Performance and calibration of the ATLAS Tile Calorimeter

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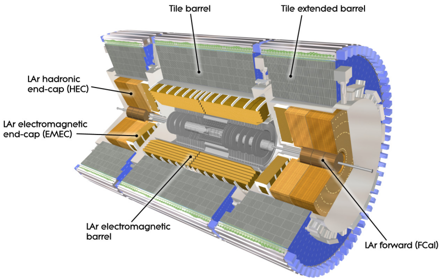
Introduction

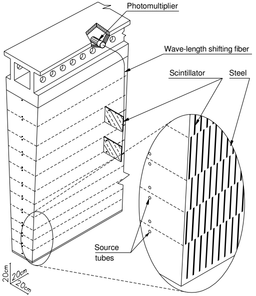
ATLAS Tile Calorimeter

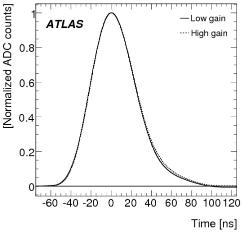
- The Tile Calorimeter (TileCal) is the hadronic calorimeter of the ATLAS detector covering the central pseudorapidity range of $|\eta| < 1.7$
- TileCal performs identification and energy measurements of hadrons, jets, tau leptons decaying hadronically and participates in the measurement of the missing transverse momentum
- It also provides input information for the L1Calo Trigger and muon identification



Signal Reconstruction

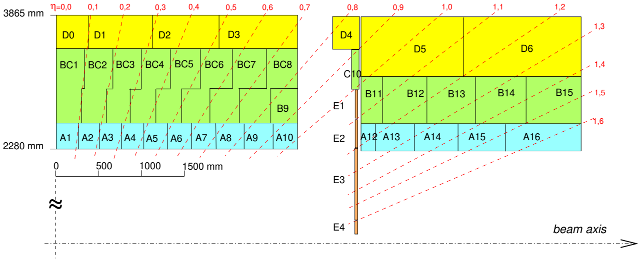
- TileCal consists of tiles of plastic scintillator serving as an active material and steel plates as an absorber
- Light produced in the scintillating tiles is collected by wavelength-shifting (WLS) fibres transporting the light to the photomultiplier tubes (PMTs)
- The signal is shaped and digitised in the front-end readout electronics
- Two readout gains for signal - high gain and low gain (64:1 ratio)
- Signal pulse sampled every 25 ns
- The signal amplitude is reconstructed from 7 samples with the optimal filtering (OF) algorithm in units of ADC counts





TileCal Readout Geometry

- The WLS fibres from individual tiles are grouped to a given PMT creating a readout cell geometry
- There are usually two PMTs (channels) for a given readout cell (total of 9852 channels, 5182 readout cells)
- TileCal is divided into 4 partitions: two in the central Long Barrel (LBA and LBC) and two in the Extended Barrel (EBA and EBC)
- In the longitudinal direction the readout cells are divided into three layers in LB (A, BC and D) and three layers in EB (A, B and D)
- Each barrel is composed of 64 modules in the azimuthal direction



Energy Calibration

- Several systems are in place to calibrate each step of the TileCal cell energy reconstruction
  - Cesium system
  - Laser calibration system
  - Charge injection system
  - Minimum-bias system
- The energy in GeV is obtained as:

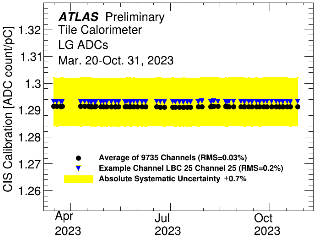
$$E[\mathrm{GeV}] = \frac{A[\mathrm{ADC}]}{C_{ADC \to pC} \times C_{pC \to GeV} \times C_{Cs} \times C_{MB} \times C_{Las}}$$

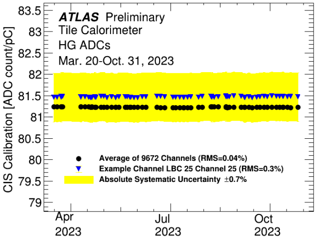
- Conversion from pC to GeV ($C_{pC \to GeV}$) is determined by measuring the response of the calorimeter to electrons in test beam campaigns

  → This calibration constant is known as the electromagnetic (EM) scale with a nominal value of 1.05 pC/GeV

Charge Injection System

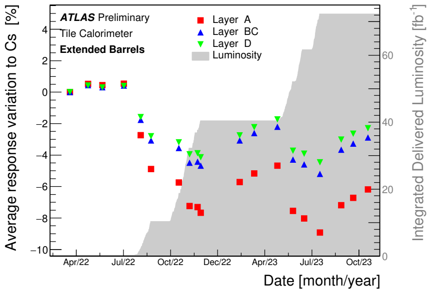
- The charge injection system (CIS) performs the calibration of the front-end electronics
- CIS injects a defined charge signal to the readout electronics (covering the full dynamic range)
- Allows us to estimate $C_{ADC \to pC}$ conversion constant from ADC counts to pC units
- Very stable over time with ~ 0.7 % precision





Cesium System

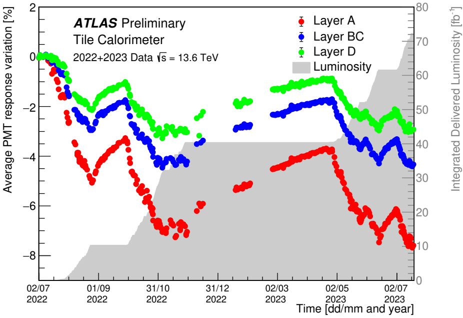
- The cesium system allows us to calibrate variations of the entire readout chain (optical components and PMTs)
- Calibration is done by applying the cesium constant C_{Cs} in the energy reconstruction
- The hydraulic system moves $^{137}\mathrm{Cs}$ capsule (radioactive γ-source with $\mathrm{E}_\gamma = 0.662\,\mathrm{MeV}$) through the calorimeter system measuring the response of every single tile
- Dedicated cesium scans are done on a monthly basis
- For regular cells the accuracy of cesium calibration is at $\sim$ 0.3 %



- Degradation in the fibers, scintillating tiles and PMTs is responsible for down-drifts in the response variation
- Higher degradation for A layer cells as they are closer to the beam pipe
- PMTs recovery can be observed in the periods without *pp* collisions

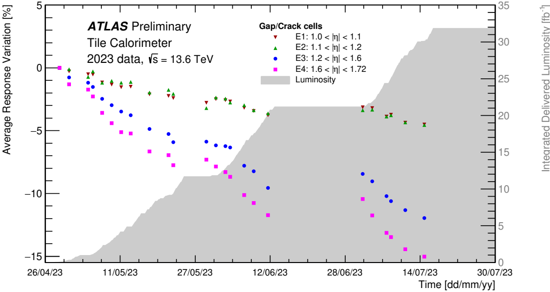
Laser System

- A single laser source produces short 10 ns light pulses with 532 nm wavelength
- Pulses are simultaneously distributed to all 9852 PMTs
- The system calibrates the variations due to readout electronics and changes in the PMTs gain
- Laser calibration constant C_{Las} in energy reconstruction
- Also used for timing corrections and monitoring
- Laser calibration runs are taken every 2-3 days
- Precision of the laser calibration at the level of $\sim$0.5 %



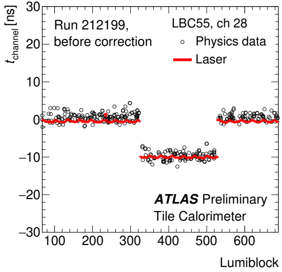
Minimum Bias System

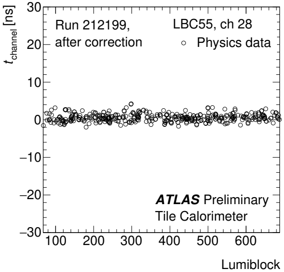
- Minimum bias events in *pp* collisions produce a PMT current proportional to the LHC luminosity
- Data collected with the integrator readout system (signal integrated in the 10–20 ms window)
- Minimum bias calibration constant C_{MB} in energy reconstruction
- Important for cells in the gap region not accessible to the cesium system



Time Calibration and Performance

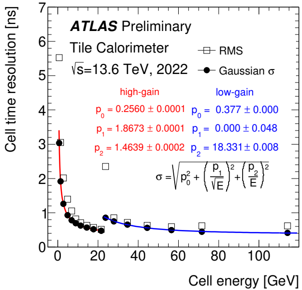
- Precise timing calibration of the Tile Calorimeter is crucial as the OF algorithm is phase dependent
- Phase calibrated so that an ultra relativistic particle travelling from the interaction point produces signal at $t = 0$
- TileCal time of flight measurements also used in searches for long lived particles
- Calibration and monitoring of the time calibration is done with the use of jet events in *pp* collisions and data from the laser calibration system
- An important part of the calibration is the correction of timing jumps (threshold recently lowered from 3 ns to 1 ns)



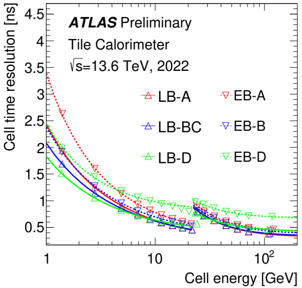


Time Calibration and Performance

- Detector time resolution as a function of energy was determined with the use of *pp* jet events
- Cell time resolution defined as the σ of a Gaussian fit of a timing distribution in a given energy slice
- Transition between high and low gain at $\sim$ 22 GeV
- Better resolution for the long barrel than the extended barrel
- Higher values of the time resolution plateau for the outermost radial D-layer



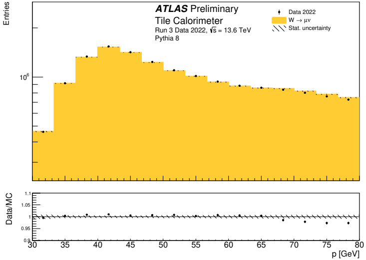
$$\sigma = \sqrt{p_0^2 + \left(\frac{p_1}{\sqrt{E}}\right)^2 + \left(\frac{p_2}{E}\right)^2}$$

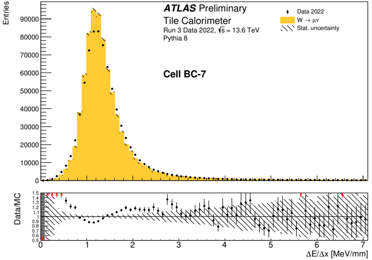


Performance - Isolated Muons

- TileCal performance studied with the use of isolated muons produced in $W \to \mu\nu$ decays from *pp* collisions
- Determination of the uniformity and stability of the cells' response and the EM scale setting checks
- The response is quantified by the truncated mean of the $\Delta E/\Delta x$ (deposited energy per path length) distribution for both data and MC, taking the double ratio

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



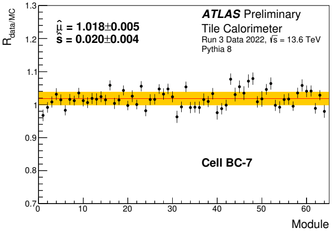


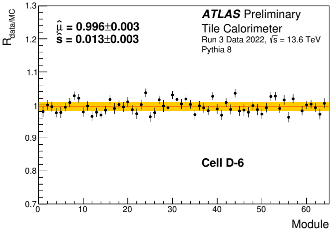
Performance - Isolated Muons

- To study the response uniformity in azimuthal direction we fit the double ratio distribution to a Gaussian likelihood function:

$$\mathcal{L} = \prod_{m=1}^{64} \frac{1}{\sqrt{2\pi}\sqrt{\sigma_m^2 + \hat{s}^2}} \exp\left[-\frac{1}{2}\frac{(R_m - \hat{\mu})^2}{\sigma_m^2 + \hat{s}^2}\right]$$

- Analysis shows good uniformity across azimuthal modules (on average $\sim$ 2.6% for 2022 data and $\sim$ 2.2% for 2023 data)



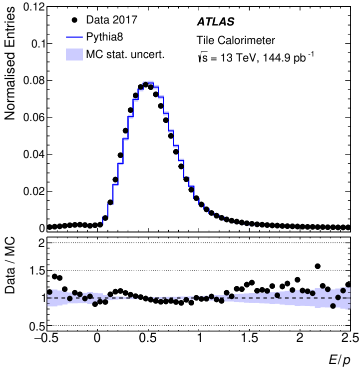


Performance - Single isolated hadron

- Probing the TileCal response by measuring the energy deposited by isolated hadrons produced in the *pp* collisions
- Analysis is selecting particles with a momentum below 20 GeV in dedicated low pile-up runs
- Response quantified by ratio R of the energy E measured by the calorimeters to the momentum p measured with the inner detector

$$R = E/p$$

- In the Run 2 analysis the obtained mean of the $\langle E/p \rangle$ distribution is 0.5896 ± 0.0001 for experimental data and 0.593 ± 0.001 for simulated data
- Analysis for Run 3 is in progress



Summary

- TileCal is continuing its operations in Run 3 data taking period
- Good performance is ensured by several calibration systems
- Calibration and monitoring procedures are being validated with dedicated performance studies with isolated muons, hadrons and jets
- First results of the Run 3 performance studies were presented here
- More results to come

References

[1] Public plots for the Tile Calorimeter:
https://twiki.cern.ch/twiki/bin/view/AtlasPublic/ApprovedPlotsTile
[2] Public plots for the Tile Calorimeter (Collision Data):
https://twiki.cern.ch/twiki/bin/view/AtlasPublic/TileCaloPublicResults
[3] ATLAS Collaboration, Operation and performance of the ATLAS tile calorimeter in LHC Run 2, arXiv:2401.16034
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[4] ATLAS Collaboration, Operation and performance of the ATLAS Tile Calorimeter in Run 1, Eur.Phys. J. C78 (2018) 987
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Thank you for your attention!