Simulation and validation of the Atlas Tile calorimeter at LHC

Outline:

- The Tile calorimeter
- Sampling fraction
- Noise
- Shower shapes and mean energy
- Energy resolution
- E/p
- Summary

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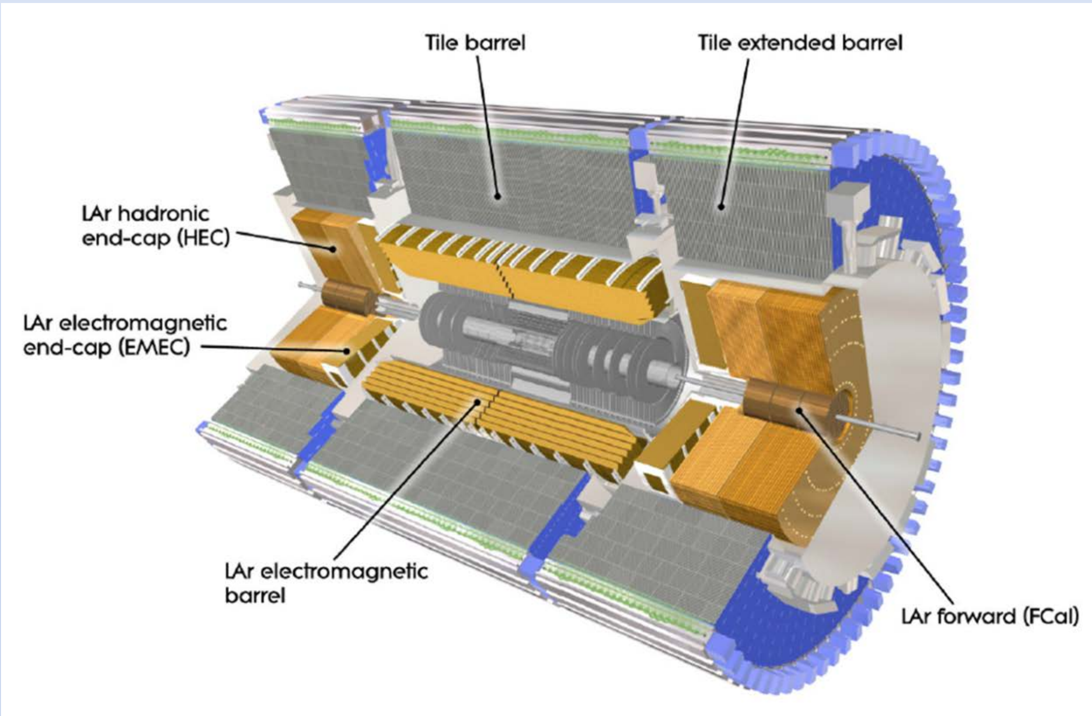
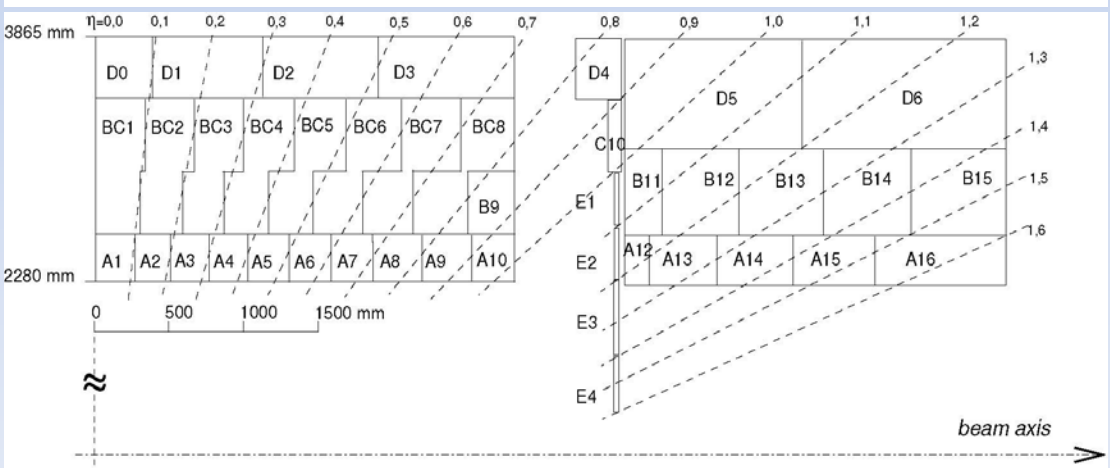
Tile Calorimeter in Atlas



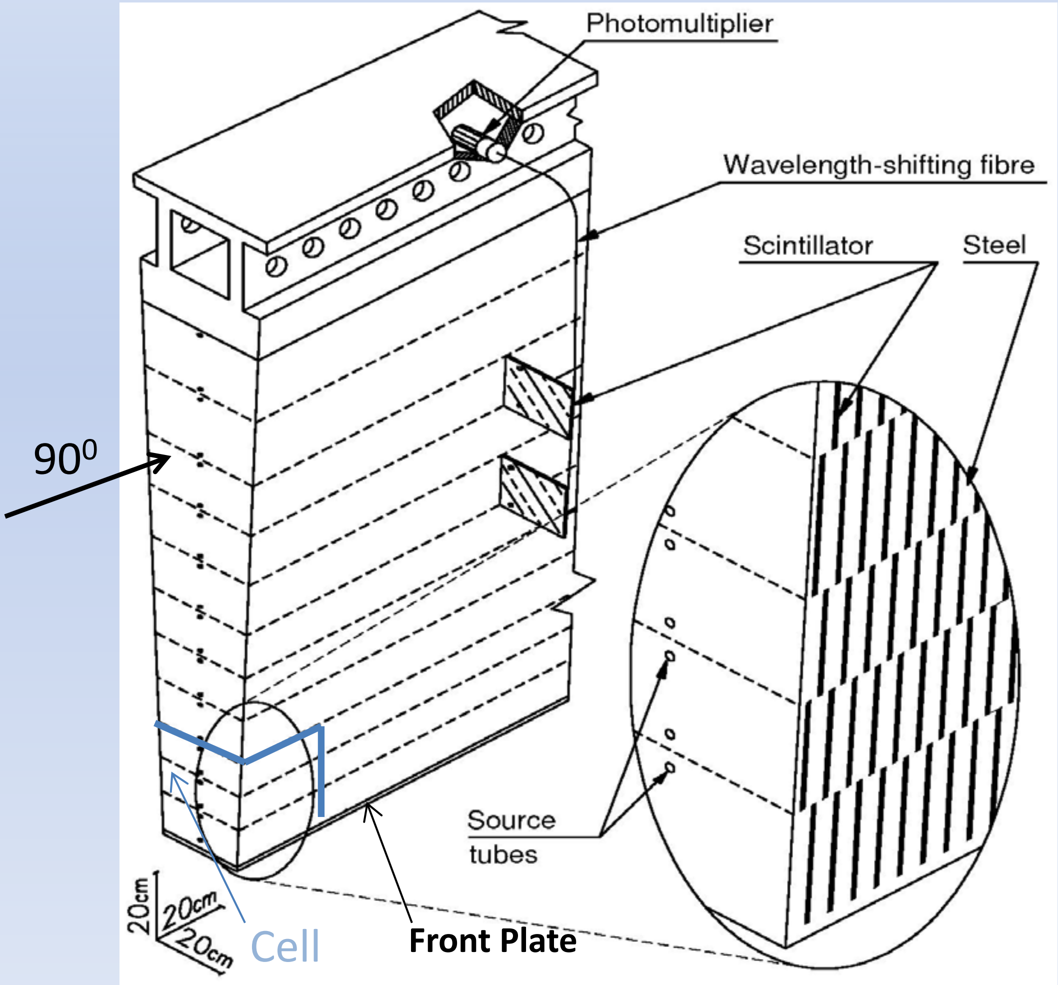
- *Total length: 12 m, diameter: 8.5 m*
- *Total thickness of TileCal:*
  7.4 λ_{int} at η=0.
- *Three radial samplings: A, BC, D*
- *Steel absorber plates with*
  Scintillating tiles
- *Coverage: |η|<1.7*
- *Four partitions, over 5000 cells,*
  Two PMTs per cell
- *Design resolution for jets*
  (LAr + Tile): $\frac{\sigma}{E} = \frac{50\%}{\sqrt{E}} \oplus 3\%$

Geometry is not completely symmetric, there are cells with special shape, asymmetric inactive material etc.

All currently known geometric details are carefully described in the MC geometry model



Module layout



- *Each barrel is divided in 64 modules in φ*
- *Cell granularity is*
  $\Delta\eta \times \Delta\varphi = 0.1 \times 0.1$
  (0.2 x 0.1 in outermost radial layer)
- *Each cell is read by two photomultiplier tubes (PMTs) from either side of the cell (except for some special cells) via wavelength shifting fibers.*

Sampling fraction calculation *test beam studies*

Output from the simulation (hit level) – energy released in the active material E_{sci}

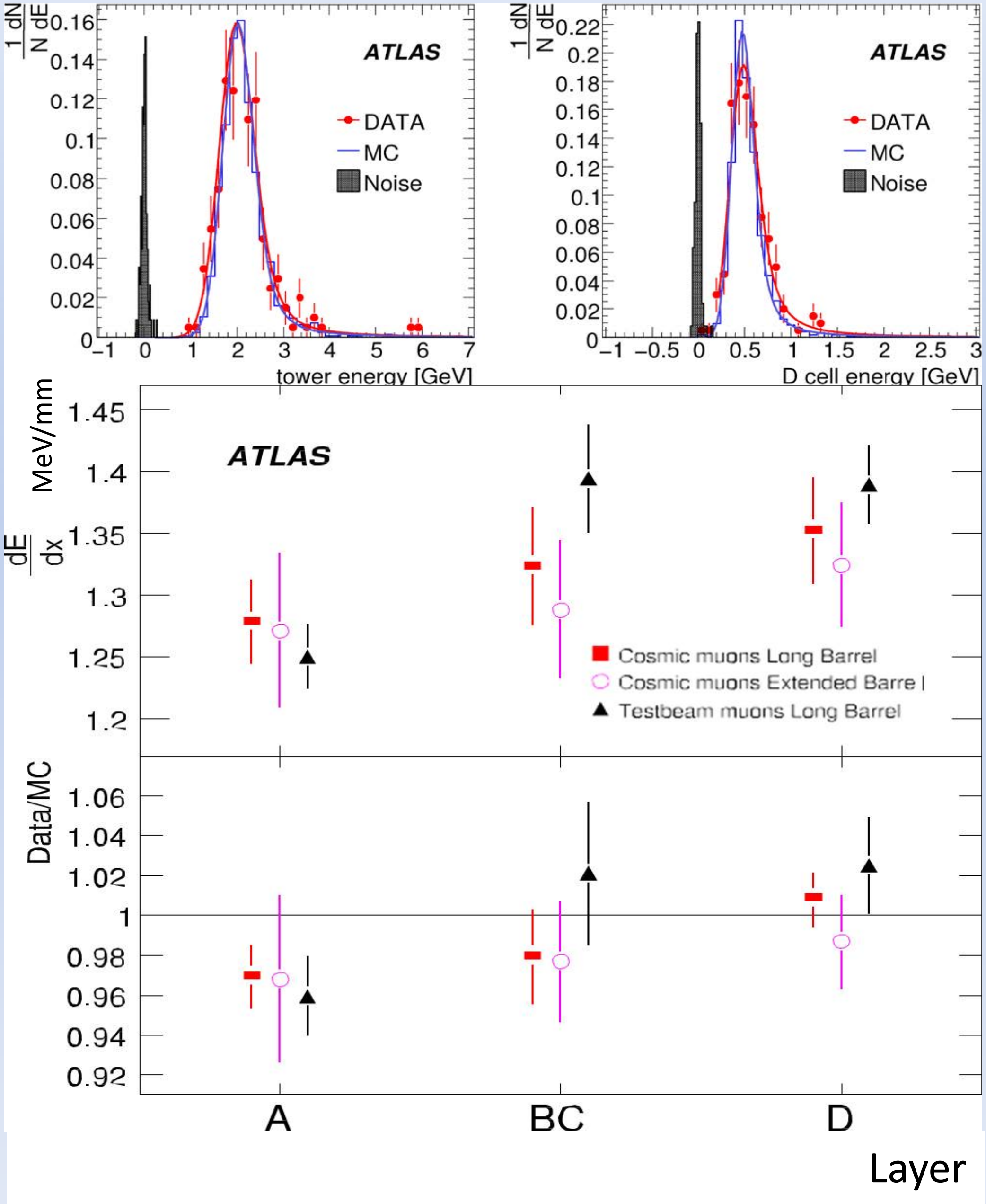
- ***Cell energy is calculated as energy in the scintillators multiplied by a constant value 1/SF (sampling fraction)***
- ***$E_{beam}/E_{sci} = 1/SF$***

Single particle simulation as in testbeam

- ***Electron beams at 5, 20 and 100 GeV, Eta-projective geometries (η from 0.05 to 0.95)***
- ***Single electron simulated samples at 90 degrees***
- ***1/SF almost constant in η range 0.25 – 0.85***
    - ***At η 0.95 – Leakage (largest effect for 100 GeV)***
- ***Fraction of energy released in scintillators increases with Energy partially due to losses in the front plate***

E_{beam} [GeV]	η 0.25-0.75	90 degrees	η & 90^0 average
5	34.341 ± 0.018	33.934 ± 0.019	34.14 ± 0.20
20	34.140 ± 0.011	33.494 ± 0.009	33.82 ± 0.32
100	34.045 ± 0.005	33.356 ± 0.004	33.70 ±0.34

Validation of EM scale with muons in Atlas



Example of the muon signal and corresponding noise for projective cosmic muons entering the barrel modules at 0.3 < |η| < 0.4.

The truncated mean of the dE/dx for cosmic and testbeam muons shown per radial compartment and, at the bottom, compared to Monte Carlo.

The error bars shown combine both statistical and systematic uncertainty summed in quadrature

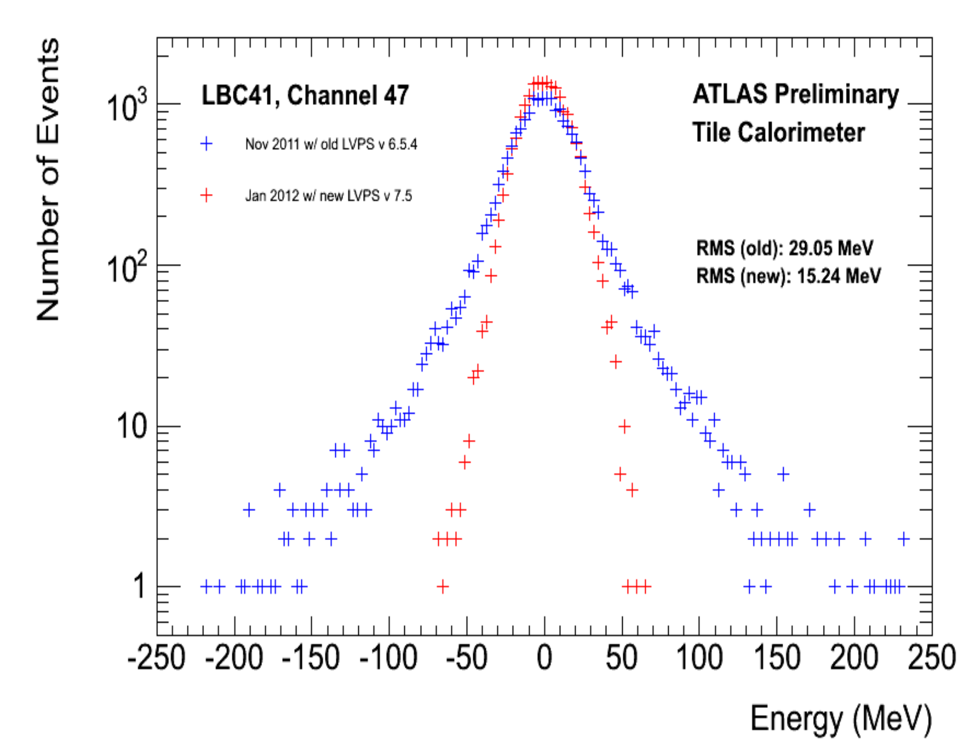
The results show that reconstructed dE/dX for MC and data are compatible to a few % level

Electronic Noise (I)

- ***Electronic noise in Tile is not Gaussian. We approximated it with two Gaussians. Mainly, it comes from the Low Voltage Power Supply (LVPS) providing power for front-end electronic.***

- ***Due to the tails we need special treatment to reduce the number of fake topological clusters.***

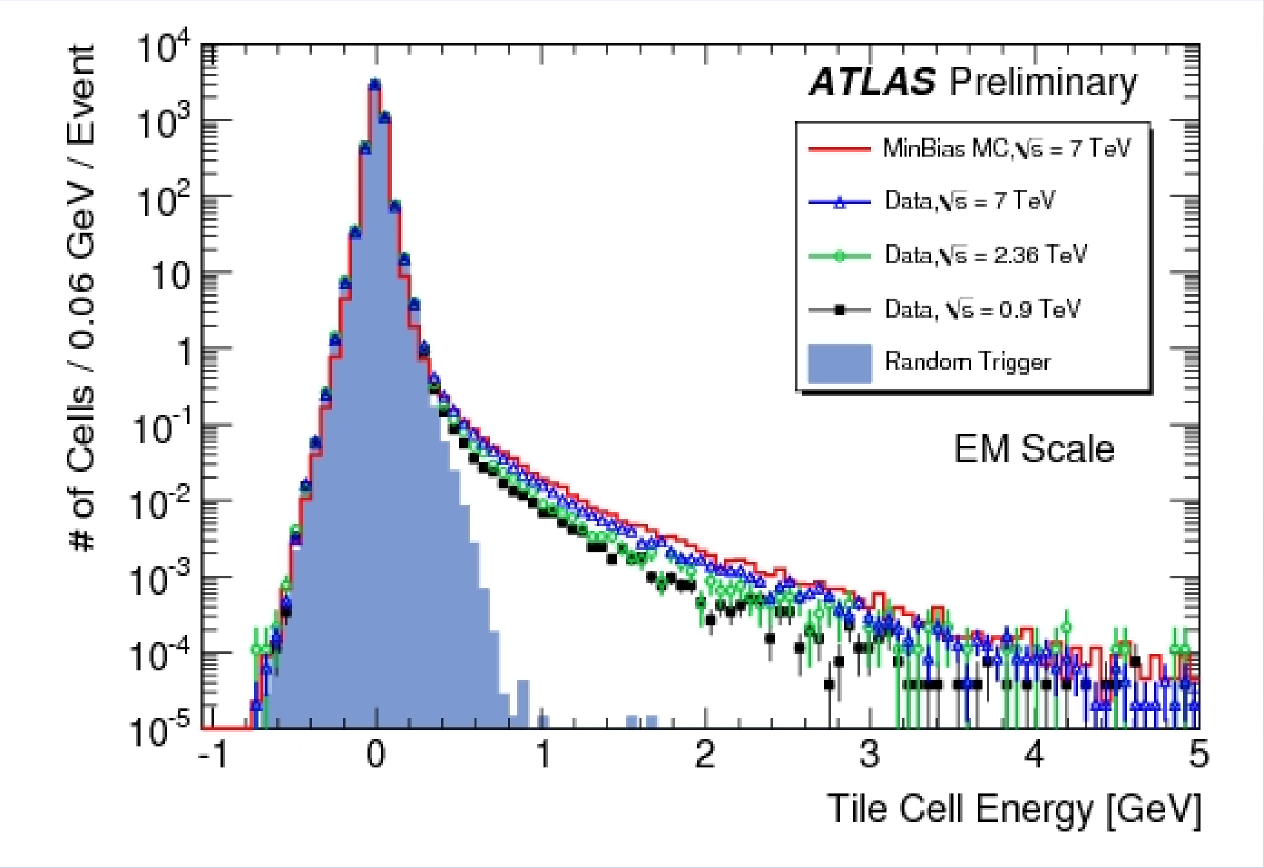
- ***Typical RMS values are ~20 MeV***



On this plot there is an example of noise for channel, which had previously high double Gaussian shape (blue). Now it is equipped with new version of LVPS (red). New LVPS also reduce correlated noise.
After the 2013 – 2014 LHC shutdown, all channels should be equipped with new LVPS showing almost perfect Gaussian noise and improved correlated noise.

Both noise cases are implemented in MC

Electronic Noise (II)



The distributions from collision , no pileup, data at 7, 2.36, and 0.9 TeV are superimposed with minimum bias Monte Carlo and randomly triggered events.

Negative side demonstrates good agreement with MC noise description using the Double Gaussian description.

Noise with pileup

- ***Pileup is characterized by the average number of minimum bias collisions μ overlaid to the hard scattering event***
- ***Its magnitude varies with the calorimeter radial layer (A, BC, D) and η***
- ***For constant bunch spacing pileup RMS is expected to scale with $\sqrt{\mu}$***
- ***Pileup constants in the database are numbers for luminosity = 10^{33} $cm^{-2}s^{-1}$ (2.3 pileup collisions and 25 ns bunch spacing (DT))***

  B = RMS(pileup) x $\sqrt{lumi}$ (lumi in 10^{33} unit)

  lumi depends on the average number of pileup collisions and bunch spacing

  lumi (μ, DT) = (μ /2.3) * (25.0 /DT)

For simulations at 14 TeV and μ = 46

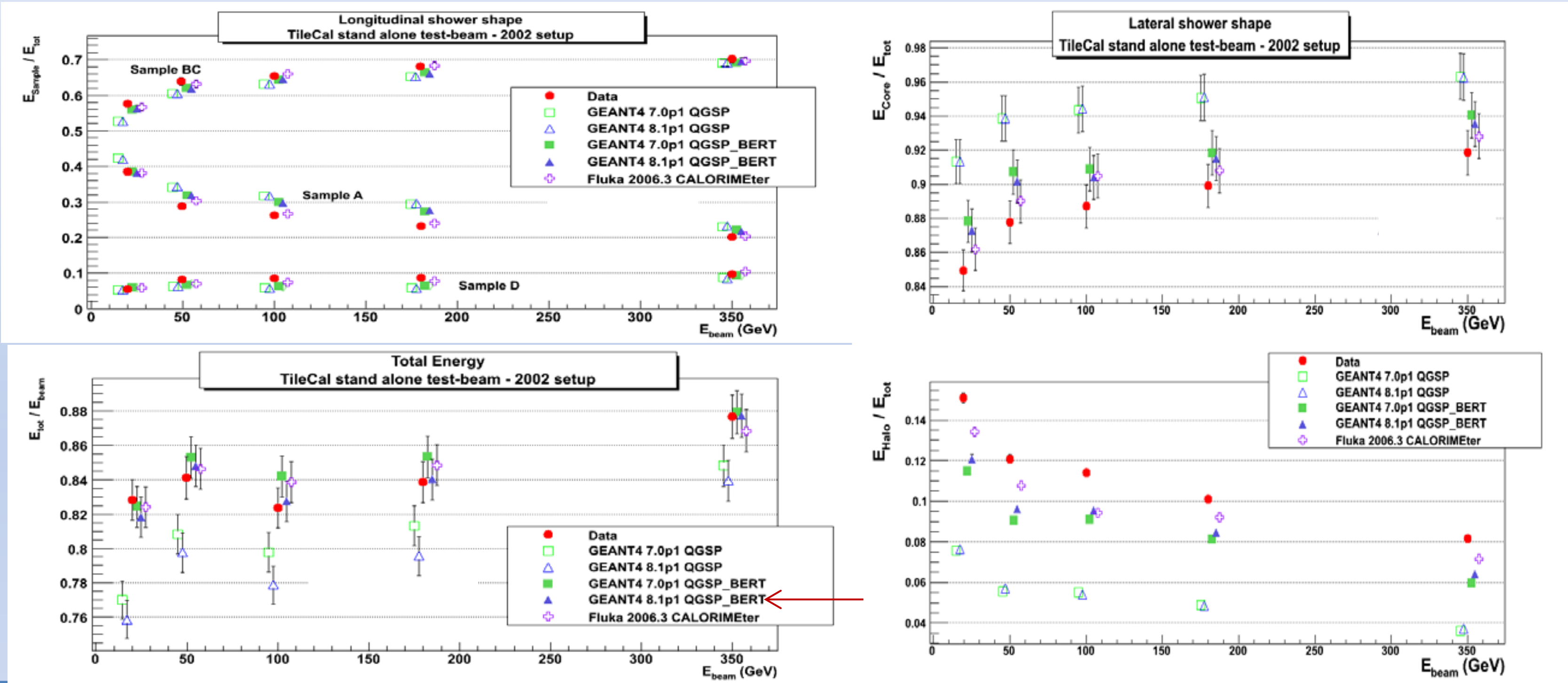
In the barrel region

- ***Largest pileup contribution in the sample A (~40-50 MeV – depending on η)***
- ***In sample BC it is ~20 MeV***
- ***In sample D pileup is ~2 times less than electronic noise***
- ***Larger pileup contribution in the endcaps compared to the barrel***

Maximum pileup RMS in the region |η| ~ 1.0 - 1.4

- ***In regions where pileup noise is dominant, the noise in the MC simulation agree with the data with ±20%***

Data-MC comparison – shower shape and mean energy



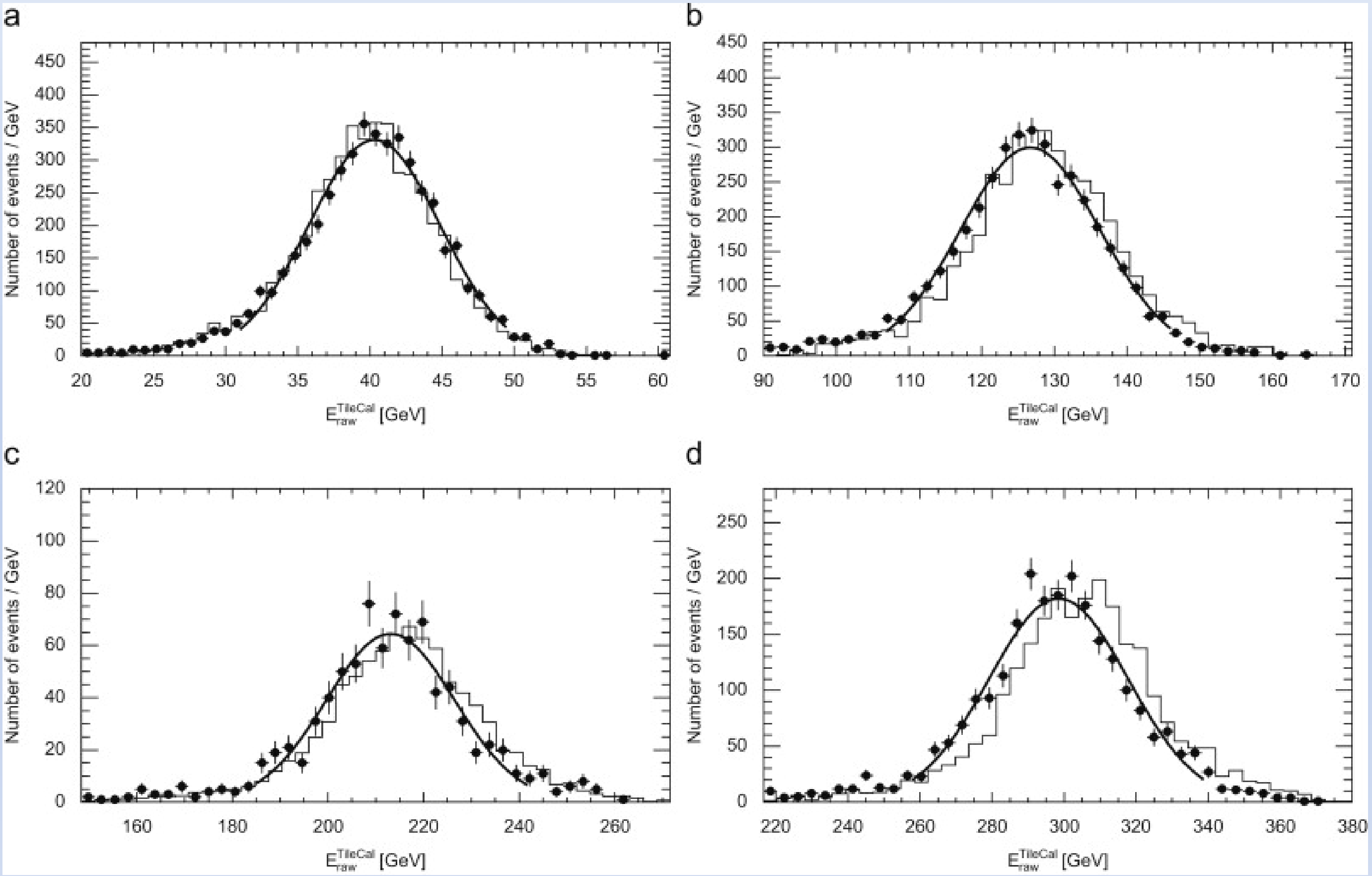
Pion test beam at $\eta = 0.35$

- *E_{CORE} is the energy released in the projective tower hit by the pion*
- *The energy in the volume around this tower measures the size of the shower halo (E_{HALO})*
- *The agreement of shower characteristics defined the choice of Geant model*
- *This level of agreement was the main element of uncertainly at high P_T for single hadrons in Atlas*

Data-MC comparison - Resolution (I)

Single pions beam tests

EM scale response TileCal

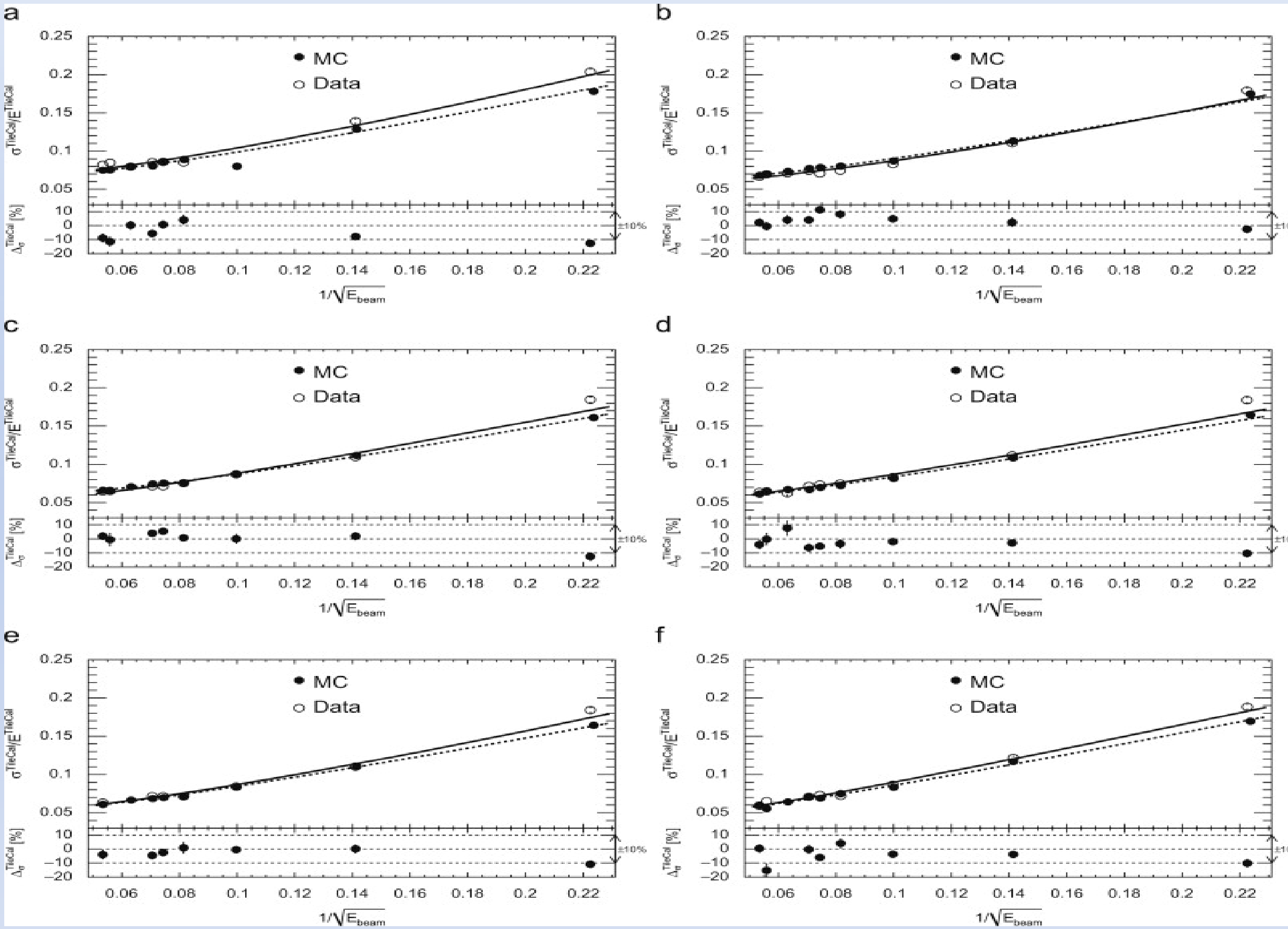


Distribution of the reconstructed energy $E_{raw}^{TileCal}$ obtained for E_{nom} equal to (a) 50 GeV, (b) 150 GeV, (c) 250 GeV and (d) 350 GeV, and η=0.45. The full points represent the experimental data. The solid curves correspond to the fit of a Gauss function to the data . The histograms correspond to the prediction of the Monte Carlo simulation (model - QGSP-Bertini)

Data-MC comparison - Resolution (II)

Single pions beam tests

EM scale response TileCal



Resolution, measured (open circles) and predicted by Monte Carlo (full points) as a function of $1/\sqrt{E_{beam}}$ for different η_{beam} values: (a) 0.20, (b) 0.25, (c) 0.35, (d) 0.45, (e) 0.55, and (f) 0.65. In the bottom of the histograms are shown the fractional differences $\Delta_\sigma^{TileCal}$. E_{beam} is in GeV. The dashed horizontal lines indicate the ±10% region. The solid (dashed) curves are fits to the data (MC) points . (QGSP BERTINI sower model)

Data-MC comparison - Resolution (III)

- ***The experimental results are well represented by the parameterization***

$$\frac{\sigma}{E} = \frac{a}{\sqrt{E_{beam}}} \oplus \mathbf{b}$$

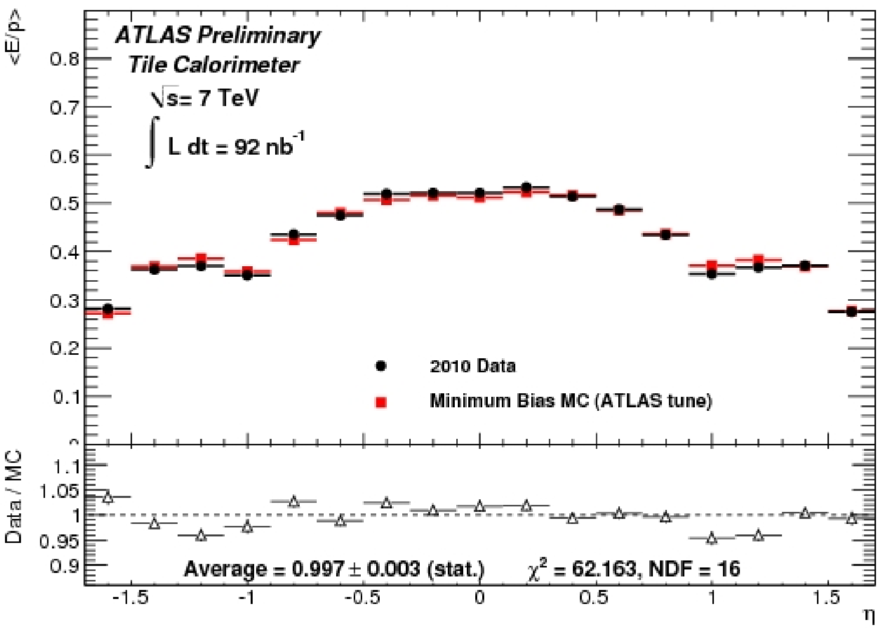
- ***The values of a and b obtained by fitting this equation to the experimental data.***

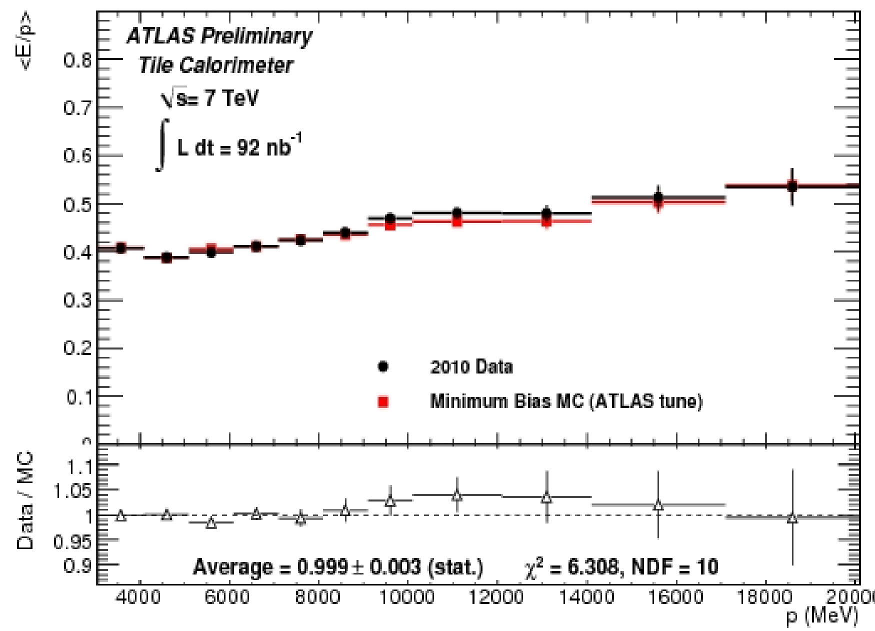
- ***The values of a (b) are ≅75% (≅5%) for Tile.***

- ***The corresponding functions are superimposed to the measurements (see plots on previous page)***

- ***Adding the noise term*** c/E_{beam}***, the fits give values of c compatible with 0***

Data-MC comparison – E/p (IV)





- ***2010 Data and Monte Carlo simulation, 7 TeV collisions***
- ***integrated over all p ranges***
- ***Single hadrons, not interacting in liquid argon EM calorimeter (TileCal only)***

Summary

- ***Comparison of the results of Monte Carlo simulations and measurements in the test beams showed good agreement***
  - ***Lateral, longitudinal shower shapes***
  - ***Mean energy vs $E_{beam,}$ Energy distributions, resolutions***
- ***The sampling fraction calculation in MC is compatible with measurements in test beams***

- ***A solid basis for the full Atlas simulation was achieved.***
  - ***Models for both electronic noise and pileup noise are implemented in Monte Carlo, and show good agreement with data***
  - ***Expect to decrease electronic noise by factor ~2 and to Gaussian replacing power supplies with new ones during LHC shutdown 1.***

- ***The thorough validation of the Tile Calorimeter simulation for the beam tests and the precise implementation of the detector characteristics for the ATLAS environment, led to a very good description of the TileCal response of the collision data by the Monte-Carlo:***
  - ***Shown in muon energy deposition and single hadron E/p measurements.***