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ANGULAR DEPEDENCE OF CLOSE-TRACK EFFICIENCY FOR CLAS.

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Abstract

The angular dependence of close track efficiency have been studied for the CLAS detector. Three different methods to study efficiency have been used: Monte-Carlo simulation within GEANT system and study of correlation function for particles with different masses as a function of relative momenta in laboratory reference system, and method based on event merging. The analysis was based on the data sample of the reaction $eA(He^3, He^4, C, Fe) \rightarrow e'h_1h_2X$ obtained by the CLAS detector at initial energy 4.46 GeV(E2 run). It was found that the efficiency has U-shape angular dependence in the region of Θ from 15^O upto 90^O.

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1 Introduction

Close track resolution is one of the specific properties of detector, which limit two particle correlation measurements at small relative momenta [1, 2], because both particles will hit the same or neighboring detector sells. As a rule, the probability to loss at least one of two tracks is higher, if those tracks are close to each other. We will discuss such additional loss of pairs at close momenta in terms of close track efficiency.

We have studied momentum dependence of the close track efficiency [3] for CLAS detector in JLAB[4]. In this paper we continued study of the close track efficiency and we have studied Θ dependence of the close track efficiency. Θ is the angle between close tracks momentum and beam line. We used three methods for close track efficiency study: Monte-Carlo simulations within GEANT framework, particle correlations with different mass and "event merging" method. Second method is based on the hypothesis that narrow physical singularities are found in the region of close particle momenta in the pair reference system, while technical singularities are expected to be in the region of close particle momenta in the laboratory reference system. In the third method we used artificial events, constructed by merging information from two real events with identified protons with close momenta. All methods were described in detail in [3].

2 Experimental data sample and definitions.

Our studies of close track efficiency partly based on experimental data accumulated by CLAS during E2a run period at the energy 4.46 GeV ($e + A \rightarrow e'h_1h_2 + X$, where A were ^3He,^4He,^{12}C,^{56}Fe, and h_j are π, p). The electron beam current was typically about 10 nA, which yielded a nominal luminosity of about $10^{34}cm^{-2}s^{-2}$, magnetic field was 50 % of maximum value (Torus current 2250 Amps and Minitourus current 6000 Amps).

We define close track efficiency $\varepsilon(q)$ as follows

$$\frac{d\sigma_{measured}}{d\nu dQ^2 d\vec{p_1} d\vec{p_2}} = \varepsilon(q) \cdot \varepsilon_1(\vec{p_1}) \cdot \varepsilon_1(\vec{p_2}) \cdot \frac{d\sigma}{d\nu dQ^2 d\vec{p_1} d\vec{p_2}}, \tag{1}$$

where ν is the energy transfer, Q^2 is the momentum transfer, $\vec{p_1}, \vec{p_2}$ are momenta of particles h_1 and h_2 in the laboratory system, $\vec{q} = \vec{p_1} - \vec{p_2}$ and ε_1 is the single particle reconstruction efficiency. We can extract $\varepsilon(q)$ by studying the ratio:

$$\frac{R_{measured}(q)}{R(q)} = \varepsilon(q) \tag{2}$$

in the processes where no real correlation at small q is expected. Here R is the correlation function which we study for two hadrons with momenta $\vec{p_1}, \vec{p_2}$ in the $(eA, e'h_1h_2X)$ reaction:

$$R(\vec{q}) = \frac{d\sigma/d\nu dQ^2 \cdot d\sigma/d\nu dQ^2 d\vec{p_1} d\vec{p_2}}{d\sigma/d\nu dQ^2 d\vec{p_1} \cdot d\sigma/d\nu dQ^2 d\vec{p_2}} \tag{3}$$

In practice, instead of (3), they usually use "mixing" [5, 6] procedure to calculate the correlation function:

$$R(\vec{q}) = \frac{N_r(\vec{q})}{N_b(\vec{q})}, \tag{4}$$

where N_r and N_b are the numbers of proton pairs combined from protons taken from the same and different events("mixing" procedure), respectively. The pairs of protons from different events are selected by the same criteria as those from the same event. Both real and mixing distributions are normalized to the same numbers of pairs in the region outside the correlation effect.

3 Monte-Carlo simulations for study of close track efficiency

In order to estimate the close track efficiency in CLAS detector we have used Monte-Carlo simulation within standard CLAS GEANT[7] simulation package (GSIM)[8]. We have simulated events with one electon and two protons. The electron emission angle and momentum are correspoded to $Q^2 \sim 1GeV^2$, $\nu \sim 2GeV$. Actually, we needed the electron only to recostruct the event by software. The protons were generated with experimental pair angular and momentum distribution(E2a-RUN). The example of generated event with close tracks are shown on both parts of Figure 1. There are one electron and two protons with close momenta. The magnetic field was the same as in experiment (50 % of maximum field value). The standard version of the CLAS reconstruction and analysis package (RECSIS)[9] was used to reconstruct simulated events. The efficiency was calculated using Equation (2). $R(q)$ was the correlation function of generated events and $R_{measured}(q)$ was the correlation function of reconstructed events. The generated correlation function had no singularities at small q, but it had a slow q-dependence due to kinematical correlations between the generated secondary particles. The event was reconstructed if all tracks passed χ^2 criterion. It means that the result of the DC hits fitting by track has reasonable χ^2. We took to the analysis the events with proton momentum range 0.3-1.0 GeV/c. Events with tracks matched the same TOF scintillator were not included in our analysis. This restriction comes from the analysis of the experimental data. Close tracks with the same matched scintillator actually had the same time of flight and so far couldn't be reconstructed correctly.

We divided the pair Θ range by seven bins to study the efficiency dependence versus Θ . We fitted the efficiency by the function:

$$\varepsilon(q) = a \cdot (1 + bq) \cdot (1 - exp(-\frac{q^2}{\varepsilon_0^2})) \tag{5}$$

Here a is normalization constant, b corresponds to smooth efficiency dependence at relatively large momenta and ε_0 is the width of Gaussian corresponding to the inefficiency at small relative momenta. Several factors (violating of energy and momentum conservation in mixed pairs, possible smooth dependence of the detector efficiency on $\vec{q}$, etc.) lead to a slow growth in the correlation functions on $\vec{q}$. This growth can be separated during data analysis both from interferometry and soft final state interaction effects, which manifest themselves as significantly sharper singularities of the correlation function. The most important parameter to our study is ε_0.

Figure 2 shows the efficiency dependence for the chosen Θ bins. The fits by eq.(5) are in agreement with the data within errors. It is important that mean pair momenta at $q < 0.1GeV/c$ are different for different angular bins. We corrected efficiency parameter ε_0 to the same mean pair monetum ($0.4GeV/c$) in according with linear momentum

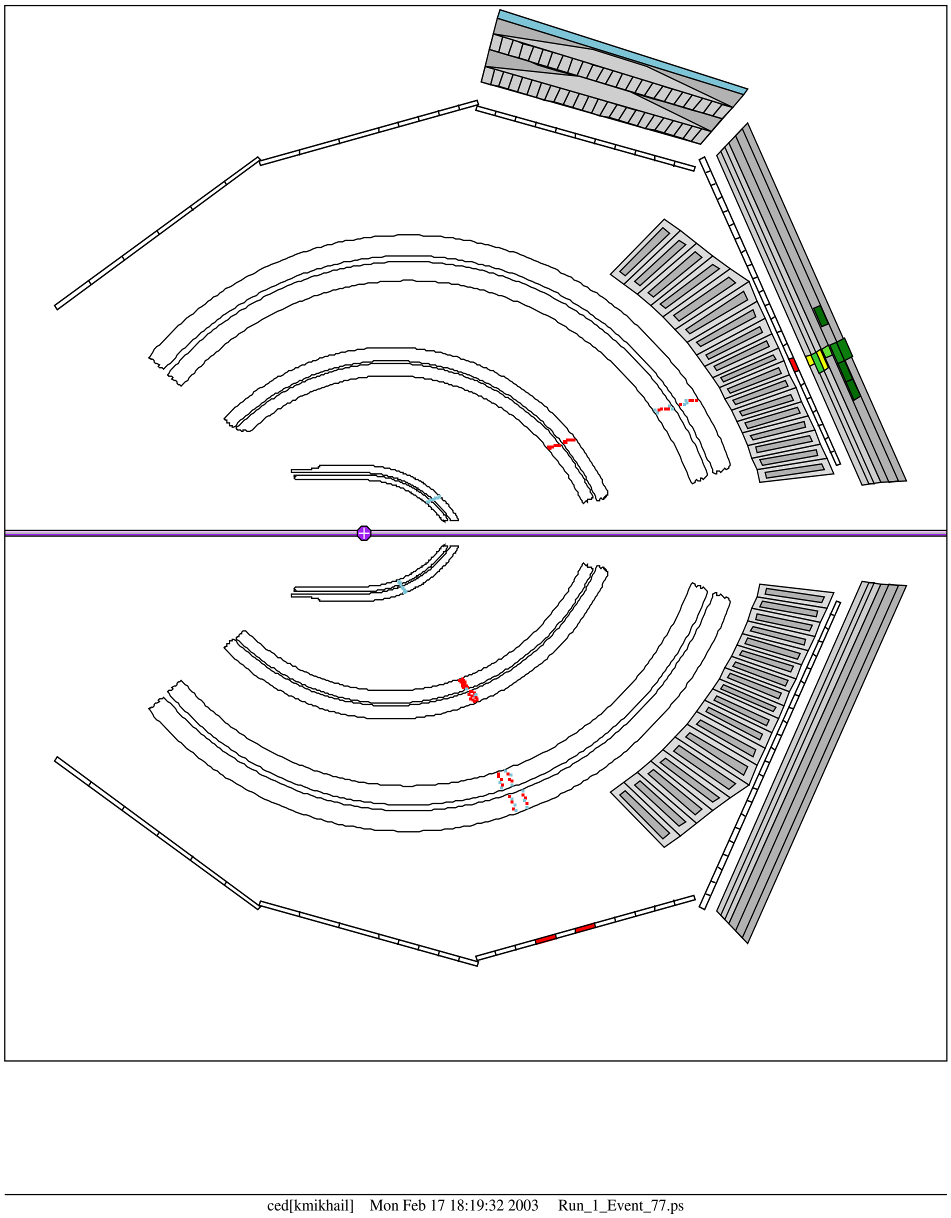

Figure 1: The example of event with eletron and two proton close tracks.

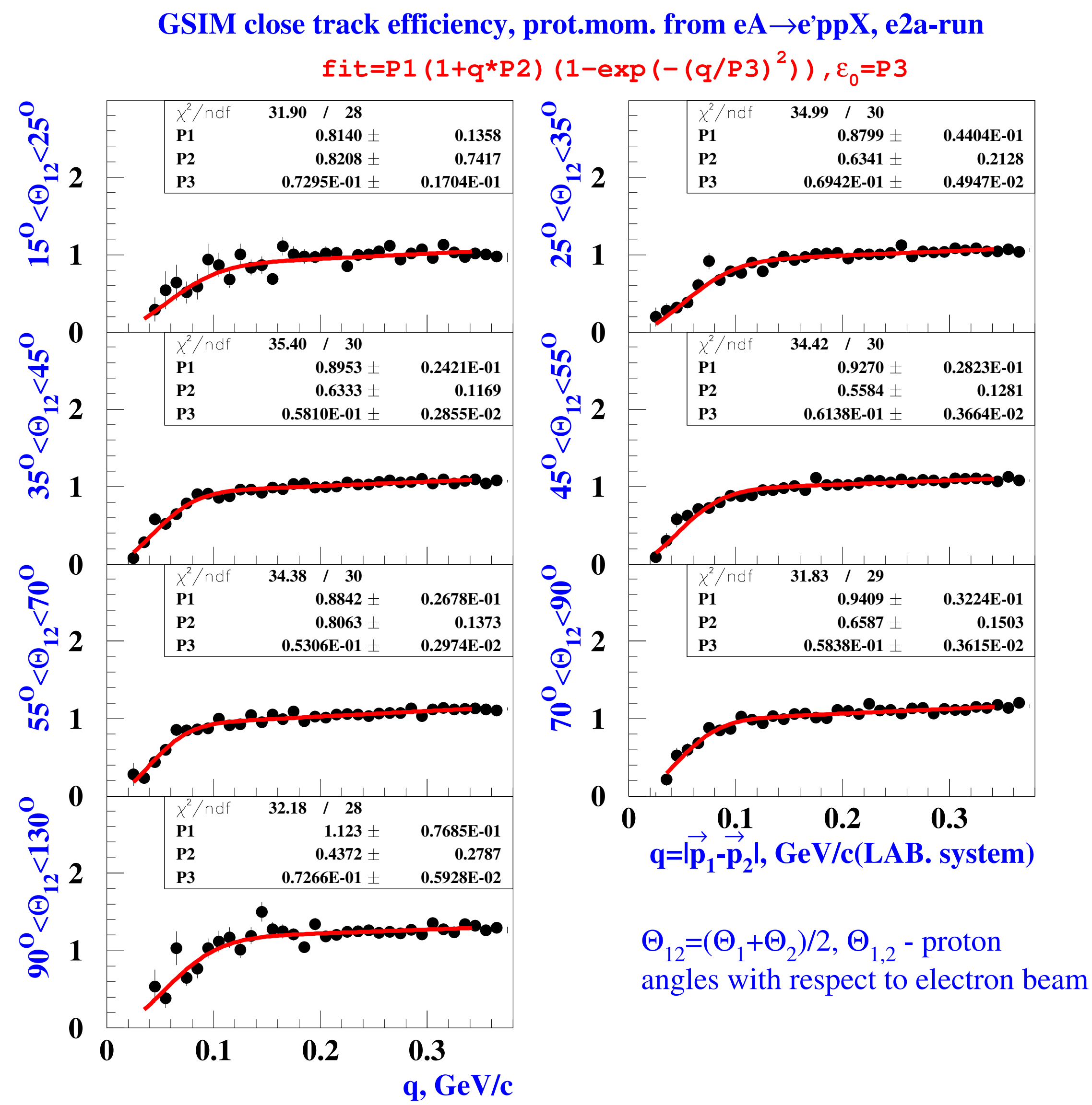

Figure 2: The proton-proton close track efficiency within GSIM for different pair momentum range, generator: $e' + 2p$. Curve represents the best fit result using parameterization eq.(5).

Table 1: The efficiency parameter ε_0 for pp at different angular bins. GSIM.

$<\Theta>$	Θ range	$\varepsilon_0 \pm stat.err.$	χ^2/ndf
102^0	$90^O - 130^O$	$.077 \pm .008$	32/28
76^0	$70^O - 90^O$	$.055 \pm .003$	35/30
62^0	$55^O - 70^O$	$.051 \pm .006$	35/30
50^0	$45^O - 55^O$	$.057 \pm .006$	34/30
40^0	$35^O - 45^O$	$.053 \pm .003$	34/30
31^0	$25^O - 35^O$	$.060 \pm .005$	32/29
22^0	$15^O - 25^O$	$.070 \pm .023$	32/28

dependence of efficiency parameter which is getting in [3]. The corrected results are in Table 1.

4 Study of close track efficiency based on experimental data on π^+p correlations.

The complexity (in comparison with the single-particle detection) in the detection of identical particles with small relative momenta $\vec{q}$ (in the laboratory system) is associated with the fact that the gaps between their tracks are thin not only near the interaction point, but also throughout their lengths. If particles have the same charge and close momenta in the laboratory reference system, but differ significantly in mass, their track proximity will be the same as for identical particles and close track efficiency is expected to be the same. To our knowledge, there is no reason for sharp singularities to appear in the correlation function of particles with different masses at small relative momenta $\vec{q}$ in the lab.system and no experimental evidence for their existence is available. We assume that such singularities are negligible, hence physical and methodical singularities for particles with different masses are separated [3].

The detection efficiencies for a pair of identical particles with small relative momenta in the proposed method are determined by measuring the correlation function of particles with different masses and small relative momenta $\vec{q}$. Thus, we suggest that the obtained dependence of such correlation function on the relative momentum $\vec{q}$ can be interpreted as a dependence of the efficiency on $\vec{q}$ [10].

Measured dependences of the $p\pi^+$ correlation functions on $\vec{q}$ for $eA \to e'p\pi^+X$ reaction at 4.46 GeV are shown in Fig.3. We corrected efficiency parameter ε_0 to the same mean pair monetum ($0.400 GeV/c$) in according with linear momentum dependence of efficiency parameter which is getting in [3]. The corrected results are in Table 2.

5 "Event merging" results

In this method we tried to combine the advantages of the two previous methods: to take the events with a well-known proton correlation function (as it is in the GEANT study),

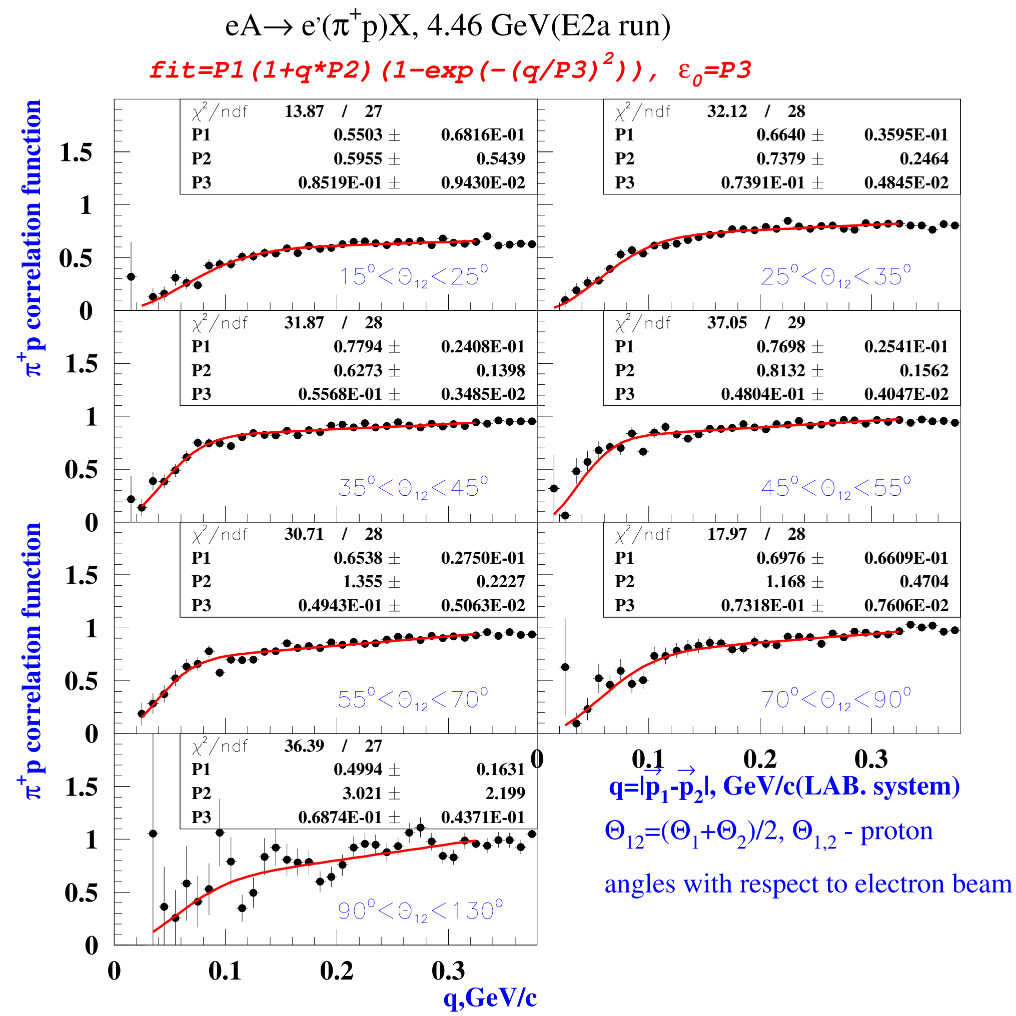

Figure 3: Correlation function for pπ^+ as a function of relative momenta q. a,b,c,d for ^3He, ^4He, ^{12}C, ^{56}Fe targets respectively. Curve represents the best fit result using parameterization eq.(5) with momentum difference range $q < 0.43 GeV/c$. Parameters ε_0 and χ^2 values for different fits are shown in table 4.

Table 2: The efficiency parameter ε_0 for pp at different angular bins. π^+p correlations.

$< \Theta >$	Θ range	$\varepsilon_0 \pm stat.err.$	χ^2/ndf
104^0	$90^O - 130^O$	$.071 \pm .049$	14/28
76^0	$70^O - 90^O$	$.075 \pm .008$	32/28
62^0	$55^O - 70^O$	$.050 \pm .005$	32/28
50^0	$45^O - 55^O$	$.048 \pm .004$	37/29
40^0	$35^O - 45^O$	$.055 \pm .004$	31/28
31^0	$25^O - 35^O$	$.071 \pm .005$	18/28
22^0	$15^O - 25^O$	$.082 \pm .009$	36/27

and to reconstruct them, using a real response from the CLAS detector elements (as it is in the case of different mass particle correlation study). So far as the reconstruction procedure for the single protons and for the proton pairs is the same, and the single protons were reconstructed, the inefficiency to the close tracks can be evaluated.

The initial information was the file with the reconstructed events, contained both raw data information and the reconstructed information such as the type of the secondary particle, it's momentum, the track parameters, the hitted TOF scintillator number, the reconstructed start time of the event, etc[3]. The start time is the reconstructed time, so that the difference between the measured TOF and the start time is a real time-of-flight of the secondary particle from the target to the detector elements.

Among the selected events the specific pairs of events were selected , where

- the momentum of the reconstructed protons are close.
- the proton tracks from those events don't hit the same TOF scintillator. That restriction came from the real events, where a pair of particles, hitting the same scintillator, was discarded from the analysis, because in a such case the measured TOF is wrong for both of them.

For those event pairs (Events **A** and **B**) a new event (event **C**) was constructed, where the raw data information of the sector with protons was the sum of both data from event **A** and **B**. It looks like the part of the event **B** is merged into the event **A**.

The TOF values and the drift times for event **B** were corrected by the start time difference of the events **B** and **A**. The DC information of event **B** can involve the same wire numbers as in the event **A**. In this case the drift times for those wires were modified to be an average of the events **A** and **B**. We checked that if, say, we used the time values from the event **A** instead, the result will be the same[3].

As a result, we have the file of the events with close proton pairs, and each proton of a pair was reconstructed separately. The possible reconstruction inefficiency will be due to the small momentum difference of those tracks.

The close track efficiency was defined according to the equation (2).The example of the narrow track efficiency is shown in Fig.4. The fit in the Fig. is due to eq.(5).

We were able to produce a large number of narrow proton pairs, because there are a plenty of events with at least one proton, which can be used for the construction of

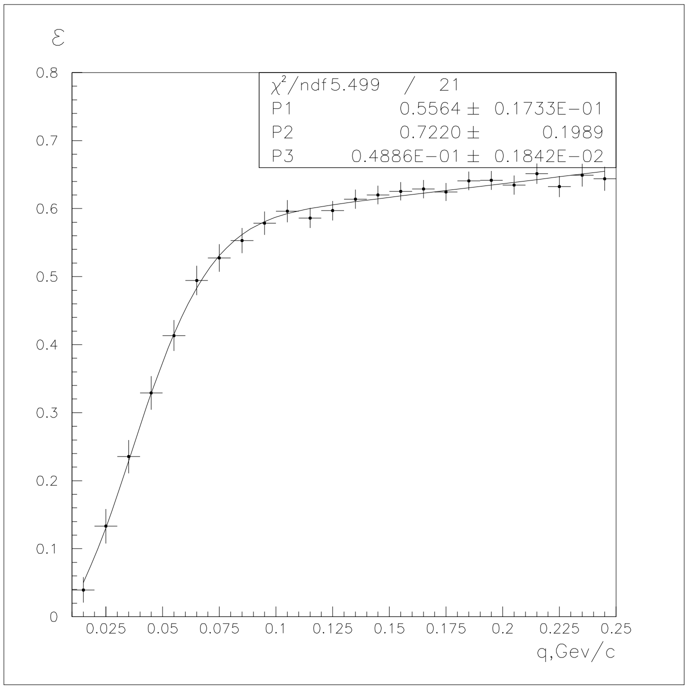

Figure 4: The efficiency of the proton pair reconstruction as a function of their momentum difference q. The curve represents the best fit result using parameterization eq.(5).

narrow proton pairs. It allows as to define two-dimension dependence of ε_0 on Θ and proton momentum.

The data was divide into 7 ranges of angles Θ and three momentum regions. Fig.4 shows the efficiency dependence at $0.3 < p_{12} < 0.5$ and $45.0 < \Theta(deg) < 55.0$.

The values of ε_0 for different p_{12} and Θ along with the mean momentum and angles values are stored in the Tab. 3

6 Comparison of the results, obtained by different methods.

The result of Θ dependence of ε_0, obtained by different methods, best be compaired, been reduced to some momentum, using the momentum dependence[3]. Fig.5 shows the Θ dependence of ε_0 at $p_{12} = 0.4$ GeV/c. All methods are in a good agreement with each other. The solid curve in the figure is a simple polinomial fit by function:

$$\varepsilon_0 = P1 + P2 \cdot \Theta + P3 \cdot \Theta^2 \tag{6}$$

The increasing of parameter ε_0 at small Θ could be related to the increasing of magnetic field ($\int Bdl$) [11]. At large Θ parameter ε_0 could be slightly higher due to higher size of SC paddles at large angles.

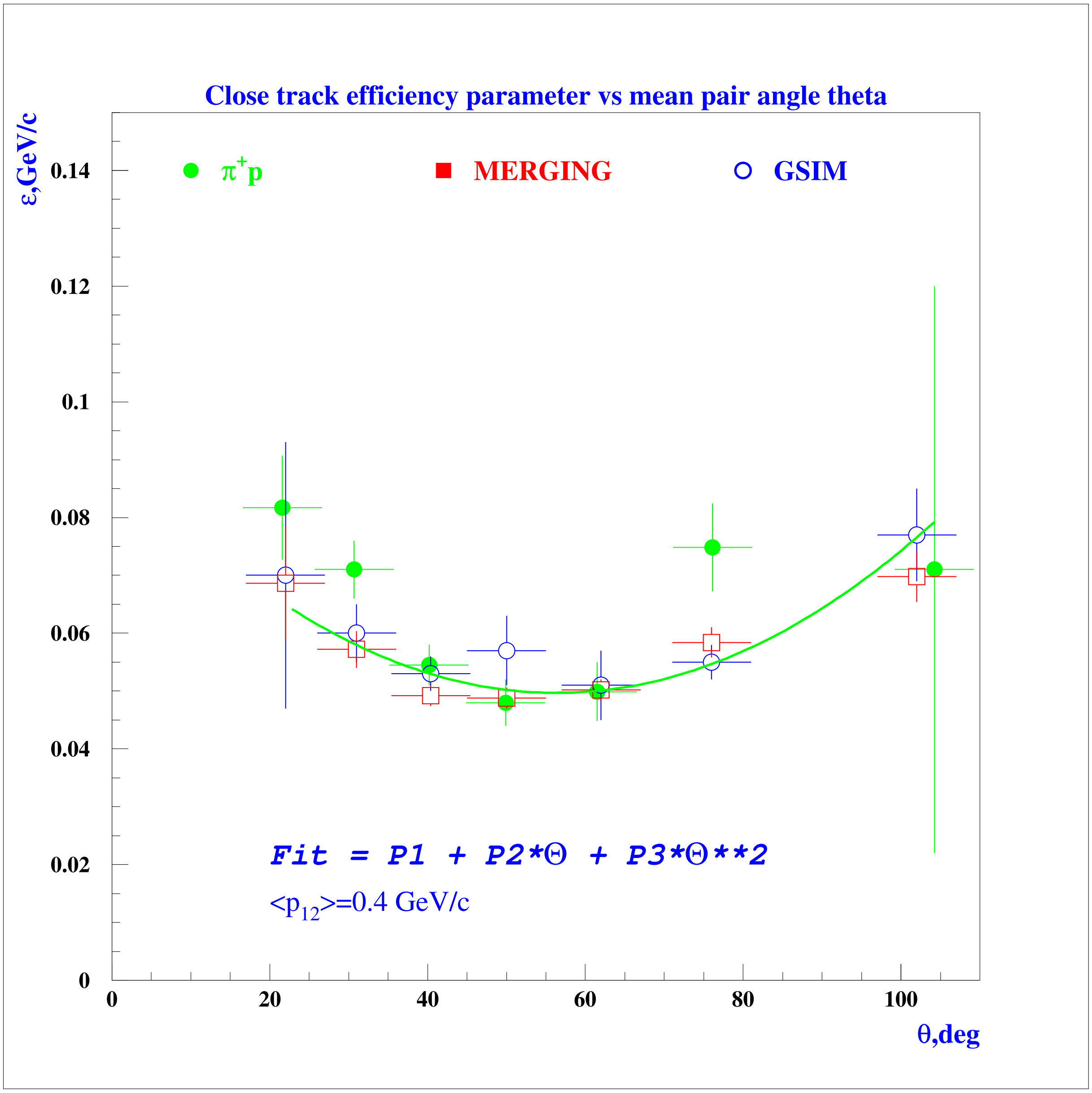

Figure 5: The theta dependence of efficiency parameter ε_0.

Table 3: The efficiency parameter ε_0 for pp at different angular and momentum bins. Upper number is ε_0 value, bottom numbers are mean angle and momentum in the cell.

Θ	$0.3 < p_{12} < 0.5$	$0.5 < p_{12} < 0.7$	$0.7 < p_{12} < 1.0$
$15^O - 25^O$	$.0688 \pm .0099$ 21.6/.435	$.0746 \pm .0047$ 21.4/.603	$.0884 \pm .0072$ 21.2/.823
$25^O - 35^O$	$.0573 \pm .0032$ 30.8/.429	$.0640 \pm .0032$ 30.4/.598	$.0787 \pm .0047$ 30.2/.819
$35^O - 45^O$	$.0493 \pm .0018$ 40.3/.423	$.0644 \pm .0026$ 40.0/.593	$.0773 \pm .0069$ 39.8/.813
$45^O - 55^O$	$.0489 \pm .0018$ 50.0/.419	$.0700 \pm .0031$ 49.9/.588	$.0864 \pm .0066$ 49.6/.809
$55^O - 70^O$	$.0503 \pm .0018$ 62.1/.415	$.0731 \pm .0046$ 61.6/.582	$.0938 \pm .0086$ 60.6/.801
$70^O - 90^O$	$.0584 \pm .0026$ 78.4/.409	$.0835 \pm .0126$ 77.2/.571	$.1431 \pm .0346$ 76.0/.776
$90^O - 130^O$	$.0698 \pm .0044$ 102.6/.399	$.1189 \pm .0221$ 101.3/.556	$.224 \pm .157$ 96.7/.754

7 Conclusion

1)Three methods are used to study close track efficiency provide the same results with sufficient for practical applications accuracy.

2) The close track efficiency depends both on particle emmision angle and momentum.

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