

Cesium and Laser calibration of the ATLAS Tile Calorimeter

Summer Student Report



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Abstract

The ATLAS experiment is one of the largest collaborations exploring the world of high energy particles. The huge complex detector gives opportunity to extend the border of the known universe with precise measurements. Continuous monitoring and adjusting is needed in order to maintain a high efficiency and good performance. In this report calibration methods of the ATLAS Tile Calorimeter are studied.

1 ATLAS Tile Calorimeter

ATLAS multipurpose detector is designed to study the $\sqrt{s} = 13$ TeV pp collisions at the Large Hadron Collider (LHC) to measure all the physical properties of the outgoing particles. One of the subdetector systems is the Tile Calorimeter (TileCal). The sampling hadron calorimeter uses metal layers as absorbers and scintillator tiles as active medium to determine the energy of the produced hadronic showers. The system is subdivided into three sections, namely the Long Barrel (LBA, LBC) in the center and two extended barrels located on the sides (EBA, EBC). The cylindrical shape provides full coverage in azimuthal direction while in pseudorapidity TileCal reaches $|\eta| < 1.7$ range. The hadron calorimeter is used for high precision energy and position measurements of the outgoing hadrons and jets. Nominal energy resolution for jets is around $\sigma/E = 50\%/\sqrt{E(\text{GeV})} \oplus 3\%$.

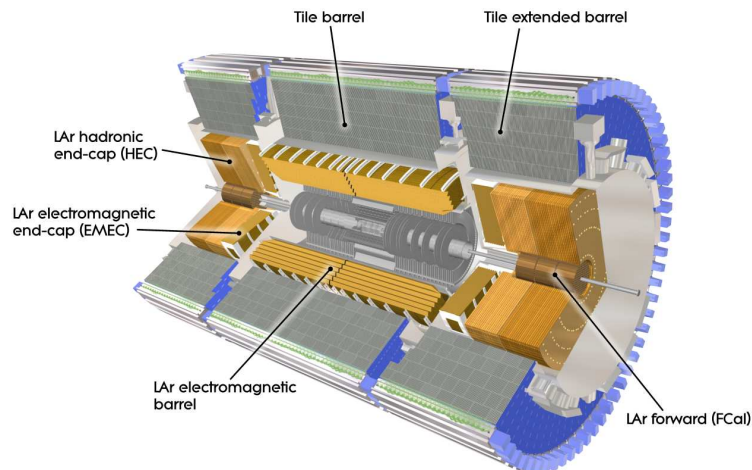


Figure 1: Inner part of ATLAS general purpose detector (tracker layers and calorimeters)

Three longitudinal layers can be found in TileCal shown in Figure 2a. The layers contain several cells to provide the $(\Delta\eta \times \Delta\phi) = (0.1 \times 0.1)$ transverse granularity for the inner layers and (0.2×0.1) for the last layer. To reach the full cover in ϕ 64 similar modules are instrumented. Two PMTs are connected to each regular channel to receive redundant readout results. Special cells are installed in the gap between Long Barrel and extended barrels to maximize the volume of active material while providing enough room for the services

and cables. Gap scintillators are in the region of $1.0 < |\eta| < 1.2$ and crack scintillators are located in the pseudorapidity interval $1.2 < |\eta| < 1.6$.

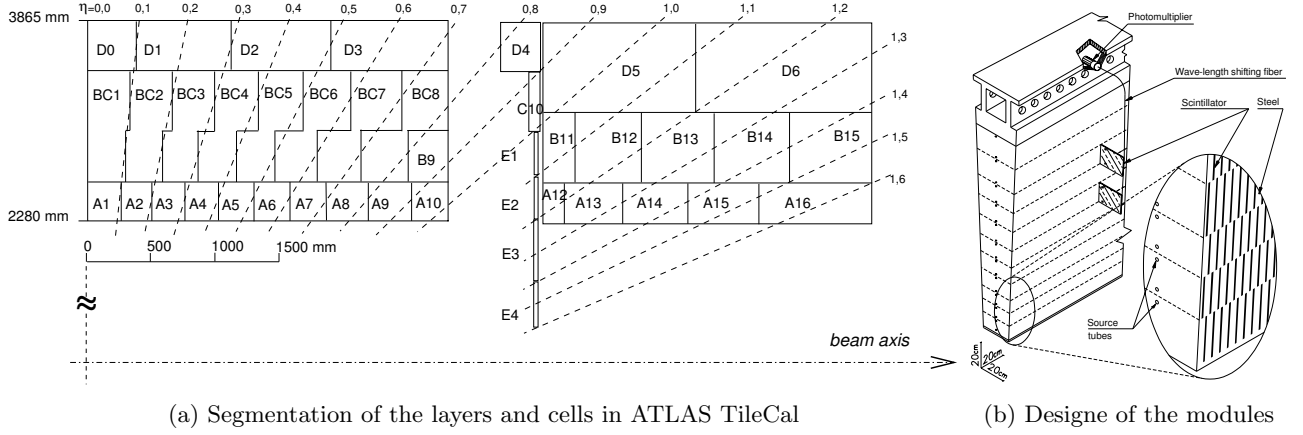


Figure 2: Instrumental details of TileCal

2 Calibration chain

Calibration of the TileCal is necessary to ensure that the measured energy corresponds to the real energy deposit. Three different methods were developed for calibration. Cesium system calibrates the whole subdetector system, laser calibration used for monitoring the PMT responses and the downstream electronics, and Charge Injection System (CIS) for the determination of the conversion factor. Pathological and misbehaving channels can be easily detected and masked excluding their measurements from the calibration. The complete chain provides enough information to match the energies to digital signals:

$$E[GeV] = A[ADC] \times C_{ADC \rightarrow pC} \times C_{pC \rightarrow GeV} \times C_{Cesium} \times C_{Laser} \quad (1)$$

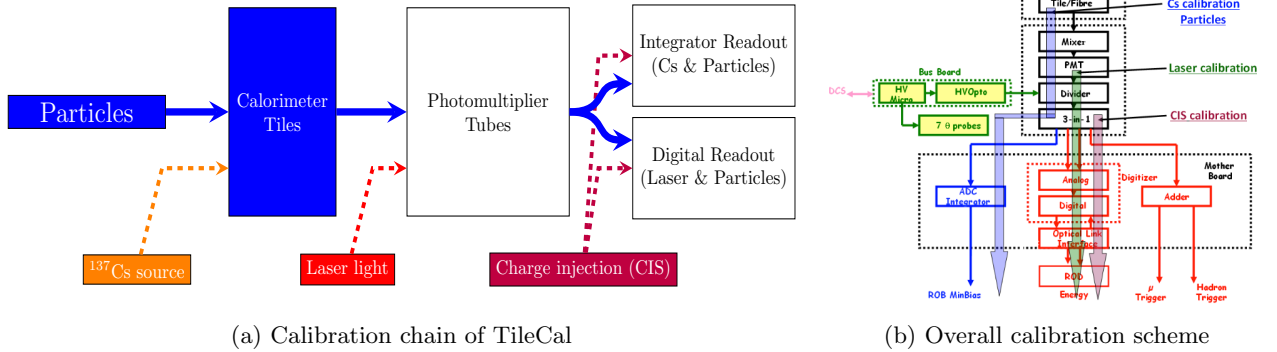


Figure 3: Calibration system of TileCal

The conversion factor between the electronic signal and energy deposit $C_{pC \rightarrow GeV}$ shown in Equation 1 is measured during test beam campaigns.

2.1 Cesium system

Cesium system uses movable radioactive gamma source which emits photons with a given energy to determine the C_{Cesium} factor in Equation 1. The ^{137}Cs source produces 665 keV gamma rays after beta decay process. During calibration measurements the source circulates through the detector layers generating scintillation light in the tiles. Monitoring the responses of the different cells provides information about the scintillators, the PMTs and also about the readout electronics. Performing the cesium scans takes long time (approximately 6 hours) so it can be applied only during long periods without collisions. Source is moved by a hydraulic system in small tubes which are placed inside the TileCal cells. Position of the tubes can be seen in Figure 2b. While

the source is going through a scintillating layer the PMTs of the given cell receive more photons therefore the responses are higher. Movement of the source is shown in Figure 4.

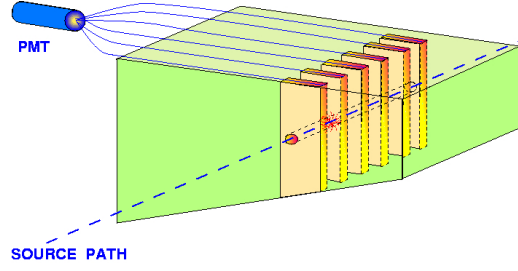


Figure 4: Movement of the source during cesium calibration scan

2.2 Laser system

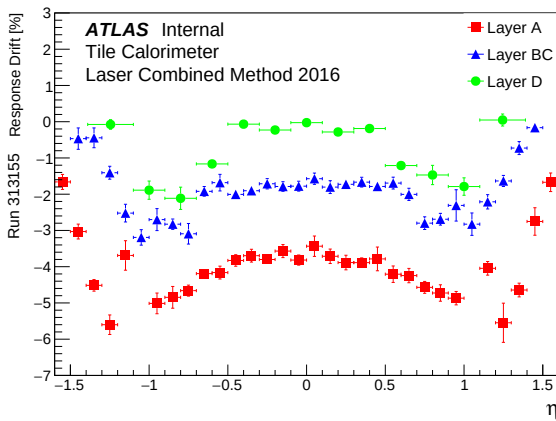
Sending photons with known monochromatic wavelength into the PMTs can be used for calibration to determine the value of C_{Laser} in Equation 1. Response of the tubes always changes in time therefore frequently repeated measurements are needed. Adjusting calibration constants helps to maintain the high precision of the measured quantities.

2.3 Charge injection system

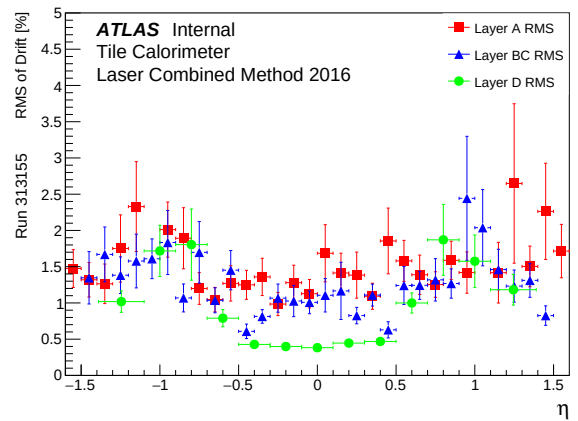
The outgoing analog signal must be converted to a digital one for further calculations. Analog to digital converters (ADC) perform the transformation but known charge injection is needed to determine the factor between ADC counts and electronic signals $C_{ADC \rightarrow pC}$ in Equation 1.

3 Laser studies

Using the Laser system the degradation of the PMTs can be easily and continuously tracked. The changing of the laser calibration constants frequently provide information about the status of the detector system. During the data taking period, the PMT gain reduces because of the degradation of secondary emission rate. If there is no data taking the tube starts recovering. Gain drift is not expected to be uniform for the different channels. Cells which are closer to the interaction point receive more radiation therefore the downdrift of the gain is higher. Since Layer A is closer to the beamline than Layer BC and Layer D the response loss is higher for A-cells. The RMS (root mean square) of the response drifts are also higher for the more irradiated cells.



(a) Average drift for different cells as a function of η



(b) RMS of the drift for different cells as a function of η

Figure 5: Laser calibration results for one particular run (313155, 20 November 2016) with respect to the reference run (294145, 1 April 2016)

One-channel distributions are fitted to Gaussian functions to reduce the effect of outlier channels. Channels identified as affected or pathological by the calibration system are also excluded. A13 cells are located in the most irradiated part of the detector therefore drifts are the highest for them.

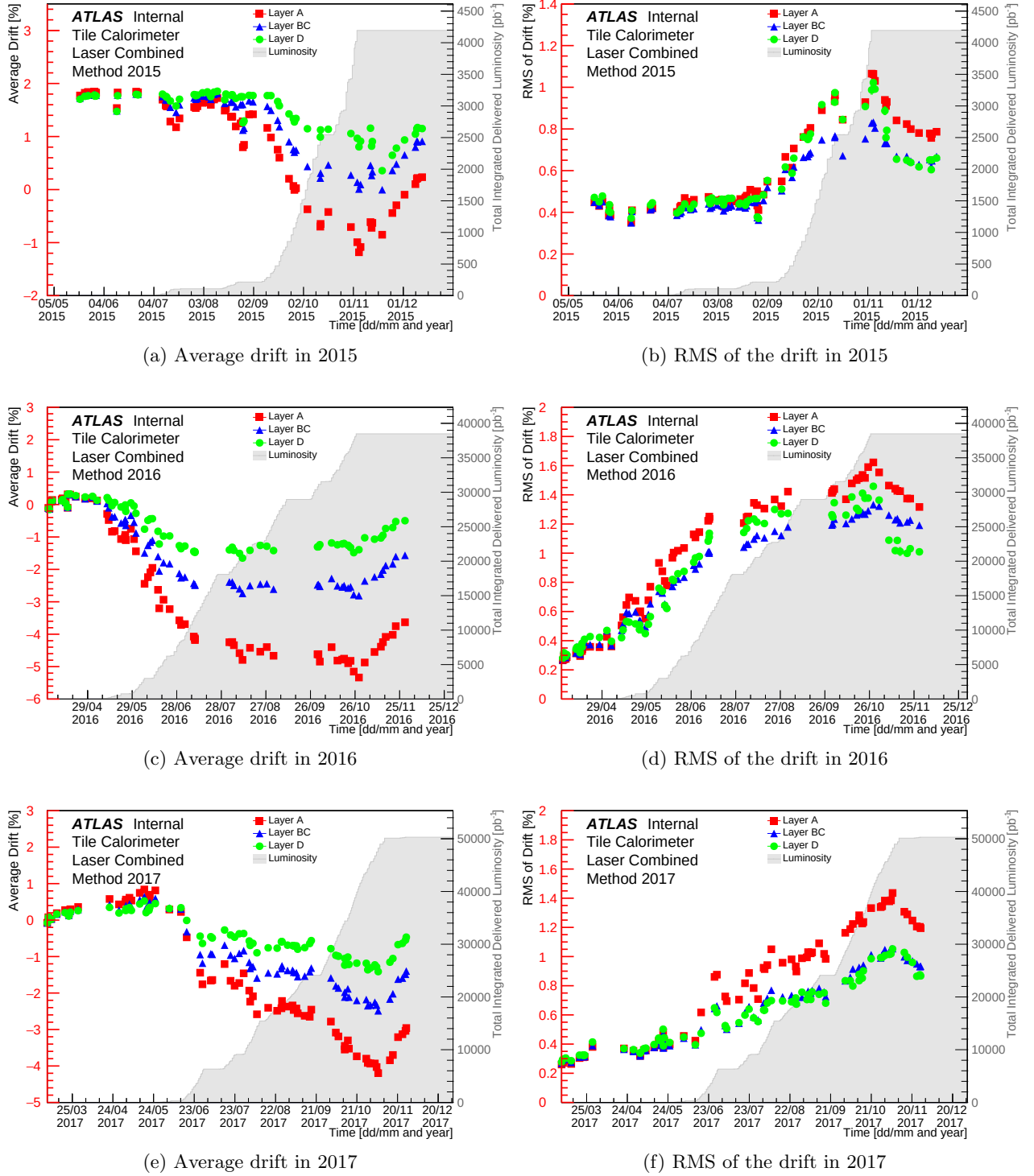
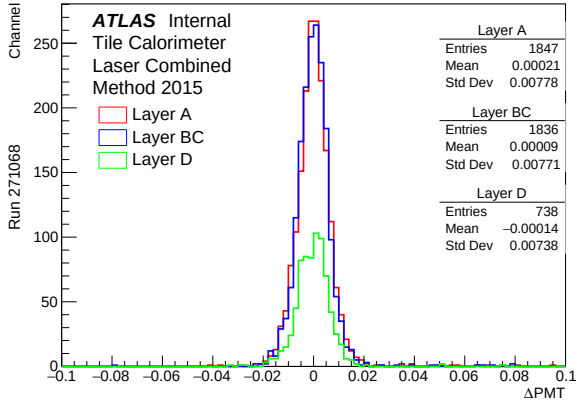


Figure 6: Time evolution of the channel responses for different layers in Run 2 (2015-2017)

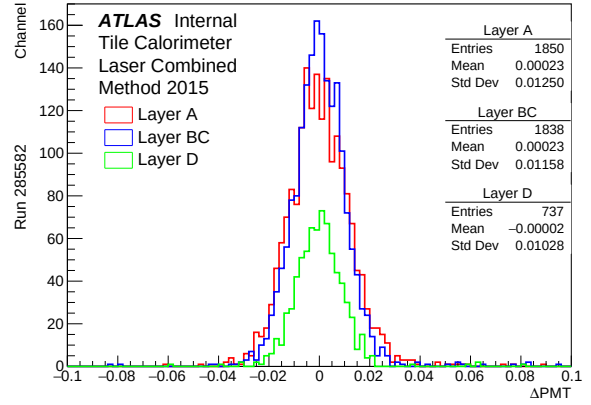
Integrated luminosity represents the collected data for a given time period. As the data taking period starts the drift increases. Recovering can be observed for the runs where no significant amount of collisions are recorded.

The C ($\eta < 0$) and the A ($\eta > 0$) side of the detector are identical so the level of the irradiation is similar for

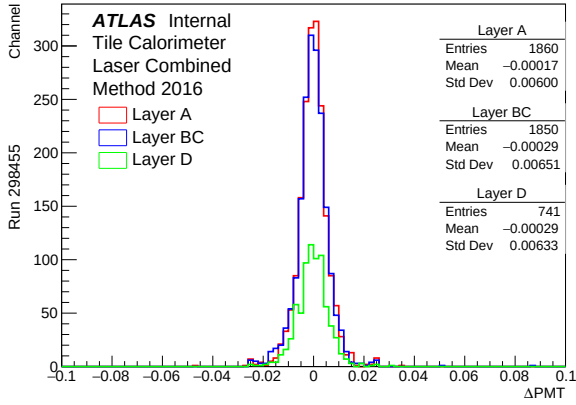
the same cells located in opposite sides. Comparing the response differences (ΔPMT) between the two PMTs connected to the same cell provides more results about the laser calibration.



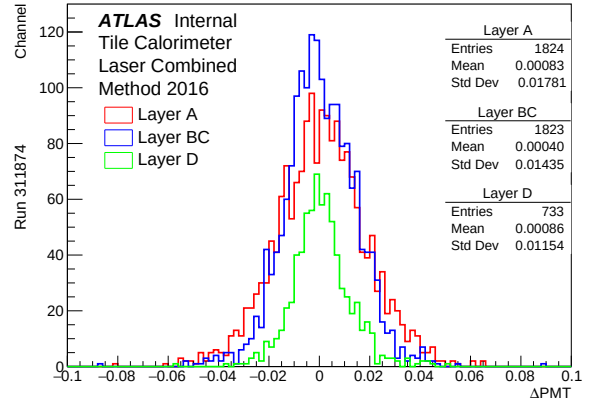
(a) ΔPMT on 9 July 2015 (run 271068)



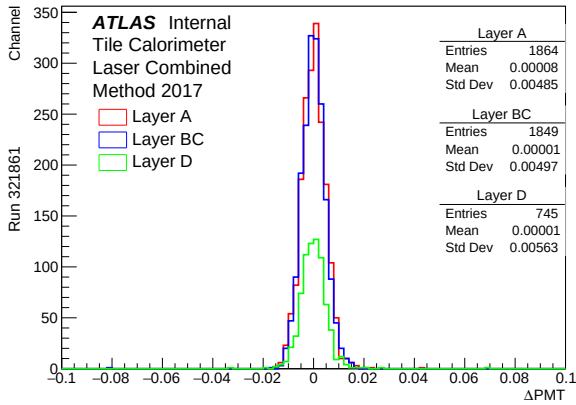
(b) ΔPMT on 12 November 2015 (run 285582)



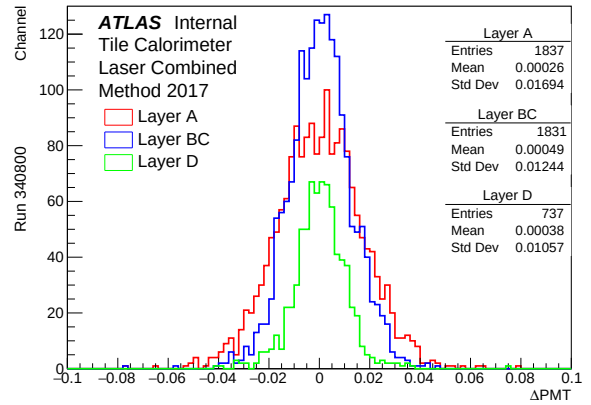
(c) ΔPMT on 5 May 2016 (run 298455)



(d) ΔPMT on 1 November 2016 (run 311874)



(e) ΔPMT on 3 May 2017 (run 321861)



(f) ΔPMT on 14 November 2017 (run 340800)

Figure 7: Response difference distributions of the same channel types for particular runs

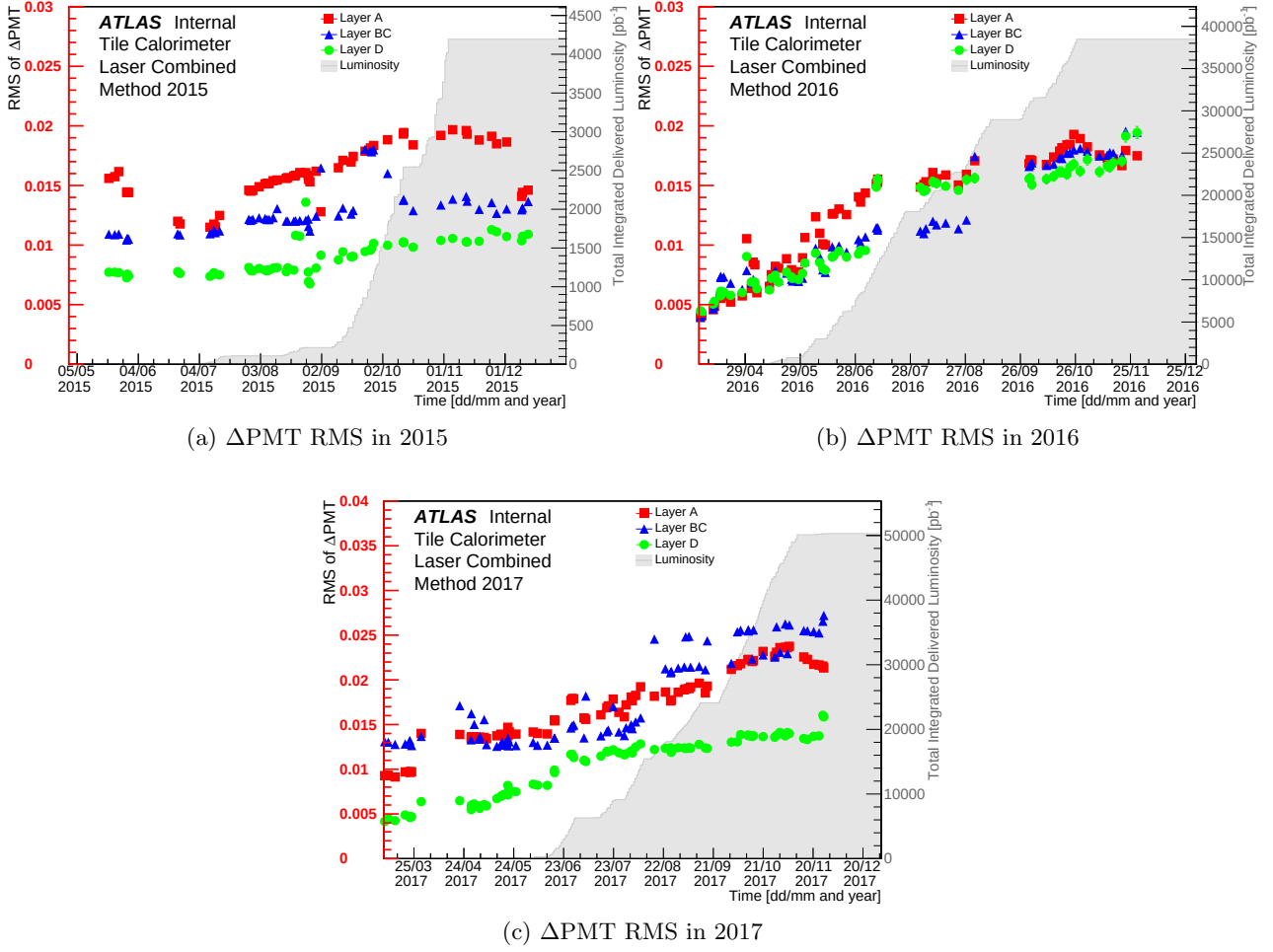
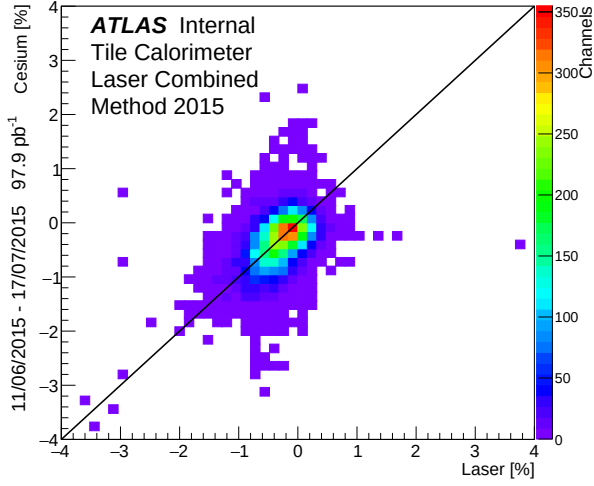


Figure 8: Comparison of response difference time evolution for the same channel types in Run 2

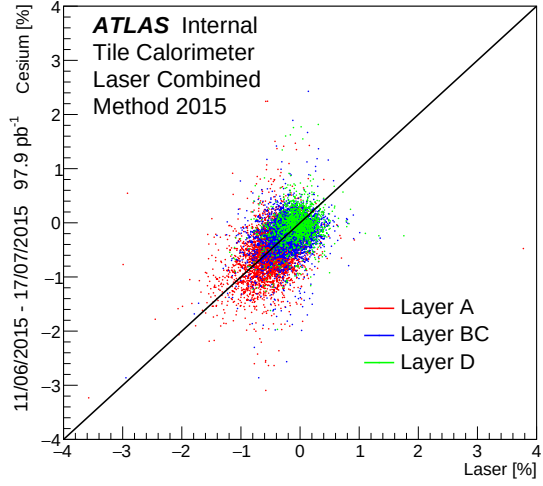
Spread of the response difference distribution increases if data is taken by the detector system. Different layers are not showing the same order as expected from the radiation dose levels in Figure 8.

4 Comparison with cesium measurements

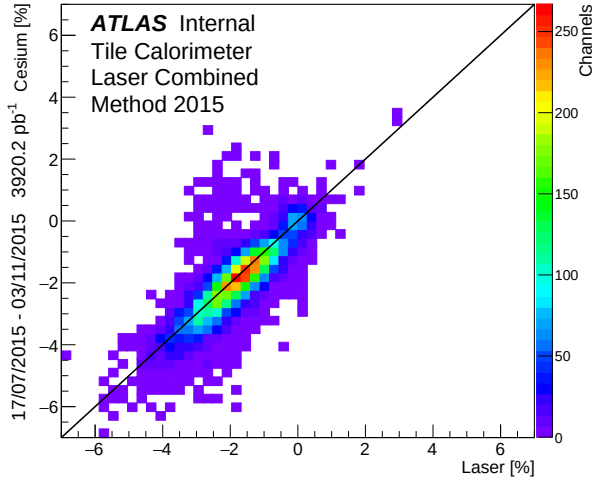
Cesium system monitors the whole subdetector system. Making a comparison between laser and cesium measurements is used for getting data about the ageing of the scintillator tiles. The particles, absorbed by the detector medium, causes gain loss which can not be corrected by the laser calibration. Analyzing the response drifts between two cesium scans helps to understand the ageing processes. Three different periods are studied, two in 2015 (11/06/2015–17/07/2015; 17/07/2015–03/11/2015) and one in 2016 (15/04/2016–24/05/2016). Significant amount of data is only collected during the second period in 2015.



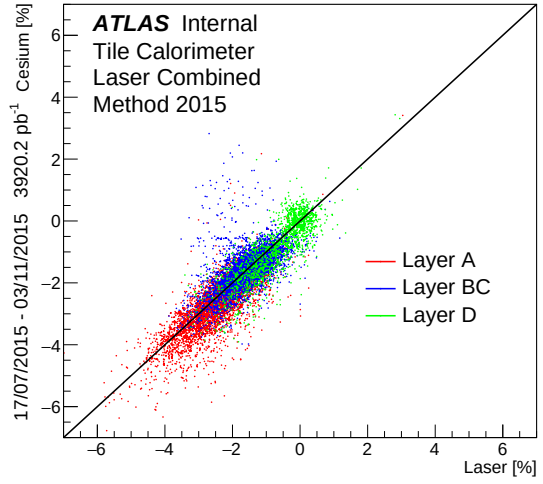
(a) All instrumented channels, Time Interval I in 2015



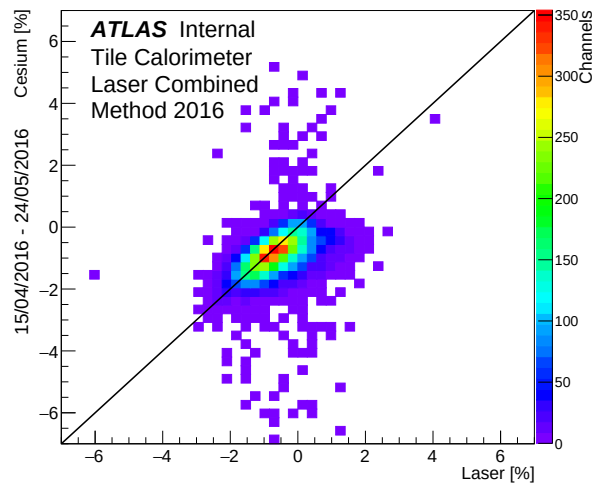
(b) Three different layers, Time Interval I in 2015



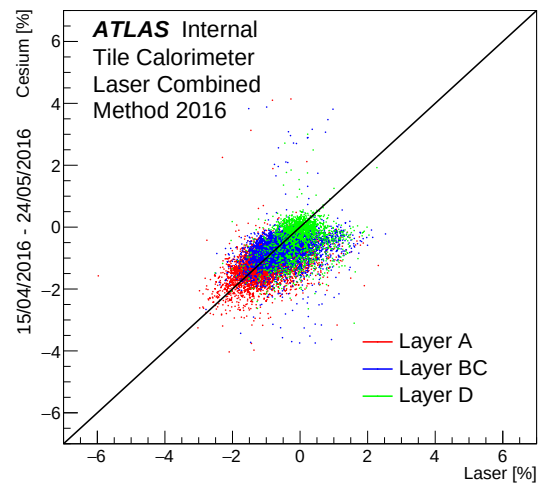
(c) All instrumented channels, Time Interval II in 2015



(d) Three different layers, Time Interval II in 2015



(e) All instrumented channels in 2016

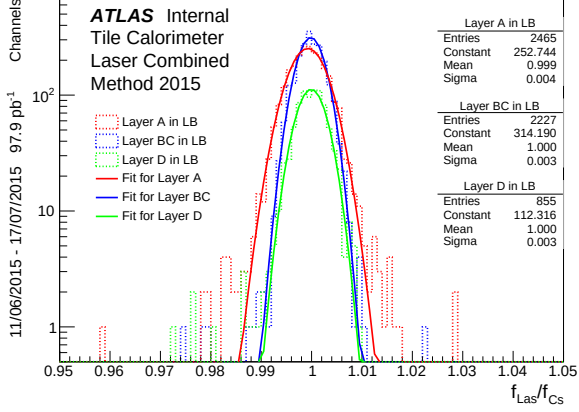


(f) Three different layers in 2016

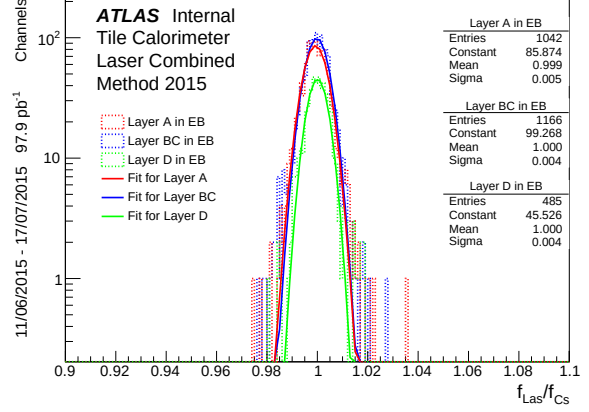
Figure 9: Distributions of cesium and laser response drifts between two cesium scans

Outside the data collecting period there is no significant shift in the distribution of cesium and laser responses. Drift can be observed while the LHC provides huge instantaneous luminosity but the distributions are still spread around the $y = x$ line. The different cell types are well separated due to the varying irradiation levels. Entries above and below the center of the distributions correspond to C10 cells, cesium scan results are ambiguous for them. Correction factor is defined to perform the analysis more effectively:

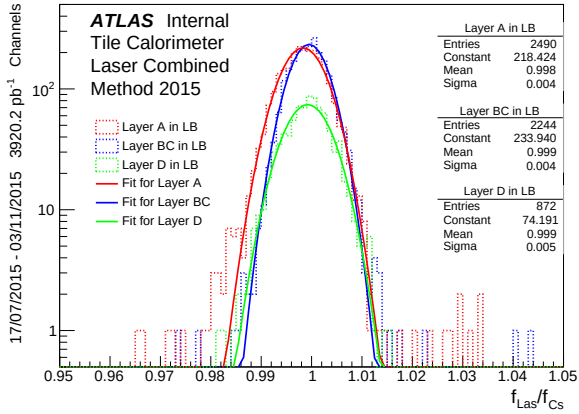
$$f = \frac{1}{1 + \Delta drift} \quad (2)$$



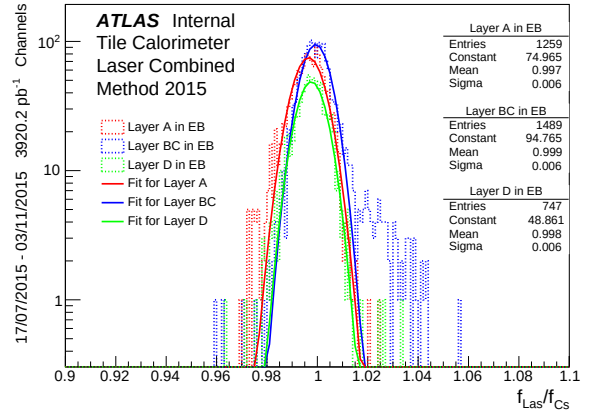
(a) Long Barrel in 2015



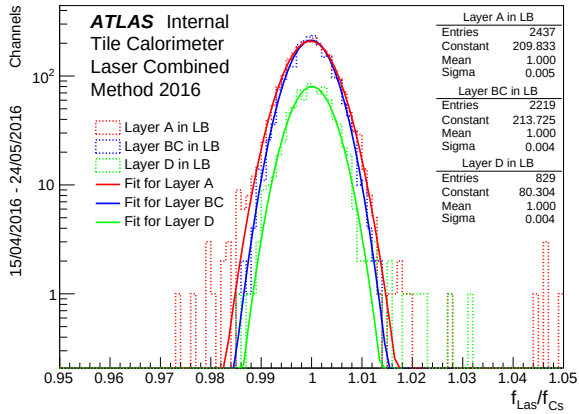
(b) Extended barrels in 2015



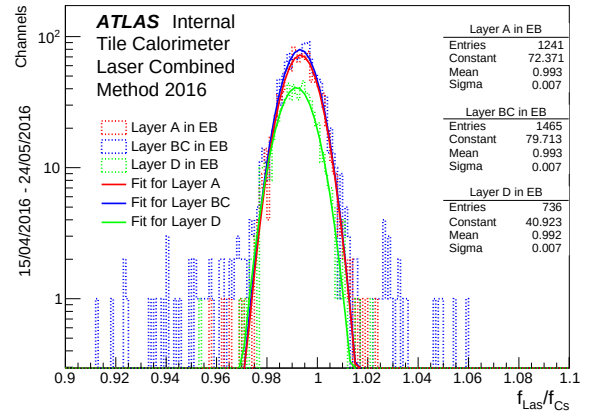
(c) Long Barrel in 2015



(d) Extended barrels in 2015



(e) Long Barrel in 2016



(f) Extended barrels in 2016

Figure 10: Ratio between the laser and cesium correction factors

The distributions are fitted to Gaussian functions to receive the mean. Standard deviation (σ) represents the systematic uncertainty of the laser measurements if negligible uncertainty from the cesium ones are assumed. The distributions in Figure 10 are centered at one, standard deviation is higher for EBA and EBC.

5 Conclusion

The combination of the different calibration methods can be used very effectively for monitoring the complete TileCal system. The analysis of the results also helps to perform real time diagnosis if one part is not working properly. Huge irradiation level must be sustained by the instrument in order to keep the efficiency within the appropriate limits during the higher luminosity runs.

6 References

- [1] ATLAS Collaboration, Tile Calorimeter Technical Design Report (1996), CERN/LHCC96-42
- [2] ATLAS Collaboration, Operation and performance of the ATLAS Tile Calorimeter in Run 1 (2018), arXiv:1806.02129