Monitoring radiation damage in the ATLAS Pixel Detector

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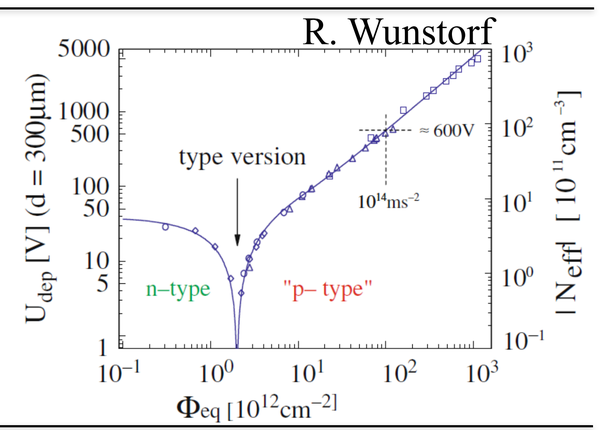
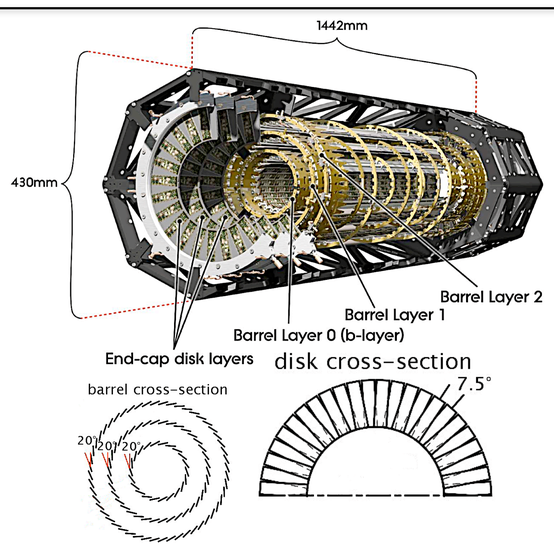
Introduction

- Radiation damage effects change the properties of the sensor:
  - Lead to a decrease in the detector efficiency.
  - Negative impact on b-tagging and tracking efficiencies.
- Thus it is crucial to monitor and validate the impact of the irradiation on a regular basis.

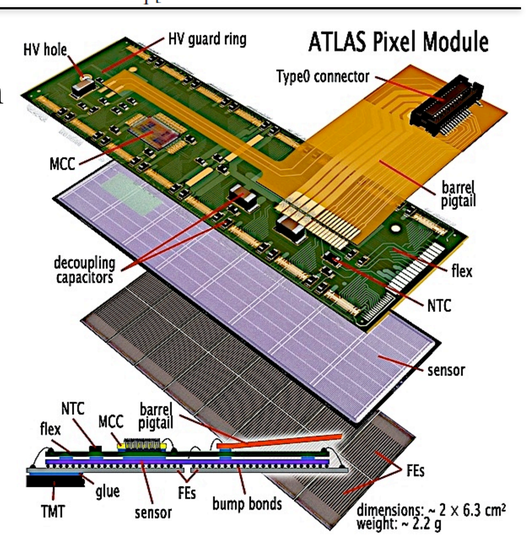


The ATLAS Pixel Detector

- Provides particle tracking within the pseudorapidity range of $|\eta| < 2.5$.
- Detector consists of 3 barrel layers and 2x3 end-cap discs.
- Holds 1744 modules and 80 million readout channels in total.
- Radiation tolerance of 500 kGy or 10^{15} 1MeV n_{eq} cm^3.

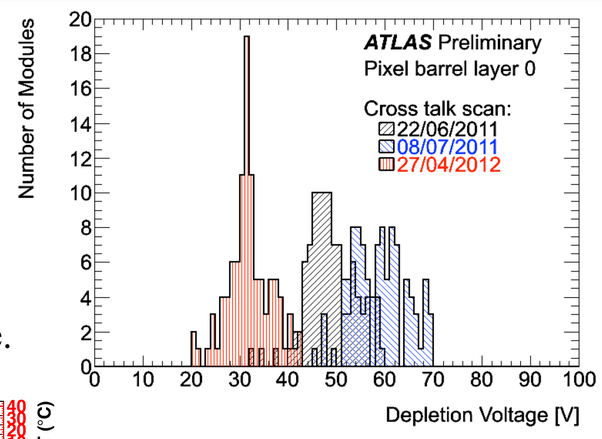


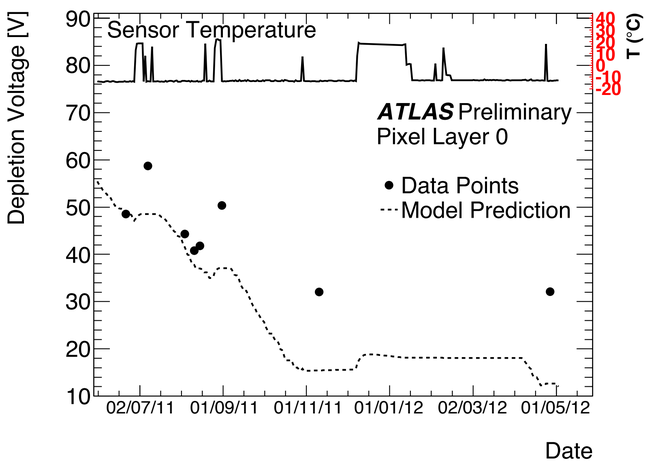
- A module consists of the sensor, the readout electronics and a flex hybrid which holds supply and control units.
- The n-on-n sensor bulk is 250 µm thick.
- A sensor has 47232 (328 x 144) pixels with a nominal size of 400x50 µm^2.
- The readout system consists of 16 FE chips each for 2880 pixels.
- Ganged and long pixels cover the gaps.



Effective depletion voltage measurements

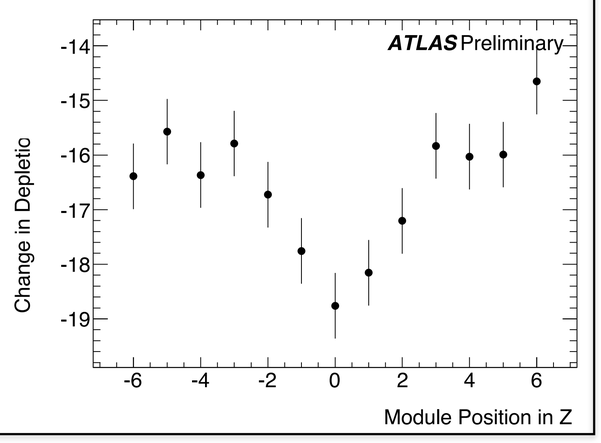
- Pixel cross talk used before type-inversion:
  - Sensor not fully depleted → short between pixels.
  - Sensor depleted → pixels isolated.
- Sequentially inject charge into 2 pixels and read out pixel in the centre.





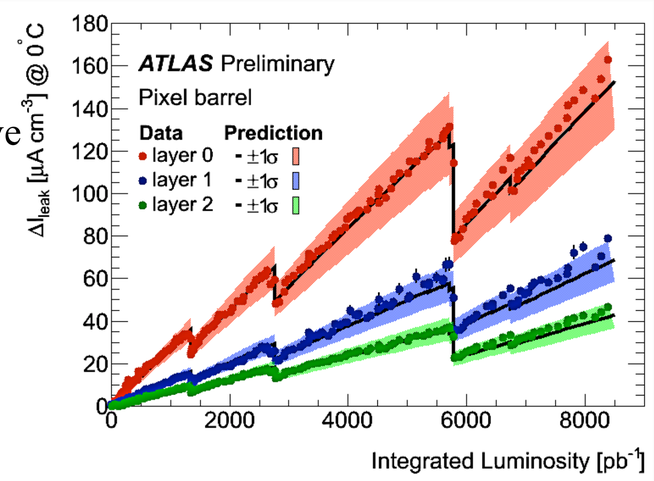
- Change in depletion voltage between first and last scan as a function of the module position along the barrel.
- Fluence is larger for modules closer to the interaction point.

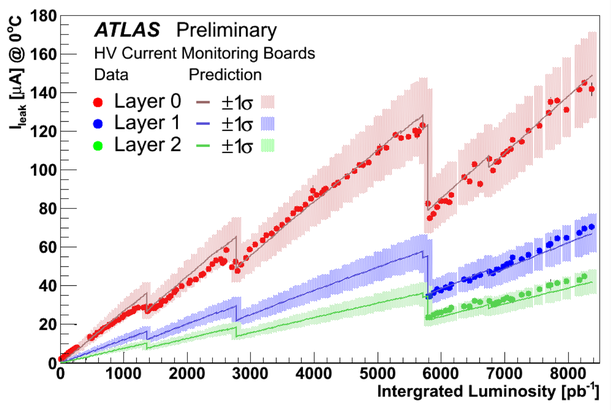
- Depletion voltage in Layer 0 is decreasing with time.
- Annealing effects induce an increase after cooling stops.

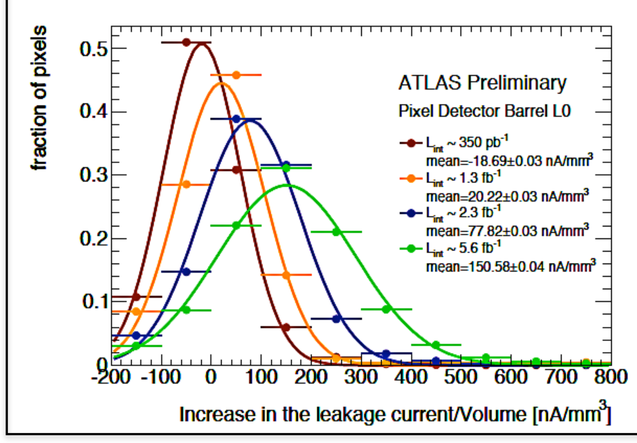


Measurements of the leakage current

- Leakage current measurements:
  - Power supplies: precision of ~80 nA per half-stave of 6 or 7 modules.
  - Current monitoring boards: precision of ~10 nA per module.
- All currents normalised to 0° and averaged for each layer.
- Increase is proportional to integrated luminosity.
- Beneficial annealing observed during cooling stops.
- Model scaled up by 15% in Layer 0 and by 25% in Layer 1and 2.



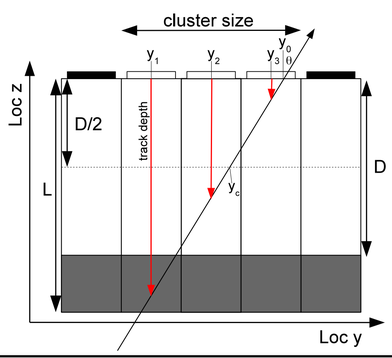




- A scan allows to measure the leakage current for each pixel.
- Increase is measured using the first scan as a reference.

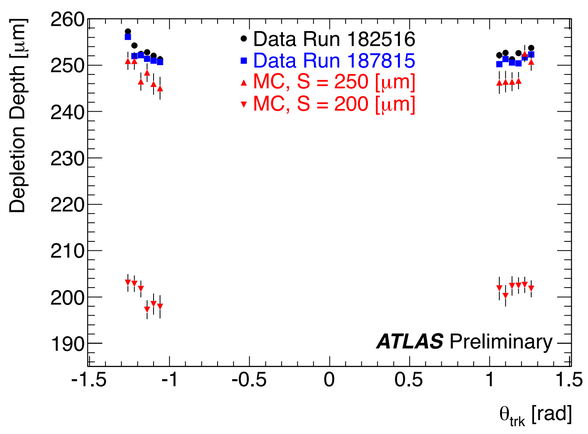
Track based depletion depth measurements

- Uses reconstructed track and cluster size to calculate the depth of the track in the sensor.
- Pixel Detector is currently fully depleted.



Track depth:

$$td = \frac{y_0 - y_i}{\tan\alpha}$$



- Measured depletion depth is in agreement with the sensor thickness.
- MC results are consistent with simulated depth S.

Summary and conclusion

- Radiation damage effects are clearly visible in data: routinely monitored by a number of methods.
- Depletion voltage close to expected minimum: type inversion is imminent.
- A Fully data driven depletion depth method has been developed.
- Continuous monitoring of the depletion depth after type inversion during normal operation.
- Measurements of the leakage current are in good agreement with each other and with the model prediction.