Study of TileCal Scintillator Irradiation using the Minimum Bias Integrators

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Abstract. The Tile Calorimeter (TileCal) is the central hadronic calorimeter of the ATLAS experiment at the LHC. It provides precise energy measurements of hadrons, jets, taus and missing transverse energy. The monitoring and calibration of the calorimeter response at each stage of the signal development is done by a movable $^{137}$Cs radioactive source, a laser calibration system and a charge injection system. Moreover, during LHC data taking, an integrator-based readout provides the signals coming from inelastic proton-proton collisions at predominantly low momentum transfer (minimum bias events) and allows monitoring of the instantaneous ATLAS luminosity as well as the response of calorimeter cells. The integrator currents have been used to detect and quantify the effect of TileCal scintillator irradiation using the data taken in 2012 and 2015 that correspond to about $22 \text{fb}^{-1}$ and $4 \text{fb}^{-1}$ of integrated luminosity, respectively. Finally, the response variation for an irradiated cell has been studied combining the information from three calibration systems (cesium, laser and minimum bias). The result of the irradiation on the TileCal response will be reported.

1. Introduction

The ATLAS experiment [1] is one of two general purpose detectors at the Large Hadron Collider (LHC) at CERN. The TileCal is described in detail in Ref. [2] and consists of steel plates and plastic scintillator material which are arranged in alternating layers. Particles are gradually stopped by the steel plates and photons are produced when the charged particles traverse the scintillator material. This scintillation light is transported by fibers to photomultiplier tubes (PMTs) equipped with an electronic readout. Fig. 1 shows the geometry of the TileCal along the beam axis. It consists of a central Long Barrel (LB) and two Extended Barrel (EB) partitions. The LB covers a region of $0.0 < |\eta| < 1.0$ in pseudorapidity, the EB covers $0.75 < |\eta| < 1.65$. The so-called A-side covers positive, the C-side negative pseudorapidities. Both LB and EB are made up of three layers: the A-layer is the one closest to the beam axis followed by the B(C)-layer and the layer farthest away is the D-layer. The cells marked in yellow are the E-cells. They cover the so-called gap/crack region with $1.0 < |\eta| < 1.6$. They are partly closer to the beam axis than the A-layer cells.

2. TileCal Calibration System

At each level of the signal development inside the TileCal there is a dedicated calibration system to monitor the behaviour of the different detector components. The cesium system tests the whole detector readout, from scintillators to fibers and PMTs. The laser system is capable of measuring gain variations of the PMTs. The charge injection system monitors the front-end
Figure 1. Longitudinal view along beam axis of the ATLAS TileCal cell geometry [3]. One quarter of the longitudinal plane is shown with Long Barrel and Extended Barrel for positive pseudorapidity. The different layers and the corresponding coverage in $\eta$ of TileCal cells are shown.

electronics. The sketch in Fig. 2 visualizes the different calibration systems along with the paths that signals from various sources take. Fast readout is used for physics analyses of collision data. The integrator readout is the core of the minimum bias (MB) system. It records slow currents from the calorimeter. Here we focus on the MB system. The integrator currents are recorded by all ($\sim 10,000$) channels of the TileCal. The data recorded includes all data used for physics analyses and is dominated by minimum bias events. Each collision run is divided into so-called luminiblocks (LBs) where a LB is the time interval with a fixed duration where the instantaneous luminosity is about constant. Integrator currents are recorded for each LB unit. The currents are averaged over about 20–25 integrator measurements per LB.

Figure 2. Scheme of the TileCal signal path [4]. Different calibration systems monitor various components of the TileCal at each stage of signal development inside the detector.

3. Luminosity and Integrator Currents
The MB system is used to monitor the instantaneous luminosity. The integrator currents measured during collisions are linearly dependent on the instantaneous luminosity. An example to illustrate this is shown in Fig. 3(a). For runs that have been recorded during the whole 2015 data taking period the current of a specific channel (D5, EBC) has been plotted against the corresponding instantaneous luminosity as measured by the dedicated LUCID detector [5] of ATLAS. The data points have been fitted by a linear function, the lower panel shows the ratio of data over fitted values. A good linear description of the data points can be observed. The cell D5 is located in the EB at $0.9 < |\eta| < 1.1$, protected from irradiation by two other TileCal layers. This cell shows a stable behaviour in time. The fitted slope corresponds to the luminosity coefficient: current/instantaneous luminosity. This quantity is constant in time.
and therefore allows the monitoring of the instantaneous luminosity via the MB system. One can retrieve these coefficients by dividing the average current over the average instantaneous luminosity. The coefficients obtained with this method are plotted against $\eta$ in Fig. 3(b) for a run in 2015. The behaviour of the luminosity coefficients is shown for all 3 layers of the TileCal and the E-cells. The latter ones measure the highest currents due to their position close to the beam axis, with less shielding material in front. Apart from the E-cells, cells A13 are the most irradiated ones and provide the highest currents.

Figure 3. (a): Current vs instantaneous luminosity for a given channel from cell D5, see Fig. 1. The data has been fitted with a linear function; the fitted parameters are displayed. (b): Luminosity coefficient vs $\eta$ for all TileCal cells as measured in run 276262 during 2015 data taking [6].

4. Detector Response Variation and Irradiation Studies
The mentioned cell A13 is used to study irradiation effects. Like the cesium system, the MB system is capable of monitoring the detector response in time. This is possible by using a reference cell which is known to be stable in time and is used for luminosity measurements. The reference cell chosen for these studies is the afore mentioned cell D5 which is protected from high irradiation. Monitoring the evolution of the currents measured by cell A13 over the currents measured by cell D5 w.r.t. a reference start run gives the detector response variation. The MB measurement is expected to give the same results as the cesium measurement as they both test all TileCal readout components. On the other hand, the laser system measures the PMT gain drifts in time. Any difference in the measurements from Cesium/MB to the laser measurement will therefore point to an effect of scintillator irradiation. The comparison of the three systems for the response variation of A13 has been performed in 2012 and 2015 data periods. Fig. 4 shows the response behaviour of A13 in 2012 and 2015 data taking periods. The 2012 measurement is described in [7]. In both plots the laser points show the PMT gain drift, where drops can be observed during collision phase and a rise during machine development phases where no particle collisions take place. Cesium and MB systems measure in addition any effect of irradiation of the scintillators when the response variation is higher than the PMT gain drift. This can be observed for the 2012 data period. The irradiation effect of the scintillator can be quantified at 2% level at maximum. This irradiation effect will not recover during machine stops. During the 2015 data period no further irradiation is observed. It should be noted that the total integrated luminosity $L$ in 2015 was $\sim$5 times lower than the one in 2012. The center of mass energy $\sqrt{s}$ was 8 TeV in 2012 and 13 TeV in 2015. Both the integrated luminosity and $\sqrt{s}$ have an impact
on the overall collected charge, $Q$. The charge $Q$ is determined with the help of the luminosity coefficient $k$: $Q(t) = k \cdot \int_{t_0}^{t} L(t)dt$, $t$ being a given time during collisions and $t_0$ is a reference start time with $L(t_0) = 0$. The irradiation effect in scintillators will depend on the collected charge and therefore depends on both the $\sqrt{s}$ and the integrated luminosity. Fig. 4 shows the

\begin{figure}[h]
\centering
\includegraphics[width=\textwidth]{figure4}
\caption{(a): Response variation of cell A13 in 2012 as measured by laser, cesium and MB system. (b): Response variation of cell A13 w.r.t. cell D5 in 2015 as measured by laser, cesium and MB system \cite{4}.}
\end{figure}

dependence of the irradiation in cells belonging to the A-layer in the EB on the collected charge for 2012 and 2015 data separately. Also, no irradiation is seen for all the A-layer EB cells in 2015, as Fig. 5(b) illustrates. This differs from 2012 results, when up to 2% loss in the light yield was reported in A13 cells (Fig. 5(a)). It is important to note, that in 2012 the collected charge in the A-layer cells of the EBs goes up to $\sim 1300$ mC while it goes up to $\sim 450$ mC at the end of 2015 data taking.

\begin{figure}[h]
\centering
\includegraphics[width=\textwidth]{figure5}
\caption{Irradiation effect in scintillators in the A-layer of the EB vs the collected charge. (a): Data from all channels during 2012 data taking. (b): Data from all channels during 2015 data taking \cite{4}.}
\end{figure}

5. Conclusion

The minimum bias system of the ATLAS TileCal has been introduced as a powerful tool to monitor both instantaneous luminosity and detector response behaviour in time. With the help
of the MB system it is possible to identify irradiation effects on the TileCal scintillators by comparing with measurements from the laser system. A total irradiation effect of at most 2% for the highest exposed cell has been observed for 2012 and 2015 data taking periods. The scintillator irradiation stems from 2012 data taking where collected charges are about three times higher than in 2015, where no further irradiation effect is observed. These studies will continue with the next data taking period in 2016.

References

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