LHCb VELO: radiation damage

The effects of radiation damage on silicon sensors close to the LHC beam

7th Workshop on Advanced Silicon Radiation Detectors, Ljubljana.
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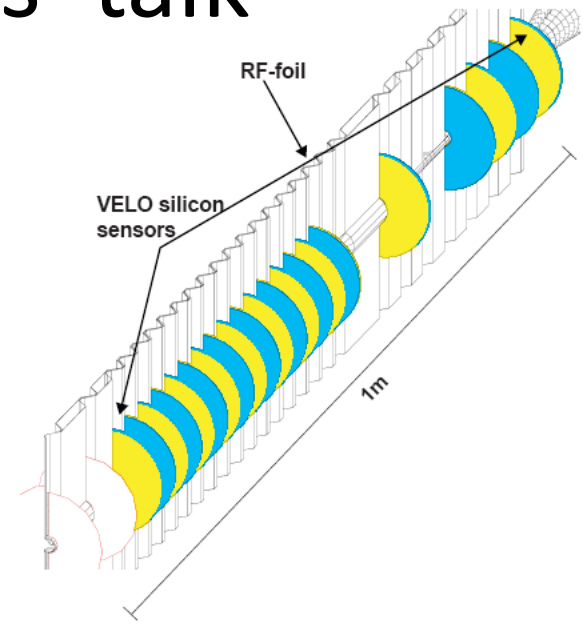
David Hutchcroft
University of Liverpool
on behalf of the LHCb collaboration

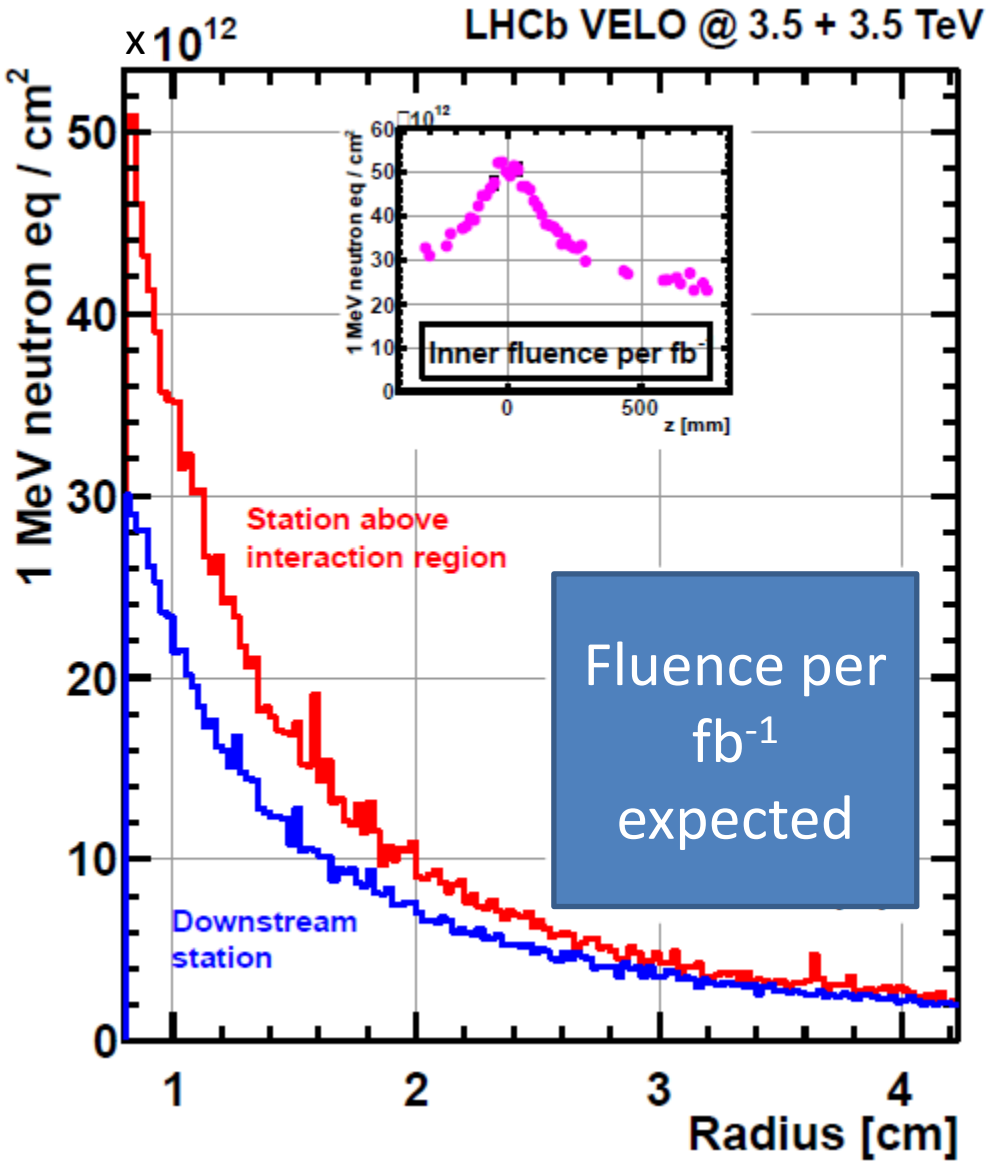
VELO parameters
for details see Eddy Jans' talk

- 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

Current dose



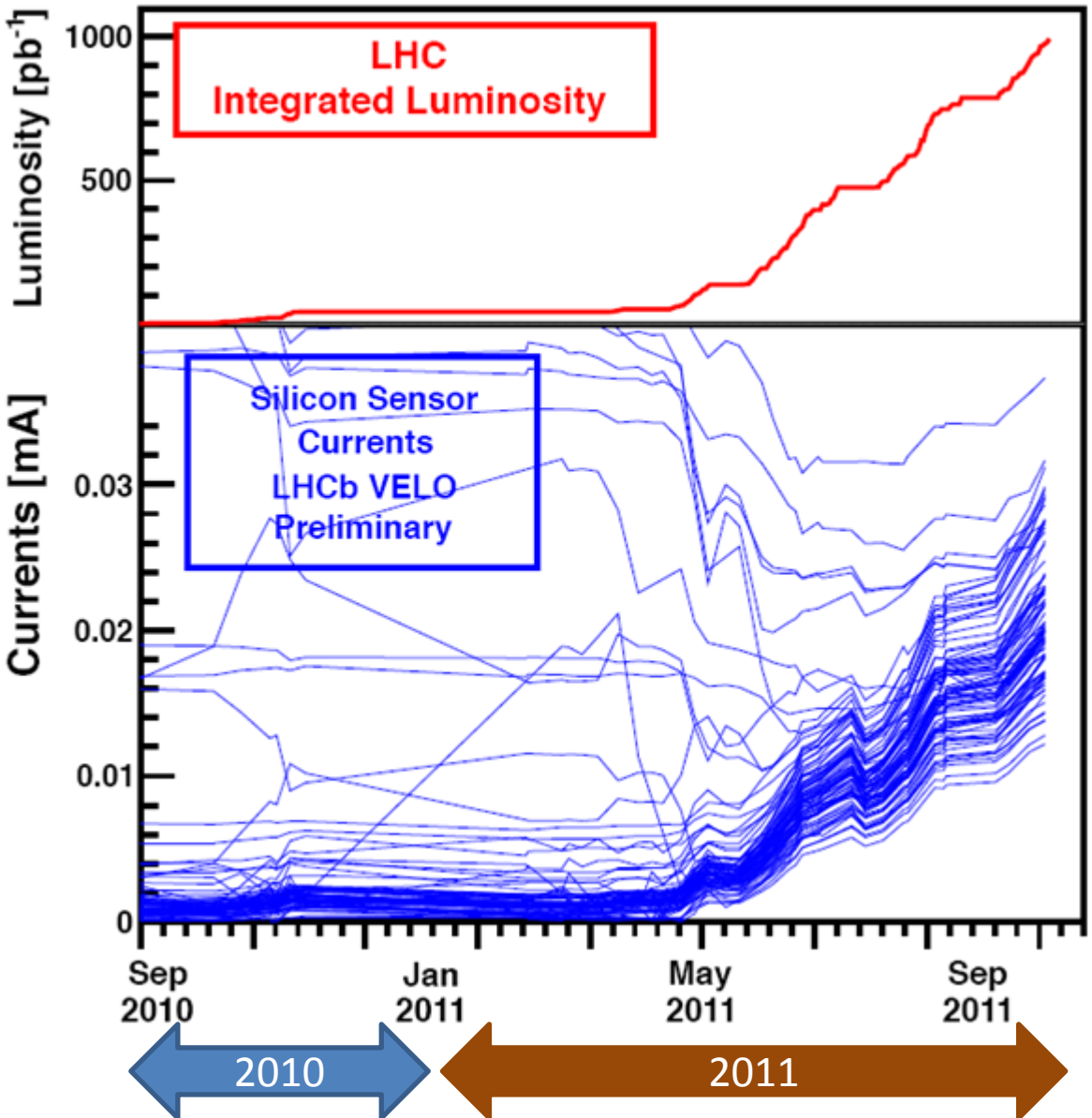
Currently operating with 7 TeV p-p collisions

Small reduction in expected does per inverse-femtobarn compared to 14 TeV

Collected about 1.22 fb^{-1} so far in 2009 to 2011

Both centre-of-mass and luminosities due to increase in 2012

Radiation effects observed



Most direct effect: leakage current increases

Currents measured at approx –8^{0}C without beam

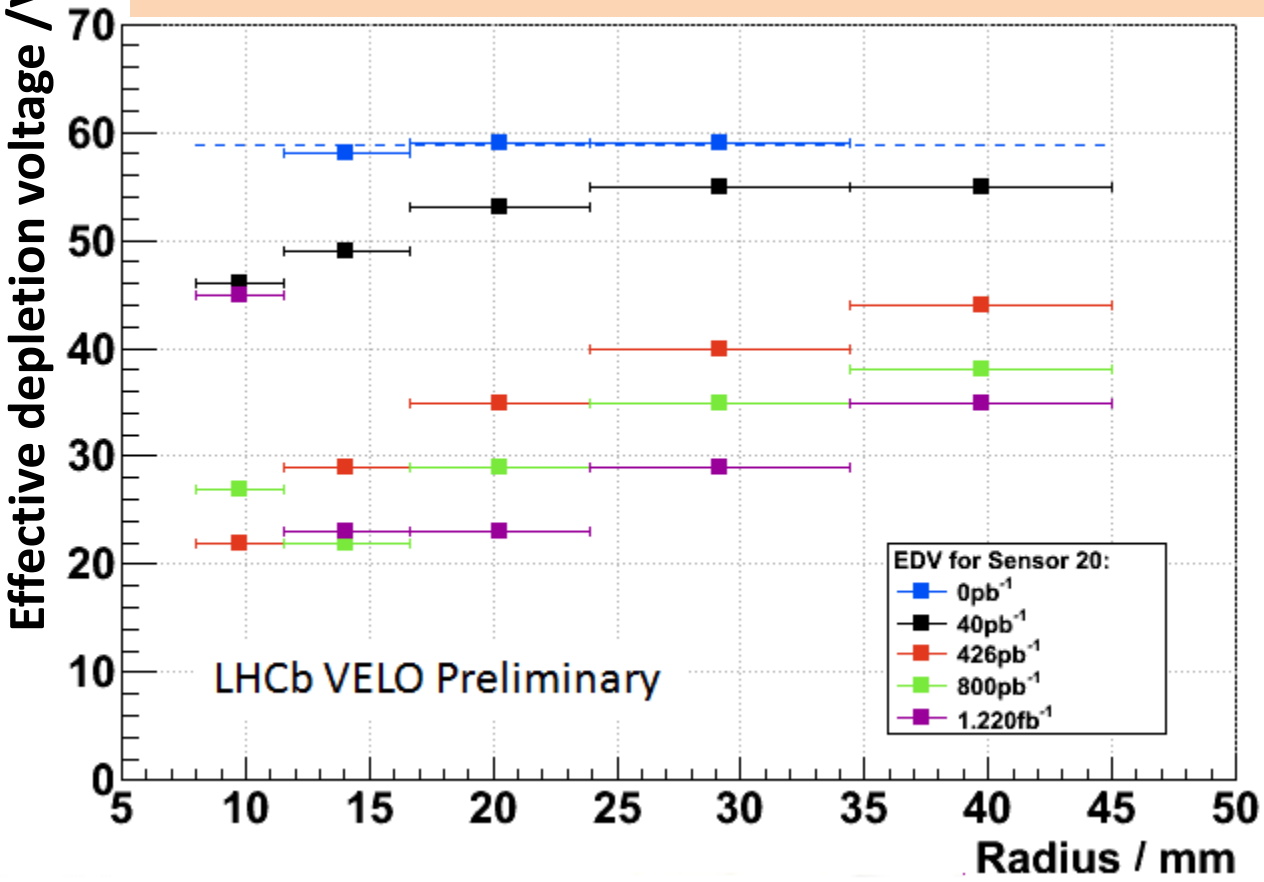
Typical increase was 1.9 μA per 100 pb^{-1}

Each line is one sensor's leakage current at 150V

The red line is the integrated luminosity

How effective depletion voltage for one sensor changes with fluence

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



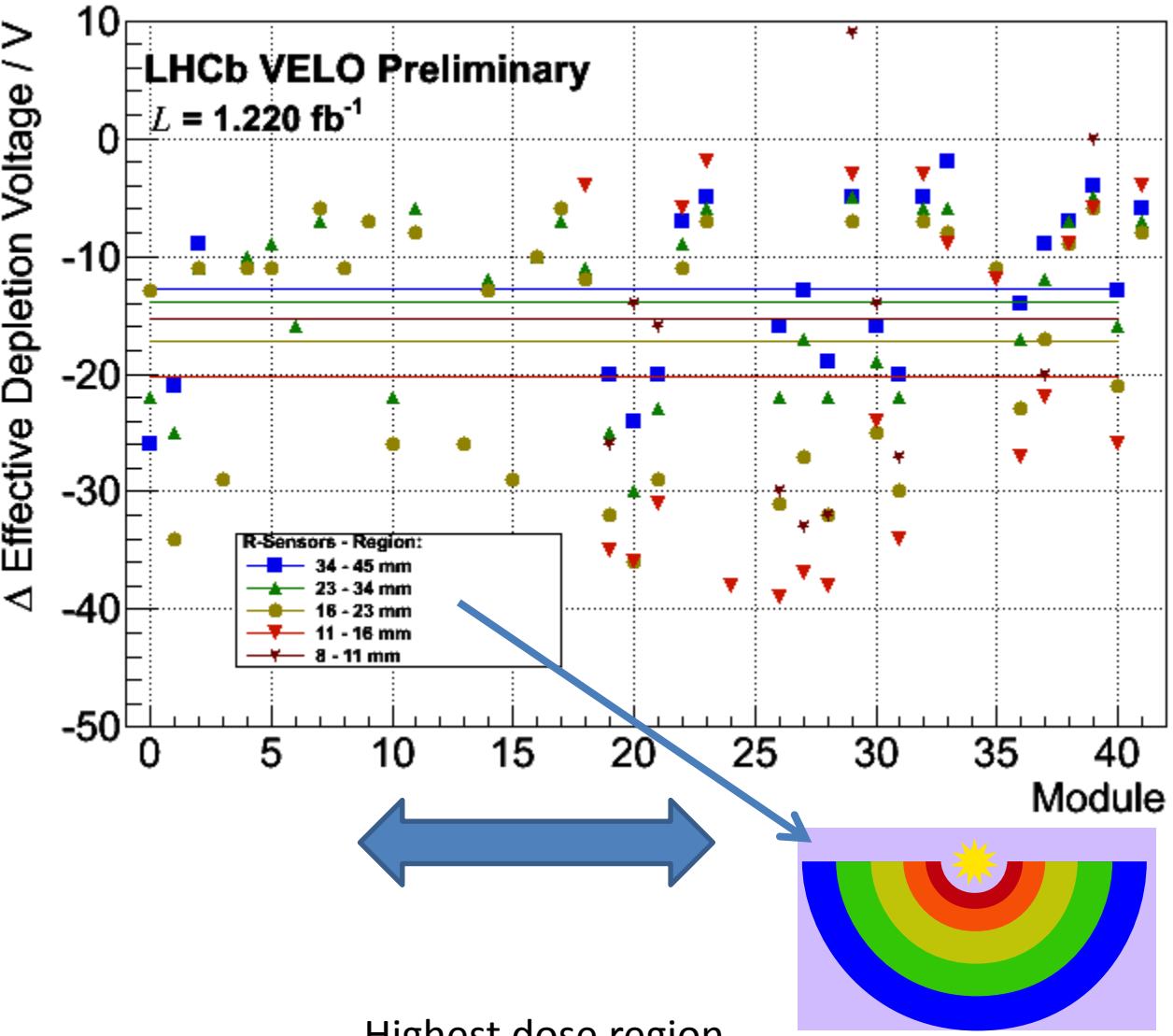
One typical sensor: Sensor 20

n-in-n R-type sensor

Close to the interaction point

Type inversion of n-bulk to p-bulk now visible at inner radius as EDV starts to rise again

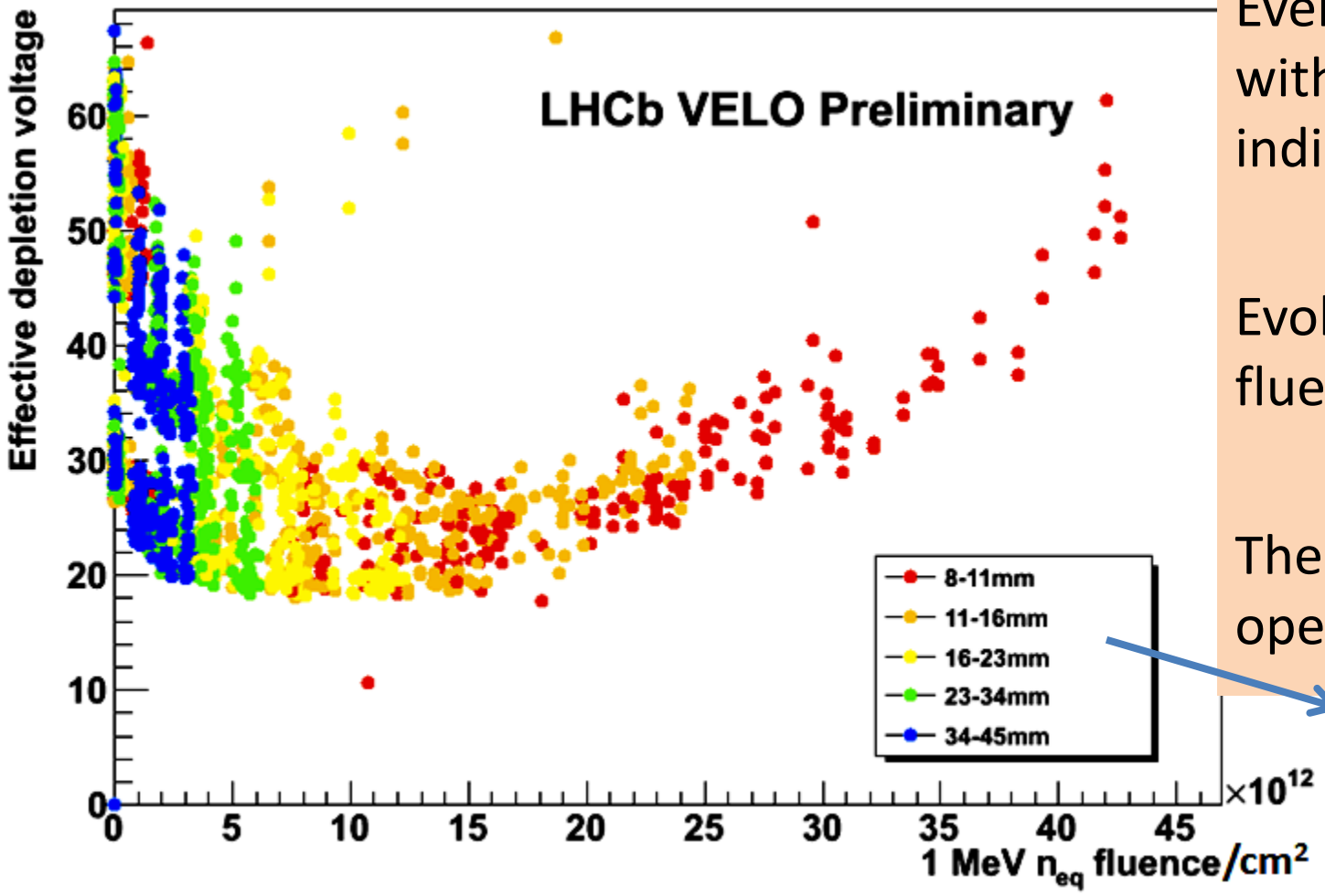
Change in depletion voltage



Highest dose region

- Estimate effective depletion voltage from charge collection efficiency measurements
- Compare installation and current values
- Overall 13V to 20V lower
- Binned in radius due to variation in dose with radius

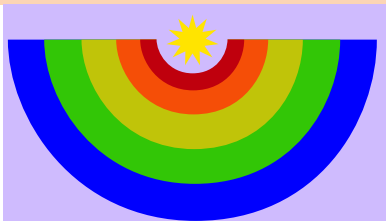
Effective depletion voltage for all sensors with fluence by radius



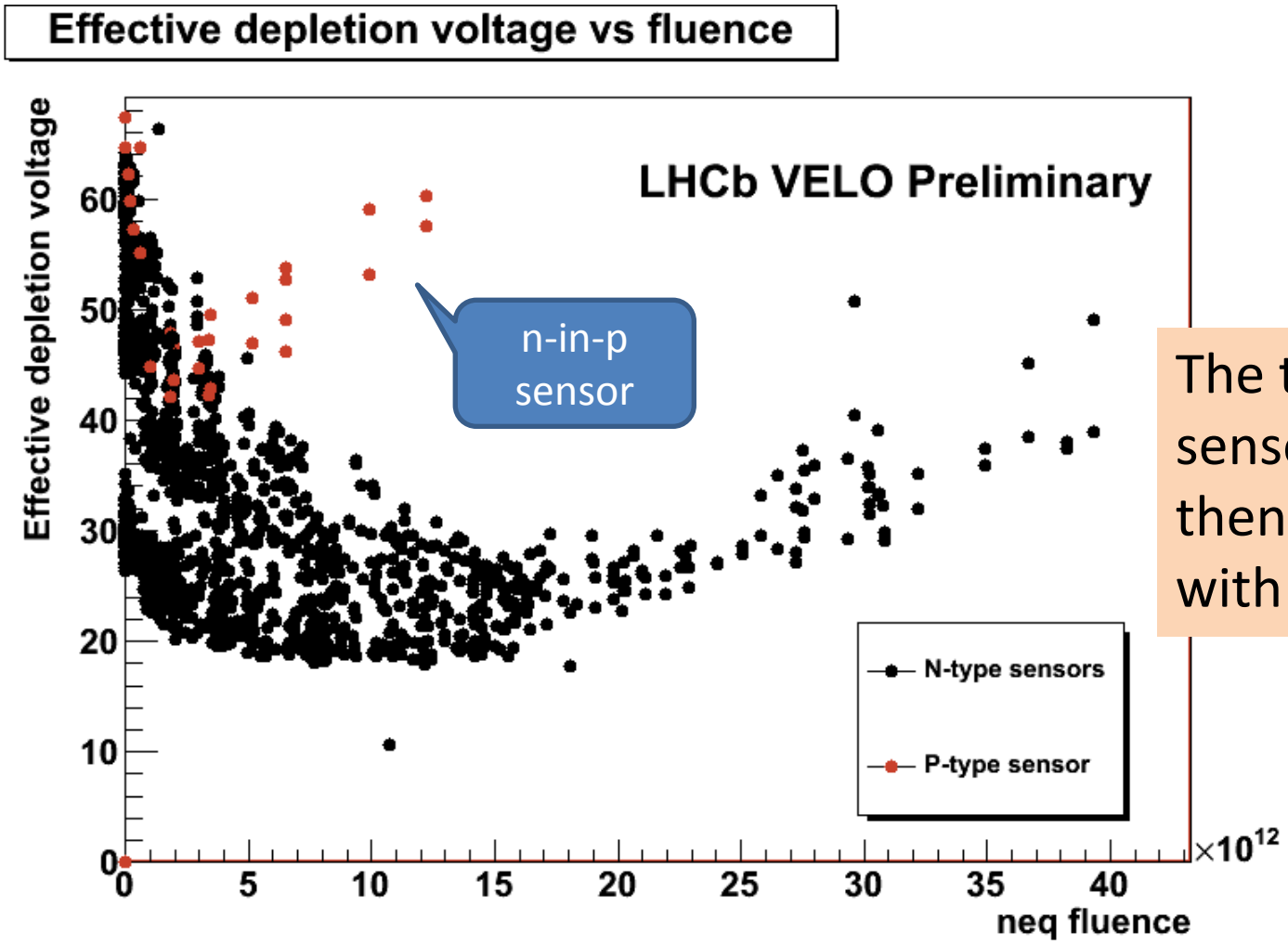
Every sensor's EDV with colours indicating the radius

Evolution with fluence shown

The HV can be operated up to 500V

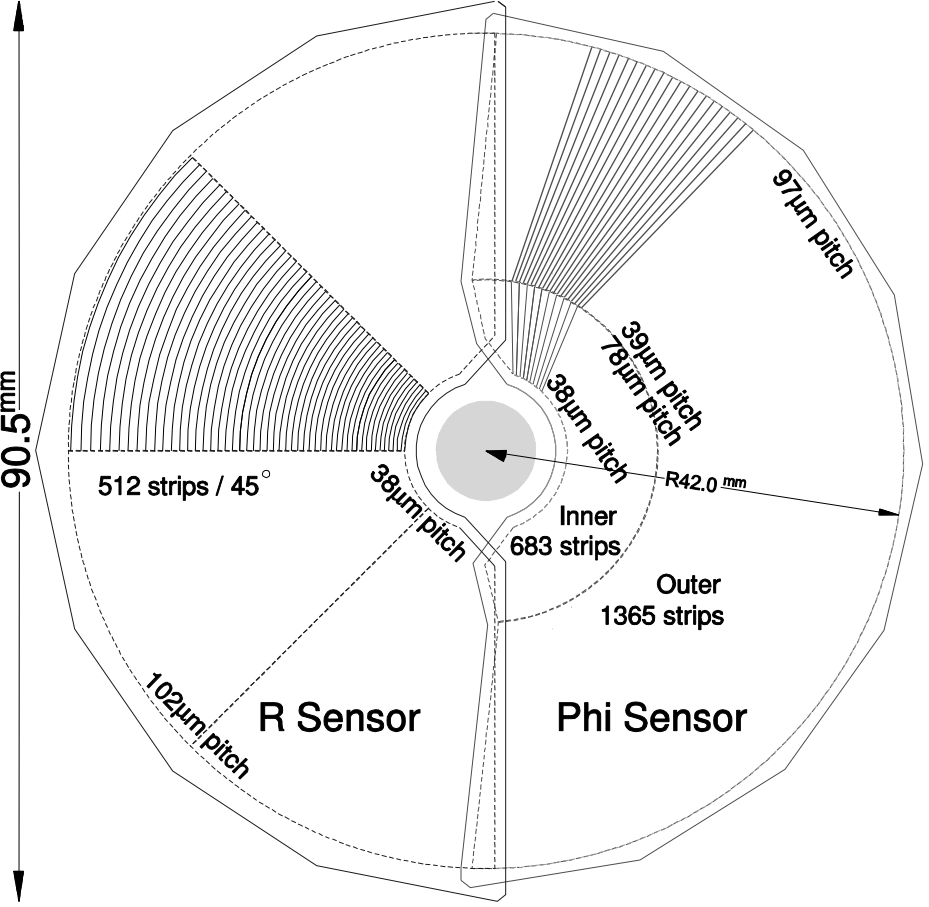


Effective depletion voltage for all sensors with fluence by type

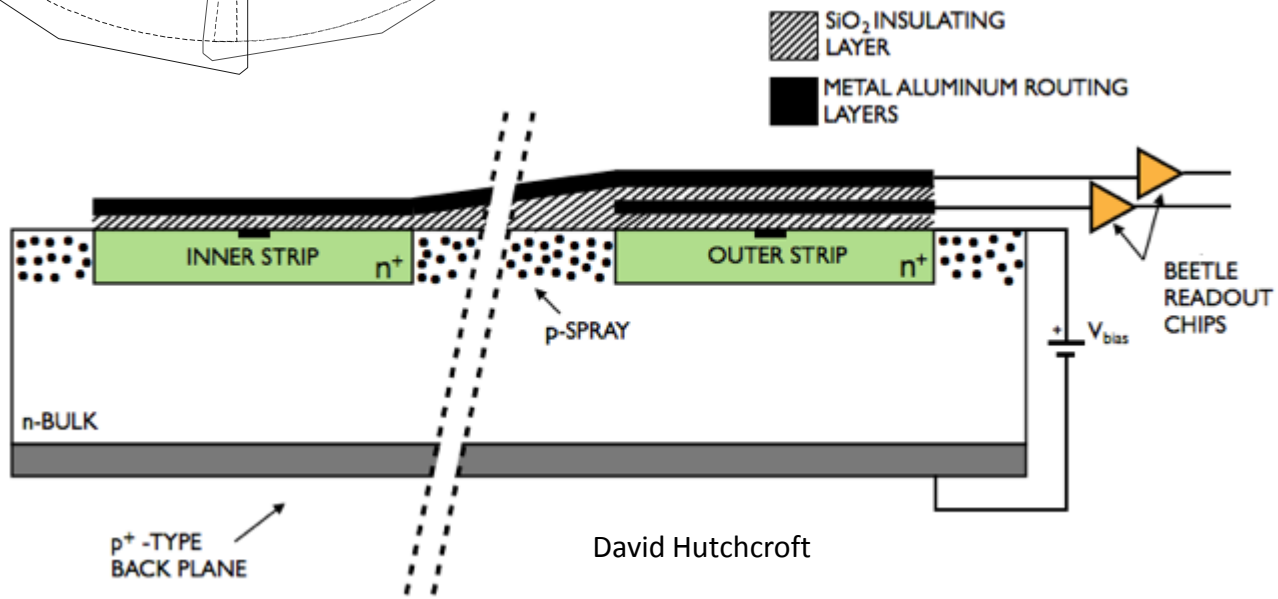


The two n-in-p sensors show a drop then rise in the EDV with fluence

Double metal effects

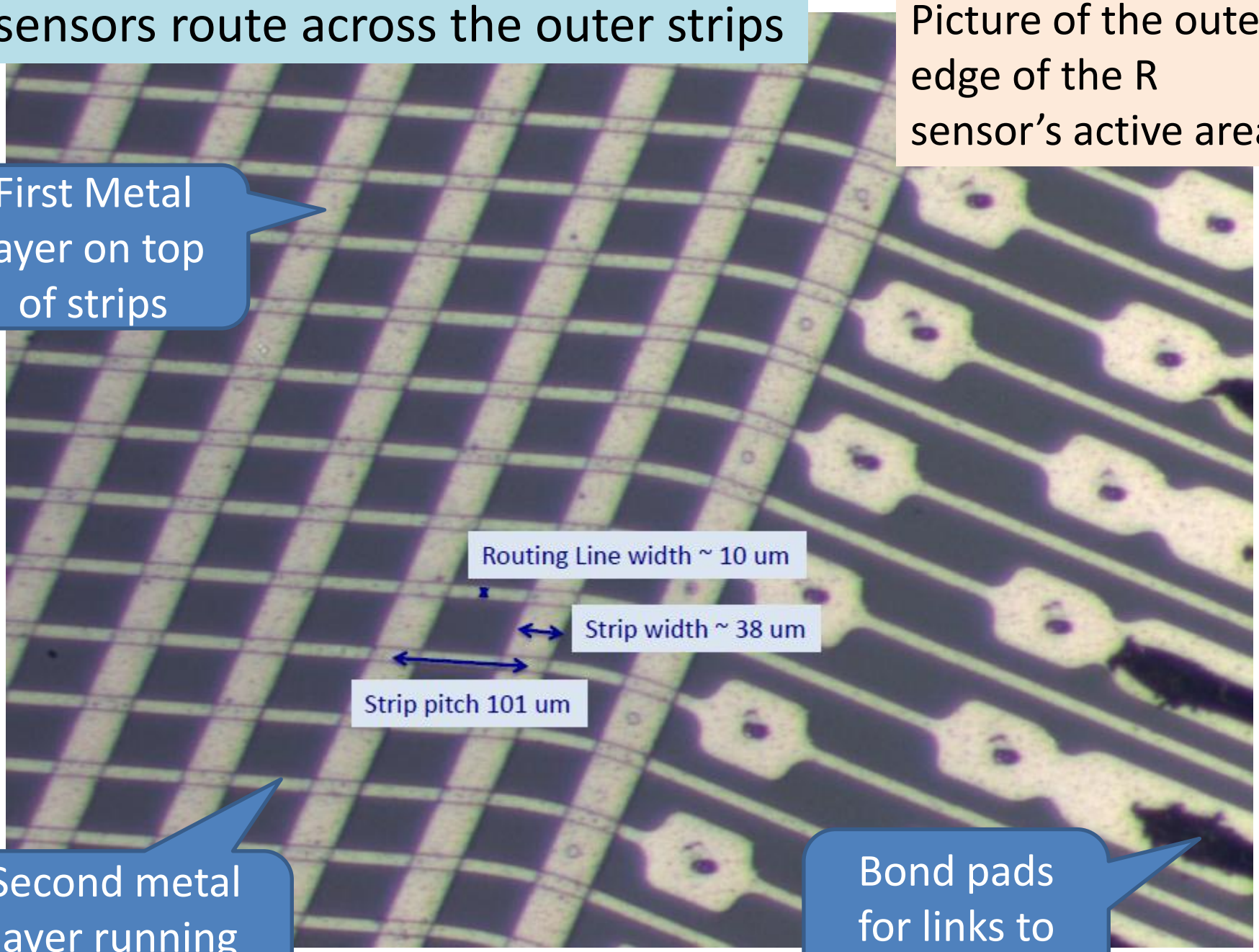


- R and phi sensors need two sets of metal lines
- One to capacitively couple to the strips, the other carrying the signal to the amplifiers over the outer strips
- Phi sensors (below) second metal routing is over the outer strips



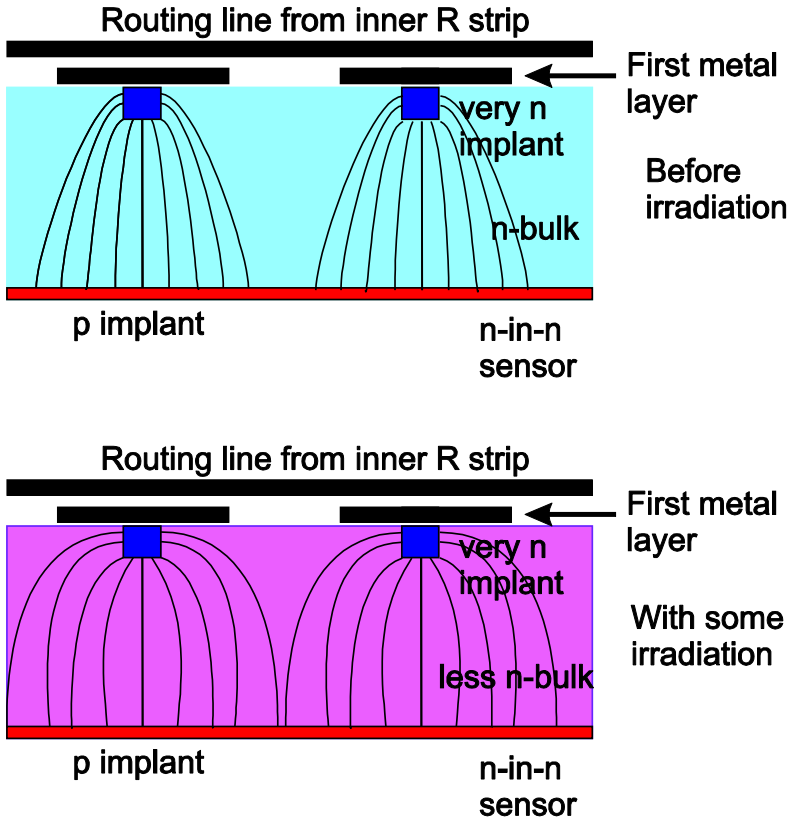
R sensors route across the outer strips

Picture of the outer edge of the R sensor's active area

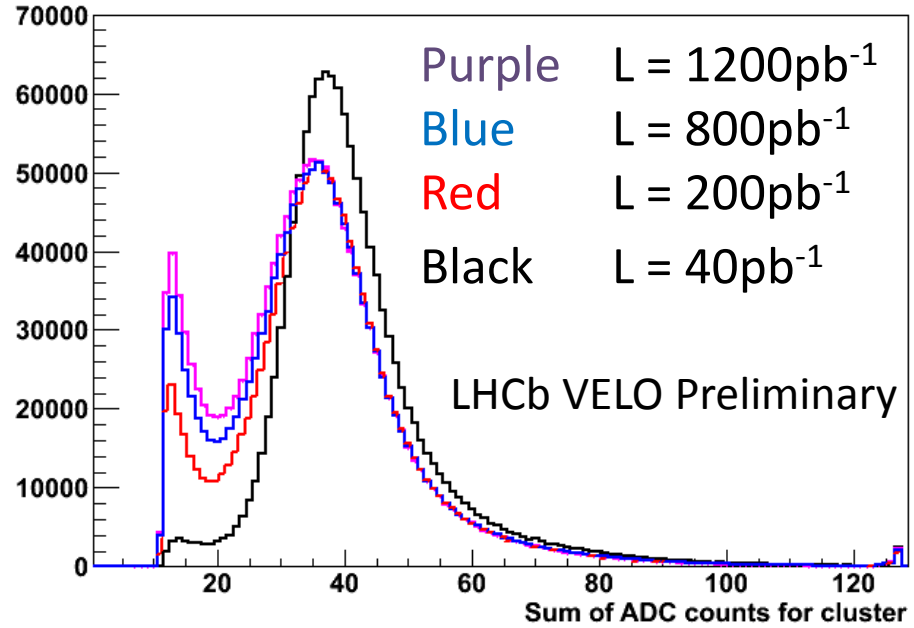


Coupling effects of signals in R sensors

- 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



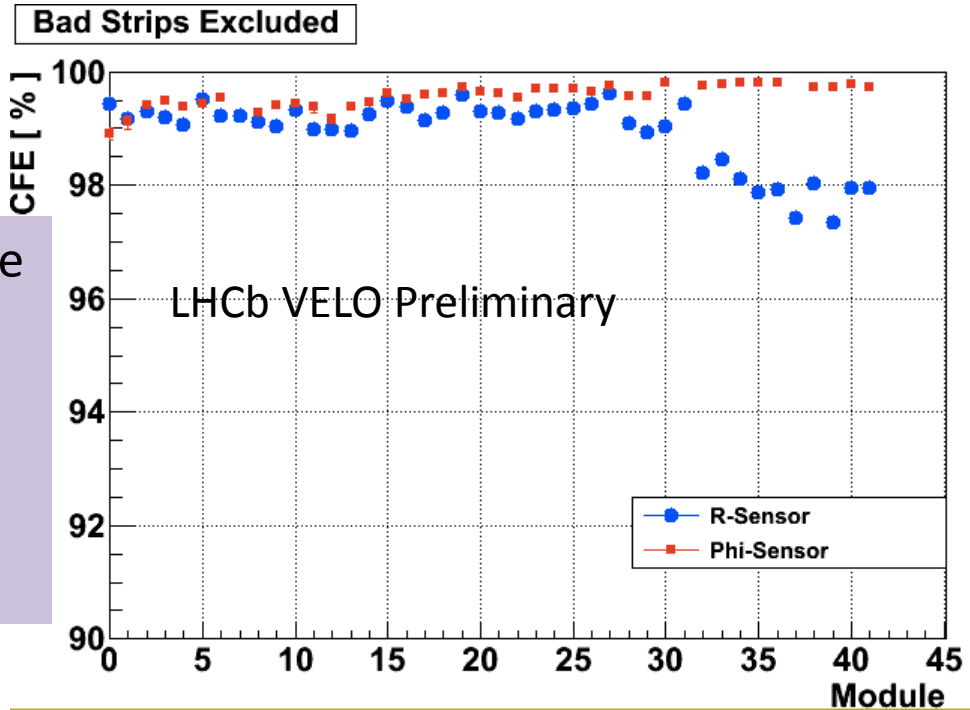
Effects in data taking



Cluster size for R sensor clusters in ADC counts for clusters not associated to tracks

Cluster on inner R strips at very low ADC counts appearing

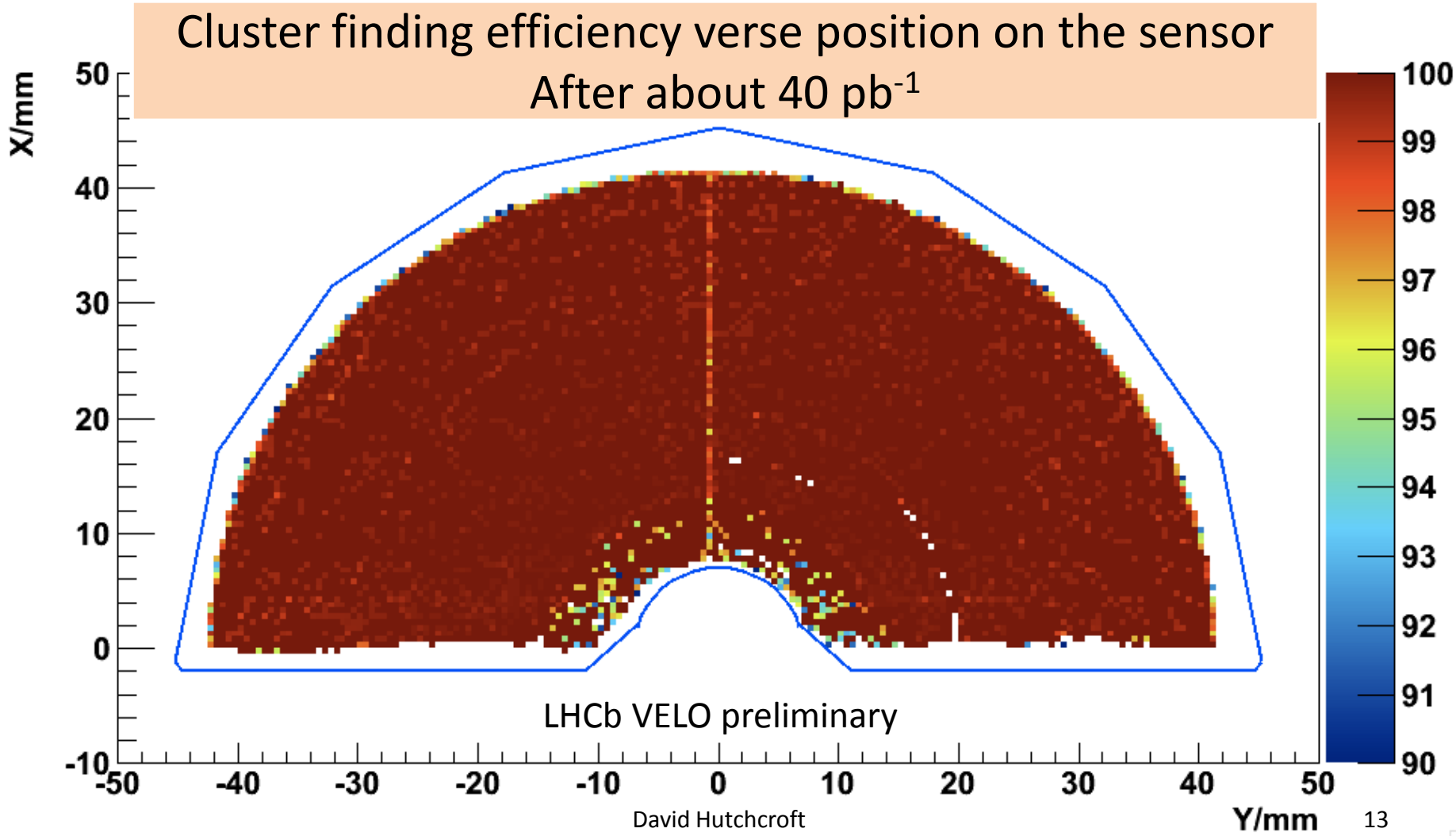
Predominately at the inner regions of the sensors, not where tracks crossed the sensors



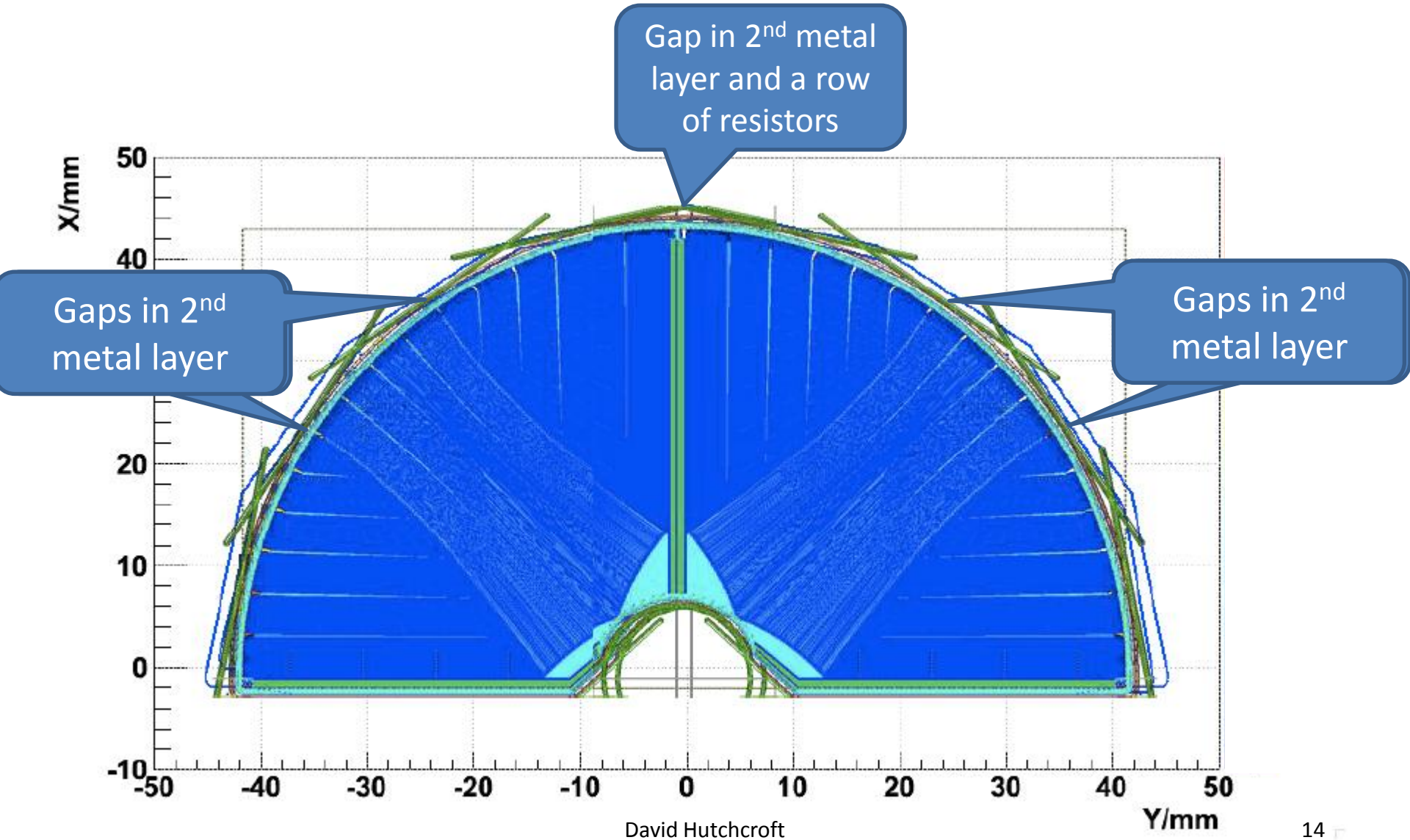
Cluster finding efficiency verse module
A reduction in the cluster finding efficiency for the R sensors

Predominately in the forward sensors and at large radius

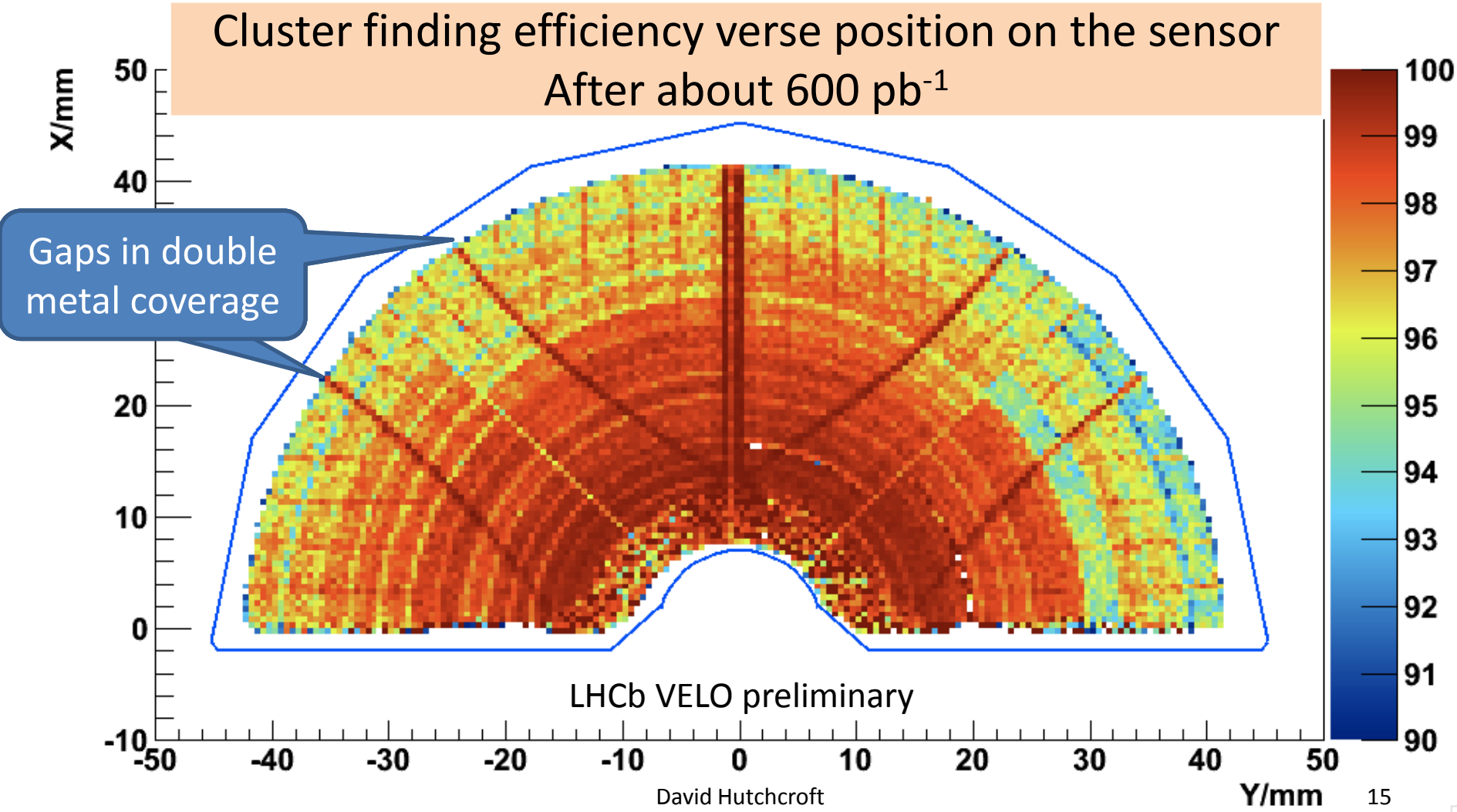
Cluster finding efficiency 2D map for one R sensor, sensor 40



Second metal layer layout for R sensors



Cluster finding efficiency 2D map for one R sensor, sensor 40



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 now always keep the detector cold to avoid unwanted annealing
- R sensors show coupling to second metal layer causing a reduction in efficiency
- Tracking efficiencies are as yet unchanged (<0.5% effects)
- Every reason to believe that we will get five more years out of these sensors

Backup slides

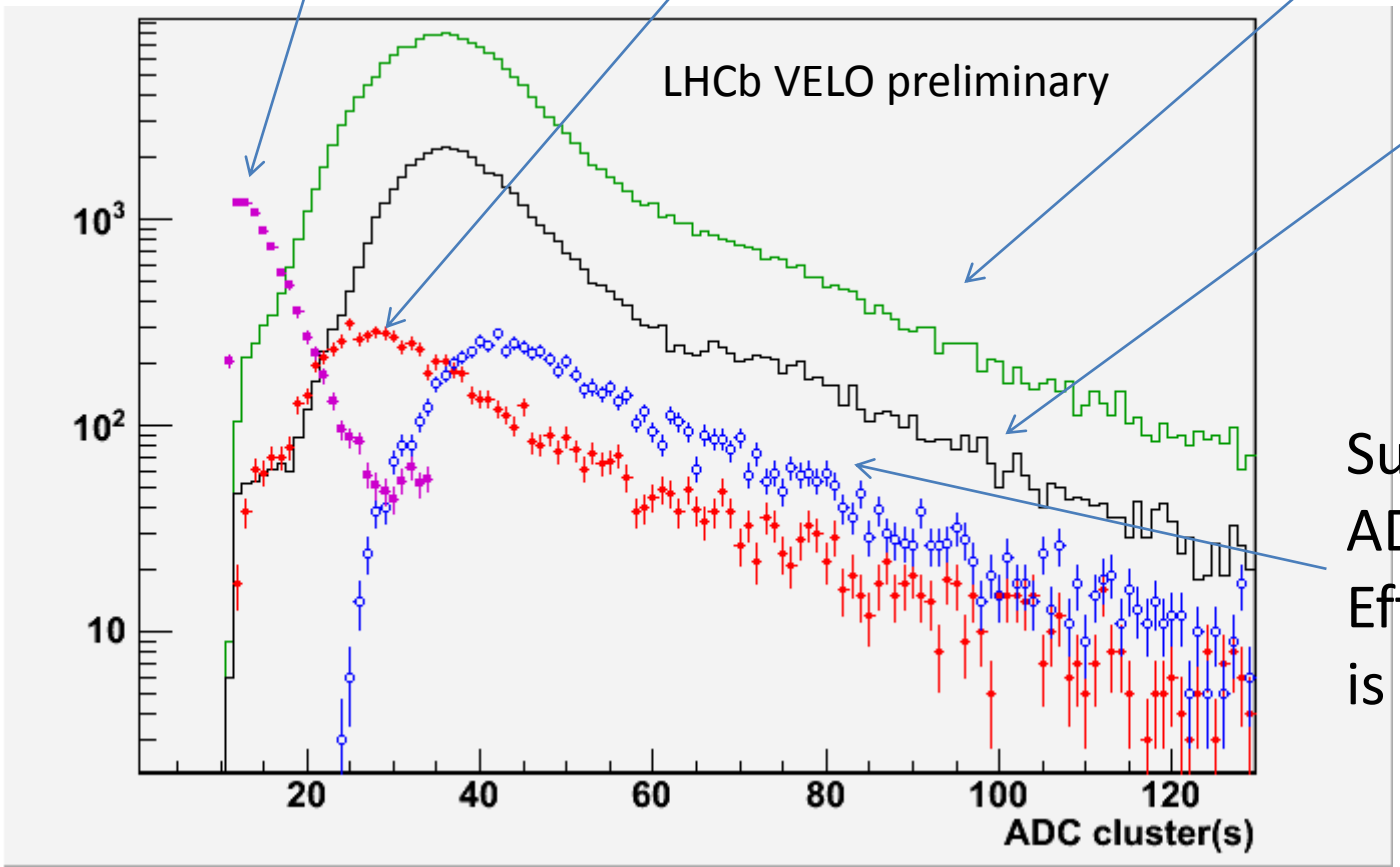
Effects of double metal effect on charge collected in ADC counts

Inner clusters (purple points)

Has inner cluster (red points)

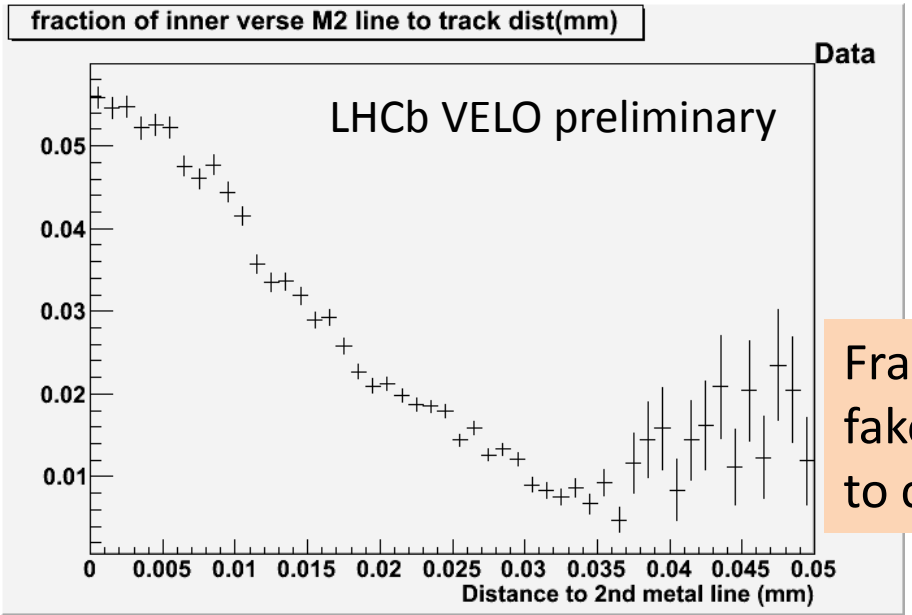
No inner cluster with routing line (Green)

No routing line (Black)



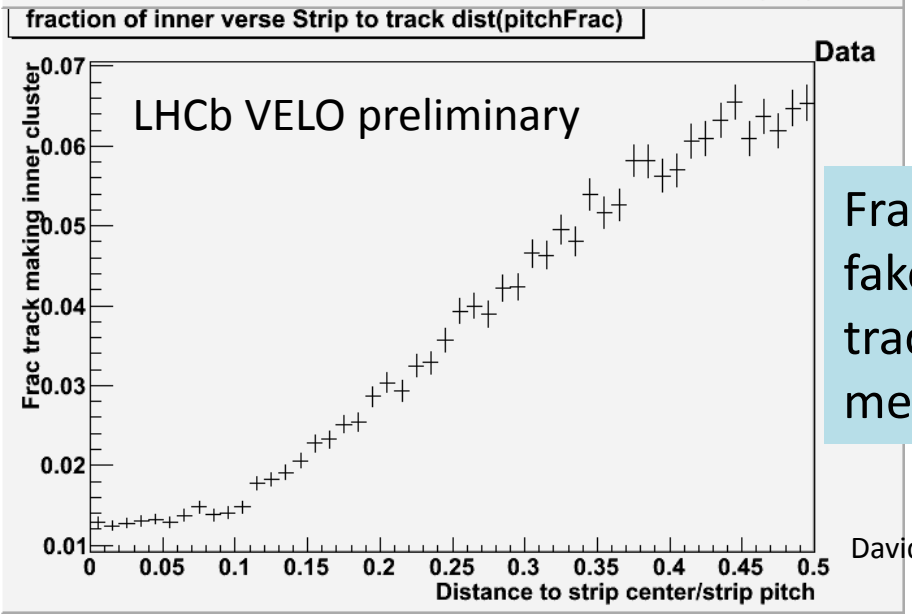
Sum of inner + outer ADCs
Effective ADC charge is **not** conserved

Parameters of double metal effects



Effects of track position on coupling to second metal layer

Fraction of tracks impact points with a fake inner cluster verse distance of track to closest 2nd metal layer



Fraction of tracks impact points with a fake inner cluster verse distance of track to centre line of the strip (1st metal layer)