ATLAS Tile calorimeter calibration and monitoring systems

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Abstract. The ATLAS Tile Calorimeter (TileCal) is the central section of the hadronic calorimeter of the ATLAS experiment and provides important information for reconstruction of hadrons, jets, hadronic decays of tau leptons and missing transverse energy. This sampling calorimeter uses steel plates as absorber and scintillating tiles as active medium. The light produced by the passage of charged particles is transmitted by wavelength shifting fibres to photomultiplier tubes (PMTs), located on the outside of the calorimeter. The readout is segmented into about 5000 cells (longitudinally and transversally), each of them being read out by two PMTs in parallel. To calibrate and monitor the stability and performance of each part of the readout chain during the data taking, a set of calibration systems is used. The TileCal calibration system comprises cesium radioactive sources, Laser and charge injection elements, and allows for monitoring and equalization of the calorimeter response at each stage of the signal production, from scintillation light to digitization. Based on LHC Run 1 experience, several calibration systems were improved for Run 2. The lessons learned, the modifications, and the current LHC Run 2 performance are discussed.

1. Introduction
The TileCal Calorimeter of ATLAS [1] is a sampling calorimeter made of scintillating tiles as active medium and steel plates as absorbers. The light produced by charged particles through scintillating tiles are collected by wavelength shifting fibres and transmitted to the PMTs. The signal from the PMTs is shaped and amplified with two gains. The sampling and the digitization is realised by ADCs. During collisions, if an event is selected by the trigger system, the digitized signals are collected and processed by a ReadOut Driver. In parallel to this, integrators measure the integrated current from the PMTs.

The reconstructed energy of each channel, \( E(\text{GeV}) \), is derived from the raw response, \( A(\text{ADC}) \), as follows:

\[
E(\text{GeV}) = A(\text{ADC}) C_{\text{ADC} \rightarrow \text{pC}} C_{\text{pC} \rightarrow \text{GeV}} C_{\text{Cesium}} C_{\text{Laser}}
\]

This relation is established for each TileCal channel. The factors can evolve in time because of instabilities in PMTs response induced by high light fluxes or optics aging. The calibration systems are used to monitor the stability of these elements, and provide per-channel calibration. The conversion constant from pC to GeV, \( C_{\text{pC} \rightarrow \text{GeV}} \), was determined during dedicated test beam campaigns. The remaining calibration constants are provided by individual systems:
• A movable cesium gamma-source to calibrate the optical components and the PMT gains.
• A Laser system to monitor the PMTs and the electronics components.
• A Charge Injection System (CIS) to monitor the electronics and extract the conversion factors from ADC counts to pC.

A monitoring of beam conditions and Tile optics with the so-called integrator system (minimum bias) can also be used in combination with Laser and cesium results to understand channel gain deviations, because the calibration tools follow different and partially overlapping readout paths allowing for easier identification of potential failure and for crosschecks.

2. The cesium calibration system

The cesium calibration system [2] uses three movable $^{137}$Cs-sources, emitting 0.662 MeV photons to illuminate scintillators. The signal generated by the Cs source is collected through a special readout that integrates the analog PMT signals. This system is used to calibrate the optical components of the calorimeter as well as to monitor the PMTs. The precision of the system is at the order of 0.3% with cesium calibration scans spaced by one to three months.

From Run 1 to Run 2 of the LHC, a new water storage system, lower pressure in the hydraulics, and more precise water level metering during the scans have been achieved to improve stability and safety of the operation.

The deviation of $C_{Cs}$ calibration constant from 1 for A cells (in %) over the period of six years (2009-2015) is shown in Fig. 1.

![Figure 1](image1.png)

**Figure 1.** Deviation of TileCal response to cesium sources per partition, in the inner radial layer (A layer), from 2009 to 2016. Figures are taken from Ref.[5].

![Figure 2](image2.png)

**Figure 2.** Time stability of the average high-gain readout calibration constants from August 2015 to October 2015 for 19421 ADC channels. The calibrations are measured in-situ with the Charge Injection System (CIS). The RMS values printed in the legend represent a measure of the fluctuations present in calibrations. Figures are taken from Ref.[5].

3. The Laser calibration system

The Laser calibration system [3] is used to measure the gain of each channel sending a known amount of light to the photocathode of the PMTs. The Laser system is used to monitor both High- and Low-gain regimes of the calorimeter readout by modifying the light amplitudes. Deviations of channel responses are considered with respect to their nominal responses (at the
time of the latest cesium calibration). The Laser calibration runs are usually taken twice a week to monitor the individual PMT gain variations between the cesium monthly scans. The typical precision on the gain variation during Run 1 of the LHC was better than 0.5% per channel. During the Long Shutdown from 2012 to 2015 of the LHC, a new Laser II system has been developed to correct shortcomings in electronics and light monitoring of the first system with the consequence to have an improved resolution. The new system has been used since the beginning of the Run 2 in 2015 to monitor the channel gain deviations as shown on Figure 3.

4. The Charge Injection System
The CIS [4] is used to calibrate the readout electronics by injecting a known charge in the ADC and measuring the electronic response. The conversion factor from pC to ADC counts, $C_{ADC\rightarrow PC}$, is extracted from this measurement for both High-Gain and Low-Gain regimes of the readout. This system is also used to monitor the front-end electronics and to correct for non-linearities. The overall stability of the calibration factor is at the level of 0.02% (Fig. 2) and usually less than 1% of the channels exhibit large fluctuations. Their calibration constants are updated if the deviation from previous measured value is above the CIS systematic error (0.7%).

5. The Minimum Bias system
The Minimum Bias system can also be used for calibration. The first purpose of this system is the monitoring of ATLAS instantaneous luminosity. Both the Minimum Bias and the cesium systems measure the signal coming from scintillators and the variation in PMT response over time is expected to be the same. The comparison

Figure 3. Difference in PMT response in % (averaged over 64 modules) measured in two Laser calibration runs in October 2015. Figures are taken from Ref.[5].
Figure 4. The upper part described the increase in the total integrated luminosity delivered by the LHC and recorded by ATLAS during 2012. The plateaus described period without collision. The bottom part described the variation of the response in cell A13 (1.2 < |\eta| < 1.3) during 2012 measured by 3 calibration systems: Minimum Bias (red squares), cesium (green squares), Laser (blue circles). The agreement between the three measurements could indicate that the origin of the deviation is the PMT. Figures are taken from Ref.[5].

between those systems and the Laser system can give insights on origins of channel drifts as illustrated in Figure 4.

6. Conclusion
The calibration systems of the TileCalorimeter were operated successfully throughout Run 1 of the LHC. The stability in time achieved using these systems during Run 1 was within 1%. During the LS1 of the LHC from 2012 to 2015, shortcomings of Laser and cesium systems have been corrected. Since the beginning of Run 2 of the LHC the calibration systems have been used attaining an improved resolution with respect to Run 1.

References
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