Track segment finding with CGEM-IT and matching to tracks in ODC postprint

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Abstract

The relative differences in coordinates of Cylindrical-Gas-Electron-Multiplier-Detector-based Inner Tracker (CGEM-IT) clusters are studied to search for track segments in CGEM-IT. With the full simulation of single muon track samples, clear patterns are found and parameterized for the correct cluster combinations. The cluster combinations satisfying the patterns are selected as track segment candidates in CGEM-IT with an efficiency higher than 99%. The parameters of the track segments are obtained by a helix fitting. Some chi-squared quantities, evaluating the differences in track parameters between the track segments in CGEM-IT and the tracks found in Outer-Drift-Chamber (ODC), are calculated and used to match them. Proper chi-squared requirements are determined as a function of transverse momentum and the matching efficiency is found reasonable.

Full Text

Preamble

Track Segment Finding with CGEM-IT and Matching to Tracks in ODC

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Abstract: The relative differences in coordinates of Cylindrical-Gas-Electron-Multiplier-Detector-based Inner Tracker (CGEM-IT) clusters are studied to search for track segments in CGEM-IT. Using fully simulated single muon track samples, clear patterns are identified and parameterized for correct cluster combinations. Cluster combinations satisfying these patterns are selected as track segment candidates in CGEM-IT with an efficiency exceeding 99%. The parameters of the track segments are obtained through helix fitting. Several ^{2} quantities, evaluating the differences in track parameters between the track segments in CGEM-IT and tracks found in the Outer-Drift-Chamber (ODC), are calculated and used for matching. Appropriate ^{2} requirements are determined as a function of transverse momentum, yielding reasonable matching efficiency.

Keywords: CGEM-IT, track segment finding, track matching
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Introduction

The Inner-Drift-Chamber (IDC) of the Beijing Spectrometer III (BESIII) [?] has exhibited gradual aging effects. The hit efficiency and spatial resolution will deteriorate over time, ultimately affecting the reconstruction of charged tracks. A Cylindrical-Gas-Electron-Multiplier-Detector-based Inner Tracker (CGEM-IT) has been proposed as a candidate to upgrade the IDC [?].

The proposed CGEM-IT consists of three layers of CGEM detectors. Each CGEM comprises one cathode, three GEM foils, and one anode. The anode readout plane features two types of strips oriented in different directions, which measure the induced charge from charged particles [?]. A GEANT4-based [?] full simulation package has been implemented for CGEM-IT, incorporating detailed detector description and simplified digitization [?]. A cluster reconstruction algorithm was developed in which contiguous fired strips are reconstructed as clusters, with positions calculated using the charge centroid method [?]. The track fitting algorithm for the Drift Chamber, based on the Kalman Filter method [?], was extended to incorporate both CGEM-IT clusters and Outer-Drift-Chamber (ODC) hits, enabling studies of spatial and momentum resolutions for tracks reconstructed within the combined CGEM-IT and ODC tracking system [?].

This paper describes the track segment finding methodology using CGEM-IT and the subsequent track matching between CGEM-IT and ODC.

2 Track Segment Finding with CGEM-IT

Since CGEM-IT comprises three layers, three clusters are typically reconstructed when a charged particle traverses the detector in a magnetic field. The two coordinates of these reconstructed clusters are the azimuthal angle and the position Z along the beam direction, with the detector center taken as the origin. Figure 1 [Figure 1: see original paper] illustrates an example of a charged track and its three induced clusters projected onto the transverse plane.

The selection of correct three-cluster combinations constitutes track segment finding in CGEM-IT. The relationship among the three clusters from a single track can be investigated through the relative differences in and Z between the first or third layer and the second layer. Each combination of three clusters can thus be represented as a point on a two-dimensional plane, where the dimensions are = − and = − (subscripts 1, 2, 3 indicate layer numbers). Similarly, three-cluster combinations can be represented on a two-dimensional Z plane (Z = Z −Z , Z = Z −Z).

2.1 Pattern in

Based on full simulation, correct three-cluster combinations for ± with uniformly distributed transverse momentum p between 0.05 and 1.0 GeV/c and polar angle satisfying |cos | < 0.93 are shown on the plane in Figure 2 [Figure 2: see original paper]. A clear anti-diagonal pattern is observed, with general behavior fitted to a linear function passing through the origin. As shown in Figure 3 [Figure 3: see original paper], the scattered points on the plane can be characterized by a signed perpendicular distance d to the fitted line (negative for points below, positive for points above) and the projected position L along the line. The d distributions at different L are studied and fitted with Gaussian functions to extract the mean and resolution . Figure 4 [Figure 4: see original paper] shows an example of the d distribution for 0.054 < L < 0.108 rad. The obtained mean and resolution values across different L , shown in Figure 5 [Figure 5: see original paper], are fitted to a third-order polynomial function without even terms and a fourth-order polynomial without odd terms, respectively. Based on this parameterization, the central line of the pattern and a selection window corresponding to ±3 for track segment candidates are determined on the two-dimensional plane, as shown in Figure 2.

2.2 Pattern in Z

Correct three-cluster combinations on the Z plane are studied at different transverse momenta using the same simulated ± sample. Figure 6 [Figure 6: see original paper] shows an example for ± with p between 0.15 and 0.25 GeV/c, where a clear anti-diagonal pattern emerges that can also be fitted to a linear function through the origin. As shown in Figure 7 [Figure 7: see original paper], the slope of this fitted line exhibits slight p dependence. Similarly, the signed distance d Z to the linear line and projected position L Z for three-cluster combinations on the Z plane are defined as illustrated in Figure 3. The mean and resolution of d Z distributions at different L Z and p are studied through Gaussian fits (one example shown in Figure 8 [Figure 8: see original paper]). The obtained mean values of d Z on the Z plane are consistent with zero. The resolution of d Z for a given p can be fitted to a second-order polynomial function with only even terms, as shown in Figure 9 [Figure 9: see original paper].

For ± in a specific p interval, the ±3 Z selection area can be determined using the corresponding slope and resolution. However, since particle momentum is unknown before track reconstruction, the 3 Z areas for different p values are merged to define a selection window for charged tracks with p > 0.05 GeV/c, as shown in Figure 6.

2.3 Efficiency of Track Segment Finding

Using the selection windows defined on both and Z planes, three-cluster combinations are selected as track segment candidates in CGEM-IT. Figure 10 [Figure 10: see original paper] shows all three-cluster combinations and those surviving selection for an independent fully simulated ± sample. Combinations inconsistent with the identified patterns arise from clusters induced by electrons from muon decay. The track segment finding efficiency is calculated as the ratio of correct three-cluster combinations after selection to the number of generated tracks. Figure 11 [Figure 11: see original paper] shows the resulting efficiency as a function of p for simulated ±, ranging from 99.1% to 99.7% depending on p . The lower efficiency at low p is caused by muon decay.

2.4 Track Segment Fitting

To quantitatively describe the identified track segments in CGEM-IT, three-cluster combinations are fitted to a helix model with five parameters. Some parameters are defined relative to a reference three-dimensional point called the pivot, which can be arbitrary but is typically taken as the interaction or origin point. The five parameters are: dr, the signed distance on the transverse plane from the pivot to the helix; , the azimuthal angle specifying the pivot relative to the helix center; , the product of particle charge and reciprocal of p ; dz, the signed distance of the helix from the pivot in the Z direction; and tan , the track slope where = /2 − and is the track polar angle.

The Least Squares Method is employed for helix fitting, with the ² defined as:

$$\chi^2_{\text{fit}} = \sum_j \sum_i \frac{(X_{i,j}(H) - X_{i,j,\text{measured}})^2}{\sigma^2}$$

where X(H) is the cluster position calculated from helix parameters H, X_measured is the cluster position measured by CGEM-IT, is the measurement error derived from residuals between measured results and MC truth information, i = 1,2 correspond to and Z, and j = 1,2,3 correspond to the three clusters. ^{2} minimization is performed using MINUIT [?].

For high-p tracks that are nearly straight in CGEM-IT, three nearby clusters with limited spatial resolution cannot determine accurately. This is reflected in the dropping success rate of 5-parameter helix fitting at high p , shown in Figure 12 [Figure 12: see original paper] (black dots). To improve the fitting success rate for high-p tracks, can be fixed to the value calculated from the three transverse cluster positions if the 5-parameter fit fails. After fixing , the helix fitting success rate remains above 99.4% and reaches 99.7% at high p , as shown in Figure 12 (blue triangles).

Residual distributions for the five helix parameters after track segment fitting are shown in Figure 13 [Figure 13: see original paper], where residuals are defined as H = H ^fit − H ^truth (i = 1 5), representing the difference between fitted parameters H^fit and true parameters H^truth from ± track generation. These distributions demonstrate that reasonably unbiased track parameters can be obtained through fitting.

3 Matching CGEM-IT Track Segments to ODC Tracks

A complete track is typically identified when both a CGEM-IT track segment and an ODC track are found and successfully matched. ODC tracks are reconstructed using the track finding algorithm [?, ?], with helix parameters obtained through fitting.

To evaluate consistency between CGEM-IT track segments and ODC tracks, a ^{2}_match quantity is calculated for each of the five helix parameters:

$$\chi^2_{\text{match}} = \frac{(H_{\text{CGEM-IT}} - H_{\text{ODC}})^2}{\sigma^2_{\text{CGEM-IT}} + \sigma^2_{\text{ODC}}}$$

where H represents a helix parameter from either the CGEM-IT track segment or ODC track, and is the corresponding error. A global ^{2} across all five parameters could be defined, but the error matrices are not perfectly evaluated here since some effects cannot be incorporated in simple helix fitting (e.g., magnetic field inhomogeneity, charged track energy loss). These effects impact the five parameters unequally, making independent parameter study preferable. Figure 14 [Figure 14: see original paper] shows example ^{2}_match distributions for the five parameters from a simulated ± sample with p = 0.8 GeV/c. Appropriate ^{2} cut values are chosen to ensure individual parameter efficiencies remain 99.5% when ^{2} cuts are applied. The determined ^{2} cut values across different p for all five helix parameters are shown in Figure 15 [Figure 15: see original paper].

The ^{2} cut value at a p between two neighboring points is obtained through linear interpolation. If all five ^{2}_match values are below their corresponding cuts, the CGEM-IT track segment and ODC track are considered matched.

The complete track finding procedure in the combined CGEM-IT and ODC tracking system proceeds sequentially through: track segment finding in CGEM-IT, track segment fitting, ODC track finding, and track matching. Figure 16 [Figure 16: see original paper] shows the absolute efficiency after each step as a function of p . The relative efficiency for track matching is approximately 99%, with total efficiency after matching ranging from 94.6% to 97.0% depending on p .

4 Summary and Outlook

As a candidate for upgrading the IDC at BESIII, CGEM-IT has been proposed and designed. Implementation and studies of the full CGEM-IT simulation and track reconstruction are ongoing. Using fully simulated ± samples, clear patterns have been identified in the relative differences of azimuthal angle and beam-direction position. These patterns are parameterized and used to select cluster combinations as CGEM-IT track segments with >99% efficiency. Quantitative track segment description is obtained through helix fitting. Chi-square quantities evaluating consistency between CGEM-IT track segments and ODC tracks are calculated and employed for matching. Appropriate chi-square requirements are established, yielding approximately 99% relative matching efficiency. A reasonable total efficiency between 94.6% and 97% (p -dependent) is achieved after track segment finding, fitting, ODC track finding, and matching.

To further improve total track finding efficiency in the combined CGEM-IT and ODC system, optimization of ODC track finding and development of a global track finding algorithm using both CGEM clusters and ODC hits are needed, particularly when good track segments are difficult to find in either subsystem. Additional efforts should focus on low-momentum charged particle tracking and fine-tuning of all charged track reconstruction algorithms for different particle types (e±, ±, ±, K±, p/p) in the presence of background.

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Note: Figure translations are in progress. See original paper for figures.