Tracking and Alignment in LHCb

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LHCb and B-physics

- LHCb - Large Hadron Collider beauty detector.
- LHCb aims lay primary in the B-physics sector.
- Nominal luminosity of about $2 \times 10^{32} \text{cm}^{-2} \text{s}^{-1} \rightarrow 10^{12} b\bar{b}$ per year.
- The dominant channel behavior explains the single-arm forward spectrometer geometry chosen for LHCb.

Gluon fusion before fragmentation
forward beaming of $b\bar{b}$ in the LHCb frame
LHCb Detector

Primary Vertex (PV)
LHCb Detector

VErtex LOcator (VELO): Silicon Detector

Tracker Turicensis (TT): Silicon Detector

Inner Tracker (IT): Silicon Detector

pitch 38-102 \( \mu m \), depth 300 \( \mu m \)

pitch 183 \( \mu m \), depth 500 \( \mu m \)

pitch 198 \( \mu m \), depth 320-410 \( \mu m \)
LHCb Detector

Outer Tracker (OT): Straw Tube Detector

radius 2.45 mm
hit resolution 200 $\mu m$
LHCb Detector

Warm Magnet: integrated magnetic field of $4 \, T \cdot m$
VErtex LOcator

- Primary Vertex (PV) is inside VELO, towards middle;
- VELO is a retractable detector, 2 VELO sides:
  - To protect from damage, VELO is in Open position before the beam is stable, and closed afterward.
  - Open VELO: sensors 30 mm further from the beam,
  - Closed VELO: sensors are about 8 mm from the beam line,

VELO double-sensor modules: \( R + \phi \)  
Schematic: one side of VELO
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Schematic VELO sensors in Open and Closed positions
Primary Vertex Resolution

- Primary Vertex (PV) is determined with VELO tracks.
- Method: randomly split event track container in two, and reconstruct PV.
- Results close to expected,
  - A residual $\approx 40\%$ difference - e.g. when using 25 tracks.
  - Improving.

<table>
<thead>
<tr>
<th></th>
<th>MC</th>
<th>Data</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\Delta x(\mu m)$</td>
<td>11.5</td>
<td>15.8</td>
</tr>
<tr>
<td>$\Delta y(\mu m)$</td>
<td>11.3</td>
<td>15.2</td>
</tr>
<tr>
<td>$\Delta z(\mu m)$</td>
<td>57</td>
<td>91</td>
</tr>
</tbody>
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PV resolution vs track used, real data

PV resolution vs track used, MC
Impact Parameter Resolution

- Impact parameter (IP) - Closest approach to PV of a track.
- IP resolution is determined primarily by:
  * random scattering in VELO material, VELO misalignments and hit resolutions.
- IP resolution for MC and data given.

Impact Parameter resolution in X

Impact Parameter resolution in Y

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Impact Parameter Resolution

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- IP resolution for MC and data given.
- 15-40 % difference between MC and data.
- Accounted for already.
  - Some disagreement in material description of MC.
  - Misalignment between VELO sides.
- Remaining:
  - residual misalignments of sensors, $\lesssim 4.4\mu m$,
  - too optimistic hit resolution in MC,
  - charge sharing.
Alignment Status of Subdetectors

- Optical alignment of VELO, OT, IT, TT: Survey.
- Updated software alignment Aligned.
- Monte Carlo results: black histograms.
- $R_{\text{track}} - R_{\text{hit}}$, measurement residual distribution gauges the alignment quality.
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Silicon Trackers: Hit Resolution

- 40-50% difference between Monte Carlo and Data for IT and TT.
- IT and TT are single-sided silicon strip detectors.
- One source of disagreement was found in the charge sharing between neighboring strips.
  - This effect was overestimated in MC.
  - After correction: an increase from 40 $\mu m$ to 50 $\mu m$ for IT hit resolution.
- We expect residual misalignments to account for the rest.

charge sharing between two strips
larger cluster of strips improve measurement resolution
Long Track Efficiency

- Long track efficiency obtainable from $K_S$ candidates.
- Method:
  * Finds VELO segment and the associated CALO cluster,
  * Gets Long tracks from reconstruction,
  * $K_S$ Candidates 1: VELO+CALO track and a Long track,
  * $K_S$ Candidates 2: 2 Long tracks.
- The method supplies IT/OT/TT efficiency in tracking.
- Results close to 100%, with MC and data agreement.

Long-Long $K_S$ candidates, mass plot

Efficiency as a function $p_T$
An Other Method for Track Efficiency

- Method, phase 1:
  - For all VELO segments, finds a corresponding CALO cluster in the bending plane \((x,z)\)
  - Checks in the non-bending \((z,y)\) plane,
  - Fits track VELO+CALO,

- Phase 2:
  - IT/OT/TT segments are matched to the found track.
  - The previous segments are provided by the various Pattern-Recognition algorithms.
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Difference in \(y\) for the track and CALO cluster position, includes all VELO+CALO tracks includes only VELO+CALO tracks, which have an associated Downstream segment

\[ \epsilon_{eff} = \frac{n_2}{n_1} \]
Particle Zoo

- Mass values of several detected particle agree with the PDG values to per mil level.
- Small signal widths, e.g. 2.8 MeV for $\Lambda$, 2.7 MeV $\Xi^-$, 8.5 MeV $D^0$, 2.5 MeV $\Omega$, etc.
Summary and Conclusions

- Already more than 100 Million 7 TeV Collisions in the 2010 LHCb data.
- Main conclusion: Alignment and tracking are in good shape for physics analysis.
- Monitoring of alignment and tracking quality in progress.
- Already done gradual improvements in:
  - Detector description,
  - Tracking tools,
  - Alignment.
- As result, MC and data reconstruction give a better agreement.
- More to do ... but “Terra Nova” / “Terra Incognita” in sight, as we reconstruct particles from 7 TeV pp collisions with high precision.
Impact Parameter (IP)

- 2010 data, VELO Closed

Impact Parameter resolution in X

Impact Parameter resolution in Y

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LHCb VELO Preliminary

2010 Data: 16.2 + 24.6/p_T μm
Simulation: 11.2 + 19.9/p_T μm

2010 Data: 15.7 + 24.4/p_T μm
Simulation: 11.9 + 19.3/p_T μm
VELO Sensor Alignment

Sensor alignment correction for 88 sensors 168 DoF in X and Y

Overview of misalignments

Sensor X and Y Alignment: 4.4 µm
Residual Distributions for IT

IT pull plots

single-sided silicon strip sensor
Primary Vertex Z

PV resolution vs track used

real data

PV resolution vs track used

MC
VELO Stability, Sensor Alignment

- VELO retractable: Left/Right sides.
  - VELO is closed after stable beam conditions fulfilled.
- Primary Vertex reconstruction with tracks from separate sides.
  - Difference gives an estimate of misalignment between VELO sides.

\[ \Delta X \text{ difference of PV (} \mu m \text{)} \]

![Graph showing \( \Delta X \text{ difference of PV (} \mu m \text{)} \) vs. Run Number.](image)
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![Graph showing \( \Delta Y \) difference of PV (\( \mu m \)) over different run numbers.](image-url)
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\[ \Delta Z \text{ difference of PV (\(\mu m\))} \]

![Graph of \(\Delta Z\) difference of PV vs Run Number]
Tracking Methods and Alignment

• Reconstruction phase:
  * various pattern recognition algorithm + Kalman-Filter tracking.

• Runge-Kutta extrapolator to deal with highly inhomogeneous field in the tracking stations.
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- Reconstruction phase:
  - Various pattern recognition algorithm + Kalman-Filter tracking.
- Runge-Kutta extrapolator to deal with highly inhomogeneous field in the tracking stations.
- “Closed-form” alignment methods used:
  - Alignment with track model based on Kalman-Filter,
  - An alignment based on Millepede method, with parametrized trajectory - Volker Blobel,
- Equivalent methods, $\chi^2$ minimization over alignment and track parameters simultaneously.
Impact Parameter and Material

RF-foil divides Sides of VELO and prevents outgasing.
Silicon Trackers: Hit Resolution

- The charge sharing depends relatively strongly on the track slope.
- Note for the experts: previous fact is detrimental to some of the alignment parameters which couple strongly to the track slope.

![Charge sharing vs. on track slope](image)
Downstream Tracks, Mass Resolutions

- The best physics candidates are made from Long tracks.
- Long lived particles: e.g., $K_S$ and $\Lambda$ may decay outside VELO.

Down-Downstream tracks for $K_S$

LHCb 2010 data, preliminary

Mass resolution vs. $z_{\text{decay}}$ for $K_S$

LHCb 2010 data, $\sqrt{s} = 7$ TeV, preliminary

- Hence, some physics studies are possible even without VELO...