Performance of the LHCb Vertex Locator

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on behalf of the LHCb Collaboration

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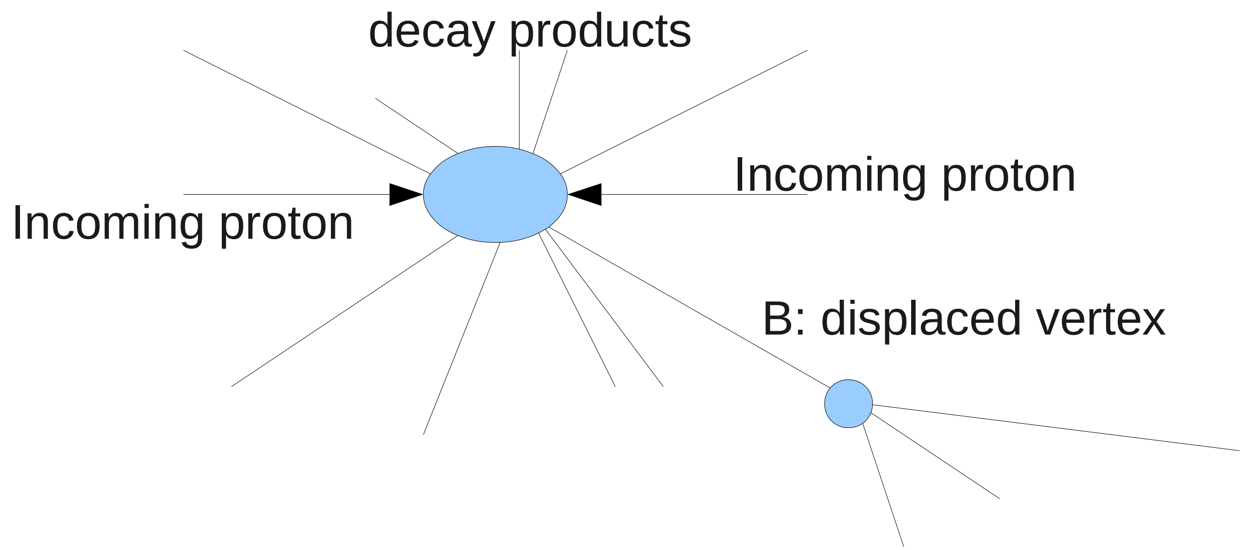
Physics with LHCb and VELO

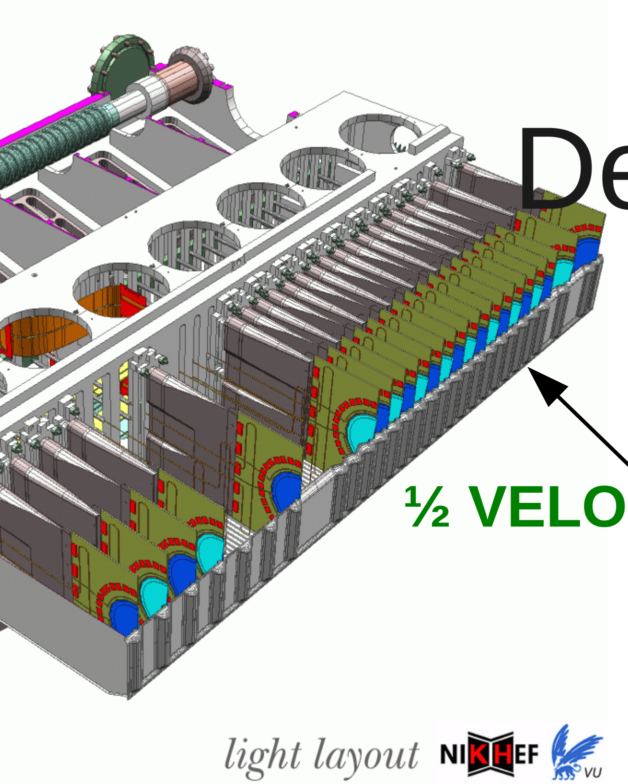
LHCb at CERN is analysing processes involving b-quarks and c-quarks to test the Stanard Model and to look for signs for new physics

B hadrons have a significant lifetime, and appear as displaced vertices

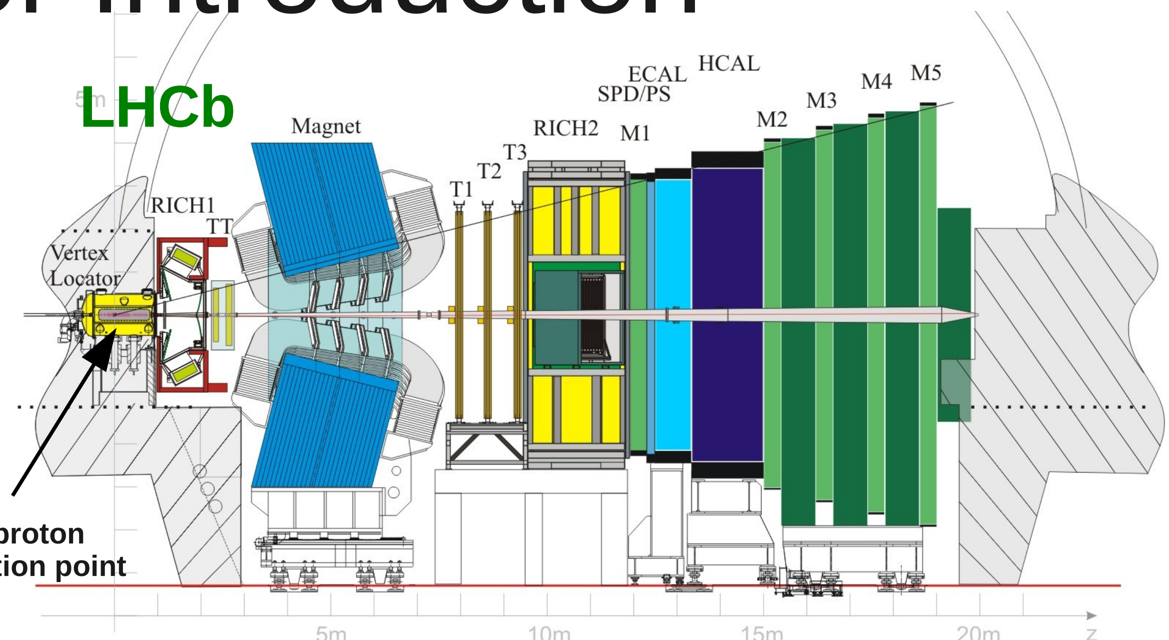
The VELO
- Reconstructs tracks and vertices
- Measures their position



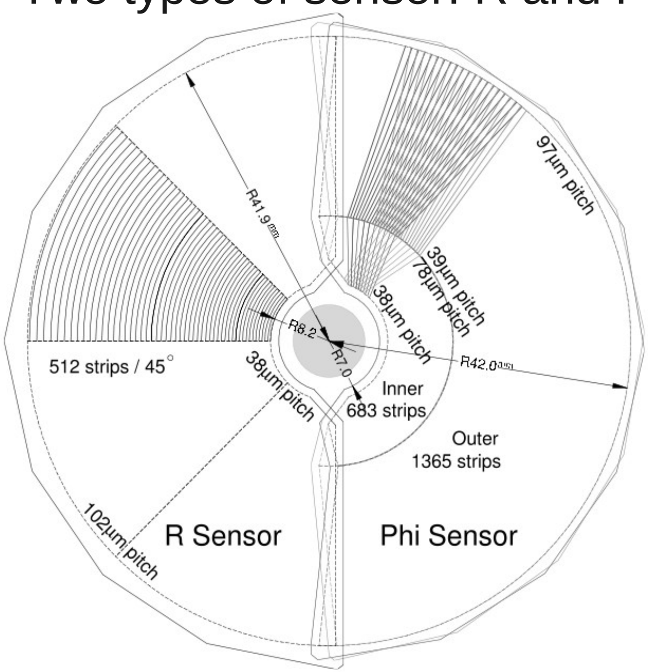
Detector Introduction



Proton-proton interaction point



Two types of sensor: R and Phi



LHC: Collisions since end of 2009, has delivered > 700 pb^{-1} of integrated luminosity to LHCb

LHCb: LHCb is a forward spectrometer
Detectors for good particle-ID, tracking, calorimetry, muons

VELO (Vertex Locator):

- 1 m long
- 42 modules spaced along the beam axis, 21 on each side
- Two retractable halves
- Sensitive area is only 8.2 mm from the beam
- Measurement of *r* and *φ* at each module
- Silicon strip sensors:
  - oxygenated n^+-on-n
  - one module with n^+-on-p

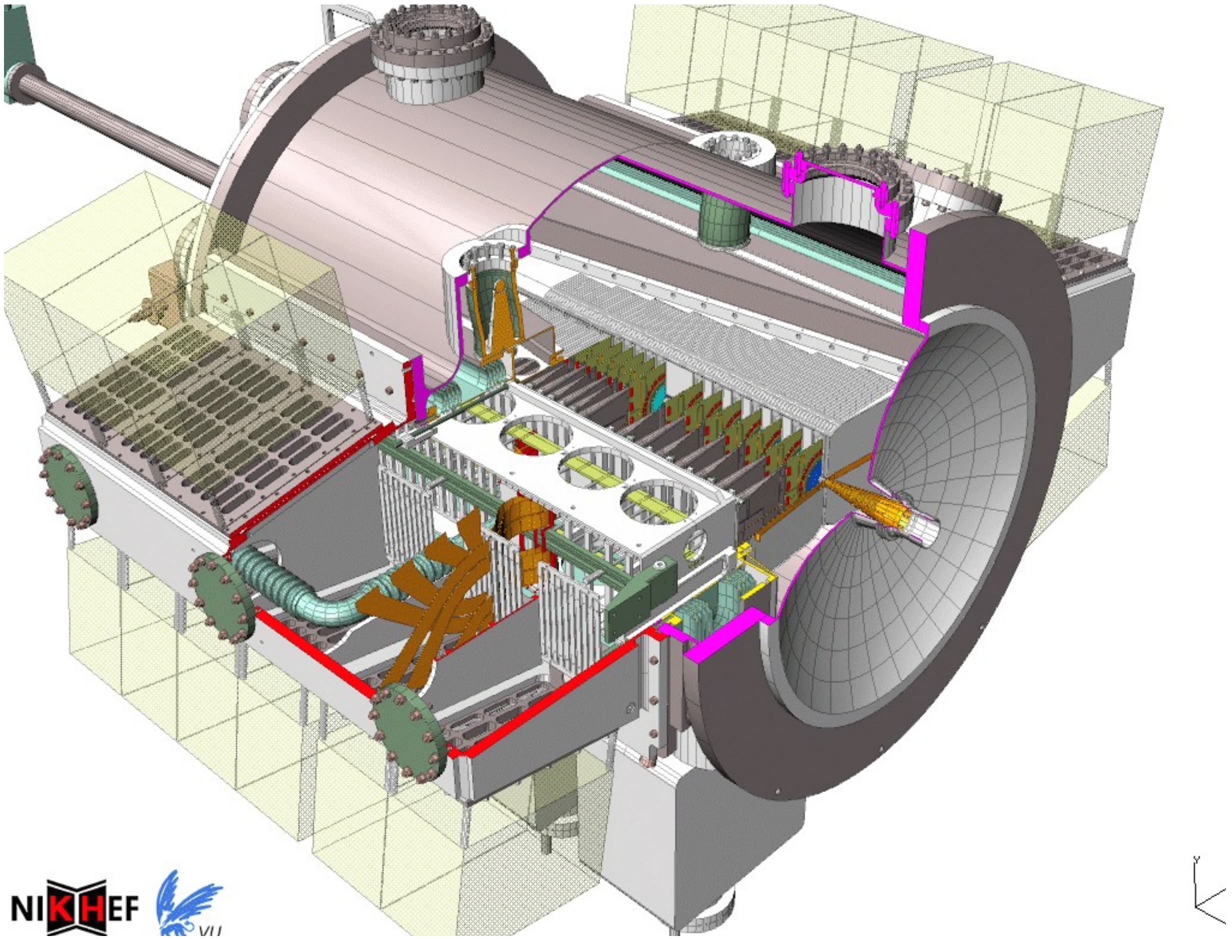
Subsystems

Vacuum: Sensors are separated from the LHC vacuum by a 0.3 mm thick aluminium foil. The foil also protects against RF noise from the beam.

Cooling: The VELO is cooled to -30 ºC by an evaporative CO_2 system. Temperature on hybrids stable to within 0.1 ºC

Motion: Protection from unstable/unfocussed beams. During stable beams, VELO measures beam position and centers around it.

These and other subsystems are monitored continuously, and alarms are used to detect anything out of the ordinary

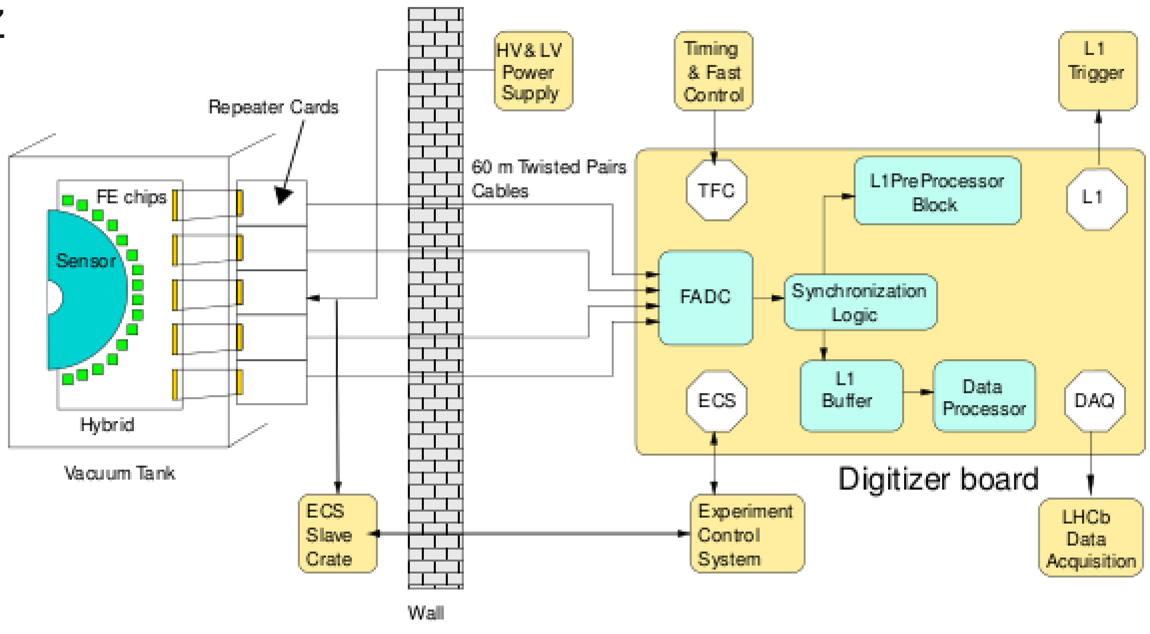


Data acquisition

Analogue signals are read out every 25 ns by the Beetle chip

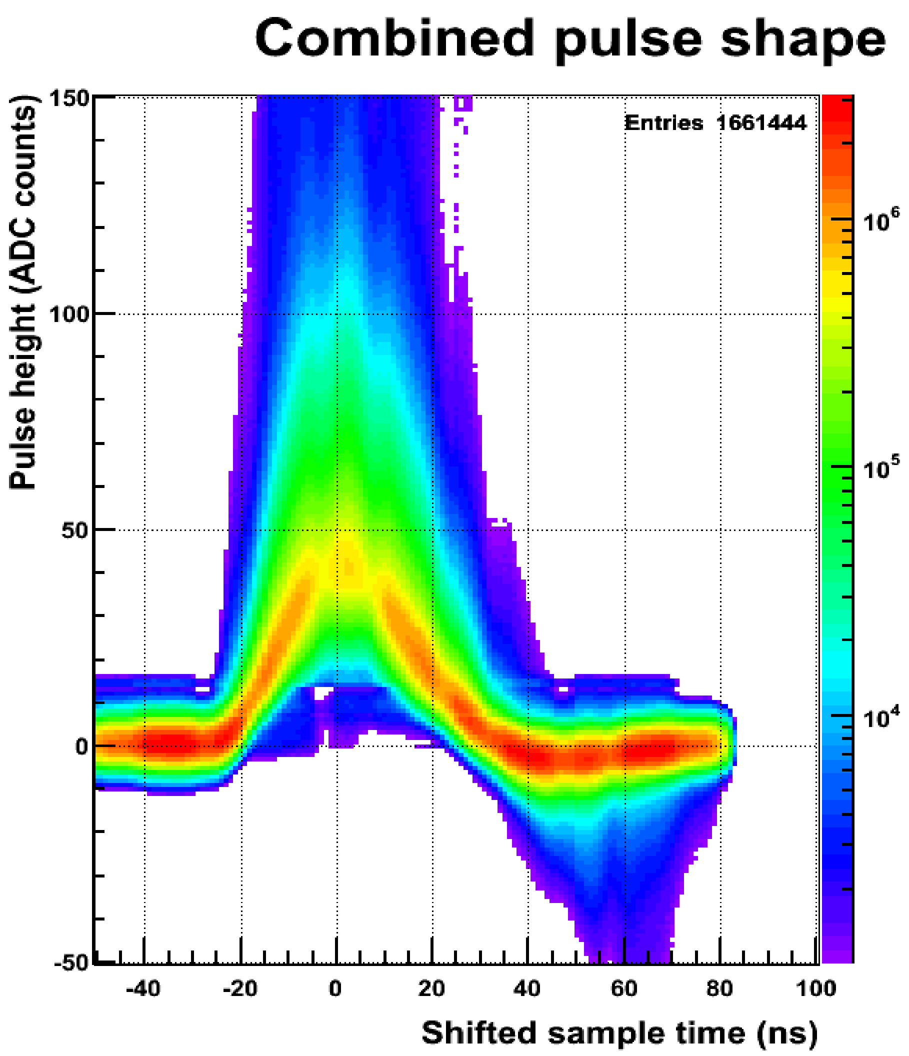
Events passing the first trigger level:
Sent to area shielded from radiation. Signals are digitised and processed using “TELL1” boards
• Pedestal subtraction
• Mean common-mode suppression
• Clusterisation (Zero-Suppression)

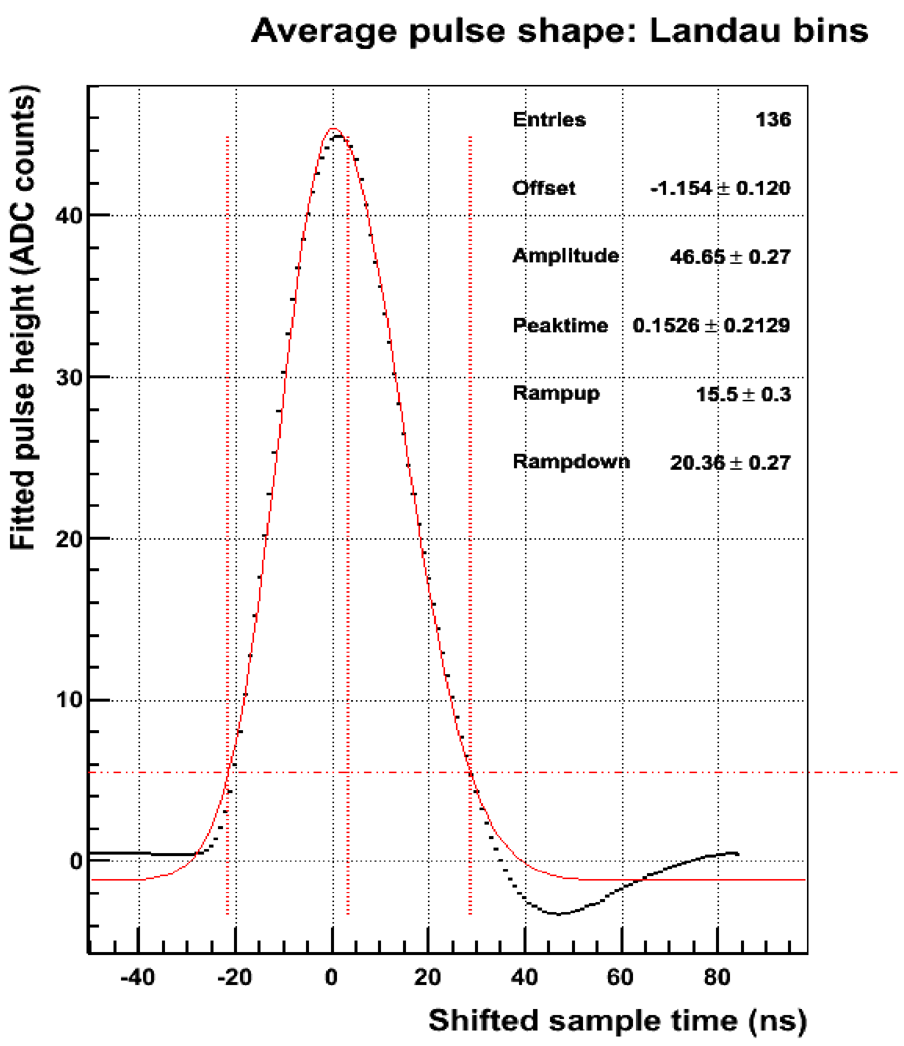
•The TELL1 also sends all digitised data for a sensor without processing at a rate of 1 Hz



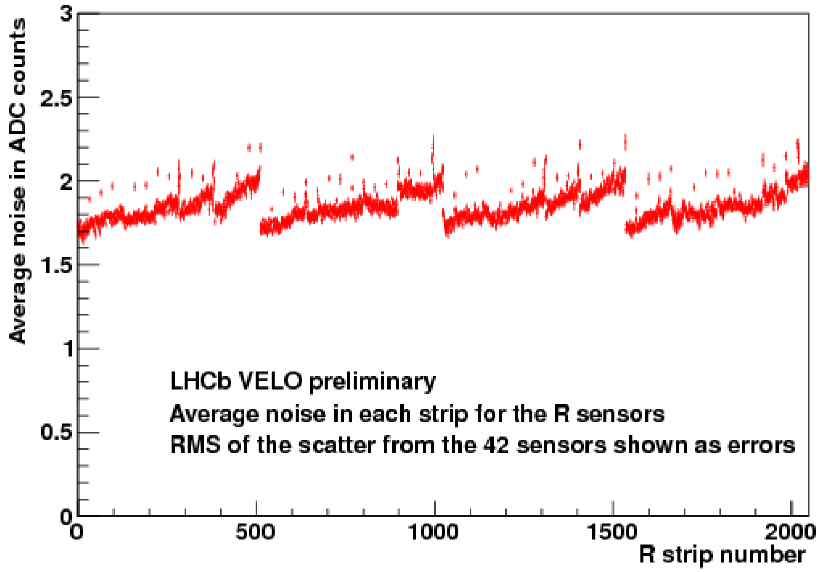
Timing

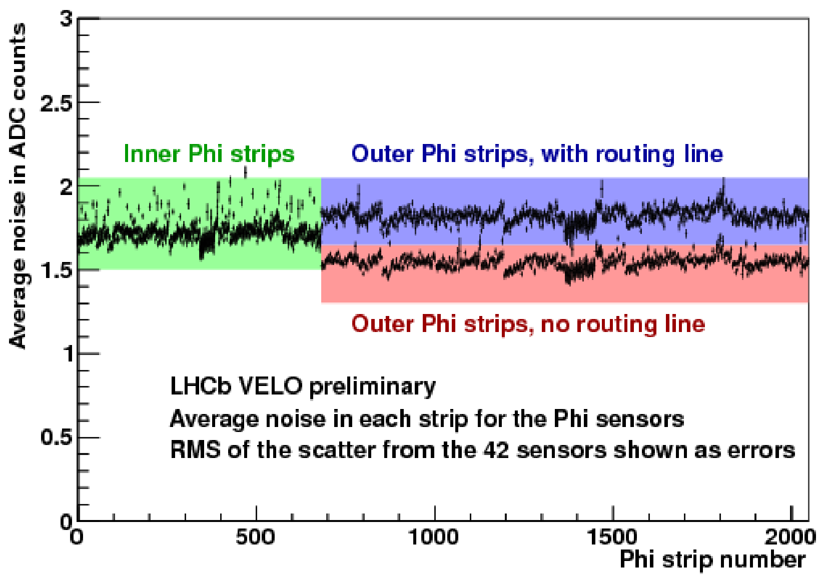
per-link calibration, accurate to < 2 ns





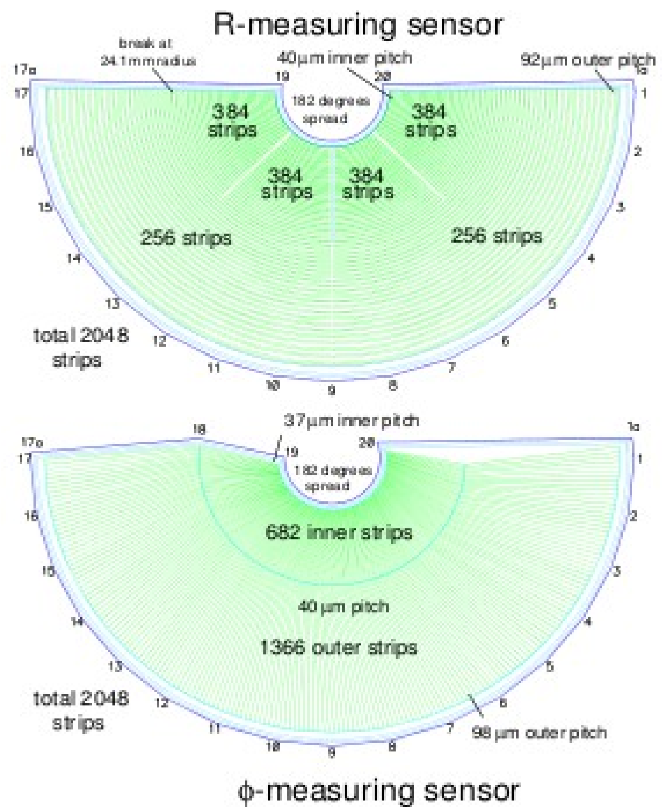
Noise





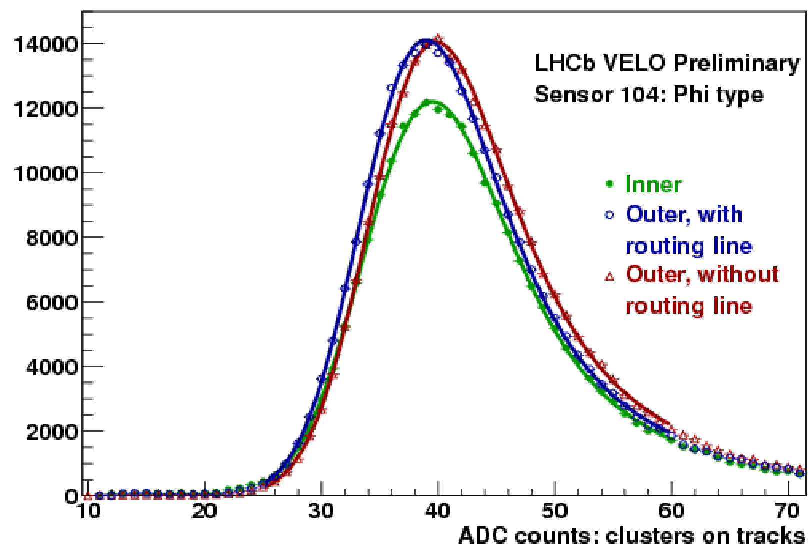
Noise level: Depends on strip geometry.
1 ADC count ~ 500 electrons

Channel numbers:
R: four sectors, from innermost strip and out in each sector
Phi: Inner strips, then outer strips

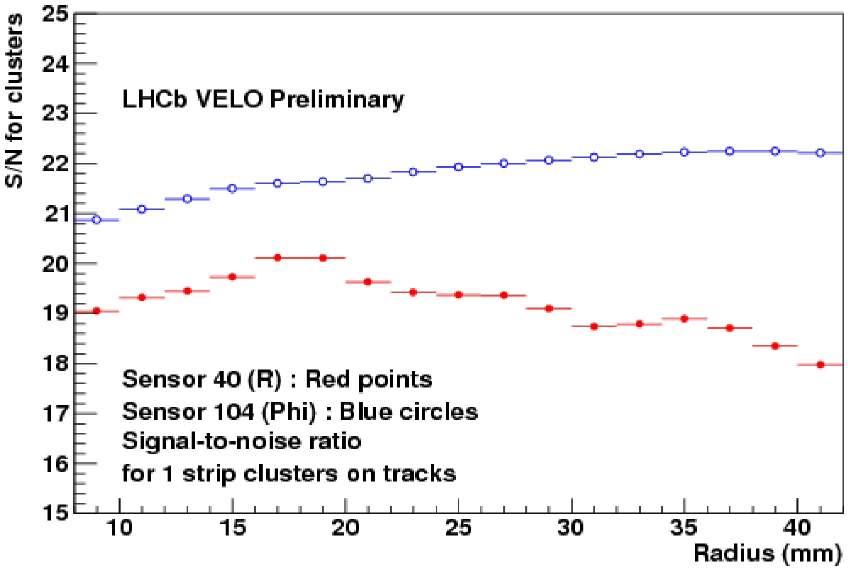


Signal

Signal distribution for a (Phi-)sensor:
Landau distribution convolved with a gaussian



Signal/Noise:



Radiation Damage

Expected radiation for one year of running (at r=0.8 cm): (0.5 to 1.4) × 10^{14} n_{eq}/cm^2

Sensors are specified to last for at least 5 years

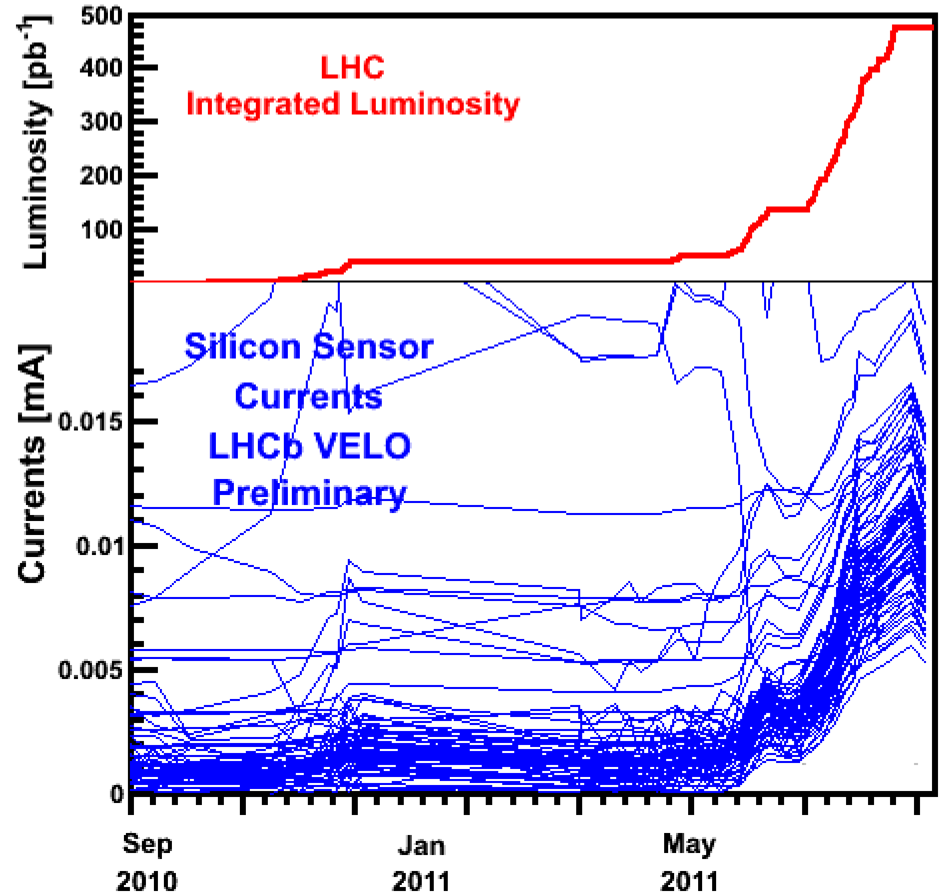
- Radiation produces acceptor-like defects
- Radiation removes donors

Conductivity type of the bulk silicon is inverted (n→p) with sufficiently great fluence

Depletion voltage is proportional to the effective doping concentration

The leakage current is directly proportional to the fluence!

Current trends (at 150 V):



Radiation Damage

Charge Collection Efficiency

Effective Depletion Voltage (EDV):
Sensor at 80 % of max. charge collection

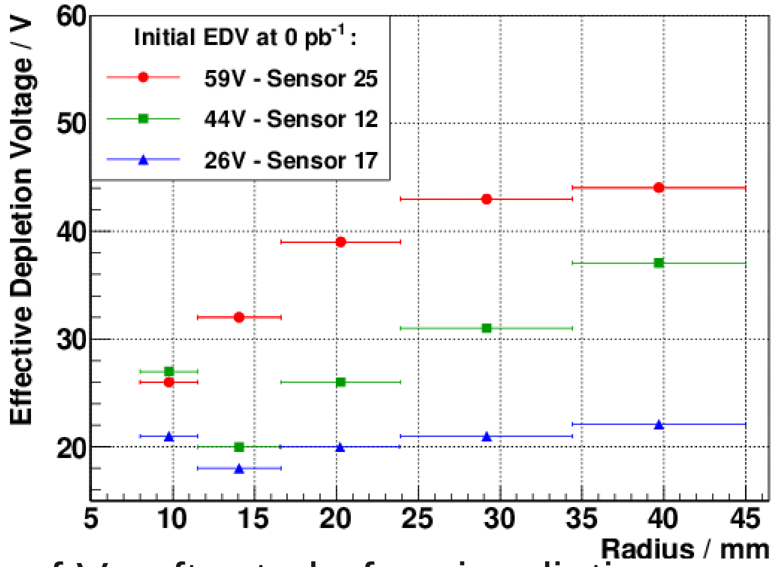
- Select a "test sensor" and vary the voltage
- Charge collection measured where tracks intercept the test sensor plane

Noise vs. voltage

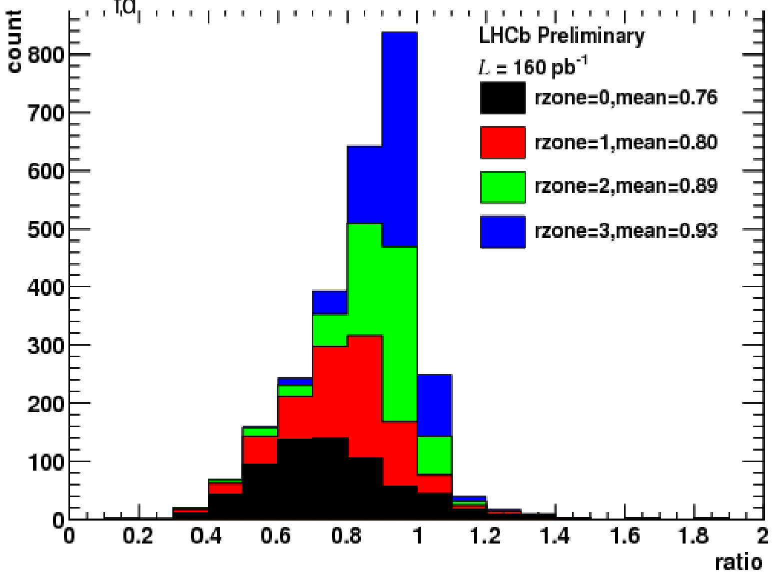
- Strip capacitance decreases until the strip is fully depleted
- Strip noise depends on capacitance

The (effective) depletion voltage can be found by measuring the noise as a function of voltage

EDV after 426 pb^{-1} as a function of r



Ratio of V_{fd} after to before irradiation

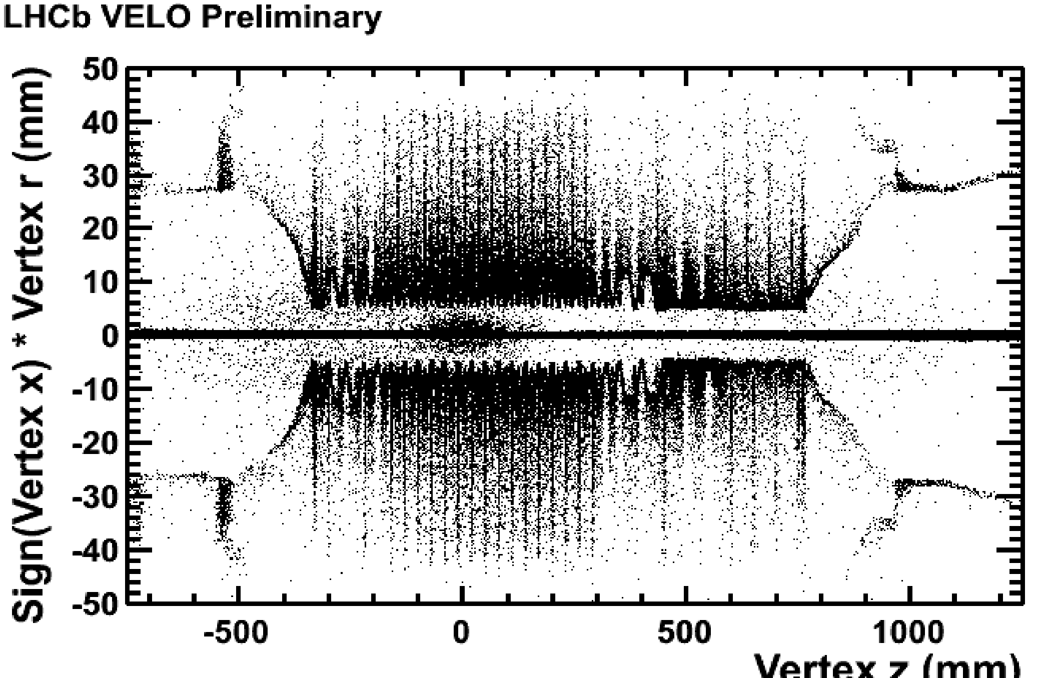


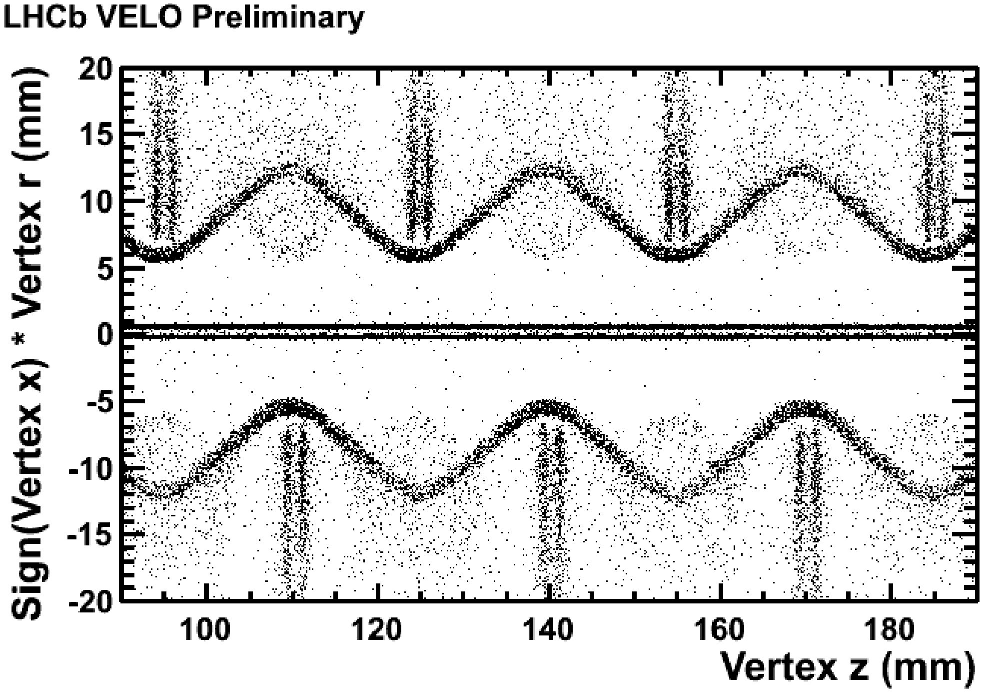
Material budget

- It's important to have a small material budget
  - Better (IP) resolution

    (less multiple scattering)

- The VELO can perform self-imaging by reconstructing vertices

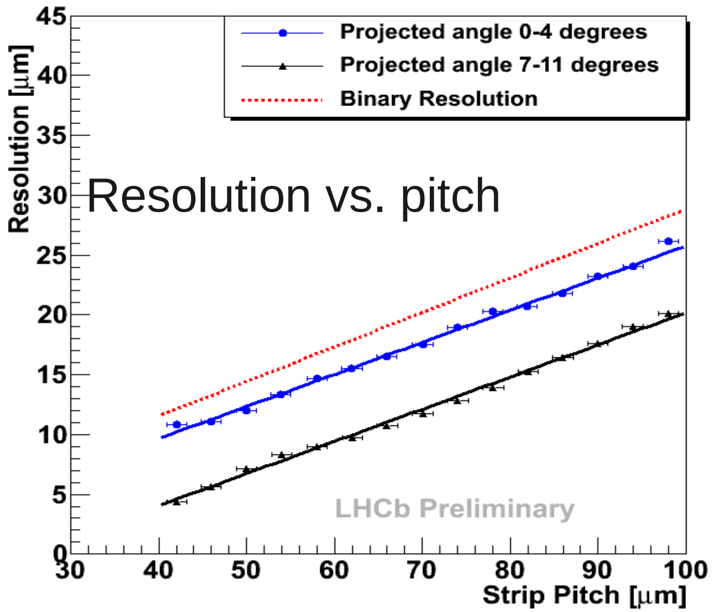




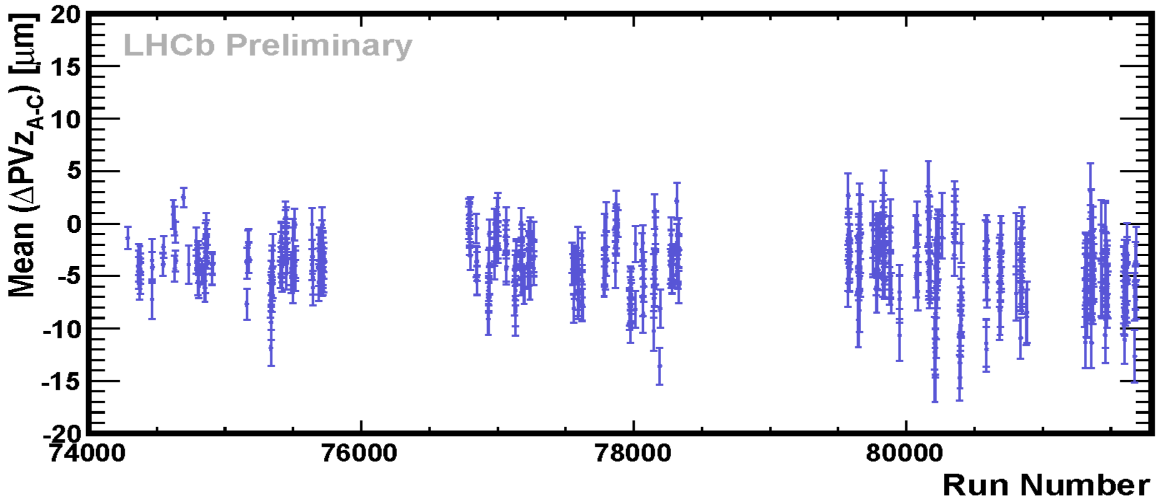
Tracking Performance

Hit resolution: resolution of cluster position measurement. Measured as the distance from the cluster to its expected position given the track fit

Alignment: The position of the sensors is measured using real data, and continuously monitored



Stability of detector alignment:
Difference in reconstructed vertex z position when reconstructing vertex with left and right half of the VELO



(data from 2010 and 2011)

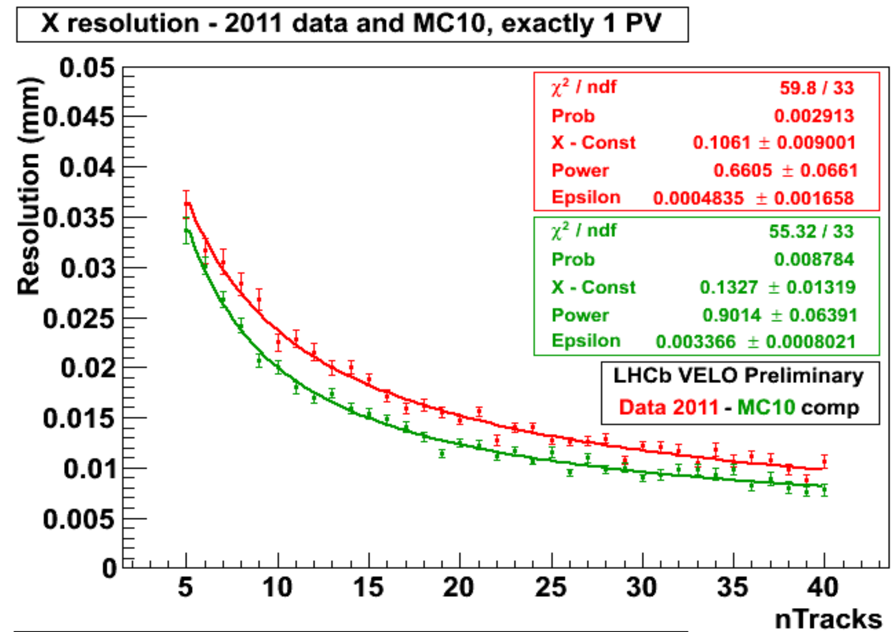
Primary vertex resolution

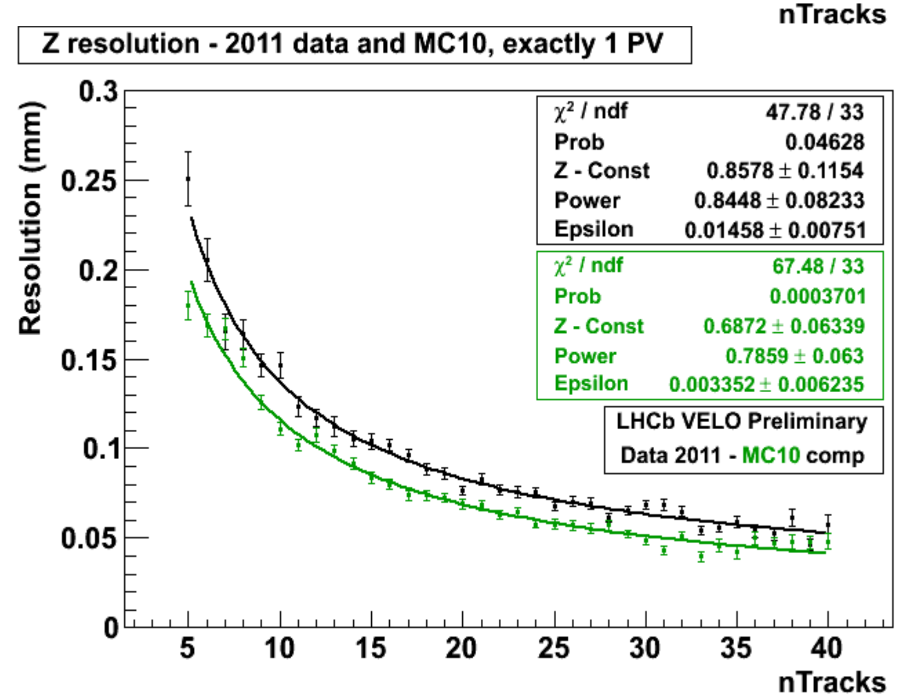
Primary vertices (PV) have more tracks (~50) than secondary decay vertices

Very important as a reference point for lifetime measurements and almost all quantities related to long-lived particles

PV resolution measurement:

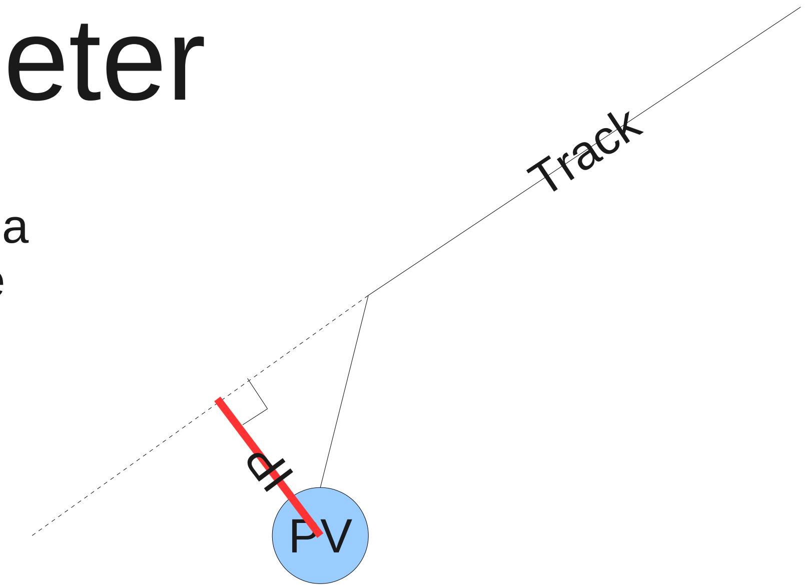
- Divide all tracks in each event into two sets, completely randomly
- Reconstruct PVs with both sets



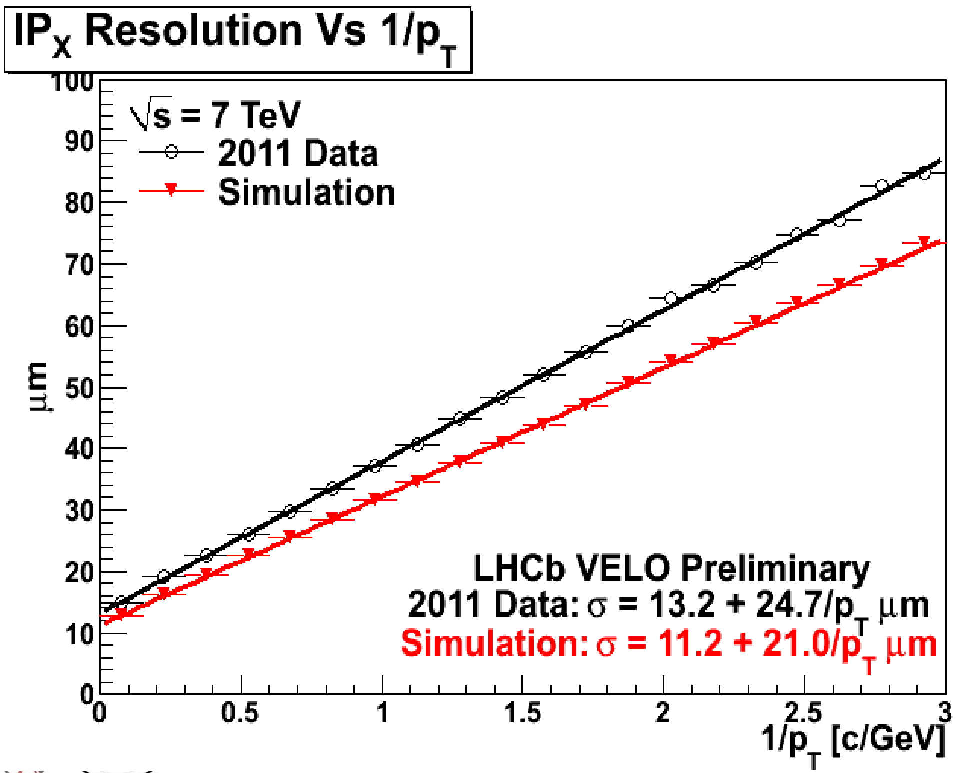


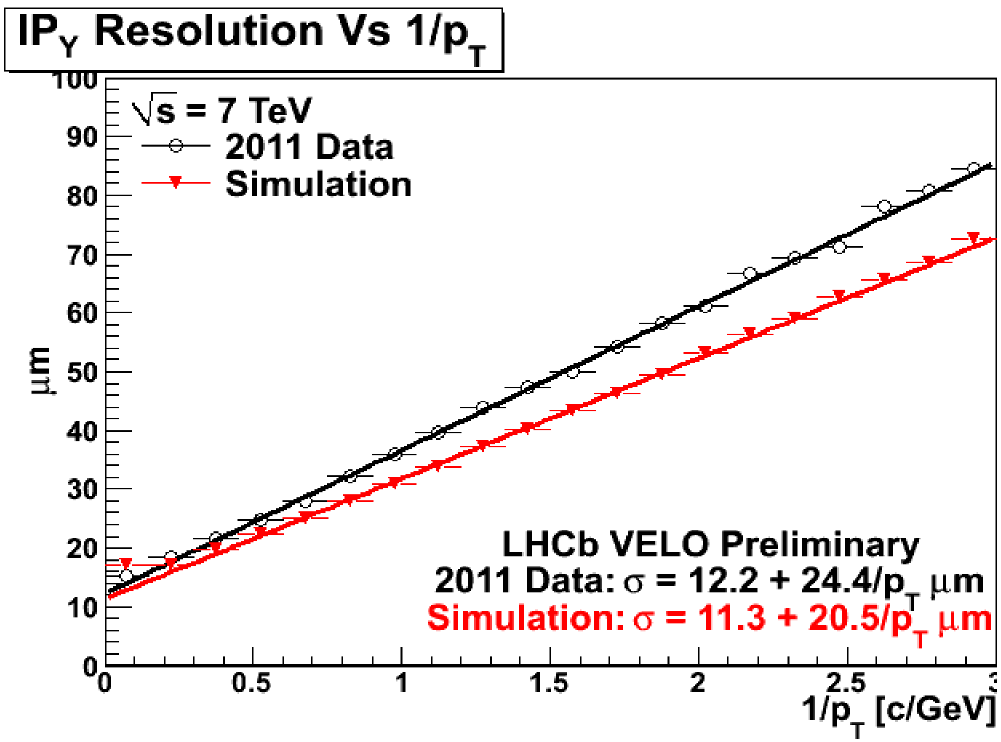
Impact parameter

Impact Parameter (IP) is the smallest distance between a track and a vertex. The IP of a particle with respect to the PV is used as a cut in many physics analyses.



IP vs. inverse transverse momentum: y-intercept depends on single hit resolution, and slope depends on the amount of material. Very good resolution.





Conclusion

- VELO subsystems are performing well
- The expected effects of radiation damage are seen in various ways
- Data from the VELO look as expected
- Physics performance is good, and resolution is the best of all LHC experiments