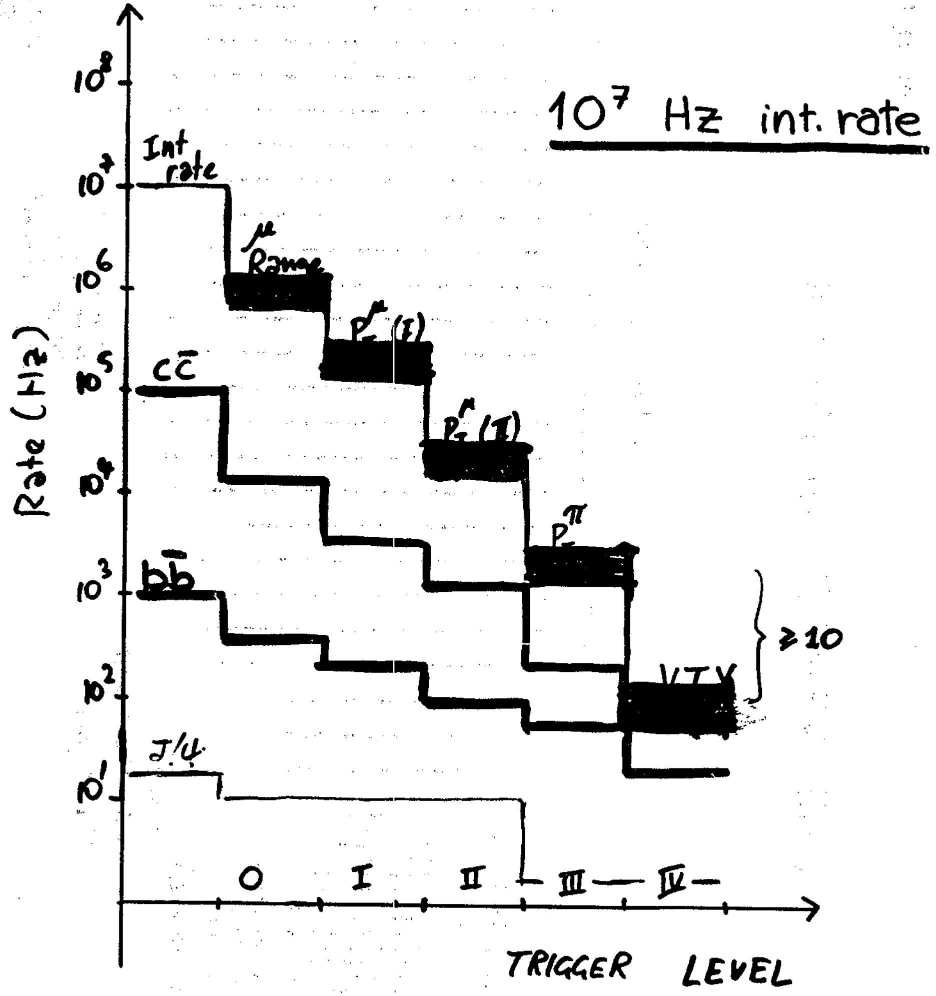


The LHB Trigger

Multi-level type with possibility of specialized triggers for particular decay channels (e.g. $B^0 \rightarrow J/\psi$ Ks and $B^0 \rightarrow \pi^+\pi^-$).

- Levels 0 to 2 : **lepton request** with P_T cut
  Rate : 10 MHz → 20 kHz
- Level 3 : **P_T cut on hadrons** (1 or more)
  Rate : → 2 kHz
- Level 4 : **Impact Parameter** trigger based on fast (< 10 μs) **Contiguity** Mask processor similar to the WA92 model .
  (see G. Darbo, L. Rossi, NIM A289, p. 584,1990).
  Rate : → less than 200 Hz

LHB trigger scheme



B° RECONSTRUCTION AND BACKGROUNDS

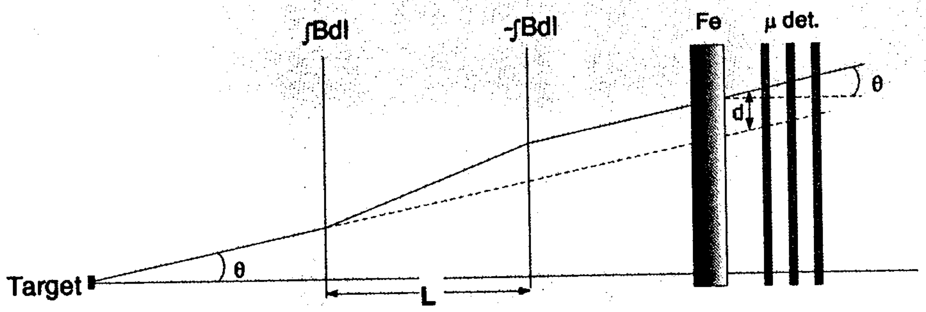
« Benchmark » channels

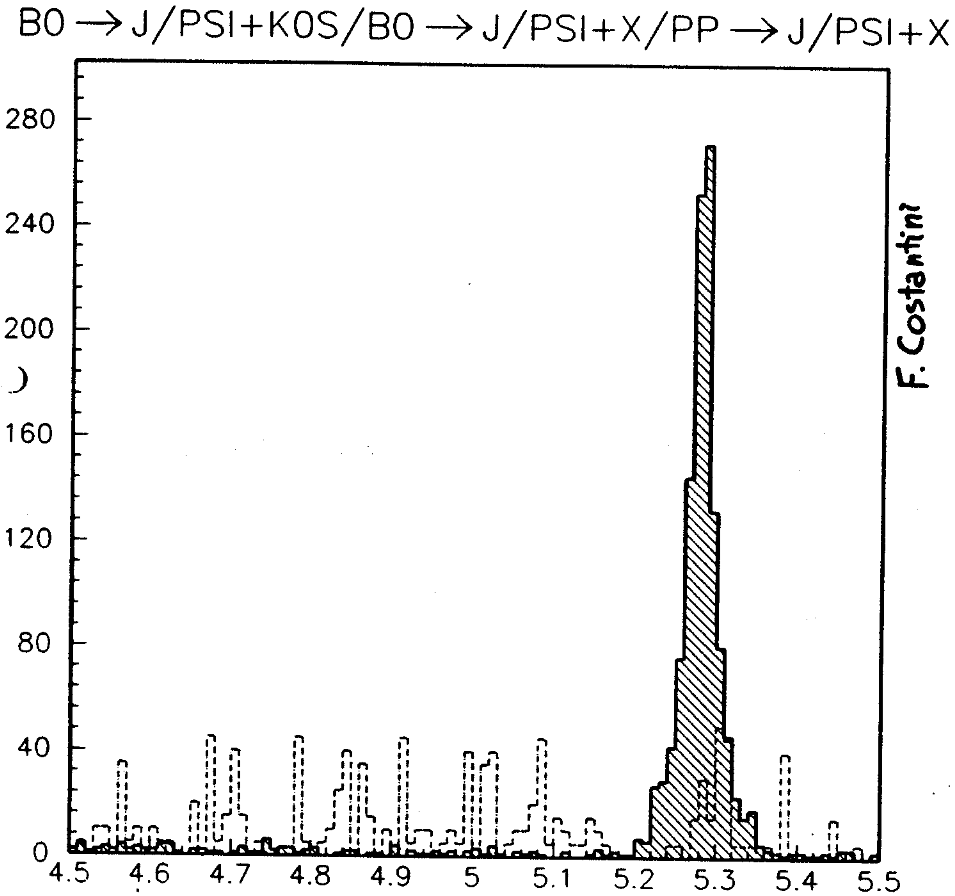
$B^\circ \rightarrow J/\psi\ K_S$

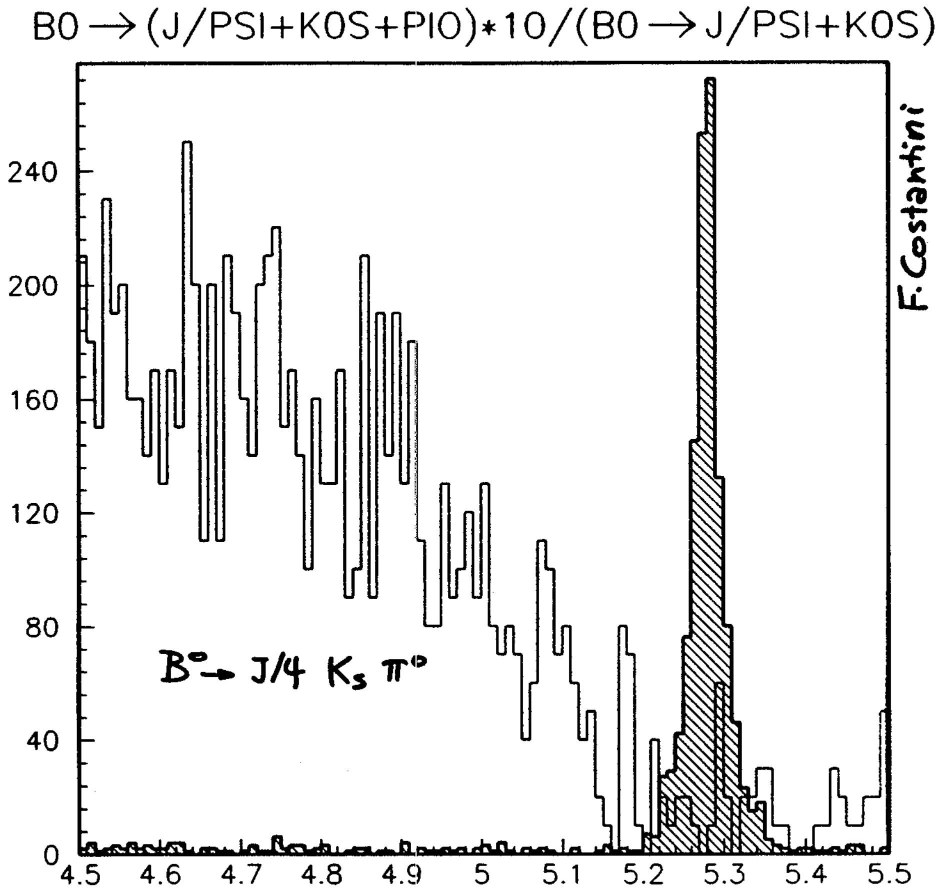
$B^\circ \rightarrow \pi^+\pi^-$

MUON TRIGGER - DOUBLE DIPOLE SCHEME

$$p_T = \frac{k\theta}{d} \qquad k \propto B \cdot L$$




B0 → J/PSI+K0S/B0 → J/PSI+X/PP → J/PSI+X


B0 → (J/PSI+K0S+PI0)*10/(B0 → J/PSI+K0S)

$B^0 \to J/\psi\, K_S \to \ell^+\ell^-\pi^+\pi^-$

BR = $2 \times 2 \cdot 10^{-5}$ $(e+\mu)$

- Reconstructed vertex from $\ell^+\ell^-$ pair at $m_{\ell\ell} = m_{J/\psi}$ and $p_T^{\ell} > 1$ GeV/c (at least 1 lepton)
- $\pi^+\pi^-$ pair at $m_{\pi\pi} = m_{K^0}$, $p_T > 0.6$ GeV/c

The $J/\psi\, K_S$ invariant mass is reconstructed from mass-coustrained fits to the J/ψ and K_S.

Backgrounds :

- Inclusive $B \to J/\psi\, X \oplus K_S$
- J/ψ event $\oplus K_S$
- $B^0 \to J/\psi\, K_S \pi^0$ resonant and non-resonant

→ even without vertex request the background can be reduced to a very small level

plots →

$B^0 \to \pi^+\pi^-$

BR ~ 2×10^{-5} (expected)

- $\pi^+\pi^-$ pair with $p_T^{\pi} > 1$ GeV/c (both π's) and good vertex quality ($d_{12} < 10\mu m$) $m_{\pi\pi} = m_B$
- Require the B momentum to point back to the primary vertex (resol. CRUCIAL)
- Reject events with $m > 2$ at vertex
- Require π tracks I.P. > 100 μm.

Backgrounds:

- $B^0 \to \pi^+\pi^-\pi^0$ (expected 4x BR)
- $B^0 \to \rho^{\pm}\pi^{\mp}$ (" " ")

S/B > 10:1

- $B^0 \to K^+\pi^-$ (expected same BR)

→ PARTICLE I.D. IS CRUCIAL **RICH ?**
$p \leq 300$ GeV/c **TRD !**

R.Wald:

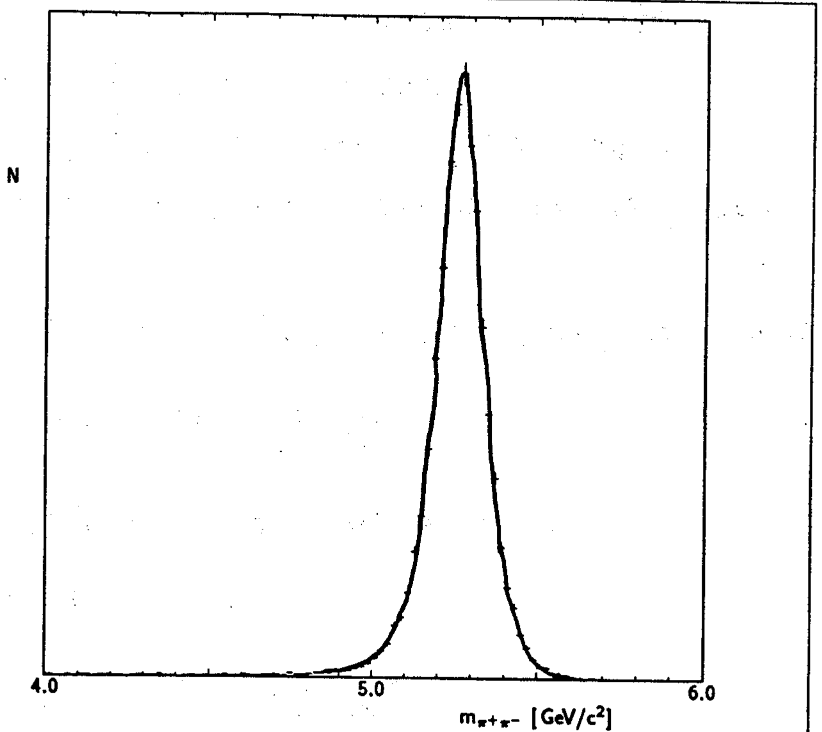


Fig. 1.2 Invariant mass of $\pi^+\pi^-$ from $B \to \pi^+\pi^-$ decays for $p_B < 600$ GeV/c, and detector resolution $\sigma_{p_z}/p_z = 1.0 \cdot 10^{-4} p_z$, $\sigma_{\theta_x} = \sigma_{\theta_y} = 1.0 \cdot 10^{-4}$ and multiple scattering $\sigma_{p_z}/p_z = 1.0 \cdot 10^{-2}$.

$\Delta m = 65$ MeV/c²

R.Wald:

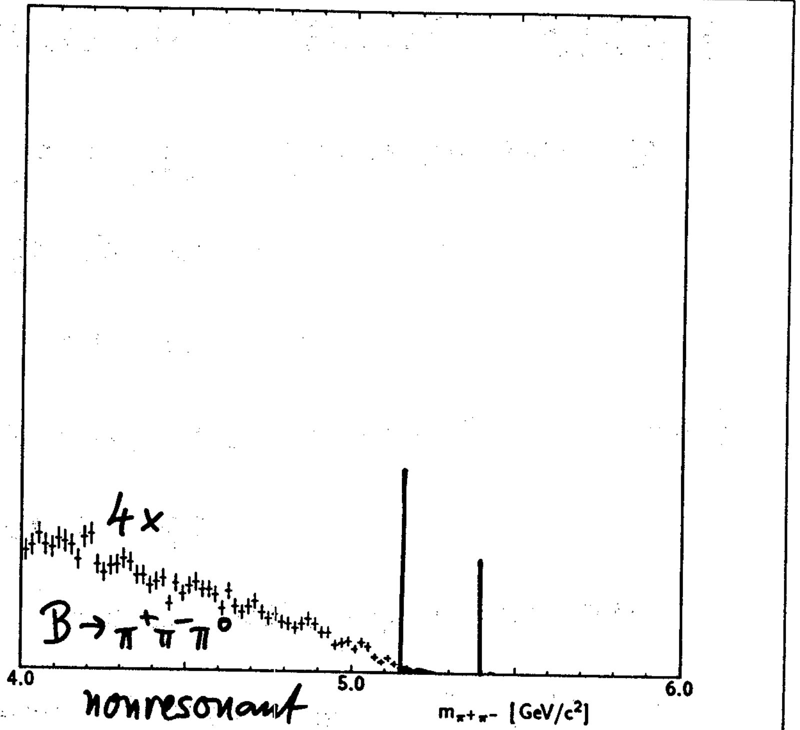


Fig. 1.2 Invariant mass of $\pi^+\pi^-$ from $B \to \pi^+\pi^-\pi^0$ decays for $p_B < 600$ GeV/c, and detector resolution $\sigma_{p_z}/p_z = 1.0 \cdot 10^{-4} p_z$, $\sigma_{\theta_x} = \sigma_{\theta_y} = 1.0 \cdot 10^{-4}$ and multiple scattering $\sigma_{p_z}/p_z = 1.0 \cdot 10^{-2}$.

add $\frac{\delta p}{p}^{2} = 1\%$ mult. Scattering

R. Wald:

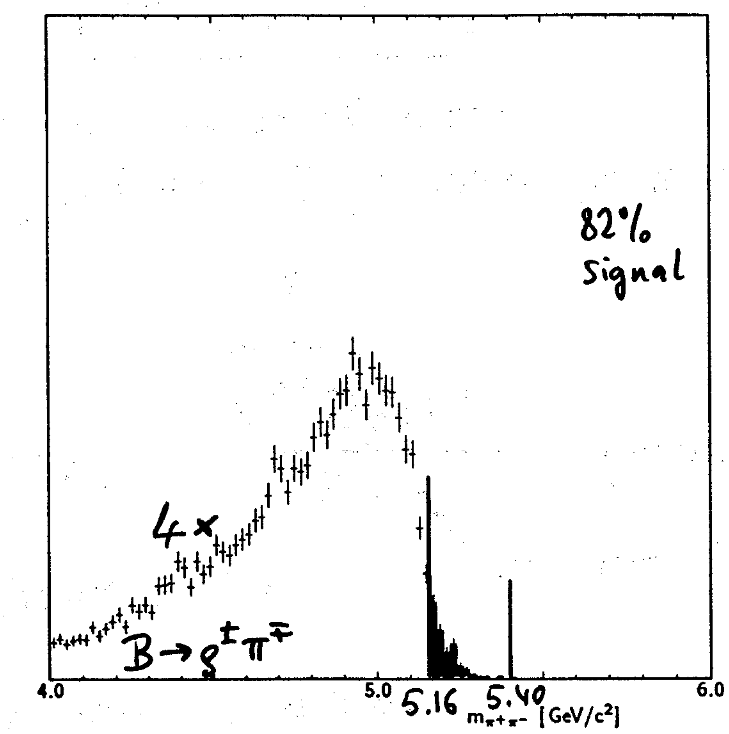
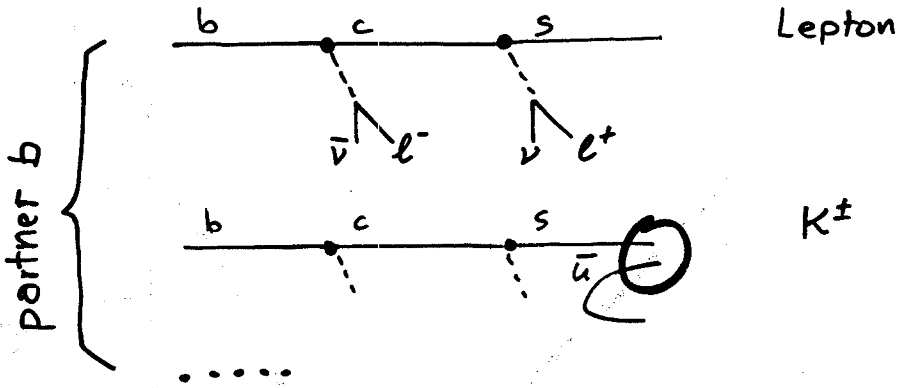


Fig. 1.2 Invariant mass of $\pi^+\pi^-$ from $B \to \pi\rho$ decays for $p_B < 600$ GeV/c, and detector resolution $\sigma_{p_z}/p_z = 1.0 \cdot 10^{-4} p_z$, $\sigma_{\theta_x} = \sigma_{\theta_y} = 1.0 \cdot 10^{-4}$ and multiple scattering $\sigma_{p_z}/p_z = 1.0 \cdot 10^{-2}$.

The tagging of B^0

$$\Lambda \sin(xt) = \frac{N(B^0,t) - N(\bar{B}^0,t)}{\underbrace{N(B^0,t) + N(\bar{B}^0,t)}_{\text{Tagging needed}}}$$

Strategies:



Mis-tags dilute the asymmetry:

$$\Lambda \to D\Lambda$$

$$D = \frac{\text{good} - \text{bad}}{\text{good} + \text{bad}}$$

no tags $\downarrow$ $D=0$

D can be measured precisely from data

Mis-tags occur becouse:

- Partner B^0_d or B^0_s oscillate:

$$\mathbf{D} = \left\langle \frac{1}{1+x^2_{d,s}} \right\rangle \approx 0.75 \quad \text{(PYTHIA)}$$

- Experimental effects:
  e.g. ℓ from c rather than b

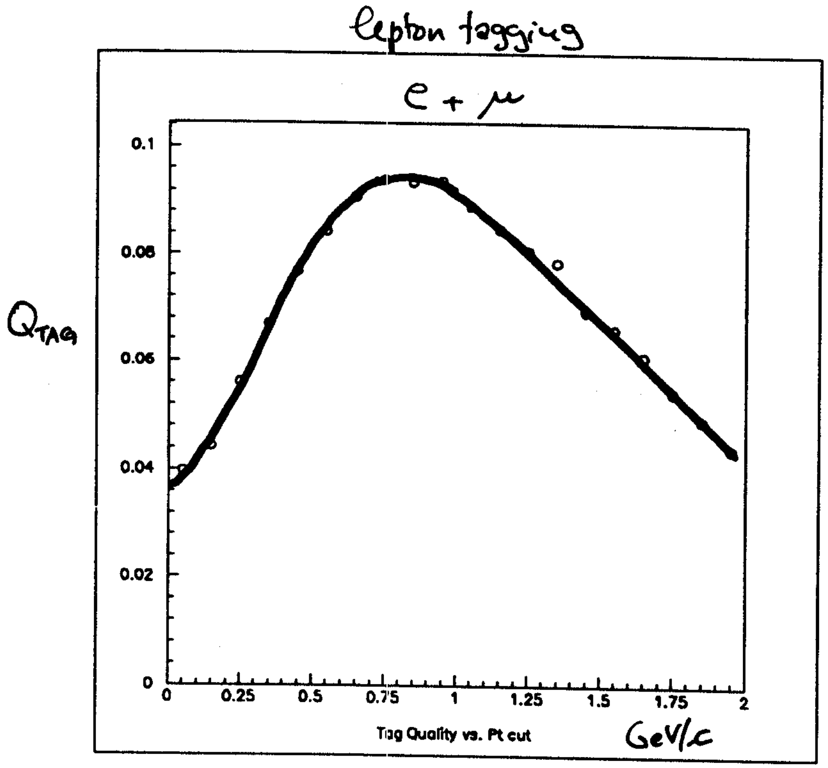
↳ Amount of dilution depends on P_T cut of lepton

ERROR ON Λ

$$(\delta\Lambda)^2 = \frac{\overset{\text{from time-fit}}{3.1}}{\underbrace{\varepsilon_{TAG}\,\mathbf{D}^2}_{\downarrow}\, N_{TOT}} \qquad \text{(statistical)}$$

∘ «Tag quality»: must be optimized as a function of cut.

$$\boxed{P_T \nearrow \rightarrow \mathbf{D} \uparrow \quad \varepsilon_{TAG} \downarrow}$$



LHB sensitivity for B → J/ψ K_s

$B\bar{B}$ pairs		2×10^{10}
Hadronization to $B^0/\bar{B}^0$	.8	1.6×10^{10}
$B^0 \to J/\psi\ K_S \to \ell^+\ell^-\pi^+\pi^-$	4×10^{-5}	640,000
Acceptance 2-75 mrad + K_s	.40	256,000
Rec. efficiency	.80	200,000
Trigger efficiency	.60	120,000
Tag. efficiency ($p_T^{\ell} > 1$)	.16	19,000
Dilution $\langle 1/(1+x^2)\rangle^2$	$(.75)^2$	10,600
$(g-b)^2/(g+b)^2$	$(.75)^2$	5,900
Fit efficiency	.32	1,900
<u>ERROR ON A</u>		± 0.023

LHB sensitivity for $B^0 \to \pi^+\pi^-$

$B\bar{B}$ pairs		2×10^{10}
Hadronization to $B^0/\bar{B}^0$	.8	1.6×10^{10}
$B^0 \to \pi^+\pi^-$	2×10^{-5}	320,000
Acceptance 2-75 mrad	.74	236,000
Rec. efficiency	.90	212,000
Selection cuts (p_T, etc.)	.45	95,000
Trigger efficiency	.60	57,000
Tag. efficiency ($p_T^{\ell} > 1$)	.16	9,000
Dilution $\langle 1/(1+x^2)\rangle^2$	$(.75)^2$	5,000
$(g-b)^2/(g+b)^2$	$(.75)^2$	2,800
Fit efficiency	.32	900
<u>ERROR ON A</u>		± 0.033

CONCLUSIONS :

PROVIDED THAT

- THE CRYSTAL EXTRACTION TEST IS SUCCESSFUL
- THE CRYSTAL CAN BE INTEGRATED INTO THE LHC LATTICE

LHB can

TRIGGER on B's

RECONSTRUCT B's

TAG B's

WITH VERY GOOD EFFICIENCY, SMALL BACKGROUND AND EXCELLENT CONTROL OF SYSTEMATICS, TO MEASURE CP VIOLATION PRECISELY.

Comparing different options: $B \rightarrow J/\psi\ K_s$

	LHB 8 TeV/c	SLAC e+e-	CDF 1.8 TeV
$B\bar{B}$ / 2 years	2×10^{10}	7×10^{7}	1×10^{10}
$B^o/\bar{B}^o$	1.6×10^{10}	1.4×10^{8}	8×10^{9}
$B^o \rightarrow J/\psi\ K_S \rightarrow \ell^+\ell^-\ \pi^+\pi^-$ (4×10^{-5})	640,000	5,600	320,000
Acceptance	.40	1.0	.0083
Trigger efficiency	.60	1.0	
Reconstr. efficiency	.80	.58	
Tagging efficiency	.16 (e,μ)	.45	.04
$(\text{Dilution})^2 \times$ fit efficiency	.10	.25	.11
<u>ERROR ON Δ</u>	± 0.023	± 0.052	± 0.29

Expression of Interest

A study of CP violation in B-meson decays using a gas jet at LHC

T. Nakada (PSI)

An experiment to study CP violation in the $B\bar{B}$ system using an internal GAS JET at LHC

CERN
Ferrara; INFN and Uni. Phys. Dept.
Genova ; INFN and Uni. Phys. Dept.
Lausanne Uni.
Paul Scherrer Institute
Saclay ; D.A.P.N.I.A.
Torino; INFN and Uni. Phys. Dept.
Yerevan; Physics Institute

- Physics:
  - CP violation in B-meson decays such as $B \rightarrow J/\psi K_s$, $\pi^+\pi^-$

  can be well predicted by two parameter of the CKM matrix ρ and η.

  - ρ and η "are" determined by B-meson decays

$$\Downarrow$$

the best way to test quantitatively

the standard model as a

description of CP violation.

golden channels

$B \to \psi K_s,\ \pi^+\pi^-$

also of interests

$B \to K\pi,\ K\bar{K}$

and to study systematics.

$B^{\pm} \to \psi K^{*\pm}$

$B^0 \to \psi K^{*0}$, $K^{*0} \to K^+\pi^-$ $\left(\bar{B}^0 \to \psi \bar{K}^{*0},\ \bar{K}^{*0} \to K^-\pi^+\right)$

⋮

---- few body final states

and many others

- Why internal gas jet target ?

☹ $\sigma_{b\bar{b}}$ is "only" $\sim 1\,\mu b$

and $\sigma_{b\bar{b}}/\sigma_{inelastic} \sim 2 \times 10^{-5}$

But

😐 the well defined primary vertex

$\sigma_{xy} \approx 75\,\mu m$: beam
$\sigma_z \approx \pm 1\,mm$: gas jet

$\Downarrow$

"fast" and "effective"
triggering based on
the impact parameter

☺ · high luminosity of $\mathcal{L} \approx 2 \cdot 10^{33}\,cm^{-2}s^{-1}$
can be exploited.
i.e. $2 \times 10^{10}\ b\bar{b}$ @ 10^7 sec

(2 events/crossing but no effect
on the impact parameter trigger)

Note that

gas jet targets have been successfully used @ ISR, $Sp\bar{p}S$, FNAL, LEAR,

-----

no interference to machines

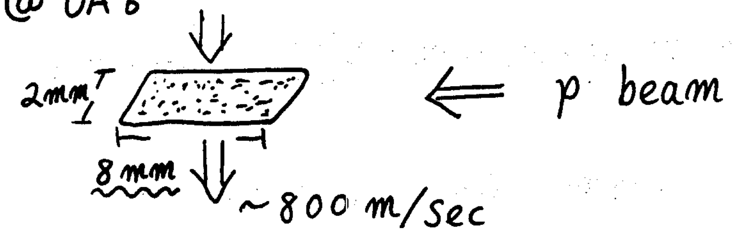
or to other experiments

$\Rightarrow$ UA6

7 years @ $Sp\bar{p}S$

- Gas jet

@ UA6



density $4 \cdot 10^{14}$ p/cm^3

~ along the beam $4 \cdot 10^{14} \times 0.8 = \underline{3.2 \cdot 10^{14} \text{p/cm}^2}$

$\Uparrow$

very "thin" target

no conversions,

secondary interactions

surrounded gas density is small

Note: 4.81×10^{14} p @ LHC

crossing 11246 times

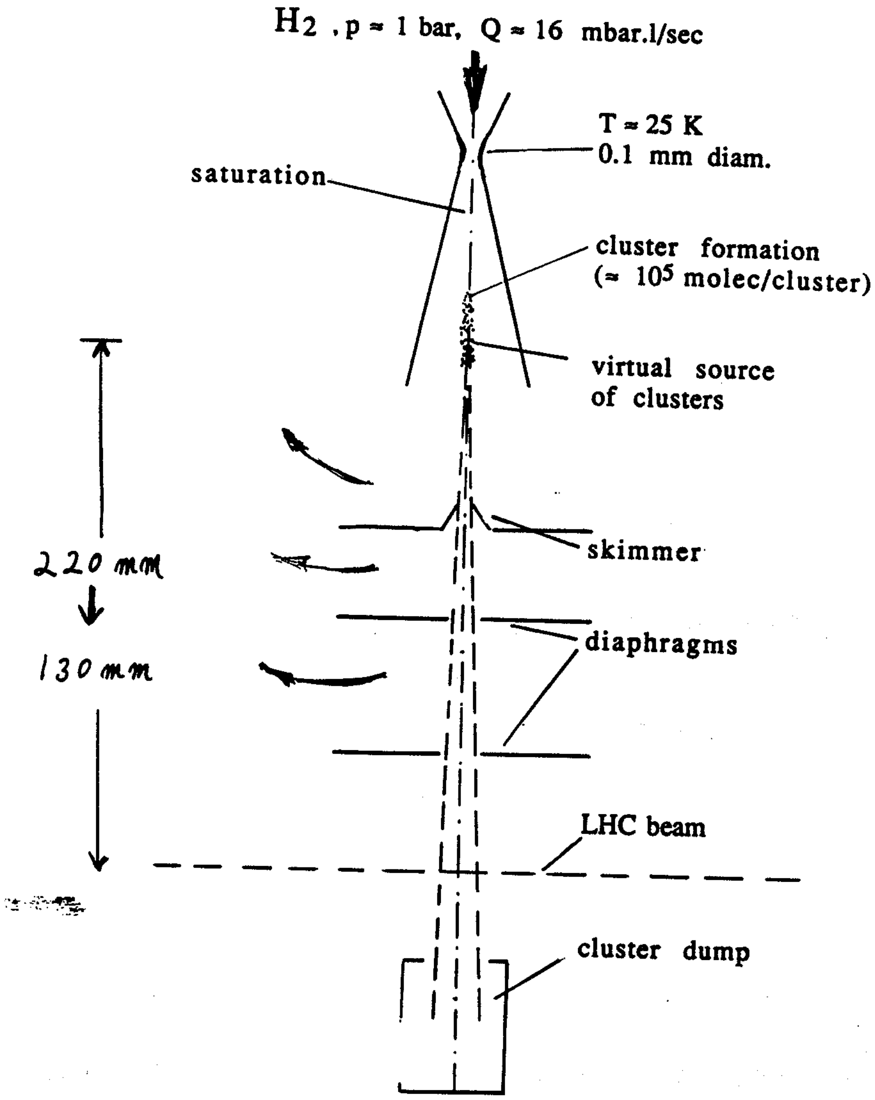
equivalent to 5.4×10^{18} p/sec

extructed beam

how can we reduce 8mm → 2mm

keeping 3.2×10^{14} p/cm^2 ?

Cluster beam



Improvements to the cluster beam

1.Reduce the dimension of the jet along the beam

from 8 mm to 2 mm

by suitably changing the skimmer shape

2.Increase the jet density by

- reducing the distance between the nozzle and the beam from 220 mm to 130 mm
- increasing the gas throughput by about a factor 1.66 (this is possible since due to the smaller skimmer and diaphragms the pressure gradient can be higher)

nominal LHC jet target thickness:

$$TT = 3.2 \cdot 10^{14} \frac{2}{8} \frac{220^2}{130^2} 1.66 = 3.8 \cdot 10^{14} \text{ atoms/cm}^2$$

• Rates with this gas jet:

$\mathcal{L}$ = jet density along the beam × No. of p circulating × LHC rev. frequency

$= 3.8 \cdot 10^{14} p/cm^2 \times 4.81 \cdot 10^{14} p \times 11246\ Hz$

$= 2 \times 10^{33}\ cm^{-2}\ s^{-1}$

gas jet @ 8 TeV LHC beam $= \sqrt{s} = 123$ GeV

$\sigma_{b\bar{b}} = 1\ \mu b$

with 10^7 sec = 100 days

$n_{b\bar{b}} = \mathcal{L} \times \sigma_{b\bar{b}} \times time$

$= 2 \times 10^{33} \cdot 10^{-30} \times 10^7$

$= 2 \cdot 10^{10}$ $b\bar{b}$ pairs

Note $\sigma_{b\bar{b}}/\sigma_{inelastic} = 2 \times 10^{-5}$ can be improved by >2.3 by a heavy gas jet, Ar .....

USE OF HEAVY GASES IN JET (ATOMIC WT. = A)

LET $\sigma^{pp}_{B\bar{B}}$ = $B\bar{B}$ PRODUCTION CROSS-SECTION IN pp COLLISIONS

$\sigma^{A}_{B\bar{B}}$ = $B\bar{B}$ PRODUCTION CROSS SECTION IN pA COLLISIONS

THEN IS EXPECTED THAT

$$\sigma^{A}_{B\bar{B}} = A^{0.95}\ \sigma^{pp}_{B\bar{B}}$$

WE ALSO KNOW THAT FOR σ_{TOT} ($\equiv$ MINIMUM BIAS)

$$\sigma^{A}_{TOT} = A^{0.72}\ \sigma^{pp}_{TOT}$$

$$\therefore \quad \frac{\sigma^{A}_{B\bar{B}}}{\sigma^{A}_{TOT}} = \underbrace{\frac{A^{0.95}}{A^{0.72}}}_{F} \cdot \frac{\sigma^{pp}_{B\bar{B}}}{\sigma^{pp}_{TOT}}$$

$F = 2.3$, FOR ARGON $A = 40$

→ FOR ARGON THE $N^{B\bar{B}}/N_{MIN.BIAS}$ WOULD ∴ BE LARGEN THAN IN HYDROGEN BY A FACTOR OF 2.3

→ EITHER HAVE ×2.3 $N_{B\bar{B}}$ THAN IN HYDROGEN

→ OR REDUCE JET DENSITY TO HAVE SAME NUMBER OF $B\bar{B}$ AS IN HYDROGEN BUT REDUCE MINIMUM BIAS AND THEREFORE OCCUPANCY AND RADIATION DAMAGE BY A FACTOR OF 2.3.

- Where can we put such an experiment ?

in one of LEP (even) interaction regions:

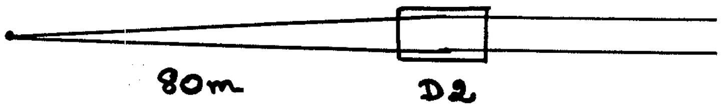
⟹ minimize excavation + infrastructure costs

with modified "cleaning optics"

WHERE ? INSTALL EXPERIMENT IN A LEP (EVEN) INTERACTION REGION IN ORDER TO MINIMIZE EXCAVATION AND INFRA STRUCTURE COSTS.

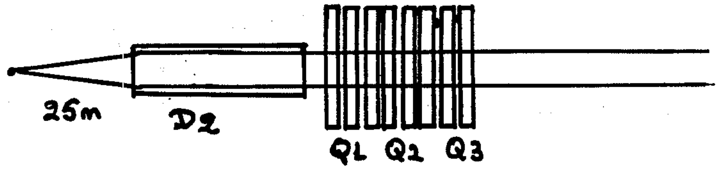
OPTICS ?

"DUMP" OPTICS



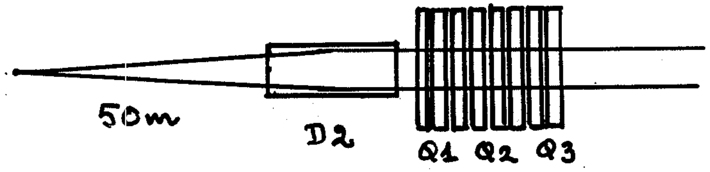
JUST NEEDS THE D2 RECOMBINATION MAGNET ± 80 m FREE SPACE BUT BEAM SIZE $\sigma = 170\ \mu m$ TOO BIG ! FOR IMPACT PARAMETER

"CLEANING OPTICS" (COLLIMATORS).



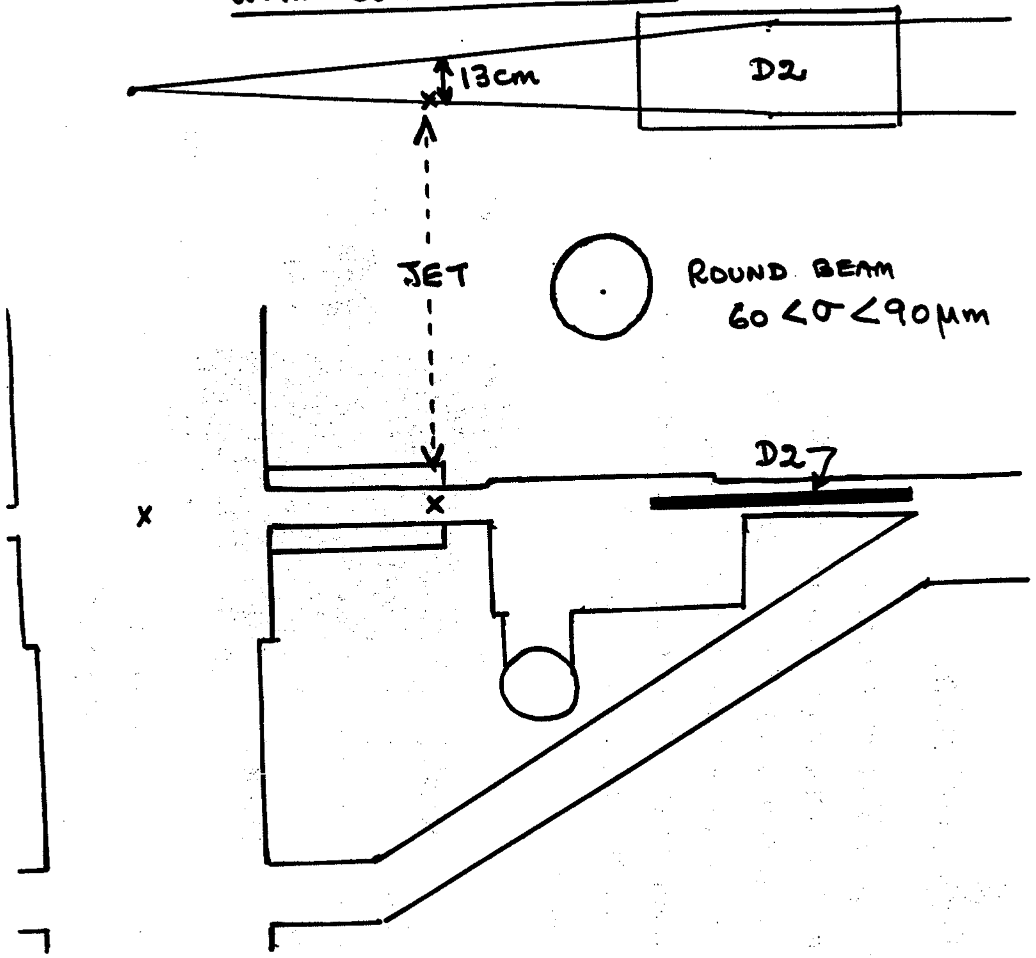
ONLY ±25m FREE SPACE

" COMPROMISE"



±50 m FREE SPACE BEAM SIZE 60 — 90 μm

JET IN EXISTING LEP INTERACTION REGION WITH "COMPROMISE" OPTICS



NOTE:- IT IS ALREADY FORESEEN TO DISPLACE BEAMS VERTICALLY BY 2mm TO SUPPRESS COLLISIONS IN REGIONS WITHOUT COLLIDING BEAM EXPERIMENTS.

- Can we design a detector?

  - triggering devices (pre-trigger)

    using

    - optical trigger (< 15 nsec)

      and

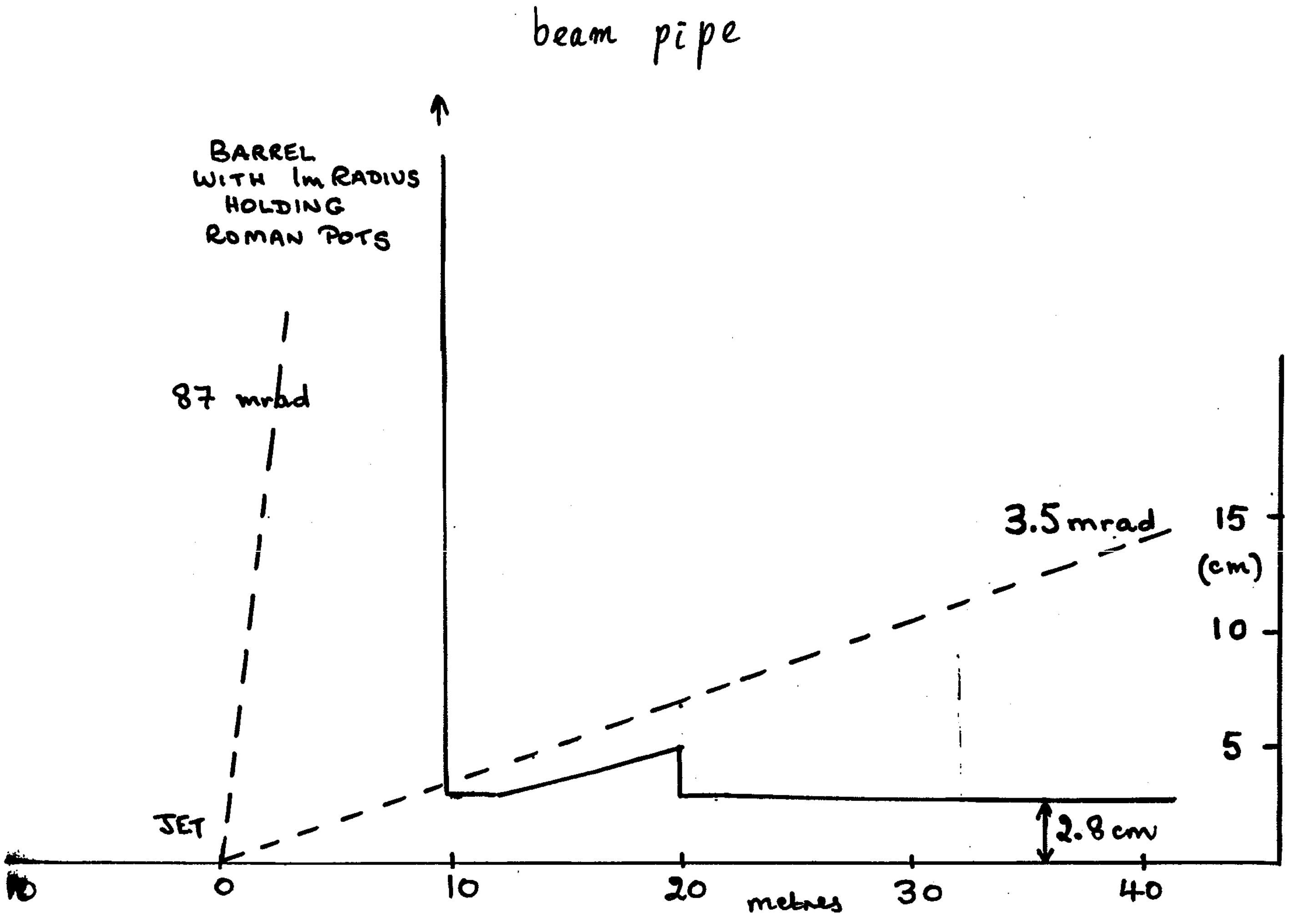
    - Si impact parameter trigger (< 300 nsec)

    placed in the Roman Pots ⇐ ISR, $Sp\bar{p}S$
    @ 15 σ_{beam}.

    Simulation study shows
    combination of two gives
    B efficiency $\varepsilon_{trig} = 30\%$
    minimum bias suppression = 1/100

    ⇒ ~1.5 μsec for futher sophisticated trigger.

    (3μ trigger for J/ψ Ks ?...)



GaSjet Detector

V: gas jet + optical trigger + Si vertex detector

T1+T2: charged particle tracking system (σ =100 μm, 2×2% X_0)

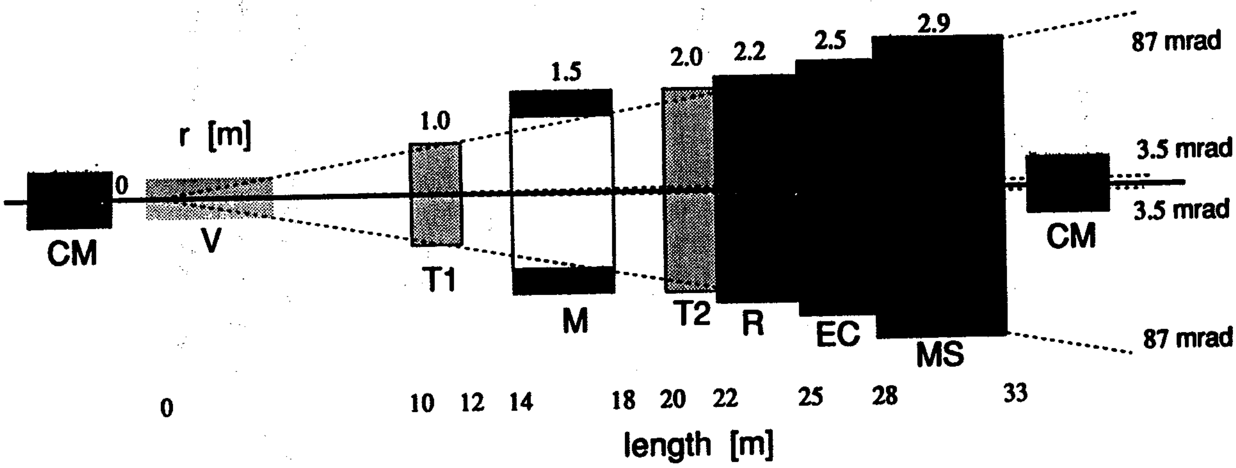
M: magnet (gap = 300 cm, BDL = 4.95 Tm ≈ 1.5 GeV P_t kick)

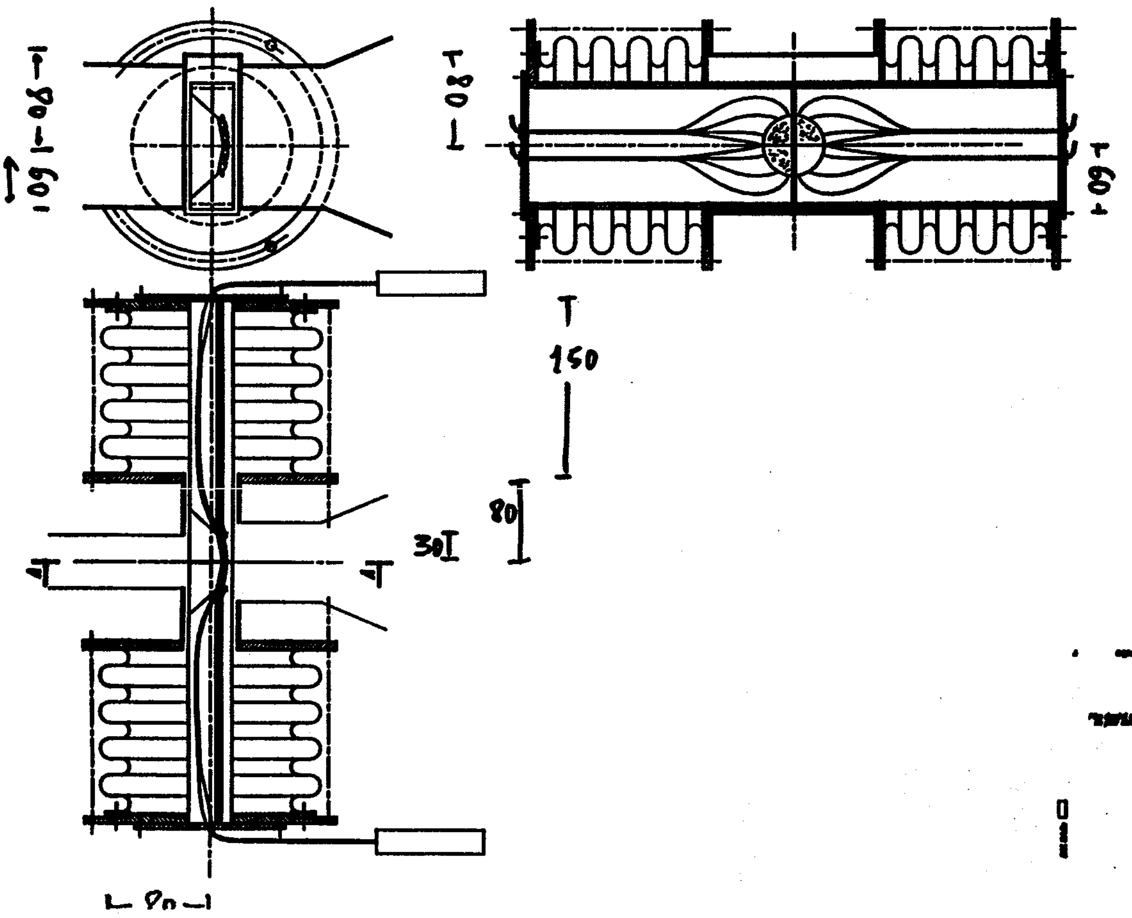
R: RICH (r = 6–220 cm, K/π separation up to 300 GeV/*c*)

EC: electromagnetic calorimeter (r=10–250 cm, e/hadron < 5×10^{-3})

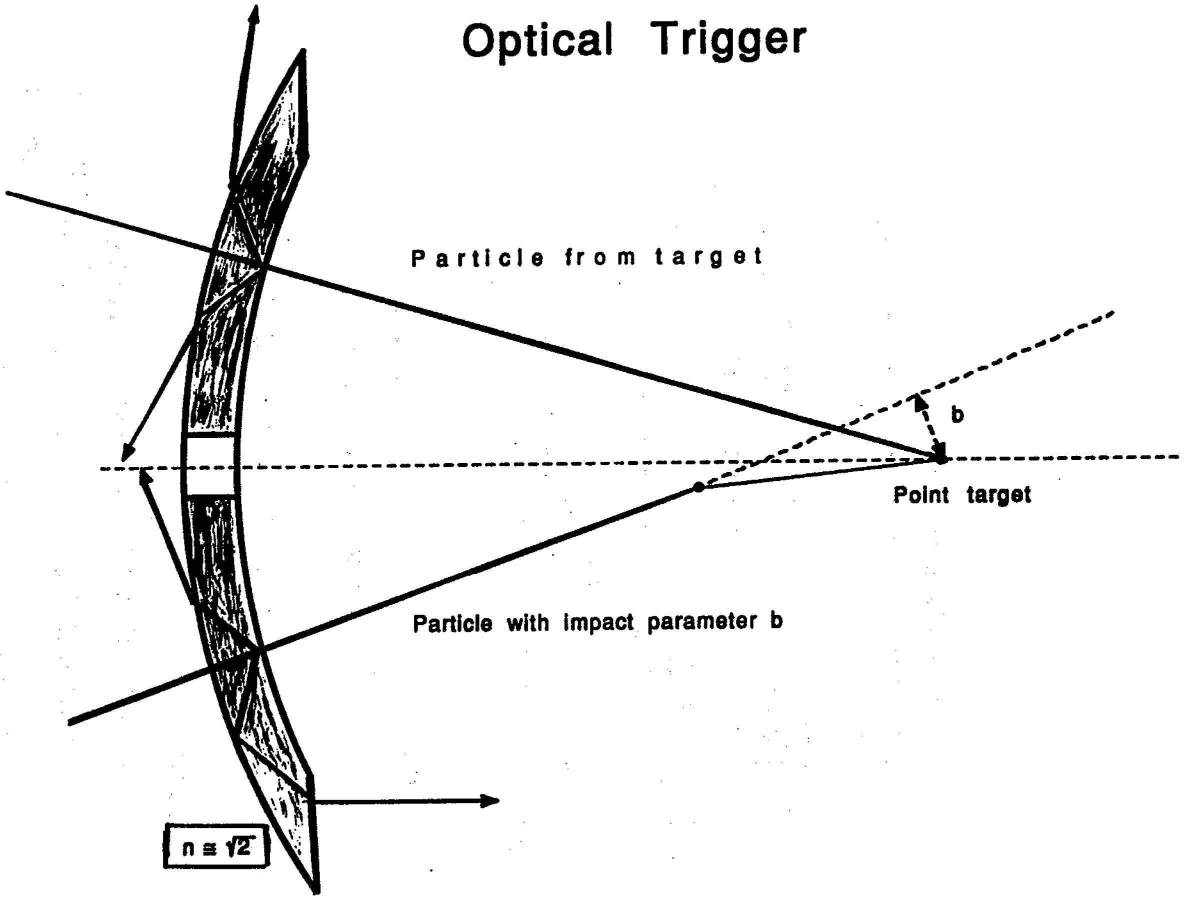
MS: muon system (r = 10–290 cm, μ/hadron < 5×10^{-3})

CM: compensating magnets



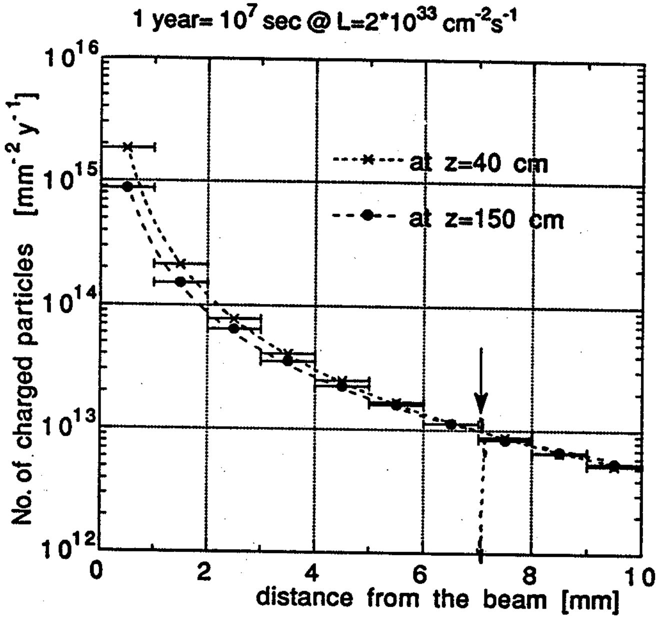


Optical Trigger



Si

how far from the beam ?



With Si, limit is @ ~ 10^{12} /mm^2

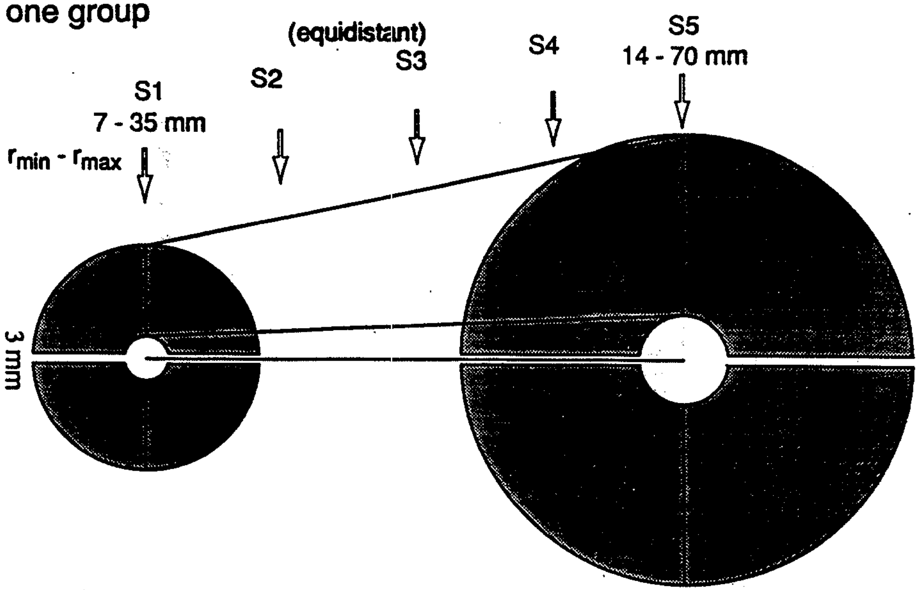
but

- electronics is far away
- small surface 924 mm^2 × 4 ← replacing several times
- no full depletion required

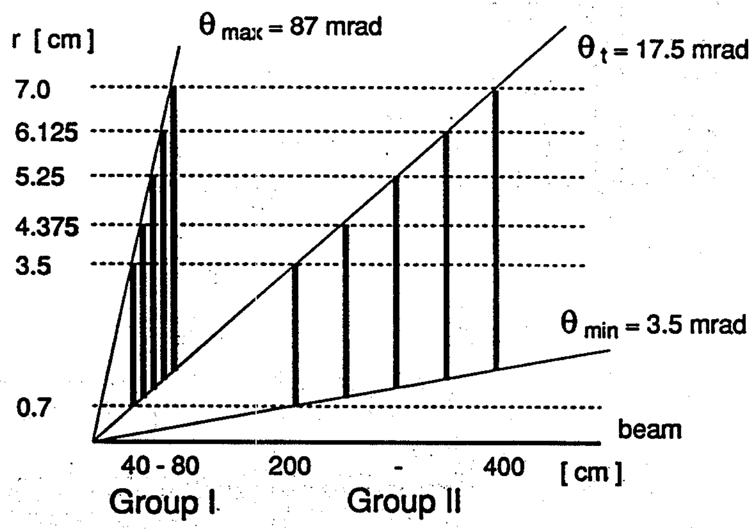
⇒ 10^{13} /mm^2

Vertex Detector system

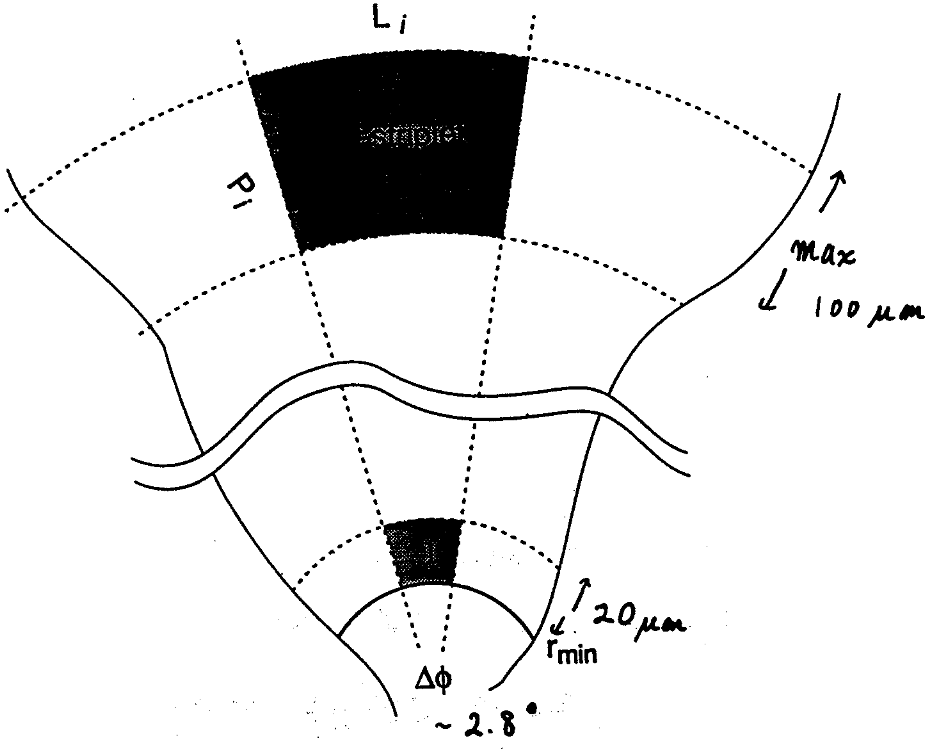
one group



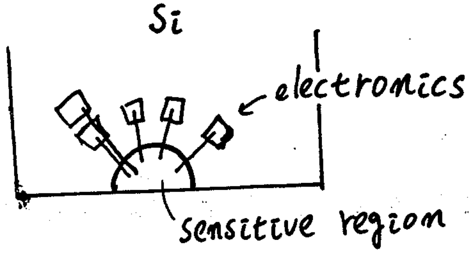
complete system



Striplet detector



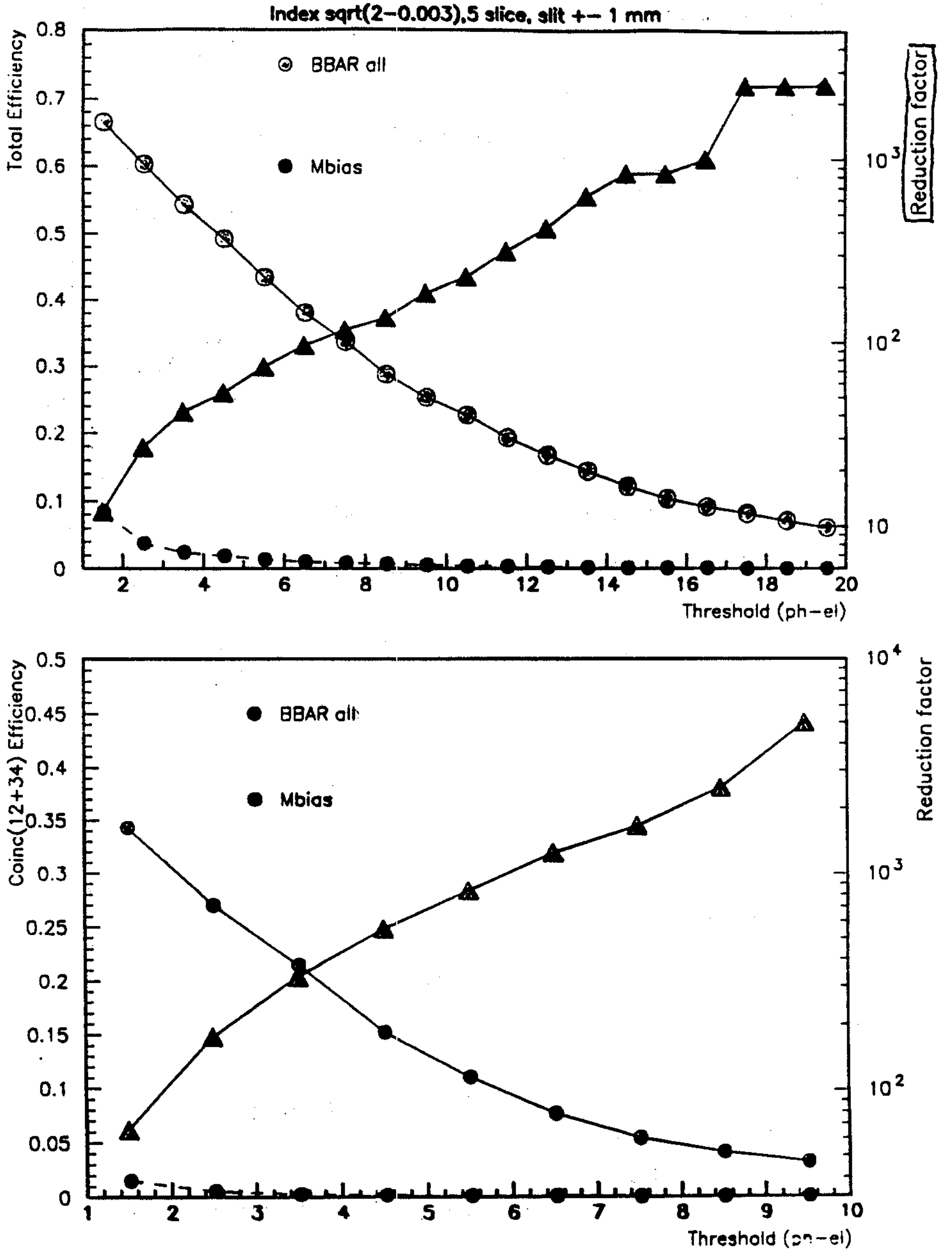
18K channels/quadrant



$\sigma_x \simeq \sigma_y = $ [illegible] μm

$\sigma_z = 1$ [illegible]

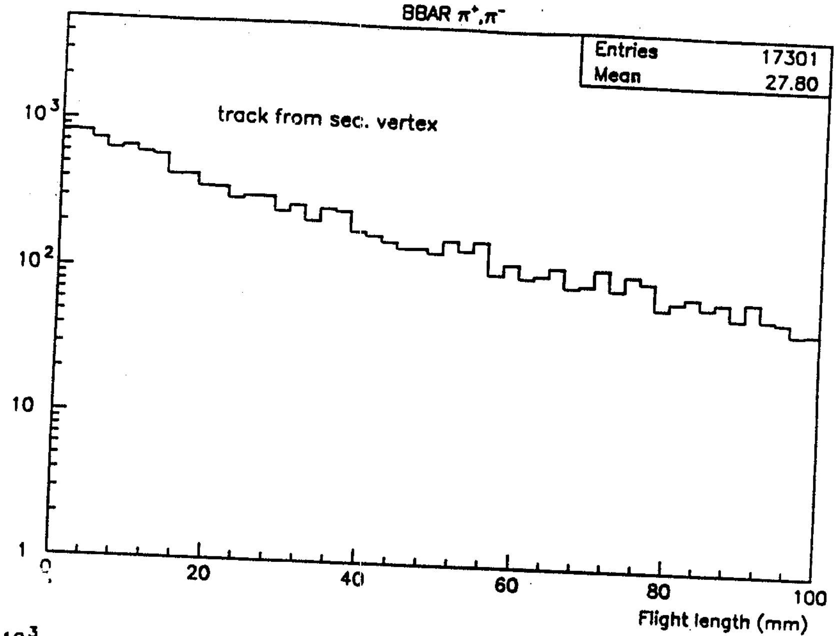
25/02/92 16.18

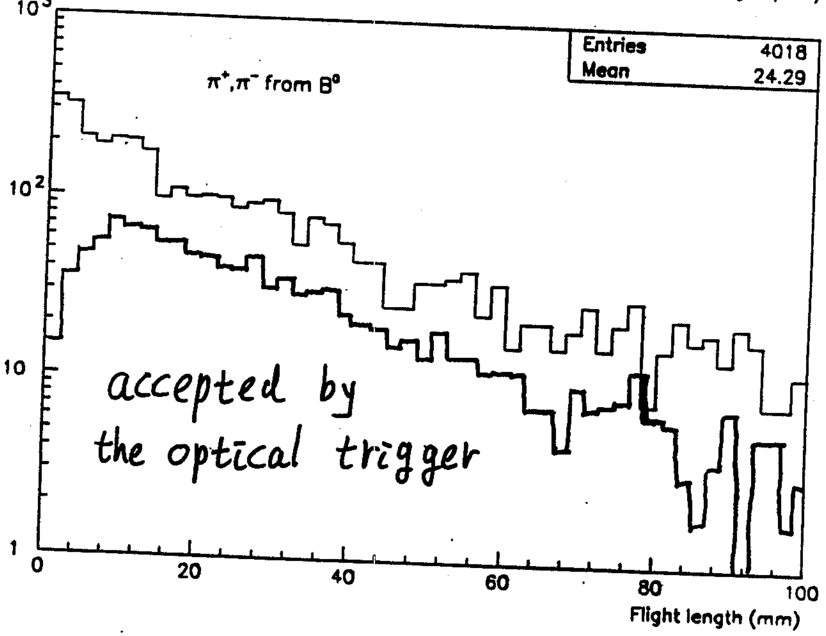


- secondary vertex reconstruction etc.

- trigger selects B decays with large flight path
  $\Rightarrow$ small loss in the off-line analysis

27/02/92 15.07





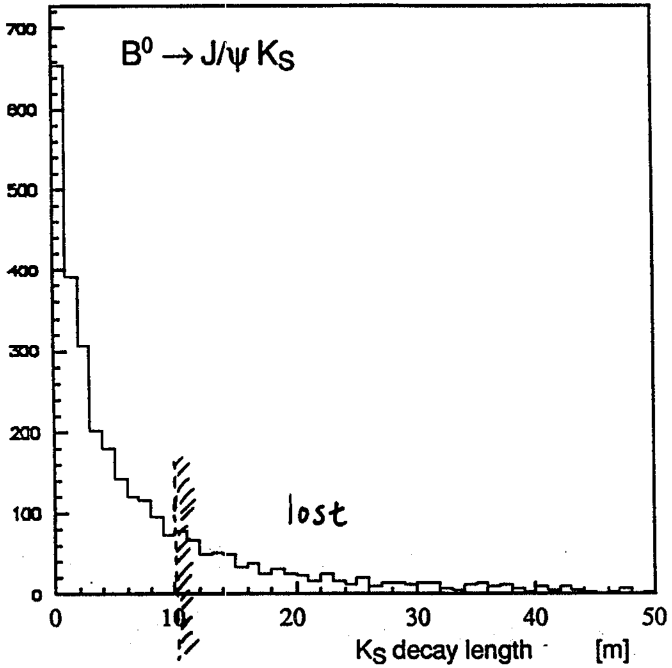
• reconstruction of final states

a magnetic spectrometer with

$$\frac{\sigma_p}{p^2} < 10^{-4}$$

- strip Si vertex detectors
  $\sigma \sim 8\mu m$

- tracking chambers @ 10 + 12 m
  $\sigma \sim 100\mu m$ for θ_{in}
  $\Rightarrow$ K_S acceptance
  @ 20 + 22 m
  $\sigma \sim 100\mu m$ for θ_{out}

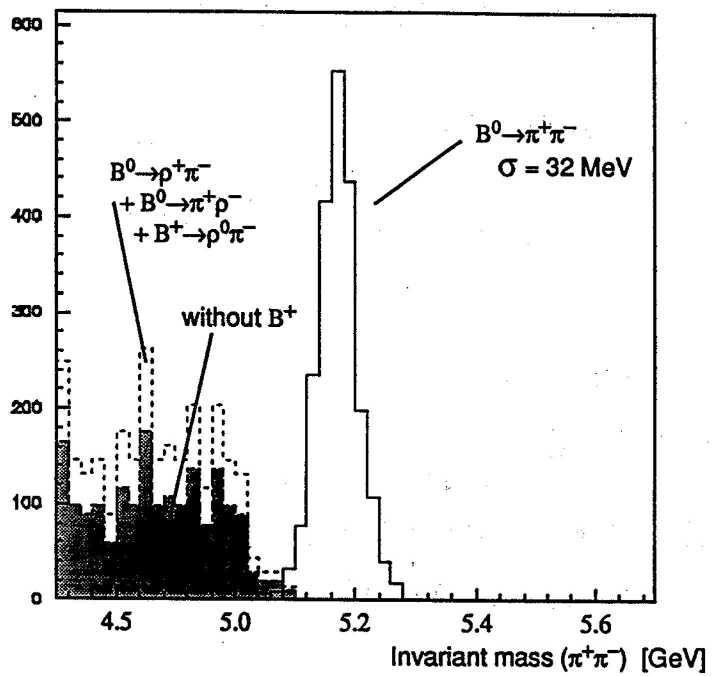


$\sigma_{m\, J/\psi\, K_S} = 27$ MeV

$\sigma_{m\, \pi^+\pi^-} = 32$ MeV ($P_\pi < 300$ MeV)

$\Rightarrow$ no need to detect π^0
for rejecting background
from other B decays.

J/ψ K_S is OK, but $\pi^+\pi^-$ ---



$B \to \pi^+\pi^-$ without particle identification;

$\begin{cases} \text{loss of events} \longrightarrow K\pi \\ \text{background event} \longleftarrow K\pi \end{cases}$

In order to keep the size of RICH small

π/K up to 300 GeV/c

with 2.5 m $CF_4 + He$ RICH

T. Ypsilantis

CERN 89-10
ECFA 89-124
24 Nov. 1989

1.4 m CF_4
$N_{pe} = 9$ -

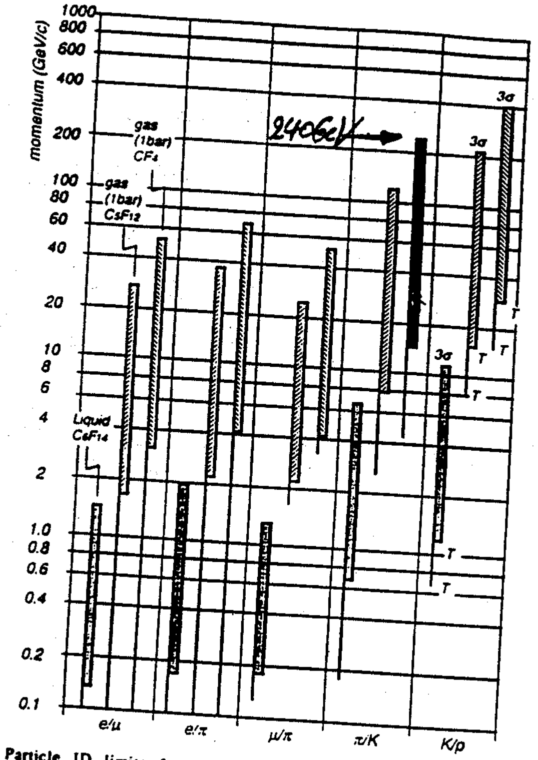


Fig.3. Particle ID limits for three radiators: 1cm liquid C_6F_{14} with proximity focusing and 0.2m lever arm; 40cm of C_5F_{12} gas with mirror focusing (f=1.8m); 140 cm of CF_4 gas with mirror focusing (f=1.8m). The thin lines show the region where particle ID is by threshold (T) and the thicker lines the region where particle ID is by the size of the ring image. The top limit corresponds to $n_\sigma=3$.

Simulation study

$B \rightarrow$

$J/4\, K_s \rightarrow \ell^+\ell^- \cdot \pi^+\pi^-$ $\qquad$ $\pi^+\pi^-$

geometrical acceptance

$J/4$ 0.56

K_s 0.46

$J/4 \cdot K_s$ 0.27

0.27 $P_\pi < 300$ GeV/c

(0.63 if $P_\pi < 600$ GeV/c)

pattum recognition, track fit etc.

0.75 $\qquad$ 0.83

over all reconstruction efficiencies

$\varepsilon_{J/4\, K_s} = 0.20$ $\qquad$ $\varepsilon_{\pi^+\pi^-} = 0.22$

Tagging: lepton tag (e+μ)

background (dominant at large P_t) reduced by

- D-decay } large P_t
- π, K decay
- hadron missidentification - $e(\mu)$/hadron $< 5 \cdot 10^{-3}$

Optimal tag is

P_t (highest P_t lepton) > 1.2 GeV

ℓ^+ : $\bar{B}^0$ tag, ℓ^- : B^0 tag

- inclusive tagging efficiency

$$\varepsilon_{tag} = \frac{\ell^+ + \ell^-}{H_b} = 0.16 \quad (\mu + e)$$

- wrong tag without oscillation

$$\omega = \frac{\text{wrong tag}}{\text{all tag}} = 0.17$$

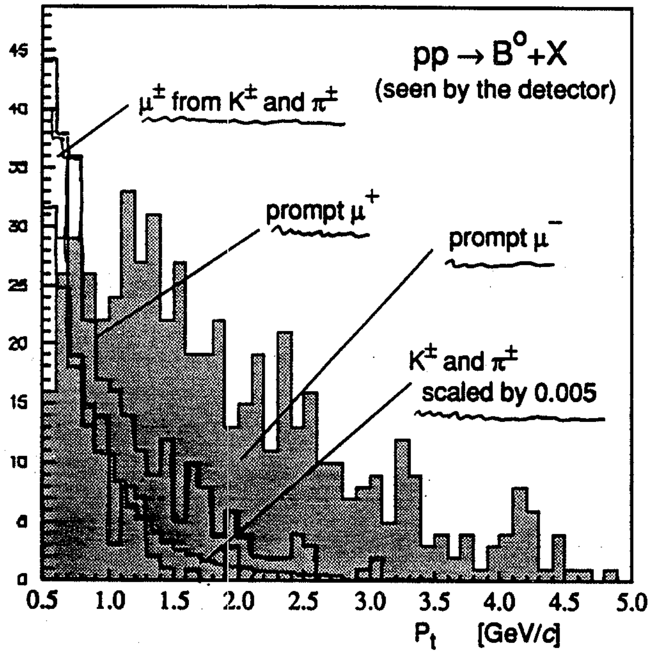
with oscillation, $\omega \longrightarrow \bar{\omega}$

$$\bar{\omega} = f^+ \omega + f^0 \left[P(B^0 \to B^0)\, \omega + P(B^0 \to \bar{B}^0)(1-\omega) \right] + 0.5 f^s$$

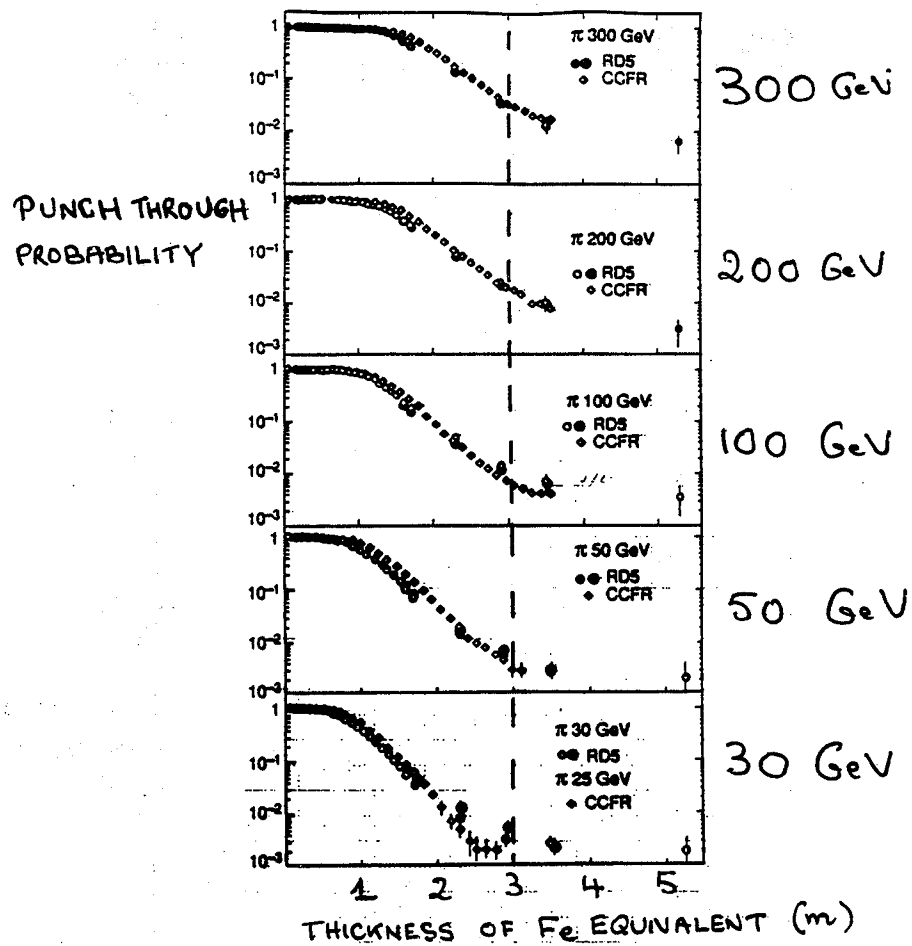
$$\left\{ \begin{array}{l} f^+ = B^+/b = 0.5, \ f^s \doteq 0.1 \\ f^0 = 0.4 \end{array} \right.$$

$$P(B^0 \to \bar{B}^0) = \frac{x^2}{2(1+x^2)}, \quad x = \Delta m / \Gamma = 0.7$$

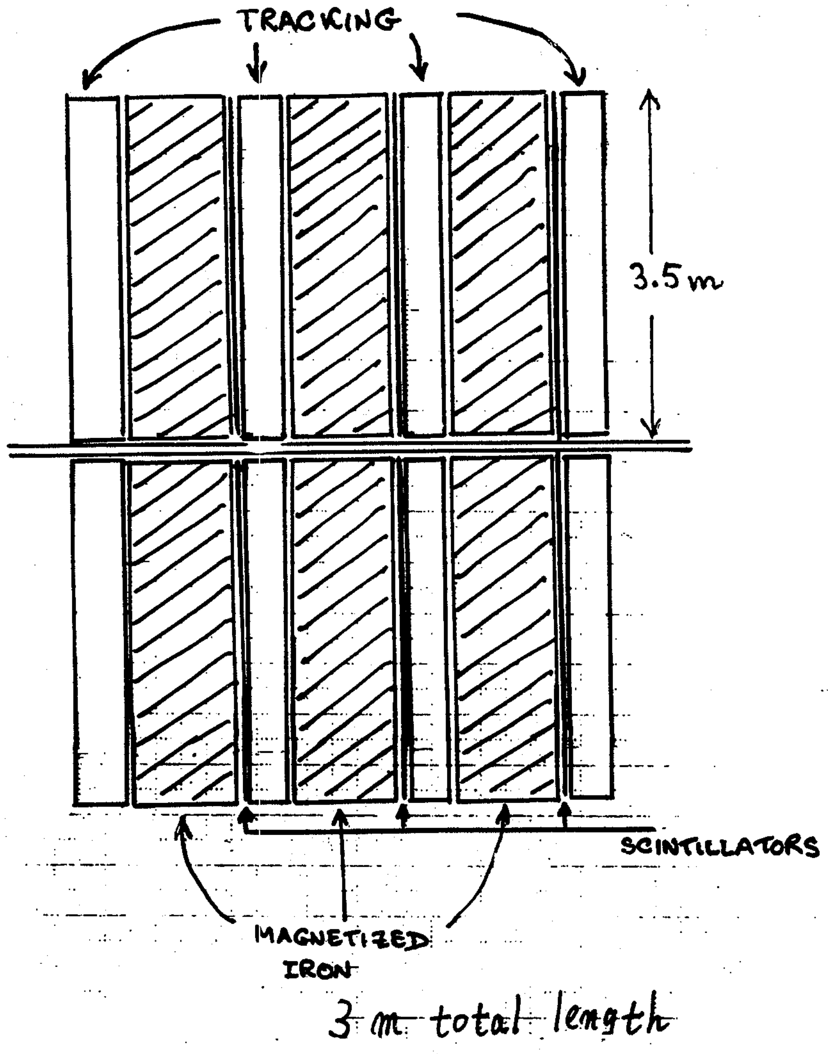
$= 0.25$

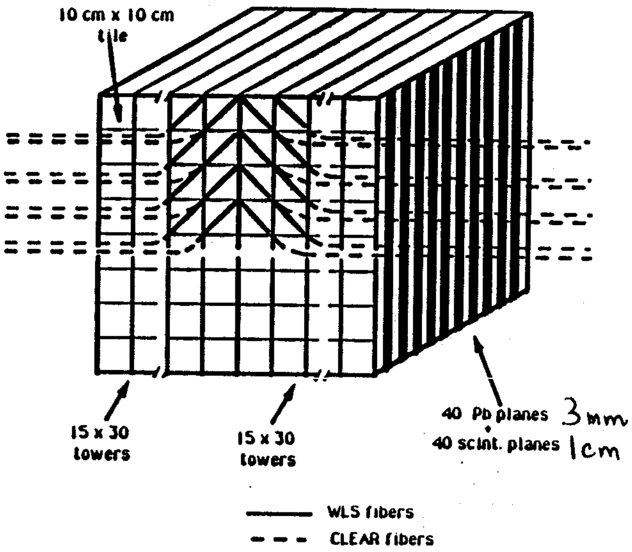


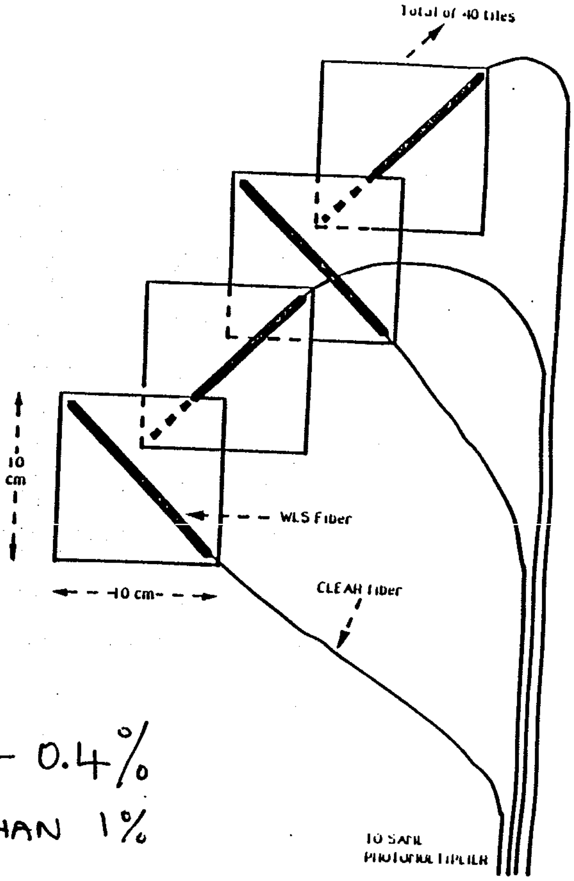
MUON FILTER



INCREASING THICKNESS OF ABSORBER BEYOND 3m DOES NOT IMPROVE HADRON REJECTION MUCH. THIS IS BECAUSE OF GENUINE MUONS FROM RAPID DECAYS OF π's AND K's IN HADRONIC SHOWER.

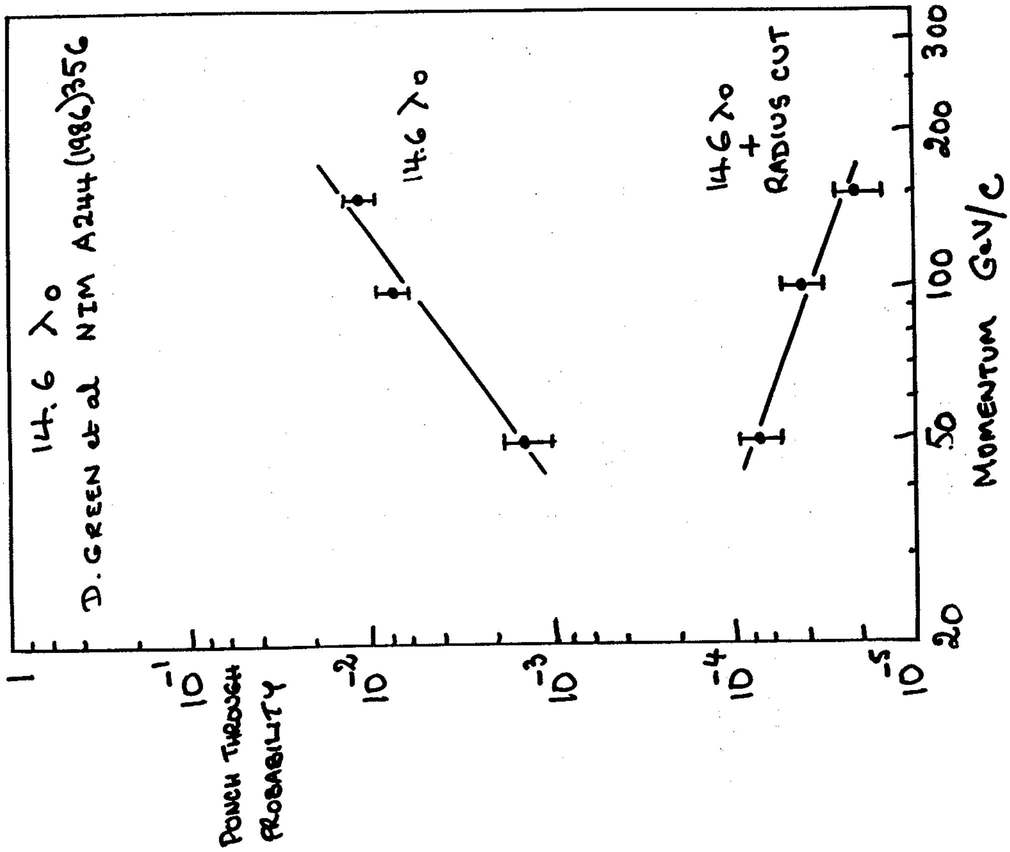


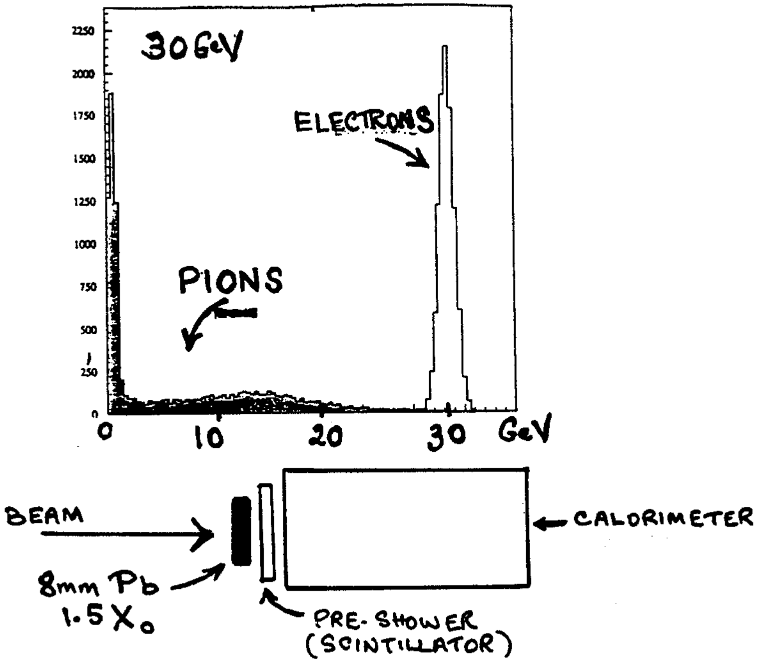


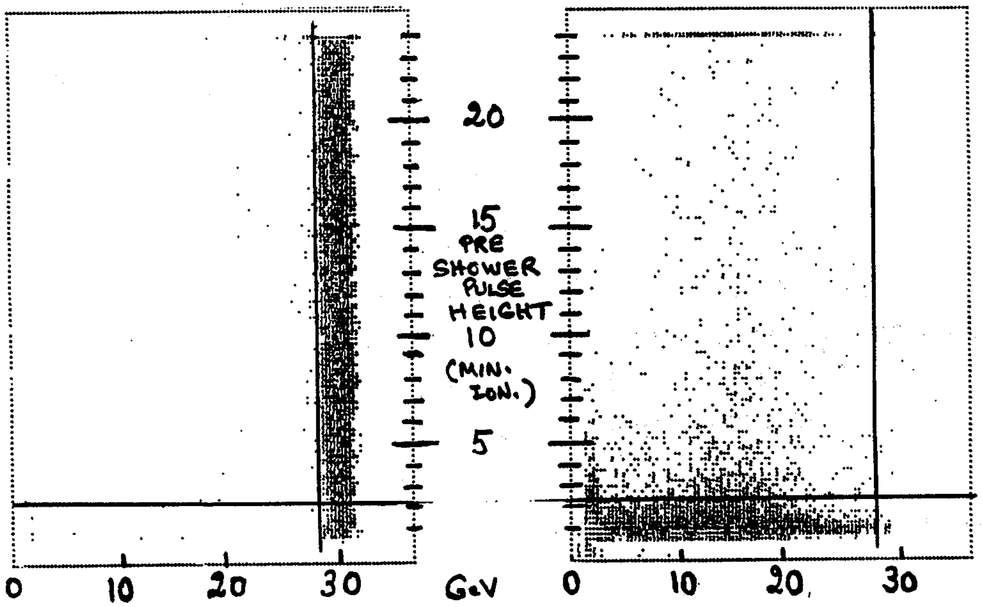


$\sigma(E)/E = 9.5\%/\sqrt{E} + 0.4\%$

LINEARITY = BETTER THAN 1%







HADRON REJECTION:- 2×10^{-3} FOR 95% ELECTRON EFFICIENCY

Sensitivity of the experiment ($@10^7$ sec)

- No. of $b\bar{b}$ $\qquad \sigma \times \int \mathcal{L}\, dt$ $\qquad 1\,\mu b \times 2\cdot 10^{39}\, cm^{-2}$ $\qquad 2\cdot 10^{10}$
- No. of $B^0 \cdot H_b + C.C.$ $\qquad \times f_0(2-f_0)$ $\qquad f_0 = B^0/\bar{b} = 0.4$ $\qquad 1.3\cdot 10^{10}$
- No. of $J/\psi K_S \cdot H_b + c.c.$ $\qquad \times \langle B_r(B\to J/\psi K_S)\rangle$ $\qquad 4\cdot 10^{-4}$ $\qquad 5.2\cdot 10^6$
- No. of $\ell^+\ell^-\pi^+\pi^-\cdot H_b + C.C.$ $\times B_r(J/\psi\to\ell^+\ell^-)\times B_r(K_S\to\pi^+\pi^-)$ $\qquad 0.14 \times 0.66$ $\qquad 4.8\cdot 10^5$
- No. of triggered $\ell^+\ell^-\pi^+\pi^-\cdot H_b + c.c.$ $\times\ \mathcal{E}_{trig}$ $\qquad \times 0.30$ $\qquad 1.4\cdot 10^5$
- No. of $(J/\psi K_S)_{reconstructed}\cdot H_b + C.C.$ $\quad \mathcal{E}_{J/\psi K_S}$ $\qquad \times 0.20$ $\qquad 2.8\cdot 10^4$
- No. of $(J/\psi K_S)_{recon.}\cdot \ell^-_{tag} + C.C.$ $\quad \mathcal{E}_{tag}$ $\qquad \times 0.16$ $\qquad 4.5\cdot 10^3$

No. of reconstructed $J/\psi K_S$ with ℓ^+ and ℓ^- tag

$$N_{J/\psi K_S} = 4.5\times 10^3$$

for $\pi^+\pi^-$ $(B\to\pi^+\pi^-\cdot 10^{-5})$ $\qquad N_{\pi^+\pi^-} = 1.4\times 10^3$

error on the CP violation parameter

$$\sigma_{\sin 2\varphi} = \frac{1}{I\,(1-2\bar{\omega})\sqrt{N_f}}$$

N_f : no. of total reconstructed and tagged events

I : statistical information $= 0.75$ (using a fit to decay time distributions)

$\bar{\omega}$: wrong tag with oscillation included $= 0.25$

With $J/\psi\, K_s$

$$\left.\begin{array}{l} \sigma_{\sin 2\beta} = 0.04 \\ \\ \pi^+\pi^- \\ \sigma_{\sin 2\alpha} = 0.07 \end{array}\right\} \text{our sensitivities}$$

Conclusions.

- An internal gas jet target can be used at LHC WITHOUT introducing disturbance to the collider and other experiments.

- NO special requirement to the collider operation.

- An experiment can be installed at one of LEP crossing points with MINIMUM excavation.

- Sensitivities of such an experiment to CP violation parameters are

$$\left\{\begin{array}{ll} \sigma_{\sin 2\beta} = 0.04 & \text{from } J/\psi\, K_s \\ \sigma_{\sin 2\alpha} = 0.07 & \text{from } \pi^+\pi^- \end{array}\right.$$

- our pretrigger allow to trigger on many different B decay final states (including b-baryons)

Expression of Interest

Neutrino physics at LHC

K. Winter (CERN)

EXPRESSION OF INTEREST

IN

NEUTRINO PHYSICS AT

LHC

BERLIN (HUMBOLDT) - BRUSSELS - CERN -
FERRARA - LOUVAIN - NAGOYA - NAPLES -
ROME I - TORINO

SPEAKER : K. WINTER, CERN

(1) PHYSICS AIMS

(2) NEUTRINO PRODUCTION SCHEMES

(3) DETECTOR SCHEMES

(1) PHYSICS AIMS

- * DOES ν_τ EXIST AS A FARTICLE ?

  DETECT REACTION

  $\nu_\tau N \rightarrow \tau^- X$

  IDENTIFY τ BY ITS CHARACTERISTIC MEAN LIFE $3 \cdot 10^{-13}$ s

- * STUDY $\overset{(-)}{\nu}_\mu N \rightarrow \mu^\mp X$ FOR $E_\nu \geq 1000$ GeV

  AT $\overline{Q^2} \sim 300$ GeV^2

  IF HERA FINDS SOME ANOMALY

(2) NEUTRINO PRODUCTION SCHEMES

$$pp \rightarrow D_{s/B_s} \rightarrow \overset{(-)}{\nu}_\tau \tau^\mp \rightarrow \overset{(-)}{\nu}{}^1_\tau \ \overset{(-)}{\nu}{}^2_\tau X$$

$$pp \rightarrow D/B \rightarrow \overset{(-)}{\nu}_\mu X$$

$$\rightarrow \overset{(-)}{\nu}_e X$$

ACCELERATOR	E_{CM}	$\sigma_{c\bar{c}}$
LHC FT	126 GeV	200 μb
LHC BEAM-BEAM	15 TeV	1 mb

NEUTRINO EVENT RATES
AT LHC

MODE	$L(cm^{-2}s^{-1})$	$N(\nu_\tau)$ [4]	$N(\nu_\mu)$ [5]
BEAM-BEAM	10^{34}	3800	55'000
FT CS JET[1]	$2\cdot10^{34}$	700	3'300
FT DUMP[2], PARASITIC	$4\cdot10^{35}$	14'000	66'000
FT DUMP[3], DEDICATED	$3\cdot10^{36}$	112'000	530'000

1) $4\cdot10^{14}$CS ATOMS/cm^3

2) LHC EVERY 8 HOURS, equ. $1.6\cdot10^{10}$p/s

3) LHC EVERY HOUR, equ. $1.3\cdot10^{11}$p/s

4) TARGET MASS 2kg/cm^2, $\Delta\theta$ = ±2.5 mrad, 10^7s

5) TARGET MASS 6kg/cm^2, $\Delta\theta$ = ±2.5 mrad, 10^7s

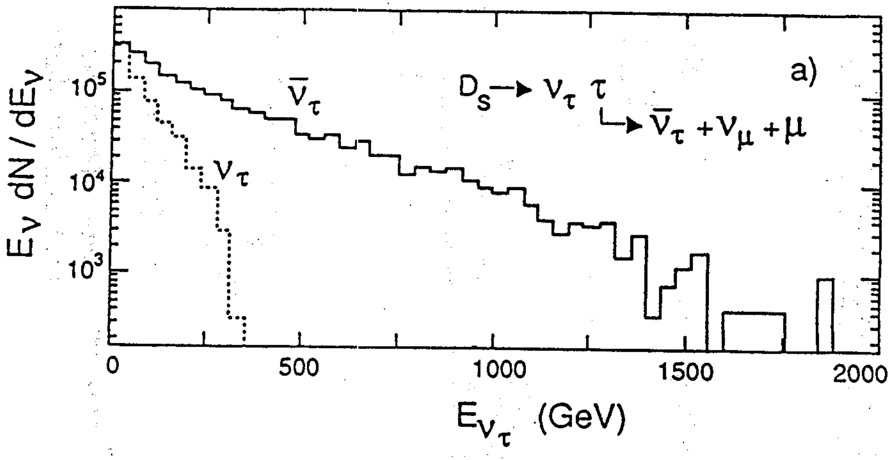
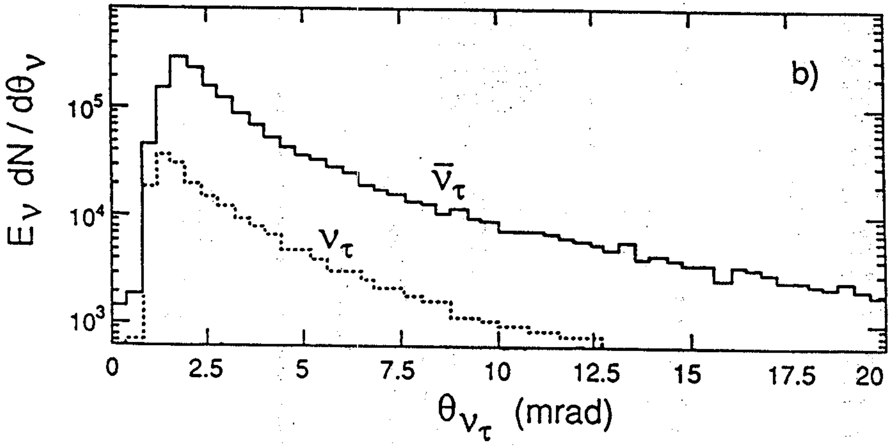


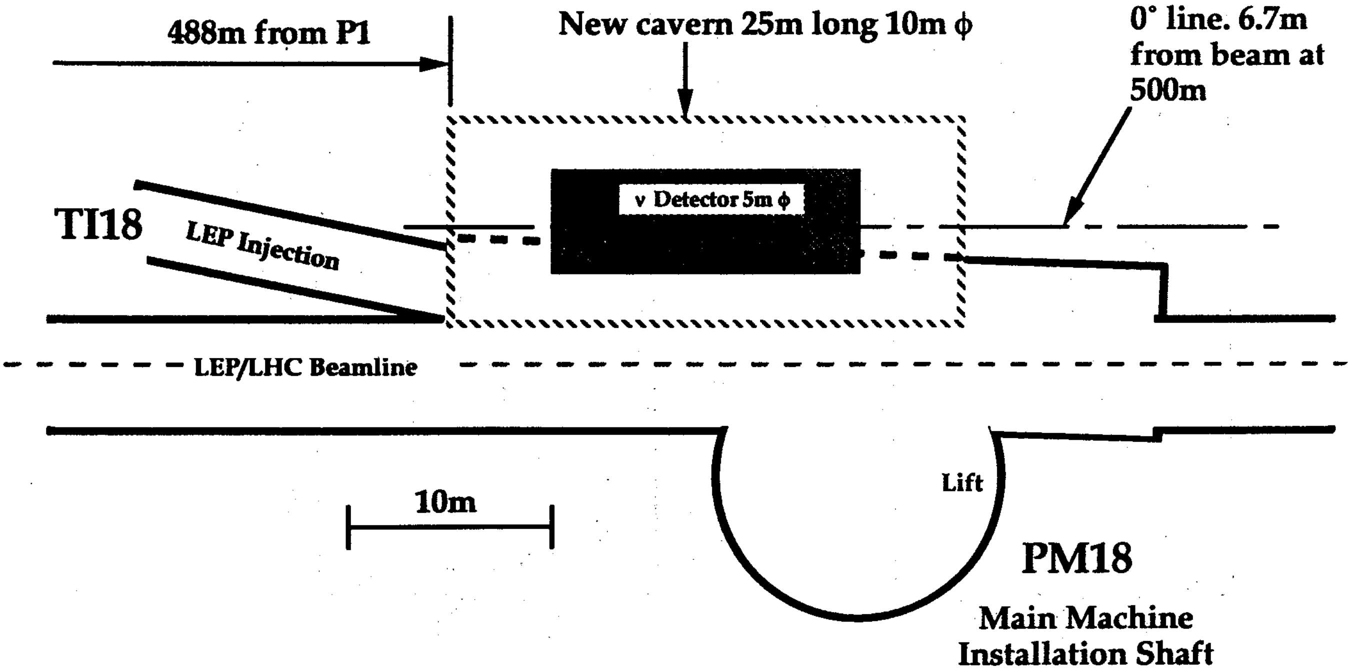
Figure 4

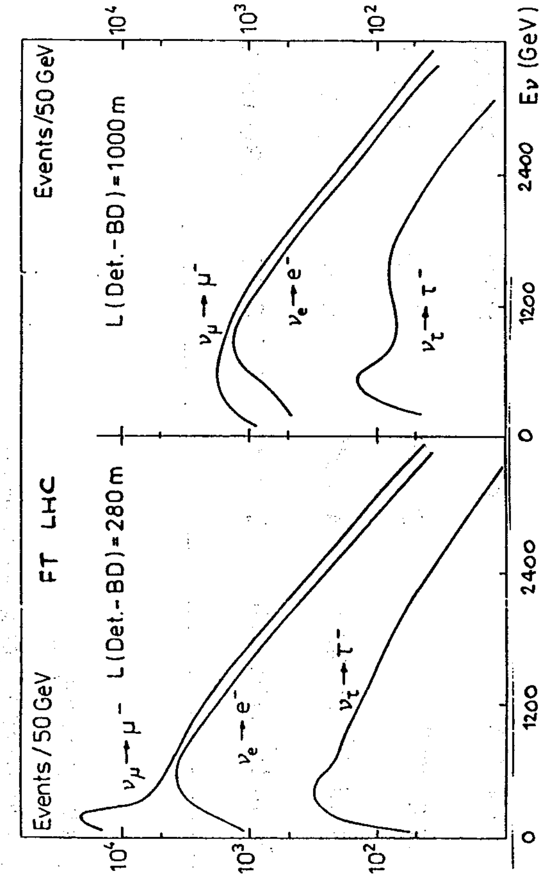
Tau-neutrino energy spectrum from D_s decay (De Rujula, Fernandez Gomez).



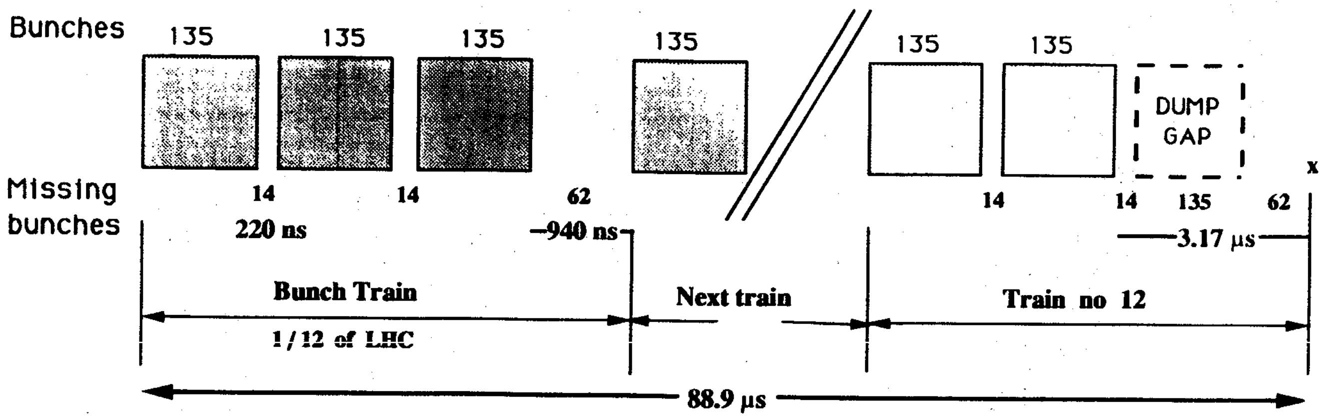
Neutrino Detector adjacent to PM18

BEAM-BEAM MODE





LHC Bunch Structure



BUNCH SPACING = 15 ns (approx. 4.5 m)

5940 RF buckets 4725 full bunches

(24 x 14) + (12 x 62) + 135 = 1215 missing bunches

10 cm RING

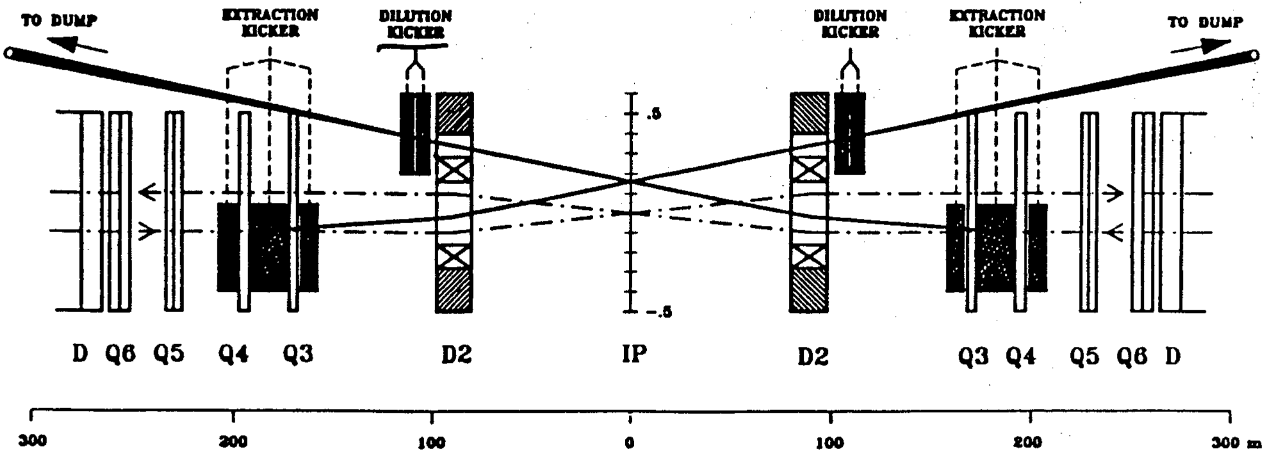


Figure 10.1: Layout of extraction elements of the beam dumping system.

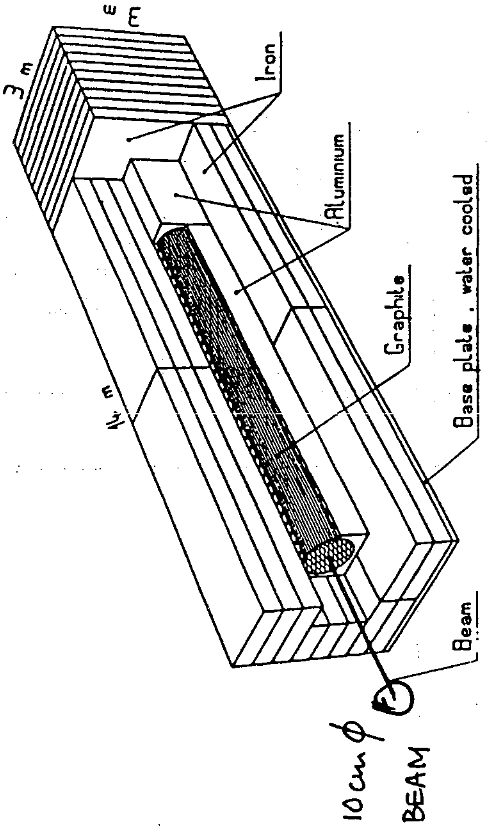


Figure 10.4: Beam dump (partially dismounted).

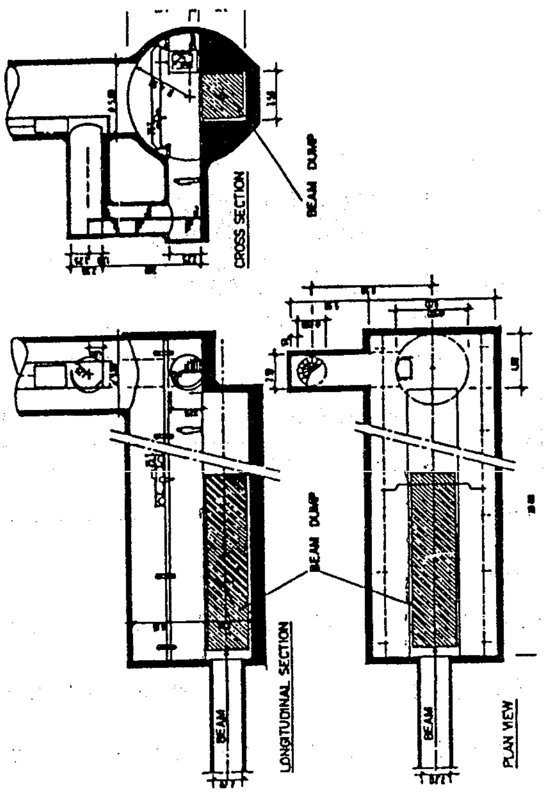


Figure 10.5: Underground cave and installation of the beam dump.

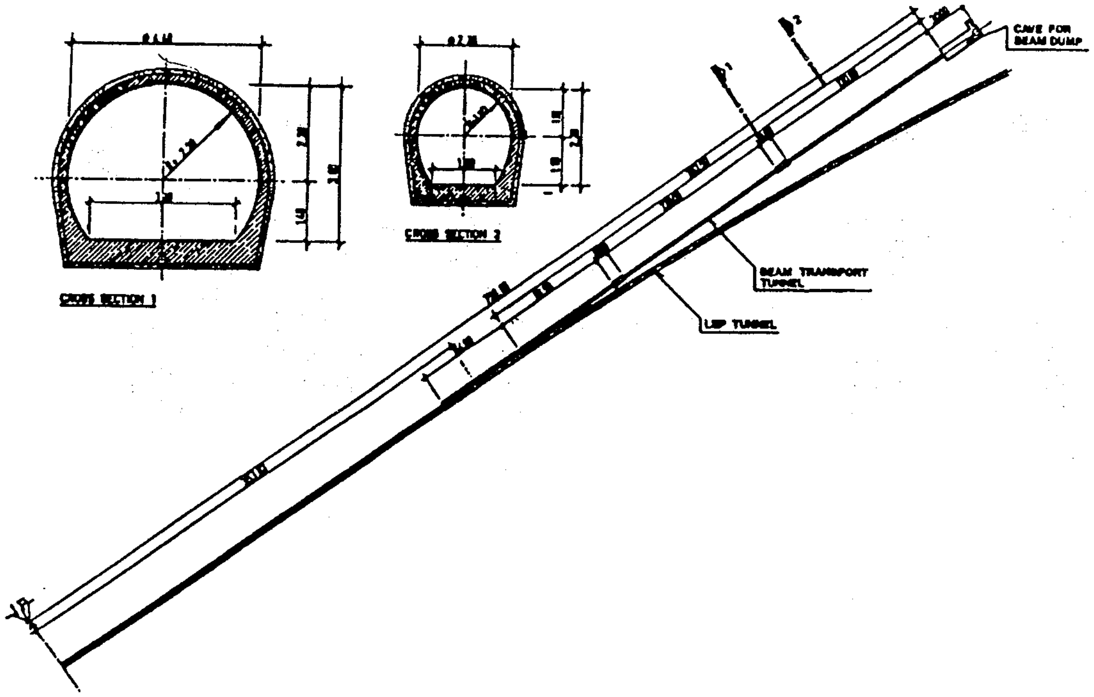
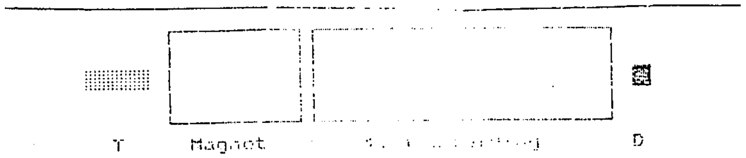
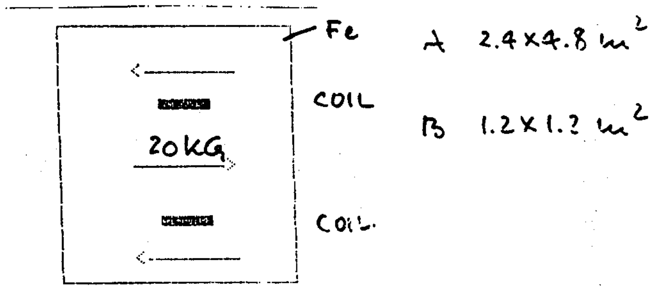
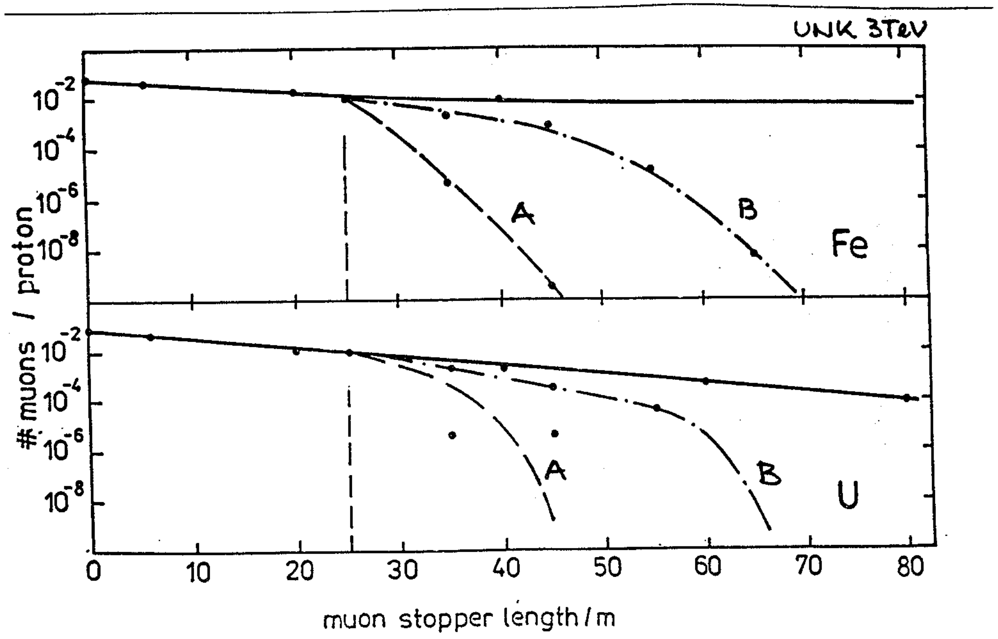


Figure 10.9: Beam transport tunnel with enlargements and cave for the beam dump.

MUON SHIELDING (S SCHLENSTEDT)







EVENT RATE PER EJECTION ONTO BEAM DUMP

IN 88 μs

FOR DETECTOR 1 , 2kg/cm²

N_τ/EJECTION ~ 40

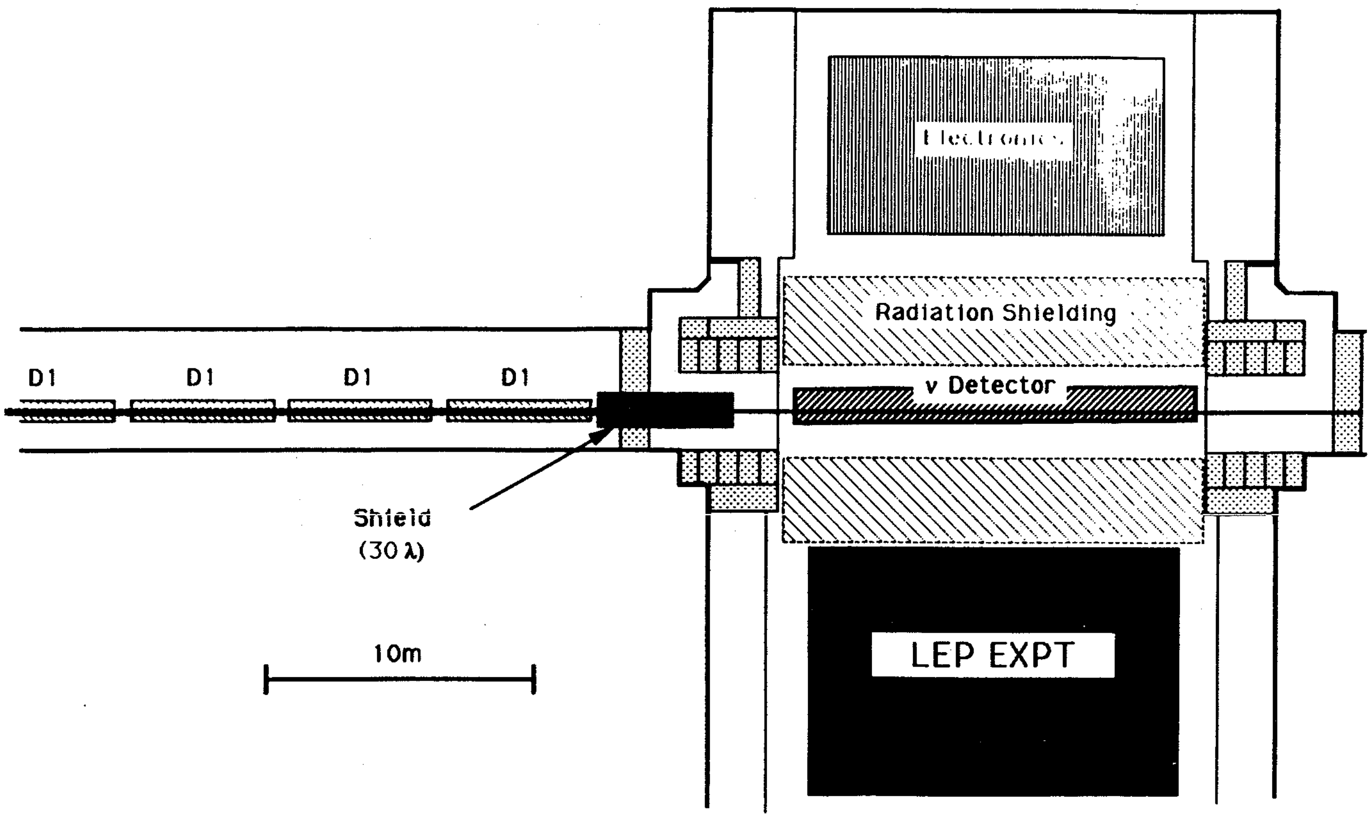
N_μ/EJECTION ~ 190

DISTRIBUTED OVER CIRCLE OF 10 cm DIAMETER BY DILUTION KICKER

- * DETECTOR MASS FOR ν_τ DETECTION IN DEDICATED MODE CAN BE REDUCED TO 0.2 kg/cm²

- * FOR N_μ DETECTION SCHEME INCREASE CIRCLE OF DILUTION KICKER

Schematic Layout of a Neutrino Detector in a LEP Cavern

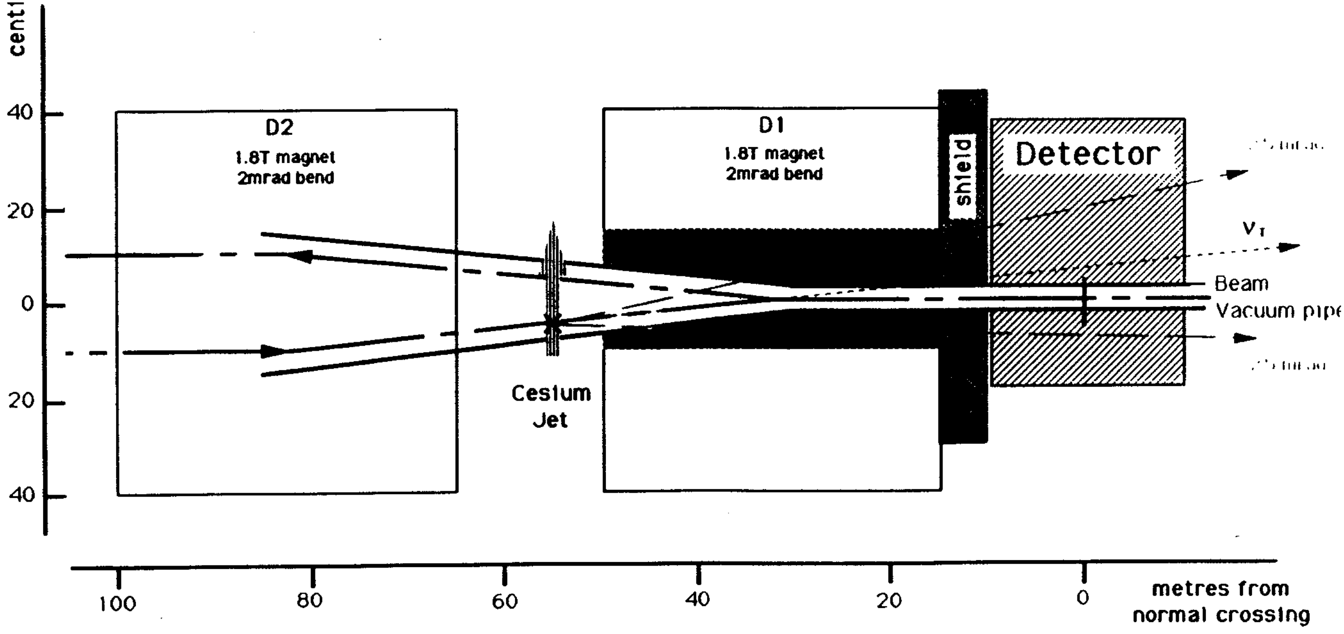


KM Potte

Schematic Layout for a Cesium Target and Neutrino Detector

Detector at normal crossing

Insertion of beam-dump type



(3) DETECTION SCHEMES FOR

$\nu_\tau N \rightarrow \tau^- X$

* FIBER TARGET DETECTOR

$\tau^- \rightarrow \mu^- \bar{\nu}_\mu \nu_\tau$

* LIQU. ARGON TPC MINI-ICARUS

$\tau^- \rightarrow \pi^- \pi^+ \pi^- \nu_\tau$

BOTH FOLLOWED BY MAGNETIC ANALYSIS
MUON FILTER / CALORIMETER
NOT DISCUSSED HERE

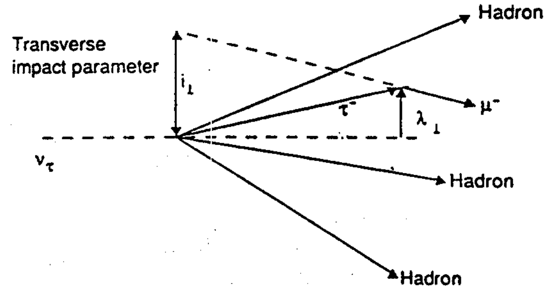


Figure 1
Illustration of the impact parameter technique.

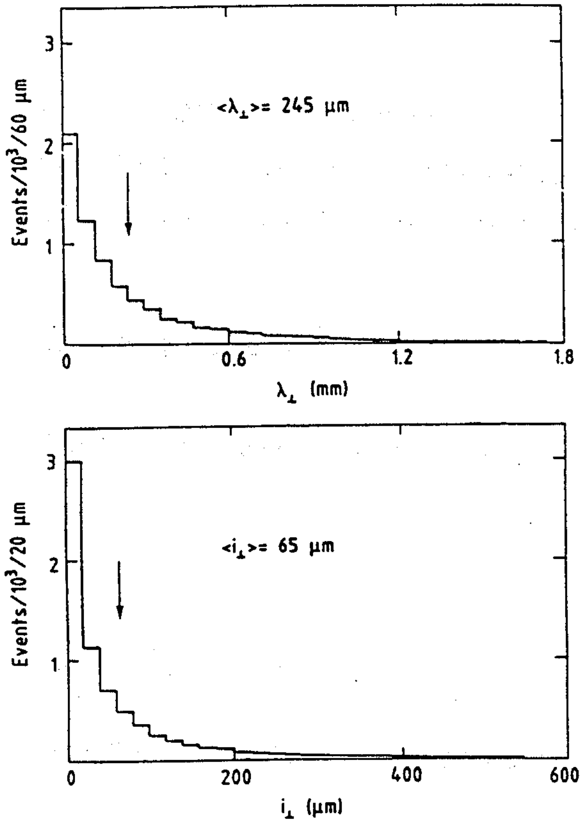


Figure 2

Distribution of transverse decay length and of transverse impact parameter of τ decays.

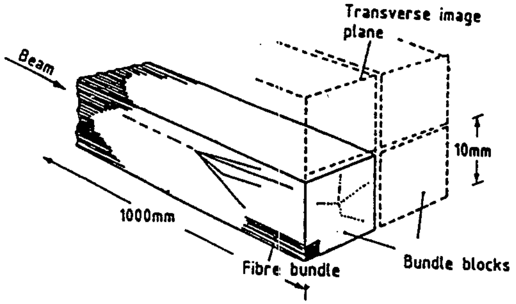
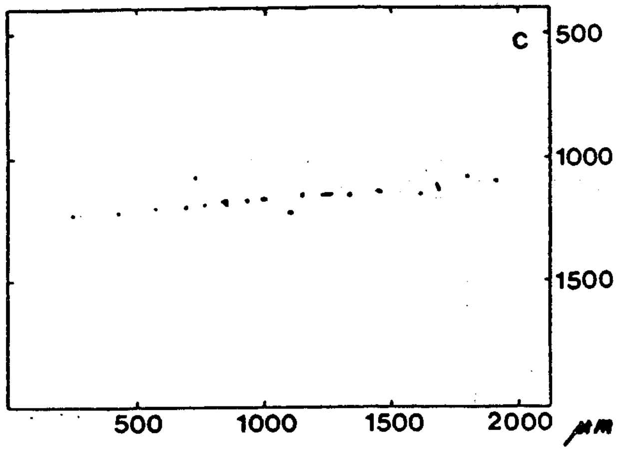


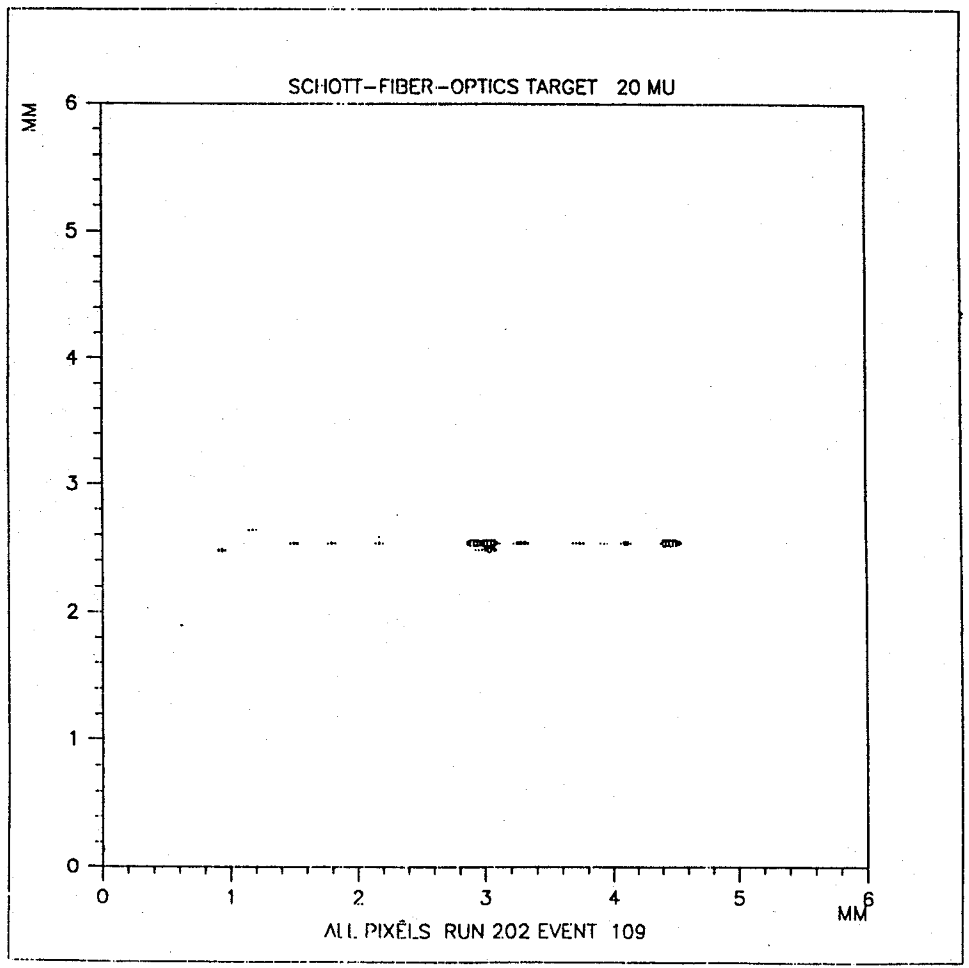
Figure 6

Schematic view of the longitudinal fibre target detector and read-out system [9].

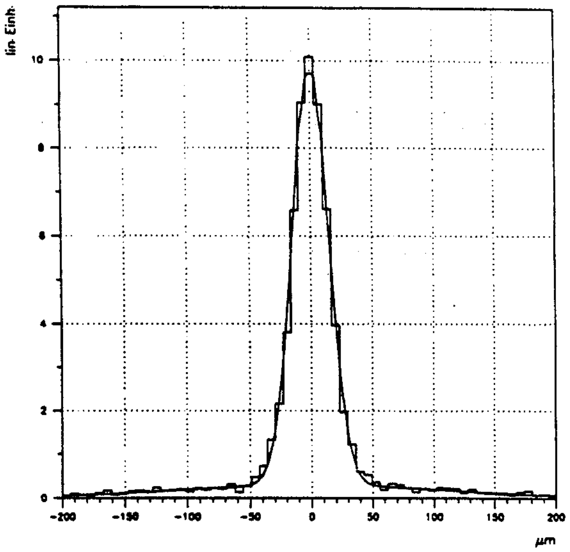
TRACKS IN 20 μm CAPILLARIES
CHARMII /WA84
EMA 1MN/PMP



HIT DENSITY FOR PERPENDICULAR
TRACKS 5 HITS/mm

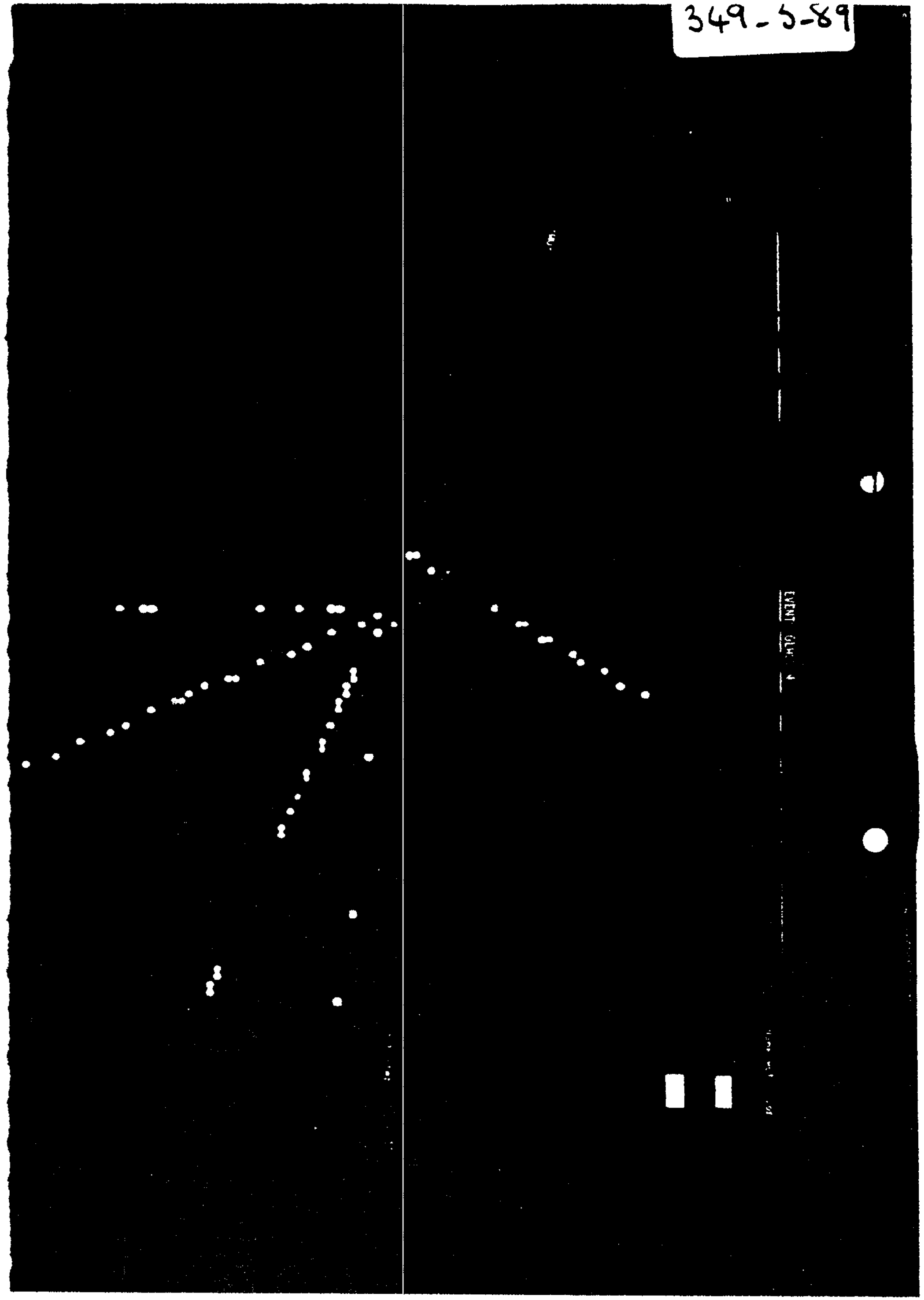


RESIDUALS $\sigma = 14.4\,\mu m$



20µm CAPILLARIES WITH EMA
1MN/PMP

CHARMII /WA 84



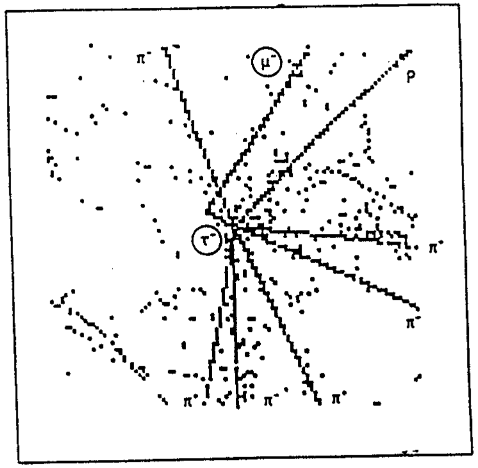


Figure 3

Simulated event of the type $\nu_\tau N \to \tau^-(\to \mu^- \bar{\nu}_\mu \nu_\tau) X$ in a 2 mm by 2 mm region of the longitudinal scintillating fiber (20 μm) detector [9]. The $\tau^- \to \mu^-$ decay kink is very spectacular in this event.

BACKGROUND

(1) $\bar{\nu}_\mu N \to (\mu^+)\bar{C}\ X$, $\varepsilon = 95\%\ \hookrightarrow \mu^- X$ $\lesssim 1\%$

$\bar{\nu}_e N \to (e^+)\bar{C}\ \hookrightarrow \mu^- X$, $\varepsilon = 25\%$ $\leq 5\%$

$\nu N \to \nu c\bar{c}\ X\ \hookrightarrow \mu^- X$ $< 1\%$

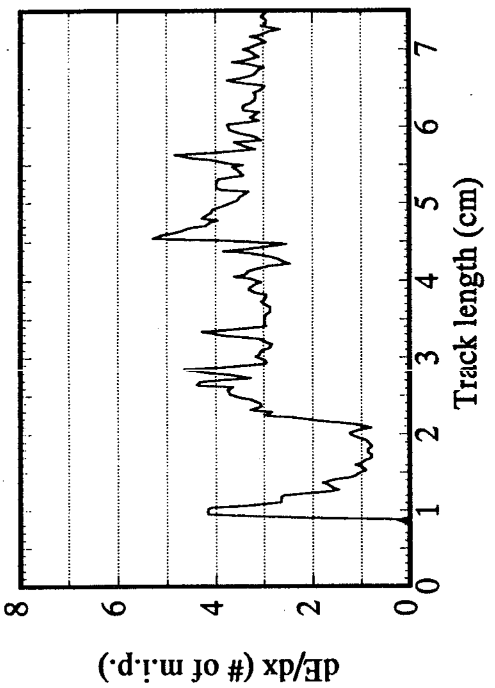
(2) $\overset{(-)}{\nu}_\mu N \to \overset{\overset{(-)}{\nu}}{\mu}\ K\ X\ \hookrightarrow \mu\nu$ $\quad X_\perp < 1\text{mm}$ $\lesssim 4\%$

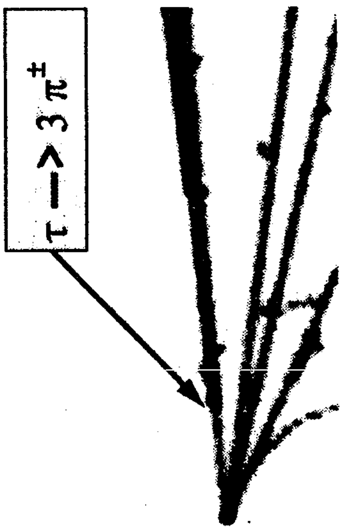
$P_\perp^\mu > 0.2\ \text{GeV}/c$

(3) $P_\perp$ SELECTION REDUCES BACKGROUNDS DUE TO ELASTIC HADRON SCATTERING NEAR VERTEX AND $K^- \to \mu^- \nu$ DECAYS

$\boxed{\text{BACKGROUND} < 10\% \text{ FOR } \tau \to \mu \nu_\mu \nu_\tau}$

Tau neutrino detection at LHC





PROTOTYPE TEST OF FIBER TARGET

4/12/1990

CHORUS

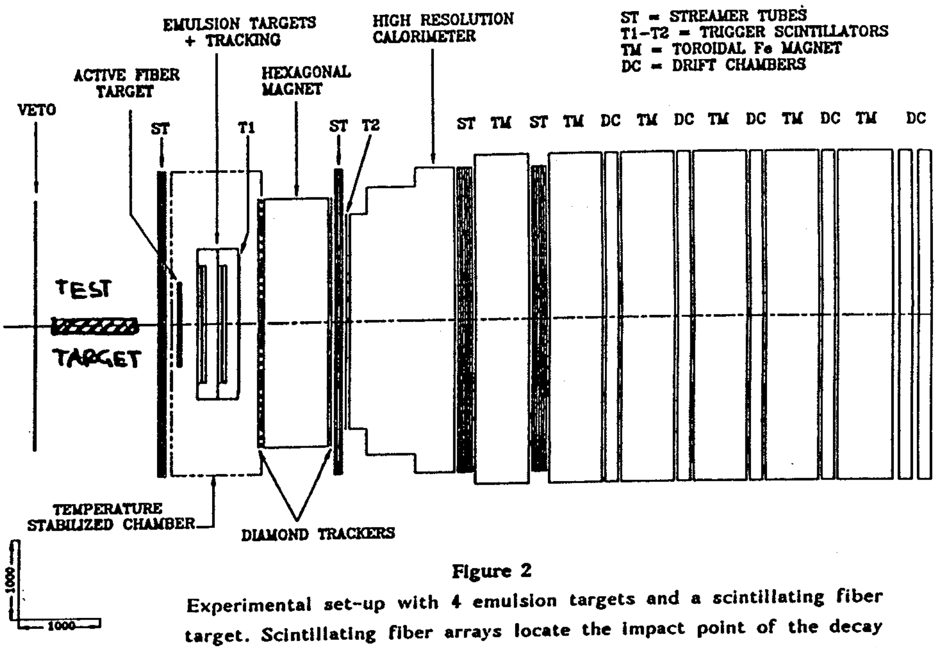
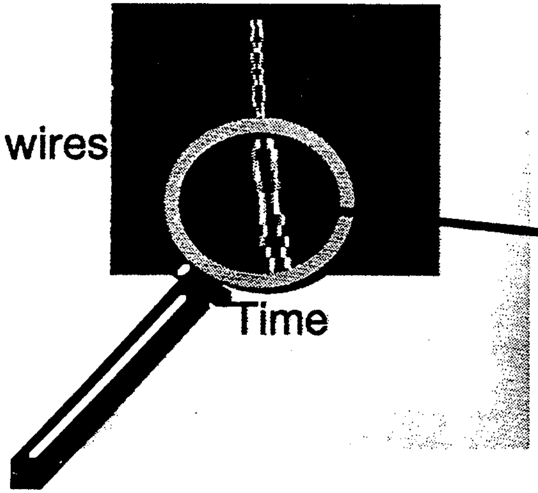


Figure 2

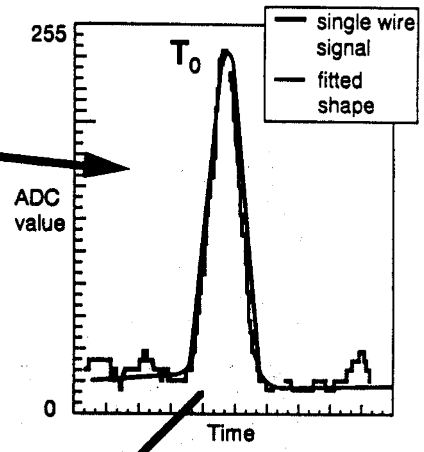
Experimental set-up with 4 emulsion targets and a scintillating fiber target. Scintillating fiber arrays locate the impact point of the decay track. A hexagonal magnet determines its charge and momentum. A high resolution calorimeter determines the direction and the energy of the hadron shower. The muon spectrometer identifies muons and determines their charge and momentum. T1 and T2 are scintillation hodoscopes for triggering.

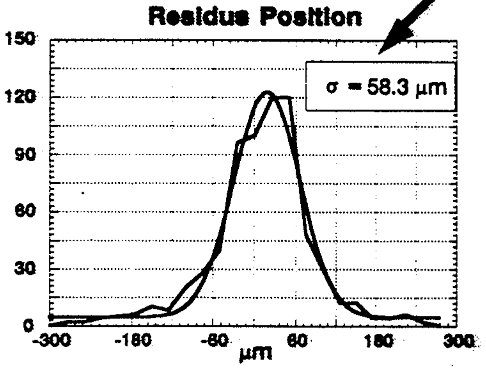
Impact Parameter Precision

Track Image

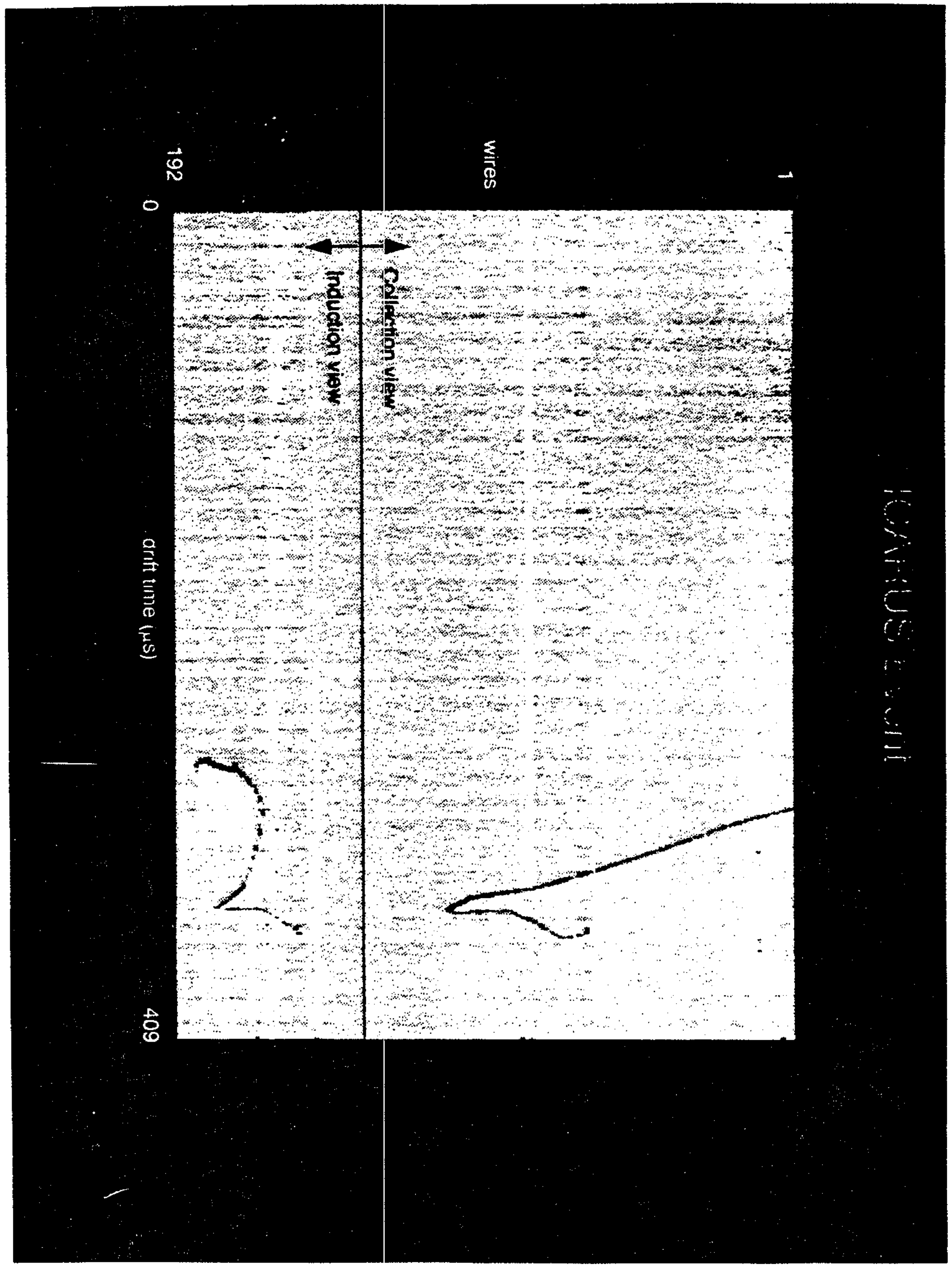


Each wire signal shape is filtered and fitted to extract T_0

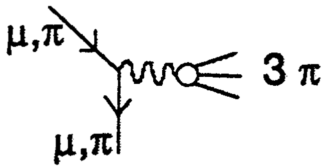




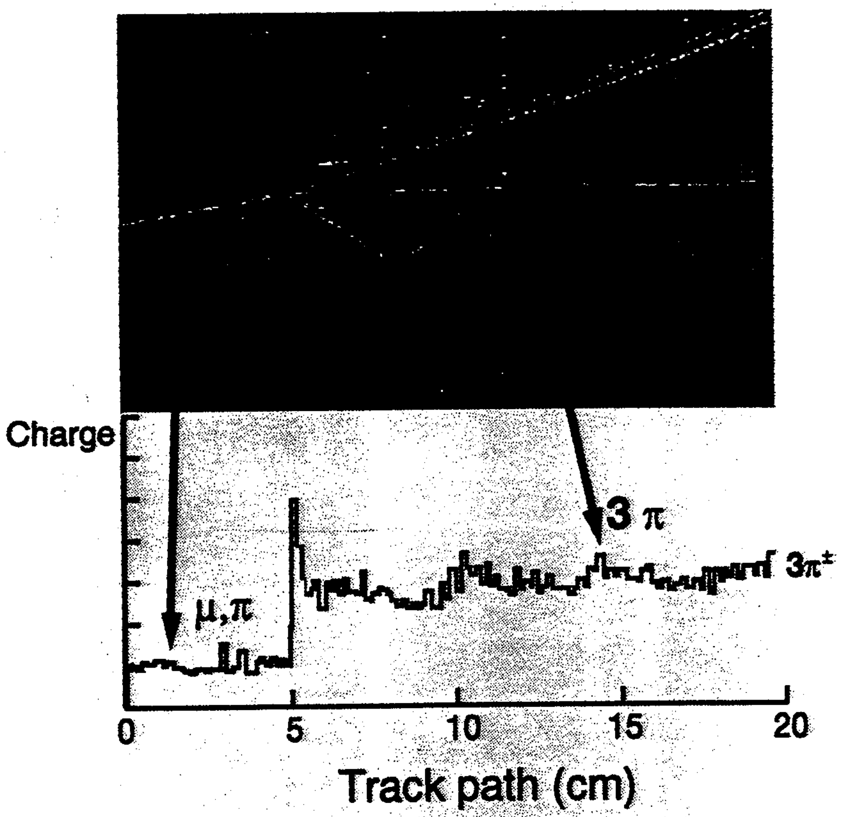
The residuals are then distributed



PROMISING TECHNIQUE FOR ν_τ DET. AT LHC



ICARUS EVENT
NUCLEAR
INTERACTION



Expression of Interest

A neutrino experiment at LHC

F. Vannucci (Paris)

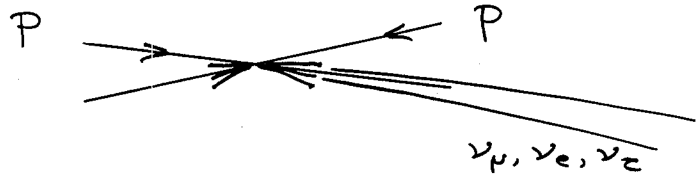
A NEUTRINO
EXPERIMENT
AT L.H.C.

NOMAD COLLABORATION

Alger, Annecy, Boston, CERN,
Dortmund, Dubna, Lund, Melbourne
Michigan, Padova, Paris, Pavia
Pisa, Saclay, Zagreb

Evian
6-3-92

NEUTRINOS AT LHC



- 2 ν beams / intersection
  high luminosity !
- highly collimated
  ~ 1 mrad
- very high energies
  ~ 1 TeV range
- large fraction of ν_τ

$$\frac{\nu_\tau}{\nu_\mu} \sim 10\%$$

At SPS $\frac{\nu_\tau}{\nu_\mu} \lesssim 10^{-6}$

oscillations at 10^{-4} level

ν PHYSICS

ν_μ, ν_e Interactions

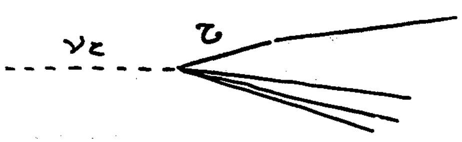
up to TeV region

ν_τ Interactions

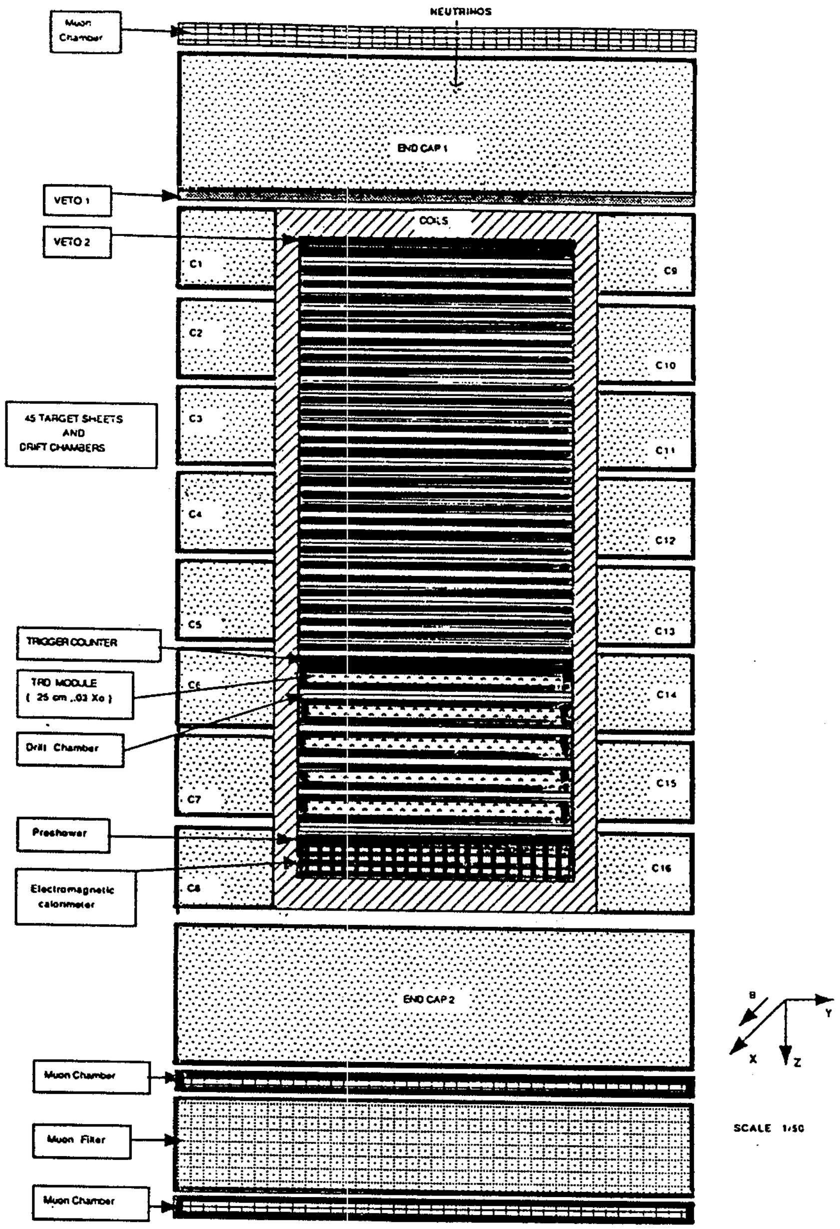
discovery (?)

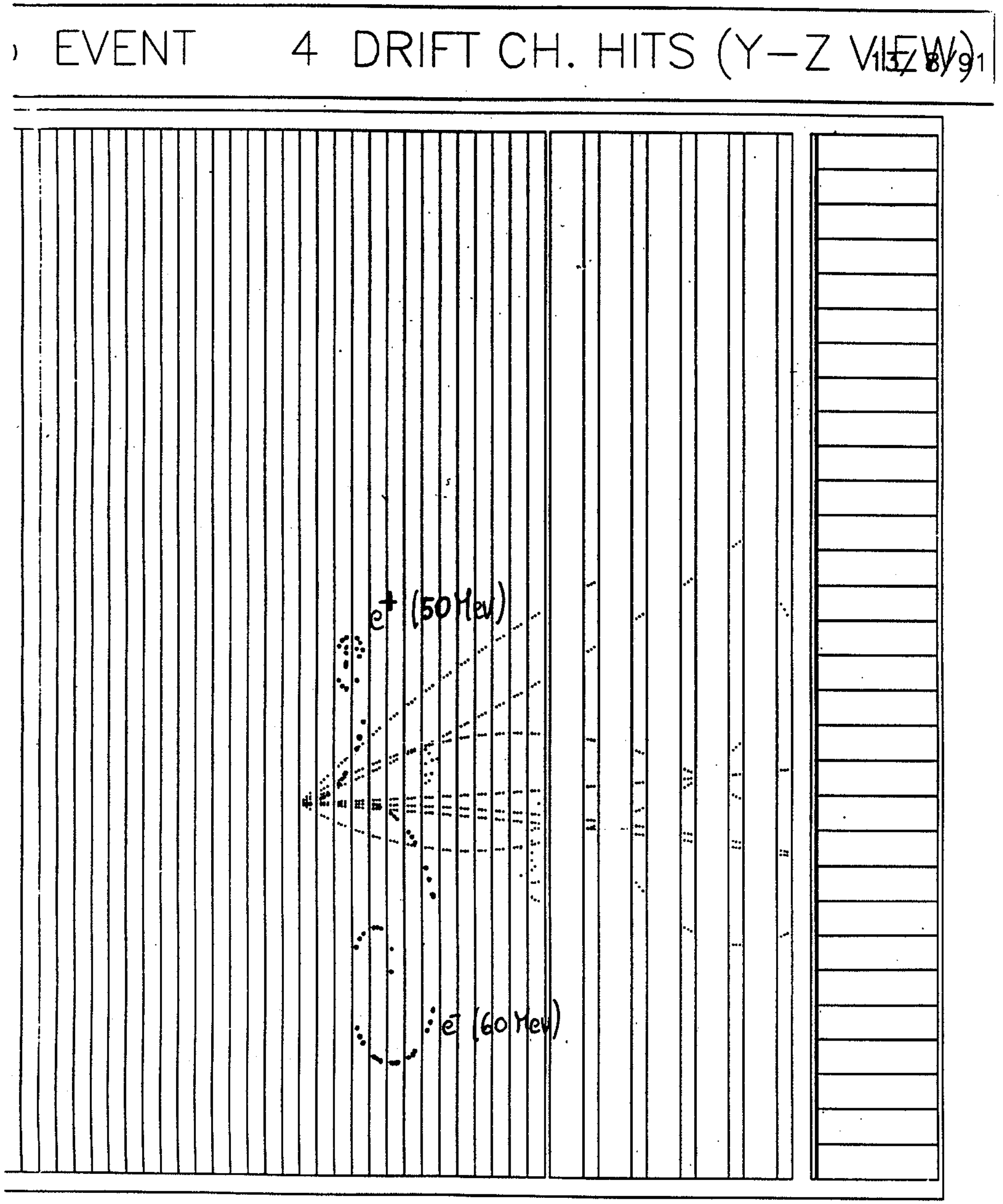
study of its properties

How to see the ν_τ ?



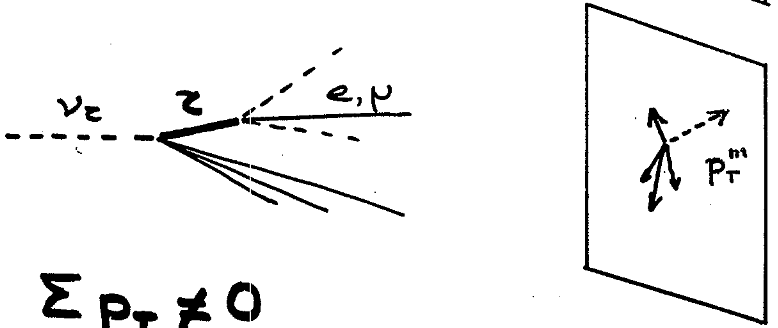
Extraction "à la Nomad"




EVENT 4 DRIFT CH. HITS (Y–Z VIEW) 13/8/91

TOPOLOGICAL CRITERIA

$$\Sigma p_T = 0$$



$$\Sigma p_T \neq 0$$

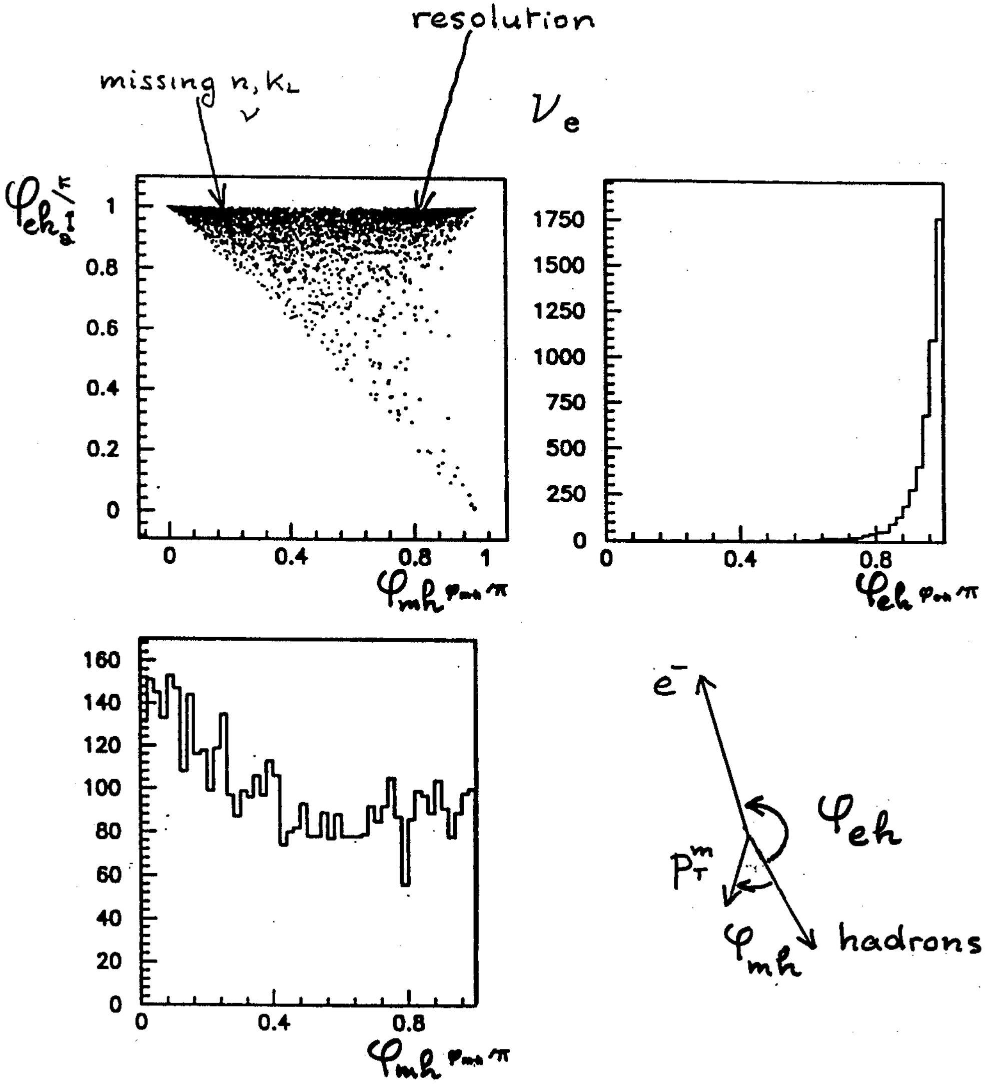
In practice n, K_L not detected

charm → ν

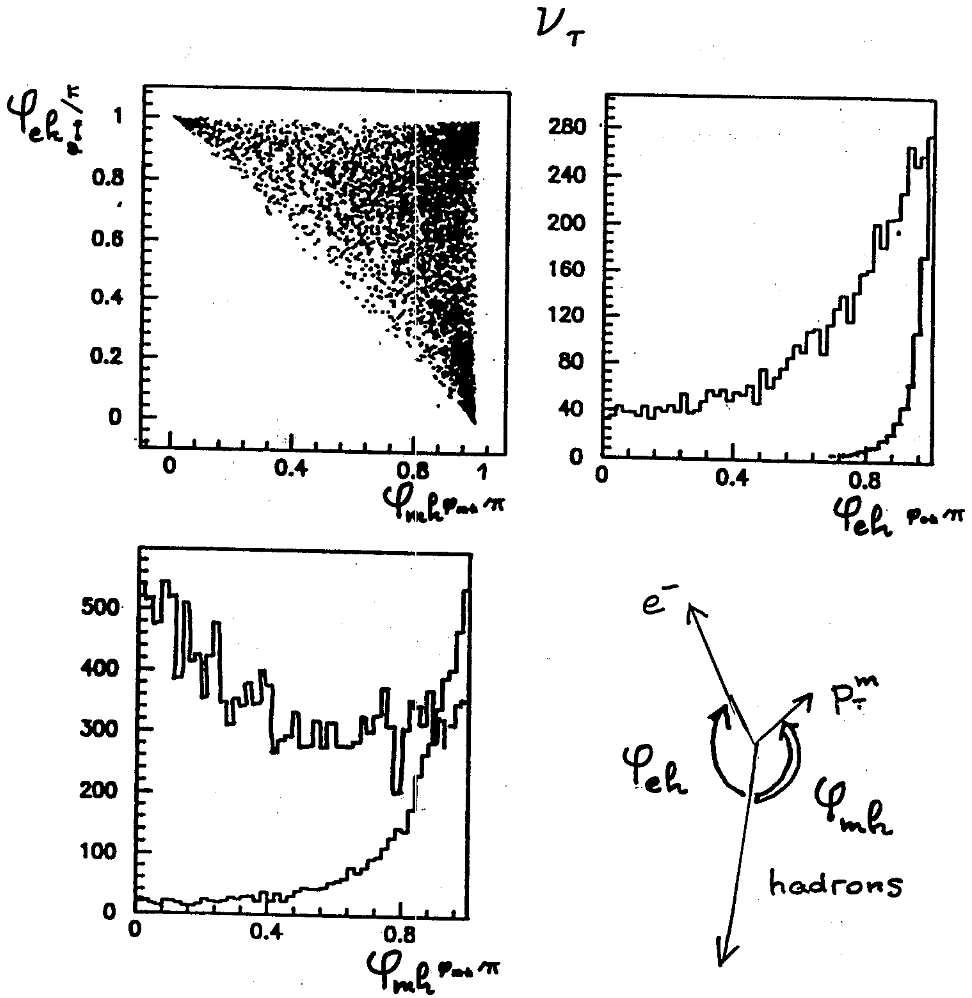
$\nu_{e,\mu} \Rightarrow p_T^m$ near the hadronic Σp_T

$\nu_\tau \Rightarrow p_T^m$ near the electron p_T

Direction of p_T^m essential



$\varphi_{e\text{-}h}$ versus $\varphi_{m\text{-}h}$



$\varphi_{e\text{-}h}$ versus $\varphi_{m\text{-}h}$

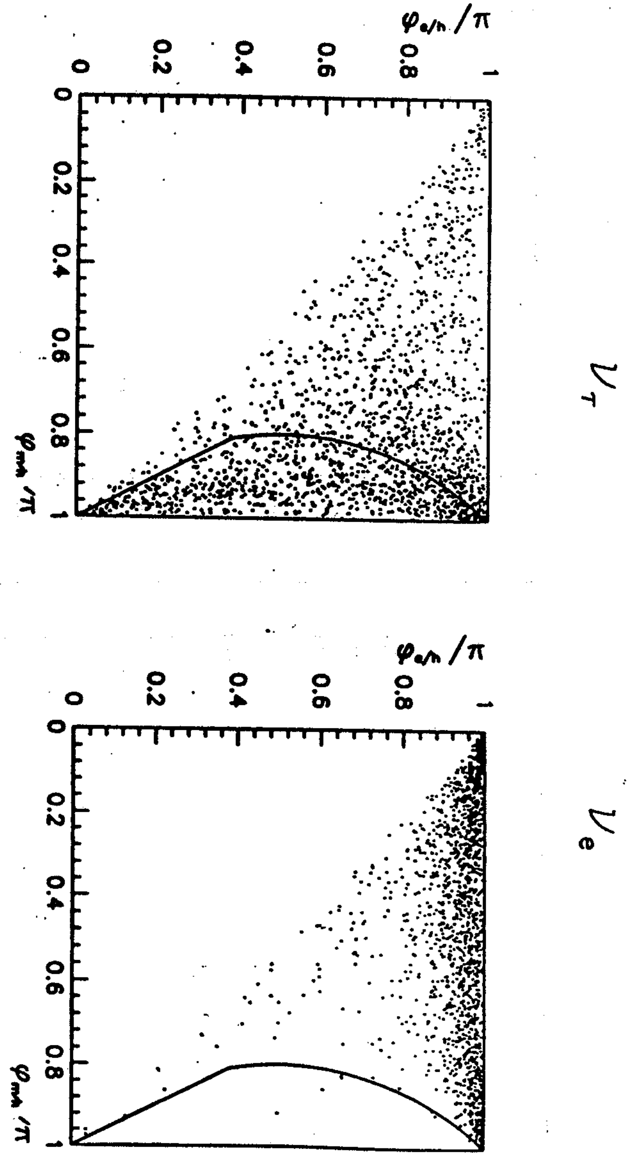
THE METHOD IMPROVES AT HIGHER ENERGIES

- Events more collimated
  less side-losses, μ definition
- Neutral energy resolution
  improves as $1/\sqrt{E}$
- Events more "jetty"

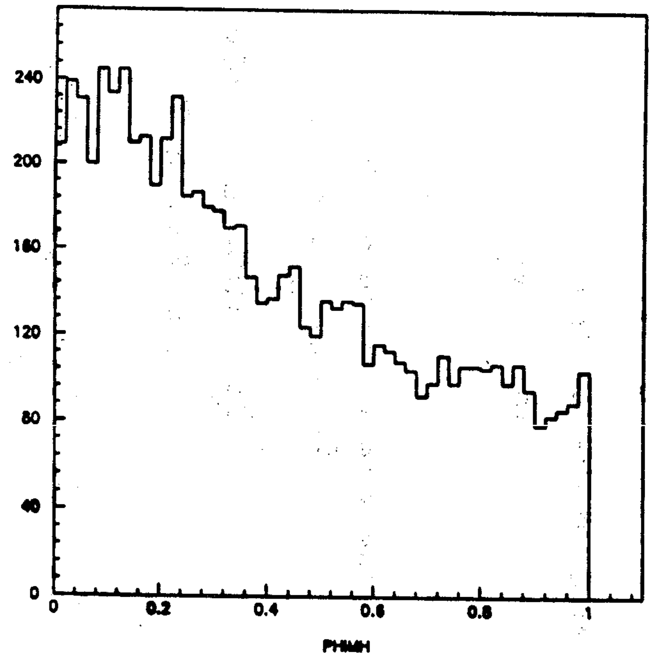
⇒ Acceptance of φφ cut
vs. energy

What about the resolution
for charged tracks ?

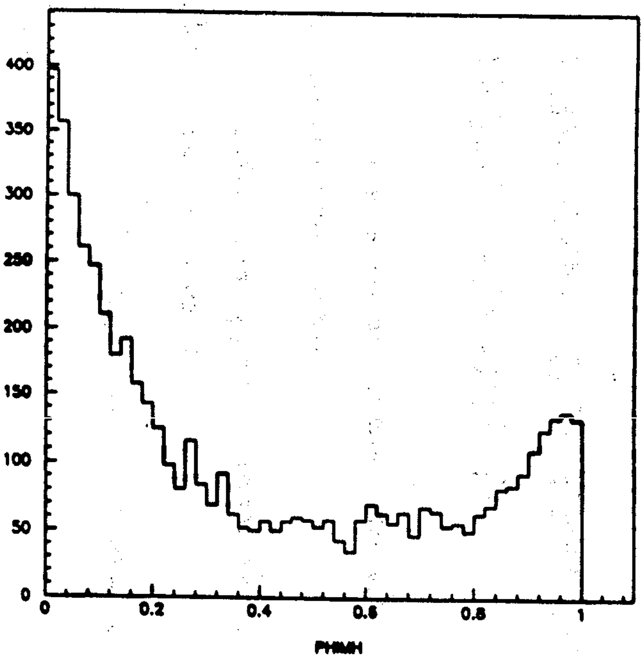
$\left(\frac{\sigma_P}{P} \sim 10\% \text{ at } 100\,\text{GeV} \right)$
for $B = 0.8\,T$



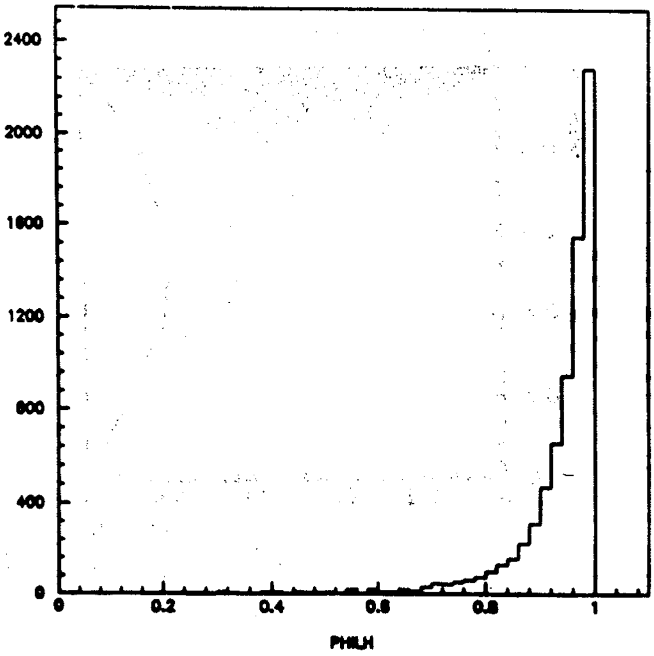
$\varphi_{e\text{-}h}$ versus $\varphi_{m\text{-}h}$



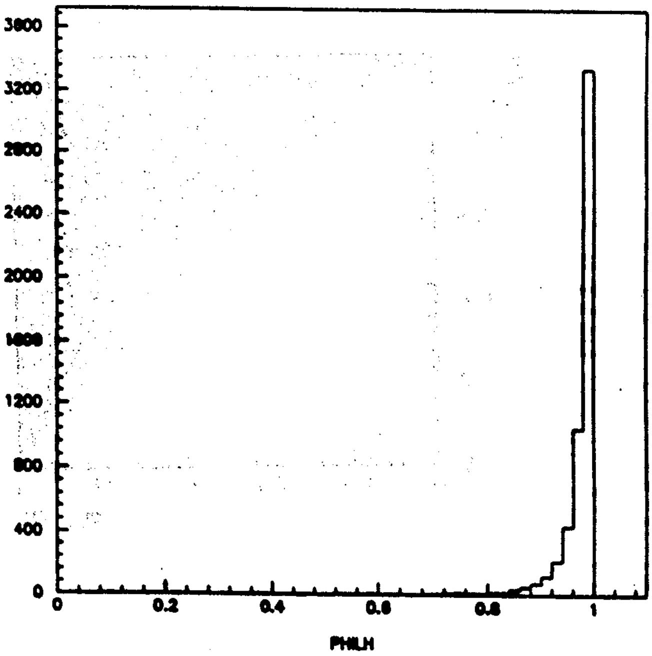
ν_μ 30 GeV



ν_μ 500 GeV

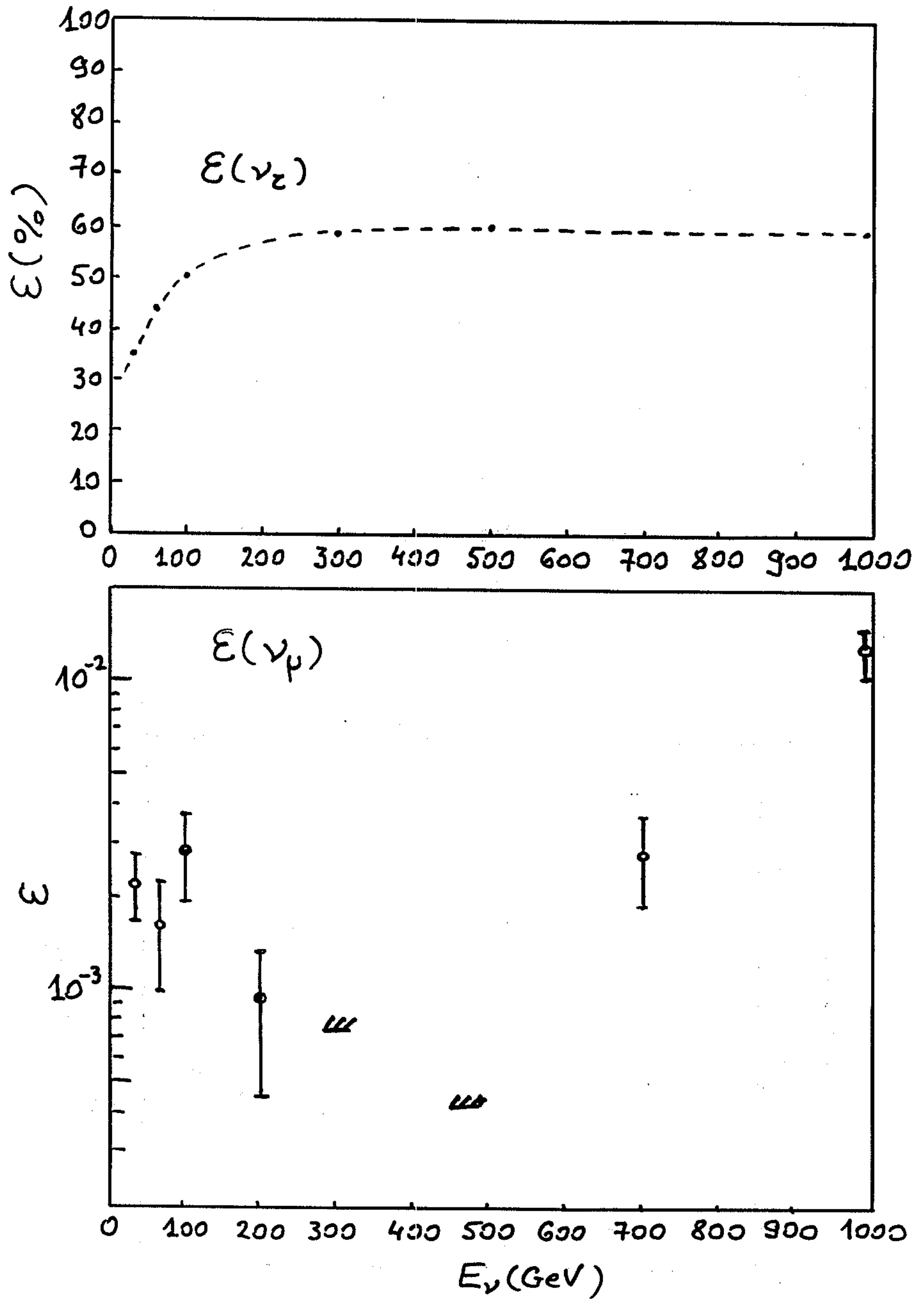


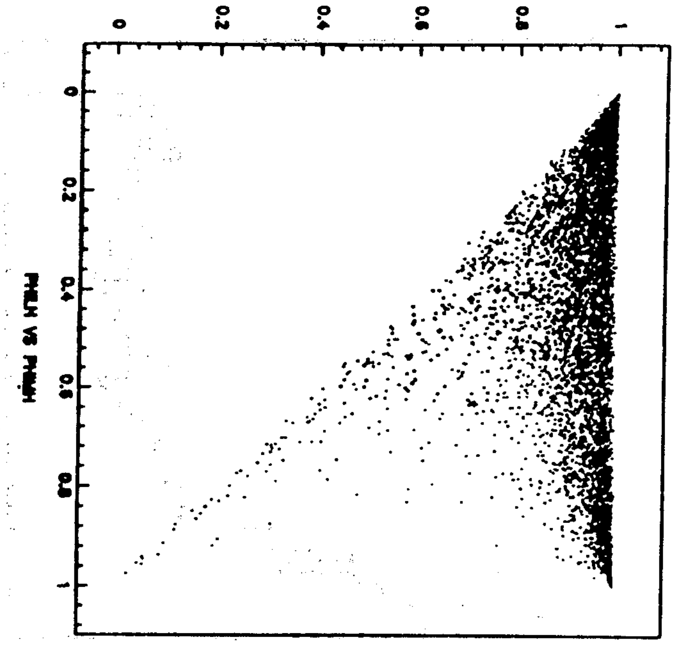
ν_μ 30 GeV



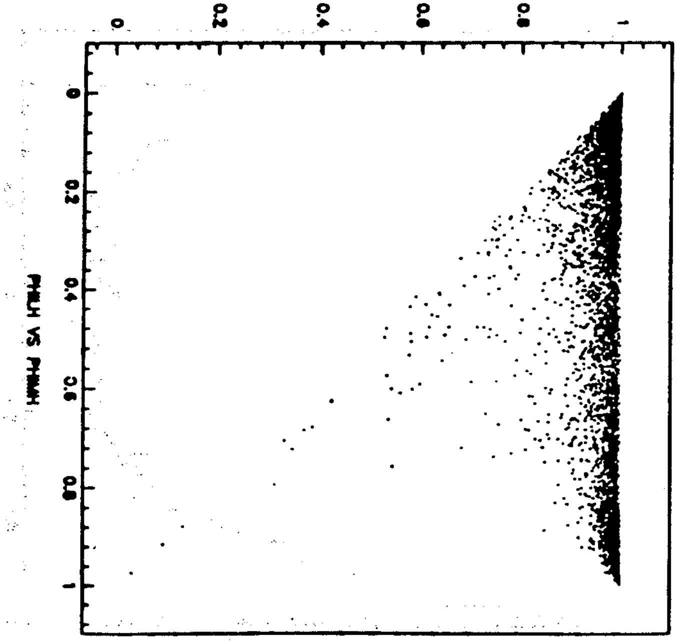
ν_μ 500 GeV

ENERGY DEPENDANCE

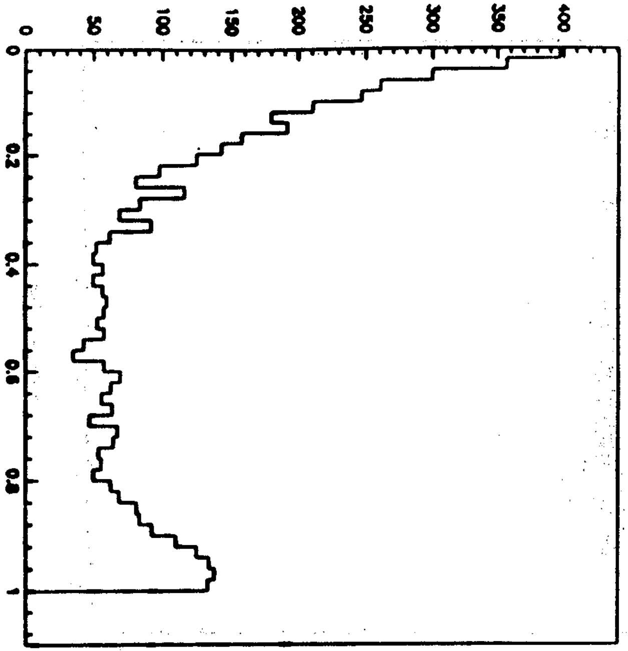




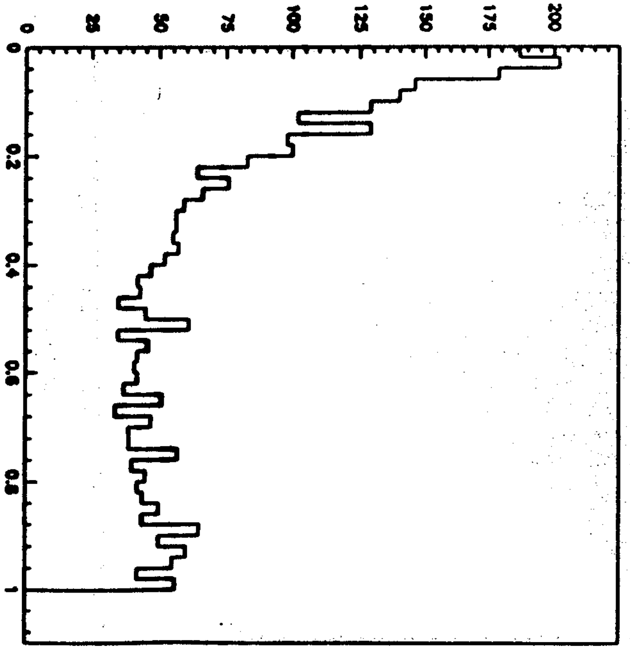
ν_μ 30 GeV



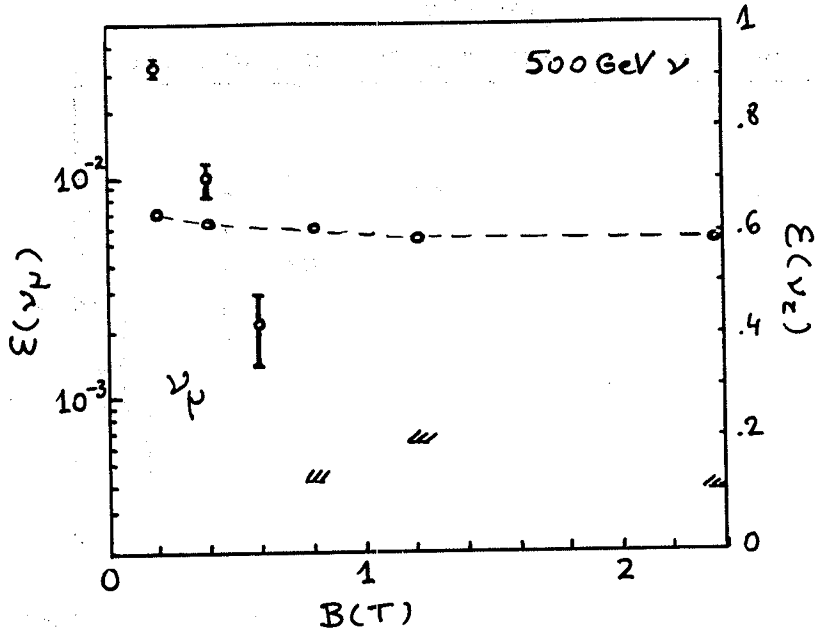
ν_μ 500 GeV



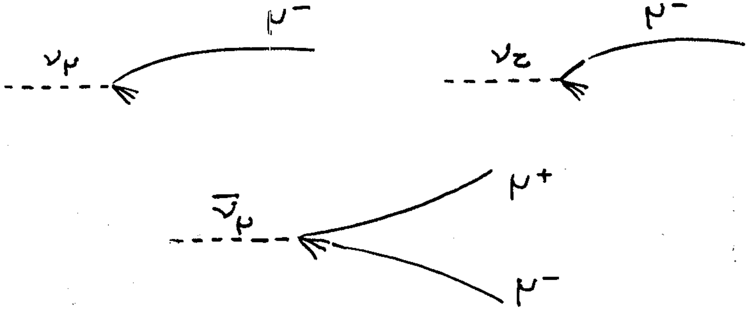
500GeV B=0.8T



500GeV B=2.4T



Charm background ?



1000 $\nu_\mu \to \mu^-$		<0.5
100 $\nu_\tau \to \tau^-$	18 $\nu_\tau \to \tau^- \to \mu^-$	11
300 $\bar{\nu}_\mu \to \mu^+$	2.5 $\bar{\nu}_\mu \to \mu^+ \mu^-$	~ 2

all μ^- accompanied by HE μ^+

CONCLUSIONS

- There are neutrinos at LHC
- A detector of the NOMAD type can:
  - study ν_e, ν_μ interactions to the highest energies
  - extract a ν_τ signal
- With the detector being built positionned 500 m from a high luminosity intersection we would get in 1 Alvaro's year

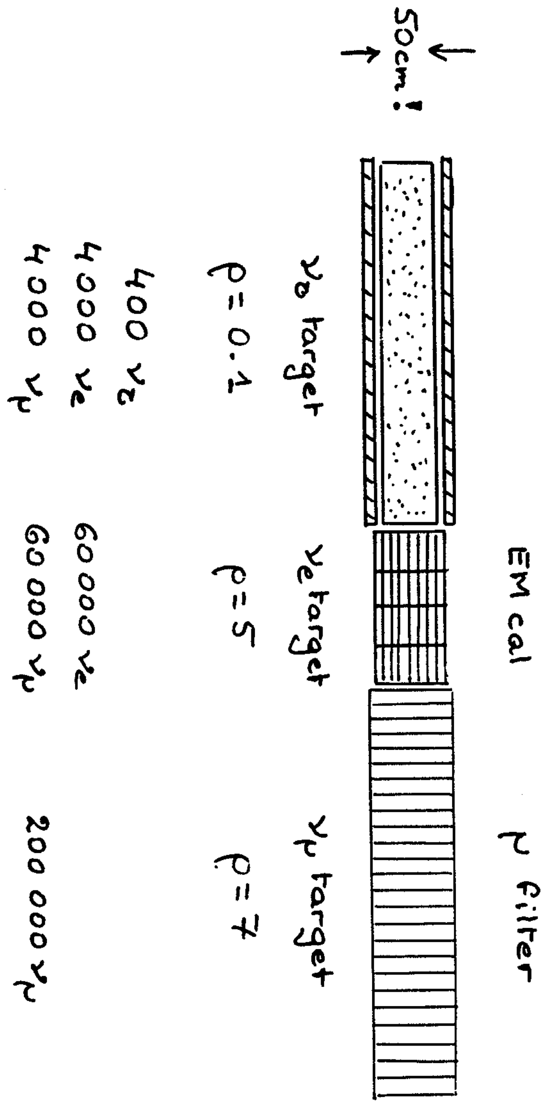
2 000 ν_μ events

2000 ν_e events

200 ν_τ events

$$\left.\begin{array}{ll} 36 & \nu_\tau \to \mu^- \\ 36 & \nu_\tau \to e^- \\ 20 & \nu_\tau \to \pi^- \\ 40 & \nu_\tau \to \rho^- \\ 30 & \nu_\tau \to \pi^-\pi^-\pi^+ \end{array}\right\} \begin{array}{c} 60\% \\ \text{reconst.} \\ \varepsilon \end{array}$$

Minimum solution



Expression of Interest

A dedicated heavy ion experiment at the LHC

J. Schukraft (CERN)

Heavy Ion Experiment at LHC

- **Strategy of HI community**
- **Design concepts for a dedicated HI detector**
- **Detector subsystems**

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Strategy of HI community

History

- ⇨ **Dec. '90:** meeting of H.I. community (after Aachen)
  - ☆ confirmation of interest in exp. at LHC
  - ☆ start to develop ideas for detector
- ⇨ **Oct. '91:** Heavy Ion Proto-Collaboration (≈ 30 Institutes, some 'newcomers' from NP & HEP)
  - ☆ common forum for all HI initiatives
  - ☆ start of concrete design work

Basis

- ⇨ HI physics at LHC integral part of initial experimental program (≈ 10% of the LHC running) (as confirmed by CERN Council Dec. '91)
- ⇨ one general purpose detector

Strategy

- ⇨ upgrade of a **LEP detector** (e.g. DELPHI)
  - ☆ should serve both LHC and LEP
- ⇨ use of a **pp detector** (i.e. CMS)
  - ☆ seems possible for high mass $\mu\mu$ and global variables
  - ☆ rare signals => high Lum, special trigger
- ⇨ **dedicated H.I. detector**
  - ☆ general purpose detector at midrapidity
  - ☆ will address MOST variables known today
  - ☆ not so rare signals => less Lum, less selective trigger
  - ☆ 'moderate' scale in size & cost (≈ like a LEP det.)

Experimental conditions

● experimental conditions

⇨ beams: ^{208}Pb+^{208}Pb (^{32}S+^{32}S, ^{108}Ag+^{108}Ag) $\approx 10^6$ s/year
(in addition: pp comparison)

⇨ lum. $\approx 2*10^{27}$ cm^{-2} s^{-1} for Pb+Pb at 6.3 TeV/n
=> rate $\approx 10^4$/s, $\approx 10^3$/s central collisions

⇨ density $(dN/dy)_{ch}$ = $(dN/dy)_g \approx 2000 - 8000$

1000 π^-, 2000 γ, 10 e^-(Dalitz), 200K^-, 70p^-, 20Λ, 1Ξ,10^{-3}J/Ψ

⇨ radiation: $\leq 10^{-3}$ of pp (high Lum.)

⇨ QED electron background (γ–γ collisions) (G. Baur/Jülich)

● consequences for detector

⇨ only loose triggers (1/10 - 1/100) => 10 - 100 Hz on tape

⇨ slow detectors & electronics ($\approx$ 100 µs between events)

⇨ high particle density => fine granularity or large distance

r (cm)	Area/Δy	particles	<d>cm	cell size (5% occ.)
10	655cm^2	3-12/cm^2	2.8-1.4mm	(0.6-.1.3 mm)^2
500	160m^2	12-50/m^2	18-14 cm	(6-12 cm)^2

Expression of Interest for a dedicated heavy ion experiment at the LHC

R. Boskovic Institute, *Zagreb*, Croatia
Inst. of Experimental Physics, Slov. Acad. of Science, *Kosice*, CSFR
Physics Inst., Czech. Acad. of Science, *Prague*, CSFR
IPN, *Lyon*, France
Lab. de Phys. Corpusculaire, College de France, *Paris*, France
CRN, CNRS-IN2P3 & Univ. of *Strasbourg*, France
G.S.I., *Darmstadt*, Germany
Inst. für Kernphysik, Univ. of *Frankfurt*, Germany
Phys. Dept., Univ. of *Giessen*, Germany
Phys. Dept., Univ. of *Heidelberg*, Germany
MPI-Physik, *München*, Germany
Phys. Dept., University of *Athens*, Greece
Variable Energy Cyclotron Centre, *Calcutta*, India
Weizmann Inst., Dept. of Physics, *Rehovot*, Israel
Phys. Dept., University and INFN, *Bari*, Italy
Phys. Dept., University and INFN, *Padova*, Italy
Phys. Dept., University la Sapienza and INFN, *Roma*, Italy
Phys. Dept., University and INFN, *Torino*, Italy
NIKHEF,*Amsterdam*, the Netherlands
KVI *Groningen*, the Netherlands
Univ. of *Utrecht* (RUU), the Netherlands
Inst. of Nucl. Physics, High Energy Physics Lab., *Cracow*, Poland
JINR,*Dubna*, Russia
ITEP, *Moscow*, Russia
Kurchatov Inst., *Moscow*, Russia
C.I.E.M.A.T *Madrid*, Spain
Div. of Cosmic and Subatomic Phys., Univ of *Lund*, Sweden
CERN, *Geneva*, Switzerland
Phys. Dept., Univ. of *Geneva*, Switzerland
Phys. Dept., University of *Birmingham*, U.K.

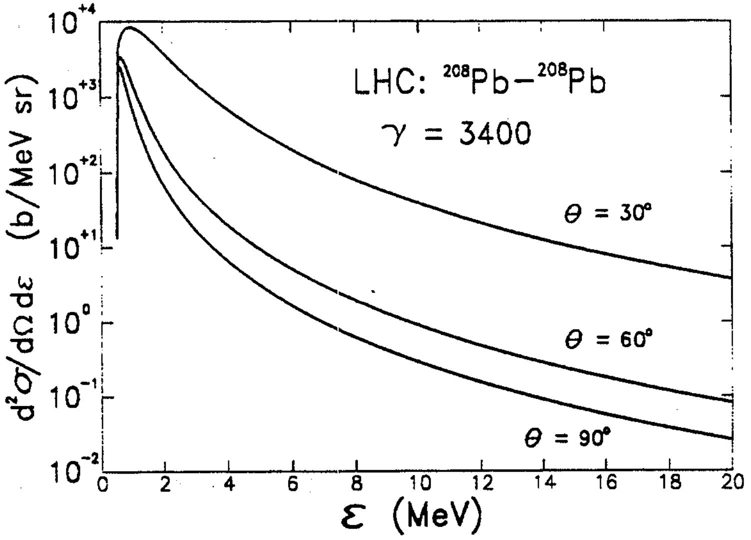
Phys. Dept., University and INFN, *Catania*, Italy
INR, *Moscow*, Russia
INP, Uzbekistan
Inst. of Physics, *Baku*, Azerbaidjan
Inst. of Physics, *Ulan Bator*, Mongolia
Inst. of Physics, *Belgrade*, Yugoslavia
Phys. Dept., University *Belgrade*, Yugoslavia
Phys. Dept., University *TitOgrad*, Yugoslavia

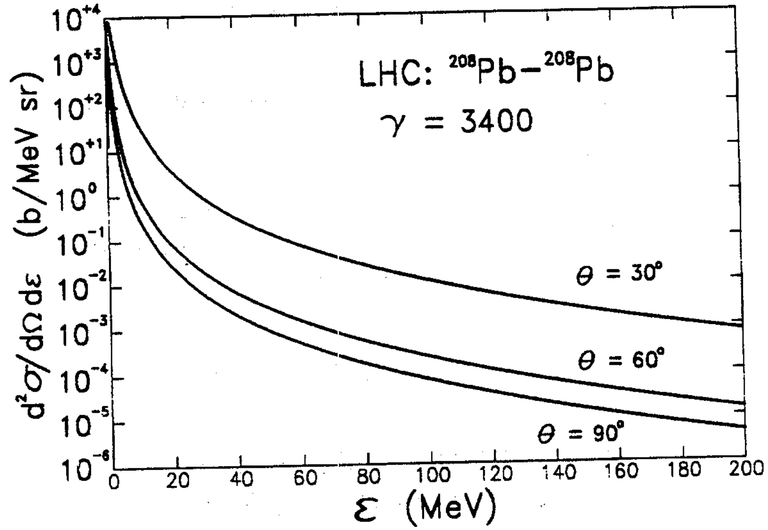
Dedicated Heavy Ion Detector

- **observables addressed**
  - ➩ event characteristics: e.m. E_t and/or dN/dy
  - ➩ identified particle spectra/ratios (π,K,p)
  - ➩ hyperons (Λ, Ξ, Ω)
  - ➩ particle interferometry (HBT)
  - ➩ direct photons (p_t > 1 GeV)
  - ➩ electron pairs: mesons (ρ, ω, ϕ, J/Ψ)
    continuum (m > 1 GeV)
  - ➩ jets (with leading particles, i.e. p_t)
- **observables left out**
  - ➩ low mass lepton pair continuum (m < 0.5 GeV)
  - ➩ dimuons (i.e Υ spectroscopy) **=>** in pp detector ?
  - ➩ hadr. E_t (global features **=>** dN/dy, jets **=>** single part.)
- **acceptance**
  - ➩ midrapidity (y=0) best place at LHC (highest ε, lowest ρ)
  - ➩ physics (probably) does not change in |y| < 3-5
  - ➩ particles at very different y are disconnected
    (longitudinal expansion => only local equilibrium in $\Delta y \approx 1$)

Acceptance determined by rates
$\Delta y \leq 2$ sufficient

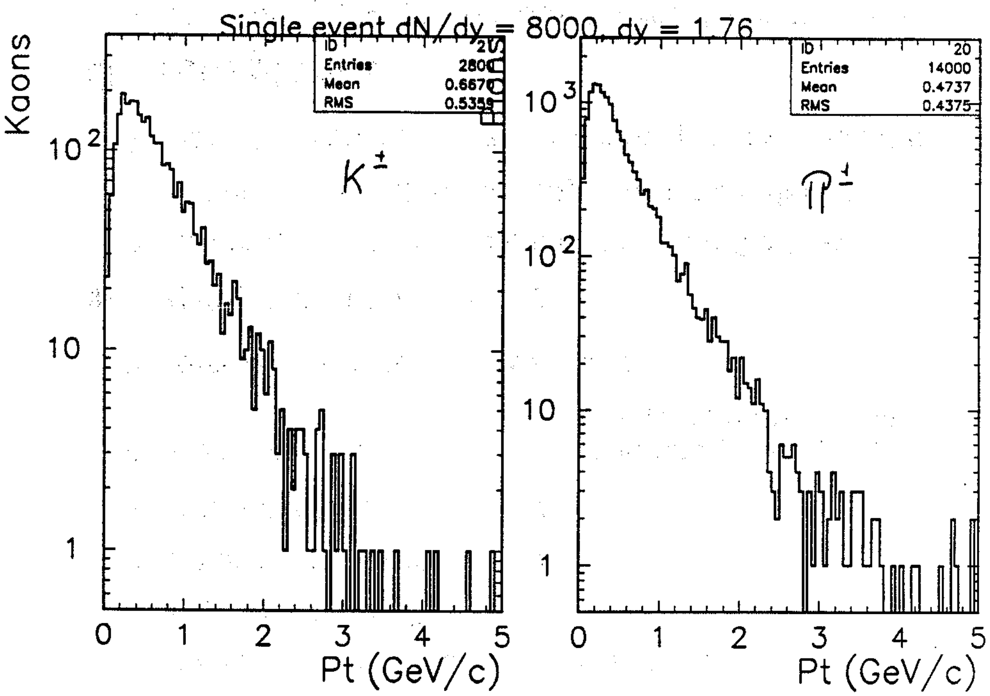
QED electrons from γ–γ





Event-by-Event Analysis

- **$dN/dy = 8000, \Delta y \approx 2$ ($\pm 45^0$)**
  - ☆ $N_{ch} \approx 14000$
  - ☆ $N_{kaons} \approx 2800$ ($K/\pi = 0.2$)
  - ☆ average p_t per event to < 1 MeV
  - ☆ K/π ratio to ≈ 2%



Central Detector

- **general purpose, 2π barrel detector with limited acceptance** ($\Delta y = \pm 0.9$, $\Delta\Theta = \pm 45°$)

⇨ **magnet**
soft particles are interesting => momentum kick ≤ 300 MeV
no gap in PID for e's => momentum kick ≤ 150 MeV

- ☆ **1) small & thin solenoid** ∅ ≈ 1m, B = 1T, Δp_t = 150 MeV
- ☆ **2) LEP-type solenoid** ∅ ≈ 6m, B=0.3T, Δp_t= 270 MeV
  (Thickness > $3X_0$ => ALL detectors inside !!)
- ☆ (L3-type large solenoid ∅ ≈12m, B < 0.3T)
  difficult tracking
- ☆ (open axial field magnet [Aachen choice])
  large stray fields

⇨ **detector subsystems**

- ☆ r=10-50: 7 high resolution planes (Silicon)
- ☆ r=100-250: TPC
- ☆ r≈450: TOF/RICH
- ☆ r>600: single arm e.m. calorimeter

⇨ **hadrons**

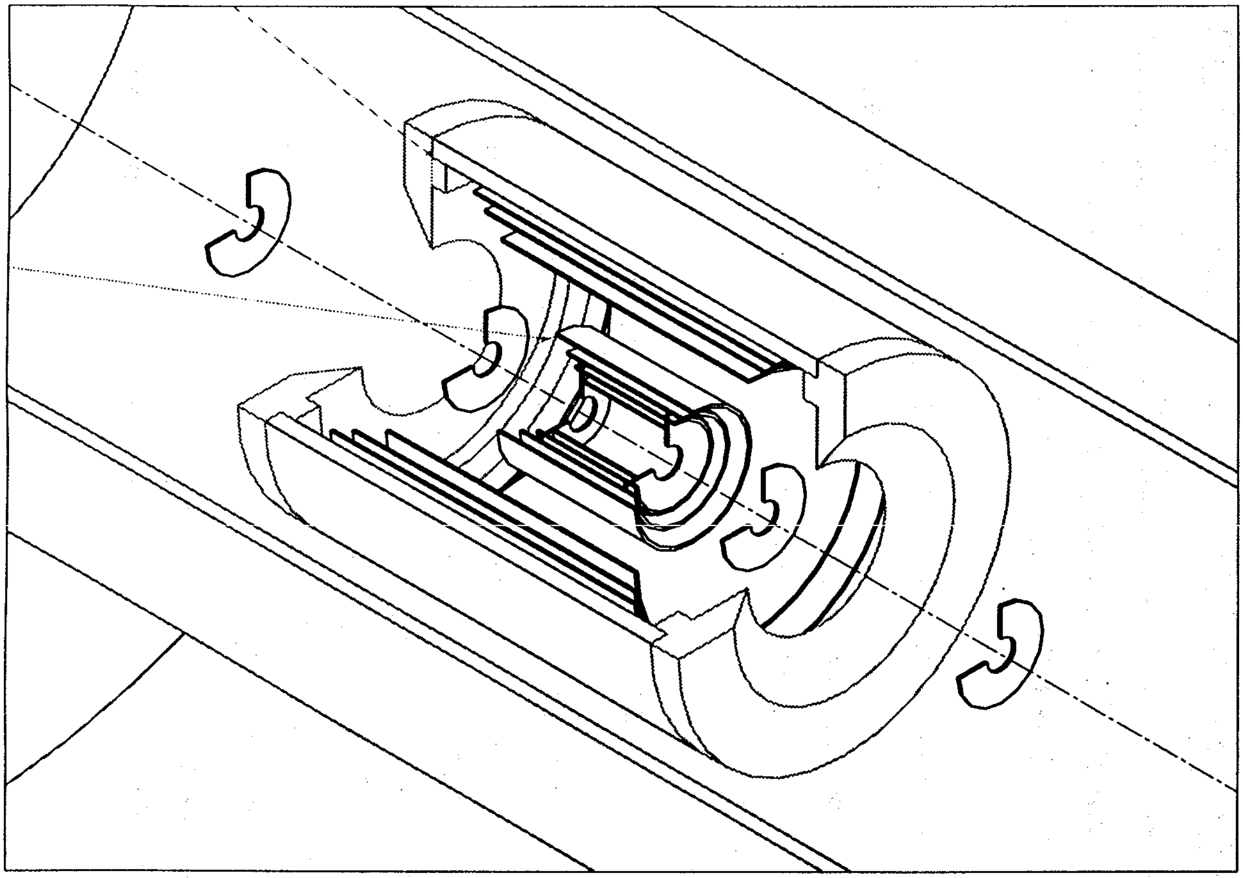
- ☆ precision tracking in weak field, best poss. resolution
- ☆ PID: dE/dx (Silicon + TPC) and TOF or RICH
- ☆ Hyperon decays with vertex det.

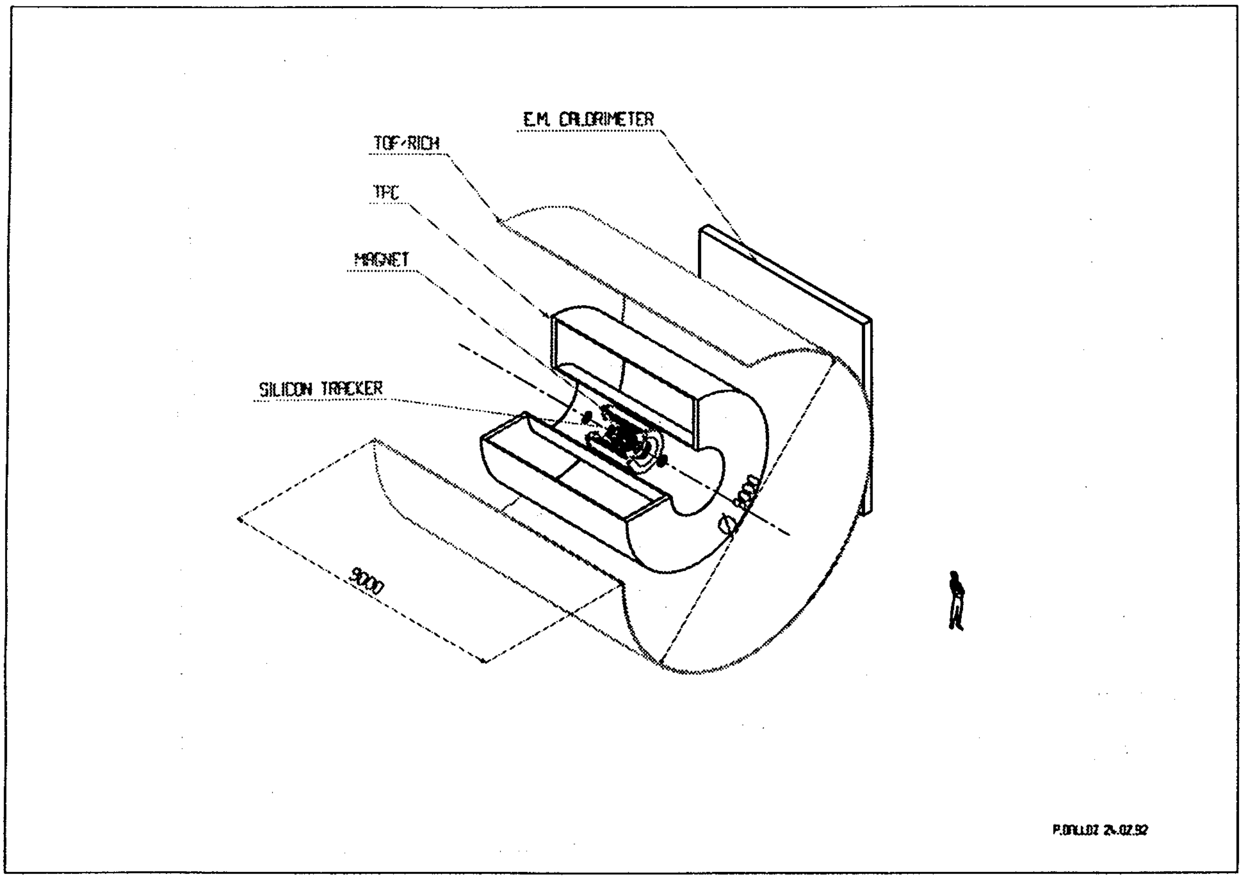
⇨ **electrons**

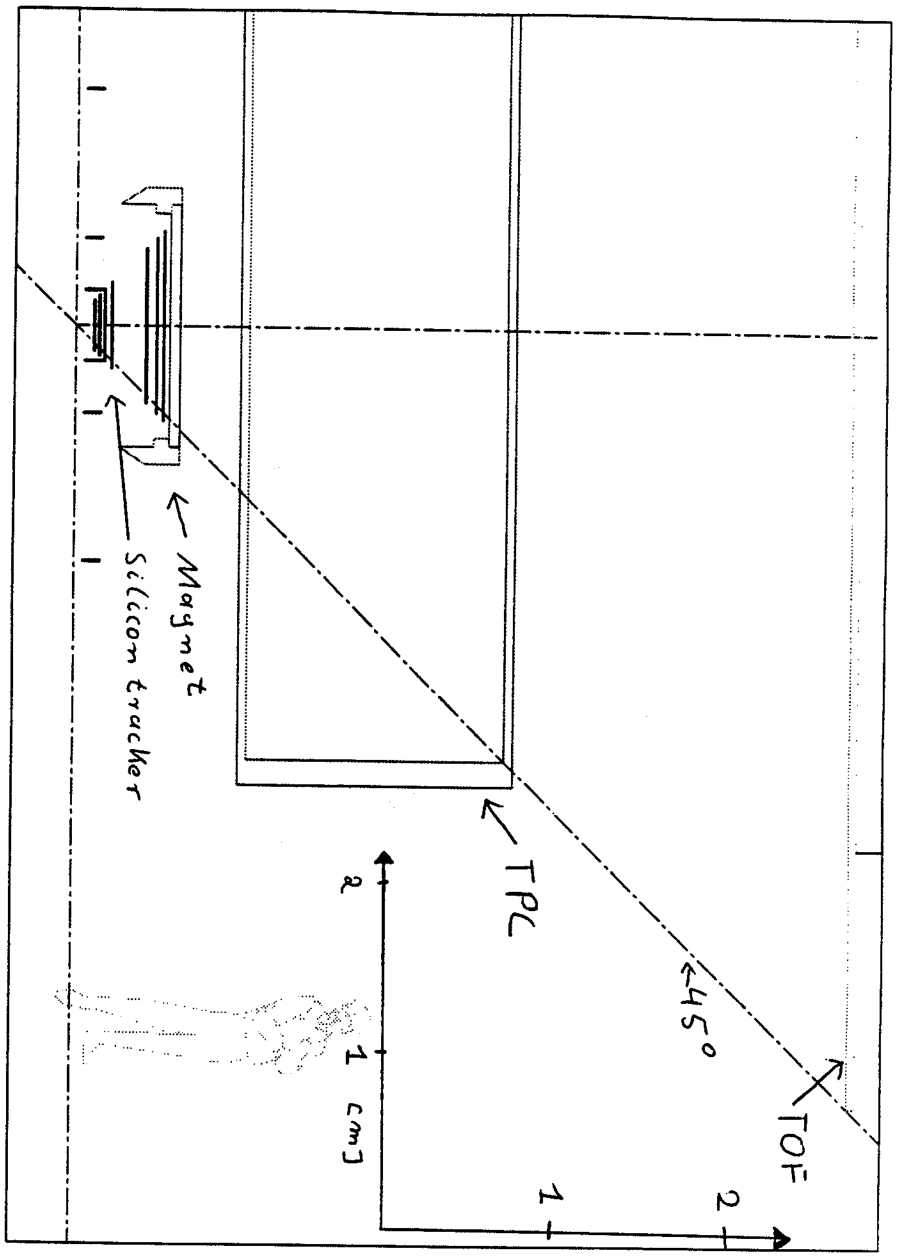
- ☆ tracking and PID like hadrons
- ☆ low mass Dalitz-pair rejection with vertex detector

⇨ **photons**

- ☆ e.m. calorimeter and with conversion method (tracking)




E.M. CALORIMETER
TOF/RICH
TPC
MAGNET
SILICON TRACKER
9000
Ø 8000
P.DALLOZ 24.02.92



Choice of Magnet

small (before TPC) vs large (behind TOF) magnet

- **weak field => MS limited (p_t <5-10 GeV) => lever arm helps little**
- **advantage of small and thin (≤20% X_0)**
  (besides cheaper)
  - ⇨ tracking over short distances
    - ☆ less alignment problems
    - ☆ less decays
  - ⇨ TPC
    - ☆ increased diffusion NO strong argument (weak field => $\omega\tau \approx$ 1-2)
    - ☆ optimize for dE/dx, not position resolution
    - ☆ straight tracks => easy pattern rec., no curling tracks
    - ☆ high pressure TPC is possible
  - ⇨ flexible set-up behind magnet
    - ☆ TOF/RHIC: 2.5 - 5 m
    - ☆ e.m. calo possible : 5 - 8 m (single arm on rails ?)
- **disadvantages**
  - ⇨ material in acceptance => secondaries
  - ⇨ sparse tracking in high multiplicity (7 space points only)

Thin solenoid

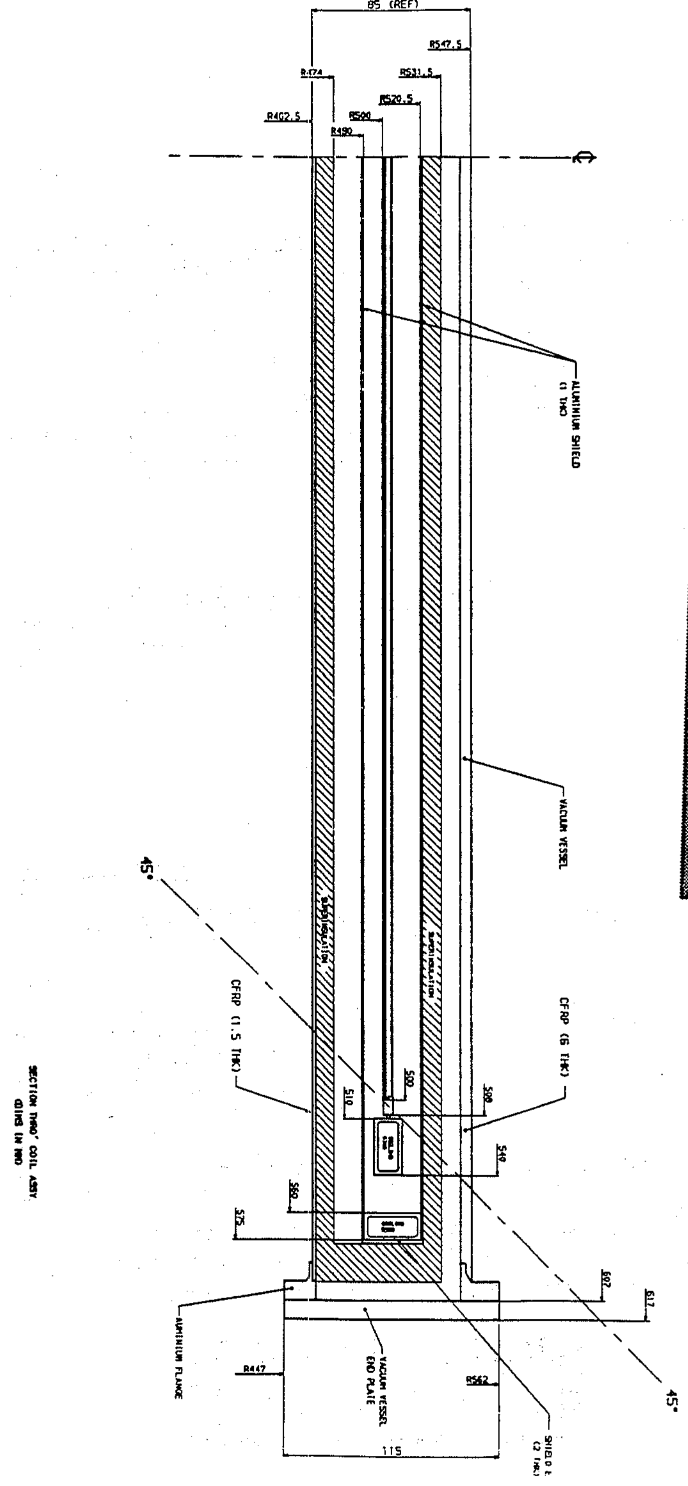
- **Thinnest so far**
  - ⇨ Astromag (Space Shuttle) B =1.2 T, ∅ = 1m, X_0 = 21%

- **RAL Design** (E. Baynham/RAL,J.Kinson/Birmingham)
  - ⇨ **characteristics**
    - ☆ B = 1T, l ≈ 1 m, ∅ = 1 m
    - ☆ 2000 Amps, 300 kJ stored energy, quench temp 100K,..
    - ☆ indirect cooling
    - ☆ carbon fibre vessel
  - ⇨ **Total thickness: 17.4% X_0, 4.2% λ**
    (equivalent to 1.5 cm Al or 7 cm Scint)
    - ☆ inner vessel + radiation shield = 1.9%
    - ☆ conductor = **7.5%**
    - ☆ shell = 3.9%
    - ☆ outer vessel + radiation shield = 4.1%
    - ☆ 1-2% reduction may still be possible
  - ⇨ **Price** (without cooling or flux return) ≈ **1.6 M SF**

  - ⇨ thickness ≈ const. for same ∫Bdl between ∅ ≈ 70cm - 2m

- **DUBNA design** (A. Vodopianov/DUBNA)
  - ⇨ B = 0.8T, l ≈ 1.2 m, ∅ = 1.6 m
  - ⇨ weight ≈ 200 tons
  - ⇨ Total thickness: **16.8% X_0**

RAL Design



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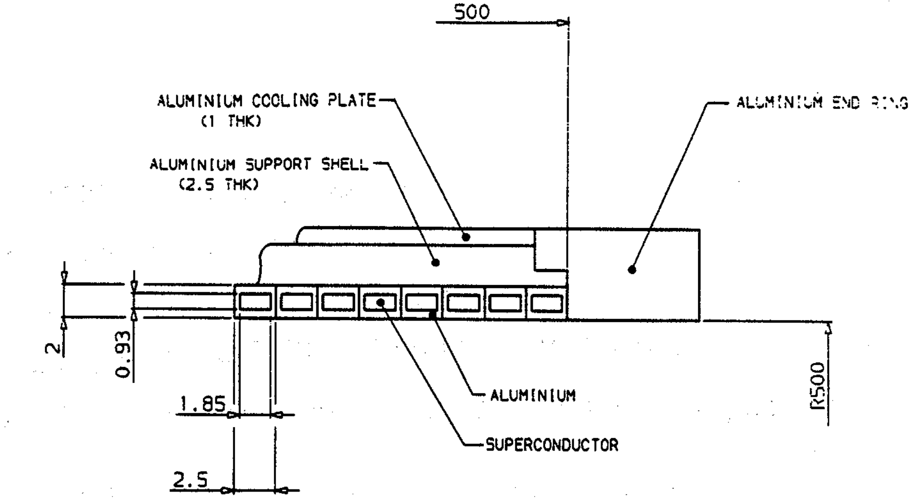
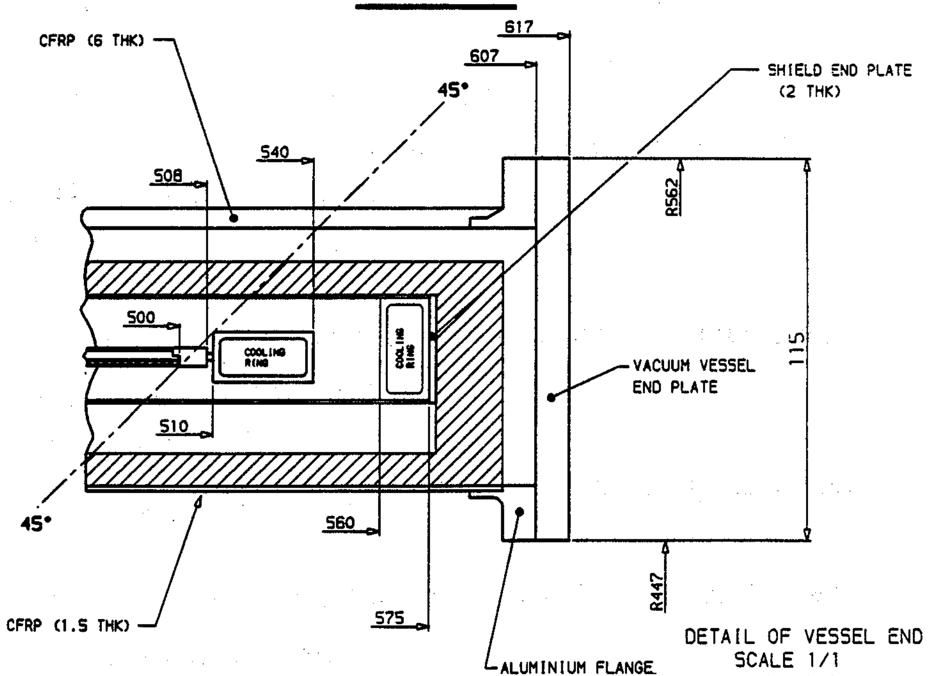
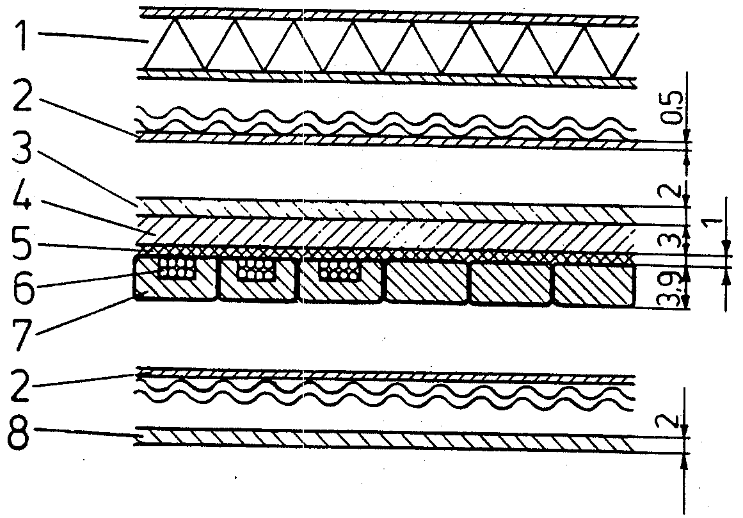


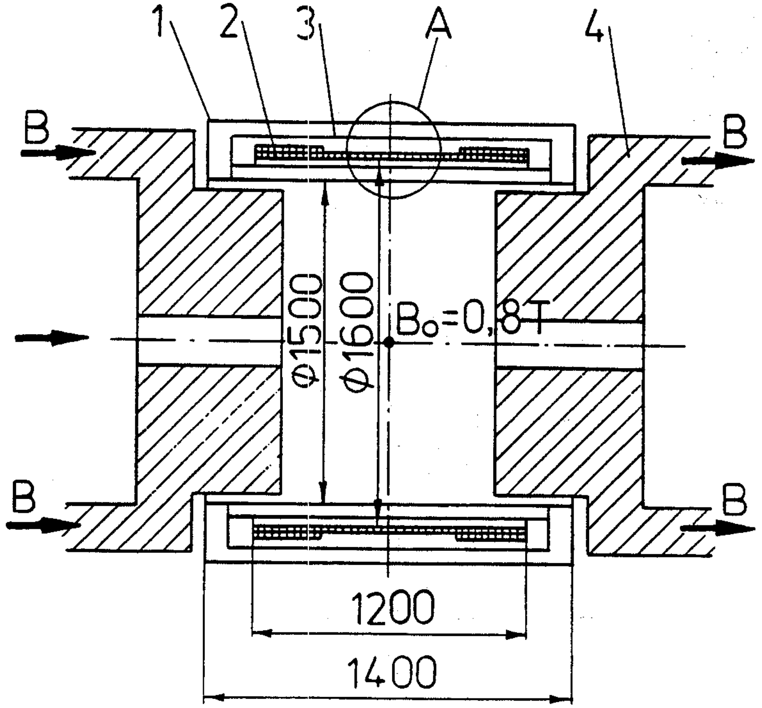
DETAIL OF COIL END
(SCALE 5/1)
DIMS IN MM



DETAIL OF VESSEL END
SCALE 1/1
DIMS IN MM

Dubna Design

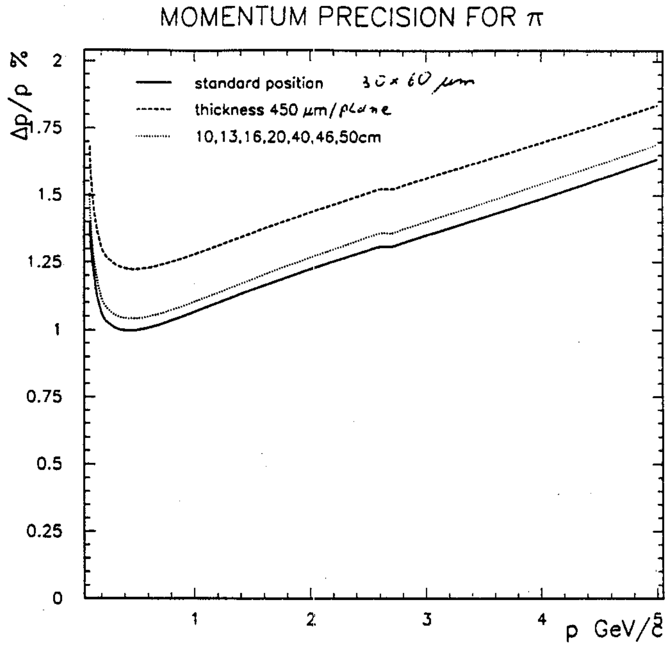


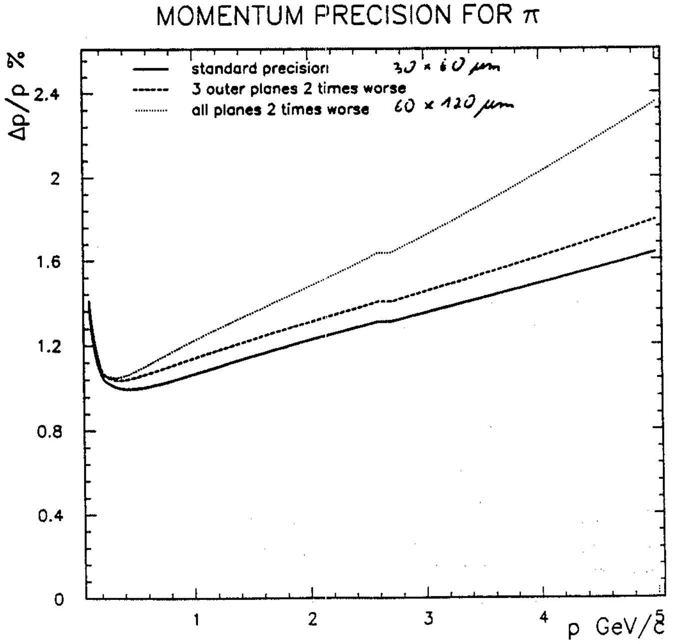


Vertex Tracker : Principle Studies

- **task**
  - ➪ best possible resolution for HBT and lepton pairs
  - ➪ particle ID in $1/\beta^2$ region with dE/dx
  - ➪ secondary vertices (Hyperons)
- **set-up (after some optimization)**
  - ➪ r = 10, 12, 16, 24, 44, 48, 50 cm
  - ➪ σ = 30 x 60 μm 30 x 1000 μm [ϕ x z] r.m.s.
  - ➪ thickness 300 μm Silicon/plane (0.3% X_0)
- **track fitting (K. Safarik et al/Paris)**
  ('optimum' method for MS and position errors)
  - ➪ $\Delta p/p \approx \sqrt{(1^2 + (0.25p)^2)}$ p[GeV] (MS = σ at 4 GeV !)
  - ➪ weak dependence on resolution (30 - > 60 μm) p < 2 GeV
  - ➪ directly proportional to √(thickness)
  - ➪ decent (5-10%) already for 3 inner planes (Δp_t = 50 MeV)
  - ➪ $\Delta\phi \approx \Delta\Theta < 0.4$ mrad (p > 500 MeV)
  - ➪ mass resolution (X->e+e-) $\Delta m/m \approx$ 1.4 - 2% (≈ sufficient)
  - ➪ large magnet (tracking VTX+TPC) comparable for 1 atm
- **patter recognition (A. Jakolkowsky et al/Paris)**
  - ➪ 6 planes/plane ε = 95%, double track res. 400 x 400 μm, 1% noise hits
  - ➪ pattern rec. efficiency (p_t > 100 MeV, >5 hits)
    ≈ 90 - 95% (depending on quality cuts)
  - ➪ 'ghosts' ≥ 10% (can be reduced by matching to TPC)
  - ➪ 'ghosts' sensitive to resolution (both in ϕ and z) & noise
  - ➪ **promising, but needs more studies**
  - ➪ optimize position of planes, use vector tracking, TPC ?

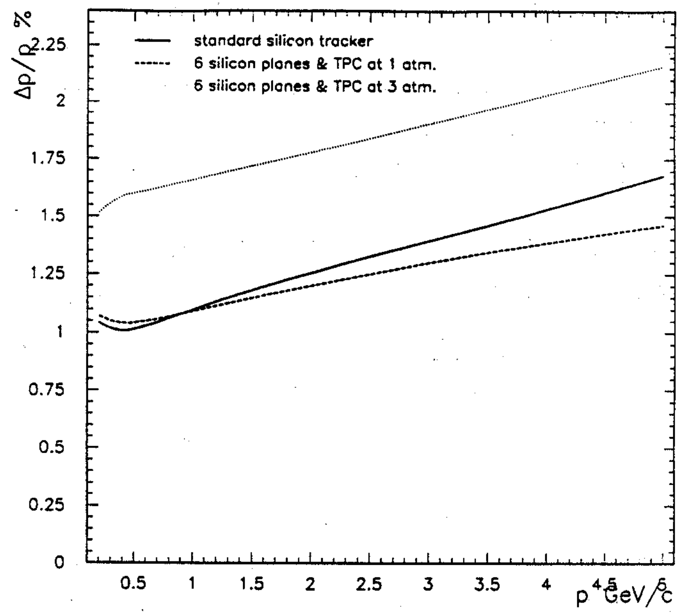
Momentum Resolution



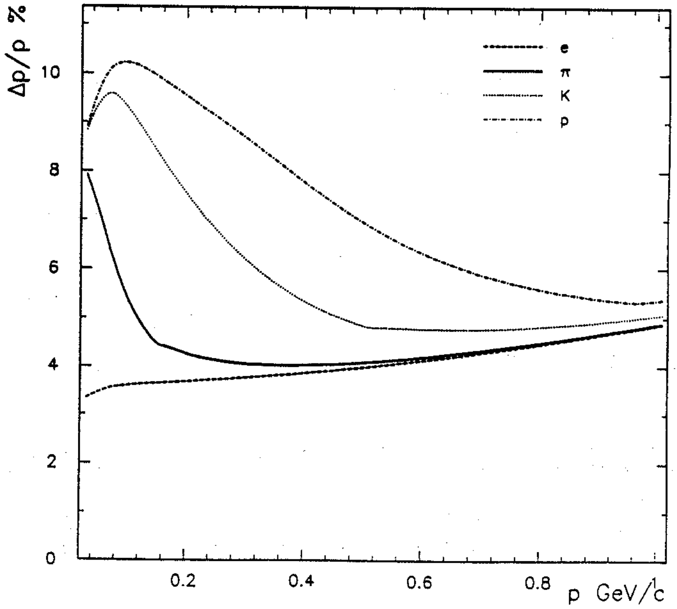


Momentum Resolution

MOMENTUM PRECISION FOR π

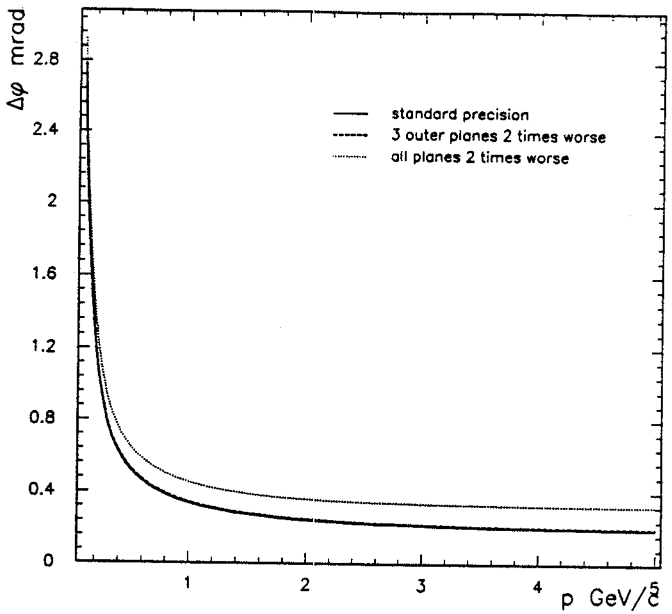


MOMENTUM PRECISION FOR (3 PLANES)

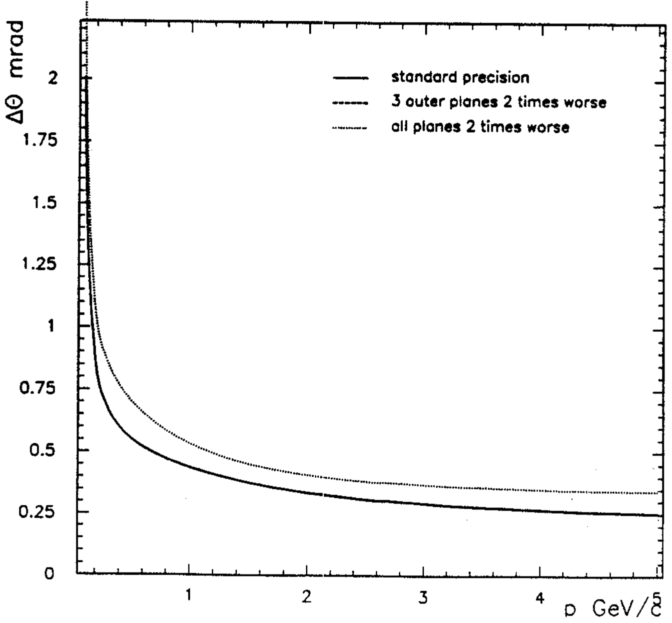


Angular Resolution

φ ANGLE PRECISION FOR π



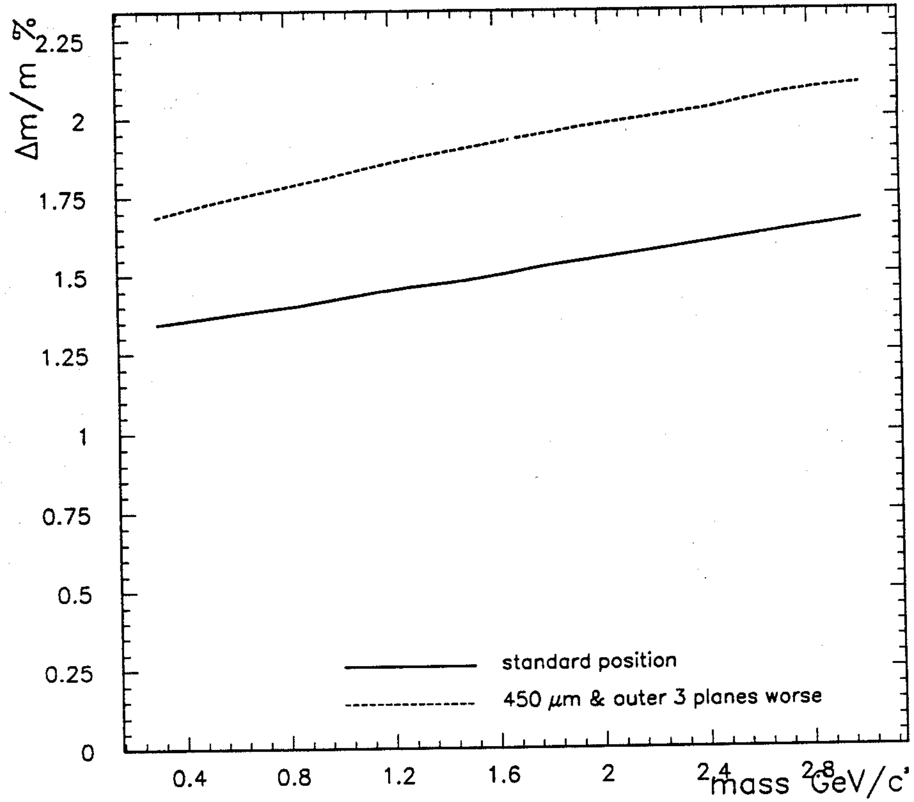
Θ ANGLE PRECISION FOR π



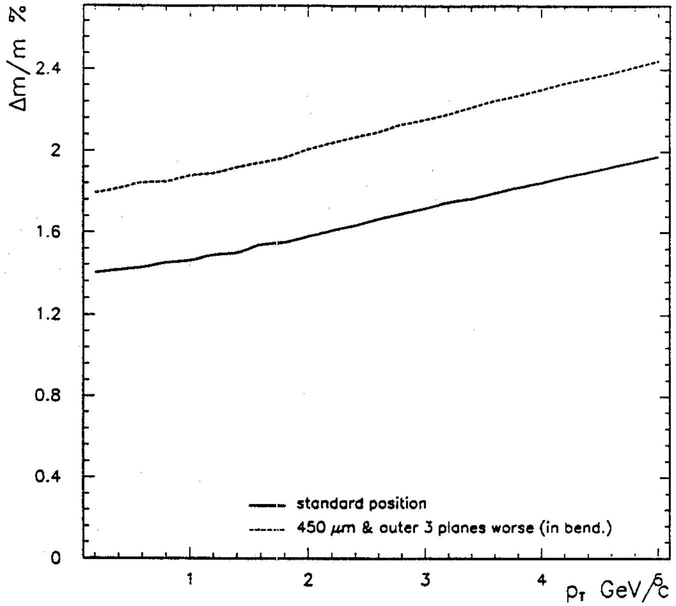
Mass Resolution X-> e^+e^-

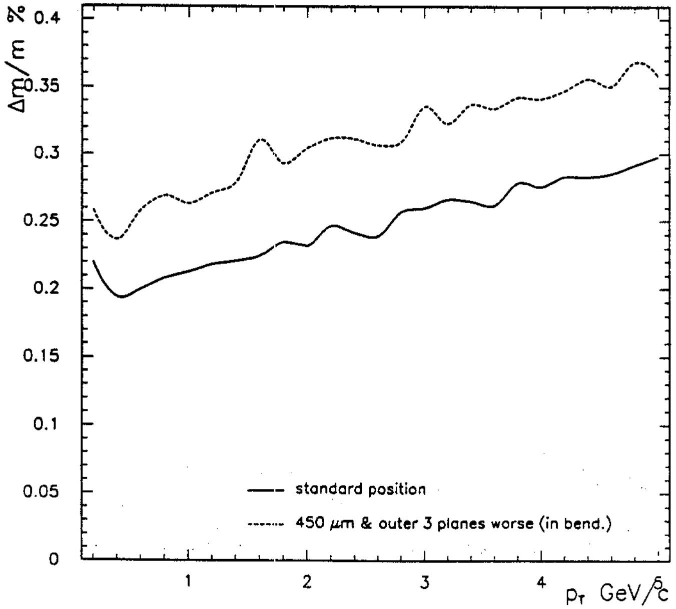
- $\Delta m(\omega) \approx 11$ MeV $\approx \Gamma(\omega)$,
  $\Delta m(\phi) \approx 14$ MeV $> \Gamma(\phi)$,
  $\Delta m(J/\Psi) \approx 50$ MeV

$\phi \to KK$ $\Delta m = 0.3$ MeV


EFF. MASS PRECISION FOR X-->e^+e^-

Mass Resolution for ϕ


EFF. MASS PRECISION FOR φ->e^+e^-

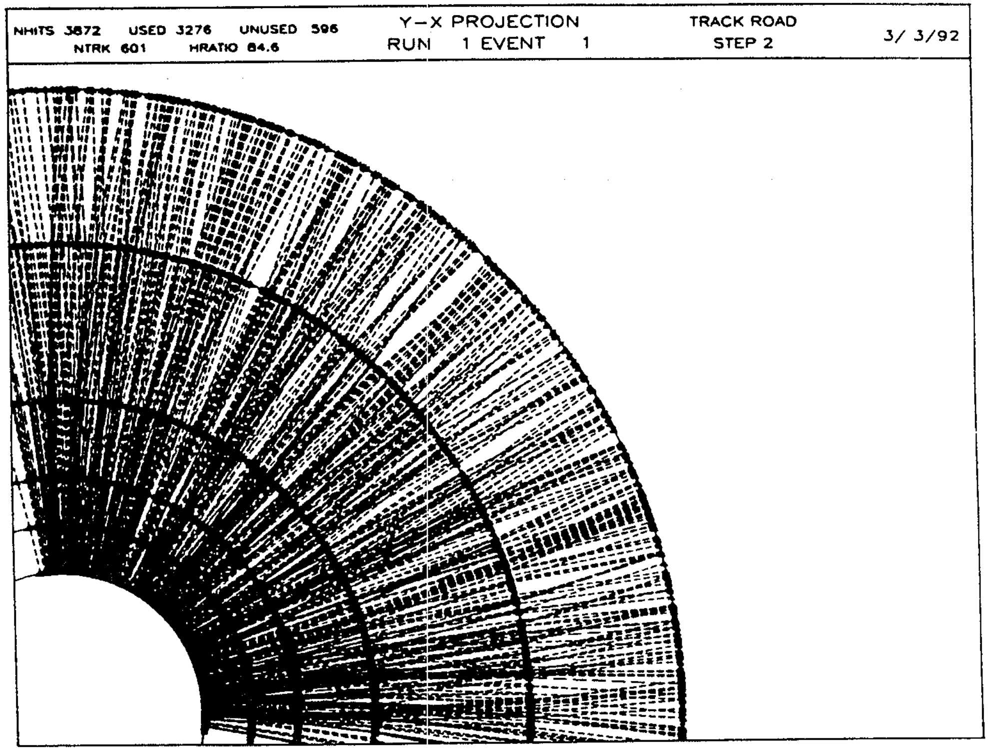

EFF. MASS PRECISION FOR φ->K^+K^-

Pattern Recognition

A. Michelon, W. Geist/Strasbourg

- 5000 tracks/Δy, $p > 500$ MeV
  (shown are 700, $\Delta y \approx .5$, $\Delta\varphi = 1/4$)

Reconstructed Tracks

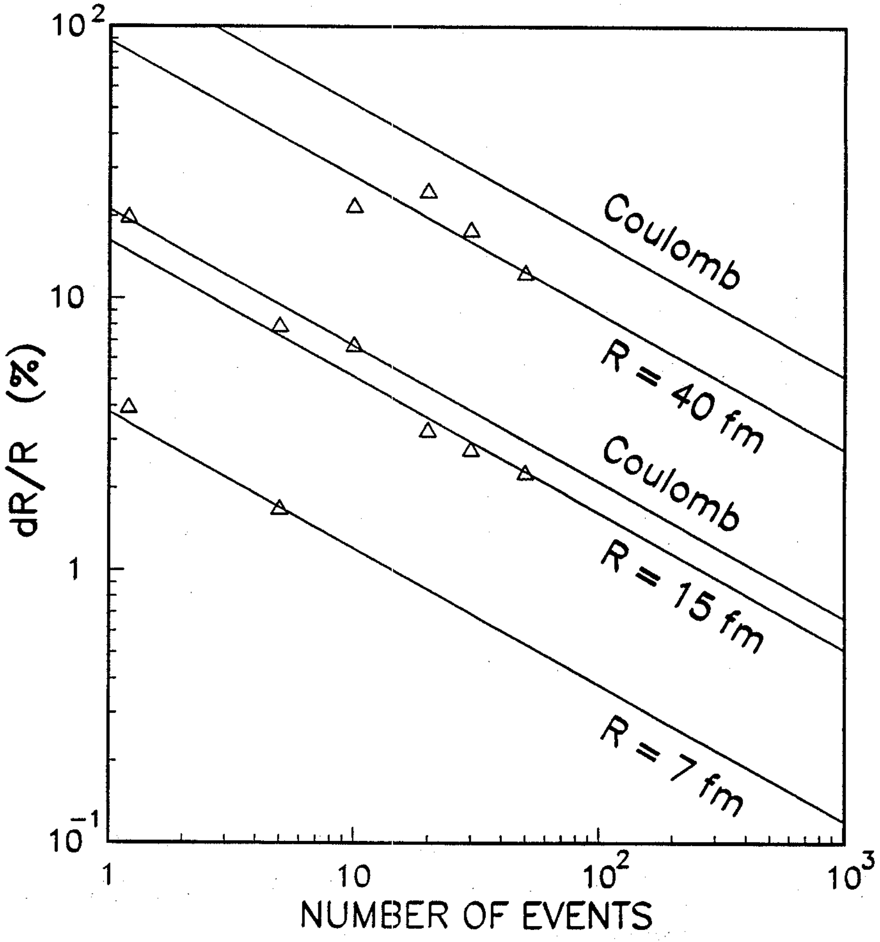


Particle Interferometry (HBT)

- **expected range of radii** (assuming no QGP)
  - ➪ $R_t \approx 20 - 40$ fm (transverse size at freeze out)
  - ➪ $R_{out} \geq R_t$ (transverse size + freeze-out time)
  - ➪ $R_l \approx 7 - 20$ fm (expansion time scale)
- **statistics** (D. Ferenc/Zagreb, R. Renford/Frankfurt)
  - ➪ single event analysis: $\Delta R/R \leq 20\%$ for $R \leq 15$ fm
  - ➪ error scales like $(dN/dy)^{-1}$ and $(\sqrt{\Delta y})^{-1}$ for large R
- **Gamov correction**
  - ➪ Coulomb repulsion reduces statistics at small Q
    => increased errors
- **double track resolution** (assuming 400 x 400 μm)
  - ➪ reduction of statistics for Q < 2 MeV
    => OK for radii up to ≈ 40 fm
- **momentum & angular resolution**
  - ➪ $\int p_t$, cut on Q_o, Q_t, $Q_l < 50$ MeV
  - ➪ $\Delta R_t \approx \Delta R_l < 0.4$ MeV $(\Delta R \approx \Delta\Theta/\Theta)$
  - ➪ $\Delta R_{out} \approx 2$ MeV $(\Delta R \approx \Delta p/p)$
  - ➪ **=>** OK for radii up to ≈ 40 fm
    (width of correlation ≈ 5 MeV)

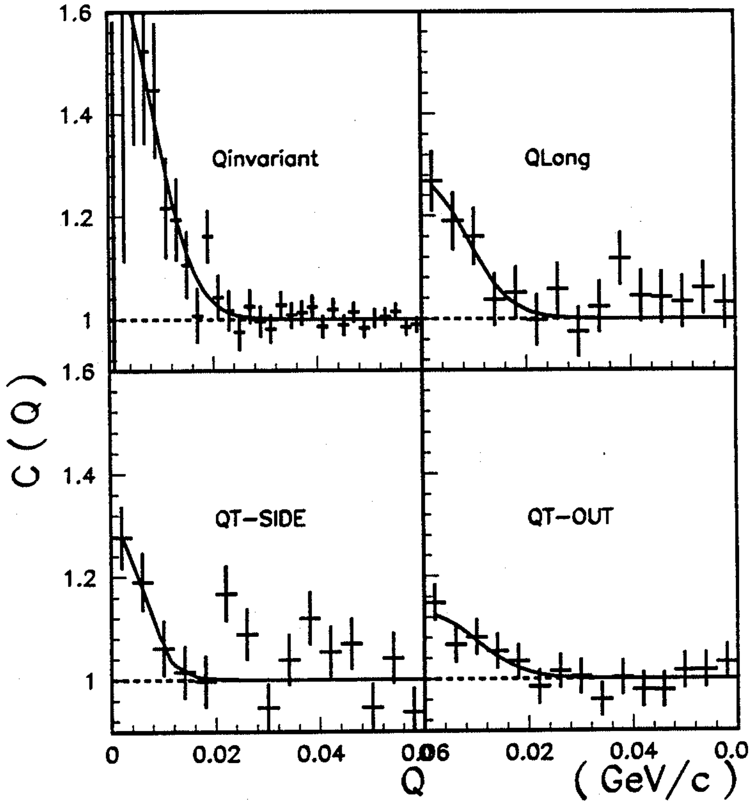
HBT: Accuracy

- **resolution $\Delta R/R$ for different radii versus number of events**
  - ☆ $dN/dy = 8000$, $\Delta y = 2$
  - ☆ with and without Coulomb repulsion



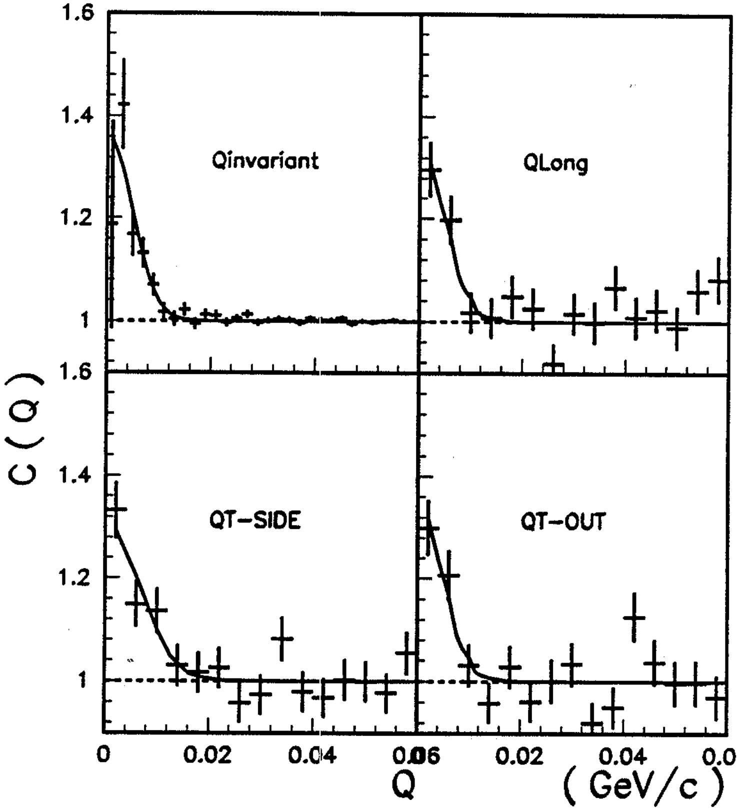
HBT: Single Events

- **single event, $\lambda = 0.5$, $R_t = R_o = R_l = 15$ fm,**
  dN/dy = 8000, $\Delta y = 2$ cut on Q_l, Q_o, $Q_t < 100$ MeV



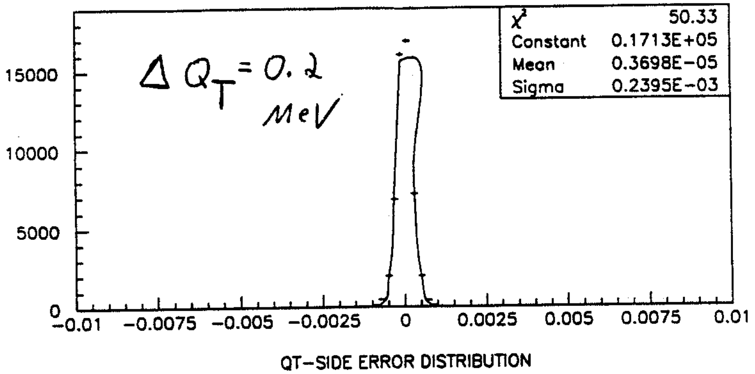
HBT: Large Radii

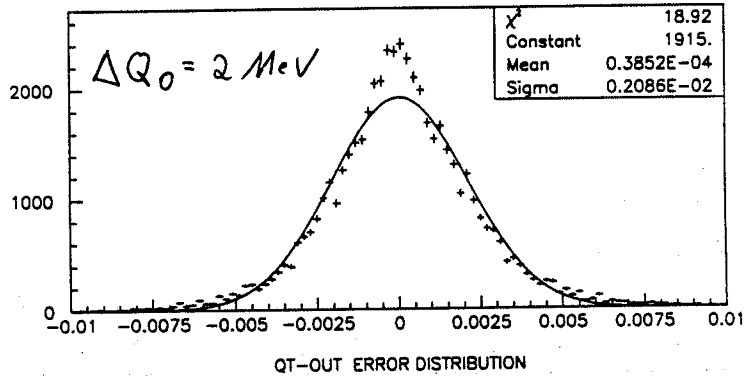
- **50 events, $\lambda = 0.5$, $R_t = R_o = R_l = 40$ fm,**
  cut on Q_l, Q_o, $Q_t < 30$ MeV

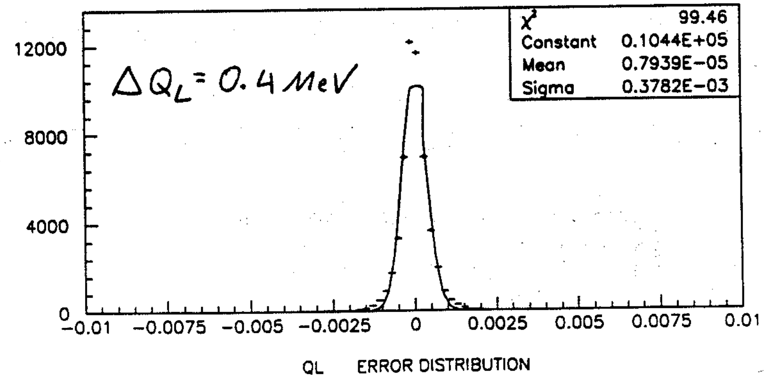


HBT: Q-Resolution

- **standard set-up & resolution (30 x 60 μm)**





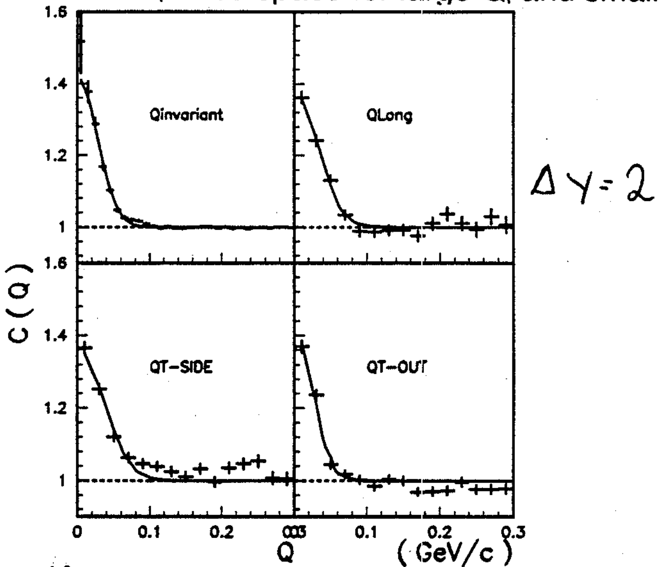


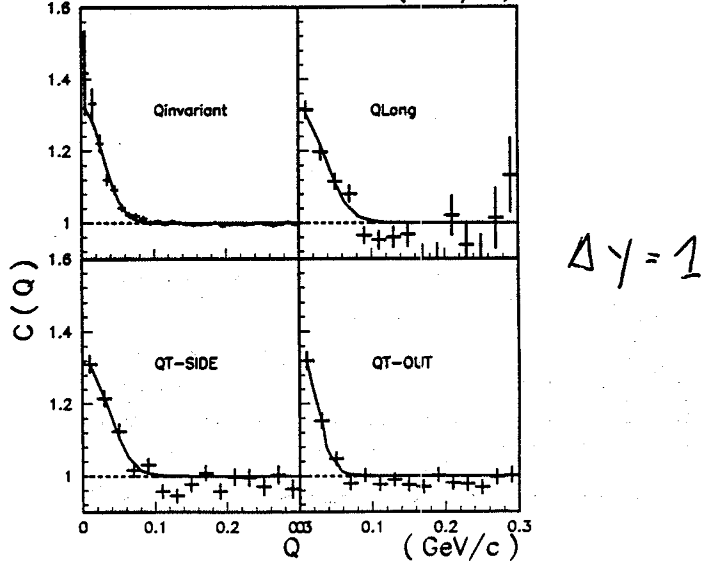
HBT: Effect of Acceptance

- **single event λ = 0.5, R_t = 6, R_o = 8, R_l = 6 fm**

  cut on Q_l, Q_o, Q_t < 30 MeV
- **Δy = 2 versus Δy = 1 (dN/dy = 8000)**

☆ no phase space for large Q_l and small Δy





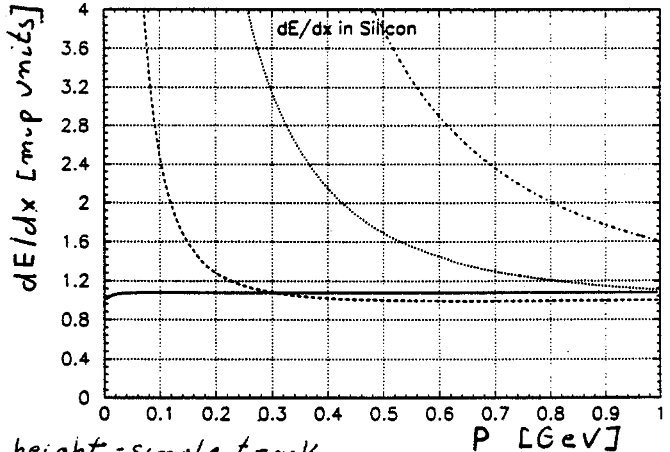
dE/dx in Silicon

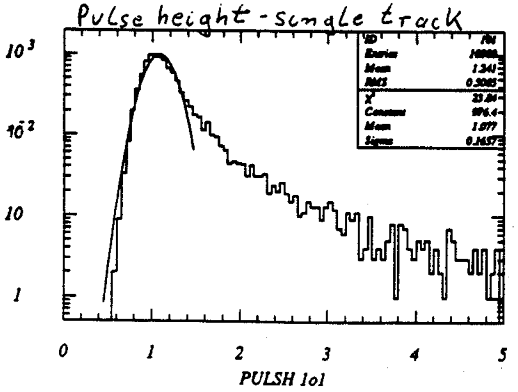
- **PID with dE/dx in Silicon in $1/\beta^2$ region:**
  - ☆ truncated mean (2 of 4 / 1 of 3): rms ≈ 12% / 14%

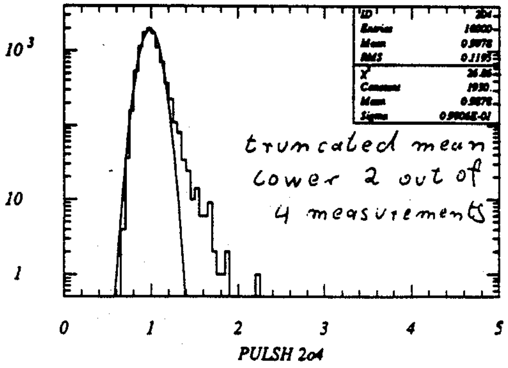
e/π<120 MeV, K/π<500 MeV, p/K<900 MeV

=> ideal low p_t spectrometer (cutoff ≈ 30 MeV ?)

- ☆ important for π/K decays
- ☆ low p_t e identification ($p_t > 30$?) (low mass pair rej.)







Tracker Hardware: Inner Planes

modest resolution (≈30-60μm), high granularity (2D), low rad., slow

- **Set-up**
  - ➪ r = 10, 12, 16, 24, 44, 48, 50 [cm²]
  - ➪ A = 0.19, 0.26, 0.42, 0.88 2.7, 3.2, 3.5 [m²]
  - ➪ Σ= 0.19 + 1.56 = 1.75 9.4 [m²]
- **Si-Pixels (RD-19, F. Navach/Bari)**
  - ➪ pixel size: 100 x 200 μm (σ < 30 x 60 μm), ideal double track res.
  - ➪ thickness: 300 + 300 μm (150 + 150 ?)
  - ➪ power: 50 μW/channel
  - ➪ cost: **15 M$/m²**
  - ➪ **plane 1:** ≈ 3 M$, 10^7 channels, 500 W, occup. 0.24%
- **Si-Drift ch. (NA45, STAR@RHIC,F. Navach/Bari)**
  - ➪ pitch: 250 μm, wafer 6x6 cm², drift time ≈ 6μs
  - ➪ 'pixel size': 400 x 400 μm (σ < 20 x 25 μm), medium double track res.
  - ➪ thickness: 300 μm (150 ?)
  - ➪ power: 30 mW/channel
  - ➪ cost: **3.5 M$/m²**
  - ➪ **plane 2-4:** ≈ 5.5 M$, 10^5 channels, 3 kW, occ. 1.6-0.4%
  - ➪ plane 1: ≈ 0.7 M$, 10^4 channels, 300 W, occup. 2.3%

Tracker Hardware: Outer Planes

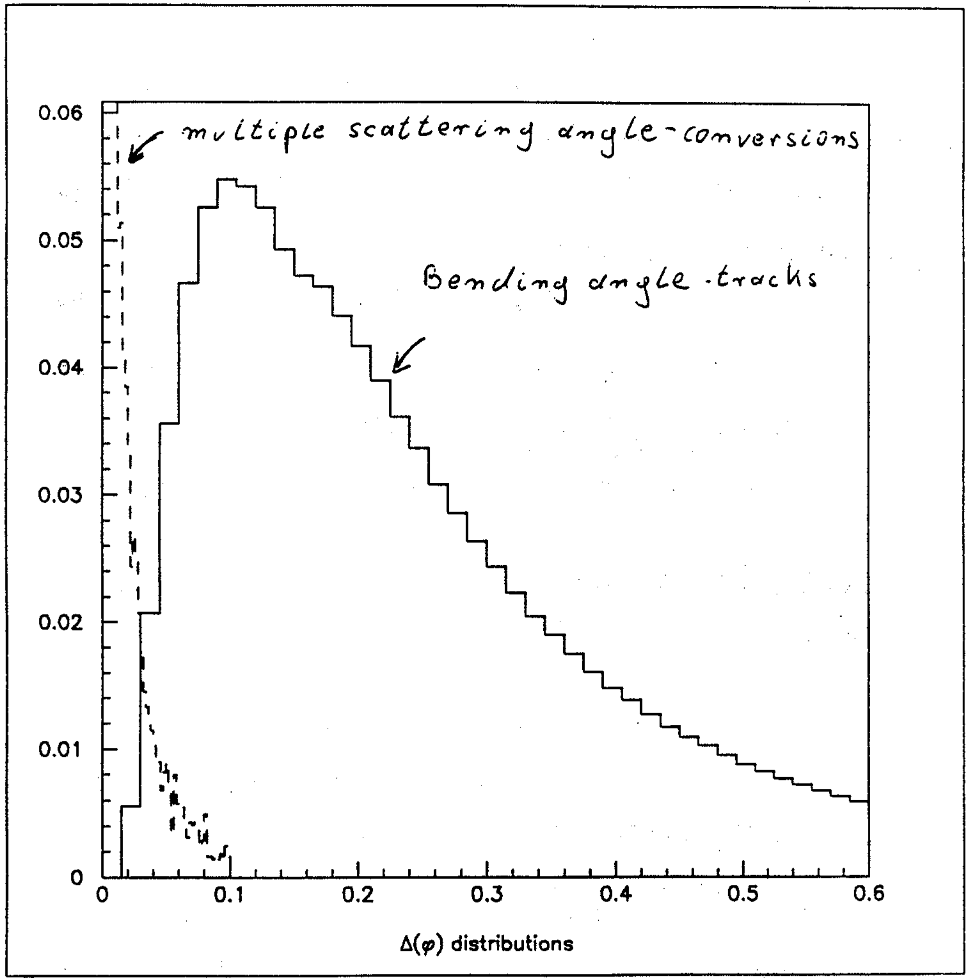
- **Si-Strips (double sided, SDC, P. Giubellino/Torino)**
  - ⇨ pitch: 100 μm, l=5 cm, 30mrad stereo ($\sigma \approx 30 \times 1000$ μm)
  - ⇨ 'pixel size': 1.5 x 50 mm (15 crossing strips)
  - ⇨ thickness: 300 μm (150 ?)
  - ⇨ power: 3 mW/channel
  - ⇨ cost: **0.7 M$/m^2**
    - ☆ det: 0.3 M$ read-out: 0.1 M$
    - ☆ aux. 0.1 M$ mech., cooling: 0.2 M$
  - ⇨ **plane 5-7:** ≈ 6.5 M$, 2*10^6 channels, 6 kW, occupancy strip ≈3%, pixel ≈ 45% => analogue pulse height matching
- **Vertex tracker ≈ 20 M SF**
- **not optimized for area**
  (smaller magnet, planes closer to VTX)
- **MSGC's** **(P. Kuijer/Utrecht)**
  - ⇨ resolution ≈ like Silicon μ-strips, double-sided possible ?
  - ⇨ potentially cheaper & thinner
  - ⇨ problem with large angle tracks (crossing 10 - 15 strips in 3 mm depth)
- **Si-drift chambers R&D project**
  in collab. with BNL

Background from Magnet

- **Geant simulation** 17%X_0, 4%λ, dN/dy = 8000
  (F. Antinori/CERN, N.v. Eijndhoven/Utrecht)
- **particle load in outer detectors**
  - ⇨ hadrons: 5% interactions , 7% increase in dN/dy
  - ⇨ photons: ≈ 10% conversions, 17% increase in dN/dy
  - ⇨ **$\sum \approx$ 25% increase:**
    unpleasant, but << uncertainty in dN/dy
- **electrons (conversion & Compton)**
  - ⇨ ≈ 1000 electrons need to be rejected
  - ⇨ 'fake e' : any track in Silicon & e with PID in TPC
- **rejection in TPC**
  - ⇨ close pairs(12%) = double dE/dx
  - ⇨ open pairs(70%) => ≈80% rejection via secondary vertex
  - ⇨ single electrons(28%) => no rejection
  - ⇨ ≈ 2/3 of electrons rejected in TPC
- **rejection via matching** (MS in magnet !)
  - ⇨ position match: rejection = 5 * 10^{-3}
    (essentially dN/dy and geometry)
  - ⇨ angular match: rejection = 2*10^{-3}
    (0.5* bending angle ≈ 150 mrad, MS angle ≈ 40 mrad)
- **Total rejection**
  > 3*10^{-5}, remaining 'fake' e ≈ 3*10^{-3}/event
  (acceptable level ≈ 1/event)

Angular Matching

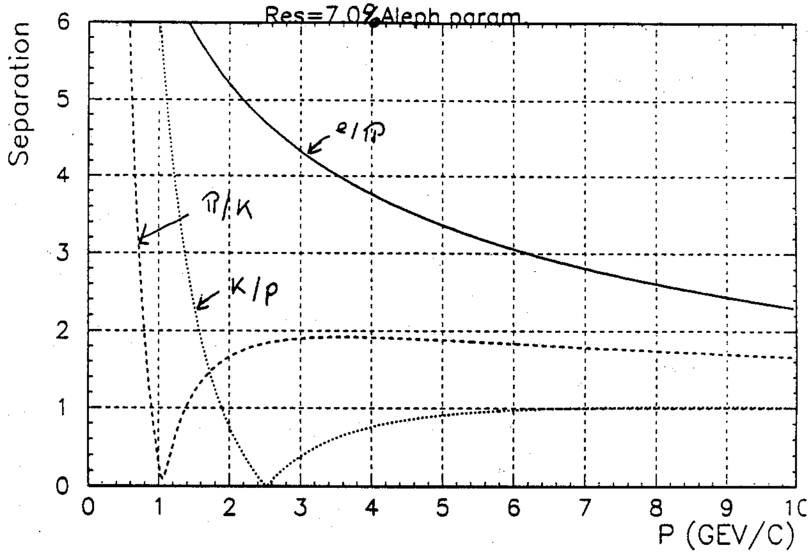
- **Phi angle distribution of tracks and conversion electrons**

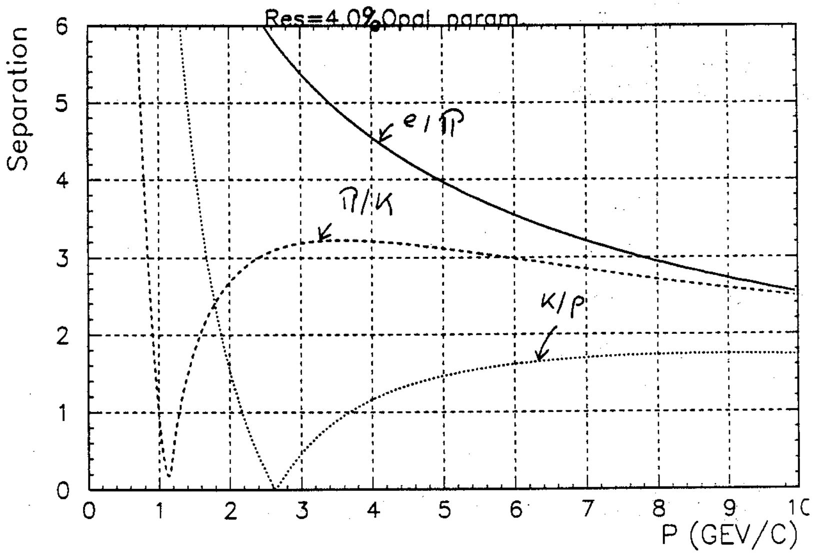


TPC

- **TPC task**
  - ➪ e ID $p_t < 5$ GeV (1 atm) and hadron ID (rel. rise) (3 atm)
  - ➪ small magnet: conversion rejection, pointing to TOF/RICH
  - ➪ large magnet: tracking
- **set-up**
  (R. Brockman et al/ GSI, V. Eckhard et al/Munich)
  - ➪ r = 100 - 250 cm, l = 2 x 2.5 m
  - ➪ r=100: 0.1 tracks/cm^2
    (NA35-TPC: 0.1-0.2, NA36: ≈ 1)
  - ➪ depth: σ(dE/dx) ≈ 6-7% (1atm)
    (NA35 ≈ 7%, Aleph ≈ 4.6% in jets)
  - ➪ high pressure: ≈ 4 % (3 atm)
    (Opal ≈ 3.8% in jets)
    - ☆ less diffusion (≈ 1/pressure) => better 2-track sep.
    - ☆ pressure tank ≈ 3 - 5 % X_0
- **design**
  - ➪ pads: 5 mm x 4 cm length (≈ NA35), analog readout
  - ➪ 38 rows, 84k channels/endplate
  - ➪ double track resolution ≈ 1-1.5 cm
  - ➪ gas: Ne/Ch$_4$ (for tracking ?) or Ar/Ch$_4$ (for dE/dx ?)
- **particle ID**
  - ➪ 1 atm: only e/π discrimination
  - ➪ 3 atm: e/π & K/π, but marginal for p/K
  - ➪ needs second system for crossing regions

Particle ID with TPC





TPC

- **cost estimate ≈ 11 M SF (STAR)**
  - ⇨ cost/channel: 40 SF

☆ electronics:	6.8	field cage:	1.0
☆ laser: 0.5		chamber:	0.5
☆ support:	1.0	gas system:	0.5-1

- **open problems**
  - ⇨ space charge (prel. estimates: OK)
  - ⇨ double track res. and dE/dx at high mult. (NA35/NA49)
  - ⇨ optimal pad length

- **R&D** **(CERN/Frankfurt/Munich,GSI)**
  - ⇨ electronics (higher integration, on board centroid finding)
  - ⇨ improved double track resolution (occupancy/cell > 10% !)
    (gap sense wire - pads < 3 mm, resistive wires ?)
  - ⇨ thin pressure vessel

TOF

task : particle ID together with TPC

- ➪ e/π rejection > 10^{-4}
- ➪ track by track π/K/p (> 3 σ separation) $p_t < 2$ GeV (abundant soft hadrons)
  - ☆ HBT, ϕ -> KK, Hyperon decays, event-by-event ratios
- ➪ statistical π/K/p (> 2 σ) $p_t < 5 - 10$ GeV (rare hard hadrons)
  - ☆ p_t-spectra, particle ratios, minijets
- ➪ trade off: distance (= resolution) and decays (= efficiency) (at 450 cm only ≈ 1/4 of Kaons survives !)
- ➪ TPC (σ = **7%**) + TOF (r = 450, σ = **75 psec)**
  - ☆ e/π > 4 σ for $p_t < 3.5$ GeV
  - ☆ π/K/p > 3 σ for $p_t < 3$ GeV
  - ☆ π/K/p > 2 σ for $p_t < 6$ GeV
- ➪ TPC (σ = **4%**) + TOF (r = 450, σ = **225 psec**)
  - ☆ e/π > 4 σ for $p_t < 5$ GeV
  - ☆ π/K/p > 3 σ for $p_t < 2.5$ GeV
  - ☆ π/K/p >~2 σ for $p_t < 10$-20 GeV

set-up

- ➪ standard (1 atm) TPC + good TOF at 450 cm
  r ≈ 450 cm, A = 255 m^2, 15% occ. => 100k pixels a 25 cm^2
- ➪ high pressure TPC + medium TOF at 300 cm
  r ≈ 300 cm, A = 113 m^2, 15% occ. => 100k pixels a 11 cm^2

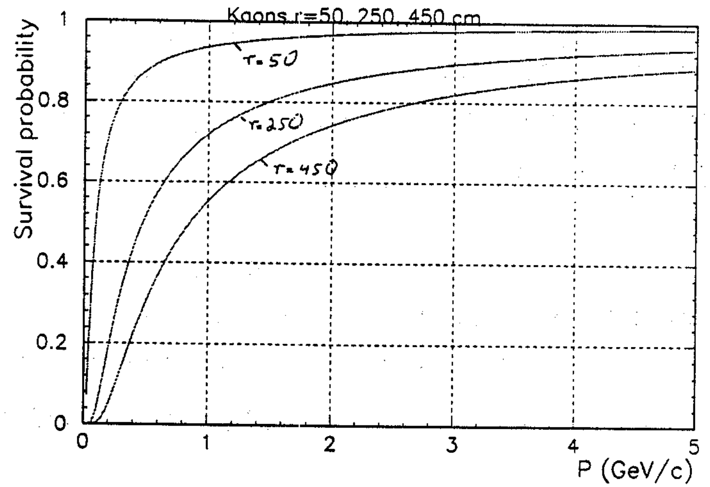
Decays

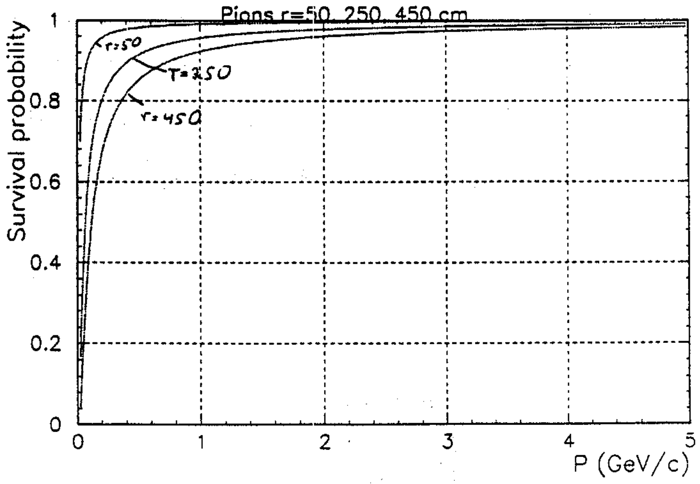
fraction of surviving particles (∫ p_t)

☆

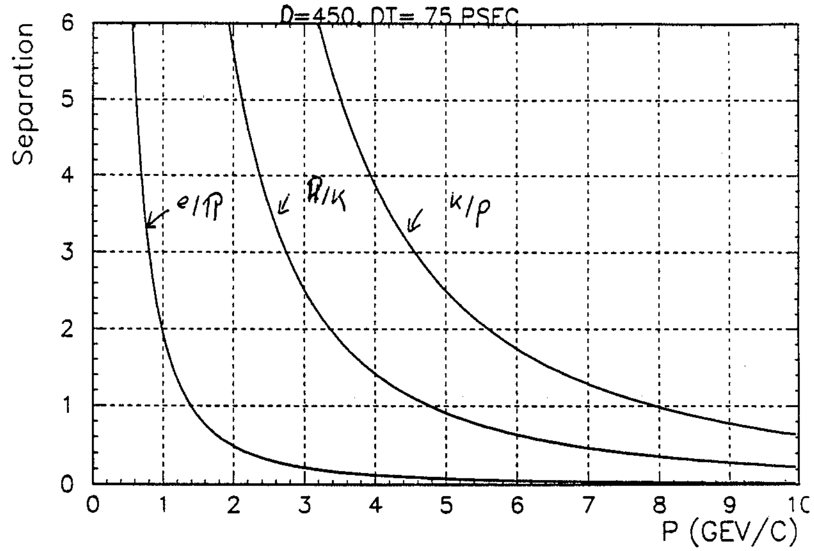
r [cm]	π	K
50	96%	78%
250	82%	41%
450	71%	**24%**

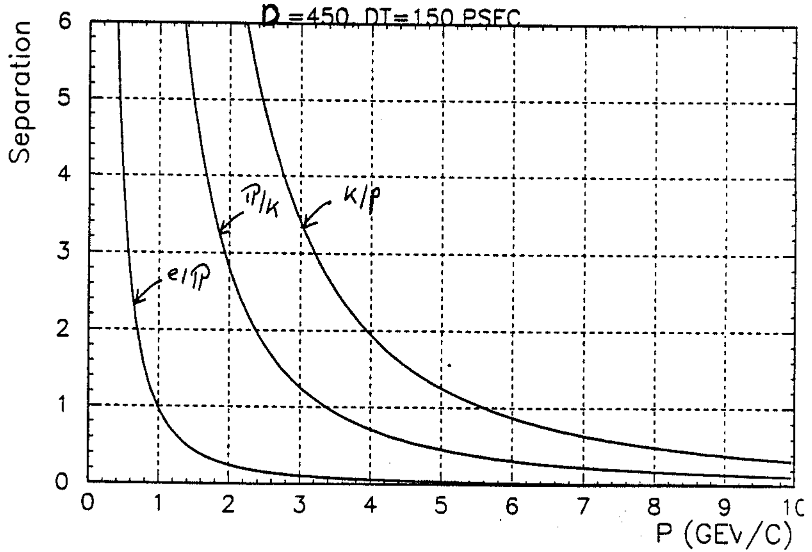
☆ importance of PID close to vertex ! (dE/dx in Silicon)



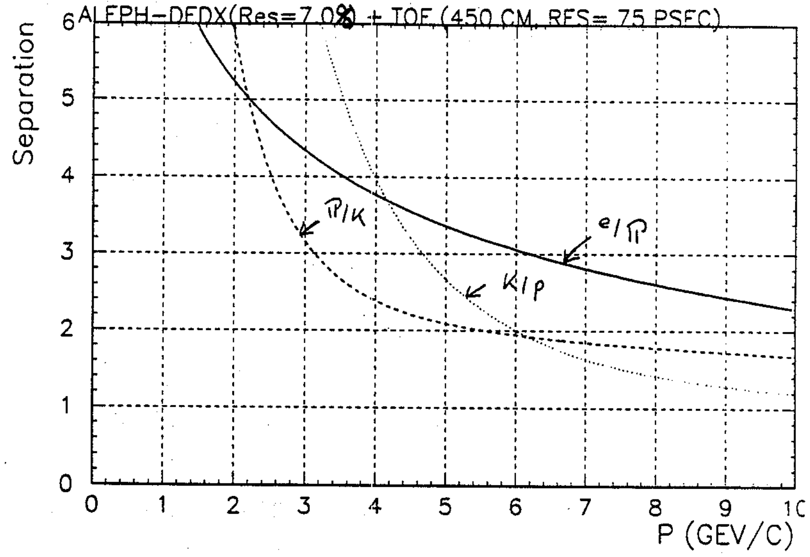


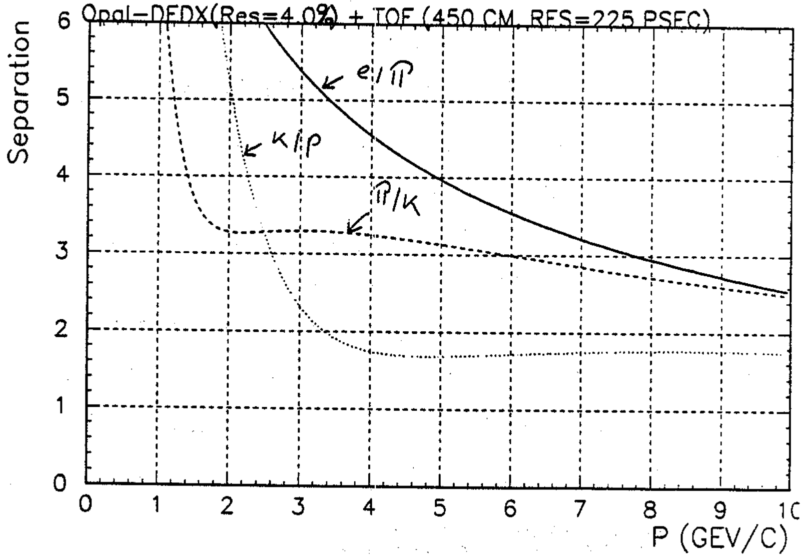
Particle ID with TOF



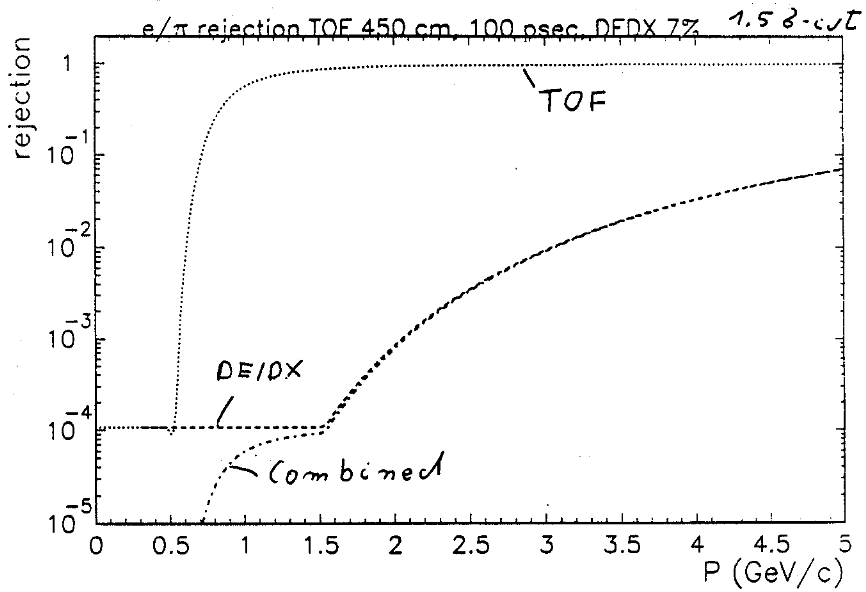


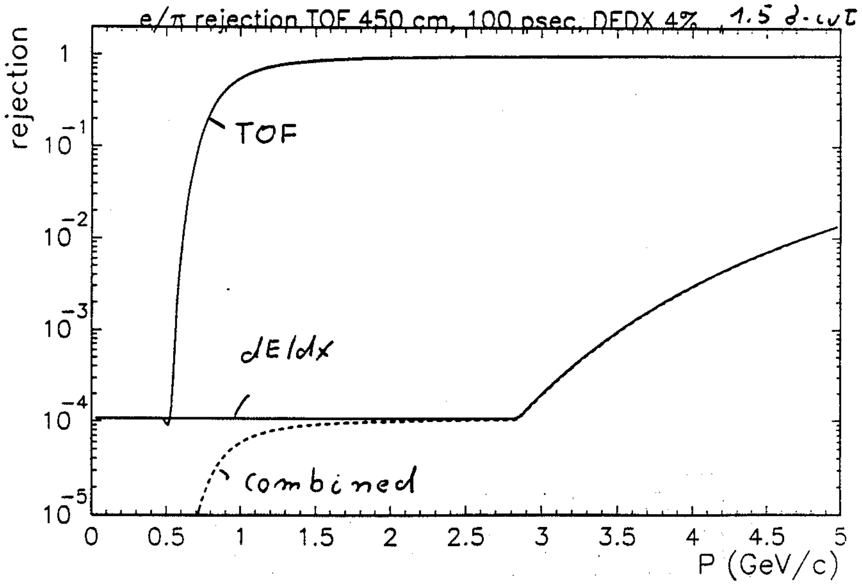
Particle ID with TOF and TPC





e/π Rejection



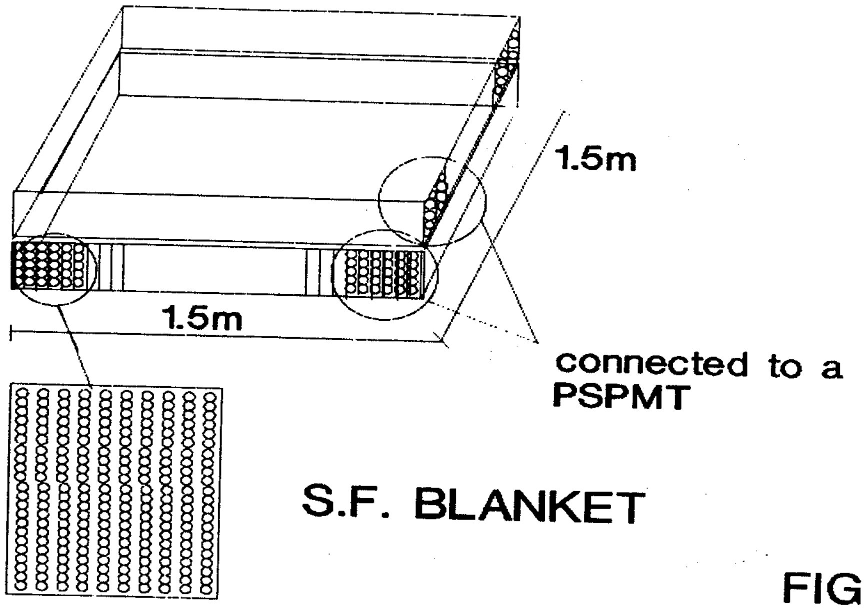


TOF Hardware

- **scintillator + PM** (A. Panagiotou/Athens)
  - ⇨ pads (25 cm^2) + PM, σ ≤100 psec (STAR)
    - ☆ price/channel ≥ 200 (PM) + 500 (electronic) SF
    - ☆ total price > **70 M SF !!**
  - ⇨ scint. fibres + position sensitive PM's
    - ☆ resolution somewhat worse
    - ☆ cheaper (PM's, larger occupancy possible)
    - ☆ **R&D:** first tests (2mm fibres, 1.5 m long) σ ≈ 150 psec
- **Pestov spark counters**
  (H. Gutbrod/GSI, Y. Pestov/Moscow)
  - ⇨ principle of operation
    - ☆ high resistivity glass, 100μm gap, overvoltage
    - ☆ >10 atm pressure for good efficiency
  - ⇨ performance
    - ☆ excellent time resolution (σ < 50 psec)
    - ☆ position resolution < 1mm (2D) with analog readout
    - ☆ large pulses (≈ 0.5 V)
    - ☆ rate (<5% dead) ≈ 1kHz/cm^2 (LHC 30 Hz/cm^2 @ 3m)
    - ☆ lifetime > 10^{10} hits/cm^2 (>> 10 y)
  - ⇨ **problem**
    - ☆ reliable large area devices (surface quality, tolerances)

  - ⇨ **R&D:** detector prototype (50x4 cm^2) test in '92
    - ☆ electronics development at GSI
    - ☆ collaboration with industry (Schott) for glass fabrication
    - ☆ projected cost ≈ 100 SF/channel, total price ≈ **10 M SF**

Scintillating Fibres + PM



S.F. BLANKET

FIG 1

TOF BARREL

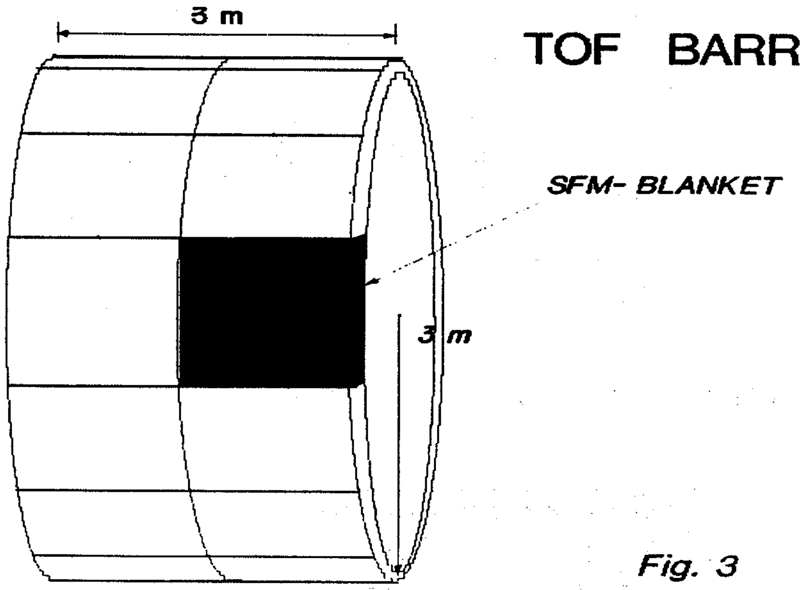
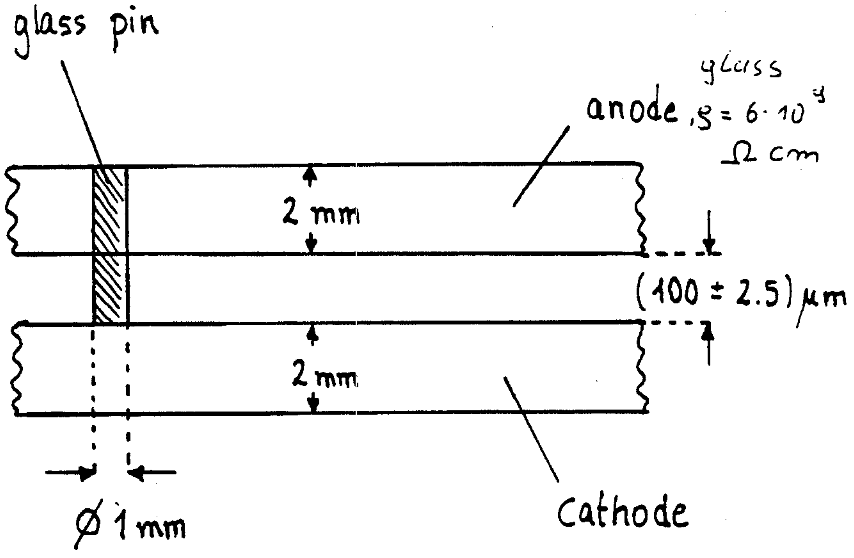
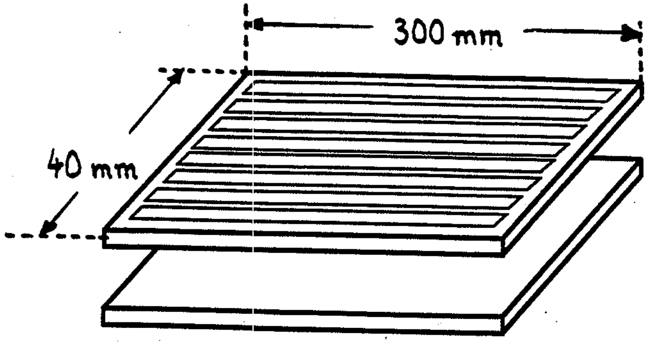


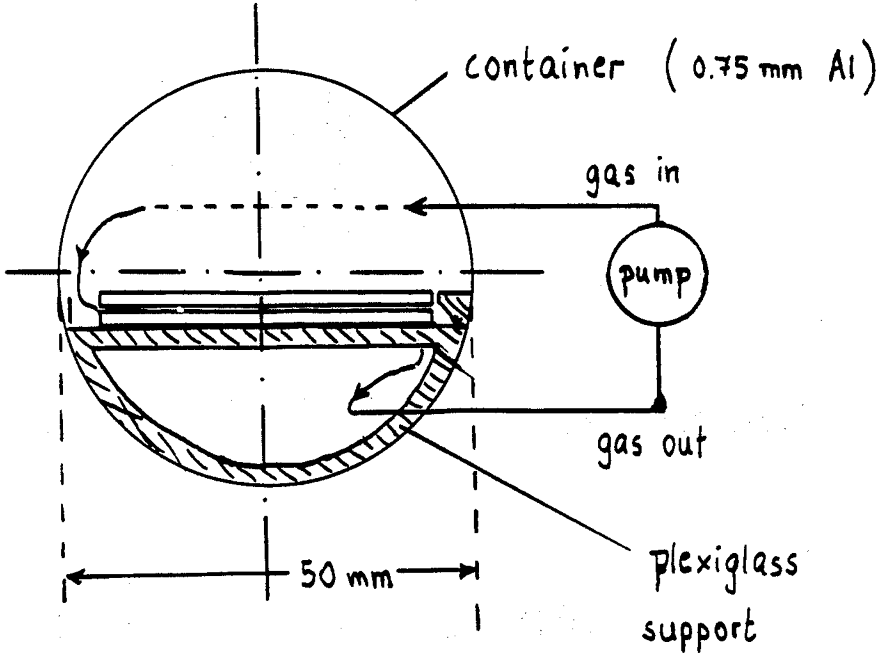
Fig. 3

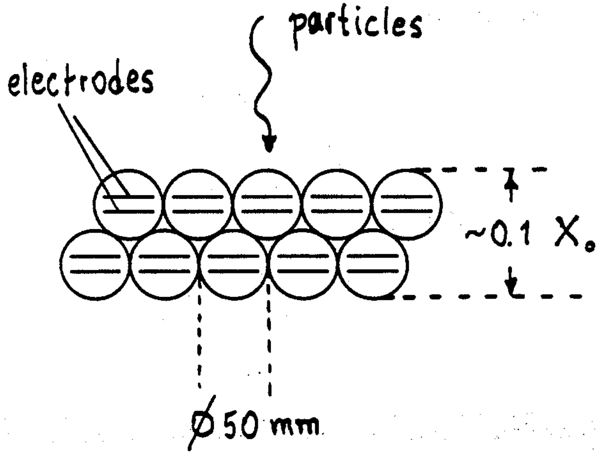
Pestov Counter





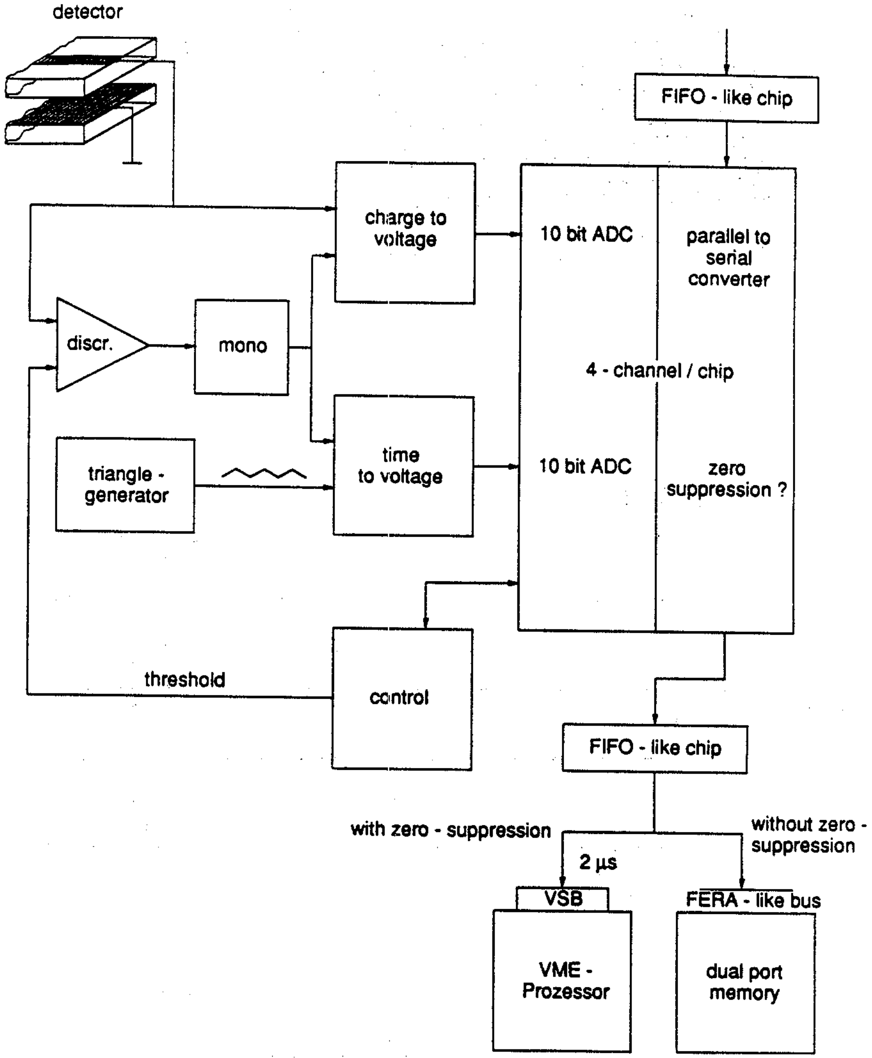
Pestov Counter





Pestov Counter Readout

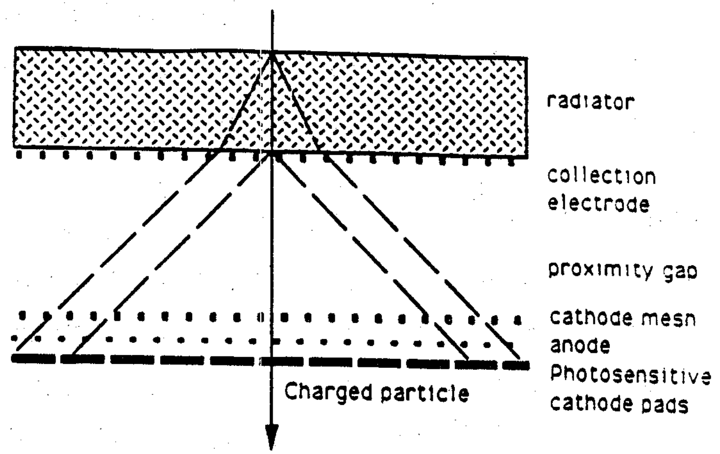
Read Out Electronics Pestov - Detector

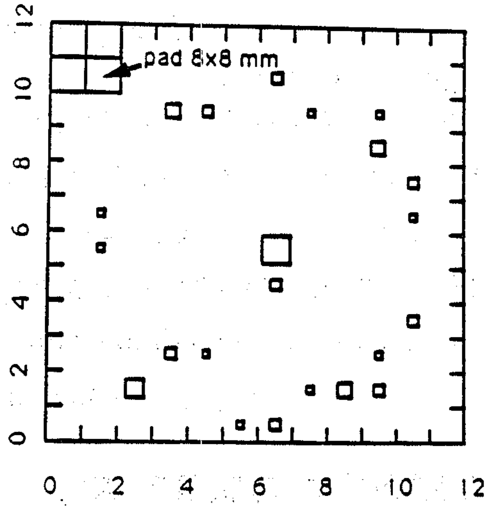


RICH

- **task**
  - ➪ same as TOF, i.e PID together with TPC
- **design** (G. Paic/Zagreb, F. Piuz/CERN, E. Nappi/Bari)
  - ➪ ≈ 1 cm liquid radiator (Freon C_6F_{14})
  - ➪ proximity focus, asymptotic ring ≈ 10 cm
  - ➪ solid photocathode (CsI + adsorbed TMAE)
  - ➪ pad readout 8x8 mm^2
- **performance**
  - ➪ max. particle density ≈ 40/m^2
  - ➪ ring resolution σ ≈ 1 mm
  - ➪ PID superior to TOF (no need for high pressure TPC)
- **set-up**
  - ➪ r = 450 cm, A = 255 m^2, 4*10^6 channels
- **R&D (Proposal P35 to DRDC)**
  - ➪ prototype (50x50 cm^2) test in April with ^{32}S in Ω (with TMAE vapour) test pattern recognition (≥ 40/m^2 ?)
  - ➪ solid photocathode
  - ➪ low noise VLSI readout chip
- **price estimate ≈ 35 M SF !**
  - ➪ price/channel ≈ 4 SF = 16 M SF
  - ➪ price/m^2 ≈ 75 kSF = 19 M SF

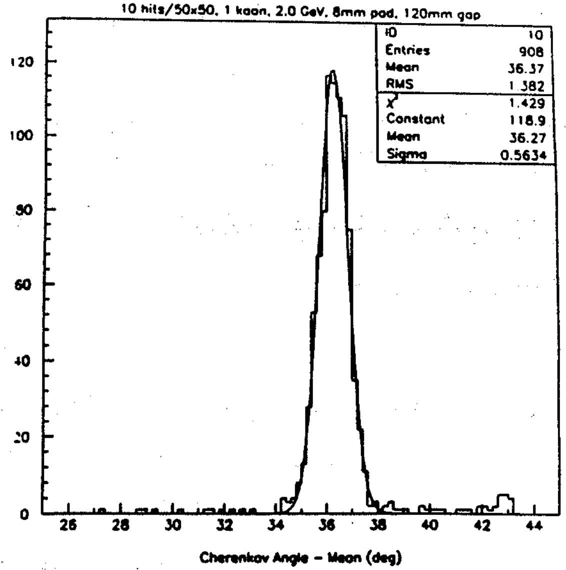
RICH

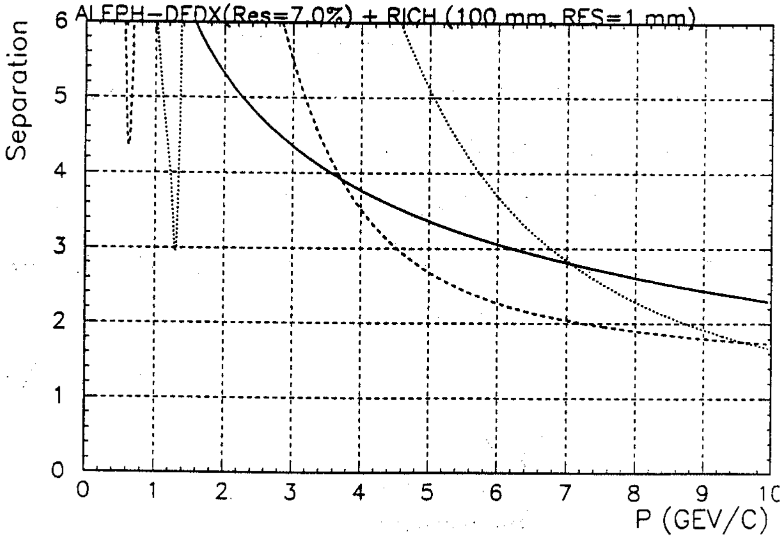




Particle ID with RICH and TPC

RICH resolution (40 particles/mm^{2,} 90%π, 10%K @2.0 GeV)



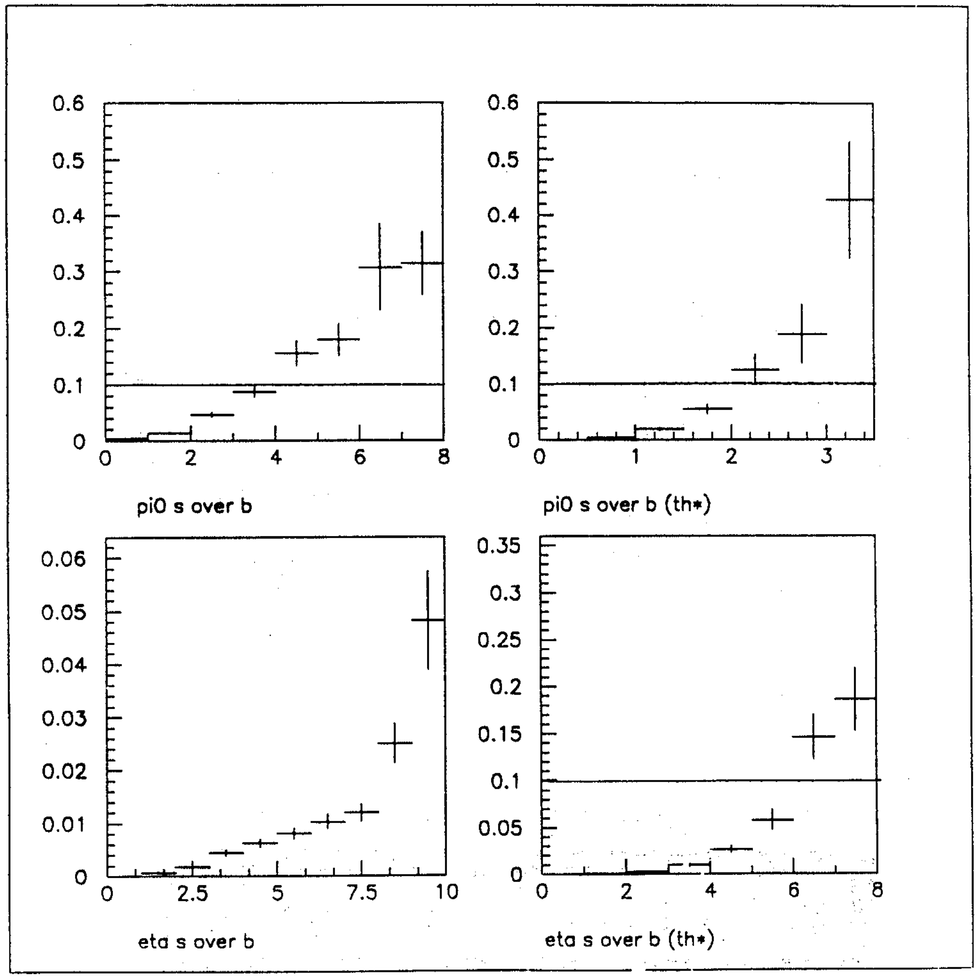


Photon Detector

- **task**
  - ⇨ direct photons $p_t > 1$ GeV
  - ⇨ e.m/hadronic energy fluctuations (CENTAURO events)
- **acceptance** (F. Antinori/CERN, N.Eijndhoven/Utrecht)
  - ⇨ inclusive γ/π => size determined by rates only
  - ⇨ background: π^0, η decay => need precise rate and p_t distr.
    - ☆ SPS (WA80): $\gamma/\pi \approx$ 10-15% syst. error without π^0, η
      $\approx$ 5% syst. error with π^0, η meas.
  - ⇨ combinatorial background
    - ☆ minimum usable signal/background > 1:10 (WA80)
    - ☆ π^0, η **only measurable for p_t >> m** => single arm ok
- **set-up**
  - ⇨ resolution: helps S/B, but gain marginal
  - ⇨ granularity: occupancy (3x3 matrix) < 30% (WA80)
    - ☆ cells 1.5 x 1.5 cm^2 => r = 4.2 m (dense sampling calo)
    - ☆ cells 2.5 x 2.5 cm^2 => r = 7.0 m (typical crystal calo)
  - ⇨ rates for 20m^2 single arm at r = 6 m (per 10^7 events)
    ($\approx$ 9% of Δy = 1, 700γ's & 700 hadrons per event)
    - ☆ **η:** 5*10^4/GeV at p_t = 5 GeV, 10^3/GeV at p_t = 10 GeV
    - ☆ **direct** **γ:** 2*10^4 at 5 GeV (assuming γ/π = 10%)
- **hardware** (20 m^2, $\approx$ 5*10^4 channels)
  - ⇨ high resolution (Crystal Calorimeter)
  - ⇨ med. resolution (Pb-glass, Liq. Argon, ...)

Signal / Background in γ

- $(dN/dy)_{ch} = 4000$, $\Delta E/E = 5\%/\sqrt{E}$, $\Delta m/m \approx 4\%$
- S/B scales liner with $(dN/dy)^{-1}$ and $(\Delta m/m)^{-1}$
- cut on asymmetry vital ($\cos \Theta^* < 0.75$)
- S/B > 0.1 for
  - ☆ π^0: $p_t > 2$ GeV (> 1.5 GeV for $\Delta E/E = 2.5\%/\sqrt{E}$)
  - ☆ η: $p_t > 5\text{-}6$ GeV (> 4 GeV for $\Delta E/E = 2.5\%/\sqrt{E}$)

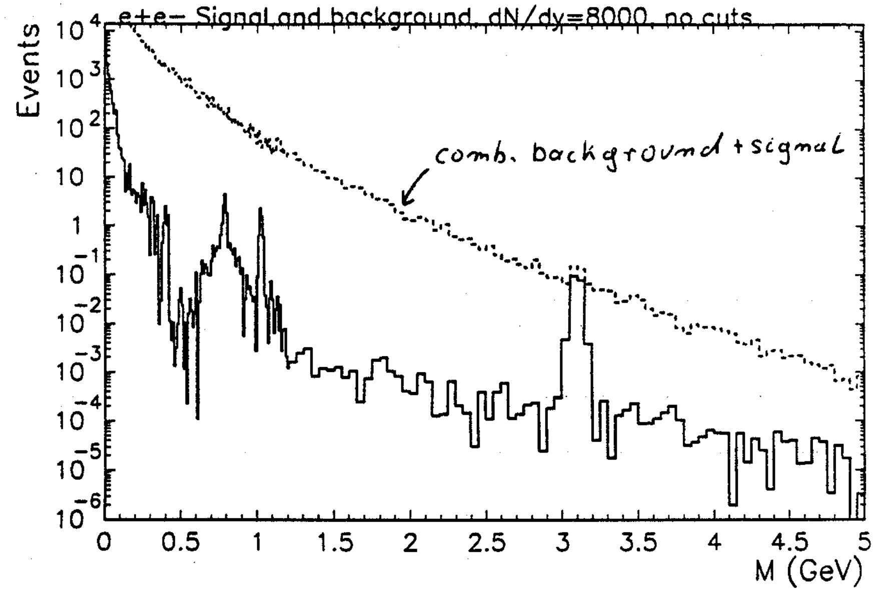


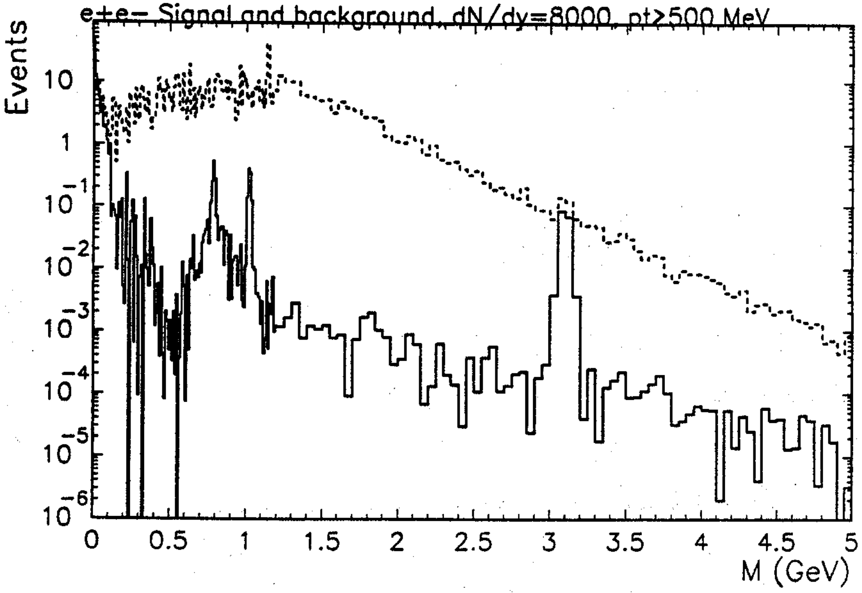
Electron pairs

(F. Antinori/CERN, W. Kühn/Giessen, H.J. Specht/Heidelberg)

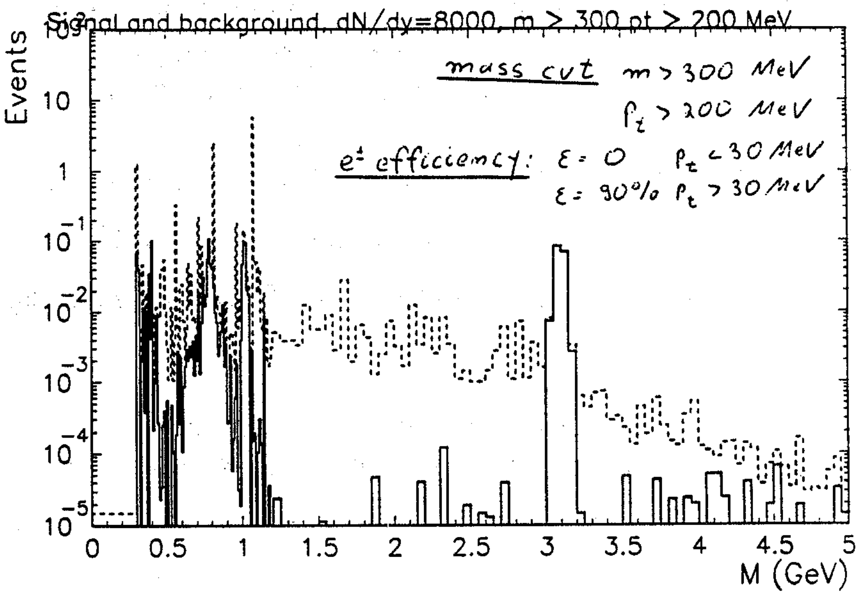
- **problem: combinatorial background**
  - ⇨ ≈ 50 Dalitzes, 0.1 signal pairs ($\rho+\omega+\phi$) ($\Delta y=1$)
    => $\int S/B \approx 1:10^4$
  - ⇨ S/B scales linear in $(dN/dy)^{-1}$
- **rejection of background**
  - ⇨ p_t-cut (Dalitz is soft)
    - ☆ p_t(single lepton) > 500 MeV required
      => loose 'thermal' mesons
  - ⇨ low mass pair cut m < 300
    - ☆ in principle very powerful
    - ☆ needs high efficiency ε to find pairs
    - ☆ asymmetric decays => need ε for low p_t electrons
      (Dalitz-partner of high p_t electron)
- **rates for J/Ψ** (J. Bohm, P. Zavada/Prague)
  - ⇨ geometric $\varepsilon \approx 30\%$ of $\Delta y = 2$
  - ⇨ $2*10^{-3}$ J/Ψ/central event/Δy, 10^7 central events, $\varepsilon = 0.3$
    => 12000 J/Ψ's
  - ⇨ uncertainty in QCD cross section > 5 ??
    (excluding suppression)
  - ⇨ marginal, but sufficient for a single point at low p_t
    (J/Ψ's at higher p_t come mainly from b-decays)

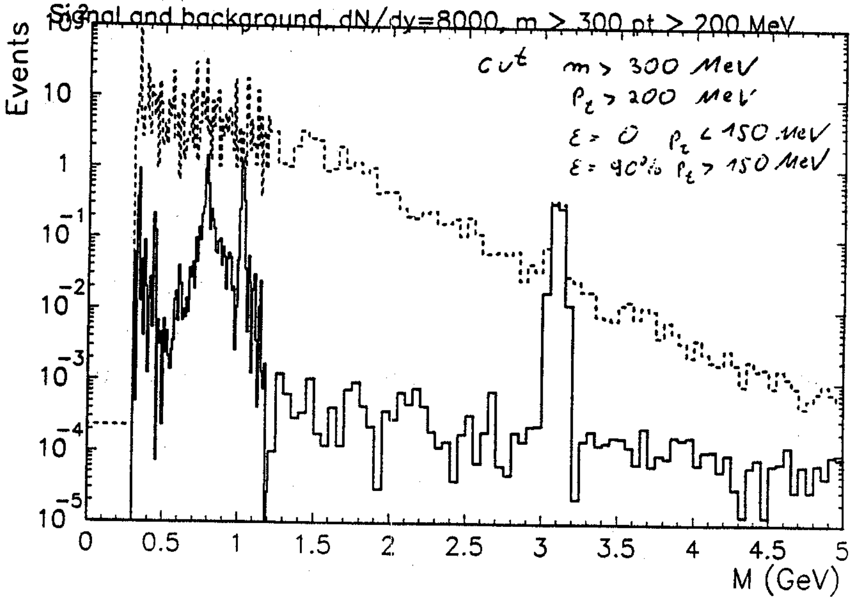
Signal / Background in e^+e^-



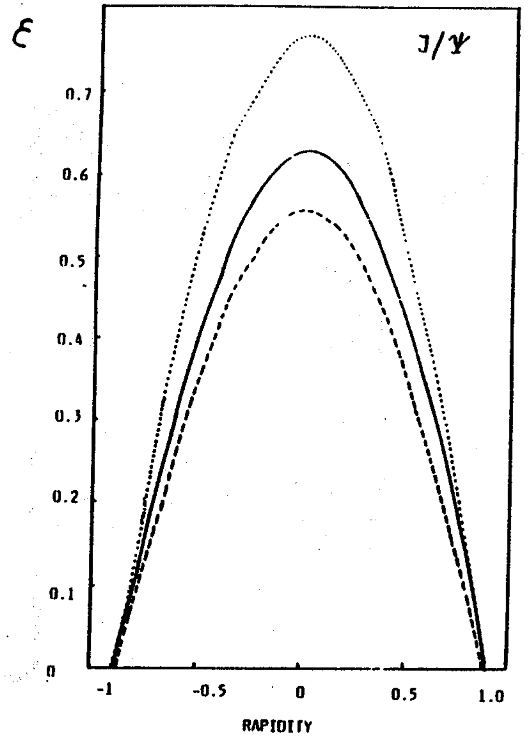


Effect of Mass cut on S/B





J/Ψ acceptance



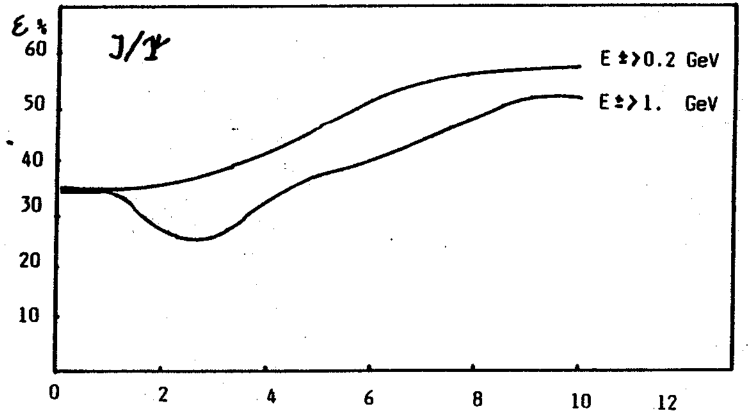
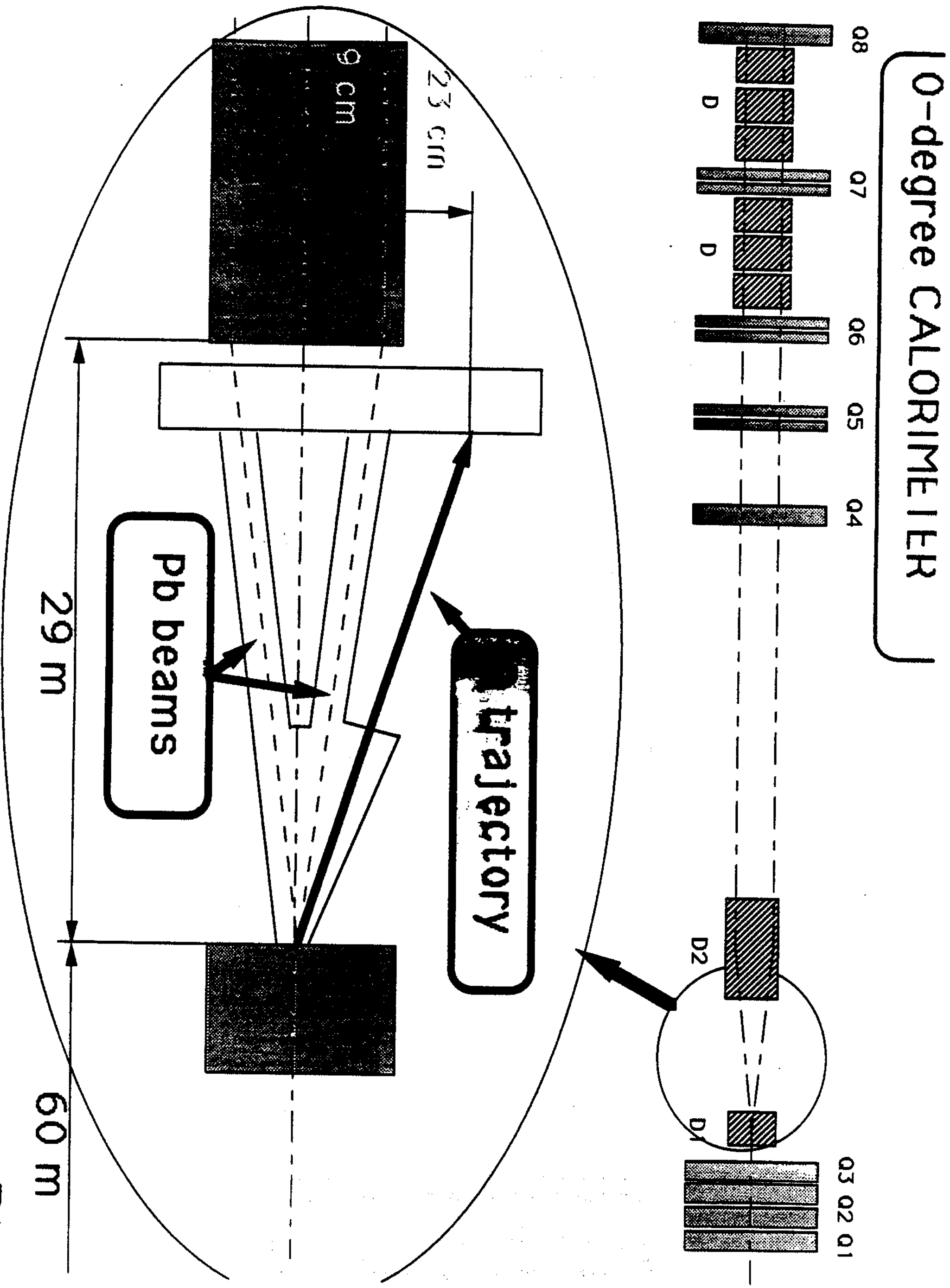


Fig. 2

High rapidity detectors

- **large area multiplicity counters y ≈ 2 - 5**
  - ➩ event characteristics, centrality trigger, dN/dy shape & fluctuations
  - ➩ **hardware:** e.g. Silicon dN/dy ≈ analog sum of pulse height
    (low granularity, $\Delta y=0.1$, $\Delta\phi = 10°$ => few 10^3 channels)
- **Zero-Degree-Calorimeter**
  (H. Gutbrod/GSI, L. Leistam/CERN)
  - ➩ centrality trigger,
    correlation impact parameter and central dN/dy
- **other ideas**
  - ➩ large area photon counting (≈ WA93)
  - ➩ high rapidity spectrometer y ≈ 2 - 4
    (Dipoles & TPC's)



7b)

DAQ & Trigger

H. Beker/Rome, B. Kolb/GSI

- **main trigger on centrality (≈ 10% of σ_{tot})**
  - ⇨ easy with dN/dy and ZeroDegreeCalorimeter
  - ⇨ other triggers on event topology (fluctuations) feasible
- **data taking rate**
  - ⇨ aim at ≈ 10 - 100 Hz (= 10^7 - 10^8 events/month)
- **event size**
  - ⇨ dominated by TPC
  - ⇨ with zero suppression: 30 Mbyte/event
  - ⇨ with centroid finding: 5 Mbyte/event
- **data rate**
  - ⇨ 50 - 500 Mbyte/sec to 'tape'
- **data storage**
  - ⇨ 10^7 events = 50 Tbyte
- **offline**
  - ⇨ guess ≈ 10 Gflops for 1 event/sec

Expression of Interest

A feasibility study of using DELPHI as a detector for heavy ion collisions at LHC

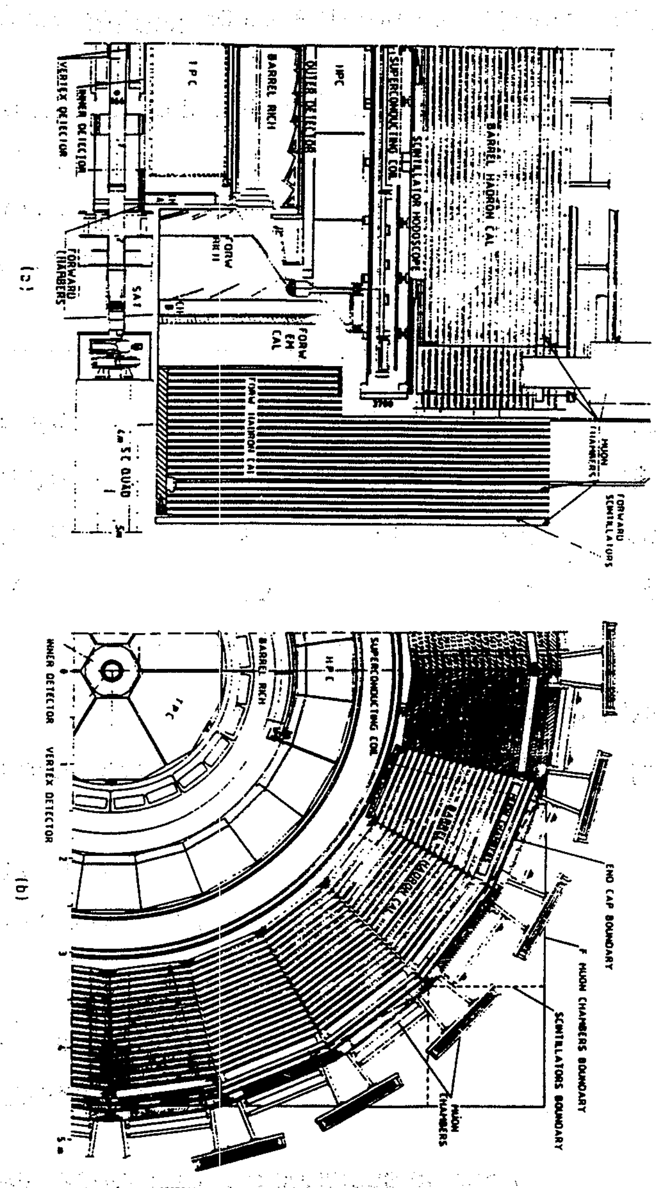
G. Jarlskog (Lund)

FEASIBILITY STUDY FOR USING DELPHI AT LHC TO STUDY HEAVY ION COLLISIONS

The DELPHI - Heavy Ion Working group*
edited by Göran Jarlskog

Participants in the DELPHI - Heavy Ion Working Group:
F. Antinori, P. Baillon, R. Brockmann, E. Dahl-Jensen, P. Delpierre, H. Foeth, D. Gamba, P. Giubellino, H.Å. Gustafsson, H. Gutbrod, A. Jacholkowski, G. Jarlskog, S. Johansson, F. Kapusta, A. Klovning, B. Koene, L. Leistam, B. Lörstad, G. Myatt, R. Möller, I. Otterlund, G. Paic, F. Piuz, R. Renfordt, V. Ruuskanen, J. Schukraft, P. Sonderegger, T. Taylor, I. Tyapkin, N. van Eijndhoven, F. Verbeure, J. Wickens, A. Vodopianov, N. Yamdagni, N. Zimine

Reference: DELPHI 92-25 GEN 126



DELPHI Collaboration / The DELPHI detector

Figure 1 Longitudinal and transverse section through the DELPHI detector

Abstract

The DELPHI detector can indeed be put into the LHC beam position. The working group has simulated central lead-lead collisions at the top LHC energy leading to charged multiplicities around 8000 per unit of rapidity and evaluated the capabilities and limitations of the existing DELPHI barrel detectors using DELSIM. Given the constraint that DELPHI might return to operation at LEP later on, the conclusions are the following:

1. A conversion to a general purpose heavy ion detector optimized on low momentum hadron and lepton identification would presumably require the replacement of all detectors inside the solenoid. It is therefore not compatible with smooth LEP running at a later time.

2. With suitable modifications and additions to the existing tracking detectors and a new electromagnetic calorimeter, DELPHI can become a competitive alternative for the study of medium to high mass electron and muon pairs. The installation of a new silicon pixel tracker between the beam pipe and the TPC would be a necessary addition.

What can we expect in Pb-Pb collisions at LHC?

Free flow (Bjorken estimate):

$\varepsilon_o \approx m_T (dN/dy)_A \, 1/V_o$

$V_o = \pi (1.15 A^{1/3})^2 \tau_o$

formation time $\tau_o \approx 1$ fm (?)

$m_T \approx 0.5$ GeV

Machine	Beam-Target	$\sqrt{s}$ [GeV]	$(dN/dy)_o$	ε_o [GeV/fm^3]	T_o [MeV]
SPS	S-U	20	200	2.4	190
SPS	Pb-Pb	17	700	2.4	190
RHIC	Au-Au	200	1400	5.1	230
LHC	Pb-Pb	6300	2600	9.0	260

From lattice calculations

$\varepsilon_c \approx 1$ GeV/fm^3

$T_c \approx 200$ MeV

but we need more than that for asymptotic freedom to set in

In this study for DELPHI we have assumed $(dN/dy)_o = 8000$!

For the present exercise the particle tracker used in heavy collisions is the one sketched in figure 2, with four layers of silicon pixel detectors at 6.5, 13.5, 20.5 and 27.5 cm radius, the TPC with 7 active layers between 93 and 111 cm radius, and the TPC of the BRICH at 140 cm radius. The charged (in some cases including neutrals) track density at increasing radii representing the entrance to the various DELPHI detectors, is given in the Table below the case of full field (B = 1.2 T). Also given is the average distance between nearby tracks, $<d_{min}>$, which determines the required two-track resolution capability.

Detector	radius [cm]	# of tracks per sr.	# of tracks per area	$<d_{min}>$ [cm]
	r	λ	λ/r^2 [m^{-2}]	$0.5\ r/\sqrt{\lambda}$
µvertex	6.5	1850	66000	0.062
TPC	32	1980	19500	0.36
TPC	90		2440	1.00
BRICH	133	1490	840	1.72
OD	197	1550	400	2.50
HPC (γ)	208	1155	267	3.06
HPC (all)		1860	430	2.41
TOF	310	133	14	13
HCAL(all)	320	370	36	8

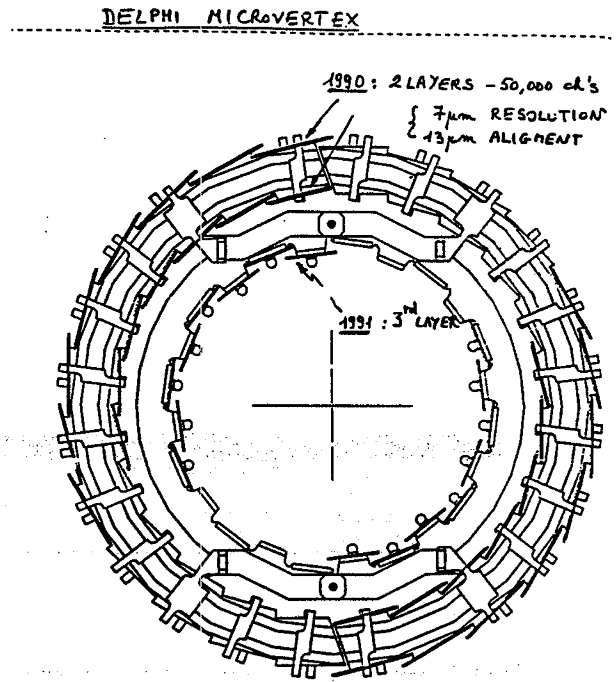


Figure 8 The present DELPHI µvertex detector

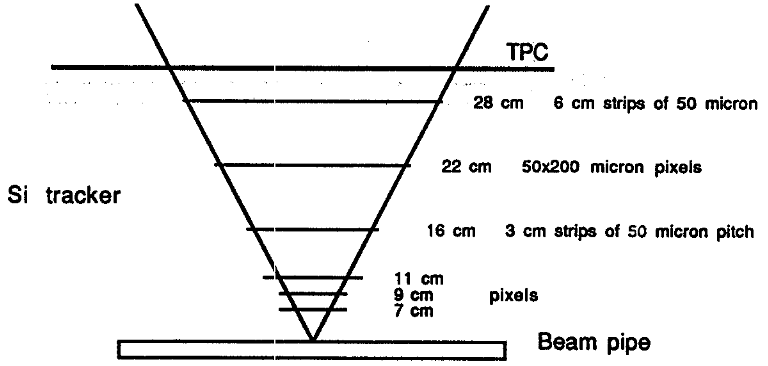
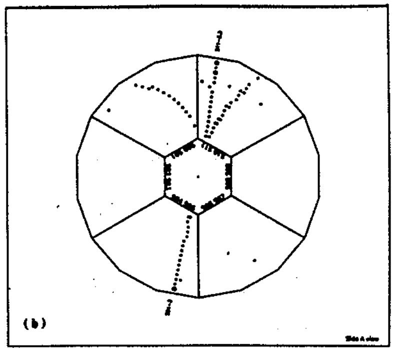
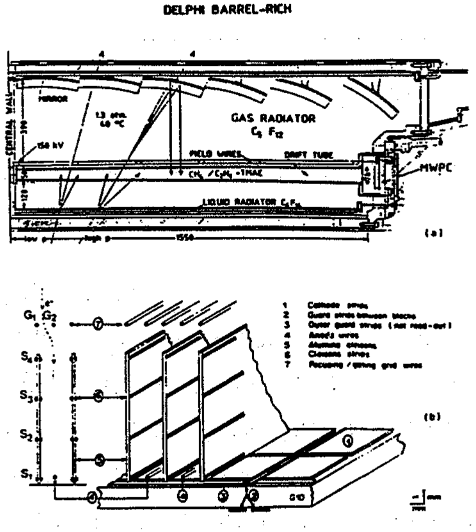


Figure 9 Proposed layout of a new silicon tracker for DELPHI



The TPC end plates with 16 equidistant radial pad rows



The BRICH

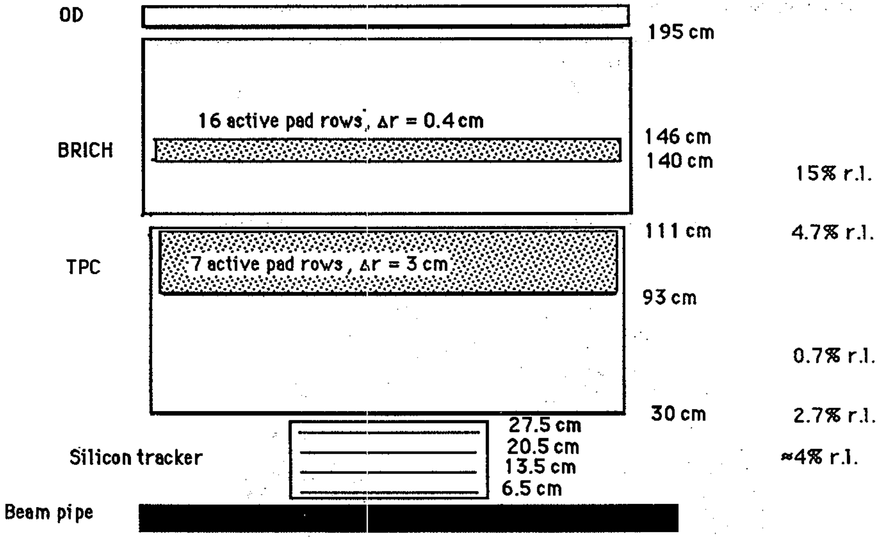


Fig. 2

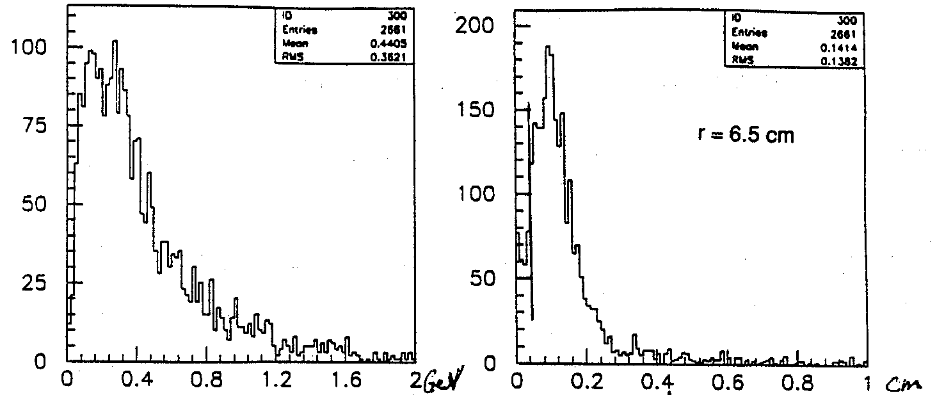


Figure 4a-b The p_T distribution of charged tracks after the beam pipe, and the distribution of distance to the nearest charged track at 6.5 cm radius compared to the assumed two-track resolution of 0.05 cm for the silicon tracker

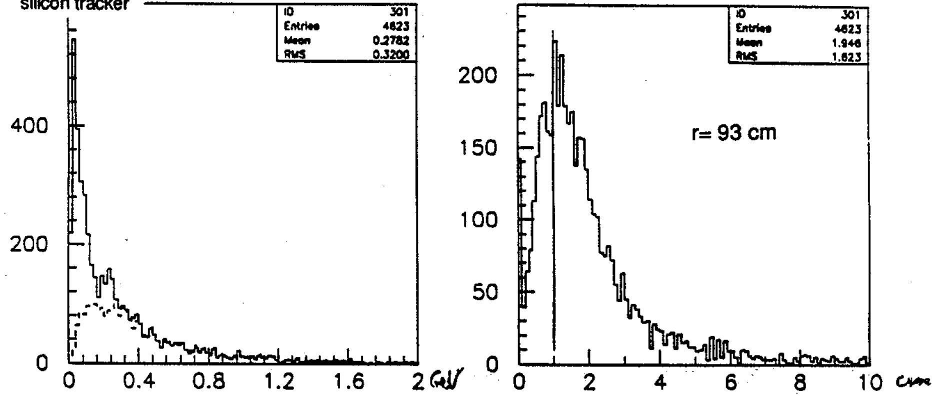


Figure 4c-d The p_T distribution of charged tracks at 93 cm radius, and the distribution of distance to the nearest charged track compared to the assumed two-track resolution of 1 cm for the TPC

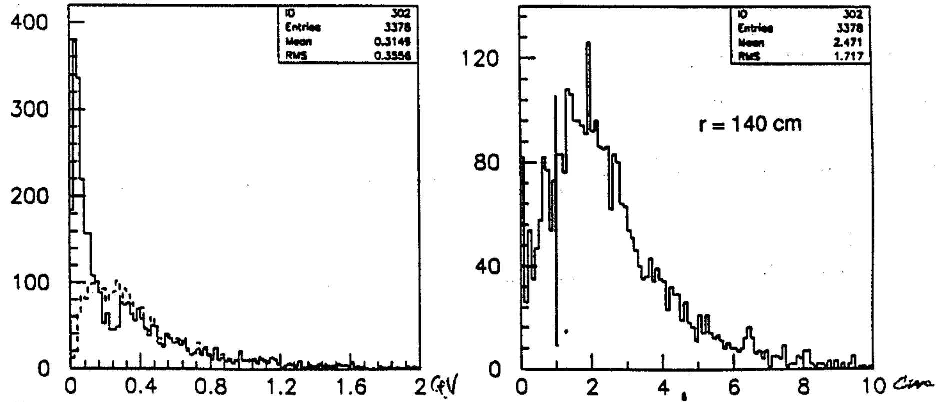


Figure 4e-f The p_T distribution of charged tracks at 140 cm radius, and the distribution of distance to the nearest charged track compared to the assumed two-track resolution of 1 cm for the BRICH

"primary tracks"

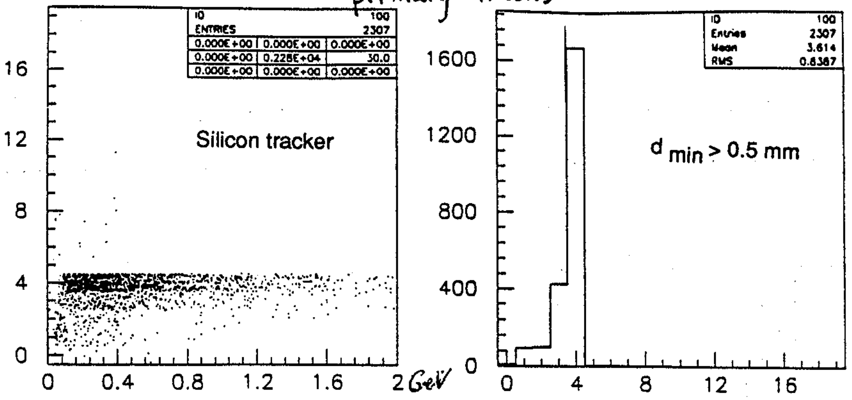


Figure 5a-b p_T-dependence of the number of hits, and its projection, for the silicon tracker

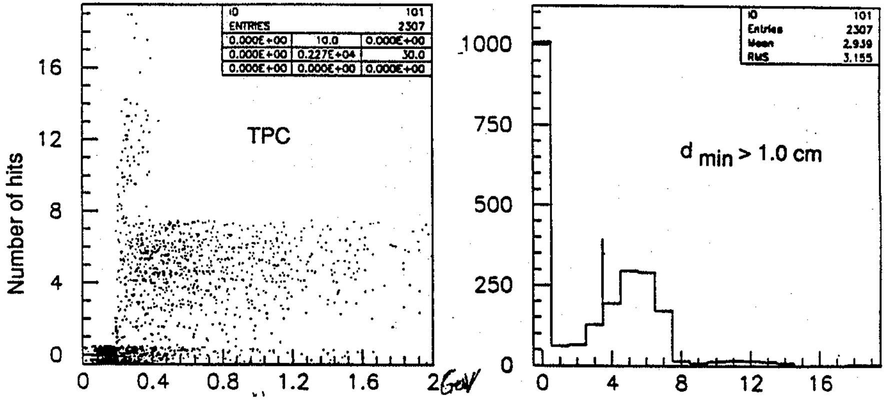


Figure 5c-d p_T-dependence of the number of hits, and its projection, for the TPC

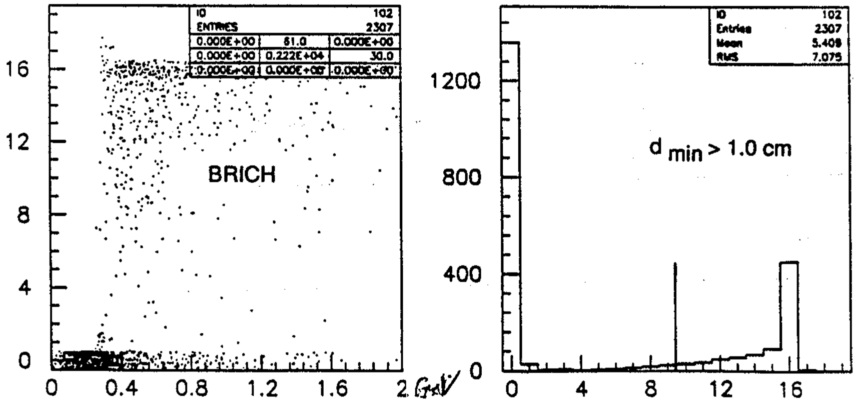


Figure 5e-f p_T-dependence of the number of hits, and its projection, for the BRICH

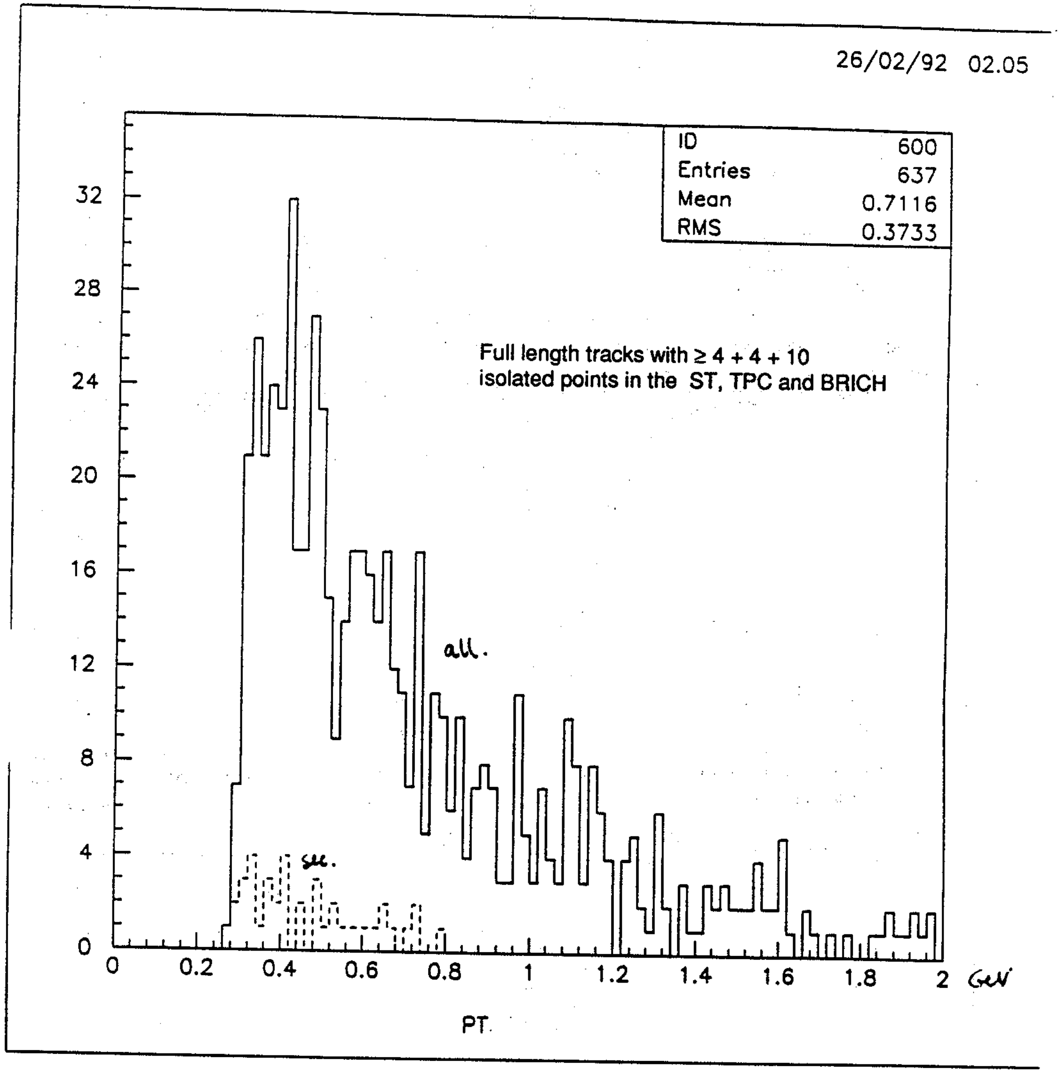


Figure 6a p_T-spectrum of accepted full length "tracks"

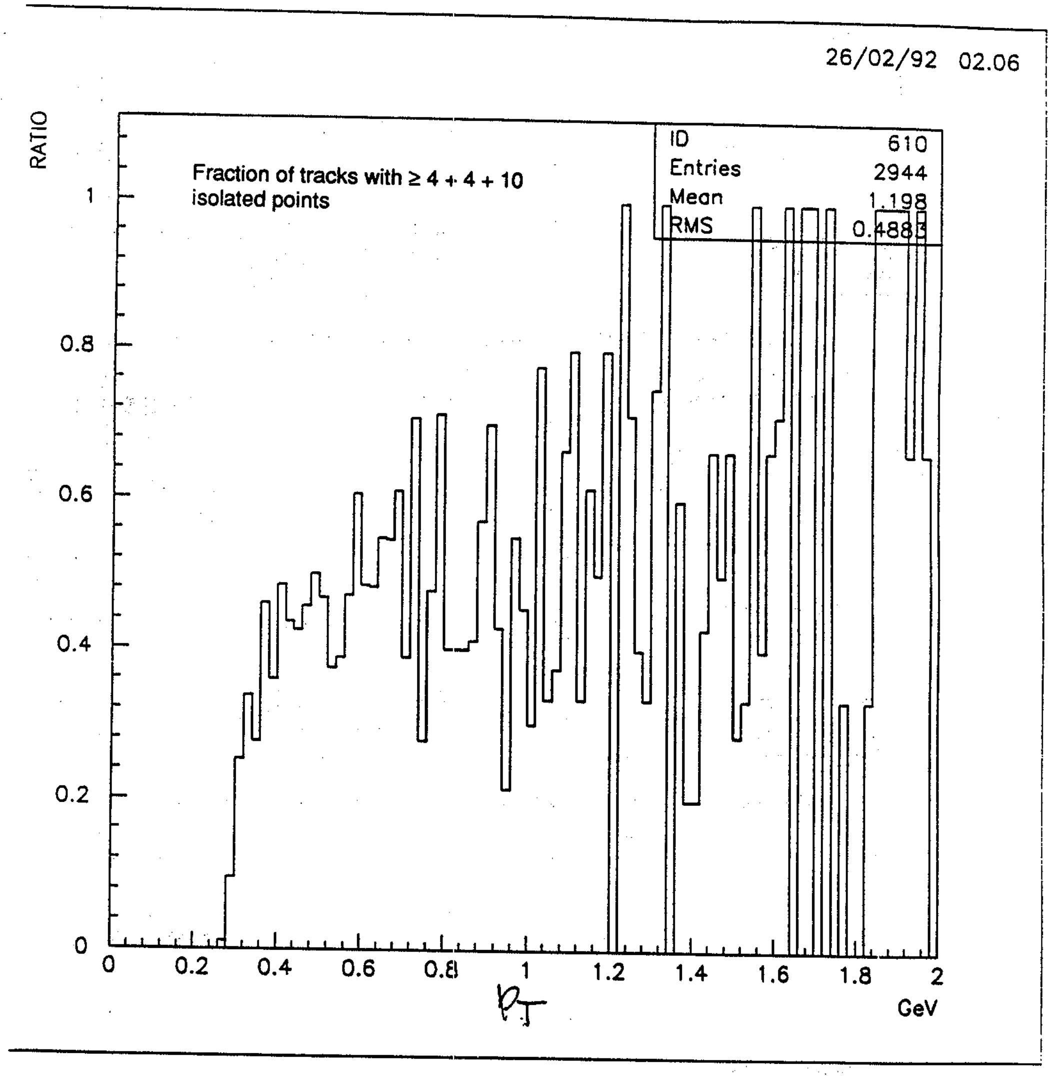
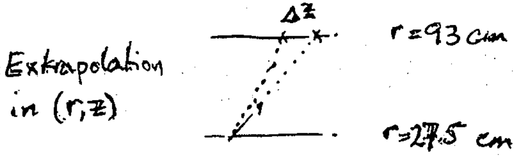


Figure 6b Fraction of accepted full length "tracks" versus p_T



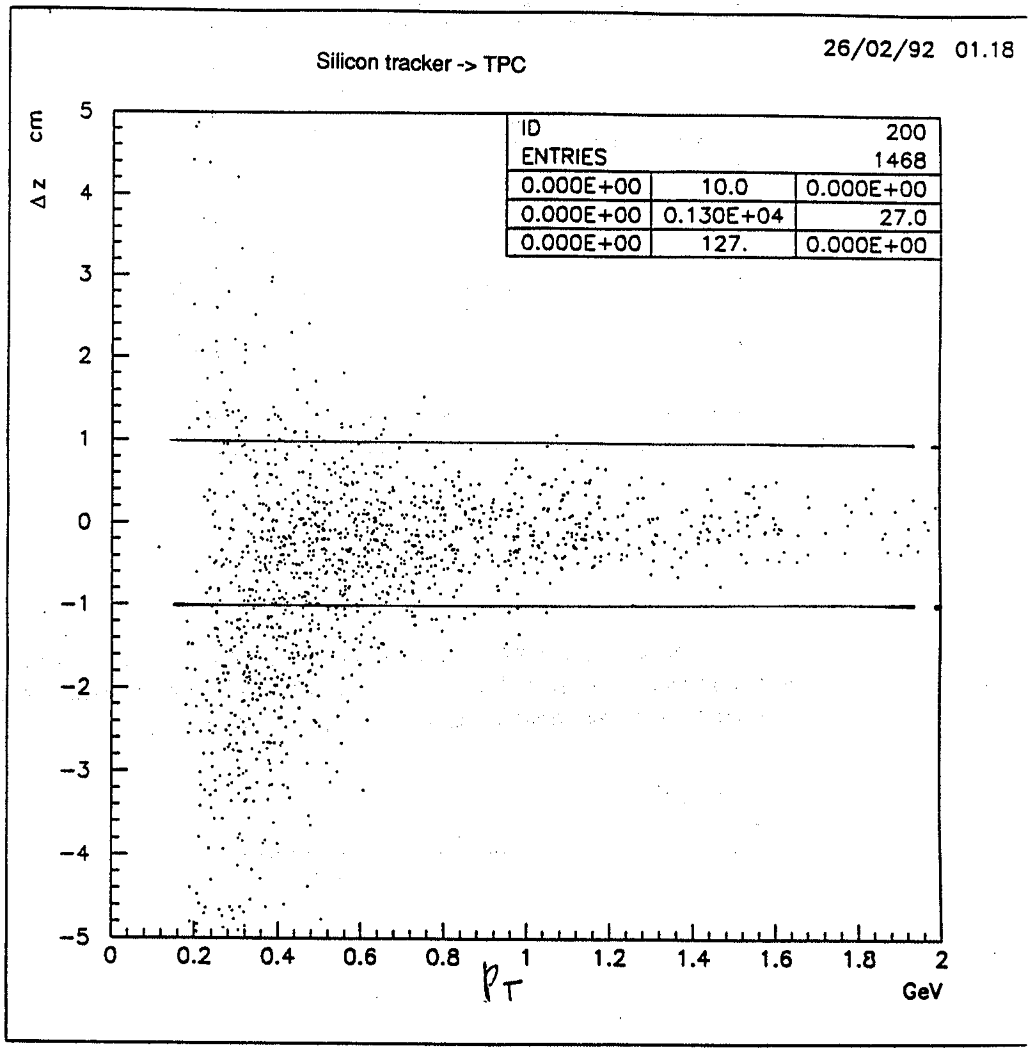


Figure 7a Deviation in the z-positions of the extrapolated track segment in the silicon tracker and of the corresponding TPC track segment versus p_T

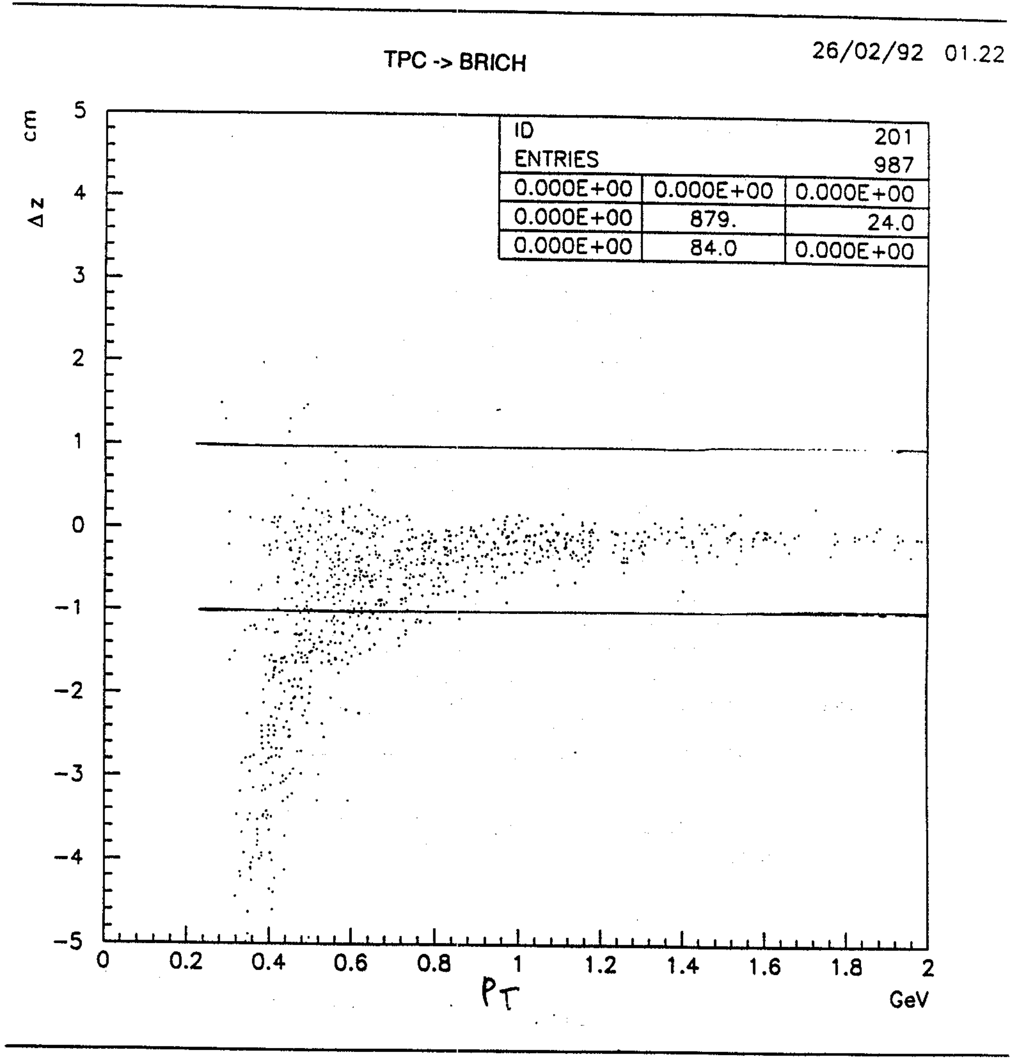
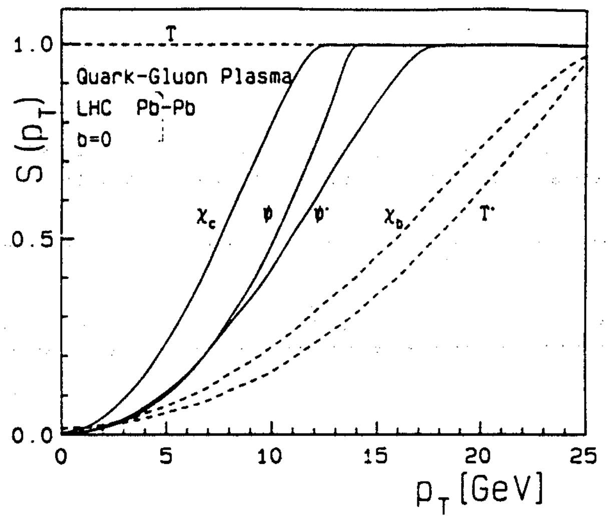
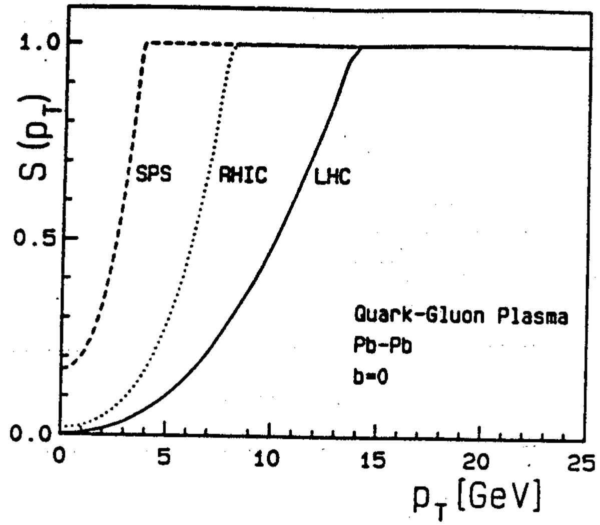


Figure 7b Deviation in the z-positions of the extrapolated track segment in the TPC and of the corresponding BRICH track segment versus p_T



S(p_T) versus p_T at 6400 GeV collision energy for various ccbar and bbar resonances. S(p_T) = N_X (E_T high, p_T) / N_X (E_T low, p_T), where E_T low i s the lowest bin available. From F. Karsch, ECFA LHC Workshop Aachen CERN 90-10



$S(p_T)$ of directly produced ψ's versus transverse momentum at CMS energies $\sqrt{s} = 20\ GeV$ (SPS), $200\ GeV$ (RHIC) and $6400\ GeV$ (LHC).

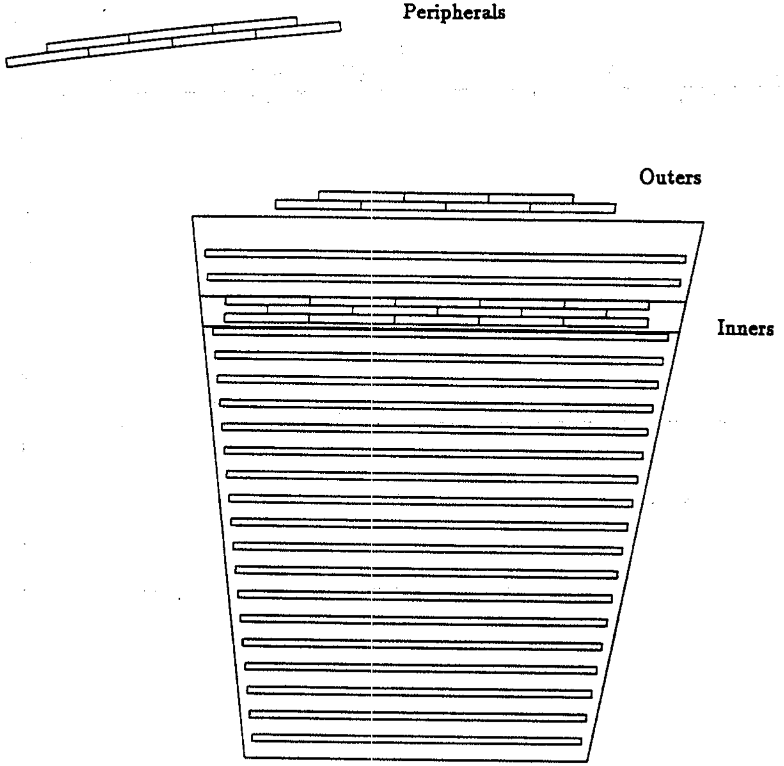


Figure 14 A sector of the Barrel Muon Chamber system

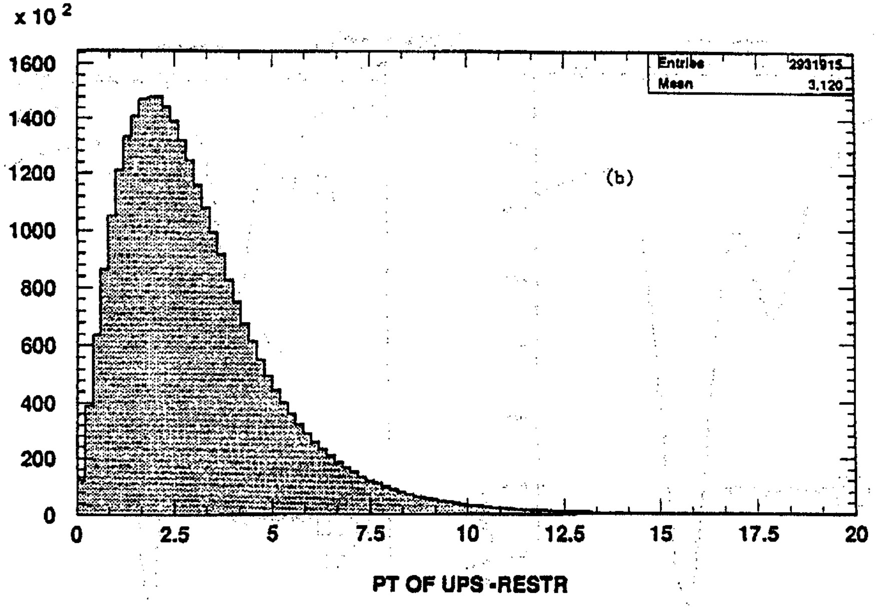


Figure 15a The p_T - distribution of accepted Y(1S) in DELPHI with |y| < 0.88

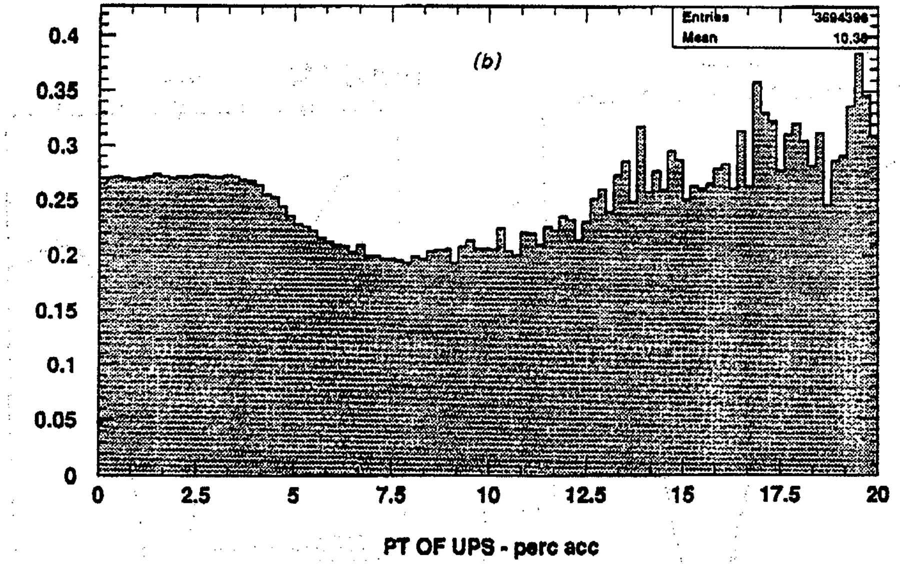


Figure 15b The acceptance of Y(1S) in DELPHI within $52 < \theta < 128^{0}$ and $p > 3$ GeV/c

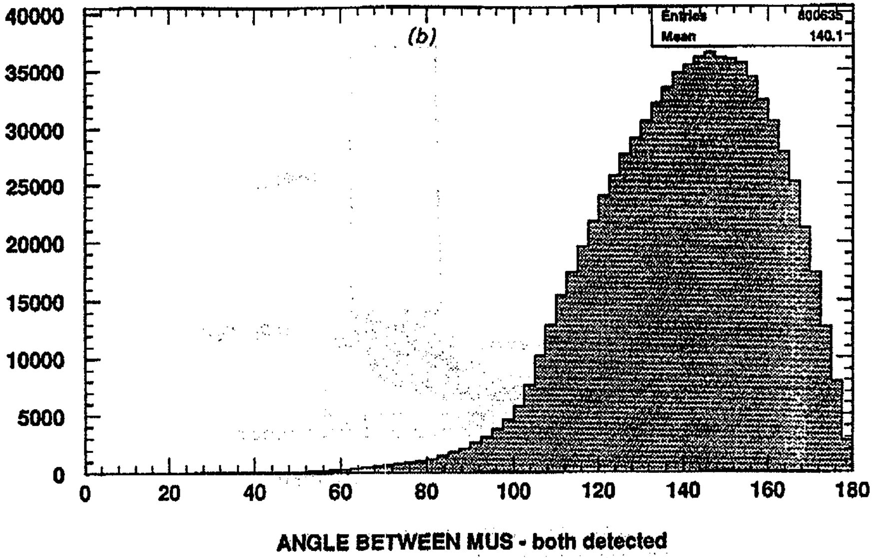


Figure 16 The azimuthal angle between accepted muons from Y deacy

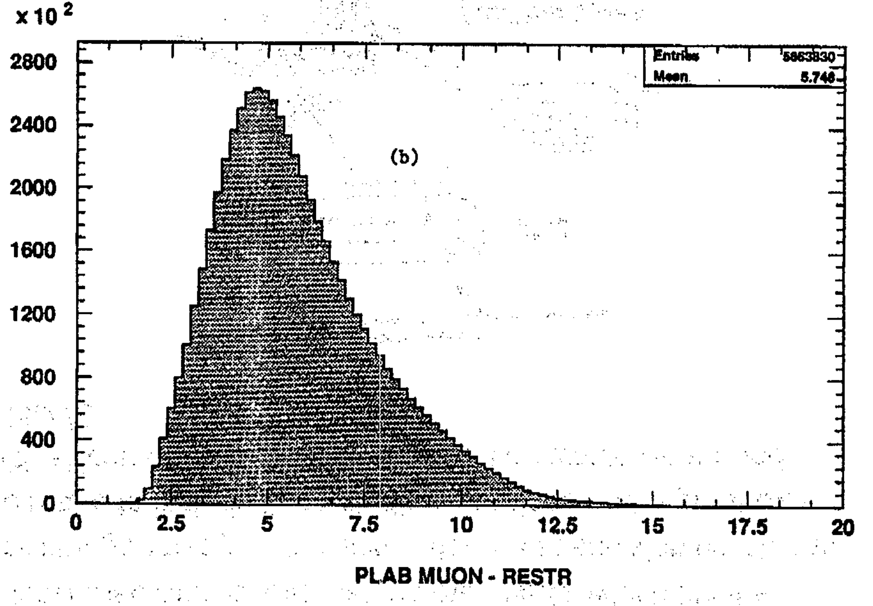
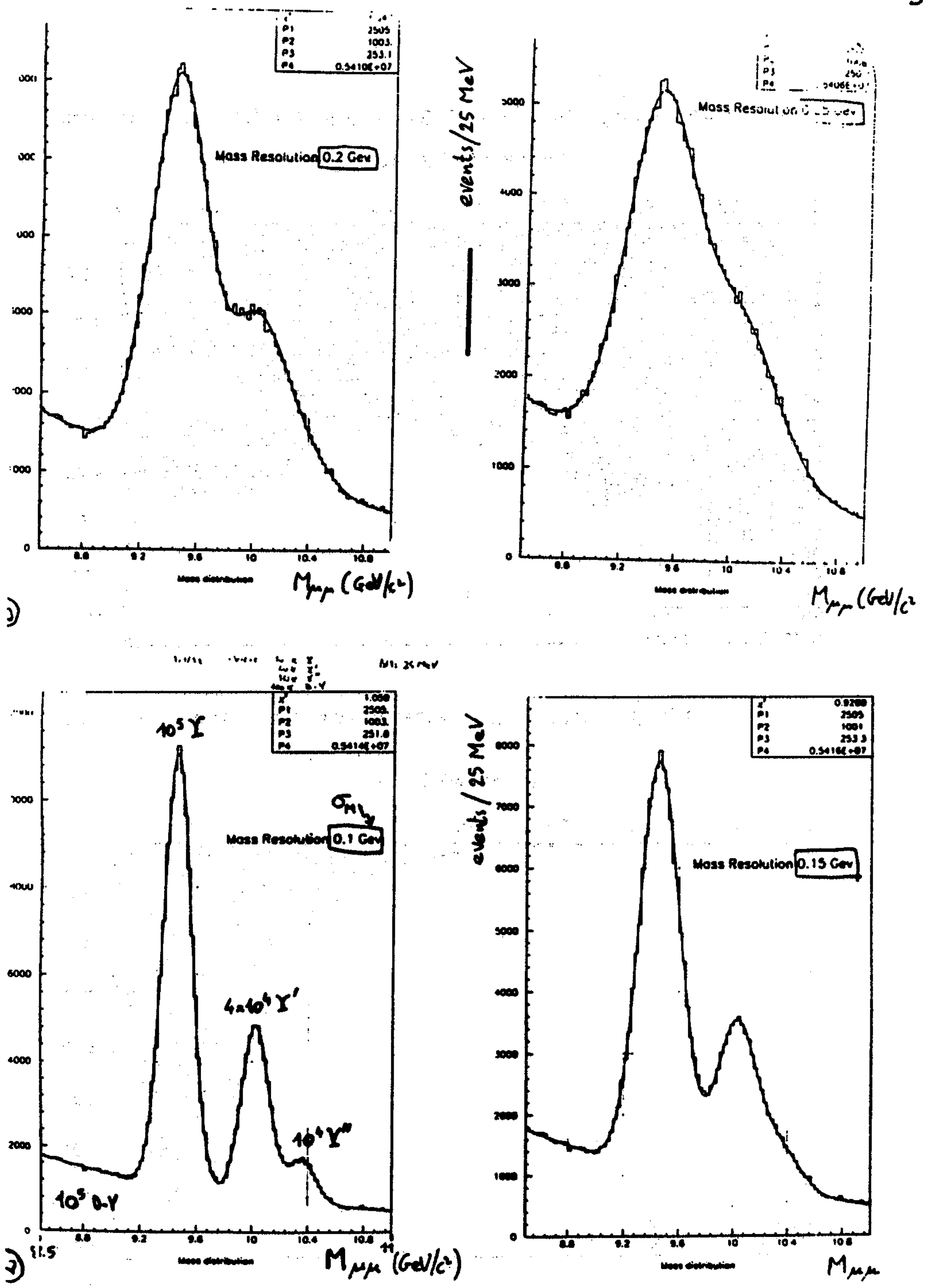


Figure 17 The (laboratory) momentum distribution of accepted muons



In DELPHI quite a detailed feasibility study has been done for a New Electromagnetic Calorimeter, NEC, which fits the present geometry. It is a scintillator-lead sandwich which can be made to include 2 longitudinal divisions and a preshower with silicon pads. The energy resolution would be around 11%/√E.

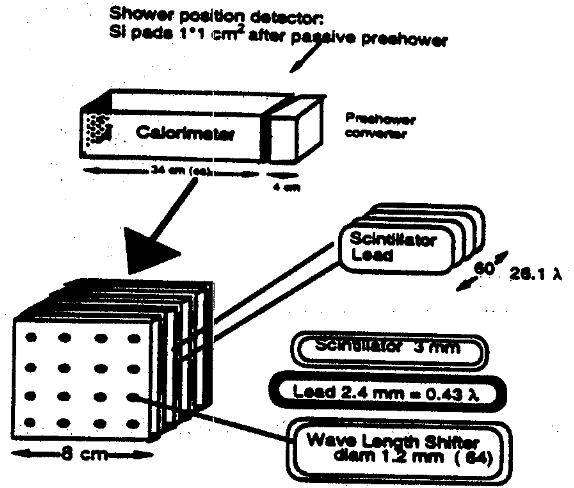
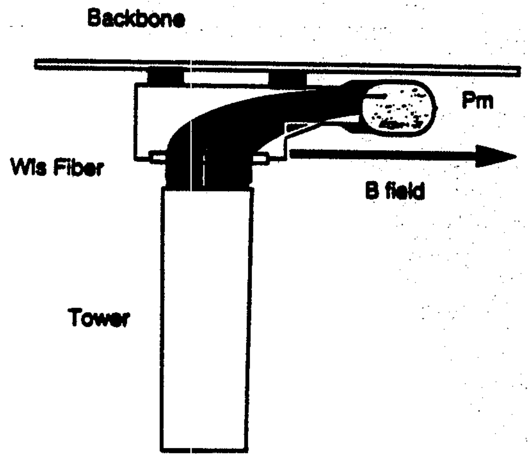
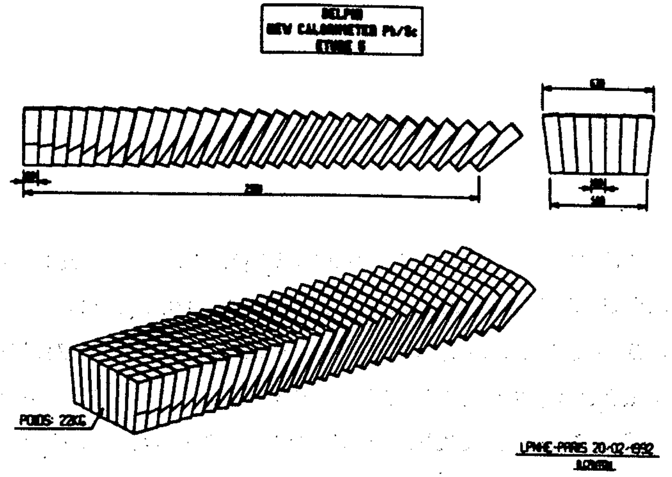


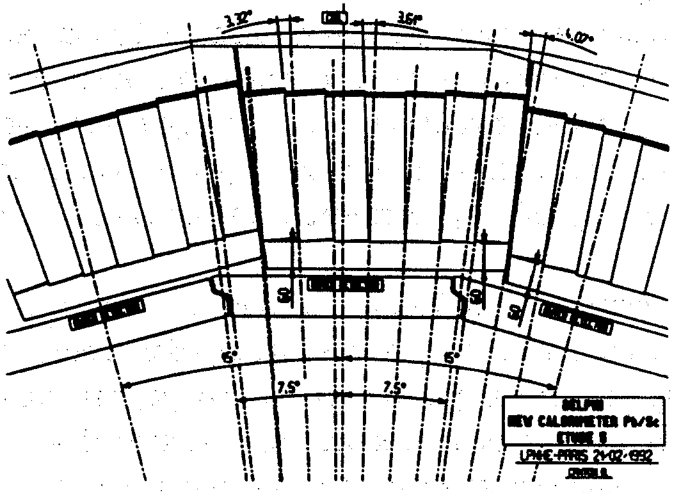
Fig 1/a : schematic layout of a tower



schematic of the assembly



details of the arrangement of the towers in a coffin



Arrangement of NEC coffins wrt HPC envelopes

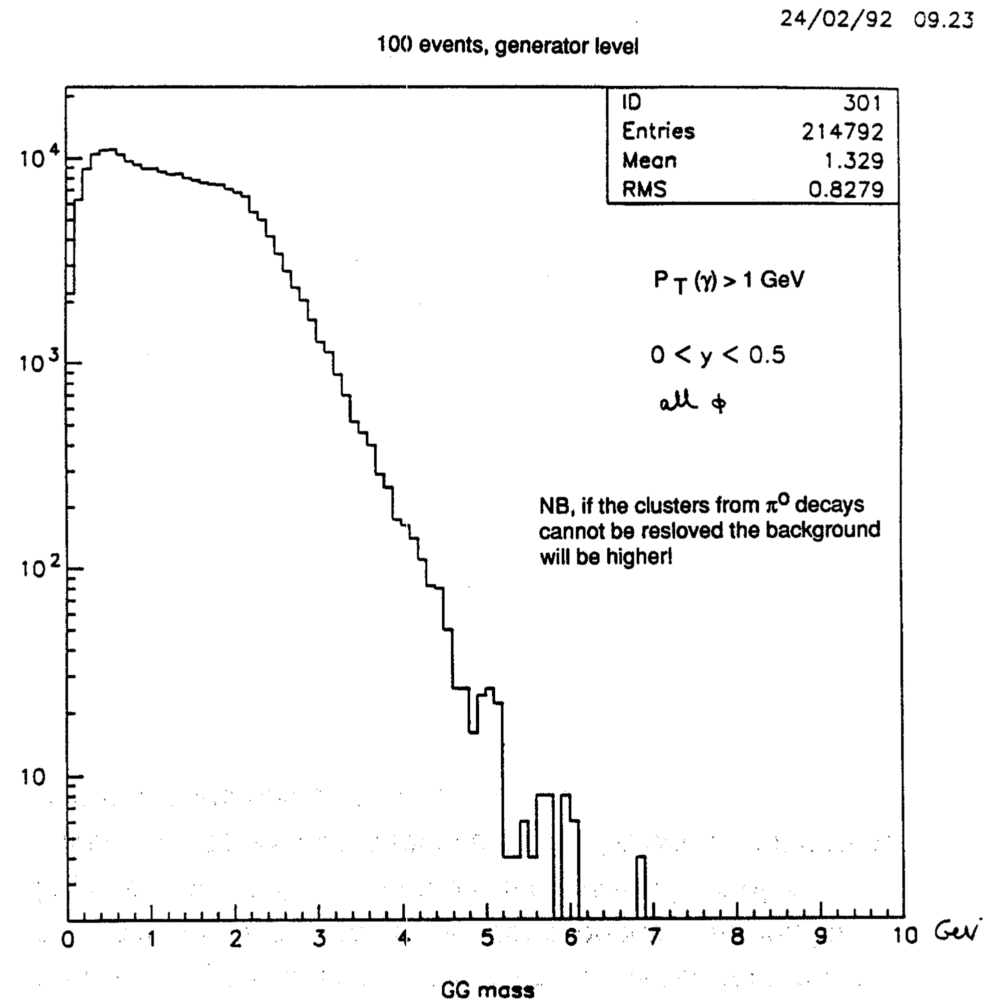


Figure 18 The invariant mass distribution of background photons recorded by an electromagnetic calorimeter covering 2π in azimuth (the plot represents 100 generated events).

With the luminosity of 2.10^{27} $cm^{-2}s^{-1}$ and $\sigma \approx 5.6$ b

10^4 collisions/s where about 2% are central

=> A first level trigger based on the energy flow into electromagnetic calorimeters can easily select central collisions. Additional selective triggers in hardware and software are needed to reduce the event rate another factor of 200 to come to tape writing speed. This is the requirement we have to put e.g. on a lepton pair trigger for Y states.

=> μ-pairs. The information available at trigger time is the range cut given by the absorber and the direction of the muon from three muon stations. Before a complete event reconstruction the muon momentum is unknown due to the multiple scattering. A central event will present an average background in the MUB due to decays of 1.5 muons. If 4 muon candidates are required in the trigger the background is reduced a factor 15, leaving another factor 15 to be gained by a software trigger (60 ms time for computation) which would have to correlate the information in the three muon stations and perform a calculation of the invariant mass for muons of opposite charge. Detailed studies are required on this.

=> electron pairs. Requires a new electromagnetic barrel calorimeter with tower structure and one longitudinal division. A study of such a device (NEC) has promised a π rejection factor of 50 at 3 GeV, and 10 at 10 GeV for an electron identification efficiency of 80 %. Contrary to the case for μ a hardware trigger can be tuned to reduce the background level by raising the energy threshold (corresponds to asking for a larger p_T for the Y). A silicon pad structure in front of the calorimeter could help to reduce the background from nearby or partly overlapping showers.

The main boundary conditions for this study are:

- there will be interleaved running between LHC and LEP
  - => there is a lack of compatibility between e.g. the charged particle tracking at small radii, and in the TPC and the BRICH
- Pb-Pb central collisions produce 8000 charged particles per unit of rapidity in the central region
  - => if one accepts the "best estimate" of 2600 charged particles per unit of rapidity there would be no need to modify the TPC, and the OD would work

The preliminary conclusions of this work, which requires a lot more work on simulation, are the following:

a) DELPHI can be upgraded into a good detector for high mass lepton pairs, in particular if an ambitious upgrade of the electromagnetic barrel calorimeter took place. The main tracking job is done by a proposed new silicon tracker, but in order to achieve the desired momentum resolution for upsilon mass reconstruction, the linking out to the full lever arm, i.e. to the outer detector, must be provided. The role of the TPC and the BRICH is limited to provide those links.

b) DELPHI can give access to a rich "smorgasbord" of interesting but less spectacular physics, ranging from pp (and light ion) minimum bias studies in a parasitic mode, to the global features of lead-lead collisions including measuring the energy density and the space time evolution.

c) There is at the moment no well defined community of institutes backing the conclusions of this study - this was not the aim either at this point. It is clear that there is a potential saving of money and time in using a LEP detector, with all its working infratructure, data acquisition and software, for heavy ion physics.

Expression of Interest

A heavy ion experiment with CMS at LHC

L. Ramello (Turin)

A HEAVY ION EXPERIMENT AT LHC WITH THE COMPACT MUON SOLENOID

- Goal of the experiment.
- The C.M.S. detector design.
- Vector mesons cross-sections and kinematics.
- CMS acceptance and resolution.
- Particle production in Pb-Pb collisions.
- Muon identification.
- Background.
- Event rates.
- Conclusion.

L. Ramello

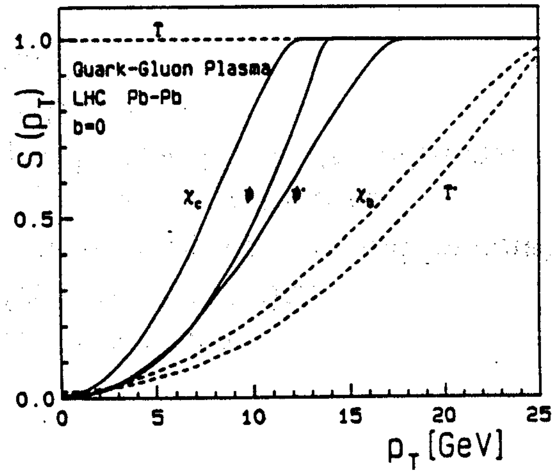
A Heavy Ion Experiment with CMS at LHC
Expression of Interest

Institut fur Hochenergiephysik der Osterreichischen Akademie der Wissenschaften, *Vienna*, AUSTRIA
Université Libre. *Brussels*, BELGIUM
Vrije Univ.. *Brussels*. BELGIUM
Université Catholique de Louvain. *Louvain-la-Neuve*, BELGIUM
Univ. Instelling Antwerpen. *Wilrijk*. BELGIUM
Univ. de l'Etat Mons. *Mons*. BELGIUM
Institute of Nuclear Research & Nuclear Energy, *Sofia*, BULGARIA
University of Sofia. *Sofia*, BULGARIA
Inst. of Physics, Acad. Sci. Byelorussia, *Minsk*, BYELORUSSIA
Research Institute for Nuclear Problems, Byelorussian State University, *Minsk*, BYELORUSSIA
Institute of Nuclear Physics, Czechoslovak Acad. Sci., Res, *Praha*, CZECHOSLOVAKIA
Inst. of Chemistry and Physics, *Tallinn*, ESTONIA
Research Institute for High Energy Physics (SEFT), Univ. of Helsinki, *Helsinki*, FINLAND
Physics Department, Univ. of Helsinki, *Helsinki*, FINLAND
Univ. of Technology, *Helsinki*, FINLAND
Physics Department, Univ. of Jyvaskyla, *Jyvaskyla*, FINLAND
Physics Department, Univ. of Oulu, *Oulu*, FINLAND
Univ. of Technology, *Tampere*, FINLAND
Physics Department, Åbo Akademi, *Turku*, FINLAND
Laboratoire de Physique des Particules (LAPP), *Annecy-le-Vieux*, FRANCE
Institut de Physique Nucléaire, *Lyon*, FRANCE
Ecole Polytechnique, *Palaiseau*, FRANCE
DAPNIA, Centre d'etudes nucléaires, *Saclay*, FRANCE
Institute of Physics, Academy of Science, *Tbilisi*, GEORGIA
Institute of High Energy Physics, Tbilisi State University, *Tbilisi*, GEORGIA
Universitat Aachen, *Aachen*, GERMANY
Universitat Kiel, *Kiel*, GERMANY
University of Ioannina, *Ioannina*, GREECE
Nucl. Research Center Demokritos, Attiki, *Athens*, GREECE
University of Athens, *Athens*, GREECE
Central Research Institute for Physics, Hung. Acad. Sci., *Budapest*, HUNGARY
Dipartimento di Fisica and INFN, Università de L'Aquila, *Coppito (AQ)*, ITALY
Dipartimento di Fisica dell'Università and Sezione dell'INFN, *Genova*, ITALY
Dipartimento di Fisica dell'Università and Sezione dell'INFN, *Torino*, ITALY
Inst. of Experimental Physics, University of Warsaw, *Warszawa*, POLAND
Institute for Nuclear Studies, *Warszawa*, POLAND
LIP, *Lisbon*, PORTUGAL
JINR, *Dubna*, RUSSIA
ITEP, *Moscow*, RUSSIA
INR, *Moscow*, RUSSIA
Lebedev Phys. Inst., *Moscow*, RUSSIA
Moscow State Univ., *Moscow*, RUSSIA
IHEP, *Protvino*, RUSSIA
CIEMAT, *Madrid*, SPAIN
CERN, *Geneva*, SWITZERLAND
Imperial College, *London*, UK
Rutherford Appleton Laboratory, *Didcot*, UK
Univ. of California, *Davis*, USA
Univ. of California, *Riverside*, USA
Univ. of California, *Los Angeles*, USA
Inst. of Nuclear Physics, *Tashkent*, UZBEKISTAN

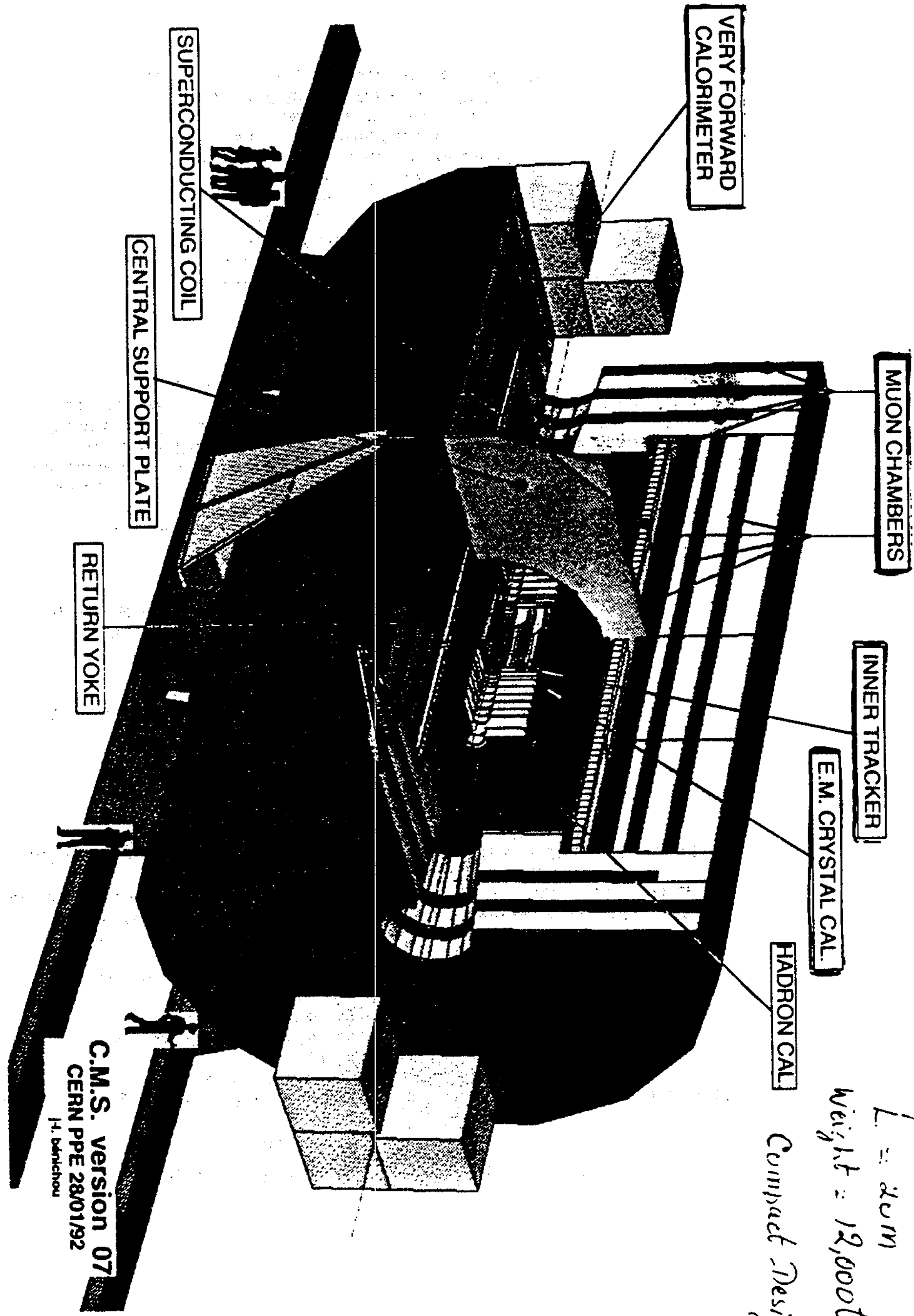
GOAL OF THE EXPERIMENT

Measure production of dimuons from :
J/ψ, ψ', Υ, Υ', Υ'', Drell-Yan
as a function of global observables of A-A collisions.

- Vector meson production vs P_T probes Quark Gluon Plasma formation.

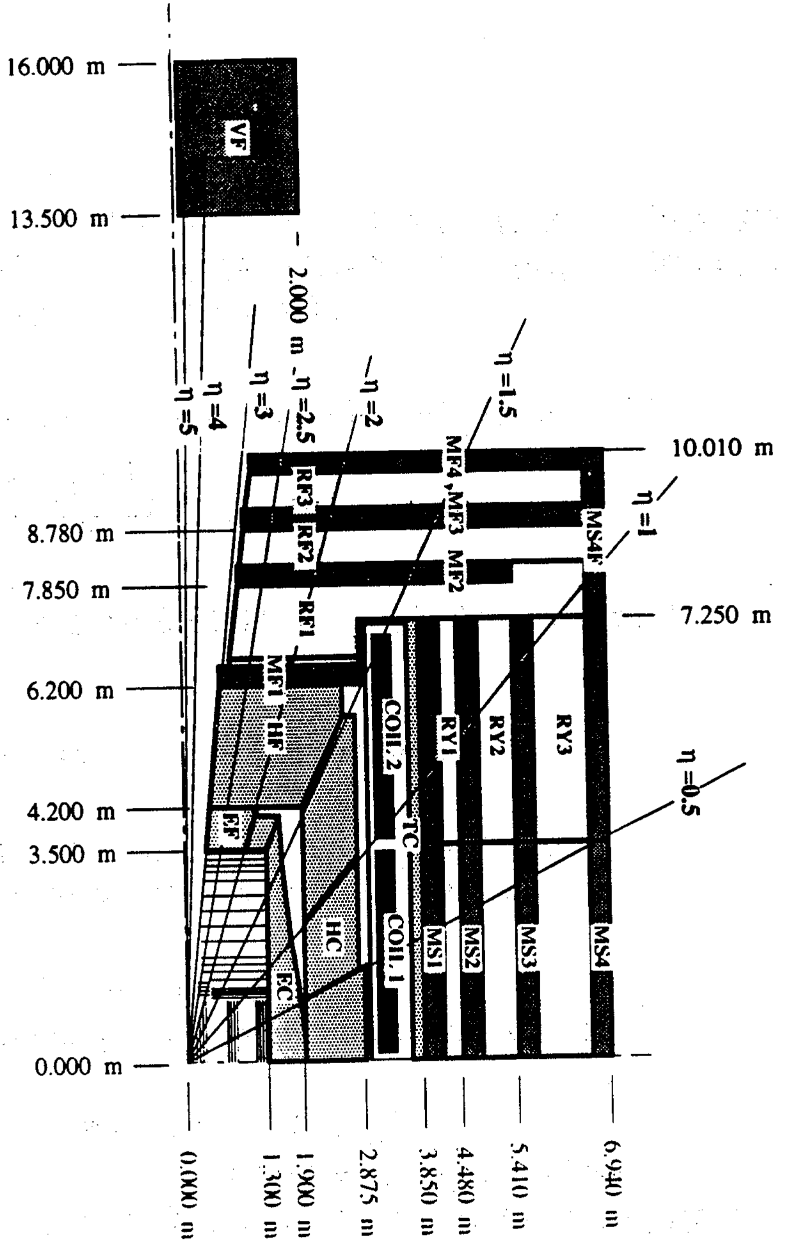


- Global observables of A-A collision :
  → Energy density
  Neutral transverse energy + multiplicity
  → Volume of interaction
  Energy in very forward region
- Vary energy density :
  Increase beam mass from proton to Lead



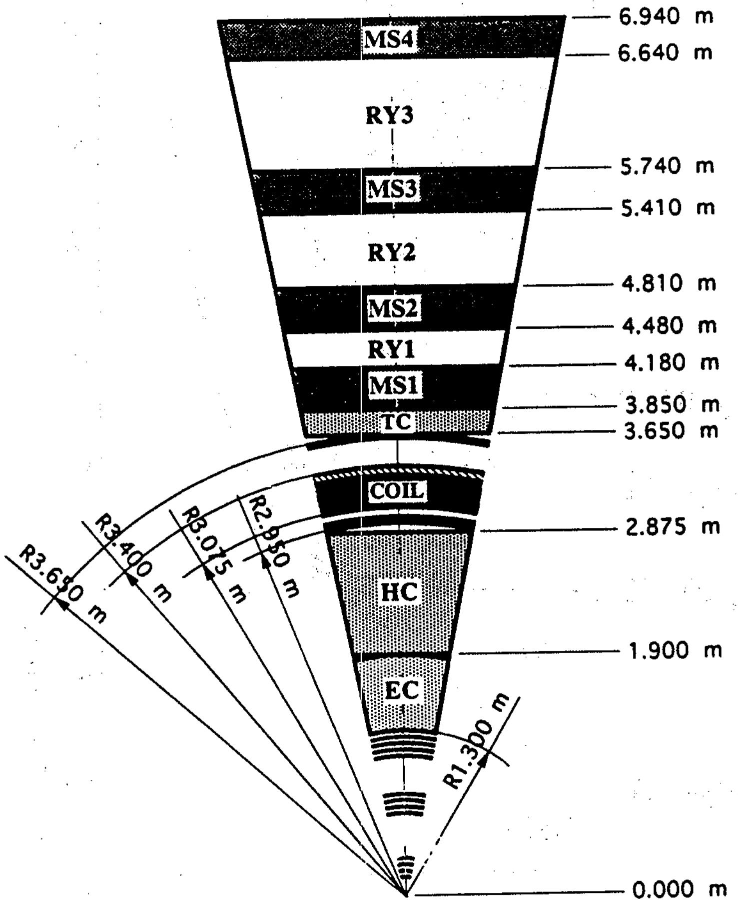
C.M.S. version 07
CERN PPE 28/01/92
J-l. bénichou

= 14m
L = 20m
Weight = 12,000tons
Compact Design



C.M.S. version 07-B
CERN PPE 16-12-91
jl bénichou

C.M.S. Version 07-B



CERN PPE
j-l bénichou
16-12-91

J/ψ and Υ CROSS SECTIONS

Two possible extrapolations of N-N data up to LHC :
- Saturation of cross-section with $\sqrt{s}$ (Craigie).
- Linear increase with $\sqrt{s}$ (QCD).

A dependence from present measurements A^{α}

$$\alpha_{J/\psi} = 1.8 \qquad \alpha_{\Upsilon} = 1.9$$

Estimated ratios between different states
$\psi^{'} = 0.01\ J/\psi,\ \ \Upsilon^{'} = 0.3\ \Upsilon,\ \ \Upsilon^{''} = 0.1\ \Upsilon$

(B decays into J/ψ not yet included)

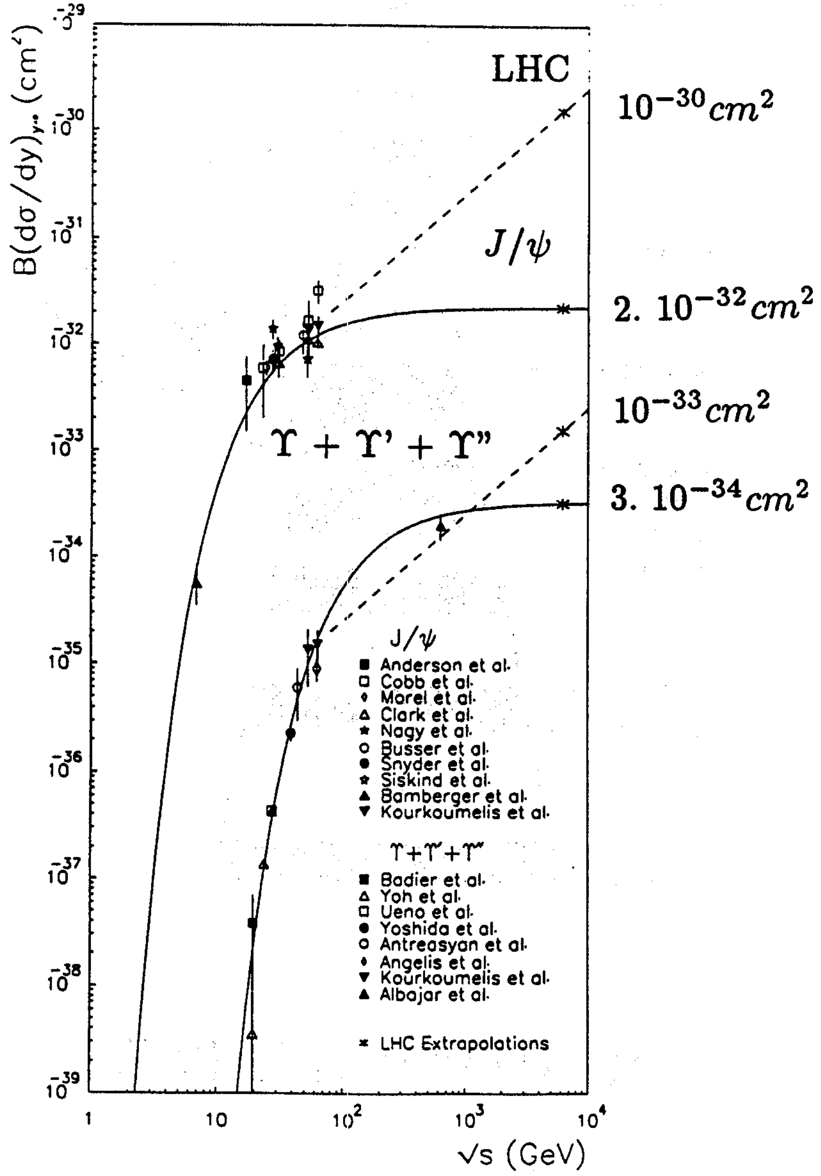
P_T AND y DISTRIBUTIONS OF J/ψ AND Υ

$$\frac{d\sigma}{dP_T} = \frac{P_T}{\left[1+(\frac{P_T}{P_{T_0}})^2\right]^{3.5}} \quad \text{(fit present data)}$$

$$\frac{d\sigma}{dy} = 1 \text{ for } |y| < 3 \text{ and } \exp[-|y-y_0|^2/2] \text{ for } |y| \geq 3$$

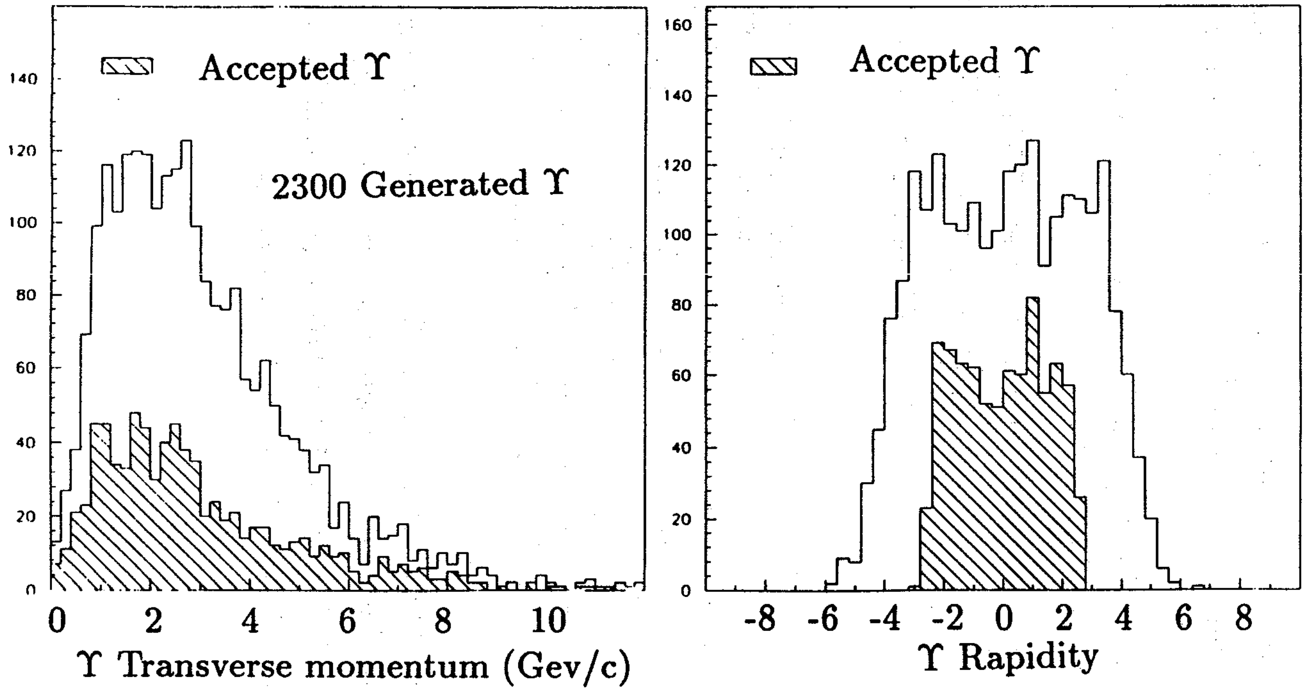
Extrapolation to LHC energy :
J/ψ : $P_{T_0} = 2.3$ GeV/c, $<P_T>= 1.6$ GeV/c , $y_0 = 3.5$
Υ : $P_{T_0} = 4.7$ GeV/c, $<P_T>= 3.0$ GeV/c , $y_0 = 3.0$

J/ψ AND Υ CROSS SECTIONS INTO $\mu^+\mu^-$ N-N DATA EXTRAPOLATION TO LHC



$\Upsilon \rightarrow \mu^+\mu^-$ ACCEPTANCE IN CMS

34 %



CMS ACCEPTANCE AND RESOLUTION

- Simulation with GEANT + C.M.S. geometry.
- Trigger condition : two muons arriving at μ-chambers.
- Muon momentum reconstruction with vertex
+ 4 outer MSGC's.

Spatial resolutions :

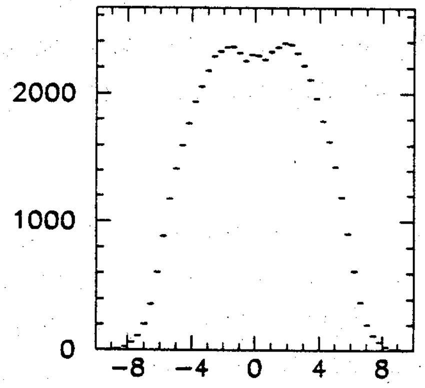
	$\sigma(r\phi)$	$\sigma(z)$
Vertex	20 μm	3 mm
MSGC	60 μm	1 mm

Acceptance is 34% for the Υ.
Due to its smaller $<P_T>$ value the J/ψ acceptance is 6%, essentially in the rapidity range 1 to 3.
The full P_T range is covered for both resonances.

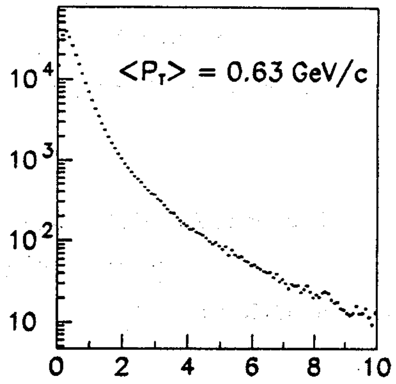
Dimuon mass resolution is 1% FWHM at the Υ, good enough to resolve the different states which are separated by at least 300 MeV/c^2.

PARTICLE PRODUCTION IN Pb-Pb COLLISIONS.

- Central Pb-Pb events generated with VENUS 3.11 :
  $dn/dy)_{y=0} \simeq 3000$



dN(charged)/dη vs. η



dN(charged)/dP_T vs. P_T

- Simulation in CMS inner cavity :

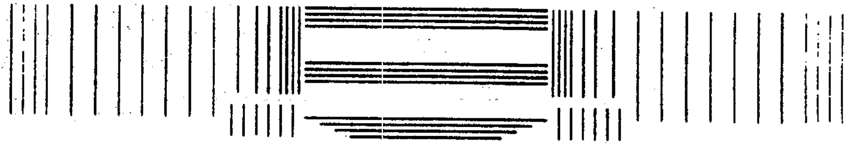
at R = 50 cm 0.200 particle/cm^2
at R = 125 cm 0.011 particle/cm^2
Flat distribution in η in barrel

With MSGC's granularity of 0.25 cm^2 and a mean 3 hits per track, occupancies in barrel are :
15 % at R = 50 cm
0.8 % at R = 125 cm (last MSGC)

MUON IDENTIFICATION

Goal is to find Υ decay muons in the inner tracker using roads defined by vertex and μ-chambers.

Study for typical Υ decay muons of $P_T = 4.$ GeV/c at $\eta = 0.5, 1., 2.$

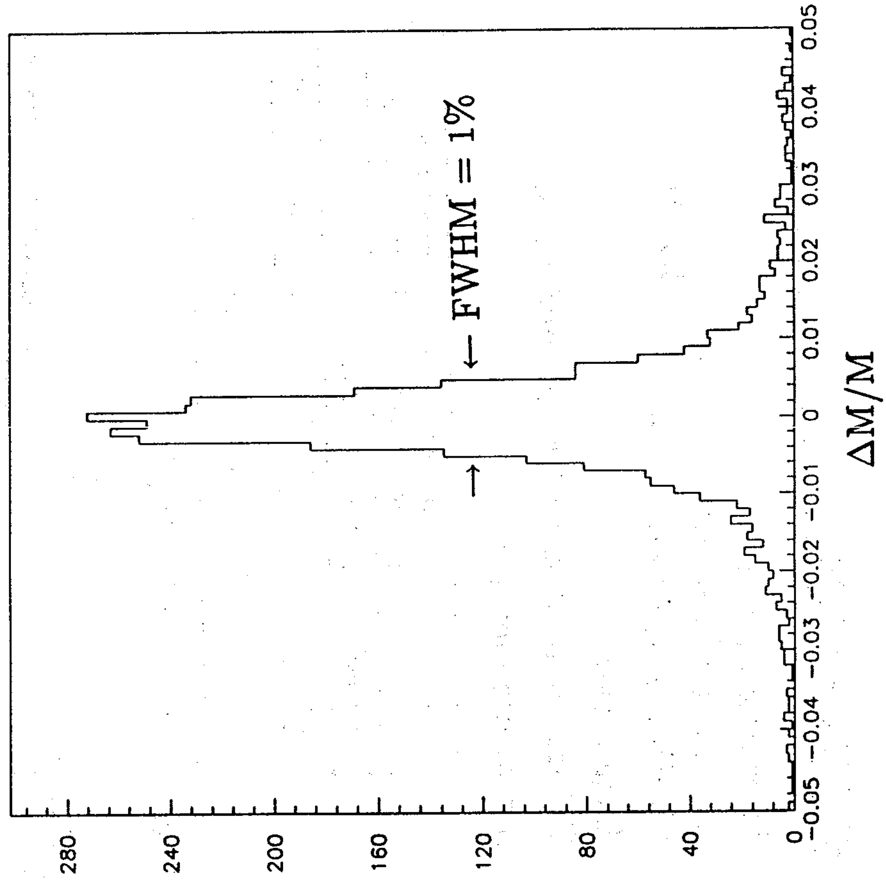


η_μ	p_μ	Reconstruction with muon chambers		MSGC tracks /cm^2	MSGC tracks in road
		$\Delta p/p$	MSGC road, cm^2		
0.5	4.5	5%	139	.011	1.6
1.0	6.2	8%	113	.034	3.8
2.0	15.	16%	26	.078	2.0

Reconstruction of the few candidate tracks with the last MSGC's will determine the one matching the external muon momentum (additional tracks have lower transverse momentum on average).

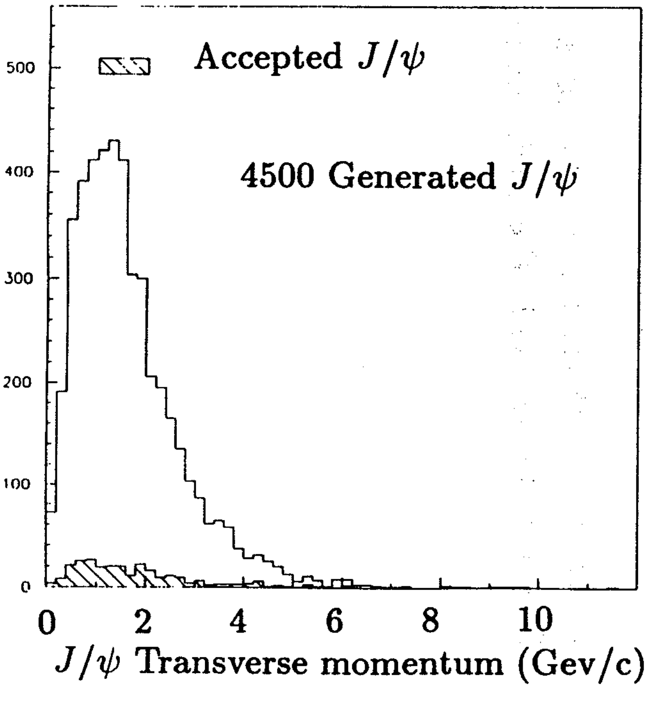
ϒ MASS RESOLUTION IN C.M.S.

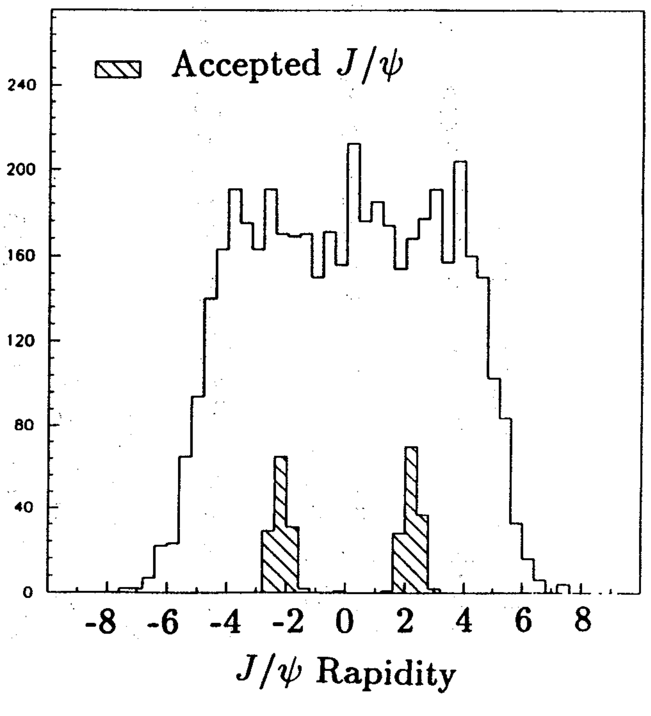
- Vertex + last 4 MSGC's : $\Delta M/M(\mathrm{FWHM}) = 1\ \%$
- FWHM could reach 0.8% with full inner tracking.
- FWHM varies between 0.4 % and 1.5 % for dimuon pseudorapidities between 0 and 4.



$J/\psi \rightarrow \mu^+\mu^-$ ACCEPTANCE IN CMS

6 %





BACKGROUND

- Main background source :
  random combinations of μ's from π and K decays.

- Study with Pb-Pb collisions generated with
  VENUS 3.11.

- Background reduction cuts (to be optimized) :

$P_T^{\mu} > 4$ GeV/c
$\Delta\eta(\mu^+,\mu^-) < 2$
$115^\circ < \Delta\phi(\mu^+,\mu^-) < 230^\circ$

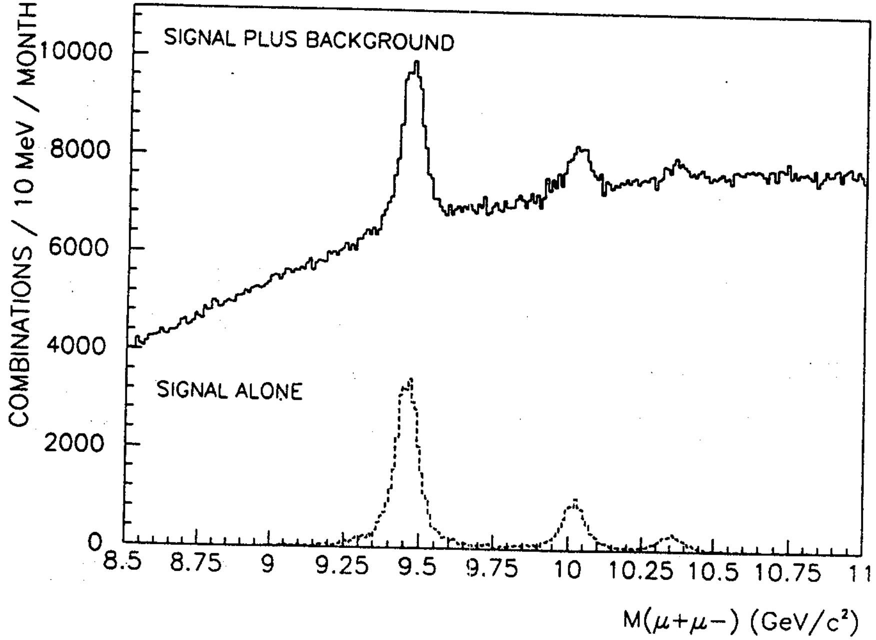
Leads to a 44% reduction of Υ signal with a factor 100 decrease in the background.

EVENT RATES

- Interaction rate :
  $L = 1.8\ 10^{27}\ \mathrm{cm}^{-2}\mathrm{s}^{-1}$
  Pb-Pb cross-section 7 barn $\Big\}$ 12.6 kHz
- Trigger rate :
  600 Hz dominated by Background pairs.
- Signal per month :

state	detected events per month	detected after additional cuts
$J/\psi+\psi'$	$8.4\cdot10^5$ - $4.2\cdot10^7$	
$\Upsilon+\Upsilon'+\Upsilon''$	$1.0\cdot10^5$ - $3.4\cdot10^5$	$5.6\cdot10^4$ - $1.9\cdot10^5$

Pb−Pb Collisions AT LHC



CONCLUSION

CMS is a unique tool to do both p-p physics
at high luminosity and heavy ion physics.

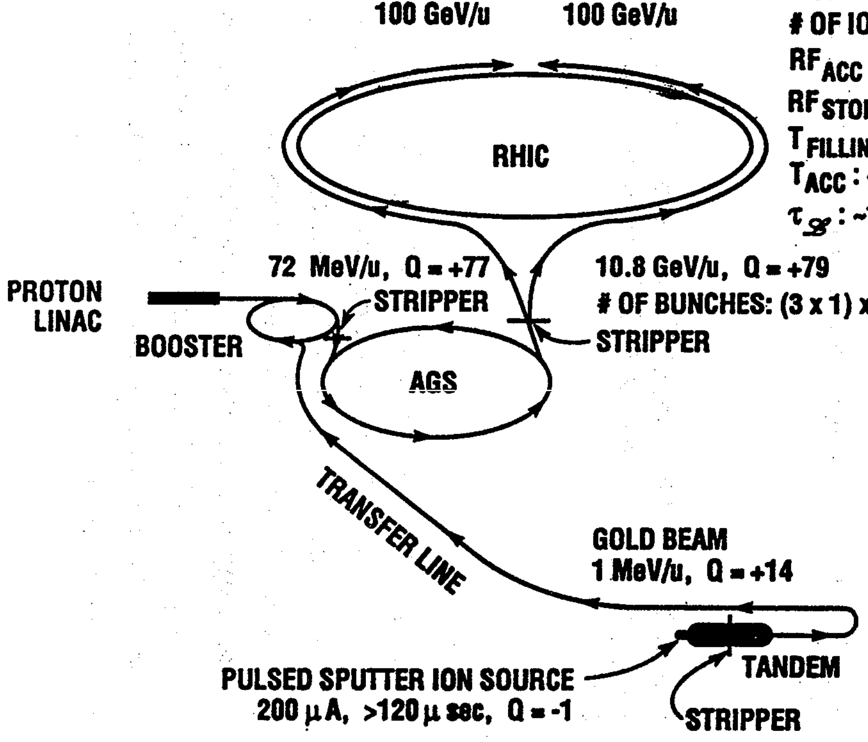
The design for p-p physics meets requirements
for dimuon production study at heavy ion collider :

- Large rapidity acceptance :
  - $|\eta| < 2.6$
- 10 λ_I before μ-Chambers :
  - Kill tracks with $P_T < 3.5$ GeV/c
- 4T magnetic field :
  - Reduce occupancy in last MSGC's
  - Identification of muons requires only track reconstruction in the last MSGC's
- Inner tracking :
  - Resolve Υ states, sample charged multiplicity
- EM-calorimeter :
  - estimate energy density
- Hadron calorimeters :
  - measure jet production $|\eta| < 2.6$
  - measure impact parameter of collisions $3 < |\eta| < 5$

The RHIC experimental programme

T. Ludlam (Brookhaven)

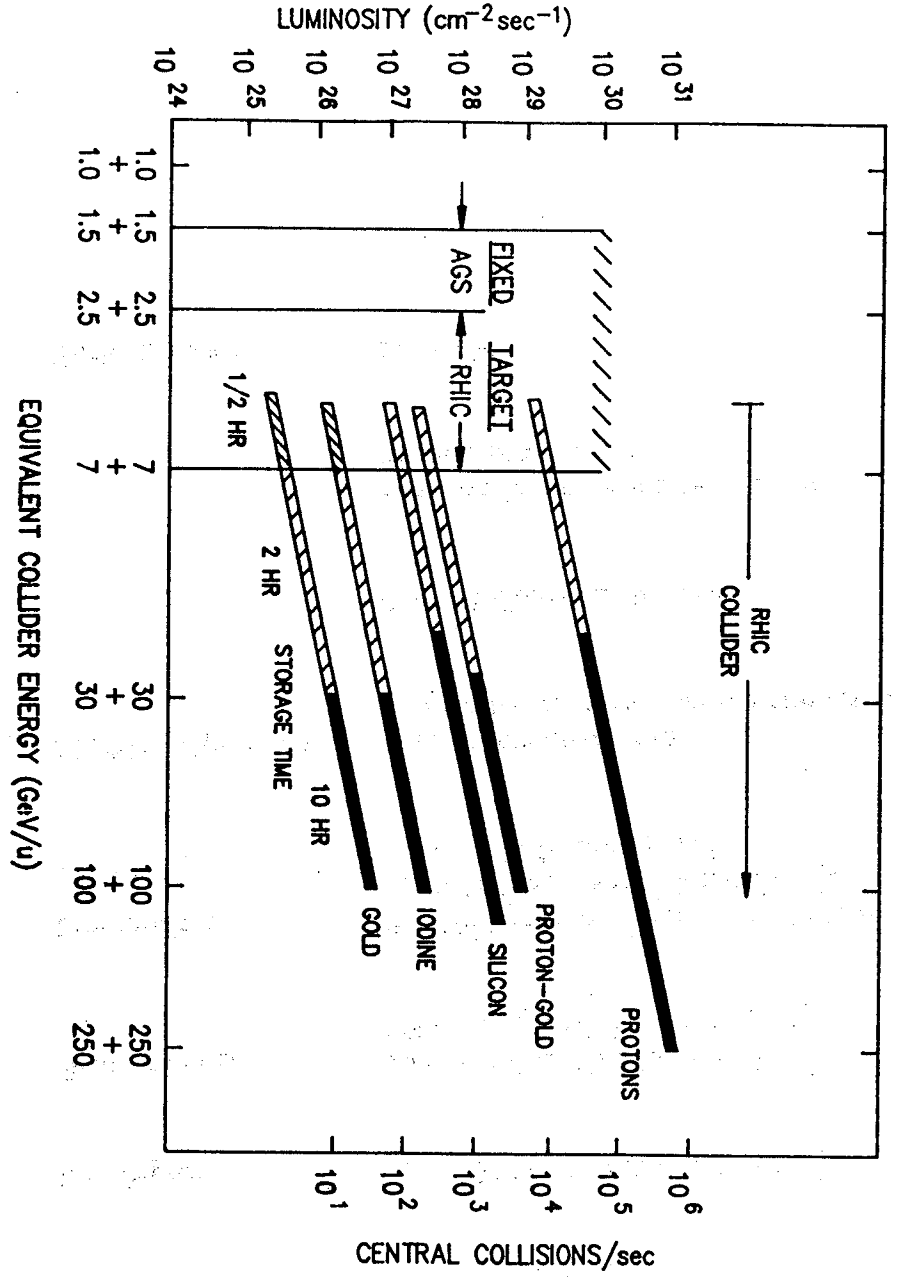
RHIC ACCELERATION SCENARIO Au



OF BUNCHES: 57
OF IONS/BUNCH: 1x10^9
RF$_{ACC}$: 26.7 MHz, 0.4 MV
RF$_{STORAGE}$: 160 MHz, 4.5 MV
T$_{FILLING}$: ~1min
T$_{ACC}$: ~1min
$\tau_{\mathcal{L}}$: ~10 hrs

RELATIVISTIC HEAVY ION COLLIDER
RHIC Project at Brookhaven

Ion Types:	A ~ 200 (Au) to A = 1 (proton)
Beam Energy:	100 + 100 GeV/u for A ~ 200 (Au) 250 + 250 GeV for A = 1 (protons)
Luminosity:	2 × 10^{26}cm^{-1}sec^{-1} for A ~ 100 (Au) 1.4 × 10^{31}cm^{-1}sec^{-1} for A = 1 (P) × 10 in future upgrade
Machine Operation:	Two Independent Rings → Collision of unequal ion species O.K. 4 ⟶ 6 Collision Regions ~ 40 weeks operation per year for nuclear physics
Begin Operations:	Late 1997



RHIC Accelerator Construction Status

- **AGS Booster Synchrotron to be Commissioned for Au ions March/April 1992**

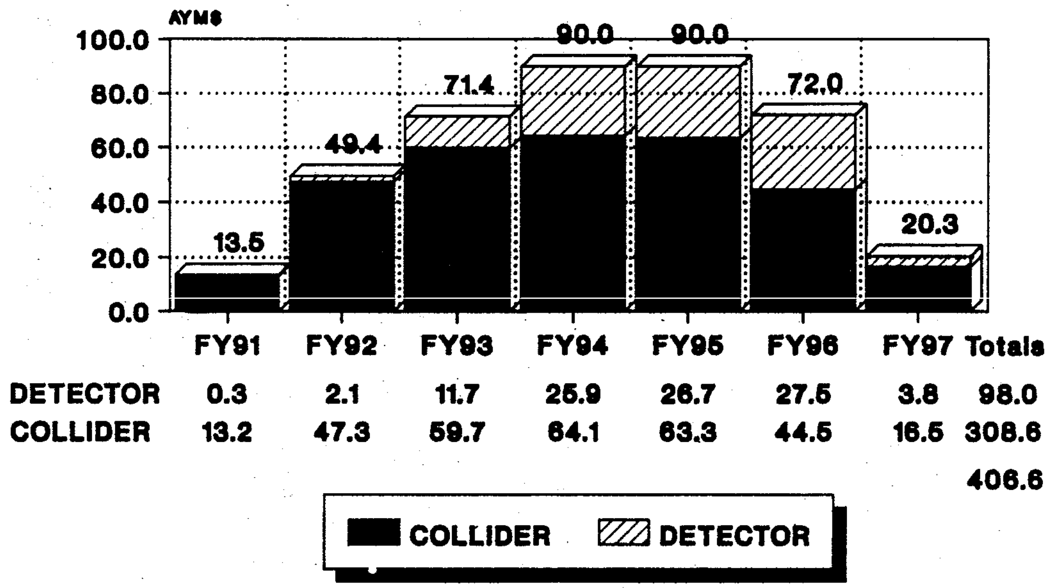
- **RHIC Construction Project Began January 1991**
  FY '91: $13.5M
  FY '92: $49.4M

- **Full Construction Authorization Received January 1992**

- **Fiscal Year 1993 Budget Submitted to U.S. Congress includes $ 71.4M for RHIC Construction + $7.2M for R&D**

- **Procurement**
  30 strand S/C cables for arc dipoles and quads
    1.8 Mft, $6.8M: Oxford Superconducting Tech.
  36 strand S/C cables for insertion magnets
    100 kft, $1M: OST and Furukawa
  8cm dipoles for arcs and insertions: 373 units
    Vendor selected, contract in DOE review
  RFP for arc quads and sextupoles in preparation (Mar-Apr)

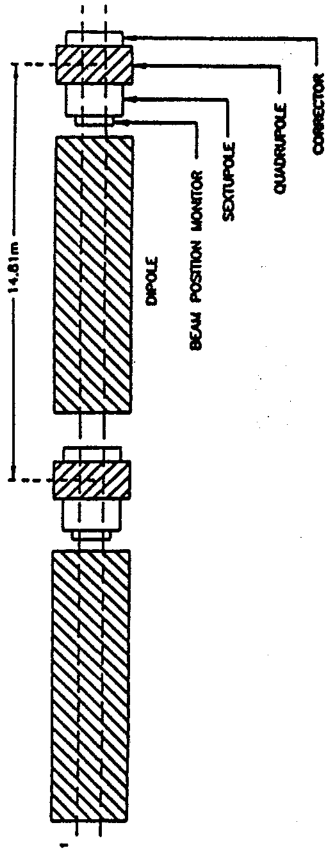
RHIC
COLLIDER & DETECTORS
CONSTRUCTION PROFILE



	FY91	FY92	FY93	FY94	FY95	FY96	FY97	Totals
DETECTOR	0.3	2.1	11.7	25.9	26.7	27.5	3.8	98.0
COLLIDER	13.2	47.3	59.7	64.1	63.3	44.5	16.5	308.6
								406.6

RHIC\FEB92\RHIC0016

RHIC MAGNET FULL CELL TESTS



THERMAL CYCLES	
300 k → 4.2 k → 300 k	2
300 k → 80 k → 300 k	12
POWER CYCLES (MAIN CIRCUIT – DIPOLES & QUAD's)	
580 A → 5000 A → 580 A	375
QUENCH TEST	
MAIN CIRCUIT QUENCH (ALL IN DIPOLES)	26
1st QUENCH	6168 A
SUBSEQUENT QUENCHES	>7000 A
(OPERATING CURRENT	5000 A)

TRIM CIRCUITS
SEXTUPOLES, CORRECTORS
NO QUENCH FOR ±50 A

RHIC ARC MAGNETS PERFORMED AS EXPECTED WHEN OPERATED AS A SYSTEM.

SO/FullCell.txt
9/16/91

Experiments for RHIC

- **Four Completed Experimental Areas**

  Two Undeveloped Areas

- **Project funding includes $99.3M (= 80M FY 1991 dollars)**

  for Detector Construction,
  + $15M for Detector R&D

- **Initial Complement :**

  Two large detectors + "small" experiments

  Allocation of Project Construction funds (FY 1991 $)...

STAR Detector	**$ 30M** + α
PHENIX Detector	**30M** + β
Small experiments, **+ general support**	**20M**
	$ 80M

- **Both Large Detector Collaborations are actively discussing contributions from foreign participants.**
  and other Sources

Evolution of RHIC Detectors — II

- Letters of Intent
  - 9 LOI received in October 1990:

    Approx. 450 scientists, with broad representation of U.S. Nuclear Physics Community + Europe, Japan, China. Over 60 institutions world-wide.
  - April 1991. Open Meeting on Detectors:

    Discuss physics priorities and possible consolidation of effort. Four concepts for "Major" Detectors
- Present Status
  - Two Collaborations of former LOI groups are preparing Conceptual Designs for the large detectors · · ·

    STAR: Large solid angle tracking with TPC; emphasis on hadrons (soft processes) + jets (hard scattering). CDR expected in June 1992.

    PHENIX: Leptons, photons and hadrons in selected solid angles, with high rate capability. CDR expected in November 1992.
  - CDRs will provide the baselines for detector construction phase. Define the scope consistent with a $30M (FY 1991 $) cap for each large detector.
  - First LOI for small experiments received January 1992.
    - ≲ $5M
    - QUICKLY IN AND OUT
    - DATA TAKING IN ONE YEAR

RHIC Letters of Intent July 1991

RLOI-1 **Total and Elastic pp Cross Sections**
[BNL/CEBAF/Case Western Reserve/Rochester/Stony Brook]
Spokesman: W. Guryn + 8

RLOI-3 **Search for a Quark Gluon Plasma and Other New Phenomena with a 4π Tracking TPC Magnetic Spectrometer at RHIC**
[BNL/CCNY/CMU/Notre Dame/Rice]
Spokesman: B. E. Bonner

RLOI-5 **An Experiment on Particle and Jet Production at Midrapidity**
[Rudjer Boskovic Inst./UC-Davis/UCLA/Creighton/Frankfurt/Johns Hopkins/Kent St./LBL/Purdue/Texas A&M/Warsaw U./Warsaw U. of Tech./Washington/Weizmann)]
Spokesman: J. W. Harris + 115 [in **STAR**, RLOI-3 + RLOI-5]

STAR

RLOI-6 **MARS (A Modular Array for RHIC Spectra)**
[BNL/Illinois/Inst. Nucl. Phys.-Krakow/Jagiellonian U.-Krakow/Brunel-U. West London/MIT]
Spokesman: W. Busza + 30

RLOI-7 **OASIS (Open Axially Symmetric Ion Spectrometer)**
[BNL/UC-Riverside/Columbia/IHEP-Beijing/Kanagawa/KEK/Korea/Kyushu/Lebedev/Leningrad/McGill/Moscow/Peking/New Mexico/Pittsburgh/Sao Paulo/Seoul/Tel Aviv/Tsukuba/Waseda/Yale/York College]
Spokesman: S. Nagamiya + 136

RLOI-8 **Forward Angle Hadron Spectrometer Experiment at RHIC**
[BNL]
Spokesman: F. Videbaek + 17

RLOI-10 **RHIC Spin Collaboration**
[ANL/BNL/Genova/Indiana/KEK/Kyoto/Marseille/MIT/Messina/Padova/Penn. St./Trieste/UCLA]
[No Spokesman] 39

RLOI-11 **A Lepton/Photon Spectrometer for RHIC Measurements of Lepton Pairs, Vector Mesons, and Photons**
[BNL/CIAE-Beijing/Georgia St./GSI/Iowa St./Kurchatov Inst.-Moscow/LLNL/LANL/Lund/Münster/ORNL/UC-Riverside/Tennessee/Vanderbilt]
Spokesman: G. Young + 78

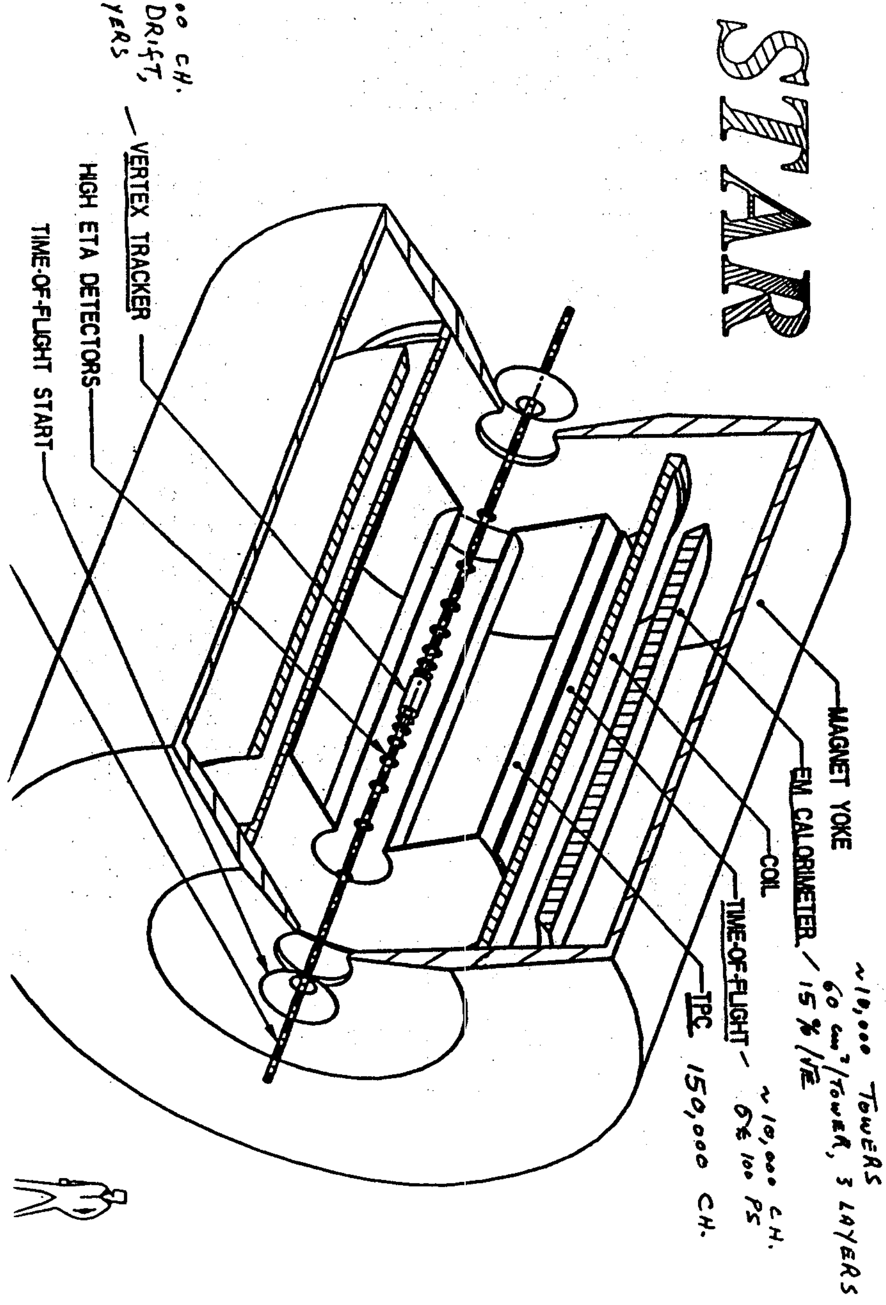
RLOI-12 **The TALES/SPARHC Experiment at RHIC**
[IHEP-Beijing/BNL/UCSSL-Berkeley/Clermont-Fd./Florida St./Hope College/INEL/Indiana/INS-Tokyo/Inst. Modern Phys.-Lanzhou/Kyoto/Louisiana St./Mississippi St./NIRS-Japan/KEK/Osaka/Sao Paulo/Stony Brook/Texas A&M/Tokyo/Tsukuba]
Spokesmen: P. Braun-Munzinger/R.S. Hayano + 79

~~RE-2~~ → PHENIX

Total: 510

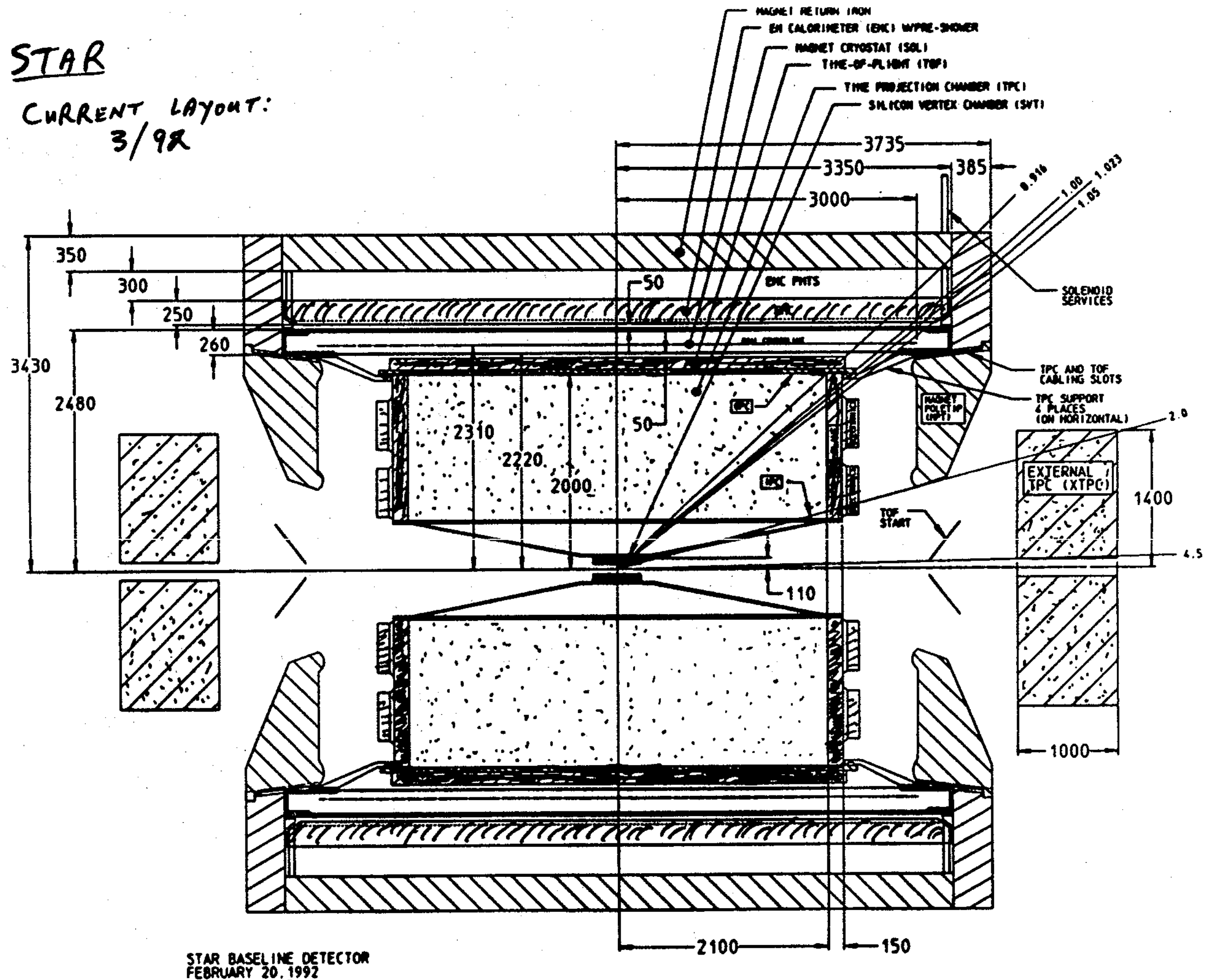
SPOKESMAN:
JOHN HARRIS
LBL

Rudjer Boskovic Insitiute/BNL/UC-Davis/UCLA/Carnegie-Mellon/Creighton/Frankfurt/Johns Hopkins/Kent State/LBL/Notre Dame/Pittsburgh/Purdue/Rice/Texas A&M/Warsaw/Warsaw Tech./Washington/Weizmann Institute / ARGONNE NAT. LAB.



STAR

CURRENT LAYOUT:
3/92



STAR BASELINE DETECTOR
FEBRUARY 20, 1992
D SHUMAN, LBL
filename: ~mhara/star/2d/star_baseline_2_20_92

STAR

Physics Goals

General

Soft Physics - Event-by-Event
- **Spectra (π, K)**
- **Strangeness ($K^\pm$, K^o_S, Φ, Λ, $\bar{\Lambda}$, Ξ^-, Ω^-)**
- **Particle Correlations (π) - HBT, speckles**
- **EM/Charged-Particle Energy,**
- **Fluctuations**
  - **(E_t^{em}, E_t^{tot}, Entropy, Multiplicity, p_t)**

Parton Physics (pp, pA, AA)
- **Jets, High p_t particles**
- Polarized Protons

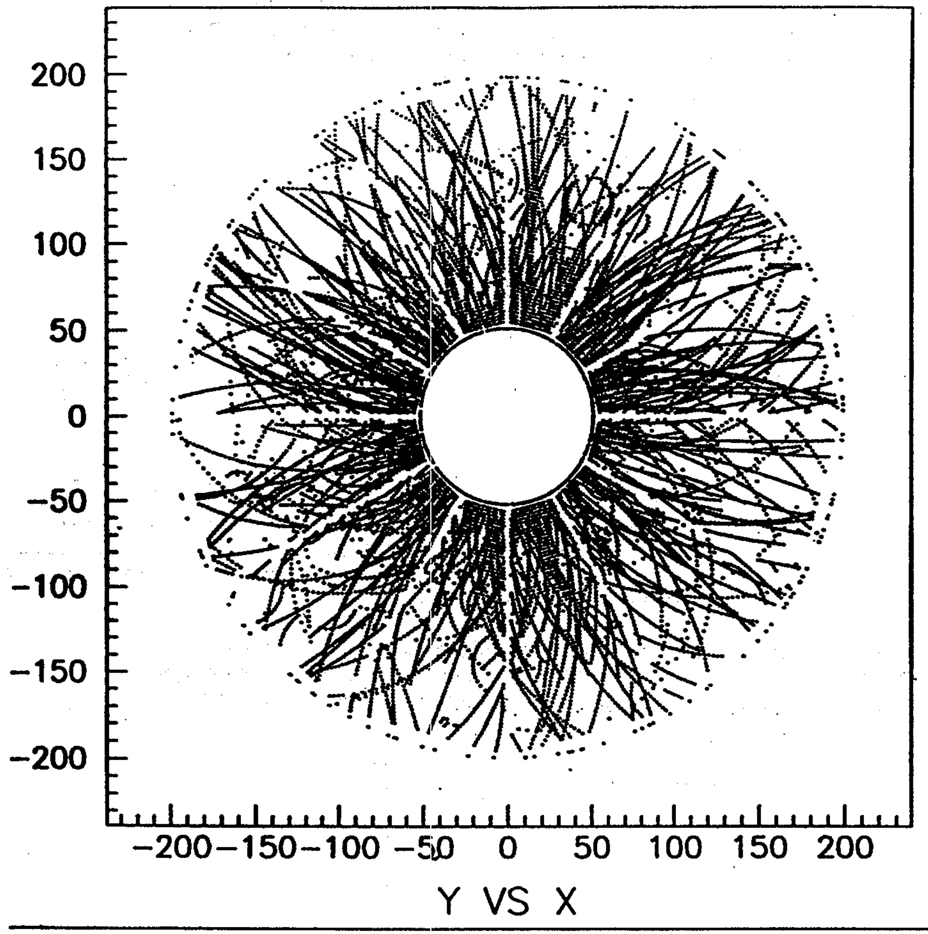
TPC Parameters

Drift Distance	2.1 m
Inner Radius	0.5 m
Outer Radius	2.0 m
Number of Sectors	12 each end
Number of Pads	75,000 each end
Pad Size	6 X 20 mm
Gas	90% Ar + 10% CH_4
	saturation field - 130V/cm
Pressure	1 atmosphere
Time samples	512
Field Cage	1 cm bands, ALEPH style, 33kV
Laser spatial calibration	UV (266 nm freq. quadrupled Nd-Yag)
B field	0.5 T

$\frac{\Delta p}{p} \simeq 1\%$ AT 1 GeV/c

$\sigma(\frac{dE}{dx}) \approx 4.5\%$ FOR 1 m TRACK

~ 80 MByte /EVENT



STAR HITS:
50 Cm. slice ALONG Z
1 EVENT ⇒ 80 MBYTE

STAR TPC Review Panel

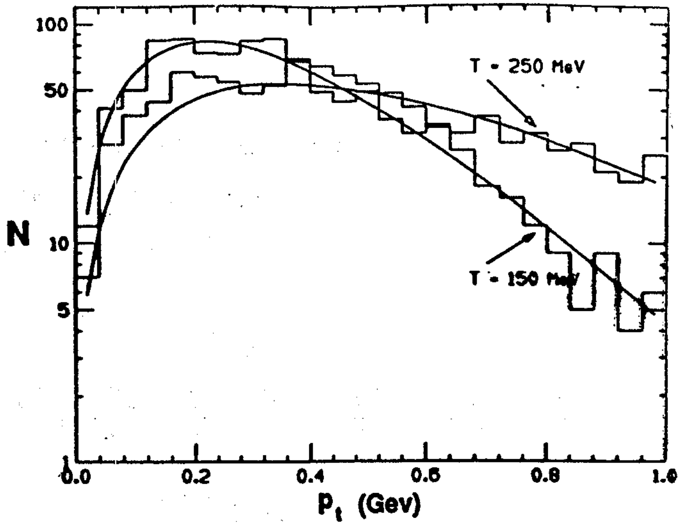
December 10-11, 1991

H. Hilke	CERN
J. Lynch	LBL
J. Marx	LBL
J. May	CERN/DESY
L. Paffrath	BNL (Chairman)
V. Radeka	BNL

---

1 EVENT:
Au + Au
CENTRAL Coll.

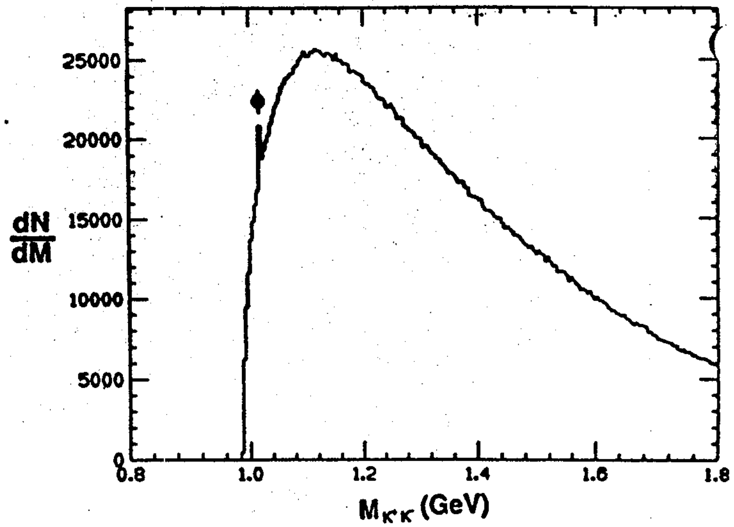
1000 PIONS



1. Simulation of the p_t spectrum for one event generated using a Boltzmann distribution of 1000 pions. The histograms correspond to single events generated with T = 150 MeV and 250 MeV. The curves are fits to the histogram using a Maxwell-Boltzmann distribution (see text).

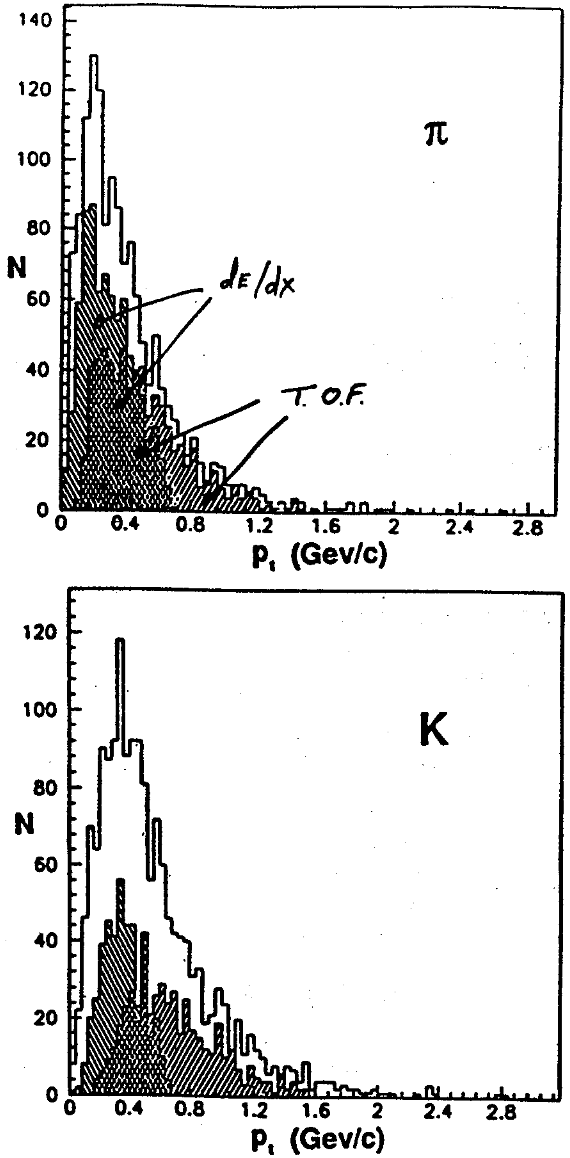
K⁺K⁻ MASS:
500 Au+Au
CENTRAL Coll.

6 φ/EVENT



3. Invariant mass distribution for K^+K^- pairs in the acceptance $|\eta| < 1$ for 500 Au + Au central events at RHIC. The φ signal is the narrow peak ($\Gamma = 4.4$ MeV) at 1.02 GeV. The mean number of φ's is six per event. The bin size is 4 MeV to correspond to the width of th although the experimental resolution is expected to be better than this.

Particle I.D.



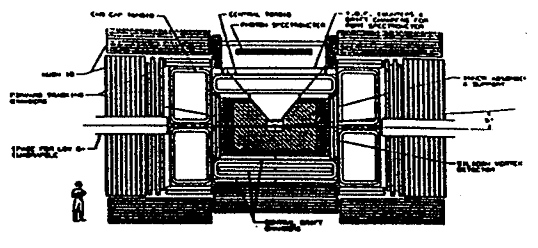
10. Transverse momentum distribution, dn/dp$_t$, for charged pions (above) and kaons (below) from the primary interaction vertex generated by the Lund/FRITIOF nucleus-nucleus code and tracked through the experimental setup. The \\\\ region contains those particles identifiable with dE/dx measurements in the TPC. The //// region contains particles identified by TOF. The cross-hatched region has particles identified by both methods and the open region by neither. Most of the particles which are not identifiable and appear in the open region either interact or decay in flight.

Proposed (& Rejected) detectors for Lepton / Photon measurements

A DIMUON SPECTROMETER

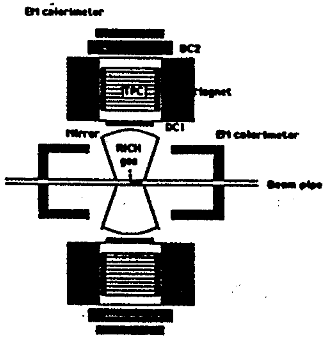
RLOI 4

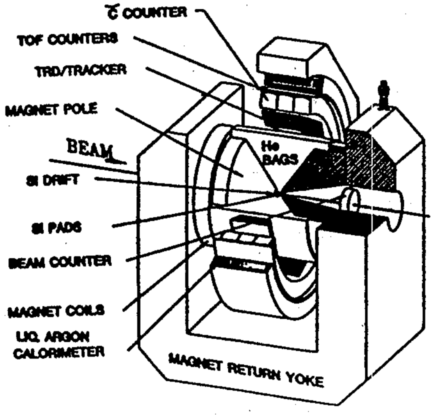
BNL/Georgia State/Iowa State/LLNL/
Los Alamos/Lund/Oak Ridge/
UC-Riverside/Tennessee/Vanderbilt



TALES RLOI 2

Tokyo/INS,Tokyo/KEK/Tsukuba/
Kyoto/Osaka/Hiroshima/BNL/
LBL-Clermont Fd.





OASIS

RLOI 7

BNL/UC-Riverside/Columbia/
Lebedev Phys. Ins./Leningrad Nucl. Phys. Ins./
Moscow Inst. of Phy. and Engr./New Mexico/
Pittsburgh/San Paulo/Tel Aviv/Tsukuba/Yale

PHENIX ORGANIZATION
(WORK IN PROGRESS)

Organization of the Collaboration:

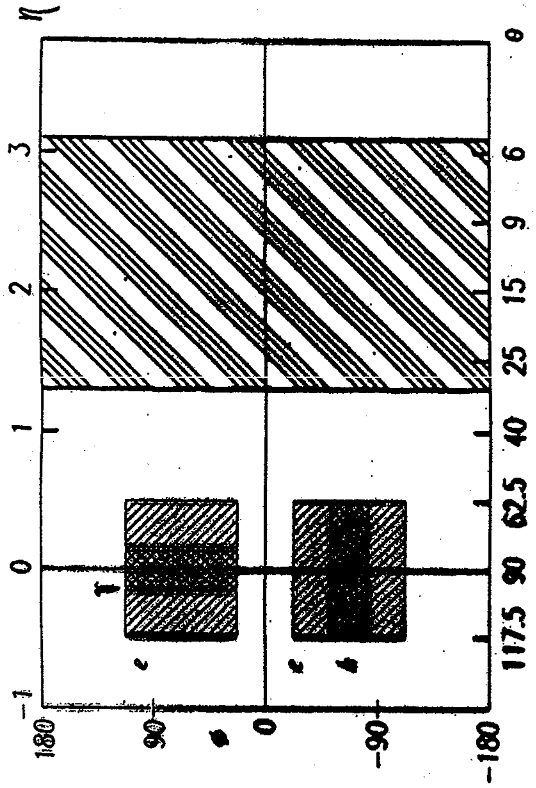
• **Spokesman**	**S. Aronson (BNL)**
• **Advisory Board**	**P. Braun-Munzinger (Stony Brook)** **R. Hayano (Tokyo)** **J. Moss (LANL)** **S. Nagamiya (Columbia)** **G. Young (ORNL)**
• **Conceptual Design Group**	**14 physicists from the new collaboration** *
• **Collaboration**	**Most of the institutions of the former Dimuon, Oasis and Tales/Sparhc collaborations are participating: 200-300 physicists** *

* WORK BEING DONE BY A LARGER GROUP OF ACTIVE PEOPLE IN THE COLLABORATION

* ~50 institutions : US, Japan, China, USSR, Germany, Korea, Canada, Sweden, Brazil, Israel, France

PHENIX GOALS

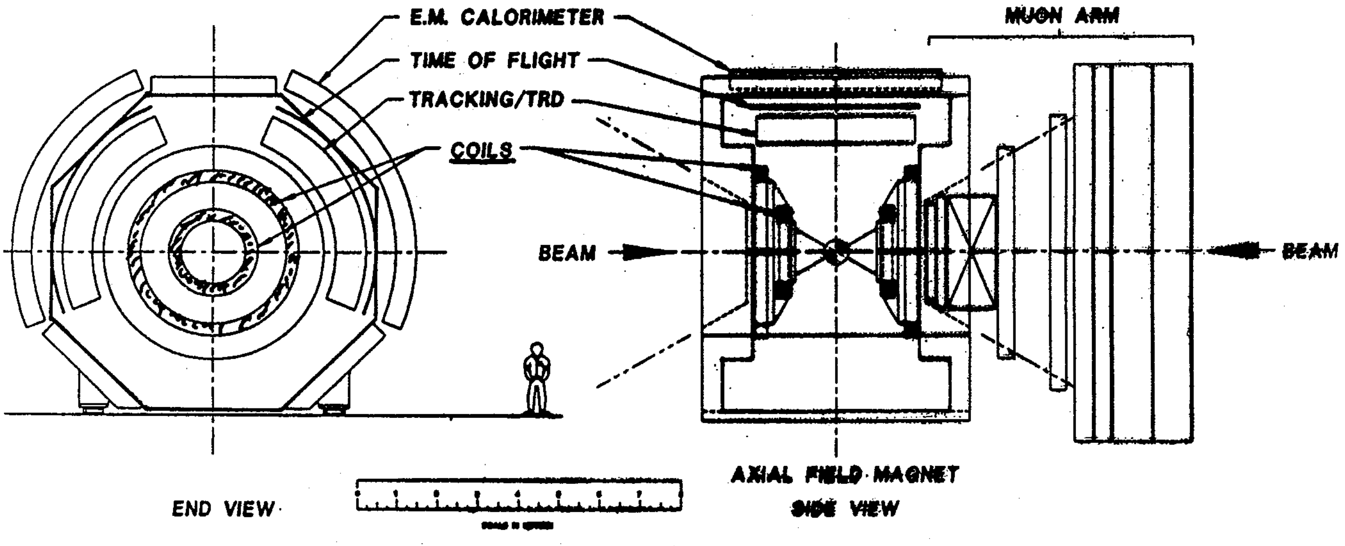
SIGNALS	PHYSICS	DETECTOR ISSUES
e^+e^-	THERMAL CONTINUUM: SHAPE & RATE	DALITZ/CONVERSION & HADRON REJECTION
	$\rho, \phi, J/\psi$	" , MASS RESOLUTI
$\mu^+\mu^-$	$\phi, J/\psi, \Upsilon$	HADRON & DECAY REJECT. MASS RESOLUTION
	DRELL-YAN	ACCEPTANCE
$e\mu$	$c\bar{c}$	HADRON REJECTION
γ	THERMAL SPECTRUM: SHAPE & RATE	ACCEPTANCE, E RESOLUT π^0, η REJECTION
HADRONS	p_T SPECTRA $\phi \to KK$ HBT JETS	P.I.D (→ TOF) MOMENTUM RESOLUTIO 2-PARTICLE SEP.



Phenix Acceptance

Spokesman:
Sam Aronson
BNL

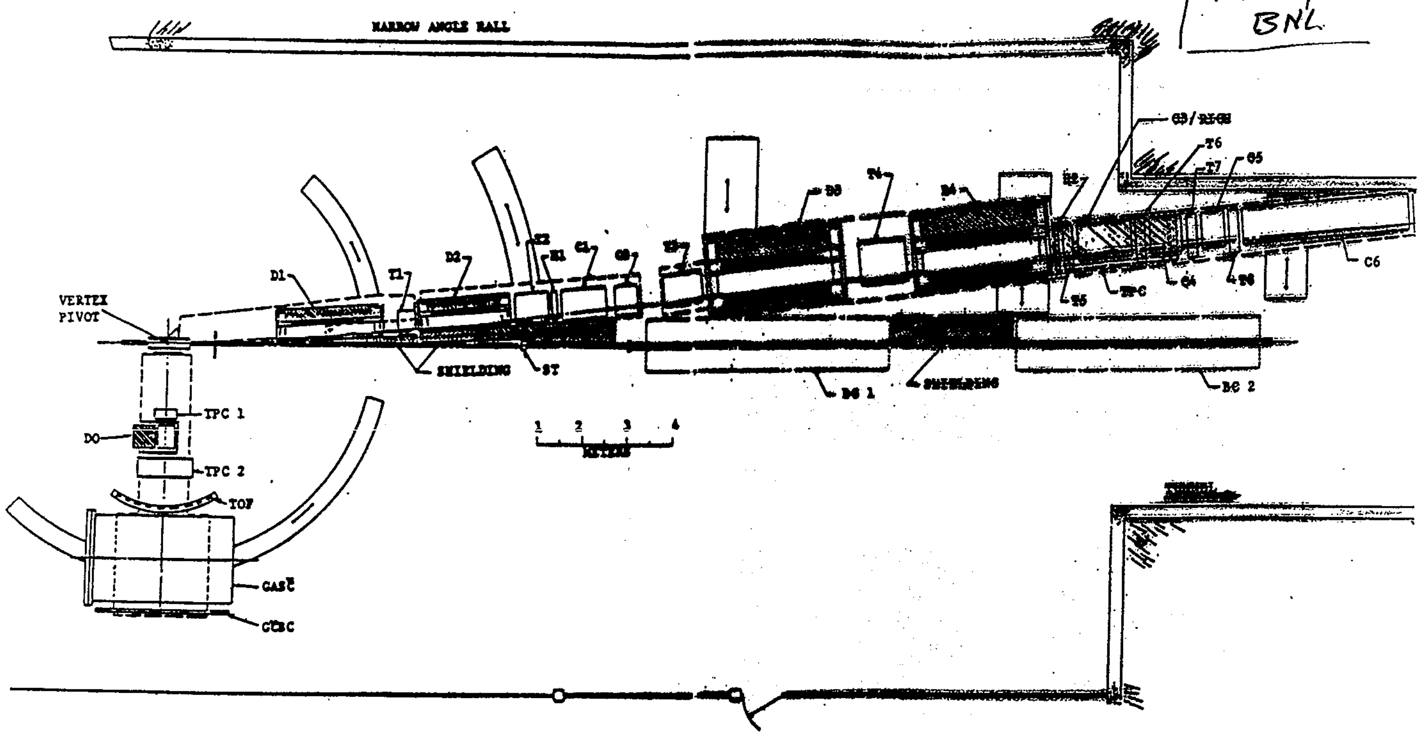
BNL/UC-Riverside/Columbia/Florida State/Georgia State/Hope College/
Idaho Natl. Eng. Lab./Indiana/Iowa State/LLNL/LANL/Louisiana State/
SUNY-Stony Brook/Miss. State/New Mexico/ORNL/Tennessee/Vanderbilt/
Wayne State/Yale + Groups from 10 foreign countries



PHENIX "Straw Man"
Detector

BNL/CRN-Strasbourg/CIAE-Beijing/NYU/Texas A&M/SSL,UC-Berkley

SPOKESMAN:
Fleming Videbaek
BNL



Forward Angle Hadron Spectrometer

PHENIX COLLABORATION

USA
- Brookhaven Natl. Lab.
- Univ. of California - Riverside
- Columbia University
- Florida State University
- Georgia State University
- Hope College
- Idaho Natl. Engineering Lab.
- Indiana University
- Iowa State University
- Lawrence Livermore Natl. Lab.
- Los Alamos Natl. Lab.
- Louisiana State University
- State Univ. of New York - Stony Brook
- Mississippi State University
- University of New Mexico
- Oak Ridge Natl. Lab.
- University of Tennessee
- Vanderbilt University
- Wayne State University
- Yale University

Brazil
- University of Sao Paulo

Canada
- McGill University

China
- Academia Sinica
- China Institute of Atomic Energy
- Inst. of High Energy Physics, Acad. Sinica
- Inst. of Modern physics, Acad. Sinica
- Peking University

France
- University of Clermont-Ferrand

Germany
- GSI-Darmstadt
- University of Muenster

Israel
- University of Tel Aviv

Japan
- Inst. for Nuclear Study (Tokyo)
- Kanagawa University
- KEK, Inst. for High Energy Physics
- Kyoto University
- Kyushu University
- Natl. Inst. for Radiation Sciences
- Osaka University
- University of Tokyo
- University of Tsukuba
- Waseda University

Korea
- Korea University
- Seoul National University

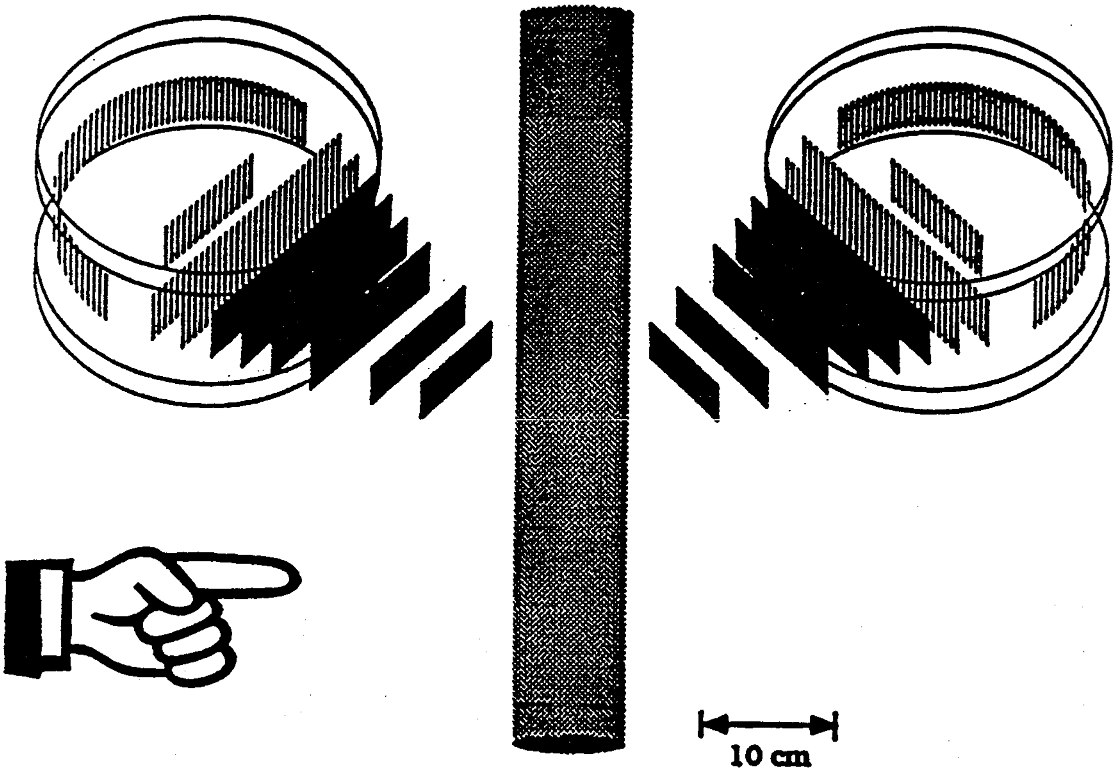
Russia
- Kurchatov Institute
- Lebedev Physical Institute
- Leningrad Nuclear Physics Institute
- Moscow Inst. of Physics and Engineering

Sweden
- Lund University

11 Nations, 48 Institutions

SPOKESMAN:
WIT BUSZA
MIT

*BNL/Iowa State/INP-Krakow/Jagiellonian U.-Krakow/
MIT/Illinois at Chicago/Maryland/Wayne State*



PHOBOS

Acceptance of the Proposed Experiment

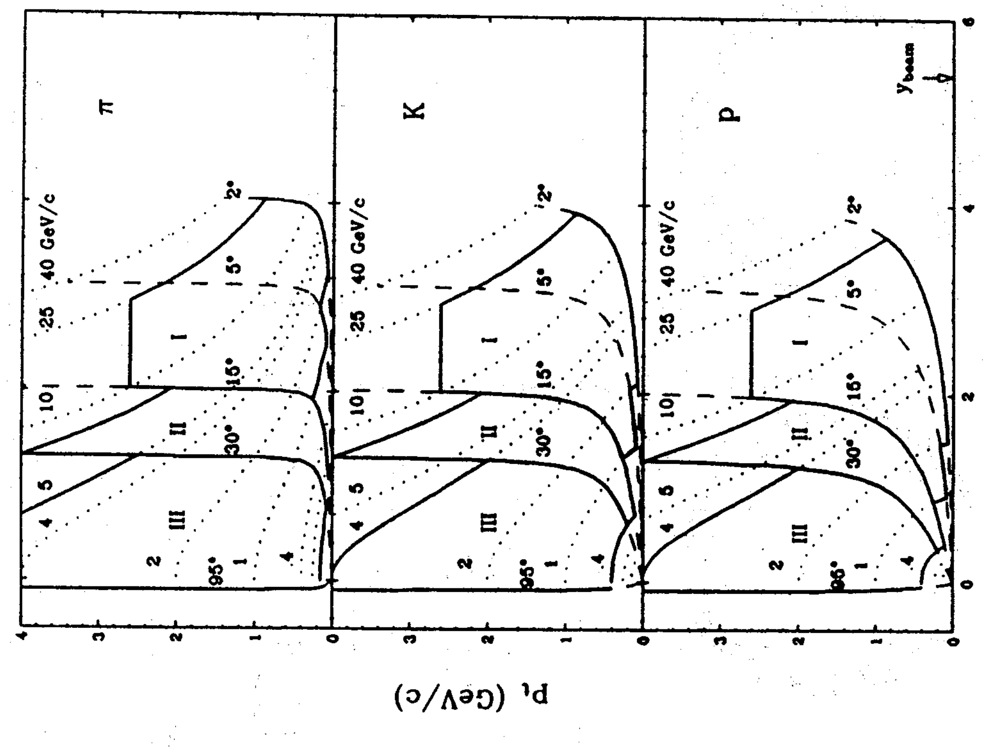


Fig. 5

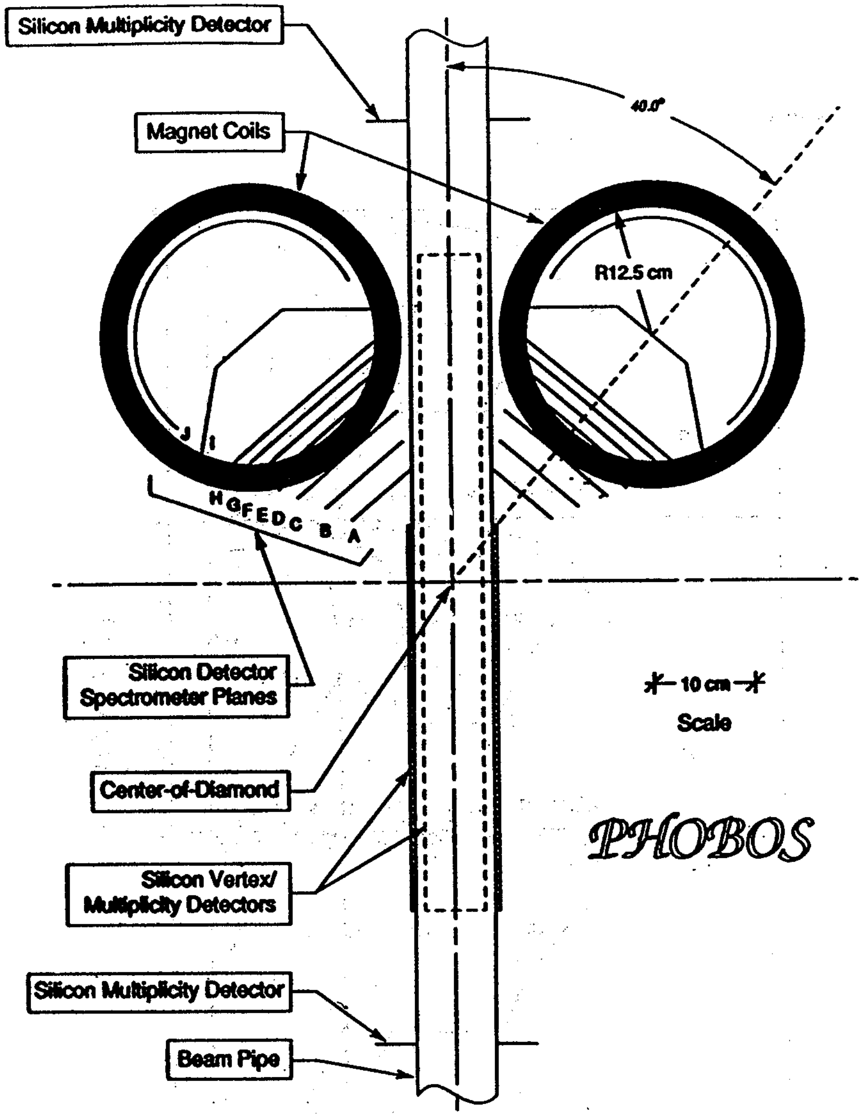


Figure 3. Plan view of the PHOBOS detector showing the superconducting coils and the location of the ten silicon detector planes of the spectrometer arms. Also shown are the silicon vertex detectors, annular silicon multiplicity detectors and the beam pipe.

TABLE II
PHYSICS MEASUREMENTS

1. Global Variables
   - E_T, $\frac{d\sigma}{dn_c}$, $\frac{dn_c}{dy}$ … } ALL

2. Hadrons
   - $\frac{d\sigma}{dp_T}$ of identified π, K, p, $\bar{p}$ …
   - Strangeness Production K^+, K^-, ϕ, Hyperons
   - HBT Interferometry: $\pi\pi$ and KK
     low ⟶ moderate p_T
   - Open charm — STAR (VTX. DET)?
     PHENIX (e-μ)?

   } STAR
   (PHENIX)
   (PHOBOS)
   → Low P_T

3. Dileptons
   - Soft Continuum
   - Non-resonant continuum 1 GeV → ≥3 GeV
   - ρ, ω, ϕ mass, width & cross section
   - J/ψ, ψ', Υ: screening

4. Photons
   - π^o, η^o, η'
   - Continuum direct photon
     Very soft ⟶ hard ($p_T > 5$ GeV/c)

   } PHENIX

5. Hard Scattering Processes
   - Jet + Jet - STAR $p_T \geq 10$ GeV/c
   - Hard Photon + Jet — PHENIX

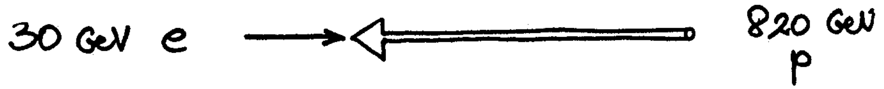
HERA news

A. Wagner (DESY)

A Wagner
Evian
7.3.92

HERA
NEWS

- Introduction
- Machine Status
- Experiments
- Outlook

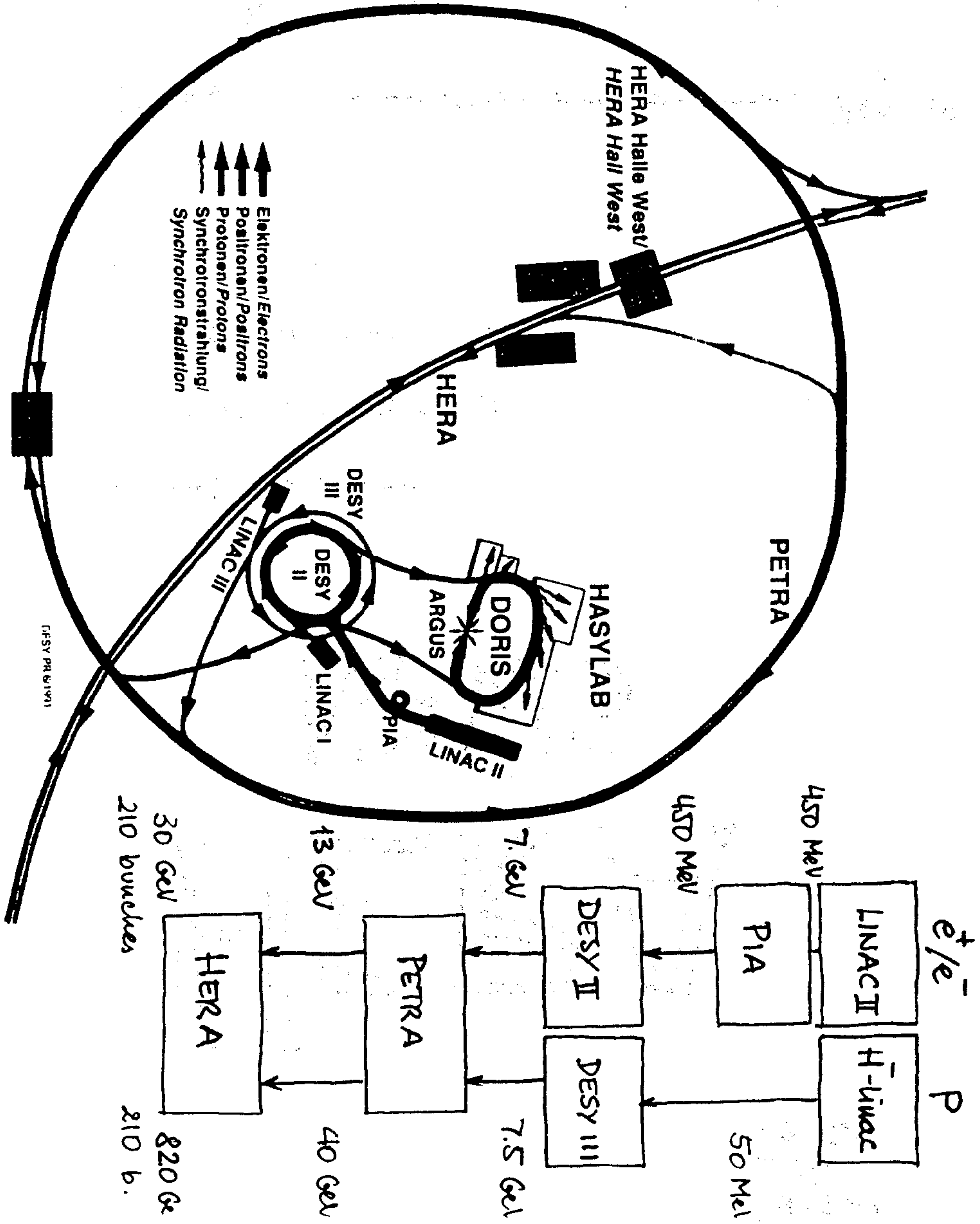

30 GeV e → ← 820 GeV p

$\sqrt{s}$ = 314 GeV   20–40
Q^2 < 40 000 GeV^2 ~ 300

The Physics Program

→ talk by G. Wolf

- deep inelastic scattering
  $Q^2 \geqslant 100$ GeV^2 $x \geqslant 10^{-2}$
  CC, NC
  continuation of (ν, e, μ) exp at high energies with 15 times better resol. for substructure
- physics at small x $x = 10^{-4} \dots 10^{-2}$
  $Q^2 \geq 4$ GeV : DIS at large parton densities
  < 4 GeV : photo production   ↳ LHC
- search for new physics
  e.g. leptoquarks   up to $m_{LQ} > 200$ GeV



HERA Commissioning + System performance

Commissioning:

e-ring : first test runs in 88/89

p-ring : beam stored at 40 GeV : April 91
at 480 GeV : Oct. 91

e-p operation: Oct - December 91

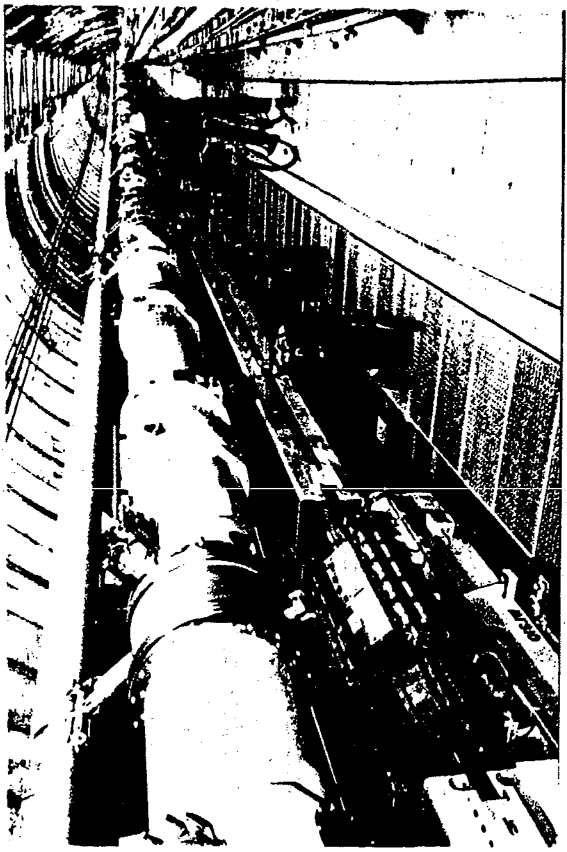
System performance:

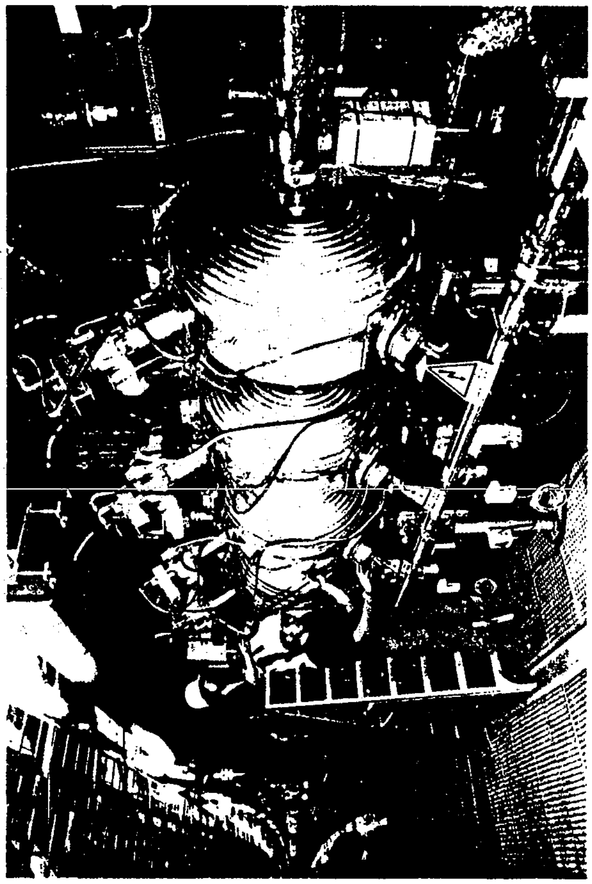
magnets very stable operation
persistent currents under control
one octant : 980 GeV
1991 : 480 GeV
current limited to 3000 A

cryosystem heatload (4.4K) : 6 kW
cooldown
(300 K → 4.4 K) : 140 h

power supplies
diagnostic tools
RF system
} work well

Lifetime (p) > 4 days .... 20 days



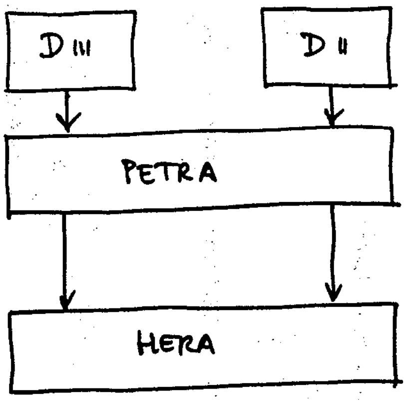


design achieved

Energy 7 GeV
bunches -
Imax -
tcycl 0.08 sec

7.5 GeV
11
150 mA
4 sec

100, <> = 70* mA



13 GeV
70
58 mA

40 GeV
70
160 mA
2.3 mA/bunch
5 min

20 mA**
1 mA in 1 h...

30 GeV
210
58 mA
.3 mA/bunch
↓
achieved .170

820 GeV
210
160 mA
.76 mA/bunch
↓
.08

↳ during Lumirun 10×10 bunches
extrapolate lumi:

$$2\cdot10^{28} \times \underset{i_e}{2} \times \underset{i_p}{10} \times \underset{n_b}{20} = 8\cdot10^{30} \checkmark$$

Problems: * dyn. apperture
** vacuum

The Luminosity measurement

between Oct. 19th, 1991
and Dec. 2nd

→ 20 h luminosity runs (26 runs)

H1 }
Zeus } luminosity monitors = working

Concept of measurement:

$ep \rightarrow e'p\gamma$ set up: →

Bremsstrahl cross section given by Bethe-Heitler

Integrated cross section $[E_\gamma = 9 \dots 17 \text{ GeV}]$:
$\hat{=}$ typical acceptance

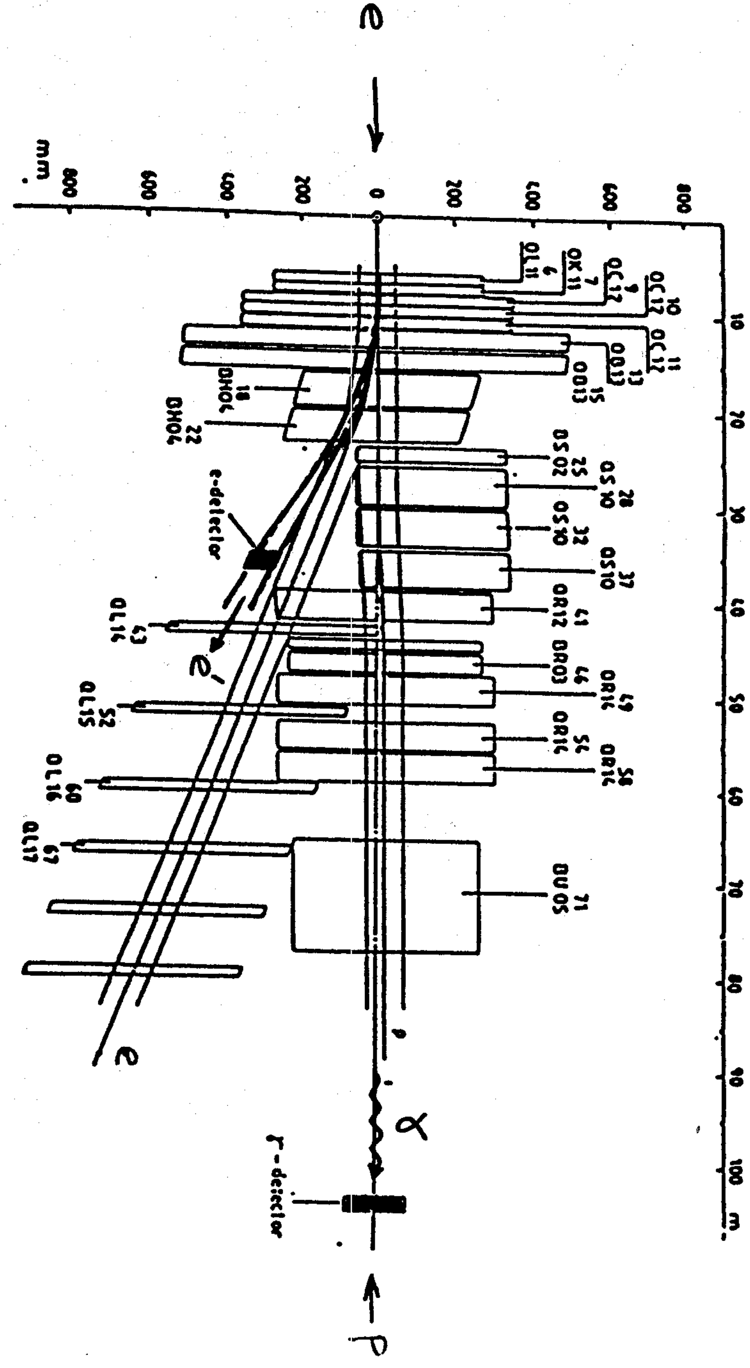
$\int (d\sigma_{BH}/dk)\, dk = 16.9 \text{ mb}$

background: Bremsstrahlung on gas

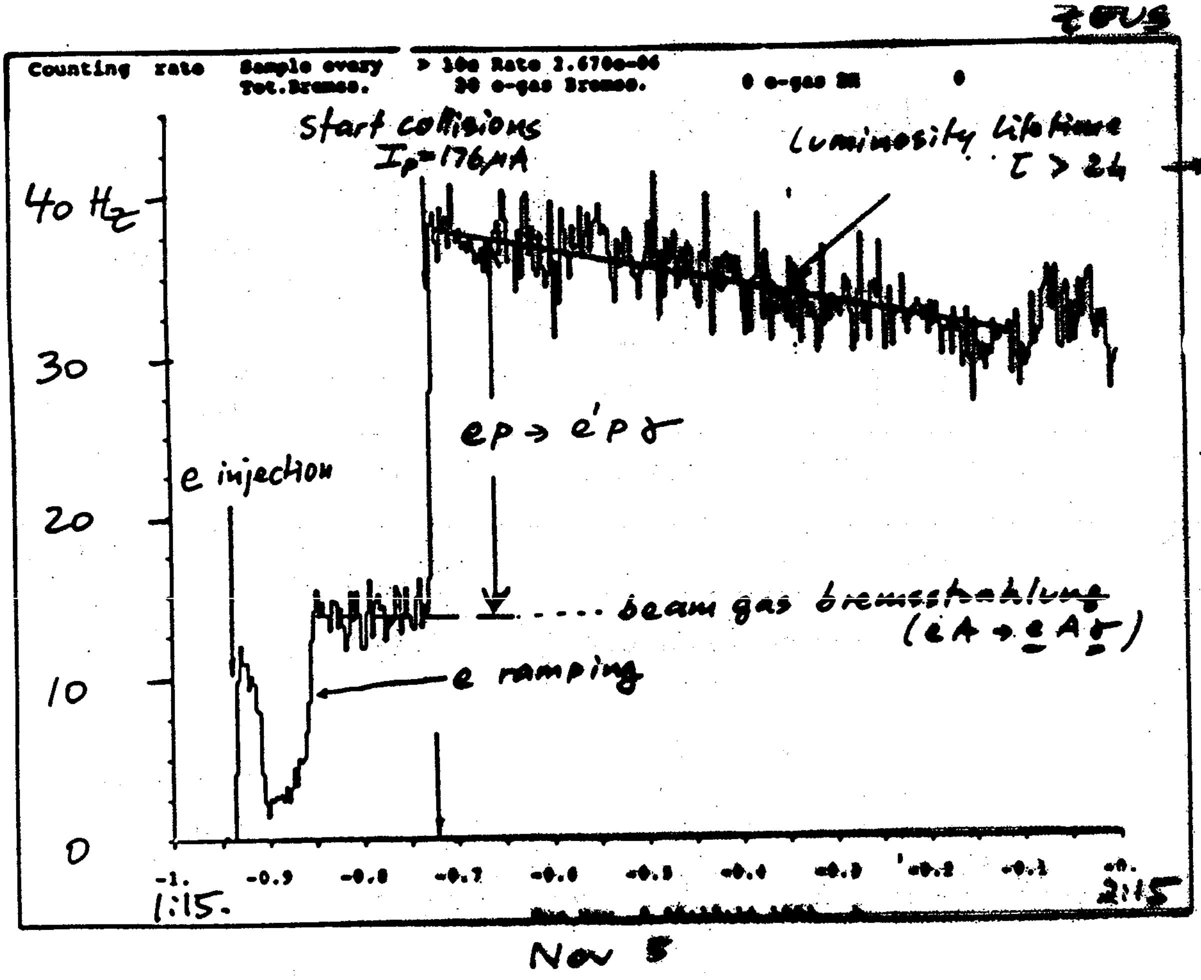
$eA \rightarrow e'A\gamma$

[illegible] ↗ separate e, p beams
↘ fill 1 extra e-bunch

The Luminosity detector setup



ZEUS



$\to > 10^h$
by adjusting
e-beam profile

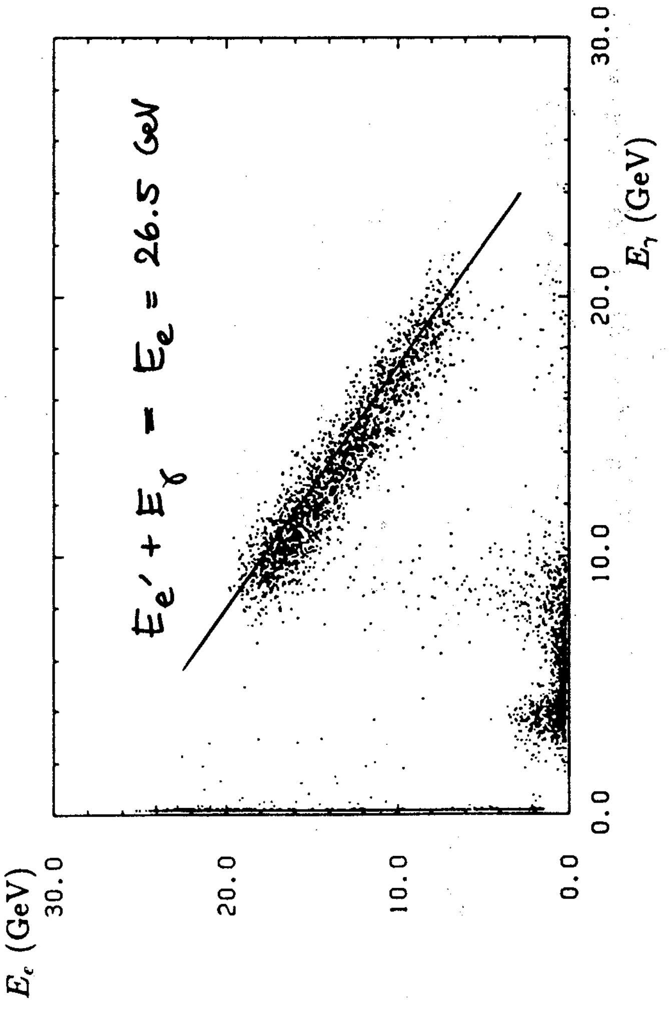
19. October : 1×1

12 GeV × 480 GeV
$L \approx 10^{26}\ cm^{-2}s^{-1}$

November : 10×10

26 GeV × 480 GeV
$L \approx 2 \cdot 10^{28}\ cm^{-2}s^{-1}$

design : 210 × 210
$L \sim 1.5 \cdot 10^{31}$



ZEUS LUMI Monitor

5/11/91, 1:33 a.m. →

$E_e = 26.5 GeV$, $I^e_{beam} = 60 \mu A$, single bunch
$E_p = 480 GeV$, $I^p_{beam} = 176 \mu A$, single bunch

HERA POLARIMETER

PRELIMINARY

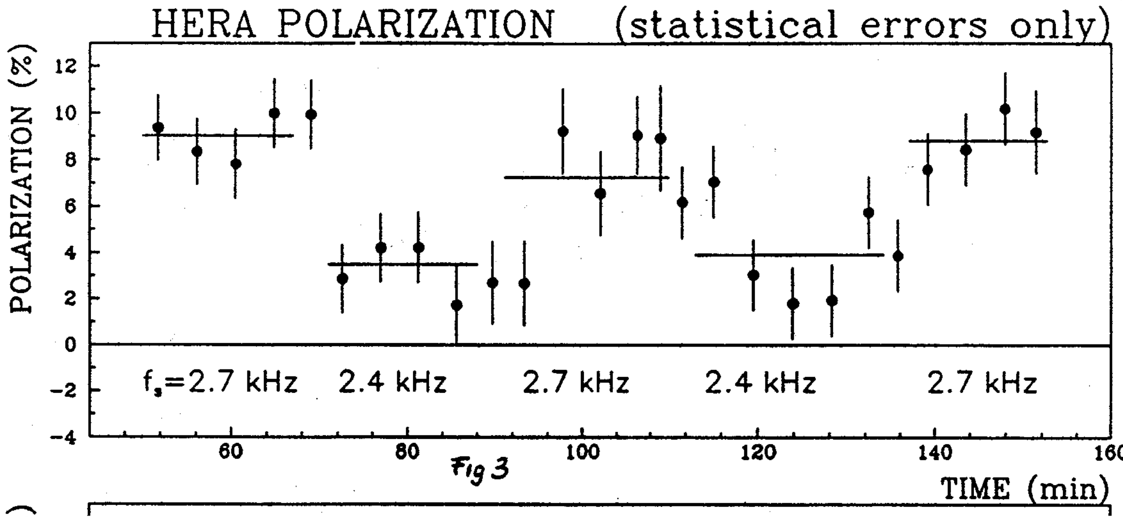


Fig 3

E_e = 26.67 GeV

Measurement by

DESY + HERMES Coll.

P = 8±2%

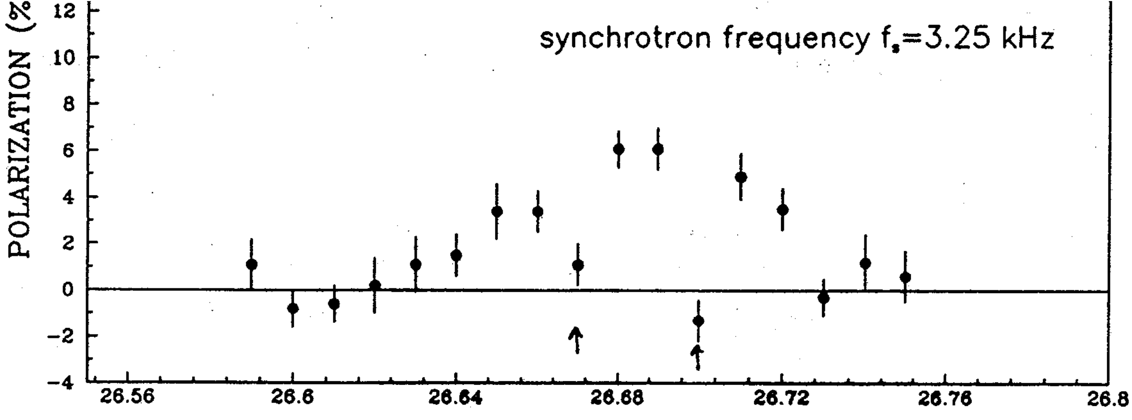


Fig 4 side bands ENERGY (GeV)

SITROS calcul. → good agreement

Measurement of machine induced background

sources : beam - gas
beam - wall
beam - beam

problems: radiation damage
trigger inefficiencies (veto counters)
high trigger rate (dead time)

results : radiation damage (ZEUS)

→ full current, 820 GeV , r = 10 cm
→ 24 rad/day ~ok

trigger inefficiencies ~ %

HERA Detectors

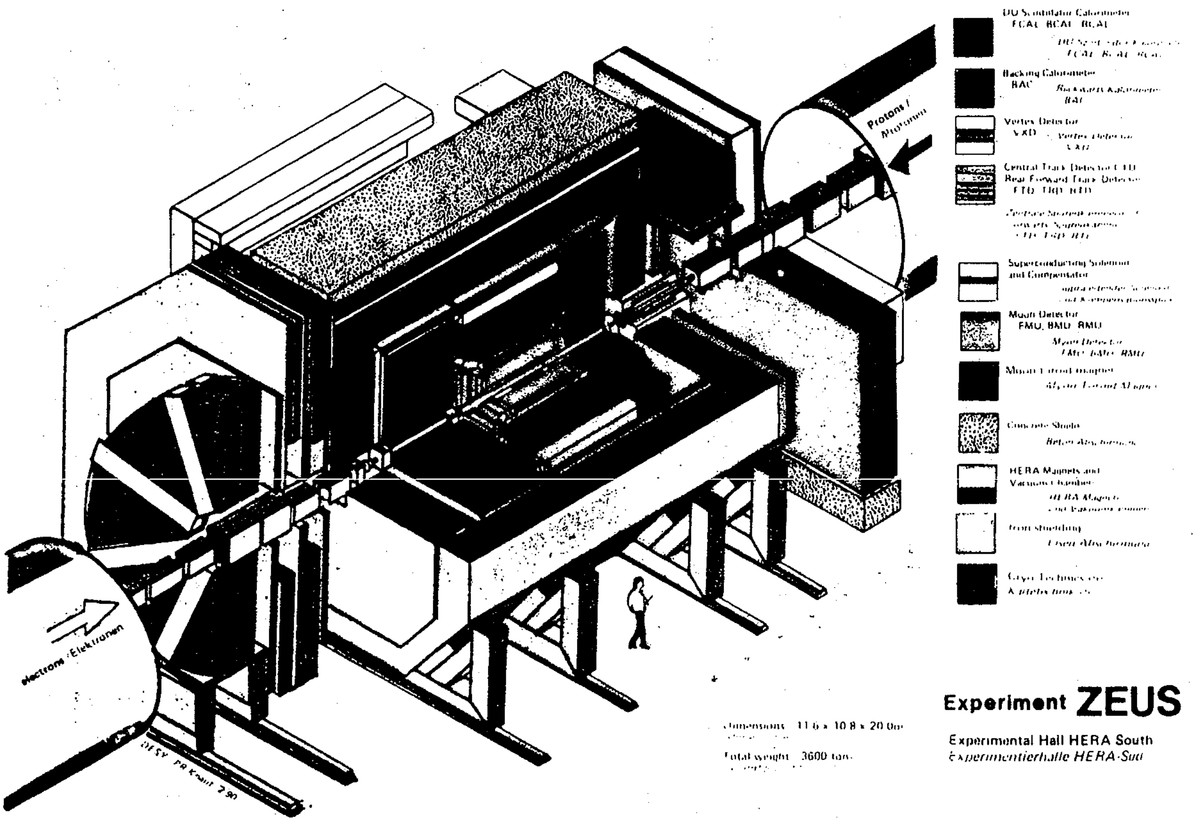
basic requirements

	H1	ZEUS
• hadronic energy flow measurement		
- good jet energy meas.		*
- high granularity	*	
- hermeticity	✓	✓
- absolute, stable calibr.	*	✓
• lepton Identification + measurmt		
- electron identification	✓	✓
- e/π separation	✓	✓
- μ identification		
• tracking in magn. field		
- lepton charge		
- p_μ		
- Jet analysis		

→ some complementarity

detector parameters

	H1	ZEUS
Calorimeter	LAr	U-Scint
$\Delta E_h / E_h$	$50\%/\sqrt{E}$	$35\%/\sqrt{E}$
$\Delta E_e / E_e$	$12\%/\sqrt{E} \oplus <1\%$	$18\%\sqrt{E}$
tower size EMC	$4 \times 4 \to 8 \times 8$ cm^2	5×20 cm^2
long. sampl. EMC	$4 \to 3$	1
tower size HCAL	$7 \times 7 - 12 \times 12$ cm^2	20×20 cm^2
long. sampl. HCAL	3	3
weight	~ 400 t	~ 700 t
material	Pb / Fe	DU
containment	$\geq 4.7\ \lambda_{abs}$	$\geq 5\ \lambda_{abs}$
# channels	45000	13000
tracking		
B field	1.2 T	1.6 – 1.8 T
tracking radius	~ 85 cm	80 cm
$\Delta p/p^2$ (barrel)	.003	.002
forward trking	$d_{max} \sim 2.7$ m	~2. m
$\Delta p/p^2$ (forward)	.001 → .0035	.002 … .01

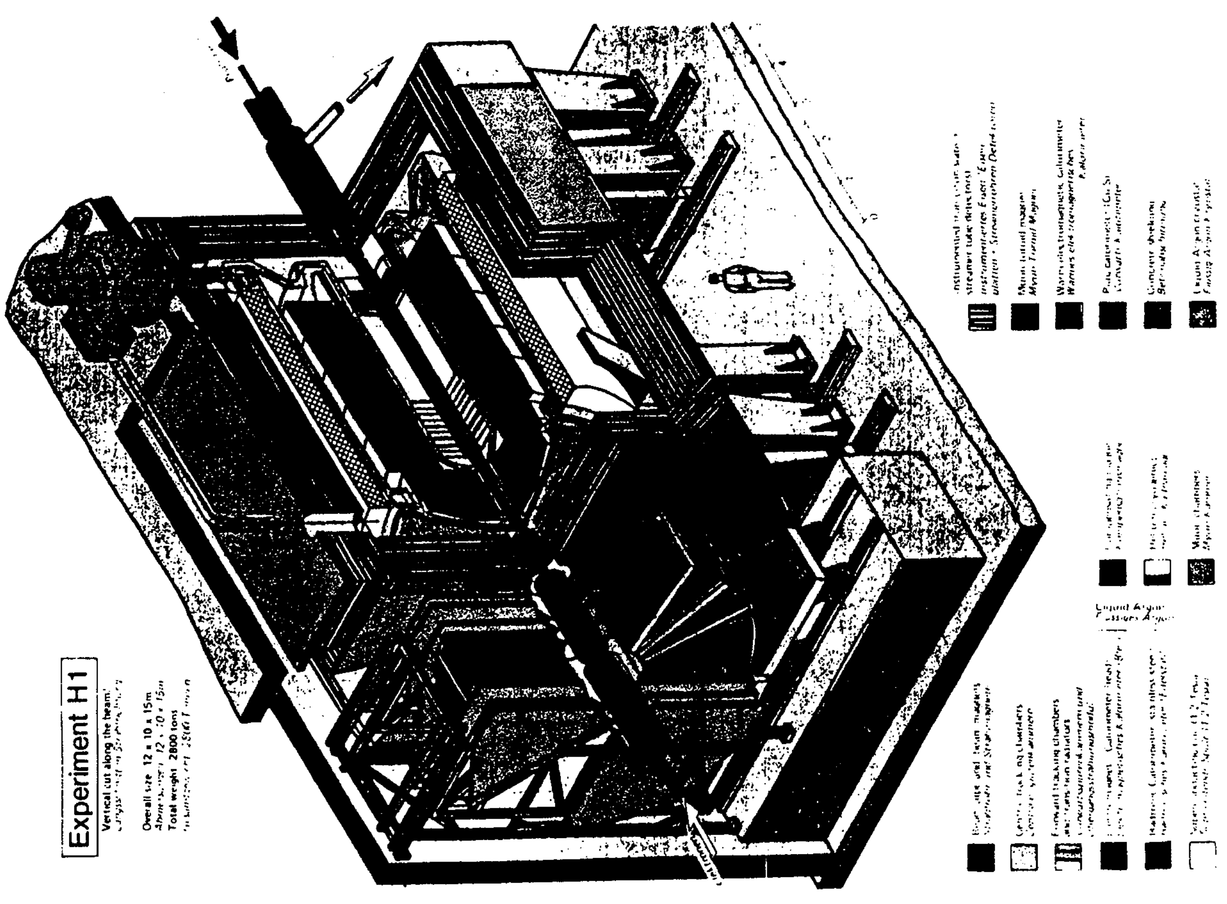


Experiment ZEUS

Experimental Hall HERA South
Experimentierhalle HERA-Süd

Dimensions 11.6 x 10.8 x 20.0m

Total weight 3600 tons

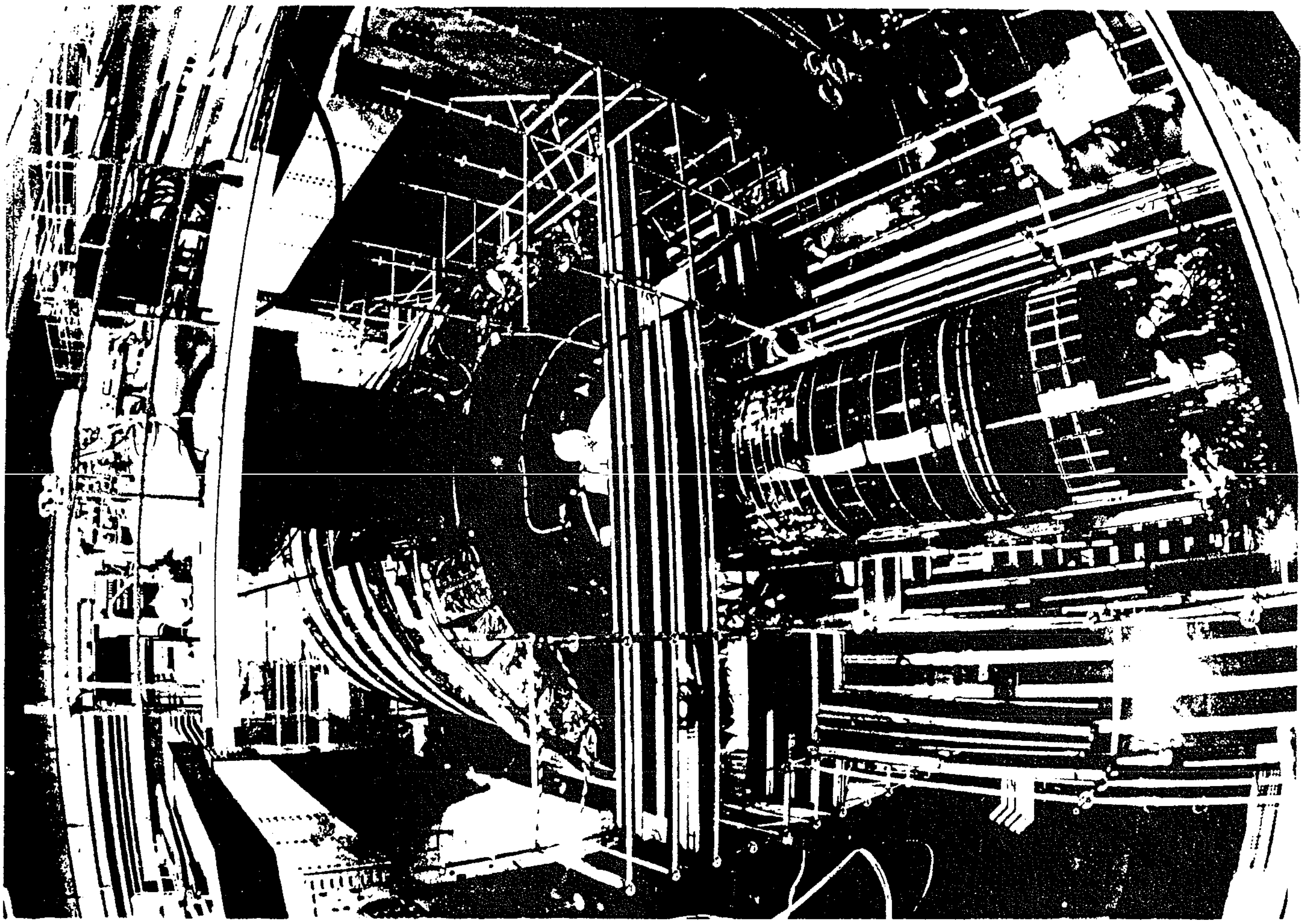


Experiment H1

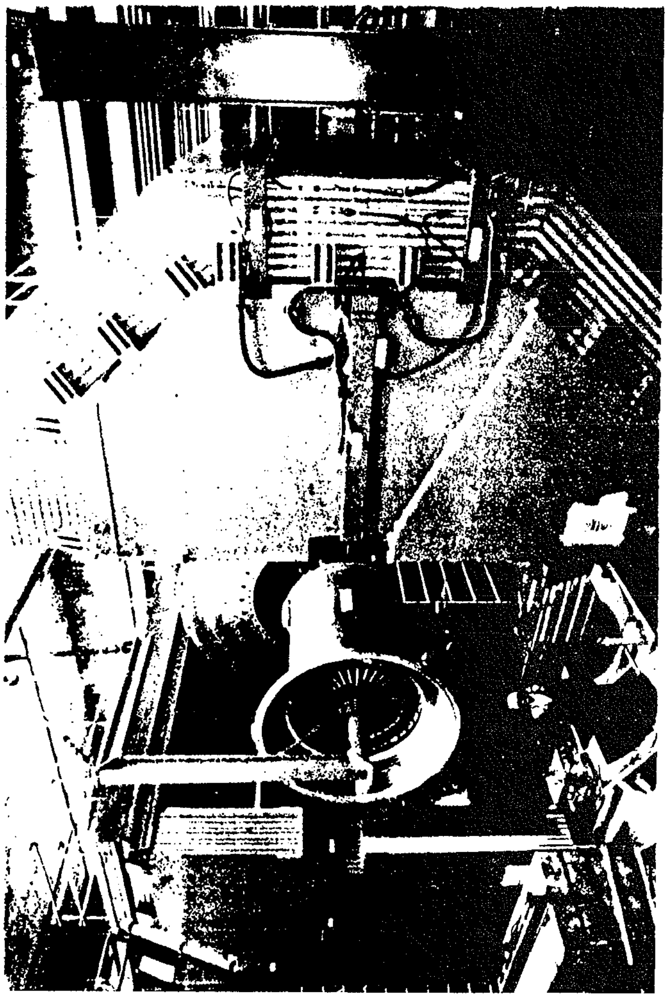
Vertical cut along the beam/

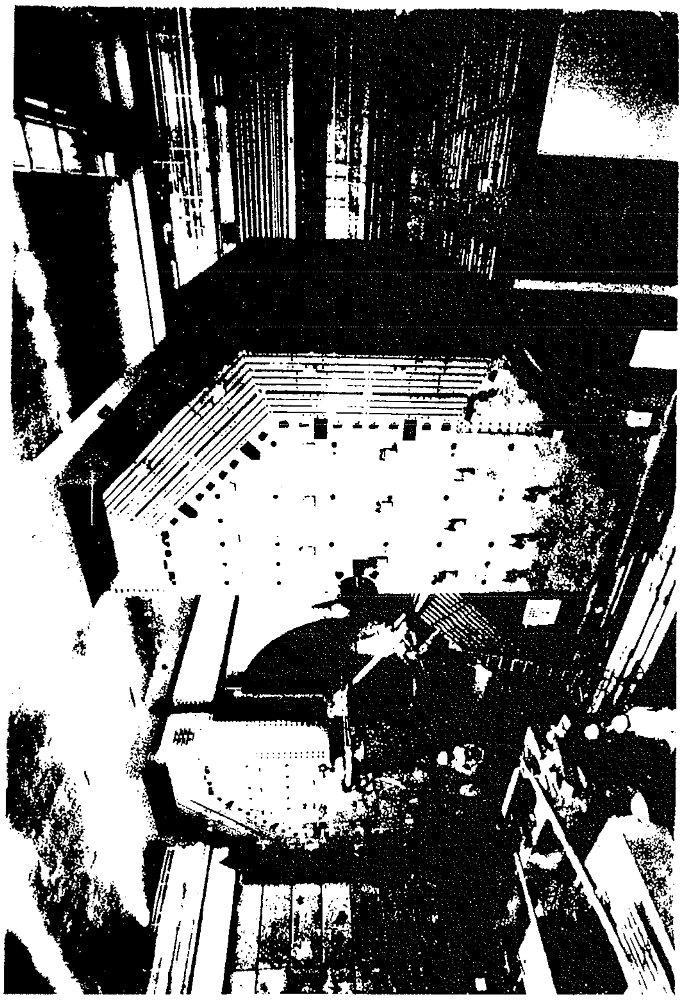
Overall size 12 x 10 x 15m
Total weight 2800 tons

UP SUPERIEURE OBEN おもて

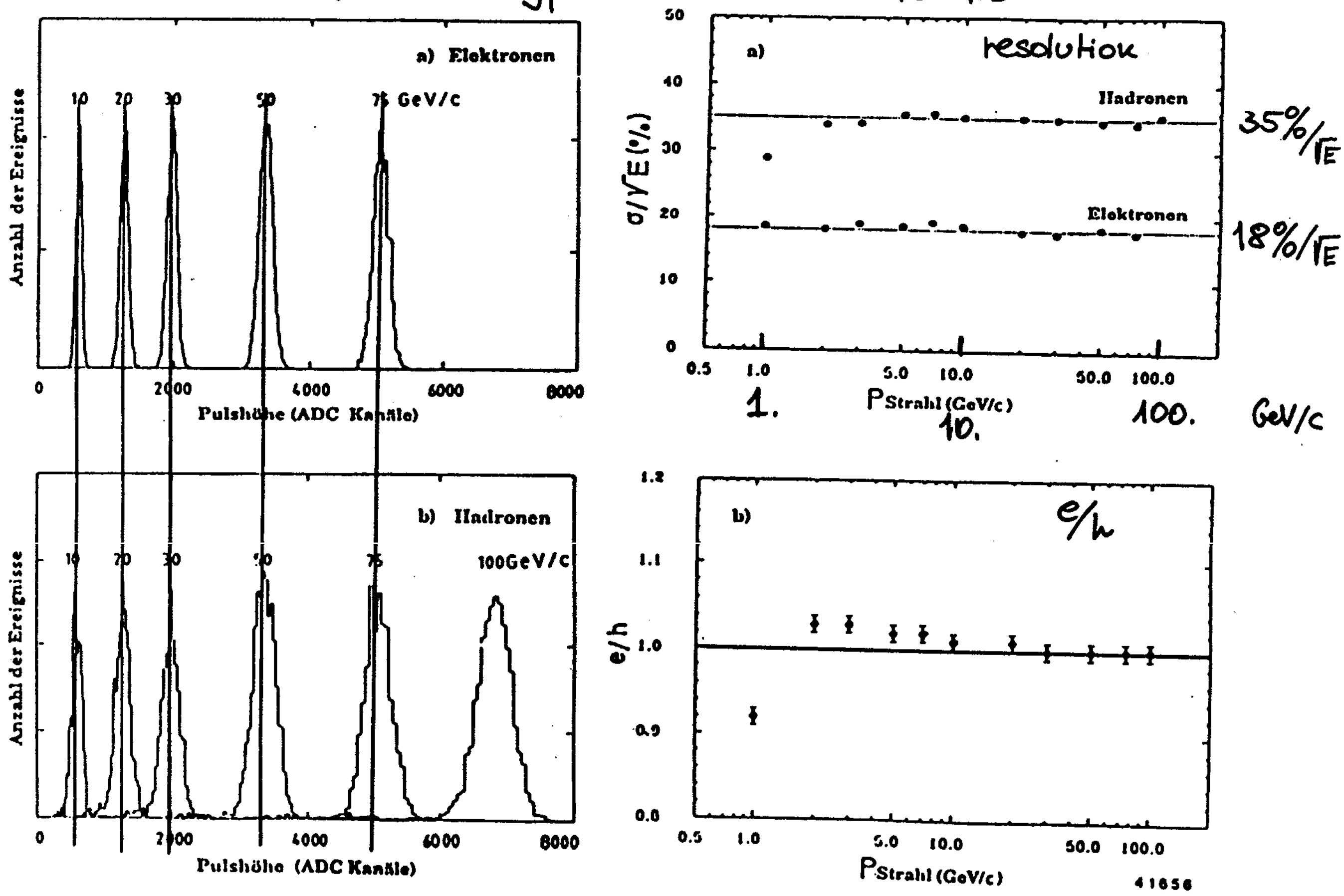


FACE SUPERIEURE

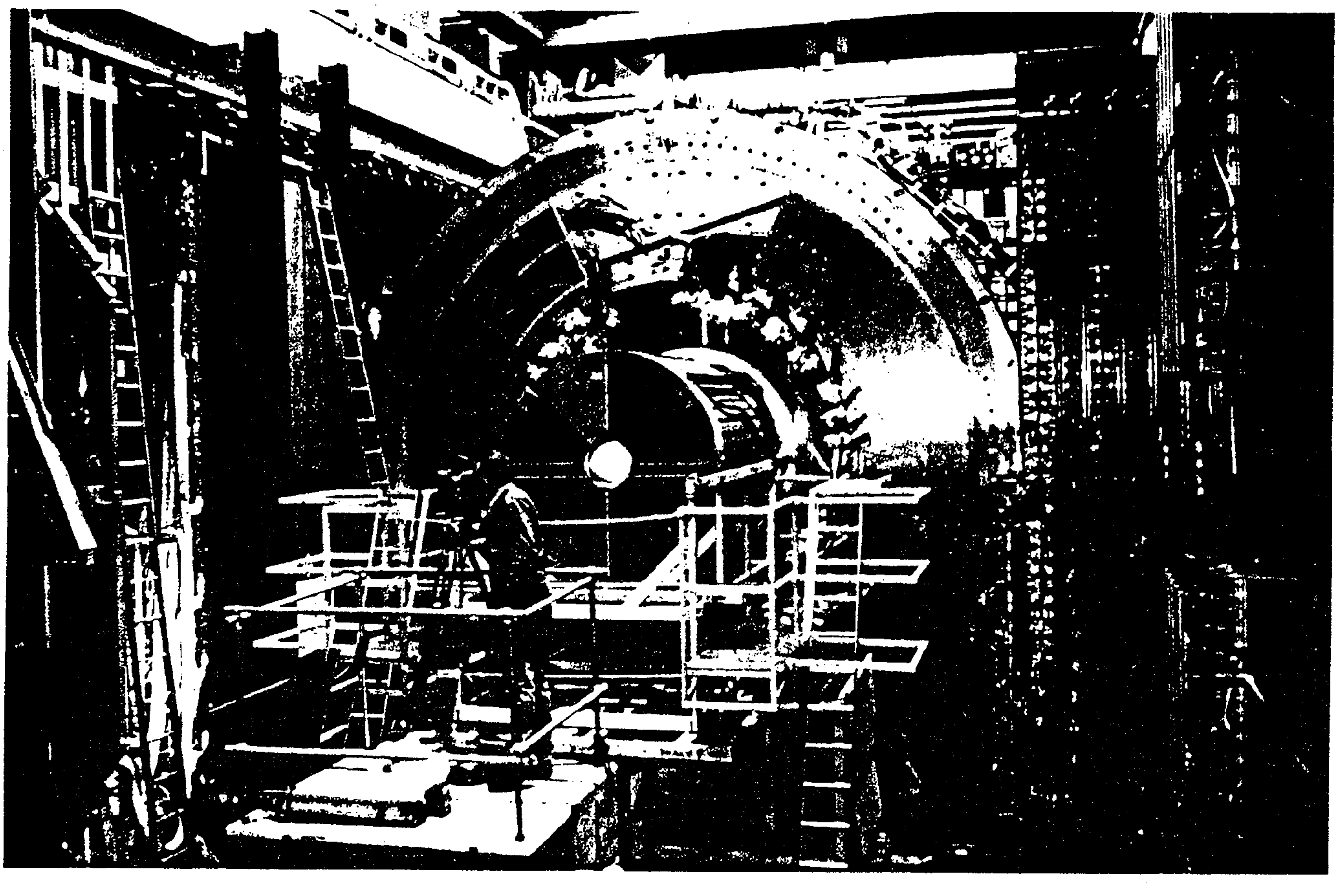




FCAL Prototype test beam results



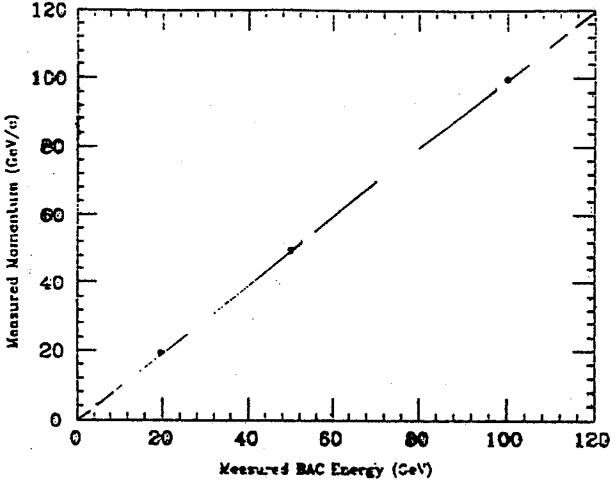
ZEUS



→ roll-in of CTD

ZEUS

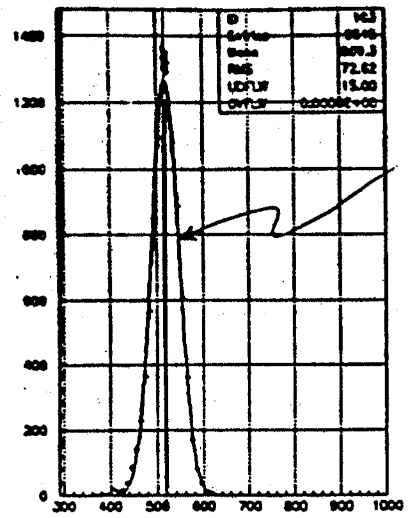
Determination of absolute momentum scale



Consistent with 1%

will get to 0.5%

Resolution and e/h ratio



50 GeV hadrons

$\frac{\sigma_{fit}}{\text{mean}} \times \sqrt{50} \approx 38\%$

position of e peak → $e/h = 1.0$

Liquid ARGON purity : H1

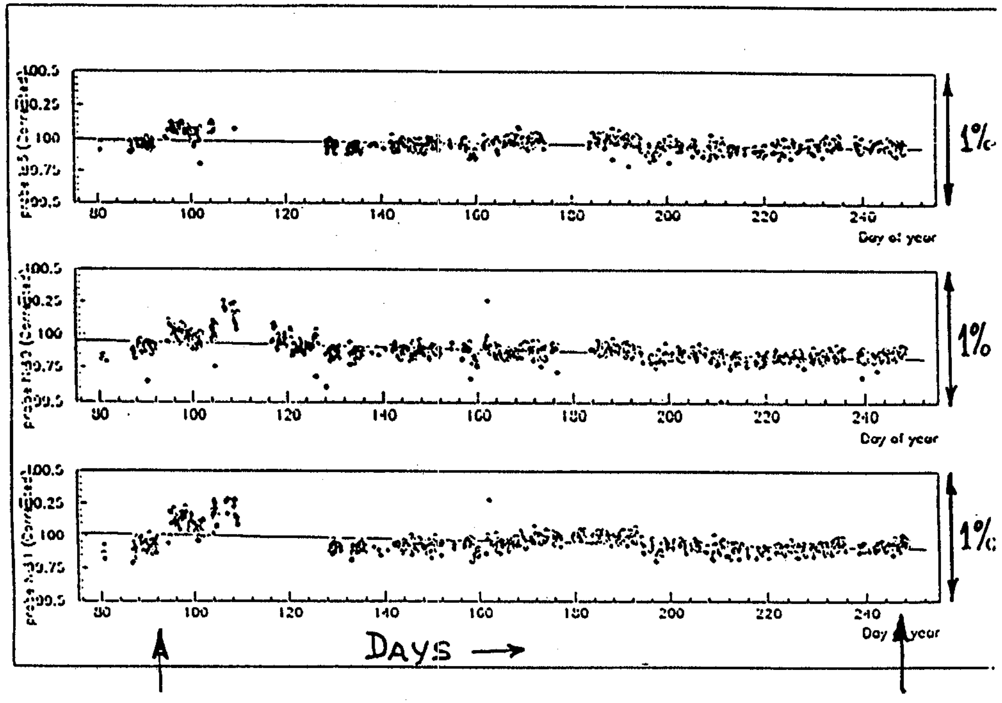
3 examples of the monitoring :

probe 5 :	middle-high and backward	variation :	- 0.10 % / year
probe 10 :	bottom and forward	variation :	- 0.29 % / year
probe 11 :	middle-high and forward	variation :	- 0.25 % / year

20/09/91

Bi^{207}

$\beta + \alpha$ source readout gaps in cryostat



April

September

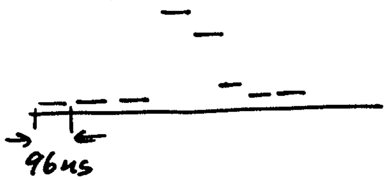
calibration not limited by purity (< 0.5%)

nor electronic stability (< 0.1%)

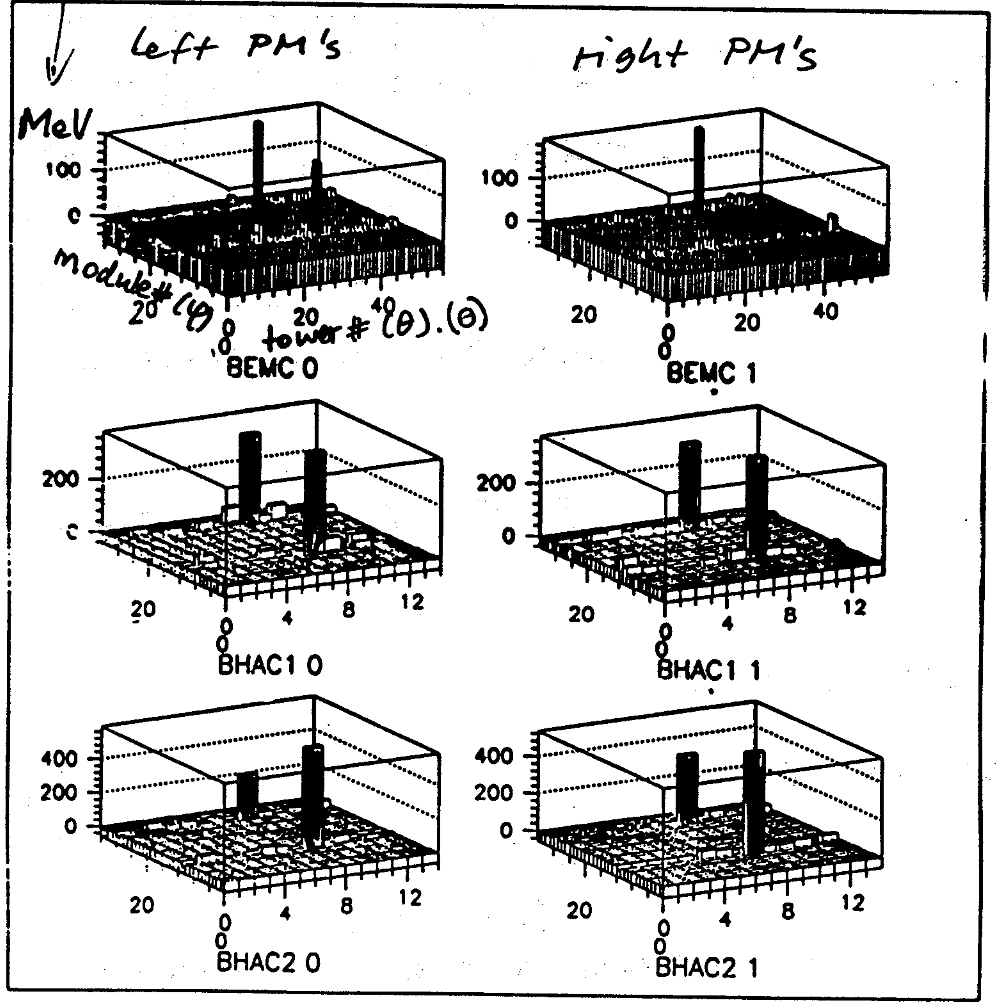
muon through upper • lower BCAL

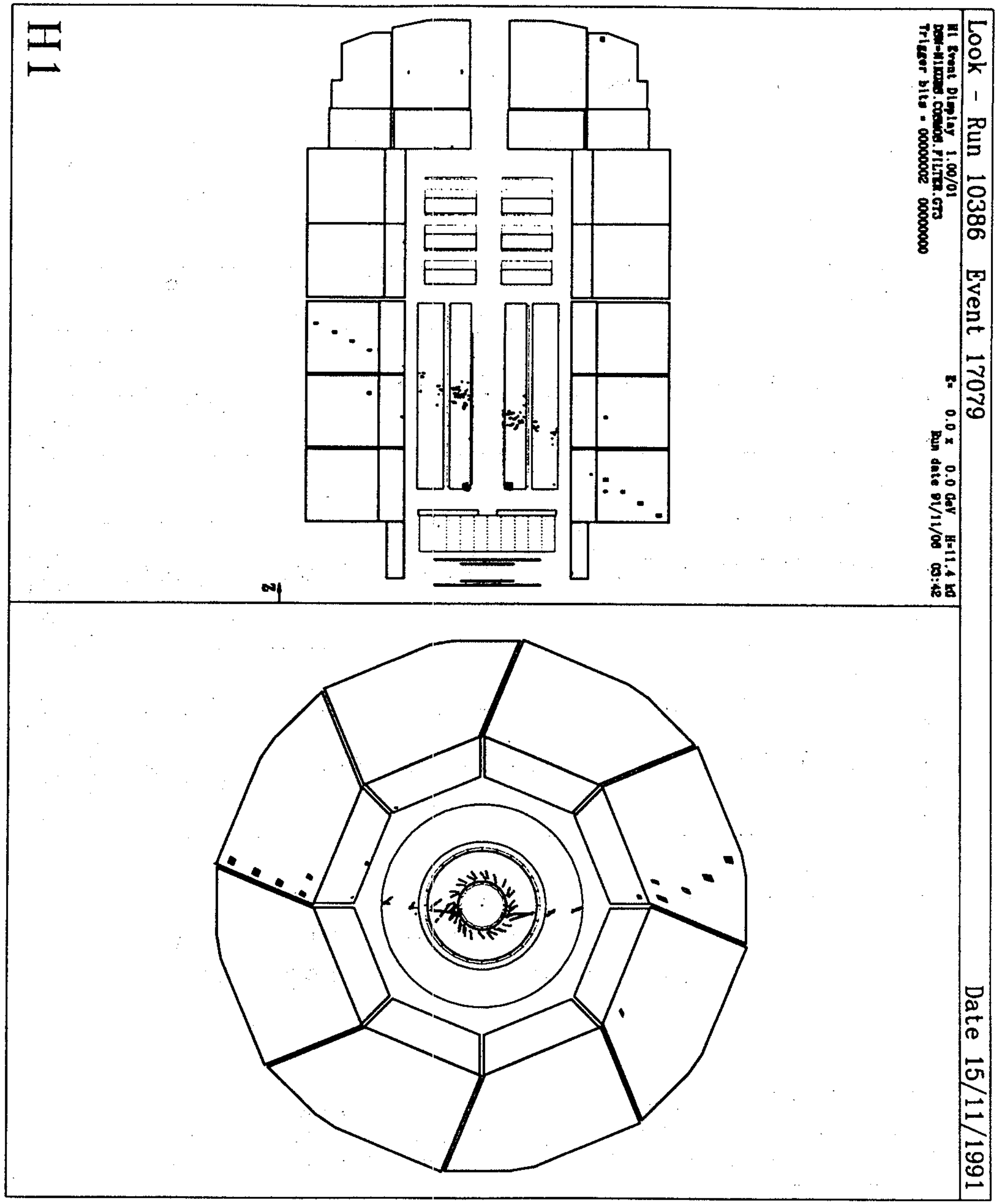
ZEUS

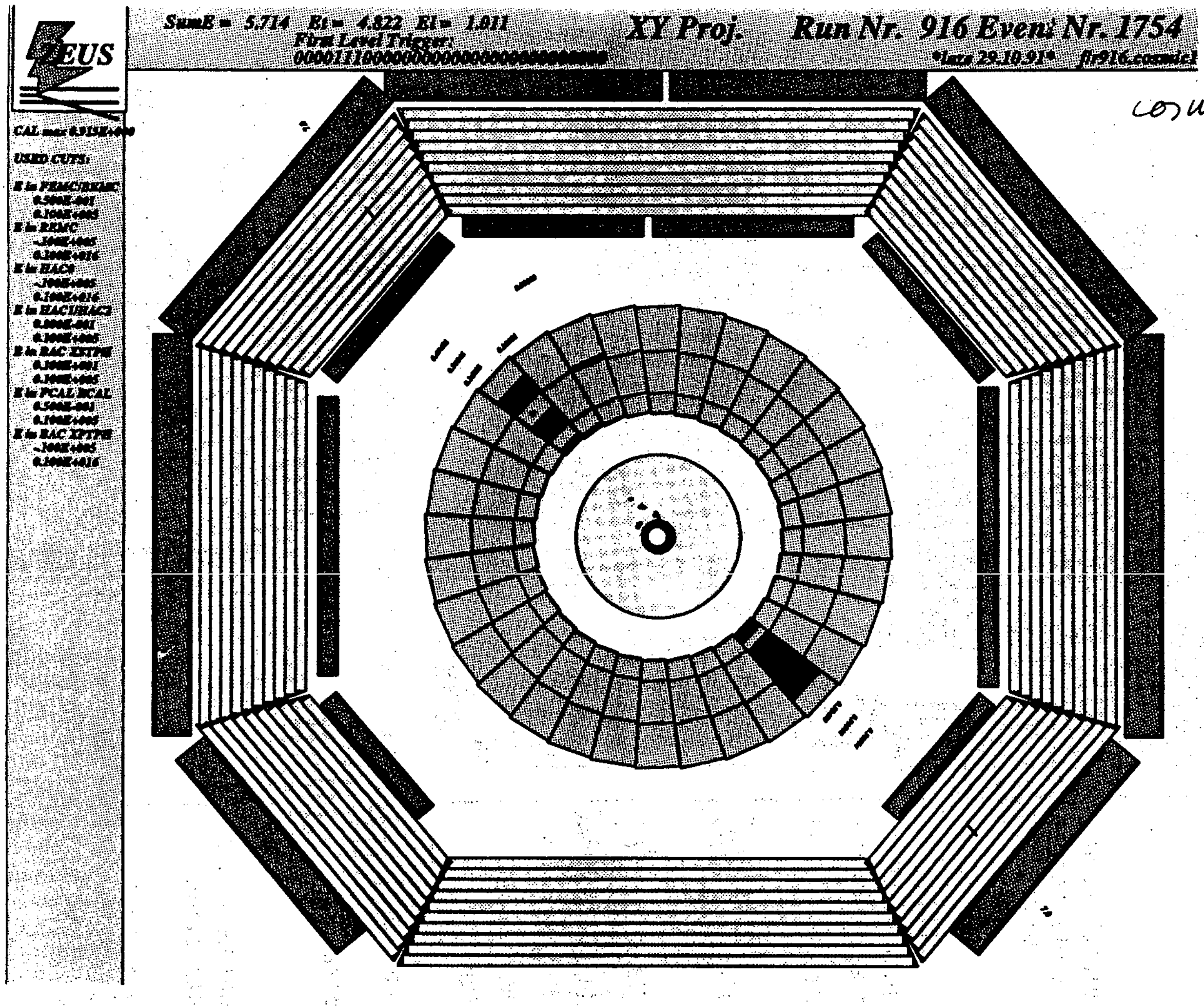
shaped PM signal / sampled every 96 ns



E calculated in DSP online from 8 samples in CAL F.E. pipeline

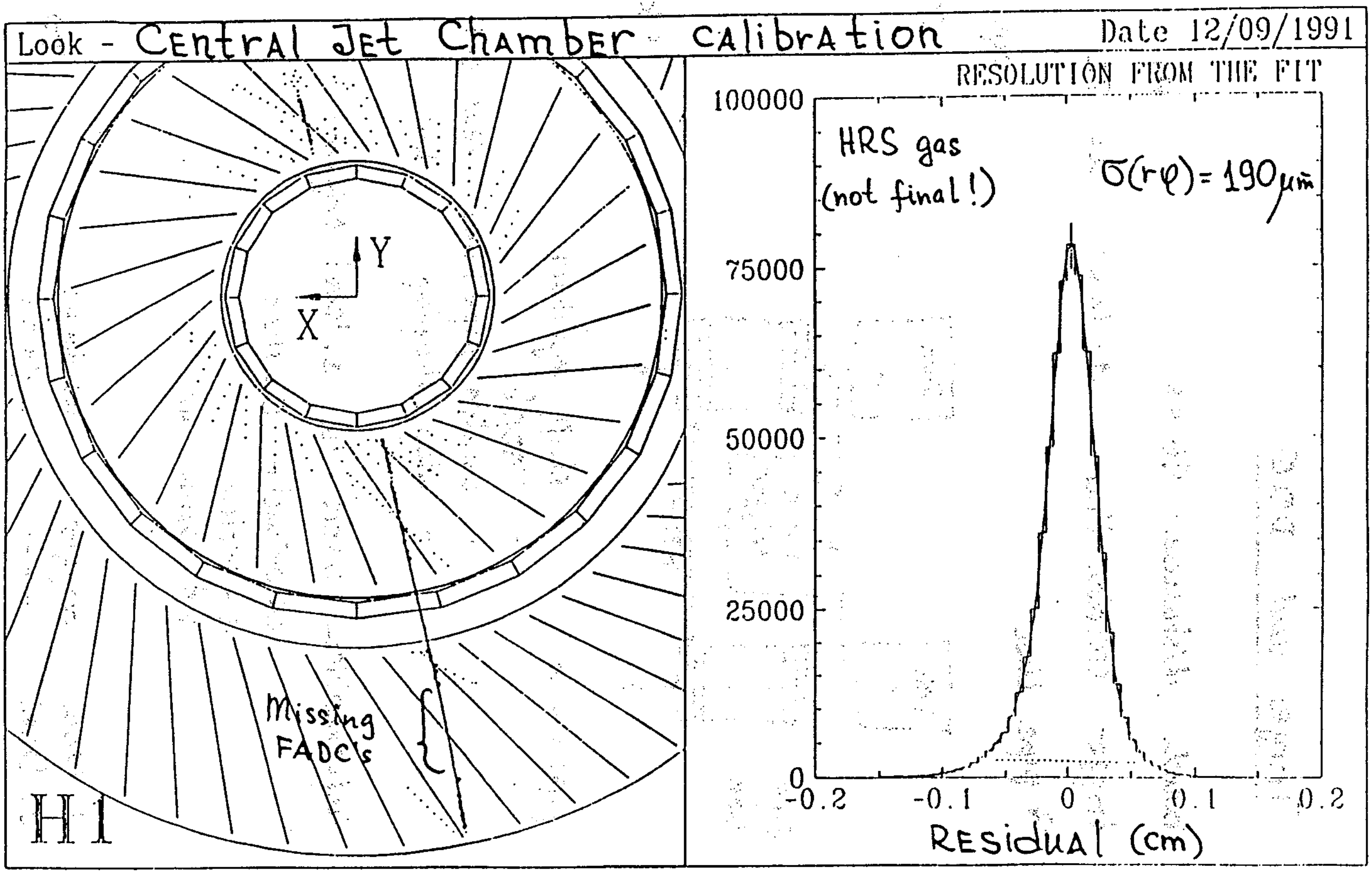






cosmics run

H1



Trigger and DAQ

bunch distance: 96 ns

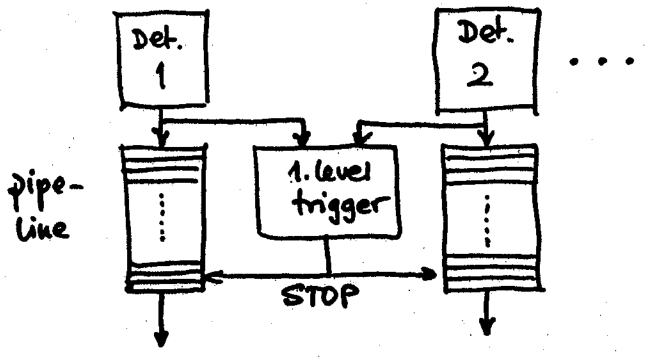
H1 Z

trigger decision time: n · 96 ns n= 25 52

↝ pipe line

exp. rates

50–100 kHz



1 kHz

pipe lines:
- shift registors
- FADC's
- analog pipe lines zeus Cal
- slow shaping LAr

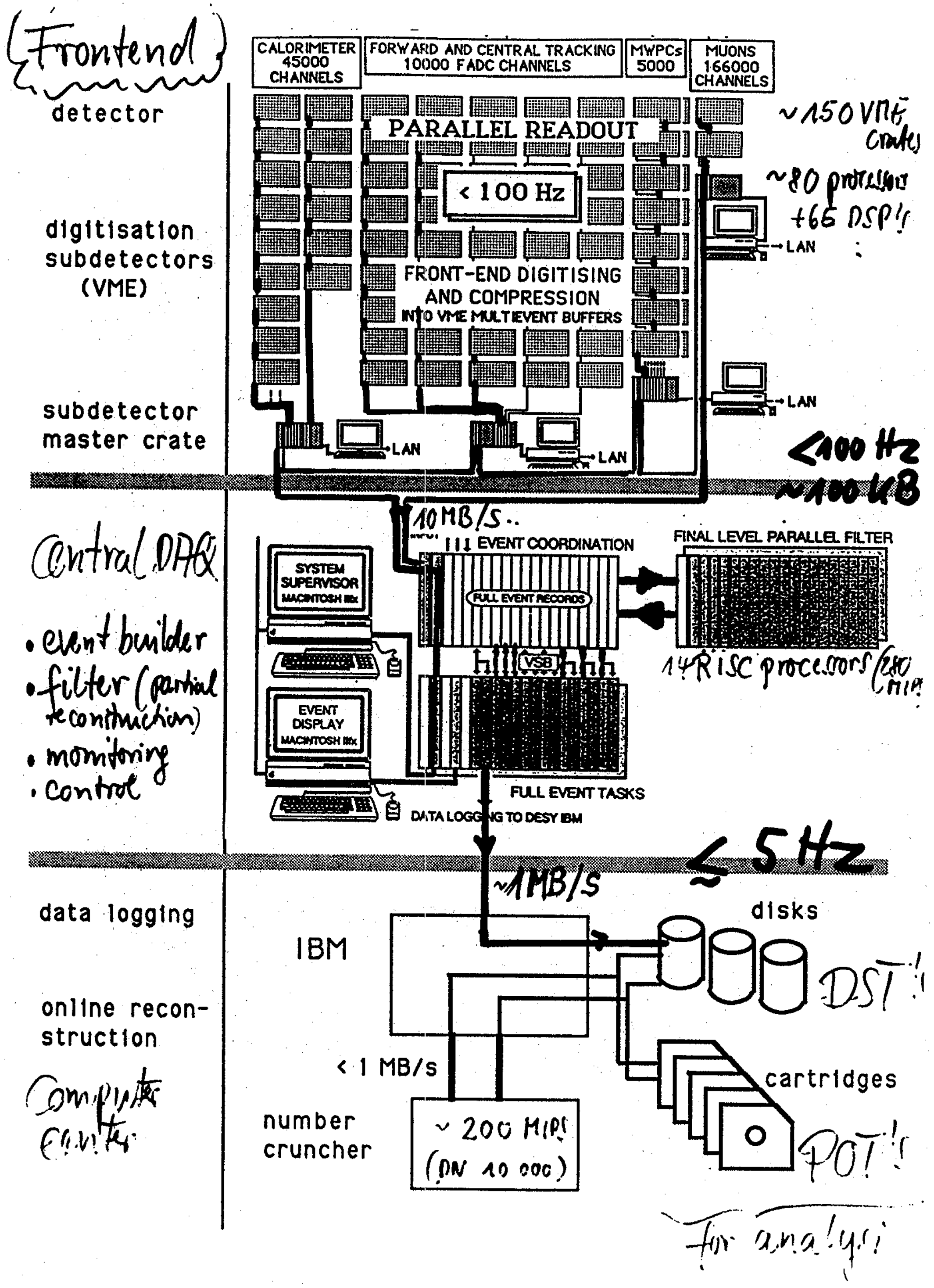
⋮

information used in 1. level trigger:

calorimeter clusters
z - vertex
rφ track nr
⋮

2. level trigger hardware
3. level —"— software
(4. level —"—) software

100 Hz



other aspects

1) staging : electronics , RHES (ZEUS)

2) upgrade plans

ZEUS : FHES
(BHES)

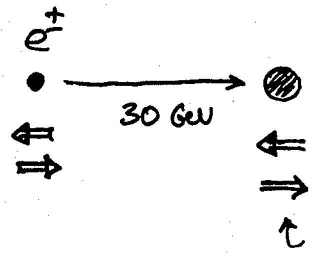
H1 : Si vertex tracker
backward tracking (small x)
backward electron measurement

3) online + offline analysis
ready to a large extent

4) physics preparation

→ HERA physics workshop Oct. 91
to be published soon

Spin dependent structure functions
of proton and neutron



p, d, ^{3}He

internal gas target
thin storage cell
~ 10^{14} atoms / cm^2
$\mathbb{P} > 90\%$

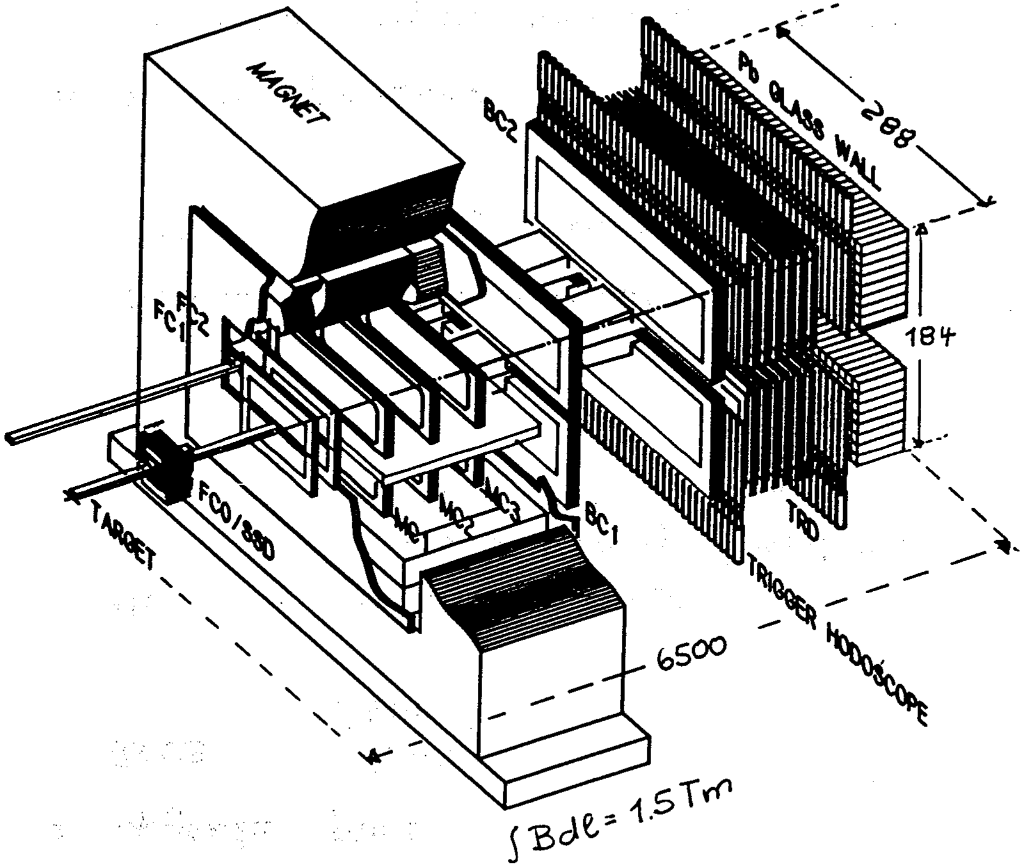
$$\sigma_{\rightleftarrows} - \sigma_{\rightrightarrows} \propto g(x) = \frac{1}{2} \sum e^2 \left[q^+(x) - q^-(x) \right]$$

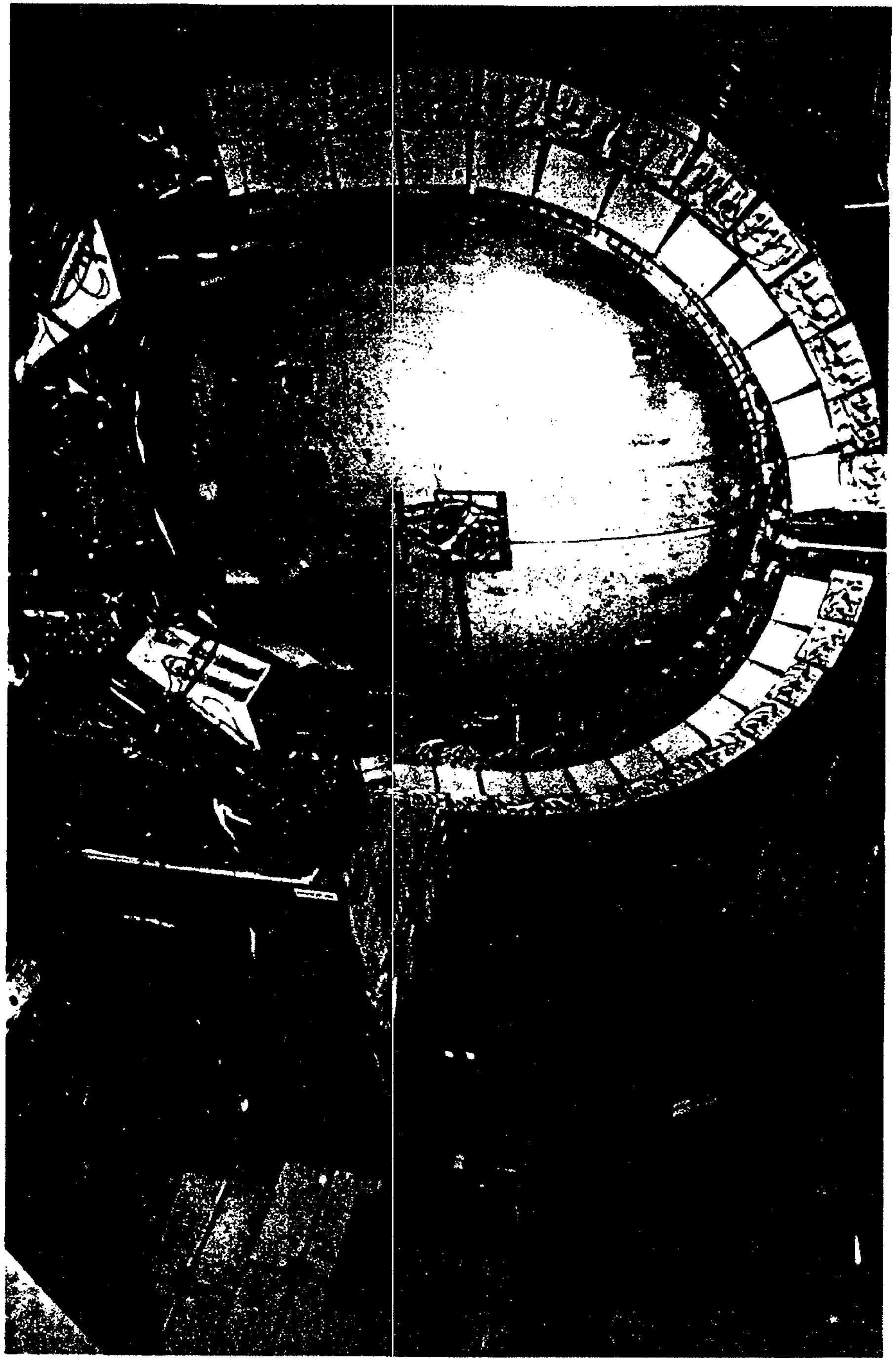
EMC/NMC: $\langle s_z \rangle_{\text{all quarks}} = 0.060 \pm 0.047 \pm 0.069$

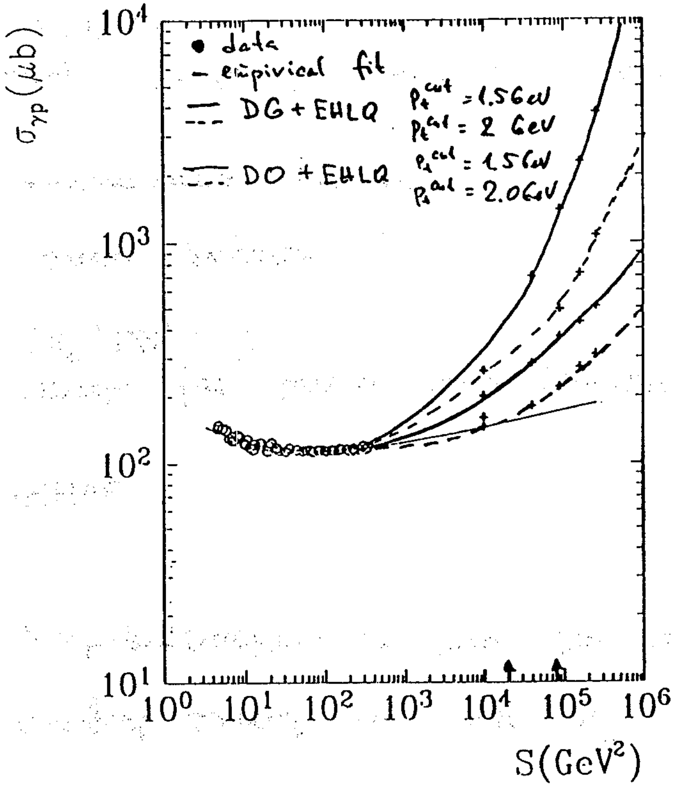
expect : 0.5

where is spin of proton ?

HERMES


MAGNET
BC2
Pb GLASS WALL
288
184
FC2
FC1
FC0/SSD
TARGET
MC1
MC2
MC3
BC1
TRD
TRIGGER HODOSCOPE
6500
$\int Bdl = 1.5\,Tm$





$\sigma_{TOT}(\gamma p)$

measurement uses • Lumi tagger
+ • Main detector

Outlook

… 31.3.92
- finish installation of H1, ZEUS
- ramp proton magnets to 820 GeV
- install SC Cavities
- install collimators
- …

April/May
- reestablish e, p beams
- collisions in single bunch mode
- multibunch operation (70)
- make Luminosity

≥ June
- share time between experiments and machine development
- hope for $L \geq 10^{29}\ cm^{-2}s^{-1}$

Conclusion

- unique physics potential of HERA
  - nucleon structure at small x
    at large Q^2
  - charged current at large Q^2
  - photoproduction at large cm energies

- competitive
  - search for heavy new particles (e^*, LQ, …)
  - charm physics
  - electroweak processes

- already 1–10 pb^{-1} provides interesting new physics

- detectors ≈ ready

↷ first results within 1 year !?

Status of detector R&D

E. Iarocci (Frascati)

STATUS
OF
DETECTOR R&D

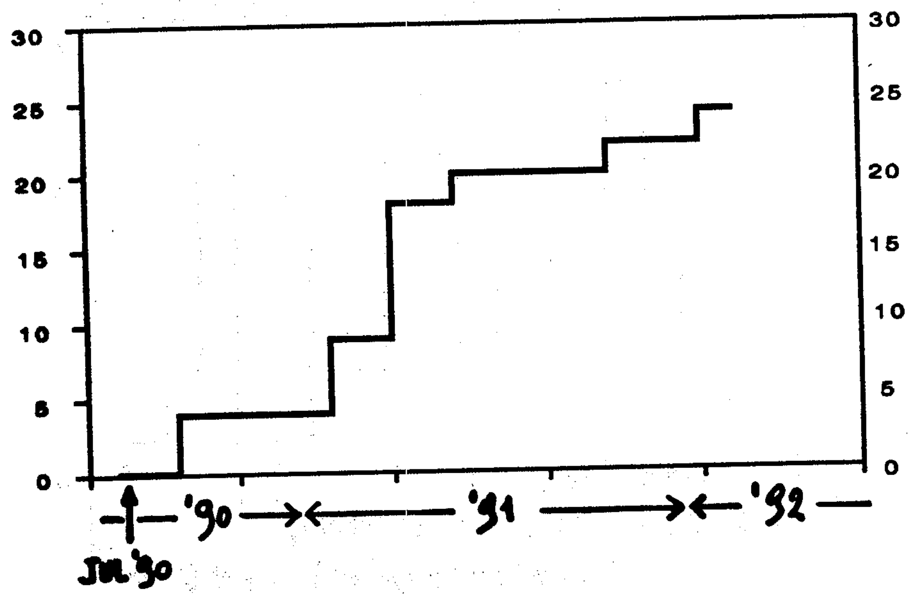
OUTLINE :

- THE R&D EFFORT (DRDC)
- CALORIMETRY
- TRACKING
- OTHER

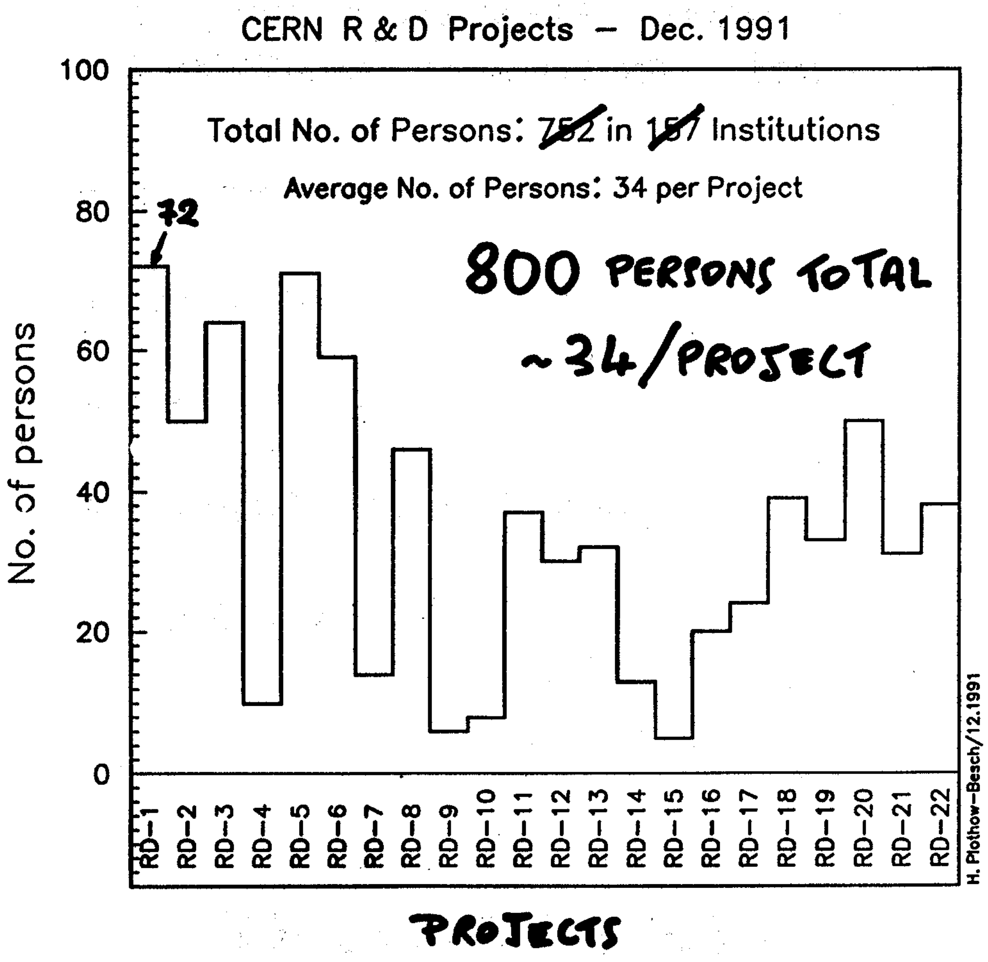
EMPHASIS ON WHAT HAS NOT BEEN COVERED IN THE PRESENTATIONS OF EOI's.

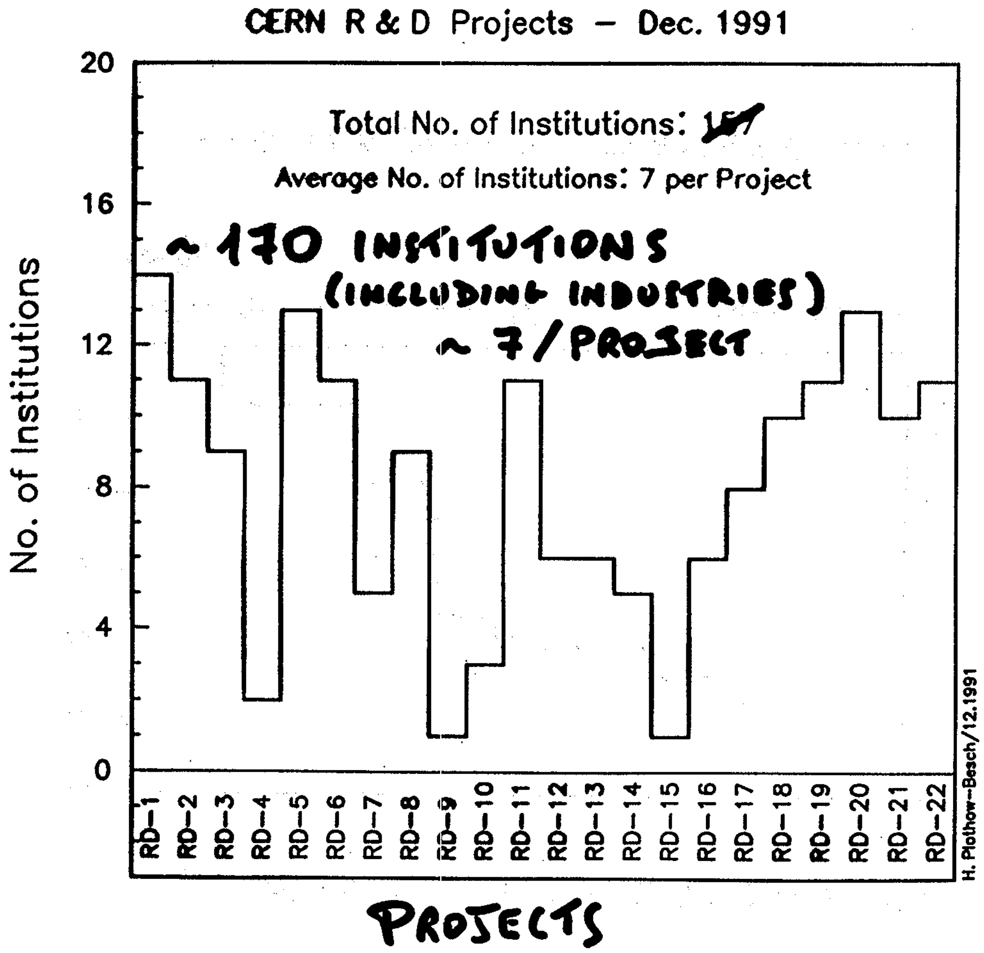
DRDC : SET-UP IN MID '90 TO STIMULATE AND COORDINATE THE R&D EFFORT IN VIEW OF LHC

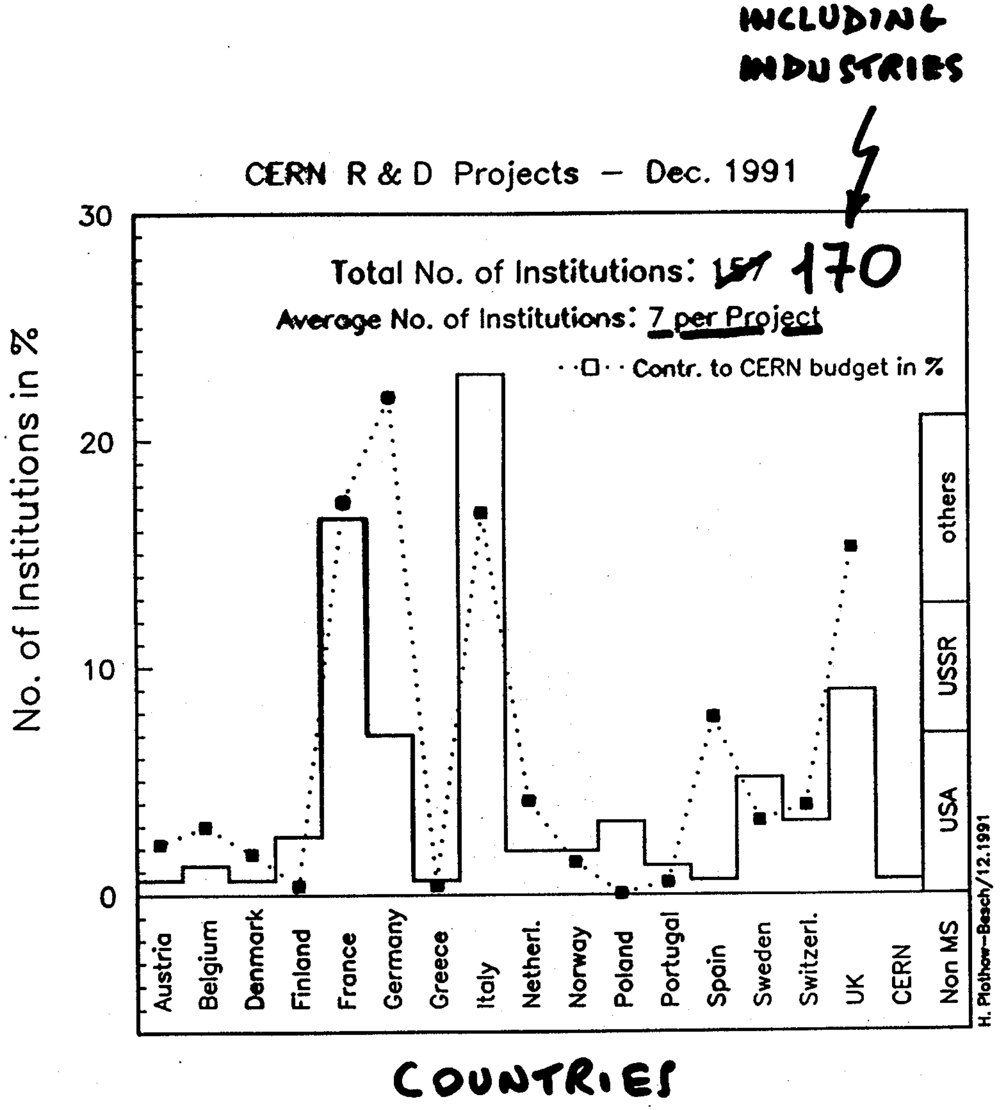
35 PROPOSALS → 24 APPROVED PROJECTS



~5 NEW PROPOSALS FORESEEN IN '92


CERN R & D Projects – Dec. 1991
Total No. of Persons: ~~752~~ in ~~157~~ Institutions
Average No. of Persons: 34 per Project
800 PERSONS TOTAL
~34/PROJECT
72
No. of persons
100
80
60
40
20
0
RD-1
RD-2
RD-3
RD-4
RD-5
RD-6
RD-7
RD-8
RD-9
RD-10
RD-11
RD-12
RD-13
RD-14
RD-15
RD-16
RD-17
RD-18
RD-19
RD-20
RD-21
RD-22
H. Plothow-Besch/12.1991
PROJECTS


CERN R & D Projects – Dec. 1991
Total No. of Institutions: ~~157~~
Average No. of Institutions: 7 per Project
~170 INSTITUTIONS
(INCLUDING INDUSTRIES)
~ 7/PROJECT
No. of Institutions
20
16
12
8
4
0
RD-1
RD-2
RD-3
RD-4
RD-5
RD-6
RD-7
RD-8
RD-9
RD-10
RD-11
RD-12
RD-13
RD-14
RD-15
RD-16
RD-17
RD-18
RD-19
RD-20
RD-21
RD-22
H. Plothow-Besch/12.1991
PROJECTS



CALORIMETRY : THE BEST UNDERSTOOD AREA

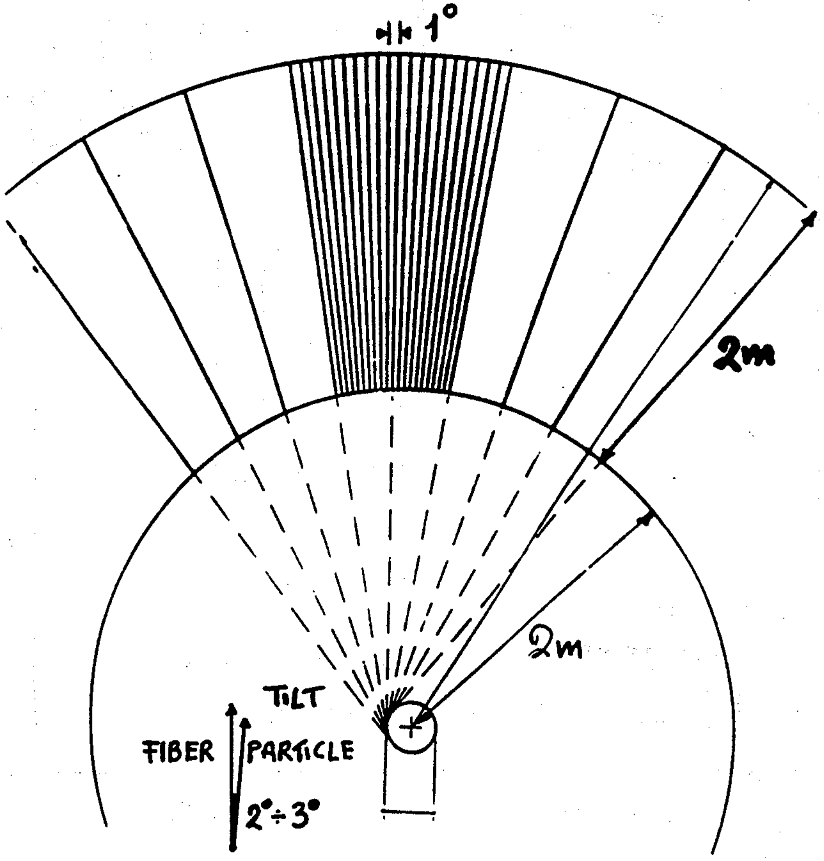
- ACCURACY, SPEED AND HOMOGENEITY: CHOICE OF GOOD CONCEPTS
- RAD. HARDNESS : GOOD CONFIDENCE
- HERMETICITY : MAJOR ENGINEERING PROBLEM : PROMISING GENERAL STUDIES

GENERAL PURPOSE {
RD1-SPACAL + P32
RD3-ACCORDION RD4-LAr DOPANTS
P34-Si HADRON CAL.

HI-ACCURACY E.M. {
RD18-CRYSTAL
RD14-LIQUID Xe OR Kr

RD1-SPACAL : CAGLIARI, CERN, CLERM.-FERR., ECOLE POLYTECH., LISBON, MARSEILLE, NAPOLI, PARIS VI, PAVIA, RIO DE JAN., UC SAN DIEGO, WEIZMANN INST.

ORIGINAL CONCEPT : INTEGRATED e.m.-h, POINTING, COMPENSATED BY SCI.FI./LEAD = 1/4



SPACAL : '91 PROTOTYPE STUDIES

① **INTEGRATED** POINTING PROTOTYPE


1mm SCI.FI., **1/4** FILLING FI./LEAD

e TEST : $\sigma_E/E = \mathbf{14.6\%}/\sqrt{E} + \mathbf{1.6\%}$
UNSATISFACTORY

→ **SEGMENTED** e.m./h & FINER e.m. SAMPLING

② e.m. POINTING PROTOTYPE


0.5mm SCI.FI., **1/4** FILLING

e TEST : $\sigma_E/E = \mathbf{9.3\%}/\sqrt{E} + \mathbf{0.6\%}$

'92 PROTOTYPES

1 e.m. PROTOTYPE


1 mm SCI.FI., **1/1.8** FILLING

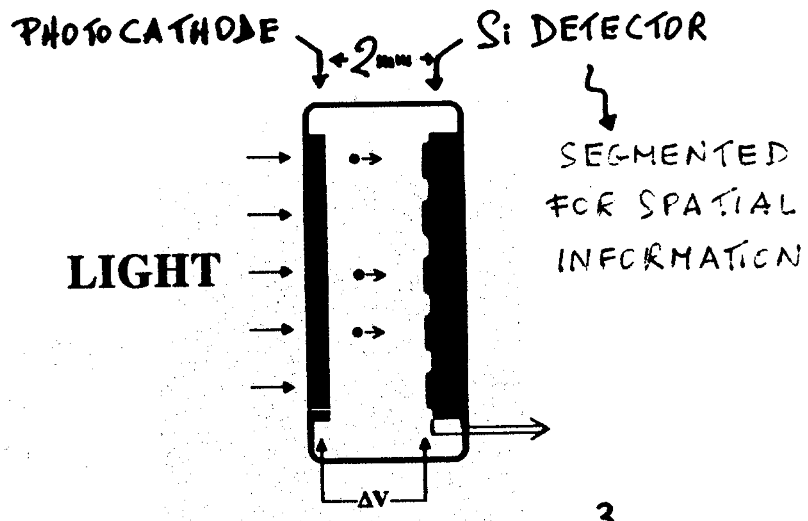
e M.C. : $\sigma_E/E = \mathbf{8}\%/\sqrt{E} + \mathbf{0.2\%}$

② hadr. PROTOTYPE WITH COARSE GRAIN

STUDIES
- RAD. HARDN., • CALIBR. & MONITORING,
- LIGHT DETECTOR, • ENGINEERING

- SPACAL LIGHT YIELD $\gtrsim$ 1 P.E./MeV

→ **NEW DEVICE BEING DEVELOPED:**
PROXIMITY FOCUSSING HYBRID PM

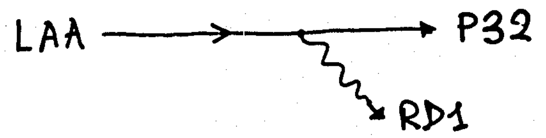


$10 \div 15$ kV → GAIN ~ 10^3
MAGN. FIELD INSENSITIVE

- OPTION: AVALANCHE PHOTODIODES

P32 - LEAD/SCI.FI. CAL.: BOLOGNA, CERN-LAA, AIN-OUSSURA, BEIJING, MOSCOW, BUCHAREST, FRASCATI, NAPOLI, TORINO, CORNELL, WORLD LAB.

SPAGHETTI CALORIMETER:



- DIFFERENT ATTITUDE: $\sigma_E/E_{e.m.} \sim 15\%/\sqrt{E} + 1.5\%$ IS WORTH THE ADVANTAGES OF THE INTEGRATED e.m.-h CAL. (FAST e-π DISCR., COST, ...)

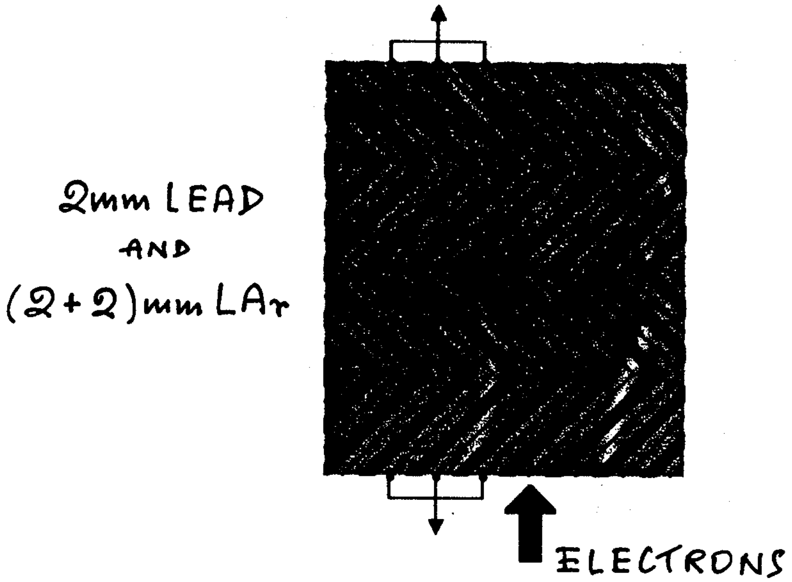
- DIFFERENT ENGINEERING

- RAD. DAMAGE STUDIES
- PERFORMANCE & ENGINEERING

being discussed in the DRDC

RD3-ACCORDION: LAPP, BNL, CERN, MILANO, LAL, SACLAY, STOCKHOLM

'90 PROTOTYPE

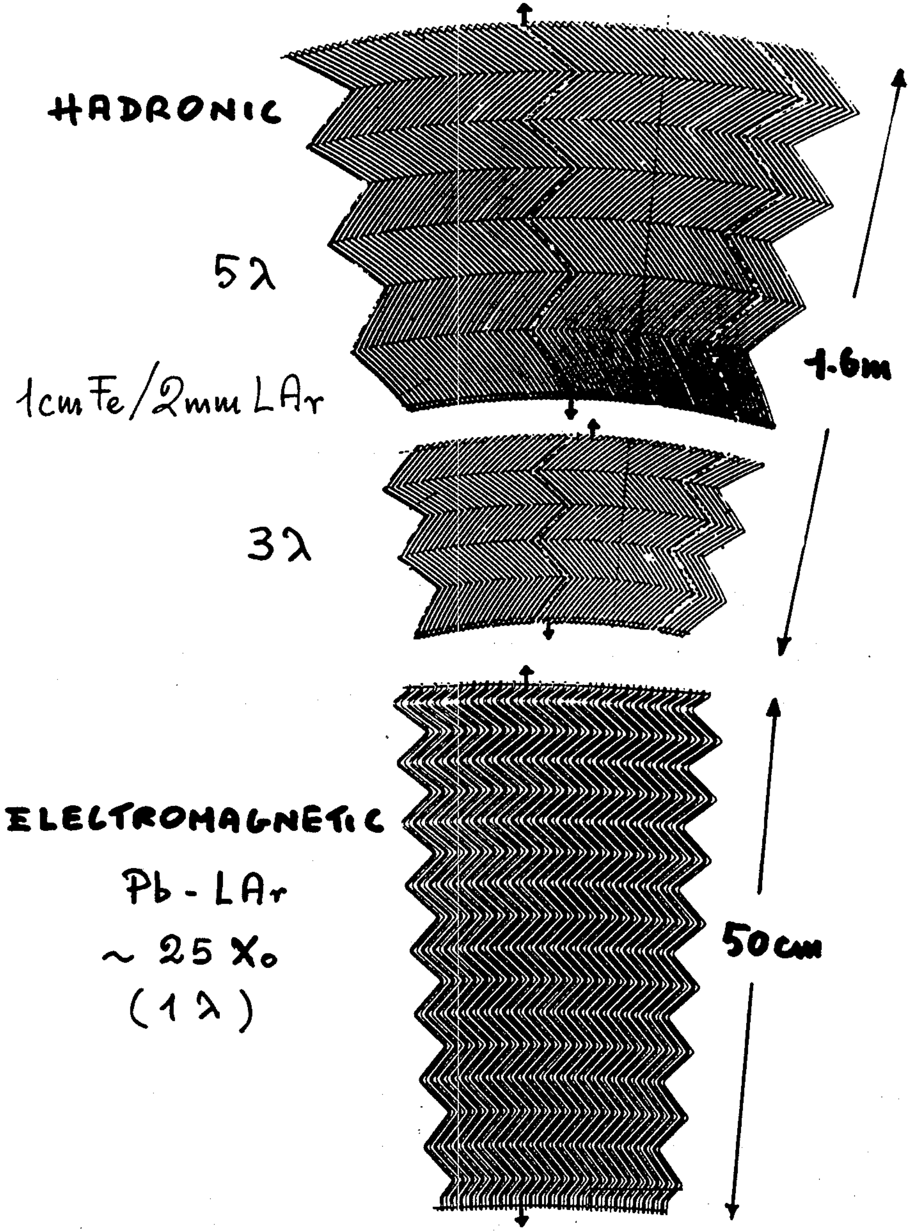


- PERFORMANCE WITH FAST ELECTRONICS : $t_p \sim 35ns$

$\sigma_E/E = 9.6\%/\sqrt{E} + 0.3\% + 0.33/E$

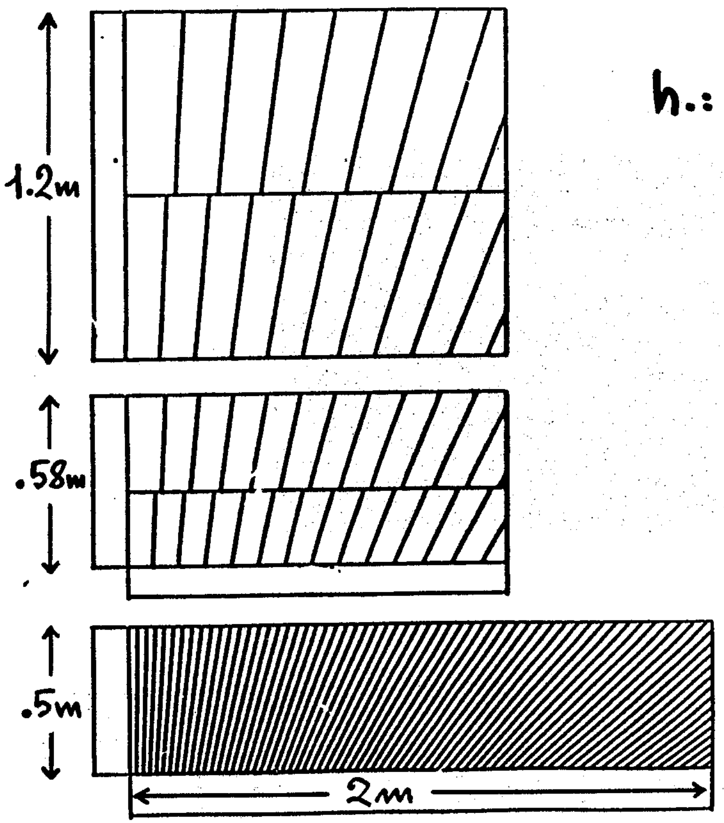
$\sigma_x = 3.7mm/\sqrt{E}$. $\sigma_\theta = 12mrad$ AT 60GeV

ACCORDION: GENERAL DESIGN STUDY



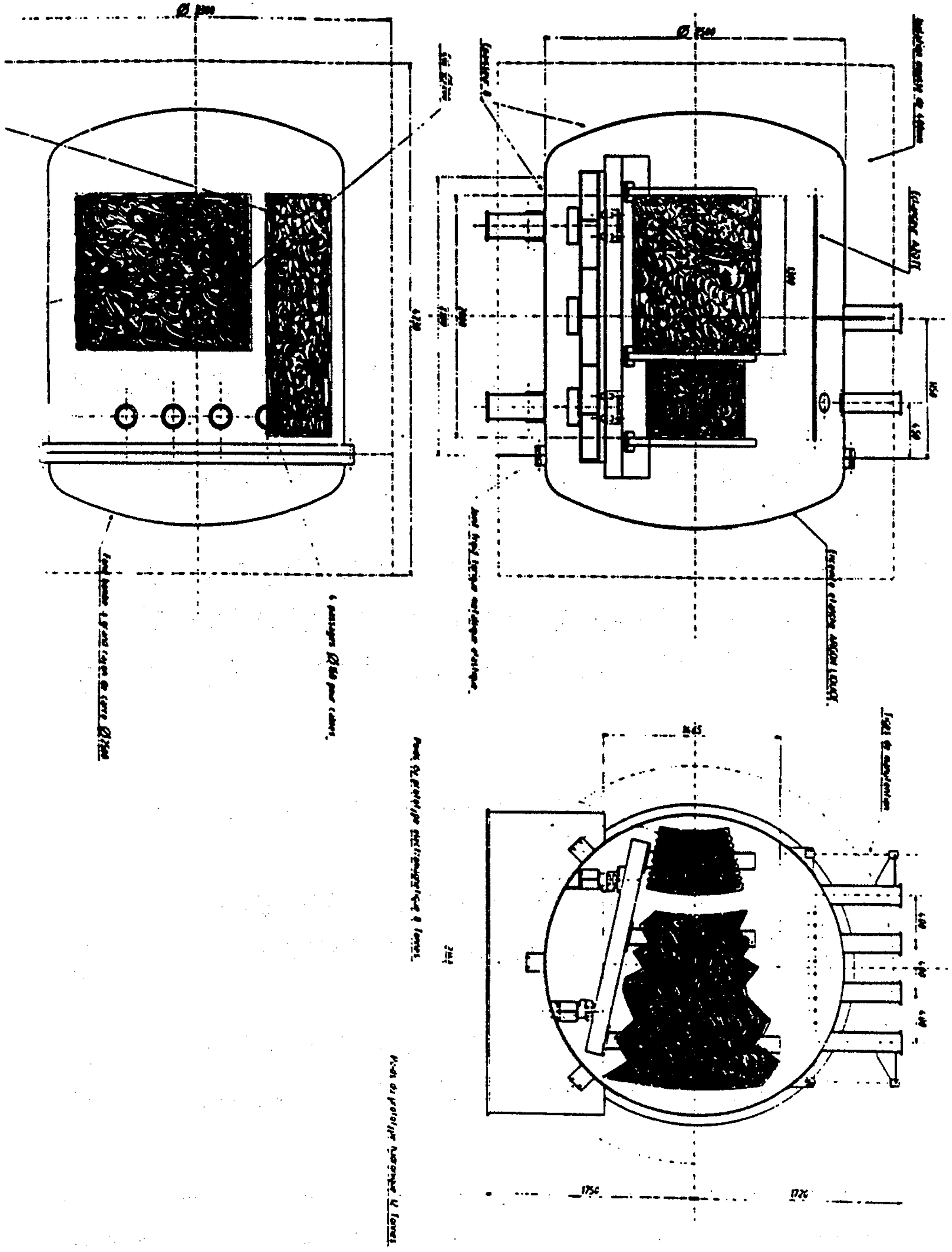
ACCORDION : POINTING PROTOTYPE UNDER CONSTRUCTION

- ENGINEERING
- e.m. PERFORMANCE

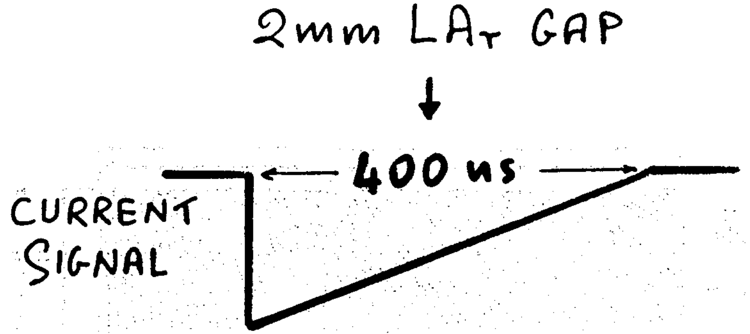


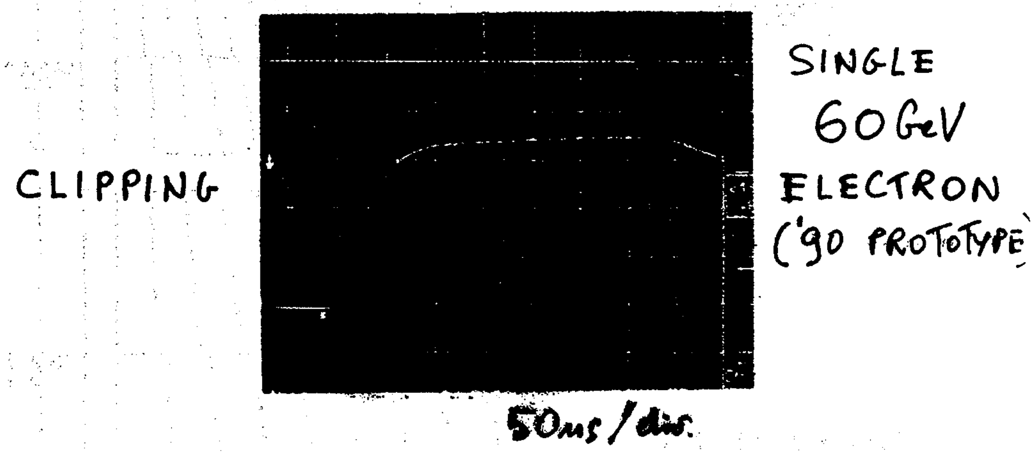
h.: 400 Ch.

e.m.:
3-FOLD SEGM.
$\Delta\eta \times \Delta\phi = .02 \times .02$
3'600 Ch.



RD4 - LAr DOPANTS : CERN, STOCKHOLM





AIM : DOPE LAr WITH HYDROCARBON :
ETHYLENE, etc

① TO INCREASE DRIFT VELOCITY OF ELECTRONS TO IMPROVE (SIGNAL/NOISE) × 2

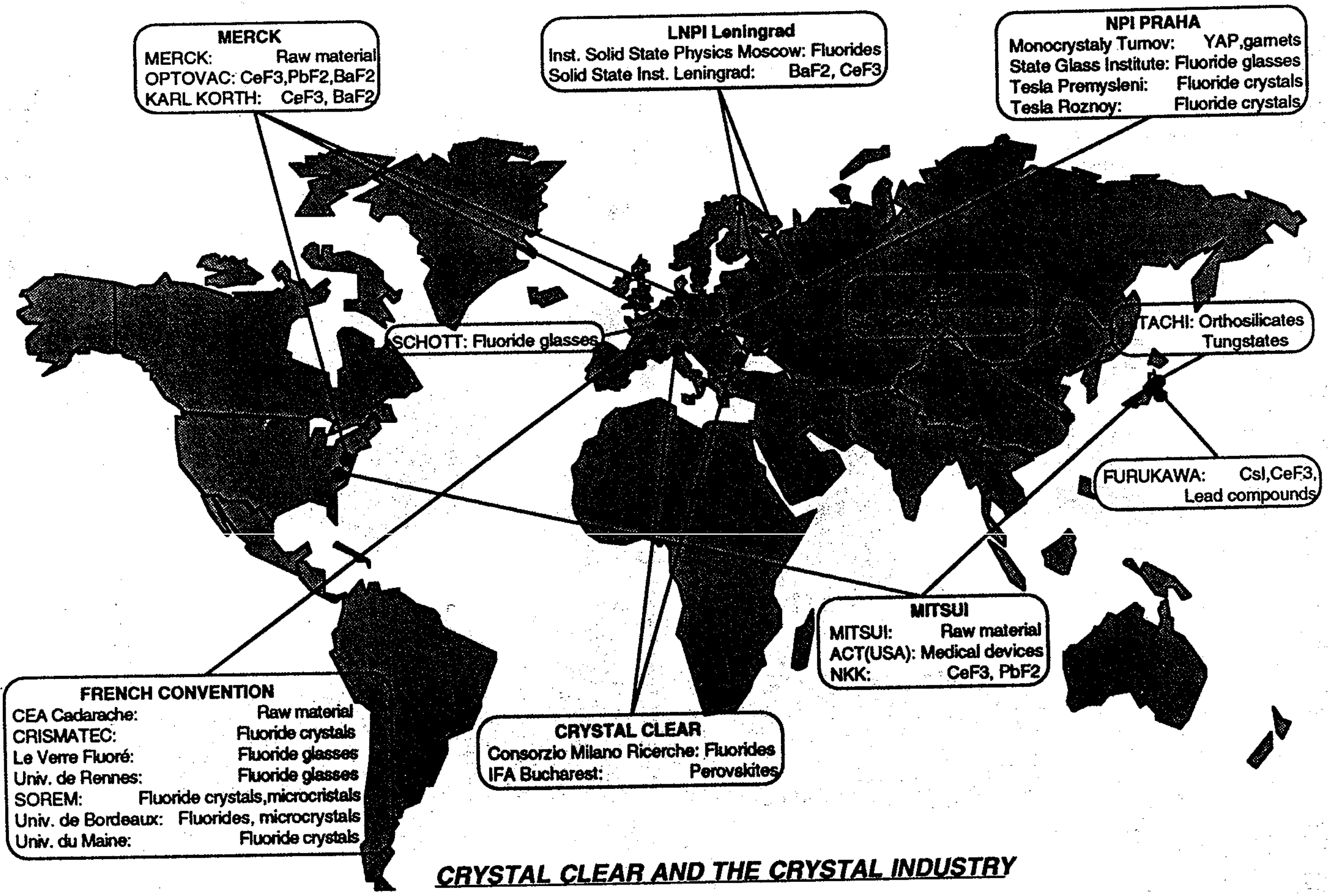
ACHIEVED AT CONCENTRATIONS $\gtrsim$ 0.2% VOL

② TO INCREASE CHARGE COLLECTION FOR DENSELY IONIZING PARTICLES (BY PHOTOIONIZATION) TO GET COMPENSATION

ACHIEVED AT CONCENTRATIONS $\lesssim$ 50 ppm

- BUT EITHER ① OR ②, NOT BOTH

CONCLUSION : ONLY MARGINAL BENEFIT



MERCK
MERCK: Raw material
OPTOVAC: CeF3,PbF2,BaF2
KARL KORTH: CeF3, BaF2

LNPI Leningrad
Inst. Solid State Physics Moscow: Fluorides
Solid State Inst. Leningrad: BaF2, CeF3

NPI PRAHA
Monocrystaly Tumov: YAP,garnets
State Glass Institute: Fluoride glasses
Tesla Premysleni: Fluoride crystals
Tesla Roznoy: Fluoride crystals

SCHOTT: Fluoride glasses

TACHI: Orthosilicates Tungstates

FURUKAWA: CsI,CeF3, Lead compounds

MITSUI
MITSUI: Raw material
ACT(USA): Medical devices
NKK: CeF3, PbF2

FRENCH CONVENTION
CEA Cadarache: Raw material
CRISMATEC: Fluoride crystals
Le Verre Fluoré: Fluoride glasses
Univ. de Rennes: Fluoride glasses
SOREM: Fluoride crystals,microcristals
Univ. de Bordeaux: Fluorides, microcrystals
Univ. du Maine: Fluoride crystals

CRYSTAL CLEAR
Consorzio Milano Ricerche: Fluorides
IFA Bucharest: Perovskites

CRYSTAL CLEAR AND THE CRYSTAL INDUSTRY

RD18 - CRYSTAL CLEAR: CERN, MILANO, ANCONA, ROMA, BUCHAREST, LYON, LAPP, LENINGRAD, LUND, PRAHA, AACHEN, TATA

AIM: SYSTEMATIC STUDY & DEVELOPM. OF HI-YIELD, FAST, DENSE, RAD.HARD, T-INDEP. **CRISTALS** (HEAVY FLUORIDES OR TERN.COMP.; **OR HEAVY GLASSES**

'92 PROGRAMME:

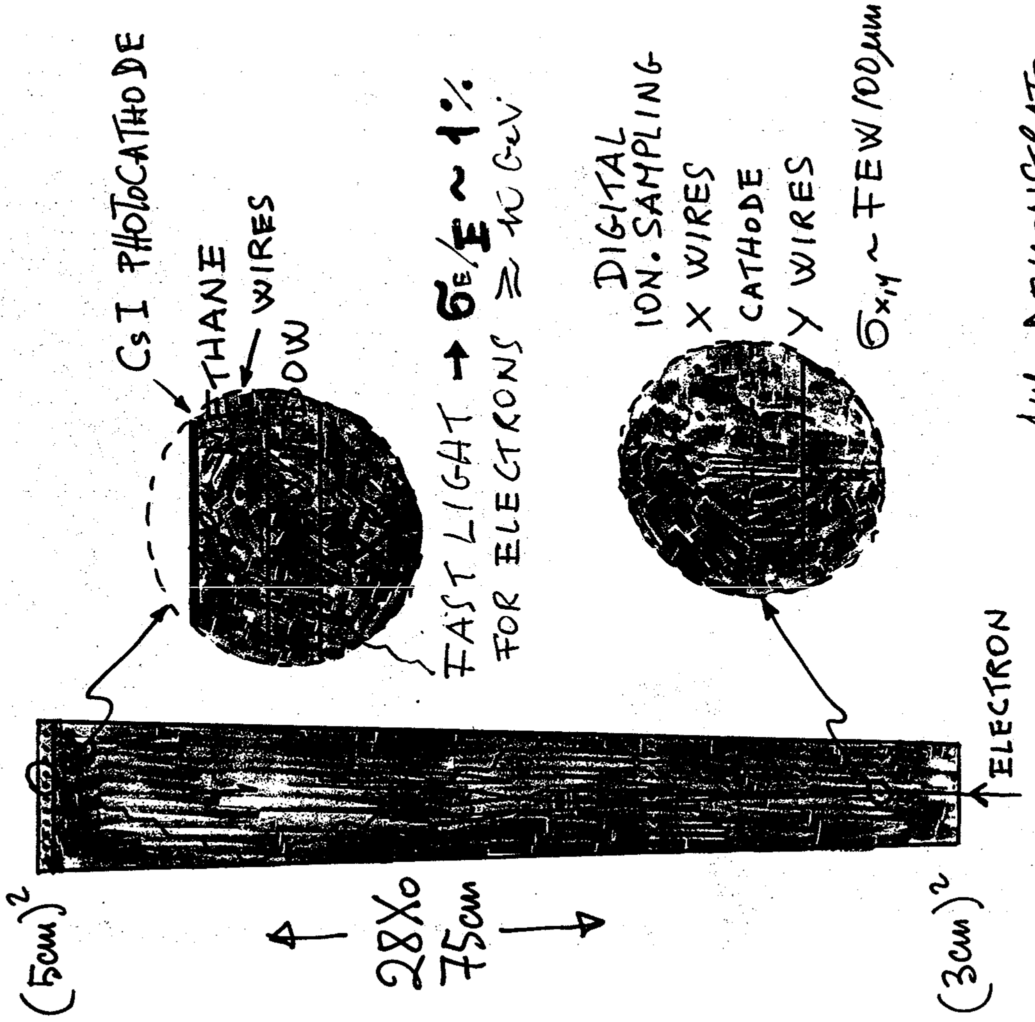
- MASS PRODUCTION STUDIES OF CeF_3
- SEARCH FOR BETTER CANDIDATES

FINAL CHOICE: 1-2 YEARS

RD14 - LIQUID Xe OR Kr : PARIS, CERN, COIMBRA, SERPUKHOV, WORL LAB.

CONCEPT OF POINTING TOWER

TOTALLY ACTIVE



AIM: DEMONSTRATE CONCEPT

~130 SAMPLES TESTED OF ~50 DIFFERENT TYPES

SOME CRYSTALS STUDIED BY "CRYSTAL CLEAR" COLLABORATION

Crystal	Density	Radiation length cm	Moliere radius cm	Decay time nsec	Peak emission nm	Radiation hardness(Gy)
[redacted]	7.13	1.11	2.33	[redacted]	480	10
[redacted]	4.89	[redacted]	3.39	[redacted]	210 310	> 10^4
[redacted]	6.16	[redacted]	2.63	[redacted]	300 340	> 10^4
YAP:Ce	5.35	2.83	2.82	35	390	> 10^5
GSO:0.5%Ce	6.71	1.39	2.42	55	435	> 10^6
GSO:2.5%Ce	6.71	1.39	2.42	31	450	> 10^6
ThF4	6.32	1.18	2.71	10 , 30	315,330,450	?
BaLiF3	5.24	2.13	3.13	2	435	?
LiYbF4	6.09	1.56	2.70	≤ 25	≈ 450	> 10^5
BaYb2F8	6.99	1.29	2.37	-	-	10^3 to 10^4
[redacted]	7.77	[redacted]	2.21	[redacted]	-	?

Also : Fluoroaluminate and fluorozirconate glasses

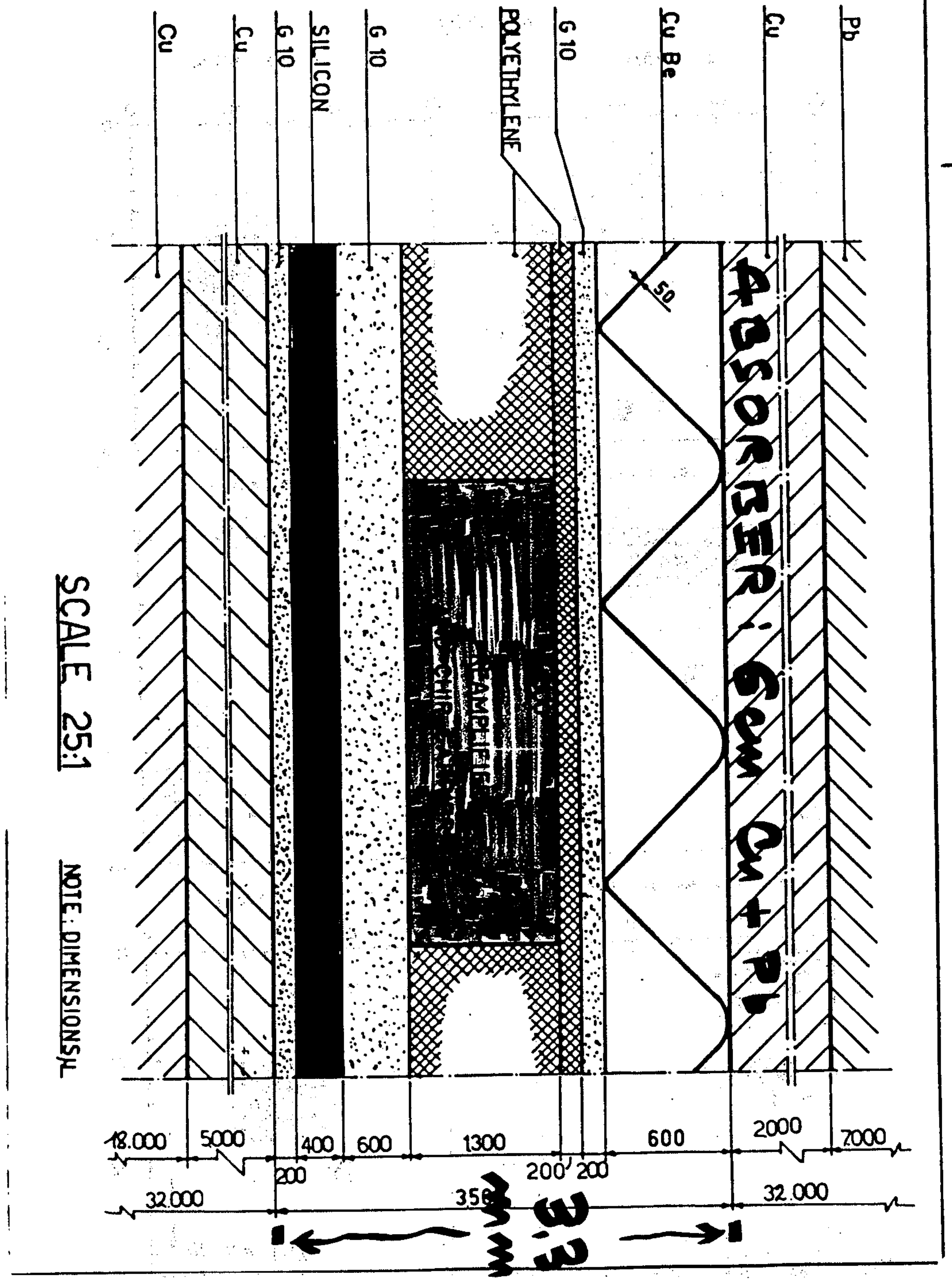
Results in CERN/PPE preprint 91-124

→ GLASS: COST = 0.2÷0.3 CRYSTAL

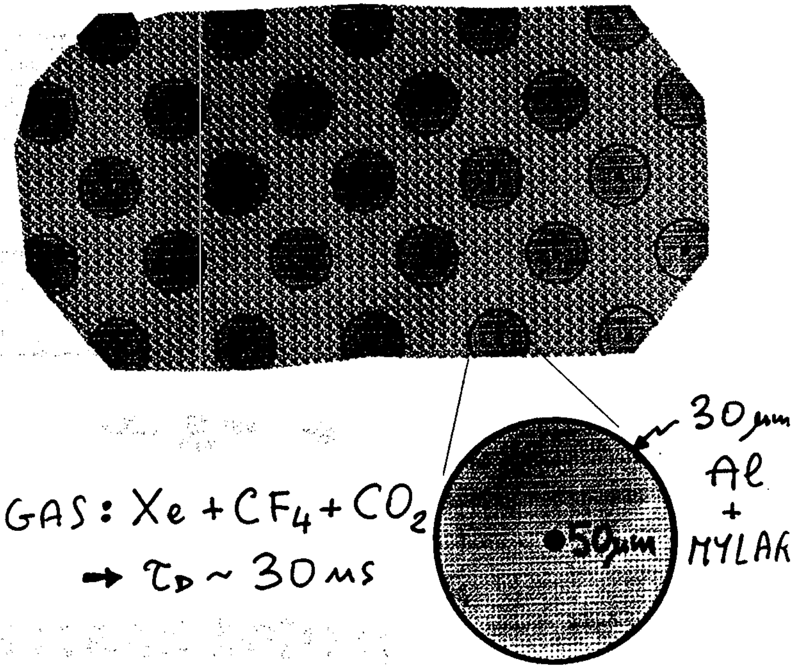
NOT ONLY JUST LOOKING FOR NEW SCINT. MAT. BUT ALSO TRYING TO MAKE NEW SCINT.

RD6 - INTEGRATED HIGH RATE TRD AND TRACKING: BNL, CERN, GLASGOW, DUBNA, LENINGRAD, MOSCOW, MPI-MUNICH, RAL

- IDENTIFICATION & TRACKING OF HIGH γ PARTICLES



Ø4mm × 0.5m STRAWS WITH POLYETH. SHEETS AS RADIATOR



GAS: $Xe + CF_4 + CO_2$

→ $\tau_D \sim 30$ ns

PRINCIPLE DEMONSTRATED BY 1000 STRAW PRO

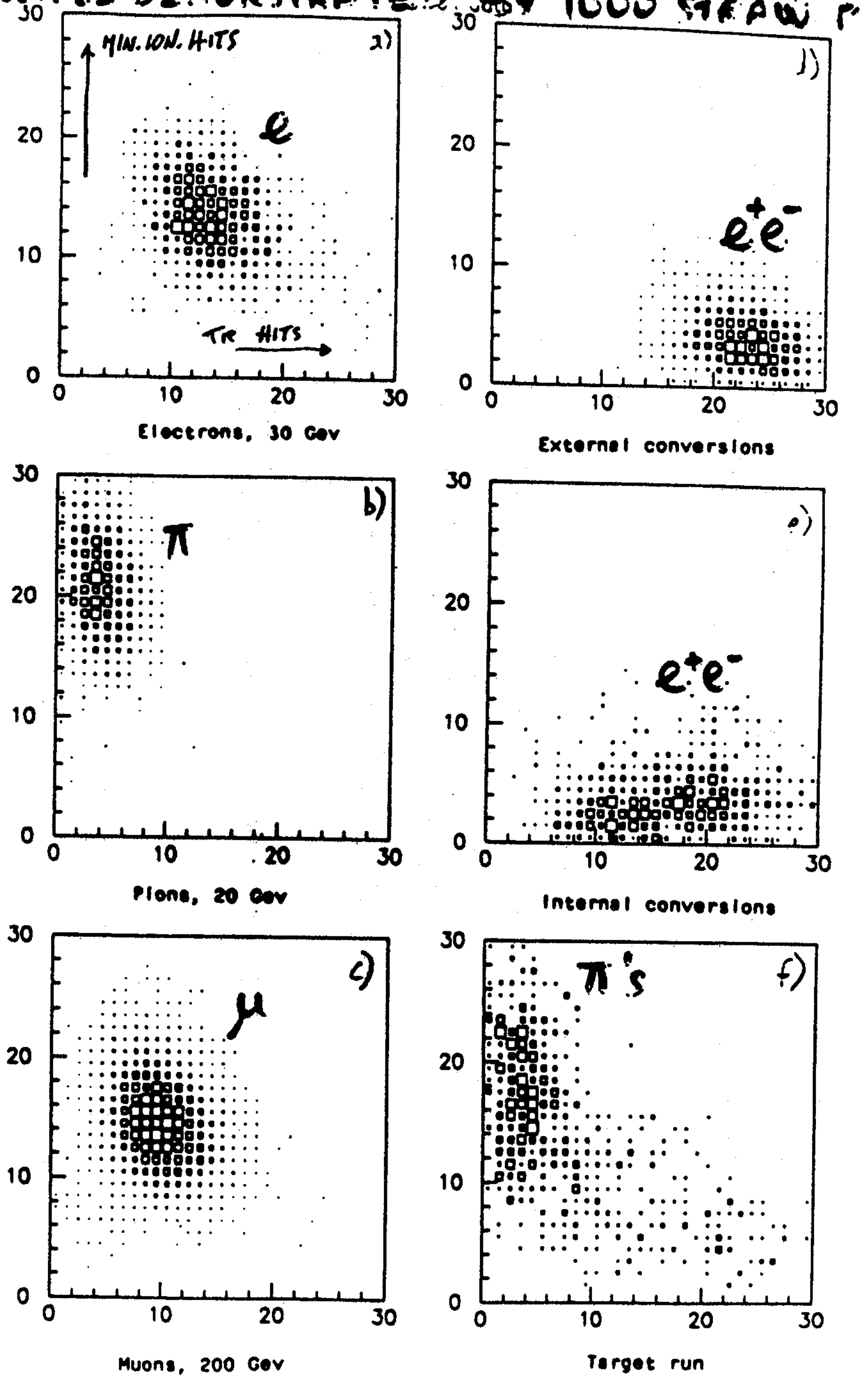
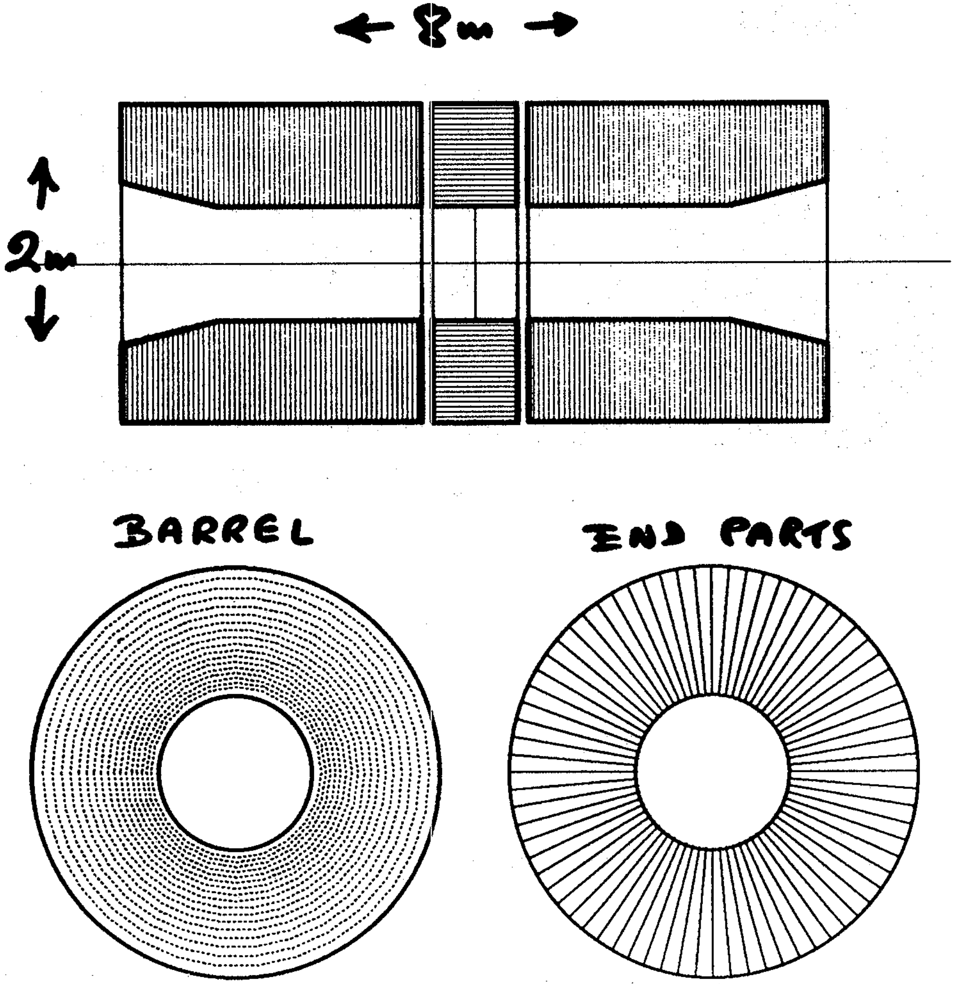


Figure 29

TRD TRACKER DESIGN



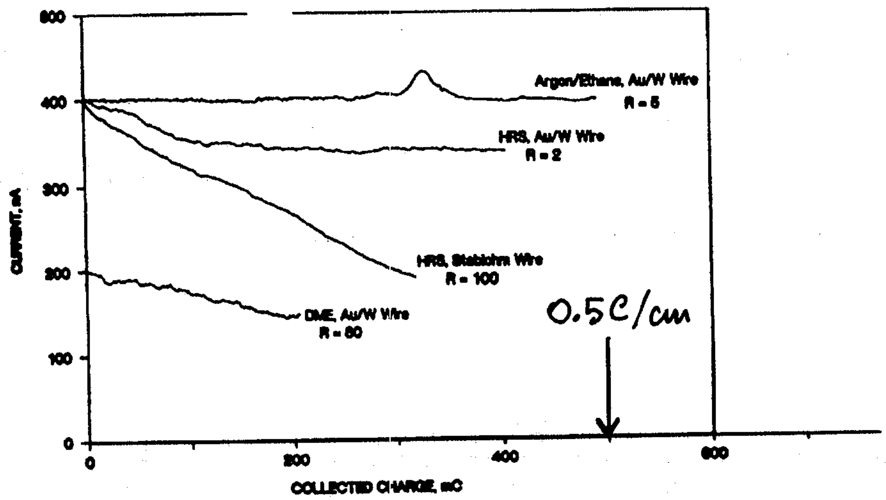
F.Sauli

AGING OF GASEOUS DETECTORS:

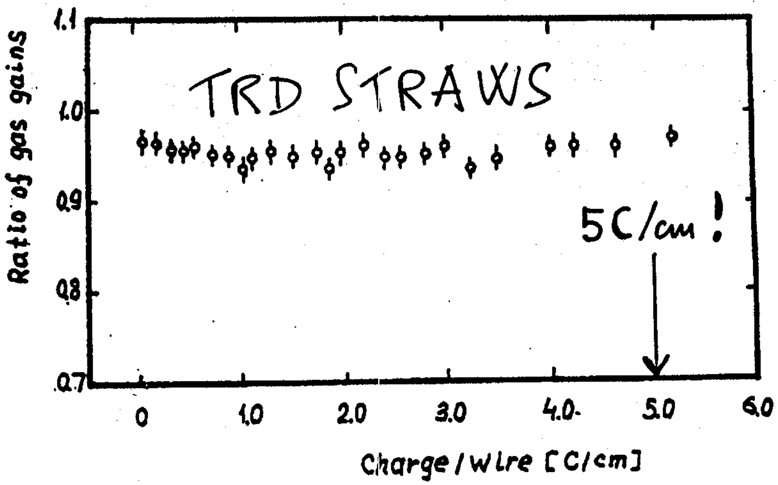
Gain drops at increasing collected charge

Terms of reference: Min.Ionizing Tracks: ≈100 e⁻ Gain 10^5 – 1pC/track
1C/cm of wire (1 mm spacing) – 10 C/cm² – 10^{13} min.ion./cm²

1 C/cm ≈ 1 MRad



J. Kadyk et al, IEEE NS-37 (1990) 478



Bondarenko et al (Moscow TRD) (1991)

'92 PROTOTYPE:
10'000 STRAWS TO
DEMONSTRATE DETECTOR

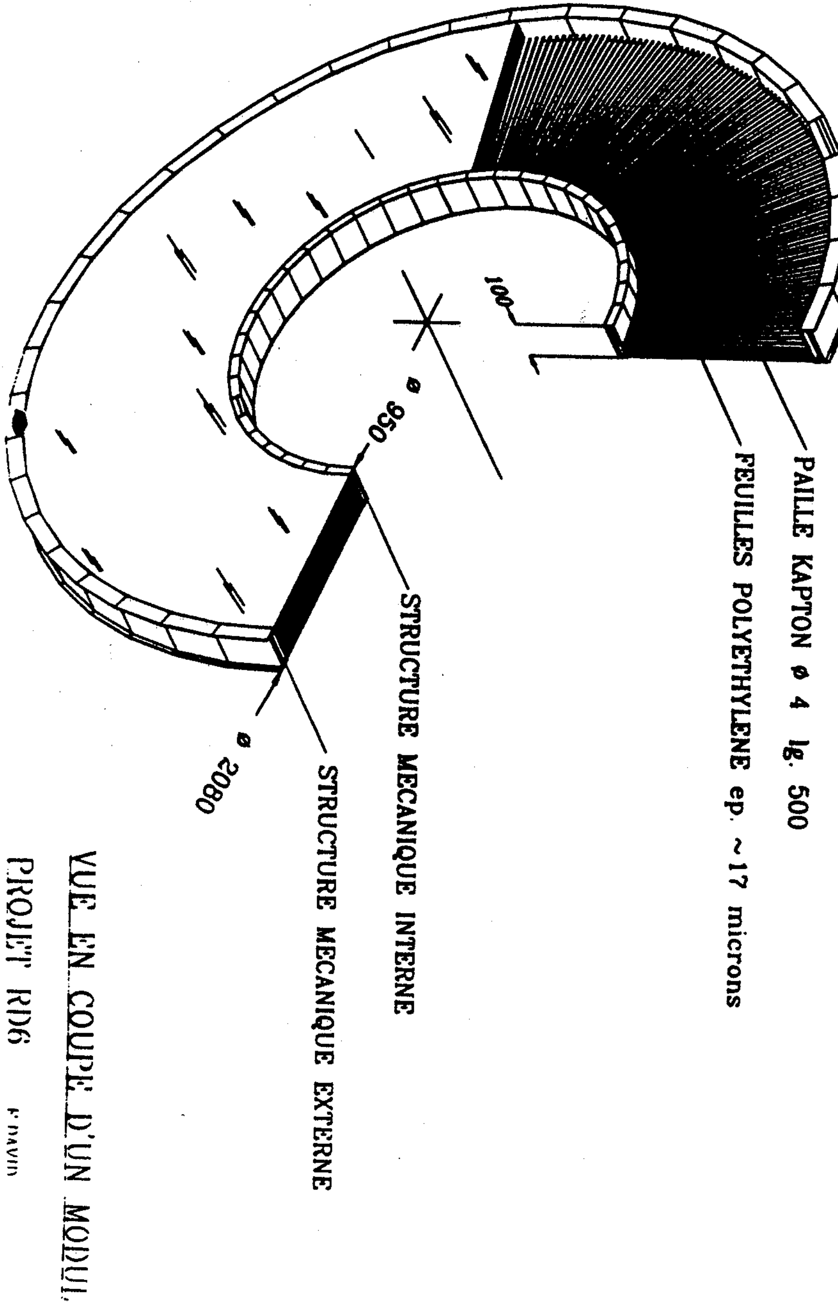
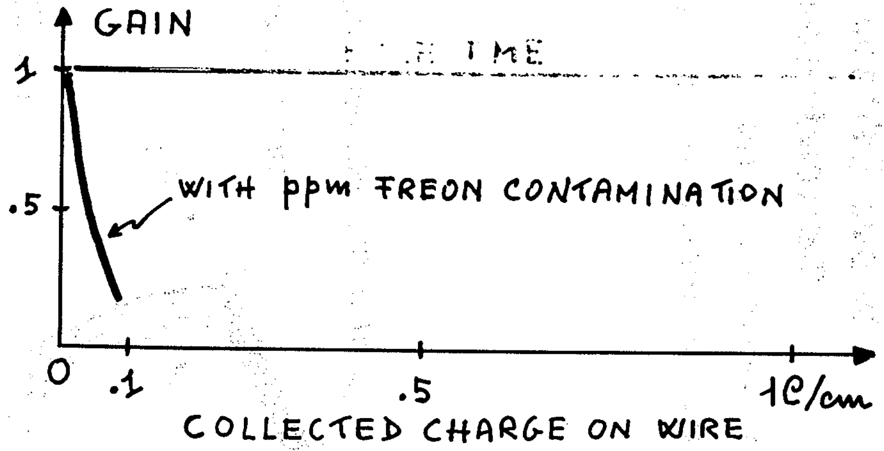


Figure 34

* GAS AGING IS NOT AN INTRINSIC PROPERTY OF GASEOUS DETECTORS BUT IS DUE TO ppm POLLUTANTS

EXAMPLE



→ RD10 : RADIATION HARDNESS OF GAS DET.

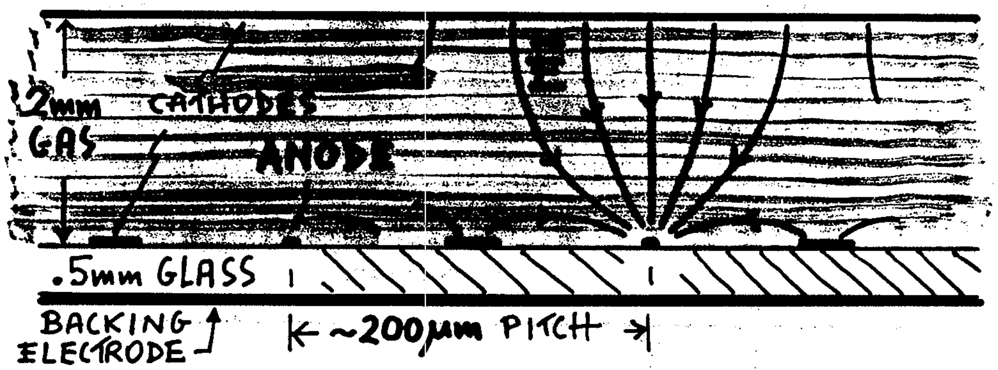
CERN, GLASGOW, EINDHOVEN

- UNDERSTAND PHENOMENA
- GIVE PRESCRIPTIONS
- MAKE AVAILABLE A TEST FACILITY

P29 : p EXTRACTION BY CRYSTAL CHANNELING

AARHUS, CERN, FRASCATI, LECCE, I.C. LONDON, PISA, ROMA, STRASBOURG, MPI-STUTTGART, TORINO, TRIESTE

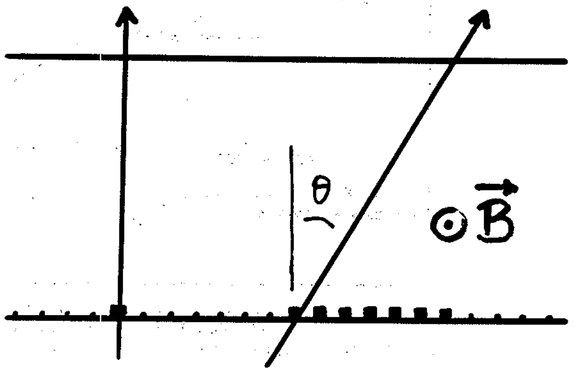
MICROSTRIP CHAMBER



LARGE $\frac{\text{GAP}}{\text{PITCH}}$

↓

ANGLE SENSITIVITY



→ SINGLE HIT = HI-p_T → TRIGGER

PROPOSAL TO BE SUBMITTED TO THE DRDC

DEVELOPMENT OF MICROSTRIP GAS CHAMBERS ON GLASS AND PLASTIC SUPPORTS

R. Bouclier, J.J. Florent, J. Gaudaen, G. Million, A. Pasta+, L. Ropelewski, F. Sauli and L. Shekhtman++

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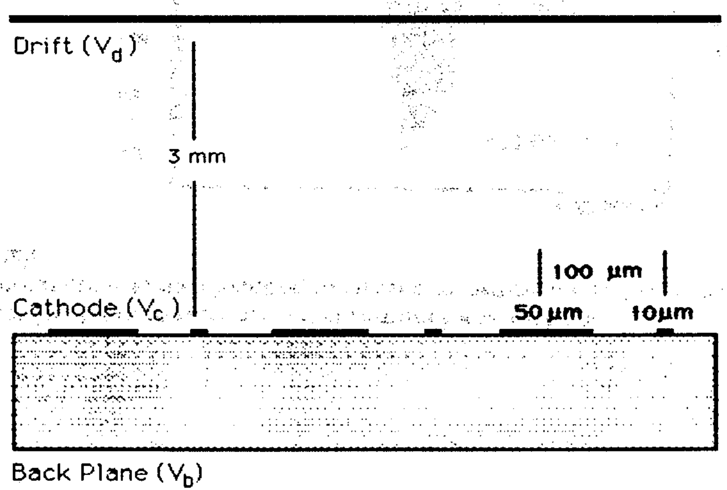
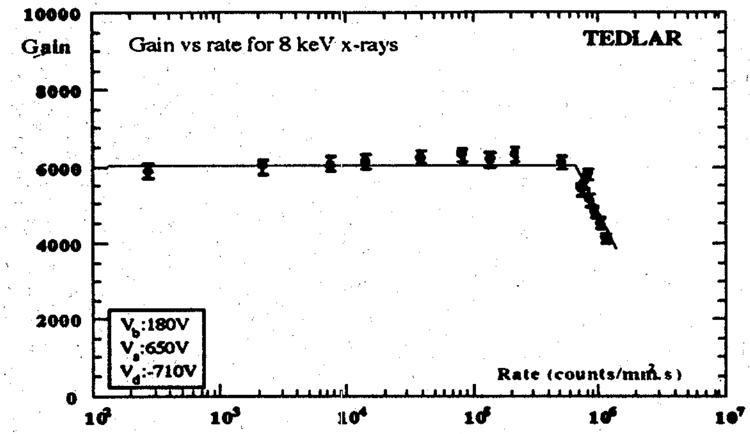


CROSS SECTION OF THE MICROSTRIP GAS CHAMBER

FOCUS ON LHC APPLICATION:

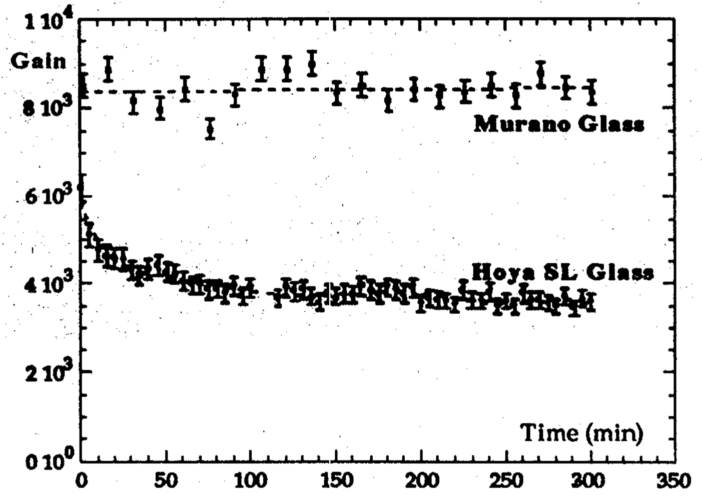
- LARGE AREA & LOW MASS STRUCTURE
- SPEED
- RAD. HARDN. (AGING)

GMSC have very high intrinsic rate capability:



R. Bouclier, J.J. Florent, J. Gaudaen, G. Million, L. Ropelewski, F. Sauli, IEEE Trans. Nucl. Sci. NS-39 (1992)

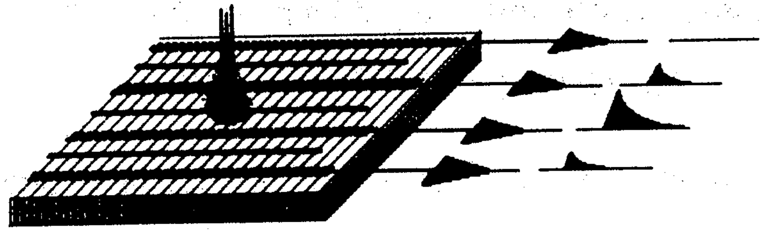
Surface charging up problems at very high flux require the use of a slightly conductive support, either in the bulk or by ion implantation:



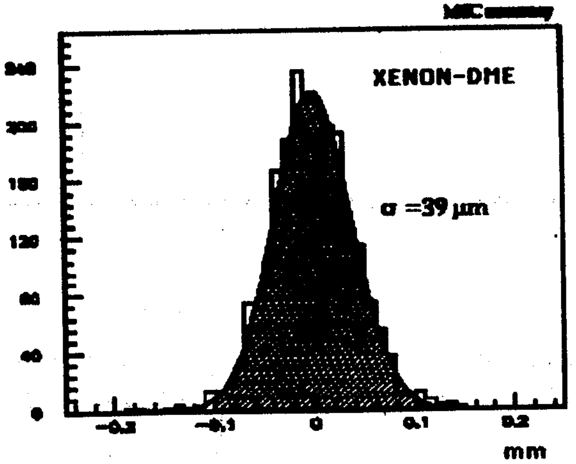
R. Bouclier, J.J. Florent, J. Gaudaen, G. Million, A.Pasta, L. Ropelewski, F. Sauli, L. Shekhtman, Vienna WCC 92

WCC92

The charge profile induced by an avalanche on adjacent cathodes reflects the original position of the ionization:



Space localization accuracy for minimum ionizing tracks perpendicular to the chamber, measured recording the cathode charge signals:

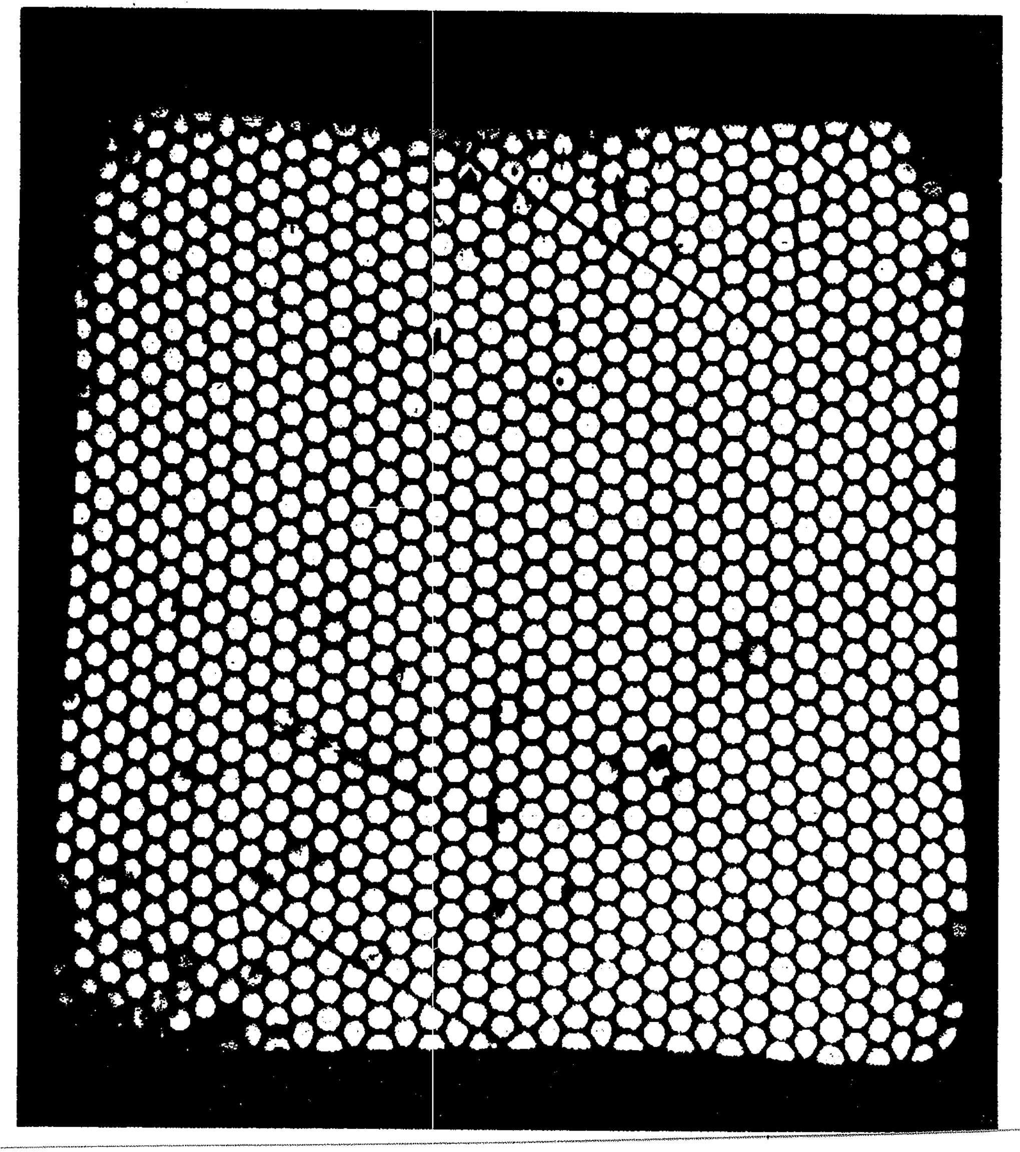


200μm PITCH

F. Angelini et al, Nucl. Physics 23A (1991) 254

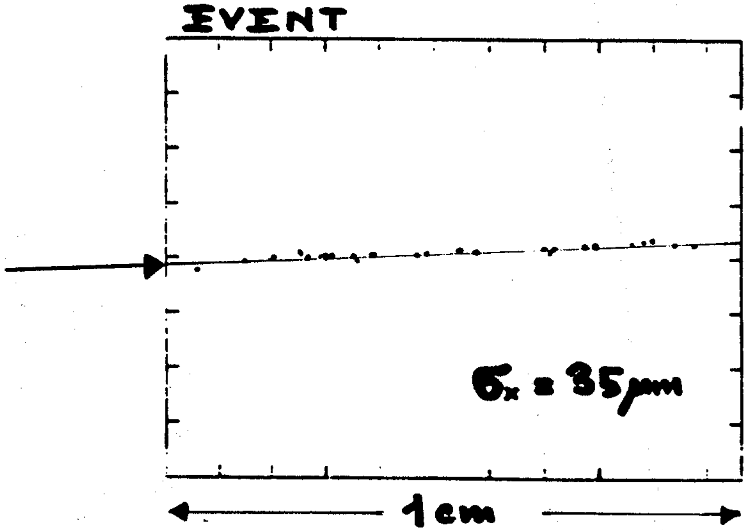
RD7 - TRACKING SCI. FI.: CERN-LAA, ZEUTHEN, KARLSRUHE, TOULOUSE, KURARAY-TOKYO, WORLD LAB.

$1 mm^2$ COHERENT BUNDLE
OF ~800 30μm SCI. FI.

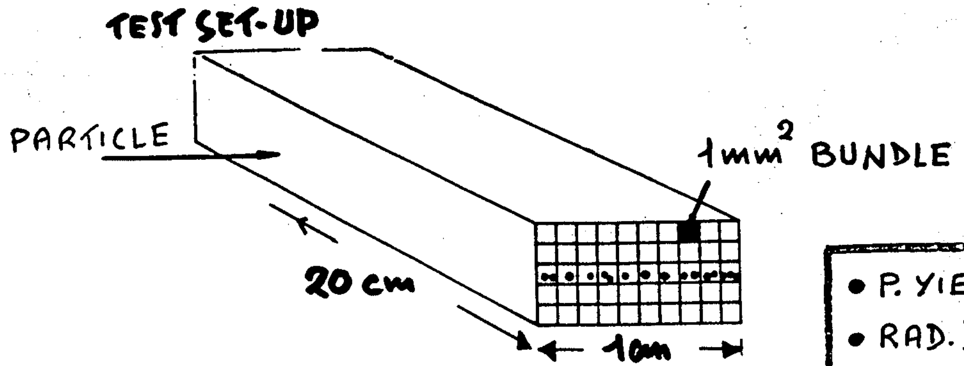


60μm FIBERS

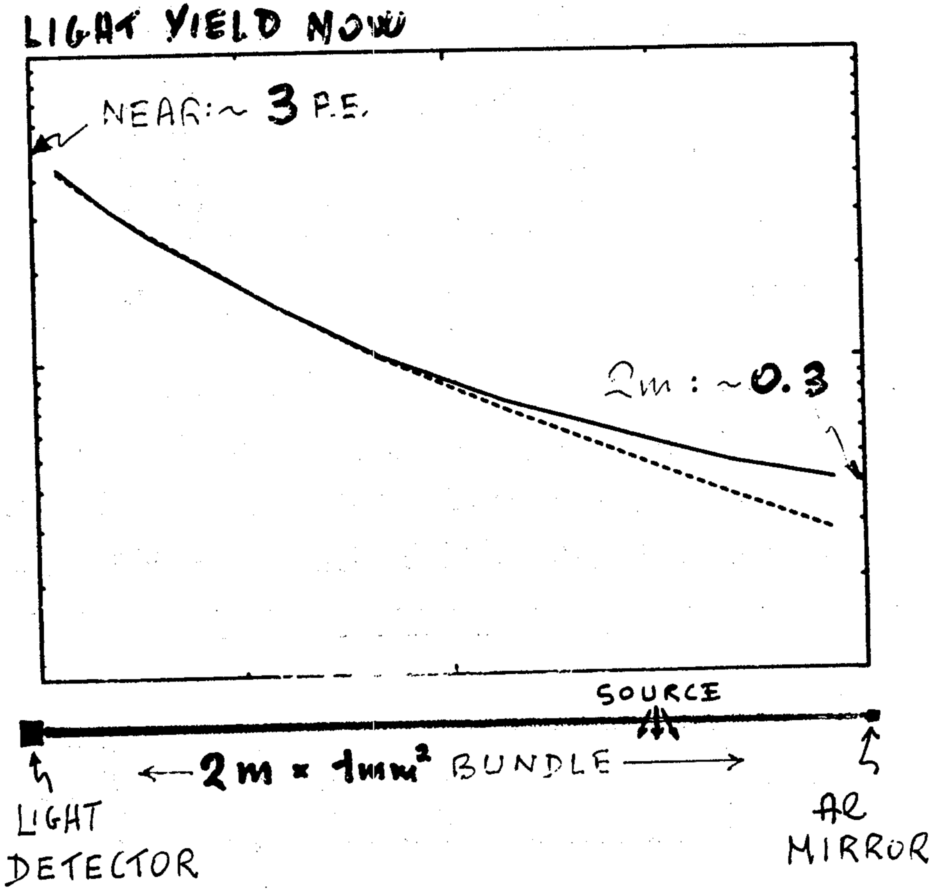
RD7 SCI.FI. TRACKER PROTOTYPE PERFORMANCE



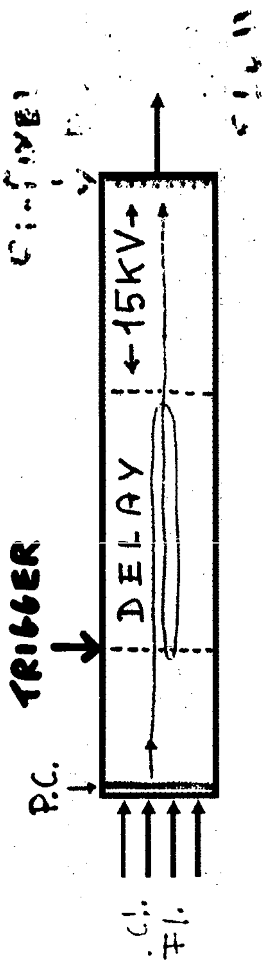
2 TRACK SEPARATION ~ 80μm



- P. YIELD
- RAD. DAM
- READOUT

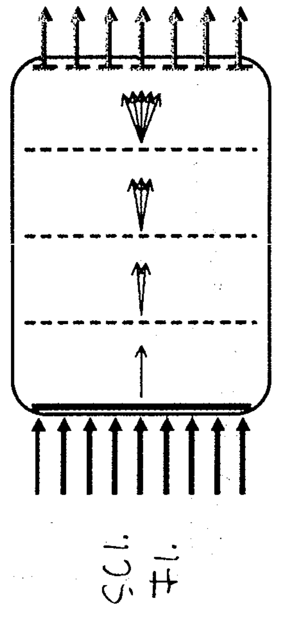


RD7 HI-SPACE ACCURACY SCI. FI. READOUT BY IMAGE INTENSIFIER TUBE



RD17 - FAST SCI. FI. READOUT BY P.S.P.M.: LAPP, CERN, FERMILAB, IOWA, KYOTO-SANGYO, MESSINA, OSAKA, TRIESTE, SERPUKHOV

POSITION SENSITIVE PHOTON MULTIPLIER



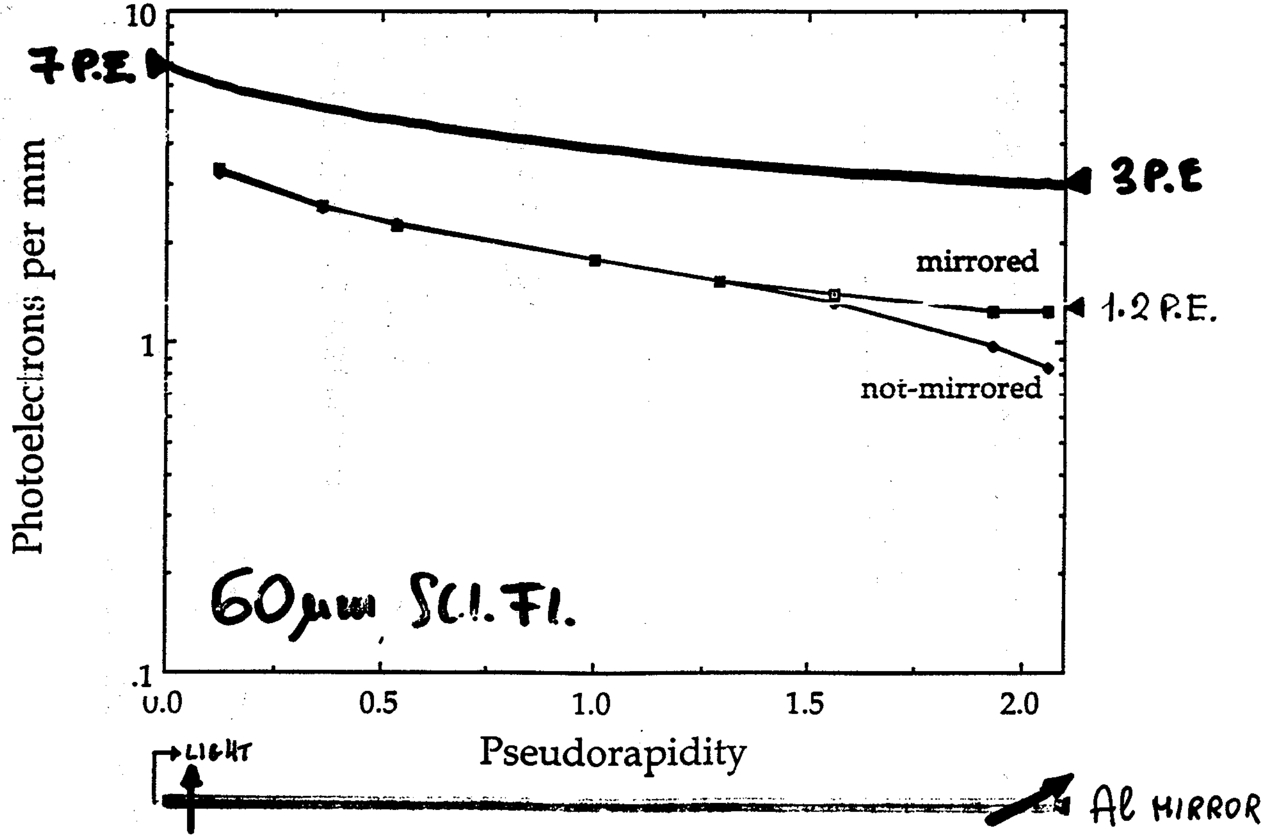
$\sim 10^3$ PIXEL ANODES

(BUT CROSS-TALK: EFFECTIVE $\lesssim 10^3$)

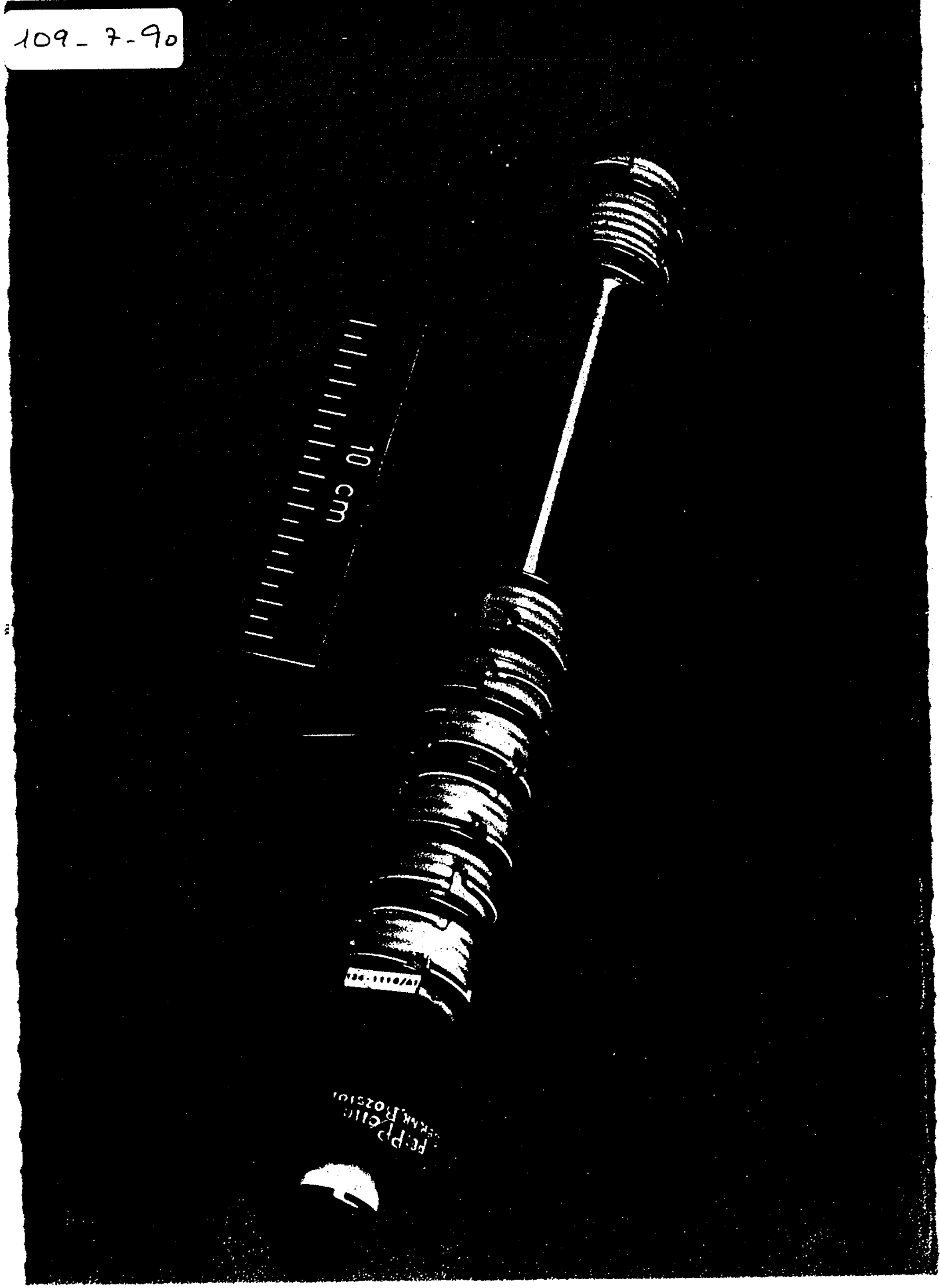
- HI-TIME ACCURACY: $\lesssim 1\,ms$ → TRIGGER

$\Delta x \cdot \Delta t \sim \cancel{SF}$ → SPACE ACCURACY LIMITED BY COST

GOAL '92 : 1) IMPROVE CLADDING : LIGHT × 2
2) IMPROVE DOPANTS : → LIGHT FAR × 1.5
↘ MORE RAD. HARD



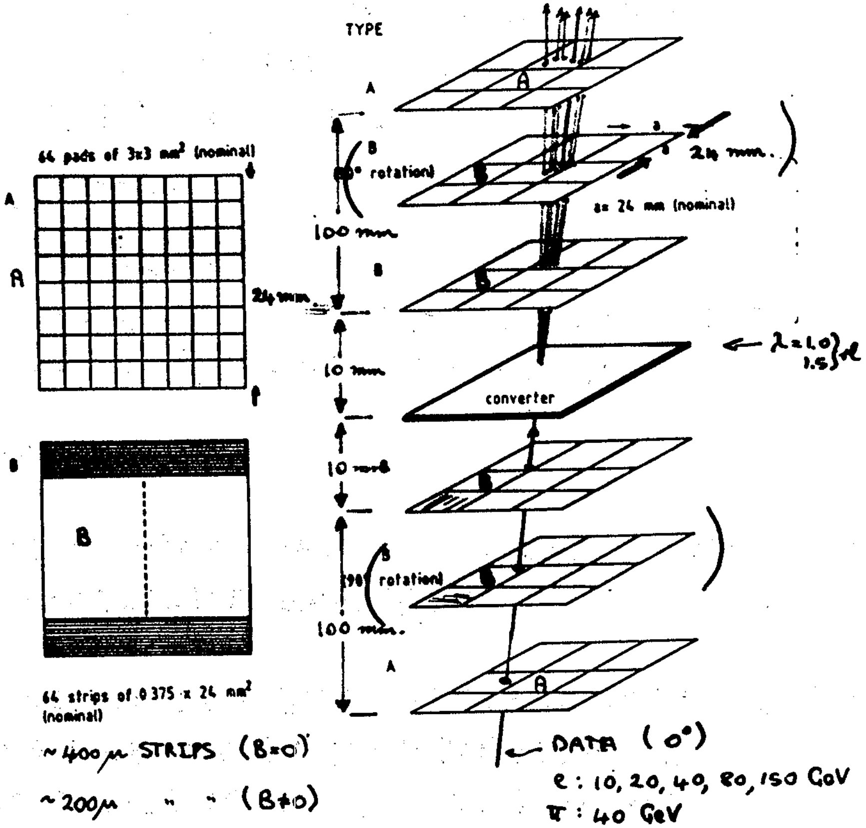
109-7-90



RD2-Si: TRACKING PRESHOWER:

DORTMUND, HAMBURG, OSLO, PERUGIA, AUSTRALIA, SACLAY, CERN, GENEVA

GROWING EMPHASIS ON TRACKING



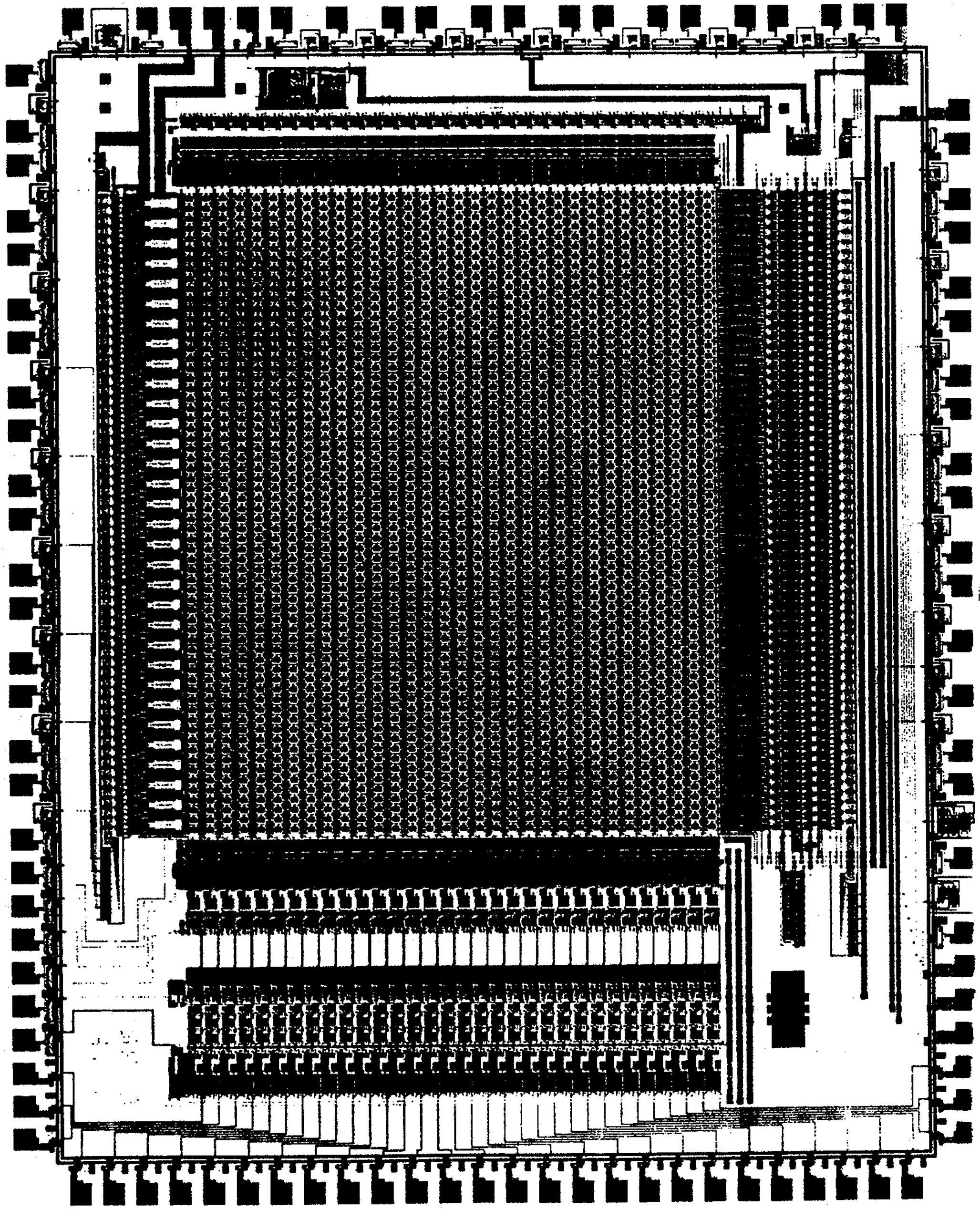
~400μ STRIPS (B=0)

~200μ " " (B≠0)

DATA (0°)

e: 10, 20, 40, 80, 150 GeV

π: 40 GeV



RD2 - SiTP : '91 ACHIEVEMENTS

- FULL SIMULATION PACKAGE IMPLEMENTED
- PROTOTYPE BUILT & TEST STARTED
- RAD. HARDNESS : GOOD CONFIDENCE
- READOUT EL.: 32 CH. × 64 CELLS BUILT & TESTED

KEY MILESTONE FOR '92:

- REALISTIC ASSESSMENT OF A POSSIBLE APPLICATION

THE ISSUES:

- SEVERAL 10^6 CH. REQUIRE LARGE DROP OF COST/CH. : POSSIBLE BY SCALING THE LEVEL OF INTEGRATION
- POWER DISSIPATION :

THEOREM
- FET PRINCIPLE
- DET. CAPACITANCE
- 2nd PR. OF THERMODYNAMICS

→ UNIVOCALLY DETERMINED

SiTP NOW : 50 ÷ 100 KW , LIMIT = $\frac{1}{2}$

COOLING BY LIQ. FLOW

RD20 - Si STRIPS: CERN, INP & INPT CRACOW, HELSINKI, I.C. LONDON, UN. & I.S. OSLO, RAL, STRASBOURG, TORINO, YALE, LIVERPOOL, MARSEILLE, VILLIGEN, UPPSALA

X-y Si MICROSTRIPS:

- WELL ESTABLISHED TECH. FOR HIGH SPATIAL ACCURACY
- ALSO : ADEQUATE SPEED

R&D GOAL : UPGRADE THE TECH. FOR LHC CONDITIONS

RD20 Goals - *elements* required for a high spatial precision tracking detector:

- radiation tolerant → PROBABLE **Silicon microstrip detectors**
- low power & low noise **front end** electronics
- low mass **mechanical structure** - ***coolable*** ~10kW

Current status of *Detectors*

Planned programme of prototype fabrication to systematically study/improve radiation hardness

i) irradiation of existing devices-
   large body of data now exists => new results

ii) p-side prototypes - *manufacture complete*
iii) n-side prototypes - *design complete*

iv) double sided - *second half 1992*

Current status of *Electronics*

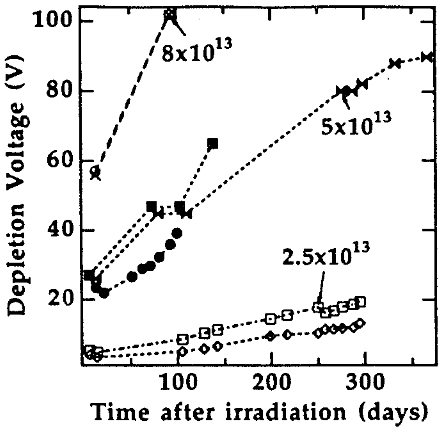
emphasis on essential elements of front end

- charge sensitive preamplifier/shaper -*exists*
  ENC ≈ 750e @ 6pF & 1.6mW/channel
  *2nd iteration => lower noise & **0.8mW/channel***
- analogue data buffer/pipeline - *in fabrication*
- analogue signal processor - *new concept*
  deconvolution

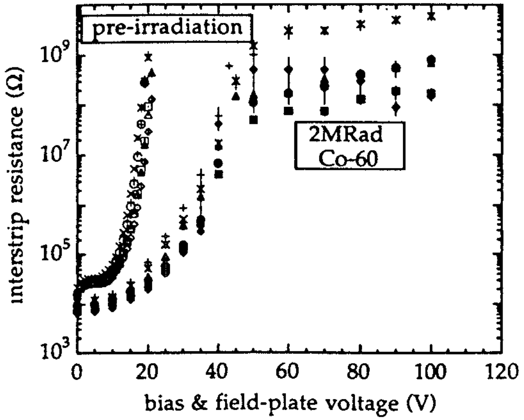
New results from radiation damage studies

Substrate doping changes
Surface charge accumulation

Annealing of doping

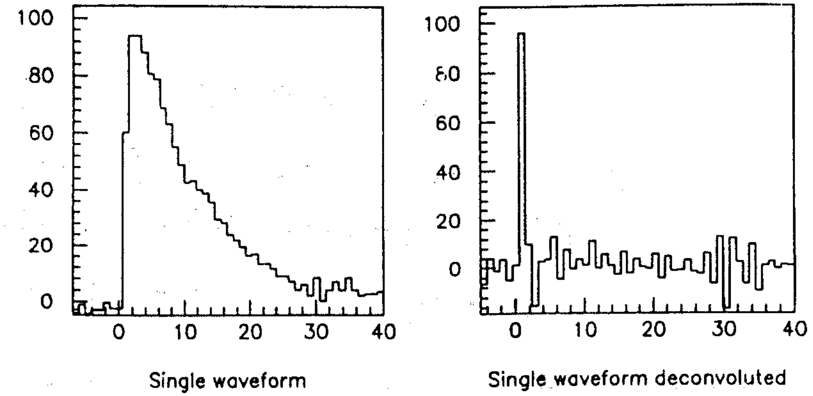


n-side interstrip resistance



Results from electronics

Deconvolution of shaped pulse
=> digital filter implemented in analogue form



Single waveform

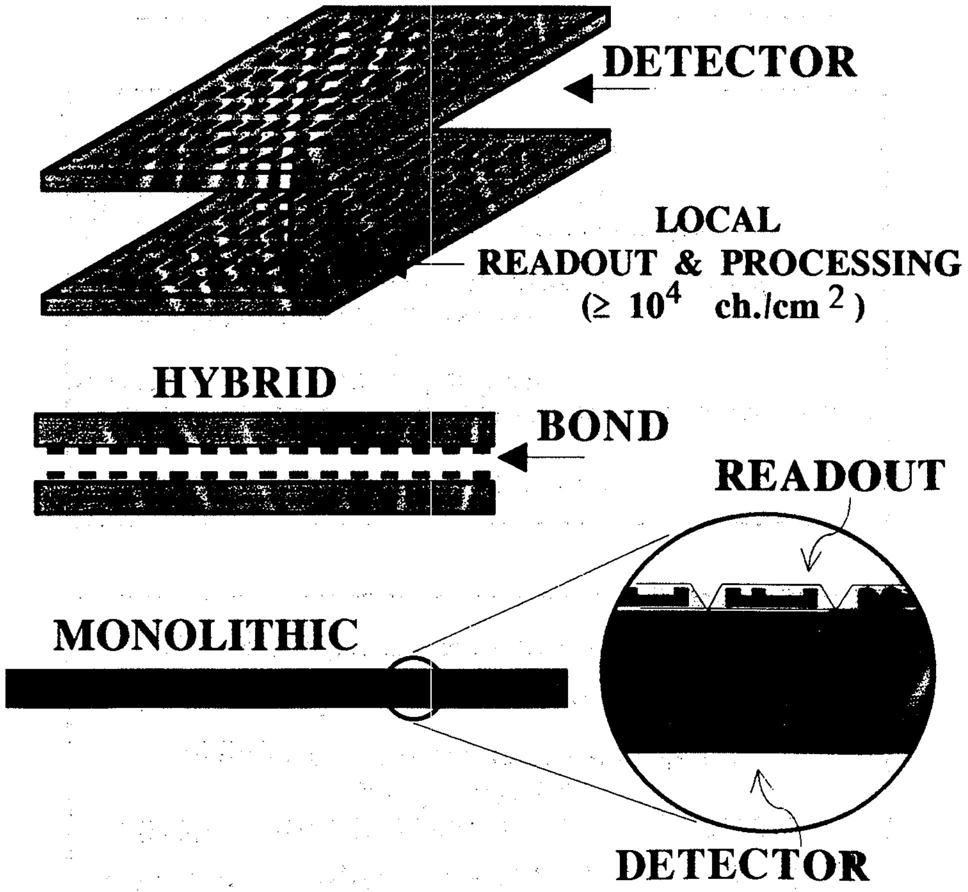
Single waveform deconvoluted

Deconvolution = fast pulse shaping
with low power (~100μW/channel)

only events passing level 1 trigger are processed

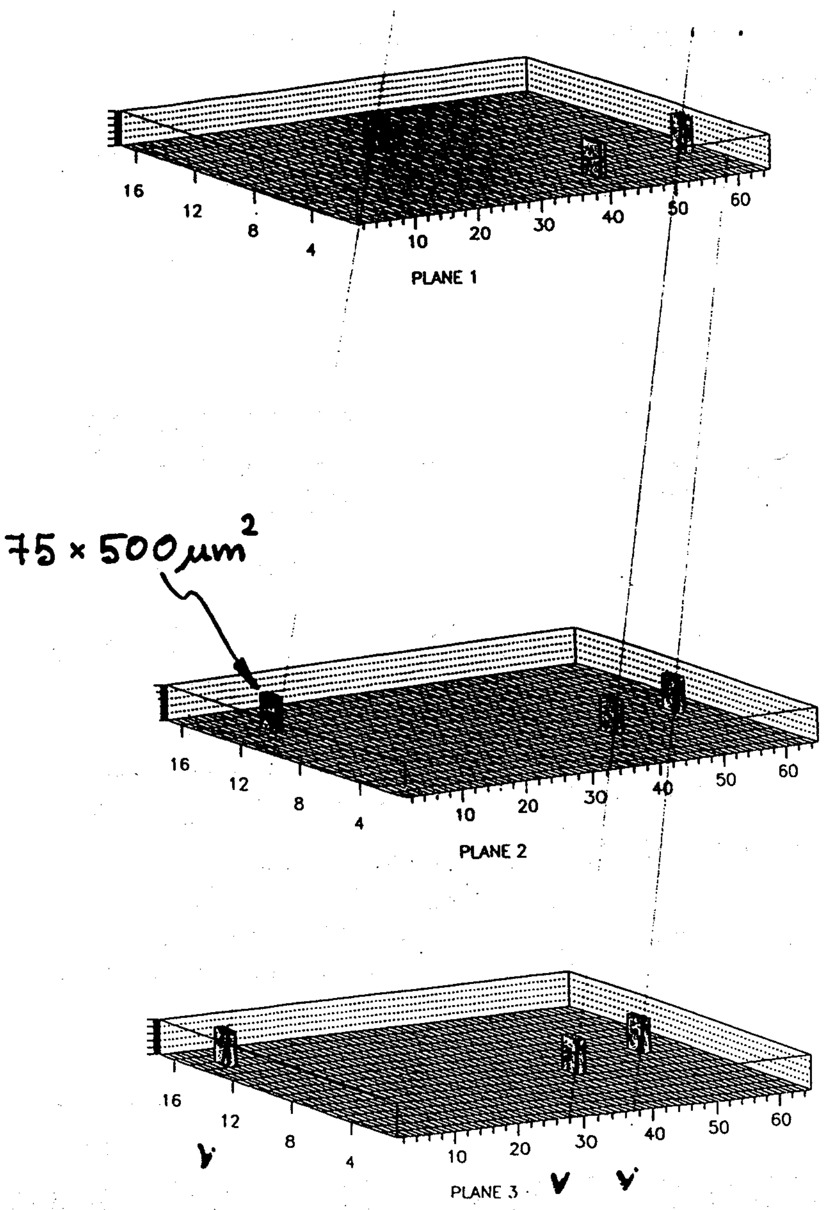
RD19 - Si PIXELS: CERN, COLL. DE FRANCE, MARSEILLE, ZURICH, IMEC, BARI, BOLOGNA, GENOVA, MILANO, MODENA, PADOVA, PISA, CANBERRA SEM., GEC-MARCONI, SMART SILICON SYSTEM

AIMS:
- ~ (100μm)² UNAMB. FINE GRAIN
- FEW μm, FEW ns ACCURACY



Si-PIXEL DETECTORS TESTED IN WA94
OMEGA HEAVY ION

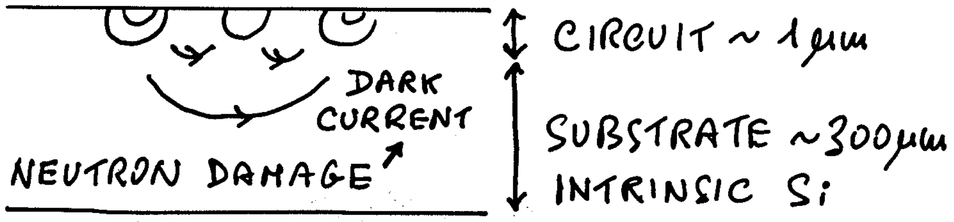
3 TRACK EVENT



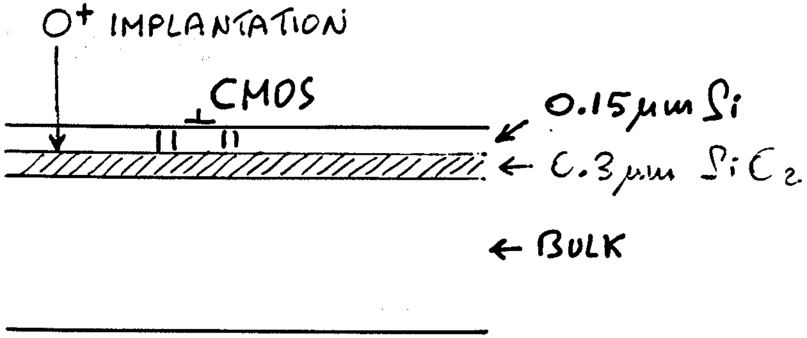
ALL THE COMPLEX CIRCUITRY
BEING DEVELOPED, MUST EVENTUALLY
BE IMPLEMENTED IN
RAD. HARD TECHNOLOGY

RD9 - SOI - CMOS RAD. HARD ELECTR.

CERN



SIMOX MATERIAL (THOMPSON)

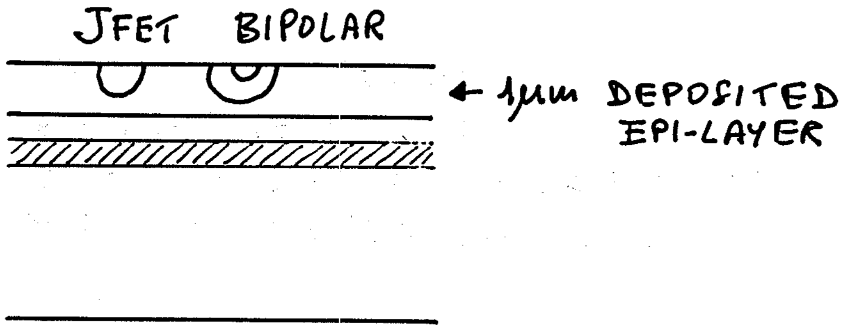


AIM : DEMONSTRATE THIS TECH. CAN BE IMPLEMENTED FOR DET. CIRCUITRY (ANALOGUE, etc.)

STATUS :

- RAD. TEST : 10 M_{rad} γ's , 2.5×10^{14} n's
  → REASONABLY GOOD
- ANALOG DEMONSTRATOR : END '92 - '93

- NEW PROPOSAL TO BE SUBMITTED BY MARSEILLE-SACLAY



- MORE FLEXIBLE BUT MORE EXPENSIVE

RD8: GaAs DETECTORS. BOLOGNA, CERN, FLORENCE, GLASGOW, RAL, LANCASTER, SHEFFIELD, MODENA

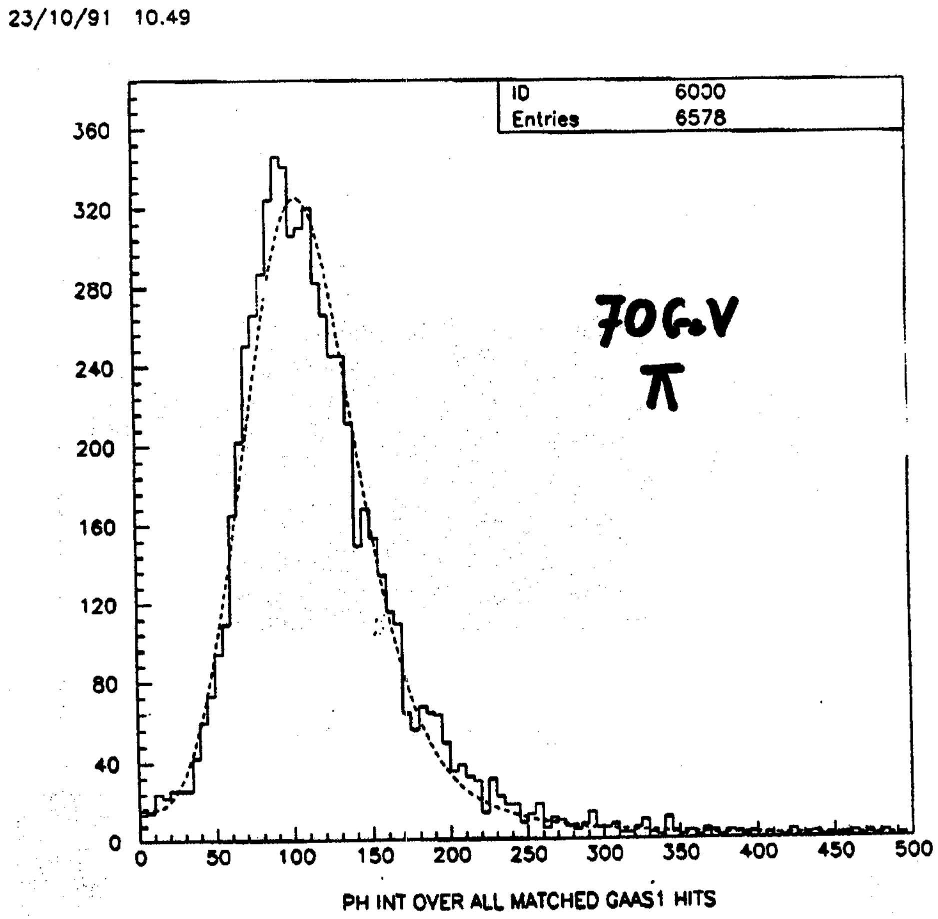
ADVANTAGES:

- RAD. HARDNESS (17 MRAD TEST)
- SPEED

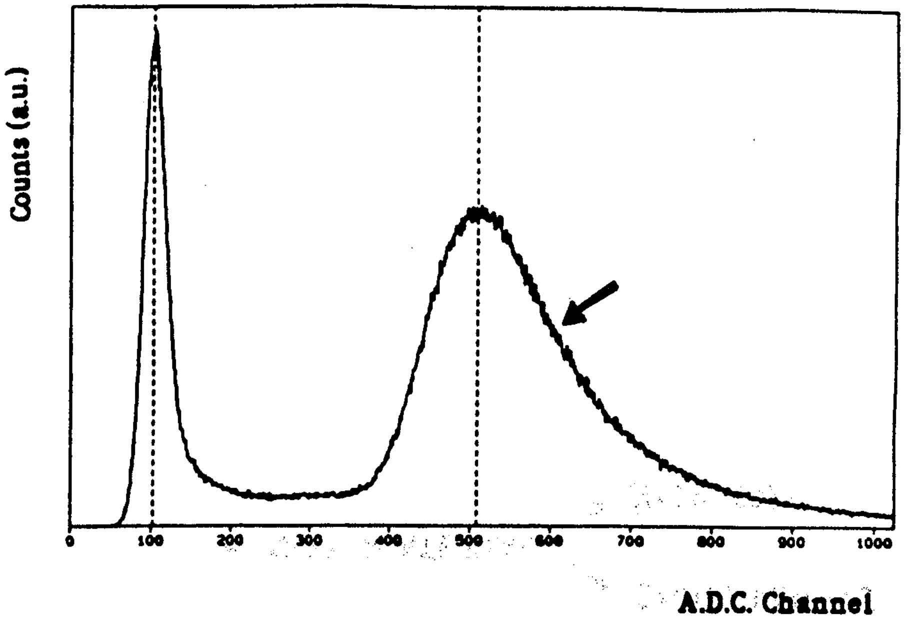
DISADVANTAGE:

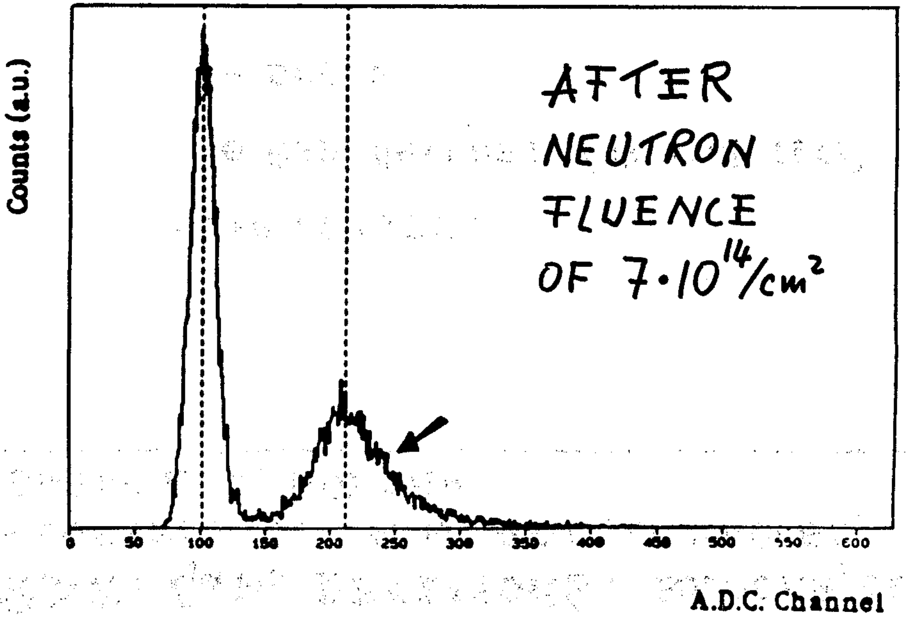
- POOR MATERIAL → SMALL WAFERS
  → HIGH COST

RD8: ΔE/Δx SPECTRUM FOR 600μm THICK GaAs DET. WITH 290μm STRIPS

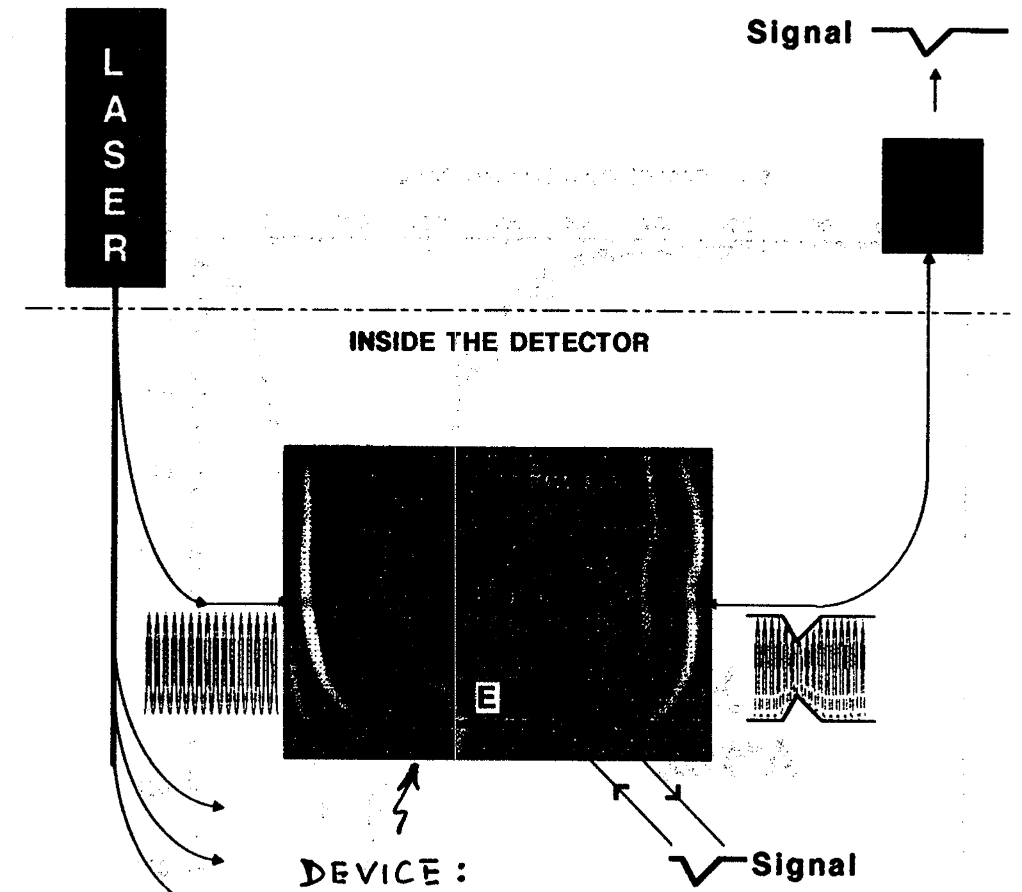


RD23-OPTOELECTRONIC ANALOGUE SIGN TRANSFER : BIRMINGHAM, CERN, LAUSANNE, GEC-MARCONI, IC LONDON, LUND, OXFORD, RAL





AFTER
NEUTRON
FLUENCE
OF $7 \cdot 10^{14}/cm^2$

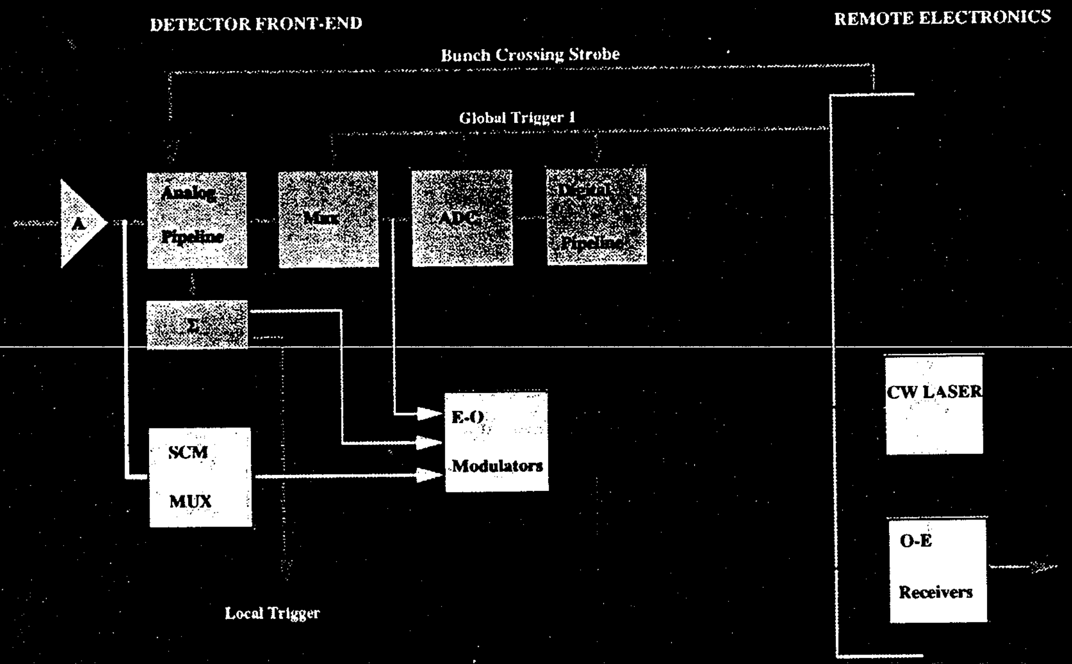


DEVICE :
MACH-ZENDER
INTERFEROMETER :
Ti DIFFUSION IN LITHIUM NIOBATE SUBSTRATE

LOW MASS, LOW POWER, RAD. HARD

Lightwave (Analog) Links in Front End Electronics-

Tracker/Preshower


DETECTOR FRONT-END
REMOTE ELECTRONICS
Bunch Crossing Strobe
Global Trigger 1
A
Analog Pipeline
Mux
ADC
Digital Pipeline
Σ
E-O Modulators
SCM MUX
Local Trigger
CW LASER
O-E Receivers

PERFORMANCE OF EXISTING DEVICE:

- INTERFERENCE → SINUSOIDAL TRANSFER CHARACTERISTIC

1% LINEARITY
1000/1 DYNAMICS

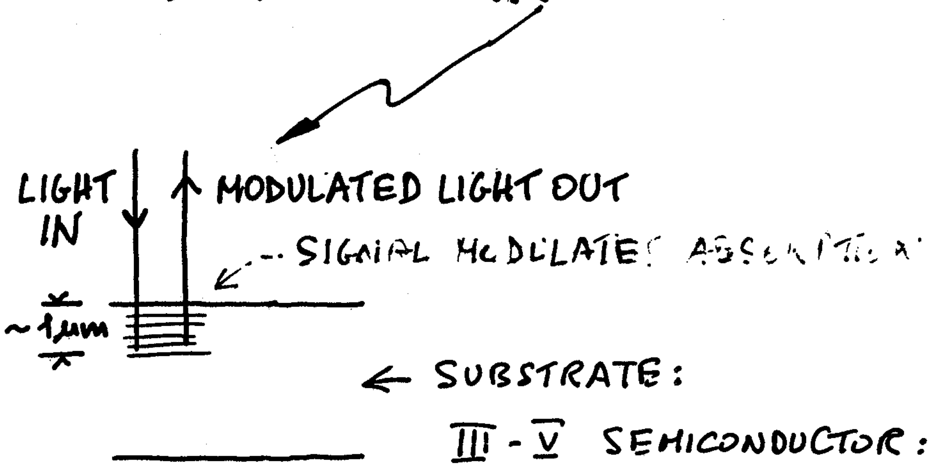
- SENSITIVITY : ~1mV OVER ~5pF
  (NOISE ~ 3fC)
- GHz SPEED

BUT EXPENSIVE NOW

- POSSIBLE REALISTIC GOAL:
  TRANSFER OF MUX ANALOGUE DATA
- PROJECTED COST (GEC-MARCONI):
  10 – 20 SF/OPT. CH.

RD23 PROGRAM

- DEVELOPE 16-CH. OPT. MODULATOR
- STUDY EXISTING **MQW** DEVICES



CAN BE INTEGRATED WITH ELECTR.

RD5 - STUDY OF μ. TRIGGER & MOMENT. RECONSTRUCTION IN A STRONG MAGN. FIELD, FOR A μ DET. AT LHC: AACHEN, CERN, MADRID, NIKHEF, PADOVA, ROMA, LOS ANGELES, RIVERSIDE, VIENNA, WARSAW

→ M. Della Negra

DAQ AREA

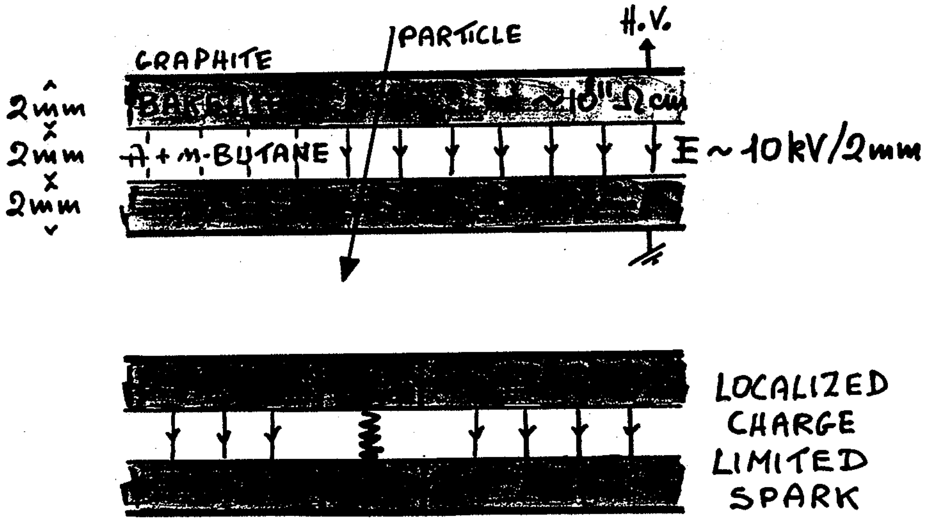
GENERAL: RD11, RD12, RD13, RD24 → S. Cittolin

DET. SPECIFIC: RD16

RD21 - R&D FOR COLLIDER b-PHYSICS AT LHC

→ P. Schlein

RESISTIVE PLATE CHAMBERS

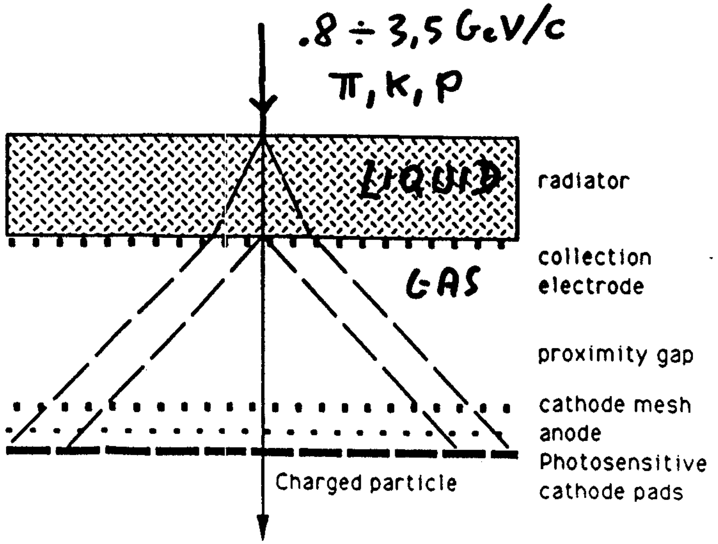


2-DIM. LOCALIZATION BY **x-y PICK-UP STRIPS**

- POTENTIAL HIGH SPACE ACCURACY **< 1mm**
- INTRINSIC HIGH TIME ACCURACY **~ 1ns**

P35 - DEVELOPMENT OF A LARGE AREA ADVANCED FAST RICH DETECTOR FOR PART. IDENTIFICATION AT LHC OPERATED WITH HEAVY IONS : BARI, CERN, COIMBRA, GIESSEN, MUNICH, PADOVA, ZAGREB

AIM : TEST OF PHOTOSENSITIVE CATHODE PADS IN A WIRE CH. RICH DETECTOR



RD22 - BEAM EXTRACTION BY CRYSTAL CHANNELING AT SPS : A FIRST STEP TOWARDS BEAM EXTRACTION AT LHC :

AARHUS, CERN, FRASCATI, LECCE, I.C. LONDON, PISA, ROMA, STRASBOURG, MPI-STUTTGART, TORINO, TRIESTE

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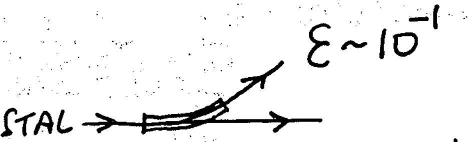
* STANDARD METHODS FOR BEAM EXTRCTION ARE DIFFICULT AT LHC

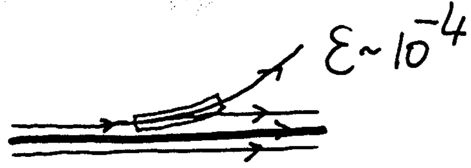
- RD22 AIM : USE SPS TO DEMONSTRATE HI-E EXTRACTION POSSIBLE BY BENT CRYSTAL WITH BEAM CONDITIONS SIMILAR TO LHC
- FINAL AIM AT LHC :

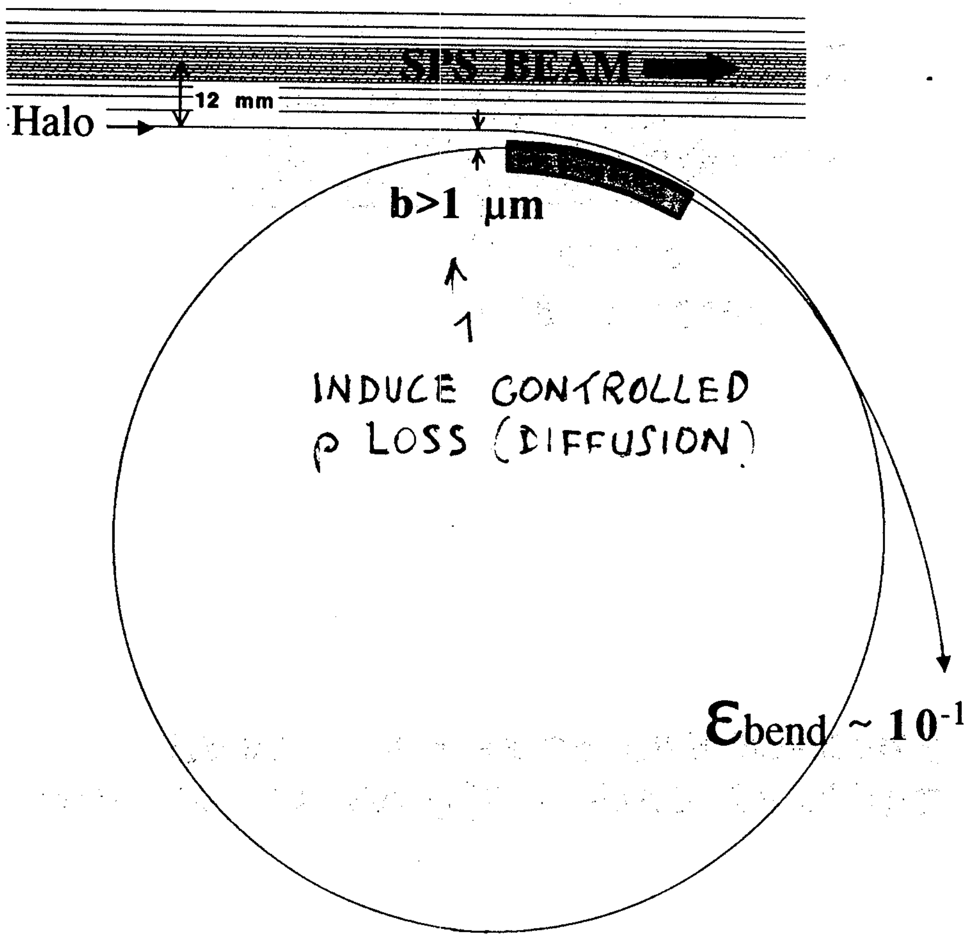
$4 \cdot 10^9 p/s$ HALO → $4 \cdot 10^8 p/s$ BEAM

DONE
- BEAM ON CRYSTAL → (H8, CERN)



- IN THE HALO (SERPUKHOV)





- CRYSTAL : $1 \times 10 \times 30\ mm^3$, $\Delta\theta = 8{,}5\ mrad$
- EXTRACTED BEAM MEASURED BY GAS μ-STRIP & SCINT. HODOSCOPE

CONCLUSIONS

- PARTICIPATION IS INTENSE & ENTHUSIASTIC, PROGRESS IMPRESSIVE: MOST OF THE 1st YEAR GOALS HAVE BEEN ACHIEVED, IN SOME CASES FASTER OR BETTER THAN PLANNED

- SEVERAL NEW POWERFUL DETECTORS ARE ALREADY AVAILABLE FOR LESS DEMANDING APPLICATIONS

- HOWEVER FURTHER PROGRESS IS NEEDED FOR LHC

- VISIBLE INFLUENCE OF PROTOCOLLABORATIONS:

  POSITIVE ASPECT: BETTER FOCUSSING ON REALISTIC GOALS

  NEGATIVE ASPECTS SHOULD BE MINIMIZED (A HOPE ...)

Triggering & data acquisition

S. Cittolin (CERN)

Triggering and Data Acquisition

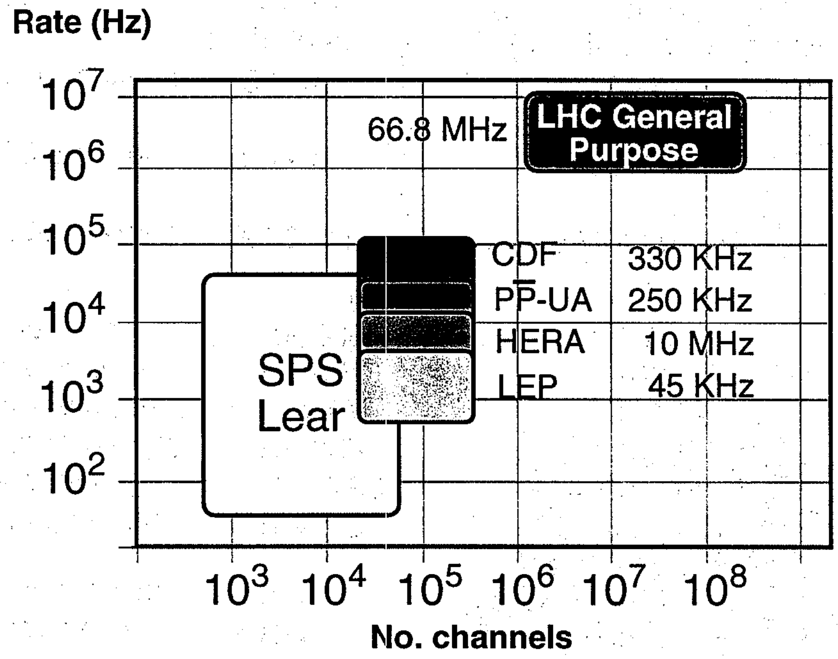
S. Cittolin / CERN-ECP. Evian, March 92

- Data acquisition architecture
- Frontend
- Trigger level 1
- Optoelectronics
- Trigger level 2
- Readout

LHC Parameters

LHC parameters

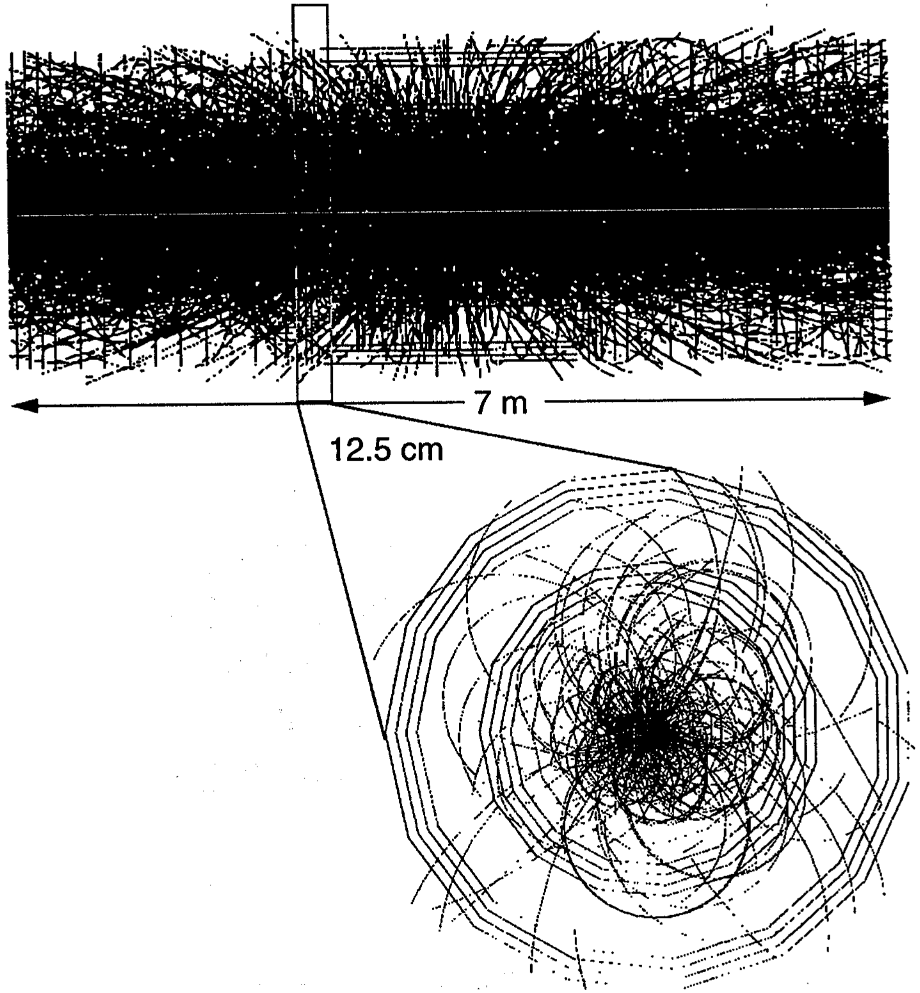
Luminosity	**1.8 •10^{34} $s^{-1}cm^{-2}$**
Bunch separation	**15 , 30, 45 ns (66.8, 33.4, 22.4 MHz)**
Event rate	≈ **GHz** (≈ 20 Ev/bunch)
No. channels	**10^6 - 10^8** General Purpose Experiment



S. Cittolin Evian March91

CMS Central Tracking

Central tracking at L = 1.8 10^{34} (50 ns integration, ≈ 2000 tracks)



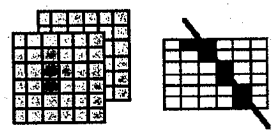
Towards LHC

	SPS Collider		LHC	
Central tracking	≈ 10^4		10^6 - 10^8 chan.	
Calorimetry	≈ 10^4		≈ 10^5	
Muon tracking	≈ 10^4		≈ 10^6	
Raw data rate	≈ 10^2 GB/s		≈ 10^6 GB/s	
Data rate LVL1	≈ 100 MB/s		≈ 10^3 GB/s	
Data rate LVL2	≈ 10 MB/s		≈ 10^2 GB/s	
Data rate LVL3	≈ 10 MB/s		≈ 1 GB/s	
Rate on tape	≈ 1 MB/s		≈ 100 MB/s	
Event size	≈ 100 KB		≈ 1 MB	
Trigger Level 1	≈ 50000 Hz		66800000 Hz	
Trigger Level 2	30 Hz	10^{-4}	100000 Hz	10^{-6}
Trigger Level 3	20 Hz (e, μ, jets)		1000 Hz (e, γ, μ, jets, W, Z_0 ...)	
Tape	≈10 Hz		≈ 10 Hz	
Analysis	≈10^{-4} Hz (W, Z_0)	10^{-4}	≈10^{-6} Hz (Higgs)	10^{-6}

100

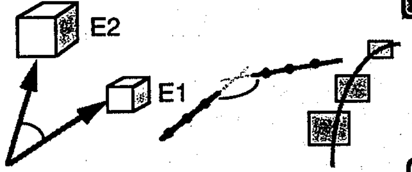
Trigger Levels

1



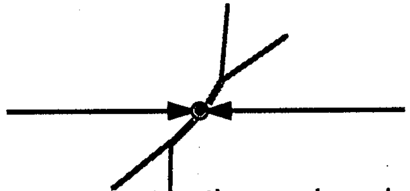
- High p_T electron, jets, muon, $\not{E}_T$
- Cluster and Track finding

2

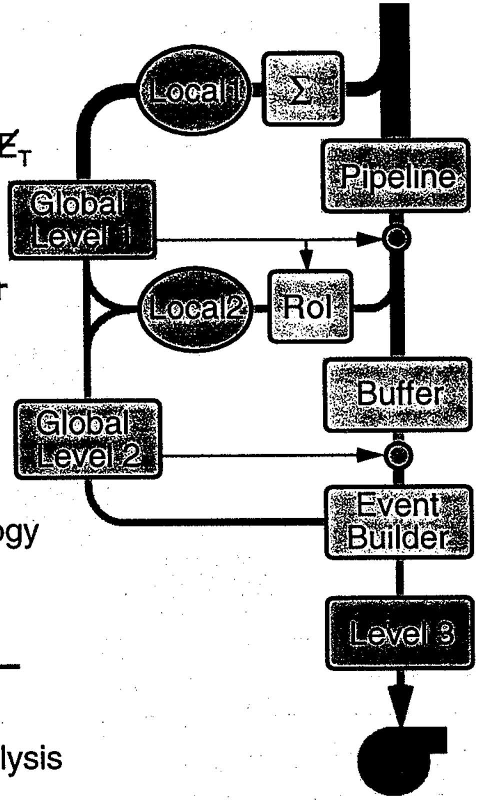


- Finer granularity
- Effective masses
- Track reconstruction
- Detector matching and topology

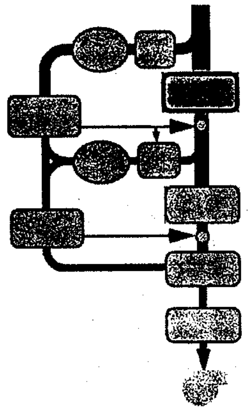
3

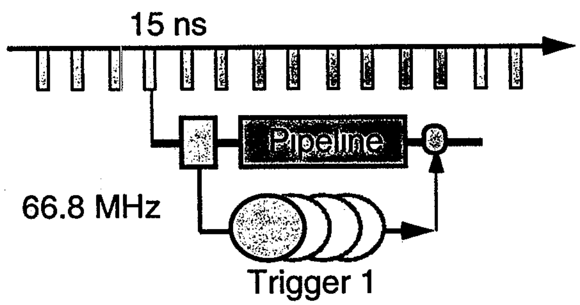


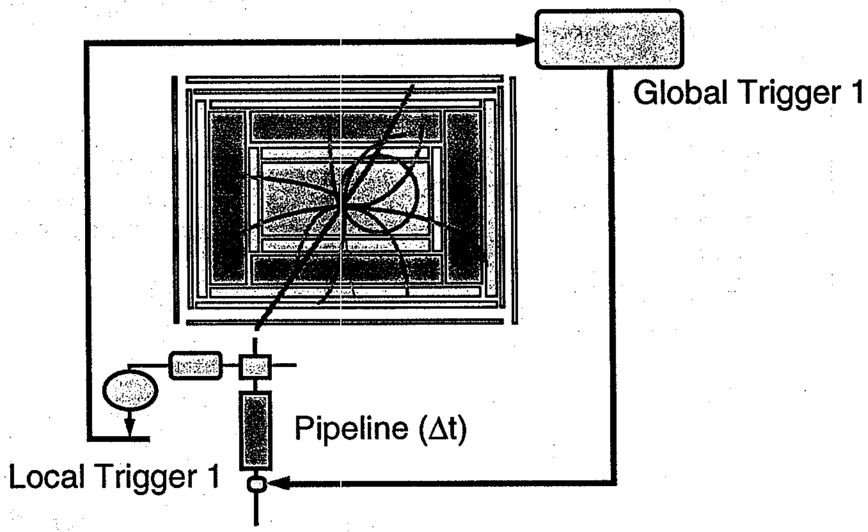
- Event reconstruction and analysis



Channel Data Pipeline

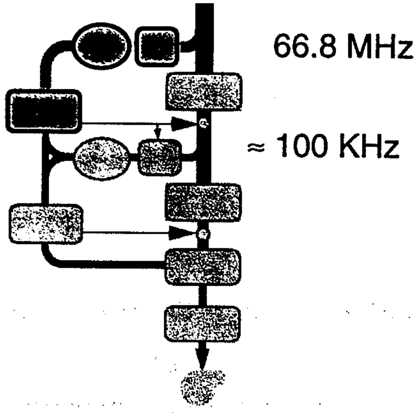






Δt = TOF + Detector + Preprocessing + Local Trigger
+ Global Trigger + Cable Delay + Distribution

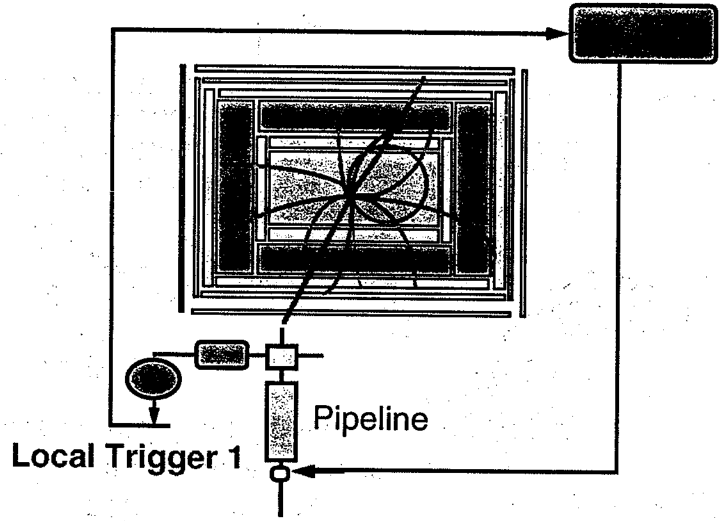
First Level Trigger

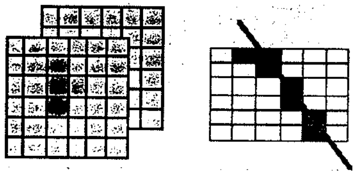


Synchrounous system
15ns pipelined

Global Trigger 1

Bunch	e#1	...	µ#1	...	Jet	...
100	✓				✓	
1200			✓		✓	
1600	✓	✓				
2100						





- High p_T electron, jets, muon, $\not{E}_T$
- Cluster and track finding

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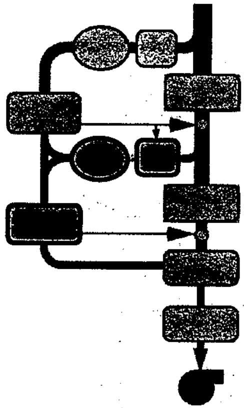
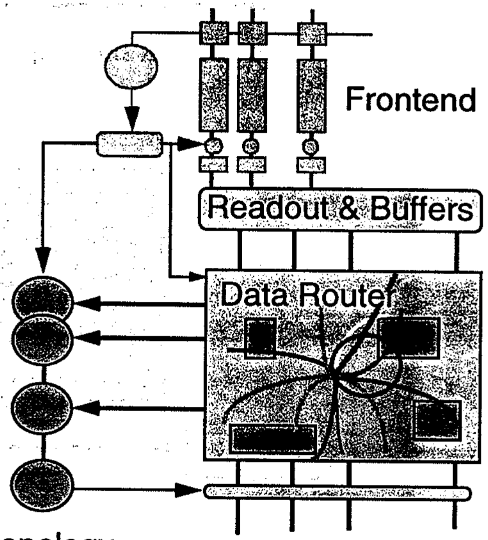
Second Level Trigger

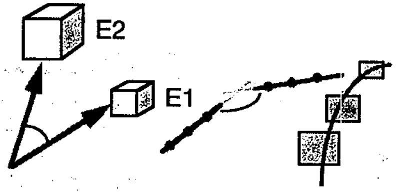


Asynchronous system
RISC, DSP farms



Feature extraction
- Make Roads
- Histograms
- Find Peaks

- Finer granularity
- Effective masses
- Track reconstruction
- Detector matching and topology



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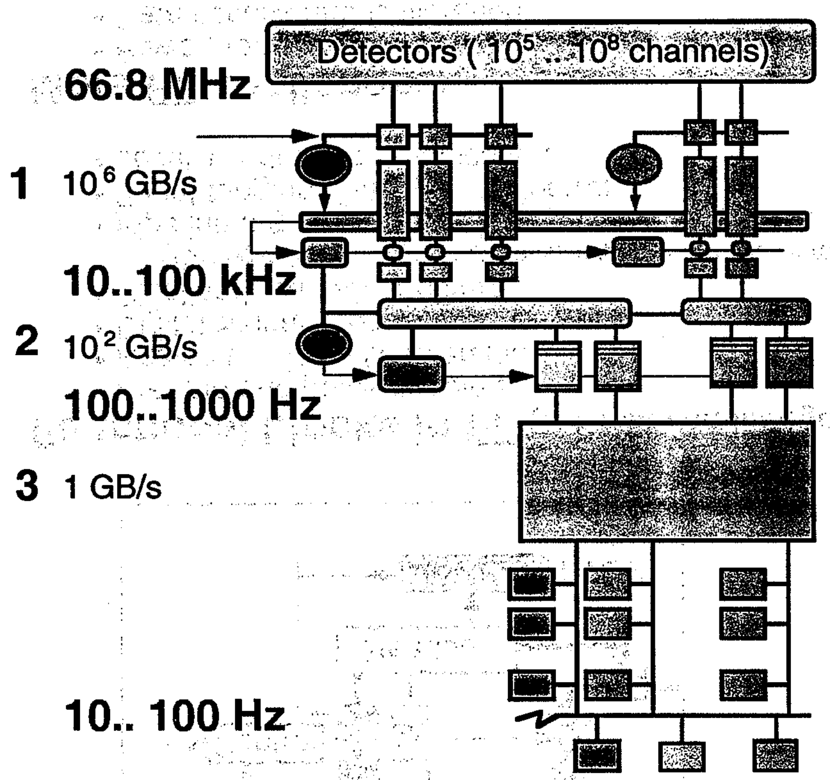
LHC Data Acquisition



Current R&D :

Subsystem developments (applied to detector R&D) :

- Select technologies and acquire expertise
- Develop concepts and implement prototypes
- Develop industry partnerships

R&D Projects

Frontend

RD-2	Proposal to study a **tracking/preshower detector** for the LHC. (CERN, Cambridge, Dortmund, Hamburg, Melbourne, Olso, Oxford, INFN Perugia, RAL, Sydney)
RD-19	Development of hybrid and monolithic silicon **micropattern detectors.** (CERN, CDF, EPFL, INFN, IMEC, CPPM)
RD-20	Development of high resolution **Si strip detectors** for experiments at high luminosity at LHC (CERN, INP Cracow, Helsinki, Norway, RAL, LEPSI, INFN Turin, Yale)
RD-9	A demonstrator analog signal processing circuit in a **radiation hard SOI-CMOS** technology. (CERN, TMS)
RD-16	**A digital front-end** and readout microsystem for calorimetry at LHC. (CERN, Linkoping, INFN, Stockholm)
RD-12	Readout system **test benches.**(CERN, LAPP, INFN, Helsinki, Tampere)
MEC2	**A micropipelined first level** storage buffer with data recalibration and selective zero suppression. (CERN/ECP-MIC)
RD-23	**Optoelectronic** analog signal transfer for LHC detectors.(CERN, Birmingham, EPFL, Imperial College, Oxford, GEC-Marconi)

Second level trigger

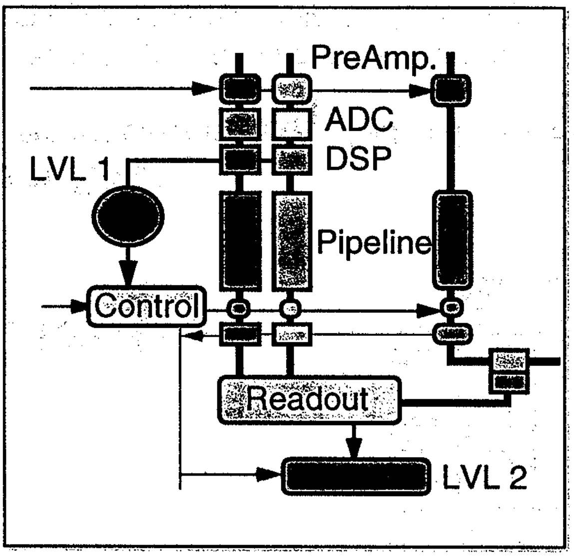
RD-11	Embedded **architecture for second-level** triggering in LHC experiments (EAST). (CERN, NIKEF, Bucharest, Budapest, Cracow, EPFL, INFN, London, Uthrech, Zeuthen)
MPPC	Massive **Parallel Processing** Collaboration. (CERN, ASPEX, Saclay, IN2P3)

Data acquisition & computing

RD-13	A scalable **data taking system** at a test beam for LHC (CERN, INFN Pavia, Rome, LBF, Saclay)
GP-MIMD	**GP-MIMD** project ((C-Esprit, INMOS, MEIKO, PATSYS, TELMAT, CERN, European universities)
RD-24	Applications of **Scalable Coherent Interface (SCI)**

Frontend

66.8 [33.4, 22.3] MHz



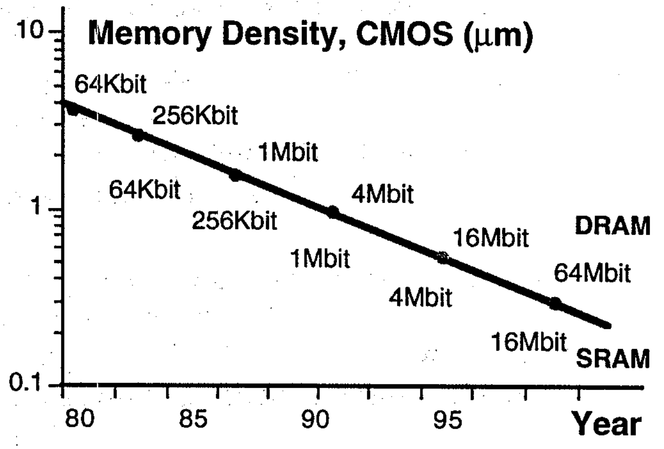
Functional blocks in FE (the main challenges):

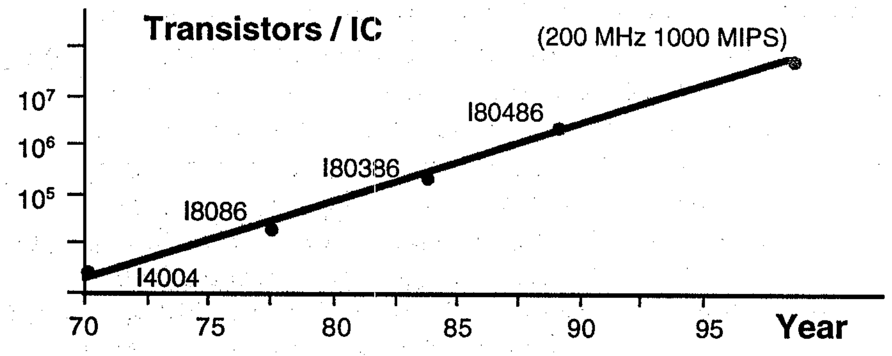
- Preamp and pulse shaping
- Analog to Digital Conversion
- Digital Signal Processing
- Pipelined readout structures
  (Analog delays / Digital pipelines, μpipelined architectures)
- Pipeline trigger and data flow processor systems
- Event tagging. Timing and Control
- Level 1-2 data communication

More FE challenges:

- Power, radhard, cabling, packaging, cooling
- Data access and Calibration

Technology Trends

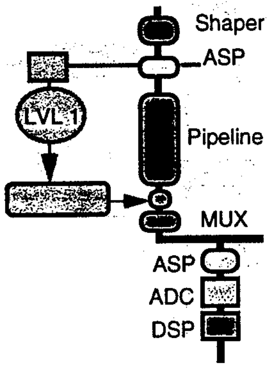




Collider/LEP	LHC
≈ 10^5 channels	≈ 10^7 channels
≈ 10^5 byte/ event	≈ 10^6 byte/ event
≈ 10^5 Hz rate	≈ 10^7 Hz rate

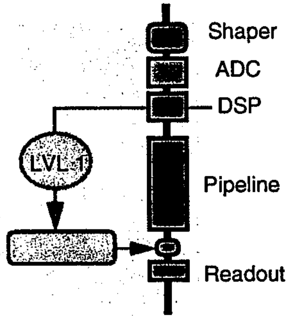
Analog / Digital frontend

ANALOG



↓ Dynamic range ↑
↓ Flexibility ↑
↑ Packaging, power ↓

DIGITAL

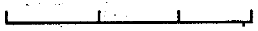


Low dynamic range (≤8bits)	Large dynamic range (15bits)
Low resolution (<8bits)	High resolution (10-11bits)
No. of channels 10^5.. 10^8	No. of channels ≤ 10^5
RD-19 Micropattern detector	RD-16 Spacal, FERMI
RD-2 Preshower. SITP	RD-12 Accordion.
RD-20 Strip detectors. APSP	µE-ECP MEC2, µDAQ system

One pipeline step (15 ns) :

≈ 1 capacitor + 4 switches

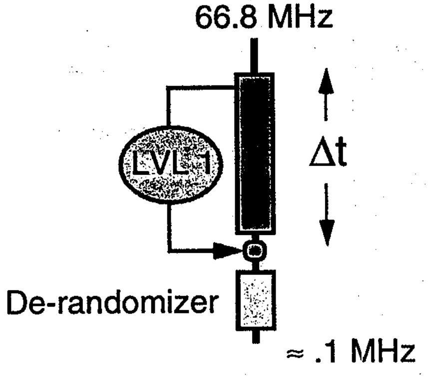
≈ 50 gates



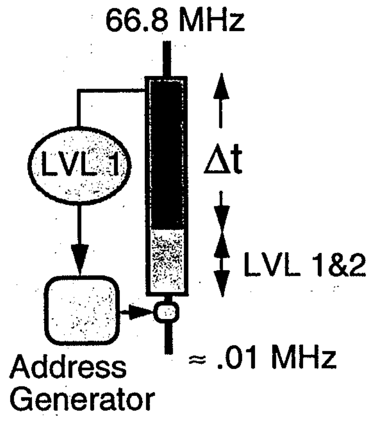
3m cable

Pipeline Architecture

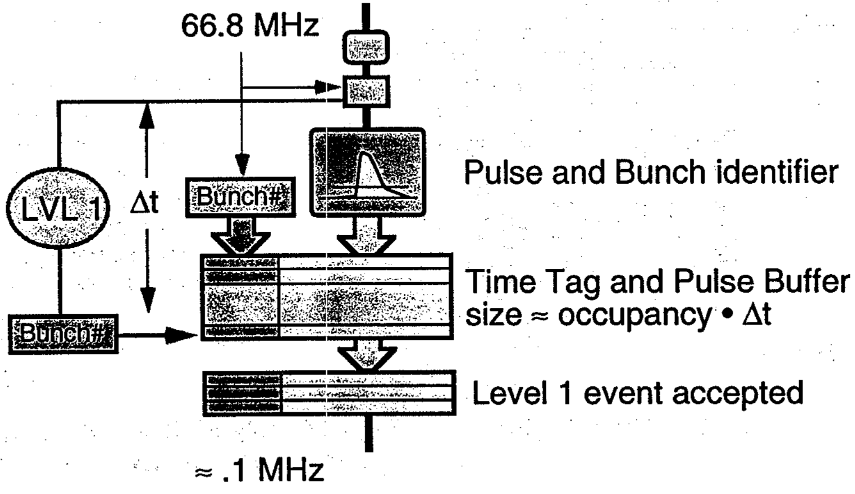
Delay Line



Memory File (SAPE, FERMI)

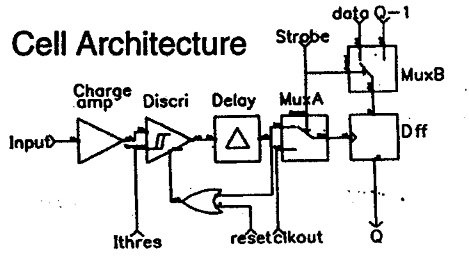


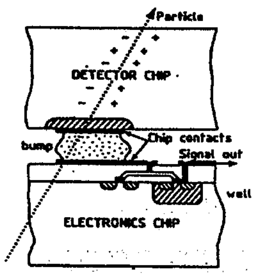
Time tagging & Time window buffering (MEC2)

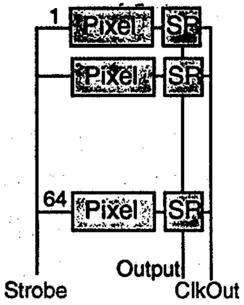


Micropattern Detector. RD-19

Cell Architecture

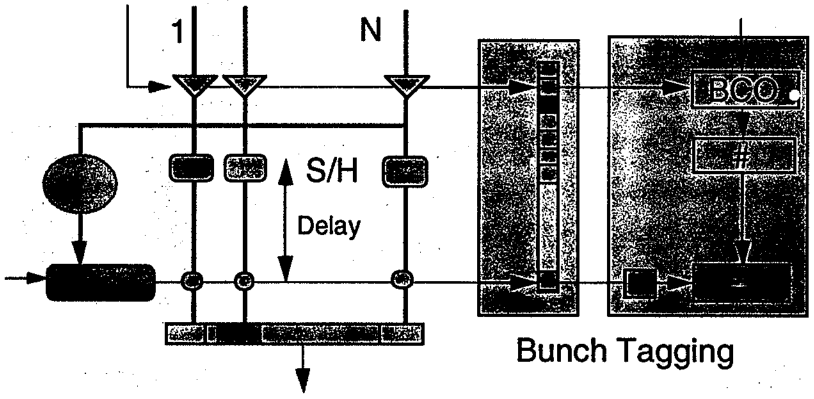






- Matrix of 16•64 pixel of 75μm•300μm. ≈ 20μW/channel
- Threshold 4000 e⁻ ± 1000 e⁻. Noise ≈ 60e⁻
- Minimum strobe width ≈ 200 ns. Maximum delay ≈ 1μs
- 16 bit serial readout at 5 MHz

Very Low occupancy detectors (Occ << Pipeline • N)



Bunch Tagging

Analog Pipeline (SITP, RD-2)

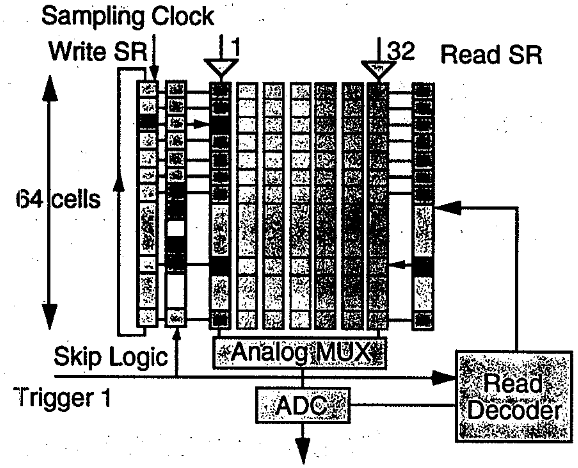
Silicon Tracker Preshower SITP. RD-2
HARP (Hierarchical Analog Readout Pipeline Processor)

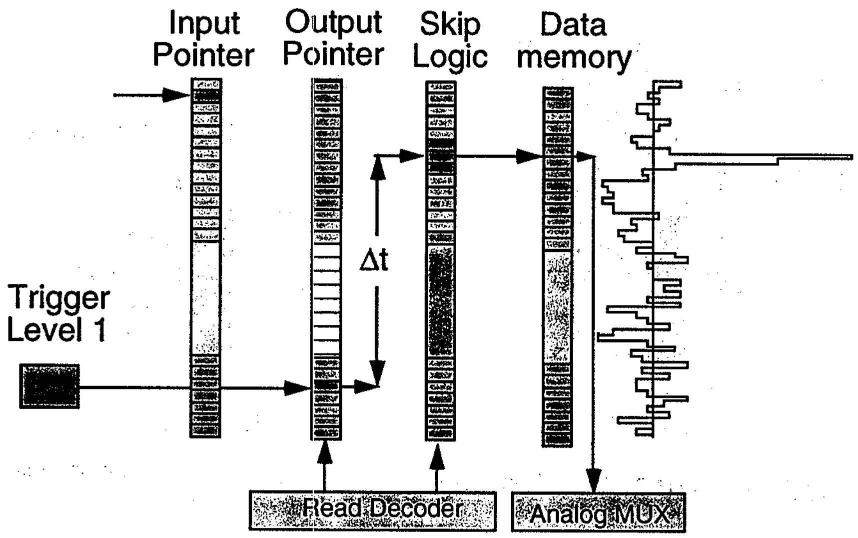
SAPE :

4 / 32 / 128 channels pipeline. 66MHz

64 storage elements using switched capacitor techniques with sparse data scan

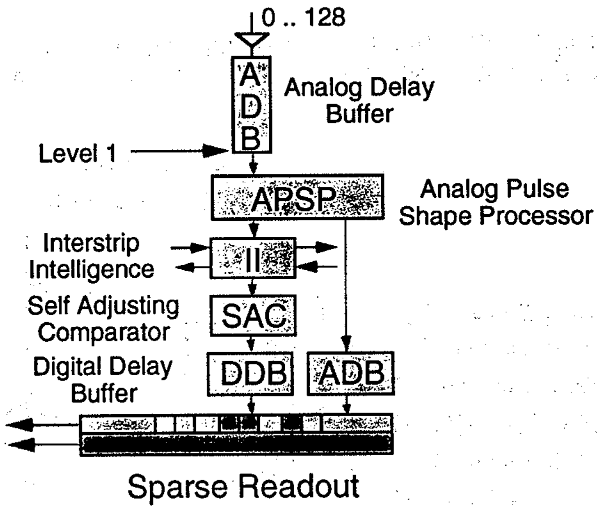
- 1.2 CMOS (SOI-CMOS). 5 - 10 mW /channel
- ≈ 400 μV output noise. 4V dynamic range
- 40 mV/MIP gain (ICON). 1 MIP = 25000 e⁻
- < 1% internal crosstalk





SI Strip detector. RD-20

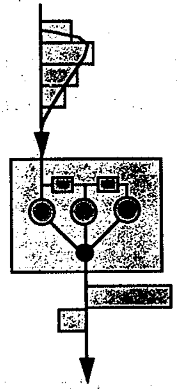
RD-20 Development of high resolution **Si strip detectors** for experiments at high luminosity at LHC



Sparse Readout

Analog deconvoluter

- Recovery of timing information
- Removal of pileup

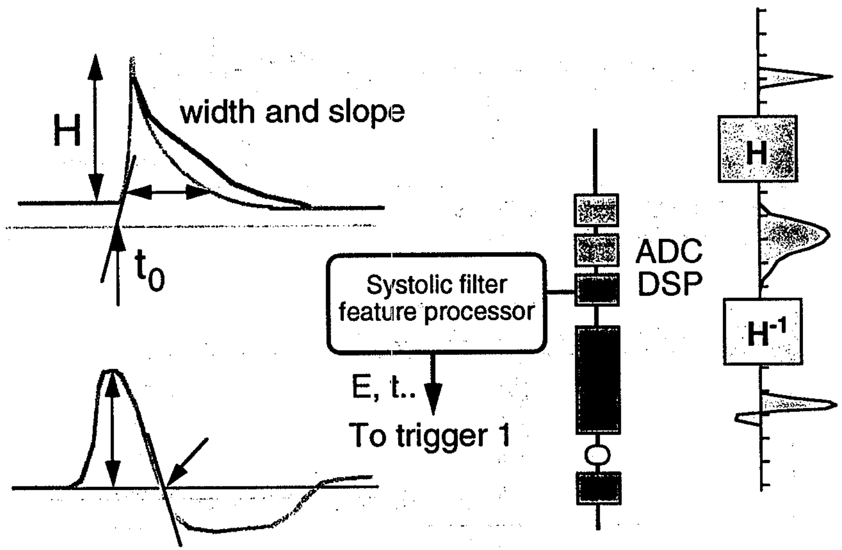


Σ h(n)•x(n-k)

15ns shaped pulse

Digital Signal Processing

The signals generated by an LHC calorimeter cell will be diffused over more than one bunch crossing. A digital channel with programmable filter capability is needed to extract the physical information and to associate events within bunch crossings.
In addition the digital analysis can be the first step of the trigger process.



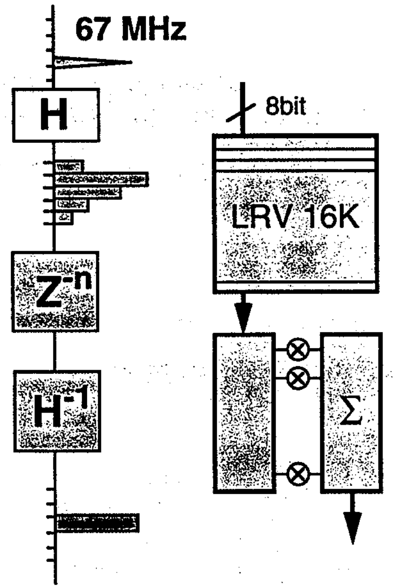
Apart from considerations of power consumption, electronics packaging and radiation hardness, it seems very attractive to go digital immediately after the preamplifiers, complementing the analog shaping with a **pipelined digital signal processor**.

Basic filter operation : $\sum \mathbf{x_i} \bullet \mathbf{w_i}$

Digital Pipe & Filter. RD-12

HDTV digital pipeline Test Bench.

IC prototypes designed and developed by CNET (Centre National d'Etudes des Telecommunications) in Grenoble in the framework of the HDTV project



LRV 16K.
Memory delay line.
2048 Bytes 72MHz FIFO

MULAC8.
Transversal filter processor.
94MHz Systolic array of
8 multiplier/adder
XOUT(30bits) = ∑ XIN(i)•W(i)
[10bit•12bit, i=1-8]

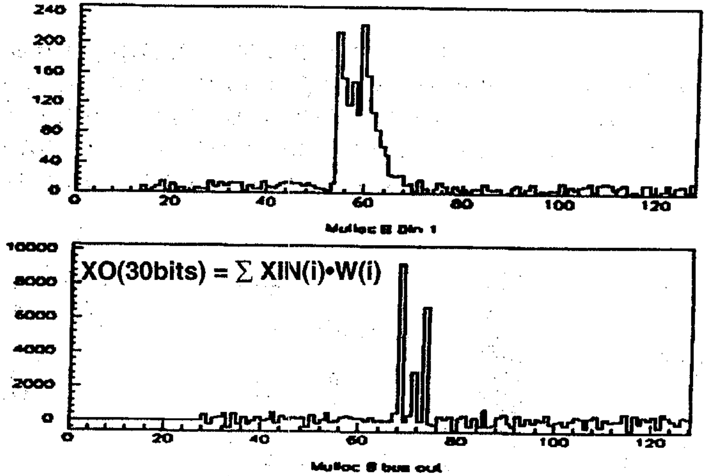
Bunch crossing identification
and energy evaluation

The new technology (.5µm) will allow the integration in a single chip of 16 bit digital filters and memory delay lines.......

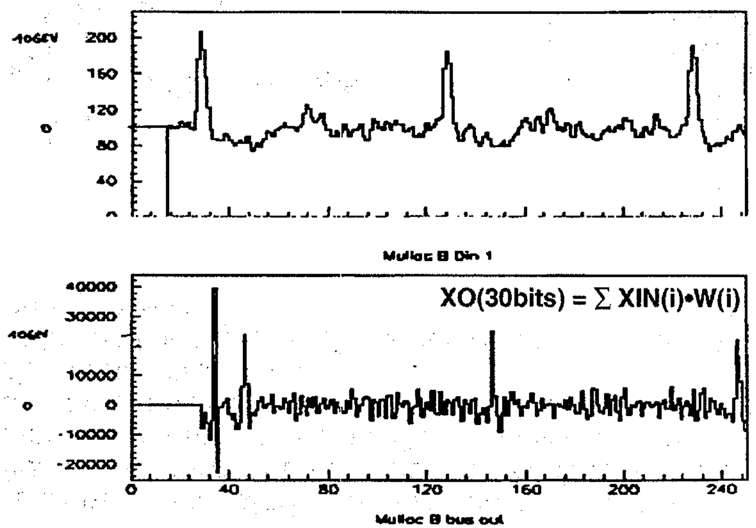
---

66 MHz Digital Deconvoluter

w1	w2	w3	w4	w5	w6	w7	w8
0	0	0	0	0	0	-32	45



w1	w2	w3	w4	w5	w6	w7	w8
230	-629	451	64	-53	-40	56	-79

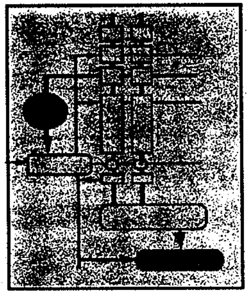


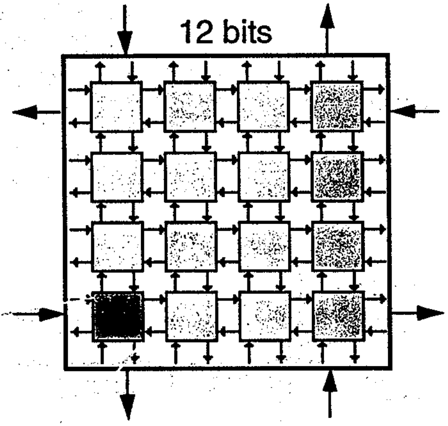
VSP test bench. RD-11 and RD-12

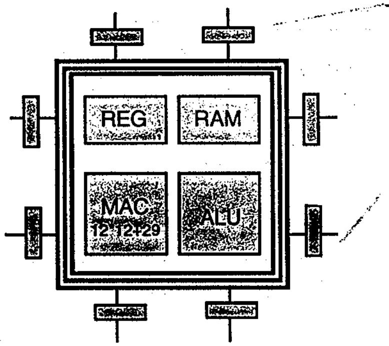
DAVIS. Data Driven Video Signal Processor

(ITT-Intermetal)

- 16 cells 125 MHz 1991 (1.2µ CMOS)
- 64 cells 200 MHz 1994 (.8µ CMOS)



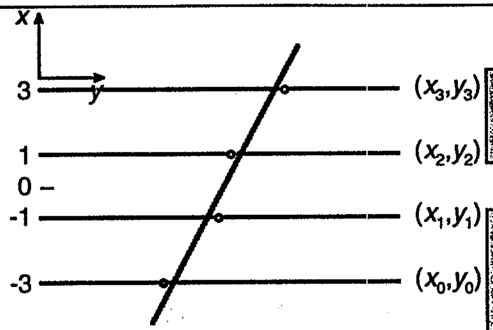




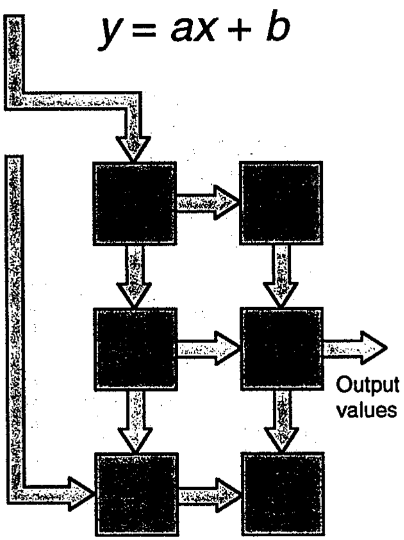
- Programmable
- Data-driven
- Pipelined (7.5 ns)
- Σ x•y. (12•12bits -> 29bit)

- Software simulation of data driven systems :
  - Pulse feature extraction : Zero-crossing, Max/Minimum, Area...
  - Computational algorithms : Least square fit, Spline....
  - Digital Filters
  - Clustering and total energy
  - Tracking
  - Image processing functions
- Prototype integration in a frontend test bench

Least mean squared error line fitting



$y = ax + b$



$$\begin{bmatrix} n & \Sigma x \\ \Sigma x & \Sigma x^2 \end{bmatrix} \begin{bmatrix} b \\ a \end{bmatrix} = \begin{bmatrix} \Sigma y \\ \Sigma x y \end{bmatrix}$$

$$\begin{cases} a = -0.15\, y_0 - 0.05\, y_1 + 0.05\, y_2 + 0.15\, y_3 \\ b = 0.25\, y_0 + 0.25\, y_1 + 0.25\, y_2 + 0.25\, y_3 \end{cases}$$

- **2 instructions / output sample pair**
- **62.5 MHz (for 125 MHz clock)**

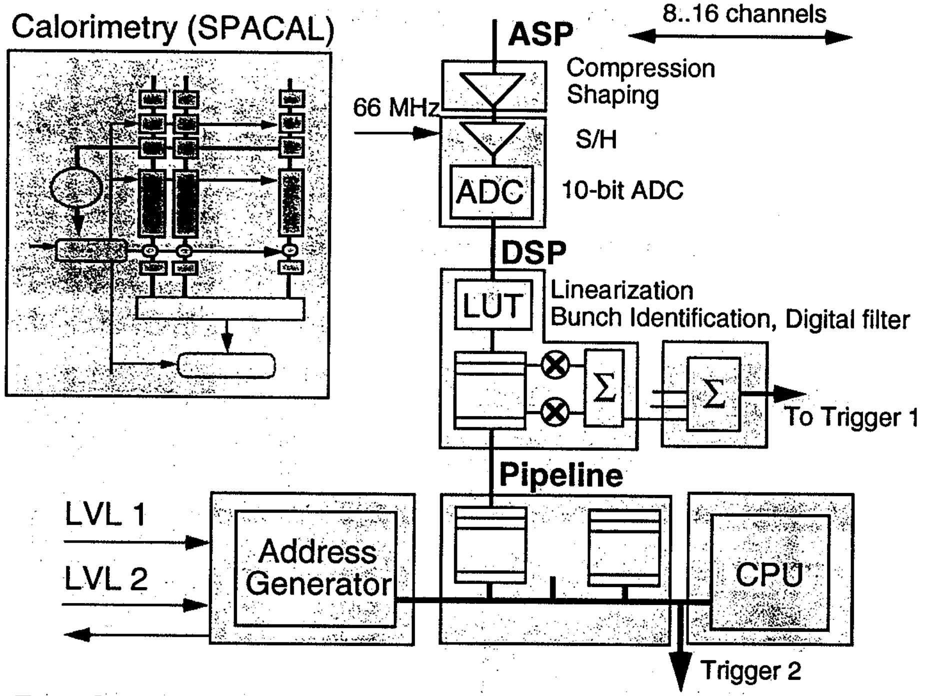
Algorithm distribution between cells

```
     .north 0, 0, 0
     .west  0, 2, 0
     .cell  0, 0, 0
     r0 = -0.15
     r1 = -0.05
     nop,                bra loop
     nop
loop acc = r0 * n,     e = n,  bra loop
     s = acc + r1 * n,  e = n
     .cell  0, 0, 1
     r0 = 0.25
     r1 = 0.25
     nop,                bra loop
     nop
loop acc = r0 * w,            bra loop
     s = acc + r1 * w
     .cell  0, 1, 0
     nop,                bra loop
     nop
loop e = n + s,             bra loop
     nop
```

```
        .cell  0, 1, 1
        nop,                            bra loop
        nop
loop    e = w,                          bra loop
        e = n + s
        .cell  0, 2, 0
        r2 = 0.05
        r3 = 0.15
        nop,                            bra loop
        nop
loop    acc = r2 * w,         e = w,    bra loop
        n = acc + r3 * w,     e = w
        .cell  0, 2, 1
        r2 = 0.25
        r3 = 0.25
        nop,                            bra loop
        nop
loop    acc = r2 * w,                   bra loop
        n = acc + r3 * w
        .end
```

FERMI. RD-16

FrontEnd Readout MIcrosystem

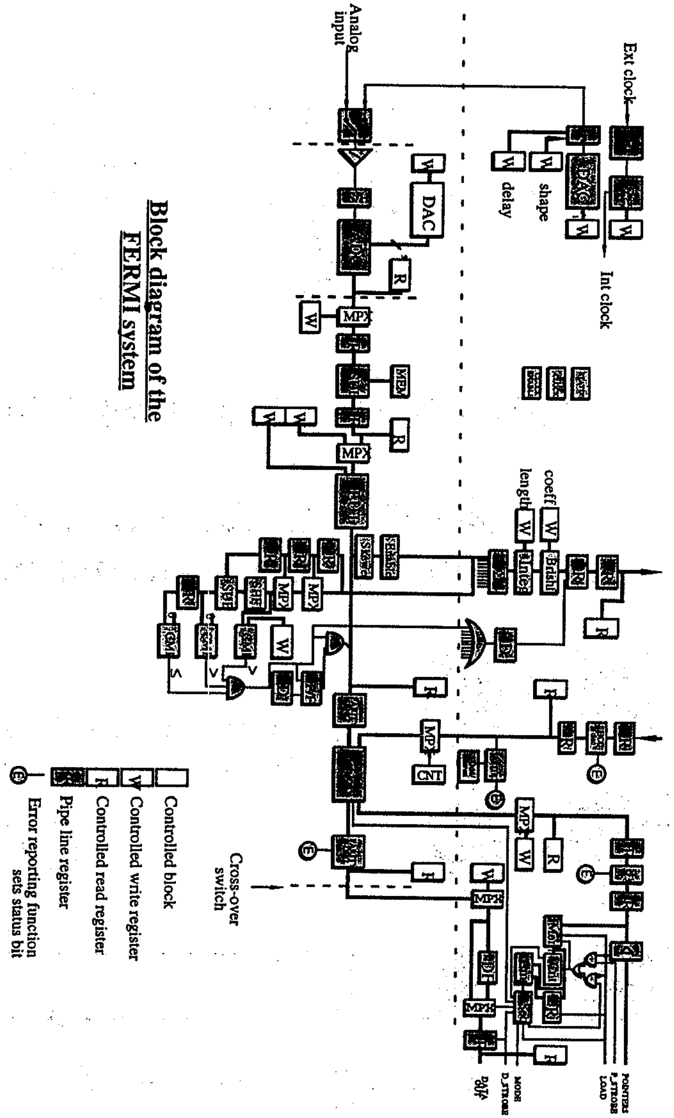


Design Goals :

- CMOS 1µm
- 15 bit (compressed) dynamic range
- Pipelined ADC. 10 bit resolution
- Digital Signal Processing. Time tagging, Level 1 Sums
- Data storage during LVL1 & LVL2 latency
- Fault tolerance & reconfigurability
- Si-on-Si Microsystem architecture

and . . . .

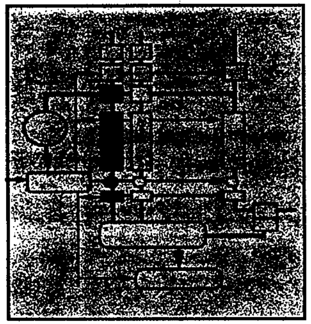
- Power, radhard, connectivity, packaging, cooling
- Data transfer (bandwidth), calibration



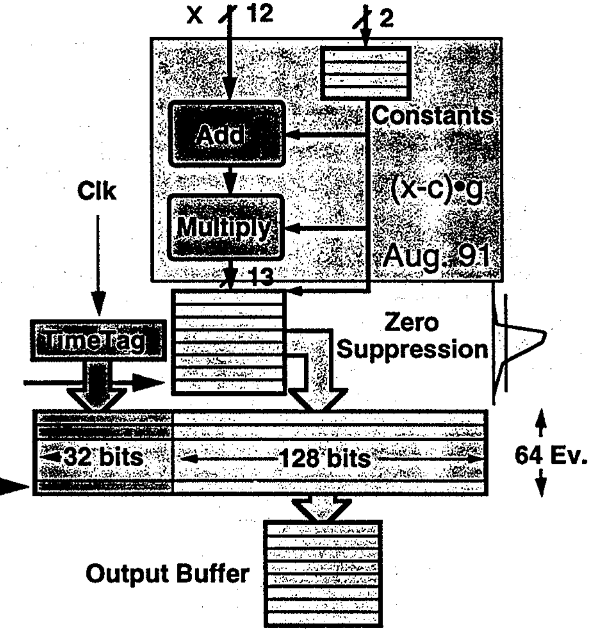
Block diagram of the FERMI system

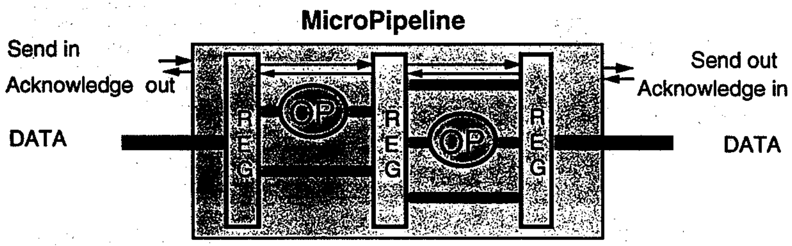
MEC2 μpipeline

Micropipelined Equalizator Corrector and first level storage buffer (CERN/ECP-MIC)

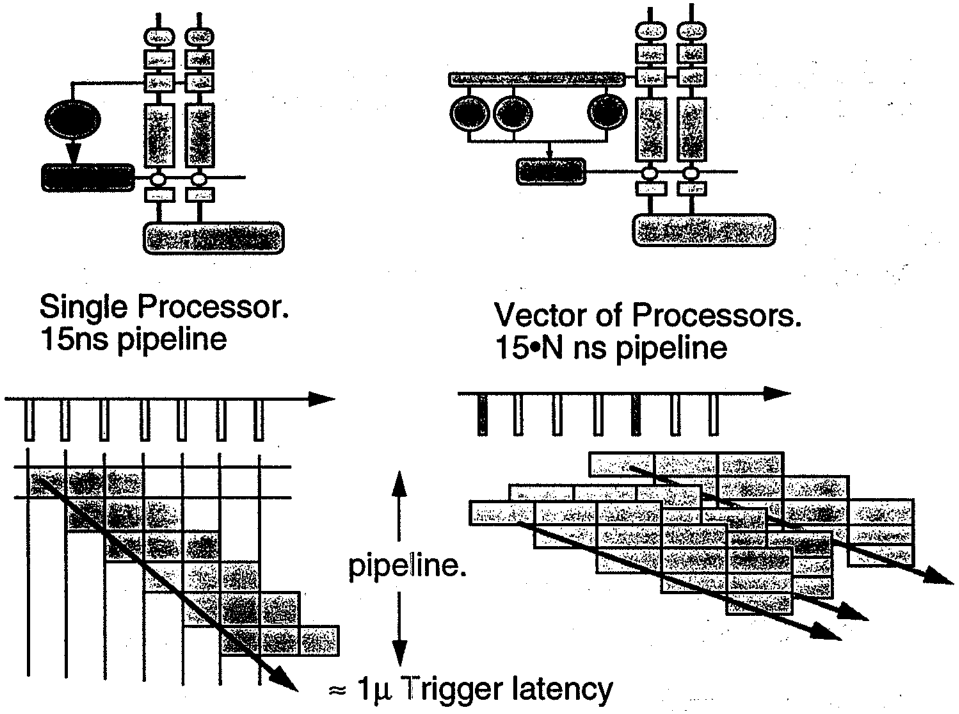


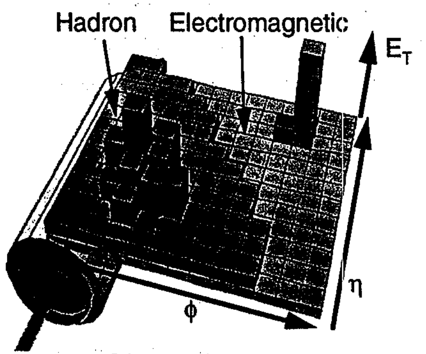
1.2µ CMOS.
40 MHz, 7ns internal pipeline



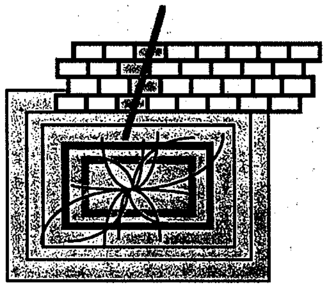


First level trigger





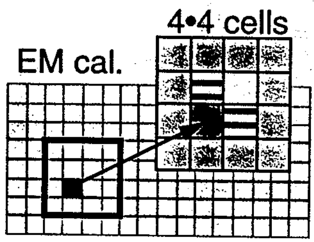
Clustering



Tracking

A first level calorimeter trigger

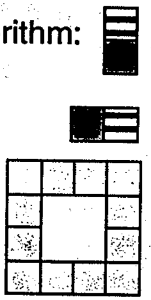
Demonstrator project for a first level calorimeter trigger
(Birmingham, Queen Mary and Westfield College, RAL)



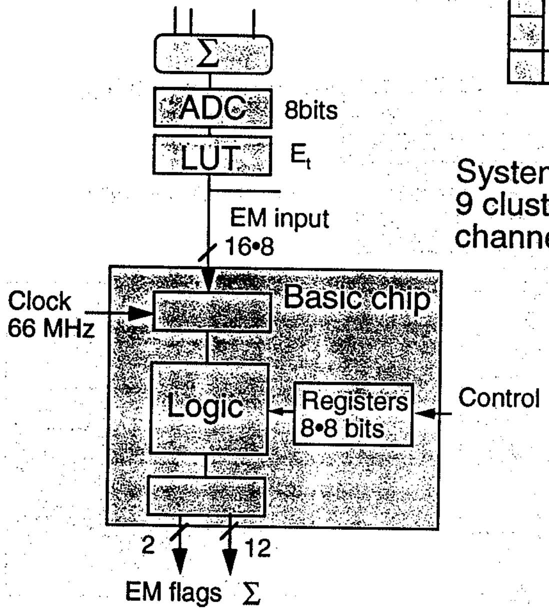
$\Delta\phi \bullet \Delta\eta = .1 \bullet .1$

A digital processor chip
- **15ns pipeline < 500 ns latency**

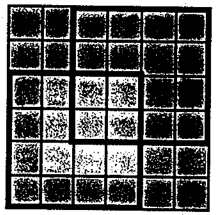
Algorithm:



> E_t cut
or
> E_t cut
and
< E_t cut



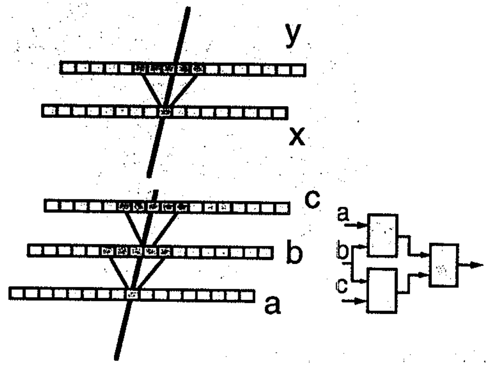
System modularity:
9 cluster finding chips each 36 em channels for 9 reference cells

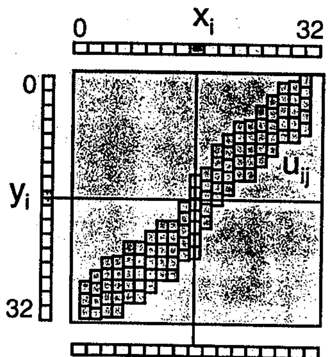


- .8 μm CMOS gate array

Muon trigger

Segment identification in low occupancy detectors.

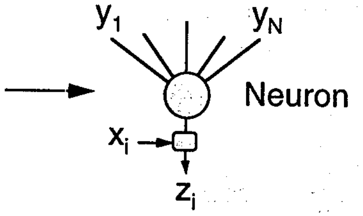


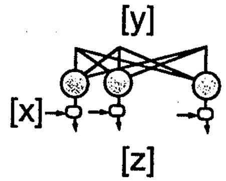


$z_i = \sum x_i \bullet u_{ij} \bullet y_j$

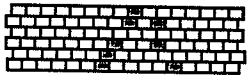
- Desy-H1 μ trigger. 32•32matrix 48 ns, 2μ CMOS (RAL)
- CERN-WA92 μ trigger. PAL 25 ns (INFN Rome.)

$z_i = x_i \bullet \sum u_{ij} \bullet y_j \longrightarrow$

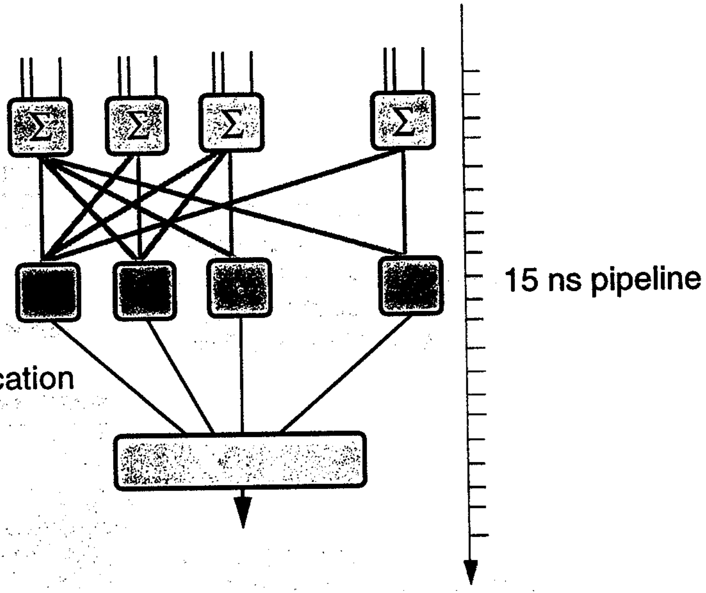




Neural Net tracking algorithms and
ASIC implementation (RD11 & RD12)



Level 1 Structure



Prompt readout

Preprocessing

Interconnection

Processing

Data communication

Control logic

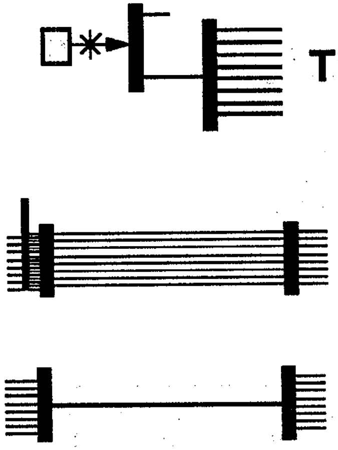
≈ 100 Million Instruction / second

Digital microelectronics

Giga Interconnections / second

Neural Net Technology

Optoelectronics



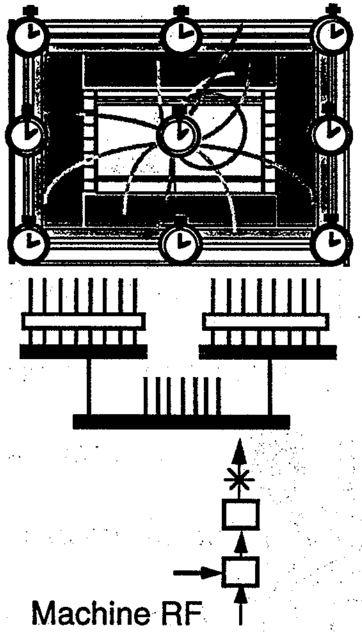
Timing and control distribution

Analog signal readout

Data transmission

Timing & Control.

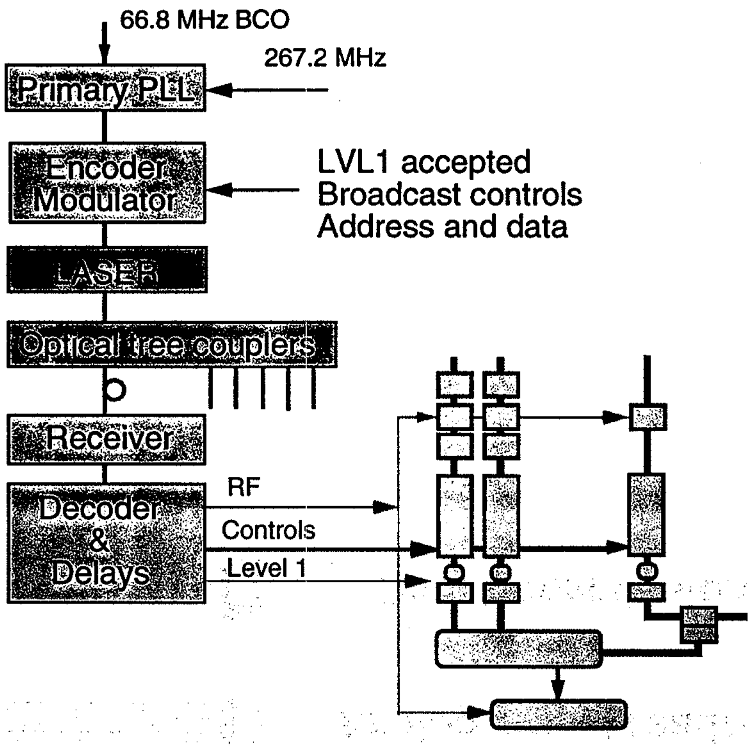
Timing & Control test bench (RD-12)
Development of basic hardware and software components of a **multichannel optical-fibre timing distribution system** for LHC detector front-end electronics, and investigation of the feasibility of simultaneously exploiting the timing system for transmission of the level-1 trigger acceptance and addressable control information


Machine RF

Need to compensate:
- Variable propagation delays
- Particle TOF • Drift times
- Electronics

Need to broadcast :
- Bunch crossing
- Trigger-1 acceptance
- Control
- Test pattern

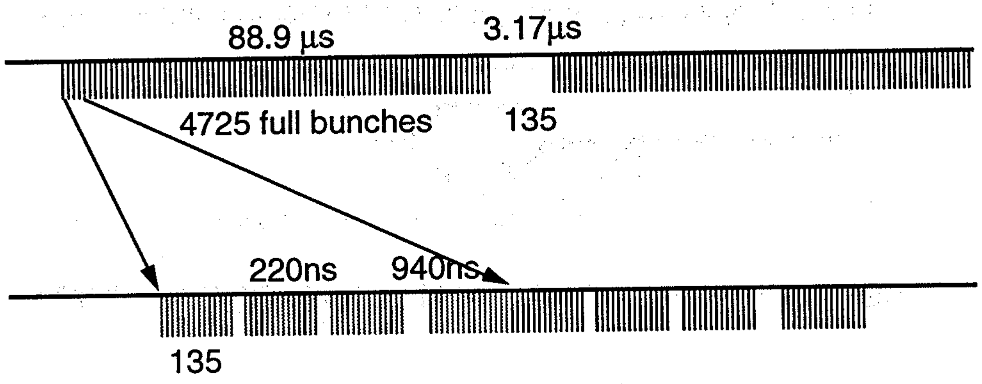
Timing & Control Test bench. RD-12


66.8 MHz BCO
267.2 MHz
Primary PLL
Encoder Modulator
LVL1 accepted
Broadcast controls
Address and data
LASER
Optical tree couplers
Receiver
Decoder & Delays
RF
Controls
Level 1

RD12. Timing test bench :
- Digital modulator/demodulators
- Optical splitters
- Receivers
- Clock recovery
- Programmable delays
- Timing calibration
- High power Laser
- CATV, FTTH technologies

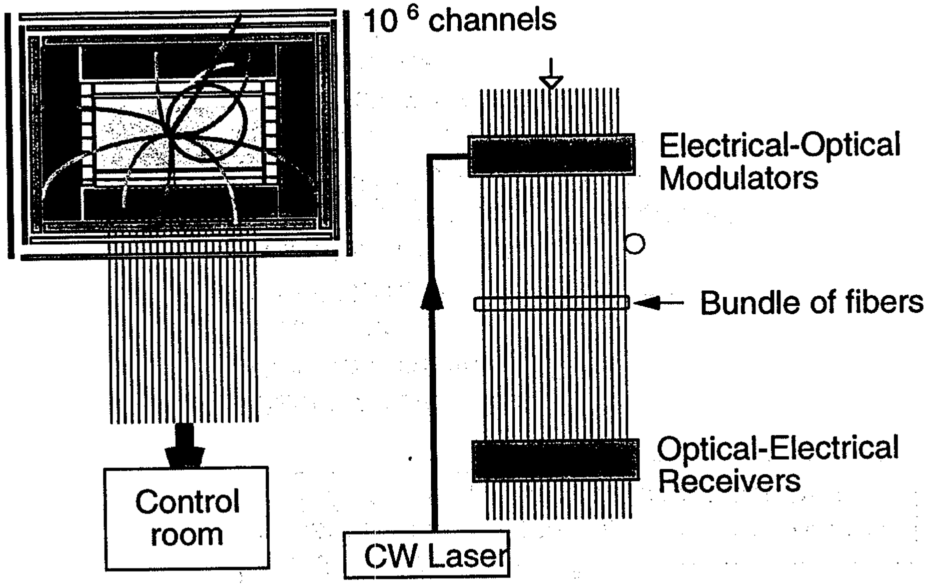
LHC Bunch Structure

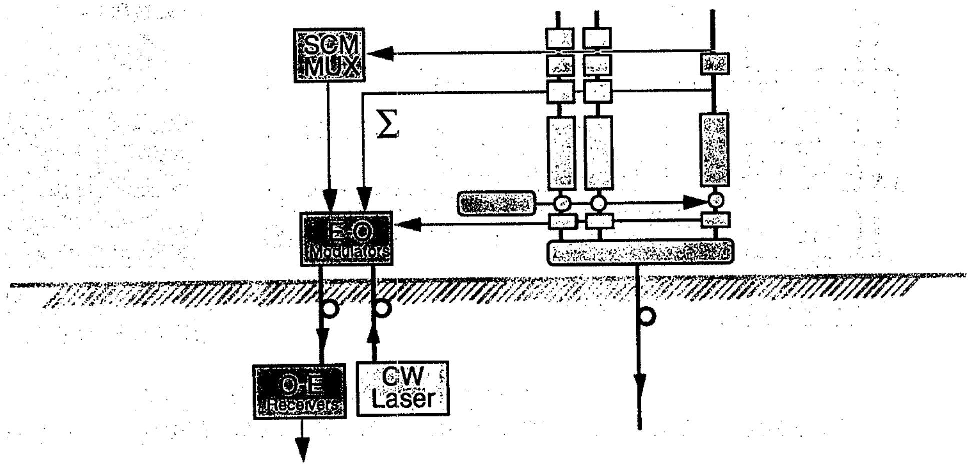
SPS injection kicker gap	220ns
LHC injection kicker gap	940ns
LHC extraction kicker gap	3.17μs



- Synchronous electronics controls
- Timing calibration

Optoelectronics





Optoelectronics (RD-23)

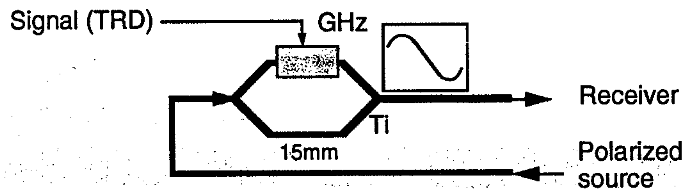
Analog signal transfer

Needs :
- Readout of large number of channels (10^6 .. 10^8)
- Radiation hardness
- Power dissipation and cabling.

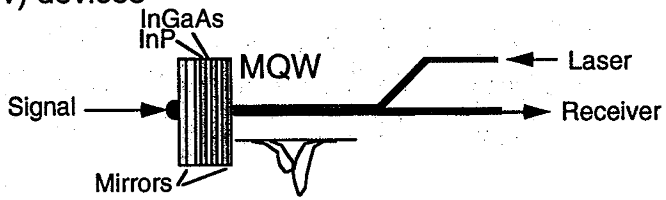
RD-23 study of optoelectronics analog signal transfer (CERN, Birmingham, EPFL, Imperial College, Oxford, GEC-Marconi)

- Multi-channel electro-optic intensity modulators.
- Optical fibre (ribbon) links and receivers
- Study of engineering, packaging and production processes
- Assess performance with LHC detectors R&D

- Lithium Niobate ($LiNbO_3$) Mach-Zehnder interferometer (BNL)



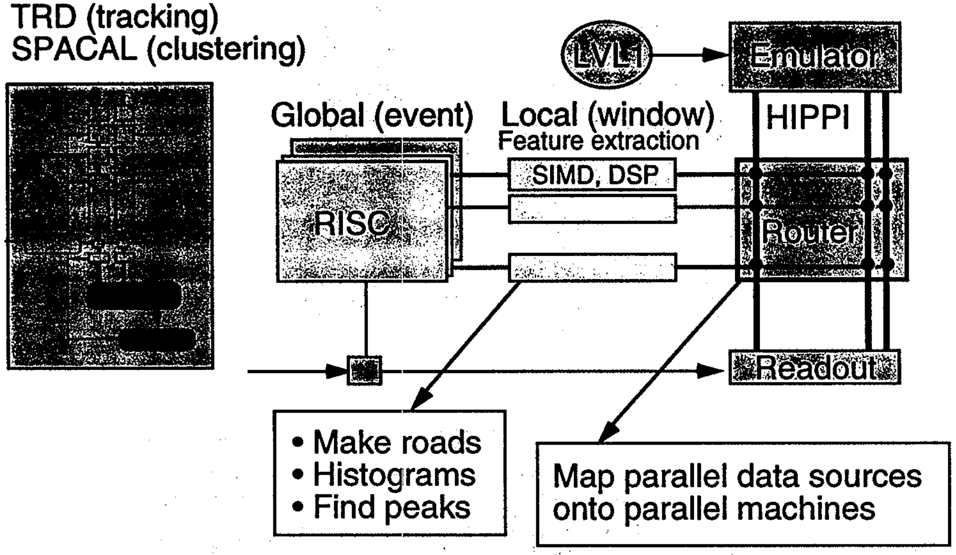
- III-V semiconductors (GaAs, InP-based) multiple quantum well (MQW) devices



Second level trigger. RD-11

RD-11 Embedded architecture for second-level triggering in LHC experiments (E.A.S.T.)

TRD (tracking)
SPACAL (clustering)



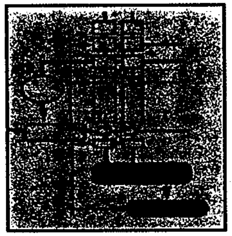
- Make roads
- Histograms
- Find peaks

Map parallel data sources onto parallel machines

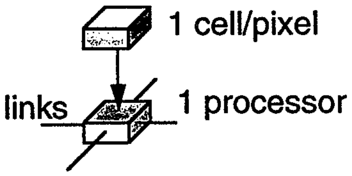
- Data emulator (SLATE)
- Point to point link (HIPPI)
- Data router
- Local/Global LVL 2 simulation
- Algorithm Benchmarking
  - Image processors (MaxVIDEO)
  - DSP and VSP (DAVIS)
  - General-purpose SIMD (APS)
  - Custom Hardware
  - MasPAR
  - RISC farms

SIMD. MPPC

Massive Parallel Processing Collaboration

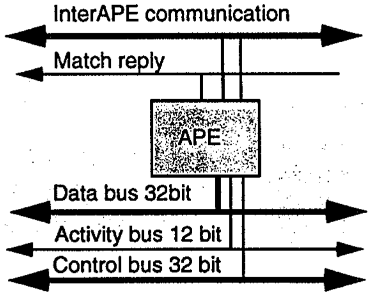


A SIMD machine for second level trigger fine grain parallelism

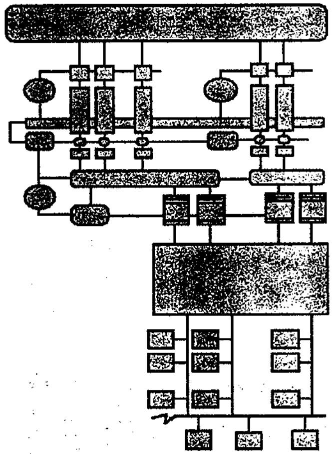


SIMD architecture

- String/loop of associative processing elements:
  APE (2µm CMOS 64Ape/chip, 25MHz)
  - 64bit associative memory cell
  - 70bit comparator
  - 1bit processor
  - 10bit activity and flag
  - Communication capabilities
- Programmable structure
- Scalable.

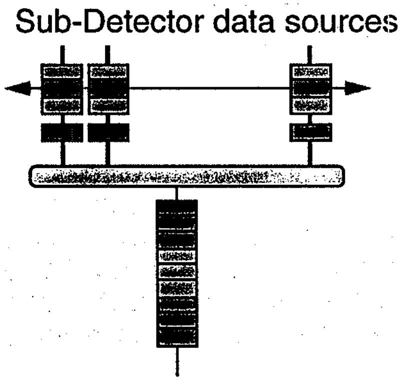


Readout

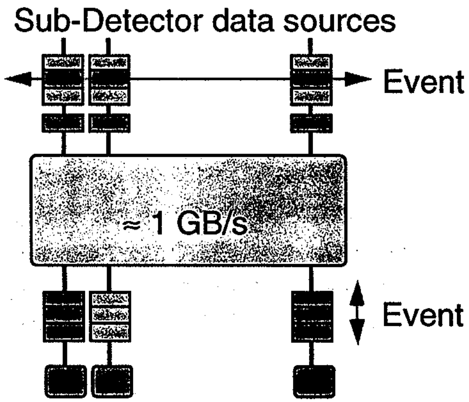


- Frontend sparse readout
- Level 2 data routing
- Event builder

Data Merger



Event Builder

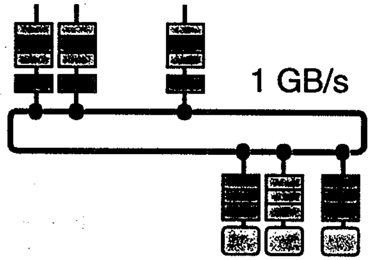


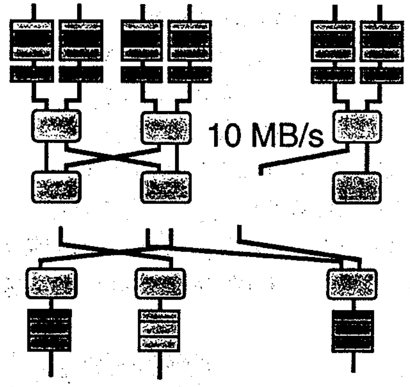
Event Builder Interconnect

RD-24 SCI.

Scalable Coherent Interface.
High speed multi-node memory interconnection system

Computer industry





Microelectronics

Switch matrix network

Telecommunication industry

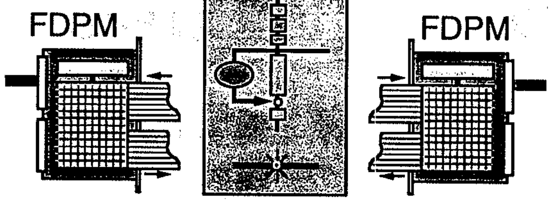
HIPPI, Transputers, FutureBus..

Readout System Test Benches. RD-12

Develop and exploit multipurpose **Personal Computer-based Test Benches** to support the evaluation and design of the basic elements required for digital front-end readout and data transmission systems for an LHC experiment.

They will support components such as **fast ADCs, hybrid fibre-optic transceivers, and the prototype VLSI systolic array and data-flow processors** currently being developed in national research laboratories and by the emerging European HDTV industry.

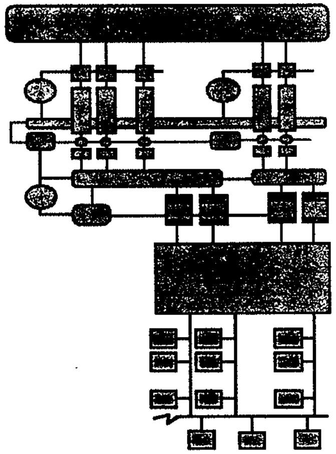
Test benches



Fast Dual Port Memory
- 133 MHz, 24 bit. CMOS
- Programmable Memory Control. VLSI sequencer (Padova)

- Digital pipelines (MEC2, HDTV, FERMI)
- Hybrid fibre-optic transceivers (Helsinki)
- Timing distribution
- Data flow processors

DAQ. RD-13



RD-13.

A scalable data taking system at a test beam for LHC

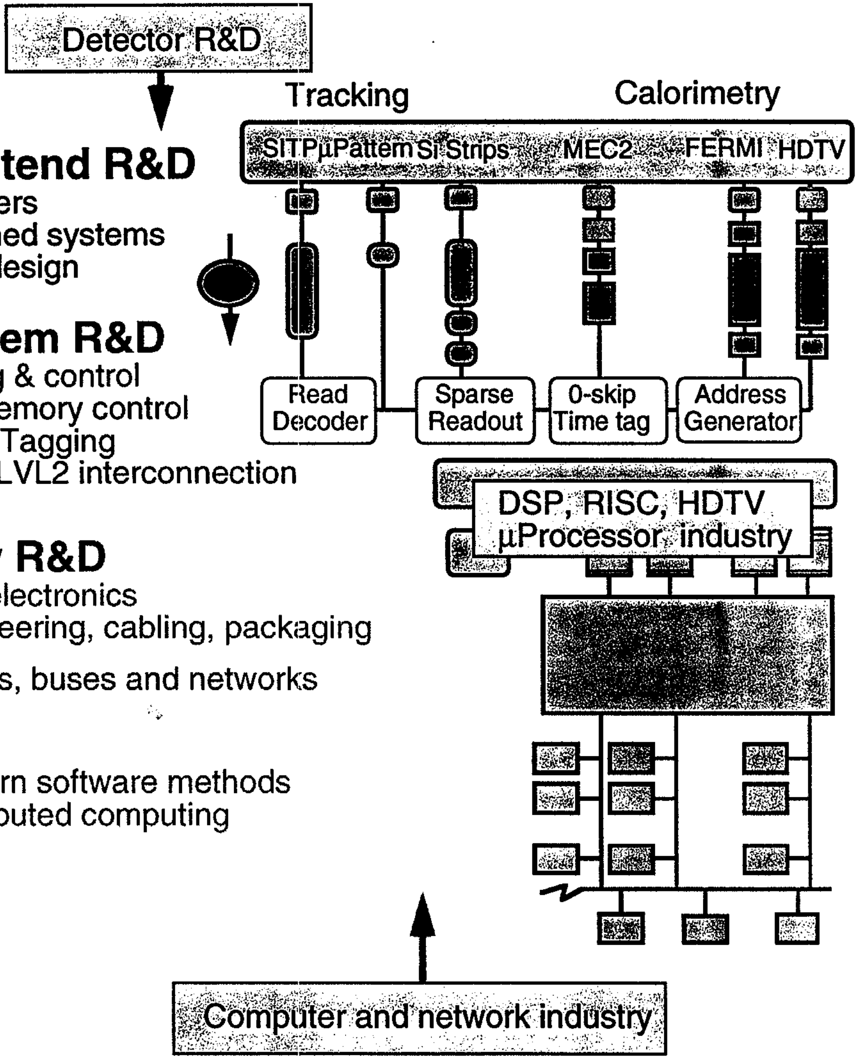
A test beam setup for the simultaneous testing of :
- Detector prototypes
- Readout electronics
- Trigger architectures
- DAQ software

Basic configuration :
- **SUN work stations**
- VME as I/O interface concentrator and control system
- CES RAID8235 **MIPS3000 VME based processor**
- **LynxOS** as UNIX real time system
(adopted by the accelerator division)

Introduce UNIX operating system and modern software methods in a data acquisition environment

---

Status



Frontend R&D
Digitizers
Pipelined systems
VLSI design

System R&D
Timing & control
F/E memory control
Event Tagging
LVL1-LVL2 interconnection

New R&D
Optoelectronics
Engineering, cabling, packaging

Protols, buses and networks

Modern software methods
Distributed computing

Computing & networking

P.G. Innocenti (CERN)

COMPUTING and NETWORKING

P. G. Innocenti

ECP Division, CERN

Disclaimer

The presentation reflects necessarily the poor predicting power in the field of informatics, in terms of features, trends and timescales.

Apologies.

Manufacturers names and trade marks are used loosely, and sometimes with unprecise language, to focus more efficiently on developments. Also, comparable developments by more than one manufacturer are attributed to one only for simplicity.

Outline of the presentation

- Which model of computing for HEP
- Where is technology going in:
  - Computer hardware
  - Computer software
  - Networks
- How will LHC experiments use the new technologies?

A Model of Computing for HEP

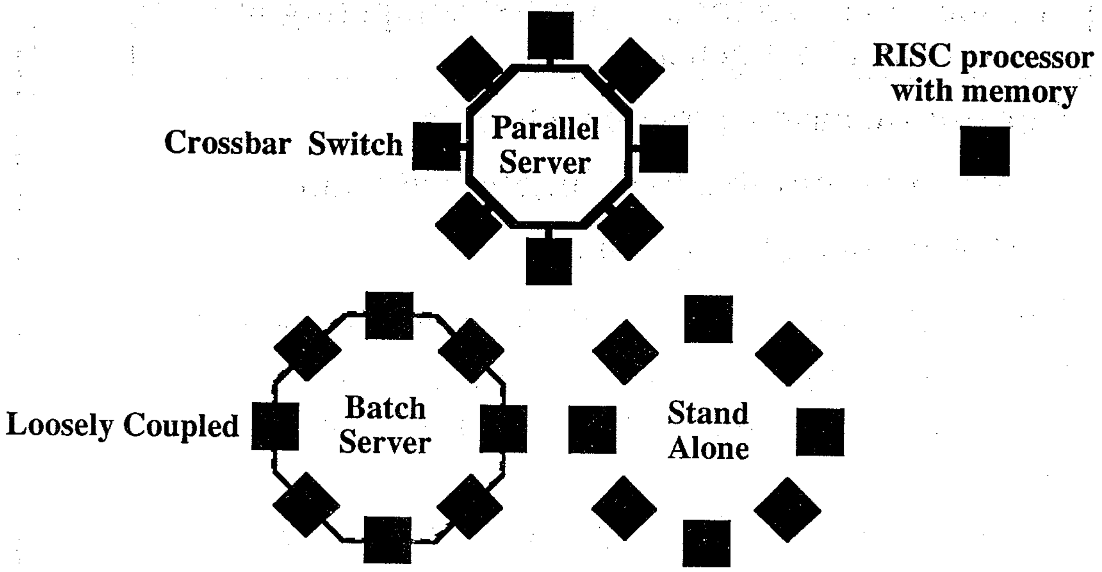
- Fully market driven evolution of hardware and software
- Standardization, by the entire HEP community, of selected (non proprietory) products
- More computations near the experiments in (quasi)-real-time
- Access data for the analysis on a physicist's workstation from a data repository of generalized DSTs.
  Computing power will be either local to the end user, or local to the data repository or elsewhere (compute server).
- Increase of network traffic for both data and results.
- Use of computing power where it is optimal in terms of cost, availability, features of the processors, network bandwidth

RISC Processors, MPP and Supercomputers

- **Generalization of the concept of RISC Processor Farm**
  - RISC (multi)processors
  - Clusters of RISC (multi)processors with a unique address space (64 bit), covering the entire distributed memory
  - Clusters of RISC processors sharing a **large** central memory
  - UNIX

PGI, Evian, March 7, 92.

The IBM model



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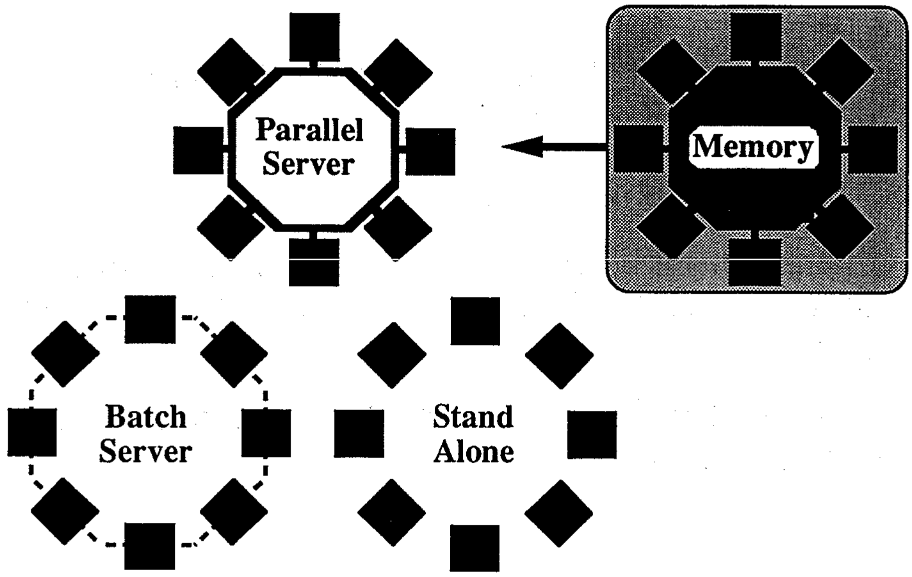
The IBM model revisited



Parallel Server

Memory

Batch Server

Stand Alone

Vectorization and Parallelism

The success of vector and parallel computing in HEP, so far, is local not general

Suppose we have a program which is

90% parallelizable to infinitely fine grain

10% irreducibly sequential

This program runs in 100 s on a sequential computer.

If run on a MPP of 100 processors each one as fast as the sequential computer, the execution time will be 10.9 s

If run on a MPP of 10000 processors, the execution time will be 10.009 s

Vectorization and Parallelism (cont'd)

- Hence the nature of the problem, its logical and mathematical formulation and the programming methods and languages may defeat the power of computers with vector and parallel features

---

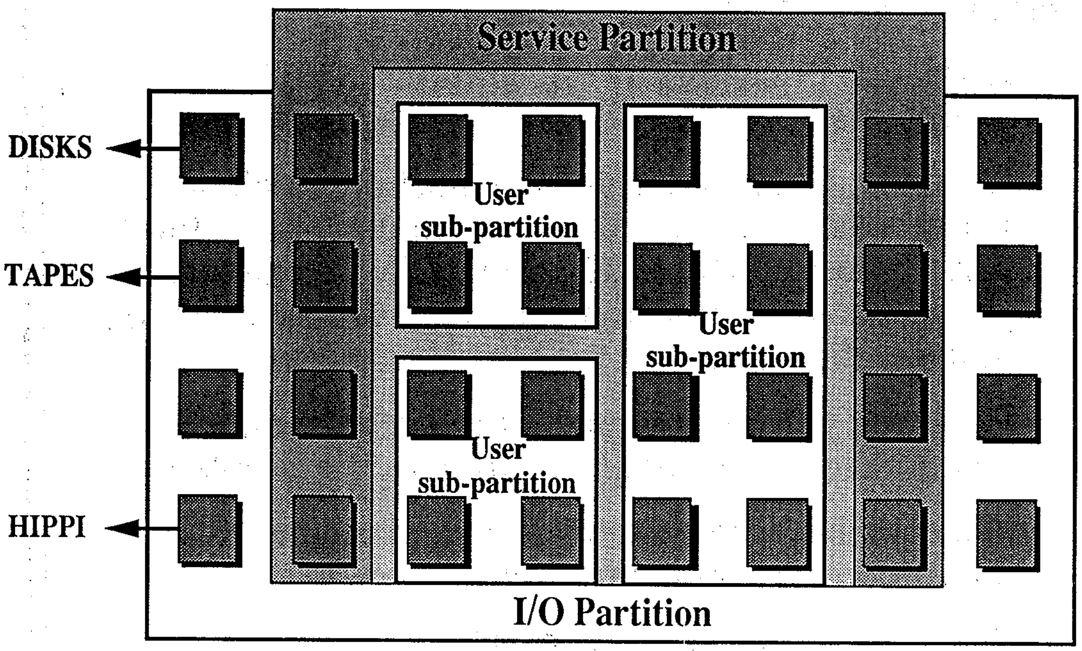
Massively Parallel Processors

- From SIMD to MIMD?
  - Attractive price/performance ratio of RISC processors
  - Example: Evolution of the Connection Machine from a custom designed one bit processor to a third party processor (SPARC). Some SIMD features, as program synchronisation, are preserved as an option in the architecture
  - However: SIMD structures, if affordable, may continue to be advantageous for specific problems
  - Scalable hardware with little degradation of interprocessor communications
  - Processor monitoring and reliability

MPP (cont'd)

- Software problems
  - Operating system should hide the structure of the machine
  - Code must scale with number of processors, from one to thousands, either from a small to a large machine, or by running on a subset of a given machine, depending on resource availability
  - UNIX flavours
  - A programming environment which helps the programmer to "think parallel" and, ideally, matches code to parallel hardware automatically
  - Parallel FORTRAN and parallel C

User sub-partitions



Massively Parallel Processing is a Software Problem

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Supercomputers

- The CPU cycle evolution
- Multiprocessors
- Memory capacity
- Memory bandwith, determined by memory cycle time and number of banks, determines the limit to performance: Rule of thumb: For highly parallel programs, sustainable performance in FLOPS is typically 1/3 peak MOPS (Memory Operations Per Second)
- Massively Parallel Processors:
  If you can't beat them, join them!
  (or how to use MPP with a supercomputer)
- The software problem remains

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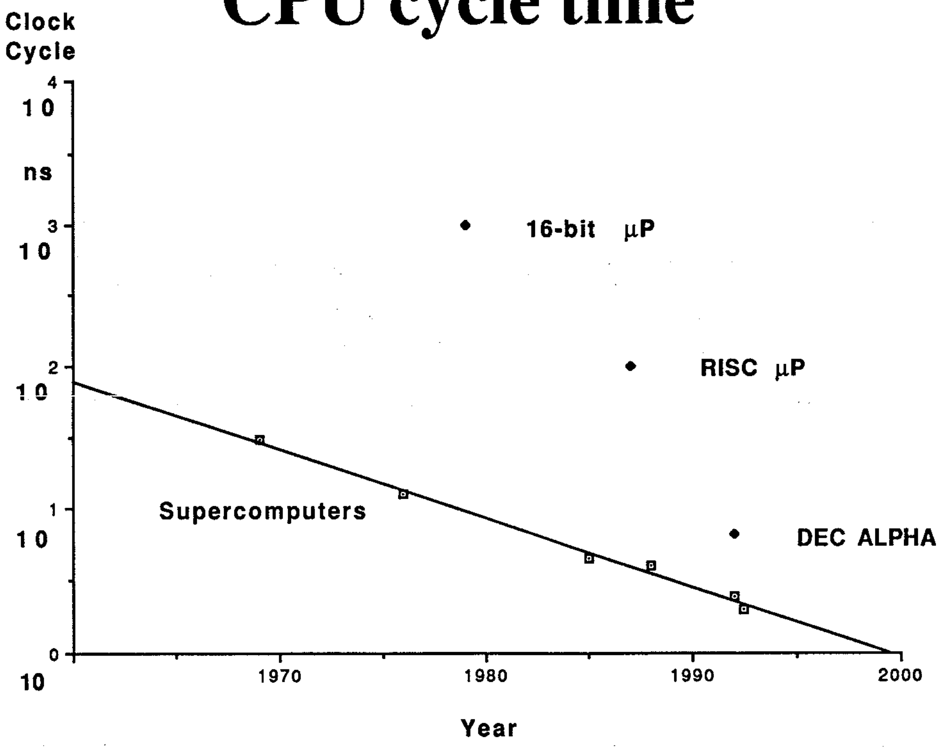
CPU cycle time



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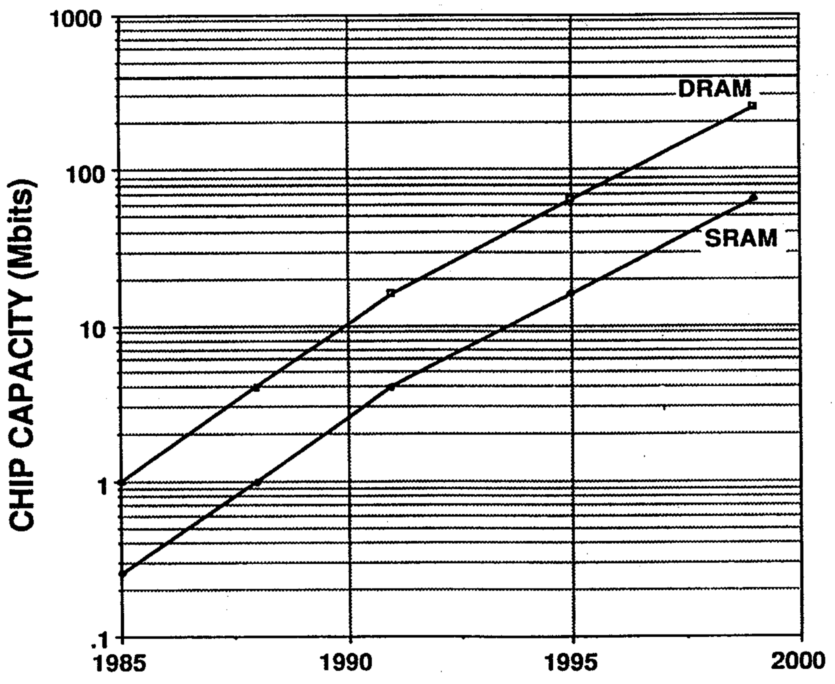
Memory Capacity Trends



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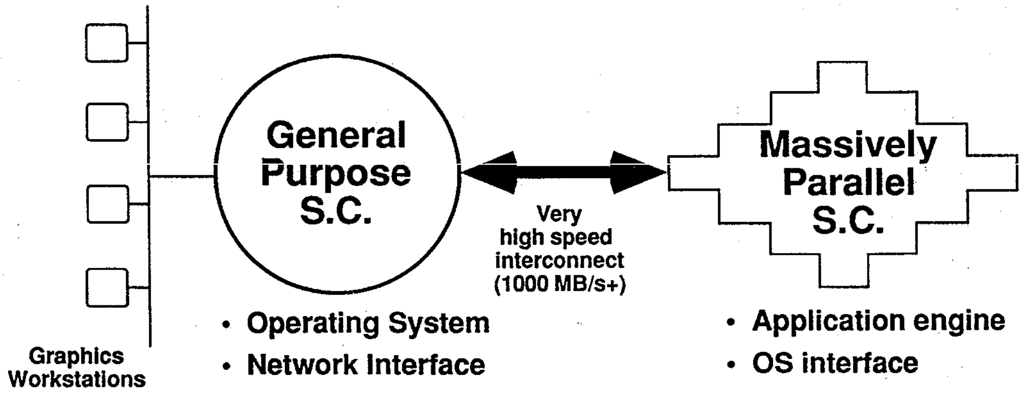
Extending the Supercomputing Environment

The future of supercomputing systems is parallel, heterogeneous and distributed.



- Operating System
- Network Interface
- I/O
- Compilers, tools

- Application engine
- OS interface

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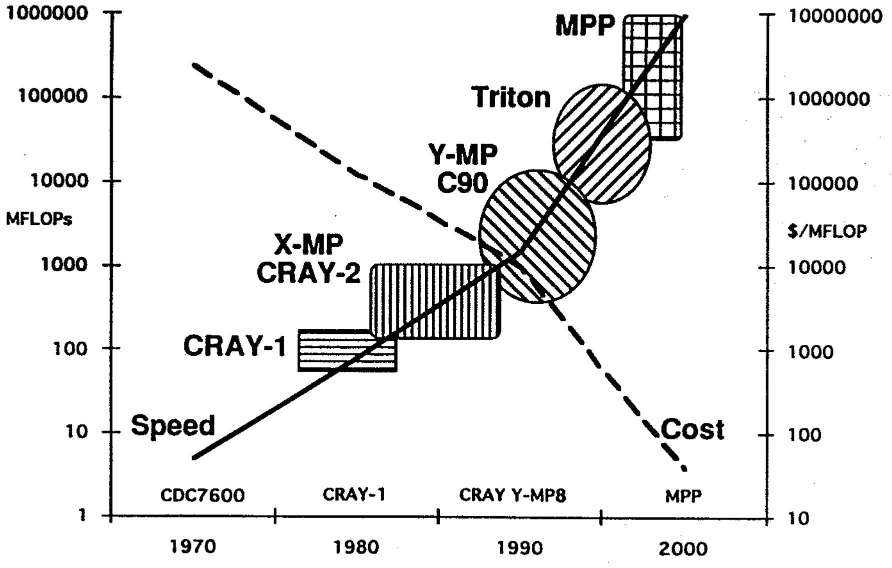
Sustained Processing Speed

according to CRAY Research Inc.



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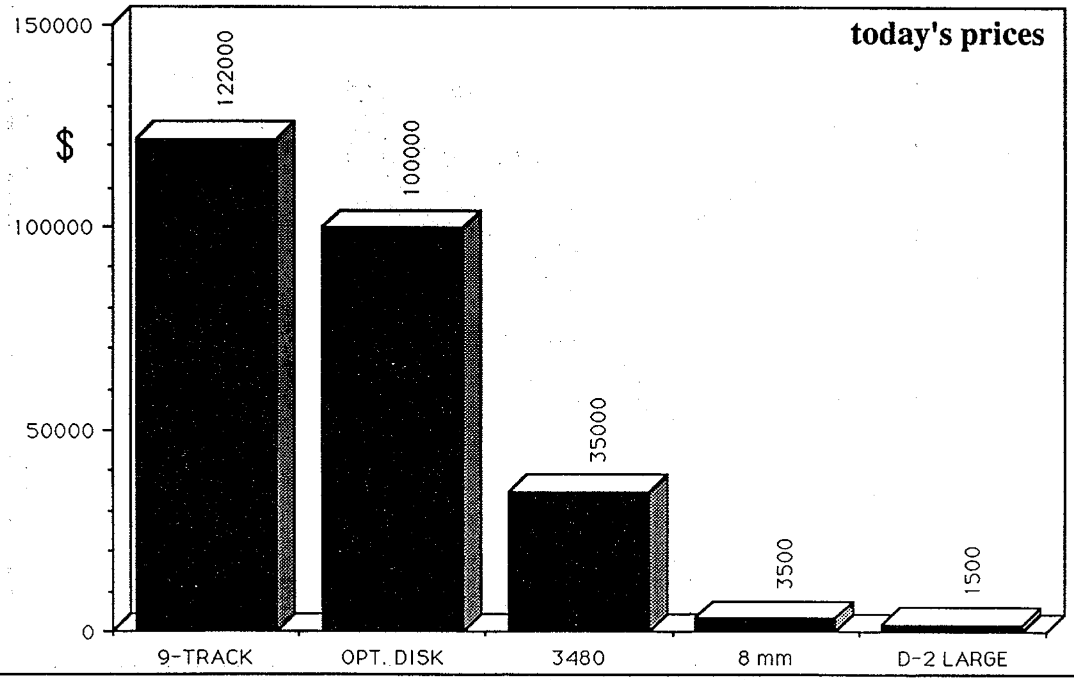
Mass storage

- Recording densities in excess of 2 Mbit/sq mm
- Helical scan Data D-2 technology using video recording cassettes: 20 Mbyte/s,165 Gbyte/cassette
- Redundant Arrays of Inexpensive Discs (RAID), 5 Mbyte/s,
  2 Gbyte/disk
- Parallel Transfer Discs (PTD): 30 Mbyte/s, 2.4 Gbyte/disk

One Terabyte of Data



Display Technology

"sensory computing"

- Better resolution, crisper images
- Wide colour palette
- Higher refresh rates
- Higher banwidth into display at HIPPI or HDTV rates
- Multimedia
- Virtual reality
- Animation

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Programming environment

- **Software tools for:**
  - Analyzing the problem
  - Specifying the requirements
  - Favouring communications
  - Well engineered code design
  - Automatic code writing and conversion
  - Keeping coherence
  - Software project planning and management
  - Documentation
- Tools lead to **objects** in many cases: does this influence the choice of languages ?

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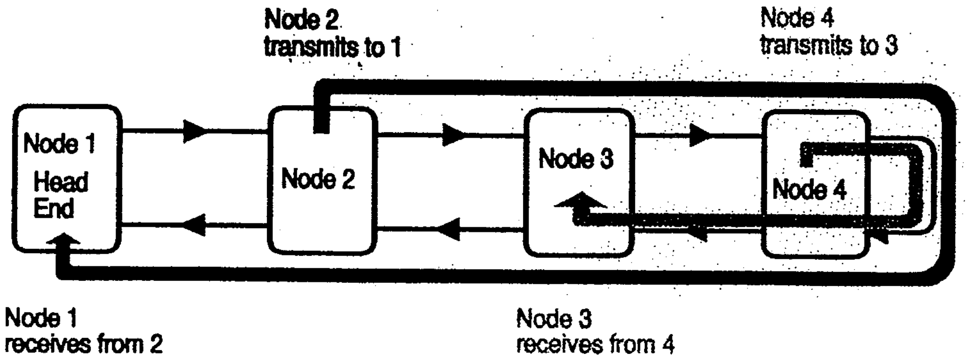
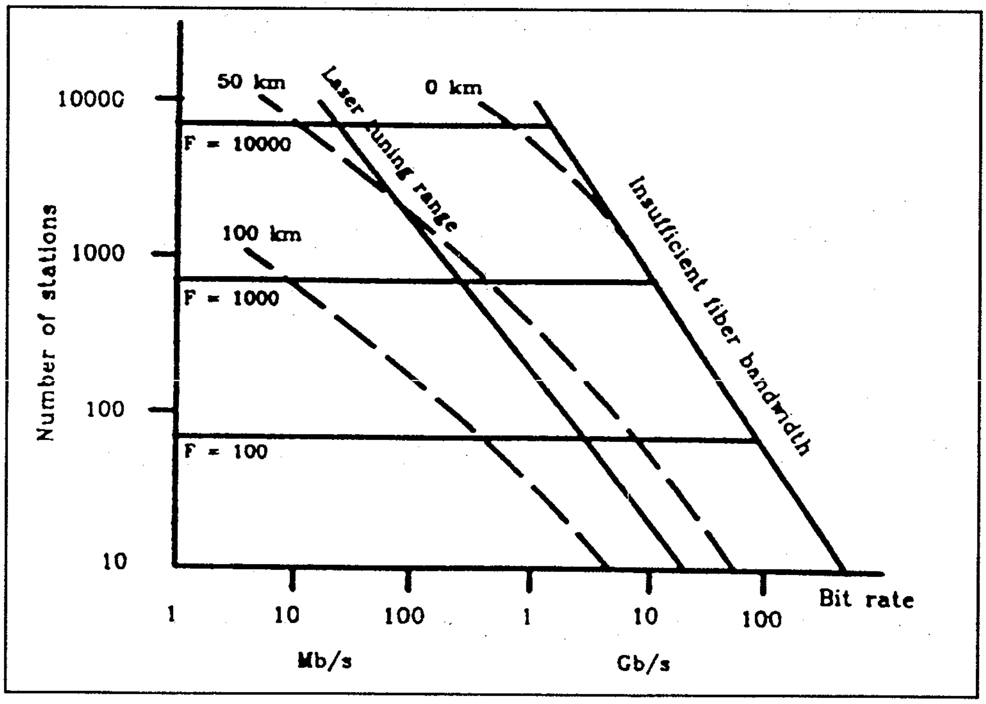
Network Limitations

- **Bandwidth**
  - One-directional synchronous transmission: RINGS (alternatively, full duplex made with two cables or a folded bus, in both cases a collapsed ring)
  - Bandwidth limitations:
    - by the dispersion of the medium,
      >100 Gbit/s on optical fibres depending on length
    - by transmitters and receiver technology,
      >20 Gbit/s
    - by number of Wavelength Division Multiplexing (WDM) channels,
      >100 in a window of .2μm around 1.55μm

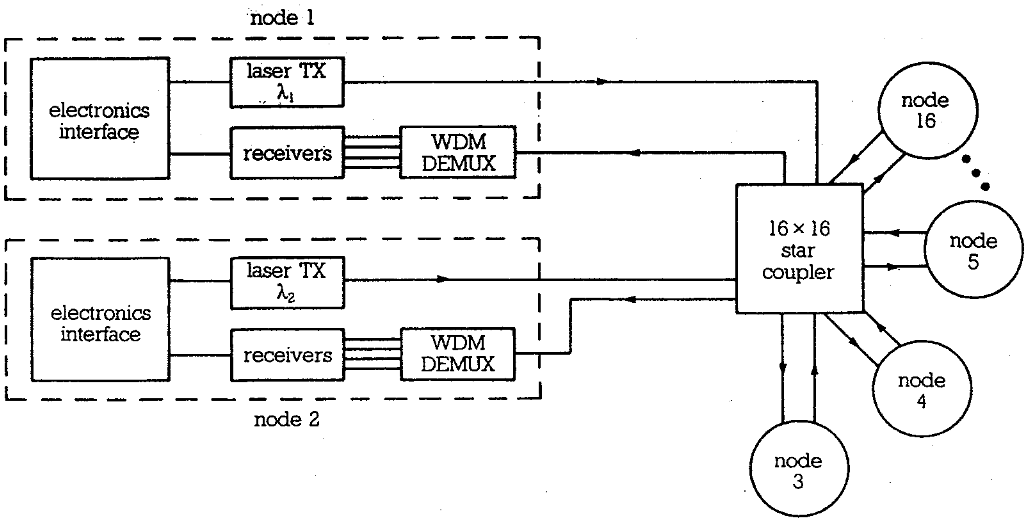
Transmit/Receive over a Folded Bus



WDMA Limitations



LAMDBANET Topology



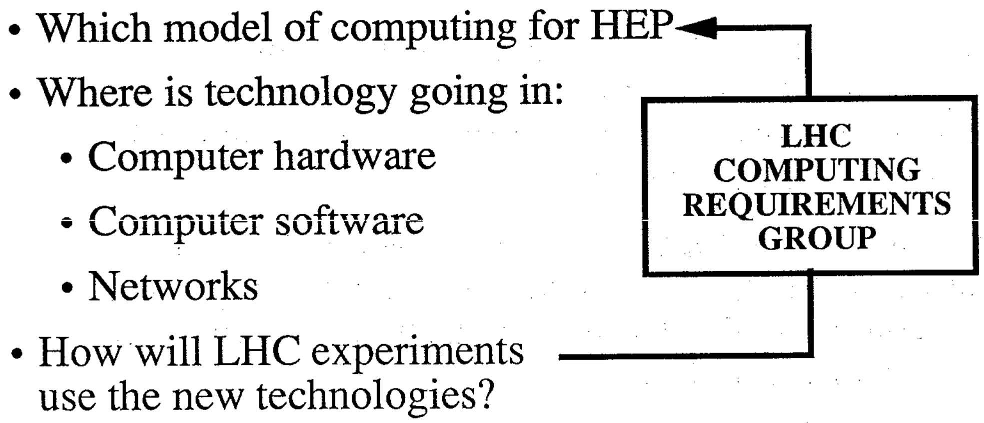
Network Limitations (cont'd)

- **Latency**
  At 10 Gbit/s and 100 WDM channels, 1 Km of O. F. cable gives a delay of 5μs and stores 5 Mbit of information
- **Protocols**
  - Beneficial effects of low Bit Error Rate (BER) up to 1 Gbit/s
  - Effects of latency
  - Need for new protocol design and standardization

Networking for the Research Community

- Very important issue for the LHC Collaborations
- Complicated environment, with conflicting forces driving either to no change or to a complete deregulation
- Multitude of initiatives
- References:
  HEPNET Requirements Committee Report to Plenary ECFA, by M. Delfino on Dec. 6, 1991
  Data Networking for the European Academic and Research Community, by D. O. Williams and B. E. Carpenter, Report CERN/CN/91/10, October 1991

Feedback



- Which model of computing for HEP
- Where is technology going in:
  - Computer hardware
  - Computer software
  - Networks
- How will LHC experiments use the new technologies?

LHC Computing Requirements Group

(while waiting for a better name)

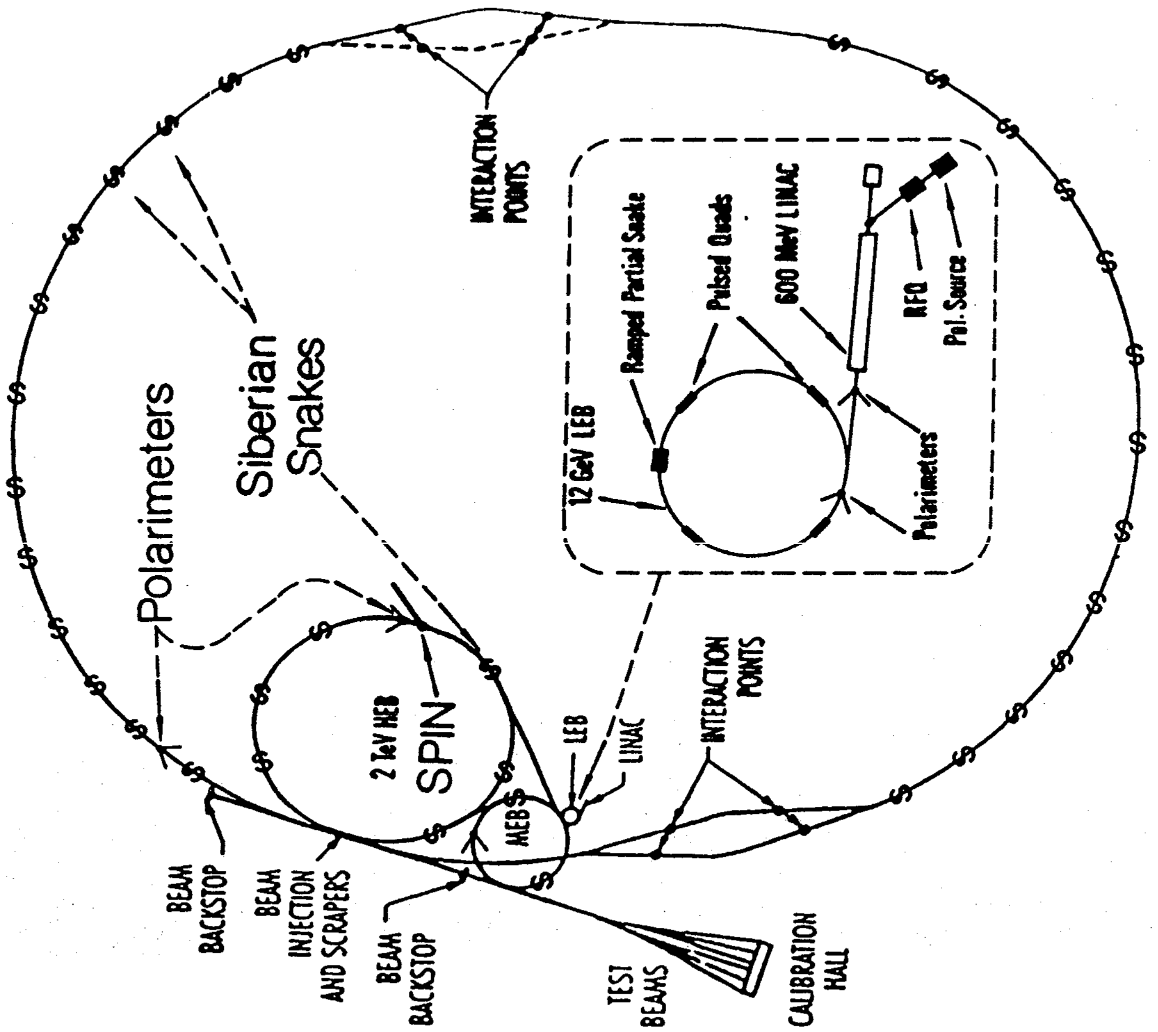
- Understand the computing requirements of LHC experiments in terms of performance and resourses
- Monitor technology evolution and forecast impact on experiments
- Promote standardization
- Group will be formed shortly after this meeting

Conclusions

- The computer industry will be meeting our requirements in computing power, mass storage and network bandwidth at an affordable cost, the market being driven by other forces
- Imaging technology advances, driven by the consumer market and helped by inexpensive computing power and commercial software packages, will help in all aspects of computing
- A radical change in programming habits is ahead of us, through advanced software development tools and parallel algorithms

The SSC experimental programme

R. Stefanski (SSC Laboratory)



SSC Laboratory **Physics Research Division**

The SSC Experimental Program

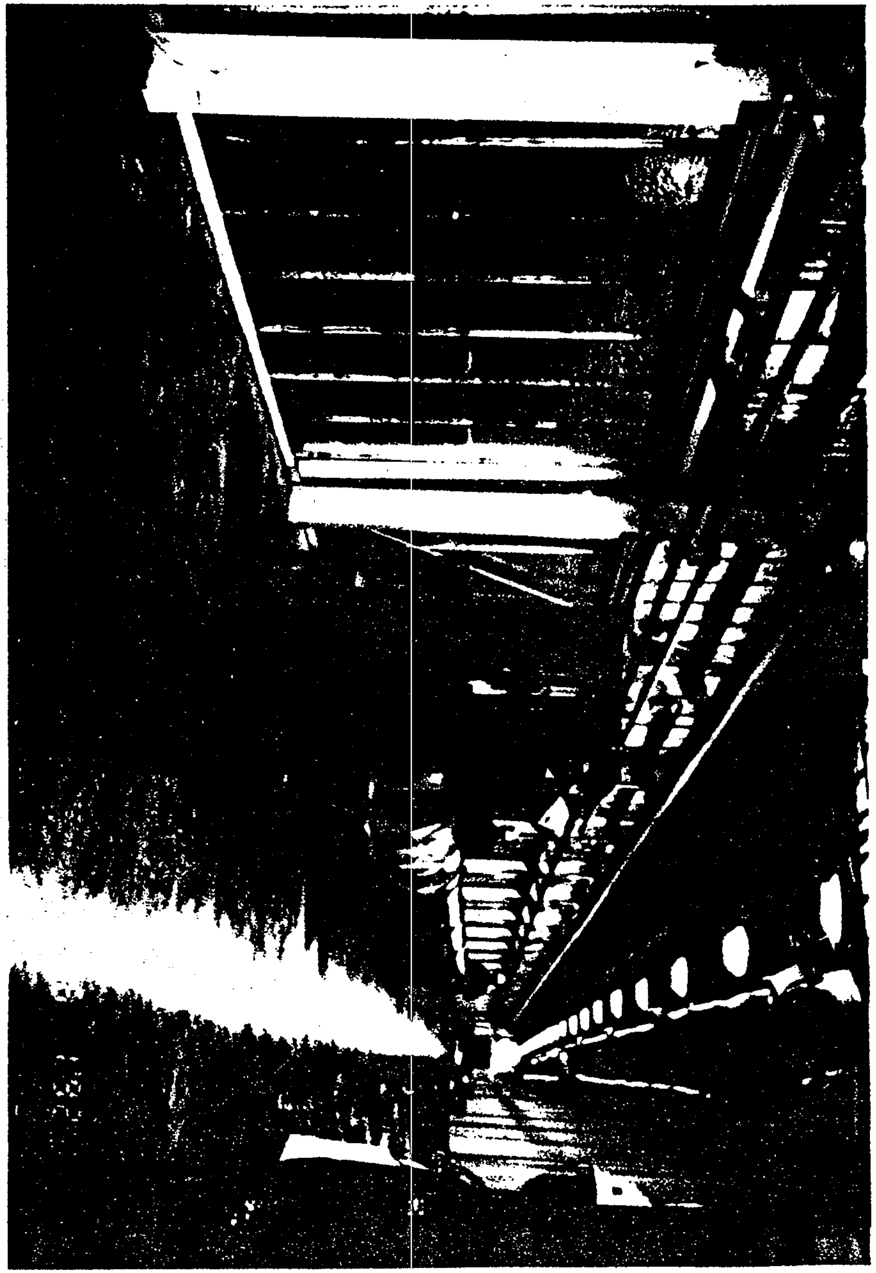
Ray Stefanski

SSC Laboratory

March 8, 1992

ACCELERATOR SYSTEMS STRING TEST (ASST)

- THE ASST IS A MAJOR SSC MILESTONE TO BE DELIVERED BY OCTOBER THIS YEAR.
    - The ASST Will Power Test String of SSC Magnets--a Collider Half-Cell Composed of Five Dipoles and a Quadrupole.
    - The String Test Will Use the First Industrially-Fabricated Collider Dipole Magnets (50-mm Aperture).
    - Collider Cryogenic, Electrical, and Magnet Quench Protection Systems Will Also Be Tested.
- AS A PRELUDE TO THE ASST, A STRING COMPOSED OF THE OLDER 40-mm APERTURE DIPOLE MAGNETS WAS SUCCESSFULLY POWER TESTED AT FNAL LAST YEAR.
- THE CURRENT ASST STATUS IS:
    - Nine Magnets Have Individually Passed Power Tests on Test Stands at FNAL and BNL--Five Were Industrial.
    - All ASST Buildings Were Occupied By Mid-January.
    - The First Industrial Dipole Was Installed January 31.
    - The Refrigerator Cold Box Was Vacuum Tested and Installed.
    - Compressors and Cryo Piping Installation Began in January.
    - Power Supplies were Installed in February.
    - A Prototype Spool Piece Has Been Installed in the String Test at FNAL to Provide a Cryogenic Test in April.
    - Currently All Systems for the ASST Are in the Installation Phase. Plan Is to Cool the String in June. Power Tests to Be Completed by the End of Summer.



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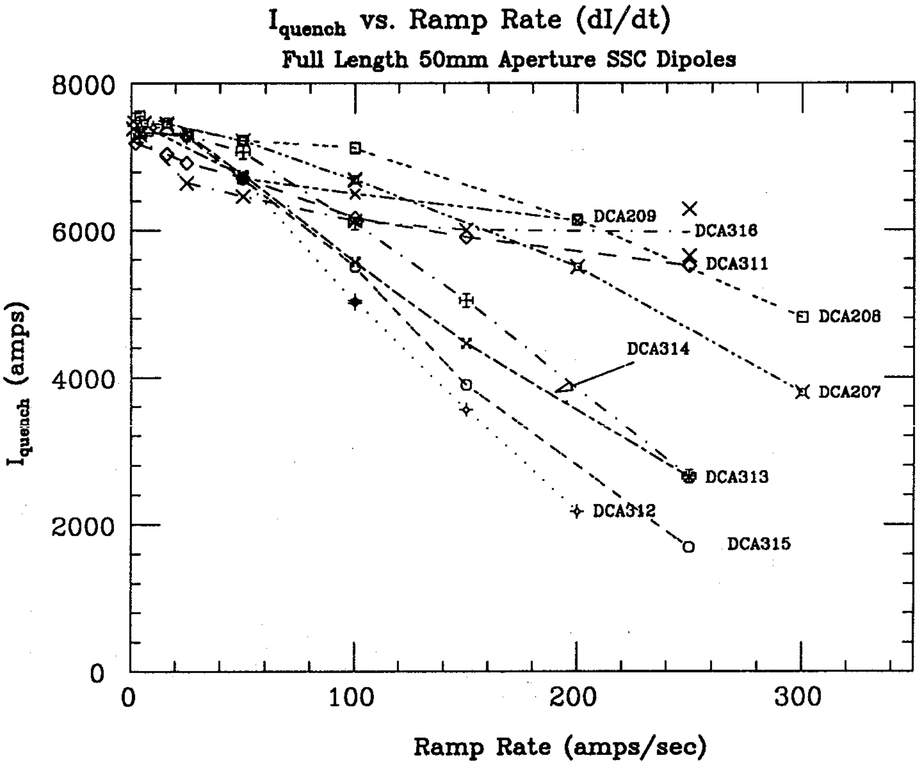

DCA200 Series – BNL
flow rate ~ 150 gm/sec
DCA300 Series – FNAL
flow rate ~ 40-50gm/sc

312 – 315 same
inner cond.
209 & 316 same
inner cond

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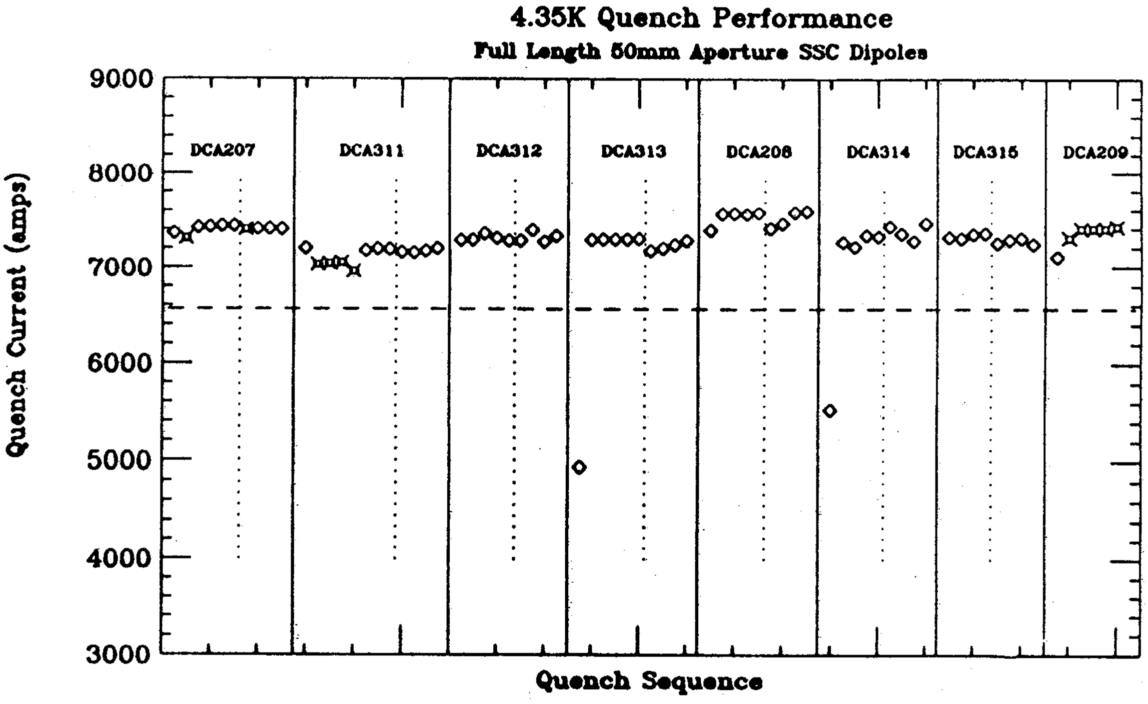

Notes:

(1) – DCA200 series magnets are BNL; DCA209–on BNL/WEC
– DCA300 series magnets are FNAL; DCA313–on FNAL/CDSS
(2) – dotted line indicates thermal cycle
(3) – after first two magnets (DCA207, DCA311), ramp to quench
sequence was: 16A/sec to 6500A, wait 10min, 4A/sec to quench

Quench Origins:
◇ – upper inner coil
× – lower inner coil

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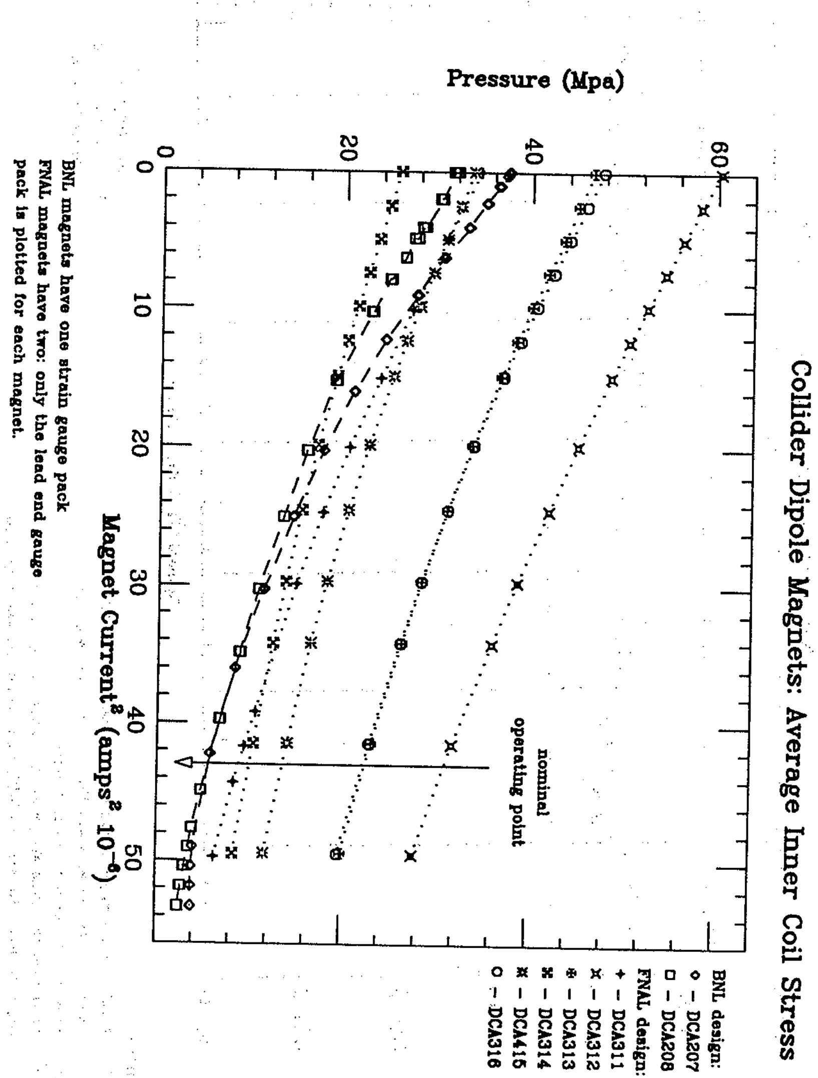


BNL magnets have one strain gauge pack
FNAL magnets have two: only the lead end gauge pack is plotted for each magnet.

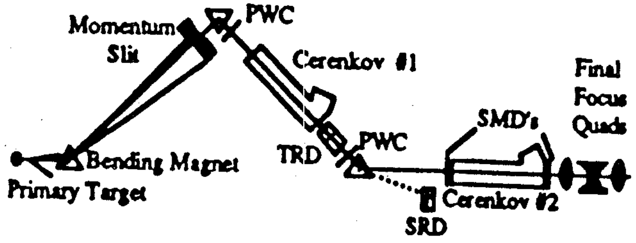


Figure 2. Beamline Instrumentation Schematic

Expermient	dX (mm)	dP/P Rel.	dP/P Abs	Part. ID Rejection
SDC				
Vertex	0.01			
Inner Tracker	0.01			
Fibers	0.30			
Straws	0.10			
E-Cal	2.00	2.4%	0.4%	1000:1
H-Cal		6.4%	1.1%	
Muon	0.15			
L*				
Inner Tracker	0.01			
Fibers	0.30			
Straws	0.10			
E-Cal		0.3%	0.05%	1000:1
H-Cal		8.0%	1.3%	
Muon	0.15			
SFT				
Silicon	0.01			
PWC's	0.30			
RICH				200:1
E-Cal		1.7%	0.3%	
Muon	1.00			

Table 1. Summary of Test Beam Tagging Requirements

III. INSTRUMENTATION PLANNED TO MEET THE SPECS

SSC Laboratory Physics Research Division

B Physics at the SSC

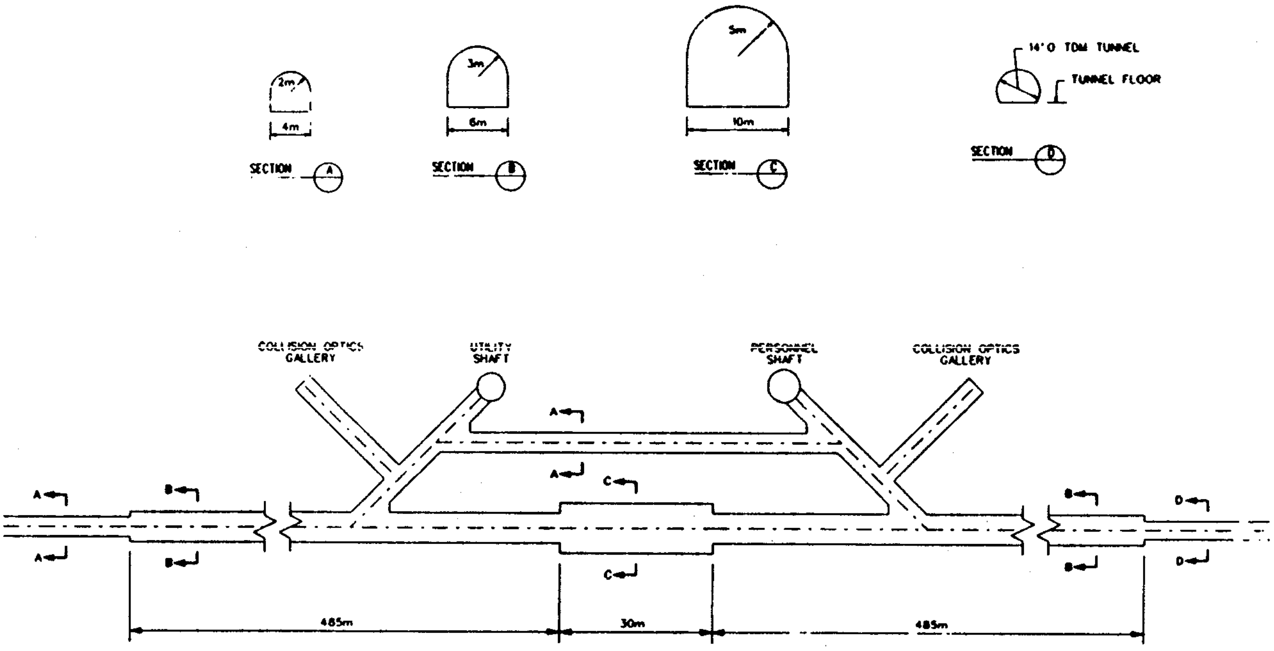
- "The SSC has special capabilities for B-physics. Both the fixed target and collider modes have the potential of going well beyond other accelerator facilities."
- Substantial progress continues at Fermilab, CERN and in resolving the B-factory options.
- The SSCL should hold a workshop in late 1992, to examine in depth the strategy for B physics at the SSC. "The workshop should address the basic questions of whether the collider or fixed target approach is optimal for the initial program and of the appropriate design of a B physics experiment."
- An important constraint in choosing among designs will be the funds available for such an effort.

R. Stefanski 10/15/91

SSC Laboratory Physics Research Division

EOIs Submitted to SSCL

	EOI - 1	Krisch	Spin - Spin Effects @ 2 & 20 TeV
*	EOI - 2	Orear	Low Pt Physics
L	EOI - 3	Trilling	SDC
	EOI - 4	Sobel	Neutrino Oscillations @ 200 GeV
	EOI - 5	Willis	High luminosity at the SSC
	EOI - 6	Marx	EMPACT
	EOI - 7	Lander	10**34
	EOI - 8	Lockyer	BCD
	EOI - 9	Kagan	Compact Diamond-Based Detector
	EOI -10	Ting	L*
	EOI -11	Reucroft	TEXAS
	EOI -12	Kanofsky	(to be submitted)
	EOI -13	Rosen	Internal Target Beauty Physics
	EOI -14	Cox	SFT
	EOI -15	Giacommelli	Magnetic Monopoles
	EOI -16	Atiya	A High Resolution Detector
	EOI -17	Bryant	Relativistic Atomic Physics
	EOI -18	Linn	Electromagnetic and Muon Dtetector for the SSC
*	EOI -19	Bjorken	Low and Intermediate Mass Detector
L	EOI -20	Barrish	GEM
	EOI- 21	Schlein	B Physics at the SSC



Potential East Cluster Layout

SSC Laboratory **Physics Research Division**

B-Physics in Large detectors

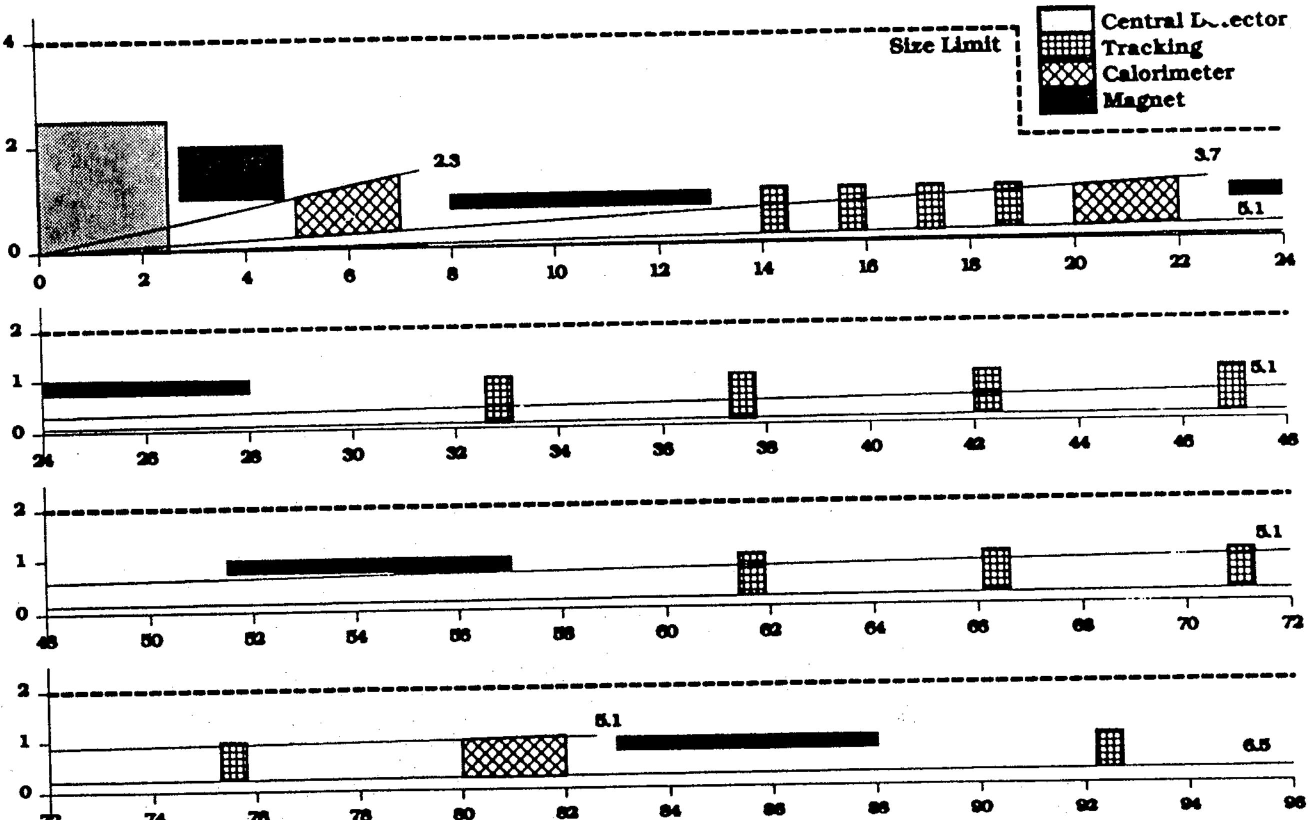
From the SDC Technical Proposal:

> **"A complete assessment of the b physics potential of SDC is still missing, but it is conceivable that b physics will be one of the main items of an initial low luminosity run, and it is our intention to explore this possibility more thoroughly in the future."**

Detector Milestones

- SDC milestones:

Submit Technical Proposal	April 1, '92
PAC Technical Review Panels	May 4-9
PAC meeting	July 10-17
DOE review for SDC	Oct/Nov



NOTE: Section continues in a similar manner to 505 m.

Scale - 1:100

Quarter Section
SSC-EOI-0019

Some SDC Physics Goals

Study of Electroweak Symmetry Breaking
$H \to Z + Z \to (l^+ + l^-) + (l^+ + l^-)$
$\to (l^+ + l^-) + (\nu + \bar{\nu})$

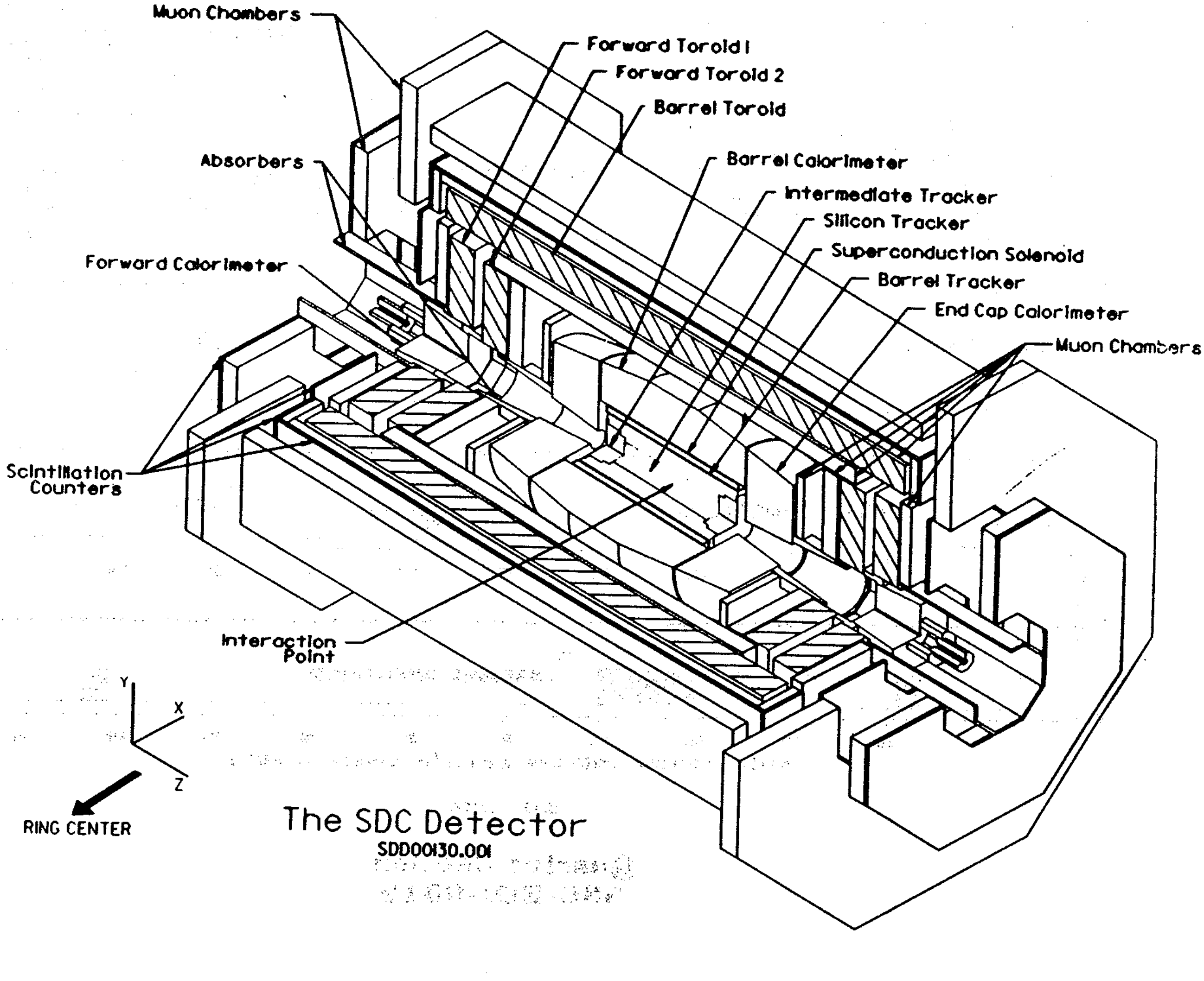
Top Quark Properties
$t \to W + b \to (e/\mu + \nu) + \text{b-jet}$
$(\text{jet} + \text{jet}) + \text{b-jet}$
$t \to$ other modes

Search for New Heavy Gauge Bosons
$W' \to e/\mu + \nu, \quad Z' \to e/\mu^+ + e/\mu^-$

Quark and Lepton Substructure
$p + p \to$ High p_t jets, $l^+ + l^-$ (Drell-Yan)

Supersymmetry
$\tilde{g} \to q + \bar{q} + \tilde{\gamma}$

EXPLORATION AND SEARCH FOR NEW PHENOMENA



The SDC Detector
SDD00130.001

SDC DETECTOR SUMMARY

SOLENOID MAGNET
Tracking Volume: 3.4 m diameter by 8m long

CENTRAL TRACKING AND HIGH RESOLUTION VERTEX DETECTION (COVERING $|\eta| < 2.5$)
Inner Silicon Systems in both Barrel & Intermediate-Angle Region
Outer Straw-Tube or Scintillating-Fiber System in Barrel Region
Outer Gas/Microstrip or Intermediate-Angle Region

PRECISION HERMETIC CALORIMETRY(COVERING $|\eta| < 3$)
Scintillating Tile with Fiber Readout with Pb (EM), Fe (Had.) Absorber
High Spatial Resolution EM Shower Max Scintillation Detector

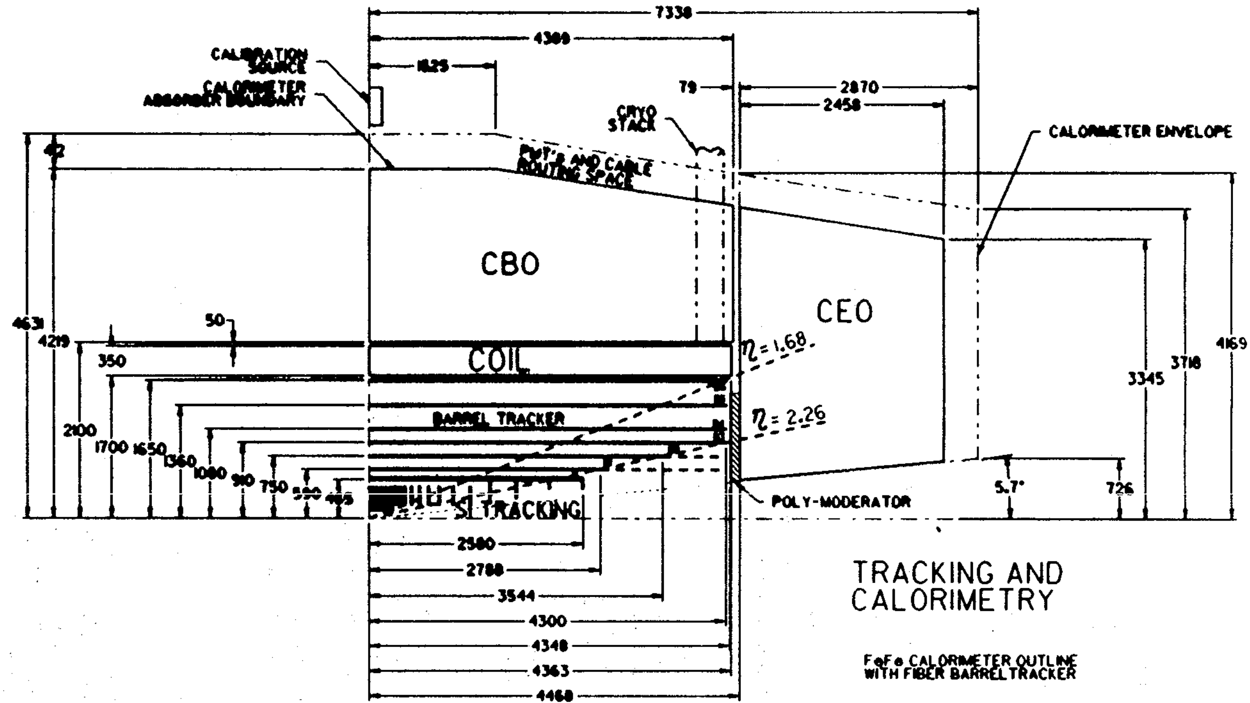
FORWARD CALORIMETRY(COVERING $3 < |\eta| < 5$)

MUON SYSTEM WITH IRON MAGNETIC TOROIDS (covering $|\eta| < 2.5$)
Tracking Chambers and Scintillation Counters

ID & PRECISION ENERGY MEASUREMENT OF ELECTRONS/MUONS
Electrons: Central Tracking Plus Calorimetry
Muons : Central Tracking Plus Muon System

Summary of preliminary baseline detector parameters.

Tracking system	
Silicon tracker	
Number of channels	5.8×10^6
Measuring layers (double-sided) ($\|\eta\| < 2.5$)	6–8
Total active area (m^2)	17
Barrel straw-tube tracker	
Number of channels	187,164
Number of superlayers	5
Rapidity coverage	$\|\eta\| < 1.8$
Intermediate gas microstrip tracker	
Number of channels	1.4×10^6
Number of superlayers (each end)	3
System performance $\Delta p_t/p_t$ @1 TeV/c p_t ($\eta = 0$)	0.16
Calorimetry	
Barrel-scintillating tile-fiber	
Number of tower channels	10,240
Number of shower maximum detector channels	28,672
EM1 depth ($\eta = 0$)	21 X_0, 0.85 λ
HAC1 depth ($\eta = 0$)	4.1 λ
HAC2 depth ($\eta = 0$)	4.9 λ
Total depth including coil ($\eta = 0$)	$\geq 10\ \lambda$
Total weight (metric tons)	≥ 2400
Endcap-scintillating tile-fiber	
Number of tower channels (both ends)	9,600
Number of shower maximum detector channels	18,432
EM1 depth	6.9 X_0, 0.3 λ
EM2 depth	18.3 X_0, 0.8 λ
HAC1 depth	5.0 λ
HAC2 depth	6.0 λ
Total depth ($\eta = 3$)	12.1 λ
Forward-high pressure gas or liquid scintillator	
Number of tower channels (both ends)	1056
Number of depth segments	2
Total depth	12 λ
System performance	
Central calorimenter ($\|\eta\| < 3$)	
$\Delta E_t/E_t\|_{EM}$	$\sim 0.15 \oplus 0.01$
$\Delta E_t/E_t\|_{HAD}$	$\sim 0.50 \oplus 0.04$
Muon system	
Magnet	
Barrel toroid weight (metric tons)	16,406
Forward toroids weight (metric tons) (both ends)	4,689
Number of chamber layers	
Barrel (BW1, BW2, and BW3)	22
Intermediate (IW2, IW3)	14
Forward (FW1, FW2, FW4, and FW5)	24
Number of scintillator layers	
Barrel (BS2 and IS2)	1
Forward (FS4 and FS5)	2
Number of muon chamber channels	117,089

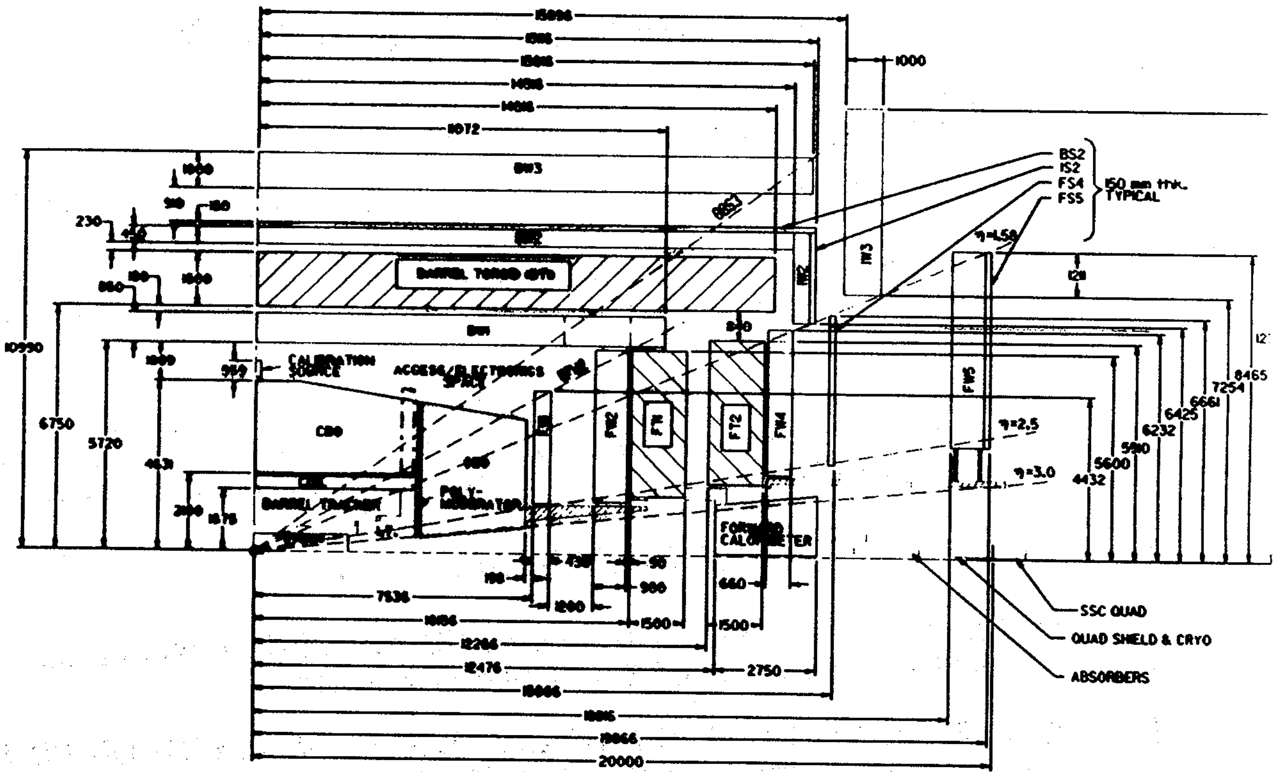


TRACKING AND CALORIMETRY

FeFe CALORIMETER OUTLINE
WITH FIBER BARREL TRACKER

SSC DRAWING #sdd000081.004
24-FEB-1992

NOTE: ALL DIMENSIONS ARE IN MILLIMETERS.



SDC DETECTOR
TECHNICAL PROPOSAL DIMENSIONS

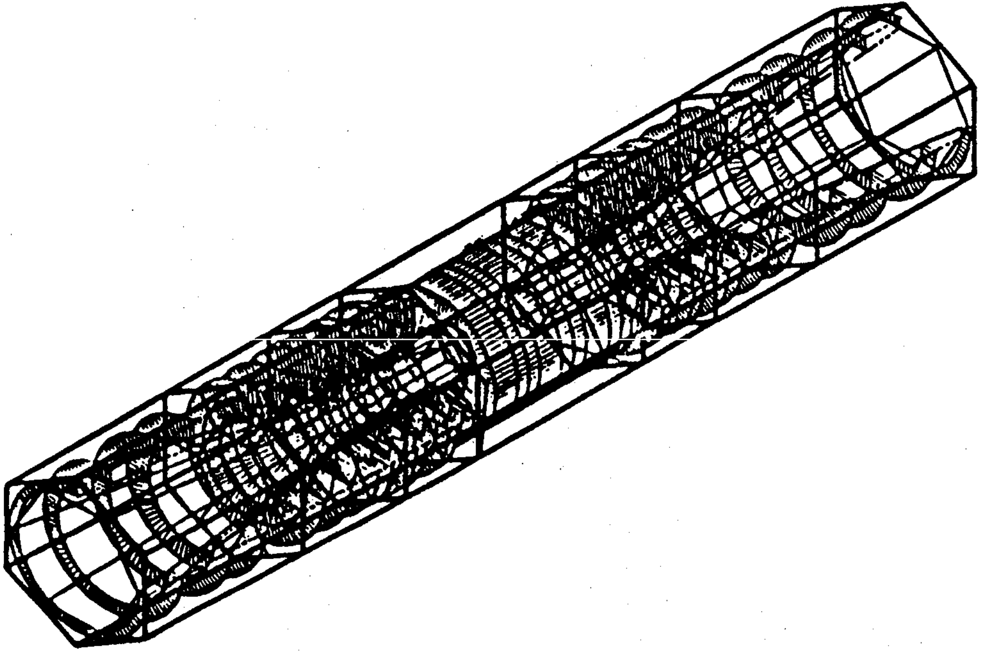
SDC INTEGRATION SDD-000081.004 24-FEB-1992

0 1 2 3 4 5M

NOTE: DIMENSIONS ARE IN MILLIMETERS

SILICON TRACKING SYSTEM

SILICON WAFERS AND SPACE FRAME

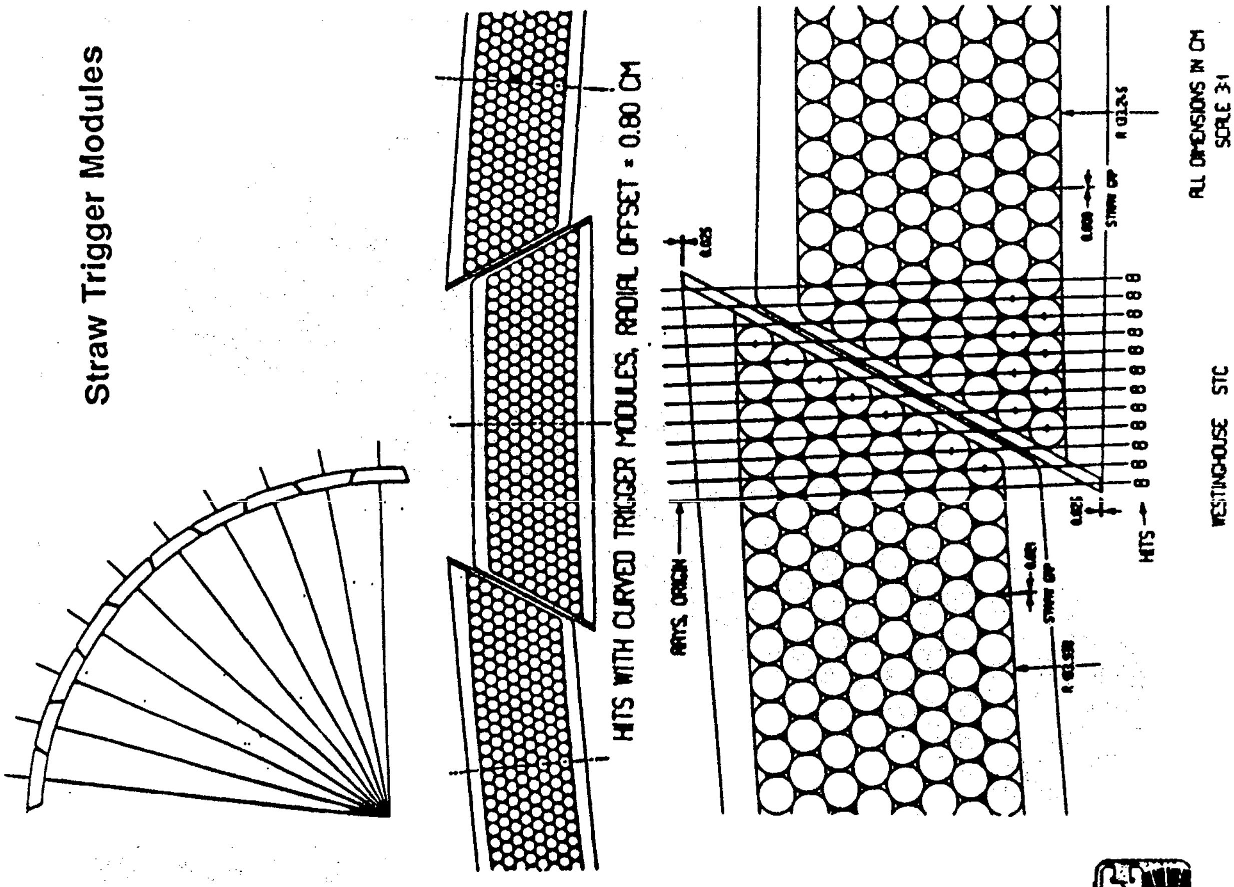


LOS ALAMOS

SDC TRACKING SYSTEM

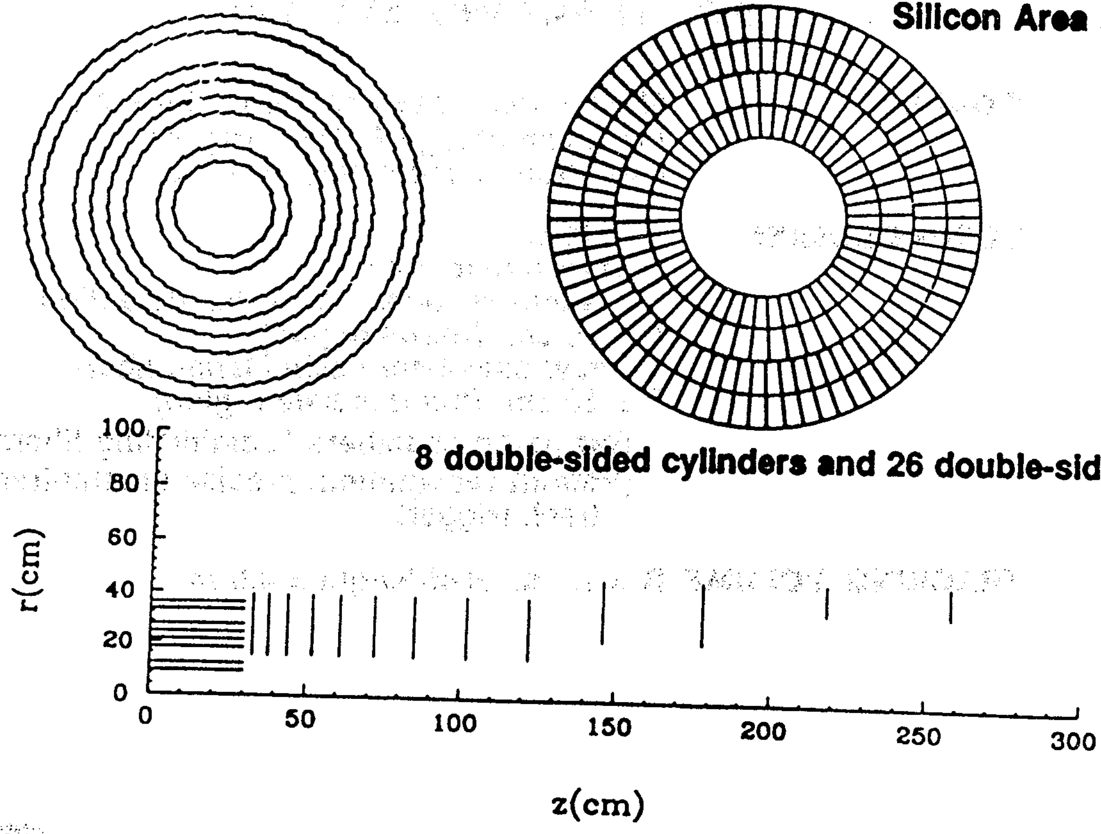
GOALS	Momentum measurement for $\lvert\eta\rvert < 2.5$ Provision of high-Pt track trigger Detection of secondary vertices
TECHNOLOGIES	$R < 50$ cm Silicon detectors (Pattern recognition, vertex detection) $R > 50$ cm (barrel region) Straw chambers / scintillating fibers $R > 50$ cm (intermediate region) Gas μstrip chambers / scintillating fibers (Pattern recognition, precise momentum, track trigger)
TRACKING VOLUME	R = 1.7 m, Half-length = 4.0 m

Straw Trigger Modules



Silicon System Layout

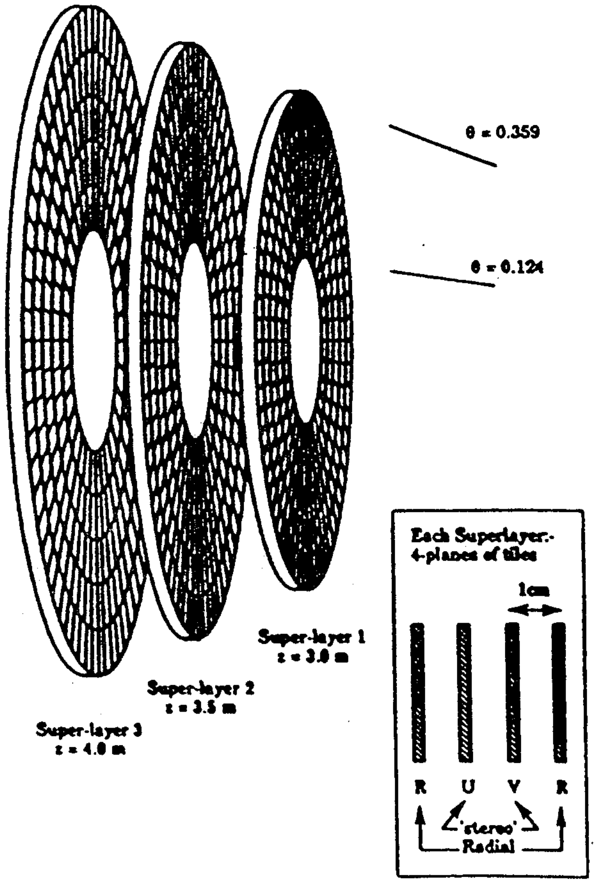
Silicon Area = 17.4 m²



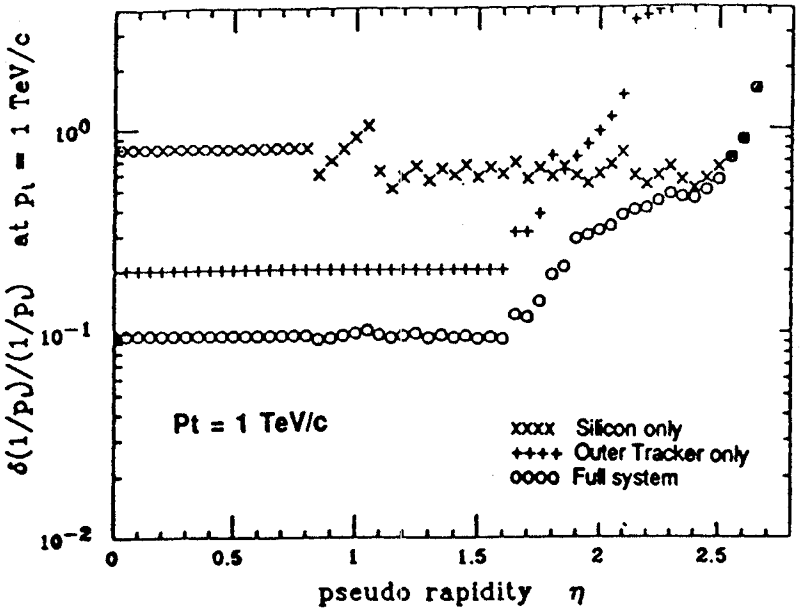
8 double-sided cylinders and 26 double-sided disks

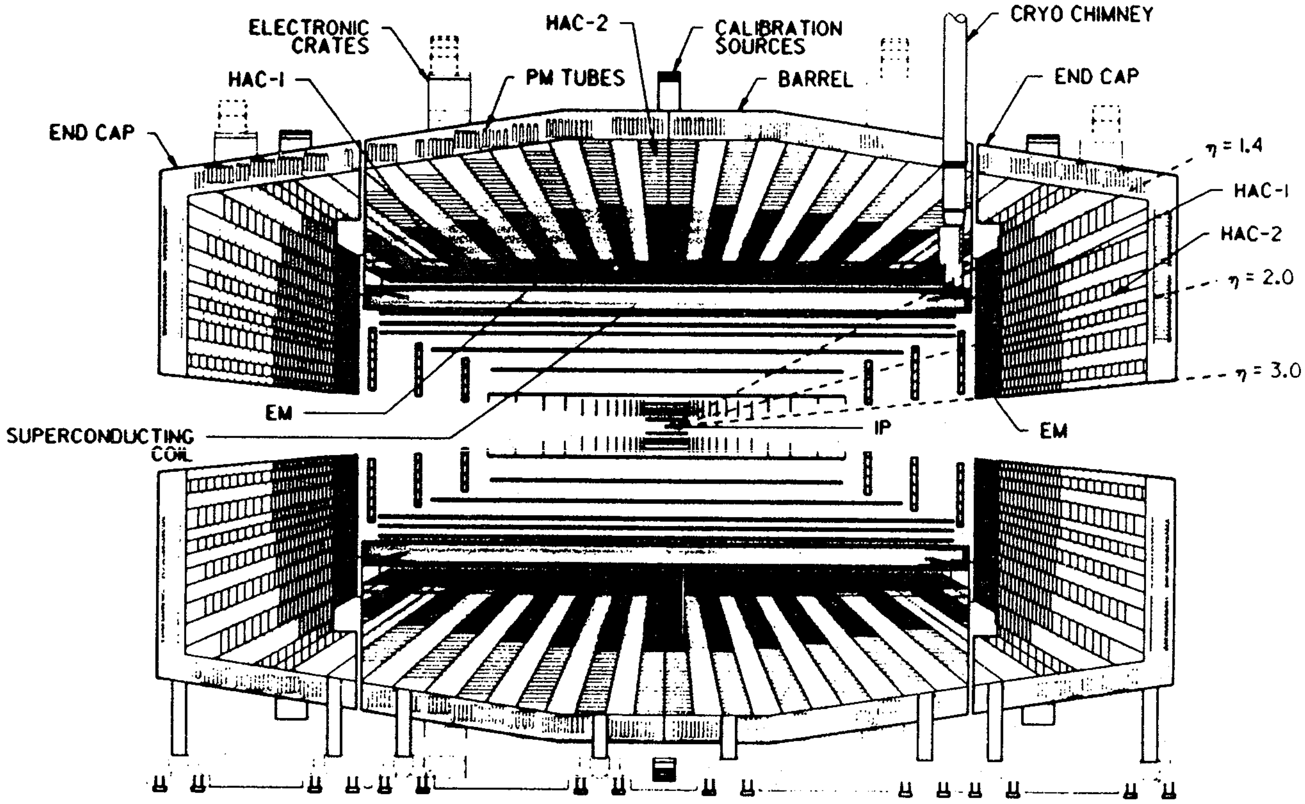
Gas-Microstrip Tracker Design

ITD



Momentum Resolution (Beam-constrained)





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TENTATIVE CENTRAL CALORIMETER CHOICES

(To be reviewed and finalized at end January)

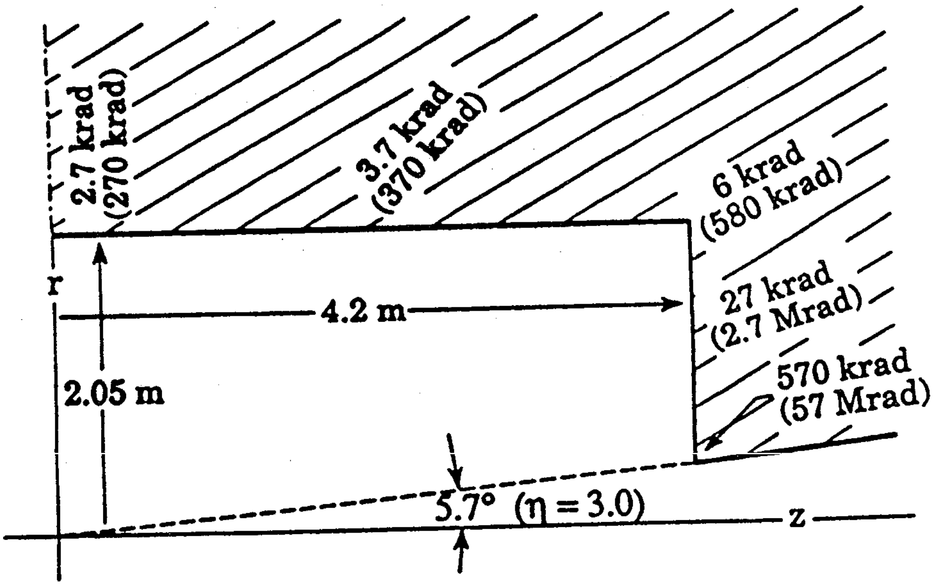
EM SECTION
- Barrel: 1 longitudinal section upgradable to 2
- Endcap: 2 longitudinal sections
- Transverse segmentation: 0.05 x 0.05
- Pb thickness: 4 mm (barrel), 6.2 mm (endcap)
- 4 mm scintillator
- Shower max segmentation: 0.05/8 x 0.2 in both directions

HAC1 SECTION
- Absorber: iron
- Fe thickness: 24 mm (barrel), 51 mm (endcap)
- Transverse segmentation: 0.1 x 0.1 upgradable to 0.05 x 0.05

HAC2 SECTION
- Absorber: iron
- Fe thickness: 54 mm (barrel), 108 mm (endcap)
- Transverse segmentation: 0.1 x 0.1

Total Depth: 10 λ at 90°

Maximum Ionizing Dose in the SDC Calorimeter



Maximum ionizing dose in calorimeter (at EM shower maximum) for 1 year at 10^{33} and in parentheses for 10 years at 10^{34} .

FORWARD CALORIMETRY

FUNCTIONS: Help measure missing-Et, and detect forward jets in such processes as Higgs production

REQUIREMENTS: $|\eta|$ fiducial coverage 3 - 5

$\sigma(E)/E < 10\%$, Adequate depth (under study) and hermiticity

Transverse segmentation 0.2 x 0.2 ($\eta \approx 3$) to 0.4 x 0.4 ($\eta = 5$)

Technologies being pursued in SDC
- High pressure gas ionization calorimetry
- "Liquid spaghetti"..Liquid scintillator inside small tubes

SDC expects to decide on no more than two technological options by February 1, 1992

MUON SYSTEM

FUNCTIONS: Muon ID, muon momentum measurement with central tracker, Level 1 trigger, contributions to Level 2 and 3 triggers

ELEMENTS OF MUON SYSTEM

Iron toroids in both central and intermediate regions,

Scintillation/[redacted] counters for trigger and bunch crossing ID,

Drift chambers for trigger, momentum measurement and muon ID.

SACLAY

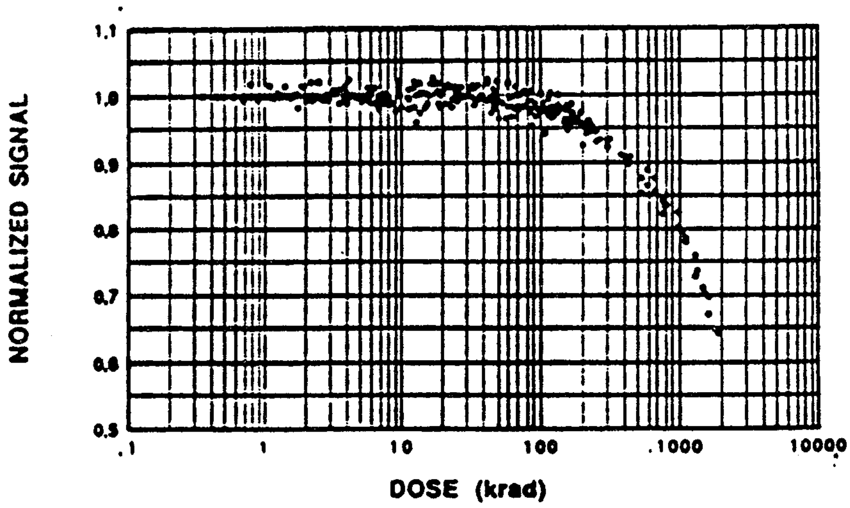
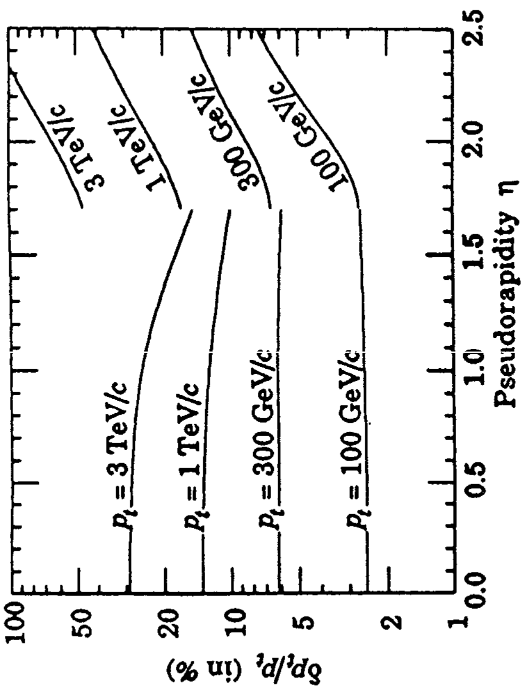
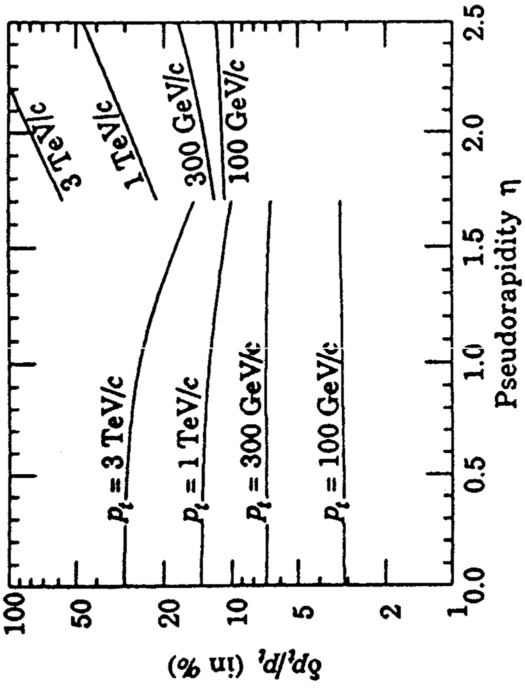


Figure 8: Relative signal, normalized to tile # 20 (see text), as a function of the dose received.

MUON SYSTEM MOMENTUM RESOLUTION



MUON SYSTEM MOMENTUM RESOLUTION
High Luminosity Performance



MUON TRIGGER

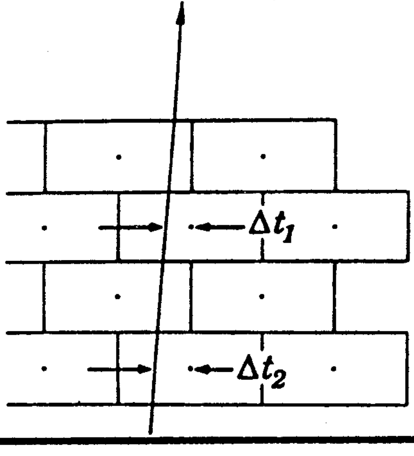
LEVEL 1

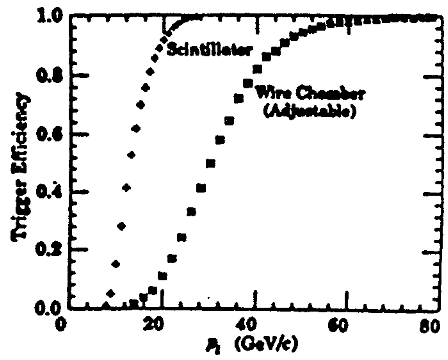
2 scintillation layers with strips aligned in θ plus combination of muon wire chamber hits also aligned in θ.

LEVEL 2

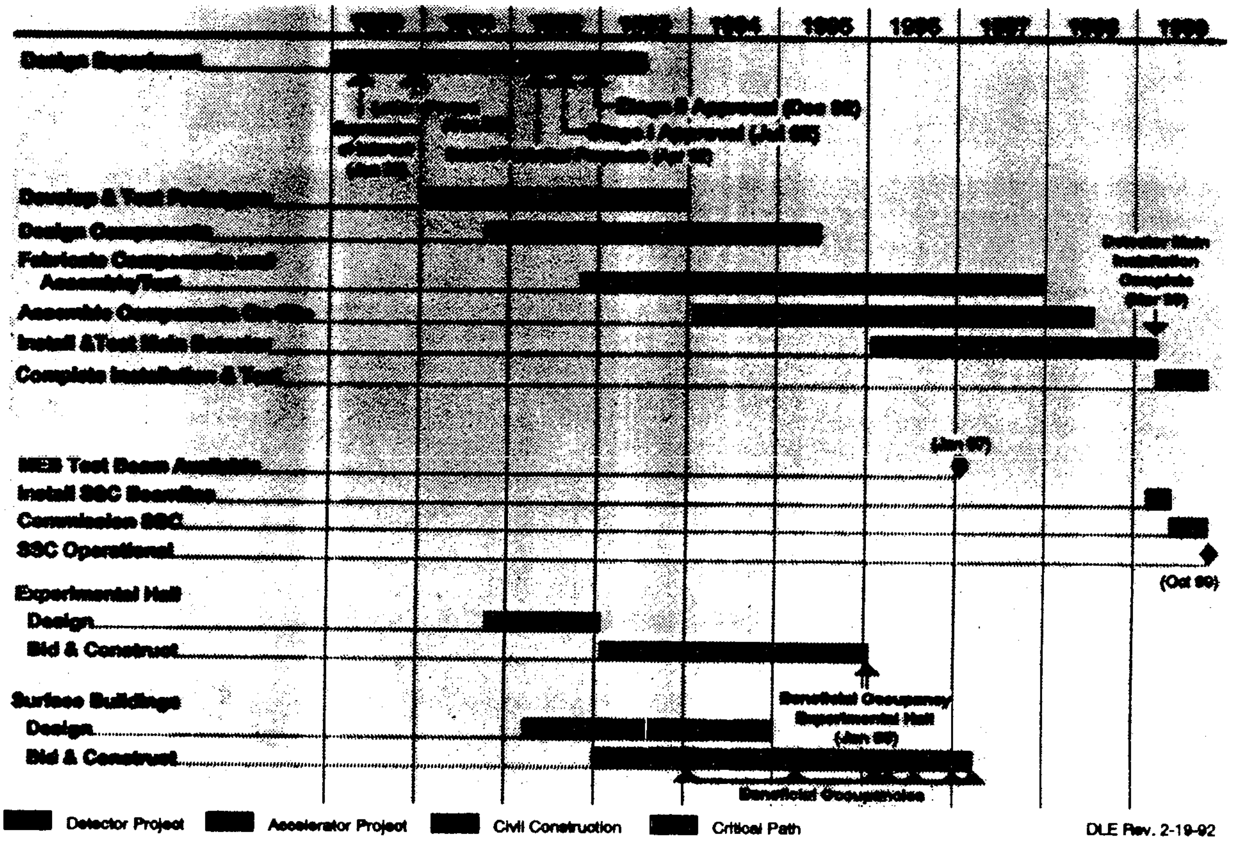
Central region: ϕ information from muon chambers combined with outer layers of central tracker.

Intermediate region: θ angle-angle measurement in forward toroid .

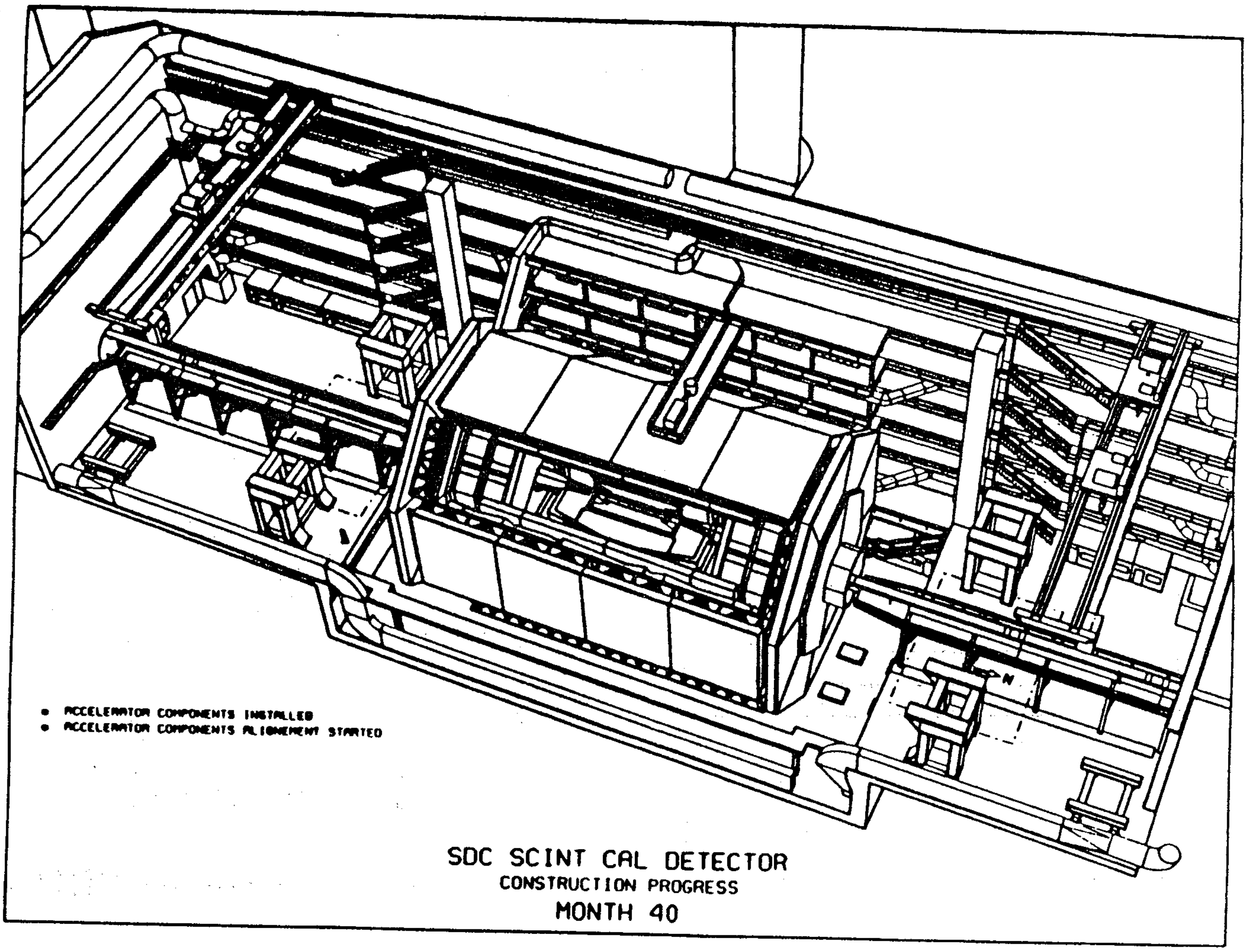




SUMMARY SDC DETECTOR SCHEDULE

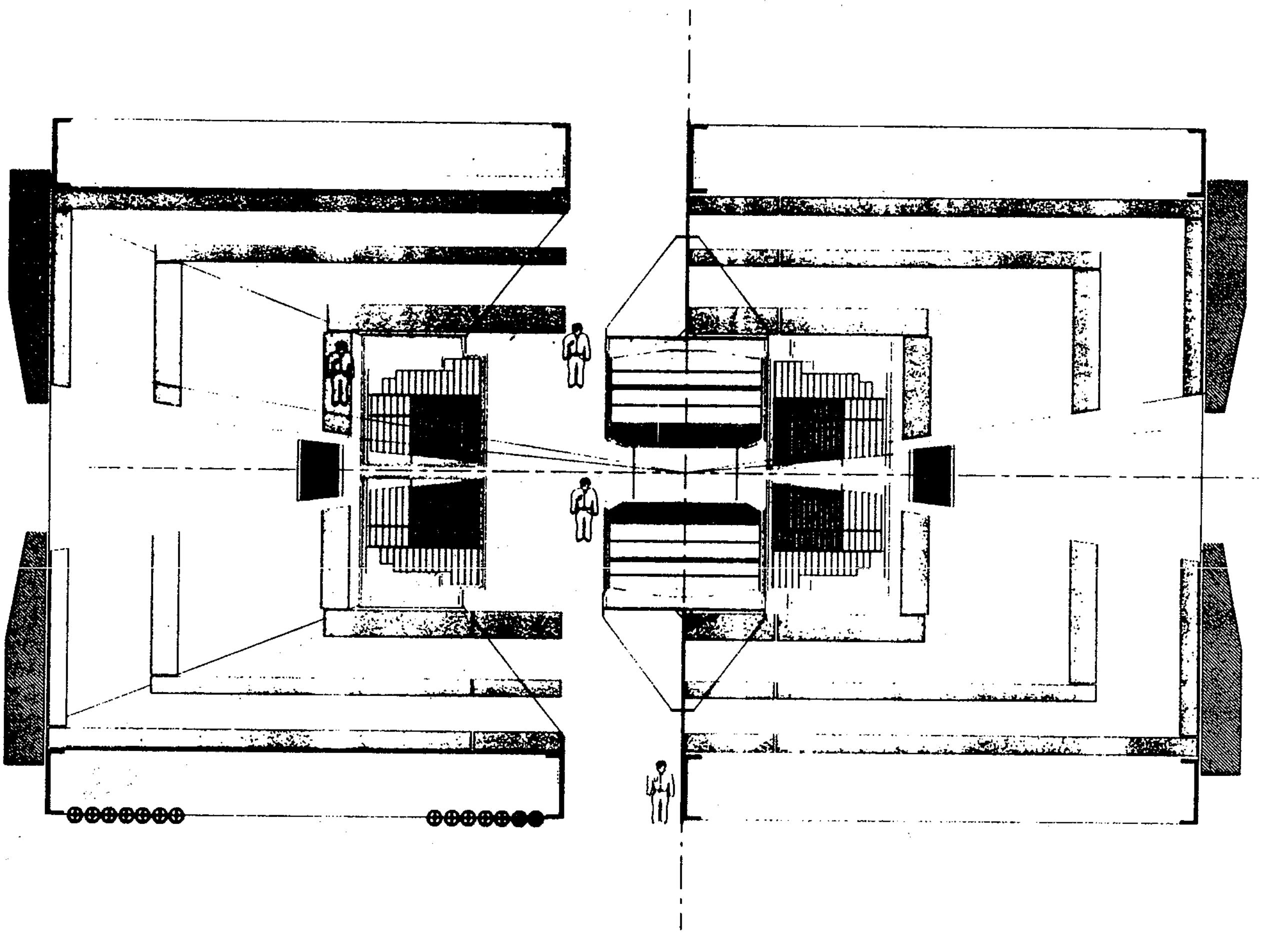


DLE Rev. 2-19-92

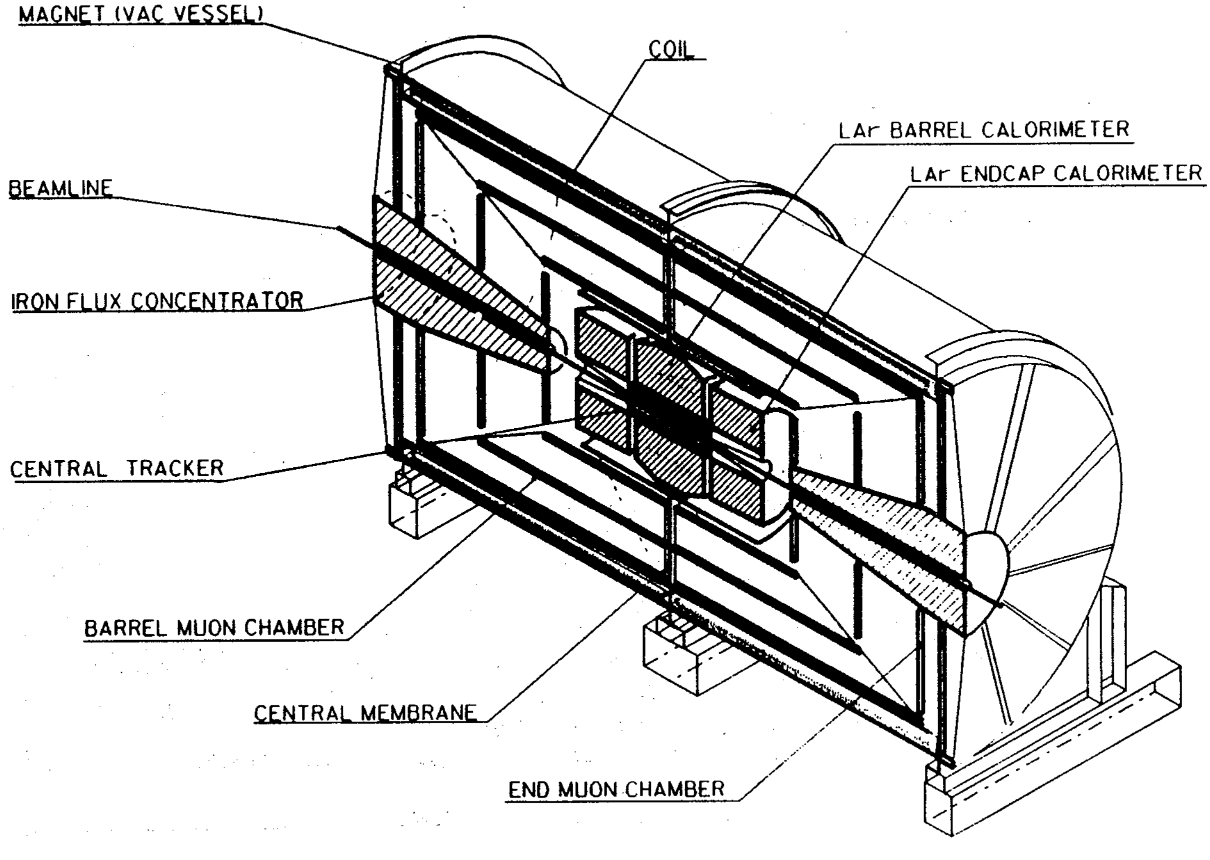


- ACCELERATOR COMPONENTS INSTALLED
- ACCELERATOR COMPONENTS ALIGNEMENT STARTED

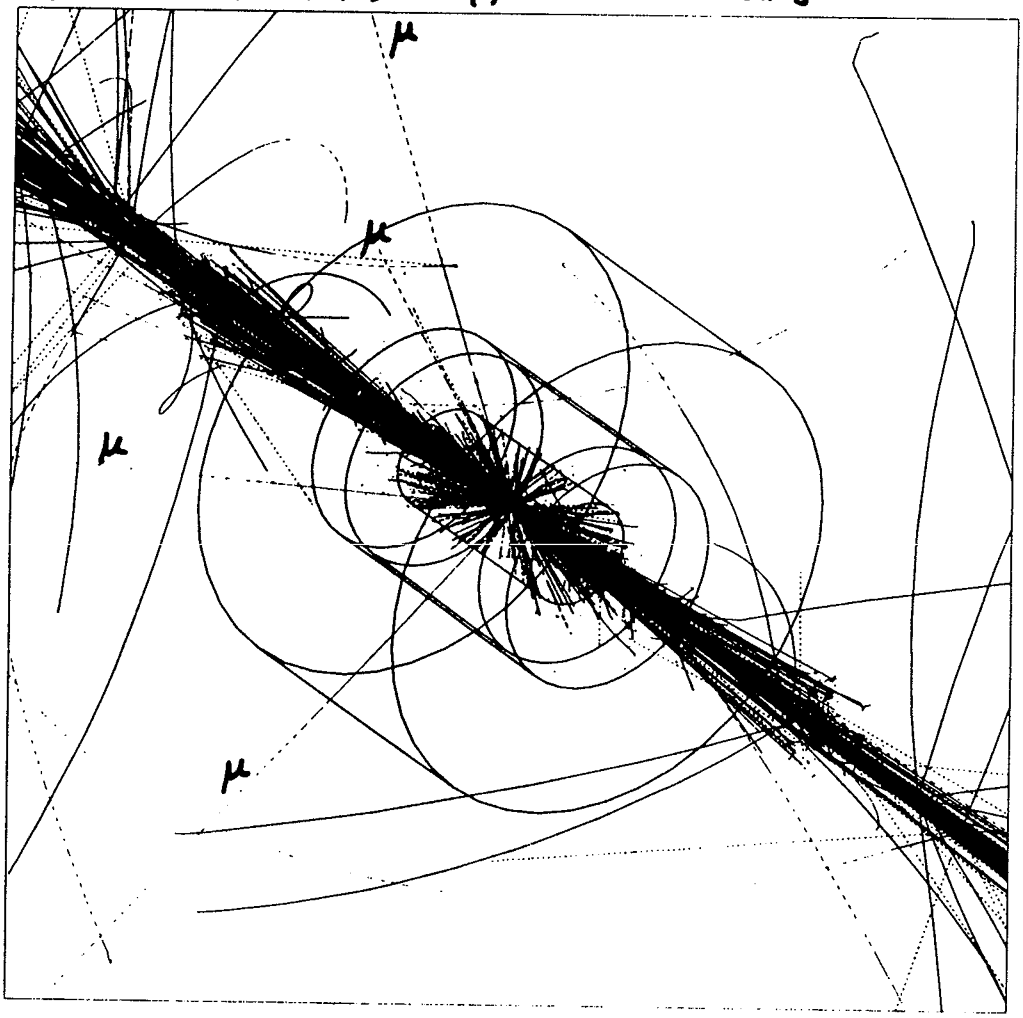
SDC SCINT CAL DETECTOR
CONSTRUCTION PROGRESS
MONTH 40



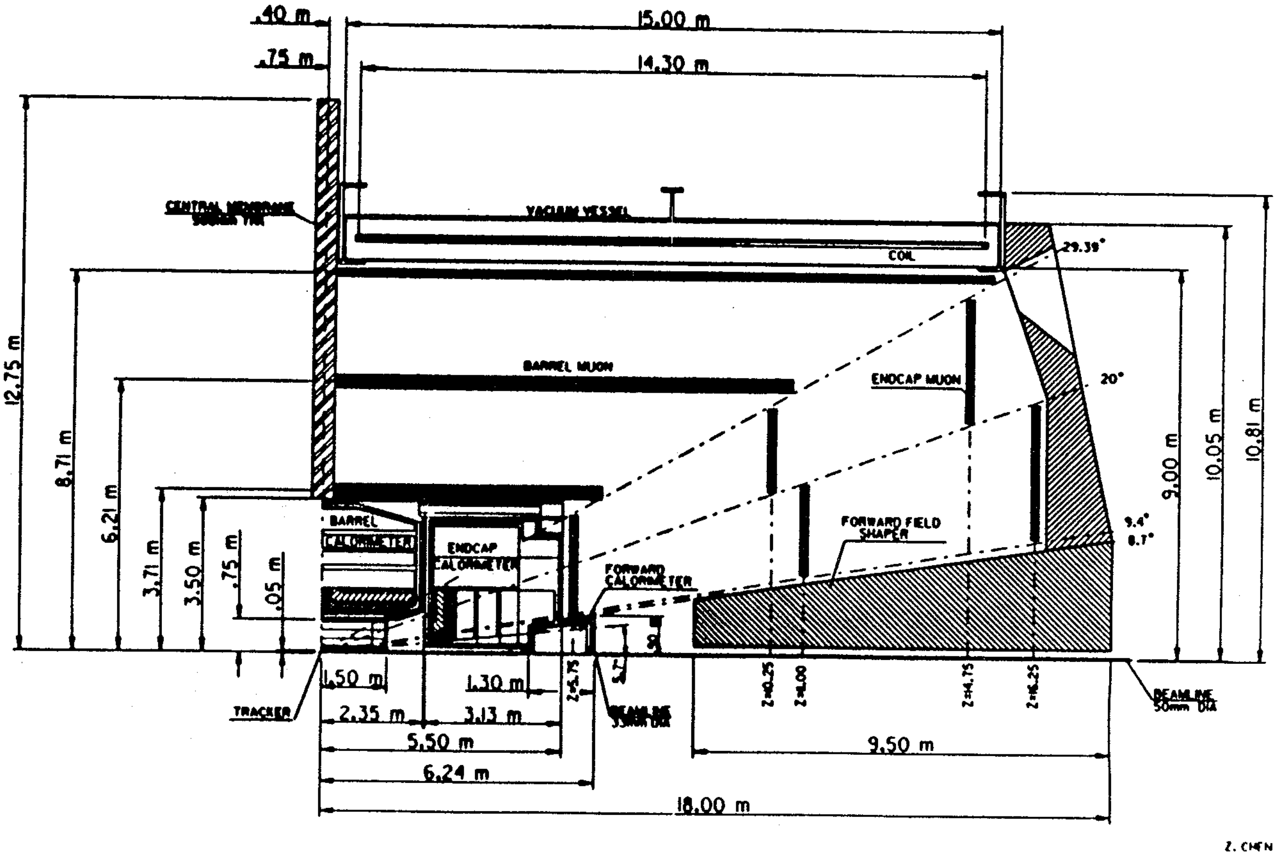
GEM DETECTOR



GEM: $H^{\circ}(400\,GeV/c^{2}) \longrightarrow 4\mu$ at $\mathcal{L} = 10^{-}\,cm^{-2}s^{-1}$



GEM DETECTOR ELEVATION



Z. CHEN

NEW PHYSICS POSSIBILITIES AND SIGNATURES AT $O(1\,\text{TeV})$

PHYSICS	*SIGNATURES*
Standard H^0	$\gamma\gamma$, $ZZ^* \to \ell^+\ell^-\ell^+\ell^-$; $ZZ \to \ell^+\ell^-\ell^+\ell^-$, $\ell^+\ell^- jj$, $\ell^+\ell^-\bar{\nu}\nu$
Extended H^0, h^0, $H^\pm$	Same as above; Heavy $f\bar{f}' \Rightarrow$ flavor tags, isolated $\ell^\pm$, $W^\pm \to jj$, etc.
Heavy $\overline{Q}Q$	$W^\pm q \to$ jets + isolated $\ell^\pm$
W', Z' (mass, width, asym.)	$\ell^\pm + \not{E}_T$, $\ell^+\ell^-$
Strong VV scattering	WW, WZ, $ZZ \to$ isolated $\ell^\pm$ + jets, $\not{E}_T$
Technicolor	$\rho_T \to WZ(\to \ell^+\ell^-\ell^\pm\not{E}_T,\ \ell^+\ell^- jj)$, $\pi_T\pi_T$; $\pi_T \to$ heavy $f\bar{f}'$, dijets
Supersymmetry	multi-isolated $\ell^\pm$, jets, $\not{E}_T$
q Substructure	high-mass dijets; more?
q/ℓ Substructure	high-mass dileptons, $\not{E}_T$; more?
None of the Above!	All of the Above!

- New physics *is* near 1 TeV, but *we do not know what that physics is!*
- **All** new physics signatures involve γ, $e^\pm$, $\mu^\pm$, $\tau^\pm$, jets, $\not{E}_T$, b, t.
- ***All*** new physics possibilities were proposed $\gtrsim$ 10 years ago!

SSC ENERGY, LUMINOSITY AND EXPERIMENTS ARE NEEDED FOR GUIDANCE AND ANSWERS TO THE EWSB AND FLAVOR/FSB MYSTERIES.

GEM Parameters for Physics Studies

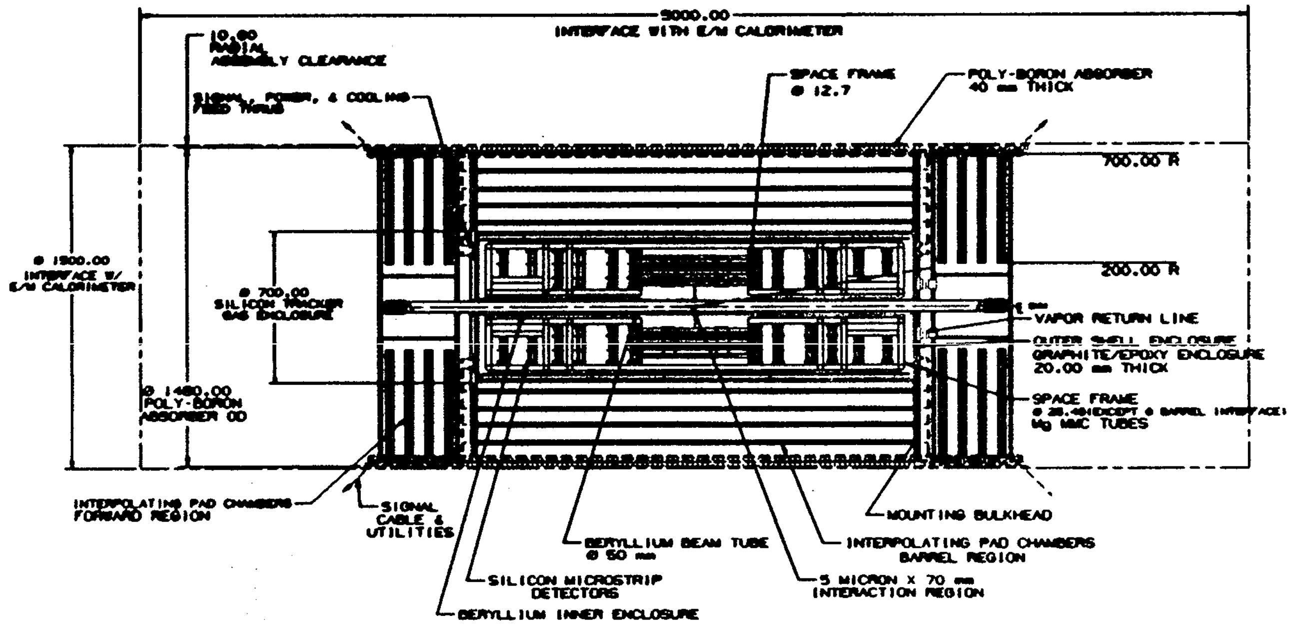
1. Magnet
   - $B = 0.8$ T
   - Inner radius = 9.0 m
   - Length = 30 m

2. Muons
   - $|\eta| < 2.5$
   - $\Delta p_T/p_T^2$ = 10 %/TeV for $|\eta| \le 1.5$
   - 30 %/TeV @ η = 2.5
   - No reliance on central tracking
   - Operable to $\mathcal{L} = 10^{34}$ cm^{-2}s^{-1}

3. EM Calorimeter (BaF₂ or LAr/Krypton)
   - $\frac{\Delta E}{E} = (2-7)\%/\sqrt{E} \oplus 0.5\%$ BaF
   - .4 LA
   - $|\eta_{em}| < 2.5$
   - segmentation $\Delta\eta \times \Delta\phi = 0.02 \times 0.02$

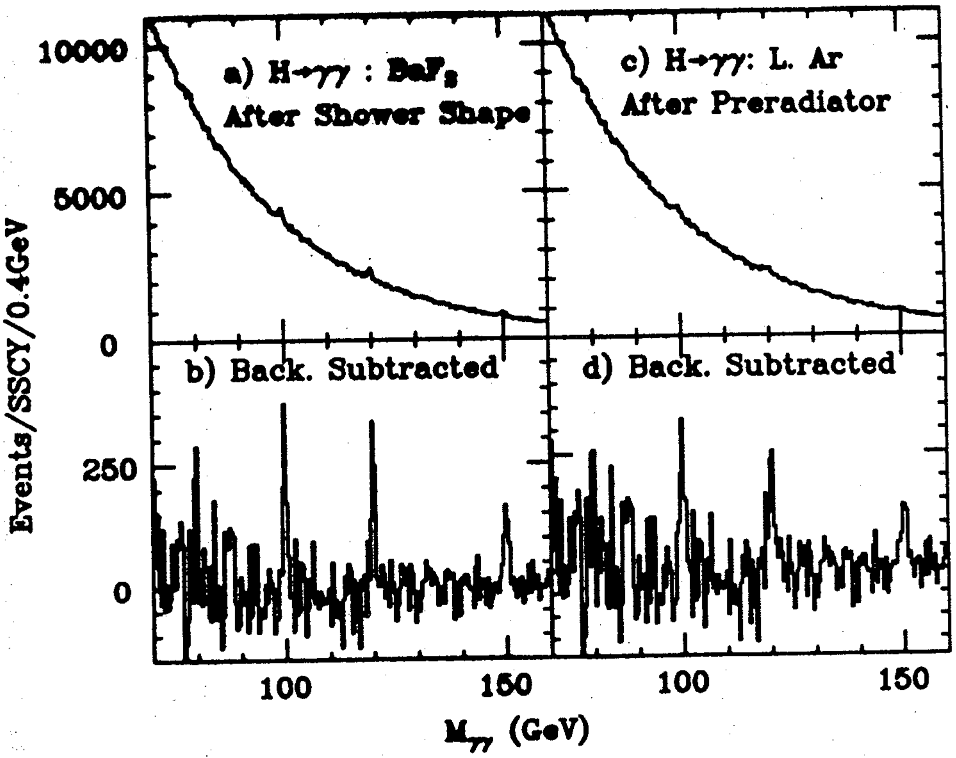
4. Hadron Calorimeter
   - Special on LAr
   - $\frac{\Delta E}{E} = (50-60)\%/\sqrt{E} \oplus 4\%$
   - $|\eta| < 3$
   - segmentation $\Delta\eta \times \Delta\phi = 0.05 \times 0.05$
   - forward calorimeter $3 \le |\eta| \le 5$
   - integrate w back of end cal
   - $5 \le z \le 6.4$ m

5. Central Tracking
   - Si Strip (inside)
   - IPC
   - Unambiguous space points to $|\eta| = 2.5$
   - Sign selection to 400 GeV 95%

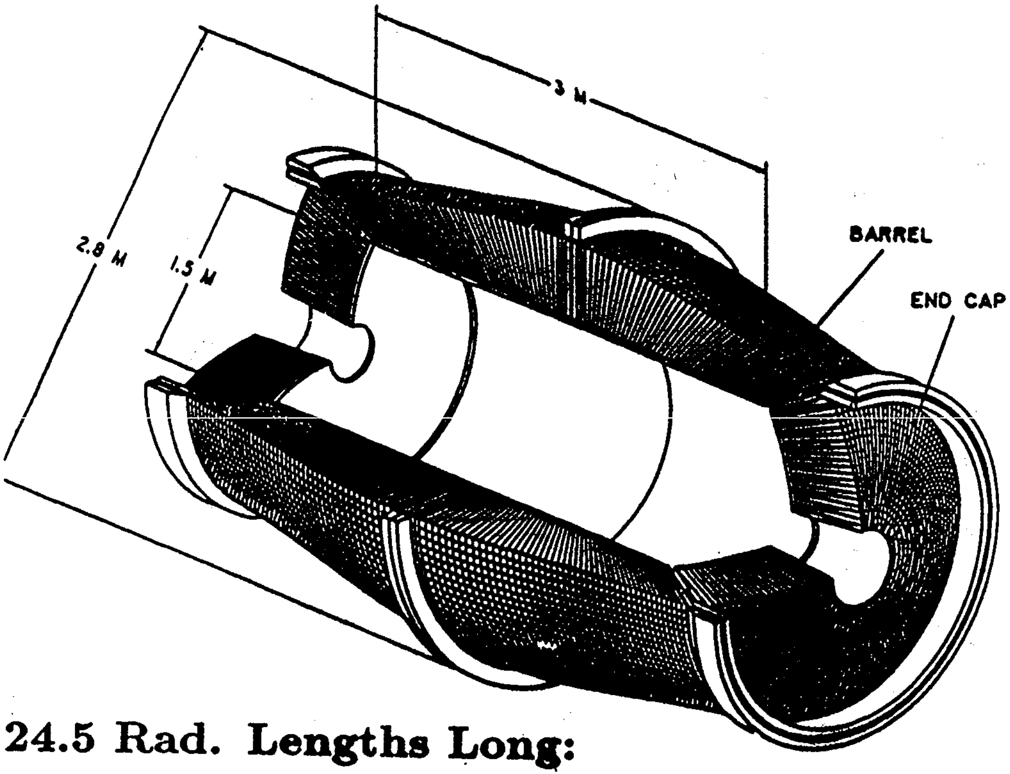


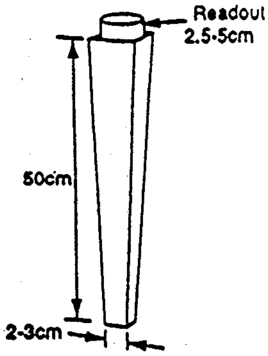
GEM CENTRAL TRACKER

$H \rightarrow \gamma + \gamma$



BARIUM FLUORIDE
PRECISION EM CALORIMETER





24.5 Rad. Lengths Long:
Total 16,060 Crystals,
$10.3\ m^3$, 50.2 Tons

Table 2.5-1 Design Parameters for GEM Central Tracking

Outer Radius	70 cm
Length	±150 cm
Rapidity Coverage	$\|\eta\| \leq 2.5$
Magnetic Field	0.8T
[redacted]	
at $\mathcal{L} = 10^{33}\ cm^{-2}s^{-1}$	$\leq 1\%$
at $\mathcal{L} = 10^{34}\ cm^{-2}s^{-1}$	$\sim 3\%$
2σ charge separation	$p \leq 400$ GeV/c
Momentum Resolution at 90°	
at high momenta (measurement limited)	$\Delta p/p^2 \sim (1\ to\ 3) \times 10^{-3}$ $(GeV/c)^{-1}$
at low momenta (multiple scattering limited)	$\Delta p/p \sim 2$ to 4%
Vertex Resolution	
along beam direction	$\delta z \sim 1$ mm
impact parameter	$\delta b \sim 20\ \mu m$ above 10 GeV/c

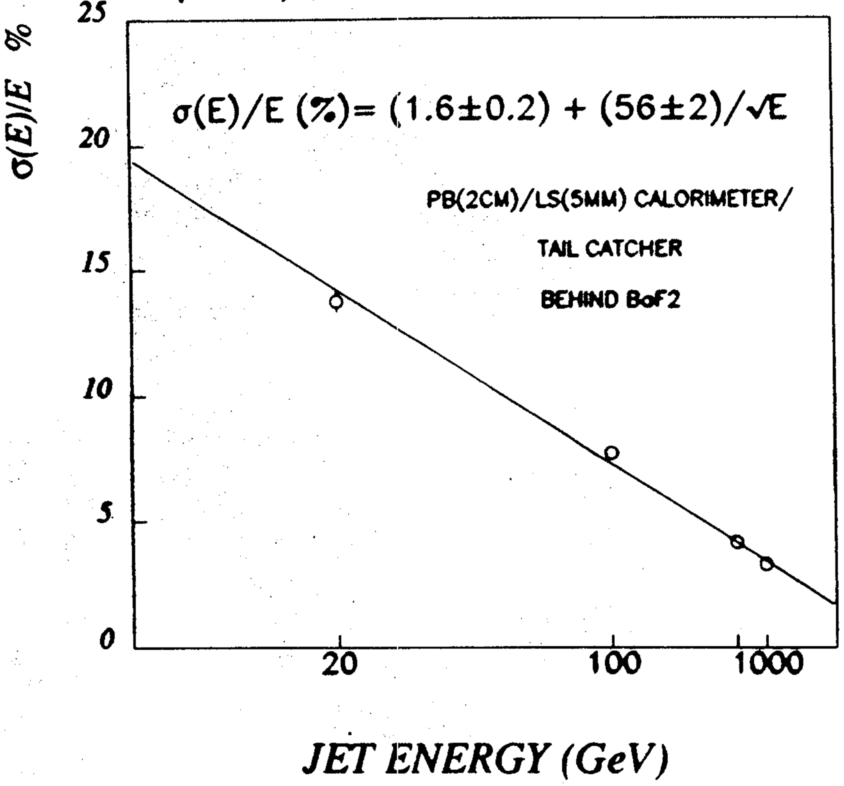
Table 2.4-3 Features of the BaF_2 Calorimeter

Detector	Barrel	Two Endcaps
Rapidity Coverage	$\lvert\eta\rvert \leq 1.32$	$1.32 \leq \lvert\eta\rvert \leq 2.5$
Crystal Front/ Rear Face (cm^2)	3.1 × 3.1 / 5.1 × 5.1	2.3 × 2.3 / 3.1 × 3.1
Crystal Length (cm)	50	50
Crystal Number	10,880	4144
Crystal Volume (m^3)	8.4	2.2
Crystal Weight (t)	41.1	10.7

Spaghetti
Hadron Calorimeter

JET RESOLUTION - GEANT3

(after optimisation for α∗BaF2 + β∗Pb/LS)

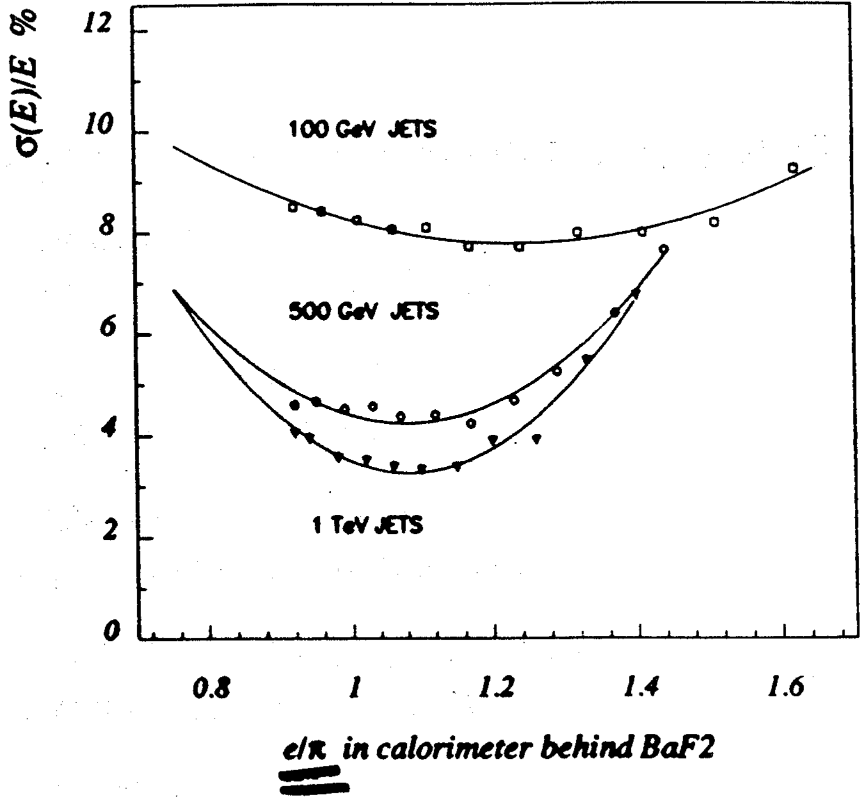


Compensation

GEANT3 - JET RESOLUTION for BaF2+scint.HADRON calorimeter

here BaF2 $<e/\pi>$ = 1.7

After optimisation for α*BaF2 + β*HC



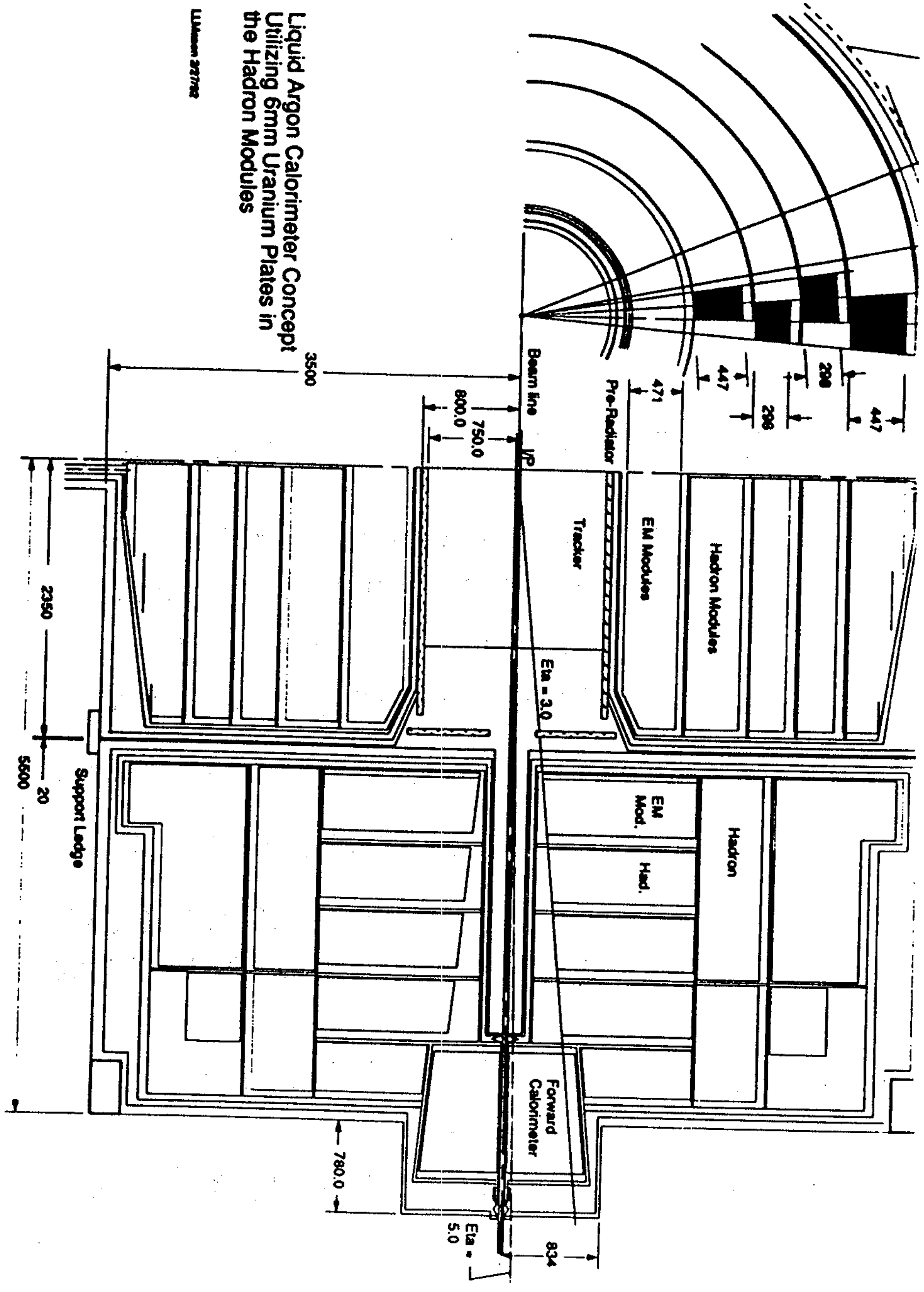
BaF$_2$ CRYSTAL PRODUCTION
and
RADIATION RESISTANCE

- **Studies of Critical Impurities and Radiation Hardness**
  - **at SIC, BGRI, IHEP (Beijing)**
- **Purify Raw Materials:**
  - **Eliminate Selected Metals (Ce, Pb, Co) To < 1 ppm**
  - **Specifically Eliminate O$_2$, OH$^-$ During Pre-Treatment and Growth**

EXPERT REVIEW PANEL

BaF_2 ELECTROMAGNETIC CALORIMETER FEATURES

- **Speed:**
  Gating Time $\leq$ 16 nsec
- **Energy Resolution:**
  $\Delta E/E = (2.0/\sqrt{E} \oplus 0.5)\%$
- **Position Resolution:**
  Δx and $\Delta y \approx 1$ mm
- **Segmentation:**
  $\Delta\eta \approx \Delta\phi \approx 0.04$
- **$e/\pi, \gamma/jet$, and e/jet**
  Separation: $\sim 10^{-4}$
- **Radiation Resistance:** $\geq$ 10 MRads.?



Liquid Argon Calorimeter Concept Utilizing 6mm Uranium Plates in the Hadron Modules

LLMason 2/27/92

$$\sigma = \frac{a}{\sqrt{E}} + b$$

Table 2.4-1 Effect of Energy Resolution: a and b

a =	2.0	5.0	7.5	10	15
b = .25	0.63	1.2	1.7	2.2	3.3
b = 0.5	1.0	1.4	1.8	2.3	3.4
b = .75	1.4	1.7	2.1	2.6	3.6
b = 1.0	1.8	2.1	2.4	2.9	3.7

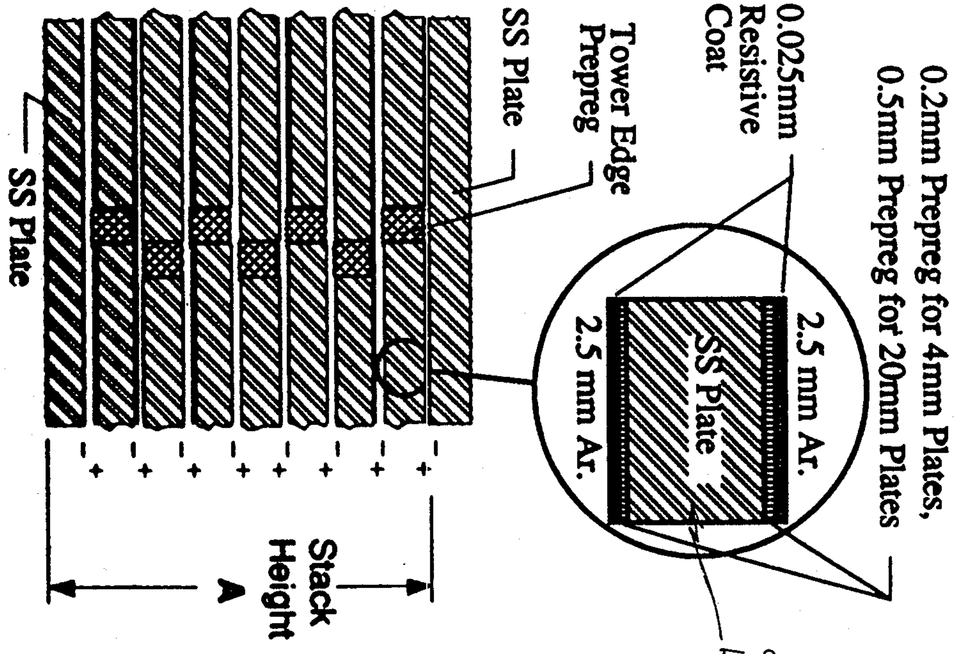
Liq Ar/kr

BaF₂

$$H \rightarrow \gamma + \gamma$$

$$E_\gamma \sim 100 \text{ GeV}$$

Electrostatic Transformer to reduce capacitance



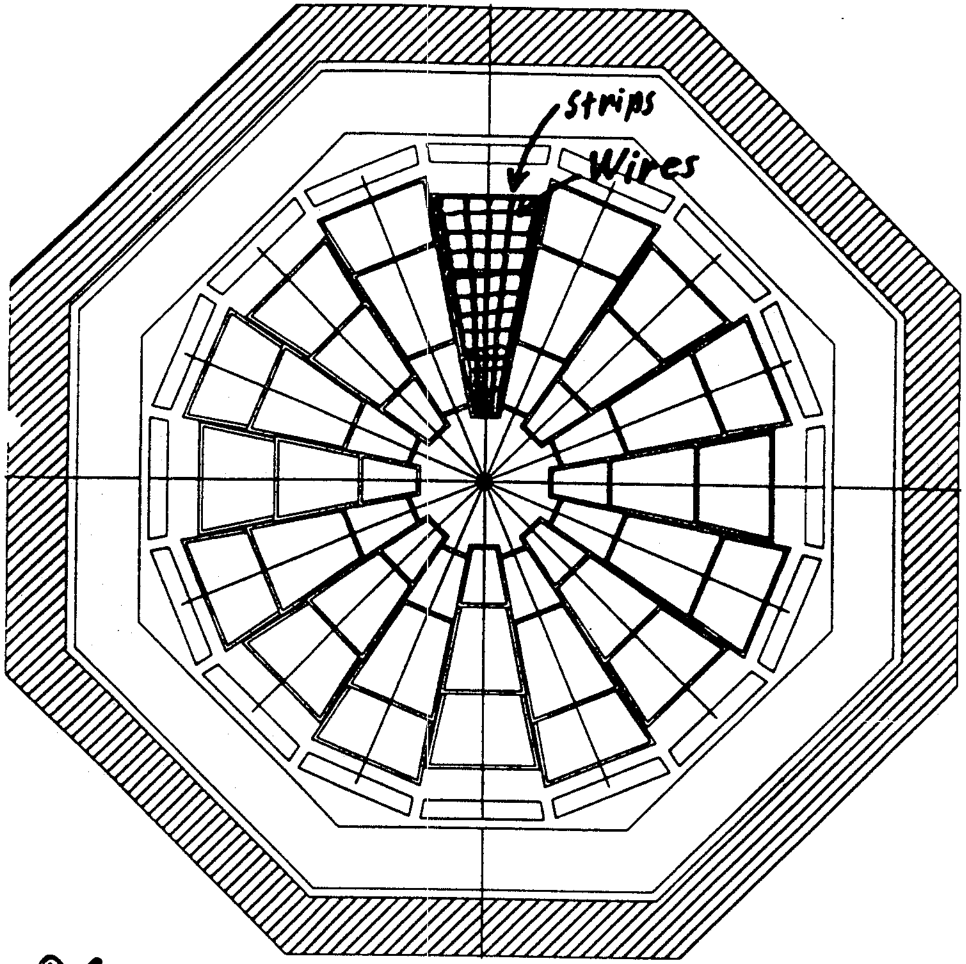
Changed to Uranium tiles

GEM MUON SYSTEM

BARR[illegible] - **Drift tubes** for tracking
RPC's for timing / trigger

END-C[illegible]AP - **Cathode Strip Chambers**
for tracking, timing + trigger

CATHODE STRIP CHAMBERS IN ENDCAPS



① **Strips** can be layed out radially - ideal for **p measurement** and **trigger**

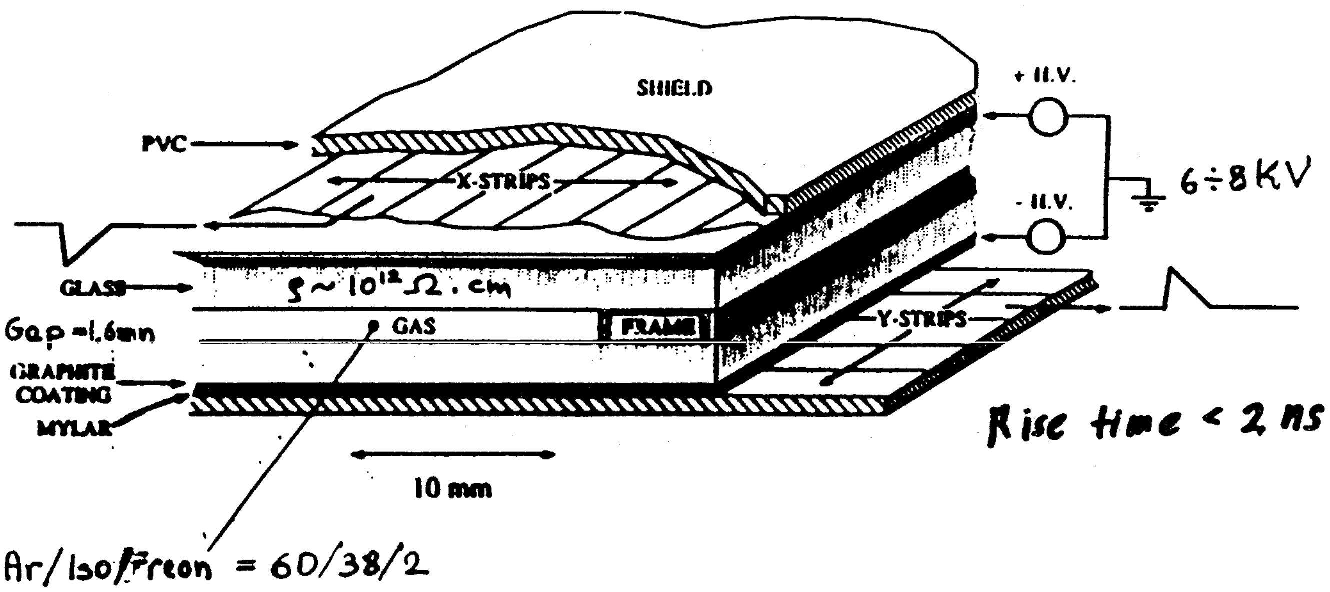
② **Wire** pitch can be made small enough to enable **beam cross tagging**

L* 20MW Magnet Version/4

Muon Spectrometer Volume

C Grinnell
scale 1 100
version 4 5 14 02 90
from 20MW/4 13 10 89

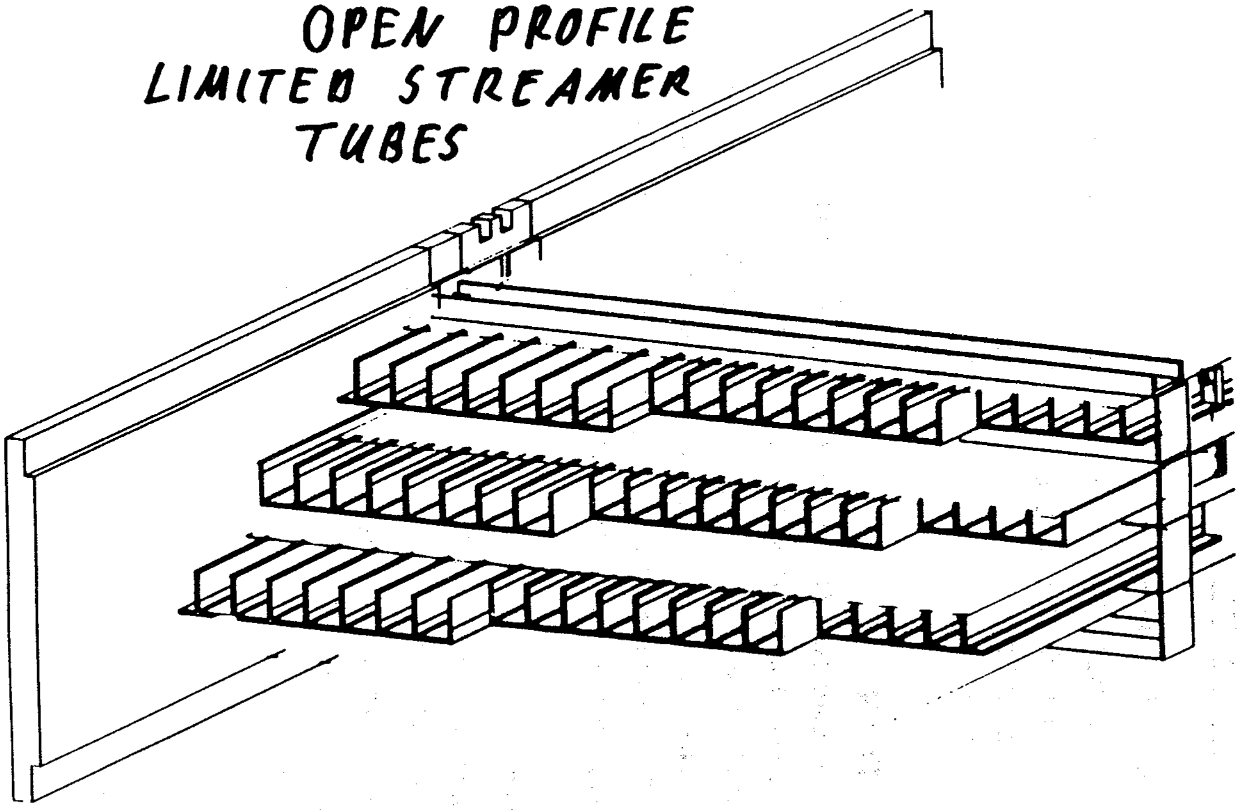
Glass Spark Counter * (RPC)
(Resistive Plate Counter)



* R&D project for a new version of large gap parallel plate counters (GLASS)

Being tested also in RD5

OPEN PROFILE LIMITED STREAMER TUBES



R. STROYNOWSKI/SMU 682
11/1/91

MAGNET

1. BASE-LINE DESIGN

SINGLE COIL SUPERCONDUCTING SOLENOID

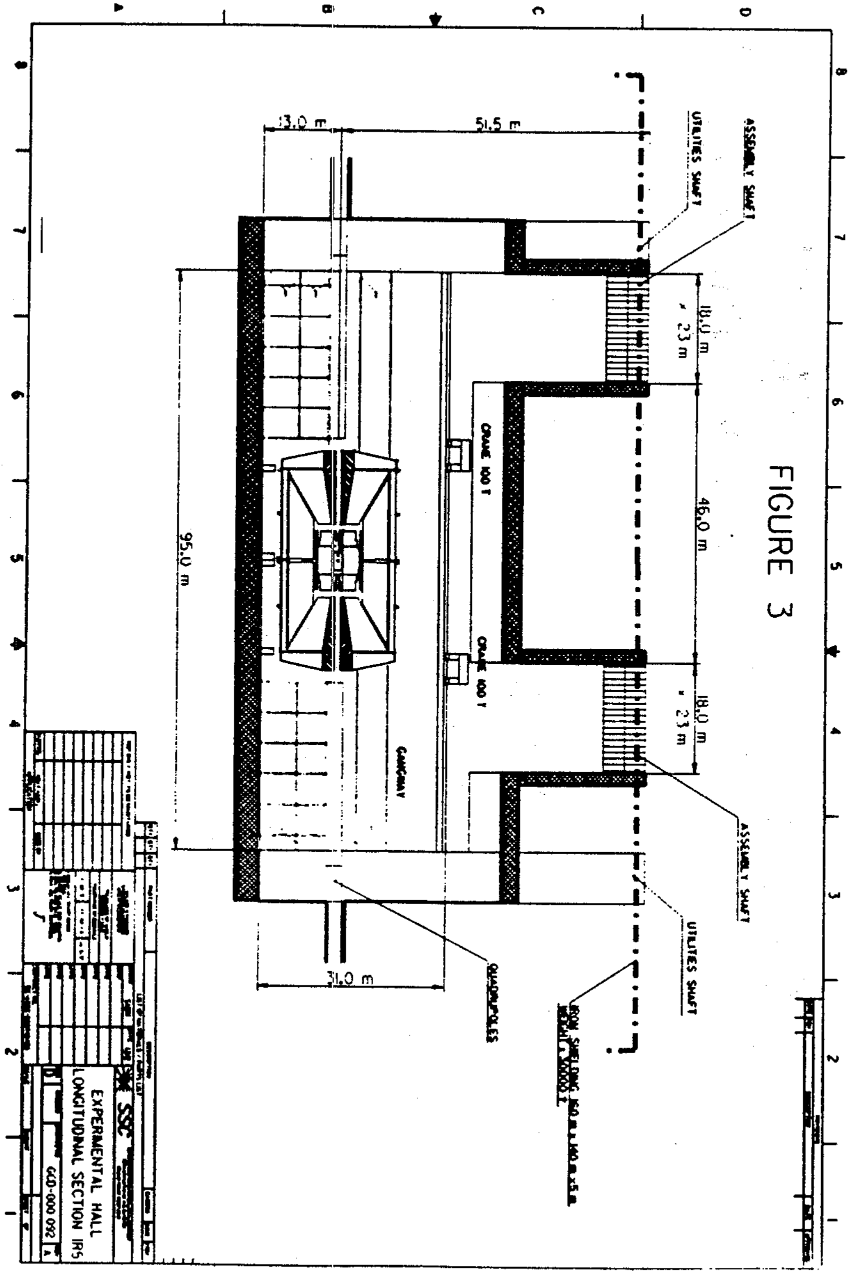
INNER DIAMETER	18.0 m
LENGTH	30 m
FIELD	0.8 T

- DESIGN TEAM
  - LLNL - LAWRENCE LIVERMORE NATIONAL LABORATORY
  - MIT PLASMA FUSION MAGNET LABORATORY
  - NATIONAL HIGH MAGNETIC FIELD LABORATORY (FLORIDA)
  - + EXTENSIVE CONSULTATIONS FROM GEM MAGNET ADVISORY PANEL (MAGNET DESIGN EXPERTS FROM EUROPE, NATIONAL LABORATORIES AND INDUSTRY)

2. PARAMETERS

OPERATING CURRENT	52.5 kA
STORED ENERGY	1.84 GJ
OVERALL OUTER DIAMETER	20.1 m
CHARGE/DISCHARGE TIME	~2 hr
EMERGENCY DISCHARGE TIME	5 min

FIGURE 3



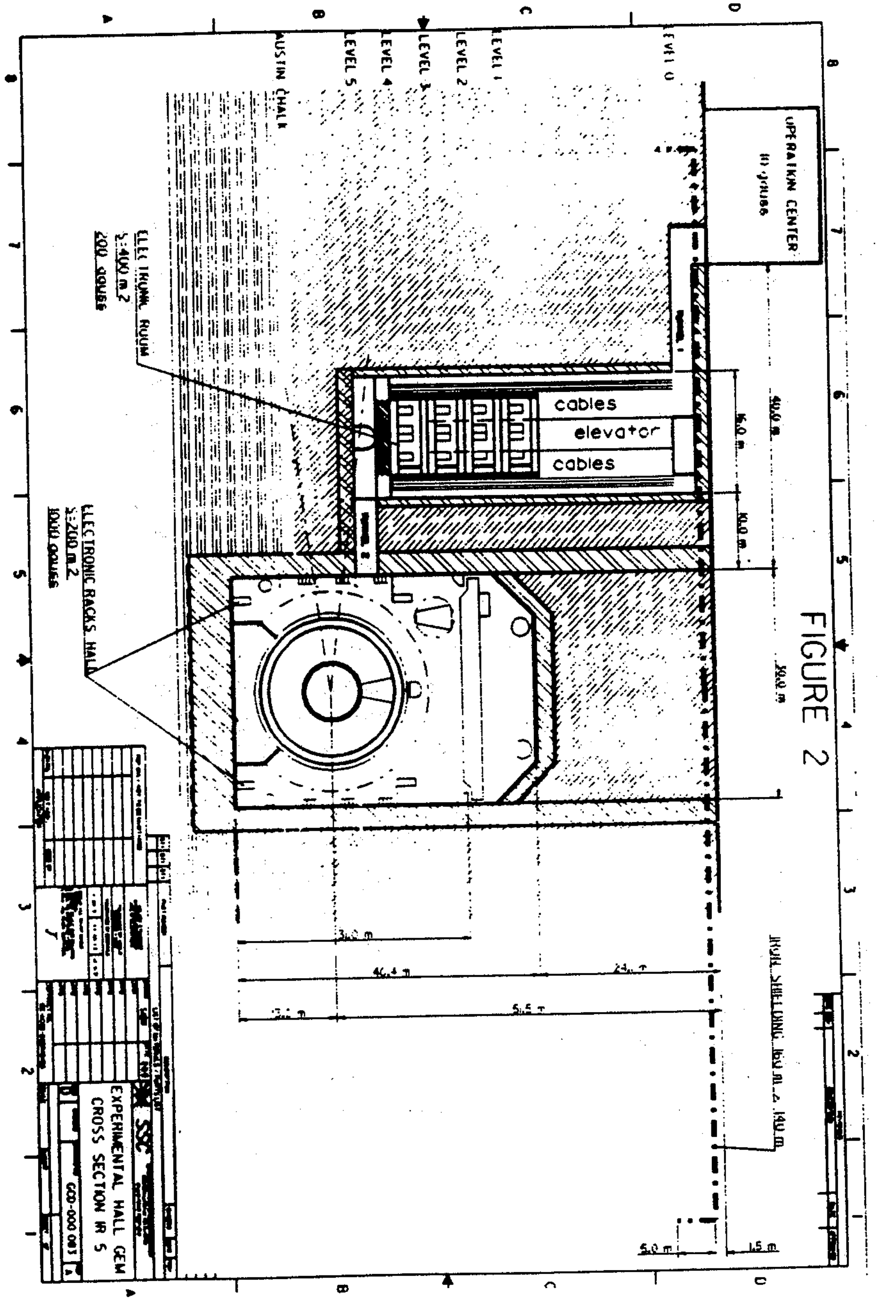
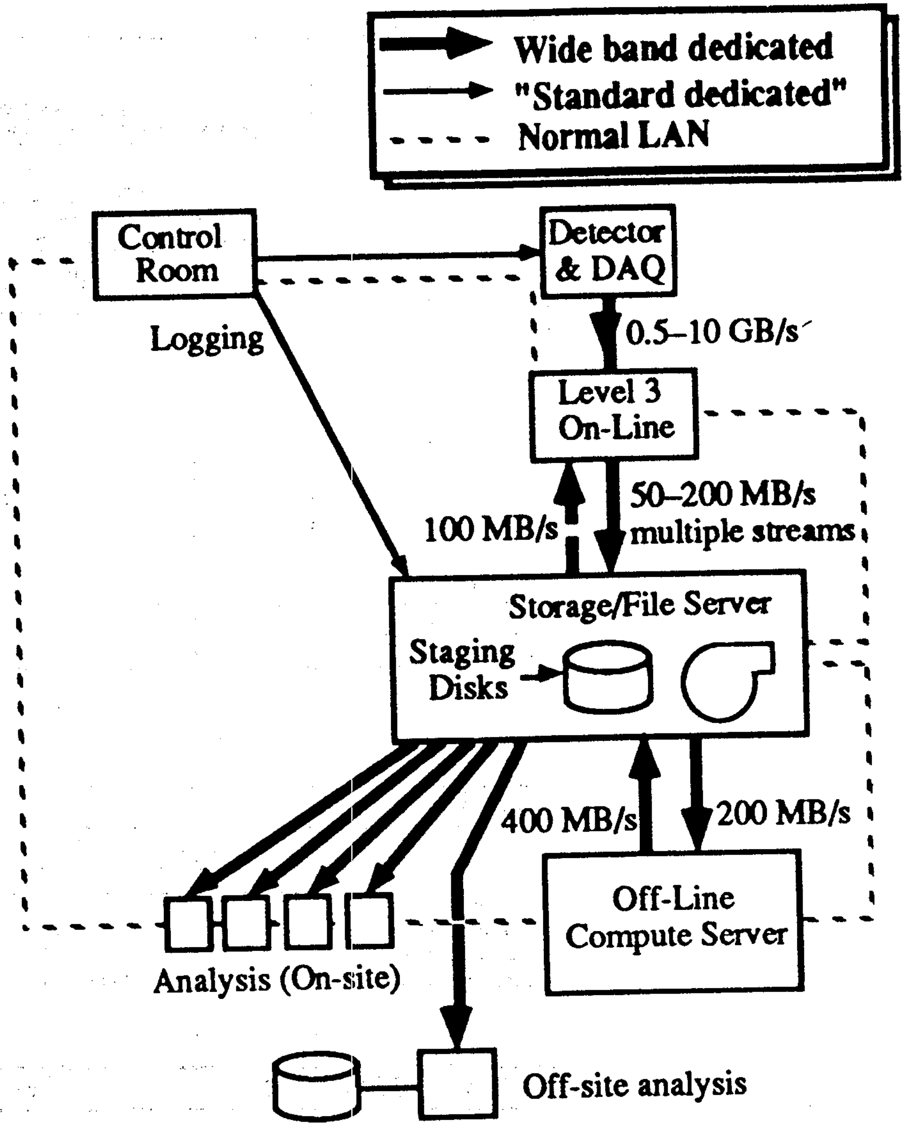
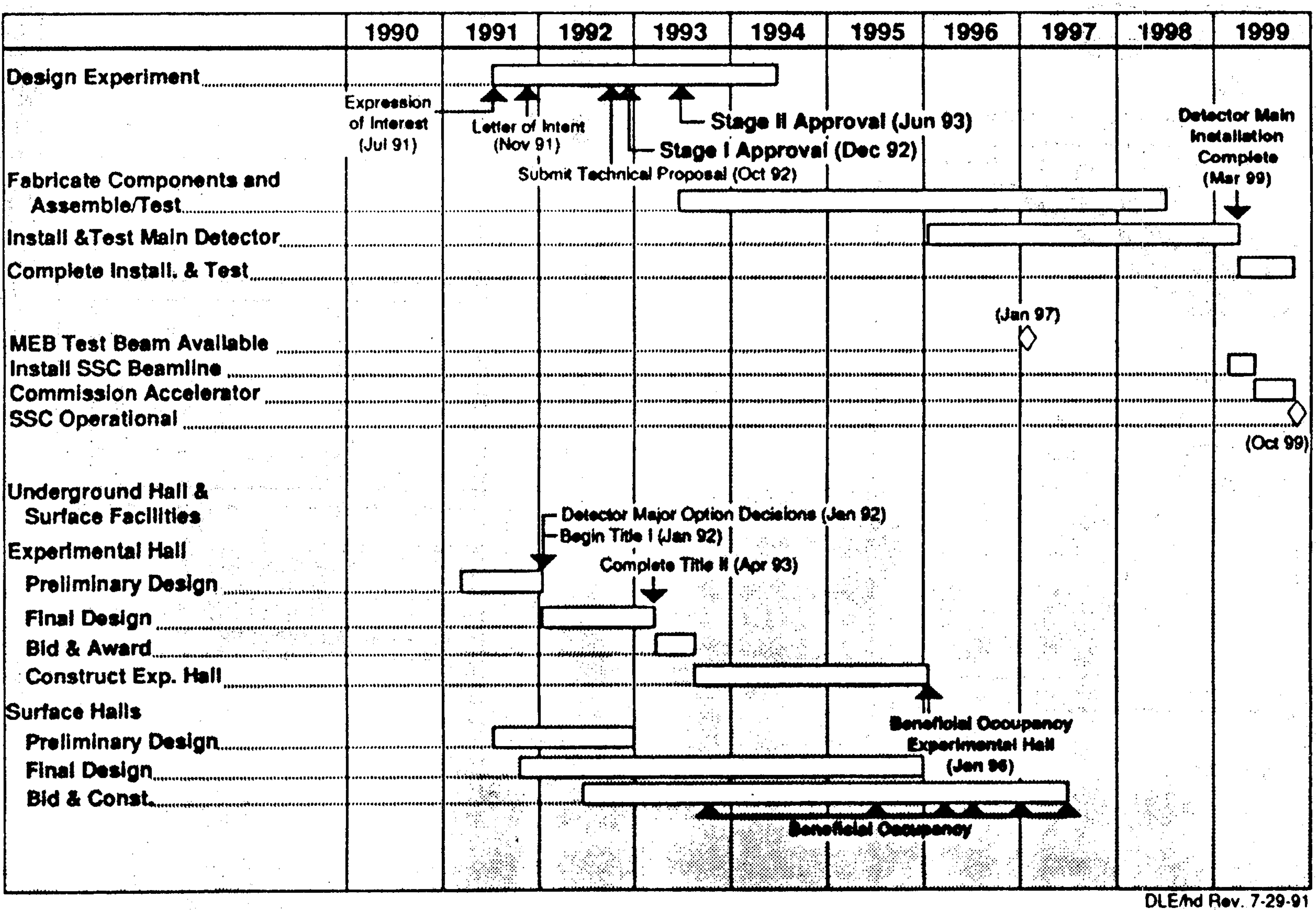

OPERATION CENTER
10 gauss
LEVEL 0
LEVEL 1
LEVEL 2
LEVEL 3
LEVEL 4
LEVEL 5
AUSTIN CHALK
40.0 m
30.0 m
16.0 m
10.0 m
cables
elevator
cables
IRON SHIELDING 160 m × 140 m
1.5 m
5.0 m
24. m
55 m
40.4 m
30.0 m
ELECTRONIC ROOM
S:400 m 2
200 gauss
ELECTRONIC RACKS HALL
S:200 m 2
1000 gauss
SSC
EXPERIMENTAL HALL GEM
CROSS SECTION IR 5
GCD-000 083

FIGURE 2


Wide band dedicated
"Standard dedicated"
Normal LAN
Control Room
Detector & DAQ
Logging
0.5–10 GB/s
Level 3 On-Line
100 MB/s
50–200 MB/s multiple streams
Storage/File Server
Staging Disks
400 MB/s
200 MB/s
Off-Line Compute Server
Analysis (On-site)
Off-site analysis



DLE/hd Rev. 7-29-91

The LHC machine

G. Brianti (CERN)

LHC Main Parameters

		pp	e p	**Pb-ions**
Max cm energy	TeV for B=9.5T	**15.4**	1.36	**1262**
Luminosity	$cm^{-2} s^{-1}$	**$1.6\ 10^{34}$**	$2.8\ 10^{32}$	**$1.8\ 10^{27}$**
Number of bunches		**4725**	508	**800**
Bunch spacing	**m | ns**	**4.5 | 15**	49.4 | 164.7	**31.5 | 105**
Particles/bunch		**10^{11}**	$9.2\ 10^{10}$ $3.0\ 10^{11}$	**$6.2\ 10^{7}$**
Particles/beam		**$4.7\ 10^{14}$**	$4.7\ 10^{13}$ $1.5\ 10^{14}$	**$5.0\ 10^{10}$**
Number of experiments		**3**	1	**2**
β at interaction point	m (βx.βy)	**0.5**	0.85,0.26 32.7,3.05	**0.5**
r.m.s. radius at int. pnt.	μm (x,y)	**15**	120 . 37	**12.4**
r.m.s. collision length	cm	**5.3**	3.8	**5.3**
Crossing angle	μrad	**200**	0	**200**

STATUS REPORT on LHC MACHINE

G. Brianti March 1992

****

1. INJECTORS
    - *SOME BEAM TESTS*
2. OPTIMIZATION E vs. B
    - *NEW CELL LAYOUT*
3. MAGNET MODELS/PROTOTYPES
    - *RECENT RESULTS*
    - *PROGRAMME*
4. OTHER SYSTEMS
    - *CRYOGENICS*
    - *VACUUM*
    - *RF*

LHC INJECTION SCHEME

LINAC 2	50 MeV	190 mA for ≥ 7μs	1.2 μm
with RFQ 2	achieved	170 mA 20μs	1.5 μm
PSB	1.4 GeV	1.75*10^{12}/ring	2.5 μm
	achieved	in one PSB ring	

three- turn injection ; new RF h=1/6KV, h=2/3KV

⇩ 2 pulses

PS	26 GeV	10^{11}/bunch 1.35*10^{13} tot.	3 μm

new RF h=140/600KV (66MHz)

⇩ 3 pulses

SPS	450 GeV	10^{11}/bunch 4.05*10^{13} tot.	3.5 μm

new RF h=1540/2MV (66 MHz)

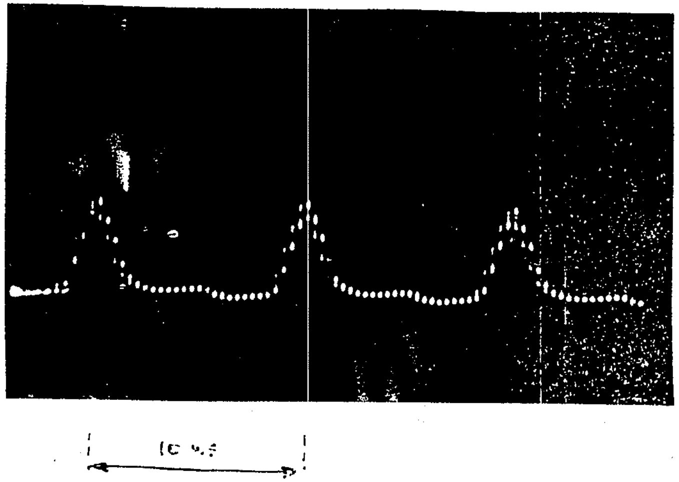
⇩ ⇩ 2*12 pulses

TWO NEW TRANSFER LINES

LHC	450 GeV=>7.7 TeV	10^{11}/bunch 4.7*10^{14} tot.	3.75 μm

inject.

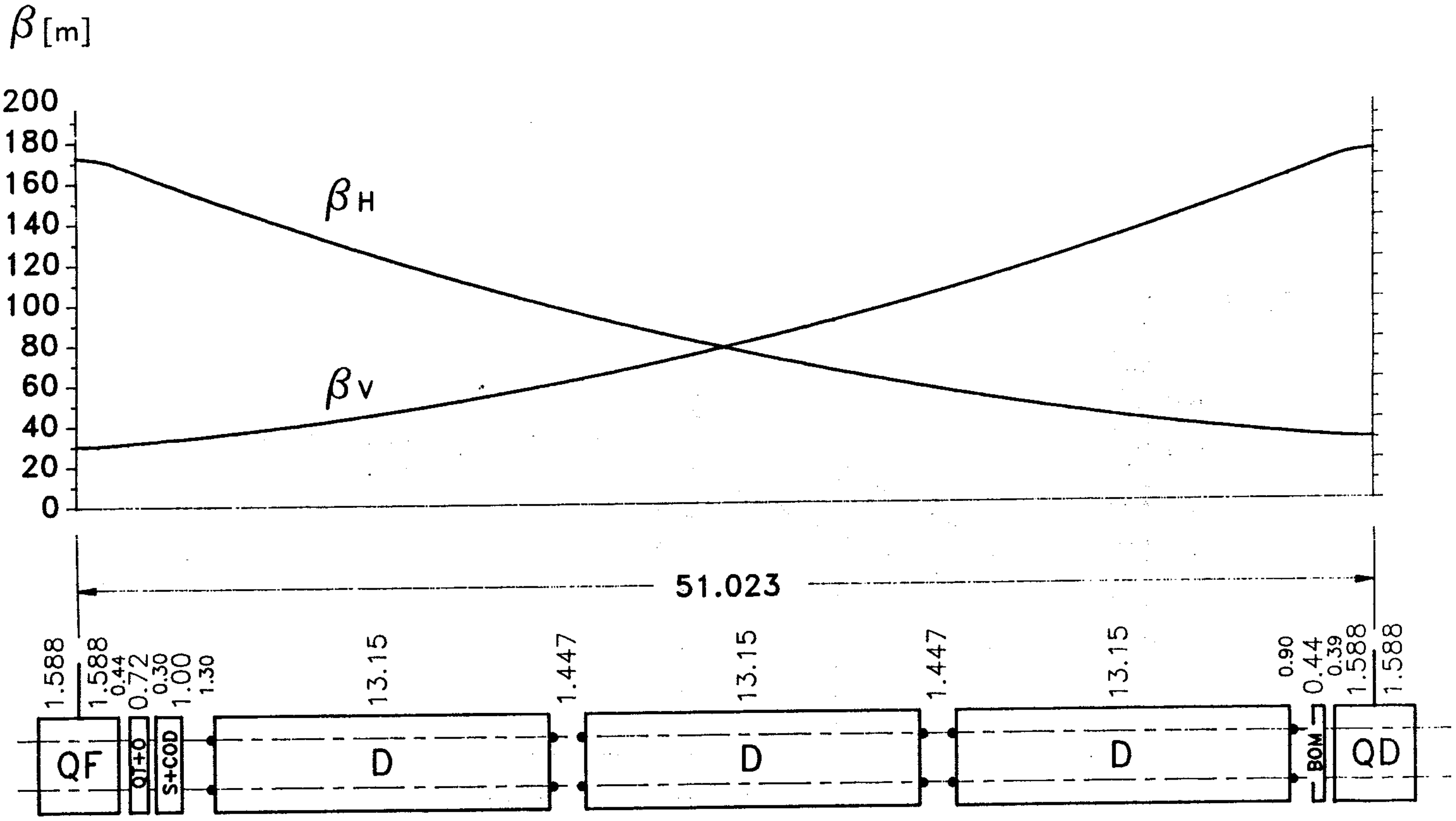
LHC BEAM IN THE SPS



Capture of one PS batch at 26 GeV with the 100 MHz system (bunch spacing = 10 ns) and acceleration to 300 GeV with the 200 MHz RF

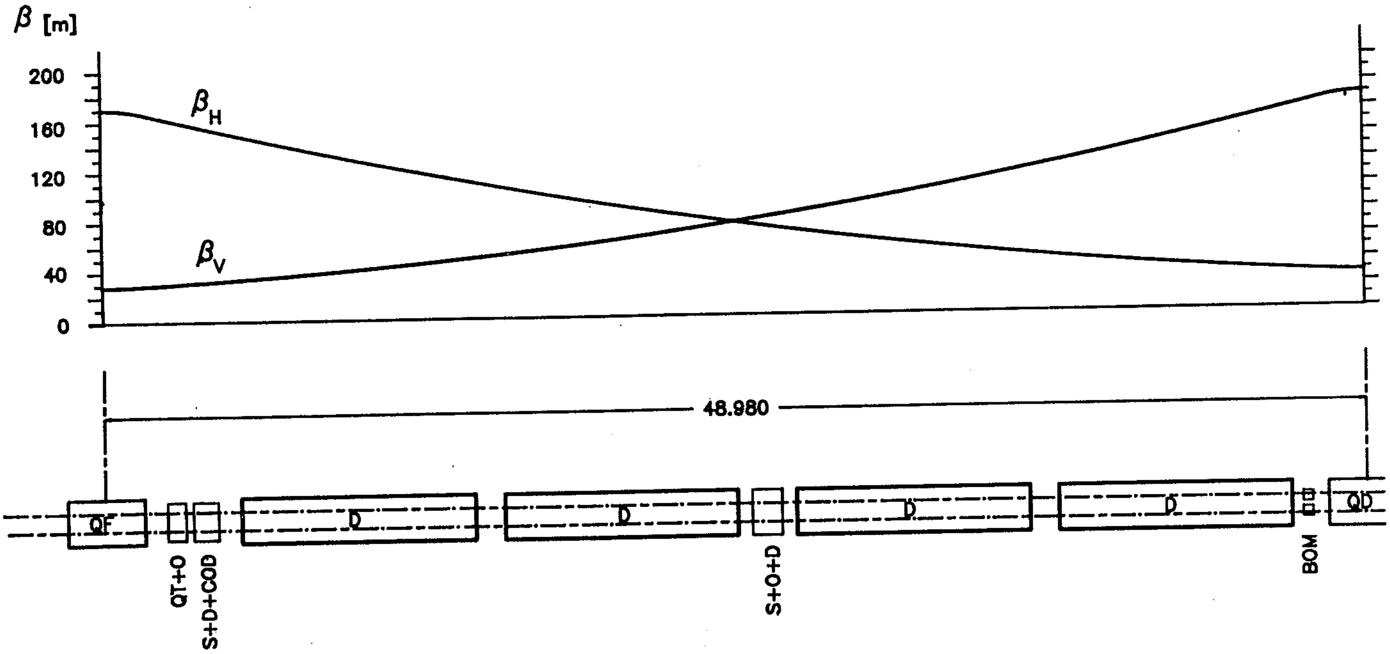
Achieved : $I_b \simeq 4\,10^{10}$/bunch , $A = 0.35$ eVs limited by η at 26 GeV.

In 1992 new experiments with $Q=21$ (γ_{tr} ↓) in the SPS to reach higher intensities.



D:dipole magnets, Q:quadrupoles, QT+O:combined tuning quadrupole and octupole corrector
BOM:beam observation monitor, S+COD: combined sextupole, and dipole corrector
-•-: sextupole and decapole correctors

Layout of the standard half-cell



D:dipole magnets, Q:quadrupoles, QT+O:combined tuning quadrupole and octupole corrector BOM:beam observation monitor,
S+D+COD:combined sextupole, decapole and dipole corrector, S+O+D:combined sextupole, octupole and decapole corrector.

Layout of the standard LHC half-cell

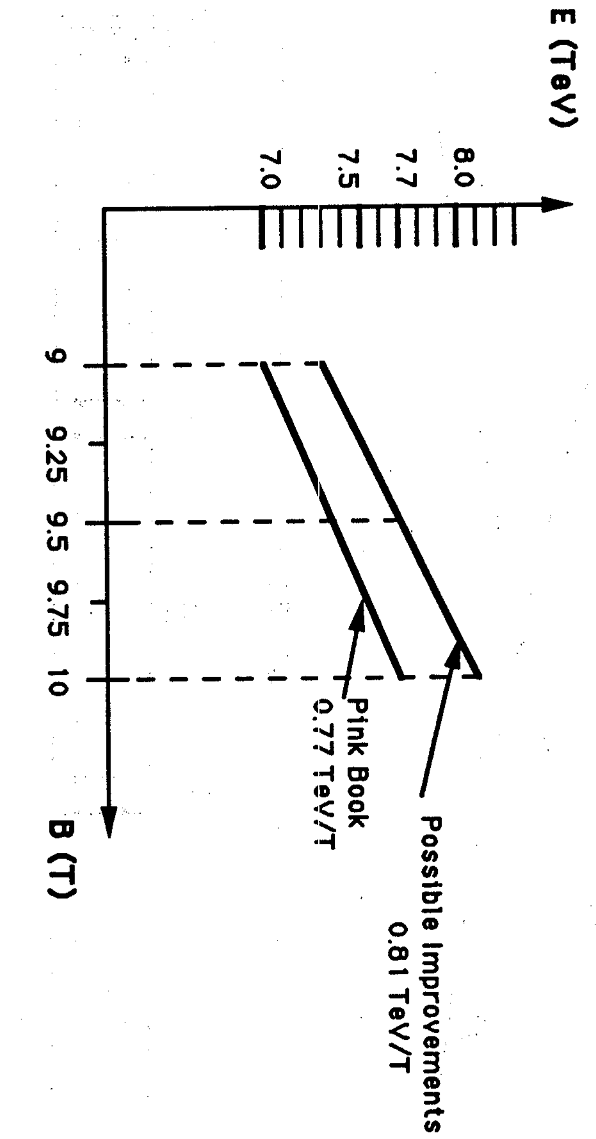
NUMBER OF ELEMENTS IN NORMAL ARCS

"PINK BOOK" CELL LAYOUT :

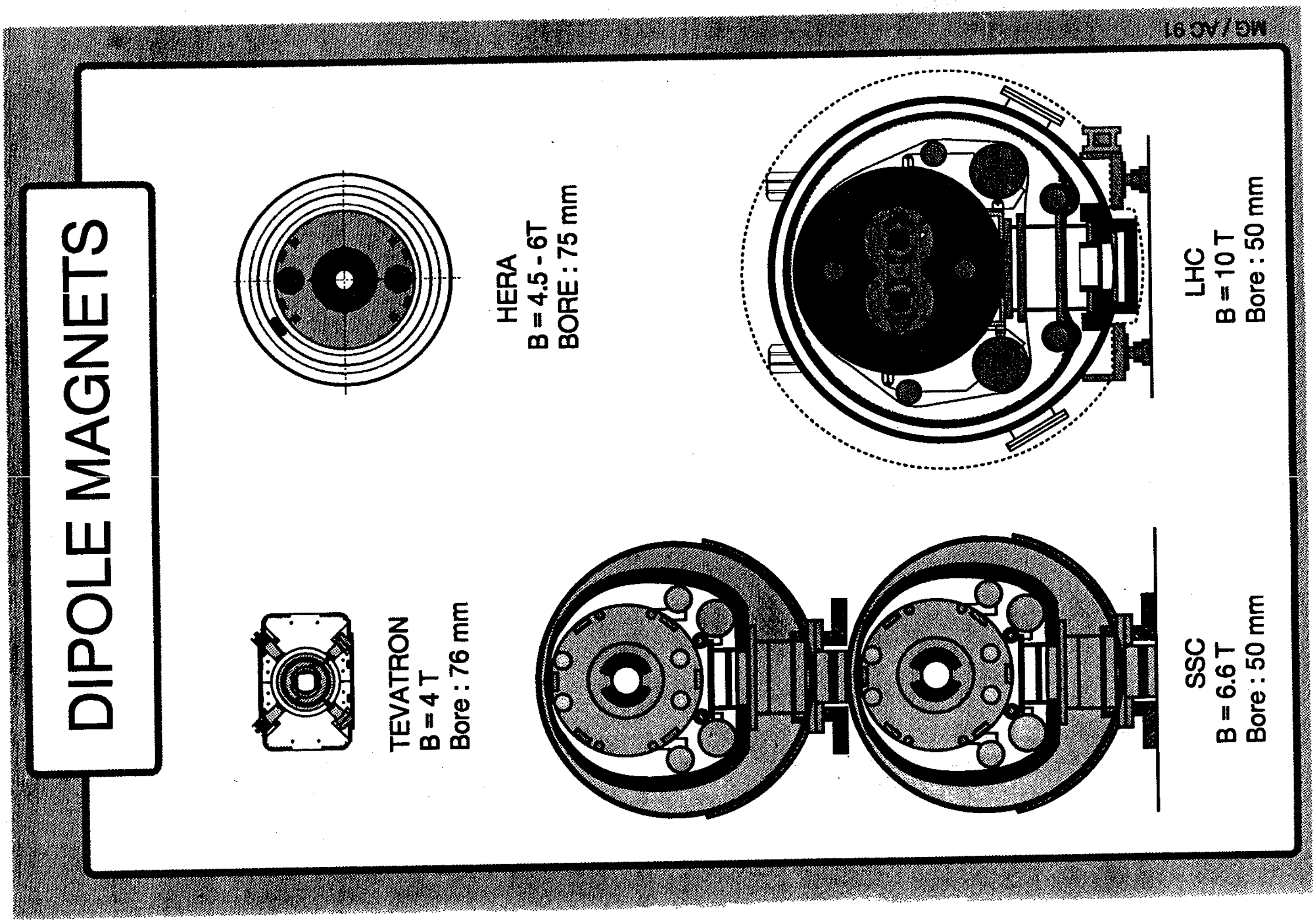
Number of Dipoles (9.45 m)	=> 1600
Number of Quadrupole Assemblies	=> 400

NEW CELL LAYOUT :

Number of Dipoles (13.58 m)	=> 1152
Number of Quadrupole Assemblies	=> 384



LHC BEAM ENERGY vs. FIELD



DIPOLE MAGNETS

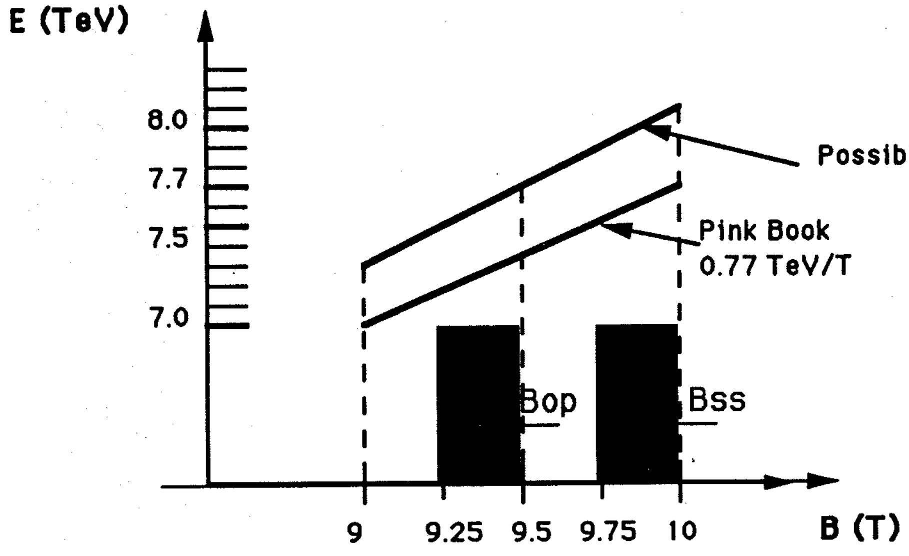
TEVATRON
B = 4 T
Bore : 76 mm

HERA
B = 4.5 - 6T
BORE : 75 mm

SSC
B = 6.6 T
Bore : 50 mm

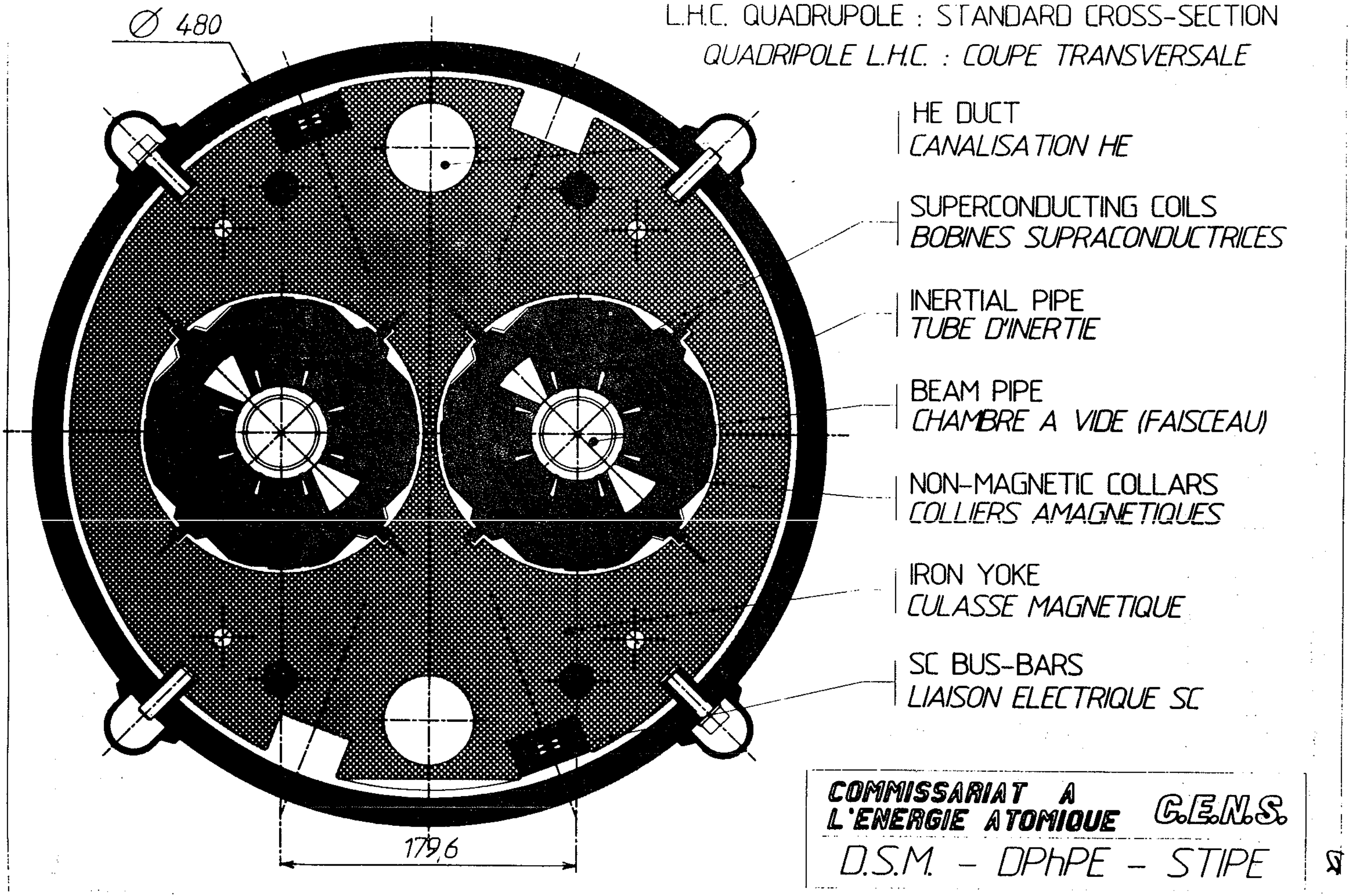
LHC
B = 10 T
Bore : 50 mm

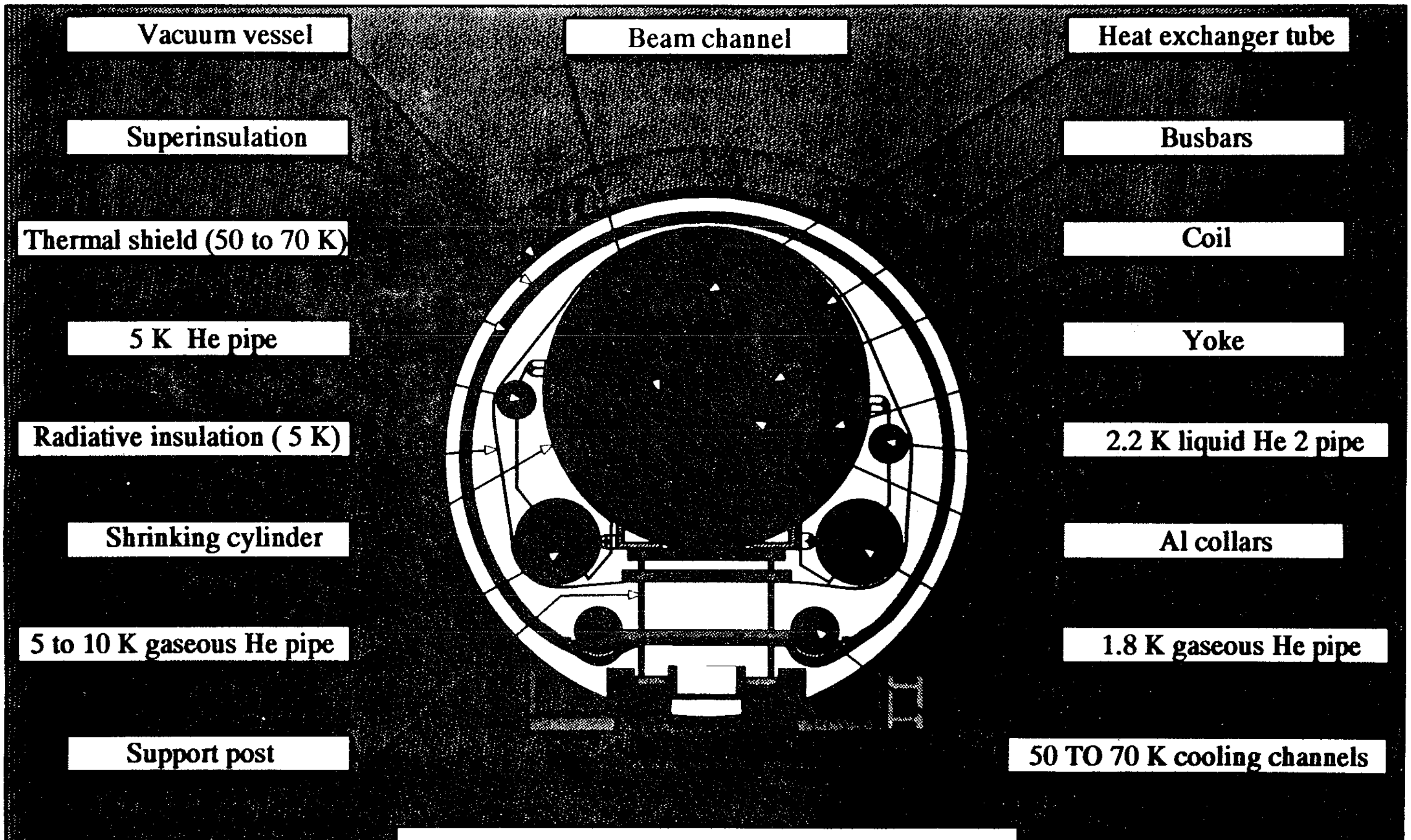
MG / AC 91



LHC BEAM ENERGY vs FIELD

L.H.C. QUADRUPOLE : STANDARD CROSS-SECTION
QUADRIPOLE L.H.C. : COUPE TRANSVERSALE





CROSS SECTION OF LHC DIPOLE

HE107

CENTRAL FIELDS of a SUPERCONDUCTING MAGNET

Bss => Maximum "short sample" field
It corresponds to the max. (critical) current that the cable can carry (as measured in a short sample submitted to an independent external field).

Bq => Maximum field at which the magnet quenches after the initial training

Bo => Maximum operational field for the nominal machine parameters

---

Normally : Bss = Bq

Bo = Bq - margin (He temperature, "worst" magnet installed, etc.)

margin => - 0.5 to 0.8 T

MAGNET MODEL TESTS

In October 1991, a TWIN-APERTURE MAGNET MODEL (photograph) reached 10 T. The peak field seen by the superconductor was at least 10.2 T and the current corresponded to the short sample limit of the cable. Another MTA tested in Feb. 1992 reached its short sample field of 9.8 T.

TENTATIVE CONCLUSIONS

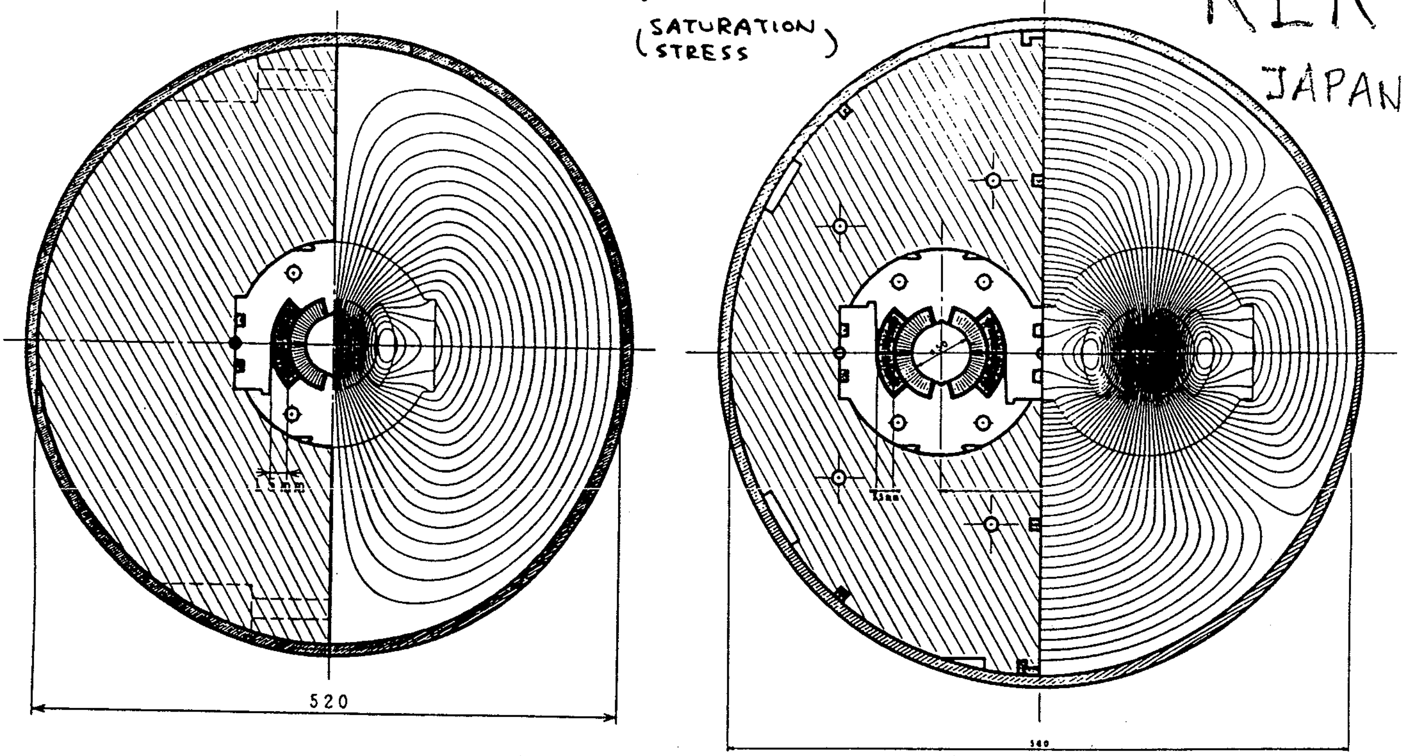
1. A field Bq = Bss = 10 T can be reached
   Note that cables available to-day could sustain a Bss > 10 T.

2. No indication that the TWIN Structure "per se" influences the behaviour.

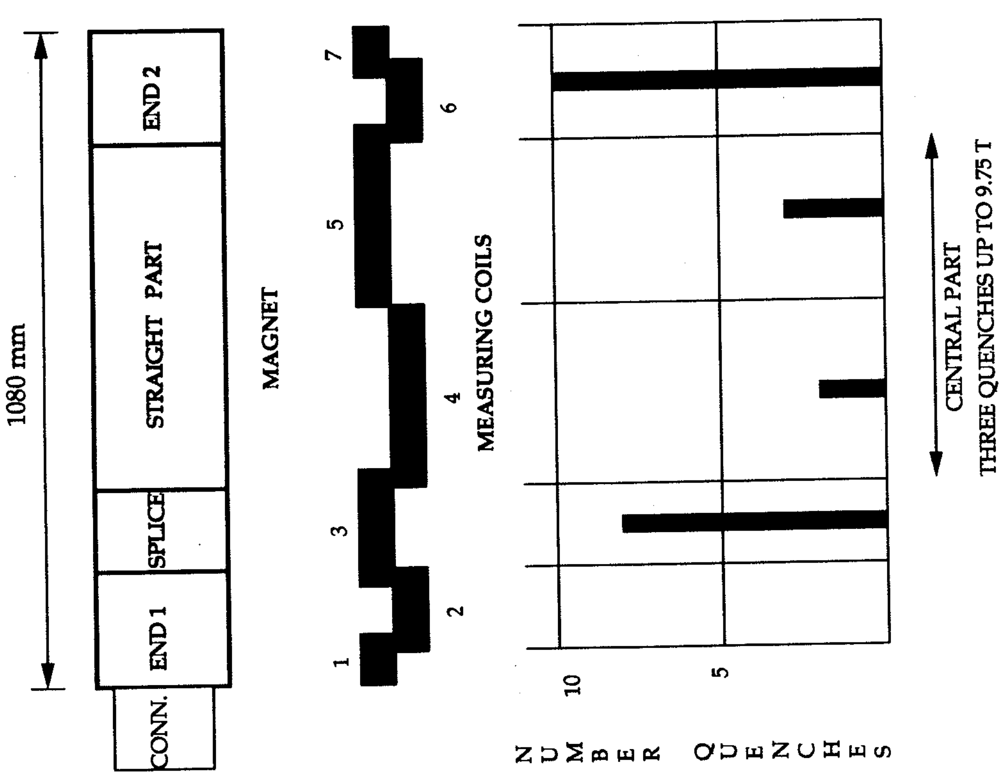
3. Quenches occur mostly in the coil ends.

IRON CONTRIBUTION & μ EFFECTS ON FIELD
(SATURATION
STRESS)

KEK
JAPAN



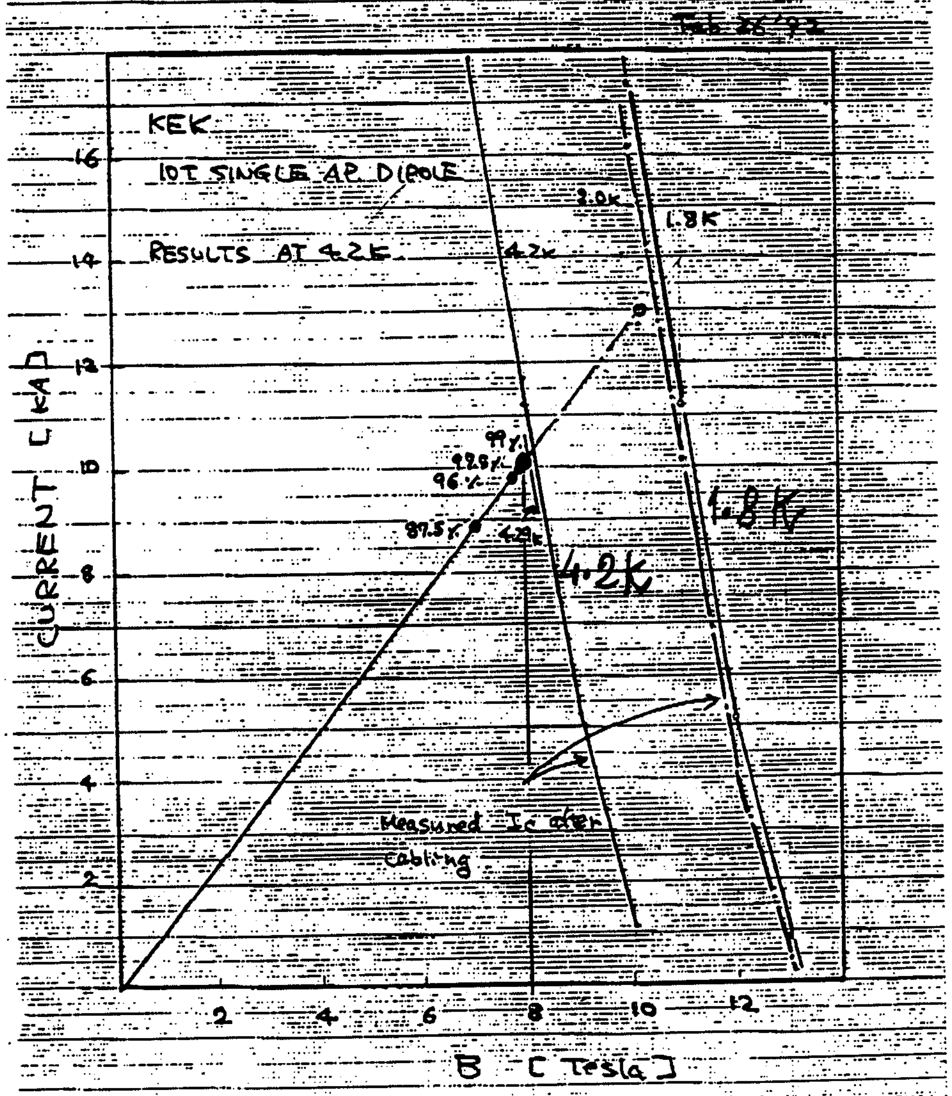
EFFECT OF IRON IN THE LHC MAGNET



RESULTS of TWIN APERTURE MODEL - H

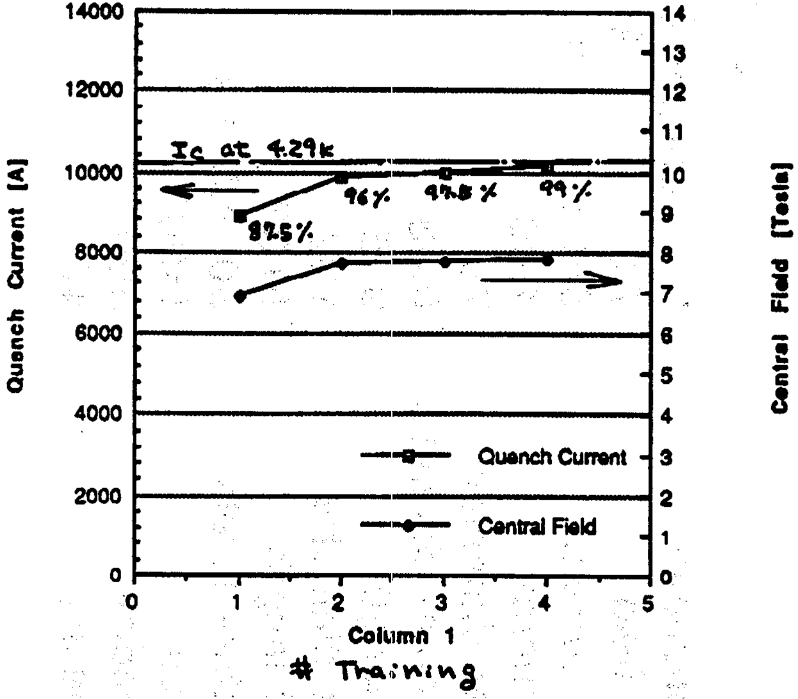
KEK-JAPAN

LHC MOD. SINGLE APERTURE



Feb.26'92

Training of KEK Single Aperture Dipole Model at 4.2 K.



TAP CRYOMAGNET PARAMETERS

		ACHIEVED	
Superconductor	NbTi/copper cable		
Nominal field	7.5	8·3	T
Nominal current	8625	9500	A
Stored energy	4.06		MJ
Coil inner diameter	75		mm
Magnet outer diameter	0.58		m
Magnet length	9.15		m
Cryostat diameter	1.02		m
Cryostat length	10.33		m
Temperature levels	80, 4.5, 1.8		K
Cold mass	15000		kg
LHe capacity	390		l
LN2 capacity	40		l

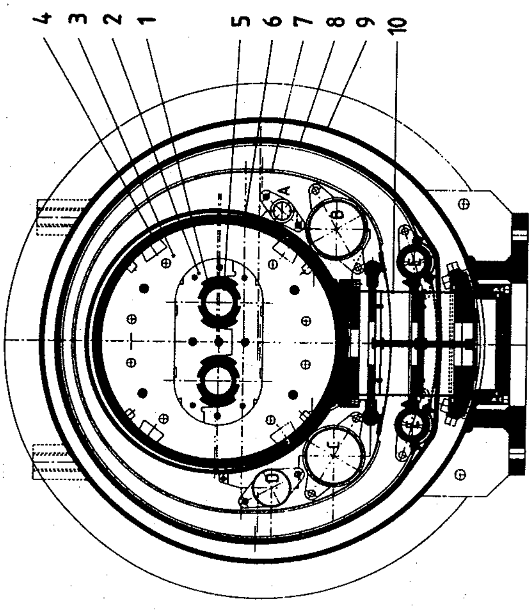


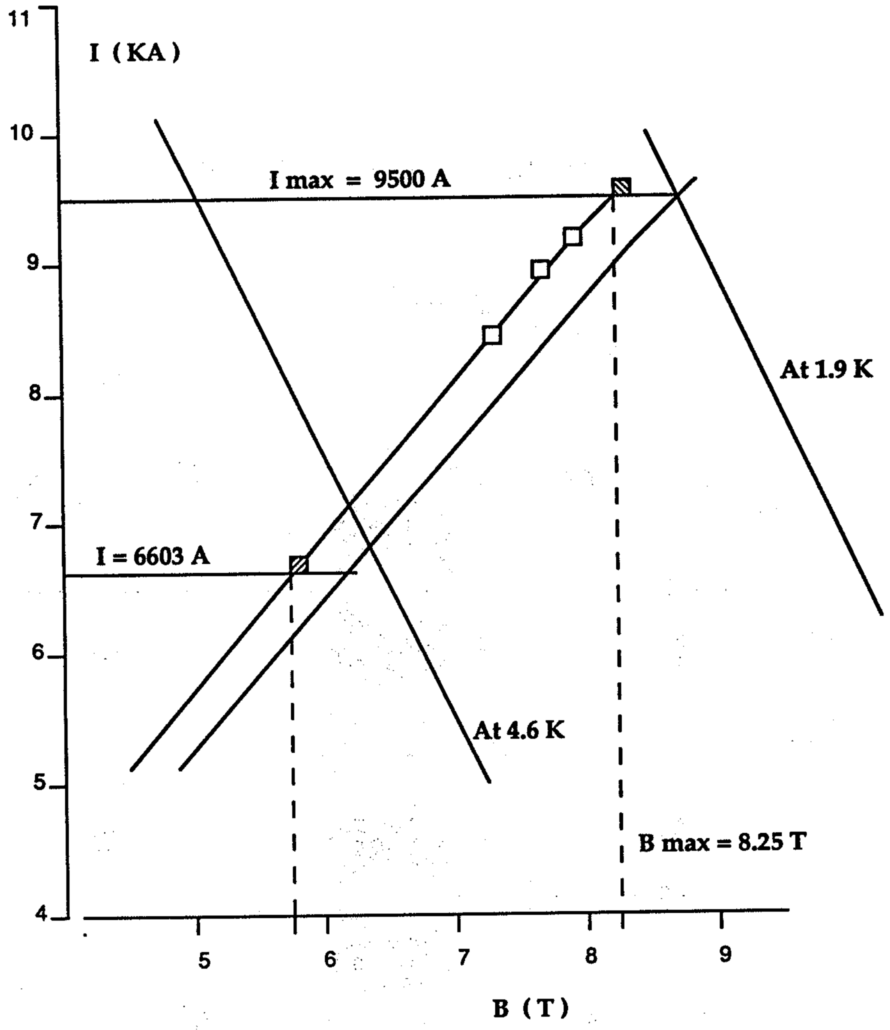
Figure 1 Transverse cross-section of the cryomagnet

1: HERA-type superconducting coils
2: collars
3: magnetic circuit
4: shrinking cylinder
5: cold bore tube
6: helium vessel
7: radiation screen
8: superinsulated LN2 screen
9: vacuum vessel
10: support post

A & B: 1.8 K helium pipes
C & D: 4.5 K helium pipes
E: liquid nitrogen pipes

TAP

Figure 2 Longitudinal cross-section of the cryomagnet



TWIN APERTURE PROTOTYPE (10 m - long, HERA coils)

OTHER MAGNETS

QUADRUPOLES

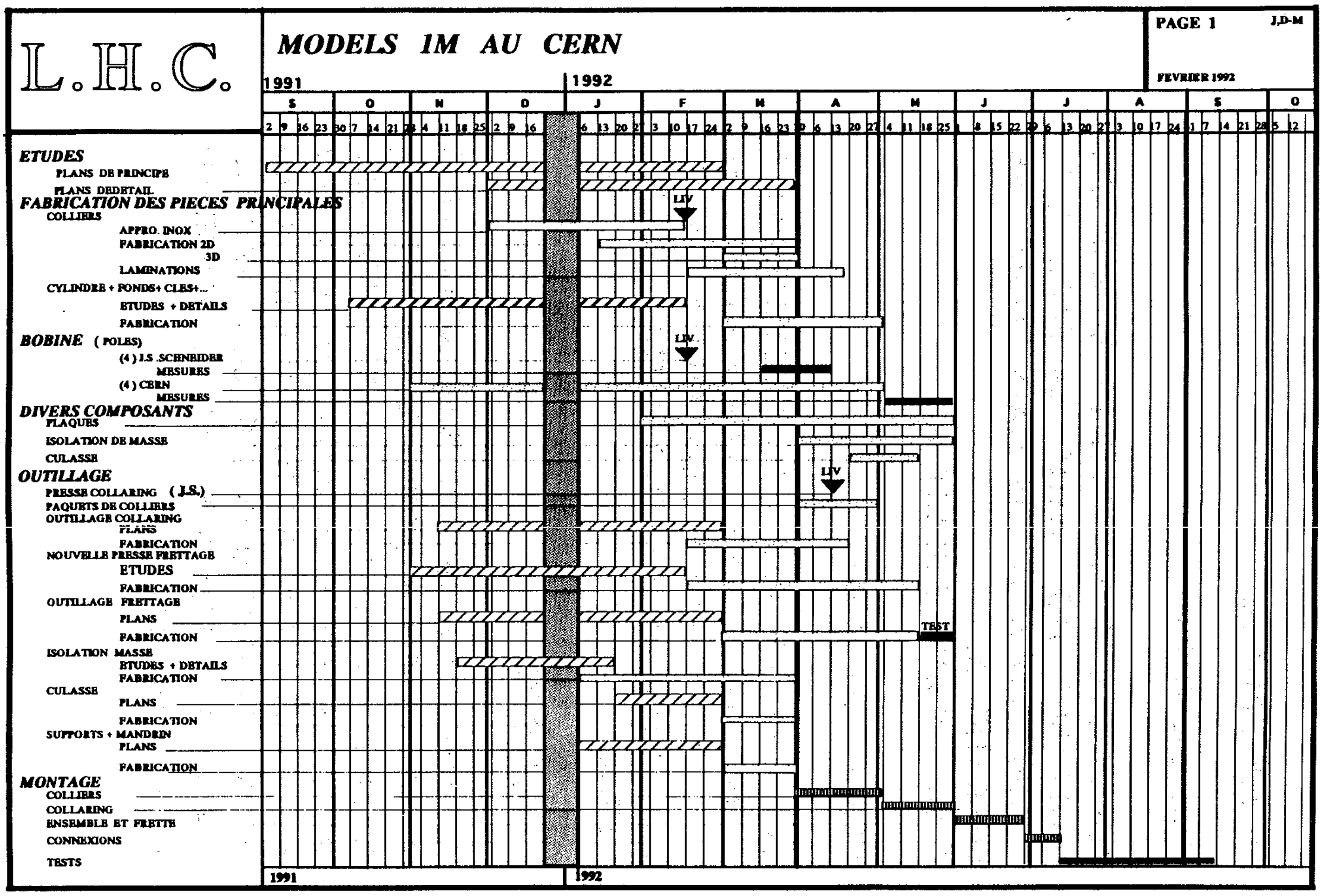
THE DESIGN OF THE LATTICE QUADRUPOLES (COLLABORATION WITH CEA SACLAY) IS COMPLETED AND THE MAIN TOOLS ARE OPERATIONAL.
COIL WINDING IS STARTING.

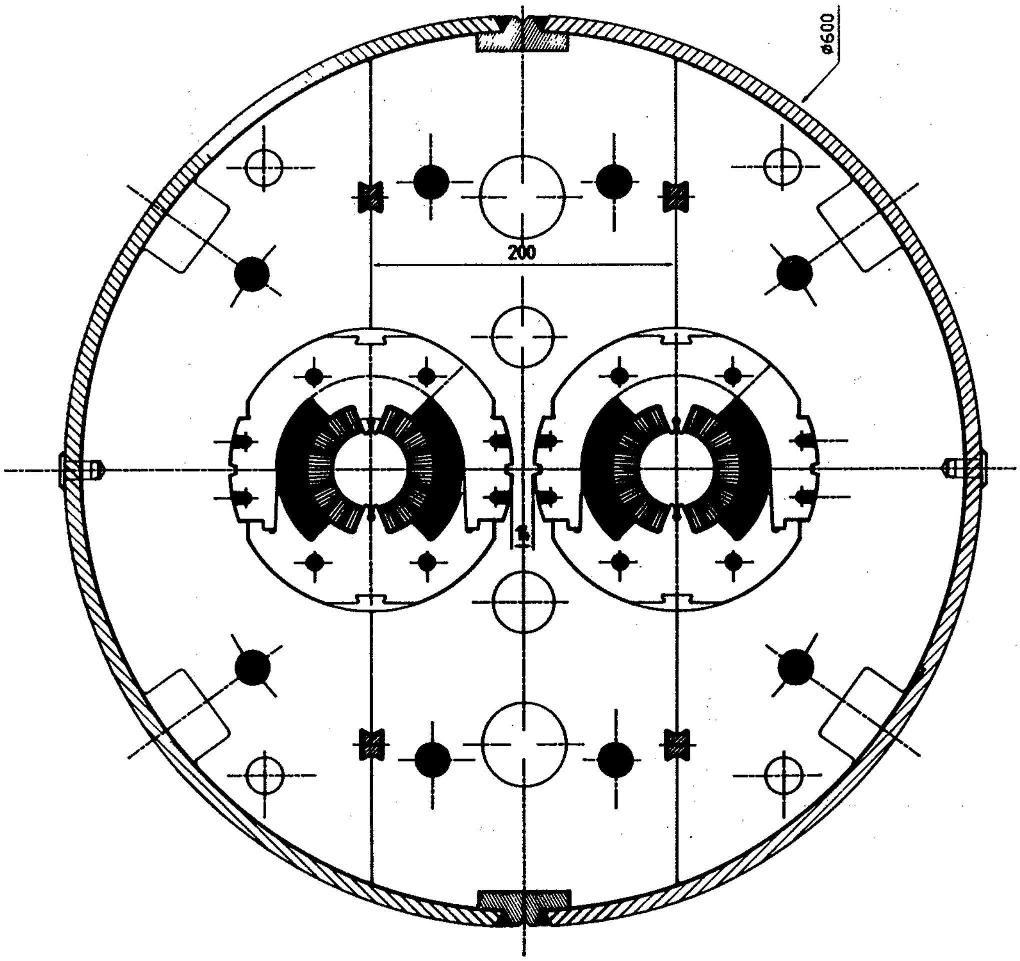
CORRECTOR MAGNETS

THE PROTOTYPE SEXTUPOLE/DIPOLE CORRECTOR MAGNET, MANUFACTORED BY A BRITISH FIRM IN COLLABORATION WITH RAL AND CERN WAS SUCCESSFULLY TESTED IN RAL.

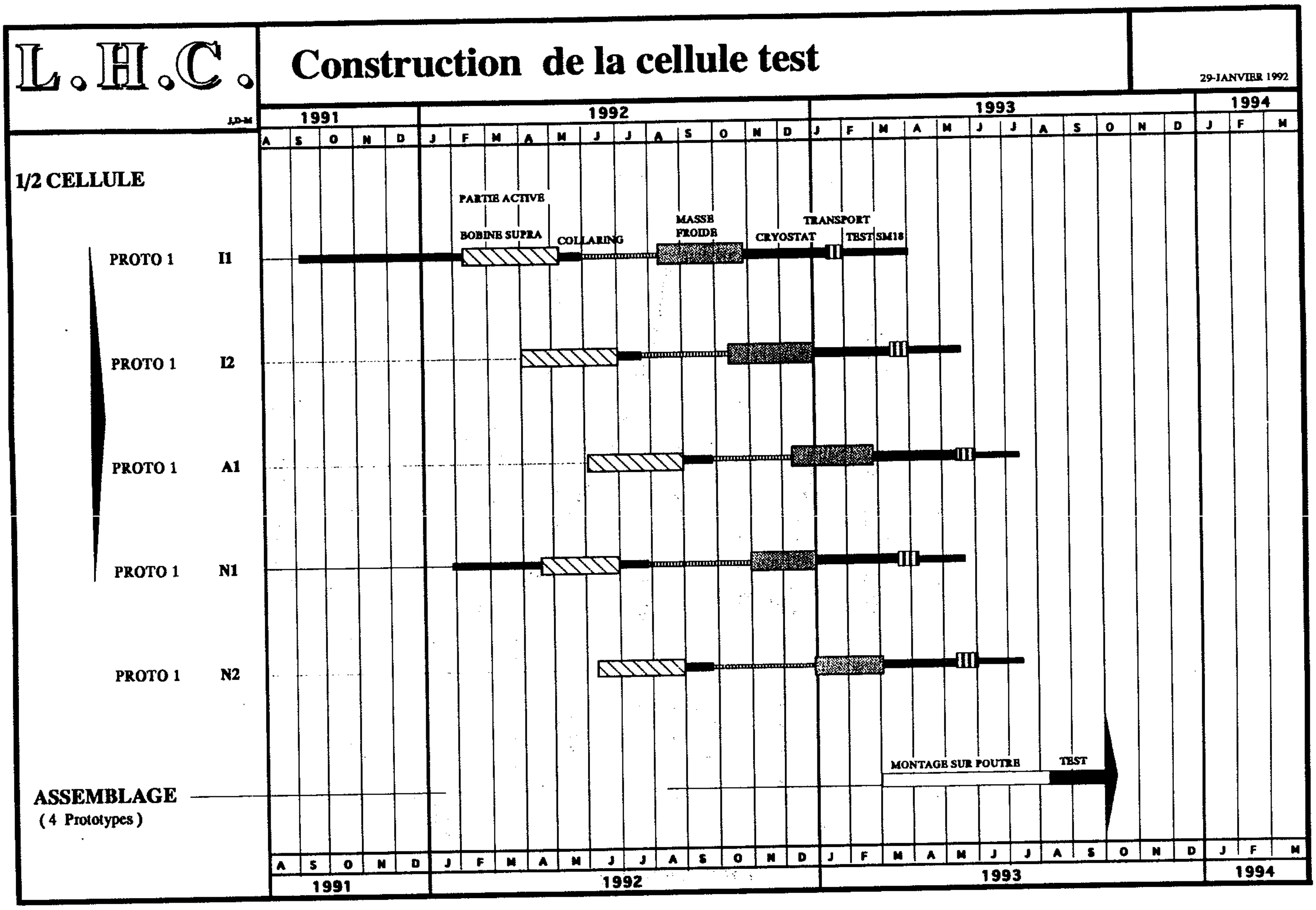
CRYOGENICS

AN IMPORTANT TEST OF THE RING COOLING SYSTEM WITH SUPERFLUID HELIUM WAS CARRIED OUT IN AN EXPERIMENTAL INSTALLATION SIMULATING 25 m OF THE MACHINE. IT PROVED THAT THE EXPECTED POWER DEPOSITED IN THE COILS DURING MACHINE OPERATION CAN BE ABSORBED WITH SOME MARGIN.





CROSS SECTION PROTOTYPE DIPOLE 2/1

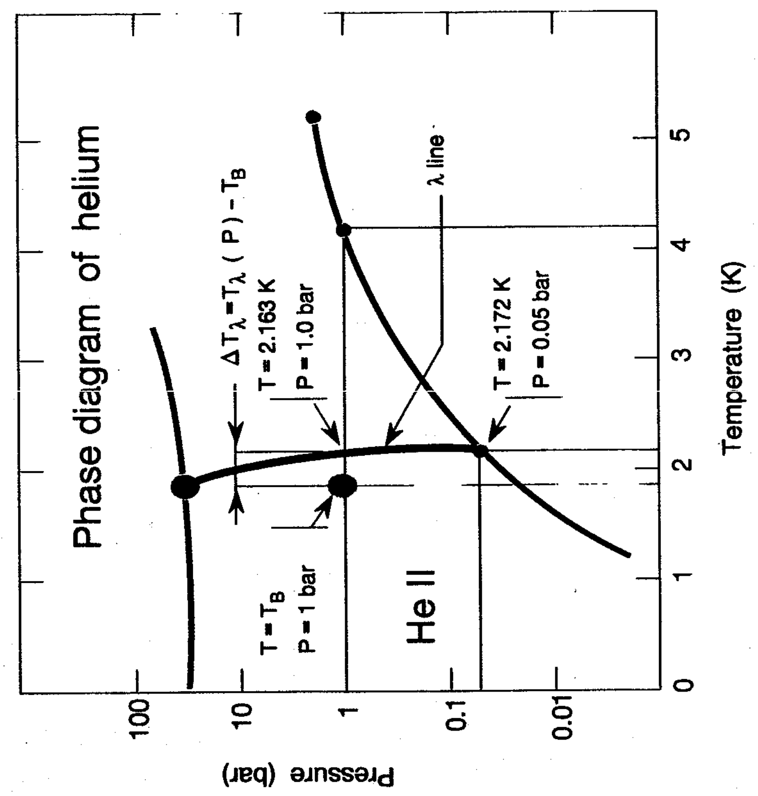


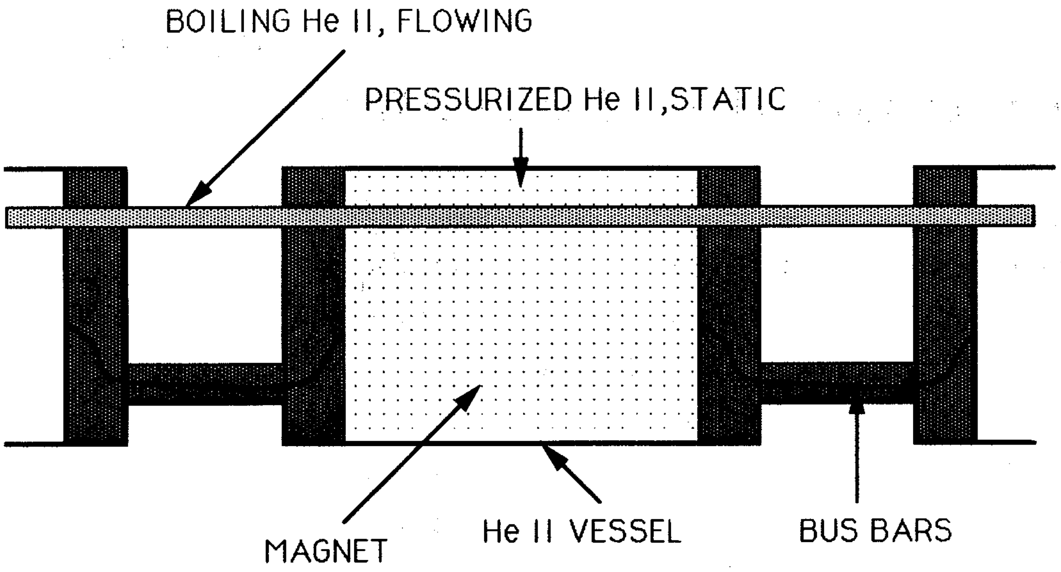
Feb. 1992

NEW LHC MAGNET MODELS/PROTOTYPES

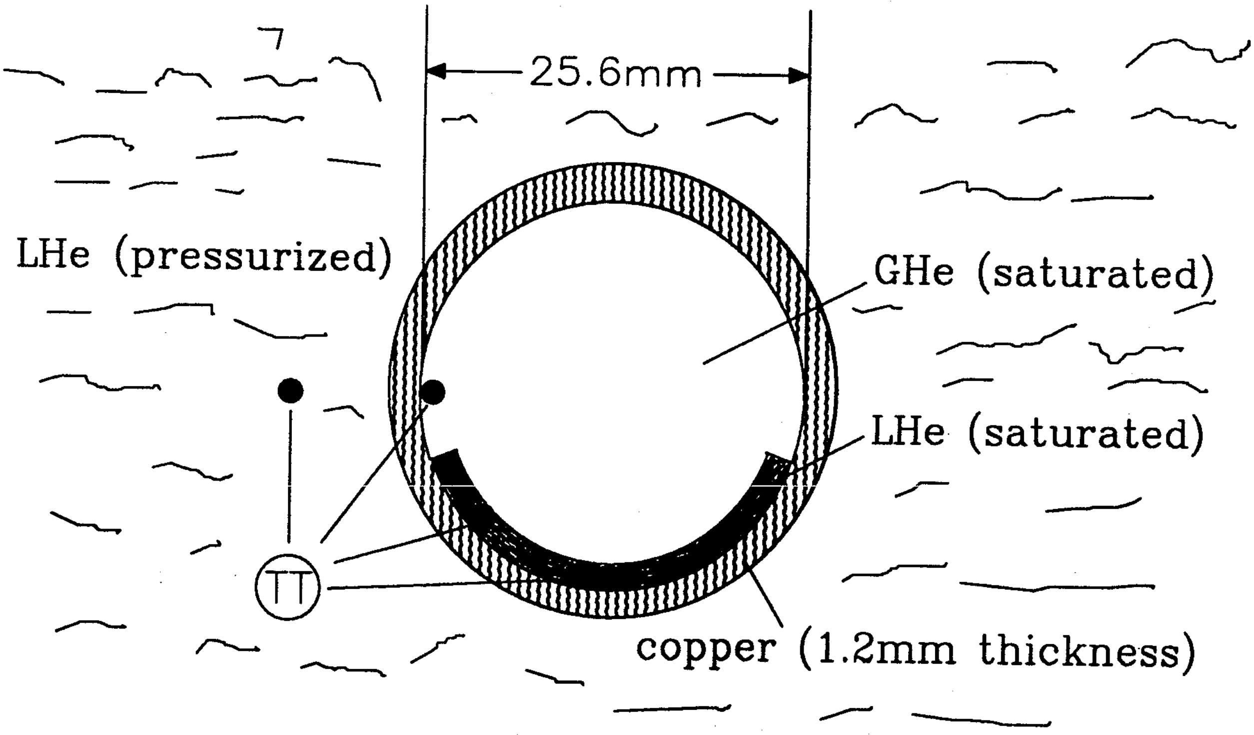
FIRM	MODEL	PROTOTYPE
ALSTHOM./J.S.	1 MTA-1	1 MBP-3
ANSALDO	1 MTA-1	3 MBP-1
ELIN	1 MTA-1, 1 MSA-2	
HOLEC	1 MTA-1	
ELIN/HOLEC		1 MBP-2
NOELL		2 MBP-1
CERN	1 MTA-2 1 MTA-3	
CEA-SACLAY		2 MQP-1
ABB/FBM		1 TAP (Hera coils)

G.





PRINCIPLE of LHC MAGNET COOLING



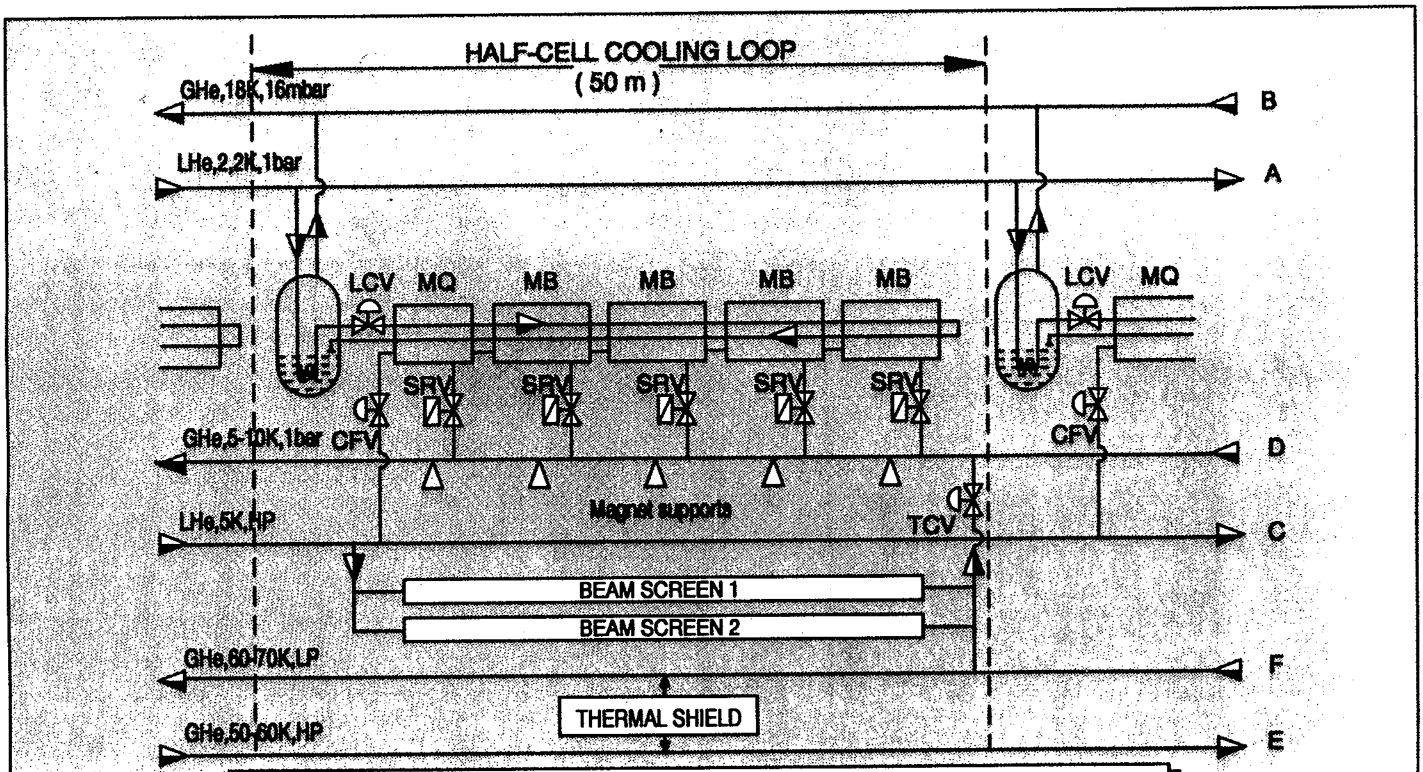


Fig 4 FLOW-SCHEME OF LHC CRYOGENIC LOOP

MQ	Quadrupole magnet	LCV	Level controlled valve
MB	Dipole magnet	SRV	Safety relief valve
CFV	Cool-down and fill valve	TCV	Temperature controlled valve

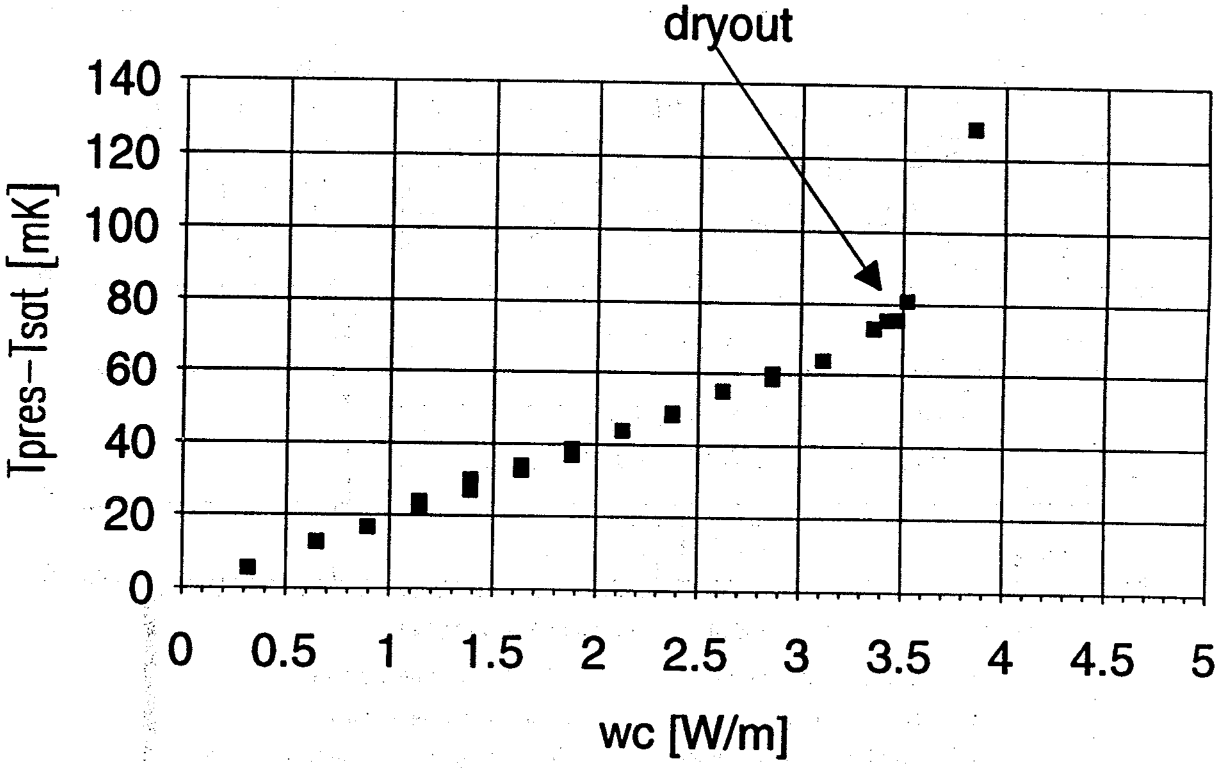
DISTRIBUTED HEAT LOADS IN STEADY OPERATION [W/m]

Temperature	50-75 K	5-10 K	1.9 K
Heat inleakage*	6	0.4	0.15
Resistive heating	-	-	0.15
Beam-induced losses**	-	1.7	0.01
Total	6	2.1	0.31

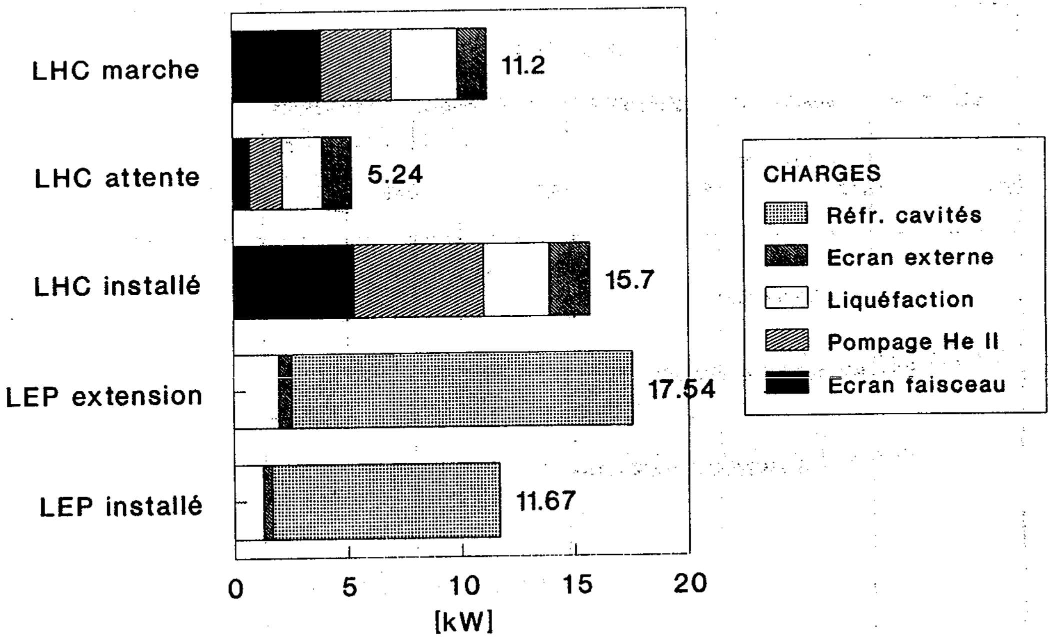
* no contingency

** singular heat load of 25 W/50 m not included

PhL/1991



REFRIGERATEUR D'OCTANT LHC
PUISSANCES EQUIVALENTES @ 4,5 K



PhL/1992

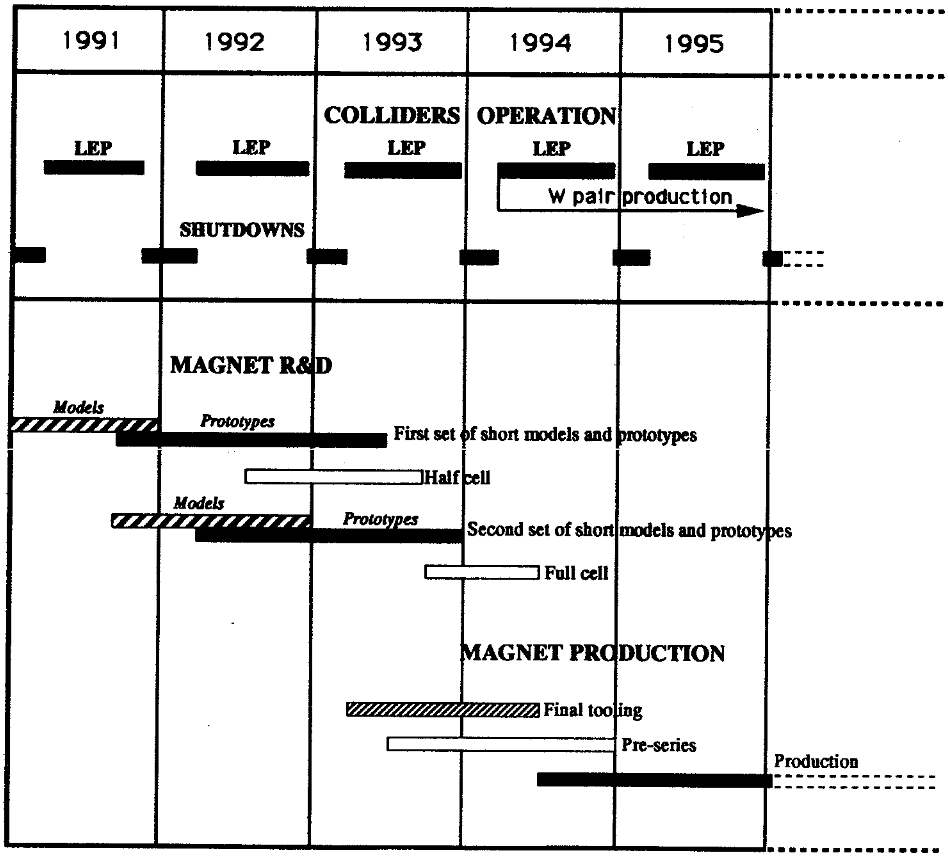
L. TAVIAN
NOTE LHC 164

LHC DIPOLE CRYOSTAT
ESTIMATED HEAT INLEAKS [W]

Temperature [K]	50-75	5-10	1.9
Support posts	7.3	1.2	0.06
Radiation	49.6 *	0.4 **	0.82 **
Relief valve	1.1	-	0.24
Instrumentation	0.3	-	0.17
Total	58.3	1.6	1.29

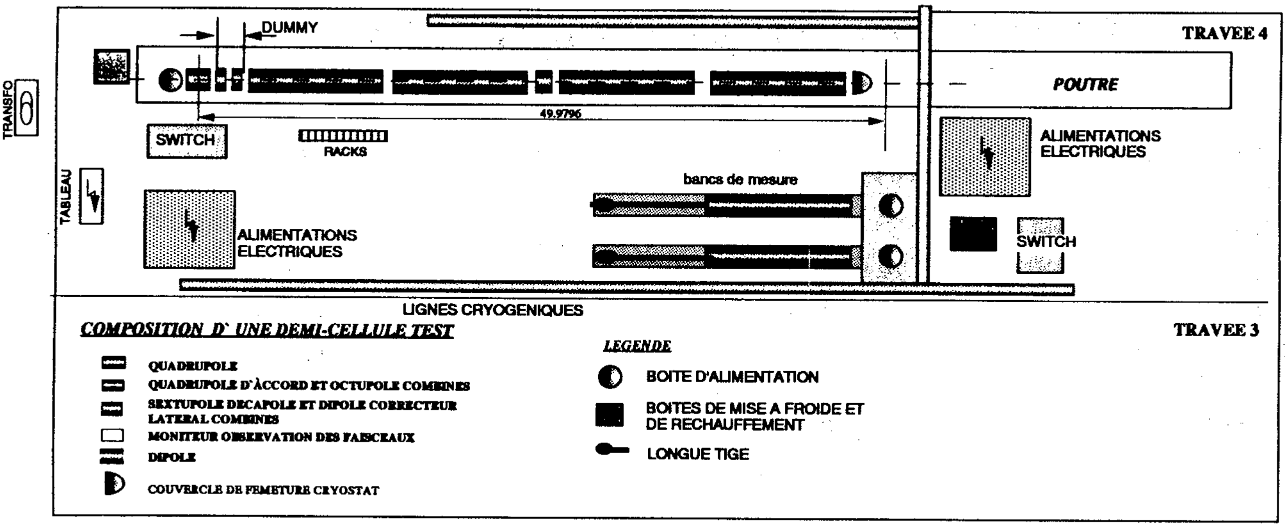
* 30 layers aluminized film insulation
** 10 layers aluminized film insulation

PhL/1991



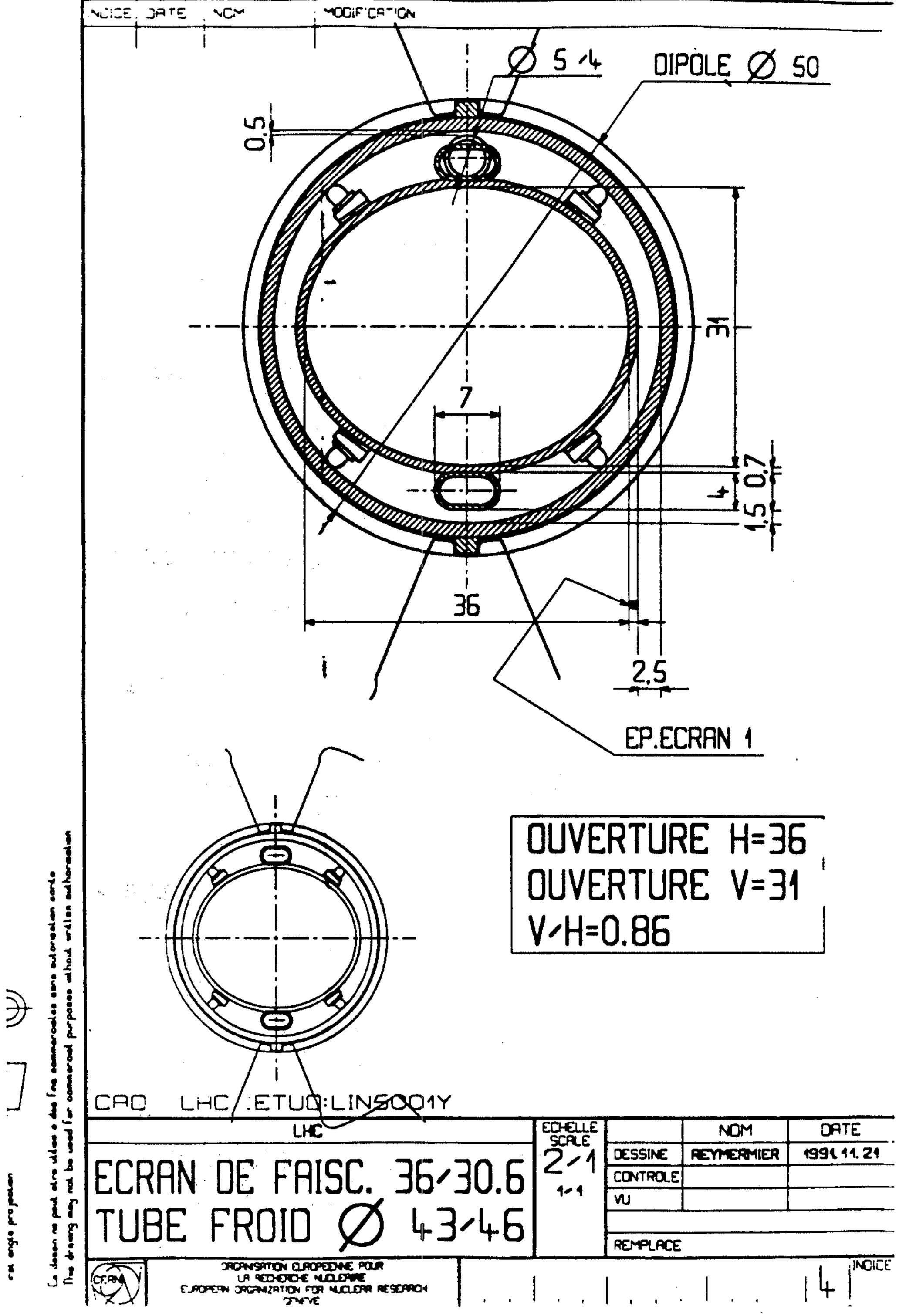
SCHEDULE OF LHC MAGNET R&D AND START OF PRODUCTION

SCHEMA DE MONTAGE DE 1/2 CELLULE AU SM18



BEAM SCREEN DESIGN CRITERIA

- electrical conductivity < 5 10^{-10} ohms m in 10 T
- able to withstand quench forces (~1.5 ton/m)
- evacuate the synchrotron radiation power (~0.6 W/m) at a temperature >1.9 K
- provide sufficient aperture for beam (36 mmX32.6 mm)
- acceptable heat leak to 1.9 K
- low photon induced gas desorption
- contain holes for pumping to the 1.9 K surface
- provide acceptable beam impedance



POSSIBLE TREATMENTS TO REDUCE PHOTON INDUCED GAS DESORPTION

1) TEMPERATURE

Easy to apply to long thin tubes
170°C 1hour OK - RRR better
340°C 1hour OK - RRR better
950°C 2hours BAD - RRR unacceptable
check other temperatures and times

2) IONS

D.C. Glow discharge
Difficult to apply to long thin tubes
Needs central wire, hence supports
Risk of mechanical damage to 0.1 mm Cu layer
Implantion of ions into surface-effect on RRR

3) ELECTRONS

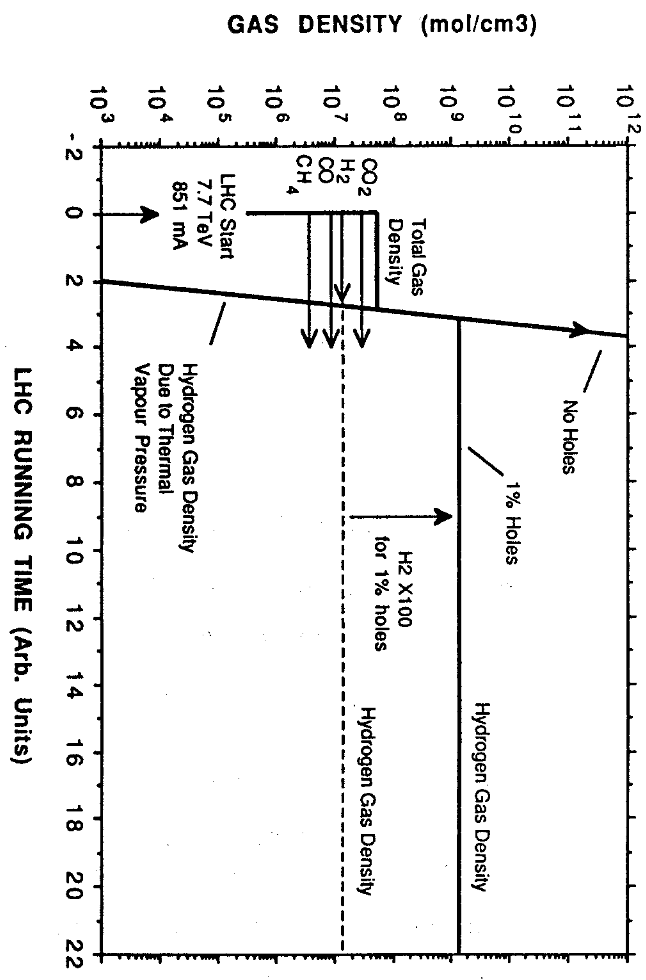
Difficult to apply to long thin tubes
Needs long, linear electron source

4) REACTIVE GASES

NO, O_3 (ozone generator or UV light)
Easy to apply to long thin tubes
May have to be done at few 100°C
Security problems but workable

5) REACTIVE PLASMAS

O_2 or H_2 containing RF discharges
No central electrode
No ion implantation
Must propagate in long, thin tubes - check
Effect on RRR - check



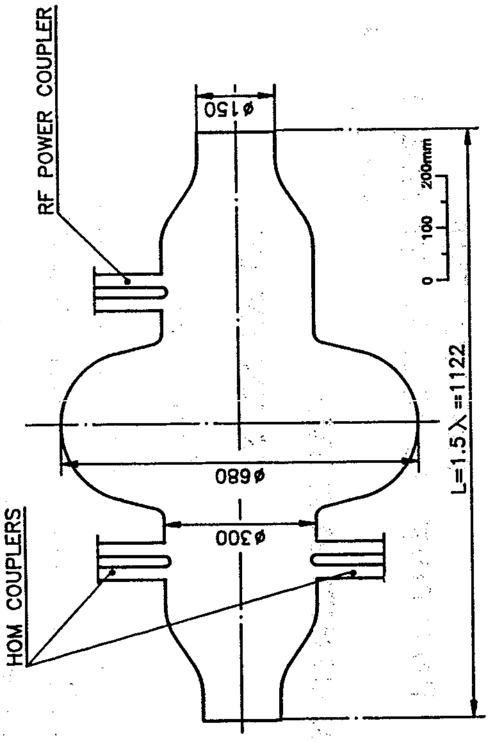


Fig.8.1 Single-cell superconducting cavity for acceleration of both beams.

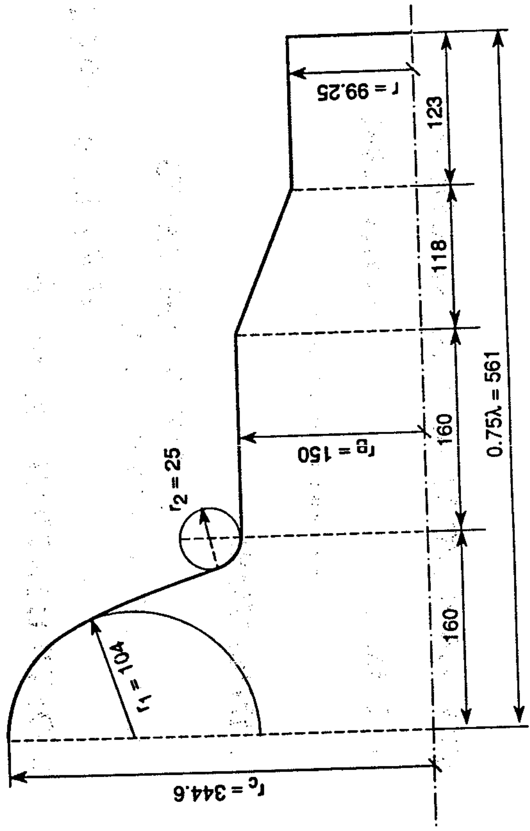
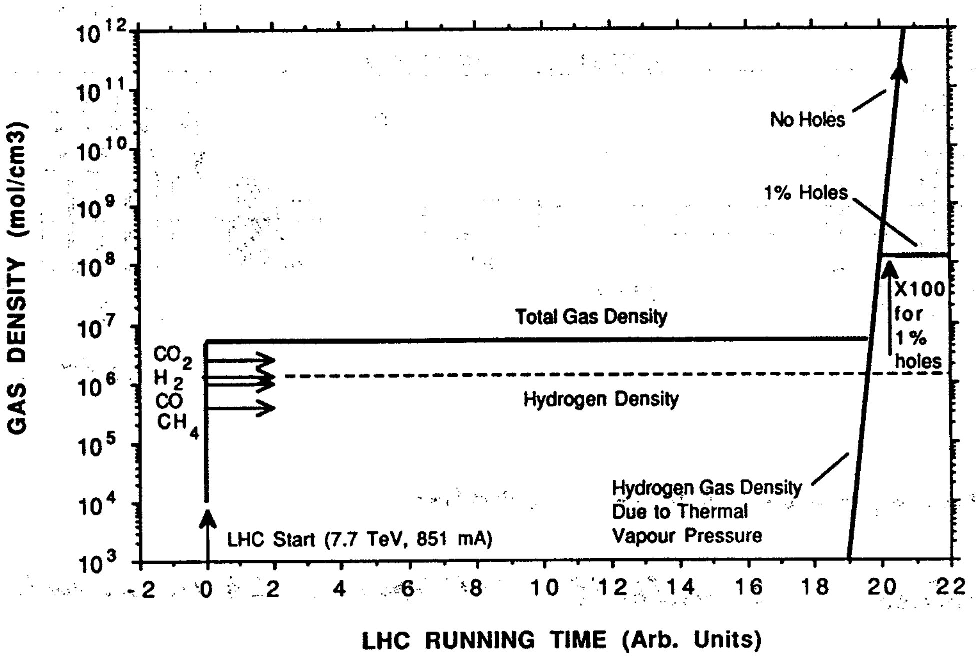


Figure 4: Geometry of a tapered 400 MHz cavity.



STATUS REPORT on LHC MACHINE

G. Brianti March 1992

****

1. INJECTORS

SOME BEAM TESTS
in LINAC, BOOSTER, SPS
VERY ENCOURAGING

2. OPTIMIZATION E vs. B

NEW CELL LAYOUT

3. MAGNET MODELS/PROTOTYPES

RECENT RESULTS

PROGRAMME
POSITIVE DEVELOP. TOWARDS
FINAL MAGNETS

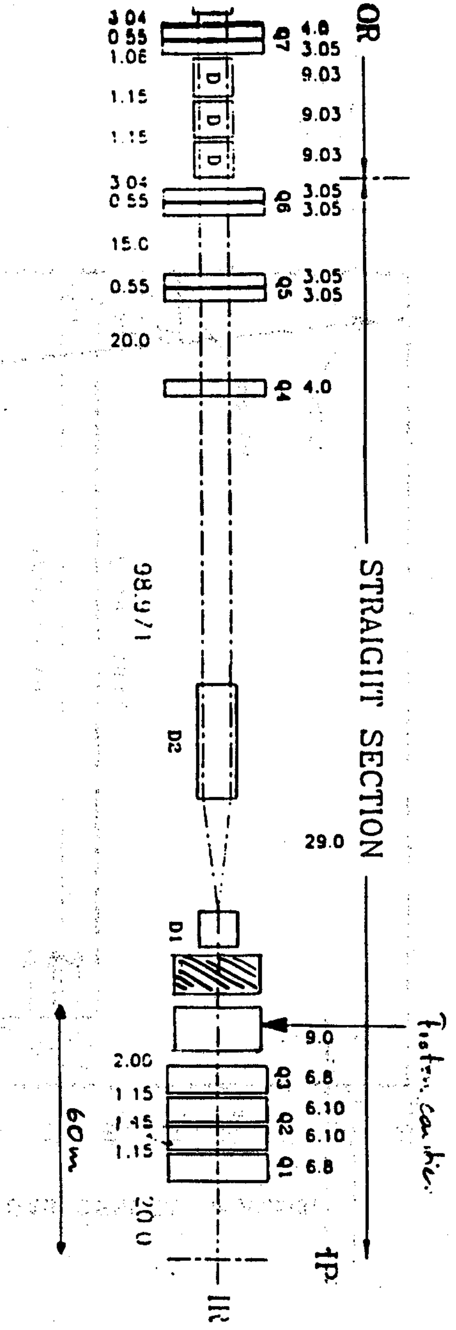
4. OTHER SYSTEMS

CRYOGENICS

VACUUM

RF

SOLID INDICATIONS THAT
PROJECT READY TO TAKE OFF AT T,



Max beam separation ± 6mm (protons)

Additional Ion cavities : 3 multicell (LEP type) = 24 MV on each side of IR.

Experimental areas + scenarios

K. Eggert (CERN)

LHC Main Parameters

		pp	e-p	Pb-ions
Max cm energy	TeV for B=9.5T	15.4	1.36	1262
Luminosity	$cm^{-2}\ s^{-1}$	$1.6\ 10^{34}$	$2.8\ 10^{32}$	$1.8\ 10^{27}$
Number of bunches		4725	508	800
Bunch spacing	m | ns	4.5 | 15	49.4 | 164.7	31.5 | 105
Particles/bunch		10^{11}	$9.2\ 10^{10}$ $3.0\ 10^{11}$	$6.2\ 10^{7}$
Particles/beam		$4.7\ 10^{14}$	$4.7\ 10^{13}$ $1.5\ 10^{14}$	$5.0\ 10^{10}$
Number of experiments		3	1	2
β at interaction point	m ($\beta x.\beta y$)	0.5	0.85,0.26 32.7,3.05	0.5
r.m.s. radius at int. pnt.	μm (x,y)	15	120 , 37	12.4
r.m.s. collision length	cm	5.3	3.8	5.3
Crossing angle	μrad	200	0	200

Experimental Areas and Scenarios

K. Eggert, L. Leistam, K. Potter

- Machine performance and luminosity considerations
- Experimental areas and installation considerations
  - for pp experiments
  - for Heavy Ion experiments
- Specialized experiments
  - low lumin. beauty exp.
  - fixed target gas jet exp's (beauty, neutrino)
  - crystal extraction
  - neutrinos from pp collisions
- General scenario

presented by K. Eggert at the General Meeting on LHC at Evian, 5-8 March 1992

Variation of Luminosity with number of Experiments

Luminosity $L=N^2kf\gamma/4\pi\varepsilon_n\beta^* = Nkf\gamma\xi/r_p\beta^*$

Beam-Beam tune-shift parameter per collision

$$\xi = Nr_p/4\pi\varepsilon_n$$

N is the number of particles per bunch
k is the number of bunches
f is the revolution frequency
ε_n is the normalised emittance of the beam
β^* is the betatron function at collision pnt
r_p is the classical proton radius

Limits arise from:

- **Total beam-beam tune shift parameter**

  $$n_x.\xi \le 0.01$$

  n_x collision points

- **Maximum circulating current**

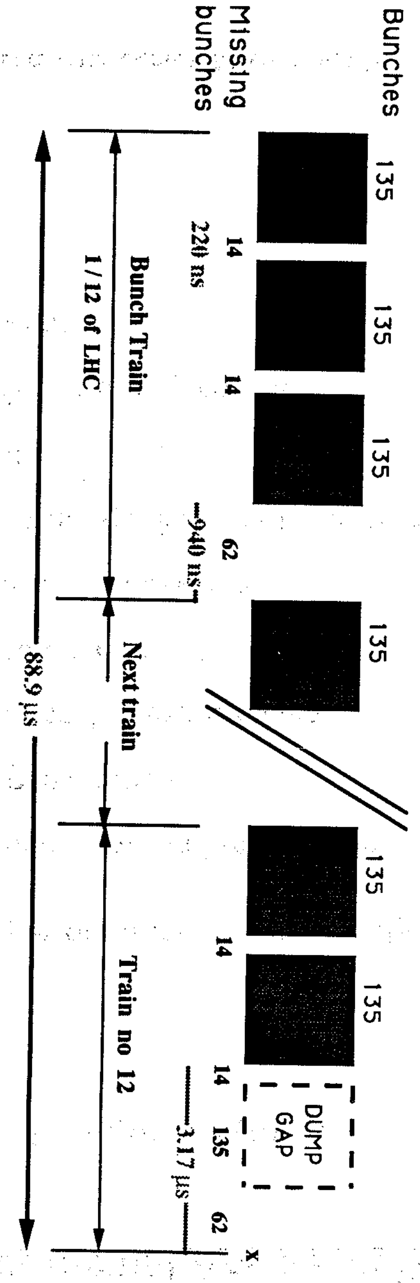
  $$I \le 0.85\ A$$

cryogenic cooling power for synchrotron radiation 0.6W/m

Respecting both limits gives:

$L(n_x)$

LHC Bunch Structure



Low Luminosity for individual experiments.

- calibration of heavy-ion experiments with protons

  $(L \approx 10^{29})$

- dedicated Beauty physics with vertex detector

Low Luminosity can be obtained by:

- changing β^*

  standard collision optics gives a factor of 30

  $L \geq 5 \times 10^{32}$ $cm^{-2}s^{-1}$ $\quad$ ξ is unchanged

  new optics is required for $\beta^* \approx 1$ km

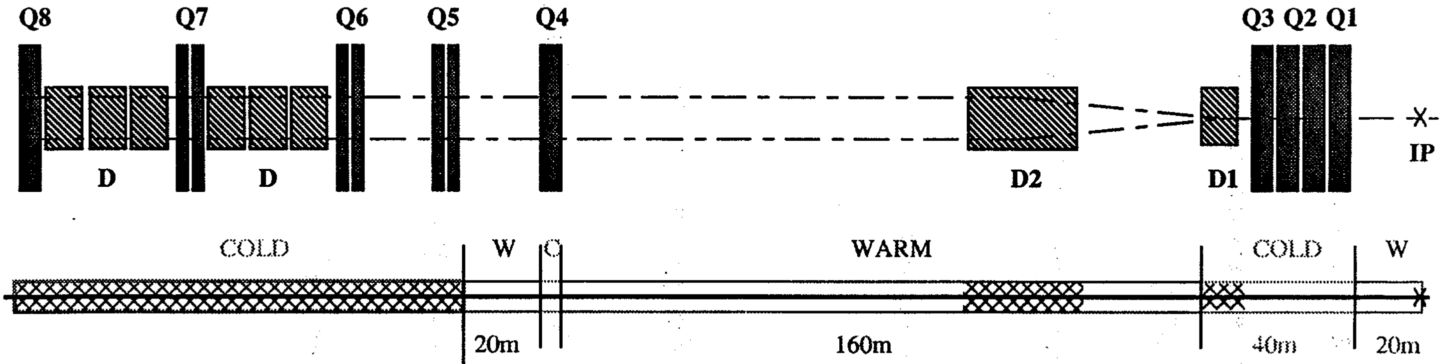
  $L \approx 7 \times 10^{30}$ $cm^{-2}s^{-1}$

Maximum Luminosity f(number of experiments)

No. of collision points	Protons/ bunch	Bunch spacing (ns)	Lum/Expt $(cm^{-2}\ s^{-1})$	< n > (events/ crossing)	Limits Max nx.ξ	Max I	Comments
1	$3.0\ 10^{11}$	50	$4.5\ 10^{34}$	172	x	x	New RF in PS & SPS
2	$1.5\ 10^{11}$	30	$1.86\ 10^{34}$	43	x		New RF in PS
3	$1.0\ 10^{11}$	15	$1.65\ 10^{34}$	19	x	x	Normal scheme
4	$7.5\ 10^{10}$	15	$9.3\ 10^{33}$	11	x		
5	$6.0\ 10^{10}$	15	$5.9\ 10^{33}$	7	x		

K. M. Potter

Beam-Gas Scattering in the LHC



Synchrotron Radiation 560 mW/m

20 mW/m

(200 mW/m)

Residual Gas Densities

H2	1.1×10^{7}	Mol/cm^3
CO	1.0×10^{7}	
CO2	2.5×10^{7}	
CH4	3.9×10^{6}	

Residual Gas Densities

H2	3.3×10^{6}	Mol/cm^3
CO	5.0×10^{5}	
CO2	5.0×10^{5}	
CH4	5.0×10^{5}	

3×10^4 int/m.s
in arcs of 24km

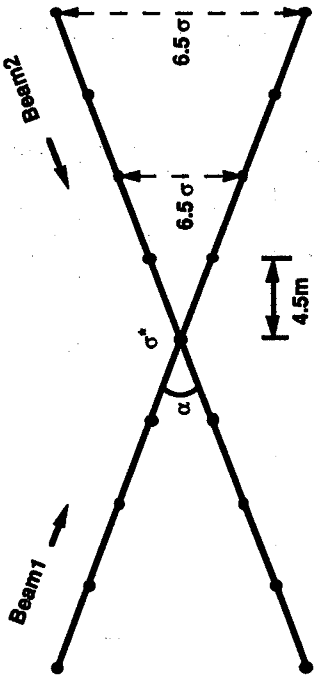
4.7×10^{14} protons
0.85 A in each beam
5.2×10^{18} protons/s

1×10^3 int/m.s
in straight section of 500m

- vertical separation of the beams

$L_S = L_o.e^{-(S^2/4)}$ s = separation in beam σ's

But $s \geq 6\sigma$ for negligible ξ and stable operation for other experiments



$L_S \leq 2 \times 10^{30}$ cm^{-2}s^{-1}

Method	β* (m)	Luminosity cm^{-2}s^{-1}	Comments
Standard optics	0.5-15	$1.6\ 10^{34}$ - $5.0\ 10^{32}$	ξ unchanged
Special optics	≈1000	≈$7.0\ 10^{30}$	ξ unchanged new insertion layout
Vertical separation	0.5-15	≤$2.0\ 10^{30}$	s≥6σ luminosity fluctuations high background

Luminosity-Lifetime Considerations

beam losses due to: beam-beam interaction   beam-gas interaction

$$\frac{dN}{dt} = -\frac{\sigma_{tot} L_0}{N_0^2} N^2 - \rho\sigma c N$$

→ gas density in beam pipe

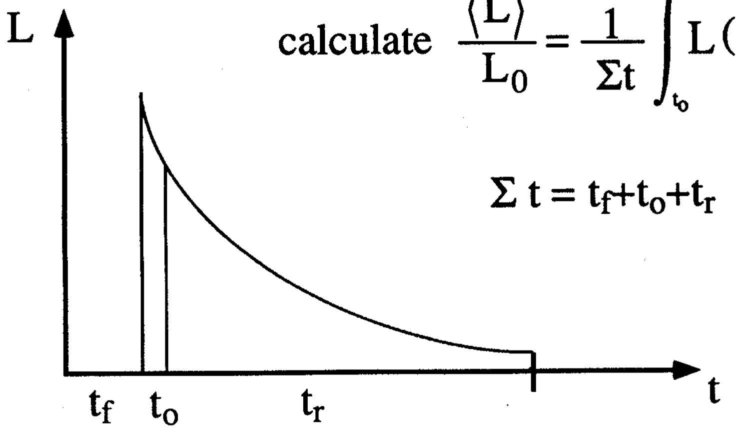
$$t_{bb} = \frac{N_0}{\sigma_{tot} L_0} \bullet \frac{1}{n_x} \qquad t_{bg} = \frac{1}{\rho\sigma c}$$

n_x: number of experiments

$$N(t) = \frac{N\, e^{-t/t_{bg}}}{\frac{t_{bg}}{t_{bb}}\left(1 - e^{-t/t_{bg}}\right) + 1}$$

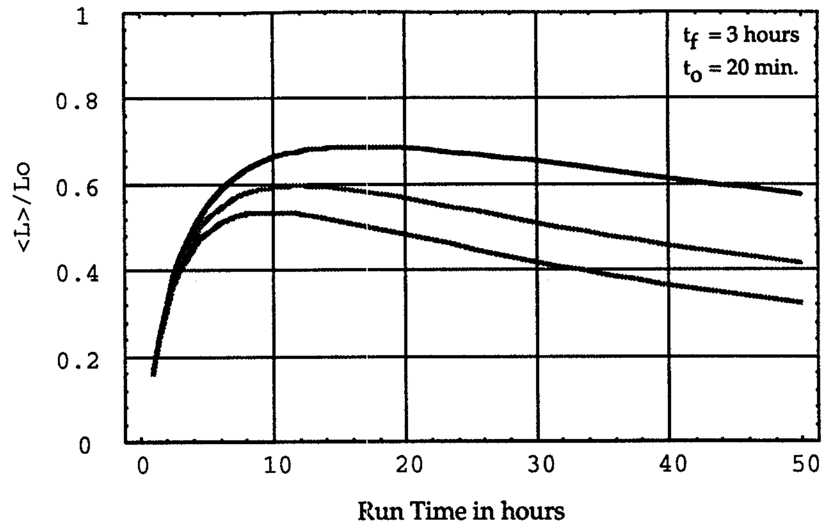
$$\text{calculate} \quad \frac{\langle L \rangle}{L_0} = \frac{1}{\Sigma t} \int_{t_0}^{t_0+t_r} L(t)\, dt$$

$$\Sigma t = t_f + t_o + t_r$$

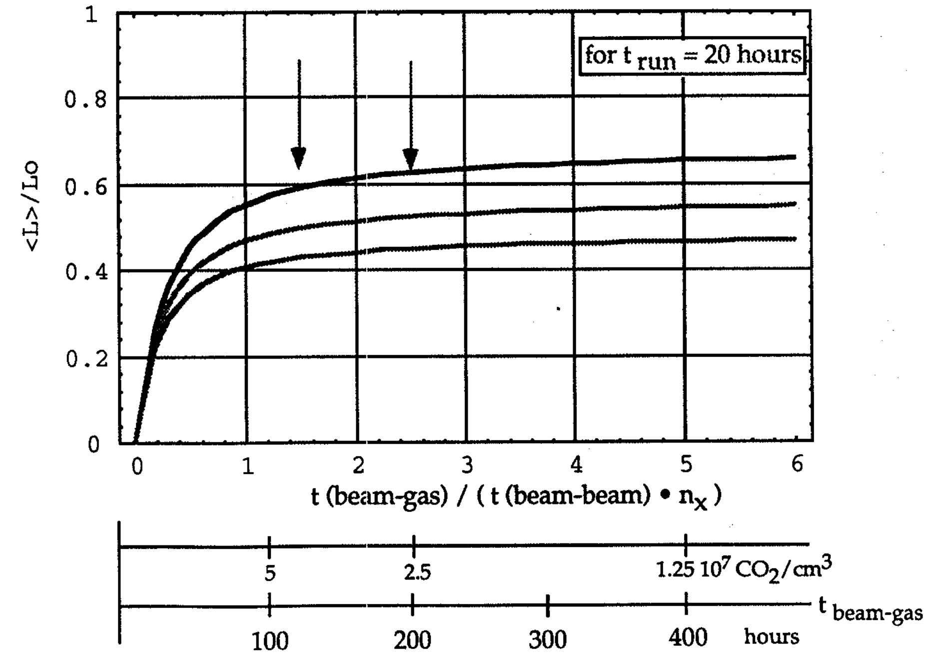


Luminosity lifetime

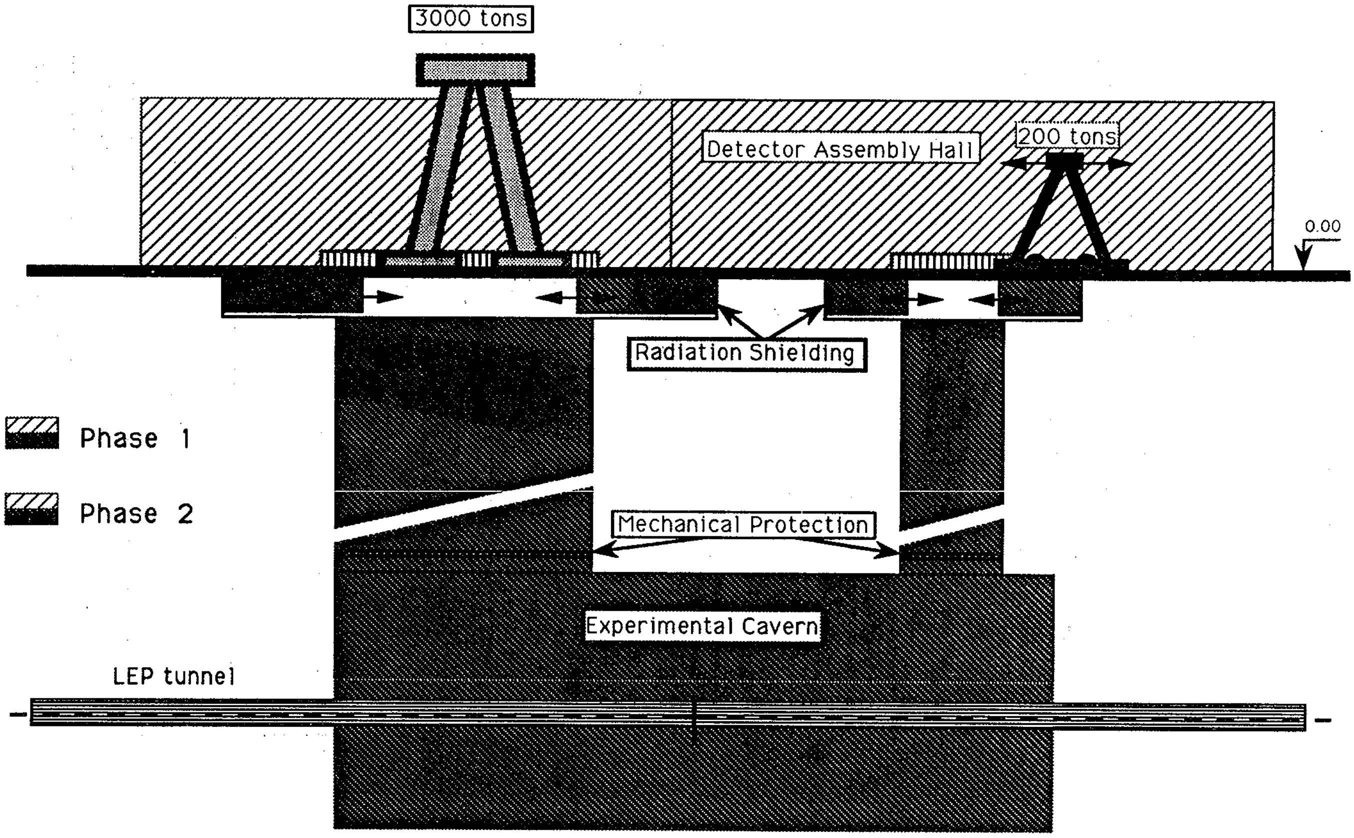
Av. Rel. Lumin. for 1, 2 and 3 experiments, L = 1.65 10^{34} , no beam gas

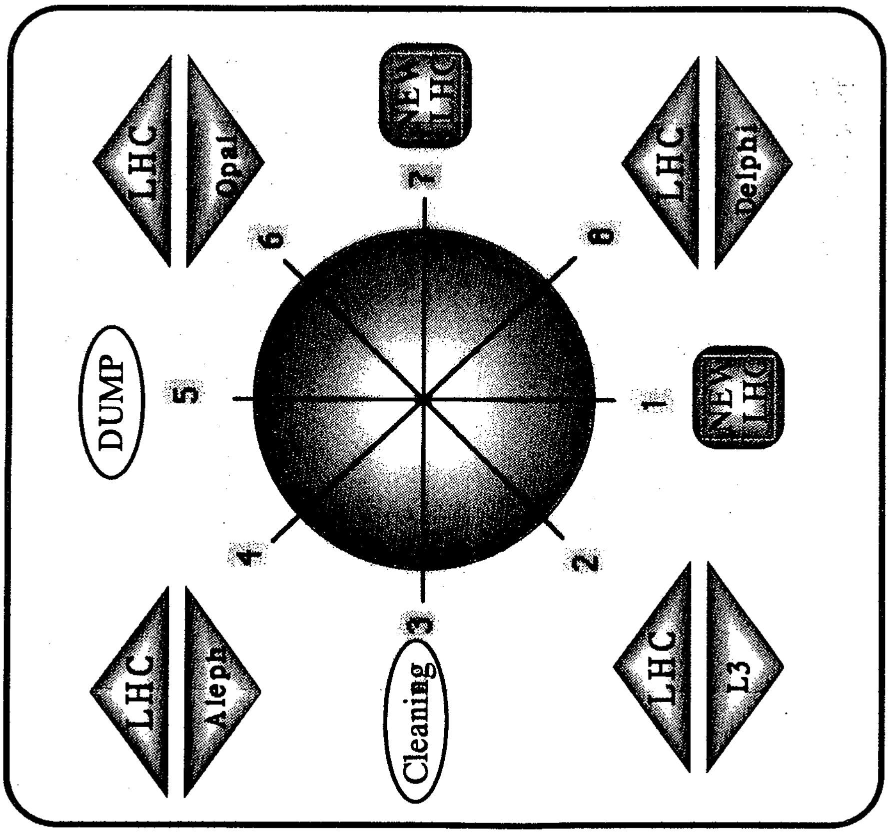


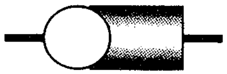
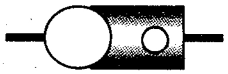
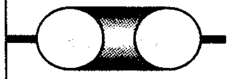
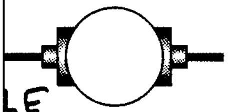
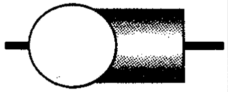
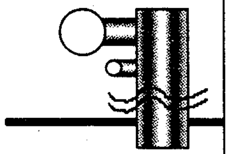
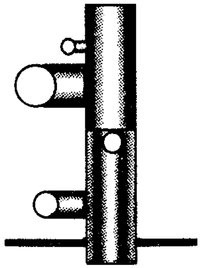
Av. Rel. Lumin. for 1, 2 and 3 experiments, L = 1.65 10^{34}

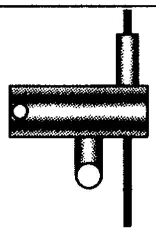
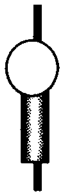
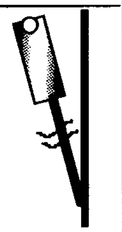


Schematic of an LHC Experimental Area



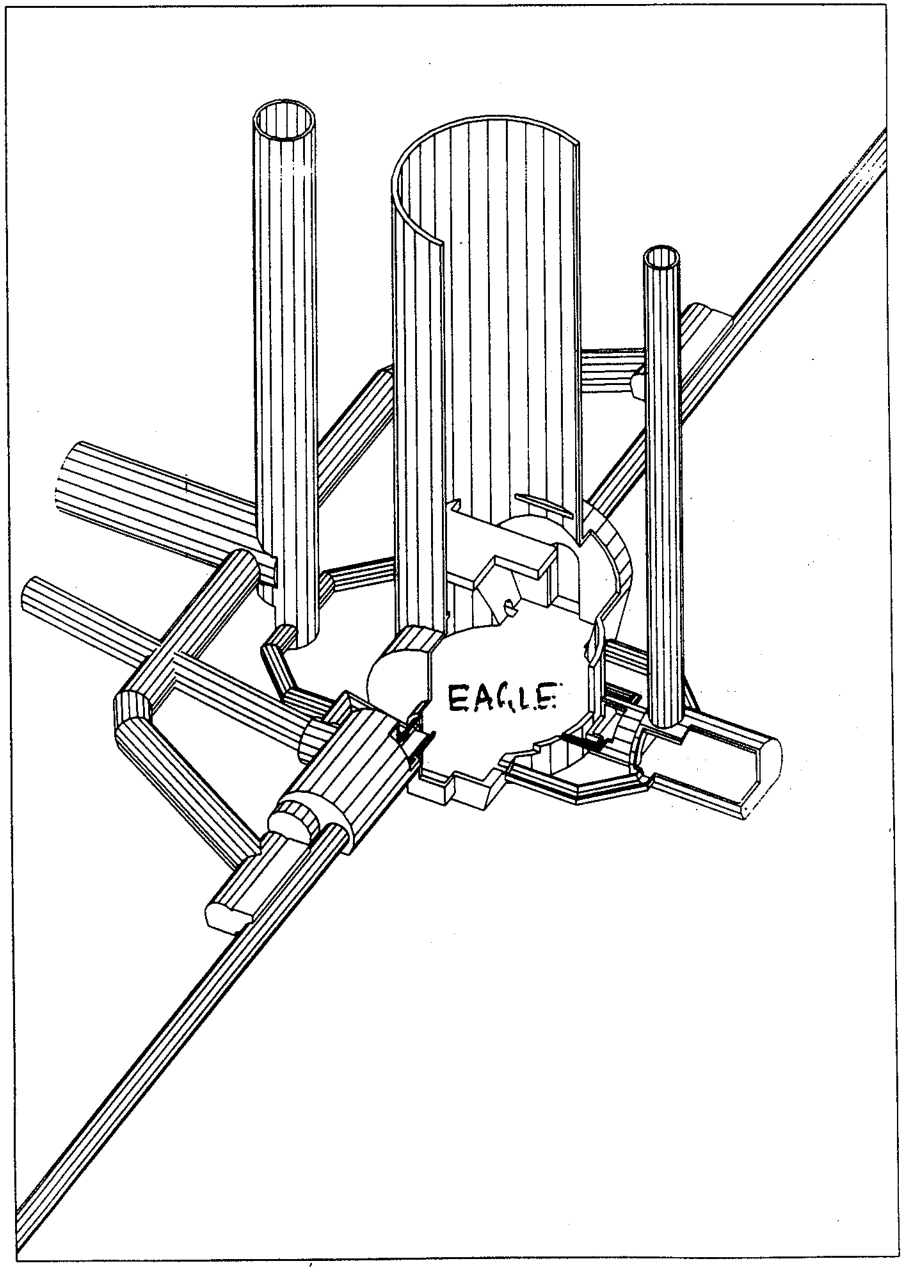


NO.	TYPE	Dimensions [m]	Volume [m3]	Rel.Cost Civ.Eng.
1 CMS L3		**Point 2 type** Shaft 1 ø 24 m Cavern ø 24 m Length 53 m	77.000	1.00
2		Shaft 1 ø 24 m Cavern ø 24 m Length 53 m Shaft 2 ø 9 m	83.000	1.08
3		**Two shafts** Shaft 1 ø 24 m Cavern ø 24 m Length 58 m Shaft 2 ø 24 m	121.000	1.42
4 EAGLE		**Single shaft** Shaft 1 ø 33 m Length 40 m Alcove 1 ø 24 m Alcove 2 ø 10 m	116.000	1.31
5 ASCOT		**Large P2 type** Shaft 1 ø 33 m Cavern ø 30 m Length 53 m	128.500	1.54
6		**Large LEP type** Shaft 1 ø 20 m Cavern ø 35 m Length 100 m Shaft 2 ø 5 m	157.000	2.31
7		**LEP Extension** Shaft 1 ø 20 m Cavern ø 21 m Shaft 2 ø 5 m Length 1 82 m Length 2 40 m	90'000	1.50

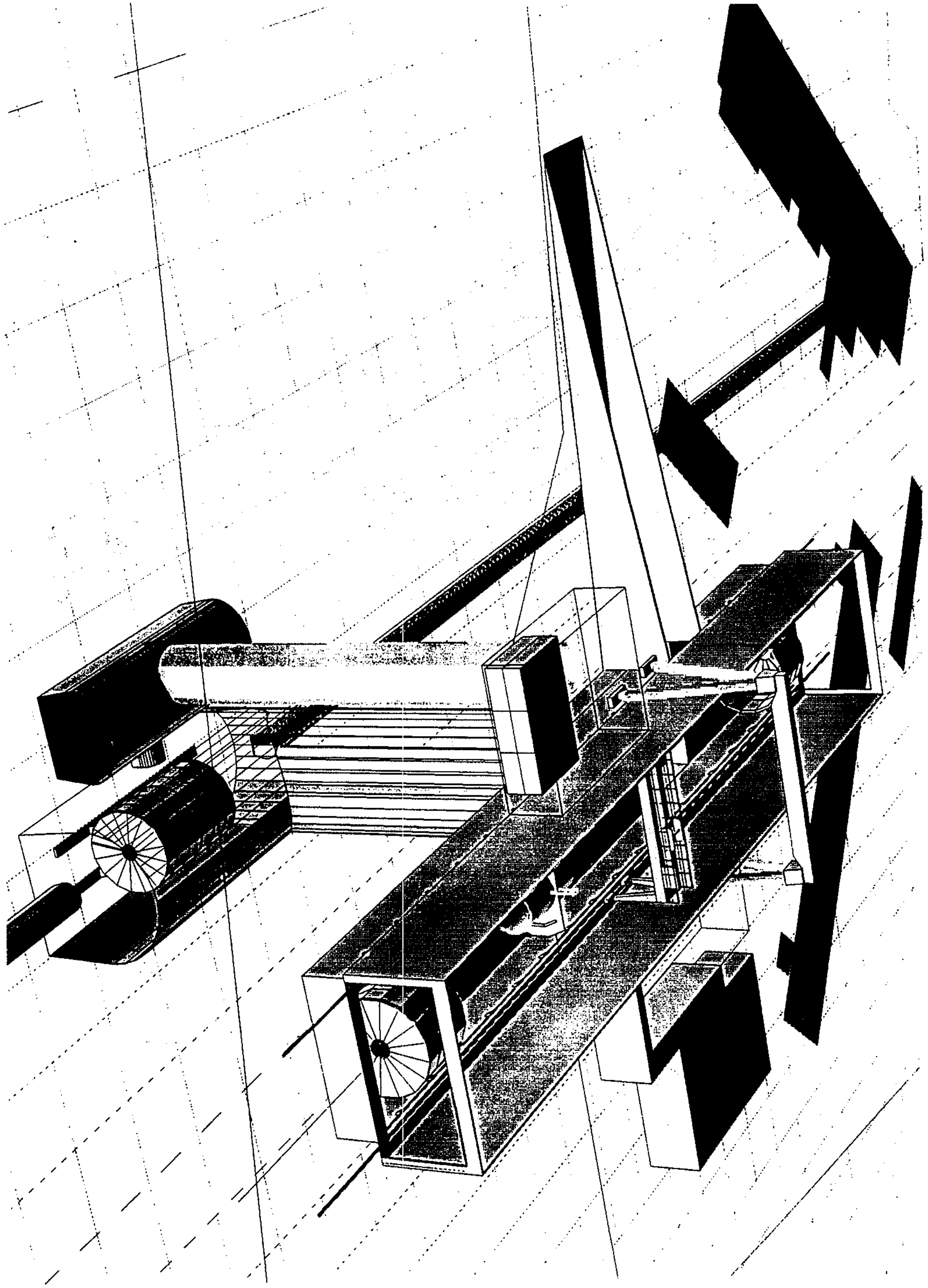
NO.	TYPE	Dimensions [m]	Volume [m3]	Rel.cost Civ.Eng
8		**Gas jet alcove** Alcove ø 8 m Length 28 m	2'600	0.15
9		**Gas jet in straight section** Shaft ø 20 m Cavern ø 8 m Length 28 m	37'300	0.73
10		**Extracted beam** Shaft ø 6 m Cavern ø 12 m Length 70 m Tunnel 350m	14'100	0.58

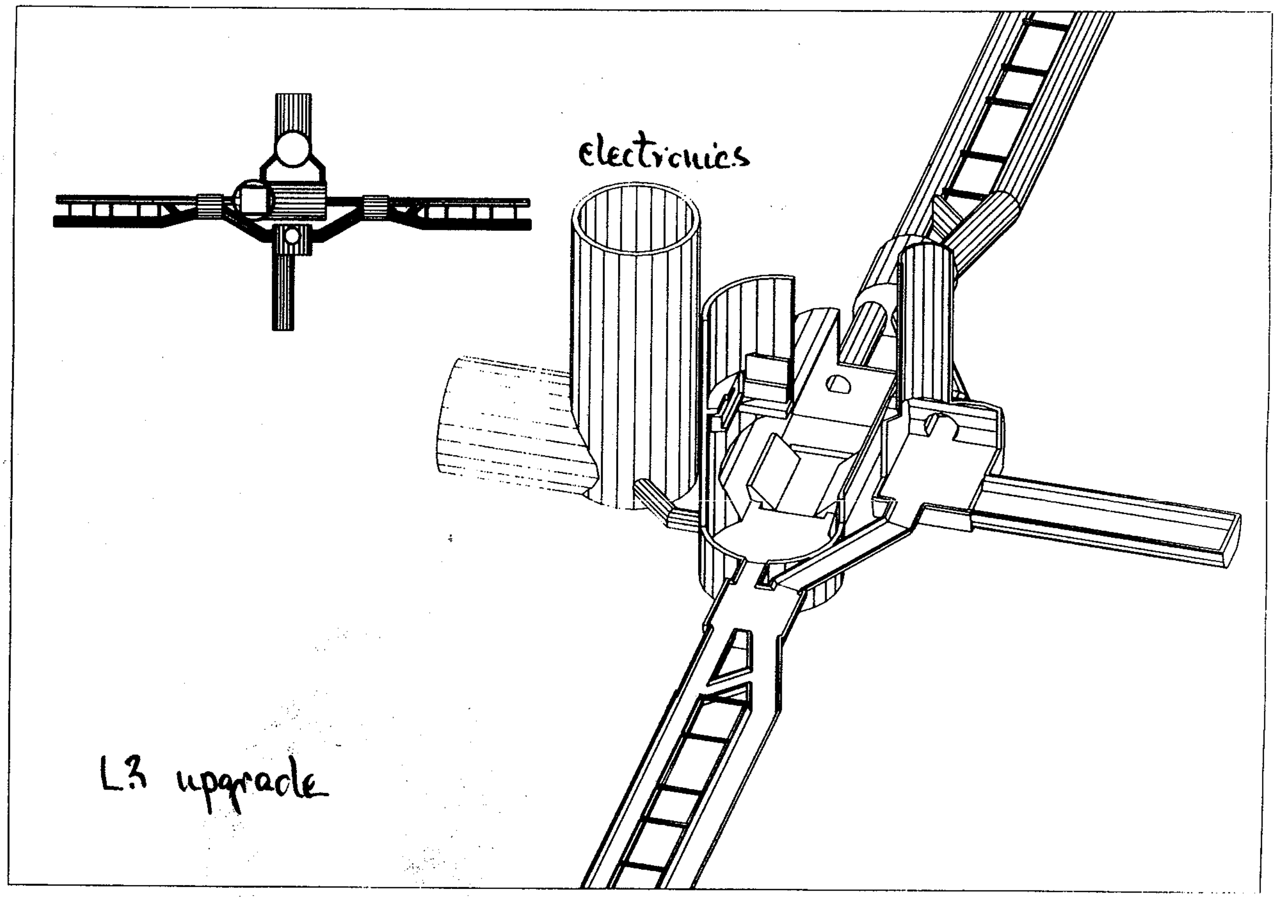
New cavern geometries for the large LHC detectors

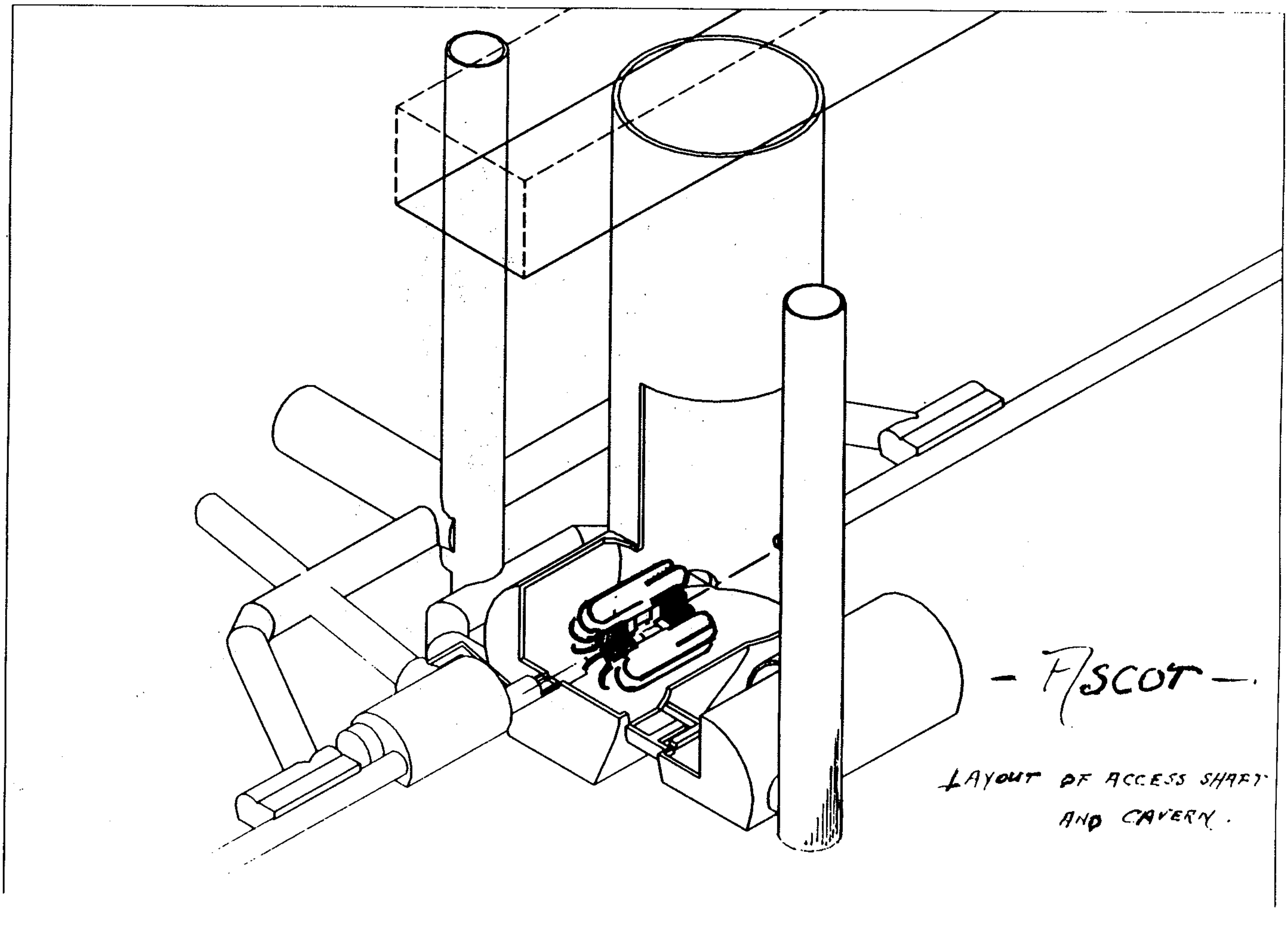
Experiment	Dimensions		Weight	Access shaft	Installation long. move		Access		
	Length	Ø	[ton]	[m]	with	without	end	central	end
ASCOT	26	22	10000	33	X		X		(X)
CMS	20	14	12000	24	X		X		(X)
EAGLE	27	18	27000	33		X		X	



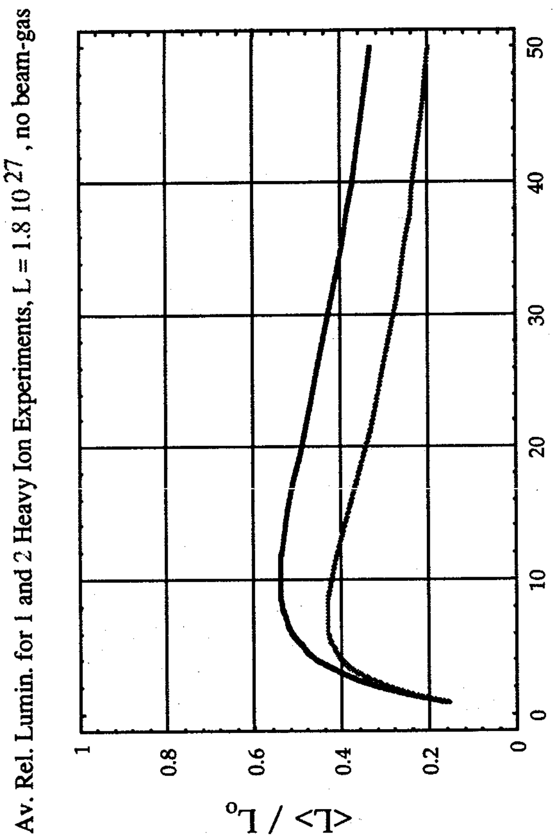
EAGLE




electronics
L3 upgrade


- ASCOT -
LAYOUT OF ACCESS SHAFT AND CAVERN.

Luminosity Considerations for Heavy Ions



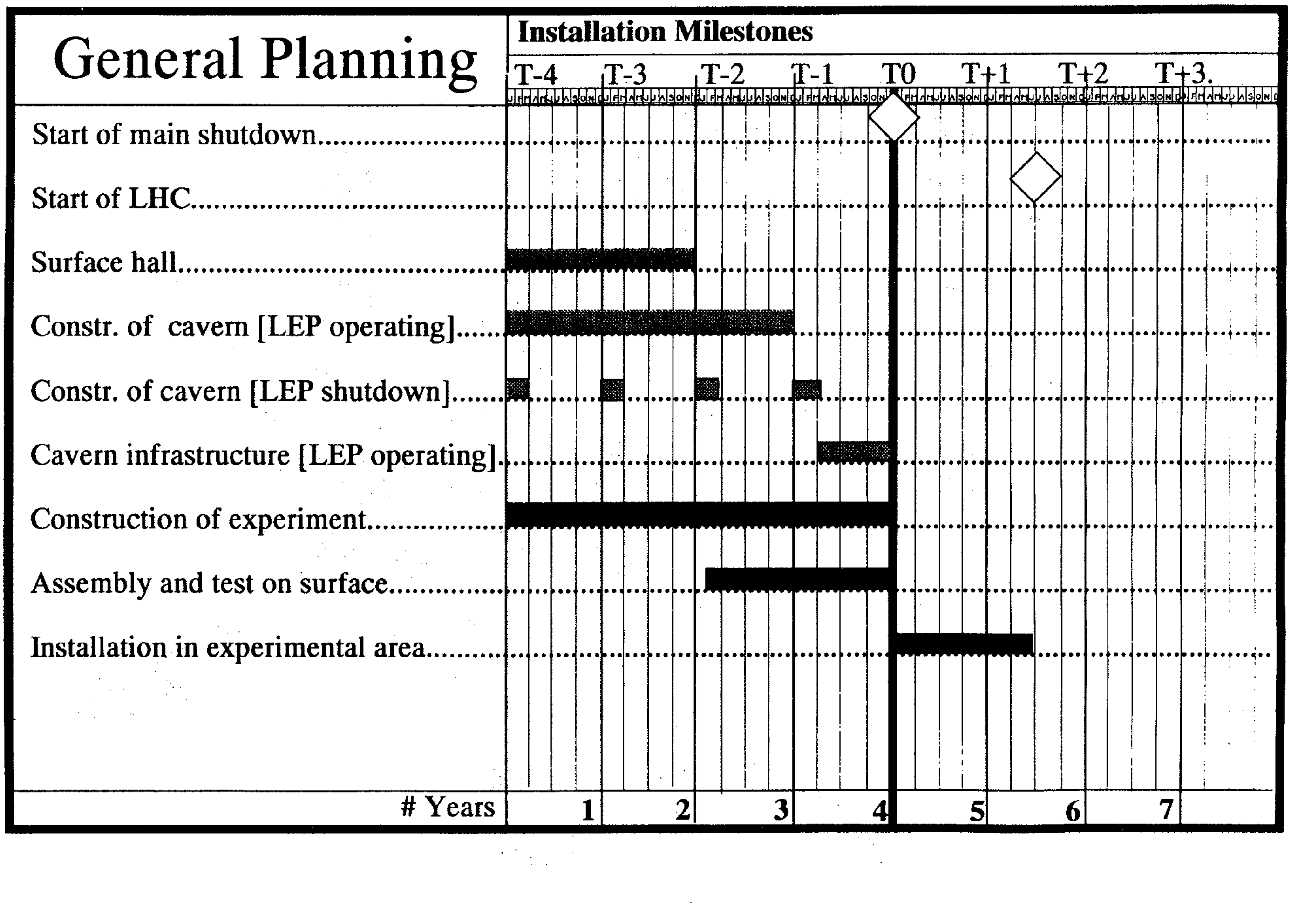
σ (Pb-Pb) ~ 6 barn, but beam losses due to :
Weizsäcker-Williams and
electron pair production followed by electron capture
σ ~ 300 barn

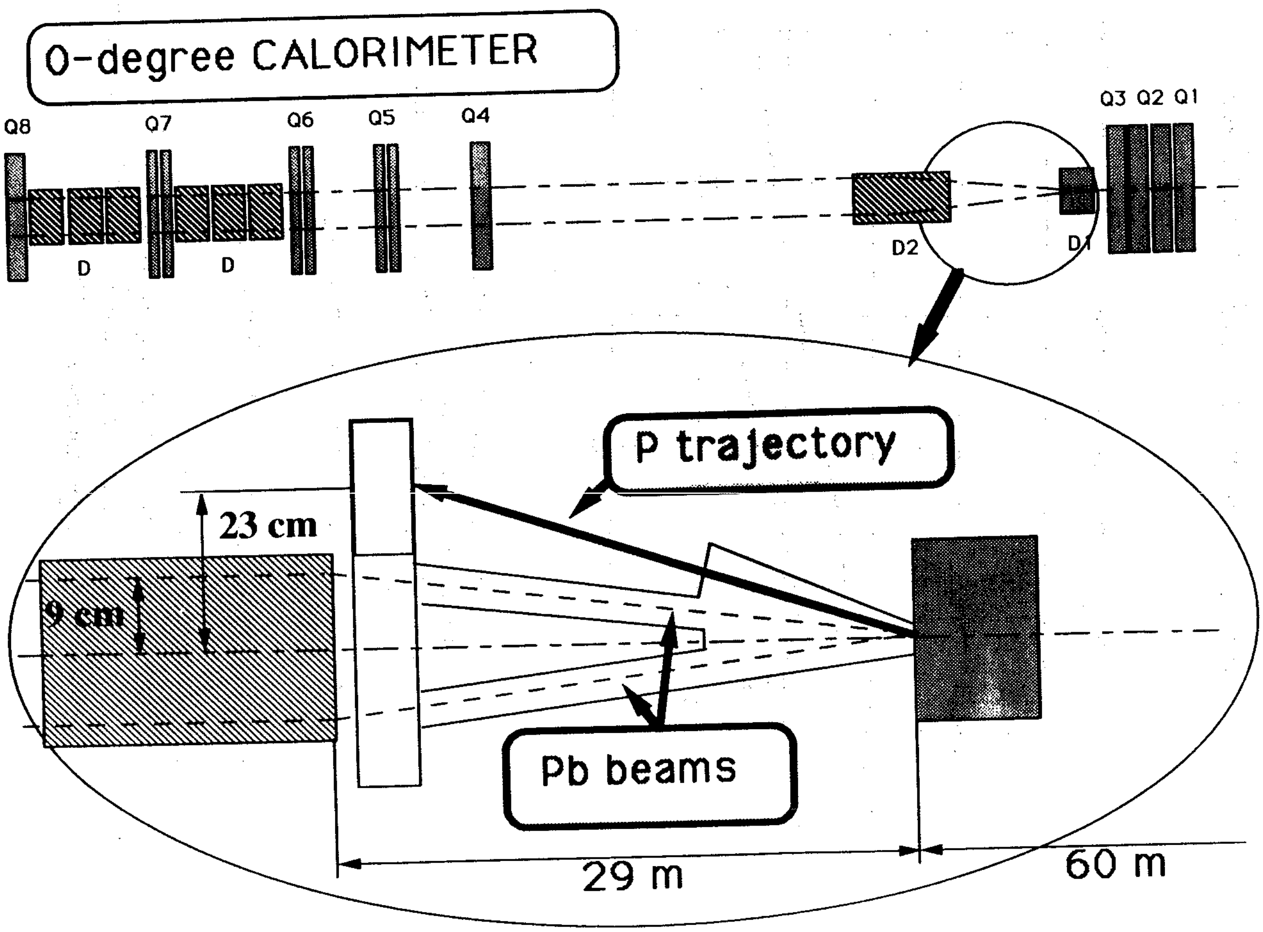
beam- lifetime $t_{bb} = 27.5$ hours / n_x ⇒ $t_{Lumi.} = 11.4$ hours/ n_x

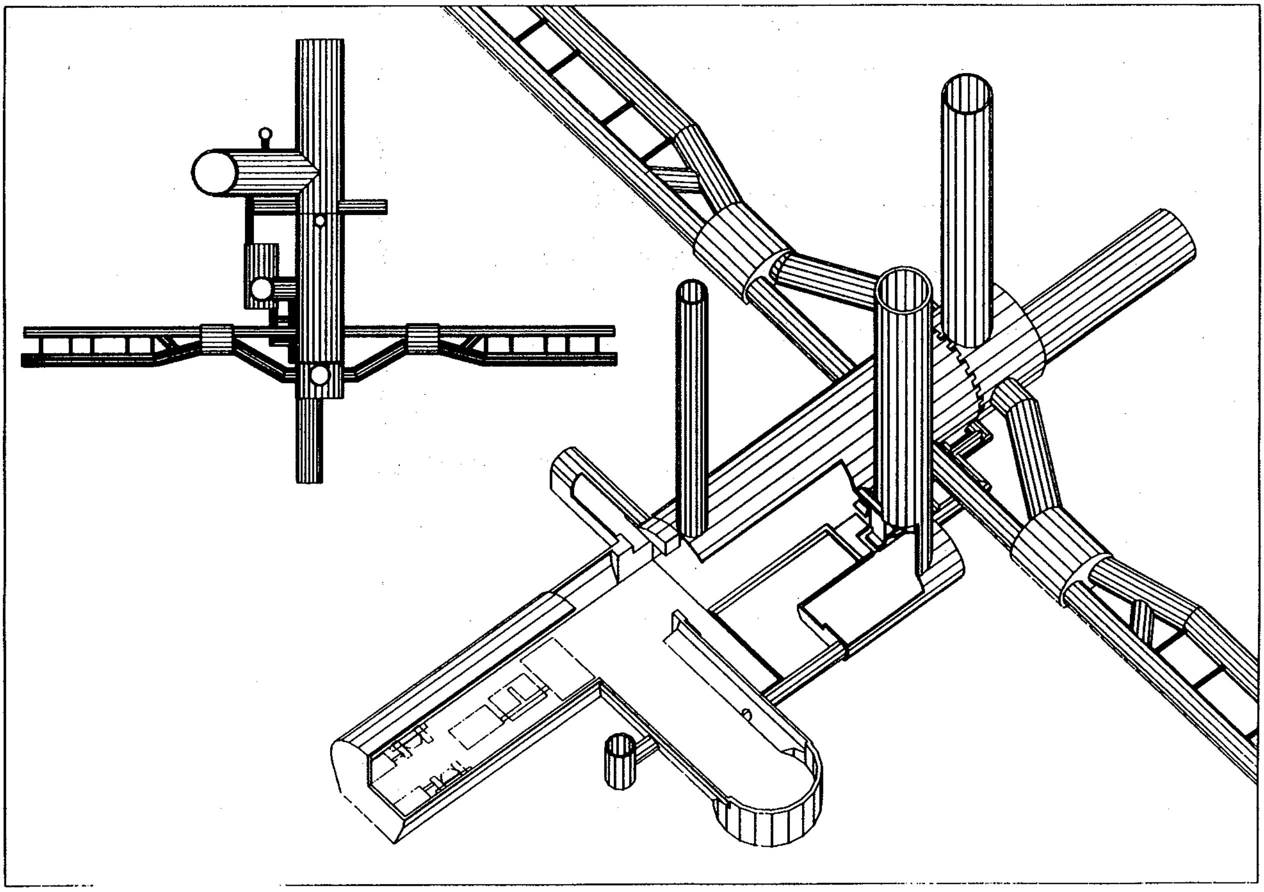
Possible running scheme for heavy ions

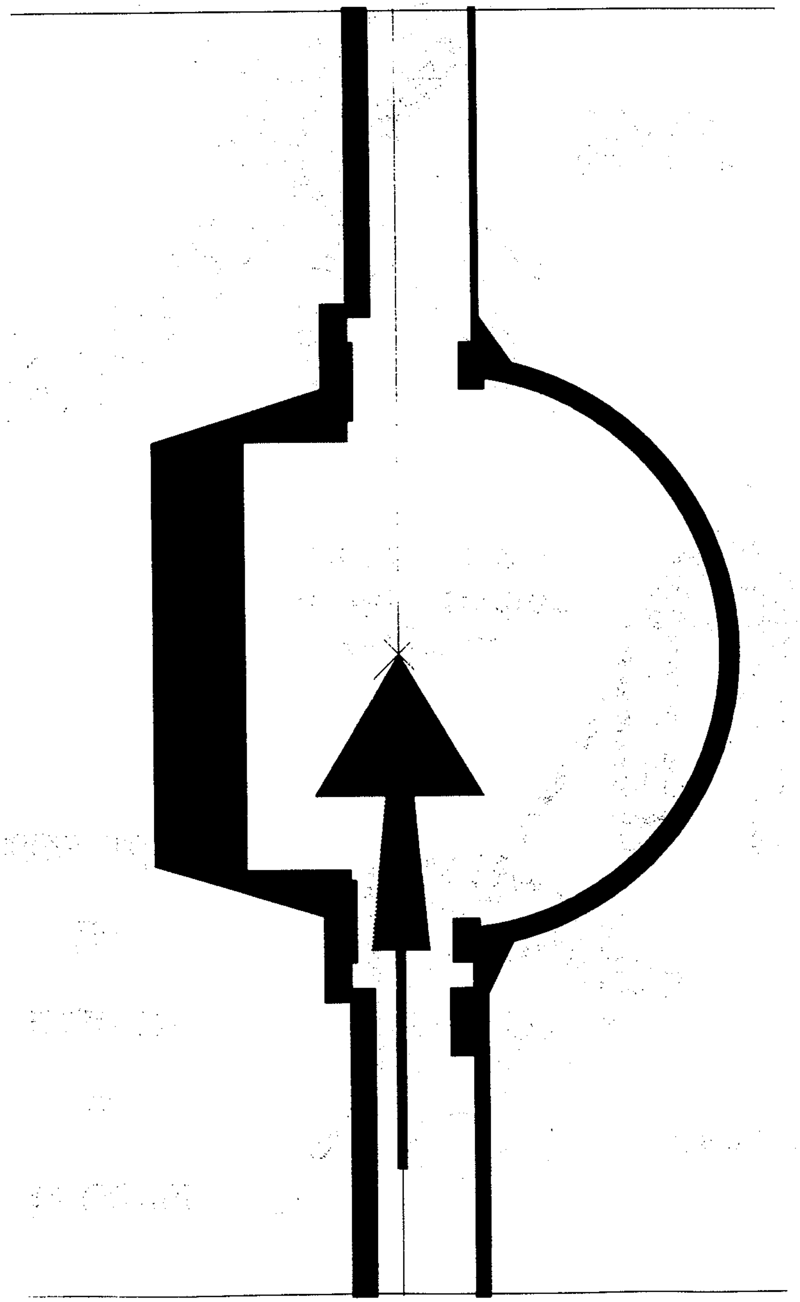
10 % of the year with heavy ions
with one dedicated low luminosity experiment ($L \sim 10^{26}$) and
one high luminosity experiment ($L \sim 2\ 10^{27}$), possibly a pp experiment
special low luminosity pp running at $L \sim 10^{28}$- 10^{29}

General Planning



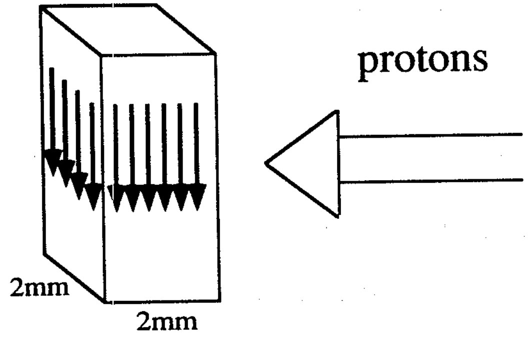

0-degree CALORIMETER
Q8
Q7
Q6
Q5
Q4
Q3 Q2 Q1
D
D
D2
D1
P trajectory
23 cm
9 cm
Pb beams
29 m
60 m





Internal Gas Jet for Beauty Physics

vertical
molecular jet
(like UA6)



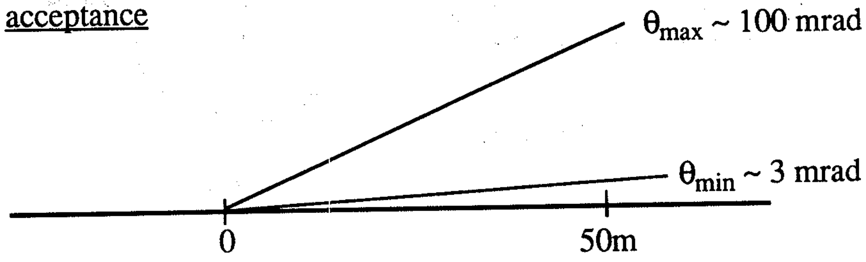
$$L = \rho \bullet l \bullet N_p \bullet f$$

protons/cm^3	length (cm)	circ. protons	revol. frequenc
1.6 10^{15}	0.2	4.8 10^{14}	11246

$L = 1.7\ 10^{33}\ \mathrm{cm}^{-2}\mathrm{sec}^{-1} \rightarrow \sim 10^{10}\ B\bar{B}$/year

small target ± 1mm < b decay length >~ 3 cm

acceptance



Roman pots 2mm/1m
detector 10σ away from beam ⇒ $\sigma_{beam} \sim 100\text{-}200\ \mu$
detector length ~ 50m

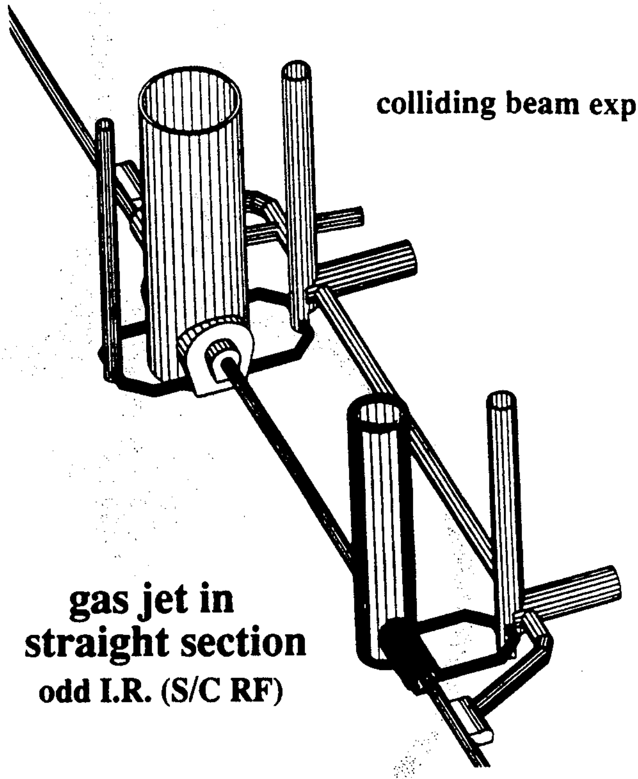
Location

of

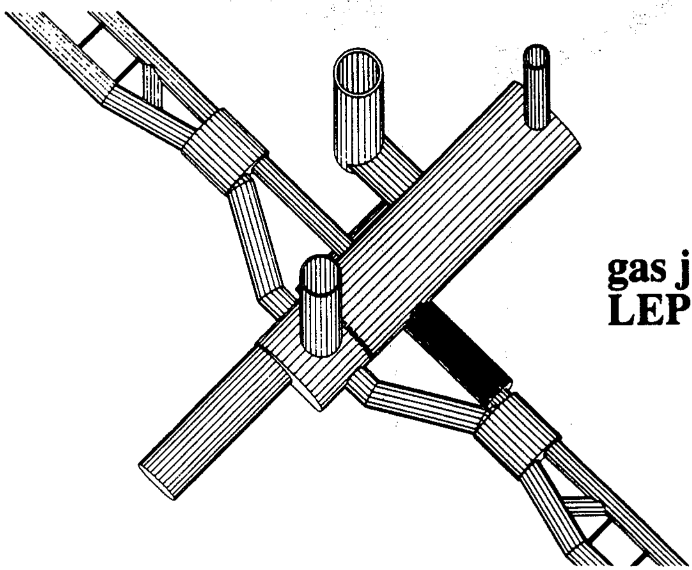
a gas jet

for

beauty physics

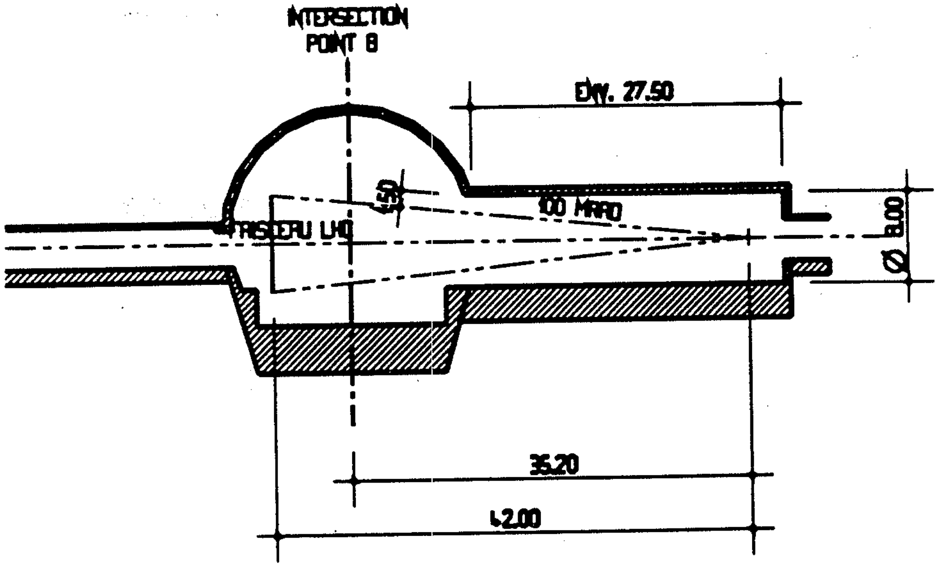


gas jet in straight section
odd I.R. (S/C RF)



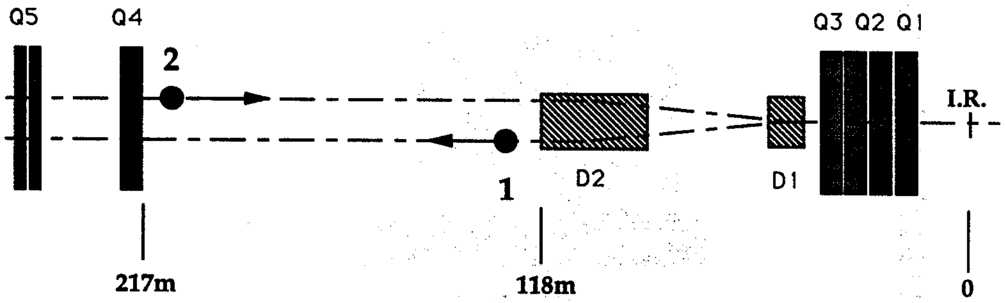
gas jet in LEP I.R.

Gas Jet in a LEP Intersection Region



- use of dump optics, i.e. no nearby Quads
- beam size at 6 σ is ~ 2mm (Roman pots)
- beams must be seperated at I.P. to avoid collisions
- arrangement such that only one beam will hit gas jet
- experimental areas :
  no major changes in I2
  minimal excavation of new forward alcoves in I 4,6,8

Gas-jet in a Straight Section
free space ≈ 90m



	β function		Beam size	
	Horiz	Vert	Horiz	Vert
1	500m	2000m	280µm	630µm
2	80m	300m	110µm	270µm

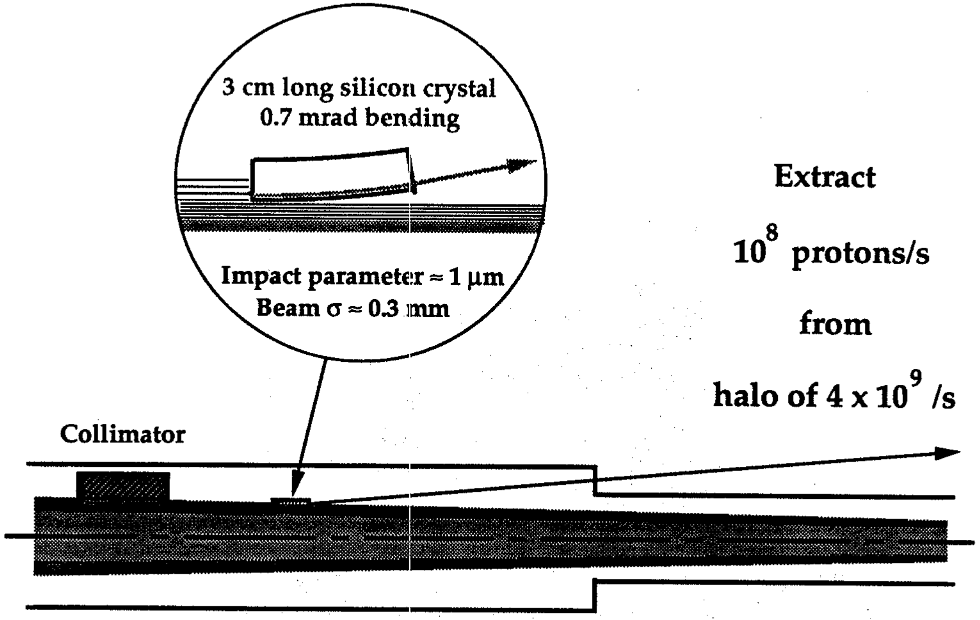
- possible next to I1 and I7

-secondaries go towards the intersection region and D2

- but D2 is a warm magnet

-new experimental cavern is needed away from
the infrastructure of the I.R. (~24m ϕ , 30m long)

Halo Extraction using Channeling
in a Bent Crystal



Extract

10^8 protons/s

from

halo of 4×10^9 /s

Extraction of a few % of the beam halo by channeling in a bent crystal.

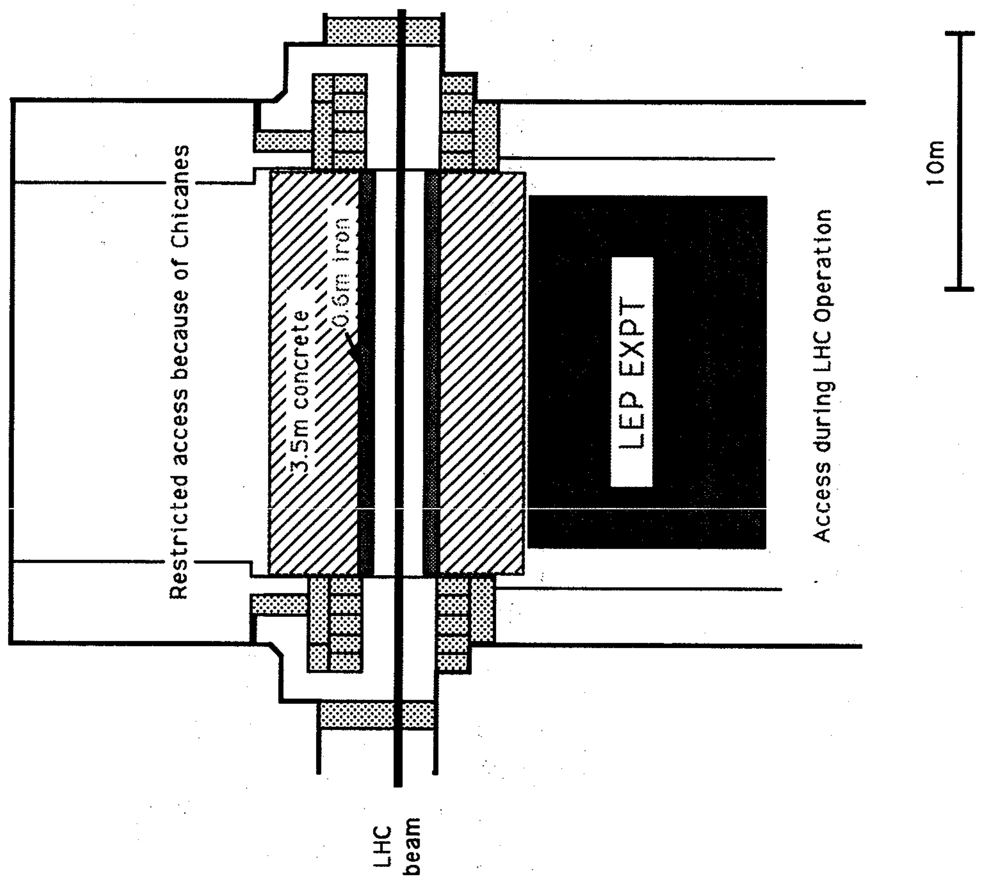
Test of the principle at SPS next year.

At the LHC a whole straight section is devoted to limiting the beam halo to 6 σ and protecting the superconducting magnets. A crystal inside 6 σ will severely disturb this beam cleaning.

? Special optics will be needed combining extraction with collimation ?

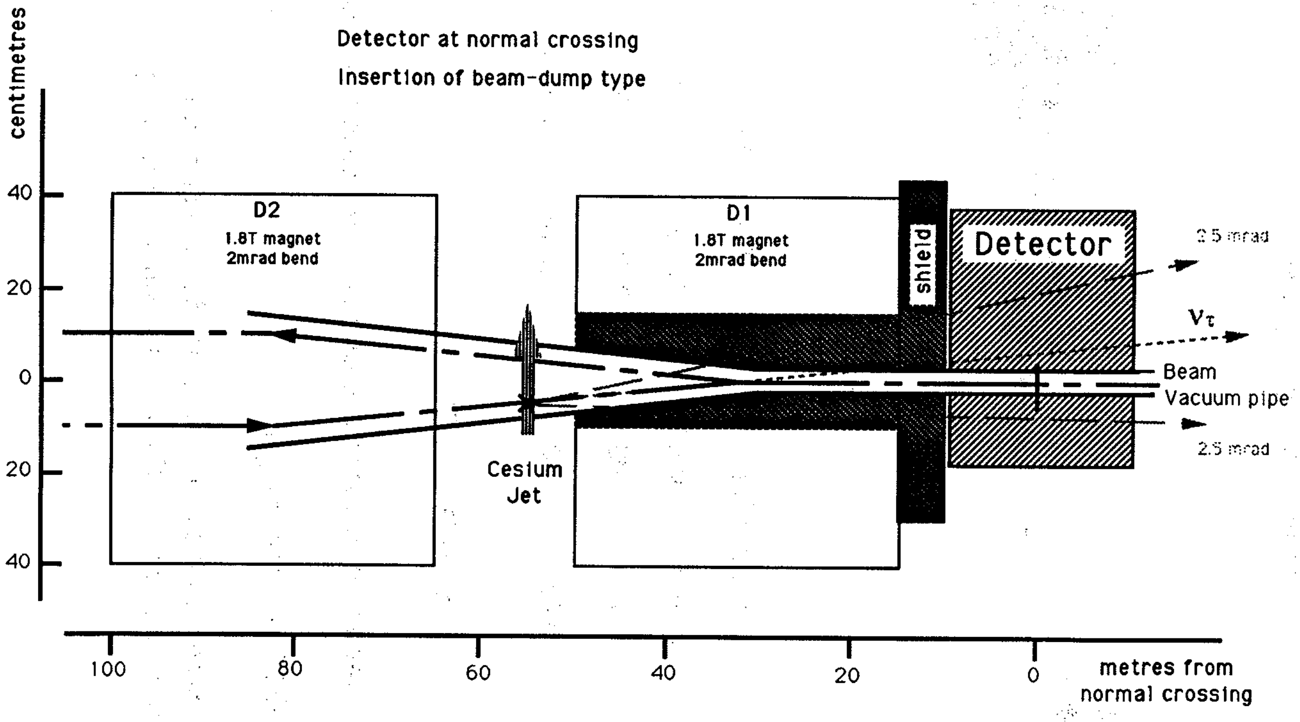
K.M. Potter

Shielding the LHC beam in a LEP Cavern

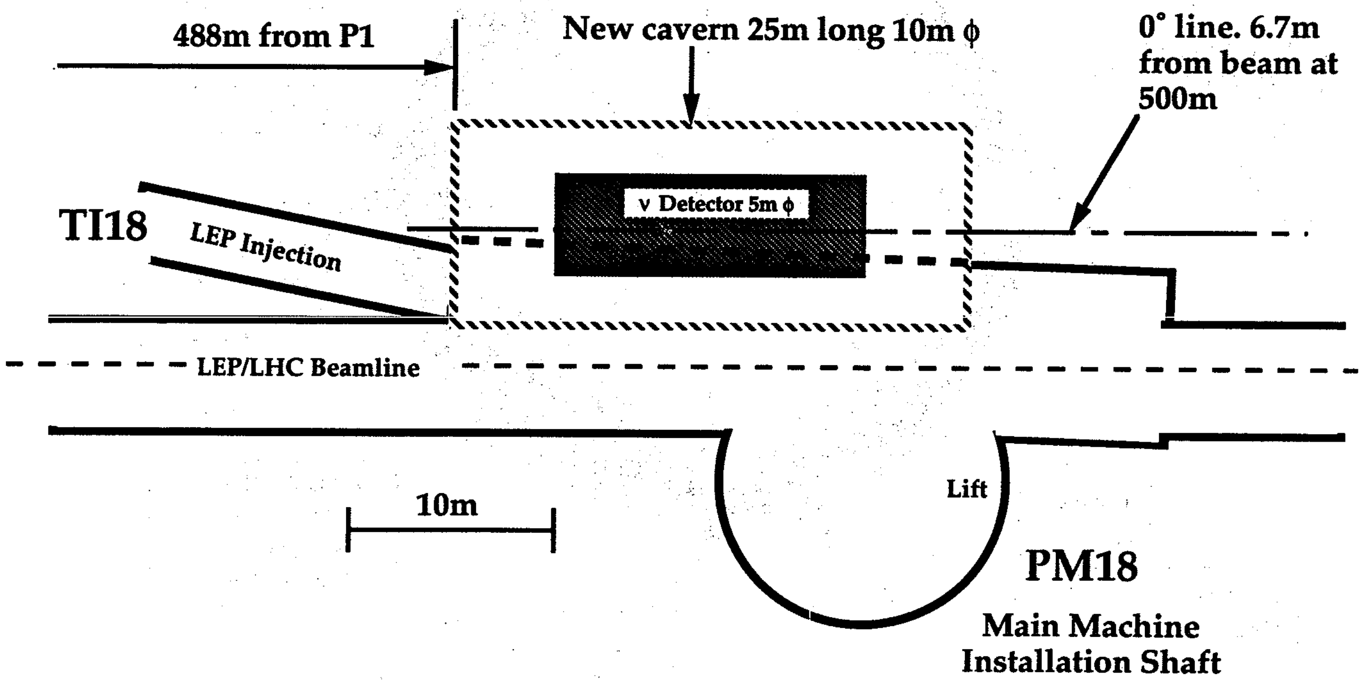


K.M. Potter

Schematic Layout for a Cesium Target and Neutrino Detector



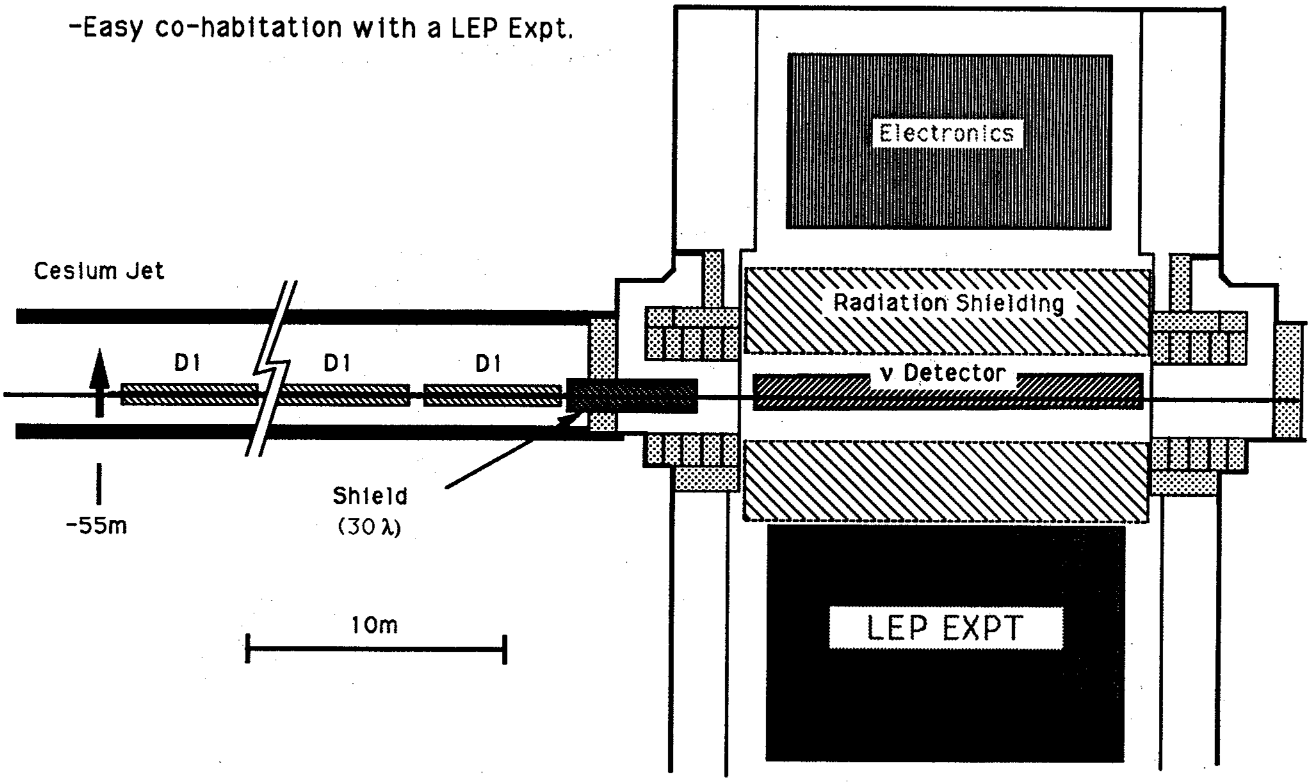
Neutrino Detector adjacent to PM18

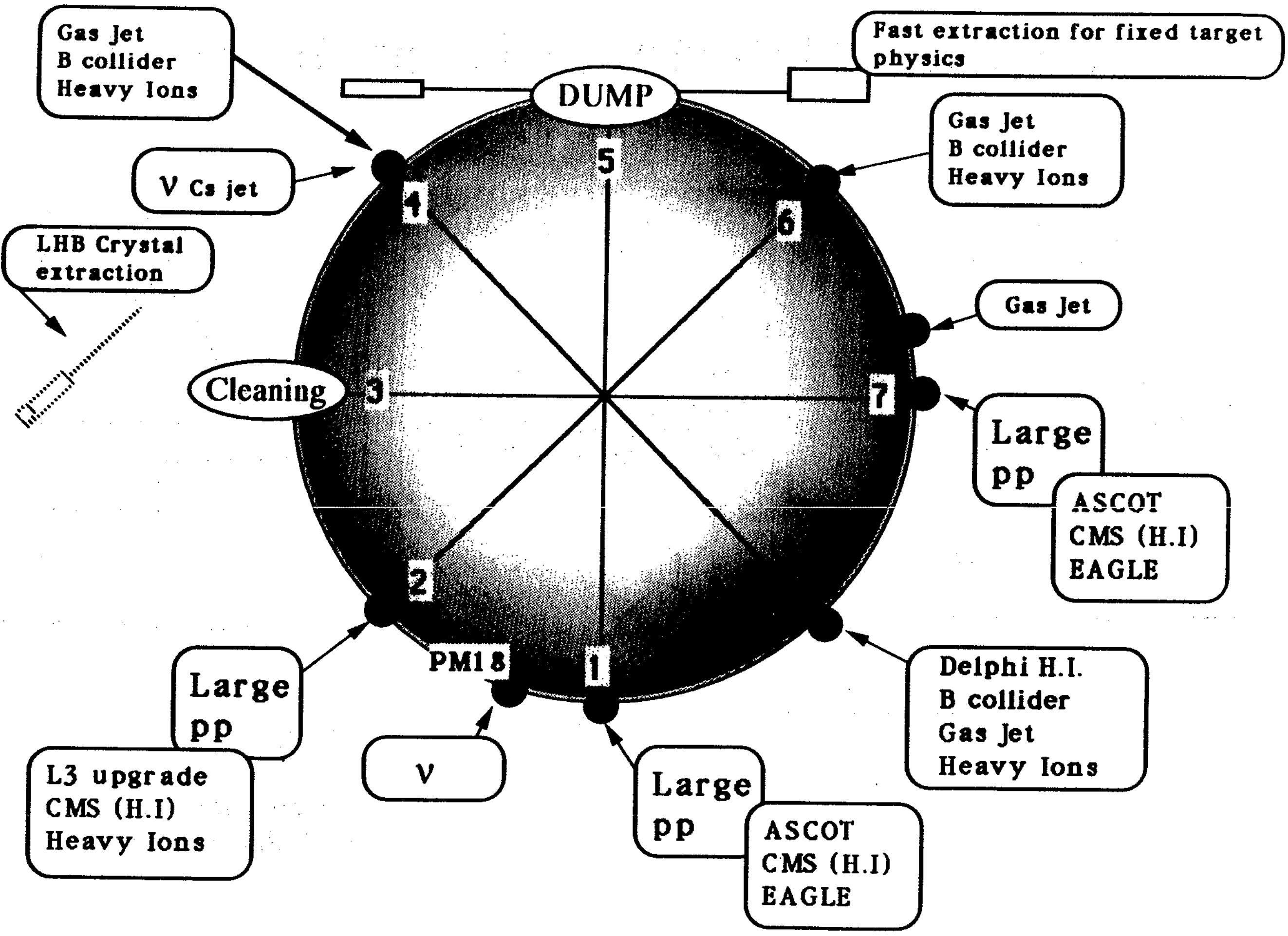


Schematic Layout of a Neutrino Detector in a LEP Cavern

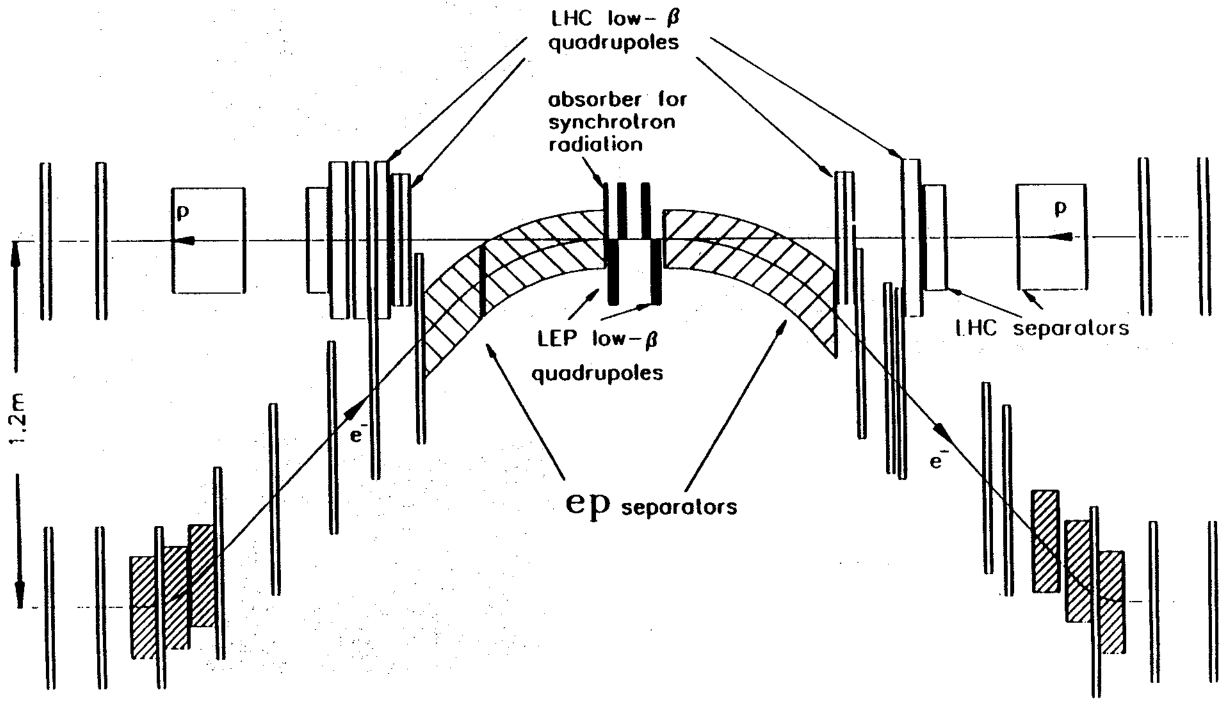
K.M. Potter

-Easy co-habitation with a LEP Expt.





Schematic Layout of an e-p Interaction Region



Suitable for P7 and adaptable for P4, P6 & P8 with some LEP RF cavities removed

Closing remarks

C. Rubbia (CERN)

Towards the LHC Experimental Programme

General Meeting on LHC Physics & Detectors

Closing Remarks

C. Rubbia

8 March, 1992
Evian-les-Bains, France

MEMBER STATES RESPONSE TO THE LHC PROJECT

☐ A two step procedure toward LHC has been proposed by the CERN management, namely

(1) an "Approval in Principle" of LHC as the right and next project for CERN, pending a number of further clearly defined conditions and

(2) the Final Approval with the consequent starting of construction and final approval of the experimental programmes.

☐ For optimum progress of the project, the Approval in Principle was requested for not later than June 1992 and – provided that all conditions can indeed be met – a final LHC approval should be given during the second half of 1993, namely in about two years from today."

☐ Step (1) has already been completed: CERN Council, on 20 December 1991 adopted unanimously a resolution (see transp) endorsing the management's and SPC recommendations

CERN/SPC/634
CERN/CC/1891
Original: English
25 November 1991

ORGANISATION EUROPÉENNE POUR LA RECHERCHE NUCLÉAIRE
CERN EUROPEAN ORGANIZATION FOR NUCLEAR RESEARCH

SCIENTIFIC POLICY COMMITTEE	COMMITTEE OF COUNCIL
Hundred-and-sixty-eighth Meeting	Two-hundred-and-third Meeting
Geneva - 16 and 17 December 1991	Geneva - 18 and 19 December 1991

GUIDELINES FOR THE LARGE HADRON COLLIDER
(LHC)

A two step procedure toward LHC is proposed, namely (1) an "Approval in Principle" of LHC as the right and next project for CERN, pending a number of further clearly defined conditions and (2) the Final Approval with the consequent starting of construction and final approval of the experimental programmes. For optimum progress of the project, the Approval in Principle should be reached not later than June 1992 and — provided that all conditions can indeed be met — a final LHC approval should be given during the second half of 1993, namely in about two years from today.

- The Director-General has been asked to provide <u>before the end of 1993</u> a detailed information on the costs, the involvement of the Member and non-Member States and on the factors set out in 2.2 of Document CERN/CC/1891, so that Council may move towards a decision on the LHC;
- In particular, information is required on the following aspects:
  a) the technical feasibility of the project;
  b) the best estimate of the final cost of the machine, the sources of funding and the delivery schedule of the components, including the possible participation of non-Member States according to the so-called "HERA Model";
  c)a definition of the experimental programme, its goals and its direct costs to CERN as well as the indirect costs to be sustained by the Funding Agencies of the main participating institutions".
- This meeting is the first consequent step in defining the experimental programme of the LHC, as requested by Council.

COUNCIL RESOLUTION ON LHC

COUNCIL,

Following presentations of both the needs of the science and of the nature of the proposed machine done at its Session on 19 December 1991, as well as of the preliminary indication of costs,

Agrees:

1. that in all these respects, the LHC is the right machine for the advance of the subject and of the future of CERN;
2. that the Director-General be asked to provide before the end of 1993 detailed information on the costs, the involvement of Member and non-Member States and on the factors set out in 2.2 of Document CERN/CC/1891, so that Council may move towards a decision on the LHC;
3. In particular, information is required on the following aspects:
   a. the technical feasibility of the project;
   b. the best estimate of the final cost of the machine, the sources of funding and the delivery schedule of the components, including the possible participation of non-Member States according to the so called "HERA Model";
   c. a definition of the experimental programme, its goals and its direct costs to CERN as well as the indirect costs to be sustained by the Funding Agencies of the main participating institutions.

* * *

CERN/1904
Original : English
3 February 1992

ORGANISATION EUROPÉENNE POUR LA RECHERCHE NUCLÉAIRE
CERN EUROPEAN ORGANIZATION FOR NUCLEAR RESEARCH

NINETY-THIRD SESSION OF COUNCIL
Geneva - 20 December 1991

COUNCIL RESOLUTION ON LHC

☐ We operate under the initial assumption that the initial programme for the LHC consists of:

- ☛ 1 or 2 general purpose detector(s) to study proton-proton collisions. In case of >1 detector ,"complementarity" must be ensured
- ☛ 1 dedicated heavy-ion facility +parasitic use of the other detectors
- ☛ 1 or 2 non-mainstream experiments (beauty, neutrino, ...)

☐ This guide-line has been endorsed by the SPC and constitutes:

– a broad and competitive programme fully exploiting the diverse physics opportunities of the LHC, while

– taking into account the inevitable limitations in manpower and financial resources, which exclude unnecessary duplication of experimental efforts.

☐ It is assumed that a possible electron-proton option will only be considered at a later stage and on the basis of the results of HERA.

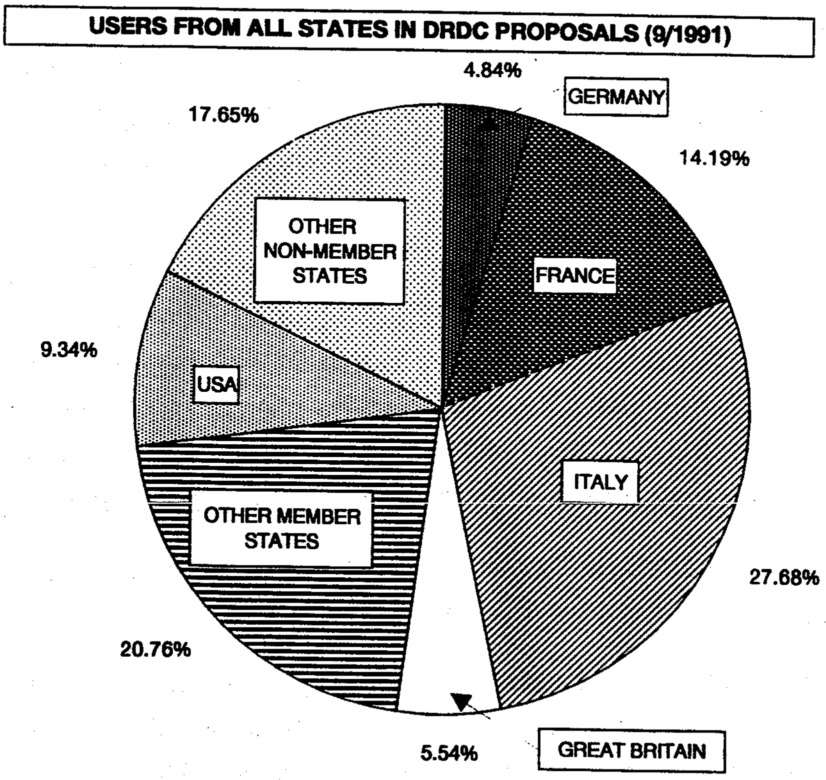
DRDC

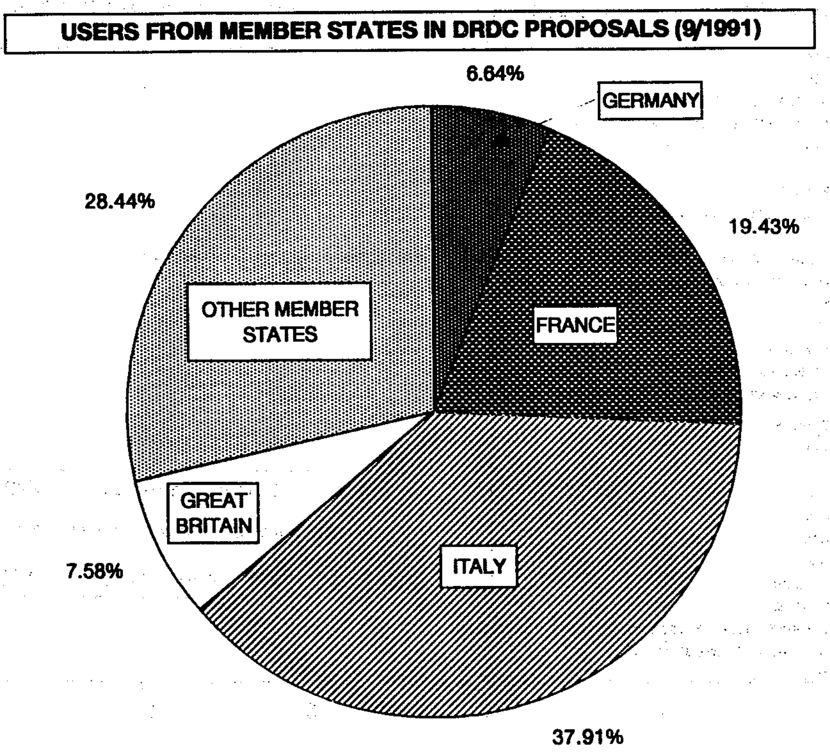
☐ With the LHC becoming a real project, the CERN management suggested at the beginning of 1990, to establish a Detector Research and Development Committee (DRDC). It was considered too early to move already then to the EOI stage, on the other hand it was clear that a significant amount of detector R&D had to be done and that it should be done in the most cost effective way. The DRDC was therefore asked to evaluate (peer review) R&D proposals, with the main emphasis on detector system development, stimulating collaboration and avoiding duplication of efforts.

☐ The enthusiasm in the physics community for exploiting LHC for physics can be measured by the large number of R&D proposals (35 up to now) involving about 1000 physicists (Member State and non-Member State partners). The Committee started to work under the chairmanship of Prof. E. Iarocci. So far 24 proposals have been approved and funded. CERN is spending about 3.5 MCHF a year and about a factor 2 more is spent outside CERN, corresponding to a total effort of about 10 MCHF/year for all DRDC related activities.

- The spirit in which these activities are organized is to cover all aspects of instrumentation in a LHC detector in a first approximation, irrespective of a link to a specific LHC (proto)-collaboration. This has actually worked out, as demonstrated by the EOI in Evian, which rely to a large extent on common R&D projects.
- It is important to encourage and continue a strong detector R&D programme in order to assure the success of a project as ambitious and complex as the LHC. The technical expertise embodied in the DRDC and the experimental responsibility of the future LHCC will have to be merged to maintain proper guidance for the development of the LHC, at least for the next few years. The DRDC will ~~therefore have to be involved in the choice of experimental projects.~~
- There is the risk that the "technology clock" will stop soon after the approval has crystallized proposals and this must be avoided.
- Before embarking in the mass production of the detector elements, the equivalent of the so-called "full string test" for the machine is necessary, with the corresponding need of large amount of test beams and R&D.

Number of Institutions in Proposals to DRDC by Country (NO DOUBLE COUNTING)





50. Users from Member States in DRDC proposals (September 1991).

E. IAROCCI

CONCLUSIONS

- PARTICIPATION IS INTENSE & ENTHUSIASTIC, PROGRESS IMPRESSIVE: MOST OF THE 1st YEAR GOALS HAVE BEEN ACHIEVED, IN SOME CASES FASTER OR BETTER THAN PLANNED
- SEVERAL NEW POWERFUL DETECTORS ARE ALREADY AVAILABLE FOR LESS DEMANDING APPLICATIONS
- HOWEVER FURTHER PROGRESS IS NEEDED FOR LHC
- VISIBLE INFLUENCE OF PROTOCOLLABORATION

  POSITIVE ASPECT: BETTER FOCUSSING ON REALISTIC GOALS

  NEGATIVE ASPECTS SHOULD BE MINIMIZED (A HOPE ...)

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GENERAL REMARKS

❐ The interest shown by the large number of participants at the Evian meeting and the impressive number of institutions indicating their interest in joining the experimental programme demonstrates that indeed the LHC is the right machine for the future of CERN.

❐ The physics case since Aachen has been confirmed and strengthened both on the theory front and on the feasibility front in all areas, as obvious for instance from the presentations of Expression of Interest:

☛ proton-proton

- ➥ complementarity, more than one detector,
- ➥ highest luminosity, how high?
- ➥ general purpose vs "specialized"
- ➥ matching detector vs.machine parameters (one bunch crossing ?)
- ➥ cost & construction time: evolutionary approach

SUMMARY OF EXPRESSIONS OF INTEREST

• **PP** :	a) Main Detectors	- ASCOT	P. Norton
		- CMS	M. Della Negra J.C. Lottin
		- EAGLE	P. Jenni
		- L3+1	S.C.C. Ting
	b) B Physics	- CP Violation in B (forward spectrometer in collider mode)	P. Schlein
		- CP Violation in B (extracted beam FT)	G. Carboni
		- CP violation in B (GAS JET FT)	T. Nakada
• **Heavy Ions** :		- Dedicated general purpose detector	J. Schukraft
		- DELPHI	G. Jarlskog
		- CMS	L. Ramello
• **Neutrinos** :			K. Winter
			L. Vannucci

☛ B physics :

- ➥ LHC is competitive and complementary to dedicated B factories
- ➥ how to extract the beam vs internal target option?
- ➥ it must be done (CP)

☛Heavy ions

- ➥ very fundamental physics (QCD & vacuum phase transitions: hydrogen atom vs solid state)
- ➥ LHC has a clear advantage over RHIC and SSC is not interested
- ➥ detector occupancy very high , but not so much higher than high luminosity pp + pileup
- ➥ low event rate, time-multiplexed data acquisition (TPC)
- ➥ Second generation studies with not so spectacular signatures: muons, strange particles, J/Ψ etc

❐ The large interest for the LHC programme can be judged by the impressive amount of work which was done in the past two years and by the open and frank discussions which followed each presentation. However, much work is still to be done to fully exploit the broad physics potential of LHC and to optimize resources. Let me offer some remarks on this subject:

☛ There is a need to confirm that there is an optimal match between the machine and the detectors.

☛ There is some lack of focus in the detector approach resulting in compromised detector performance. Generally speaking, lack of definition grows going from the outside to the inside:

- ➥ muon detection
- ➥ hadron calorimeter
- ➥ e.m. calorimeter
- ➥ tracking

☛ There is a need to optimize detector cost versus detector performance.

☛ a number of interesting ideas but need a lot of DRDC type of work. One cannot invest 50-100 MSF without accurate testing and pilot prototypes

☛ Can one do it all in less than two years ? When shall we

- ➥ be ready with a final design and give “approval” ?
- ➥ have the programme fully defined and prices known with precision ?

❐ Experiments will obviously be approved in the first place on their physics merits. However, financial considerations have to play an important role from the start and will be an important element in the approval process. An optimum has to be found for the ratio of physics potential to costs, with “de-scoping” iterations to be avoided.

❐ Evolutionary vs. “all the way” approach to the detector construction. Strong temptation in view of money constraints. Easy ("light"(<300 GeV)H^{o},Z',top) vs. second generation, sophisticated physics (heavy H^{o},$H^{\pm}$,strongly inter. W&Z, SUSY)

❐ While the size of the LHC detectors is partly dictated by the physics needs, big is not necessarily beautiful and “megalomania” should be suppressed.

Bergen 1992-02
Harvard-DAS-92/1

Theoretical Determination of the Masses of the Higgs Boson and the Top Quark in the Standard Model

Per Osland*
Department of Physics, University of Bergen, Allégt. 55
N-5007 Bergen, Norway

and

Tai Tsun Wu§
Gordon McKay Laboratory, Harvard University
Cambridge, Massachusetts 02138, U.S.A.

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ABSTRACT

By purely theoretical arguments involving the absence of certain divergences in the Standard Model, the masses of the Higgs and the top quark have been found to be

$$m_H = 190 \text{ GeV} \qquad \text{and} \qquad m_t = 120 \text{ GeV}.$$

This value of m_t is within the range favored by existing phenomelogy. The Higgs of this mass has a width of 1 GeV, with the major branching ratios of 77%, 22% and 1% into W^+W^-, ZZ and $b\bar{b}$, and is quite easy to detect at SSC and LHC even without enhanced luminosity.

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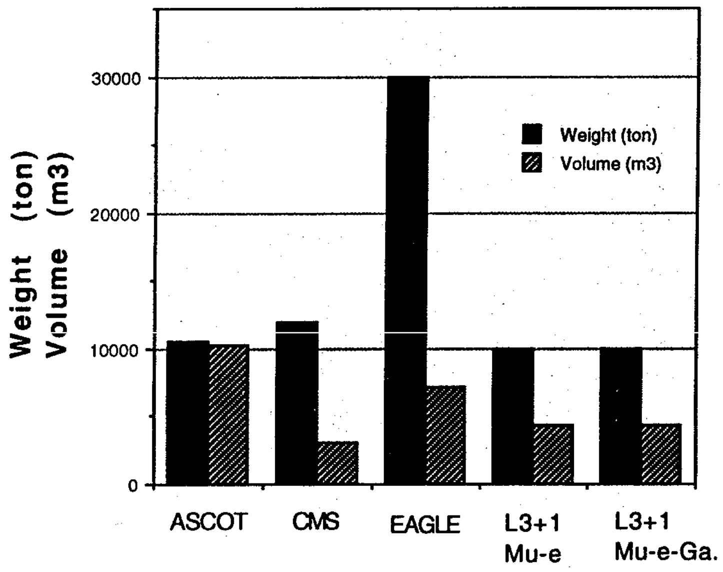
* Work supported in part by the Norwegian Research Council for Science and the Humanities.

§ Work supported in part by the U.S. Department of Energy under Grant DE-FG02-84ER40158.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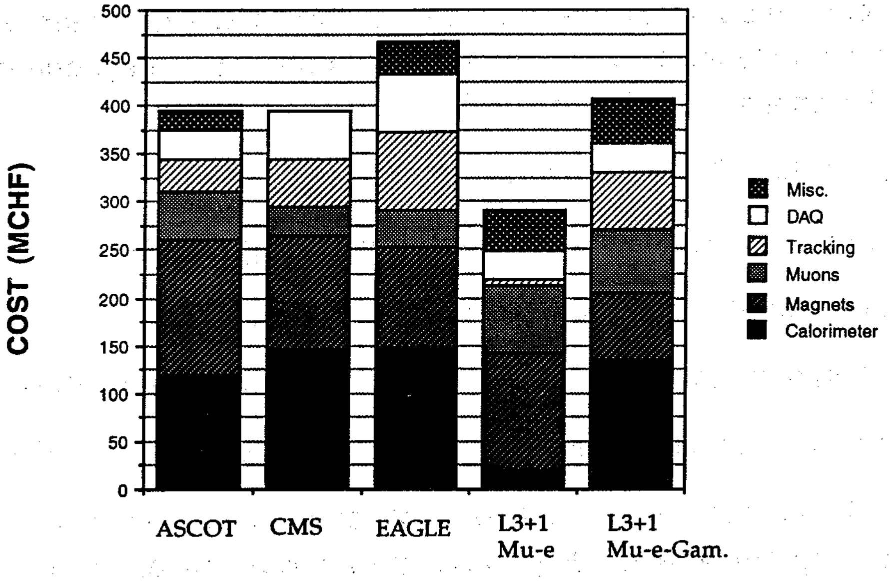
Mu-e-Ga.

LHC-EOI


COST (MCHF)
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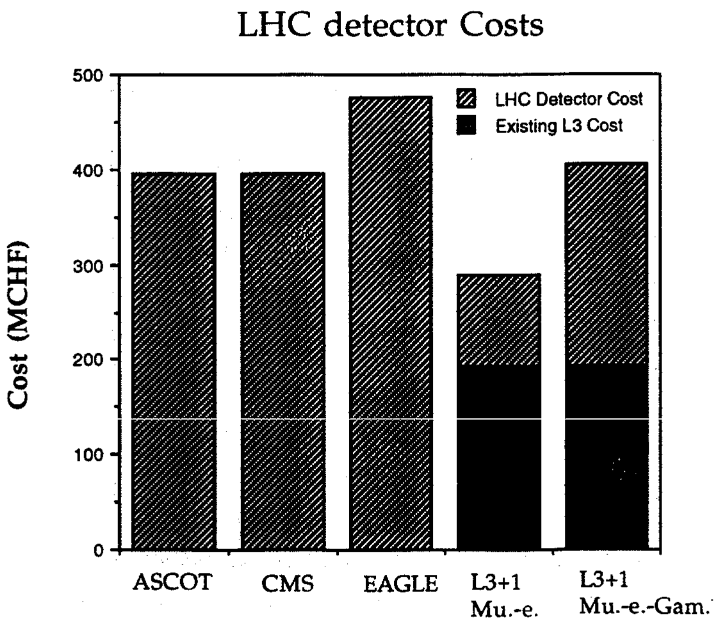


NEXT STEPS

☐ The process leading to the definition of the LHC experimental programme should be concluded by the end of 1993, in order to be synchronized with the intended formal approval of the LHC.

☐ This implies the following tentative timetable:

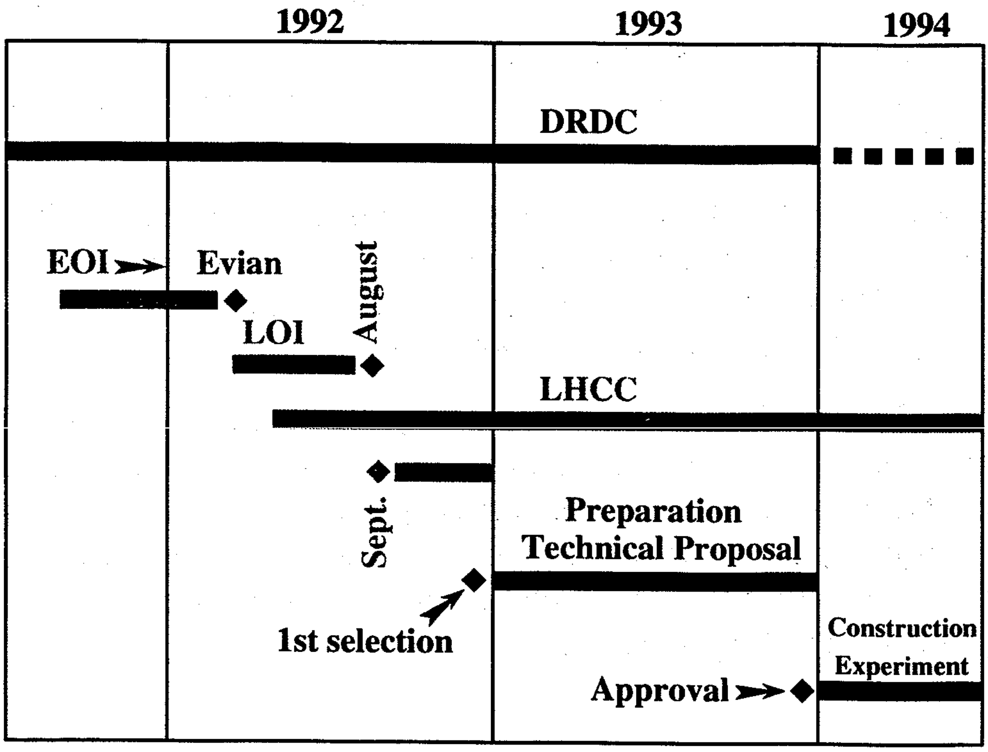
☛letters of intent (L.o.I.) to be submitted by 1 August 1992

☛open presentations of L.o.I. in September 1992

☛ selection of projects toward of a full technical proposal by the end of 1992

☛final approval of experiments by end of 1993, depending on Council decision

☐ An LHC Committee (LHCC) will be established in the next few months to organize this programme according to the standard practices of the CERN experimental committees.



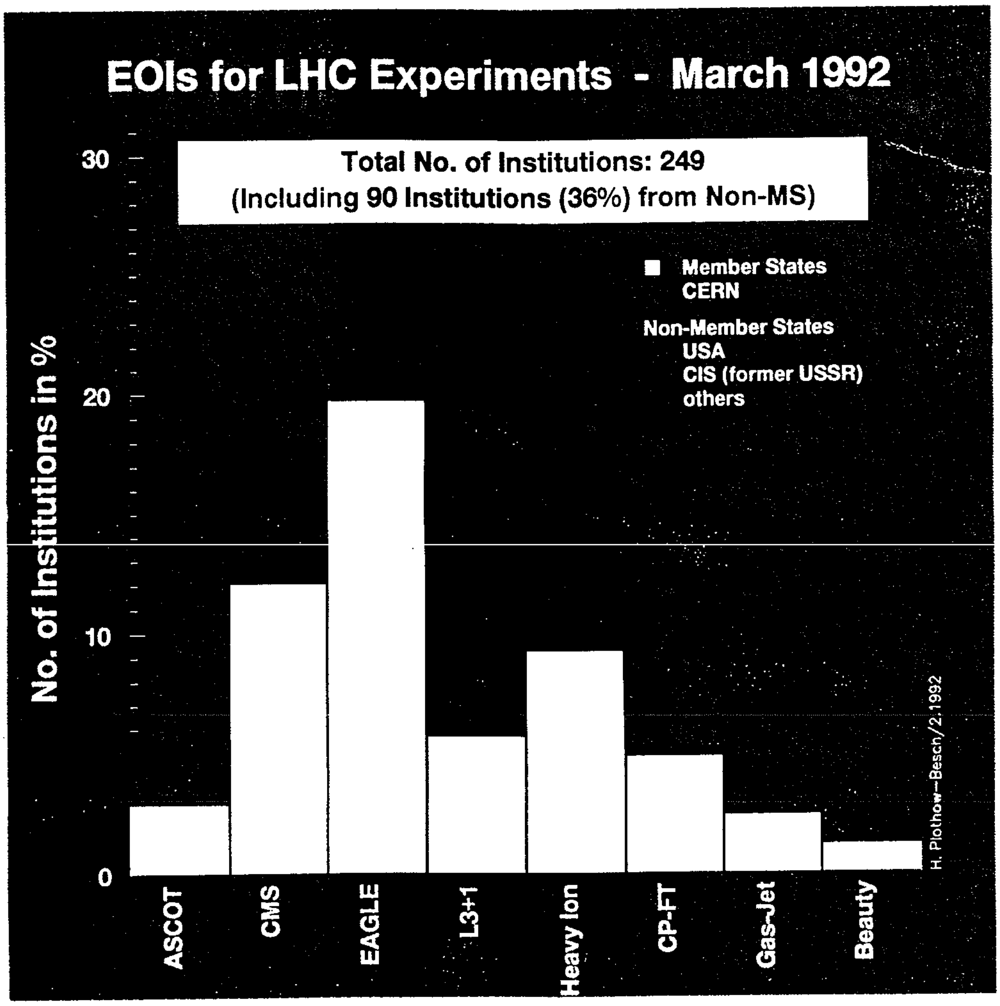
☐ The approval procedure for experiments is not "scale invariant". A 400 MSF project cannot follow the same procedure for say, a 400 kSF experiment. The CERN Management, National Laboratories and Funding Agencies must actively participate in the process. But the Management will try to preserve the peer review mechanism that we are accustomed to in our field.

NON MEMBER STATES PARTICIPATION

- The LHC will be a unique facility offered by CERN to the particle physics community and it is confirmed that indeed the LHC is the right machine for the future of CERN.
- It is good to see that the enthusiasm for the LHC extends, as is the case for other elements of the CERN programme, to a large number of groups from non-Member States. The LHC will therefore continue CERN's tradition of offering frontline facilities to a large world-wide community.
- The LHC will be CERN's most ambitious project requiring an unparalleled effort in both the realization of the machine and, together with the users, of the detectors. It is obvious that in providing these physics opportunities CERN is expecting the many non-Member States intending to participate in the LHC programme to make a substantial effort in making the project feasible thus assuming their responsibility in making the LHC a success.

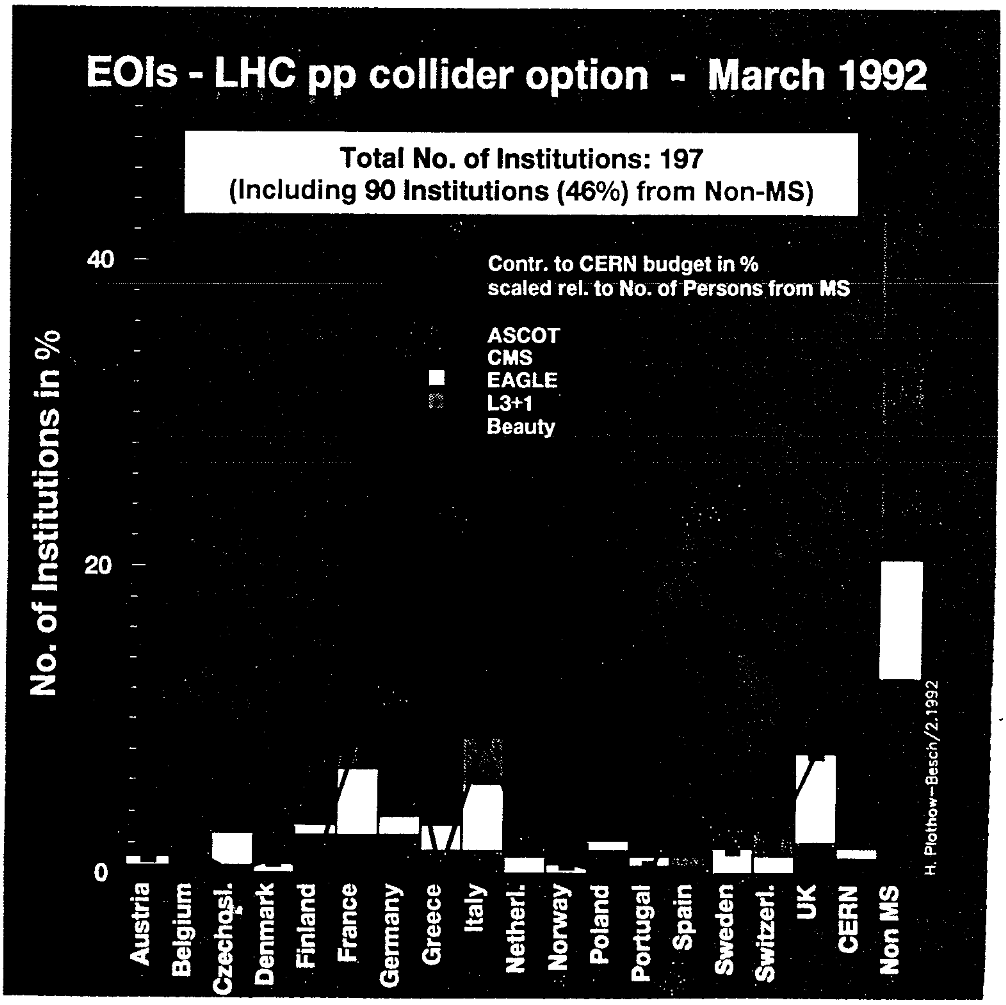
CONCLUSION

- LHC is a project of a new magnitude for CERN and for the entire international High Energy Physics community.
- The CERN management has to be closely associated not only to the construction of the facility (the LHC accelerator complex) but also to the experimental programme. At the same time it is important to preserve the peer review mechanism that we are accustomed to in our field.
- The LHC programme has an extraordinary scientific potential. It is very much a project for the young generation of physicists which will certainly find in LHC a tremendous challenge and a new frontier.



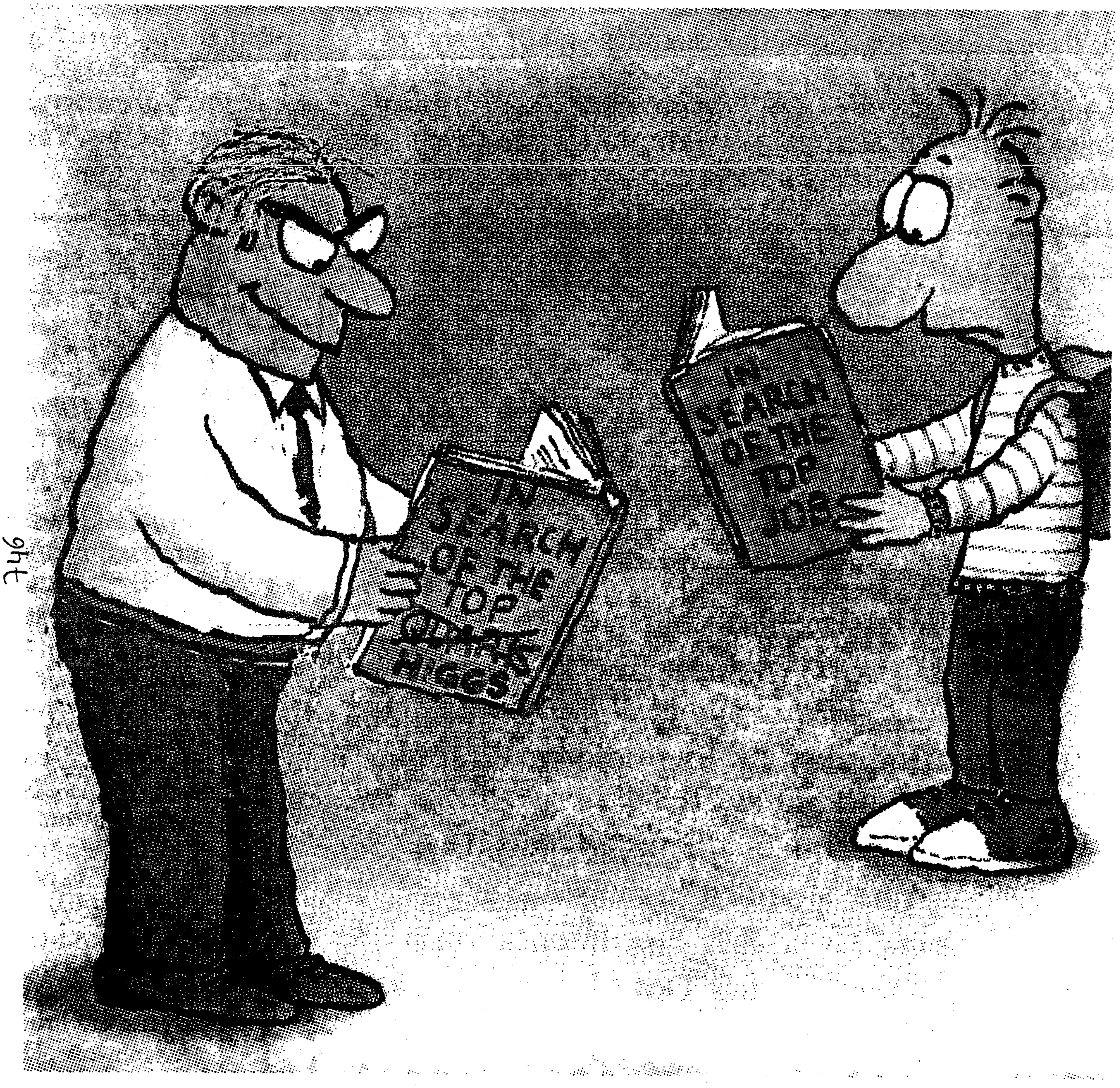
EOIs for LHC Experiments - March 1992

Total No. of Institutions: 249
(Including 90 Institutions (36%) from Non-MS)



EOIs - LHC pp collider option - March 1992

Total No. of Institutions: 197
(Including 90 Institutions (46%) from Non-MS)


IN SEARCH OF THE TOP QUARKS HIGGS
IN SEARCH OF THE TOP JOBS

Expressions of Interest not presented at the meeting

Physics with a jet target at LHC

Low p_t physics at the LHC

Total cross section, elastic scattering and diffraction association at LHC

Expression of Interest
PHYSICS WITH A JET TARGET AT LHC

Bonn[1] - CERN - Ferrara[2] - Geneva - Lausanne - Milano[2] -
Prague[3] - Torino[2] - Trieste[2] - Virginia - Yerevan

A gas jet – target apparatus (H_2, D_2 or higher-Z molecular cluster jet and atomic H, D polarized beam jet [1]) is under development by the HELP Collaboration [2], in the perspective of installing such a target in the LEP tunnel. A preliminary feasibility study of an installation compatible both for LEP and LHC operation of the jet target apparatus has been outlined [3].

In conjunction with LHC, the jet target would represent a relatively simple and inexpensive method of performing fixed - target physics at C.M. energies of 123 GeV and luminosities up to 10^{34}cm^{-2}s^{-1}, with cluster jet (unpolarized) and 10^{32}cm^{-2}s^{-1}, with (polarized) atomic beam target.

The jet target provides a practically point-like source, without effects of secondary interactions, thus allowing efficient triggering and pattern reconstruction of the events. In the case of polarized targets, even more significant advantages are:

- high degree of polarization (>90 %) for pure H or D target nuclei;
- easy orientation and frequent reversal of the target polarization.

We would like to exploit this apparatus at LHC for studing the dynamical role of spin in the hard inclusive production of (heavy flavour) hadrons and photons, dimuons and heavy quarkonia. The main motivations in our view are:

- contrary to expectations, spin effects have been shown to remain important at the highest energies and transverse momenta recently measured; will such effects survive at energies up to 8 TeV ?
- the partonic spin composition of the proton is still intensely debated;
- the role of transverse spin at the constituent's level has been recognized to be important.

The new regime accessible with LHC - very high energy and large transverse momenta (owing to the high luminosity) - and the superior quality of the jet as polarized target, give a novel possibility to study polarization phenomena in hard processes involving not only the light flavours, but also sufficiently large yields of heavy flavours (c and b) to be statistically significant for high precision polarization studies. By orienting the polarization of the target in the longitudinal direction, studies of parity violating effects could be performed.

The technique of the jet - target, and its use in a storage ring, with a full compatibility with collider operation, have already been established at Sp$\bar{p}$S, by the UA6 Collaboration; based on this experience the conceptual design for the LHC apparatus relies on the following points:

- the target assembly will comprise a special beam pipe section, to minimize obstructions for particles emitted from the target over a large solid angle;
- a magnetic spectrometer with successive stages of superconducting magnets, up to approximately 100 m from the target, with an acceptance ranging from 2 mrad up to 100 mrad, in order to cover almost the full C.M. solid angle.

The spectrometer will be instrumented with high-resolution, fast tracking detectors; some of these will be contained in special insertions of the vacuum chamber, in order to cover the smallest angles *.

Besides particle identification, a distinct role will be played by E-M calorimeters and principally by active muon filters; owing to their modest size, these detectors can be finely segmented at moderate cost. Identification and tracking of muons would provide a powerful event selection method in the high-rate, high-multiplicity LHC environment.

With unpolarized cluster jet target, very high luminosities can be reached; in this case the muon signature becomes essential in order to achieve a high sensitivity for rare or new effects.

[1] L. Dick and W. Kubischta, CERN - EP / 88 - 135 (1988).
G. Arduini et al., *Polarized gas jet target developement at CERN.* To appear in Proc. of Workshop on Polarized Gas Targets for Storage Rings, MPI Heidelberg 23-26 Sept 1991.

[2] HELP Collaboration (CERN - Ferrara - Lausanne - Milano - Trieste - Yerevan), CERN/LEPC 88-16 (LEPC/I9) (1988) and CERN/LEPC 89-10 (LEPC/M88) (1989).

[3] H. Laporte, *Faisibilité d'une zone souterraine au Point 5 pour l'experience "Jet Target"*, Memorandum CERN-LEP-GC/HL/200 (28 april 1989).

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[1] SKP Bonn, [2] INFN and Dipartimento di Fisica, [3] Charles University.

* Members of the HELP collaboration are engaged in the development of large-area silicon drift devices and fine - grain scintillating fiber hodoscopes, that seem very promising for high spatial resolution and high rate capability; anyvay, the small (lab) solid angle subtended by the spectrometer,would afford the most appropriate status-of-the-art equipment (within the time scale of LHC).

LOW p_t PHYSICS AT THE LHC

An Expression of Interest

Contact Person: M.R. Mondardini, Cornell University

R. DeSalvo, M. Lundin - CERN/LAA
C. Avila, M.R. Mondardini, J. Orear - Cornell University
N.A. Amos, S. Shukla, S. Pruss - FERMILAB
J. Bai, H.He, L.Liu, K. Wang, X. Xia, C. Yang, M. Zhao - World Lab

Abstract

Experimental systems and detectors are proposed which can measure

- small angle elastic scattering into the coulomb region;
- large angle elastic scattering;
- single diffraction dissociation;
- other small angle processes which would be missed by a typical 4π detector.

The small angle elastic scattering is used via the optical theorem to obtain σ_{tot} and the ρ value. Requirements on accelerator design are discussed.

Expression of Interest

Total Cross Section, Elastic Scattering and Diffraction Dissociation at LHC

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We wish to express our interest to perform the following measurements at LHC.

Elastic Scattering. Elastic scattering events will be observed with high-resolution detectors placed inside "Roman pots" in an insertion having high-value of β, the betatron function at the crossing point. This technique was pioneered at the CERN ISR many years ago and then successfully employed at the $S\bar{p}pS$ Collider by experiment UA4 and at Fermilab by experiment E710. The extrapolation to the LHC from present Collider energies was already discussed in some detail in the LHC Workshops [1,2].

We plan to make use of a "mini" version of the standard "Roman pots" with scintillating fibers, silicon pixels or gaseous microstrips. These detectors have already sufficient spatial resolution. The choice will be imposed by the requirement of radiation hardness and operational reliability. One has in fact to keep in mind that the detectors for this experiment must be operated very close (distance of the order of 1 mm) to an intense proton beam.

The basic requirements on the high-β insertion were defined at the Aachen Workshop [2] and recently discussed at the Experimental Requirement Committee [3]. We expect that an insertion with $\beta = 1 \div 2\ km$ should be suitable to detect elastic scattering down to a momentum transfer squared $-t = 5.10^{-3} GeV^2$. A first study of a high-β insertion with $\beta = 750m$ was presented at the Aachen Workshop [4]. In order to measure elastic scattering in the Coulomb interference region, an insertion with higher β is needed. The β of the insertion should be tunable, the high-β mode allowing detection of low-t events with low luminosity and the medium or low-β mode of large-t events with high luminosity.

Total Cross Section. The total cross section will be obtained with the so called luminosity independent method, i.e. by a simultaneous measurement of elastic scattering at low-t and of the rate of the inelastic interactions. With minimum momentum transfer of $5.10^{-3}GeV^2$, assuming a forward slope $b \approx 20GeV^{-2}$, the extrapolation to the optical point will be of only 10%. As discussed in ref. 2, the measurement of the inelastic rate should be done with a vertex detector which observes charged tracks and reconstructs the interaction point. Extrapolating from UA4[5] and E710[6] to LHC, one finds that the coverage of the vertex detector should be at least three pseudorapidity units (from 6 to 9), corresponding to production angles in the range from 0.25 mrad up to about 6 mrad.

In practice the design of the detectors to measure the inelastic rate will follow the final design of the insertion itself.

The error on the measurement of σ_{tot} could be of $2 - 3\%$. Because the LHC beams cross each other at an angle, the feasibility of implementing the Van der Meer method to measure the luminosity as at the ISR, is worth studying. The measurement of σ_{tot} would be considerably simplified.

Diffraction Dissociation. We plan to study the process $pp \rightarrow pX$ by detecting the proton scattered quasi-elastically with the "Roman pots" and measuring the decay products of the system X in a vertex detector. The mass distribution of X will be measured together with the pseudorapidity distribution of its decay products.

Diffraction dissociation was extensively studied at the ISR and at the $S\bar{p}pS$ Collider by UA4 and UA8. It has a substantial cross section, $\sigma_{SD} \approx 0.2\ \sigma_{inel}$, but the basic mechanism and its connection with elastic scattering still remain rather obscure today.

Very Forward Particle Production. The centre-of-mass energy of the LHC is equivalent to $1.4 * 10^{17}\ eV$ incident $p-p$ interaction, which corresponds to the high energy tail of the cosmic ray spectra. The cosmic ray experiments are mostly sensitive to particles produced very forward. As shown by UA7 [7], the measurement in an accelerator experiment of the particles produced at $y \approx y_{beam}$, is useful to fix the energy scale for the cosmic ray experiments allowing a much better understanding of the production mechanism. In addition the amount of scaling violation in the rapidity distribution in the forward region can be measured. We then propose to install in the "Roman pots" at the LHC small calorimeters to measure particle production, in particular photons and electrons at very small angles.

References.

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