Introduction and Layout

- Four layers of silicon pixelated detector and 2x3 endcap disks in the ATLAS Inner Detector [1,2]
- Innermost layer (IBL) inserted in 2014 (planar & 3D sensors)
- First layer at 3.3 cm and outermost 12.3 cm away from interaction point
- Essential for tracking and vertexing (b-tagging)

Radiation Effects on the Front-End

- Early IBL LV current increase due to low TID effect [3]
- Counteract this beginning of Run 2 by changing operating temperatures and voltages
- At higher instantaneous luminosities, single event effects (SEEs) became an issue for the IBL [4]
- SEEs cause bit-flips in front-end registers and can make pixels get noisy or become silent → reflected in LV
- Mitigation strategies to reconfigure global front-end registers without dead-time were introduced → if not counter-acted, radiation effects will become more of an issue in Run 3 because of the higher integrated luminosity LHC fills

Mitigating Effects of Radiation Damage

- Detector kept cold (also in periods of shutdown) to minimise reverse annealing
- Frequent retuning (about every 5 fb⁻¹) of IBL to ensure uniform detector response
- Hybrid threshold tuning (n-dependent) in second pixel layer (B-Layer) to balance charge loss and bandwidth usage
- Threshold decrease necessary to retain tracking performance

Detector Operation in Run 2

- Run 2 data taking period of LHC between 2015 and 2018
- Collision rate of 40 MHz
- LHC delivered instantaneous luminosity of up to 2 x 10^{34} cm⁻² s⁻¹ → double with respect to LHC design (only IBL designed for those values)
- At the start of fill, the average pile-up (+µ-) extended to above 60
- Despite challenging conditions (bandwidth limitation & radiation effects), the detector performed well with a data-quality efficiency of 99.5%
- Dead-time contribution to ATLAS by Pixel only 0.2% (end of Run 2)
- Less than 5% of the modules not operational → good performance in Run 2

Radiation Damage on the Silicon Sensors

- IBL received fluence up to 10¹⁰ 1 MeV nₑq cm⁻²
- Charge trapping due to introduced defects → less charge
- Counteract this by decreasing thresholds
- HV increase to ensure full depletion
- Regularly perform HV scans to derive depletion voltage. Is input for radiation damage modelling → predict HV needed for full depletion and expected leakage currents
- Predicted leakage currents at the end of Run 3 within design limits
- Developed and deployed radiation damage modelling for Run 3 Monte Carlo simulation [5] → constant monitoring of radiation damage → predictions for operational parameters throughout Run 3

Conclusion and Outlook

- Good performance of the ATLAS Pixel Detector throughout Run 2, despite increasingly harsh conditions and radiation damage
- Radiation damage had measurable impact on the collected charge, but could be mitigated by lowering the thresholds → challenge with increased hit rates
- Extension of Run 3 poses challenges to Pixel, with the risk of having to run the B-Layer underdepleted
- Constant monitoring of the detector provides good modelling for the future
- For Run 3, additional pixel level register reconfiguration has been put in place to mitigate SEEs → Pixels ready for Run 3 and LHC intensity ramp-up

Operational Experience and Performance with the ATLAS Pixel detector at the Large Hadron Collider at CERN

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[1] G. Aad et al., ATLAS pixel detector electronics and sensors, 2008 JINST 3 (P07007)