2011 IEEE NSS-MIC Valencia

A Novel Alignment Procedure and Results for the LHCb Silicon Tracker Detector

Frédéric Dupertuis

on behalf of the Alignment and Silicon Tracker group

Laboratoire de Physique des Hautes Energies (LPHE)
Ecole Polytechnique Fédérale de Lausanne (EPFL), Switzerland

25th October 2011

Outline

1) Introduction (See V. Fave's talk on *Performance of the LHCb Silicon Tracker*)

- The LHCb Experiment
- The Silicon Tracker

2) Detector Alignment Procedure

- Survey and Software Alignment
- LHCb Software Alignment
- Tracks from Vertex & Mass-constrained Resonances

3) Track extrapolation with Magnet Off data

- Y Alignment with LHCb Software Alignment
- Silicon Tracker Geometry
- Y Alignment using Track extrapolation with Magnet Off data

4) Conclusion

The LHCb Experiment @ LHC (CERN)

- Vertex Detector : Silicon (*VeLo*)
- Tracking : Silicon (*VeLo*, *TT*, *IT*), Gaseous Straw Tubes (*OT*)
- Magnet : 4Tm *Dipole*
- Calorimetry : *ECAL* and *HCAL*
- Particle ID : Ring Imaging Cherenkov detectors (*RICH 1 & 2*)
- Muon Chambers : *M1...M5*

Silicon Tracker

Tracker Turicensis (TT)

- Silicon p-on-n micro-strip detectors operating @ 0 °C
- Four planes ($0^\circ, +5^\circ, -5^\circ, 0^\circ$)
- Pitch: 183 μm ; Thickness : 500 μm
- Long readout strips (up to 37 cm)
- 143360 readout channels
- Total Silicon area is 8 m²

Inner Tracker (IT)

- Silicon p-on-n micro-strip detectors operating @ 0 °C
- 3 Stations along Z :
 - 4 boxes per stations
 - Four planes ($0^\circ, +5^\circ, -5^\circ, 0^\circ$)
- Pitch: 198 μm
- Thickness : 320 & 410 μm
- Readout strips (up to 22 cm)
- 129024 readout channels
- Total Silicon area is 4.2 m²

Survey and Software Alignment

Survey

- During assembly and installation in the cavern, survey measurements were performed and constitute our first knowledge on detector element positions.

Software Alignment

- To achieve good mass resolution, the tracker must be aligned well below its single hit resolution ($\lesssim 60 \mu\text{m}$ for ST).
- Idea : Use good quality tracks to get better detector elements position.
- A software framework has been developed to use track-based Alignment.

LHCb Software Alignment

- For each track, a χ^2 can be calculated from track fit residuals as :

$$\chi^2 = [m - h(x)]^T V^{-1} [m - h(x)] \quad (1)$$

where m is the measurement vector, h the measurement model vector, V correlation matrix and x the track parameters.

- An algorithm minimizes the χ^2 with respect to Alignment parameters α ^a :

$$\frac{d\chi^2}{d\alpha} = 0 \quad (2)$$

- An iterative solution using Newton-Raphson method is used.
- Alignment parameters are constrained using survey measurements (χ^2 penalty term).
- Till 2010, the LHCb Alignment is performed with high momentum tracks with quality cuts (track fit χ^2 , number of hits on track, ...).

^aW.D. Hulsbergen, NIM **A 600** (2009) 471-477

Tracks from Vertex & Mass-constrained Resonances

- Since 2010, Vertex and Mass constraints have been added to the LHCb Alignment framework using tracks from clean resonances such as $J/\psi \rightarrow \mu^+ \mu^-$ and $D^0 \rightarrow K^- \pi^+$ resonances.
- Tracks from clean Resonances : To avoid tracks with ghost hits that worsen the Alignment quality.
- Vertex constraint : Makes sure that tracks come from the same point and avoid global movements in the VeLo for example.
- Mass constraint : Constrain the invariant mass of the resonance to its known value. This constraint fixes the track curvature radius and prevents global shearing →
- This strategy also contributes to a faster convergence of the algorithm (fewer tracks needed), and helps connecting distant detector elements.

ST Alignment Results : w/o Vertex & Mass-constraint

- The J/ψ mass resolution went from 16.0 to 10.5 MeV/c^2 without/with D^0 vertex and mass constraint.

ST Alignment Results : Module Biased Residuals

IT Sector Biased Residuals

TT Sector Biased Residuals

- With the 2011 selected DOF, we get an RMS of the Bias Residuals of :
 - IT : $\sigma_{res}^{IT} = 15.6 \mu\text{m}$
 - TT : $\sigma_{res}^{TT} = 16.7 \mu\text{m}$

Y Alignment with LHCb Software Alignment

Weak Mode

- Track Y position is retrieved in LHCb using a combination of a X (0°) and a Stereo ($\pm 5^\circ$) measurement.
- This introduces a weak mode in the Alignment :
Relative X shift of X-Stereo modules gives almost the same result than a Y shift of both modules.
- To partially solve the ambiguity, the survey constraint becomes important.
- Competition between relative X ($\sigma_{\Delta X} \approx 100 \text{ } \mu\text{m}$) and Y ($\sigma_Y \approx 1 \text{ mm}$) survey position accuracies lead to unphysical vertical (Y) movements.
- Results : Shift of **4 mm for TT** and **up to 4 mm for IT boxes**.

IT Boxes Y Global Position Difference between Y Alignment and Survey

Silicon Tracker Geometry

Inner Tracker (IT)

Tracker Turicensis (TT)

IT/TT relevant insensitive regions perpendicular to Y axis

- Guard rings that surround each silicon sensors (1 mm for IT and 1.37 mm for TT).
- Bond gap (0.15 mm for IT/TT).
- And, of course, outside the silicon sensors.
- ... Meaning that **Gaps** and **Edges** are expected in **Y Hits distributions** for each module.

Y Alignment using Track extrapolation on Magnet Off data

Edges described by error functions

Y Alignment procedure

- By construction (database), the module must be centered around zero in its local Y frame. Example : The center calculated from both **Edges** of IT modules, in the **local Y Hits distribution**, **must be at zero**.
- Idea : Measure the **Y Misalignment** w.r.t. zero using data taken without magnetic field from a **VeLo segment** that is linearly extrapolated to the IT/TT stations.

Active Length

Length = $|\mu_l| + |\mu_r|$
 where μ_l and μ_r are
 mean parameter ...

... of the left and
 right error function
 respectively.

- From IT module drawings, we expect 108 mm for one silicon sensor and 218.15 mm for two silicon sensors modules → Good agreement !

Silicon Tracker Y Alignment Results

IT Y Position

TT Y Position

- Survey accuracy for full TT System and IT Boxes is ≈ 1 mm and indeed the Y misalignments are measured to be within 1 mm $\rightarrow$ OK !
- The statistical precision of the method is measured to be better than $100 \mu\text{m}$ with LHCb 20 millions Magnet Off data sample.
- Using simulated events, the systematics for full TT System and IT Boxes Y corrections are estimated to be around $100\text{-}200 \mu\text{m}$.

Conclusion

Tracks from Vertex & Mass-constrained Resonances

- The use of tracks from vertex & mass-constrained resonances in the Alignment has been presented.
- The J/ψ mass resolution improved from 16.0 to 10.5 MeV/ c^2 when performing the vertex and mass constraint of the D^0 resonance.
- The 2011 spatial module biased residuals RMS is :
 - IT : $\sigma_{res}^{IT} = 15.6 \mu\text{m}$
 - TT : $\sigma_{res}^{TT} = 16.7 \mu\text{m}$

Y Alignment using Track extrapolation with Magnet Off data

- A novel procedure to align vertically the LHCb ST has been presented.
- The survey accuracy has been confirmed.
- The TT system and IT boxes are Y aligned within a precision of 200 μm .

Thank you for your attention