

PAPER • OPEN ACCESS

## Calibration and Performance of the ATLAS Tile Calorimeter

To cite this article: Krystsina Petukhova and on behalf of the ATLAS Collaboration 2019 *J. Phys.: Conf. Ser.* **1390** 012107

View the [article online](#) for updates and enhancements.

You may also like

- [Upgrade of Tile Calorimeter of the ATLAS Detector for the High Luminosity LHC.](#)  
Eduardo Valdes Santurio and On behalf of the ATLAS Tile Calorimeter System
- [Upgrade of the ATLAS Tile Calorimeter Electronics](#)  
F Carrió and (on behalf of the ATLAS Tile Calorimeter System)
- [ATLAS Tile Calorimeter electronics and future upgrades](#)  
G. Usai



### 244<sup>th</sup> Electrochemical Society Meeting

October 8 – 12, 2023 • Gothenburg, Sweden

50 symposia in electrochemistry & solid state science

Abstract submission deadline:  
**April 7, 2023**

Read the call for  
papers &  
**submit your abstract!**

# Calibration and Performance of the ATLAS Tile Calorimeter

**Krystsina Petukhova, on behalf of the ATLAS Collaboration**

Charles University, Institute of Particle and Nuclear Physics, V Holešovičkách 2, 18000  
Prague, Czech Republic

E-mail: [krystsina.petukhova@cern.ch](mailto:krystsina.petukhova@cern.ch)

**Abstract.** The Tile Calorimeter (TileCal) of the ATLAS experiment at the LHC is the central hadronic calorimeter designed for the reconstruction of hadrons, jets, tau-particles and missing transverse energy. This sampling calorimeter uses steel plates as absorber and scintillating tiles as active medium. The light produced by the passage of charged particles is transmitted by wavelength shifting fibers to photomultiplier tubes (PMTs). The readout is segmented into about 5000 cells, each of them being read out by two PMTs in parallel. The TileCal calibration system comprises Cesium radioactive sources, laser, charge injection elements, and an integrator based readout system. Combined information from all systems allows to monitor and to equalize the calorimeter response at each stage of the signal evolution, from scintillation light to digitization. The performance of the calorimeter has been established with cosmic ray muons and the large sample of the proton-proton collisions. The response of high momentum isolated muons is used to study the energy response at the electromagnetic scale, isolated hadrons are used as a probe of the hadronic response. The calorimeter time resolution is studied with multi-jet events. A description of the different TileCal calibration systems and the results on the calorimeter performance during the LHC Run 2 will be presented.

## 1. Introduction

The Tile Calorimeter (TileCal) measures energy deposited by hadrons and provides key information for reconstruction of jet 4-vectors [1]. The TileCal assists in estimation of missing transverse energy (MET) and identification of muons. The detector symmetrically covers the main interaction point and spans over  $|\eta| < 1.7$  \* (figure 1(a)). Full  $4\pi$  coverage is provided by 64 azimuthal modules (figure 1(b)). The TileCal cells constitute three radial layers (A, BC, and D) (figure 2(a)). To provide redundancy and reliability, a typical cell is readout by two independent channels. Overall, The Tile Calorimeter comprises 5182 cells which are readout by 9856 channels.

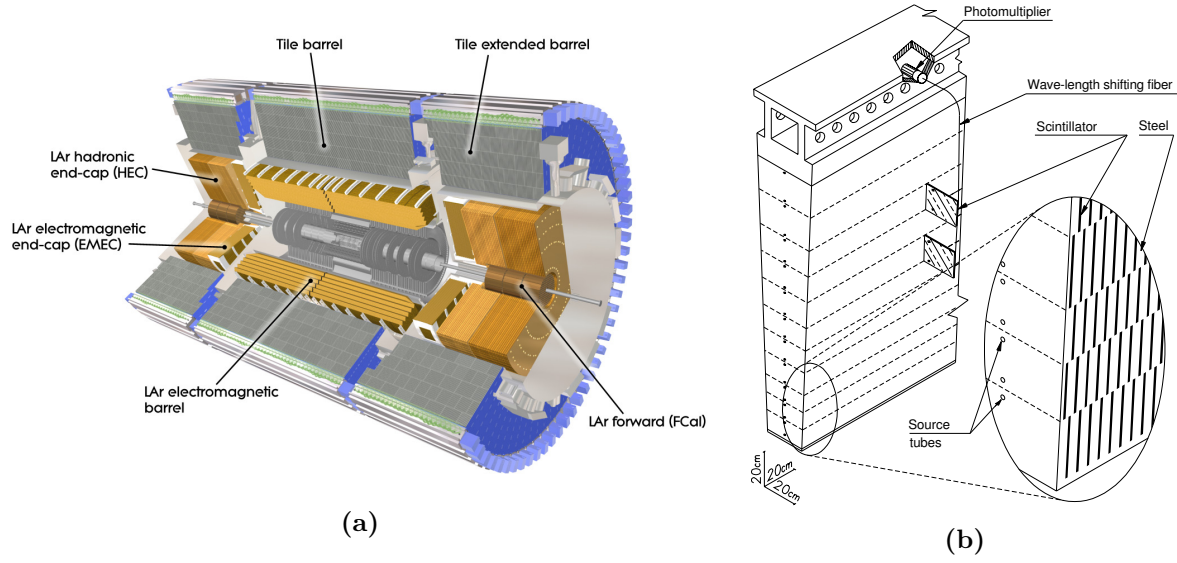
The light produced by particles going through scintillator is converted into electric charge by the PMTs. Depending on its value, signal is processed in high or low gain, with ratio of amplification equal to 64:1, respectively. Ten-bit digitizers sample and convert analog signal

\*ATLAS uses a right-handed coordinate system with its origin at the nominal interaction point (IP) in the center of the detector and the  $z$ -axis along the beam pipe. The  $x$ -axis points from the IP to the center of the LHC ring, and the  $y$ -axis points upward. Cylindrical coordinates  $(r, \phi)$  are used in the transverse plane,  $\phi$  being the azimuthal angle around the  $z$ -axis. The pseudorapidity is defined in terms of the polar angle  $\theta$  as  $\eta = -\ln \tan(\theta/2)$ .

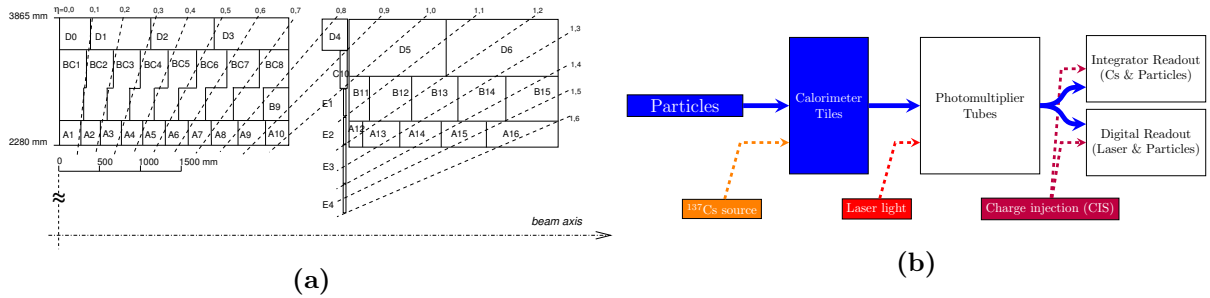
© 2018 CERN for the benefit of the ATLAS Collaboration. CC-BY-4.0 license.



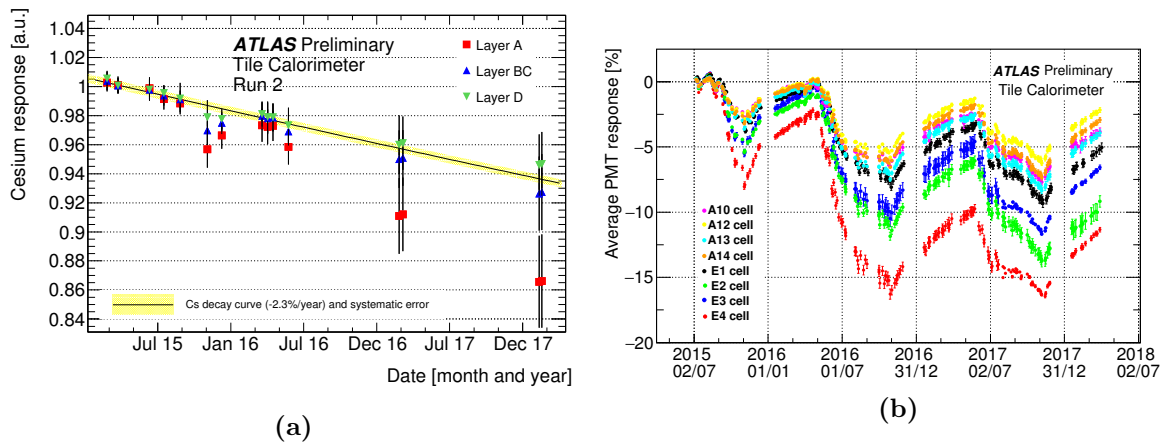
Content from this work may be used under the terms of the [Creative Commons Attribution 3.0 licence](https://creativecommons.org/licenses/by/4.0/). Any further distribution of this work must maintain attribution to the author(s) and the title of the work, journal citation and DOI.



**Figure 1.** A cut-away drawing of the ATLAS inner detector and calorimeters (a) [2]. A scheme of the mechanical assembly and the optical readout of the Tile Calorimeter module (b) [2].



**Figure 2.** A layout of the TileCal cells (a) [2]. Flow diagram of the TileCal calibration tools: Cesium, Laser, and Charge Injection systems, and Integrator System readout (b) [3].



**Figure 3.** Time evolution of the TileCal response to Cesium source (a) [4]. Time evolution of the TileCal average PMT response over Run 2 (b) [4].

into digital output at the current LHC rate of bunch crossing (40 MHz). The signal amplitude  $A$  is calculated based on raw response in seven consequent samples with the Optimal Filtering algorithm [5]. Energy is reconstructed from the amplitude as follows:

$$E_{\text{channel}}[\text{GeV}] = A[\text{ADC}] \cdot C_{\text{ADC} \rightarrow \text{pC}} \cdot C_{\text{pC} \rightarrow \text{GeV}} \cdot C_{\text{Cs}} \cdot C_{\text{laser}}. \quad (1)$$

Electromagnetic (EM) scale factor  $C_{\text{pC} \rightarrow \text{GeV}}$  was measured during test beam campaigns [5]. EM scale describes the detector responsiveness and reflects the amount of charge (pC) collected during exposure to electron beam of the known energy (GeV).

## 2. The TileCal calibration

The TileCal response is calibrated and constantly monitored at each step of signal path (figure 2(b)). Cesium system calibrates optical components: scintillators, fibers, PMTs ( $C_{\text{Cs}}$ ). Laser factor  $C_{\text{laser}}$  addresses PMT drifts. Charge Injection system (CIS) calibrates response of electronics to known charge ( $C_{\text{ADC} \rightarrow \text{pC}}$ ). Integrator (Minimum Bias) system monitors luminosity and the detector optical path performance. To ensure sufficient cross-check and to facilitate identification of component failures, the path of the TileCal calibration systems partially overlap.

### 2.1. Cesium Calibration System

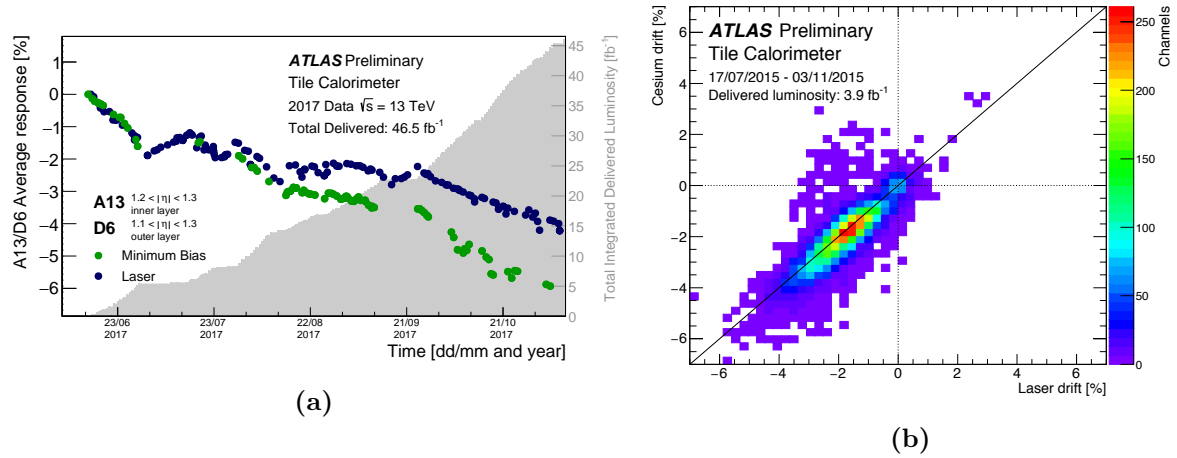
Movable  $^{137}\text{Cs}$  radioactive  $\gamma$ -source (662 keV) enters the TileCal modules through source tubes and illuminates tiles. The current in PMTs is readout by the Integrator system. The Cesium System calibrates optic components and allows to identify PMT drift. Cesium calibration factor  $C_{\text{Cs}}$  is the main tool to equalize the detector response to the EM scale measured during the test beam campaign. Large deviations in the response are addressed by adjusting PMT gain via high voltage change. Before Run 2, safety and stability of the Cesium calibration system were improved. Precision of measurement of channel response is below 0.3%. Cesium calibration is performed few times a year. Between Cesium scans, the Laser calibration system is used to track fast change in PMTs gain. The Tile Calorimeter response to Cesium source is declining during exploitation. This effect is caused by scintillator and PMTs damage by the anode current and light. The scintillator degradation (as explained in 2.5) and variation of drift are more pronounced for the tiles closest to the beam axis (figure 3(a)).

### 2.2. Laser Calibration System

Controlled amount of light (532 nm) is sent to the photocathode of each PMT via  $\sim 400$  fibers [6]. Laser calibration system tracks PMT gain drifts, and monitors electronics components. The response to laser shots fluctuates with variations of anode charge and changes of HV. For Run 2, an improved Laser system II with better precision was introduced. The precision of gain variation measurement for typical channel is better than 0.5%. Laser calibration is performed usually on weekly basis to track short-term PMT gain drifts. The down-drifts of the PMT response seen in figure 3(b) coincide with  $pp$  collision periods and mostly affect PMTs reading out the most exposed cells. The response partially recovers during technical stops.

### 2.3. Charge Injection System

Voltage source injects into capacitor (100 pF) charge of known value (between 0 and 800 pC). The dependence of the mean of ADC-count spectrum on the injected charge is studied. Its slope is used as CIS calibration factor,  $C_{\text{ADC} \rightarrow \text{pC}}$ . calibration of analog Level 1 trigger. The CIS calibration factors are updated every month.



**Figure 4.** Time evolution of the variation of the TileCal response to Minimum Bias and Laser events (a) [4]. Gain variation observed by the TileCal Laser and Cesium systems. (b) [4].

#### 2.4. Integrator (Minimum Bias) System

Integrator (Minimum Bias) system identifies response to the Minimum Bias events (soft interactions during  $pp$  collisions) over relatively long period of time ( $\sim 10 \mu\text{s}$ ). The MB system monitors full optical route and provides estimation of instantaneous luminosity [7]. The Integrator System readout is used for calibration of E-cells and Minimum Bias Trigger System.

#### 2.5. Combined Energy Calibration

The difference in the response to MB events and Laser pulses is interpreted as scintillator light yield loss (ageing) due to irradiation (figure 4(a)). Average response measured by MB system matches to Cs system measurements. Comparison of PMT gain variation seen by the Laser and the Cesium systems (figure 4(b)) gives information about scintillator ageing effect or/and bias in the laser measurement. Cs and Laser measurements agree for majority of the channels. Larger drifts are seen for the layer A which is closer to the collision point, as seen in figure 3(a).

#### 2.6. Time Calibration

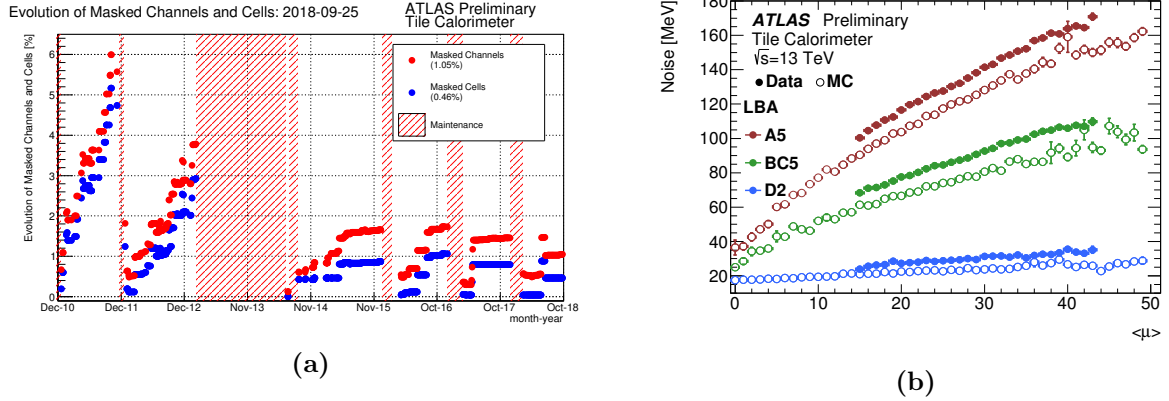
The aim of the TileCal time calibration is to adjust digitizer sampling clock to the peak of signal produced by the particle traveling through the cell. Their synchronization is crucial for precise energy reconstruction. Time calibration is performed with multi-jet events. Stability of time calibration is monitored using laser shots emitted during empty orbits upon data-taking. In Run 2, timing is remarkably stable, due to new low voltage power supplies (LVPS) and improved digitizer settings. Resolution of time measurement is below 1 ns for  $E_{\text{cell}} > 20 \text{ GeV}$ .

### 3. TileCal Performance

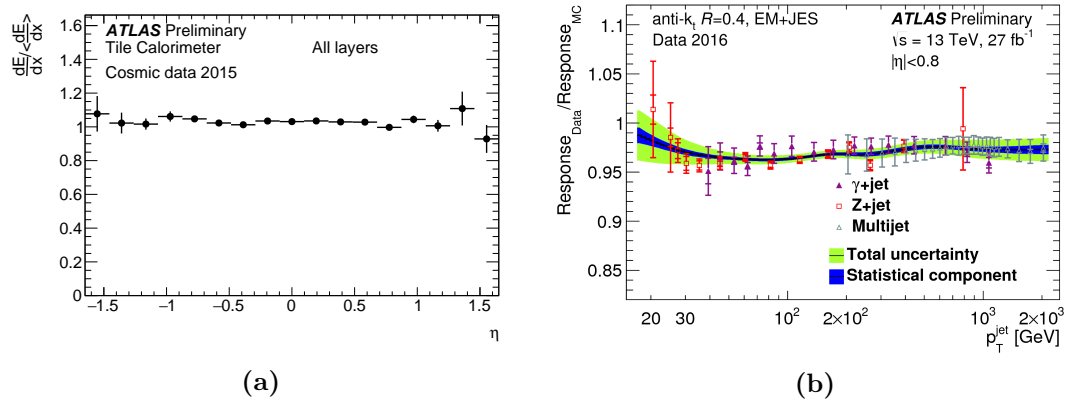
Calibration factors, cell response and time stability are continuously monitored, and necessary fine corrections are seasonably applied. Currently, 0.46% of cells and 1.05% of channels are masked (figure 5(a)), and data quality efficiency is above 99%.

#### 3.1. Noise Measurement

Noise in the TileCal cells comes from two sources: electronics and pile-up. Electronic noise is estimated as RMS of pedestal measured in dedicated runs. For most of the TileCal cells, the electronic noise is about 20 MeV. In Run 2, better gaussianity of electronic noise was achieved



**Figure 5.** Evolution of number of masked TileCal cells and channels (a) [4]. The TileCal total noise dependence on the average number of interaction per bunch crossing  $\langle\mu\rangle$  (a) [4].



**Figure 6.** Ratios of the truncated means of the energy deposited by cosmic muons per unit of path length as a function of  $\eta$  (a) [4]. Ratio of jet response in data to MC as  $p_{\text{T}}$  function (b) [8].

with new LVPSs. Pile-up noise (multiple interactions occurring in the same readout window) is defined by studying dependence of the cell noise on the average number of interactions per bunch crossing. The most exposed to the beam A-cells experience higher pile-up (figure 5(b)).

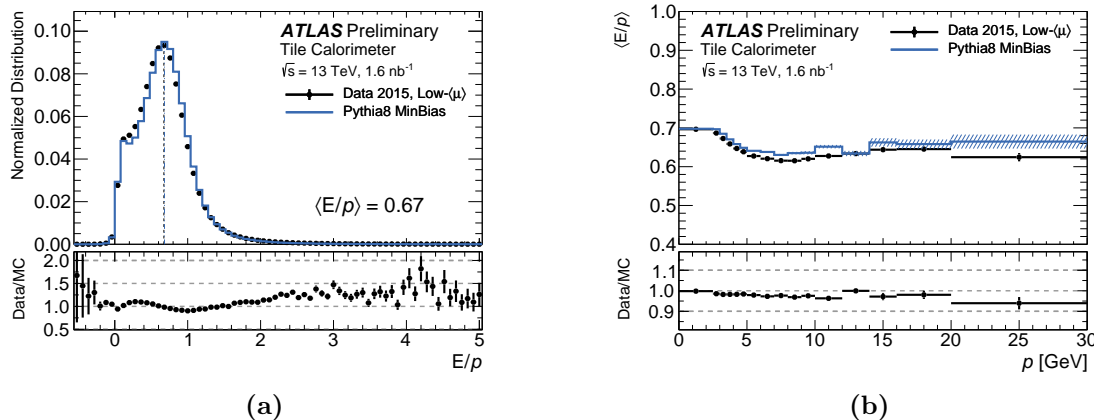
### 3.2. Performance with cosmic-ray muons

Inter-calibration of the TileCal cells as well as derivation of EM scale with *in situ* methods are performed with muons using cosmic data. Cell response is estimated as the energy deposited by the muon per the length of track path ( $dE/dx$ ). The TileCal response uniformity is studied with the ratio of  $dE/dx$  to the detector average  $\langle dE/dx \rangle$  in a range of  $\eta$ - $\phi$ . Good energy response uniformity over  $\phi$  is observed. Non-uniformity in  $\eta$  is below 5% (figure 6(a)).

### 3.3. Performance with isolated charged hadrons

Response to single isolated charged hadrons is described by the ratio of energy at EM scale to track momentum using low- $\langle\mu\rangle$  (MB) events. The ratio  $\langle E/p \rangle$  is used for evaluation of calorimeter uniformity and linearity (figure 7(b)). As shown in figure 7(a), the average response is 0.67 (below the unity due to non-compensating nature of the Tile Calorimeter). Zero-bias data and MB Monte Carlo (MC) samples are in agreement within 5%, showing linearity and uniformity of the detector response.





**Figure 7.** The TileCal response to single isolated charged hadrons (a) [9]. The TileCal response to single isolated charged hadrons as a function of momentum, averaged over  $\eta$  and  $\phi$  (b) [9].

### 3.4. Performance with jets

Energy scale correction is defined by jet response ratio in data and MC simulation [10]. The value of jet energy scale (JES) correction value is consistent between all measurement methods: Z+jet,  $\gamma$ +jet, multi-jet, as seen in figure 6(b). The difference between JES in data and MC is within 5%. This correction is applied for further physics analyses.

## 4. Conclusion

The Tile Calorimeter provides decisive information for reconstruction of jets and MET in the ATLAS experiment. Cell energy scale stays stable within 1%. Uniform, linear, and stable response is ensured by control over energy and time calibration. Employment of multiple systems based on diverse physical effects ensures well-timed identification of malfunctions and high precision of measurements. The TileCal performance and response uniformity is verified with isolated charged hadrons and cosmic-ray muons. A number of inefficient cells is kept below 0.5% due to readout system redundancy, careful monitoring and effective maintenance. In Run 2, the TileCal collects data with efficiency exceeding 99%.

## Acknowledgments

The author would like to thank the Visegrad fund for financial support.

## References

- [1] ATLAS Collaboration 1996 *ATLAS tile calorimeter: Technical Design Report* Technical Design Report ATLAS (Geneva: CERN) URL <https://cds.cern.ch/record/331062>
- [2] ATLAS Collaboration 2013 Approved Detector Reference Figures And Schematics URL <https://twiki.cern.ch/twiki/bin/view/AtlasPublic/ApprovedDetectorReferenceFiguresAndSchematics>
- [3] ATLAS Collaboration 2018 (*Preprint arXiv:1806.02129*)
- [4] ATLAS Collaboration 2018 Approved Plots Tile Calibration URL <https://twiki.cern.ch/twiki/bin/view/AtlasPublic/ApprovedPlotsTileCalibration>
- [5] ATLAS Tile Collaboration 2009 *Nucl. Instrum. Meth. A* **606** 362–394
- [6] ATLAS Tile Collaboration 2016 *Journal of Instrumentation* **11** T10005
- [7] ATLAS Collaboration 2013 *Eur. Phys. J. C* **73** 2518 (*Preprint arXiv:1302.4393*)
- [8] ATLAS Collaboration 2017 JES Public Plots for Moriond 2017 URL <https://atlas.web.cern.ch/Atlas/GROUPS/PHYSICS/PLOTS/JETM-2017-003>
- [9] ATLAS Collaboration 2016 Approved Plots Tile Single Particle Response URL <https://twiki.cern.ch/twiki/bin/view/AtlasPublic/ApprovedPlotsTileSingleParticleResponse>
- [10] Klimek P (ATLAS Collaboration) 2018 URL <https://cds.cern.ch/record/2319854>