Journal of Physics: Conference Series

PAPER • OPEN ACCESS

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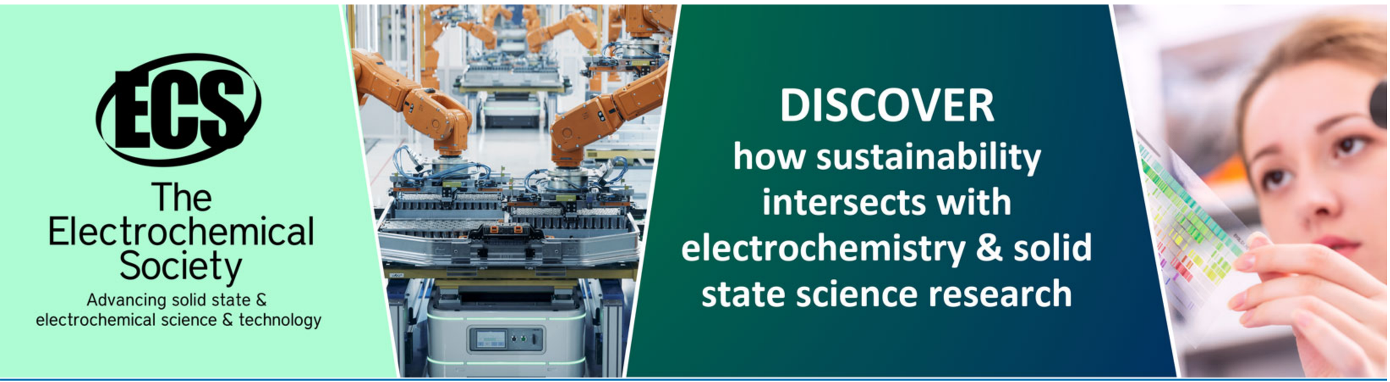
To cite this article: T Davidek and on behalf of the ATLAS Collaboration 2017 *J. Phys.: Conf. Ser.* **928** 012003



IOP Conf. Series: Journal of Physics: Conf. Series **928** (2017) 012003 doi:10.1088/1742-6596/928/1/012003

ATLAS Tile Calorimeter time calibration, monitoring and performance

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Abstract. The Tile Calorimeter (TileCal) is the hadronic calorimeter covering the central region of the ATLAS experiment at the LHC. This sampling device is made of plastic scintillating tiles alternated with iron plates and its response is calibrated to electromagnetic scale by means of several dedicated calibration systems.

The accurate time calibration is important for the energy reconstruction, non-collision background removal as well as for specific physics analyses. The initial time calibration with so-called splash events and subsequent fine-tuning with collision data are presented. The monitoring of the time calibration with laser system and physics collision data is discussed as well as the corrections for sudden changes performed still before the recorded data are processed for physics analyses. Finally, the time resolution as measured with jets and isolated muons is presented.

1. Introduction

The Tile Calorimeter is part of the ATLAS experiment [1], which explores the proton-proton (and also lead-lead) collisions at unprecedented high energies achieved at the LHC. TileCal surrounds the liquid-argon electromagnetic and hadronic end-cap calorimeters and it spans over the ATLAS central region ($|\eta| < 1.7$). Mechanically, the calorimeter is divided into a central part (Long Barrel) and two Extended Barrels. Each part consists of 64 wedges (modules), see Fig. 1.

The readout cells are organized into 3 radial layers of the total depth of $7.4\,\lambda_{\mathrm{int}}$. The cell segmentation in pseudorapidity is 0.1 ($\Delta\eta = 0.2$ in the outermost radial layer), while in azimuthal direction the cell size is defined by the module geometry ($\Delta\phi = 2\pi/64 \approx 0.1$). Each cell is readout by two PMTs and the signals are further processed by the readout electronics.

1.1. Calibration systems

TileCal exploits three dedicated calibration systems. Each of them monitors different stage of the signal processing:

- Cesium system measures the signal induced by ^{137}Cs radioactive source that passes through all tiles in dedicated calibration runs. It calibrates optics and PMTs, the signal is read out through dedicated slow electronics used for Cs system and minimum bias monitoring.
- Laser pulses are used to measure the PMT response combined with the fast readout electronics that is also used for physics data.

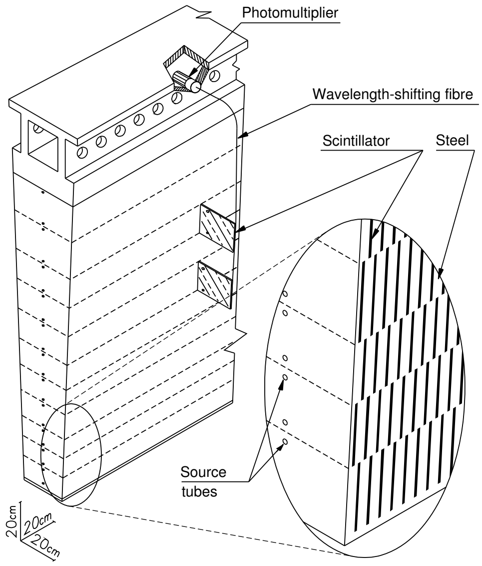

Figure 1. The sketch of one TileCal module shows its geometry and the principle of the signal readout [2]. The scintillating tiles are oriented parallel to the incoming particles. They are readout on both edges by wavelength-shifting (WLS) fibers, which route the light to the photomultipliers (PMTs) housed in the outer part together with the front-end electronics. The readout cells are defined by grouping the fibers onto a PMT.

- Charge injection system calibrates the fast readout electronics by injecting pulses of specified charge into the fast readout electronics.

The combination of the results from individual calibration systems allows to calibrate the detector response at the electromagnetic scale as well as to spot where the problem is in case of unexpected behaviour [2]. The calibration systems and their performance are also detailed in another contribution presented at the same conference [3].

1.2. Signal reconstruction

The analog pulse from the PMT is shaped and split into two branches (high- and low-gain, gain ratio 64:1) to ensure both good signal-to-noise ratio for small signals (e.g. from muons) and large dynamic range up to $\sim$ 800 GeV in each channel.

Each pulse is then sampled every 25 ns and the amplitude A (proportional to the deposited energy), time t_0 and quality factor are reconstructed. Currently, the Optimal Filter (OF) is used in physics data reconstruction [4]:

$$A = \sum a_i S_i \quad (1)$$

$$t_0 = \frac{1}{A} \sum b_i S_i \quad (2)$$

where S_i represent individual values of the sampled pulse. The OF constants a_i, b_i, derived from the known pulse shape, depend on the pulse arrival phase, which is determined in the time calibration.

2. Time calibration

As already discussed in Section 1.2, the time calibration is important for the energy measurement. Nevertheless, the precise time synchronization is also relevant for the removal of signals which do not originate from the proton-proton (pp) collisions as well as for the time-of-flight measurement of hypothetical heavy slow particles that would enter in the calorimeter [5].

The aim of the time calibration is to set the phase in each channel so that a particle travelling from the ATLAS interaction point at the speed of light produces the signal with measured time equal to zero. The time calibration is performed in the two following steps.

2.1. Splash events

Special single beam data-taking sessions (runs) used by various detectors for calibration purposes are usually organized at the beginning of the LHC data-taking period. During these runs, only one bunch of about $5 \cdot 10^8$ protons is circulating in LHC and it hits the closed collimator approximately 40 m upstream of the ATLAS detector.

Many high-energy particles are produced in these so-called splash events. Since TileCal is located in the central part of the ATLAS experiment, high energy muons produced parallel to the beam axis are the main component of the particle flux entering the calorimeter. Large signals are observed during splash events in all calorimeter cells, allowing a precise time measurement of the pulses. Time constants are derived in each channel after accounting for the time of flight of the particles crossing the calorimeter.

2.2. Calibration with jets

The pp collisions are also used to calibrate the timing of the calorimeter cells. Events with jets pointing to the TileCal η-range and satisfying standard quality criteria are used for this purpose. In order to avoid possible bias from non-collision background, only cells/channels being a part of reconstructed jets are considered in the given event. Since the average cell time slightly depends on the energy deposited in a cell (see Section 4), a specific energy range has to be used. In each channel, the condition $2 < E_{\text{channel}} < 4$ GeV is further imposed as a trade-off between the statistics and the Gaussian shape of the time response.[1]

The time constants are determined as a Gaussian mean of the time distribution in each channel, obtained with the above mentioned procedure.

3. Time monitoring

Laser calibration events are shot during physics runs in the empty bunch-crossings[2] with a frequency of about 1 Hz. Since all PMTs are illuminated at the same time, these data provide good statistics to monitor the time calibration. Laser events are not synchronized with the LHC clock, therefore a phase correction (average of the reconstructed time in all TileCal channels) is applied in every event. A dedicated tool analyzing these events was set up in order to spot sudden changes in the time synchronization. An example is shown in Fig. 2. The laser-based results are available soon after the physics run is over, therefore the corresponding time constant correction can be applied before the collision data are reconstructed for the physics analyses.

The impact of the time constant correction was investigated with jet collision data, the results are displayed in Fig. 3. While the Gaussian core of the time distribution remains unchanged (it corresponds to non-affected channels), the tails are reduced significantly.

A complementary time monitoring tool exploiting the jet collision data was developed for Run-2. It is based on the same principles as the time calibration with jets (see Section 2.2). These results are used as a cross-check to that from laser.

4. Time performance

As already noted in Section 2.2, the mean cell time measured with jets depends on the energy deposited in the cells. Figure 4 shows the mean cell time as a function of the cell energy after correcting for the run-to-run differences due to changes in the beam phase with respect to the LHC clock.

[1] The lower energy bins are more populated, but the corresponding time spectra exhibit high-time tails due to slow hadronic component of the shower.

[2] When LHC is filled with proton bunches, some consecutive positions are left empty. This translates into short interval (5.6 μs) without collisions in every LHC orbit. These intervals are used by individual sub-detectors for taking calibration events.

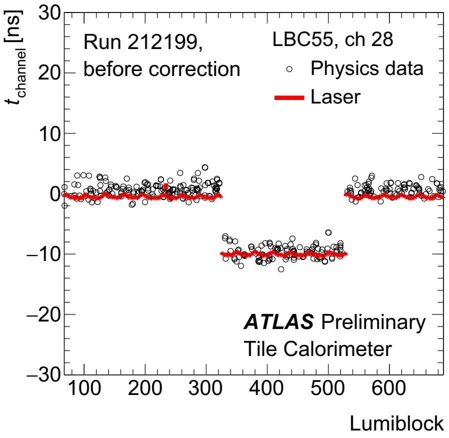

Figure 2. Example of sudden change in the time calibration as detected by the laser-based tool in one channel [6]. Superimposed are the results obtained with the jet collision data.

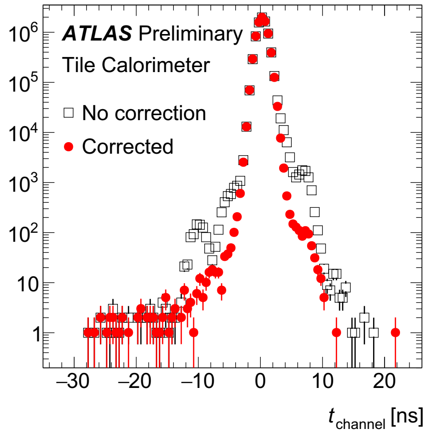

Figure 3. The impact of the time constant corrections for sudden changes in the time calibration, as observed for one data-taking period in Run-1 [6]. The RMS of the measured time distribution improves from 0.90 ns to 0.82 ns.

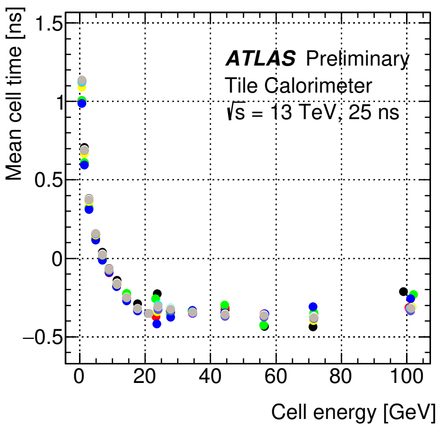

Figure 4. The mean cell time as measured with jet collision data as a function of energy deposited in the cell, after correcting for the run-to-run differences [6]. Symbols of different colours correspond to different runs.

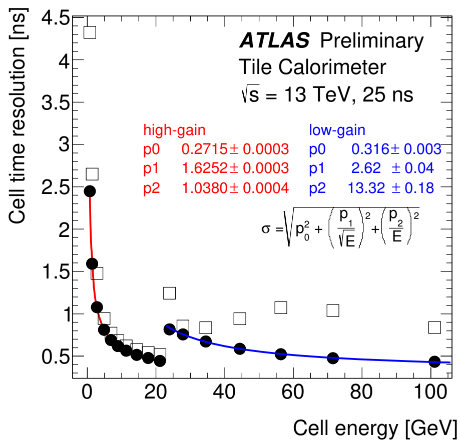

Figure 5. The cell time resolution as measured with jets [6]. Full circles denote Gaussian widths and open squares indicate the RMS of the underlying time spectra. The discontinuity around 25 GeV corresponds to the transition between the high- and low-gain.

Similar studies were performed already with Run-1 data [6]. While the mean time in jet events shows the same behaviour, the mean time obtained with isolated muons is independent from the cell energy, as no hadronic component is involved.

The time resolution was also studied and the results obtained with jets in Run-2 are shown in Fig. 5. The RMS values are systematically higher than Gaussian widths, indicating non-Gaussian tails in the measured time distribution that originates from the concurrent interactions in neighbouring bunch-crossing.

The time resolution was also compared between jet and muon events. The results were found to be compatible with one another [6].

5. Conclusions

Two methods for the time calibration in the ATLAS Tile Calorimeter were presented: one with single beam data and another with proton-proton collisions. The time synchronization is monitored during the physics data taking by means of the laser calibration events as well as with jet data, allowing for time constant correction before the data are processed for the physics analyses. Due to the frequency of sudden changes in the time calibration during Run-1, these corrections resulted in significant tail reduction and improvement of the RMS of the measured time distribution.

The mean cell time as a function of the deposited energy in jet data was presented as well as the time resolution, where the constant term approaches 300 ps.

Acknowledgments

The support from the Ministry of Education, Youth and Sports of the Czech Republic is acknowledged.

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