Lectures on calorimetry

Christophe Ochando
(LLR/Ecole Polytechnique/CNRS)

Lecture 4

HIGHTEC
High Granularity
Hybrid Timing
and Energy Calorimetry
a P2IO project by LLR, LAL and IRFU

esipap
European School of Instrumentation in Particle & Astroparticle Physics

esi
European Scientific Institute

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cnrs IN2P3 Les deux infinis

LLR

l'X ÉCOLE POLYTECHNIQUE UNIVERSITÉ PARIS-SACLAY

Plan of lectures

Lecture 1

Why/what calorimeters ?

Physics of EM & HAD showers

Calorimeter Energy Resolution

Lecture 2

Example of Calorimeter

Calorimeter Objects & Triggering

Exercises

Lecture 3

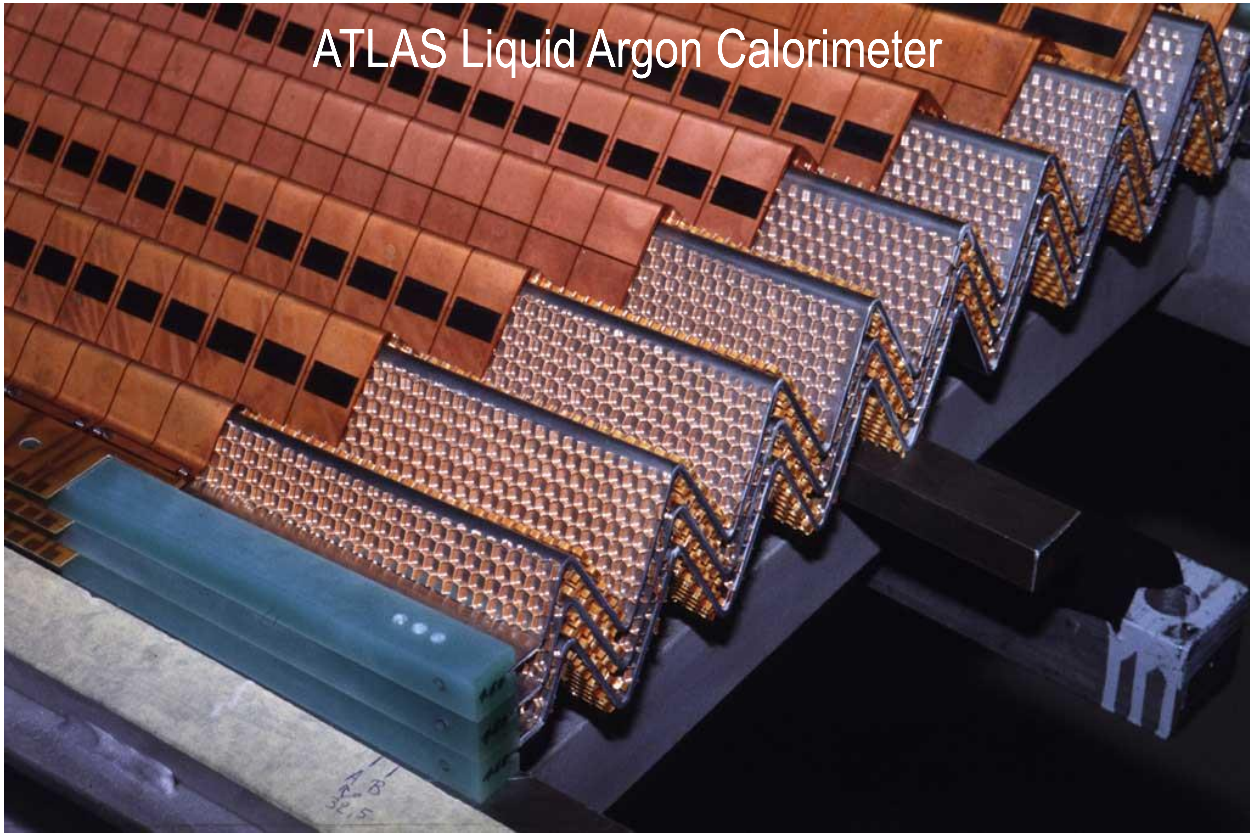
Future of calorimetry

Lecture 4

Example of calorimeters (suite)

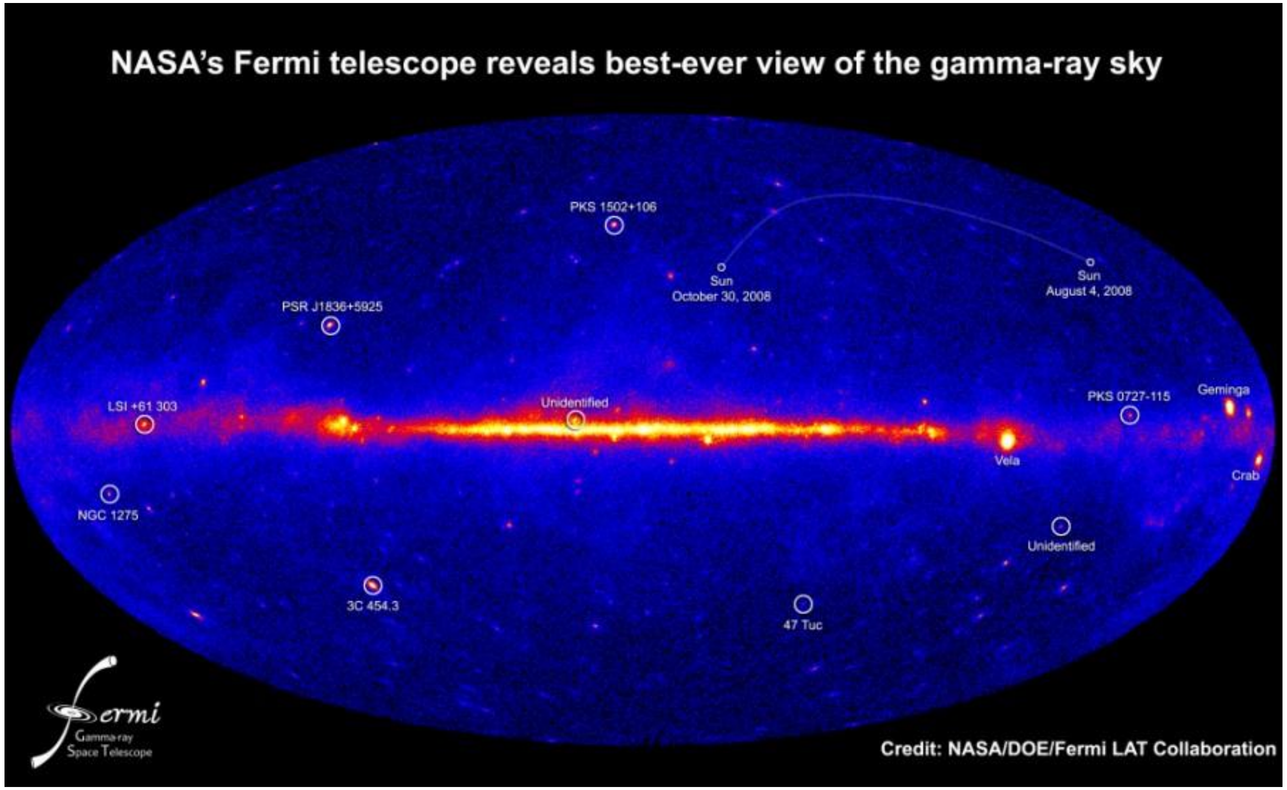
Exercises

Calorimeters: example (suite)



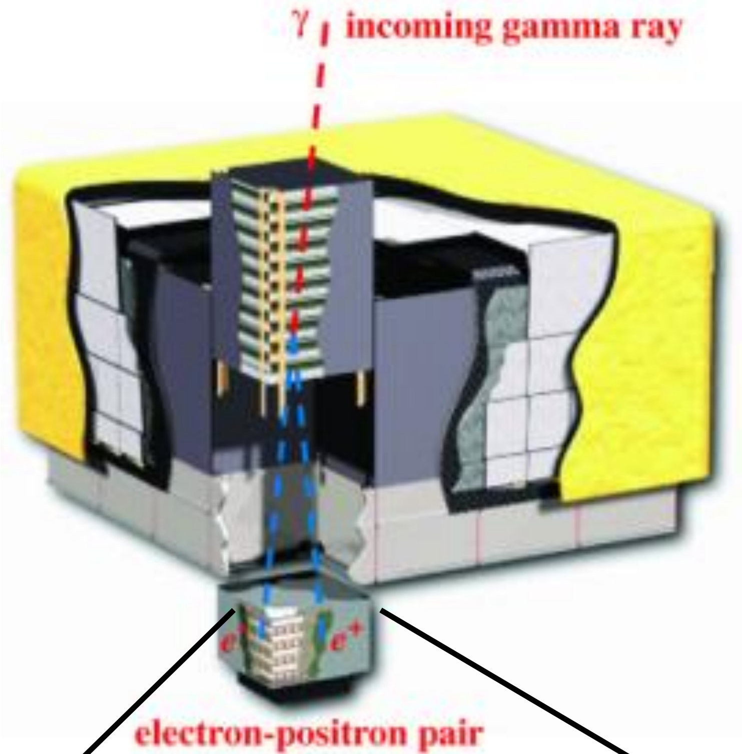
Calorimeters in space: FERMI/LAT

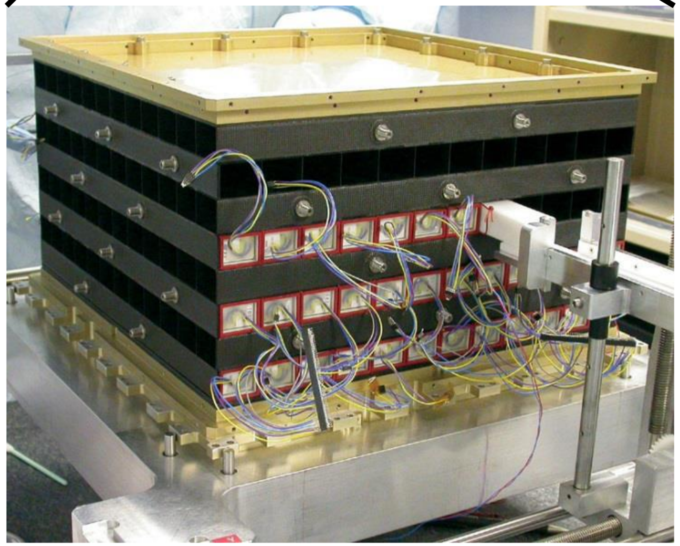
- **Fermi Satellite with Large Area Telescope (LAT) instrument.**
- **Gamma-Ray Telescope**
  - (200 MeV < γ < 300 GeV)
- Launched June 11 2008
- Consists of:
  - Tracker: Pb foils + Si strips
  - Calorimeter (**see next slide**)
  - Anticoincidence Detector : plastic scintillator tiles



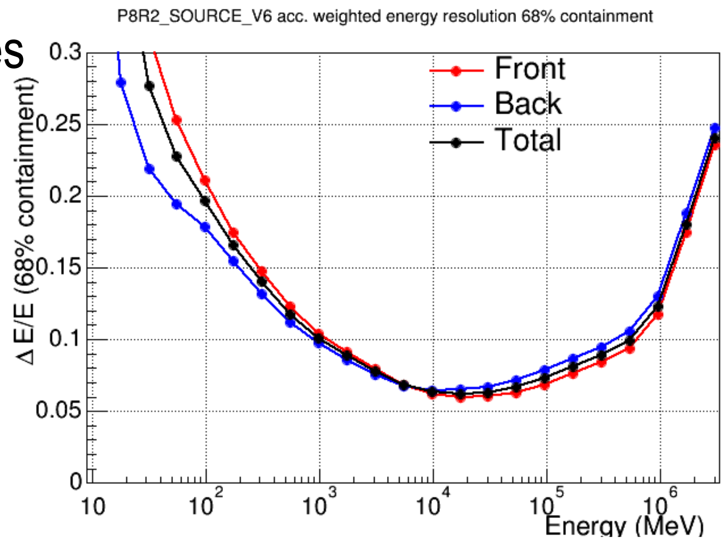
Calorimeters in space: FERMI ECAL

Homogenous calorimeter made from 1728 CsI(Tl) scintillating crystals





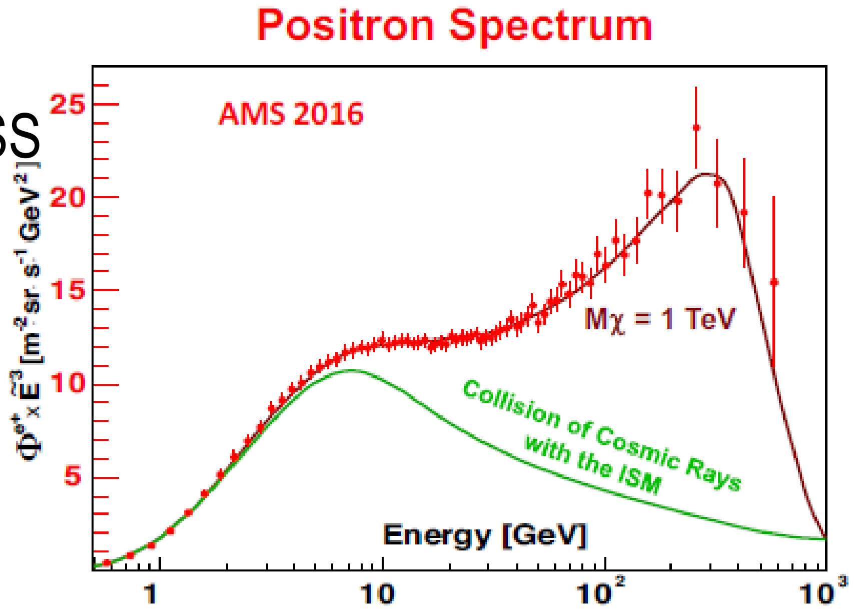
- 18 modules (400mmx400mmx250mm) ~100 kg each
- 1 module:
  - carbon-fiber alveolar structure +
  - **96 CsI(Tl) crystals (2.7 cm x 2.0 cm x 32.6 cm)**
  - arranged in 8 layers of 12 crystals each
- Each module aligned 90° wrt its neighbors, forming x,y (hodoscopic) array
- **Depth**: 8.6 X_O (10.1 including tracker)
  - $\Rightarrow$ **Need shower leakage correction**
- Light read by 2 photo-diodes

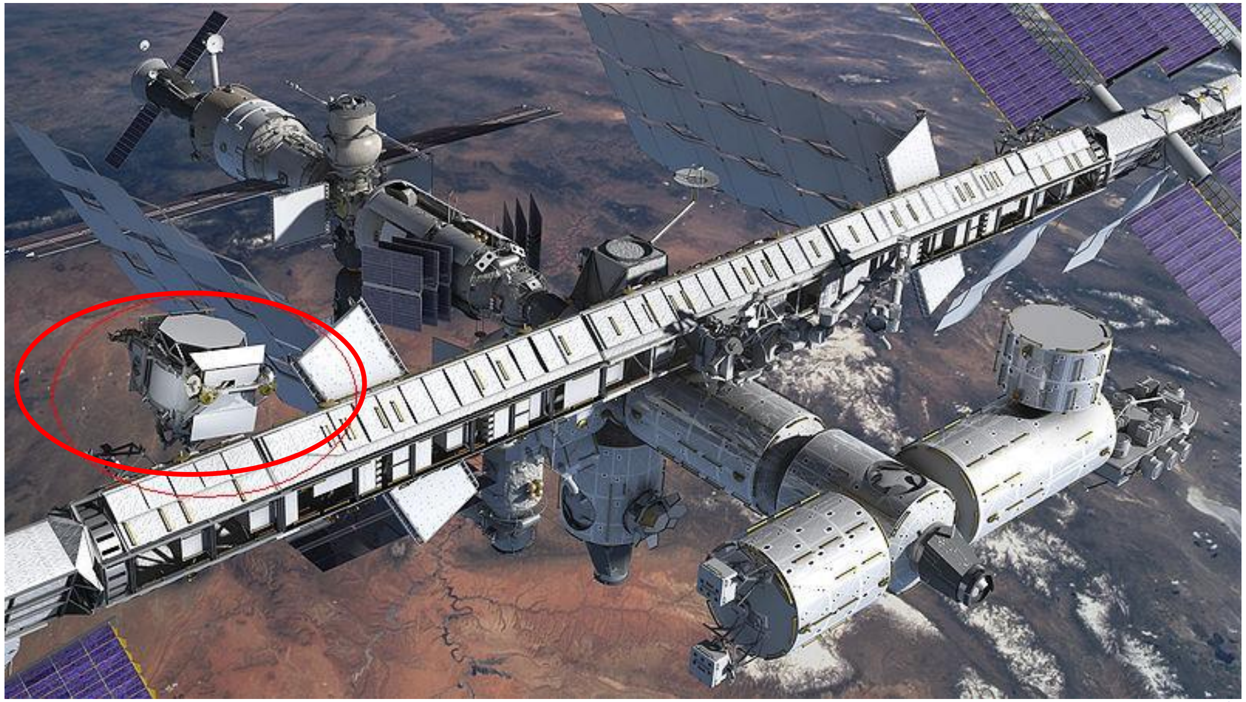


Calorimeters in space: AMS-02

- **Alpha Magnetic Spectrometer (AMS):**
  - HEP-like detector operating as external module on ISS
  - Launched in 2011

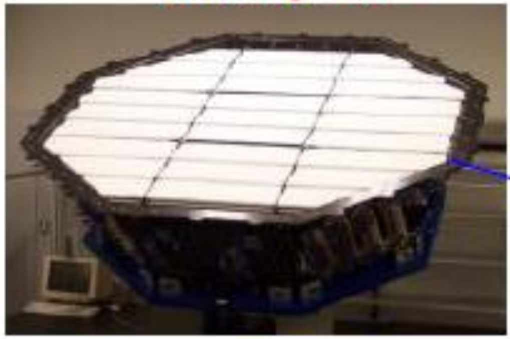
- Search for Dark Matter, anti-matter, precise study of high energy cosmic ray (flux, composition), gamma rays.



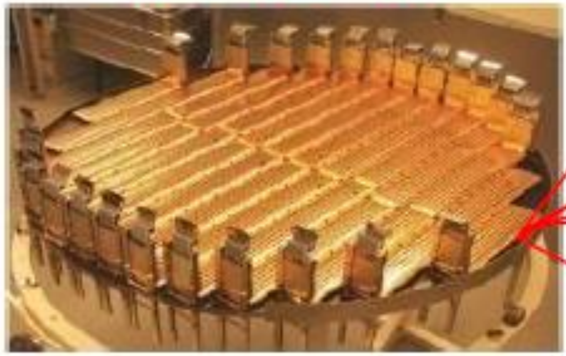


AMS: A TeV precision, multipurpose, magnetic spectrometer

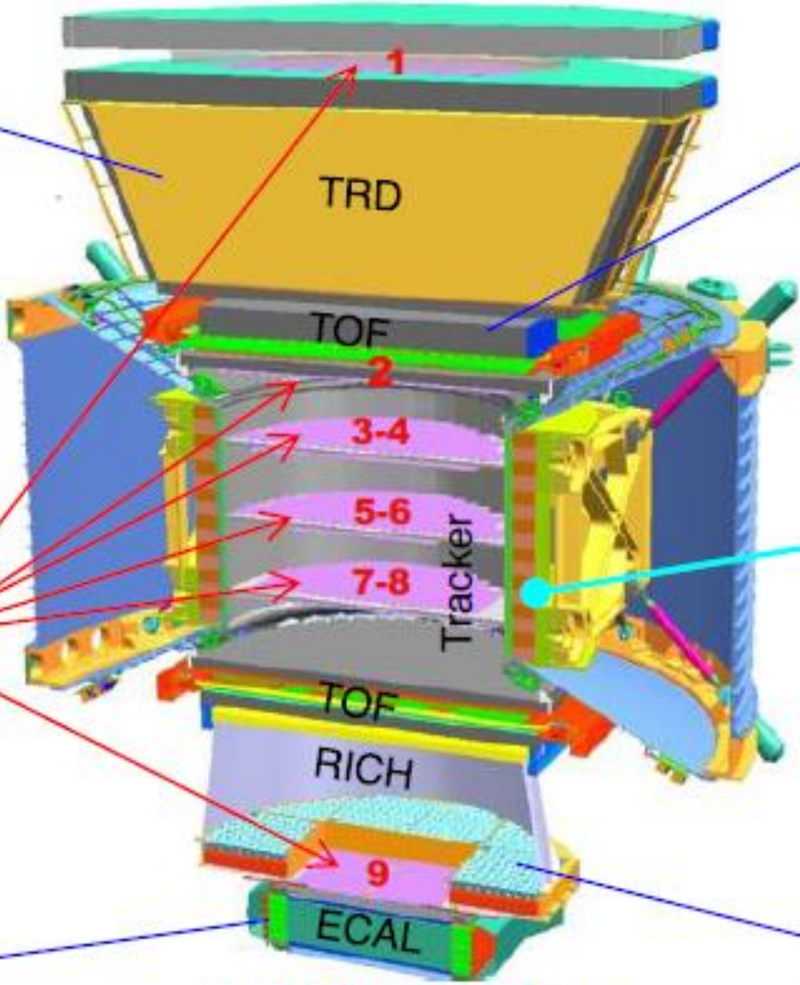
Transition Radiation Detector
(TRD)
Identify e^+, e^-



Silicon Tracker
Z, P or R=P/Z



Electromagnetic Calorimeter
(ECAL)
E of e^+, e^-



Z and P, E or R are
measured independently by Tracker,
ECAL, TOF and RICH

Time of Flight
(TOF)
Z, E

Magnet
±Z

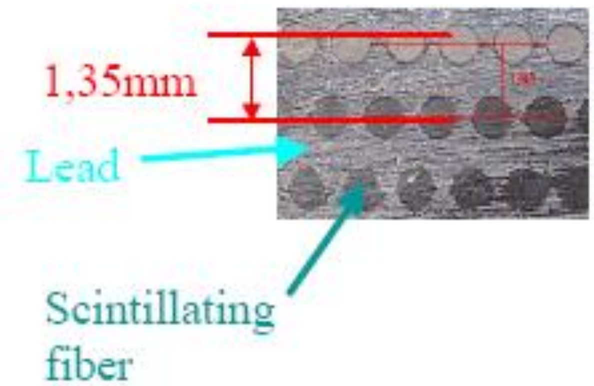
Ring Imaging Cherenkov
(RICH)
Z, E

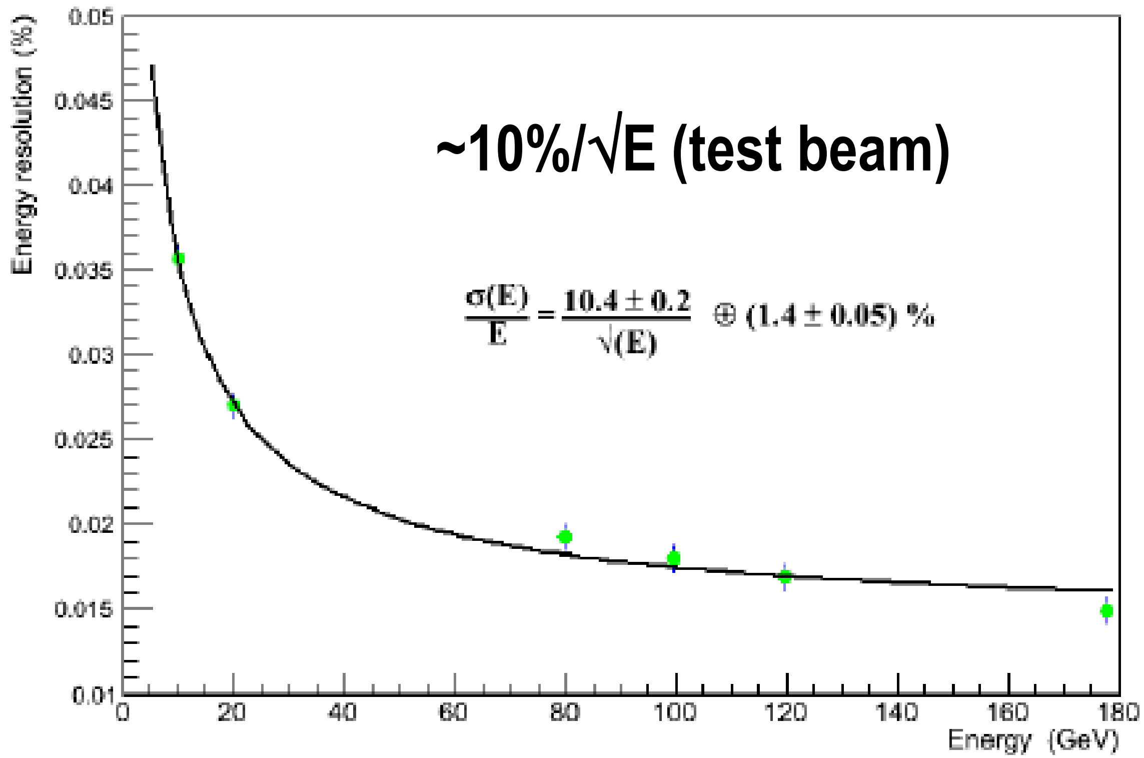
The AMS-02 ECAL

Sampling calorimeter made from Lead + Scintillating fibers

- **3-D imaging of shower development**
  - 9 Super-Layers (SL) alternatively oriented along X and Y axis (5 SL along X, 4 long Y)
- 1 Super-Layer (~18.5mm):
  - 11 grooved, Pb foils (1mm thick) interleaved with 10 layers of scintillating fibers (Ø~1mm) glued by epoxy-resin
- **Depth:** ~17 X0
- Fibers read by PMT

ECAL support structure





Exercises (suite)

Useful Formulas (EM showers) [1]

Radiation Length:

$$X_0 \approx \frac{180A}{Z^2}$$ (g.cm^{-2})

Radiation Length for composite material:

$$\frac{1}{X_0} = \sum \frac{w_j}{X_j}$$

w_j: fraction of material j
X_j: radiation length of material j (in g.cm-2)

Moliere Radius:

$$R_M = \frac{21MeV}{E_C} X_0$$

Moliere Radius for composite material:

$$\frac{1}{R_M} = \sum \frac{w_j}{R_{M\,j}}$$

w_j: fraction of material j
R_{Mj}: Moliere Radius of material j (in g.cm-2)

Energy Resolution:

$$\frac{\sigma}{E} = \frac{S}{\sqrt{E}} \oplus \frac{N}{E} \oplus C$$

$\oplus$: quadratic sum
S: Stochastic
N: noise
C: constant

Useful Formulas (EM showers) [2]

$$E_C(solid) = \frac{610\ \mathrm{MeV}}{\mathrm{Z}+1.24}$$

$$E_C(liquid) = \frac{710\ \mathrm{MeV}}{\mathrm{Z}+0.92}$$

E_C: critical energy

Shower maximum

$$t_{\max} = \frac{\ln E_0 / E_C}{\ln 2}$$

$$N(t_{\max}) \approx \frac{E_0}{E_C}$$

Longitudinal containment:

$$t_{95\%} = t_{\max} + 0.08Z + 9.6$$

$$\frac{\sigma_E}{E} = 3.2\% \sqrt{\frac{E_c\ [\mathrm{MeV}] \cdot t_{abs}}{F \cdot E\ [\mathrm{GeV}]}}$$

(stochastic contribution)

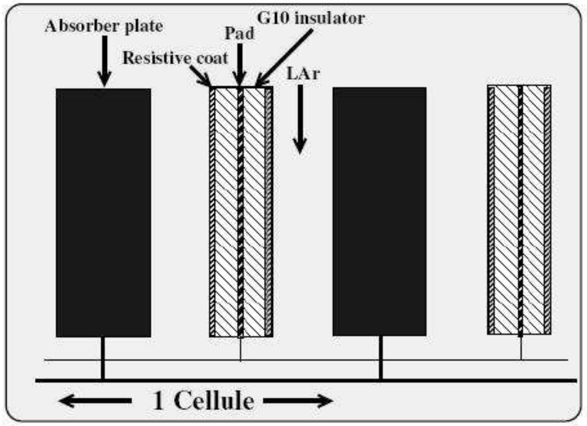
t_{abs}: thickness of absorber (in units of X_0)
F: factor (~0.2 for liquid noble gaz, 0.06 for Si, ~1 for scintillators)

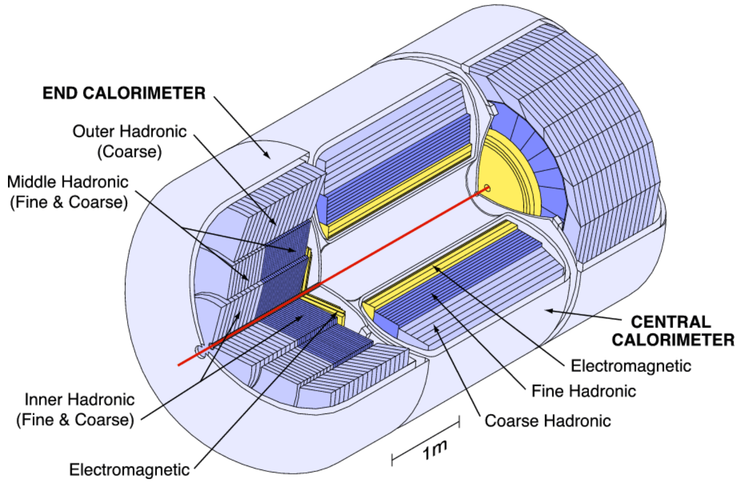
Exercise: EM showers in various materials

Take e- with E=100 GeV and E=1 TeV going through Cu (Z=29) and W(Z=74)

1) Compute the critical energy E_C for each material.
2) For each material and energy, where does the shower max occurs (in unit of X0)
   - Use the formula: $t_{max}= \ln(E/E_c) - t1$, t1=1 for e-, 0.5 for γ
3) Compute the 95% longitudinal containment (in unit of X0) in each case
4) Compute the Moliere Radius of each material.
5) Which material would you choose to build an EM calorimeter. Why ?

Exercise: DØ Calorimeter





	Z	X0 ($g.cm^{-2}$)	ρ ($g.cm^{-3}$)
U	92	6	19
LAr	18	19.6	1.4

		ηxφ
EM1	2 X0	0.1 x 0.1
EM2	2 X0	0.1 x 0.1
EM3	6.8 X0	0.05 x 0.05
EM4	9.8 X0	0.1 x 0.1

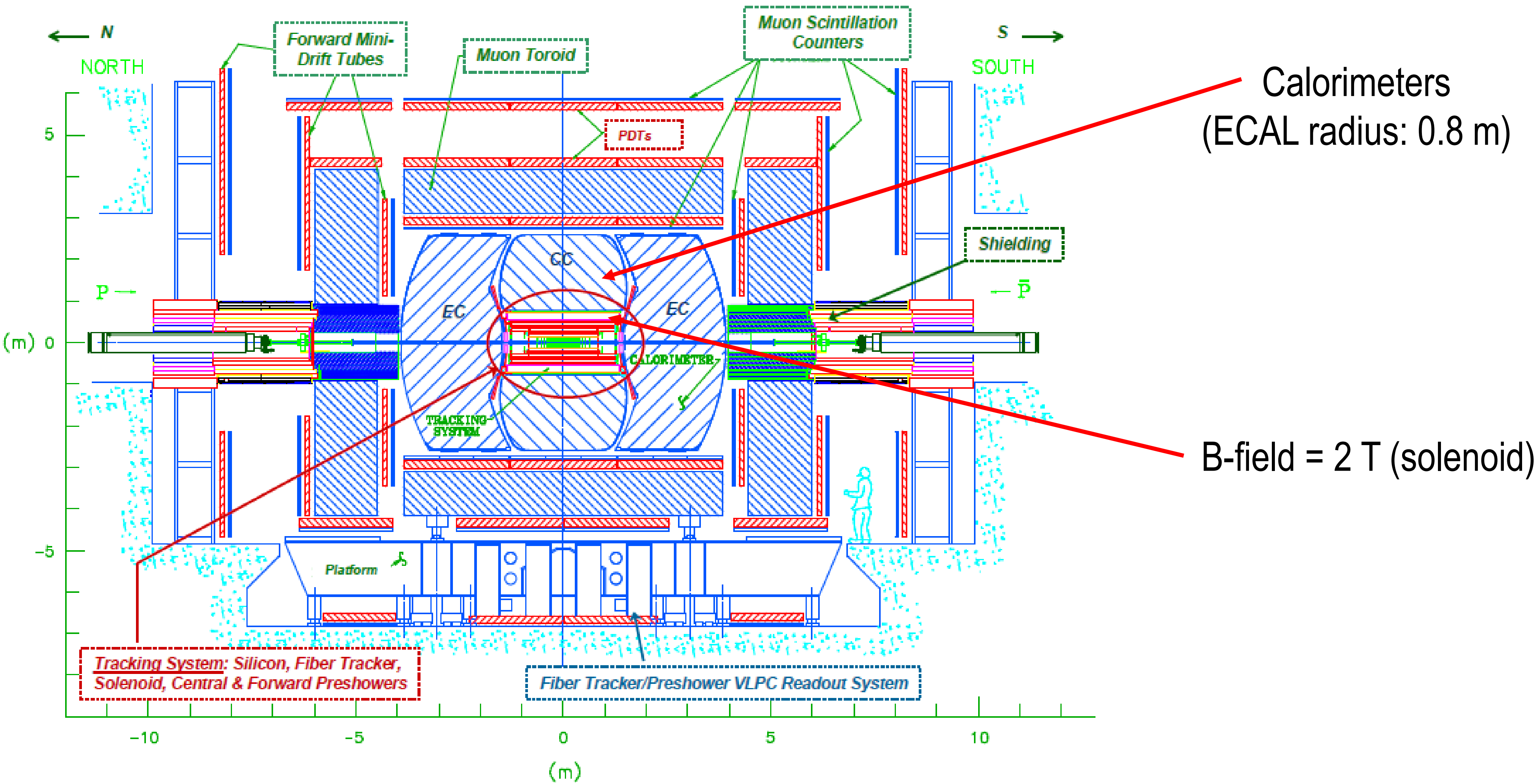
One cell of the U/LAr central EM calorimeter of DØ is made of a sandwich of 3mm U plate and 2x2.3mm LAr gap.

4) Compute the position of the shower max (in units of X0) for an electron with E=45 GeV (consider only Ur, Ec=65 MeV)

5) The EM part has four sections with different granularity and X0.
Comment wrt to the result on question 4.

6) During RunII, a magnet was added before the calorimeters as well as a pre-shower (Pb/scintillating fibers). What is the impact on the shower max ? What are the consequences on the calorimetric performance ? What is the role of the pre-shower ?

Particle Flow & DØ



Can you imagine a Particle Flow algorithm with this detector ? Why ?

BACK UP SLIDES