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Upgrade of the ATLAS Hadronic Tile Calorimeter for the High Luminosity LHC

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The Tile Calorimeter (TileCal) is a sampling hadronic calorimeter covering the central region of the ATLAS experiment, with steel as absorber and plastic scintillators as active medium. The High-Luminosity phase of LHC delivering five times the LHC nominal instantaneous luminosity, is expected to begin in 2029. The TileCal will require new electronics to meet the requirements of a 1 MHz trigger, higher ambient radiation, and to ensure better performance under high pile-up conditions. Both the on- and off-detector TileCal electronics will be replaced during the shutdown of 2026-2028. PMT signals from every TileCal cell will be digitized and sent directly to the back-end electronics, where the signals are reconstructed, stored and sent to the first level of trigger at a rate of 40 MHz. This will provide better precision of the calorimeter signals used by the trigger system and will allow the development of more complex trigger algorithms. The modular front-end electronics feature radiation-tolerant commercial off-the-shelf components and redundant design to minimise single points of failure. The timing, control and communication interface with the off-detector electronics is implemented with modern Field Programmable Gate Arrays and high speed fibre optic links running up to 9.6 Gb/s. The TileCal upgrade program has included extensive research and development and test-beam studies. A demonstrator module with backward compatibility with the existing system was inserted in ATLAS in August 2021 for testing in actual detector conditions. The ongoing developments for on- and off-detector systems, together with expected performance characteristics and results of test-beam campaigns with the electronics prototypes will be discussed.

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1. Introduction

The ATLAS Tile Calorimeter (TileCal) is the central hadronic calorimeter of the ATLAS detector at the Large Hadron Collider (LHC) at CERN [1, 2]. It was designed to perform the precise measurement of hadrons, jets and missing transverse momentum, as well as provide input signals to the Level 1 (L1) calorimeter trigger. The TileCal is longitudinally divided into three cylindrical sections and each of them is azimuthally segmented into 64 modules. An individual module consists of alternating steel (absorber) tiles and plastic scintillating (active media) tiles with a Super Drawer (SD) housing the Front-End (FE) electronics inside the module. The light produced by a charged particle passing through a plastic scintillating tile is transmitted to photomultiplier tubes (PMTs). Scintillating tiles are read out via wavelength shifting fibers coupled to around 10000 PMTs. The readout of TileCal is grouped into pseudo-projective geometry cells, where each cell is read out by two PMTs. There are 256 SDs located at the outermost part of the modules [1, 2].

2. Phase-II Upgrade electronics of the ATLAS Tile Calorimeter

The following section describes the major changes to TileCal planned for the HL-LHC upgrade. New SD proposed for the HL-LHC upgrade is divided into 4 Minidrawers (MDs) each of which has a separate power source and independent readout. Twelve Front-End Boards (FEB) are replaced with the Front-End for the New Infrastructure with Calibration and Signal Shaping (FENICS) and twelve PMTs are hosted in a MD. The main board's (MB) 12-bit ADCs cover a 17-bit dynamic range while shaping, amplifying (two gains), and digitizing the input (approximately 0-1000 pC in low gain and 0-25 pC in high gain). The Daughterboard (DB) connects the on- and off-detector circuitry, distributes the LHC clock settings and transmits the high-speed output to the back-end. The Tile PPr (Preprocessor), calculates trigger objects at the LHC rate, buffers data from all of the MDs in the off-detector pipelines and distributes the sampling clock and detector control data. Accepted data are transmitted to the Front End LInkeXchange (FELIX) via the Trigger and Data Acquisition interface (TDAQi) [2]. Better temperature and voltage stability, as well as local or remote control, are new features of the improved High Voltage (HV) and Low Voltage Power Supply (LVPS). The LVPS has point-of-load regulators and more radiation tolerant.

3. Test-Beam campaigns

Eleven test-beam campaigns were carried out at CERN from 2015 to 2022 with the aim to validate modules equipped with prototype electronics for the HL-LHC. During those campaigns, modules were exposed to different particles (muons, electrons and hadrons) and energies. The distributions of the total energy deposited in the calorimeter obtained using electron beams of 20, 50 and 100 GeV are shown for both experimental (solid) and simulated (dashed) data in Figure 3 (Left). The energy response ratios, measured (red circles) and predicted by Monte Carlo simulation (black squares) as a as a function of incident beam E_{beam} are shown in Figure 3 (Right) for the case of proton beams. The red solid (black dashed) curves are fits of the experimental (simulated) data points [2–4].

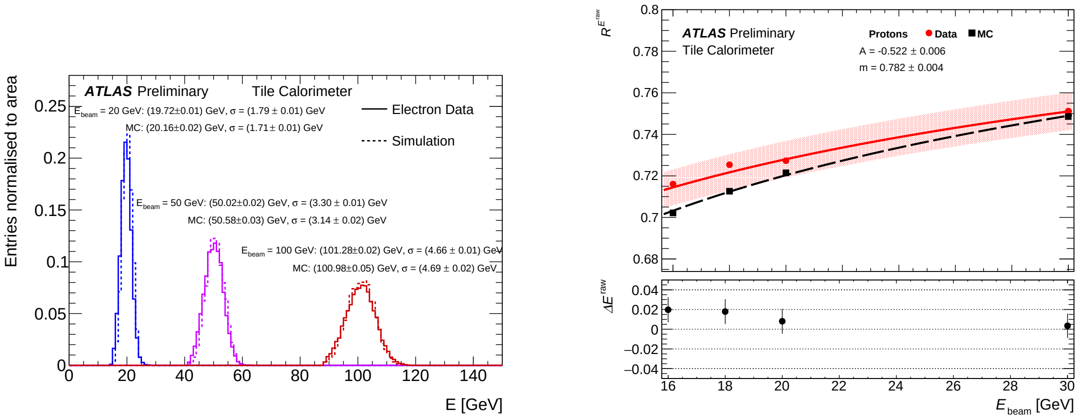

Figure 1: Left: Distributions of the total energy deposited in the calorimeter obtained using electrons beams at different energies. Right: The energy response ratios, $\Delta R^{<Eraw>} = < Eraw > /E_{beam}$, measured and predicted by Monte Carlo simulation as a function of beam energy obtained in the case of proton beams. [3, 4].

4. Conclusions

New conditions imposed by the HL-LHC impells a redesign of TileCal. All the front-end and back-end electronics will be replaced for the HL-LHC, and the new readout structure will include a full digital readout and trigger. Several tests of the design were performed during the test-beams campaigns from 2015 to 2022. The data taken during test-beam are used to set limitations on detector simulation frameworks that represent hadron interactions in matter. The demonstrator module with the new electronics was inserted in the ATLAS detector in 2021. It shows good and stable performance. Many components have entered into the pre-production or the production phase.

References

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[4] The ATLAS Collaboration, Study of energy response and resolution of the ATLAS Tile Calorimeter to hadrons of energies from 16 to 30 GeV. (2021), arXiv:2102.04088