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Study of BESIII MUC offline software with cosmic-ray data*

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Abstract Cosmic-ray data of 90 M events have been collected and used for calibration, alignment as well as detector tuning. A special tracking algorithm for the BESIII muon counter is developed and verified with Monte-Carlo simulation and then further confirmed with the cosmic-ray data. The obtained strip resolutions are in good agreement with the design values. A new alignment approach for the BESIII muon counter is confirmed with the cosmic-ray data and proposed to be used in future analysis of experimental data.

Key words Muon counter, reconstruction, cosmic-ray, alignment

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1 Introduction

The Beijing Spectrometer BESIII[1] is a high quality detector, which will be running on the upgraded Beijing Electron-Positron Collider (BEPC II), designed for many important physics targets.

BESIII consists of four sub-detectors: the main drift chamber (MDC), the time-of-flight counter (TOF), the electro-magnetic calorimeter (EMC), and the muon counter (MUC). The muon counter, a gaseous detector based on resistive plate chambers (RPCs), is one of the most important components of the BESIII detector. The main function of the MUC is to measure the position and penetrating depth of charged particles (muon).

This paper introduces the structure of the MUC first, followed by the reconstruction algorithm of the cosmic ray. In Sec. 4, we introduce the cosmic ray sample. Sec. 5 gives the performance of reconstruction. Then we study the calculation of residuals of strips and the alignment of RPC boxes.

2 Structure of the BESIII muon counter

The muon detector consists of the endcap (east and west) and barrel parts. There are 8 detecting layers in the endcap and 9 layers in the barrel, for each layer, it is made of one superlayer, in which two RPC layers and one pickup strip layer are compacted as a sandwich. The total amount of RPC units is 978, and the yielding area is up to 1272 m^2. Its coverage of the solid angle is about 0.83(cosθ), and the width of the readout strip is from 20 mm to 39 mm with 12 mm intrinsic special resolution for all the 9152 electronics channels. A mixture of argon (50%), F134a (42%) and iso-butane (8%) is chosen as the working gas.

3 Reconstruction algorithm for the cosmic ray

In the first data taking of the cosmic ray, the magnetic field is unavailable. In the software[2], there is one MDC reconstruction algorithm, MdcxReco, specially designed for the cosmic ray event without a magnetic field. This algorithm could reconstruct a charged track in MDC by a straight line. With this MDC track from MdcxReco, we then extrapolate it to the first layer of the muon counter to match the hits in the MUC for reconstruction of the MUC track[3]. This method depends critically on the MDC reconstruction efficiency, for some cosmic ray events without long tracks in MDC, the MUC reconstruction efficiency is very low.

We develop an algorithm to do the track reconstruction using the MUC information only. In this algorithm, we first construct a line with two fired layers in one readout dimension, such as the XY or the ZR dimension in the barrel part and the ZX or the ZY dimension in the endcap, then extrapolate the line in each readout dimension to other layers and attach the fired strip if its distance to the expected hit location is smaller than a predefined window. Finally, we combine the two 2D lines to one 3D track. With the attached strips, the track is fitted and some quantities, such as penetrating depth, χ^2, etc., are calculated. A list of the expected fired strips is also saved in order to do a calibration. Fig. 1 shows the reconstruction of an event in the barrel part.

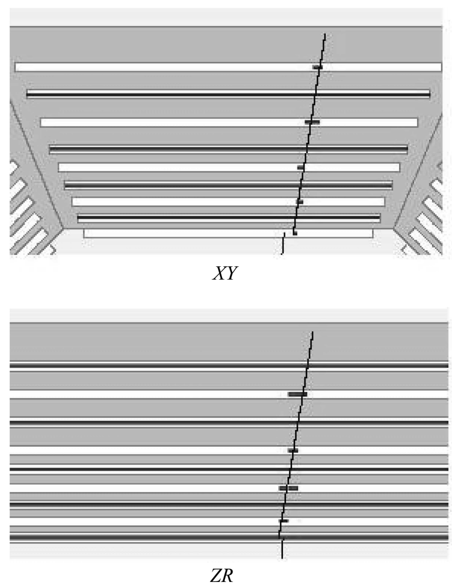

Fig. 1. The reconstruction process.

4 Cosmic ray sample

We use an event generator from ATLAS to simulate the cosmic ray generation. In this generator, the muon fluxes are interpolated at different energy or angle using the data measured by Allkofer[4]. The energy and angle (θ between the cosmic ray and the vertical axis) are sampled according to the experimental data[4, 5]. cosθ is bigger than 0.36 by default. ϕ is sampled in 2π uniformly. The momentum is calculated from energy, θ, and ϕ. The charge of muon is also sampled. The vertex is sampled randomly in a rectangle which is close to the upper surface of the BESIII detector. To keep the sampling real and efficient, the size of the vertex rectangle is chosen to be large enough (6 times longer) than the detector dimension, so the cosmic ray outside this vertex surface could not pass through the BESIII detector.

The output of the cosmic ray generator are momentum, vertex, and charge. A particle keeping this information is generated and put into the BESIII detector simulation[6].

In the cosmic ray data taking, there were two main trigger conditions used. One trigger, LtrkBB, requires two long tacks back to back within about 40° (15 cells) in the drift chamber, and the other, BTofBB, requires two hits back to back within 13 scintillators in the TOF counter. Some physics distributions are sensitive to the trigger conditions. In the Monte Carlo simulation, we choose same trigger conditions with experimental data.

We generate 2000000 cosmic ray events, among which 15028 events pass the trigger. In the next study, this Monte Carlo sample is used to check the performance of reconstruction, and study the feasibility of the alignment method.

As for experimental data, 200000 cosmic ray events in Run2536 are chosen and used in further study.

5 Performance of the reconstruction

The quality of the reconstruction based on the new algorithm can be checked by this Monte Carlo sample. The direction of a track from reconstruction can be compared with that of the MC. The uncertainty of the angle difference between the reconstructed and the simulated track is about 3°. Fig. 2 shows the angle between the cosmic ray in Monte Carlo and that after reconstruction. For a cosmic ray, one up track and one down track can be usually reconstructed, and the uncertainty of angle difference between the two tracks is about 5° which is a little bigger than the above value due to multi-scattering. This means the reconstruction algorithm is reasonable and reliable.

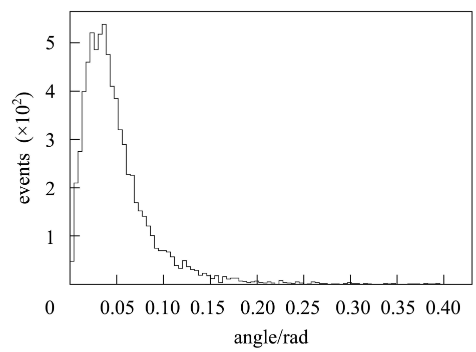

Fig. 2. The angle between the cosmic ray in Monte Carlo and that after reconstruction.

6 Spatial resolution

In the barrel, there are 9 detecting layers. The widths of strips in the odd layers are 37 mm, while the widths of strips in the even layers increase from 18 mm to 35 mm with layers. The intrinsic resolution is theoretically the width divided by $\sqrt{12}$.

The spatial resolution is defined as the spread of the measured position with the predicted one (residual distribution). Since the extrapolated track from the drift chamber is less accurate than the reconstructed MUC track because of larger multi-scattering in the material between the drift chamber and the muon counter, we use the MUC track as the expected or predicted one. In a layer, the predicted hit location is calculated using a track that has been fitted by hits in all layers[7] except the current layer. When two or more adjacent strips in a layer have signals (multiplicity), the hit location used for particle tracking is averaged. The width of the strip is different layer by layer in the barrel part, we take the first layer in the barrel part as an example. With one strip hit in the layer, the standard deviation is 13.7 mm, and it increases to 16.2 mm and 24.4 mm (Fig. 3(a), respectively, for two and three strip hits.

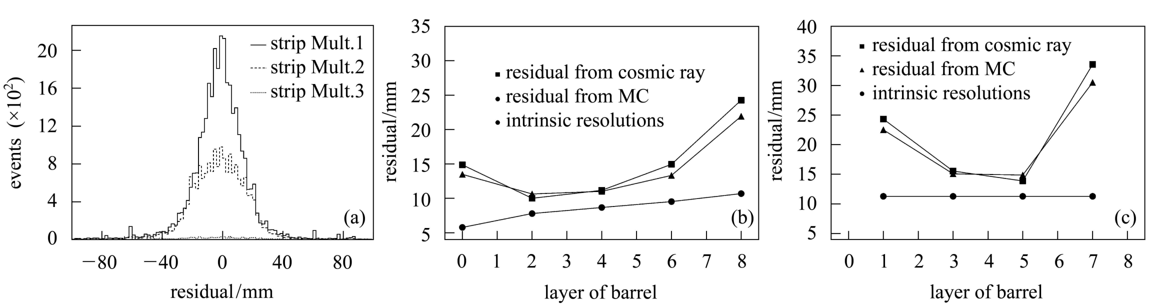

Fig. 3. Graph (a) is the residual distributions for different multiplicities for gap0 in the barrel. (b) and (c) are the residual distributions for the even and odd layers.

The standard deviations in odd and even layers are compared with Monte Carlo and plotted in two graphs (Fig. 3(b, c)) because they have different dimensions and are fitted separately. The resolutions for the first and last layers are bigger obviously than other inner layers, because they have less constraints in the fitting than others.

The spread of the residual distribution comes from the error of the MUC track, the error of track fitting, and the intrinsic resolution. The spatial resolutions calculated in this way are close or bigger than the intrinsic resolutions, but for data and Monte Carlo, they are consistent.

7 Alignment

For the muon counter, there are 8 detecting layers in the endcap and 9 in the barrel, for each layer, two RPC layers and one pickup strip layer are compacted as a sandwich and encapsulated into an aluminum box. The positions of the aluminum boxes were measured when they were placed in the gap of the yoke, but there are still some differences between the real detector and the geometry we used in the software. With the first cosmic ray data, the displacement of the aluminum boxes in the readout dimension can be retrieved. As we have pointed out, the MDC extrapolated track is less accurate (with larger errors) than the MUC reconstructed track, so at an early stage we tried to use the MUC track as a reference for alignment. Suppose one aluminum box has a shift in the readout dimension, the mean value from the residual distribution in this layer will change, but the mean values in other layers will change too because we have used the shift box in track fitting. This method is too complicated to use, and it can not reflect the shift or incline of the whole segment. In this paper, we try to use the Mdc extrapolated track as a reference to provide the predicted hit location. As we will see, although its error is bigger, its mean value can be used for alignment, the alignment we get this way is then relative to the drift chamber.

The rotation of the box in a gap can be neglected and the shift in other dimensions can hardly be retrieved. So the main work for alignment is to extract the shift of boxes in the readout dimension.

7.1 Feasibility study

With the cosmic ray generator, we simulate the cosmic ray event and record the MC information, such as the track positions and directions at the first layer of the muon counter and the outer surface of the drift chamber. In reconstruction, these quantities are calculated and compared with simulation. The angle error at the MDC edge is about 5 mrad, and its position errors are about 0.5 mm in ϕ dimension and 2 mm in Z dimension. The position errors in the first layer of MUC reach 10 mm and 20 mm in dimension because of multi-scattering in the TOF, EMC, and coil. Even though the errors are very big, the mean value is still useful (close to zero).

The distance distribution cannot be well fitted by a single Gaussian. Instead, we chose a double Gaussian (Fig. 4) as the fitting function, and the mean value of one Gaussian with a smaller width is used to calculate the displacement of the boxes.

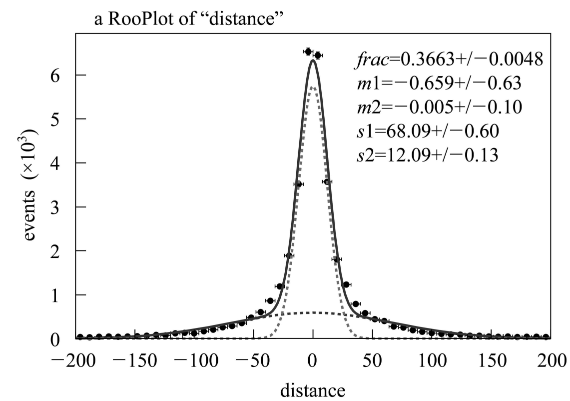

Fig. 4. Fitting of distance distribution with a double Gaussian function.

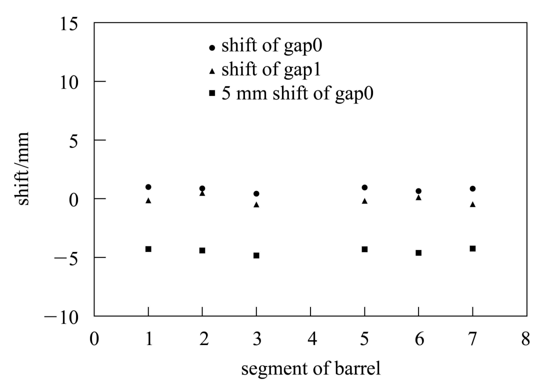

Fig. 5. Systemic displacement of gap0 and gap1 for six segments of the barrel.

We test this new method by Monte Carlo simulation. If we use the same geometrical data in both simulation and reconstruction, the systematic displacement of RPC boxes are supposed to be very small (close to zero). It is indeed the case and can be seen in Fig. 5. Suppose we shift some boxes by 5 mm in reconstruction, we try to use this new alignment method to see if the shift can be retrieved. In Fig. 5, the circular points are the original displacement of boxes in gap0, the quadrate points are the displacement after 5 mm shift in reconstruction. The triangle points are the original displacement of boxes in gap1. The triangle points and circular points are close to zero as is our expectation. The distance between the circular points and the quadrate points is close to 5 mm, which means that this method is effective to retrieve the value of shift. We also study the shift of boxes in gap1, and the shift is retrievable too.

7.2 Extract displacement of boxes from data

With this method and the cosmic data, we retrieve the displacement of the box for each layer of the barrel (Fig. 6(a)). In reconstruction, we compensate for these displacements in the original geometry. The displacements recalculated are close to zero when the new geometry is applied (Fig. 6(b)). We also check it with other cosmic-ray data with the same trigger condition taken afterwards.

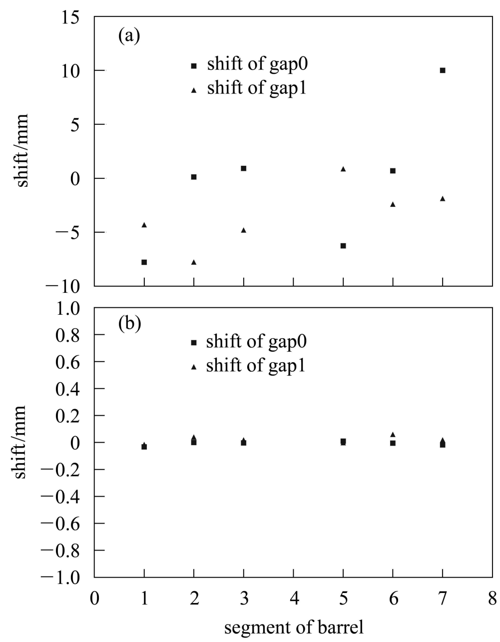

Fig. 6. Graph (a) is the displacement of gap0 and gap1 in six segments of the barrel. And graph (b) is that with new geometry.

The early alignment method with the MUC track as a reference is difficult to use because one move of a box affects the other boxes in the same readout dimension. But this method is still useful. The mean value is close to zero when the same geometry is used in reconstruction and simulation. That means this method could judge whether the geometry we construct is close to the real detector.

With the results of alignment from the new method, we construct new geometry. Then we apply the first method to the cosmic ray data with old and new geometry. The mean value with the new geometry is close to zero and obviously smaller than that with the old geometry.

8 Summary

We develop a reconstruction algorithm using only the muon counter information for the first cosmic ray data taken at the BESIII detector. Some important physics quantities, such as the muon track direction, and spatial resolution are compared with the Monte Carlo simulation, and they are generally consistent. We also developed a new alignment method using an extrapolated track from the main drift chamber. It is proven to be effective by Monte Carlo and currently used for the experimental data.

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