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ATLAS Pixel Detector during Run 2

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Summary. — Silicon pixel detectors are at the core of the current and planned upgrade of the ATLAS detector at the Large Hadron Collider (LHC). During Run 2 of LHC the detector had to sustain many challenges in order to keep the performances and quality of data taking constant in time, against the increasing instantaneous luminosity, increasing pile-up, and radiation damage. This work presents how the operational parameters of the detectors were changed in order to keep the data acquisition, the occupancy, and the resolution evolution constant with time. The effects of the radiation damage on charge collection efficiency and their dependency with time are also presented.

1. – The ATLAS Pixel Detector

The ATLAS [1] Pixel Detector [2] is the innermost component of the Inner Detector. It consists of four barrel layers and three disk layers per end cap. The barrel layers are composed of n^+-in-n planar oxygenated silicon sensors and n^+-in-p 3D pixel sensors.

The innermost layer, called Insertable B-Layer (IBL) [3], is located at just 3.3 cm from the beam pipe and is made of pixels of $50\times250\,\mu\text{m}^2$ in size and 200 μm thick except in the region with high $|z|$ where there are the 3D pixel sensors of $50\times250\,\mu\text{m}^2$ in size and 230 μm thick. The other barrel layers are respectively at 5.05 cm (B-Layer), 8.85 cm (Layer 1), and 12.55 cm (Layer 2) from the beam pipe and consist of pixels of $50\times400\,\mu\text{m}^2$ in size and 250 μm thick. The IBL was installed in ATLAS in May 2014 before the start of LHC Run 2 campaign, while the other three layers have been there since the beginning of Run 1. The detector was operated at twice the designed instantaneous luminosity (during Run 2 the instantaneous luminosity reached a maximum value of $2\times10^{34}\,\text{cm}^{-2}\text{s}^{-1}$) and with an efficiency of data acquisition of 99.8%, with inefficiency due to dead time of single modules less than 0.2%.

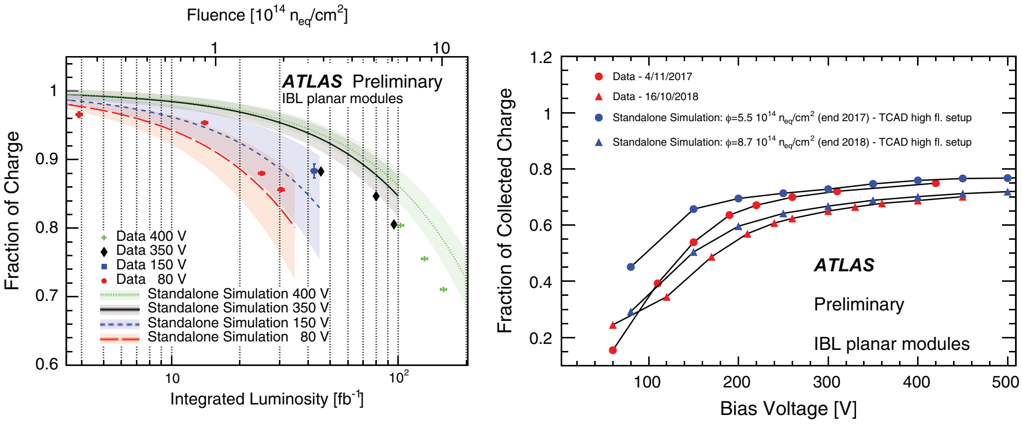

Fig. 1. – Left: charge collection efficiency as a function of luminosity. Right: charge collection efficiency as a function of bias voltage [4].

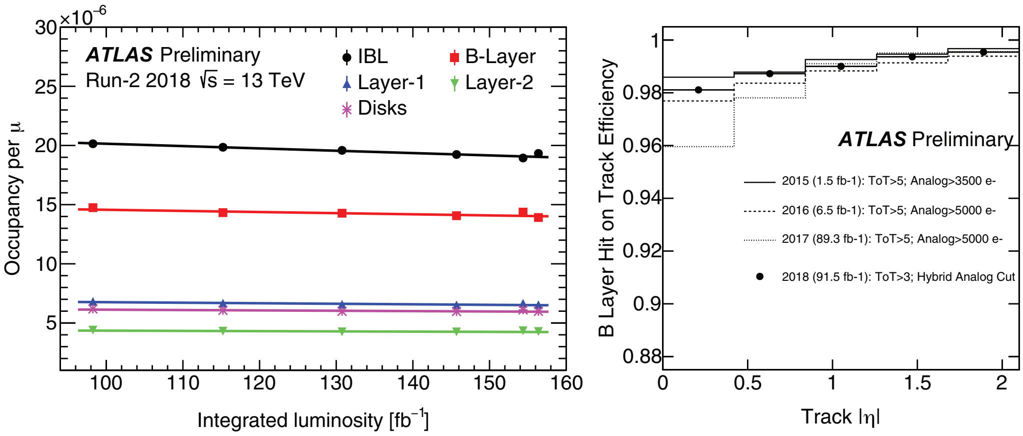

Fig. 2. – Left: the hit occupancy (the number of hits per pixel per event) per μ as a function of the total integrated luminosity for 2018 data, for each layer of the Pixel detector [5]. Right: efficiency for B-layer hits associated to a reconstructed particle track as a function of the track pseudo rapidity $|\eta|$ in Run 2 [6].

2. – Radiation damage effects

The ATLAS Pixel detector has been exposed to a significant amount of radiation over its lifetime as the detector component closest to the interaction point. Radiation creates defects in the sensors and, over time, reduces their efficiency, causing a degradation of the performance of the whole detector to reconstruct physical quantities. The IBL received a total fluence of $\sim 1 \times 10^{15}$ $n_{\text{eq}}/\text{cm}^2$ by the end of Run 2 (corresponding to a luminosity delivered by the LHC of 159 fb^{-1}), and effects are already visible. Figure 1 shows the charge collection efficiency as a function of integrated luminosity (on the left), and bias voltage (on the right), for both data and simulation that accounts for radiation damage effects [7]. It is possible to notice that, at end of Run 2, the efficiency has dropped to around 80%. Operational points of the detector such as the bias voltage are changed to ensure a constant efficiency in the data taking, using the prediction obtained from the simulated samples. Another effect due to the radiation damage is the reduction of the occupancy per μ (average number of interactions per collision), as fig. 2 (left) shows, due to the loss of charge that reduces the number of pixels over threshold. To mitigate this effect, while at the same time keeping a low level of noise, during Run 2 the thresholds were lowered for IBL from $2500e$ to $2000e$, while B-Layer threshold was also lowered from $5000e$ to $4300e$. This reduction also allowed to recover the hit efficiency at low η for the B-Layer. This is shown in fig. 2 (right).

3. – Conclusion

The effects of radiation damage are already visible in the ATLAS Pixel Detector. This is noticeable in the reduction of the collected charge, that impacts the occupancy and the tracking efficiency. However the changes in the operational working points, helped also by simulated samples, have allowed to maintain an adequate data quality with an efficiency of data acquisition of 99.8% during the whole Run 2.

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