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COLLIDER PHYSICS

The ATLAS Tile Calorimeter Performance and Its Upgrade towards the High-Luminosity LHC

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Abstract—The Tile Calorimeter (TileCal) is a sampling hadronic calorimeter covering the central region of the ATLAS experiment. TileCal uses steel as absorber and plastic scintillators as active medium. The scintillators are read-out by the wavelength shifting fibres coupled to the photomultiplier tubes (PMTs). The analogue signals from the PMTs are amplified, shaped, digitized by sampling the signal every 25 ns. Each stage of the signal production is monitored and calibrated to better than 1% using multistage calibration systems. The performance of the calorimeter has been measured and monitored using calibration data, cosmic ray muons and the large sample of proton—proton collisions acquired during LHC Run II. The high-luminosity phase of LHC, delivering five times the LHC nominal instantaneous luminosity, is expected to begin in 2027. TileCal will require new electronics to meet the requirements of a 1 MHz trigger, higher ambient radiation, and to ensure better performance under high pileup conditions. Changes to the electronics will also contribute to the data integrity and reliability of the system. New electronics prototypes were tested in laboratories as well as in beam tests. Results of the calorimeter calibration and performance during LHC Run II are summarized, the main features and beam test results obtained with the new front-end electronics are also presented.

Keywords: collider physics, ATLAS, calorimeter calibration

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1. INTRODUCTION

The ATLAS Tile Calorimeter (TileCal) is the central hadronic calorimeter located at $|\eta| < 1.7$ of the ATLAS experiments [1] at the Large Hadron Collider (LHC). The TileCal performs several critical functions within ATLAS such as the measurement and reconstruction of jets, hadrons and missing transverse energy. It also contributes to muon identification and provides inputs to the Level 1 calorimeter trigger system. The Phase-II upgrade will prepare the ATLAS experiment for the high luminosity LHC (HL-LHC), which is planned to deliver upto 4000 fb^{-1}. The TileCal will replace both on- and off-detector electronics during the shutdown of 2025—2026.

2. TileCal CALIBRATION AND PERFORMANCE DURING RUN II

TileCal employs three calibration systems to provide the necessary data to calibrate the energy measurement. The deposited energy of each TileCal channel is evaluated from the raw response as follows: $E[GeV] = A[ADC] \times C_{pc\to\mathrm{GeV}} \times f_{ADC\to pC} \times f_{Cs} \times f_{\mathrm{Laser}}$, where A[ADC] is the signal amplitude and the different f factors are calibration constants derived from the three calibration systems, cesium, laser and charge injection system (CIS).

During the cesium calibration, ^{137}Cs radioactive γ-source go through a system of steel tubes travers-

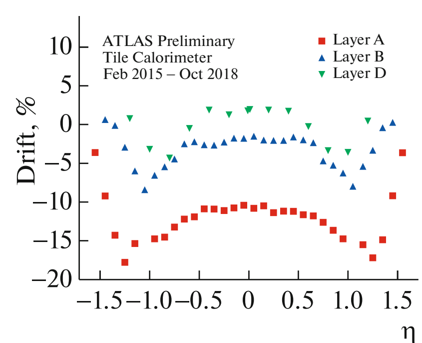

Fig. 1. Cell drift during entire Run II, seen by the cesium calibration system [2].

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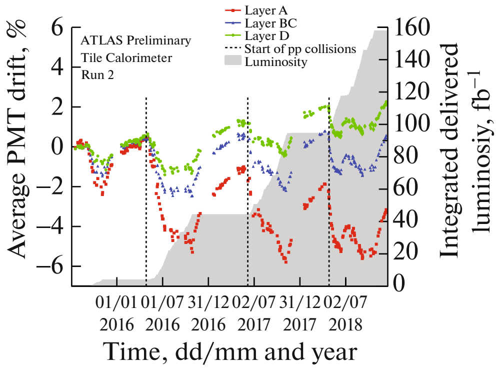

Fig. 2. PMT drift during entire Run II, seen by the laser calibration system [2].

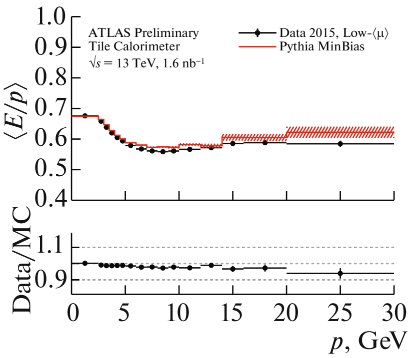

Fig. 3. Calorimeter response to single isolated charged hadrons characterised by $\langle \frac{E}{p} \rangle$ as a function of track momentum p, during pp collisions. The data and MC agree within 5% [3].

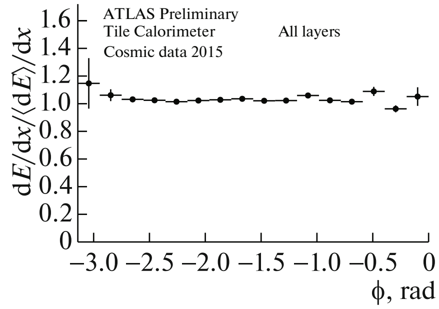

Fig. 4. Ratio of the truncated means of the distributions of the energy deposited in the layers by cosmic-ray muons per unit of path length $\mathrm{d}E/\mathrm{d}x$, obtained using 2015 data as a function of ϕ [3].

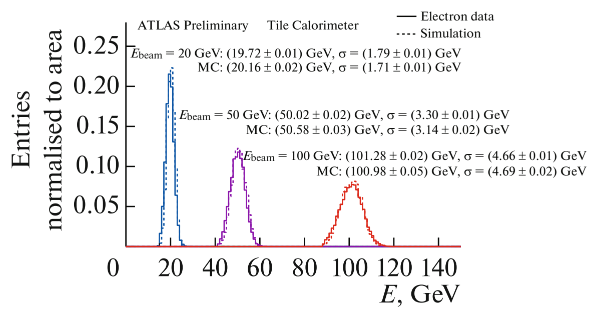

Fig. 5. Data and MCarlo response with electrons to determine the EM scale of the TileCal in pC/GeV and verify linearity [3].

ing all the scintillating tiles. The system provides calibration constant f_{Cs} and is used to calibrate the entire optical chain, i.e., scintillators and PMTs.

In Laser calibrations, a controlled amount of light (532 nm) is sent to the photocathode of each PMT through clear fibers. The main purpose of the system is to monitor and measure the individual PMT gain variations between the cesium scans and provide a calibration constant f_{Laser}.

The CIS injects the charge of a known value (between 0 and 800 pC) into the capacitor and measures the response of the electronics in ADC counts. CIS provides $f_{ADC\rightarrow pC}$ which is used to calibrate the readout electronics. Additionally Minimum Bias system gives information about the instantaneous luminosity and monitors the full optical route. Figure 1 shows the variation of the TileCal response measured by the Cs system during Run II. Figure 2 shows the average response variation of the three longitudinal layers as seen by the Laser Calibration system during Run II period. In both figures, the biggest drift is observed in the layer A, which is the closest to the collision point and thus have highest energy deposits.

The performance of TileCal is evaluated with isolated particles. The TileCal energy response can be probed using single hadrons and jets. Isolated muons from cosmic rays are used to study inter calibration of Tile cells and verifies the measured energy at EM scale. Figure 3 shows TileCal response to single isolated charged hadrons characterised by $\left\langle \frac{E}{p} \right\rangle$ as a function of track momentum. Figure 4 shows that the observed TileCal cell response non-uniformity in pseudorapidity is better than 5%.

3. TileCal UPGRADE FOR HL-LHC

For the HL-LHC the whole readout electronics of the TileCal will be replaced. The new readout architecture will provide a fully digital trigger system with full precision and granularity to improve the event selection. Currently, each module of TileCal is housing a super drawer (SD). For the upgrade, a SD is divided into 4 minidrawers (MD), each with independent readout and power supplies. A MD hosts 12 PMTs, 12 front-end boards (FEBs), a mainboard (MB), and a Daughter Board (DB). The MB shapes,

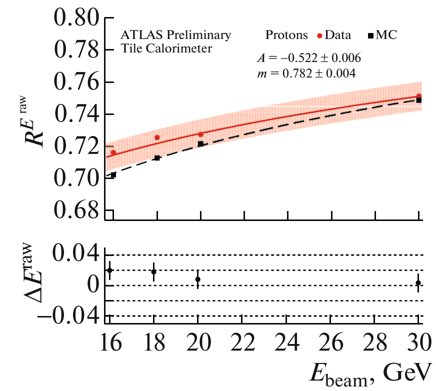

Fig. 6. Data and MC response with hadrons to validate and improve the modelling of the jets energy characterisation of the ATLAS simulation [3].

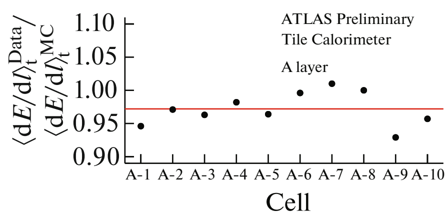

Fig. 7. Data and MC response with muons to verify the new electronics performance, which review and improve the TileCal calibration procedure [3].

amplifies (two gains) and digitizes the input with 12-bit ADC and the DB transfers the high-speed output to the back-end, distributes LHC clock settings and connects the on- and off-detector electronics [4]. All the data generated in the detector will be transferred to the preprocessors (TilePPr) located off-detector for every bunch crossing.

The modules equipped with Phase-II upgrade electronics together with modules equipped with legacy electronics were exposed to different particles and energies in eight test beam campaigns at the CERN SPS. The Detector energy response and resolution were studied using electron beams with different energies (Fig. 5). The results obtained using muons and hadrons are in agreement with the calibration settings obtained using the old electronics and with the expectations obtained using simulated data. All the results are consistent with the previous measurements (Figs. 6 and 7).

4. CONCLUSIONS

The ATLAS TileCal performed very well during LHC Run II in operation, calibration, performance and stability. The TileCal plays a key role in jet and MET reconstruction and provides a stable (within 1%) response. All TileCal on- and off-detector electronics will be replaced during Phase-II upgrade. All the tests demonstrated good performance of the new components.

CONFLICT OF INTEREST

The author declares that she has no conflicts of interest.

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