Performance and calibration of the ATLAS Tile Calorimeter

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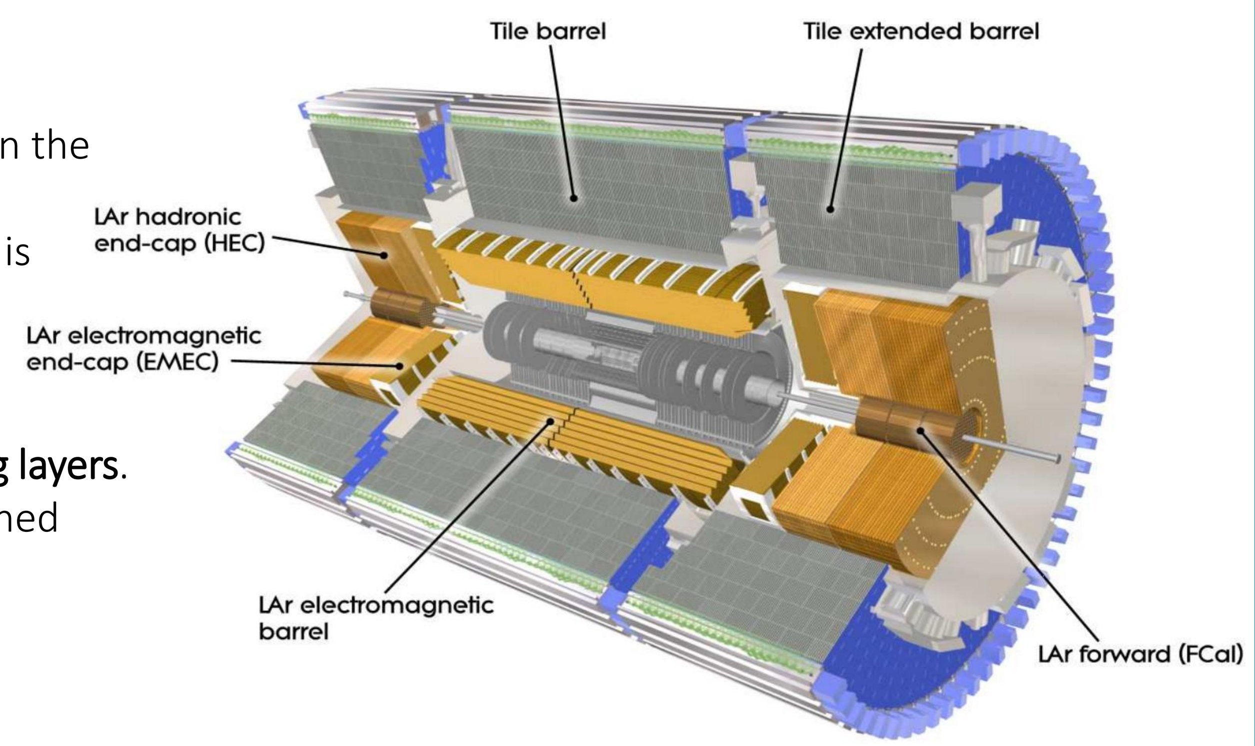
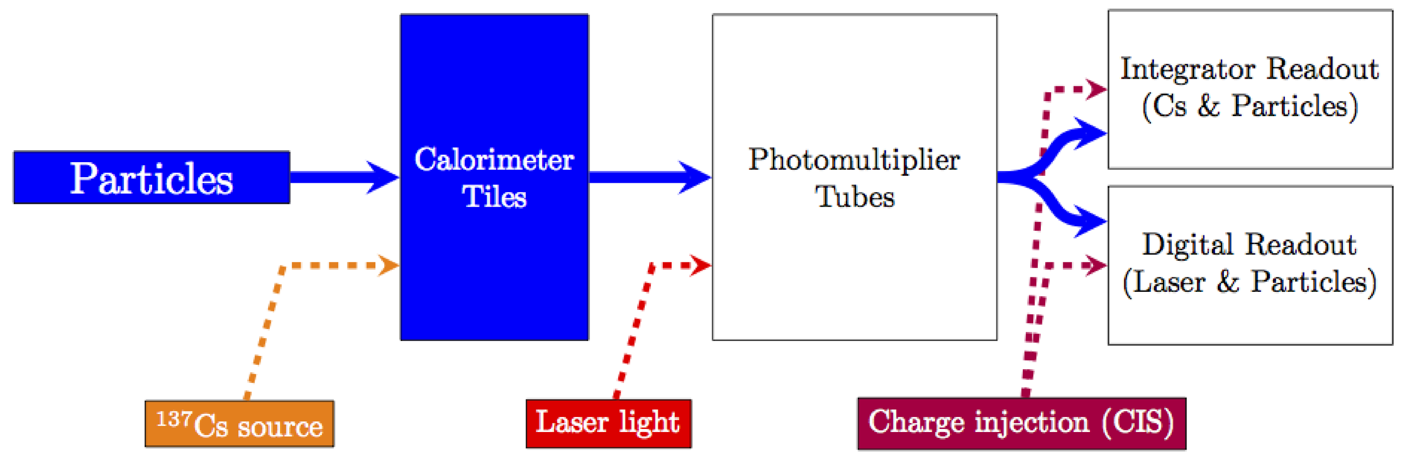
ATLAS Tile Calorimeter

- The **ATLAS Tile Calorimeter (TileCal)** is the central **hadronic calorimeter** of the ATLAS experiment. It plays a crucial role in the measurement of **jets** and **missing transverse energy**.
- It is a sampling calorimeter formed by **scintillating tiles** as active medium and **iron plates** as absorbers. The calorimeter is divided in:
  - Long barrel ($|\eta| < 1.0$)
  - Two extended barrels ($0.8 < |\eta| < 1.7$)
- Each barrel is segmented in **64 modules** with equal $\Delta\phi = 0.1$ width. TileCal is subdivided in **three longitudinal sampling layers**.
- Tiles are read out by **photomultiplier tubes** (PMT) via wavelength shifting fibers. In each module, readout cells are defined grouping fibers from individual tiles to the same PMT.
- Most cells are read out by two PMTs. In total, TileCal has **5182 cells** and around **10000 channels**.
- Signal from each PMT is shaped, amplified in **two gains** (low and high gains) with a ratio 1:64 and **digitized each 25 ns**. Amplitude and time are reconstructed using the **Optimal Filtering** technique.



1. Calibration



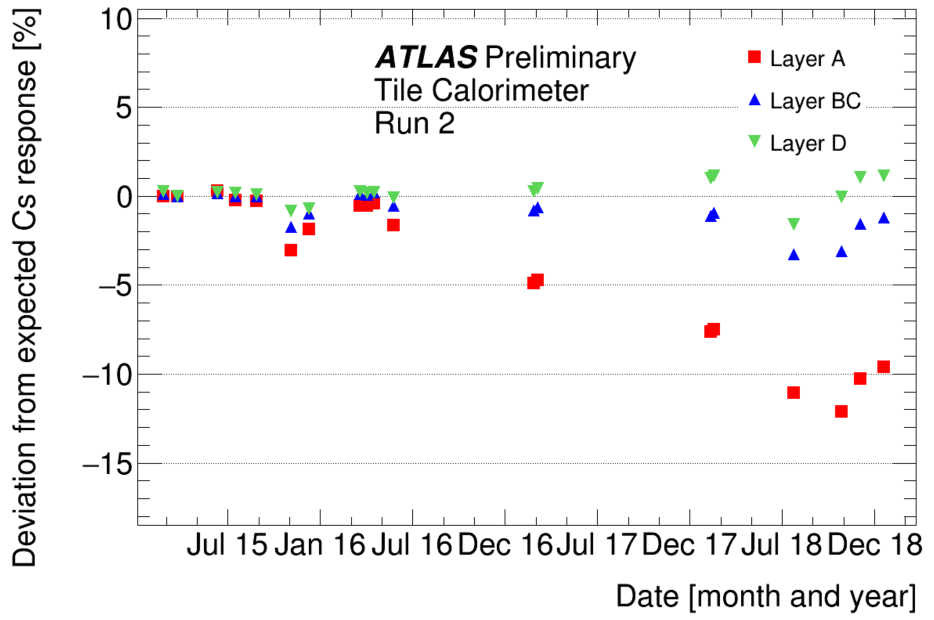
- The **energy** in each channel is evaluated from the reconstructed amplitude:

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

- $C_{\text{pc}\rightarrow\text{GeV}}$ was measured with electrons in dedicated campaigns with beams of known energy.
- Calibration constants can evolve with time due to **variations in the PMT response** (high-voltage changes and stress caused by high light flux) and **scintillator degradation**. Different calibration systems to control each part of the readout chain:
  - **Cesium System** (C_{Cs}): calibrates scintillators and PMTs responses.
  - **Laser System** (C_{Laser}): measures PMT gain variations between cesium scans.
  - **Charge Injection System** ($C_{\text{pc}\rightarrow\text{GeV}}$): calibrates readout electronics.
  - **Minimum Bias System:** monitors stability of full optical chain (cross-check with Cesium System).

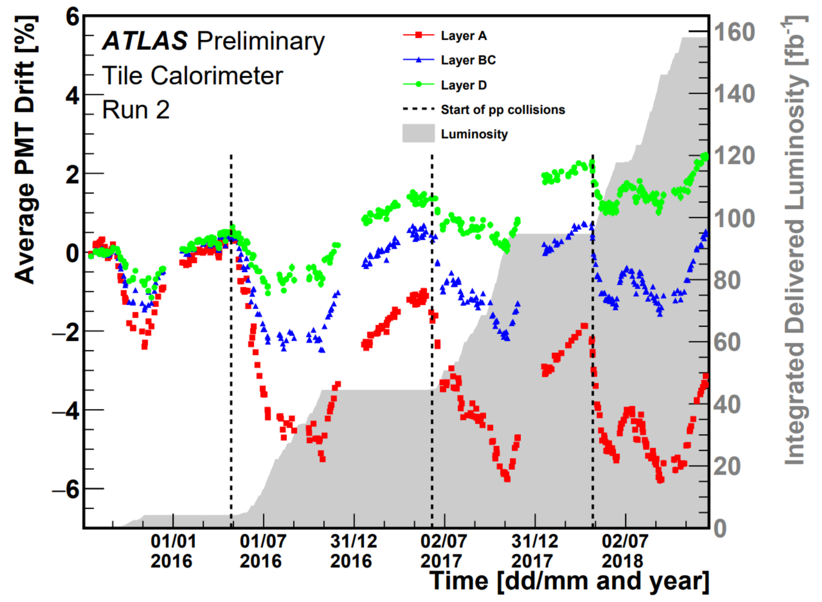
1.1. Cesium System

- Three ^{137}Cs γ-sources are moved to scan individual cells and calibrate the **optical chain** (**scintillators** and **PMTs**) .
- Deviations from expected response are translated into calibration constants.
- These deviations are due to **aging of the scintillators** and **PMT drifts** (recoverable, see Laser System).
- Cesium scans taken **few times per year**. Precision at the level of 0.3%.



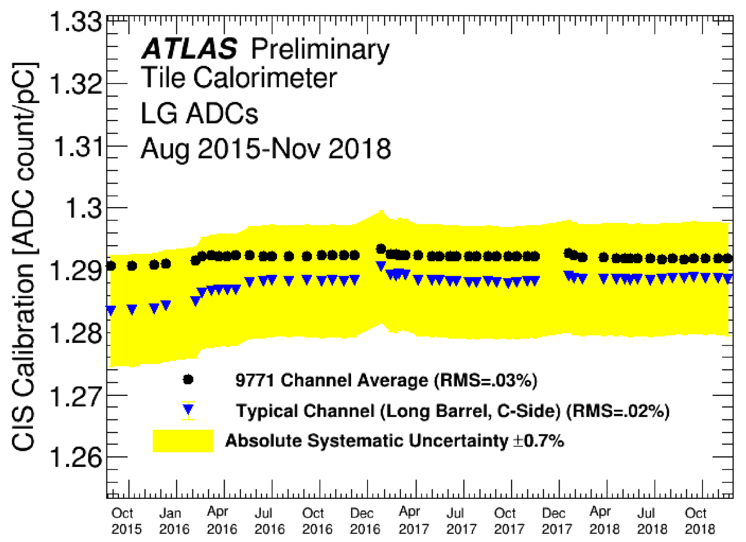
1.2. Laser System

- The main purpose is to measure **PMT variations between Cesium scans**.
- Send a controlled amount of light (532 nm) onto PMT photo-chatodes to measure drift with respect to last Cesium scan.
- Laser calibrations are done **weekly**. The precision of the system is better than 0.5%.
- **Maximal drifts** in cells with **highest energy deposits** (as for Cesium calibration, in inner radius layer A).
- PMTs response variation due to three factors: i) **up-drift** when PMTs are in **rest**, ii) **down-drift** during high instantaneous luminosity period when PMTs are **under stress**, iii) partial **recovery** during **technical stops**.



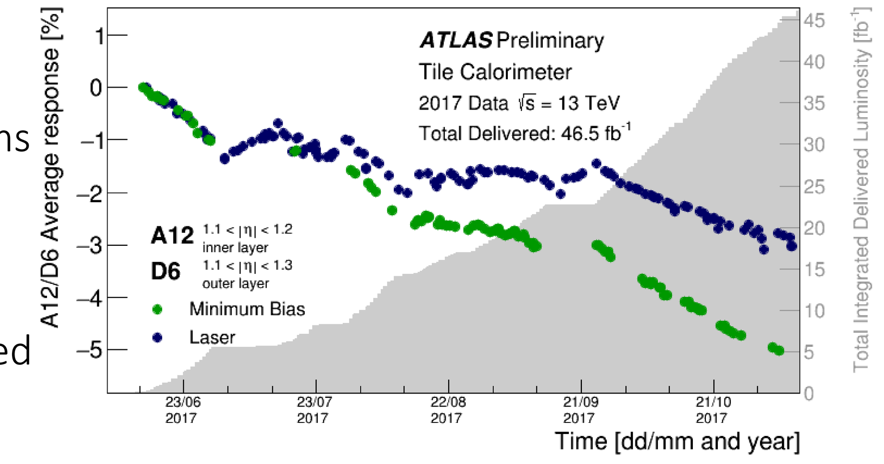
1.3. Charge Injection System

- A known charge (0 to 800 pC) is injected to calibrate **ADCs response** and evaluate **linearity**.
- Linear fit yields the pC/ADC calibration constants.
- Calibration runs taken **daily to weekly**.
- Precision of 0.7% and stability over time of the order of 0.03%.



1.4. Minimun Bias (MB) System

- Proton-proton collisions dominated by soft parton interactions.
- PMT currents due to MB events are integrated over 10 ms time window.
- Provides **instantaneous luminosity measurement** and monitors **stability of optical chain**.
- Differences between MB and Laser system are interpreted as **effects of scintillator irradiation**. Corrections applied in the abscense of Cs calibration.

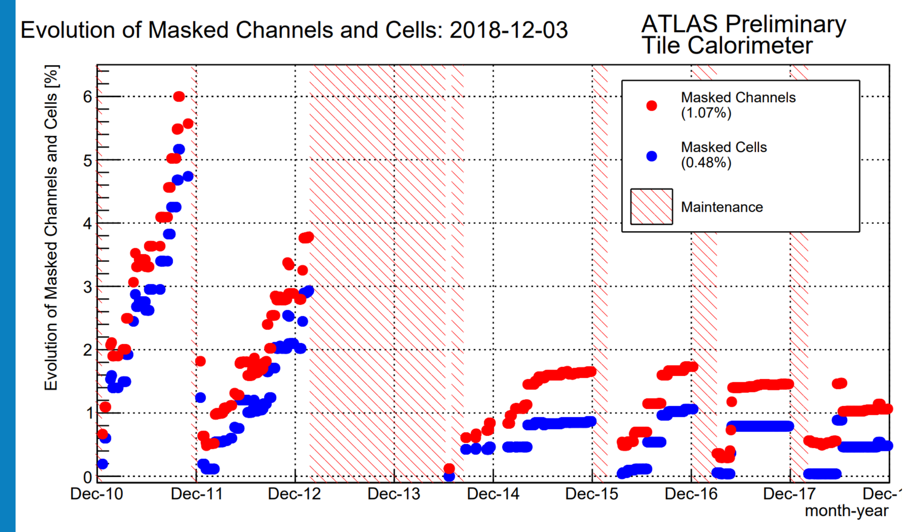


2. Performance

- High-momentum isolated muons are used to study the electromagnetic scale, while hadronic response has been studied with isolated hadrons.
- Calorimeter time resolution studied with multi-jet events.

2.1. Data quality

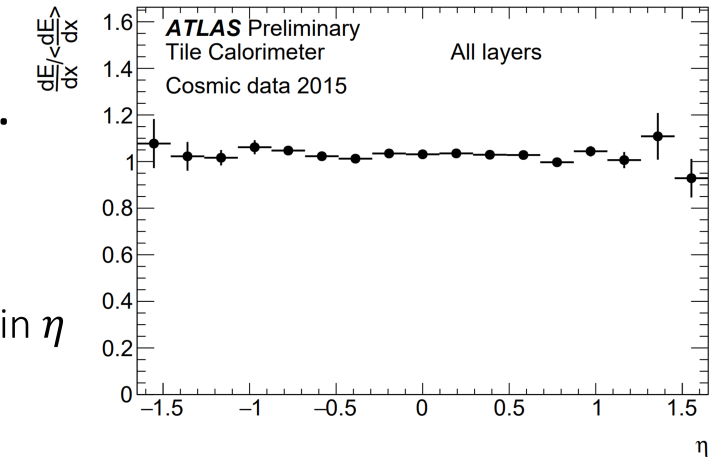
- Performance in monitored **online** during data-taking. **Offline detailed monitoring** also done within two days after the stable run, correcting calibration constants if needed.
- **Problematic cells and channels** that can affect physics analysis are **masked**.
- TileCal achieved 100% of data quality efficiency in 2015, 99.3% in 2016, 99.4% in 2017 and 100% In 2018.



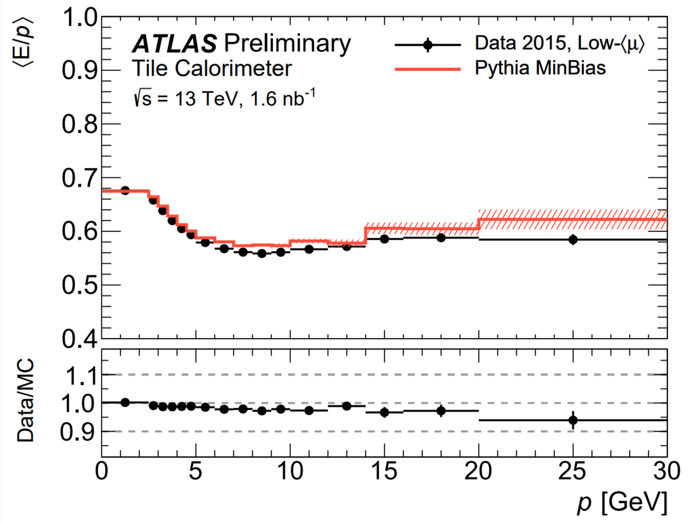
Plot showing time evolution of masked cells and channels. Problems mostly fixed in dedicated **maintenance campaigns**. Due to redundancy, only 0.48% cells masked at the end of Run-2.

2.2. Single particles and muon response

- **Cosmic muons** are used to study the **electromagnetic scale** and the **calorimeter cell intercalibration.** Good energy response uniformity in ϕ. Non-uniformity in η better than 5%.

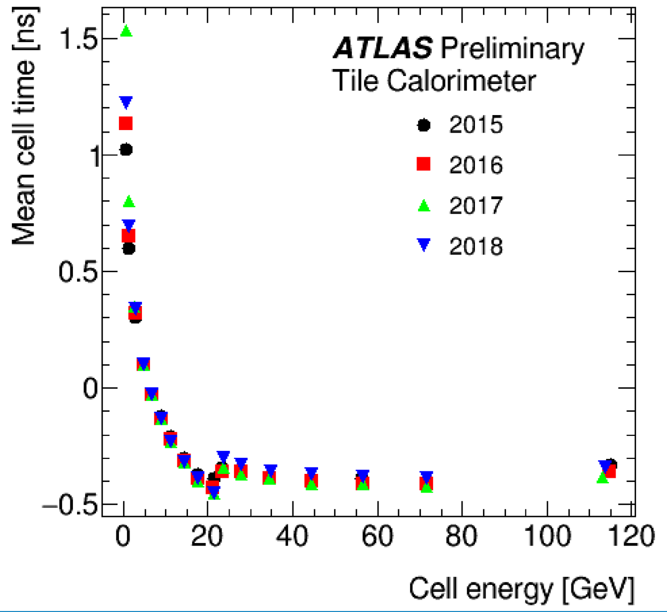


- The ratio of energy measured by TileCal to the track momentum (E/p) is used to evaluate **uniformity** and **linearity**. Expected to be < 1 due to non-compensating nature of the calorimeter. Data and Monte Carlo simulations agree within 5%.



2.3. Time resolution

- **Time calibration sets** the **phase** in each channel so that a particle traveling at the speed of light from the interaction point generates a signal pulse peaking at the central sample, equivalent to the reconstructed time equal to zero.
- **Laser events** and events containing **jets** are used to **monitor channel time stability**.
- The mean cell time measured with jets **depends** on the **deposited energy**. The cell time resolution in jet events is better than 1 ns for $E_{\text{cell}} > 4$ GeV.



3. Conclusions

- The Tile Calorimeter plays an important role in the ATLAS detector. Several calibration systems guarantee the stability of the cells response. They allow to control several parts of the readout chain and provide calibrating corrections for variations.
- The TileCal performance is checked with isolated hadrons and cosmic muons. During Run-2, the data quality efficiency exceeded 99.65%. The stability of the detector respons was better than 1%.

4. References

ATLAS Collaboration, Operation and performance of the ATLAS Tile Calorimeter in Run 1, Eur. Phys. J. C 78 (2018) 987

ATLAS Collaboration, ATLAS data quality operations and performance for 2015–2018 data-taking, JINST 15 (2020)