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The ATLAS Tile Hadronic Calorimeter performance at the LHC

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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 spectrometer in the identification and reconstruction of muons. TileCal is built of steel and scintillating tiles coupled to optical fibers and read out by photomultipliers. The calorimeter is equipped with systems that allow to monitor and to calibrate each stage of the read-out exploiting different signal sources: laser light, charge injection, a radioactive source and the signal produced by minimum bias events. The performance of the calorimeter has been measured and monitored using calibration data, random triggered data, cosmic muons, splash events and most importantly the large sample of pp collision events. Results that are discussed demonstrate how the calorimeter is operated, how it is monitored and what performance has been obtained. These results also show that the Tile Calorimeter is performing well within the design requirements and is giving essential input to the physics results.

1. Introduction

The ATLAS experiment at CERN [1] is successfully taking data at the LHC at 0.9 TeV, 2.47 TeV, 7 TeV and 8 TeV center-of-mass energy since 2009. The Tile Calorimeter (TileCal) [2] is the central hadronic section of the ATLAS Calorimeter. TileCal is a sampling calorimeter made of scintillating tiles as active medium and steel plates as absorbers. It is divided into four partitions, two barrels (LB) and two extended barrels (EB), covering in total a pseudorapidity range of $|\eta| < 1\ .7$ and is segmented into 64 modules along the azimuth ϕ. Wavelength shifting fibers collect the light generated in the scintillating tiles and carry it to photomultipliers (PMT) (see Fig. 1). Two fibers, attached to every tile from different sides in ϕ, go to different PMTs, providing redundant double readout of a signal. Each PMT receives signals from multiple tiles which are grouped into cells of different size depending on their pseudorapidity and depth. Three longitudinal layers A, BC, D are defined inside the modules and the dimensions of the cells are optimized to obtain a structure of projective towers with granularity of $\Delta\eta \times \Delta\phi = 0.1 \times 0.1$ in the first two layers and $\Delta\eta \times \Delta\phi = 0.2 \times 0.1$ in the last layer (see Fig. 2). Cells of an additional special layer E, attached to the extended barrel modules, are read out by a single PMT each. In total, TileCal has 5182 cells and 9852 channels.

Because of the double readout of most of the cells, single channel failure does not impact the energy measurement. More serious failures in on-detector electronics, which cannot be fixed remotely, might require to disable the readout from a whole module - 22 cells in barrel and 18

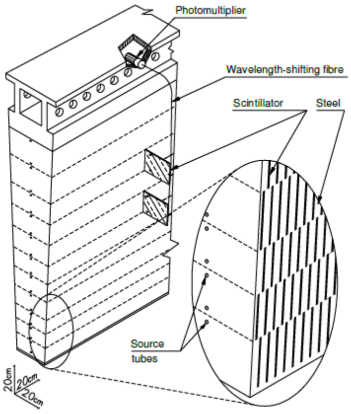

Figure 1. Schematic of one of the 64 azimuthal modules of TileCal showing the system of signal collection.

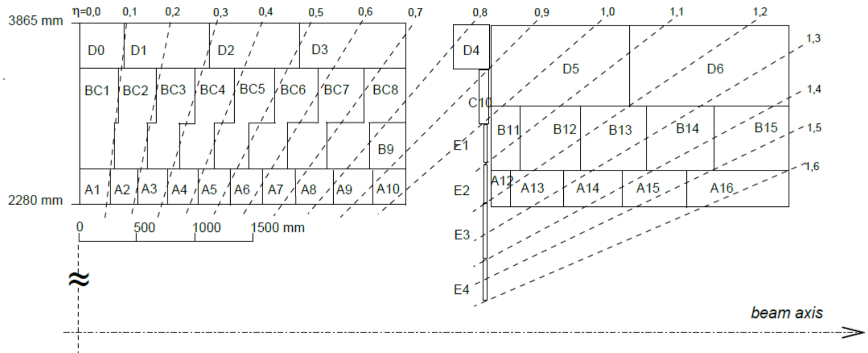

Figure 2. Drawing of a half of the calorimeter divided into a barrel and an extended barrel part with the cell division scheme depicted.

cells in extended barrel are masked in this case. The energy deposited in the masked cells is recovered offline using interpolation between working neighbors, thanks to the good calorimeter spatial granularity. Before the maintenance period of winter 2011-2012 5% of the cells were unusable for physics and all of them were successfully repaired. The amount of unusable cells at the end of August 2012 is 1% (see Fig. 3).

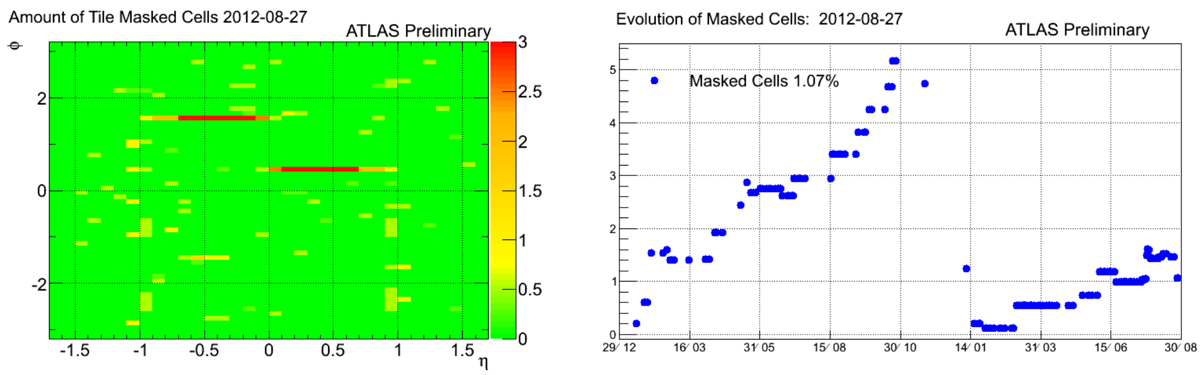

Figure 3. (left) Two dimensional $(\eta;\phi)$ map showing the number of cells masked per tower, each tower being composed by three cells from the layers A, BC, D.
(right) Evolution in time of the percentage of masked cells.

2. The new low voltage power supplies

The low voltage power supplies (LVPS) adopted for the front-end electronics are located in the detector hall, in a high radiation environment. Each module is equipped with an independent LVPS, with a total of 256 LVPS units. In 2011, the collaboration faced a rate of 0.8 LVPS trips per inverse picobarn, and a procedure to restore the data taking after each trip was adopted. After a trip, and during the configuration preceding the normal operation mode, the channels of the module affected by a LVPS trip are dynamically masked, and the energy is recovered offline

Journal of Physics: Conference Series **404** (2012) 012007 doi:10.1088/1742-6596/404/1/012007

using interpolation between working neighbors. Despite the high rate of trips, TileCal had in 2011 a very high efficiency in recording high quality data, used for the physics analysis.

In 2012, 40 LVPS units were substituted with a new production of power supplies[1]. Thanks to the new design which gained from the better knowledge of the operation environment and groundings, these new LVPS are more robust against radio-technical noise. Fig. 4(left) shows the number of trips per LVPS unit in 2012. It is evident the improvement in stability of the new LVPS (in green and blue), compared to the old models (in red). Another important improvement of the new LVPS design is the reduction of the non Gaussian noise induced in the front-end electronic, and affecting the measurement of the signals, as shown for a specific channel in Fig. 4(right).

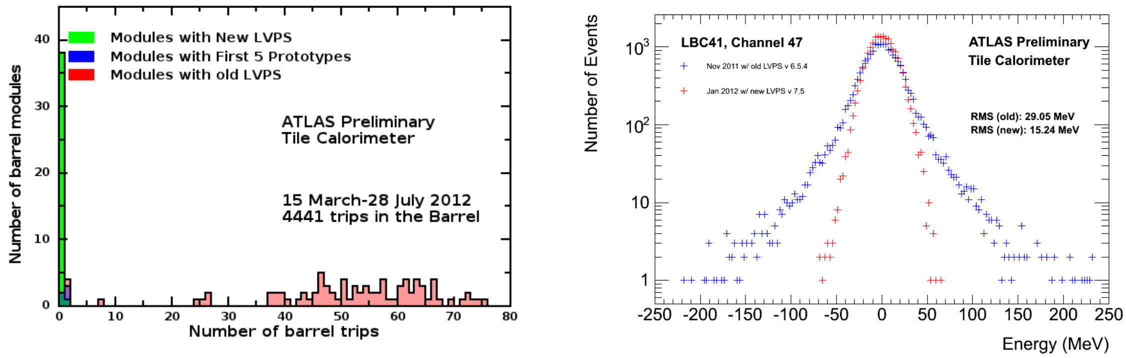

Figure 4. (left) Number of trips in the central barrel per LVPS unit, in the period from March 13th 2012 to July 28th 2012. The old power supplies are shown in red. The new LVPS are shown in green and blue (5 prototypes).
(right) Distribution of the reconstructed energy in two high statistics dedicated pedestal runs, for a given channel. The RMS of the distribution goes down by almost a factor 2 in the channel after changing LVPS.

3. Energy measurement and timing

A fraction of 11% of the TileCal modules were calibrated in the beam tests in 2001-2003. Electron and muon beams were used to establish the electromagnetic scale (EM) and to inter-calibrated the different layers. After installation of the whole TileCal in the ATLAS experimental hall, cell inter-calibration was done with the help of the Cesium calibration system. The Cesium source was moved through every calorimeter cell and high voltage of every PMT was adjusted to have the cell response equal to the response measured during beam tests. The comparison between cosmic ray data and Monte Carlo (MC) prediction and between beam test muons and cosmic muons has confirmed that propagation of the electromagnetic scale from the beam tests to ATLAS was successful. Non-uniformity within one layer as seen by muons turned out to be at the level of 2-3%, the maximal difference between layers is 4%.

3.1. Stability of the detector response

The calorimeter is equipped with systems that allow to monitor and to calibrate each stage of the read-out exploiting different signal sources: laser light, charge injection, a radioactive source and the signal produced by minimum bias events. Fig. 5 shows the drift of the energy response of TileCal cells A14 with respect to D5, both located in one of the extended barrels (EBC).

[1] In addition to the 40 new LVPS, 5 prototypes were installed during the 2010-2011 maintenance period.

Because of its stability, at the level of 0.2%, cell D5 is used as a reference cell in order to be able to study the stability of the detector response combining the various TileCal calibration systems and identify the possible source(s) of the drift. The three monitoring systems shown in the plot (laser, cesium and minimum bias integrator), are sensitive to different possible sources of the drift. Since all of them show a similar behavior, the drifts that are observed can be attributed mostly to a variation of A14 photomultiplier response and not to the scintillator irradiation. The downdrift periods coincide with the periods of data taking with high instantaneous luminosity, while the updrifts coincide with the technical stops (no collisions). The maximum variations in the response of any cell type of the TileCal are below 1% over all 2011 data taking period with an integrated luminosity of $\sim$5.6 fb^{-1}. The cesium calibration system is used every month to recalibrate all the cells and to restore the electromagnetic scale.

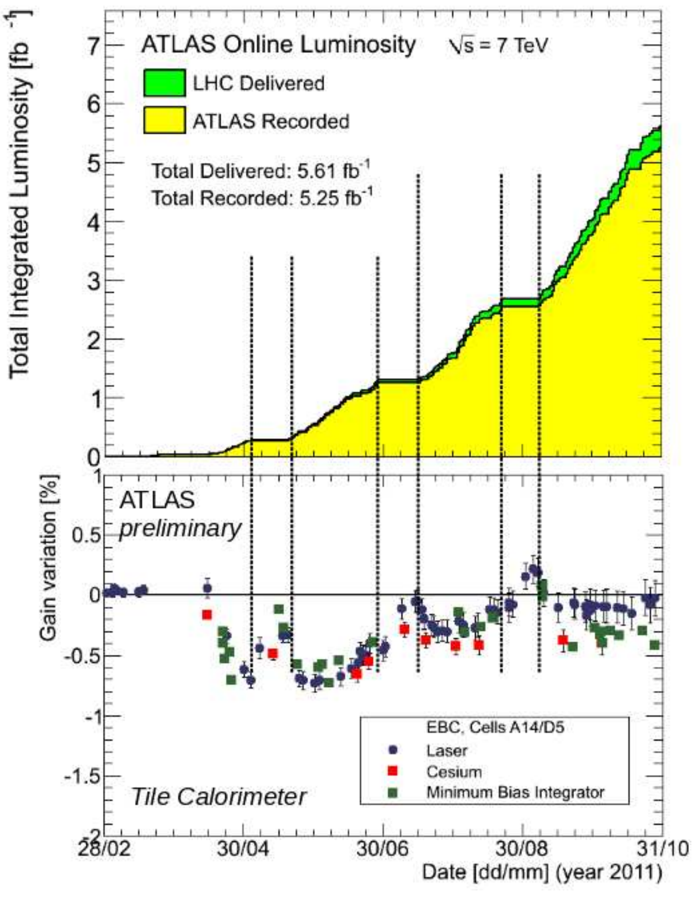

Figure 5. (Top) The evolution of ATLAS total integrated luminosity. (Bottom) The evolution of the ratio between the response of cells A14 (located at η=1.35 and inner radius 2300 mm) and the most outer radius cell D5 (η=1.0 and inner radius 3140 mm) as a function of time in EBC. The response is measured by the Cesium, the Laser and the Minimum Bias calibration systems. Each point on this plot corresponds to an average over 64 modules in ϕ. The measurements are normalized to the first run taken as a reference (taken on 18th February 2011). The error bars correspond to the statistical uncertainty on the average.

3.2. Timing

To reconstruct the signal amplitude correctly [3], the peak pulse time with respect to the electronic sampling clock has to be known with good precision. The cell times were synchronized to a single reference channel in every partition using the laser calibration system. Inter-calibration between partitions was also performed using single-beam splash events. In such events some protons from the beam collide with collimators placed at about 140 m from the nominal interaction point and produce a very large number of minimum ionizing particles reaching the detector parallel to the beam axis and depositing a large amount of energy in the whole TileCal. The signals produced by these particles, and the knowledge of their time of flight, have been used to synchronize all the TileCal cells with the precision of better than 1 ns.

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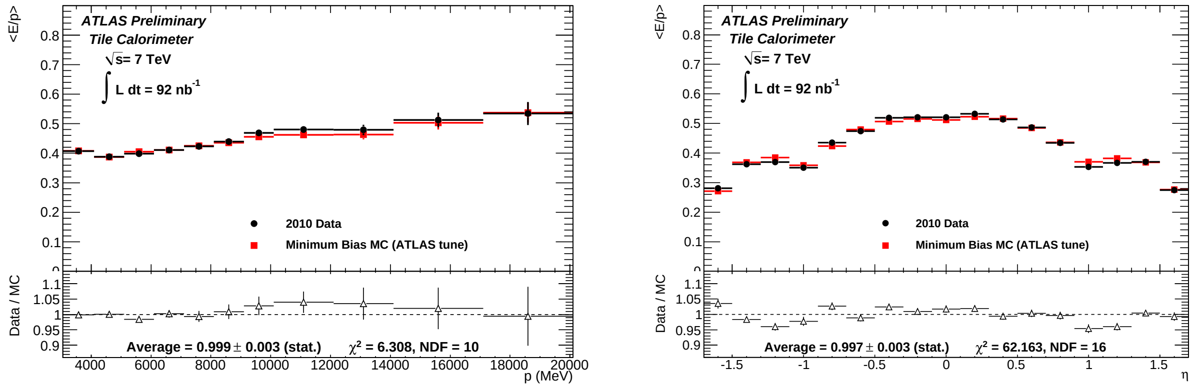

Figure 6. Mean value of the ratio between energy deposited in TileCal and the track momentum p (measured by the Inner Detector) as a function of p (left) and η (right) of the impinging particle.

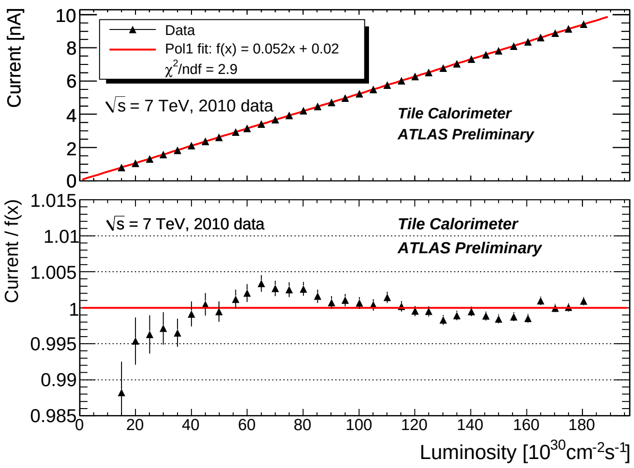

Figure 7. The anode current for a cell of the TileCal is shown as a function of the instantaneous luminosity on full data sample taken in 2010. The errors on the current are the quadratic sum of the statistical and systematic errors. The red line is obtained from the linear fit of the data points.

4. Performance in collisions

The response of TileCal to particles produced in collisions has been extensively studied in proton-proton and heavy ion collisions and for different center-of-mass energies. These studies have the twofold goal of cross-checking the performance of the detector, and of improving its Monte Carlo description. As an example, isolated tracks of momentum p were required to deposit little energy, consistent with minimum ionizing particles in the electromagnetic calorimeter in front of TileCal, to be sure their whole energy E is deposited in the hadronic calorimeter. For these tracks (mostly pions), the ratio E/p has been compared with the Monte Carlo description of the detector. The mean value $< E/p >$ is shown in Fig. 6, as a function of p and η of the impinging particle. In all the cases good agreement between data and MC was found.

4.1. Luminosity measurement

TileCal is also used to monitor the luminosity during physics runs with collisions. This is possible by integrating the signals from particles produced in low-momentum transfer inelastic pp collisions (minimum bias events) whose rate is proportional to the LHC luminosity. A dedicated TileCal read-out provides the anode currents from each photomultiplier and it is used to measure the Minimum Bias current, which is proportional to the interaction rate (and to the luminosity). The top plot in Fig. 7 shows the relation between the anode current for a cell integrated over few ms and the luminosity during collisions using Minimum Bias events. Given the stability and the linearity of the dedicated read-out (highlighted in the ratio in the bottom plot in Fig. 7), TileCal is participating to the on-line and off-line determination of the ATLAS luminosity measurement.

5. Conclusions

The first years of data taking at the LHC demonstrate good performance of the ATLAS Tile Calorimeter, which is well within the design specifications, and its ability to operate in proton-proton collisions at different center of mass energies, and in different pile-up scenario. The TileCal calibration and monitoring systems ensure stability in time of the calorimeter response, and also uniformity within 2-3% in η and ϕ. The energy scale uncertainty, which was successfully extrapolated from the beam tests to ATLAS, is conservatively considered to be 4%. The time synchronization between cells is well below 1 ns and has been verified with single beam, with cosmic muons and in collisions.

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