Monitoring radiation damage in the LHCb Silicon Tracker

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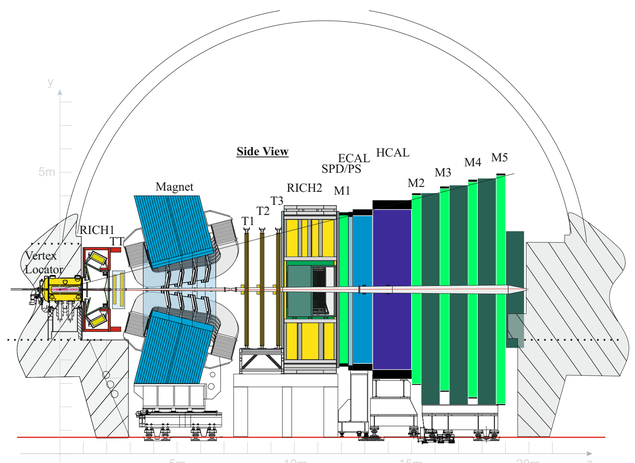
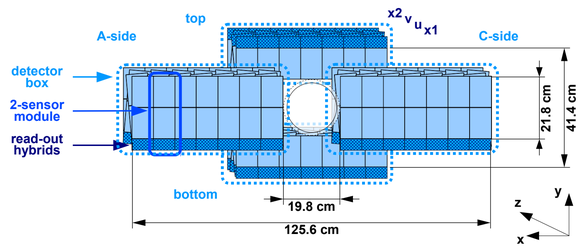
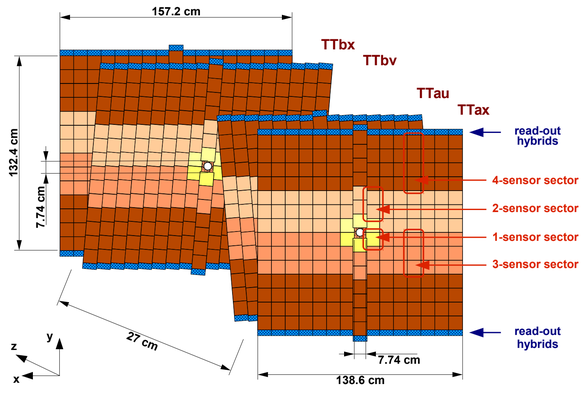
The LHCb Silicon Tracker (ST)

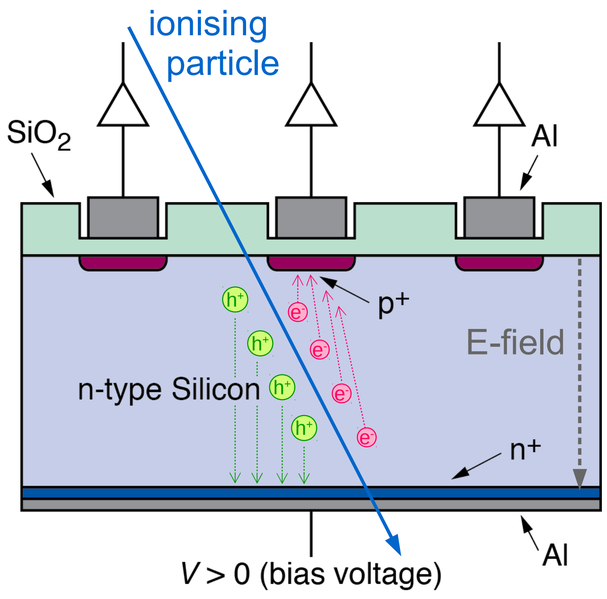
The ST comprises the tracking station upstream of the magnet (TT) and the inner section of each of the three downstream tracking stations (IT). Both employ p^+-in-n 320 to 500 µm thick silicon micro-strip sensors, grouped into readout sectors according to their occupancy.







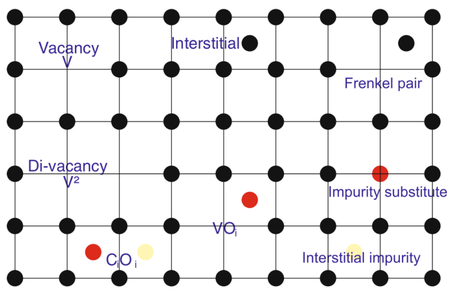
Silicon sensors

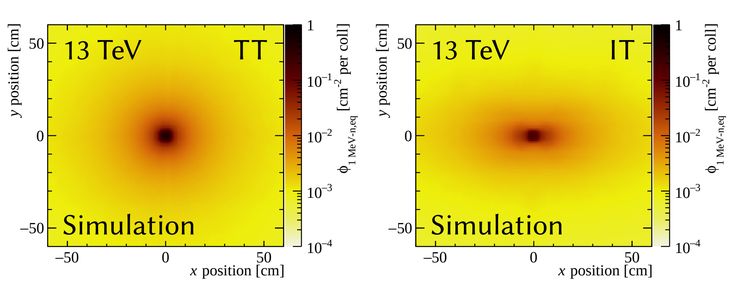


Silicon sensors are *pn* junctions operated in reverse bias mode. Charged particles create h^+e^- pairs in a region depleted of thermal charge carriers by means of the applied bias voltage. Charges are then collected at the metal implant and read out. The mobility of the charge carriers depends on the magnitude of V_{bias}.

Radiation damage in silicon [1]

- Fluence $\Phi \sim 10^{15}$ cm^{-2} integrated over LHC Run I–II
- Irradiation creates defects in the silicon lattice
- Crucial to monitor the evolution of the sensors properties



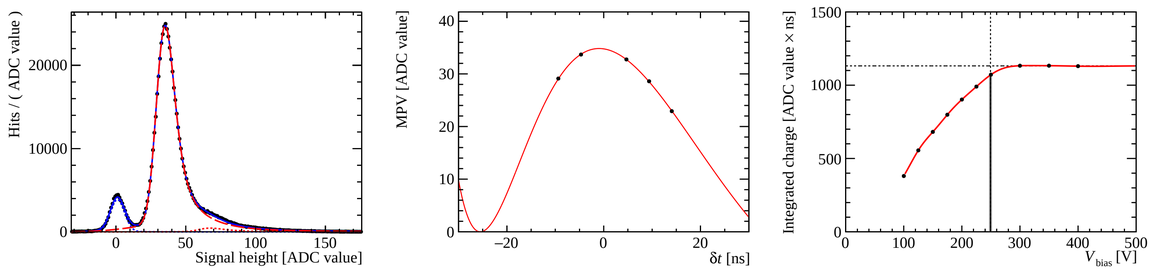


Monitoring the ST radiation damage

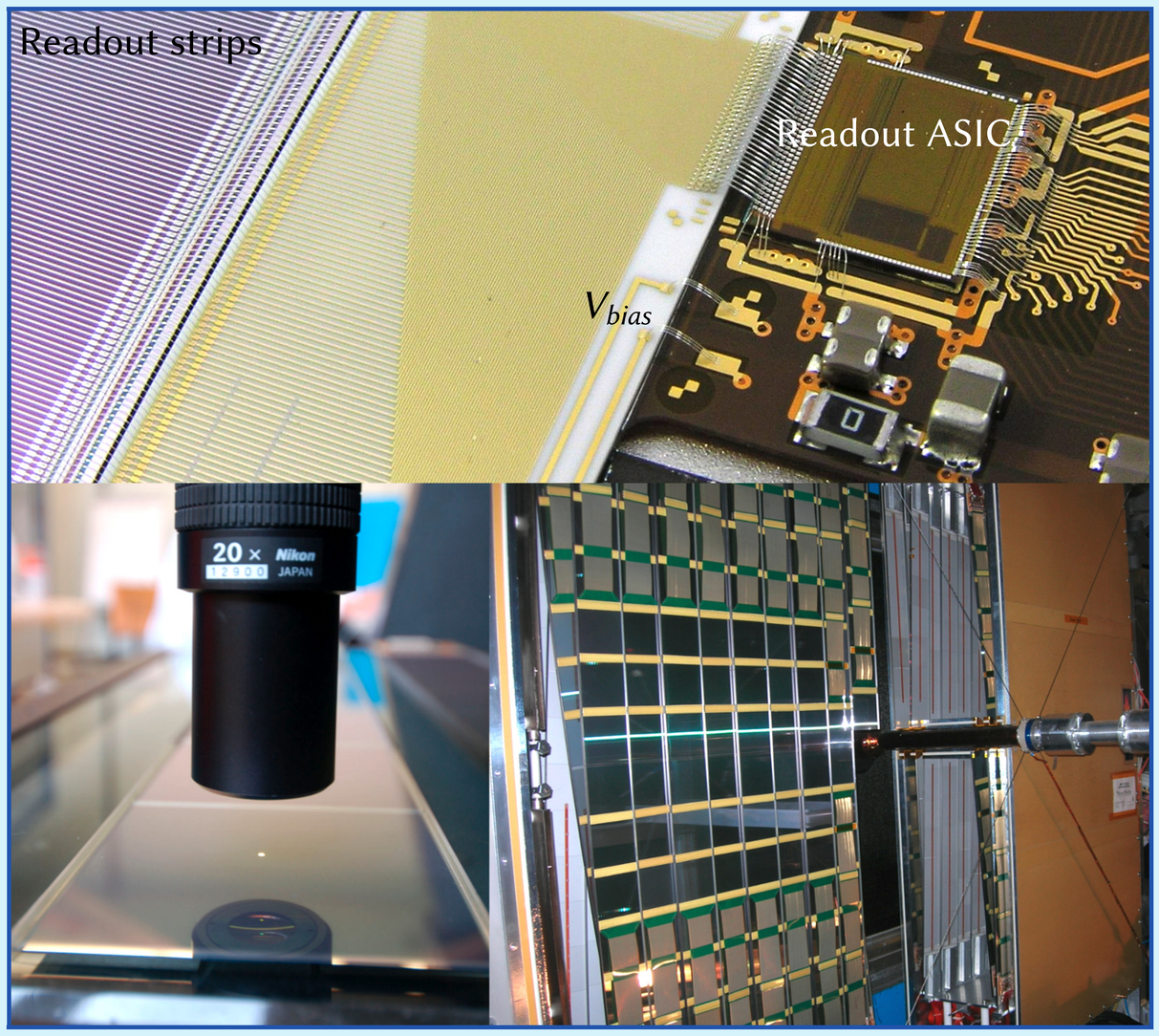
Two observables are monitored:

1. the sensor leakage current (registered in the HV channels),
2. the sensor depletion voltage, with dedicated **CCE** scans.

Charge **C**ollection **E**fficiency is measured as a function of increasing bias voltage. For each tested V_{bias}, a timing scan is performed, to collect the whole signal regardless of its speed.



The results are compared to predictions based on FLUKA irradiation maps simulated for the various beam energies from 2010 to 2017, on the measured detector temperature, and on the luminosity delivered to LHCb.



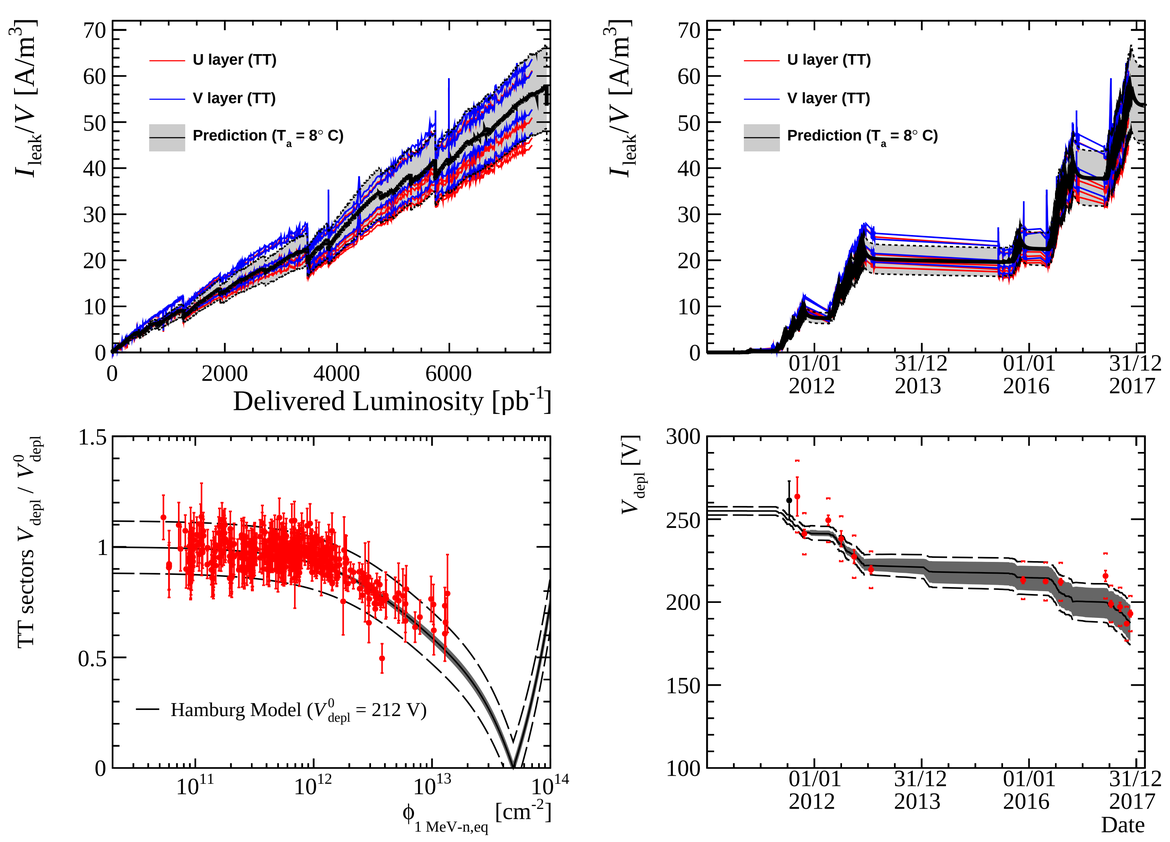
The Hamburg model for silicon ageing [2]

The change $\Delta n_{eff} \equiv n_c + n_a + n_r$ in the effective doping concentration can be described by three different contributions:

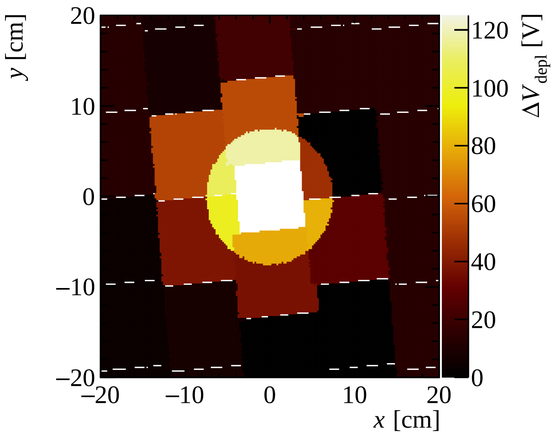
- removal of donors and introduction of stable acceptors due to a change in the band structure: $n_c = n_c^0\left(1 - e^{-c\Phi}\right) + g_c\Phi$
- temperature-dependent annealing of defects: $n_a = g_a\Phi e^{-t/\tau_a}$
- temperature-dependent combination of individual defects ("reverse annealing"): $n_r = g_r\Phi\left[1 - 1/\left(1 + t/\tau_r\right)\right]$

Defects in the silicon bulk lead to an increase in leakage current given by $\Delta I/V = \alpha\Phi$, where $\alpha = \alpha_0 + \alpha_1 e^{-t/\tau_I} + \alpha_2 \log t/t_0$.

Results



Smooth agreement with ageing predictions. Both TT and IT will withstand operation until the end of Run II, even in the inner regions. After Run II they will be replaced in the context of the LHCb upgrade.



References

[1] F. Hartmann. "Evolution of Silicon Sensor Technology in Particle Physics". In: Springer Tracts Mod. Phys. 231 (2009), pp. 1–204.

[2] M. Moll. "Radiation damage in silicon particle detectors: Microscopic defects and macroscopic properties". PhD thesis. Hamburg U., 1999.

∗ on behalf of the LHCb collaboration