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First alignment of the Inner Tracker using data from the TI-8 sector test

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Abstract

A first software alignment of the Inner Tracker using data from the LHC synchronization test is described. Residual plots are used to adjust the position of the Inner Tracker boxes and layers in the x-direction and to verify the correctness of the survey data. With the corrections determined in this note the position of the x-measuring ladders is known to a precision of 100 μm or better.

1 Introduction

The Inner Tracker (IT) covers a cross-shaped area around the beam-pipe in each of the three tracking stations located downstream of the spectrometer magnet [1]. The layout of an IT station is shown in Fig. 1. A station consists of four independent boxes where each box contains four layers of silicon micro-strip detectors. To the left and right of the beam-pipe the ladders are 22 cm long whilst above and below the beam-pipe the ladders are 11 cm long.

At the end of August 2008, during the start-up of the LHC, the machine carried out several synchronization tests. Runs were taken where a beam of

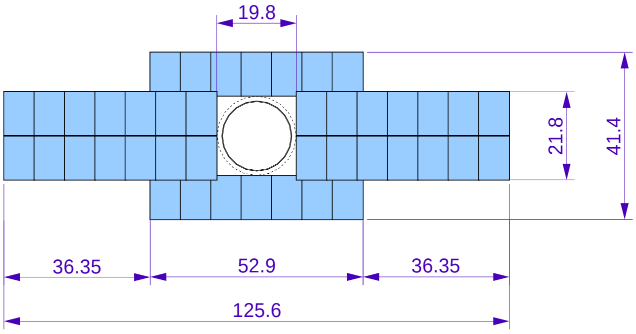

Figure 1: Layout of an Inner Tracker station.

450 GeV protons extracted from the SPS was dumped on to a beam stopper (the 'TED') located 350 m downstream of LHCb. The subsequent spray of particles gave a clear signal in the detector that allowed a first time and spatial alignment of the Inner Tracker. As can be expected given the nature of the test the environment is quite dirty. Figure 2 shows the number of hits in the Inner Tracker during 'TED' running. Typically there are 4000 - 5000 hits observed in each 'shot' on the TED. This is twenty times the occupancy expected in the detector during running at a luminosity 2×10^{32} $\mathrm{cm}^{-2}\mathrm{s}^{-1}$.

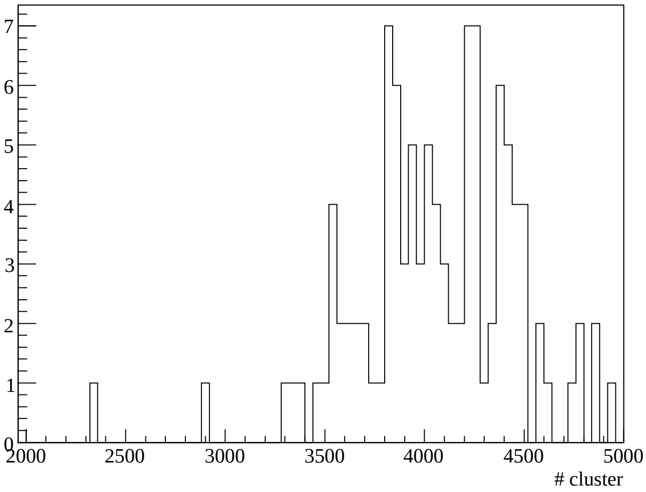

Figure 2: Number of clusters in the Inner Tracker during the TED running.

2 Method

The high occupancy in the TED data creates a challenging environment for track reconstruction. A simple but robust approach has been used to provide a first alignment of the detector boxes and layers in x. The algorithm proceeds as follows. First, a pair of hits is chosen. It is required that the first hit is in the first layer of station 1, the second is in the last layer of station 3 and that both hits are in the same type of detector box. In addition, to reduce background from random combinations it is required that the x-slope of the line defined by the hits is less than 20 mrad and that combination is consistent with originating from the TED (-2 $< x_{TED} <$ 7 m). Next, a search is made for hits in the other x measuring layers of stations 1 and 3. If the pair is confirmed by the presence of another hit in station 1 or 3 within a 0.75 mm window the distance from the hits to the line in the other x layers (called the residual) is calculated. The alignment of the other x measuring layers relative to the first and last layers is then extracted from these residual distributions.

As in Ref. [2] it assumed that due to mechanical constraints the U layers (which were not surveyed) in each station are displaced by the same amount as the corresponding X1 layer. Similarly, the V layers are displaced by the same amount as the corresponding X2.

3 Results

The results presented in the following sections are obtained using Run 30933 taken on the 21^{st} of August. This run consists of around 100 shots on the TED each containing 3×10^9 protons.

3.1 Box Alignment

The first step of the procedure is to align the four boxes in station 2. Figure 3 shows the residual distribution in station 2 for each box using the survey data [2]. In each case a clear peak is seen which corresponds to the correct combination of hits. The smallest peak is for the A-Side where the occupancy is highest. The offsets for the four boxes are obtained by fitting a Gaussian combined with a flat background. In Table 1 the results are summarized. It can be seen that the peak is shifted from zero by up to 0.9 mm. From these values the accuracy of the survey of the box positions in x is inferred to be 0.7 mm. A precision of the survey itself of 0.5 mm is quoted in Ref. [2]. However, other effects such as the fact that the survey was carried out when the detector was in the open position need to be factored in and an overall precision of 1 - 2 mm is quoted in Ref. [2].

For comparison, Fig. 4 shows the plots obtained with the nominal geometry. Apart from the Top Box no clear peak in the residual distribution is seen. This demonstrates that the survey geometry is a better starting point for the reconstruction. Given that sizeable corrections are observed in the survey data compared to the ideal geometry at the level of boxes, layers and ladders this is not unexpected.

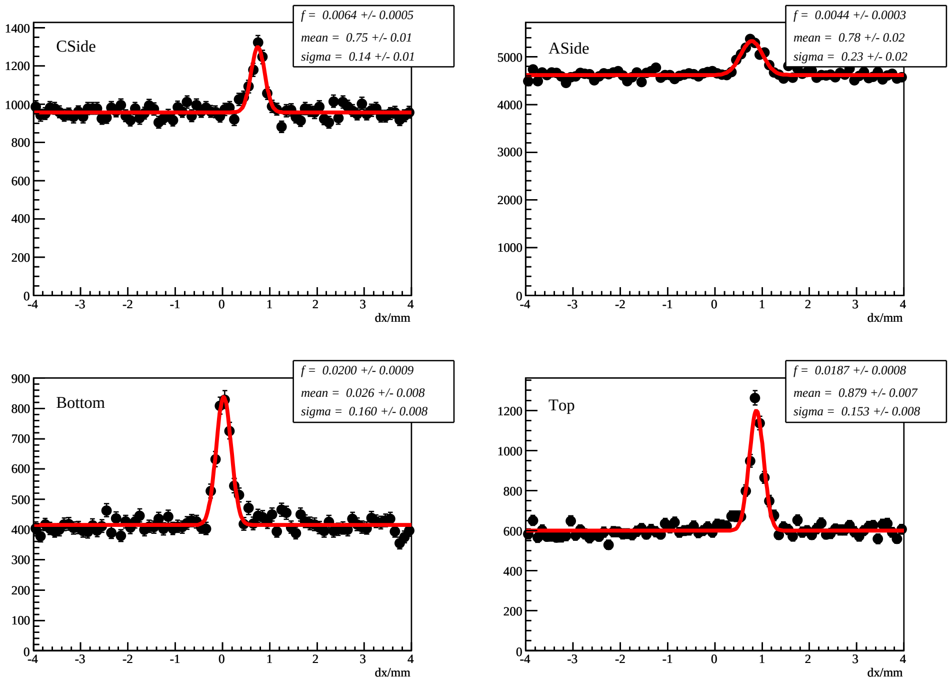

Figure 3: Residuals in station T2 using the survey geometry.

3.2 Layer Alignment

In a second step the positions of the individual layers in T2 and the unconstrained layers in T1 and T3 were adjusted. For the layers in T2, as in the

Box	**Tx/mm**
CSide	0.75
ASide	0.78
Bottom	-0.03
Top	-0.88
RMS	0.7

Table 1: Translation in x for the four detector boxes in T2, relative to the survey Δ, in the local frame. The RMS is calculated relative to zero displacement, i.e. assuming the survey is perfect.

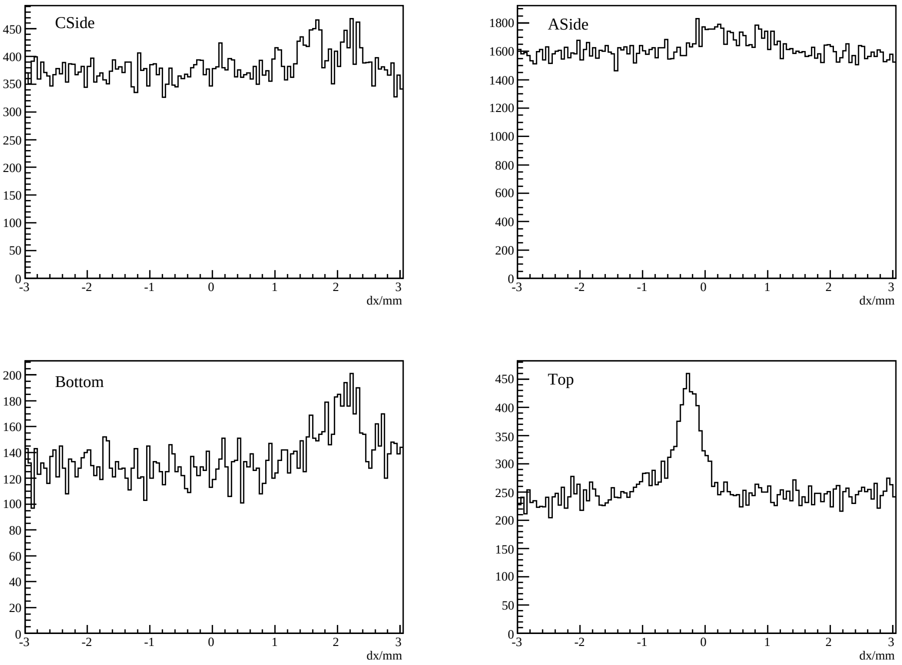

Figure 4: Residuals in station 2 using the nominal geometry.

box alignment, a fit to a Gaussian together with a flat background was made. The uncertainty on the fitted value of the offset is 10 μm. In the case of the layers in T1 and T3 this model is not appropriate as there is an additional non-flat background component due to the high track density and hit selection procedure. Therefore, for these layers the position is adjusted such that the peak is centered on zero. The offsets found relative to the survey are summarized in Table 2. From these numbers the precision of the survey is estimated to be 140 μm. This should be compared to the expected value of 50 μm given in Ref. [2]. A possible reason for the discrepancy is the effect of layers rotations which are not taken into account in this procedure.

Layer	**Tx/mm**
ITT1CSideX2	-0.10
ITT1ASideX2	0.04
ITT1BottomX2	-0.20
ITT1TopX2	0.09
ITT2CSideX1	0.06
ITT2ASideX1	0.11
ITT2BottomX1	-0.09
ITT2TopX1	0.04
ITT2CSideX2	0.09
ITT2ASideX2	0.09
ITT2BottomX2	-0.06
ITT2TopX2	0.02
ITT3CSideX1	-0.05
ITT3ASideX1	-0.07
ITT3BottomX1	-0.28
ITT3TopX1	0.30
RMS	0.140

Table 2: Tx for the x layers relative to the Δ(Tx) given by the survey (in the local frame). *Nota Bene*, the local frame of some layers is inverted in x with respect to the global frame.

The precision of the layer alignment has been checked using Run 32484 from the second TED data taking period in September 2008. Using the alignment parameters determined from Run 30933 the layers in T2 were found to have offsets consistent with zero with an RMS of 20 μm.

3.3 Quality of the Ladder Alignment

The width of the distributions for the layers in station 2 allows the quality of the ladder survey and the size of the remaining misalignments to be judged. In Table 3 the σ's are given by the Gaussian fit to the residual distribution. It can be seen that the σ's lie in the range 0.12 to 0.2 mm.

Layer	σ**/mm**
ITT2CSideX1	0.12
ITT2CSideX2	0.12
ITT2ASideX1	0.19
ITT2ASideX2	0.20
ITT2TopX1	0.15
ITT2TopX2	0.13
ITT2BottomX1	0.16
ITT2BottomX2	0.13
Mean	0.15

Table 3: σ of the residual distributions after the alignment procedure.

Four factors determine the width of the residual distributions:

- The intrinsic resolution of the detector.
- Multiple scattering in the detector. The size of this effect depends on the particle momentum. Unfortunately, for the TED running the momentum spectrum is unknown.
- In a high density environment the assumption that the background is flat may not be valid. In the case 'wrong' combinations will degrade the width of the distribution.
- Residual misalignments of the detector ladders.

The size of the first three effects has been studied using Monte Carlo samples generated in DC08 conditions [3]. Events were generated with a particle gun that contained 500 muons 'shot' uniformly over the Inner Tracker surface. This gives a track density of 0.06 particles/cm^2 roughly half that of the TED running. Since the momentum of the particles traversing the Inner Tracker in the TED running is unknown samples were generated with 5, 10, 20, 40 and 80 GeV. Fig. 5 shows the expected width of the distribution as function of momentum for tracks passing through the Top and A-Side boxes. If the particles traversing the Inner Tracker are produced close to the TED it seems reasonable to expect that their momentum is 20 GeV. This would give a σ of 60 μm dominated by the detector resolution. To fully explain the observed resolution in terms of multiple scattering a mean momentum of 5 GeV is needed. The slightly worse performance observed for the A-Side boxes is due to the higher occupancy.

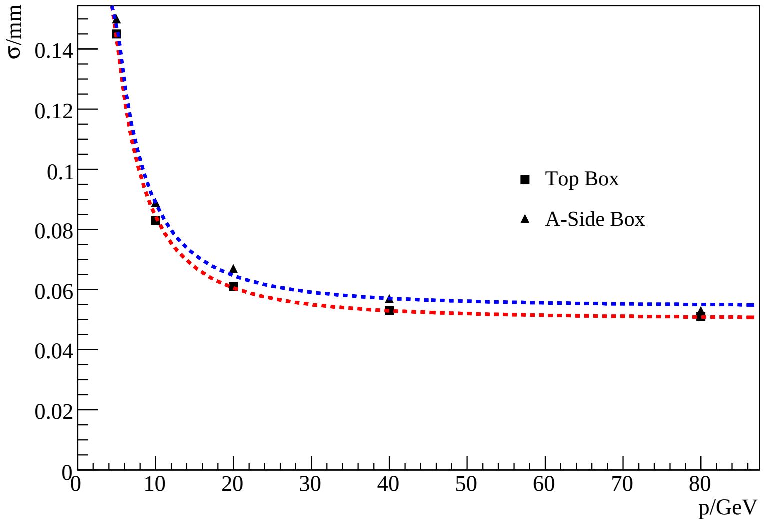

Figure 5: Residuals in station T2 versus p/GeV obtained using the TED Monte Carlo samples. The results of fits to the function form $\sigma = \sqrt{A^2 + (B/p)^2}$ are superimposed. For the Top box the fitted parameters are $A = 0.050$ mm and $B = 0.67$ GeV mm. In the case of the A-Side box the fit gives $A = 0.054$ mm and $B = 0.71$ GeV mm.

To understand the effect of misalignments on the results a Toy Monte Carlo has been used. Tracks were generated with angles in the range -20 to 20 mrad and transported through a simplified implementation of the Inner Tracker geometry. The impact point of the track on each sensor was smeared by 57 μm to simulate the detector resolution and an offset applied to simulate the misalignment of each sensor. This offset was also generated from a Gaussian distribution. If the width of this distribution was chosen to be 100 μm then the $\sigma = 150$ μm observed in the data, is reproduced. Under the assumption that the momentum of the particles is ~ 20 GeV, it is concluded that ladder misalignments of the order of 100 μm remain. This is twice the quoted survey precision of 50 μm. However, the former value is consistent with the size of misalignments seen at the layer level (Section 3.2).

It should be noted that in these studies only the effect of x translations has been considered. A 50 μm degradation of the residual distribution can also be caused by rotations of the order 1-2 mrad. Given the size of the survey corrections effects of this magnitude cannot be ruled out.

4 Summary

In this note a first alignment of the Inner Tracker using data taken during the TED running in 2008 has been described. These studies have verified the precision of the survey made of the Inner Tracker before installation. After the corrections applied here it is concluded that position of the x measuring ladders is known with an effective precision of 100 μm. These studies have focused on the alignment of the x measuring ladders. To align the stereo ladders a full track reconstruction is needed. Given the high occupancy environment of the TED running this is a considerable challenge. Futhermore, since it was not possible to survey the stereo ladders before installation the knowledge of the initial positions of these ladders is poor. Studies of 3-D track reconstruction using the TED data will be described in a subsequent note.

References

[1] The LHCb Collaboration. The LHCb detector at the LHC. *Journal of Instrumentation*, 3(S08005), 2008.

[2] G. Conti and F. Blanc. IT Survey Measurements Analysis and Implementation in the LHCb Software. LHCb-note 2008-069.

[3] Gauss v35r0, Boole v17r0.