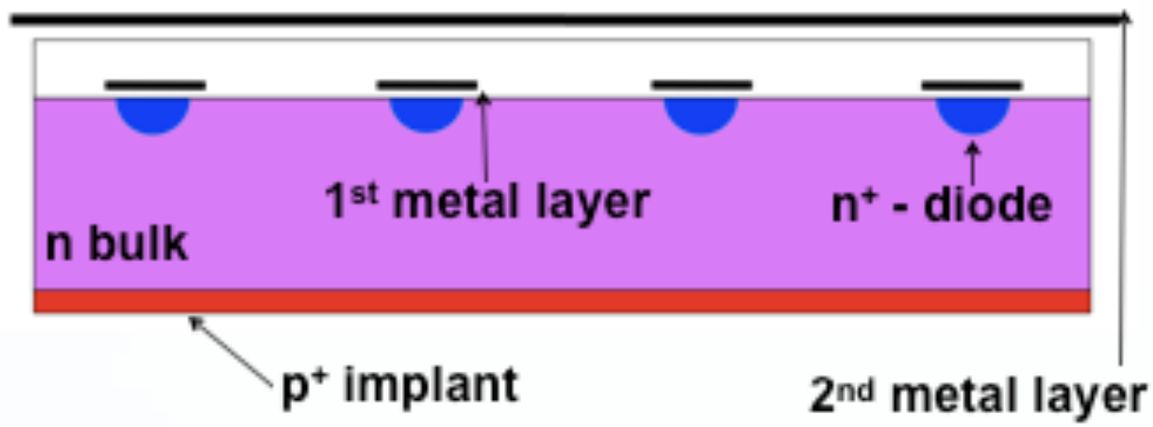
Effective Depletion Voltage & 2nd Metal Layer effects in the LHCb VELO

Dermot Moran on behalf of LHCb VELO

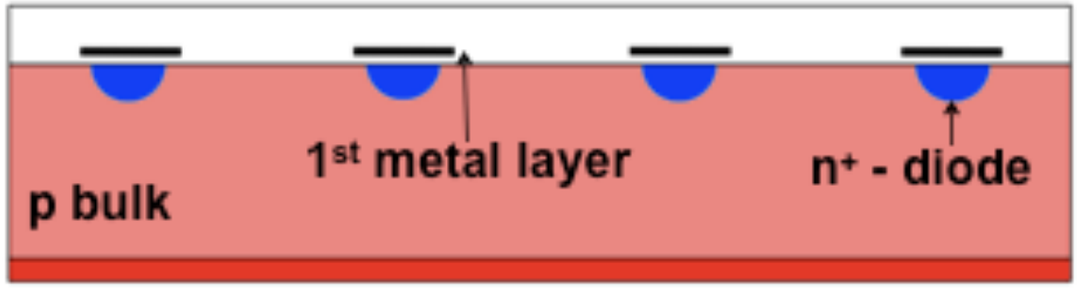
20th RD50 Workshop on Radiation hard semiconductor devices for very high luminosity colliders, Bari 2012

VELO Strip Sensors

- n^+-on-n 300 um sensors
- Oxygenated
- Double Metal Layer



- 2 Sensors are n^+-on-p
- Backwards region (not important for Physics analyses)

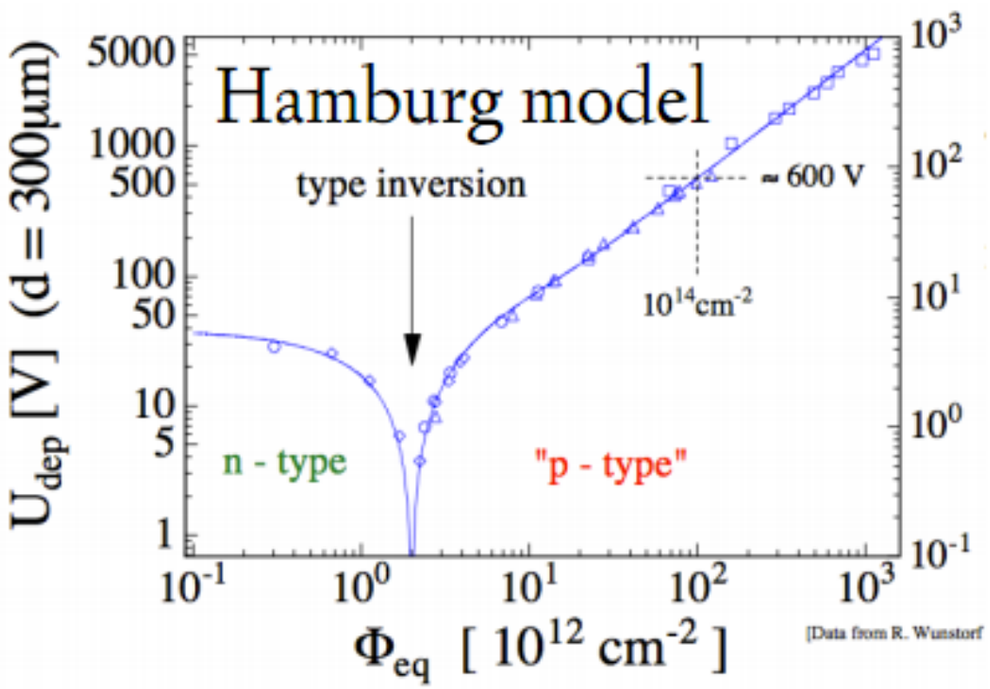


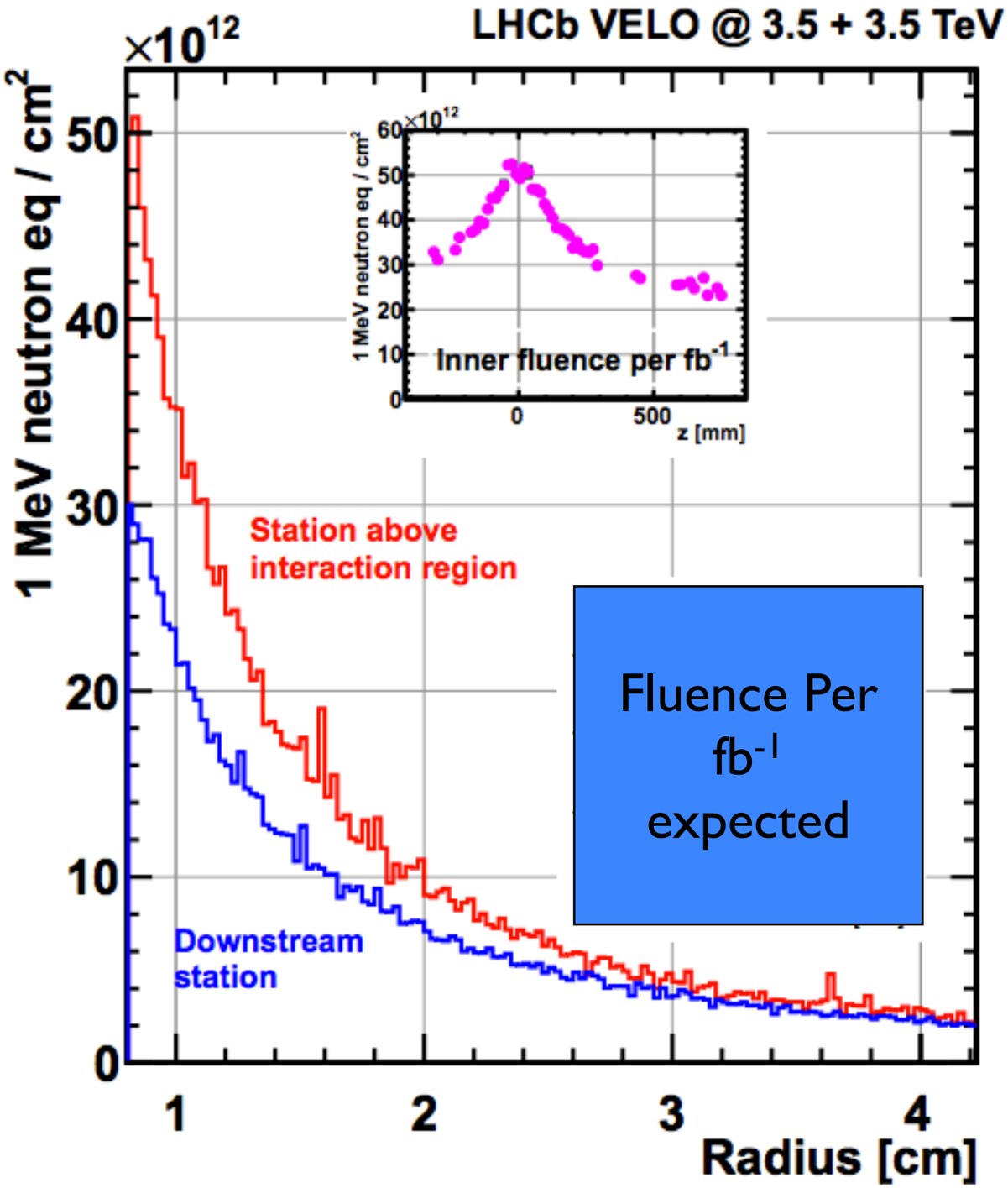
- VELO consists of 42 Modules
  (Module: adjacent R and Phi geometry strip sensors)

Inner most strips are 8mm from beam
Exposed to highest levels of radiation at the LHC

Fluence Prediction

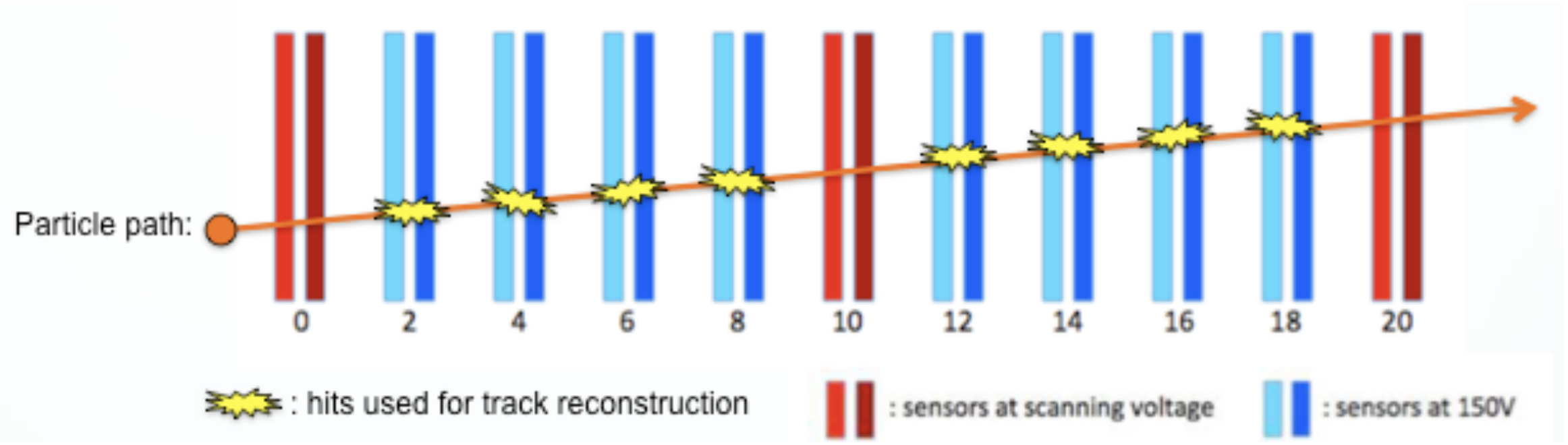
- Have collected ~ 1.22 fb^{-1} from 2009 to 2011
- 7 TeV pp collisions in 2010/11
- MC studies give expected radiation as a function of
  Z: Sensor position along beam pipe
  R: Radial distance from beam pipe





CCE Methodology

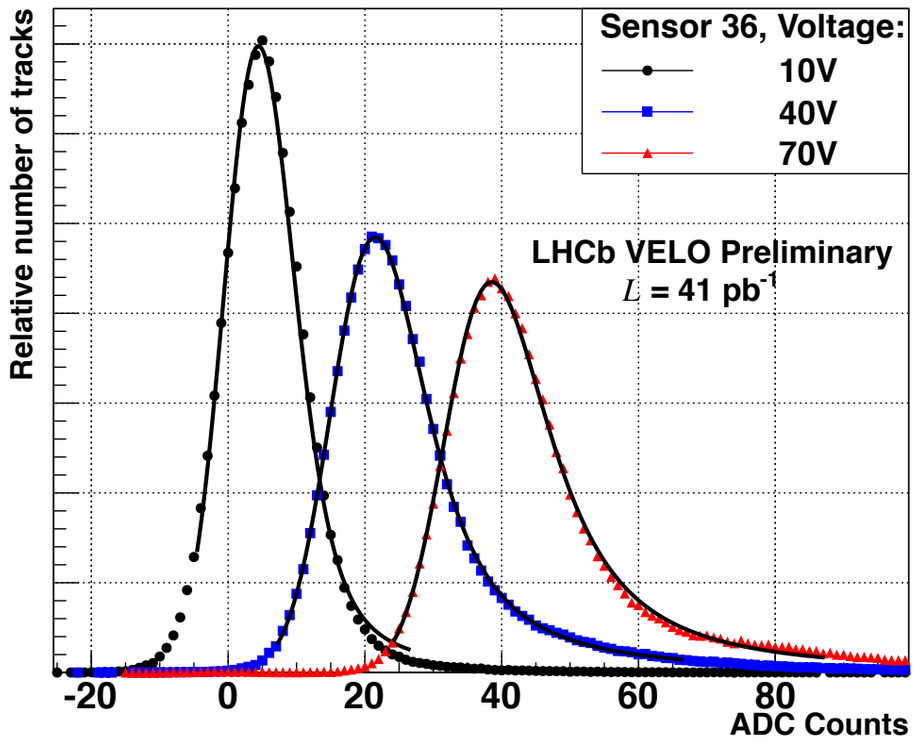
- Reconstruct Tracks with every 5th module **excluded**
- Extrapolate track to **Test Sensor** and determine the charge collected in this area



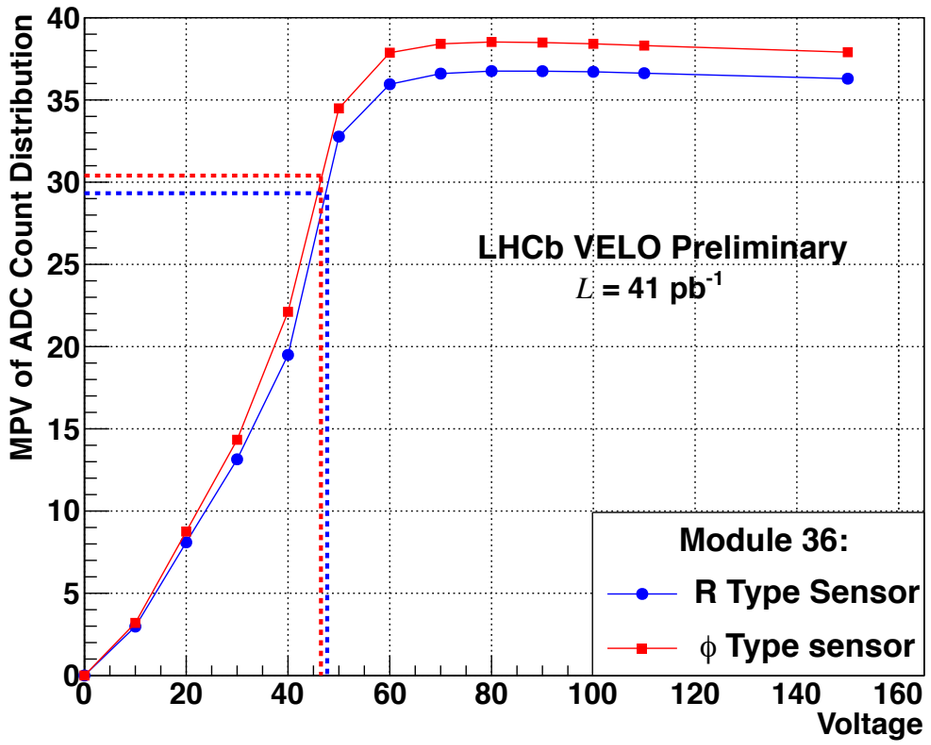
- Repeat with the **Test Sensor** operated at a number of different bias Voltages (0-150V)

CCE Methodology

- Determine the Charge Collection MPV at each Voltage

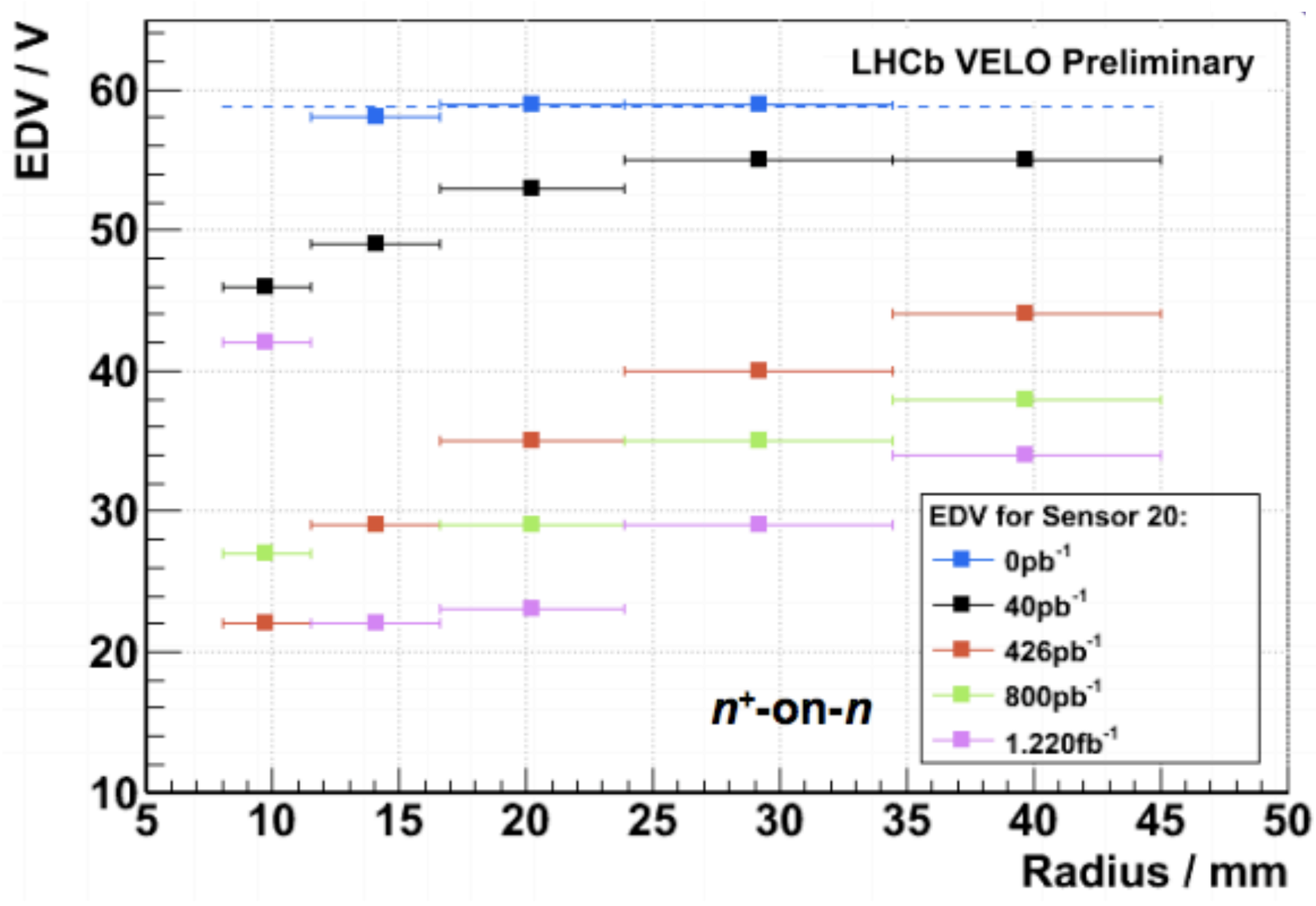


- Plot MPV Vs voltage and define the Effective Depletion Voltage(EDV) as the voltage at which the MPV reaches 80% of its maximum value



EDV Vs Fluence

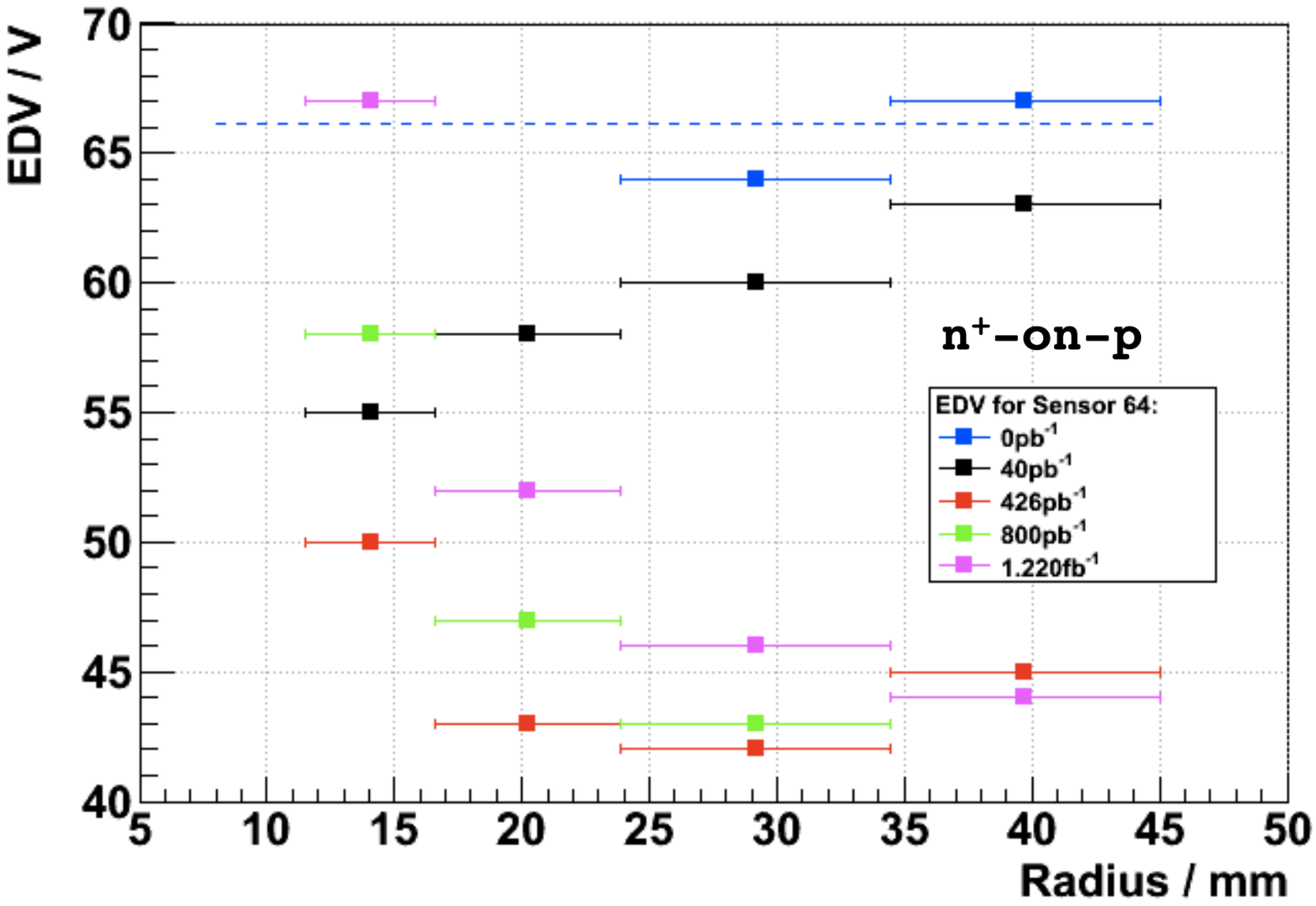
n^+-on-n sensor



- Type inversion of n-bulk to p-bulk visible at inner radius

EDV Vs Fluence

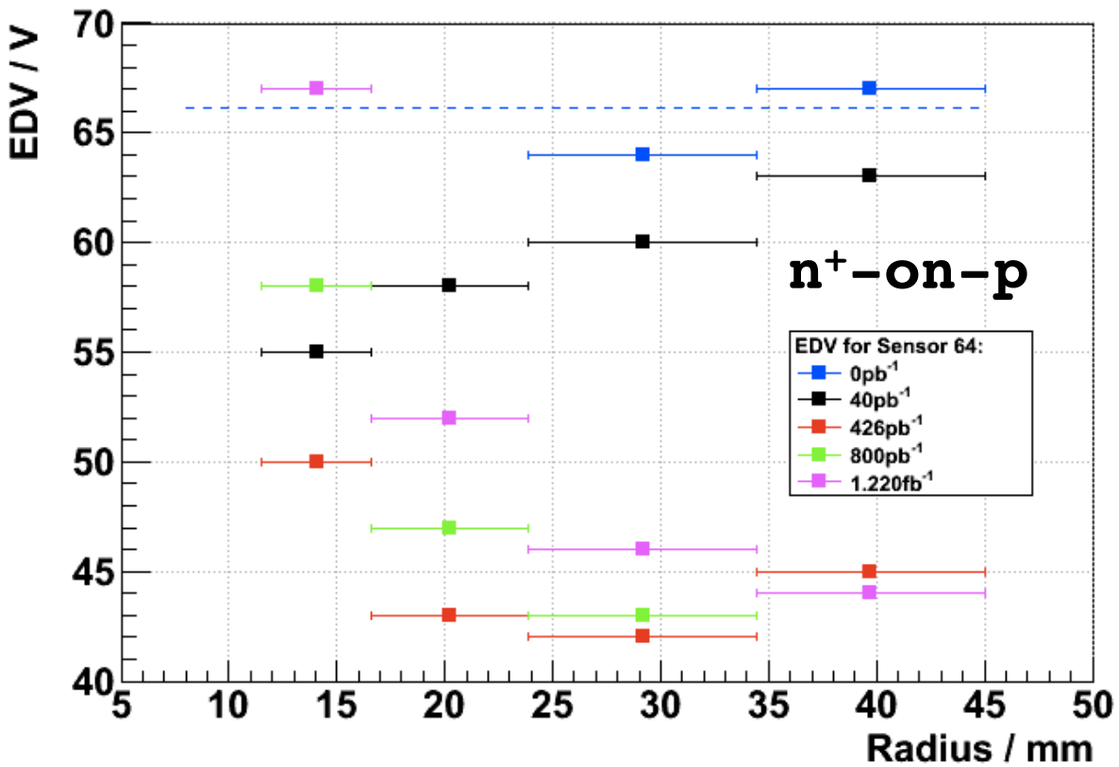
n^+-on-p sensor



- Initial drop in EDV followed by an increase

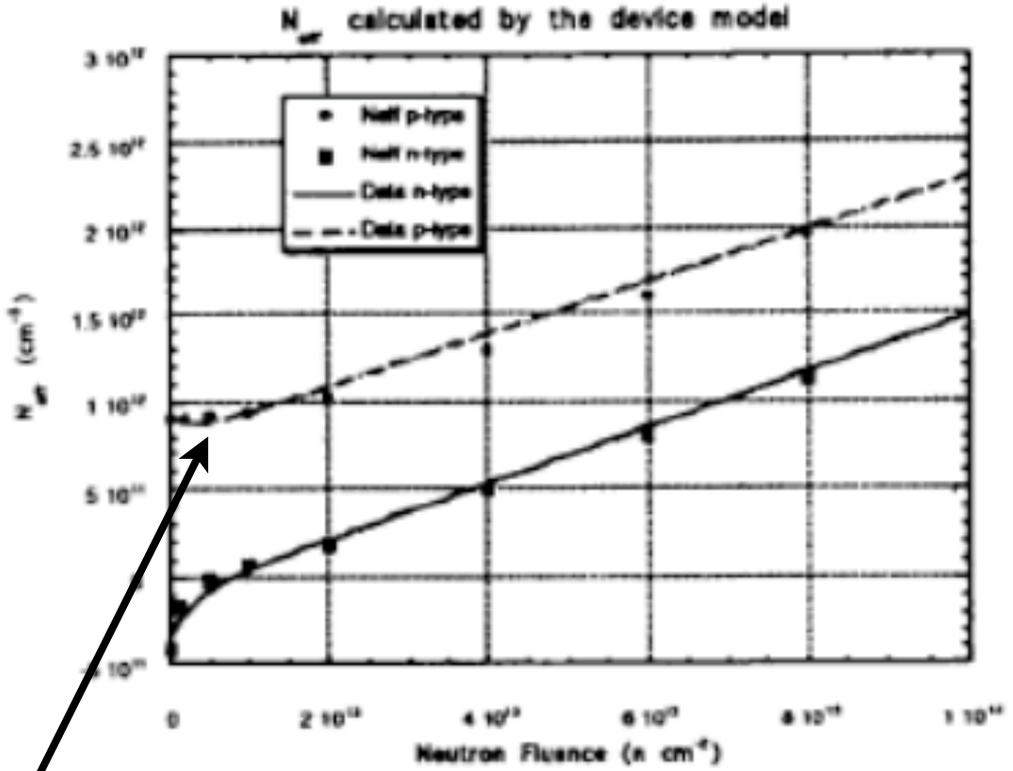
EDV Vs Fluence

n^+-on-p sensor



RD-2 1993

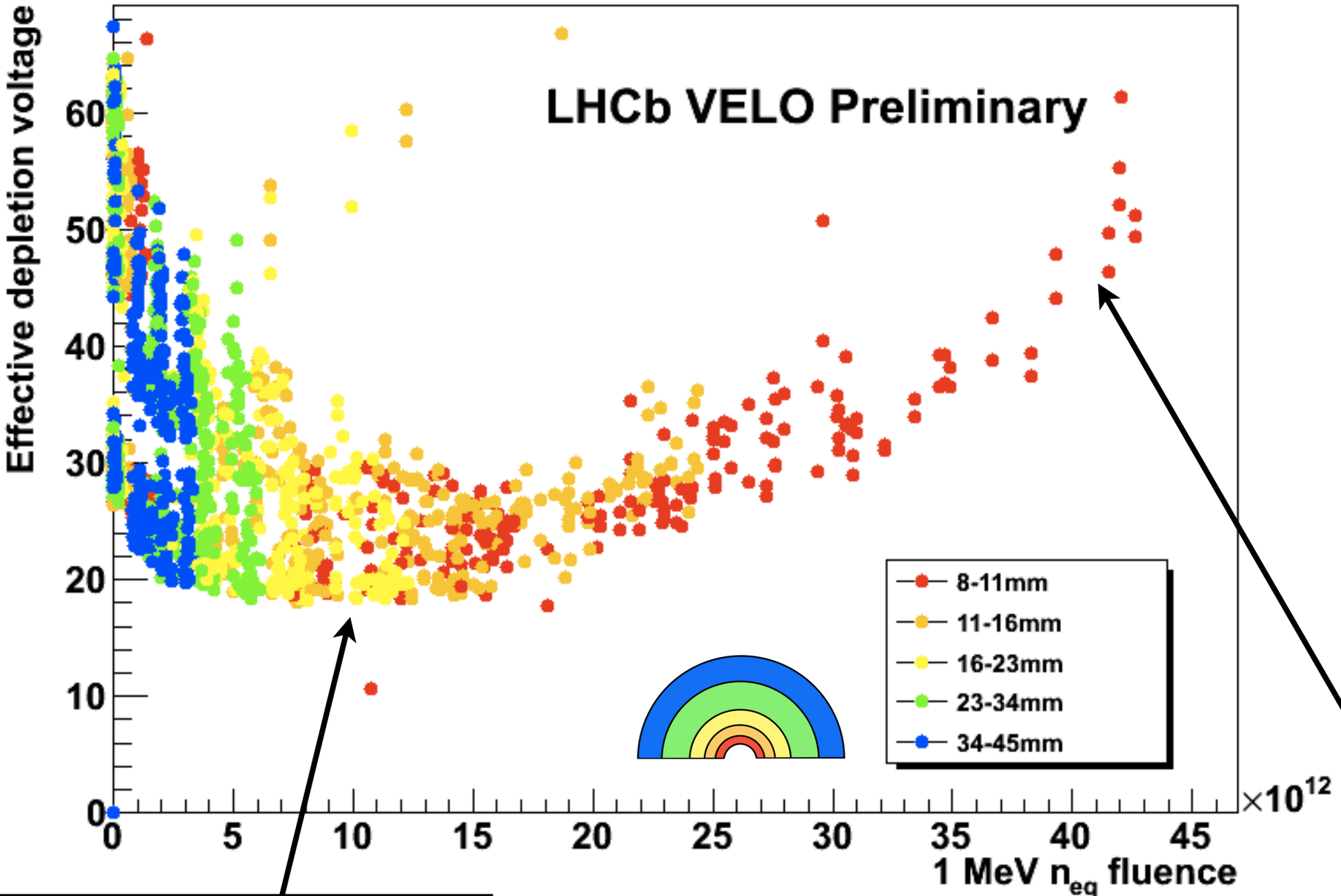
(thanks to Steve Watts)



Initial acceptor removal
Initial decrease in EDV

EDV Vs Fluence

All sensors EDV (split into different radius regions)

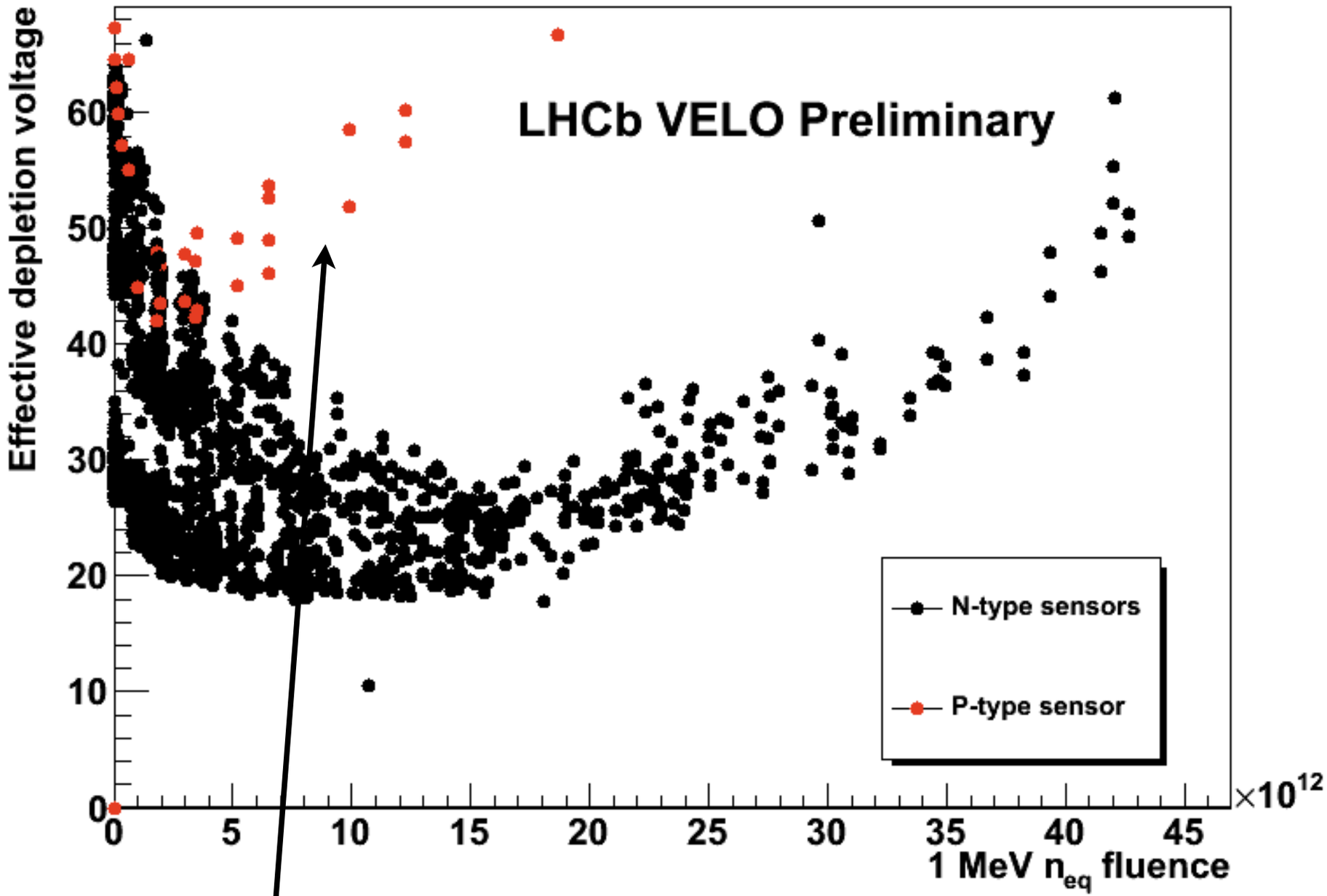


Common Inversion Point at ~ 10^{13} 1 MeV n_{eq}

Sensor tips have type inverted

EDV Vs Fluence

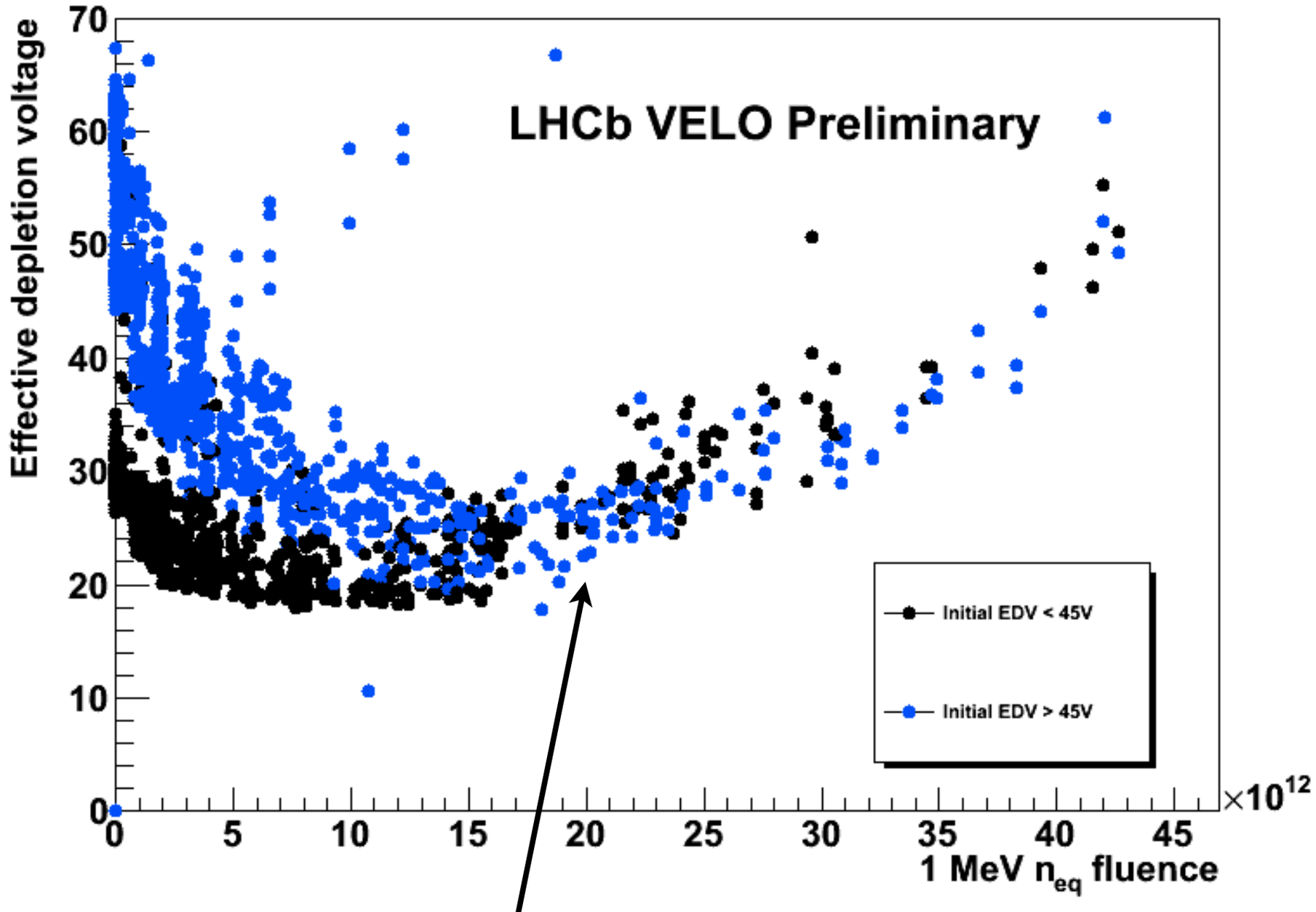
All sensors EDV (split into n^+-on-n and n^+-on-p)



n^+-on-p see a drop in EDV before increasing at lower fluence than n^+-on-n

EDV Vs Fluence

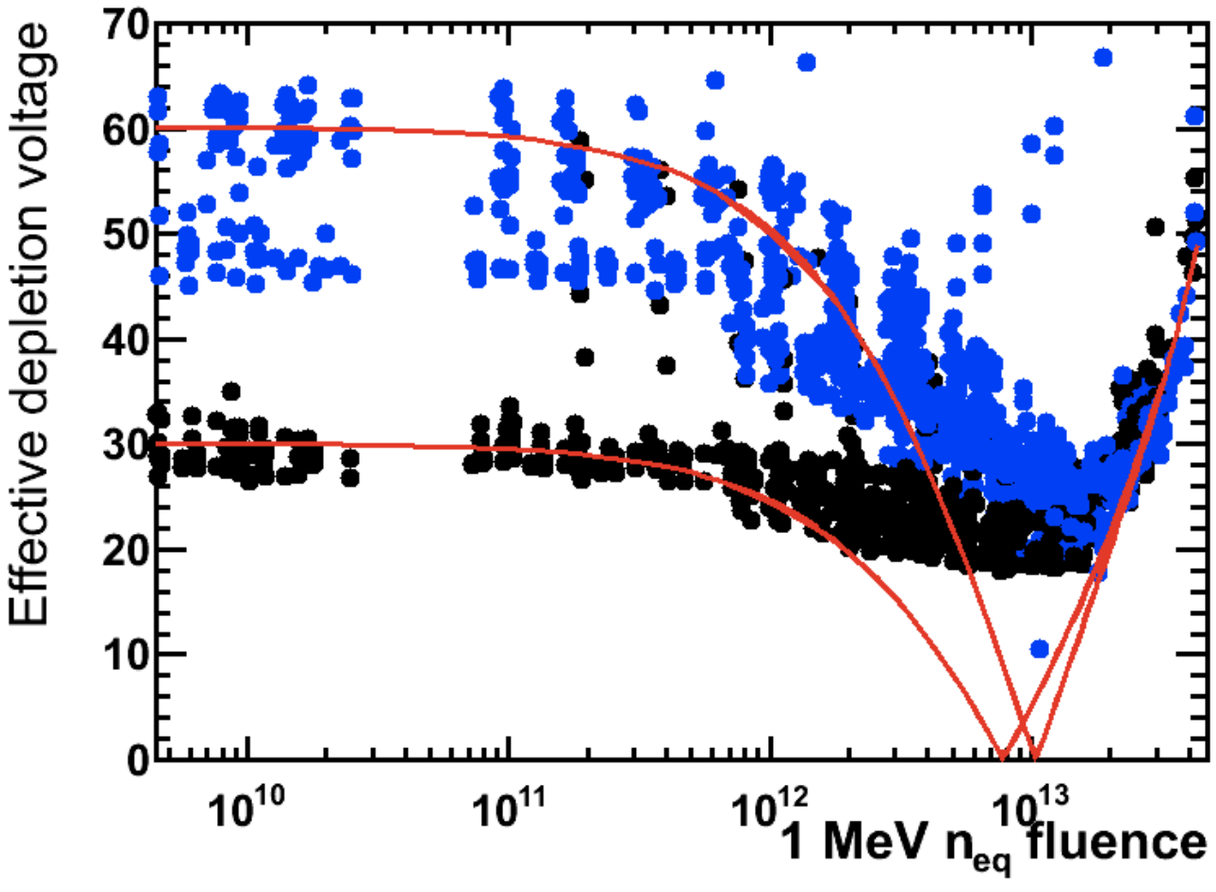
All sensors EDV (split into Low and High initial EDV)

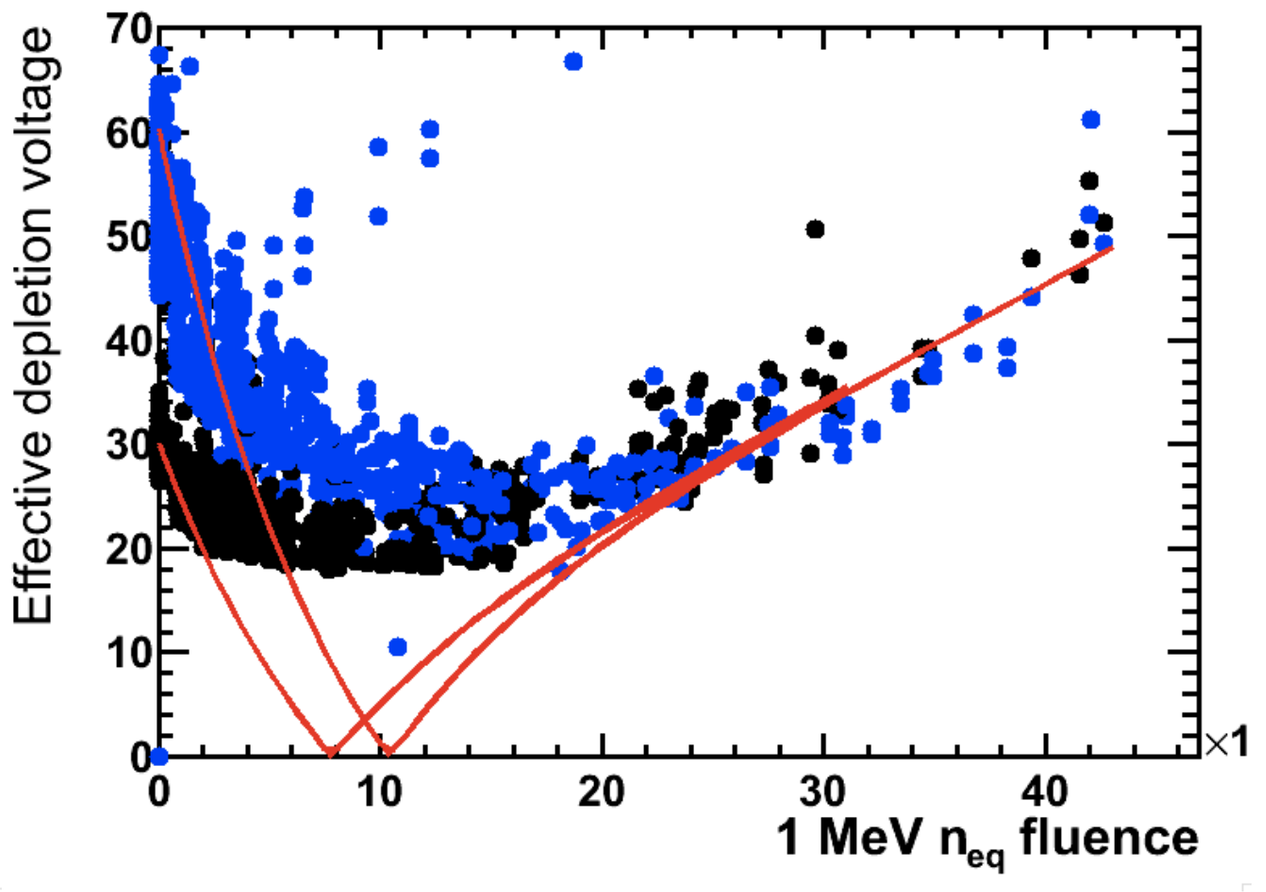


After type Inversion all sensors show similar behavior

Hamburg Model Comparison

Comparison with Hamburg Model

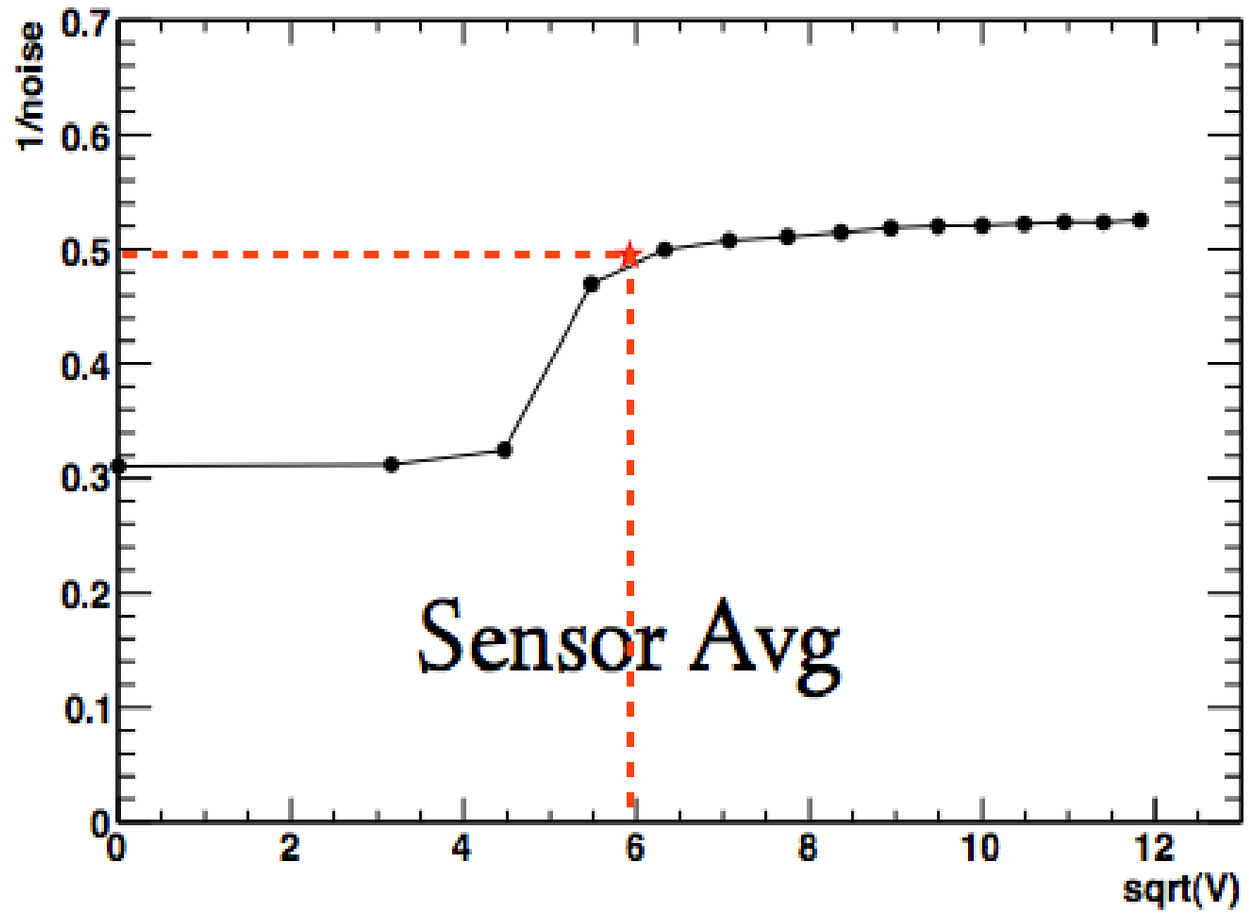




Good agreement before and after type inversion

Noise Vs Voltage Methodology

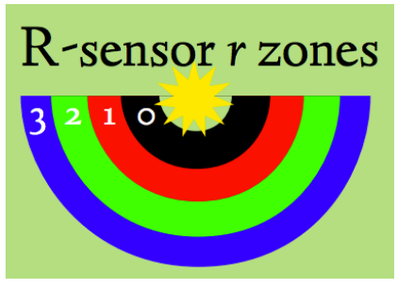
- Intrinsic noise is proportional to capacitance
- Depleted Sensor: lower capacitance and so lower noise
- Underdepleted Sensor: higher capacitance and so higher noise



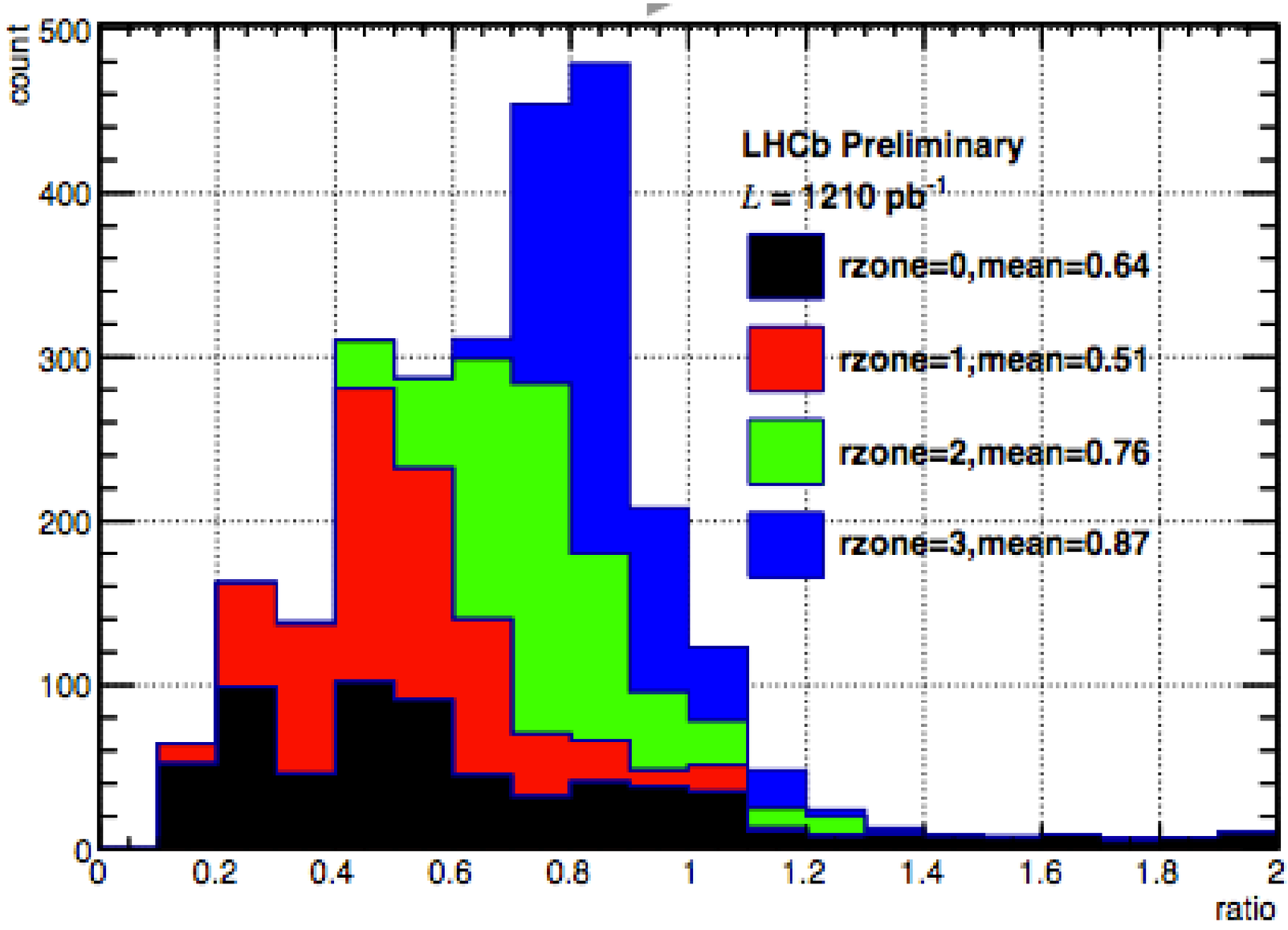
- Noise Effective Depletion Voltage(NEDV) defined as the voltage at which 1/Noise reaches 80% of its maximum value

NEDV Vs Fluence

- Sensor divided into 4 radial regions
- Compare NEDV before and after significant radiation



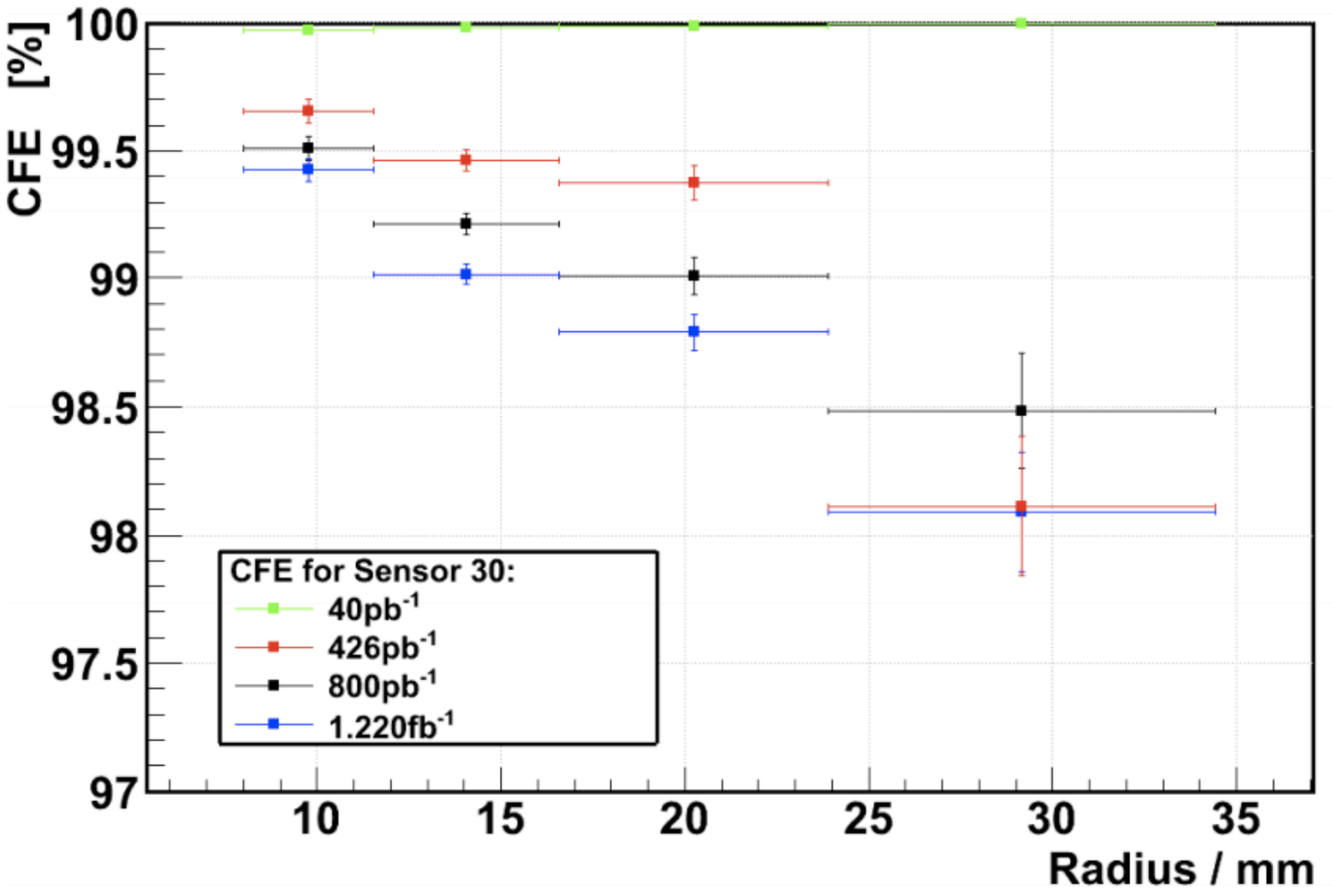
$$\text{Ratio} = \frac{\text{NEDV(final)}}{\text{NEDV(initial)}}$$



Cluster Finding Efficiency

- **CFE: Fraction of tracks for which a cluster is found at the track sensor intercept**

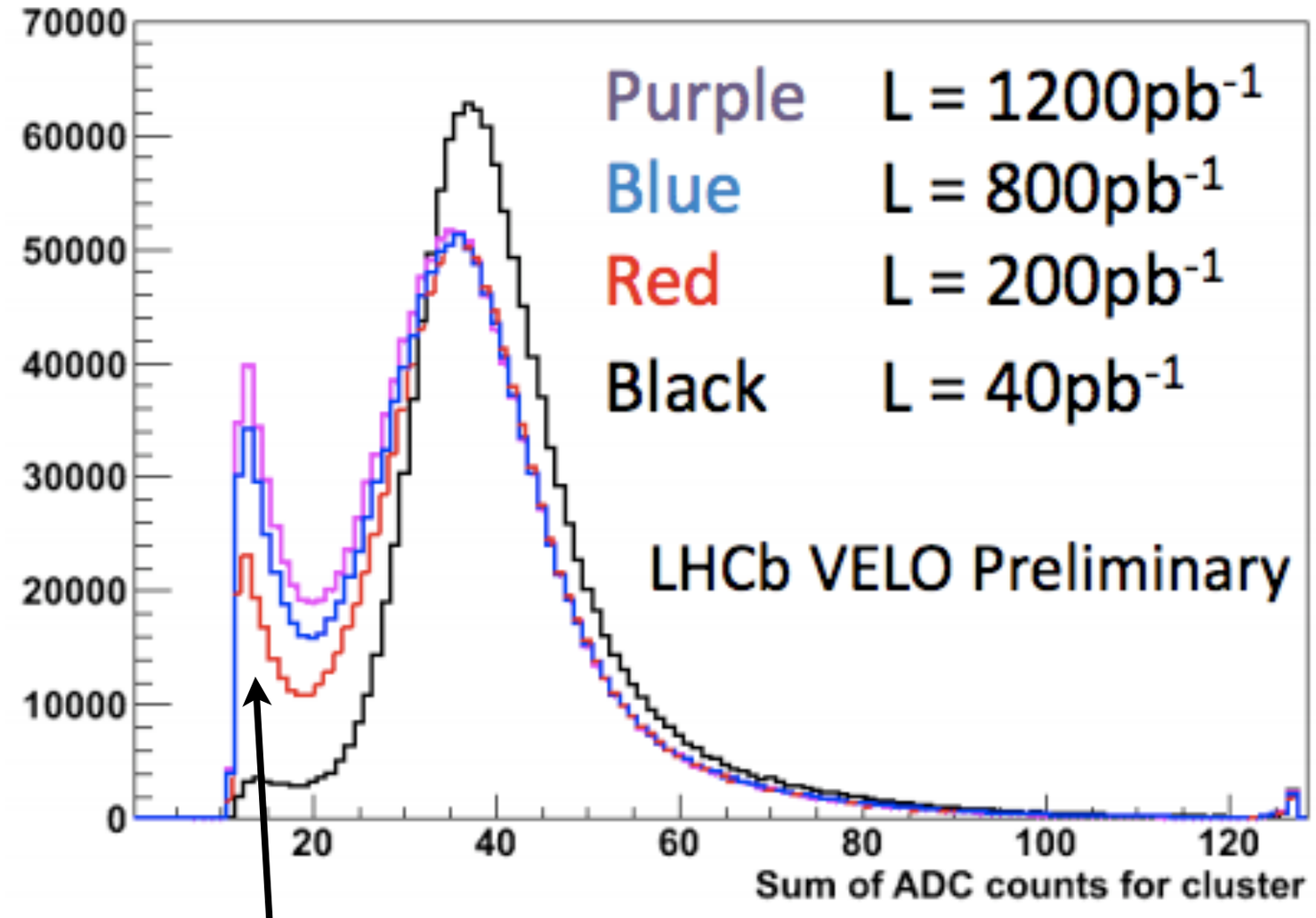
n^+-on-n R sensor



After radiation exposure a drop in the CFE of R sensors has been observed, especially at large radii

Investigation of CFE drop

- Check size of clusters not associated to tracks

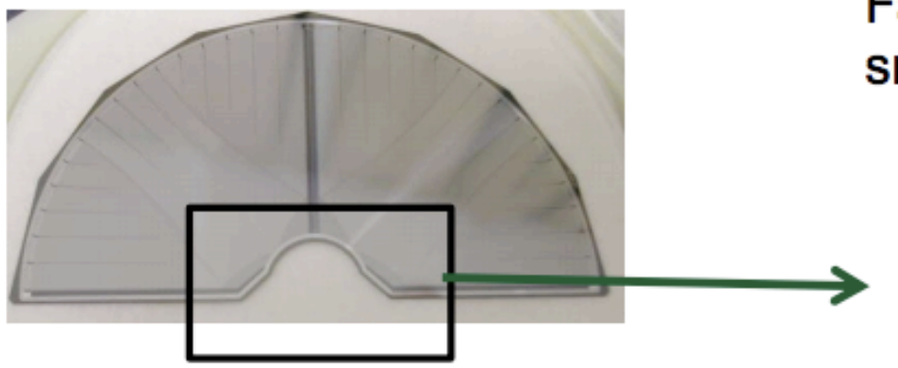


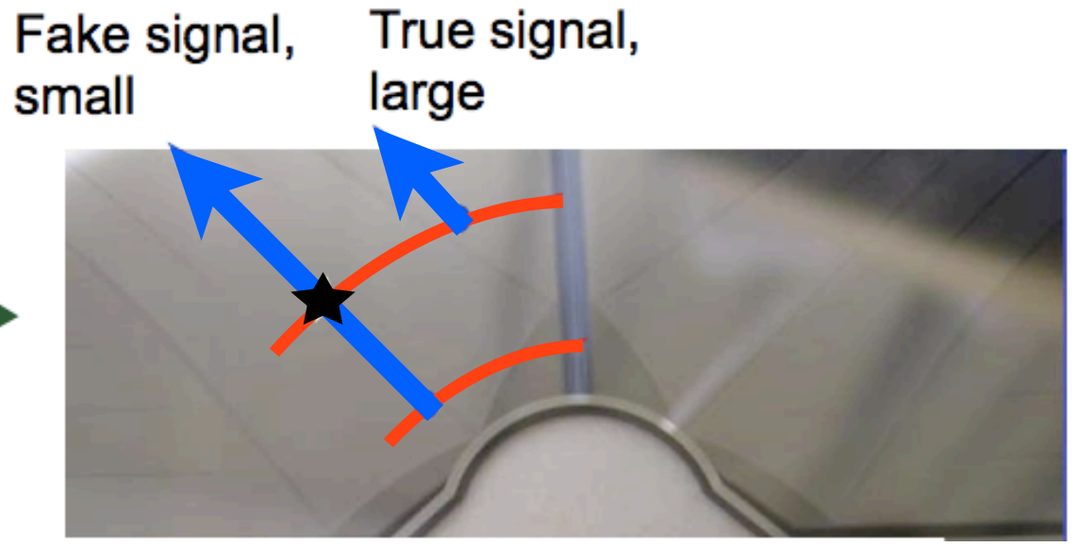
After radiation very small clusters appearing

- Predominantly at Inner region of sensors

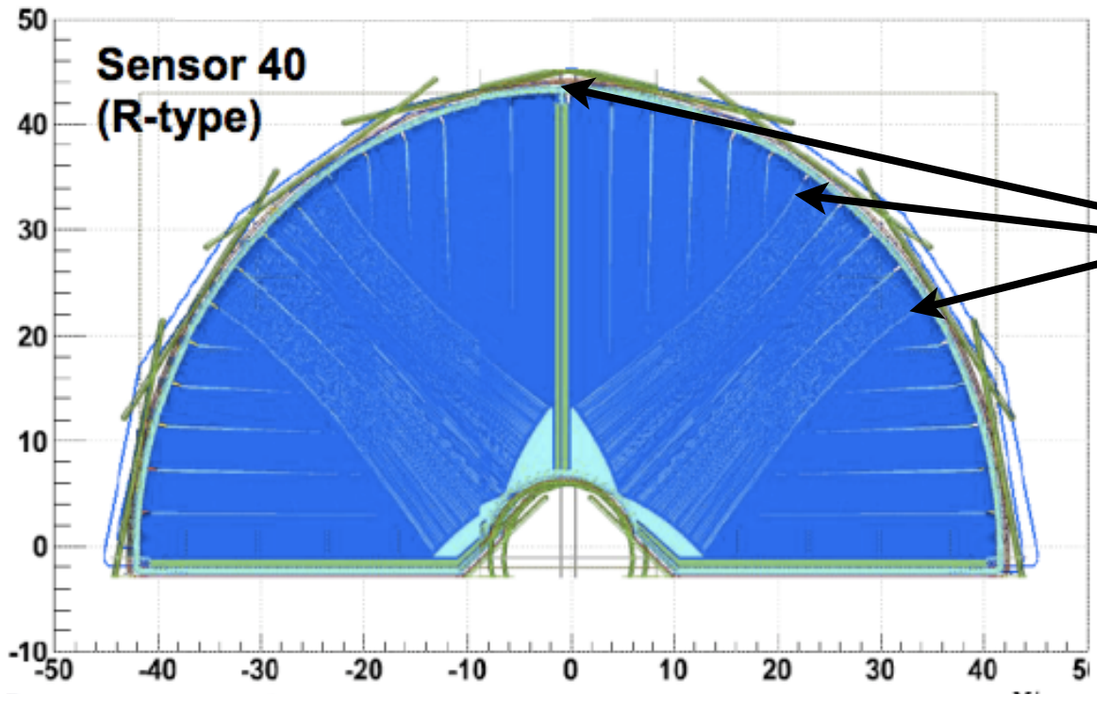
2nd Metal Layer explanation

- **2nd routing layer runs from inner strips over the outer strips**



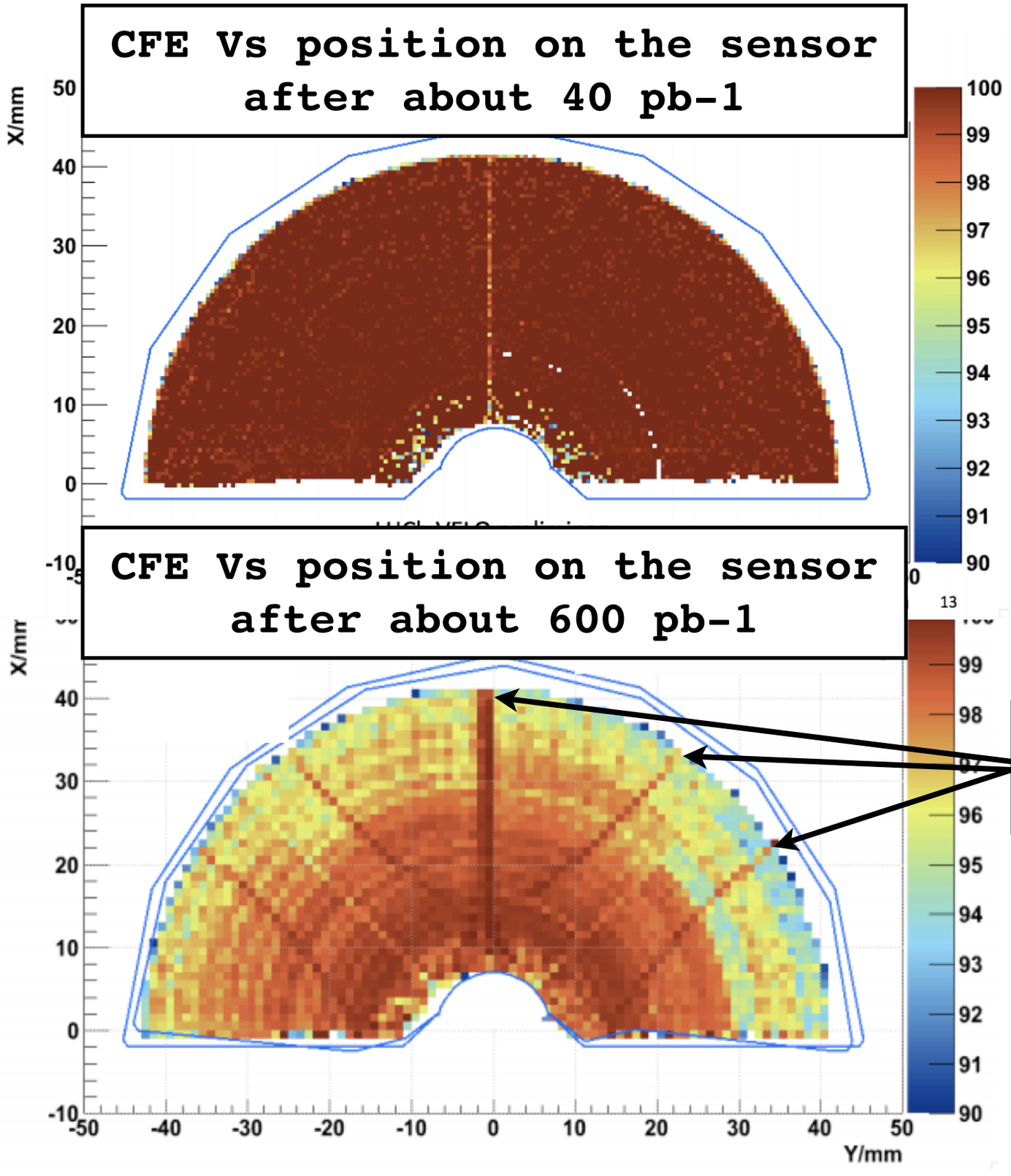


- **Track impact at ★**
- **Small signal seen on Blue 2nd metal layer**
- **Fakes a cluster on inner strip**



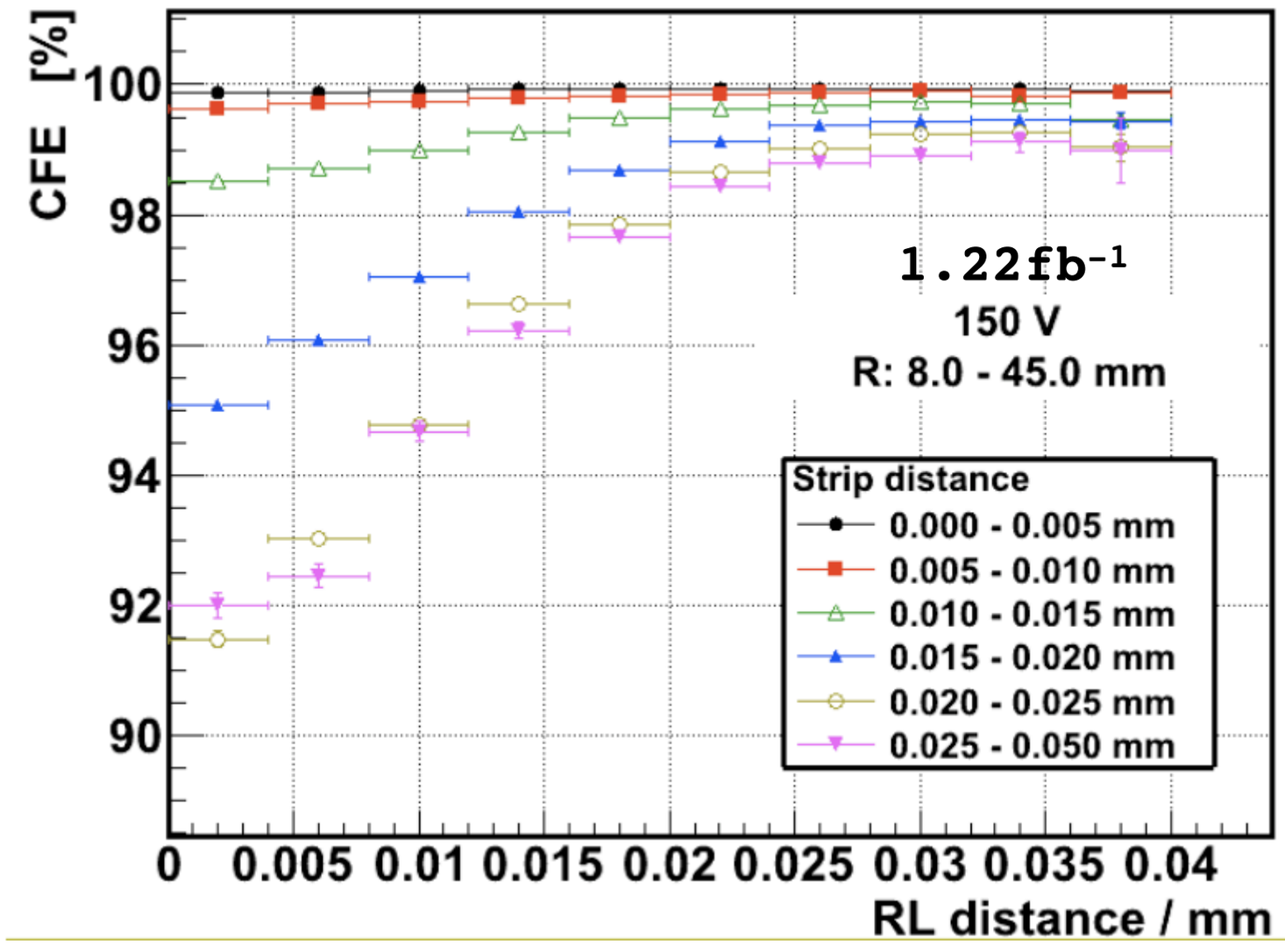
Gaps in 2nd metal layer

Evidence


CFE Vs position on the sensor after about 40 pb-1
CFE Vs position on the sensor after about 600 pb-1
X/mm
Y/mm
Gaps in 2nd metal layer

Evidence

CFE Vs position



After radiation CFE depends on distance to strip and distance to second metal layer

Conclusion

- LHCb VELO sensors have seen radiation damage
- Type inversion observed at the inner edge of the sensors
- R Sensors show coupling to 2nd metal layer causing a reduction in efficiency
- Tracking Efficiency unchanged so far (<0.5% effect)
- Sensors should last for 5 more years

BACKUP

Noise Vs Voltage Methodology

- **Shape of 1/Noise curve depends on the sensor bulk type**

<u>n^+-on-n:</u> Depletion region grows from side opposite strips

<u>n^+-on-p:</u> Depletion region grows from strips