NUKLEONIKA 2004;49(Supplement 2):S85–S88

PROCEEDINGS

Methods for close-track efficiency study

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Abstract We describe two new methods for the study of close track efficiency. One is based on the study of a correlation function for particles with different masses as a function of their relative momenta in the laboratory reference system. The other method is based on the analysis of artificial events, constructed by merging raw data from separate events. Both methods and the standard Monte Carlo method were applied to data from the CLAS detector at Jefferson Laboratory. All three methods provide the same result for close track efficiency with an accuracy sufficient for practical application.

Key words particle correlations • close track efficiency

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Received: 12 December 2003

Introduction

Some important physical tasks need both particle identification and precise momentum measurement for an extremely difficult configuration: two particles with the same charge and close momenta. It is well-known that the correlations of particles with small relative velocities (which means close particle momenta for identical particles) are sensitive to the space-time intervals between the emission points, due to quantum interference effects and to the strong and Coulomb final state interactions [3, 5, 6]. Two-track resolution restricts two-particle correlation measurements at small relative momenta, because both particles can hit the same or neighbouring detector cells. As a rule, the probability to lose one of the two tracks is higher if those tracks are close to each other.

Some details of the new methods for close-track efficiency study can be found in [9–11].

Experimental setup and definitions

New methods were developed within the study of the close track efficiency for the CLAS [8] detector in the Thomas Jefferson National Accelerator Facility (JLab). To study the close track efficiency we have used the data from the "E2" run at energy 4.46 GeV ($e + \mathrm{A} \rightarrow e'h_1h_2 + X$, where A are ^{3}He, ^{4}He, ^{12}C, ^{56}Fe, and h_i are π,p,d). The electron beam current was typically about 10 nA, which yielded a nominal luminosity of about 10^{34} cm^{-2}s^{-1}, the magnetic field was 50% of the maximum value.

The close track efficiency $\varepsilon(\vec{p},\vec{q})$ can be defined as

$$\varepsilon\left(\vec{p},\vec{q}\right) = \frac{R_{measured}\left(\vec{p},\vec{q}\right)}{R\left(\vec{p},\vec{q}\right)} \quad (1)$$

where $R(\vec{p},\vec{q})$ is the two-hadron correlation function as seen with an ideal detector, $\vec{p} = \vec{p}_1 - \vec{p}_2$ and $\vec{p} = (\vec{p}_1 + \vec{p}_2)/2$ are the pair momentum difference and mean momentum, respectively. We consider the efficiency ε and correlation function R to be functions of the norms of $\vec{q}$ and $\vec{p}$ only: $\varepsilon \equiv \varepsilon(q,p)$ and $R \equiv R(q,p)$. In this article we will use "mixing" procedure [4] for the correlation function R calculations.

The different mass method

The experimental difficulty in the detection of identical particles with small relative momenta is associated with the fact that the gaps between their tracks are small not only near the interaction point, but also throughout their length. If the 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 so the close track efficiency is expected to be the same.

For a pair of particles with different masses, the Coulomb and strong final-state interaction can also be important, but only in the kinematical region characterized by small relative velocities, which means small relative momenta in the center-of-mass reference frame (CMRF) and invariant masses near threshold [1, 7]. To the best of 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 laboratory reference frame (LRF) and no experimental evidence for their existence is available. We assume that such singularities are negligible.

The measured q dependences of the $p\pi^+$ correlation functions for $e + \mathrm{A} \rightarrow e'h_1h_2 + X$ reaction at 4.46 GeV are shown in Fig. 1 (upper). The decrease of the correlation function at small q was interpreted as the two-track efficiency dependence on q. One also can see the smooth growth of the correlation function with q.

The efficiency was fitted by:

$$e(q) = a \cdot (1 + bq) \cdot \left(1 - \exp\left(-\frac{q^2}{e_0^2}\right)\right). \tag{2}$$

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

The "event merging" method

The idea of this method is to use raw (ONLINE) data from the detector for events with reconstructed single proton for the production of artificial events with proton pairs. It should be noted that in these events the protons are not correlated due to the construction procedure. Then, a standard reconstruction procedure was applied to those events. Because the reconstruction procedure for single proton events and for proton pair events is the same, and since the single protons were reconstructed, the inefficiency due to close tracks can be evaluated.

Possible reconstruction inefficiency in the merged events is due to the small momentum difference of those tracks. The close track efficiency was defined according to the equation (1). For CLAS, all six sectors are of the same quality and the estimated efficiency was the same within errors. It should be noted that when we merge the hits from two events, then the drift chamber (DC) occupancy is generally increased, which can result in a lower track efficiency. But usually the DC occupancy in the CLAS is of the order of 1% and it cannot affect the efficiency significantly.

The method is good also from the statistical point of view – we can construct enough events for the statistical errors to be negligible.

Discussion and conclusion

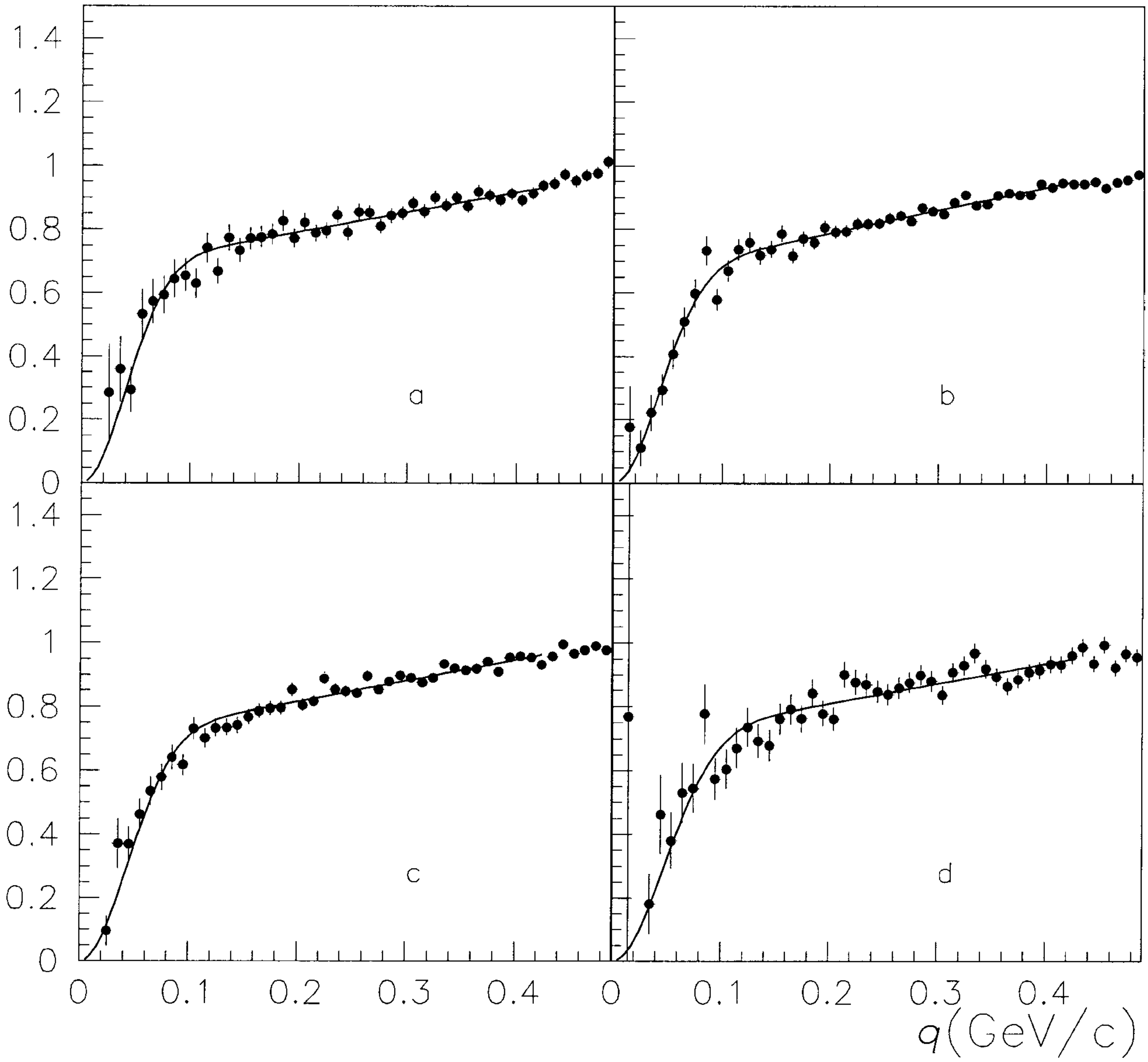
In addition to these two methods, the close-track efficiency was estimated also by using the Monte Carlo simulation by standard CLAS GEANT simulation package – GSIM [2]. Two types of secondary particle generators were used. For the first type, we have simulated the reaction e + 2p → e' + 2p + 2π using the phase space generator GENBOD. To better reproduce the experimental spectra of the protons, we explored a second type of generator for GSIM simulation. In the second generator, two-proton events were generated with a pair momentum spectrum similar to the experimental one. For example, Fig. 1 (lower) shows the efficiency estimated by all methods for particles with mean momentum p = 0.5 GeV/c. One can see that all methods are in good agreement.

To summarize, a new method for studying the close track efficiency, based on the study of the correlations for particles with different masses, has been tested successfully. The advantage of the method is that it is based on the real detector hardware and software without any simulations.

Another new method for studying the close track efficiency, which is based on the "events merging" procedure, provides results comparable with those from the other methods. The method looks very promising, because it provides the possibility to study the efficiency with excellent statistical accuracy, and because it relies on very few assumptions about the detector response.

The simulation of the detector properties with the present version of GSIM is reliable with respect to the close track reconstruction. All three methods of the close track efficiency studying provide the same results with an accuracy sufficient for practical applications.

Acknowledgment We particularly wish to thank V. Burkert, P. Degtiarenko, F. Klein, G. A. Leksin, B. A. Mecking, B. Niczyporuk, N. Pivniouk, S. Stepanyan and L. Weinstein for helpful discussions and remarks. The authors from ITEP are also pleased to acknowledge the Department of Energy, USA, for the support during our visits to the JLab.



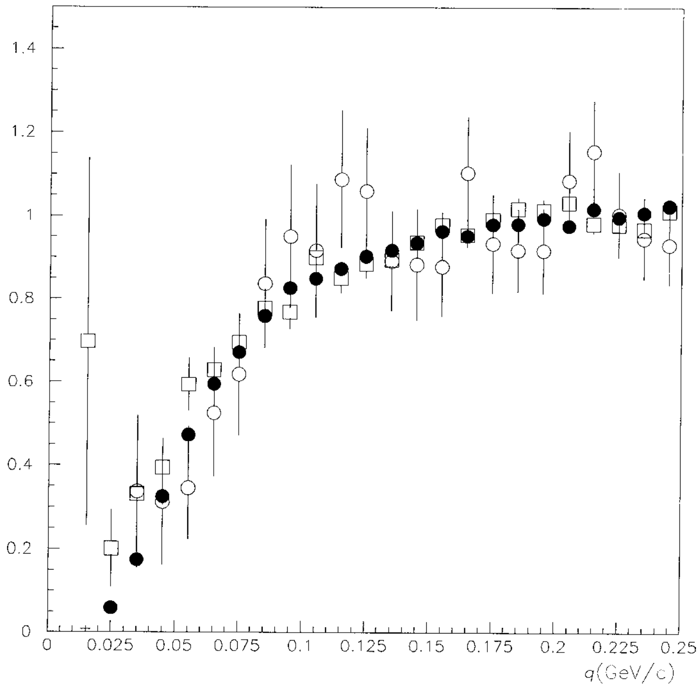


Fig. 1. Upper – the p correlation function *vs.* the relative momenta q, a, b, c, d stand for the complete and targets, respectively. The curves represent the best fit (2) within the range $q < 0.43$ GeV/c. The mean momentum of a particle is 0.42 GeV/c. Lower – the efficiency estimated by different methods for mean particle momentum $p = 0.5$ GeV/c. Full circles – event merging method; boxes – different mass method; open circles – Monte Carlo simulation.

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