LHCb Silicon Detectors: The Run 1 to Run 2 transition & First Experience of Run 2

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On behalf of the LHCb VELO & ST Groups

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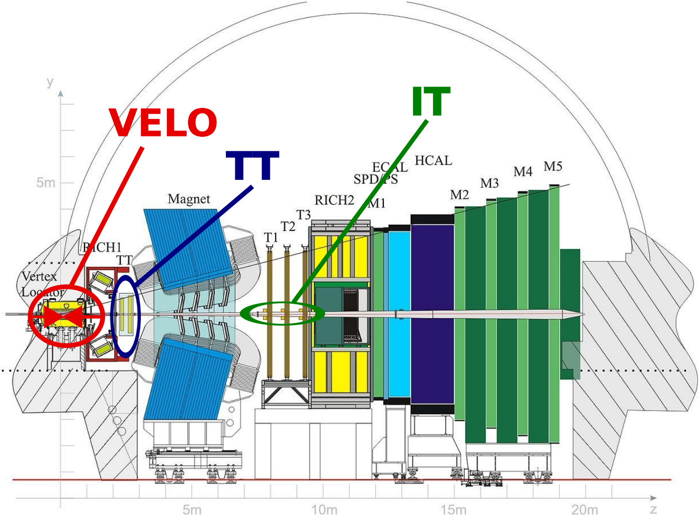
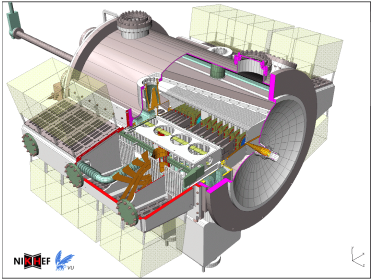
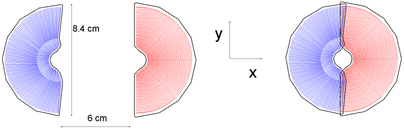
The LHCb Detector



More on tracking in Stefano's talk (up next)

The Vertex Locator (VELO)



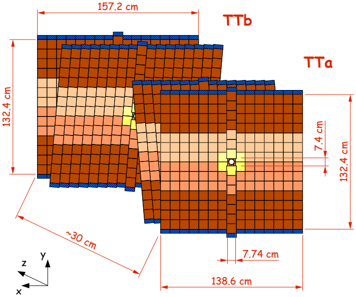


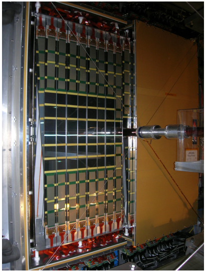
VELO fully open

VELO fully closed
(stable beam)

- Retractable detector halves
- 21 R/Phi modules per half
  +4 R-type PU veto
- 2048 strips on each sensor
- Pitch varies from 40 μm to 100 μm
- Best hit resolution 4 μm
- First strip at 8.2 mm
- Operates in secondary vacuum
- Bi-phase CO_2 cooling,
  Si at -10 °C
- Separated from beam vacuum by 300 μm thick Al foil

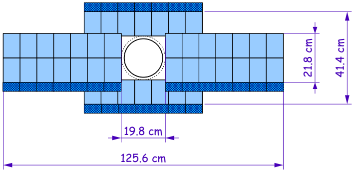
The Tracker Turicencis (TT)

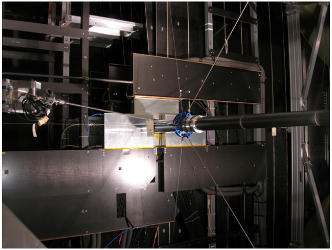




- Silicon microstrip sensors, p-on-n by HPK
- Thickness 500 μm
- Strip Pitch 183 μm
- Readout strip length up to 37 cm ⇒ up to 60 pF
- ∼144k readout channels
- Total area: 8 m^2
- Sensors at ∼ 8° C
- 99.7% working channels (Run I average)
- Resolution 53.4 μm

The Inner Tracker (IT)





- Silicon microstrip sensors, p-on-n by HPK
- Twelve layers
- Thickness 320 μm (1 sensor, 11 cm) or 410 μm (2 sensors 22 cm)
- Strip Pitch 198 μm
- $\sim$130k readout channels
- stereo angles ($xuvx$) 0°,−5°,+5°,0°,
- Total area: 4.2 m^2
- Sensors ar $\sim$ 8° C
- 98.6% working channels (Run I average)
- Resolution 54.9 μm

Evaluation of Radiation Damage

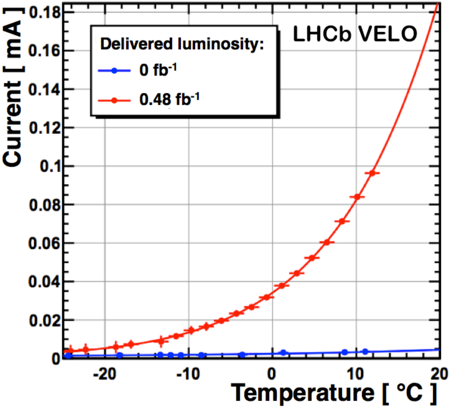
Methods with and without beam:

- Current vs. temperature (IT)
- Changes of current vs. voltage (IV)
- Changes of effective depletion voltage
- Cluster finding efficiency

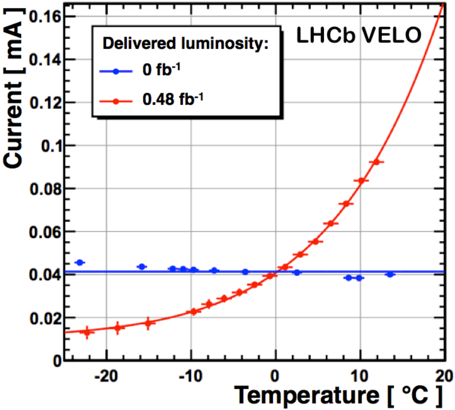
Leakage Current (VELO)

- Two contributions: bulk and surface current
- Surface contribution negligible after irradiation

Bulk dominated before
Bulk dominated after



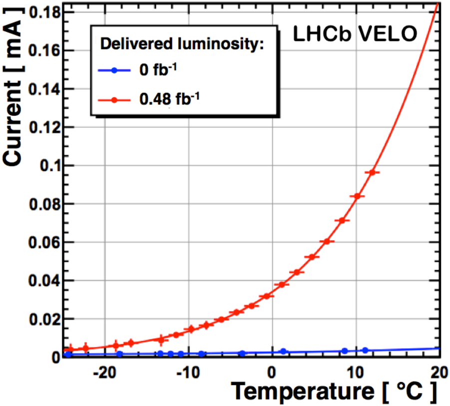
Surface dominated before
Bulk dominated after



Leakage Current (VELO)

- Measurement of the effective bandgap energy.
  $I(T) \propto T^2 exp(\frac{-E_g}{2kT})$

Bulk dominated before
Bulk dominated after

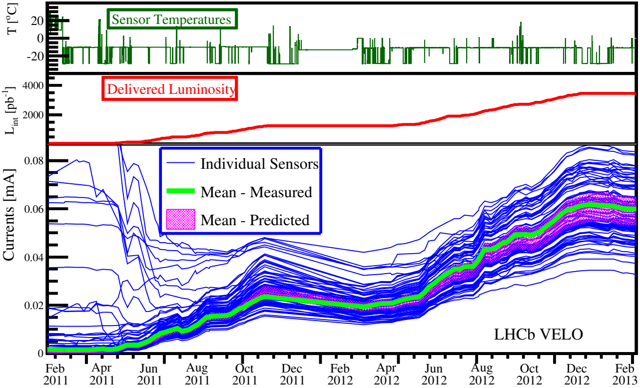


Luminosity Voltage [fb^{-1}] [V]	E_g [eV]
0.48 100	$1.17 \pm 0.07 \pm 0.04$
0.48 150	$1.18 \pm 0.05 \pm 0.04$
0.82 150	$1.14 \pm 0.06 \pm 0.04$
1.20 150	$1.15 \pm 0.04 \pm 0.04$

Literature: E_g = 1.21 eV

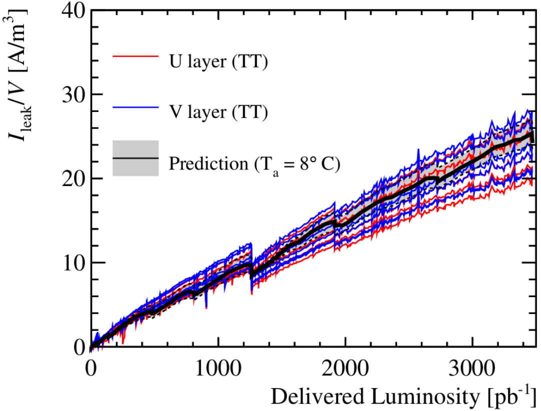
Leakage Current (VELO)

- IV-scans performed weekly in data taking periods
- Bulk currents increase with fluence as expected
- Occassional drops due to annealing



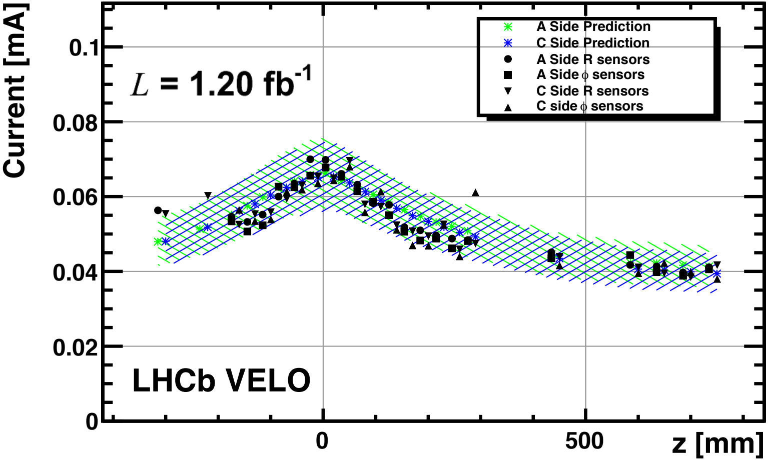
Leakage Current (TT + IT)

- Data normalised to a temperature of 8°C (E_g = 1.21 eV)



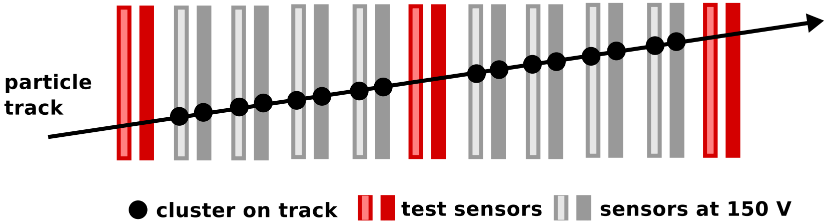
Predicted Fluence (VELO)

- Good agreement with prediction
- Particle fluences well understood



Charge Collection Efficiency (VELO)

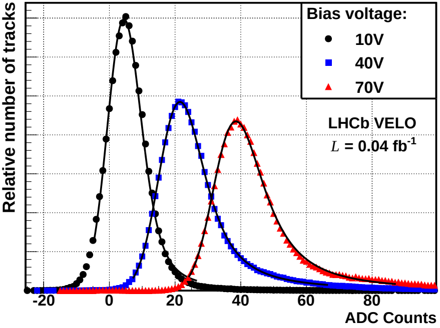
- Use reconstructed unbiased tracks
- Extrapolate to test sensor and record nearby charge
- Vary voltage between 40 and 250 V

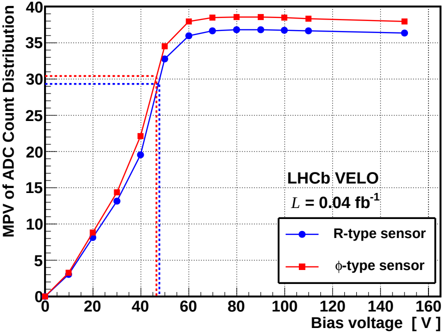


Same concept for ST, scans are simultaneous.

Charge Collection Efficiency (VELO)

- Collect data for various bias voltages for each sensor
- Fit the MPV distribution
- Define effective depletion voltage (V_{ED}) as the voltage where MPV is 80% of maximum

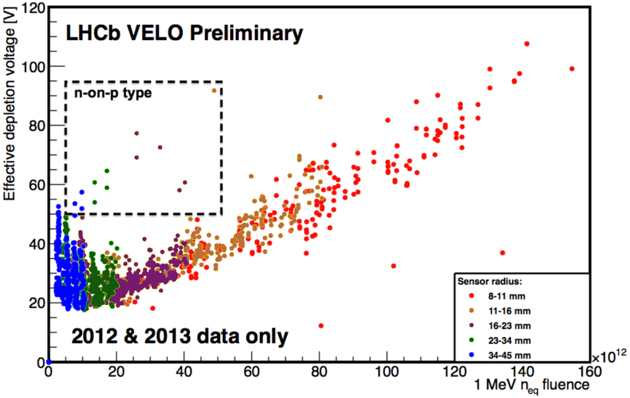




Same concept for ST, scans are simultaneous.

V_{ED} Dependency on Fluence (VELO)

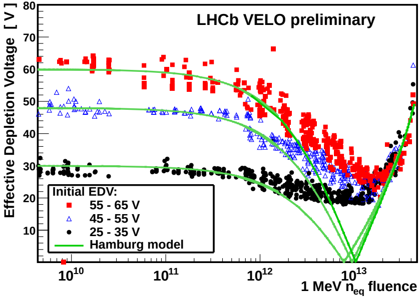
- V_{ED} decreases with fluence to a minimum of ∼18 V for n-type sensors
- Inversion point is $10-15 \times 10^{12} n_{eq} cm^{-2}$
- After inversion n-in-n increase at a similar rate as n-in-p



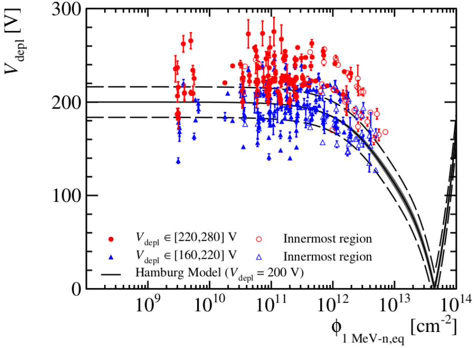
Comparison with Hamburg Model

- Good agreement apart from inversion region
- No inversion observed for ST

VELO



ST



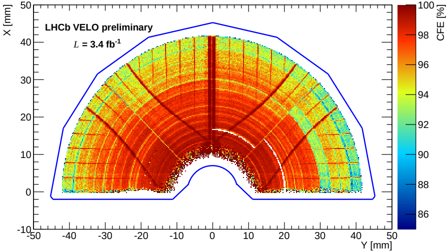
VELO V_{ED} Predictions for Run 2

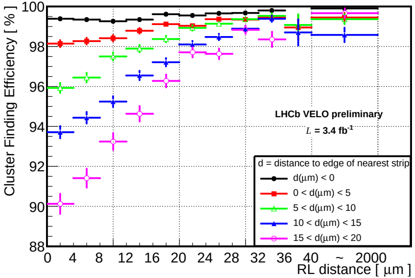
Sensor	V_{ED} at 4.4 fb^{-1} [V]	V_{ED} at 10 fb^{-1} [V]
R	172 ± 12	432 ± 30
ϕ	164 ± 11	404 ± 26

- V_{ED} will no longer be uniform across sensors
- Different voltage steps in CCE scans
- Well below 500 V in worst case

Second Metal Layer (VELO)

- CFE depends on distance to routing lines
- Effect seems to reduce after type inversion
- No effect on track finding efficiency observed





Maintenance during LS 1

- The detectors have been kept cooled and monitored.
- Regular scheduled operations to ensure all is well.
- The VELO LV system has been refurbished.
- The IT adjusted to nominal position and a new alignment monitoring system has been installed.
- Maintenance of VELO cooling & vacuum system and new cooling plant for ST.
- Some challenging times with the VELO under Ne and no beam pipe attached.
- PVSS is now called WinCC/OA – many changes/improvements to control infrastructure.

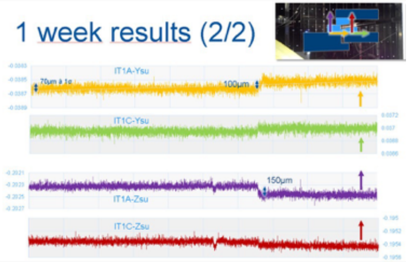
And more. . .

New ST Cooling Plant

- Cooling performace degraded over Run1, due to lubricant contaminating coolant.
- Manual recirculating necessary ervery 2-3 days.
- New Cooling plant installed for Run 2; better insulation needed.

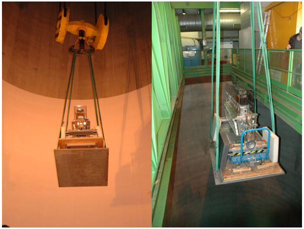
IT Postion

- After installation of new beam pipe IT could be moved to its nominal position.
- New position monitoring system installed (BCAM).



VELO Maintenance Examples

- VELO under Ne w/o beampipe required installing mechanical support.
- Replaced LV bulk supplies with A3485 units to mitigate connector problems.
- VELO 2 (emergency spare) moved back upstairs.



Preparational Data Taking

TED

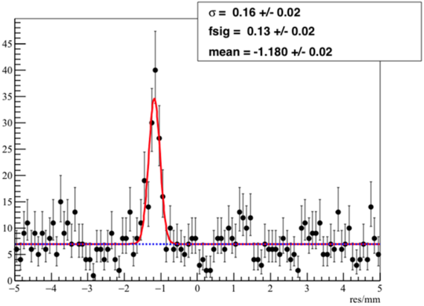
- Shots on transfer line beam absorber.
- Results in muon showers at LHCb in the upstream direction.
- Many parallel tracks, unlike collissions.
- Special timing settings.

SMOG

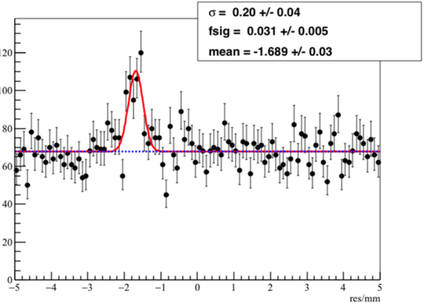
- Injection of Ne in the primary LHC vacuum at LHCb.
- Was done simultaneously with injection energy (450 GeV) collissions.
- No stable beams declared, so VELO was open.
- Allowed to power because beams were “quiet”.

TED: IT Track Residuals

IT Top

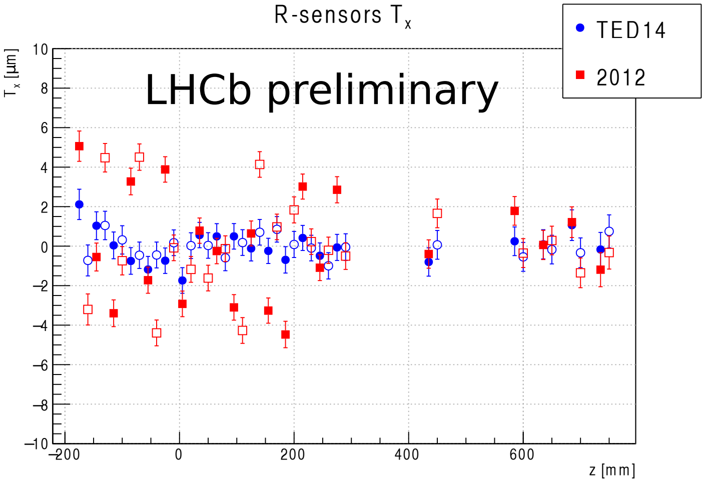


IT A-Side

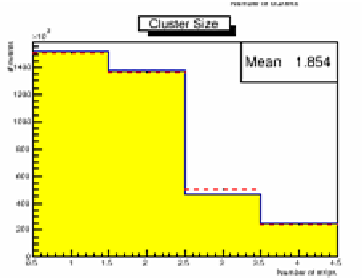


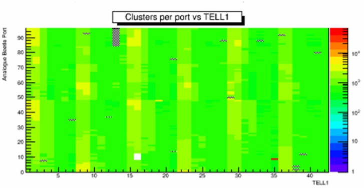
TED: VELO Alignment

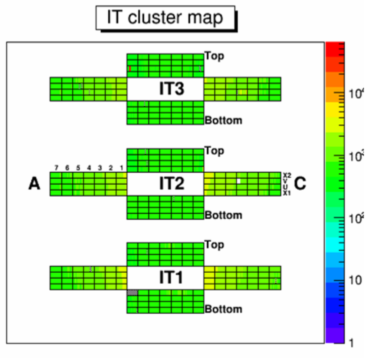
Translation along x



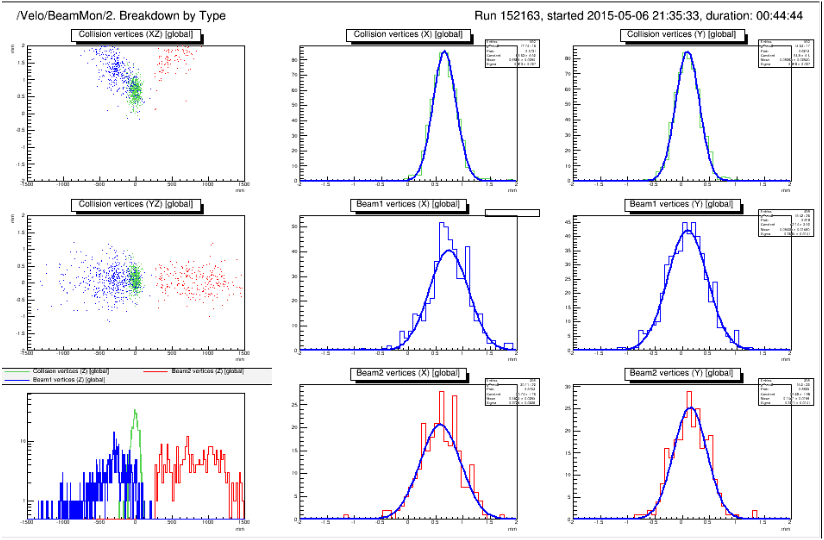
SMOG: IT CLuster Distributions







SMOG: VELO Beam Monitor



Summary

- The LHCb silicon detectors have been maintained & monitored well during LS1.
- Radiation damage is well understood.
- Many improvements have been put in place over LS1.
- The detectors performed well during injection line tests and first collision runs.
- We will be recording data with stable beams this week!

VELO & ST are in good shape and ready for LHC Run 2

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References

- **Performance**
  Int. J. Mod. Phys. A 30 (2015) 1530022
  J. Instrum. 9 (2014) P09007
- **Radiation Damage**
  JINST 8 (2013) P08002