Response to Laser Pulses Sent in Empty Bunches During Physics Runs of the ATLAS TileCal PMT Channels

Summer Zuber[1,*]

[1]University of California, Physics, Santa Cruz, 95060, United States
[*]sczuber@ucsc.edu

Introduction

The ATLAS Tile Calorimeter (TileCal) is the central hadronic calorimeter of the ATLAS experiment at the Large Hadron Collider (LHC)[1]. It is located directly outside of the electromagnetic detector. It is a sampling detector which uses alternating tiles of Iron and plastic scintillator as absorber and scintillator respectively. The TileCal detector consists of a central, or long barrel (LB) and two extended barrels (EB) and each of these cylinders is made of 64 wedge modules. The scintillation light travels through optical fibers to photomultiplier tubes (PMTs). Each module is divided into cells and each cell is read out by two PMTs located along the outer radius of the module. There are about 5,000 cells in total, or about 10,000 PMTs. Figure 1 shows a map of the cells relative to the beam axis and interaction point.

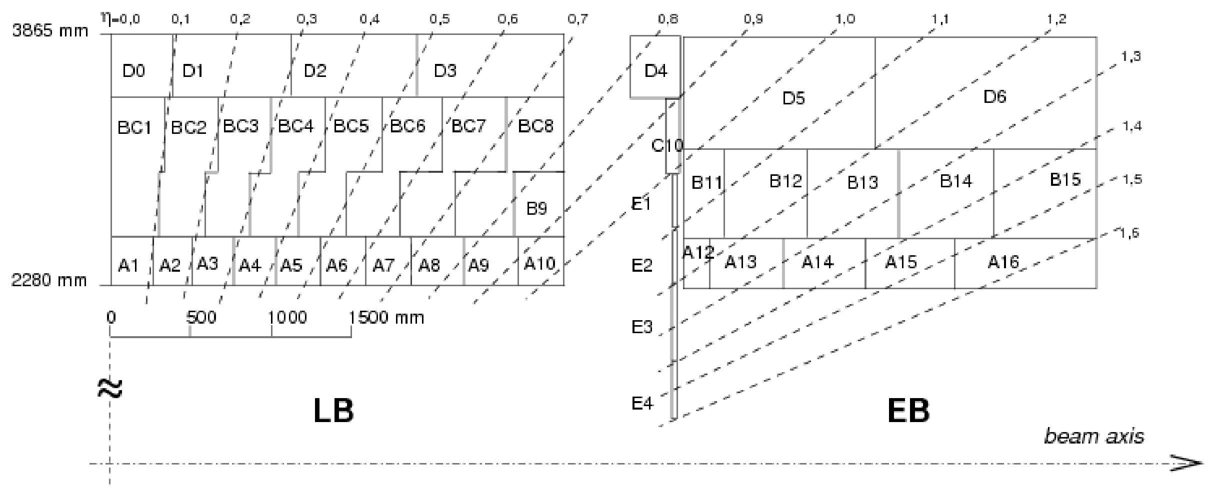

Figure 1. A map of the locations of all cells in the LB and the EB, as well as the special cells located in between the LB and the EB, for the positive η end of the detector.

For accurate reconstruction of the kinematics of physics events, it is important to understand precisely how the output of the readout electronics corresponds to the energy of incident particles. Therefore, it is important to control for the stability and resolution of TileCal[2]. This is the purpose of the TileCal calibration system. The TileCal calibration procedure consists of three subsystems to calibrate different stages of the data acquisition chain.

The Cesium system calibrates the entire readout chain beginning with the scintillating tiles, the laser system calibrates the readout chain beginning with the PMT response by sending a known amount of laser light into the photocathode of each PMT, and the charge injection system calibrates the readout chain beginning with the readout electronics by injecting a known amount of charge into the analog to digital converters (ADCs). The purpose of these systems is to reconstruct the energy of each channel from the raw response of ADC counts processed by a Read-Out Driver. For each PMT, the energy is reconstructed using the simple formula

$$E = A \times C_{CIS} \times C_e \times f_{Cs} \times f_{Las}$$

where A is the ADC counts recorded, C_{CIS} is the conversion factor from ADC counts to pC, C_e is the conversion factor from pC to GeV, f_{Cs} is the calibration factor determined from the Cesium calibrations, and f_{Las} is the calibration factor determined from

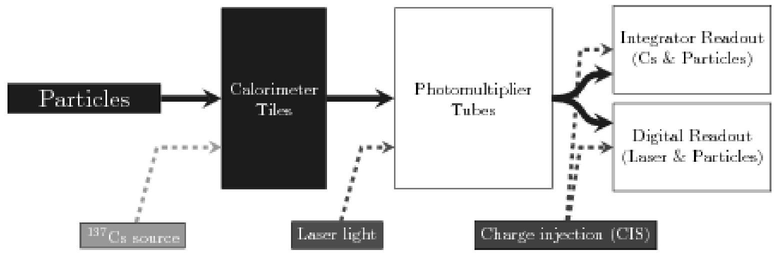

Figure 2. A schematic of the three calibration systems of TileCal.

the Laser calibrations. During Run 1 of LHC Cesium calibrations were done every few weeks, or months and laser calibration runs were done much more often in between Cesium scans[3]. If a channel had variations since the last Cesium scan, a laser calibration constant was produced[3].

This report documents part of a study of the PMT response to the laser calibration system. The current laser calibration procedure is based on the assumption that the PMT response is stable throughout a run. The PMT response to laser pulses sent in empty bunches during physics runs is studied in order to control for instabilities in the PMT response during physics runs. The long term goal of this study is to understand the evolution of the PMT response during a physics run as well as in between physics runs and the most recent calibration runs so that any instabilities can be taken into account in the calculation of the calibration constant associated with the PMT response and the reconstruction of the channel energy.

The optical fibers of TileCal carry the scintillation light from the tiles to the photocathodes of the PMTs. Each tile is read out by two fibers[2], one on each side. These are grouped into bundles, two bundles for each cell, read out by two PMTs (except for the E cells which are a special case and read out by only one PMT each).

Methods

The code I used for this study was derived from the code developed by Giulia DiGregorio to analyze 2015-2016 TileCal laser calibration data. Giulia wrote this code to analyze the PMT response associated with all 10,000 readout channels of TileCal. This code takes as input h2000 n-tuples of eos which contain the response of all channels to laser pulses sent in empty bunches during physics runs. In this study, some of the first collision runs of 2017 are analyzed.

Three cases are studied: the raw response of the PMT, the response normalized to the response of diode 0, and the response normalized to diode 6. Diode 0 and diode 6 are used to monitor the laser intensity at different points of the optical path. The response normalized to diode 0 is particular physically meaningful, as laser intensity fluctuation should be absorbed in this case. I primarily focused on the response of four of the TileCal cells. In particular, the cells A10, A13, D6, and E4. These cases are interesting because A10 is the most irradiated cell in the long barrel (LB), A13 is one of the most irradiated cells in the extended barrel (EB), D6 is the least irradiated cell in the EB and E4 is a special case of a very highly irradiated cell in between the LB and the EB.

Firstly, bad channels that are flagged already with the flag `CHSTATUS!=12` in the calibration output n-tuples are identified and written to a text file. In the analysis of physics runs the average is taken over all events in each 25 LumiBlock period of each individual PMT, averaging over the following three quantities separately: the raw response of the PMT, the response normalized to the response of diode 0, and the response normalized to the response of diode 6. For each PMT now these three sets of averages are used, denoted μ, μ_0 and μ_6 respectively. Individual PMTs are only included in this average if the condition `CHSTATUS==12` is passed.

Some changes were made to the algorithm for selecting additional bad modules. The original algorithm was as follows. The μ, μ_0, and μ_6 values were normalized to the first bin after stable beams are declared in collision runs and these normalized values were denoted y, y_0, and y_6. Then, for each PMT, these values were averaged over all bins after stable beams are declared and the RMS was calculated. For each of these three cases if the average was less than 0.96 or more than 1.02, or if the RMS divided by the average was greater than 0.015 then the corresponding module was added to one of three lists of additional bad modules, corresponding to each normalization case. Then only the modules in the corresponding list were excluded in the analysis of the corresponding normalization case.

The new method is the following. The μ_0 values are normalized to the first bin after stable beams are declared, and these normalized values are denoted y_0. Then, for each PMT, these values are averaged over all bins after stable beams are declared and the RMS is calculated. If the average over all LumiBlocks after stable beams are declared is above 1.04 or below 0.96, or if the RMS divided by the average is above 0.015 this PMT is flagged as an anomalous bad module. The same list of anomalous bad modules is excluded in the three cases.

Table 1. The list of runs included in this study, including the start and endtime of the run and the peak luminosity.

Run Number	Start and endtime (local)	Peak Luminosity ($10^{33} cm^{-2} s^{-1}$)
325713	Mon Jun 05 2017 00:23:29 - 12:34:11	3.2
325790	Tue Jun 06 2017 00:29:48 - 08:51:59	2.9
326657	Wed Jun 14 2017 20:01:19 - Thu Jun 15, 02:08:38	6.2
326695	Thu Jun 15 2017 04:34:29 - 13:11:15	6.1
326834	Thu Jun 15 2017 21:51:46 - Fri Jun 16, 12:37:30	7.7
326945	Sat Jun 17 2017 05:36:04 - 14:28:47	7.9
327103	Sun Jun 18 2017 13:09:23 - 17:28:27	11
327342	Tue Jun 20 2017 13:39:19 - Wed Jun 21, 13:34:44	13
327636	Fri Jun 23 2017 13:54:43 - 21:44:54	12
327764	Sun Jun 25 2017 04:38:39 - Mon Jun 26, 00:07:58	14

For each PMT type (i.e. A10 Left Partition A) the μ, μ_0, μ_6 and y, y_0, y_6 values for each bin are averaged over all modules not excluded using the algorithm described above. These values are then plotted as a function of LumiBlock.

Results

In many of the first collision runs of 2017, machine studies were done in which beam parameters, such as the beam crossing angle, were adjusted during the run, even after stable beams were declared. Moreover, in some runs the laser intensity is unstable. The list of runs included in this study can be found in Table 1.

Run 325790 is a good example of a clear jump when stable beams are declared. Figure 3 shows the time profile of the left PMTs in partition A for cells D6, A10, A13, and E4 respectively from left to right. The location of the cell relative to the interaction point is denoted in the cell map below. Cell D6, exposed to very low irradiation, shows no visible jump. The jump becomes increasingly larger from left to right, as does the cell exposure. Run 326834 has the feature that the "turn on period"

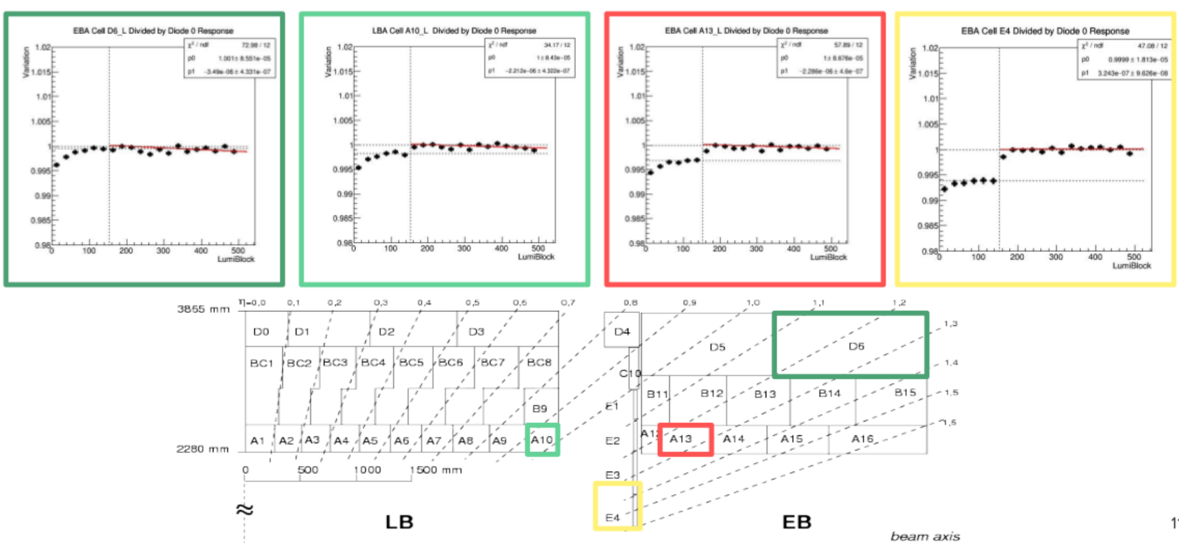

Figure 3. From left to right: the time profile of the response of cells D6, A10, A13, and E4 with the locations of each cell relative to the interaction point denoted below.

that appears in the plot based on the event response without dividing by diode response vanishes in the plot where the event response is normalized to the diode response. Figure 4 shows the time profile of cell E4 without diode normalization, a clear turn on period is seen, followed by a sharp jump when stable beams are declared. Figure 5 shows the time profile of cell E4 with diode normalization, instead of a turn on period the response is flat until stable beams are declared at which point there is a jump. This same general behavior is exhibited in all four cells considered in this study. Run 327342 is an example of a run with a particularly strange PMT response time profile. Figure 6 shows the time profile of the response of cell A10 normalized to the diode response. It should be noted that, clear in Figure 7, the laser intensity is not stable and is fluctuating by as much as 2%. Run 327764 is another example of a run with a very irregular time profile, shown in Figure 8.

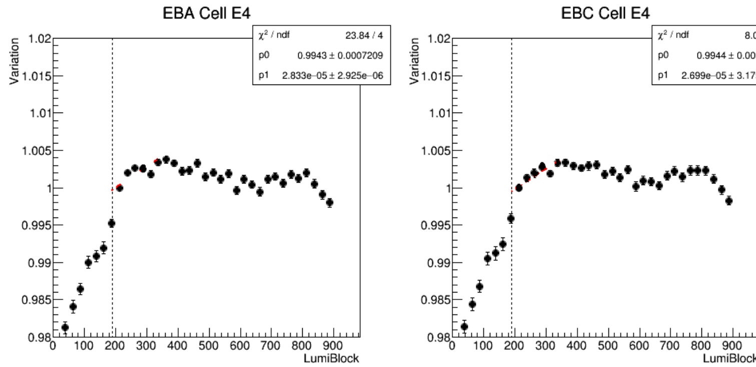

Figure 4. The time profile over run 326834 of the response of cell E4, in the case where event response is not normalized to diode 0 response. Each bin is normalized to the first bin after stable beams are declared.

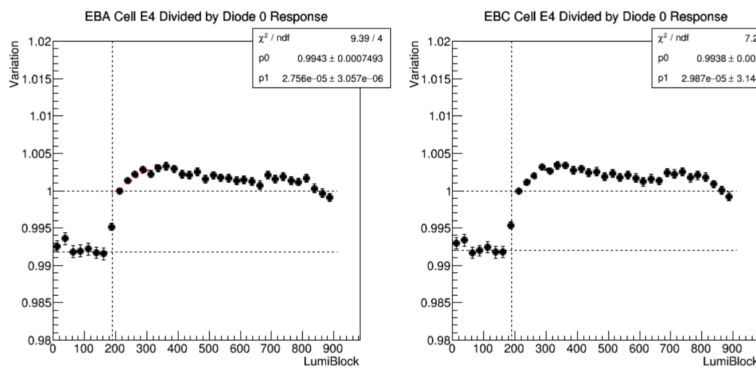

Figure 5. The time profile over run 326834 of the response of cell E4, in the case where event response is normalized to diode 0 response. Each bin is normalized to the first bin after stable beams are declared.

The response time profiles of these runs are less regular than in the 2015-2016 study. Consequently, common sense criteria were used on a case by case basis to compute the jump size, whereas in the 2015-2016 study[4] the same points before and after the jump were averaged in each run. The jump size for the four (or two in the case of E4) time profiles associated with each of the four cell types were averaged to determine a jump value for each of the four cell types for each run. Whereas in the 2015-2016 study, a clear linear relationship was observed between the jump size and the peak luminosity[4] of the run, in this study there is no such clear relationship. See Figure 9, a plot of the average jump size versus the peak luminosity of the run. In most cases, however, the more exposed cells have a larger jump when stable beams are declared.

Discussion and the Future

The time profiles of ten individual calibration runs from 2017 have been analyzed. A significant jump in the normalized PMT response is observed in most collision runs, as it was in the 2015-2016 collision run data. Differently from the 2015-2016 analysis, no clear linear correlation between the jump amplitude and the peak luminosity was observed.

I began a study comparing each physics run with the most recent calibration run. I developed a macro which can be used to produce observables relating a physics run to the most recent calibration run, only including common good modules to both runs. I believe that the systematics of this study are not fully understood with respect to the diode normalization at the event level. In any case the preliminary results of this study are not yet fully understood and are therefore not included in the scope of this report.

These studies must be repeated using runs in which all important beam parameters are stable throughout the run, especially after stable beams are declared. However, perhaps an attempt to correlate parameters such as the crossing angle with the evolution of the PMT response could shine light on the origin of some aspects of the PMT evolution we have observed.

Another important next step in disentangling the nature of these changes in the PMT response is a study of the evolution of the PMT gain. A package has been developed for analyzing the time profile of the PMT gain but more time is needed to

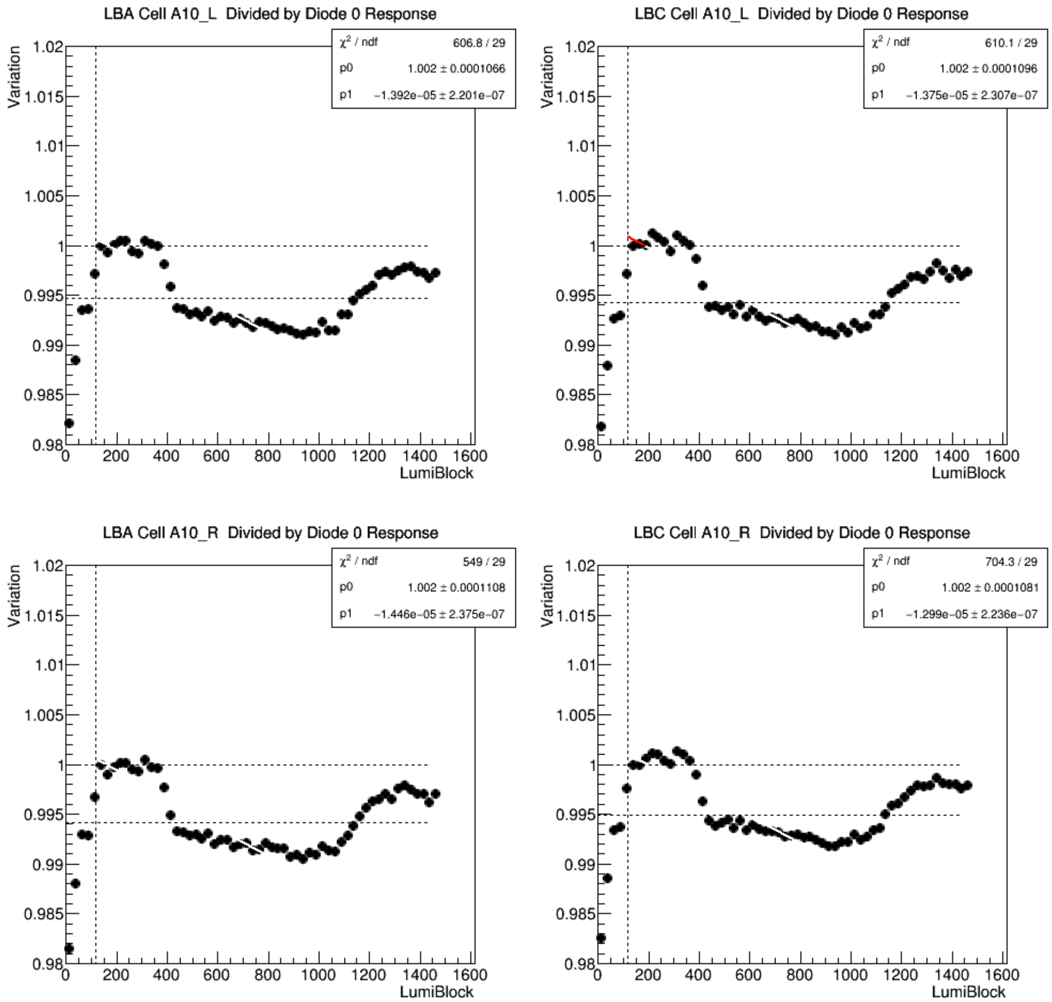

Figure 6. The time profile over run 327342 of the response of cell A10, in the case where event response is normalized to diode 0 response. Each bin is normalized to the first bin after stable beams are declared.

produce results. By looking at the evolution of the gain in comparison to the response evolution hopefully one can begin to disentangle variations due to the PMT electron multiplication, cathode quantum efficiency, and cathode window transparency.

References

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Acknowledgements

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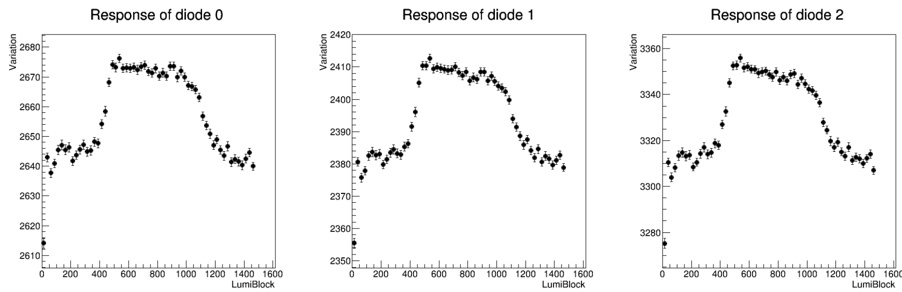

Figure 7. The time profile over run 327342 of diodes 0, 1, and 2.

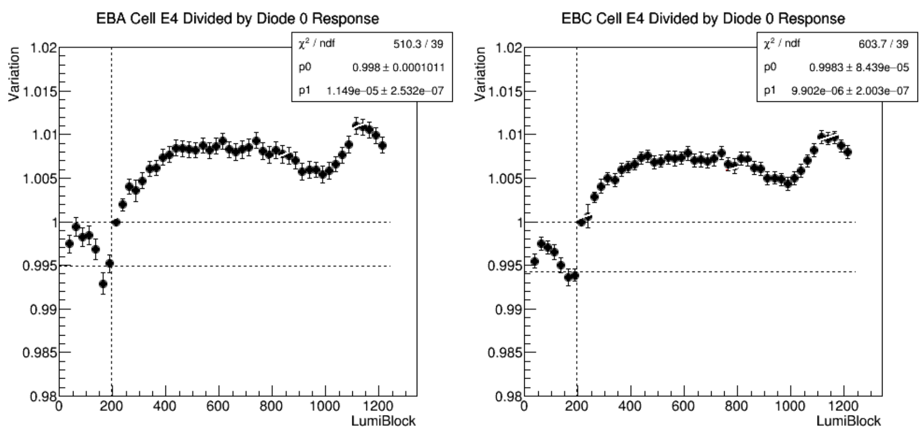

Figure 8. The time profile over run 327764.

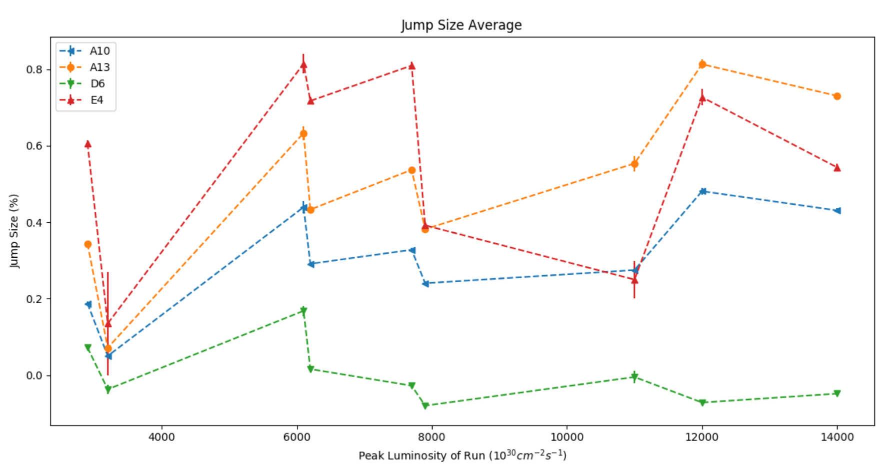

Figure 9. The jump in the time profile of each cell plotted versus the peak luminosity of the run.