The alignment of the BESIII drift chamber using cosmic-ray data

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Abstract. BESIII experiment adopts a drift chamber as the central tracking detector. Big distortion of the chamber due to mechanical imperfection causes bad momentum resolution. Software alignment is the only possible strategy to estimate the displacements of sub-endplates of the chamber. We have developed an alignment software in the framework of the BESIII Offline Software System. Cosmic-ray data are used in preliminary alignment. The alignment method is introduced in the paper. The results of the alignment are also presented.

1. Introduction

The upgraded Beijing Electron Positron Collider (BEPCII) is a high luminosity, multi-bunch collider with a design peak luminosity of $10^{33} cm^{-2} s^{-1}$ at 1.89 GeV [1]. The BESIII detector is designed for high-precision measurements and new physics searches in this energy region [2]. These goals require that exclusive final states from the $e^+ e^-$ collision be reconstructed efficiently and with high resolution. BESIII adopts the drift chamber as central tracking detector, operating in a 1T magnetic field. The chamber is required to provide maximal solid angle coverage, good spatial resolution (130 $\mu m$), good momentum resolution (0.5%@1 GeV/c), efficient tracking down to 50 MeV/c and good dE/dx resolution (6% ~ 7%). In order to meet these requirements, the drift chamber uses a small-cell geometry. The working gas is chosen to be $He/C_3H_8$ (60/40), which, together with the use of other low-mass materials, minimizes multiple scattering.

Displacement of the chamber endplates due to mechanical imperfection in the summer shutdown has great impact on the reconstruction. The momentum resolution of 1.89 GeV Bhabha tracks taken in 2010 is about 26 MeV/c, shown in figure 1, which is much worse than we expected. From the plot of momentum as a function of the azimuth angle which is shown in figure 2, we see big distortion of the chamber. In order to reduce the misalignment effect in the track fit and improve the momentum resolution, software alignment is necessary. Cosmic events are preferred to align the detector. And it is easy to accumulate enough cosmic tracks at the beginning of the data taking. An alignment software has been developed in the BESIII Offline Software System to do the preliminary alignment using cosmic-ray events for the BESIII drift chamber.

2. The drift chamber

Mechanical structure of the BESIII drift chamber is introduced in reference [3]. We give a brief introduction in this paper for the necessary of alignment. The drift chamber radial extent is from 59 to 810 mm. The shape of the endplate is conical to provide the space required by the focusing...
magnets while allowing measurement of charged particles trajectories within \(|\cos\theta| \leq 0.93\). Each endplate consists of an inner section, a stepped section and an outer section (see Fig. 3). Both the inner and outer sections are machined from an integrated aluminum plate, respectively, and a multi-stepped conical structure are used. The stepped section is assembled from a set of 6 aluminum rings interconnected with nonmagnetic steel bands via radial screws.

The drift cell of the BESIII drift chamber has an almost square shape (see Fig. 4); 6796 cells are arranged in 43 circular layers. Each layer contains a field layer (with all field wires) and a sense layer (with alternating sense and field wires). The first eight layers are located in the inner section and all the wires in this section are stereo. There are 12 layers located in the stepped section and each ring contains two layers. Wires in the this section are all axial. The other 23 layers are arranged in superlayers with half cell staggering to solve left-right ambiguity. Each superlayer consists of four layers except the last one. Table 1 shows the configuration of layers.

3. Alignment parameters

The chamber consists of 16 independent sub-endplates. For each sub-endplate there are six free parameters:

- translation in x direction (\(\Delta x\)),
- translation in y direction (\(\Delta y\)),
- translation in z direction (\(\Delta z\)),
- rotation around x axis (\(\theta_x\)),
- rotation around y axis (\(\theta_y\)),

\(\alpha = 0.025899 \pm 0.000064\)
\(\sigma = 1.882380 \pm 0.000075\)
\(n = 1.030 \pm 0.020\)
Table 1. Configuration of the sense layers of the BESIII drift chamber

| Layer | Number of cells in each layer | Type     | Location  |
|-------|-------------------------------|----------|-----------|
| 1 - 4 | 40, 44, 48, 56               | Stereo (-) | inner section |
| 5 - 8 | 64, 72, 80, 80               | Stereo (+) | inner section |
| 9 - 10| 76                           | Axial     | 1st step  |
| 11 - 12| 88                        | Axial     | 2nd step  |
| 13 - 14| 100                       | Axial     | 3rd step  |
| 15 - 16| 112                       | Axial     | 4th step  |
| 17 - 18| 128                       | Axial     | 5th step  |
| 19 - 20| 140                       | Axial     | 6th step  |
| 21 - 24| 160                       | Stereo (-) | outer section |
| 25 - 28| 176                       | Stereo (+) | outer section |
| 29 - 32| 208                       | Stereo (-) | outer section |
| 33 - 36| 240                       | Stereo (+) | outer section |
| 37 - 40| 256                       | Axial     | outer section |
| 41 - 43| 288                       | Axial     | outer section |

- rotation around z axis ($\theta z$).

For axial layers, $\Delta z$ has no influence on the track fit. The contribution of $\theta x$ and $\theta y$ to track $\chi^2$ are very small For stereo layers, the impact of these three parameters on the track fit are small too. We can not estimate them accurately in the preliminary alignment. But they will be taken into account in the further alignment with high precision. Only $\Delta x$, $\Delta y$ and $\theta z$ are most sensitive to the track residual for all layers. So we choose $\Delta x$, $\Delta y$ and $\theta z$ in the preliminary alignment. For the outer section, we estimate its parameters from the BESIII mechanical measurement data. The alignment parameters of the other sub-endplates are obtained from tracks.

4. Alignment method

Displacement of the wire in different directions causes different misalignment effects on the residual. Fig. 5 shows some misalignment effects on the track residuals. Translation in x direction causes dependence of the residual on $\sin \phi$, where $\phi$ is the azimuth angle. Translation in y direction causes dependence of the residual on $\cos \phi$. And rotation around z axis causes a shift of residuals which are independent of $\phi$.

So we can estimate alignment parameters from residual fits. Select those tracks near the endplate. Plot residuals as a function of $\phi$ and fit them to the formular (1):

$$r = c_0 - c_1 \sin \phi + c_2 \cos \phi$$  \hspace{1cm} (1)

where $c_1$ and $c_2$ are estimated values of $\Delta x$ and $\Delta y$, respectively. $\theta z$ can be estimated from $c_0$:

$$\theta z = c_0 / R_{\text{layer}}$$  \hspace{1cm} (2)

where $R_{\text{layer}}$ is the mean value of radii of layers located in the measurement sub-endplate.

Cosmic tracks pass through the drift chamber from up to down. Hits in both sides can be fit to the same track. In order to reduce the correlation, hits in the sub-endplate which is aligned must be removed from the track fit. So we use hits in the outer section to fit the track and align the inner and stepped sections simultaneously. Many iterations are necessary to obtain convergence.
5. Alignment results

After alignment we get all alignment parameters shown in Fig. 6, 7 and 8. We see big shifts of east sub-endplates in x direction. The displacement of the east inner sub-endplate is more than 500 μm.

**Figure 6.** Δx of each sub-endplate after alignment.  
**Figure 7.** Δy of each sub-endplate after alignment.  
**Figure 8.** θz of each sub-endplate after alignment.

Fig. 9 shows the momentum distribution of Bhabha after alignment. $\sigma P$ is improved to
15.5 MeV/c. From Fig. 10 we see that the plot of momentum as a function of azimuth angle becomes much flatter. We use dimu tracks to check the alignment results. Fig. 11 shows the plots of momentum as a function of azimuth angle before and after alignment. From these results we see that the preliminary alignment with residual fits of cosmic tracks is effective to align those sub-endplates with big displacement. Misalignment effects are reduced and the momentum resolution is improved significantly.

![Figure 9. Momentum distribution of Bhabha.](image9)

![Figure 10. Momentum as a function of azimuth angle from Bhabha.](image10)

![Figure 11. Momentum as a function of azimuth angle from dimu.](image11)

Fig. 12 shows the plot of momentum as a function of \( \cos \theta \) of dimu tracks after alignment. From figure 10, 11(b) and 12 we see that misalignment effects still exists. It indicates that the precision of this method are low. We will use another method with high precision based on the preliminary alignment results. We have started the study of Millepede matrix method [4]. In addition, in order to obtain accurate alignment results, it is important to use different data samples to avoid undefined or weakly defined global degrees of freedom [5]. A disadvantage of cosmic-ray data is lack of horizontal tracks. More data sets, including dimu, are taken into account in further alignment. And in order to describe the distortion of the chamber more accurately, more alignment parameters will be introduced.

6. Conclusion
Serious misalignment effects in BESIII drift chamber are obtained in the reconstruction of Bhabha events taken in 2010. Preliminary alignment has been carried out using cosmic-ray
data with residual fits. Locations of some sub-endplates with big displacements are corrected. Misalignment effects are reduced effectively after alignment. The momentum resolution is also improved significantly. Study of alignment methods with high precision has been started.

7. Acknowledgments

Authors wishing to acknowledge assistance from D. Peterson from Cornell University and Yuanbo Chen, Rongguang Liu, Xiaoyan Ma from the Institute of High Energy Physics CAS.

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