Integration of the ALTI module in the ATLAS Tile Calorimeter system

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Abstract. The Tile Calorimeter of the ATLAS experiment is currently preparing for Run 3 data-taking period. As part of the ongoing Phase I upgrades, the Tile Calorimeter is replacing a part of the Timing, Trigger and Control system. The legacy Timing, Trigger and Control system is being replaced with a new advanced electronic board. The new ATLAS Local Trigger Interface module, is a 6 unit Versa Module Europa board which integrates the functionalities of four legacy modules currently used in the experiment: Local Trigger Processor, Local Trigger Processor interface, Timing, Trigger and Control Versa Module Europa bus interface and the Timing, Trigger and Control emitter. The ATLAS Local Trigger Interface module will provide the interface between the Level-1 Central Trigger Processor and the Timing, Trigger and Control optical broadcasting network, to the Front-End electronics for each of the ATLAS sub-detectors. The implementation and validation of the data acquisition software for the ATLAS Local Trigger Interface module in a Tile Calorimeter test station is complete. The TileCal Back-End electronics consists of four legacy Timing, Trigger and Control partitions, and the integration of the ATLAS Local Trigger Interface module in the Tile Calorimeter requires the insertion of four new ATLAS Local Trigger Interface modules in the Timing, Trigger and Control crates. Calibrations and data quality validations are performed in order to certify the readiness of the new trigger system for Run 3 data-taking period in early 2022.

1. Introduction

The ATLAS experiment [1] is a multipurpose particle physics experiment at the Large Hadron Collider (LHC) [2]. It is designed to study a large range of physics at a TeV scale. In 2012, the ATLAS experiment was one of the two experiments that contributed to the discovery of the Higgs boson. It is made of several sub-detectors and the Tile Calorimeter (TileCal) being the central hadronic calorimeter, is responsible for providing the energy and position of hadrons [3]. TileCal is made out of iron plates and plastic scintillators. It is divided into three cylinders along the beam axis and each cylinder is azimuthally segmented into 64 wedge-shaped modules, staggered in the ϕ direction. It has one central long barrel (LB), consisting of two partitions LBA and LBC side. The other two short extended barrels consist of two partitions EBA and EBC side. The Front-End (FE) electronics are housed inside the outermost part of the wedge-shaped modules, and are connected to the Back-End (BE) read-out electronics through optical Timing, Trigger and Control (TTC) distribution network. These four partitions are controlled by their corresponding TTC crates in the BE electronics. The TileCal utilises the ATLAS

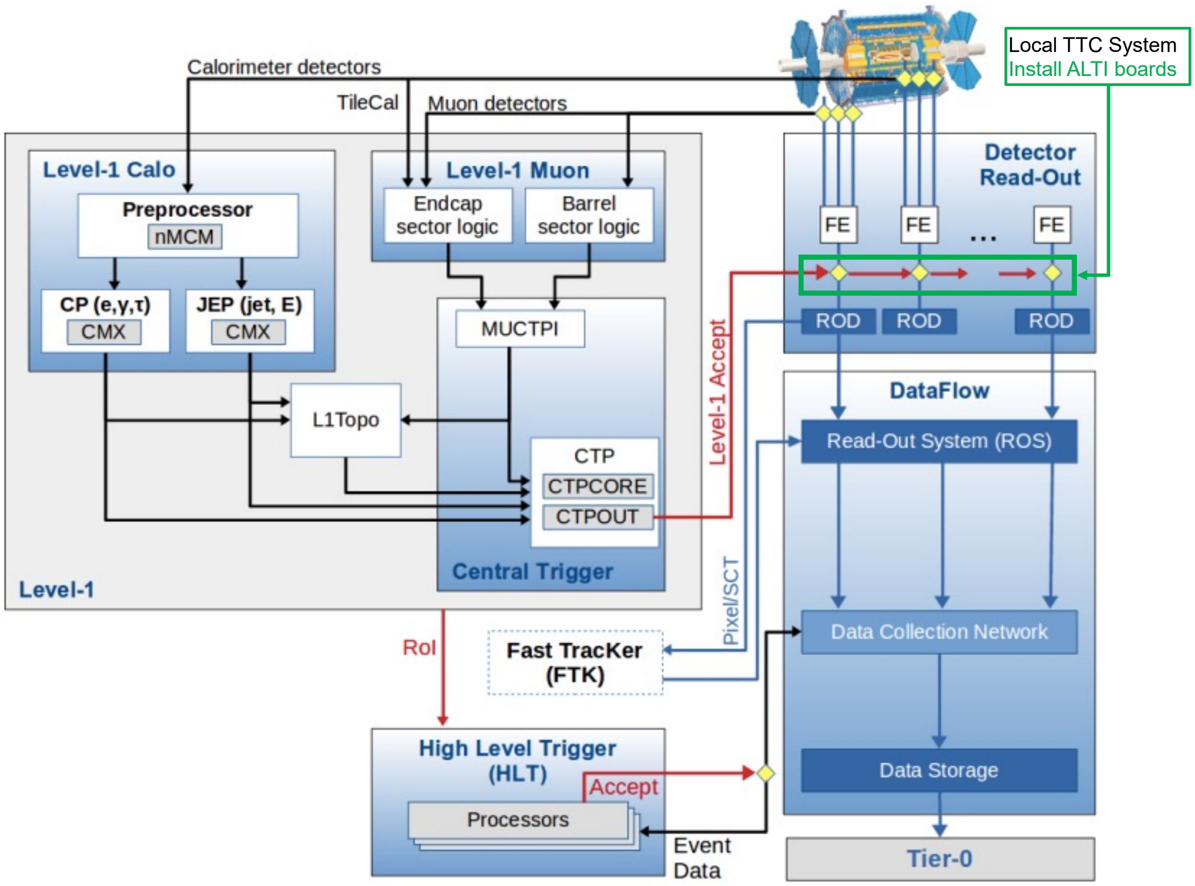

Figure 1: The schematic diagram of the ATLAS TDAQ system, with emphasis on the upgrade of the local TTC system [7].

Trigger and Data Acquisition (TDAQ) system for data collection. The TDAQ system, shown in figure 1 selects events with distinguishing characteristics that might be interesting for physics analyses. It is structured in a 2-level architecture, hardware Level-1 and High Level trigger (HLT) system. The Level-1 trigger (Level-1 Calo and Level-1 Muon) gives a fast identification of interesting events based on specific inputs from the muon detectors and the calorimeters. It uses the Central Trigger Processor (CTP) to reduce the accepted events from an input rate of 40 MHz (25 ns) to 100 kHz [4, 5]. The corresponding event signal produced by the CTP is called Level-1 Accept (L1A). The rate of accepted events is further processed in the HLT, to reduce the rate of recorded events from 100 kHz to 1 kHz [4]. The ATLAS experiment is upgrading the TTC system hardware with new electronics. The ALTI module is being integrated into the TileCal TTC system, in preparation for Run 3 data-taking period commencing in 2022. In order to operate the ALTI module in the TileCal, the TileCal online software,[1] has been adapted to integrate the new ALTI libraries provided by the ATLAS TDAQ group [6].

[1] The TileCal online software is a set of TDAQ software, used for the operation of the TileCal. Its main purpose is to readout, transport and store physics data originating from collisions at the LHC.

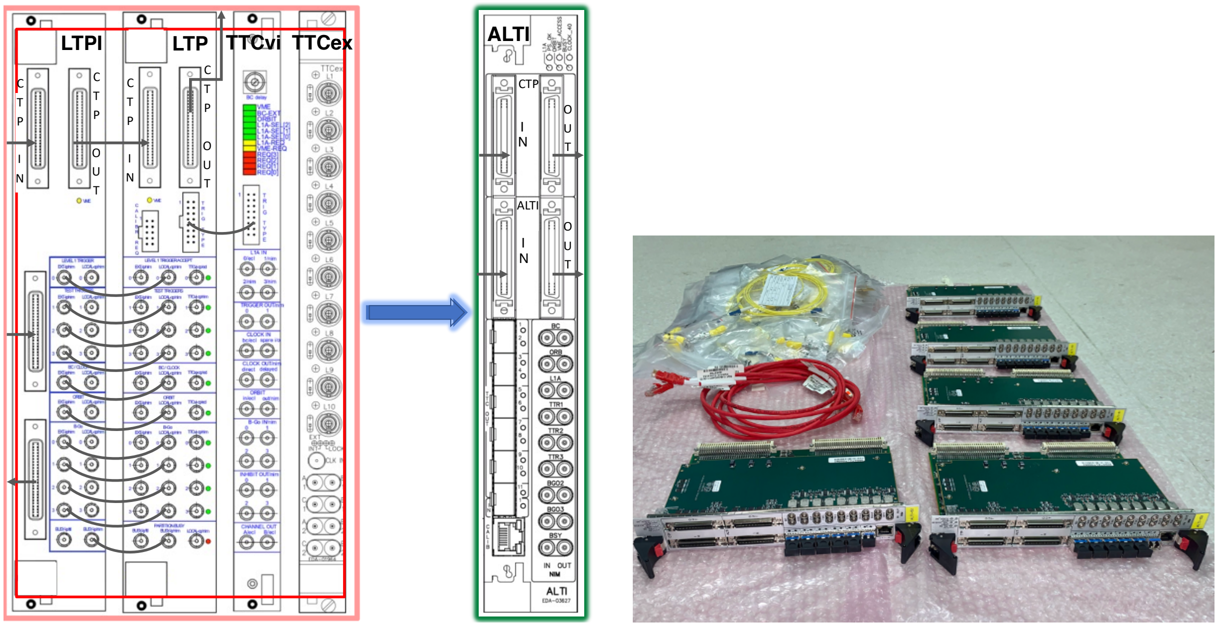

Figure 2: The four legacy TTC modules (LTPi, LTP, TTCvi and TTCex) will be replaced by the ALTI module (left). ALTI modules with new optical fibres, ready to be installed in the TTC crates of the BE electronics (right).

2. The ALTI project

The ALTI module is a new electronic board designed for the ATLAS experiment at CERN as part of the TTC system [8]. It integrates the functionalities of the four existing modules shown in figure 2 (left), which are currently used in the local TTC system of experiment: Local Trigger Processor (LTP), Local Trigger Processor interface (LTPi), TTC VME bus interface (TTCvi) and the TTC emitter (TTCex). The primary function of the ALTI board is to provide interface between the Level-1 CTP and the local TTC system of the sub-detector. It is made of state-of-the-art components and the logic is implemented in a single FPGA, which allows for more flexibility and added functionalities. During the operation of the detector, the ALTI module receives the TTC signals from the CTP through parallel twisted-pair of low voltage differential signaling cables and distributes them to the sub-detector electronics through the optical TTC distribution network. The full LHC turn consists of 3564 bunch crossings (BCs). The signals received from the CTP are the bunch clock, orbit signal, L1A with 8-bit trigger type and the event counter reset. The bunch clock is the main timing signal produced by the LHC and has a frequency of 40 MHz and the orbit signal is the second timing signal that indicates the start of a new LHC turn and allows the identification of the BCs.

3. Installation of ALTI modules

Five ALTI modules shown in figure 2 (right) were prepared for the installation in the BE electronics counting room in ATLAS USA15 cavern shown in figure 3 (left). Additional material include forty 0.5 m Lucent Connector (LC) to Straight Tip (ST) patch fibres with forty ST-ST connectors, five TTC loop fibres for the TTC decoder and four calibration request cables. The connection scheme shown in figure 3 (right) was prepared prior the installation to properly configure the ALTI modules. All the LTP, TTCvi and the TTCex modules in EBA, LBA, LBC and EBC TTC crates and the laser crate were removed and replaced with the five ALTI modules.

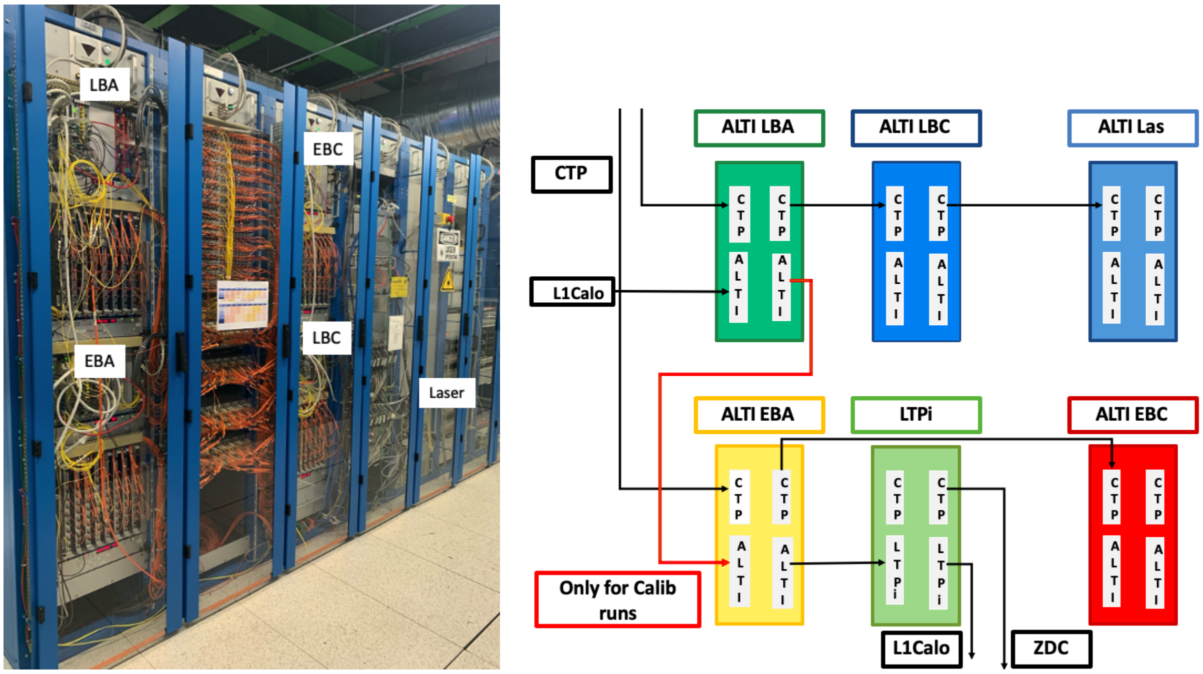

Figure 3: The TileCal TTC crates are located above the read-out driver crates in the BE electronics (left). The connection scheme shows the distribution of the TTC signals from the CTP and Level-1 Calo, to the ALTI modules in the TTC crates (right).

The ALTI modules are configured to use two different configurations for physics and calibration runs. During physics runs, all the ALTI modules are configured to be in slave mode and receive the CTP input. During the calibration runs, the LBA ALTI module is configured as the master and it generates the signals through the pattern generator and propagates them to the other TTC crates. EBA ALTI module is configured as the slave to the LBA ALTI module. All the other ALTI modules in LBC, EBC and the laser crate are configured as slaves to receive the CTP input. The database, OKS (Object Kernel Support), an object-oriented database with storage based on XML (Extensible Markup Language), has been modified to include new configuration objects.

4. Calibration systems and the Diagnostics and Verification System

The implementation of the new TileCal ALTI software involved the upgrade of the calibration systems [9] and the Diagnostics and Verification System (DVS) [10]. These systems have been extensively validated in relation to the legacy TTC system.

4.1. The Calibration systems

The TileCal uses highly accurate and precise calibration systems to achieve good energy determination and to account for changes in the readout electronics, which might be due to irradiation, ageing, and electronic failures. The calibration systems are the Cesium system, Laser system, Charge Injection Scan (CIS) and the Minimum Bias System. Each system tests a specific element in the readout electronics chain, as shown in figure 4. A combination of these tests provides the overall calibration of each readout channel. The tests are taken using seven data samples per event, which means that the read-out window is $25\,\mathrm{ns} \cdot 7 = 175\,\mathrm{ns}$. The calibration runs are taken during beam interruption periods. These calibration systems require a special handling of their calibration signal requests, which has been adapted for the ALTI

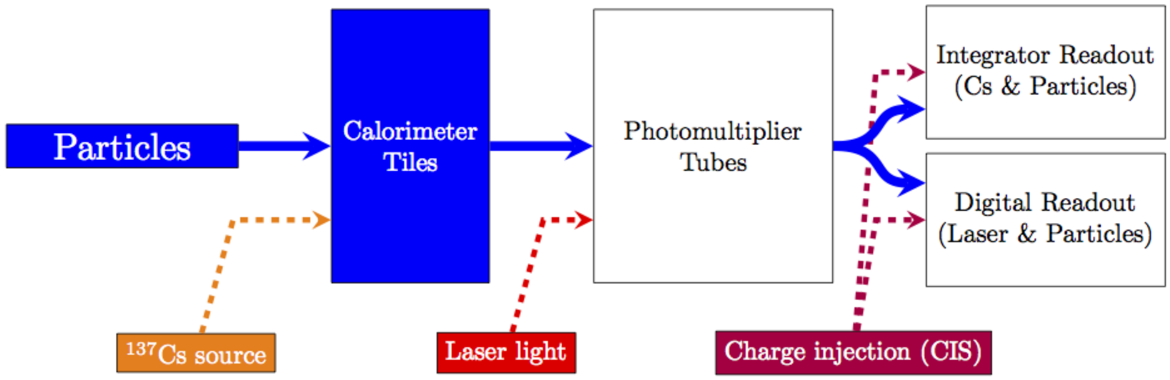

Figure 4: Flow diagram of the signal readout chain of different calibration systems in TileCal [9].

system.

4.1.1. The Laser system The Laser calibration system sends laser pulses to the PhotoMultiplier Tubes (PMTs), allowing for calibration with respect to each PMT's response. This allows for the calculation of corrections to the optical gain of the PMT and a test for the stability of each PMT over time. Laser pulses are also sent during empty bunch crossings of the LHC and the events are used in monitoring the evolution in time of the time calibration.

4.1.2. The Charge Injection Scan This calibration system consists of the simulation of physics signals through the injection of known charge values into the readout electronics. This is achieved by using dedicated capacitors (5 pF and 100 pF) plus a 4096 Digital Analog Converter controlled by an Analogue-to-Digital Converter (ADC). The relation of the peak amplitude in the response of the electronics (measured in ADC counts) to the value of charge injected (in pC) gives the calibration of each ADC in units of ADC counts/pC. This enables verification and identification of errors with the readout chains and allows for calibration of single ADC outputs of each PMT.

4.1.3. Minimum Bias System The proton-proton collisions denoted as "Particles" in figure 4 are dominated by soft parton interactions, known as Minimum Bias (MB) events. The MB readout system identifies response to Minimum Bias events over a time window of approximately 10 ms. Data produced by the integrator are continuously recorded during proton-proton collisions. The response of the TileCal to signals induced by the MB interactions, provides an estimation of instantaneous luminosity [11]. The MB system monitors the stability of the full optical chain and provides an independent cross-check of the Cesium calibration [12].

4.2. Diagnostics and Verification System
The DVS is part of the ATLAS TDAQ online software packages used for configuring and executing tests for TDAQ components [10]. The DVS software package has been modified for the TileCal ALTI system. In the TileCal system the tests are a set of checks for the digital read-out of the super-drawers and gives immediate results. CIS and pedestal are the two main types of tests. CIS checks the existence of the pulse reconstructed with the seven samples shown in figure 5 (left). Noise for a given channel is defined as the standard deviation of the signal in pedestal events.[2] For a given channel, the signal in a pedestal event is sampled seven times and

[2] Empty events where no physics signal is expected in the calorimeter

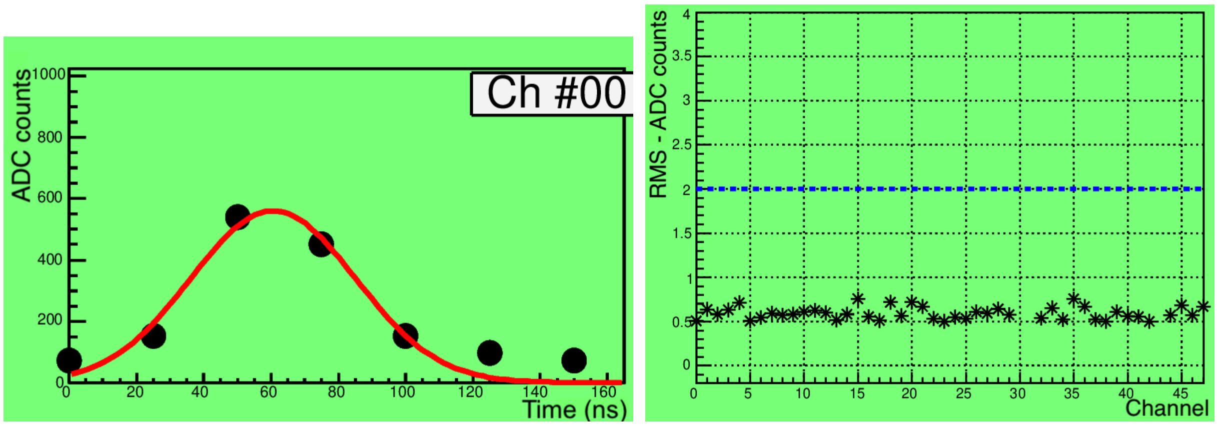

Figure 5: The CIS DVS test taken for one read-out module in good working condition, shows a good reconstructed pulse of the ADC counts against time, for seven samples per channel (left). The pedestal DVS test shows the RMS ADC counts against the channel number and the electronics noise level is below the threshold for all read-out channels (right).

the standard deviation of the samples is averaged over all events and termed "high frequency noise". Likewise, for a given channel, the value of the first of the seven samples is recorded for all pedestal events and the standard deviation of this distribution is called the "low frequency noise". The pedestal test can be run in ATLAS mode (seven samples with auto-gain at 100 kHz) performing the analysis in the read-out drivers, discarding all the events and reading results out at the end of the test. Figure 5 shows part of the DVS test results taken with the ALTI system.

5. Conclusions

During the Long shutdown 2 period (2019-2021), the TileCal has been undergoing maintenance and Phase-I upgrades, in preparation for the Run-3 (2022-2025) data-taking period. As part of the ATLAS Phase-I upgrade, TileCal replaces its local legacy TTC system with the new local ALTI system. The ALTI module integrates the functionalities of four legacy TTC modules: LTP, LTPi, TTCvi and the TTCex. The TileCal ALTI online software has been developed and tested in the test station and is being fully validated for the ATLAS detector at CERN. Five ALTI modules have been installed and configured for physics and calibration runs in the counting room in ATLAS USA15 cavern. The ALTI system is being tuned for data taking.

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