# Elementary Particle Physics: theory and experiments

**Experiment:**

**Detectors for HEP: ATLAS at LHC**

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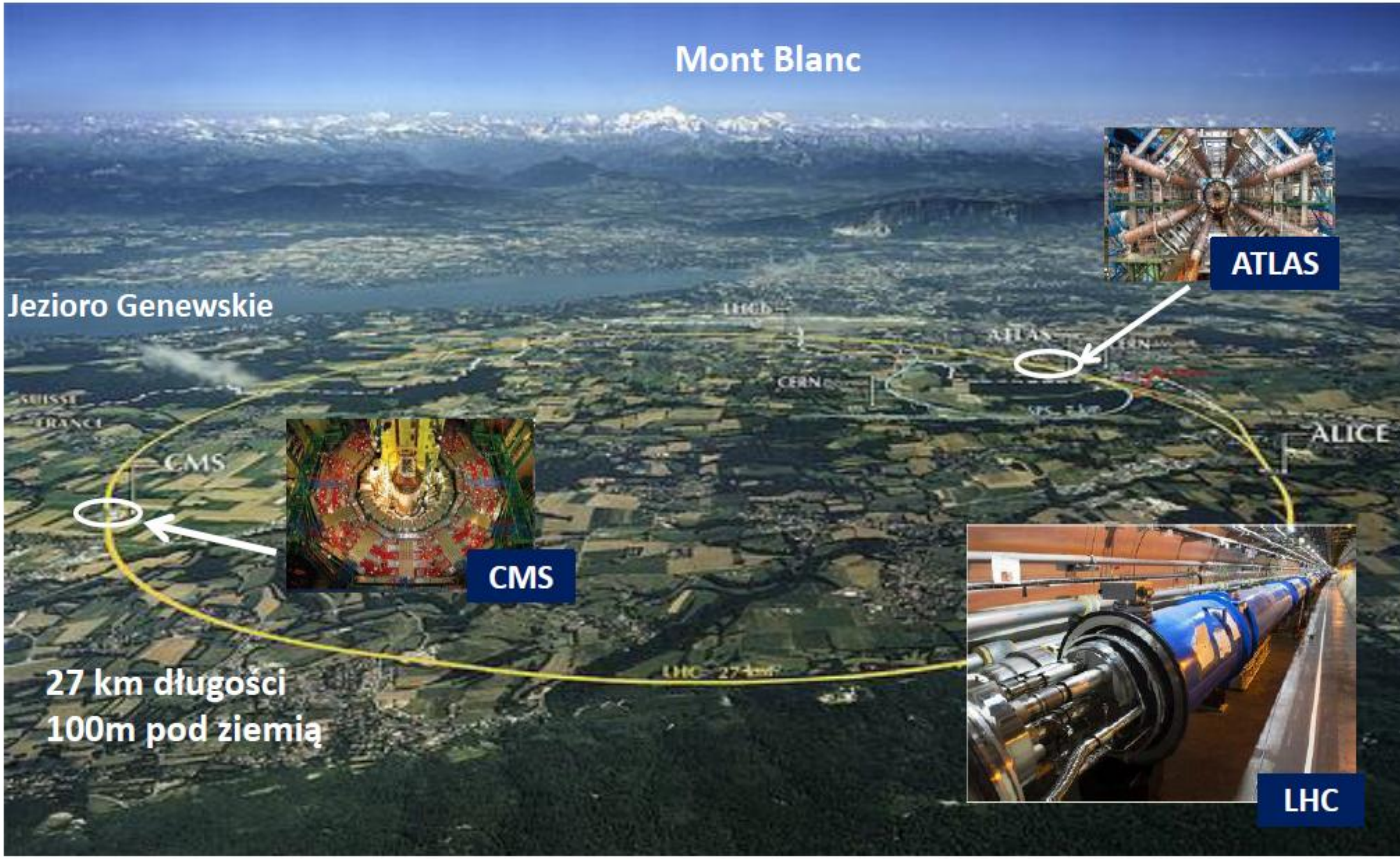
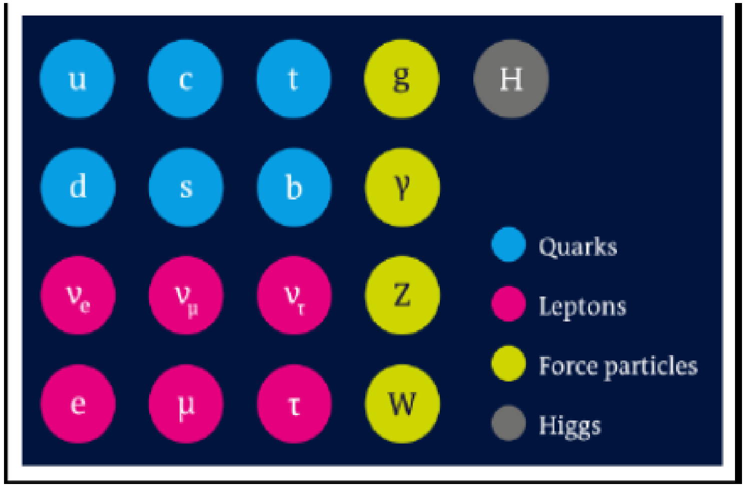
# Detectors for high energy physics
# (ATLAS at LHC)

# LHC (Large Hadron Collider )

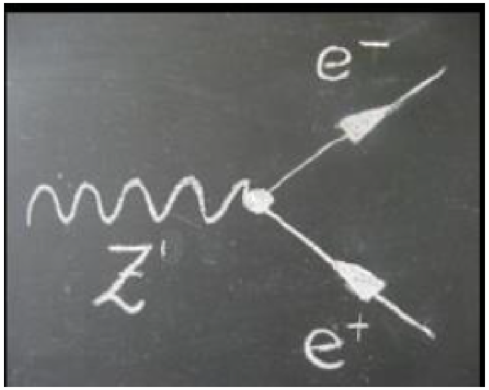


# Which particles are detected?

1) **Charged leptons, photons and hadrons: e, $\mu$,$\gamma$,$\pi$,K,p,n…** (maybe new long-lived particles, i.e. particles which enter detector)
2) B (and D) mesons and $\tau$ leptons have c$\tau$ ~ 0.09 ..0. x $10^{-3}$m large enough for additional vertex reconstruction
3) Neutrinos (maybe also new particles) are reconstructed as mising transverse momentum
4) All other particles which decay or hadronise in primary vertex (top quark decays before hadronises)

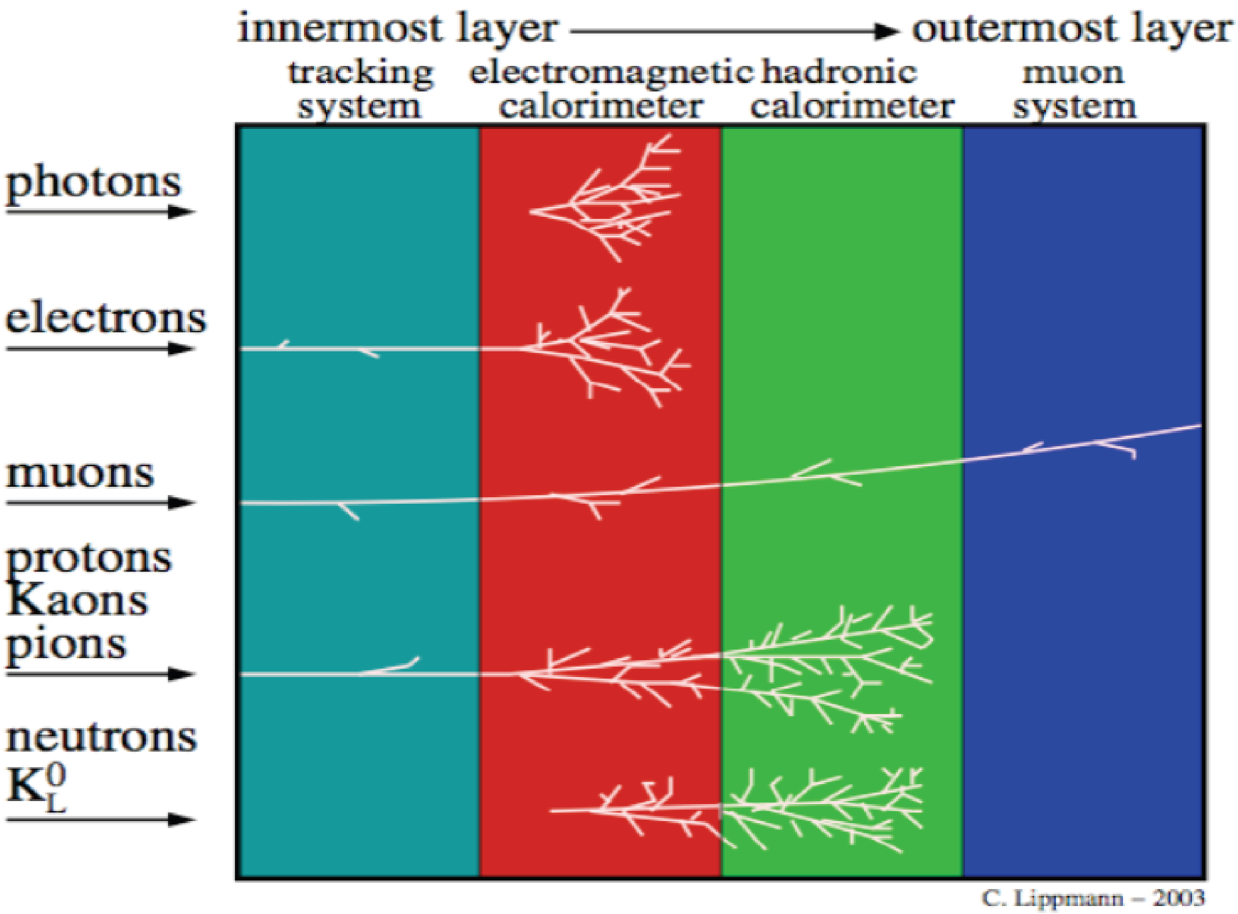



**Only e, $\mu$, $\gamma$ of the fundamental Standard Model Particles are directly detected**



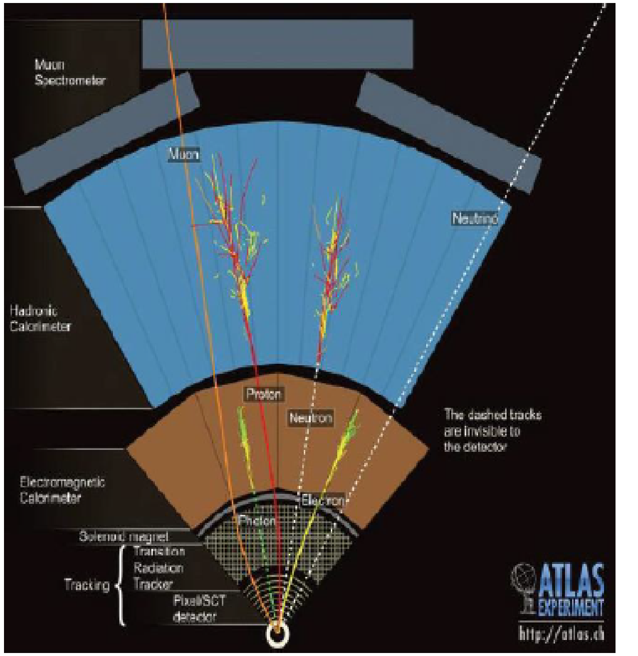

**Heavy particles W, Z decay immediatelly**

# Sketch of particles interaction with detector



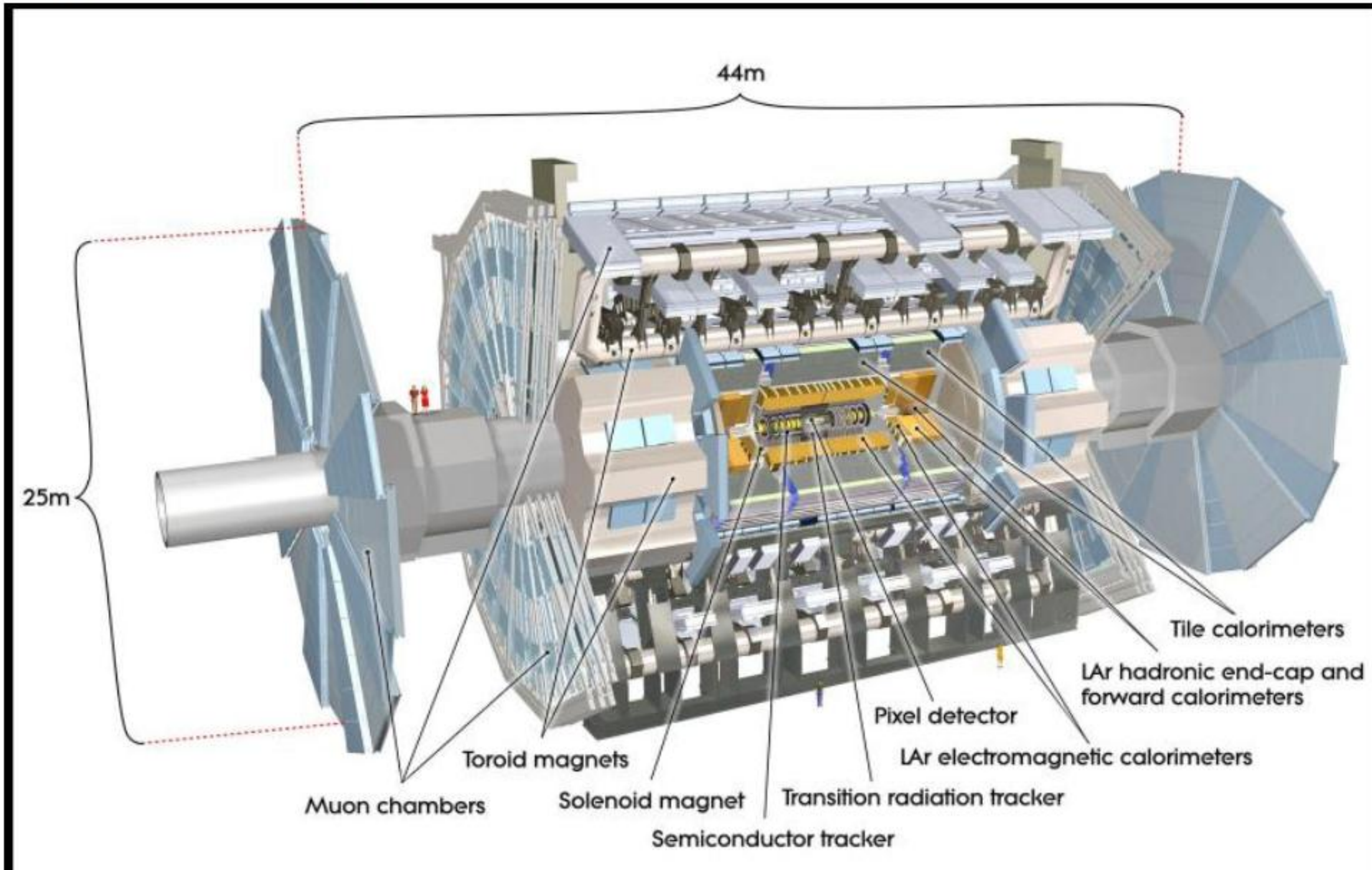
# The observables?

1) Photon makes photo-efect, Compton scattering and **pair production**. It has no track but an **electromagnetic cascade** in the calorimeter.
2) Charged particles makes scattering, **ionisation**, excitation and bremsstrahlung, transition and cherenkov radiation. They produce **tracks**.
3) Electrons make **electromagnetic cascades** (clusters) in the calorimeter
4) Hadrons also interact strongly via inelastic interactions, e.g. neutron capture, induced fission, etc. They make **hadronic cascades** (clusters) int he hadronic calorimeter.
5) Only weakly interacting particles (neutrinos) are reconstructed as **missing transverse momentum** („missing energy”).



# The ATLAS example

## Typical $4\pi$ cylindrical onion structure



# Reconstructed properties

From the hits, tracks, clusters, missing transverse momentum and vertices we reconstruct the particles properties:

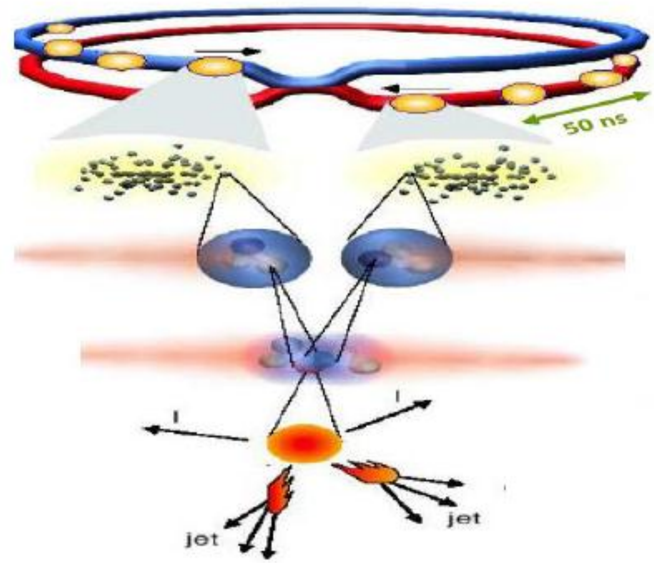
1) Momentum from curved tracks
2) Charge from track curvature
3) Energy from full absorption in calorimeters and curved tracks
4) Spin from angular distributions
5) Mass from invariant mass from decay products
6) Lifetime from time of flight measurement
7) Identity from dE/dx, lifetime or special behaviour (like transition ratiation)

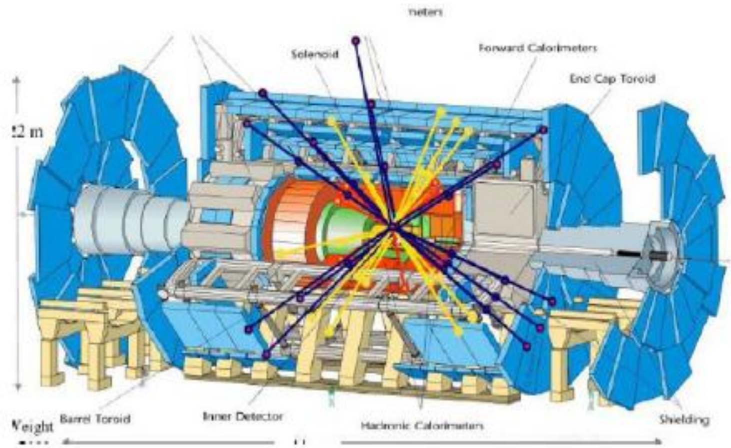
# Detector design constraints (I)

- **Constraints from physics:**
  1) High detection efficiency demands minimal cracks and holes, high coverage
  2) High resolution demands little material like support structures, cables, cooling pipes, electronics etc. (avoid multiple scattering)
  3) Irradiation hard active materials to avoid degradation and changes during operation
  4) Low noise
  5) Easy maintenance (materials get radioactive)
  6) …

# Detector design constraints (II)

- **Enviromental contraints, i.e. from LHC design parameters:**
  1) Collision events every ~ 25ns
  2) Muons from previous event still in detector when current enters tracker
  3) High occupancy in the inner detector
  4) Pile up (more proton proton collisions in each bunch crosing)
  5) High irradiation
  6) ...





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# Size and field examples

**ATLAS barrel toroid**
**20.5 kA, 3.9 T**

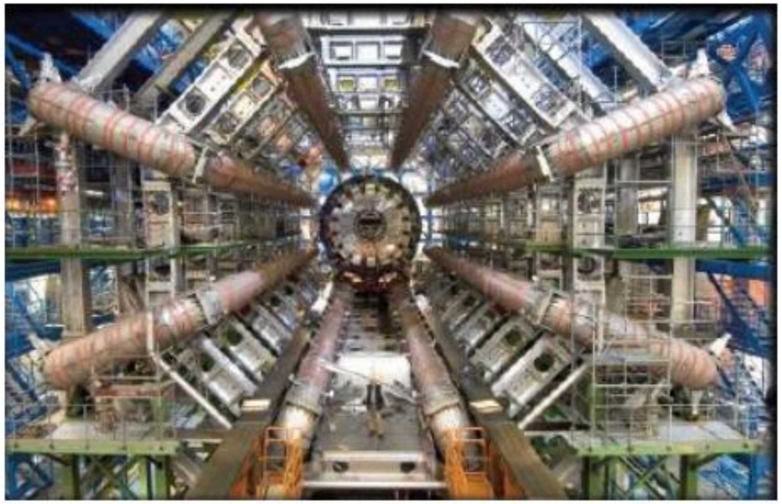
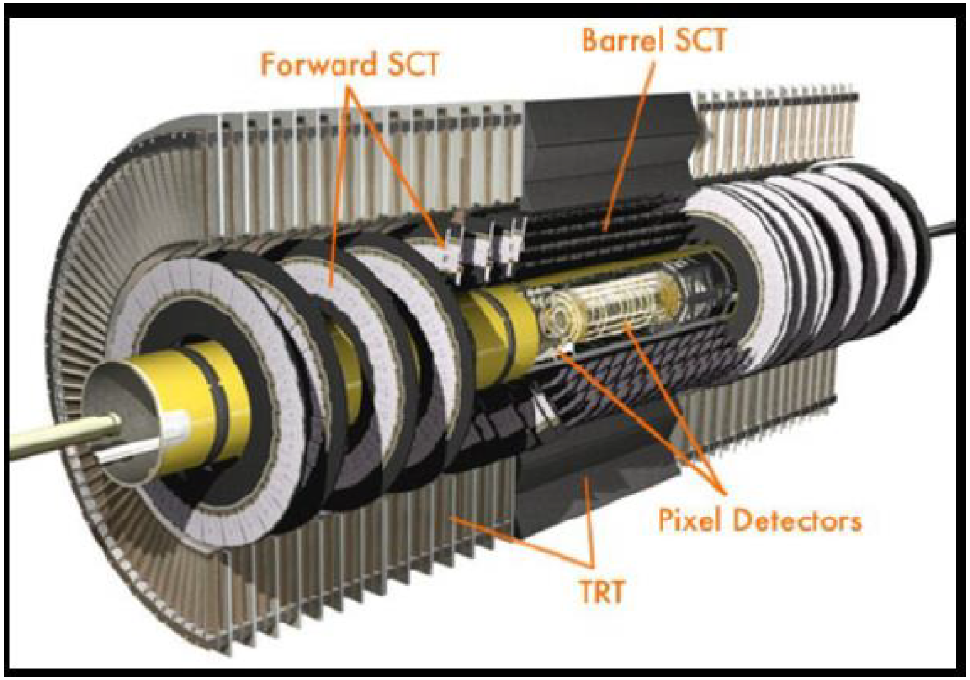


**Table 1**
Main parameters of some HEP detector magnets (solenoids).

| | CDF | CLEO-II | ALEPH | ZEUS | H1 | KLOE | BaBar | Atlas | CMS |
|---|---|---|---|---|---|---|---|---|---|
| $B$ (T) | 1.5 | 1.5 | 1.5 | 1.8 | 1.2 | 0.6 | 1.5 | 2.0 | 4.0 |
| $R$ (m) | 1.5 | 1.55 | 2.7 | 1.5 | 2.8 | 2.6 | 1.5 | 1.25 | 3.0 |
| $L$ (m) | 4.8 | 3.5 | 6.3 | 2.45 | 5.2 | 3.9 | 3.5 | 3.66 | 12.5 |

The magnet layout is a major constraint for the rest of the detector!
See A. Gadi, A magnet system for HEP experiments, NIMA 666 (2012) 10-24

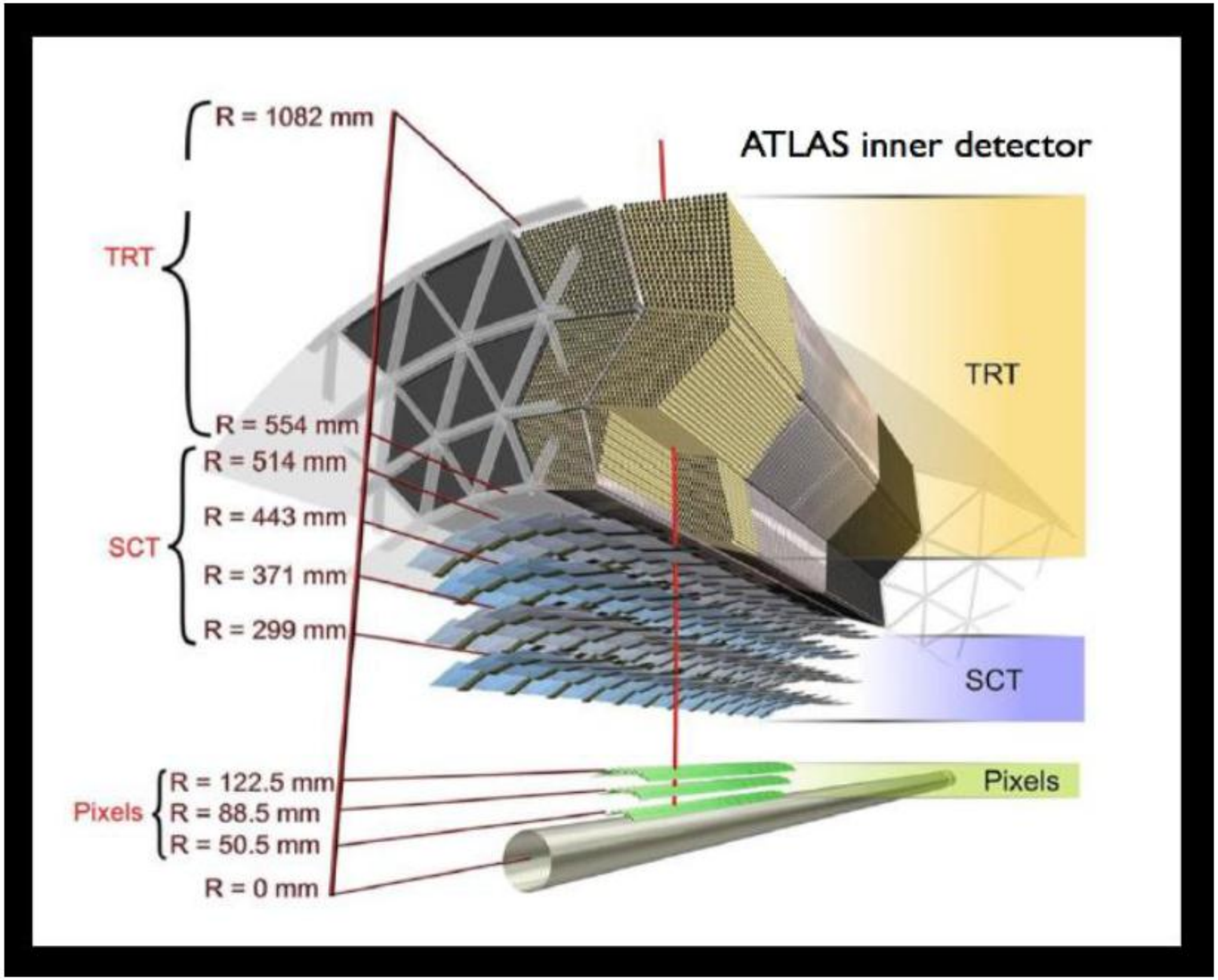
# ATLAS Inner Detector




- 3 layers of pixel modules in barrel
- 2x5 disks of forward pixel disks
- 4 layers of strip (SCT) modules in barrel
- 2x9 disks of forward strip modules

Figure : ATLAS Inner detector (ID) in LHC run 1 with pixel and strip (SCT) silicon and transition radiation (TRT) detectors. The length is about 5.5 m.

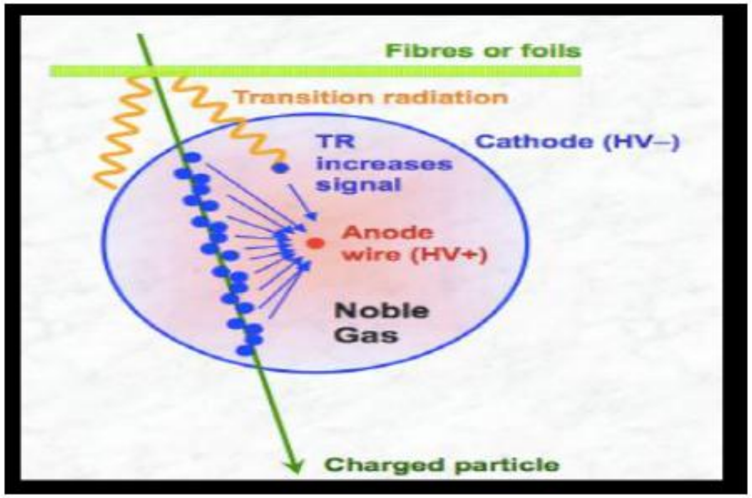
# ATLAS Inner Detector

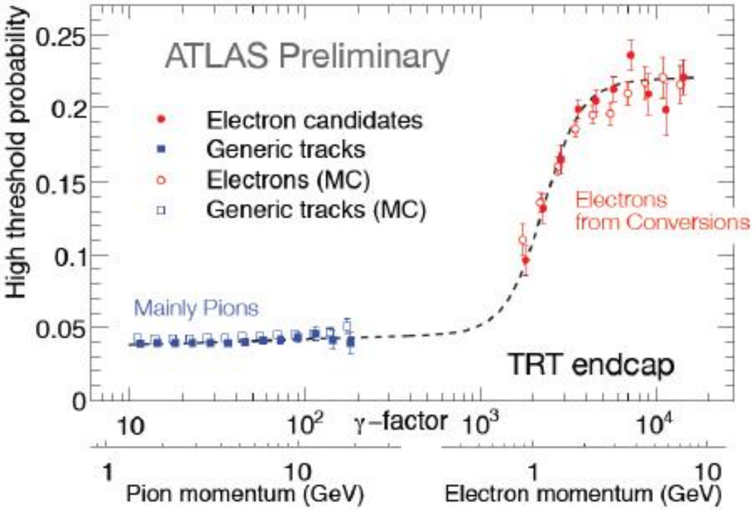


# Transition Radiation Tracker

Combine tracking with particle identification (PID)

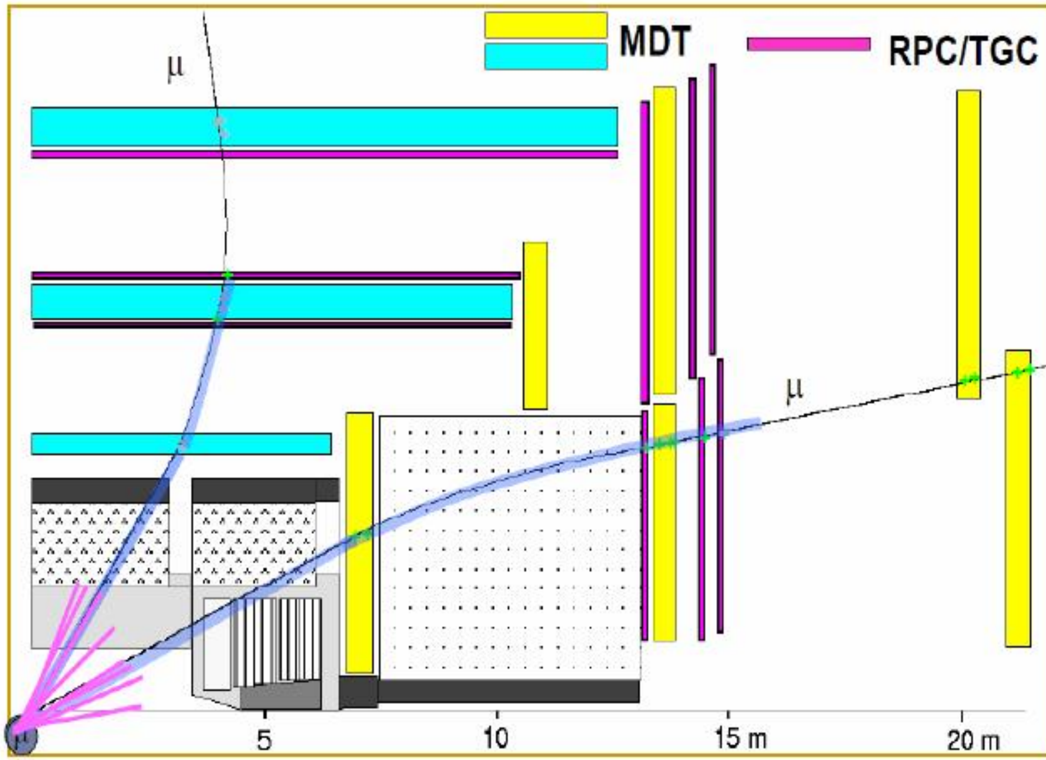
- Charged particles radiate photons when crossing material borders.
- $E^{+-}$ radiate x-rays more than heavier particles.
- Use this particle PID, i.e. distinguis $e^{+-}$ from hadrons.
- ATLAS has a TR detector in the inner detector. It uses gas for detection.



# Muon system in ATLAS

12 m



# ATLAS EM Calorimeter

Accordion Pb/LAr |η|<3.2 ~170k channels

- Precision measurement |η|<2.5

3 layers up to |η|=2.5 + presampler |η|<1.8

2 layers 2.5<|η|<3.2

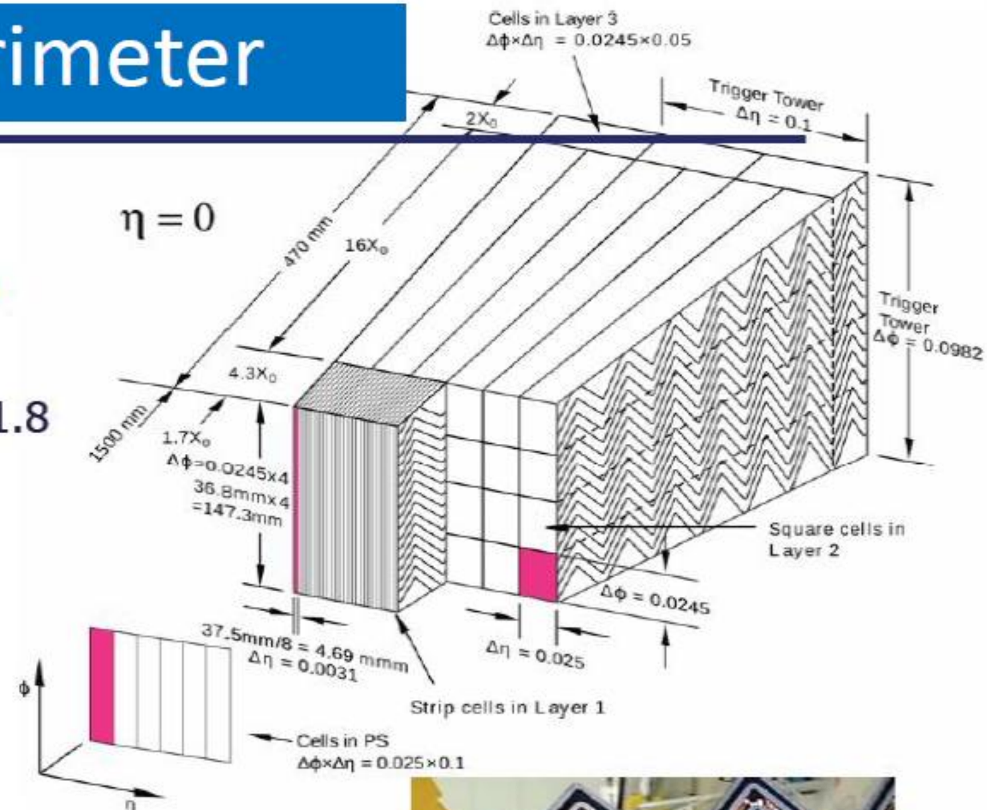
- Layer 1 ($\gamma/\pi^0$ rej. + angular meas.)
- Δη.Δφ = 0.003 x 0.1
- Layer 2 (shower max)
- Δη.Δφ = 0.025 x 0.0.25
- Layer 3 (Hadronic leakage)
- Δη.Δφ = 0.05 x 0.0.025

Energy Resolution: design for η~0

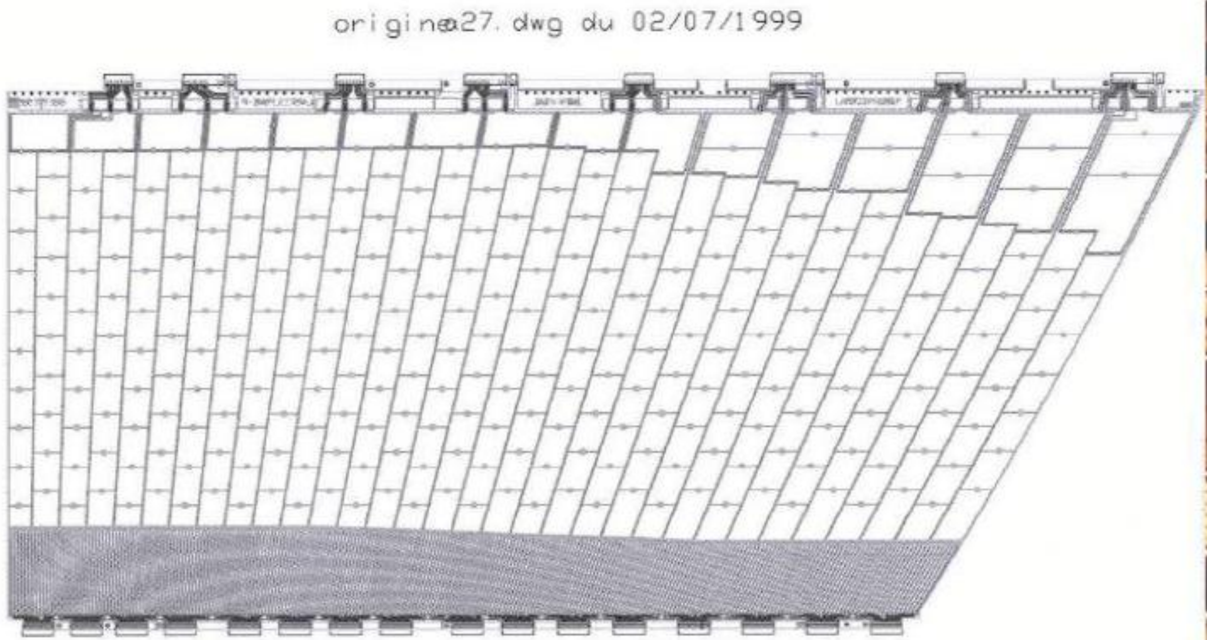
- $\Delta E/E \sim 10\%/\sqrt{E} \oplus 150\ \text{MeV}/E \oplus 0.7\%$

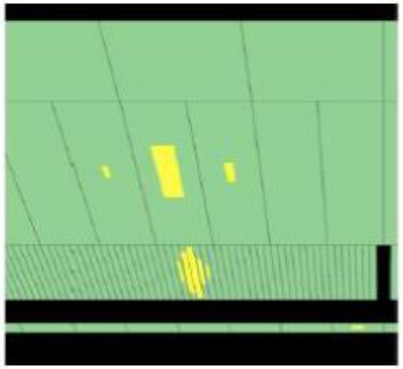
Angular Resolution

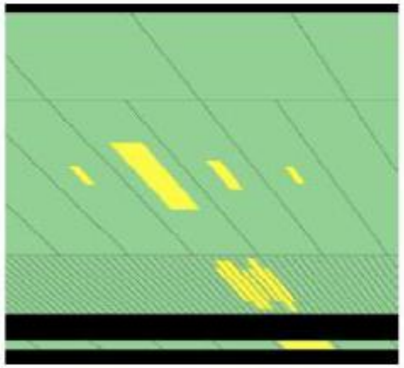
- $50\text{mrad}/\sqrt{E(\text{GeV})}$



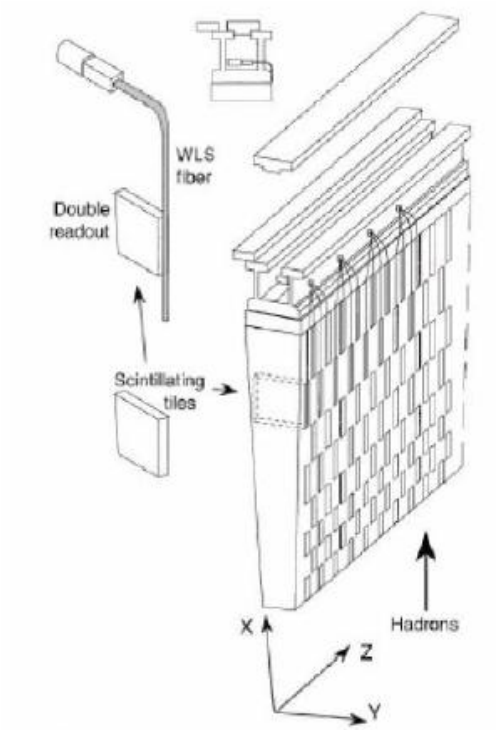

# The segmentation





# ATLAS Hadronic Calorimeter (Tile)




Fe/Scint with WLS fiber Readout via PMT

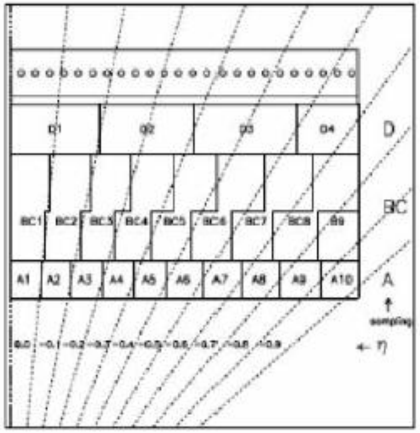



**Figure 5-15** Cell geometry of half of a barrel module. The fibres of each cell are routed to one PMT.

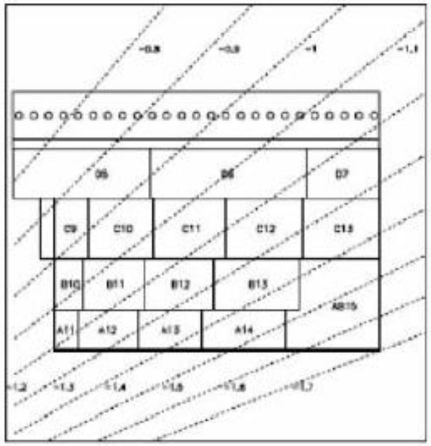


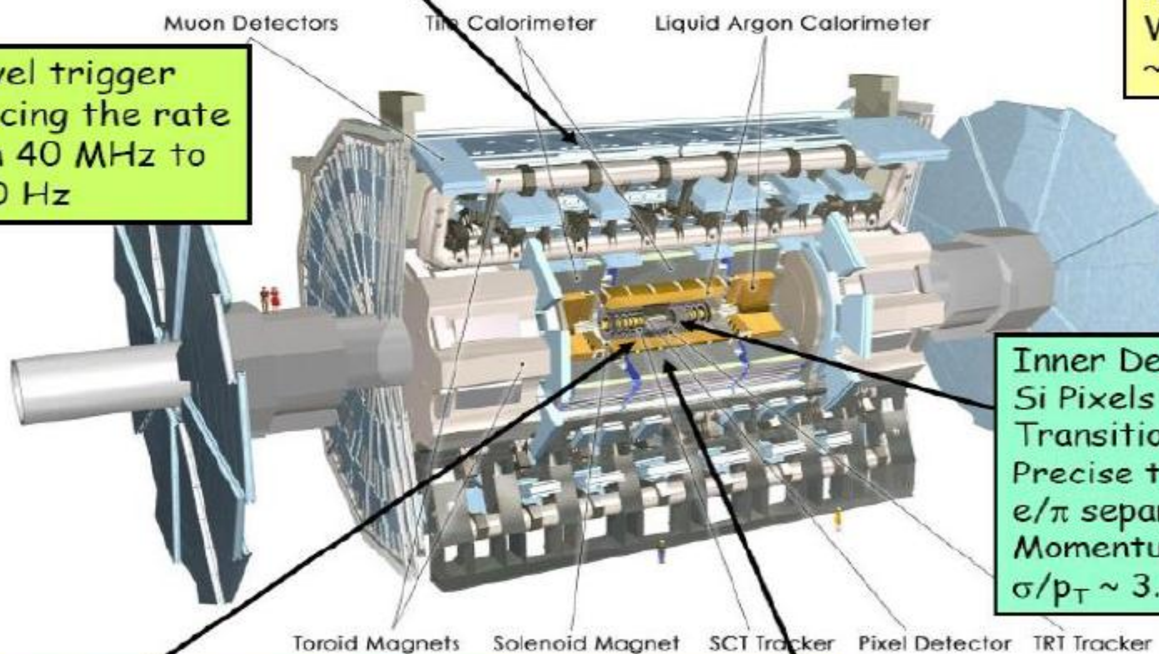
**Figure 5-16** Proposed cell geometry for the extended barrel modules (version "a la barrel").

# The ATLAS detector

Muon Spectrometer ($|\eta|<2.7$) : air-core toroids with gas-based chambers
Muon trigger and measurement with momentum resolution < 10% up to $E_\mu$ ~ TeV

Length : ~ 46 m
Radius : ~ 12 m
Weight : ~ 7000 tons
~$10^8$ electronic channels

3-level trigger reducing the rate from 40 MHz to ~200 Hz




Inner Detector ($|\eta|<2.5$, B=2T):
Si Pixels and strips (SCT) +
Transition Radiation straws
Precise tracking and vertexing,
$e/\pi$ separation (TRT).
Momentum resolution:
$\sigma/p_T \sim 3.4\times10^{-4}\ p_T(\mathrm{GeV}) \oplus 0.015$

EM calorimeter: Pb-LAr Accordion
$e/\gamma$ trigger, identification and measurement
E-resolution: ~ 1% at 100 GeV, 0.5% at 1 TeV

HAD calorimetry ($|\eta|<5$): segmentation, hermeticity
Tilecal Fe/scintillator (central), Cu/W-LAr (fwd)
Trigger and measurement of jets and missing $E_T$
E-resolution: $\sigma/E \sim 50\%/\sqrt{E} \oplus 0.03$

# Nuclear Instruments & Methods in Physics Research

topical issue

**Instrumentation and detector technologies for frontier high energy physics**

*Volume 666, pages 1 - 222 (21 February 2012)*

Edited by:
Archana Sharma (CERN)

Technological advances in radiation detection have been pioneered and led by particle physics. The ever increasing complexity of the experiments in high energy physics has driven the need for developments in high performance silicon and gaseous tracking detectors, electromagnetic and hadron calorimetry, transition radiation detectors and novel particle identification techniques. Magnet systems have evolved with superconducting magnets being used in present and, are being designed for use in, future experiments. The alignment system, being critical for the overall detector performance, has become one of the essential design aspects of large experiments. The electronic developments go hand in hand to enable the exploitation of these detectors designed to operate in the hostile conditions of radiation, high rate and luminosity. This volume provides a panorama of the state-of-the-art in the field of radiation detection and instrumentation for large experiments at the present and future particle accelerators.