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Non-identical particle correlations in central Pb+Au collisions at 158 AGeV

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Abstract Two-dimensional pion-proton correlation functions were analyzed in the central Pb+Au collision data taken by CERES at the top SPS energy. The correlations between the same- and the opposite-sign particles exhibit a minimum and a peak, respectively, at low relative momentum, caused by the mutual Coulomb interaction. The clearly visible asymmetry of the peak in the direction parallel to the pair momentum indicates that protons, on average, freeze-out at larger radii or at earlier times than pions. A similar result was obtained previously by the STAR experiment and was connected to the transverse flow. The high statistics of the CERES data set and the power of the two-dimensional analysis allow one to study how the observed displacement between the sources of pions and protons evolves with the transverse momentum.

Key words non-identical correlations • asymmetry

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Introduction

The two-particle correlation function is defined as the ratio between the two-particle density and the product of single particle densities

$$C(p_1 p_2) = \sigma_0 \frac{d^6\sigma}{d^3 p_1 d^3 p_2} \Bigg/ \frac{d^3\sigma}{d^3 p_1} \frac{d^3\sigma}{d^3 p_2} \qquad (1)$$

Using this equation, one can obtain information about the space-time-momentum distribution of particles at the freeze-out in a nuclear collision [3]. The correlations between non-identical same- and opposite-sign particles exhibit a minimum and a peak, respectively, at low relative momentum $q \equiv p_2 - p_1$, caused by the mutual Coulomb interaction. A difference between the average freeze-out position or time of two particle species reveals itself as an asymmetry of the correlation function $C(p_1,p_2)$ at small q [2]. The asymmetry in the pion-proton correlations indicate that the proton source is located at a larger radius than the pion source or that protons are emitted earlier than the pions.

Experimental setup

The CERES spectrometer at the CERN SPS was upgraded in 1998 with a cylindrical Time Projection Chamber (TPC), which allows to measure charged hadrons and leptons with the momentum resolution of $\Delta p/p = 2\% \oplus 1\%\ p/\text{GeV}$. For the analysis presented

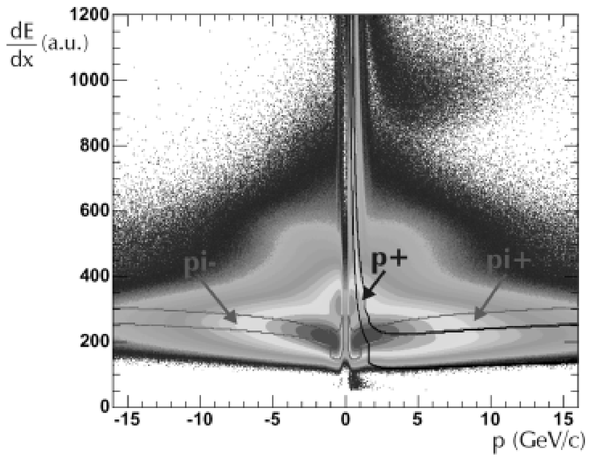

Fig. 1. Energy loss vs. momentum with the selected ranges assigned to the given particle species, the grey and black lines for pion and proton, respectively.

here, mainly information from the TPC was used. The acceptance of the CERES TPC is from 8° to 15° in polar angles, matching the acceptance of the other detectors. The active volume of about 9 m^3 at a length of 2 m is surrounded by 16 readout chambers. Each chamber is divided into 20 planes with 48 readout channels for each plane. More detailed information about the experimental setup one can find in [4, 6].

Data analysis

In the 2000 run, about 32 millions central Pb+Au collision at a top SPS energy of 158 GeV per nucleon events were recorded. A subset of this statistic was used in this analysis (about 21 M and 2 M events of the 8% and 20% geometrical cross section, respectively). The tracks chosen for the analysis came mainly from the vertex (2σ matching between the TPC and the vertex reconstruction detector) and fulfill a set of cuts. To avoid

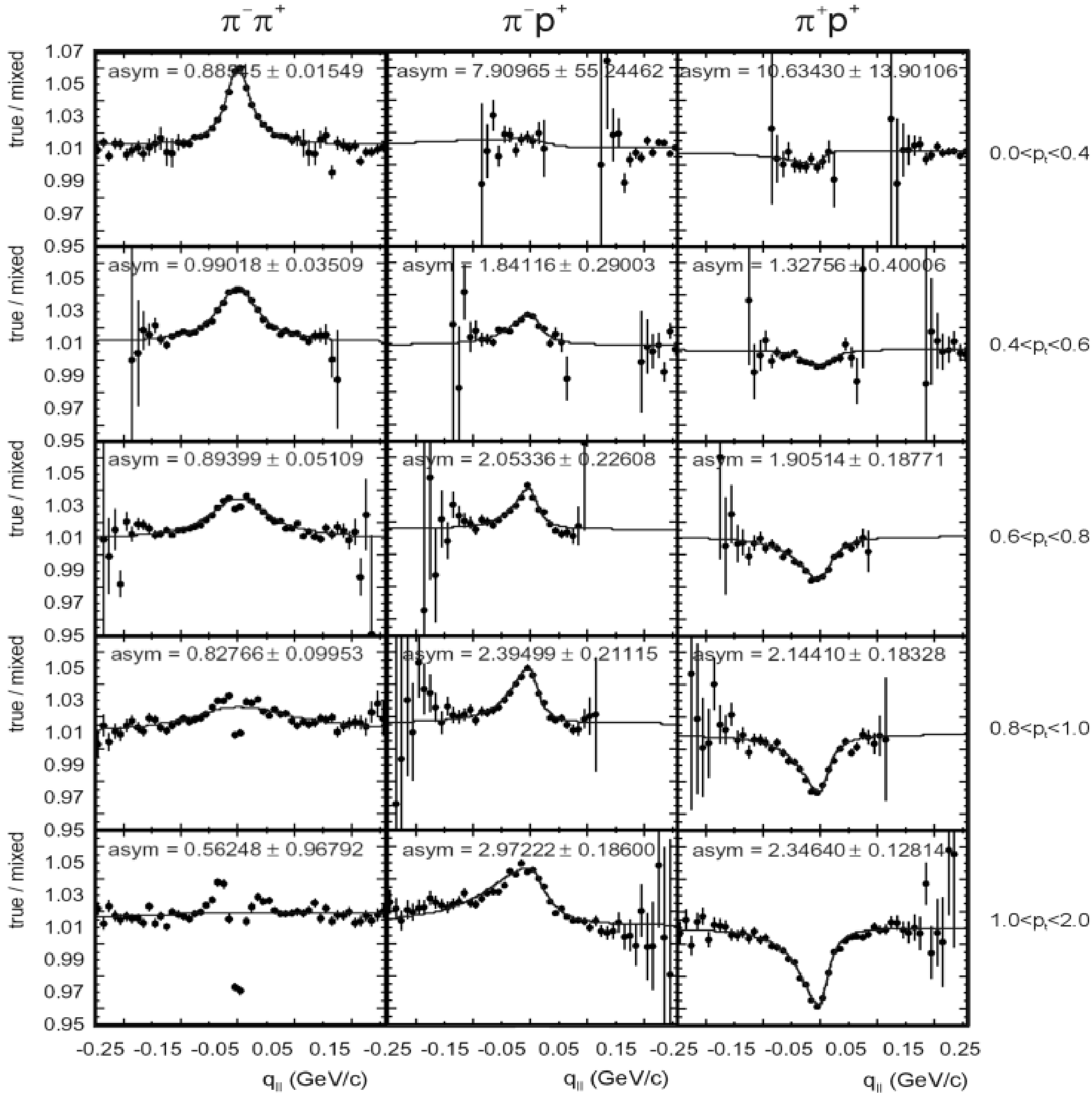

Fig. 2. Non-identical correlation functions for the three pair combinations in bins of pair transverse momentum $P_\perp$ (GeV/c). The black line is a Lorentz fit with two widths.

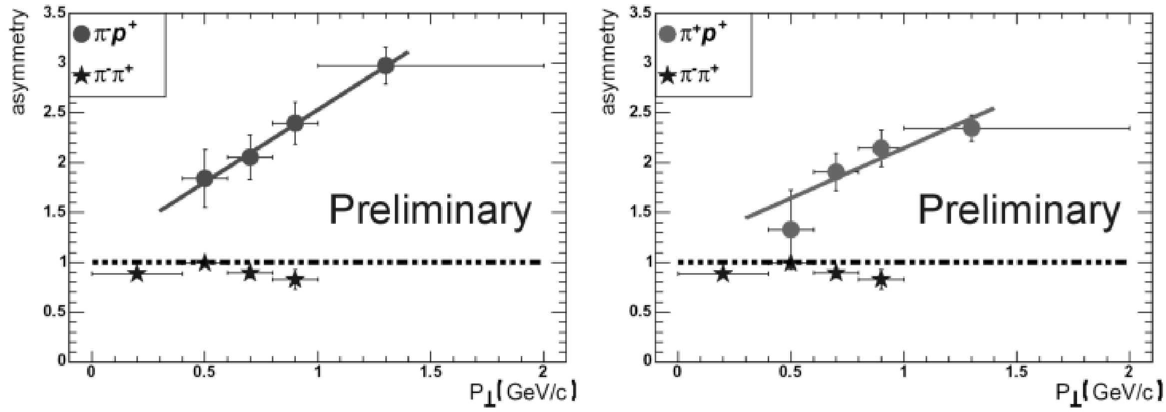

Fig. 3. The pair transverse momentum dependence of the asymmetry for the pion-proton pairs and the comparison with the unlike pion pairs.

inefficiency due to the two-track resolution, a minimum opening angle requirement was applied to pairs from the signal and the background distribution. Background distribution was generated using event mixing.

Only events with similar centrality and coming from the same reaction target were mixed. Particle identification was based on the information from the TPC. In Fig. 1, the energy loss versus momentum from the TPC track is presented. Selected ranges were assigned to the given particle species based on the Bethe-Bloch formula [8].

The correlation functions were calculated for $\pi^-\pi^+$, π^-p, and π^+p pairs in the pair center of mass frame in five bins of pair transverse momentum. In this frame, variables $q_{||}, q_\perp$ are defined as $q_{||} = q_{\text{out}}$, $q_\perp = \sqrt{q^2_{\text{side}} + q^2_{\text{long}}}$ where $q_{\text{out}}, q_{\text{side}}, q_{\text{long}}$ are the components of the momentum difference vector $\vec{q} = \vec{p}_2 - \vec{p}_1$. The q_{long} is the component parallel to the beam, q_{side}, is perpendicular to the beam and to the transverse pair momentum, and q_{out} is perpendicular to q_{long} and q_{side} [1]. Two-dimensional histograms $n(q_\perp, q_{||})$ for the signal and background distribution were projected in the direction parallel to the pair momentum with condition on $q_\perp \in \{0{,}50\}$ MeV. Projection results were divided to obtain a one-dimensional correlation functions. Figure 2 shows the three correlation functions in the $P_\perp$ bins. For the quantitative parameterization of the asymmetry, a Lorentz curve with two widths was fitted to the spectra. The asymmetry is defined as the ratio between the two widths.

Results

The non-identical particle correlations are mainly caused by mutual Coulomb interaction. Examples of non-identical correlation functions are shown in Fig. 2. The visible asymmetry for pion-proton correlation functions indicate that the proton source is, on average, located at a large transverse radius or at earlier time than the pion source. The preliminary result on the asymmetry as a function of the transverse momentum is shown in Fig. 3. The straight solid line is a fit to the data points. It points to unity at $P_\perp = 0$ as expected from symmetry considerations. The different slopes in the plots from Fig. 3 could be caused by the two-track resolution, this is under investigation.

Discussion

In order to study the asymmetry as a function of the displacement between particle sources a Monte-Carlo generator was written. Each generated track was described by the momentum and position four-vectors. The source position of the track was generated according to a three-dimensional Gauss distribution with the width taken from the experimental data. The momentum was obtained from the experimental momentum distribution. These tracks were combined into pairs using very similar algorithm as for the experimental data. For each generated pair, the Coulomb factor was calculated based on the quantum-mechanical description [5]. The histograms for signal and background distribution were filled with the weight, the Coulomb factor and the unity, respectively. The shift between the particle sources was applied to the transverse component for the proton before Coulomb factor was calculated. The obtained two-dimensional histograms $n(q_\perp, q_{||})$ were analyzed in the same way like experimental data to extract the asymmetry. The results of this simulation for a given range of transverse momentum are shown in Fig. 4. Simulation shows that the best agreement with the data was obtained for the displacement between pion and proton sources equal to about 6.5 fm. This result is similar to the value observed by STAR [7]. A more quantitative analysis of the asymmetry is in progress.

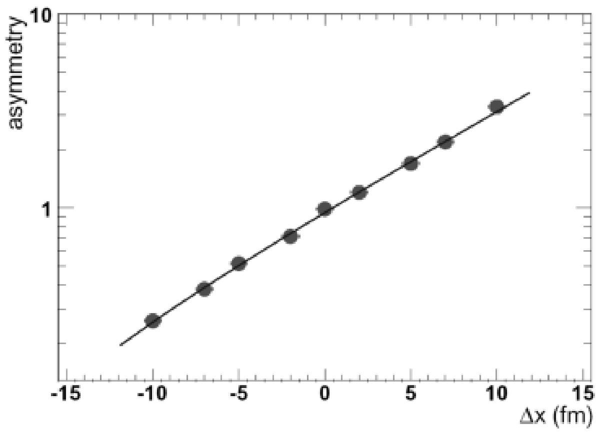

Fig. 4. Separation between pion and proton sources for pair $P_\perp$ between 0.8–1.0 GeV/c.

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