IL NUOVO CIMENTO **41 C** (2018) 87
DOI 10.1393/ncc/i2018-18087-6

Colloquia: IFAE 2017

Operation and radiation damage studies of the ATLAS pixel detector

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received 21 April 2018

Summary. — The ATLAS pixel detector provides the innermost layers of the Inner Detector tracker. Due to its proximity to the collision region the pixel detector has been exposed to considerable levels of radiation during its operation at the LHC, up to $2 \cdot 10^{14}\, n_{eq}/\text{cm}^2$. By the end of Run 3, in 2023, the integrated luminosity and fluence will have increased further by an order of magnitude. The radiation damage effects are already noticeable and will increasingly affect the detector performance in the coming years. Monte Carlo simulation are becoming necessary to model the change in detector response.

1. – Fluence levels

The innermost layer of the pixel detector is the Insertable B-Layer (IBL). The prediction of the expected Non-Ionizing Energy Loss (NIEL), referred to as the fluence, for this layer is presented in ref. [1]. The expected fluences corresponding to $40\,\text{fb}^{-1}$ (luminosity integrated by the end of 2016) and $300\,\text{fb}^{-1}$ (luminosity expected by the end of Run 3) are $2.4 \cdot 10^{14}\, n_{eq}/\text{cm}^2$ and $1.8 \cdot 10^{15}\, n_{eq}/\text{cm}^2$, respectively.

2. – Digitizer overview

In order to estimate the effects of the radiation on the sensor, a software (digitizer), has been developed. The input to the digitizer is an energy deposition from a charged particle, produced by Geant4. Electric-field maps of the sensor are evaluated with Technology Computer Aided Design (TCAD) using the radiation damage model developed by Chiochia and collaborators [2]. Energy deposits are transformed in electron and hole charges which are separately drifted through the sensor accordingly to the electric and magnetic field, and, therefore, moving along the direction of the Lorentz angle, in discrete steps. In each step the probability of the charge to be trapped and the induced charge on the pixels are evaluated. The collected charge is then put together in cluster, then used to compare with collision data.

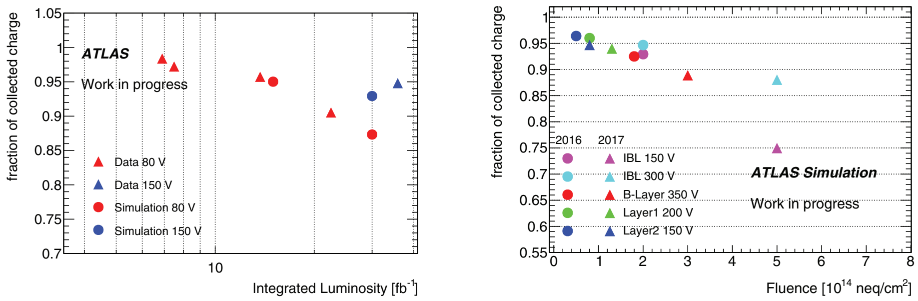

Fig. 1. – CCE as a function of inetgrated luminosity for data and simulation (left) and predicted CCE as a function of fluence (right).

3. – Validation on data

One of the variables relevant to the performance of the pixel detector is the Charge Collection Efficiency (CCE): the fraction of charge collected by the sensor with respect to a non-irradiated sensor. The CCE of the IBL module as a function of the integrated luminosity for both data and simulation is shown in fig. 1 on the left.

4. – Prediction

The good agreement with data suggests that we can use this simulation to make predictions for higher fluencies (and therefore integrated luminosities). The CCE for different layers of the barrel of the pixel detector is shown in fig. 1 on the right as a function of the fluence and bias voltage. The layers are at different distance from the beam pipe and, therefore, the corresponding fluences are different for the same integrated luminosity, which has been chosen to correspond to the level at the end of 2016 and 2017, respectively. Moreover, the bias voltage of the different layers is different. A significant degradation of CCE for the IBL is expected at the current operating voltage of 150 V, which can however be largely mitigated raising the bias voltage.

5. – Conclusion

Radiation damage effects are already visible in the pixel detector, and their inclusion in the detector simulation is needed in order to account for the loss of efficiency. A proposal for a simulation of the radiation damage has been presented and it is in good agreement with data.

Predictions have been made for increasing fluences and it appears clear that for the innermost layer an increase in the bias voltage will reduce the loss in CCE to a level comparable with the other layers.

REFERENCES

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