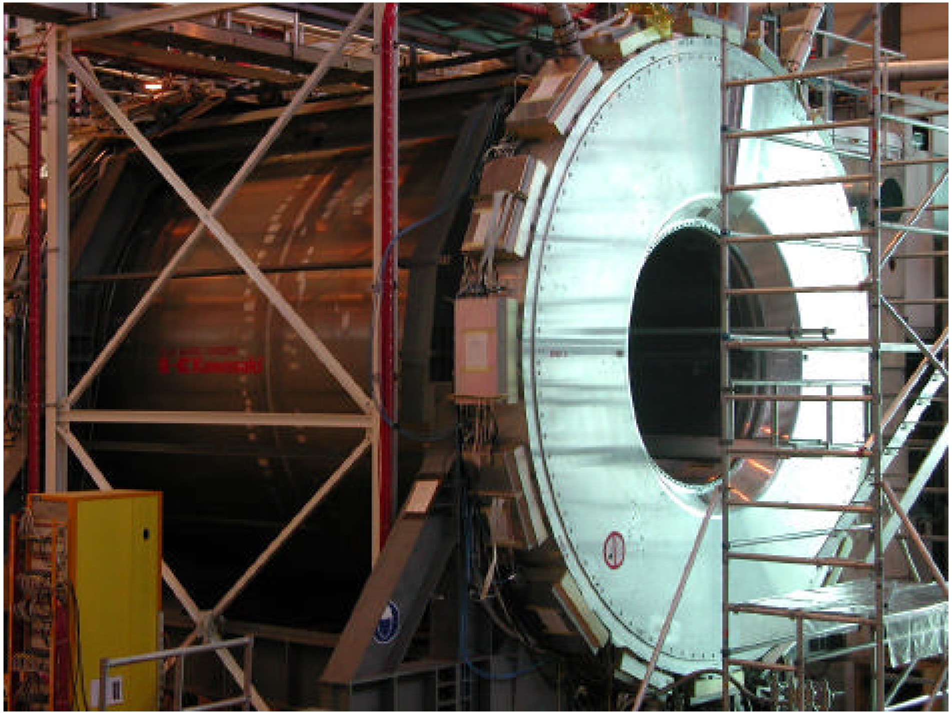
ATLAS Liquid Argon electromagnetic calorimeter

G.Sauvage (on behalf of the ATLAS LAr group)

Construction status and overview of beam test performances



EM barrel

inside its cryostat

Talk Outline

- Calorimeter physics requirements
- Brief calorimeter description
- Construction status
- Beam test performances

Calorimeters requirements

Primarily designed for Higgs physics with decays in $\gamma\gamma$ or 4 $e^{\pm}$
(mass range 114.4 GeV/c^2(LEPII limit) to $2m_Z$ ~ 180 GeV/c^2),
the calorimeter is expected to have :

- Good energy resolution for electron/photon $10\%/\sqrt{E} \oplus 0.7\ \%$

  → mechanics/electronics calibration…

- A linearity better than 0.1 %

  → presampler for dead material, electronics calibration

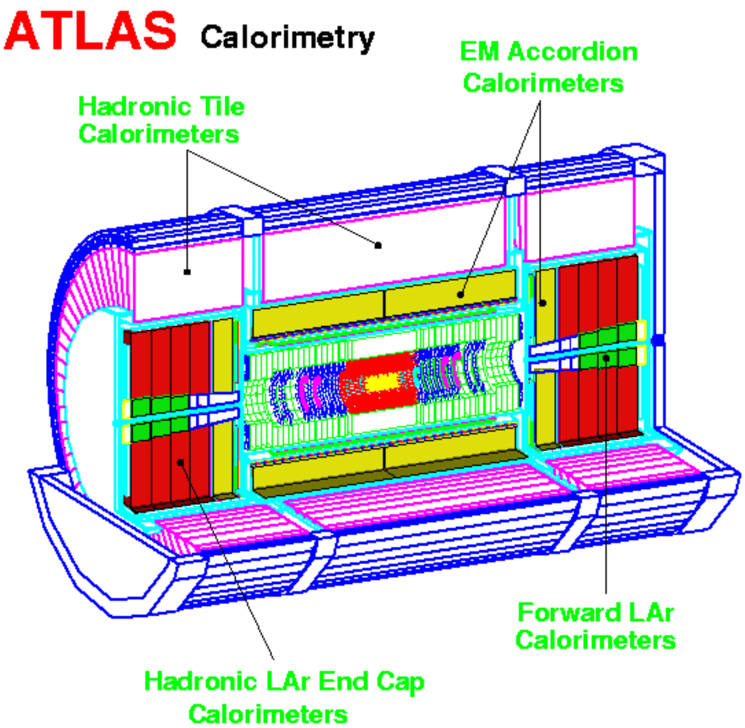
- Particle identification : $e^{\pm}$/jets , γ/π^0 (Rej.>3 at p_T=50 GeV/c)
- Angular measurements : 50 mrad/$\sqrt{E}$

  → lateral and longitudinal segmentation

- Time measurement : 100 ps constant term
- Large dynamic range : 20 MeV → 2TeV (Z’ up to a mass of 6 TeV)

  → electronics read out

Sketches of the calorimeters

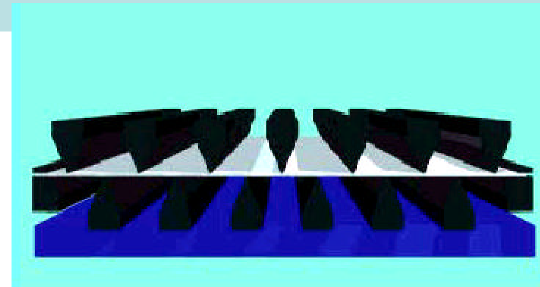


Lead/Liquid argon sampling calorimeter with accordion shape

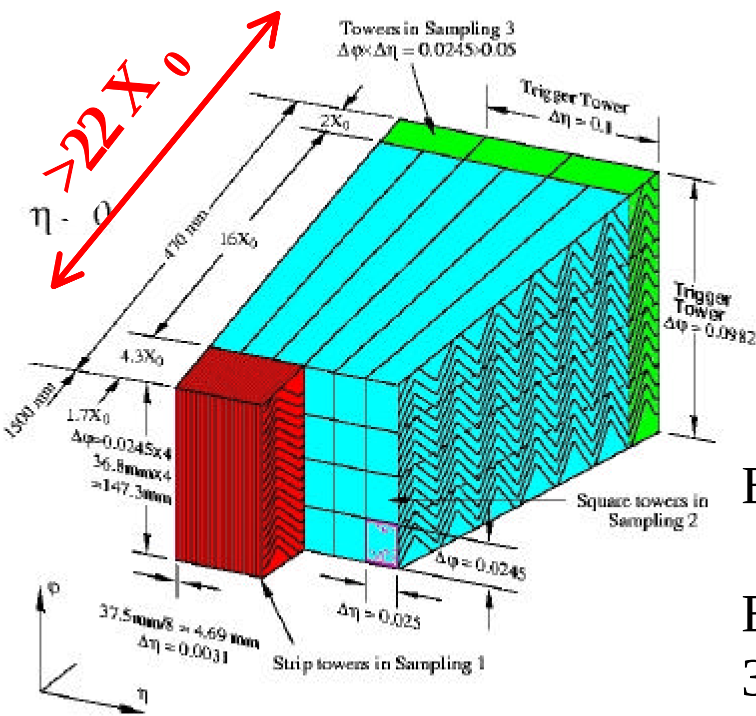
Barrel (0<|η|<1.475)
gap = 2.1mm @ 2000 V
lead 1.5 (1.1) mm for |η| < 0.8 (>0.8)

Endcap (3.2>|η|>1.375)
gap vary with radius : 3.1→0.9 mm
variable HV by steps

Accordion Liquid Argon calorimeter



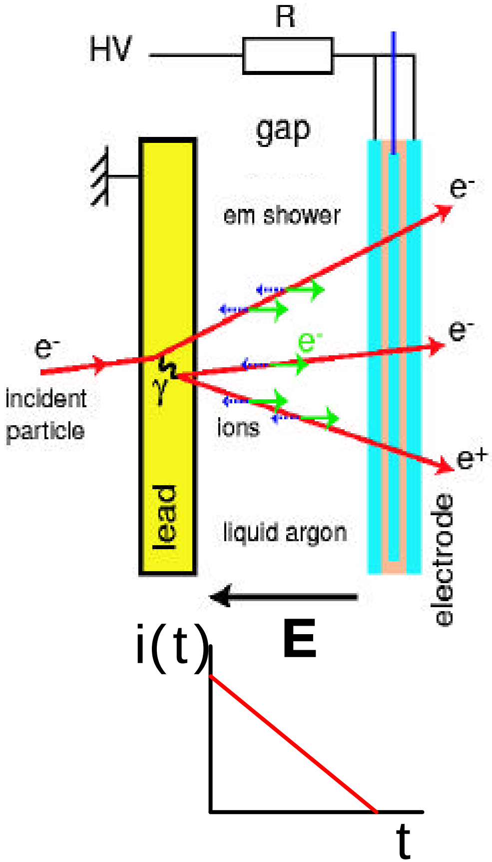
Lead/Liquid argon sampling calorimeter
with accordion shape :



- Full azimuthal coverage
- Rapidity coverage up to 3.2
- High granularity (>200000 channels)
- Longitudinal segmentation
- Presampler for η < 1.8
- radiation hard

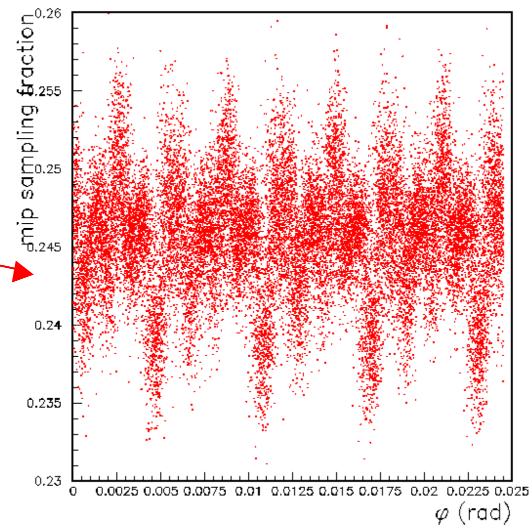
Barrel (0<|η|<1.475) : gap = 2.1mm @ 2000 V
lead 1.5 (1.1) mm for |η| < 0.8 (>0.8)
Endcap (3.2>|η|>1.375) : gap vary with radius
3.1→0.9 mm : variable HV by steps

Signal collection



Calorimeter signal sensitive to :

- Lead / argon thickness
  → local effect versus φ

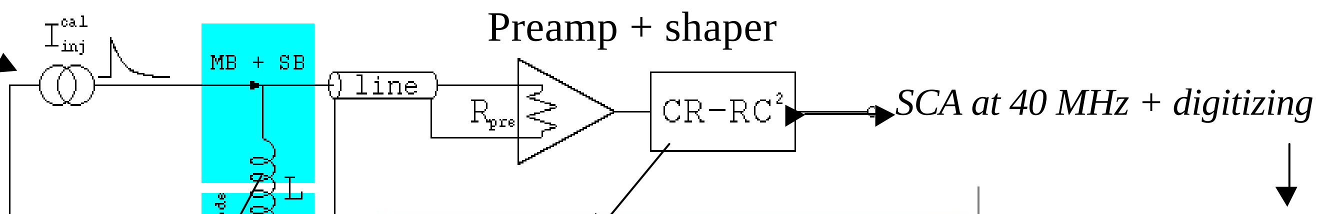


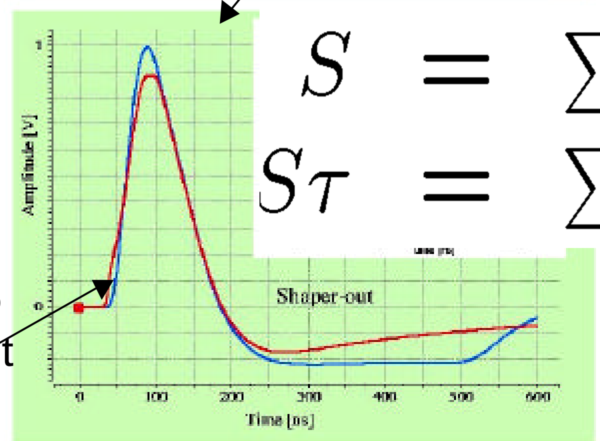
- High Voltage
  → Correction in endcap
- Temperature (-2%/c) : ~1° gradient + temperature probes
- Attachment : maintain pollution at ~0.1 ppm (purity monitors)
- Ion build up : negligible up to η = 2.5

Signal reconstruction

Calibration Signal : ~2 ‰

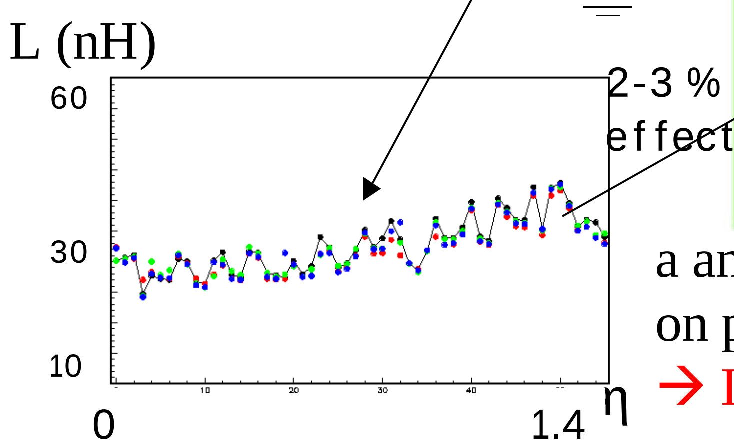
Physics signal





$$S = \sum_{i=1}^{5} a_i s_i$$

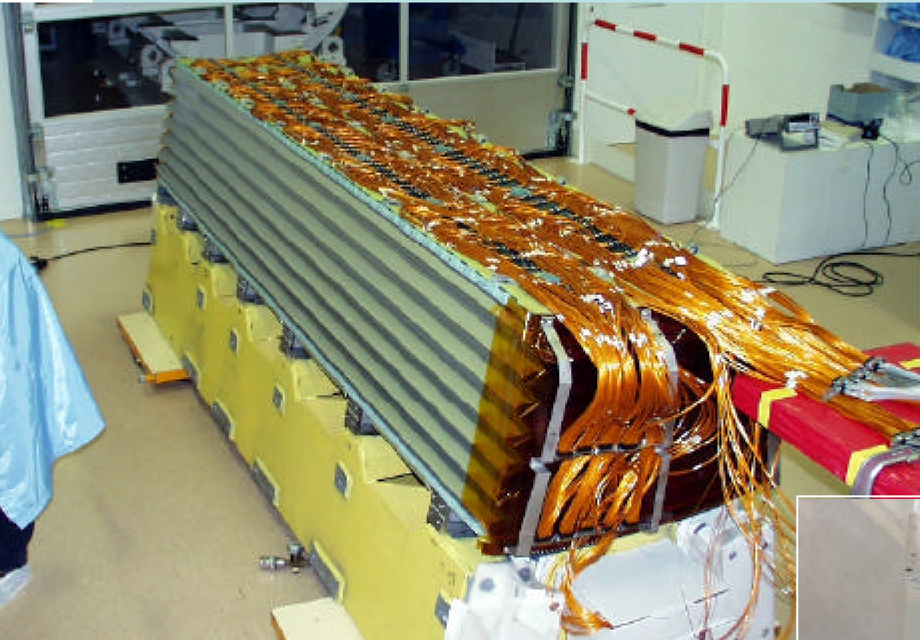
$$S\tau = \sum_{i=1}^{5} b_i s_i$$



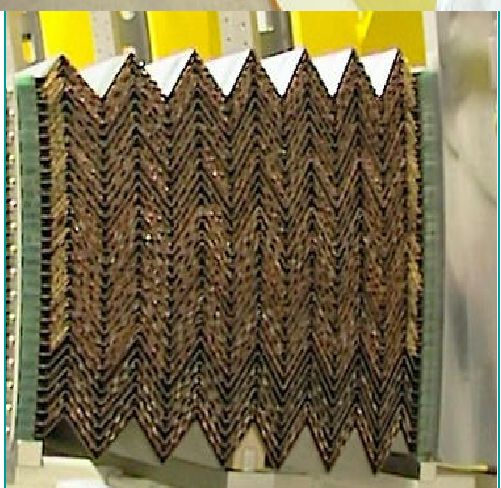
a and b coefficients strongly dependant on physics shape knowledge :

→ Intense activity over last year

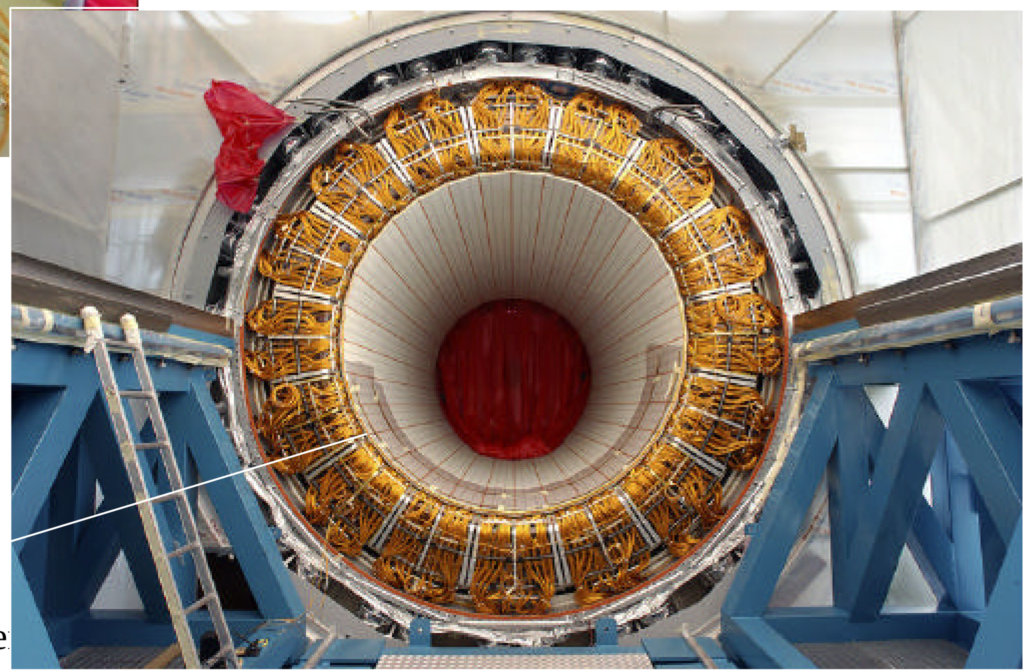
Barrel calorimeter



32 modules produced and tested at cold between 2001-2003
Assembly/insertion in cryostat end 2003



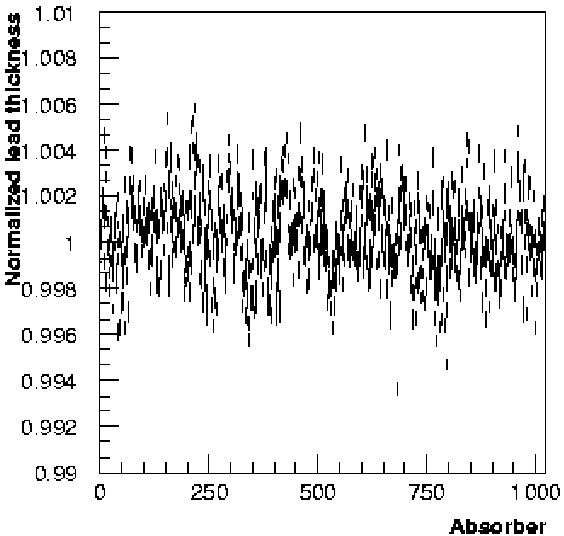
presampler

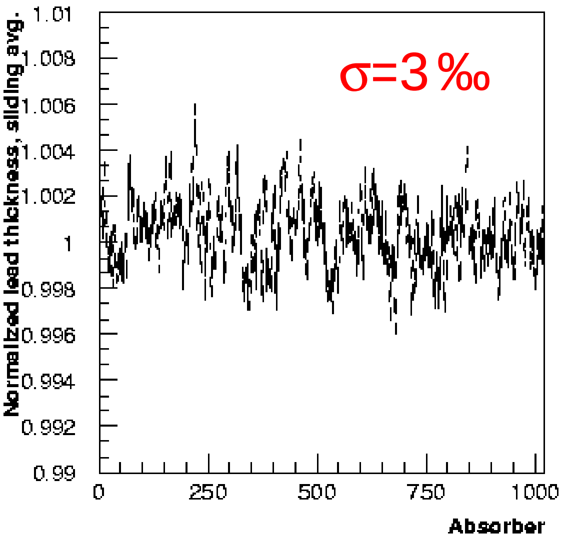


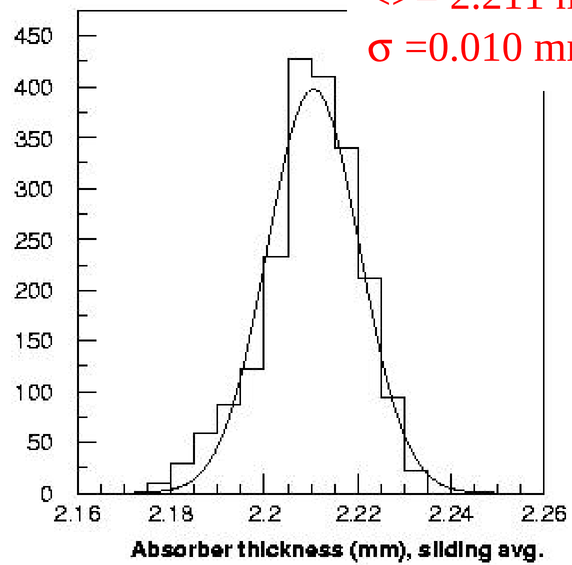
Quality control measurements

Lead thickness → averaged over 5 absorbers

Absorber thickness





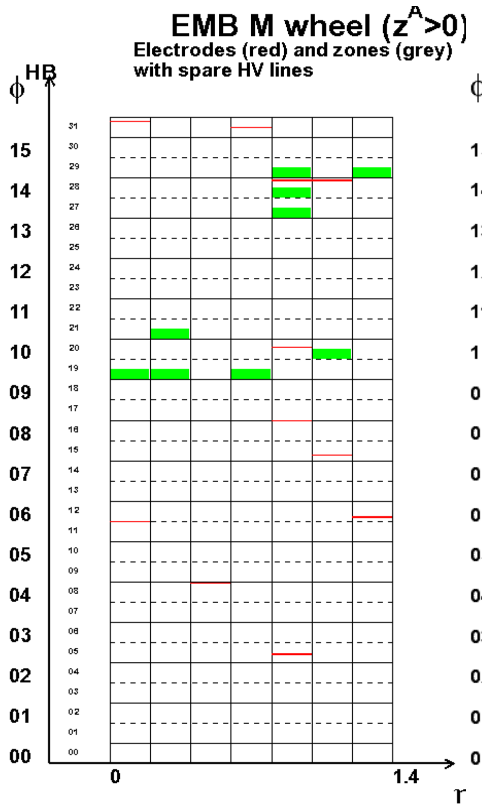


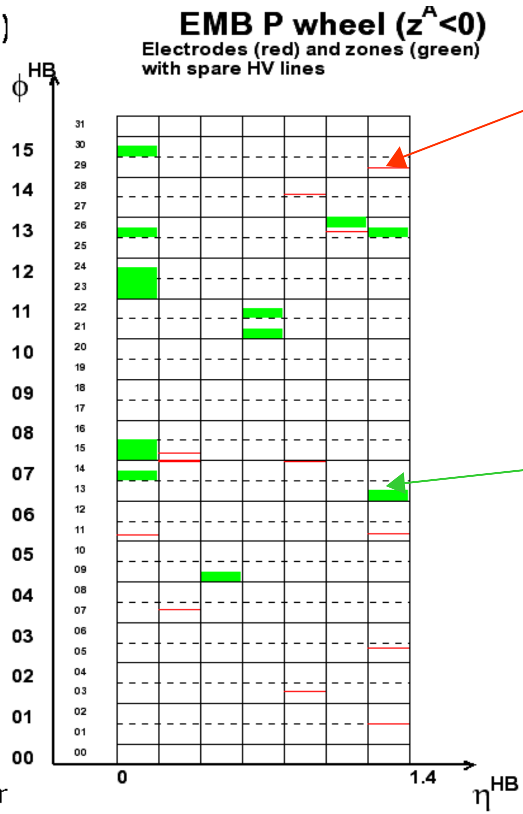
Energy sensitive to 0.6 x averaged thickness
→Contribution to calorimeter constant term
is 1.8 ‰

→induce gap variation
~1 ‰ on constant term

HV quality controls

Electrode is supplied on each side by different HV line in a sector of $\Delta\eta x \Delta\phi$ = 0.2 x 0.2 (32 electrodes)





Electrode with problems in a sector have been isolated on individual HV line :

23 / 28672 = 0.8 ‰

→small correction needed but no acceptance loss

In some sector problem occurred at cold and disappeared at warm

→Divide the HV sector in two separate HV lines

Never observed problems on both electrode side !

Electrical quality controls

All channels have been pulsed via calibration line and checked :

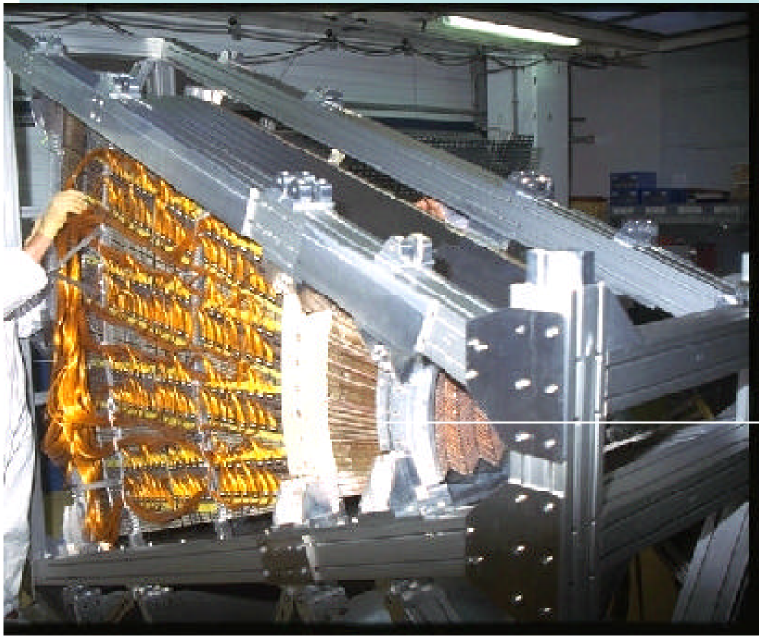
Barrel | 1st end cap

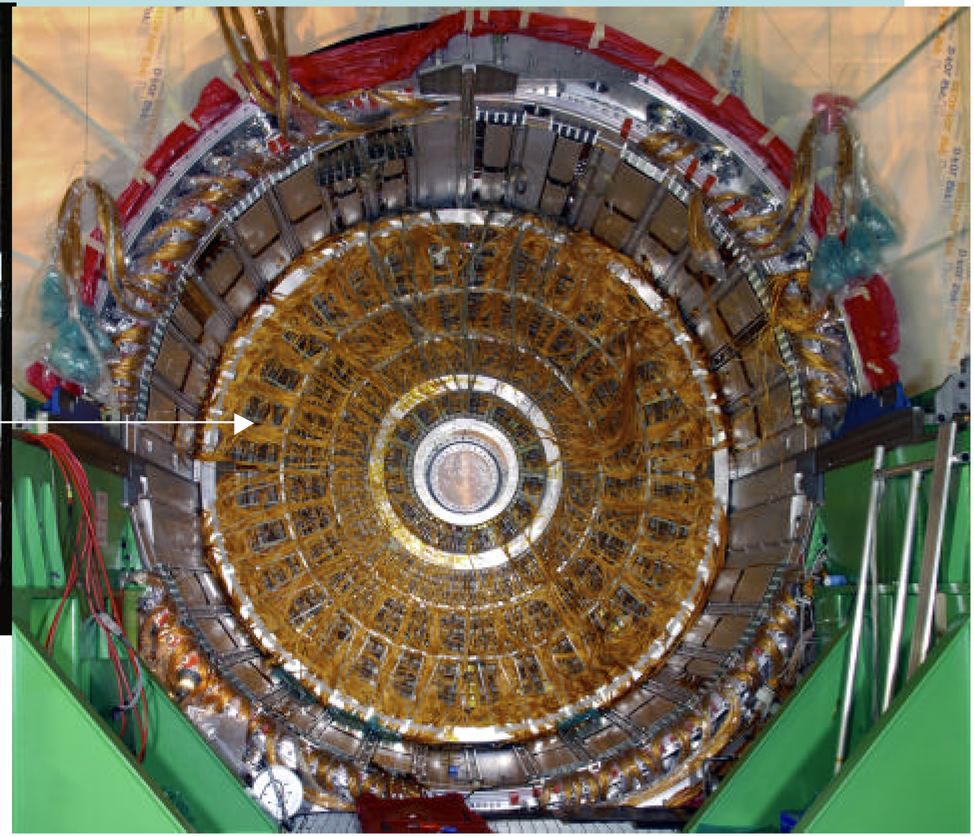
Layer/channels	Warm	criteria	Layer/channels	Warm	criteria
PS / 7808	0	< 4	PS / 768	0	< 1
Strips / 57344	9 = 0.15 ‰	< 64	Strips / 14272	2 = 0.14 ‰	< 17
Middle / 28672	2 = 0.07 ‰	< 14	Middle / 11712	1 = 0.08 ‰	< 7
Back / 13824	0	< 6	Back / 13824	0	< 4
Barrel End / 2048	3 = 1.4 ‰	< 2	Calib lines / 2976	0	< 3

Total number of dead channels < 0.14 ‰ !

Calibration injection resistors measured with ‰ accuracy
and network analyzer measurements to extract LC per cell

Endcap calorimeter





8 modules / wheel and 2 wheels
All modules produced and cold tested. One wheel inserted.

18 problems on spare HV lines : 1.5 ‰

Calorimeter beam tests

• Beam tests have been essential to finalize calorimeter design : results of barrel and endcap module 0 have led to modifications in Mother/Summing boards (cross-talk), electrode (missing ground return)…

• 4 barrel modules and 3 endcap modules have also been exposed to beam to validate production during 2001-2002 in H6 and H8 beam lines at CERN. Whole scan of each module has been performed + a few dedicated studies.

→ A lot of data, near finalizing the analysis (preliminary results here)

Beam test performances

Electron uniformity and energy resolution :

- Response uniformity : easy to reach ~1% (online) but quite a hard and long work to reach ultimate performance
- energy resolution
- Linearity response : new and detailed analysis on dead material correction + leakage

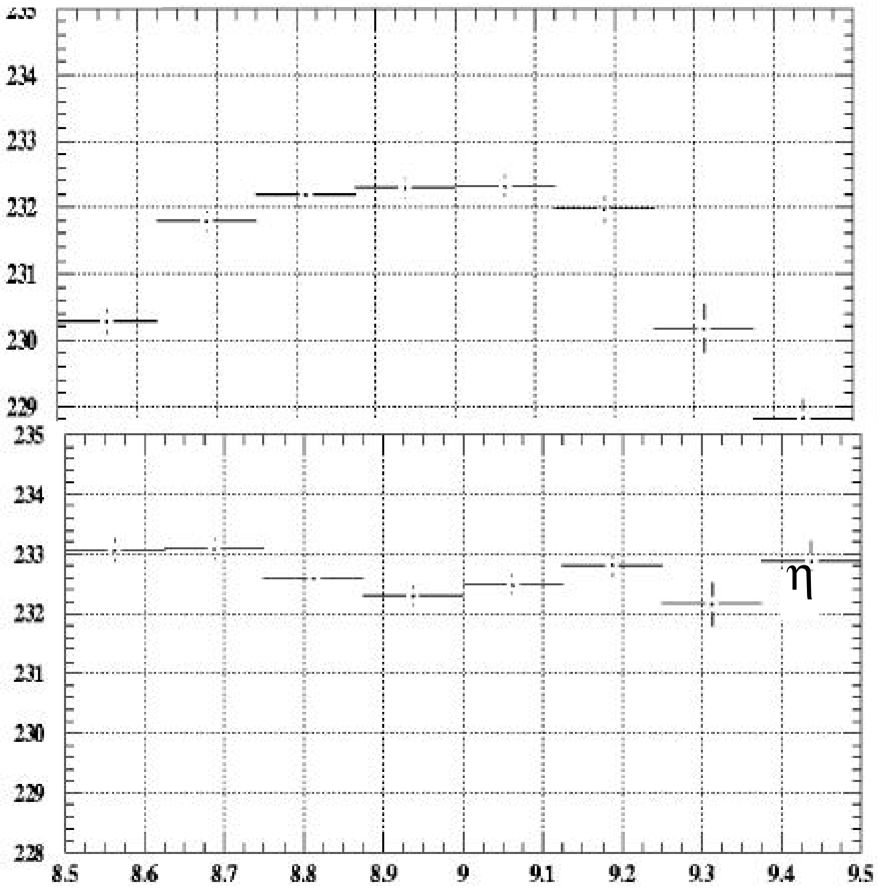
But also a lot of other studies :

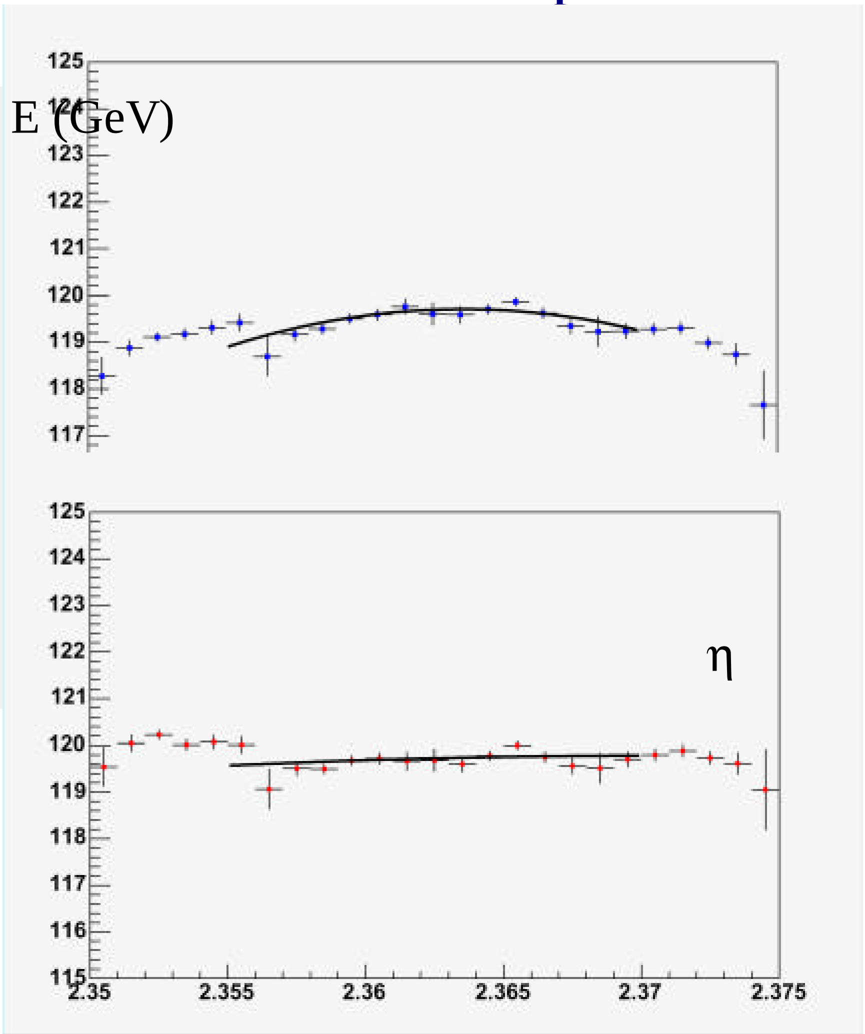
- Use of segmentation : Angular/position measurements + particle identification (γ/π^0, [e/π]…)
- [Time resolution]
- Learning for commissioning …

Corrections - Cluster effect (3X3)

- Barrel
- End-cap

E (GeV)

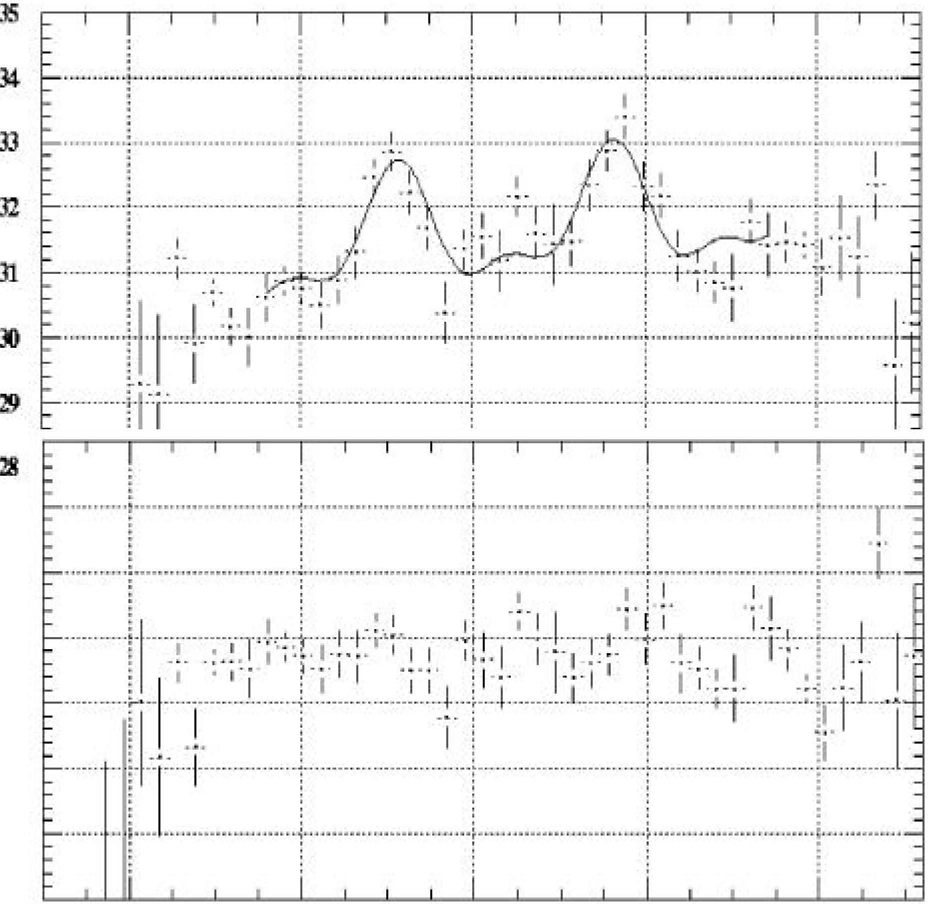




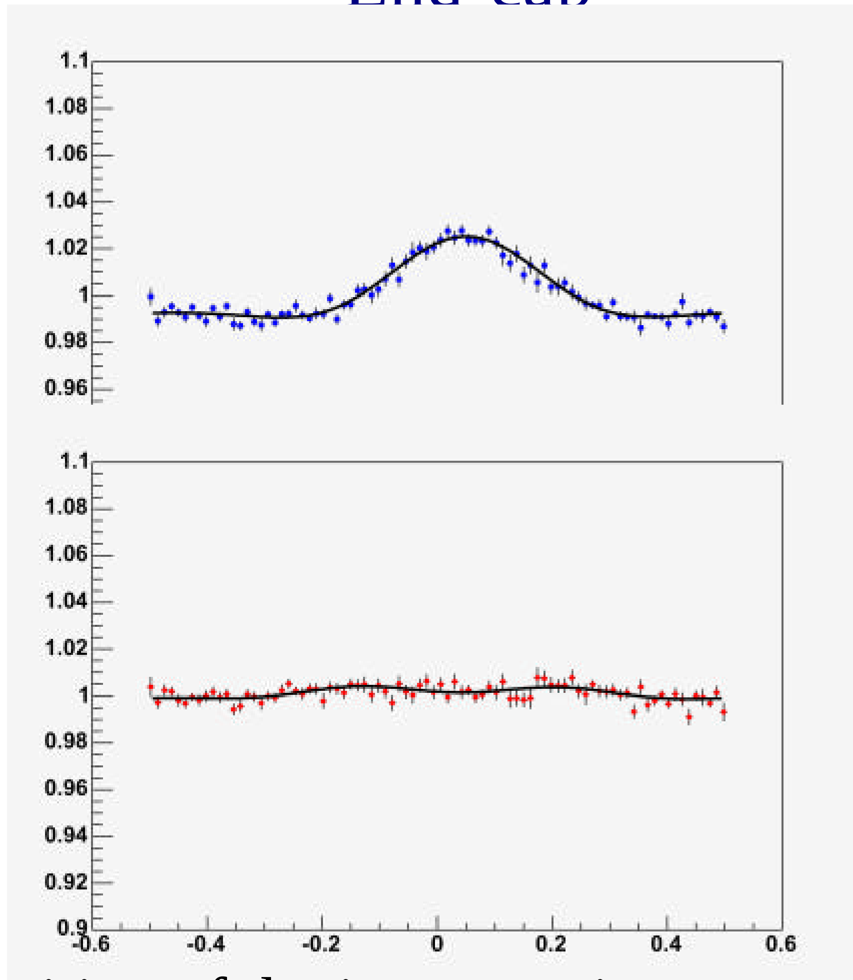
➾ η modulation corrected by a 2[d] order polynomial

Corrections - Accordion φ modulations

- Barrel



- End-cap



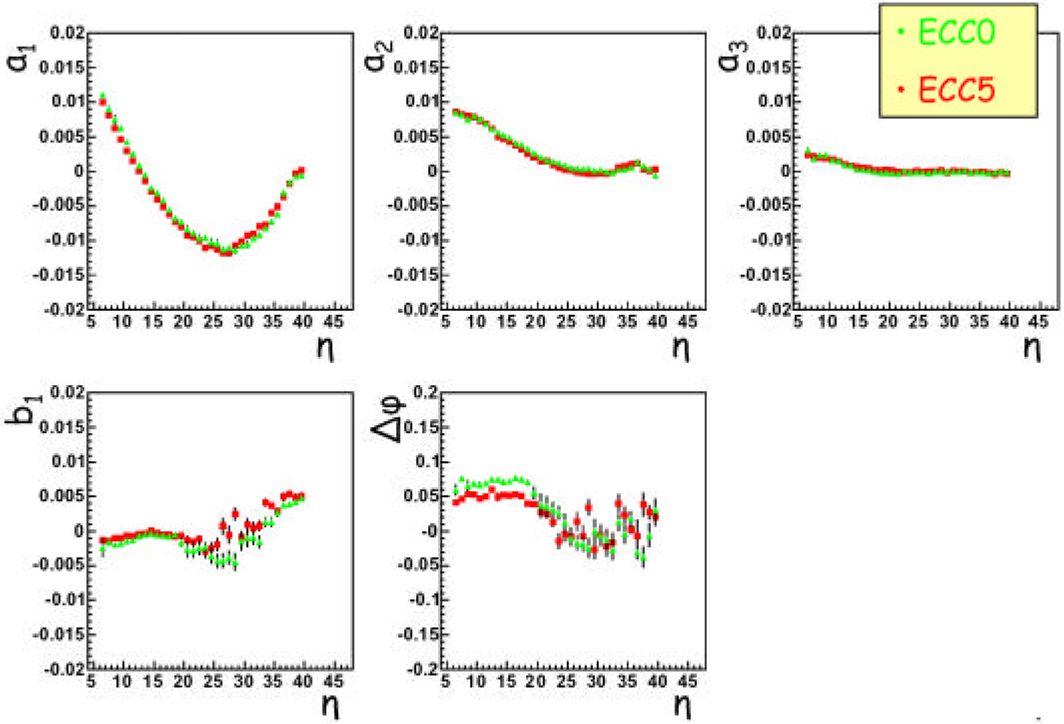
➩ Lead thickness varying wrt φ position of the impact point

➩ φ modulation corrected by a Fourier like sum (assumed to be odd for the barrel)

Reproducibility of the corrections

Function used for fitting φ modulations in the end-caps :

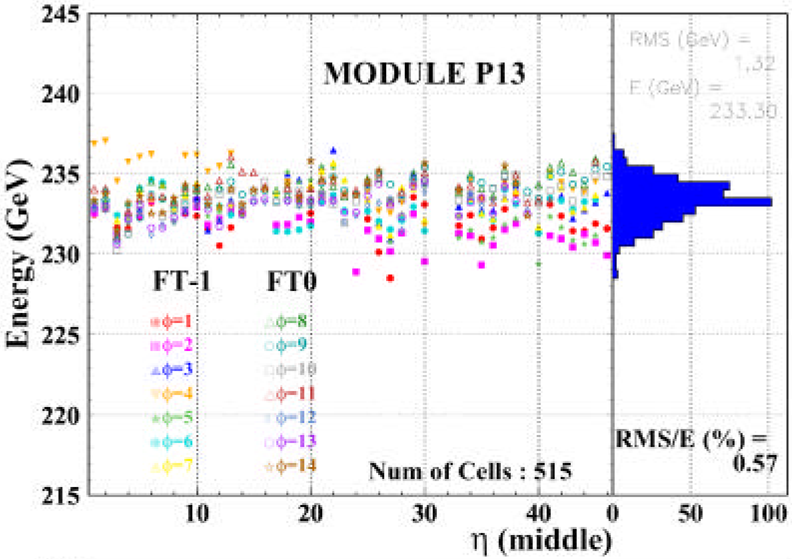
$$a_0\left(1+\sum_{i=1}^{3} a_i \cos(2i\pi(\varphi_{abs}-\Delta\varphi))+b_1 \sin(2\pi\varphi_{abs})\right)$$

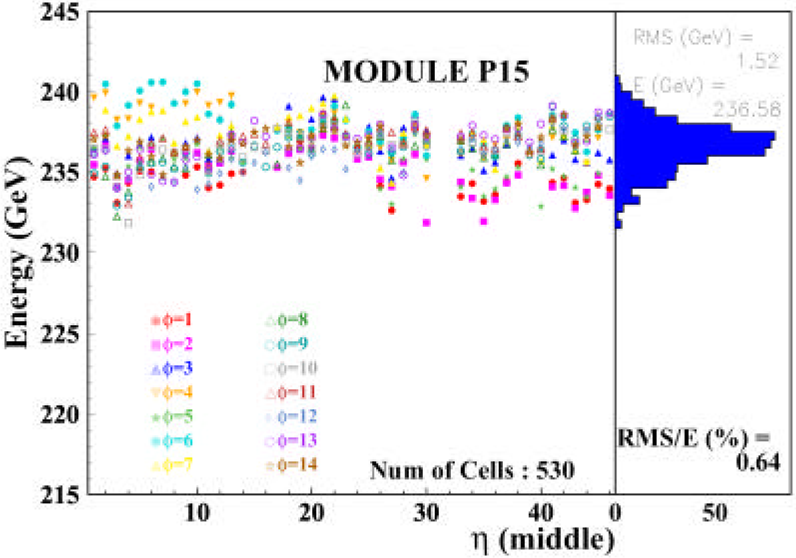


✓Good agreement between modules

✓Expected behaviour

Global uniformity for the barrel



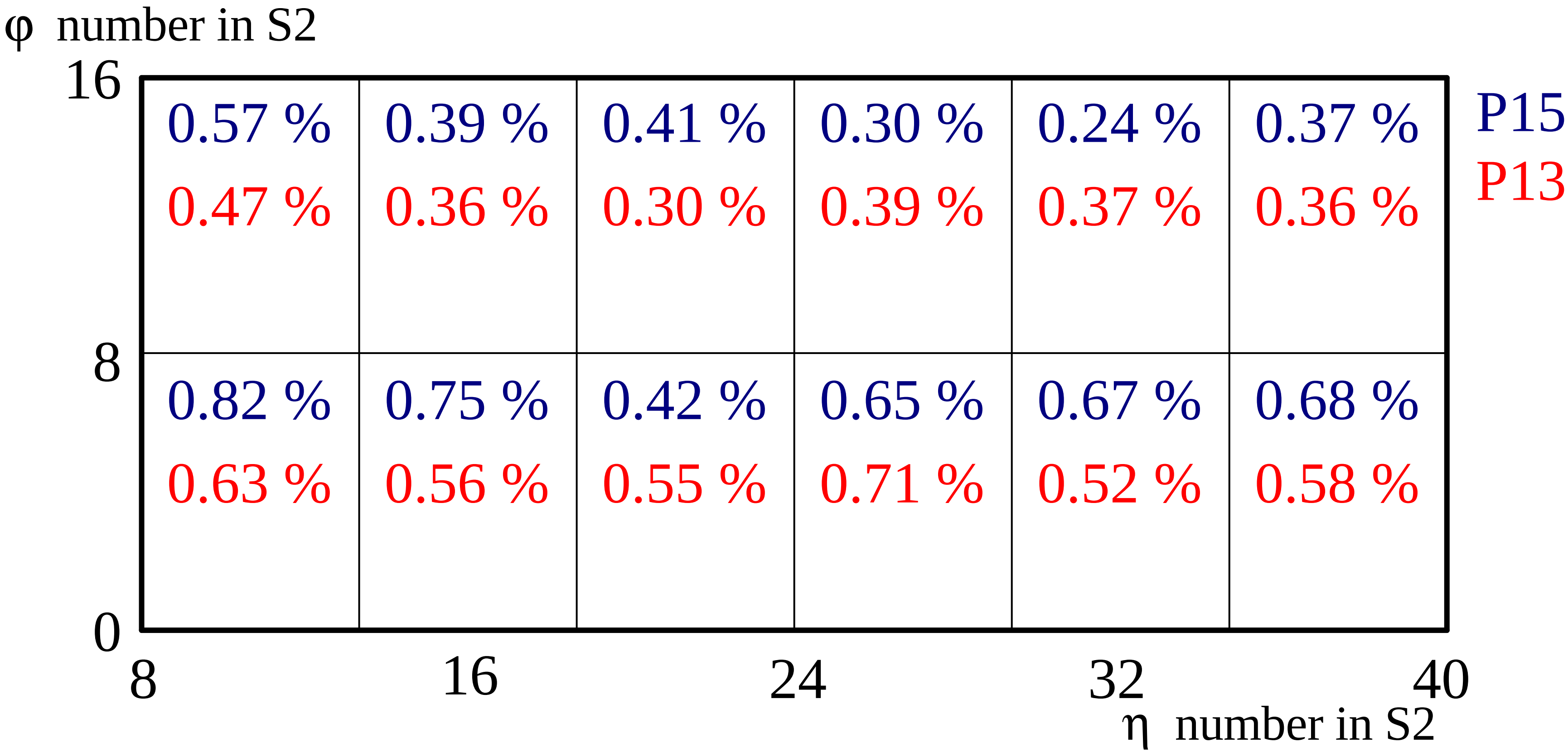


	<E>	RMS	RMS/<E>
P13	233.3 GeV	1.32 GeV	0.57 %
P15	236.6 GeV	1.52 GeV	0.64 %

Good uniformity for both modules

Difference in the mean energy due to the **difference of temperature** of the argon for each module : ≈ 2%/°K

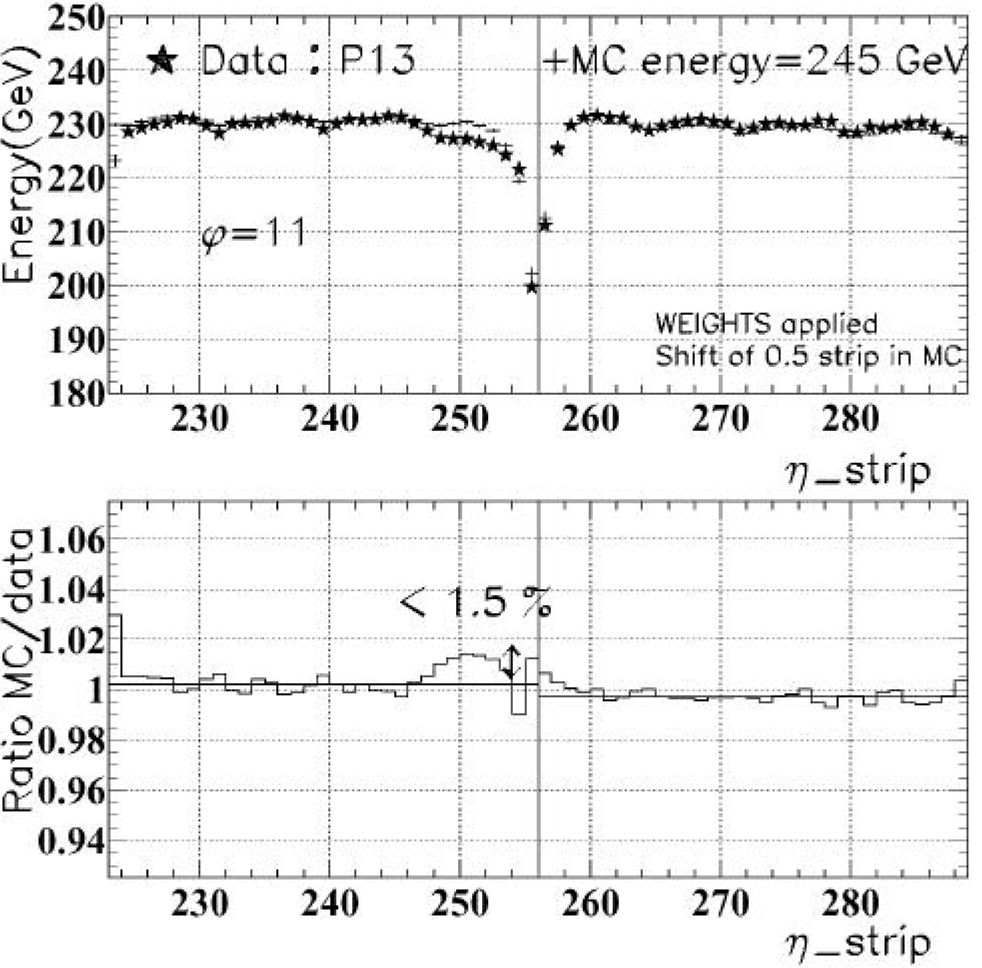
Uniformity for the barrel (ΔηxΔφ = 0.2x0.2)



Meet the requirements : < 0.50 %

Peculiar corrections for barrel

- η=0.8 crack study



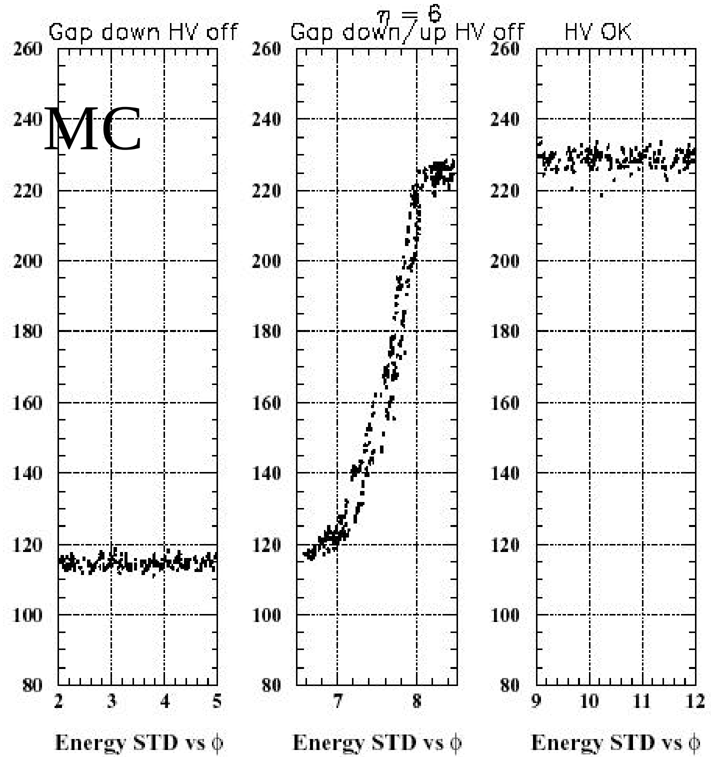
➯The electrode change at η=0.8

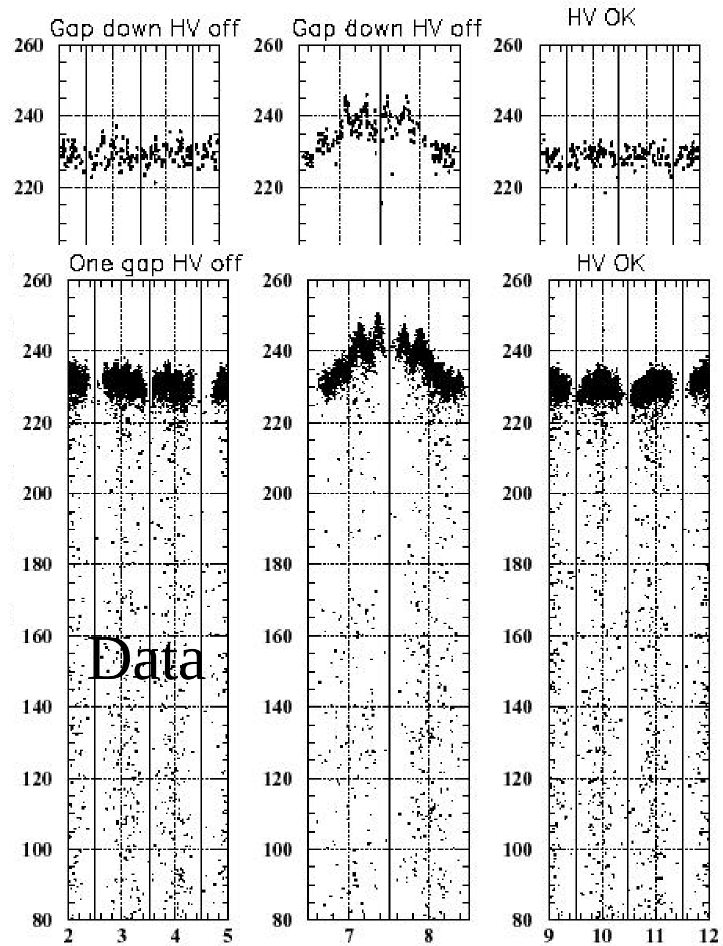
➯Lack of energy (≈30 GeV for 245 GeV electrons)

➯Now well described (and understood) in the MC description of the calorimeter

Peculiar corrections for barrel (3/3)

- HV problem – no HV on one side of the electrodes





Energy x 2 (before clustering)
where HV is missing

Data : After correction $E_{9-12}/E_{2-5} = 0.9974 \pm 0.0003$

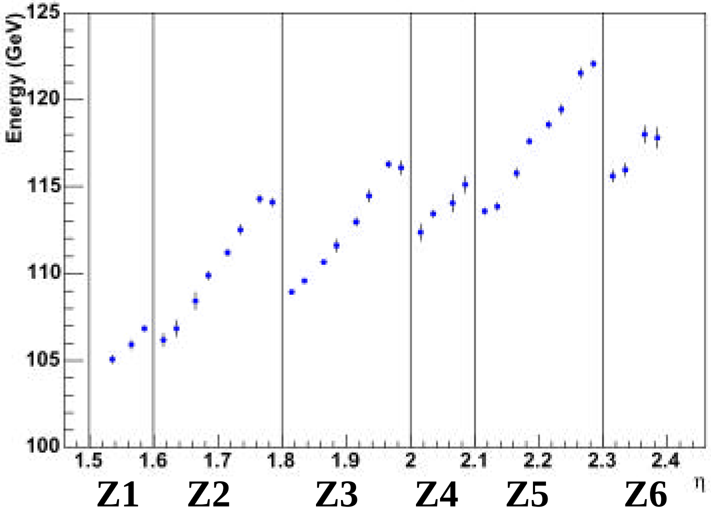
Peculiar corrections for end-caps

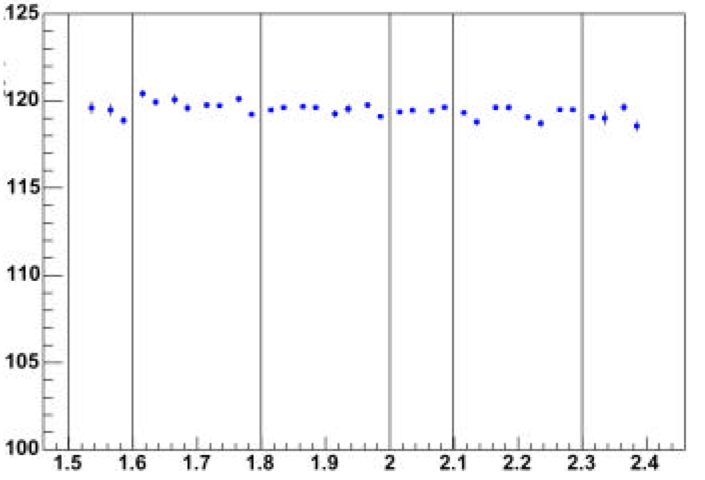
•HV corrections

• 6 HV sectors ⇒ Electric field differs from a sector to an other (to compensate variation of the thickness of the gap)

⇨ 1st step : make the fit for each φ line

⇨ 2d step : make the average over φ for each HV zone





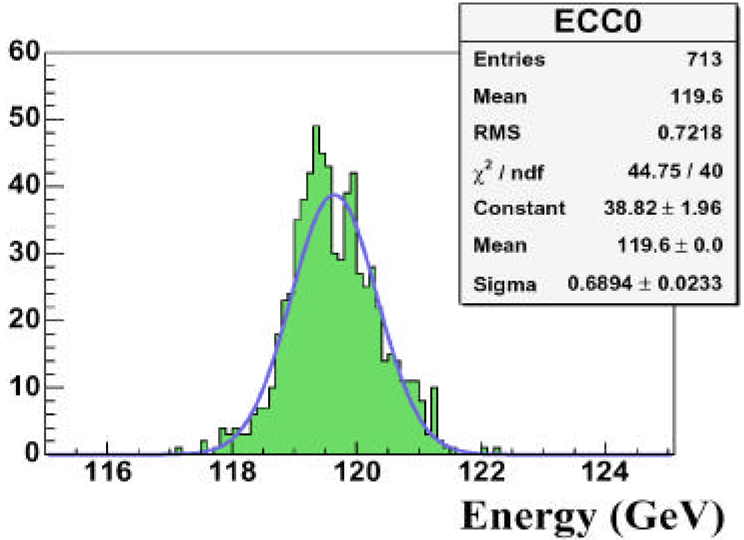
• Function fitted : $E = \beta E/(1+\alpha(\eta-\eta_c))$

• Good correlation between modules

- Þ **Can use average values**

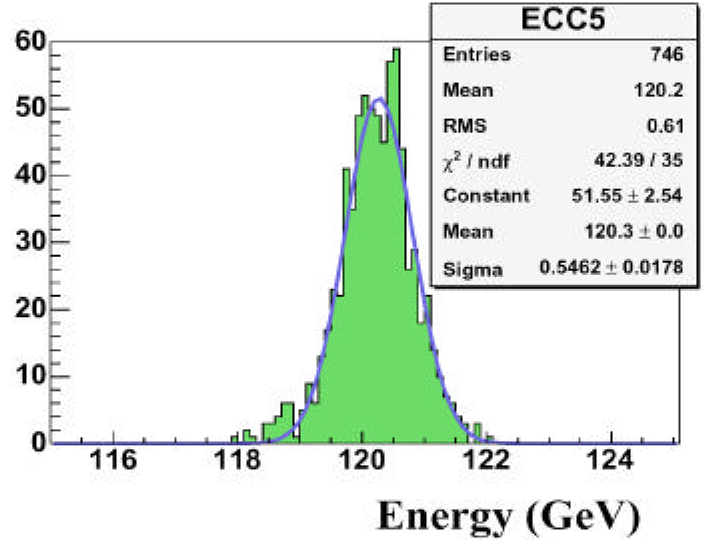
Global uniformity for the end-caps

ECC0



0.58% on 713 cells

ECC5



0.45% on 746 cells

	<E>	RMS	RMS/<E>
ECC0	119.6 GeV	0.72 GeV	0.60 %
ECC5	120.2 GEV	0.61 GeV	0.51 %

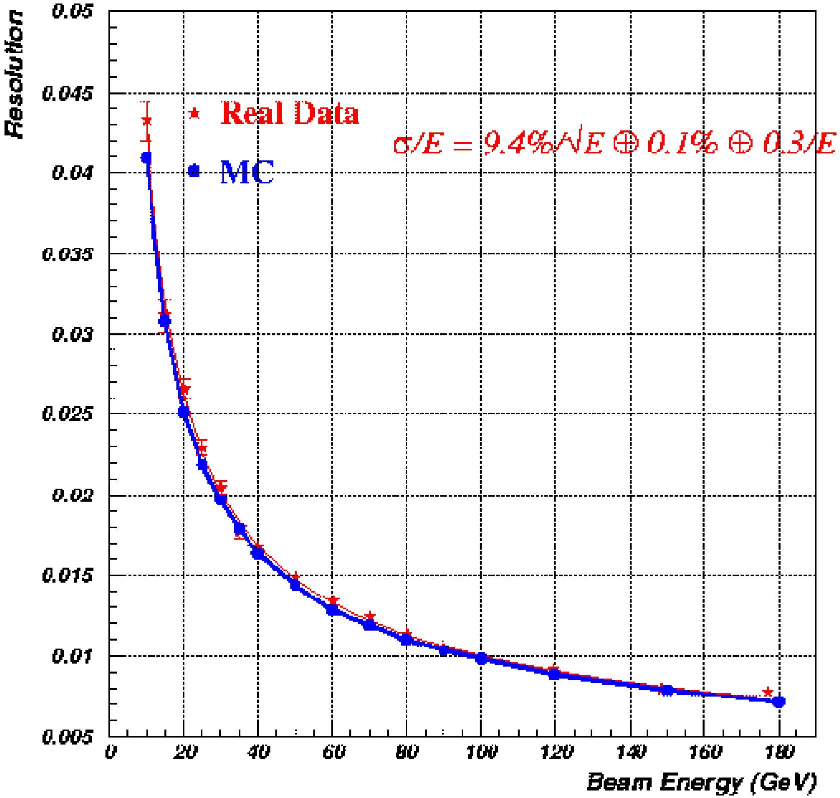
Uniformity for the end-caps
($\Delta\eta x \Delta\varphi$ = 0.2x0.4)

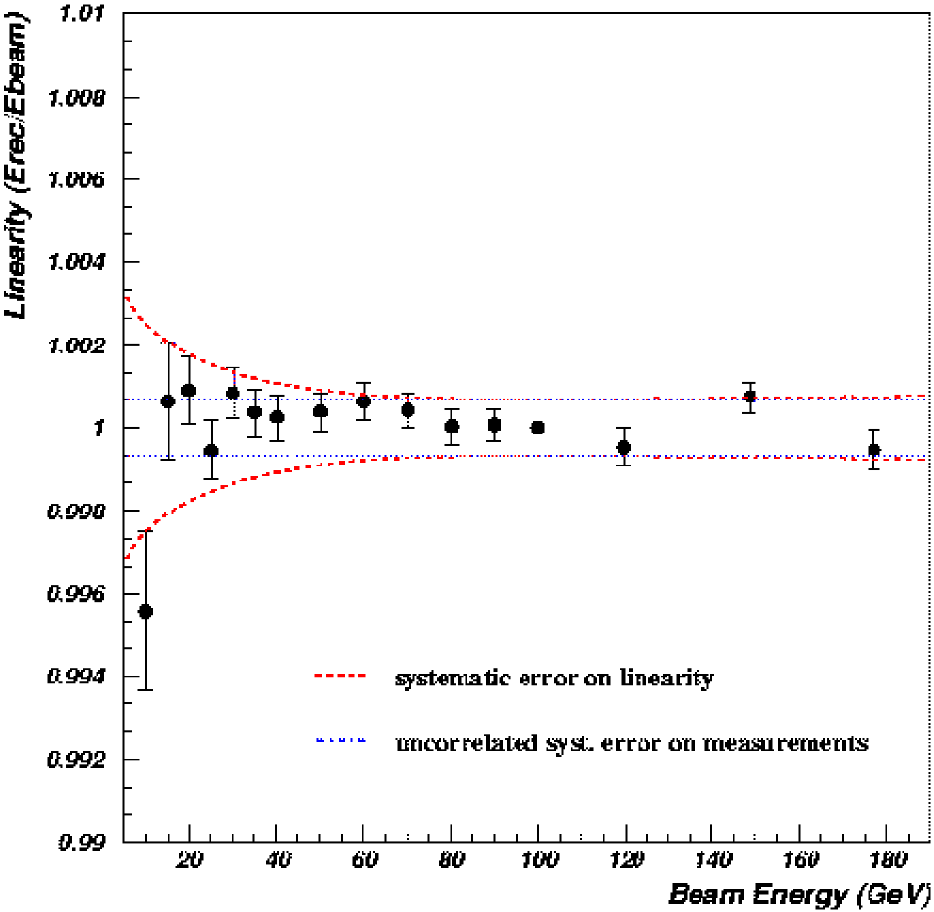
φ number in S2 \ η number in S2	8–16	16–24	24–32	32–40
16–32	ECC0: 0.56 % ECC5: 0.59 %	ECC0: 0.50 % ECC5: 0.42 %	ECC0: 0.49 % ECC5: 0.43 %	ECC0: 0.70 % ECC5: 0.77 %
0–16	ECC0: 0.42 % ECC5: 0.40 %	ECC0: 0.47 % ECC5: 0.35 %	ECC0: 0.40 % ECC5: 0.32 %	ECC0: 0.71% ECC5: 0.56 %

ECC0
ECC5

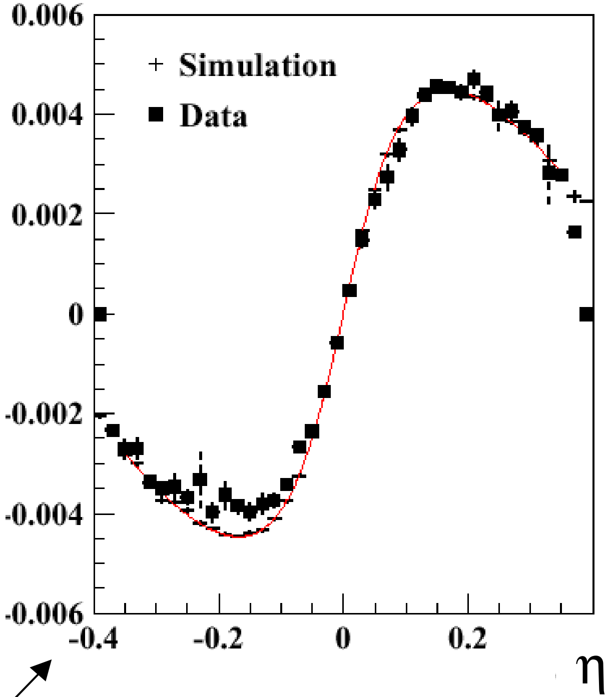
Meet the requirements : < 0.60 %

Energy resolution and linearity (barrel)



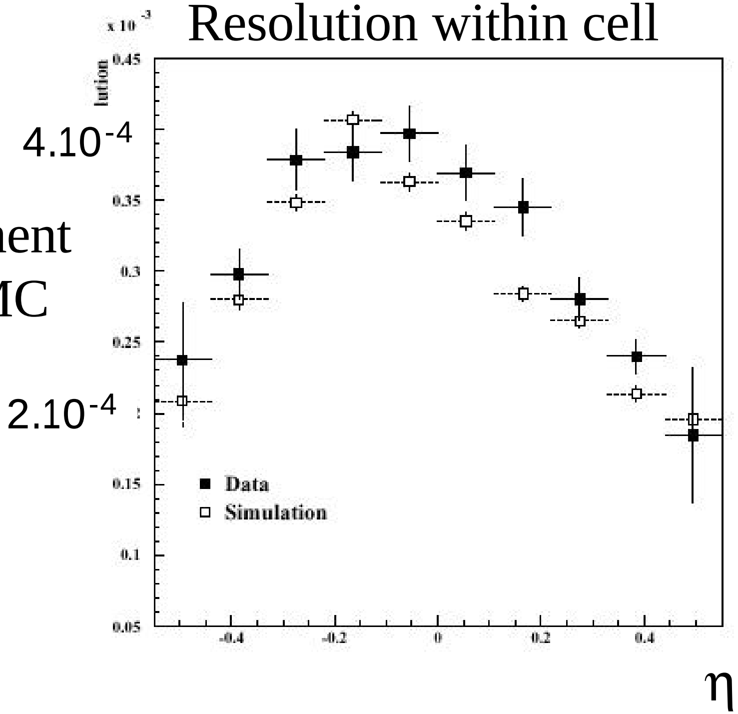


Position measurements (1)



Agreement data/MC

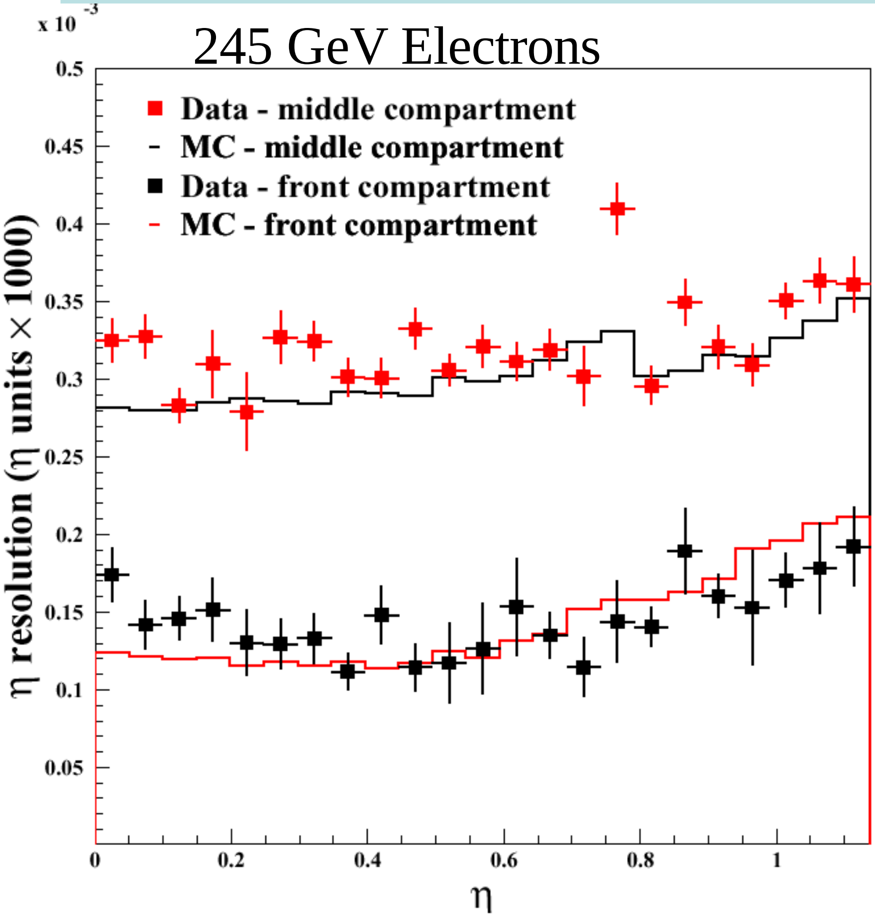
Resolution within cell



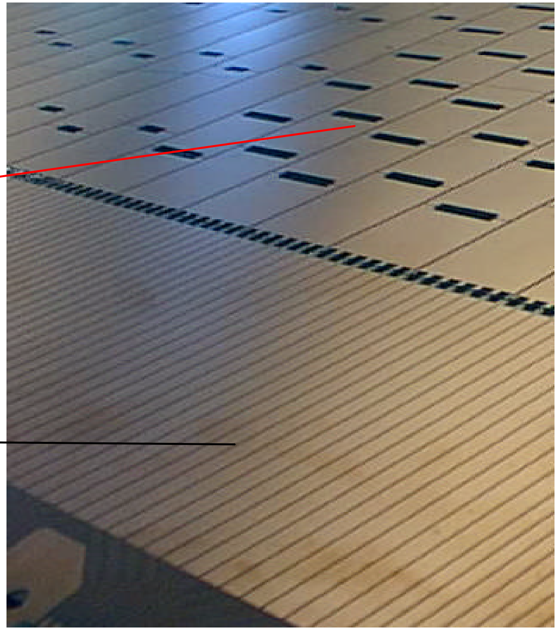
Linear energy weightings + S shape correction in middle

Log method for strips section used instead of S shape correction

Position measurements (2)



~550 µm at η=0

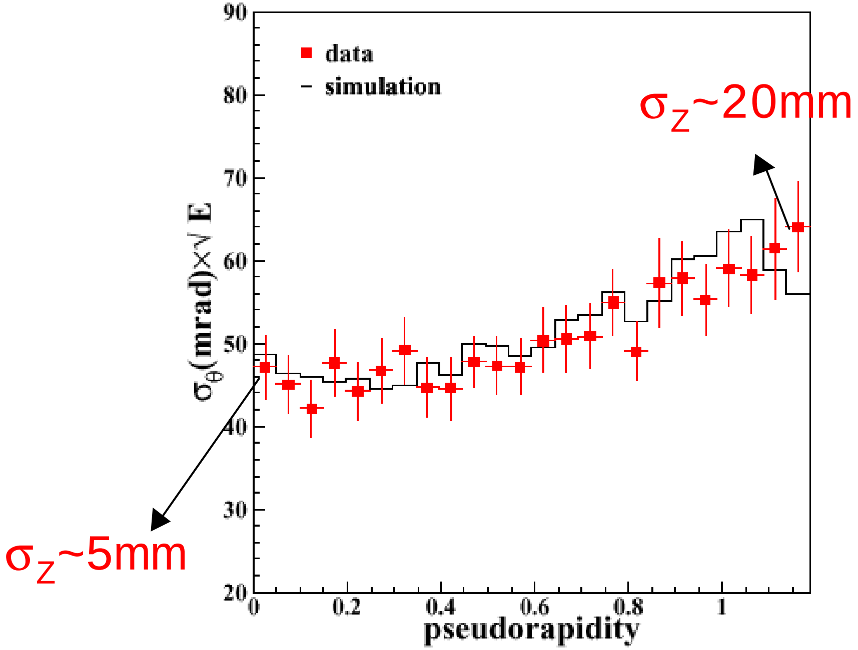


~250 µm at η=0

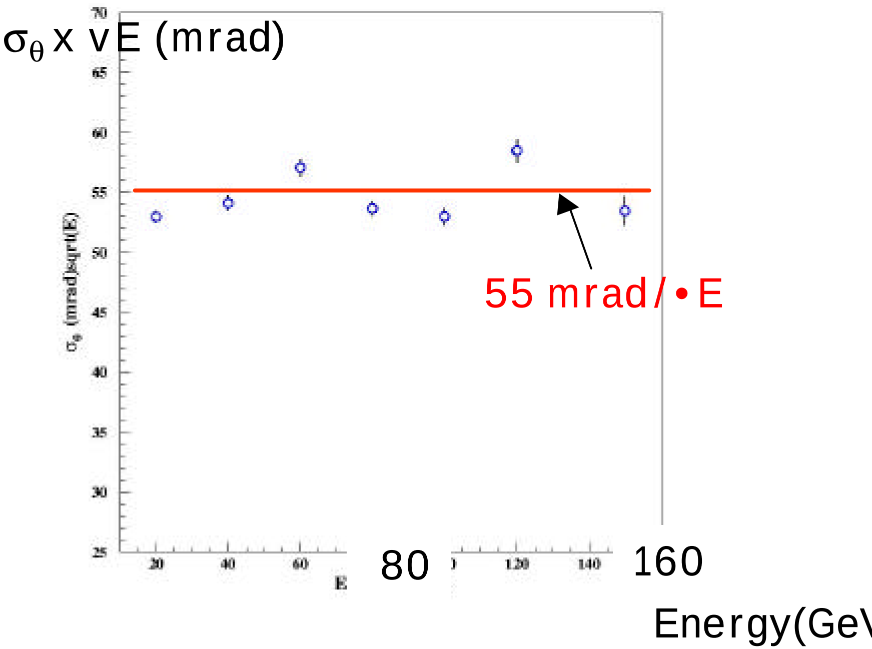
Similar level of performance in endcap

Angular measurement

Barrel E=245 GeV



Endcap η~1.8



LHC interaction point : σ_Z~56mm

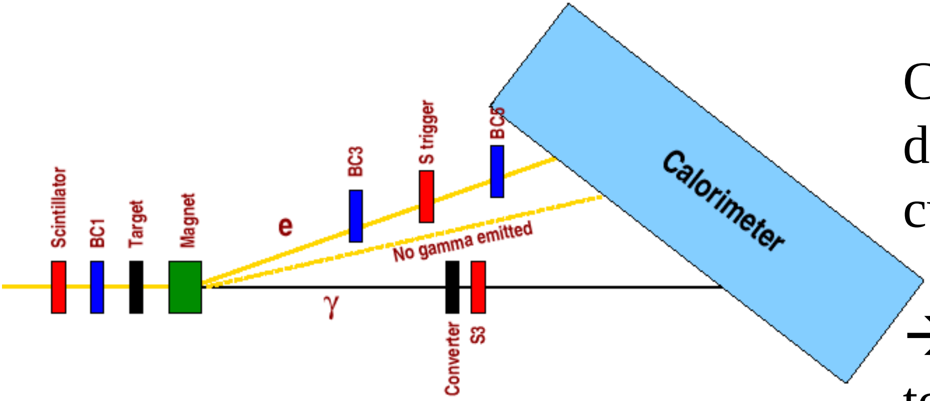
H→ γγ vertex reconstructed with 2-3 cm accuracy in ATLAS

γ/π^0 rejection (1)

Reducible background to H→γγ is faked photon from jet-jet (γ-jet) events with a typical rate larger by 10^6 (10^3) :

- Strip section depth has been designed to reject jets with leading π^0, needs R~3 at 50 GeV transverse energy with 90 % efficiency for photons

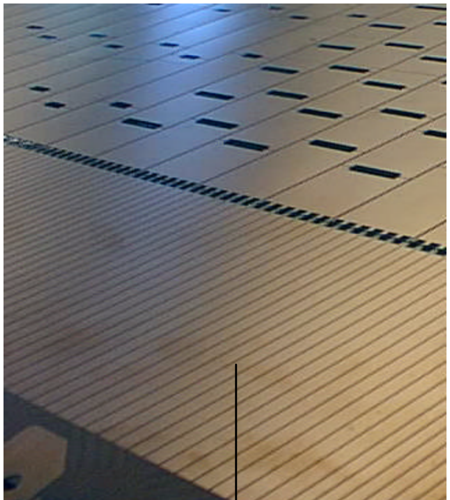
→ Dedicated setup to produce photon in H8 beam line



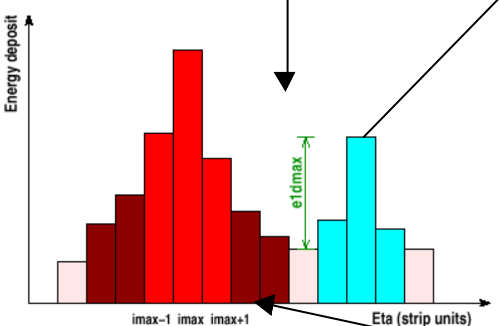
Covers 5-70 GeV spectrum with different beam energy and magnet current

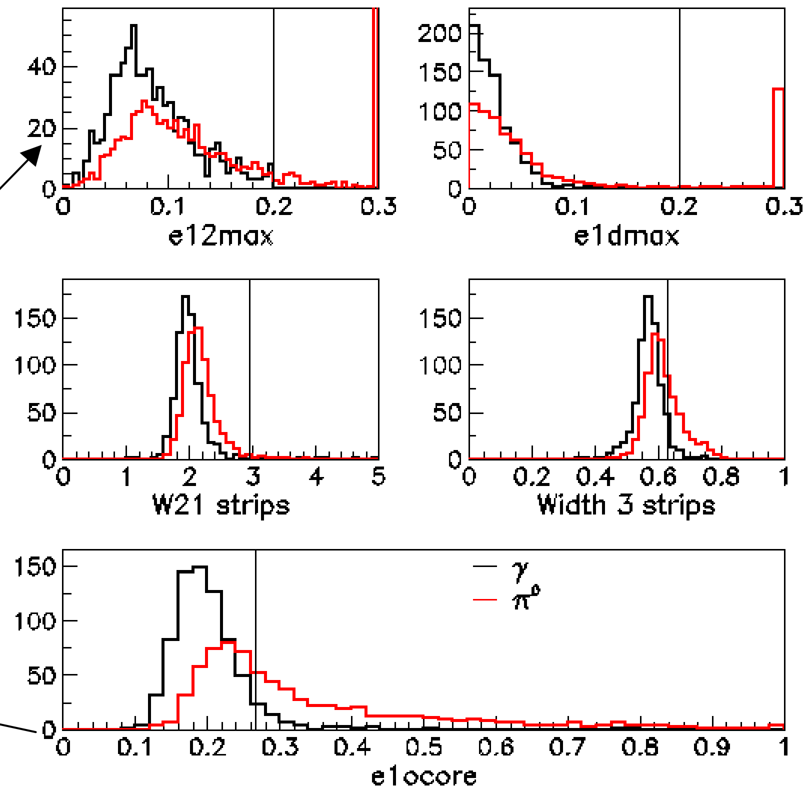
→Superimpose photon showers to simulate π^0 with 50 GeV p_t

γ/π^0 rejection (2)



Discriminating variables strongly based on fine strip first layer :



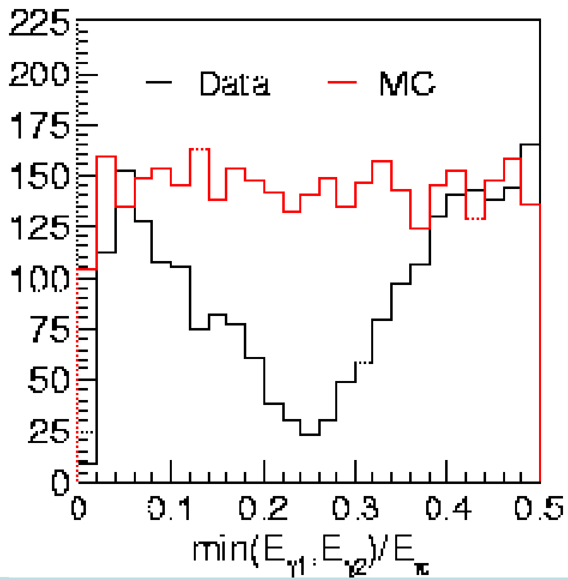


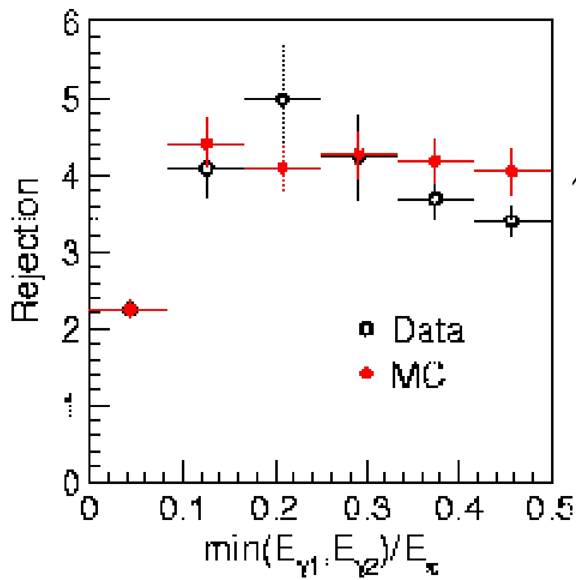
ε= 90 % for 50 GeV photons

γ/π^0 rejection (3)

Data spectrum not flat due
to beam energy/B field used

ε_γ = 90 %





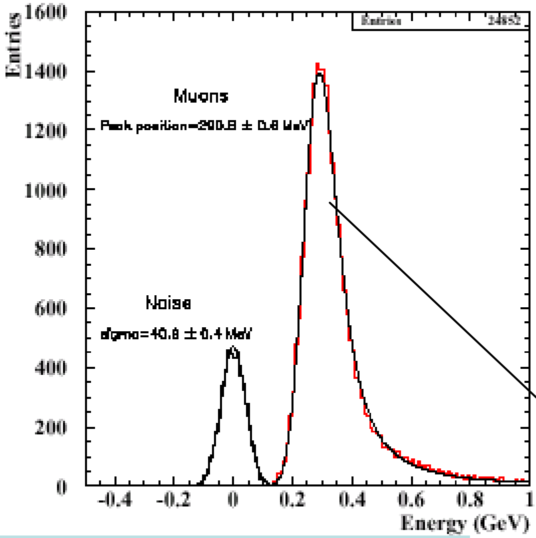
Symmetrical
π^0 decay

R (data) = 3.54 ± 0.12 (stat)
R (MC) = 3.66 ± 0.10 (stat)

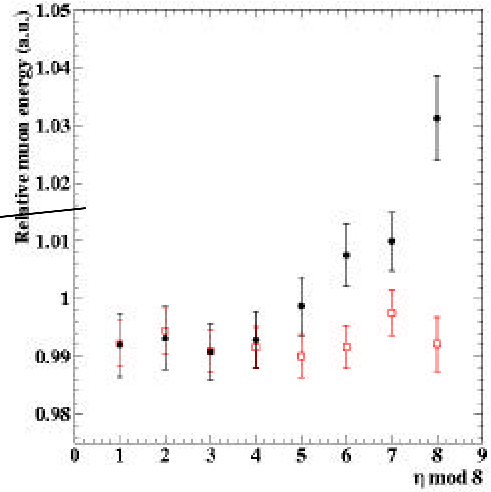
← ~84 % single photon
← +0.23 on direct π^0

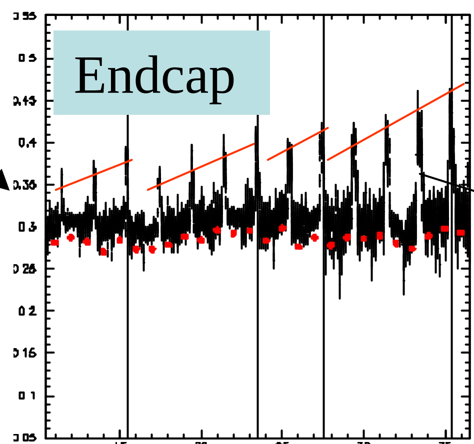
μ performances

μ signal large enough to be a powerful tool :



Was used to detect a missing ground return on electrode Module 0 every 8 channels



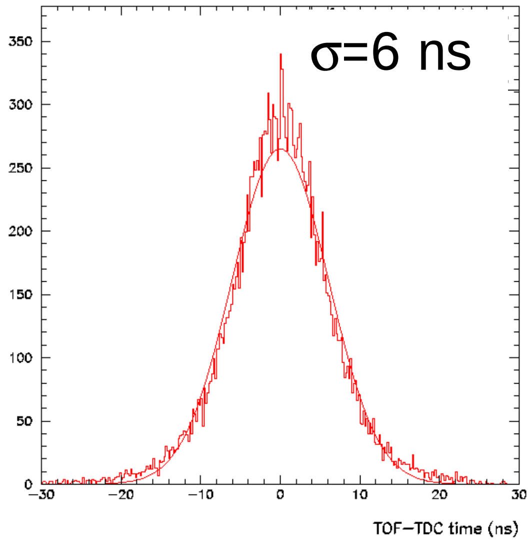


Here μ is seeing Middle + back constant depth → Can measure HV residual effect at cell level…

S/B : 7 in endcap
S/B :7 → 10 in barrel
for middle layer

Cosmic muons and commissioning …

Expect cosmics in 2006 inside the pit with rate ~Hz for projective μ (>3months)



Physics pulse intercalibration with 1 ns accuracy

Position measurement can also be derived with μ :
-in ϕ, better than 5 mm due to accordion energy sharing
-in η, strip cell can be found with good efficiency (S/B~4-5)→ 5 mm

Signal reconstruction : uniformity vs η (LC effect) can be checked at 2-3 ‰
→ Should be enough to start LHC with a "good" calorimeter…

Conclusion / prospects

- Barrel calorimeter construction is finished (2001-03). Solenoid has been inserted and cryostat is closed :

  → Cooling of cryostat has started (T=175K last monday). HV +electrical tests

  → Ready for pit in September 2004
- Second end cap wheel is completed and and will be inserted in its cryostat in July 2004. First end cap cold test in August 2004
- Beam tests have allowed to assess calorimeter performances
- Combined beam test in 2004 (Tile/EM barrel/Inner det. /muons) with final electronics (Front End + RODs)
- μ commissioning in 2006

→Still a lot to learn/do to go from one module to complete calorimeter (calibration/reconstruction) to be ready for D-day…