INSTITUTE FOR COLLIDER PARTICLE PHYSICS
UNIVERSITY OF THE WITWATERSRAND

Performance of the ATLAS Tile Calorimeter

Instrumentation for Colliding Beam Physics (INSTR-20)

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on behalf of the ATLAS Collaboration

University of the Witwatersrand

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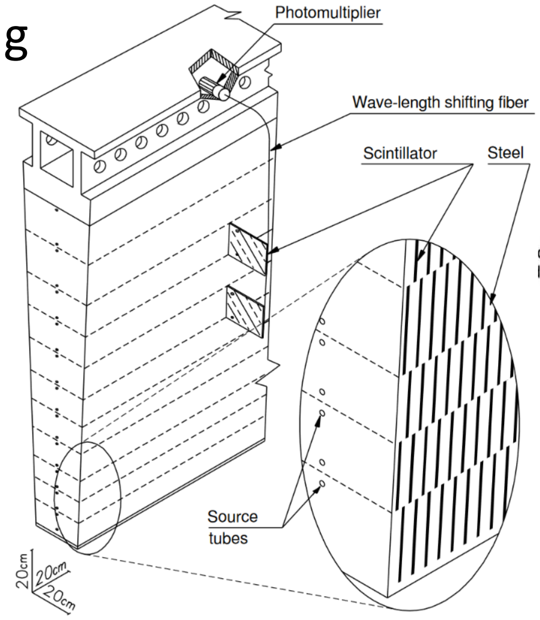
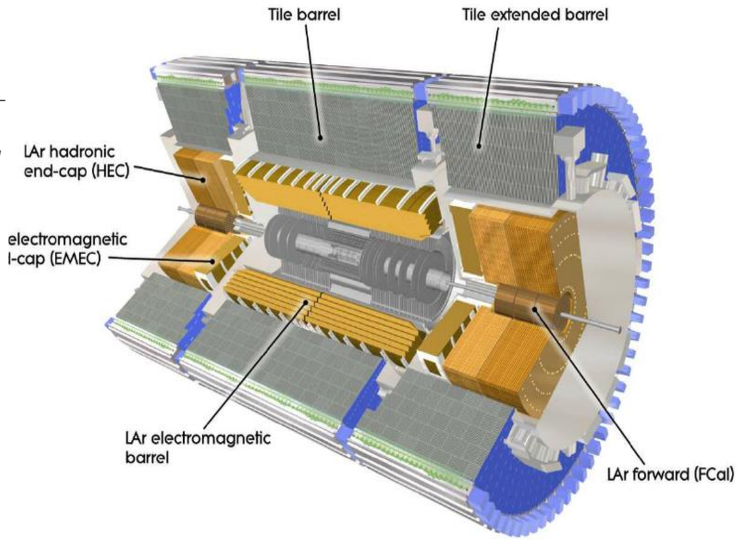
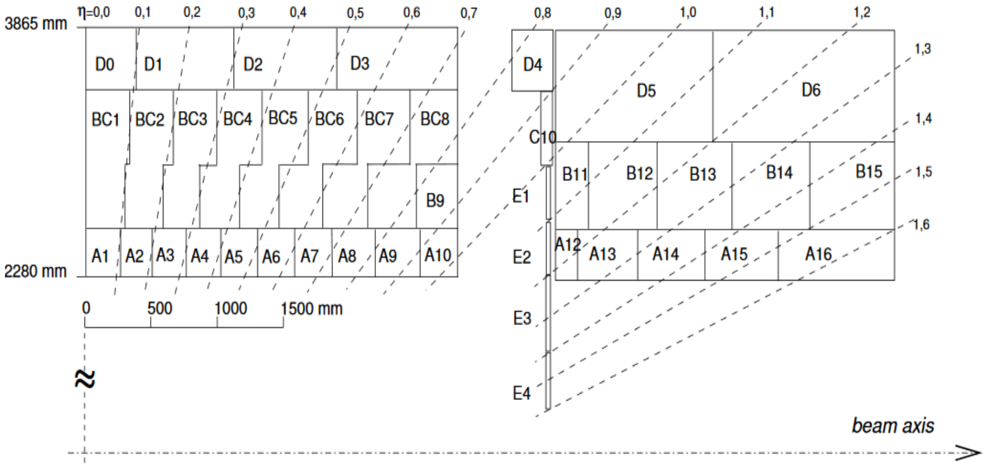
ATLAS Tile Calorimeter

- The central hadronic scintillator-steel sampling calorimeter
- Divided into three sections
  - Long Barrel: $0 < |\eta| < 1.0$
  - Two Extended Barrels: $0.8 < |\eta| < 1.7$
- It provides ATLAS Level-1 trigger information
  - Measures the 4-vectors of the jets and the missing transverse energy
- Sampling Calorimeter
  - plastic scintillator tiles – Active medium and steel plates – Absorber
- Double photomultiplier readout using wave length shifting fibers



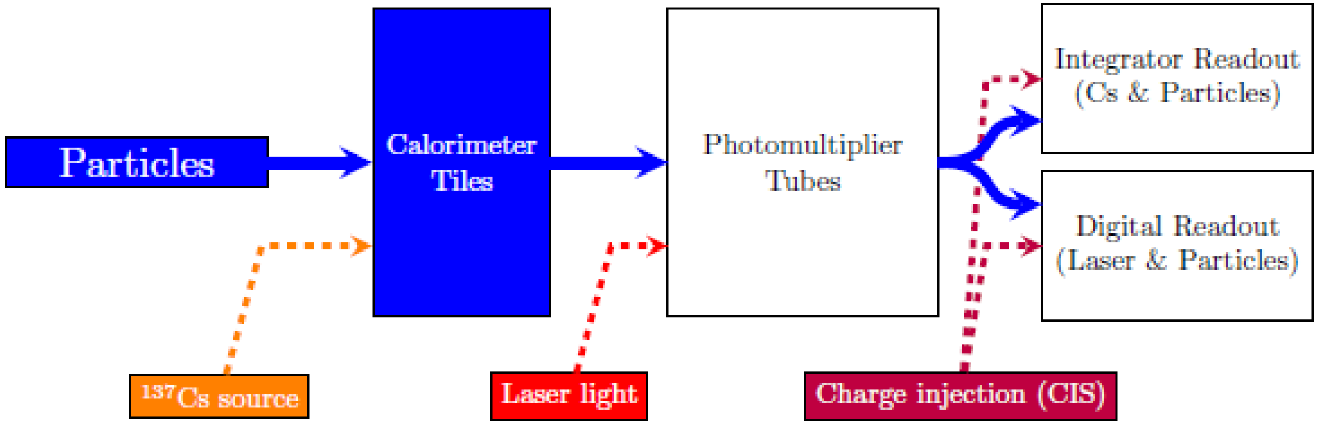




Calibration systems

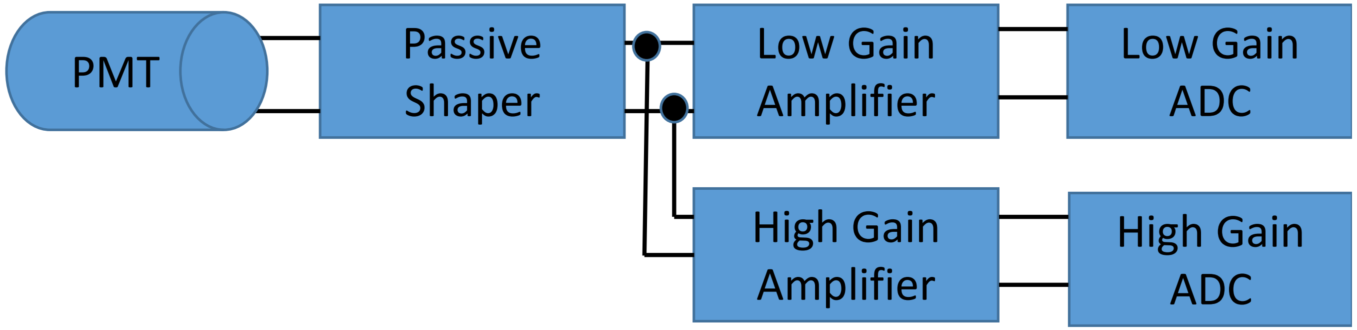
The reconstructed energy is derived from the raw response:

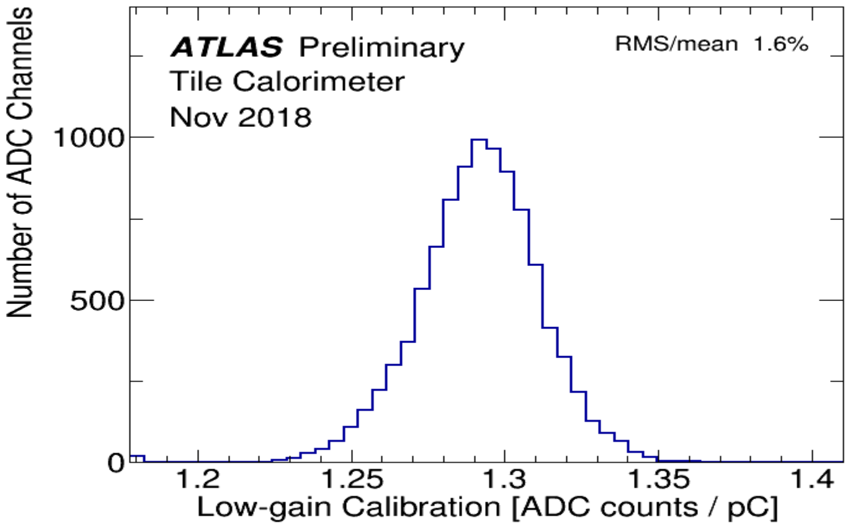
$$\mathbf{E[GeV] = A\,[ADC] \cdot C_{ADC \rightarrow pC} \cdot C_{pC \rightarrow GeV} \cdot C_{Cs} \cdot C_{Las}}$$



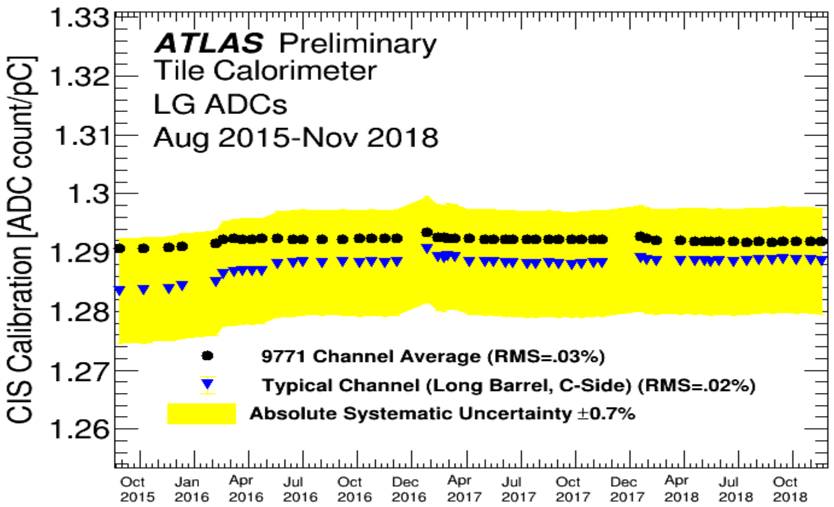
- Charge Injection System (CIS): Calibrates the response of ADCs (electronics): $\mathbf{C_{ADC \rightarrow pC}}$
- Electromagnetic scale constant measured during test beam campaigns: $\mathbf{C_{pC \rightarrow GeV}}$
- Cesium system: Calibrates optical components and PMT gains: $\mathbf{C_{Cs}}$
- Laser System: Calibrates variations due to electronics and PMTs: $\mathbf{C_{Las}}$
- Minimum Bias System (MB): Monitors beam conditions, optical components and PMT gains.

Charge Injection System (CIS)



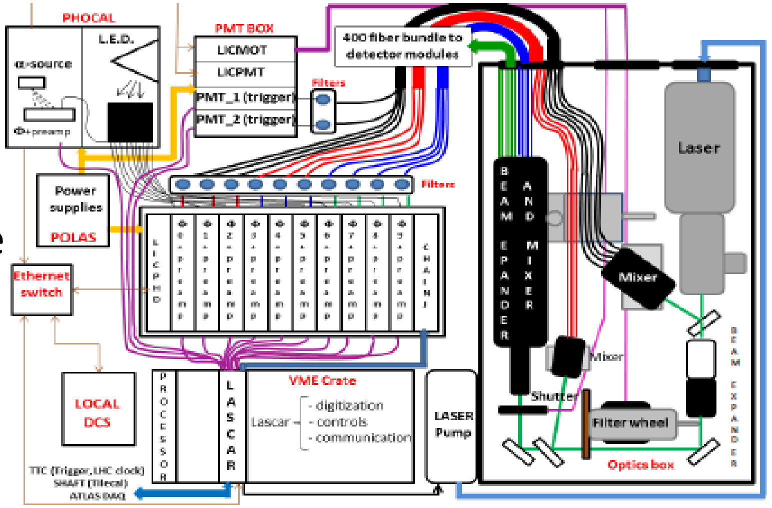


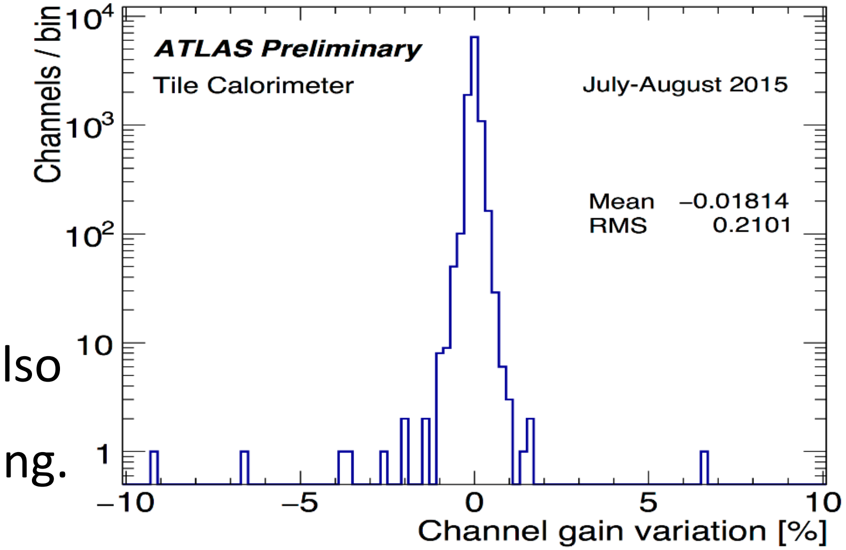
- Calibrates the response of ADCs (electronics) and linearities
- The system injects a signal of known charge and measures the electronic response
- Extract the conversion factors from ADC counts to pC ($\mathbf{C}_{\mathbf{ADC}\rightarrow\mathbf{pC}}$)
  - Spanning the full ADC range (0-800 pC; 1 pC~1 GeV).
  - Monitors both LG and HG for all channels
- Precision of 0.7%, stability over time of 0.03%



Laser System

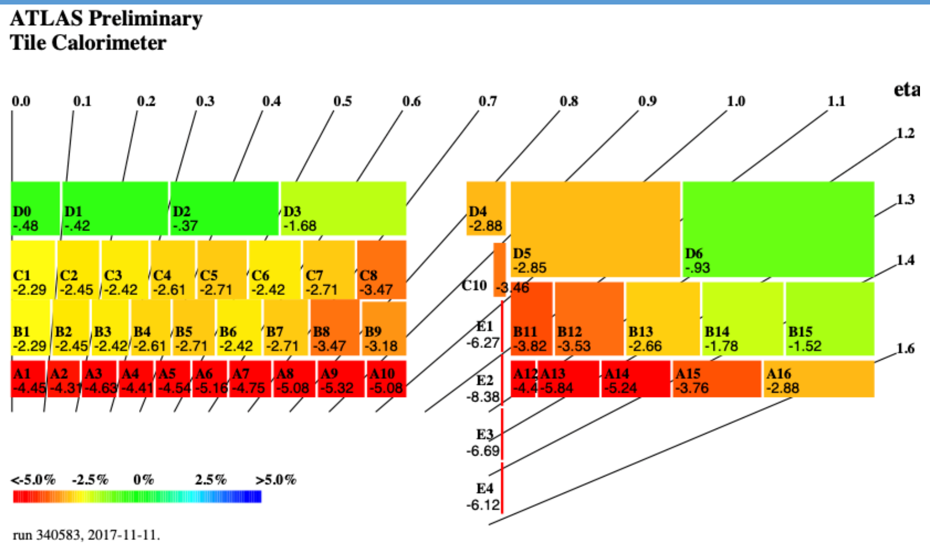
- The gain stability of each PMT is measured using the Laser system.
  - PMT gain drifts affects the detector response and thus should be measured regularly.
- The system sends a controlled amount of light into each PMT (532 nm)
- The gain variation is measured between two Cesium scans: Laser measures the drift seen in PMTs w.r.t the last Cesium scan.
- Performed during dedicated calibration runs. Laser pulses also sent during collision runs (empty bunches), to calibrate timing.

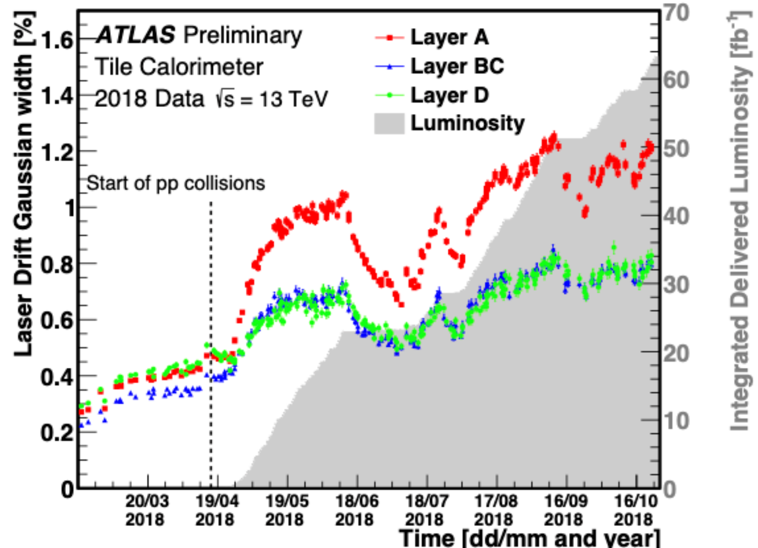




Laser System

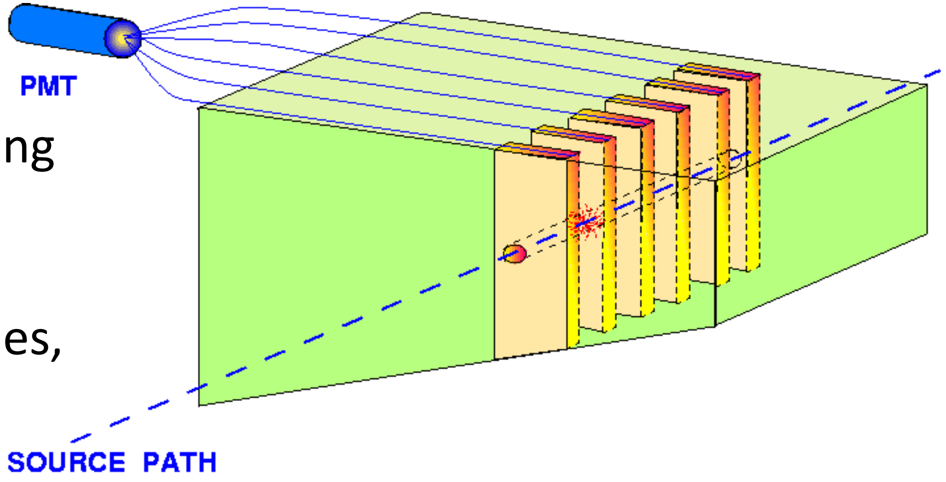
- Precision better than 0.5%
- Updates to calibration constants are done as often as weekly, to track changes in PMT responses
- The mean gain variation (in %) in the PMTs as a function of eta and radius of corresponding cells
- The maximal drift is observed in the most exposed cells with high currents in the PMTs
- In Layer A the Gaussian width increases faster with time due to different drift of cells at different eta positions.





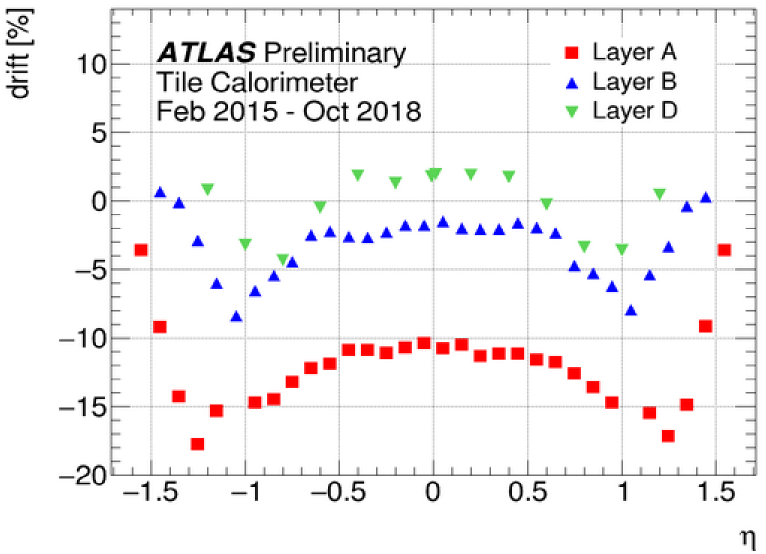
Cesium Calibration

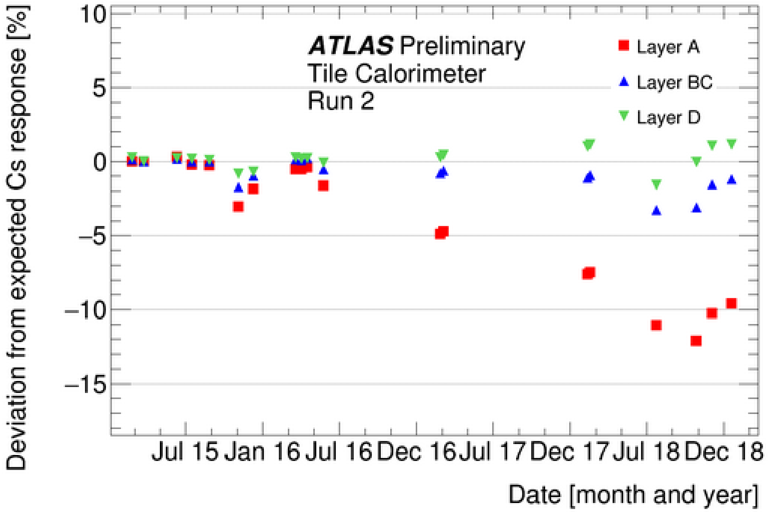
- The Cesium system is based on three moveable radioactive sources ($t_{1/2}$~30 years) using a hydraulic control through a system of steel tubes.
- The ^{137}Cs γ-sources move inside the calorimeter, emitting 0.662 MeV photons to illuminate the scintillators.
- Calibration of the complete optical chain (scintillator tiles, fibers, PMTs) and monitoring of the detector response over time: C_{Cs}
- Between Run I and Run II: improvement of stability and safety of the operation (new water storage system, lower pressure, precise water level metering).

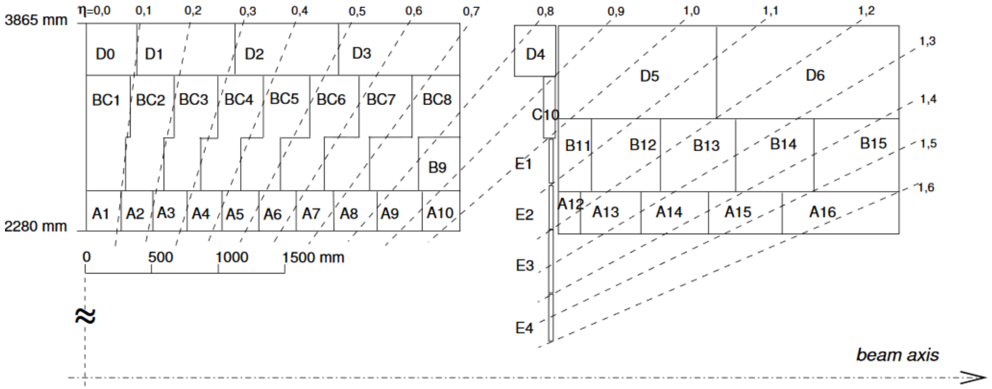


Cesium Calibration

- Variation of TileCal channels response measured in Cesium calibration runs
- Cell response is not constant in time due to the PMT gain variation and scintillator degradation due to the exposure to beam
- Precision of the system in a single typical cell is approximately 0.3%

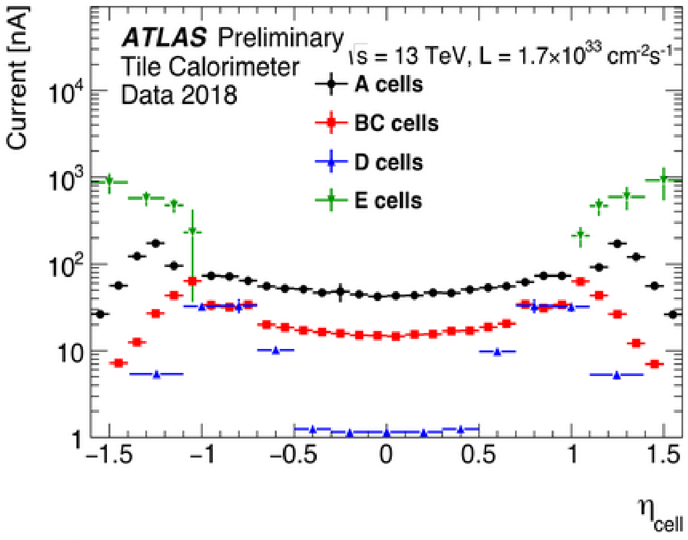


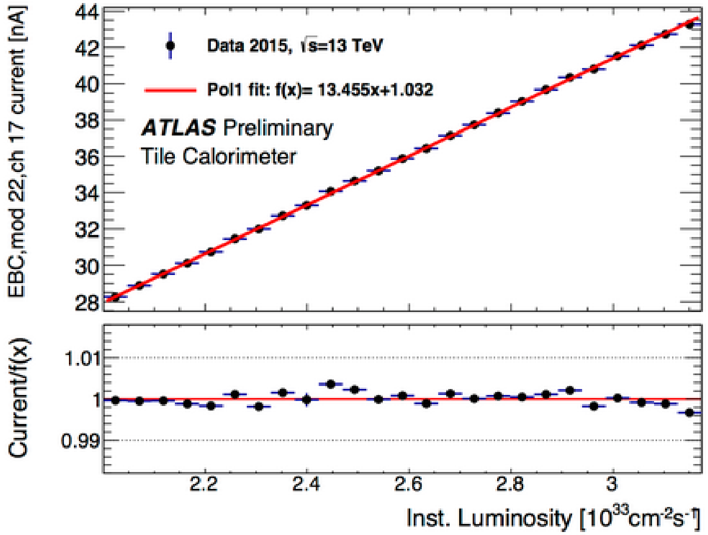




Minimum Bias System (MB)

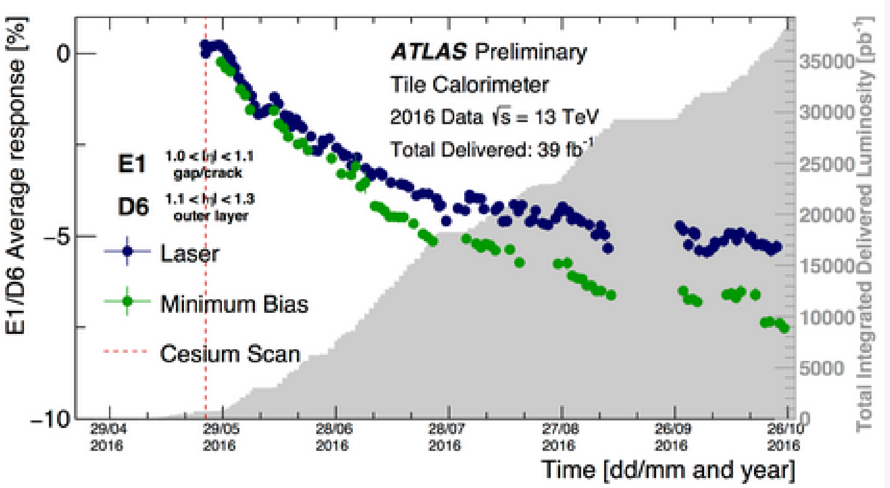
- High energy proton-proton collisions are dominated by soft parton interactions (MB events).
- The integrator readout measures integrated PMT signals over a large time (∼10 ms).
- As the Cesium system, the MB system monitors the full optical chain.
- Measured currents are linearly dependent on the instantaneous luminosity.
- The system is used to measure instantaneous luminosity given an initial calibration (luminosity coefficient computed from a single run)



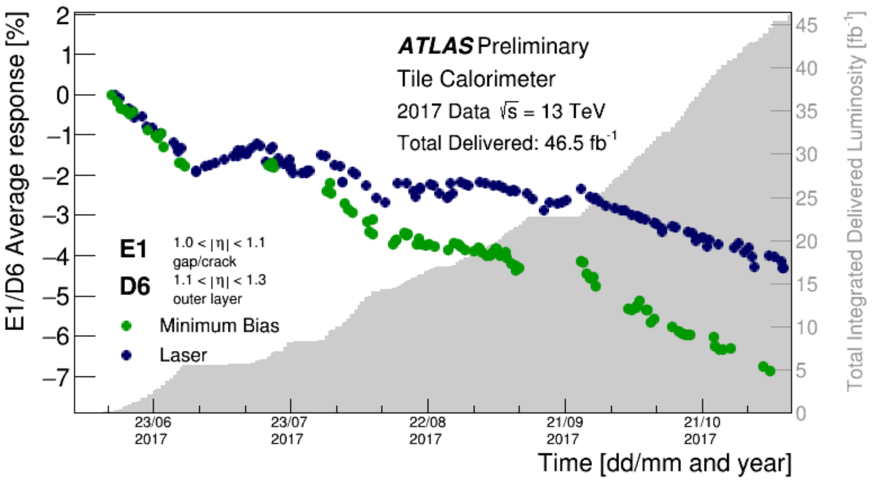


Combined calibration

2016 Data taking period



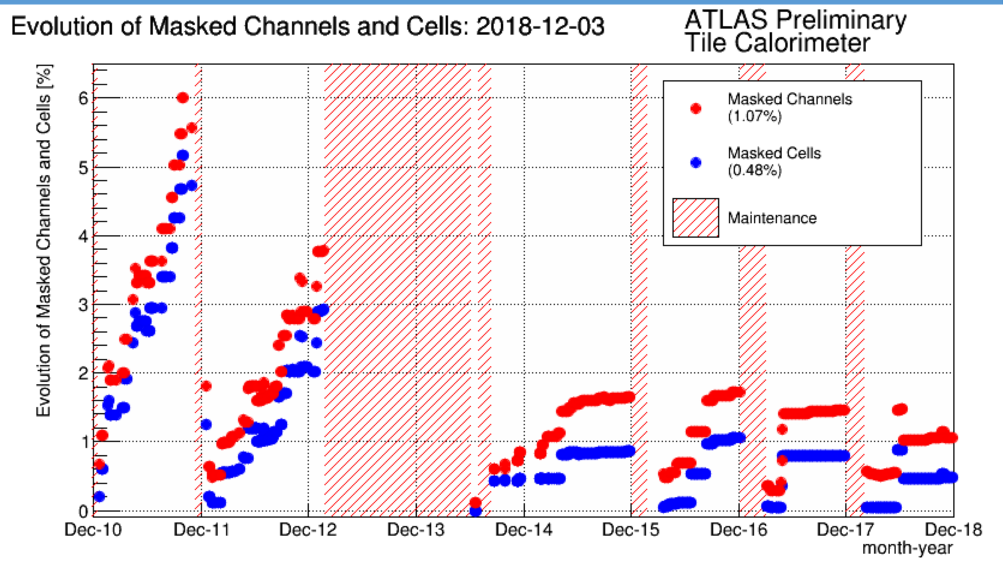
2017 Data taking period

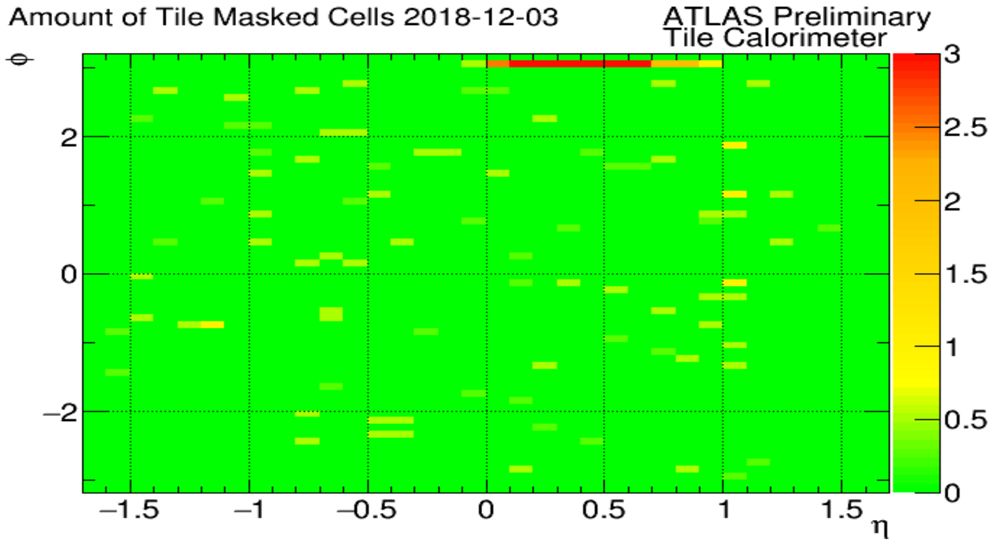


- Comparison cell response variation by Cesium, MB and Laser measurements
  - Cesium and MB access PMT gain drift and scintillator aging while laser only monitors PMT gain drifts
- Down drifts observed during collisions. Up drifts during maintenance periods and machine developments
- Differences between Cesium, MB and Laser measurements interpreted as a scintillator aging due to irradiation

Detector Status and Data Quality

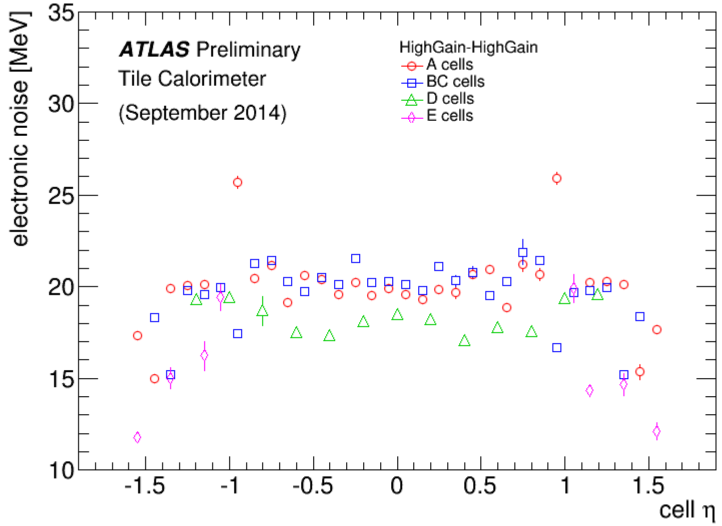
- Monitoring of TileCal is performed to identify and mask problematic channels correcting for monitoring data corruption, timing jumps or other hardware issues
- These issues are fixed during maintenance periods to allow good recovery of the system. Typical errors are:
  - Digital errors, HV off for some module's channels,
  - Cooling leaks, Trigger tower low or no signal, etc
  - The red line correspond to the complete module off due to cooling leaks
- The fraction of the masked cells at the end of each year is decreasing
- Tile had 99.7% DQ efficiency in Run-2:
  - 2015: 100%, 2016: 99.3%
  - 2017: 99.4%, 2018: 100%

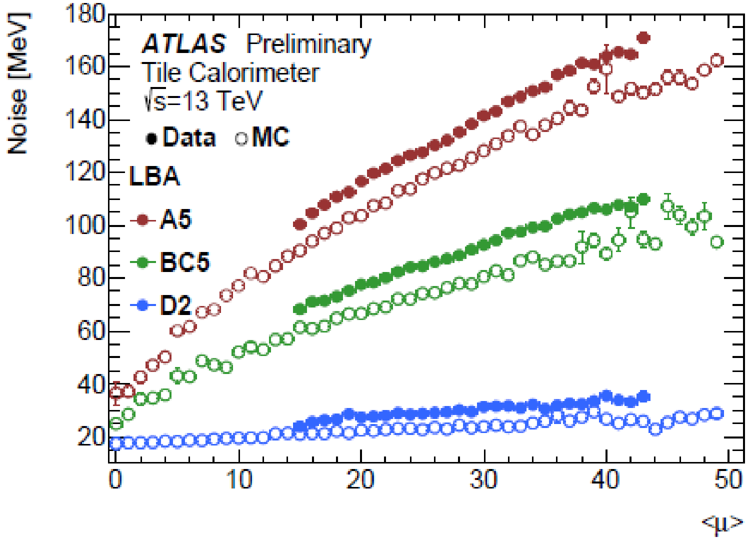




Noise

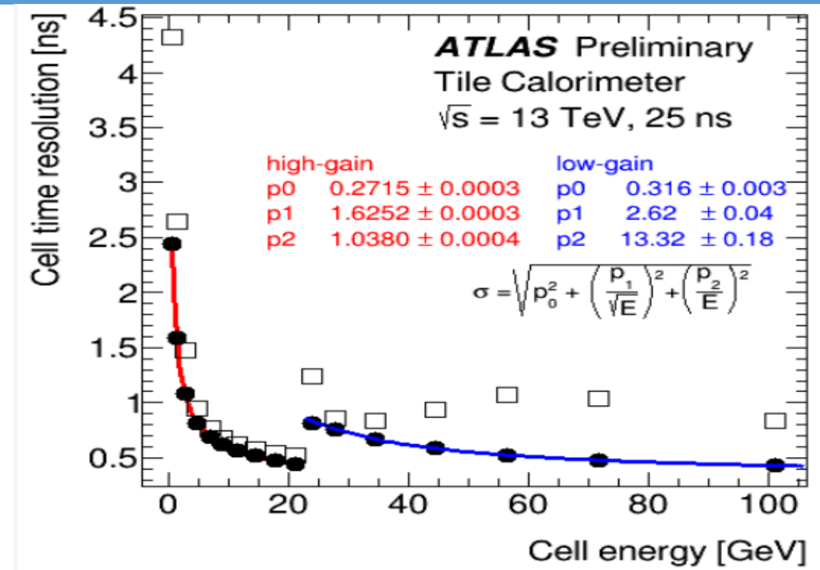
- The total noise per cell in the calorimeter comes from two sources:
  - Electronic noise – measured in dedicated runs with no signal in the detector.
  - Pile-up contribution – originates from multiple interactions occurring at the same bunch crossing or from the minimum bias events from previous/following bunch crossings
- Electronics noise stays at the level below 20 MeV for most of the cells. Pedestal and noise are measured regularly with calibration runs.
- Total noise is increasing with pile-up
- The largest noise values are in the regions with the highest exposure (A-cells, E-cells)

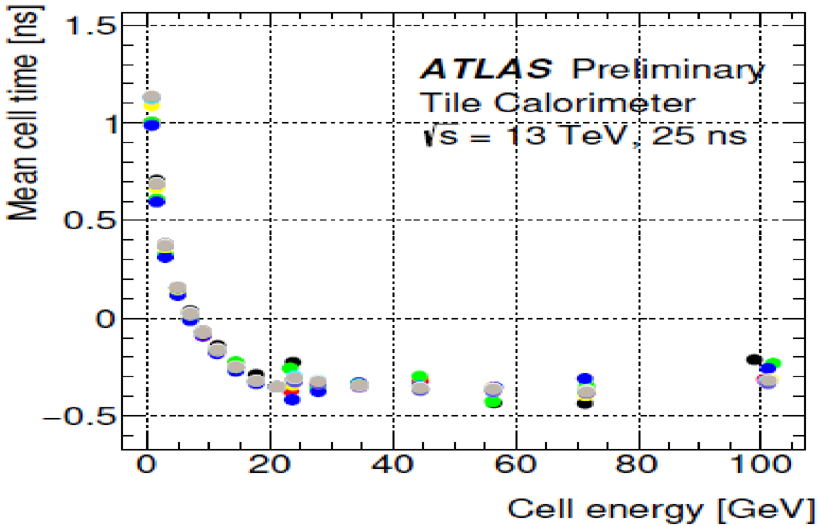




Time Calibration

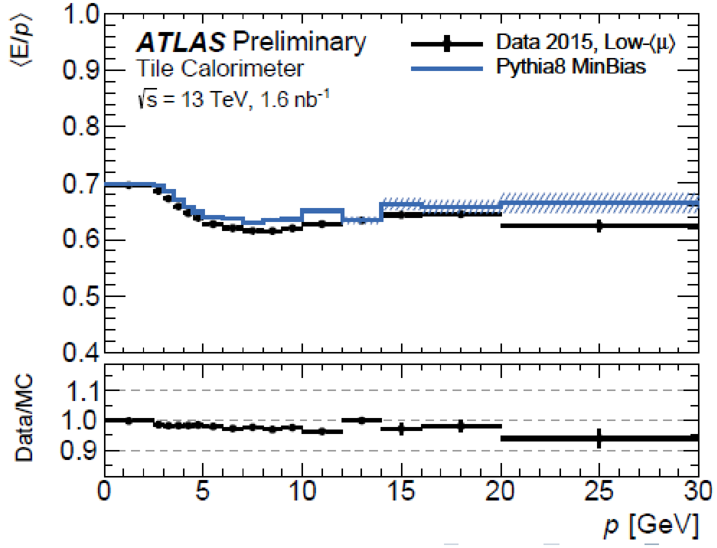
- The time calibration is important for the energy reconstruction:
  - Aims to set the phase in each channel so that a particle from the interaction point gives signal with measured time equal to zero
- Time calibration calculated using jets and monitored during physics data taking with laser
- Resolution is better than 1 ns for E_{cell} > 4 GeV

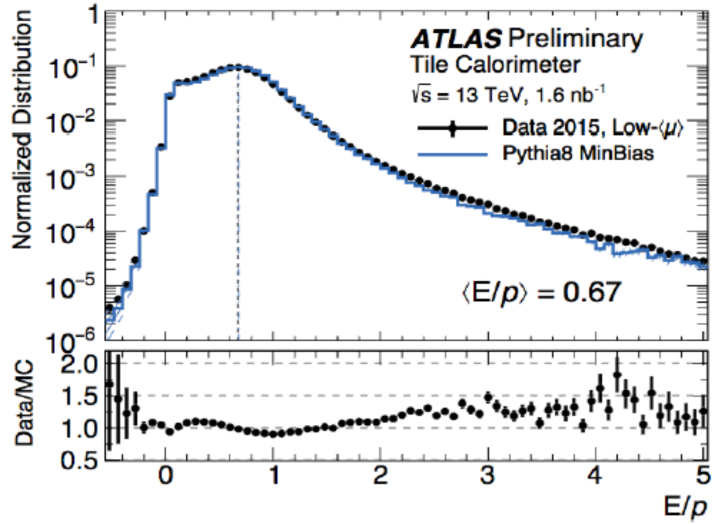




Single Particle Response

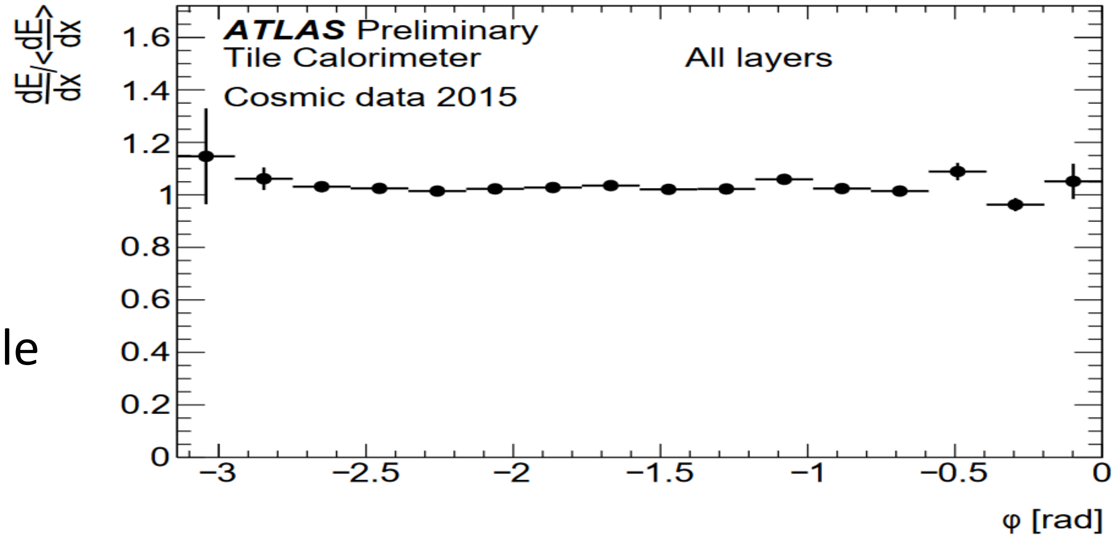
- An important Tile Calorimeter determination is the mean of energy to track momentum ratio (<E/p>) for isolated charged hadrons in minimum bias events.
  - Used to evaluate calorimeter uniformity and linearity during data taking
- Expect <E/p> <1 due to the sampling non-compensating calorimeter
- Data and simulation agree, showing linearity and uniformity in detector response
- dE/dx of minimum ionizing muons (near noise threshold) show data/MC agreement within 3%

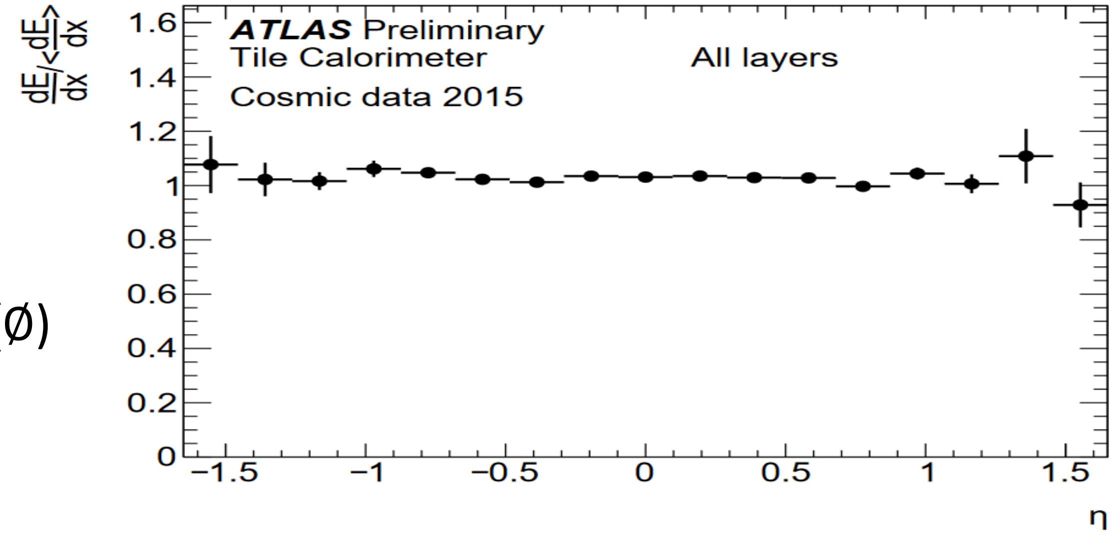




Muons

- Muons from cosmic rays, beam halo and collisions are used to check the cells inter-calibration and the electromagnetic energy scale
- Cell response is estimated as the energy deposited by the muon per the length of track path (dE/dx)
- Good energy response uniformity over radius (Ø)
- Non-uniformity in eta (η) below 5%



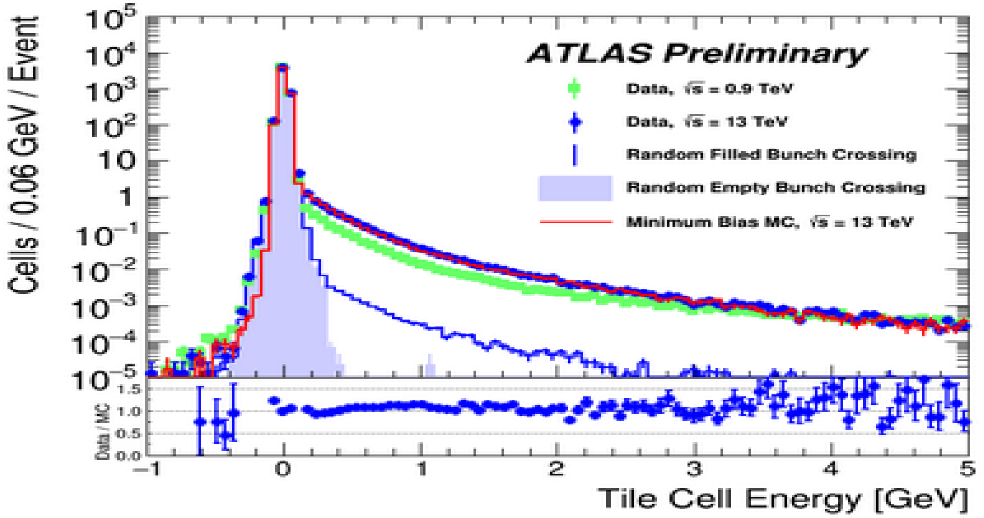


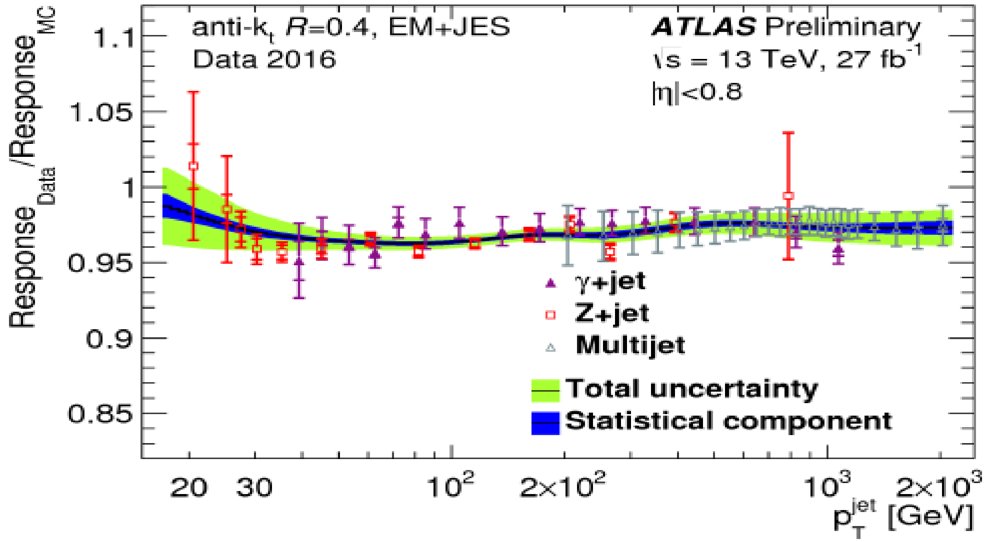
Jet Performance

- 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 e.g. for jet and missing transverse momentum reconstruction.

- Good agreement in Tile cell energy distribution.
  - To ensure exactly one interaction has occurred per bunch crossing, only events having a single reconstructed primary vertex are selected

- Jet energy resolution is around 1% at pT > 100 GeV





Conclusion

- Tile Calorimeter is an important part of ATLAS detector at LHC and provides information for reconstruction of hadrons, jets, hadronic decays of tau leptons and missing transverse energy.
- Multiple systems are used to calibrate and monitor the response of the TileCal cells.
- Inter-calibration and uniformity are monitored with isolated charged hadrons and cosmic muons
- These calibration systems allowed to achieve great performance of the calorimeter
- The stability of the absolute energy scale at the cell level was maintained to be better than 1% during Run 2 data taking