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Measurements of Luminosity in ATLAS with Tile Calorimeter

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Luminosity measurements in the ATLAS experiment are provided primarily by the LUCID detector, but rely on other detectors for determining the systematic uncertainties associated with this measurement. The Tile Calorimeter (TileCal), the central hadronic calorimeter of the ATLAS experiment, and the ATLAS Inner Detector (ID) play an important role due to their luminosity measurements being independent of pileup. Comparison of the LUCID luminosity measurements in different run conditions to those obtained by TileCal and ID, as well as a comparison of TileCal to ID, is used to measure and study the dominant systematic uncertainty associated with the LUCID luminosity measurement. In this document the methods of measuring ATLAS luminosity with the Tile Calorimeter and its transformation to a systematic uncertainty are described.

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1. Introduction

The absolute luminosity calibration [1] of the ATLAS experiment [2] is done using the Luminosity Cherenkov Integrating Detector (LUCID). LUCID is calibrated in special van der Meer (vdM) runs which consist of a series of beam scans conducted with isolated bunches at a very low luminosity for a more precise measurement of the beam parameters. The LUCID response is monitored during each scan in order to measure the beam overlap integral in each axis (Σ_x, Σ_y) which relates to the bunch intensities (n_1, n_2) and the luminosity ($\mathcal{L}$) via Equation 1 through the LHC revolution frequency (f_{LHC}):

$$\mathcal{L} = f_{\text{LHC}} \frac{n_1 n_2}{2\pi \Sigma_x \Sigma_y}. \tag{1}$$

This luminosity is related to the visible interactions per bunch crossing (μ_{vis}), and the visible cross section (σ_{vis}) via Equation 2:

$$\mathcal{L} = f_{\text{LHC}} \frac{\mu_{\text{vis}}}{\sigma_{\text{vis}}}. \tag{2}$$

2. Calibration transfer

LUCID measures μ_{vis} and relates it to the luminosity given by Equation 1 to determine the calibration constant σ_{vis}. A dependence of σ_{vis} on run conditions such as pileup (μ) is observed, therefore, additional corrections to the calibration are needed.

The ATLAS Inner Detector (ID) can provide luminosity measurements by relating the number of tracks to the luminosity. The track luminosity measurement, as well as the LUCID luminosity measurement, is sensitive over a large range of luminosities. Furthermore, the track luminosity is robust against pileup and therefore can be used to extrapolate σ_{vis} from vdM conditions to physics data taking conditions in a procedure that is known as calibration transfer. To estimate an uncertainty of the calibration transfer, another luminometer independent of pileup should be used.

3. The Tile Calorimeter as a luminometer

The Tile Calorimeter (or TileCal) is the hadronic calorimeter covering the most central region of the ATLAS experiment. It is made of low-carbon absorbing steel plates alternated with plastic scintillator tiles acting as the active material. Particles traversing a tile produce scintillation light that is transmitted by wavelength shifting (WLS) fibres to photomultiplier tubes (PMTs). The read-out cell geometry is given by a group of WLS fibres from individual tiles coupled to PMTs.

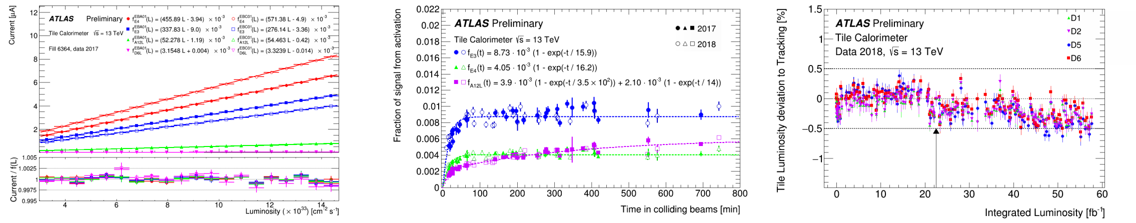
The anode current (I_{PMT}) measured by TileCal is proportional to the luminosity as shown in Figure 1a and Equation 3:

$$\mathcal{L} = \alpha \langle I_{\text{PMT}} \rangle, \tag{3}$$

where the calibration constants (α) are obtained by cross calibrating TileCal luminosity to track luminosity in what is known as an anchor run and the anode current is computed by performing a pedestal subtraction to the ADC counts and dividing by the gain as it is shown in Equation 4:

$$\langle I_{\text{PMT}} \rangle = \frac{\langle \text{ADC} \rangle - \text{pedestal}}{\text{gain}}. \tag{4}$$

The Tile Calorimeter was not originally intended to be used as a luminometer. Its utility for luminosity measurements became apparent when the need for an uncertainty on the calibration transfer arose. TileCal has at its disposal a wide range of cells that can be used for luminosity measurements. The cell position in the detector influences its sensitivity and also how isolated from radiation it is. This makes the TileCal luminosity measurement sensitive to a wide range of luminosities. Since the luminosity determined by TileCal is also independent of pileup, it becomes the perfect candidate for the calibration transfer uncertainty measurement. The deviation between the luminosity measurements provided by TileCal and by the tracking detector gives a measure of the associated uncertainty in the calibration transfer.



(a) **(b)** **(c)**

Figure 1: (a) The dependence of the PMT anode current on track-counting luminosity for a few channels of the Tile Calorimeter in fill 6364. (b) Fraction of the PMT anode current due to material activation in different cell families of the Tile Calorimeter computed on a dataset of runs from 2017 and 2018. (c) Deviation of the instantaneous luminosity measured by TileCal D-cell scintillator families of EBA and EBC to that from track-counting as a function of the integrated luminosity of 2018. The luminosity measurements by TileCal are normalised to track-counting in the fill indicated by the arrow.

3.1 Measurement non-linearities

Several non-linear effects impact the relation between the anode current and the luminosity. These include the ageing of the PMTs, the ageing of the scintillators, the small current dependence of the gain of the PMTs and activation. To overcome this, corrections can be introduced in Equation 3.

Activation refers to measurement of contamination by signals originating from excited material after irradiation which can be at the level of $O(1\%)$. These activation signals are characterized by their own time constants while some components will decay faster than others. The fraction of signal from activation can be measured by comparing the pedestals obtained immediately after the run to those measured right before the run. In Figure 1b the fraction of signal from activation is plotted as a function of the amount of time the detector is under colliding beams. A better understanding of activation signal has a positive impact on reducing the uncertainty in the calibration transfer.

3.2 Measurement stability

TileCal also contributes to the luminosity stability measurement. For this study, isolated cells such as the D cell family can be used since they are the furthest from the beam pipe and hence are less prone to ageing. Figure 1c shows the deviation of the instantaneous luminosity measured by TileCal D-cell scintillator families to that from the tracking detector as a function of the integrated luminosity of the 2018 dataset. The arrow points to the fill where the luminosity measurements by TileCal are normalised to those from the tracking detector, i.e. the anchor run. The TileCal and tracking luminosities agree within 0.5%, thus demonstrating an excellent stability of these two methods used for the ATLAS luminosity monitoring in 2018.

References

[1] ATLAS Collaboration, *Luminosity determination in pp collisions at* $\sqrt{s} = 13$ *TeV using the ATLAS detector at the LHC*, ATLAS-CONF-2019-021, (2019).

[2] ATLAS Collaboration, *The ATLAS experiment at the CERN large hadron collider*, *Journal of Instrumentation* **3** (2008) S08003.