LHCb VELO Performance and Radiation Damage

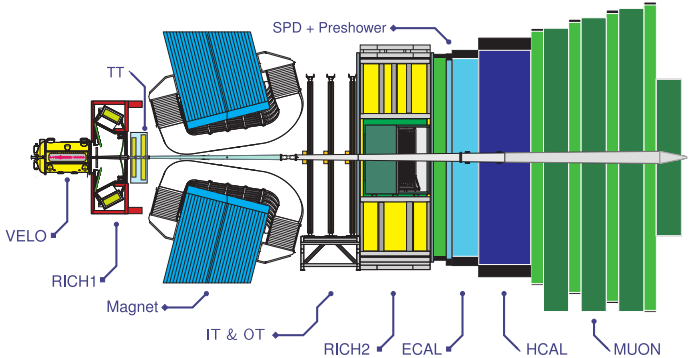
Instrumentation for Colliding Beam Physics 2014

Tim Head for the LHCb collaboration

CERN

25 February 2014

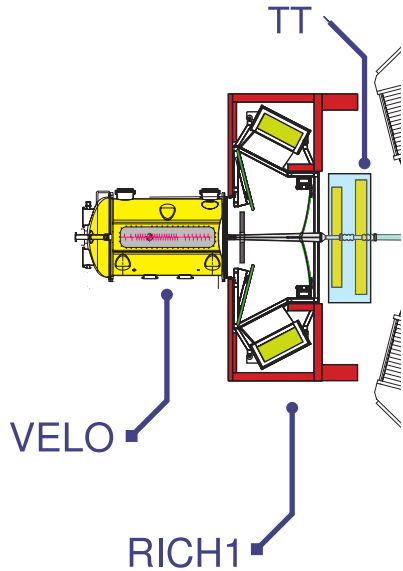
The LHCb Detector



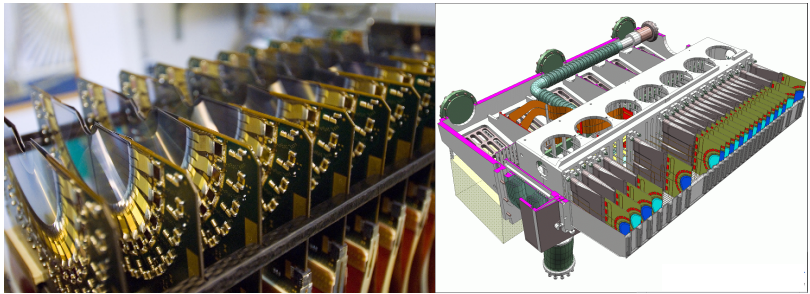
- LHCb is a single-arm ($2 < \eta < 5$) spectrometer at the LHC
  - Precision beauty and charm physics: CP violation, rare decays, heavy flavour production
- Time-dependent analyses require good time resolution: ~ 40 fs
- Efficient trigger requires precise impact parameter measurement

The LHCb Detector

- Vertex Locator (VELO) surrounds the interaction point
- Made of two halves which can open and close
  - retracted during injection, closed during data taking

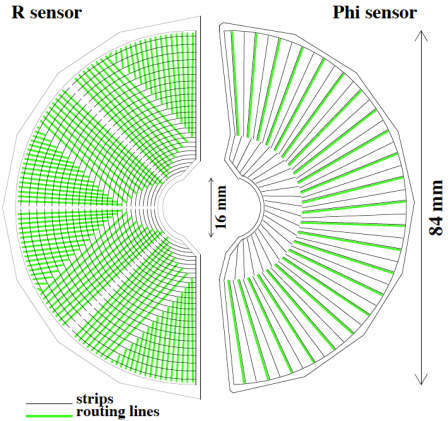


The Vertex Locator



- 88 silicon strip sensors with R-ϕ layout
- First active strip at 8.2 mm
- Evaporative CO_2 cooling, each module produces $\sim$ 16 W of heat
- In vacuum, separated from LHC by 300 μm thick foil

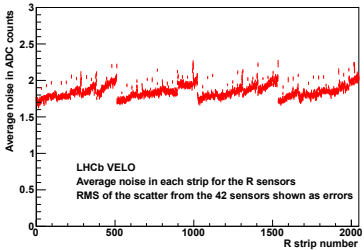
Sensor Layout

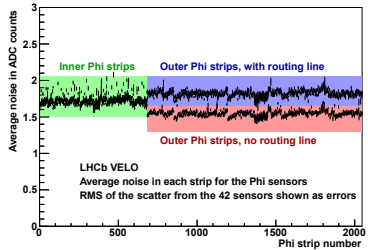


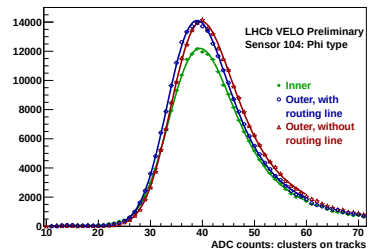
- Two sided, semi-circular microstrip sensors
- One R and one ϕ layout per module
- 300 μm thick n+-on-n sensors
  - two n+-on-p
- Strip pitches from 40 to 120 μm
- Second metal layer = routing lines


SOCHI 2014
Velo Performance

Signal over Noise



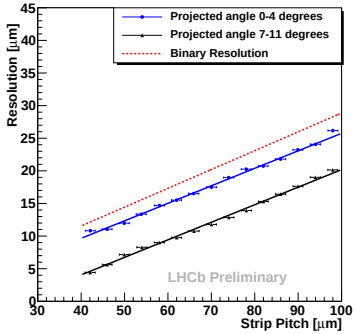




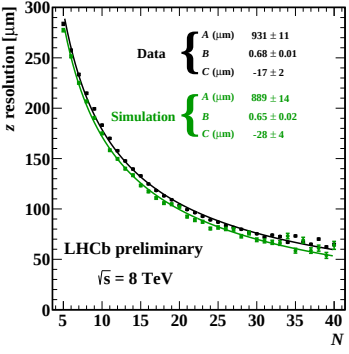
- Typical noise around 1.6-2 ADC counts
- Signal to noise > 19 (R) and > 21 (ϕ) strips
- Fit Landau convolved with Gaussian to ADC count distribution to get MPV of clusters/noise

IP and PV Resolutions

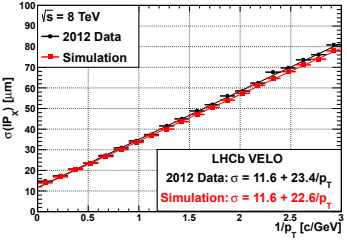
Single hit



Primary vertex



Impact parameter



$\sigma_{IP} = 11.6 + {}^{23.4}/_{p_T}\,\mu m$

Excellent spatial resolution down to 4 μm

For 25 track vertex:
$\sigma_x = \sigma_y = 13\,\mu m$, $\sigma_z = 69\,\mu m$

Well understood in data and simulation!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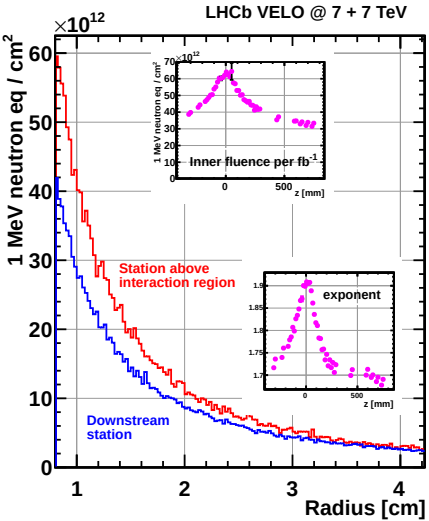
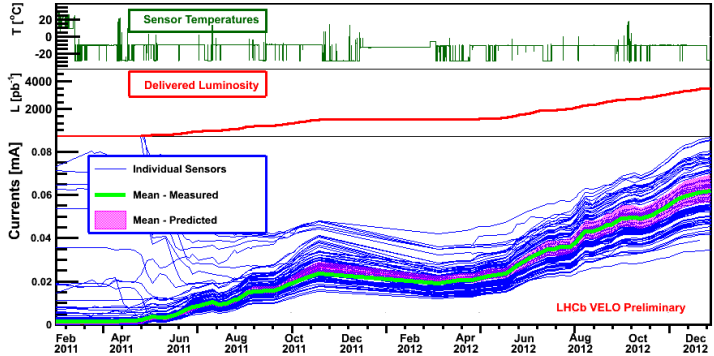
24
Radiation Damage

The Challenge



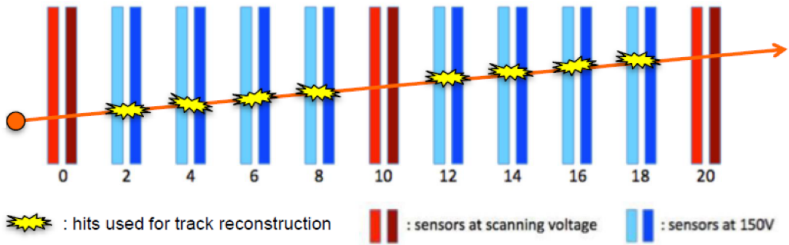
- Close to the beam → high particle fluence
- Irradiation highly non-uniform in a single sensor
  - difference of over an order of magnitude
- Fluence profile changes as function of *z*-position

Leakage Currents



- Predicted leakage currents vs time in good agreement with observation
  - typically increase by 1.9 μA per 100 pb^{-1}, dominated by bulk current
- Changes in leakage current can be related to fluence
- Well understood!

Effective Depletion Voltages



- Measure by operating 4 out of 5 sensors at nominal bias voltage of 150V and scanning voltage of fifth sensor from 0 to 150V
- Amount of charge collected depends on applied bias voltage

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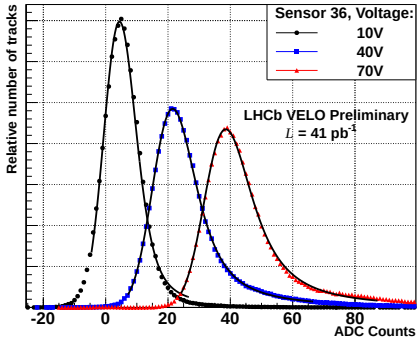

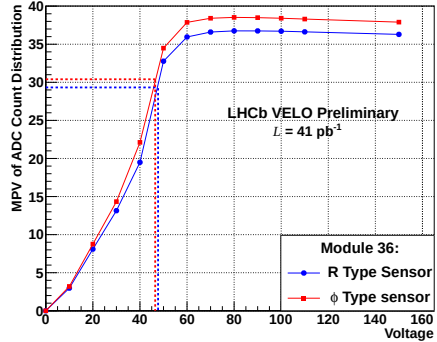

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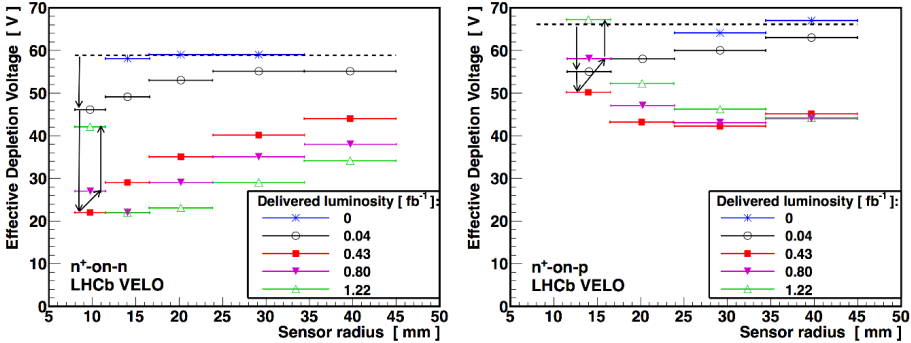
EDV over Time



- Inversion at around $(10-15)\times 10^{12}\,1\mathrm{MeV\,n_{eq}}$
- Currently operating at 150V, hardware limit at 500V
  - can comfortably run until the upgrade ($9\,\mathrm{fb}^{-1}$)!

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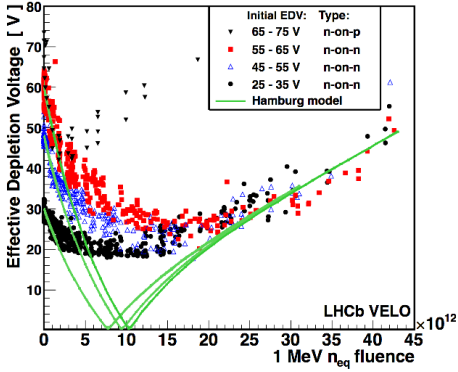

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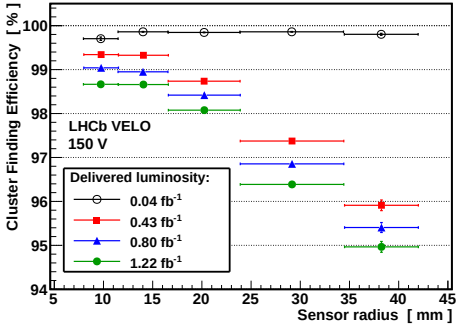
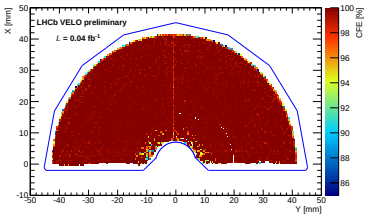
Cluster Finding
Efficiency

Cluster Finding Efficiency



- The pattern recognition builds tracks from individual clusters
- Use same method as for EDV to determine cluster finding efficiency ϵ
- Unexpected drop in ϵ, effect much smaller for ϕ-type than for R-type sensors

Cluster Finding Efficiency for one Sensor



- Uniform, high efficiency at the beginning of data taking

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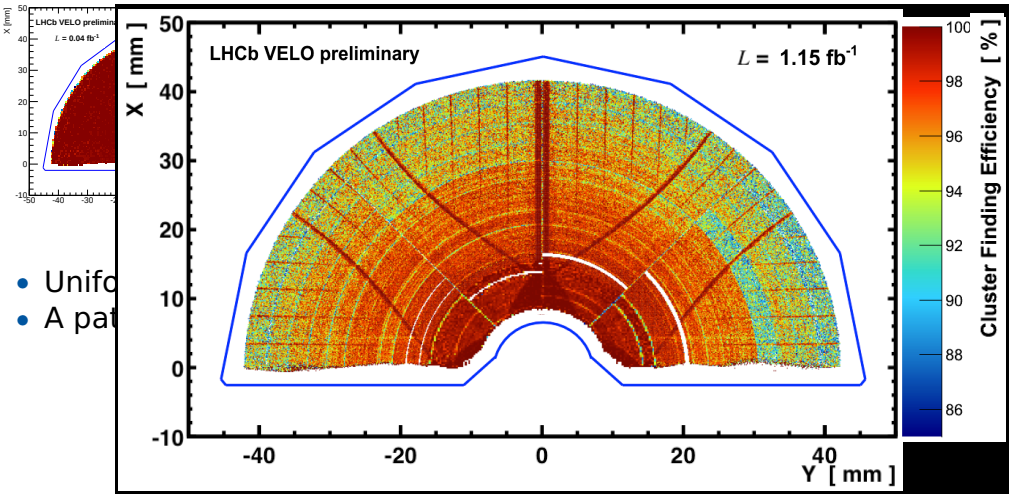

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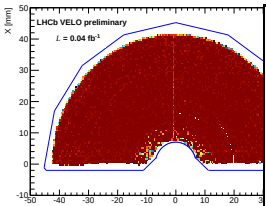

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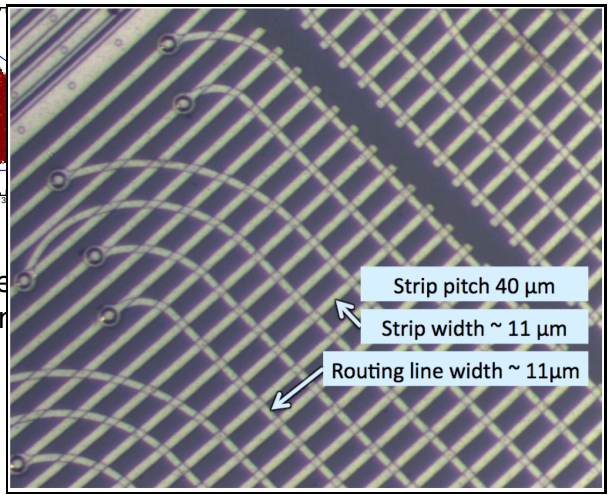

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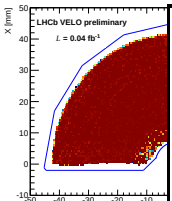

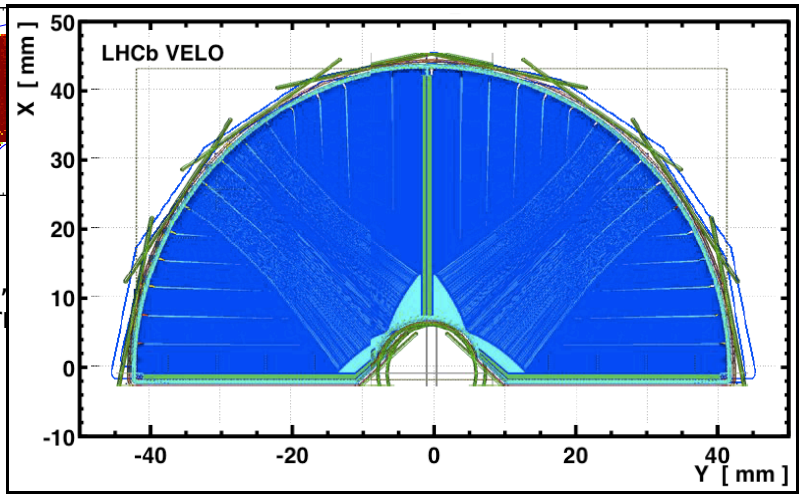

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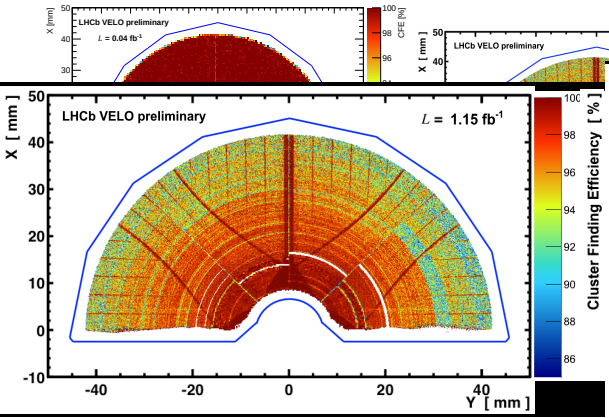

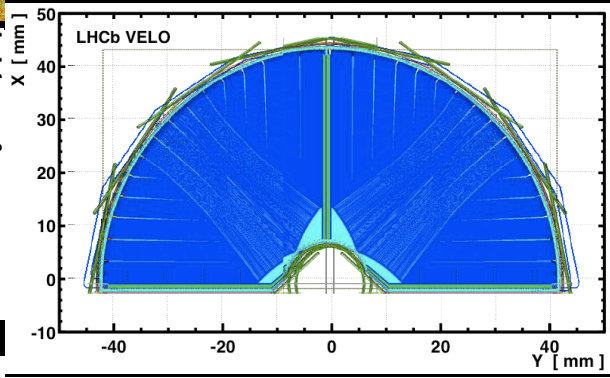

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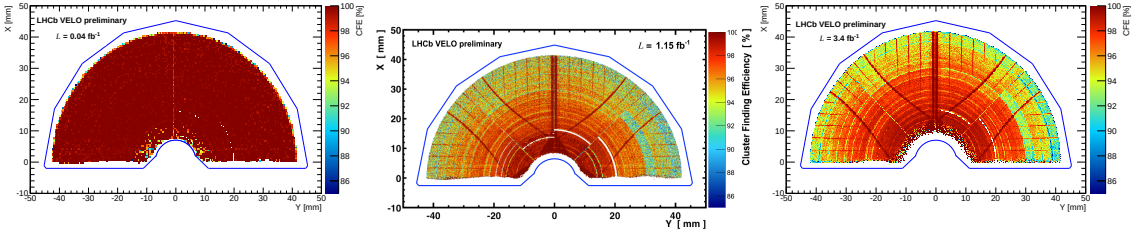

- Uniform, high efficiency at the beginning of data taking
- A pattern emerges after $\approx 1.2\,\text{fb}^{-1}$
- No further degradation at $3.4\,\text{fb}^{-1}$
- Capacitive coupling to routing lines in R-sensors
- Most likely causes: modified field lines and/or charge trapping
  - Not correlated between sensors ⇒ no effect on tracking or physics performance

Conclusions

- The Velo continues to performan extremely well!
- Velo performance paper about to be submitted
- Radiation damage summarised in: 2013 JINST 8 P08002
- Predictions about radiation damage in good agreement with observations
  - we will make it to the upgrade!
- Inner most part of sensors has undergone type inversion
- Second metal layer effect was a nice riddle that is now understood
- n-on-p sensors preferred for the upgrade
  - we’ve been testing them all along!