Evaluation der Verbundforschung an der RWTH Aachen

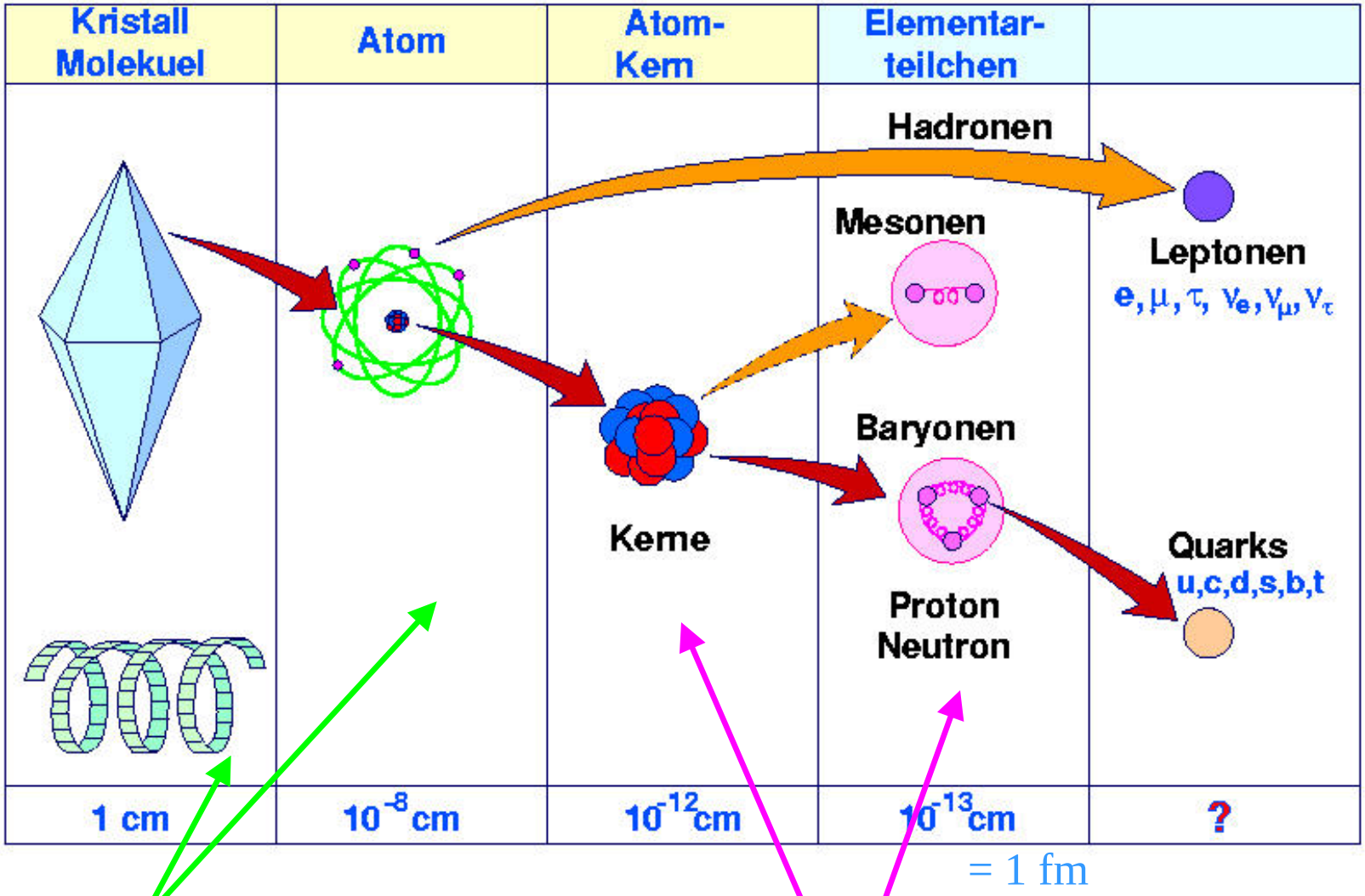
Förderung der Elementarteilchen-Physik durch das BMBF

Überblick über die Forschungsschwerpunkte

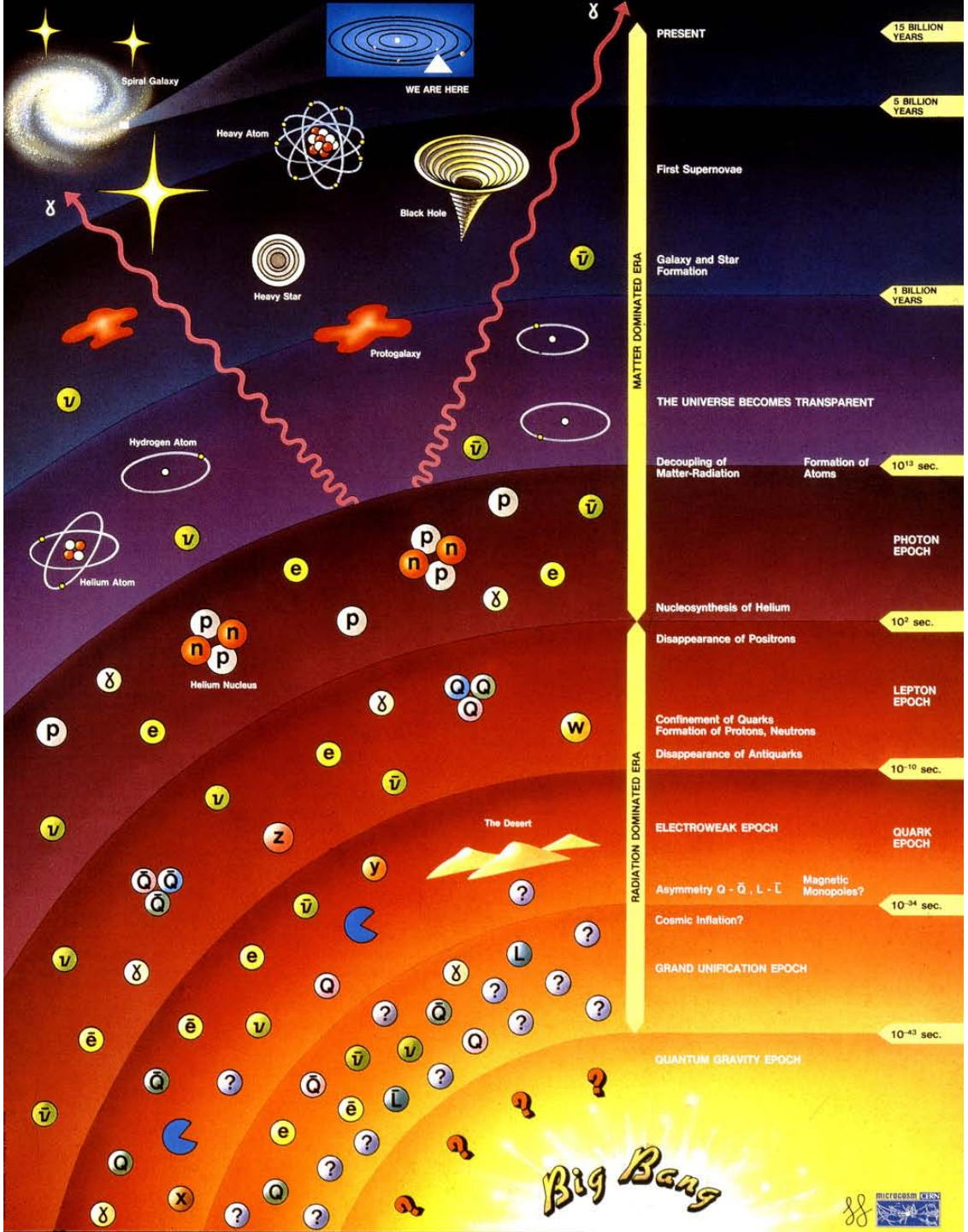
G. Flügge

Aachen, den 3. März 2004

Die Struktur der Materie



Teilchenphysik und Astrophysik



Dunkle Materie =
Neue Teilchen ?
(Supersymmetrie)

Dunkle Energie ?

Materie- Antimaterie-
Asymmetrie ?

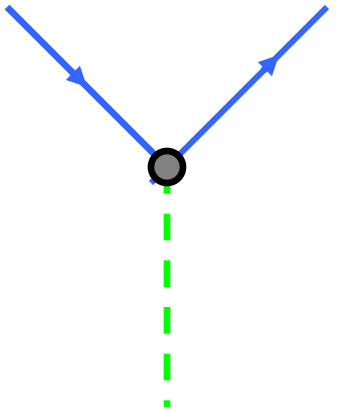
Teilchenbeschleuniger
untersuchen Prozesse
10^{-10}s nach dem Urknall

(1) Das Standardmodell der Teilchenphysik

Materie: Spin ½ - Fermionen:

Leptonen: $\begin{pmatrix} \nu_e \\ e \end{pmatrix}$ $\begin{pmatrix} \nu_\mu \\ \mu \end{pmatrix}$ $\begin{pmatrix} \nu_\tau \\ \tau \end{pmatrix}$

Quarks: $\begin{pmatrix} u\,u\,u \\ d\,d\,d \end{pmatrix}$ $\begin{pmatrix} c\,c\,c \\ s\,s\,s \end{pmatrix}$ $\begin{pmatrix} t\,t\,t \\ b\,b\,b \end{pmatrix}$



Wechselwirkungen: Spin 1 – Eichbosonen:

elektroschwach:

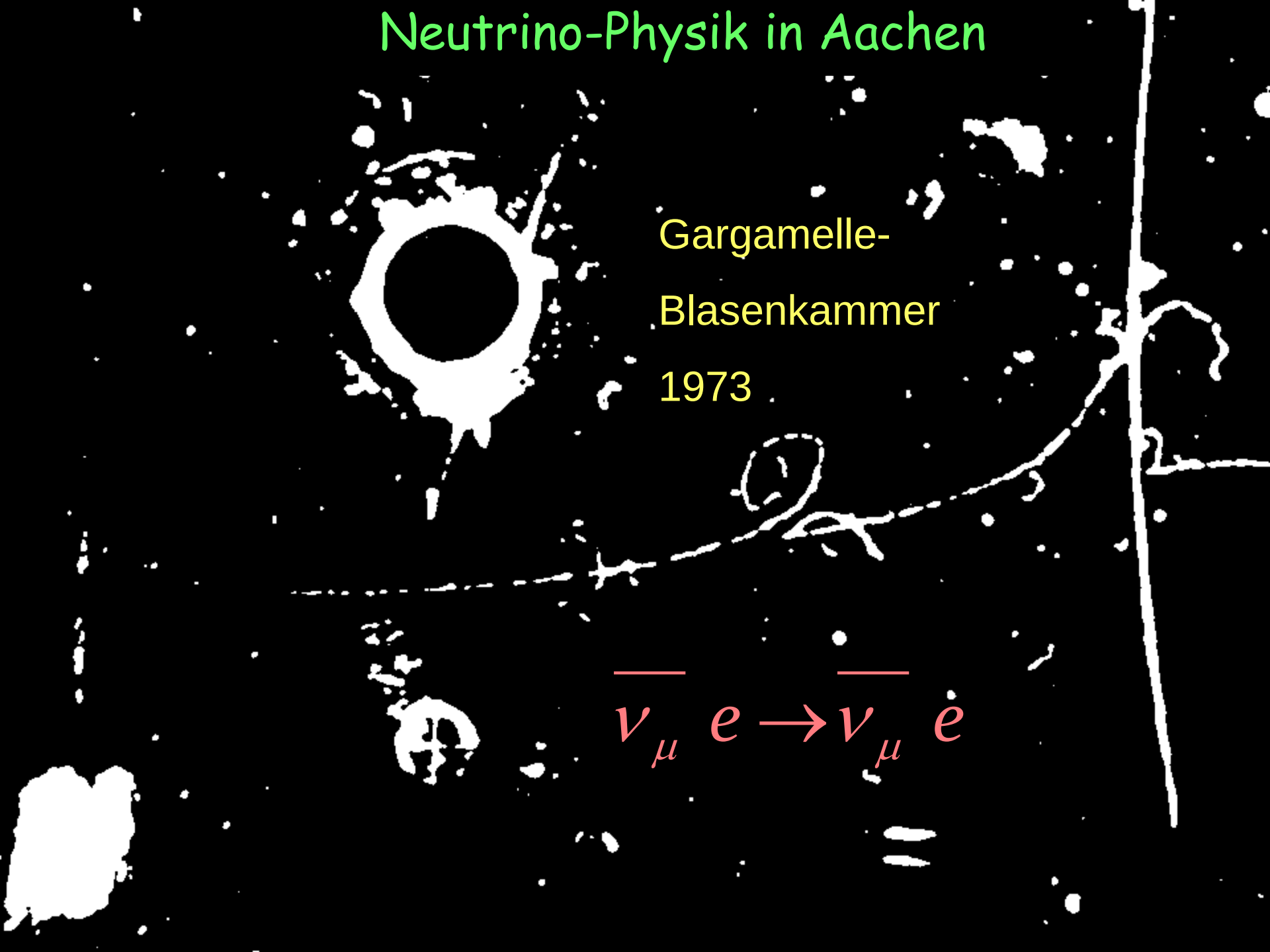
Photon	γ	masselos
Z-Boson	Z	91 GeV
W-Boson	W^+ W^-	80 GeV

stark:

Gluon	g	masselos

(Fast) alle experimentellen Daten werden akkurat beschrieben!

Neutrino-Physik in Aachen



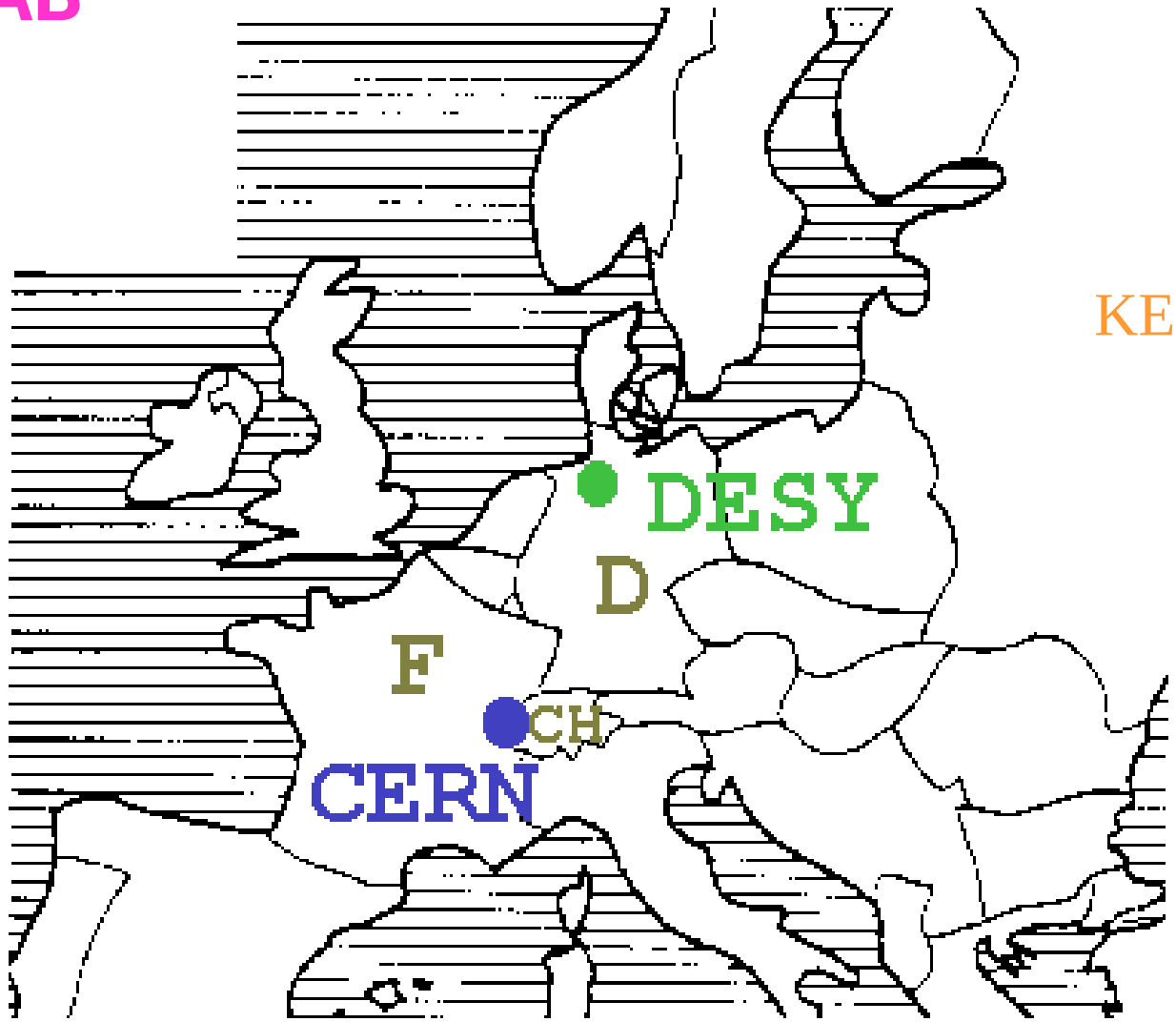
Gargamelle-Blasenkammer 1973

$$\overline{\nu}_\mu \; e \rightarrow \overline{\nu}_\mu \; e$$

Forschungszentren

FERMILAB (USA)

SLAC (USA)



KEK (Japan)

Experimentelle Elementarteilchenphysik Aachen

Institute, Projektleiter:

- **I. Phys. Inst. B**
  - Prof. S. Schael
  - Prof. C. Berger
- **III. Phys. Inst. A**
  - Prof. T. Hebbeker
  - Prof. A. Böhm
- **III. Phys. Inst. B**
  - Prof. G. Flügge
  - Prof. J. Mnich

~ 50 Physiker/innen

~ 20 Diplomanden/innen

~ 30 Ing./Techniker/innen

Experimentelle Elementarteilchenphysik Aachen

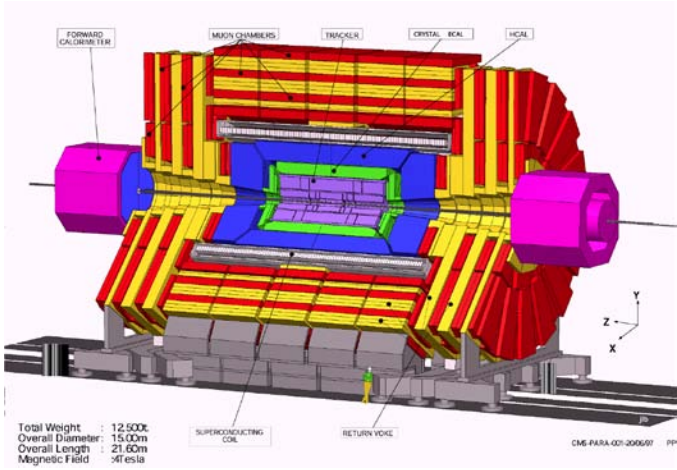
Projekte:

- Elektron-Positron-Speicherring LEP/CERN
  Experimente ALEPH (Schael), L3 (Böhm, Mnich)
- Elektron-Proton-Ring HERA/DESY
  H1-Experiment (Berger, Flügge)
- Proton-Proton-Collider LHC/CERN
  CMS-Exp. (Böhm, Flügge, Hebbeker, Mnich, Schael)
- Proton-Antiproton-ColliderTevatron/Fermilab
  D0-Experiment (Hebbeker)
- Elektron-Linearbeschleuniger TESLA (Mnich)
- AMS-Exp. auf der ISS *(Int. Space Stat.)* (Flügge, Schael)

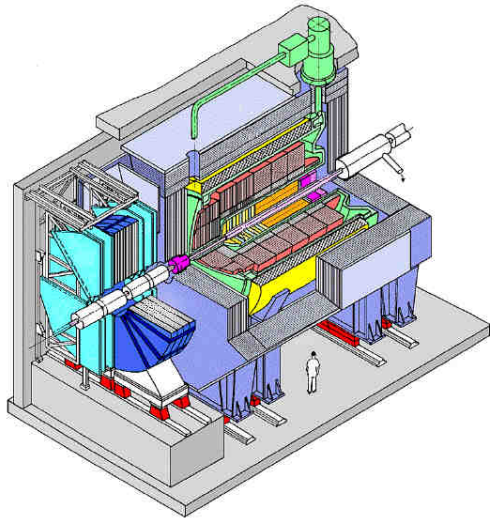
Forschungsschwerpunkt Elementarteilchenphysik an der RWTH Aachen

I. Physikalisches Institut

Lehrstuhl IA:
Prof. Dr. Stefan Schael
CMS-Experiment, CERN, Genf
AMS-Experiment, ISS im Weltraum



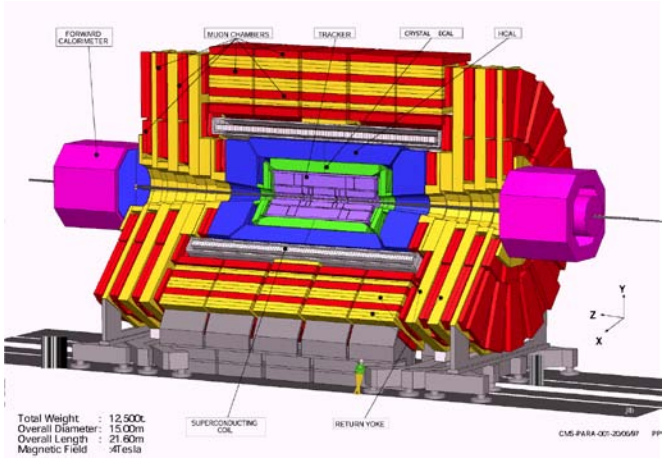
Prof. Dr. Ch. Berger
H1-Experiment, DESY-Hamburg



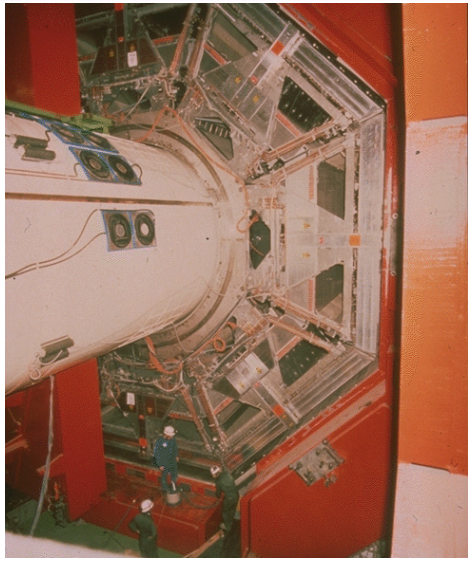
Forschungsschwerpunkt Elementarteilchenphysik an der RWTH Aachen

III. Physikalisches Institut

Lehrstuhl IIIA:
Prof. Dr. Th. Hebbeker
CMS-Experiment, CERN, Genf
D0-Experiment, Fermilab, Chicago



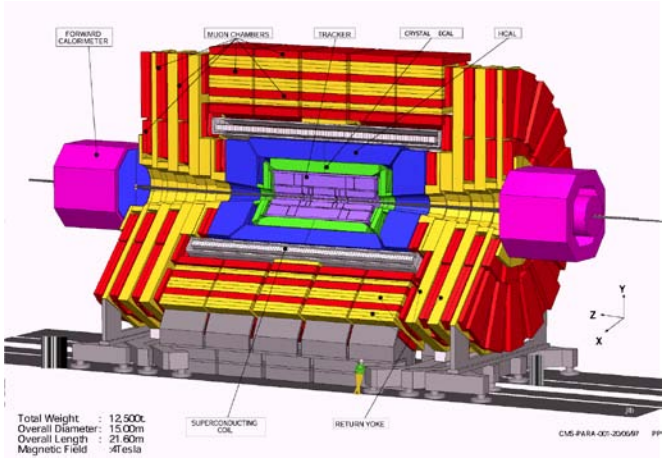
Prof. Dr. A. Böhm
L3-Experiment, CERN-Genf



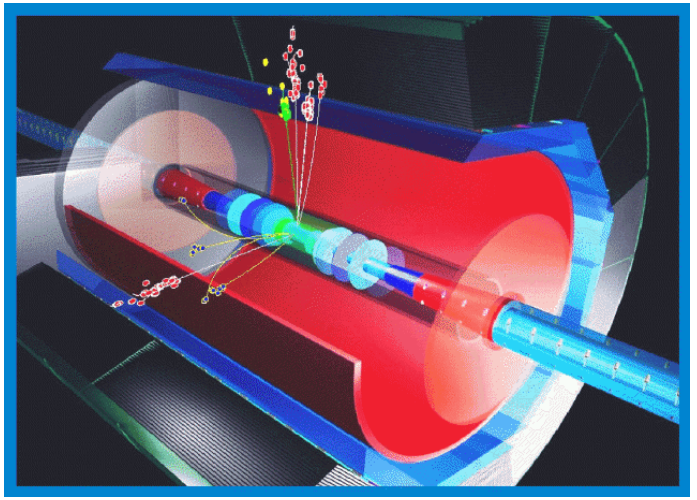
Forschungsschwerpunkt Elementarteilchenphysik an der RWTH Aachen

III. Physikalisches Institut

Lehrstuhl IIIB:
Prof. Dr. G. Flügge
CMS-Experiment, CERN, Genf



Prof. Dr. J. Mnich
CMS-Experiment, CERN-Genf
TESLA-Projekt, DESY-Hamburg



HERA am Deutschen Elektronen-Synchrotron (DESY) in Hamburg:

HERA (DESY): p (900 GeV) + e (30 GeV)

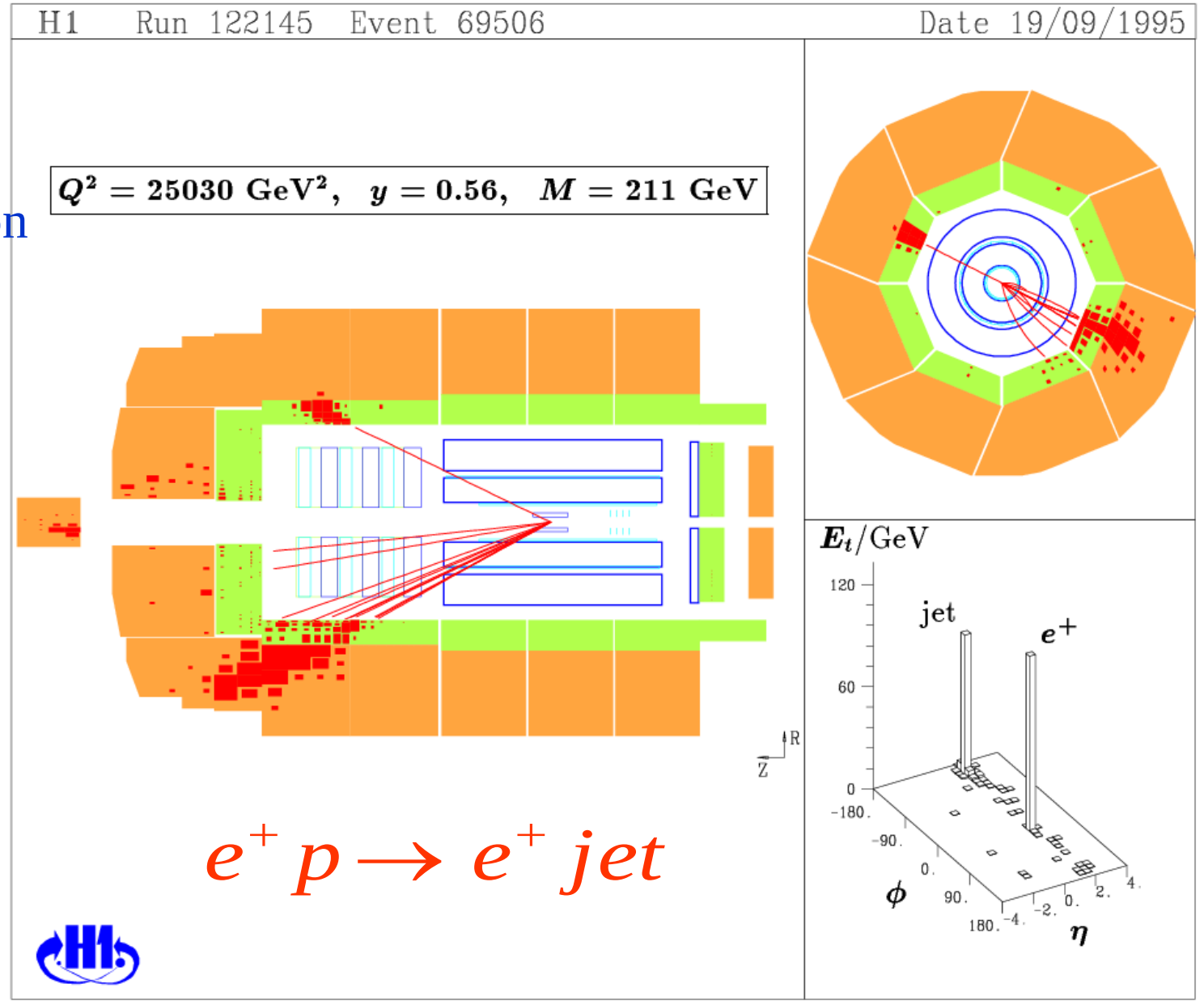
H1-Experiment bei HERA/DESY

Physik:

- Struktur Proton
- starke WW
- neue Teilchen
- ...

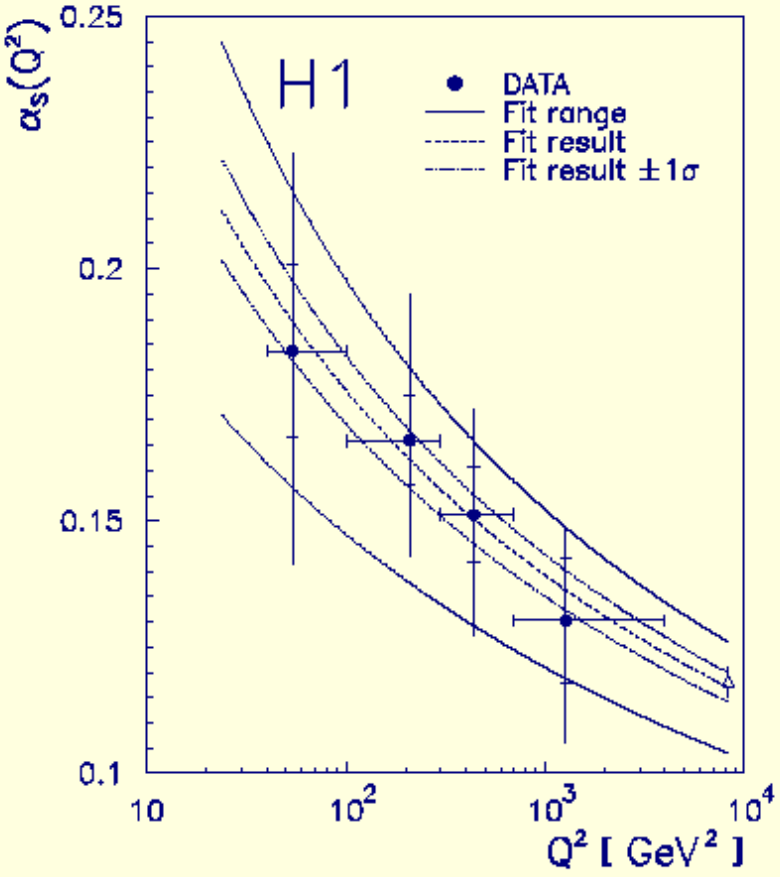
Aachen:

Datenanalyse



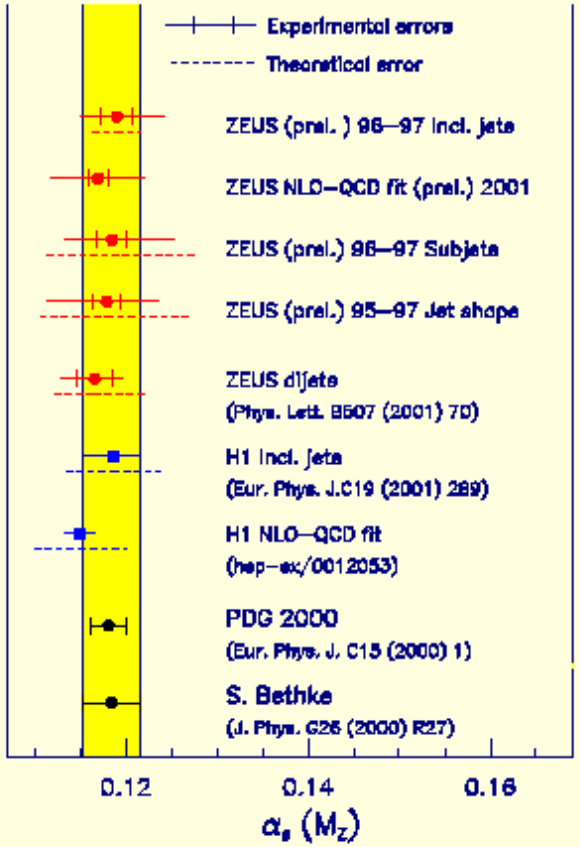
Analysen – QCD: Jets und α_s

1997-1998:



"Running" von α_s in einem Experiment!

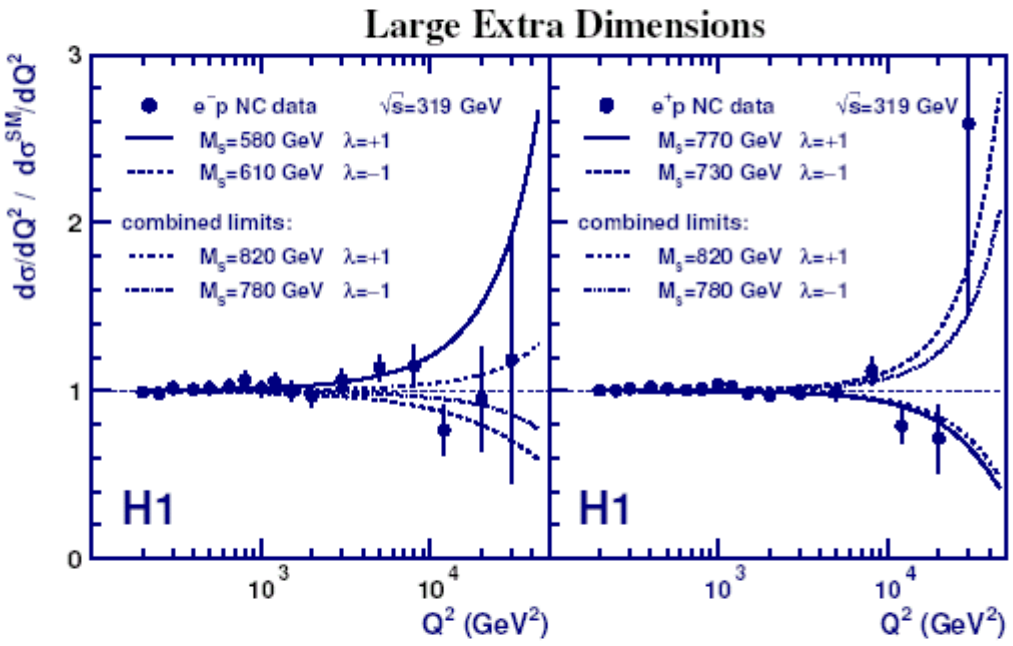
heute: HERA α_s Resultate:



Kompatibel mit Weltmittelwert in Betrag und Fehler!

Analysen – SEARCH: "Contact" Wechselwirkungen

Parametrisierung von "extra Dimensionen" durch effektiven Term



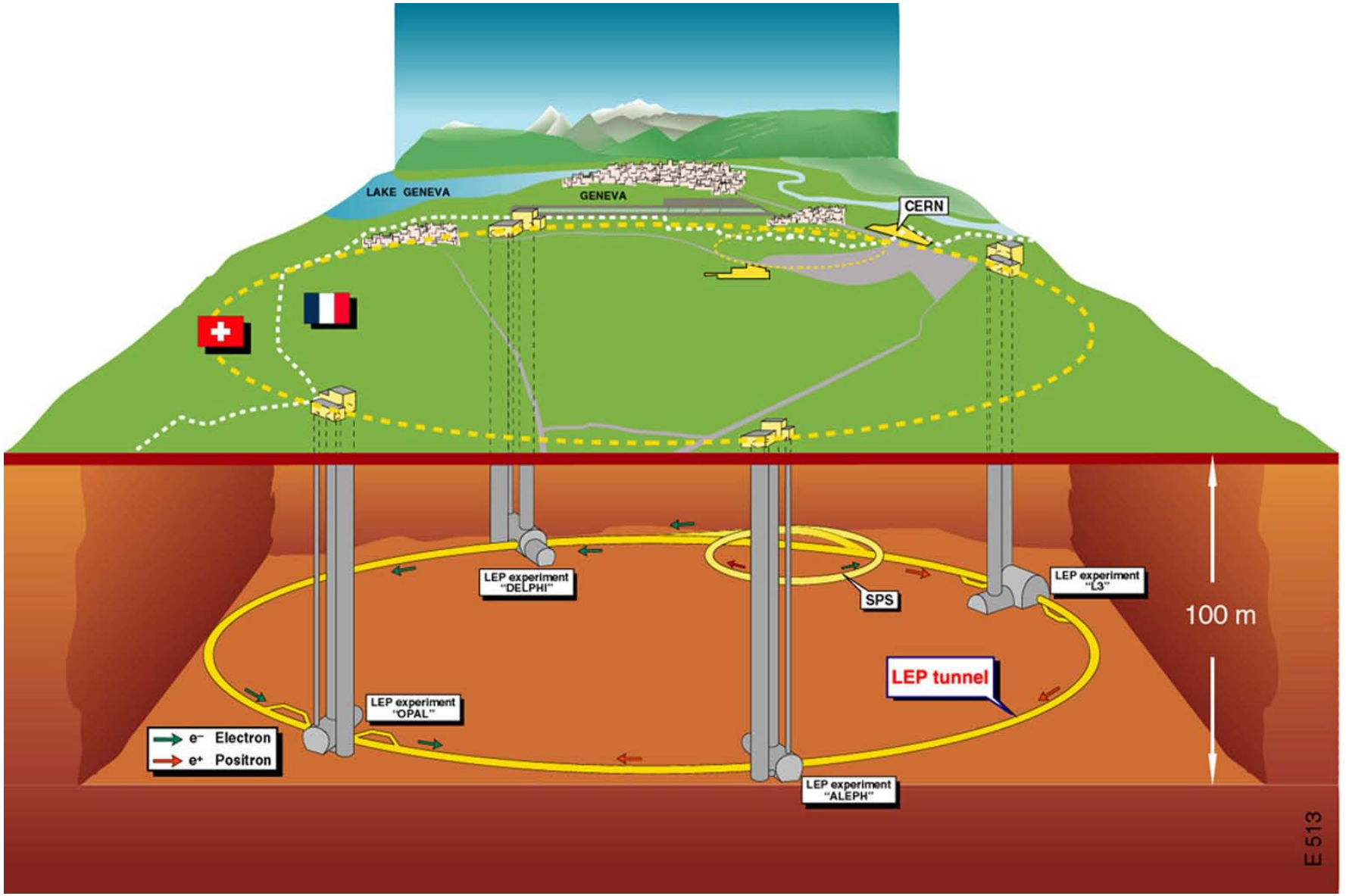
Suche nach Abweichungen bei hohen Impulsüberträgen:

- Neue Dimensionen
- Substrukturen
- Leptoquarks
- .....

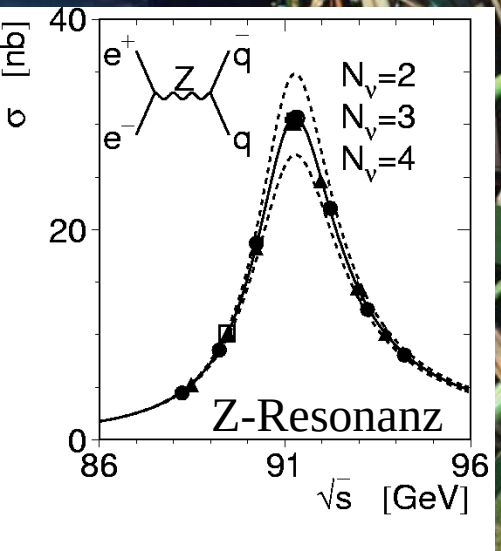
$\Rightarrow$ CI, LQ, "extra Dimension" Limits bei $\Lambda^{+-} \approx$ 1-5 TeV

$\Rightarrow$ Quark Radius $< 10^{-18}$ m

Elektron-Positron-Teilchenbeschleuniger LEP am CERN

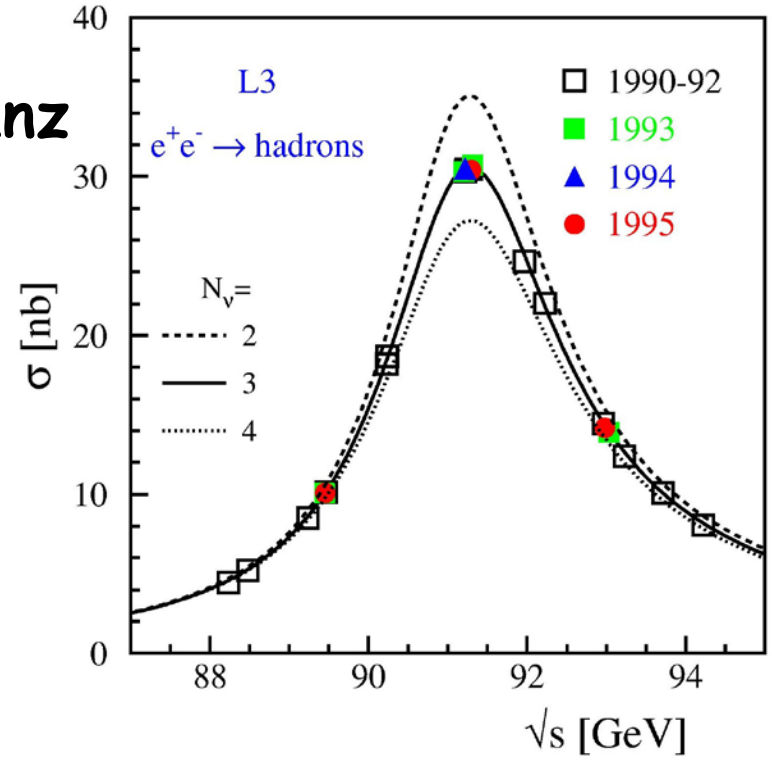


LEP-Detektor L3



Die Z-Resonanz

LEP-Ergebnisse von der Z-Resonanz



Masse

$m_Z = 91.1875 \pm 0.0021$ GeV

Breite

$\Gamma_Z = 2.4952 \pm 0.0023$ GeV

Höhe

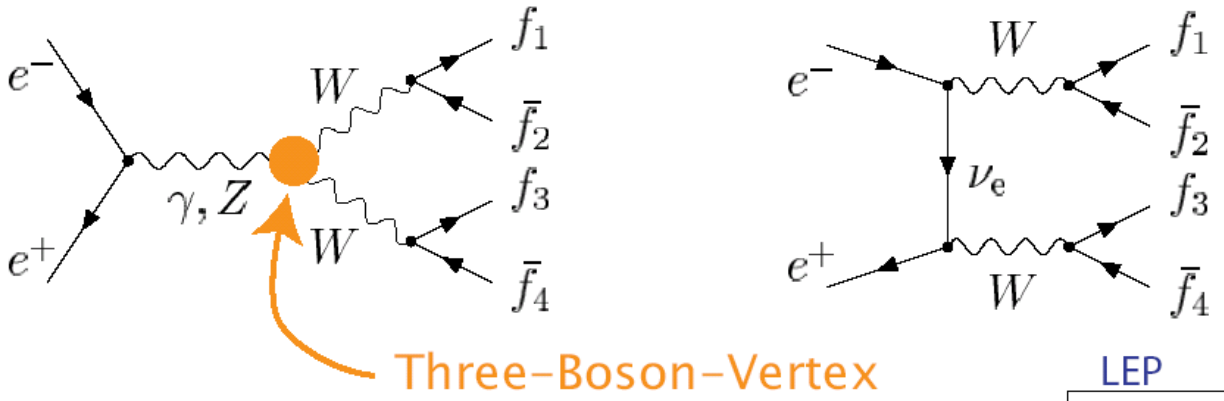
$\sigma^0_{had} = 41.540 \pm 0.037$ nb

$\Delta m_Z / m_Z = \pm 2.3 \cdot 10^{-5}$

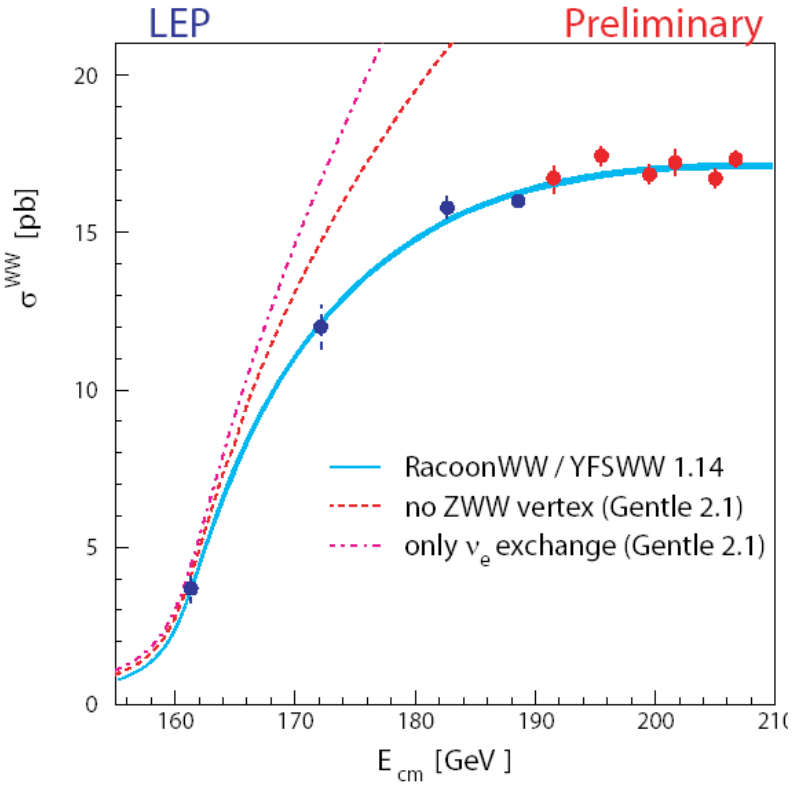
Zahl der Neutrino-Familien:

$N_\nu = 2.9841 \pm 0.0083$

Erzeugung von W-Paaren



Einzelbeiträge vom
ν, γ und Z Austausch divergent!



W-Paar-Ereignisse

$e^+ e^- \rightarrow qq\,qq$

- vier hadronische Jets
- balanciertes Ereignis

Anteil 46 %
Effizienz ≈ 85 %
Reinheit ≈ 85 %

$e^+ e^- \rightarrow qq\,l\nu$

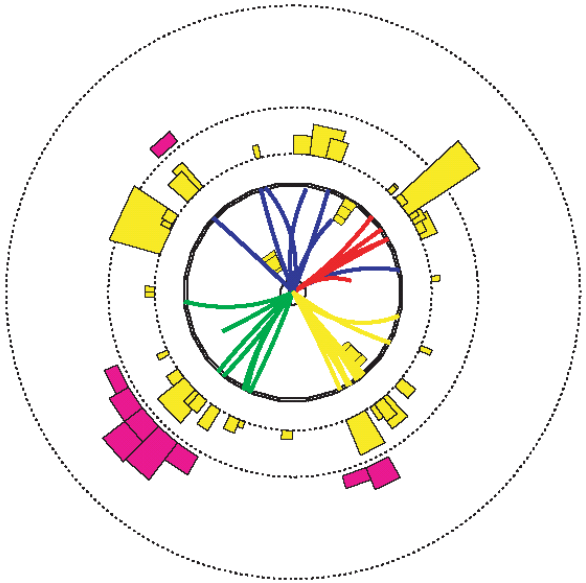
- 2 Jets und 1 Lepton
- fehlende Energie

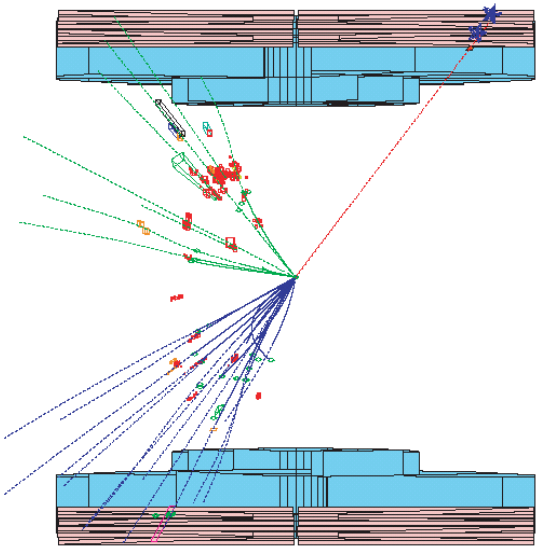
Anteil 44 %
Effizienz ≈ 70%
Reinheit ≈ 95 %

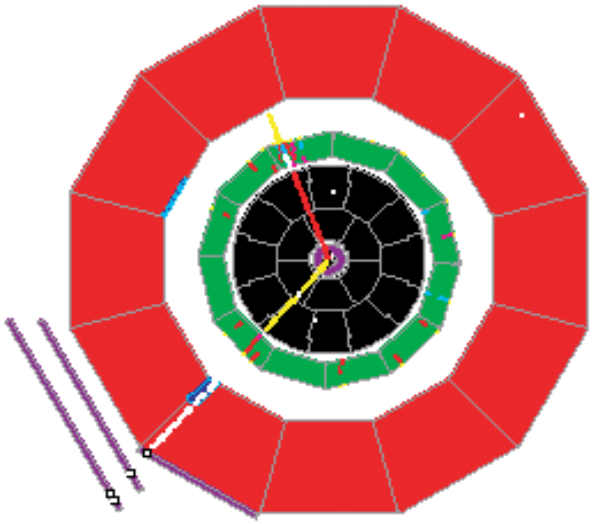
$e^+ e^- \rightarrow l\nu\,l\nu$

- zwei Leptonen
- fehlende Energie

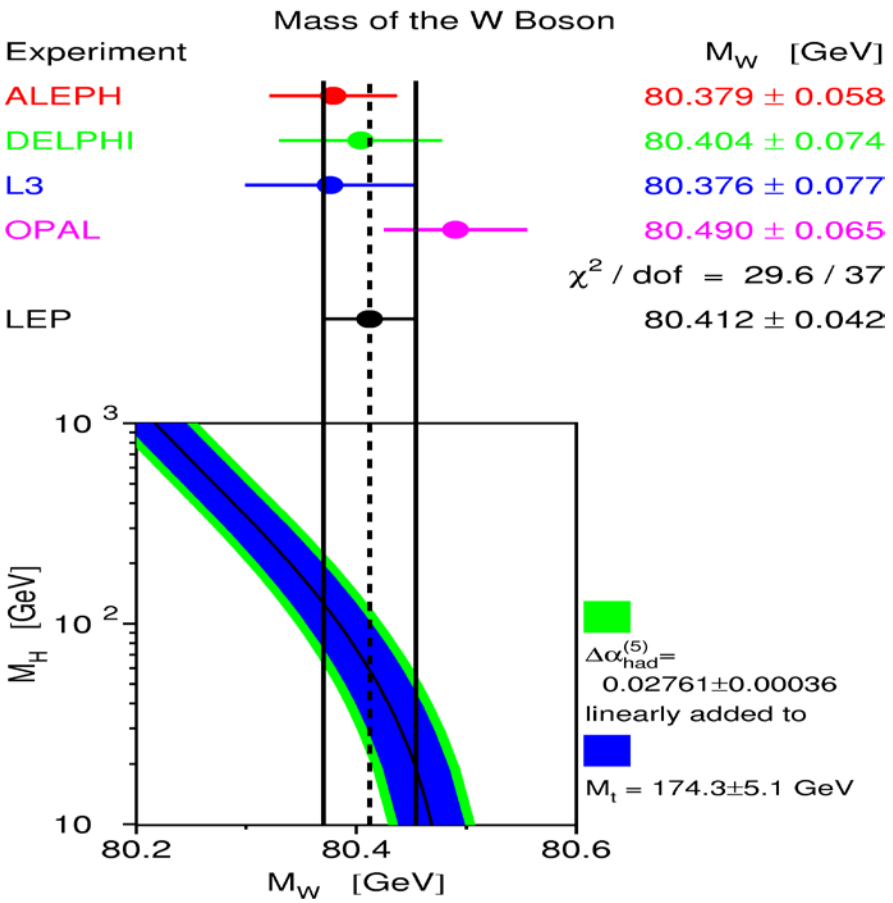
Anteil 10 %
Effizienz ≈ 50 %
Reinheit ≈ 90 %







W-Masse von LEP

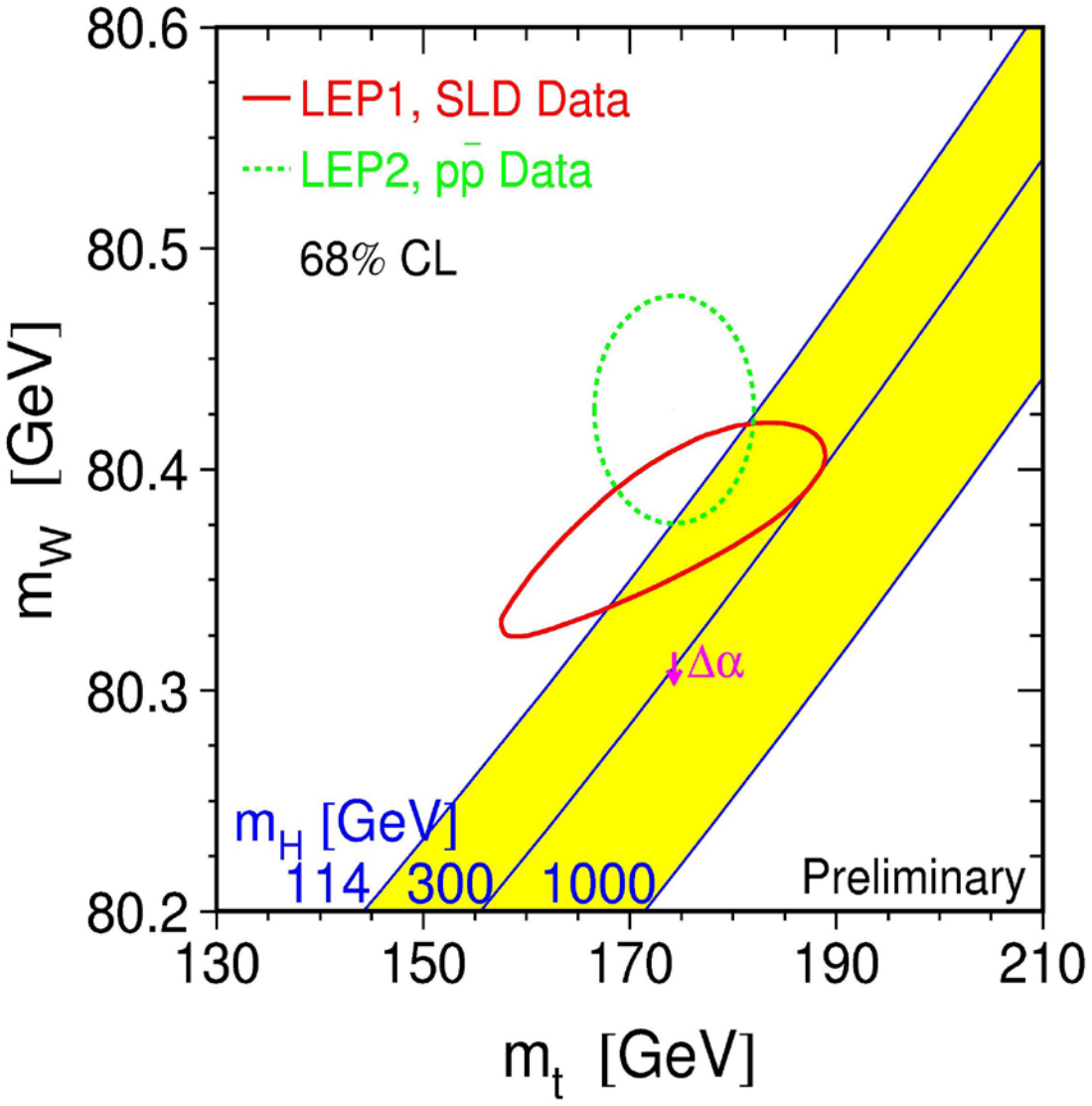


Tendenz zu leichtem Higgs

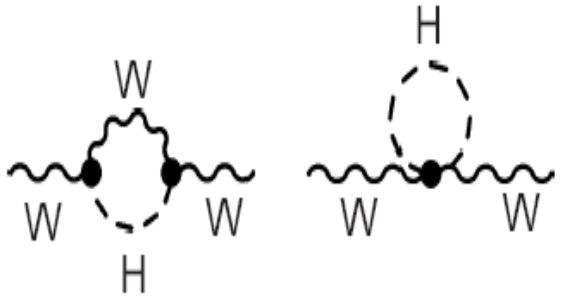
Kombination der vier LEP Experimente:

$$m_W = 80.412 \pm 0.029(\text{stat}) \pm 0.031(\text{syst}) \text{ GeV}$$

Vergleich mit SM Vorhersage



Abhängigkeit von Higgs-Masse:



$$\propto \log\left(\frac{m_H}{m_W}\right)$$

LEP-Datenauswertung (ALEPH, L3)

BEISPIEL

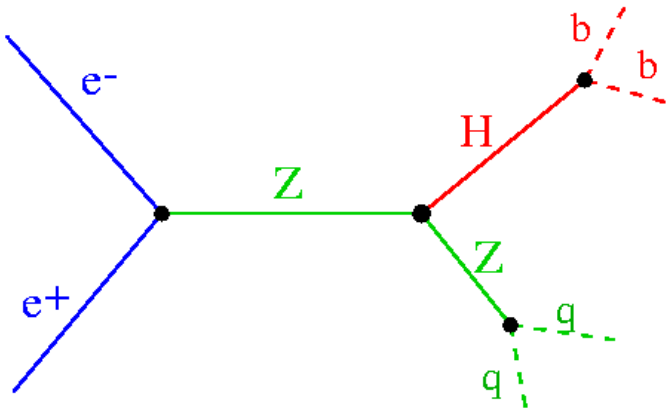
Higgs: Neutrales Spin-0 Boson

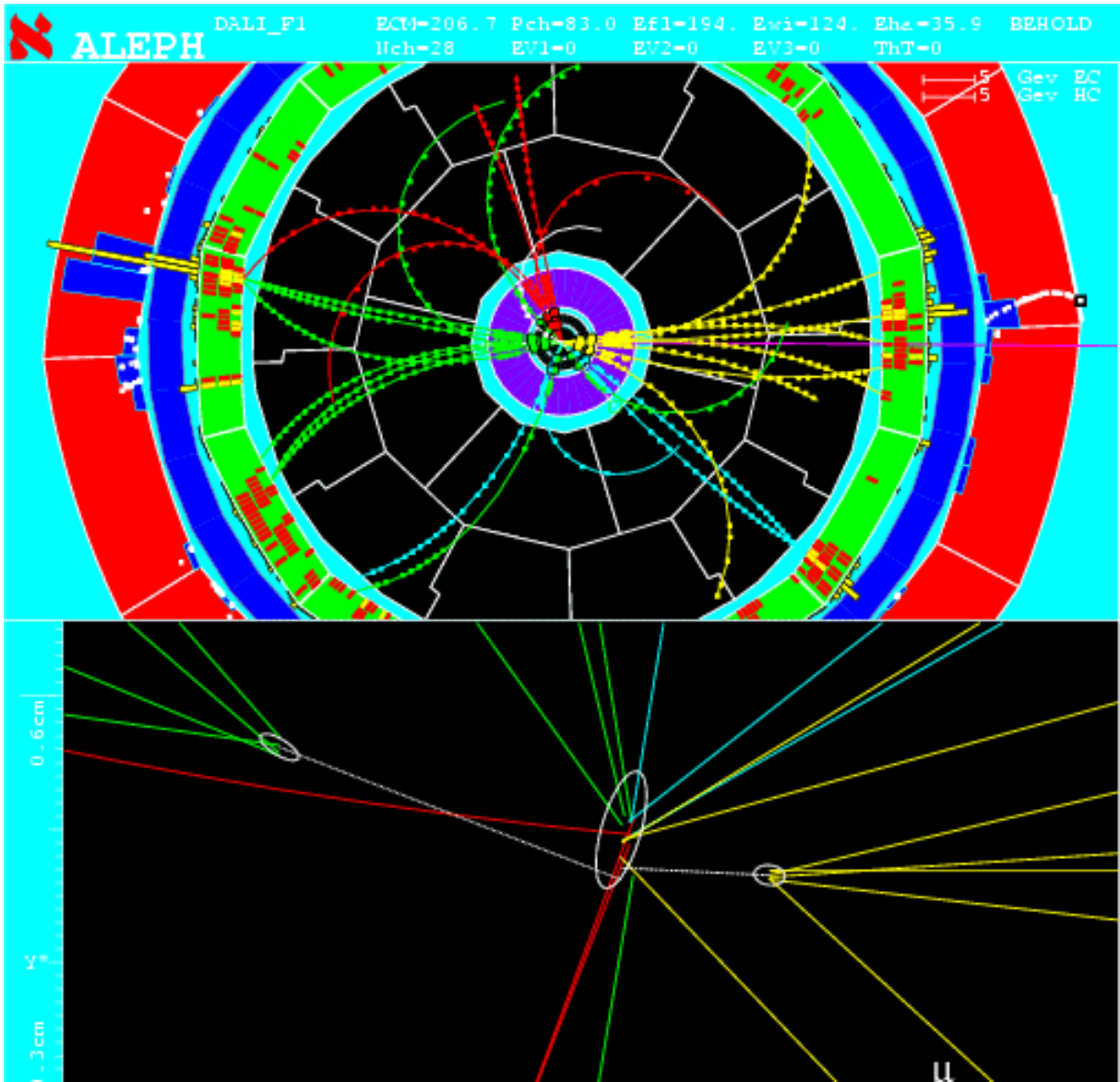
Fundamental: erzeugt

Masse aller Teilchen !

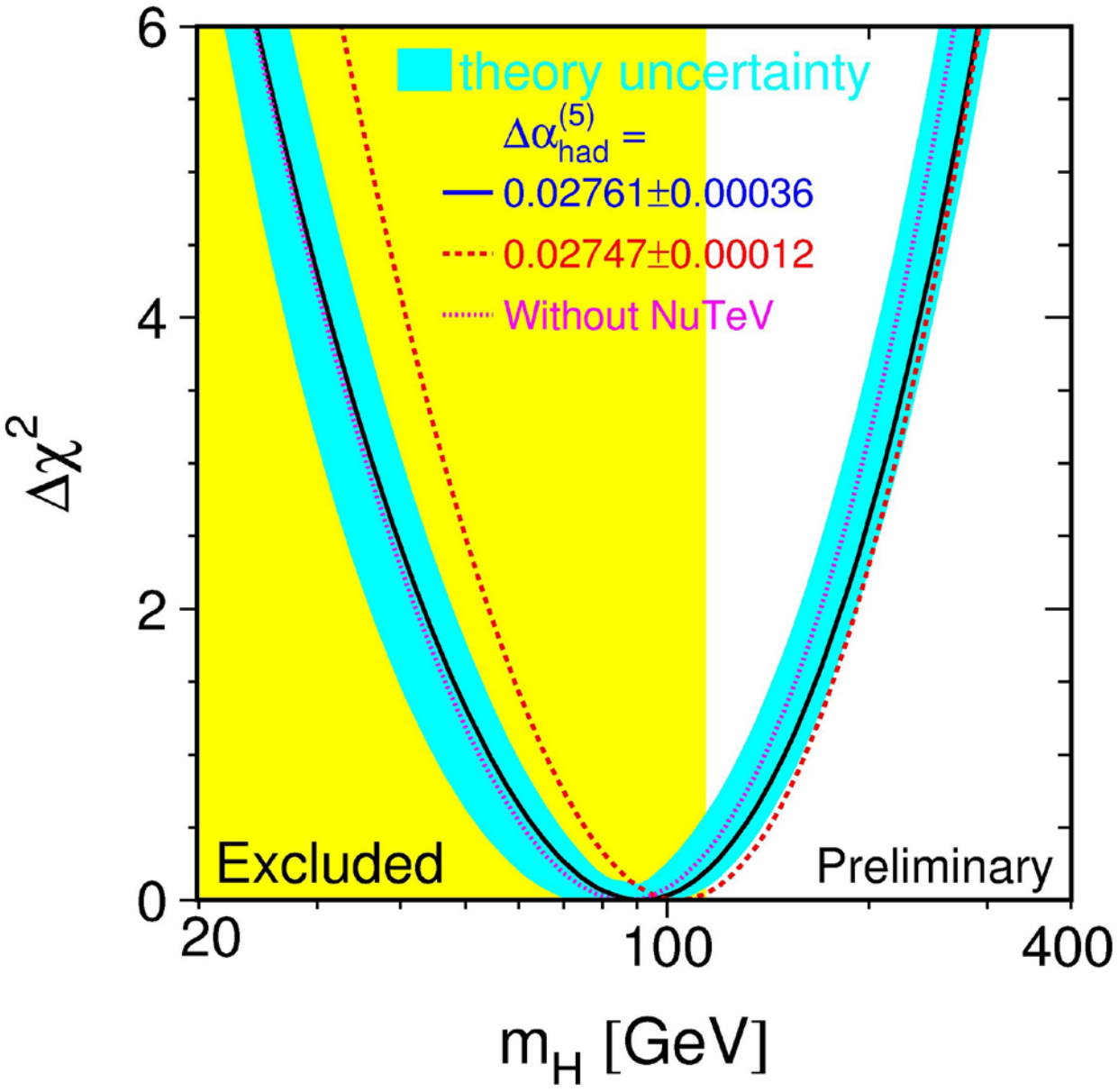
Erzeugung und Zerfall

bei LEP:





The Higgs Mass from Weak Radiative Corrections:



$$\log m_H/\mathrm{GeV} = 1.96\,^{+0.21}_{-0.23}$$

$$m_H = 91\,^{+58}_{-37}\ \mathrm{GeV}$$

95% CL upper limit

m_H < 211 GeV

Das Standardmodell der Teilchenphysik

3 „Familien“

Materie-Teilchen:

Leptonen:	$\begin{pmatrix} \nu_e \\ e \end{pmatrix}$	$\begin{pmatrix} \nu_\mu \\ \mu \end{pmatrix}$	$\begin{pmatrix} \nu_\tau \\ \tau \end{pmatrix}$
Quarks:	$\begin{pmatrix} u \\ d \end{pmatrix}$	$\begin{pmatrix} c \\ s \end{pmatrix}$	$\begin{pmatrix} t \\ b \end{pmatrix}$
	leicht	schwer	sehr schwer

? Higgs ?

Kräfte = Wechselwirkungen:

- stark: **Gluon g**
- elektromagnetisch: **Photon** γ
- schwach: **W-,Z-Bosonen**

Offene Fragen:

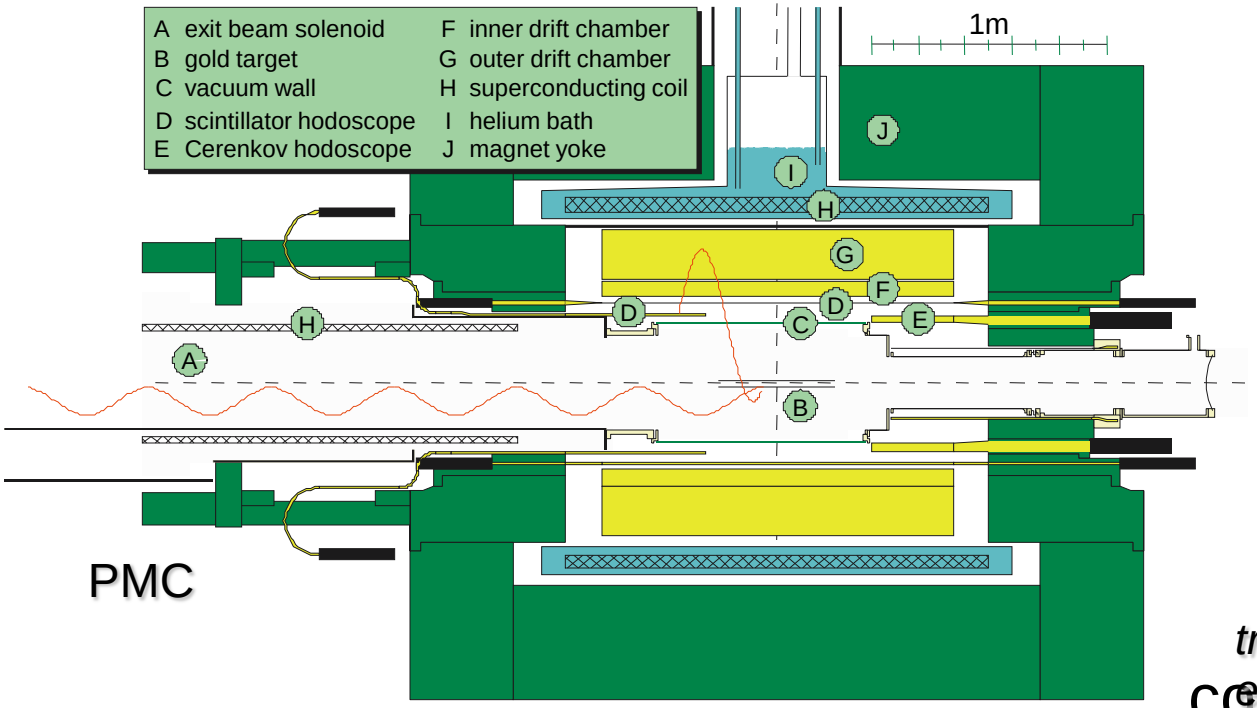
- Teilchenmassen ??
- Gravitation ??

→ Higgs-Boson

→ Supersymmetrie

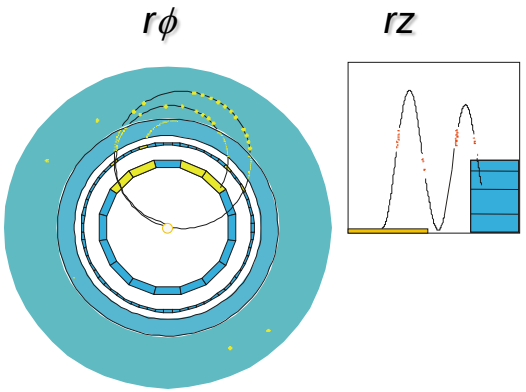
SINDRUM II Spectrometer

- Suche nach neutrinoloser Myon-Elektron-Konversion
- Verletzung der Leptonzahlerhaltung



SINDRUM II

Schematic event display:



tracks left by a ≙100 MeV e

configuration 2000

Ergebnisse

Wahrscheinlichkeut für neutrinolose

μ e - Konversion

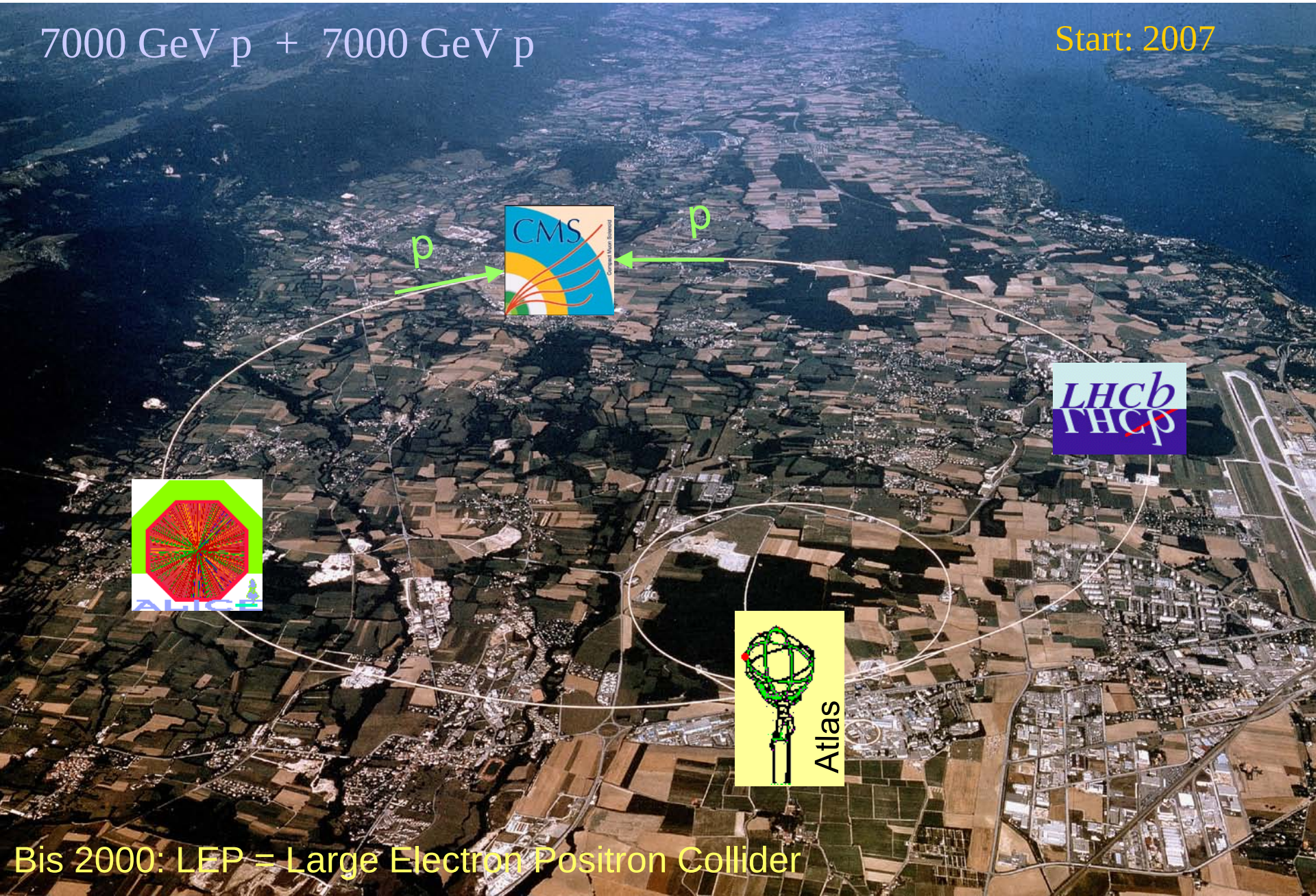
$$B_{\mu e}(Au) \leq 6 \cdot 10^{-13} \quad (90\%\ C.L.)$$

Ti 1993: $B_{mue} < 4.3 * 10^{-12}$ Phys.Lett. B 317:631-636,1993
Pb 1995: $B_{mue} < 4.6 * 10^{-11}$ Phys.Rev.Lett. 76:200-203,1996
Ti 1995: $B_{mue} < 8.0 * 10^{-13}$

No candidate events have been observed, therefore $B_{\mu e}$ becomes an upper limit with...

Preliminary !

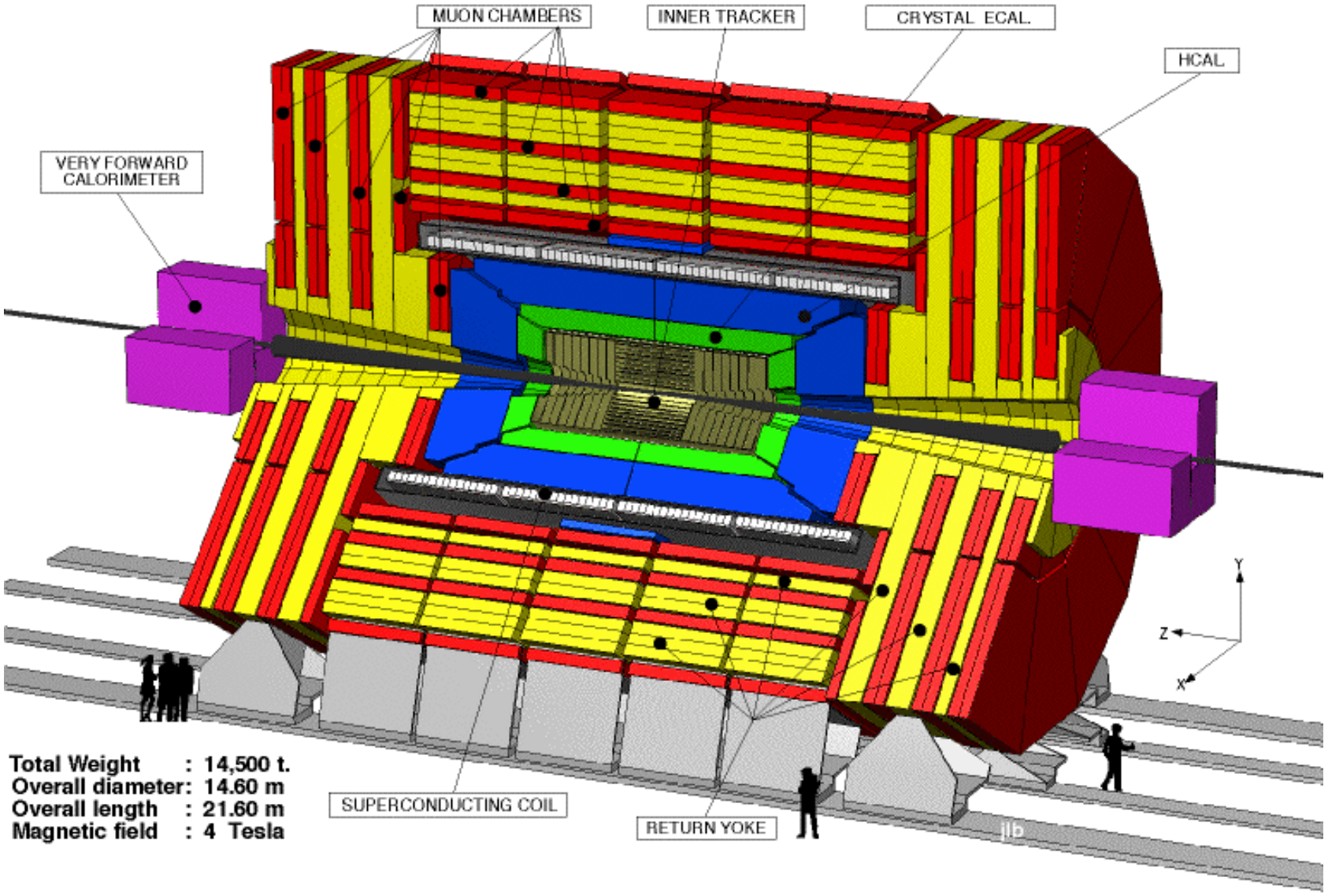
LHC = Large Hadron Collider am CERN



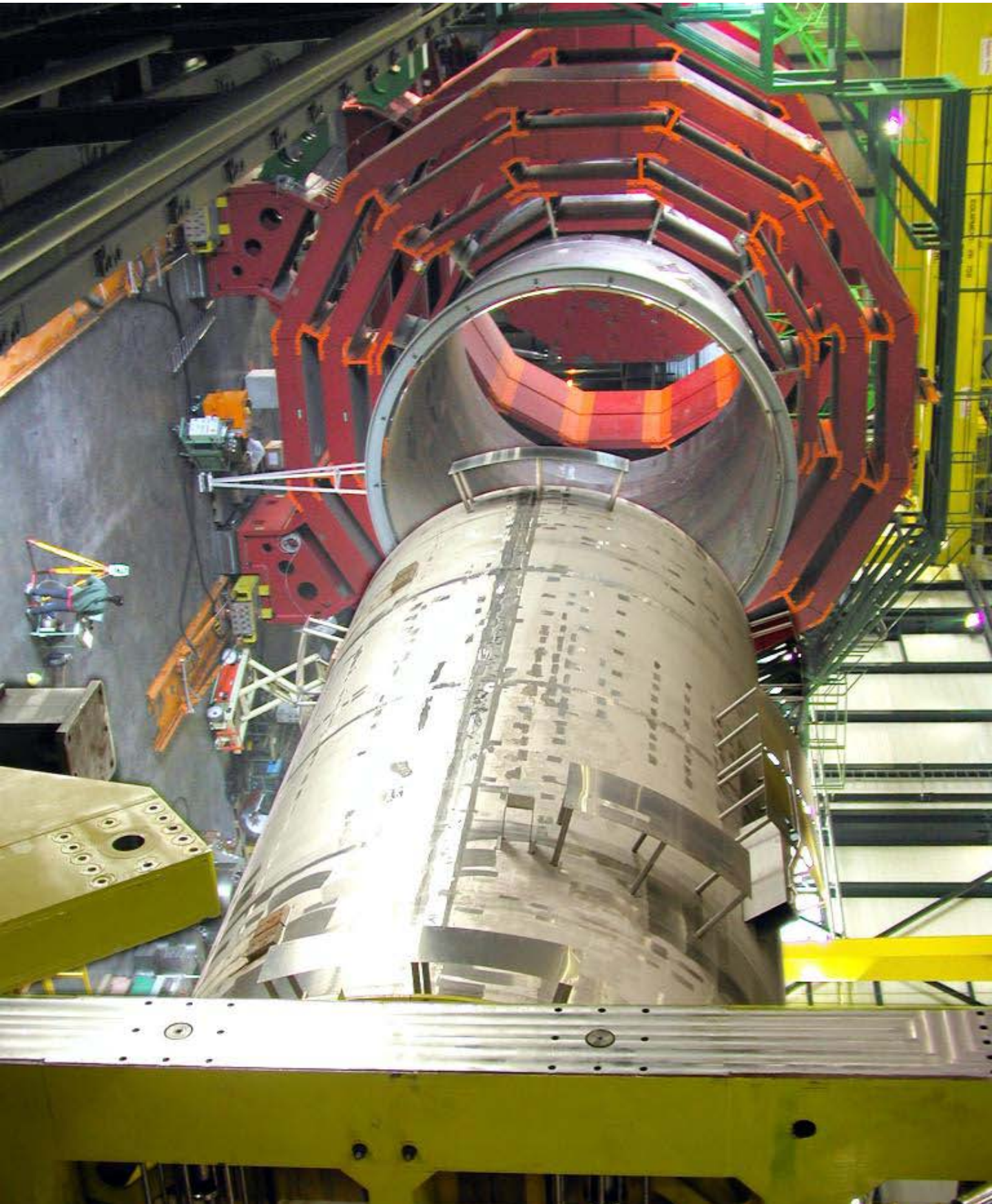
Zukunft: LHC (Large Hadron Collider) ab 2007 im LEP-Tunnel

Proton-Proton-Beschleuniger Schwerpunktsenergie 14 000 GeV

CMS-Detektor

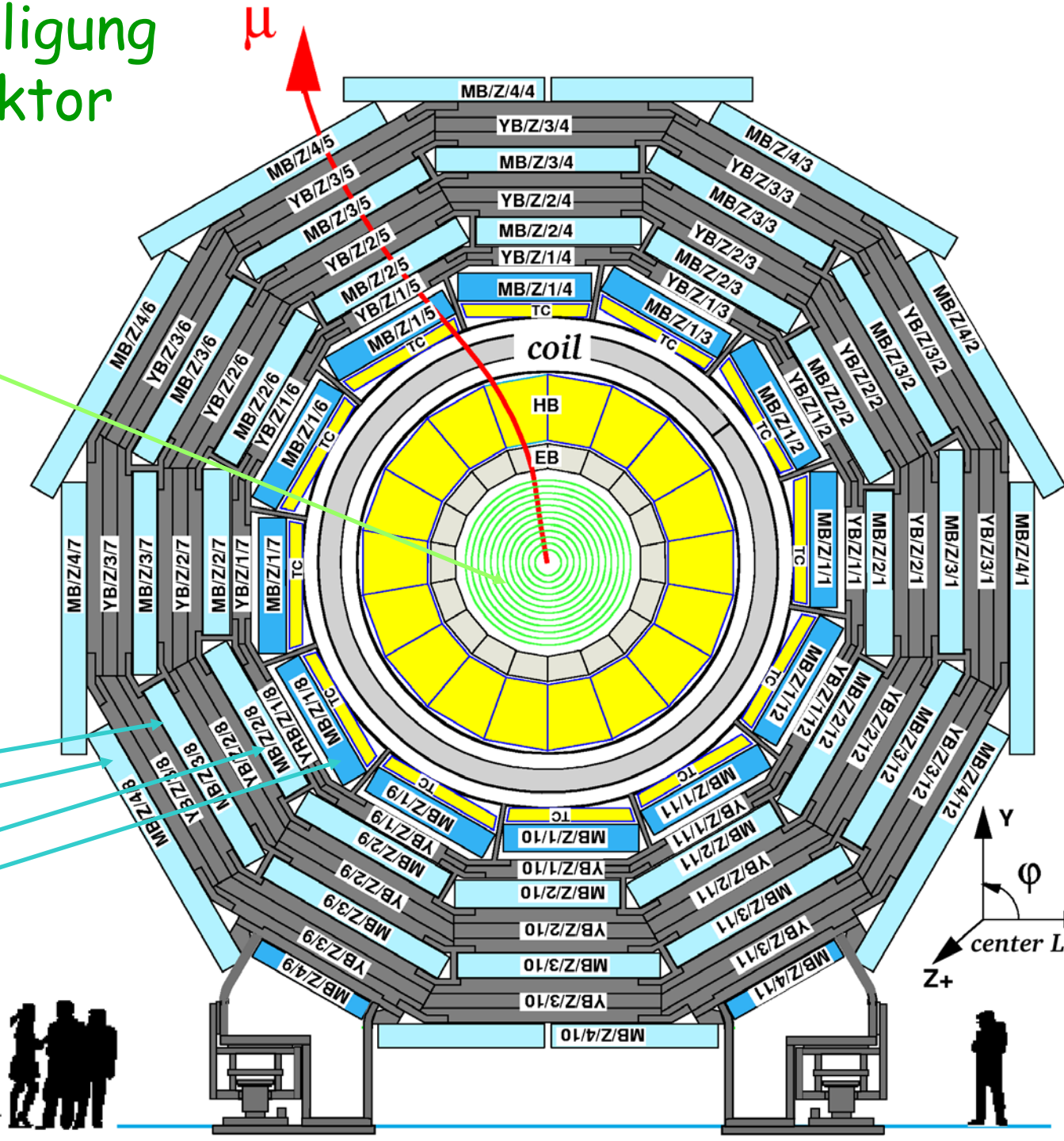


CMS-Detektor am LHC

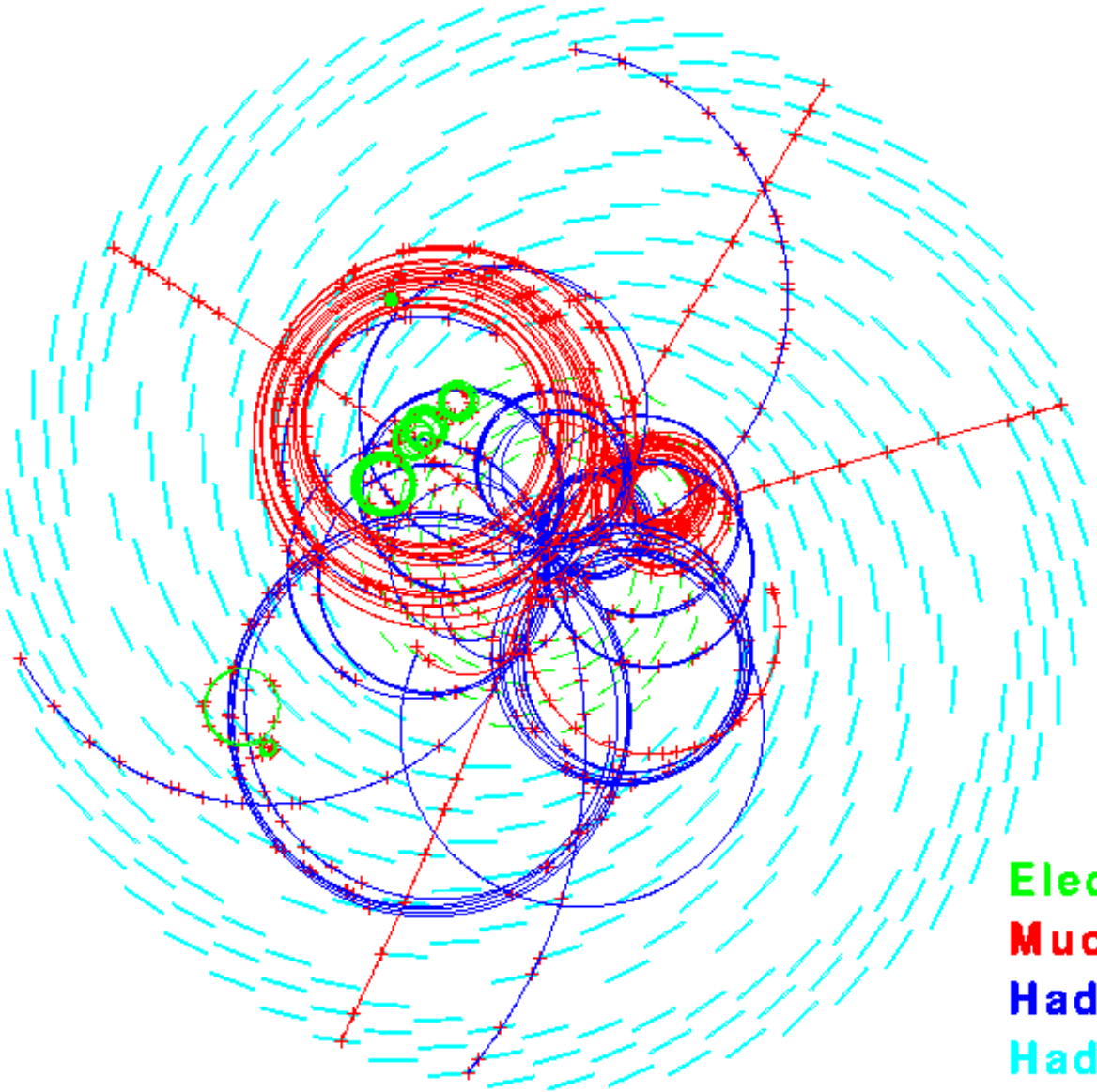


Aachener Beteiligung am CMS Detektor

- Innere Spur-kammern (Silizium)
- Myon-Detektor



Simuliertes Higgs-Ereignis

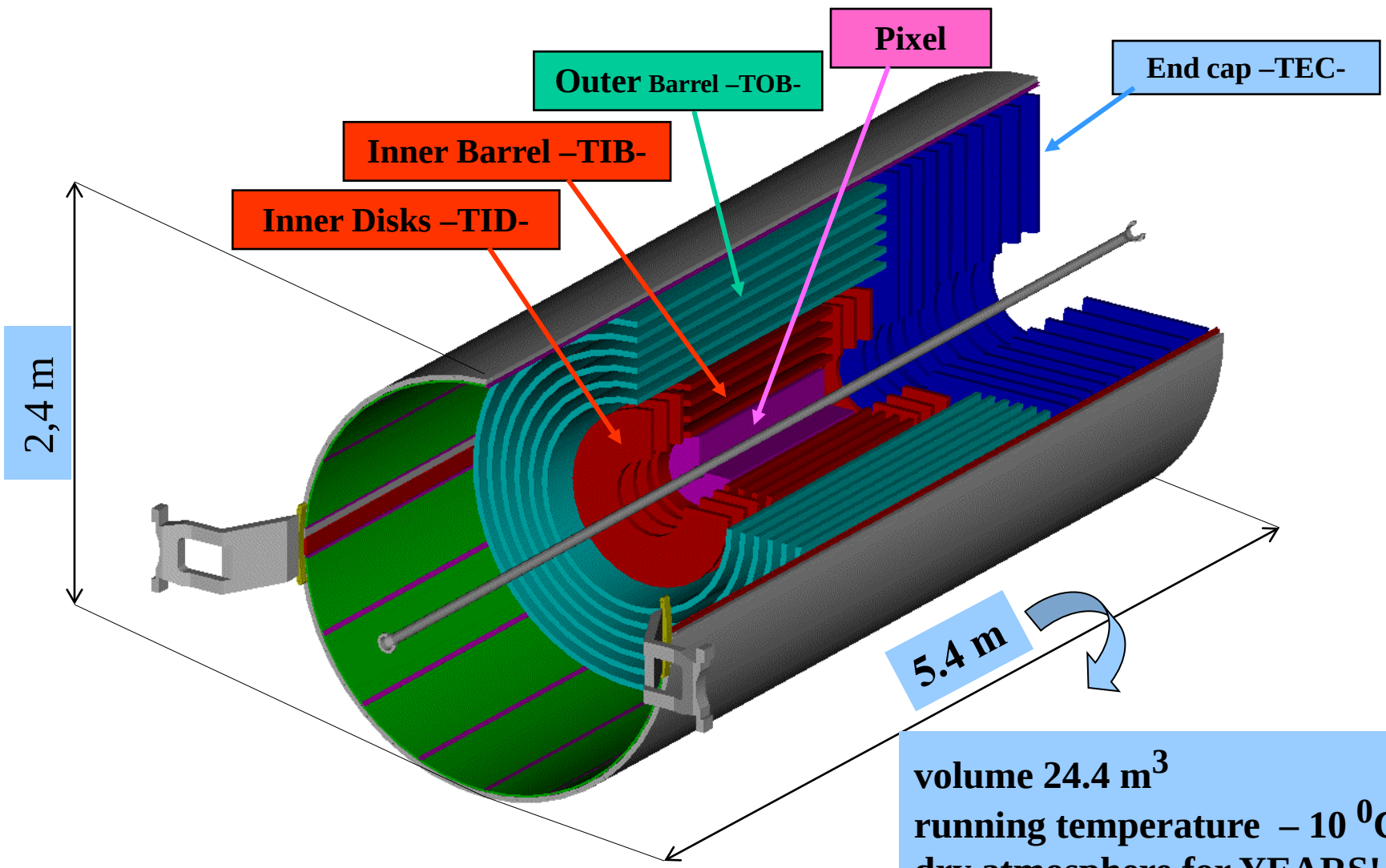


CMS

H -> μμμμ
m(H)=150GeV

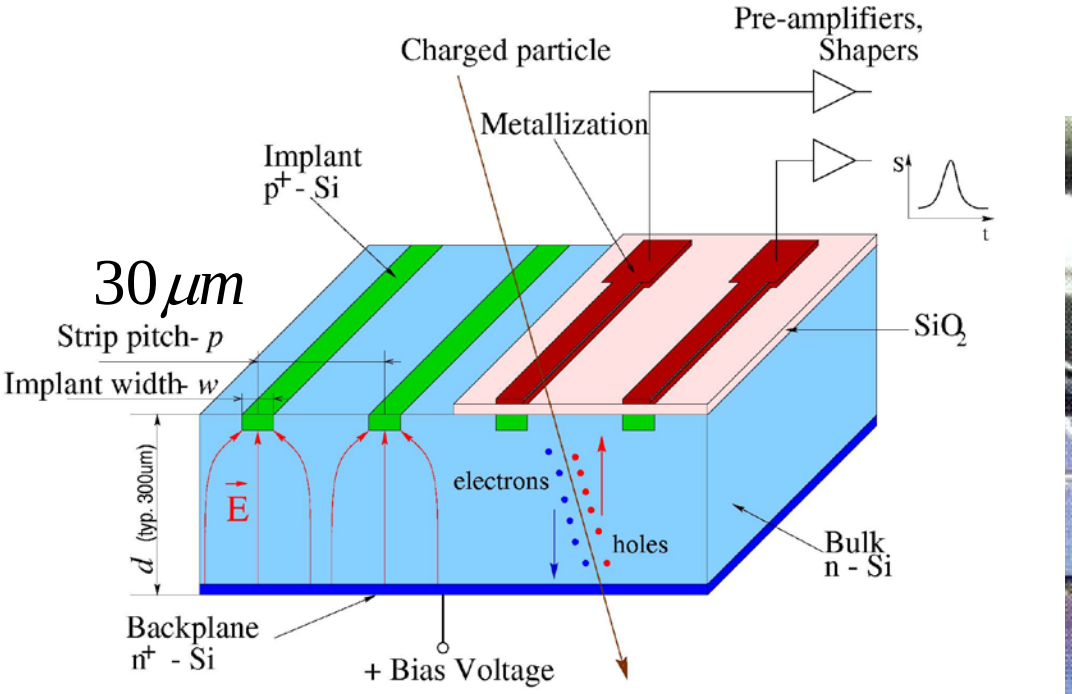
Electrons
Muons
Hadrons pt<2GeV
Hadrons pt>2GeV

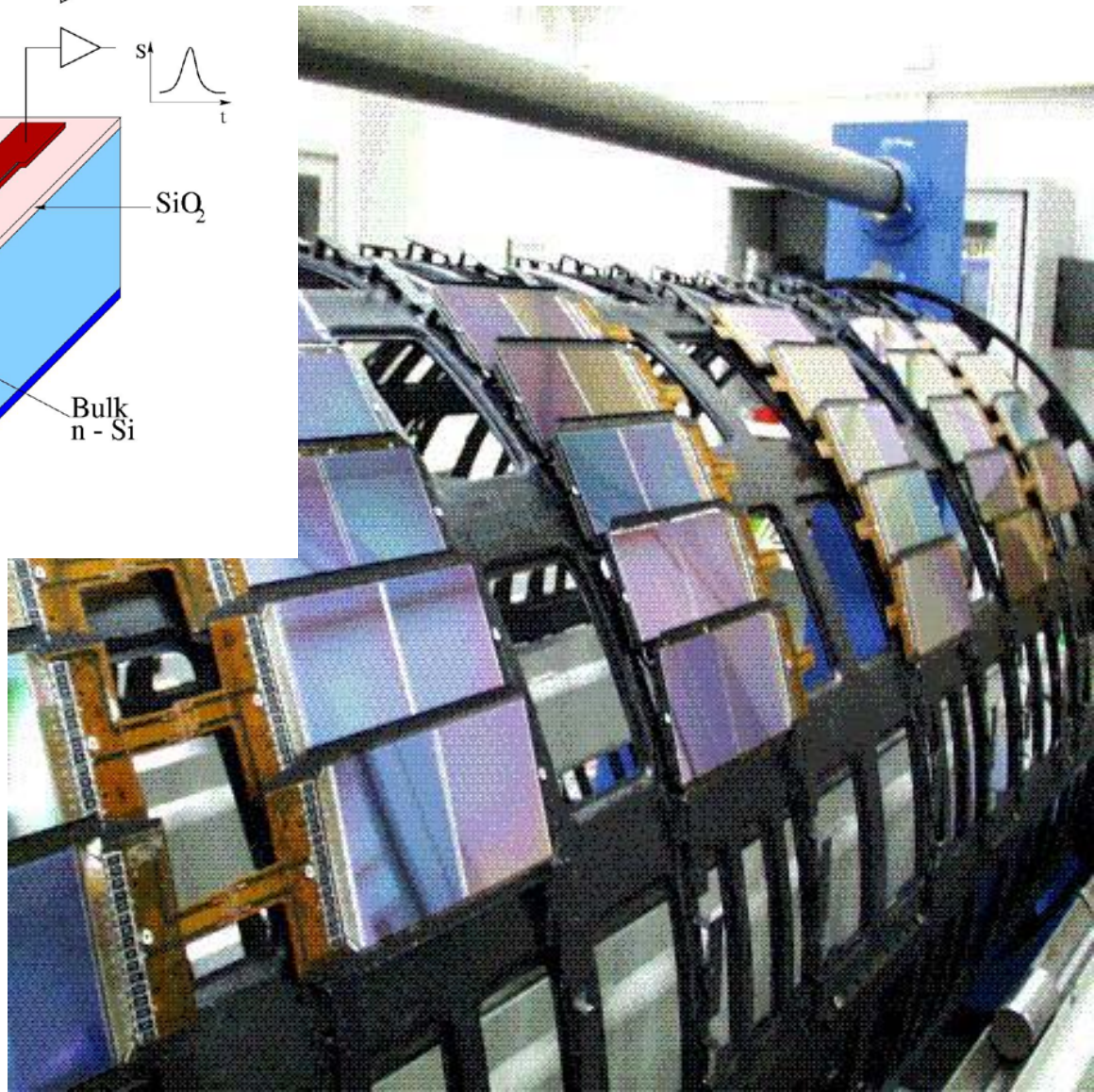
New Tracker Layout April 2000; constant since then!

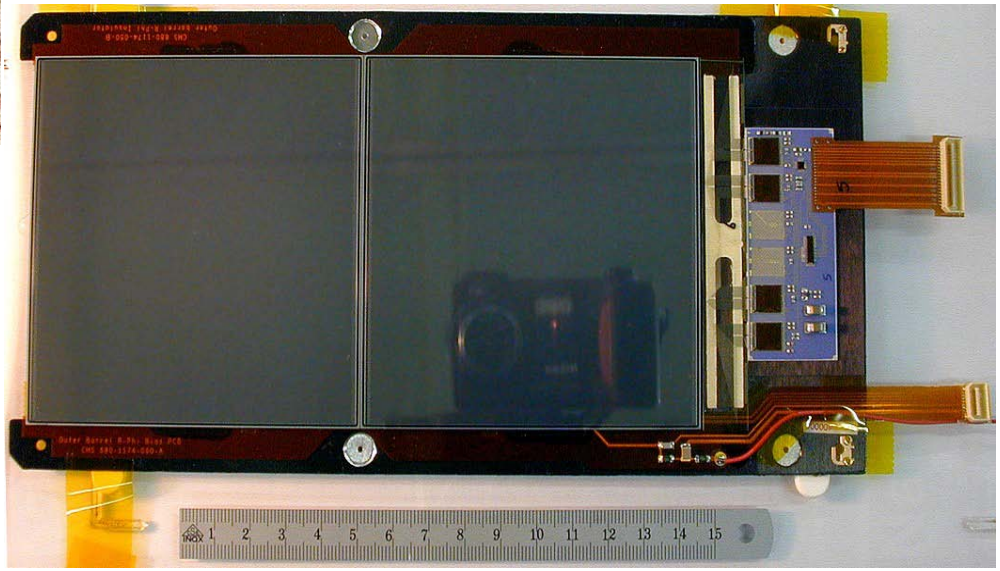


volume 24.4 m^3
running temperature – 10 ^{0}C
dry atmosphere for YEARS!

Der CMS Silizium-Detektor



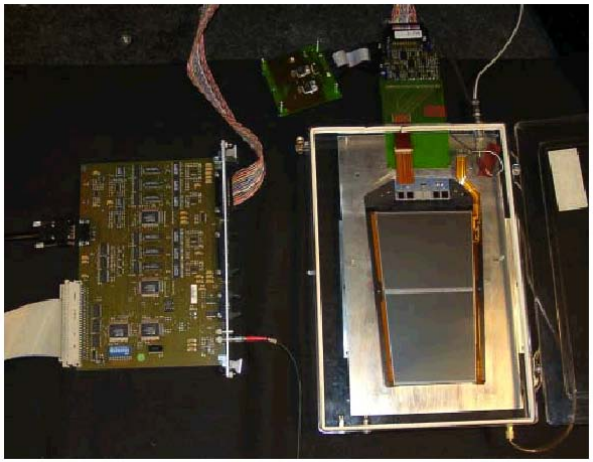




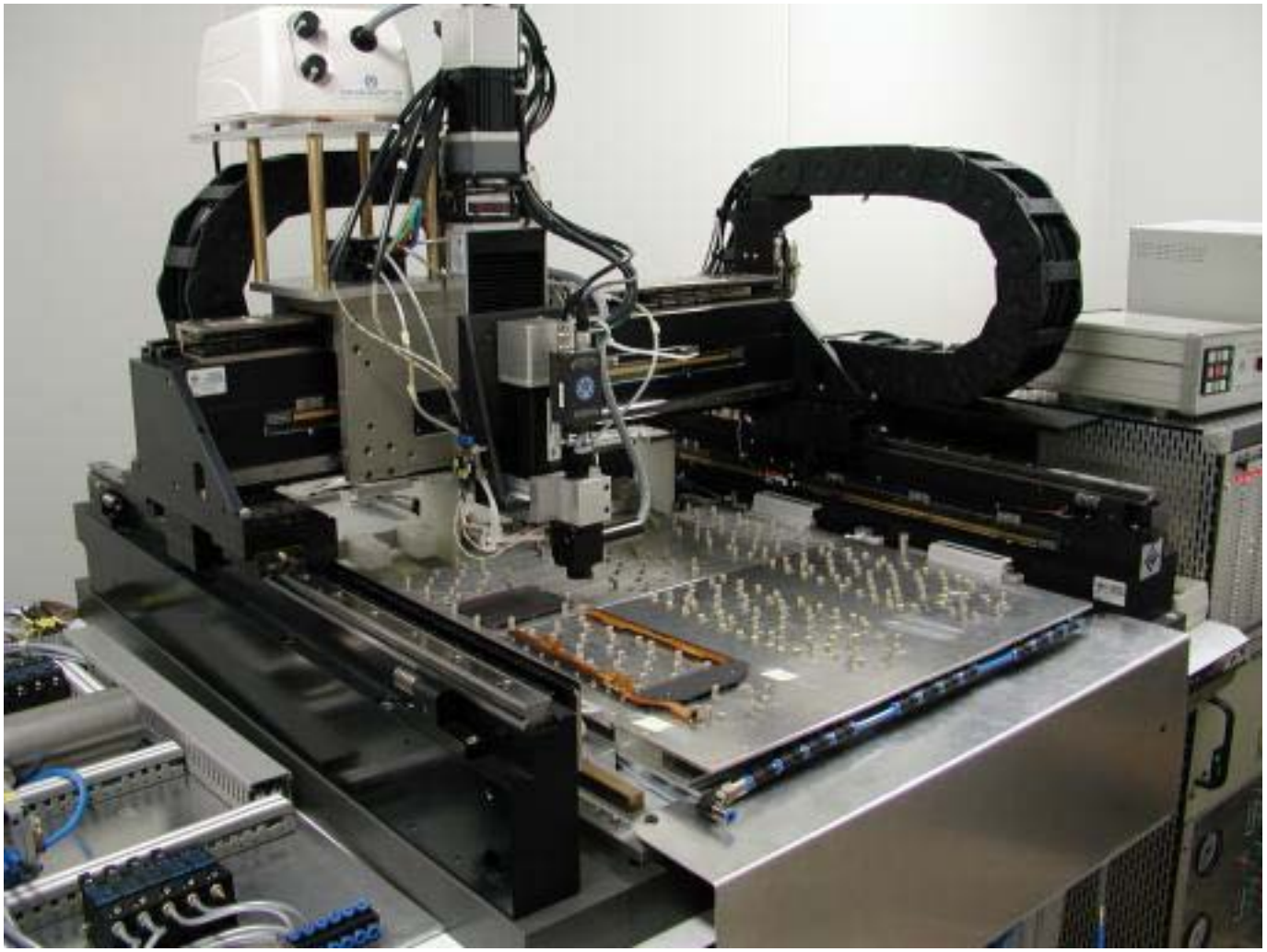
TOB Module
(rectangular)

TEC R6 Module (strips point to beamaxis)

Read out via the
ARC system



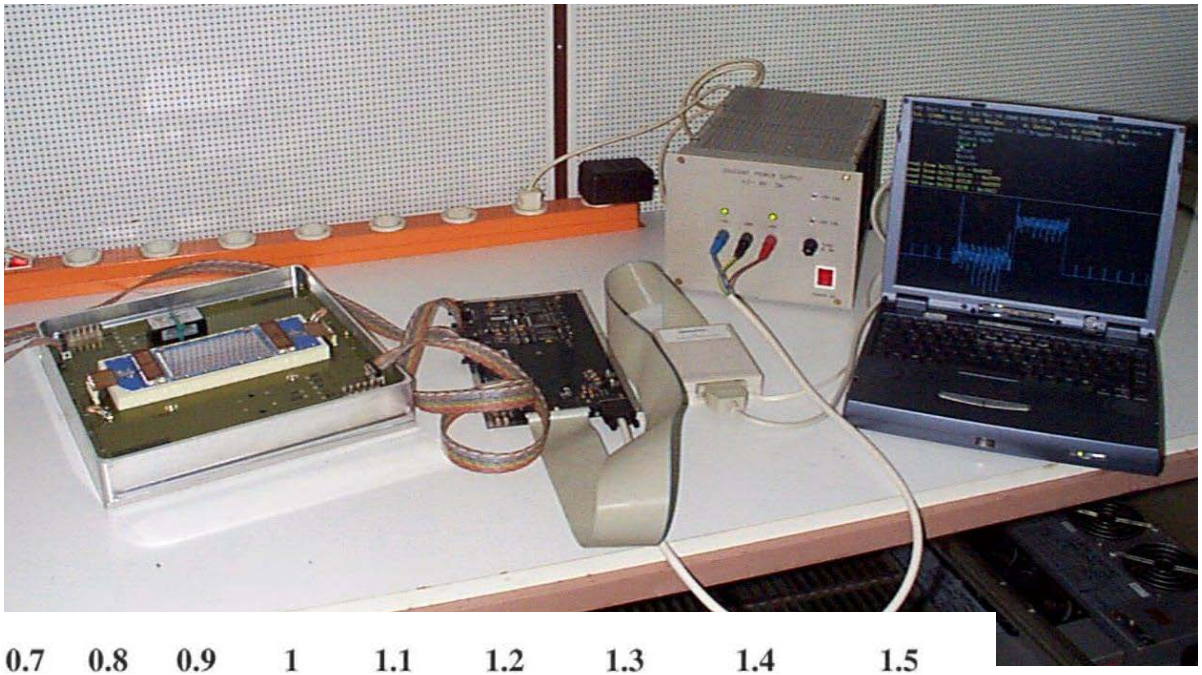
Work in Aachen Gantry:

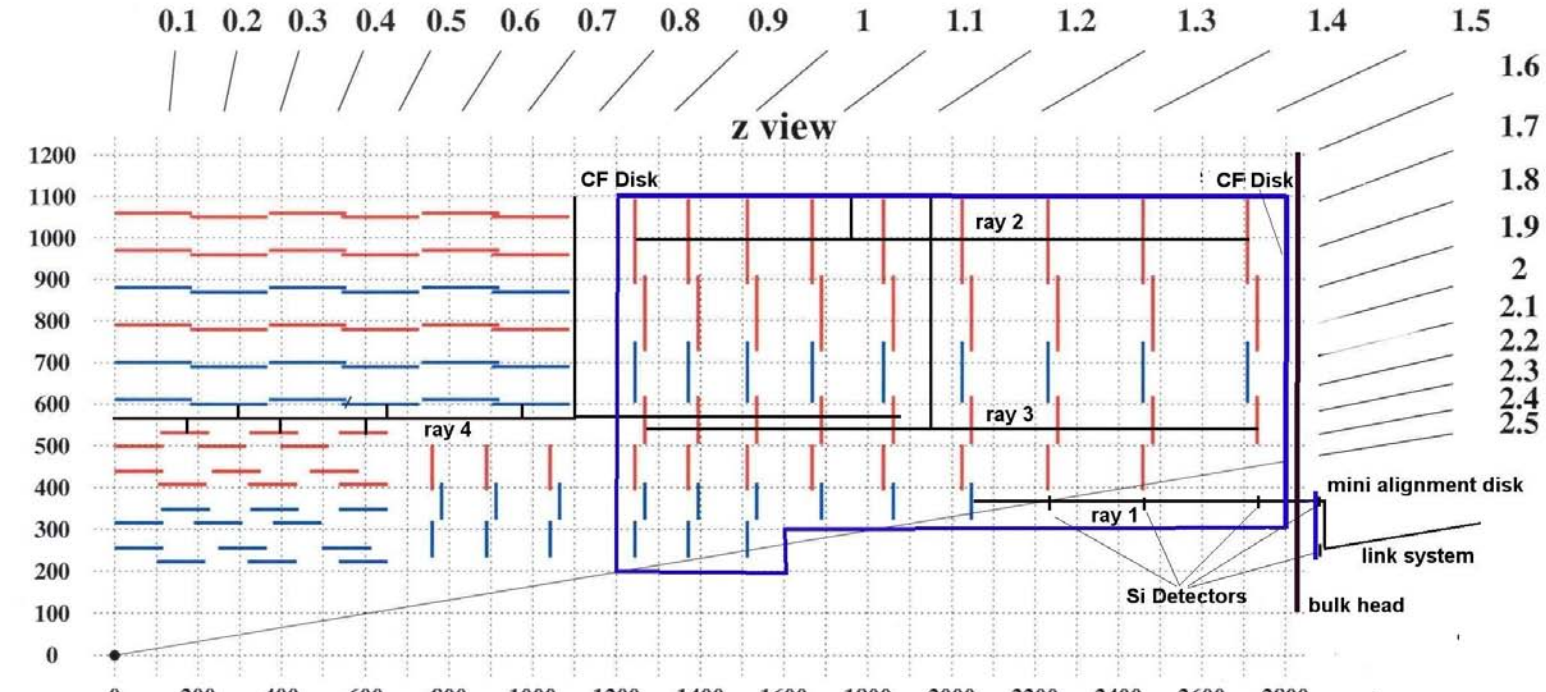


Silizium-Spurdetektor Aachen

Auslese-Elektronik:

Funktionstest
für 10 Mill.Kanäle
auf 16 000 Modulen



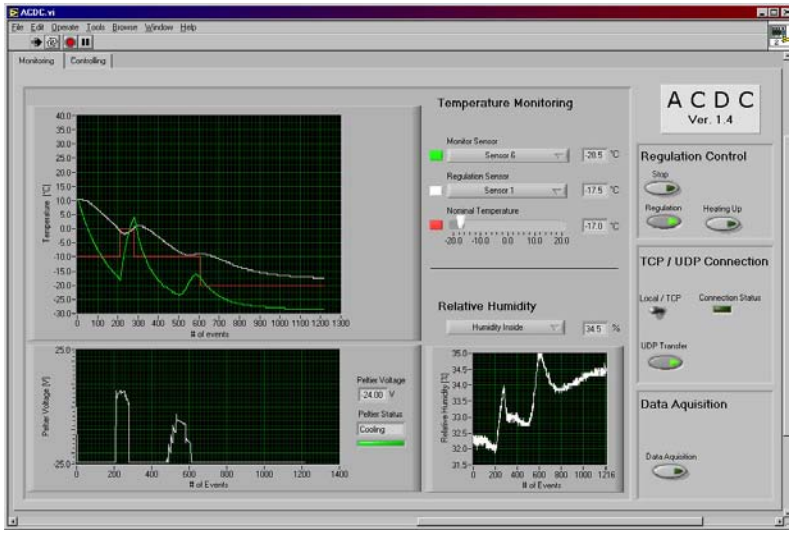


Genauigkeit
50µm in
25 m^3

Laser-

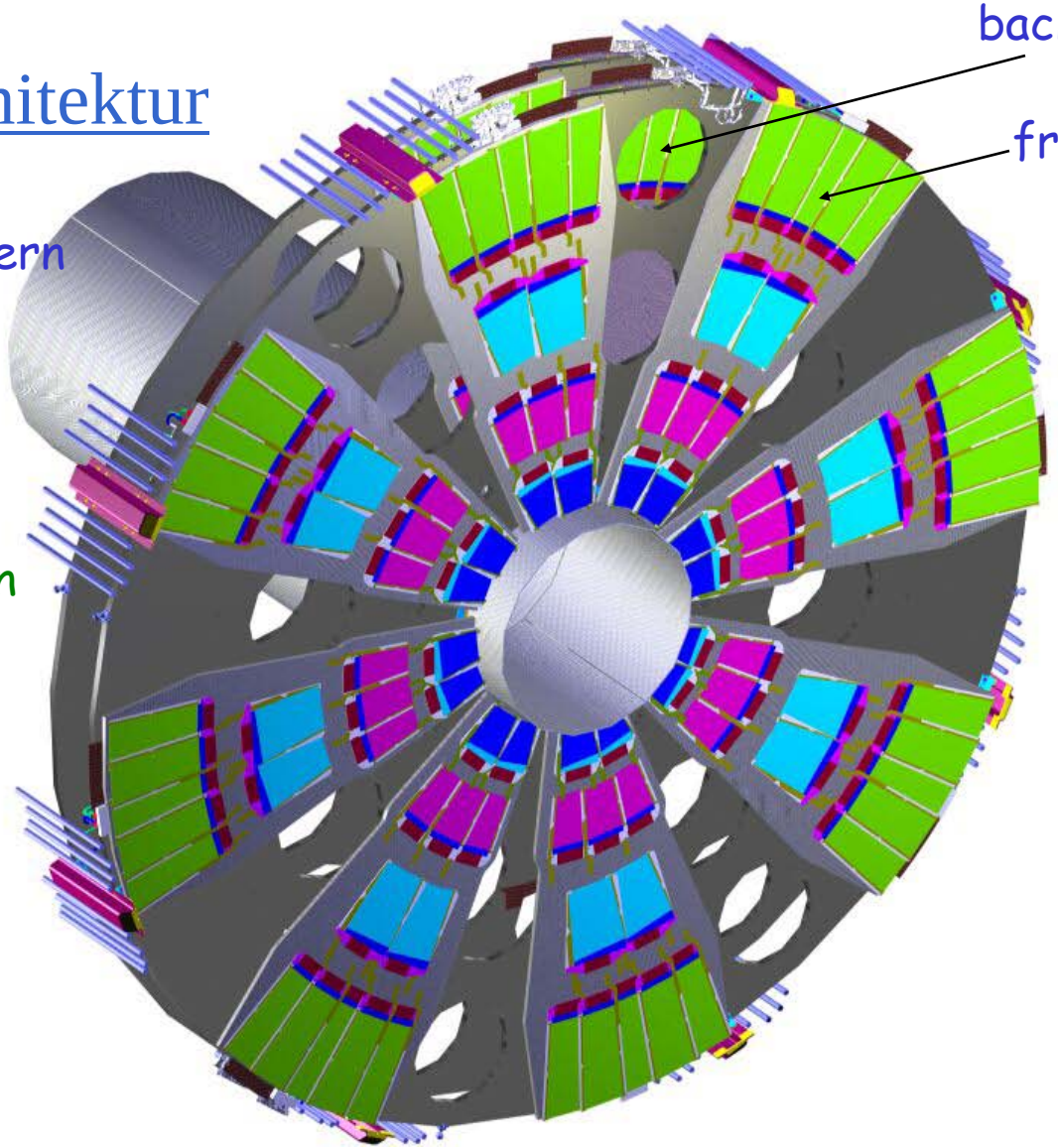
Alignment

The ARC System



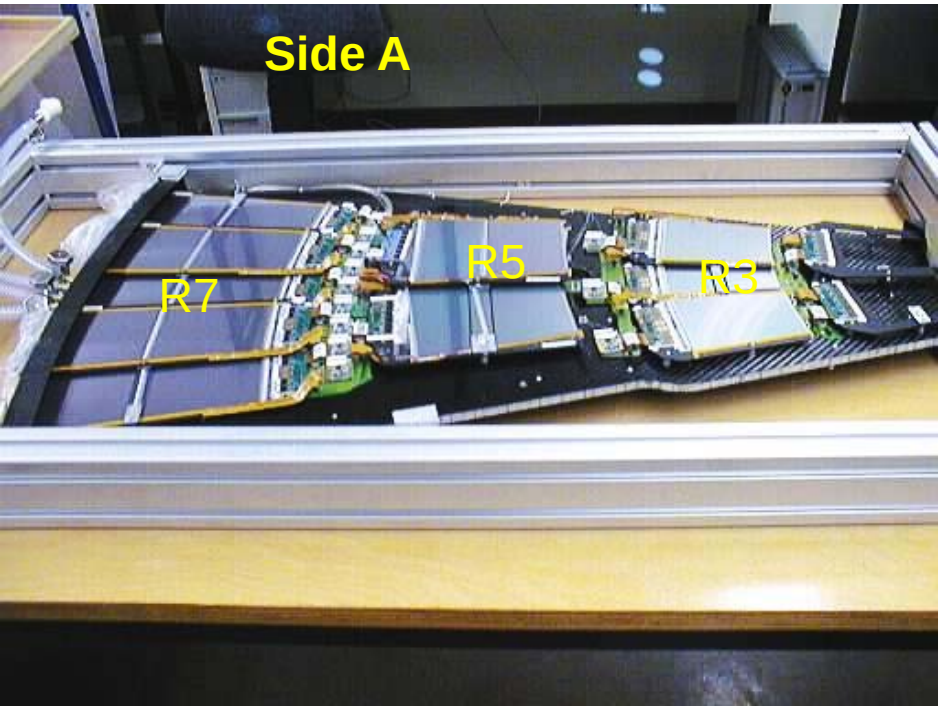
Modulare TEC Architektur

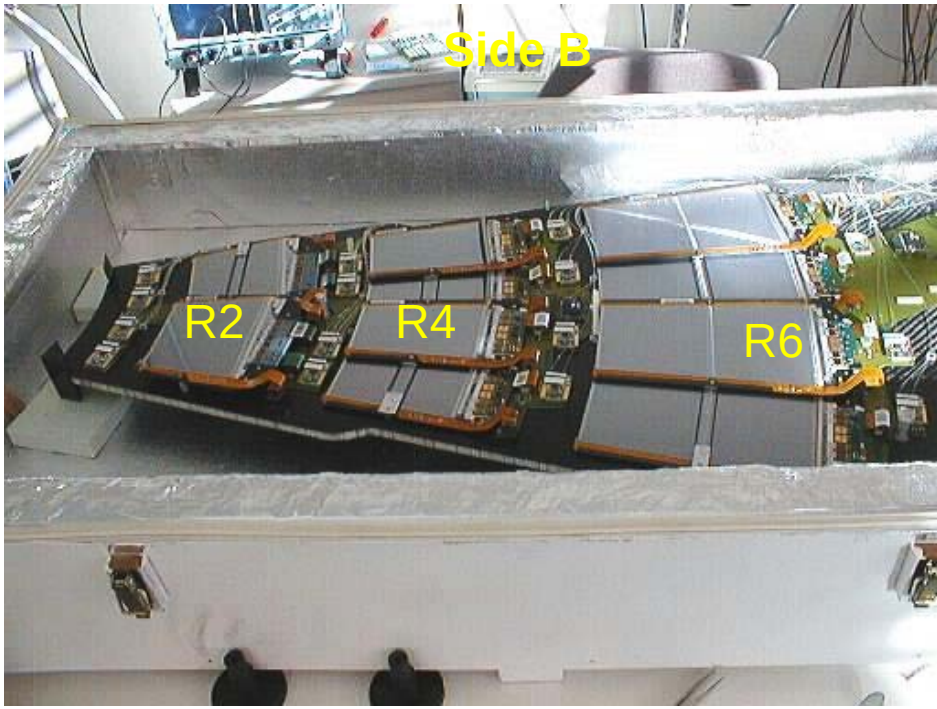
- 2 Endkappen mit je 9 Rädern
- Auf jedem Rad
  - -8 ‚front petal'
  - -8 ‚back petal'
- 'petal' mit trapezförmigen Modulen bestückt



Petal im Teststrahl

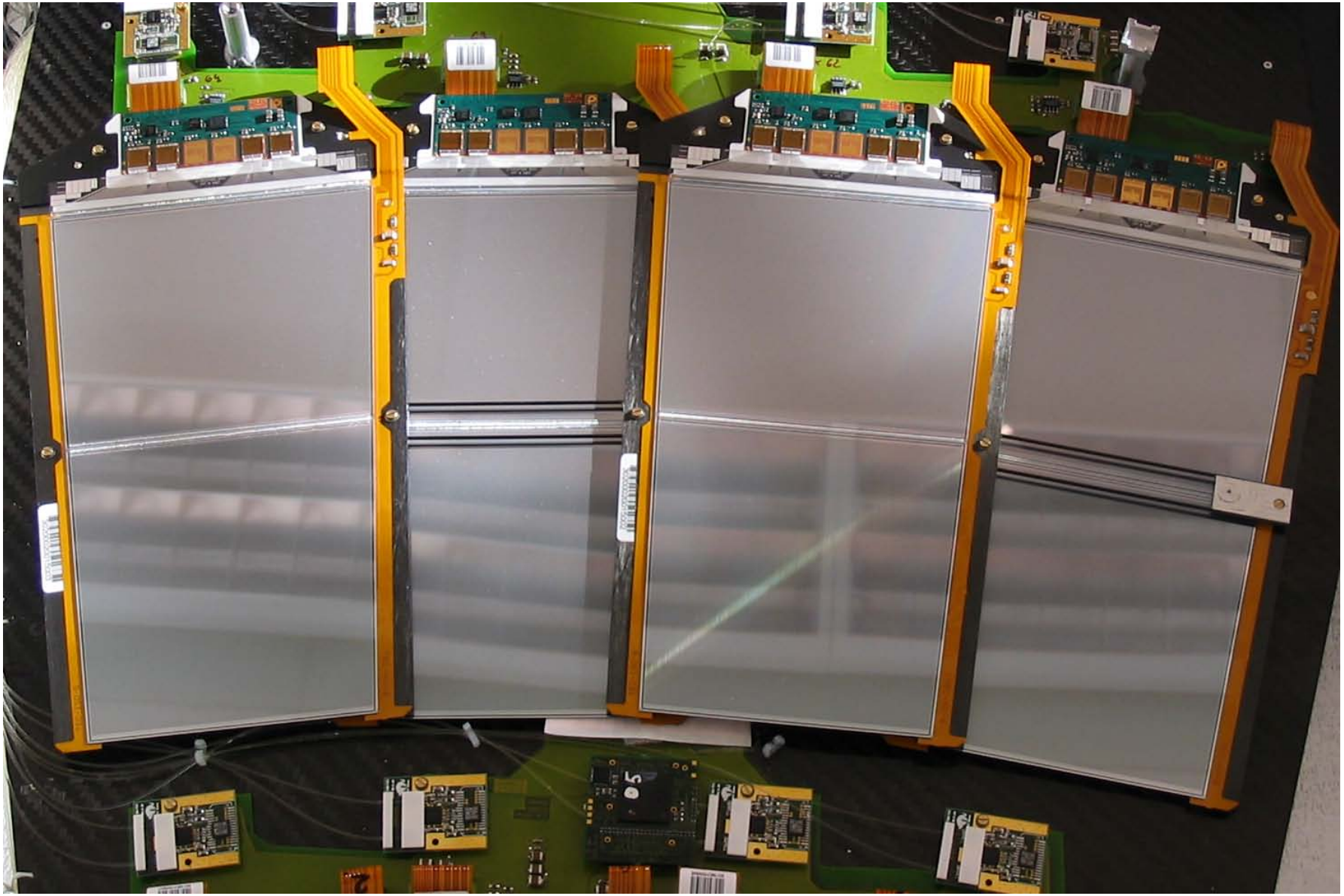
Petal System Test



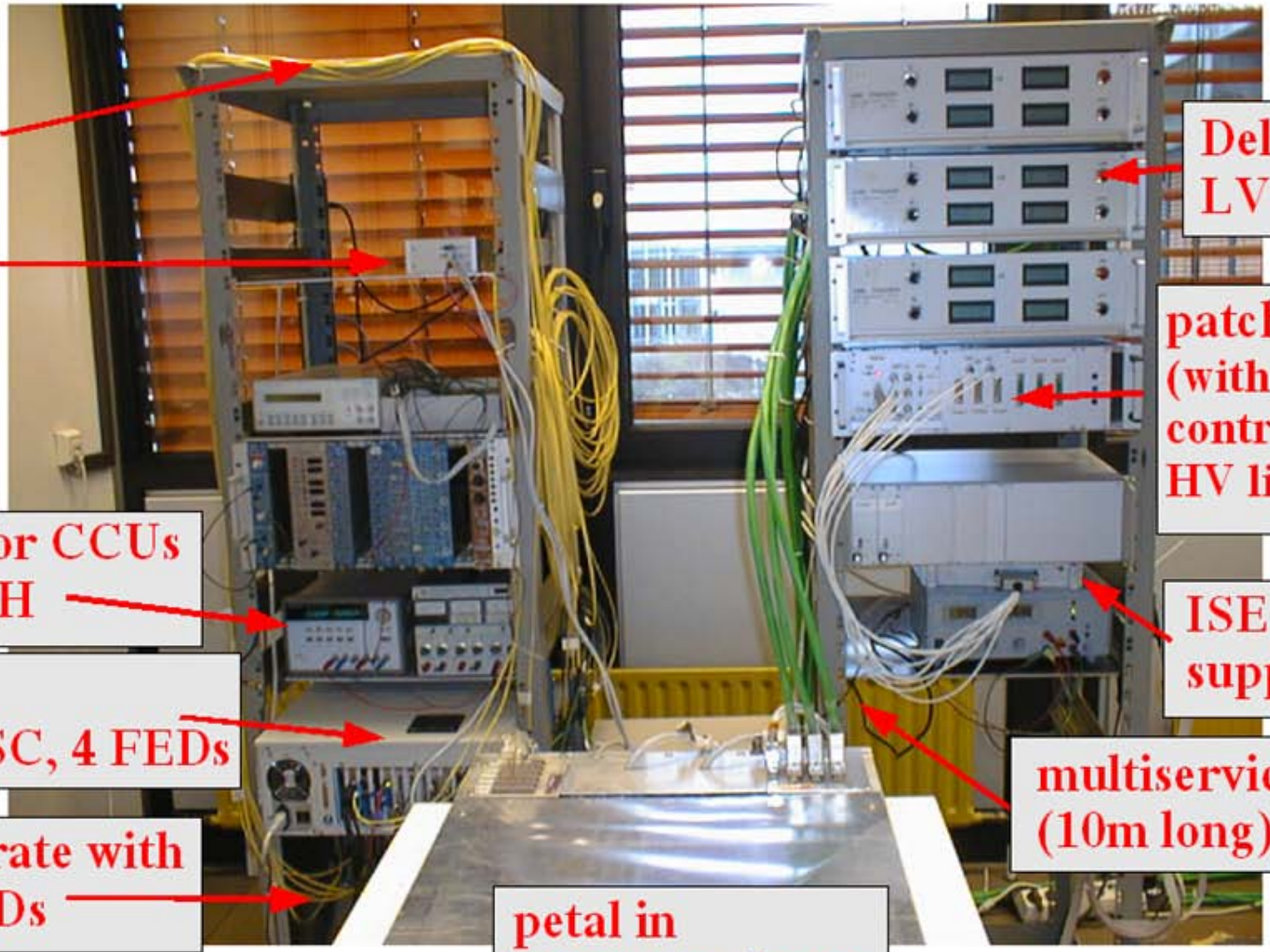


Tetal im Kühltest-Stand

4 Module auf dem Petal (Ring 6)



System test setup



TEC Structure

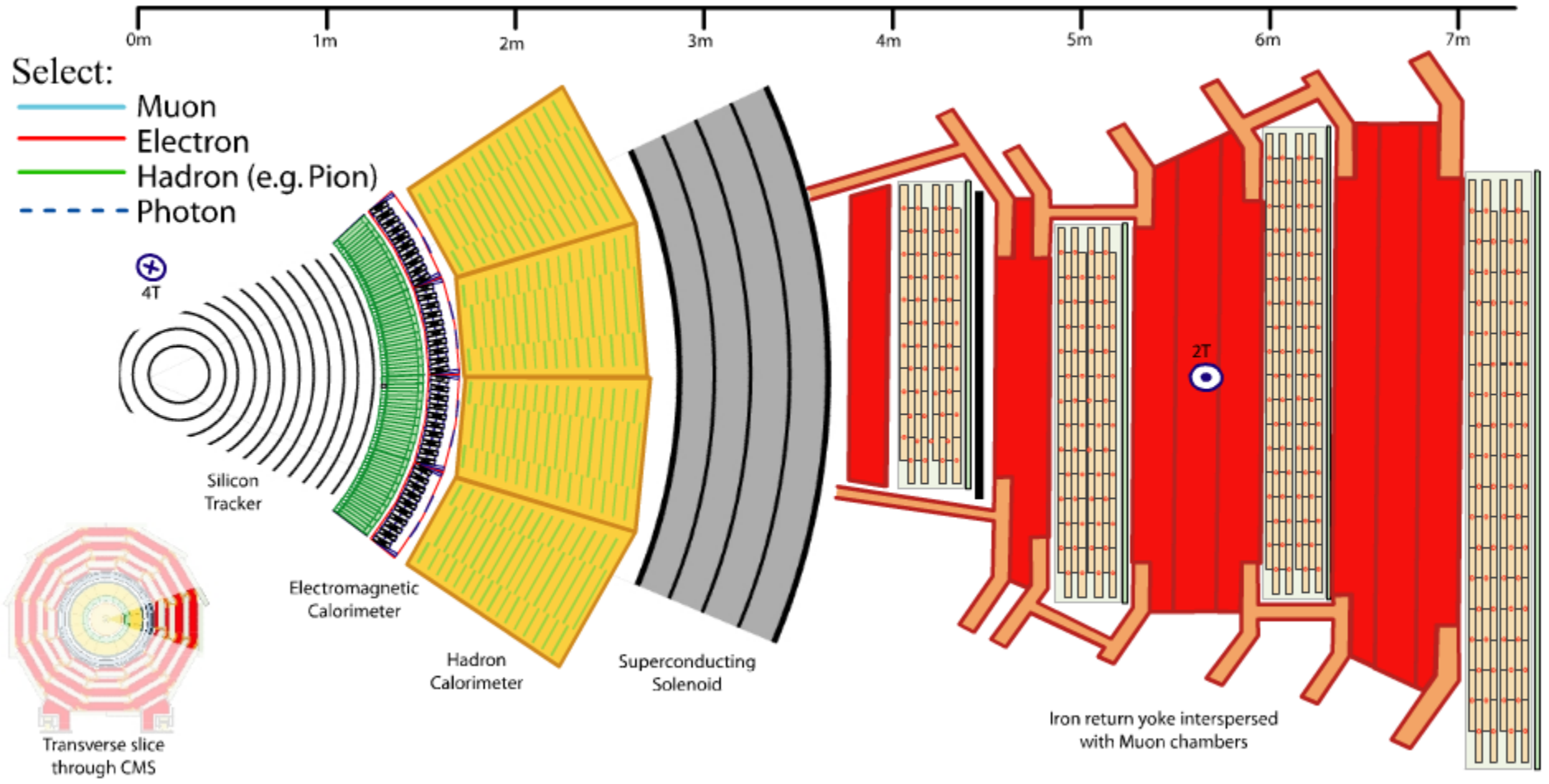
Production of the 18 CFC-Disks completed.

Senkrechter Schnitt durch den CMS Detektor:

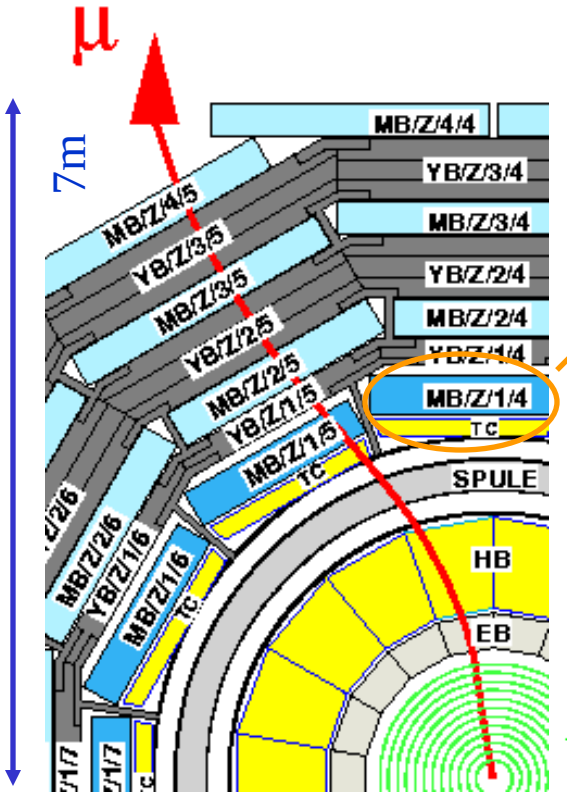
Computersimulation der Signale verschiedener Teilchen,

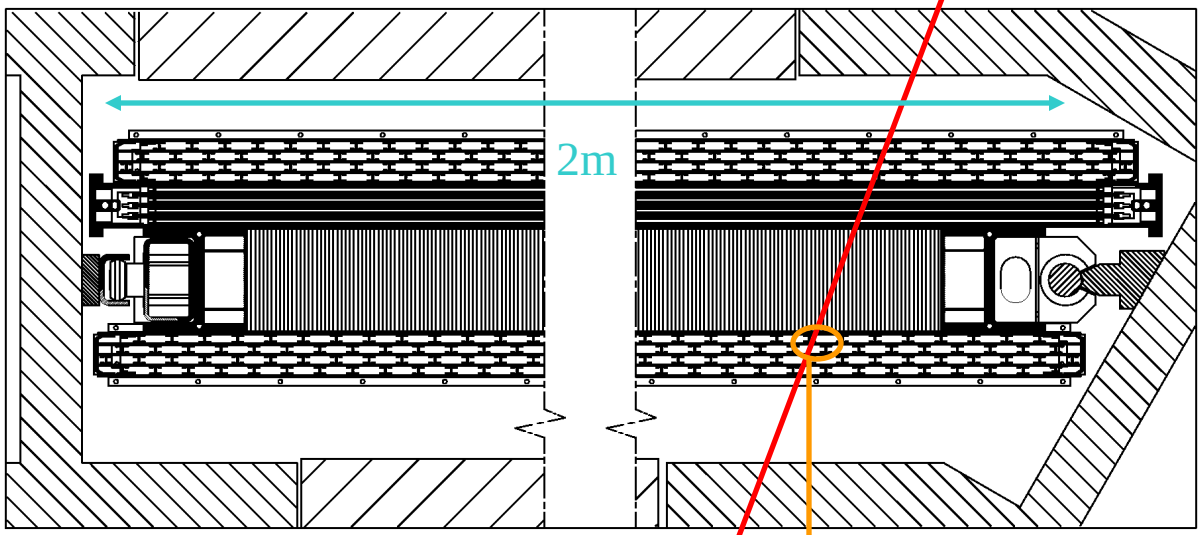
die am Kollsionspunkt erzeugt werden

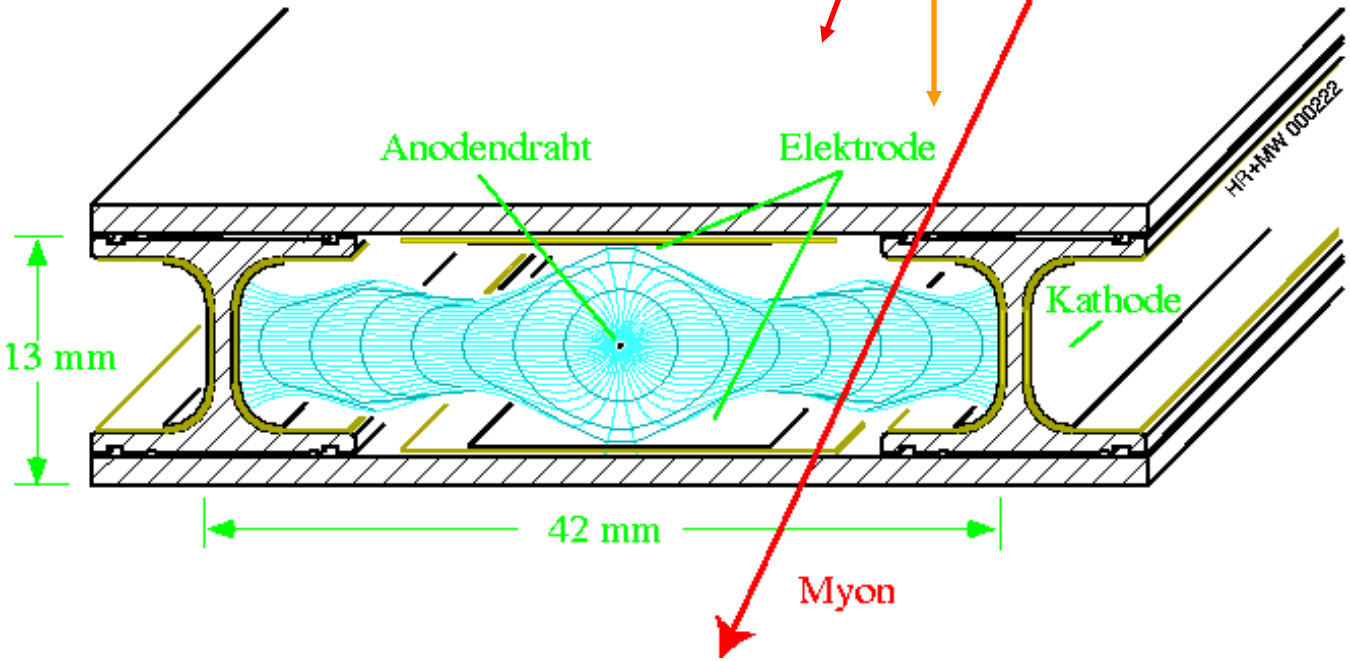
Extreme Zeitlupe, da sich alle Teilchen mit Lichtgeschwindigkeit bewegen!



Die CMS-Myonkammern

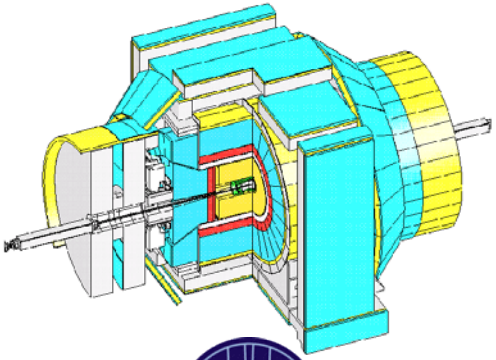


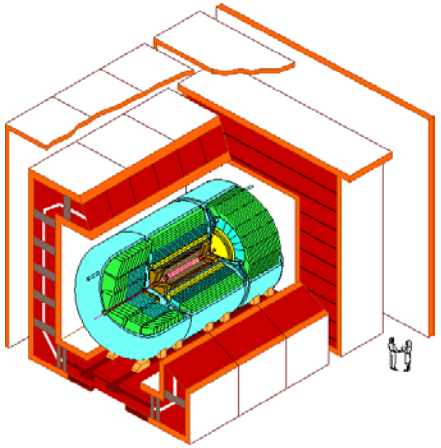


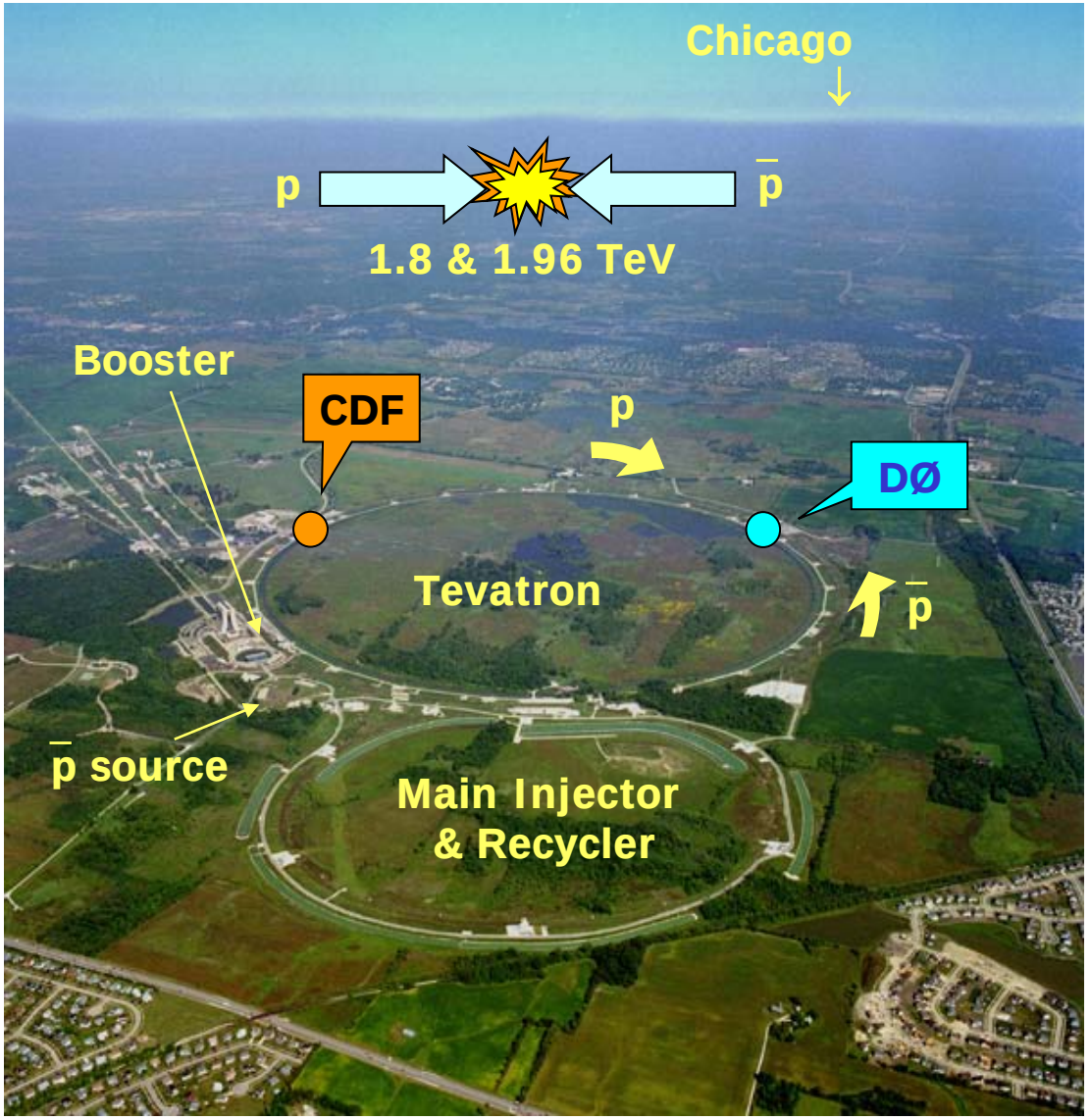


Kammerproduktion Aachen

Tevatron Experimente: Aachen bei DO







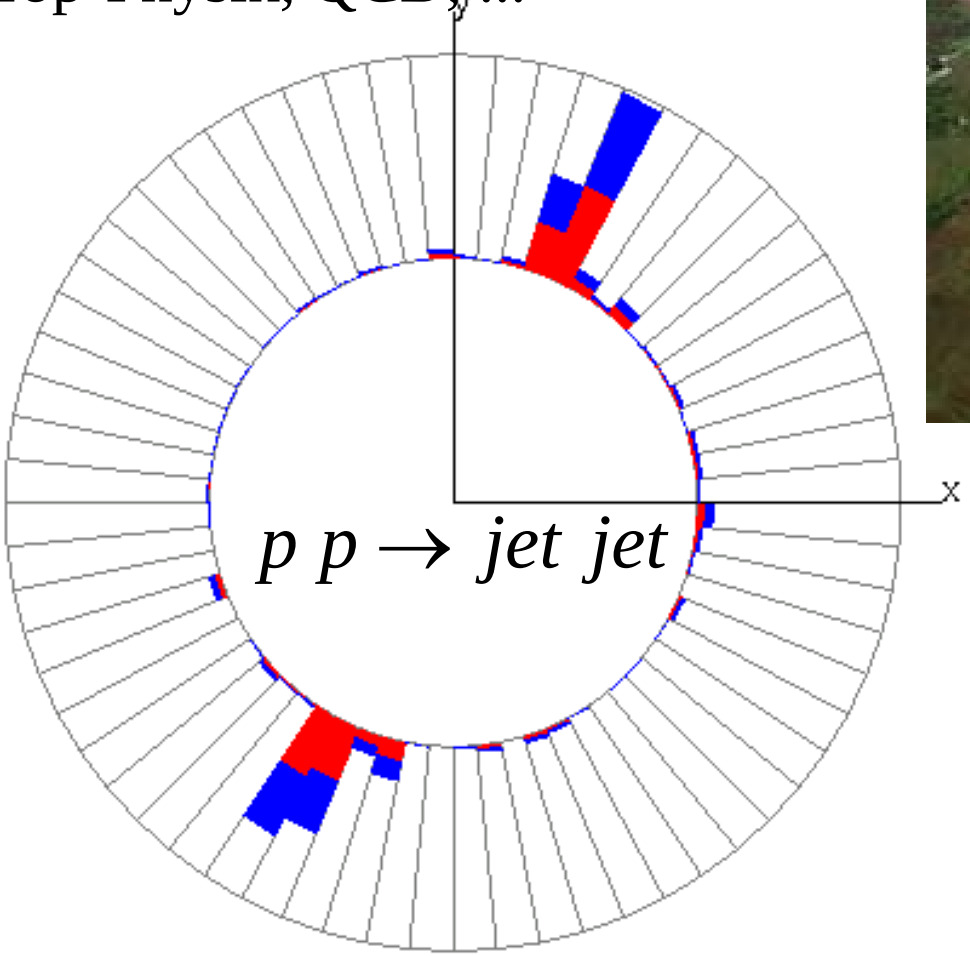
Fermilab: DO-Detektor am Tevatron

DØ-Experiment am Tevatron

p (1 TeV) + $\bar{p}$ (1 TeV)

Bisher:

Top-Physik, QCD, ...

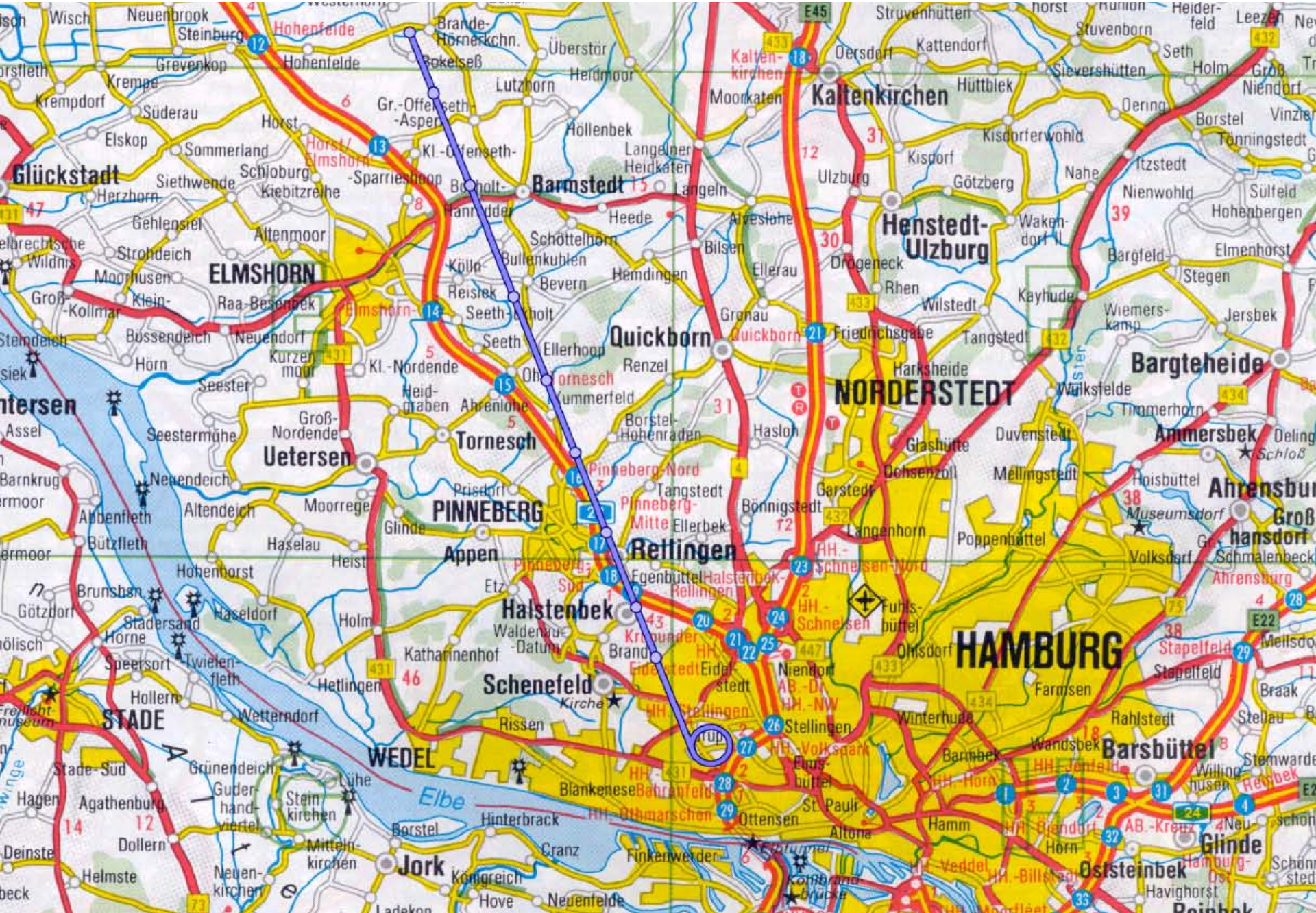


seit 2001(erhöhte Luminosität):

Suche nach

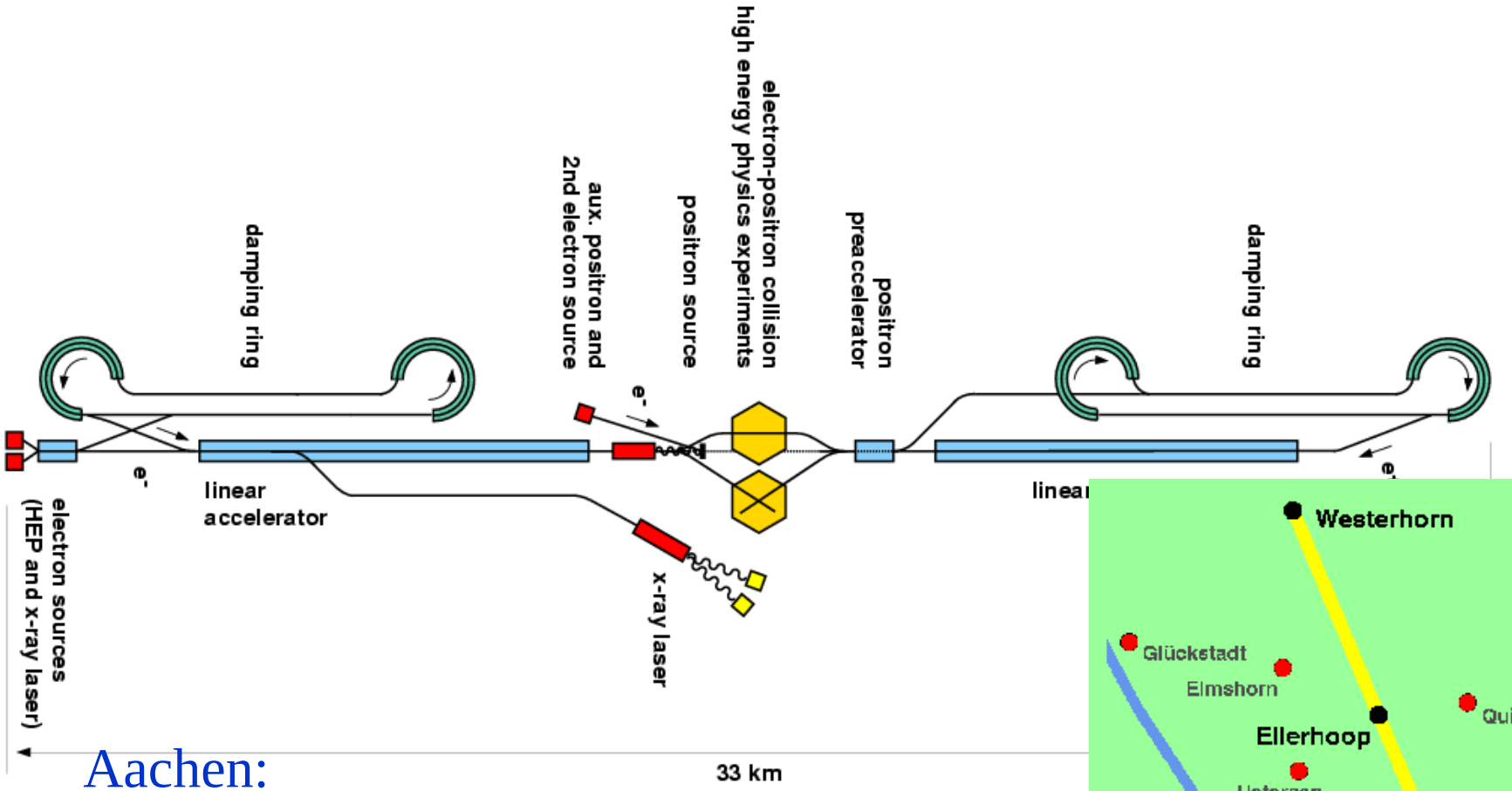
- Higgs
- Supersymmetrie ...

Geplanter TESLA Elektron-Positron-Beschleuniger



Vision: TESLA-Linearbeschleuniger + Detektor

= TeV Energy Superconducting Linear Accelerator $(e^+e^-\ 500\,GeV)$

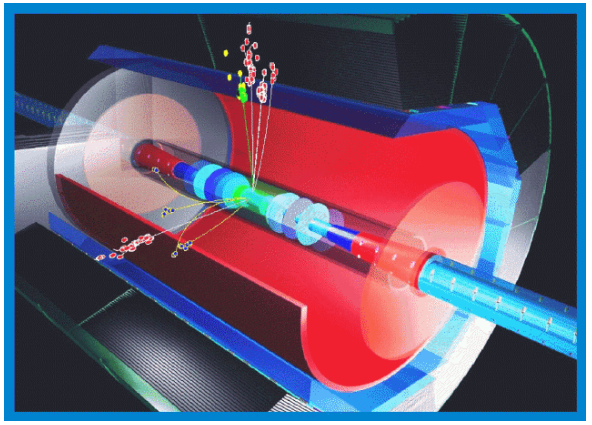


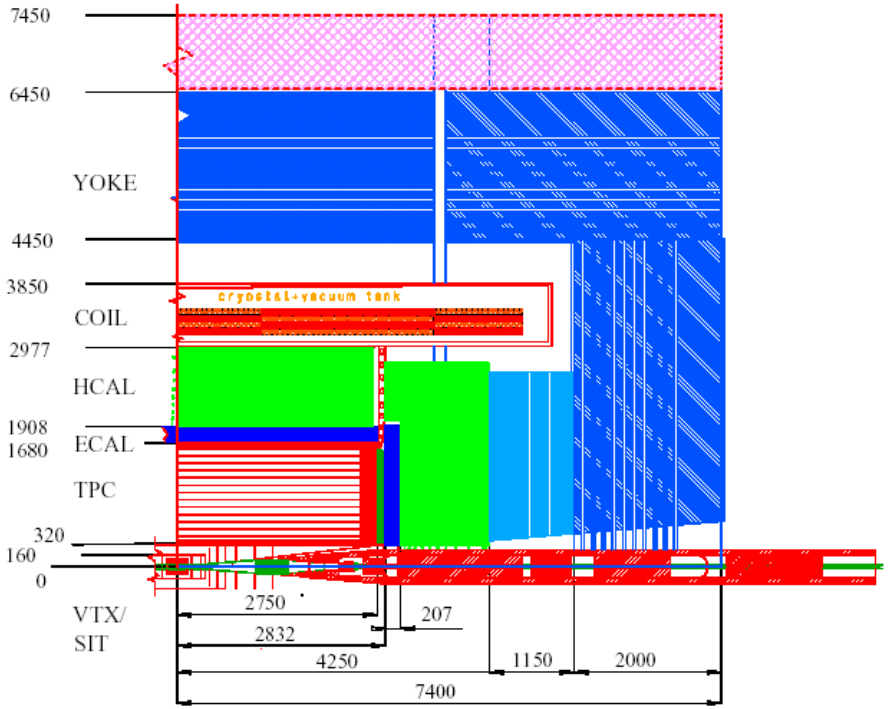
Aachen:

- Beschleunigerphysik
- Detektorentwicklung

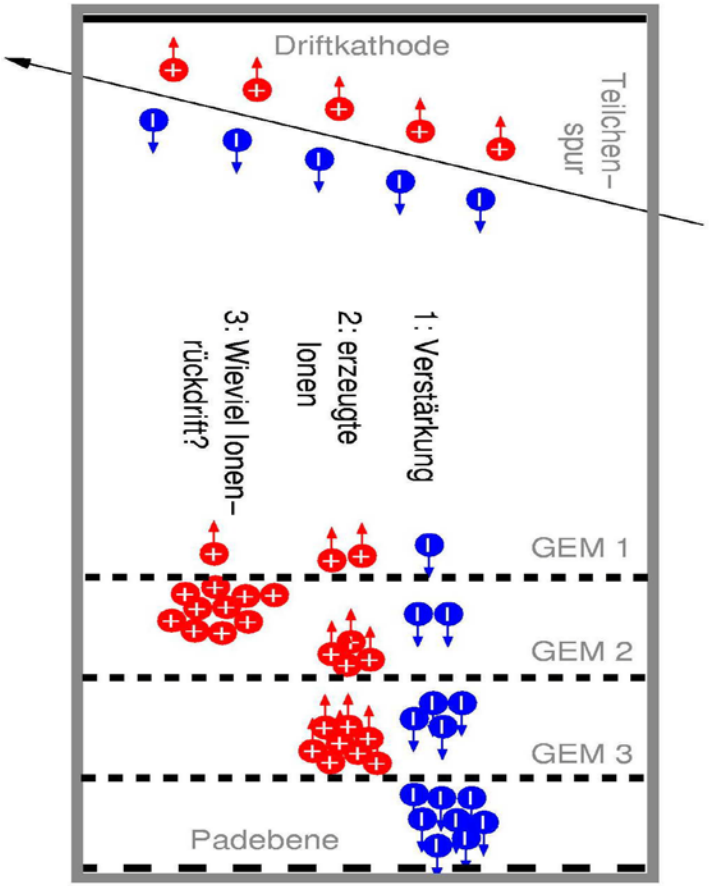
Ein Detektor für TESLA

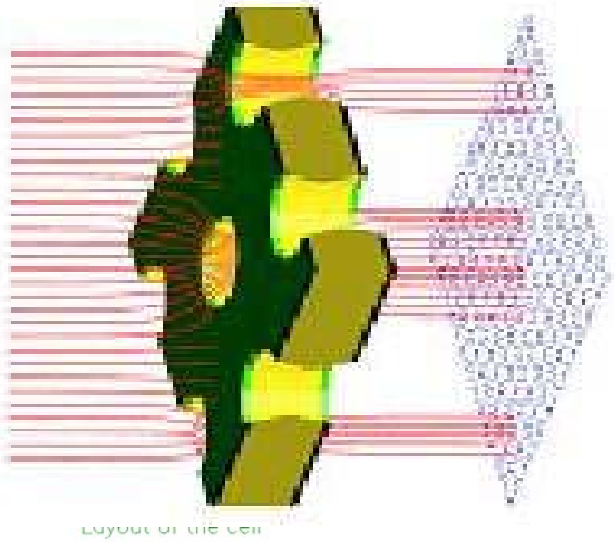
AACHEN beteiligt sich
an der Entwicklung
einer neuen Driftkammer
(TPC)

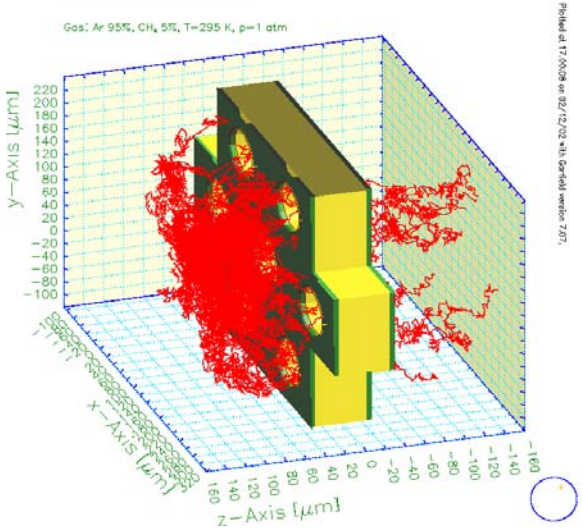




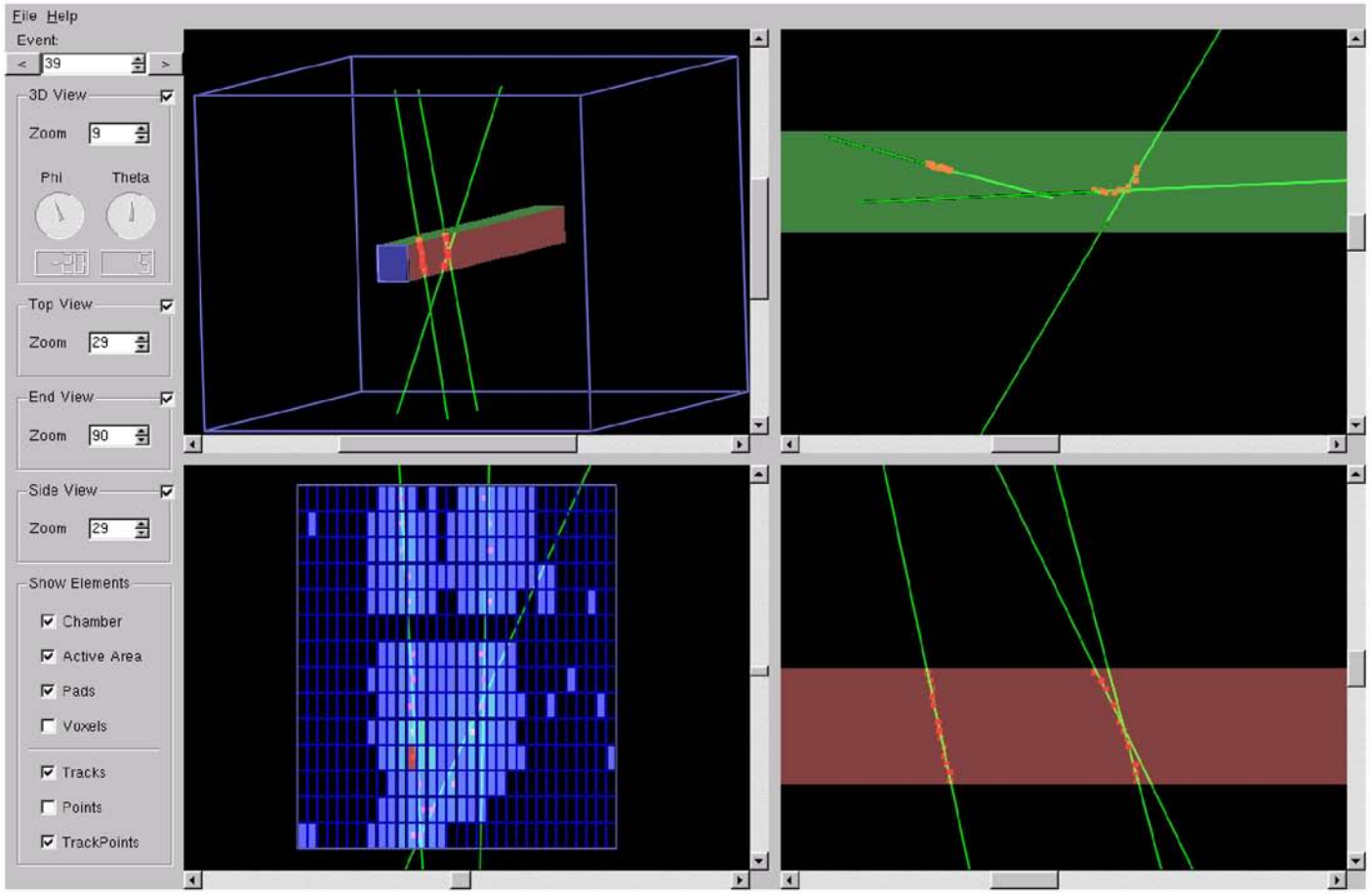
Grosse Driftkammer mit GEM



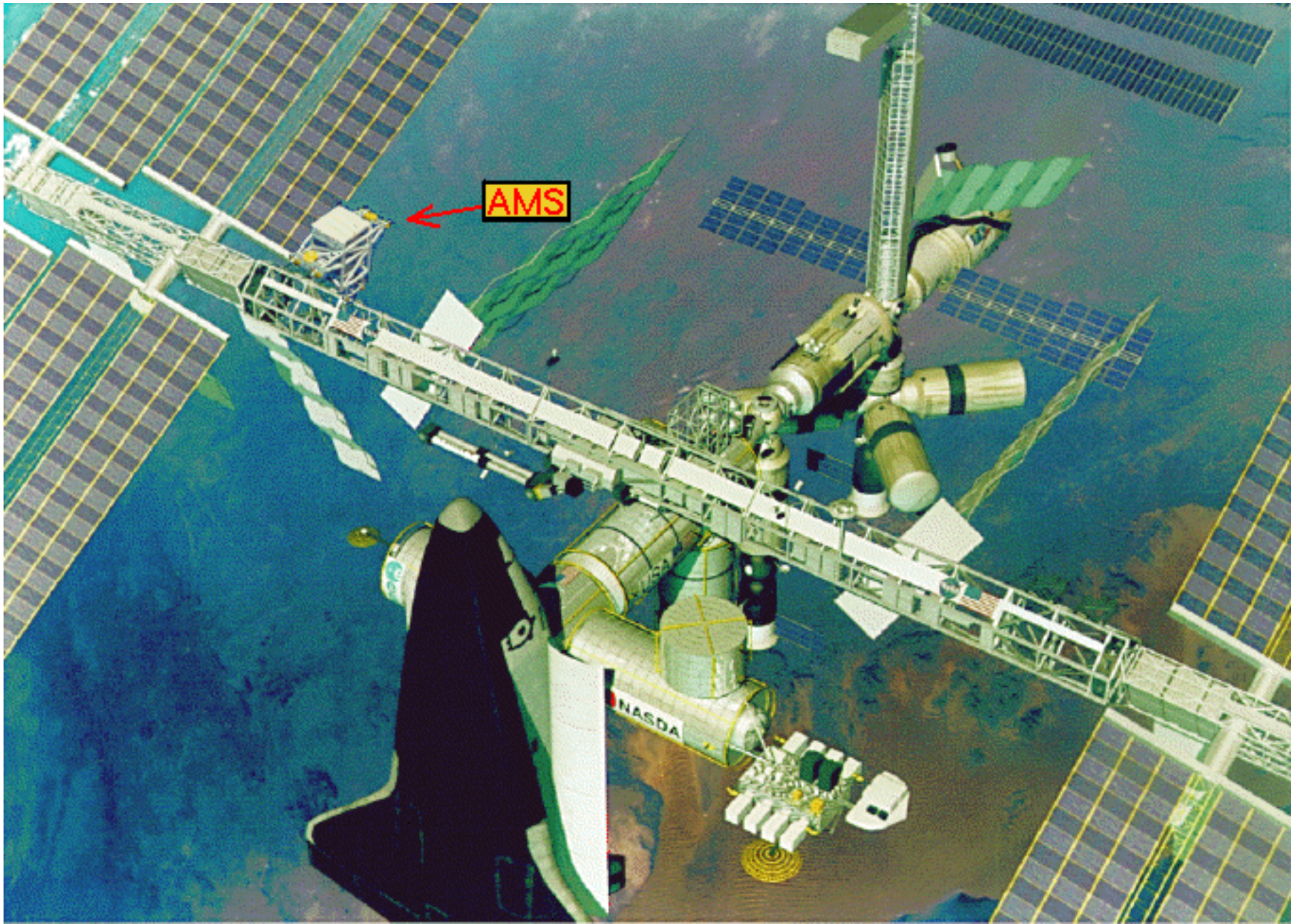




Spur aus kosmischer Strahlung

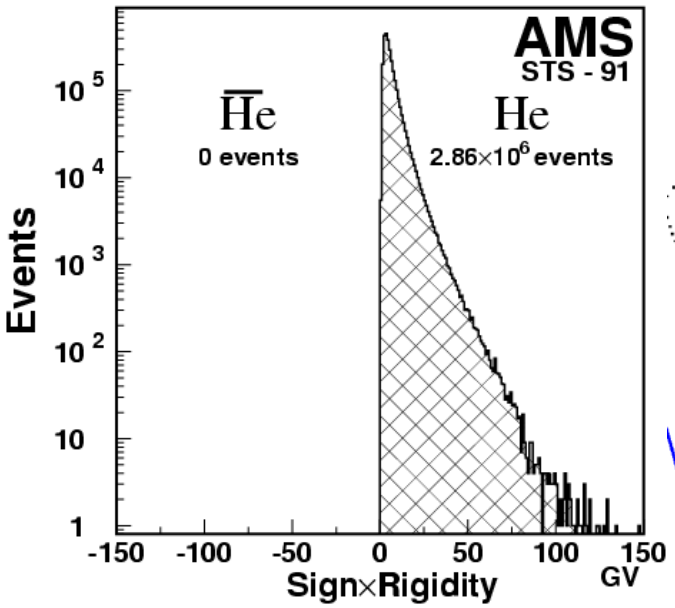


AMS: Spektrometer auf der ISS



AMS=Alpha Magnetic Spectrometer

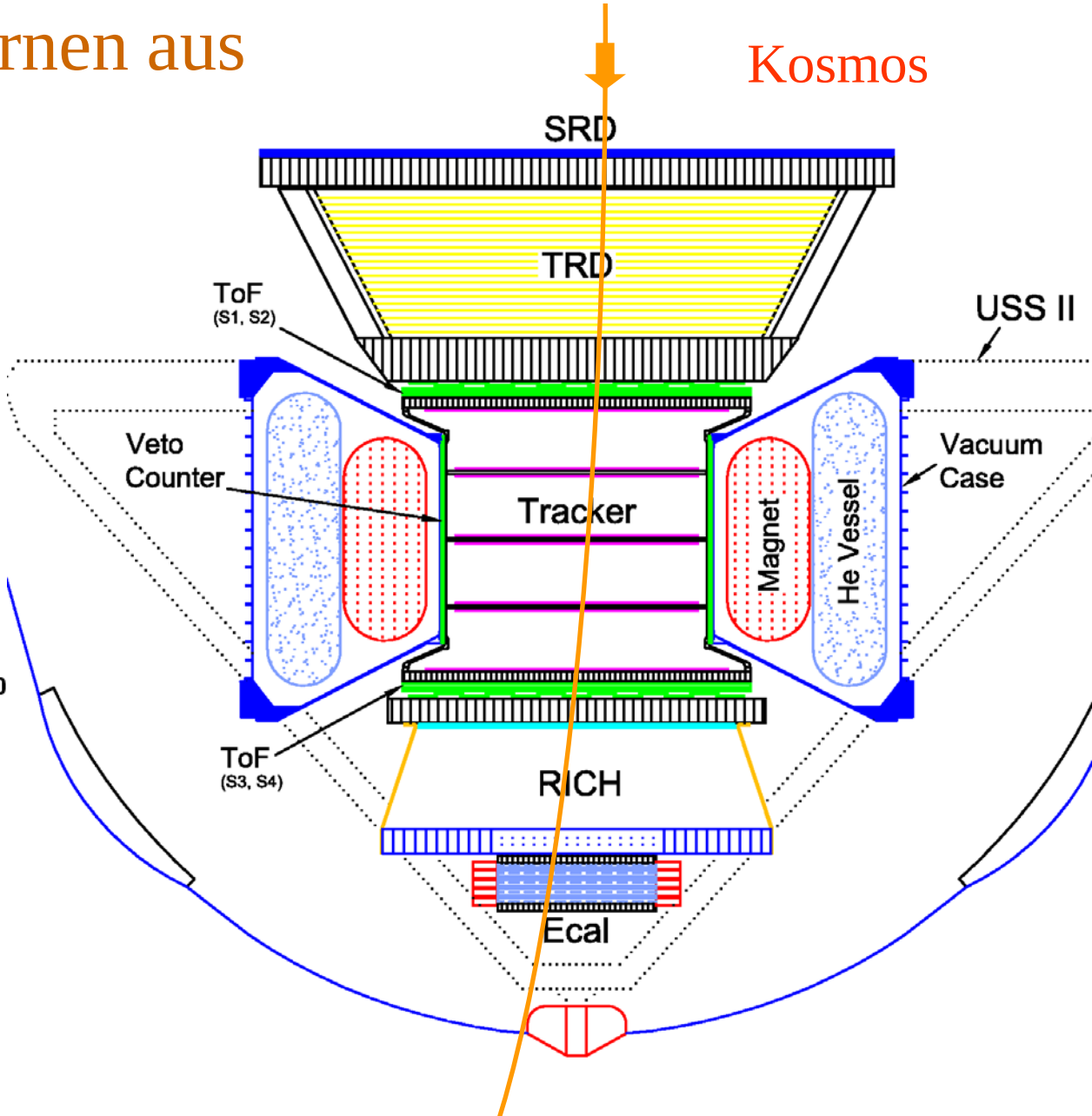
Suche nach Antikernen aus Antigalaxien (u.a.)



Aachen:

- Übergangsstrahlung
- Alignment
- Antizähler

aus dem Kosmos



Personal Hochenergiephysik RWTH

	IB	IIIA	IIIB	Summe	Theo
Professoren	**2**	**2**	**2**	**6**	**3**
Wiss. Ang.	**15**	**8**	**7**	**30**	**3**
• Land	10	6	5	21	3
• BMBF	5	2	2	9	1
Doktoranden	**7**	**9**	**9**	**25**	**6**
• Land	1	2	2	5	
• BMBF	2	4	5	11	1
• Grad. Coll.+DFG	4	3	2	9	5
Diplomanden	**7**	**9**	**7**	**23**	**4**
Nichtwiss.Ang.	**21**	**16**	**10**	**47**	**1**
• Land	15	13	8	36	1
• BMBF	6	3	2	11	
Personal ges.	**52**	**44**	**35**	**131**	**17**

Projektmittel aus BMBF-Verbundförderung

	Förderung (M €)	Diplom-Arbeiten	Doktor-Arbeiten
LEP (CERN) 1989 - 2004	16.988	48	38
H1 (DESY) 1989 - 2004	8.122	78	41
SINDRUM PSI 1989 - 2001	1.001	16	12
CMS (CERN) 1996 - 2006	18.139 (+ 1.6 M €)	44	18
Detektorentwickl. TESLA etc.	2.940	53	23
Summe	47.190	239	132

+1.329 M € Theorie

Übersicht experimentelle Hochenergiephysik

	laufend. Jahr	**Gesamt** (seit 1989)	Verwendung
Land:			
• **Wissensch.-Stellen**	**30**	**ca. 22.5 M €**	**Forschung + Lehre**
• **laufende Mittel**	**350 T €**	**ca. 5.0 M €**	**vorwiegend Lehre**
• **Berufungszusagen**		**ca. 1.9 M €**	**Labor**
• **Werkstatt+Labor**	**4900 m^2**		**vorw. Forschung**
darin techn. Personal	**25**	**ca. 11.3 M €**	**vorw. Forschung**
Land + Bund:			
• **HBFG + DFG**		**ca. 1.9 M €**	**Rechner + Labor**
• **Grad.-Kolleg**	**240 T €**	**ca. 2.2 M €**	**vorw. Forschung**
darin Stellen	**9**	**(seit 1992)**	**vorw. Forschung**
Bund:			
•**BMBF-Verbund**	**2.3 M €**	**ca. 47 M €**	**Forschung**
darin Stellen	**15**	**(bis 2006)**	**Forschung**
•**DLR für AMS**	**1.4 M €**	**ca. 7 M €**	**Forschung**

Besichtigungsprogramm
Experimentelle Elementarteilchenphysik

Physikzentrum Seffent/Melaten

Führung 11:00 bis 12.00 Uhr: Prof. T. Hebbeker, Prof. S. Schael

I B:

CMS Silizium-Spurkammer

III A:

CMS Myondetektoren

III B:

CMS Elektronik für Spurkammer

Zusammenfassung Elementarteilchenphysik

Standardmodell:

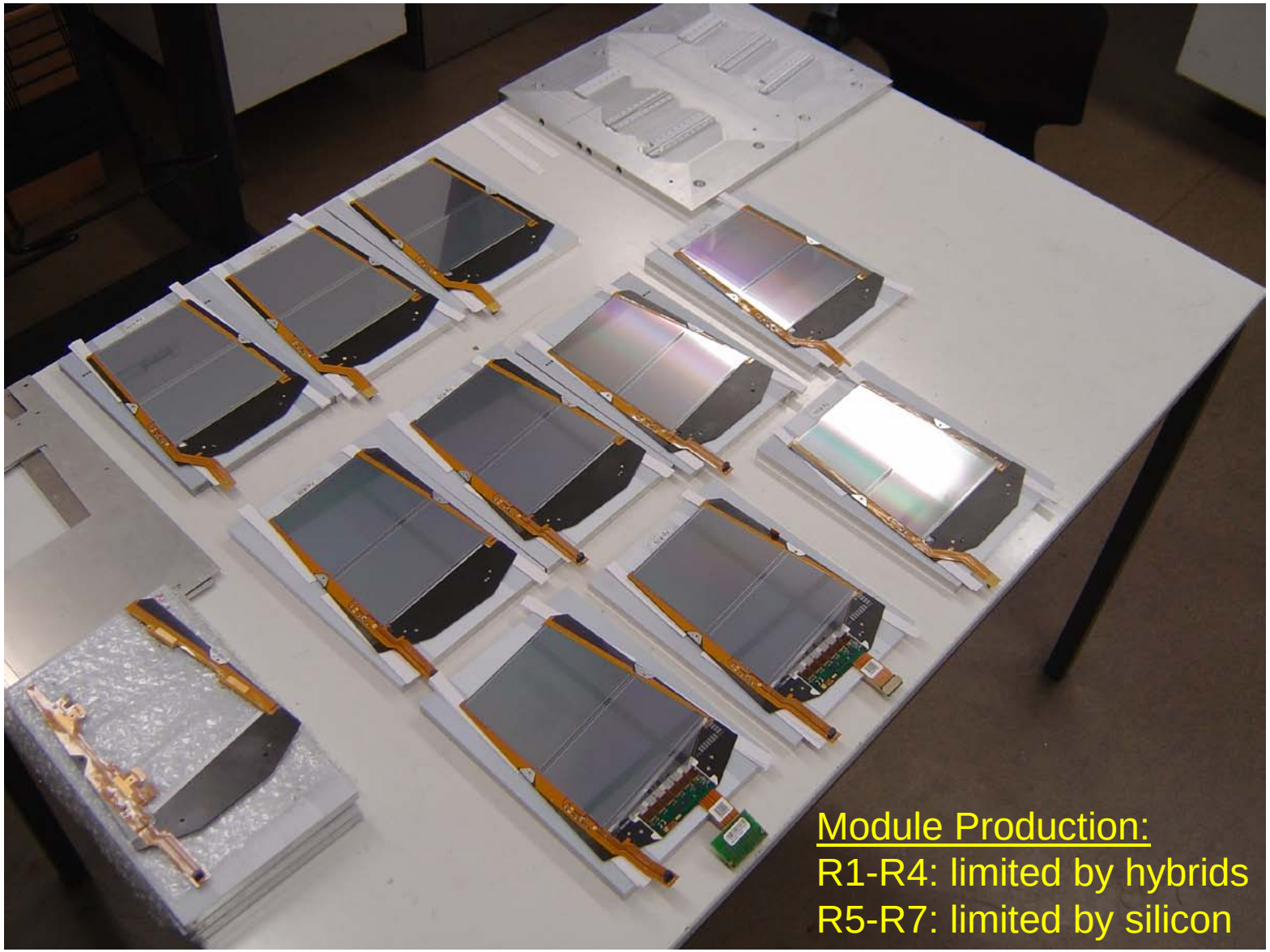
3 Familien von Leptonen und Quarks

Starke und elektromagnetische und schwache Kraft

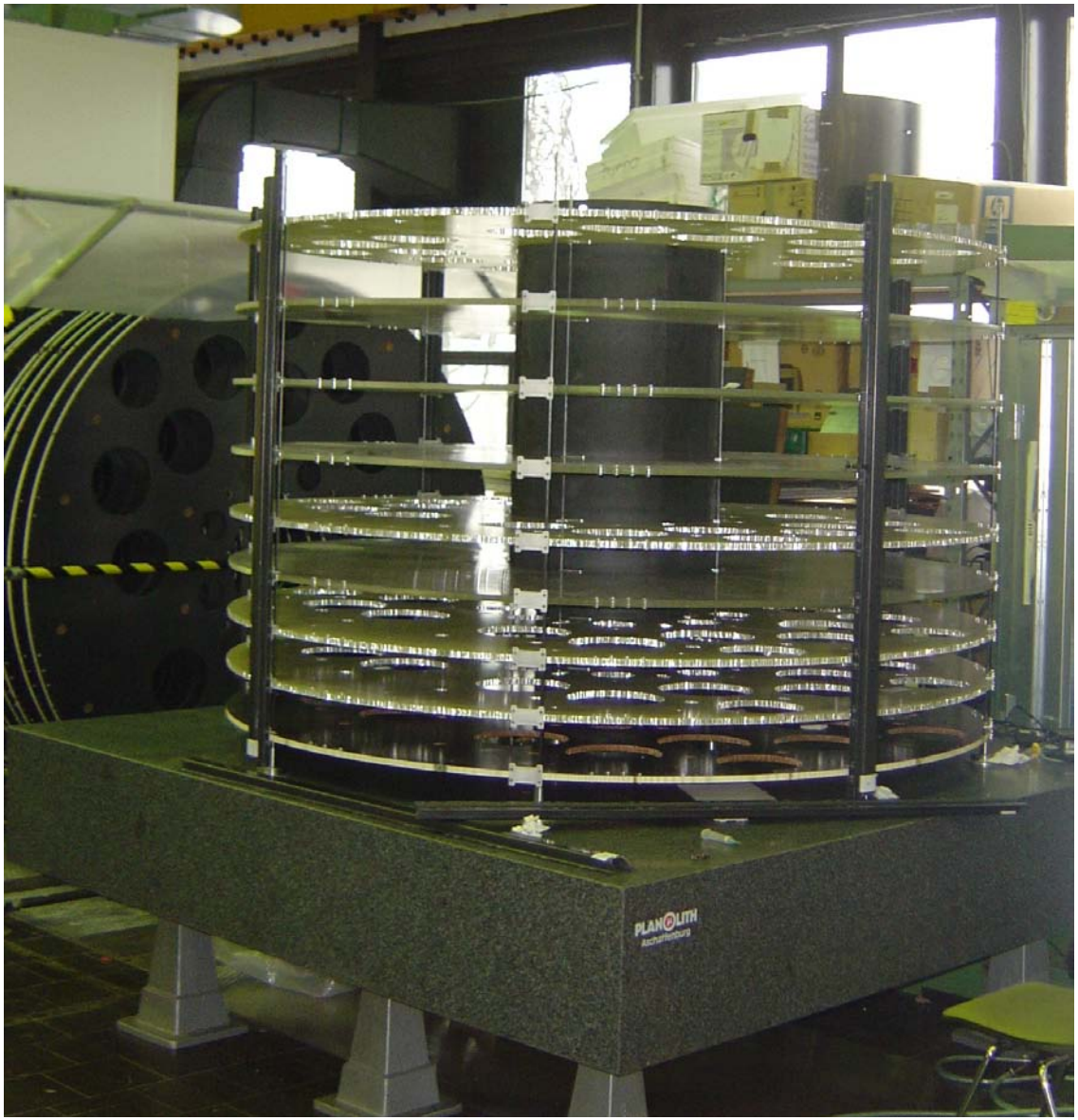
? Higgs ?

Fermilab

R5S/R5N Modules

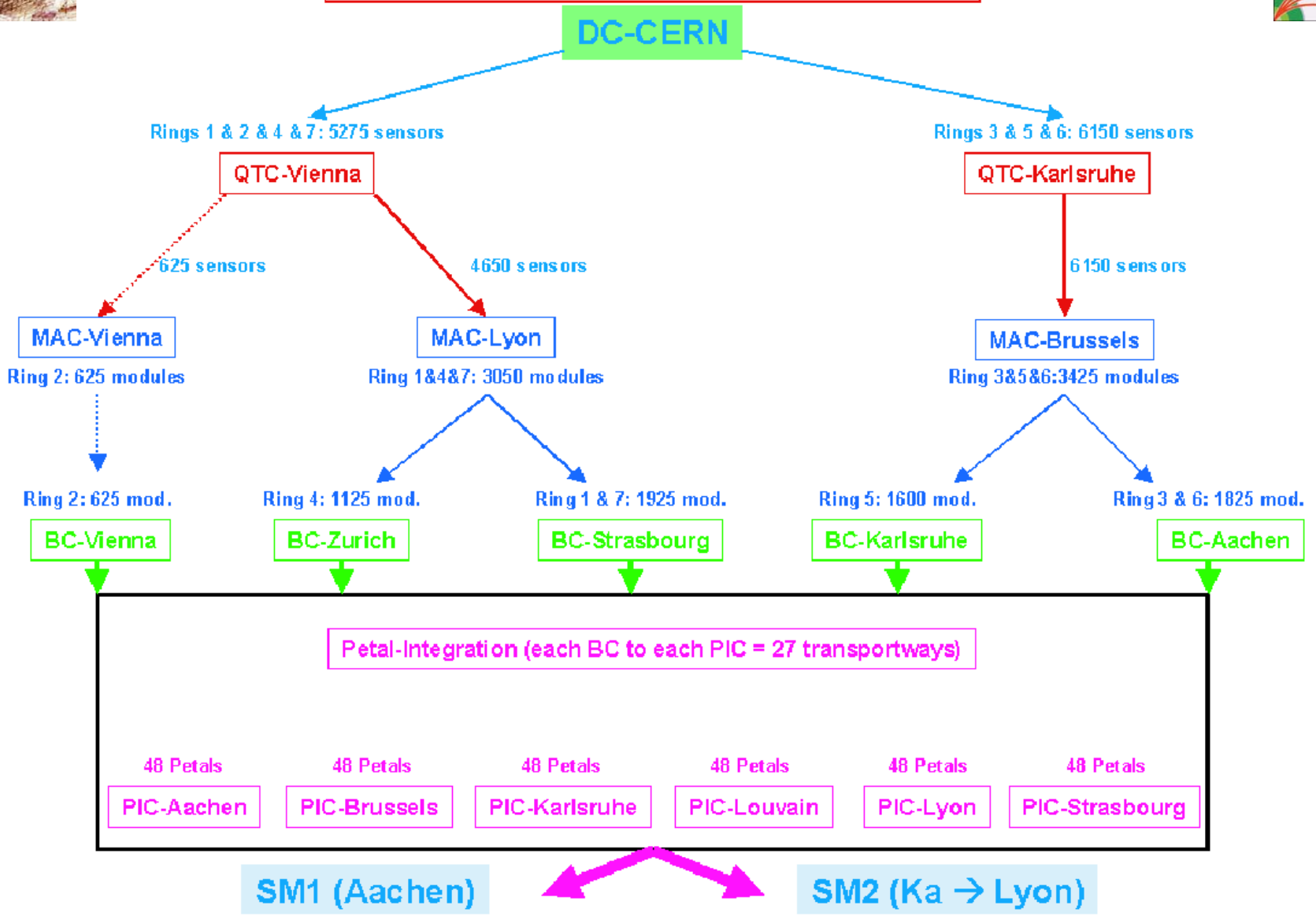


Mock-Up scale 1:1 nearly compled



Logistic for the Tracker End Cap

11425 sensors / 7100 modules (including 10% contingency)



Details of the Fit:

χ^2/dof = 25.5/15

TEC Front Petal

Side B

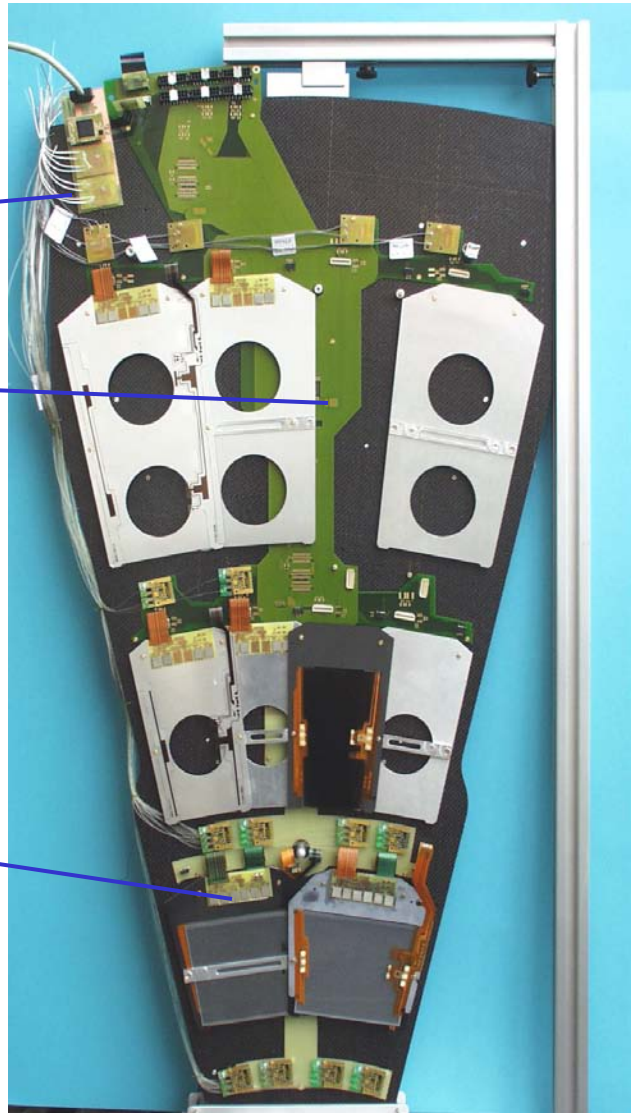
Side A

Digital Optical Hybrid

Interconnect Board

Analogue Optical Hybrid

Frontend Hybrid



R#6

R#4

R#2

R#7

R#5

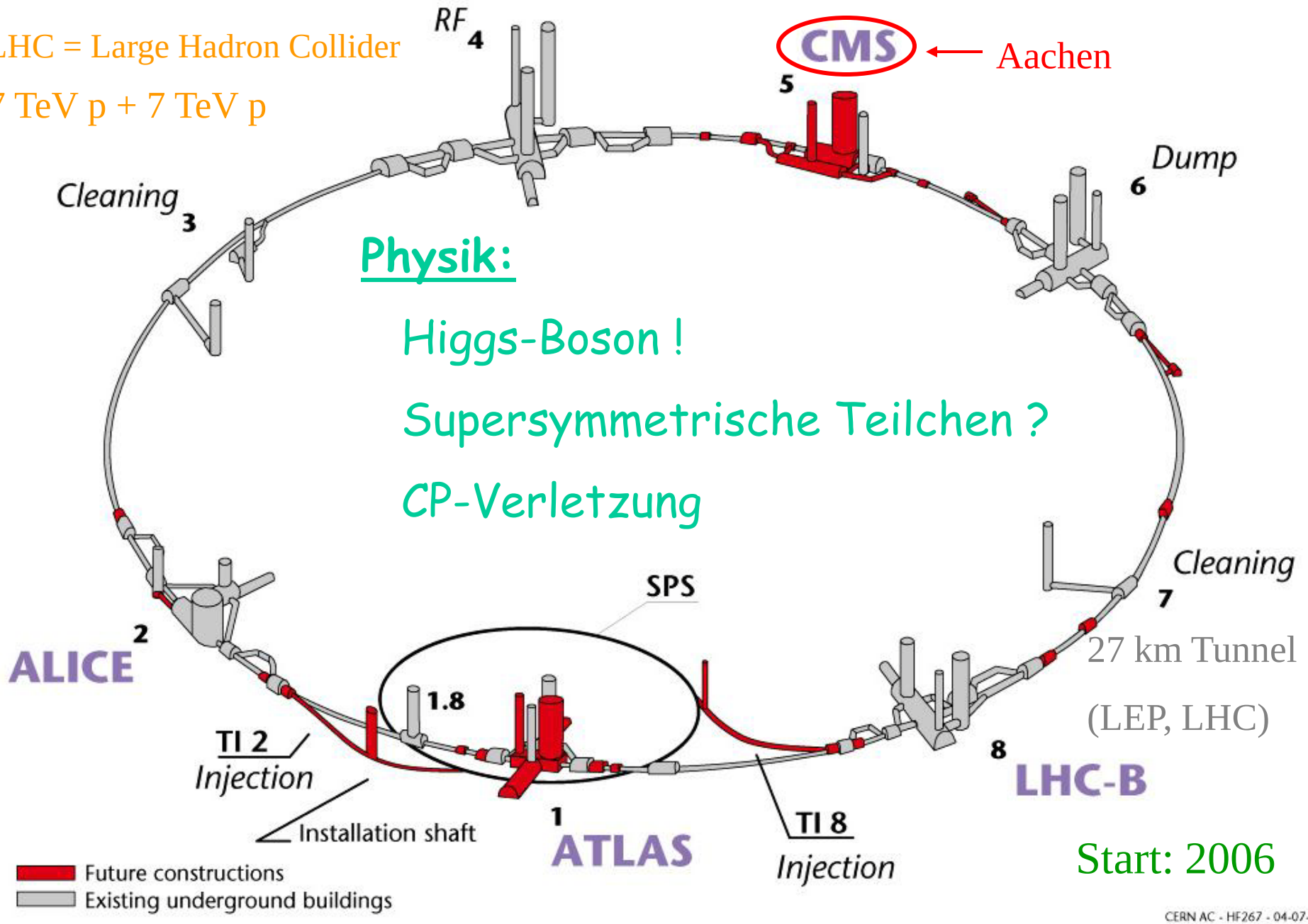
R#3

R#1

Zukunftsprojekt LHC am CERN

LHC = Large Hadron Collider

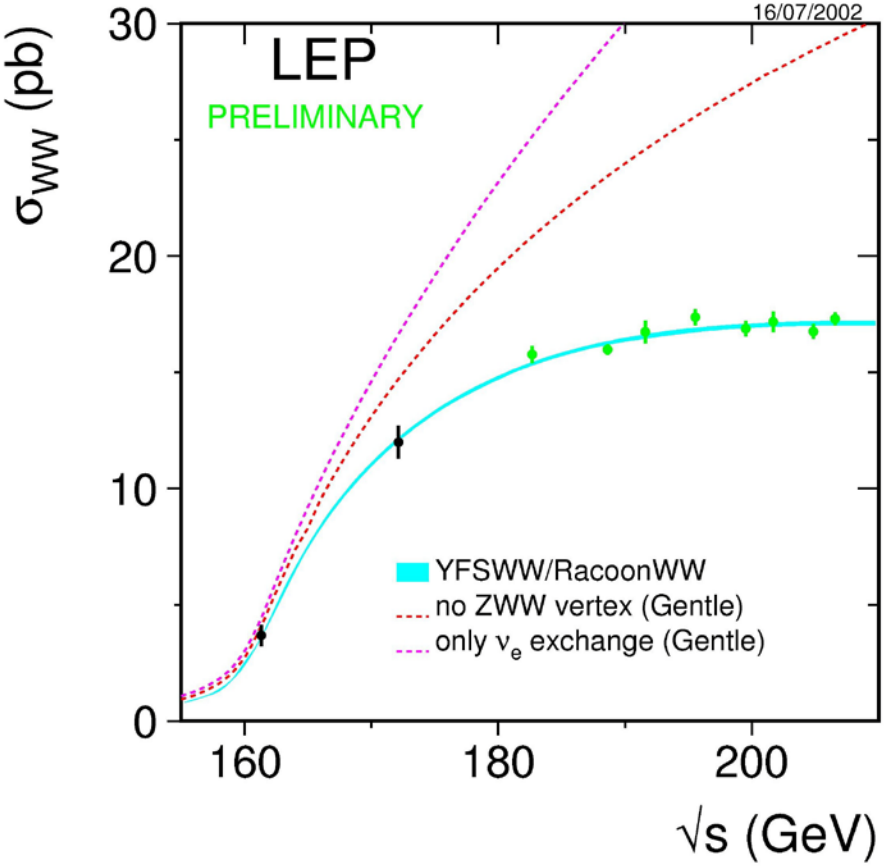
7 TeV p + 7 TeV p



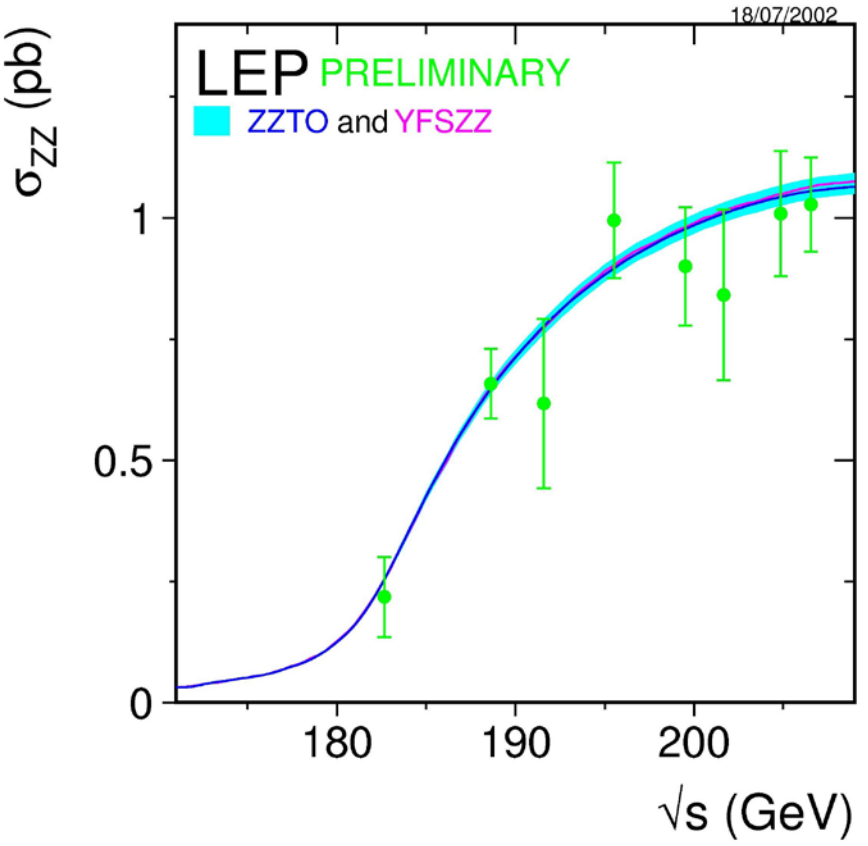
LEP II: Boson Pair Production

- Total cross sections

$e^+e^- \to W^+W^-$

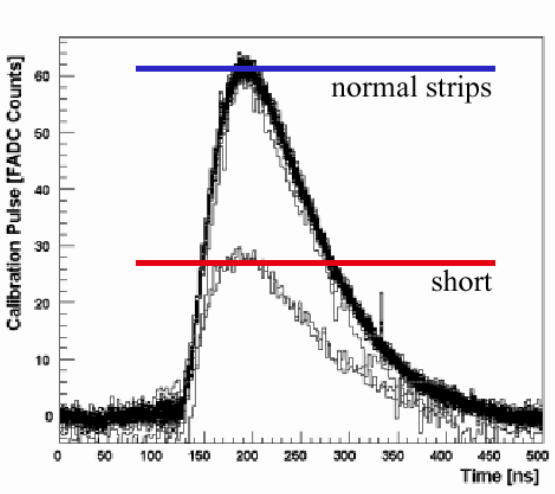


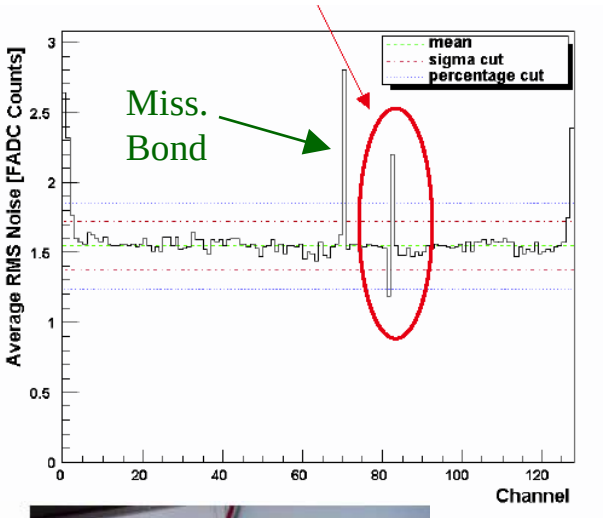
$e^+e^- \to ZZ$

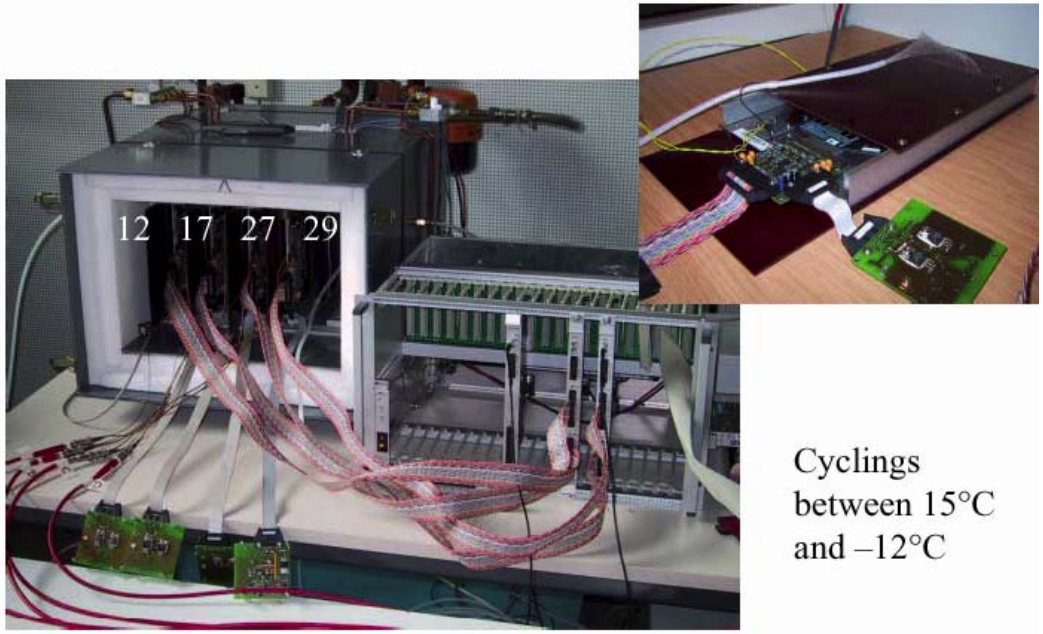


→ ZWW & γWW vertices exist → no ZZZ or γZZ vertex

TEC Express Lines: > 30 R6 modules – All very good!





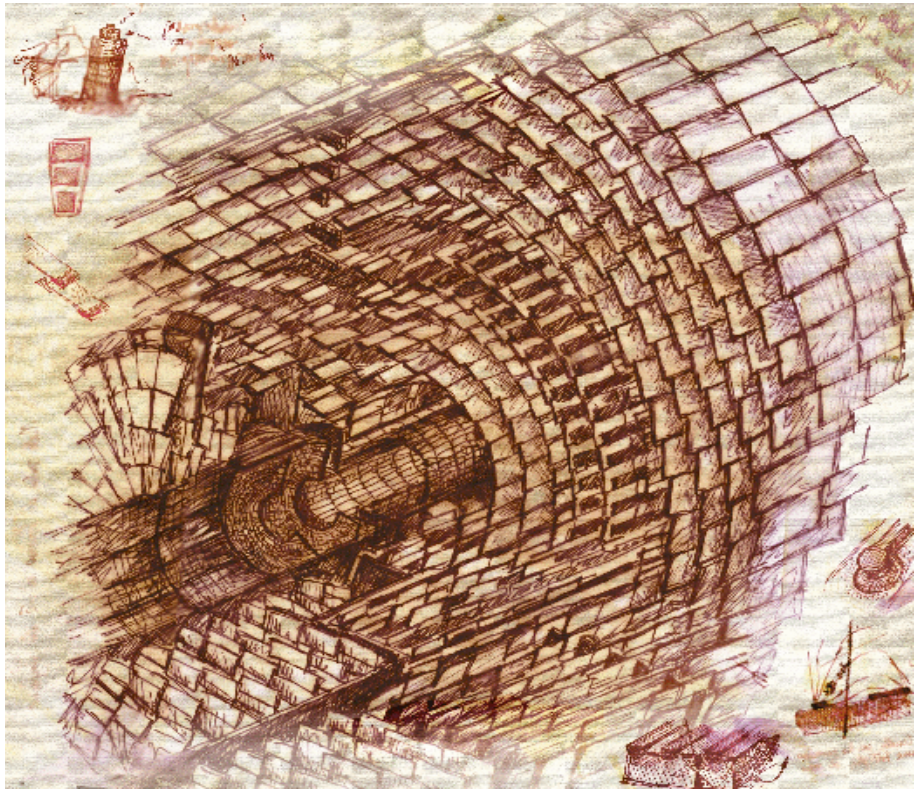


Cyclings between 15°C and –12°C

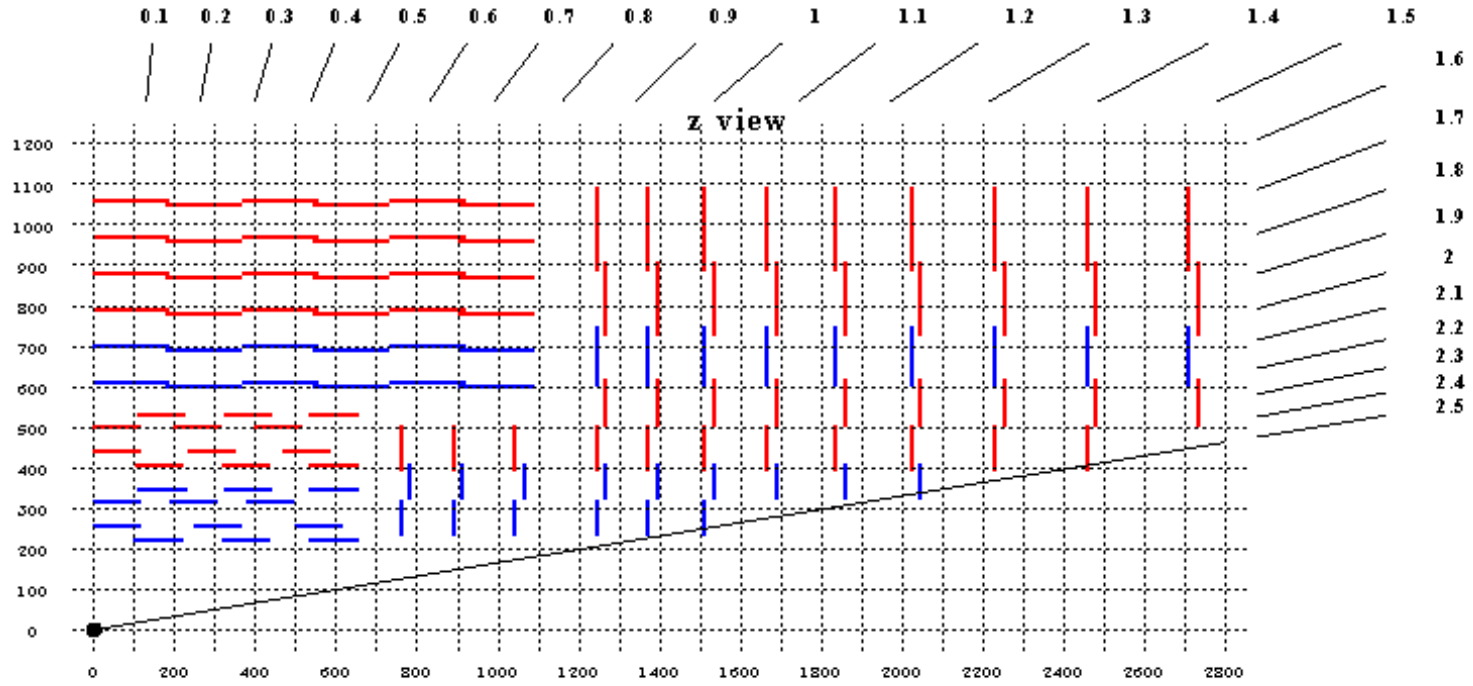
Thermal Cycling

4 TEC Modules,
2 ARC Boards

CMS Silicon Tracker

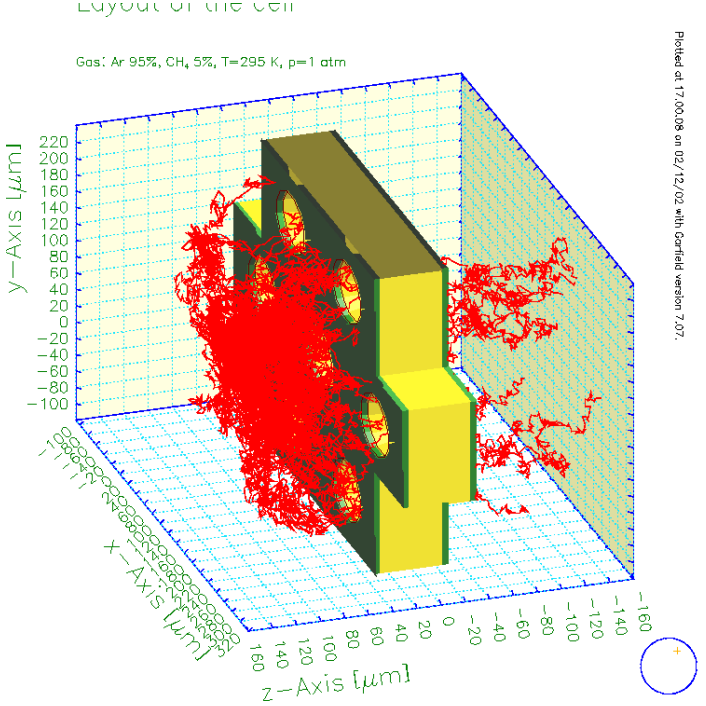


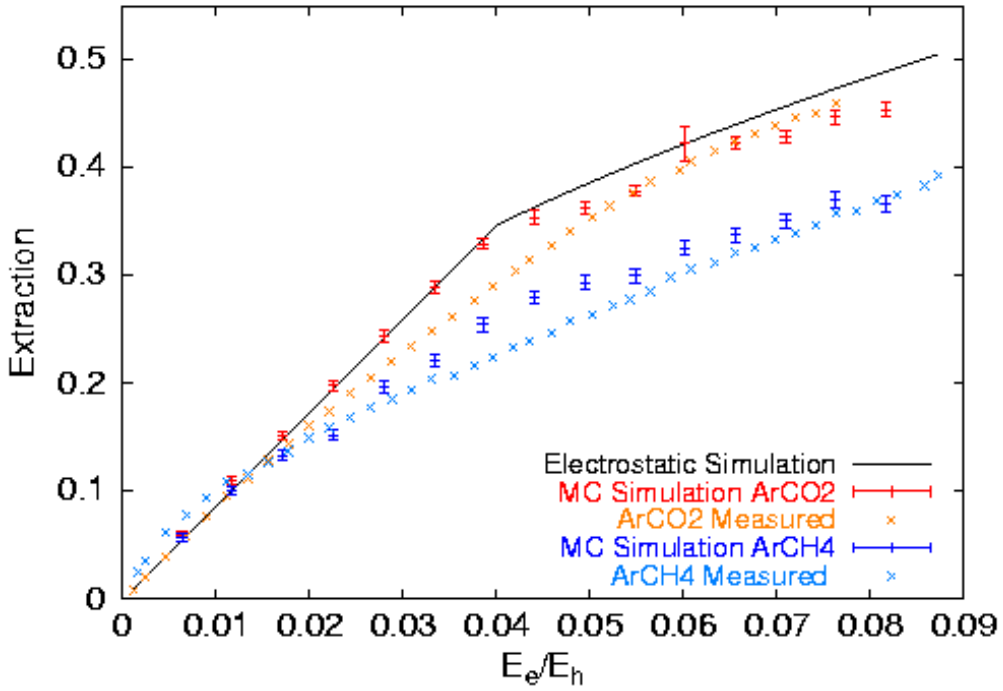
Layout in detail (1)



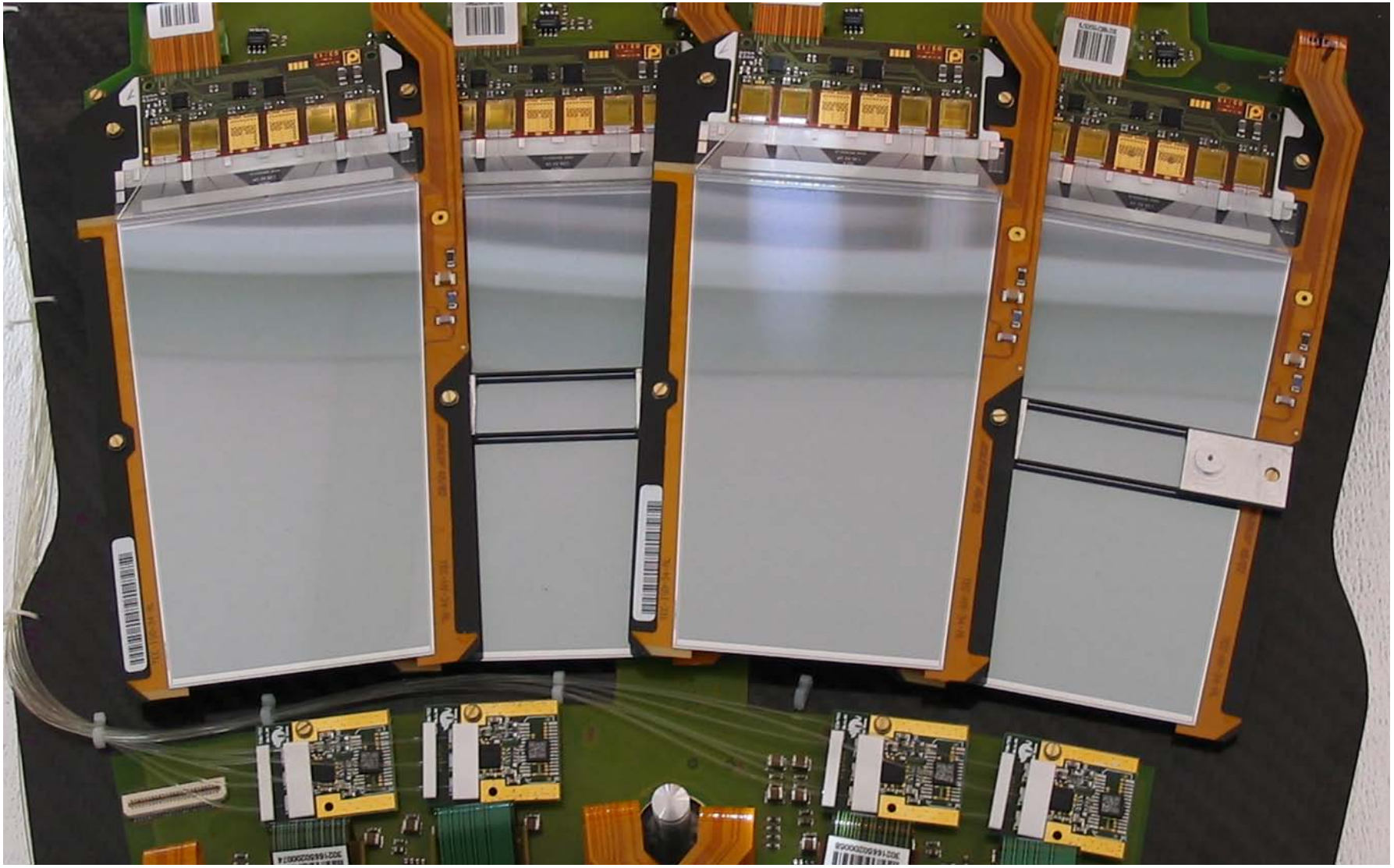
Simulationen

- Numerische Berechnung des elektrischen Feldes mit MAXWELL
- Eingabe der Resultats in die Gasdetektor-Simulation GARFIELD
- Monte-Carlo Simulation der Driftlinien einzelner Elektronen
- Berechnung von Transferparametern (z.B. Extraktionseffizienz)

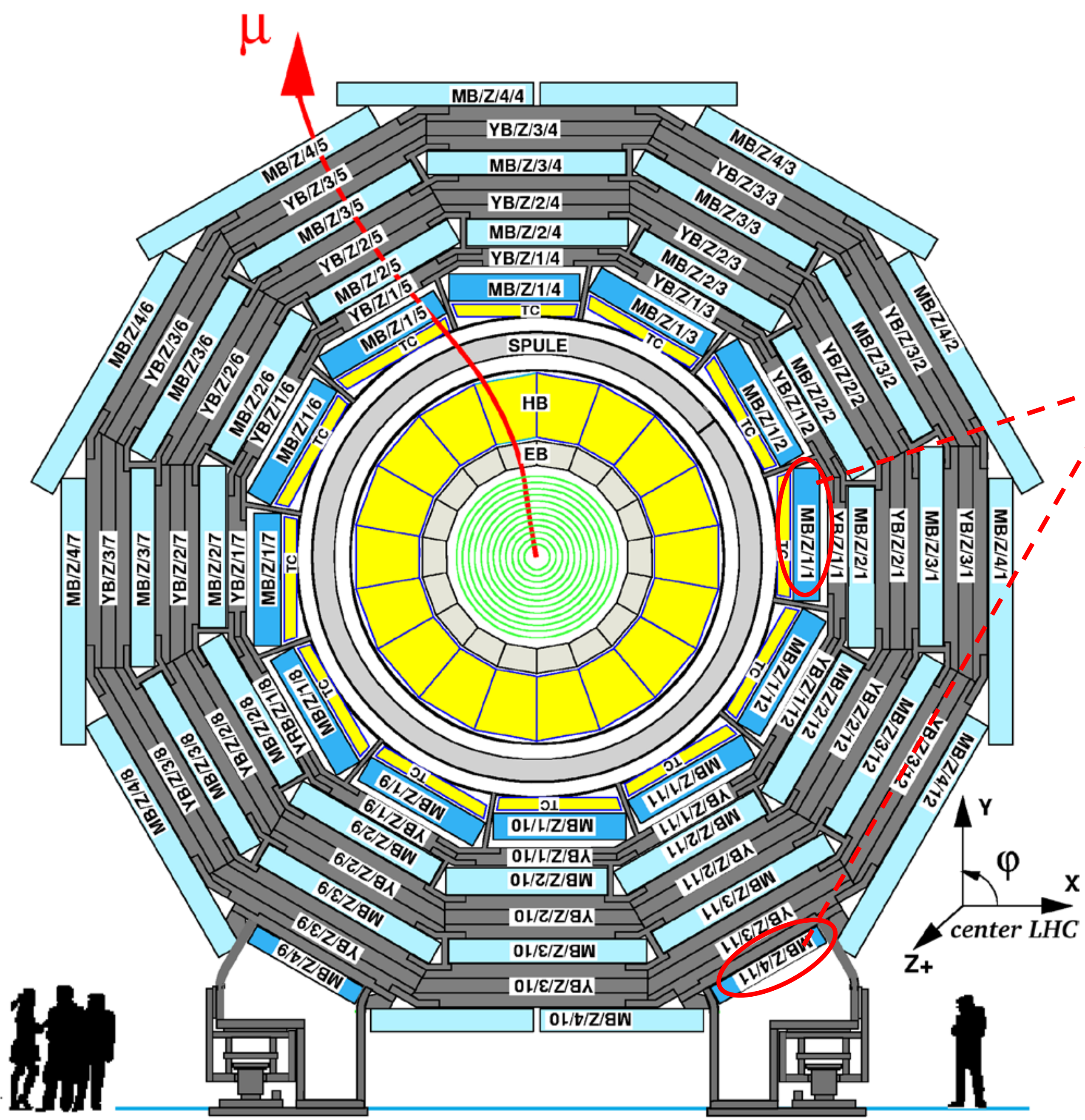




4 Module auf dem Petal (Ring 4)



CMS-Detektor



Barrel-
Myondetektoren =
Driftkammern

Aachen = dunkelblau

70 Kammern

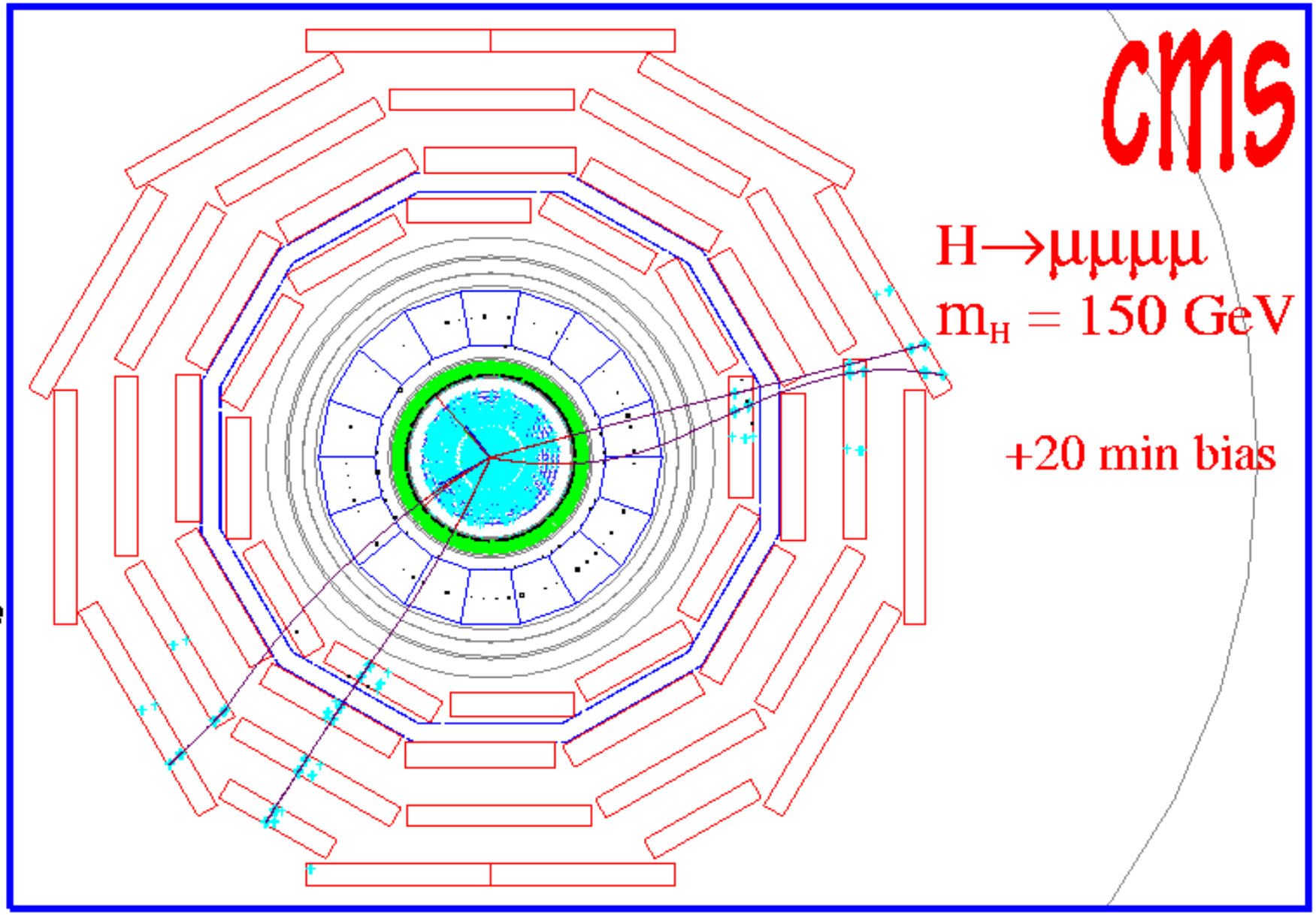
je 2 m x 2.5 m,
12 Lagen

Insgesamt:
4000 qm,
40000 Zellen

Ortsauflösung
pro Kammer:

0.1 mm

Simuliertes Higgs-Ereignis in CMS



CMS-Detektor im Aufbau