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DATA-DRIVEN ALIGNMENT OF HERA-B OUTER TRACKER

I. Belotelov [1], *A. Lanyov* [2], *G. Ososkov* [3]

Joint Institute of Nuclear Research, Dubna, Russia

In this paper, results of applying a method of internal alignment of HERA-B OTR PC chambers are discussed. The method is based on simultaneous fit of the track and alignment parameters using Millepede matrix reduction and singular value decomposition. After extensive tests of the method on different Monte-Carlo models, a number of studies have been done using real data taken by HERA-B in a 2002–2003 run period. Misalignment influence on reconstruction of individual tracks and physics signals, decays of J/ψ and K_S^0, has been studied.

В данной работе представлены результаты применения метода внутреннего геометрического выравнивания внешней трекинговой системы эксперимента HERA-B. Метод основан на одновременном определении параметров треков и геометрических поправок, с использованием процедуры редукции матрицы нормальных уравнений метода наименьших квадратов, и сингулярном разложении для определения числа внешних степеней свободы. После детального изучения на различных моделях Монте-Карло метод был применен для данных, измеренных в эксперименте HERA-B в 2002–2003 гг. Было также изучено влияние отличия реальной геометрии установки от номинальной на реконструкцию отдельных треков и физических сигналов — распадов J/ψ и K_S^0.

INTRODUCTION

Modern complex detectors can be considered as an assembly of many separate modules, positions of which can be displaced during assembling and the detector maintenance despite of any preventive means. Therefore, an alignment procedure is needed to detect possible distortions. We follow here a concept of a data-driven alignment, i. e., the use of data sets of real measurements produced by the tracking system. Misalignment of detector modules can be found by analyzing residuals between the measured values and fitted track coordinate. Several approaches are suggested to be used for track-based alignment; in our previous paper [1] they have been discussed and optimal strategy has been selected and studied in detail with full Monte Carlo model of HERA-B Outer Tracker.

The HERA-B OTR geometry was described in [1]. Since OTR PC geometry is rather complicated and track multiplicity is high, in order to provide accurate results all the internal parameter correlation should be taken into account, external degrees of freedom should be known and properly fixed.

[1] E-mail: Ivan.Belotelov@jinr.ru
[2] E-mail: lanyov@cv.jinr.ru
[3] E-mail: Gennadi.Ososkov@jinr.ru

1. TEST ON DATA

1.1. Track Selection. To apply our alignment algorithm to data, we should develop the track selection strategy, which will provide reconstructed tracks satisfying some precondition of linear least squares fit (LSF).

Because of high track multiplicity in OTR, hit residual distribution has a large tail. In order to satisfy LSF precondition on limited covariance matrix, we have to apply a cut on residual, so it limits initial misalignment Millepede could detect. In order to manage this problem, our procedure should be used only after some coarse alignment is applied. Since the autumn of 2002 HERA-B has been using magnet-off runs for alignment purposes. For OTR alignment on magnet-off data, tracks reconstructed in vertex detector system (VDS) are propagated as straight lines to OTR, and hit residuals are calculated. Momentum estimation is impossible on magnet-off data, so no momentum cut was applied. Because of big extrapolation length, residual width in OTR was up to a few millimeters, although the magnet-off alignment procedure provides good and stable results.

By using magnet-off alignment the reconstruction of normal magnet-on data has been carried out in ARTE to collect some number of tracks. The following set of cuts to select tracks in ARTE has been used:

• PC reconstructed segment (RSEG) belongs to reconstructed track (RTRA).

• This RTRA has RSEG in VDS.

• If extrapolated PC RSEG points to ECAL, RTRA has to include matched ECAL cluster.

• If extrapolated PC RSEG points to TC, RTRA has to include matched TC RSEG.

• Momentum cut for tracks in the central part of outer tracker ($|x_f| < 100$ cm) is 5 GeV, where x_f is track x at the beginning of OTR.

• Momentum cut for outer tracks is three times lower: 1.7 GeV.

• The number of hits in PC > 20.

These cuts allow us to preselect ≈ 4 tracks/event. After tracks are collected we pass them to alignment procedure. The requirement for track to have at least 20 hits in PC helps us to reject ghost tracks. We tested some additional cuts, and found that it could be useful to require that drift distance be more than $0.15 \cdot$ (pitch size). It helps to reject hits with possible errors in left-right ambiguity solution, because for hits with small drift distance the probability of having wrong left-right ambiguity solution is higher than for the hits with large drift distance. After this hit selection, track should have more than 8 hits.

1.2. Tests and Comparison. To check the alignment quality on data we use some benchmarks. The width of residuals in OTR as well as the average number of reconstructed tracks per event and the number of hits associated with reconstructed tracks could be good measurements of detector internal alignment. Residuals were calculated relative to the track fitted once with all its hits:

$$r = u_{\text{meas}} - u_{\text{fit}}, \tag{1}$$

where u_{meas} is tracks measurement and u_{fit} is fitted track position. Tracks in PC region were fitted by a straight line.

We check different modes of Millepede-based alignment procedure [1–3], and compare it with magnet-off alignment and iterative residual-based alignment [4,5]. For Millepede-based alignment procedure we use 100000 events of normal magnet-on data, and for the comparison we use 10000 events of the same run.

Magnet-off based alignment procedure does not perform track reconstruction in PC region, but extrapolates tracks from VDS. Because of big extrapolation length the precision of individual GEDE positioning is lower than that for alignment strategies based on tracks reconstructed in PC, the residuals in the inner part after Millepede alignment are smaller than those after magnet-off alignment and similar to residuals after residual-based alignment.

In the outer parts GEDEs are longer than in the inner part, possible rotation misalignment could be more visible. Also track slopes t_x in the outer part are larger, and we are able to detect Δz shifts. The residuals in the outer part for Millepede alignment show the advantages of including rotation and Δz shifts (Fig. 1).

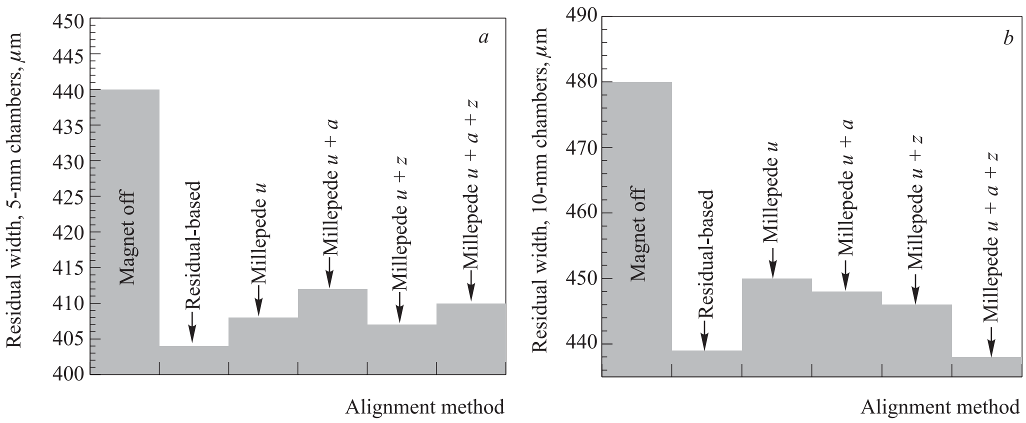

Fig. 1. Width of hit residual in the inner (*a*) and outer (*b*) parts of OTR

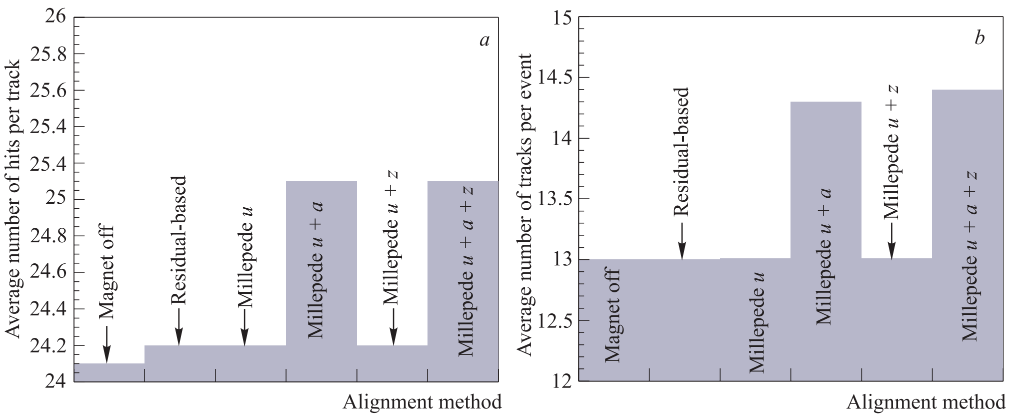

Fig. 2. Average number of hits per track (*a*) and average number of tracks per event (*b*)

Figure 2 shows that the tracking procedure is especially sensitive to rotational misalignment — after including corresponding corrections both track and hit efficiencies are improved. Improvements from including Δz and α parameters come mainly from 10-mm modules, while short modules in the inner part are insensitive to the rotational misalignment.

2. OTR MISALIGNMENT INFLUENCE ON RECONSTRUCTION

Several different approaches were suggested to estimate alignment corrections for HERA-B Outer Tracker (OTR) modules [4, 5]. Different indicators are used now to estimate the quality of alignment corrections provided by different methods.

Here we suggest that simple check should be used to estimate an influence of OTR misalignment on the quality of data taken.

In order to simulate misalignment, alignment correction for every GEDE in PC was mixed with normally distributed random numbers with different σ:

$$du_i \to du_i + \delta u_i,$$

where $\delta u_i \sim N(0, \sigma^2)$.

A number of samples of alignment files misaligned with random shifts sampled from Gaussian distribution of width 0.001–0.1 cm were prepared and their influence on different reconstruction parameters was studied.

2.1. Internal Outer Tracker Reconstruction Parameters. Figure 3 shows the influence of misalignment on the reconstructed track quality. For this study 10000 events from magnet-on run data were used. The alignment and calibration constants used for this study differ a bit from those used for tests in the previous section, so the results for zero additional misalignment are also a little bit different.

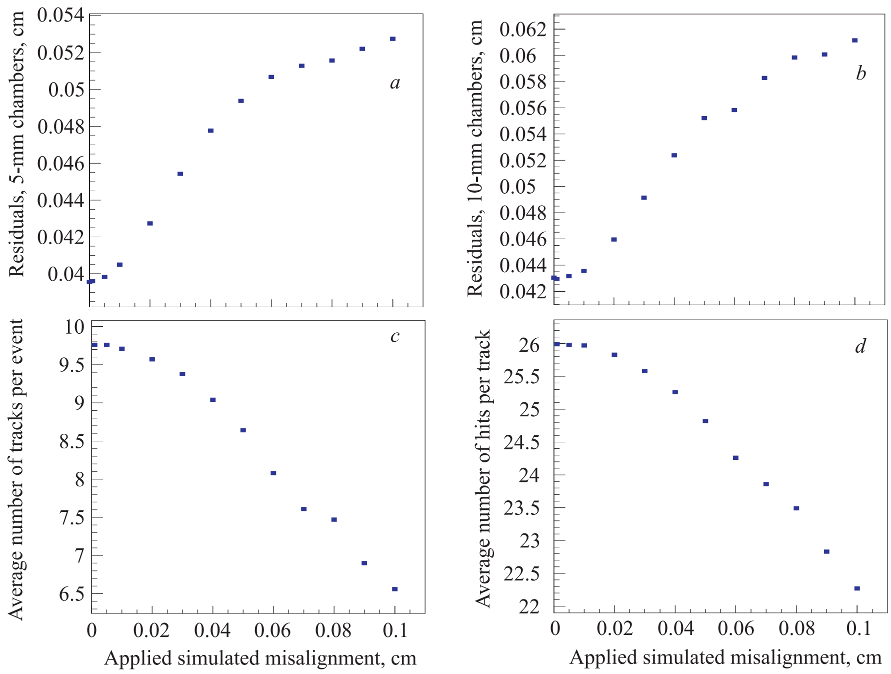

Fig. 3. Width of residual distribution for 5-mm (*a*), 10-mm (*b*) cells, mean number of tracks per event (*c*) and hits per track (*d*) vs. simulated misalignment

First parameters used as benchmark are the width of residual distribution in the inner and outer parts of OTR. It is shown in Fig. 3, *a* and Fig. 3, *b*.

HERA-B Outer Tracker PC chambers consist of 24 honeycomb drift layers. Some of these layers are double layers. Each particle passing the PC could produce up to 2 hits in each single layer. In our study we use all tracks longer than 15 hits in PC. The mean values of the number of used hits per track are shown in Fig. 3, *d*.

Also the average number of reconstructed track segments in PC was watched. They are shown in Fig. 3, *c*.

When no misalignment is applied, the width of residual distribution in the inner part is $\approx 400\ \mu$m. Increase of the residual width in the inner part of PC is much smaller than applied misalignment. If misalignment is smaller than 100 μm it hardly affects residuals, because it is of the same order as multiple scattering, and the fitter can tolerate it. Residuals are most sensitive to misalignments $\approx 100-500\ \mu$m. If misalignment is greater than 500 μm, hits are recognized as outliers and are not included in track; therefore, residuals are hardly affected, but the tracks length is decreased.

2.2. Parameters of Reconstructed $J/\psi \to \mu\mu$ Decays. To estimate misalignment influence on reconstructed J/ψ distribution, we measure the width of $J/\psi \to \mu\mu$ peak and number of events under J/ψ peak as a function of applied misalignment (Fig. 4). For this study, special $J/\psi \to \mu\mu$ selection was used, it contains $\approx$ 2000 $\mu\mu$ pairs (J/ψ candidates and background with di-muon mass greater than 2.5 GeV).

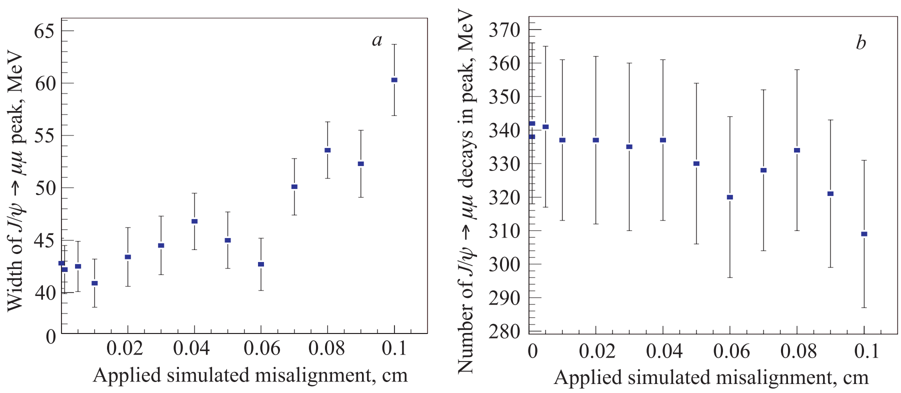

Fig. 4. Parameters of $J/\psi \to \mu\mu$ decays vs. simulated misalignment. *a*) Peak width; *b*) number of events under the peak

The plots show that if misalignment is smaller than a few hundred microns, J/ψ is hardly affected.

2.3. Parameters of Reconstructed K_S^0 Decays. To estimate misalignment influence on reconstructed K_S^0 distribution, we measure the width of K_S^0 peak and number of events under K_S^0 peak (Fig. 5). We used part of statistics containing 100000 events for this study.

K_S^0 seems to be a bit more sensitive to OTR misalignment than J/ψ, but still misalignment smaller than a few hundred microns does not seriously affect the distribution.

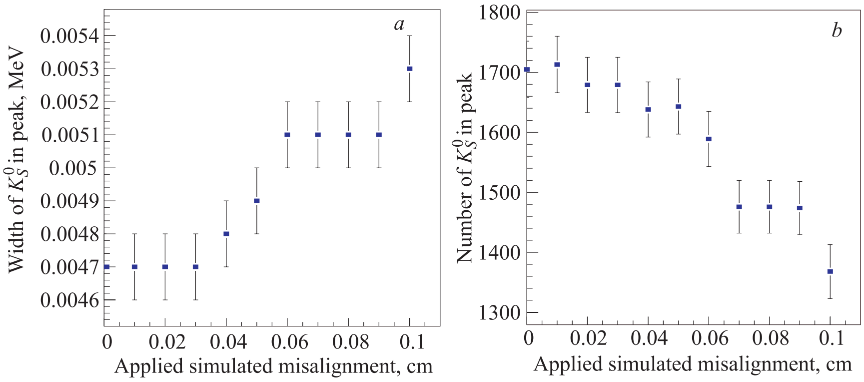

Fig. 5. Parameters of reconstructed K_S^0 decays vs. simulated misalignment. *a*) Peak width; *b*) number of events under the peak.

CONCLUSION

A method of detector alignment using simultaneous fit of track and alignment parameters was applied for data taken by HERA-B in a 2002–2003 run period.

Linearization of the alignment problem proposed in [1] has been used.

The method appears to be suitable to solve the problem with $\approx 10^6$ track parameters and $\approx 10^3$ alignment parameters.

Test on the data shows that on the one hand this method allows one to reach high precision of individual GEDE positioning, and on the other it allows one to keep global degrees of freedom fixed. Alignment corrections for some run periods were stored in HERA-B alignment database and used for reconstruction.

An additional study on data has been done to check the influence of OTR PC misalignment on the reconstruction of tracks and J/ψ and K_S^0 decays.

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