The LHCb Vertex Locator: status and future perspectives

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The LHCb Detector

Mission: Explore interference of virtual “new physics particle” in the decays of b’s (& c’s) with W’s & Z’s⇒complementary to other experiments at the energy frontier (ATLAS and CMS)
The Vertex LOCator

- Two halves each with 21 modules (retractable)
- Detectors in secondary vacuum $\sim 10^{-5}$ mbar
- 8mm close to the beam during operation

- R-\(\phi\) geometry optimized for tracking of particles originating from beam-beam interactions.
- Fast online 2D (R-z) tracking.
- Fast offline 3D tracking in two steps (R-z then \(\phi\)).
- Primary vertices resolution 42 \(\mu\)m x 10 \(\mu\)m (beam direction and xy plane)
Velo Module

- Silicon micro-strip, n+ on n substrate sensors, as radiation expected at inner radius is $1.3 \times 10^{14}$ neq cm$^{-2}$ y$^{-1}$ (compatible with other LHC detectors), highly non-uniform.
- 40–100 μm pitch, 300 mm thickness

Module design aiming at minimizing material budget
- Cooled (-5°C on sensor) by a CO$_2$ circuit via cooling cookies mounted on the carbon fiber surface.
A brief history of VELO

6 Visual Inspections, 6 Metrologies, 7 Electrical Tests, 4 Vacuum Tests
Burn-In Set-up

- Reception and Visual inspection of modules transported from Liverpool to check integrity
- Uncover any possible weakness introduced in components
- Modules operated in vacuum and thermally stressed temperature between 30.0°C/-30.0°C, pressure levels ~10^{-5}/10^{-6} mbar
Quality Assurance Goals and Outcomes

- Confirm bad channel list from Liverpool QA and look for any new ones after burn-in
- Combination of VI and electrical data analysis
- Analysis criteria:
  Cuts on raw and common mode suppressed noise.
  Raw and CMS noise of each channel compared to average values per link.
- Good, noisy, dead, shorted

<table>
<thead>
<tr>
<th></th>
<th>Bad Channels (%)</th>
<th>Agreement (%)</th>
<th>Shorted (%)</th>
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</thead>
<tbody>
<tr>
<td>R sensors</td>
<td>0.7%</td>
<td>76%</td>
<td>13%</td>
</tr>
<tr>
<td>Φ sensors</td>
<td>0.5%</td>
<td>83%</td>
<td>15%</td>
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Final Production Statistics

- 42 installed modules produced over 10 months
  - 63% yield of hybrids
  - 87% yield of sensors
- 0.6% bad channels per module
- ~100 man-hours per module

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• CM noise of 32 channels in each link is suppressed.
• Noise is stable throughout the data taking and is 1.9-2.6 ADC counts for R sensors and 1.7-2.2 ADC counts for φ sensors (1 ADC ~ 500 e⁻)
• Different noise levels understood, primary reason strip geometry and routing.
Tracking and Vertexing

- tracking resolution $\sim$8.5-25 $\mu$m depending upon strip pitch (may be improved upon with better charge weighting algorithms)
- Vertex reconstructed from interaction between proton beam (180 GeV) and sensors or targets.

Reconstructed target vertices before alignment

...and after alignment

Alignment working!
LHCb detector upgrade capable of withstanding $O(100fb^{-1})$ integrated luminosity and including vertex trigger at L0 (in ~2013)

- Adequate radiation tolerance ($\sim 10^{16}$ 1 MeV $n_{eq}/cm^2$)
- Close coupling with trigger for "intelligent" Level-0 decisions.
- Maximum spatial resolution
- Secure technology
A very promising option for VESPA: hybrid pixel devices

- Measurement of 3D space points, with very few additional noise hits, implies excellent pattern recognition capabilities:
  ⇒ Fast vertex reconstruction

- Optimal radiation resistance (⇒ inner detector in all LHC devices):
  - Allows operation with smaller $r_{\text{min}}$ & higher luminosity without replacement for the duration of the experiment
  - Low noise ($\sim 200$ e$^-$ @ 25 ns) allows more precise charge interpolation & (in principle) thinner detectors.
Well understood technology

- Predictions from Monte Carlo simulation validated in extensive test beam studies
- Sensor design well established (Atlas, BTeV)
- Lots of experience in system issues during CMS/ATLAS commissioning
- Proven front end electronics design

![Graph showing spatial resolution vs. track angle with legend BTeV pixel TB 1999]
R&D activities in progress

• Substrate material to ensure maximum radiation resistance (in collaboration with RD50):
  – p-type substrates
  – Magnetic Czochralski
• Alternative considered
  – 3D sensors
• Test beam program to validate design (1\textsuperscript{st} chapter Fermilab MTEST February 2008)
Conclusions

• The VELO detector system has reached its final destination and is being commissioned in IP8
• We are actively pursuing a strategic R&D program that will ensure an exciting physics program in the next decade and beyond
• We are looking forward to the first data!
Additional information
Looking into the future

p-type VELO sensor

• After ~3 yrs of operation we expect to need replacement of modules

• We are planning to use sensors built on p-type substrates & we have built and characterized full scale prototypes

• Note: first sLHC full size silicon detectors!
p-Type Sensor HV scan (test beam Nov. 2006)

M26ϕ (TELL1 30), $V_{\text{depletion}} \approx 90$ V

- $V_{\text{applied}} = 10$ V
- $V_{\text{applied}} = 50$ V
- $V_{\text{applied}} = 100$ V
- $V_{\text{applied}} = 150$ V

Charge of Cluster (ADC Counts)

- Incoherent noise $\sim 1.8$ ADC counts (same as baseline sensors)
- When $V_{\text{applied}} < V_{\text{depletion}}$, partial charge is collected corresponding to effective depletion depth

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