Calibration and performance of the ATLAS Tile Calorimeter in Run 3

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*On behalf of the **ATLAS Collaboration***

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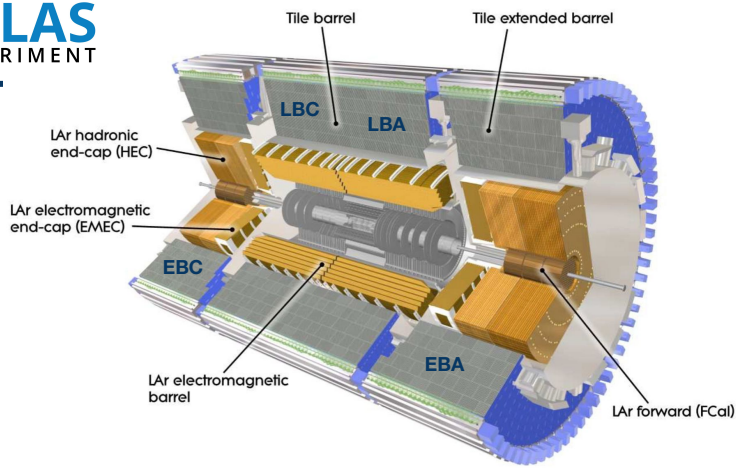
ATLAS EXPERIMENT

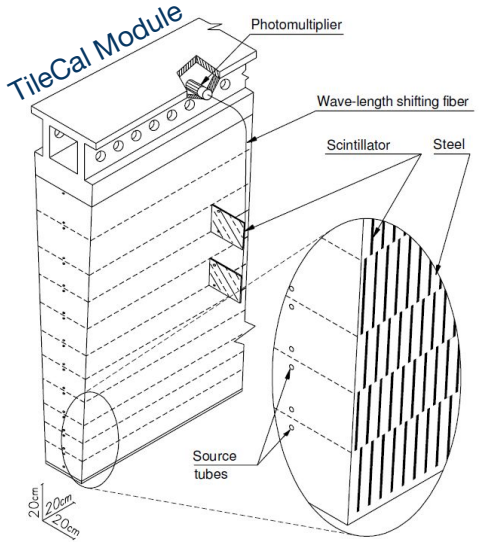
The ATLAS Tile Calorimeter

Eur. Phys. J. C 84 (2024) 1313



- The Tile Calorimeter (**TileCal**) is the central section of the hadronic calorimeter of the **ATLAS experiment** ($|\eta| < 1.7$)

- Sampling calorimeter:
  - steel → absorber
  - scintillator → active material



- The light produced in the scintillating tiles by crossing particles is collected by Wavelength-shifting (WLS) fibers and transmitted to PhotoMultiplier Tubes (PMTs)

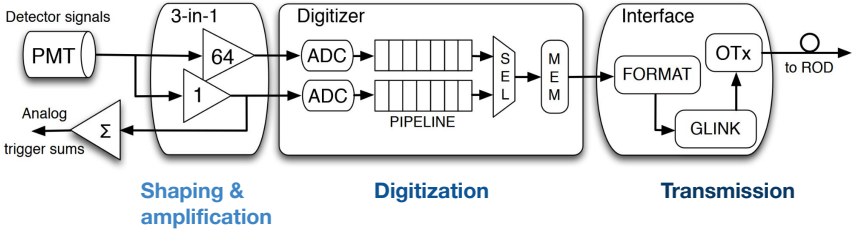
- **TileCal** is divided into two halves of the central barrel (LBC and LBA) and two extended barrels (EBC and EBA)

- Each section is further segmented into cells. The detector comprises 5182 cells in total, read out by approximately 9852 PMTs

Signal reconstruction

- The PMT signal is shaped and amplified using two separate gains (64:1) and digitized by 10-bit ADCs every 25 ns, synchronously with the bunch crossing. Signals are transferred off-detector after the Level-1 trigger accept (max rate 100 kHz)

arXiv:2010.13516



- Signal amplitude **A** and time offset **τ** are reconstructed from 7 digital signal samples with the Optimal Filter algorithm:

$$A = \sum_{i=1}^{n=7} a_i S_i, \qquad A\tau = \sum_{i=1}^{n=7} b_i S_i,$$

- The reconstructed energy (at EM scale) of the signal is determined by

$$E[\text{GeV}] = A[\text{ADC}] \times C_{\text{ADC}\to\text{pC}} \times C_{\text{laser}} \times C_{\text{Cs}} \times C_{\text{pC}\to\text{GeV}}$$

From calibrations

From test beam, 1.05 pC/GeV

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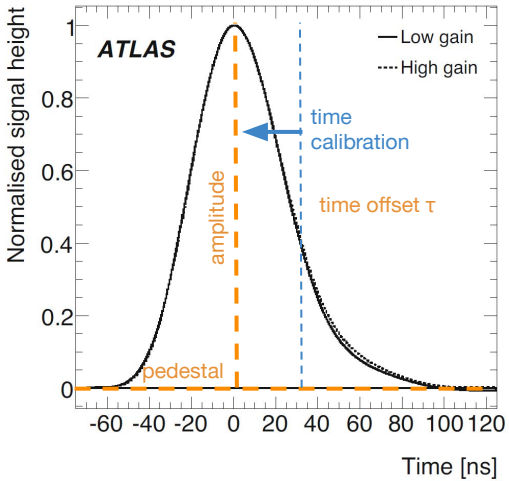
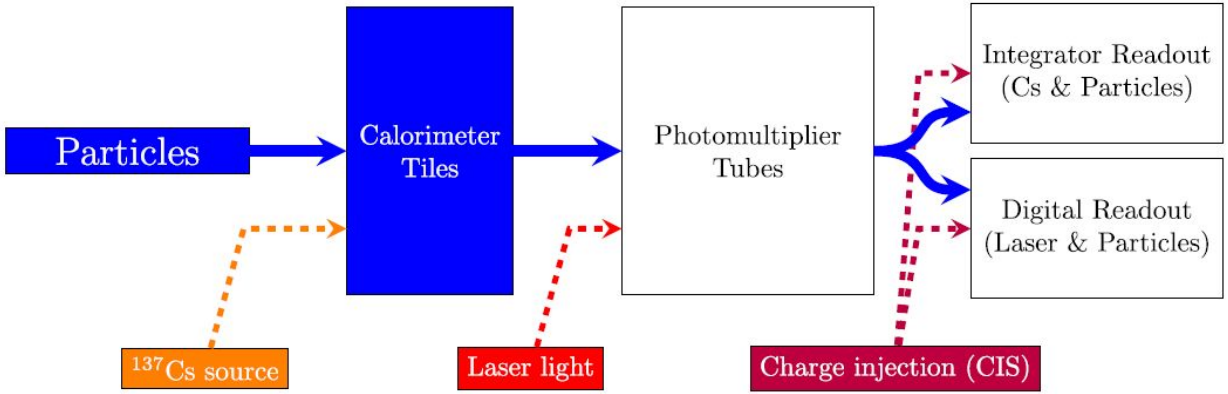


ATLAS Tile Calorimeter
Calibrations

TileCal calibration systems



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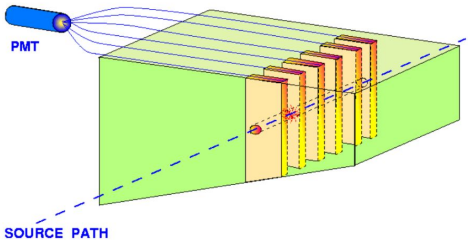
- TileCal uses **three main calibration methods**:
  - **Cesium system**: gamma-radiation Cs source passing through the detector
    It calibrates the optical chain (scintillators and fibers) and the PMTs
  - **Laser system**: light injected directly in the PMTs
    It estimates variations in PMTs response and timing
  - **Charge injection system**: charge is injected into the front-end electronics
    It calibrates fast readout electronics covering the entire dynamic range

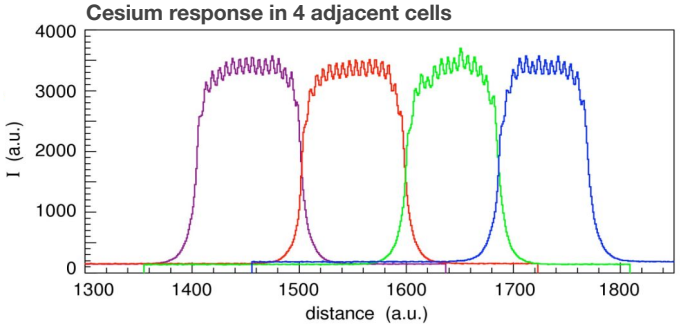
$$E[\text{GeV}] = A[\text{ADC}] \times C_{\text{ADC}\to\text{pC}} \times C_{\text{laser}} \times C_{\text{Cs}} \times C_{\text{pC}\to\text{GeV}}$$

Cesium scan calibration

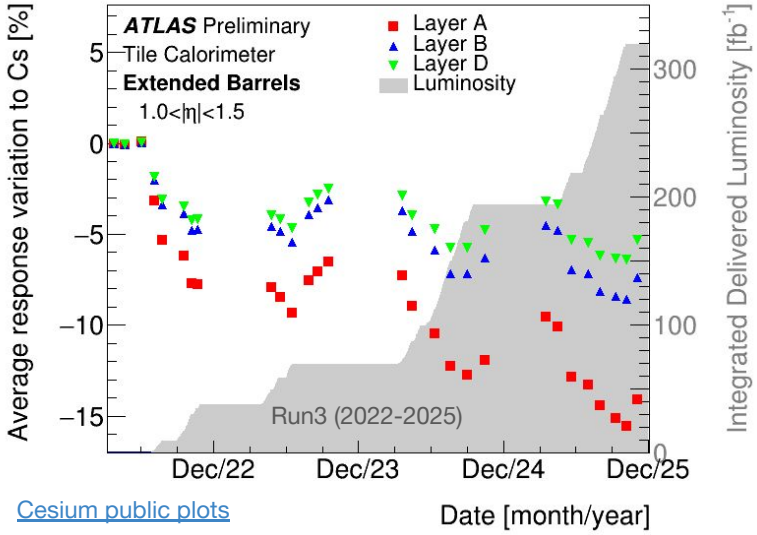
- Used to evaluate the damages provoked by radiation on the optical readout chain (WLS fibers, scintillating tiles and PMTs)
- Cesium scans are performed ~ monthly during periods without collisions
- The accuracy of cesium calibration is better than ~ 0.3%

2020 JINST 15 P03017





An hydraulic system moves capsules with ^{137}Cs (radioactive γ-source with E_γ = 0.662 MeV) through the calorimeter system. The response of every tile cell is measured with the integrator readout

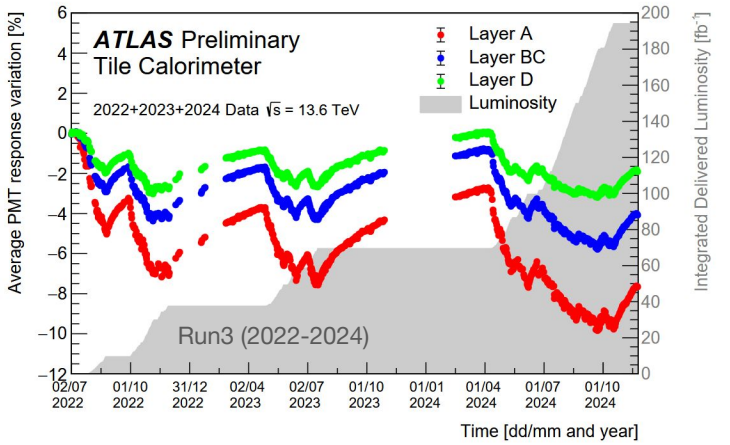


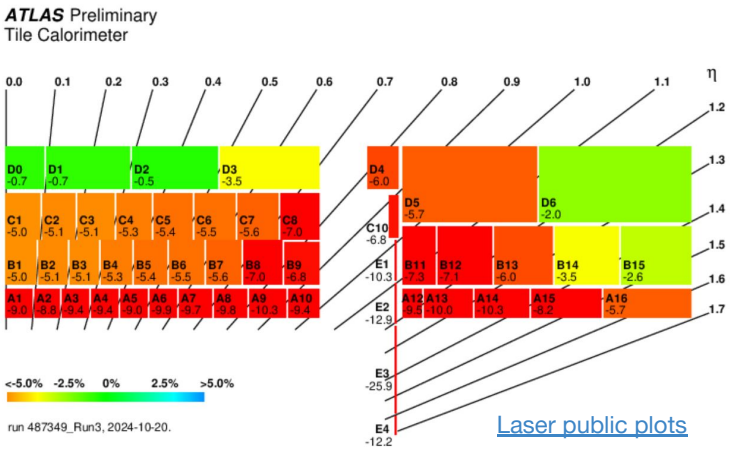
Cesium public plots

Laser calibration

- Used to evaluate the variation of the PMTs response and the readout electronics and **timing monitoring**
- Calibrations runs are performed ~ daily, in dedicated calibration sessions
- The accuracy of laser calibration is ~ 0.5%

A single laser source (λ=532 nm) located off-detector is used to produce pulsed light signals sent to all the PMT photocathodes via dedicated optical fibers



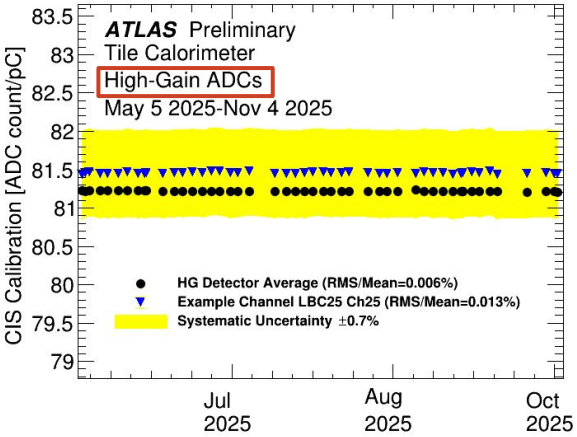


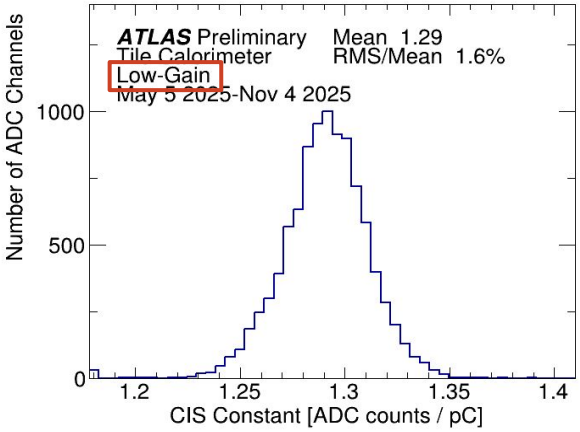
Laser public plots

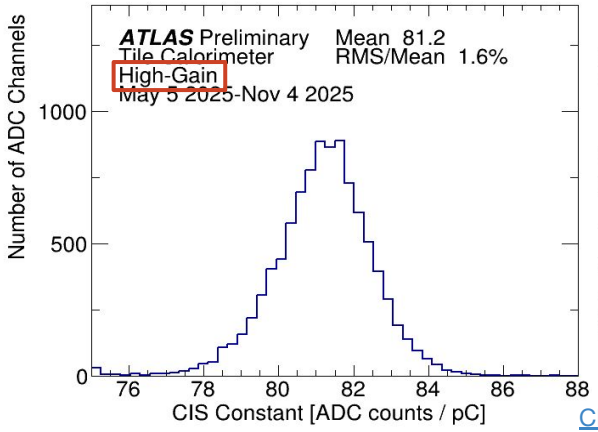
Charge Injection System (CIS)

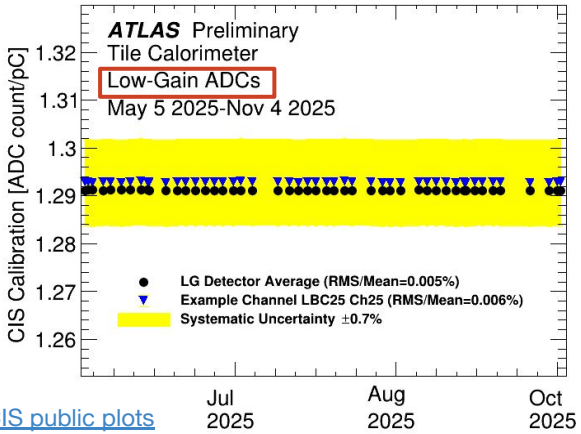
- Used to determine the conversion factor from amplitude [ADC counts] to charge [pC] and to calibrate the calorimeter response used in the Level-1 trigger system
- CIS calibrations are taken twice per week
- The accuracy of CIS calibration is ~ 0.7%

CIS injects charge signals over the full dynamic range (**low** and **high** gain regions) of the readout electronics using a 10-bit DAC and measures the corresponding ADC counts









CIS public plots

ATLAS Tile Calorimeter
Performance

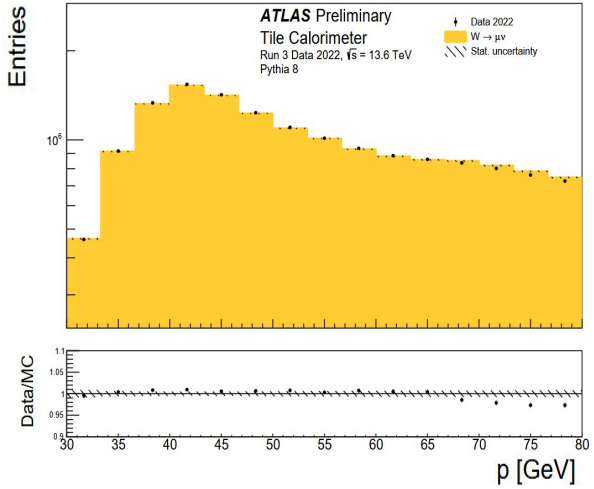
Isolated muons

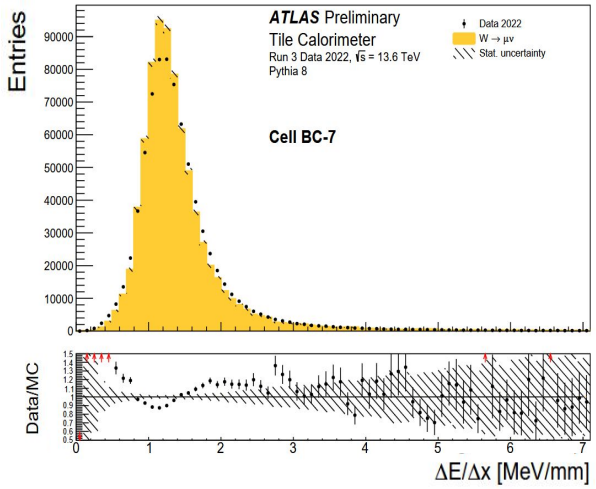
- **Isolated muons** with energies between 20 and 80 GeV from **W → μν** decay data are used to assess the electromagnetic scale and to evaluate the response uniformity over the azimuthal direction. They are selected through requirements on transverse mass m_T, missing transverse energy E_T^{miss}, and muon isolation
- The energy deposited in the calorimeter is dominated by ionization, with ΔE scaling with the path length Δx inside each cell
- The detector response is evaluated using the Data/MC double ratio of the muon *dE/dx* distribution, after truncating the highest 1% of values to suppress outliers:

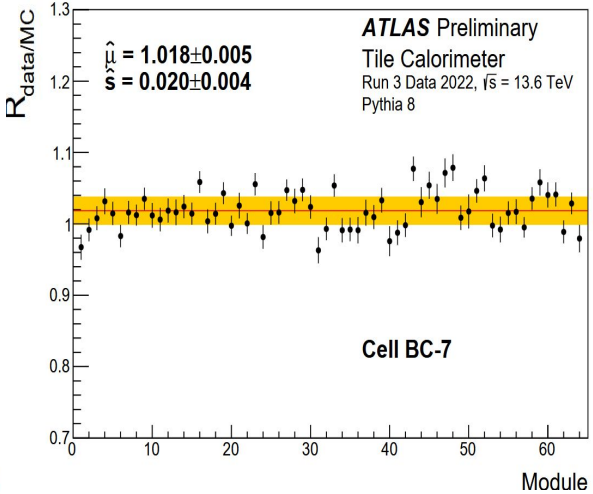
$$R \equiv \frac{\langle \Delta E/\Delta x \rangle_{Data}}{\langle \Delta E/\Delta x \rangle_{MC}}$$

MC = Monte Carlo simulations

Single particle response public plots







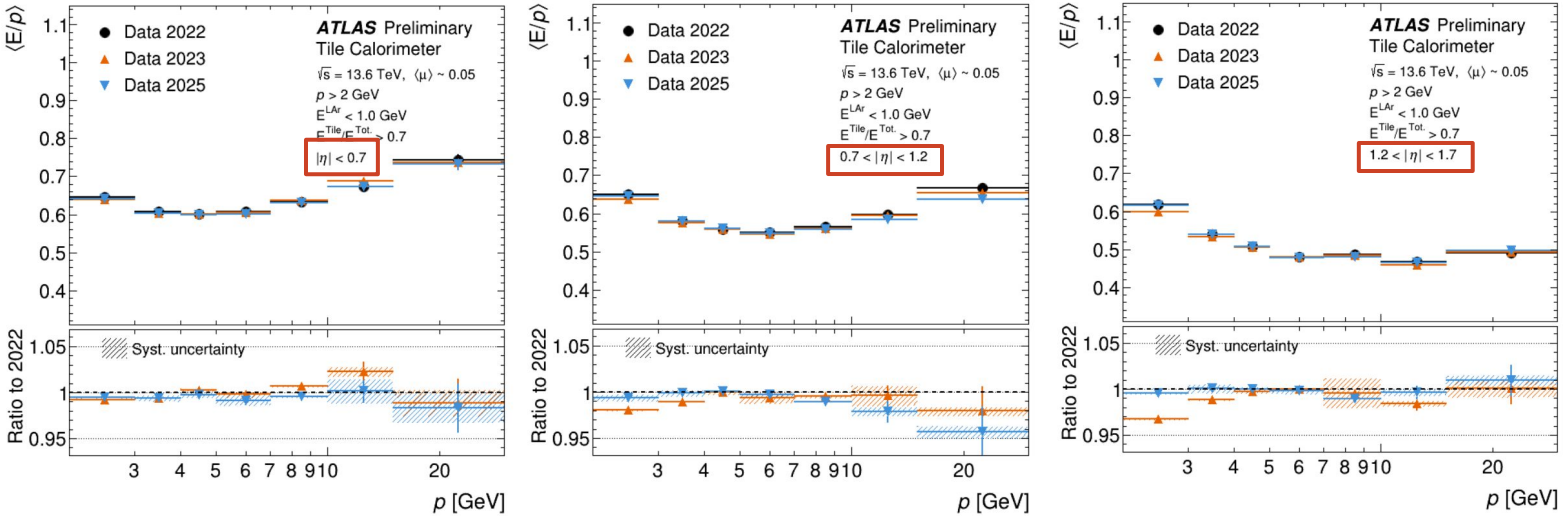
Isolated hadrons

- TileCal energy response is also evaluated measuring the energy deposited by **isolated hadrons** using the *E/p* ratio and dedicated low pile-up runs

- **Isolated single charged hadrons** are defined via:
  - Energy *E* obtained by summing topo-cluster contributions in the calorimeter
  - Momentum *p* measured by the tracker

- The ratio <E/p> is less than 1 due to TileCal non-compensating behaviour

Single particle response public plots



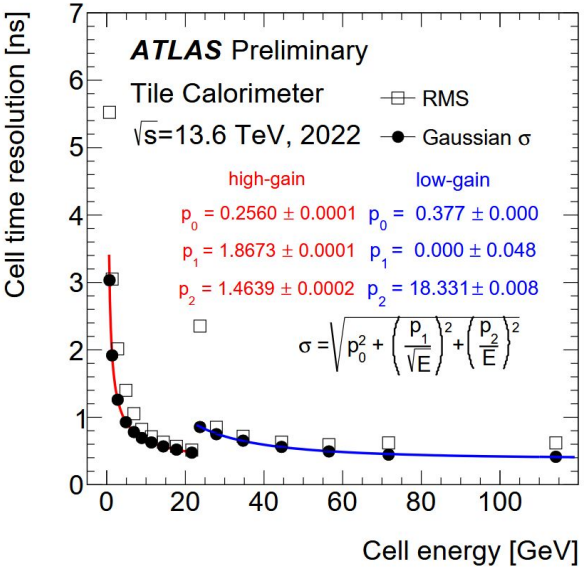
Time resolution

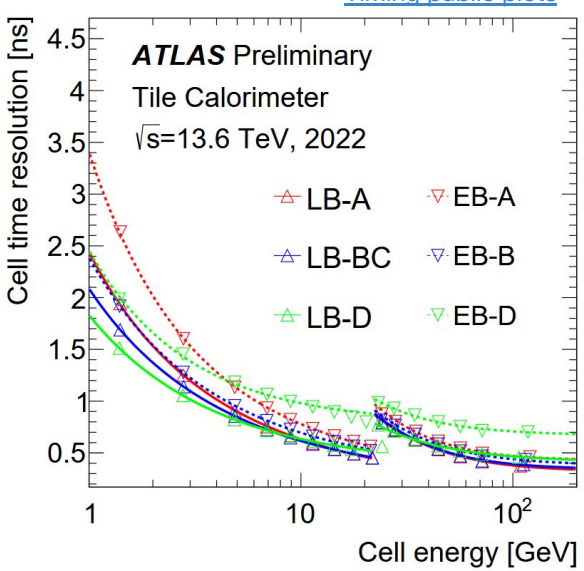
- The cell **time resolution** is studied using cells associated with jets from collision events. It is quantified as the width of a Gaussian fit to the cell time distribution

- Variations in the resolution are driven by:
  - cell volume
  - distance from the interaction point
  - pile-up conditions

- A time resolution better than 1 ns is achieved for cells with energy above 4 GeV

Timing public plots





Conclusions

- The **ATLAS Tile Calorimeter** is showing excellent performance during Run 3, with stable operation throughout the data-taking period. Stable performance is expected to continue through the remainder of Run 3
- Dedicated calibration procedures are routinely applied throughout the different stages of signal reconstruction, reaching a precision of 1%
- Run 3 performance studies have been presented, including analyses of isolated muons/hadrons and timing resolution measurements. They show detector performance consistent with design requirements and good data/MC agreement
  - Studies of **isolated muons** show good uniformity of the calorimeter response across the azimuthal angle at the level of approximately 2%
  - The ⟨E/p⟩ ratio of **isolated hadrons** is approximately 60%, consistent with the non-compensating behavior of TileCal
  - A **time resolution** better than 1 ns is achieved for cells with energy above 4 GeV

Backup