Tracking and Alignment in LHCb

Florin Maciuc for the LHCb Collaboration

Max Planck Institut für Kernphysik, Saupfercheckweg 1, D-69117 Heidelberg, Germany

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This paper reports on the status of tracking and alignment for the LHCb detector. Topics covered are: tracking efficiency, primary vertex precision, impact parameters, and software alignment of the tracking sensors. Special emphasis is placed on the agreement between data and Monte Carlo. The first physics results are discussed in relation to the alignment and tracking quality, and the LHCb tracking detectors and sensor types are described.

1 LHCb Detector

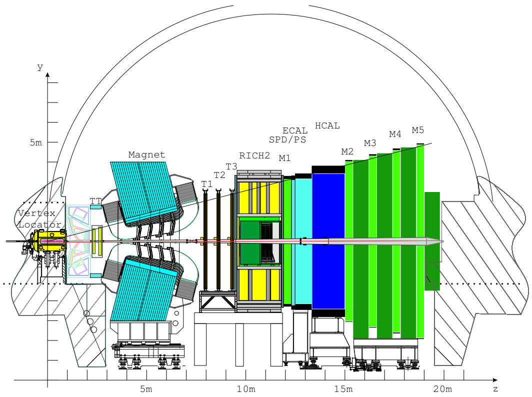

Figure 1: LHCb spectrometer

The LHCb - Large Hadron Collider beauty - detector is optimized for precision measurements of CP violation and rare decays of B-mesons. At a collision energy of 14 TeV and nominal luminosity of $2 \times 10^{32} cm^{-2} s^{-1}$, the expected production rate of $b\bar{b}$ pairs is 10^5 Hz, leading to about 10^{12} $b\bar{b}$ pairs produced per year.

LHCb is a single-arm forward spectrometer with an angular coverage close to the beam between 15 to 300 mrads in the magnet bending plane and 15 to 250 mrads in the transverse plane. The setup is schematically given in Fig. 1, with the Primary Vertex (PV) inside the VErtex LOcator (VELO) to the extreme left. The tracking detectors of LHCb are: VELO, Inner Tracker (IT), Outer Tracker (OT) and Tracker Turicensis (TT), with the latter just before the magnet. The most precise LHCb tracking detector is the VELO, a silicon strip detector with the pitch varying between 38 to 102 μm. This subdetector is split in two halves - to the right and left of the beam - which are retractable. The retracting of the VELO halves allows to protect the silicon sensors during beam injections and during the times when the LHC beams do not have the desired stability.

The OT is a straw tube detector with an estimated hit resolution close to 200 μm. Behind the magnet, both IT and OT have 3 stations, T1-T3, with stereo layers of sensors. The stereo angle sequence of $0^0, -5^0, 5^0, 0^0$ per each station, means the measurement of a trajectory is most precise in the x direction, where the xz plane is the bending plane, z the beam direction and y the main magnetic field component direction. Similarly to VELO, the IT and TT are silicon strip detectors with a pitch of 196 μm and 183 μm, respectively. The IT has sensors that span the LHCb acceptance closest to the beam where the particle occupancy is the highest, and its acceptance is roughly complementary to the OT acceptance.

To obtain an estimate for the particle momentum, the track before the magnet of VELO+TT is matched with its equivalent behind the magnet, which is a particle track in OT or IT. The bending in the particle trajectory gives a precise momentum estimate. This report quotes values based on the 2010 early LHCb data at 7 TeV center of mass collision energy, with low luminosity and closed VELO.

2 Primary Vertex and Impact Parameter Resolutions

To obtain a value for the primary vertex (PV) resolution, for each event the VELO track sample is split in two and the PV position is obtained for each subsample. The difference between these positions gives a distribution with an RMS that approximates the sought resolution. The agreement between Monte Carlo (MC) and data was improved with respect to the first reconstruction, however overall there is a residual disagreement persisting. Remaining misalignments between VELO sensors at a level of 4 μm account for half of the previous discrepancy, with the other half generated by a difference in the hit error estimates between data and MC. The origin of the last effect is explained in more detail in the end of Sec.3, when discussing the IT hit resolution. The PV resolution is given in Tab.1 for each coordinate, when 25 VELO tracks were used.

The Impact Parameter (IP) is the distance of the closest approach to the PV for a track. This parameter is essential in tagging prompt particles and for vertexing. Causes that lead to a finite IP resolution are the random scattering of particles in the VELO and residual misalignments. In addition, as before for the PV resolution, the different VELO hit resolution in data and in MC explains half of the difference in the IP resolution values that are given in Tab.2. The remaining difference is mostly due to misalignments.

$r(\mu m)$	MC	Data
Δx	11.5	15.8
Δy	11.3	15.2
Δz	57	91

Table 1: PV resolutions

	$\Delta\,(IP_X)$ (μm)	$\Delta\,(IP_Y)$ (μm)
Data	$16.2 + 24.6/p_T$	$15.7 + 24.4/p_T$
MC	$11.2 + 19.9/p_T$	$11.9 + 19.3/p_T$

Table 2: Table with IP resolutions

3 Alignment

The nominal geometry of the trackers was first changed to account for the optical survey values. Subsequently, the software alignment uses the survey geometry as the starting geometry, and obtains alignment corrections to the sensors positions. The alignment was done for each detector: VELO, TT, IT and OT, and the final alignment precision of the relevant coordinate was estimated to be much lower than the intrinsic hit resolution - e.g., the residual misalignment in x for an IT sensor is estimated to be about 15 μm, less than the intrinsic hit resolution of 50-60 μm for IT. We have already seen that the VELO alignment is precise to 4 μm, and TT has similar alignment precision to IT's.

The quality of alignment can be inferred directly from the distribution of the measurement residuals. These are given for two detectors in Figs.2 and 3. The observed differences between MC residuals and data residuals obtained for the aligned geometry, are mostly the result of

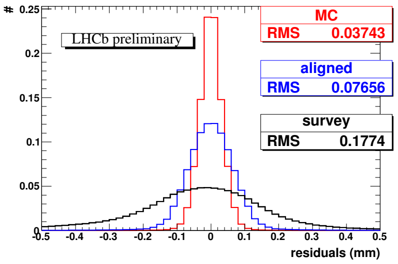

Figure 2: IT residuals

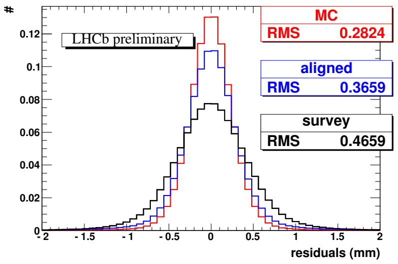

Figure 3: OT residuals

unresolved misalignments. For IT the disagreement appears larger, however in this case the main cause is not the persistent misalignment, but the overestimation in the MC of the charge sharing between the strips. This effect is described in the next paragraphs.

As the other silicon detectors of LHCb, the IT has silicon-strip sensors. The measured position, and implicitly the track coordinate, is given by a cluster of strips on the surface of the silicon sensor. The resolution of the measurement is directly correlated with the number of strips in the cluster. A charge sharing between adjacent clusters increases the number of strips for a measurement, and hence generally increases the measurement precision. In the past, the charge sharing was overestimated, and as a consequence in the silicon trackers the hits are more precise in the MC when compared to real data. The MC was using an average IT hit resolution value close to 40 μm, however, in data it was found out that a more realistic value is about 55 μm. After correcting the hit resolution in the MC, the average was found to be close to 52 μm. TT exhibits the same problem, with almost the same degree of severity. The same problem, but much less severe, was found for the VELO, which explains in part the difference between MC and data for the IP and PV resolutions. After the measurement resolutions were corrected in the MC, the data and MC results look similar. Yet, at the level of alignment there are still problems with some less constrained degrees of freedom, e.g., for IT the alignment in the beam direction poses a problem as this degree of freedom is weakly constrained by the measurements, which are mostly x measurements.

4 Tracking Efficiency

We define the tracking efficiency as the probability for a particle to have a corresponding reconstructed track, when the particle is emitted into the detector acceptance and remains within this acceptance all the way till the last tracking station. This definition includes the hit efficiency and the track reconstruction efficiency, but it does not include any acceptance related efficiency. Because usually the tracks are required to have a precise momentum estimate, we restrict the following topic to the sample of *"Long"* tracks with segments in both regions before and after the magnet. To estimate the tracking efficiency we have used mainly two methods. The first method uses the K_S signal and its two-pion final state. Here, a selection of K_S candidates is done and the final sample is split in two types of candidates:
- candidates with two Long tracks of opposite charge as final state pions;
- candidates with a Long track and a VELO track with an associate calorimeter cluster.
The calorimeter hit behind the last tracking station, insures that the second pion is within acceptance, and provides a way to better estimate the momentum. In Fig.4, the signals for the

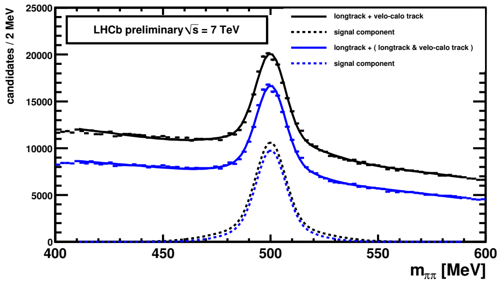

Figure 4: K_S signal for two samples, the dashed lines are after background subtraction

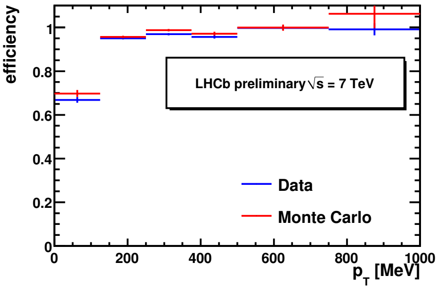

Figure 5: Tracking efficiency vs p_T of K_S

two subsamples are compared. The difference is given by the probability to have a reconstructed track segment in IT, OT respectively, for the second pion. In Fig.5 the close agreement between data and MC is highlighted in a plot of efficiency versus the transverse momentum of the parent.

The second method is based on matching calorimeter clusters and VELO segments, and extracting the tracking efficiency after the magnet by finding the number of tracks which have the corresponding segments after the magnet in IT (OT). The fraction of Long tracks to the total gives an estimate of the efficiency. As the combinatoric background is very large for this method, a cut must be imposed on the number of calorimeter clusters and VELO segments for a given event. The results of both methods are close, with overall efficiency numbers:

1. First method, for data $92.3 \pm 0.3\%$, for MC $93.0 \pm 0.5\%$, ratio 0.99 ± 0.01;
2. Second method, for data $92.8 \pm 1.6\%$, for MC $93.9 \pm 1.3\%$, and the ratio 0.99 ± 0.02.

5 Conclusions

LHCb early data analyses have shown that, overall, tracking leads to similar results in MC and in data. Many problems were fixed, as it is the case with the silicon strip tracker error estimates, missing materials in MC, and alignment of trackers to precision better than the intrinsic hit resolution.

Some disagreements persist - e.g., though MC and data values are close, primary vertex and impact parameter resolutions are different. However, the tracking tools and the present status of the alignment have already allowed very precise measurements. One such measurement is highlighted by the Λ mass peak in Fig.6 where the width of the signal is 2.8 MeV and the mass value within 50 KeV of the Particle Data Group (PDG) value. Other particle masses were found to agree with their corresponding PDG values on the percent level, or better. The physics results of the early data showed that the tracking and alignment quality is sufficient. Additional tuning of the MC and tracking tools is ongoing. The alignment quality is monitored, and we hope to achieve an even better alignment than we have right now.

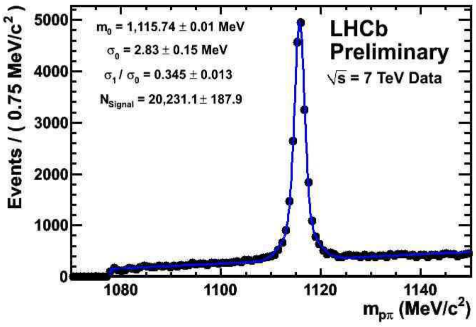

Figure 6: Angular distribution for $b\bar{b}$ pair.