Monitoring the Radiation Damage of the ATLAS Pixel Detector

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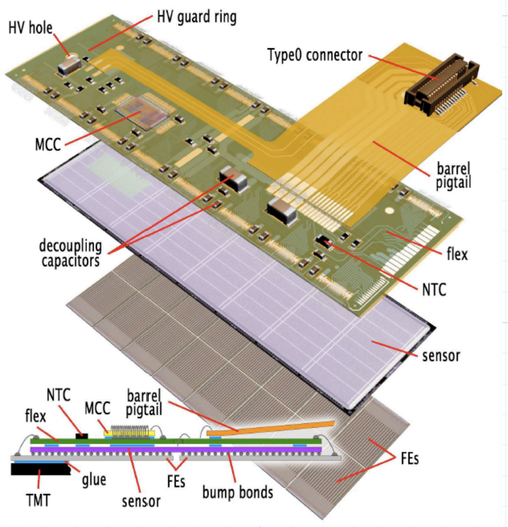
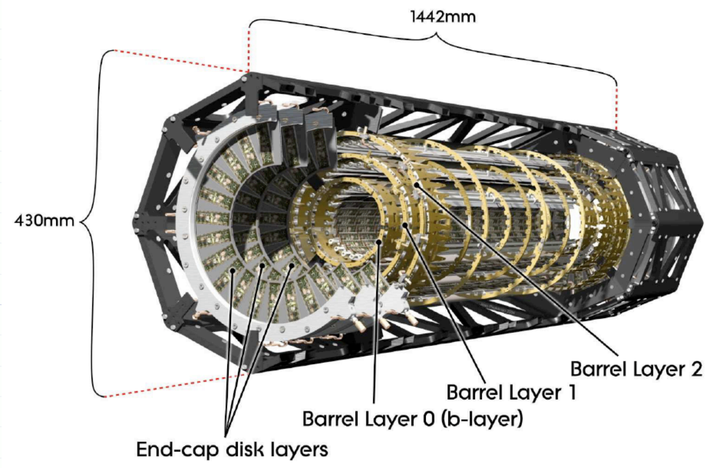
on behalf of the ATLAS Collaboration

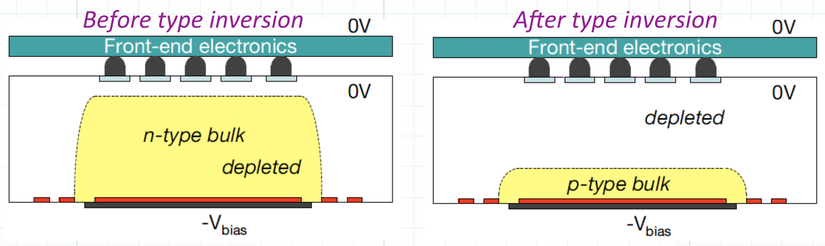


The pixel detector is the innermost charged particle tracking component employed by the ATLAS experiment at the CERN Large Hadron Collider (LHC). The detector consists of approximately 80 million pixels, with a typical size of 50 µm x 400 µm, grouped on modules composed of a silicon sensor, front-end electronics, and flex-hybrids with control circuits. The radiation dose on the innermost layer is expected to reach 500 KGy (or about 10^{15} n_{eq} cm^{-2}) after approximately 5 years of LHC operation at 10^{34} cm^{-2} s^{-1}. The outer layers are expected to reach this dose after approximately 10 years. Methods based on depletion properties and leakage current are used to monitor the evolution of the radiation damage.

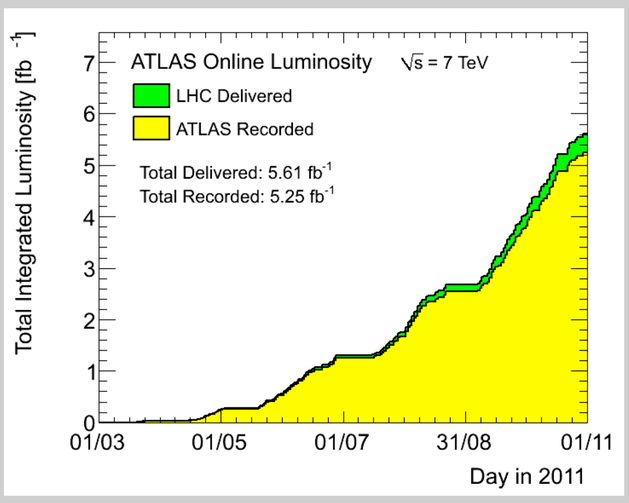


n+ -in- n Sensor Technology

The sensor consists of a 256 ± 3 µm thick n-bulk with n+ implants on the readout side and the p-n junction on the back side. Pixels are segmented with moderated p-spray between the n+ implants. As a bias voltage is applied, sensor depletion starts at the back side (p). The pixels are not fully isolated until full depletion is achieved. After sufficient radiation damage the bulk will convert to p-type (type inversion). The junction then moves to the readout side, isolating the pixels even if the bulk cannot be fully depleted.



Luminosity Profile of 2011 Run



Basic parameters of the barrel region

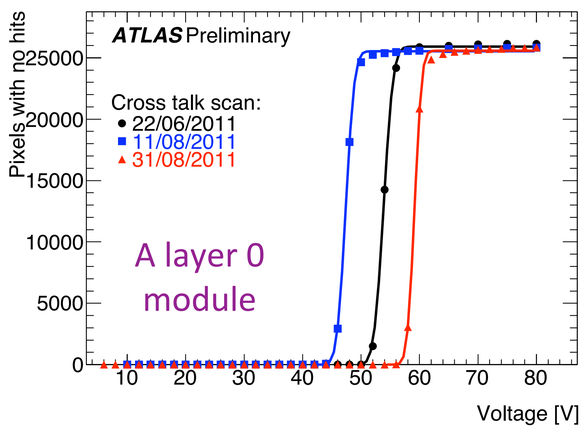
Layer Number	Mean Radius [mm]	Number of Staves	Number of Modules	Number of Channels	Active Area [m^2]
0	50.5	22	286	13,178,880	0.28
1	88.5	38	494	22,763,520	0.49
2	122.5	52	676	31,150,080	0.67
Total		112	1456	67,092,480	1.45

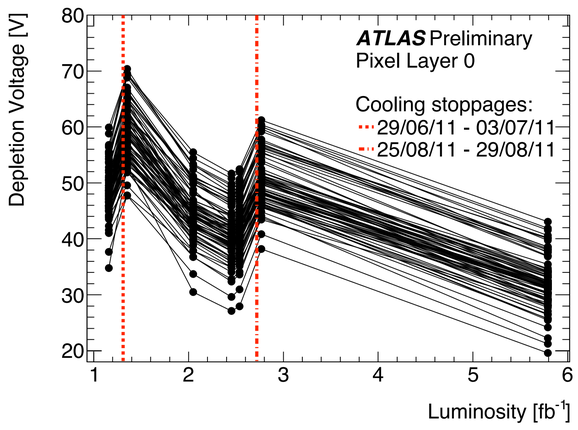
Basic parameters of the endcap regions

Disk Number	Mean z [mm]	Number of Sectors	Number of Modules	Number of Channels	Active Area [m^2]
0	495	8	48	2,211,840	0.0475
1	580	8	48	2,211,840	0.0475
2	650	8	48	2,211,840	0.0475
Total one endcap		24	144	6,635,520	0.14
Total both endcaps		48	288	13,271,040	0.28

Depletion Voltage From Cross-Talk Scans

Before type inversion, the depletion voltage is measured by the "cross-talk" scan, whereby charge is injected into a neighbor of a given pixel being readout. The measurement is repeated over a range of bias voltages. When fully depleted pixels are isolated and hence the number of pixels without cross-talk hits is maximal.

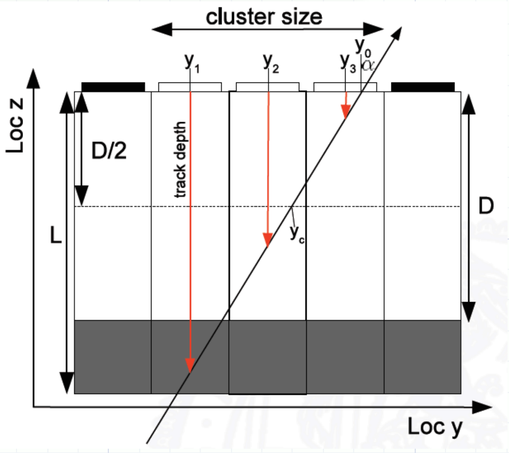


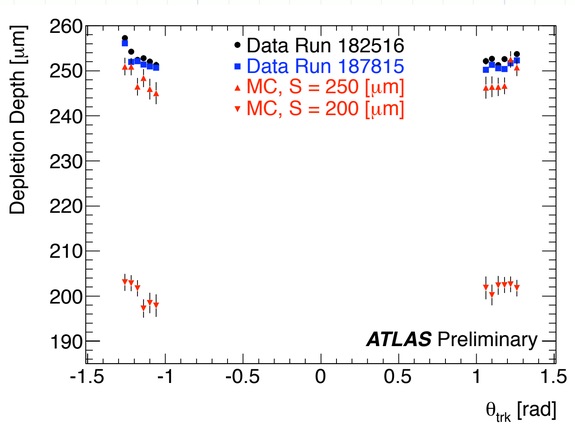


The depletion voltage is observed to decrease with integrated luminosity, reflecting the impact of radiation damage and evolution towards type inversion. The increase at the cooling stoppages is a consequence of beneficial annealing.

Depletion Depth From Tracks in Data

Type inversion of the innermost layer is expected in late 2012, after which the cross-talk method is no longer viable for monitoring the depletion voltage. Instead, a collision data based method using tracks will be used to measure the depletion depth. The input values are the cluster size, the angle of incidence, and the entry point.



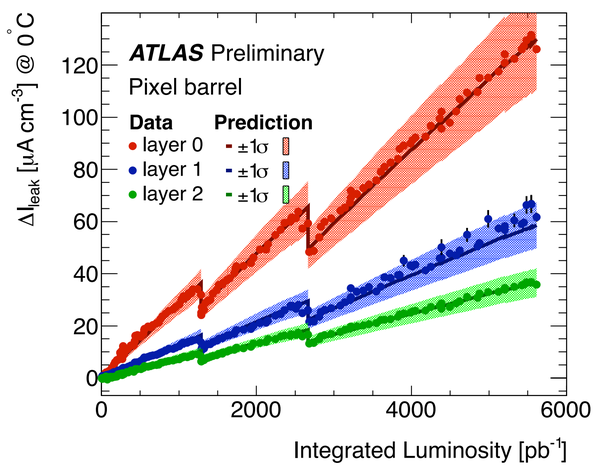


During the 2011 run the sensors were operated fully depleted. The measured depletion depth is therefore in agreement with the sensor thickness 256 ± 3 µm. The errors shown are statistical. The total uncertainty is 10 µm.

Leakage Current From High Voltage Power Supply

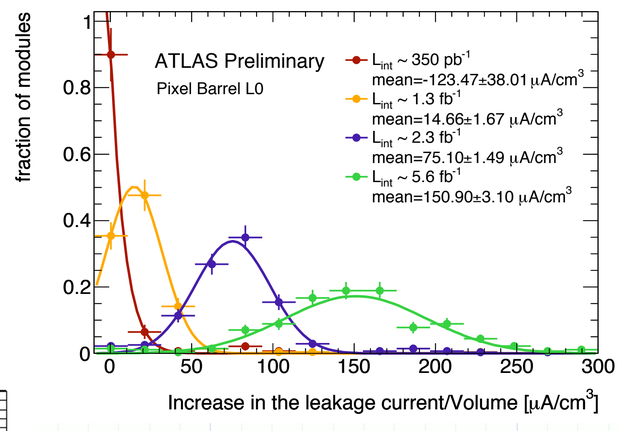
Another consequence of radiation damage is an increase in the leakage current. The current is measured with 80 nA precision for groups of 6/7 modules at the output of the high voltage power supply. The leakage current is corrected to a reference temperature at 0° C and shows a linear correlation with the integrated luminosity. The discontinuities are a consequence of beneficial annealing during the cooling stoppages. The prediction shown is based on the delivered luminosity, the expected fluence (Phojet+FLUKA simulation), and a damage coefficient α. The absolute prediction has been scaled up by +15% (Layer 0), +30% (Layers 1 and 2).

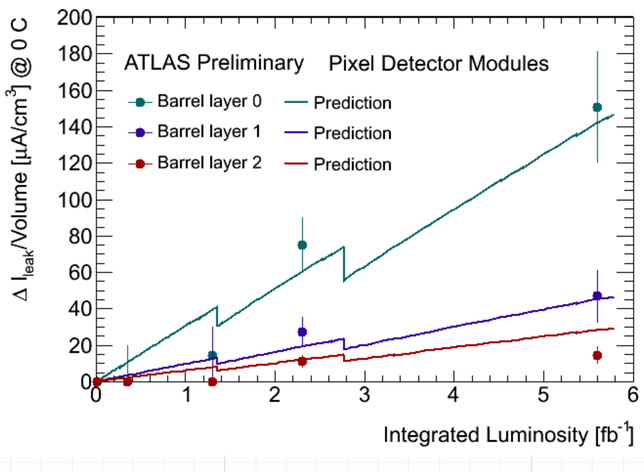
Current monitoring boards for single module leakage current measurements with 10 nA precision are being deployed. Results from the installed boards are in good agreement with those from the power supplies.



Leakage Current From Feedback Circuit

The pixel front-end chip FE-13 allows the measurement of the single pixel leakage current. The current in the feedback branch of the pixel preamplifier is mirrored and digitized with 10-bit precision over the range 0.125 nA to 128 nA.





For comparison with the measurement at the high voltage power supply, the pixel level leakage currents are converted here to module level leakage currents. Good agreement is observed between the two techniques.

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