LHCb VELO detector

performance and radiation damage

Hella Snoek for the LHCb VELO group

9th HSTD - Hiroshima 2013

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Contents:

- Introduction to LHCb VELO
- Performance
- Radiation damage

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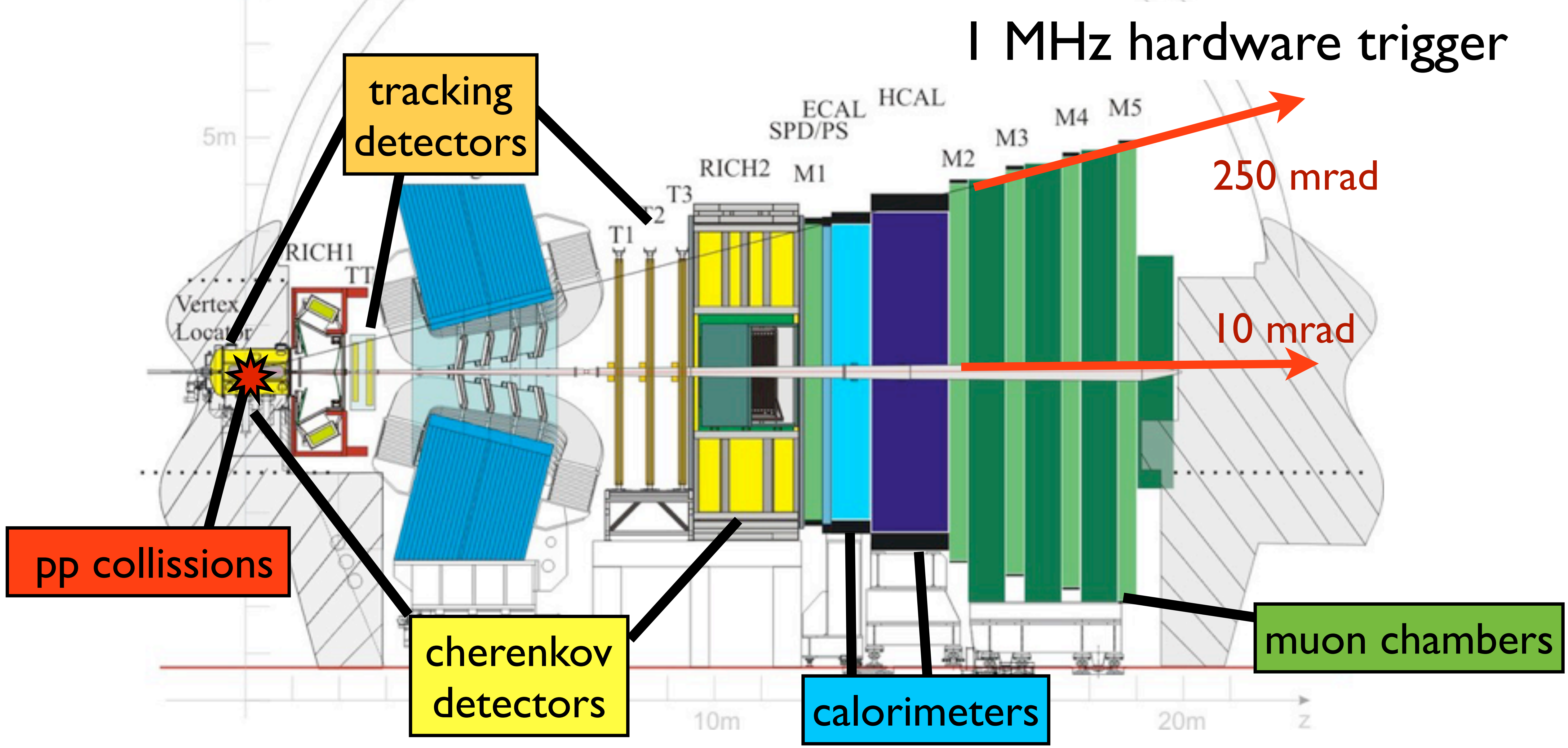
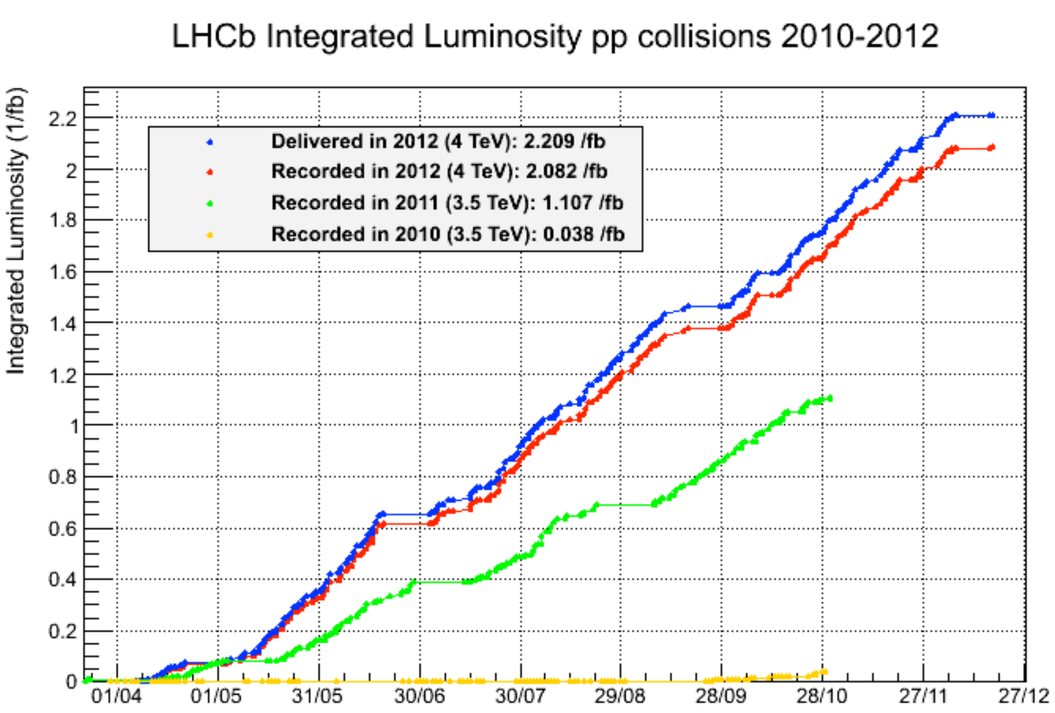
LHCb

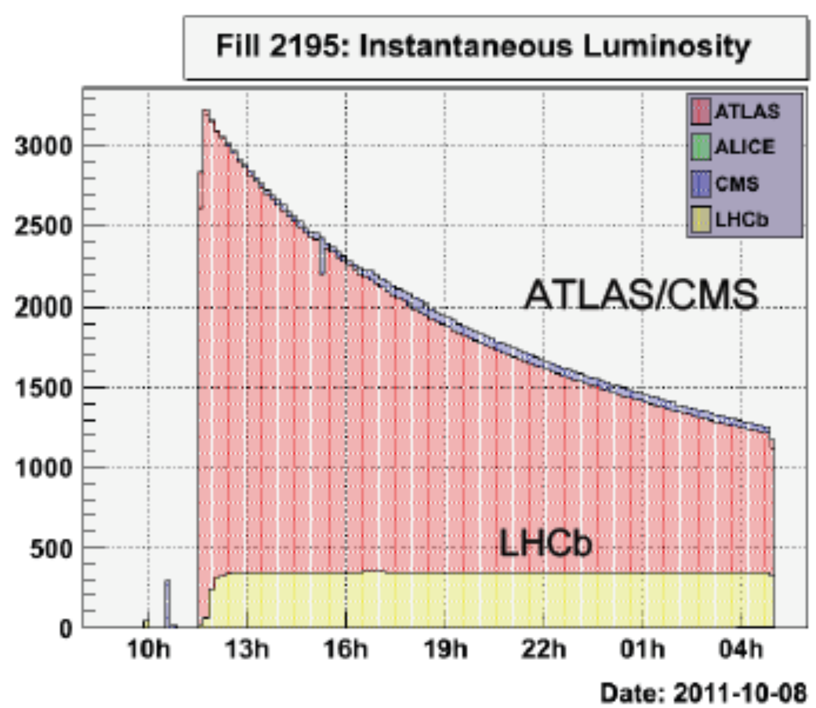
- Dedicated experiment to investigate CP-violation and New Physics using b- and c-mesons
- Detector must posses excellent position, vertex and momentum resolution and particle identification

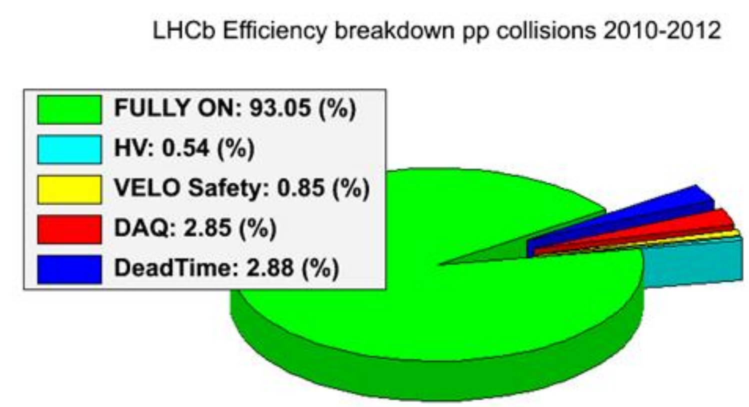


Beam conditions at LHCb

- Beam energy in 2012 at 4 TeV
- Data delivered between 2010 and 2012: 3.4 fb^{-1}
- Luminosity leveled at 4×10^{32} [cm^{-2} s^{-1}]
- 1.6 visible interactions per crossing
- LHC will resume in 2015

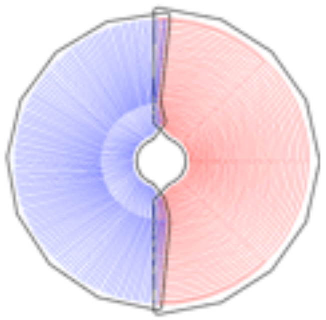




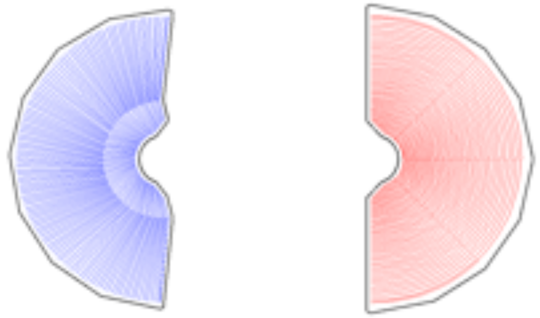


the VELO

- **42 modules with R (*40 - 101.6 μm*) and Φ sensor (*35.5 - 96.6 μm*) + 4 pile up modules**
- **300 μm n+-on-n sensors, one module n+-on-p**
- **Designed to cope with the harsh radiation environment at LHC** *2 retractable detector halves, 8(30) mm from beam when closed(open)*
- **300 μm corrugated foil separates primary beam vacuum from secondary vacuum with sensors**
- **Cooled to -30°C (-8°C at sensor) with bi-phase CO_2 cooling syst.**



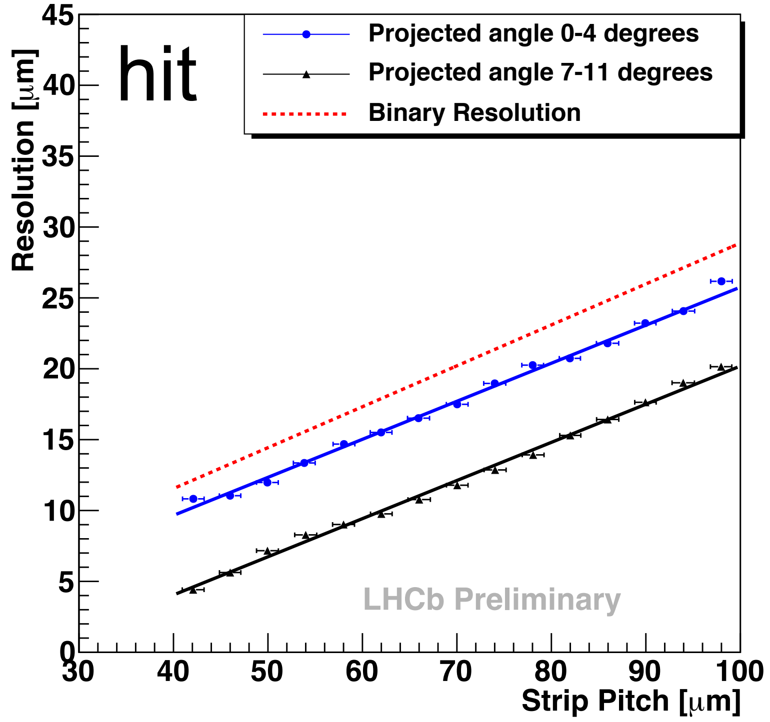
stable beams

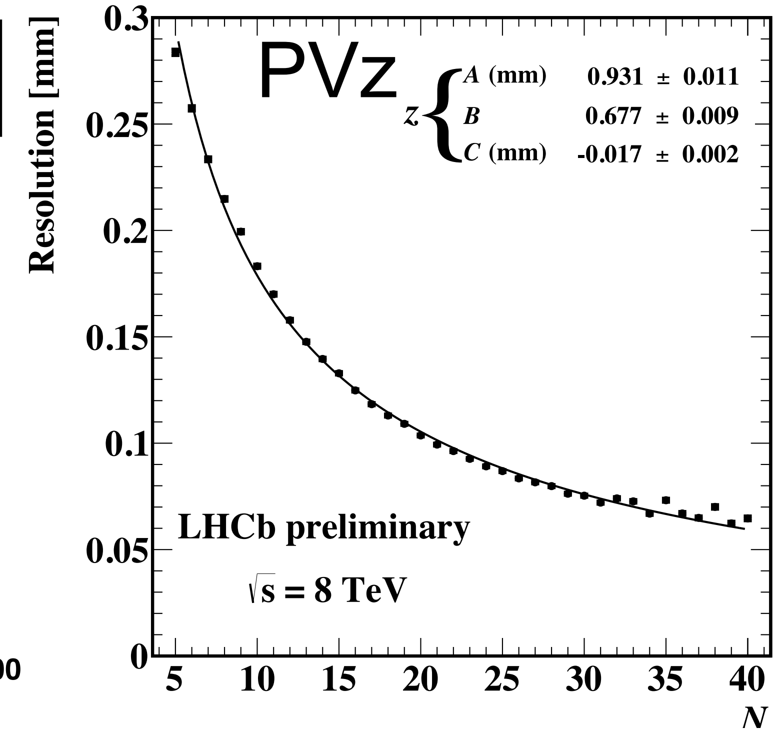


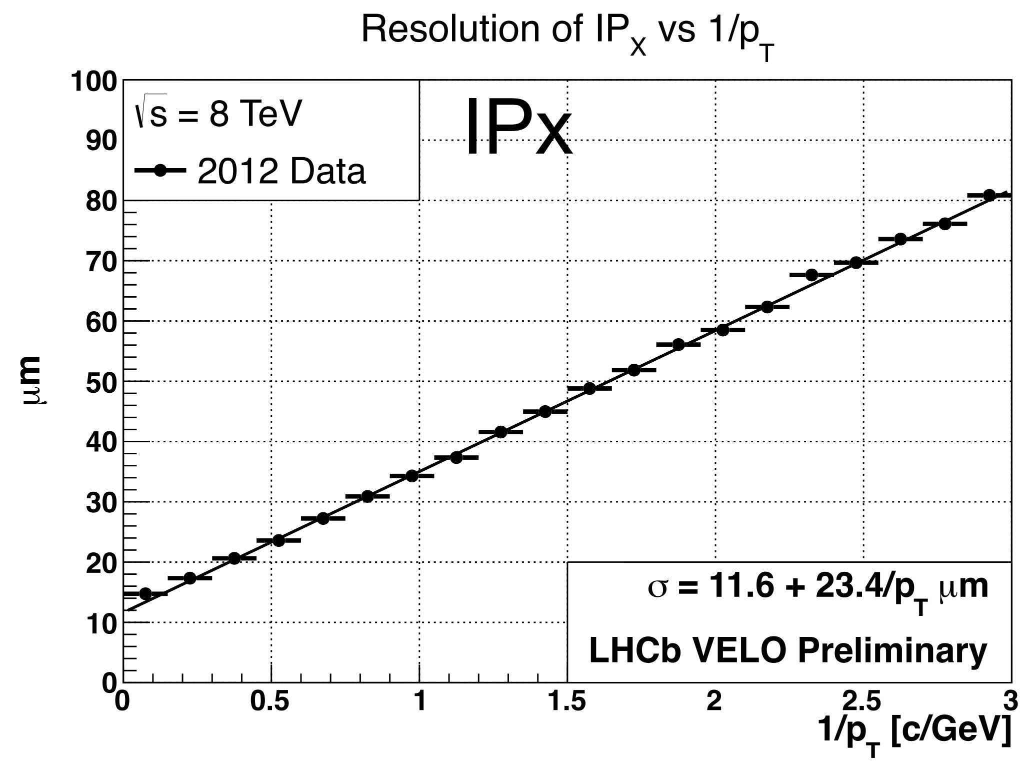
beam injection

one half

Resolution







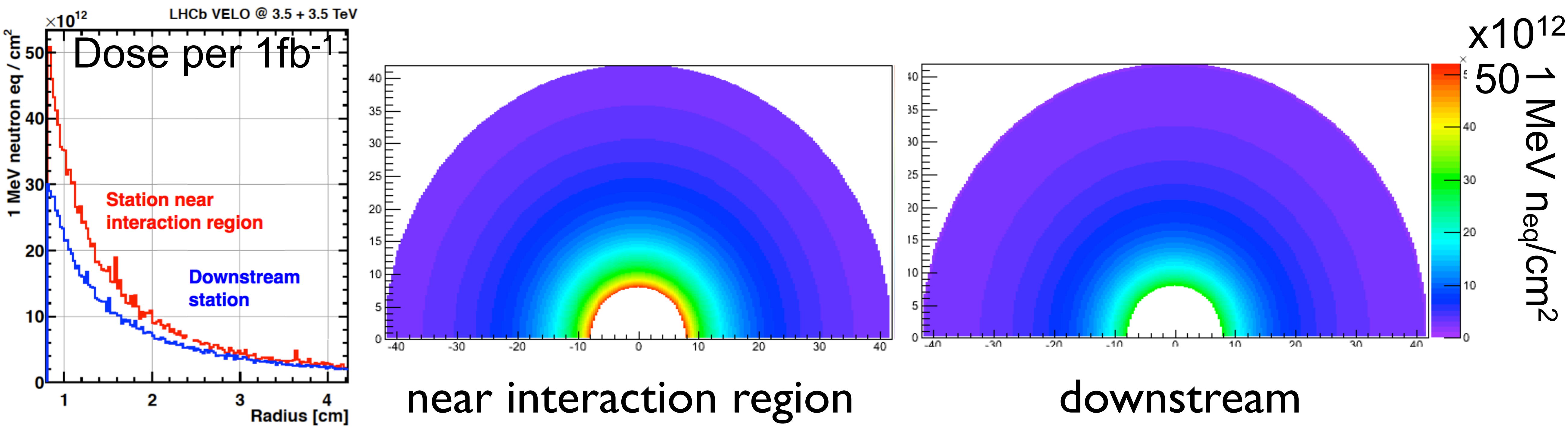
- **Excellent spatial resolution**
  4μm in optimal region with small impact angle

- **High vertex resolution**
  for 25 tracks: $\sigma_{PVx/y}$ = 13 μm, σ_{PVz} = 69 μm

- **IP resolution excellent for physics programme**
  $\sigma_{IP} = 11.6 + 23.4/p_T$ μm

Radiation

- Close proximity to the beam → high particle fluence (per 1 fb^{-1} up to 5 x 10^{13} 1 MeV n_{eq}/cm^2)
- This leads to bulk damages due to the particle irradiation.
- Irradiation highly non-uniform in sensor.
- Fluence as function of radius for each sensor: Ar^{-k}



Radiation

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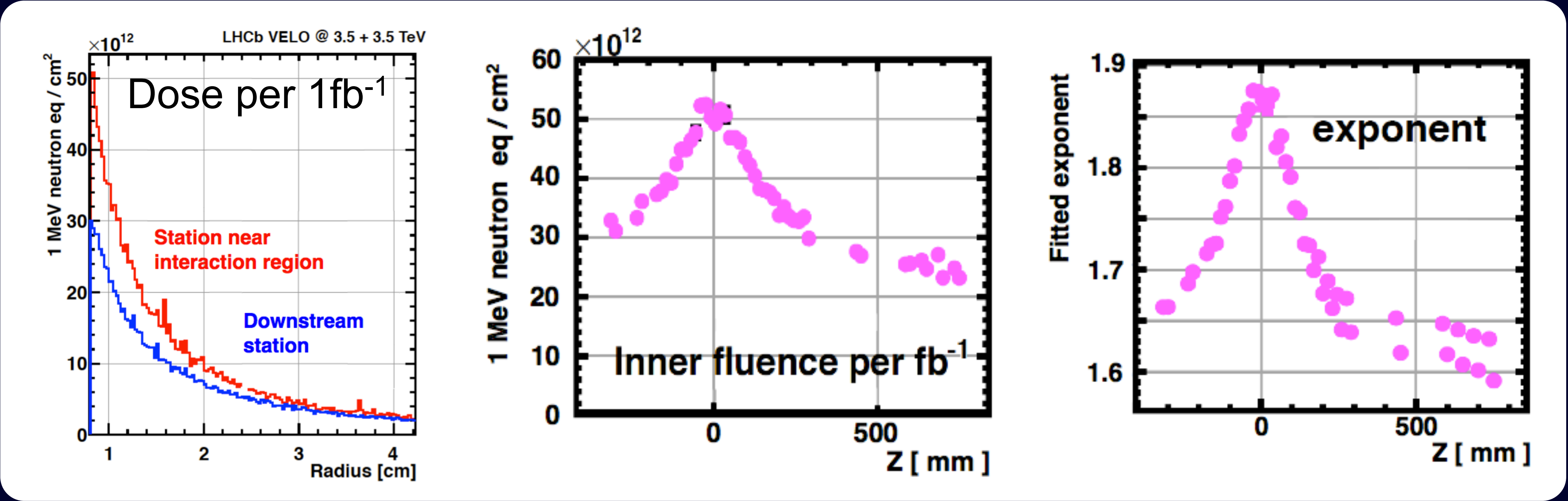


Radiation damage monitoring

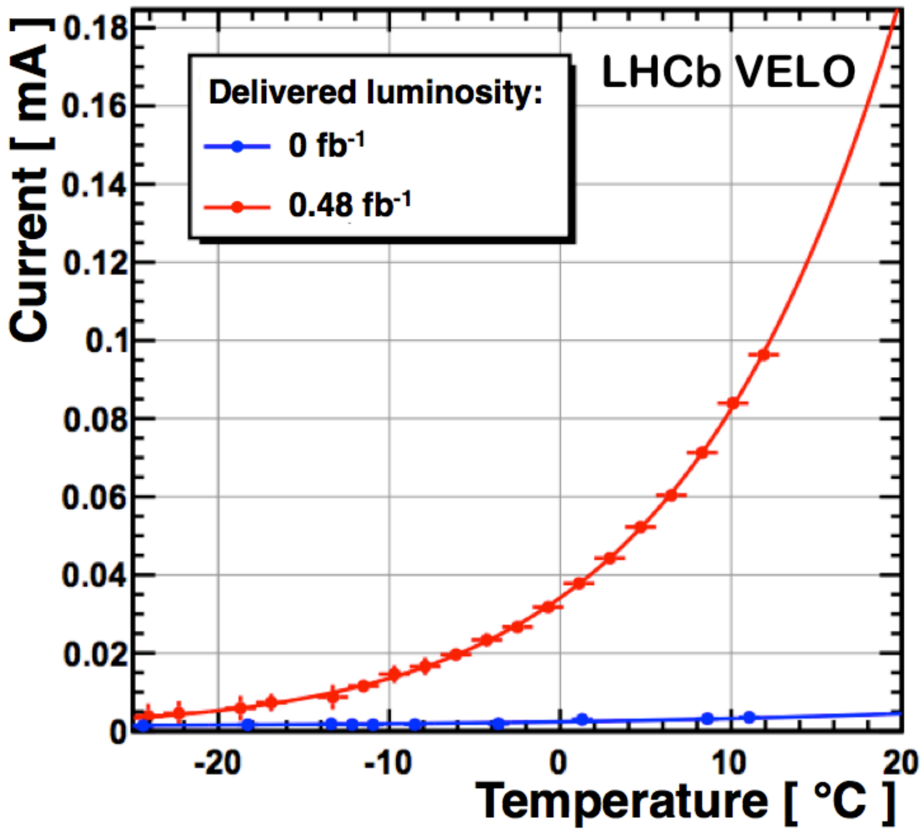
- Four monitoring methods used:

1. current versus temperature (IT curves)
2. current versus time
3. full depletion voltage
4. clustering finding efficiency

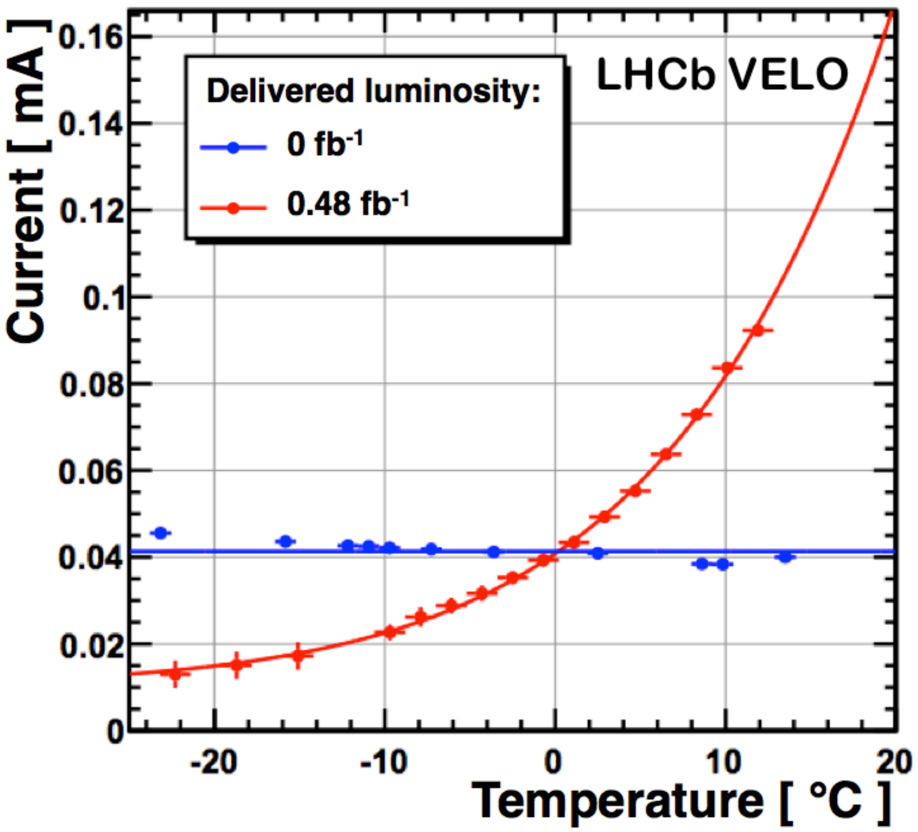
- Second metal layer radiation effect

Current - temperature scans

Initially I_{bulk} dominated

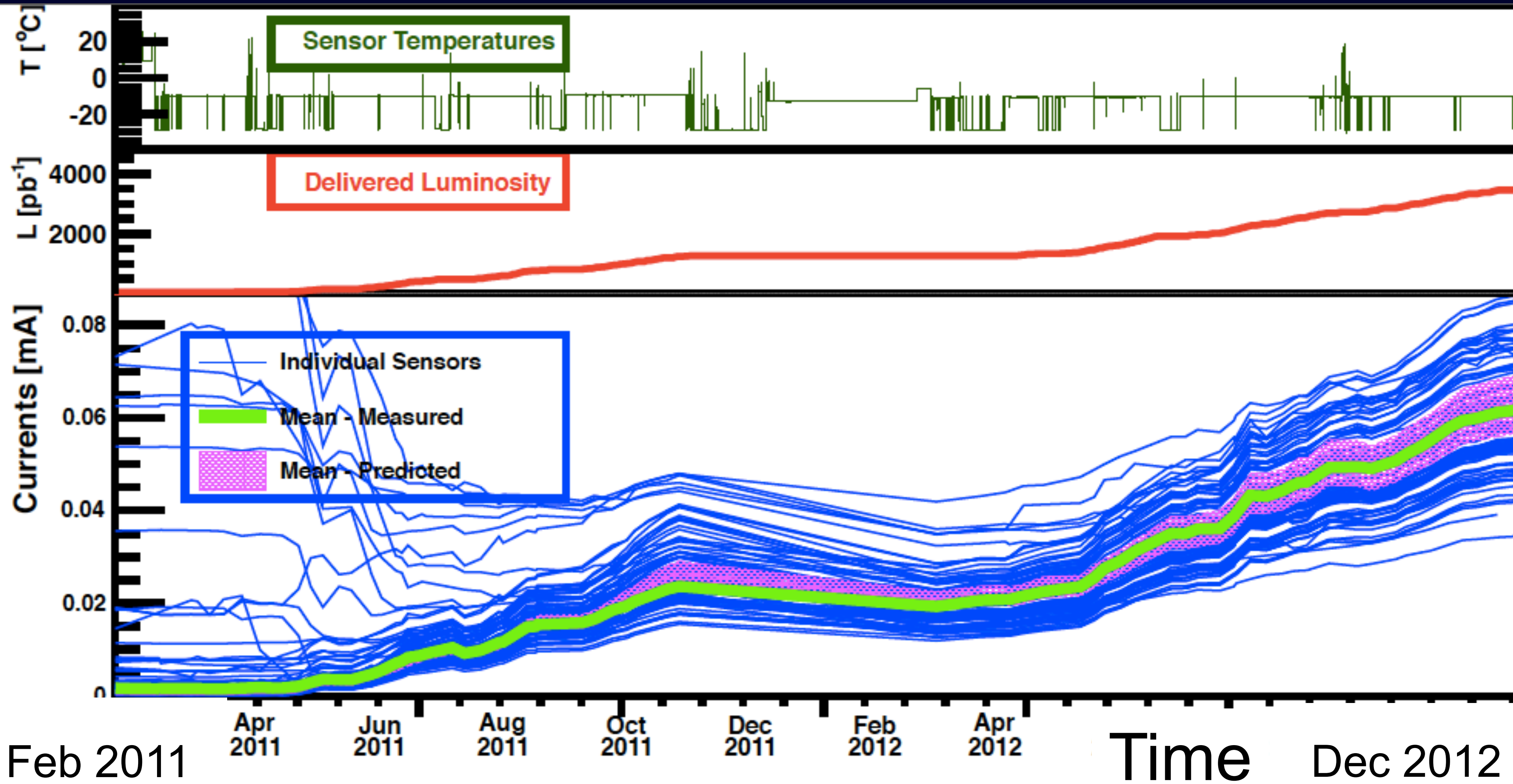


Initially $I_{surface}$ dominated



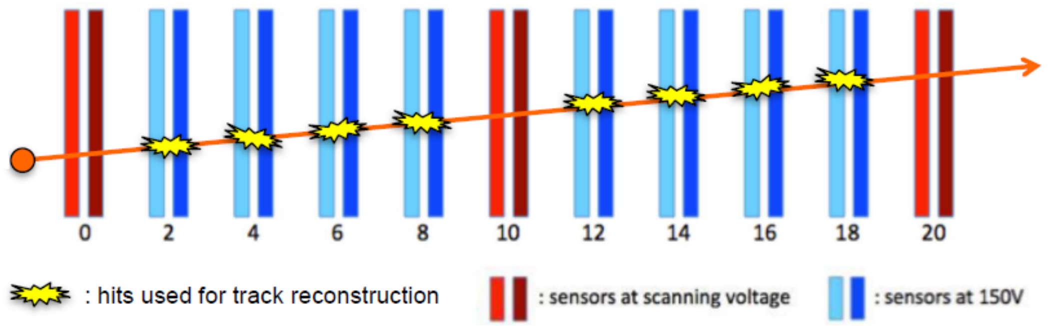
- **Bulk currents have exponential behavior**
  surface currents also have linear component
- **Before irradiation both bulk- and surface-dominated current sensors exist**
- **Surface defects anneal ➜ after irradiation all sensors bulk dominated**
- **Effective band gap energy using** $I(T) \propto T^2 exp(-\frac{E_g}{2kT})$
  E_g=1.16 ± 0.03 ± 0.04 eV compatible with 1.21 eV from literature

Current versus time

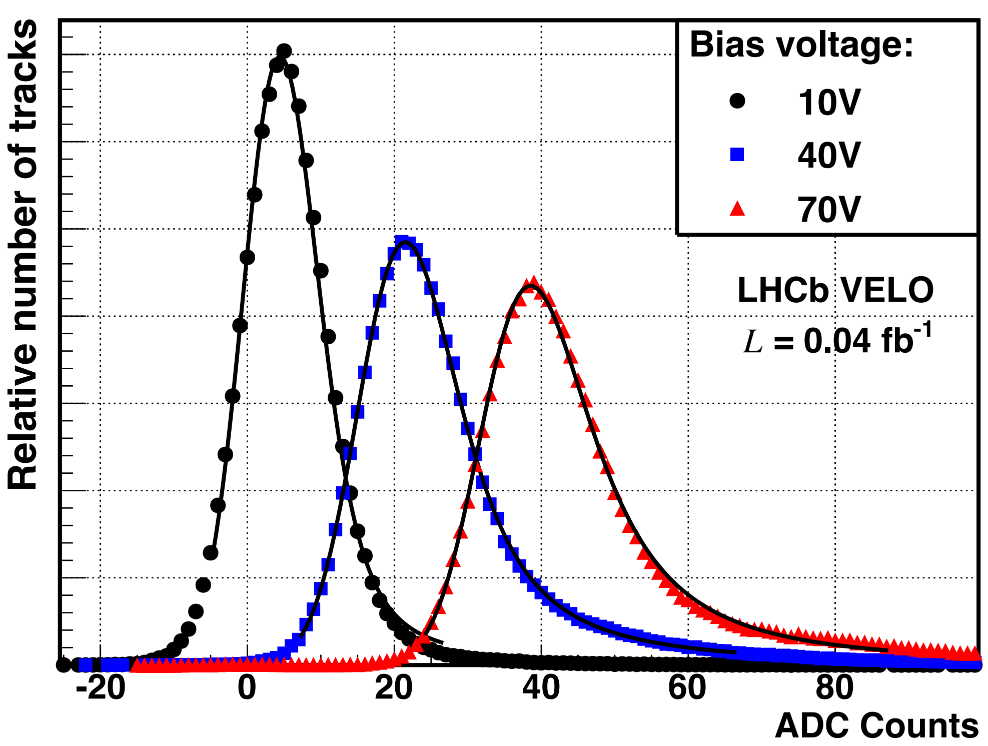


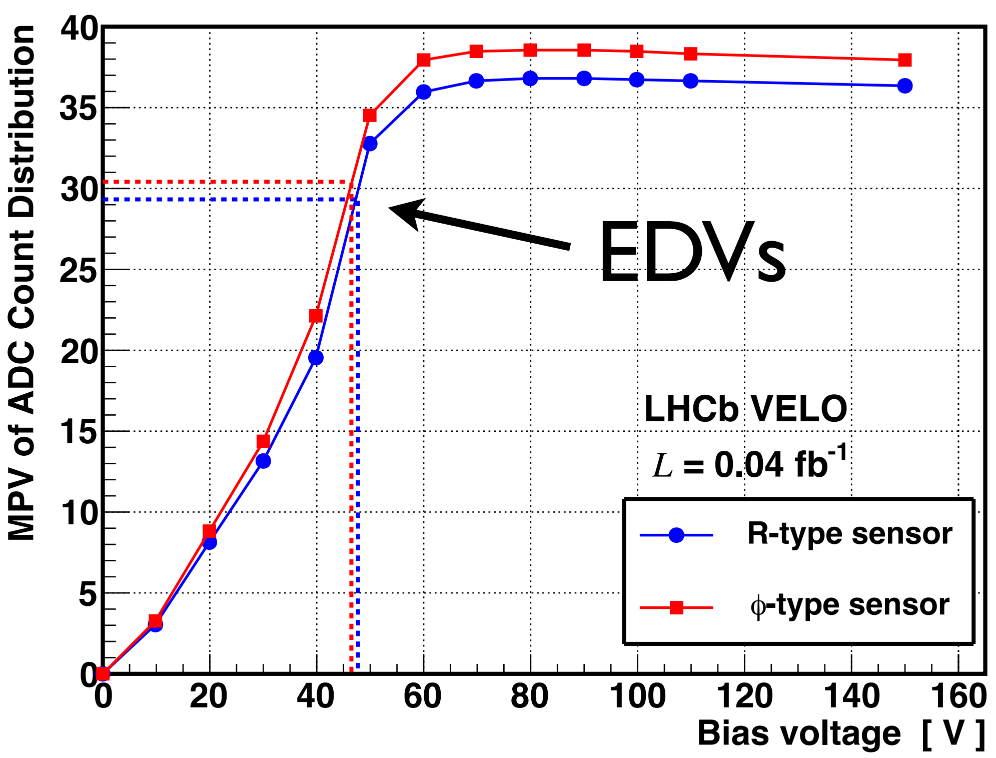
- **Current versus time:**
  All sensors at nominal bias (150 V) and at -8°C
  Typical increase 1.9 μA per 100 pb $^{-1}$
- **Bulk current increases with fluence, proportionally to the delivered luminosity**
  Good agreement with expectations from: *Nucl. Instrum. Meth. A315 (1992), no. 13 149*

Effective depletion voltage

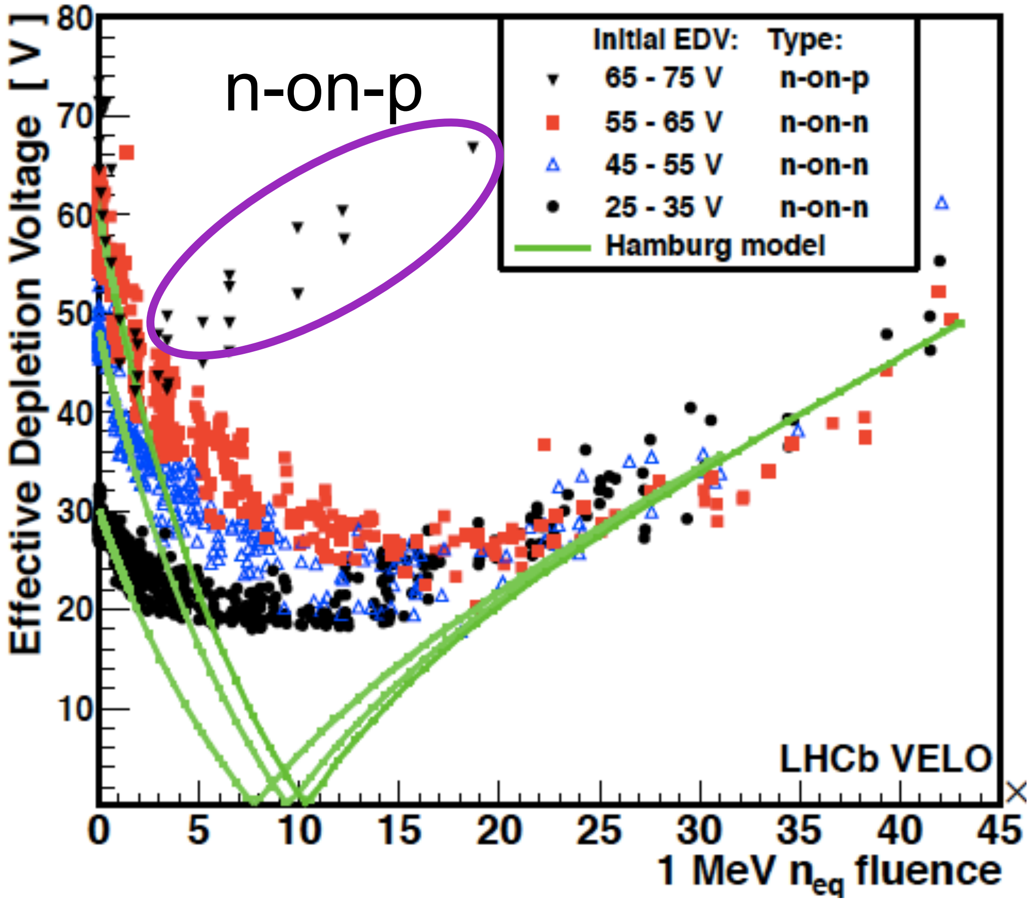


- **Effective depletion voltage (EDV) measured to study behavior (type inversion)**
- **Every fifth sensor probed**
  Other sensors used for track reconstruction
- **Charge deposit in track intercept in probe sensor**
- **The EDV is defined as 80% of the maximum MPV (per sensor)**
  (Point agrees with CV scan measurement.)

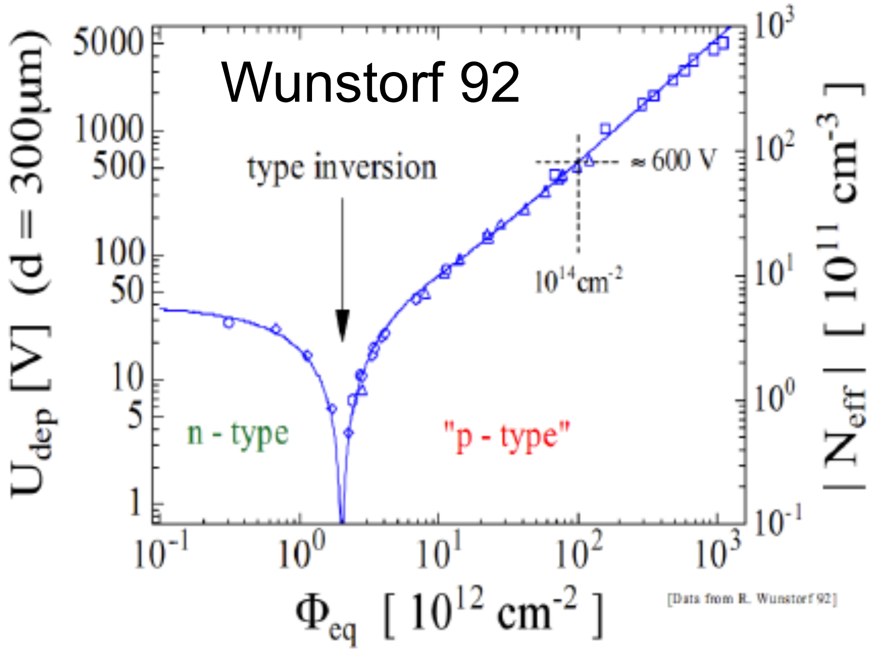




Effective depletion voltage

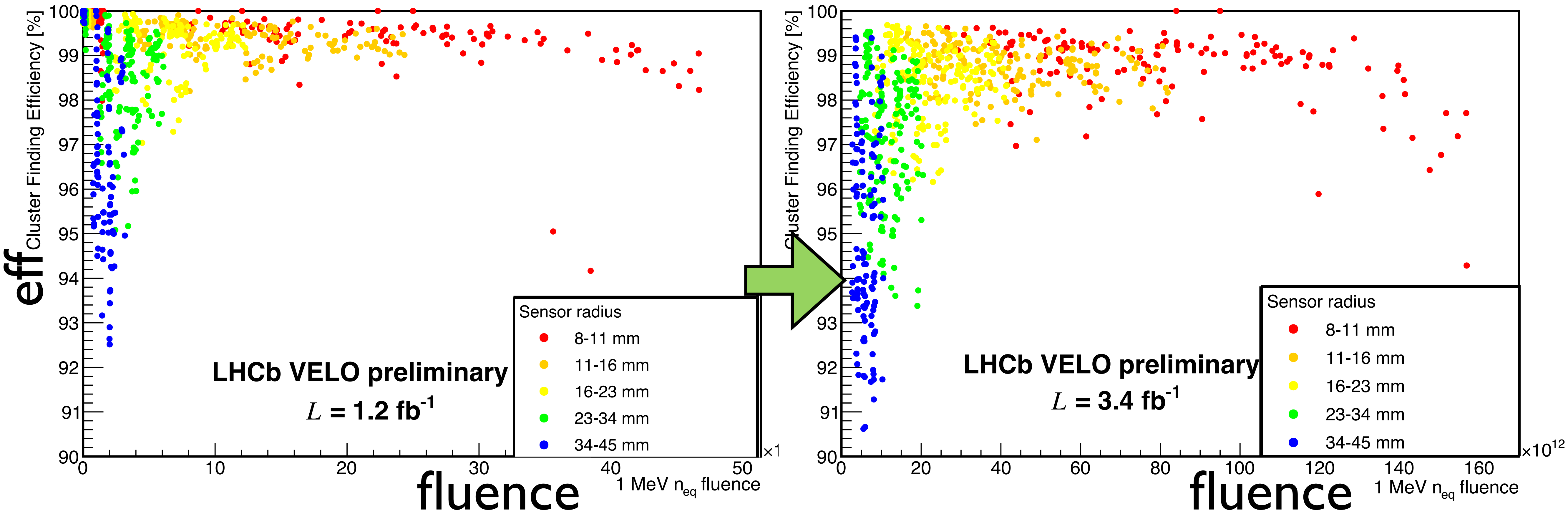


Hamburg model:
Nucl. Instrum. Meth. A315 (1992), no. 13 149



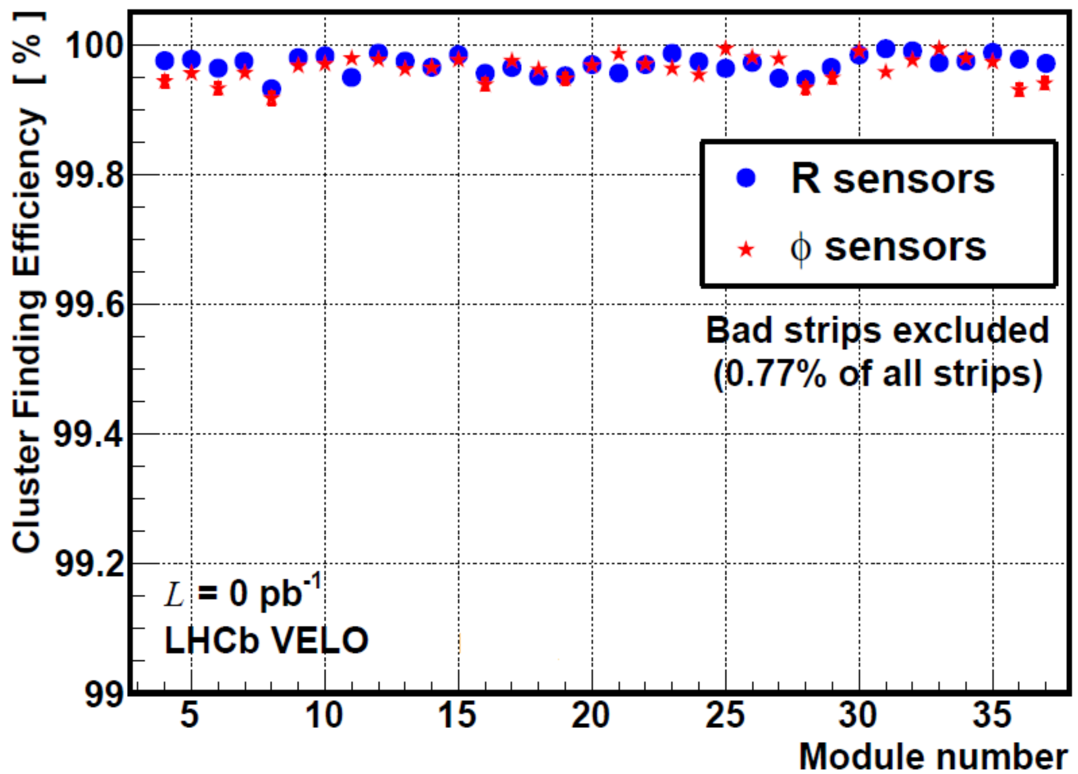
- **Due to limited signal integration time no sensitivity <20V**
- **Initial decrease with delivered luminosity**
  Good agreement with Hamburg model
- **Inner part of the sensor type inverted**
  Inversion at 10-15 x 10^{12} 1 MeV n_{eq}
- **Now bias voltage at 150V, hardware limit at 500 V**
  9 fb^{-1} comfortably reached

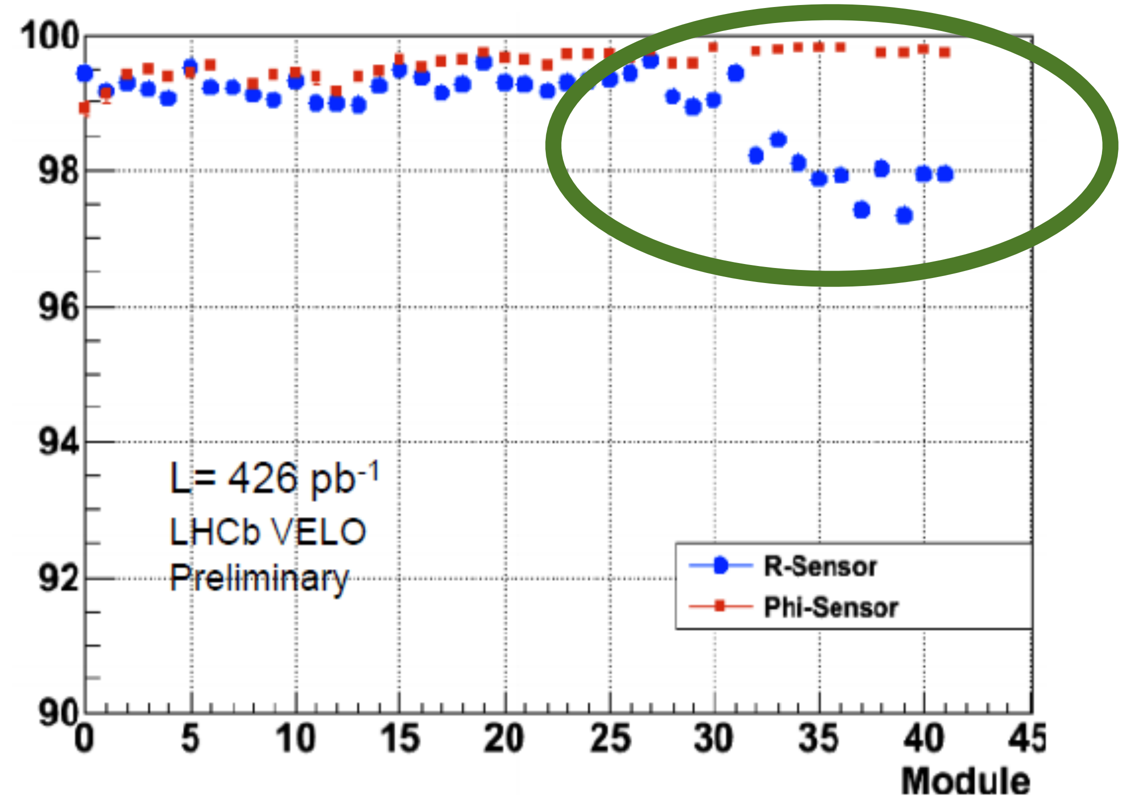
Cluster finding efficiency



- Cluster finding efficiency determined using propagated tracks to sensor
- Efficiency drops after more delivered luminosity
- Largest effect in areas with higher fluence

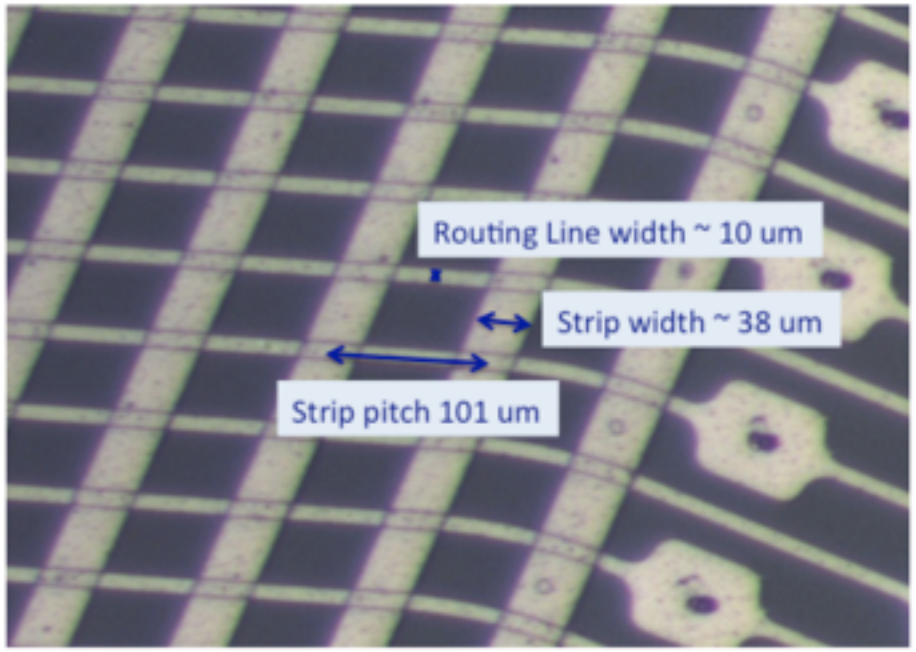
Cluster finding efficiency

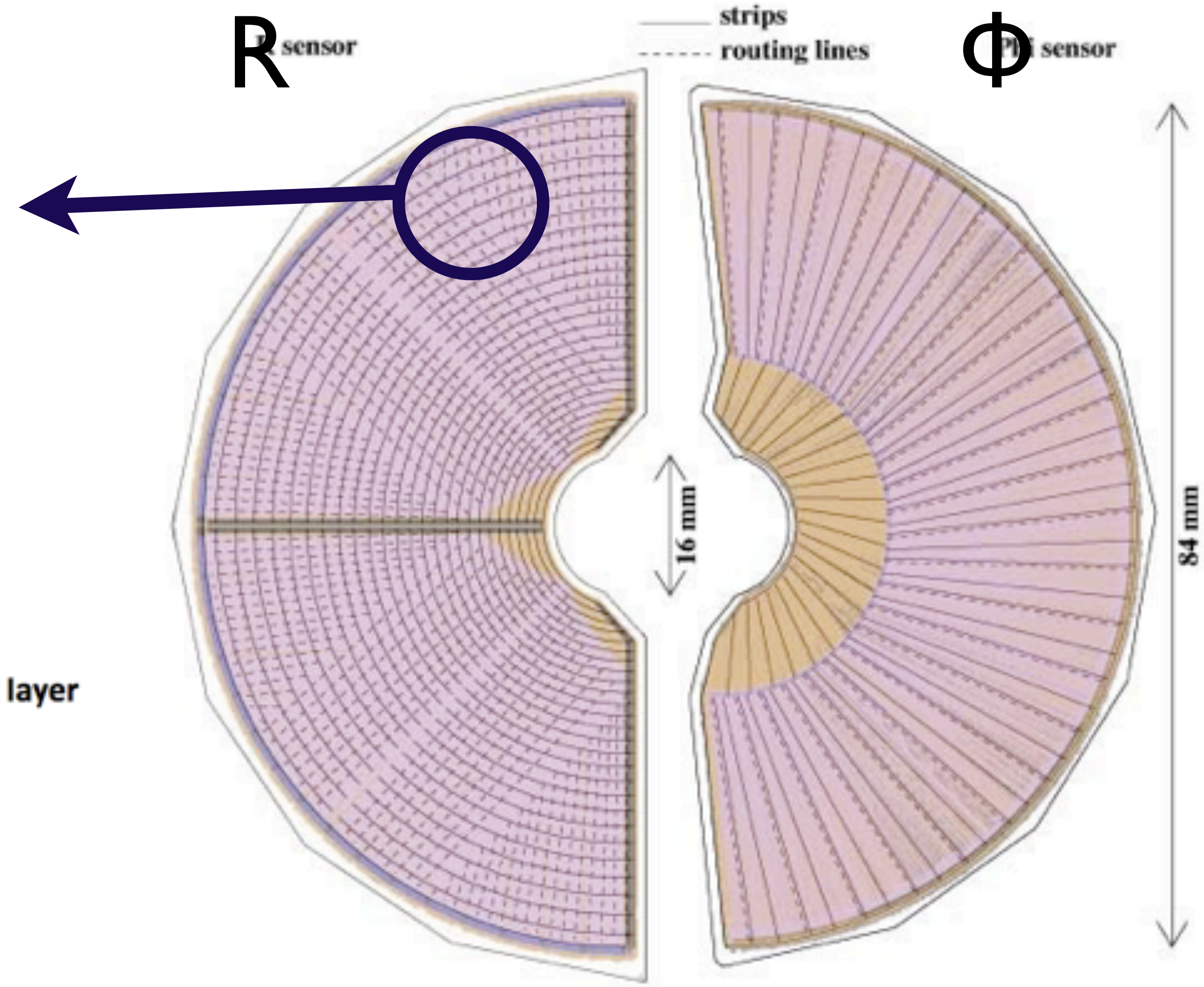


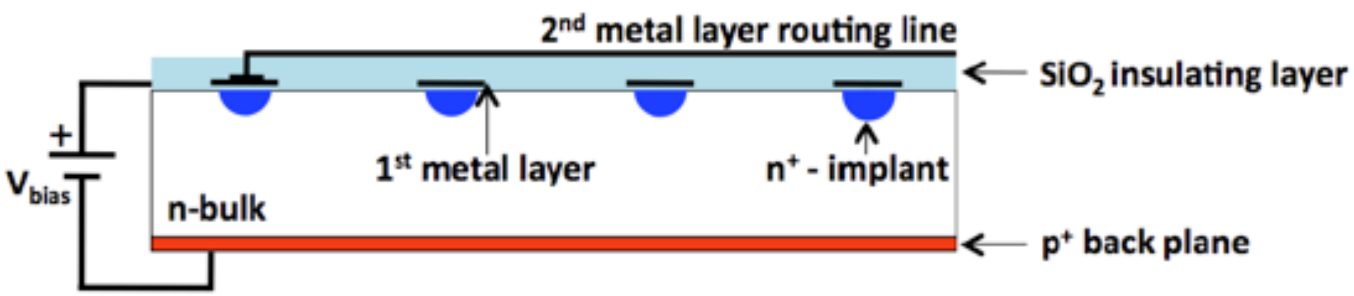


- The cluster finding efficiency has dropped in the outer part of the R-sensors.
- Effect not seen on Φ sensors.
- This was not expected ➜ detailed study has been performed

2nd metal layer





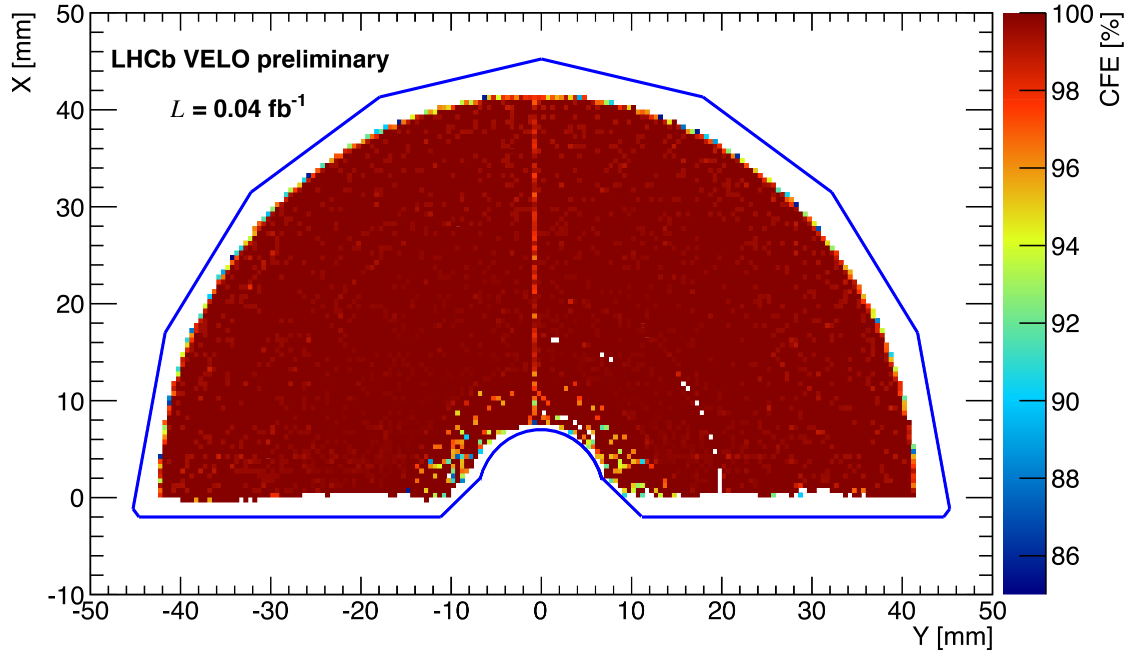


- 1st metal layer couples to strips.
  2nd metal layer (routing lines) carries the signal to the electronics
- The routing lines run parallel to strips in the phi sensor and perpendicular to strips in R-sensors

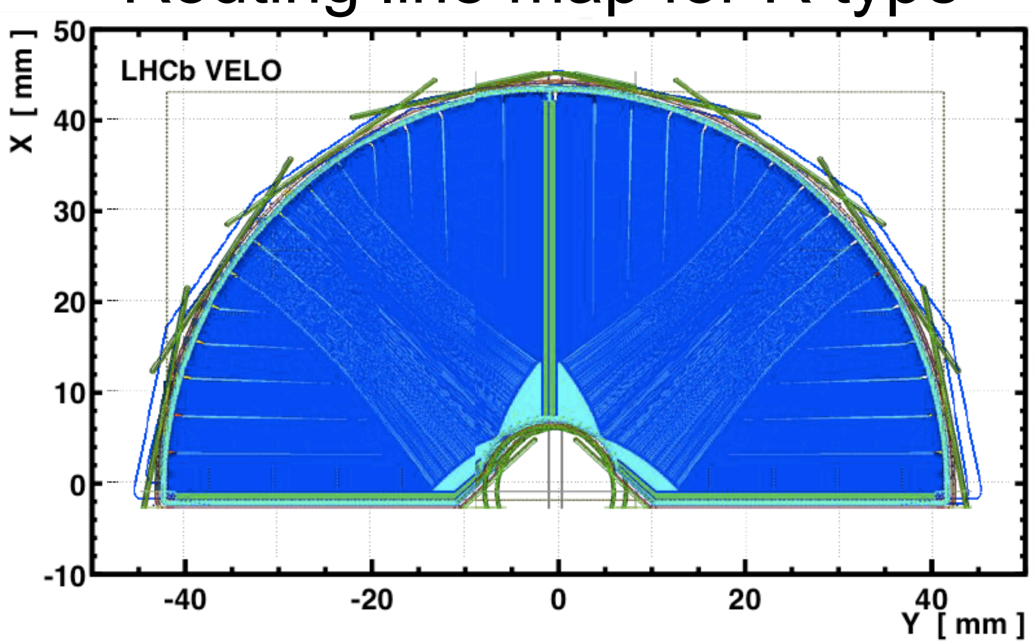
Second metal layer effect

- Plotting the CFE across the sensor shows a structure.
- Same structure as in the routing lines.
- High CFE preserved in low-density routing line-regions
- Average distance between hit and strip (14.5-31.5 μm) while between hit and routing line constant 25μm

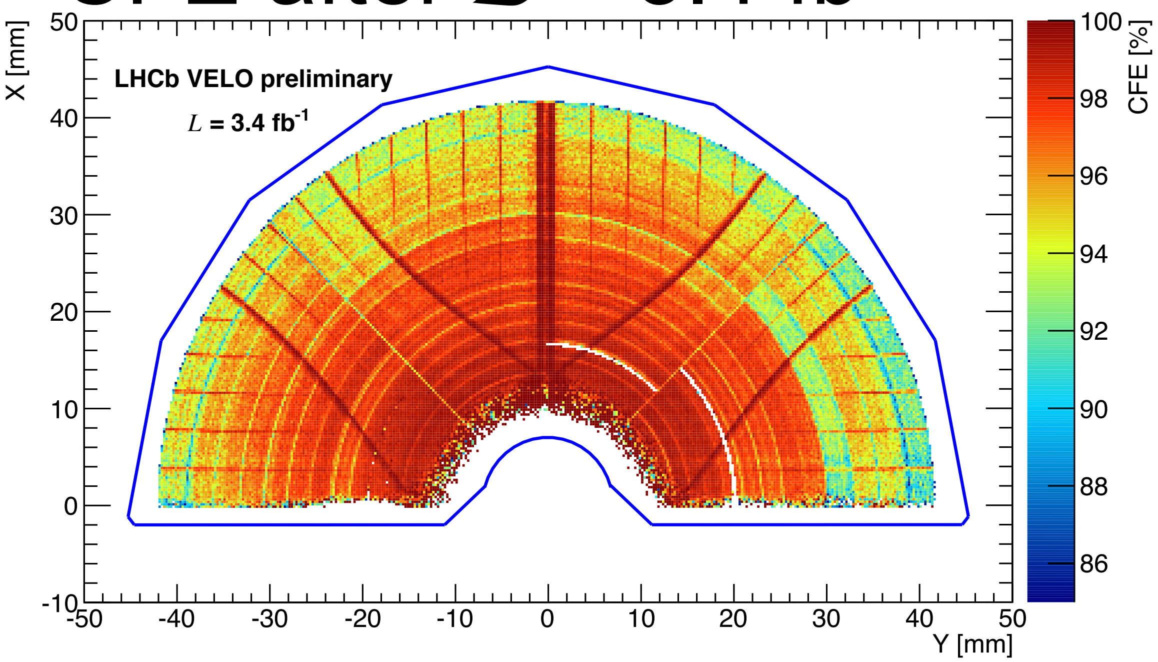
CFE after $\mathcal{L}$ = 0.04 fb^{-1}



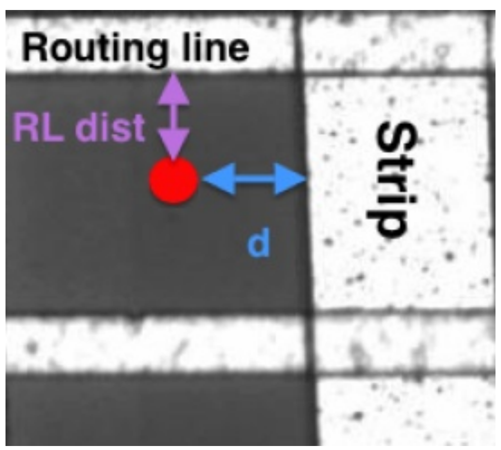
Routing line map for R type

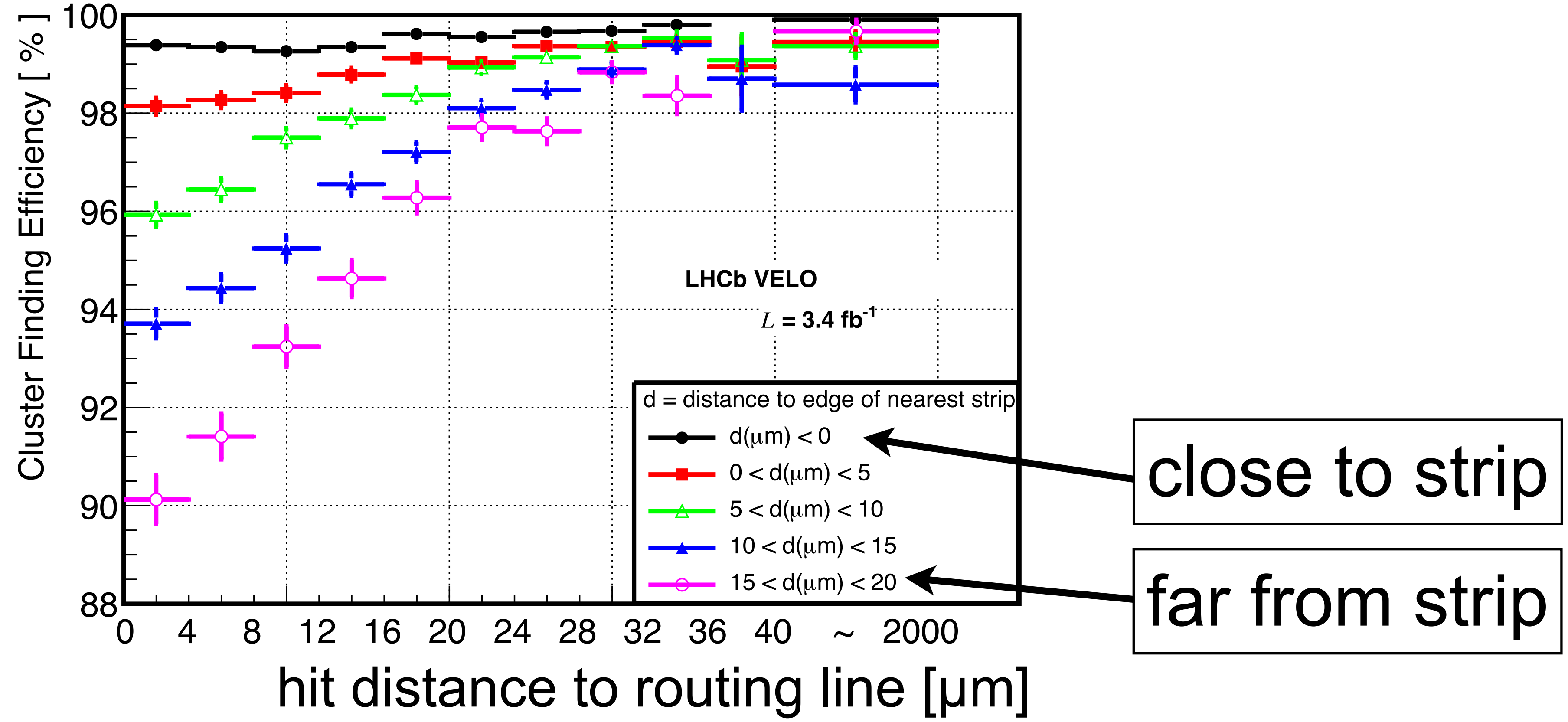


CFE after $\mathcal{L}$ = 3.4 fb^{-1}



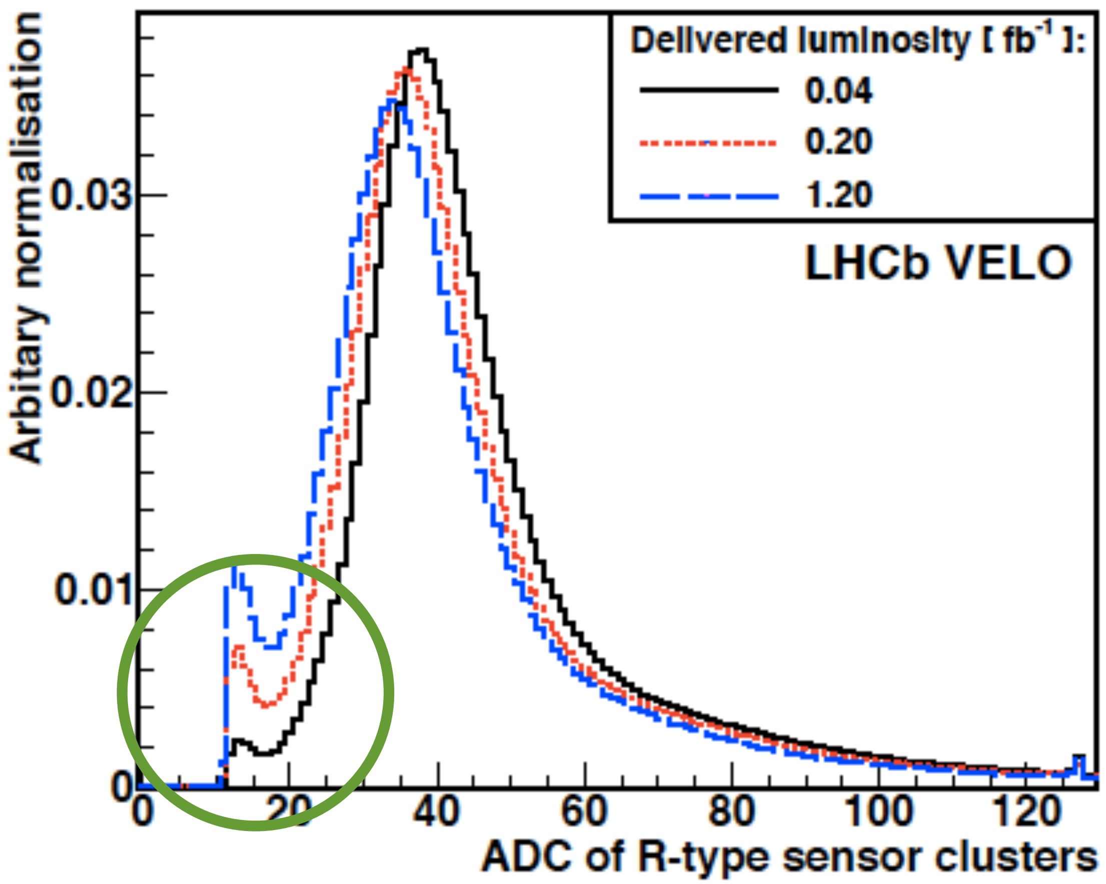
Second metal layer effect





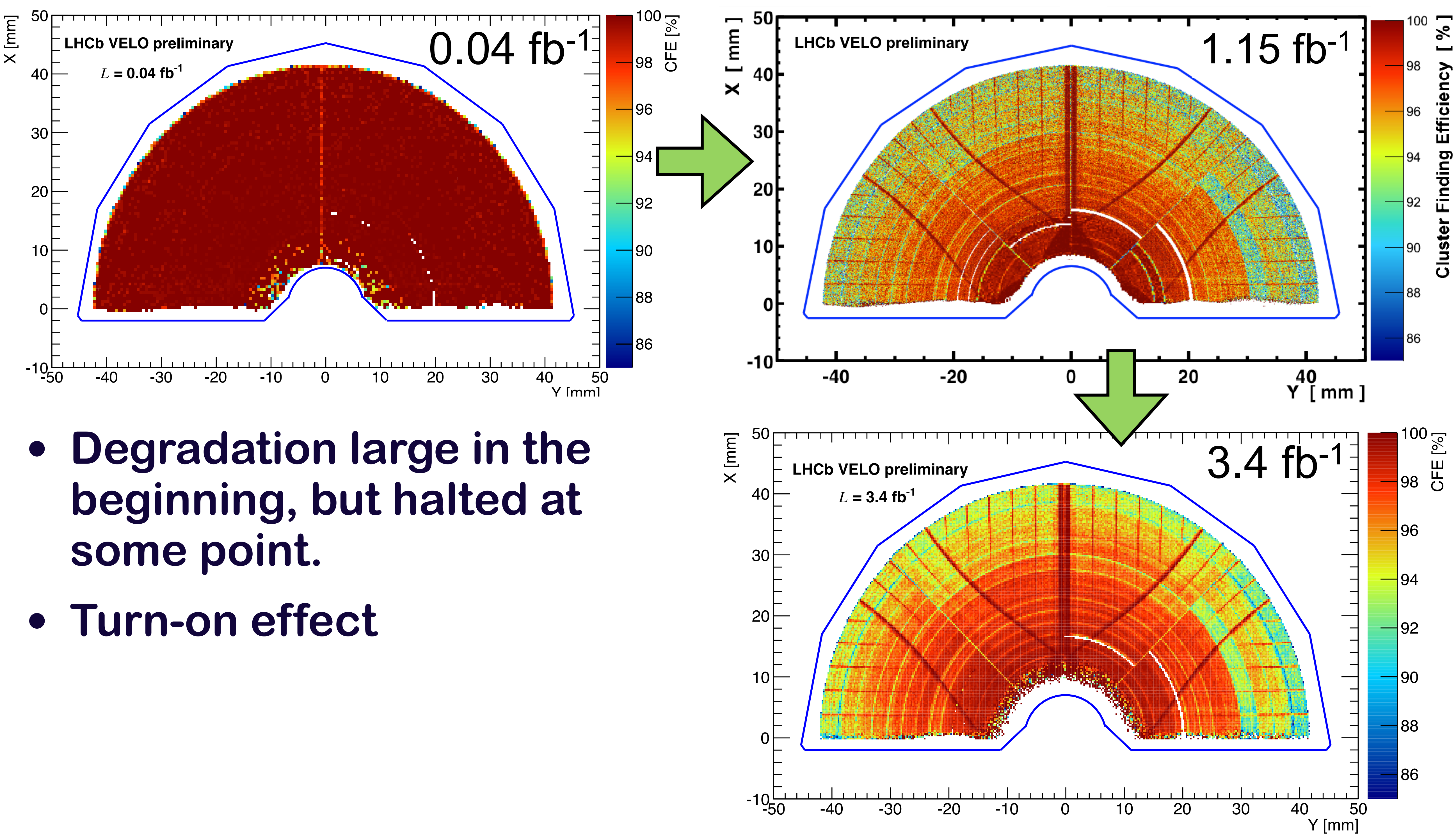
- The loss in CFE is largest if the hit is close to a routing line and far from the strip.
- Effects depends on the delivered luminosity.
- Increasing the bias voltage only made it worse!

Second metal layer effect



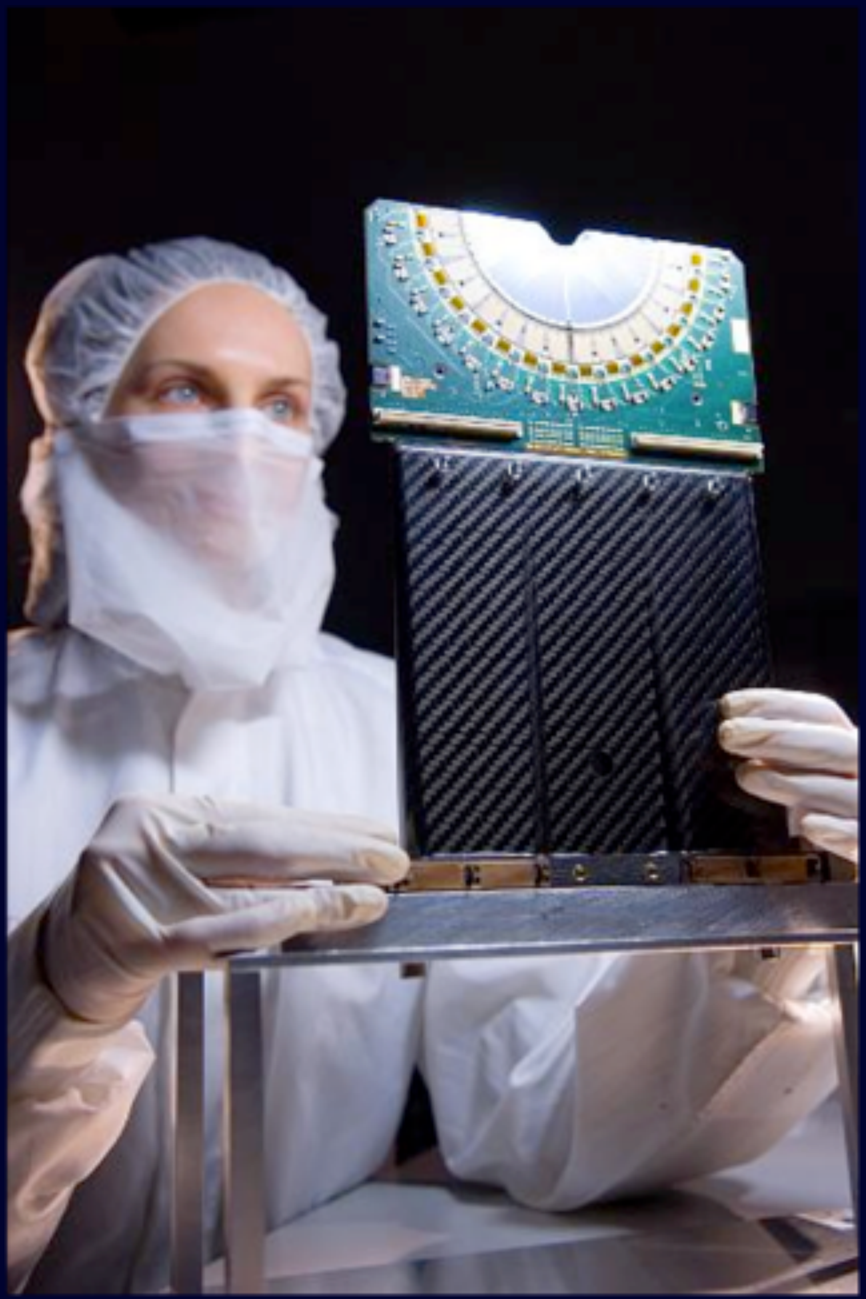
- **The charge that flows to the routing line creates 'fake' low charge clusters**
- **No effect on tracking as they have no correlation with other sensors.**
  Does not affect physics performance

Second metal layer effect



- **Degradation large in the beginning, but halted at some point.**
- **Turn-on effect**

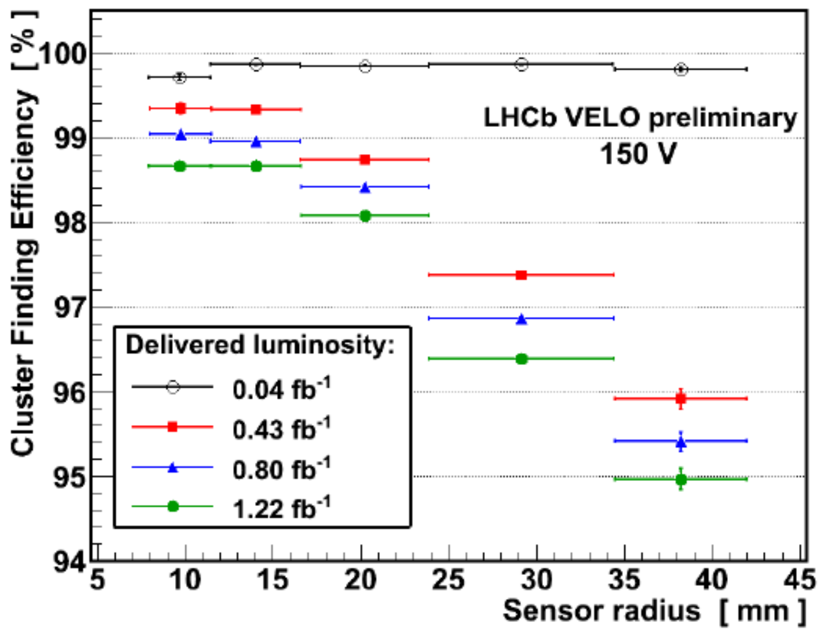
Summary

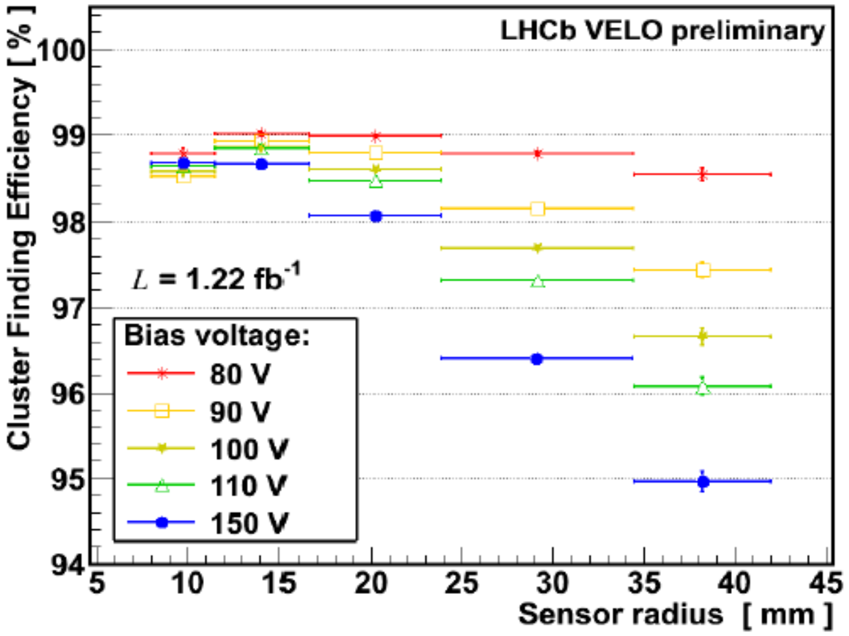


- VELO detector is performing very well
- Various methods in place to monitor radiation damage to the VELO sensors
- Effective depletion voltage follow the expectations
  type inversion taken place for inner part of sensors
- Cluster finding efficiency shows unexpected drop due to second metal layer effect
- Studies on radiation damage published:
  2013 JINST 8 P08002

Start of backup slides

Cluster finding efficiency

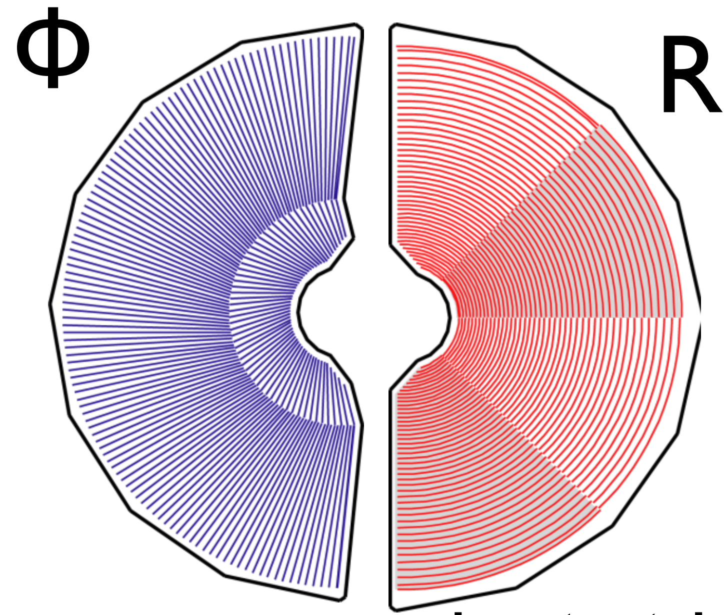




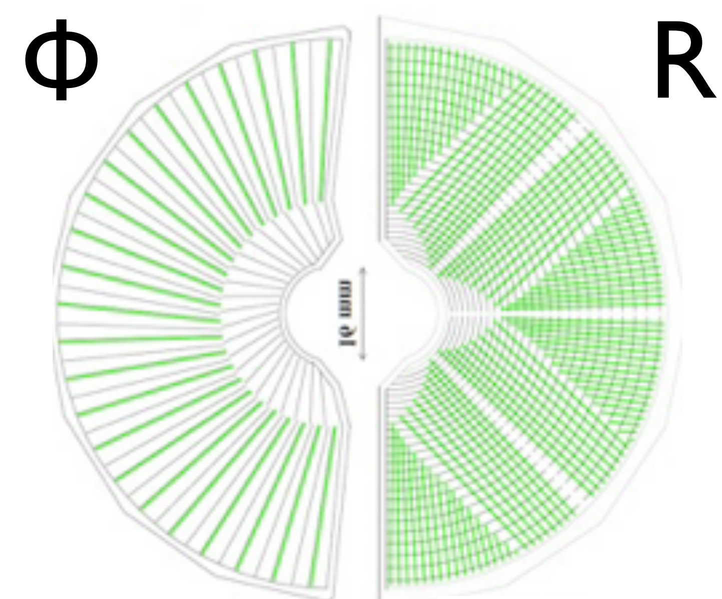
- **Effects depends on the delivered luminosity.**
- **Increasing the bias voltage only made it worse!**

VELO sensors

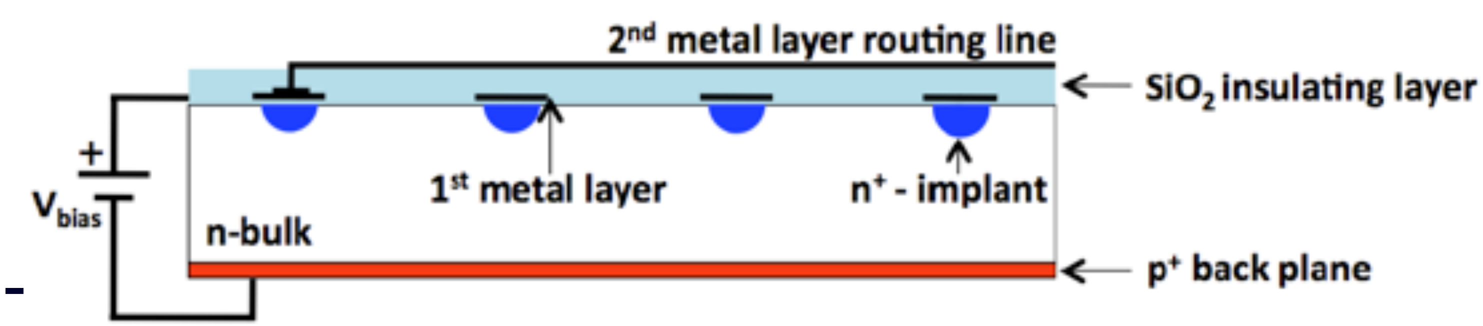
- **300 µm n+-on-n sensors (MICRON)**
  two n+-on-p (MICRON)
- **R sensors:**
  45 degree quadrants
  pitch 40 - 101.6 µm
- **Φ sensors:**
  2 regions (short and long strips)
  pitch 35.5 - 96.6 µm
- **2048 strips per sensor, total 172k strips**
- **Signal routing by double metal layer**
- **Active region starts at R=8mm**



readout strips



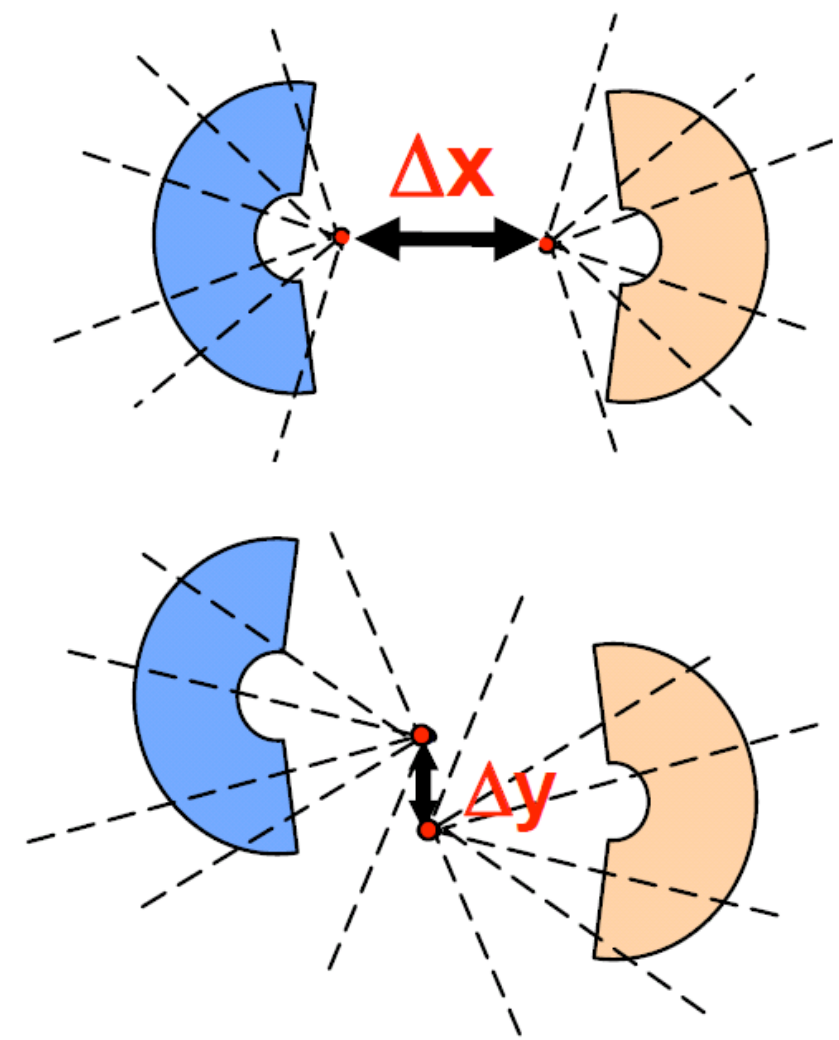
routing lines

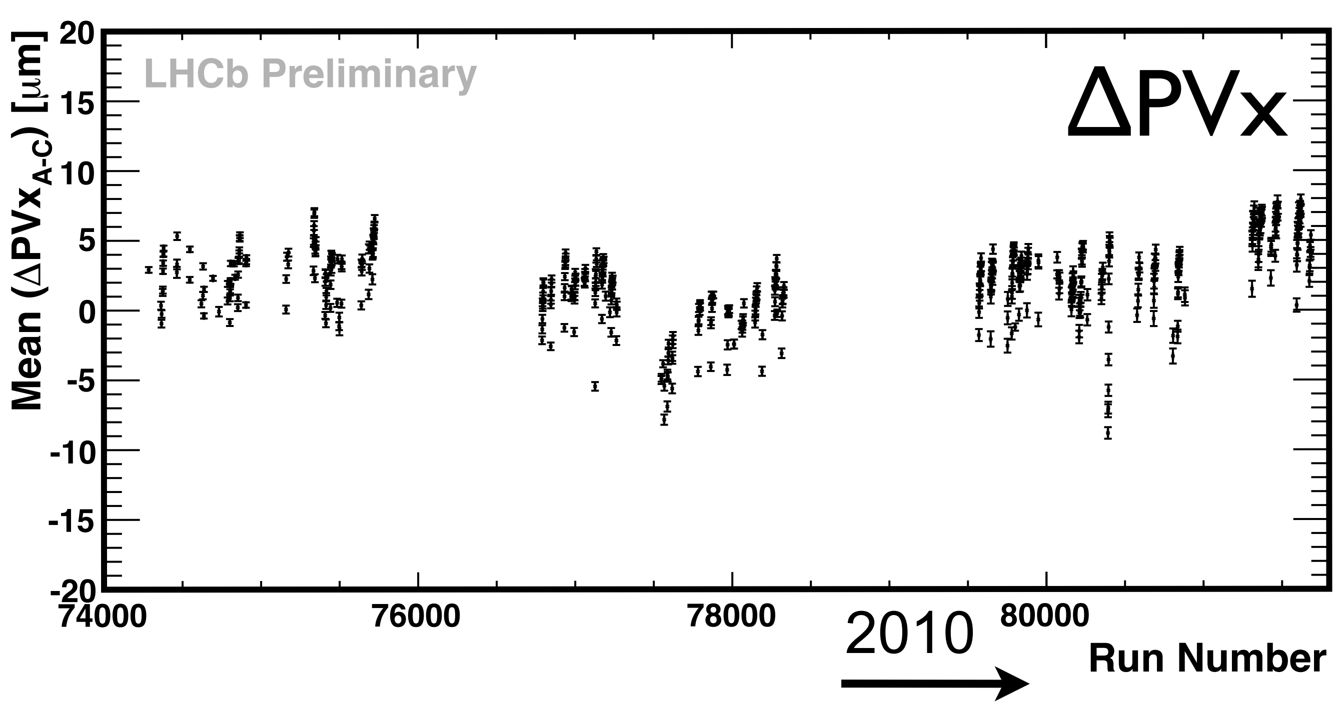


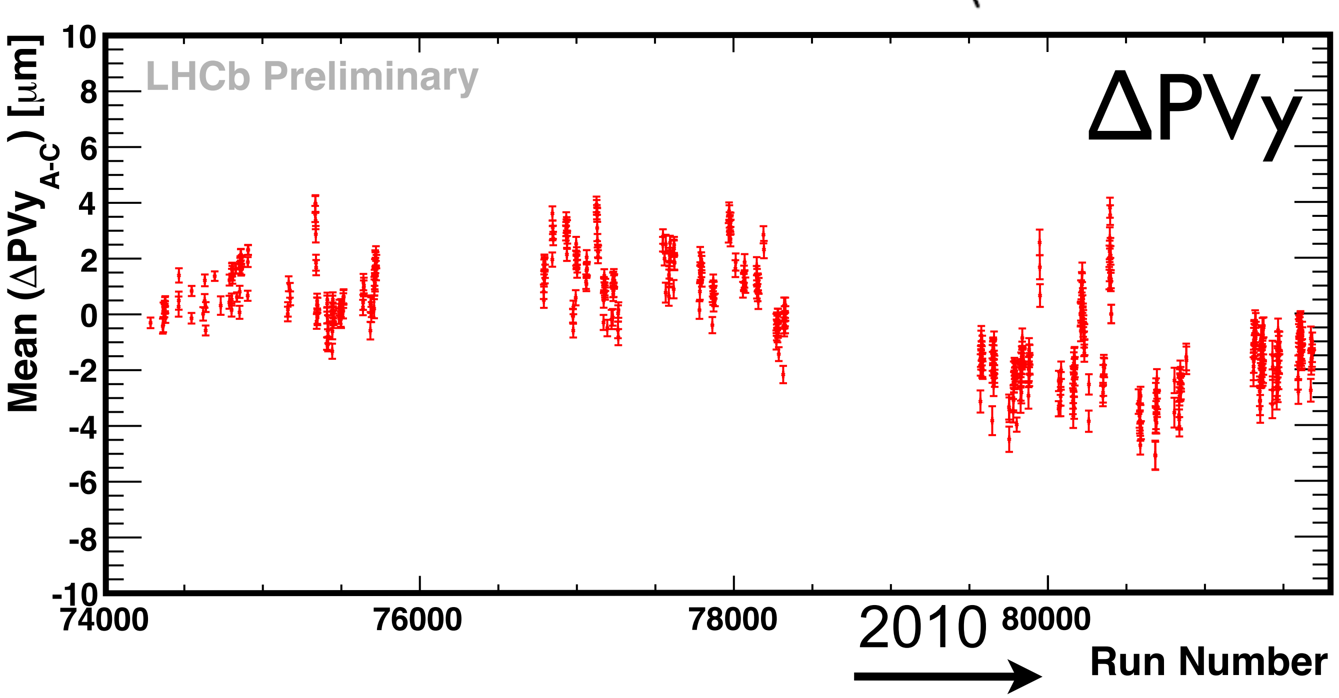
Closing the velo

- **VELO halves are closed each beam fill when beam are declare stable**
  - **Fully automated procedure, takes 210 sec**
  - **Stable within +- 5 µm**

1. **Beam position calculated independently by both detector halves**
2. **Misalignment calculated from distance between the 2 reconstructed vertices**

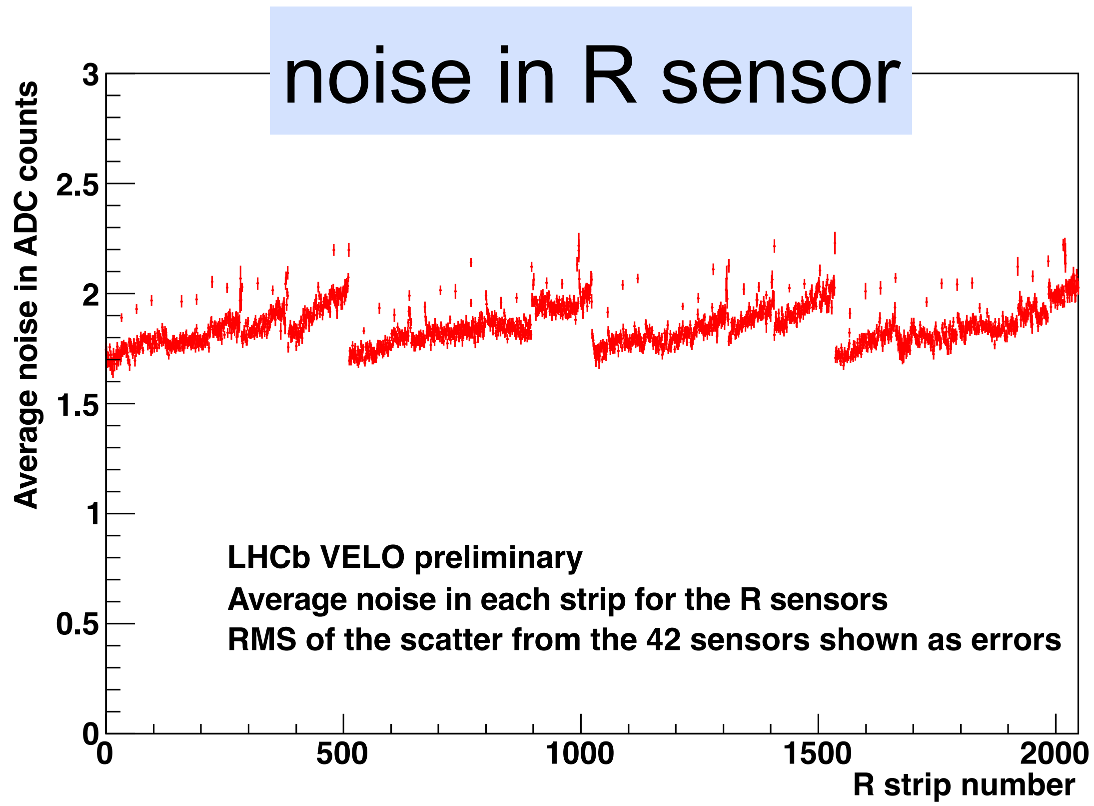


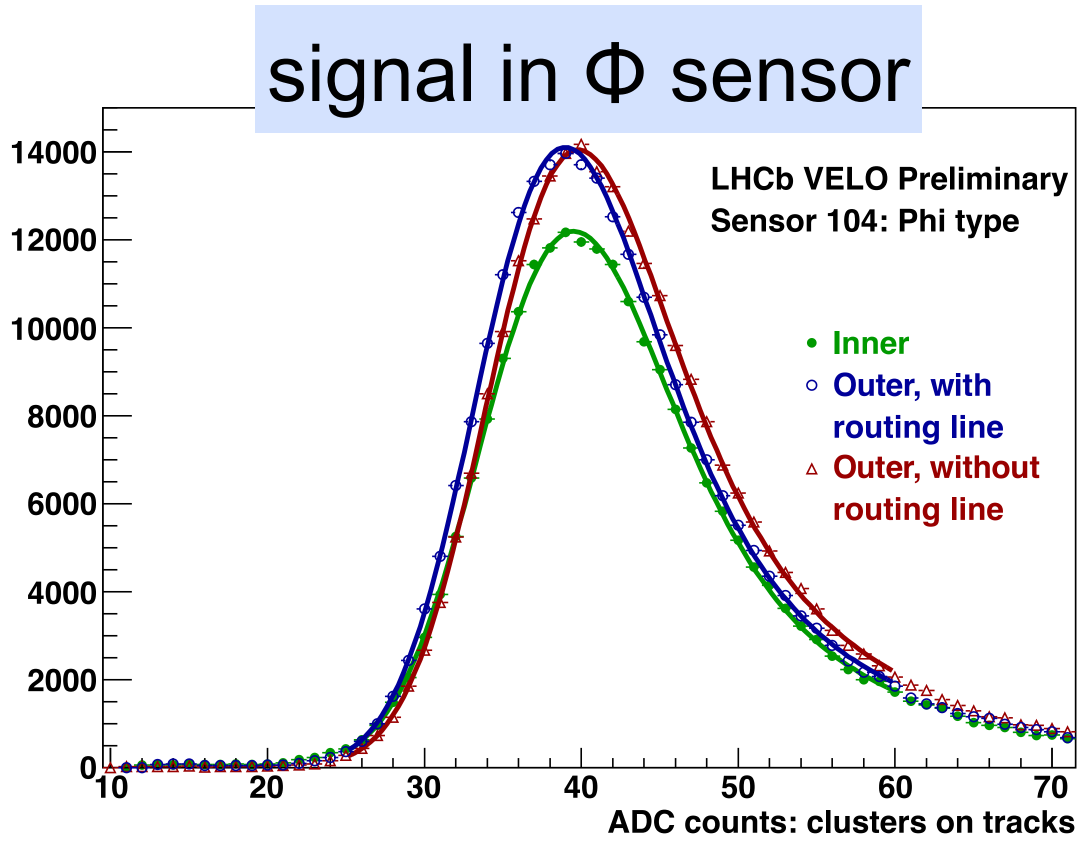


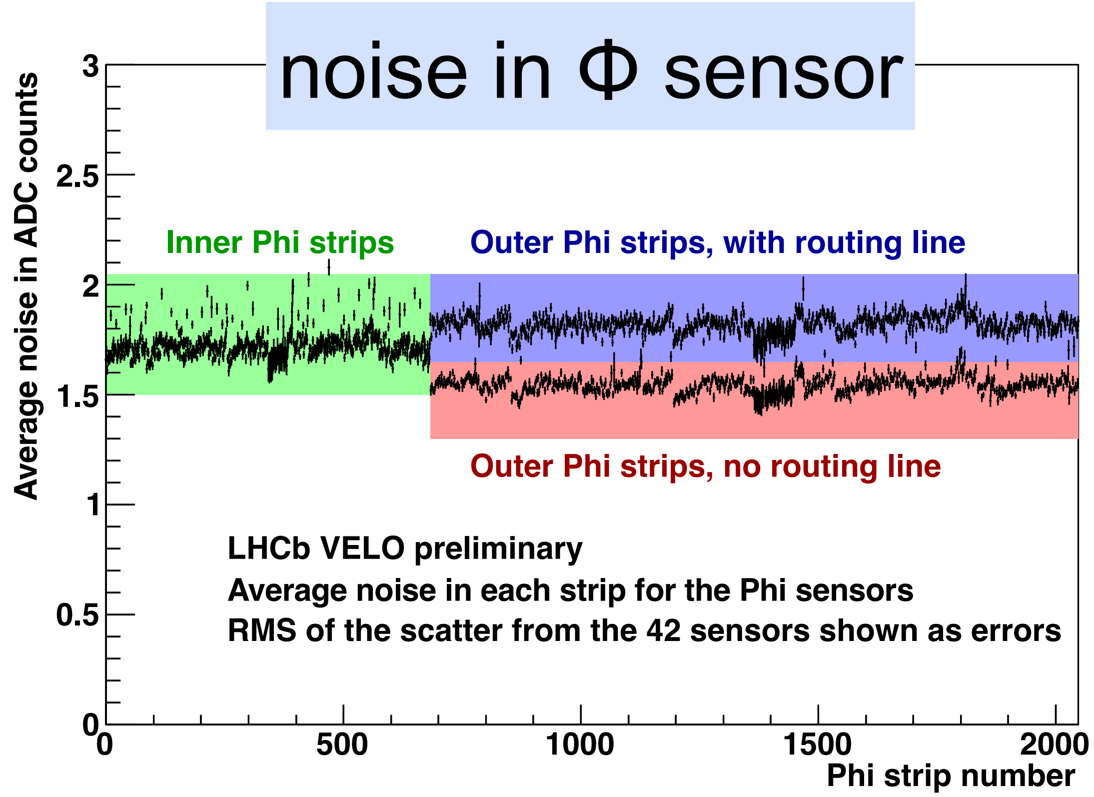


Signal to Noise

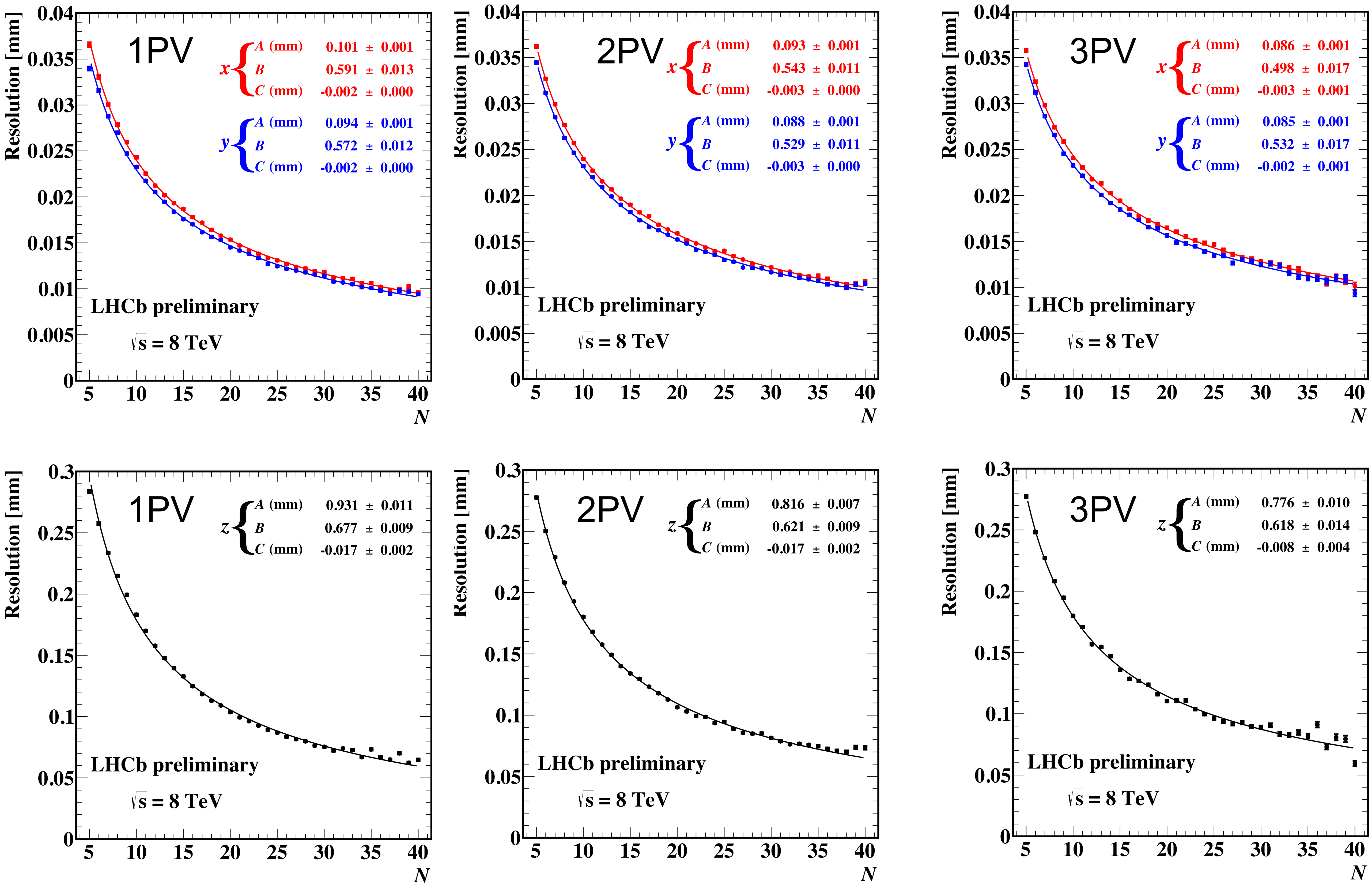
- Stable over running period (2010 -2012)
- Typical noise in sensors ~2ADC
- Signal/Noise>19 after 2 years of operation (excellent time alignment)





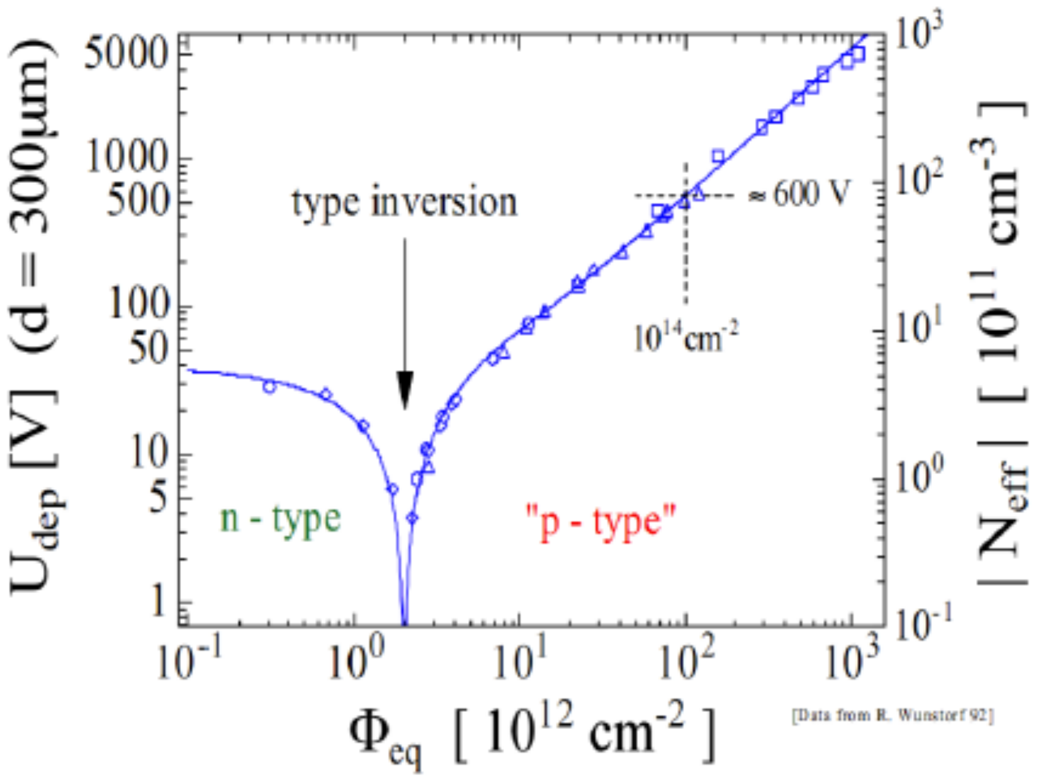


PV resolutions



Effective depletion voltage

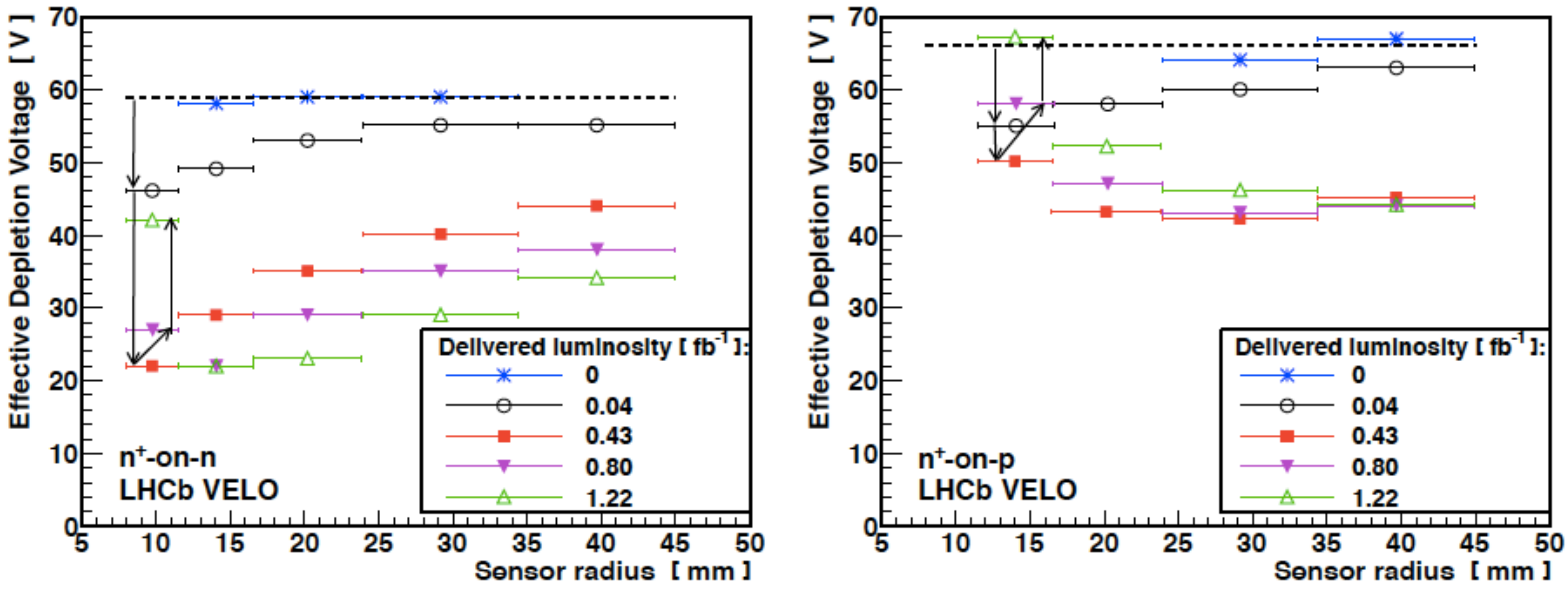
- **Type inversion of bulk material expected for n+ on n sensors:**
  Initial drop of V_{FD} followed by increase



- **Before installation CV scans performed to find V_{FD}**
  This cannot be repeated after installation

- **Alternative, in-situ, method developed to find the effective depletion voltage**

EDV versus radius



- EDV as a function of radius at various delivered luminosity points
- Different behavior for n+-on-p sensor: only outer part of the sensor not type inverted