Calibration and Performance of the ATLAS Tile Calorimeter During the LHC Run 2

CALOR 2018

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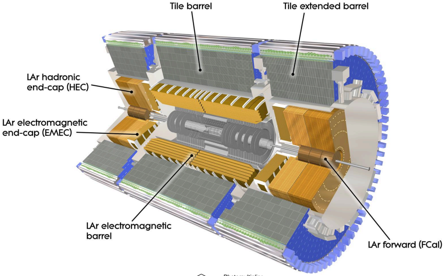
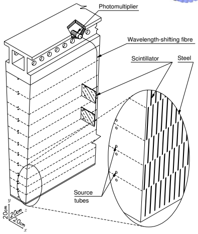
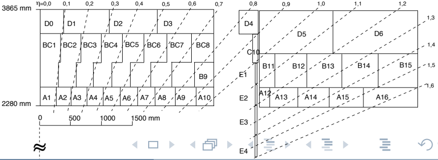
The Tile Calorimeter

- Central hadronic calorimeter ($|\eta| < 1.7$) in ATLAS detector
- Used to measure the 4-vectors of the jets and the missing transverse energy and in the ATLAS Level-1 trigger
- 9892 PMTs
- Sampling calorimeter: steel and scintillating plastic tiles
- Double photomultiplier readout using wave length shifting fibers





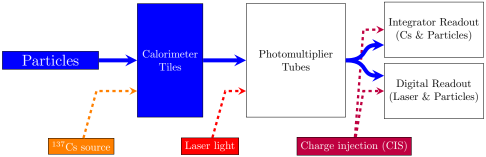


Calibration Systems

- Systems used for calibration in Tile calorimeter
  - Charge Injection System (CIS): Calibrates the response of ADCs: $C_{\mathrm{ADC}\to\mathrm{pC}}$
  - Cesium system: Calibrates optical components and PMT gains: C_{Cs}
  - Laser System: Calibrates variations due to electronics and PMTs: C_{Las}
  - Minimum Bias System (MB): Calibrates optical components and PMT gains
- $C_{\mathrm{pC}\to\mathrm{GeV}}$ measured during dedicated test beam campaigns

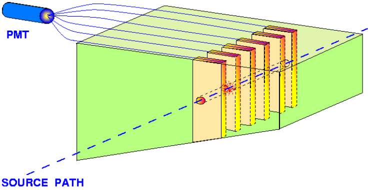
- Cell response is not constant in time due to the PMT gain variation and scintillator degradation due to the exposure to beam

$$E\ [\mathrm{GeV}] = A\ [\mathrm{ADC}] \cdot C_{\mathrm{ADC}\to\mathrm{pC}} \cdot C_{\mathrm{pC}\to\mathrm{GeV}} \cdot C_{\mathrm{Cs}} \cdot C_{\mathrm{Las}}$$



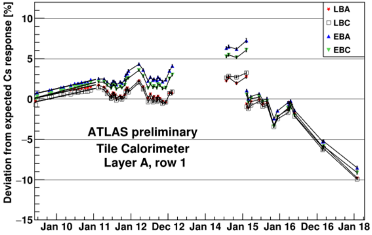
Cesium Calibration

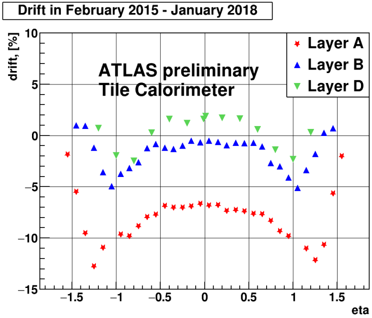
- A moveable radioactive source ^{137}Cs passes through the calorimeter body
- The source emits γ-rays with well known energy 662 keV
- It uses the integrator readout system during source movement
- Calibration of the complete optical chain (scintillators, fibres, PMTs) and monitoring of the detector response over time: C_{Cs}
- Between Run I and Run II: Improvement of stability and safety of Cesium system and procedure (new water storage system, lower pressure, precise water level metering)



Cesium Calibration

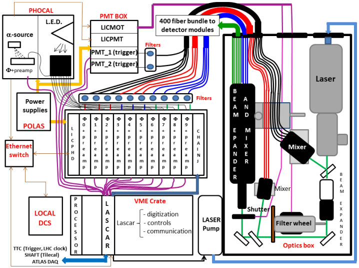
- Precision of the system in a single typical cell is approximately 0.3%
- Larger deviations of the cell response in time is caused by the PMT gain variation and scintillator degradation due to the exposure to beam
- Maximal drift is observed for layer A, that is closer to the collision point
- It allows to adjust PMT gain (changing high voltage) to restore calorimeter response uniformity

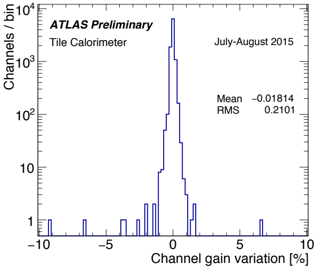




Laser Calibration

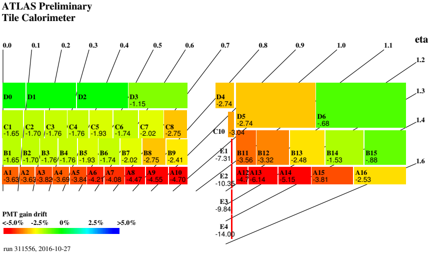
- PMT gain drift affects the detector response and calibration thus it is measured regularly
- A controlled amount of light with a wavelength close to the one of physical signals sent into each PMT (532 nm light)
- The gain variation is measured between two Cesium scans: Laser measures the drift seen in PMTs w.r.t the last Cesium scan. Also allows to detect the HV changes
- Laser pulses also sent during collision runs (empty bunches), used to calibrate timing
- Between Run I and Run II: upgraded electronics and optical components, better control of the emitted light

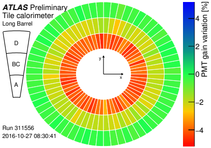


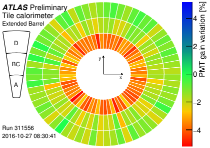


Laser Calibration

- Precision better than 0.5%
- Since 2016, updates of calibration constants are done weekly in order to track changes in PMT responses
- The maximal drift is observed in A- and E-cells which are the cells with highest energy deposits
- Deviations of any channel response with respect to nominal is translated into a calibration constant: C_{Las}

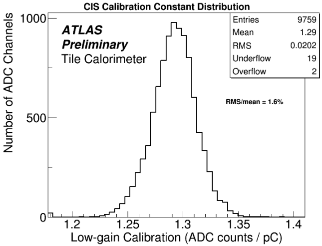


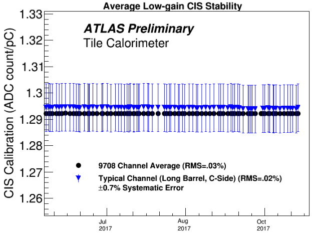




Charge Injection Calibration

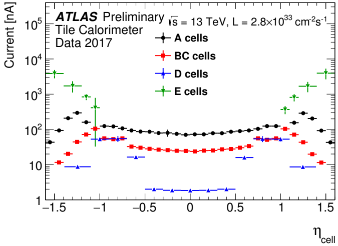
- Calibrates the response of ADCs (electronics) digital gains and linearities
- The system injects a signal of known charge and measures the electronic response
- Spanning the full ADC range (0-800 pC) and saturate both LG and HG for all channels
- Also used to calibrate analog L1 calo trigger
- Extract the conversion factors from ADC counts to pC: $C_{\mathrm{ADC}\to\mathrm{pC}}$
- Precision of 0.7%

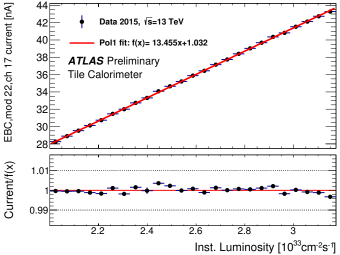




Minimum Bias System

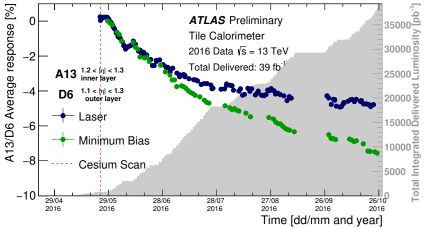
- High energy proton-proton collisions are dominated by soft parton interactions (Minimum Bias events)
- The integrator readout measures integrated PMT signals over a large time (~ 10 ms)
- As the Cesium system, the Minimum Bias system monitors the full optical chain. Also used to calibrate E-cells and MBTS.
- Measured currents are linearly dependent on the instantaneous luminosity
- The system can be used to monitor the instantaneous luminosity or provide an independent measurement given an initial calibration (luminosity coefficient)

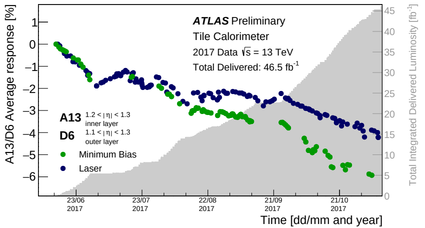




Detector Response Variation

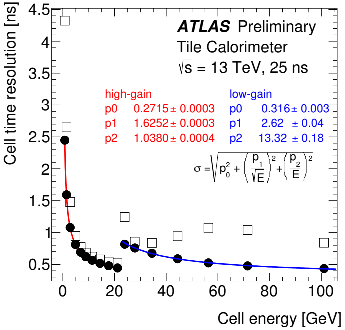
- Comparison of cell response variation between Laser and Minimum Bias measurements
  - Minimum Bias access PMT gain drift and scintillator aging
  - Laser only monitor PMT gain drifts
- Down drifts observed during collisions
- Up drifts during maintenance periods
- Differences between Laser and MB measurements can be interpreted as a scintillator aging due to irradiation
- In 2016 and 2017 this effect was clearly observed for some of the most irradiated cells in the A- and E-cells

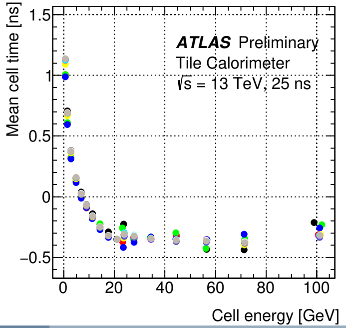




Time Calibration

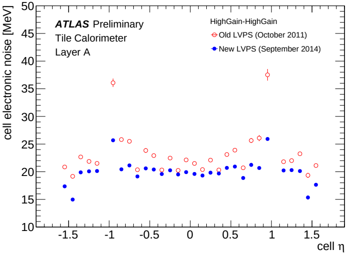
- A precise time calibration is important for the cell energy reconstruction
- Used to set the phase so a particle traveling from the interaction point at the speed of light gives the signal with measured time equal zero
- Can also be exploited in TOF measurements, e.g. in search for heavy R-hadrons
- Time calibration calculated using jets and monitored during physics data taking with laser
- Resolution is better than 1 ns for $E_{\mathrm{cell}} > 4$ GeV

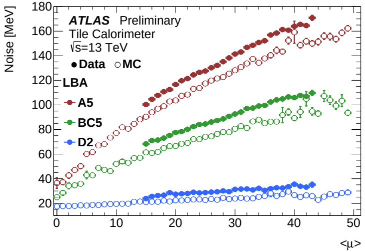




Noise

- 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.
- New power supplies (fLVPS), installed in the long shutdown (2014), have better performance and more Gaussian noise
- Total noise is increasing with pile-up
- The largest noise values are in the regions with the highest exposure (E-cells, A-cells)

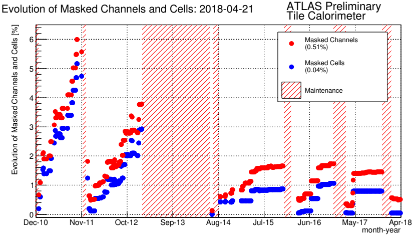


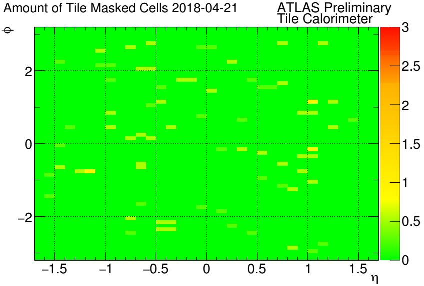


Detector Status and Data Quality

- TileCal monitoring includes identifying and masking problematic channels correcting for miscalibrations, monitoring data corruption or other hardware issues
- During maintenance periods there is a campaign to fix all issues, allowing for a good recovery of the system
- Redundancy of cell readout system reduces the impact of masked channels
- Currently only two cells masked
- Tile achieved 100% data quality efficiency in 2015, 98.8% in 2016 and 99.4% in 2017

Current TileCal status





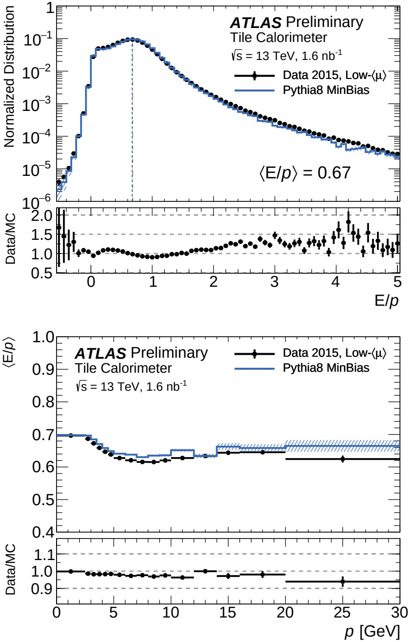
Single Particle Response

- An important Tile Calorimeter characteristic is the ratio of energy at EM 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

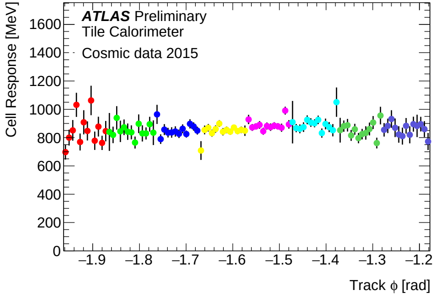
- Expect $\langle E/p \rangle < 1$ due to the sampling non-compensating calorimeter

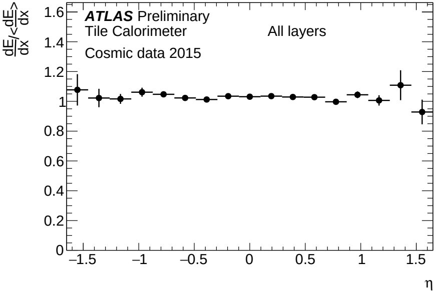
- Data and Pythia8 simulation do agree well



Muons

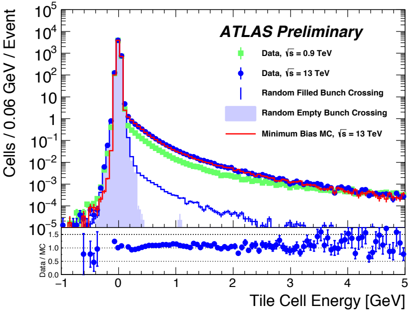
- Muons from cosmic rays are used to study in situ the electromagnetic energy scale and intercalibration of Tile cells
- A good energy response uniformity between calorimeter cells
- $< 5\%$ response non-uniformity in η with cosmic muons





Jet Performance

- A 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

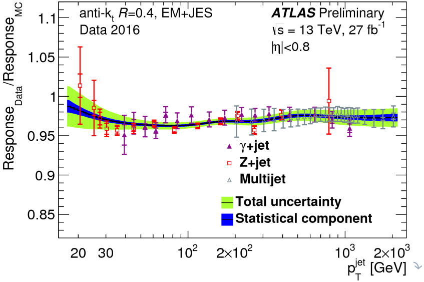


- Good agreement in Tile cell energy distribution

- Consistent overall jet energy scale

- Jet energy resolution is around 1% at $p_{\mathrm{T}} > 100$ GeV

- Constant term is within expected 3%

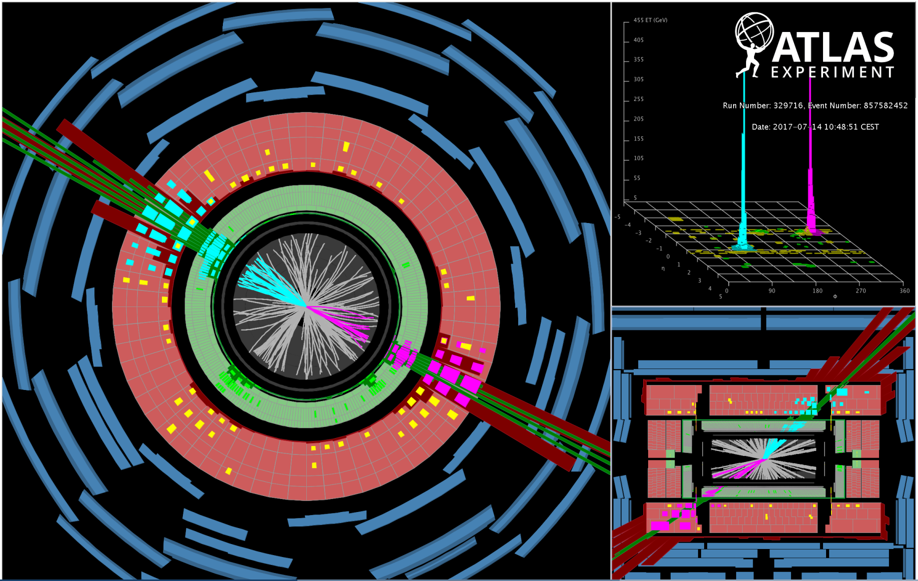


Conclusions

- Tile Calorimeter is an important part of ATLAS detector at LHC
- It is a key detector to measure the 4-vectors of the jets and missing energy
- A set of calibration systems is used to calibrate and monitor the calorimeter 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 be better than 1% during Run 2 data taking

The Di-jet Event Produced in 2017

Two jest with $p_{\mathrm{T}} = 2.9$ TeV and $m_{jj} = 9.3$ TeV



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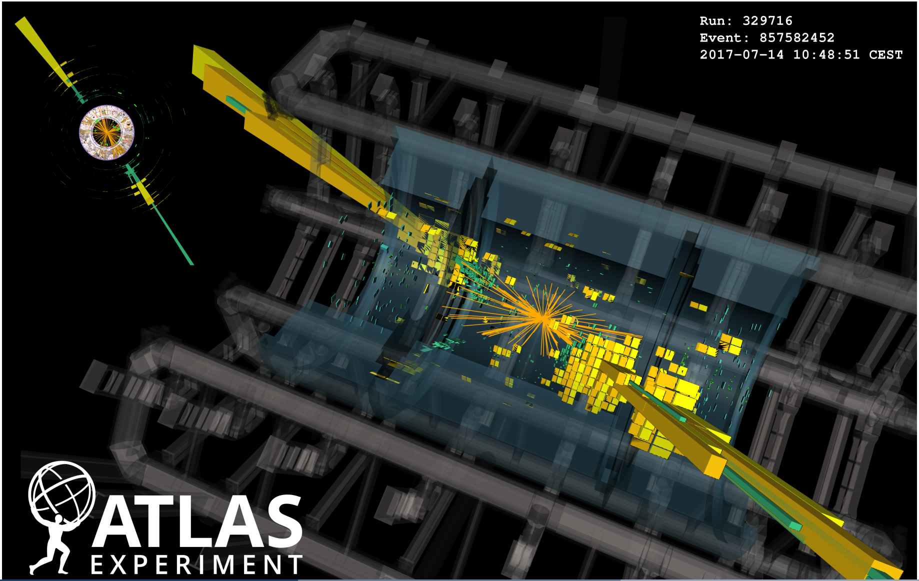

Back-up

Calibration System