Alignment Challenge

at

LHCb

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LHCb Experiment

- Large Samples of b decays for New Physics searches in CPV & rare B (&D) decays
- B production predominately at small polar angles
- LHCb optimized as single forward arm spectrometer

LHCb Tracking System

- 21 stations R and $\phi$ sensors
- Vertex Locator
- Muon system

LHCb Experiment

- 250 mra
- 10 mra
Tracking System Challenges

- Large track density

- Trigger uses tracking info,
  - Requires good alignment
  - Online updating of constants if needed.

- Tracking algorithms need to be FAST, as they are executed online. Want offline pattern recognition very similar to online version, except for fine tuning of alignment & calibrations.

- Minimize material (no surprise here)
**Vertex Locator**

- **21 tracking stations**
  - 4 sensors per station with r/φ geometry
  - Optimised for
    - Fast online 2D tracking
    - Vertex reconstruction
    - Offline track reconstruction

**R-sensors**
- 2048 strip in 45° sectors
- Strip pitch increase with R: 40μm → 100μm

**Φ-sensors**
- 2048 strip in inner and outer regions
- Strip pitch increase with R: 36μm → 97μm
Most precise device in LHCb moves
- Retracted by ~ 3 cm in-between fills
- Reinserted to ~ 8 mm after stable beams

Integral part of the trigger
- RZ (2D) tracking/trigger scheme requires transverse alignment between modules <20 μm.
- Internal alignment monitoring/updating as necessary (online vs offline), 2D vs 3D
- Rest of tracking system (online vs offline)
  - Momentum estimate using VELO-TT in HLT.

Need for “same” tracking in HLT and offline:
  - tradeoffs of speed/efficiency/ghost rate

- ~4% ghost rate (3D)
- ~7% ghost rate (2D)
**Tracking Stations**

- **Outer Tracker**
  - 5.0 mm Straws
  - Double-layer straws

- **Silicon Strips**
  - 198 μm pitch
  - 1-2 sensor ladders
  - 4 layers: XUVX
  - 336 ladders to be aligned

- **Inner Tracker**
  - 125.6 mm

**Trigger Tracker (TT)**

**Silicon Strips**
- 183 μm pitch
- 128 7-sensor ladders
- 128 ladders to be aligned
**Magnetic Field**

Very small field in VELO

Non-zero field in region of TT integral part of trigger: $\Delta p/p \sim 30\%$

Non-uniform, non-negligible field in region of T Stations

$$\int B \, dl = 4 \, Tm$$

$$\int B \, dl = 0.12 \, Tm$$
Silicon Strips
- 183 μm pitch
- 128 7-sensor ladders
- 4 layers: X,U(5°),V(-5°),X
- 128 ladders to be aligned
- 2% occupancy, max.
Inner Tracker

Silicon Strips
- 198 μm pitch
- 1-2 sensor ladders
- 4 layers: XUVX
- 336 ladders to be aligned, 6 pars each

Strip Occupancy
Outer Tracker

- Very large!
- 5.0 mm Straws
- Double-layer straws
- Single Hit Resolution ~ 200 μm.
- High occupancy

Detector is planar to within 0.9 mm
Hardware Alignment at LHCb

- Generally, fiducial points on all detectors will be surveyed by the TS-SU group at CERN.

- Precision is typically 0.3-0.5 mm (1σ) level in X, Y and Z, depending on the precision needed. VELO box surveyed to 0.3 mm.

- All points given with respect to the global LHCb frame nominal interaction point is (0,0,0).

- Where appropriate, these will be used to determine the starting values for various alignment parameters.
  (After translation from external measurements to internal positions)
General Strategies
- Magnet OFF data crucial
  - Separate magnetic field effects from geometrical ones.
  - Commissioning
  - After access to service tracking system
  - Otherwise, periodically, based on unexplainable change in alignment

- Pre-selected track samples
  - Low multiplicity events
  - Isolation requirements around track
  - Magnet OFF: Use energy from calorimeter

- Magnet ON data
  - Tweak alignments from Magnet OFF
  - Cross-check with $K_s$, $J/\psi$, $Y$, $D \to K\pi$, $Z^0$, etc
    (after dE/dx corrections and B field map validated)
General Flow of Alignment

- **VELO Alignment**
  - Align +X (-X) modules to one another
  - Align +X VELO to -X VELO

- **IT Alignment**
  - Align IT to OT using overlap regions and tracks with hits in both detectors

- **OT Alignment**
  - Align OT to the system

- **Align VELO to IT/OT System**
  - Align TT using long tracks

- **After Tracking System Alignment**
  - Align RICH
  - Align ECAL
  - Align HCAL
  - Align MUON

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Tracking System, Expected Performance

Momentum resolution

Impact parameter resolution

$\delta p/p = 0.35\% - 0.55\%$

$\sigma_{IP} = 14\mu + 35\mu/p_T$
Some Impacts of Misalignment
Random Velo Misalignment

Mechanical placement, $\sigma < 20 \, \mu\text{m}$,

S. Viret
Misalignment of OT

- Tracking robust against misalignments up to \( \sim 500 \, \mu\text{m} \), but:
  - \( \sim 20\% \) degradation in momentum (not acceptable from physics view)
  - fewer hits per track
- Expect transverse alignment to be at the \( \sim 50 \, \mu\text{m} \) level, or better.

![Graph showing misalignment in X in T1 & T3: Scaled Tracking Efficiency](image)

For misalignments larger than 3 mm the hits of T1 are ignored.

![Graph showing momentum resolution](image)

- Gaussian width
- For misalignments larger than 3 mm the hits of T1 are ignored.

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- Tracking robust against misalignments up to \( \sim 500 \, \mu\text{m} \), but:
  - \( \sim 20\% \) degradation in momentum (not acceptable from physics view)
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- Expect transverse alignment to be at the \( \sim 50 \, \mu\text{m} \) level, or better.

Toy MC; Gaussian Smearing of Momentum

- \( \overline{B}^0 \rightarrow K^+\pi^- \)
- \( B_s \rightarrow K^+\pi^- \)

\[ \sigma_{p/p} = 0.004 \quad \text{and} \quad \sigma_{p/p} = 0.005 \]
**VELO – TT Misalignment @ L1**

- Fraction of tracks above 2.5 GeV $p_T$
- Double apparent rate at ~ 300 micron miss alignment
- Trigger requires X misalignment below ~100 micron
Summary

- LHCb Trigger requires “good” online alignment
- Extraction/re-insertion of VELO every fill requires updating of some subset of alignment constants
  - Probably default alignment constants from previous run to start off (aside from an overall $\Delta X$ ($\Delta Y$) from VELO motion controller between fills)
  - Update if “necessary”
- Large number of planes and overlap regions facilitate alignment
- Magnet OFF data critical to decoupling geometry from B field effects
  - More work needed on proving that $dE/dx$ and B field mapping “issues” can be de-convoluted.
- Fine tuning of alignment for final offline analysis.
- Monitoring:
  - Low-level: #Hits/track, $\chi^2$, IP, residuals, #tracks/event, etc
  - High level: Masses, mass resolutions, relative particle yields.