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

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Summary. — The Tile Calorimeter (TileCal) is the hadronic calorimeter covering the central region of the ATLAS detector at the Large Hadron Collider. It is a scintillator-steel sampling calorimeter read out via wavelength shifting fibers coupled to photomultiplier tubes (PMT). The Large Hadron Collider (LHC) has envisaged a series of upgrades towards a High Luminosity LHC (HL-LHC) delivering five times the LHC nominal instantaneous luminosity. The ATLAS Phase II upgrade (2024–2025) will accommodate the upgrade of the detector and data acquisition system for the HL-LHC. In particular, TileCal will undergo a major replacement of its on- and off-detector electronics. In the new architecture, all signals will be digitized and sent to the first level of trigger at the 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. Changes to the electronics will also contribute to the reliability and redundancy of the system. A hybrid demonstrator compatible with the current ATLAS detector has been developed. The demonstrator is undergoing extensive testing and is planned for future installation into the ATLAS detector.

1. – Introduction

The ATLAS [1] detector is a multi-purpose detector at the Large Hadron Collider (LHC) at CERN. The Tile Calorimeter (TileCal) is a hadronic calorimeter that covers the central region of ATLAS, see fig. 1. It consists of a central barrel and two extended barrels, each made up of 64 modules, each covering the azimuthal angle, ϕ, $2\pi/64 \sim 0.1$ [2,3]. A module is made of alternating layers of iron plates and scintillating tiles. The modules are divided up into cells as shown in fig. 2. The scintillating tiles within a cell are readout by wave-length shifting fibers on both sides of the module. These fibers deliver the light to photomultiplier tubes (PMTs). A cell is readout by

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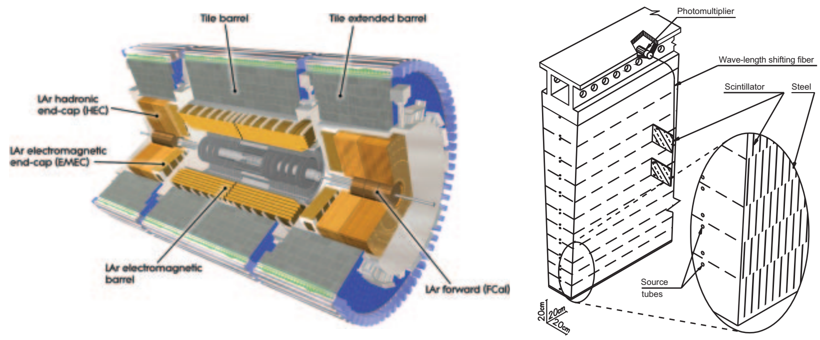


(a) ATLAS Detector (b) TileCal Module

Fig. 1. – TileCal within ATLAS. (a) is a cut-away drawing of the ATLAS inner detector and calorimeters and (b) is a schematic showing how the mechanical assembly and the optical readout of the tile calorimeter are integrated together.

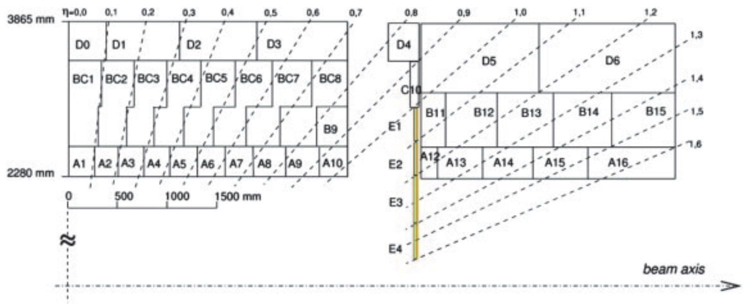


Fig. 2. – Segmentation of TileCal modules into cells for central (left) and extended (right) barrels.

2 PMTs, one for each side of the module. Drawers containing the Front-End electronics and PMTs are inserted in the outermost part of the module.

The LHC will be upgraded to a High Luminosity LHC (HL-LHC) which will be capable of delivering five times the LHC nominal instantaneous luminosity. To accommodate this the ATLAS detector must be upgraded accordingly. TileCal on- and off-detector electronics will be replaced to meet new trigger requirements and improve reliability. TileCal detector components (steel absorbers, scintillating tiles, and fibers) will not be replaced.

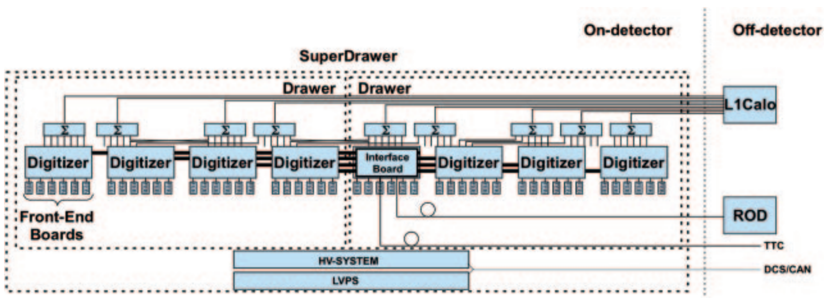


Fig. 3. – Layout of the front-end electronics currently being used in TileCal.

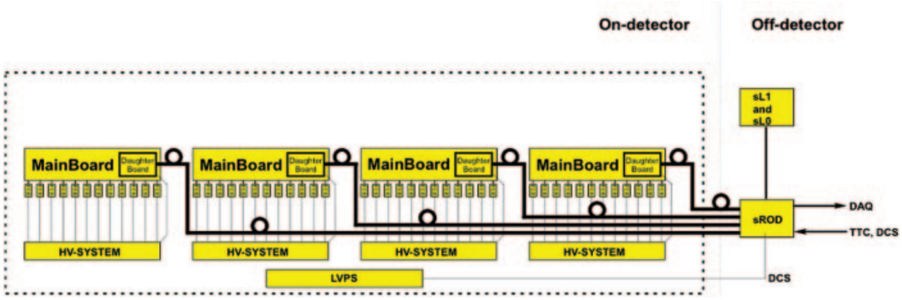


Fig. 4. – Layout of the front-end electronics in the upgrade design.

2. – Current system in ATLAS

In the current system the signals from the PMTs are shaped and amplified in two gains with relative ratio 1:64 by so-called 3-in-1 cards. Each signal is then digitized at 40 MHz using 10-bit ADCs and stored in the front-end pipeline memory. Upon arrival of a trigger, seven samples from one of the gains are sent to the back-end electronics where energy and time are reconstructed. High gain is sent if none of the seven samples are saturated, otherwise low gain is sent. In the current system the calorimeter trigger uses a low-granularity ($\Delta\eta \times \Delta\phi = 0.1 \times 0.1$) analog sum of PMT signals.

The organization of the readout electronics for a TileCal module in the current (Run 2) detector are shown in fig. 3. The low voltage for a drawer is supplied by a single Low Voltage Power Supply (LVPS). In this design, failure of the LVPS results in the loss of an entire drawer. High Voltage (HV) for the PMTs is supplied to each drawer by a single cable. HV Opto boards located in the drawer are responsible for regulating and monitoring the HV for each individual PMT. The digitized PMT signals for trigger events are sent to the off-detector electronics via optical fibre connections through a single on-board interface card.

3. – The upgrade design

Three separate front-end designs were proposed, built, and tested at test beams. The QIE (Charge Integration and Encode) design used ASIC chips and measured the PMT signal using charge integration. The FATALIC (Front-end ATlAs tiLe Integrated Circuit)

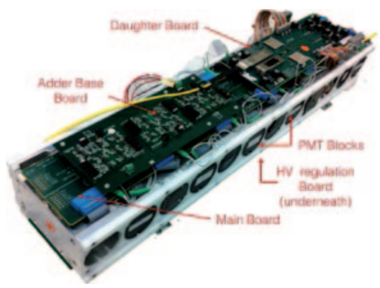
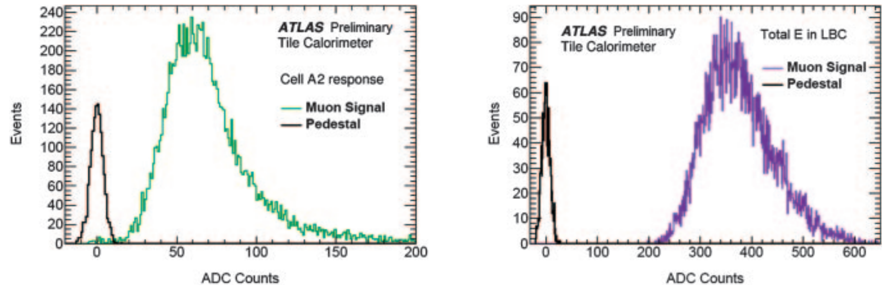


Fig. 5. – Picture of a minidrawer for the upgrade design.

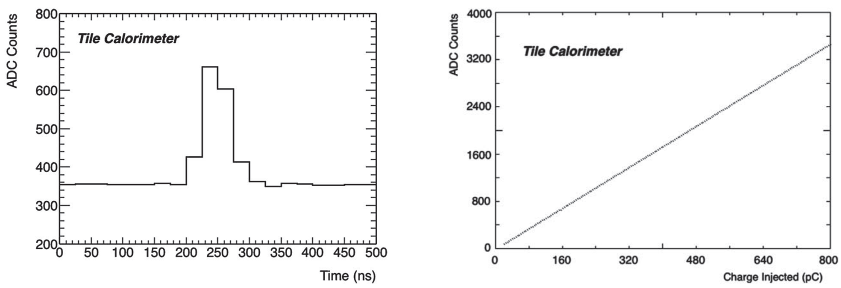


(a) Energy in a Single Cell with Muon Beam

(b) Total Energy in Demonstrator with Muon Beam

Fig. 6. – Energy response of demonstrator for a 100 GeV muon beam hitting the Demonstrator through A2 cell. (a) is the energy of the muon beam reconstructed in cell A2 while (b) is the total energy of the muon beam summed using all cells in the Demonstrator.

design also used ASIC chips, but used active pulse shaping to measure the PMT signal. The upgraded 3-in-1 design, the design selected for the upgrade, is similar to the current design, where the reliability is improved through redundancies. The organization of the readout electronics for the upgraded design are shown in fig. 4. In the upgraded design each drawer is made up of four independent mini-drawers. A mini-drawer consists of a main board, daughter board, and twelve 3-in-1 cards as shown in fig. 5. The 3-in-1 card shapes and amplifies the signals from the PMTs, which are then digitized at 40 MHz using 12-bit ADCs. The full digital signals from all channels will be sent to the trigger. Each mini-drawer has two LVPSs which supply LV to each side. If one side's LVPS fails the other is capable of supplying LV to both sides of the mini-drawer. There were two HV options being considered. The selected one is the remote HV option in which the HV is supplied to each PMT separately. The other option is the HV opto boards used in the current system.



(a) Low Gain Digitized Laser Pulse

(b) CIS Scan using the Demonstrator

Fig. 7. – (a) shows the Demonstrator low gain response to a laser pulse in the hundreds of GeV and (b) is a CIS scan using the Demonstrator. Each charge injection step is sampled 50 times and the average is plotted.

4. – Demonstrator test beam results

To test the upgraded 3-in-1 design a demonstrator drawer was created. The Demonstrator is a hybrid drawer of the upgraded 3-in-1 design that is also compatible with the current system in ATLAS. It has been tested in 5 separate test beams. The Demonstrator could be inserted in the current system during one of the short LHC shutdowns during Run2.

During test beams, data were collected using muon, electron, and hadron beams. The demonstrator shows good separation between pedestal events and muon signal, as is shown in fig. 6. Both the current system and the upgrade system have a charge injection system (CIS) that allows each channel's charge to be calibrated to ADC counts. One such CIS scan is shown in fig. 7 as well as a typical pulse after being digitized.

REFERENCES

[1] ATLAS Collaboration, *J. Instrum.*, **3** (2008) S08003.
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[3] ATLAS Collaboration, *Eur. Phys. J. C*, **70** (2010) 1193.