Interlude

Charged particle in magnetic field

Charged particle in magnetic field

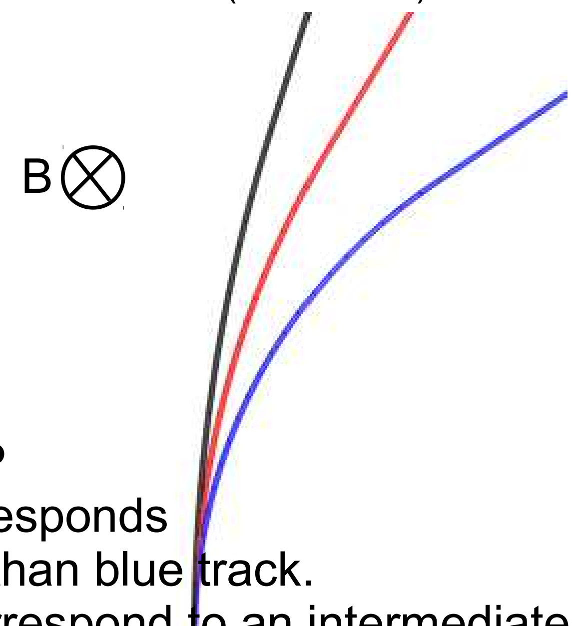
Phys. Rev. 51 (1937) 884

The experimental fact that penetrating particles occur both with positive and negative charges suggests that they might be created in pairs by photons, and that they might be represented as higher mass states of ordinary electrons.

Independent evidence indicating the existence of particles of a new type has already been found, based on range, curvature and ionization relations; for example, Figs. 12 and 13 of our previous publication.[1] In particular the strongly ionizing particle of Fig. 13 cannot readily be explained except in terms of a particle of e/m greater than that of a proton. The large value of e/m apparently is not due to an e greater than the electronic charge since above the plate the particle ionizes imperceptibly differently from a fast electron, whereas below the plate its ionization definitely exceeds that of an electron of the same curvature in the magnetic field; the effects, however, are understandable on the assumption that the particle's mass is greater than that of a free electron. We should like to suggest, merely as a possibility, that the strongly ionizing particles of the type of Fig. 13, although they occur predominantly with positive charge, may be related with the penetrating group above.

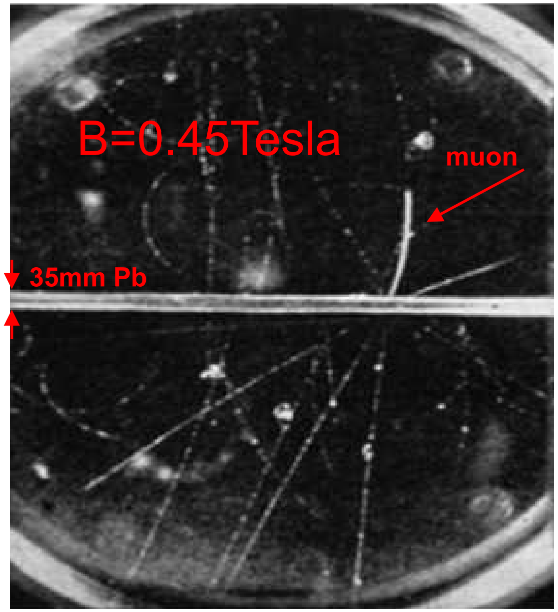
Carl David Anderson
(1905-1991)

Observation



For a given B and P
the black track corresponds
to a heavier object than blue track.
So the red track correspond to an intermediate
mass object

Charged particle in magnetic field



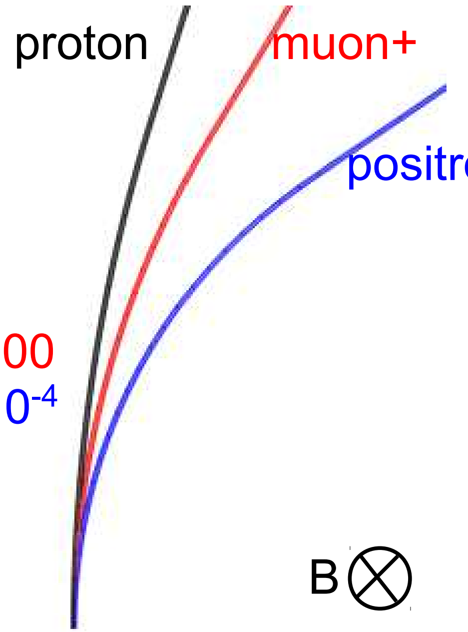
Lorentz force:

$$\vec{F} = q\vec{v} \times \vec{B}$$

↓

$$P \sim 0.3 \cdot R \cdot B$$

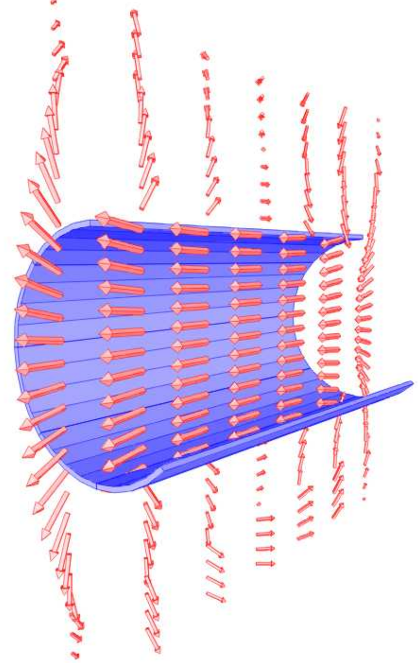
P: momentum (GeV)
R: curvature (m)
B: Magnetic field (Tesla)



Proton mass: ~1
Muon mass: ~0.100
Electron mass: $\sim 5.10^{-4}$

Remark: the curvature in this example does not correspond to the relative curvature between proton, muon & electron

Charged particle in magnetic field



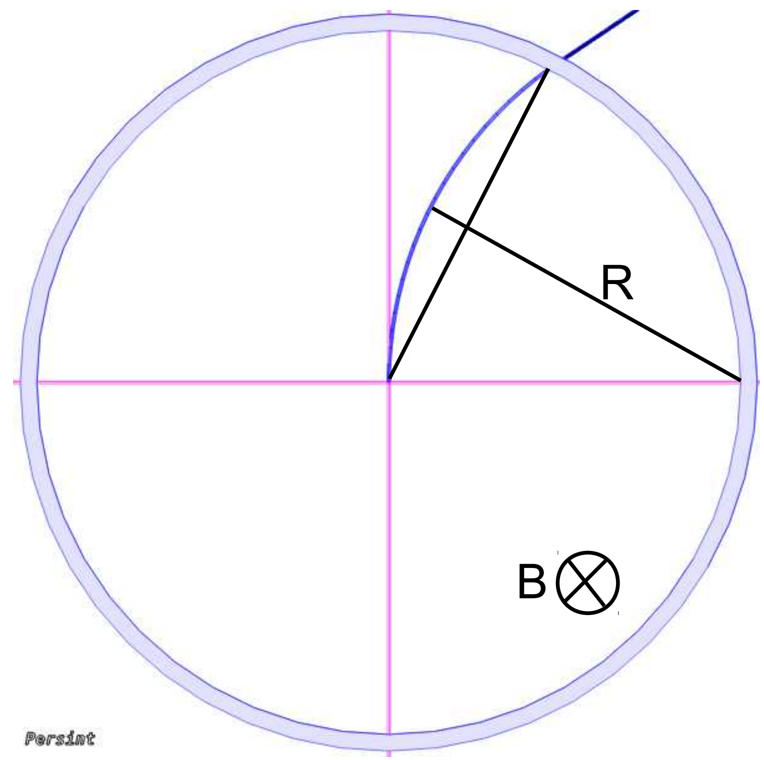
Solenoid (CMS,ATLAS,Delphi...)

Lorentz force:

$$\vec{F} = q\vec{v} \times \vec{B}$$

↓

$$P \sim 0.3 \cdot R \cdot B$$



P: momentum (GeV)
R: curvature (m)
B: Magnetic field (Tesla)

Charged particle in magnetic field

Lorentz force:

$$\vec{F} = q\vec{v} \times \vec{B}$$

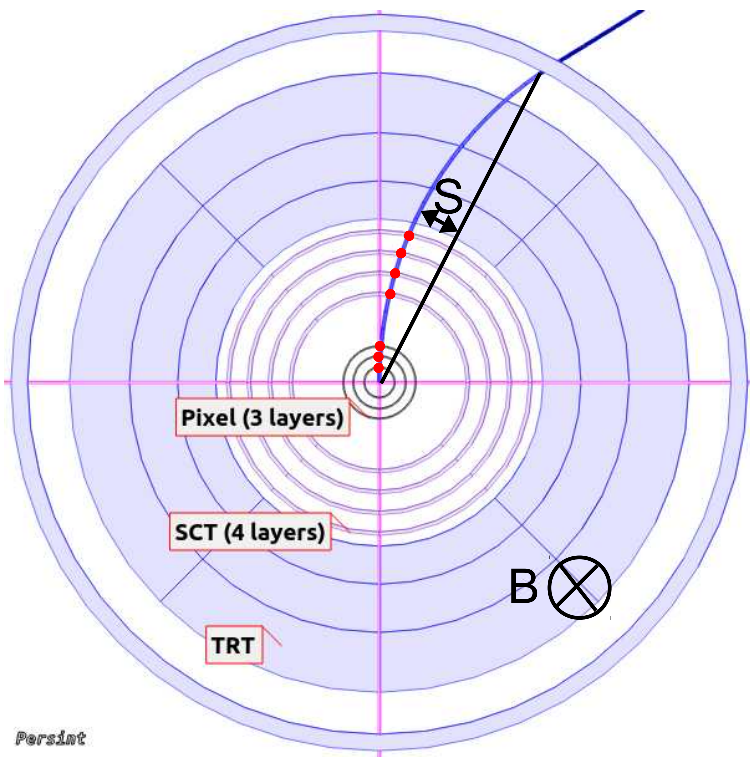
$$\downarrow$$

$$P \sim 0.3 \cdot R \cdot B \qquad R \rightarrow \frac{1}{S}$$

P: momentum (GeV)
R: curvature (m)
B: Magnetic field (Tesla)

Charged track => signal in detectors
=> reconstruction program
=> Sagitta (=1/R) determination

Solenoid (ATLAS Inner Tracker)



Charged particle in magnetic field

Lorentz force:

$$\vec{F} = q\vec{v} \times \vec{B}$$

$$P \sim 0.3 \cdot R \cdot B \qquad R \rightarrow \frac{1}{S}$$

P: momentum (GeV)
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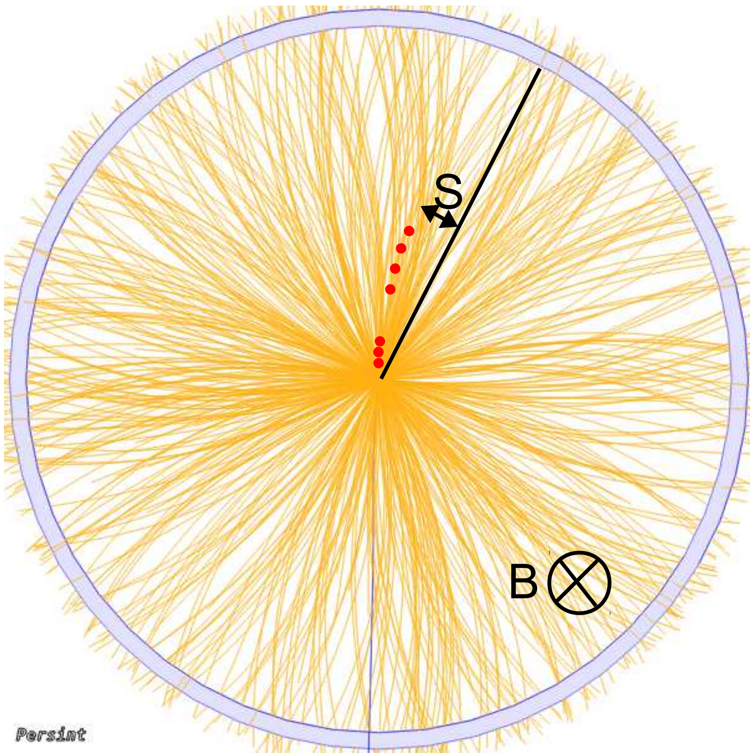
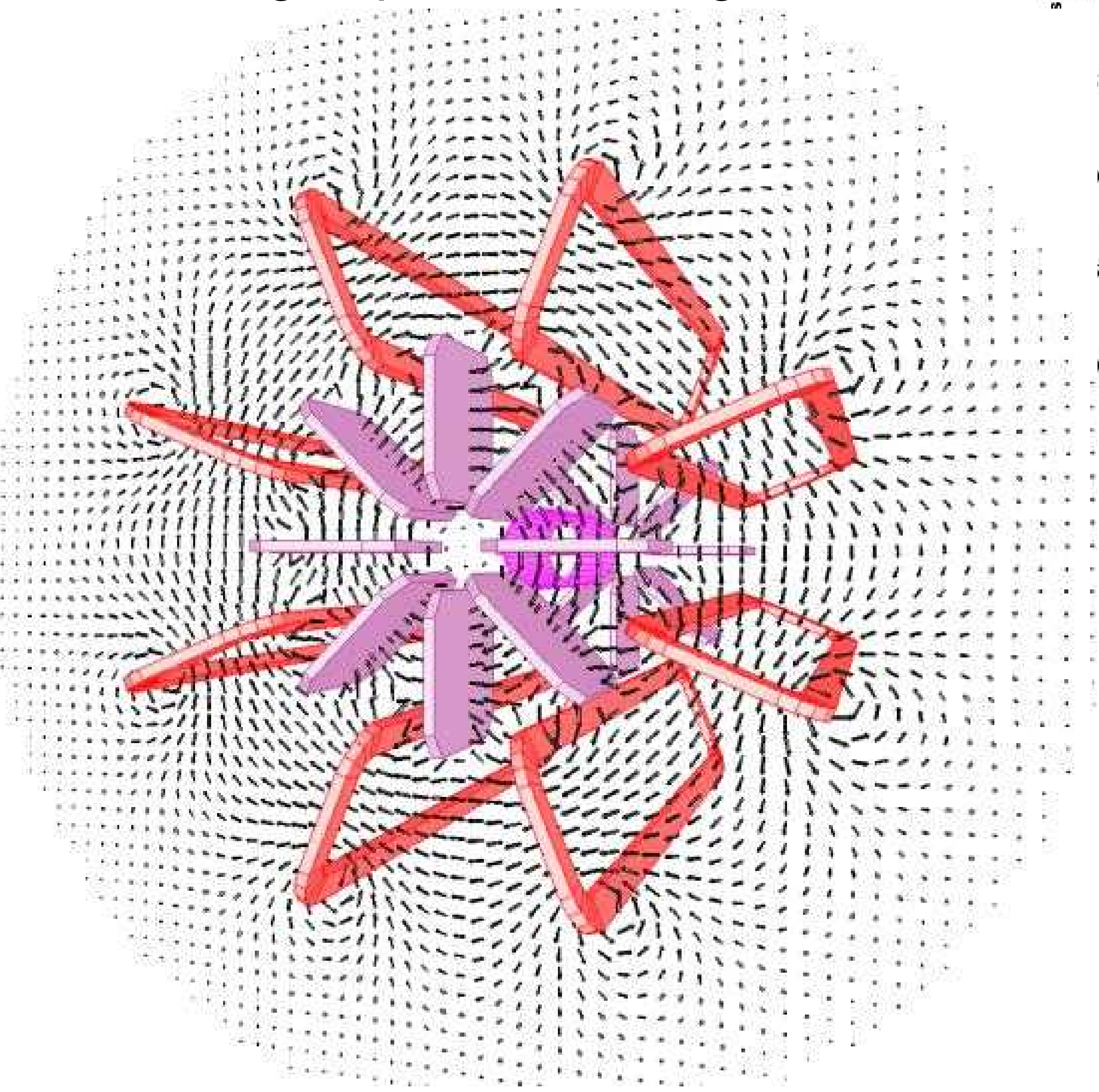
Solenoid (ATLAS Inner Tracker)

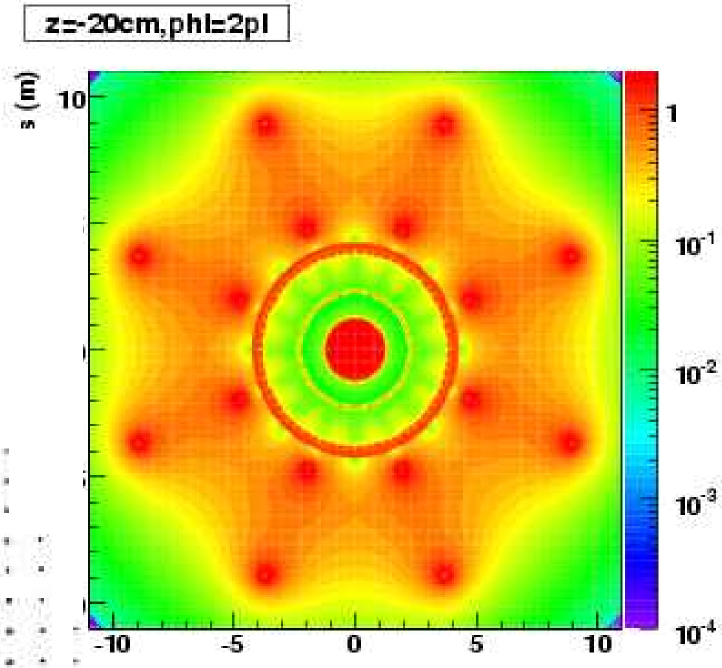


Charged track => signal in detectors
=> reconstruction program
=> Sagitta (=1/R) determination

Reconstruction can be complicated

Charged particle in magnetic field



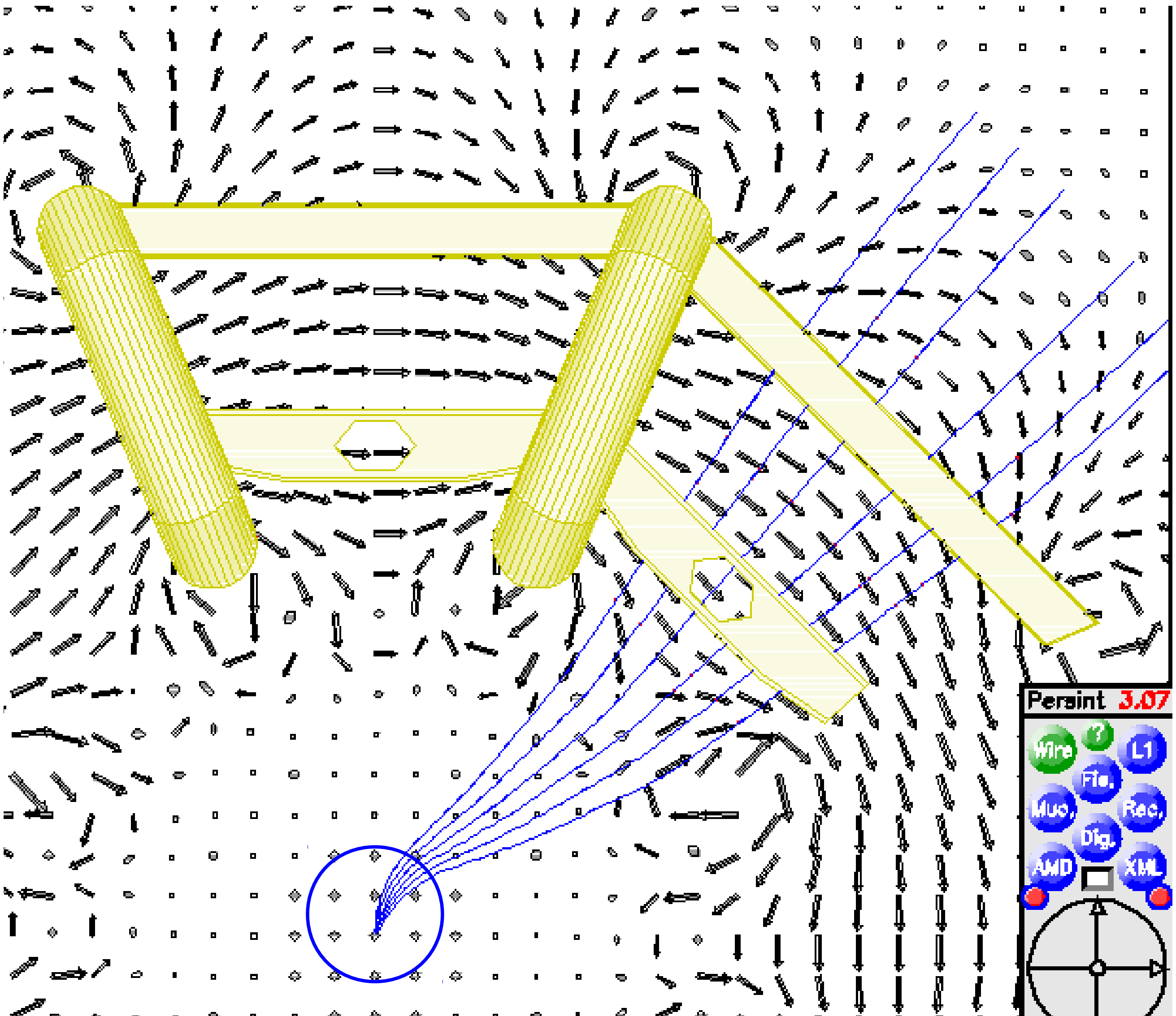


ATLAS magnetic field
1 solenoid
3 toroids

Charged particle in magnetic field

ATLAS magnetic field
1 solenoid
3 toroids

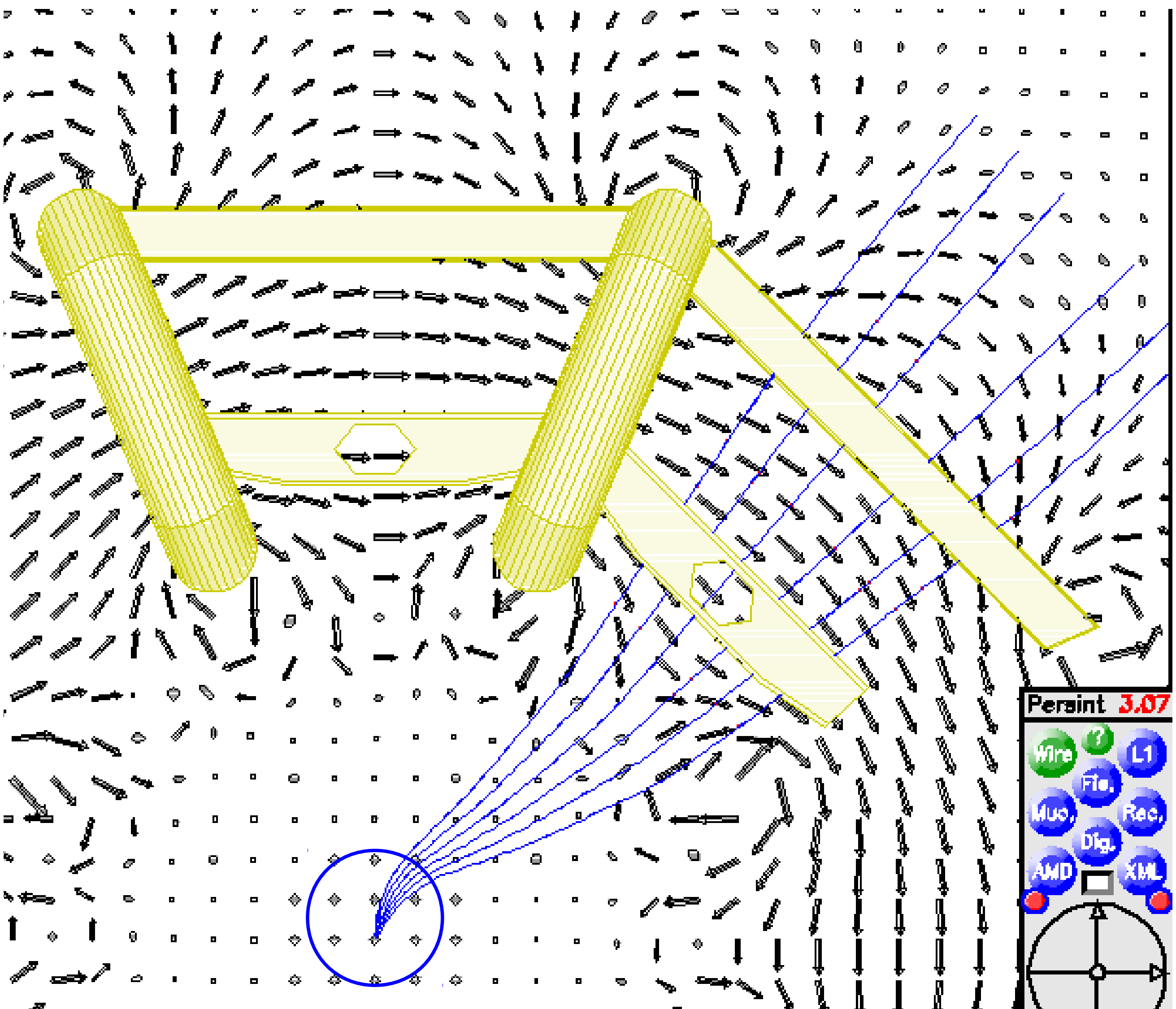
R–ϕ projection



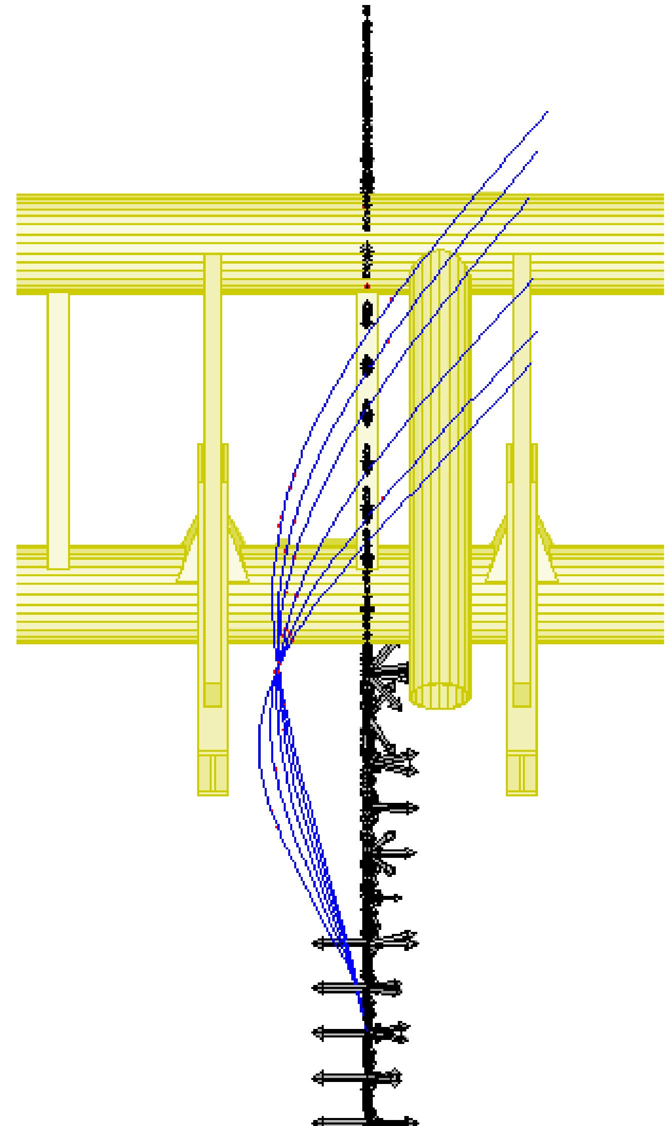
Charged particle in magnetic field

ATLAS magnetic field
1 solenoid
3 toroids

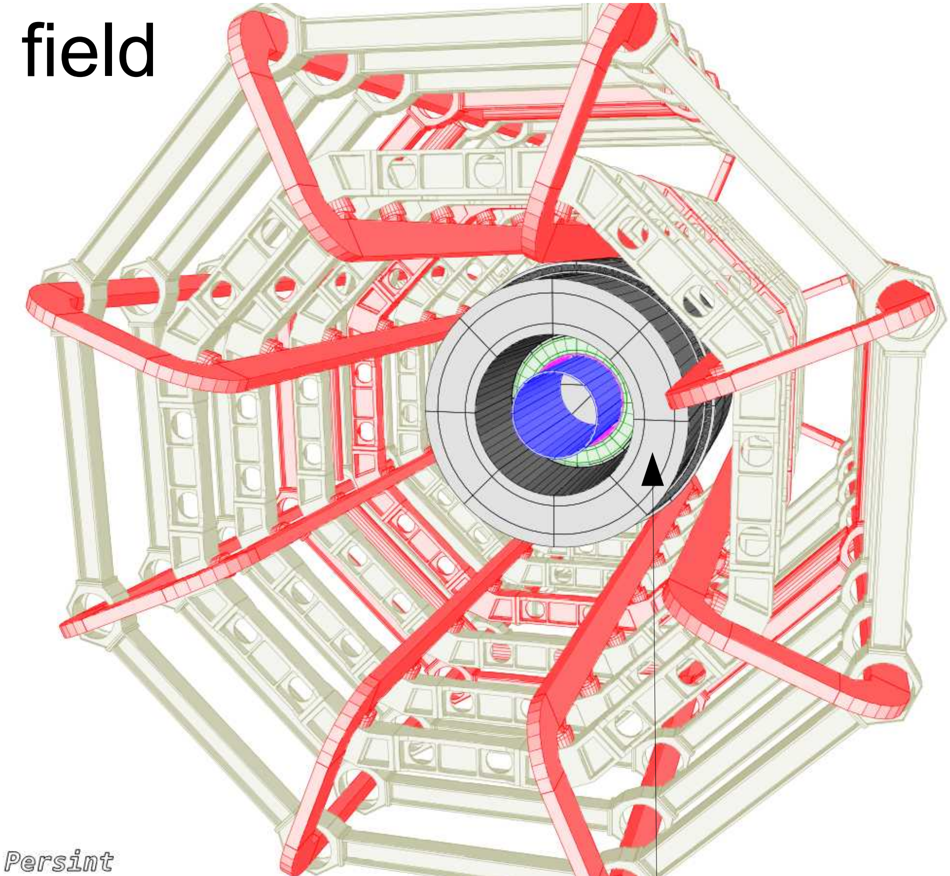
R–ϕ projection



R-Z projection



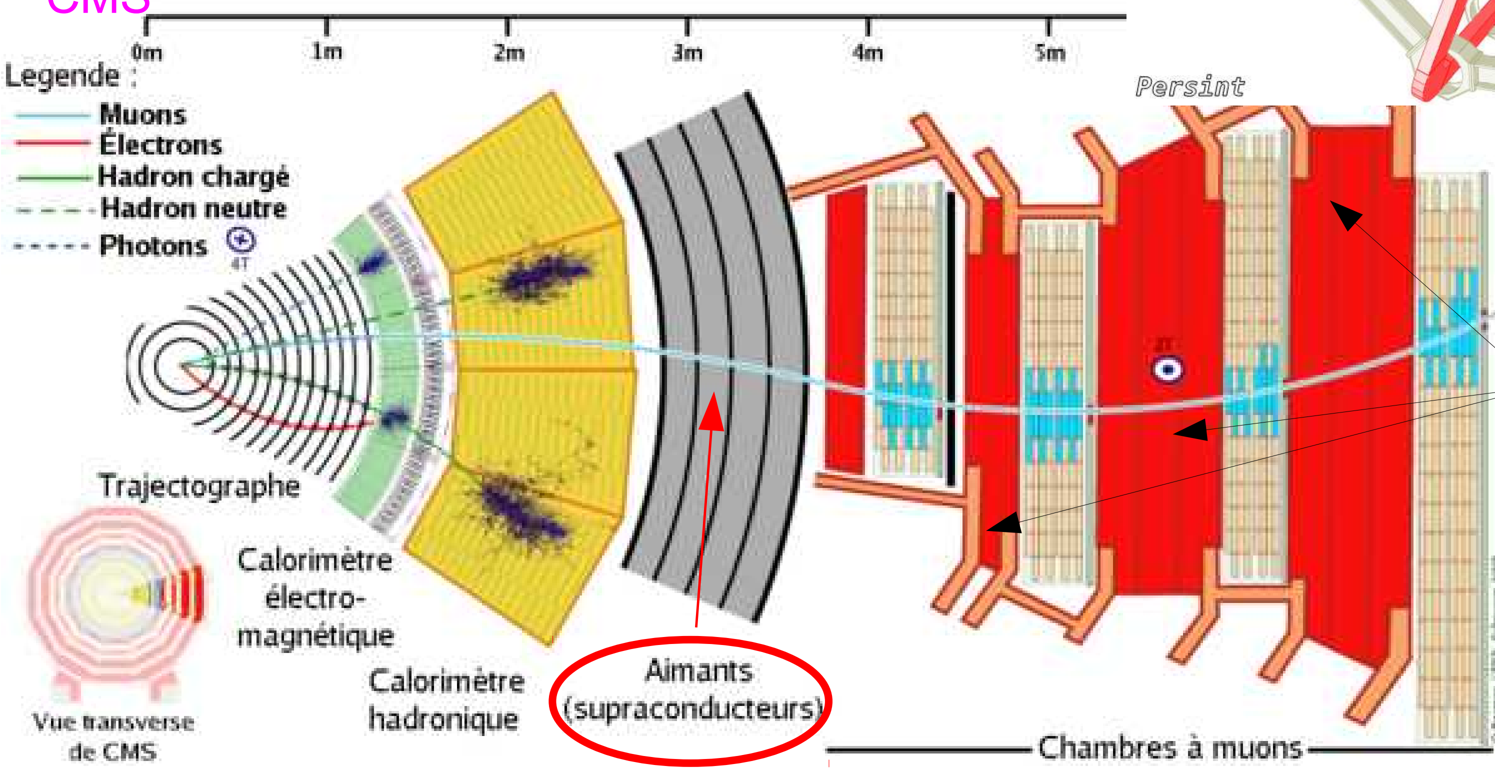
Charged particle in magnetic field



Order of Magnitude:

- Toroid ATLAS: B~0.5 Tesla
- Solenoid ATLAS(R=1m): B~2.0 Telsa
- Solenoid CMS (R=3m): B~3.8 Telsa

CMS



Solenoid Return Yoke

Charged particle in magnetic field

Order of Magnitude:
- Toroid ATLAS: B~0.5 Tesla
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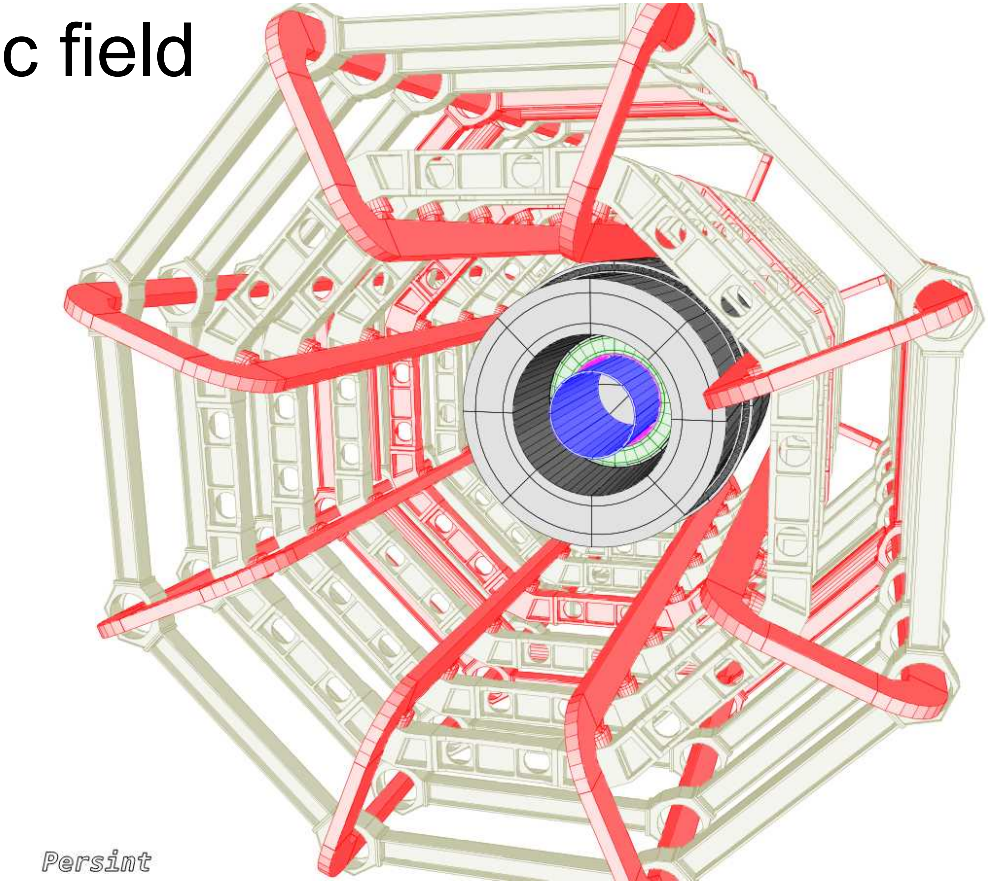
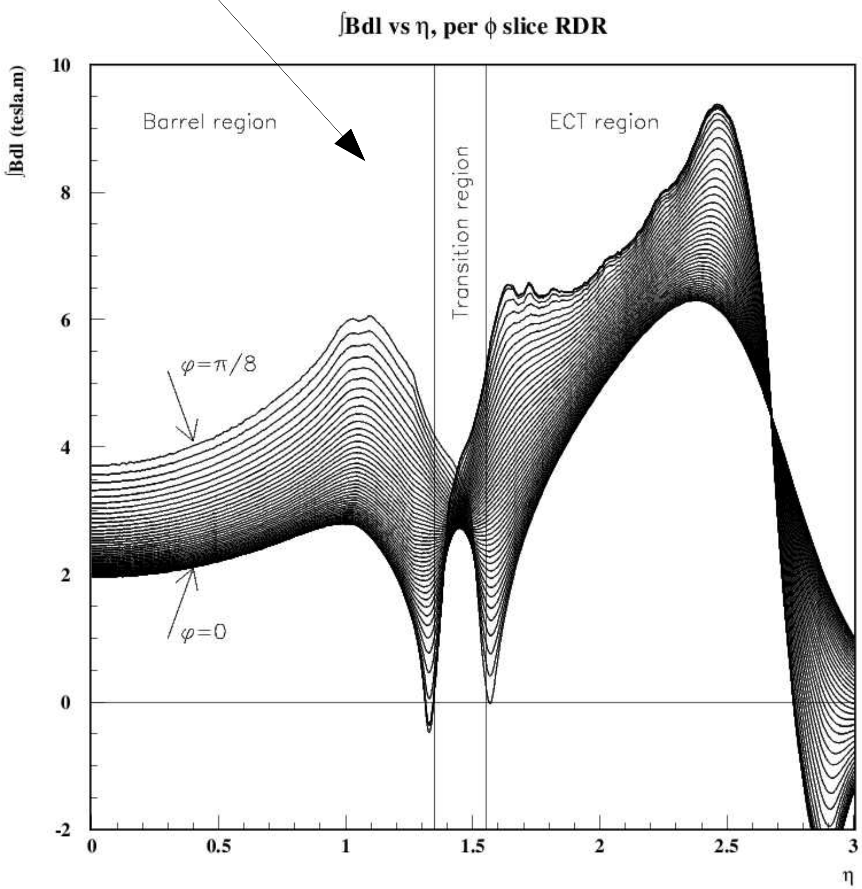
- Solenoid CMS (R=3m): B~3.8 Telsa



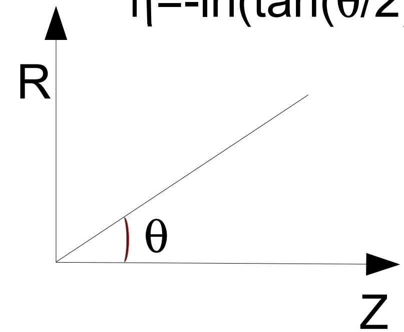
Int Bdl is the relevant parameter for a magnet



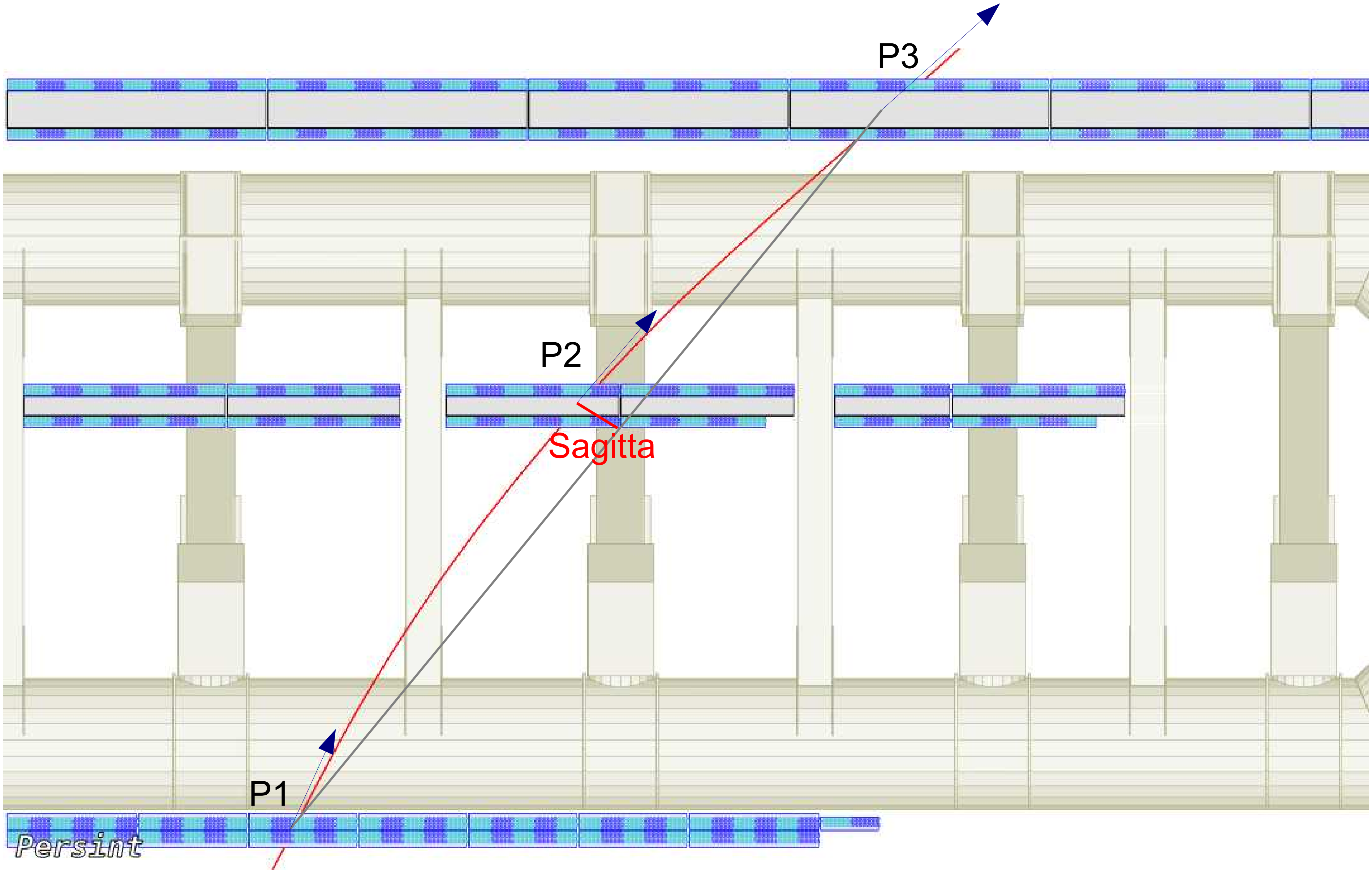
Solenoid: IntBdl ↘ η

Toroid: IntBdl → with η

$\eta = -\ln(\tan(\theta/2))$



Charged particle in magnetic field



3 measurement points (p1,p2,p3): d(p1,p3) straight line
Sagitta: distance between d(p1,p3) & p2

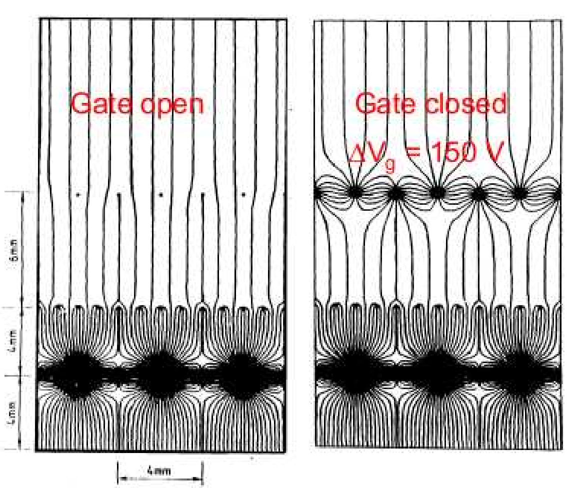
Interlude: Fin

Back to Detectors

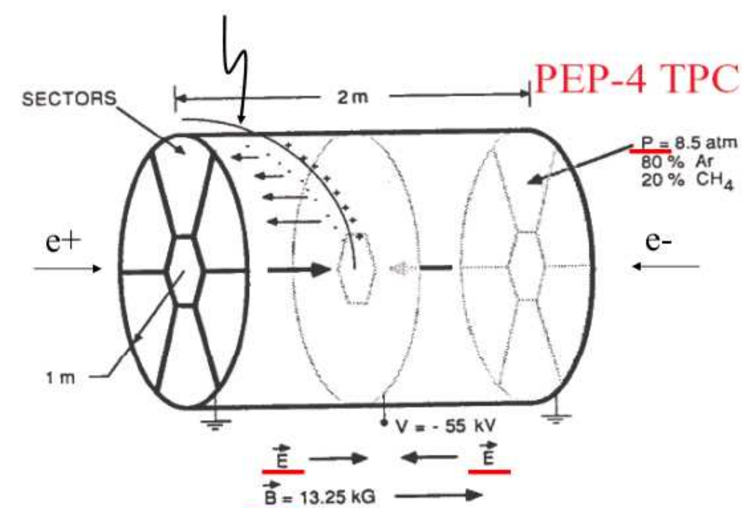
Detectors(Gaseous)

Time Projection Chamber (TPC)

- BNL (PEP-4) 1974
  - 3D tracks measurement (tracker) + particle identification!
  - Signal on 185 wires over 80cm (first coordinate Y)
  - Signal induced on the segmented cathode (8mm) (second coordinate X)
  - Drift time measurement (third coordinate Z, beam axis)
  - Gaseous: Ar-CH4, P= 8.5 atm
  - E (=150KV / m) // B (=1.5 Tesla)
  - Momentum measurement: Track + magnetic field
  - Control of the drift velocity of the ionization electrons! ~ 7cm / ms
  - Spatial resolution in Z (direction of field lines E & B) ~ mm / m
  - Drift electric field decoupled from the avalanche electric field



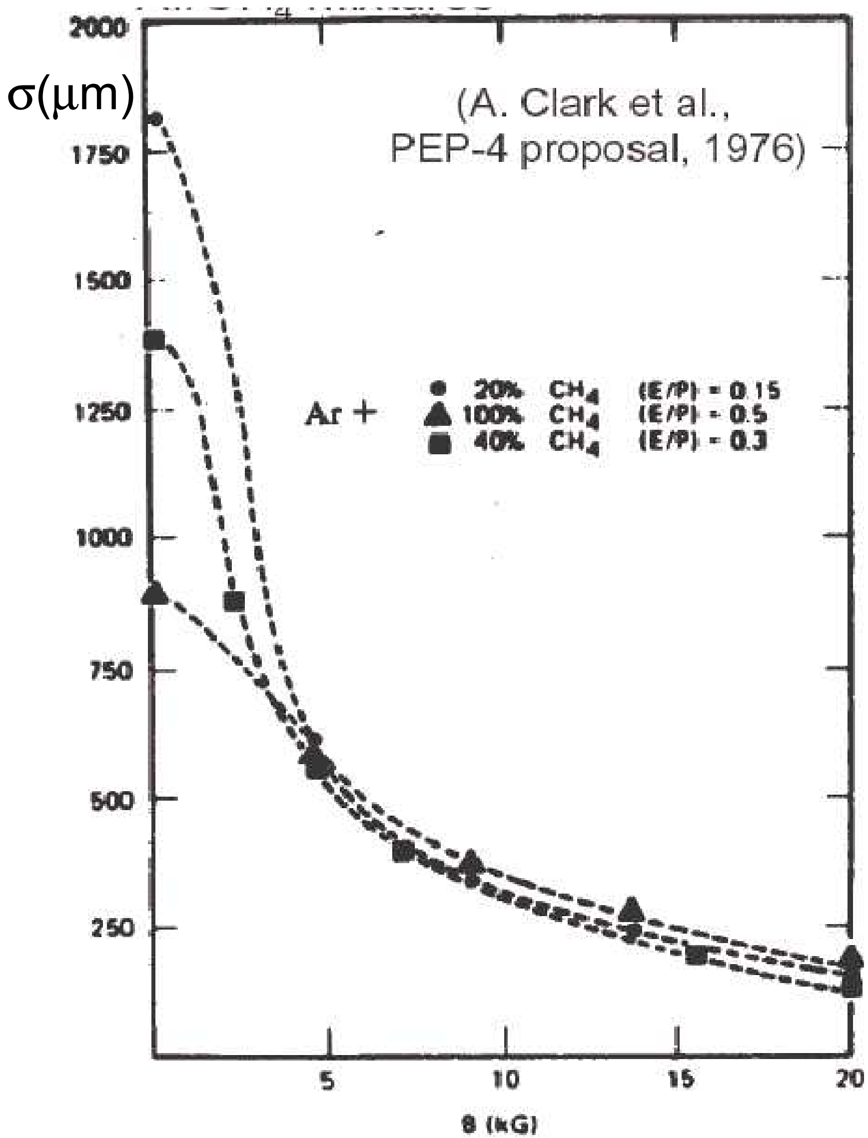
Remark:
To prevent that the ions disturb the TPC:
A gate (150V) is closed between collisions

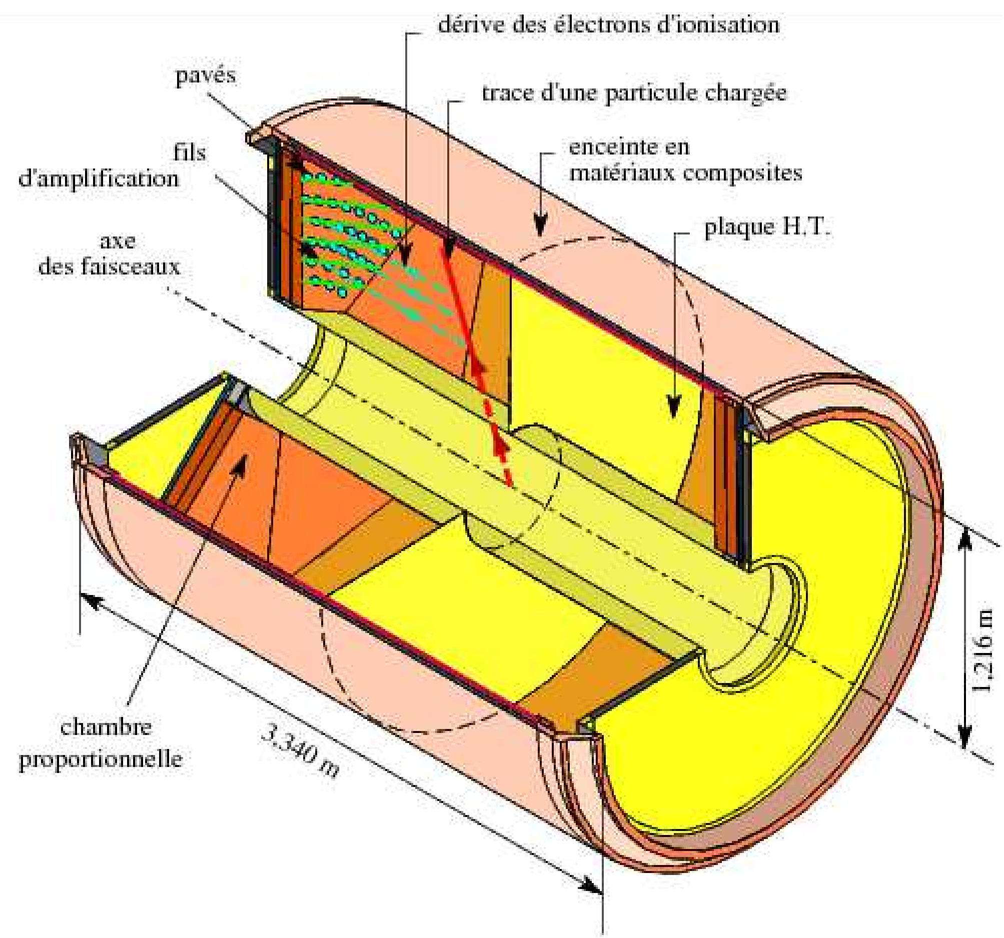


Detectors(Gaseous)

Time Projection Chamber (TPC)

- E//B transverse diffusion reduced by a factor 7
  - Thanks to Lorentz the drift of the ionization electrons spiral along the electric field line

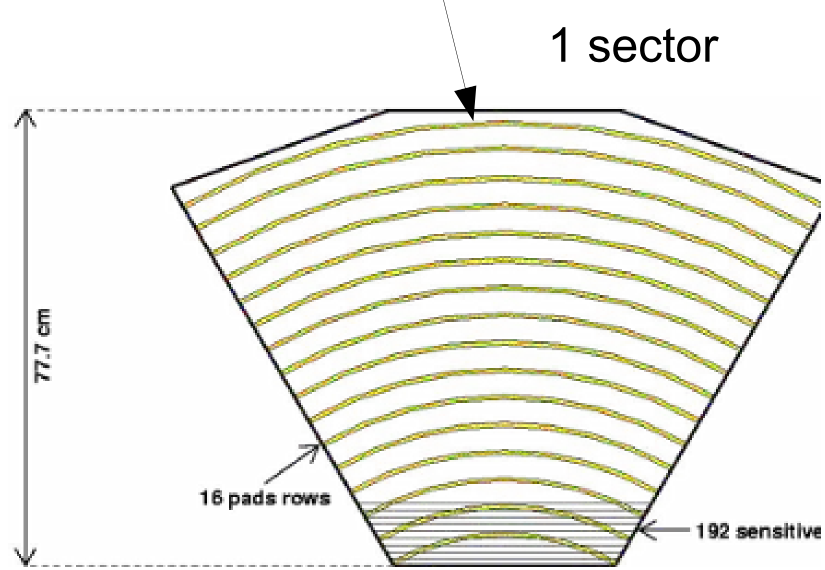




Detectors(Gaseous)

TPC: Delphi, Lep 1992

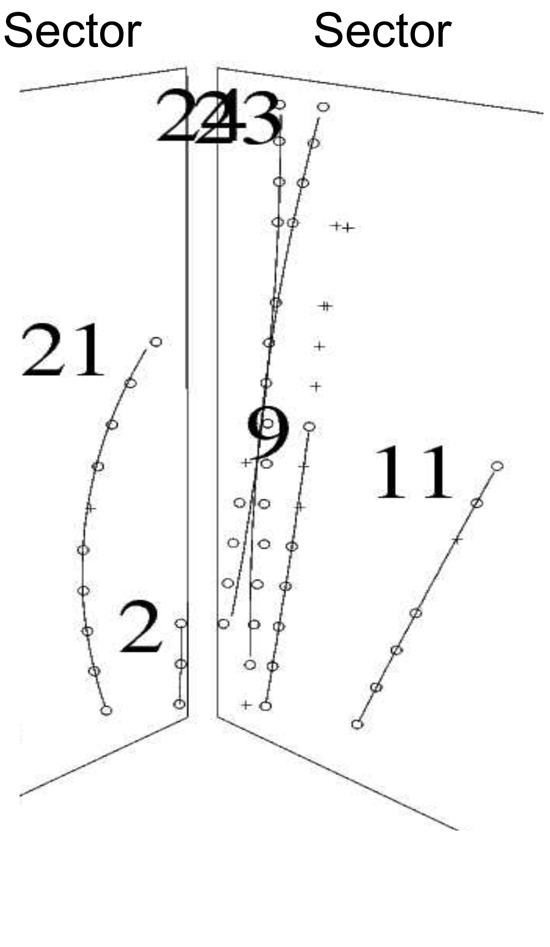
- PEP-4 close evolution, better spatial resolution
- B = 1.2T, E = 150 V / cm, Ar (80%) - CH_4 (20%) & P = 1atm
- 27 Primary & Secondary electrons / cm
- 6.7 cm / µs, transverse diffusion ~ 100 µm / sqrt (cm)
- 2 x 6 sectors, 192 wires, 16 Pad (segmented cathode)
- 16 three-dimensional points
- 2 x 1.34 m, 0.325 m < Radius < 1.160 m
- Spatial resolution: Rphi ~ 250µm, Z ~ 1mm

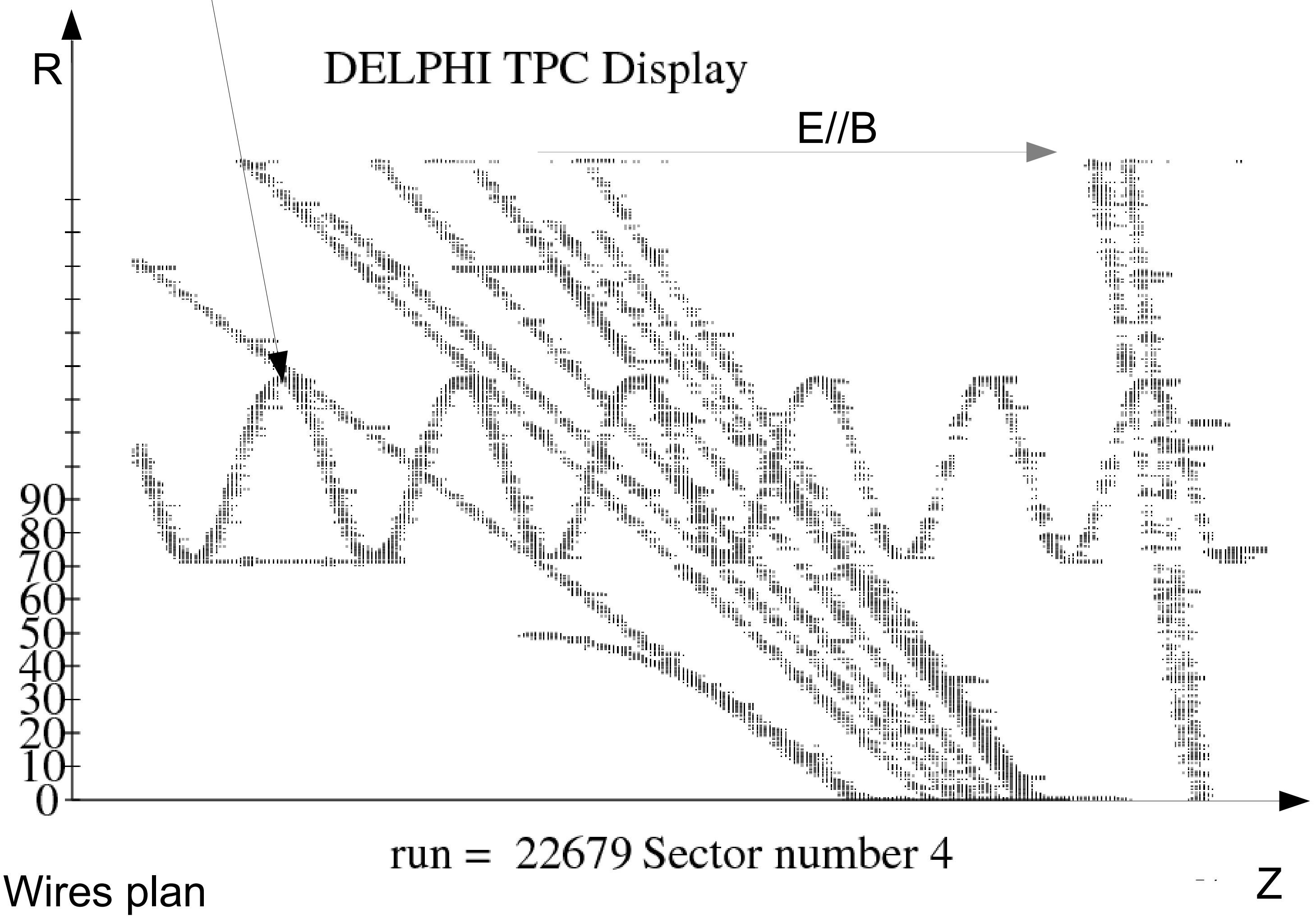


Detectors(Gaseous)

TPC: Delphi

- 2 views: RZ (left) & Rϕ(right)
- We see clearly a spiralling electron



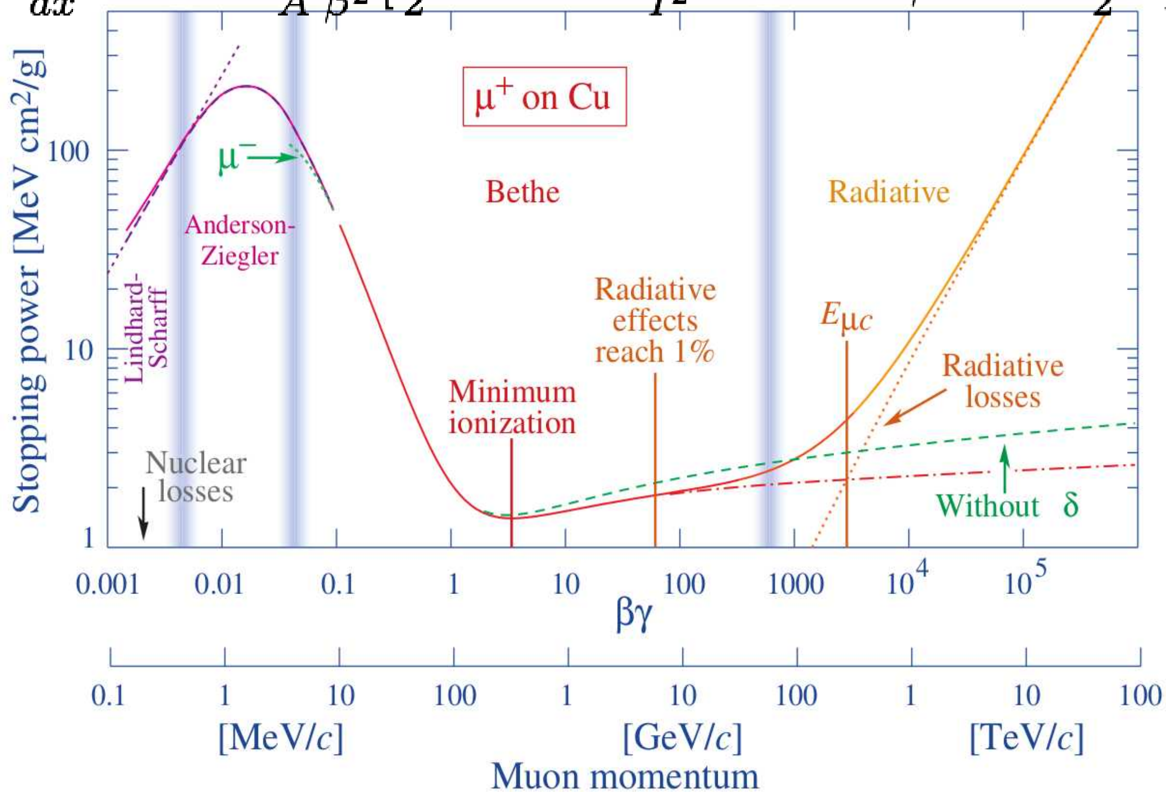


Detectors(Gaseous)

TPC: Delphi vs PEP-4

- No conceptual difference
- Only the Pressure is different: Delphi: 1 atm & PEP-4: 8.5 atm
  - Bigger Ionisation in PEP-4
    - More electrons S/B better
    - dE/dx resolution better
  - BUT
    - dEdx curves very close, improvement not so big
    - TPC walls thicker more X0 means more conversion

$$-\frac{dE}{dx} = Kz^2 \frac{Z}{A} \frac{1}{\beta^2}\left[\frac{1}{2} \ln \frac{2m_e c^2 \beta^2 \gamma^2 T_{max}}{I^2} - \beta^2 - \frac{\delta(\beta\gamma)}{2}\right]$$

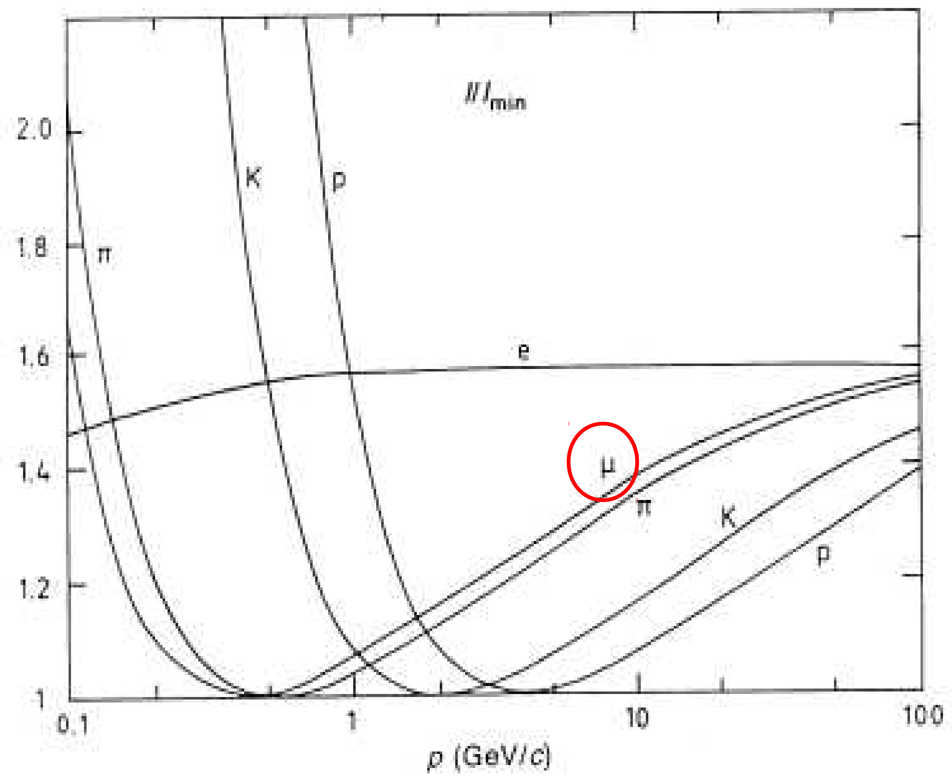


Detectors(Gaseous)

TPC: dE/dx

- Muon identification in the energy range: 1 to 10 GeV

$$-\frac{dE}{dx} = Kz^2\frac{Z}{A}\frac{1}{\beta^2}[\frac{1}{2}\ln\frac{2m_ec^2\beta^2\gamma^2T_{max}}{I^2} - \beta^2 - \frac{\delta(\beta\gamma)}{2}]$$



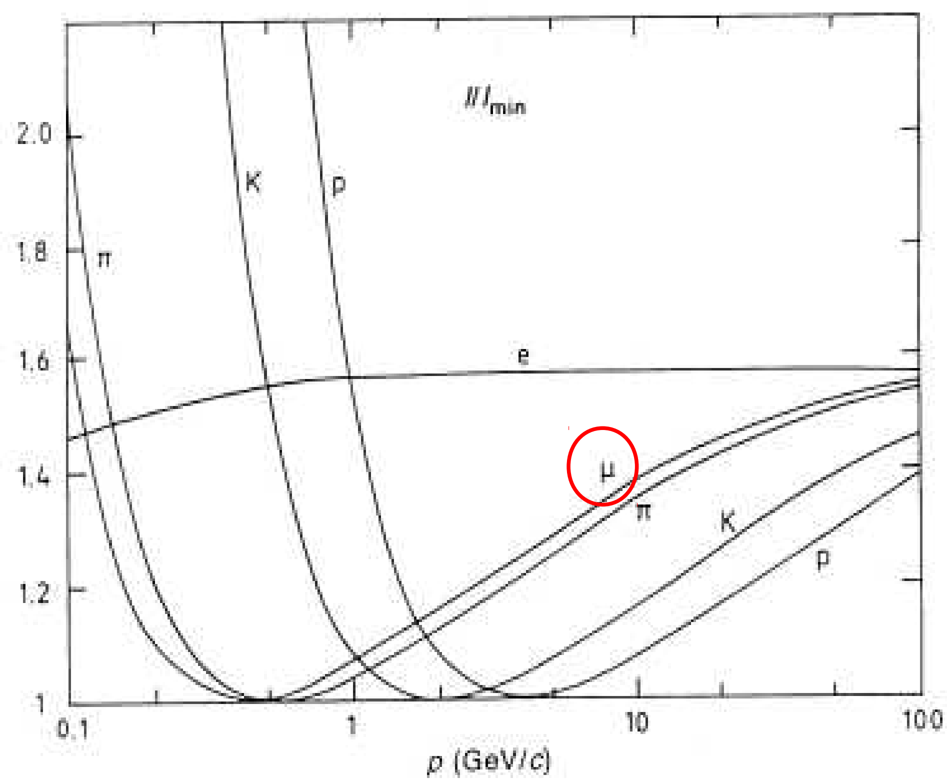
Calculation

Detectors(Gaseous)

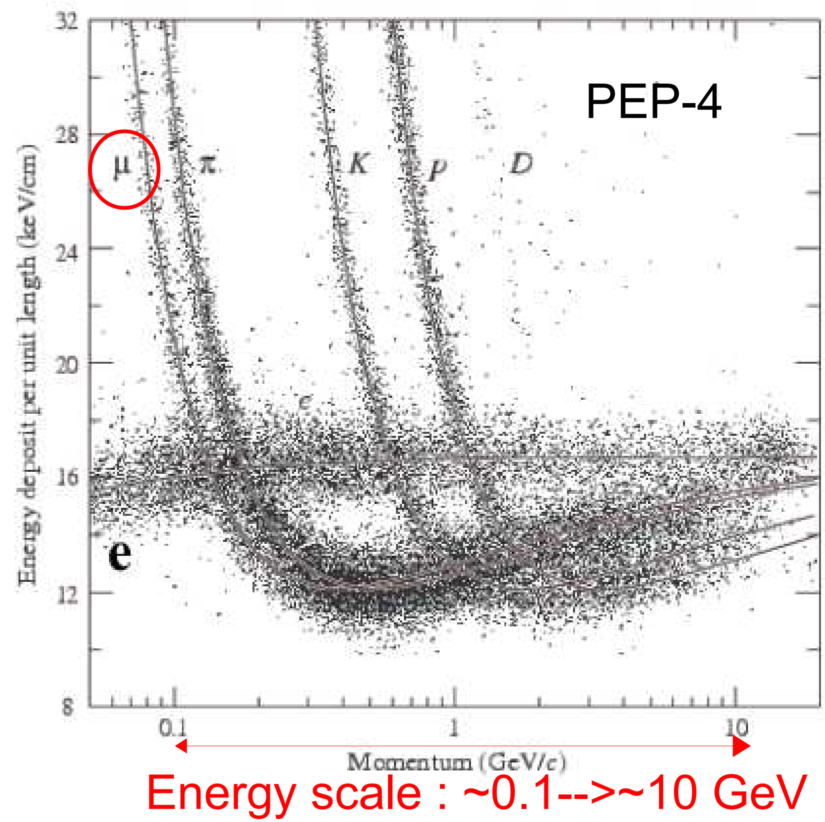
TPC: dE/dx

- Muon identification in the energy range: 1 to 10 GeV

$$-\frac{dE}{dx} = Kz^2 \frac{Z}{A} \frac{1}{\beta^2} \left[\frac{1}{2} \ln \frac{2m_e c^2 \beta^2 \gamma^2 T_{max}}{I^2} - \beta^2 - \frac{\delta(\beta\gamma)}{2} \right]$$



Calculation



Data

Detectors(Gaseous)

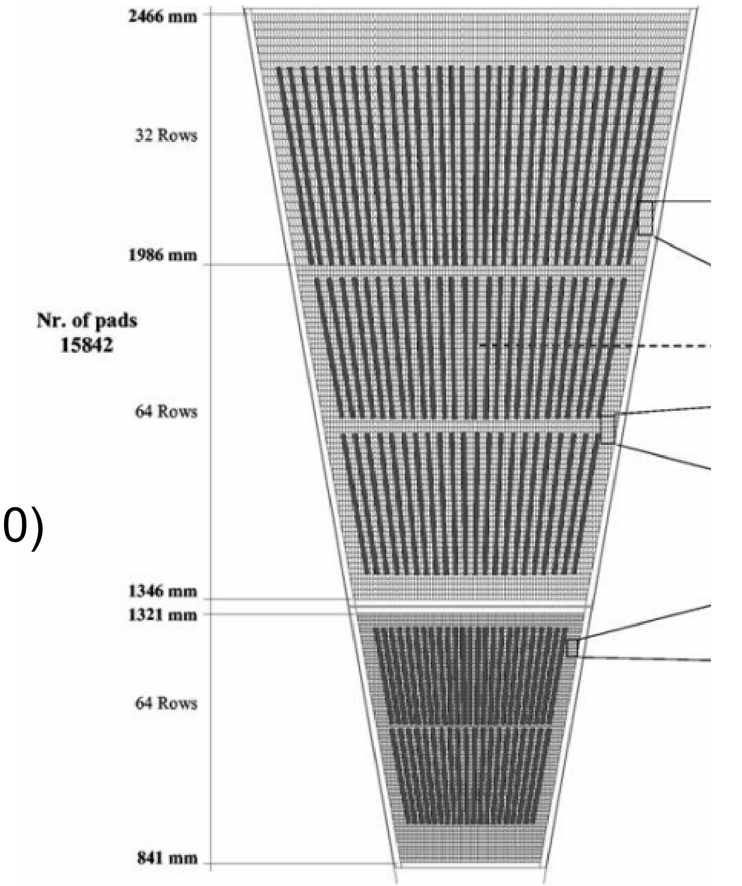
TPC: dE/dx

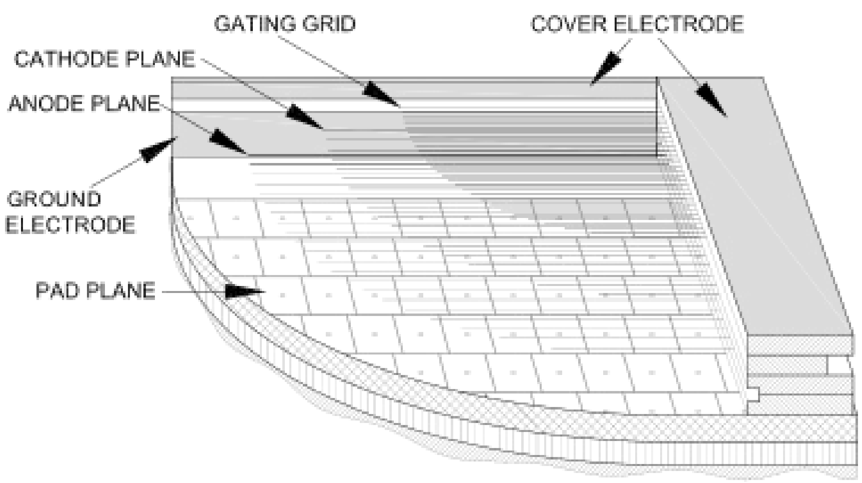
- Muon identification in the energy range: 1 to 10 GeV

Detectors(Gaseous)

TPC: Alice (LHC: Pb-Pb)

- Same principle as Delphi and PEP-4
- more complicated
  - 5.1m long (2x2.5m), 18 sectors (MWPC)
  - Diameter = 5.6 m, volume = 88 m3
  - Inner radius = 0.9 m, outer radius = 2.5 m
  - Number of Channels: 577568 (Delphi: 20160)





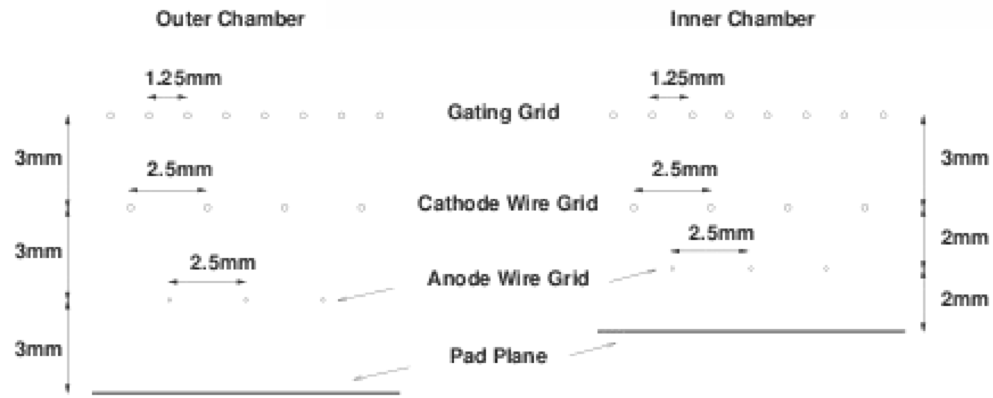
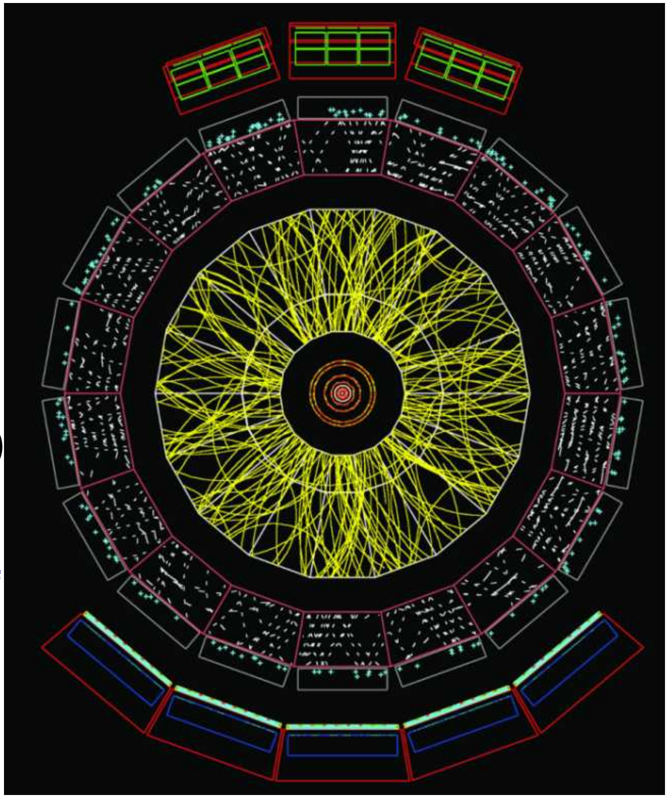


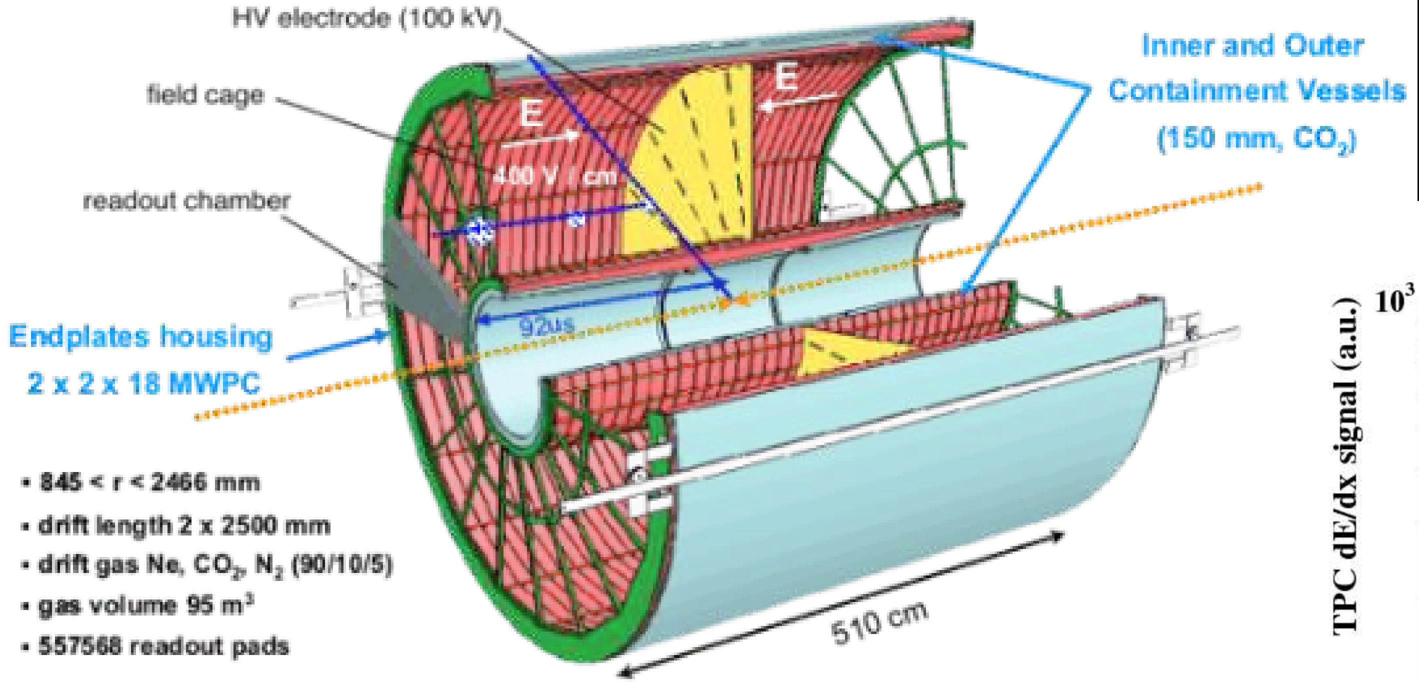
Figure 10: Wire geometries of the outer (left) and inner (right) readout chambers.

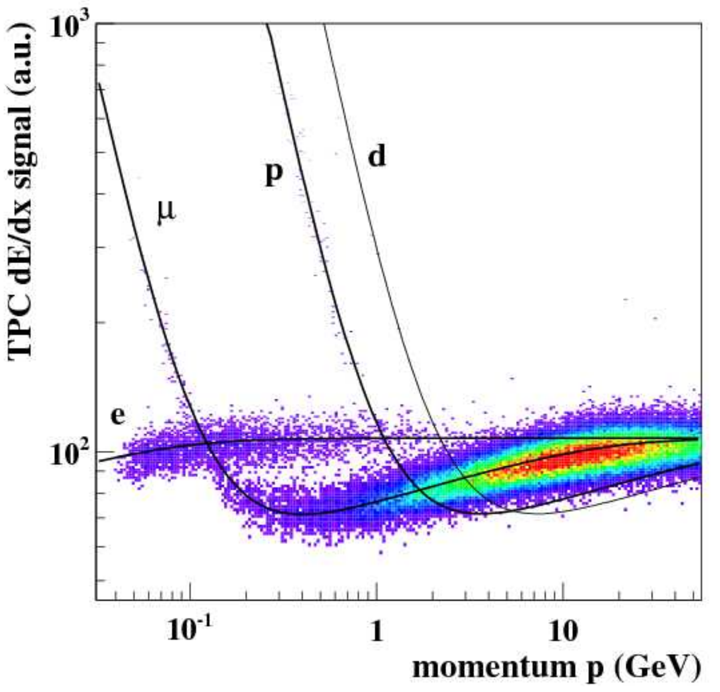
Detectors(Gaseous)

TPC: Alice (LHC: Pb-Pb)

- Biggest TPC never built
- more complicated
  - Spatial resolution 500 μm
  - Momentum resolution 1% (1GeV), 5%(10 GeV)





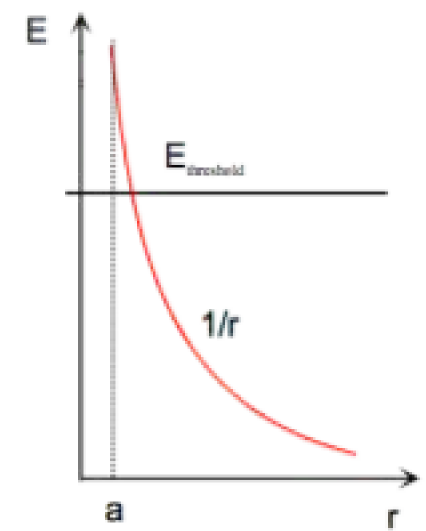


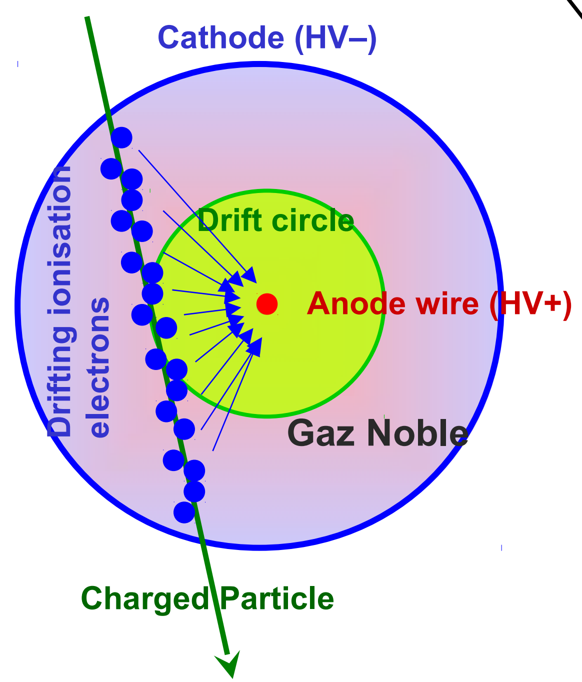
Detectors(Gaseous)

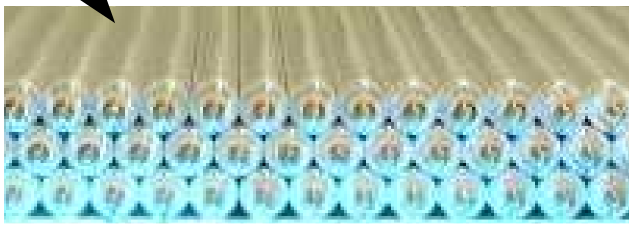
Drift Tube

- Back to Geiger tube
  - MWPC limits:
    - size, cross-talk, energy range
- ~100 e-
- Electric field in 1/r
- Gain ~10^4 to 10^5
- Not 1 tube but hundred of thousand tubes

$$E = \frac{C V_0}{2 \pi \epsilon_0} \ln\left(\frac{1}{r}\right)$$





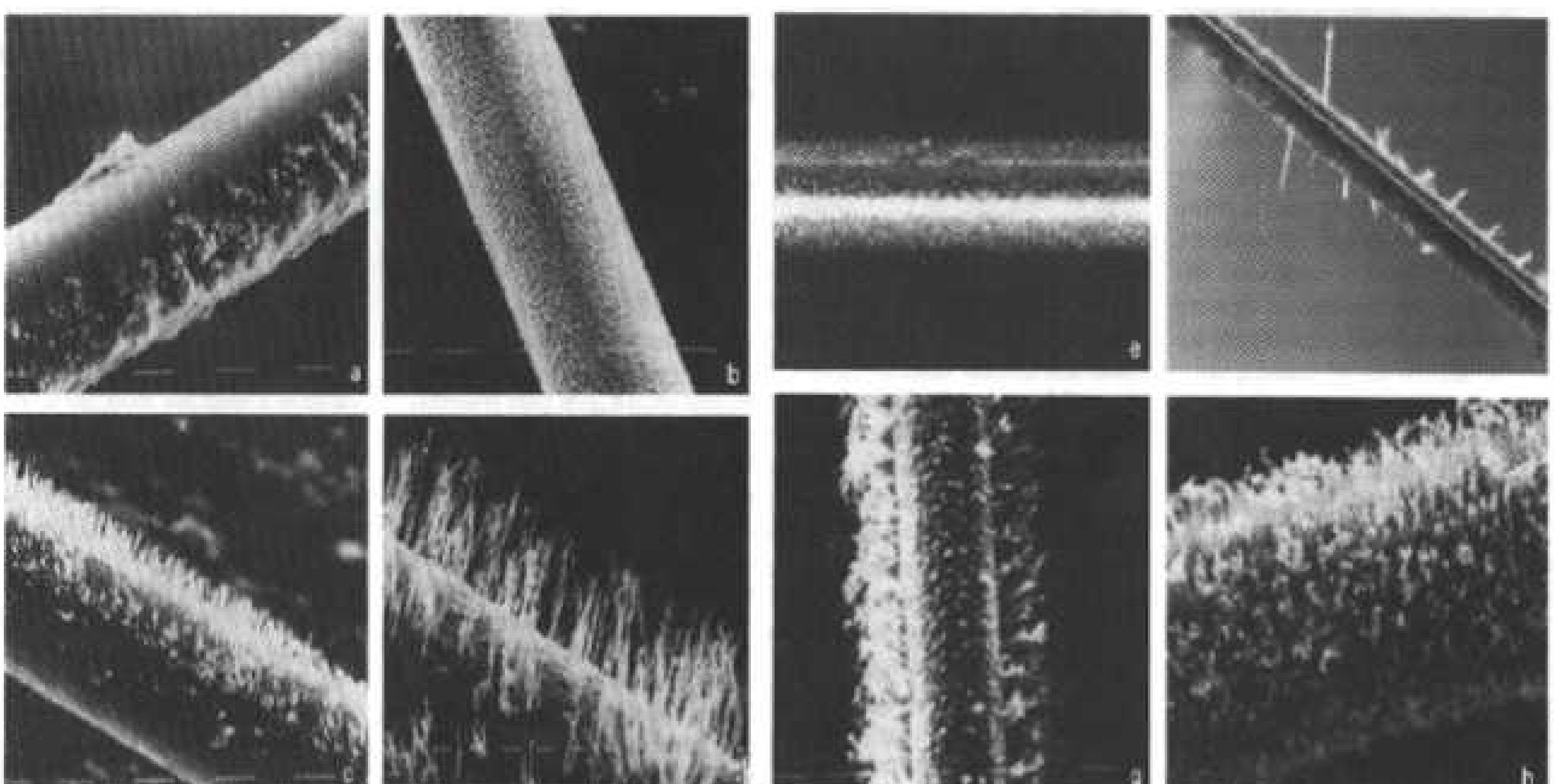


Charged particle: Muon

Detectors(Gaseous)

Drift Tube

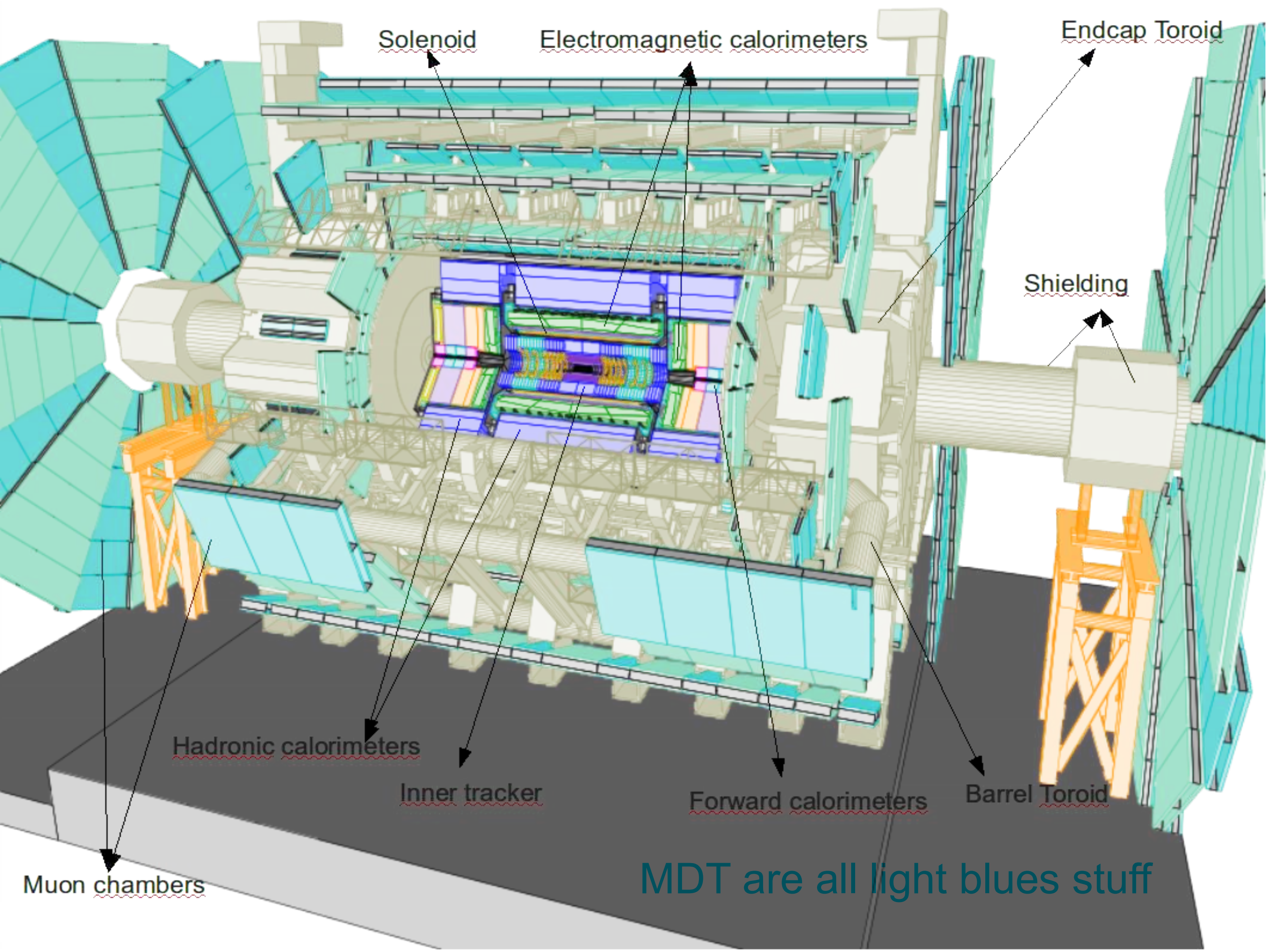
- Main problem: ageing!
  - Careful choice of materials (no Si or similar)
  - Highest gas gas purity
  - Avoid exceedingly high currents
    - Gas impurities or high currents may lead to the development of deposits on the wires in the form of tiny whiskers (polymerization of chemical elements in the gas)
      These may lead to HV instabilities and inefficiencies and in the worst case they may make chambers completely unusable

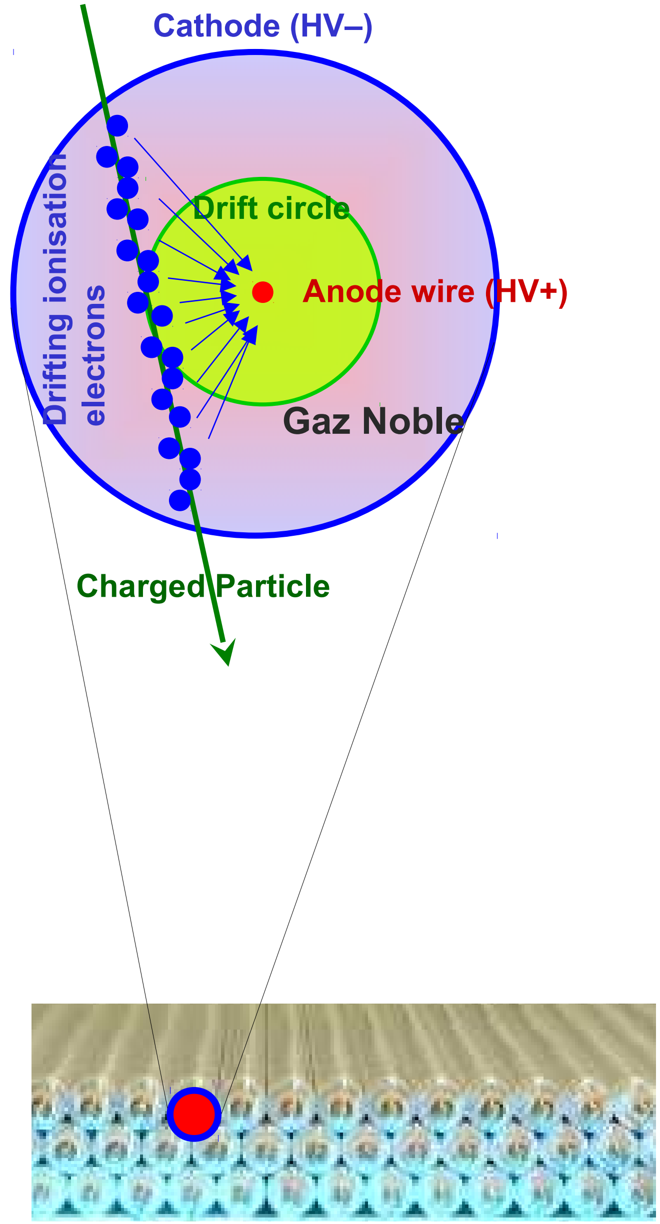


Detectors(Gaseous)

MDT: Monitored Drift Tube

- ATLAS ~3.7 10^5 tubes
  - ~5500 m^2 , 3 layers (barrel + endcap)



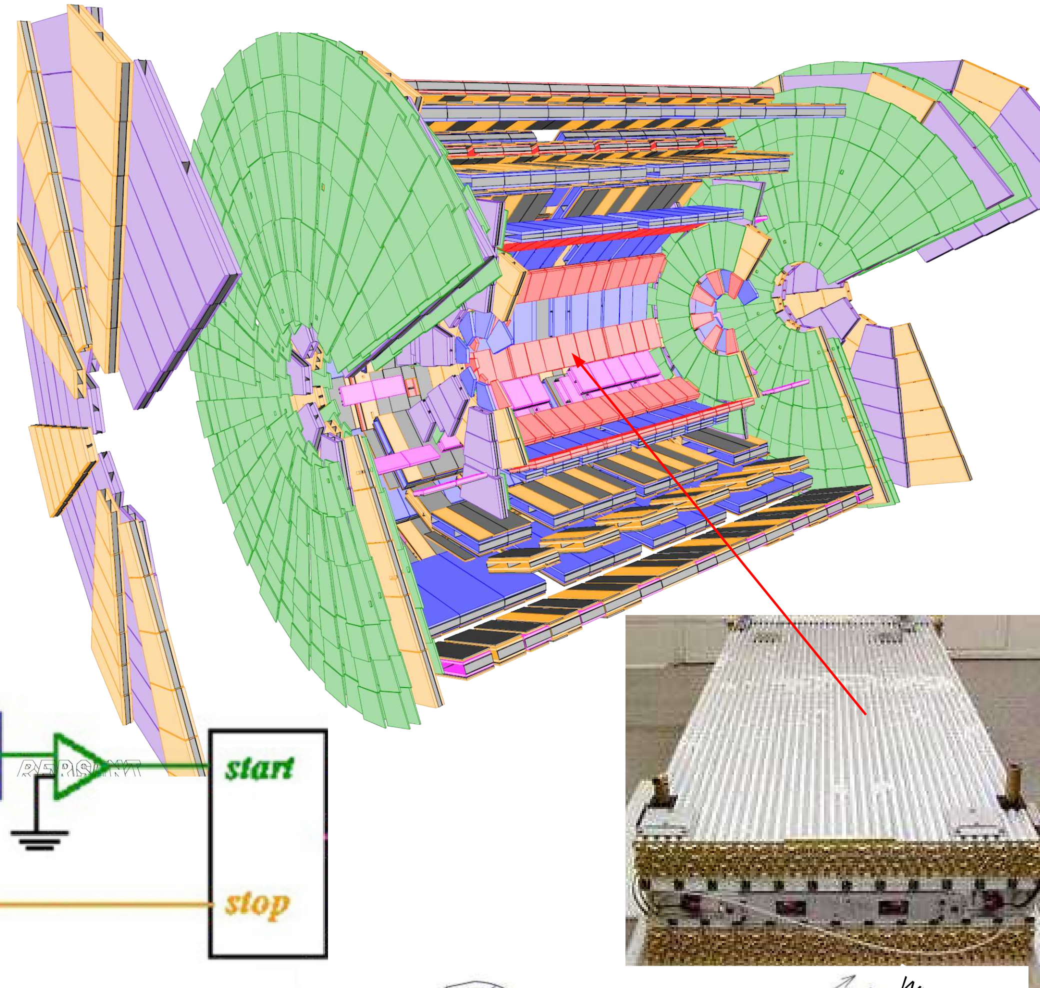


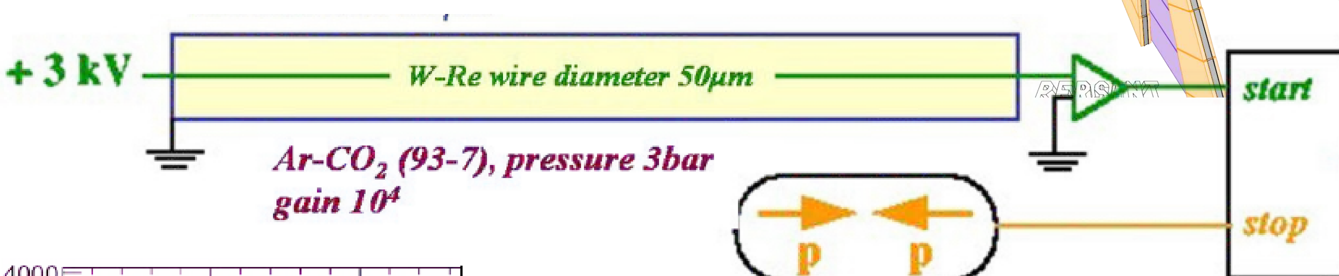
MDT are all light blues stuff

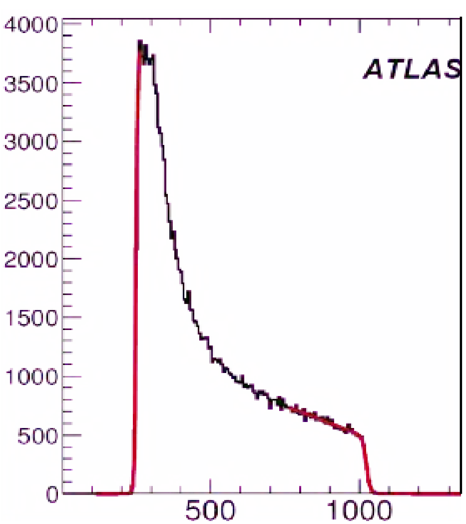
Detectors(Gaseous)

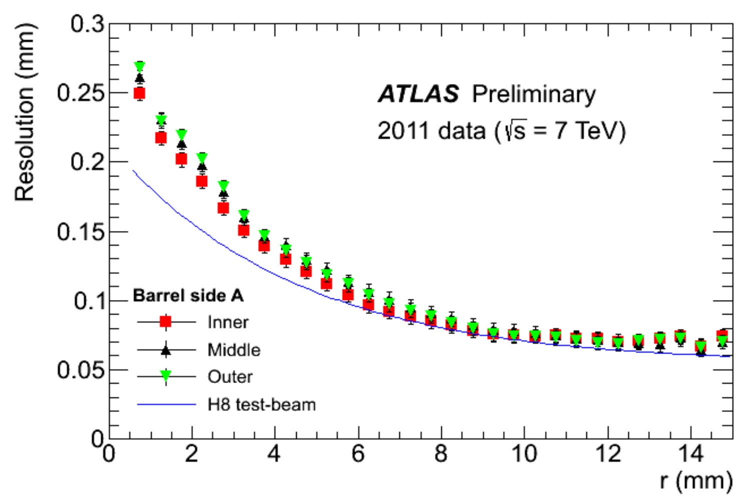
MDT: Monitored Drift Tube

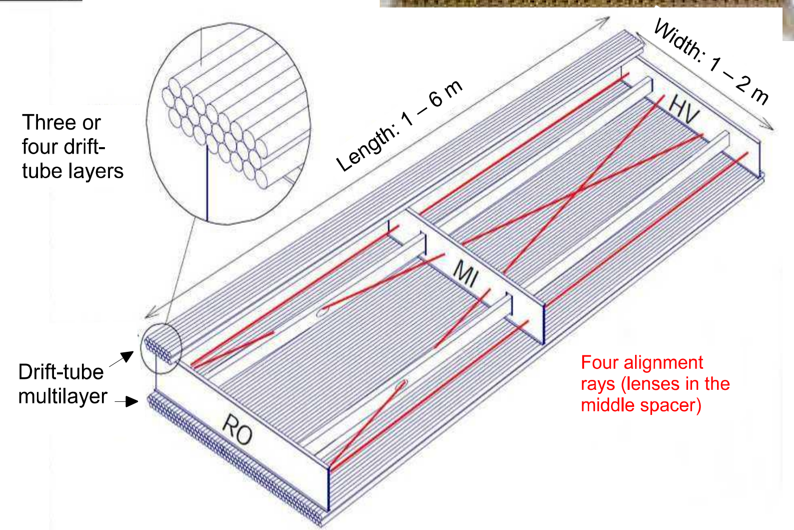
- ATLAS Muons spectrometer
  - Drift chamber (1 to 6m tube long)
  - Wire 50 µm, 30 mm diameter tube
  - V = 3000 volts
  - Pressure = 3 atm (300 pairrs / cm)
  - Gain: 2.10^4
  - Max drift time: 700 ns
  - Drift velocity ~ 3cm / µs
  - Spatial resolution ~ 80 µm (→ ~100 µm data)
  - Ar (93%) - C02 (7%)







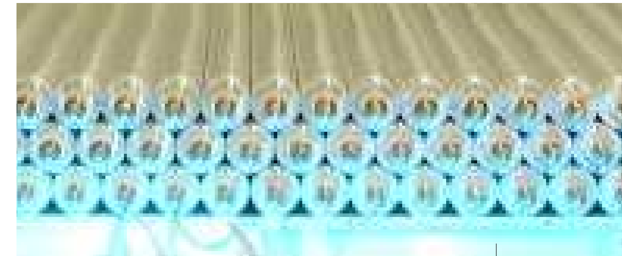


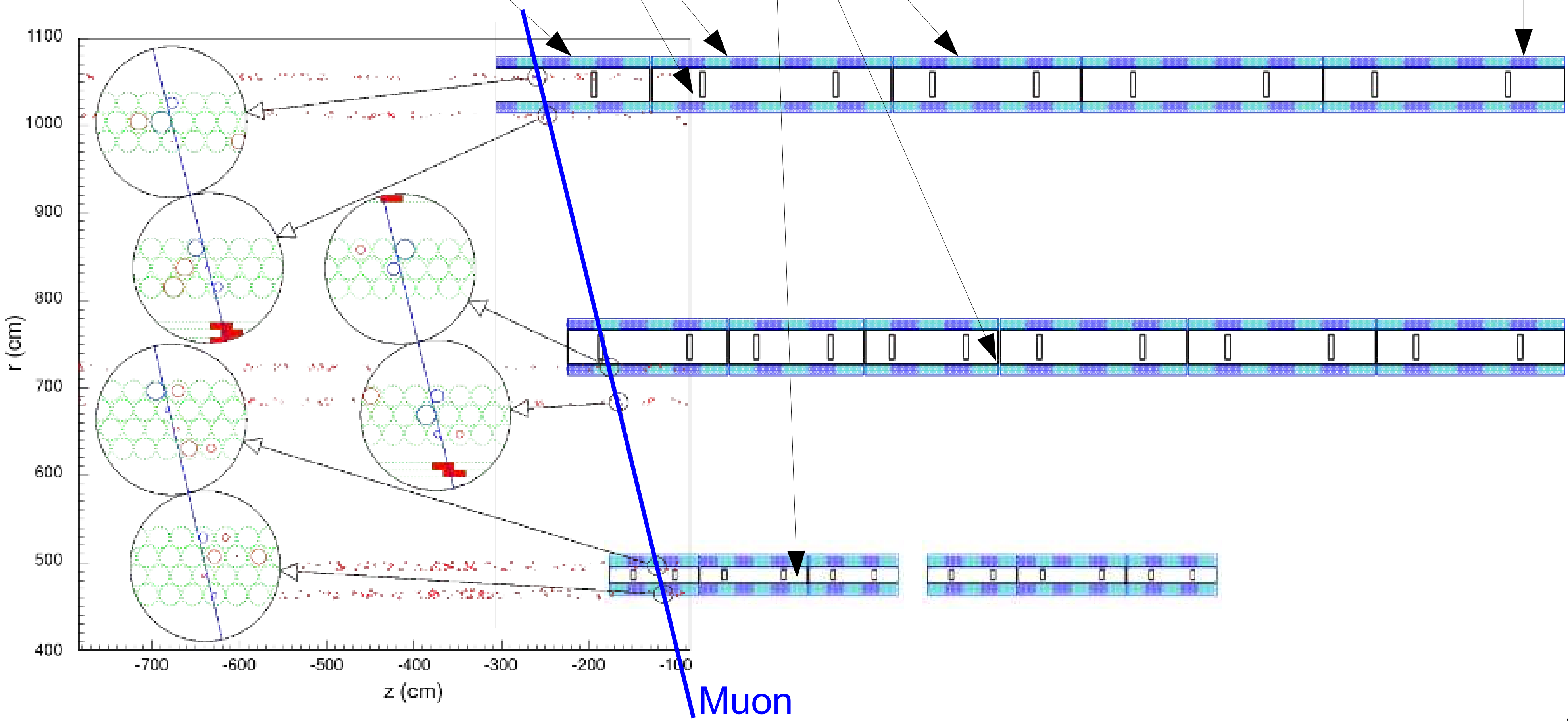


Detectors(Gaseous)

MDT: Monitored Drift Tube

- ATLAS Muons spectrometer
- 3 (4) tubes x 2 (layers) x 3 (positions)

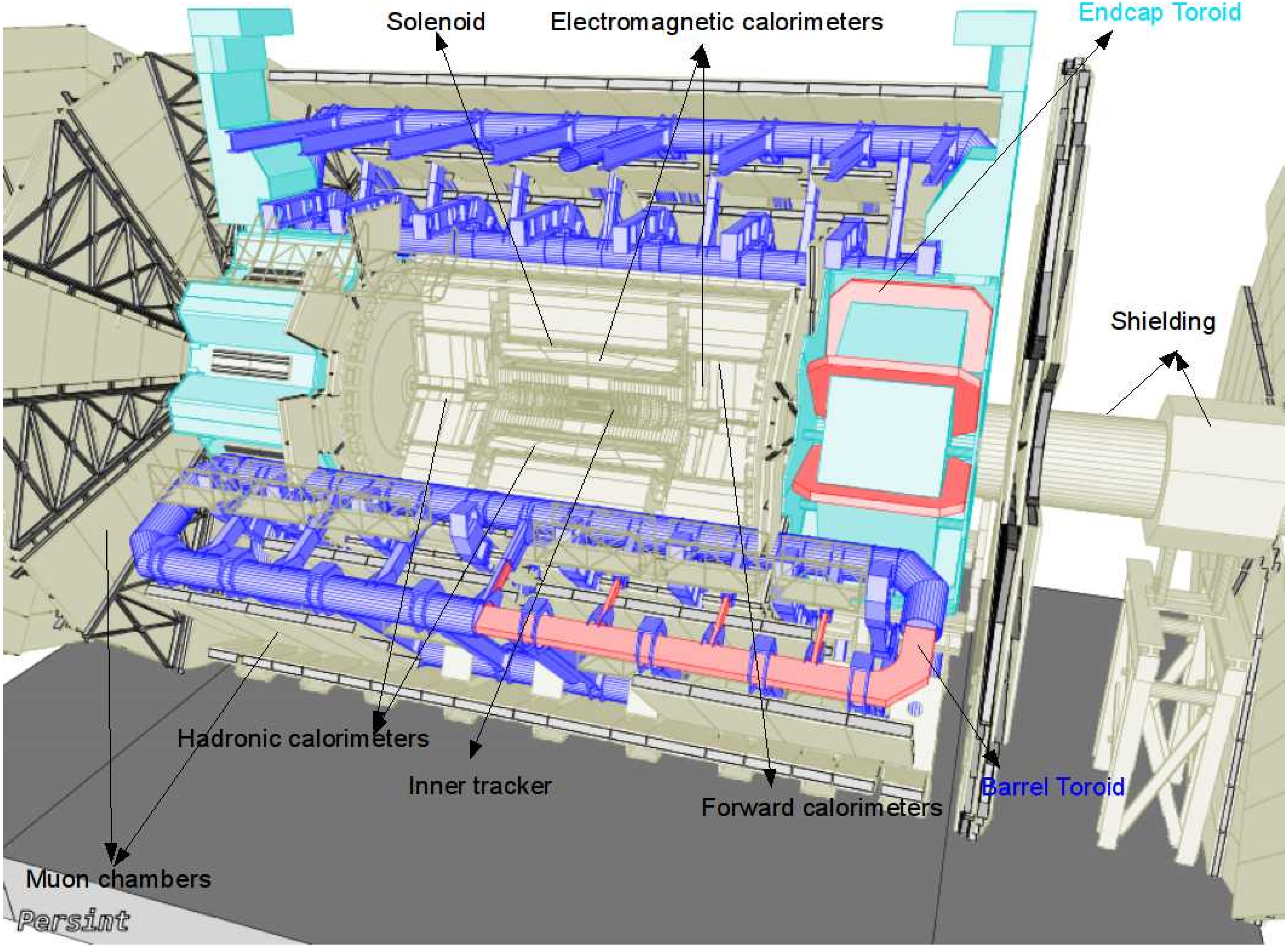




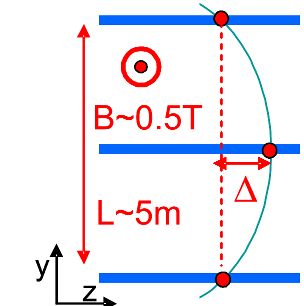
Detectors(Gaseous)

MDT: Monitored Drift Tube

- ATLAS Muons spectrometer
  - Air core Toroid => Magnetic field => Muon momentum measuremnt

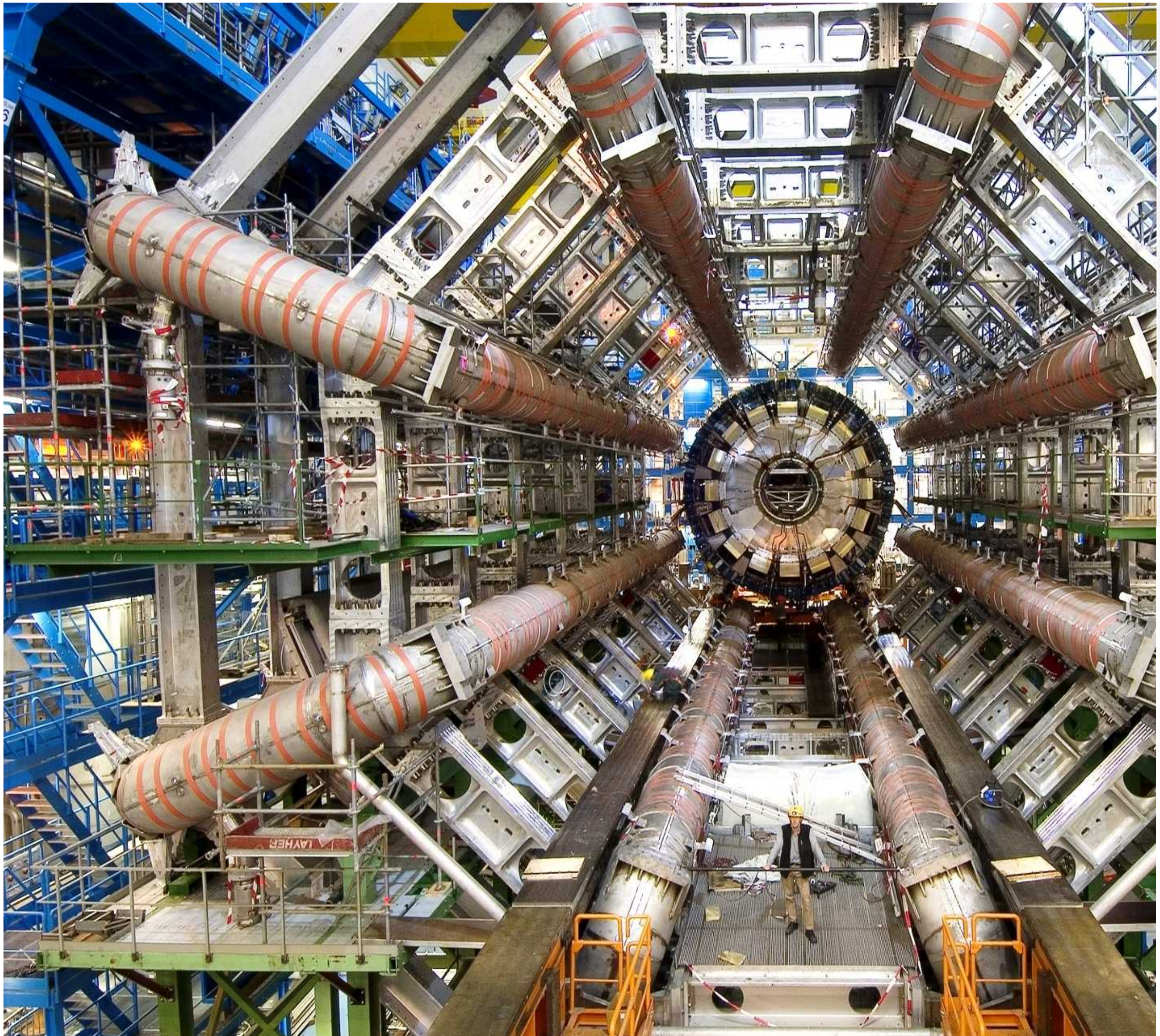


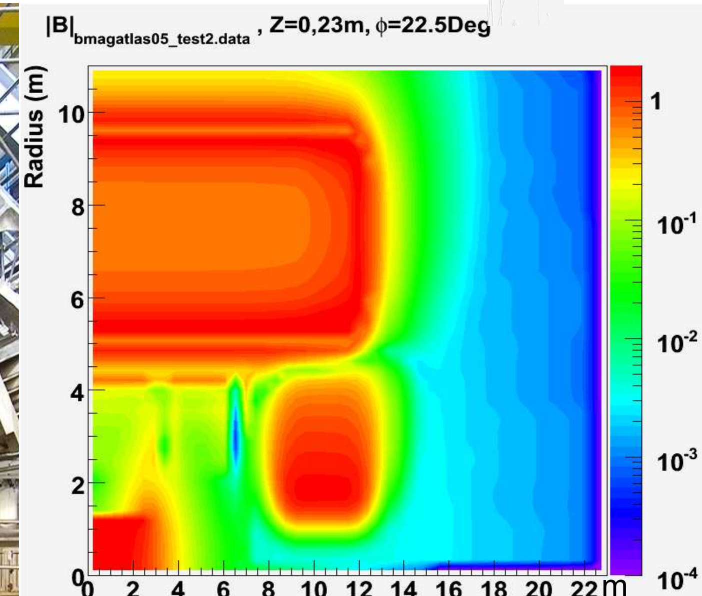
Detectors(Gaseous)

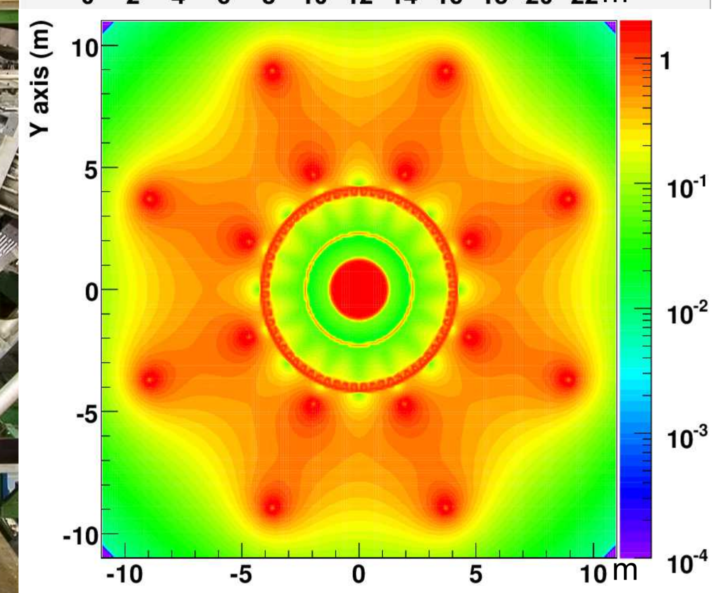


MDT: Monitored Drift Tube

- ATLAS Muons spectrometer
  - Air core Toroid => Magnetic field => Muon momentum measurement



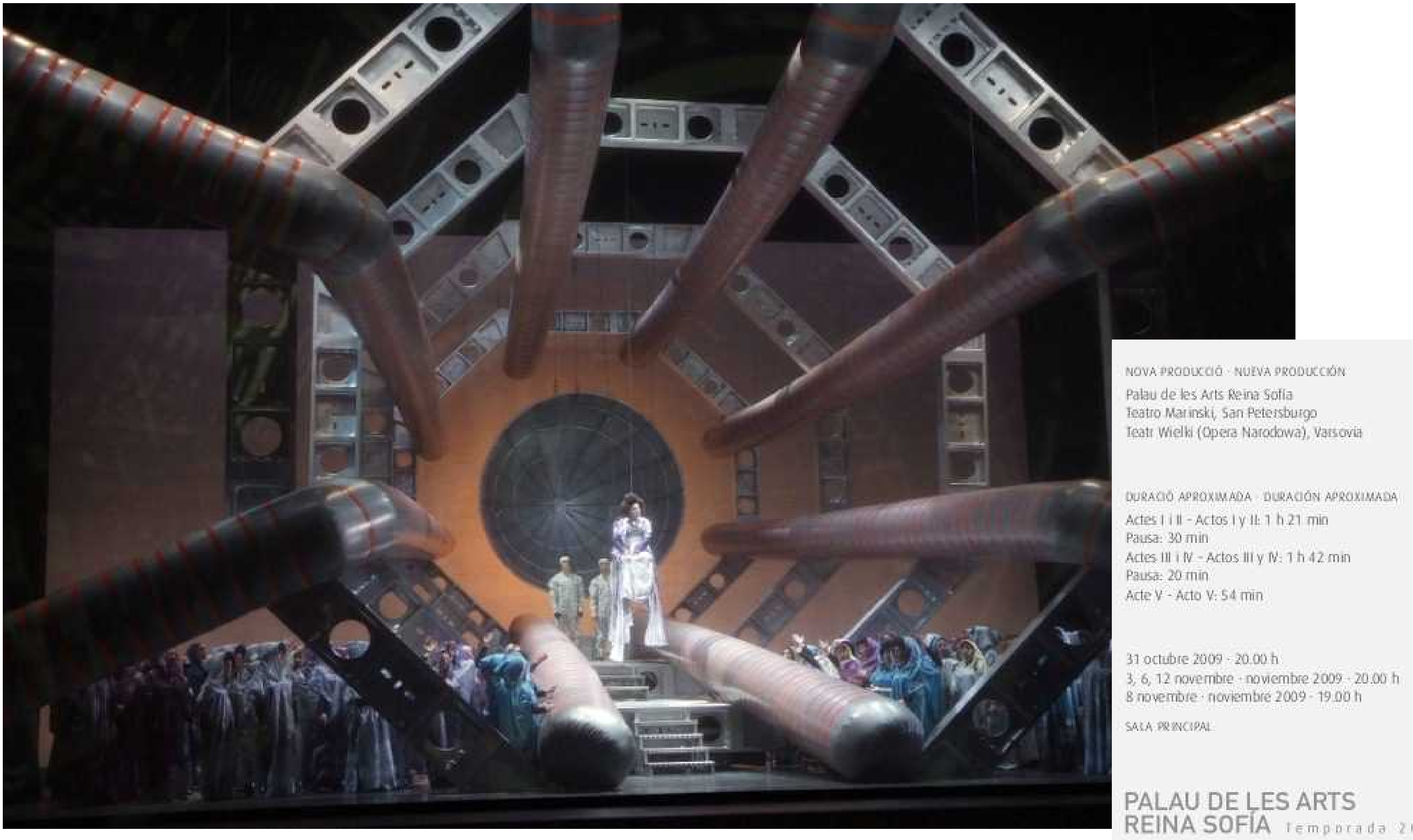




Detectors(Gaseous)

MDT: Monitored Drift Tube

- ATLAS Muons spectrometer
  - Air core Toroid => Magnetic field => Muon momentum measuremnt

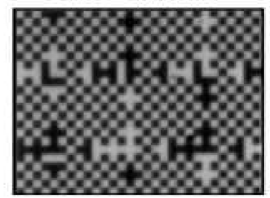


Detectors(Gaseous)

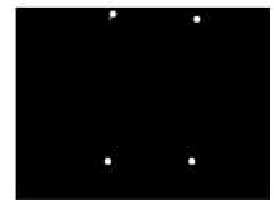
MDT: Monitored Drift Tube

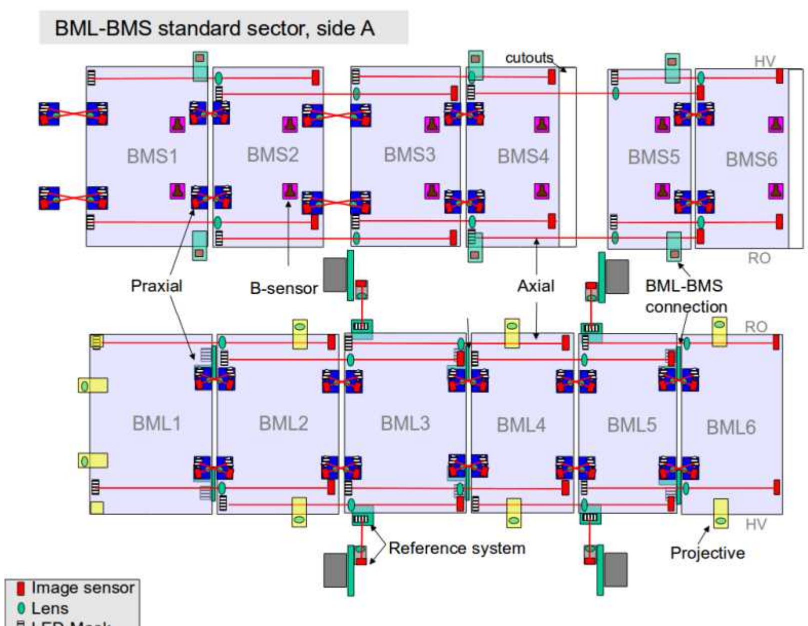
- ATLAS Muons spectrometer
  - Relatif Alignment of ~1200 chambers* 6 par. position + 11 par. Deformation
  - 20000 free parameters!

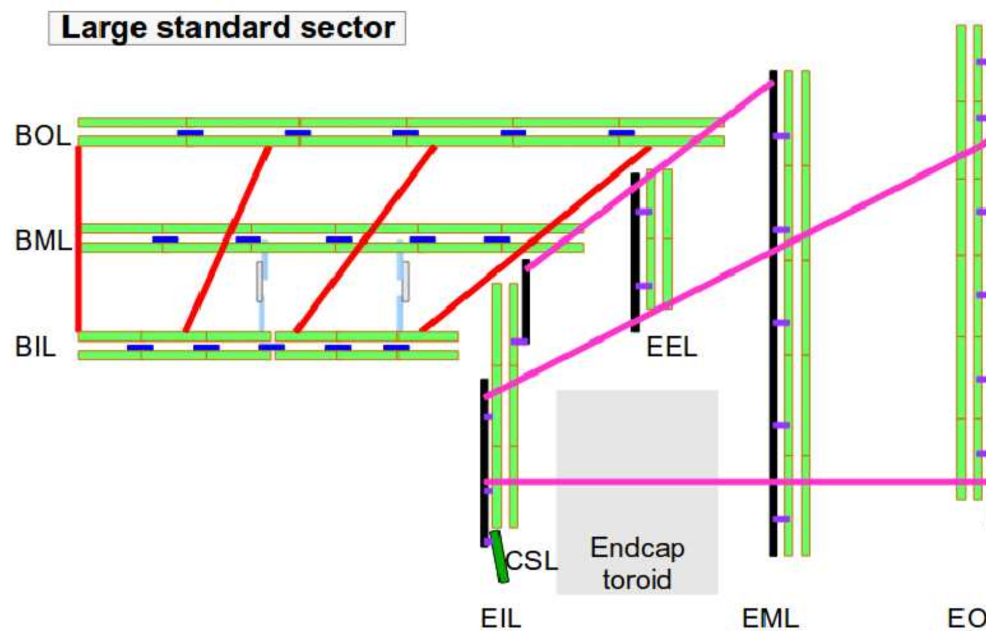
Cible Rasnik



Cible Led





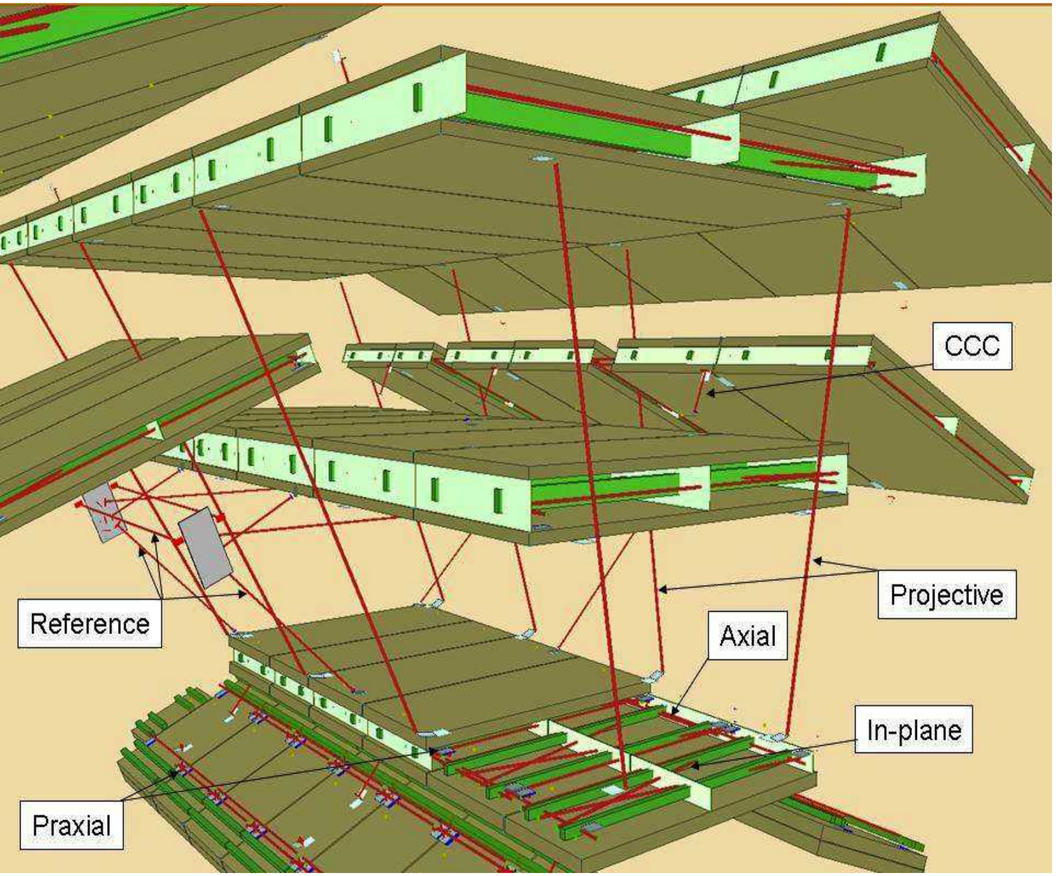


Detectors(Gaseous)

MDT: Monitored Drift Tube

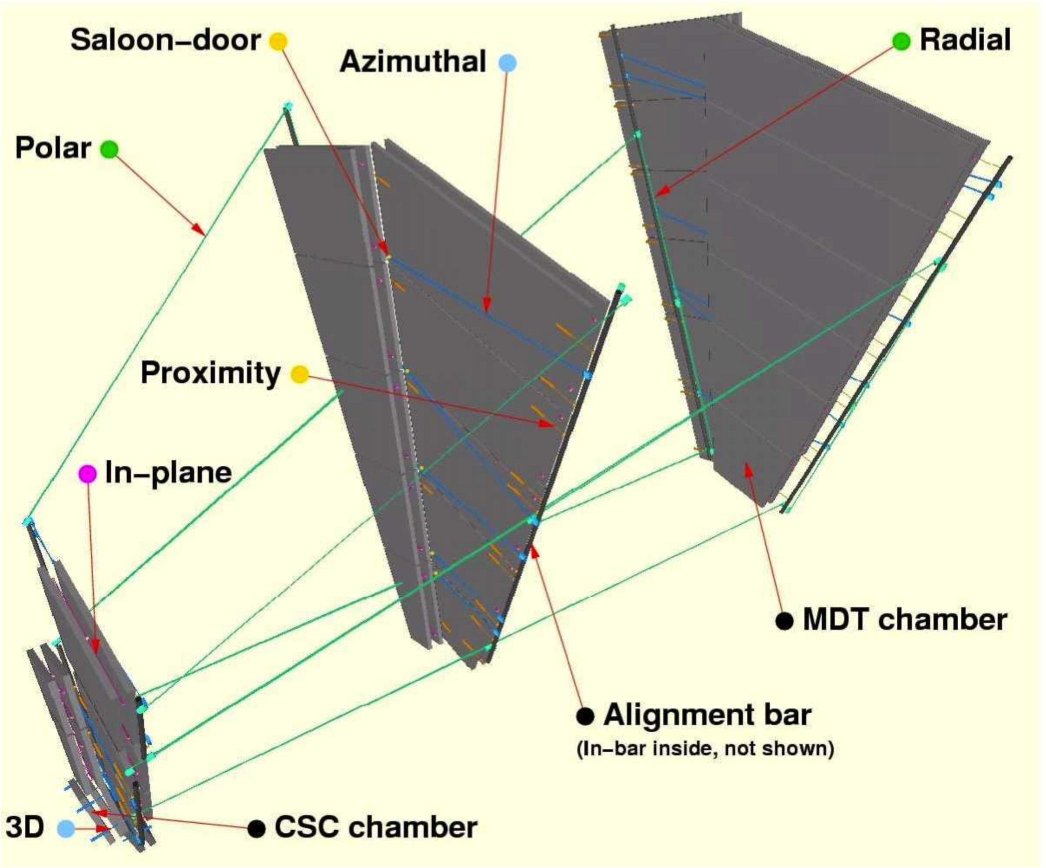
- ATLAS Muons spectrometer alignment

Barrel



Only the chambers in the odd sectors (between coils) are projectively 'aligned'.The chambers of the even sectors are aligned with tracks through chamber overlaps

endcap

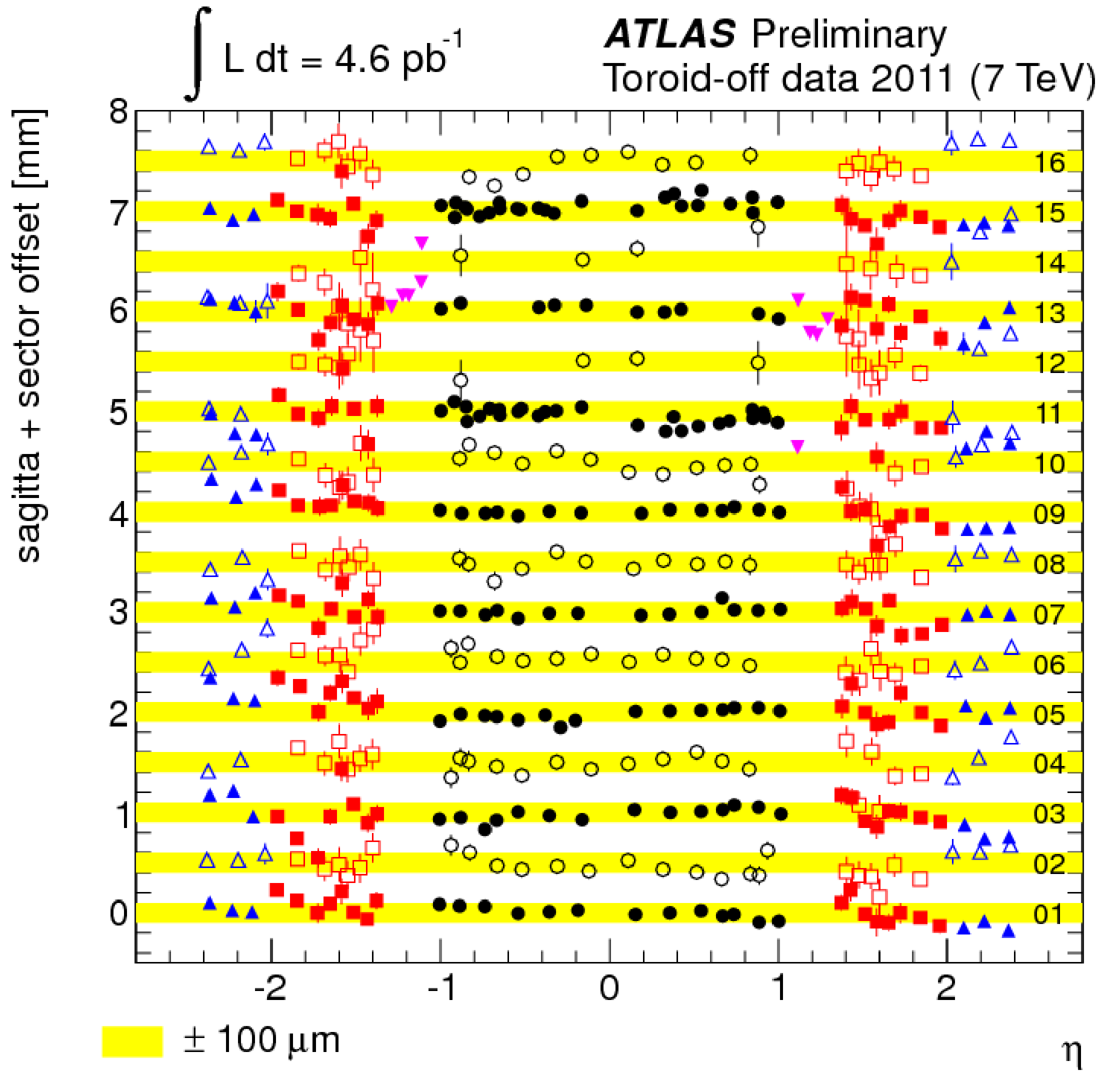


A set of alignment bars, optically interconnected, creates an external reference system. Azimuthal optical lines monitor the relative position of the chambers to these bars.

Detectors(Gaseous)

MDT: Monitored Drift Tube

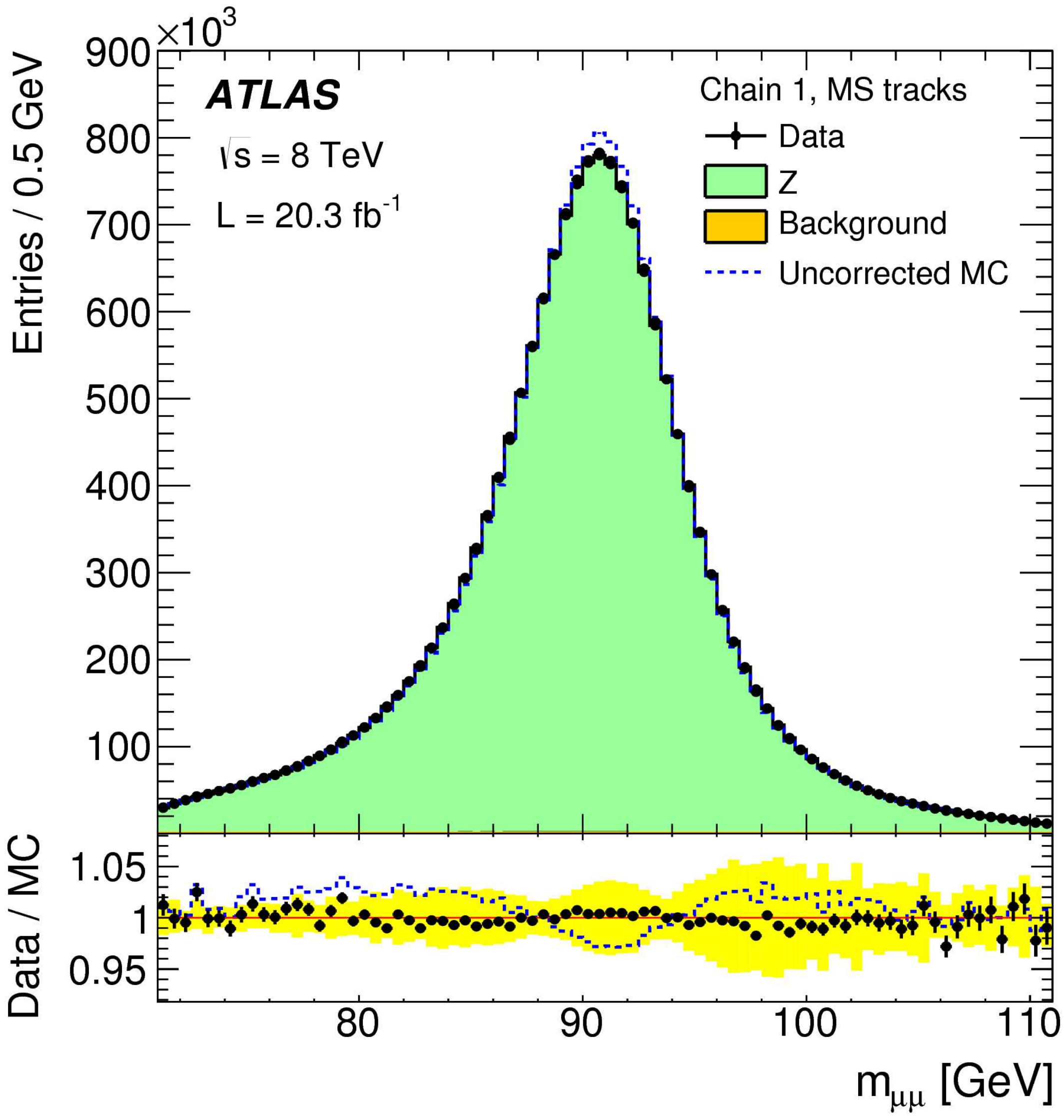
- ATLAS Muons spectrometer
  - To day sagitta is controlled at ~40μm

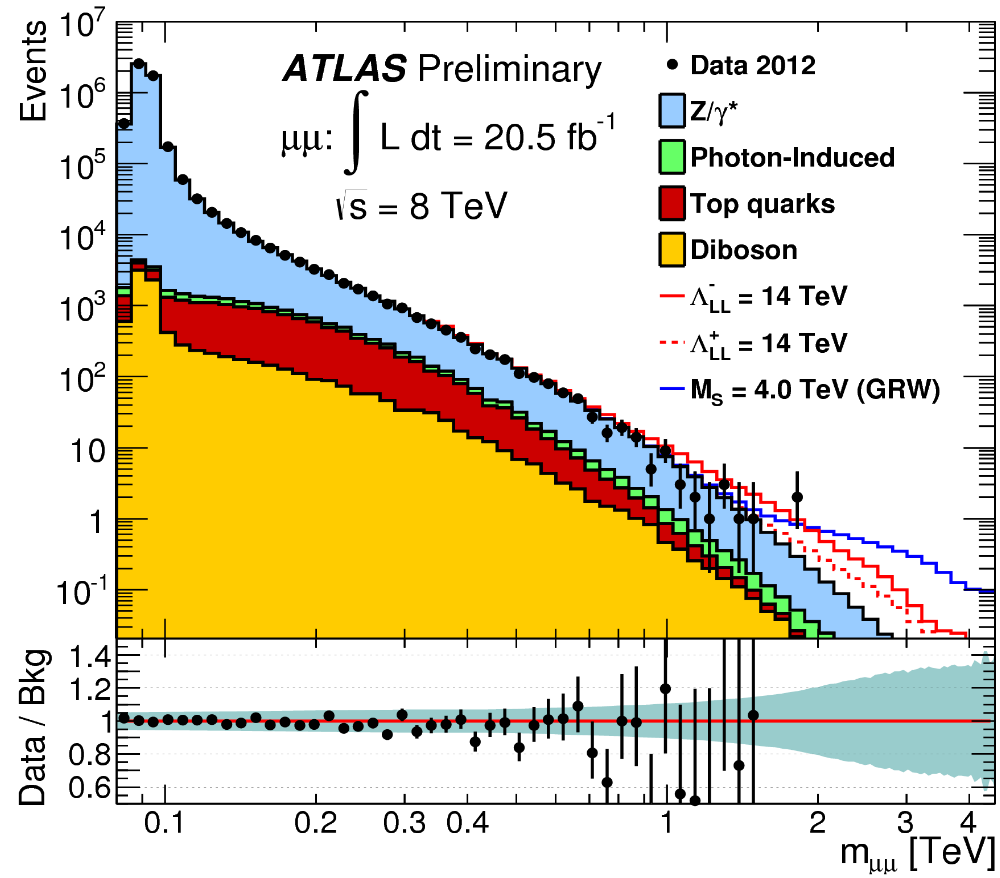


Detectors(Gaseous)

MDT: Monitored Drift Tube

- ATLAS Muons spectrometer: μμ invariant mass

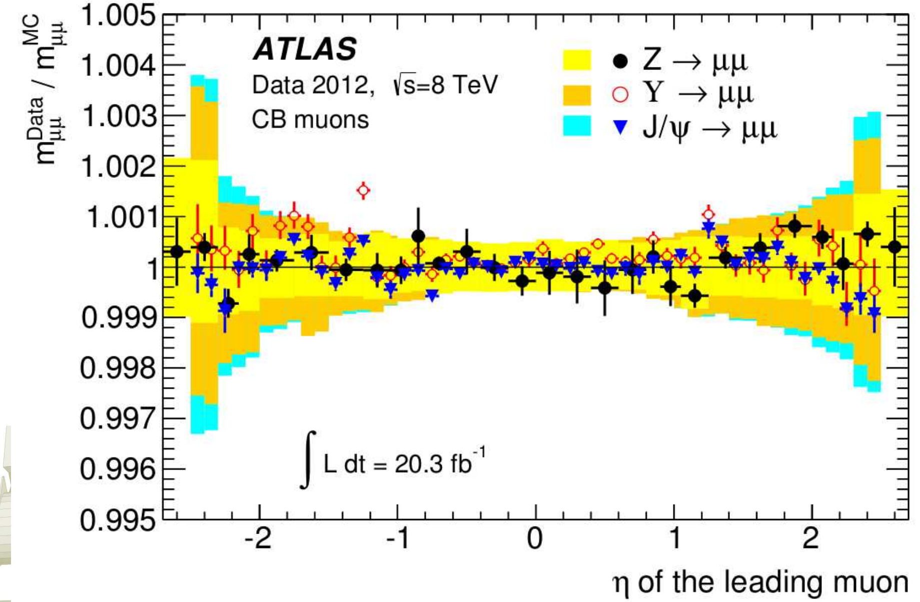


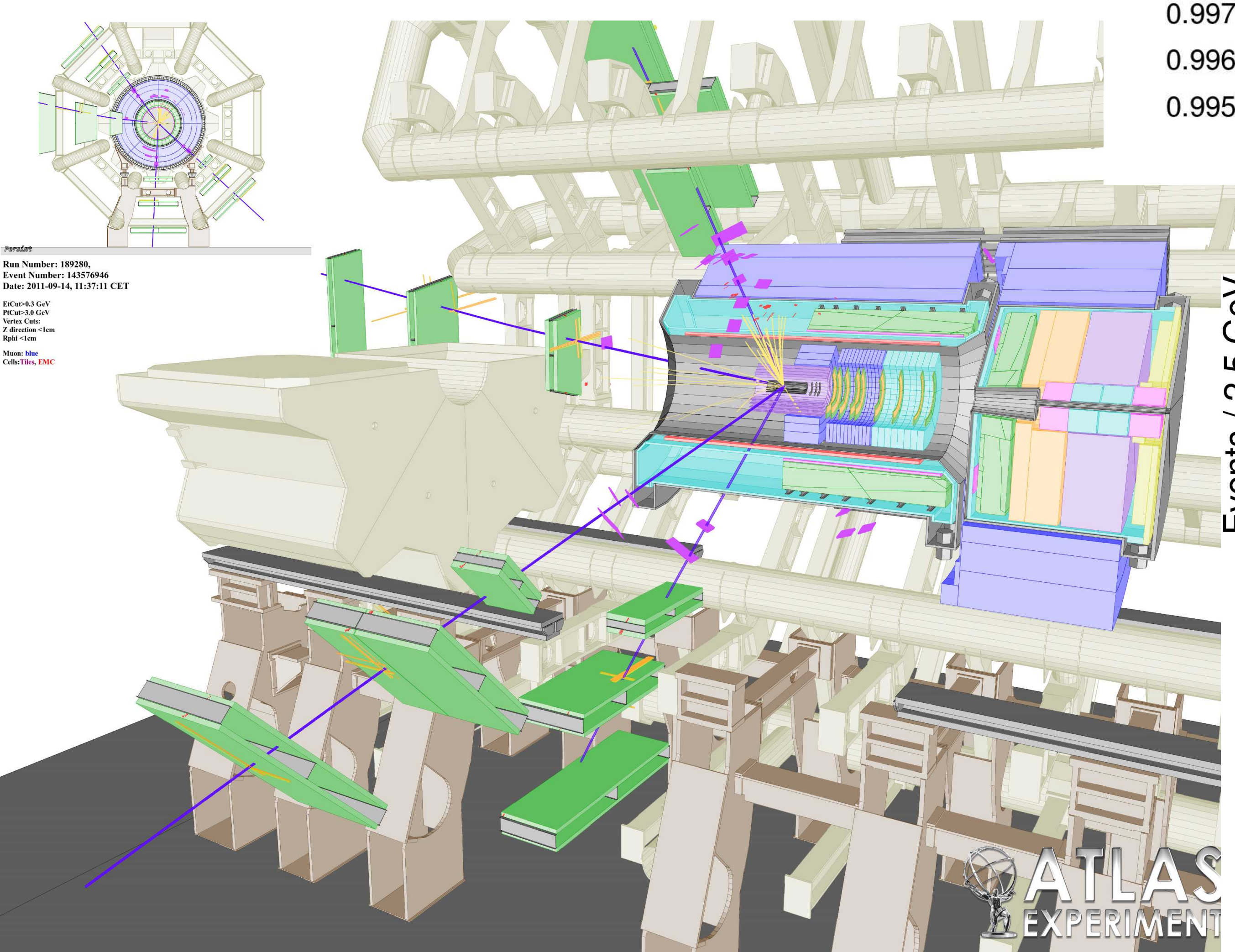


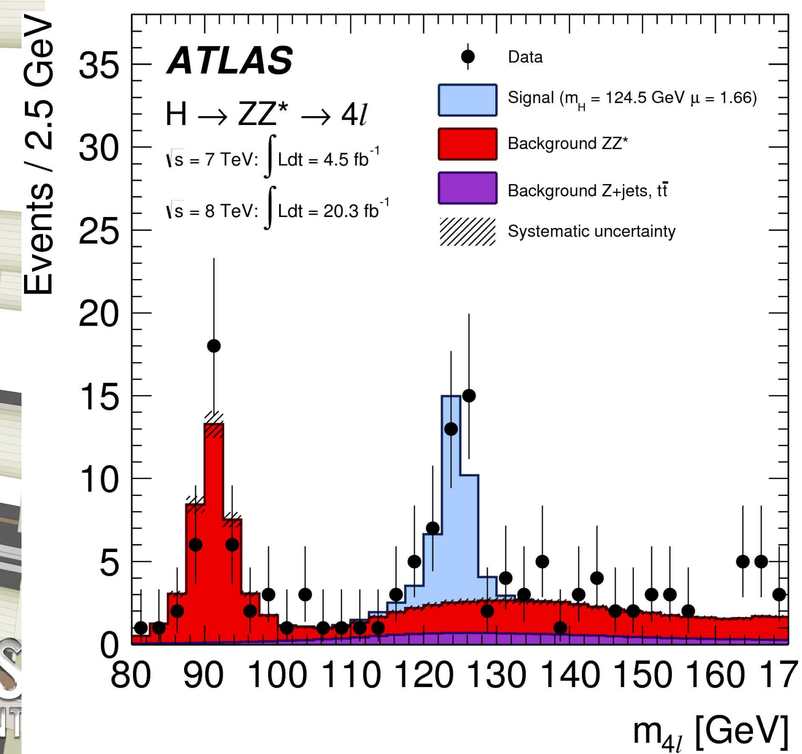
Detectors(Gaseous)

MDT: Monitored Drift Tube

- ATLAS Muons spectrometer: μμμμ invariant mass Higgs!



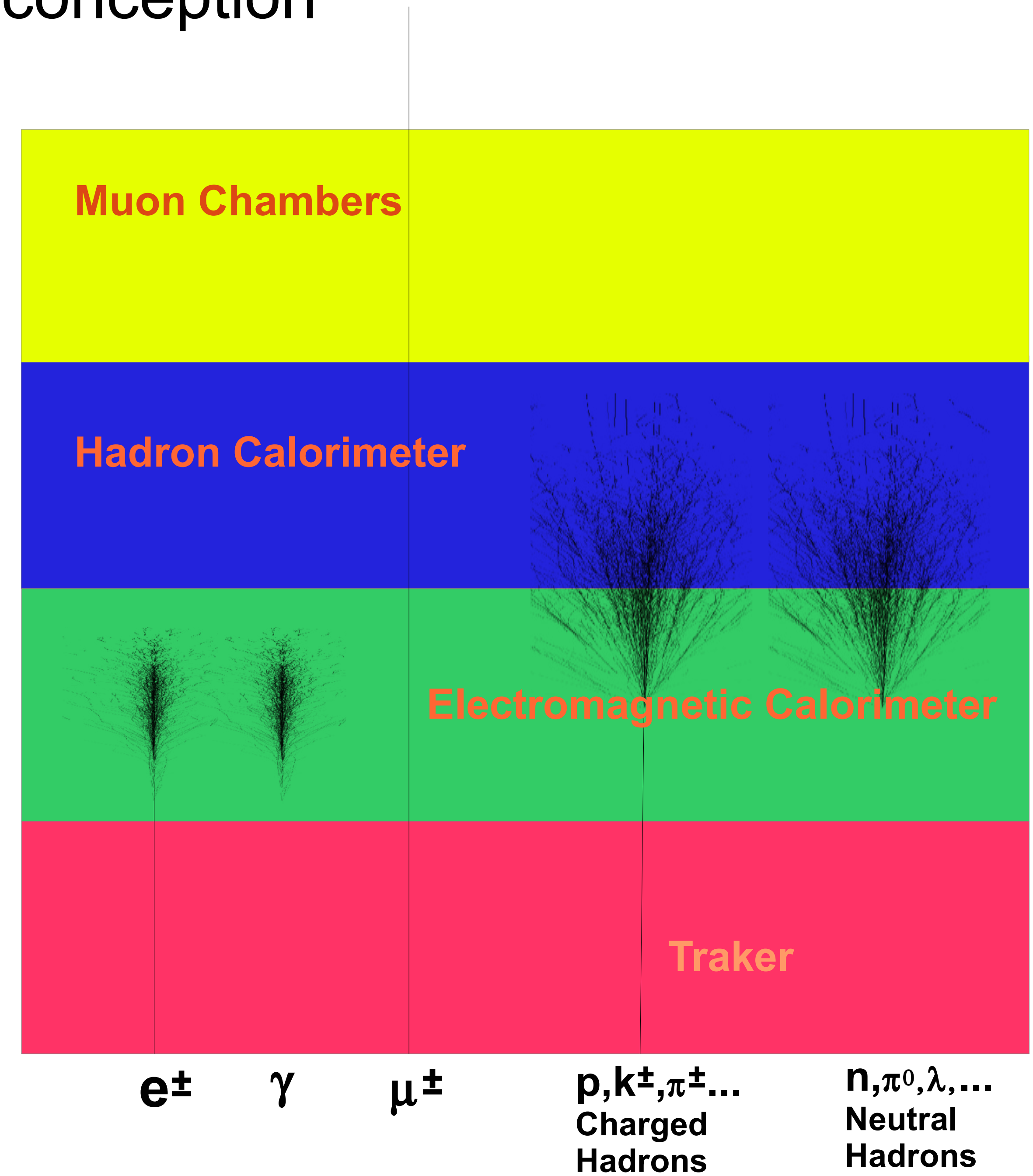




Interlude: Detectors conception

Principle

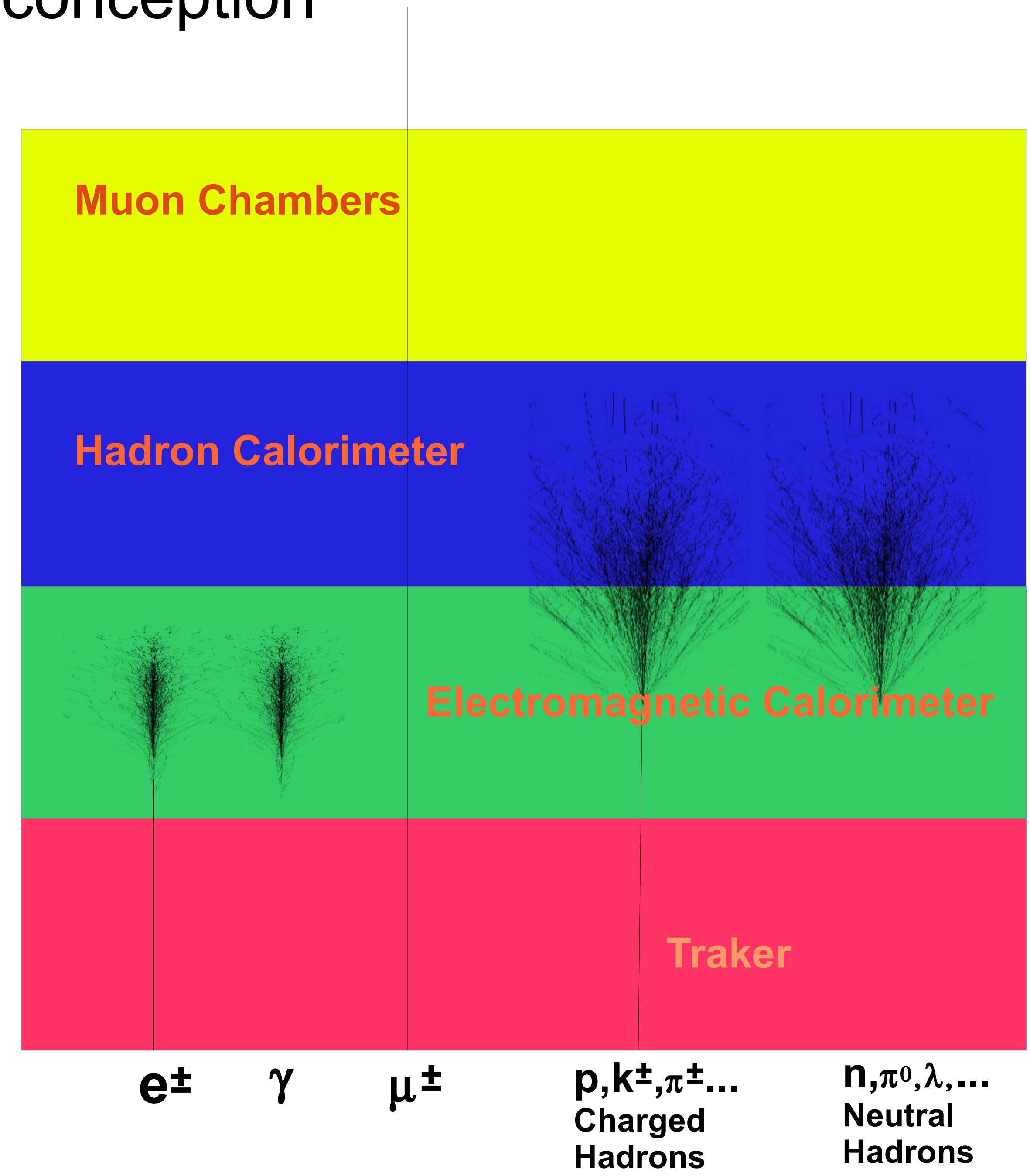
- Muon detection:
  - Tracker (charged particle)
  - MIP in calorimeter
  - Tracks in Muon chambers



Interlude: Detectors conception

Principle

- Muon as Tool
  - Trigger
  - Veto
    - Ice Cube
    - Double Chose
  - Calibration MIP
    - LHC
    - Hess (Telescope)

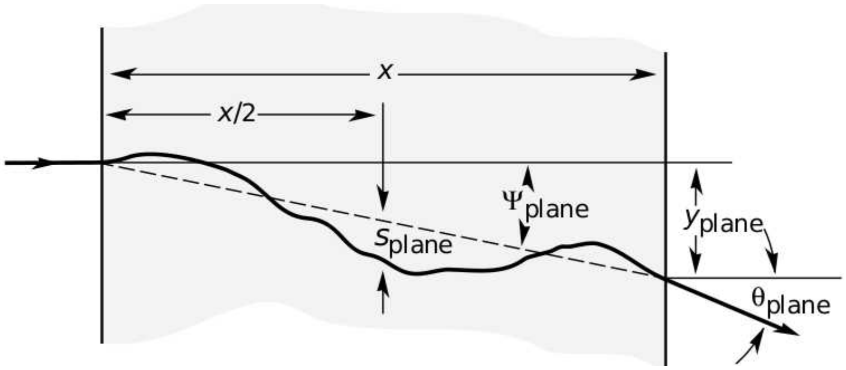


Interlude: Detectors conception

Coulomb scattering

- Multiple scattering : perturbation (degradation)
  - Deflection
  - => minimize matter ex: Muon spectrometer (ATLAS)

$$\theta_0 = \frac{13.6\ \mathrm{MeV}}{\beta c p}\, z\, \sqrt{x/X_0}\Big[1 + 0.038 \ln(x/X_0)\Big]$$



Detectors conception

Principle

Muon detection:
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- MIP in calorimeter
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CMS