# *LHCb VELO:* Radiation Damage Effects and Operations in Run 2

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VCI VIENNA CONFERENCE ON INSTRUMENTATION

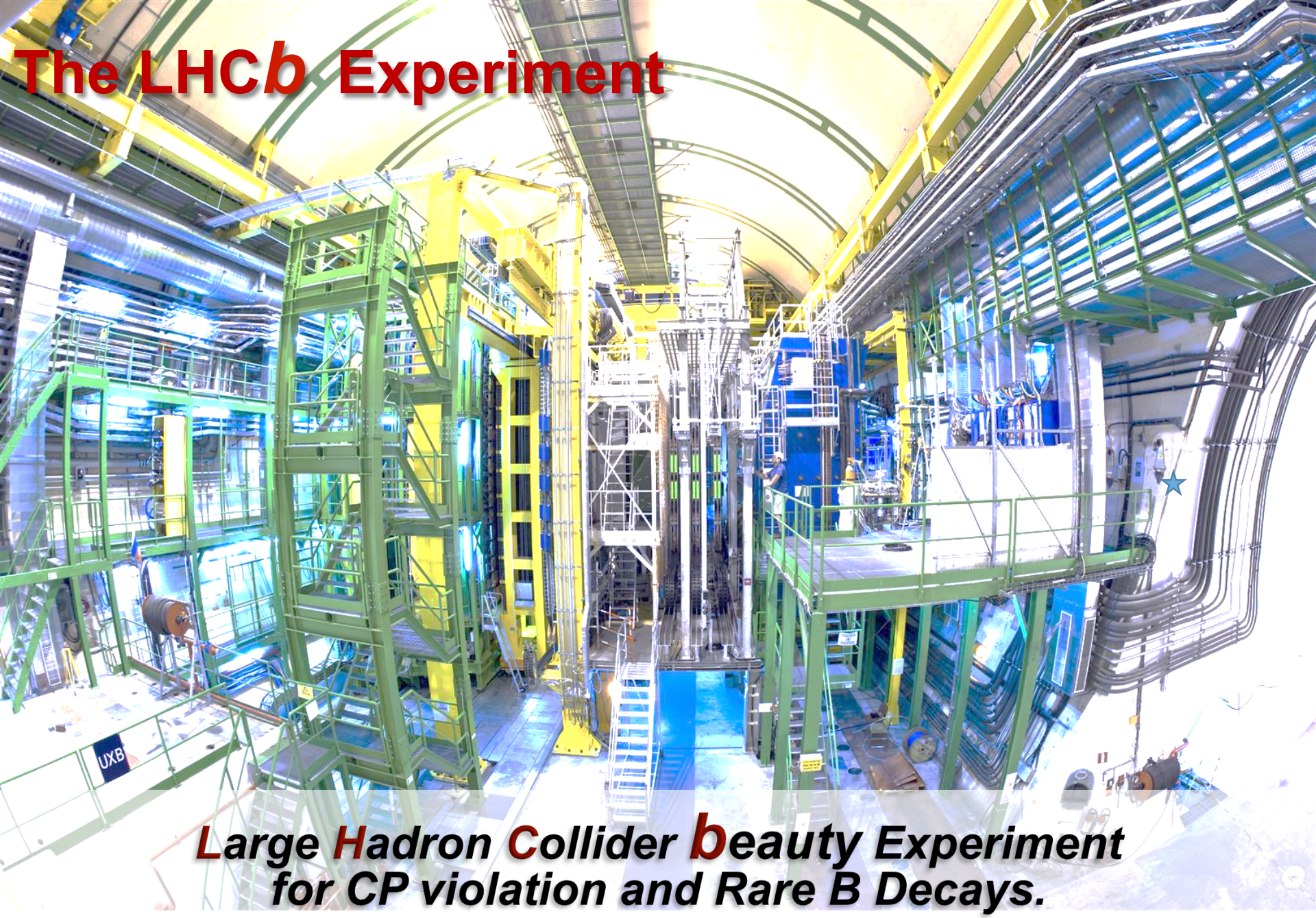
**14TH VIENNA CONFERENCE ON INSTRUMENTATION**

UNIVERSIDADE FEDERAL DO RIO DE JANEIRO

LHCb VERTEX LOCATOR

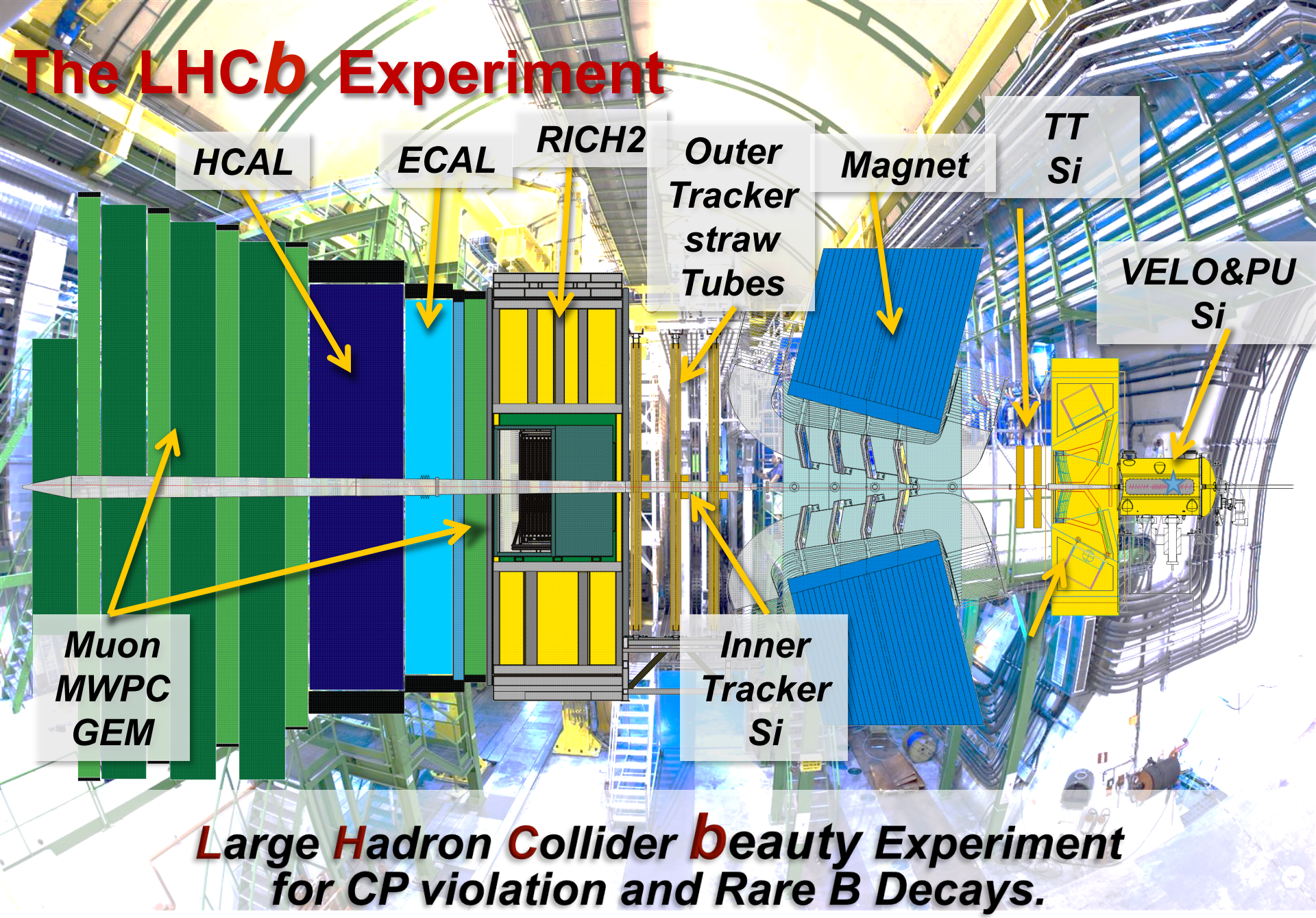
CERN

# The LHC*b* Experiment



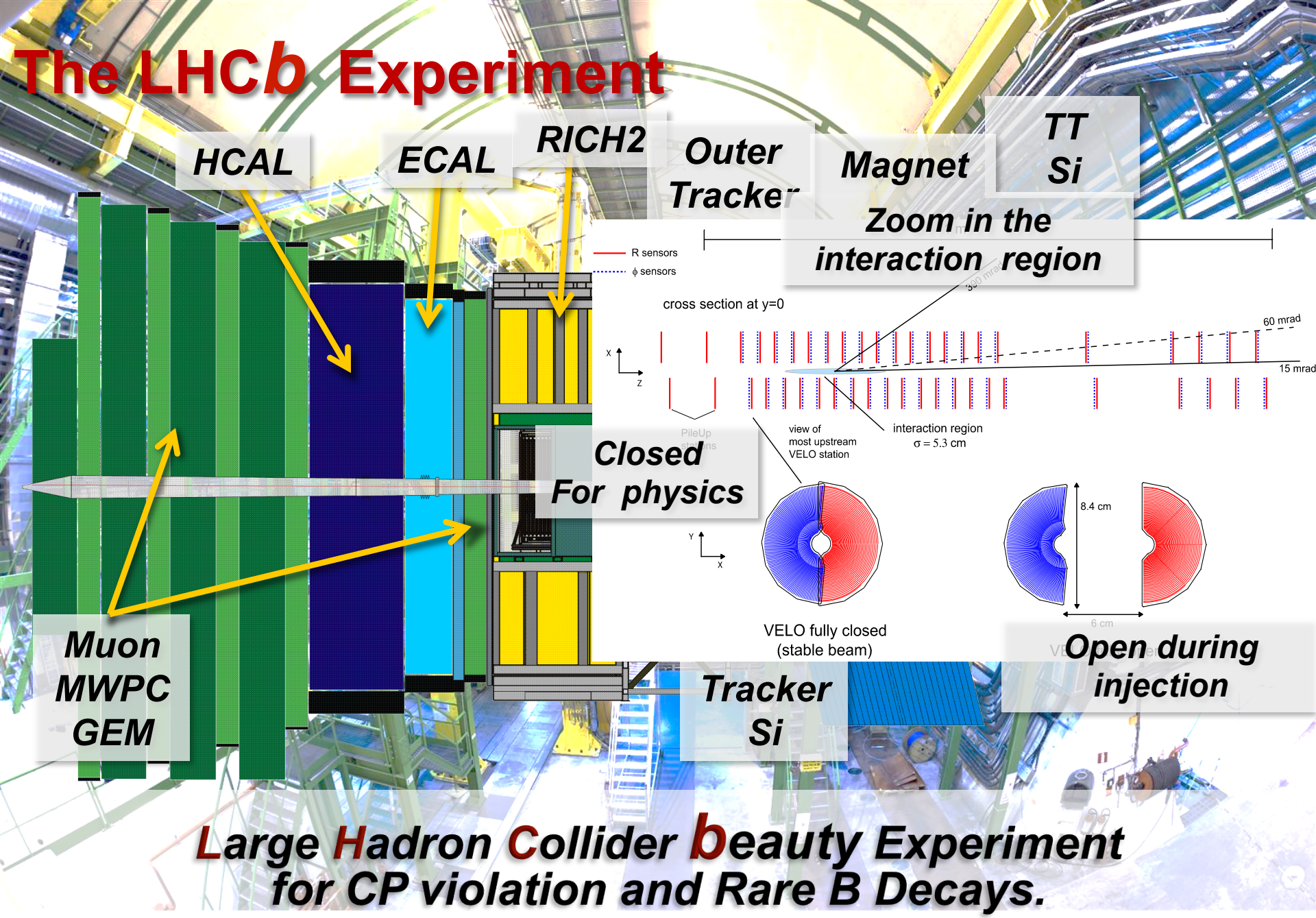

***Large Hadron Collider beauty Experiment***
***for CP violation and Rare B Decays.***

# The LHC*b* Experiment



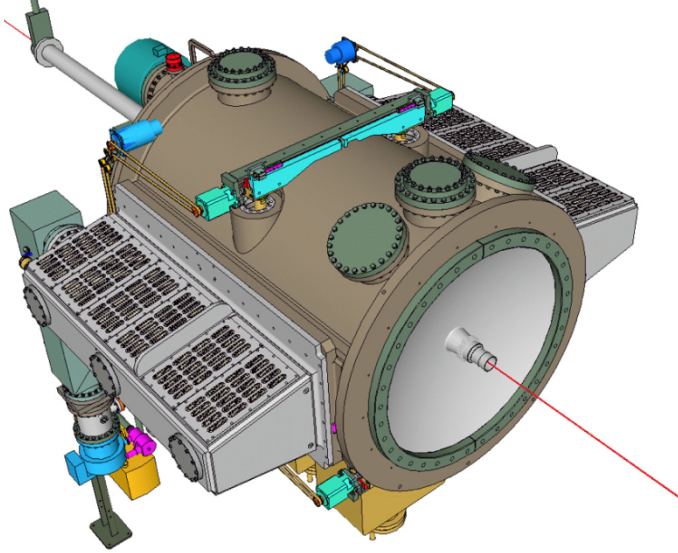

**Large Hadron Collider beauty Experiment for CP violation and Rare B Decays.**

# The LHCb Experiment

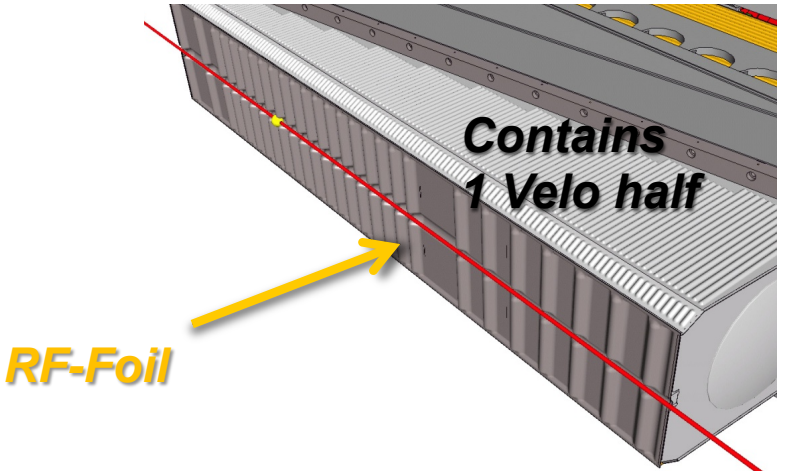



**Large Hadron Collider beauty Experiment for CP violation and Rare B Decays.**

# VELO system



- Operated in a secondary ***vacuum***, sensors and front-end
- A 300 μm thick Al ***foil*** separates the VELO Vacuum from the LHC

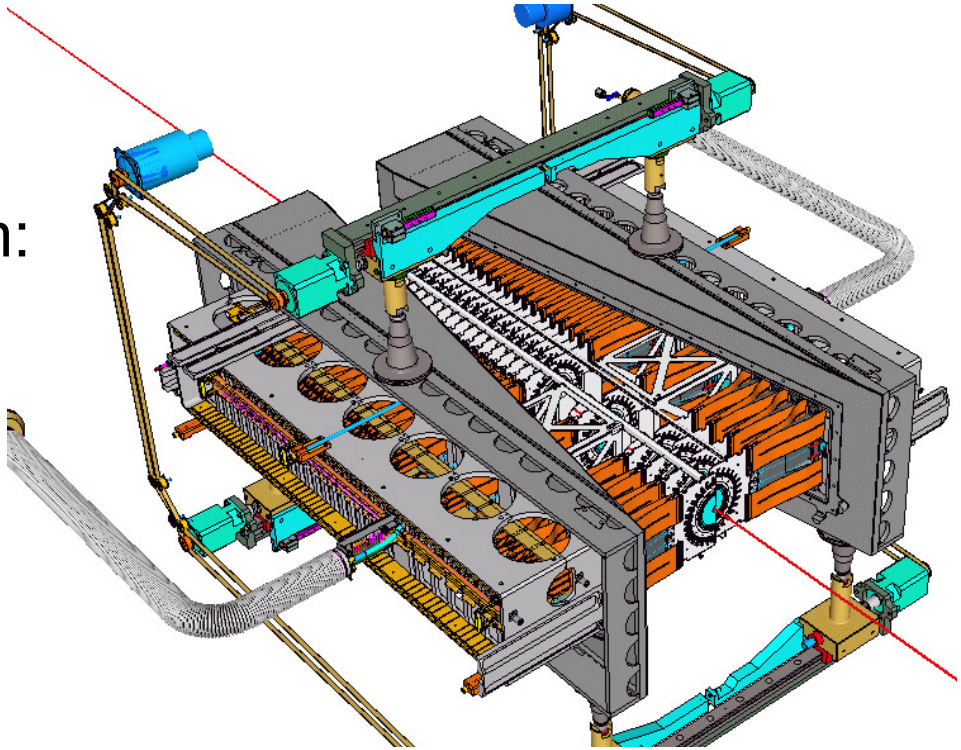



The VELO was designed for:

- Minimal material budget.
- Excellent primary and secondary vertexing and tracking.
- Outstanding impact parameter resolution.

# VELO system

- 2 Moveable halves
- Bi-phase $CO_2$ cooling system: Operation at -30°C
- ➔ sensors at **-10°C** in operation



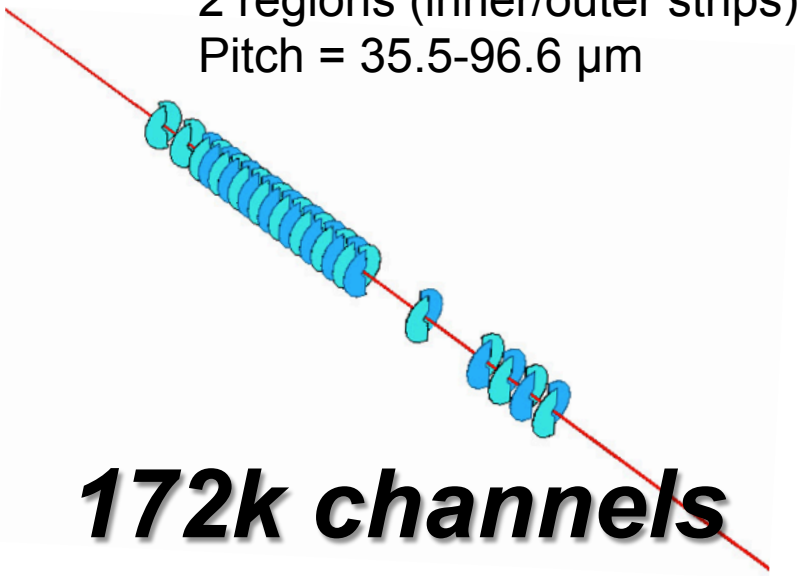
# VELO system

- 42 Modules
- ***1R & 1φ*** sensors/module
- 2048 strips/sensor
- 300 μm ***n-on-n*** sensors!
  - 2 ***n-on-p***
- Active @ ***8 mm*** from beam
- ***Non-uniform and high*** radiation exposure:

| LHC RUN I | Delivered Luminosity | Highest Fluence* per $fb^{-1}$ |
|---|---|---|
| *CMS pixel* | *~29.5 $fb^{-1}$* | *3x$10^{12}$ 1MeV $n_{eq}/cm^2$ At 39 mm* |
| *VELO* | *~3.4 $fb^{-1}$* | *5x$10^{13}$ MeV $n_{eq}/cm^2$ At 8 mm* |

*Estimated

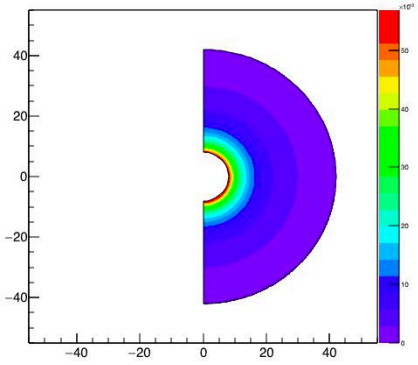
R-sensors:
45 degree quadrants
Pitch = 40-101.6 μm.
Φ-sensors:
2 regions (inner/outer strips)
Pitch = 35.5-96.6 μm



***172k channels***

***0.112 $m^2$***

***Analogue readout at 1.1MHz***

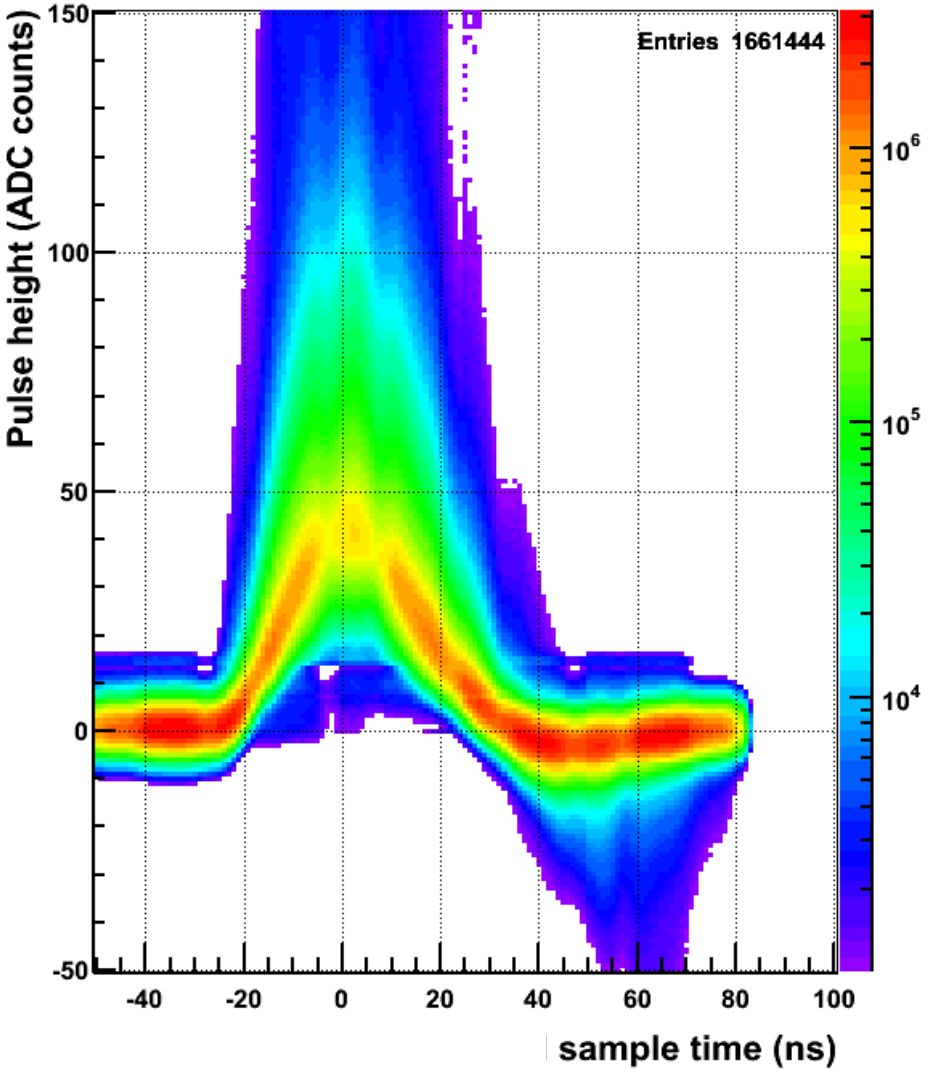


# Challenges for Run II

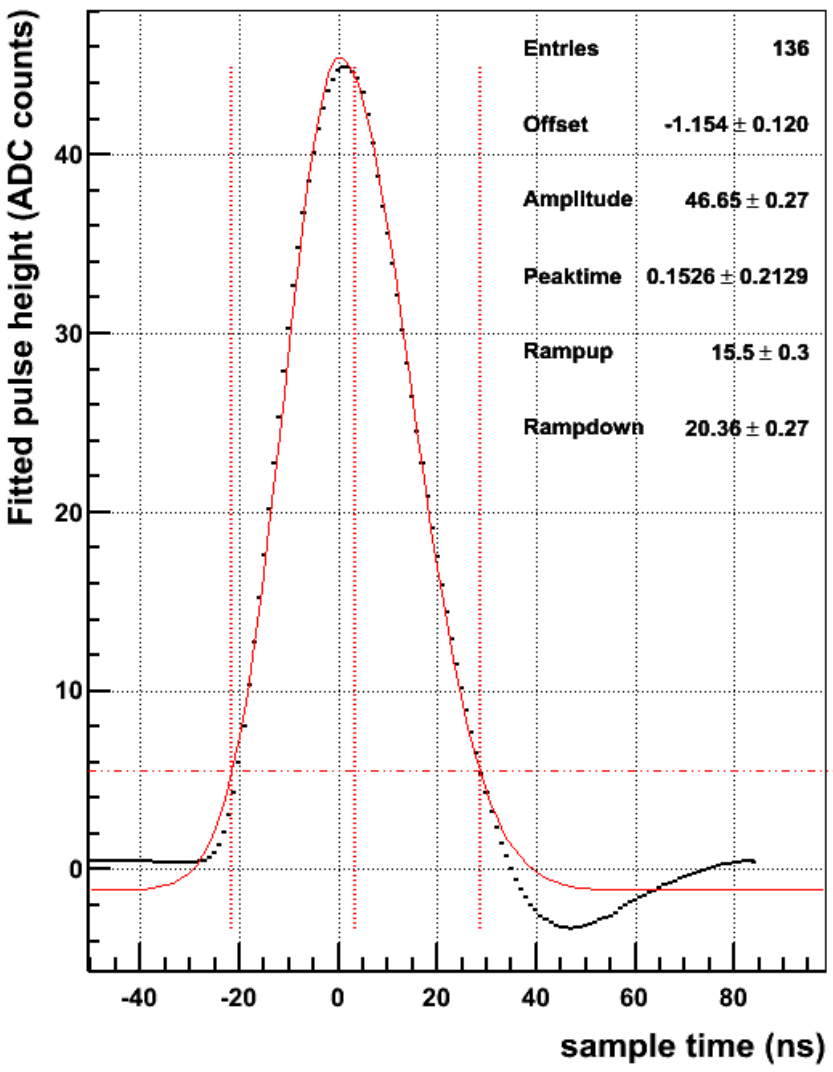
- Higher ***rate***, higher ***energy***, slightly more ***occupancy***
  - Although the front-end readout remains the same, the bunch spacing reaches ***25 ns***, twice as fast as Run I.
- Monitoring the ***data quality***:
  - This involves making sure the physics won't degrade with radiation
  - More ***automated*** checks and ***trending*** ➔ machine triggered alarms
- A gracefully ***aging*** detector:
  - The measurements in Run I indicate that the detector is ***more resistant*** than designed for.
  - In Run I: ***~40% of the expected luminosity*** of the total expected till the end of Run II.
  - Careful operation, attention to ***cooling*** and ***annealing***.
- Ion-Ion Collisions
  - Low rate but high occupancies
    ➔ First time operating the VELO with ***Heavy Ion collisions***.

# Timing

- Pulse shapes measured with beam. Each sensor is optimised for equal spill-over between bunch crossings

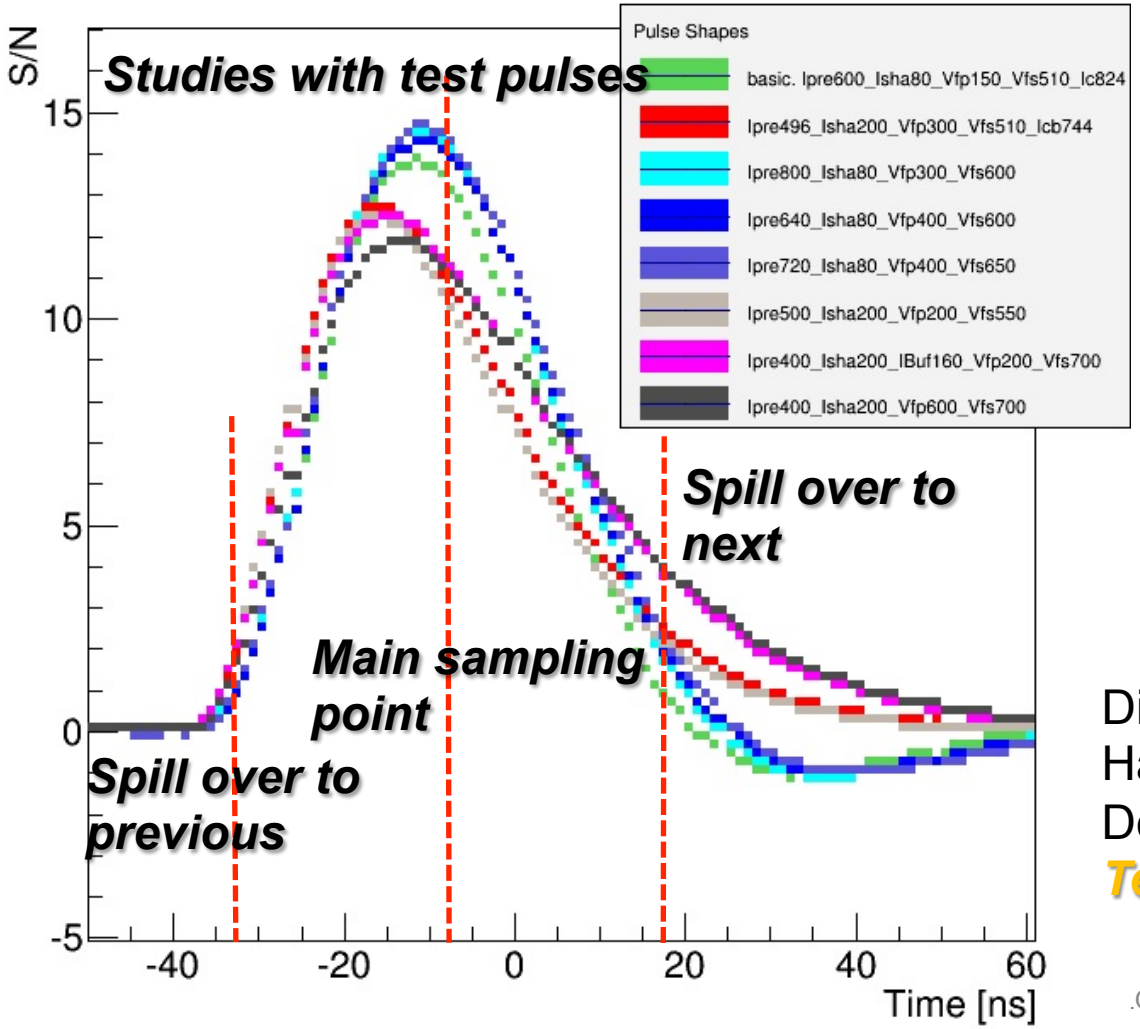


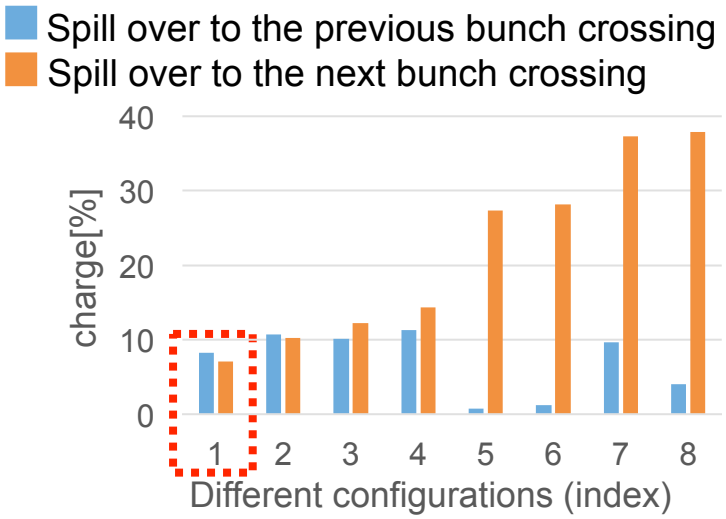

**Average pulse shape: Landau bins**



# Pulse shape studies

- The ***25 ns bunch spacing*** could introduce spill-over tracks.
- The analogue pulse of the front-end chips was optimized for ***fast readout*** and signal to noise.

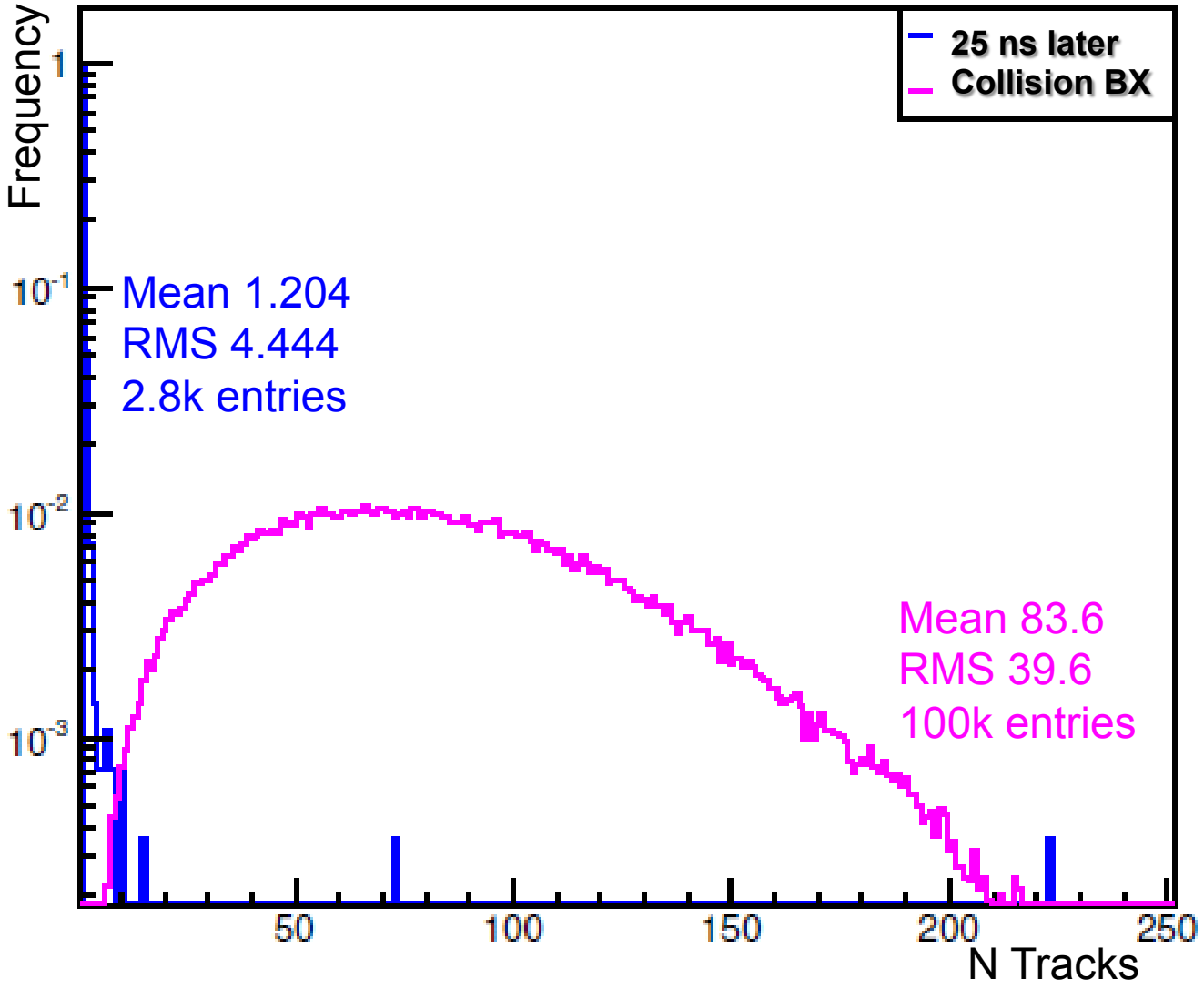



2015 setting

Different configurations can also Have ***lower power*** consumption Decreasing the operational ***Temperature***.

# Spill over effects on Tracking




- The number of ***spurious tracks*** "spilling over" bunch crossings is ***negligible***.

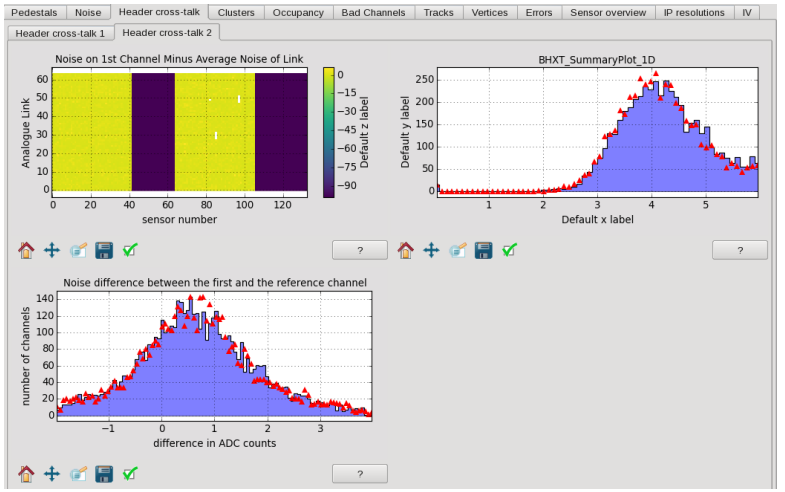
# Monitoring

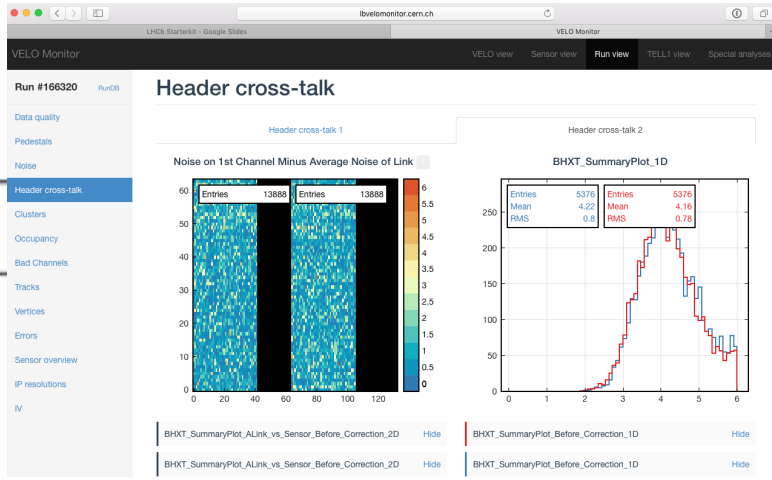
**Run #166329** RunDB

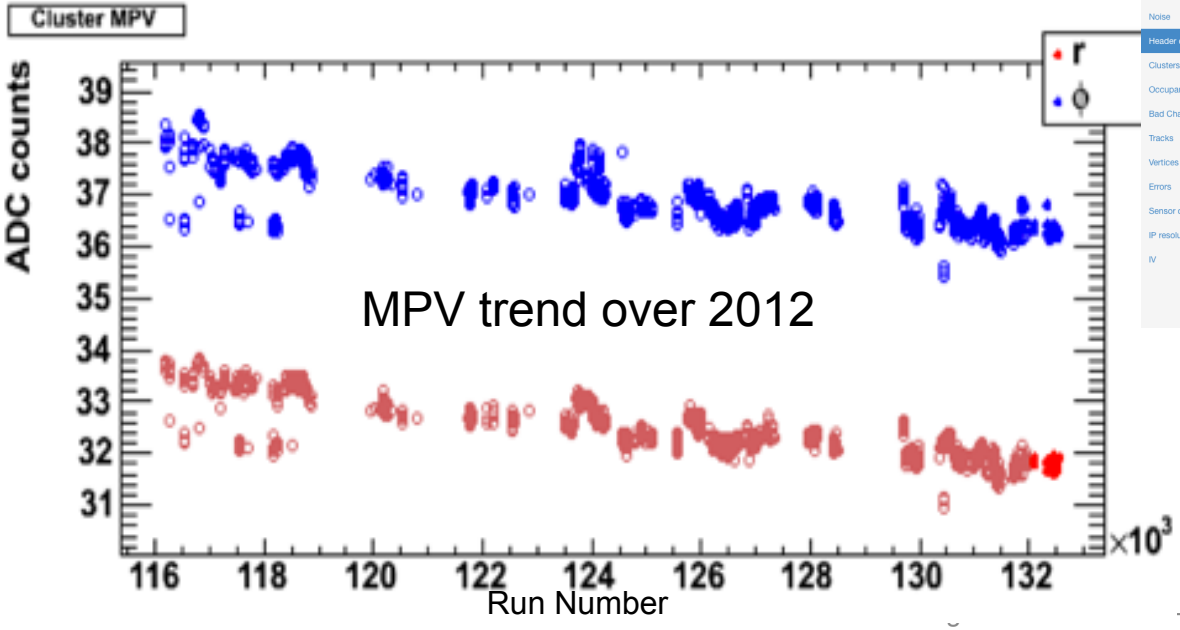
- Data quality
- Pedestals
- Noise
- Header cross-talk
- Clusters
- Occupancy
- Bad Channels
- Tracks
- Vertices

## Data quality

- Clusters
  - Number of Active Chip Links per Sensor 69
  - Number of Clusters per Event 75
  - Cluster Size 19
- Crosstalk
  - Crosstalk 73
- Noise
  - Noise (Phi) 100
  - Noise (R) 100
- Pedestals
  - Pedestal Proj Data 0
  - Pedestal Quality Check 100



# Radiation Damage

- Study the damaging of the current detector is a perfect ***lab for our Upgrade***
  - ***Non Uniformity*** is unique to the VELO.
  - Keep it ***cold***. Avoid prejudicial annealing
  - Observed ***loss of collected charge*** due to bulk damage

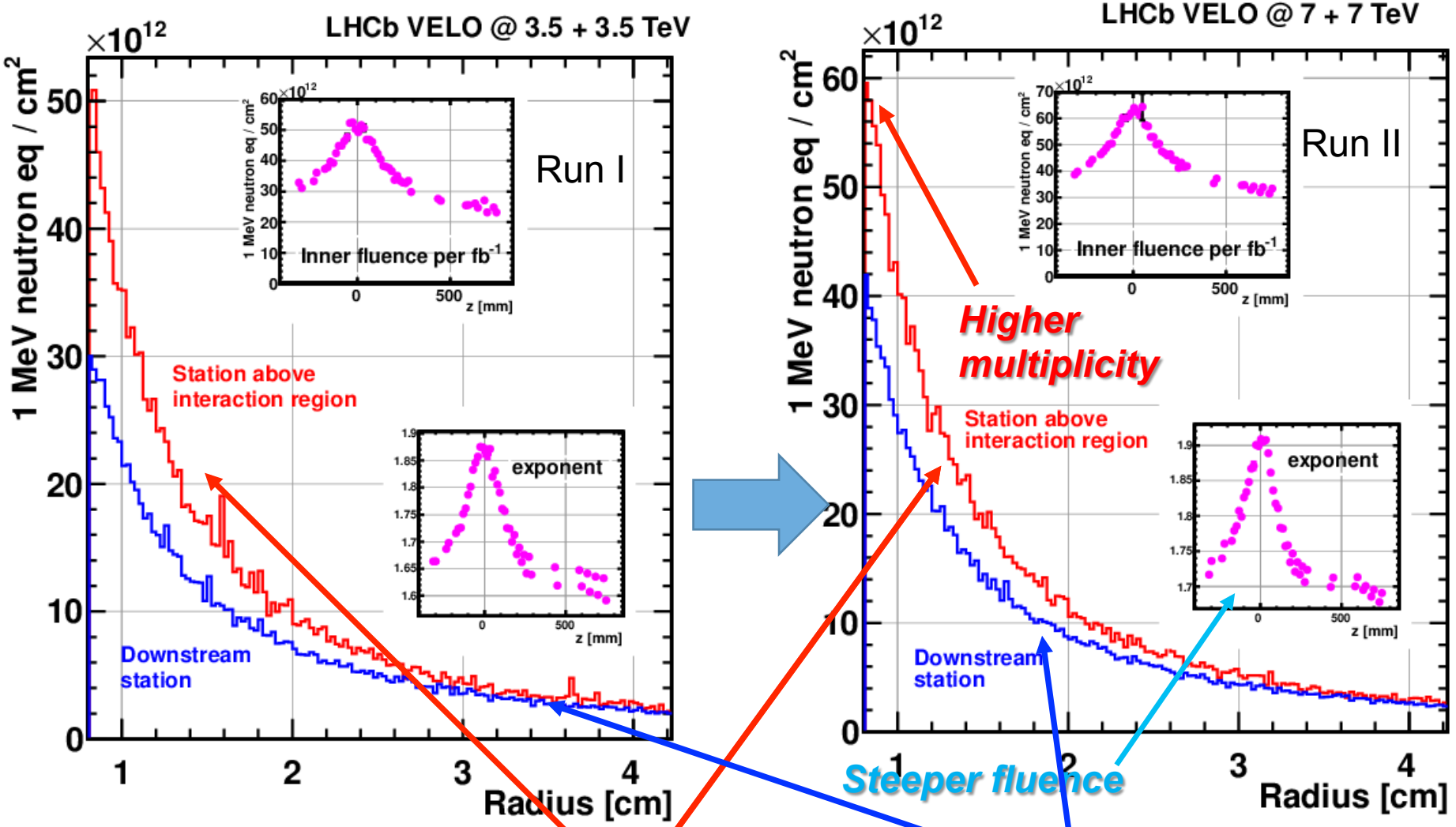
- ***Radiation damage*** is measured with a few approaches, mainly:

  - Constant ***IxV*** curves and occasional IxT measurements – Monitor ***currents*** and compare to expected values – Avoid ***thermal runaway***

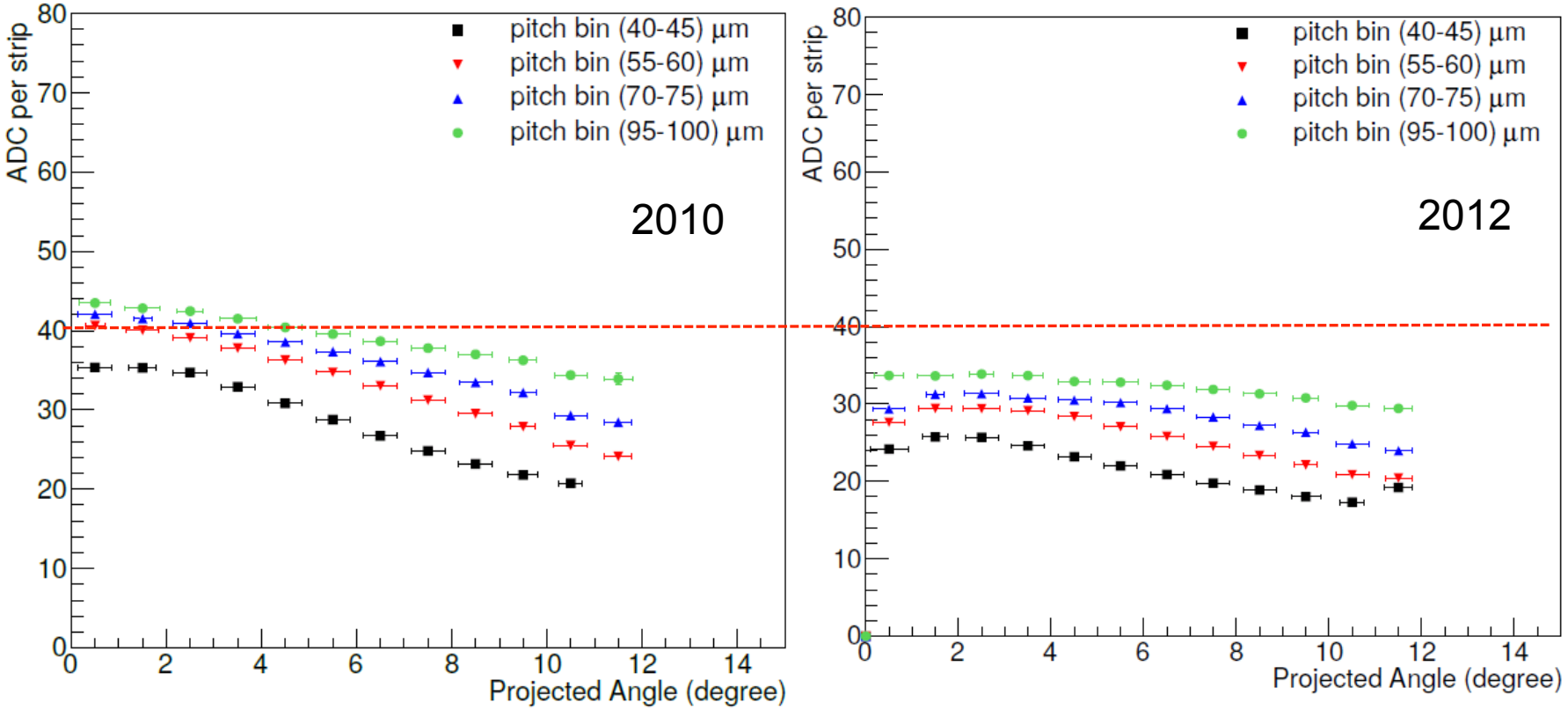
  - Measurement of the ***Collected Charge***. This dictates the operational voltage values, set for the most irradiated regions – Regular ***HV scans*** taken with beam

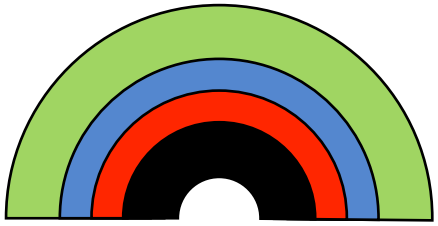
- Unforeseen effects – ***double metal layer***

# Expected increase in fluence = C/Radius$^{exp}$

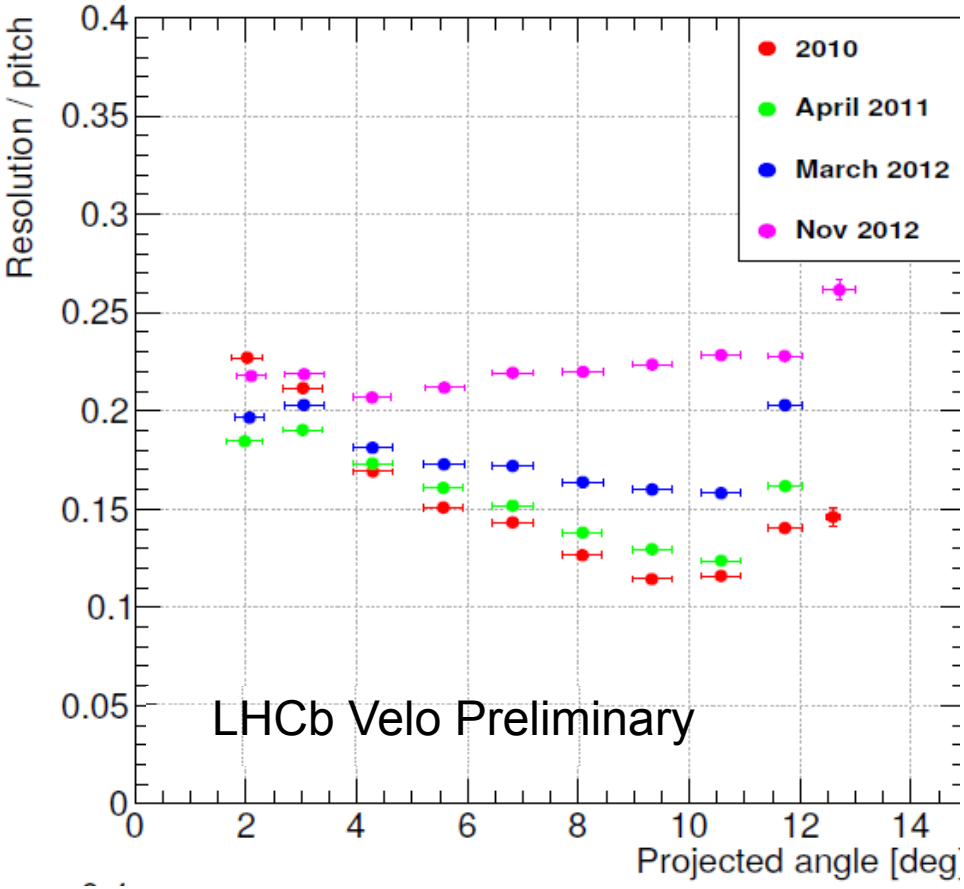


# Collected charge

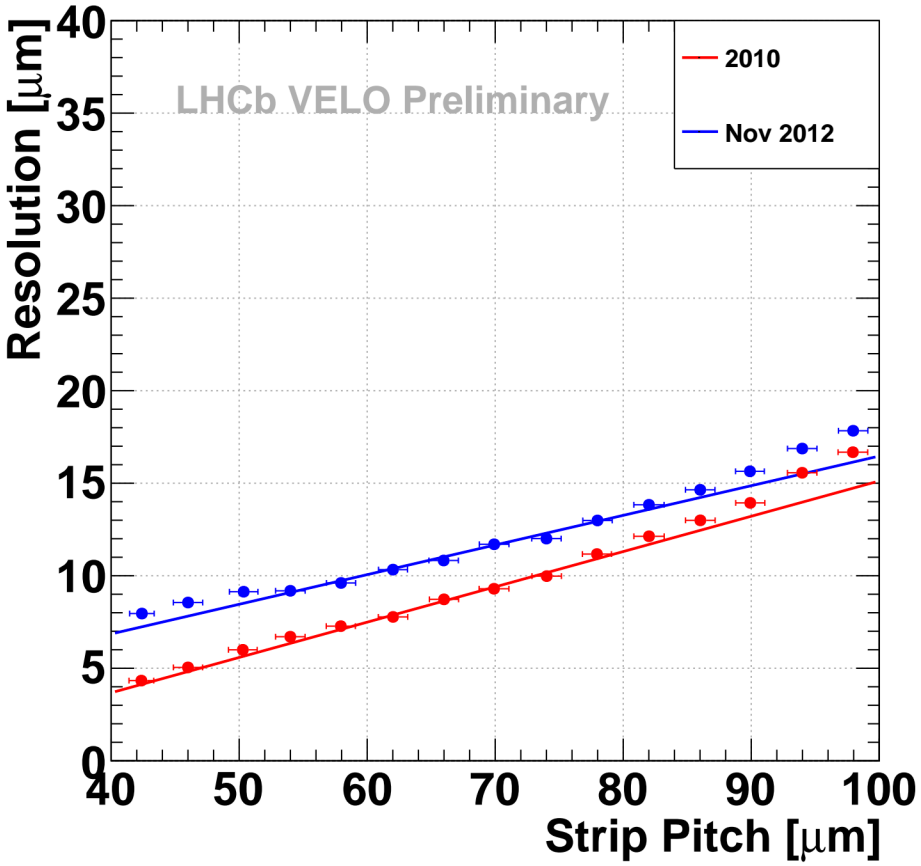


# Hit resolution

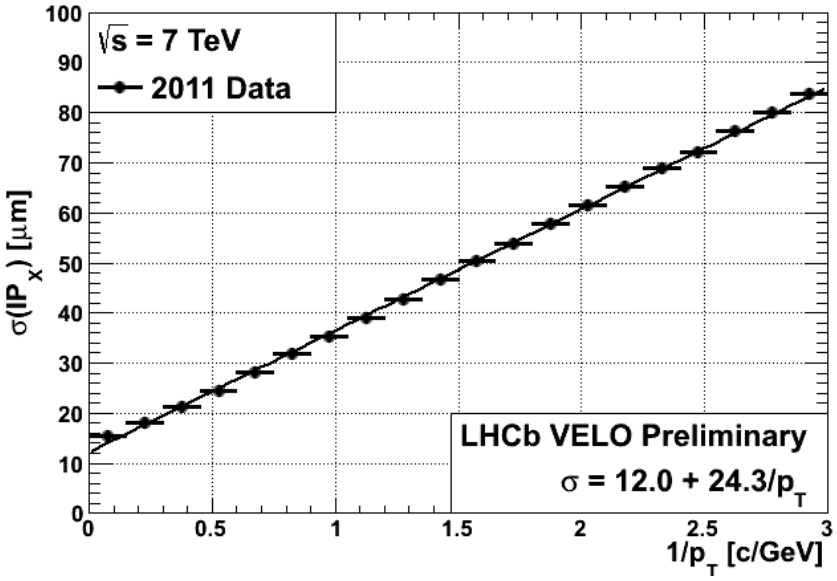



Hit Resolution as function of track angle

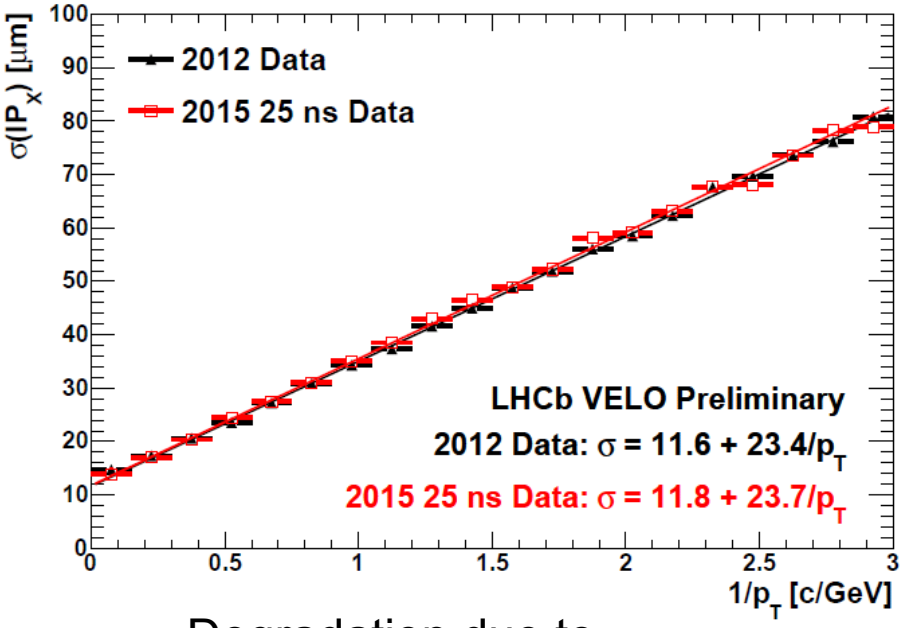



As function of strip pitch, 9 degrees

# Impact parameter Resolution



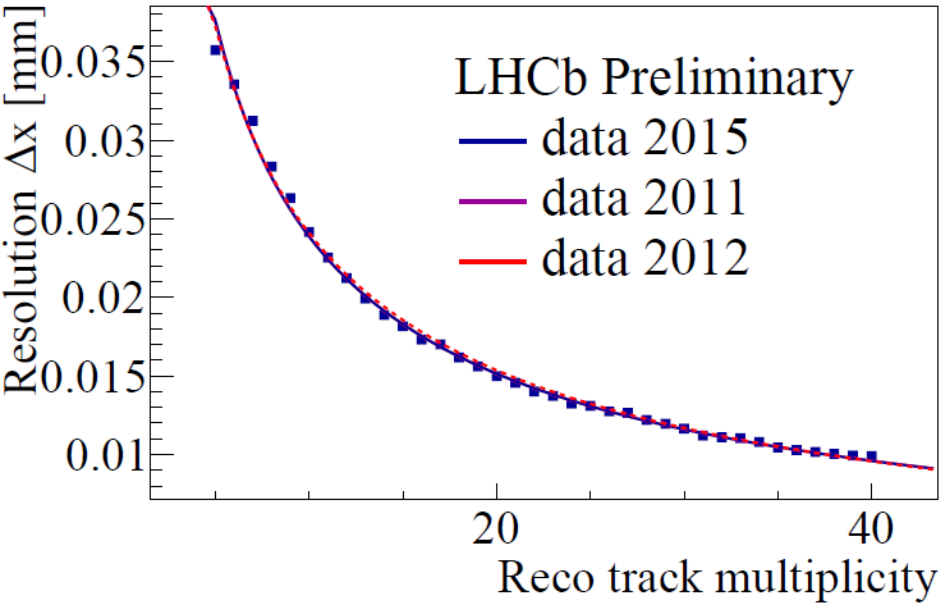

2011 Data. >***1fb$^{-1}$*** exposure

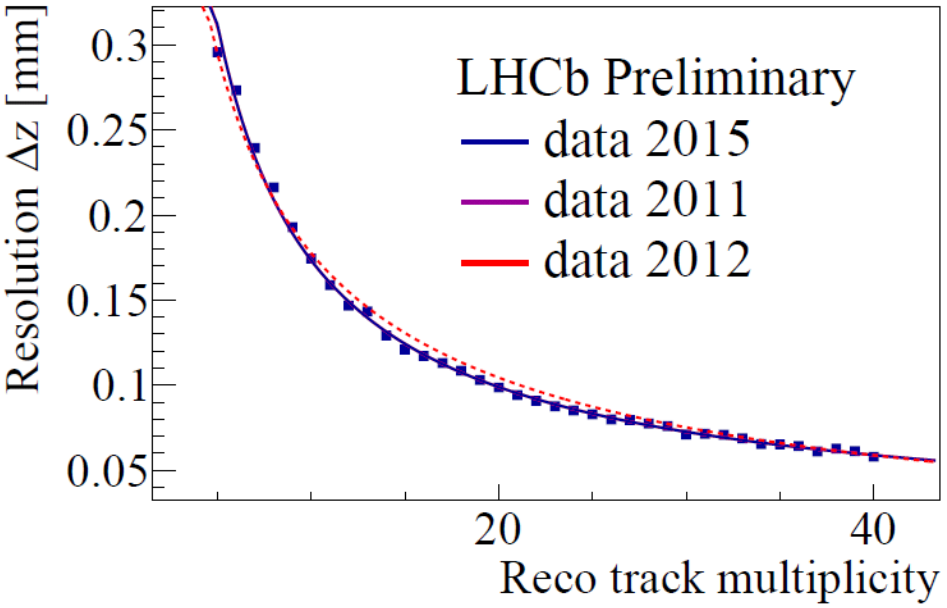



Degradation due to
Radiation damage still ***negligible***

2012 and 2015 Data.
>***3.41fb$^{-1}$*** integrated

# Primary Vertex resolutions



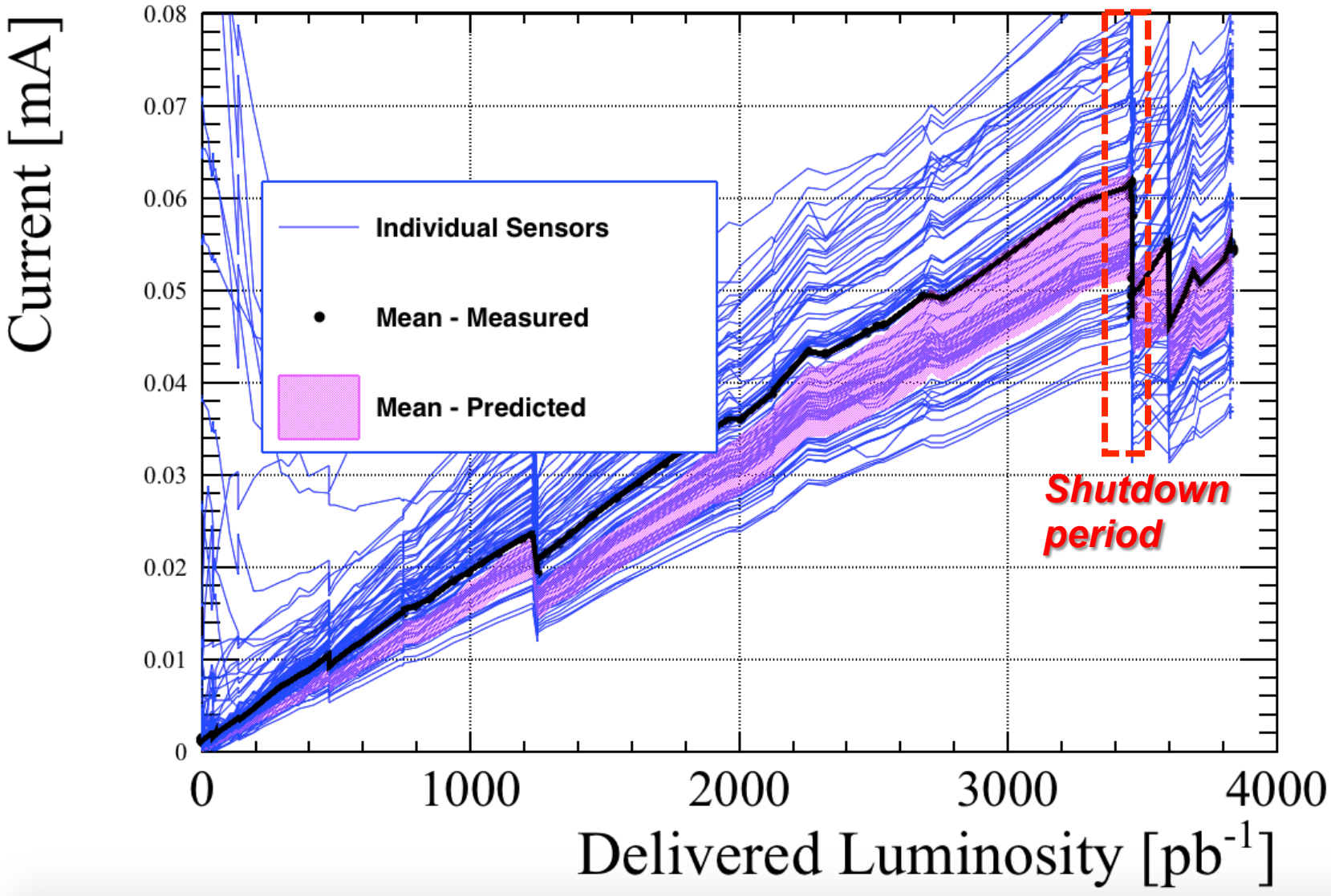




- Although some degradation was observed through Run I, ***High level physics*** quantities remain with ***good resolution***

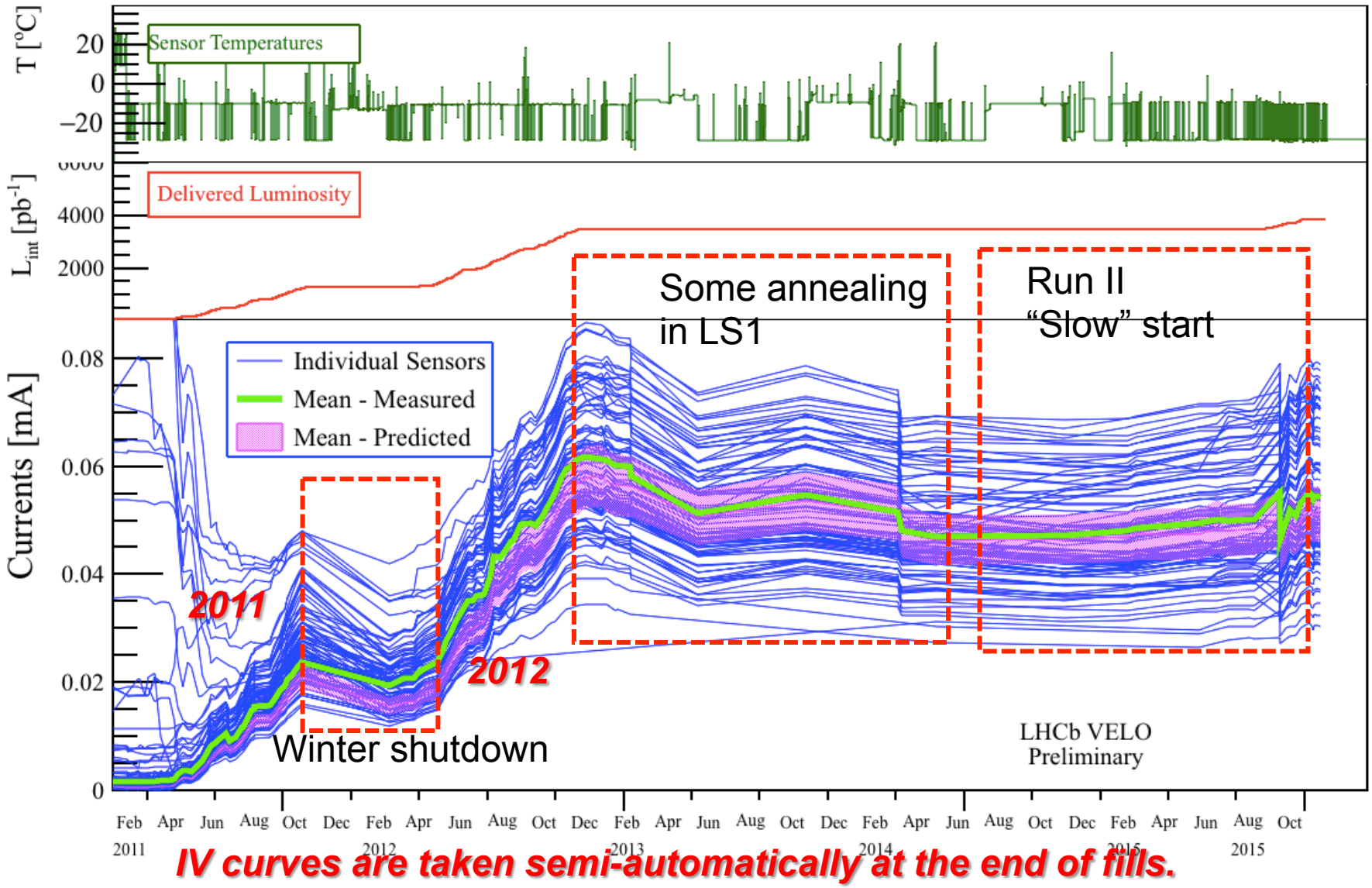
# Monitoring radiation damage

- ***Detector currents***
- ***Charge Collection Efficiency***

# Currents at 150 V – approx. 19 μA/fb$^{-1}$



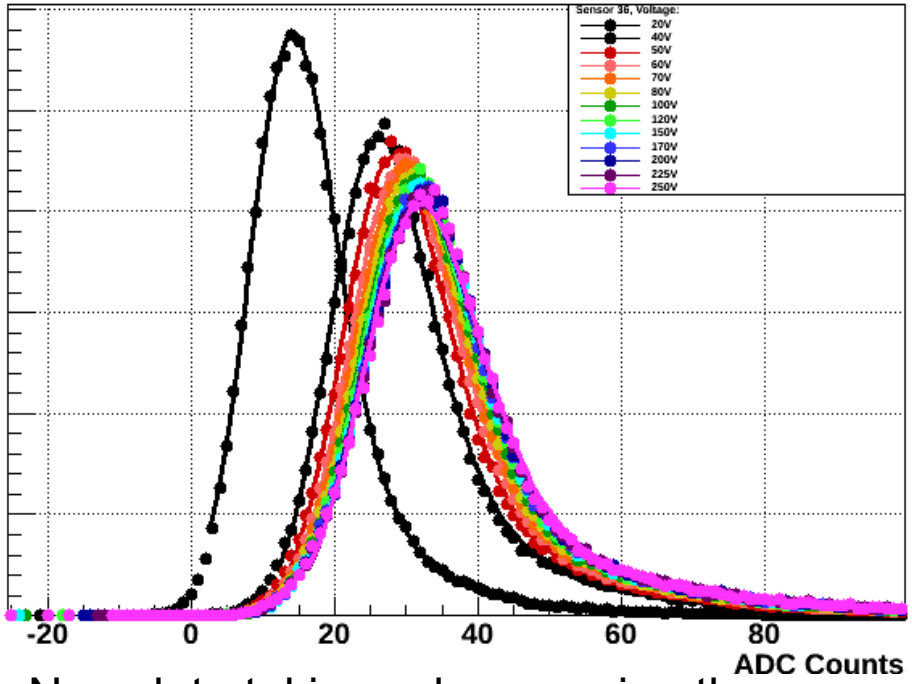
# Currents as function of time (150 V)



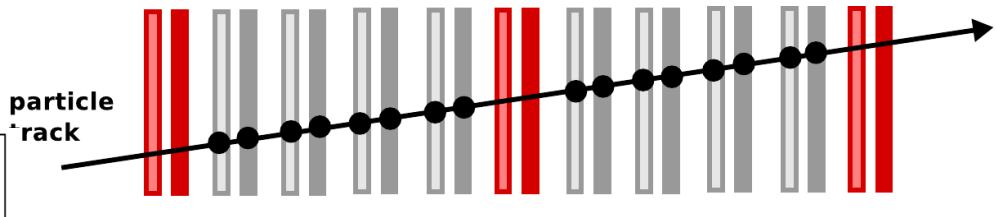

***IV curves are taken semi-automatically at the end of fills.***

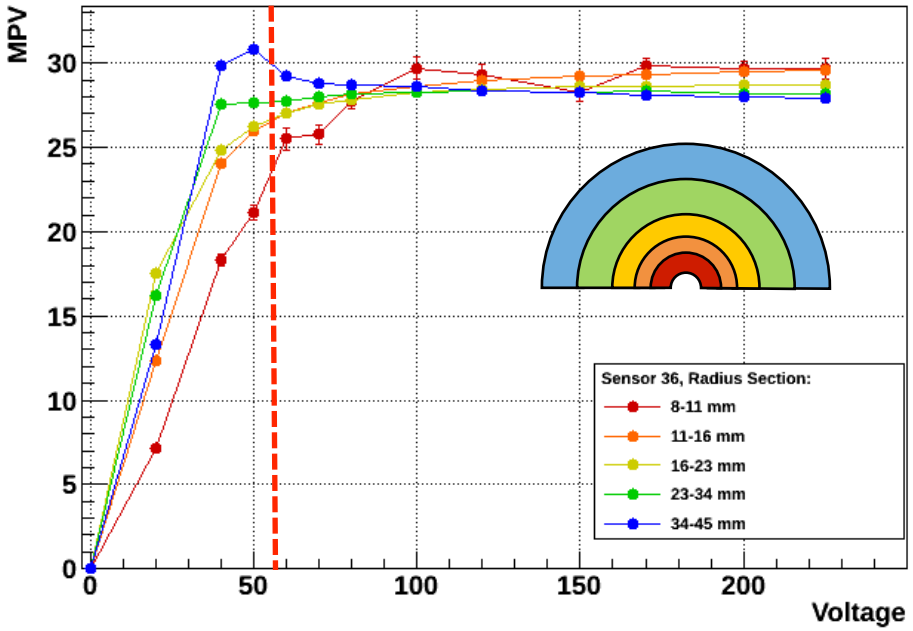
# Charge Collection efficiency – HV scans.

- ***Few sensors*** are scanned the others act as a ***telescope***



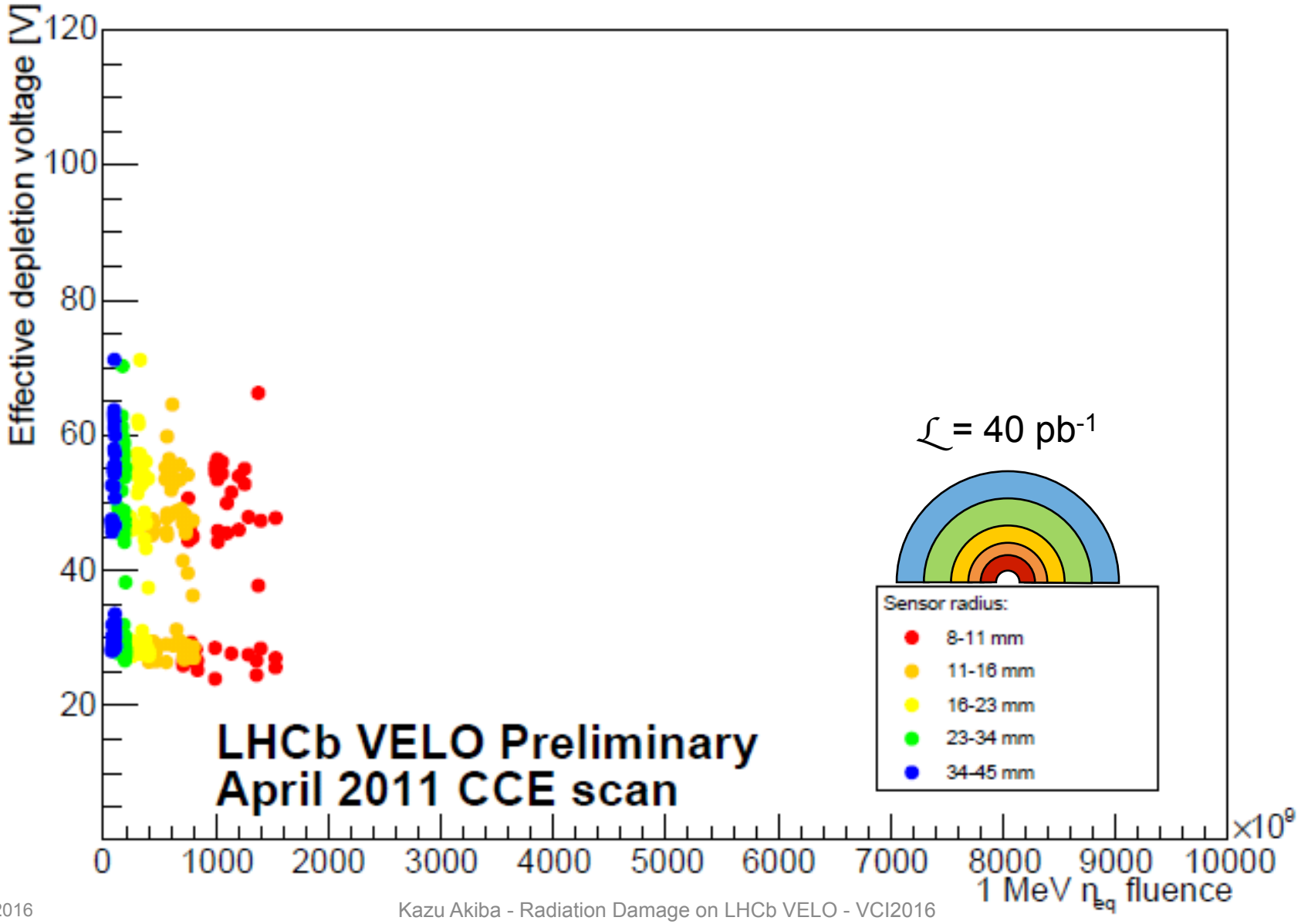

New data taking scheme using the Buffering on the LHCb HLT nodes was able to provide ~***1 Mtracks/step***. The scan takes ***1 hour*** for ~ 65 steps.




***Effective Depletion voltage*** is determined, Op. Value set for the most irradiated part of the sensor

# Effective Depletion Voltages



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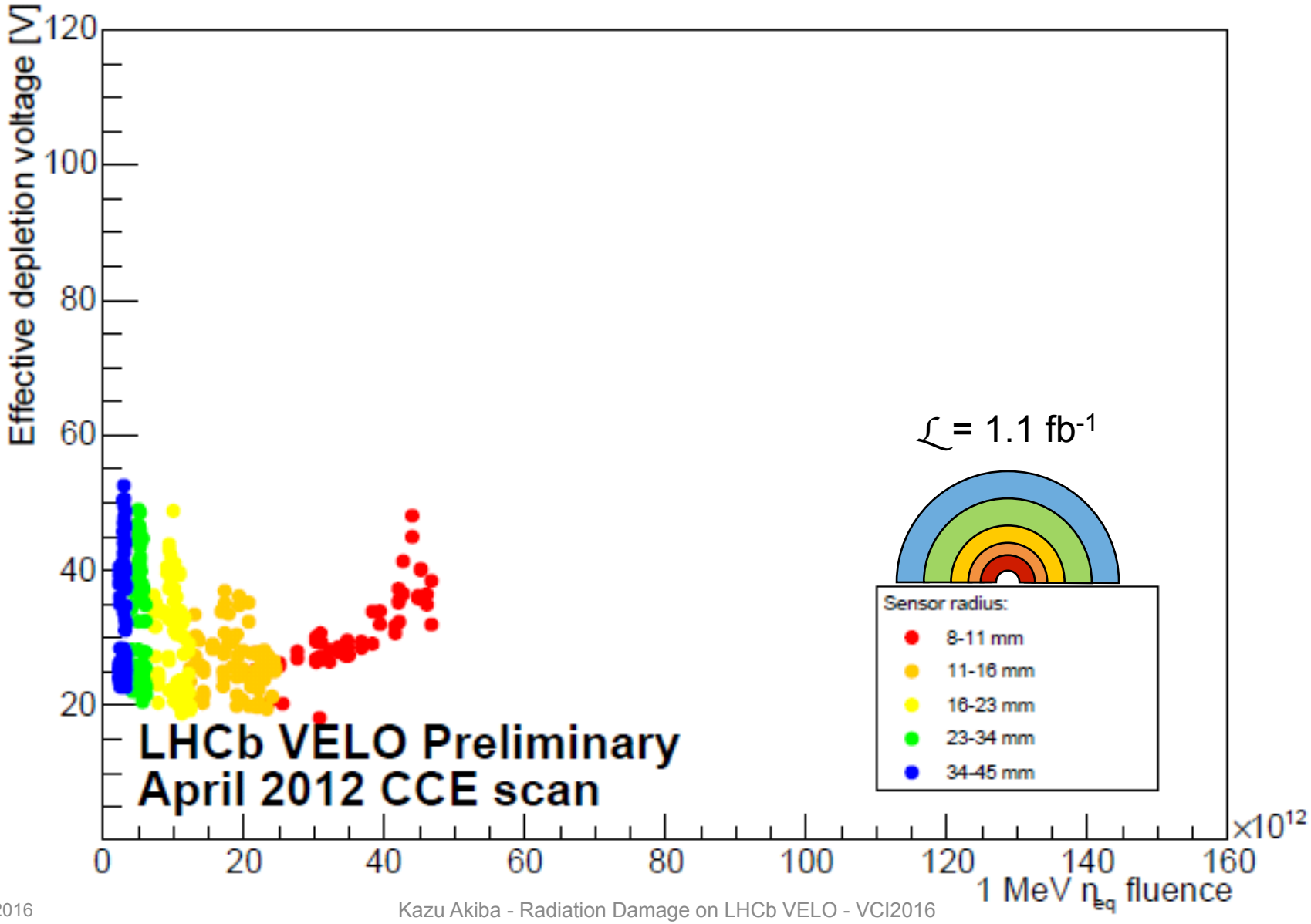

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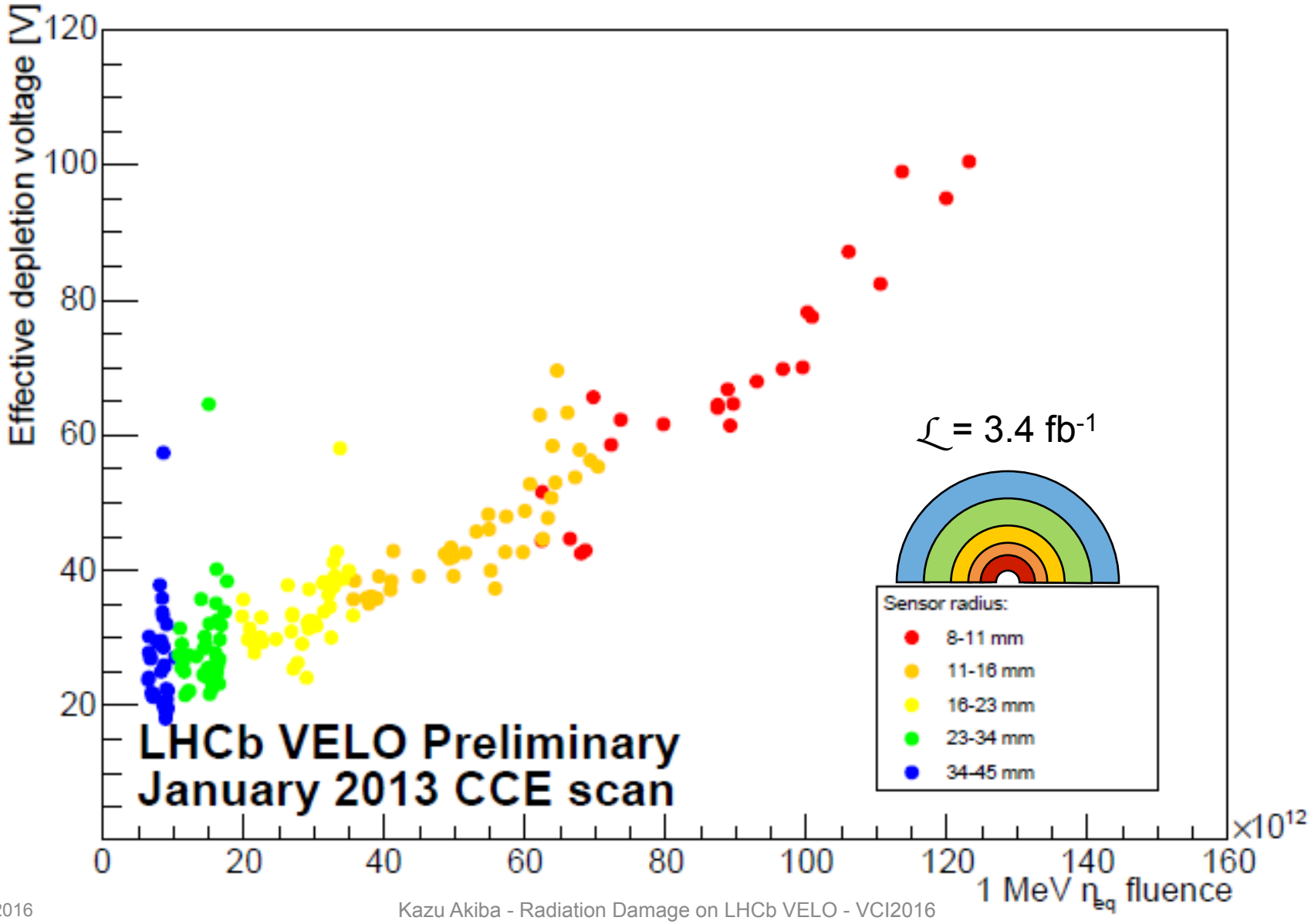

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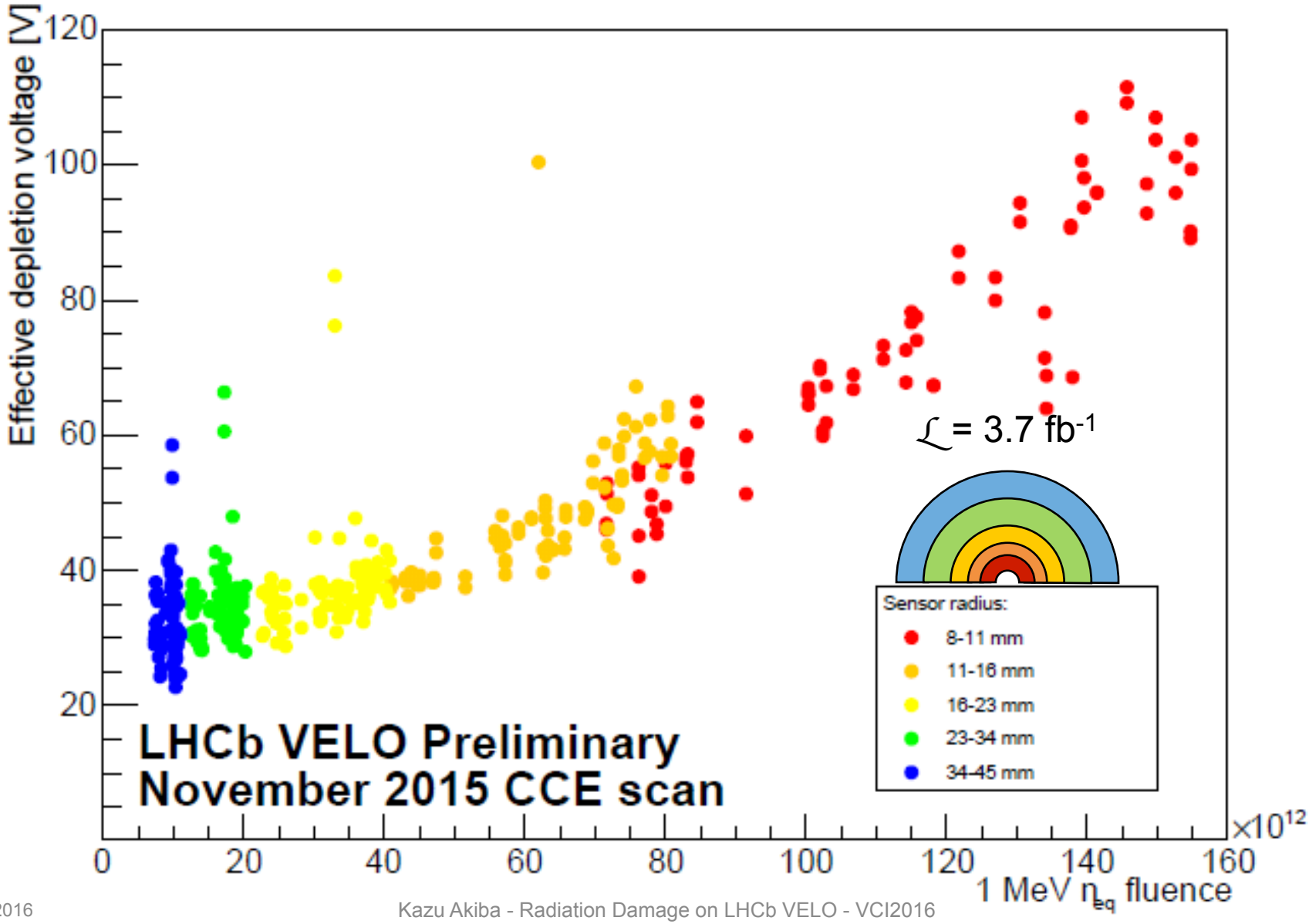

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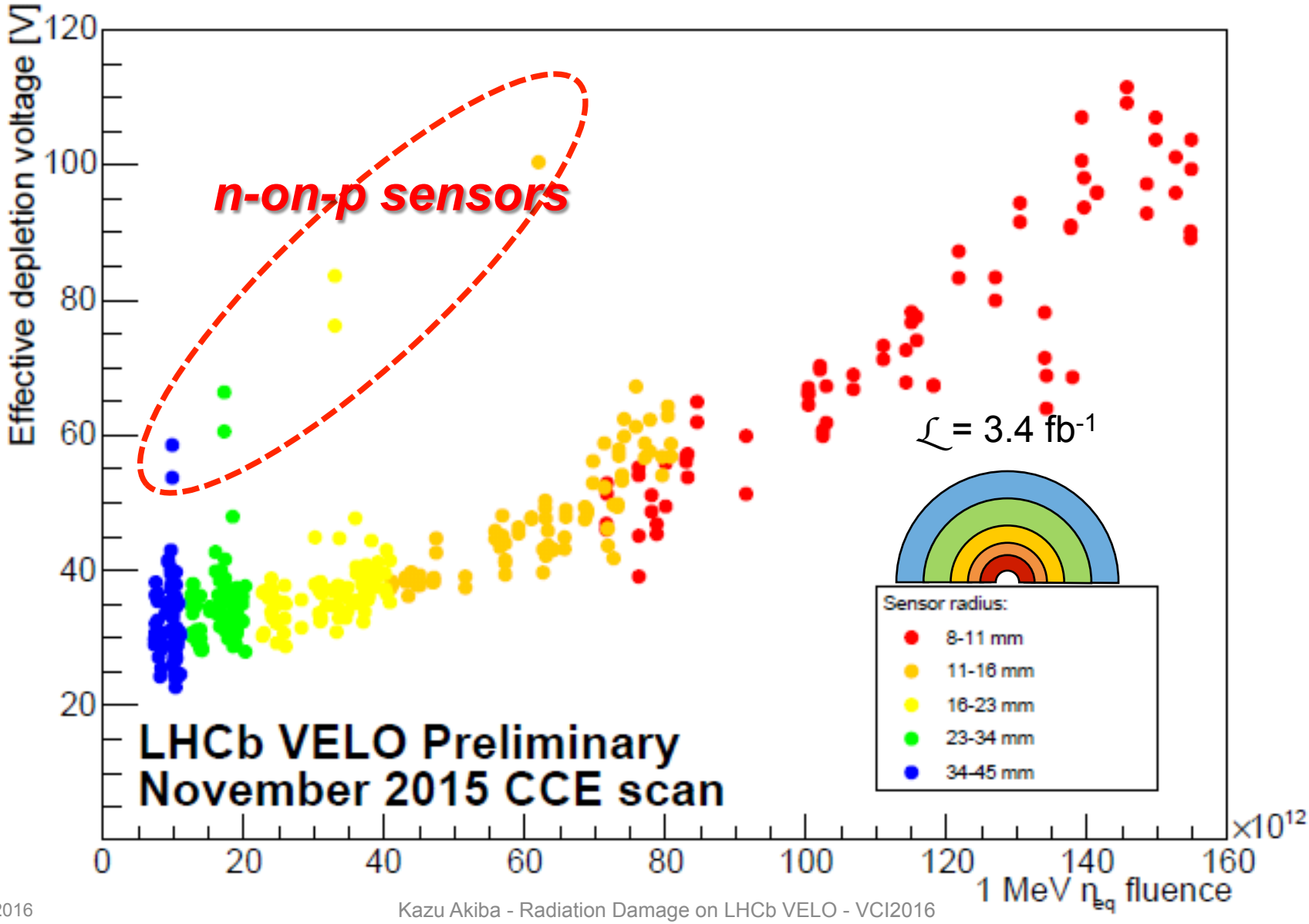

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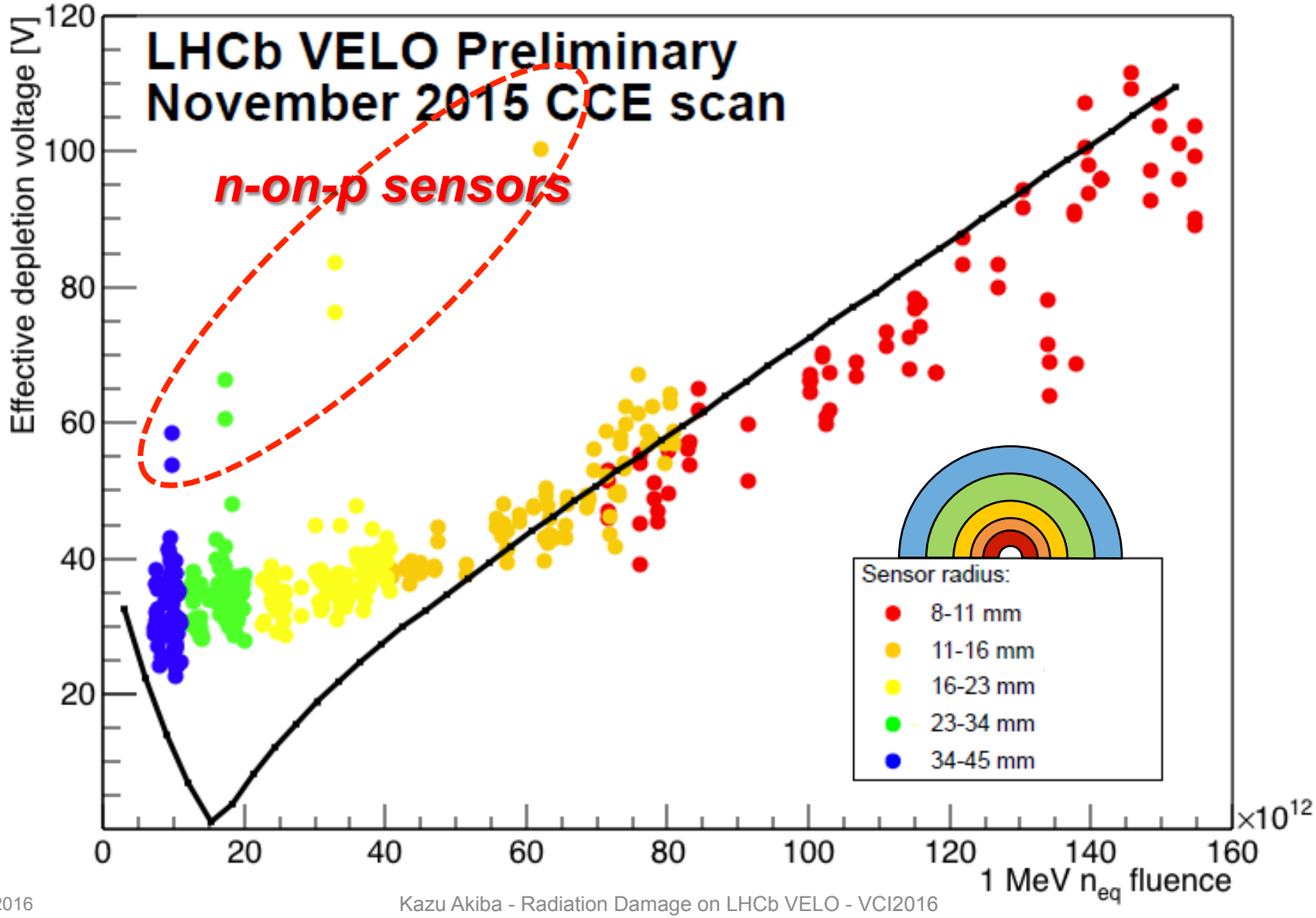
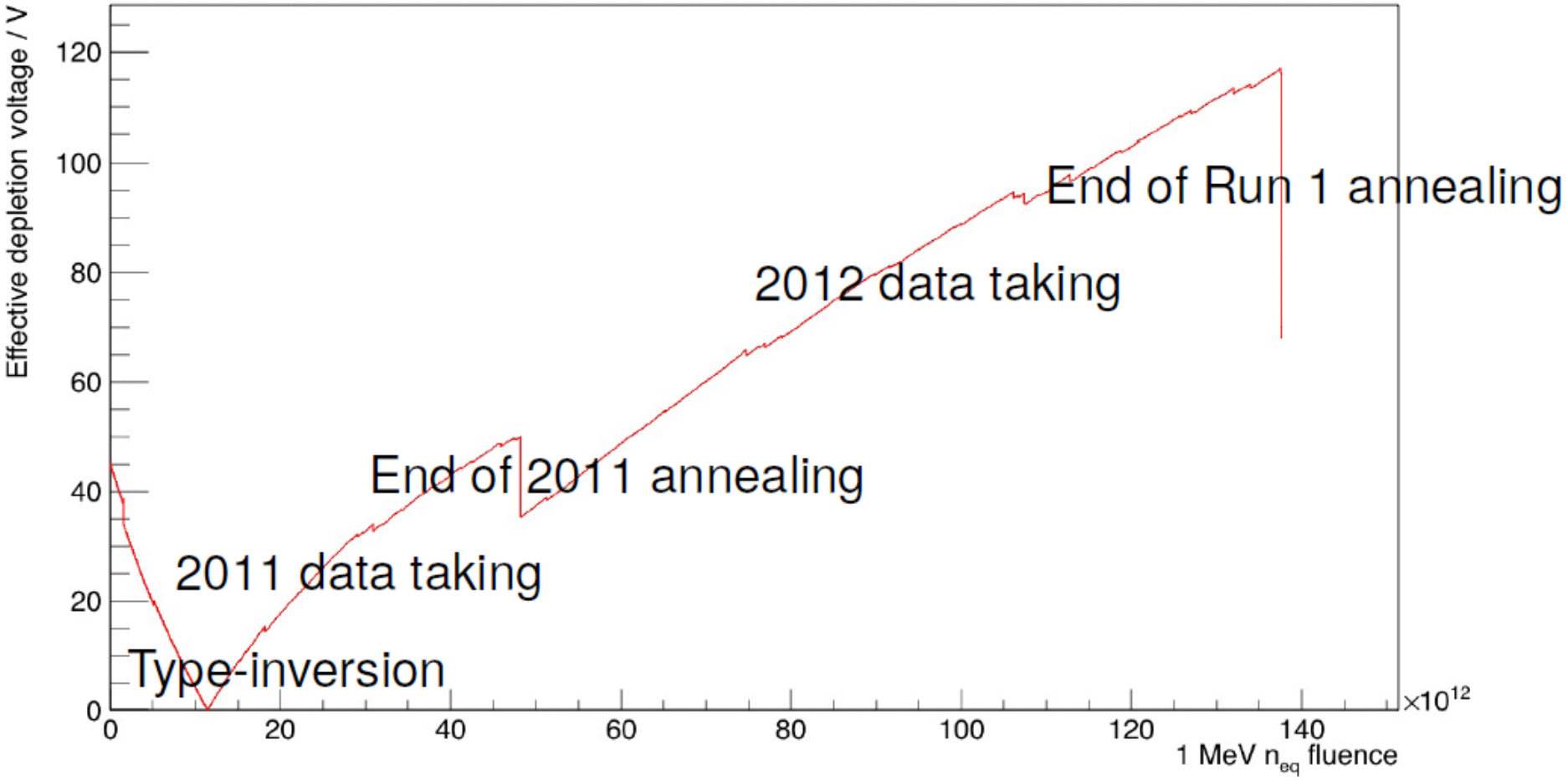
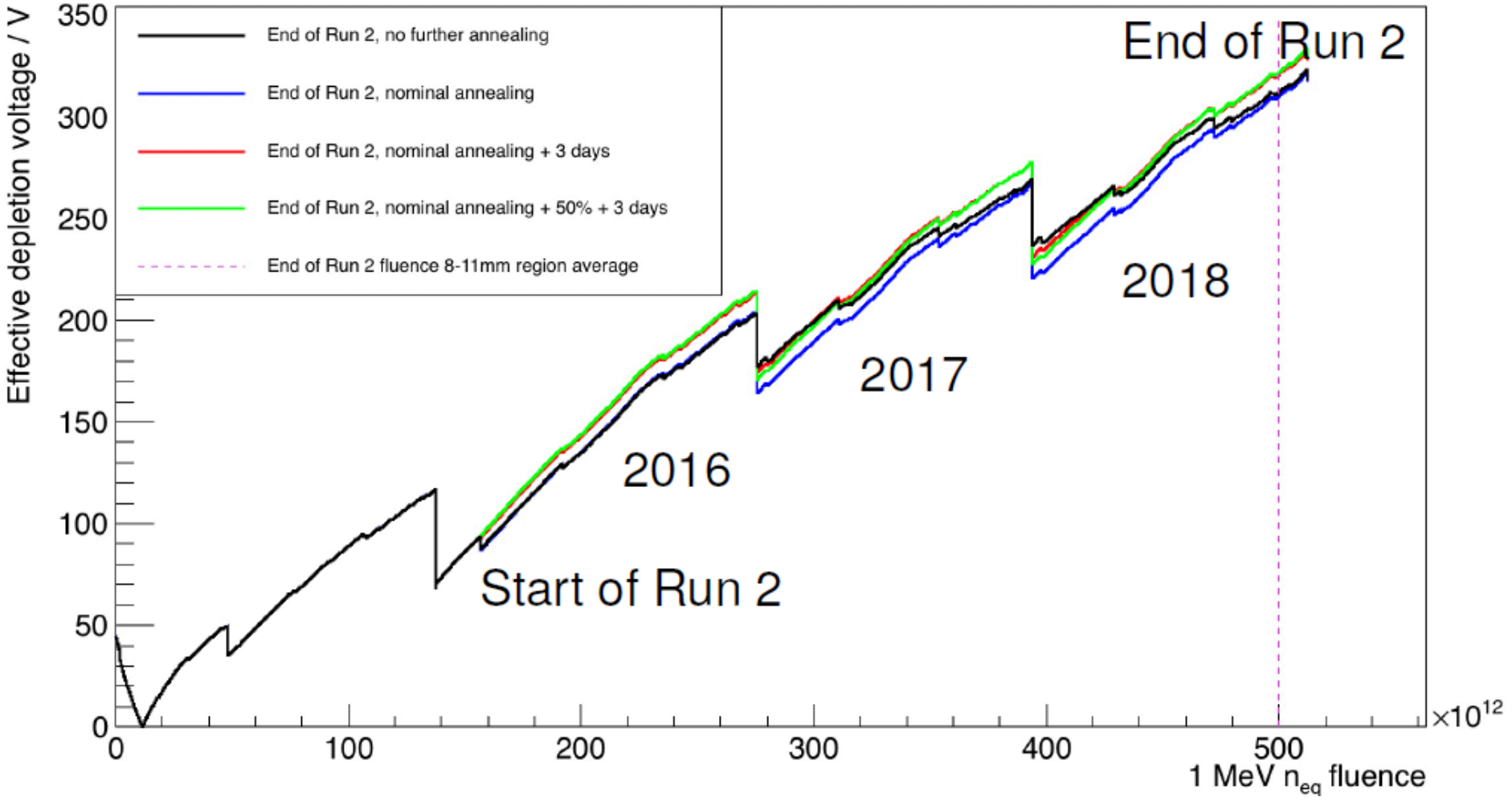


# Prediction based on the Hamburg Model

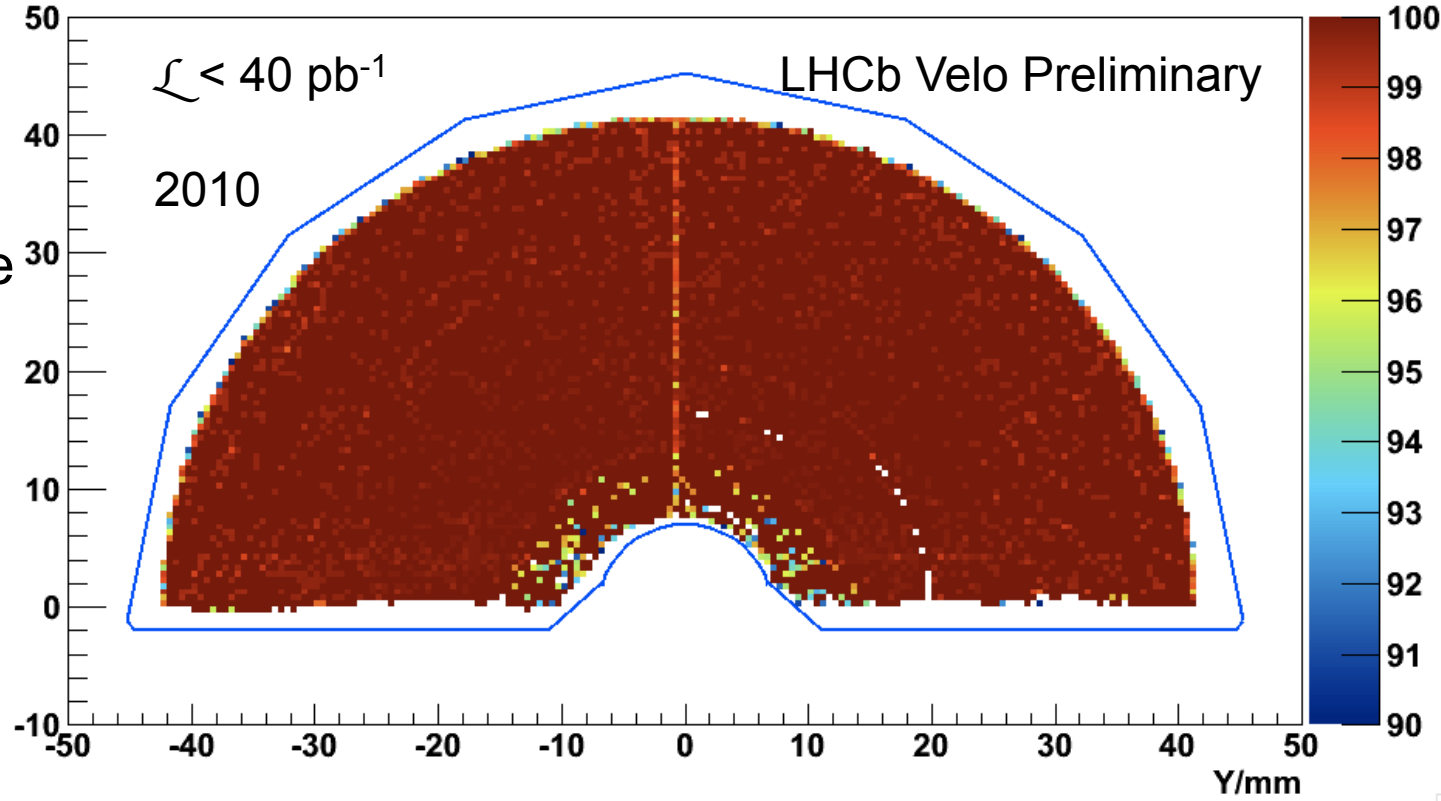


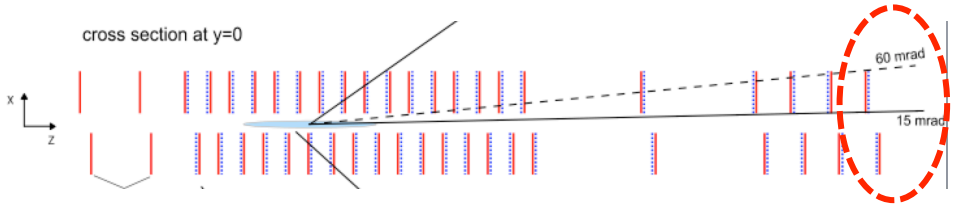
# Expectations for Run II



# Cluster Finding Efficiency

- Higher than expected loss in efficiency in the outer parts of the sensors,
- Specially R sensors in the most forward positions



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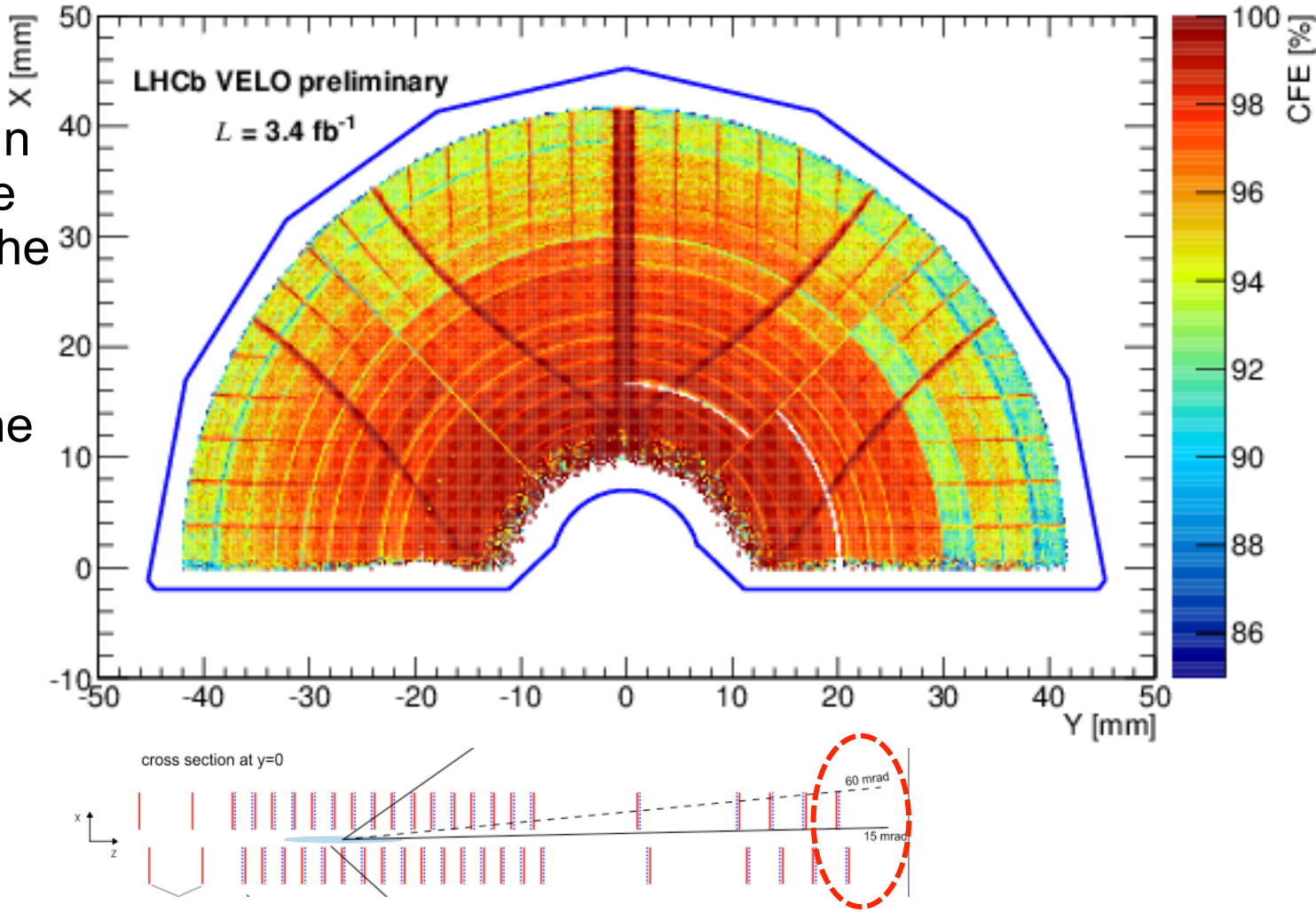
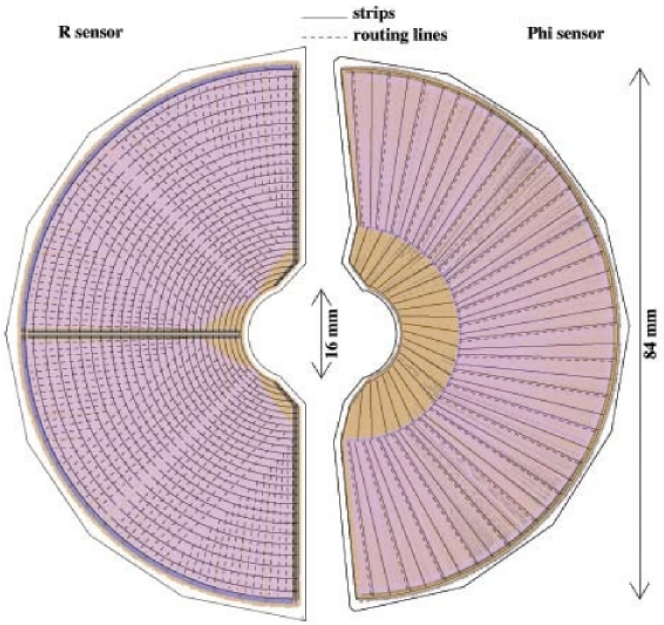
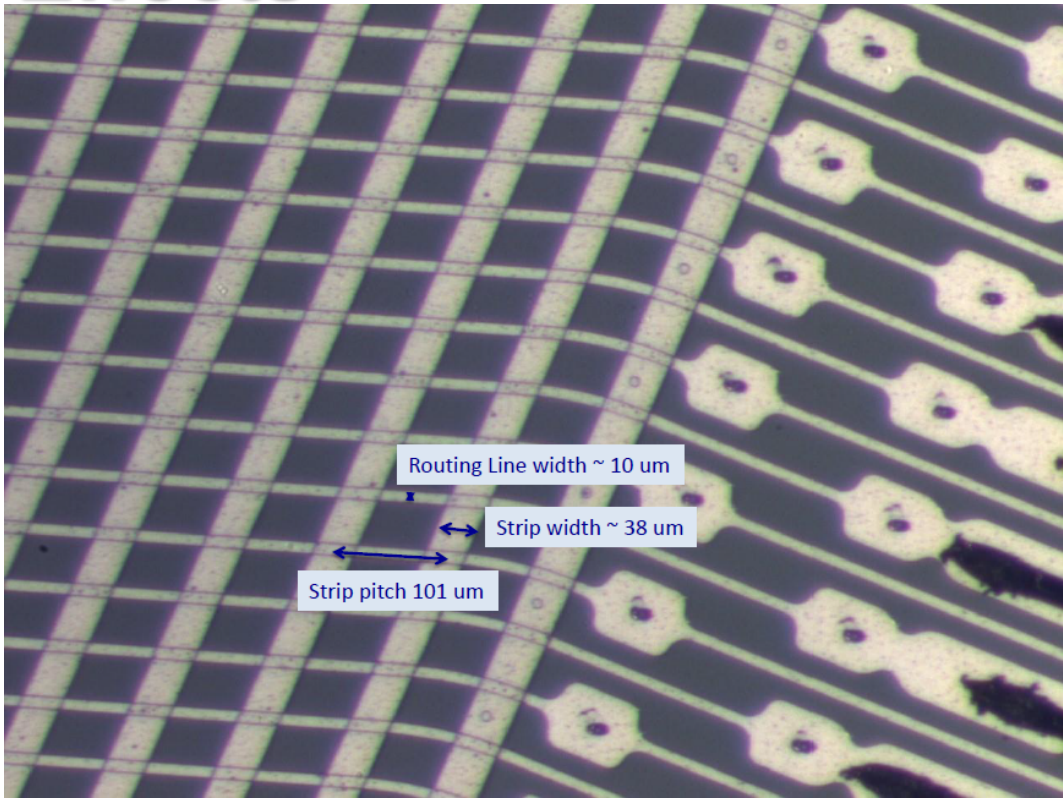
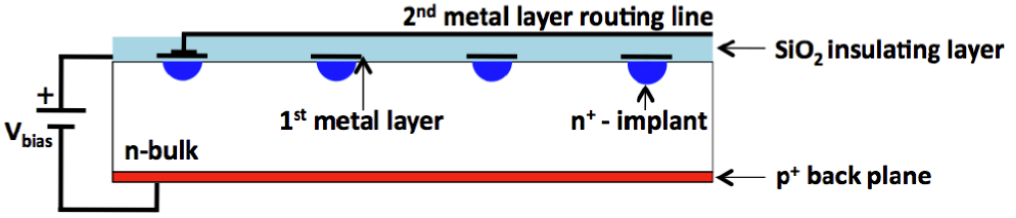


# Second Metal Layer Effects

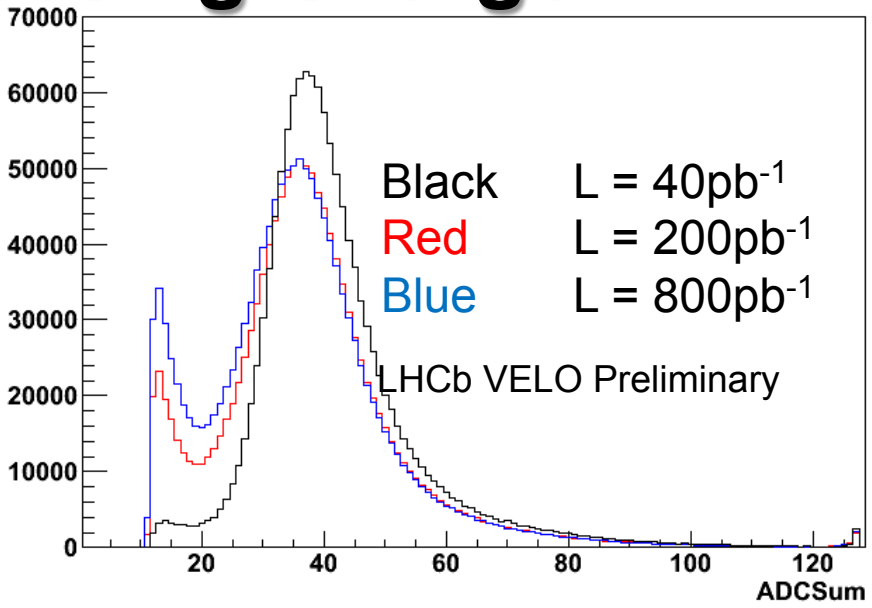


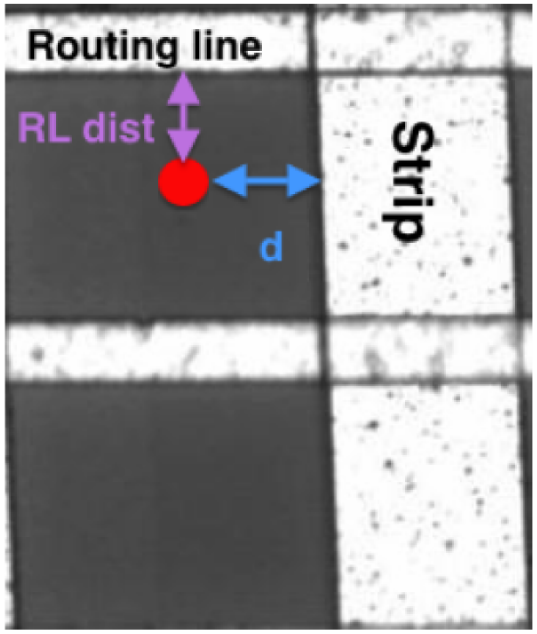




- Sensors are ***AC coupled***. One metal layer couples to the ***strip*** and the other routes the signal to the periphery of the sensor.
- ***Routing lines*** are ***perpendicular*** to the strips in ***R-sensors*** and ***parallel*** to the ***$\phi$-strips***.

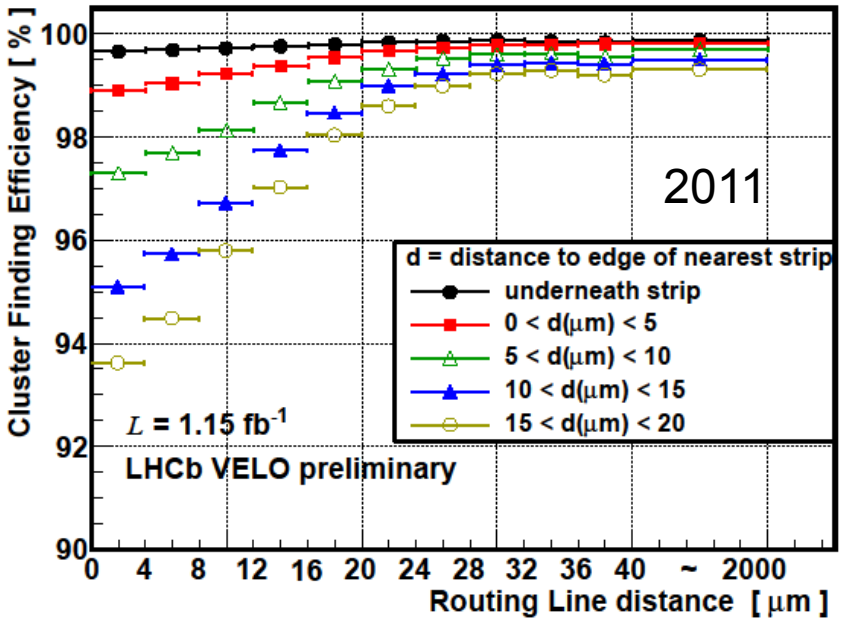


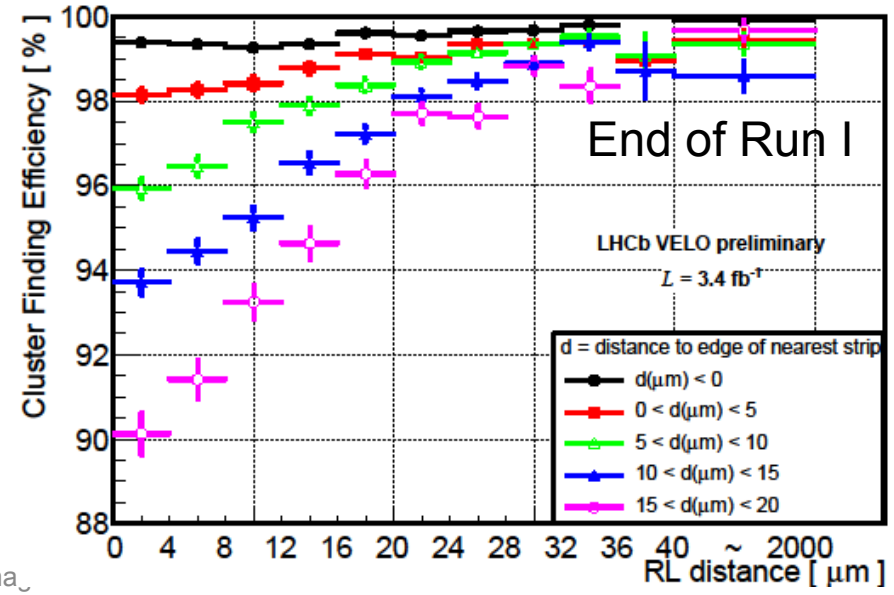
# Losing Charge



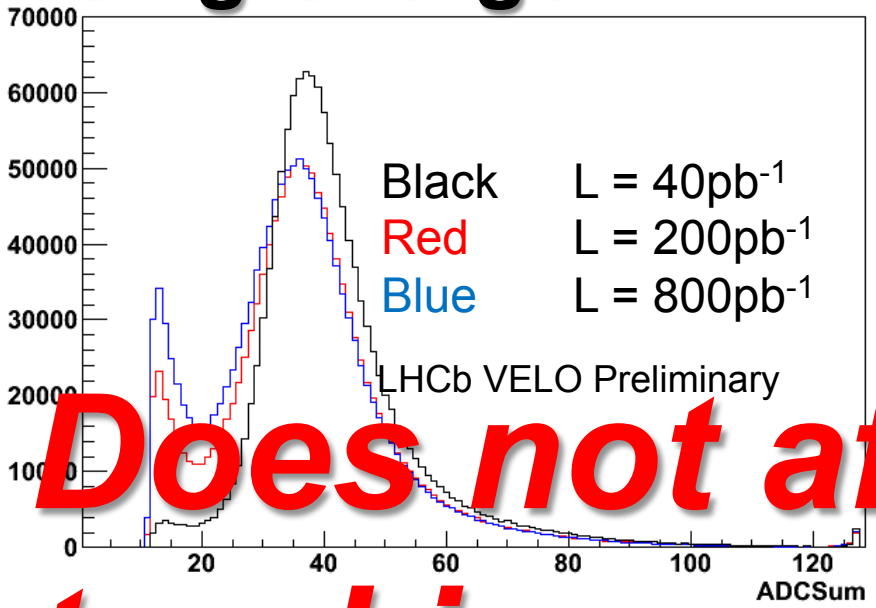



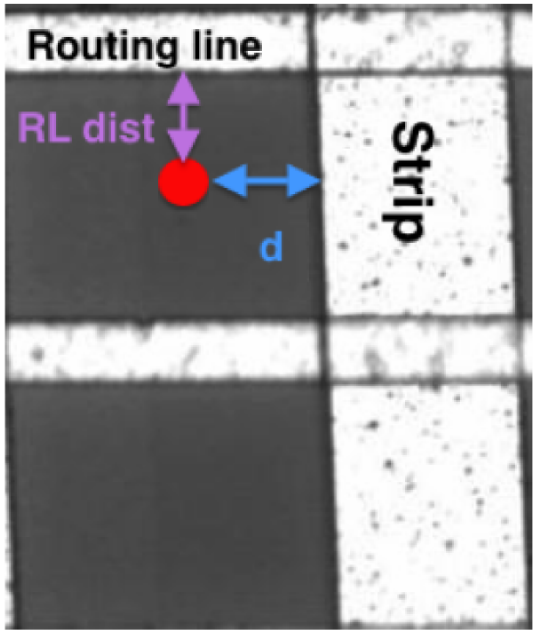

***Rate of degradation, seems to have slowed down.***



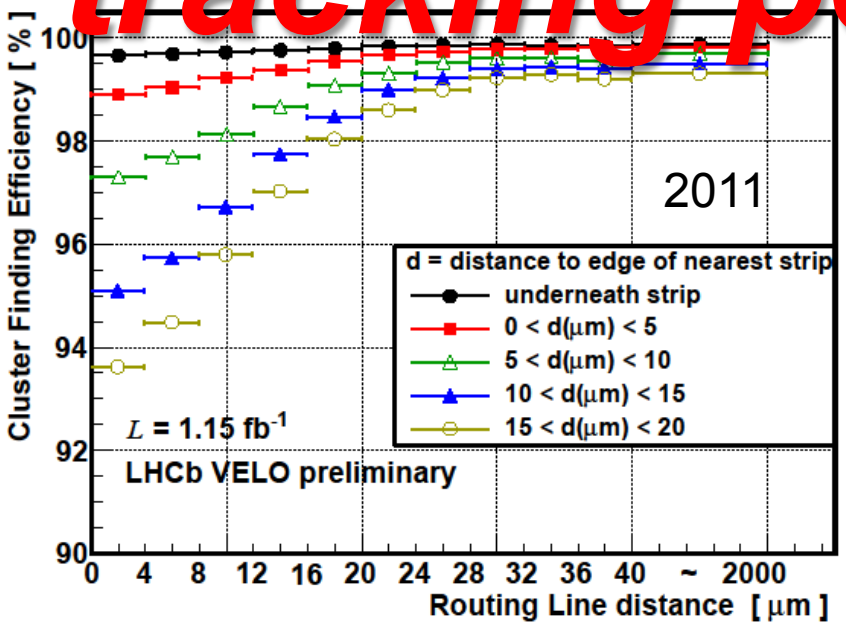
# Losing Charge

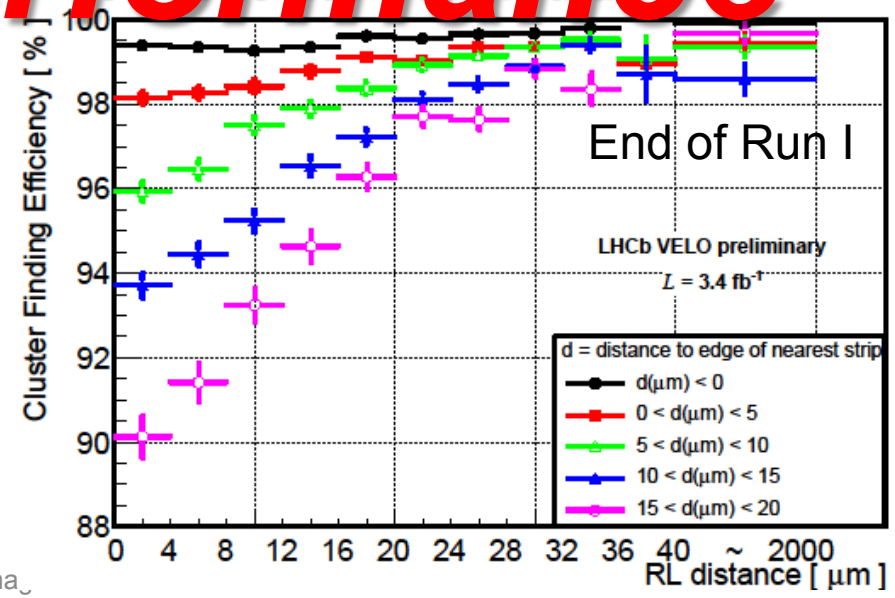



**Does not affect tracking performance**

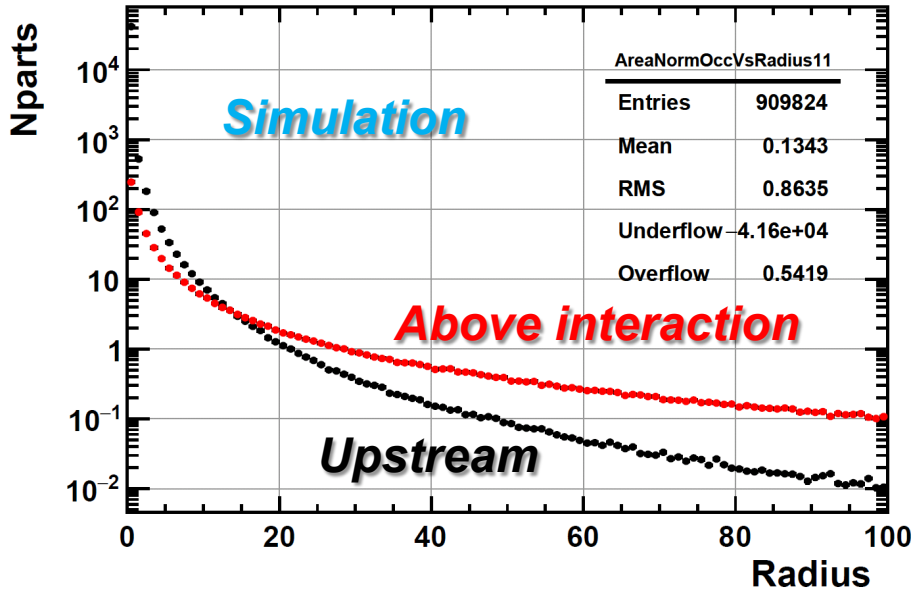
*Rate of degradation, seems to have slowed down*

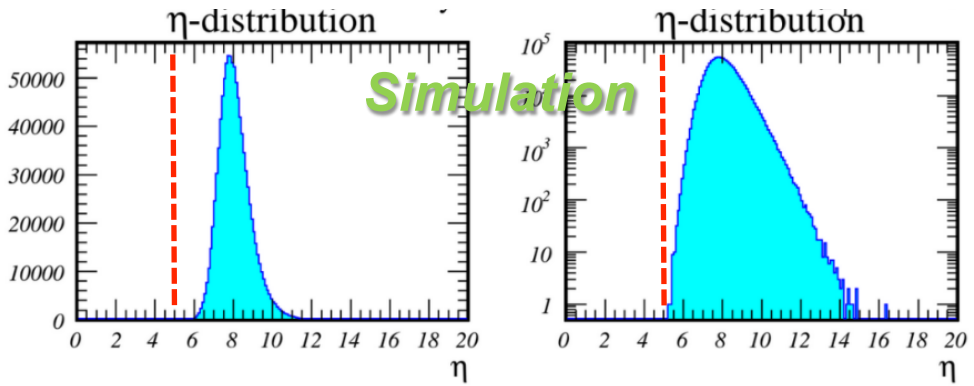


# Ion Run

- A Careful assessment was performed to take into account the ***safety*** of the detector.
- Relatively ***small total dose*** taking into account lower cross sections.
- The increased number of ***MIPs*** did not pose a significant danger to the front-ends (SEUs).
- Checked the number of ***heavy nuclear fragments*** in simulation ➔ neglible in acceptance.
- Concluded that operation would be ***safe*** even with ***detector closed***.

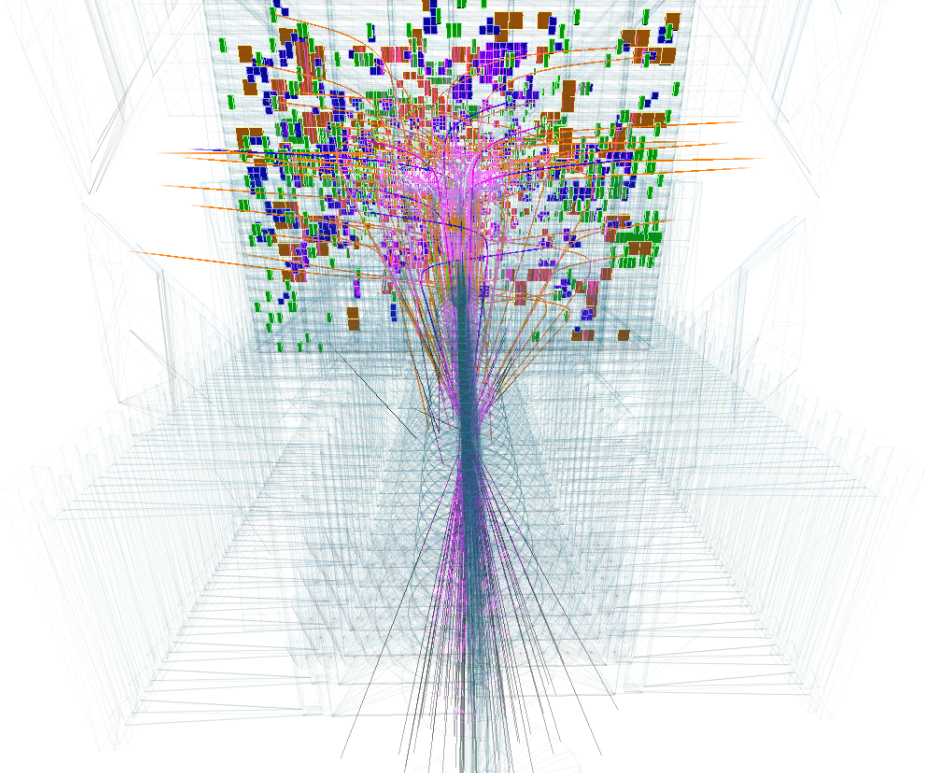



Heavy fragments

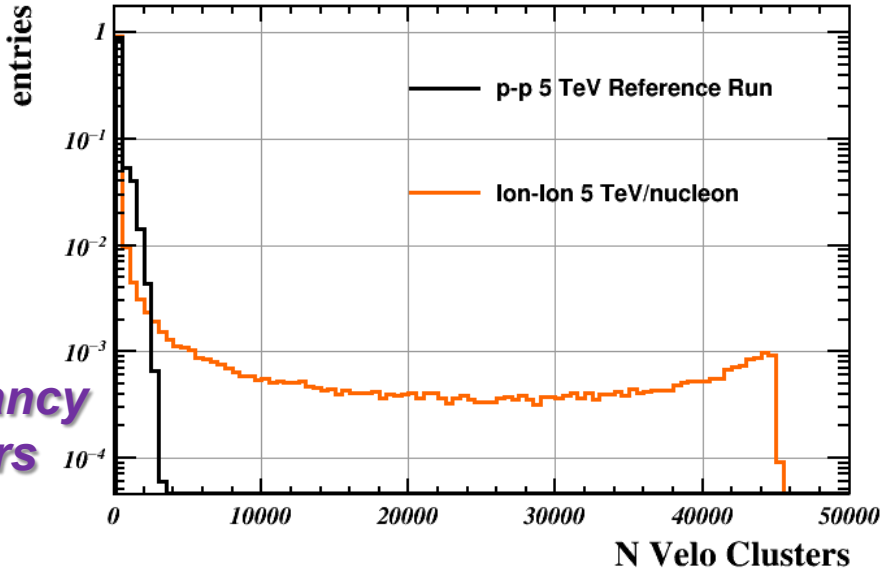
# Ion-Ion Collistions

- First fills had very careful ***power on procedure***.
- The ***closing*** counts on ***vertices*** to center the detector ➔ procedure was much ***slower*** than usual due to ***lower rate***.
- The multiplicity ***"seems"*** to have reached the ***physical limit*** of the DAQ boards.
- The reconstruction is very difficult for ***too high multiplicities***.

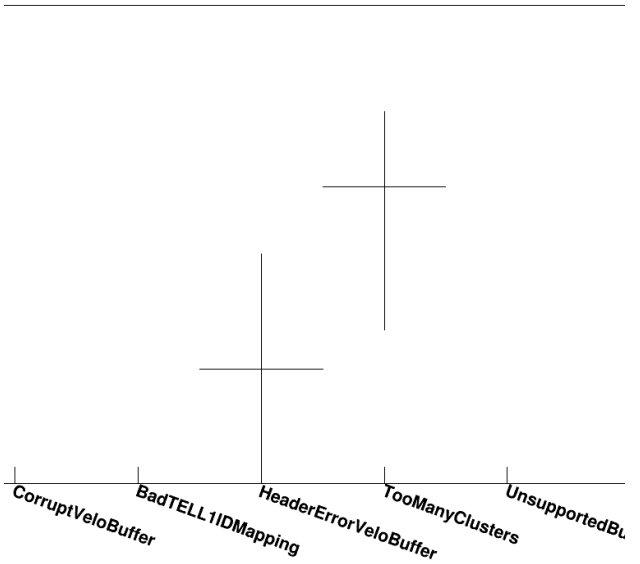


Number of ProcStatuses of each type found so far

$\mathcal{L} \sim 6\ \mu b^{-1}$
$\cong$ 2 $nb^{-1}$ of p-p




***>25% Occupancy @ 45 kClusters***



# Conclusions

- Vertex locator is a radiation hard detector taking data ***successfully*** across LHC Run I and Run II.
- Detector optimized for ***25 ns*** bunch spacing.
- The detectors are ***kept cold*** as much as possible to avoid annealing.
- ***Non uniform radiation*** exposes the sensors to very high damages ➔ constant monitoring of the currents to avoid thermal runaway.
- ***Operational voltages*** are expected to be within the designed range up to ***8 fb$^{-1}$*** with full depletion, now at ***3.7 fb$^{-1}$***
- First attempt to take data with ***Ion-Ion*** collisions in 2015. ***Successful*** operation of the detector.
- Expect more radiation damage in the upgrade… see K.Hennessy's talk: http://indico.cern.ch/event/391665/session/5/contribution/382

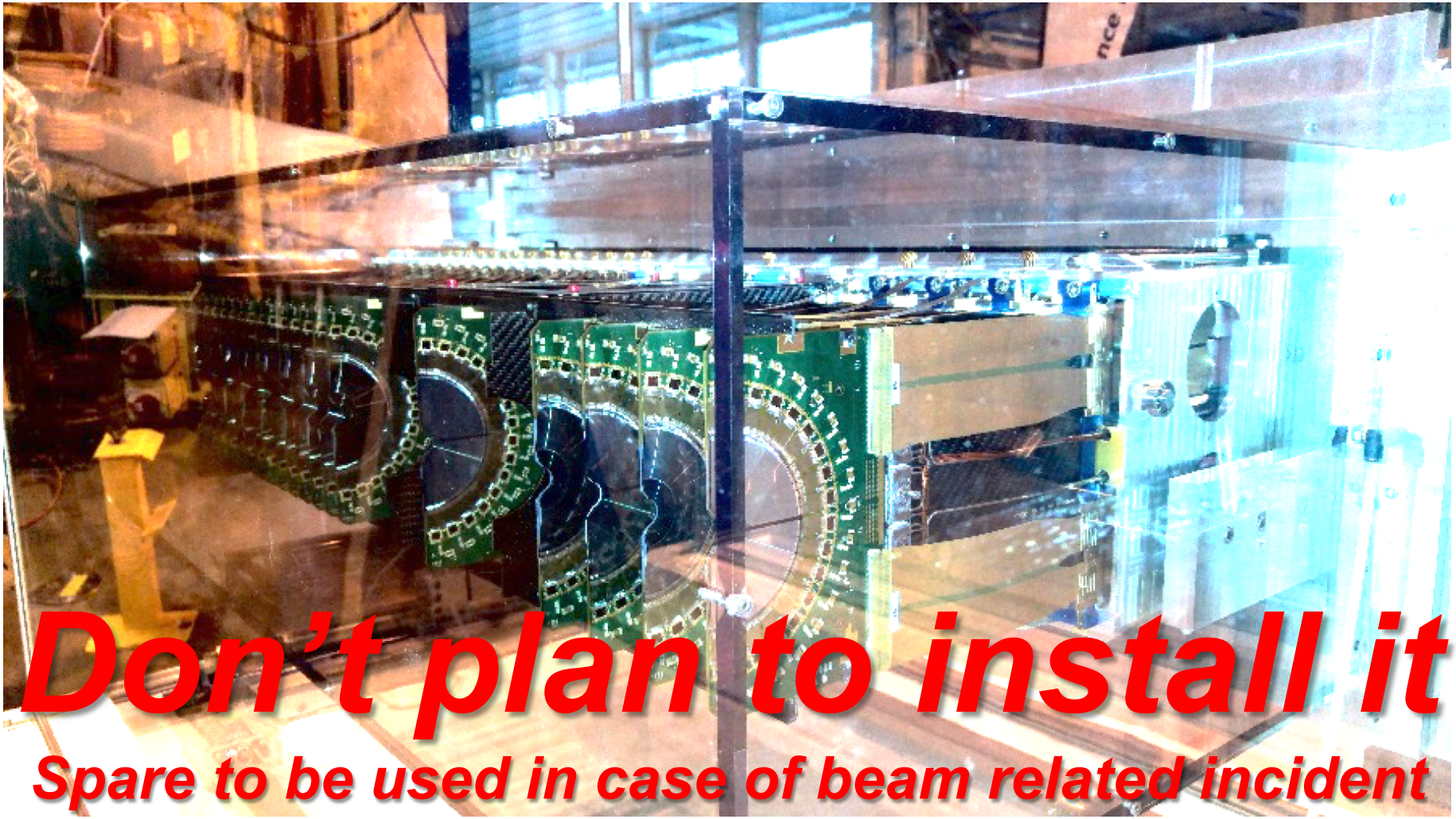
# Back up slides

# Monitoring

- Dedicated interface to provide ***Data Quality*** assessment per run
- ***Automated*** scripts run over freshly taken data.
- Results are saved and ***trended*** over time.
- Can be accessed from the ***web***.
  - That should have all the functionality of the executable interface
  - Same meta-analysis and code framework
- Computation of ***"scores"*** for the difference between the run and a reference.
  - Generation of ***warnings and alarms*** depending on the score.

# We have 2 of them!

- Fully Functional and Tested spare sensors and frontend electronics



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