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Irradiation effect on the response of the scintillators in the ATLAS Tile Calorimeter

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The Tile Calorimeter (TileCal) is the central hadronic calorimeter of the ATLAS experiment at the LHC. Together with the other calorimeters, it provides precise measurements of hadrons, jets, taus and missing transverse energy. The monitoring and equalisation of the calorimeter response at each stage of the signal development is allowed by a movable ^{137}Cs radioactive source, a laser calibration system and a charge injection system. Moreover, during the LHC data taking, an integrator based readout provides signals coming from inelastic proton-proton collisions at low momentum transfer and allows monitoring the instantaneous ATLAS luminosity as well as the response of calorimeter cells. Minimum bias currents have been used to detect and quantify the irradiation effect of TileCal scintillators using the data taken during 2012 which corresponds to about 22 fb^{-1} of integrated luminosity. 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 effect of the irradiation on the calorimeter response are reported.

Technology and Instrumentation in Particle Physics 2014
2-6 June, 2014
Amsterdam, the Netherlands

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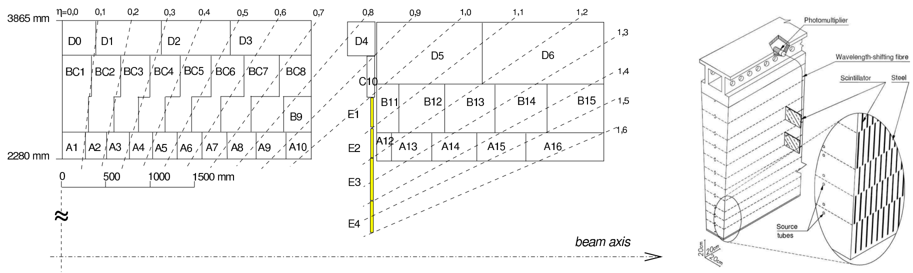
1. Introduction

The ATLAS detector [1] is one of the four main experiments at the LHC. It is a complex general purpose detector, whose physics goals are precision Standard Model measurements and search for particles beyond the Standard Model.

The ATLAS central hadronic calorimeter, TileCal [2], is a cylinder with a length of 12 m along the beam axis, covering the most central region ($|\eta|<1.7$) of the detector [1]. It is a sampling calorimeter made of iron plates as absorber medium and plastic scintillating tiles as active medium. TileCal consists of four partitions, two Long Barrels (LB) and two External Barrels (EB), and it is divided in two sides, A ($\eta > 0$) and C ($\eta < 0$). Each partition is segmented in 64 wedges, or modules, which correspond to a granularity of ~ 0.1 rad in the ϕ coordinate. Each module is radially segmented in three layers, called A, B(C) and D, with a segmentation of 0.1 in η for layers A, B(C) and of 0.2 for layer D. A scheme of the TileCal cells and of the module structure are shown in Figure 1(a) and 1(b), respectively. The energy loss of the particles produced in the collisions, while passing through the calorimeter, gives rise to scintillating light which is proportional to the energy deposition in the tiles. Wavelength shifting fibers conduct the light from the scintillating tiles to the photomultiplier tubes (PMTs).



(a) (b)

Figure 1: Schematic representation of the TileCal cells *(a)* and of the module structure consisting of iron and scintillating tiles *(b)*.

1.1 TileCal calibration systems

The monitoring and calibration of the calorimeter response at each stage of the signal treatment are allowed by different calibration systems. A scheme of the TileCal calibration systems and the corresponding readout signal paths is shown in Figure 2. In the following, the three calibration systems used in this study will be briefly described.

1.1.1 The cesium system

A ^{137}Cs radioactive source, which emits γ's of 662 keV, is driven through the calorimeter (see Figure 1(b)) using hydraulic control during dedicated Cesium (Cs) scans [3]. The current

[1]The coordinate system used by ATLAS is a right-handed Cartesian coordinate system. The positive z-direction is defined as the direction of the anti-clockwise beam. Pseudorapidity is defined as $\eta = -\ln\tan(\theta/2)$, where θ is the angle with respect to the z-axis. The azimuthal angle in the transverse plane ϕ is defined to be zero along the x-axis, which points toward the center of the LHC ring.

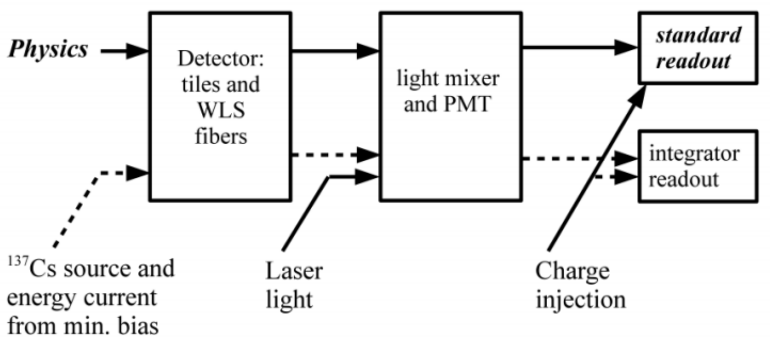


Figure 2: A scheme of the TileCal calibration systems and the corresponding readout signal paths. The first box stands for the optical components such as the scintillating tiles and the wavelength shifting fibers, which are monitored using the Cesium and the Minimum Bias systems. The second box represents the PMTs which are monitored by illuminating them with a Laser system. Finally, a Charge Injection System (CIS) is implemented for the calibration of the front-end electronic gains.

originating from the energy deposited in the scintillating tiles is read out from the integrator circuits of each channel and normalised to the cell size along the beam axis (see Figure 1(a)). The Cesium scans, which are performed with a periodicity of one or two months, are used to equalize the response of the calorimeter at the electromagnetic scale [2] and to monitor the stability of the optical components. The precision of the calibration using the Cesium source is better than 0.3%.

1.1.2 The laser system

The laser calibration system [4] makes use of light from a 532 nm laser and is used to monitor and calibrate each of the TileCal PMTs. The light is emitted in short pulses (∼15 ns) similar to physics signals. The laser signal is sent to each PMT by means of optical fibers. Laser measurements are performed on a weekly timescale and are used for monitoring the PMTs response stability and linearity between two Cesium scans and for timing adjustment of the electronics. The laser allows determining the PMT gain variation with a precision better than 0.5%.

1.1.3 The minimum bias system

Soft parton interactions, or Minimum Bias (MB) events, are dominating processes in the high energy proton-proton collisions at the LHC. The integrator system [5] of each PMT integrates the response to the MB signals over time and allows monitoring the response of all calorimeter cells during data-taking as well as the ATLAS instantaneous luminosity [6]. The integrator is printed on a circuit board plugged to the so-called 3-in-1 card [5]. A 12-bit ADC card digitises the integrator output which ranges up to 5 V before saturating the ADC. The integrator gain can be varied by selecting one among six predefined resistors that also define the integration time, which ranges between 10-20 ms. The integrator gains are configured depending on the instantaneous luminosity. The average gain stability has been better than 0.1% during the first run of the LHC [6].

2. Study of the cells response variation

A method for estimating the effect of irradiation on the TileCal scintillators has been developed, exploiting three different calibration systems: the Minimum Bias (MB) and the Laser for the direct evaluation of the effect and the cesium as a cross check. The study considered only the cells in the Extended Barrel, since those are the most exposed to irradiation. The combination of the calibration systems has also allowed studying the evolution of the response of a very irradiated cell as a function of the time and the integrated luminosity.

The main idea underlying these studies is the fact that the MB and Cs currents are sensitive to both PMT gain variation and scintillator irradiation, while the Laser currents are sensitive to the PMT gain variation only. One can therefore subtract the gain variation measured by Laser from the total response variation seen by Cs or MB. MB currents are chosen because there are more MB runs than the Cs scans. In the following subsections, the method used to treat the data will be illustrated.

2.1 The method

Since MB currents depend on the instantaneous luminosity and cannot provide an absolute measurement of the cell response variation, one needs to consider the variation of the ratio between a probe cell and a reference cell. The criteria adopted in the choice of the reference cell include the requirement that the cell is rather protected from irradiation but at the same time it has enough signal to be usable. The cell in the outer layer of the Extended Barrel with $0.9 < |\eta| < 1.0$, called D5 (see Figure 1(a)), has been chosen for this purpose. The ratio between the currents measured by the PMTs reading the probe cell and the reference cell, indicated as $Cell_{probe}/Cell_{ref}$, does not depend on the variation of luminosity and should be flat in time. Any deviation from the flat behaviour is an indication that the probe cell response is evolving in a different way with respect to the reference cell. By varying the probe cell position from a low to a high irradiation zone, it should be possible to see a correlation between the decrease of response and the radiation amount.

The variation of the cells response does not depend only on irradiation of the active material (scintillators). The gain of the PMTs reading the cells fluctuates as well, depending on the current they integrate (the gain decreases during data taking and recovers during technical stops). This effect reflects on the cell response variation, though it has nothing to do with the radiation damage, and can be subtracted using the Laser system (which is only sensitive to the PMT gain variation).

The study has been performed using data from MB collisions collected between the end of April and the end of November 2012. The total integrated luminosity delivered in this period corresponds to $\sim$22 fb^{-1}. The integrator current evolves as a function of the LumiBlock number [2] for each minimum bias data taking period (run). For each channel, the average of the integrator current over all the measurements in a single LumiBlock is computed. The ratios $Cell_{probe}/Cell_{ref}$ between the average currents per LumiBlock are used to build a distribution which is fitted with a Gaussian function in order to estimate its parameters μ and σ for a given run. The μ values of the fitted functions are then used to compute the response variation of the probe cell relatively to the

[2]The atomic unit of ATLAS data is the Luminosity Block (LumiBlock). One LumiBlock contains 2 minutes of data taking, but this can vary due to run conditions and other operational issues.

reference cell D5, using the formula

$$\text{Relative response variation} = \frac{[\text{channel/D5}]}{[\text{channel/D5}]_{ref}} - 1, \quad (2.1)$$

where *ref* refers to the first data taking period in chronological order, taken as a reference.

Since both the Cesium and the Minimum Bias calibration systems deal with the same optical components of the calorimeter, they are supposed to be sensitive to the same effects and thus to give rise to very similar cell responses. For this reason it is interesting to plot the distribution of the difference between the values of the cell response variations as measured by the MB and the Cs systems. This distribution is shown in Figure 3. The difference between Cs and MB variation is required to be less than 1% in order to discard measurements potentially affected by occasional readout errors. With this selection, less than the 2% of the total number of measurements are discarded.

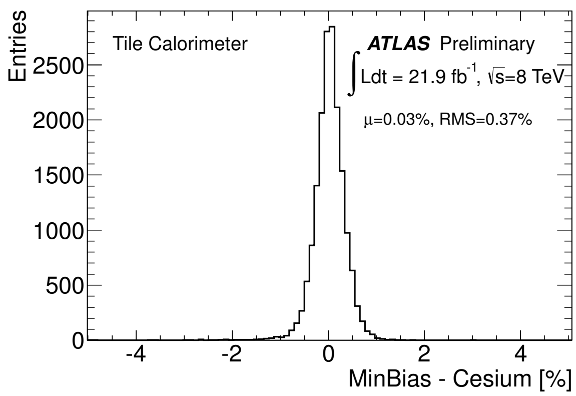


Figure 3: The distribution of the difference between the relative variation of the response to Minimum Bias and Cesium currents. The points correspond to all inner and middle layer cells in the Extended Barrel, covering the region $1.0 < |\eta| < 1.7$ [7].

3. Results

The combined use of the three calibration systems has allowed estimating the response variation of all the cells in the inner and middle layer of the Extended Barrels and to detect and evaluate the effect of the radiation damage on their scintillators. The results of this study will be presented in the following paragraphs, starting from the case of a very exposed cell.

3.1 Response variation of a very exposed cell

The variation of the response as measured by MB, Cesium and Laser systems for cells in the inner layer of the Extended Barrel, covering the region $1.2 < |\eta| < 1.3$, as a function of the time is showed in Figure 4.

MB data cover the period from the beginning of April to the end of November 2012. The Cesium and Laser data cover the period from mid-March to mid-December. The integrated luminosity quoted in the plot is the total delivered in this period.

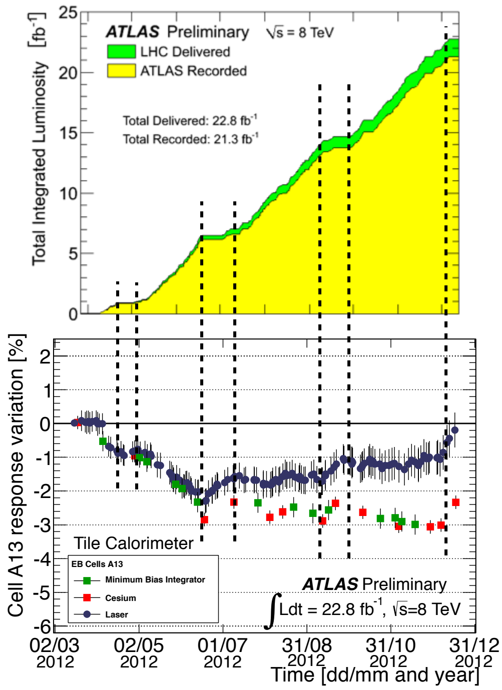


Figure 4: The variation of the response to Minimum Bias, Cesium and Laser for cells in the inner layer of the Extended Barrel, covering the region $1.2 <|\eta|< 1.3$, as a function of the time, compared to the time evolution of the total integrated luminosity collected by ATLAS. [7]. More details in the text.

As already observed in 2011 data, the down-drifts of the PMT gains (seen by Laser) coincide with the collision periods while up-drifts are observed during machine development periods and at the end of the proton data-taking (beginning of December). In the case of MB and Laser, the absolute response variation for cell A13 has been obtained by multiplying the variation of the ratio of currents A13/D5 by the absolute response variation of cell D5 seen by the Cesium system. The variation versus time for the response of the three systems is normalized to the first Cs scan (taken in March, before the start of collisions data taking).

3.2 Effect of radiation damage on the scintillators

Under the assumption that the radiation impact comes from the integrated energy flux, the integrated charge is an appropriate observable which would allow comparing the irradiation effect on the same scale for all cells independently from their position in the calorimeter. One of the goals of this study is, in fact, to show that all cell responses follow the same pattern vs the collected integrated charge.

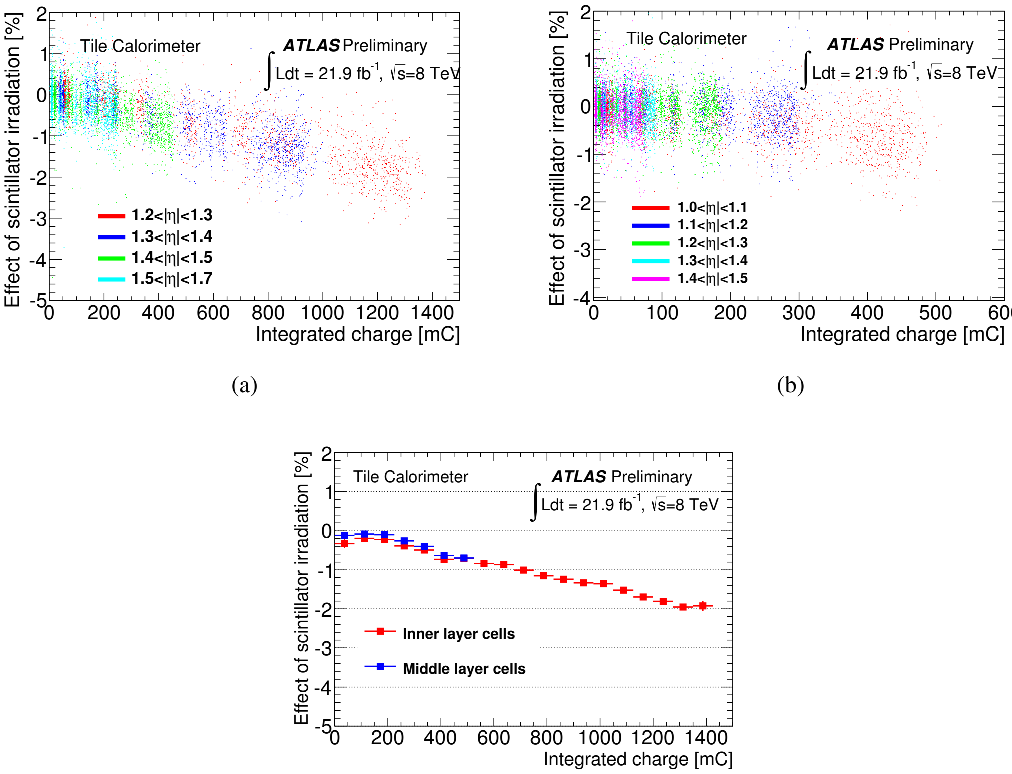
In order to compute the integrated charge collected in each of the cells considered in this analysis, one has to consider the linear dependence between MB signal and the instantaneous luminosity [6]. For each channel i one can compute the constant factors $\alpha_i = I_i(t)/L(t)$, where $I_i(t)$ is the anode current and $L(t)$ the instantaneous luminosity. The factors α_i depend on the cell size and position. The constant factors are computed using a single minimum bias data taking period, averaging over 10 successive LumiBlocks.

The total integrated charge up to a given time is therefore given by

$$Q_i(t) = \alpha_i \int_{t_0}^{t} L(t)dt, \tag{3.1}$$

where t_0 is the starting time of the reference run. The ATLAS integrated luminosity, which is provided by the ATLAS Luminosity Task Force, is the total delivered one, and not the one corresponding to stable beam periods only.

The relative variation of the response to MB currents, after the subtraction of the Laser component, has been plotted in Figure 5 as a function of the integrated charge for all the cells in the A (Figure 5(a)) and B (Figure 5(b)) layers of the Extended Barrels. Cells in the A layer collected more integrated charge (maximum charge ∼1400 mC) with respect to those in the B layer (maximum charge ∼500 mC). Figure 5(c) shows the profiles of the plots in the Figures 5(a) and 5(b). It can be seen that, as expected, the two sets of cells show the same behaviour as a function of the collected integrated charge.



(a) (b) (c)

Figure 5: The relative variation of the MB response, after the subtraction of the Laser component, as a function of the integrated charge for the cells in the A *(a)* and B *(b)* layers of the EB and the average variation for the two sets of cells superimposed *(c)* [7]. The cells considered are A13, A14, A15, A16, B11, B12, B13, B14, B15 and B16 (see Figure 1(a)).

4. Conclusions

After a brief overview of the ATLAS Tile Calorimeter and of the three calibration systems: Cs, Laser and MB, a method for estimating the effect of the irradiation on the calorimeter scintillators, based on the combined use of the three systems, has been described.

The combination of the Cesium, Laser and Minimum Bias calibration systems allowed determining the evolution of the response of very irradiated cells as a function of the ATLAS integrated luminosity in 2012. A loss of $\sim$2% in the channel response has been detected as the maximum irradiation effect.

The effect of the irradiation damage on the scintillators of the TileCal cells in the Extended Barrels has also been detected and quantified.

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