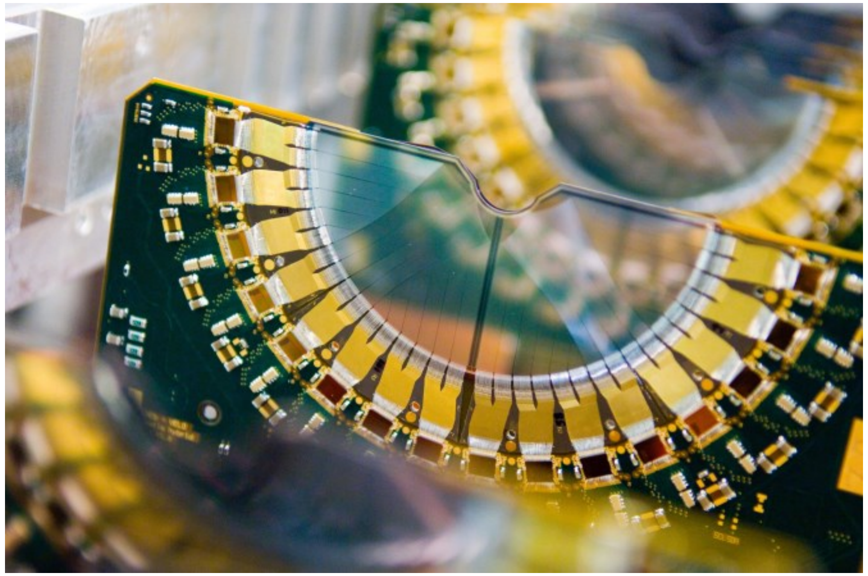
LHCb VELO detector
the effects of radiation damage so far



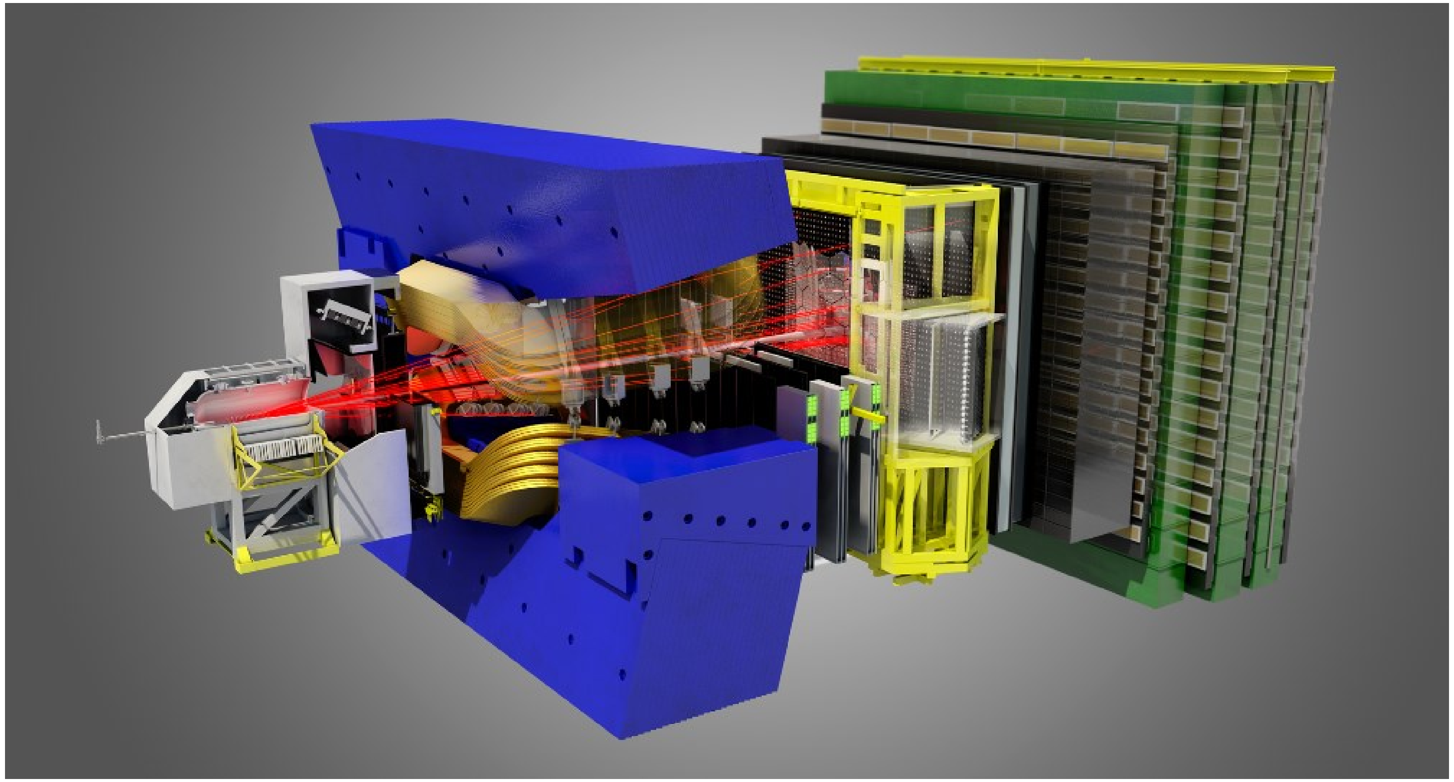
David Hutchcroft

University of Liverpool

on behalf of the LHCb collaboration

LHCb experiment

- LHCb is a dedicated heavy flavour experiment at the LHC

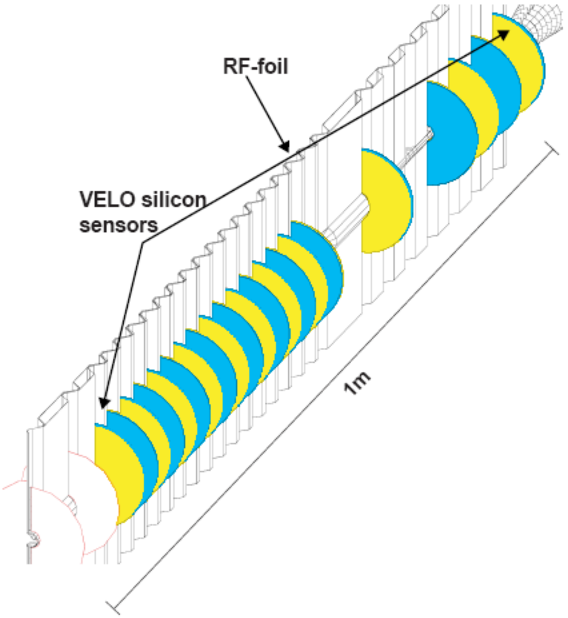


- Very precise vertex detector (VELO)
- One tracking stations before and three after a vertical dipole magnet
- Two ring imaging Cherenkov detectors
- Three layers of calorimetry
- Five of muon detectors interspersed with iron shielding walls

The LHCb Detector at the LHC, JINST 3 (2008) S08005

VELO parameters

- 42 modules with pairs of sensors all n-in-n
  - Except one n-in-p (module 0 in later plots)
- R/ϕ geometry strip detector
  - Inner most strips are 8mm from the beam, outer most 42mm from the beam
- Designed to tolerate 5 years running at LHC



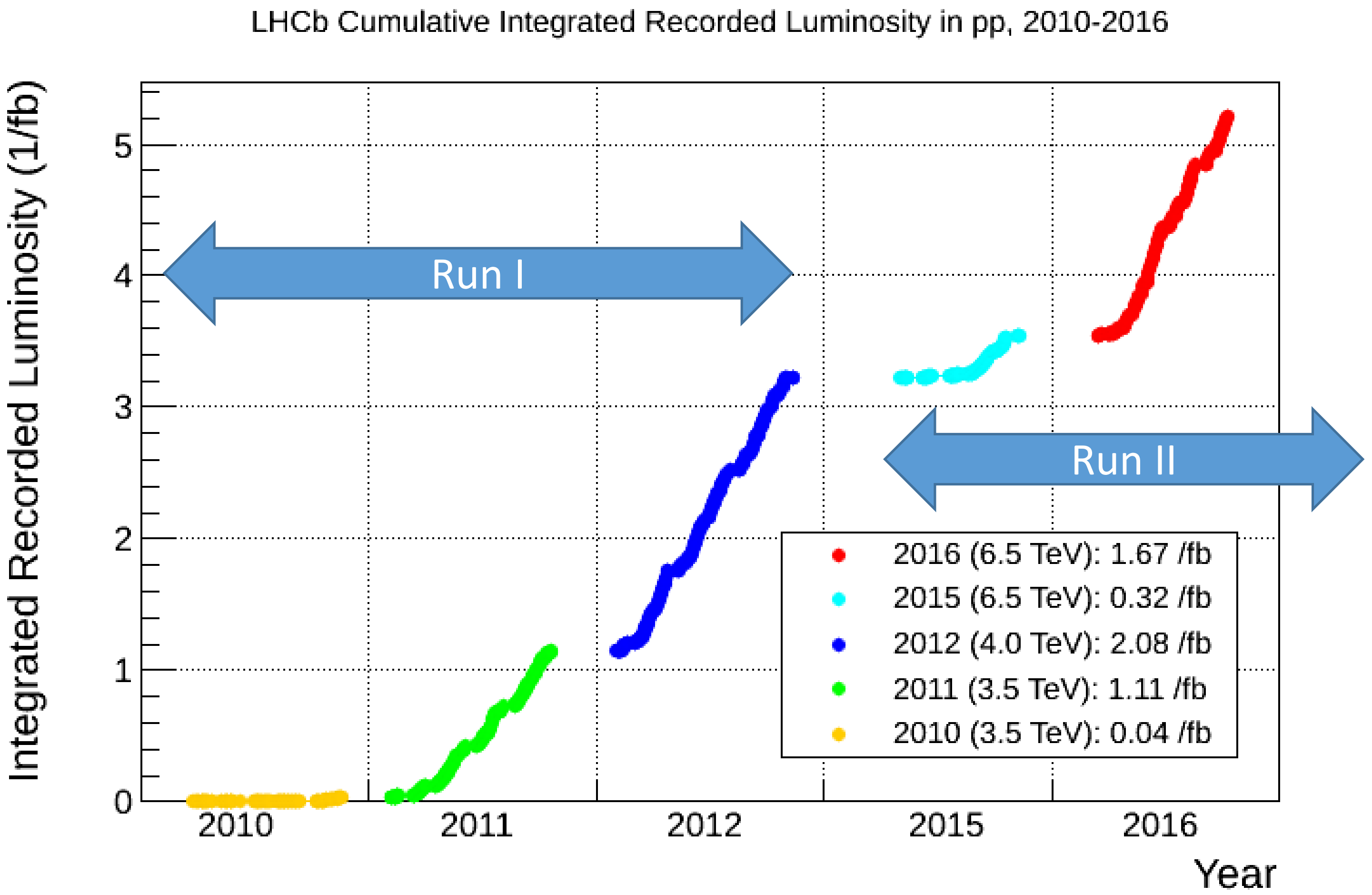
- Sufficiently radiation hard to be used without modification in a proton therapy beam at Clatterbridge Oncology centre

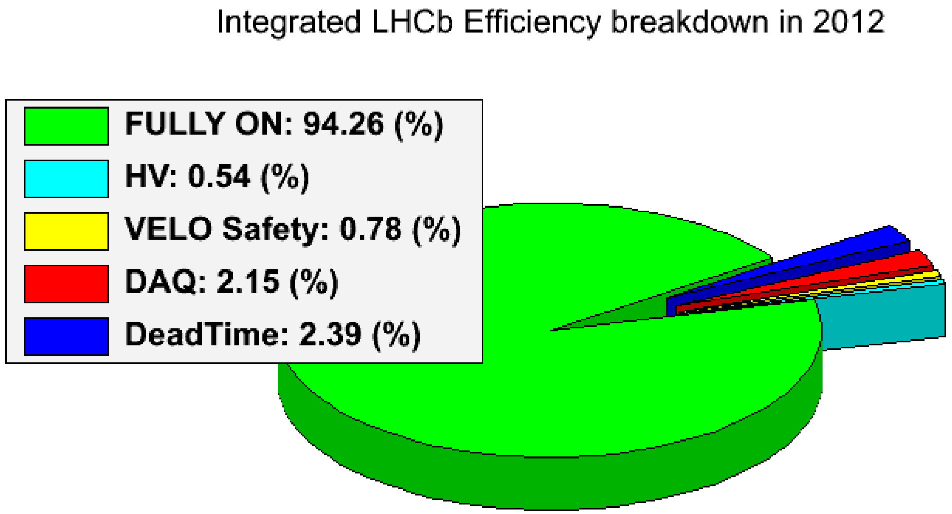
LHCb data taking

Results are quoted on

Year	$\sqrt{s}$	Luminosity
2010 & 2011	7 TeV	1.2 fb^{-1}
2012	8 TeV	2 fb^{-1}
2015 & 2016	13 TeV	2 fb^{-1}

LHCb uses luminosity levelling so we get less luminosity than ATLAS & CMS

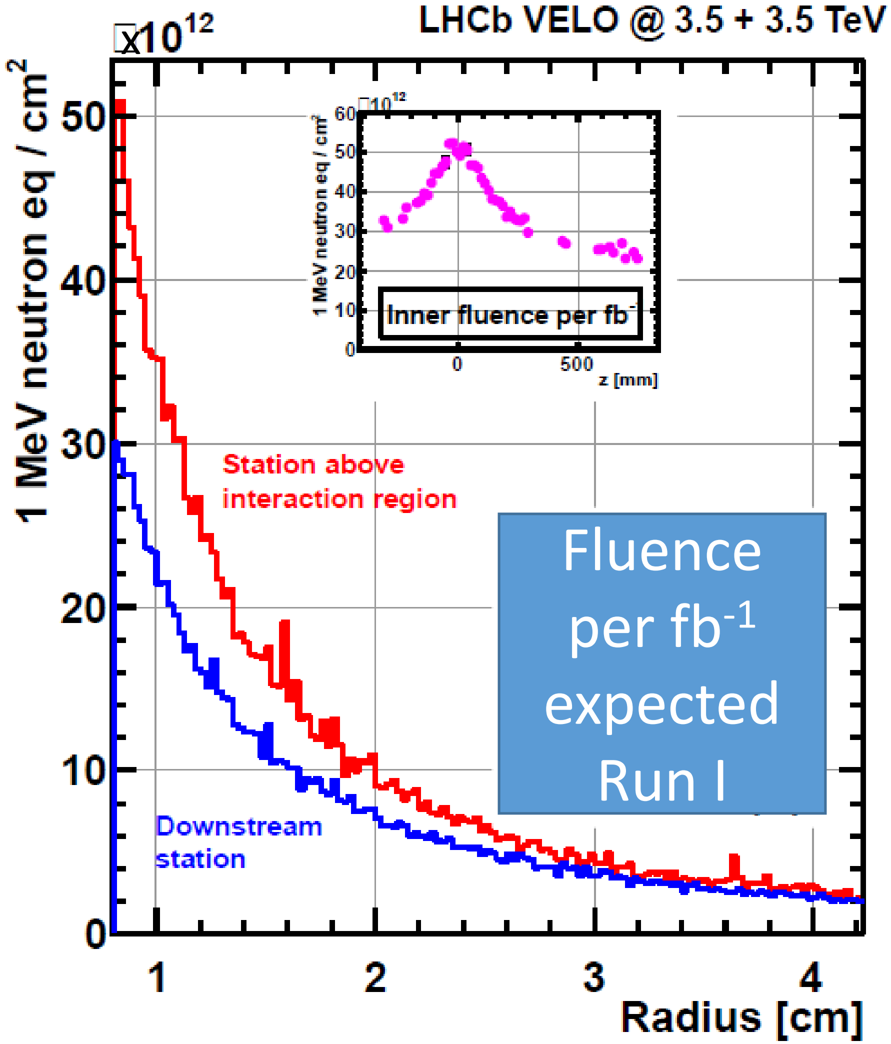


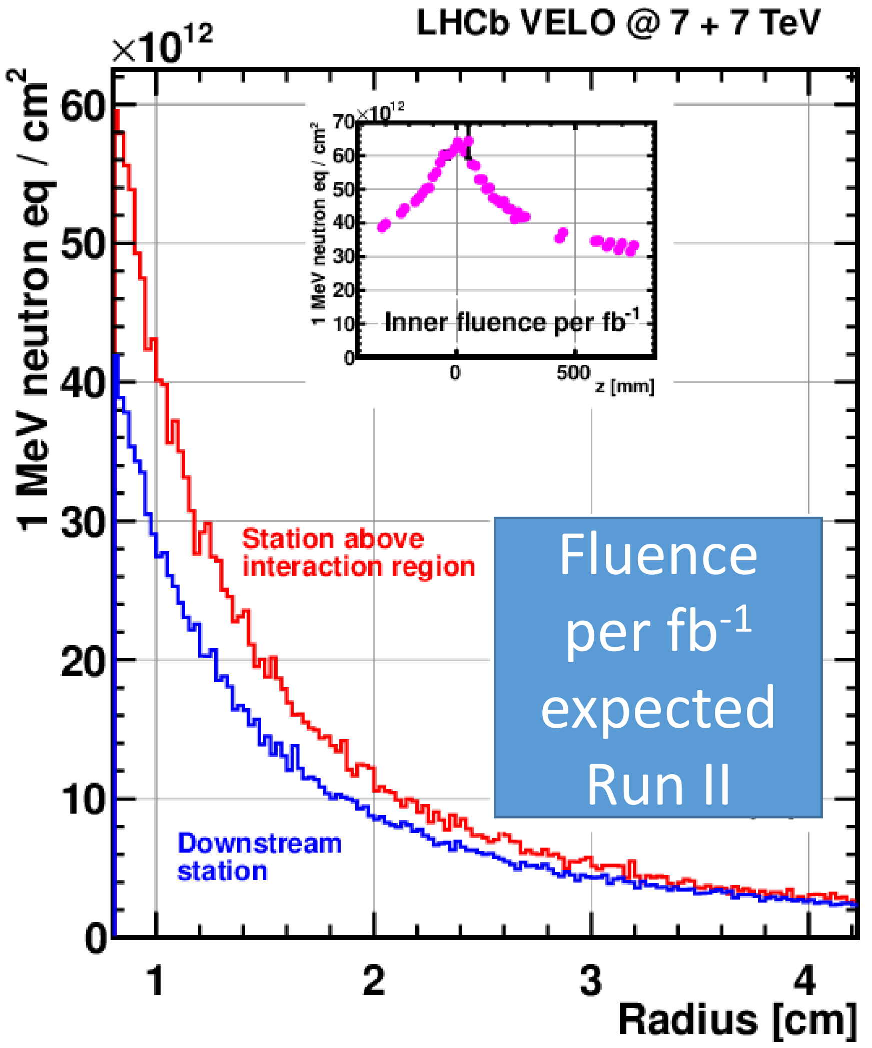


http://lhcb-operationsplots.web.cern.ch/lhcb-operationsplots/index.htm

Plus a small amount of beam-beam p-Pb, Pb-p, Pb-Pb collisions and also p-A where A is Helium or Argon for beam gas events

Radiation dose delivered





Fluence per fb^{-1} expected Run I

Fluence per fb^{-1} expected Run II

x3 this for Run I total dose

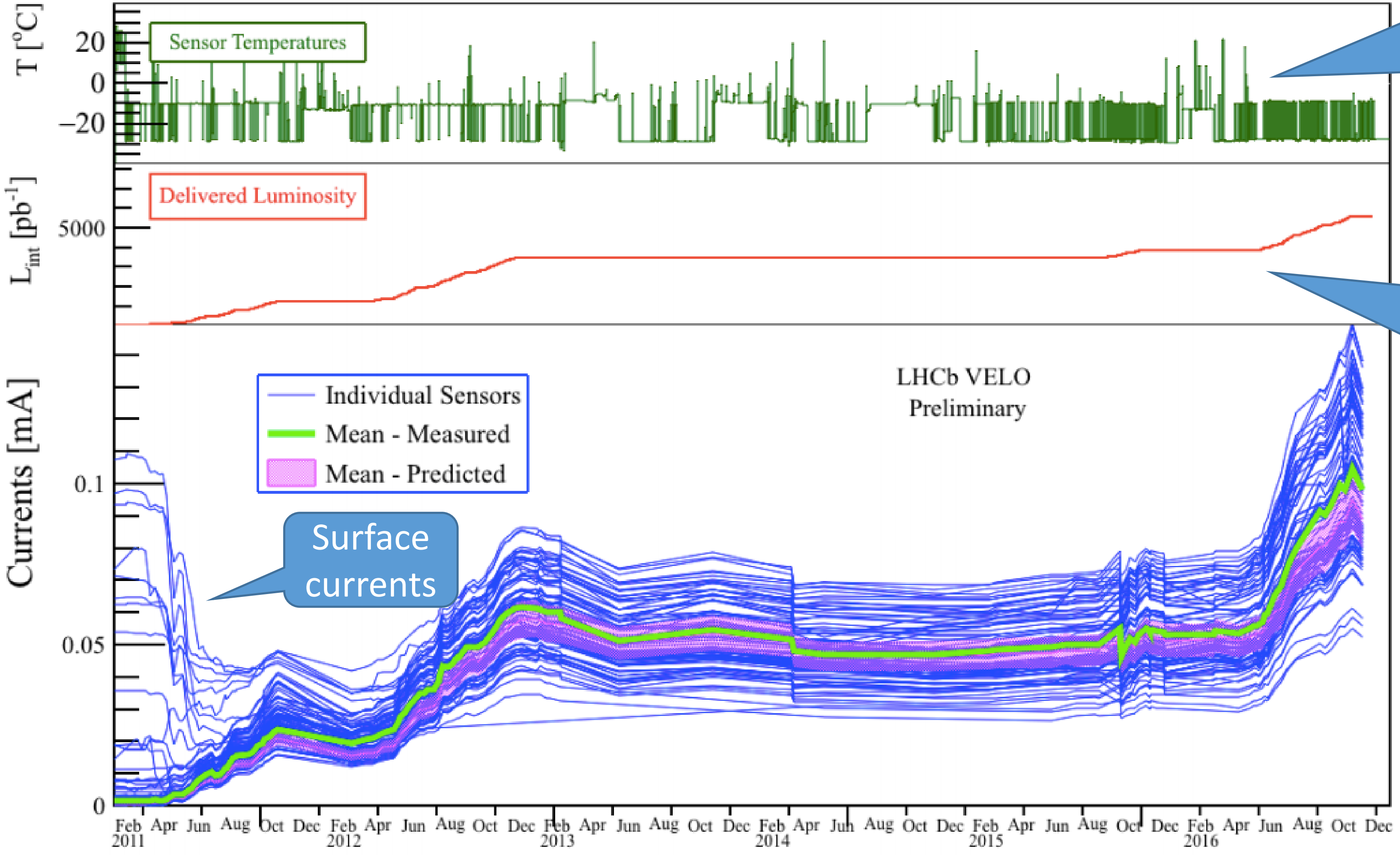
x2 this for Run II dose so far

Fluence varies exponentially with radius and by x2 between stations

Effects of $\sqrt{s}$ are smaller, about 30% between Run I and Run II

LHCb VELO (VErtex LOcator) : Technical Design Report
CERN-LHCC-2001-011

Leakage currents for the sensors



Run I | Long Stop I | Run II

Operational temperature is about -8°C. Sensors at -30°C when the chips are unpowered

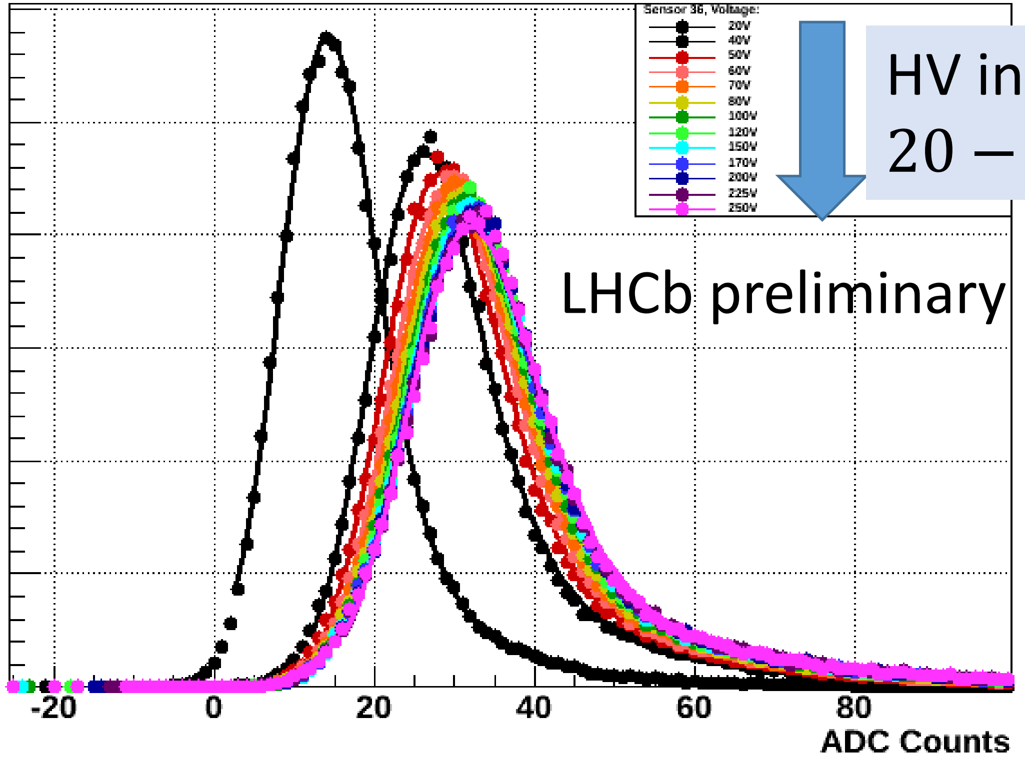
Long periods between data taking due to LS1 and end of year shutdowns
Need to avoid annealing

Currents measured at approx –8°C without beam

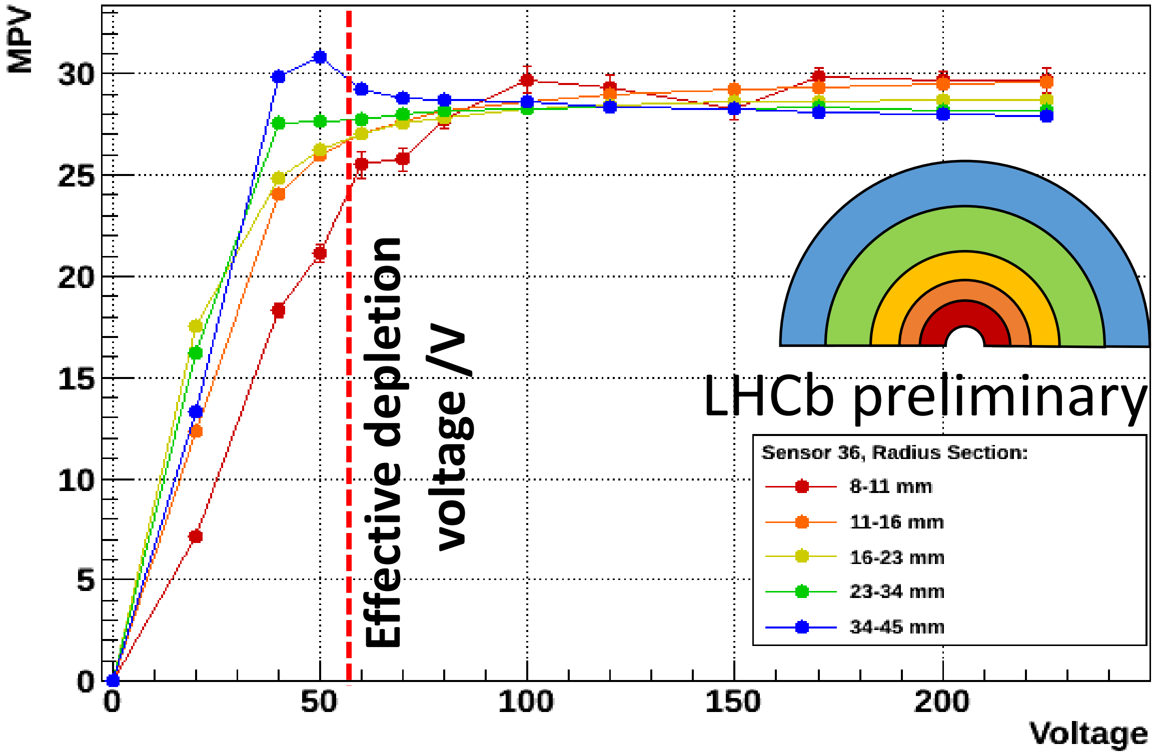
Typical increase was 1.9 µA per 100 pb^{-1}

Effective depletion voltage

An R sensor toward the end of the detector



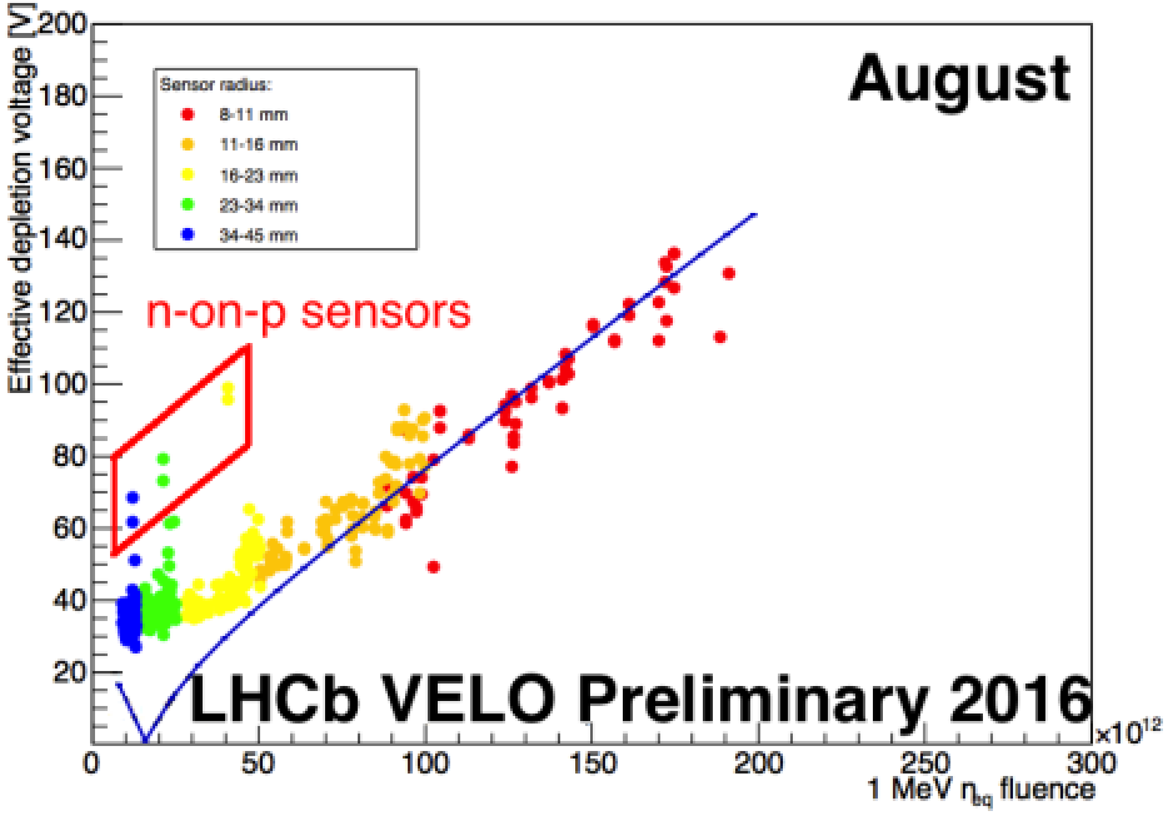
HV increasing
20 – 250 V

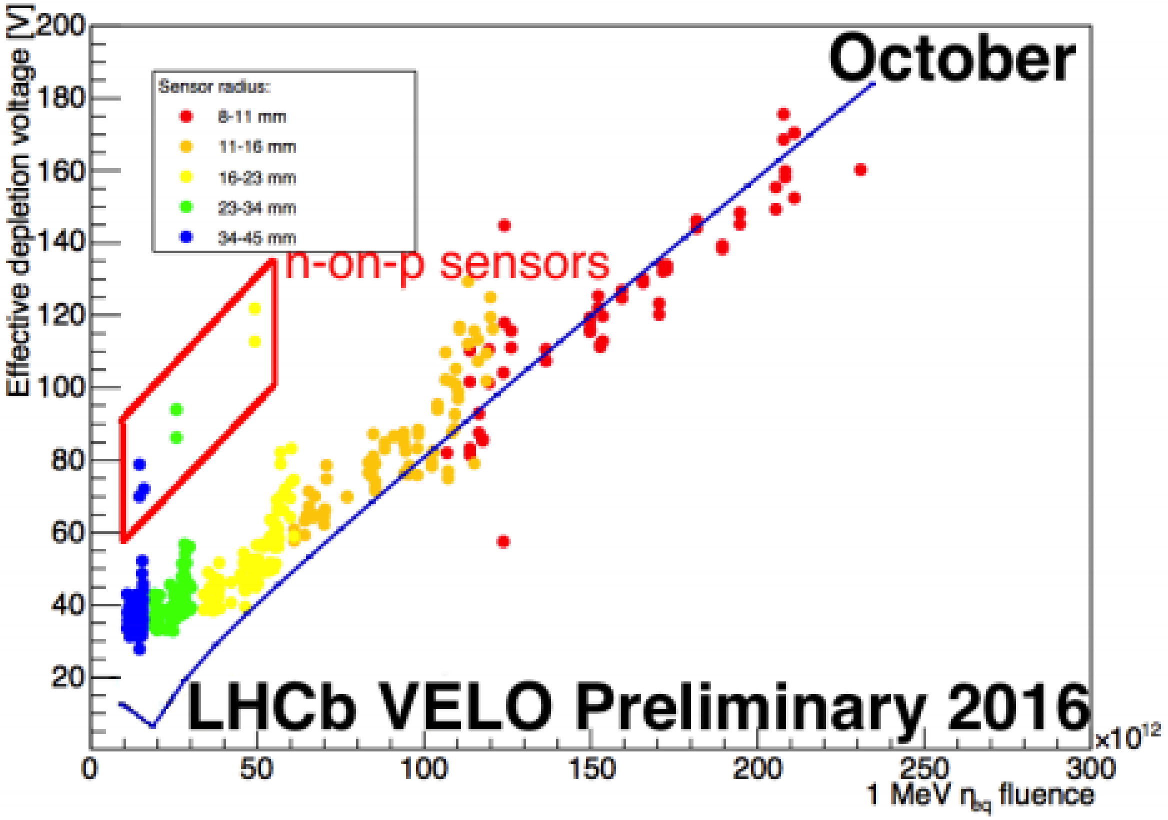


Measure EDV during HV scans in data taking by looking at the charge collection efficiency vs Voltage curves

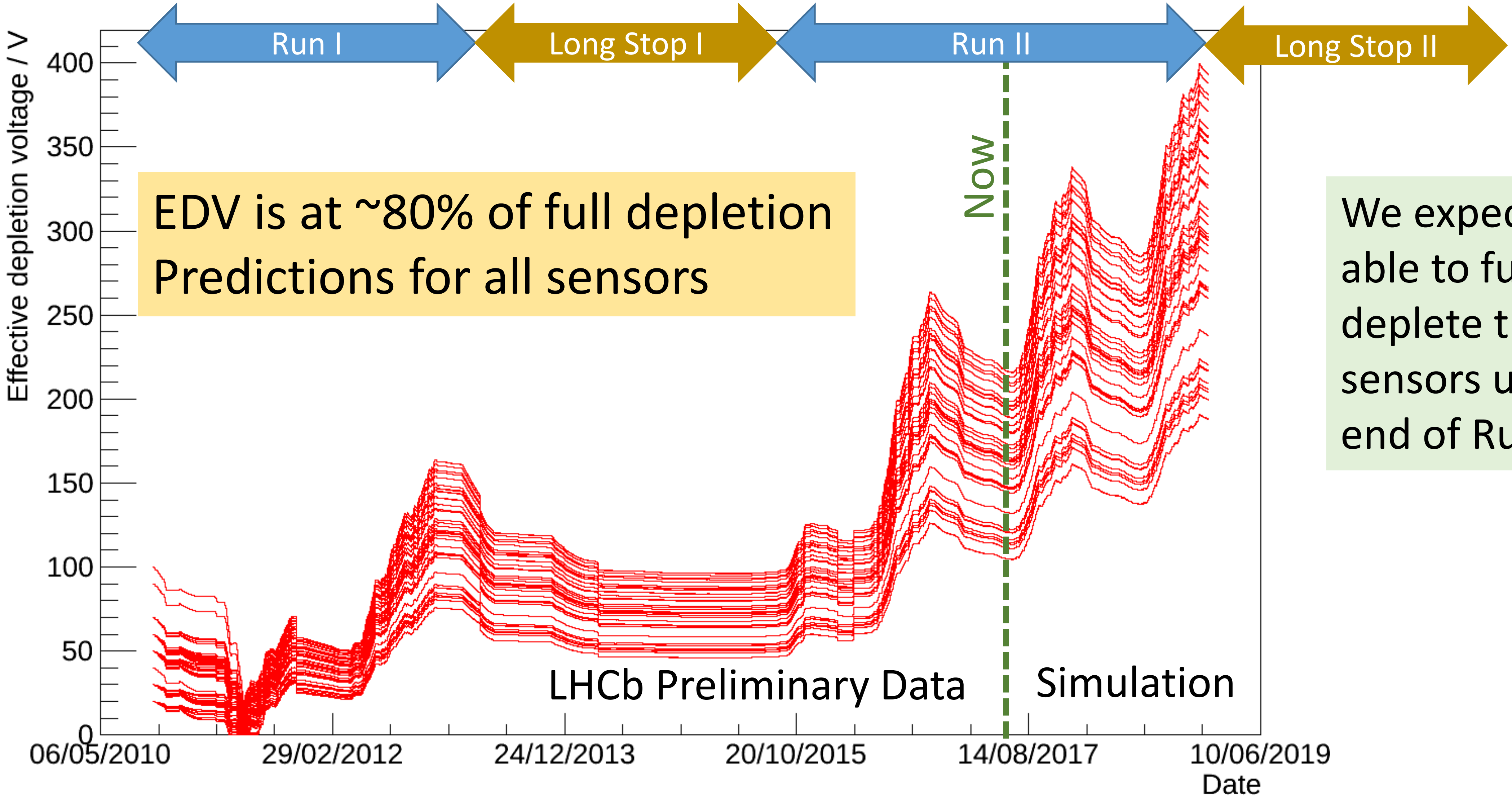
Running all sensors fully depleted at 150V, with one at 250V to test the effects

Effective depletion voltage in 2016





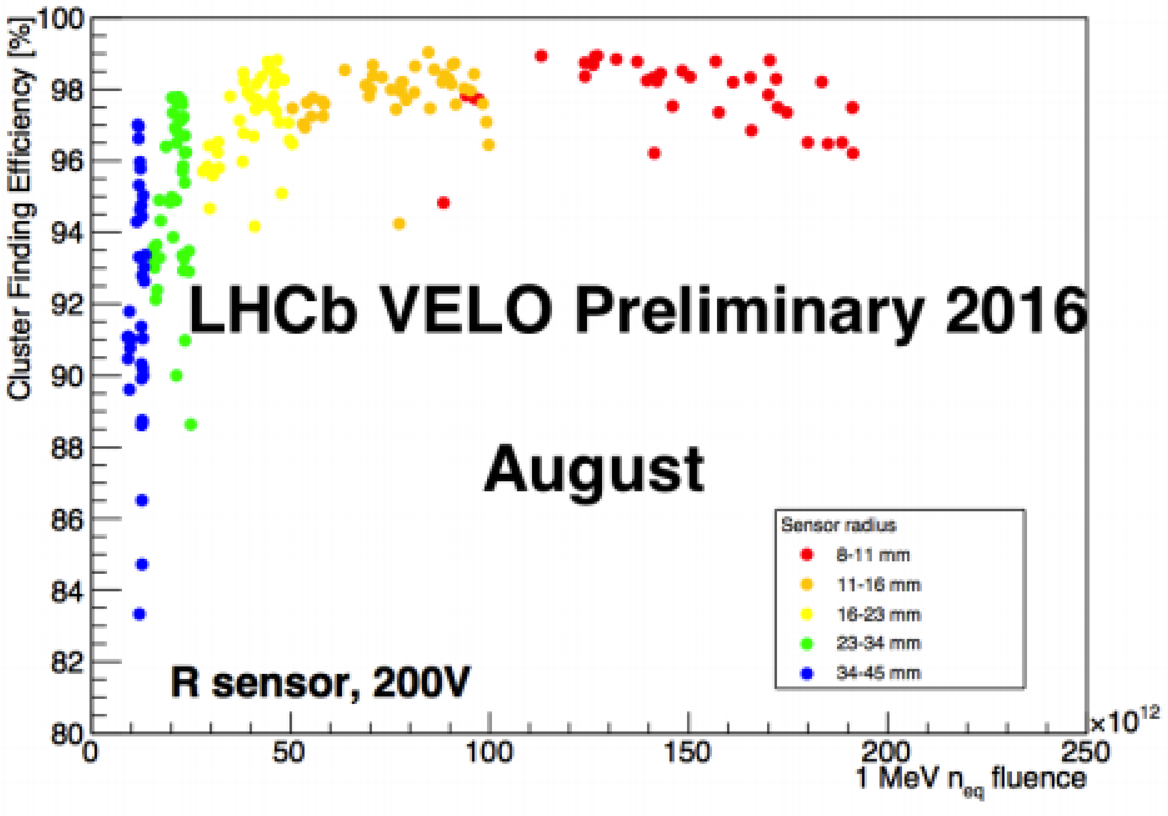
Predicting the EDV by the end of Run II

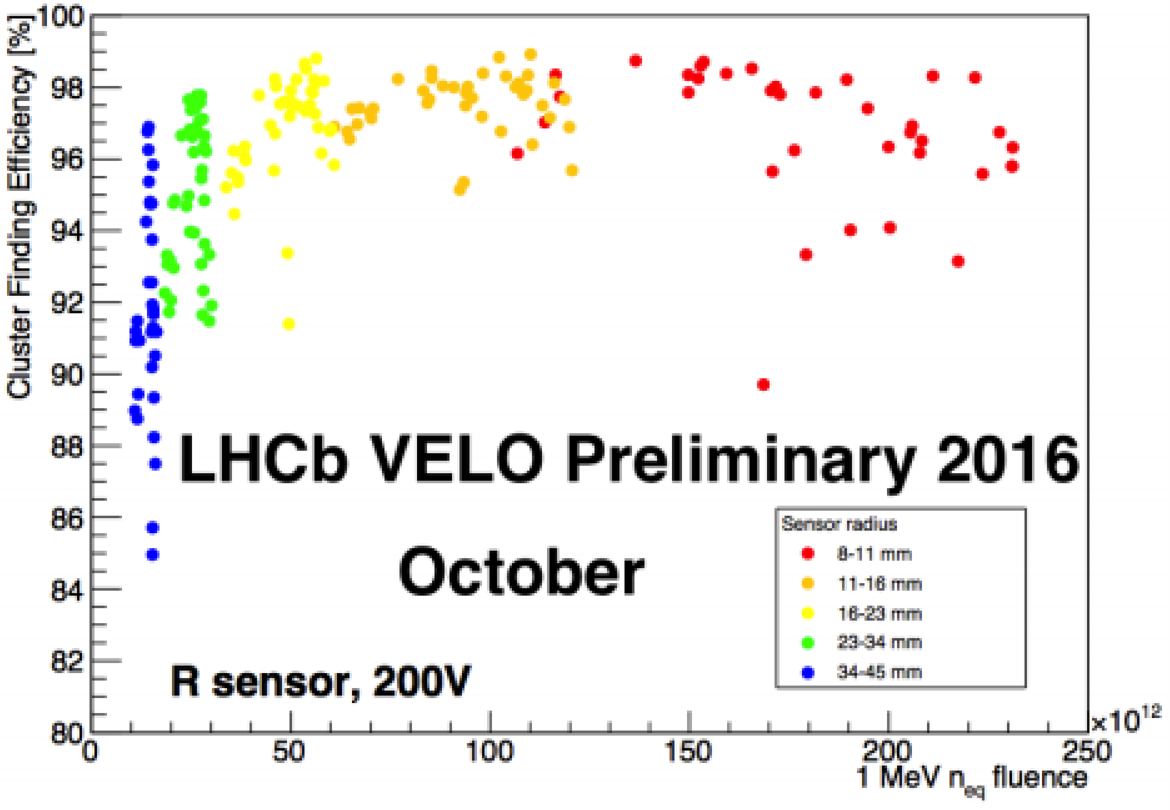


EDV is at ~80% of full depletion
Predictions for all sensors

We expect to be able to fully deplete the sensors up to the end of Run II

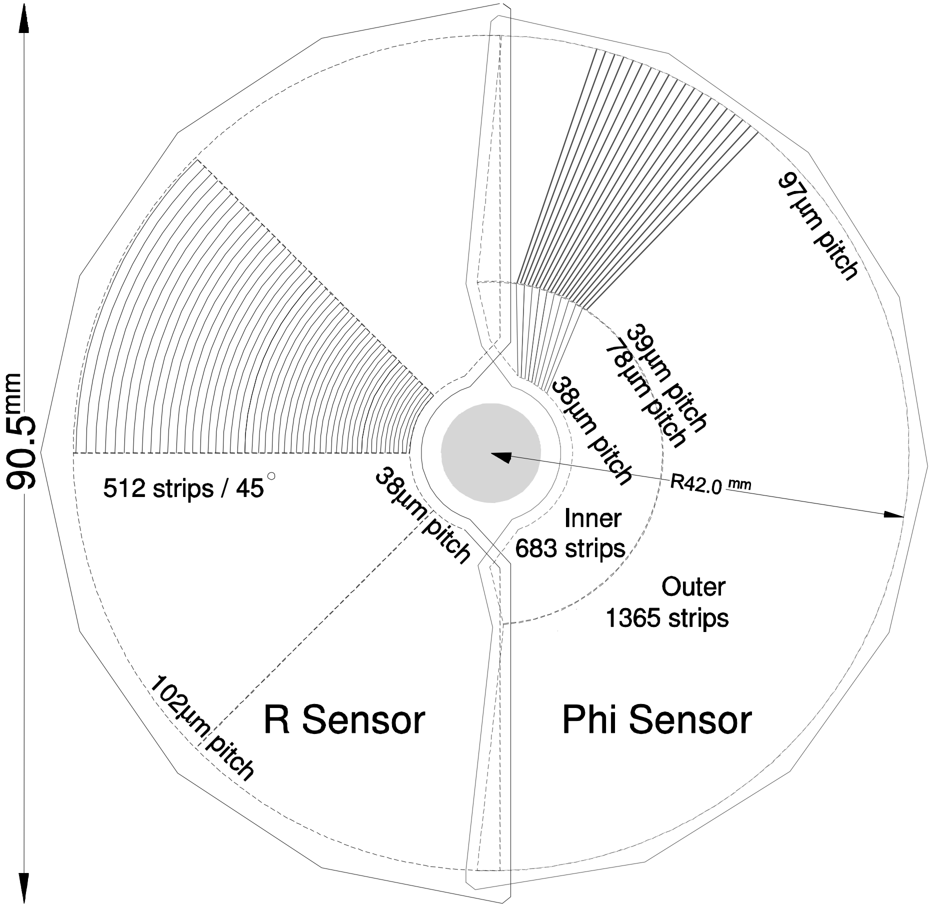
Cluster finding (pseudo) efficiency

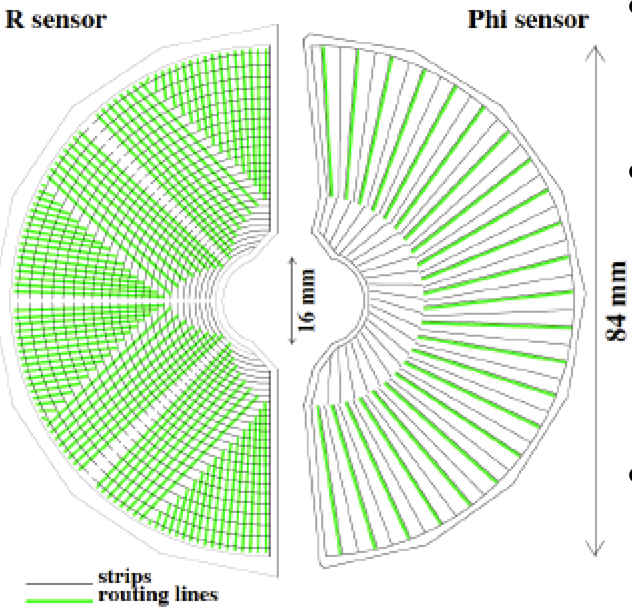




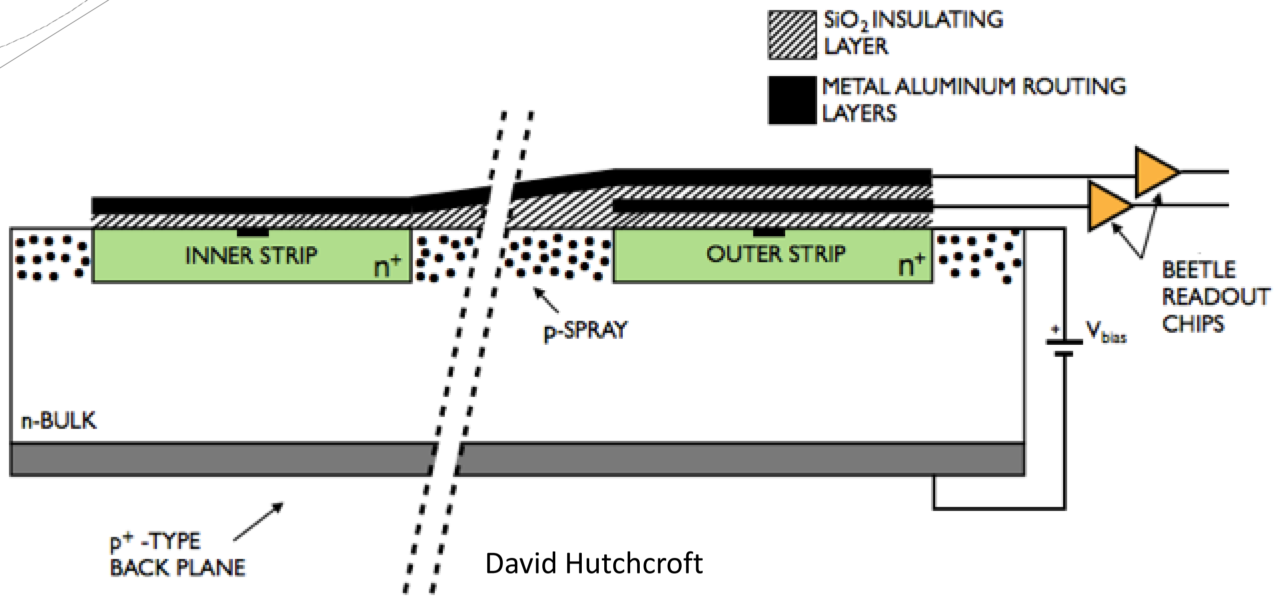
Note: these points are affected by fake tracks, reducing the apparent efficiency

Double metal effects





- R and phi sensors need two sets of metal lines
- One to capacitively couple to the strips, the other carrying the signal to the amplifiers over the outer strips
- Phi sensors (below) second metal routing is over the outer strips

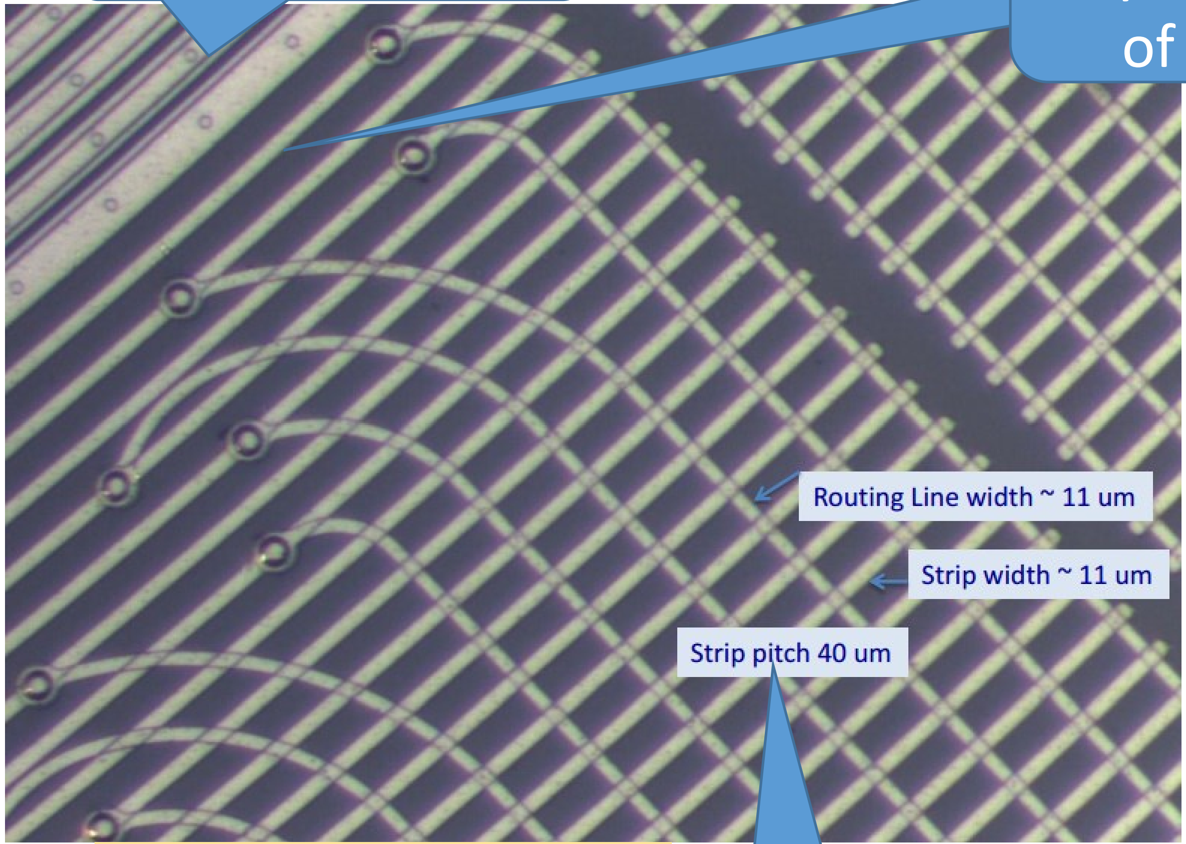


R sensors route across the outer strips

Picture of the R sensor's active area

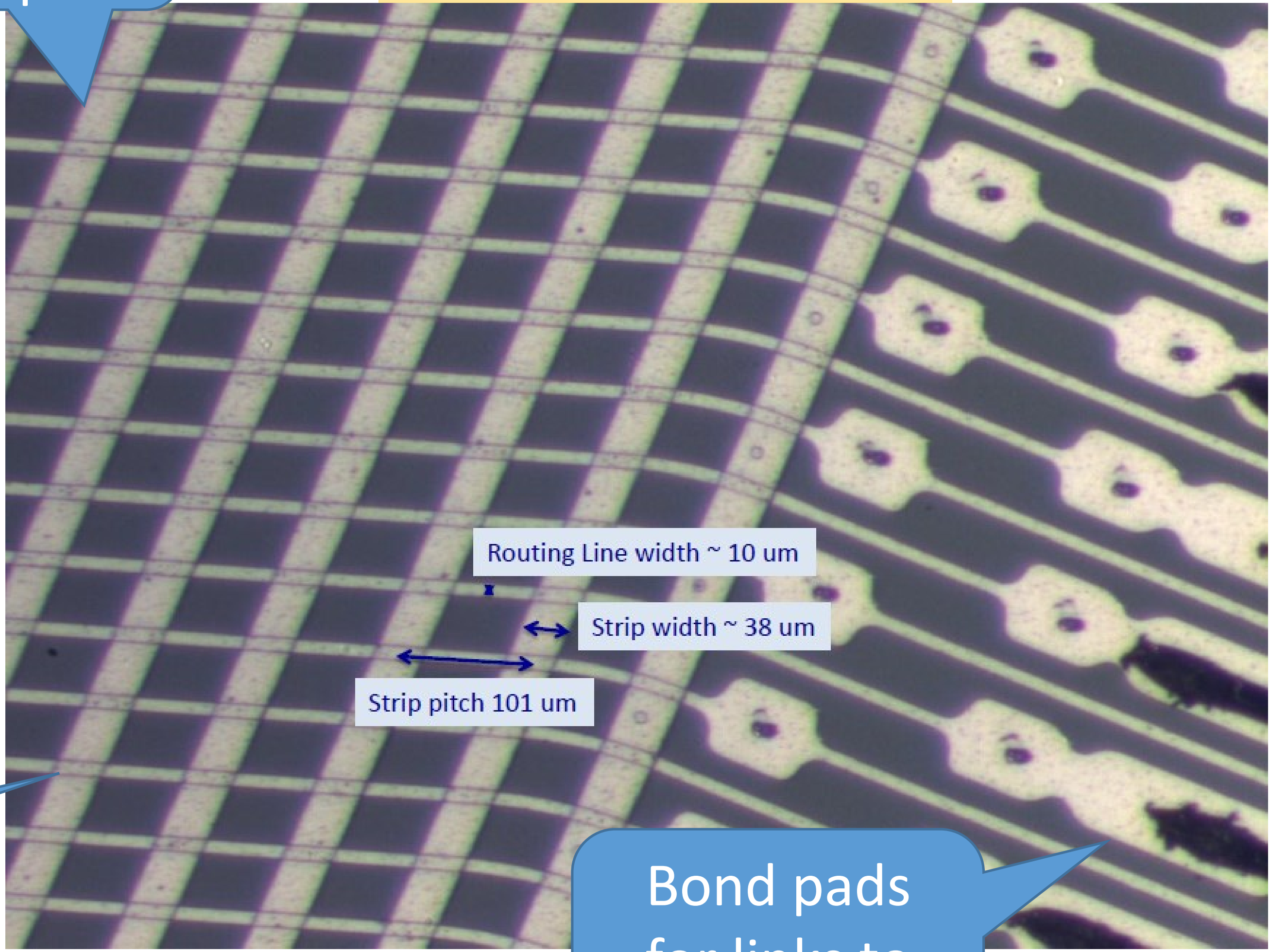
Guard rings

First Metal layer on top of strips



Inner edge of sensor

Outer edge of sensor

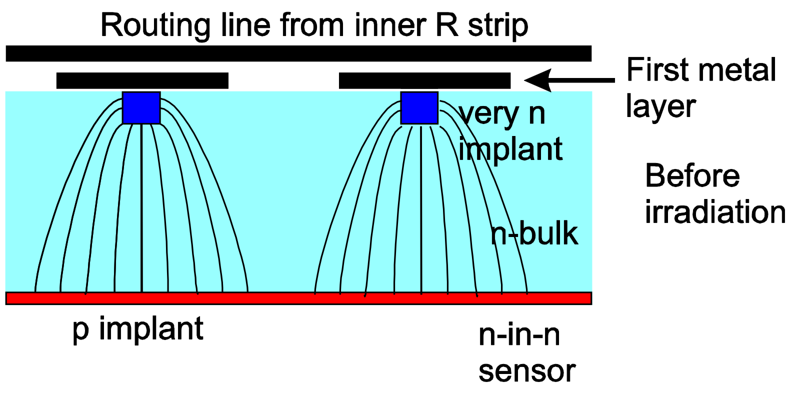


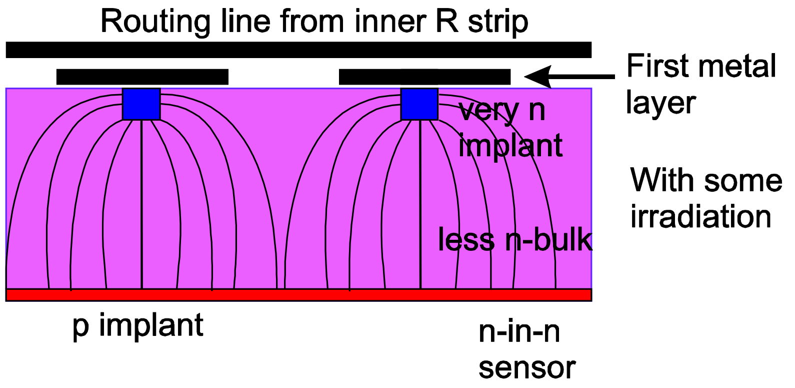
Second metal layer running across the strips

Bond pads for links to readout chips

Coupling effects of signals in R sensors

- Before irradiation there was no visible coupling to between inner and outer strips
- When a signal passes between the strips both layers of routing lines couple to the moving charge
- Before irradiation free surface charges can act as a shield as does the 1st metal layer
- After irradiation we see phantom signals in the inner strips

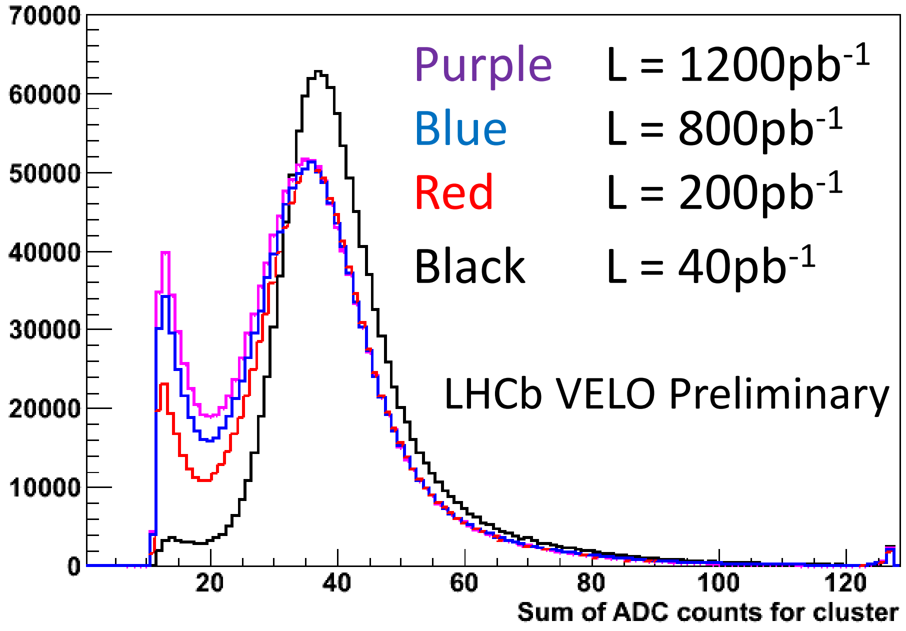




Effects see during data taking

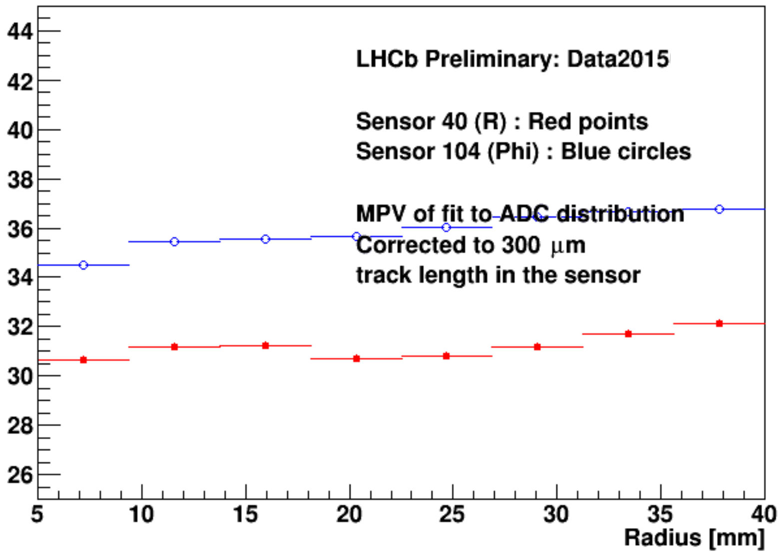
Cluster on inner R strips at very low ADC counts appearing

Predominately at the inner regions of the sensors, not where tracks crossed the sensors

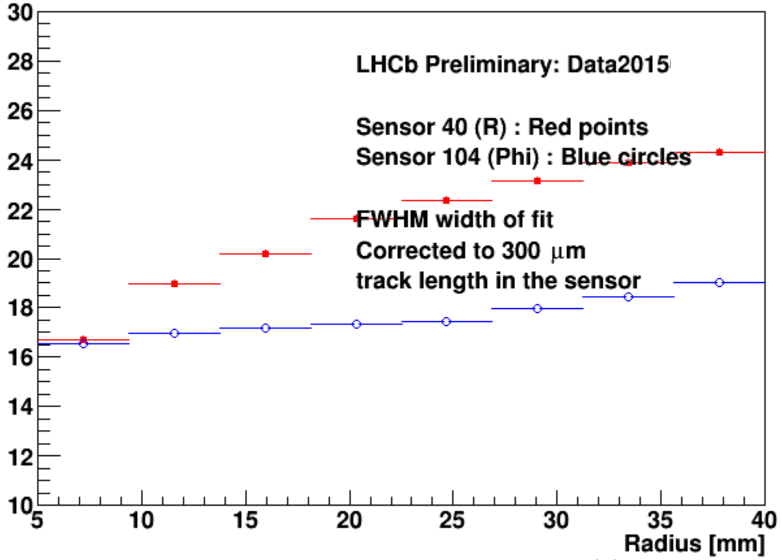


Cluster size for R sensor clusters in ADC counts

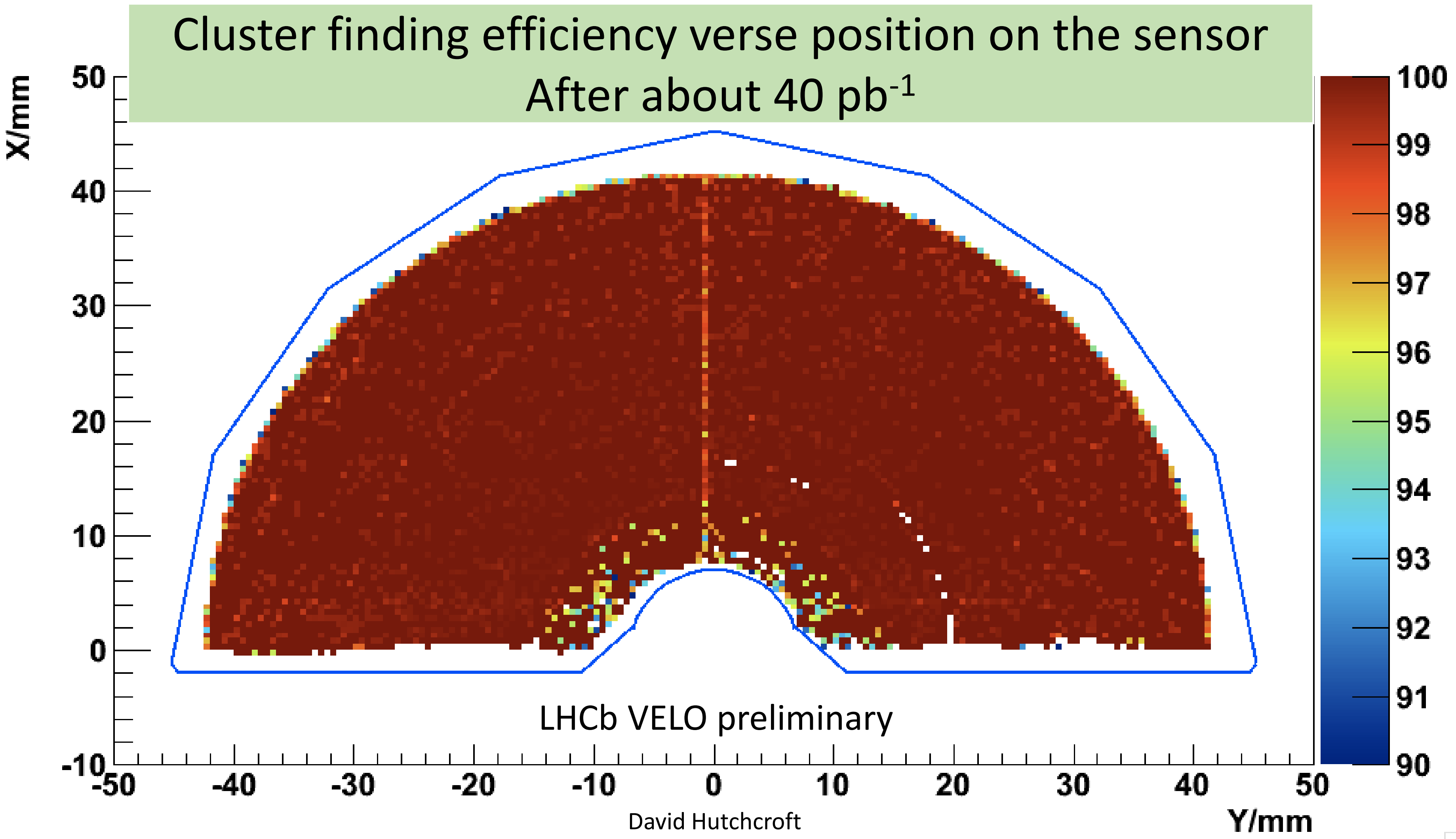
Lower charge collected in R sensors than phi sensors



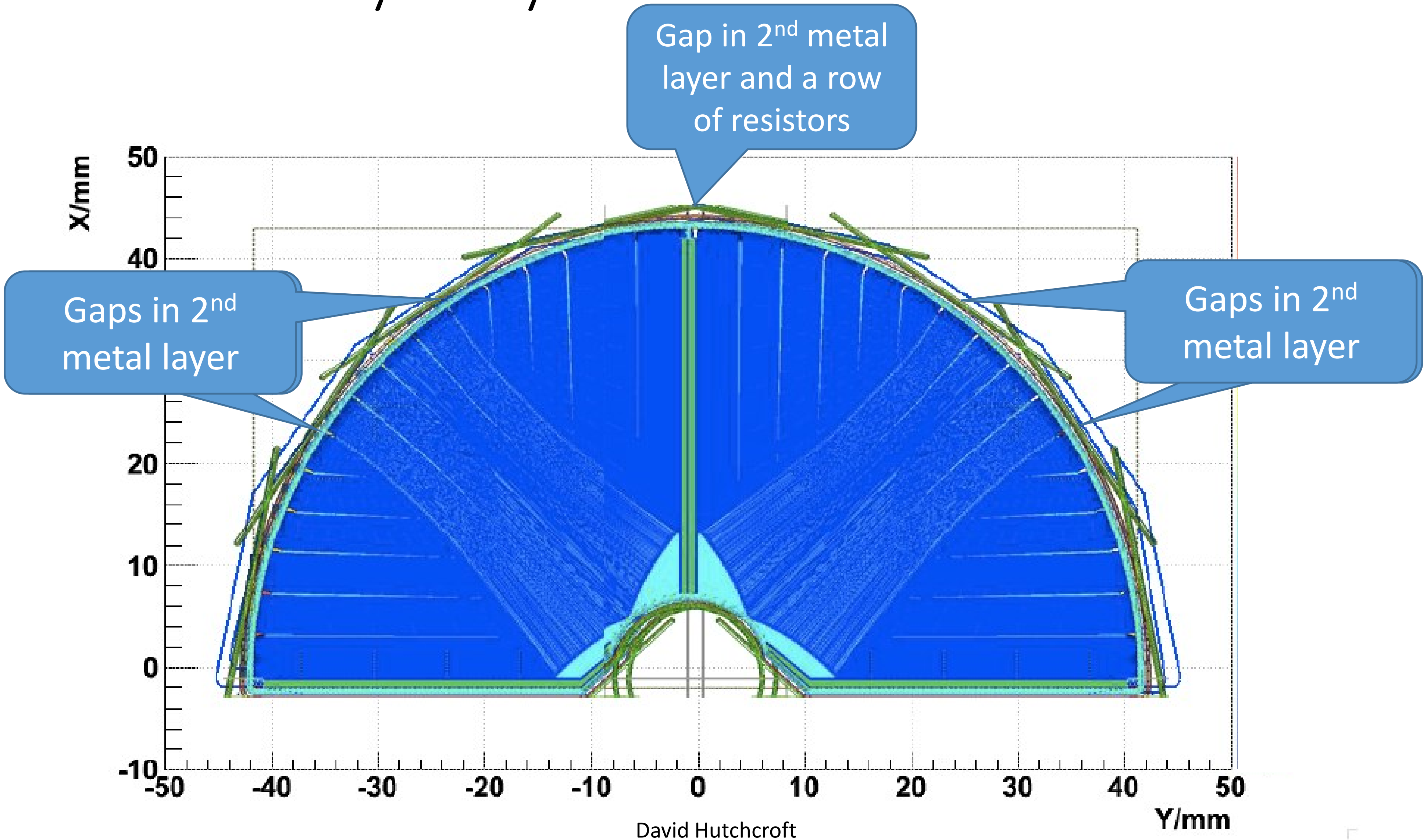
Wider distribution due to only some clusters losing charge



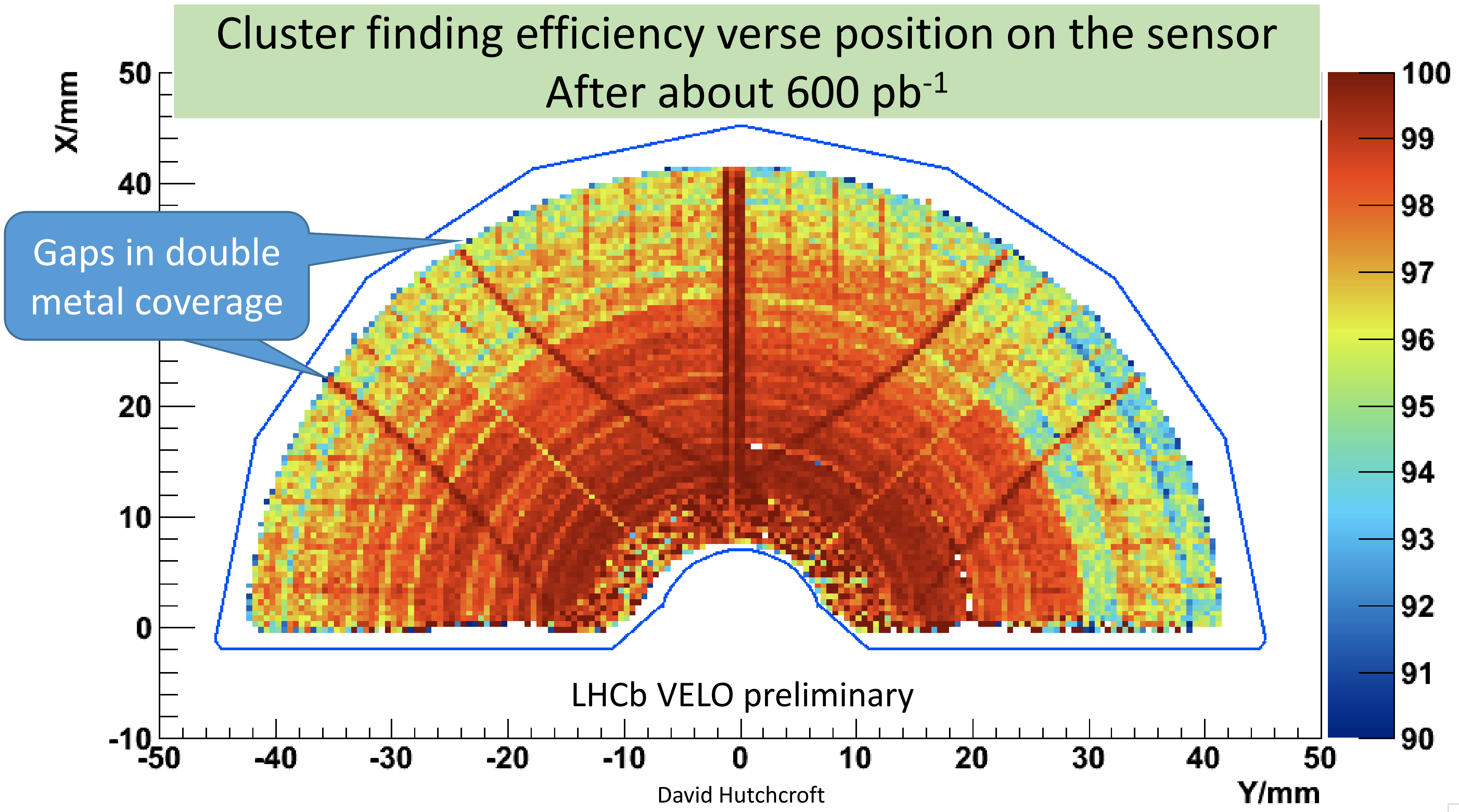
Cluster finding efficiency 2D map for one R sensor, when new…



Second metal layer layout for R sensors

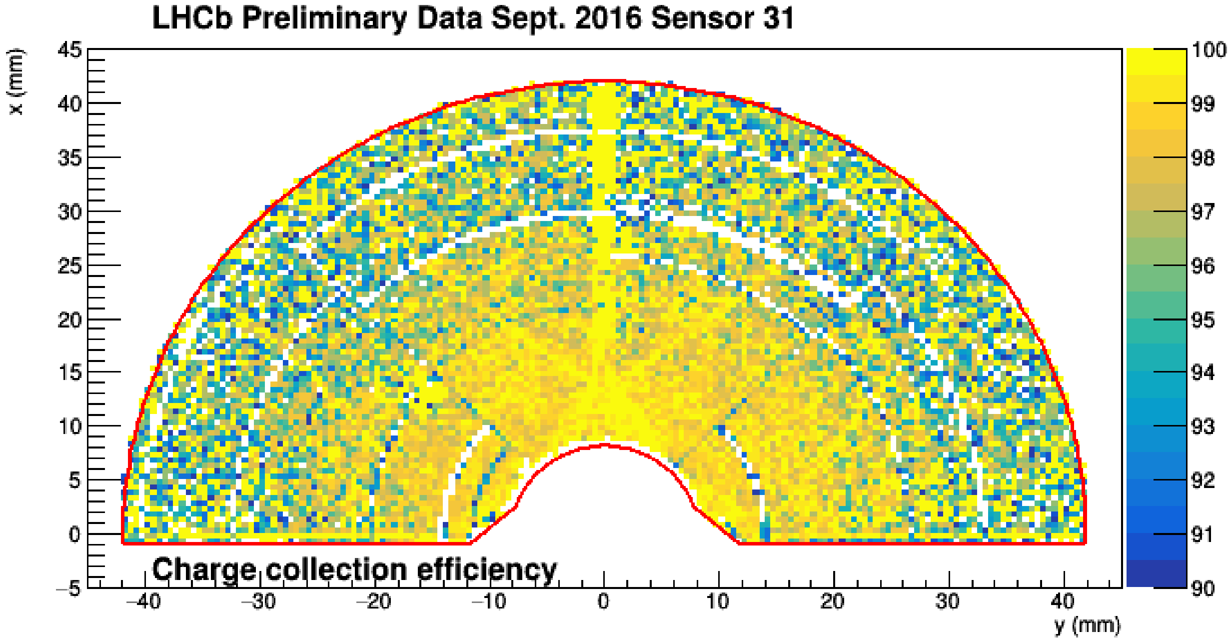


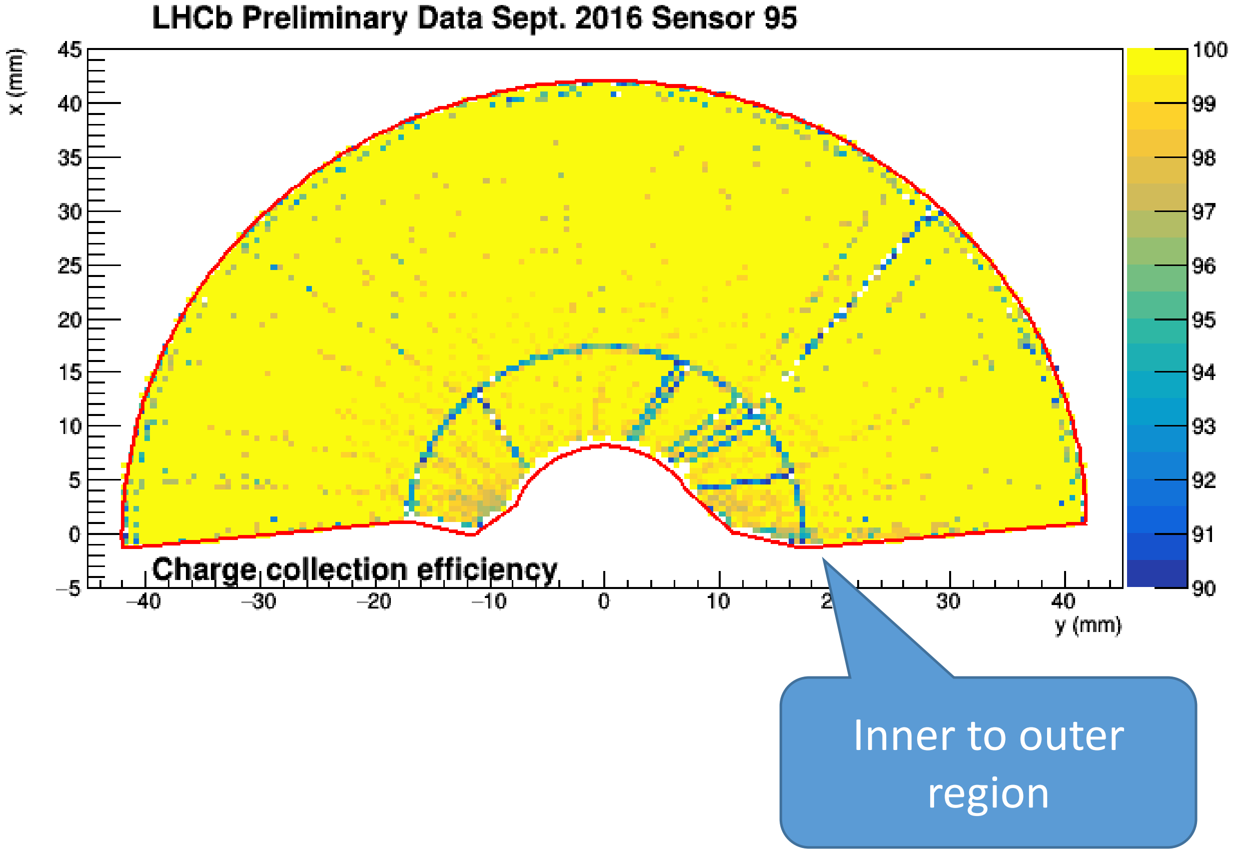
Cluster finding efficiency 2D map for one R sensor, in the second year of data taking



Cluster finding efficiency 2D map for one R & phi sensor, September 2016

After about 5000 pb^{-1}

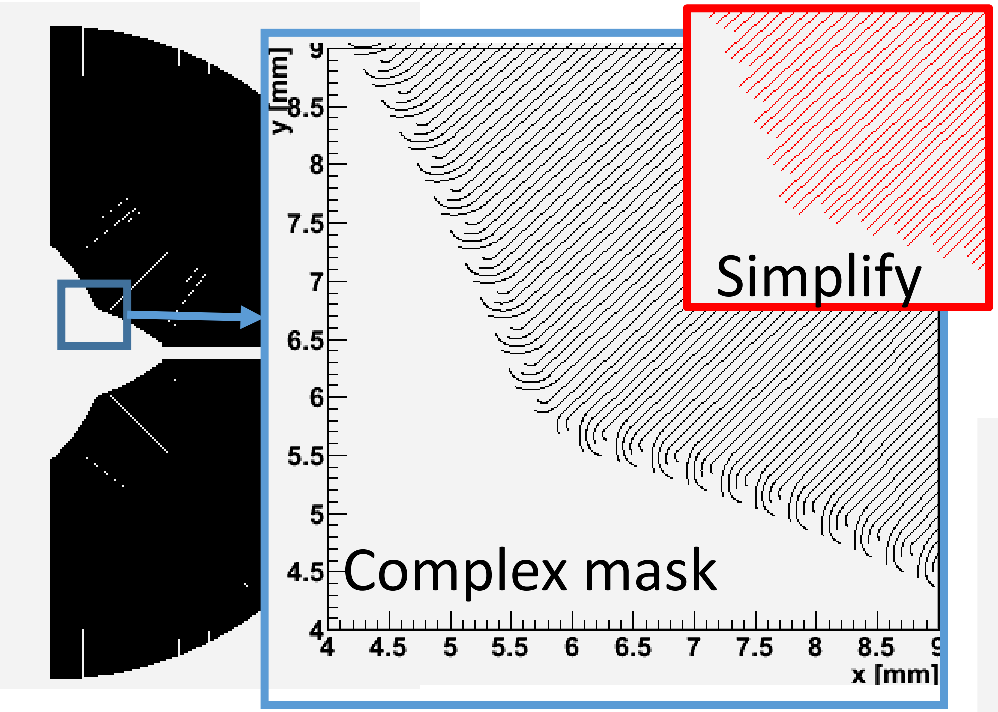




Different R sensor, so different pattern of dead strips

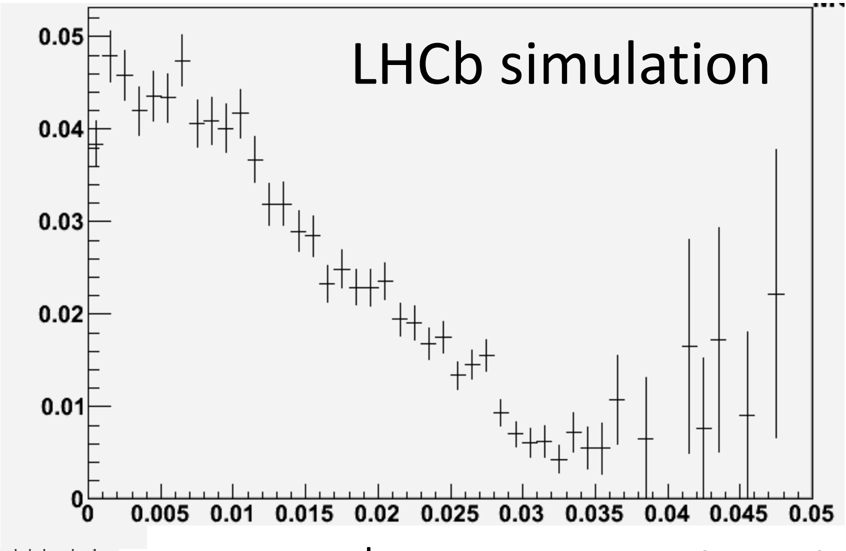
Simulation of the effects

To simulate the 2nd metal effects we had to add the 2nd metal to the detector description

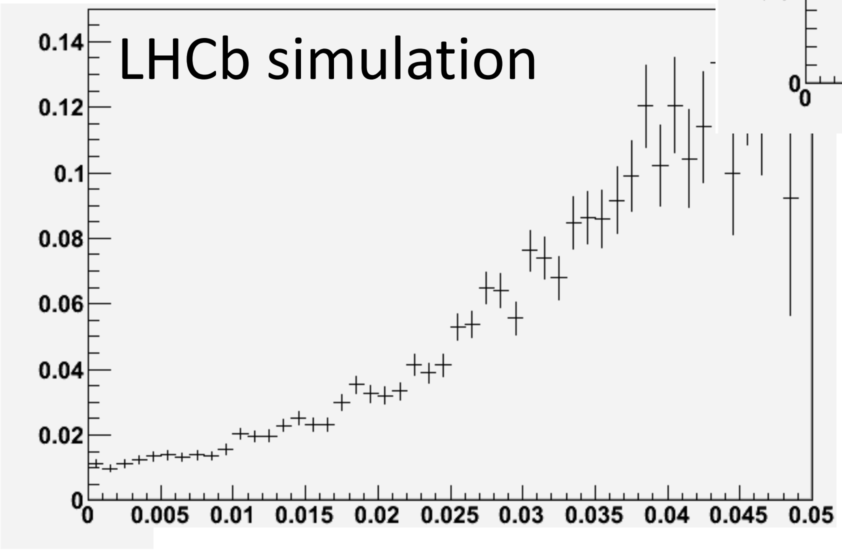


Real routing lines are complex to fit Micron's design criteria

Need to correct charge sharing for the track position wrt the 1st and 2nd metal layers



Dist. 2nd metal layer (mm)



Dist. 1st metal layer (mm)

Use rate of production of fake clusters to tune simulation

Conclusions

- LHCb VELO detectors do see radiation damage
- Type inversion now confirmed for inner edges of sensors close to beam spot
- Leakage currents rising linearly with luminosity
  - We try to always keep the detector cold to avoid unwanted annealing
- R sensors show coupling to second metal layer causing a small reduction in efficiency
- Tracking efficiencies are as yet unchanged
- Every reason to believe that we will get to the end of Run II in good shape
  - We have a full spare VELO available just in case and we'll start constructing the VeloPix replacement for Run III this year

Thank you for listening!

Any questions?