Tile/hadronic Calorimeter design viewed from ATLAS

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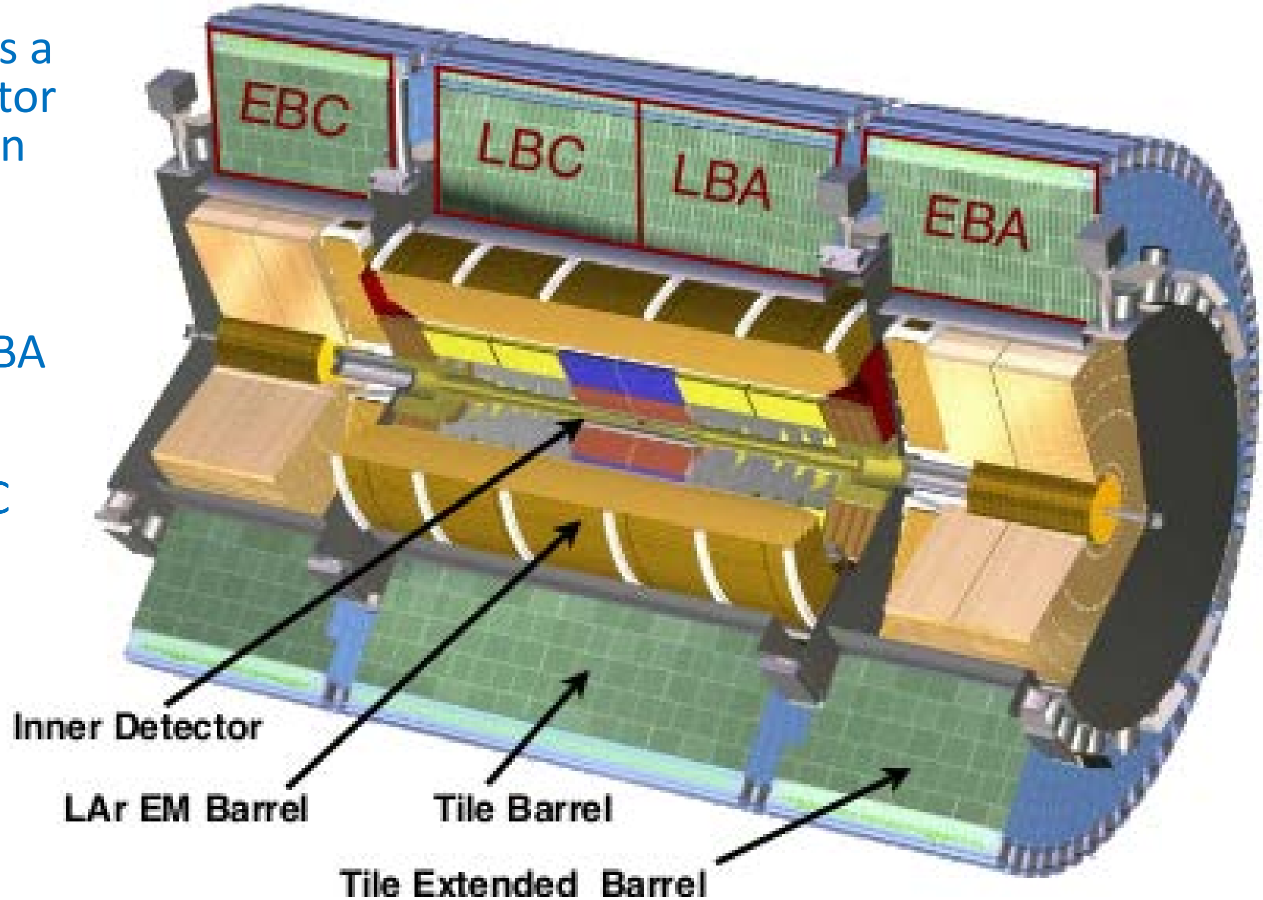
On behalf of the ATLAS Collaboration

Outline

- The detector
- Beam test results
- Detector response studies in the experimental hall
- Conclusions

The Tile Calorimeter

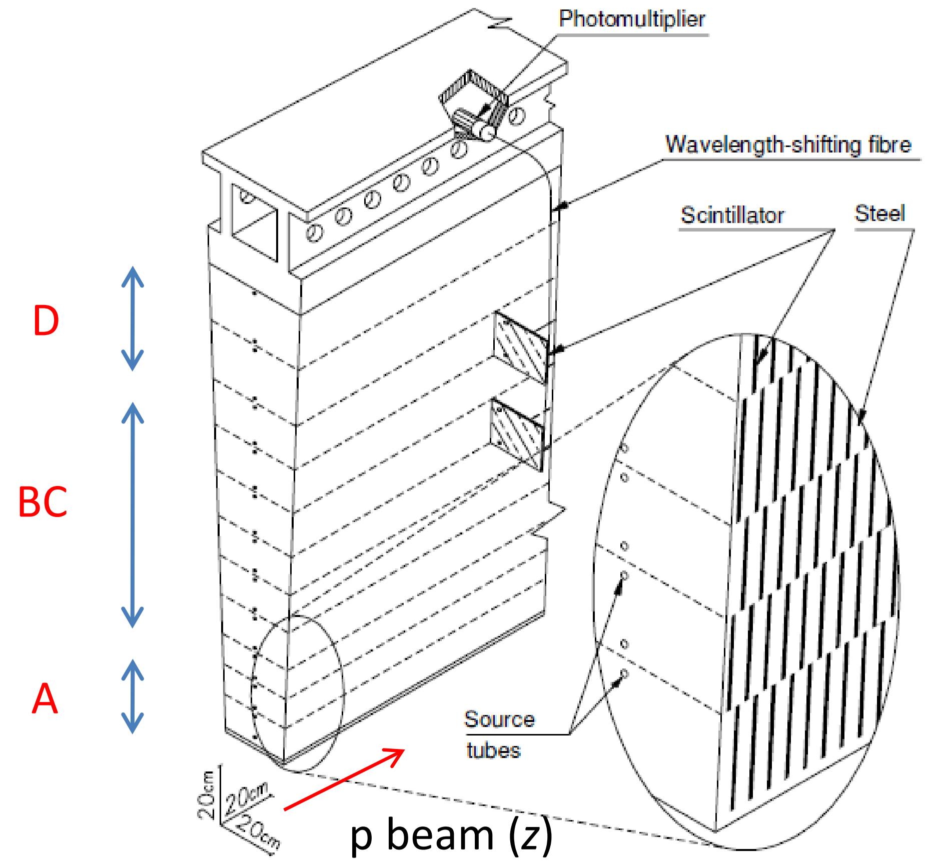
- The calorimeter TileCal is a sampling plastic scintillator /steel detector, located in the region $|\eta| < 1.7$.
- It is divided into three cylinders one Barrel and two Extended Barrels, EBA and EBC. The Barrel consists of two readout parts: LBA ($\eta>0$) and LBC ($\eta<0$).
- The gap regions are equipped by 4 sets of scintillators
- Inner radius: 2.28 m
- Outer radius: 4.25 m
- Total length: 12 m
- Weight: 2900 tons



Aim for Jet energy resolution: $\sigma(E[GeV])/E[GeV] \simeq 50\%/\sqrt{E} \oplus 3\,\%$

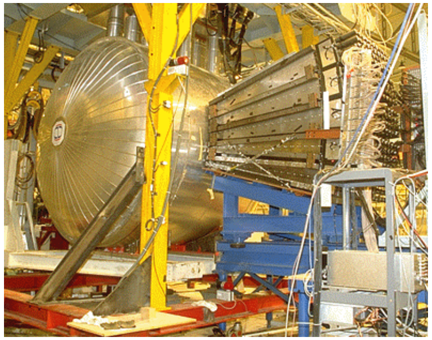
The TileCal Modules

- Each cylinder is composed of 64 azimuthal modules each spanning $\Delta\phi = 2\pi/64 \cong 0.1$.
- The steel plates 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.
- The 3 radial layers span 1.5, 4.1 and 1.8 λ_{int} in the barrel and 1.5, 2.6 and 3.3 λ_{int} in the extended barrels.
- The resulting typical cell dimensions are $\Delta\eta\times\Delta\phi = 0.1\times0.1$ (0.2×0.1 in the last layer)
- This segmentation defines a quasi-projective tower structure

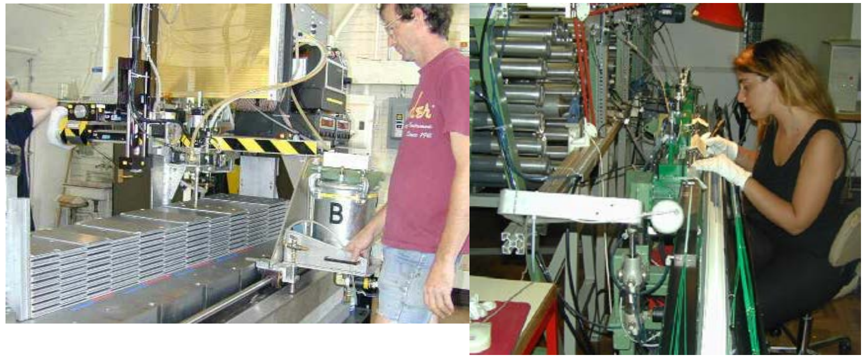


Channels	Cells	Towers
9836	5182	2010

A bit of history

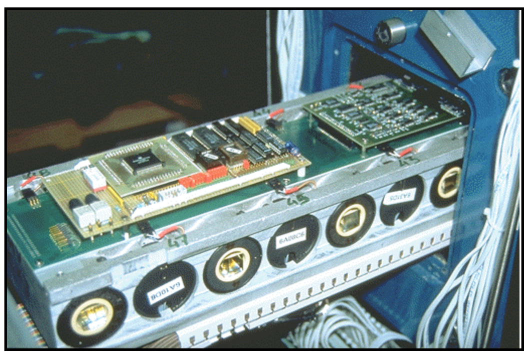


1993-1995 R&D

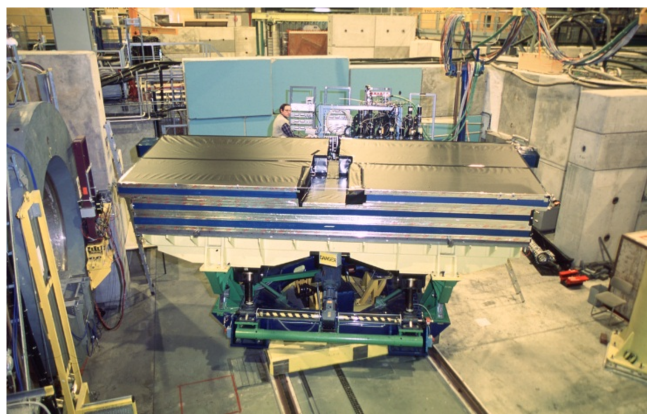


1996-2002 Mechanics and optics construction

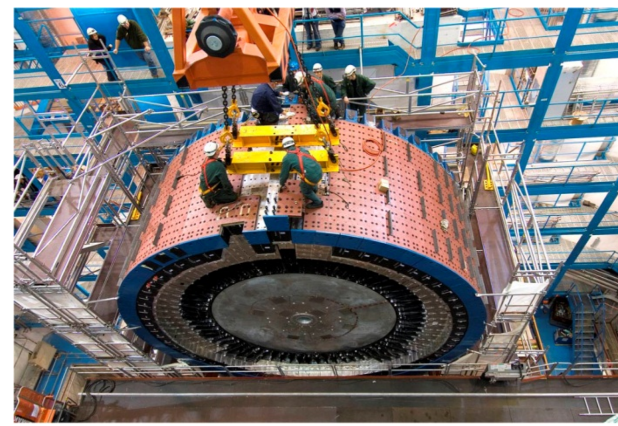
1999-2002 Instrumentation



1999-2004: Electronics construction



2000-2004: Calibration at the beam test

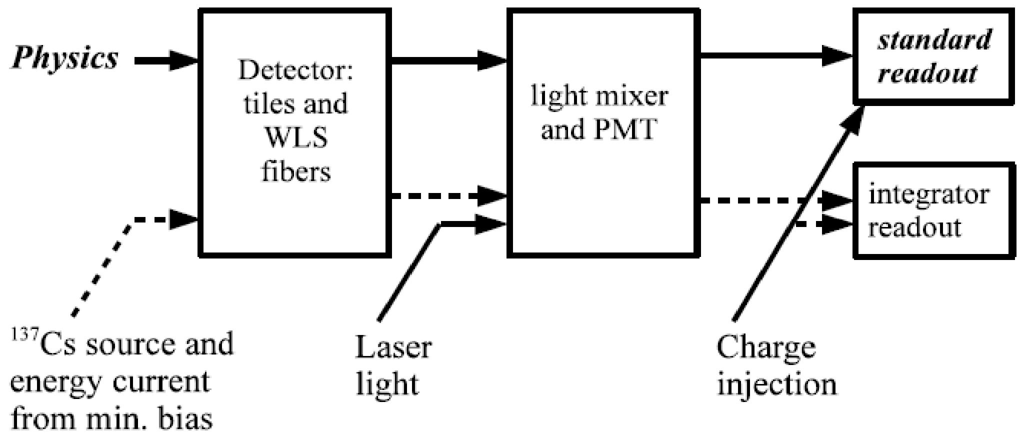


2004-2006: Installation

2005-2009 Commissioning using cosmic muons and calibration triggers in the experimental hall

Since 2009 Continuous operation in p-p collisions with yearly maintenance in Christmas shutdown

The Monitoring Systems

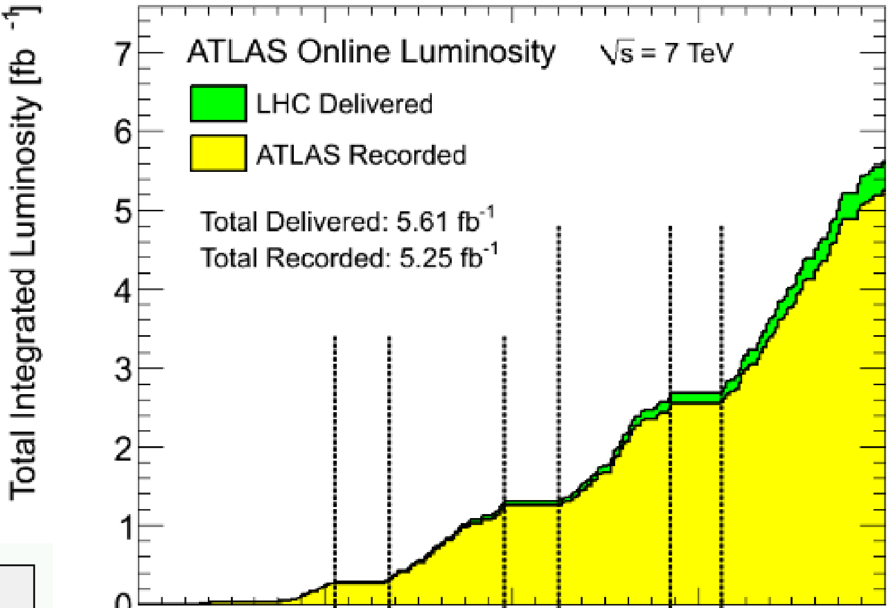


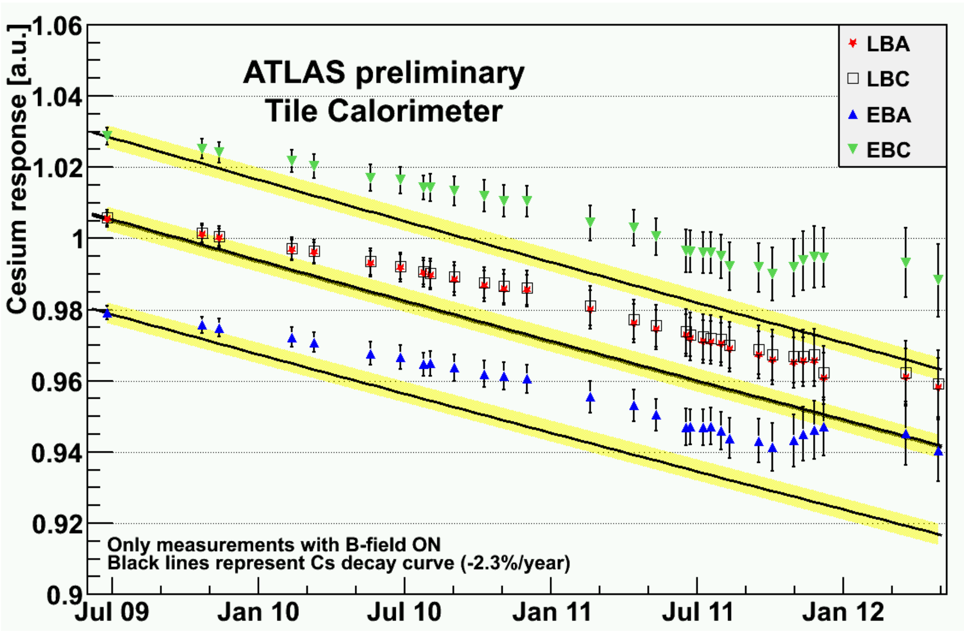
- Cs source (precision: 0.3%)
  - PMT voltage adjustments to inter calibrate cells and keep gain to the level established with electron beams at standalone beam tests.
  - Calibrate scintillating tiles optics, PMTs and integrator readout
- Laser (precision: 1-2%)
  - Measuring stability of PMT response and electronics, linearity and relative timing of digitizer boards.
- Charge Injection (stability: 0.7%)
  - Gives correspondence ADC counts->pC and electronics linearity.
- Minimum Bias current monitoring system
  - It integrates energy to monitor the cell response evolution and luminosity

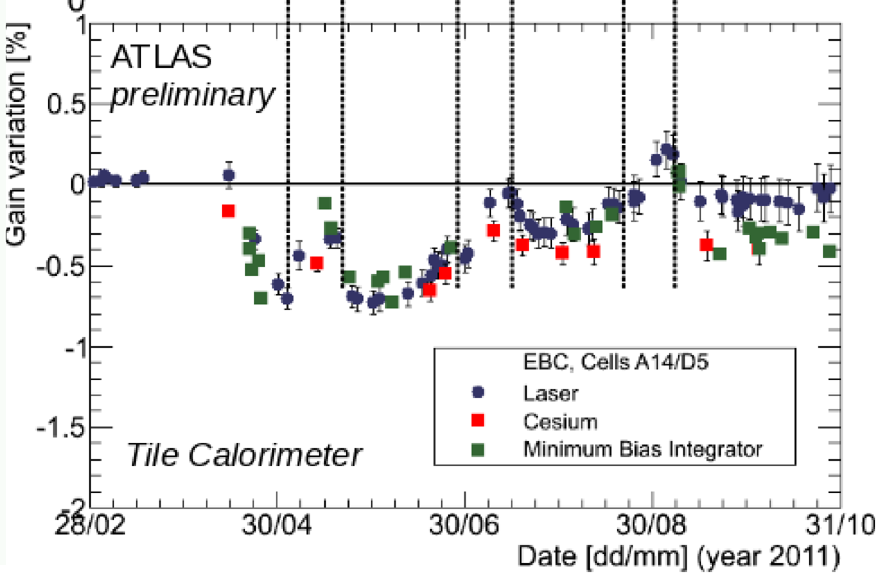
Detector Response Stability

- 2010: up drift of Cs response (about 1%/year)
- 2011: Up/Down drift oscillation (<1%) during beam/no beam periods.
  - o Consistent behaviour seen by all thee calibration systems
  - o Drift dominated by PMT gain effects

Corrections applied to the PMT response

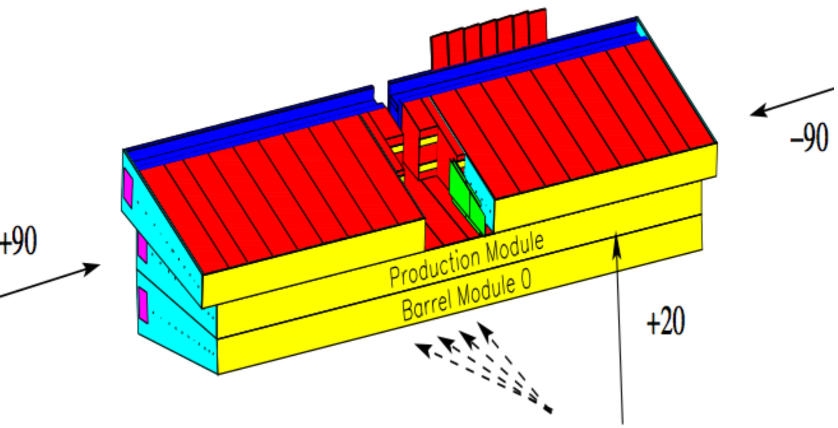




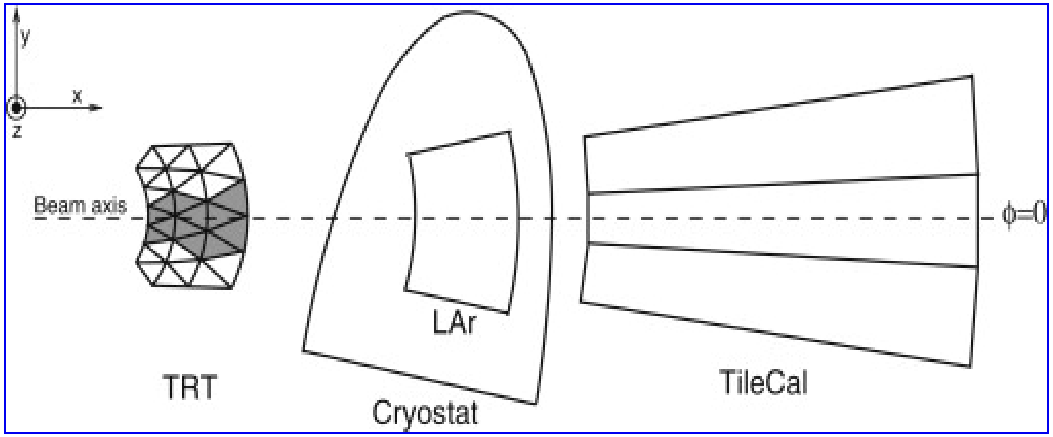


Beam Tests results

TileCal Standalone (2000-2003)



CTB (2004)



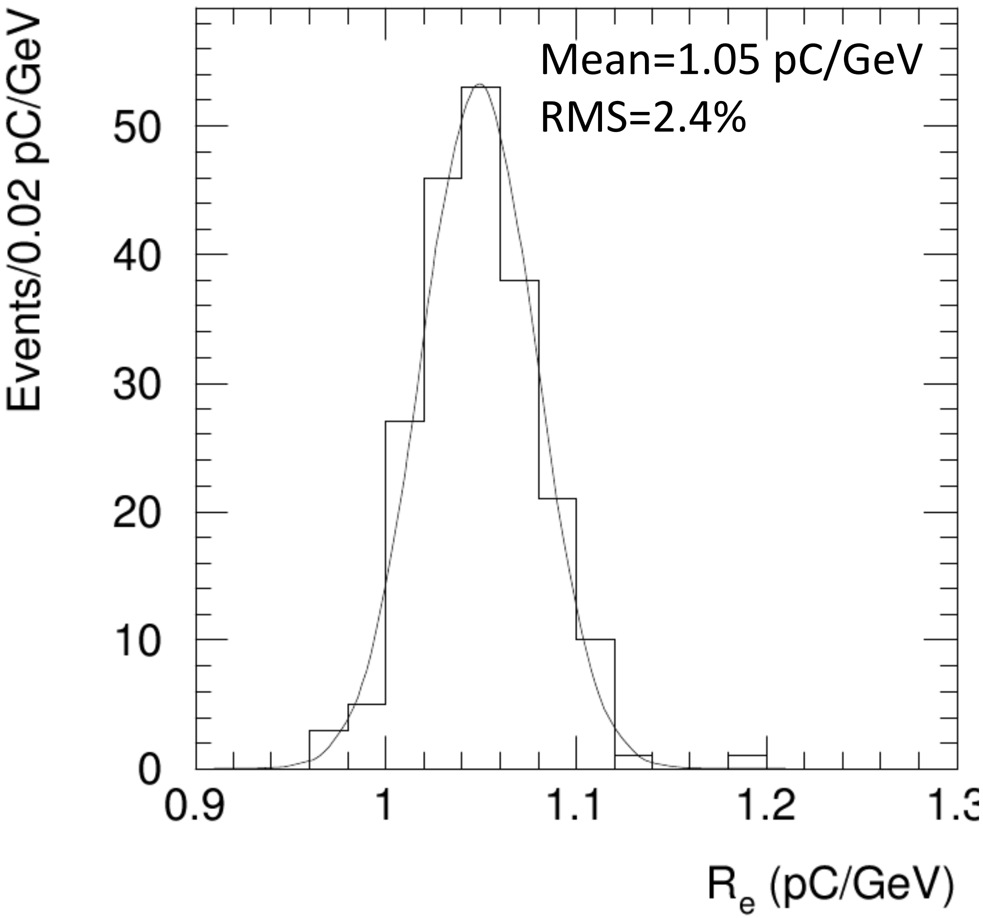
- Achievements

TileCal StandaAlone	CTB
• EM scale using electrons • Validation of design performance • Cell response uniformity • Comparison with (Tuning) Geant 4 MC	• Energy reconstruction/validation using two calorimeters • Comparison of response, resolution, shower shapes with Geant 4 MC • Low energy pions studies

- The measurements show good performance and Data/MC agreement

TileCal Standalone: Setting the electromagnetic scale

- 11% of all Tilecal modules brought to beam test in H8/ SPS/CERN
- Using electrons with E=20-180GeV ; θ=20^o incident beam in innermost radial layer cells
- EM scale (Response/E_{beam}) : mean =1.05pC/GeV ; RMS=2.4% (dominated by optics fluctuations)

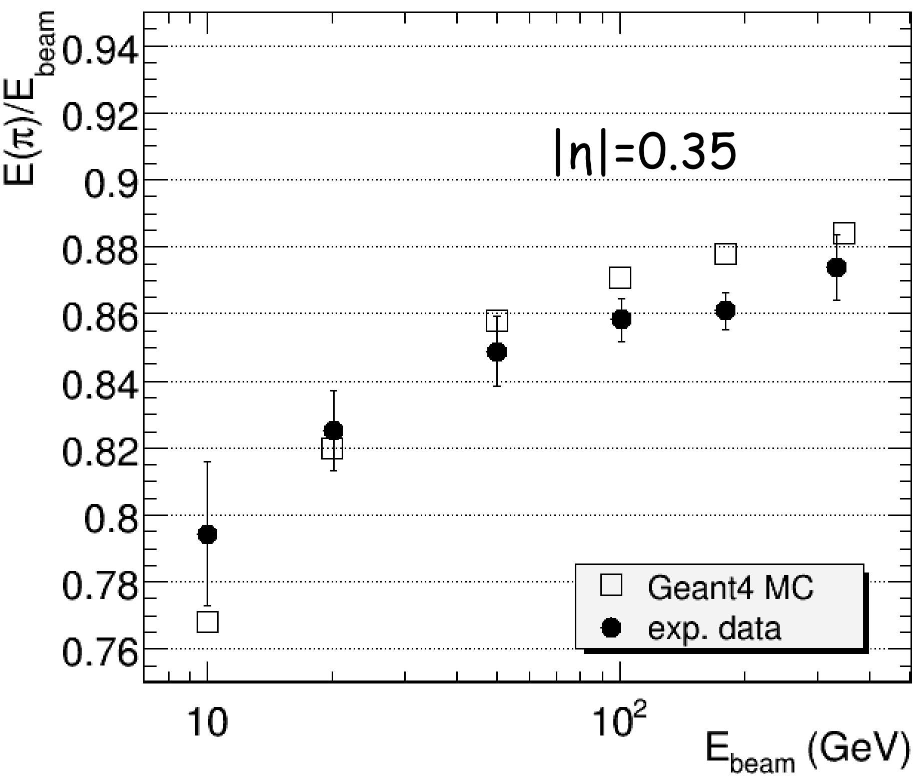


- The scale is transferred to ATLAS using the Cs measurements.
- Corrections are applied to make the PMT response to Cs equal to the one when the EM scale was measured at beam tests (Taking into account the Cs lifetime)

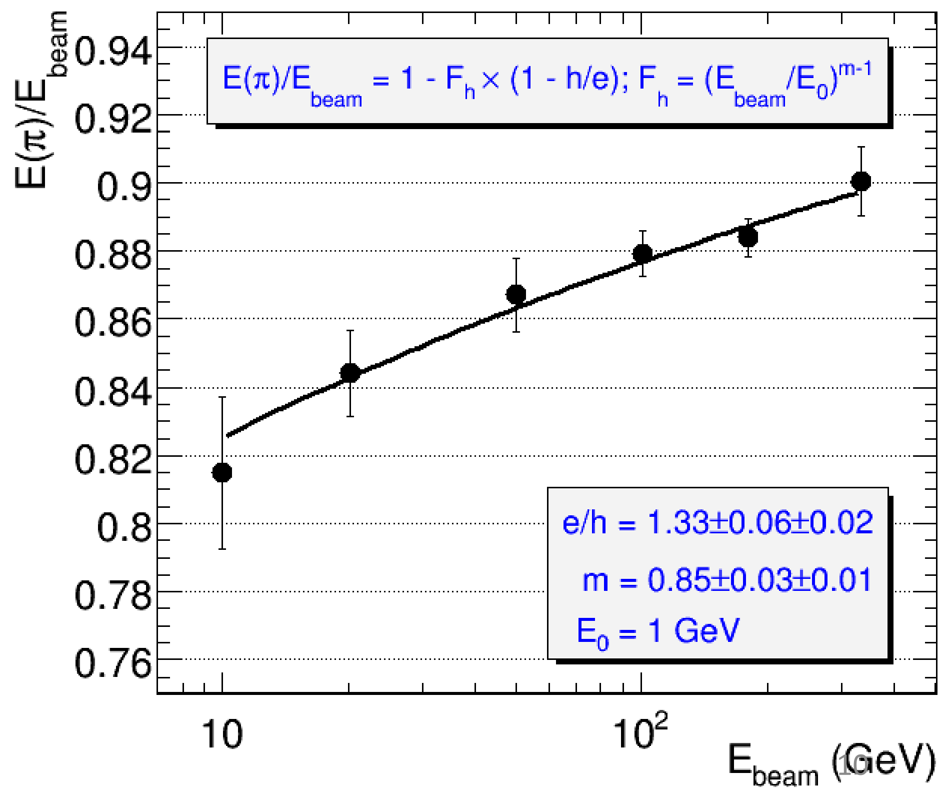
TileCal Standalone: Pion response Linearity

- The pion non linear energy dependence is due to calorimeter non-compensation
- e/h=1.33 using Groom's parameterization of the non-EM component of hadronic showers

Without leakage corrections

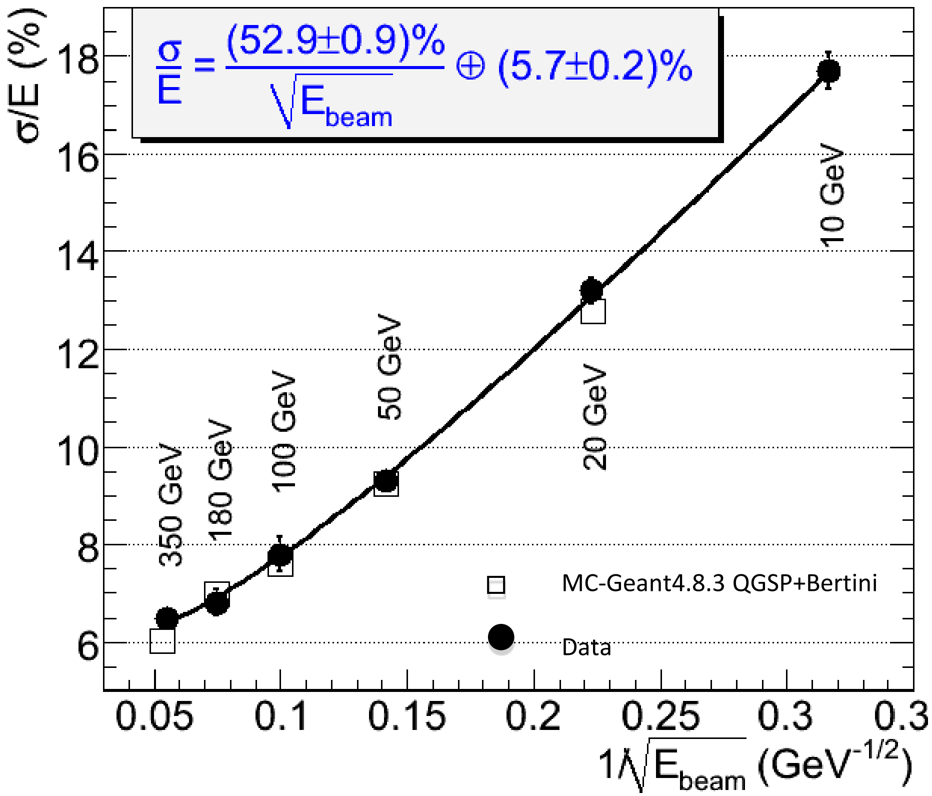


Data with leakage corrections



TileCal Standalone: Pion response Resolution

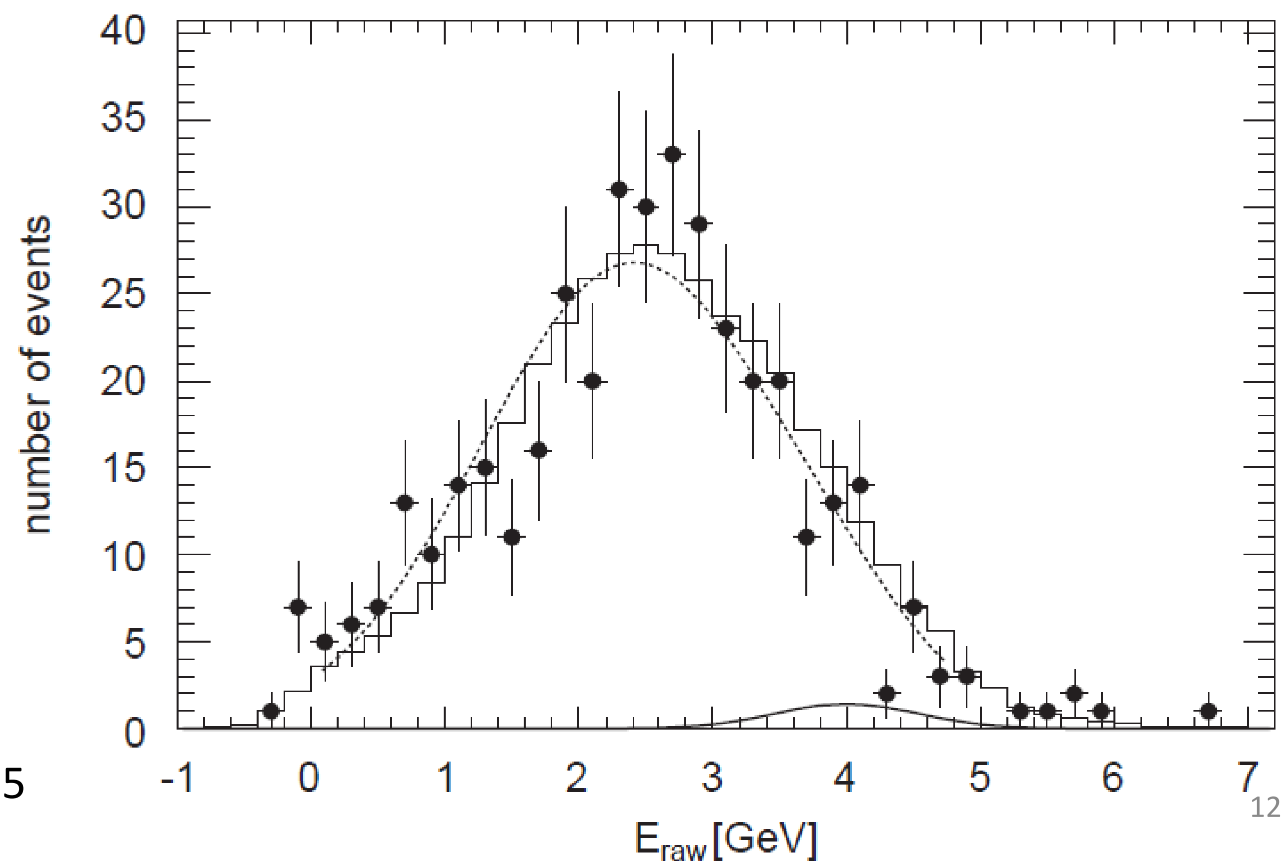
$\eta=0.35 \rightarrow$ depth=7.9 λ



- 5.7% constant term affected by longitudinal containment

CTB: LAr+TileCal response to pions of E = 3-350 GeV

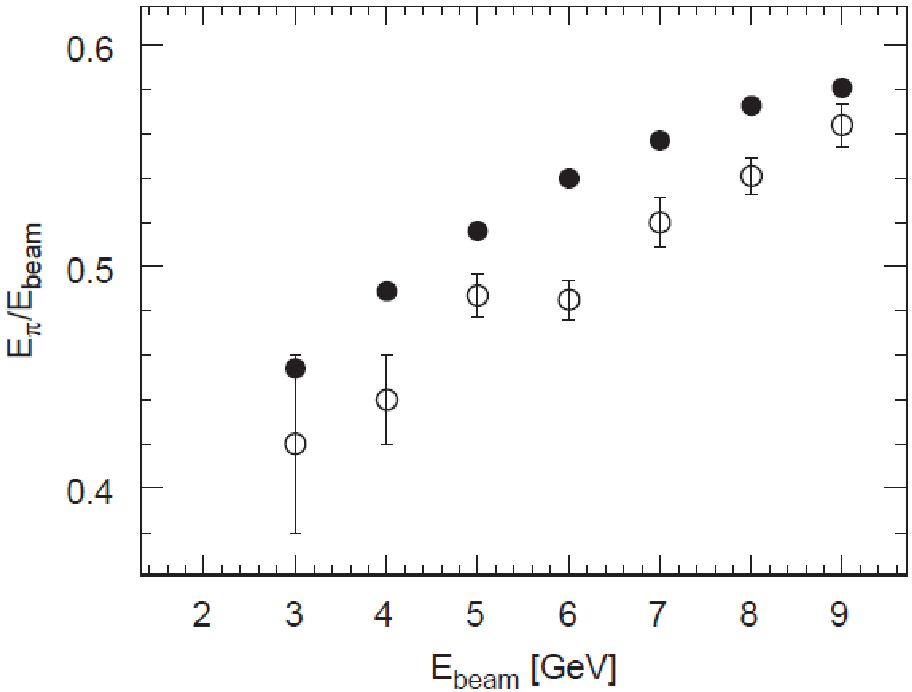
- The reconstructed energies were obtained without any correction for dead material and non-compensation of the calorimeters.
- The measurements at different energies’ down to 3 GeV, and incident angles were compared to simulated results obtained using Geant 4.
- A large fraction of jet energy is carried by particles of few GeV. For example, in a 150 GeV jet, particles with energy smaller than10 GeV carry about 25% of the total energy



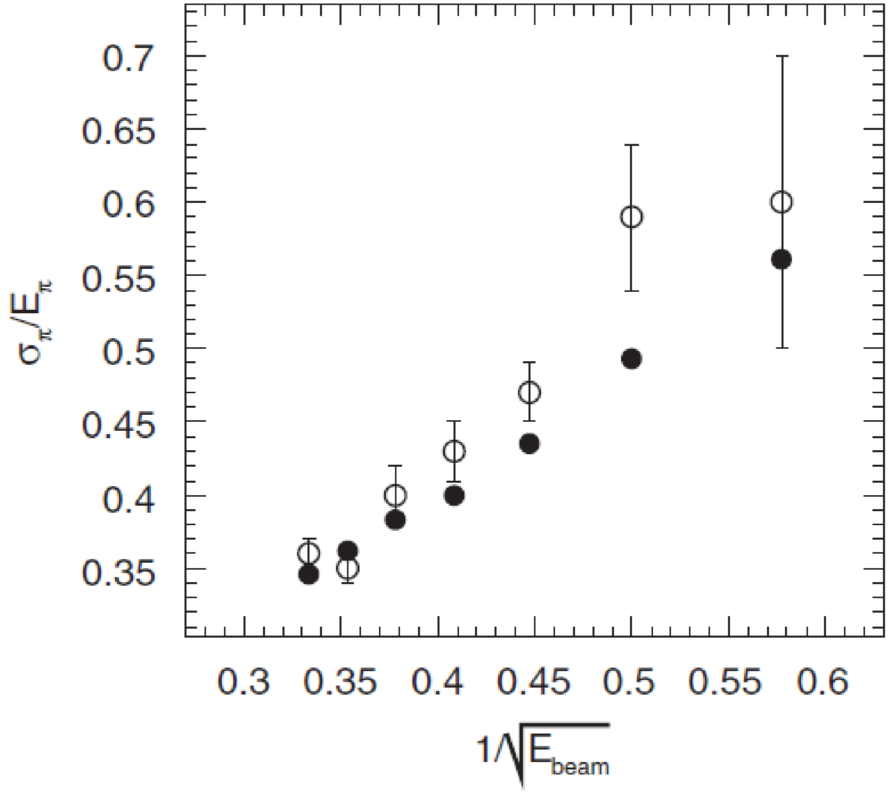
5 GeV pions at $\eta = 0.35$

CTB: Low energy pion Response and Linearity

Energy response ratio. Data: open points and MC: full points vs Ebeam at η = 0.45



Fractional resolution. Data: open points and MC: full points vs Ebeam at η = 0.45

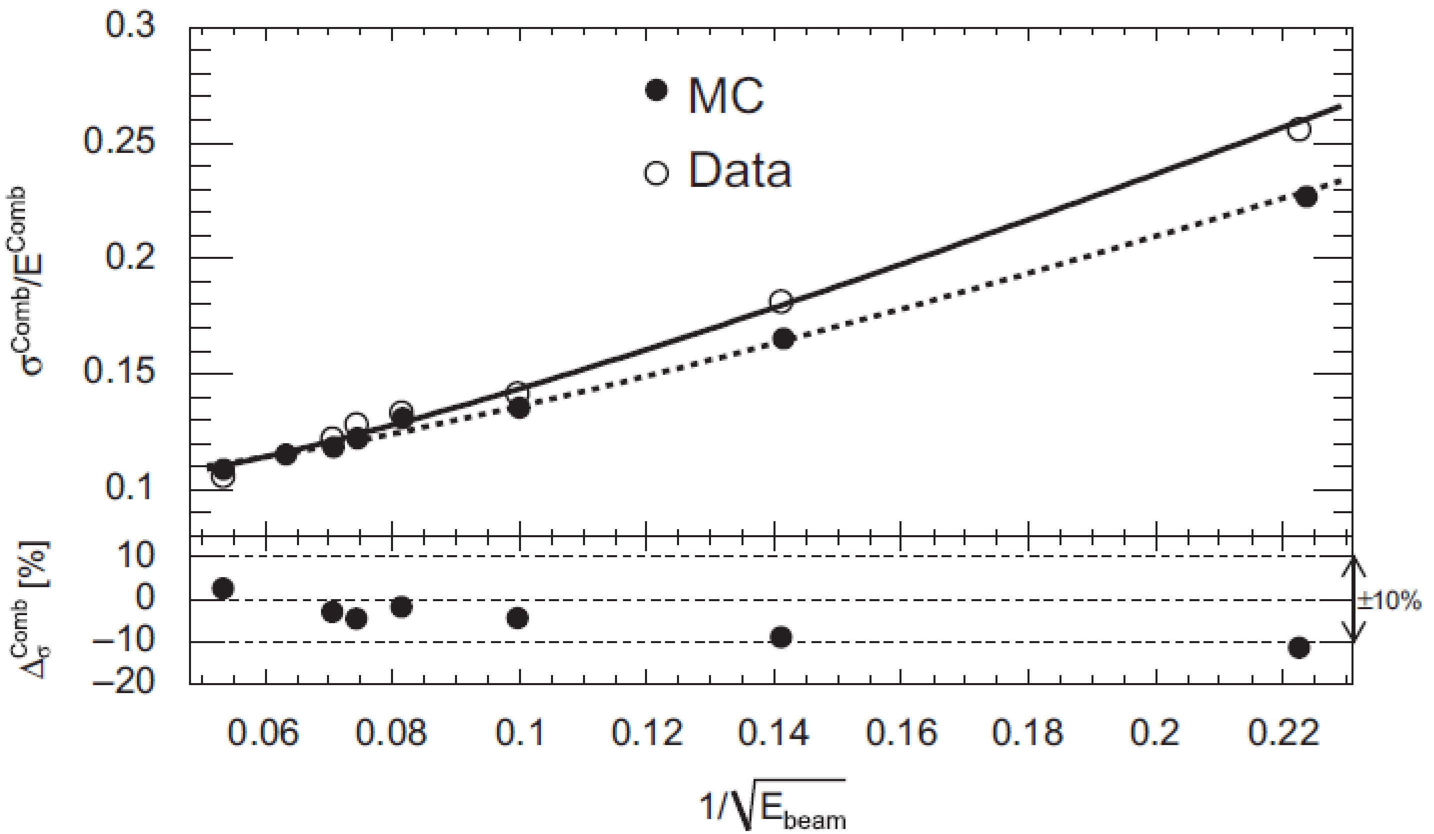


- The precision of the measurements varies from about 10% at 3 GeV to few percent at 9 GeV.
- The simulated response is larger than the measured one. It ranges from +5% at 9 GeV to +15% at 3 GeV.
- The MC show a better resolution. The agreement seems to improve at higher E_{beam} and to get worse at larger η

CTB: Response and Linearity of high energy pions

- The response has been determined with un uncertainty of about 2%.
- The error on the resolution is equal to ≅ 1% for all the energies.
- The MC is able to reproduce the response to within a few percent. The energy resolution in general is narrower in the simulation than in the data.

Energy resolution. Data: open points and MC: full points vs. E_{beam} at η = 0.55

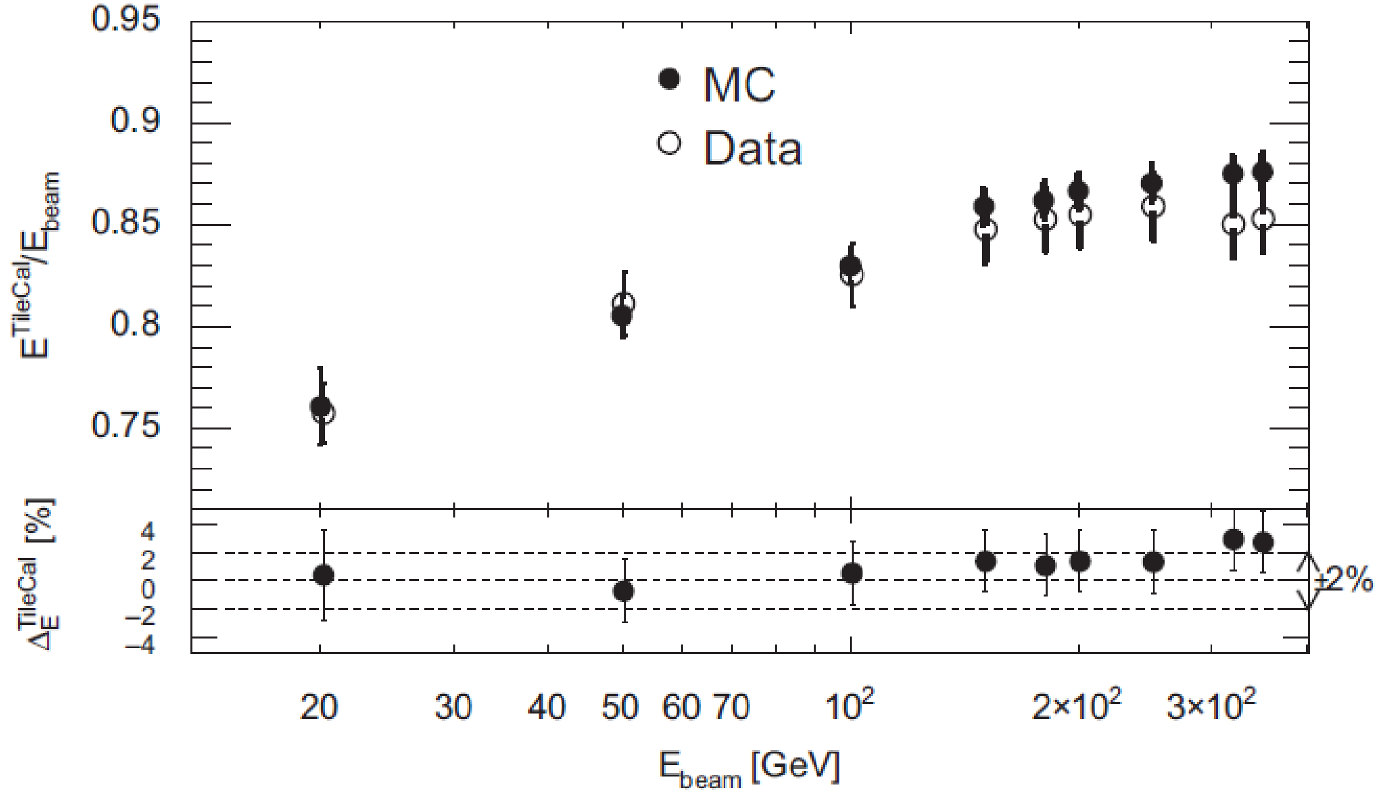


CTB: Response and Linearity of high energy pions showering in TileCal

- Shower selected requiring a MIP in LAr

- The response has been determined with un uncertainty of about 2.5%.
- The error on the resolution is equal to ≅ 2% for all the energies.
- The MC is able to reproduce the response to within a few percent. The energy resolution in general is narrower in the simulation than in the data.

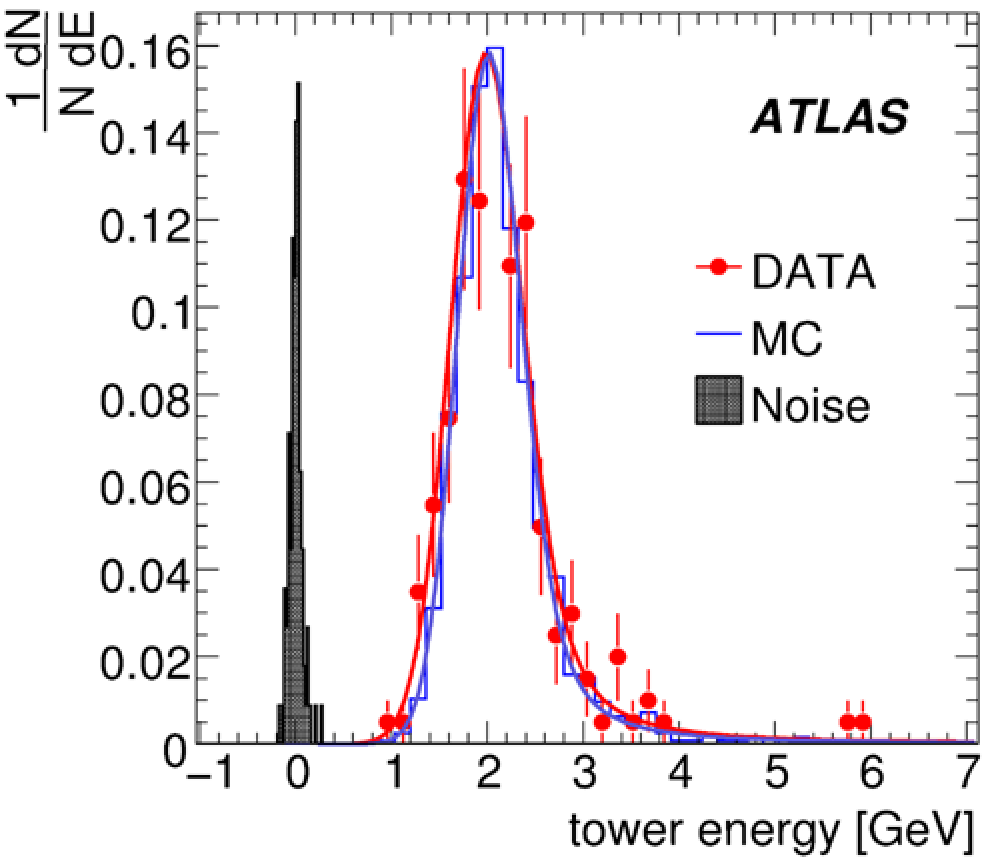
Energy response ratio. Data: open points and MC: full points vs E_{beam} at $\eta = 0.25$



Detector response studies in the experimental hall

- Performance with cosmic rays muons
  - Check detector response uniformity and stability
  - Check the transportation of the EM scale from the test beam to ATLAS
- Performance with isolated pions
  - Check detector response uniformity and stability
  - Comparison with Geant 4 MC
- Performance with inclusive p-p events
  - Check detector response uniformity and stability
  - Comparison with Geant 4 MC

Performance with single muons

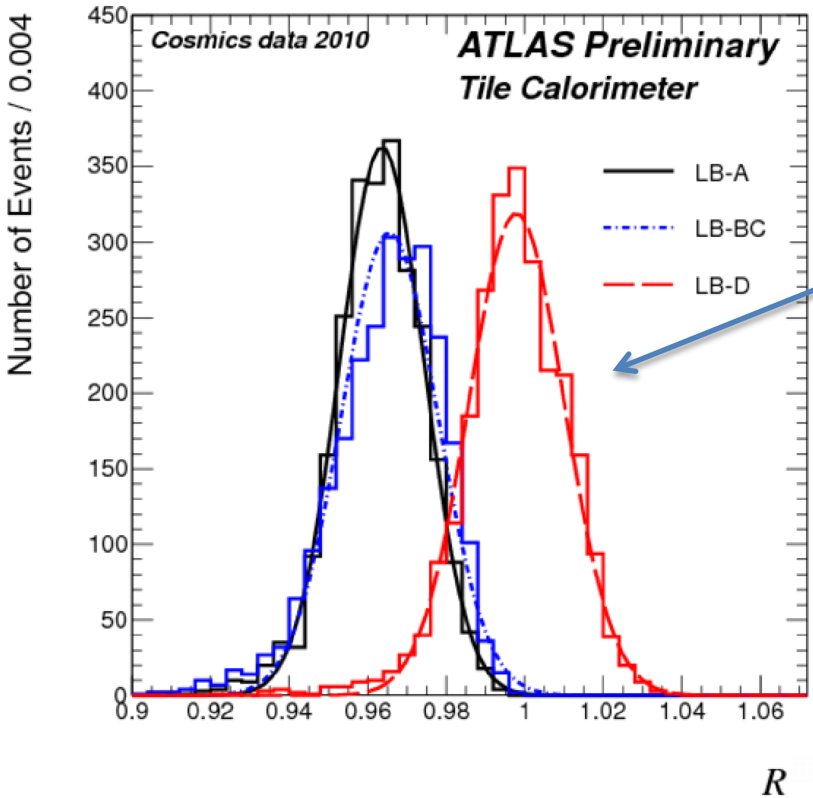


- Muon signal in TileCal is well separated from noise
- Cosmic muons can be used to cross-check cell energy inter-calibration and overall EM scale
- Data and MC dE/dx comparisons as a function of η and ϕ show good cell inter-calibration within one layer (within 2-4%)

Validation of absolute EM scale

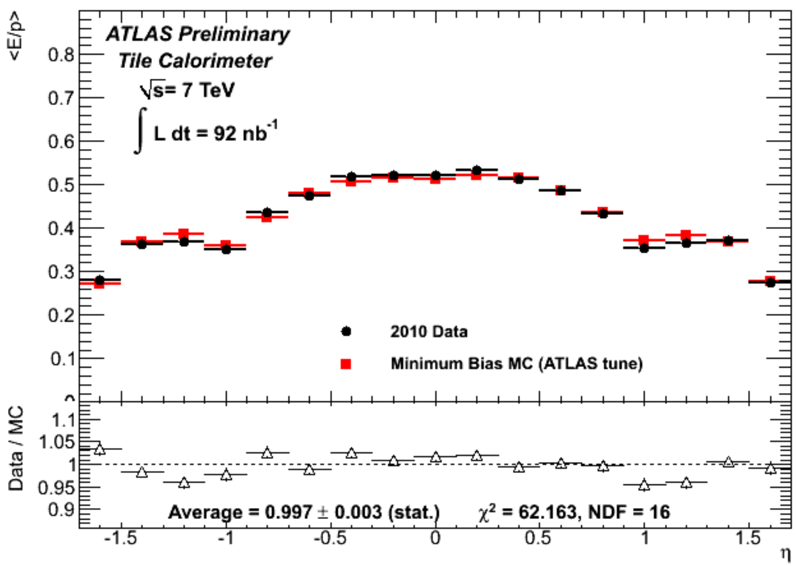
<dE/dx> Data/<dE/dx> MC

Layer	2008	2009	2010
LB-A	0.966 ± 0.012	0.972 ± 0.015	0.971 ± 0.011
LB-BC	0.976 ± 0.015	0.981 ± 0.019	0.981 ± 0.015
LB-D	1.005 ± 0.014	1.013 ± 0.014	1.010 ± 0.013
EB-A	0.964 ± 0.042	0.965 ± 0.032	0.996 ± 0.037
EB-B	0.977 ± 0.018	0.966 ± 0.016	0.988 ± 0.014
EB-D	0.986 ± 0.012	0.975 ± 0.012	0.982 ± 0.014

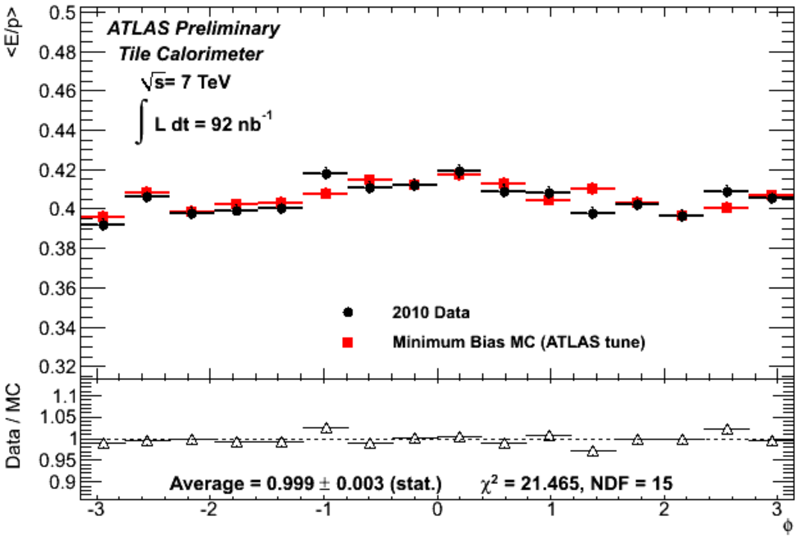


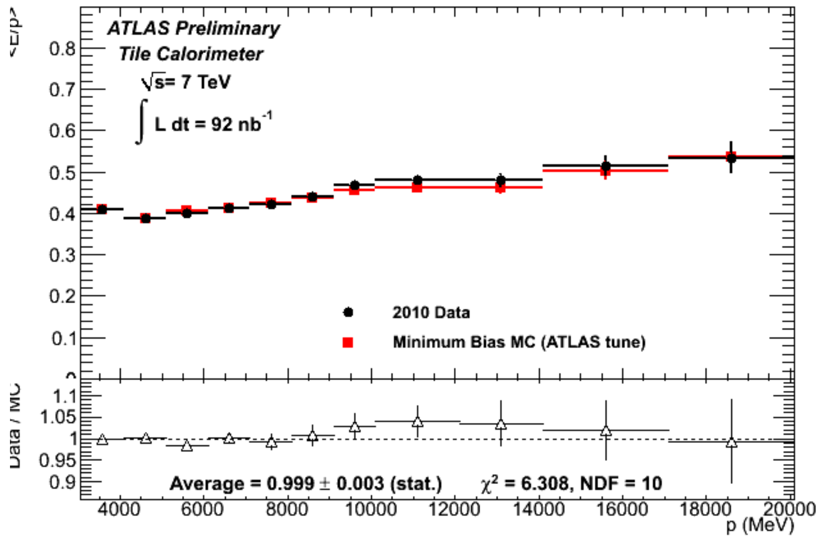
- Comparison of cosmic muon signals over 3 years shows that signal in 3 barrel and 3 extended barrel layers is stable over time
  - Results prove that the Cs calibration applied during this 3-years period is correct
- The ratio between the actual value of the EM energy scale in ATLAS and the value set at the beam tests is consistent with 1 within ±2%
- Difference between barrel layer D and all other layers is observed
  - Distributions of the pseudo measurements ratios of the experimental and simulated truncated means. The pseudo measurements were obtained changing the criteria applied to select and to reconstruct events

E/p from hadrons in collisions (2010)

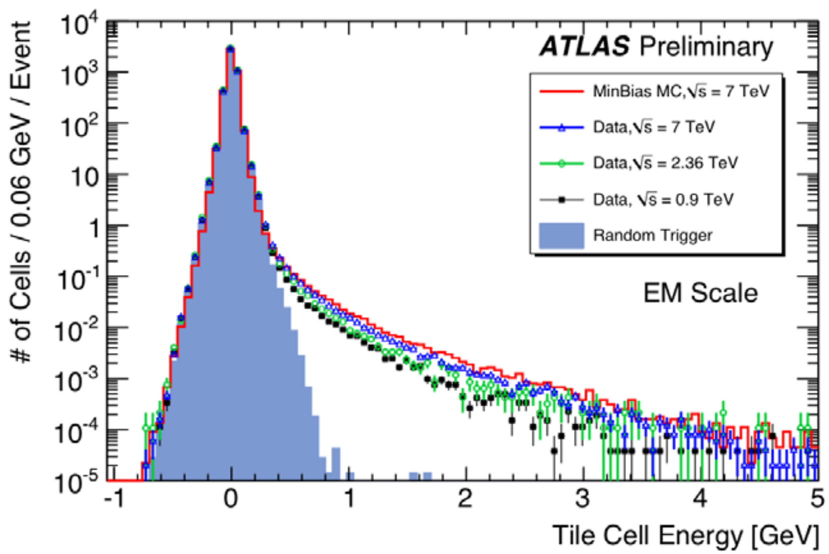


- Isolated particles showering in TileCal are selected
  - Particles are "MIPs" in the Electromagnetic Calorimeter
- Momentum is measured with tracking inner detector
- Excellent agreement with MC is observed (hadron shower tuned on testbeam data)

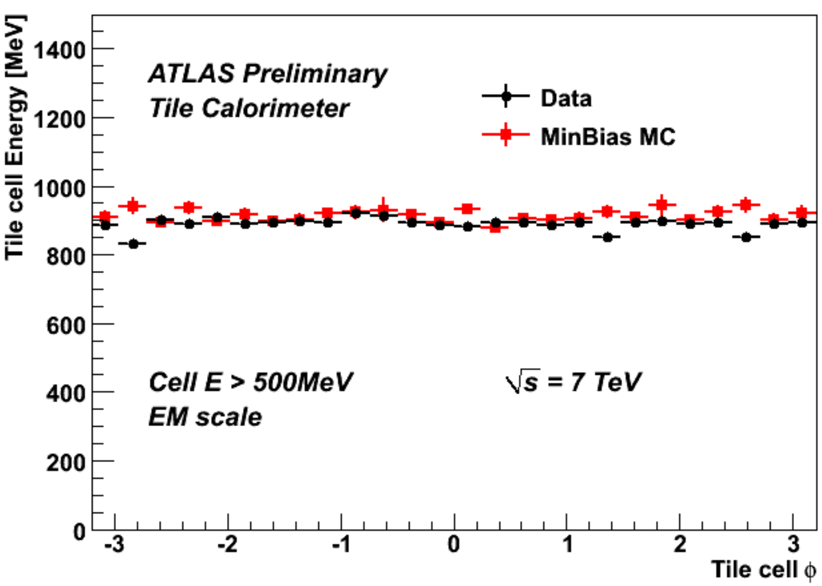


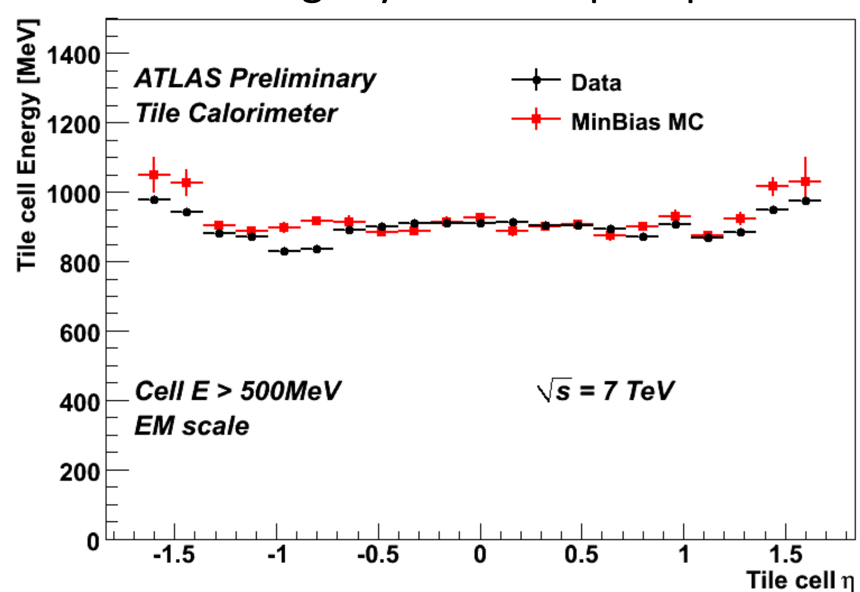


Inclusive p-p events (2010)



- Good agreement between Data and MC is observed in cell energy spectra in Minimum Bias events
  - o Agreement in negative energy tail confirms correct description of noises in MC
- Good uniformity between modules (ϕ distribution), small differences between Barrel and Extended Barrel partitions due to pileup (η distribution)
  - o and slightly different pileup in MC





Conclusions

- TileCal is performing well during the first years of LHC data taking. It fulfills the design goal
- Despite of the 5.1% masked cells, TileCal provided 99.2% of good data for physics at the end of 2011
- EM scale has been successfully transferred from beam tests and validate with cosmic rays muons (Maximum difference between radial layers is 4%)
- The calibration systems are commissioned and are working well. Precision of individual system is below 1%. Calibration constants applied to data make response stable in time
- MC simulation agrees well with data (noise description, response to muons, single hadrons and p-p events)

A project 20 years old …

P. Jenni – Expression of interest – EAGLE collaboration
General Meeting on LHC Physics and Detectors
Evian-les-Bains, France, 5 - 8 Mar ***1992***

Scintillator tile hadron calorimeter conceptual design

Novel concept for a simple and economic hadronic scintillator calorimeter with Fe absorber and possibly integrated magnetic field return

Vertical scintillator plates (w.r.t. barrel axis) read out with straight wave length shifting fibers at two edges (light collection experimentally checked)

Granularity $\Delta\eta \times \Delta\phi \sim 0.1 \times 0.1$ with 4 longitudinal samples, 15000 channels total

η-projectivity by grouping WLS readout fibers of the longitudinal samples to form approximatively pointing towers

Expected jet resolution (MC simulation assuming a 25 X_o Pb - LAr EM calorimeter in front)

$$\sigma(E)/E = 41\%/E + 2\%$$