Modeling Radiation Damage to Pixel Sensors in the ATLAS Detector

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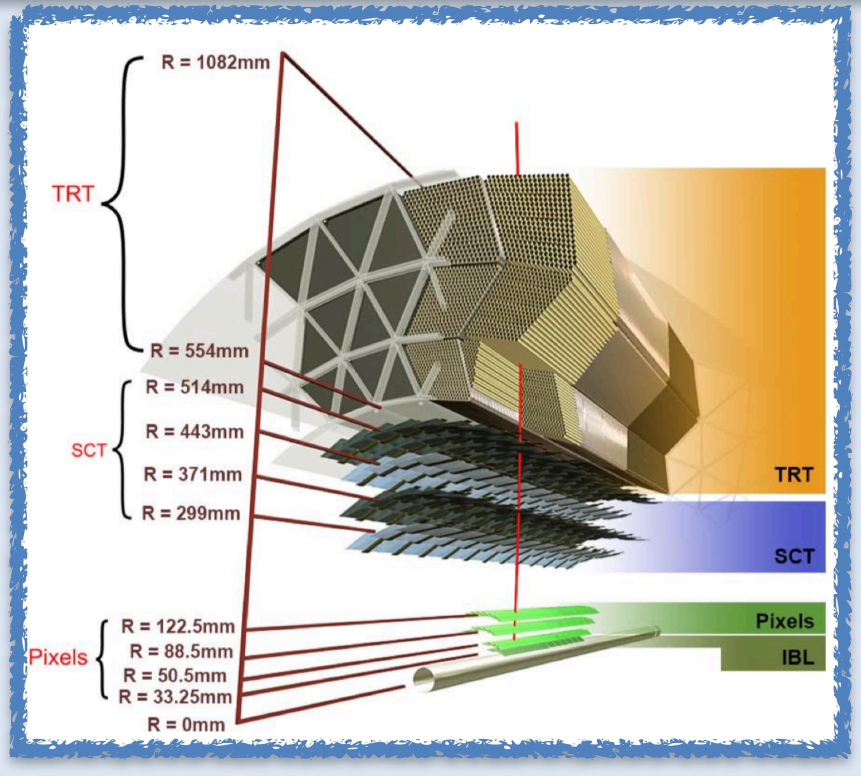
The ATLAS Pixel Detector

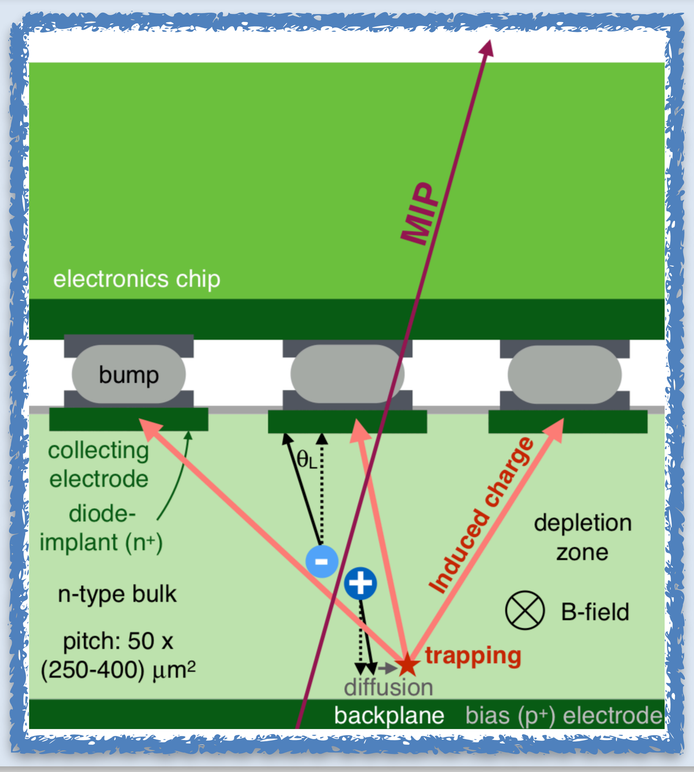
The ATLAS Inner Detector is composed of three sub detectors with the innermost one being the **Pixel Detector** [1][2]: 4 Barrel + 2×3 Disk Layers.
The barrel consists of three outer layers (B-Layer, Layer 1 and 2) with 50x400µm² pixels with a thickness of 250µm, and an innermost layer (IBL) of 50x250µm² pixels with a thickness of 200(230)µm for the planar (3D) sensors.

Due to its proximity of 3.3 cm away from the beam pipe, the IBL [2] is the most impacted layer by radiation damage.



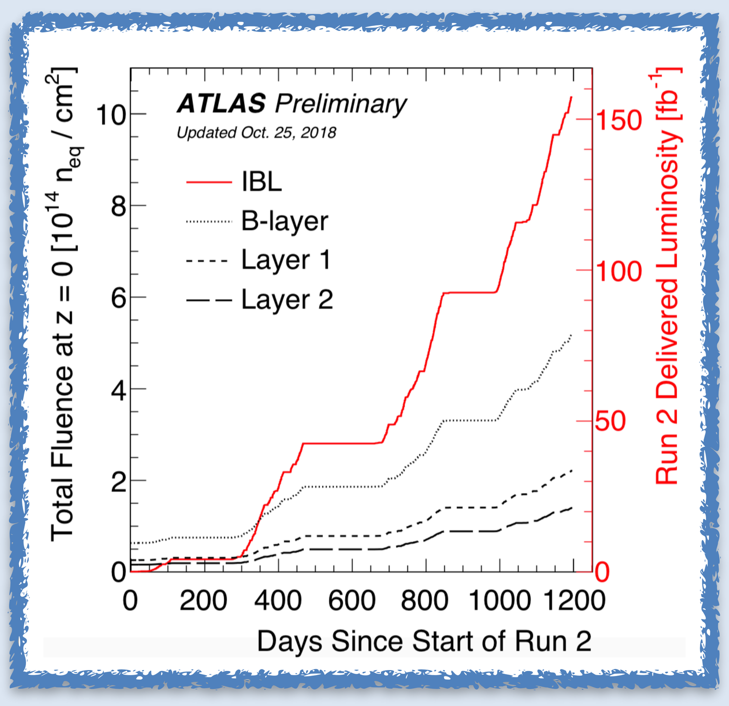
Radiation damage digitizer

- Software simulating the charge induced by particles has been developed to include radiation damage effects [3]
- Simulated physics processes include:
  - Charge drift
  - Lorentz angle
  - E-field modification (from TCAD simulations [4])
  - Trapping
  - Diffusion
  - Ramo potential



Fluence levels

- IBL accumulating fluence over time at higher rate than other layers
- end of Run2: $\sim 10 \times 10^{14} n_{eq}/cm^2$
- end of Run3: $\sim 18 \times 10^{14} n_{eq}/cm^2$

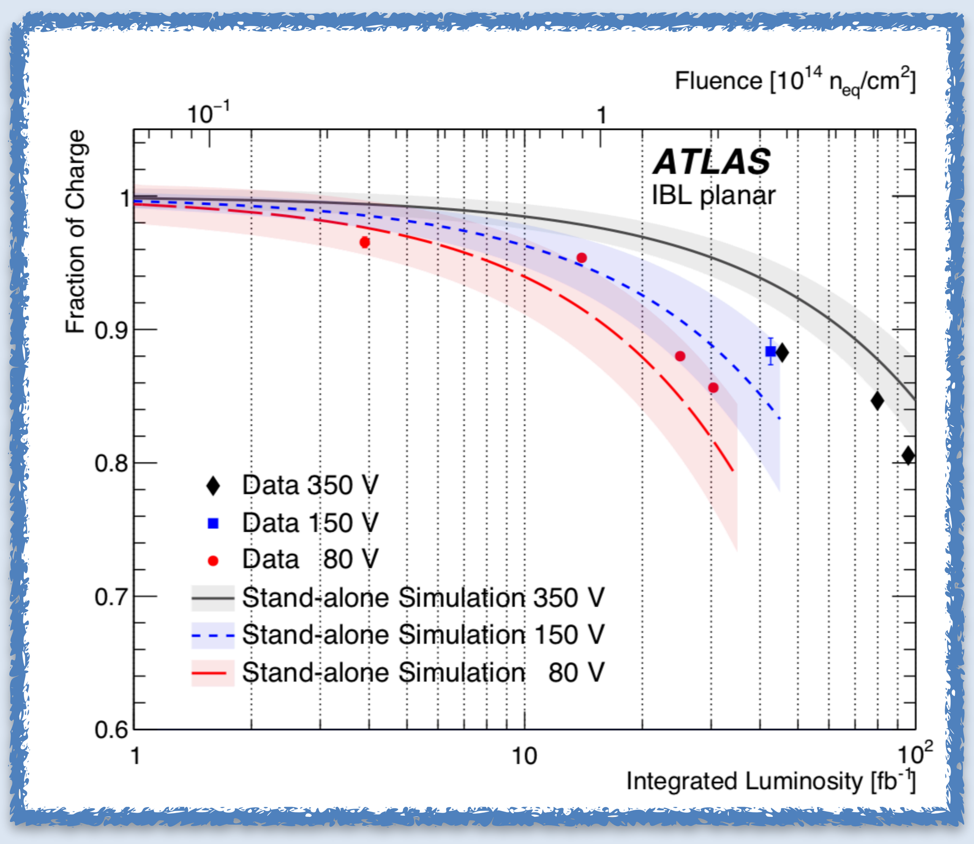


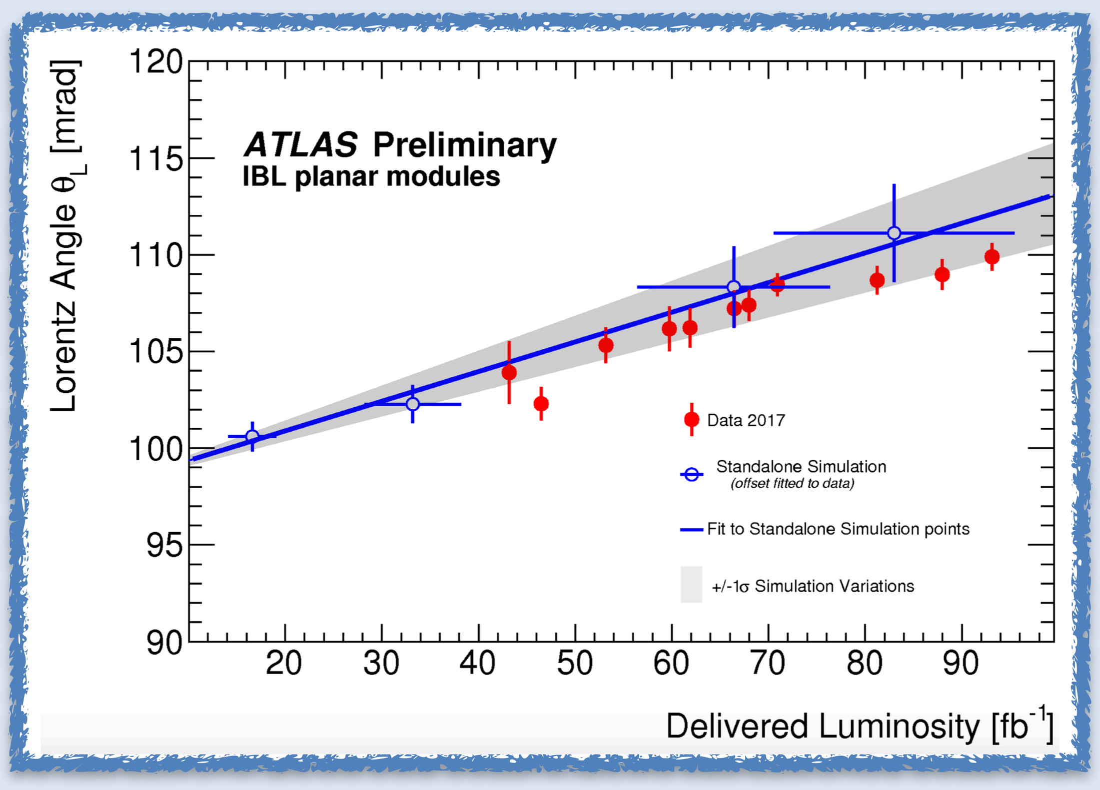
Results

- Direct way to see the impact of radiation damage: charge collection efficiency
- More fluence means more trapping so less charge collected

- Lorentz angle: angle minimizing the transverse cluster size
- Perfect compatibility between simulation and measurement

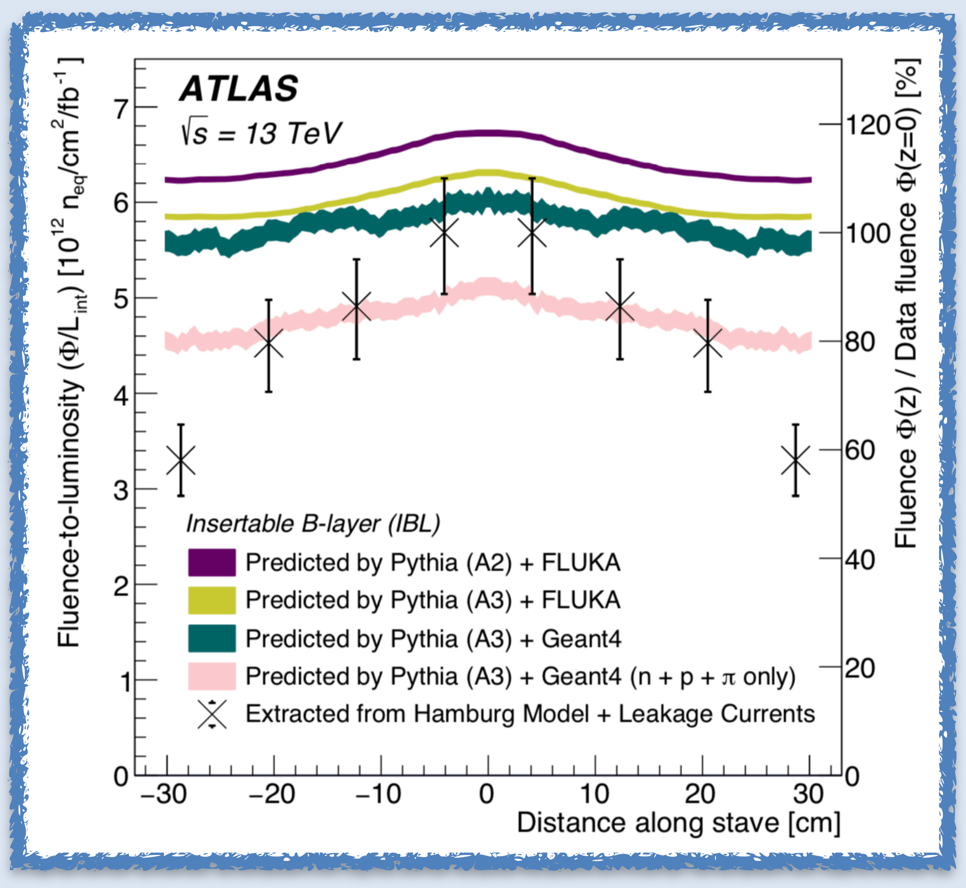
- Simulation error bars include radiation damage model parameter variations (trapping constant, introduction rates, and capture cross-sections)





Fluence measurement

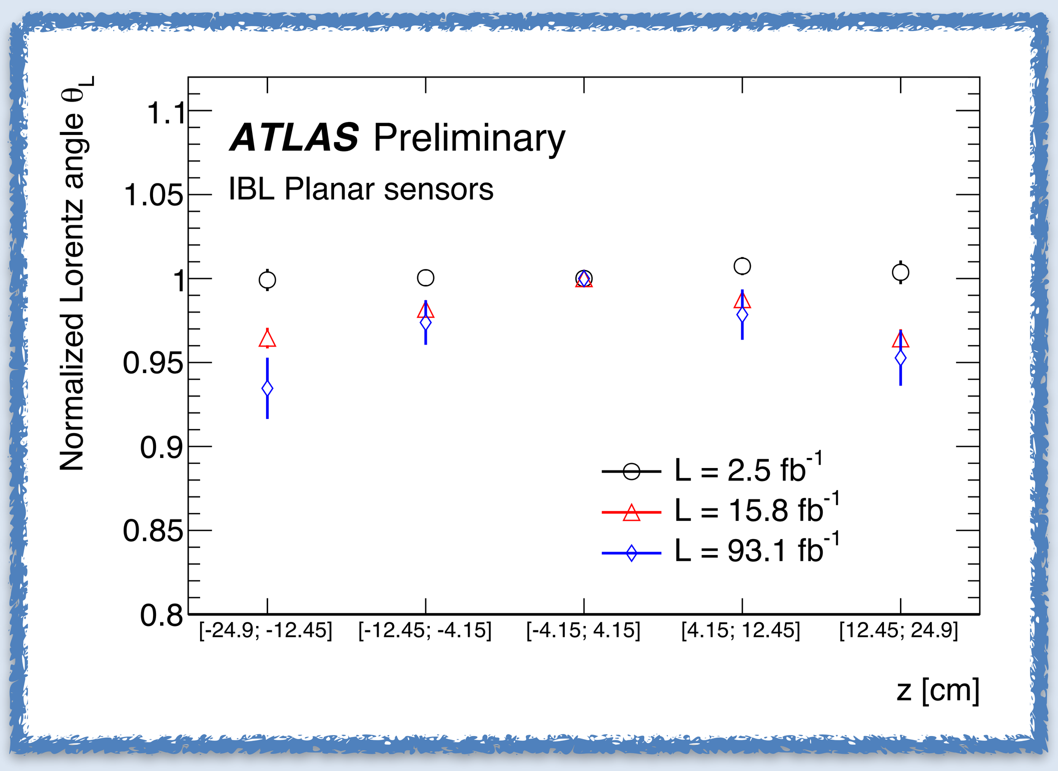
- Fluence is most important input to the simulation
- Measured using leakage current [3]
- Predictions agree with measured values at z=0
- Stronger z-dependence in measurement than in predictions for higher |z|



Latest measurements

z-dependency is also seen in other observables:

- **Lorentz angle:**
  More radiation in center of detector
  → Higher fluence values
  → Lower Electric field
  → Higher Lorentz angle
- Coherent trend in **depletion voltage** too



References

[1] G. Aad et al., “ATLAS pixel detector electronics and sensors”, JINST 3 (2008) P07007.
[2] Abbott, B. et al., “Production and Integration of the ATLAS Insertable B-Layer", JINST 13 (2018) no. 05,T05008
[3] ATLAS Collaboration, “Modelling radiation damage to pixel sensors in the ATLAS detector”. In: JINST 14 (2019), P06012
[4] V. Chiochia et al. “A Double junction model of irradiated silicon pixel sensors for LHC”. Nucl. Instrum. Meth., A568:51–55, 2006.

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