Lecture 23 – Detector systems

Detector Systems

Remember: we want to have info on...

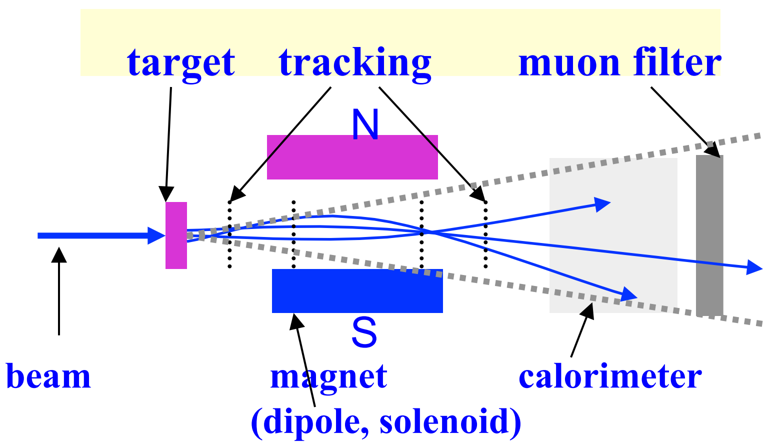
- number of particles
- event topology
- momentum / energy
- particle identity

} Can't be achieved with a single detector !

→ integrate sub- detectors to a detector systems

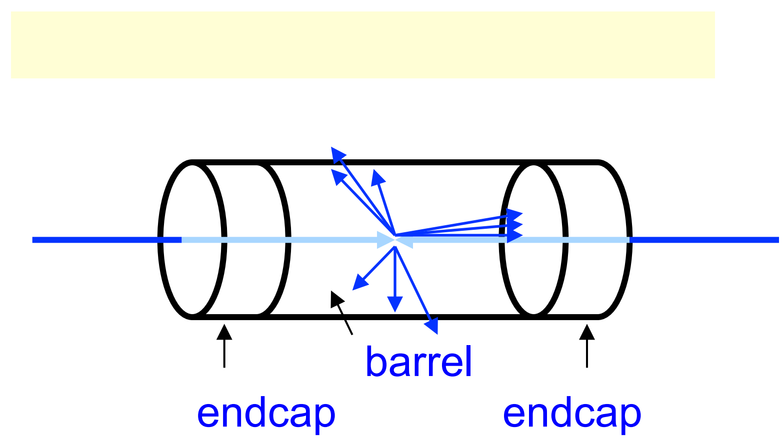
<u>Geometrical concepts</u>

Fix target geometry
"Magnet spectrometer"



- Limited solid angle dΩ coverage
- relatively easy access (cables, maintenance)

Collider Geometry
"4π Multi purpose detector"

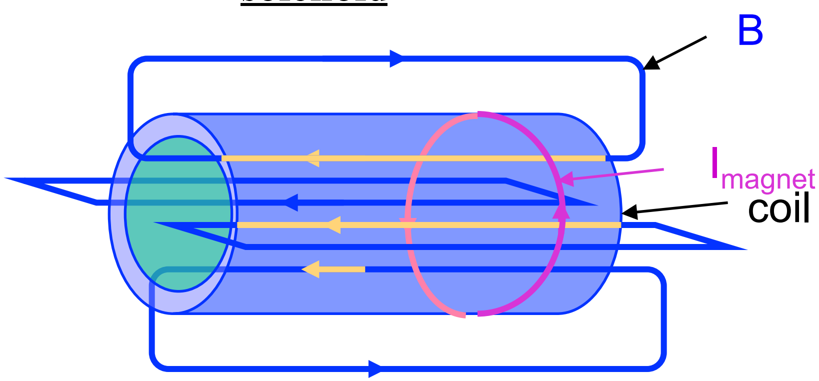


- "full" dΩ coverage
- very restricted access

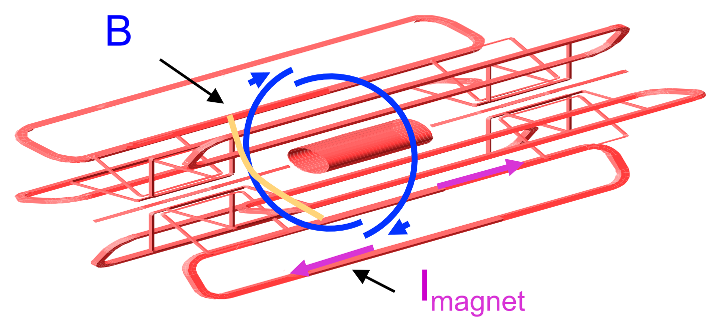
Collider geometry

Magnetic field configurations

solenoid



toroid



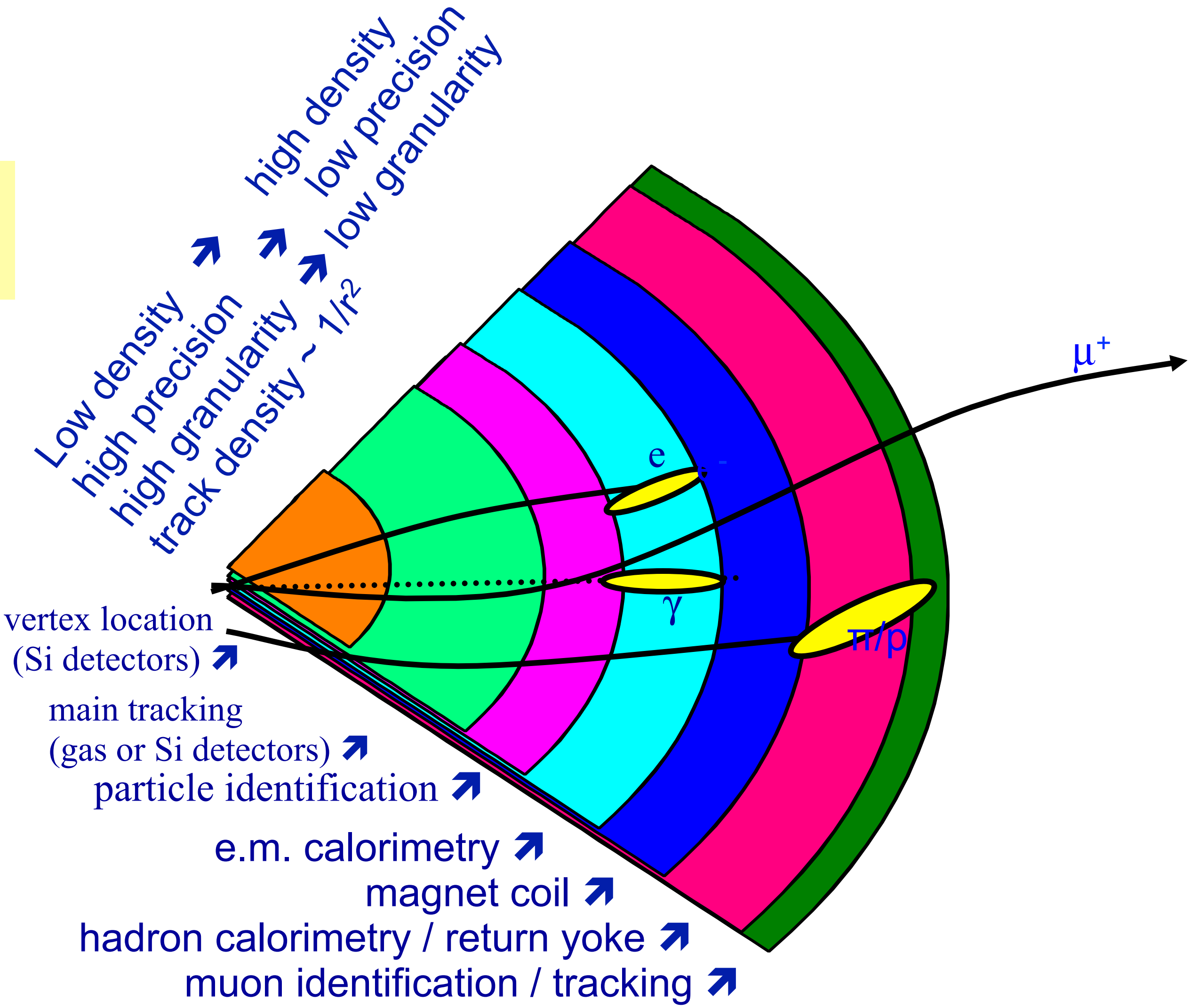
\+ Large homogenous field inside coil
\- weak opposite field in return yoke
\- size limited (cost)
\- relatively high material budget

\+ Rel. large fields over large volume
\+ Rel. low material budget
\- non-uniform field
\- complex structure

Examples:
- DELPHI (SC, 1.2T)
- L3 (NC, 0.5T)
- CMS (SC, 4T)

Example:
- ATLAS (Barrel air toroid,
- Superconducting, 0.6T)

Typical arrangement



ATLAS and CMS require high precision tracking also for high energetic muons ➔ large muon systems with high spatial resolution behind calorimeters.

Practical considerations

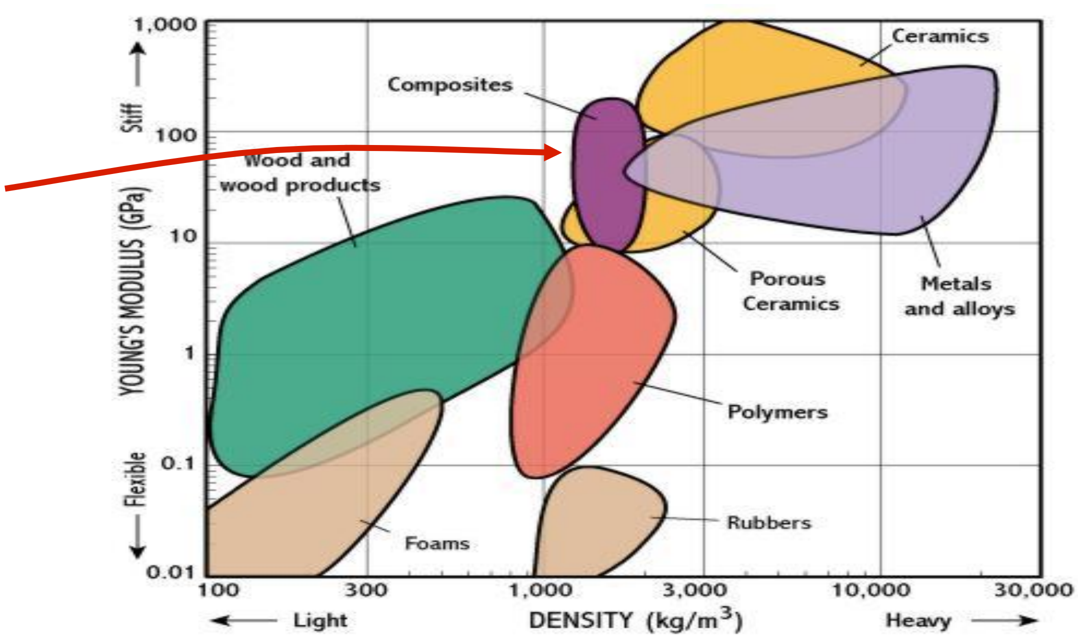
Find compromises and clever solutions …

- **Mechanical stability, precision → distortion of resolution (due multiple scattering, conversion of gammas)**
- **Hermeticity → routing of cables and pipes**
- **Hermeticity → thermal stability**
- **Hermeticity → accessibility, maintainability**
- **Compatibility with radiation**

… and always keep an eye on cost

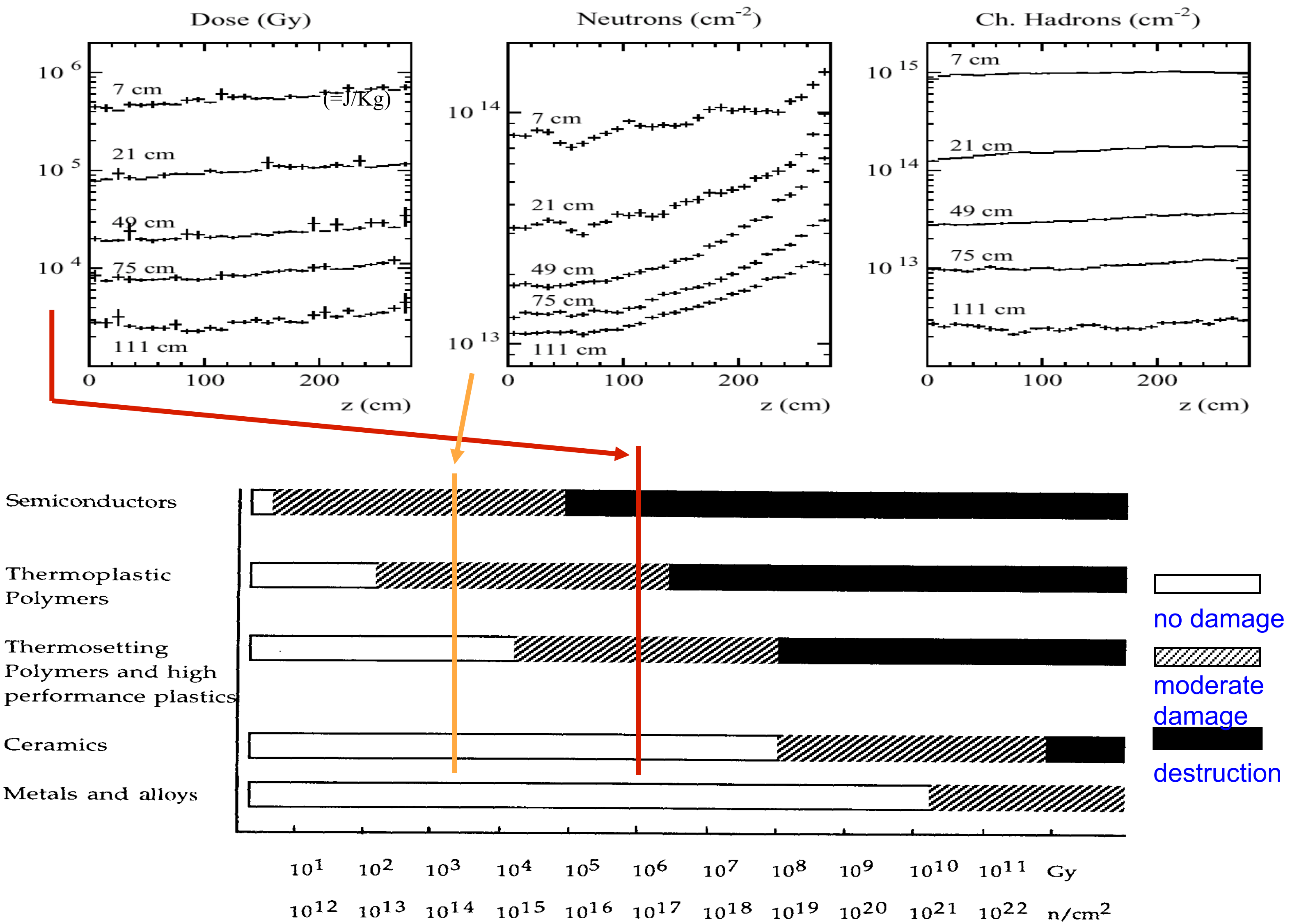
$$E[\mathrm{N/m^2}] = \frac{F/A}{\Delta L/L} \qquad \left(\text{Young's modulus} = \frac{\text{stress}}{\text{strain}}\right)$$

Composites are very interesting candidates, e.g. glass or carbon fiber reinforced epoxy materials.

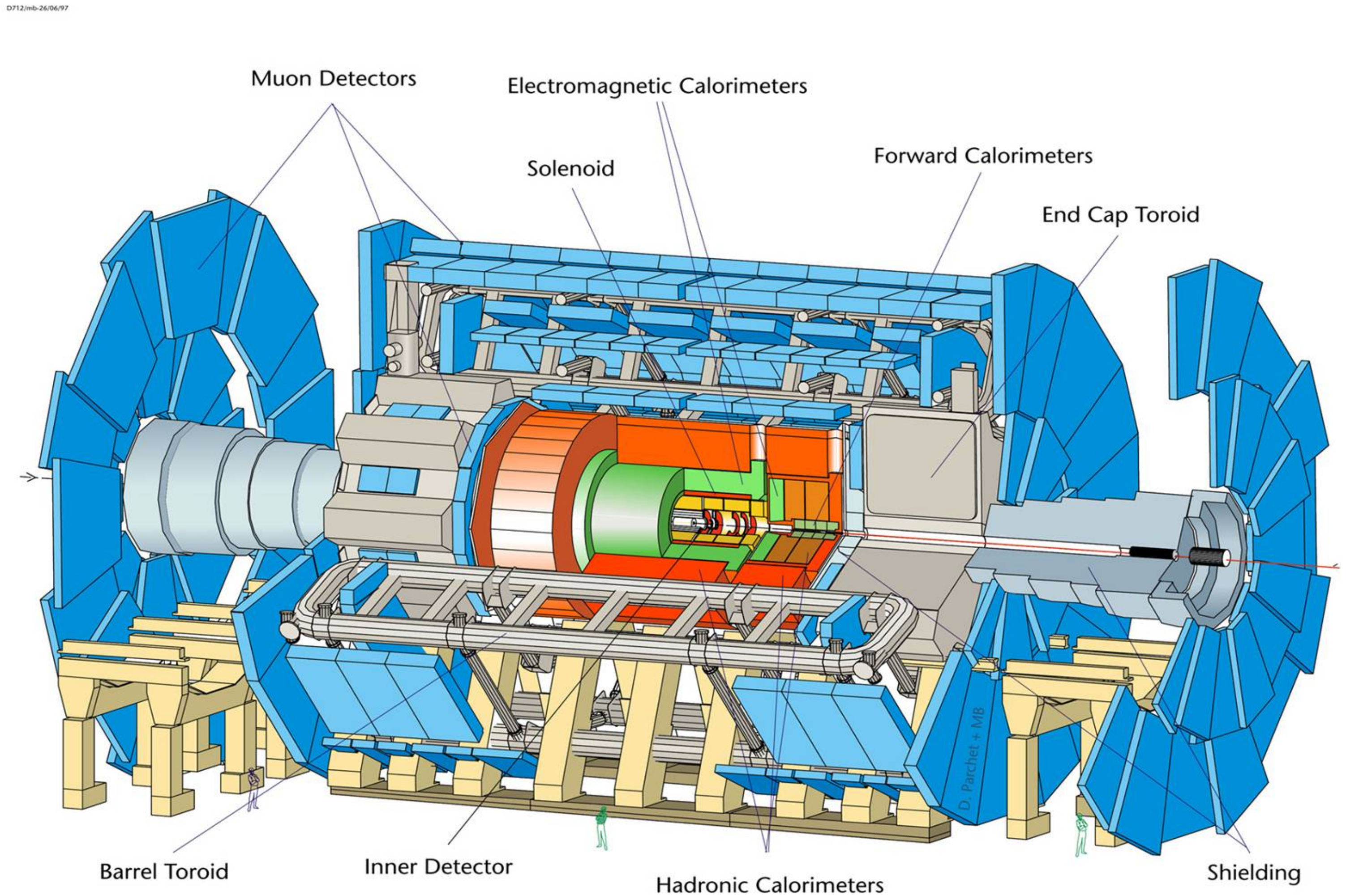


Radiation damage to materials

Radiation levels in CMS Inner Tracker (0 < z < 280 cm)



ATLAS Detector



Diameter	*25 m*
Barrel toroid length	*26 m*
End-cap end-wall chamber span	*46 m*
Overall weight	*7000 Tons*

ATLAS Components (starting from the center/beam line)

Tracker system to measure trajectories of outgoing particles:
Pixels: 140 million pixels 50 x 50 x 300 mm (digital)
Si strips: 6.2 million channels 8 mm x 12.8 cm (digital)
Straws: 420,000 channels 4 mm x 108 cm (digital+analog)

Solenoid magnet with 4 Tesla field encloses the tracker

Electromagnetic Calorimeter to identify electrons and photons and measure their energies
Barrel and 2 endcaps 220,000 channels (analog)

Hadronic Calorimeter to identify pions, kaons and protons and to measure their energies
PMT readout, 10,000 channels (analog)

Muon system to identify muons and measure their momentum
4 technologies, 12,000 m^2 covered with 50 mm position resolution, 1.232 million channels (digital)

Toroid magnet systems (barrel+2 endcaps) enclose muon chambers with 0.8 Tesla field.

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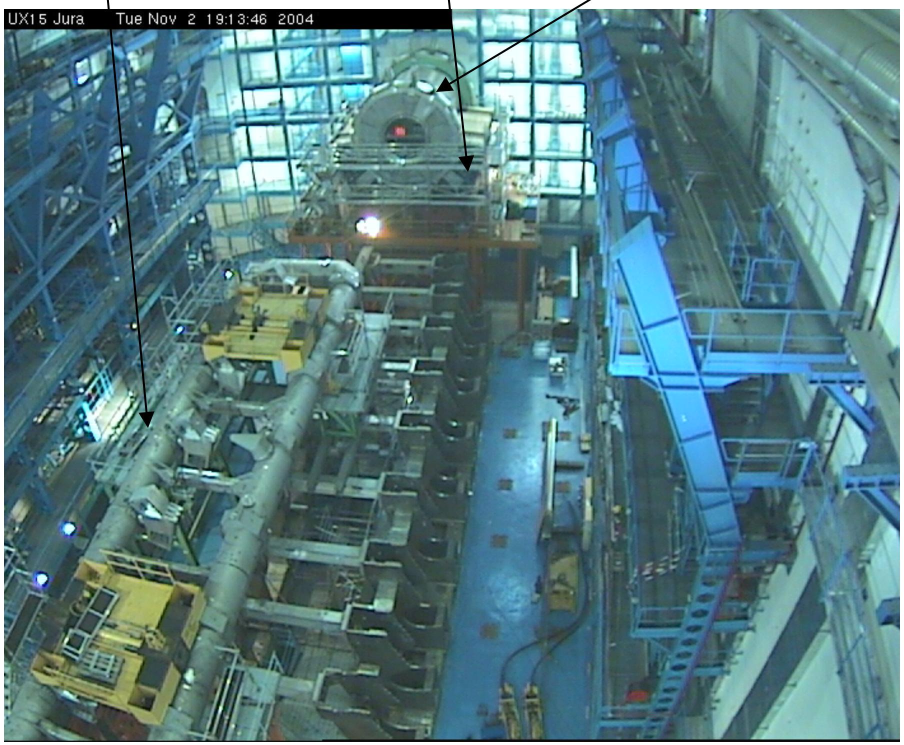
UX15 cavern

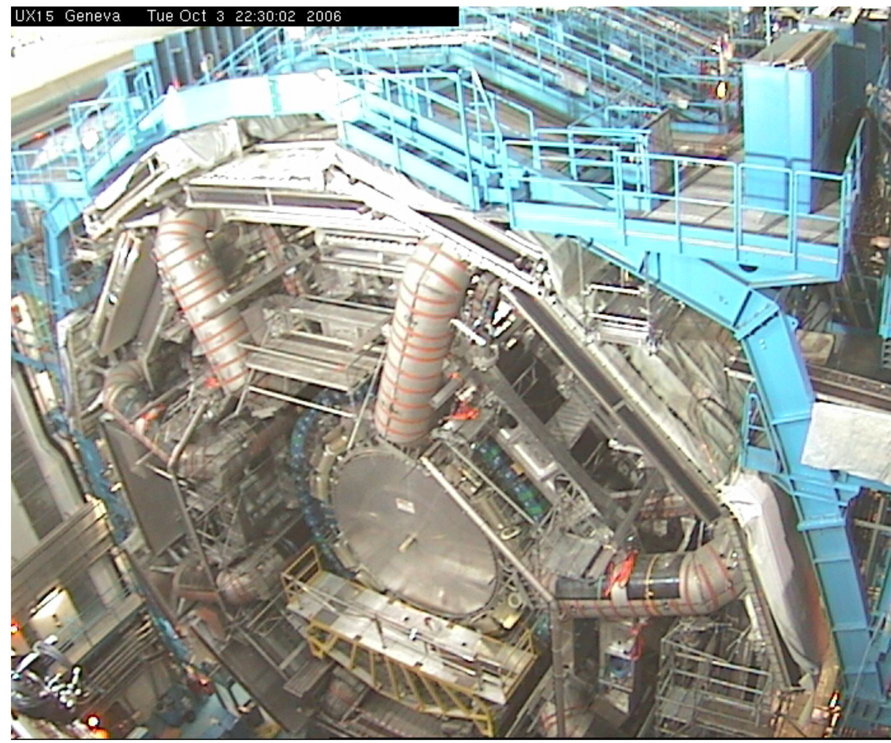
Tile (hadronic) calorimeter

First toroid coil

Barrel electromagnetic calorimeter



November 2003

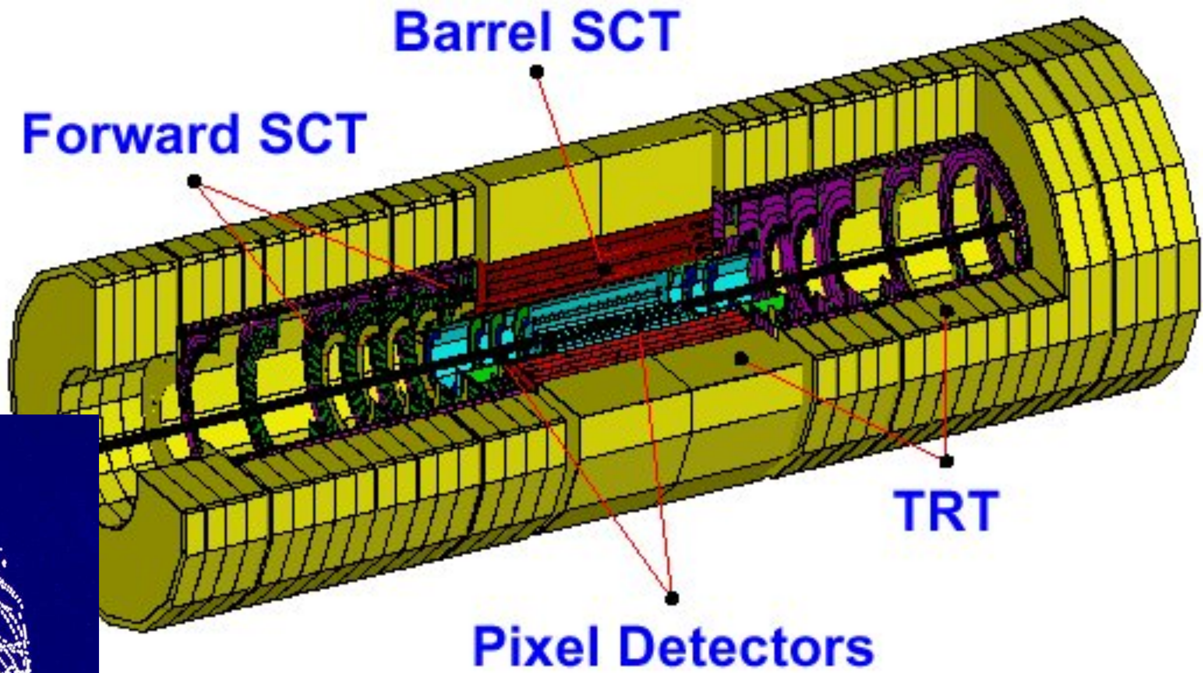


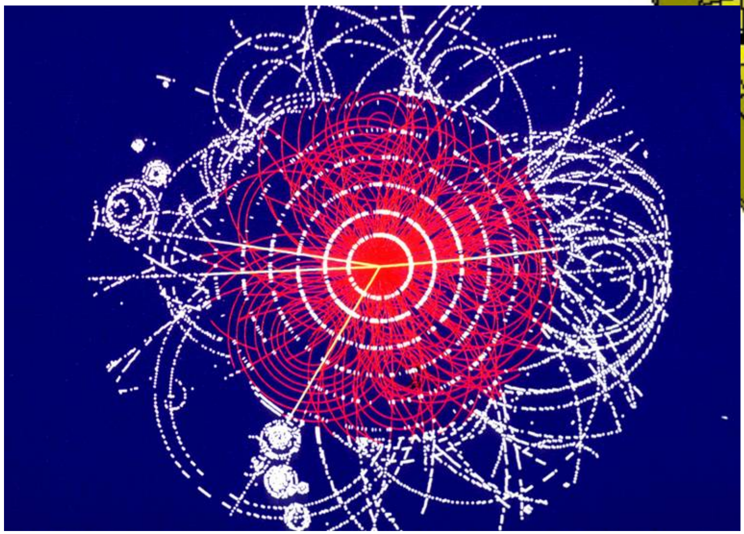
October 2006

Detector (ID)

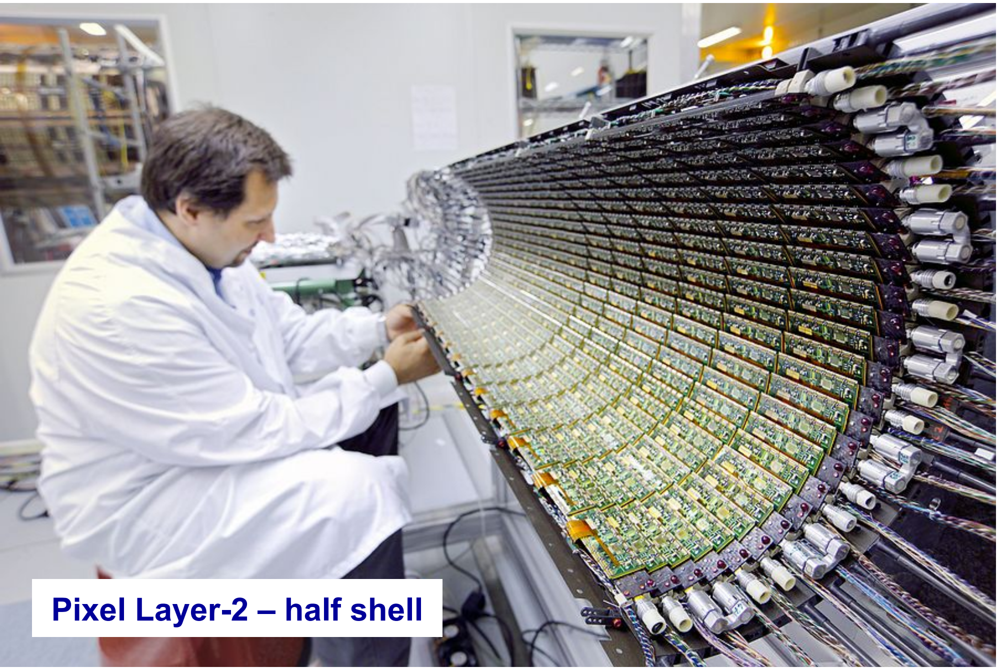
The Inner Detector (ID) is organized into four sub-systems:

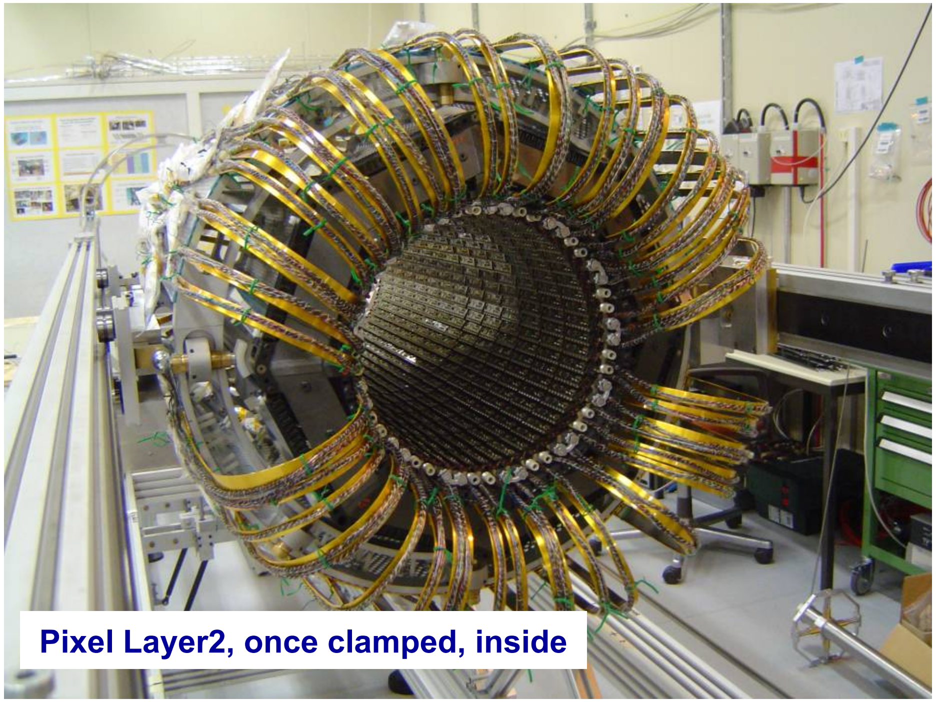
- **Pixels**
- **Silicon Tracker (SCT)**
- **Transition Radiation Tracker (TRT)**
- **Common ID items**

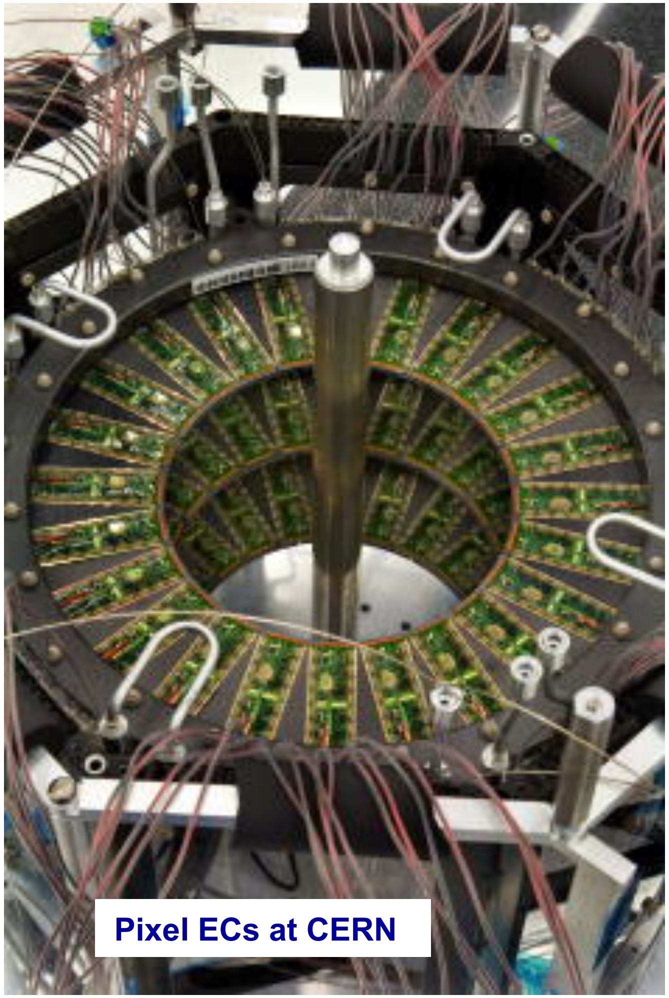




Lot of progress on the Pixels!

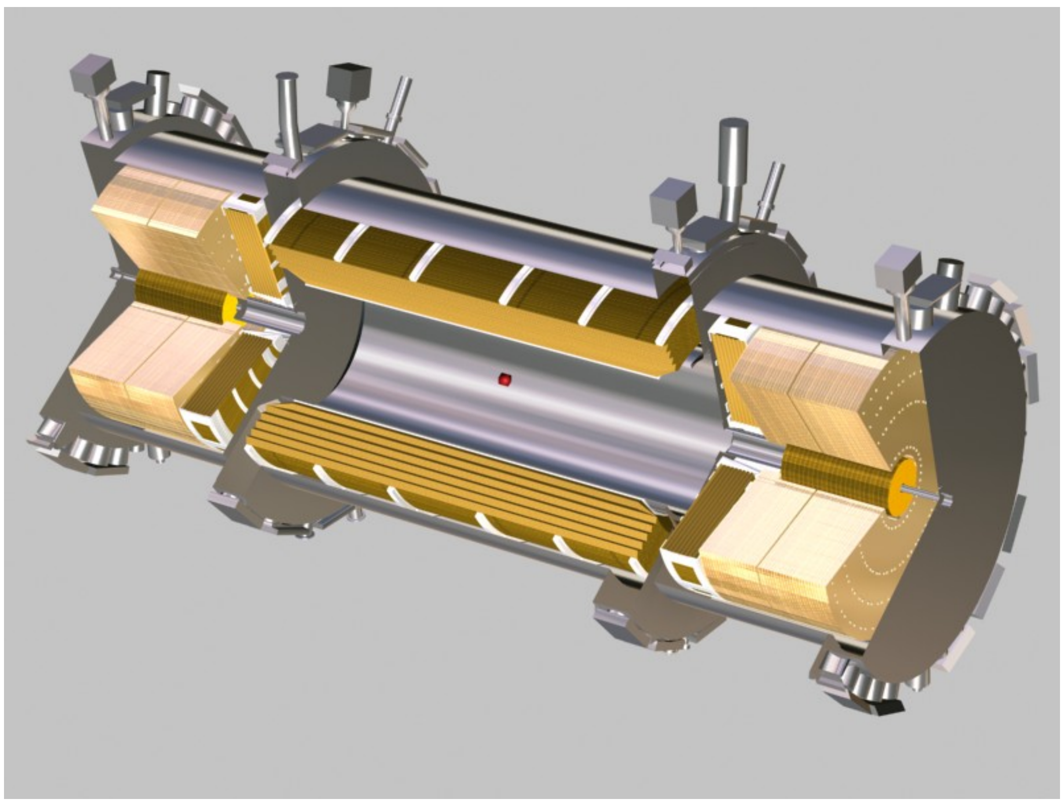


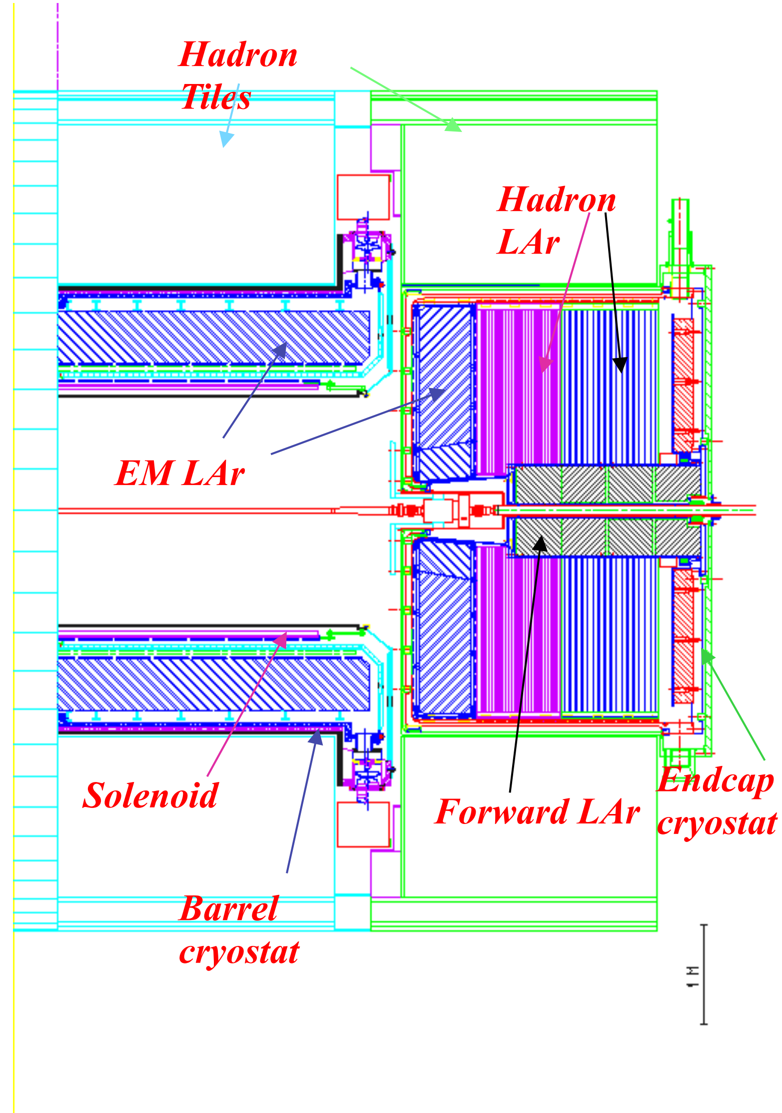




Calorimetry

The LAr calorimetry (pre-samplers, EM, hadronic end-caps, and forward calorimeters)





Calorimeters

Electromagnetic calorimeter - Liquid Argon detector with accordion geometry

housed in 3 cryostats: barrel + 2 endcaps

barrel section – presampler + 3 radial segments

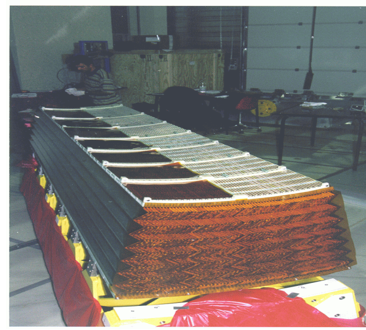
endcap section – 1.4< η <2.5 3 segments

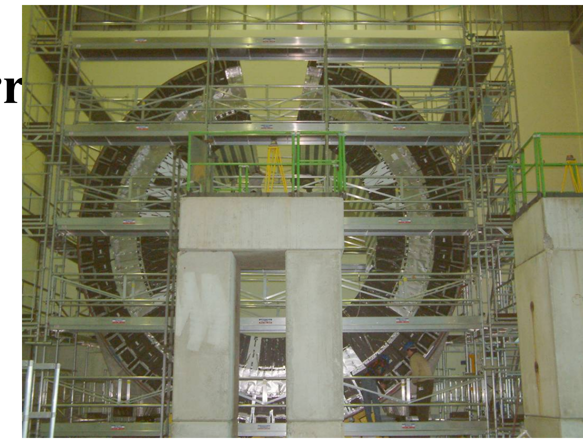
2.5< η <3.2 2 segments

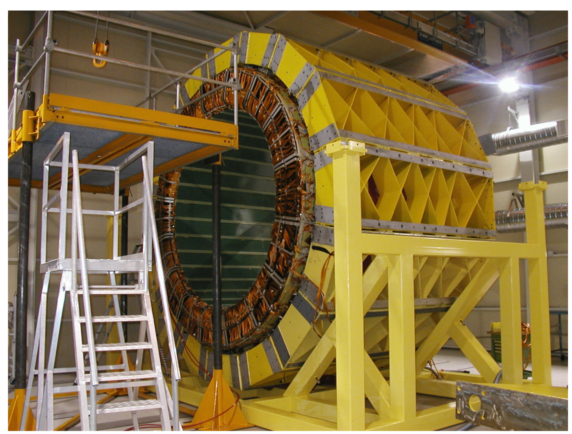
Hadronic calorimeter > 11 λ ... barr

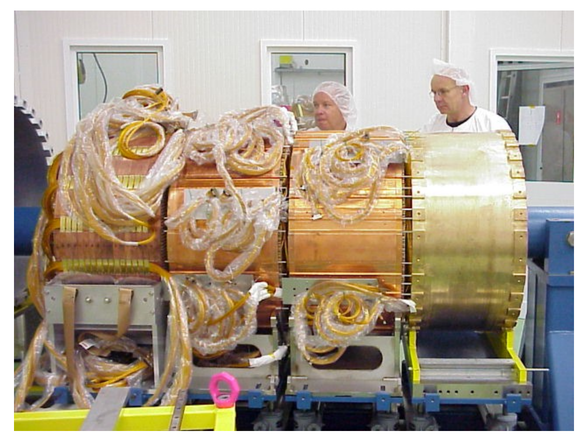
LAr hadronic endcap

LAr –W/Cu Forward



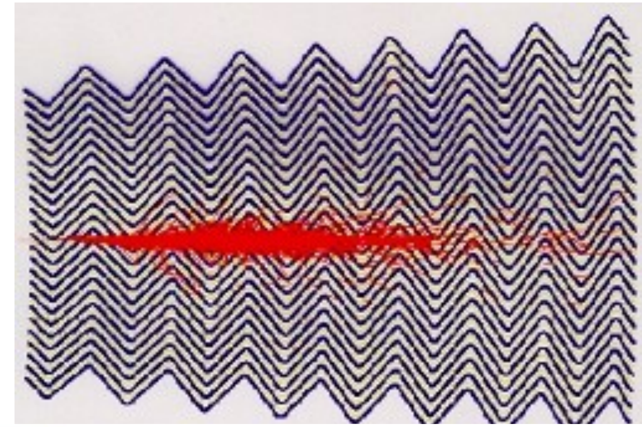


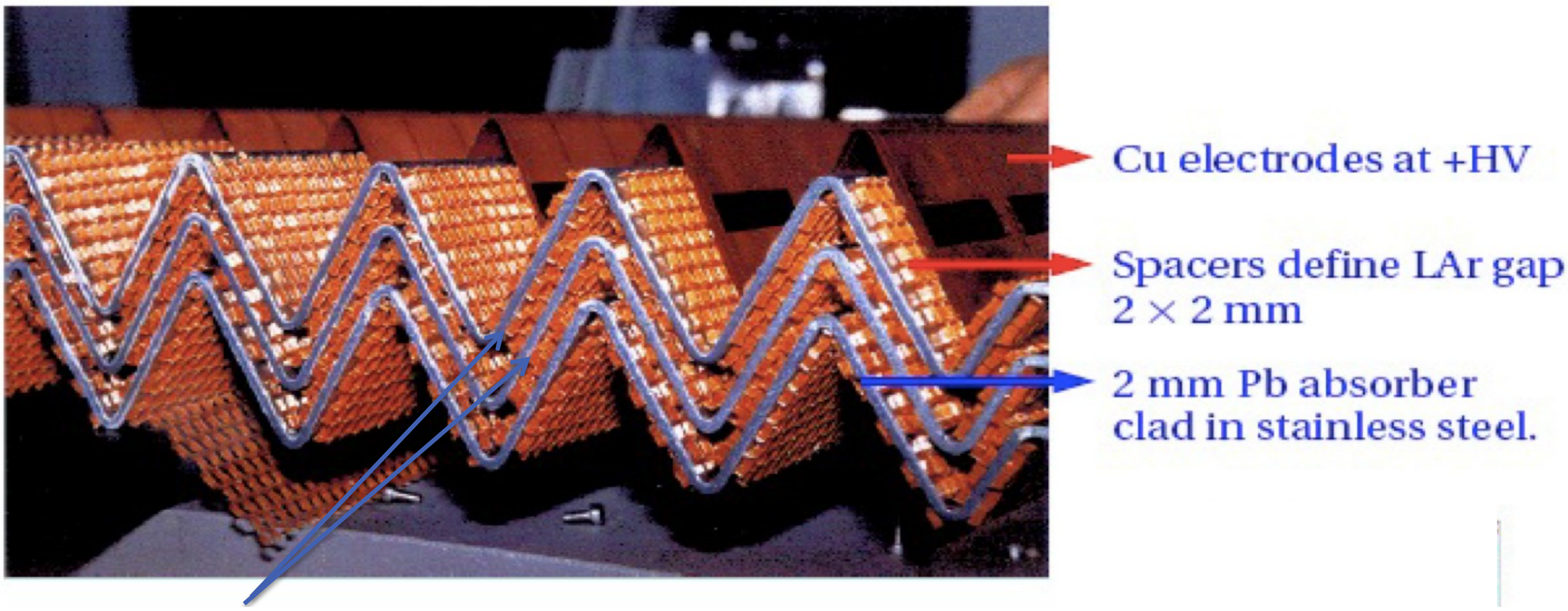


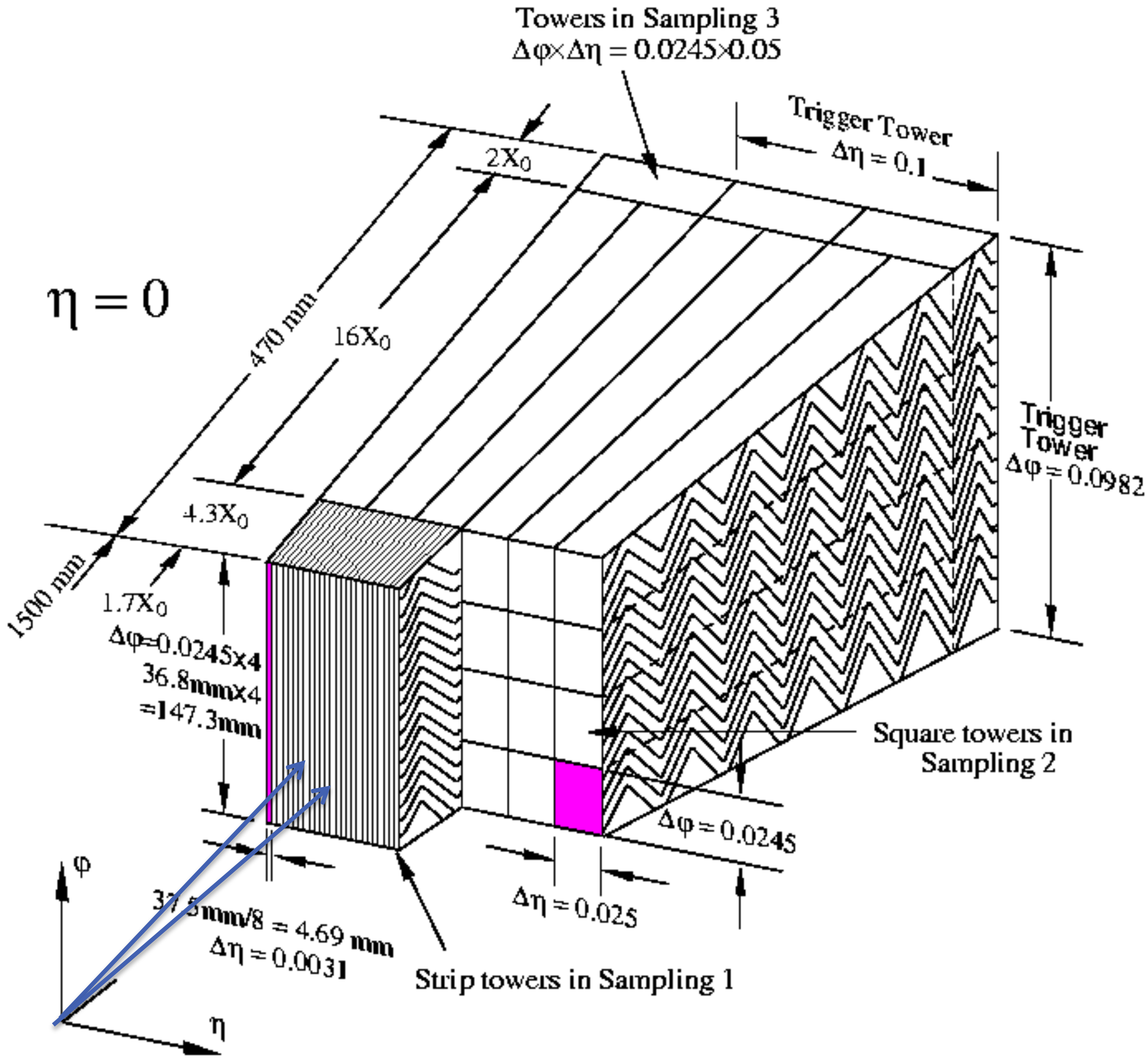


ATLAS Liquid Argon ECAL

~220,000 individual readout channels multiplexed into towers for trigger







Towers in Sampling 3
Δφ×Δη = 0.0245×0.05
Trigger Tower
Δη = 0.1
2X0
η = 0
470 mm
16X0
Trigger Tower
Δφ = 0.0982
4.3X0
1500 mm
1.7X0
Δφ=0.0245x4
36.8mmx4
=147.3mm
Square towers in Sampling 2
Δφ = 0.0245
φ
Δη = 0.025
37.5mm/8 = 4.69 mm
Δη = 0.0031
Strip towers in Sampling 1
η

GEM at SSC

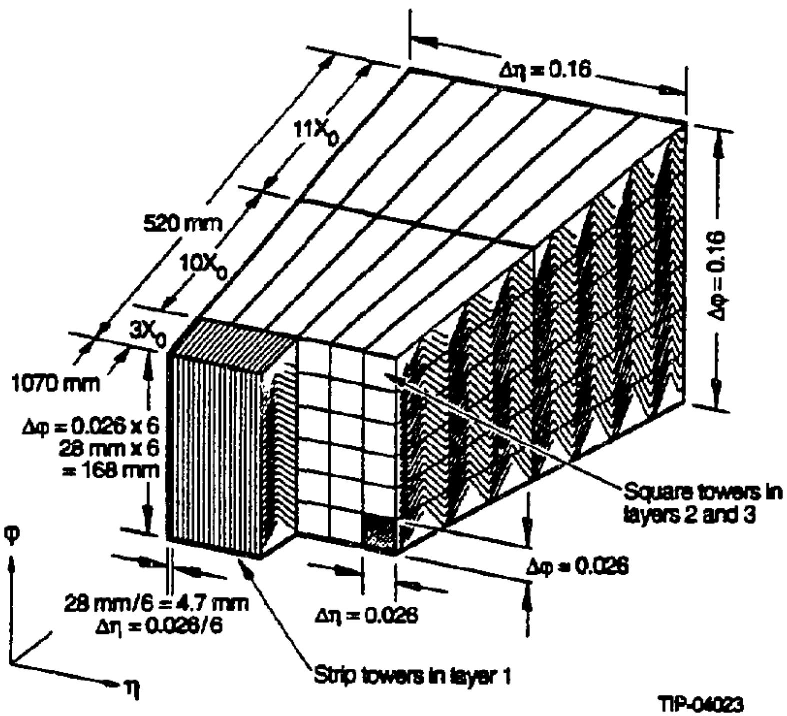
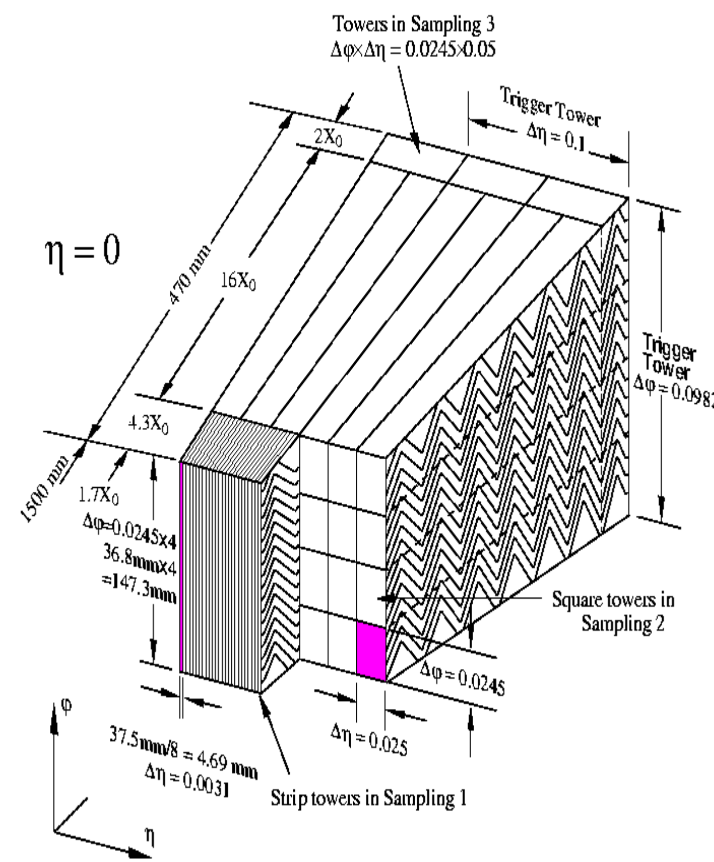


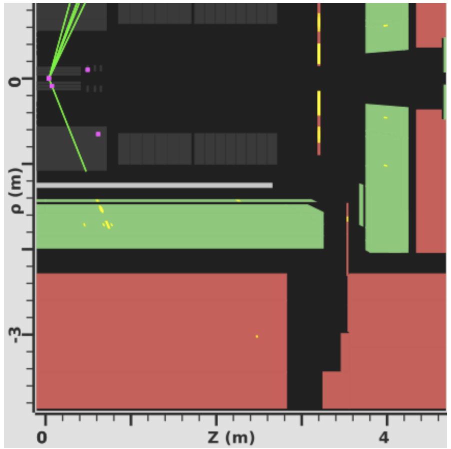
FIG. 5-4. Transverse and longitudinal segmentation of the Inner Barrel EM Calorimeter.

ATLAS at LHC

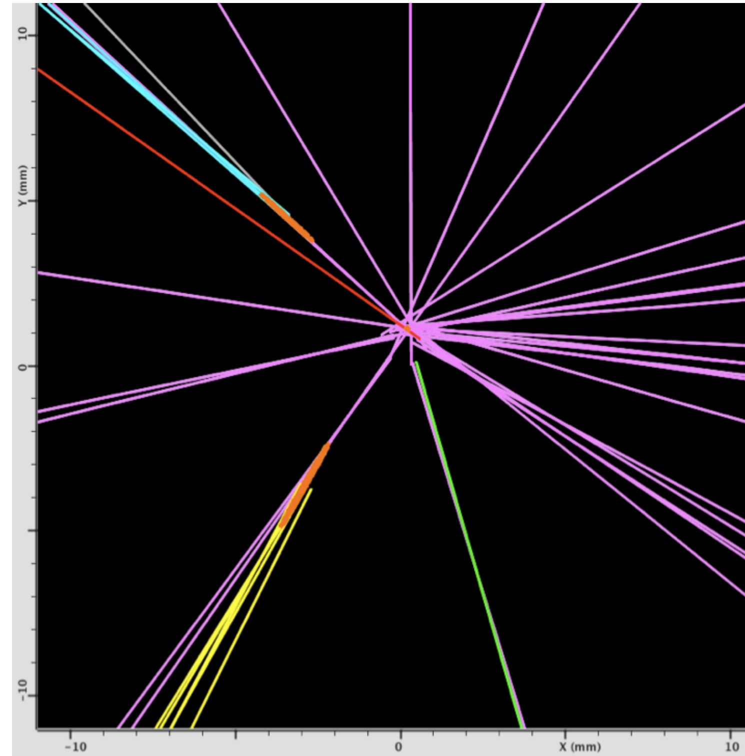


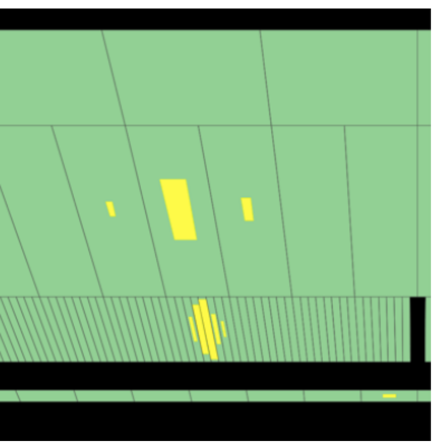
Signatures

electron

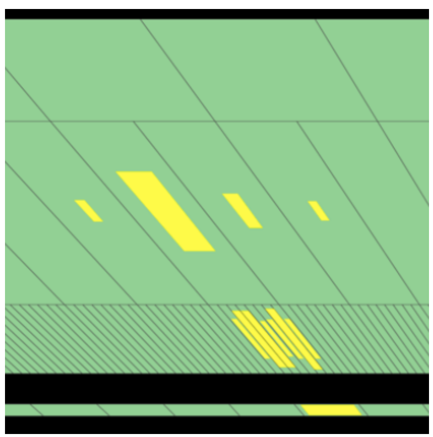


b-jet



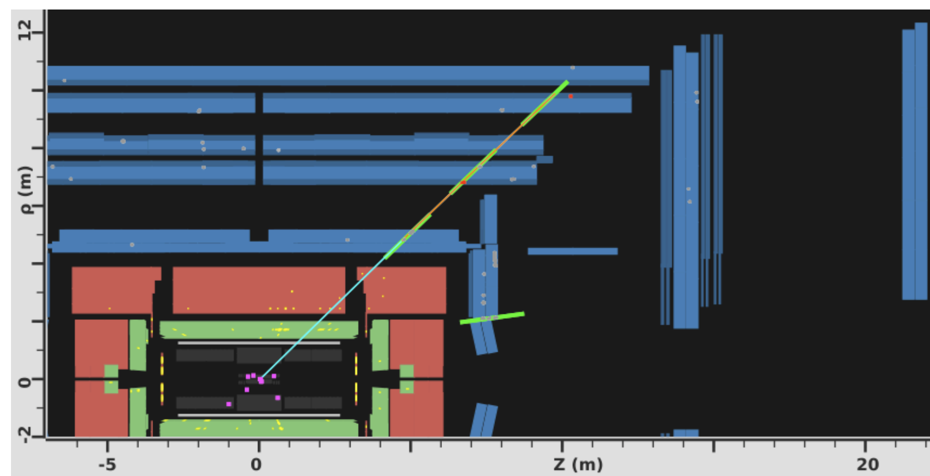


photon



π^0

muon



Energy resolution

- Ideally, if all shower particles counted $E \propto N \qquad \sigma_E \approx \sqrt{N} \approx \sqrt{E}$
- In practice

$$\sigma_E = a\sqrt{E} \oplus bE \oplus c \qquad \frac{\sigma_E}{E} = \frac{a}{\sqrt{E}} \oplus b \oplus \frac{c}{E}$$

- a: stochastic term
  – intrinsic statistical shower fluctuations
  – sampling fluctuations
  – signal quantum fluctuations (e.g.
- b: constant term
  – inhomogeneities (hardware or calibration)
  – imperfections in calorimeter construction (dimensional variations, etc.)
  – non-linearity of readout electronics
  – fluctuations in longitudinal energy containment (leakage can also be ~ E-1/4)
  – fluctuations in energy lost in dead
- c: noise term
  – readout electronic noise
  – Radio-activity, pile-up fluctuations

Effects on energy resolution

ATLAS EM calorimeter

Different effects have different energy dependence

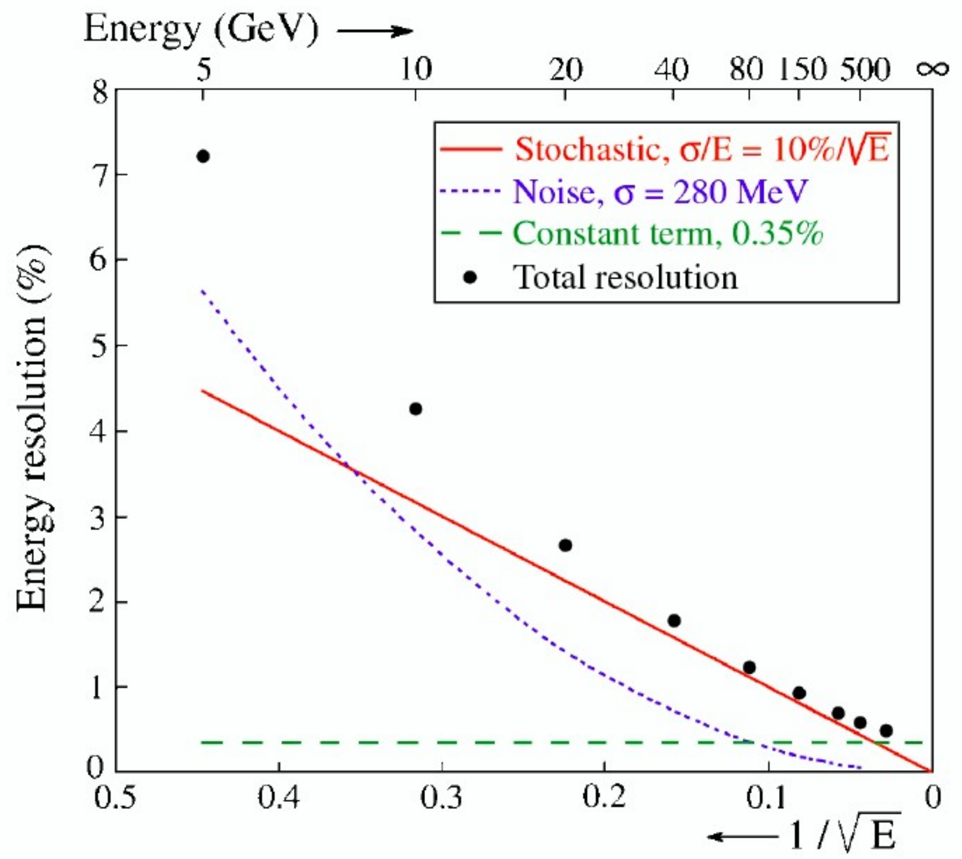
– Sampling fluctuations $\sigma/E \sim E^{-1/2}$

– shower leakage $\sigma/E \sim E^{-1/4}$

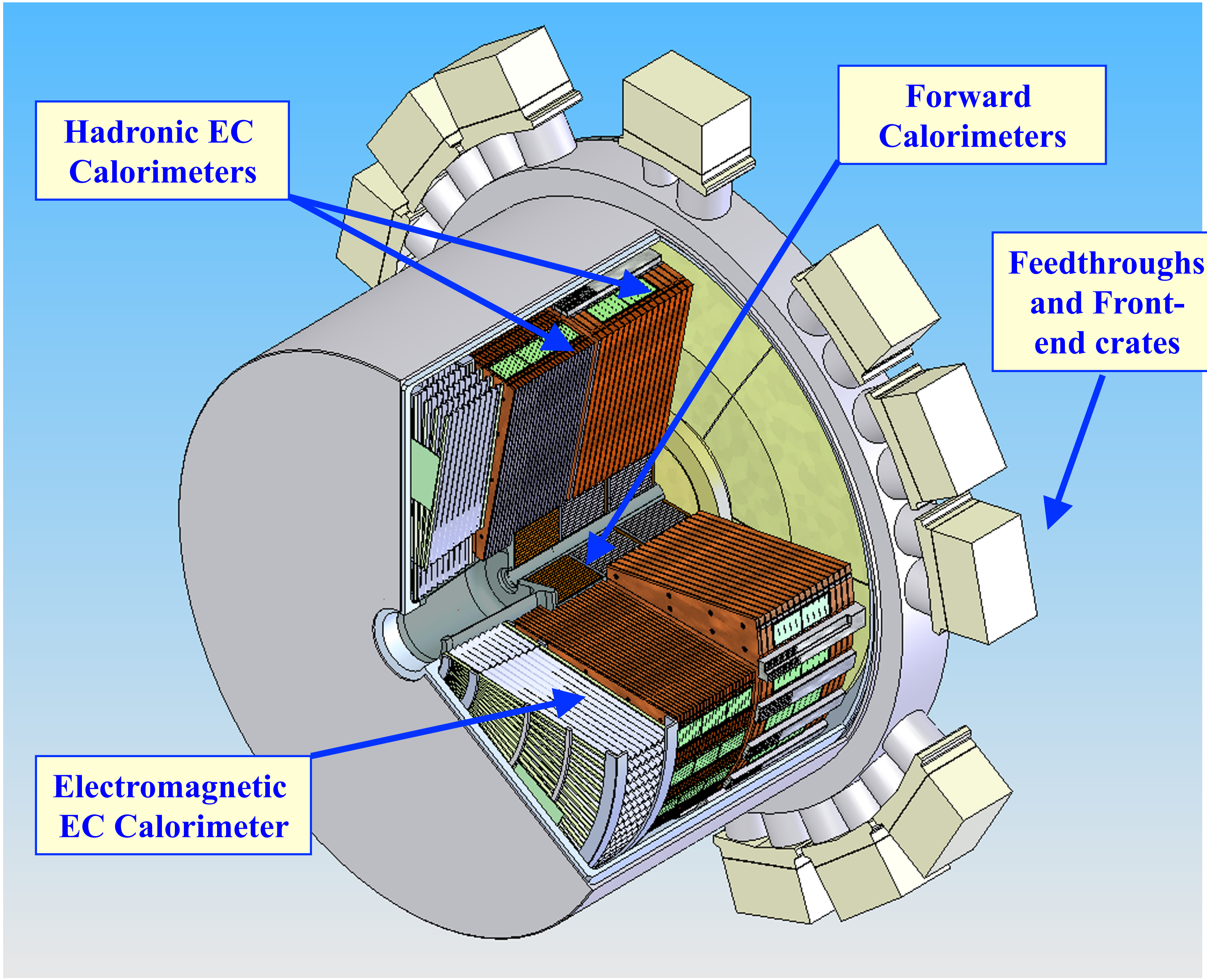
– electronic noise $\sigma/E \sim E^{-1}$

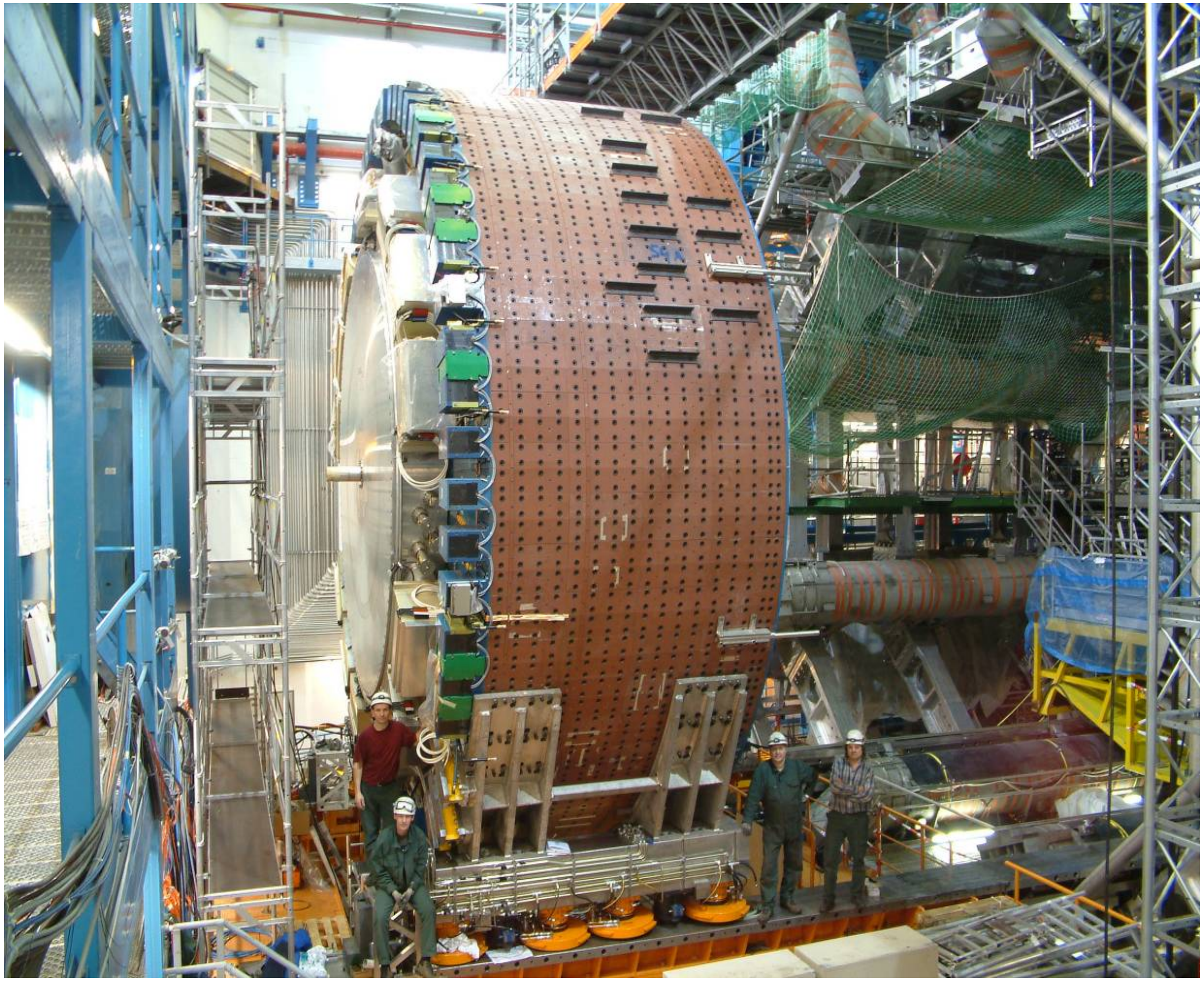
– structural non- uniformities: σ/E = constant

$$\frac{\sigma(E)}{E} = \frac{10\%}{\sqrt{E}} \oplus \frac{170MeV}{E} \oplus 0.7\%$$



ATLAS LAr End-Cap Calorimeters

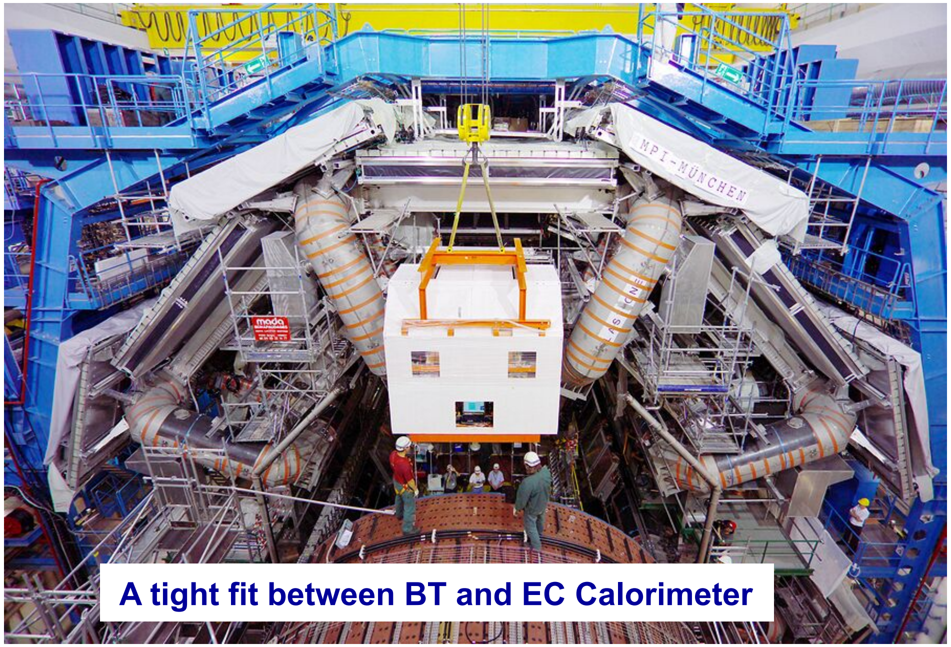




Completed end-cap calorimeter side C,
just before insertion into the detector

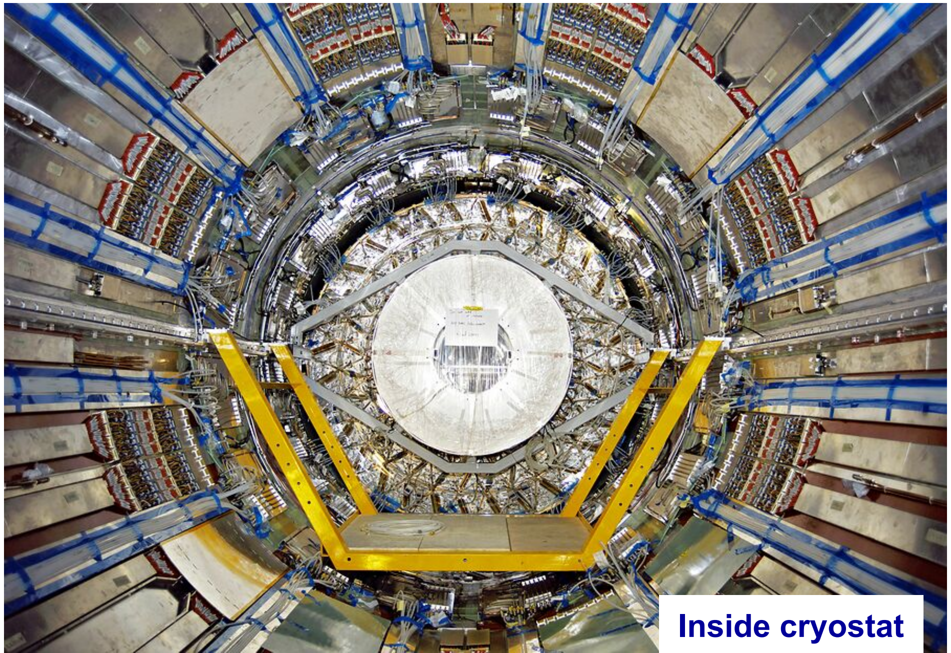
TRT+SCT barrel travelled to the pit, 24th Aug 2006

Through the parking area



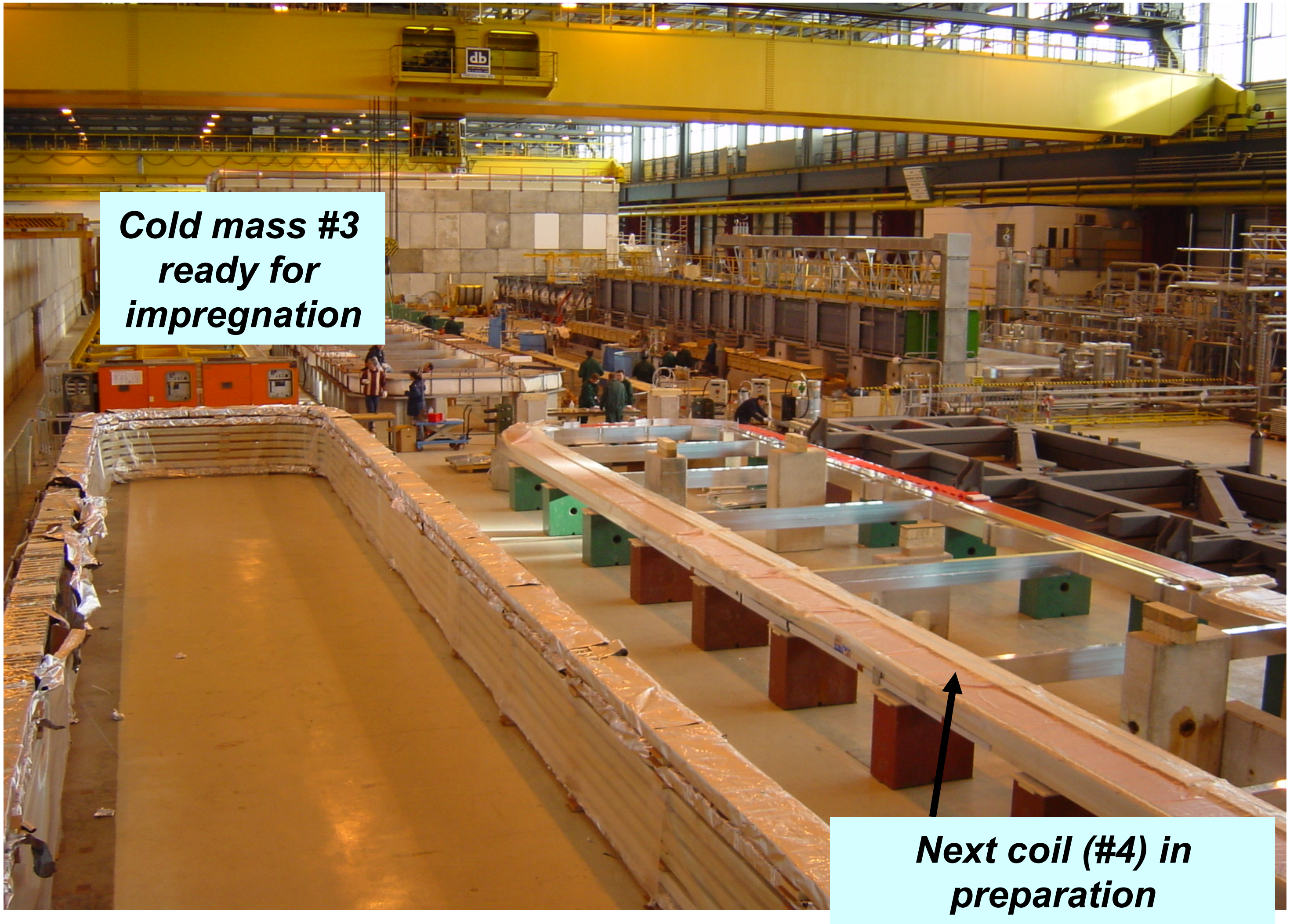
A tight fit between BT and EC Calorimeter

From the trolley to the support rails

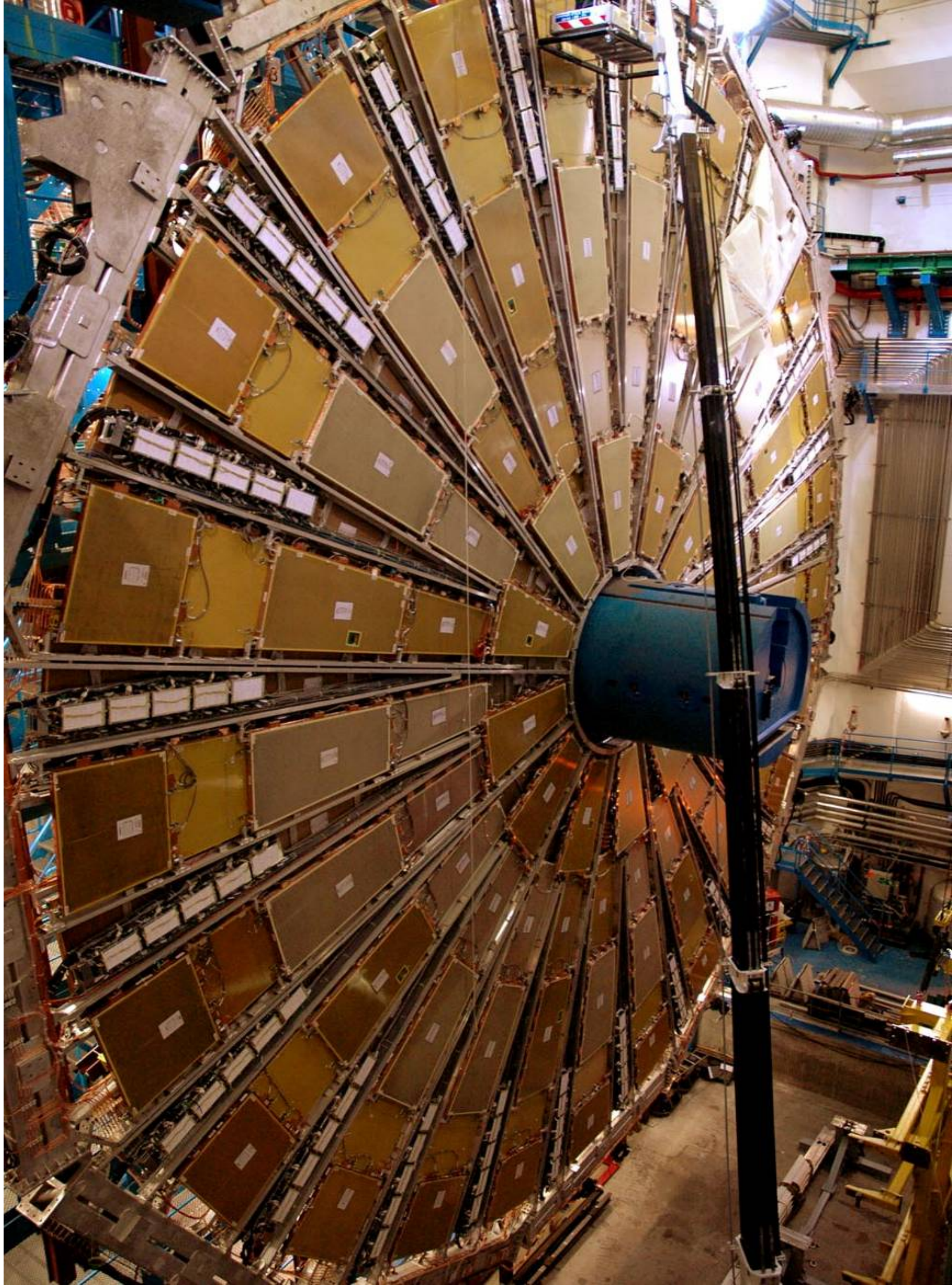


Inside cryostat

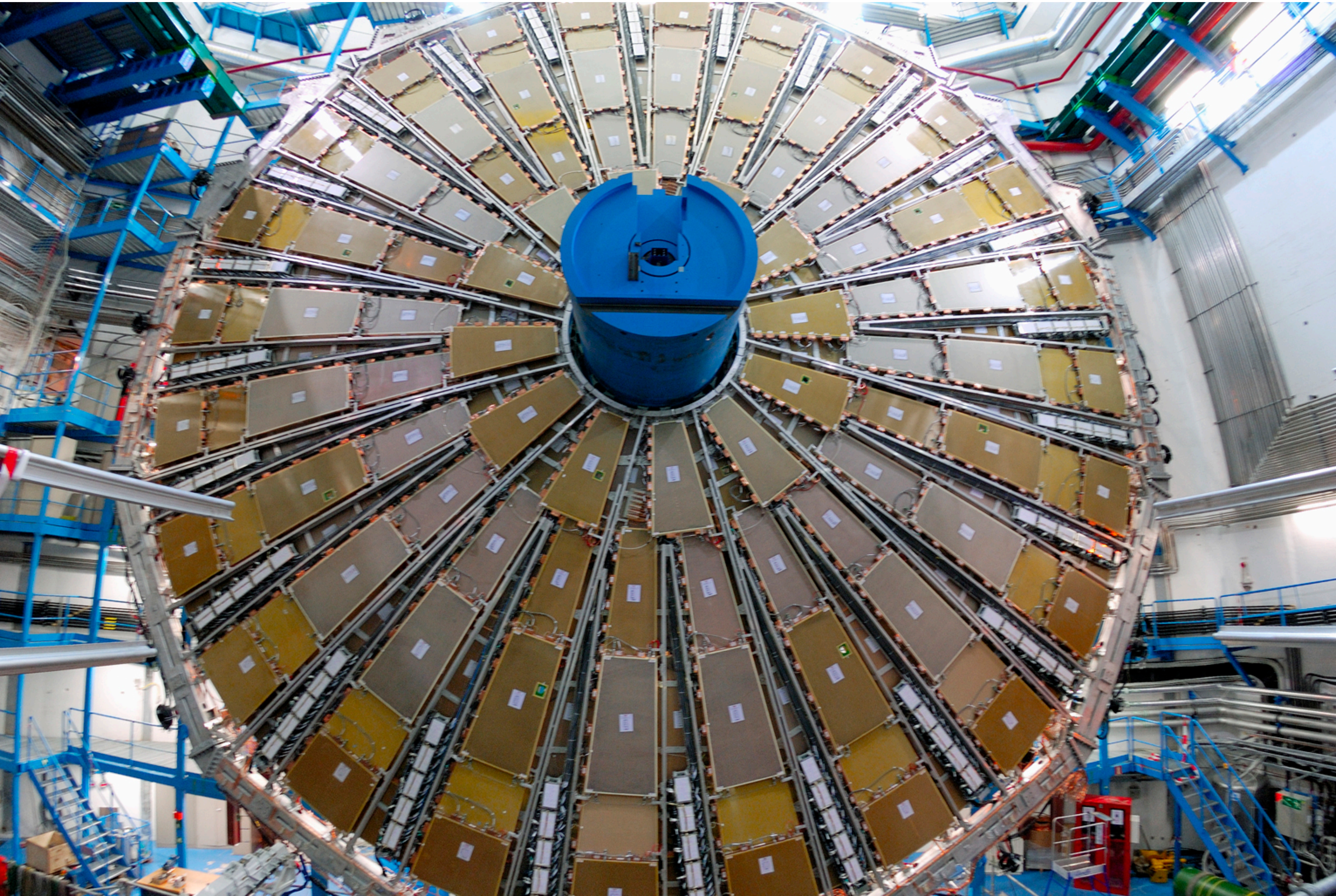
Toroid Magnet



Muon chambers

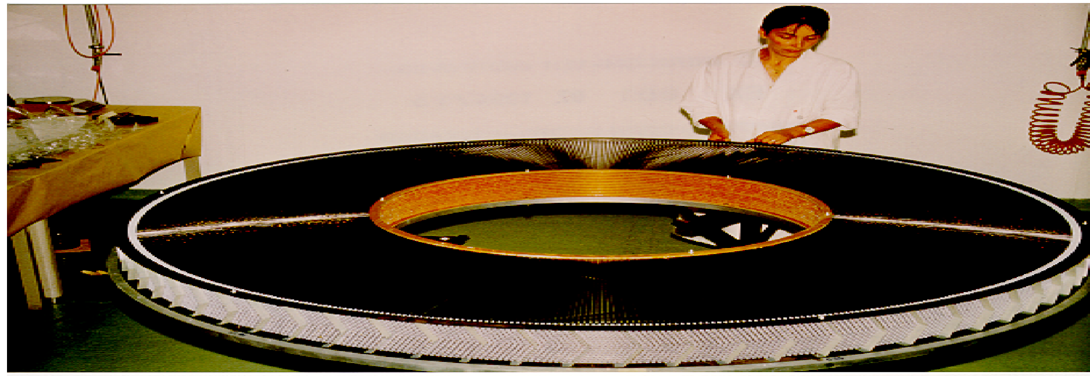


One more view of the first installed TGC Big Wheel



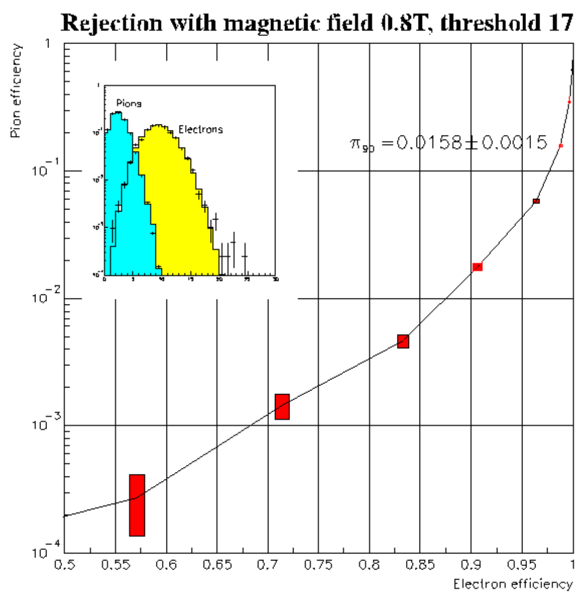
ATLAS Transition Radiation Tracker

A prototype endcap “wheel”.



X-ray detector:
straw tubes (4mm)
(in total ca. 400.000 !)

TRT prototype performance
Xe based gas



Pion fake rate at 90% electron detection efficiency:

p_{90} = 1.58 %