Performance of the ATLAS Calorimeters using Cosmic Muons

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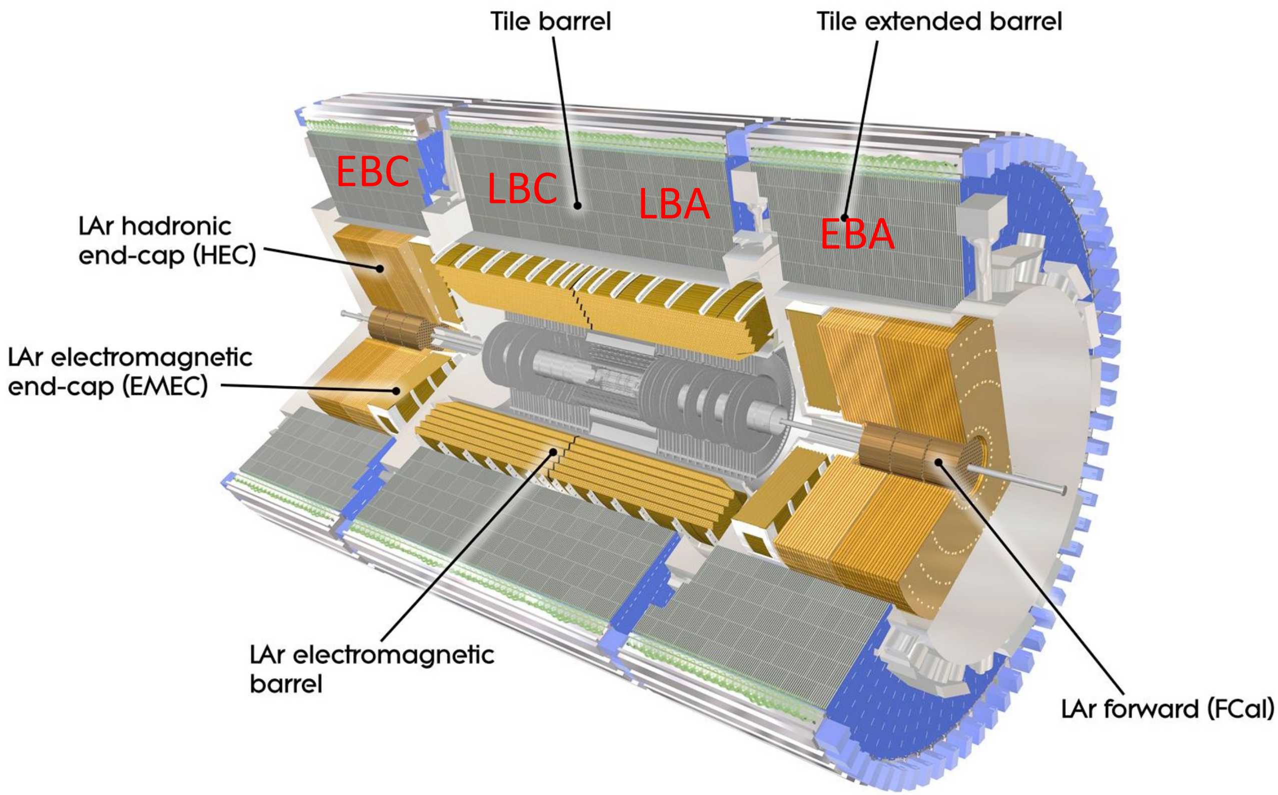
On behalf of the ATLAS Collaboration

Layout

- Reconstruction of cosmic rays events in the ATLAS calorimeters
- LAr Calorimeter uniformity
- Studies of electromagnetic showers from radiative cosmic muons in the LAr calorimeter
- Uniformity of the response of the cells of the hadronic calorimeter (TileCal)
- Test of the TileCal energy measurement scale (EM scale)

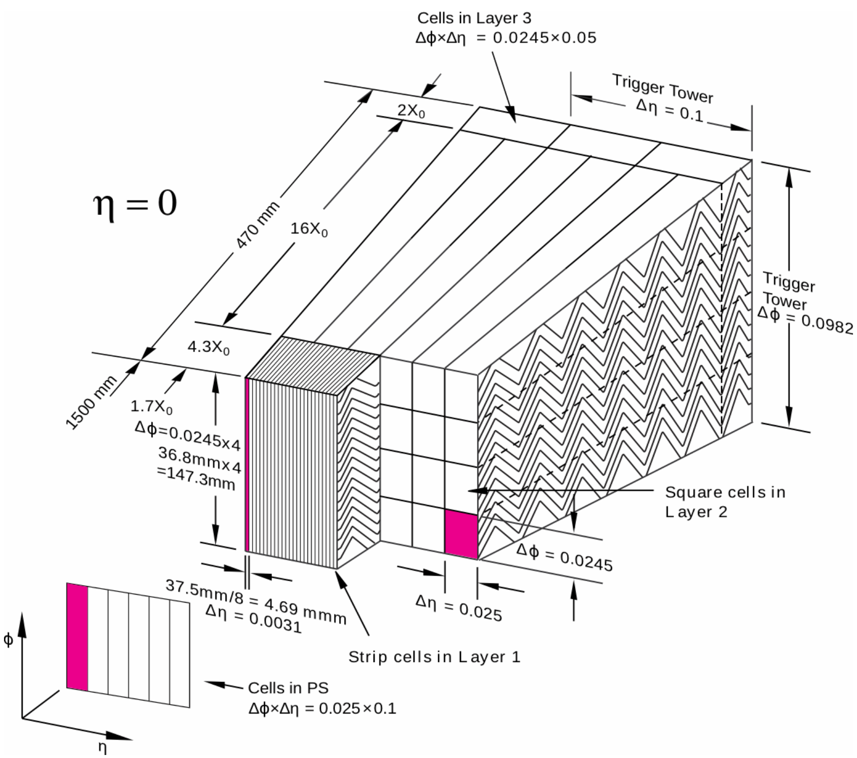
The ATLAS Calorimeter (1)



	Absorber	Active medium	Coverage	Readout Channel	Working [%]
EM					
EB, EMEC	Pb	LAr	$\|\eta\|<3.2$	173k	98.0
Hadronic					
HEC	Cu	LAr	$1.5<\|\eta\|<1.8$	5.6k	99.9
Fcal	Cu/W	Lar	$3.1<\|\eta\|<4.9$	3.5k	100
TileCal	Steel	Scintillator	$\|\eta\|<1.7$	10k	95.6

For more information about the ATLAS detector see the talk of D. Dobos

The High Granularity Electromagnetic Barrel Calorimeter



		Thickness $[X_0]$	$\Delta\eta\times\Delta\phi$
PS	Recover energy loss		0.025×0.1
Layer 1	γ/π^0 separation	4	0.0031×0.1
Layer 2	Shower development	16	0.025×0.025
Layer 3	Shower end	2	0.025×0.05

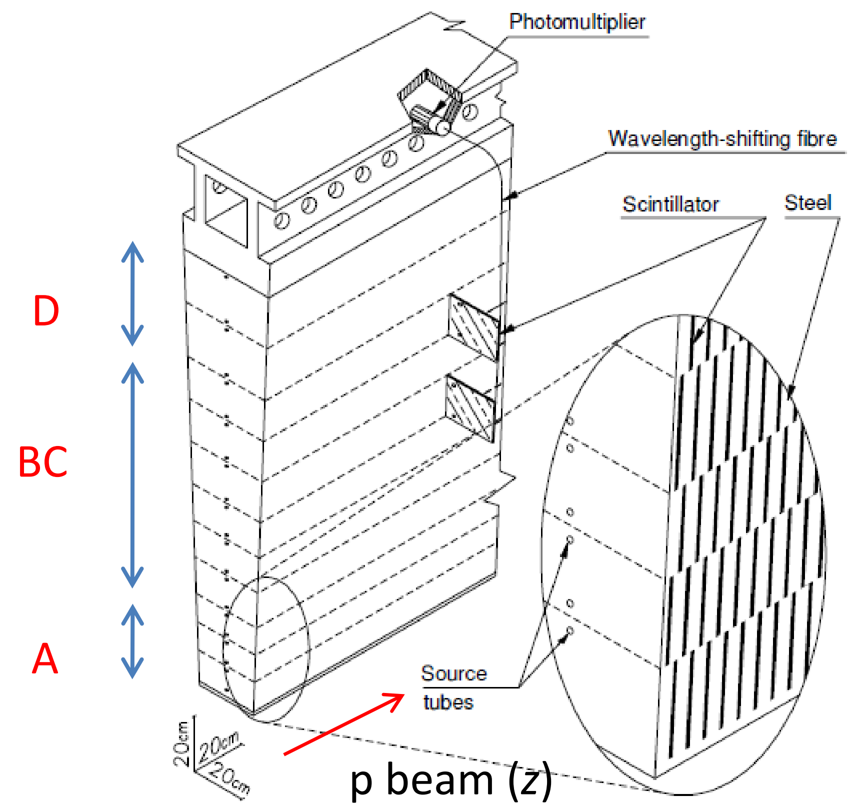
Good γ/π^0 and e/jet separation and e(γ) energy resolution

The TileCal Calorimeter

- It is divided into three cylinders one Barrel and two Extended Barrels, EBA and EBC. The Barrel consists of two parts: LBA ($\eta>0$) and LBC ($\eta<0$).
- Each cylinder is composed of 64 azimuthal segments (modules) subtending $\Delta\phi=2\pi/64\cong0.1$.
- The steel and scintillating tiles are perpendicular to the beam.
- Two sides of the scintillating tiles are read out by wave-length shifting (WLS) fibers into two separate PMT's.
- By the grouping of WLS fibers to specific PMT's the modules are segmented in *z* and radial depth (cells)

Radial Layer	Barrel Cell Dimensions $[\Delta\eta\times\Delta\phi\times R]$
LB-A	$0.1\times0.1\times1.5\ \lambda_{int}$
LB-BC	$0.1\times0.1\times4.1\ \lambda_{int}$
LB-D	$0.2\times0.1\times1.8\ \lambda_{int}$

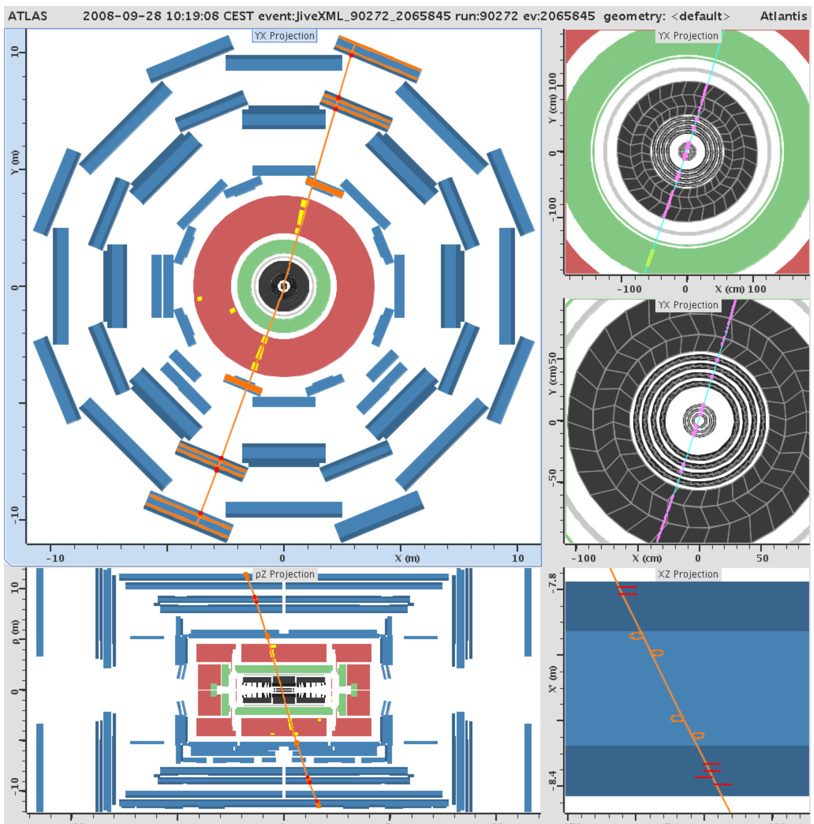
One module of TileCal



Good jet energy resolution

Cosmic events in ATLAS

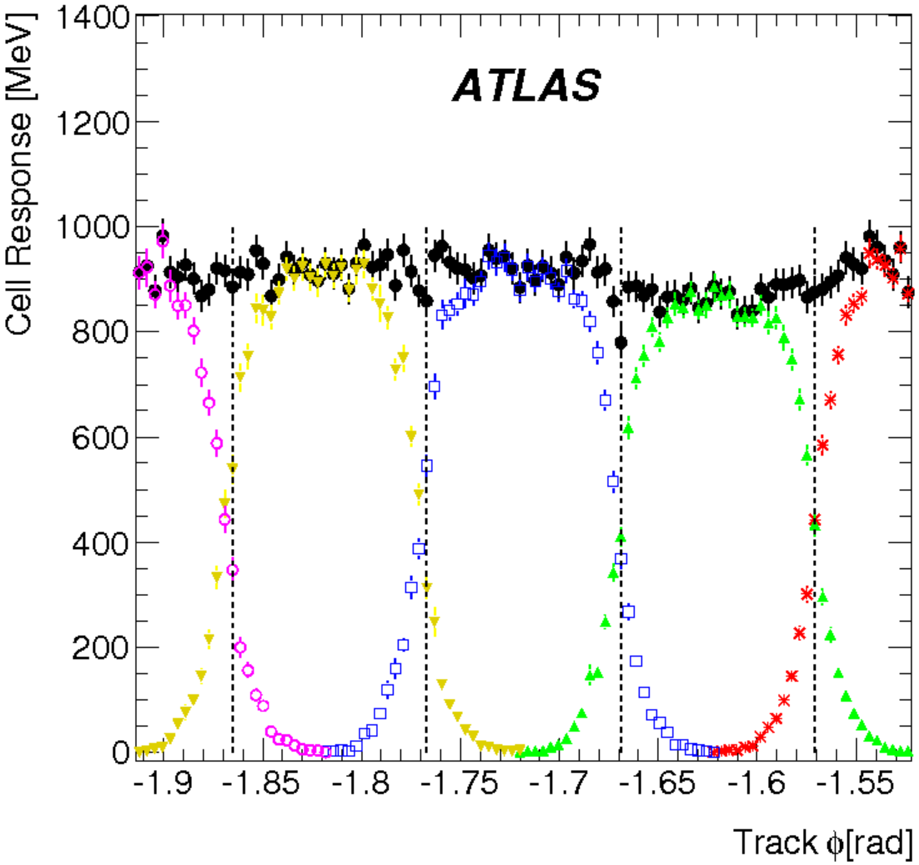
Display of a cosmic ray event. Both solenoid and torid magnetic field were on



- Cosmic rays triggered by the muon chambers
- Events reconstructed using the Inner Detector
- Tracks extrapolated to the calorimeters

Cosmic rays in TileCal

Response of cells in the BC layer as a function of the track ϕ-coordinate. Vertical lines denote nominal edges of the modules ($\Delta\phi \cong 0.1$)

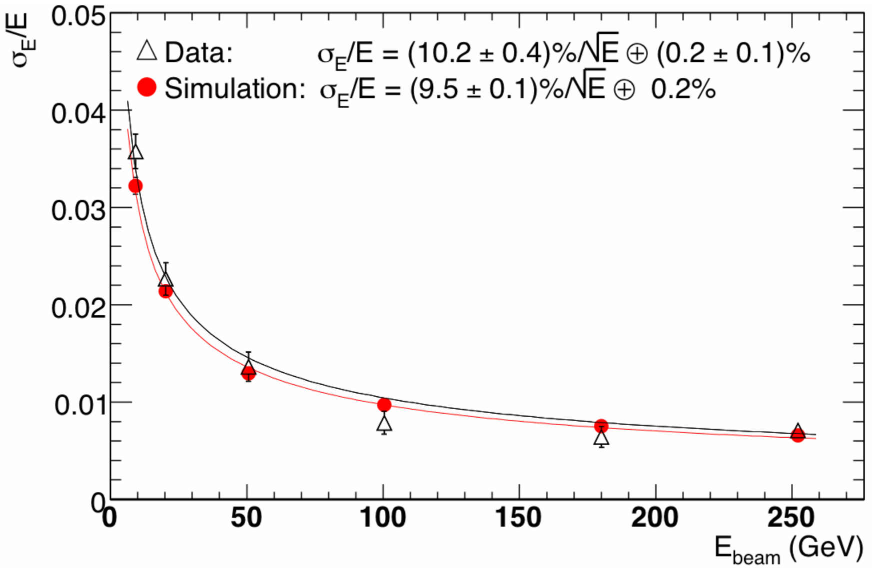


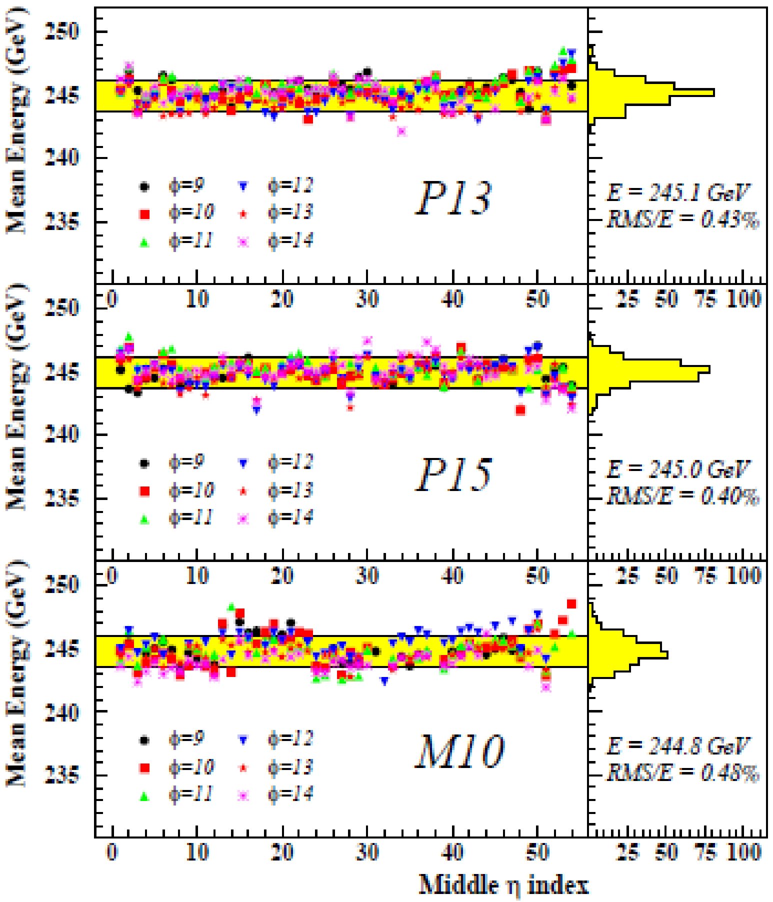
Cosmic rays events have been used to test the Uniformity of the EB Calorimeter

LAr electron Resolution at Test Beams

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

Target: b_{global} = 0.7%

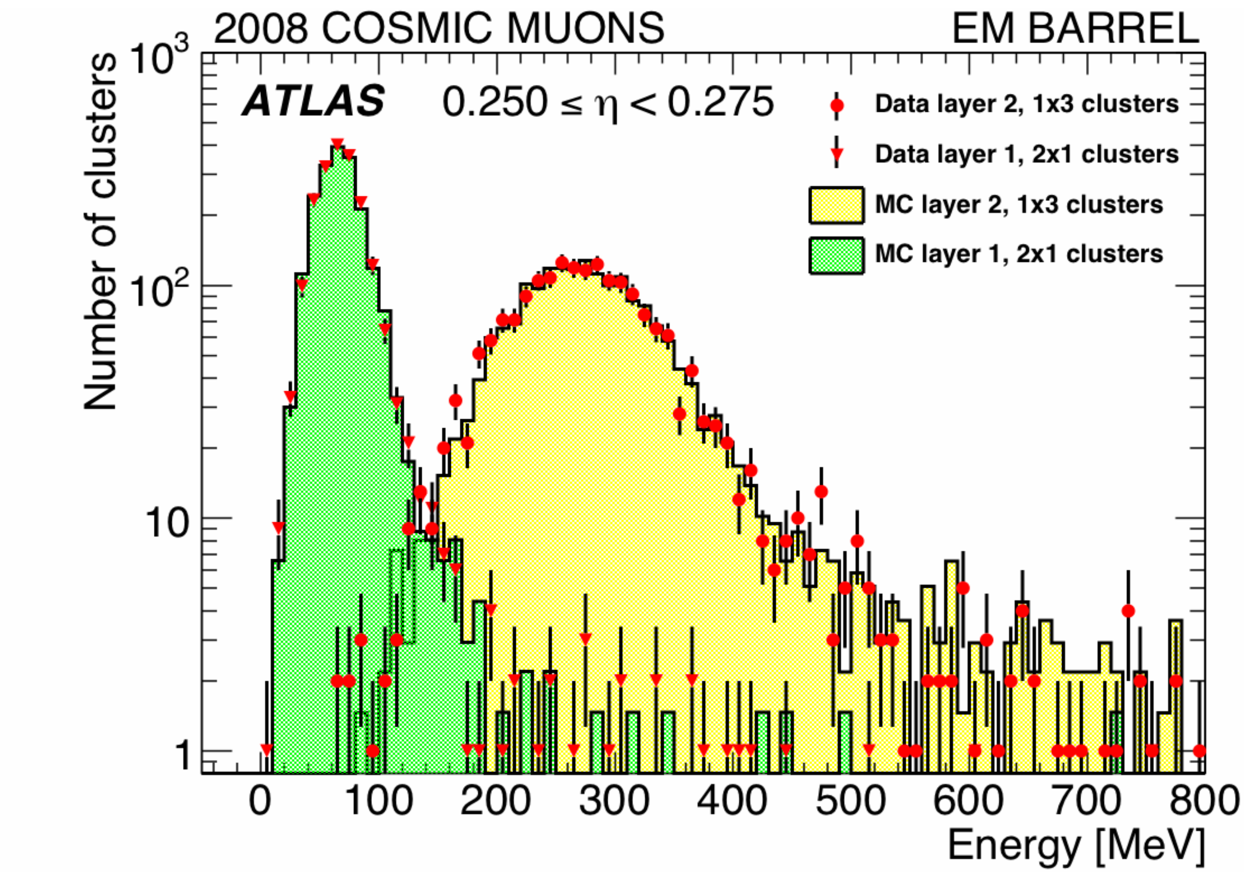




Electron Test Beams results		
a [(E)$^{1/2}$%]	b_{local} [%]	b_{global} [%]
10.2	0.2	0.4-0.6

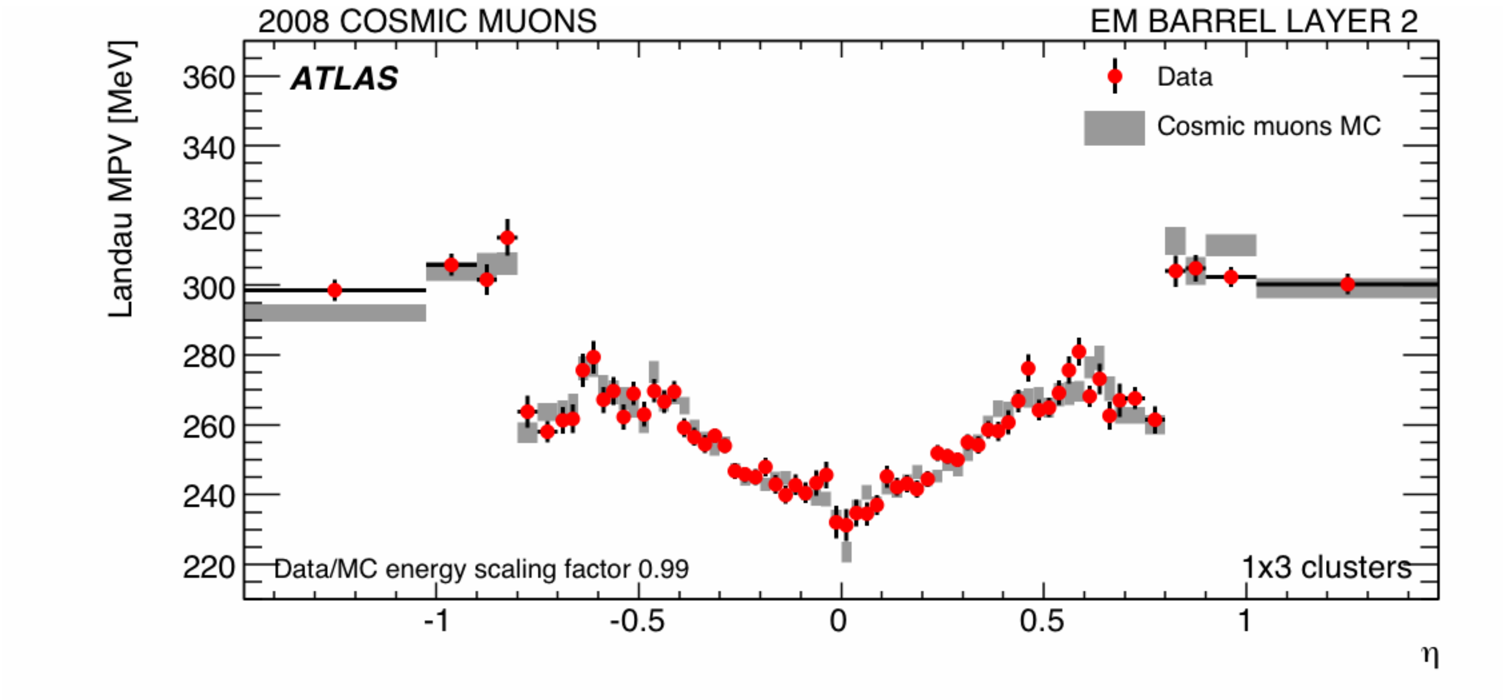
Cosmic rays energy reconstruction in LAr

Energy in a $\Delta\eta\times\Delta\phi$ = 2×1 cluster in the 1st layer and in 1×3 cluster in the 2nd LAr layer



LAr Response Uniformity along η using muons (1)

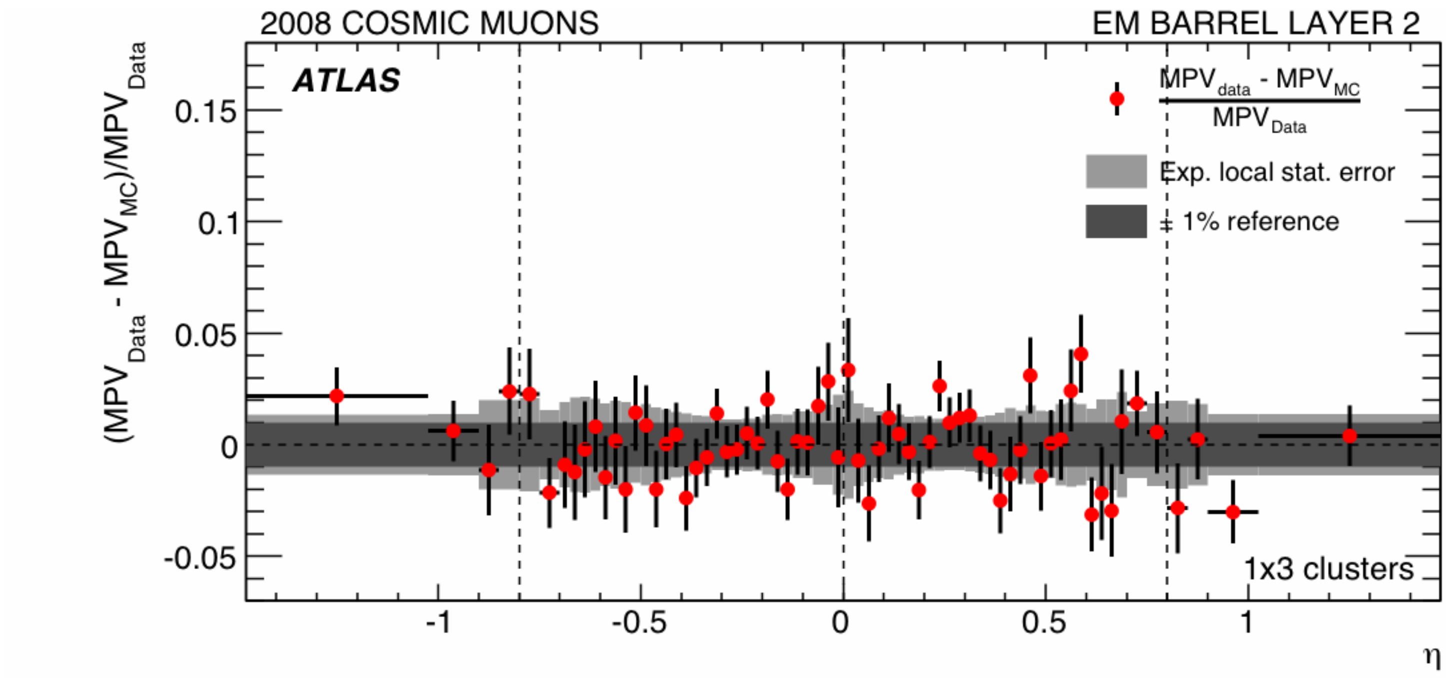
The estimation of the muon energy in each η-bin is done with a fit of the cluster energy distribution using a Landau function convoluted with a Gaussian



Landau MPV as a function of η in the 2nd layer for the data (red points) and MC (grey band)

LAr Response Uniformity along η using muons (2)

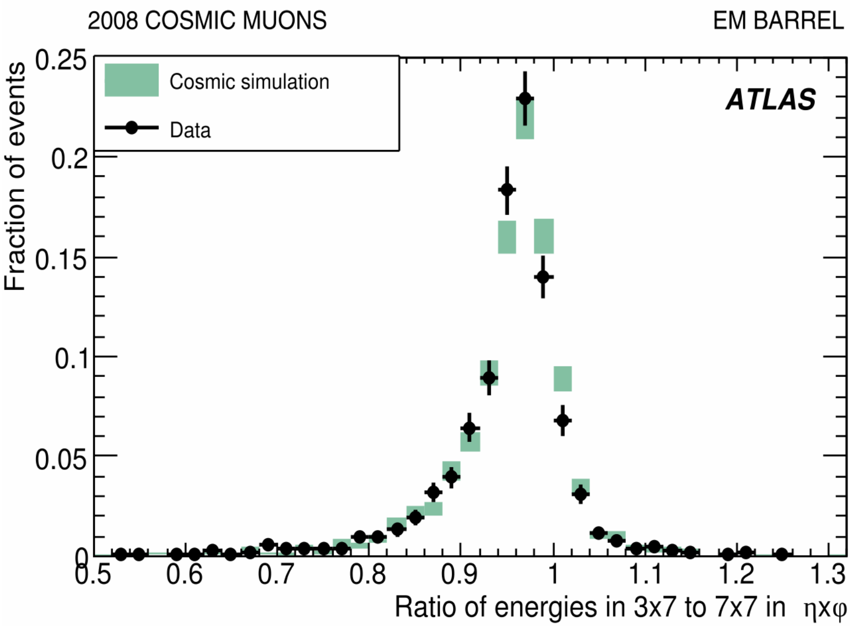
Measured (red points) and expected dispersions as function of η for the first layer of the EM barrel (light grey band). The dark grey band indicate a ±1% strip for reference



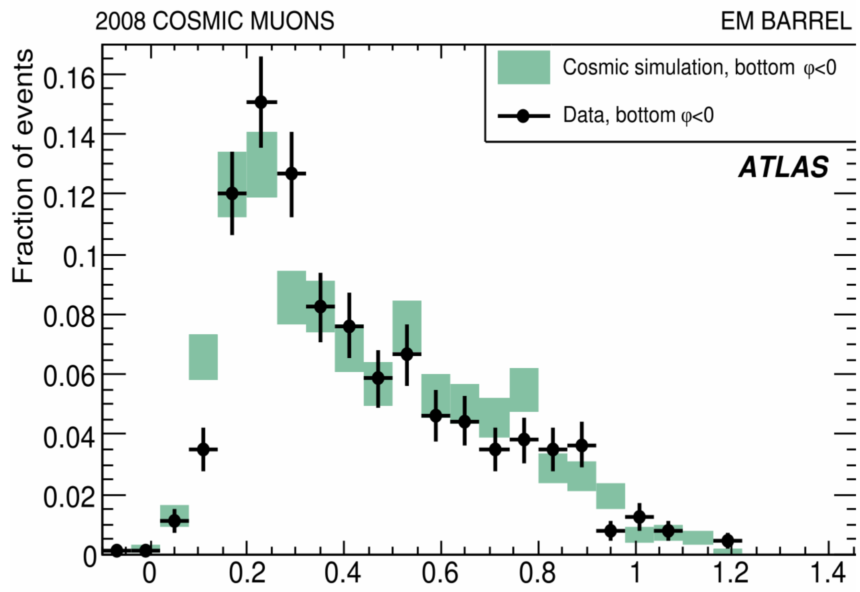
The RMS of the measured uniformities are 2.4±0.2% in the first layer and 1.7±0.1% in the second layer. The fluctuations mostly remain within the limits of the band representing the expected values. The RMS of the later distribution is 2.2% in the first layer and 1.6% in the second layer.

LAr Electromagnetic Shower Studies

Radiative cosmic muon events were studied to validate the MC simulation of the distribution of some key calorimeter variables used in the ATLAS e/γ identification



in the 2nd layer



$F_{side}=(E_{\pm3}-E_{\pm1})/E_{\pm1}$ in the 1st layer

This variable distinguishes electromagnetic showers, contained in 3 cells in η, from hadronic showers, leaking outside these 3 cells

This variable separates photons, where little energy is deposited outside the core energy, from π^0's, where the two photons deposit some energy outside the core region

Cosmic rays events have been used to test the Calibration of TileCal

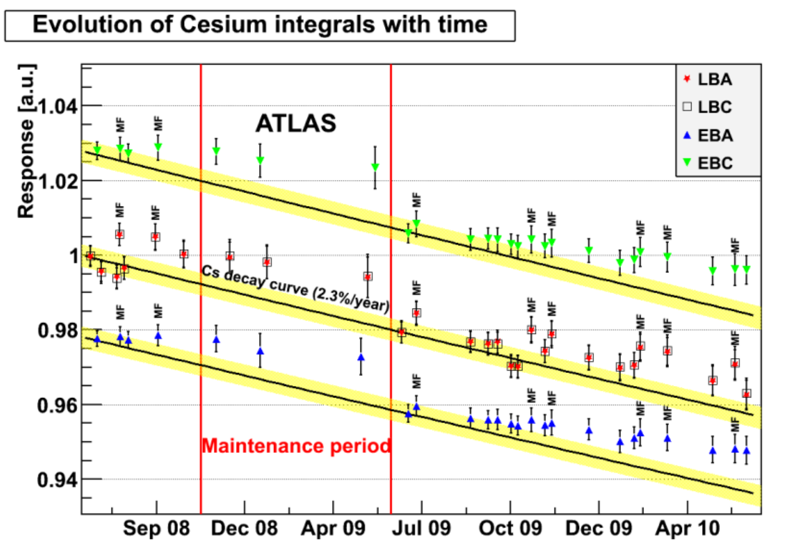
Inter Calibration and Scale of the Energy Measurement in TileCal (1)

- The equalization of the cell PMTs responses is obtained using movable radioactive ^{137}Cs sources (see Slide 5).
- Corrections due to the different sizes of the tiles in the three layers are determined using 90^{o} muons at test beam.

Inter Calibration and Scale of the Energy Measurement in TileCal

$$E_{PMT} = A \times C_{ADC \rightarrow pC} \times C_{pC \rightarrow GeV} \times C_{Cs}$$

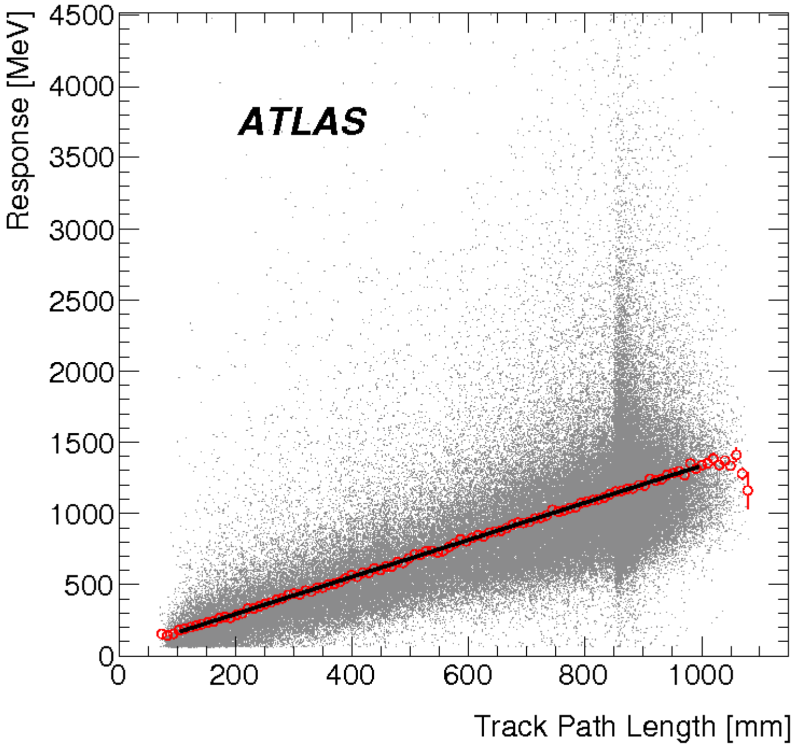
- A : measured energy in ADC counts
- $C_{ADC \rightarrow pC}$: Conversion factor of ADC to charge
- $C_{pC \rightarrow MeV}$: Conversion factor of charge to energy. Defined at test beam for a subset of modules via the response to electrons (EM scale)
- C_{Cs} : The Cs correction is applied to make the response to Cs is equal to the one when the EM scale was measured



TileCal response to Cs as a function of time

The Cosmic ray Response in TileCal

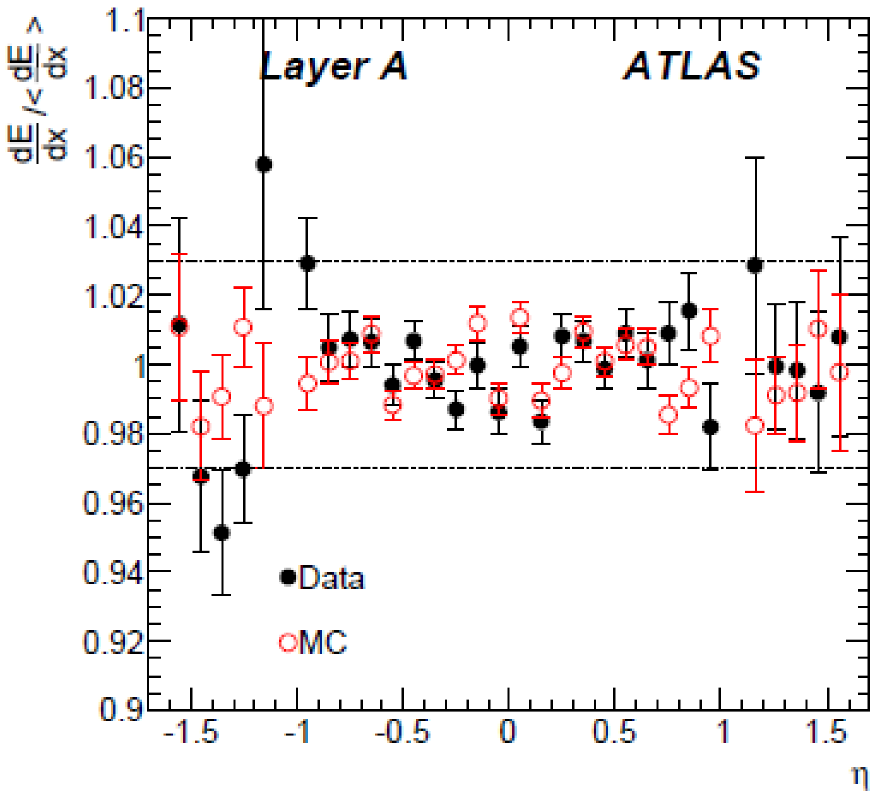
Energy deposited the barrel module BC cells, *dE,* as a function of the track cell path length. A straight line fits well the data



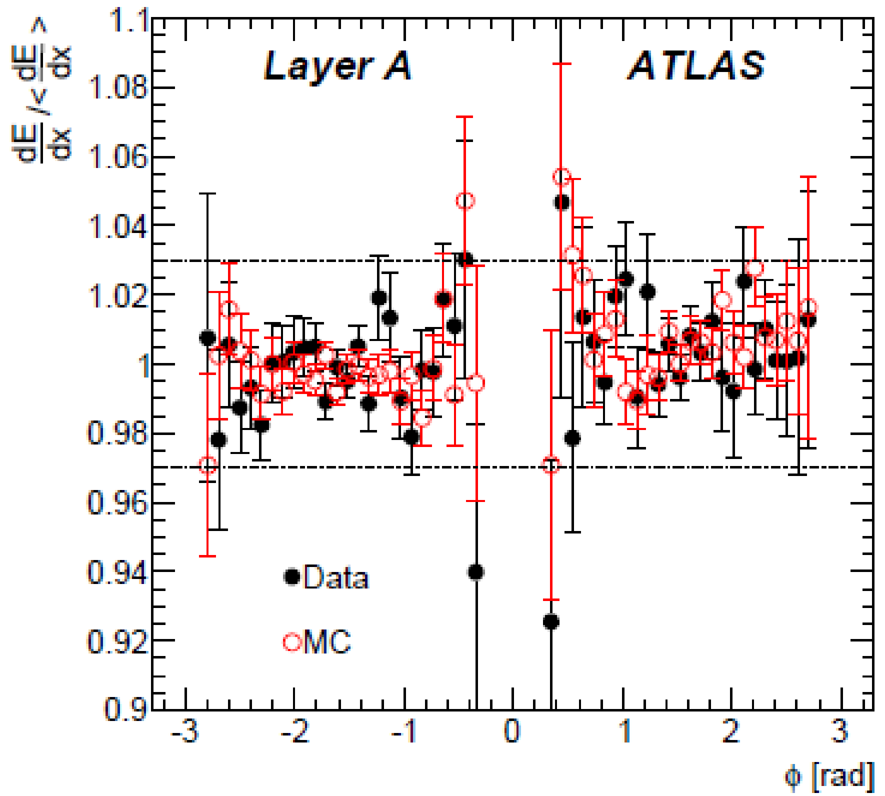
- The estimator of the cell response is defined as the mean value of the *dE/dl* distribution restricted to the low value region containing 99% of the.
- Use the tracks with momentum between 10 and 30 GeV
- *dl* > 200 mm

TileCal η and ϕ Uniformity

Uniformity as function of η for the cells of the Layer A. The response is integrated over all cell in each η bin. The data are compared to the normalized MC results.

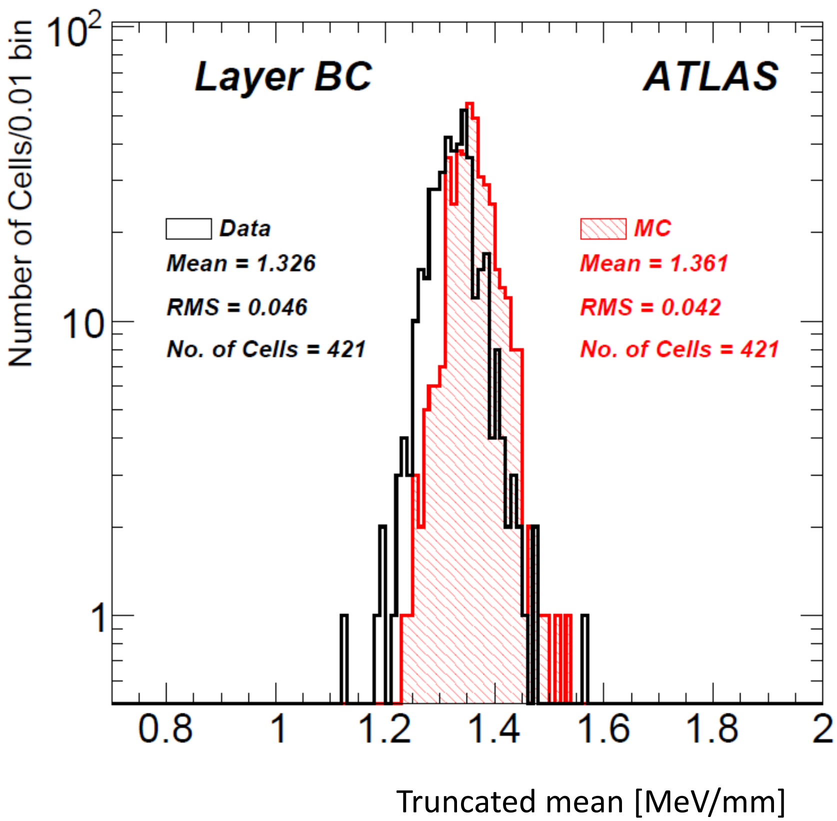


Uniformity as function of ϕ for the cells of the Layer A. The response is integrated over all cell in each module. The data are compared to the normalized MC results.



Values within 3%

Tile Cal Cell Uniformity



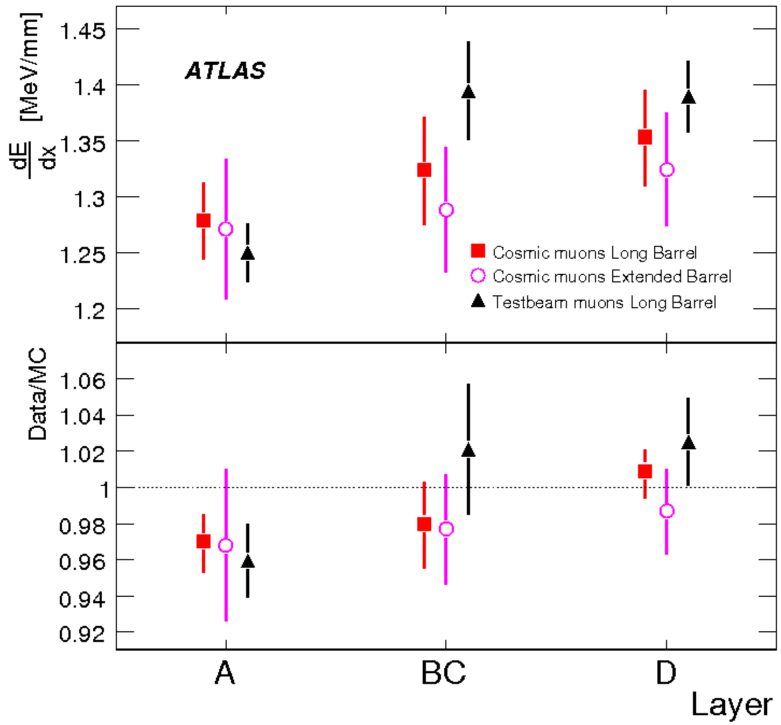
Layer	Number of cells	Fraction of cells [%]	RMS Data [%]	RMS MC [%]	Quadratical subtraction
A	352	18	6.0	4.9	3.5
BC	421	22	4.6	4.3	1.6
D	316	38	5.3	4.8	2.2

- The cells of a same layer are reasonably inter-calibrated
- There are off-sets between the experimental and simulated cell average values

Only the cells with more than 100 tracks are used in this analysis

TileCal Layer Inter Calibration

The truncated mean of dE/dx (MeV/mm) for cosmic and test beam projective muons shown per layer and, at the bottom, compared to MC.



- To reduce systematic uncertainties the ratios of the Data and MC determinations were used.
- The errors correspond to the diagonal elements of the error matrix , dominated by systematic (2-3%).
- Since the values are strongly correlated the maximum difference between the measurements (4%) is used as indicative of the layer miss calibration

The Transporatation of the TileCal EM scale from the test beam to ATLAS

- Use the truncated means obtained analyzing cosmic rays and projective muons data at the test beam when the EM scale was determined

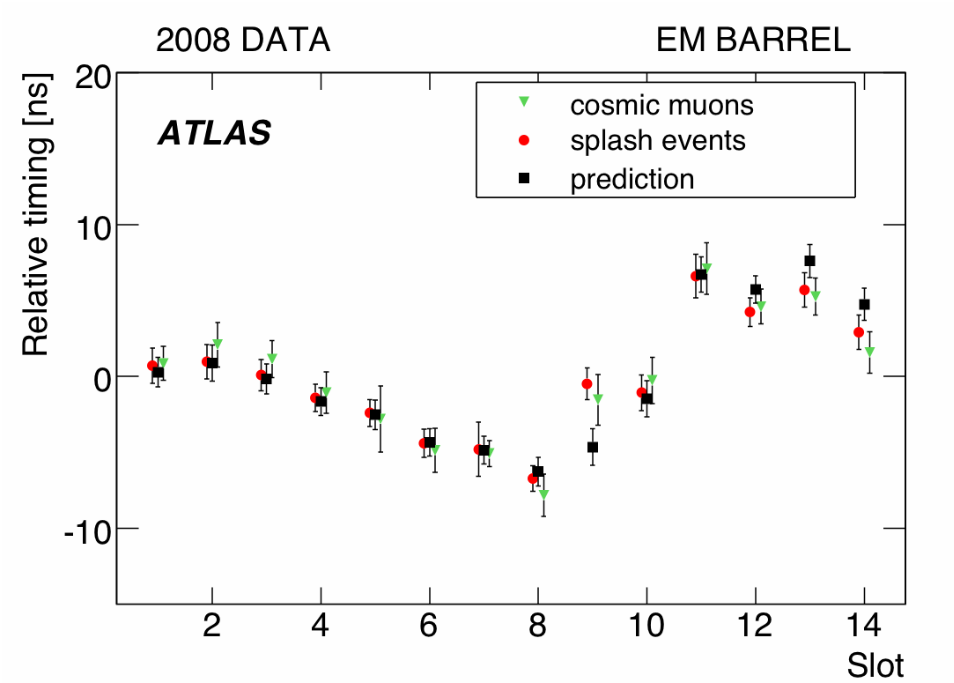
Radial layer	A	BC	D
$\frac{(Data\ /\ MC)_{Cosmic\ \ Rays}}{(Data\ /\ MC)_{Test\ \ Beam}}$	1.01±0.03	0.96±0.04	0.98±0.03

- The errors correspond to the diagonal elements of the error matrix (Cosmic muons ⊕ TB) dominated by systematic.
- The determinations are not combined because they are correlated.
- The systematic error on the EM scale was assumed to be equal to the absolute value of the maximum observed deviation from 1: ±4%.

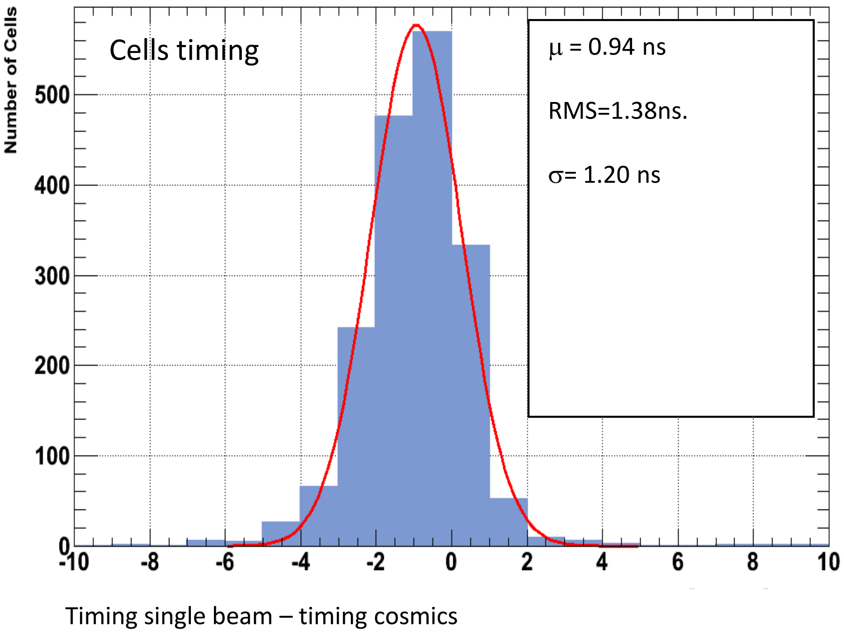
The contribution of this result to the present uncertainty on the jet energy reconstruction in ATLAS is discussed in the talk of M. Petteni.

Timing calibration with cosmics and splash beam

Relative predicted and measured Front-End Board times in the EB



Difference between the time corrections from cosmic muons and the single beam results in TileCal



- Timing precision already better than 2%

Conclusions

- The non-uniformity of the EM barrel calorimeter response to cosmic muons is consistent at the percent level with the simulated response. This indicates that the reach of a global constant term in the resolution of 0.7% is achievable.
- The cell response uniformity in TileCal, as measured with the muon track is at the level of 2-3%.
- The EM scale is consistent with 1 with an uncertainty of 4%.

TileCal analysis of 2009 and 2010 cosmics data are in progress with the aim to reduce the error to 1-2%. One can use also isolated muons produced in proton interactions.

The results allow for strong confidence in the good performance of the ATLAS Calorimeters