Radiation Damage in the LHCb VELO

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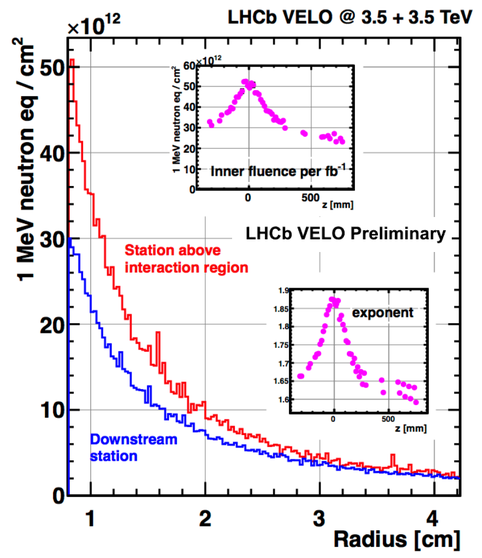
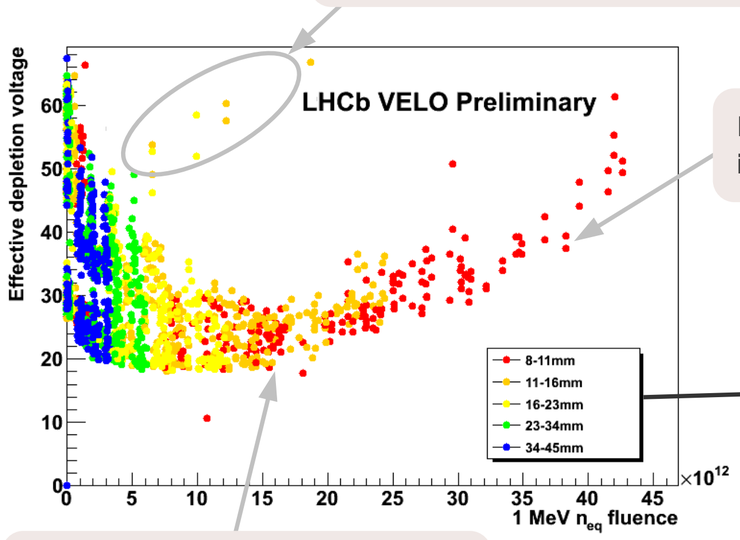
Expected and Current Dose

- The VELO was designed to tolerate 5 years of running with the LHC at 14 TeV.
- In 2011 the LHC operated with 7 TeV p-p collisions so we expect a small reduction in expected dose per inverse-femtobarn.
- So far ~1.22 fb^{-1} collected between 2009 and 2011.
- Both the centre-of-mass energy and luminosity are increased for 2012.

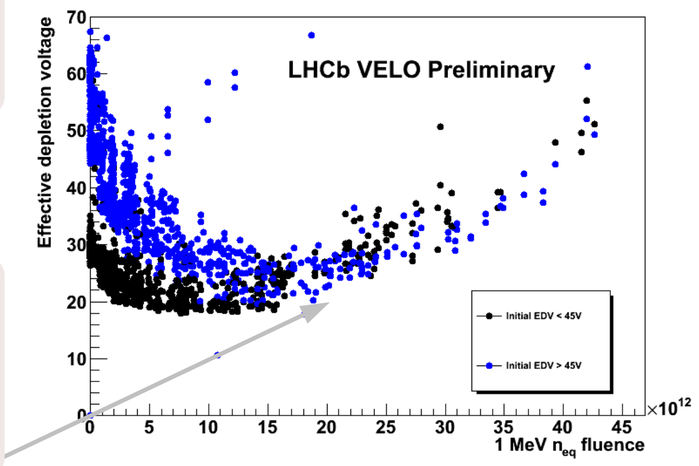


The **n-on-p sensors** also see a drop in EDV before increasing at a much lower fluence than the **n-on-n**.



Inner radius regions are **type inverted**

Common inversion point at ~10^{13} 1 MeV n_{eq} fluence, in line with expectations.

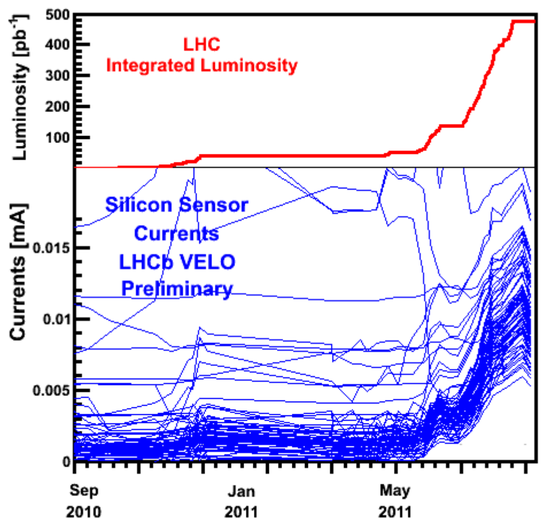


When the same data is split between sensors with **initial EDVs** greater than, and less than, 45V. No dependence on the initial EDV after type inversion.

Radiation Damage Data

- Of the 88 sensors in the VELO, 2 are n-on-p and the rest are n-on-n. They exhibit different behaviour under irradiation.
- Dedicated datasets were taken to measure the radiation damage in the VELO.
- The bias voltage of every 5th module is varied between 0V and the nominal 150V, whilst the others remain at the nominal voltage.
- Particle tracks are reconstructed using hits from only the nominal voltage modules. Tracks can then be extrapolated to a point on the variable voltage sensors.
- The charge (in ADC counts) for the strips at this point is recorded. From a fit to the ADC count distribution a Most Probable Value (MPV) is found for each voltage.
- The voltage at which the MPV is 80% of the maximum is defined to be the Effective Depletion Voltage (EDV).

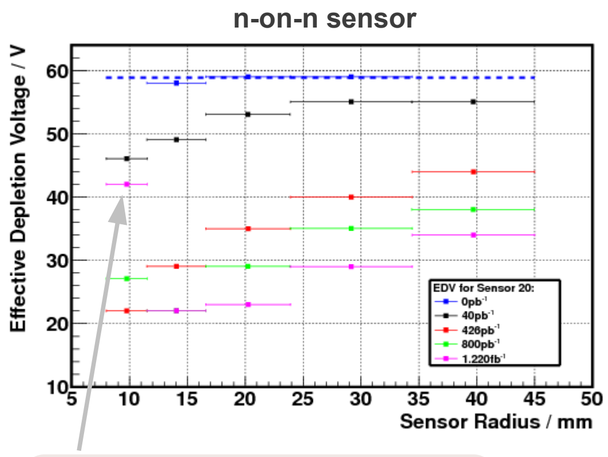
Leakage Currents



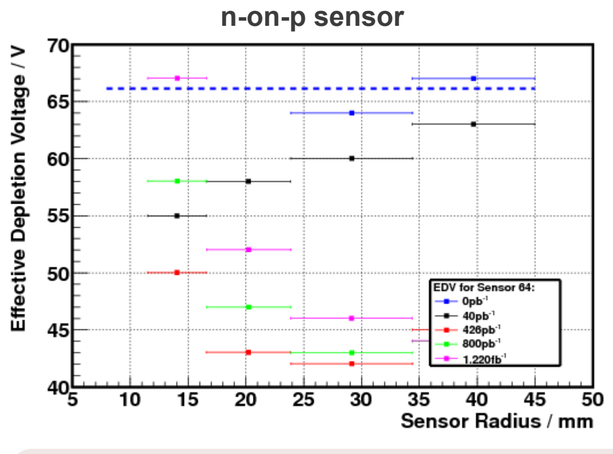
The **leakage currents** of all 88 sensors plotted against time. Currents are measured at -8 °C without beam. The LHC integrated luminosity is also shown as a guide to the fluence.

EDV vs. Radius

The EDV as a function of radius is an effective measure of the radiation damage with increasing fluence (smaller radius).

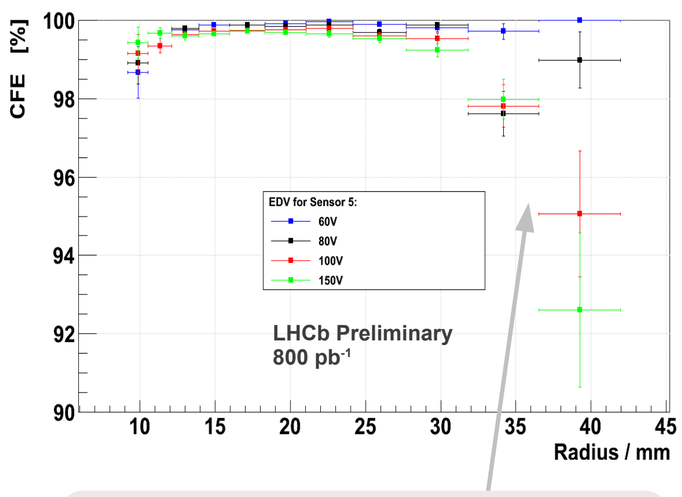


Type inversion for the lowest radius/highest fluence area.



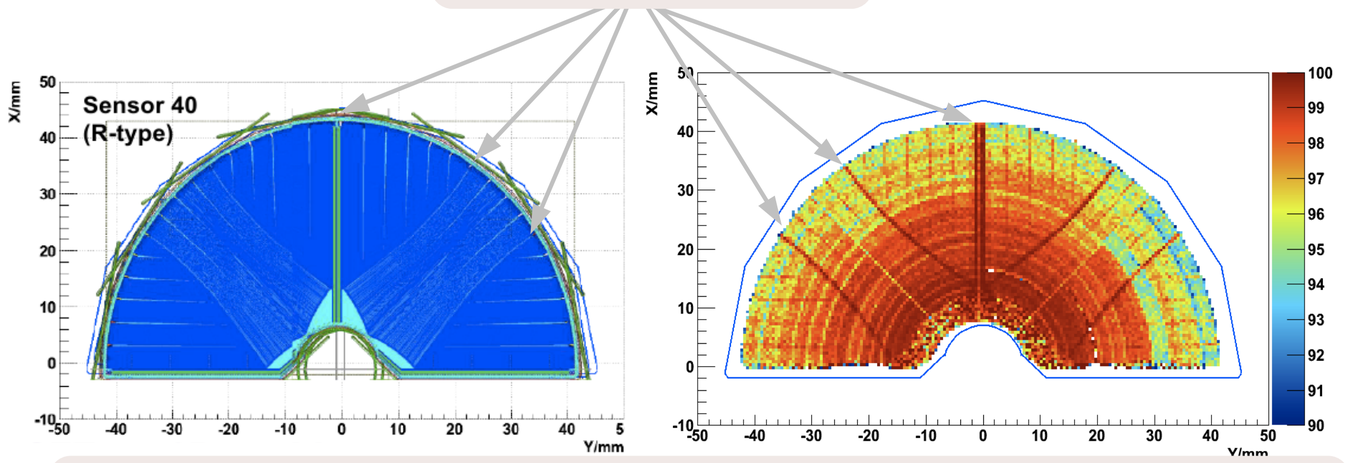
See an initial drop in EDV with increasing radiation exposure, followed by an **increase** which is more pronounced in the inner regions.

Double Metal Layer Effects



Reduction in the **Cluster Finding Efficiency (CFE)** of an R sensor at higher radii (operating at 150V).

Higher CFE matches the gaps in the **2nd metal layer**.



In R-type sensors, the inner routing lines run over the outer strips causing lower CFE. Areas with gaps in this 2nd metal layer correspond to higher CFE.