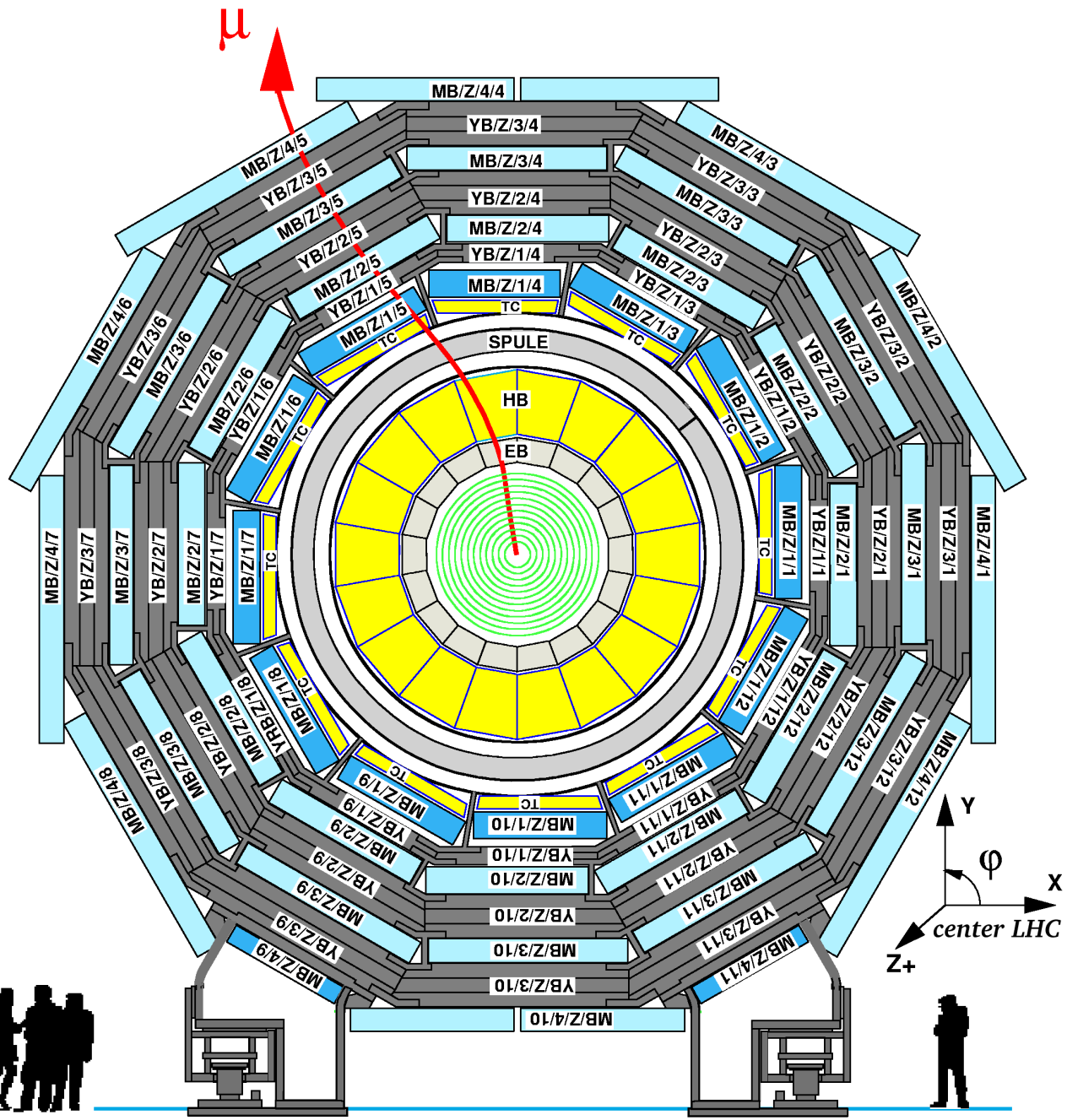
The CMS Muon Detector



Searching for New Physics with High Energy **Muons**

Thomas Hebbeker
Aachen

July 2001

Outline

- LHC and CMS
- energy, luminosity, background
- discoveries with muons
- muons in CMS
- detectors for muons
- Aachen muon project

LHC at CERN

27 km circumference

14 TeV c.m.e. (p p)

1200 TeV (Pb Pb)

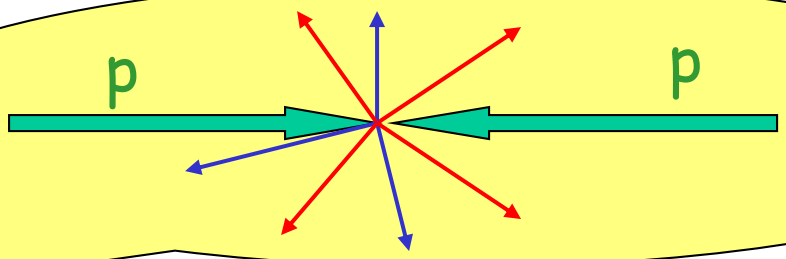
Large

p + p

A + A

no antiparticles !

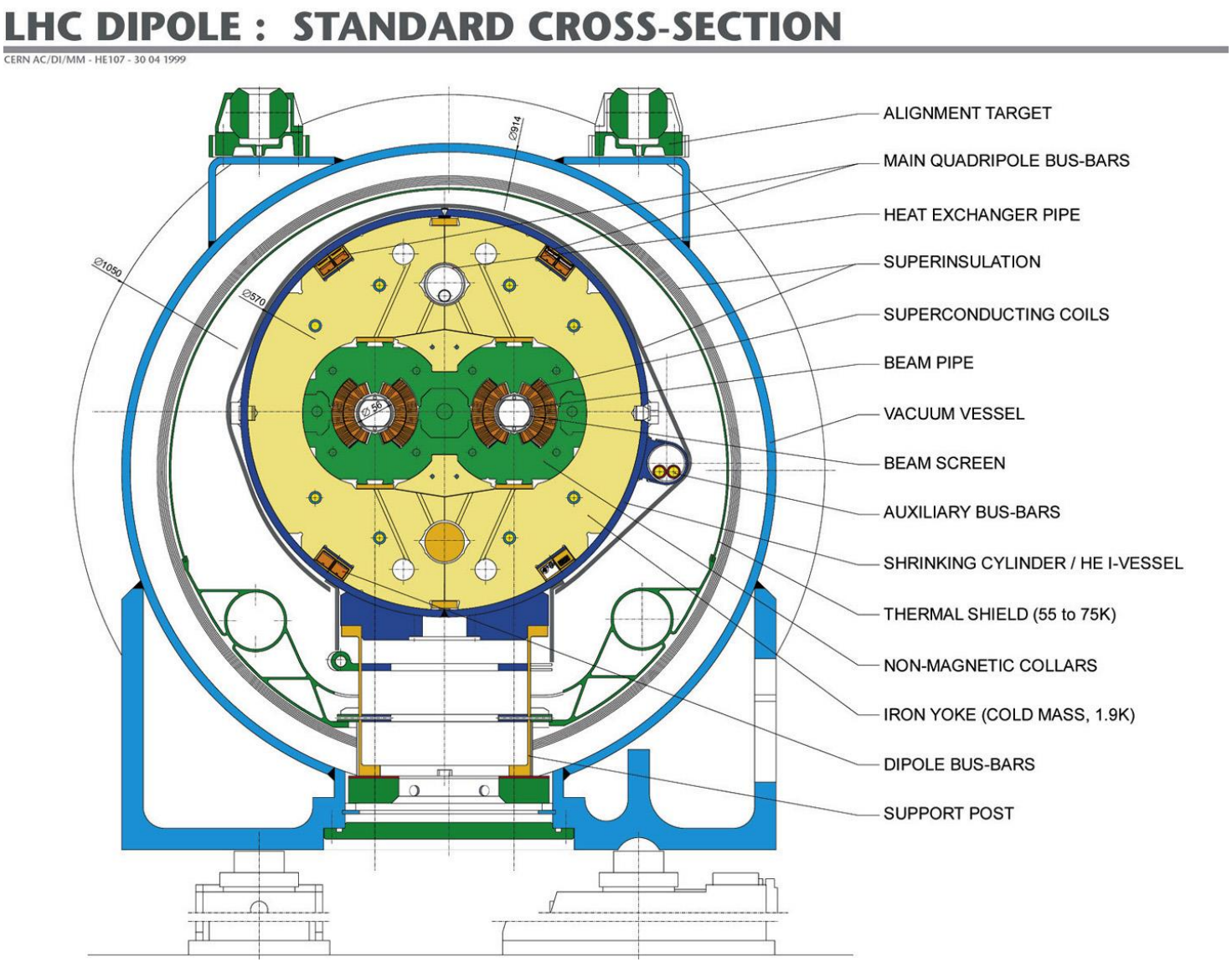
Hadron



Collider

LHC

LHC superconducting magnets

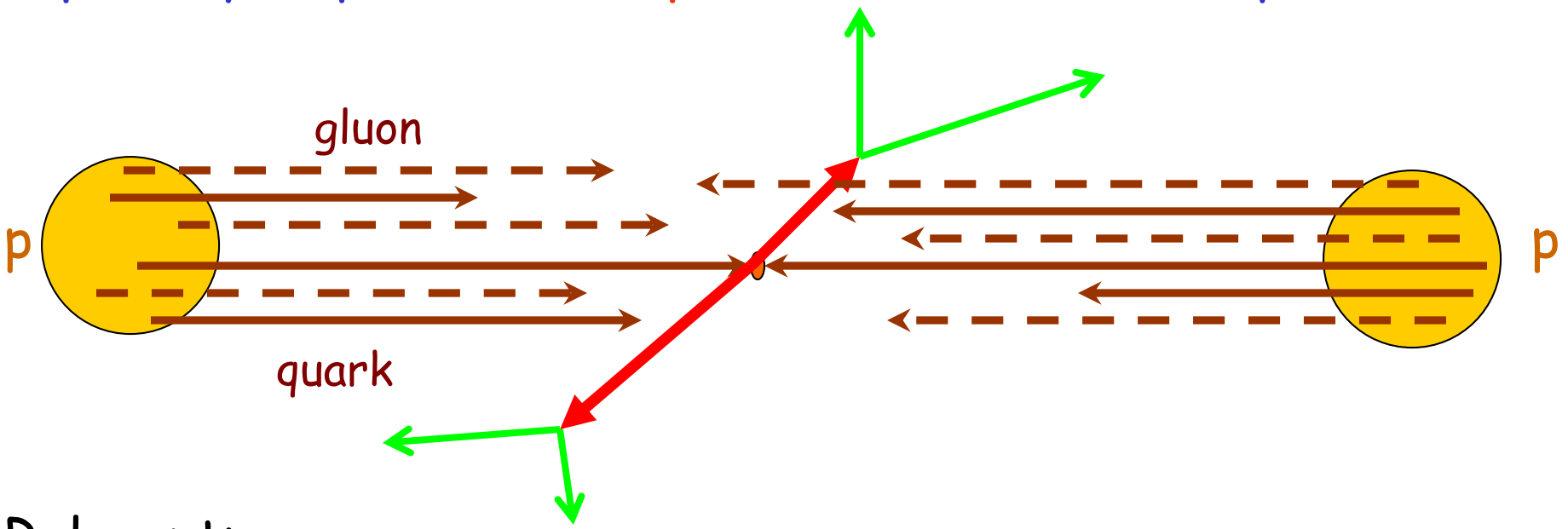


8.3 T 1.9 K 14.3 m 1232 x

Center of Mass Energy $\sqrt{s}$

Required:

capability to produce new particles with masses up to 1 TeV !



Relevant:
center of mass energy $\sqrt{s'}$ of colliding constituents (q, g)

Rough estimate: $\sqrt{s'} \approx \frac{1}{2} \bullet \frac{1}{3} \bullet \sqrt{s}$

Need: $\sqrt{s} \approx 6 \bullet 2 \bullet 1 TeV \rightarrow 14 TeV$

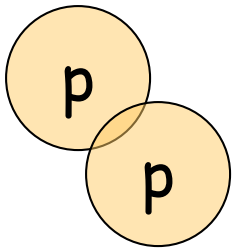
Cross Section and Luminosity

Event rate $\dot{N} = \sigma \cdot L$

> 1/hour

BACKGROUND

Total inelastic cross section

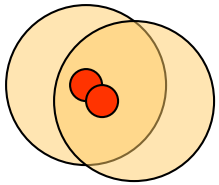


strong

$\sigma \approx 10\, fm^2 \approx 10^{-25}\, cm^2$

SIGNAL

Pointlike cross section



electroweak

$\sigma \leq \frac{\alpha^2}{s} \approx 10^{-36}\, cm^2$

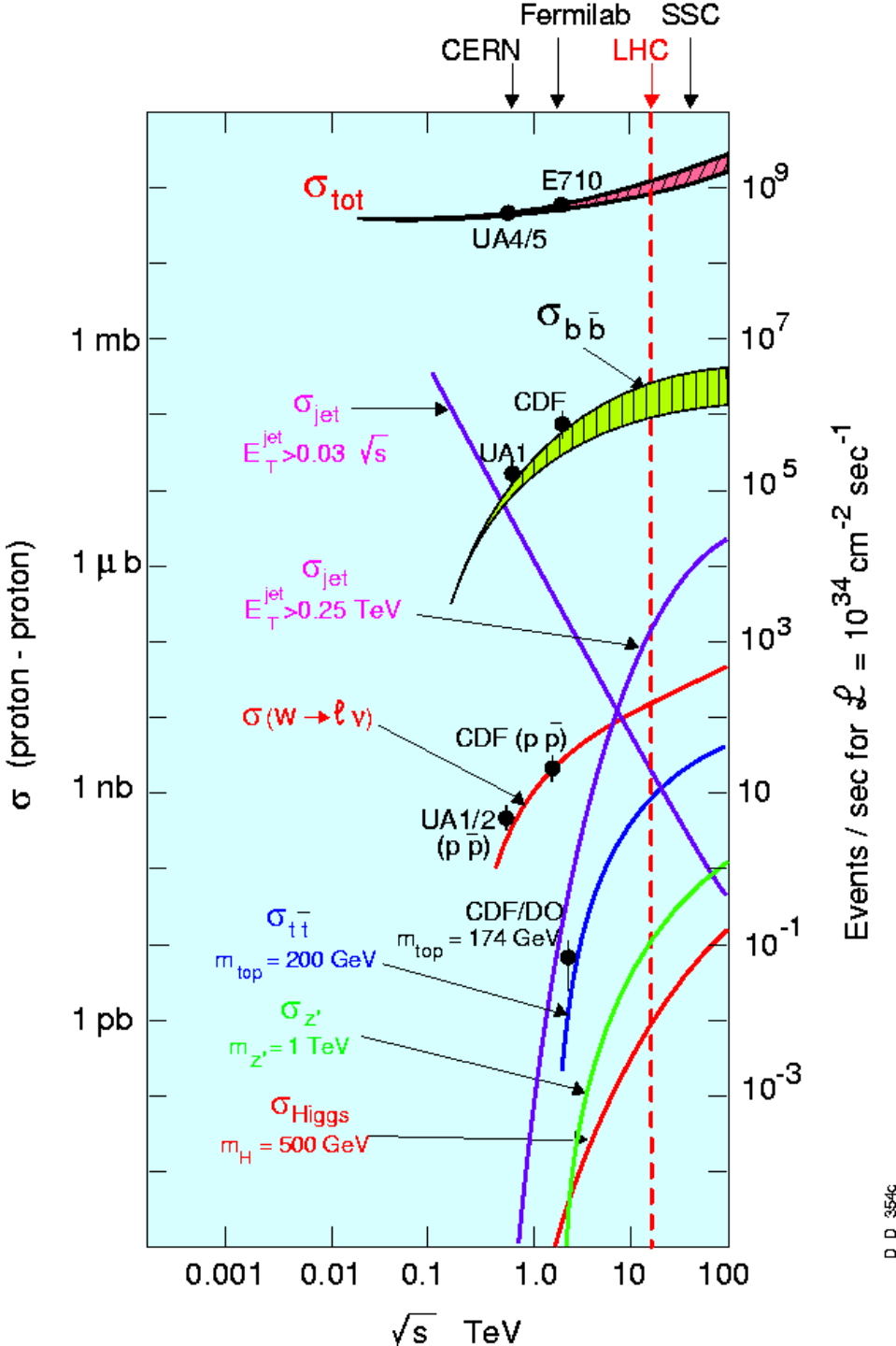
$L = 10^{34} / cm^2 / s$

100 particles /collision

huge background !

10^{11} particles /s

Cross Sections at Hadron Colliders



CMS

diameter = ~~22~~ m 15 m

length = ~~42~~ m 22 m

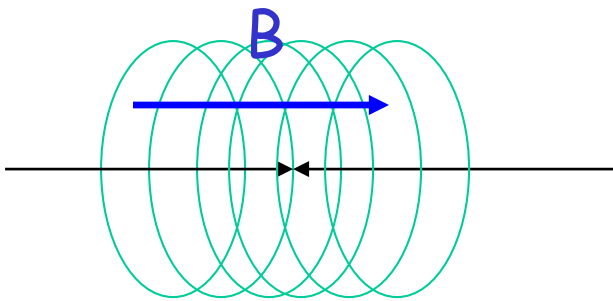
weight = 14500 t

Compact

Excellent signature for new physics

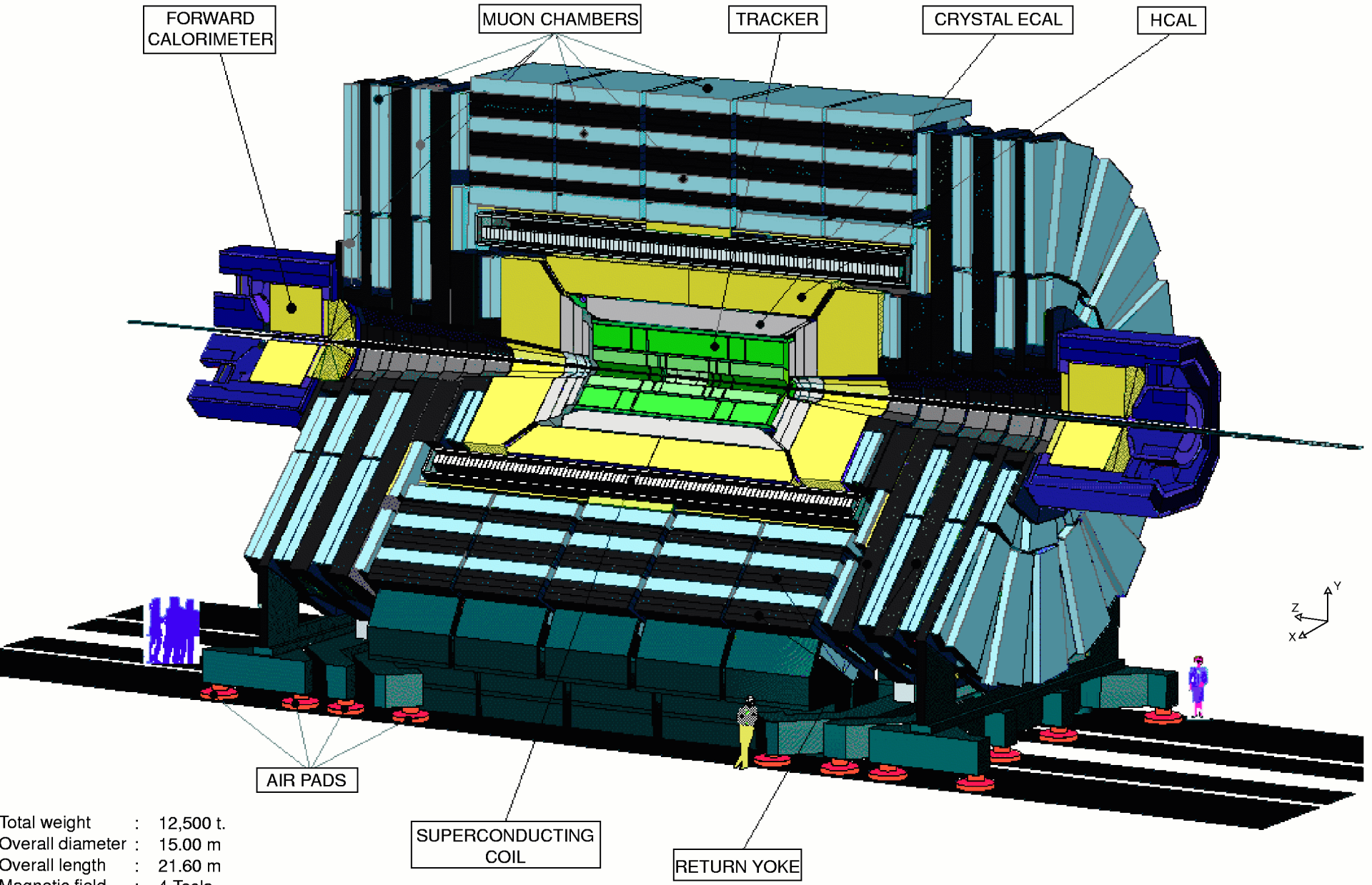
Muon

magnet type



Solenoid

CMS Detector



Total weight	:	12,500 t.
Overall diameter	:	15.00 m
Overall length	:	21.60 m
Magnetic field	:	4 Tesla

Muon

$\rightarrow e\ \nu_\mu\ \nu_e$

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

$s = \frac{1}{2}$

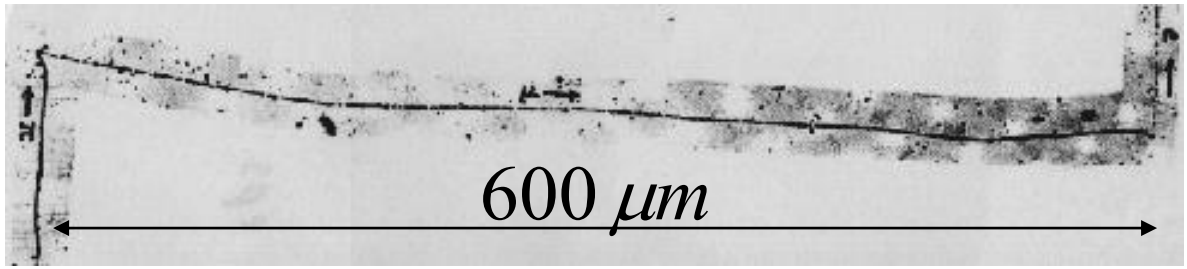
m = 0.106 GeV

τ = 2.20 μs

Discovery: 1933 (Kunze), 1937 (Anderson, Neddermeyer)

Rabi: „Who ordered that ?"

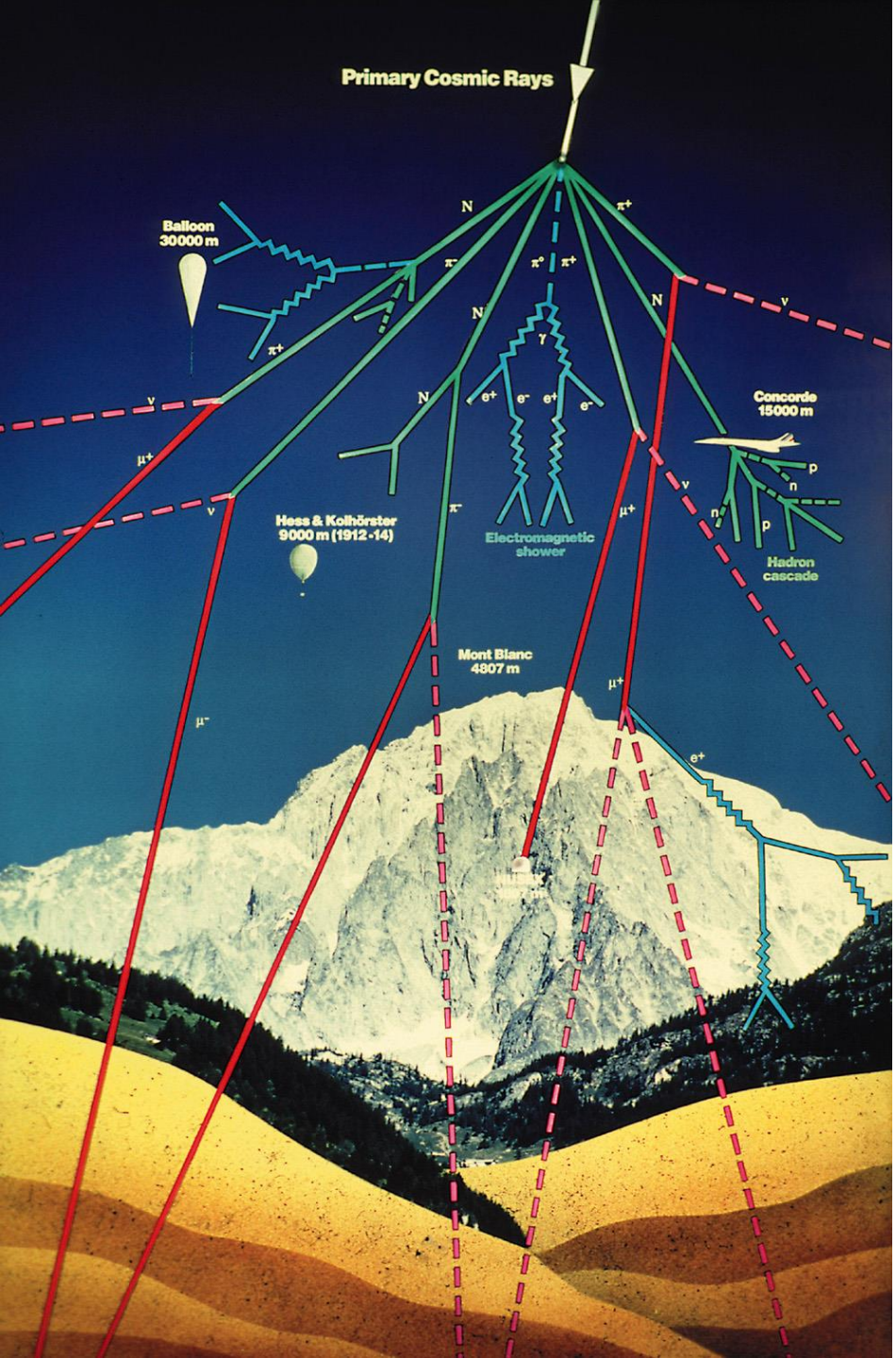
$\pi \rightarrow \mu \rightarrow e$



Decay length: $L = \beta\ \gamma\ c\ \tau \sim E/m\ c\ \tau$

E = 1 TeV: L ~ 6000 km

„stable"



Cosmic Rays

=

Atmospheric Muons

$$200\,muons\ /\ m^2\ /\ s$$

= 0.5 mSv = 50 mrem

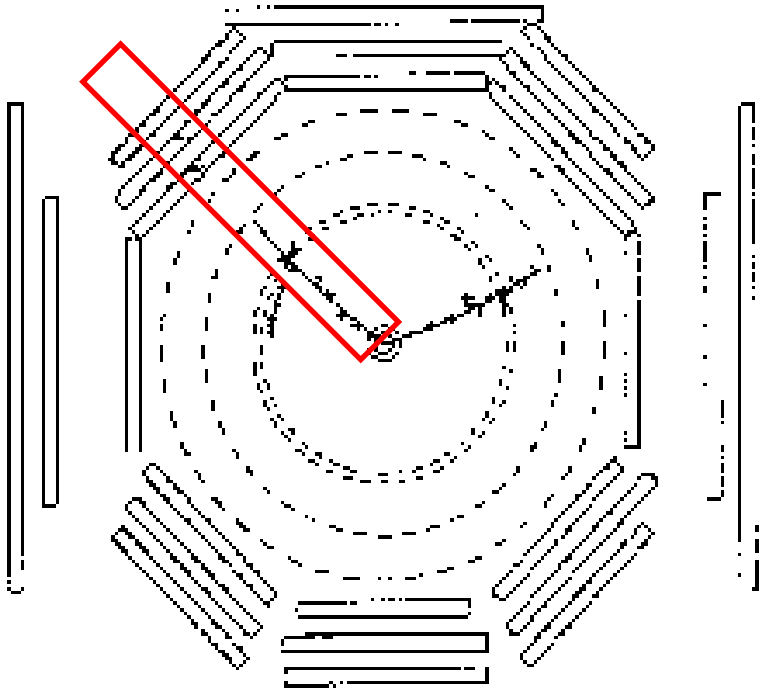
Muons and Discoveries - Examples

Tau Lepton:

SLAC 1975

Martin Perl et al.

$$e^+e^- \rightarrow \tau^+\tau^- \rightarrow \mu^- \; e^+ \; \nu's$$



Bottom quark:

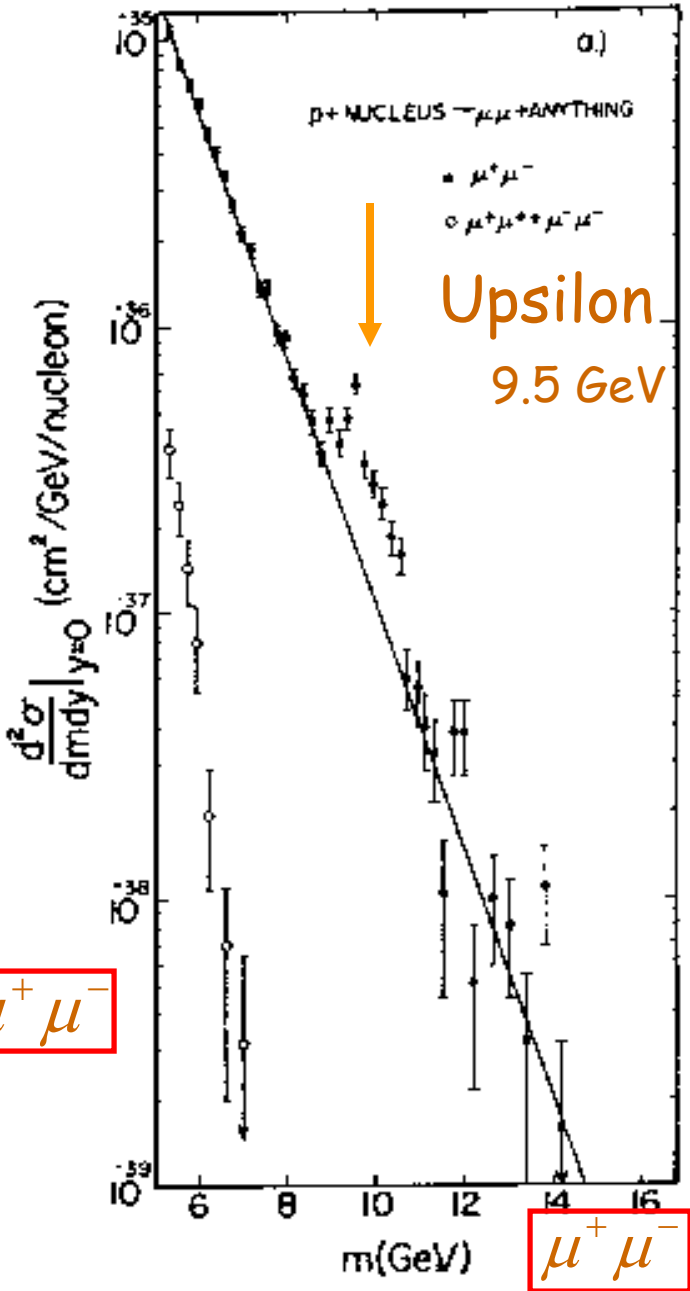
Fermilab

1977

Leon Lederman et al.

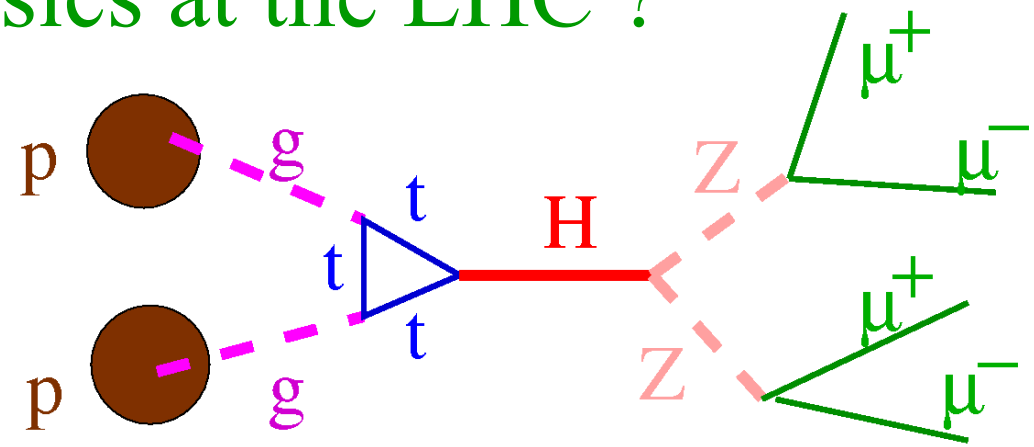
$$p + A \rightarrow \Upsilon \rightarrow \mu^+\mu^-$$

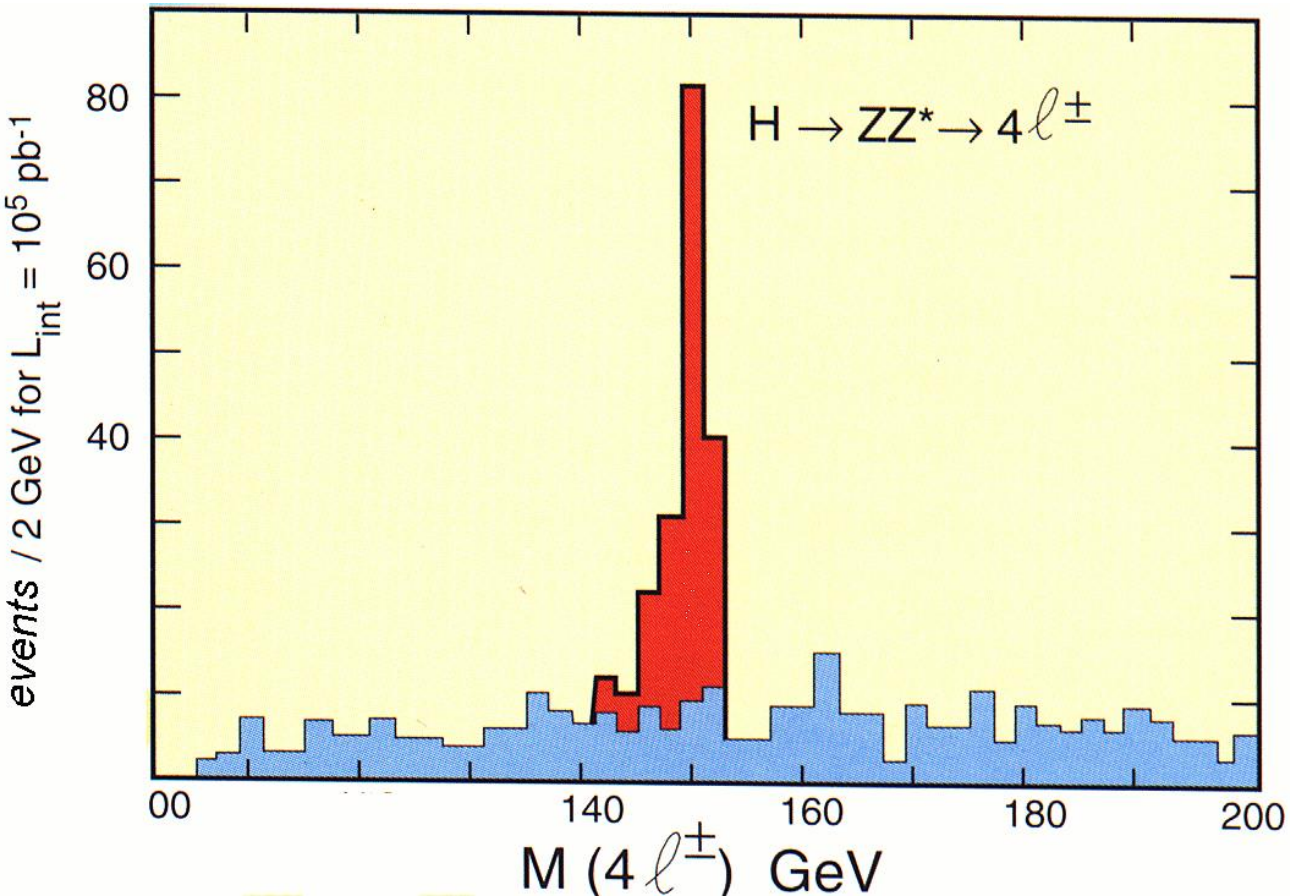
$b\bar{b}$



New Physics at the LHC ?

Higgs boson:



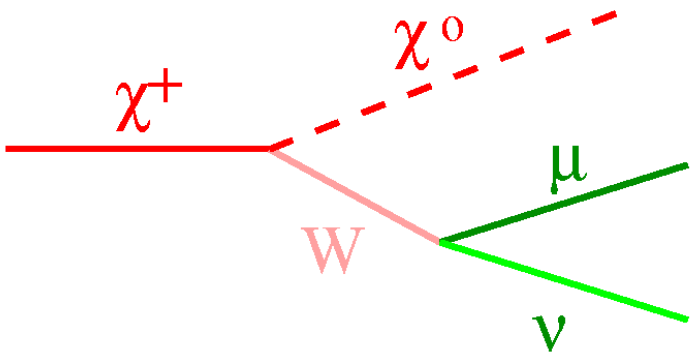


New Physics at the LHC ?

Supersymmetric Particles:

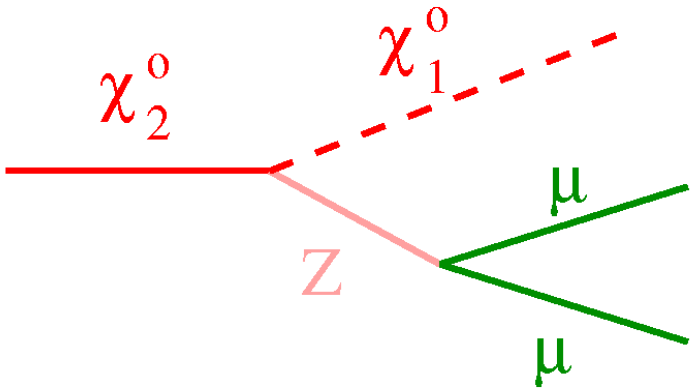
Chargino :

(partner of W)



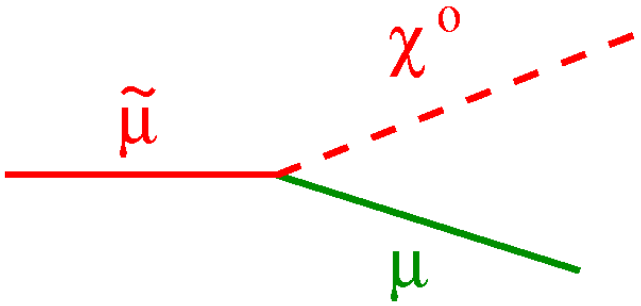
Neutralino :

(partner of Z, γ)



Smuon :

(partner of muon)

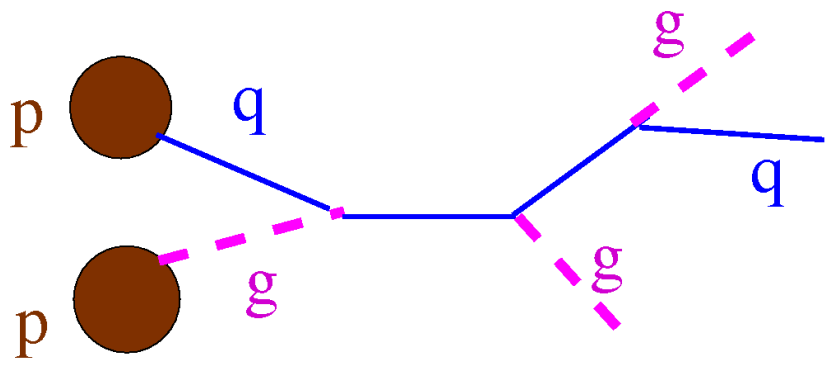


Hadron Colliders and Muons

Background (frequent):

strong interaction

-> quarks, gluons



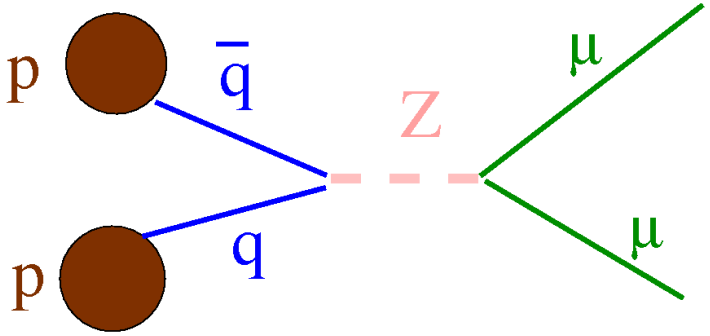
(LHC: ~ 20 p – p collision events per bunch crossing)

Interesting events (rare):

electroweak processes,

decays of heavy particles

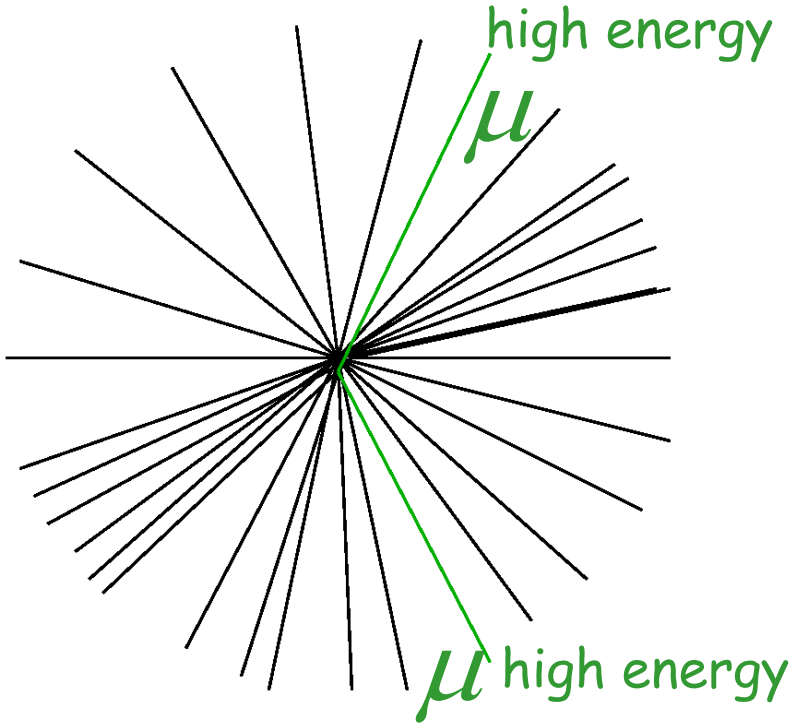
-> Leptons

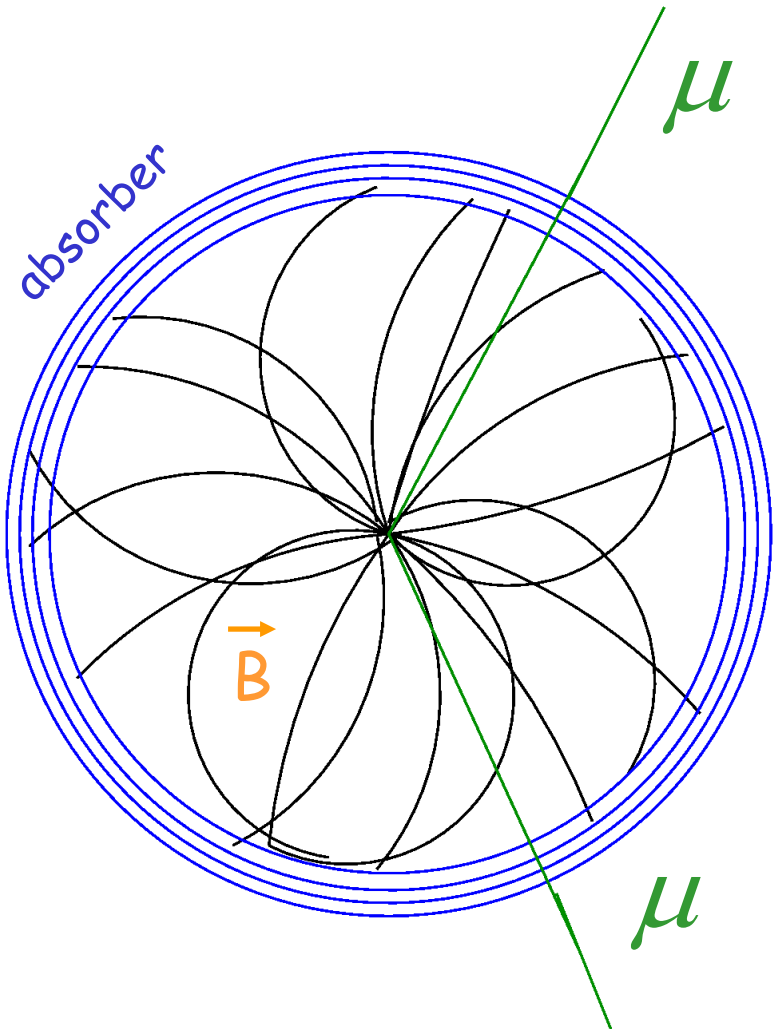


Hadron Colliders and Muons

one bunch crossing

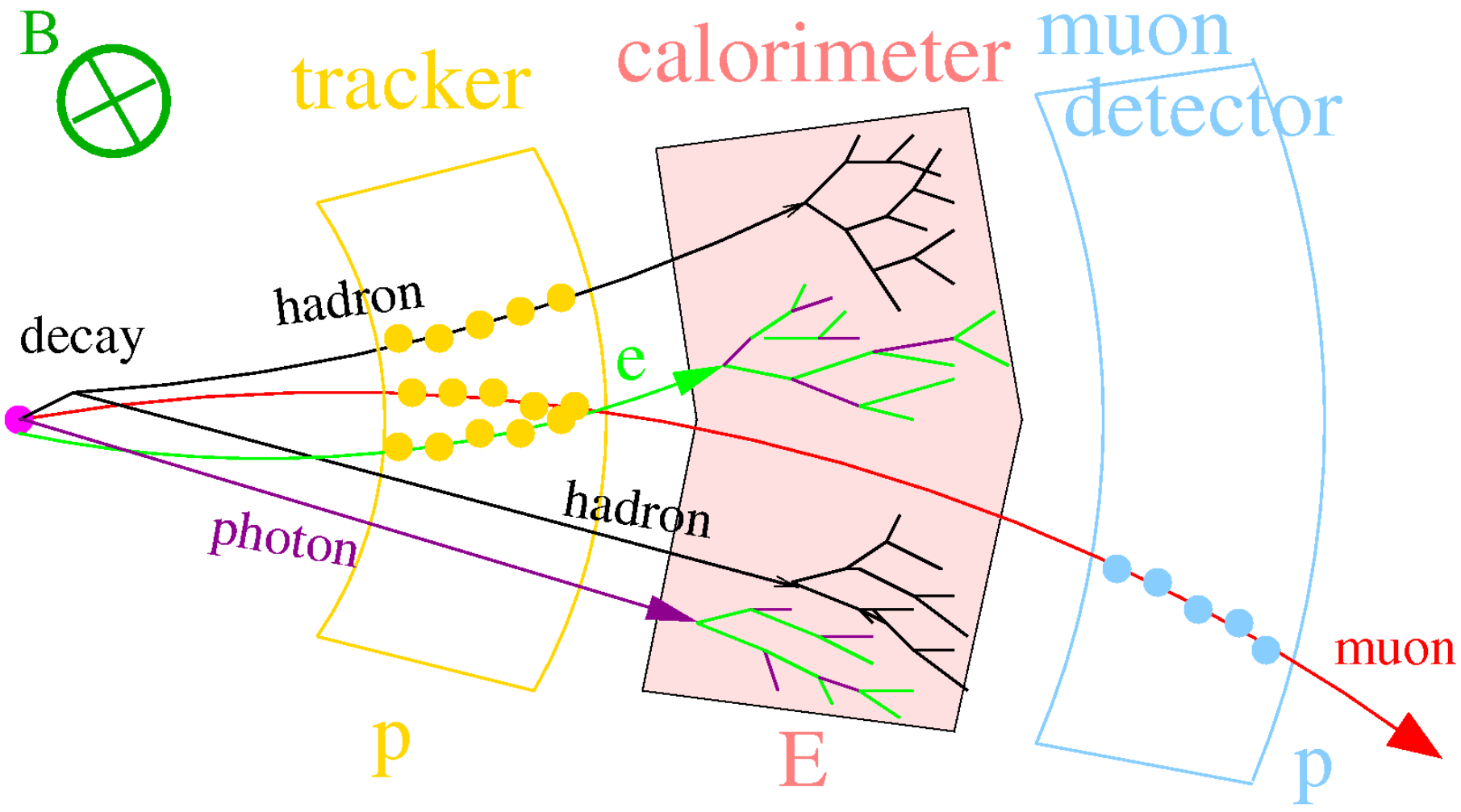
(= 20 events superimposed):





inside detector

Particle Detection



Muon Properties

muon mass

$m_\mu = 0.106\,GeV$

- NO strong interaction
- electromagnetic interaction:
  - NO (little) radiation
  - ionisation
- long lifetime

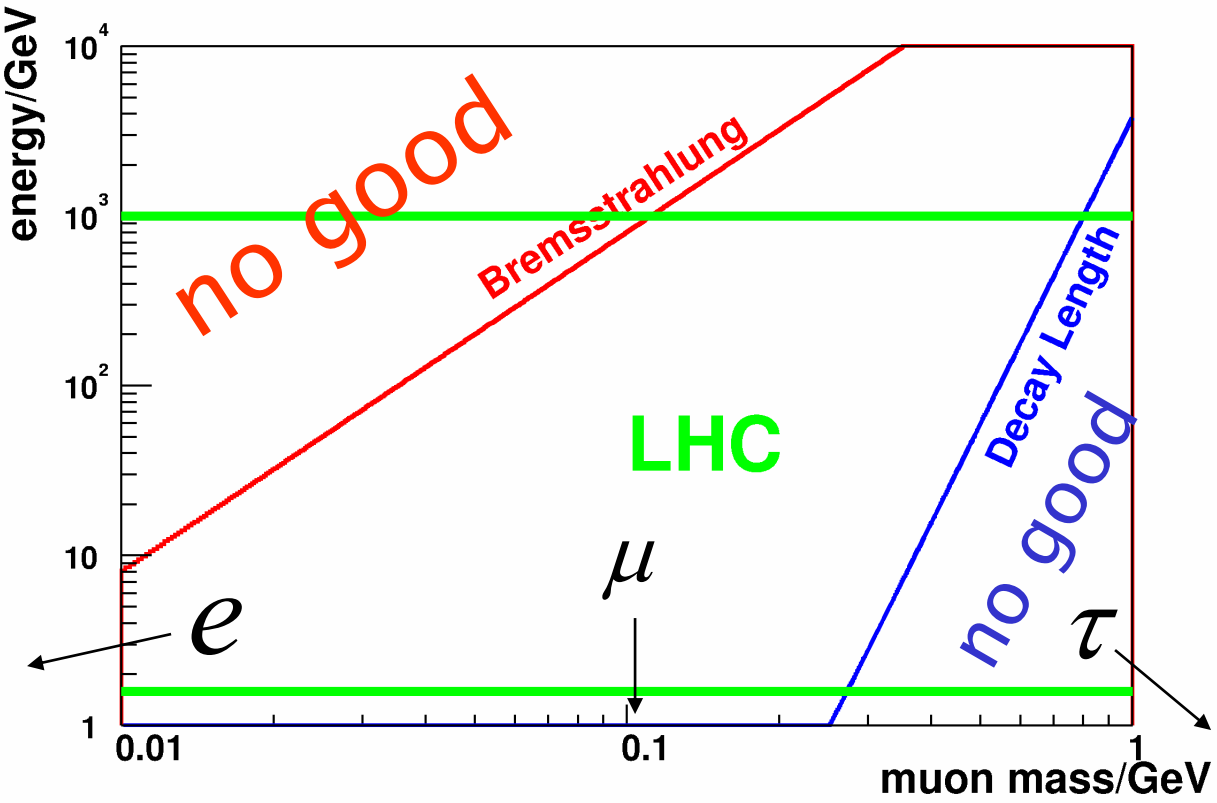
energy loss negligible if

m_μ **large**

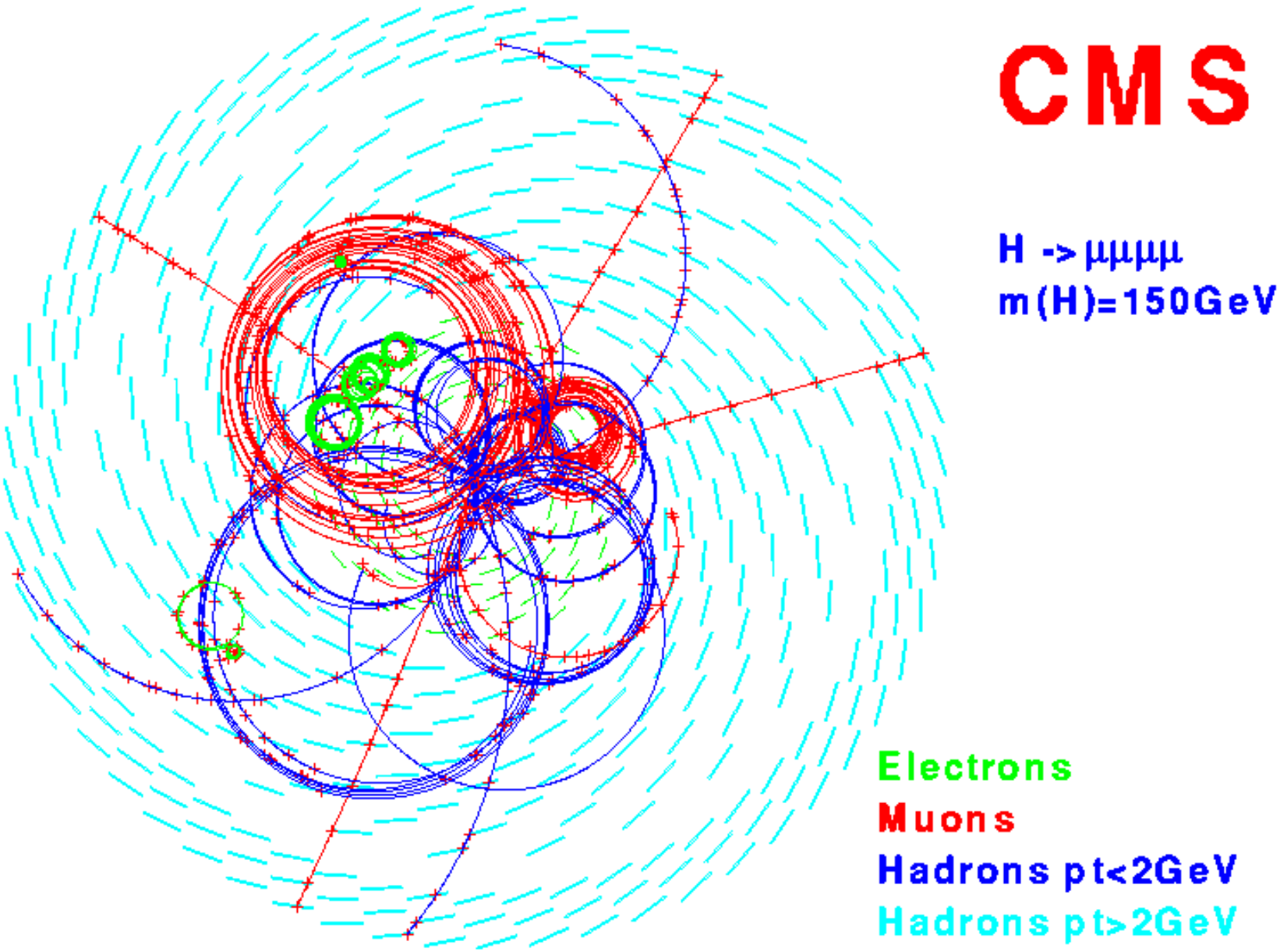
weak interaction

decay length exceeds 100 m if

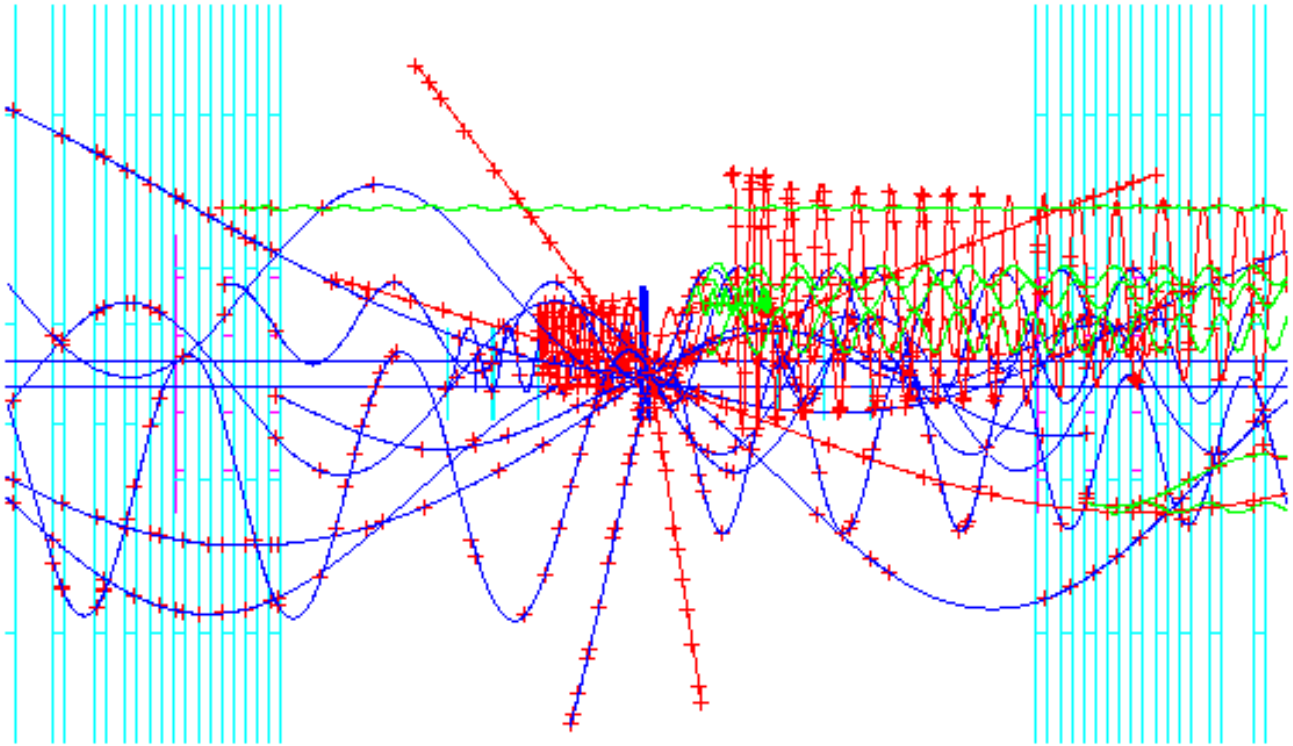
m_μ **small**



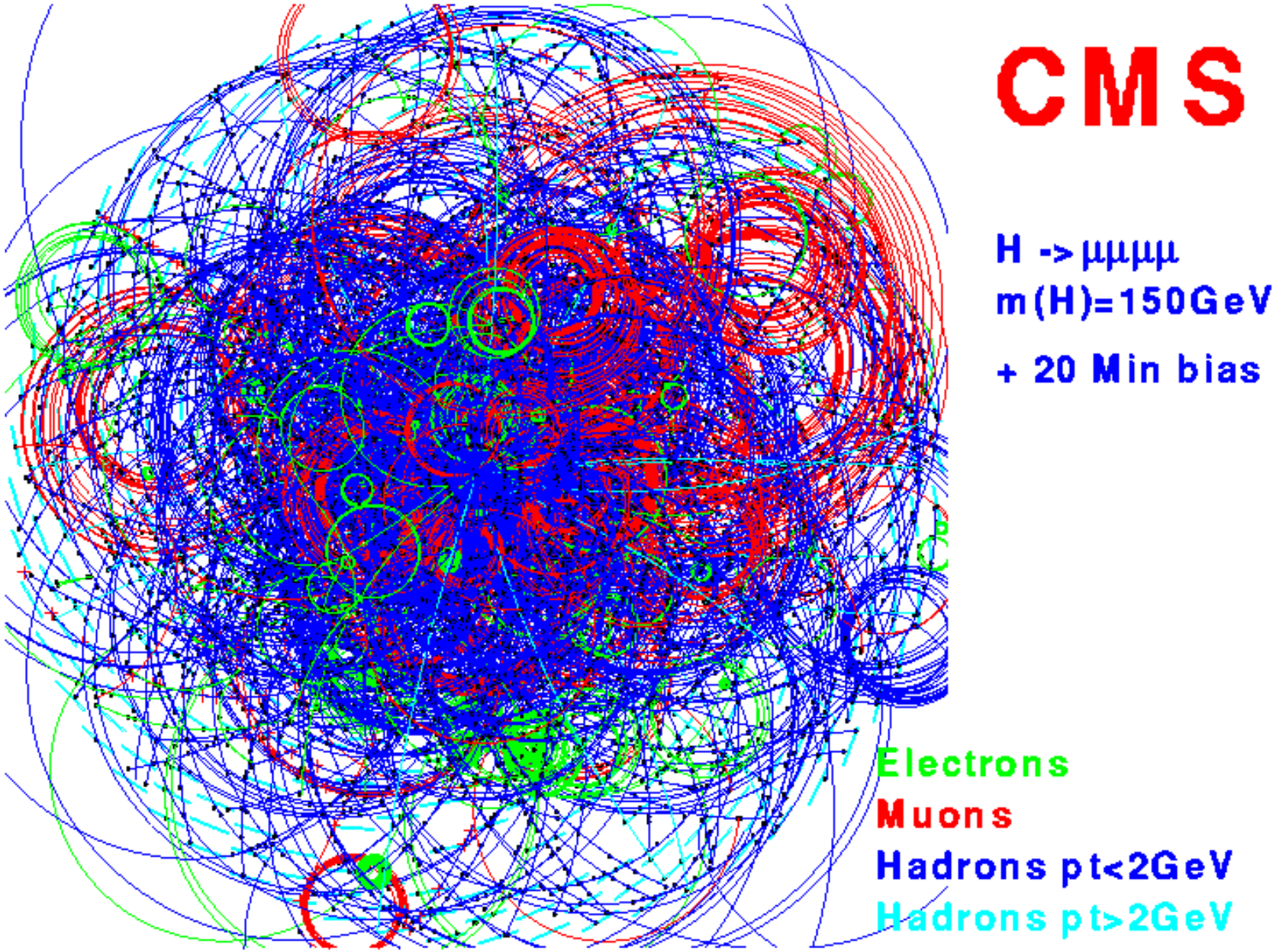
Higgs event in CMS tracker



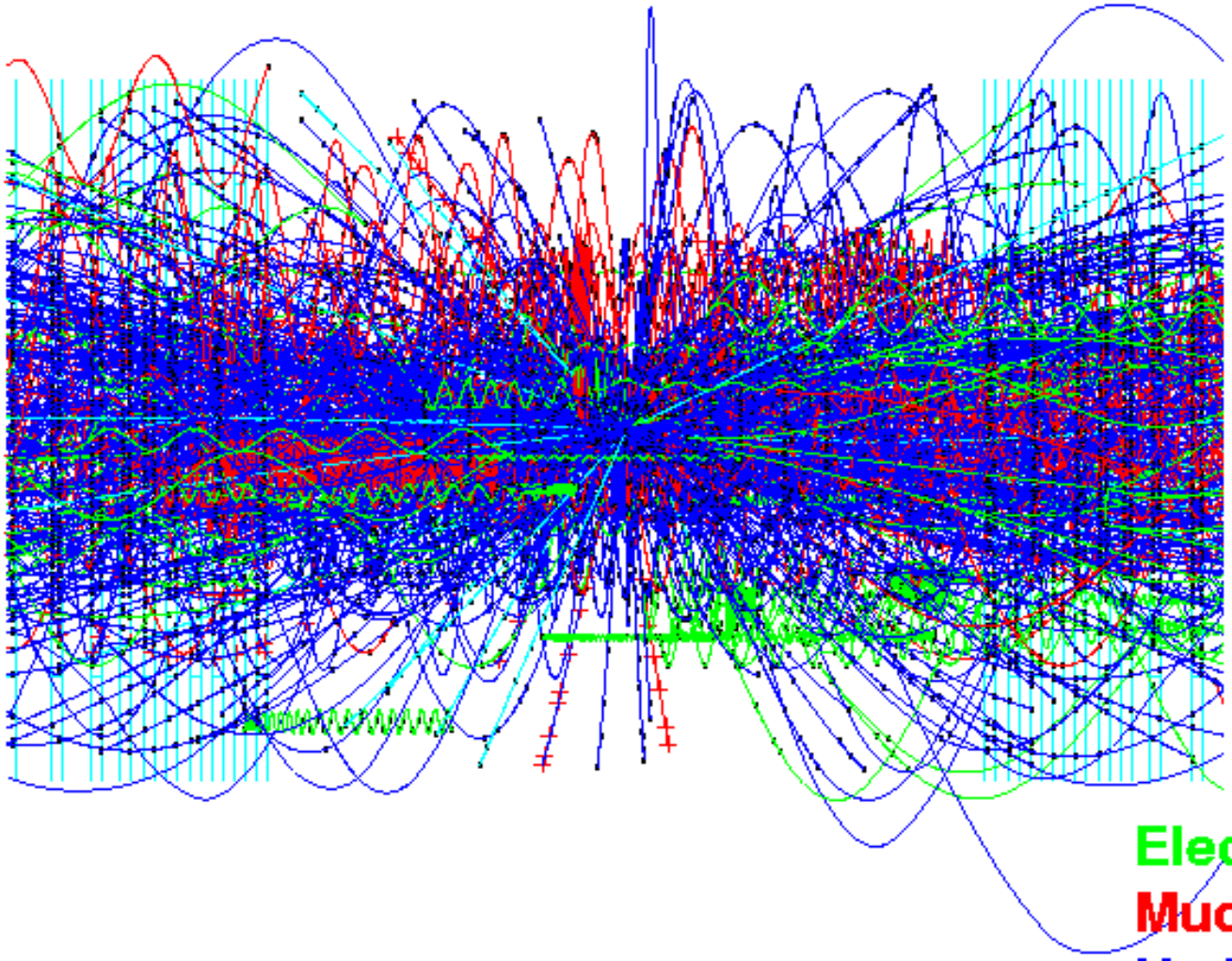
Higgs event in CMS tracker



Higgs event in CMS tracker



Higgs event in CMS tracker

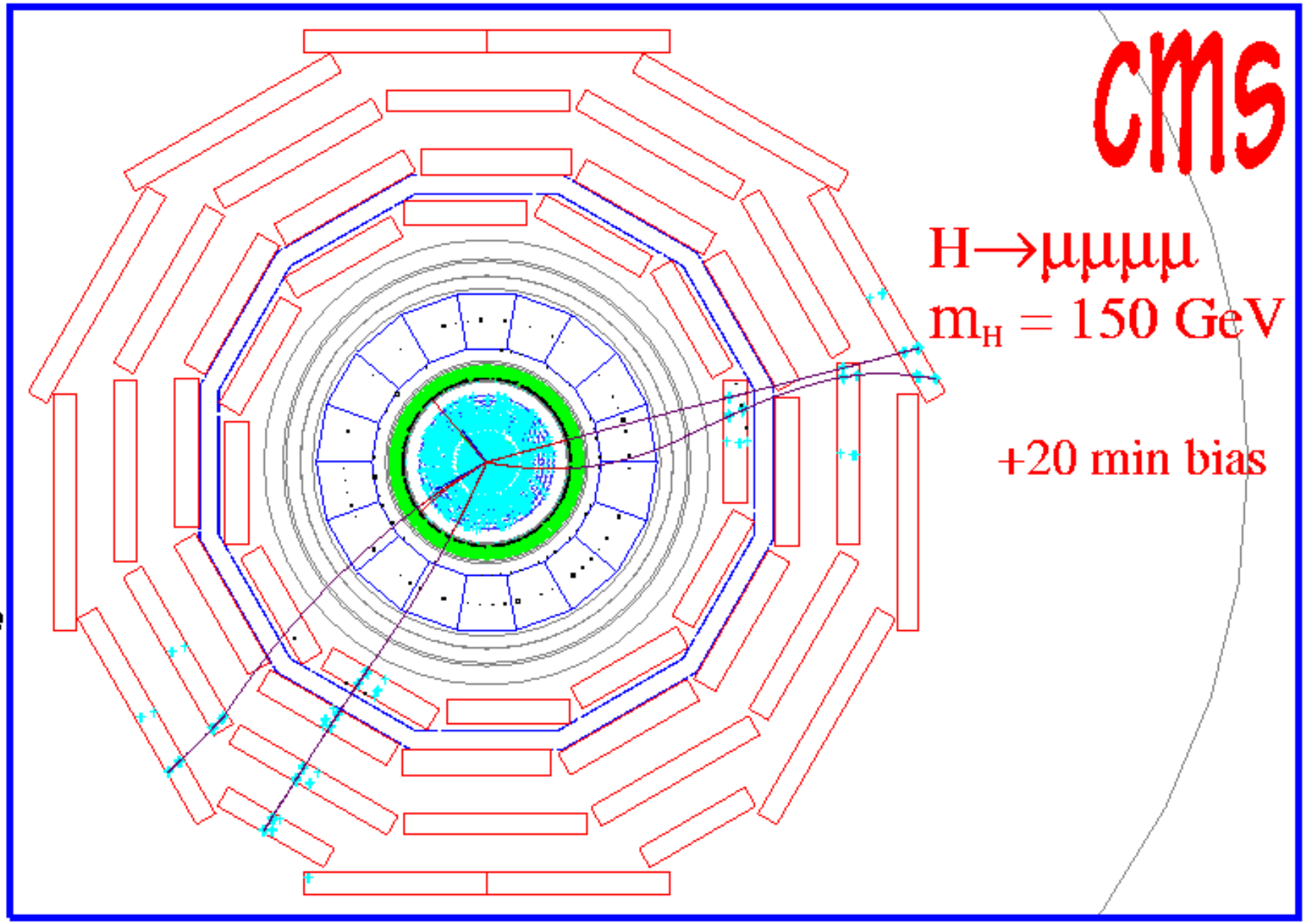


CMS

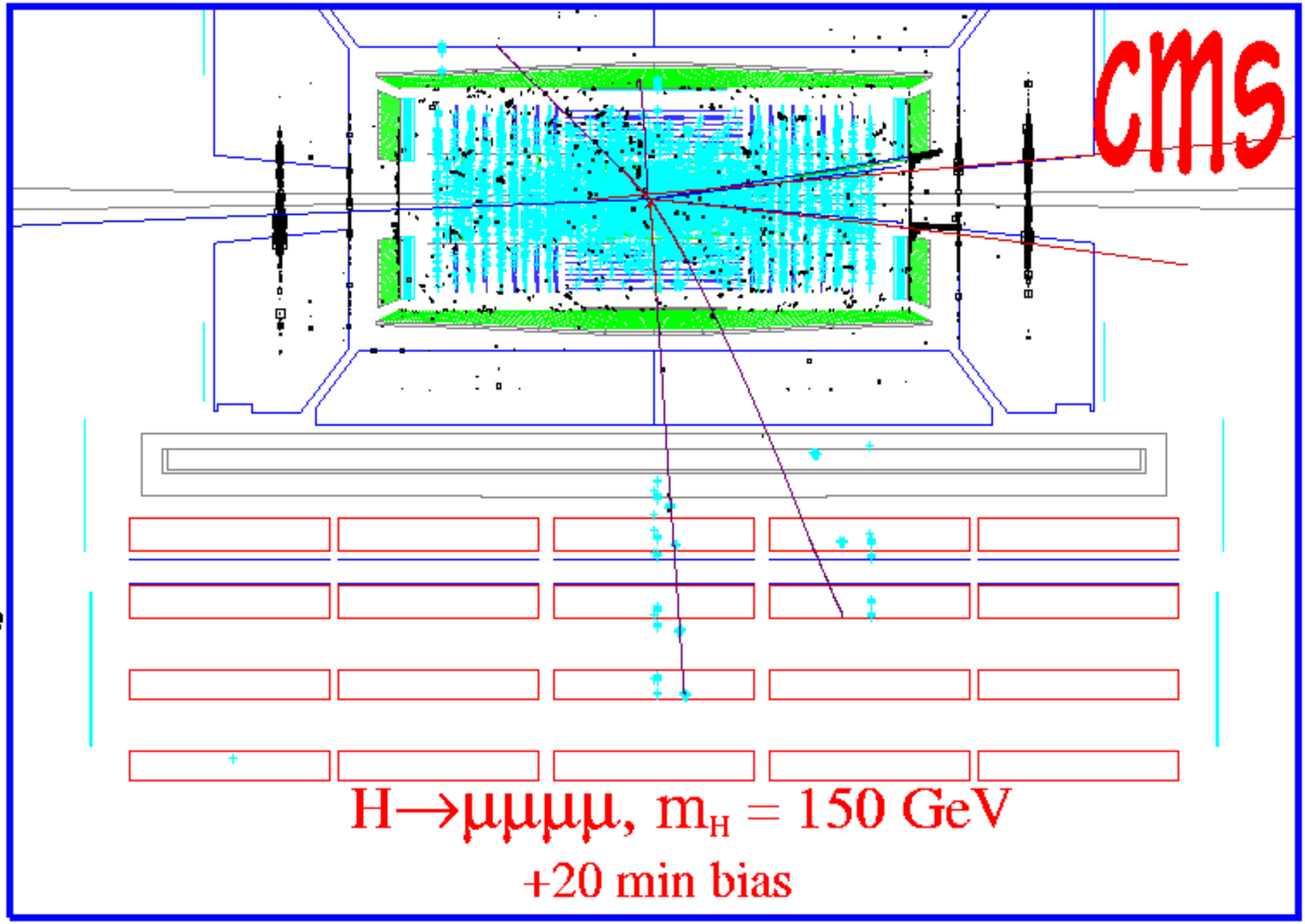
H -> μμμμ
m(H)=150GeV
+ 20 Min bias

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

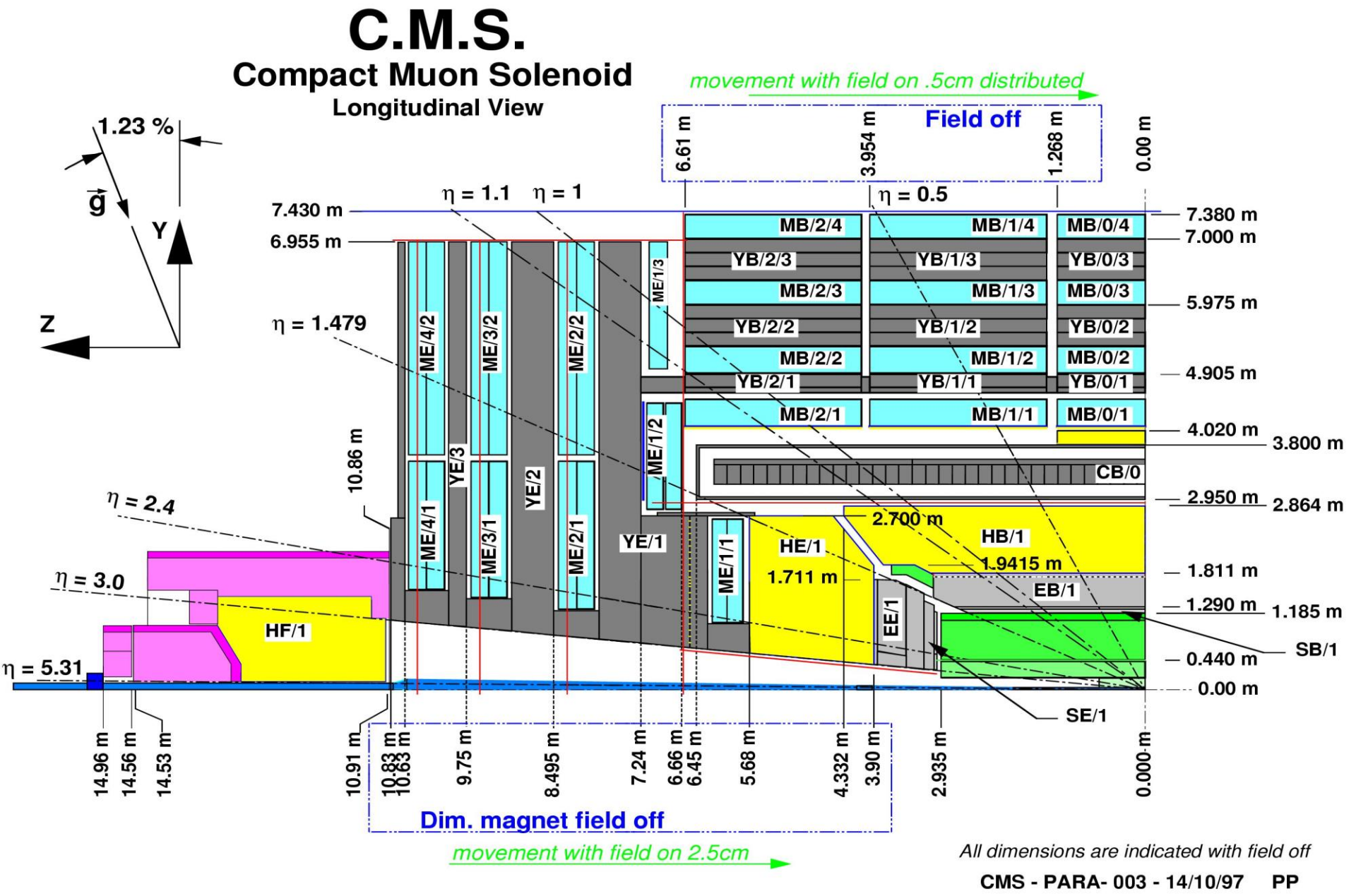
Higgs event in CMS



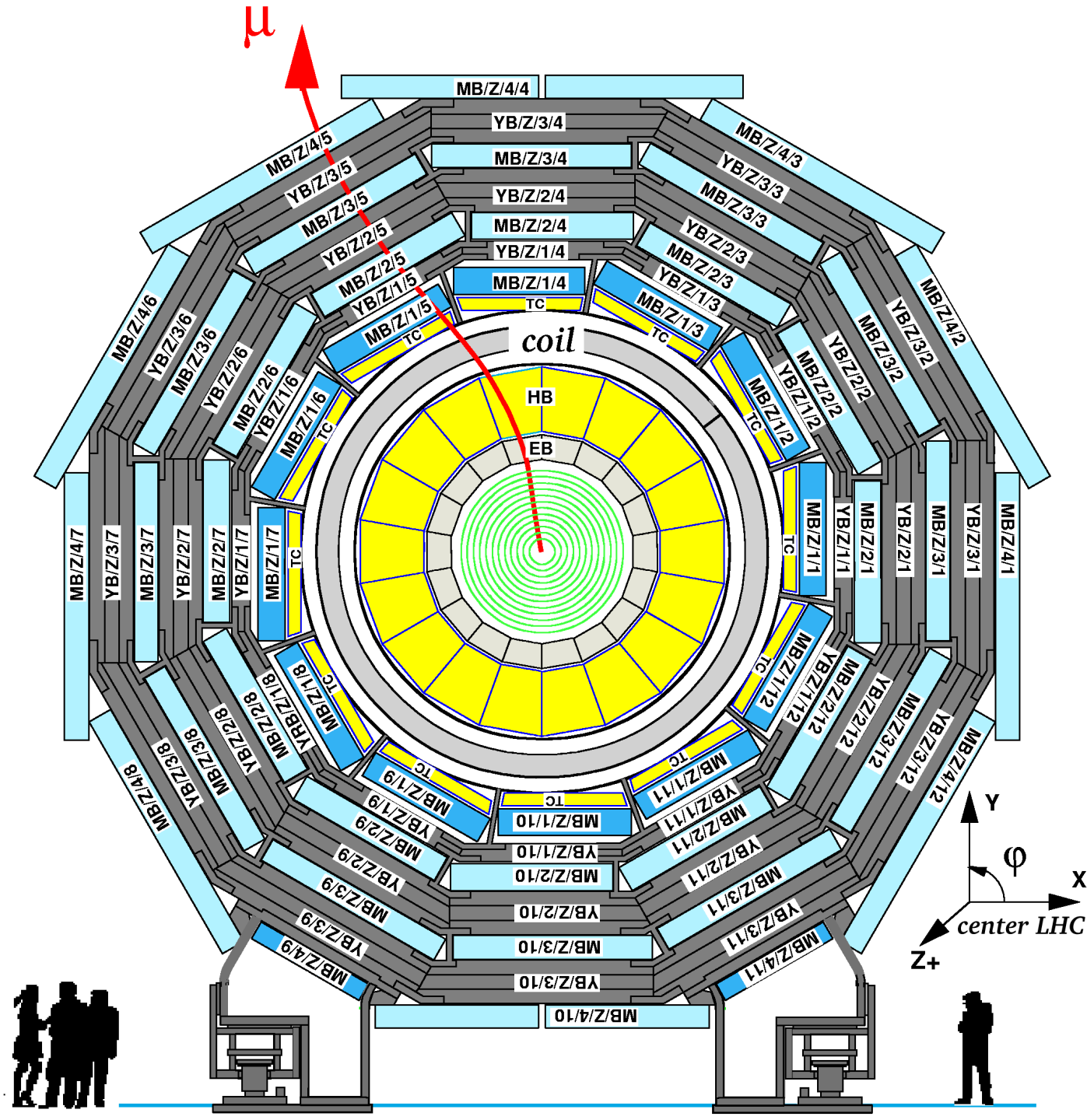
Higgs event in CMS



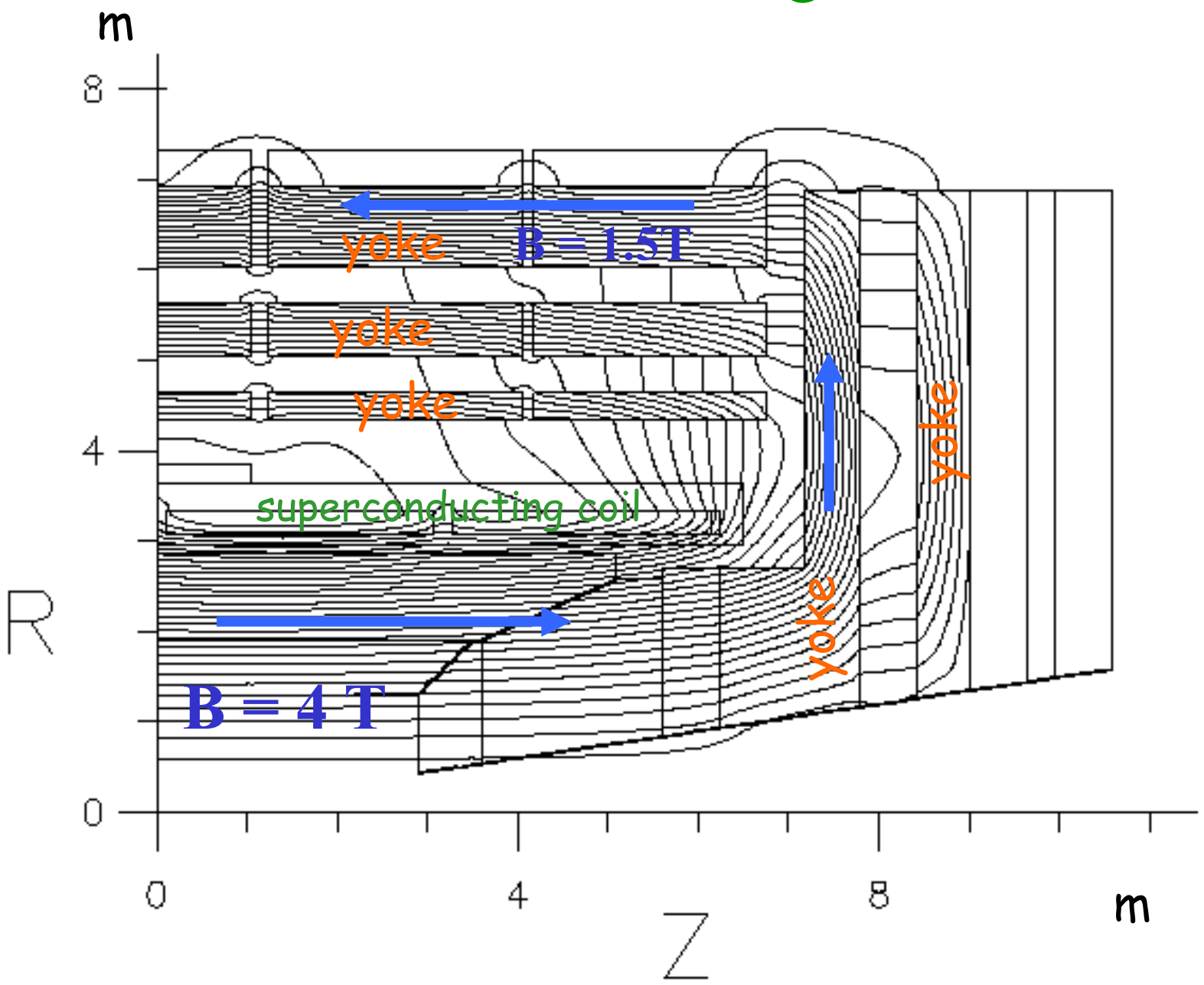
The CMS Muon Detector



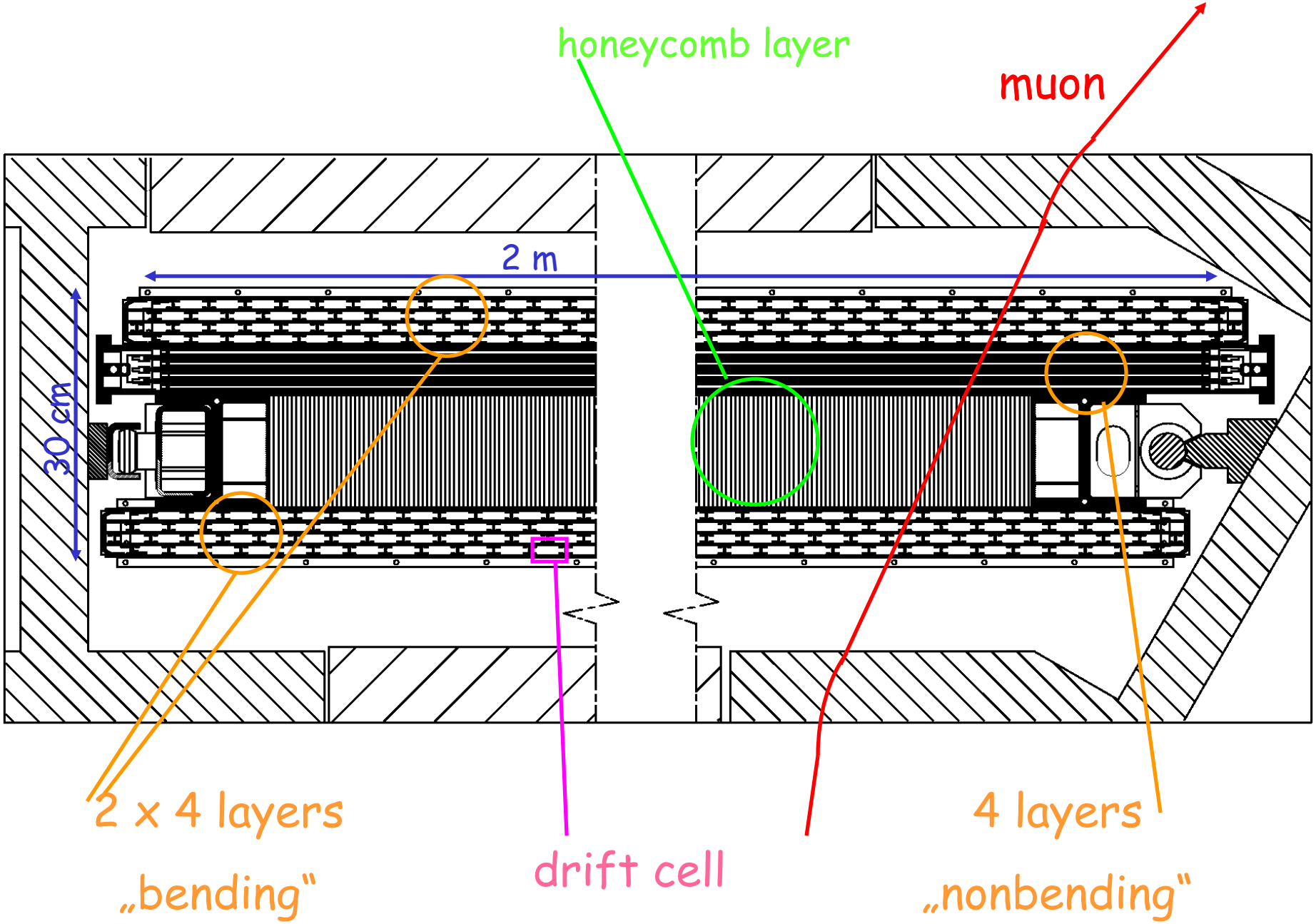
The Central CMS Muon Detector



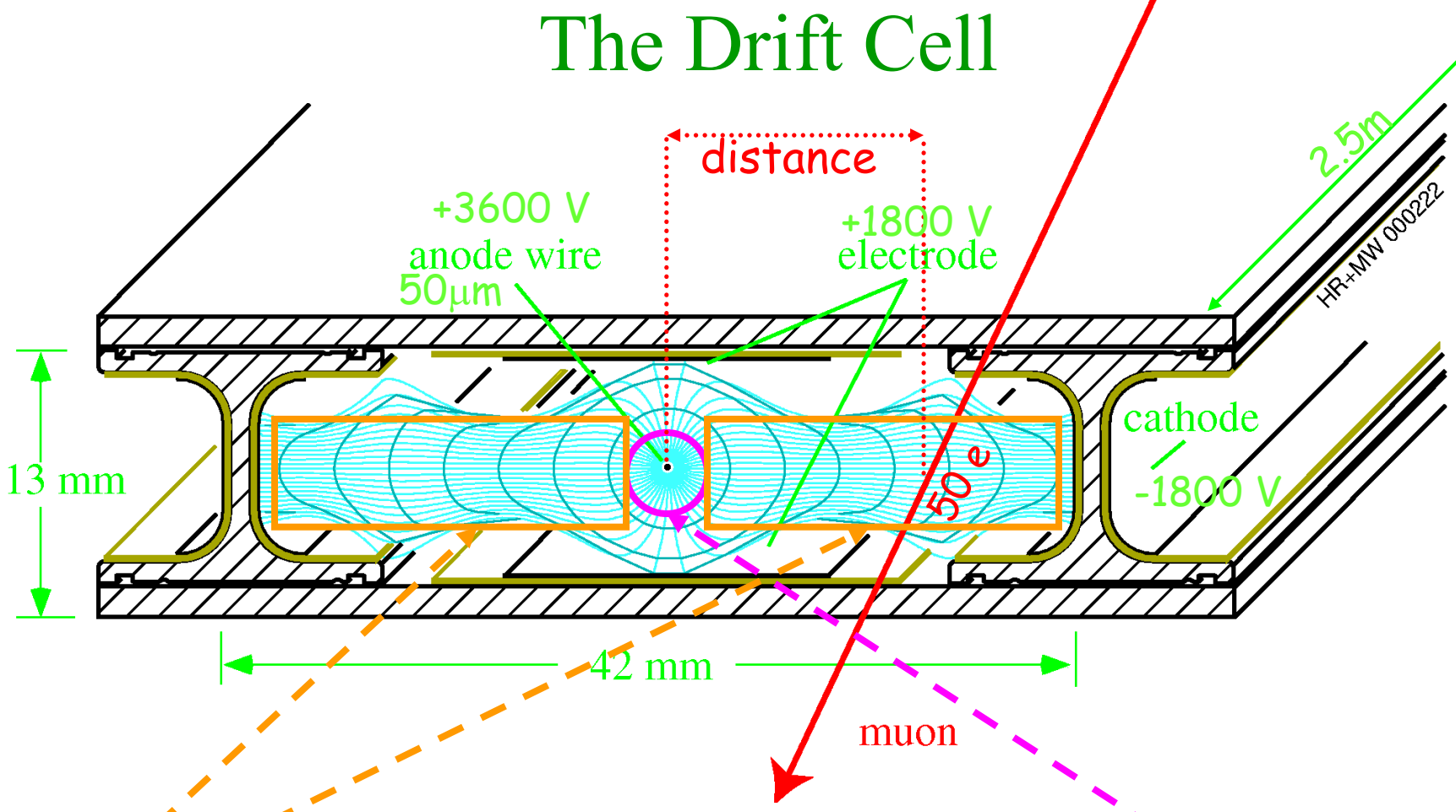
The CMS magnet



The Central CMS Muon Chambers



The Drift Cell



drift region

E ~ 2 kV/cm ~ const

v = 5.7 cm / μs ~ const

distance = time/v $\sigma \sim 250\,\mu m$

amplification

E ~ 1/r -> 150 kV /cm

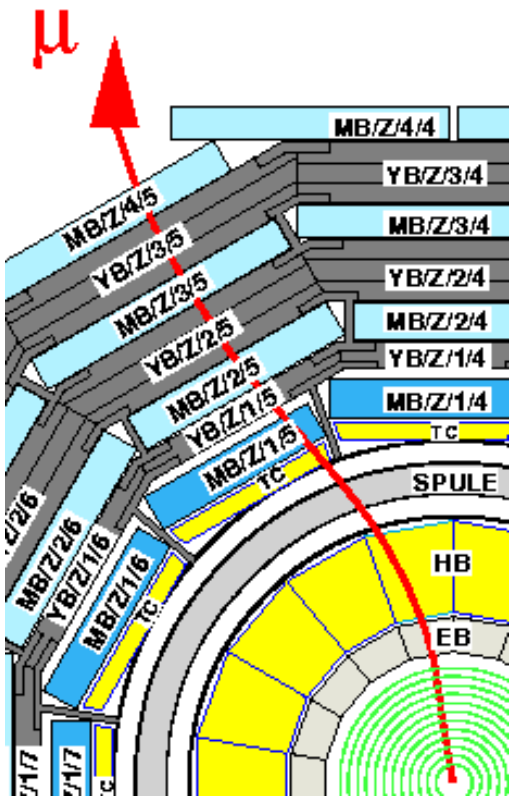
$A \sim 10^5$

Q ~ 500 fC -> amplifier

(Transverse) Momentum Measurement

$\eta = 0$

muon detector alone:



precision $\approx 100\,\mu m$

iron, B $\approx 1.5\,T$

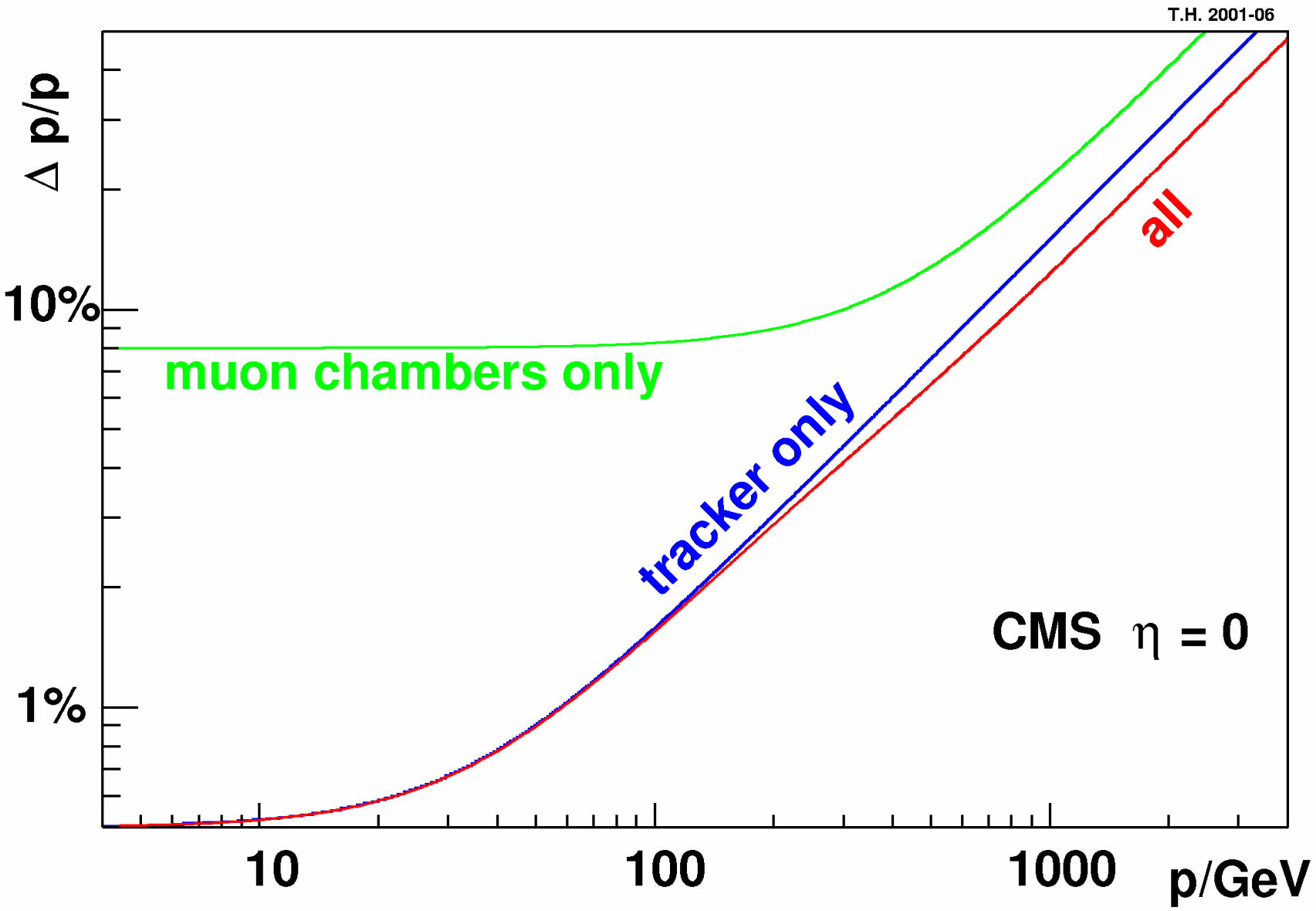
vertex (interaction point) $\approx 20\,\mu m$

B field + coordinate measurements
+ vertex constraint:

$$\frac{\Delta p}{p} \approx 20\% \bullet \frac{p}{TeV}$$

multiple scattering (iron, calorimeters): $\oplus\ 8\%$

CMS Muon (transv.) Momentum Resolution

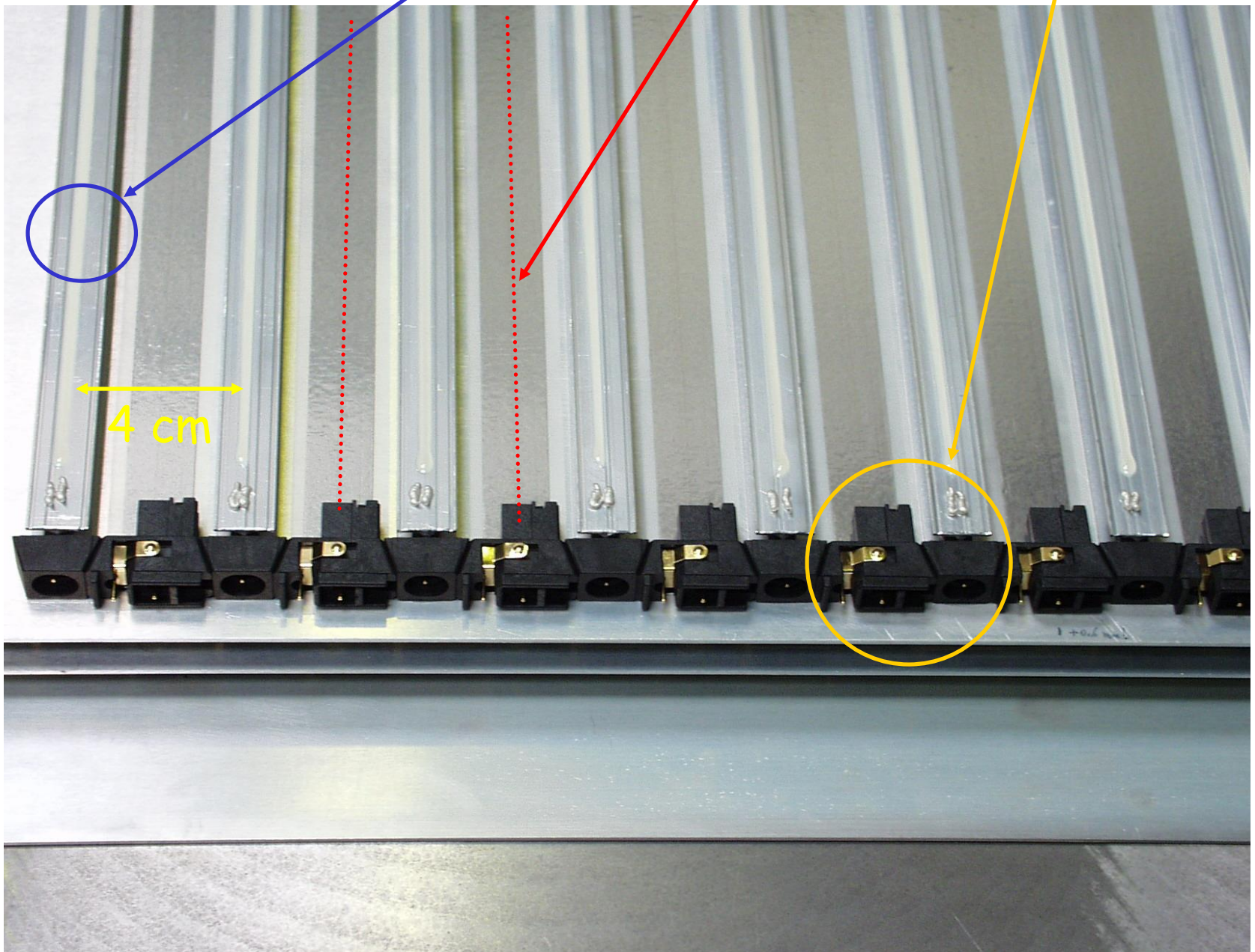


Chamber Production in Aachen

Chamber Production Experts

Chamber Gluing

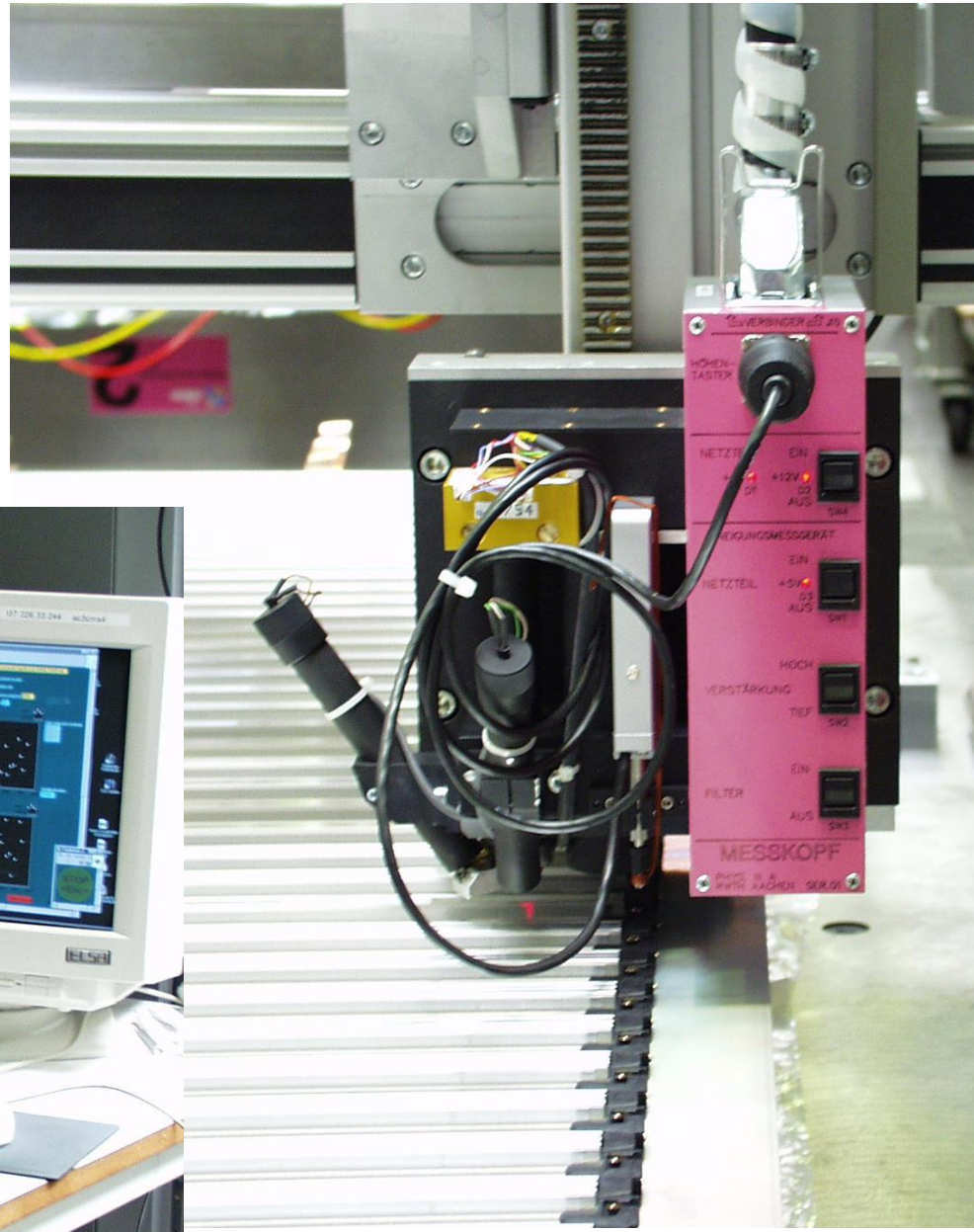
Layer with I-Beams, Wires and End Pieces



Measurement of Wire Position

CCD camera

resolution = few microns



Determination of Wire Tension (3 N)

Yoke: Installation of first wheel

Outlook

- Muon chamber production:
  - started 2001,
  - first chambers will be installed in 2002
- LHC and CMS will start data taking in 2006

... Higgs ...

... chargino ... stop ... smuon...

... ☙■♦❍♦□♓◆...

... extra dimensions ...

... tohu ... vabohu..

... gravitons ...

Muons and CMS

collision rate: 40 MHz

transverse momenta > 3 GeV:

- **muons from new particles** **<< 1 Hz ?**
- muons from W decays 100 Hz
- muons from bottom decays 100 kHz
- low energy hadron decay products > 1 MHz
- cosmic muons 10 kHz

TRIGGER: transverse momenta > 20 GeV: 1 kHz

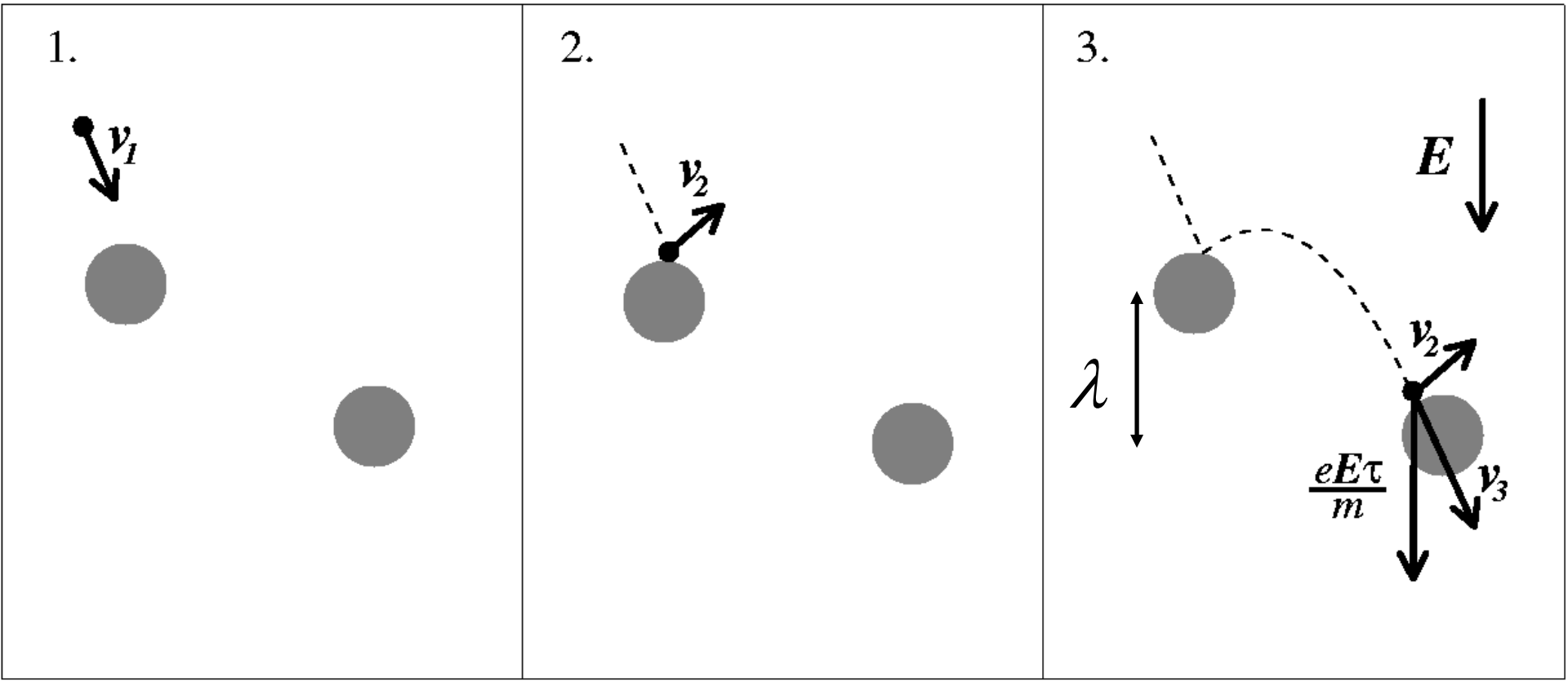
Background (central detector):

hadron „punchthrough"

neutron induced $(n + A \rightarrow A^* \rightarrow \gamma \rightarrow e^-)$

$$< 10 Hz / cm^2$$

Electron Drift in Gas

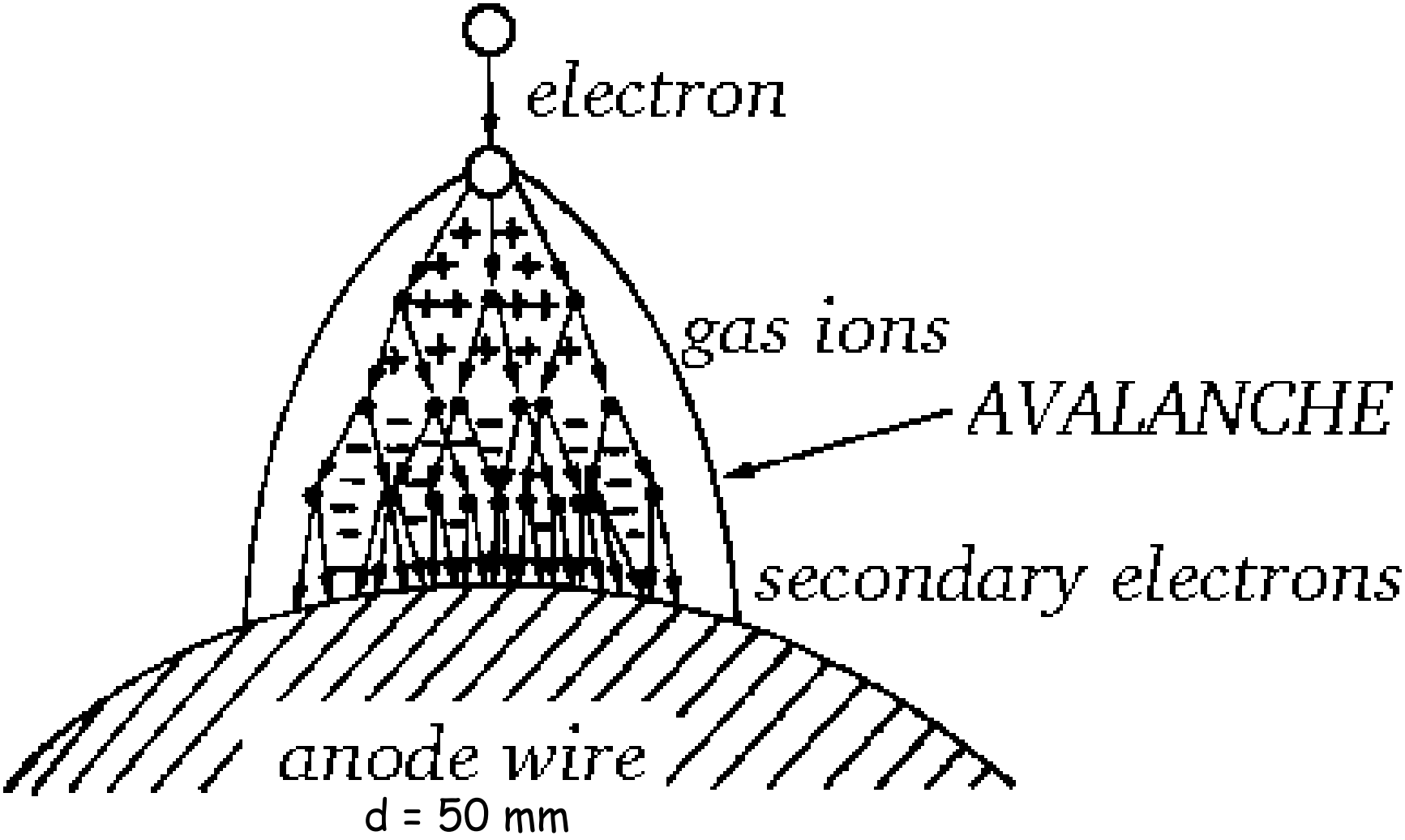


typical values:

λ = 3 μm τ = 30 ps

E = 1 kV/cm v = 5 cm/μs

Avalanche in Wire Chamber



E ~ 1/r

avalanche very close to wire

Muon mean timer