PROCEEDINGS OF SCIENCE

Upgrade of ATLAS Hadronic Calorimeter for the High Luminosity LHC

Bernardo Sotto-Maior Peralva[a,*] **on behalf of the ATLAS Collaboration**

[a] *Polytechnique Institute, Rio de Janeiro State University,*
Rua Bonfim, 25, Vila Améla, 28625-570, Nova Friburgo, RJ, Brazil

E-mail: bernardo@iprj.uerj.br

The Tile Calorimeter (TileCal) is the hadronic calorimeter covering the central region of the ATLAS experiment. The High-Luminosity phase of LHC, delivering five times the LHC nominal instantaneous luminosity, is expected to start in 2029. 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. Approximately 10% of the PMTs, those reading out the most exposed cells, will be replaced. 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 components and redundant design to minimize single points of failure. The timing, control and communication interface with the off detector electronics is implemented with modern Field Programmable Gate Arrays (FPGAs) and high speed fibre optic links running up to 9.6 Gb/s. The TileCal upgrade program has included extensive RD and test beam studies. A Demonstrator module equipped with the new electronics but with reverse compatibility with the existing readout system was inserted in ATLAS in August 2019 for testing in actual detector conditions. The status of the various components and the results of test-beam campaigns with the electronics prototypes will be discussed.

ATL-TILECAL-PROC-2024-012
30 October 2024

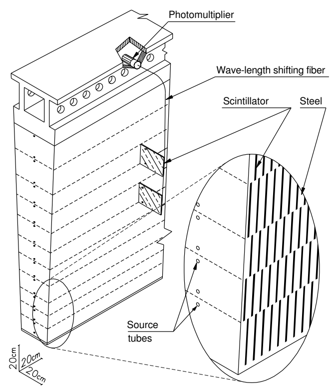
12th Large Hadron Collider Physics Conference (LHCP2024)
3-7 June 2024
Boston, USA

1. The ATLAS Tile Calorimeter

The ATLAS experiment [1] is one of the major LHC experiments designed to measure the by-products of collisions, adopting a general-purpose strategy. It was built to analyze the widest possible range of physical phenomena that can be generated in proton-proton collisions at the LHC, from the search for the Higgs Boson to extra dimensions and particles that could comprise dark matter. As the particle beams from the LHC collide at the center of the ATLAS experiment, it creates by-products in the form of new particles, which propagate in all directions from the collision point. In ATLAS, six distinct detector subsystems are arranged in layers around the collision point to measure the trajectory, momentum, and energy of the particles, in order to assist their identification. Measuring 44 m in length, 25 m in height, and weighing approximately 7000 tons in a cylindrical shape, ATLAS is the largest experiment at the LHC.

The ATLAS experiment heavily relies on its state-of-the-art calorimetry system for absorbing and measuring the energy of particles produced in collisions. The calorimeters' data is crucial in determining the key properties of particles, which plays a pivotal role in differentiating between particle types [2]. The ATLAS calorimetry system includes two primary components: the Liquid Argon Calorimeter (LAr) for electromagnetic calorimetry and the Tile Hadronic Calorimeter (TileCal) for hadronic energy measurements. For example, the Tile Calorimeter (TileCal) of the ATLAS experiment employs a sampling technique with plastic scintillator tiles as the active material, interspersed with layers of steel as the absorber, as illustrated in Fig. 1. Covering a wide pseudo-rapidity range of $|\eta| < 1.7$ with full azimuthal coverage, TileCal plays a crucial role in the ATLAS calorimetry system.

Figure 1: Structure of a TileCal module.



TileCal is a cylindrical structure with an inner radius of 2.28 m and an outer radius of 4.23 m, divided into two partitions: the Central Barrel (LB) covering $|\eta| < 1$ and the Extended Barrel (EB) covering $0.8 < |\eta| < 1.7$, each split into side A and side C. These partitions are denoted as LBA, LBC, EBA, and EBC. Each barrel consists of 64 wedge-shaped modules arrayed in the ϕ direction. The modules in TileCal are segmented into three layers of cells, A, BC, and D, with cell granularity of 0.1×0.1 for layers A and BC, and 0.2×0.1 for layer D. Additionally, TileCal features a special layer of cells (layer E) composed solely of scintillators without heavy material. Each module in both the central and extended barrels contains 23 and 16 dual-readout cells, respectively, totaling approximately 10,000 readout channels.

As hadrons traverse the calorimeter, they generate a shower of secondary particles, losing energy as they pass through the passive material (steel) and interact with the active material (scintillator tiles), emitting light. This light is channeled through multiple optical fibers forming a cell's signal. These fibers converge and lead to a photomultiplier, which produces an electrical pulse in response to the light signal. The pulse generated by the PMT is conditioned by a shaping circuit (*shaper*), yielding a pulse with a known shape and amplitude proportional to the deposited energy. This analog pulse is digitized by an Analog-to-Digital Converter (ADC) at a sampling rate of 40 MHz and the time samples are stored in the pipeline. For the events accepted by ATLAS Level-1 Trigger, a 7-sample digital window, which covers approximately the entire pulse, is sent to the Readout Drivers (ROD) in the back-end system. To increase the dynamic range of energy readings, the pulse is digitized at two gains, high and low.

2. TileCal Readout Upgrade

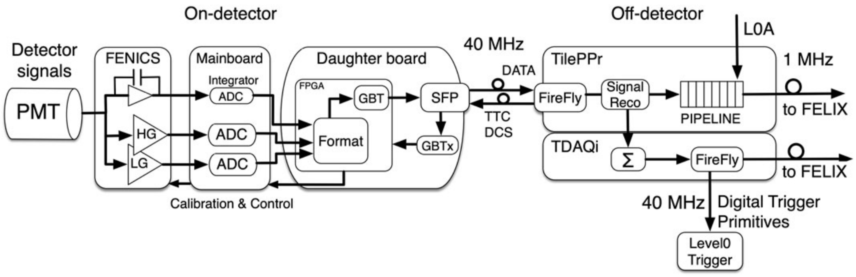
The High-Luminosity Large Hadron Collider (HL-LHC) [3] represents a major upgrade to the existing LHC, set to be operational around 2029. This enhancement is designed to significantly increase the collider's luminosity by a factor of ten, boosting its capability for scientific discoveries. Luminosity is defined as the proportional factor between the number of events per second and the cross-sectional area of the particle beam.

The High-Luminosity upgrade program focuses on intensifying the rate of particle collisions, thereby facilitating an increase in data collection and enabling more profound insights into the mysteries of particle physics. Therefore, the HL-LHC will provide a much deeper understanding of fundamental physics, exploring new phenomena and potentially unveiling new particles. This endeavor requires a significant increase in data acquisition to ATLAS and it presents new challenges in electronics and signal processing. To cope with such intense operation, a comprehensive upgrade of the detector and associated systems has been planned and underway.

These upgrades are pivotal to ensuring the detector's readiness for the challenges posed by the HL-LHC, including the requirements for a 1 MHz trigger rate, increased ambient radiation levels, and enhanced performance under conditions of high pile-up. As part of these comprehensive modifications, both on- and off-detector TileCal electronics will undergo a complete overhaul. This entails the digitization of signals from every TileCal cell, which will then be relayed directly to the back-end electronics for signal reconstruction, storage, and subsequent transmission to the first level of the trigger system at a 40 MHz rate [4]. Such advancements are not only expected to refine the precision of calorimeter signals utilized by the trigger system but also facilitate the development of more intricate trigger algorithms. The schematic of this new electronics can be seen in Fig 2.

The analog pulses from the PMTs undergo conditioning and digitization in the first stage of the electronics, and transferred to the Daughter board at 40 MHz. The digital data are formatted and transmitted to the PreProcessor (PPr) modules through high speed fiber optic links. The PPr stores the digital data in pipelines and in parallel computes and transmits digital sums to the Trigger System through the Trigger and Data AcQuisition Interface (TDAQi) module. Upon the reception of the L0 accept signal, the digital signal are processed and transferred from both gains to the FELIX system. Unlike the current scheme, the updated system will require an energy response for each bunch-crossing. Therefore, from a signal processing perspective, the goal is to estimate

Figure 2: Diagram of the TileCal trigger and readout electronics at the HL-LHC.



amplitudes in a free-running mode, meaning that for each sample in a continuous data set, an associated amplitude is to be estimated. To this end, a large number of time samples (e.g 15) may be used for the digital filter design. Previously, an amplitude value associated with a given readout window composed of seven samples was estimated.

3. Conclusions

The design of the ATLAS Tile Calorimeter upgrade for HL-LHC has been successfully implemented, where all parts of the system have been prototyped and validated in standalone test-benches as well as in integration tests together with other components of the TileCal system. Particularly, the design and architecture of the TilePPr (Tile PreProcessor) module, which serves as a crucial interface between the on-detector electronics and the central systems of the ATLAS experiment, including Data Acquisition, Detector Control, and Trigger systems, has been validated to be employed during the HL-LHC operation.

Acknowledgements

The author is thankful to CAPES, CNPq, FAPERJ (Process: E-26/201.304/2022), FAPEMIG, RENAFAE for the support. This study was financed in part by the Coordenação de Aperfeiçoamento de Pessoal de Nível Superior - Brasil (CAPES) - Finance Code 001.

References

[1] ATLAS Collaboration. The ATLAS Experiment at the CERN Large Hadron Collider. JINST, 3:S08003, 2008.

[2] Wigmans, R., Calorimetry: Energy Measurement in Particle Physics, Clarendon Press, 2017. ISBN 9780198502968.

[3] ATLAS Collaboration, Letter of Intent for the Phase-II Upgrade of the ATLAS Experiment, CERN-LHCC-2012-022, LHCC-I-023.

[4] Valero A. , Carrió F. , Fiorini L. , Cervelló A. , Hernandez D. , Ruiz Martinez A., The PreProcessor module for the ATLAS Tile calorimeter at the HL-LHC, Frontiers in Detector Science and Technology, v.1, 2023.