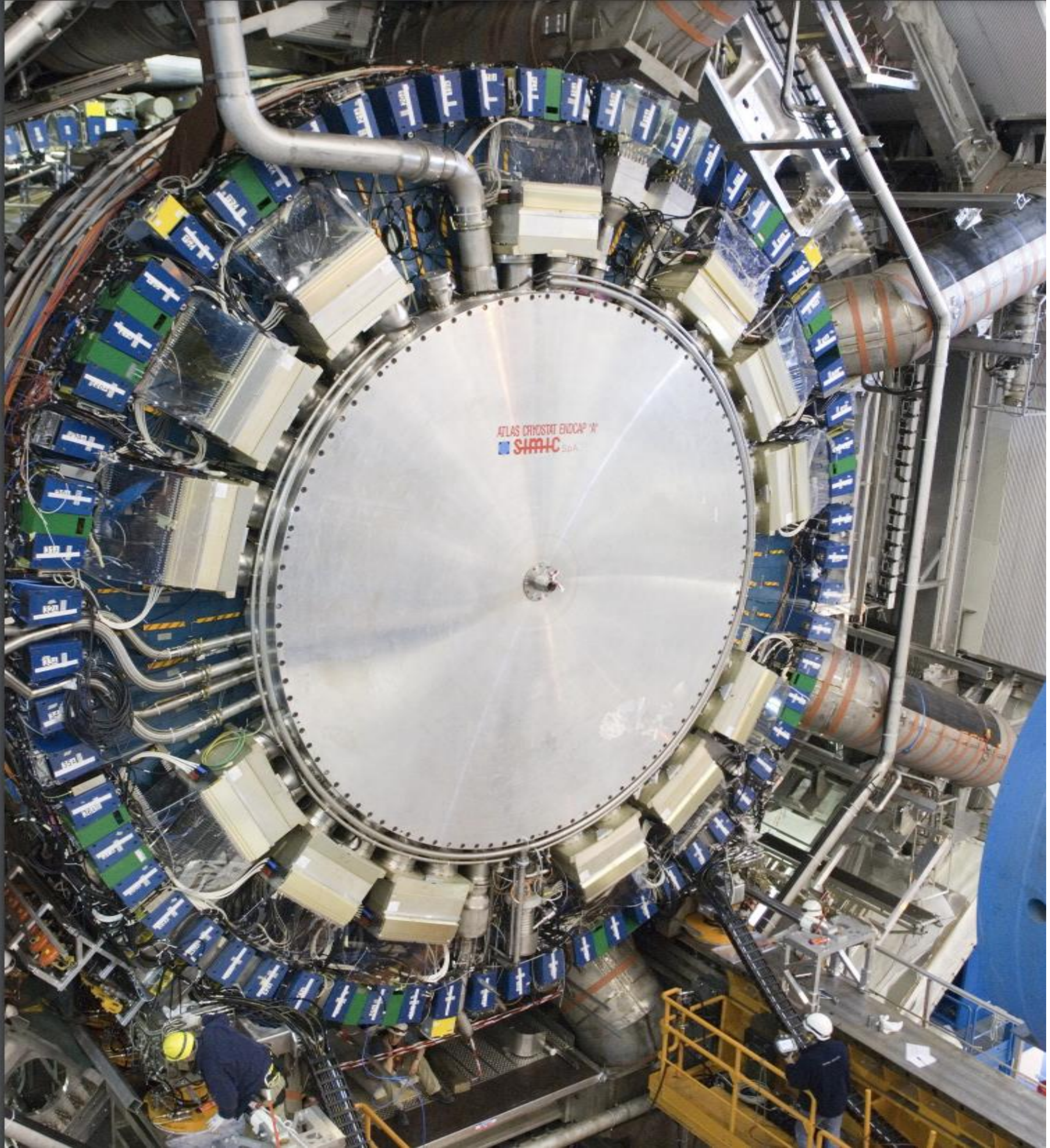

Performance and Calibration of the ATLAS Tile Calorimeter

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on behalf of the ATLAS Collaboration

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Prague, Czech Republic

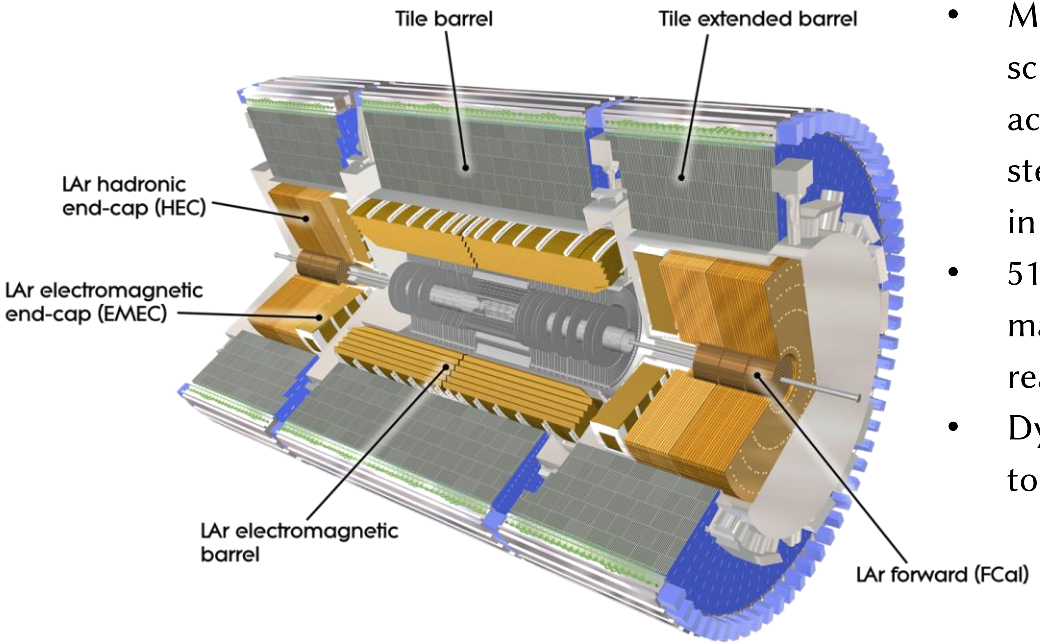
Stockholms universitet

ATLAS EXPERIMENT

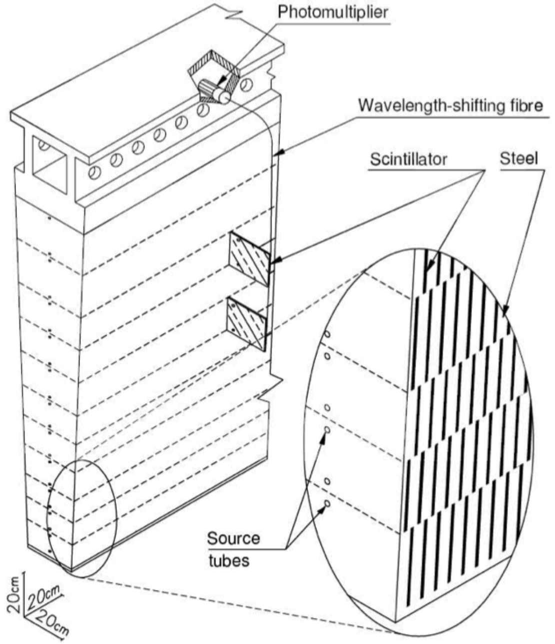
Tile Calorimeter

PMT: Photomultiplier Tube

- Central hadronic calorimeter (|η| < 1.7) of the ATLAS detector
  - Provides information for the reconstruction of hadrons, jets, tau leptons and missing transverse energy
  - Provides inputs to L1 trigger and muon identification
  - 4 partitions: 2 halves of central long barrel and 2 extended endcaps, with 64 modules in each partition



- Modules composed of scintillating tiles as active medium and steel plates as absorber in alternate layers
- 5182 cells in total, majority of which readout by 2 PMTs
- Dynamic range 10 MeV to 2 TeV per cell



Signal Processing

PMT: Photomultiplier Tube
MBTS: Minimum Bias Trigger Scintillator
ADC: Analog-to-Digital Converter

- Signal production
    - Light produced by charged particles passing through scintillating tiles transmitted to PMTs via the Wavelength-shifting fibres
- Signal reconstruction
    - The shaped PMT signals are then divided into two branches, low gain (LG) and high gain (HG), and amplified with a relative ratio of 1:64
    - Both HG and LG signals are sampled every 25 ns using a 10-bit ADC, producing seven amplitude measurements centred around pulse peak
    - The optimal filtering algorithm is used to reconstruct the signal parameters: amplitude (A), time (t), pedestal (P)

$$A = \sum_{i=1}^{7} a_i \cdot S_i, \qquad t = \frac{1}{A}\sum_{i=1}^{7} b_i \cdot S_i, \qquad P = \sum_{i=1}^{7} c_i \cdot S_i,$$

S_i: readout of sample i a_i, b_i, c_i: coefficients derived from test beams measurements

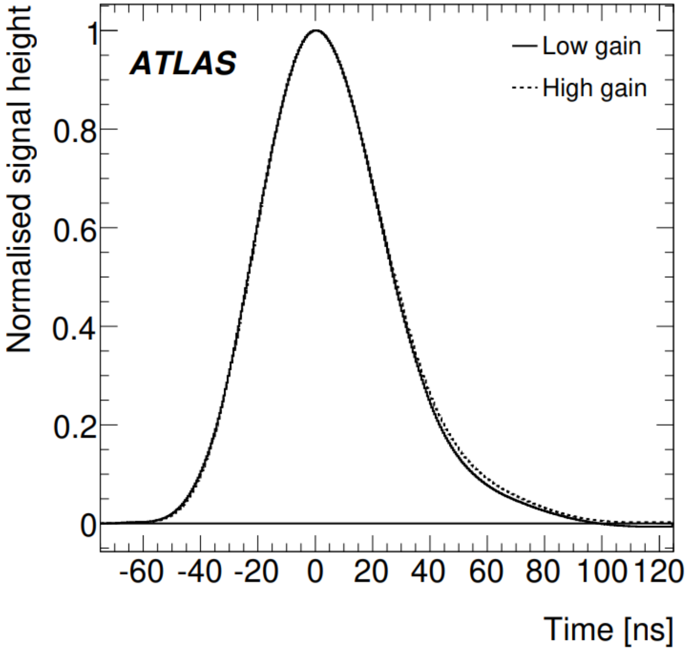


Illustration of pulse shapes for low gain and high gain

Calibration Systems

PMT: Photomultiplier Tube
ADC: Analog-to-Digital Converter

- Various calibration systems are used to monitor the readout chain

Cesium System

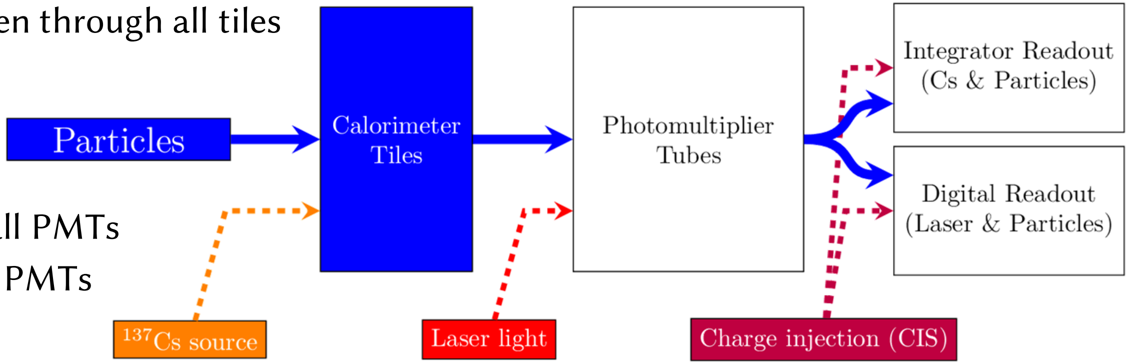
radioactive ^{137}Cs source hydraulically driven through all tiles
calibrates optical components and PMTs
performed on a monthly basis

Laser System

short laser pulses simultaneously sent to all PMTs
calibrate variations due to electronics and PMTs
performed daily during data-taking

Charge Injection System (CIS)

known charge injected into readout electronics
calibrates the response of ADCs
performed twice a week



Calibration systems of Tile Calorimeter

arXiv:2401.16034

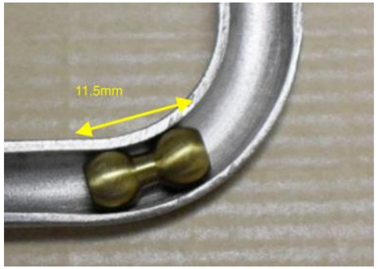
$$E\ [\mathrm{GeV}] = \frac{A\ [\mathrm{ADC}]}{C_{\mathrm{ADC}\to\mathrm{pC}} \times C_{\mathrm{pC}\to\mathrm{GeV}} \times C_{\mathrm{Cs}} \times C_{\mathrm{MB}} \times C_{\mathrm{Las}}}$$

obtained from test beams

obtained from minimum-bias collisions

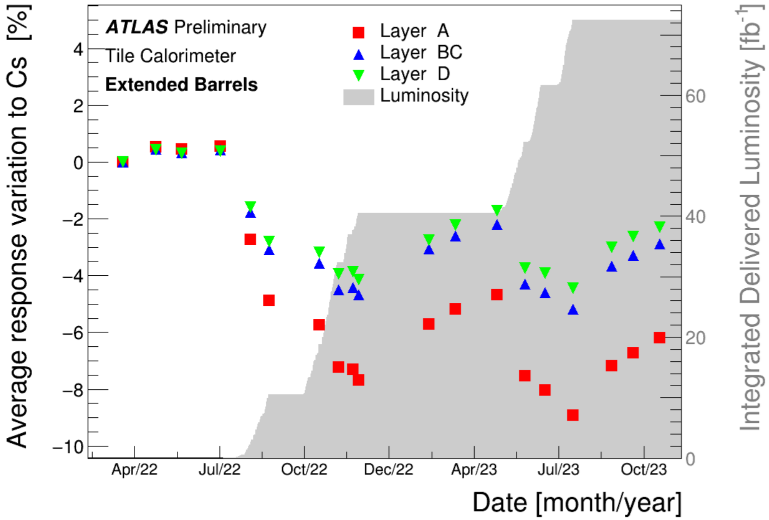
check Danijela's poster for more on calibration systems

Calibration - Cesium

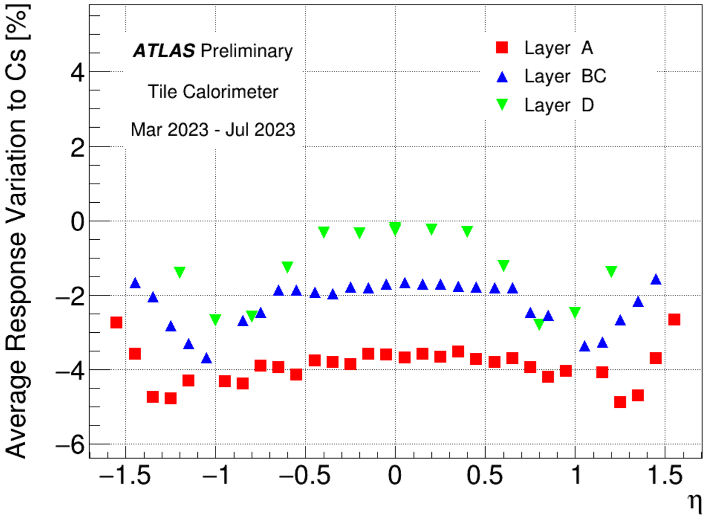


- Capsules with ^{137}Cs γ-radiation source via hydraulic circuit
  - Signals readout by a dedicated integrator system
  - Precision of the system at the level of 0.3% in typical calorimeter cells
  - Cells with largest response variation located at the innermost radial layer (layer A) due to higher radiation exposure

Layer averaged response variation of Tile cells to Cesium source
Extended Barrels, March 2022 – November 2023

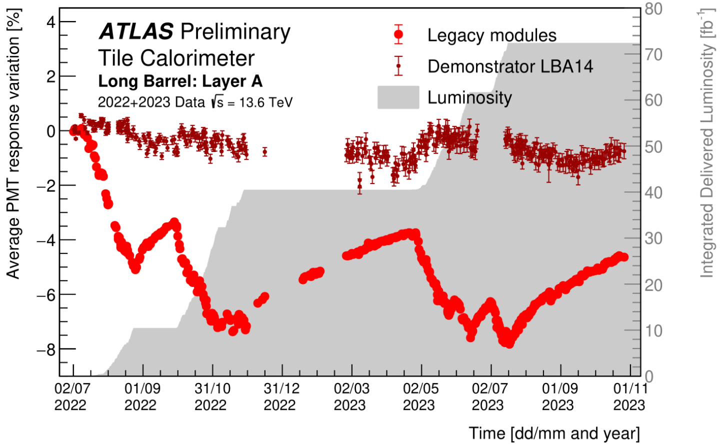


Layer averaged response variation of Tile cells to Cesium source
Tile Calorimeter, March 2023 – July 2023



Calibration - Laser

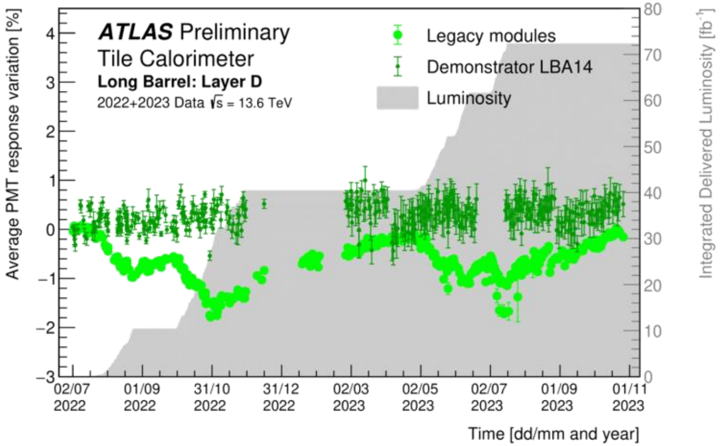
- Laser source with 532 nm 10 ns pulses
  - Signals collected in dedicated calibration runs and in the LHC empty bunches during ATLAS physics runs
  - Precision of the system at the level of 0.5%
  - Provides PMT gain and timing corrections in all channels

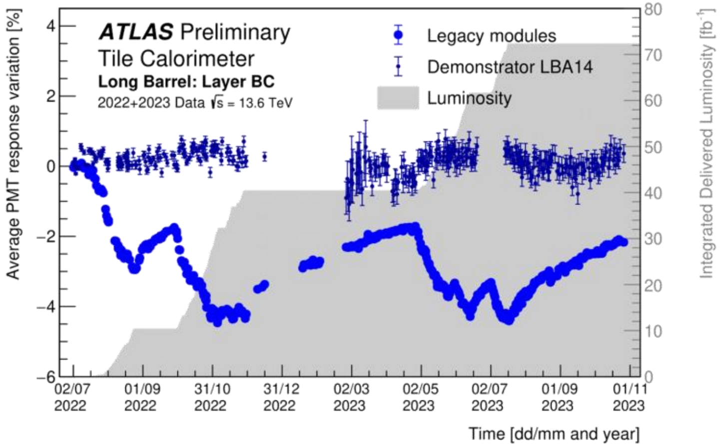


Averaged response variation of Tile cells in PMTs
Long Barrels, February 2022 – November 2023

better stability in time is observed for the demonstrator module (upgraded electronics with backward compatibility to current readout system)

check Agostinho's talk for more on demonstrator

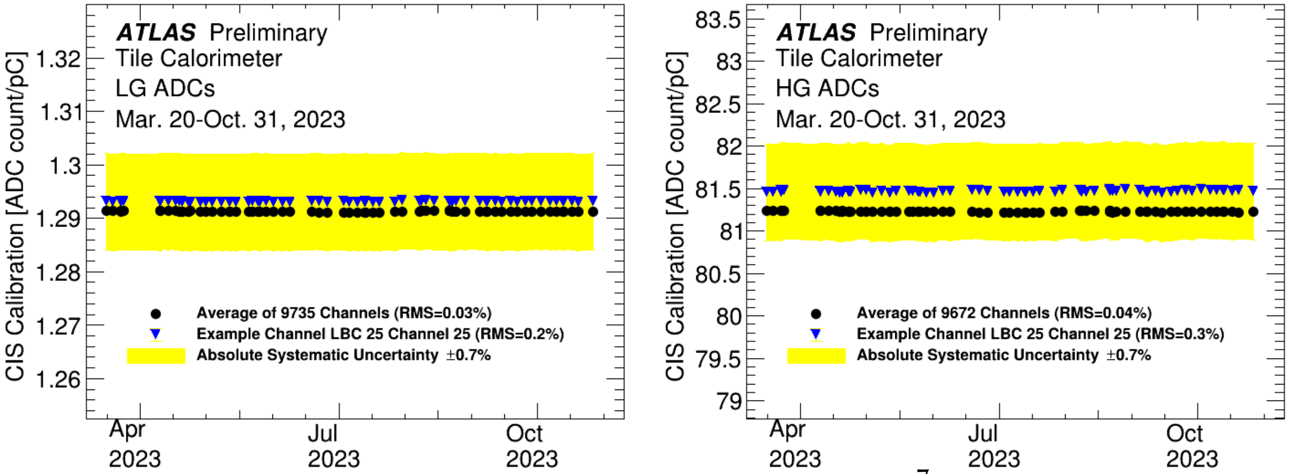




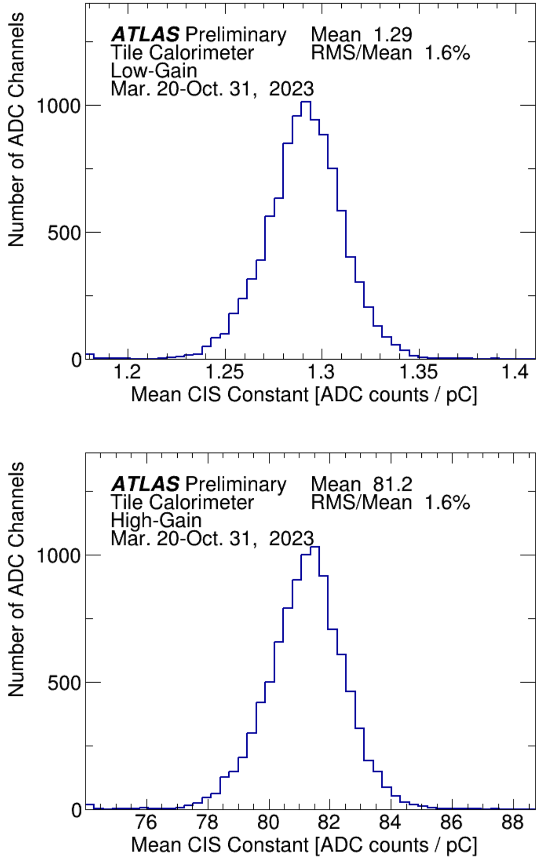
Calibration - Charge Injection

- Well defined charges injected into readout system
  - Determines the conversion factors from sample amplitude (ADC count) to charge (pC)
  - Precision of the system at the level of 0.7%
  - Very good stability over time

Stability of CIS constants compared to a single channel (LBC25)
Tile Calorimeter, March 2023 – October 2023



Distribution of the average CIS constants per channel



Performance - Energy Response

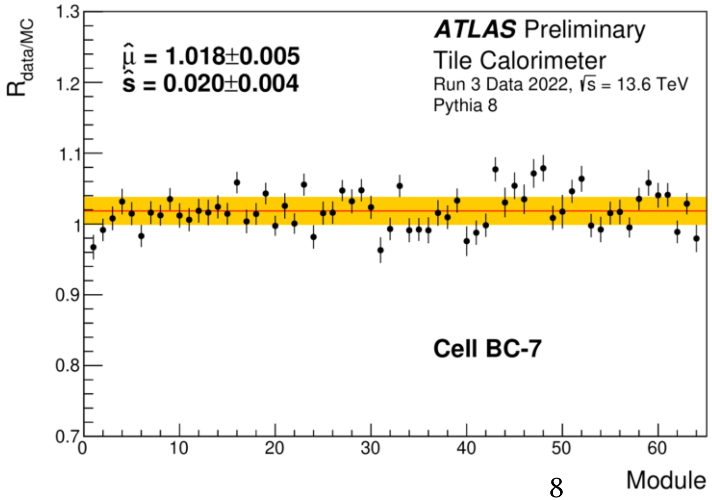
- Response to single muons
  - Checks EM scale and response uniformity performed using $W \rightarrow \mu\nu$ events
  - Ratio of the truncated mean of the muon energy loss per unit distance calculated without considering 1% of the events in the upper tail
  - Uniformity observed across Tile modules

$$R \equiv \frac{\langle \Delta E / \Delta x \rangle^{\text{data}}_{F=1\%}}{\langle \Delta E / \Delta x \rangle^{\text{MC}}_{F=1\%}}$$

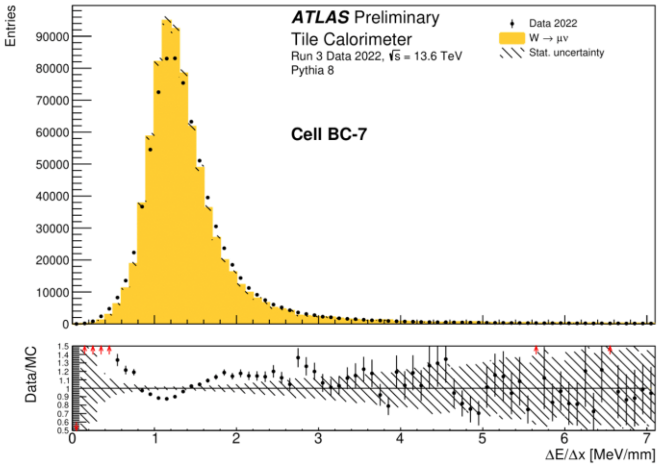
studies on single hadron response using Run 3 data currently ongoing

check Tadeas' poster for more on energy response studies

Uniformity of isolated muon response across modules
Cell BC-7, February 2022 – November 2022



Spectrum of the muon energy loss per unit distance
Cell BC-7, February 2022 – November 2022

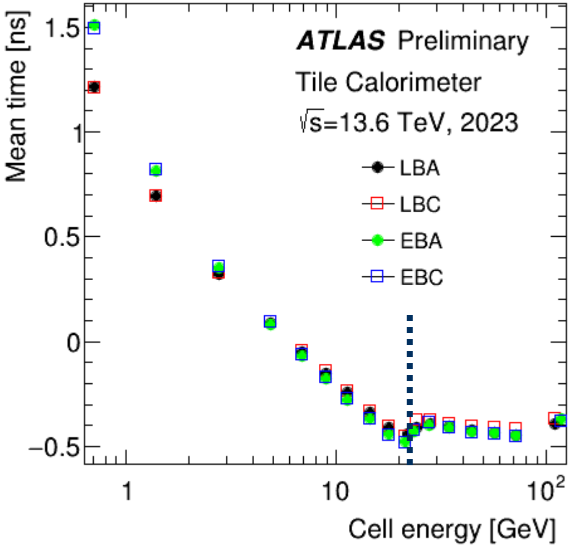


Performance - Time

- Mean cell time
  - Evaluated using reconstructed jets with p_T > 20 GeV
  - Decrease due to less neutrons and slow hadronic components of shower at higher deposited energy

- Time resolution
  - Slightly worse resolution in Extended Barrels (EBA, EBC) due to larger cell size when compared to Long Barrels (LBA, LBC)

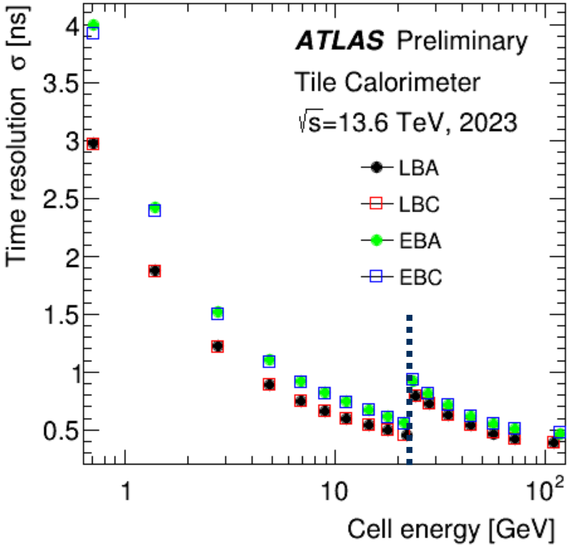
Mean cell time vs. deposited energy
Tile Calorimeter, May 2023



▪▪▪ : transition between low gain and high gain at around 22 GeV

check [Martin's poster] for more on time calibration, monitoring and performance

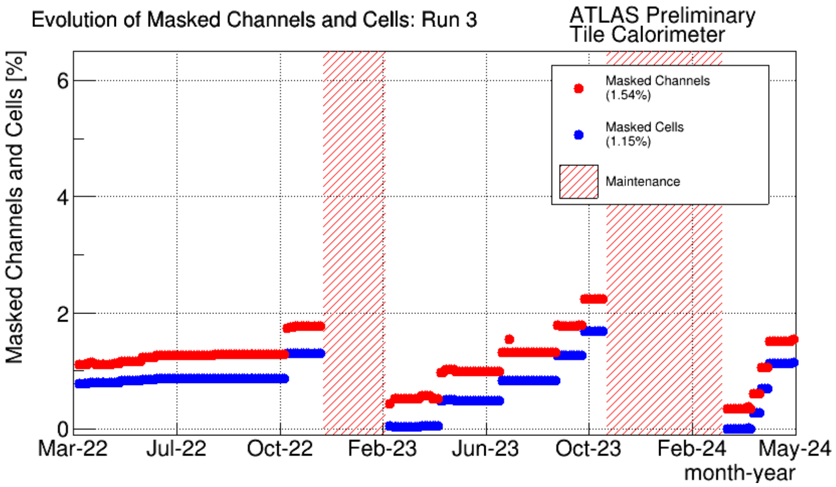
Time resolution vs. deposited energy
Tile Calorimeter, May 2023



Summary

- The ATLAS Tile Calorimeter is operating well in LHC Run 3
    - The team has been monitoring the response with various calibration systems and physics data

- Updates on the Tile performance studies using Run 3 data
    - EM response validated using isolated muons
      good uniformity across modules
    - Hadronic response studies using isolated hadrons ongoing
    - Time performance checked using jets in collision data
      resolution better than 1 ns for cell energy > 4 GeV



Thank You!

Backup Materials

Calibration - Minimum Bias

- Inelastic proton-proton collisions at low momentum transfer
  - Signals readout by the same integrator system as used by Cesium calibrations
  - Precision of the system at the level of 1.2%
  - PMT response to Minimum Bias events proportional to the instantaneous luminosity
  - Allowing for degradation studies of cells inaccessible to the Cesium system, e.g. in gap/crack region (E cells)
  - Response variation derived with respect to the inner detector tracking-counting luminosity

Averaged response variation of Tile cells to Minimum Bias
Gap/crack region, April 2023 – July 2023