Radiation Damage Modeling for 3D Pixel Sensors in the ATLAS Detector

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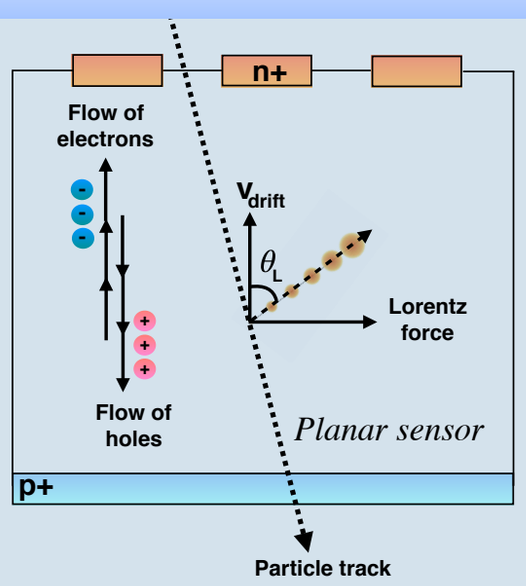
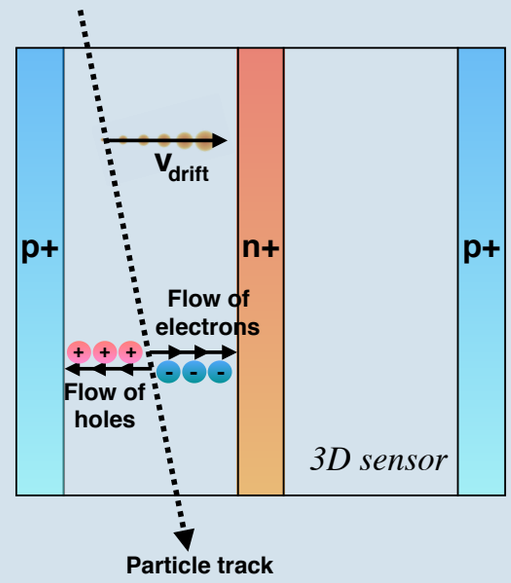
Radiation Damage in 3D Pixel Sensors

- Pixel sensors subject to extreme radiation environment result in decreased signal efficiency by causing charge carrier trapping in silicon bulk
- 3D sensors reduce charge collection time to lower risk of trapping, making them suitable for innermost pixel layer for HL-LHC upgrade, expected to receive fluence above $\Phi=10^{16}$ n_{eq}/cm^2 during its lifetime
- ATLAS pixel detector first high-energy physics application to use 3D sensors



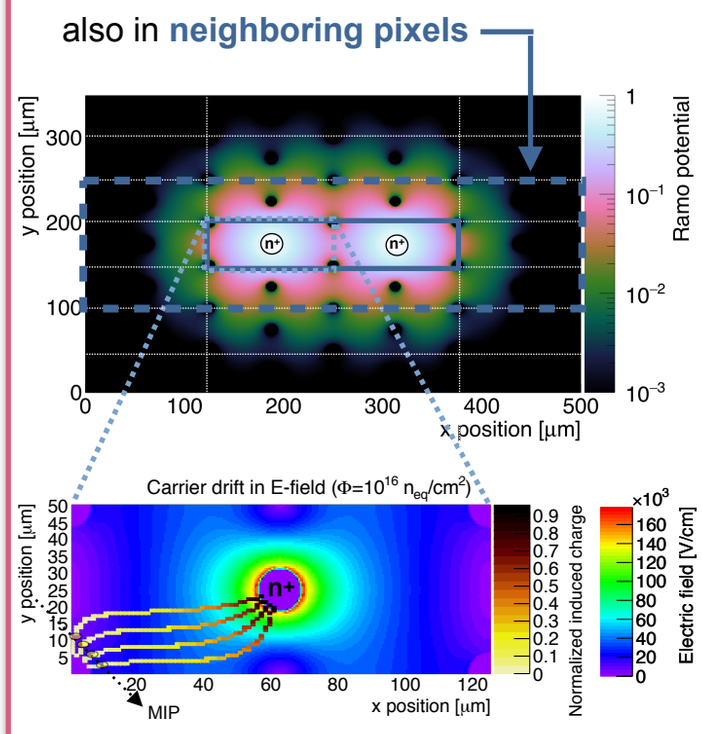


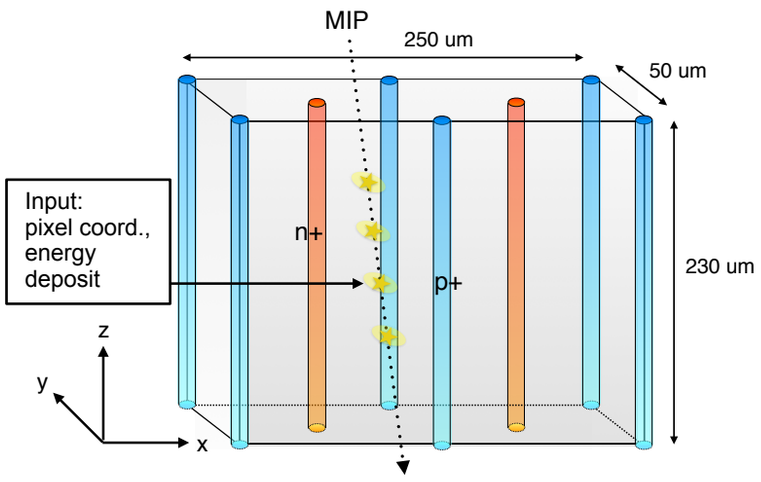
Charge Collection Model

- Charge induced by carriers moving in electric field computed through geometry-dependent ***Ramo Potential*** ϕ
- Carrier of charge q created at position (x_0, y_0) and getting trapped at position (x, y) induces charge

$$Q = -q[\phi(x,y) - \phi(x_0,y_0)]$$

also in **neighboring pixels**





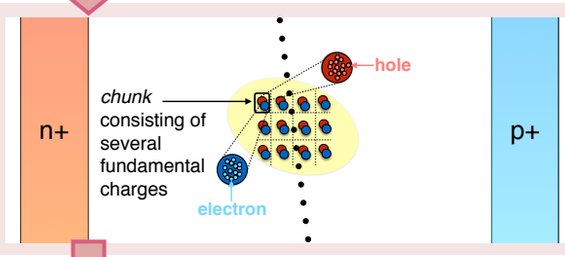
Inclusion of radiation damage effects in **digitization** step of ATLAS detector simulation:

Digitizer

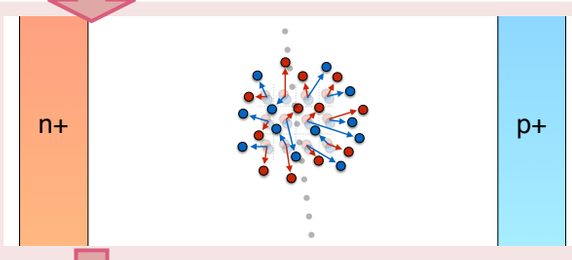
"hits"

Each "hit" of deposited energy gets divided into *charge chunks*, propagated separately.

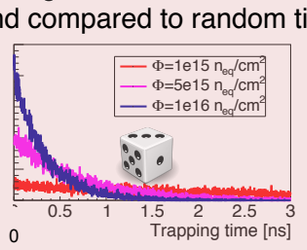
For each chunk:

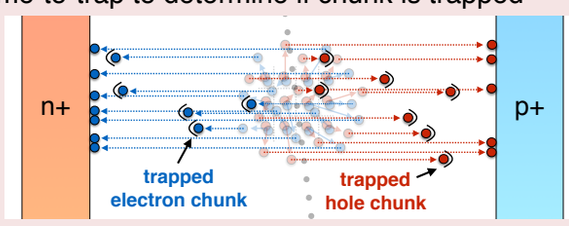


- Diffusion modeled by spreading chunks through random one-step jump in *x,y* drawn from Gaussian distribution



- Charge collection time retrieved from **lookup tables** and compared to random time-to-trap to determine if chunk is trapped

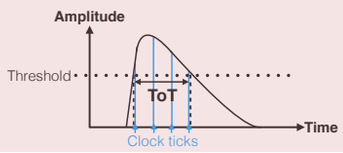




time-to-trap < collection time → trapped!

- **Induced charge** computed and **correction** applied

Charge contributions from all chunks added and converted to Time-over-Threshold (ToT) value, or "digit".

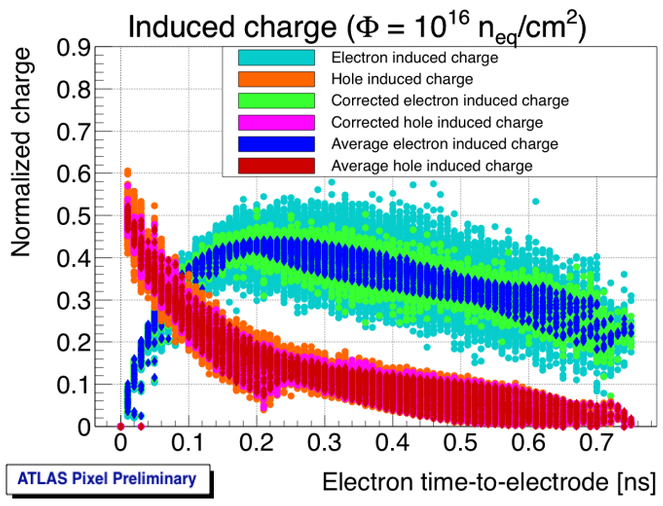


"digits"

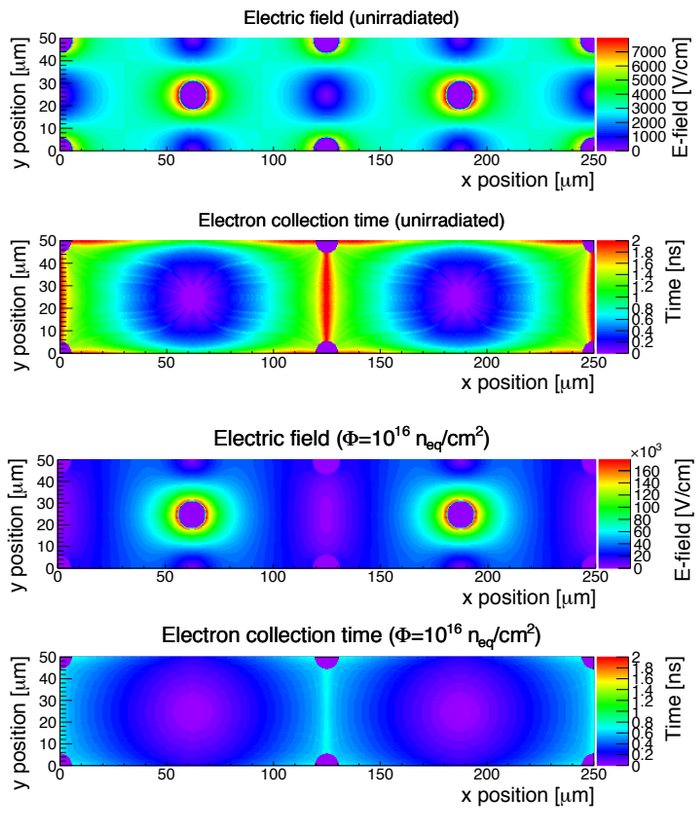
Output: ToT

Collectively propagating several charge carriers (~10) as "chunks" results in increased fluctuations of induced charge that are corrected for using the pre-calculated mean charge $\langle Q \rangle$ and number of fundamental charges in each chunk n

$$Q \rightarrow Q + \frac{1}{n}(Q - \langle Q \rangle)$$

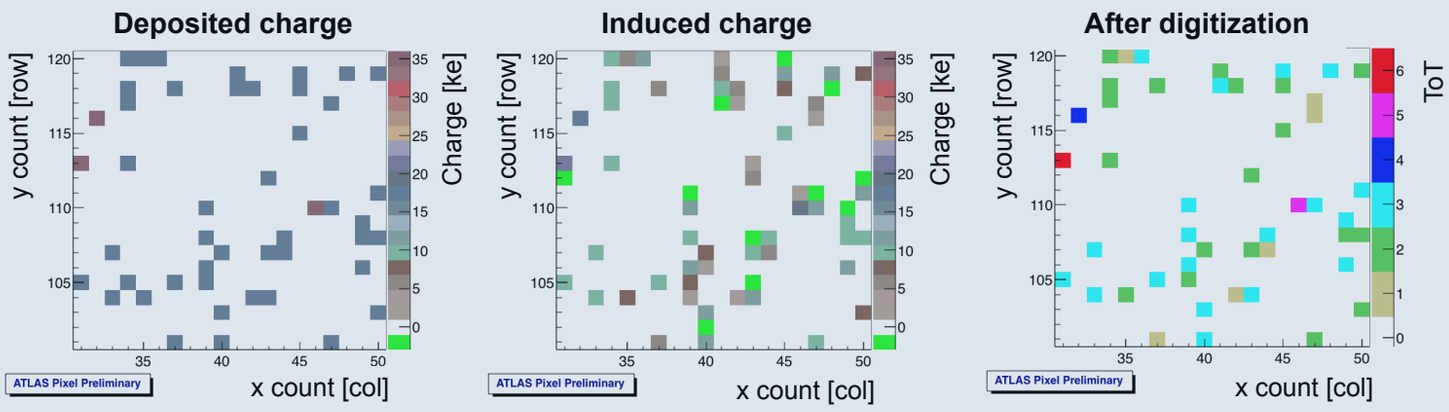


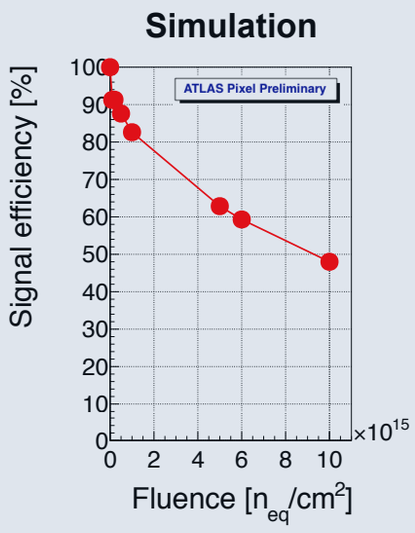
Electric field data gathered from simulations of the *Perugia model* [1] with the Synopsys TCAD package and used to compute carrier position and **collection time**, stored in lookup tables.

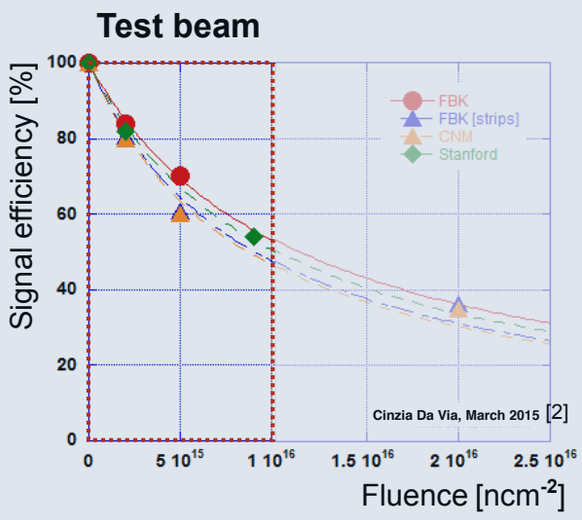


Results

Predictions from 3D digitizer model proved to agree with experimental data.







[1] F. Moscatelli et al., *Combined Bulk and Surface Radiation Damage Effects at Very High Fluences in Silicon Detectors: Measurements and TCAD Simulations, IEEE Transactions on Nuclear Science* **63** (2016) 2716

[2] C. Da Via et al., *3D active edge silicon sensors: device processing, yield and QA for the ATLAS IBL production, Nucl. Instrum. Meth* **A 699** (2013) 18

ATLAS EXPERIMENT