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AZIMUTHAL DEPENDENCE OF TWO-PION CORRELATIONS IN RELATIVISTIC HEAVY-ION INTERACTIONS

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We have investigated two-pion normalised pseudorapidity correlation for pions from ^{12}C-emulsion interactions at 4.5 A GeV at azimuthal angles $\phi \leq 180^\circ$ and $\phi > 180^\circ$. By comparing experimental correlation values with those of Monte-Carlo simulation values, we found that experimental two-pion normalised pseudorapidity correlations depend on azimuthal angle.

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1. Introduction

High-energy inelastic nucleus-nucleus interactions are intensively investigated with the advent of high-energy heavy-ion accelerators. For the understanding of the particle-production process, single-particle distributions are not sufficient, although they carry much information [1]. Multiplicity distributions in Regge-pole-dominated intensive reactions did not show a simple Poisson distribution which is, according to Mueller [2], due to higher correlation functions f_2, f_3 etc., that are direct measures of non-Poisson nature of the multiple particle production. This non-Poisson nature of the multiplicity distribution is a convenient expression of deviation from the independent particle production. Horn and Silver [3] showed by investigating the charged-pion multiparticle production reactions that the data points do not reproduce well the Poisson distributions, indicating that the pions are not emitted independently. Dao et al. [4] showed a correlation by measuring the projected production angle and pseudorapidity in pp interactions at 303 GeV/c.

Stone et al. [5] presented correlation between low values of longitudinal momentum (p_L) and transverse momentum (p_T), although this may have been due to the peripheral resonance production. They also investigated the correlation between the transverse momenta of pairs of outgoing particles in the two-body inclusive reactions. By studying the inclusive pp interactions between 13 and 28 GeV/c in hydrogen buble chamber, Berger et al. [6] showed that the multiplicity distribution of π^- is non-Poisson type because $(\langle n(n-1)\rangle - \langle n\rangle^2)\neq 0$, and it depends on $s^{0.5}$ (c.m. energy). Here n is the number of negative pions per inelastic collision. Shepard et al. [7] presented rapidity distributions for the one- and two-particle inclusive reactions in π^+p interactions at 18.5 GeV/c and π^-p interactions at 18.5 GeV/c. They observed that the two-particle correlation functions for these reactions depend on the rapidities of the final-state particles and on the momentun of the incident particle. By studying a sample of 67463 π^- pairs obtained from a 31-events/μB K$^+$p interaction experiment at 12 GeV/c, Ko [8] showed that the produced negative pions reveal a rapidity-separation-dependent rapidity correlation. At small rapidity separation (Δy), the π's are strongly correlated.

The study of two-particle correlation deals with the modifications induced in the single-particle spectra.

Although investigations on two-pion pseudorapidity correlations at various energies have been done by many researchers, more work should be done in this field.

We have investigated the dependence of two-pion pseudorapidity correlations of relativistic particles from the ^{12}C-emulsion interactions at 4.5 GeV/c at azimuthal angles $\phi \leq 180°$ and $\phi > 180°$.

2. *Experimental data*

The required data on ^{12}C-emulsion interactions were obtained using the NIKFIBR2 nuclear research emulsion plates (25 cm × 10 cm × 600 μm thick), irradiated horizontally with ^{12}C beams from the JINR synchrophasotron [7].

Primary inelastic events of ^{12}C-emulsion interactions at 4.5 A GeV have been investigated. We have classified the charged secondary particles in black (b), gray (g) and shower (s) particles following the usual nuclear-emulsion methodology:

1) s-particles denote relativistic charged particles of relative ionization $g/G < 1.4$ (corresponding to proton energy $T_{\mathrm{p}} > 400$ MeV), where g/G is the ionisation measured at primary beam track.

2) g-particles denote particles with relative ionisation $g/G > 1.4$ and range in the emulsion $R > 3000$ μm (corresponding to proton energy 26 MeV $< T_p <$ 400 MeV).

3) b-particles denote particles with the range $R < 3000$ μm.

Only the tracks with emission angles greater than 3° were considered to exclude the contamination of projectile-associated fast fragments.

Here θ is the emission angle, and ϕ is the azimuthal angle of the produced secondary charged particle, where the incident beam direction is taken as the positive

z-axis. Target is taken as the origin of the coordinate system. Pseudorapidity is defined by $\eta = -\ln\tan(\theta/2)$.

3. Method of analysis

The pseudorapidity space has been divided into eight non-overlapping bins: (-4.0 to -3.0), (-3.0 to -2.0), (-2.0 to -1.0), (-1.0 to 0.0), (0.0 to 1.0), (1.0 to 2.0), (2.0 to 3.0) and (3.0 to 3.6).

Normalised one-particle and two-particle pseudorapidity distributions are given by [11]

$$\rho^{(1)}(\eta) = \frac{1}{\sigma_{\rm in}}\,\frac{{\rm d}\sigma}{{\rm d}\eta}\,, \tag{1}$$

where $\sigma_{\rm in}$ is the inelastic cross-section

$$\rho^{(2)}(\eta_1,\eta_2) = \frac{1}{\sigma_{\rm in}}\,\frac{{\rm d}^2\sigma}{{\rm d}\eta_1{\rm d}\eta_2}\,, \tag{2}$$

where $\rho^{(1)}(\eta)$ and $\rho^{(2)}(\eta_1,\eta_2)$ are single-particle and two-particle densities, respectively, while ${\rm d}\sigma/{\rm d}\eta$ and ${\rm d}^2\sigma/{\rm d}\eta_1{\rm d}\eta_2$ are single and double exclusive cross-sections, respectively.

Normalised two-particle correlation function is given by

$$R(\eta_1,\eta_2) = \frac{\langle n_1 n_2\rangle}{\langle n_1\rangle\langle n_2\rangle} - 1, \qquad \text{for} \qquad \eta_1 \neq \eta_2\,, \tag{3}$$

$$R(\eta_1,\eta_2) = \frac{\langle n_1(n_1-1)\rangle}{\langle n_1^2\rangle} - 1, \quad \text{for} \quad \eta_1 = \eta_2\,. \tag{3}$$

The variance of R can be calculated by [11]

$$\begin{aligned}\widetilde{V}[R] = \frac{1}{N\langle n_1\rangle^4\langle n_2\rangle^4}\big\{&\langle n_1^2 n_2^2\rangle\langle n_1\rangle^2\langle n_2\rangle^2 - 2\langle n_1^2 n_2\rangle\langle n_1 n_2\rangle\langle n_1\rangle\langle n_2\rangle^2 \\ &-2\langle n_1 n_2^2\rangle\langle n_1 n_2\rangle\langle n_1\rangle^2\langle n_2\rangle + \langle n_1^2\rangle\langle n_1 n_2\rangle^2\langle n_2\rangle^2 + \langle n_2^2\rangle\langle n_1 n_2\rangle^2\langle n_1\rangle^2 \\ &+2\langle n_1 n_2\rangle^3\langle n_1\rangle\langle n_2\rangle - \langle n_1 n_2\rangle\langle n_1\rangle^2\langle n_2\rangle^2\big\} + O(1/N^2)\,, \quad \text{for} \quad \eta_1 \neq \eta_2\,,\end{aligned} \tag{5}$$

$$\begin{aligned}\widetilde{V}[R] = \frac{1}{N\langle n_1\rangle^6}\big\{&\langle n_1^4\rangle\langle n_1\rangle^2 - 4\langle n_1^3\rangle\langle n_1^2\rangle\langle n_1\rangle + 4\langle n_1^2\rangle^3 - \langle n_1^2\rangle^2\langle n_1\rangle^2 + 2\langle n_1^3\rangle\langle n_1\rangle^2 \\ &-4\langle n_1^2\rangle^2\langle n_1\rangle + 2\langle n_1^2\rangle\langle n_1\rangle^3 + \langle n_1^2\rangle\langle n_1\rangle^2 - \langle n_1\rangle^4\big\} + O(1/N^2)\,, \quad \text{for} \quad \eta_1 = \eta_2\,.\end{aligned} \tag{6}$$

Here n_1 is the number of pion tracks in the pseudorapidity interval $(\eta_1 - \Delta\eta_1/2)$ to $(\eta_1 + \Delta\eta_1/2)$, and n_2 is the number of pion tracks in the pseudorapidity interval $(\eta_2 - \Delta\eta_2/2)$ to $(\eta_2 + \Delta\eta_2/2)$. N is the total number of events. The term $O(N^{-2})$ has been neglected.

To search for two-pion pseudorapidity correlations for $\phi \leq 180°$ and $\phi > 180°$, we have compared the experimental data of ^{12}C-emulsion interaction events with the Monte-Carlo simulated events which were calculated assuming the independent emission. We have done the Monte-Carlo simulation assuming the following:

(i) Particles of all types are independent of each other.

(ii) The multiplicity distribution in each ensemble of Monte-Carlo events reproduces the empirical multiplicity spectrum of the real ensemble.

(iii) The pseudorapidity distribution of all types of particles coincides with the corresponding empirical semi-inclusive (i.e. at fixed n_b, n_g and n_s) distribution.

For a fixed value of η, we define that $\Delta R|_\eta$ is equal to the difference between the normalised two-pion pseudorapidity correlation calculated from experimental data at some value of η and normalised two-pion pseudorapidity correlation calculated from Monte-Carlo simulation values at the same value of η,

$$\Delta R|_\eta = (R_{ii})_{\mathrm{ex}} - (R_{ii})_{\mathrm{M-C}} \;, \tag{7}$$

where $(R_{ii})_{\mathrm{ex}}$ is the value of the two-pion pseudorapidity correlation derived from the experimental data, and $(R_{ii})_{\mathrm{M-C}}$ is the value of the two-pion pseudorapidity correlation calculated from the Monte-Carlo simulation values.

In the following we will write ΔR in place of $\Delta R|_\eta$ (in the text and in the graphs).

The variance of ΔR is given by the formula

$$\widetilde{V}[R] = \widetilde{V}[(R_{ii})_{\mathrm{ex}}] + \widetilde{V}[(R_{ii})_{\mathrm{M-C}}] \,. \tag{8}$$

4. *Results and conclusion*

We have calculated the normalised two-pion correlation function R_{ii} (i.e., $R(\eta_1, \eta_2)$ for $\eta_1 = \eta_2$) with the help of Eq. (4), and ΔR using Eq. (7). The statistical errors of experimental correlation values were obtained with the help of formula (6).

The statistical error of ΔR was calculated with the help of Eq. (8).

Figure 1 presents the normalised one-particle pseudorapidity distribution of pions, $\rho(\eta)$, in two regions of ϕ, for azimuthal angles $\phi \leq 180°$ (solid line) and for $\phi > 180°$ (dashed line). From the figure, we find that for $\phi > 180°$, $\rho(\eta)$ is negligible for $\eta = -2.5$. We also find that for $\phi \leq 180°$, $\rho(\eta)$ is negligible for $\eta = -1.5$. So. we have neglected those points of respective ϕ-regions for the derivation of results from experimental data.

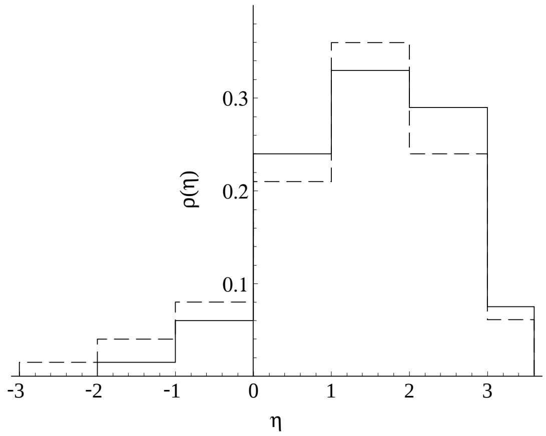

Fig. 1. Plot of normalised one-particle pseudorapidity distribution of pions, $\rho(\eta)$, vs. pseudorapidity η for the regions $\phi \leq 180°$ and $\phi > 180°$. The solid-line histogram represents the values for $\phi \leq 180°$ and the dashed-line histogram for $\phi > 180°$.

It is found from Fig. 1 that the normalised one-particle pseudorapidity distribution $\rho(\eta)$ depends on azimuthal angle. It is to be mentioned that the Monte-Carlo simulated distribution is identical with the experimental distribution for the two ϕ-regions. So, R_{ii}s are also ϕ-dependent.

Figures 2 and 3 show the normalised two-pion correlation function calculated from experimental data along with the Monte-Carlo simulated values for the two ϕ-regions. In these figures, the solid circles and the solid curves represent R_{ii} calculated from experimental data and Monte-Carlo simulated values, respectively.

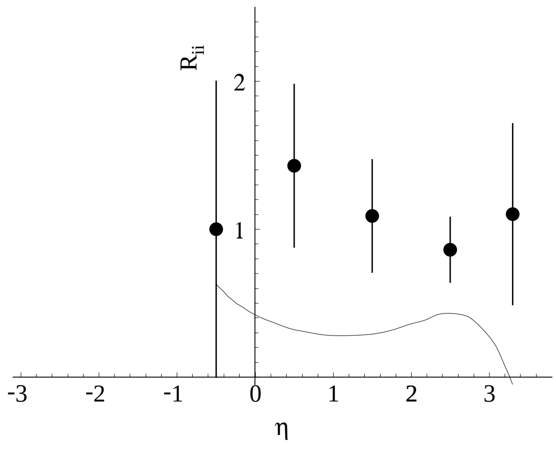

Fig. 2. Normalised two-particle pseudorapidity correlation function R_{ii} derived from the experimental data vs. pseudorapidity η (solid circles) and R_{ii} obtained by Monte-Carlo simulation (solid curve) for shower tracks from ^{12}C-emulsion interactions at 4.5 GeV/n for $\phi \leq 180°$.

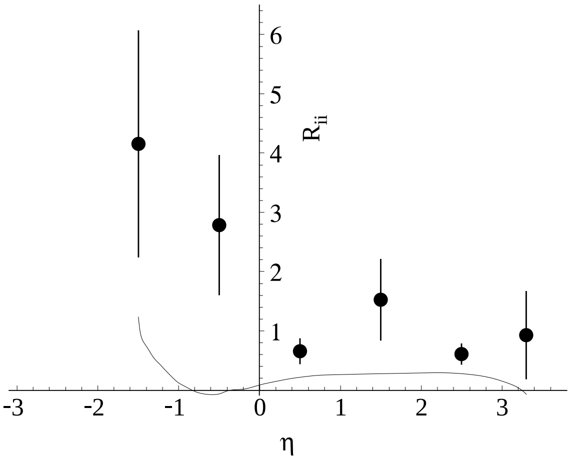

Fig. 3. Normalised two-particle pseudorapidity correlation function R_{ii} derived from experimental data vs. pseudorapidity η (solid circles) and the plot of R_{ii} calculated from Monte-Carlo simulated values (solid curve) for shower tracks from ^{12}C*-emulsion interactions at* 4.5 GeV/n *for* $\phi > 180°$.

Figures 2 and 3 show that $(R_{ii})_{\rm ex}$ and $(R_{ii})_{\rm M-C}$ are η as well as ϕ dependent. This is due to the fact that pseudorapidity distribution depends on η and ϕ. It is also found from those two figures that the values of $(R_{ii})_{\rm ex}$ and $(R_{ii})_{\rm M-C}$ are not the same for a fixed value of η in either of the two ϕ-regions. Nevertheless, Monte-Carlo simulated data yield the same pseudorapidity distribution as the experimental data, in each of the two ϕ-regions.

In Figs. 4 and 5, we present the variation of ΔR with η for $\phi \leq 180°$ and for $\phi > 180°$, respectively. Figures 4 and 5 reveal the existence of the two-pion correlation function for the two respective ϕ-spaces.

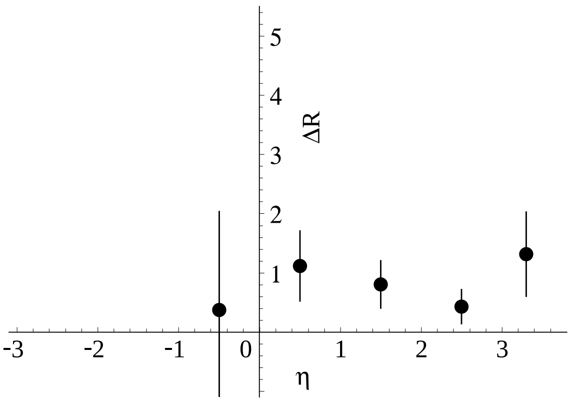

Fig. 4. Plot of ΔR vs. η for $\phi \leq 180°$.

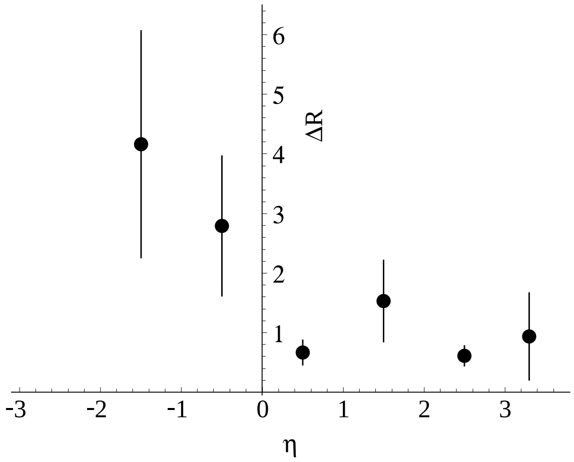

Fig. 5. Plot of ΔR vs. η for for $\phi > 180°$.

Comparing graphs of ΔR vs. η for the two ϕ-regions, we can conclude that the value of ΔR depends on ϕ-space. So, we can conclude that $(R_{ii})_{\rm ex}$ depends not only on η, but also on ϕ-space.

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AZIMUTALNA OVISNOST DVOPIONSKIH KORELACIJA U RELATIVISTIČKIM SUDARIMA TEŠKIH IONA

Istraživali smo dvopionsku normaliziranu korelaciju pseudorapiditeta za pione nastale u sudarima ^{12}C u emulzijama pri 4.5 A GeV i za azimutalne kutove $\phi \leq 180°$ i $\phi > 180°$. Usporedbom eksperimentalnih korelacija s vrijednostima izračunatim Monte-Carlo simulacijom utvrdili smo ovisnost eksperimentalne dvopionske korelacije pseudorapiditeta o azimutu.