The ATLAS Tile Calorimeter performance at LHC in pp collisions at 7 TeV

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Abstract The Tile Calorimeter (TileCal), the central section of the hadronic calorimeter of the ATLAS experiment, is a key detector component to detect hadrons, jets and taus and to measure the missing transverse energy. Due to the very good muon signal to noise ratio it assists the muon spectrometer in the identification and reconstruction of muons. The performance of the calorimeter has been measured and monitored using calibration data, random triggered data, cosmic muons, splash events and more importantly LHC collision events. The results presented assess the absolute energy scale calibration precision, the energy and timing uniformity and the synchronization precision. The results demonstrate a very good understanding of the performance of the Tile Calorimeter that is well within the design expectations.

1 Introduction

The ATLAS Tile Calorimeter (TileCal) [1] is the central section of the hadronic calorimeter of the ATLAS [2] experiment at the CERN Large Hadron Collider.

The ATLAS calorimeter system provides accurate energy and position measurements for electrons, photons, isolated hadrons, taus and jets. It also contributes in particle identification and in muon momentum reconstruction. Together with the electromagnetic barrel calorimeter, TileCal allows precise measurements of hadrons, jets, taus and the missing transverse energy.

The large physics programme and the experimental conditions at the LHC drive the performance requirements:

- a very good sensitivity is necessary to measure physical processes taking place at the TeV-scale; the TileCal energy resolution for hadrons should be $\sigma/E = 50\%/\sqrt{E} \oplus 5\%$;
- on average, about one third of the jet energy is deposited in TileCal; in order to perform very precise measurements, the jet energy scale uncertainty should not exceed the 3% limit;
- the response linearity of the Tile Calorimeter is required to be within 2% in the energy range between 30 MeV and $\sim$ 2 TeV; this is crucial for the observation of new physics signatures.

The main goal of this paper is to present the TileCal performance measurements using data from different experimental sources, and to show that the calorimeter meets the design requirements.

The paper is organized as follows: in Section 2, a brief description of the calorimeter is given, while Section 3 presents some performance results, which make use of different datasets: muon cosmic data (Sect. 3.2), splash events (Sect. 3.1), collision data and Minimum Bias current measurements (Sect. 3.3). The conclusions show that the TileCal performance is within the design expectations and well understood.

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2 The Tile Calorimeter

TileCal is a sampling calorimeter with steel as absorber medium and scintillating tiles as active material; the tiles are housed in the steel plates' structure and arranged perpendicularly to the beam axis to guarantee hermeticity.

The calorimeter readout is divided in four cylindrical partitions, two central sections (Long Barrels LBA and LBC) and two endcaps at higher pseudorapidity (Extended Barrels EBA and EBC), globally covering the region with $|\eta| < 1.7$. The four partitions are azimuthally segmented in 64 instrumented wedges (*modules*); each wedge is further split into three layers along the radial coordinate, which are approximately 1.5, 4.1 and 1.8 λ thick at $\eta = 0$. The achieved $\Delta\eta \times \Delta\phi$ segmentation is 0.1×0.1 for the first two radial layers, and 0.2×0.1 for the third layer, while the radial thickness allows to contain the hadronic showers.

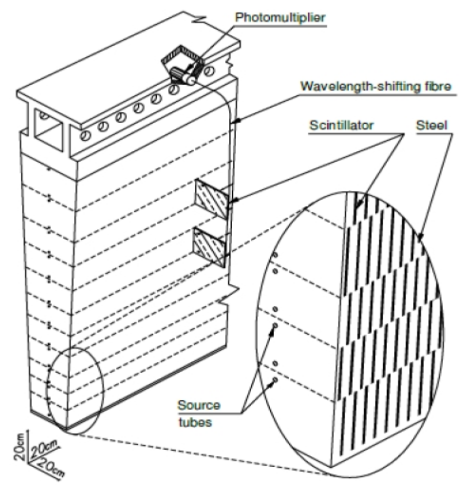

Figure 1. Schematic view of one of the 64 azimuthal modules of TileCal. The module structure and the signal collection system are shown.

The ϕ, η and radial segmentations define the three dimentional TileCal cells, formed by dozens of iron plates and scintillating tiles. The scintillating light from tiles is collected by wavelenght shifting fibers read by two different photomultipliers (PMTs) per cell (Figure 1). The double read-out system improves the response uniformity and provides redundancy. The PMT signals are shaped and sampled independently in dedicated channels, with about 10000 channels in total for the Tile Calorimeter.

The whole read-out system is calibrated and monitored at each stage (optics, PMTs and front-end electronics) by using three different signal sources: Cesium radioactive sources to equalize the cell signals, laser light to monitor each photomultiplier's response, and a charge injection system to calibrate the readout electronics for each channel.

TileCal also feeds the Level-1 trigger system providing the analog sum of the PMT signals in groups of cells forming projective towers of $\Delta\eta \times \Delta\phi = 0.1 \times 0.1$.

3 TileCal Performance

Due to the crucial role of TileCal in physics measurements, it is important that the energy scale and the timing synchronization are measured precisely and monitored to be kept within the design expectations. The following subsections expose the measurements which prove and validate the performance on the items mentioned above.

3.1 TileCal cell timing

During special single-beam runs in 2011, the beam was made to hit a closed collimator located at a distance of 140 m upstream the nominal interaction point. The resulting interaction event is called a *splash event*, and it is characterised by millions of particles arriving almost simultaneously and parallel to the beam axis in the ATLAS detector, depositing large amounts of energy in the Tile Calorimeter. The signals coming from a splash event are correlated in time, therefore they can be used to evaluate the TileCal cells synchronization after it has initially been set using the laser data.

The signals propagate from one side of the calorimeter to the other, so they have to be corrected for the time of flight of particles as compared to the ones originating from the nominal interaction point.

Figure 2 shows the distribution of the TileCal timing measured in the cells as a function of the z coordinate of the cells (along the beam axis) after the corrections are applied. The results for the three different layers integrating over cells in the ϕ coordinate are presented. All cells are synchronized within 1 ns.

3.2 Cell energy uniformity

Cosmic muons are muons coming from the showering of cosmic rays travelling through the atmosphere. Since the interaction of muons with matter is well understood, the expected calorimeter response to ionization loss is reliable; therefore cosmic muons depositing energy in the hadronic calorimeter and in the Inner Detector are used to provide information on the EM scale calibration and uniformity across TileCal cells. Muon tracks reconstructed in the inner tracker are extrapolated to the TileCal cells where their energy is measured.

The estimator for the muon response is the truncated mean of $\mathrm{d}E/\mathrm{d}x$, defined as the mean after 1% of the events in the high-energy tail of the distribution were removed.

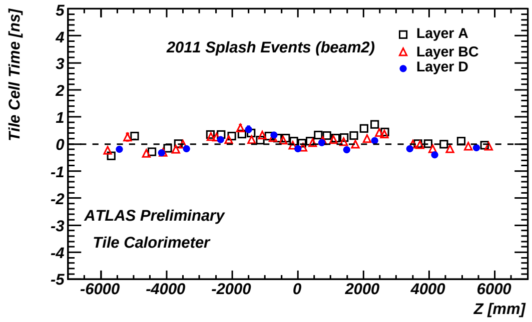

Figure 2. TileCal cell synchronization as a function of the cell z coordinate along the beam axis. The plot shows the results for the three radial layers after corrections for particle time-of-flight and fiber-lenght have been applied. The different layers are shown using different markers.

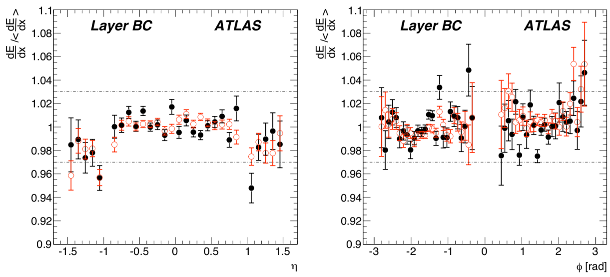

Figure 3. Cell energy uniformity using cosmic muon rays. The TileCal cell energy is uniform within 3% both in η and ϕ coordinates inside each radial layer. Data (closed circles) are well reproduced by Monte Carlo predictions (open circles). The horizontal lines limit the ±3% bands.

The truncated mean is less sensitive to the muon's radiative losses in the cells.

The plots in Figure 3 show the normalised truncated mean of $\mathrm{d}E/\mathrm{d}x$ as a function of the η (on the left) and the ϕ (on the right) cell coordinate integrating over ϕ and over η respectively. This study has been performed separately for each radial layer of the TileCal modules; the plots in Figure 3 refer to the middle layer. The results for data (closed circles) are compared to Monte Carlo predictions (open circles).

When investigating the response uniformity as a function of the pseudorapidity, the signal distribution is flat and uniform within 3% over the considered range for almost all points; the larger statistical uncertainties at higher pseudorapidity in the Extended Barrels are due to reduced coverage than in the central region.

Also the uniformity over modules in the ϕ coordinate shows a good agreement between data and Monte Carlo predictions and a response uniformity within 3%; the gap in the region around $\phi = 0$ corresponds to horizontal modules poorly populated by muons passing through the Inner Detector.

3.3 Performance in collisions

The LHC started operating in 2009 at $\sqrt{s} = 900$ GeV center-of-mass energy, swicthing to 2.36 TeV and finally to 7 TeV. The TileCal performance has been evaluated in collision data and in this section the achieved time resolution, the response from single hadrons and the luminosity monitoring measurements are presented.

A cell time resolution of the order of a few ns is required in order to distinguish signals in the calorimeter coming from different events close in time or to tag out-of-time energy deposits coming from non-collision backgrounds or exotic particles. Using muons and jets, the cell time resolution has been studied as a function of the cell energy (Figure 4) using 2011 collision data at $\sqrt{s}$ = 7 TeV

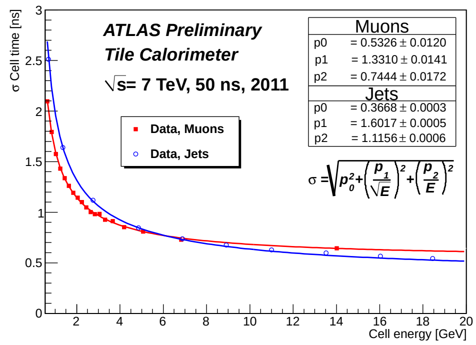

Figure 4. TileCall cell timing resolution with collision data with high luminosity environment and $\sqrt{s}$ = 7 TeV. The timing resolution has been studied for jets and muons as a function of energy.

and high luminosity (50 ns bunch spacing).

The resolution decreases at higher energies as expected and it is below 1% above 3 GeV for both muons and jets; since muons deposit a small fraction of energy in the calorimeter, the corresponding data mainly cover the low energy range. The data are fitted with a resolution function separately for muons and jets, with the fit parameters shown in Figure 4.

The in-situ calorimeter response to single pions has been investigated. Isolated tracks in the Inner Detector with momentum p were required to deposit small energy in the electromagnetic calorimeter in front of TileCal; this is consistent with minimum ionizing particles releasing the largest fraction of their energy E via showers in the hadronic section. Figure 5 shows the mean value of the ratio E/p as a function of η for 2010 data; a comparison between Monte

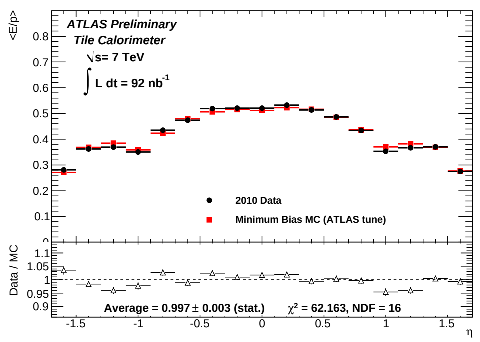

Figure 5. E/p ratio as a function of η for 2010 collision data (black circles) compared to Monte Carlo predictions (red circles) at $\sqrt{s}$ = 7 TeV using isolated charged particles. The data are reproducted at the level of a few percent, showing a good understanding of the combined performance.

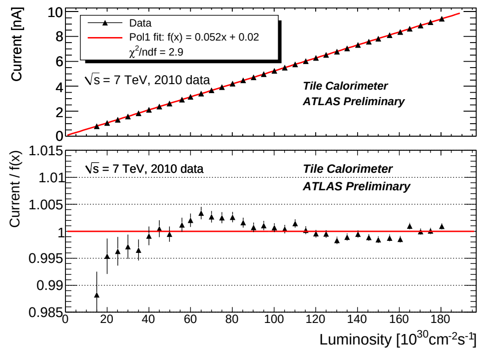

Figure 6. The Minimum Bias current during collisions follows the instant luminosity profile: on top, the data points fitted with a polynomial function; on the bottom, the same data divided by the fit result.

Carlo predictions and data is presented, showing an agreement at the level of few percent.

Collision data are also used to monitor the relative luminosity during physics runs. This is possible by means of Minimum Bias events, which are inelastic pp collisions characterized by low-momentum transfer and whose rate is proportional to the LHC luminosity and almost uniform in the azimuthal coordinate.

A dedicated TileCal read-out providing the anode currents for each photomultiplier is used to measure the Minimum Bias current, which is proportional to the interaction rate. The top plot in Figure 6 shows the relation between the anode current for a cell integrated over few ms and the luminosity during collisions using Minimum Bias events. The 2010 data have been used to prove they follow the luminosity evolution within 5‰ (bottom plot in Figure 6).

4 Conclusions

The first years of data taking at the LHC demonstrate the good performance of the ATLAS Tile Calorimeter which is well within the the design expectations.

The calibration systems ensure the time stability and the energy uniformity of the calorimeter, the time synchronization between cells being well within 1% and the energy response uniform in η and ϕ coordinates within 3%. The performance evaluated with collisions data demonstrate a very good cell timing resolution for muons and jets for a wide range of deposited energy. The single particle response using cosmic muons and hadrons from collisions shows a very good agreement with the Monte Carlo predictions. The Minimum Bias current measurement has proven to follow the luminosity evolution to the few permille level.

References

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3. A. Solodkov, *The ATLAS Tile Calorimeter performance at the LHC in pp collisions at 7 TeV*, proceedings for the 13th ICATPP conference on Astroparticle, Particle, Space Physics and Detectors for Physics Applications, (2011)