

# Timepix3 Luminosity Determination of 13 TeV Proton-Proton Collisions at the ATLAS Experiment

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**Abstract**—Medipix and Timepix devices, installed in the ATLAS cavern at the LHC, have provided valuable complementary luminosity information. Results are presented from measurements with Timepix3 (TPX3) detectors. In contrast with previously employed frame-based data acquisition, the TPX3 detector remains active continuously, sending information on pixel hits as they occur. Hit- and cluster-counting methods were used for the luminosity determination of the LHC proton-proton collisions. The LHC luminosity versus time is determined using these two methods and fitted to a simple model, which incorporates luminosity reduction from single bunch and beam-beam interactions. The precision of the luminosity determination could be improved by counting the number of clusters, instead of just pixel hits. The internal precision and long-term stability of the TPX3 luminosity measurement are below 0.5%. TPX3, owing to its 1.56 ns time-tagging, is able to resolve the time structure of the luminosity due to the collisions of individual proton bunches when integrated over an LHC fill.

## I. INTRODUCTION

Precision luminosity measurements are of particular importance for many analyses in high-energy physics. Networks of hybrid active pixel detectors from the Medipix/Timepix family [1] installed in ATLAS cavern [2] successfully demonstrated their potential to determine luminosity [3], [4]. Recently, the latest generation Timepix detectors, namely Timepix3 (TPX3) [5], were installed in the ATLAS cavern at CERN [6]. The TPX3 device closest to the LHC interaction point is used in this analysis to measure the primary and secondary particle fluxes originating from 13 TeV proton-proton collisions. The data were taken between April and October 2018 during the LHC Run-2 operation.

The use of the TPX3 device for luminosity measurements has several advantages compared to the previous luminosity measurements at the LHC during Run-1 (MPX devices) [3] and Run-2 (TPX devices) [4].

1) *The possibility of (quasi-) continuous operation:* The dead-time caused by the readout of the frames is about 6 s for MPX and 0.12 s for TPX devices, requiring a compromise between sensor occupancy and relative dead-time minimisation. Cluster-counting with MPX and TPX devices is possible with high particle fluxes only when the exposure time is much shorter than the dead-time. Otherwise, overlapping clusters could not be separated. Therefore, hit-counting is necessarily used for previous high rate luminosity analyses. Furthermore, the TPX devices can be operated in either of three modes: time-over-threshold (energy deposits, ToT), time-of-arrival

(ToA), and Medipix (counting) mode; in contrast, the TPX3 device measures ToT and ToA information simultaneously. A novelty of TPX3 is the pixel-comparator-driven (event-driven) data transmission which replaces the frame-based transmission of the TPX devices.

2) *An improved cluster separation:* In the previous MPX and TPX luminosity analyses, no cluster (particle) counting with high statistics was possible. Thus, to achieve statistically significant short-term luminosity measurements, a hit-counting method was applied. The devices were used in the Medipix mode, where each pixel counts the number of pixel hits per frame. A source of statistical uncertainty arose from the large variance of hit counts per interacting particle. Owing to the precise pixel time-stamping of TPX3, cluster identification and separation could also be done in high flux conditions. This leads to a higher precision of the luminosity measurements. Furthermore in TPX3 data, clusters were defined by temporally and spatially concurrent hits on the sensor.

3) *A higher time resolution:* The previous MPX and TPX luminosity measurements were LHC bunch-integrated as the exposure time was much longer than the bunch separation of 25 ns. As already demonstrated, with the time resolution of TPX3 and proper triggering, it was possible to resolve the bunch structure of the LHC beam [6]. This article provides a proof of principle, as it demonstrates the luminosity determination of individual colliding proton bunches when the data are integrated over an LHC fill.

In summary, an important innovation is that the TPX3 device allows for cluster counting up to high particle rates, since pixel data are digitized and read out as a stream rather than accumulated on-pixel until a full frame is transmitted. Additionally, if clusters partially overlap, they can now be reconstructed separately using the time stamps in the pixels.

Moreover, the two-layer structure of the TPX3 device doubles the measurement statistics and, in this analysis, allows one to determine the internal precision and long-term time stability of individual TPX3 devices. Here, ‘internal’ refers to the luminosity precision being determined only based on the TPX3 device and not with respect to other luminosity determination possibilities.

This extended abstract outlines a future article which is structured as follows. First, the TPX3 device is described, along with the concept of LHC luminosity monitoring by hit-counting and cluster-counting. Further, the LHC luminosity versus time is determined and the internal TPX3 measurement precision is evaluated. The internal precision of luminosity determination is obtained by computing the difference between two layers of the TPX3 device. The internal long-

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term luminosity precision is given from the comparison of layer-1 and layer-2 luminosity measurements. Additionally, the relative long-term stability is also given with respect to other ATLAS luminosity monitors (Section II). Finally, as a proof of principle, the luminosity determination of individual LHC bunch crossings is described, followed by conclusions (Section III).

## II. LONG-TERM STABILITY WITH RESPECT TO OTHER ATLAS LUMINOMETERS

The relative long-term stability of TPX3 luminosity measurements was already compared to that of other ATLAS luminometers for 2017 data [7]. Figure 1 shows the fractional differences between the run-integrated luminosities measured from TPX3, track-counting, EMEC, FCal, and TILE with respect to the baseline LUCID algorithm. The luminosity measurements from the other detectors have been normalised to that of LUCID for a reference run. The values for each run are plotted as a function of the cumulative delivered luminosity fraction, ranging from zero at the start of the year to one at the end of the year. This results in an axis monotonically increasing in time. Short runs with less than about two hours of data-taking are not shown. The run-to-run agreement between the various luminosity measurements is generally at the percent level or better for the bulk of the data, with various short- and long-term trends being visible.

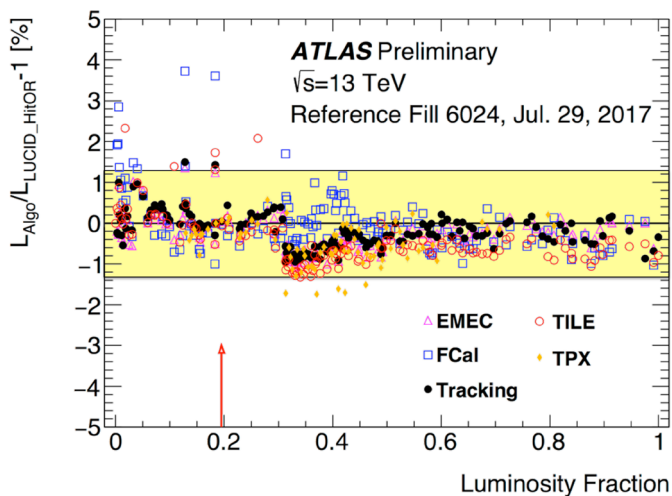


Fig. 1. Fractional differences in run-integrated luminosity between the LUCID BiHitOR algorithm and the TPX3, track-counting, EMEC, FCal, and TILE measurements, plotted as a function of the cumulative delivered luminosity normalised to the 2017 total. The luminosity measurements from the other detectors have been normalised to that of LUCID in the reference run indicated by the arrow. The assigned  $\pm 1.3\%$  long-term stability uncertainty is shown by the yellow band [7].

## III. CONCLUSIONS

A double layer TPX3 device installed in the ATLAS detector cavern has successfully taken data at the LHC during Run-2 with 13 TeV proton-proton collisions. The relative internal short-term precision of the TPX3 luminosity measurements was determined from the LHC luminosity curve to be less than 0.5% for 60 s time intervals. It is observed that cluster-counting improves the luminosity precision compared to hit-counting, since one particle typically corresponds to one cluster of hits. The internal short-term precision was determined in a complementary evaluation by studying the relative difference in luminosities measured by the two TPX3 sensor layers using cluster-counting and a relative precision of 0.4% was observed. The deviation from the internal long-term time stability of the TPX3 device for luminosity measurements was below 0.4%. When integrated over an entire LHC fill, it is demonstrated that the TPX3 device used in this study even has the capability to determine the time structure of the luminosity due to the collisions of individual LHC proton bunches.

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