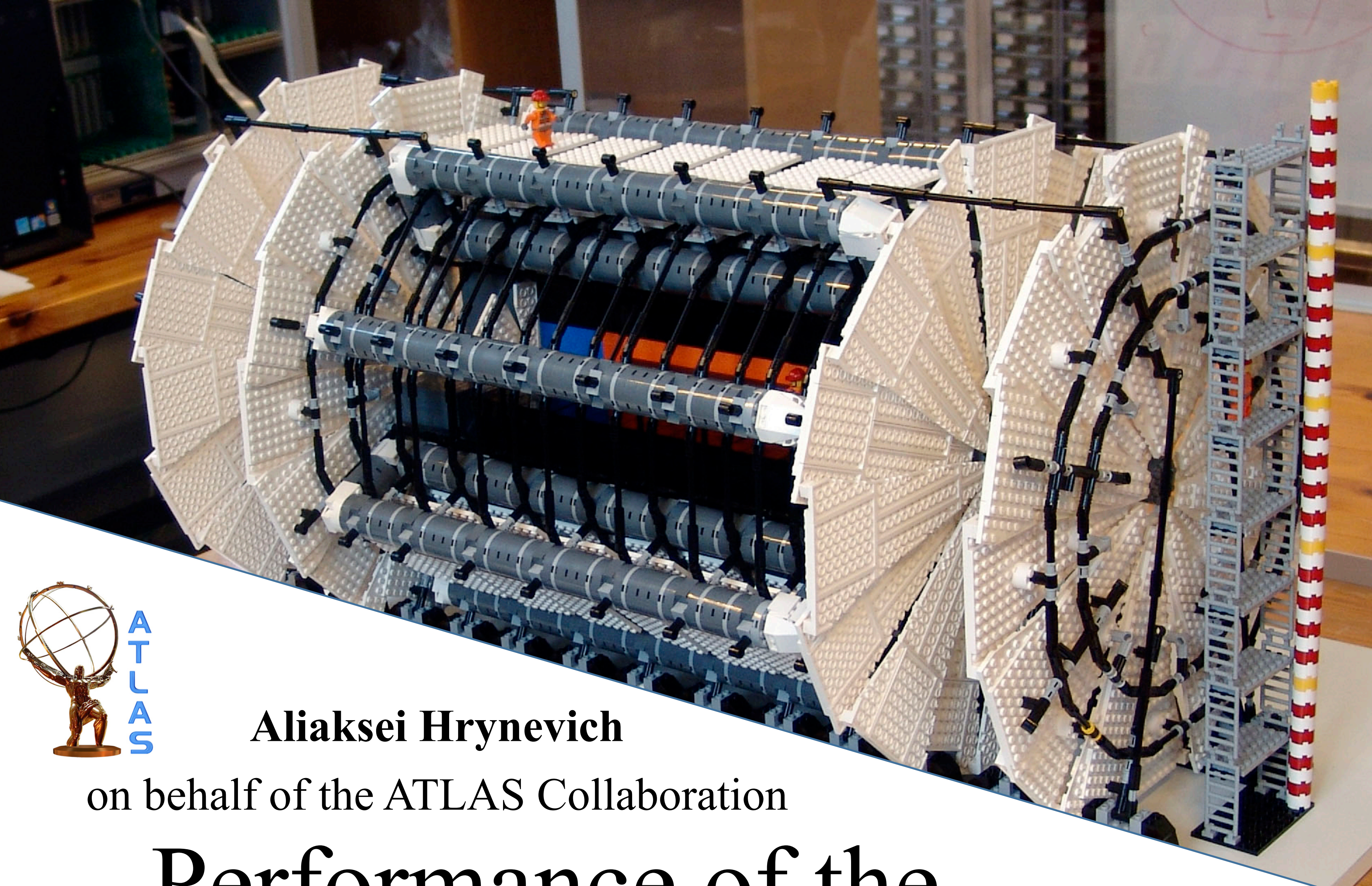


Aliaksei Hrynevich

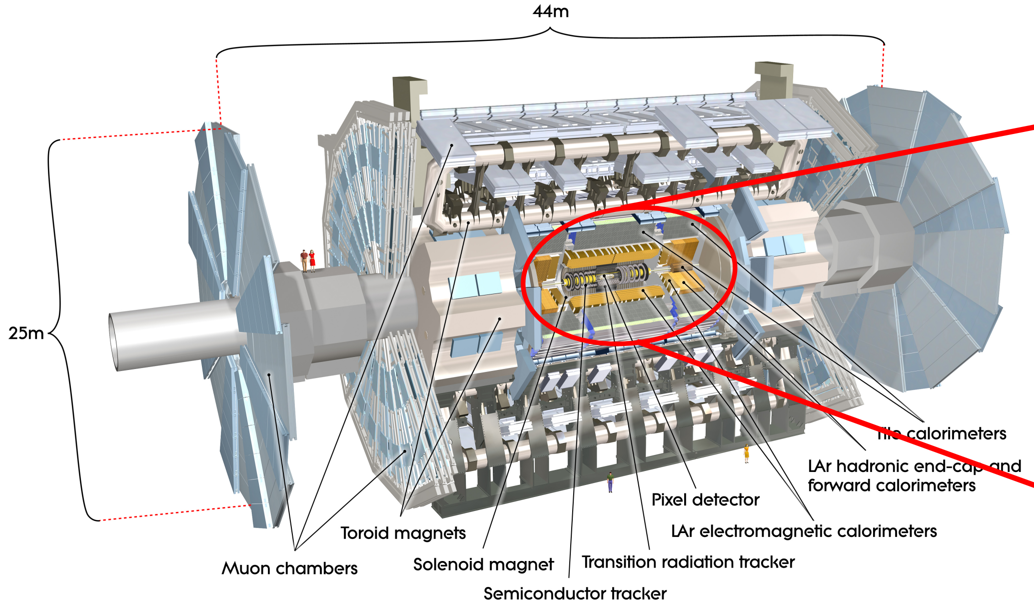
on behalf of the ATLAS Collaboration

Performance of the ATLAS **Tile Calorimeter**

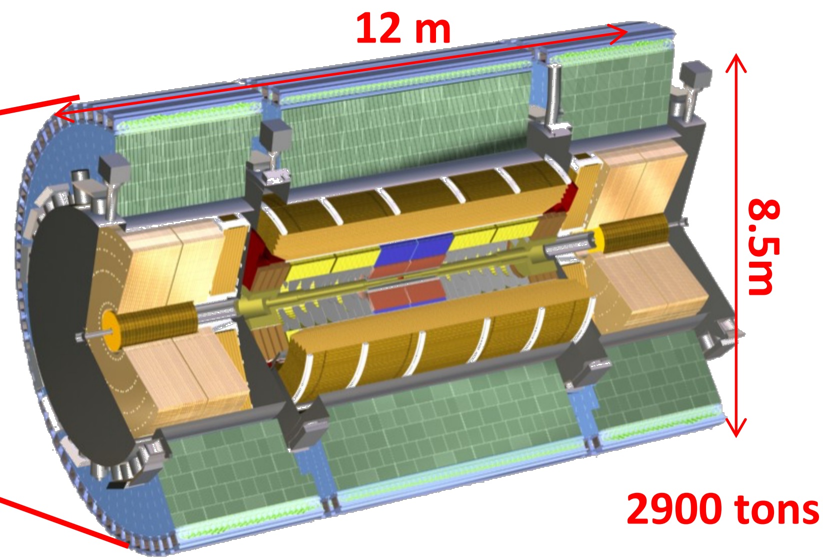
INSTR17
Novosibirsk
March 1st, 2017

Introduction

ATLAS detector



Hadronic Tile Calorimeter

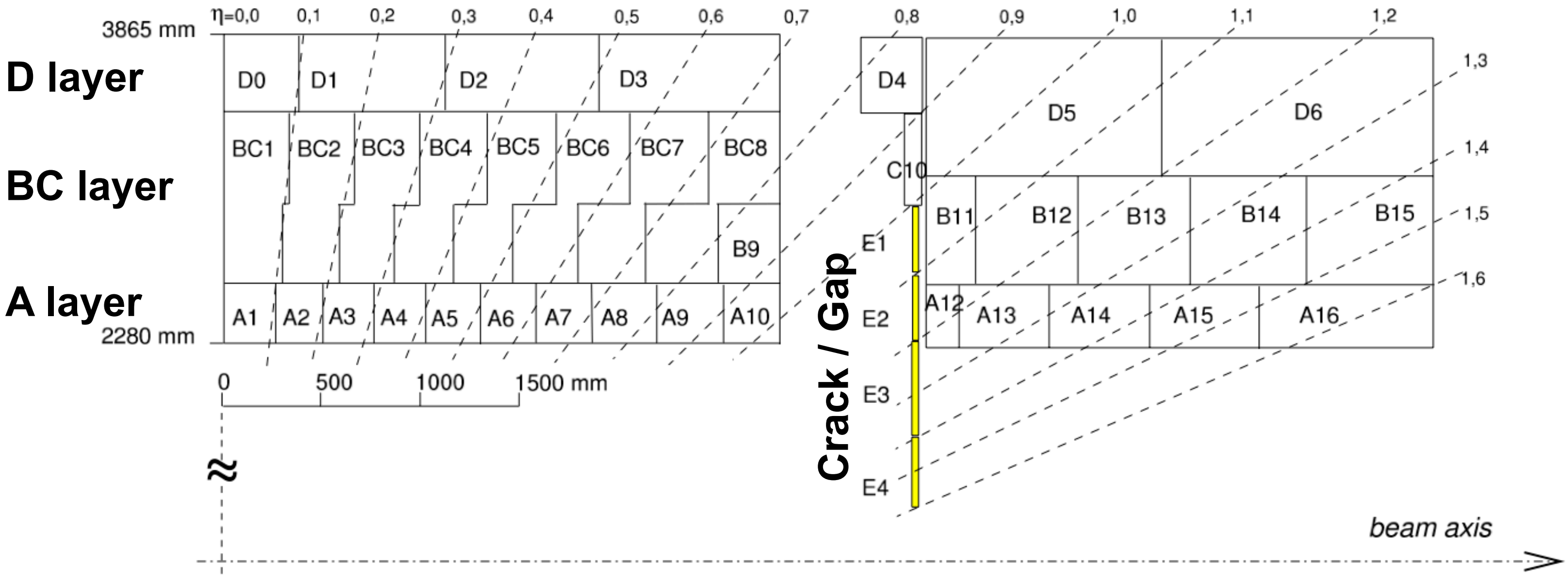


- ATLAS is the multipurpose detector at the LHC.
- Consists of internal tracker, electromagnetic and hadronic calorimeters, and external muon spectrometer.
- Allows a wide spectrum of high energy physics studies both within the Standard Model and Beyond.

- Tile Calorimeter is the hadronic sampling detector within ATLAS
- Located at the outer barrel of the ATLAS calorimetry system
- Intended for energy measurements of jets, single hadrons, tau-particles and missing transverse energy

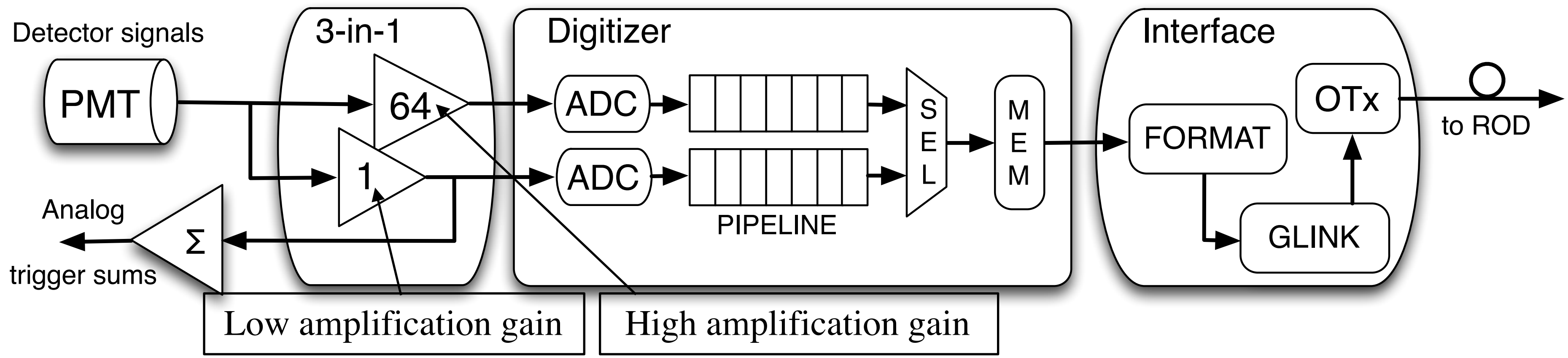
Tile Calorimeter structure

Long barrel (LB) $|\eta| < 1.0$ **Extended barrel (EB) $0.8 < |\eta| < 1.7$**

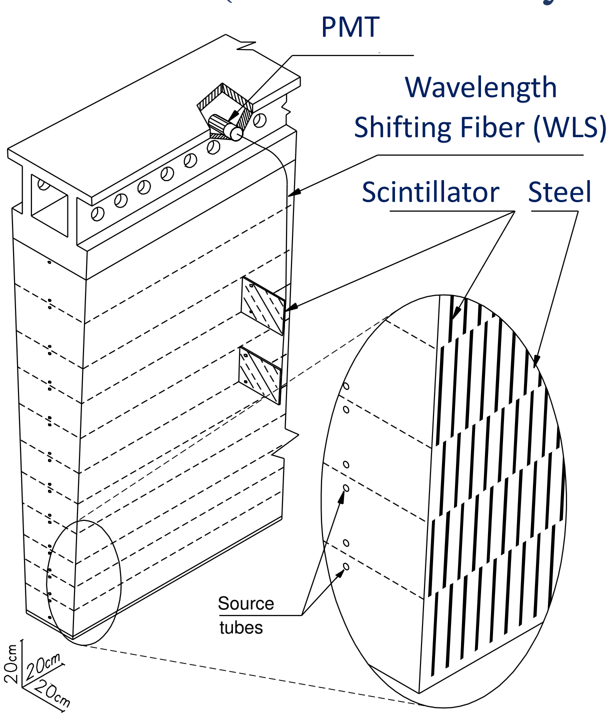


- Tile Calorimeter consists of one central Long Barrel cylinder and two Extended Barrels cylinders covering $|\eta| < 1.7$ and $0<\varphi< 2\pi$
- Segmented into 64 modules in azimuth
- Has three radial layers (7.4 λ_{int}) and the longitudinal Gap/Crack layer between barrels
- The granularity is $\Delta\eta \times \Delta\varphi = 0.1 \times 0.1$ (0.2 x 0.1 in the last radial layer)
- Consists of 5182 readout cells
- Designed energy resolution $\sigma/E = 50\%/\sqrt{E} \oplus 3\%$

Tile Calorimeter Read-Out

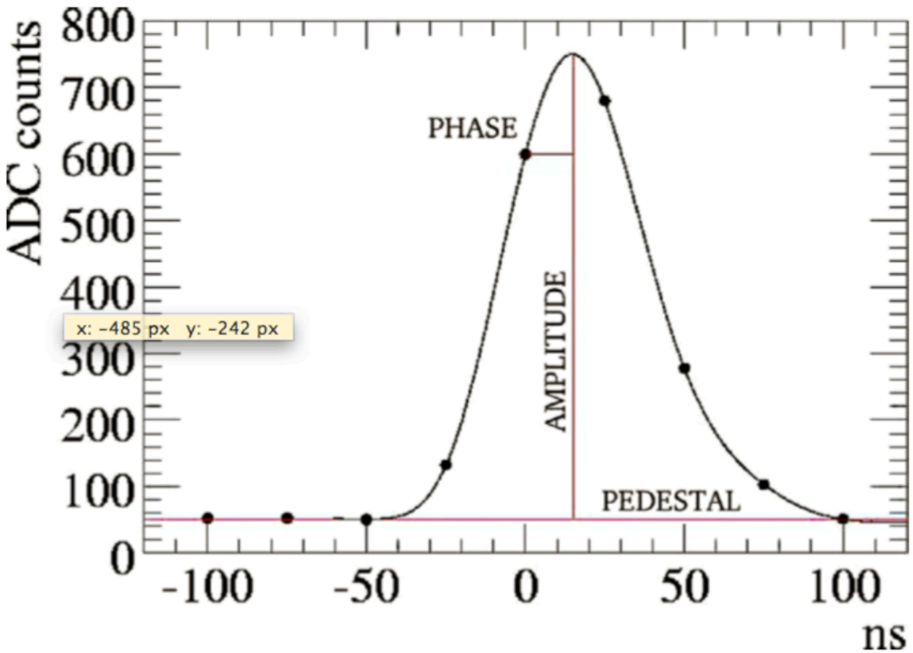


Tile Calorimeter is the sampling detector made of plastic scintillator and steel as absorber (scintillator only in crack/gap cells)



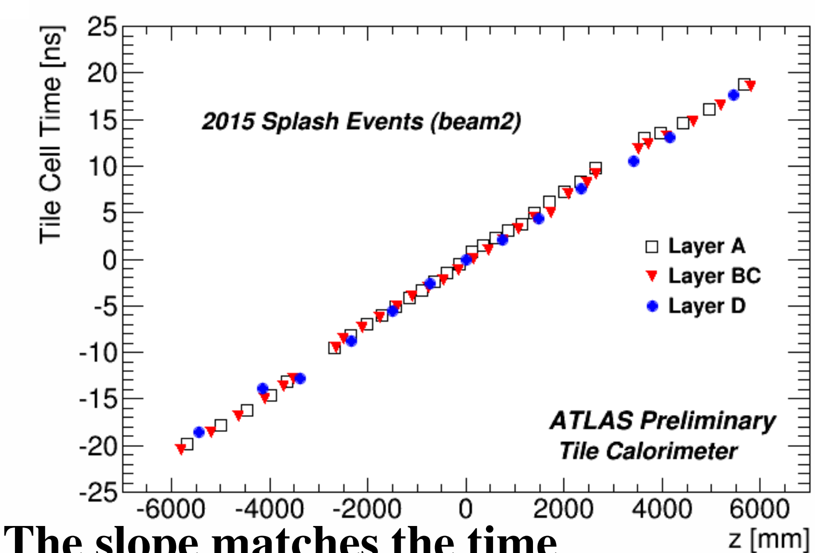
- Signal from each cell is routed by WLS to two PMTs (giving 9852 readout channels)
- Analog signal from each PMT is amplified by two gains (1:64), shaped and digitized by 3-in-1 card every 25 ns
- The digitised samples are stored in pipeline awaiting for L1 trigger accept
  - Analog signals contribute to L1 trigger
- The slower Integrator readout is routed before amplifiers and used for Cs (or MinBias) calibration

Signal reconstruction



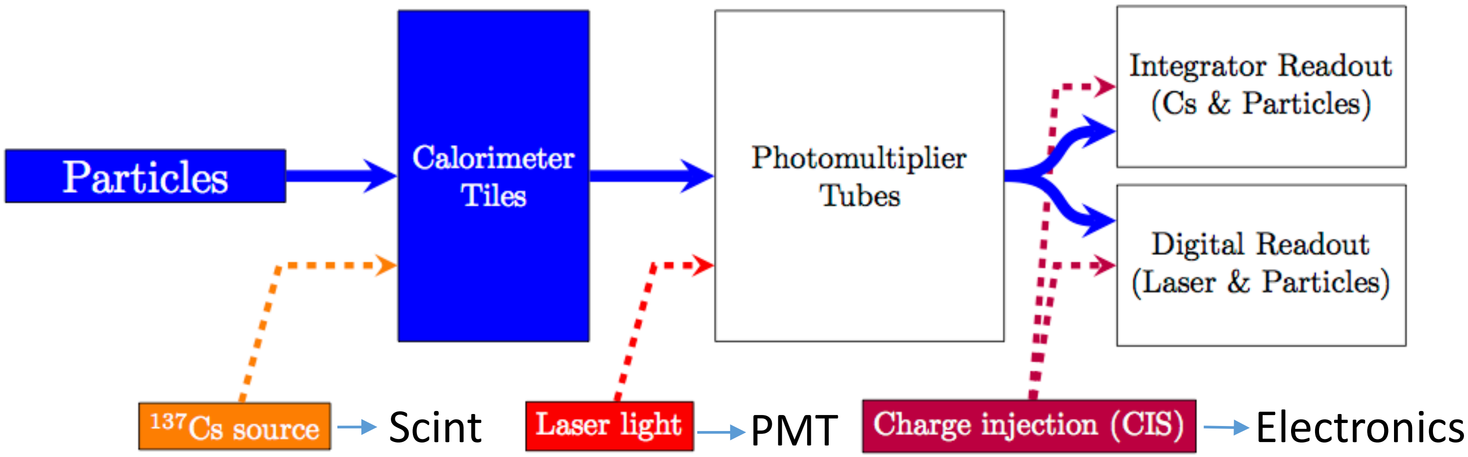
- 7 sets of ADC counts (samples) spaced by 25 ns are used for signal reconstruction (150 ns window)
- Amplitude (A), time (t_0) and quality factors (QF) are obtained with Optimal Filter (OF) algorithm
- OF uses weighted sum of samples (S_i) in order to minimise noise
- $A = \sum a_i S_i, t_0 = \frac{1}{A}\sum b_i S_i,$
  $QF = \sum (S_i - (Ag_i + At_0 g_i + Ped))^2$

- The time calibration is important for OF performance
- Time measurements and calibration is performed using "splash" events (single beam events hitting closed collimator)
- Tuned later with collisions, exploiting jet events



The slope matches the time the particles cross calorimeter across beam axis

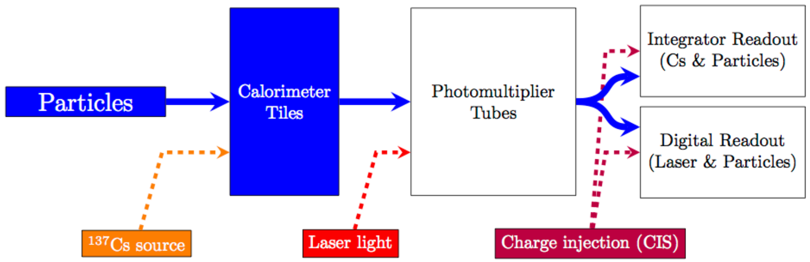
Energy calibration

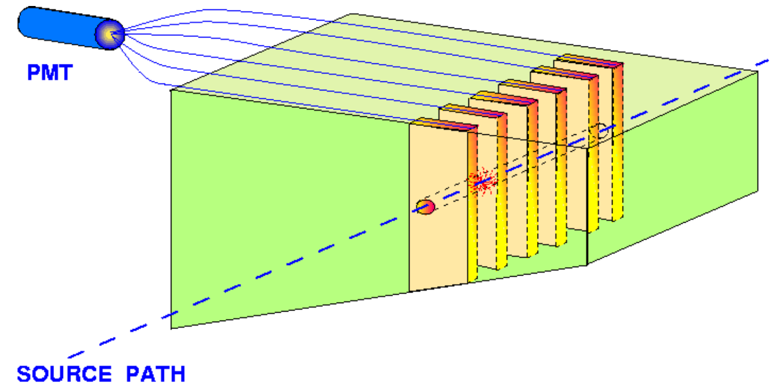


$$E = A \cdot C_{Cs} \cdot C_{Laser} \cdot C_{ADC \to pC} \cdot C_{pC \to GeV}$$

- The energy calibration allows to reconstruct the energy of jets in GeV.
- Performed using various calibration systems (with precision of 1% of the cell response)
  - The injection of known charge to digitiser (CIS) allows to calibrate electronics ($C_{ADC \to pC}$)
  - $C_{pC \to GeV}$ conversion factor has been defined at testbeam via the response to electron beams of known momentum (setting the absolute energy scale)
  - Injected laser light with known intensity allows to equalise PMT response (C_{Laser})
  - Cs source moved through all the cells (except crack scintillators) allows to equalise scintillator response (C_{Cs})
    - Scintillator response equalisation can be improved using Minimum Bias events

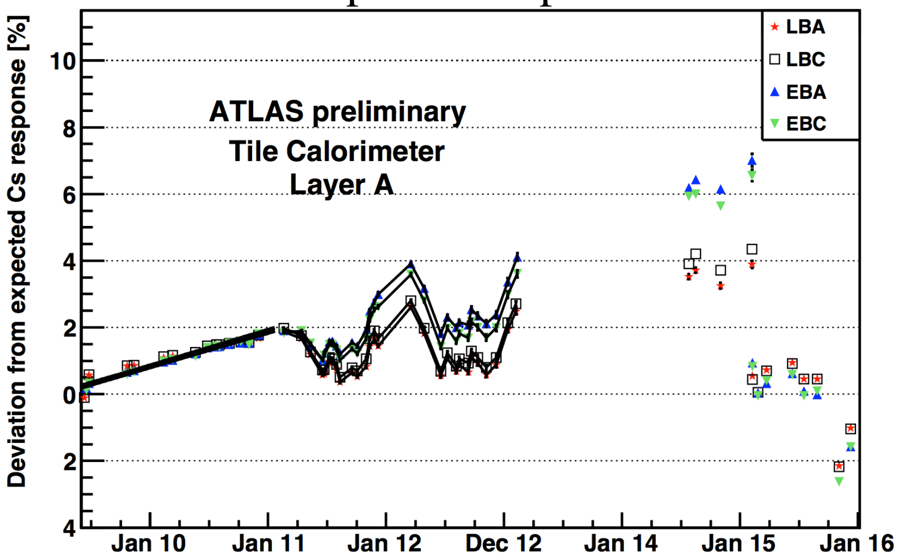
Energy calibration: Cs





$$E = A \cdot \boxed{C_{Cs}} \cdot C_{Laser} \cdot C_{ADC\rightarrow pC} \cdot C_{pC\rightarrow GeV}$$

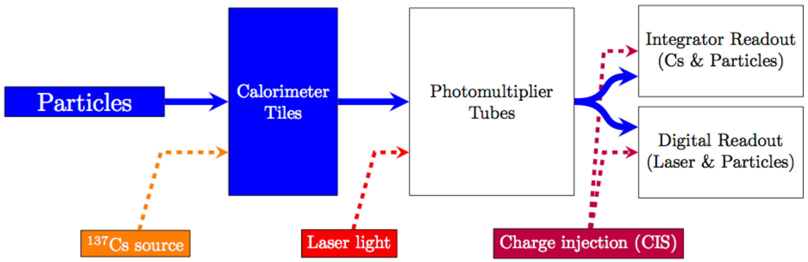
Deviation from expected response in 2009-2015



The deviation from expected response rises due irradiation effects in scintillators, variations of PMT gain.

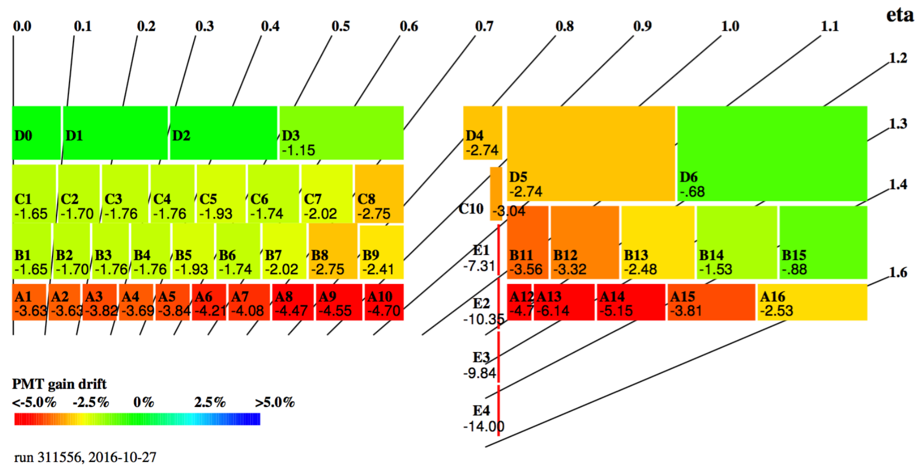
- Calibration of the initial part of the signal readout path (scintillator response) with movable radioactive ^{137}Cs γ-sources ($E_\gamma = 0.662\ MeV$)
- The signal is read out through a special "slow" integrator
- The correction applies to maintain global conversion factor and corrects for residual cell differences
- The calibration is usually performed ~1th per month (was not available in 2016 due to water leak)

Energy calibration: Laser



$$E = A \cdot C_{Cs} \cdot C_{Laser} \cdot C_{ADC \to pC} \cdot C_{pC \to GeV}$$

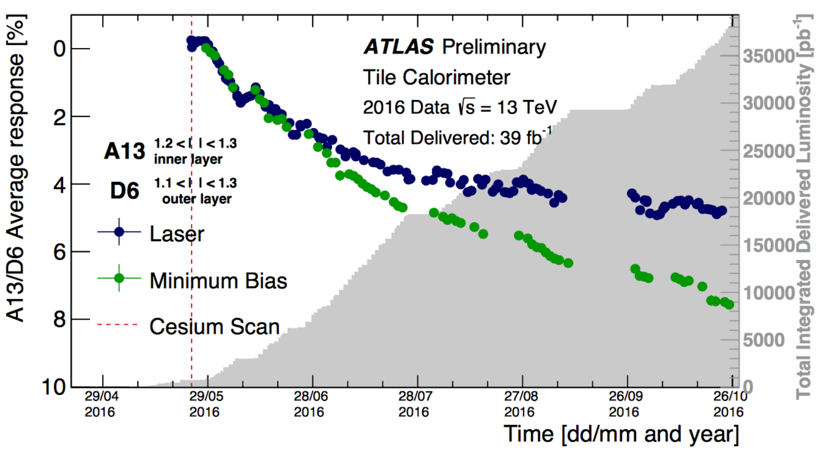
PMT gain variation in 2016



Highest PMT gain variations are observed during 2016 pp collisions: 5% to 10% in cells closest to beam pipe

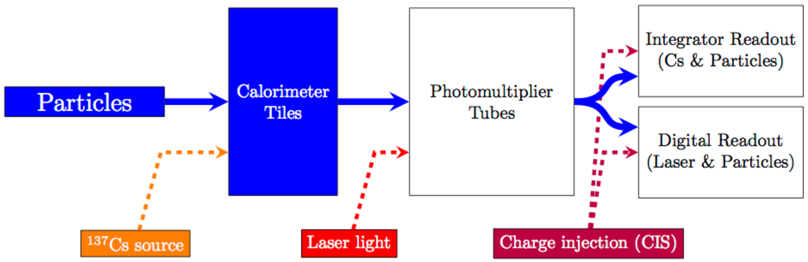
- Laser light pulses are sent directly to PMT to measure PMT gain variation and correct for non-linearities of the readout electronics
- Laser is also used for time calibration and monitoring
- Calibration is usually done 2 times per week (or even more often in case Cs is n/a)

Scintillator irradiation in 2016



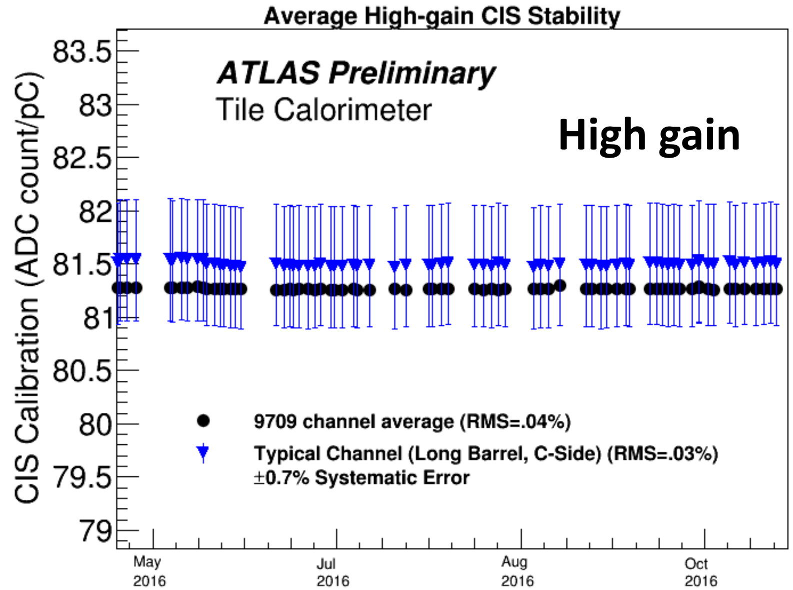
The difference between Laser and MinBias (or Cesium) response allows to estimate the effect of the scintillators irradiation.

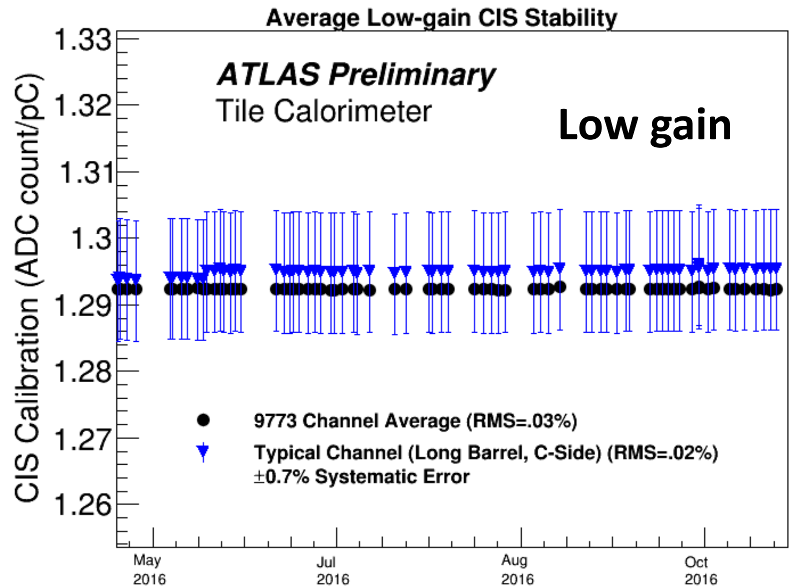
Energy calibration: CIS



$$E = A \cdot C_{Cs} \cdot C_{Laser} \cdot C_{ADC\rightarrow pC} \cdot C_{pC\rightarrow GeV}$$

- Calibration of the front-end electronic gains with a charge injection system (CIS) located in 3-in-1 card (allows to test each channel)
- Fires both amplification gains
- Corrects for non-linearities of electronics associated to the PMTs
- Performed 2 times per week for monitoring

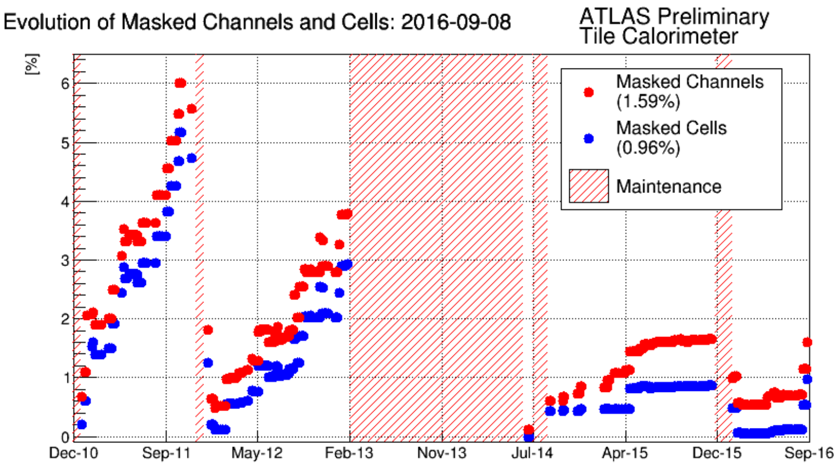




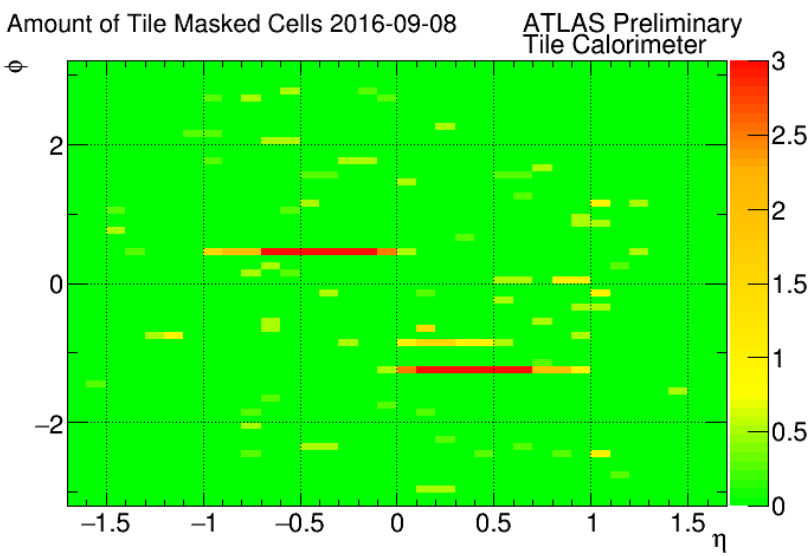
CIS calibration was very stable during 2016 data taking

Detector status by the end of 2016 pp collisions

Evolution of TileCal masked cells in 2010-2016



The eta-phi map of masked cells in 2016



The 2016 was the best year for the Tile Calorimeter from the beginning of LHC data taking.

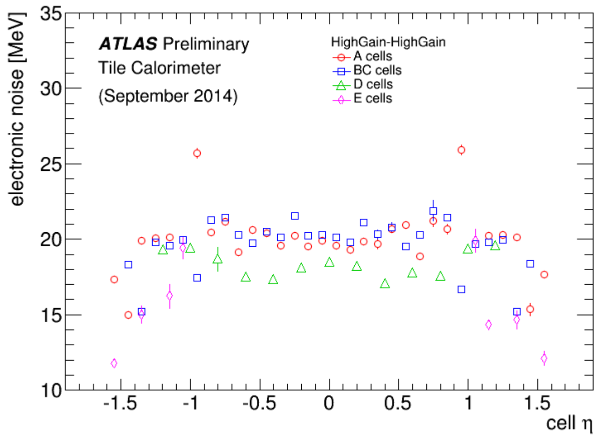
- Good stability of electronics

Less than 1% cells were excluded from reconstruction at the end of 2016 pp collisions.

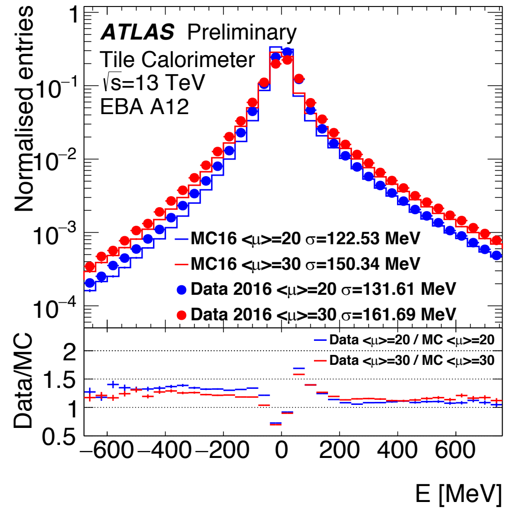
- One module is excluded due to the water leak in cooling system
- Another module had readout problems

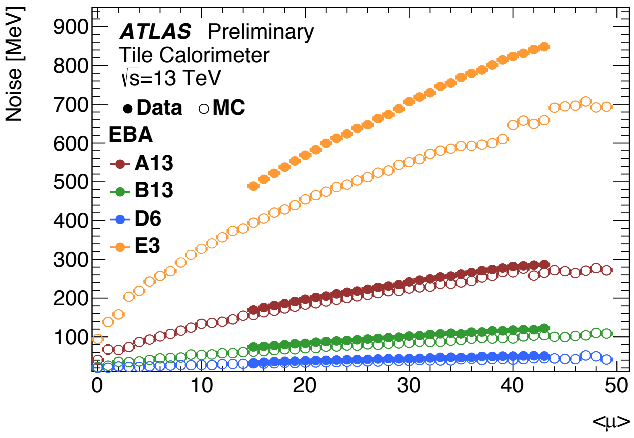
Noise performance

Electronics noise



Pile-up noise



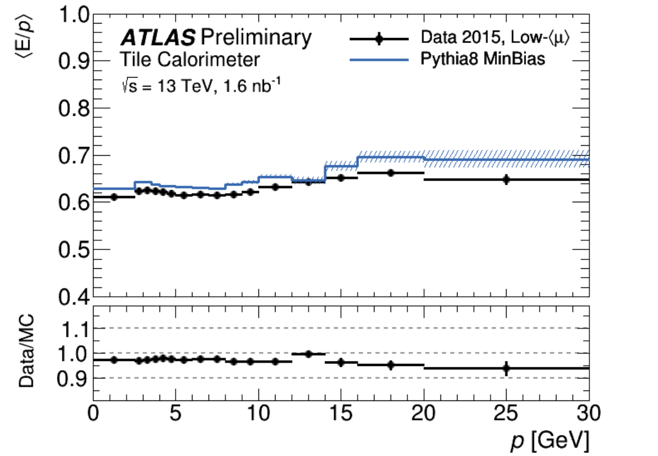


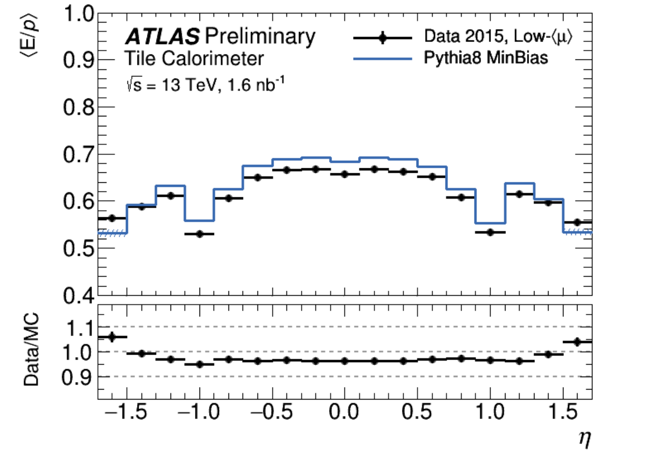
- Electronics noise is measured and monitored in special runs without collisions
- Defined as the width of Gaussian fit to the reconstructed cell energy distributions
- Stays at the level of 15-20 MeV for most of cells

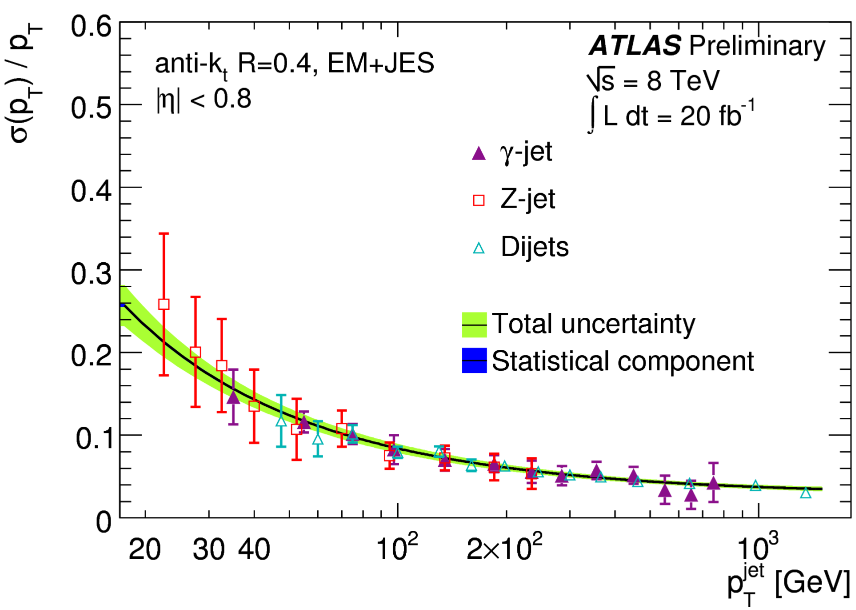
- Energy distribution in Tile Calorimeter cells gets wider and larger in presence of pile-up
- Total noise (standard deviation of the energy distribution) is increasing as the function of average number of interactions per bunch crossing (driven by pile-up contribution)
- Cells closest to beam beam pipe are affected by higher noise

Performance with jets and hadrons

- The ratio of the calorimeter energy over the track momentum (E/p) of **single hadrons** is used to evaluate TileCal uniformity and linearity during data taking
- The calorimeter calibration at the electromagnetic scale results in E/p<1, while jets are further calibrated in a more complicated way
- Good linearity and uniformity is observed. The data/MC agreement is within 3%.





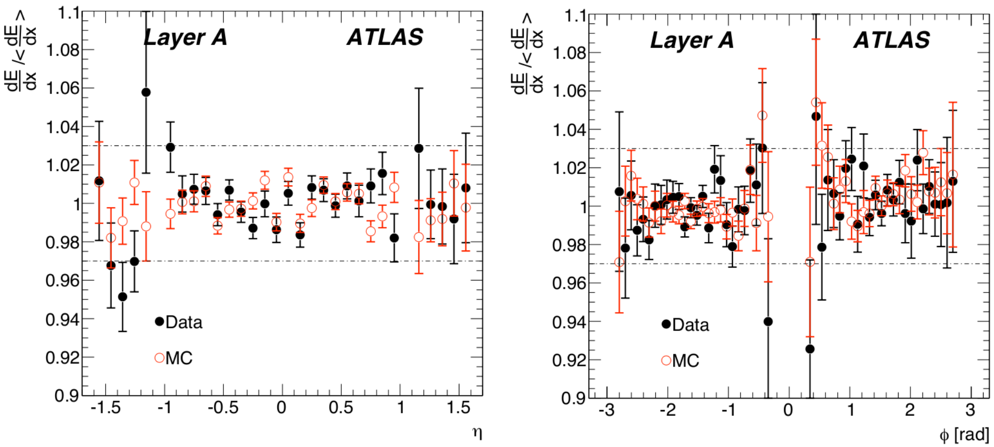


- The jet energy resolution is below 10% for **jets** with $p_T > 100$ GeV.
- The constant term is at the level of 3%, compatible with the expectations

Performance with muons

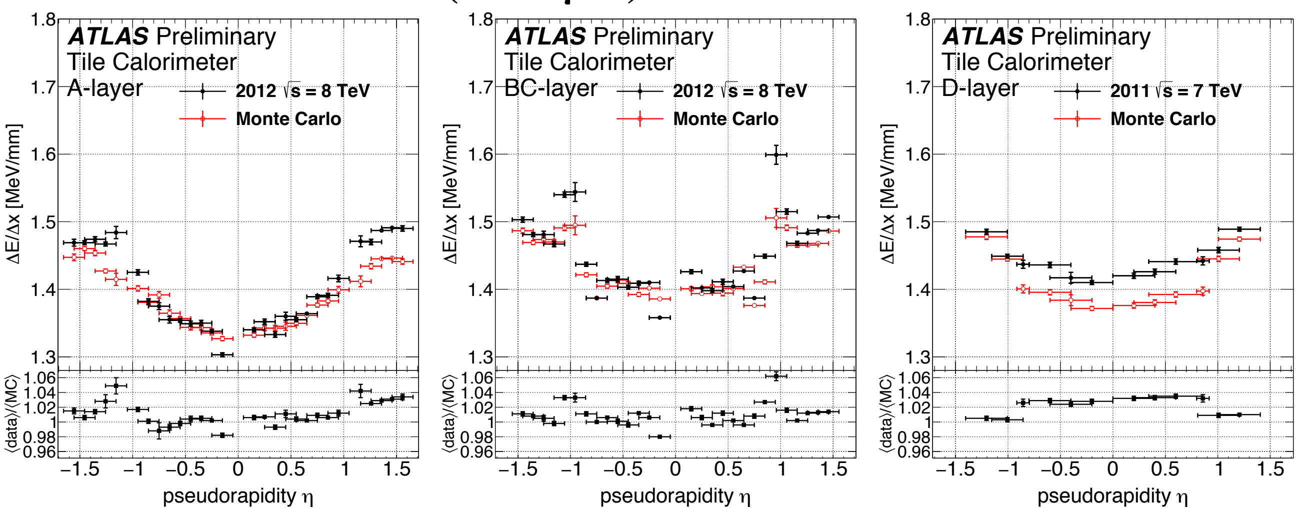
- Muons from cosmic rays, beam halo and collisions (e.g. $W \rightarrow \mu\nu$ events) are exploited to study the electromagnetic energy scale in-situ
- Energy deposited by muons in scintillator proportional to its path length (dE/dx)

Cosmic muons



- 1% response non-uniformity with η in Long Barrel
- 2-3% response non-uniformity with η in Extended Barrel
- The response is uniform across φ within 2%

Collision muons (W->$\mu\nu$)



- A good energy response uniformity is found with 8 TeV collisions data in all calorimeter layers
- The data/MC agreement is within 3%

Summary

- Tile Calorimeter has shown a great performance in 2016 year of data taking providing 98.9% of good data for physics analyses
- Solid multistep calibration and monitoring system allows to maintain uniform and stable cell energy response with precision better than 1%
- The results show that the Tile Calorimeter performance is within the design requirements and gives essential contribution to reconstructed physics objects and physics results