Performance of the LHCb Vertex Locator

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On behalf of the LHCb VELO group

- Introduction to LHCb and the VELO
- Performance
- Radiation damage
- Summary
Introduction to LHCb

- LHCb dedicated to
  - CP violation and rare decays in the B-system
  - Search for new Physics

- Forward spectrometer (1.9 < η < 4.9)

- Only 2% of solid angle, but captures 27% of heavy quark production cross-section
Introduction the Vertex Locator

- **Task:** accurate reconstruction of primary and decay vertices
  - Impact Parameter resolution
  - B-lifetime
- **Vertex detector (VELO) requirements**
  - High resolution -> fine pitch strips
  - As close as possible to interaction point
    - First active strip at 8.2 mm from beam
  - Least possible amount of material between vertex and detector
    - Operate in vacuum
  - Radiation hardness
Introduction to the VELO

- Two halves, 21 stations each
- R and Phi coordinates
- VELO retracted by 30 mm during injection of beams
- Closed and centered when stable beams declared
- Operated in secondary vacuum
  - Inside an Aluminium ‘RF-box’
- Evaporative CO₂ cooling
One VELO half
Silicon details

- 300 µm DOFZ n-on-n sensors
- + 4 n-on-p sensors
- R- and Phi- measuring sensors mounted back-to-back
- 2048 strips each
- 40-100 µm pitch
- Double metal routing
- First strip at 8.2 mm from beam

- Analog readout with Beetle chip
  - 128 channels, ~20 ns peaking time
- Whole detector readout in 900 ns
Signal and Noise

Signal in Phi-sensors

Noise in Phi-sensors

Noise in R-sensors

Signal to Noise > 17
Closing and alignment

- VELO halves centered around beam every fill
  - Beam position determined from vertex reconstruction
  - Individual X-movement, common Y-movement
  - VELO closed in 3.5 minutes, fully automated

- Stability of alignment determined by reconstructing vertices in two halves separately

Stable within ±5 µm
Spatial Resolution

- Resolution depends on pitch and projected angle
- As low as 4 $\mu$m for smallest pitch and best angle
  - Best resolution at the LHC
Vertex Resolution

- Vertex resolution is function of number of tracks
- Primary vertex resolution for 30-35 tracks
  - $\sigma_x, \sigma_y \approx 12 \, \mu m$  
  - $\sigma_z \approx 65 \, \mu m$

![Graphs showing X and Z resolution vs nTracks](image-url)
“Self Imaging”

- Reconstruction of interactions in detector material
- Nicely shows the sensors
- And the secondary vacuum box
Impact Parameter Resolution

- Very good Impact Parameter resolution!
- Still significant discrepancy w.r.t. MC
- IP slope due to multiple scattering
- Too much material in VELO?
  - No big discrepancies found
- Too little material in MC?
  - Complex shape of sec. vacuum box
  - Also investigating multiple scattering modeling in Geant4
- Not conclusive yet
Radiation Damage

- LHCb is running at twice its design luminosity -> aging at higher speed
- Collect ~1 pb\(^{-1}\) per hour, VELO designed for 6 fb\(^{-1}\)
- Latest insights suggest VELO will be OK until upgrade (2017+)
  - If applying proper annealing scheme
  - A replacement is being built, ready by early 2012

- So far the detector is exposed to ~1.1 fb\(^{-1}\)
  - Does not yet affect the physics performance
  - -> clearly see effects of radiation damage

- Monitoring of leakage current
  - Weekly leakage current versus voltage scan
  - Current versus temperature scans; several per year

- Monitoring of sensor depletion voltage
  - Monthly noise versus voltage scan
  - Charge collection efficiency scan; several per year
Current scales with luminosity
  ■ As expected
Initially 2 types of sensor behaviour
  ■ With and without significant surface current contribution
After irradiation sensor behaviour is similar

bulk current dominated sensor both before and after irradiation

surface current dominated sensor before irradiation, Bulk dominated after
Charge Collection Efficiency scan

- Determination of Effective Depletion Voltage (EDV) as function of voltage
  - Sensor under test is surrounded by fully depleted sensors
- EDV is defined as 80% of charge at FDV @ 150 V
- Region at low radius has type inverted

![Graph showing EDV as a function of radius](image)
Summary

- The LHCb VELO detector is working very well
- S/N ratio > 17 after 1.1 fb⁻¹
- Vertex resolution of ~12 µm (X/Y) for 30-35 track vertex
- Very good impact parameter resolution
  - Some difference w.r.t. MC, under investigation
- Radiation damage visible
  - Actively monitored
  - According to expectation
THANK YOU
BACKUP SLIDES
Noise vs Voltage

- Effective Minimal Noise Voltage (EMNV) defined as voltage when 1/Noise passes 80% of final noise.
- Zone-0  most irradiated area
- Zone-3  least irradiated area
Determination of EDV (Effective Depletion Voltage) as function of voltage.
- Bias voltage change from 10V to 110V in 10V steps.
- Sensor under test is surrounded by fully depleted sensors.

EDV is defined as 80% of charge at FDV @ 150 V.
- Four data sets @ 0 pb-1, 41 pb-1, 426 pb-1, 767 pb-1
LHCb luminosity leveling

- Luminosity leveling by beam steering
- LHCb at max. luminosity during the whole fill
Material budget of VELO

- Material in VELO dominated by vacuum box (RF Foil)

![Material budget pie chart]

- Connectors: 0.49% (2.3%)
- Paddle+Base: 0.39% (1.8%)
- W.F. Suppressor: 0.23% (1.1%)
- Cooling Block: 0.08% (0.4%)
- R.F. Box: 1.05% (4.8%)
- Detector Supports: 1.47% (6.8%)
- Hybrids: 3.14% (14.5%)
- Sensors: 4.57% (21.1%)
- R.F. foil: 9.13% (42.1%)
- Constraint System: 0.54% (2.5%)
- Kapton Cables: 0.62% (2.9%)