Radiation hardness of the ATLAS Tile Calorimeter optical components

B Pereira on behalf of the ATLAS Collaboration
LIP, Av. Professor Gama Pinto 2, 1649-003 Lisboa Portugal
E-mail: bc.pereira@campus.fct.unl.pt

Abstract. The Tile Calorimeter (TileCal) is a sampling hadronic calorimeter and an essential part of the ATLAS experiment at the LHC. Plastic scintillating tiles are the active material. The light produced in the scintillators is transmitted to the photomultiplier tubes by wavelength shifting fibres. During the High Luminosity LHC (HL-LHC) programme, the luminosity can reach a value several times higher than the one that TileCal was designed for. Two critical points that affect the detector performance are the increased exposure to radiation that does degrade the TileCal optics and natural ageing. Since the optical components of the TileCal cannot be replaced, the radiation hardness must be evaluated. The Laser and Cesium calibration systems are used to evaluate the robustness of the TileCal optical components. These systems combined allow to isolate the response of the tiles and fibres and evaluate the evolution of the light yield with the dose. Run 2 calibration data were analysed, indicating that cells in layer A, and B11 and C10 cells have lost about 5% of light yield. No significant changes were found for the other cells. This study constitutes an essential step for predicting the calorimeter performance in future HL-LHC runs. Nevertheless, the extrapolation uncertainty is large so more data needs to be explored to reach better precision on such extrapolation.

1. Introduction
The Tile Calorimeter (TileCal) is a hadronic calorimeter, and an essential part of the ATLAS experiment at the LHC. This sampling detector, located in the central region of the ATLAS detector, is made of plastic scintillator tiles as active medium, interleaved with steel plates as absorber [1, 2]. The scintillation light produced through the passage of particles reaches the photomultiplier tubes (PMTs) through two wavelength shifting optical fibres connected to each edge of the tile. A schematic with the TileCal components is presented in figure 1. A bundle of fibres groups several tiles into a common readout by a single PMT, defining the detector cell.

TileCal is divided in three barrels: one Long Barrel (LB) located in $|\eta| < 1.0$ and two Extended Barrels (EB) located on opposite sides of the LB and covering $0.8 < |\eta| < 1.7$. Each is segmented into three radial layers — A, BC and D — and the granularity of the cell, in $\eta$ and $\phi$, is $0.1(0.2) \times 0.1$ for the A and BC(D) layers.
Figure 1. a: Schematic of the Tile Calorimeter optical readout. b: Mapping of the TileCal cells [2].

2. TileCal calibration systems

The TileCal employs three dedicated systems, presented in figure 2, to maintain the energy measurement calibrated against fluctuations of the response of any of the readout elements. The Cesium source calibration system (Cs) is responsible for calibrating the response of the fibres and tiles, the PMTs. The Laser calibration system (Las) calibrates the PMTs and the electronics. The Charge injection system is used to calibrate the electronic readout.

Figure 2. Schematic of the TileCal calibration systems [3].

3. Radiation hardness of scintillators and fibres

The current LHC plans foresee a Run 3 and a higher luminosity LHC phase, and will extend the TileCal lifetime further from the design goals. Since the optical components cannot be replaced, their radiation damage must be studied.

The deviation of the cells’ response to the Cs ($\Delta R_{Cs}$) and to the Laser ($\Delta R_{Las}$) are presented in figure 3. At the end of Run 2, the response to the Cs for the A layer has reduced by about 10% and the response of the PMTs to the Laser, for the same layer, has reduced by about 4%. The difference between the cell’s response to the Cs and the PMT’s response to the Laser corresponds to a variation of the response of the scintillators and fibres, interpreted as degradation due to radiation. Therefore, by subtracting the two responses, we can isolate the optical response. We define the relative light yield ($I/I_0$) of the cell’s scintillators and fibres as:

$$I/I_0 = 1 + \frac{\Delta R_{Cs} - \Delta R_{Las}}{100\%}.$$  

Figure 4 shows that the relative light yield decreases with the increase of the dose, obtained with GEANT4 simulation [4]. By mapping the relative light yield of the TileCal cells (figure
Figure 3. (a) Deviation of the cell response to the Cs ($\Delta R_C$) during Run 2. (b) Average PMT Drift corresponding to the deviation in the response to the Laser ($\Delta R_L$) during Run 2 [3].

4), we can have a better perception of the loss of light yield in each cell type. The cells more exposed to radiation are the cells in the A layer, and B11 and C10 cells. They have a light yield loss of the order of 5%. For the other cells no degradation is observed. The relative uncertainty is of the order of 1%.

4. Expected light yield at the end of Run 3
The relative light yield measurement was extrapolated to the end of Run 3, by fitting the Run 2 data with a simple exponential function (figure 5):

$$I/I_0 = e^{(p_0 + p_1 \times \text{dose})}.$$  \hspace{1cm} (2)

The results show that the more affected cells are in layer A, and cells B11 and C10 with an expected loss between 6 and 21%. For the remaining cells the expected loss is between 1 and 8% (figure 6). The relative uncertainty on the extrapolation ranges from 8 to 16% for cells in the A layer, in the Extended Barrel B layer, and the C10 cell, and is around 5% for the remaining
cells.

![Figure 5](image1.png)

**Figure 5.** The relative light yield for the A13 (a), B11 (b) and C10 (c) cell as a function of the simulated dose during the LHC Run 2. The black solid line is the exponential fit to the data, with the dashed black lines corresponding to the fit to the up and down uncertainty variations [3].

![Figure 6](image2.png)

**Figure 6.** Expected relative light yield of the TileCal cells in the end of Run 3, assuming an integrated luminosity of $350\, fb^{-1}$ [3].

5. Summary and conclusions

The radiation hardness of the Tile Calorimeter optics was studied in Run 2 using data from the calibration systems. One of the goals of this analysis is to predict well in advance the expected light yield degradation at the HL-LHC phase. Currently, the extrapolation uncertainty is large, and more data needs to be explored (from Run 3) to reach better precision and validate the fit model.

References

[1] ATLAS Collaboration 2008 *J. Inst.* 3 S08003
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[4] URL https://twiki.cern.ch/twiki/bin/view/AtlasPublic/RadiationSimulationPublicResults