Operational Experience with and Performance of the ATLAS Pixel Detector at the Large Hadron Collider

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Abstract

The operational experience and requirements to ensure optimum data quality and data taking efficiency with the 4-layer ATLAS Pixel Detector are discussed. The detector has undergone significant hardware and software upgrades to meet the challenges imposed by the fact that the Large Hadron Collider is exceeding expectations for instantaneous luminosity by more than a factor of two (to more than 2×10^{34} cm^{-2} s^{-1}). Emphasizing radiation damage effects, the key status and performance metrics are described.

Keywords: Radiation damage, Pixel Detector, Hit-on-track efficiency, Leakage current, Depletion voltage, dE/dx

1. Introduction

Presented here is a summary of the operational experience and requirements to ensure optimum data quality and data taking efficiency with the 4-layer ATLAS Pixel Detector. A brief overview of the Pixel Detector, which lies at the heart of the ATLAS detector [1], in section 2 serves as an orientation. Two categories are used to summarize the key status and performance metrics of the detector, with a focus on radiation damage effects: (1) charge collection efficiency related effects in section 3 and (2) sensor characteristics in section 4.

2. ATLAS Pixel Detector

The ATLAS Pixel Detector (Fig. 1) consists of four barrel layers and three disks per endcap. The new innermost layer, the Insertable B-Layer (IBL), was installed before the start of LHC Run 2 (2015); it improves tracking performance and will compensate for the anticipated aging of the B-Layer. The IBL has a radius of 3.3 cm and a 10 mm envelope, it has more than 12 million readout channels, and it consists of planar and 3D Si sensors of thickness 200 μm and 230 μm, respectively. The original detector (before the installation of the IBL) has more than 80 million readout channels and consists of n$^+$-in-n Si sensors with 250 μm thickness. It has been monitored since 2011 for radiation damage.

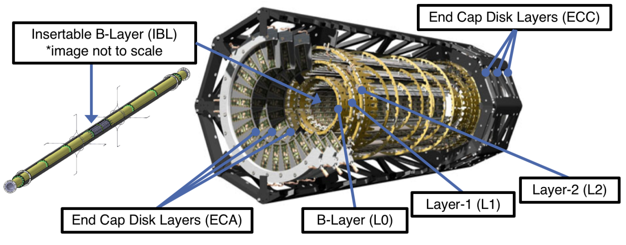

Figure 1: ATLAS Pixel Detector

3. Charge Collection Efficiency Related Effects

The hit-on-track efficiency in the Pixel B-Layer as a function of the track transverse momentum (p_T) measured in four LHC fills with increasing total integrated luminosity in 2016 is shown in Fig. 2. As the total integrated luminosity increases the hit-on-track efficiency decreases due to radiation damage.

A gradual decrease in average cluster size and dE/dx throughout 2016 is visible in Fig. 3, consistent with radiation damage. The effects of under-depletion and improvement from increasing the bias voltage are visible. dE/dx is calculated from the collected charge in each cluster (corrected for the path length of the track in the module), the energy required to create an electron-positron pair, and the material density [3].

A decrease of hit occupancy, the number of hits per pixel per event, over the number of interactions per bunch-crossing (μ) versus total integrated luminosity for 2017 data is also observed.

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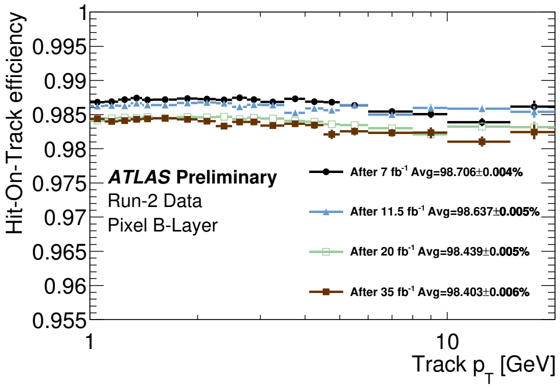

Figure 2: Hit-on-track efficiency in the Pixel B-Layer as a function of the track p_T measured in four LHC fills. See Ref. [5].

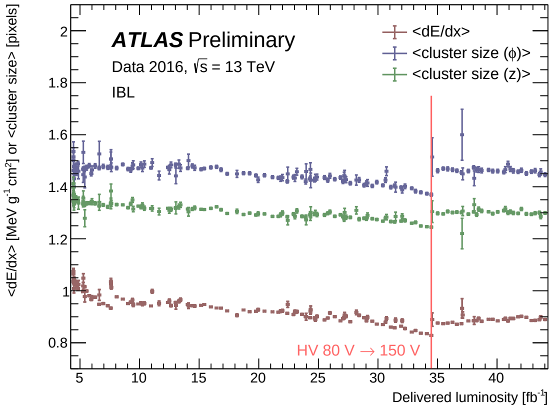

Figure 3: The dependence of the average cluster size and dE/dx on the delivered integrated luminosity. Each point represents a single fill. See Ref. [5].

4. Sensor Characteristics

The sensor bias voltage is increased before each data taking year using the predicted voltage to obtain full depletion. Measurements of the depletion voltage using the cross-talk scan and bias voltage scan methods are shown in Fig. 4. Simulated depletion voltage of the B-Layer is shown according to the Hamburg Model [4].

Observed leakage current levels are increasing as a function of integrated luminosity. The expected annealing effects are also visible. The scaled Hamburg Model matches the data and can be used to predict leakage current. Average measured leakage current data are consistent with expected higher levels of radiation for sensors closer to the beam line, as is observed in Fig. 5. The average module sensor temperature and the average module bias voltage are shown. Leakage current data have been shown to have a dependence along z (the axis of the beam line). Leakage current data are measured using single module precision with the HVPP4 subsystem and multiple module precision with the power supply subsystem.

5. Conclusions

The effects of the radiation that the Pixel Detector has been exposed to are visible in charge collection efficiency data and detector characteristics. In order to counteract performance degradation, bias voltage and threshold working points are optimized. Radiation damage is addressed through reduction of the thresholds to recover lost hits. Keeping the temperature of the detector low during operation and shutdown periods is essential for maintaining levels of bias voltage and leakage current at which the detector can operate. Predictions of depletion voltage and leakage current match the data and can be used to extrapolate to the future. Use of the IBL in Run 2 plays a crucial role in ensuring that the detector is operating with high efficiency. The investigations of radiation effects presented here, together with plans of attentive and continued monitoring, provide confidence that the Pixel Detector will continue to collect data with high efficiency through the end of LHC Run 3 in 2023.

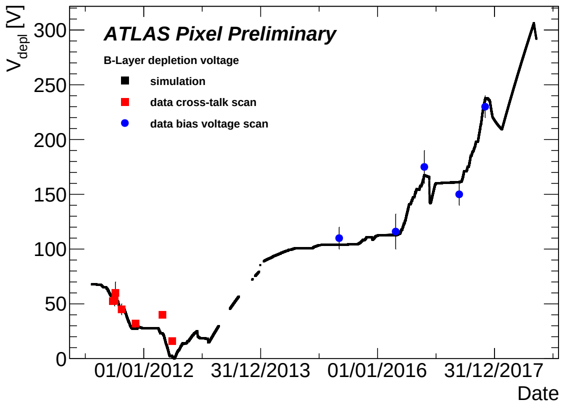

Figure 4: Simulated full depletion voltage of the B-Layer according to the Hamburg Model. The model is fit to the depletion voltage measurements. The prediction for 2018 assumes 70 fb^{-1} of integrated luminosity to be delivered to ATLAS. See Ref. [5].

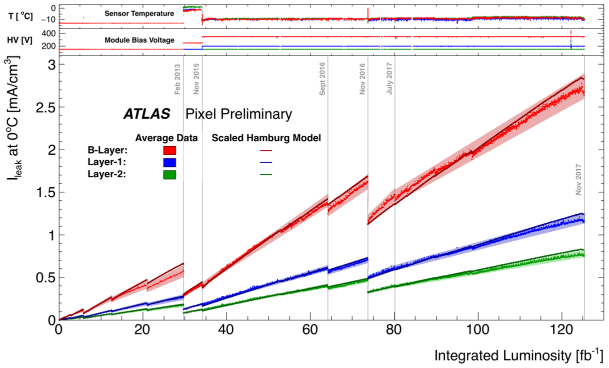

Figure 5: Average measured leakage current data of a representative sample of modules in the barrel layers. The Hamburg Model predictions have been scaled to match the measured leakage current data. See Ref. [5].

References

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