
ATLAS Tile Calorimeter calibration and monitoring systems

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On behalf of the ATLAS collaboration



Outline

ATLAS detector

Tile Calorimeter

Calibration

- Cesium calibration
- Laser calibration
- Charge Injection System
- Integrator calibration

Performance

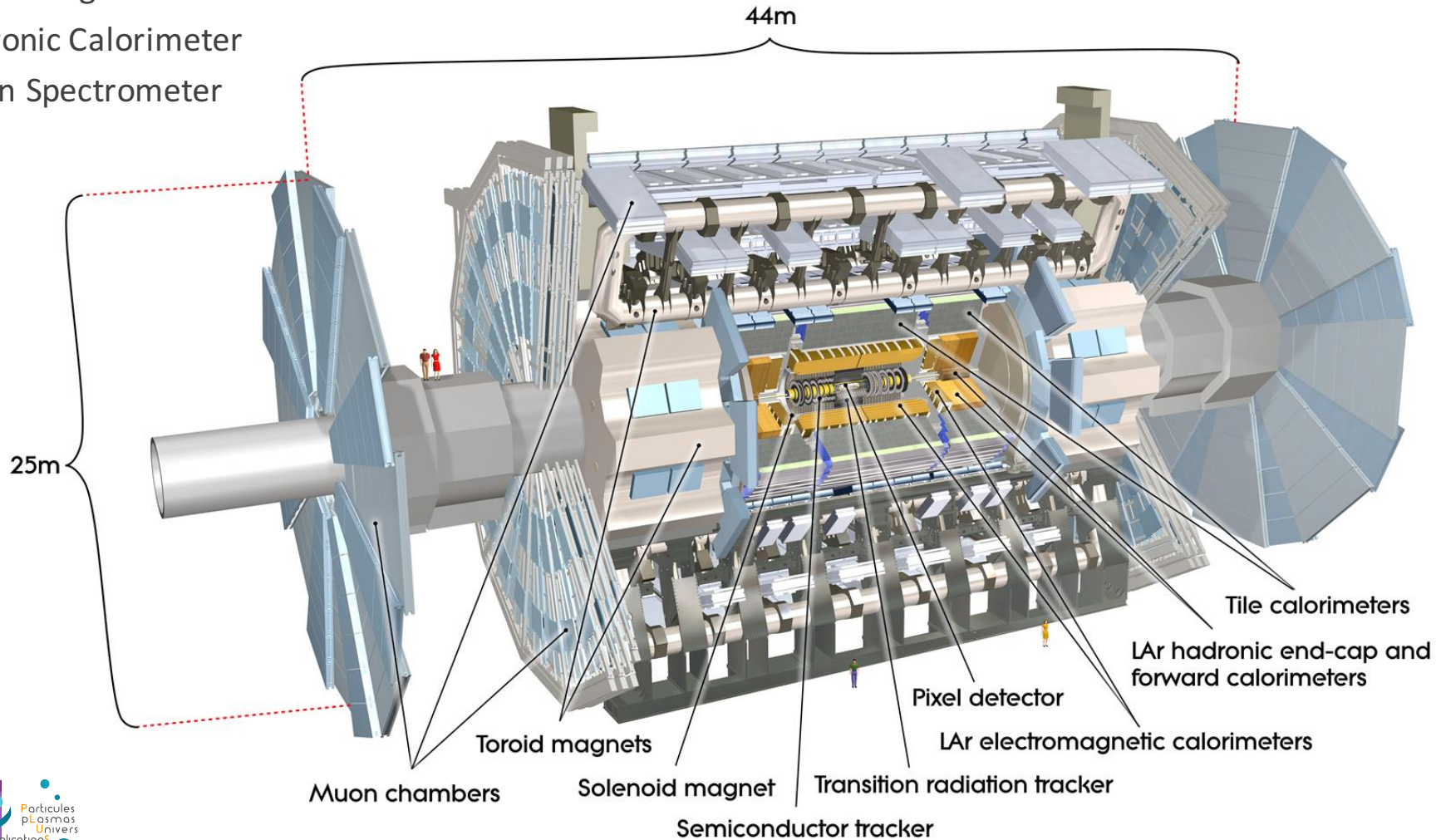
Conclusion

ATLAS detector

ATLAS is a multipurpose detector at the LHC at CERN

Composed of several sub-detectors

- Inner detector
- Electromagnetic Calorimeter
- Hadronic Calorimeter
- Muon Spectrometer



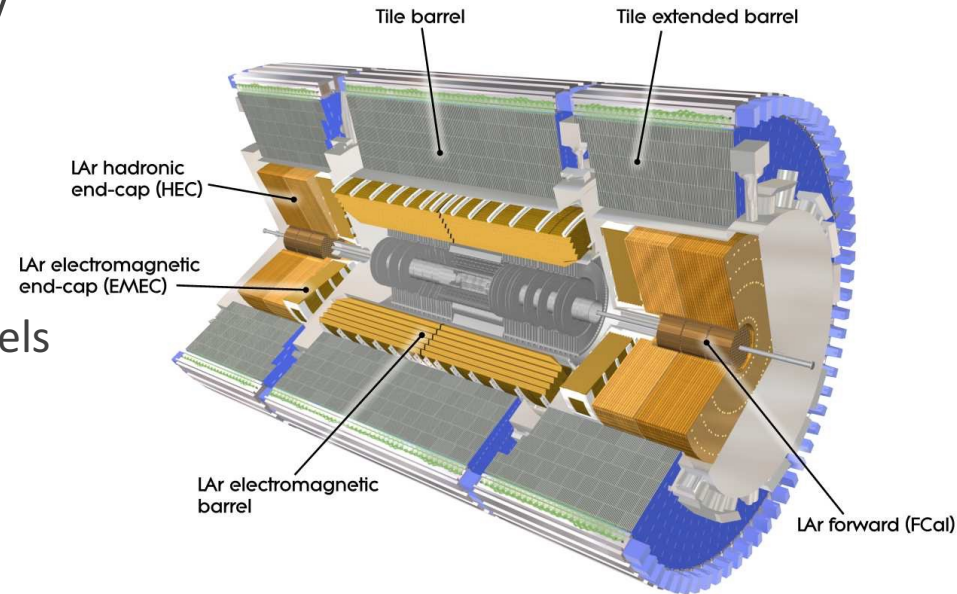
Tile Calorimeter

Tile Calorimeter (TileCal) allows for the measurements of jets, hadronically decaying tau leptons and missing transverse energy

- Also used in Level-1 trigger

It is a sampling calorimeter

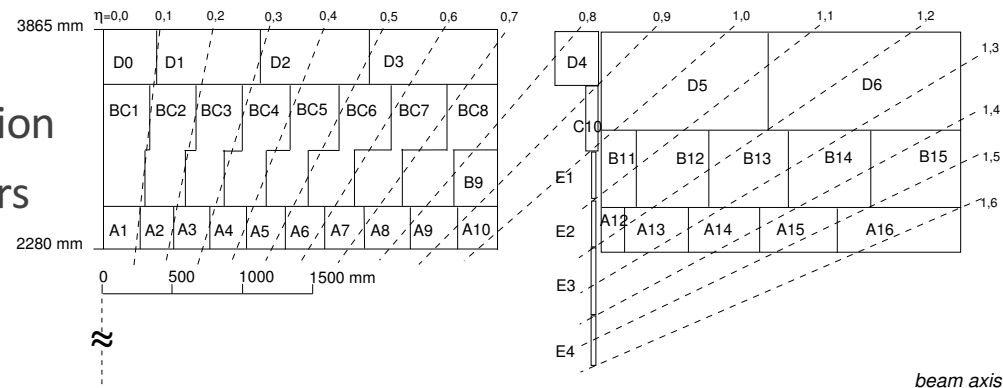
- Iron plates and scintillating tiles
- ~5000 cells
- Energy measured with 9892 readout channels
- Double photomultiplier readout using wavelength shifting fiber



TileCal covers the central region ($|\eta| < 1.7$)

It is composed of 3 cylinders

- One barrel, two extended barrels
- Each cylinder has 64 modules in ϕ direction
- Each cylinder has three longitudinal layers (A, B/C and D)
- One additional layer (E) covers gap and crack regions



beam axis

Tile Calorimeter

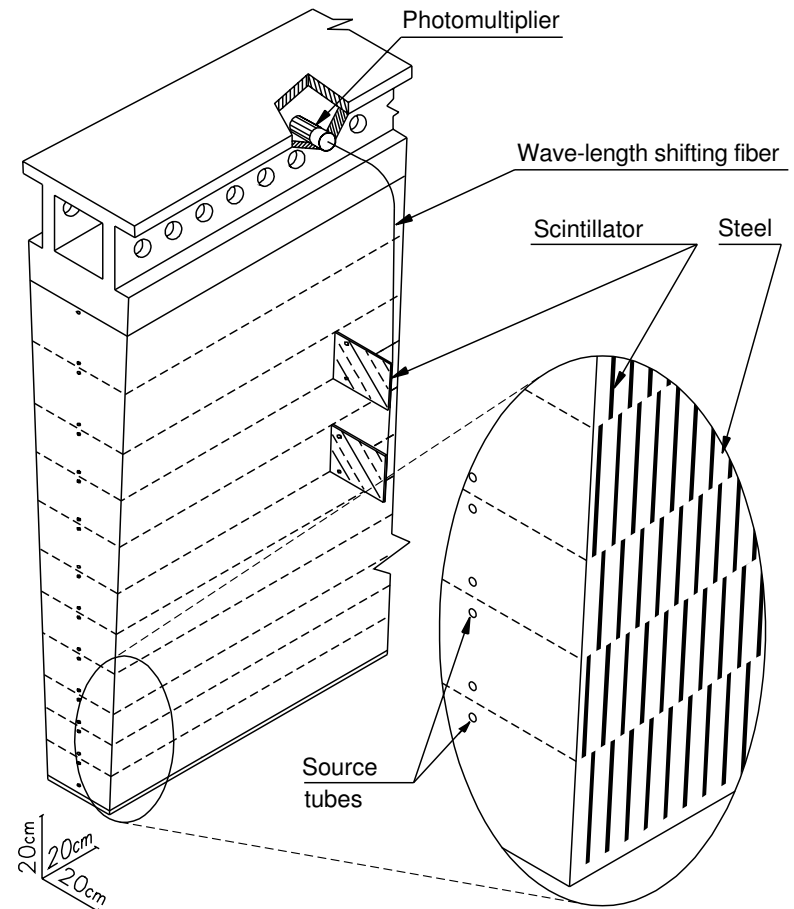
Light produced in scintillating tiles by passage of particles is converted into electric currents by Photo Multiplier Tubes (PMTs)

Signal from the PMTs is shaped and amplified using two gains (with a ratio 1:64) with a 10-bit ADC by digitizers

- Signals are sampled and digitized at 40MHz

If event passes Level 1 Trigger (40kHz)

Integrator measures the integrated current from the PMTs

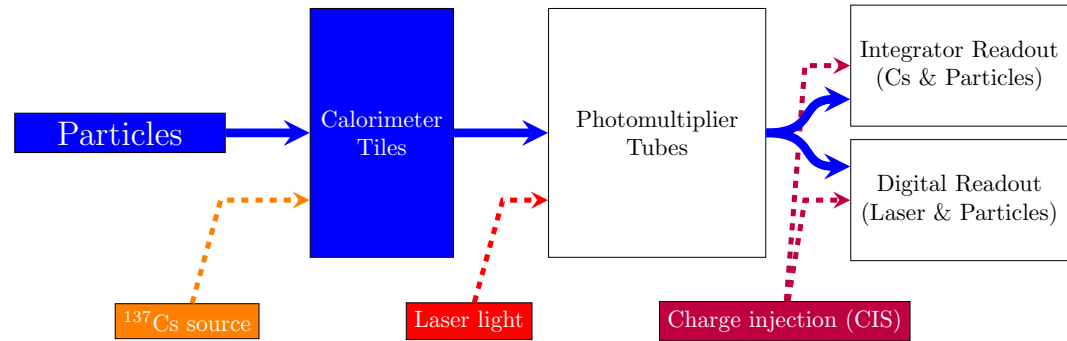


Energy Calibration of TileCal

Relation between deposited energy and channel signal has to be known and monitored

Factors that affect it:

- HV instability
- PMTs stress
- Read-out failures
- Optic aging



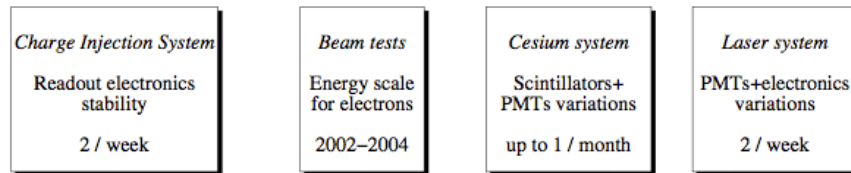
Relation is controlled with the calibration systems

- Cesium calibration: calibration of optical components and PMTs f_{Cs}
- Laser system: calibration of PMT response and readout electronics f_{Las}
- Charge injection system (CIS): calibration of the readout electronics C_{CIS}
- Integrated currents from Minimum Bias events (soft parton interactions) monitor optical components, PMTs and beam conditions

$$E [\text{GeV}] = A [\text{ADC}] \cdot C_{\text{ADC} \rightarrow \text{pC}} \cdot C_{\text{pC} \rightarrow \text{GeV}} \cdot f_{Cs} \cdot f_{Las}$$

$C_{\text{pC} \rightarrow \text{GeV}}$ measured during dedicated test beam campaigns

calibration	duration
Cesium	~ few hours
Laser	~ 1 hour
CIS	~ few min



Cesium System

A moveable radioactive source of ^{137}Cs passes through the calorimeter

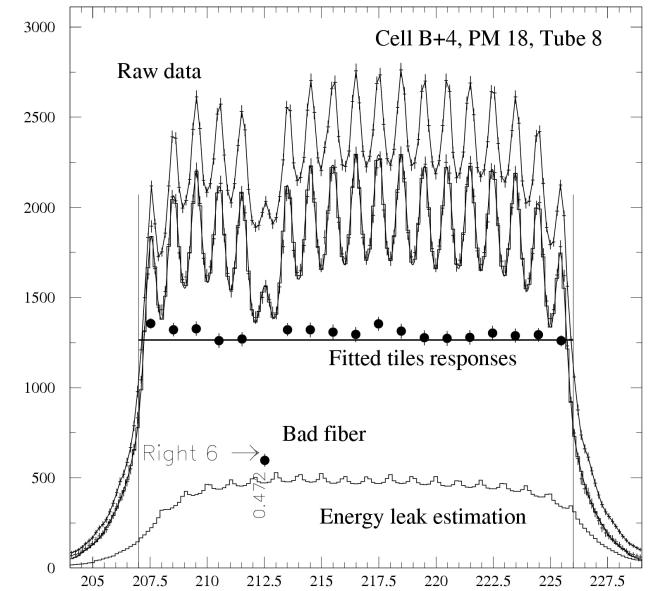
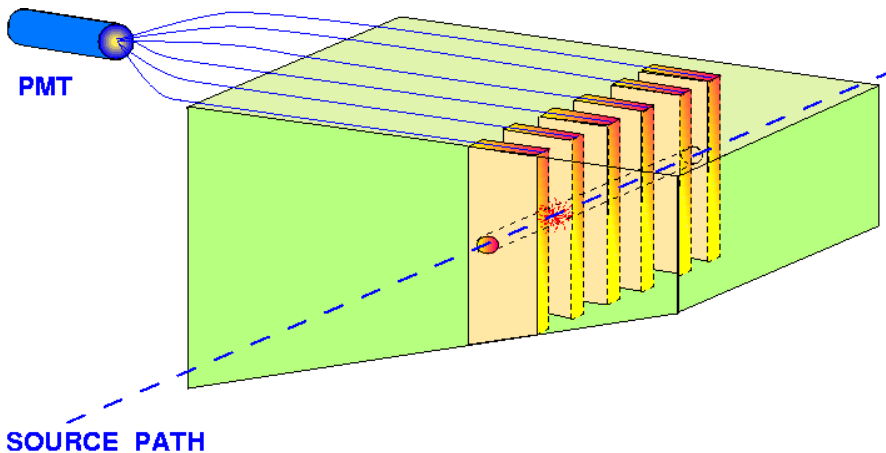
- Emits γ rays of well known energy (662 keV)

It uses integrated readout system

- Different readout than the one used for physics

Cesium system is used for:

- Check the quality of the optics and full system readout (scintillators, fibers and PMTs, electronics)
- Equalize the response of all read-out channels
- Monitor the cell electromagnetic scale in time



Upgraded Cesium System for LHC Run 2

- Improvement of stability and safety (new water storage system, lower pressure, precise water level metering)
- Precision of single channel response better than 0.3%

Cesium System

Larger deviations of the cell response in time is due to the exposure to particle flux

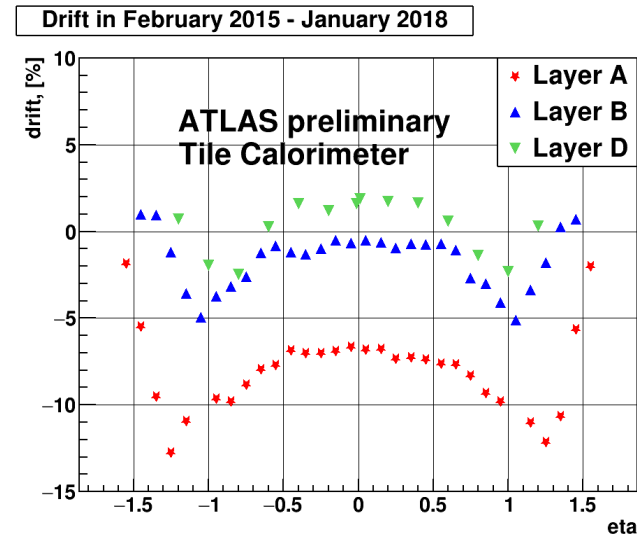
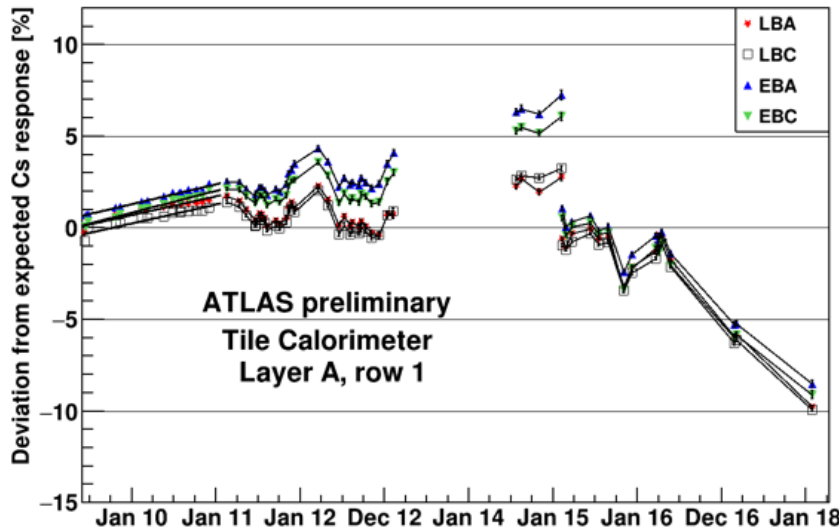
- Caused by the PMT response variation and scintillator degradation
- Maximal drift is observed for layer A (closest to the collision point)

Cesium calibration are taken at least at the beginning each year collisions and every time there is a long pause in pp collisions

Allows to measure new response after changing HV

Restores calorimeter response uniformity

Full monitoring of PMTs and optics behavior since 2009



Laser System

Sends light pulses to the PMTs with a wavelength close to the one of physical signals (532nm light)

- Controlled amount of light
- Light is sent to the PMTs through ~400 fibers

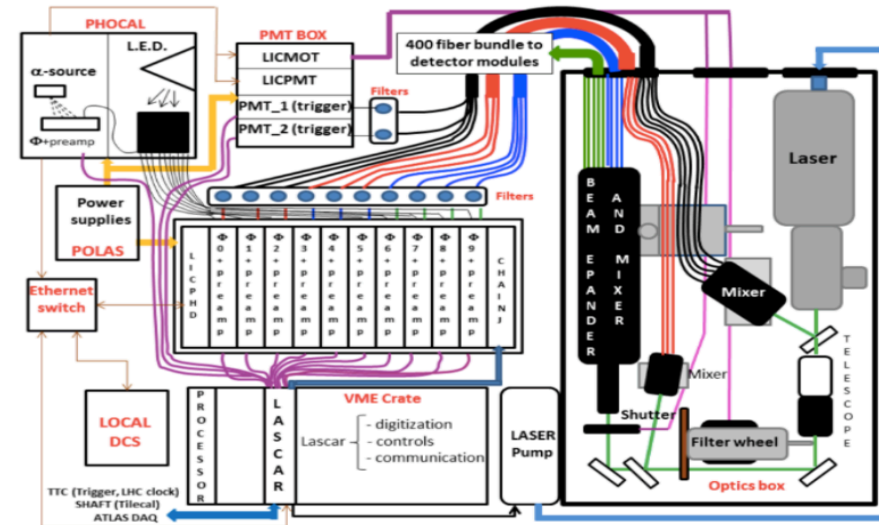
Dedicated Laser calibration runs are taken twice a week

- Laser measures the drift seen in PMT response wrt to last Cesium scan
- The response variation is measured and calibration constants are updated between two Cesium scans

Laser pulses are also sent to TileCal during empty bunch crossing (1-2Hz frequency), to calibrate timing

Upgraded Laser System for Run2

- Upgraded electronics and optical components
- Better control of the emitted light



Laser System

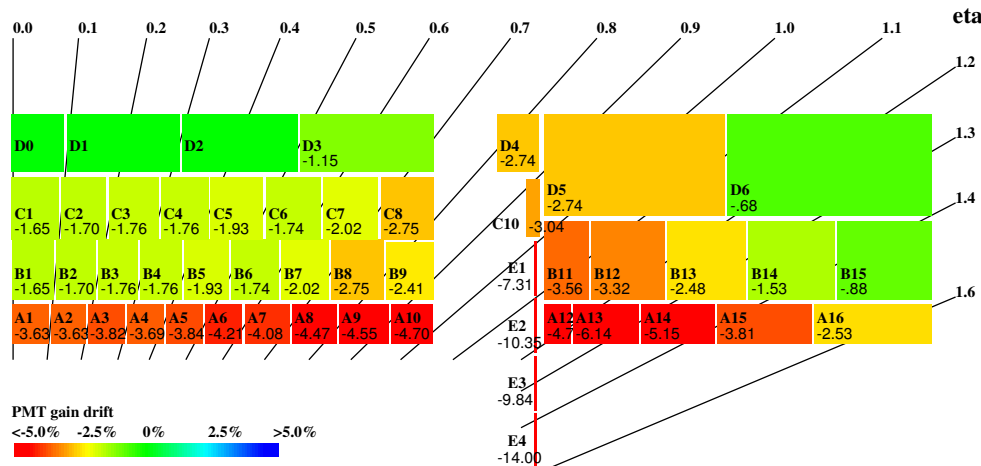
Laser system measures the PMTs response variation during data taking

Deviations of any channel response with respect to nominal is translated into a calibration constant: f_{Las}

Maximal drift is observed in E and A cells which are the cells with the highest energy deposits

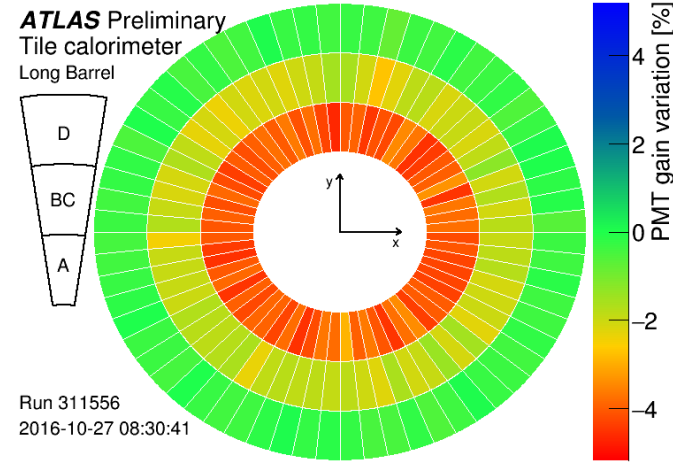
Regular (~ weekly) calibration of TileCal to correct to PMT effects

ATLAS Preliminary
Tile Calorimeter



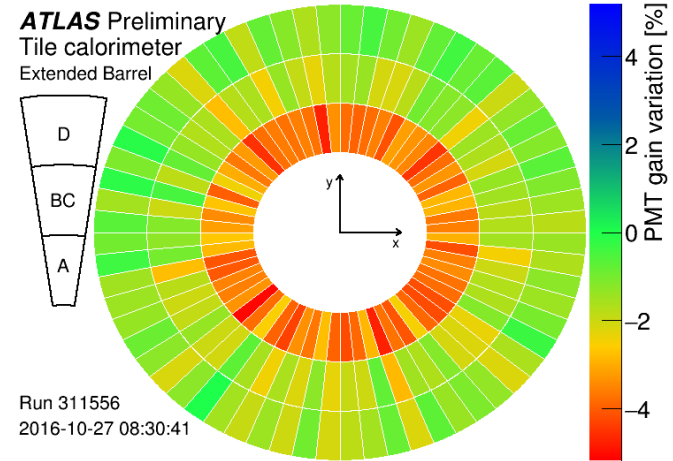
run 311556, 2016-10-27

ATLAS Preliminary
Tile calorimeter
Long Barrel



Run 311556
2016-10-27 08:30:41

ATLAS Preliminary
Tile calorimeter
Extended Barrel



Run 311556
2016-10-27 08:30:41

Charge Injection System (CIS)

Charge Injection System injects a signal of known charge and measures the electronic response

Calibration checks full ADC range (0-800pC)

- 2 gains for each PMT (LG and HG)

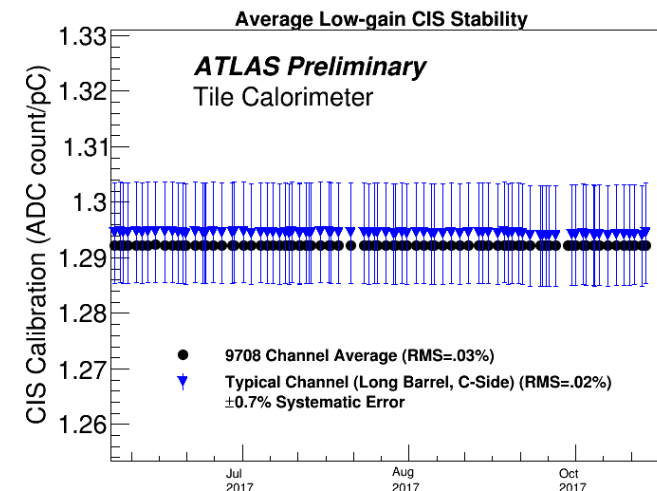
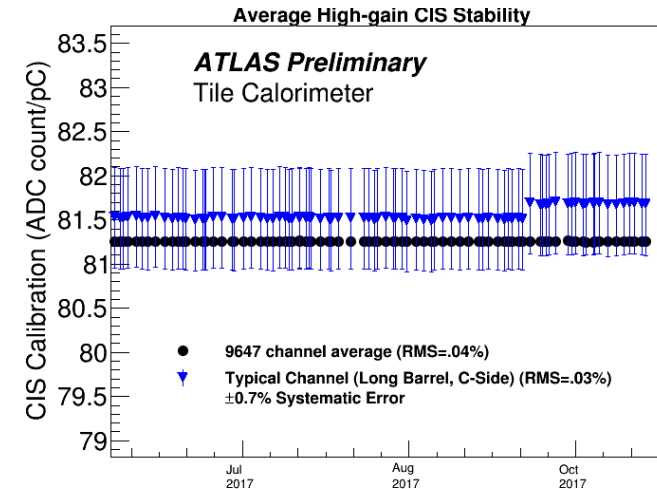
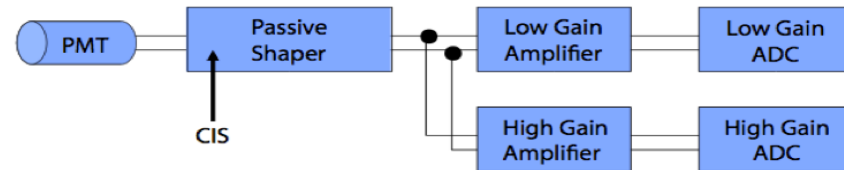
CIS calibration is taken at least twice a week

Aim is to measure the pC/ADC conversion factor and correct for non-linearities in low-gain

Also used to calibrate analog Level 1 calo trigger

CIS measurements

- Precision of 0.7%
- Factor as a function of time at the level of 0.03%



Integrator System

Integrated PMT signals over a large time window ($\sim 10\mu\text{s}$)

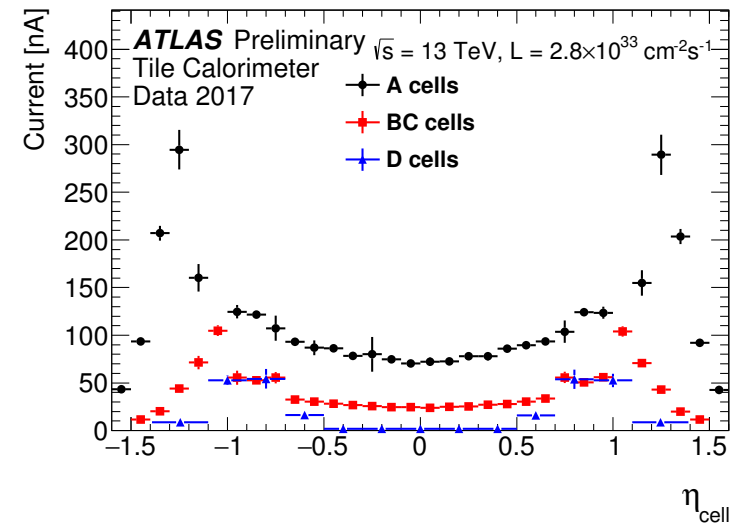
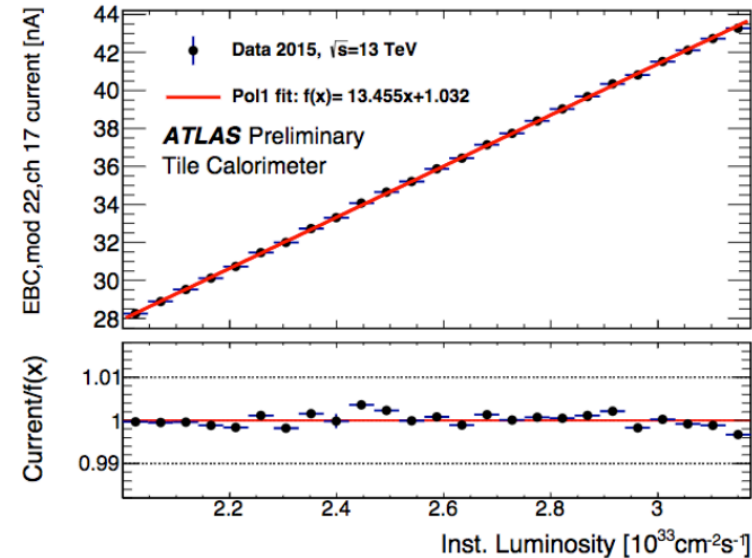
- Integrator system monitors and measures the response to the source during Cesium scans
- During Physics runs, measures the detector response to the minimum bias events
- High energy proton-proton collisions are dominated by soft parton interactions (Minimum Bias events)
- A way to monitor the instantaneous luminosity in ATLAS
- Provide an independent measurement given an initial calibration (luminosity coefficient)
- Measured currents are linearly dependent on the instantaneous luminosity

Use of the response stability to produce calibration constants in absence of Cesium calibration

- Integrator system monitors the full optical chain
- Also used to calibrate E-cells and MBTS

Integrator System Performance

- Stability of each channel is better than 0.05%
- Average stability is better than 0.01%



Integrator System

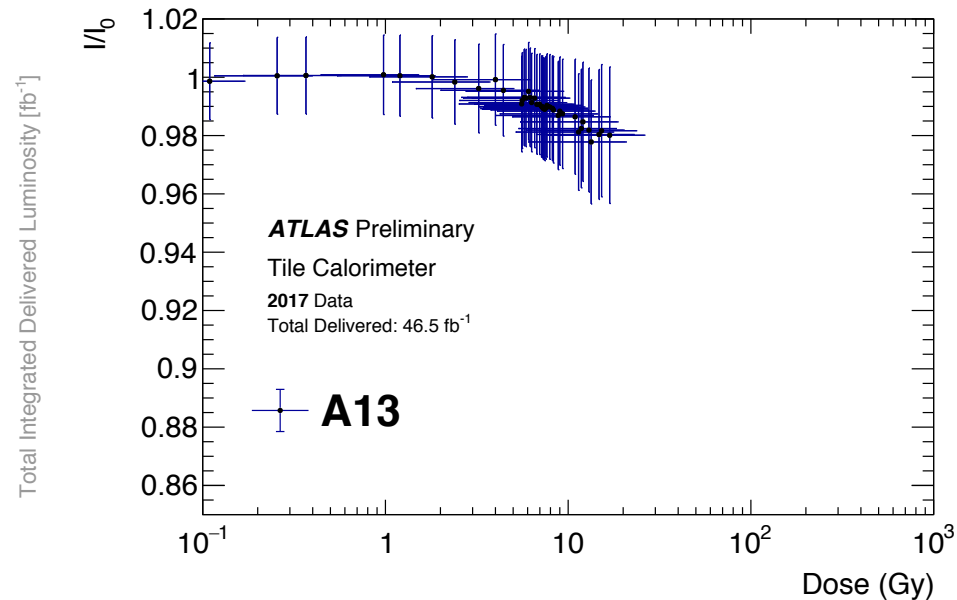
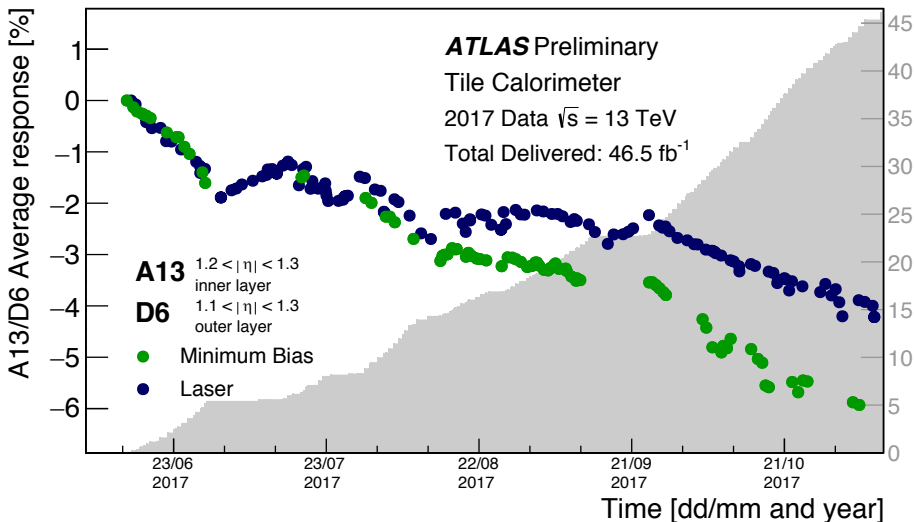
Use of Laser and Integrator system in parallel

- Integrator system monitors PMT response drift and scintillator aging
- Laser system monitors PMT response drifts

Both observe down drifts during collisions and up drifts during maintenance periods

In 2016 and 2017 a systematic difference is observed between Laser and Integrator systems

- Attributed to scintillator irradiations → extra calibration from Integrator system applied on some channels



Time Calibration

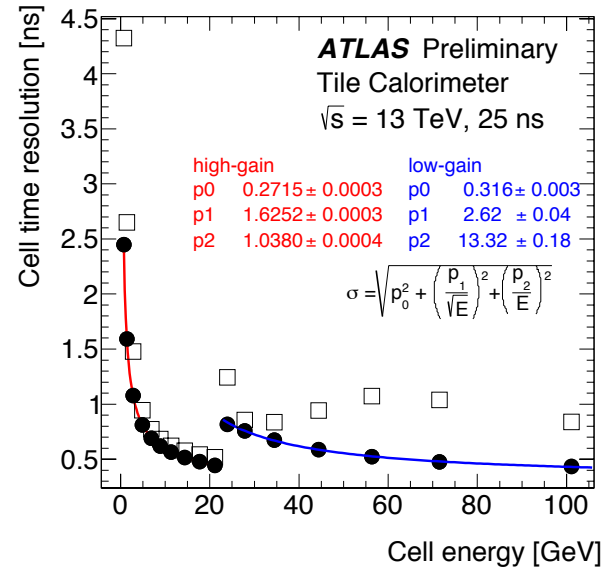
A precise time calibration is important for the cell energy reconstruction

Used to set the phase so a particle traveling from the interaction point at the speed of light gives the signal with measured time equal zero

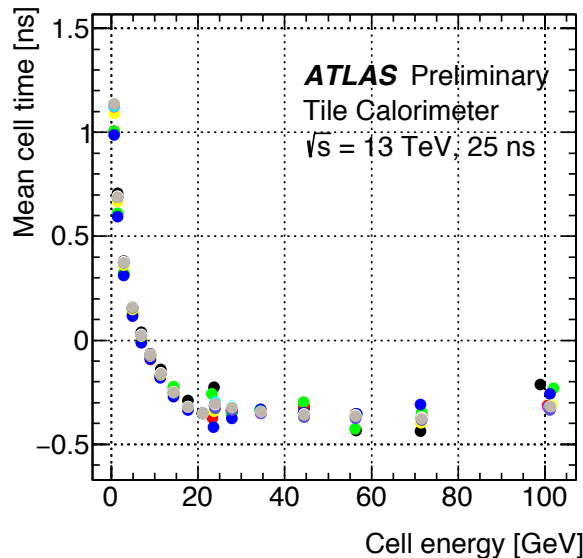
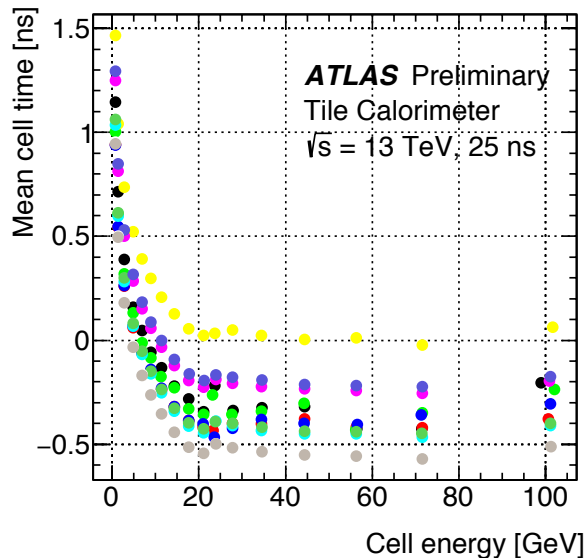
Can also be exploited in TOF (time of flight) measurements, e.g. in search for heavy R-hadrons

Time calibration calculated using jets and monitored during physics data taking with laser

Resolution is better than 1ns for $E_{\text{cell}} > 4 \text{ GeV}$



Closed circles correspond to Gaussian σ
Open squares indicate the RMS of the underlying time distributions



Each color corresponds to different run

Noise

The total noise per cell in the calorimeter comes from two sources:

- Electronic noise - measured in dedicated runs with no signal in the detector
- Pile-up contribution - originates from multiple interactions occurring at the same bunch crossing or from the events from previous/following bunch crossings

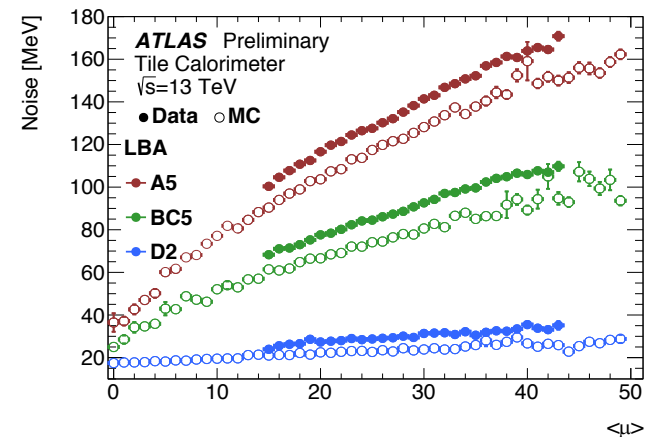
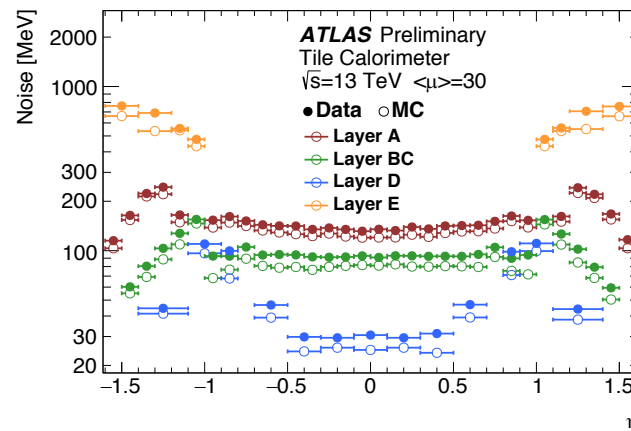
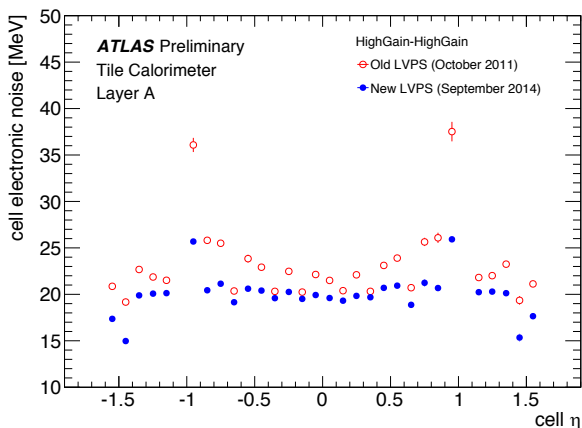
Electronics noise stays at the level below 20 MeV for most of the cells

Noise is measured regularly with calibration runs.

In 2014 new power supplies were installed giving better electronics stability and more gaussian noise shape

Total noise is increasing with pile-up

The largest noise values are in the regions with the highest exposure (E-cells, A-cells)



TileCal Status and Data Quality

TileCal channels monitored for hardware issues, timing offsets, miscalibrations,...

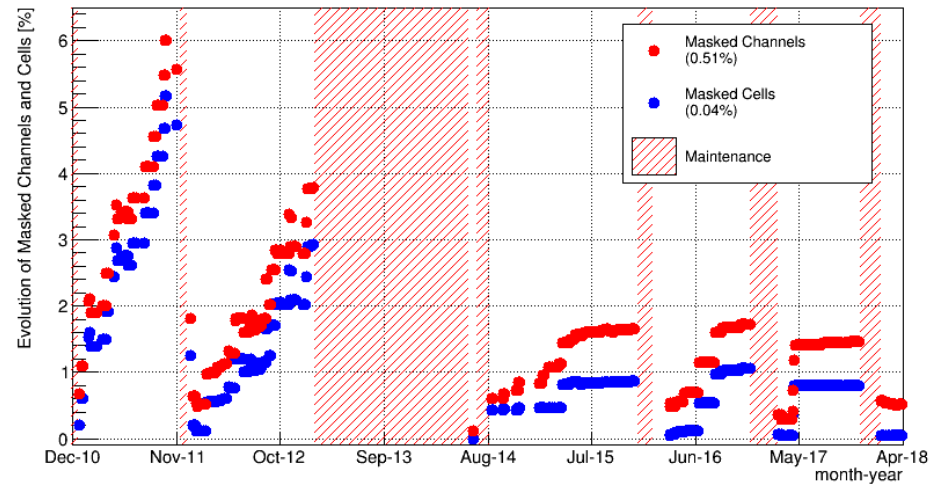
TileCal monitoring includes identifying and masking problematic channels, correcting for miscalibrations, monitoring data corruption

Use maintenance periods to fix all identified issues

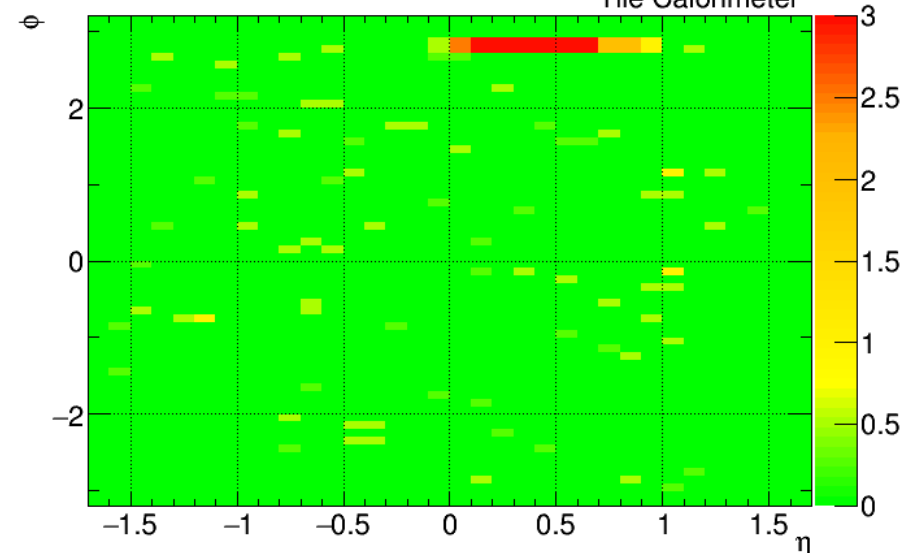
TileCal status

- Data Quality efficiency 100% in 2015, 98.8% in 2016 and 99.4% in 2017

Evolution of Masked Channels and Cells: 2018-04-21



Amount of Tile Masked Cells 2018-06-02 ATLAS Preliminary Tile Calorimeter



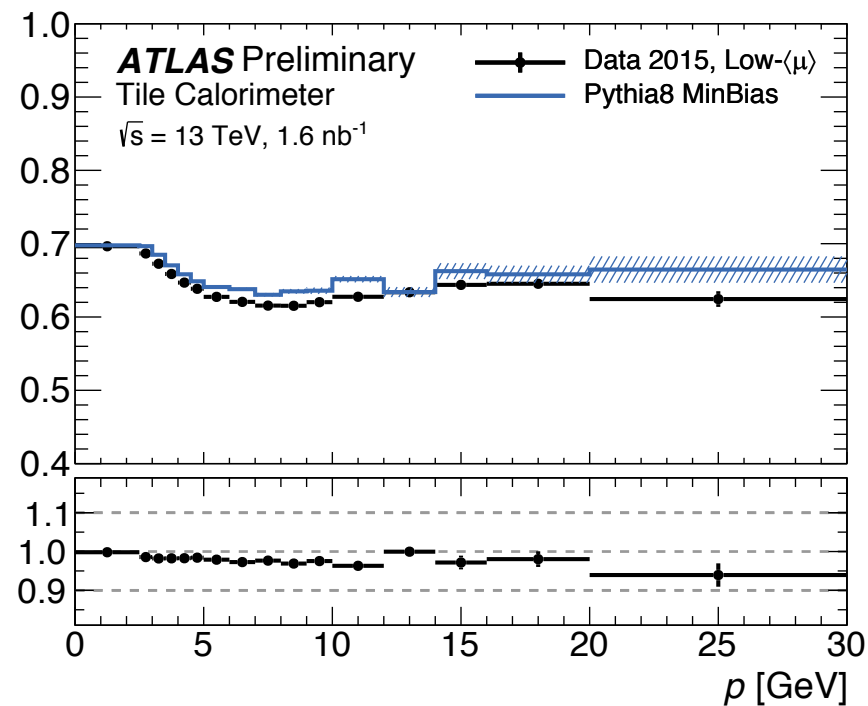
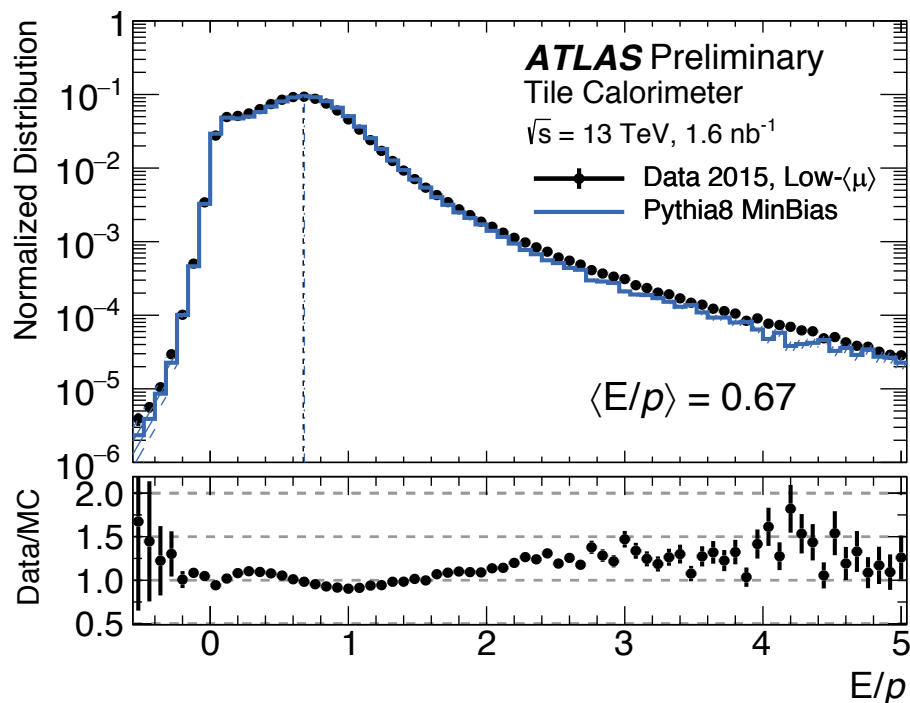
Single Particle Response

An important Tile Calorimeter characteristic is the ratio of energy at electromagnetic scale to track momentum $\langle E/p \rangle$ for isolated charged hadrons in minimum bias events

It is used to evaluate calorimeter uniformity and linearity during data taking

Expect $\langle E/p \rangle < 1$ due to the sampling non-compensating calorimeter

Data and Pythia8 simulation do agree well

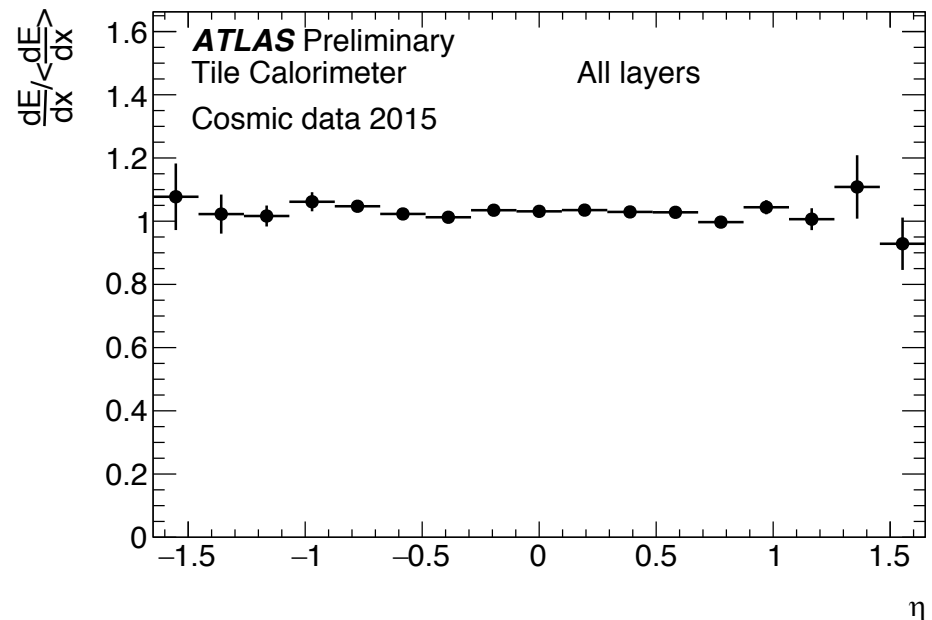
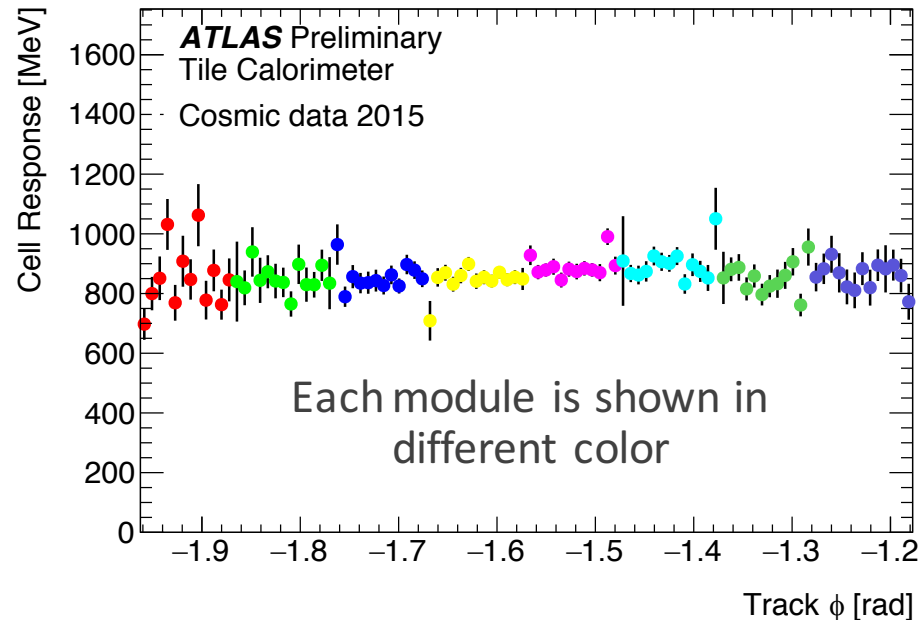


Muons

Muons from cosmic rays are used to study in situ the electromagnetic energy scale and intercalibration of Tile cells

A good energy response uniformity between calorimeter cells is observed

< 5% response non-uniformity in η with cosmic muons



Jet Performance

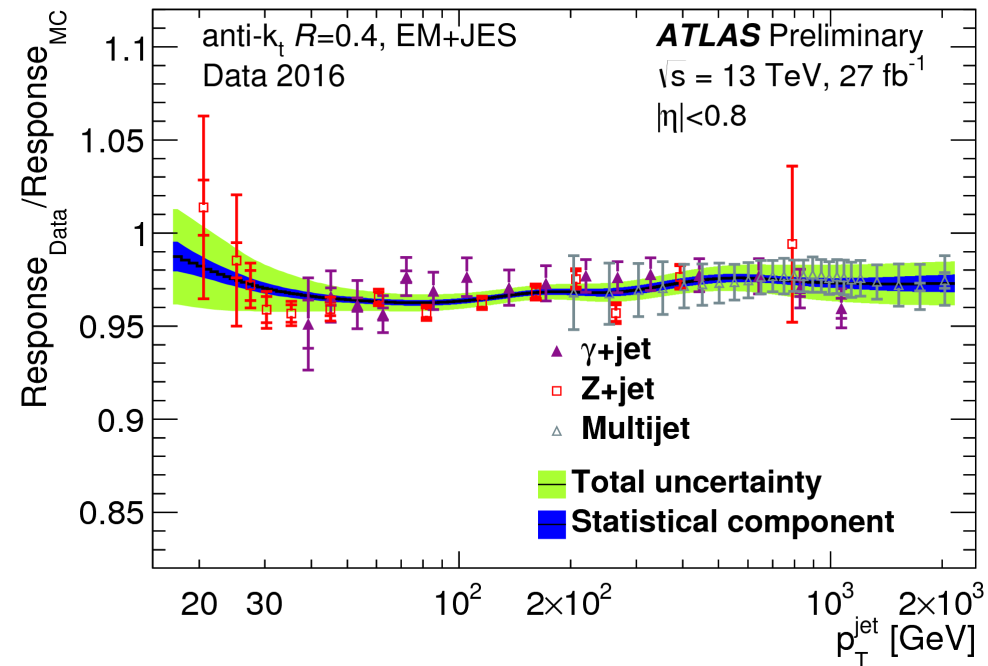
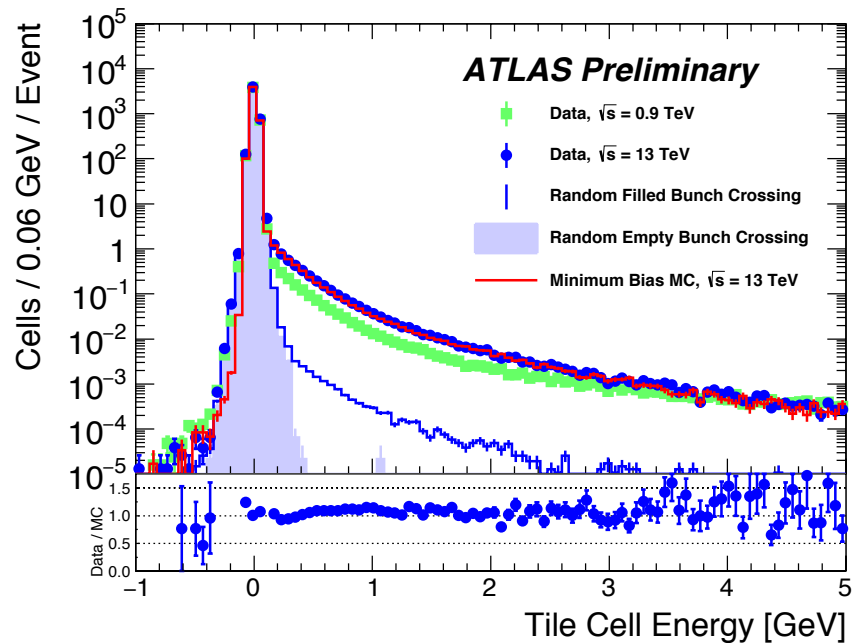
Good description of the cell energy distribution and of the noise in the calorimeter is crucial for the building of topoclusters which are used for jet and missing transverse energy reconstruction

Good agreement in Tile cell energy distribution

Consistent overall jet energy scale

Jet energy resolution is around 1% at $p_T > 100$ GeV

Constant term is within expected 3%



Conclusion

Tile Calorimeter is an important subdetector of ATLAS at LHC

- Control of its energy is essential to measure the energy of jets and the missing energy

During LHC Run2 several calibration systems used in parallel

- Cesium, Laser, Charge Injection and Integrator system

Calibration of TileCal provides an efficient monitoring and correction of fine instabilities of TileCal cells response

Intercalibration and uniformity are monitored with isolated charged hadrons and cosmic muons

The stability of the absolute energy scale at the cell level was maintained to better than 1% during LHC data-taking

Back up
