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First Studies on Software Alignment for the HERA-B Outer Tracker

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Abstract

A first study of software alignment for the Outer Tracker with the standard HERA-B software environment has been performed, using fully simulated events with an average of five superimposed interactions, and full pattern recognition.

The method of hit selection and estimation of the visible shift are discussed in detail. The method was tested in scenarios with displacements of full layers and individual sectors. The results are analized and show capabilities and principal limitations of software alignment in the Outer Tracker.

1 Introduction

The outer part of the main tracking system in the HERA-B experiment uses drift chamber technology. In the following, we will focus on the outer "pattern tracker". Its multiplanar geometry can be described as four superlayers (cf. fig. 1), each composed by six layers and each layer composed by twelve sectors (cf. fig. 2), resulting in a total amount of 288 planes each of them suitable to have a different misalignment. In the final detector geometry, each plane will be built from "modules" which will lead to additional degrees of freedom. Half the layers are tilted by ± 100 mrad and are the so called stereolayers.

Misalignments are caused by the limited accuracy of initial hardware alignment, inaccuracies in placing the wires inside the cells and from other processes that can depend, for instance, on time (settling) or temperature (dilation).

In situations where occupancies and track density are low enough, like in e^+e^- collider experiments, the software alignment can be achieved doing a loop over the hits belonging to the same reconstructed track, refitting the reconstructed track without the hit we desire to align and placing that hit in the position the refitted track points to. This can not be done in the HERA-B tracker system, since it would need a quantity of CPU time that is not acceptable. Hence, other strategies, which minimize the number of re-reconstructions, must be developed.

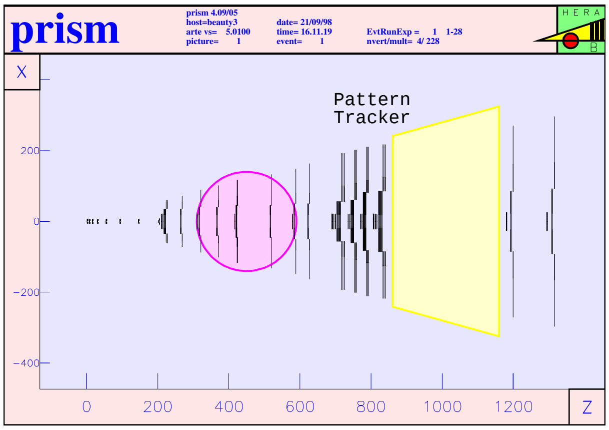

Figure 1: General view of the HERA-B tracker in the Monte Carlo geometry definition which was used for this study

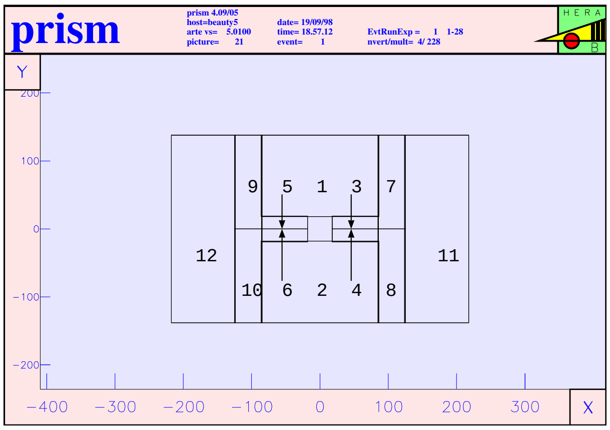

Figure 2: Sector structure of a typical outer tracker superlayer

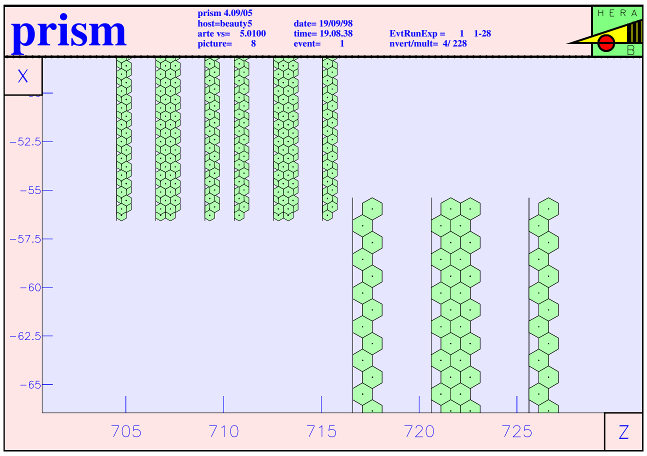

Figure 3: Detail of the pattern tracker, showing the individual honeycomb cells

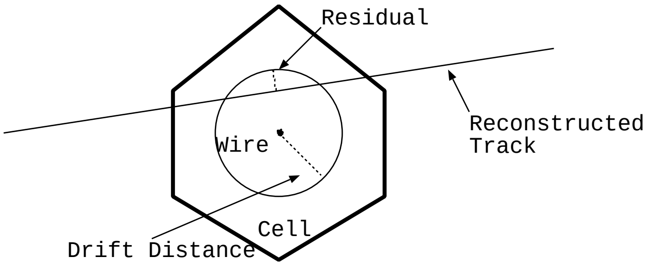

Figure 4: Definition of the residual for an outer tracker hit

2 Method

2.1 Residuals

The "Residual" is the difference between drift distance and the distance from the reconstructed track to the wire (cf. fig. 4), signed according to the side on which the particle crosses the wire. The drift distance corresponds within resolution to the spatial distance between the incident real particle and the wire and gives us the position of the impact point in a global and absolute frame (artificial and assumed in the digitization software for simulated events or in the mapping of the detector for the real experiment). The distance between reconstructed track and the wire gives us the position of the impact point related to the frame that comes from all the other planes of the detector. So the residual distribution will be clearly related to spatial differences between the relative position inside the detector and the position in the external frame. And our wish is to minimize this difference, that means all planes aligned in that global frame and, therefore, giving coincidence for global and relative frames.

2.2 Principal Limits of Internal Alignment

Any operation applied to this global frame which transforms a track into another valid track will not be detected by the residuals. Hence, with a linear track model, global translations (3 parameters), global rotations (3 parameters) or global shearing effects (3 parameters) must be detected using other alignment proceedings. The "shearing effect" (ZX, ZY and ZZ) means that we have a dependence on the Z position of the plane for the misalignment in X, Y or Z direction.

We desire to get a (preferably linear) expression between the residual distribution behaviour and many parameters related to the different possible misalignments. To achieve this hope we should try to get the parameters as independent between them as possible. To start from some point we take the misalignment in X direction in HERA-B frame. This misalignment is highly probable and the expected relation between the residual distribution and X misalignment is directly a shift of the residual distribution equal to the projection of the misalignment in the local X direction, so this shift will be the first parameter.

2.3 Computing Residuals in the Outer Tracker

The drift time can be converted to the distance to the wire, and that means we have a not resolved cylindrical symmetry. For residuals this mainly means that we have a left-right ambiguity when computing them. We really do not know at which side of the wire the particle crossed the chamber.

When computing the residuals as the difference between drift distance and distance from the reconstructed track to the wire, we are avoiding this ambiguity and we are taking the side that makes the residual smaller. Of course, it introduces some effects in the residual distribution. If they turn out severe enough to make us unable to obtain good results, we could study numerically those effects and afterwards compensate them.

2.4 Hit Selection

A residual involves a hit and a reconstructed track, and this residual will be relevant for misalignment studies if the hit and the track come from the same real particle. We must take care about including in the residual distribution as meaningful residuals as possible, and, at the same time, avoid the inclusion of uncorrelated residuals.

- Hit strategy: We take all hits in the detector, if the hit is used by Ranger to reconstruct a track we compute the residual with this reconstructed track. If not, we look for the reconstructed track that minimizes the residual. In our investigation, we can test if the hit and the track have the same Monte Carlo origin, that will mean we got a right connection, or not, it will mean background. Proceeding in this way we take into account all the hits and all the meaningful information for our studies, however we obtain a large quantity of background.

- Track strategy: We follow all reconstructed tracks crossing the planes. When a plane is crossed we look for the hit used by Ranger to reconstruct that track and compute the residual, if it does not exist, we look for the hit that minimizes the residual, when no hit in the plane no residual is computed. In our investigation, we can test if the hit and the track have the same Monte Carlo origin, that will mean we got a right connection, or not, it will mean background. Proceeding in this way, we could lose some hits and its information and count multiple times others. On the other hand, the background is smaller than in the hit strategy.

2.5 Shape of the Residual Distribution

If no misalignment exists, the residual distribution should be centered in the zero position. Its height depends on the occupancy or the number of reconstructed tracks (depending on the followed strategy), and the width should be similar to the resolution in the drift chambers for the drift time, if the background is not taken into account, that is approximately 200 μm multiplied by a factor that comes from the ratio between the number of degrees of freedom over the total number of hits for each reconstructed track. However, effects like ghost tracks or erroneous left-right assignments in the reconstruction process increase the width, and, on the other hand, left-right ambiguities in the residual computation can decrease it (cf. fig. 5).

The background can be statistically studied and understood. For the non-reconstructed hits the background is an exponential distribution centered in zero and the width depends on the track density. For the reconstructed hits the background is a gaussian distribution centered in zero and the width depends on reconstruction parameters and drift time resolution. However, many effects, like right-left ambiguities and the reconstruction process itself, convert the exponential in something non-analytical and difficult to be fitted. On the other hand, the gaussian is created by the reconstruction process and is the left-right ambiguity which mainly distorts its shape.

The widths of the residual distribution coming from reconstructed hits and its background are quite similar, and those for the non-reconstructed hits and its background are a factor of magnitude different (greater for the background).

When a misalignment in the X axis, in the local coordinates, is introduced, one expects that the mean of the residual distribution will move as this misalignment. A misalignment in Y direction, in the local coordinates of the plane, would be never detected by the residuals, because that is the direction of the wires. In HERA-B coordinates we must take into account the stereo angle, so the projection of the misalignment in the local X will be seen, not the projection in the local Y.

2.6 Estimation of Misalignment

The long-term goal is to establish a robust, automatic procedure to estimate the residual shift due to misalignment. With regard to the varying background contributions, we will not look for the mean of the residual distribution, instead we will look for the position of the maximum in the distribution.

We expect that the position of the maximum of the residual distribution will tell us the misalignment. And we will consider this shift as the detected misalignment.

3 Results

3.1 Data Sample

We are using 50 $b\bar{b}$ interactions mixed with, on average, four inelastics and use 50 μm for the binning if not otherwise stated. In the Pattern Tracker both strategies give similar results and both can be used. However, next showed sections only use track strategy.

3.2 Local Misalignment

In the following, we investigate the shift of the maximum when we only disalign complete layers.

3.2.1 Misalignment of a Single Layer

We see that the detected misalignment is always lower than the applied one up to a misalignment of about 1mm (cf. fig. 6). In this range, the majority of the hits will be accepted by ranger and reconstructed, and this behaviour may be caused by the "pull" of the hit on the track in the direction of the misalignment. The amount of reconstructed hits contributes to the total residual distribution highly enough to provoque this uncomplete detection. In the other hand, the residuals coming from non-reconstructed hits are completely sensible to the misalignment, because a non-reconstructed hit can not affect reconstructed tracks.

After a transition, where the hit reconstruction gets harder and the contribution of reconstructed hits lower, the detected misalignment follows almost perfectly the applied one. For higher misalignments, the reconstructed hits are taken almost randomly and are background.

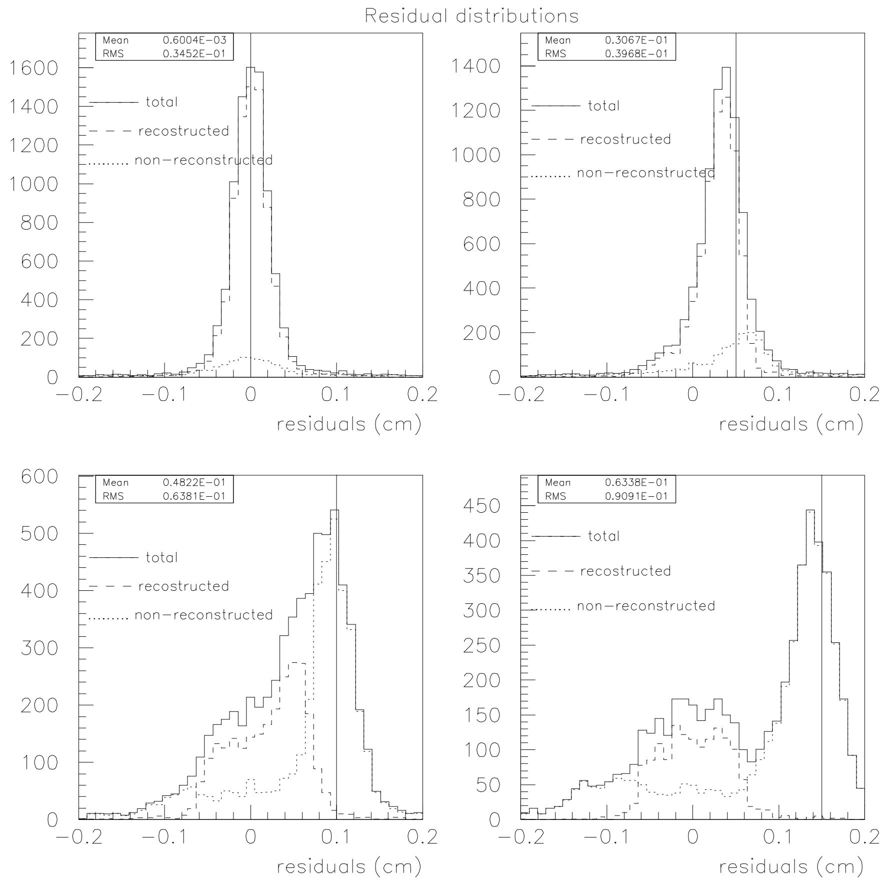

Figure 5: Residual distributions. The line shows the applied misalignment. This is for the single layer 3 in superlayer PC3.

3.2.2 Misalignment of a Double Layer

The results can be understood in a similar way to those for the single layer until we reach a new transition zone at, more or less 2mm (cf. fig. 6). Beyond this point we start to be not able to detect the misalignment. Before this point you should notice that the misalignment is harder to detect than in the single layer case. Although we do not comprehend completely these observations, the fact we have a double number of hits in the plane must be highly correlated to them.

However, it will not affect hardly our studies since they will pay attention to misalignments lower than 1mm (higher ones are supposed to be corrected using hardware techniques).

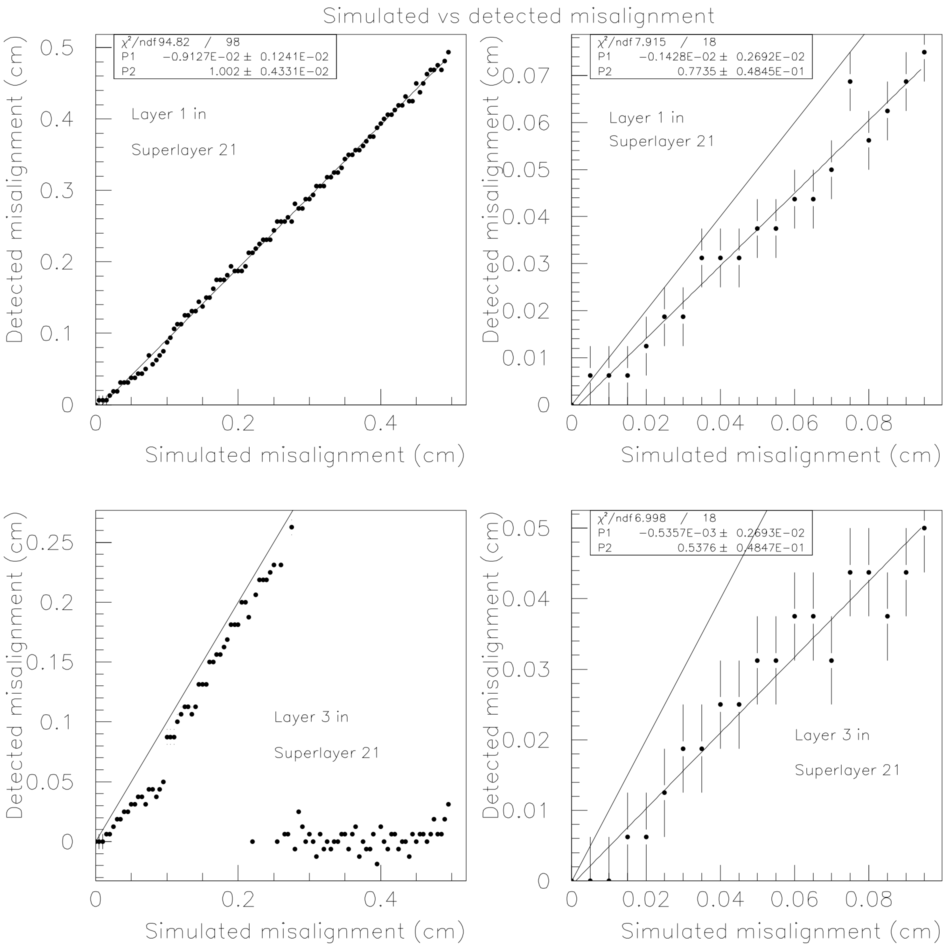

Figure 6: Detection of the misalignment. Layer 1 in superlayer PC1 is a single layer. Layer 3 in superlayer PC1 is a double layer.

3.2.3 Considerations

One might consider to refuse the reconstructed hits and only take into account the non-reconstructed ones. However, the reconstruction package has some parameters that will be optimized during data taking. The optimization of the parameters in the real experiment could relax the constraints to reconstruct a hit, then, for small misalignments, almost all non-reconstructed hits would be background. And we would lose any information about misalignment if using only them. At the same time, for other parts of the tracker, like inside the magnet where we can find particles moving in spiral tracks, using only non-reconstructed hits could give results that do not reflect the misalignment.

When misalignments are lower than 1mm, we see the detection is distorted. So, we could do two things:

- Generate a mapping. That would tell us a relation between what is detected and what should be corrected. The advantage of this method is that you only have to compute residuals one time and then obtain results. However, this mapping depends strongly on Ranger parameters and also in real occupancies and unexpected background. So, doing an acceptable mapping using Monte Carlo seems not an easy work.

- Iterate the process of detection. Applying at each iteration a correction equal to what we detected in the last iteration. Iteration will be necessary anyway in the case of several misaligned planes.

3.3 Everything disaligned

Now we will deal with the situation where many different planes suffer misalignment. We will define and use some quality factors to test our results and find out their goodness and meaning. Quality factors are the width of the total residual distribution, and also the widths and means of the distributions coming from the differences between the parameters of reconstructed tracks and Monte Carlo tracks, so-called "parameter residuals". These parameters are the X_0 and Y_0 coordinates at certain Z_0 (the Z position of the first layer in the Pattern Tracker) and the slopes of the tracks, namely TX and TY.

The initial situation will be disaligned using gaussian-distributed random numbers (mean 0 and width 0.05 cm). To detect these misalignments we fill histograms and finally look for the maximum of the distribution. As has been said before, maximum is better than mean, due to background contribution. The detected misalignment will be corrected and then histograms will be refilled and so on in an iterative process.

After six iterations, normally no more visible misalignment is detected. In this final situation we have already corrected all misalignments that can be corrected using the residual distribution. Those misalignments that can not be corrected come from global symmetries of the track model. These symmetries are global translations (3 parameters), global rotations (3 parameters) and shearing effects (3 parameters). As we are applying misalignments in X, only X global translation, Y global translation, ZX shearing and ZY shearing could happen. The differences between applied and corrected misalignments, that is the undetected misalignment, must be understood in the framework of these symmetries and the parameter residuals should show them. The means of the distributions should be directly related to these parameters. So a global translation in X should be seen in X_0 mean, Y translations in Y_0 mean, ZX shearing in TX mean and ZY shearing in TY mean. (Remember that X_0 and Y_0 are computed not at Z=0 and should be transported).

Let's see what should be the relation between undetected misalignments and those means:

δu is the total undetected misalignment. δx is the undetected misalignment in X. δy is the undetected misalignment in Y. α is the stereo angle.

$$\delta u = \delta x \cos\alpha - \delta y \sin\alpha \tag{1}$$

$$\delta x = z\, t_x + x_0 \tag{2}$$

$$\delta y = z\, t_y + y_0 \tag{3}$$

$$\begin{aligned} \delta u_+ &= (z\, t_x + x_0) \cos\alpha_+ - (z\, t_y + y_0) \sin\alpha_+ && (4)\\ &= (z\, t_x + x_0) \cos\alpha - (z\, t_y + y_0) \sin\alpha && (5) \end{aligned}$$

$$\begin{aligned} \delta u_- &= (z\, t_x + x_0) \cos\alpha_- - (z\, t_y + y_0) \sin\alpha_- && (6)\\ &= (z\, t_x + x_0) \cos\alpha + (z\, t_y + y_0) \sin\alpha && (7) \end{aligned}$$

$$\frac{\delta u_+ + \delta u_-}{2} = (z\, t_x + x_0) \cos\alpha = \delta u_0 \cos\alpha \tag{8}$$

$$\frac{\delta u_- - \delta u_+}{2} = (z\, t_y + y_0) \sin\alpha \tag{9}$$

3.3.1 Misalignment on layer level

We simulate a misalignment of all 24 layers.

The widths of the residual distribution (cf. fig. 7), TX distribution and TY distribution reach a value very similar to the starting one after less than six iterations. Widths for X_0 and Y_0 also get close to the initial value, however here should also be noticed the influence from the means of TX and TY distributions (cf. fig. 8).

Finally we can test numerically, for the showed example, if the undetected misalignment is compatible with the final means of the parameter residuals, and also if there is consistency between results coming from stereo layers and untilted layers (cf. fig. 9).

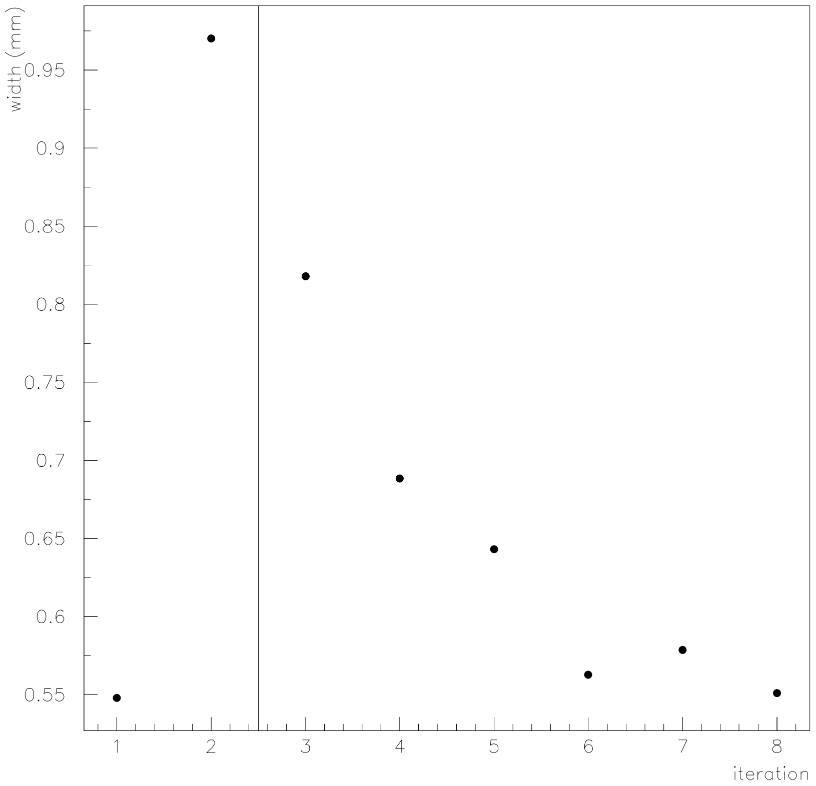

Figure 7: The width of the total residual distribution (including background). Firstly for the non-misaligned situation, then for the misaligned situation, and finally after each iteration (layer level).

$$\frac{\delta u_+ + \delta u_-}{2\ \cos\alpha} = z\ (-0.33 \pm 0.03\ \mathrm{mrad}) + 0.27 \pm 0.03\ cm \tag{10}$$

$$\frac{\delta u_- - \delta u_+}{2\ sin\alpha} = z\ (-1.8 \pm 0.4\ \mathrm{mrad}) - 1.2 \pm\ 0.3\ cm \tag{11}$$

$$\delta u_0 = z\ (-0.34 \pm 0.03\ \mathrm{mrad}) + 0.30 \pm 0.03\ cm \tag{12}$$

$$x_0(transported) = 0.04 \pm 0.03\ cm \tag{13}$$

$$y_0(transported) = -0.1 \pm 0.4\ cm \tag{14}$$

$$t_x = -0.34 \pm 0.02\ \mathrm{mrad} \tag{15}$$

$$t_y = -1.8 \pm 0.4\ \mathrm{mrad} \tag{16}$$

We see that the results coming from the fits and the parameter residuals (see the figures) are consistent within the obtained precisions.

The widths of the X_0 and Y_0 distribution show that the resolution of the drift chambers is about 200 μm (for Y_0 you should multiply by 0.087156, that is $sin(\alpha = 100\text{mrad})$). Here we do not have ghost effects and we can see that the width is smaller than 200 μm because the ratio between the number of degrees of freedom, that is the number of hits in the track minus the number of parameters (4), and the number of hits in the track is always lower than 1.

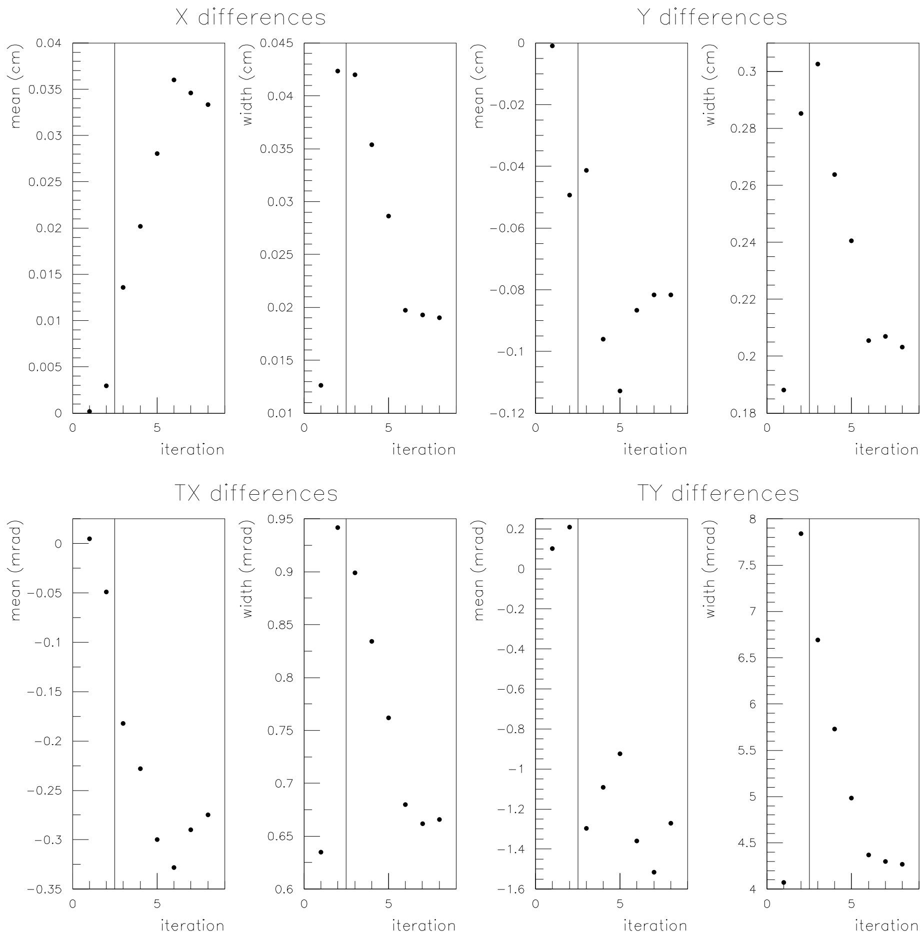

Figure 8: Residual Parameters. Firstly for the non-misaligned situation, then for the misaligned situation, and finally after each iteration (layer level).

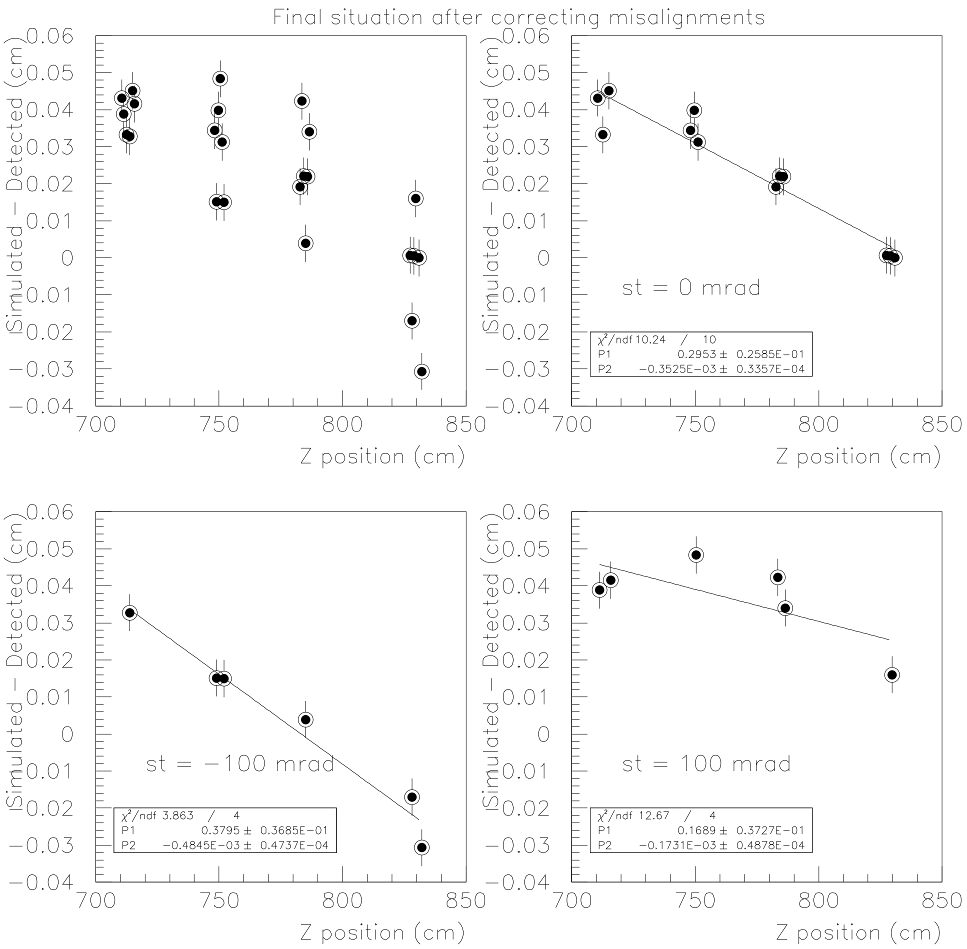

Figure 9: Undetected misalignment after six iterations (layer level).

3.3.2 Misalignment on plane level

We disalign every sector of every layer, corresponding to 288 planes. 200 $b\bar{b}$ mixed with 4 inelastics are used. We iterate six times. Bin size is 100 μm.

The obtained results show that the alignment is achieved quickly (cf. fig. 10), but the sectors are aligned independently (cf. fig. 11 fig. 12). There are not enough tracks with high slopes to provoke observable correlations for the alignments of different sectors.

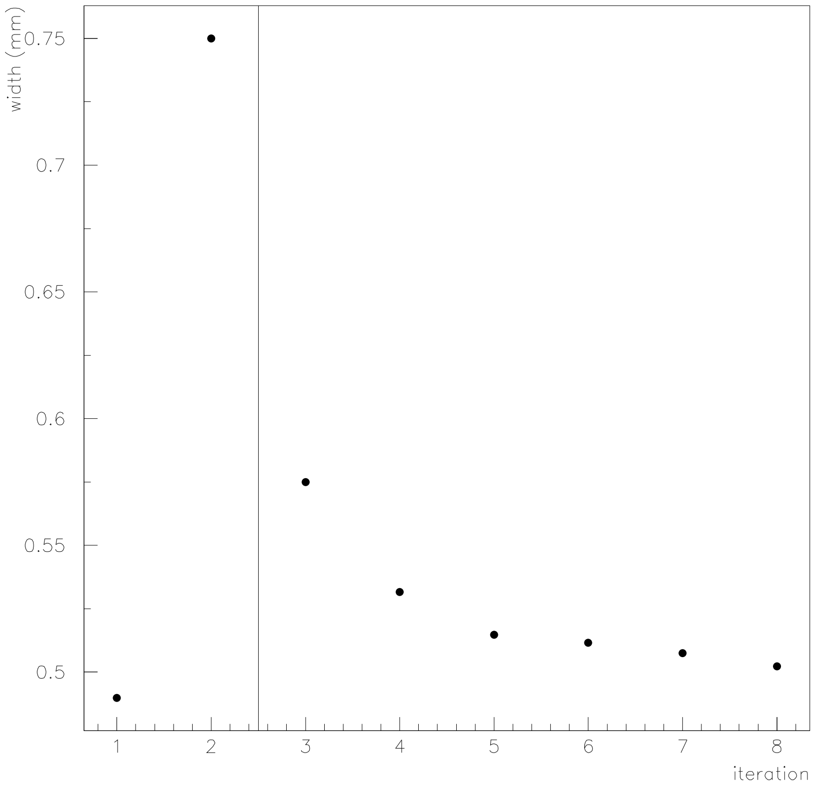

Figure 10: The width of the total residual distribution. Firstly for non-misaligned situation, then for misaligned situation, and finally after each iteration. Plane level.

Selecting those tracks with high slopes that cross different sectors or tracks passing overlap regions between sectors, we would be able to make an inter-sector alignment. However, we need a larger amount of statistics to do so, maybe increased in a factor 100 (magnet on is better than magnet off for this purposes because the magnet makes a de-parallelizing effect for tracks that will cross the pattern tracker). Tracks that cross different sectors are not typical ones, due to the kinematics of the experiment and geometry of the detector, and those that do that are more susceptible than others to come from soft particles or scattered ones.

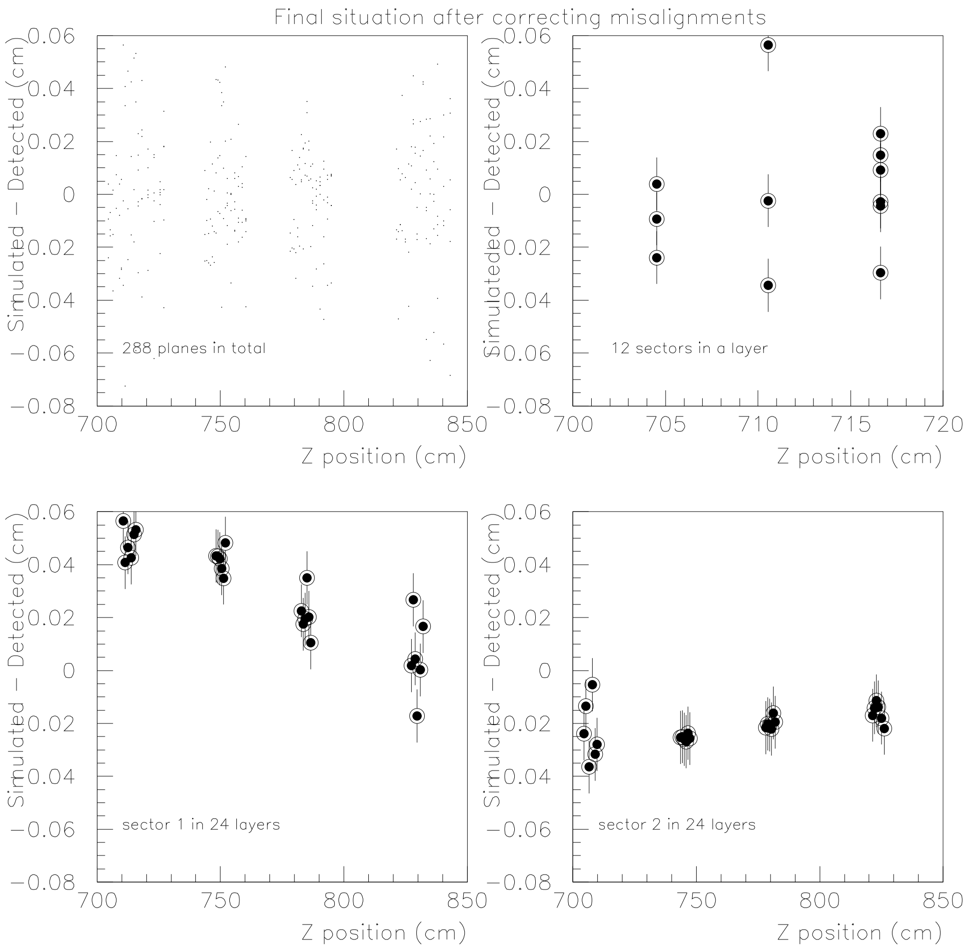

Figure 11: Undetected misalignment after six iterations. The plots show that different sectors are aligned independently (plane level).

When vertex information will be included and we will know about the existance of a common starting point of several tracks, this inter-sector alignment will be helped by just demanding that tracks start in that vertex position. Using this information no relative translations could exist between sectors.

The usefulness and reachable accuracies when including this information in the software alignment have not been studied.

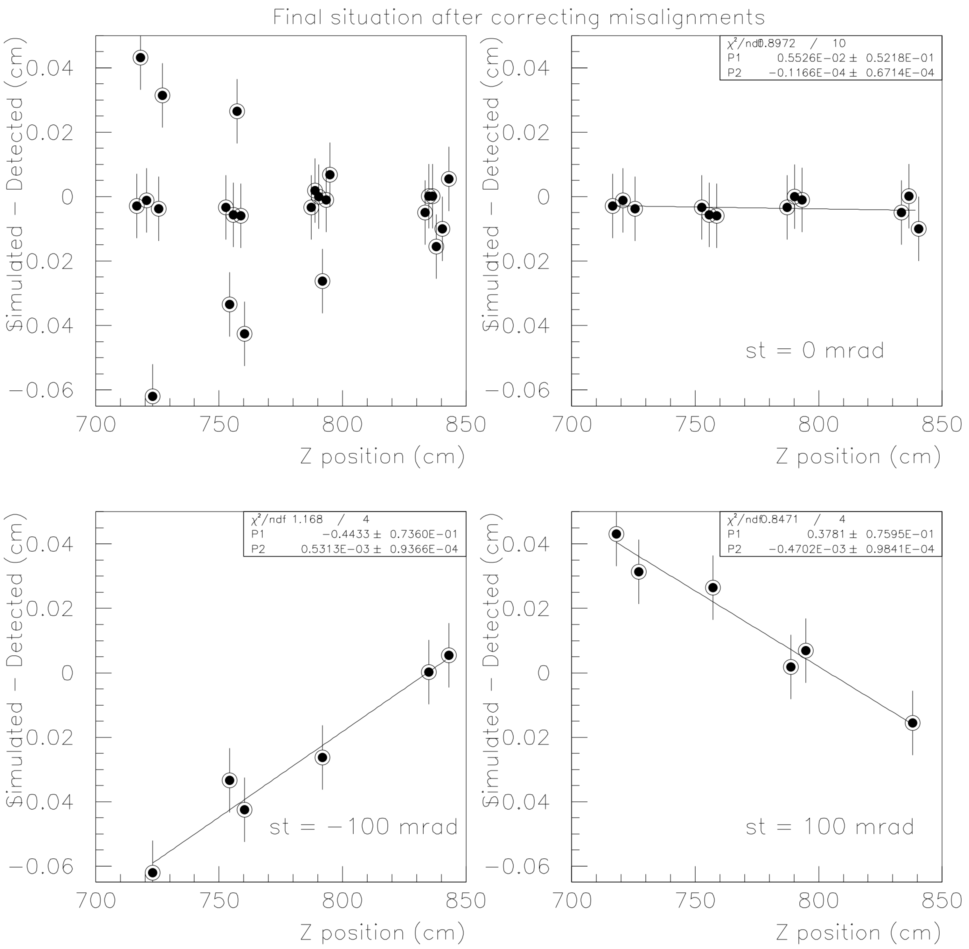

Figure 12: Difference between applied and detected after six iterations. Details for sector 9. Plane level.

4 Conclusions

- For misalignments in the XY plane due to translations, alignment can be achieved determining the position of the maximum of the residual distribution and using an iterational process of detection and correction. With a rather small amount of events and iterations we are able to align the Pattern Tracker with a precision of an order of magnitude better than expected from hardware alignment.

- Global symmetries that transform a track into a track are not detected by the residual distribution.

- Due to the geometry of the experiment and Pattern Tracker, alignment between different sectors in the layers needs a special effort or external help like vertex information.

- The obtained results encourage us to continue working on this way. This was the first step, and now we should include other types of misalignments and new parts of the tracker detector to go further in the software alignment of the outer tracker.

5 Acknowledgements

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