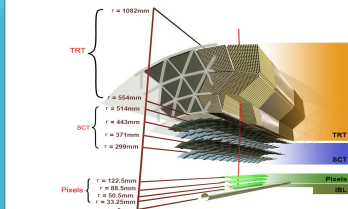


Silicon Pixel detectors are at the core of the current and planned upgrade of the ATLAS detector. As the detector in closest proximity to the interaction point, these detectors will be subjected to a significant amount of radiation over their lifetime: prior to the HL-LHC, the innermost layers will receive a fluence in excess of $10^{15} \text{ n}_{\text{eq}}/\text{cm}^2$ and the HL-LHC detector upgrades must cope with an order of magnitude higher fluence integrated over their lifetimes. This poster presents the details of a new digitization model that includes radiation damage effects to the 3D Pixel sensors for the ATLAS Detector.

ATLAS Pixel Detector



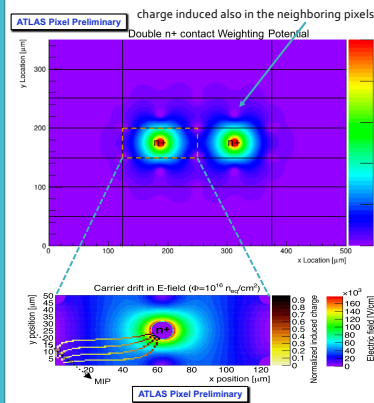
The ATLAS inner detector [1,2] is dedicated to the reconstruction of tracks from charge particles created at the point of interaction. It consists of three subdetectors; the closest to the beam pipe is a 92 Mpixel detector composed by 4 cylindrical layers and two end caps. The most internal barrel layer is the IBL (Insertable B Layer). Its proximity to the interaction point makes it particularly affected by radiation damages. The three outer layers and the IBL are mainly made of planar pixel sensors and of 3D pixel sensors.

Charge Collection and Ramo Potential

The charge induced by carriers moving in the electric field are computed through the geometry-dependent **Ramo Potential** ϕ [3]:

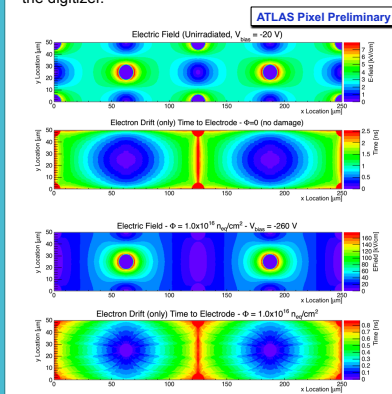
- a carrier of charge q created at a position (x_0, y_0) and trapped at (x, y) induces a charge

$$q_{\text{ind}} = -q \Delta\phi = -q [\phi(x, y) - \phi(x_0, y_0)]$$



Electric Field Maps

Electric field maps have been obtained by means of TCAD simulations (by Synopsys) in which radiation damages have been modeled through the *Perugia model* [4]. The field intensity and the corresponding drift times are stored in lookup tables for later use in the digitizer.



References

- [1] M. Capeans et al., ATLAS Insertable B-Layer Technical Design Report, tech. rep CERN-LHCC-2013. ATLAS-TDR-19.
- [2] G. Aad et al., ATLAS pixel detector electronics and sensors, JINST 3 (2008) P07007.
- [3] S. Ramo, Current Induced by Electron Motion, Proc. IRE 27 (1939) 584; W. Shockley, Currents to Conductors Induced by a Moving Point Charge, J. App. Phys. 9 (1938) 635.

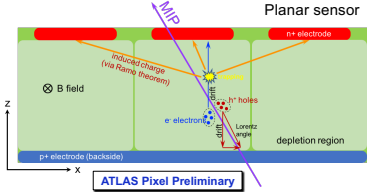
Silicon Sensors and Charge Collection

Principles of silicon detectors - Passage of a MIP particle creates electrons and holes in the sensor. Sensor is depleted and, because of the bias potential, the carriers drift towards the electrodes following the electric field E lines. Their motion is influenced also by thermal diffusion.

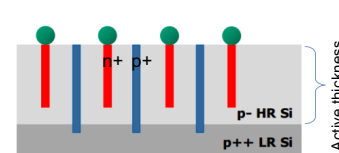
In the presence of a magnetic field B , carriers are deflected by the Lorentz angle θ_L with respect to the direction of E : θ_L is given by $\eta(E)B$ (η is the Hall scattering factor; $\mu(E)$ is the mobility).

Because of the carrier motion a charge is induced to the n+ electrode according to the Ramo's theorem [3]. This charge is used to reveal the MIP particle and to estimate its energy loss.

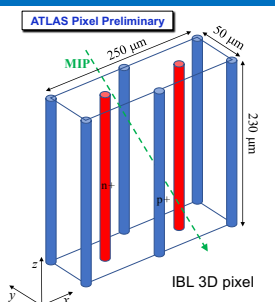
Radiation damage effects - In case of radiation damages carriers may be trapped along their path to the electrodes, thus reducing the induced charge to the electrodes.



3D Pixel Detectors



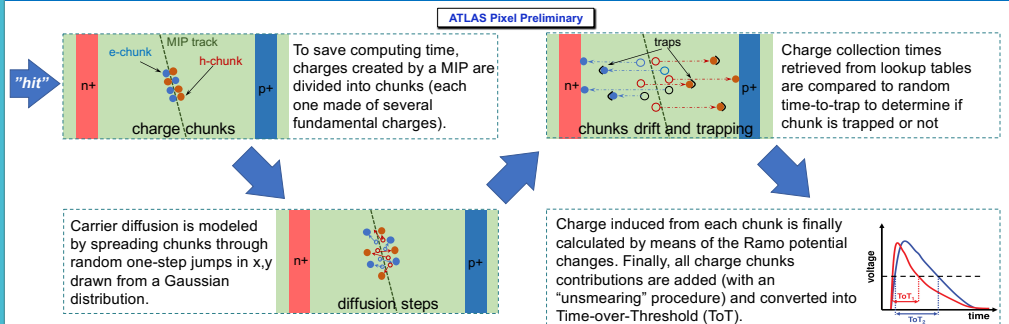
Differently from planar sensor, in 3D devices n+ and p+ electrodes correspond to vertical columns. Because of the reduced distance between n+ and p+ columns charge collection times are strongly reduced; this feature makes these detectors tolerant to radiation and particularly suited for the innermost pixel layer of the ATLAS detector (in the HL-LHC upgrade fluence is expected to reach values above $10^{16} \text{ n}_{\text{eq}}/\text{cm}^2$).



Other peculiarities of 3D pixels

- the motion of charge carriers is perpendicular to n+ and p+ columns;
- the electric field E is essentially independent on z: only 2D maps of E are needed to simulate the charge carrier motion;
- in IBL 3D sensors, θ_L is negligible due to the particular E and B configuration.

3D Pixel Digitizer: schematic structure



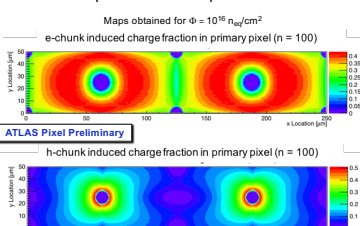
The digitizer has been implemented and tested; soon it will be integrated in the ATLAS simulation framework (ATHENA).

Alternative Digitizer Approach

A different approach has also been considered. Indeed, we verified that:

- induced charge scales linearly with the chunk size
- induced charge fluctuations are normally distributed.

On the base of these facts we demonstrated that the induced charge of chunks of any size can be retrieved from lookup tables (see the color maps) where induced charge is returned as a function of chunk initial position within a pixel.



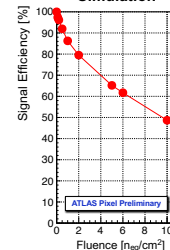
This approach allows a consistent simplification in the digitizer structure and in a relevant reduction in the simulation times.

Results and Conclusions

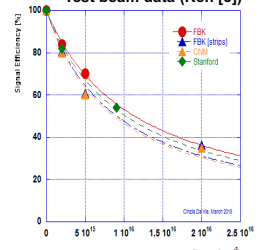
Results

- Charge Collection Efficiency predictions are in very good agreement with test beam data (see plots below).
- The hit distribution as a function of ToT follows a Landau distribution as expected.

Simulation



Test beam data (Ref. [5])



Conclusions

- The digitizer allows for an accurate evaluation of the induced charge in pixels; charge sharing effects are also included in the calculations.
- Fluctuations caused by charge chunks are accurately treated.
- Efforts to decrease the simulation time consumption have also been considered.