PROCEEDINGS OF SCIENCE

Demonstrator system for the high luminosity upgrade of the ATLAS hadronic Tile Calorimeter

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The high-luminosity upgrade to the LHC (HL-LHC) leads to considerable challenges for the ATLAS detector, including greater radiation exposure to the on-detector electronics and increased pileup from low momentum collisions affecting trigger selection performance. The ATLAS Tile Calorimeter (TileCal) is a hadronic sampling calorimeter made of steel tiles as absorber and scintillating plastic tiles as active medium. The light produced by the tiles is read out by photomultiplier tubes (PMTs). The PMT signals are shaped, conditioned, and then digitized every 25 ns before being sent off-detector. A complete replacement of the on- and off-detector electronics for Tile-Cal will take place in preparation for the HL-LHC program in 2026. The new system is designed to digitize and transmit all sampled calorimeter data to the off-detector systems, where the data are stored in latency pipelines. Quasi-projective digital trigger tower sums are formed and forwarded to the level-1 trigger. The TileCal upgrade program has included extensive R&D and test beam campaigns. The new design includes state-of-the-art electronics with extensive use of redundancy and radiation-tolerant electronic components to avoid single points of failure. Multi-Gbps optic links drive the high volume of data transmission, and Field Programmable Gate Arrays (FPGAs) provide digital functionality both on- and off- detector.
A hybrid demonstrator prototype module, instrumented with new module electronics and interfaces for backward compatibility with the present system, was assembled and inserted in ATLAS in June 2019 to gain experience in actual detector conditions. We present the current status and test results from the Phase-II upgrade demonstrator module running in ATLAS.

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1. Introduction

The upgrade of the Large Hadronic Collider (LHC) to the High-Luminosity LHC (HL-LHC) is aimed to deliver up to ten times peak luminosity [1]. HL-LHC is designed to deliver collisions at the luminosity of 7.5×1034 cm^{-2} s_{-1} and up to 200 simultaneous proton-proton interactions per bunch crossing. This environment necessitated a Phase-II upgrade of the ATLAS detector [2].

2. The Tile Calorimeter

The Tile Calorimeter (TileCal) is the central section of the hadronic calorimeter of ATLAS. It plays an important role in the measurements of jet and missing transverse momentum, jet substructure, electron isolation, energy reconstruction and triggering, including muon information. To meet the requirements of HL-LHC, upgraded electronics were tested by using The Hybrid Demonstrator in real test environment. The Hybrid Demonstrator combines fully functional up-graded Phase-II electronics with analog trigger signals to be compatible with the current ATLAS interface. The Demonstrator comprises four mini-drawers, each equipped with 12 Photo-Multiplier Tubes (PMT) with upgraded 3-in-1 cards, one Mainboard, one Daughter-board, adder cards and one high voltage regulation board. A finger Low Voltage Power supply (fLVPS) powers all four mini-drawers with 10V. The Hybrid Demonstrator is connected to an off-detector PreProcessor module via optical fibres. The Demonstrator PreProprocessor operates and reads out the hybrid Demonstrator[3].

3. Photo-Multiplier Tubes

When particles cross the scintillator tiles, produced light is transmitted by wavelength shifting fibres. Tiles in the tile calorimeter are grouped, forming cells “A”, “BC” and “D”. PMTs are responsible for converting this light coming from TileCal cells into analog signal and transfer it to the next stage of a signal chain. Every PMT is equipped with a High Voltage Active Divider (HVAD). The function of HVAD is to divide high voltage coming from high voltage system to 8 PMT dynodes. The high voltage for PMTs is in the range of 600-900 Volts. HVAD is also responsible for linear PMT response. PMT Block consists of PMT, HVAD, upgraded 3-in-1 card, iron and mu-metal cylinders. For individual PMTs and PMT Blocks, there are two different test benches to ensure their performance and correct functionality. Before PMT Blocks are assembled each PMT is tested to ensure their physical properties. After this, PMT Blocks are tested using Portable Readout Module for Tile Electronics (PROMETEO) system which ensures the correct functionality of PMT blocks alongside rest of the demonstrator components [3].

4. Upgraded 3-in-1 card

The upgraded 3-in-1 card is part of the PMT Blocks. They are responsible for shaping, amplification and integration of signal coming from the PMTs. Upgraded 3-in-1 cards feature a 16-bit dynamic range, 50 ns full width at half maximum (FWHM) time constant, fast readout with two gains (low gain and high gain), integrated slow readout, charge injection for continuous calibration over full dynamic range. The analog sums are transmitted to the current ATLAS L1Calo system. The Low/High gain and integrator signals from the 3-in-1 are digitized by ADCs in the Mainboards and then transmitted to the Daughterboards.

5. Mainboard

The Demonstrator consists of four mainboards. Currently, Mainboard went through four revisions. The Mainboard is responsible for data transfer between PMT Blocks and Daughterboard. Each of them is connected to 12 PMT Blocks. Field Programmable Gate Arrays (FPGA) are used to configure the ADCs and provide clock signal. For The PMT Block readout, the Mainboard uses 12-bit ADC at 40 Msps and 16-bit ADC for slow integration. The Mainboard is designed to be reliable and redundant, therefore it is divided into two sections called A- and B- Side. Each section is completely independent with each side having +10V LVPS supply bricks. In ordered to prevent failure caused by LVPS or total failure each side is connected with a "Diode-Or" connection to make the power supply more redundant. Other functions of the Mainboard are to provide timing signals for low- and high-gain Charge Injection (CIS) calibrations. Mainboard V4 is the final revision that will be used in HL-LHC.

6. Daughterboard

The Daughterboard is an on-detector communication board that interfaces between front-end electronics and back-end Tile Pre-Processor (TilePPr) module. This is 4th version of the Daughterboard. It sends PMT data and Detector Control System (DCS) and detector readout data to TilePPr over multi-gigabit links. Like the Mainboard, the Daughterboard is also divided into two sections for reliability and redundancy. Redundant optical fibers are also used for protection against single link failure. The GBTx chip developed by CERN is used for remote FPGA and Flash memory configuration. The Daughterboard version 6 is available and is being tested at CERN test beam facilities. Replacement with the latest version on The Demonstrator is under consideration.

7. PreProcessor

The PreProcessor (PPr) is the core element of the TileCal off-detector readout electronics. PMT digital samples are transferred to the PPr every bunch crossing. The PPr has bi-directional communication with front-end electronics. It provides DCS commands, timing, trigger and control information and the LHC clock to the front-end electronics. From front-end electronics, the PPr receives PMT data which is stored in pipeline buffers waiting for trigger decision. After the trigger decision, The PPr sends buffered data to legacy Read-Out Driver (ROD) and processes in the same way as for current modules (backward compatibility).

8. Low Voltage Power Supply

The Tile Calorimeter Low Voltage Power Supply (LVPS) provides power to all front-end electronics and provides control and feedback to the monitoring system. Previous LVPS modules were generating eight different voltages for various sub-circuits of front-end electronics. In Phase-II upgrade each super-drawer is powered by one LVPS module which now provides 10V supply to all the front-end. As the result, TileCal has 256 LVPS

boxes. Each LVPS box consists of eight bricks which converts 200V input voltage to 10V output. For redundancy eight bricks are grouped into four sets of two bricks.

9. High Voltage Power Supply

High Voltage Power Supply (HVPS) must supply high voltage to all PMTs in the system. It also needs to monitor, control and report values to DCS System. There is a total of 256 high voltage regulation boards each equipped with an ethernet interface.

10. Test Beam Results

The Demonstrator together with TileCal modules equipped with the legacy system was exposed to different particles and energies in 7 test beam campaigns at CERN SPS North Area, during 2015-2018 [3]. Analysis results of the recorded data during test beams, indicate that the Demonstrator Module performs at least as good as the legacy module.

11. Prometeo

The Portable ReadOut ModulE for Tile ElectrOnics (PROMETEO) is a mobile test-bench for the in situ certification of the TileCal on-detector electronics at the HL-LHC. It represents an independent and completely autonomous system that includes all necessary components to verify the correct functionality of Tile-Cal on-detector electronics.

12. Summary

The Tile Demonstrator Module is a prototype of the upgraded readout system for the HL-LHC. It is fully integrated into the ATLAS TDAQ and DCS systems. It was extensively tested during 2015, 2016 and 2017 test beams and demonstrated good performance. New tests will take place in November 2022 in order to validate new on-detector electronics in the radiation environment and associated off-detector electronics. The Tile Demonstrator module will also be present in Tile Calorimeter during the Run-3 period.

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