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Physics

Study of Multiparticle Azimuthal Correlations of Negative Pions at Momenta of 4.2, 4.5 GeV/c per Nucleon

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ABSTRACT. The collective properties of $^{-}$ mesons in HeC, CC, CNe, MgMg, CCu, CTa and OPb collisions at momenta of 4.2, 4.5 GeV/c per nucleon have been investigated. The data stem from the SKM-200-GIBS streamer chamber and Propane Bubble Chamber systems utilized at JINR.

Multiparticle azimuthal correlations of $^{-}$ mesons have been studied within the standard transverse momentum analysis method of P. Danielewicz and G. Odyniec. In the phase space the axis has been identified and pion correlations were observed with respect to this axis. The values of the correlations linearly depend on the mass of all colliding pairs of nuclei. *© 2011 Bull. Georg. Natl. Acad. Sci.*

Key words: *multiparticle azimuthal correlations, collision, transverse momentum.*

During last several years we have studied multiparticle azimuthal correlations of protons and pions in central and inelastic collisions (4.2, 4.5 GeV/c/nucleon) within two experiments (SKM-200-GIBS, PBC-500) of JINR in order to investigate the mechanism of nucleus-nucleus interactions. We have studied the correlations of pions both with reaction plane (directed flow) [1-4], and with other pions ("back-to back" and "side-by-side" azimuthal correlations) [5].

Pions, being copious in relativistic heavy-ion collisions, can probe the reaction dynamics independently of nucleons. Historically, the pattern of pion emission relative to the reaction plane was first studied at the BEVALC by the Streamer Chamber group [6,7] and later by the EOS collaboration [8] at SATURN by the DIOGEN group [9].

Pion production is the most important inelastic channel at our energies. The yield of pions in the final state is connected with the temperature within the reaction zone. Thus, althogh not directly related to the nuclear equation of state (EOS) [10], pions are an integral part of the effort to determine properties of nuclear matter. The transverse momentum spectra of produced pions can provide information on properties of both the initial and final state of hadronic matter. In determining the azimuthal correlations between $^{-}$ mesons we have employed the transverse analysis method proposed by Danielewicz and Odyniec [11].

Experimental Data. The experimental data have been registered in the SKM-200-GIBS set-up and the 2 m Propane Bubble Chamber of JINR.

The SKM-200-GIBS set-up consists of a 2 m streamer chamber placed in a magnetic field of 0.8 Tesla, and a triggering system. The streamer chamber was exposed to a beam of C, Mg, O nuclei accelerated in the synchrophasotron up to momentum of 4.5 GeV/c/nucleon (beam energy E_{beam}= 3.7 GeV/nucleon). The thickness of the solid target Mg, Cu, Pb (in the form of a thin disc) was (0.2 0.4) g/cm^2. Neon gas filling of the chamber also served as a nuclear target. A central trigger was used to select events with no charged projectile spectator fragments (with p >3 GeV/c) within a cone of half angle $_{ch}$ = 2.4° or 2.9°.

muthal correlation function by the relative opening angle between the transverse momentum vector sums of particles emitted forward and backward [16,17] with respect to the rest frame of the target nucleus.

The analysis has been performed event by event, in each event we denote the vectors:

$$\mathbf{Q}_B \quad {}^{n}_{y_i \quad y} \mathbf{P}_\mathbf{i} \;, \quad \mathbf{Q}_F \quad {}^{n}_{y_i \quad y} \mathbf{P}_\mathbf{i} \qquad (3)$$

where $<y>$ is the average rapidity in each event.

Then the correlation function C( ) was constructed as follows: C( ) = dN/d , where is the angle between the vectors Q_B and Q_F:

$$\arccos \frac{\mathbf{Q}_B \;\; \mathbf{Q}_F}{|\mathbf{Q}_B| \; |\mathbf{Q}_F|} \;. \qquad (4)$$

Essentially, C( ) measures whether the particles in the backward and forward hemispheres are preferentially emitted “back-to-back” (=180°) or “side-by-side” (=0°). Pions from CNe, MgMg, CCu and OPb collisions have been analysed with the use of this method and a “back-to-back” (negative) correlations have been obtained for light, symmetric pairs of nuclei (CNe and MgMg) and “side-by-side” (positive) correlation for heavy pairs of nuclei (CCu and OPb) [5]. In order to extend these investigations, the relation between $<P^x>^2$ and the angle has been obtained for protons.

Given the issues of identification, we shall apply, in particular, the technique of Danielewicz employing only $^-$ mesons in defining some plane. In order to investigate multiparticle azimuthal correlations of $^-$ mesons, in the past we have constructed the vector **Q** using solely $^-$ mesons with multiplicity $n_- > 7$ in MgMg data [18]. The correlation of $^-$ mesons with the “reaction plane” may be due to the fact that many mesons at our energy (~80%) stem from the decays of -resonances. This vector in each individual event is defined only by negative pions in the lab. system by Eq. (1), where $\mathbf{P}_\mathbf{j}$ is the transverse

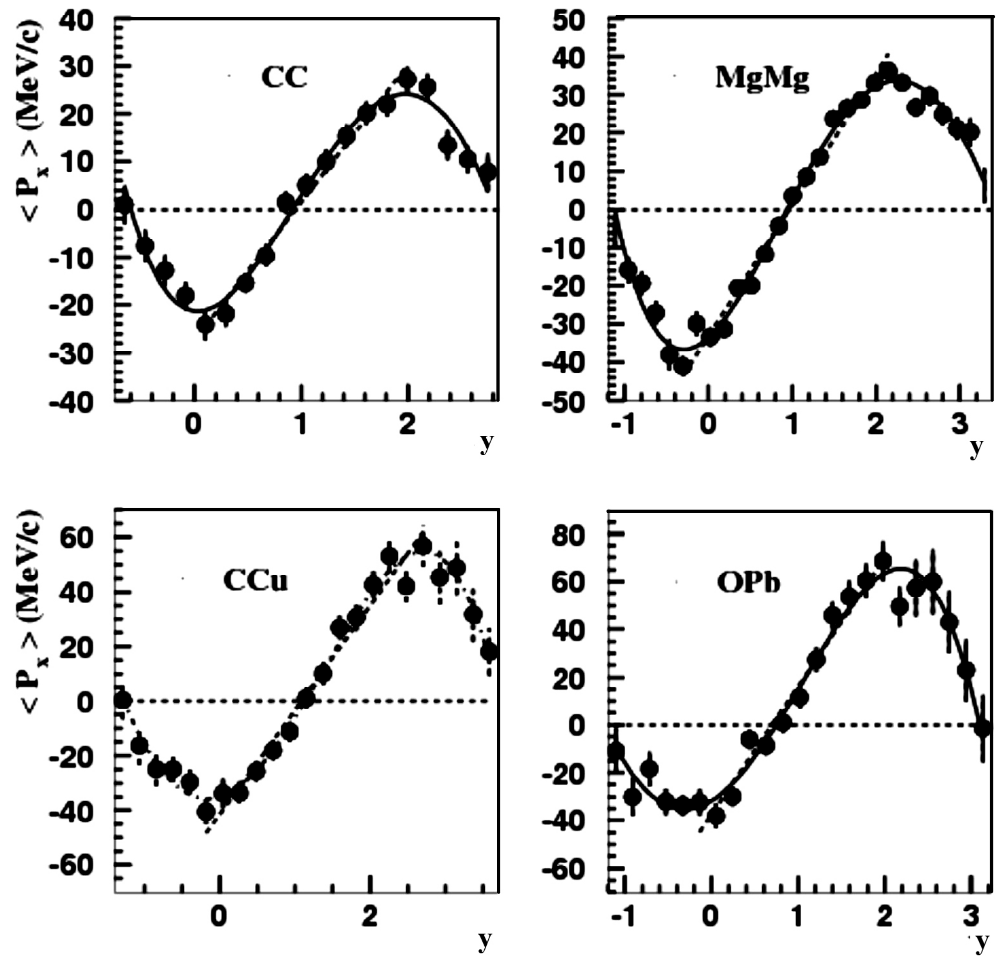

Fig.2. The dependence of $<P^x(y)>$ on y for $^-$ mesons for experimental data in CC, MgMg, CCu and OPb collisions. Straight-line stretches represent the slope of data at midrapidity cross-over, obtained by fitting the data with a linear within the rapidity region of 0.10 2.00 for CC, -0.30 2.15 for MgMg, -0.2 2.7 for CCu and -0.15 1.90 for OPb. The curved lines guide the eye over data.

momentum of $^-$ mesons, the weight factor $_i = y_i - y_c$, where y_i is the rapidity of pions i, y_c is average rapidity in each system and n is the number $^-$ mesons in the event.

This procedure has been applied in HeC, CC, CNe, MgMg, CCu, CTa and OPb collisions at momenta of 4.2, 4.5 GeV/c per nucleon. When referring a specific pion j to this vector, we estimate the direction of the latter from the vector **Q** with contribution of pion j removed,

$$\mathbf{Q_j} \quad \overset{n}{\underset{i\ \ j}{}} \quad {}_i\mathbf{P_i} \ , \qquad (5)$$

to eliminate the correlation of the particle with itself, competing with the dynamic effect we are after.

The transverse momentum of each $^-$ meson was projected onto this **Q** vector.

One commonly employed measure, quantifying the dependence of <P^x> on rapidity, which makes no distinction between the two colliding nuclei, is the slope [19] of <P^x(y)> at its midrapidity cross-over i.e. parameter of the azimuthal correlation

$$F \quad \frac{d \quad p^x}{dy}\Big|_{p^x \quad 0} . \qquad (6)$$

Characteristics of the azimuthal correlation for the measured collision events, including event number N prior to multiplicity cut, are presented in Table 1. The dependence of <P^x(y)> on y for pions has been obtained for all viewed pairs of nuclei. Figs. 1 3 show this dependence in CNe (Fig. 1), CC, MgMg (Fig. 2), CCu and OPb (Fig. 3) collisions. The data exhibits S-shape behaviour, which may be identified as collective flow of $^-$ mesons. The slopes, represented in Figs. 1 3 by straight lines, have been obtained as common, through linear fits to midrapidity data, specifically from the corresponding rapidity intervals.

The presented correlation parameter F for each nuclear system is corrected by k= 1/cos ($_R$ / 2), where $_R$ is the angle difference between the vectors $\mathbf{Q_1}$ and $\mathbf{Q_2}$. For estimation of the "reaction plane" resolution we divided randomly each event into two subevents (1 and 2) [11] and the vector in both subevents has been evaluated separately, getting $\mathbf{Q_1}$ and $\mathbf{Q_2}$. Then the azimuthal angle difference between the vectors $_R = {}_1 - {}_2$ was estimated. According to Ref. [11], the $_r$= < $_R$>/ 2> is a good measure of the "reaction plane" resolution. We have selected events with n$_-$ 4, for these collision systems (only, for HeC, CC, n$_\pm$ 3) <k> = 1.15 ± 0.07.

Figure 4 shows the dependence of the parameter F on the geometric mean of projectile and target masses

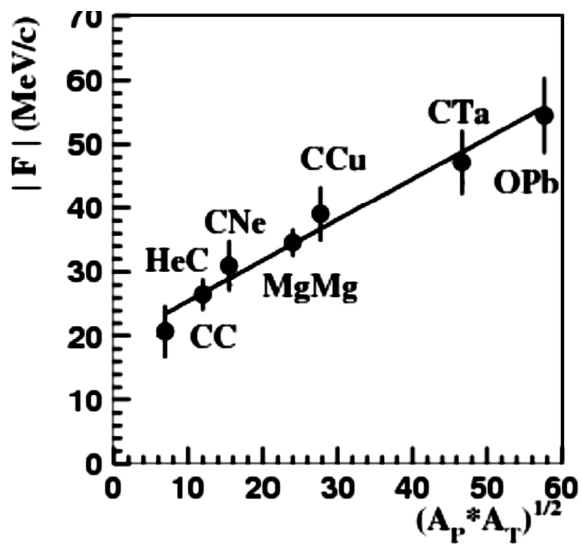

Fig. 3. The dependence of |F| on (A$_P$ * A$_T$)$^{1/2}$ for $^-$ mesons for experimental data in CC, CNe, CCu, MgMg, CCu, CTa and OPb collisions.

(A$_P$ * A$_T$)$^{1/2}$ and linear dependence has been observed.

In our opinion this behaviour demonstrates the collective transverse momentum transfer between the backward and forward hemispheres. In this case **Q** vector identifies the axis in the phase space and strong correlations of pions are observed with respect to this axis.

Conclusions

The multiparticle azimuthal correlations of negative pions in HeC, CC, CNe, CCu, CTa and OPb collisions at the momenta of 4.2, 4.5GeV/c per nucleon have been investigated.

1. The transverse momentum technique of Danielewicz and Odyniec was used for data analysis.

Clear evidence of azimuthal correlations for $^-$ mesons has been obtained. In the phase space **Q** vector identifies the axis and pions correlations were observed with respect to this axis.

2. From the transverse momentum distributions of $^-$ mesons with respect to the plane, the paramether F (the measure of the correlation function in this case) has been extracted.

The dependence of F on mass numbers of projectile A$_P$ and target A$_T$ was studied.

The value of F increases linearly with the increase of A$_P$, A$_T$ from 20.7 ± 4.1 (MeV) for HeC up to 54.5 ± 6.0 (MeV) for OPb.

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ფიზიკა

უარყოფითი პიონების მრავალნაწილაკოვანი აზიმუტური კორელაციების შესწავლა 4.2, 4.5 გევ/c ნუკლონზე იმპულსის დროს

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გამოკვლეულია $^-$ მეზონების კოლექტიური თვისებები HeC, CC, CNe, MgMg, CCu, CTa და OPb დაჯახებებში 4.2, 4.5 გევ/c ნუკლონზე იმპულსის დროს. ექსპერიმენტული მასალა მიღებულია JINR–ის დანადგარებზე SKM-200-GIBS სტრიმერული სპექტრომეტრისა და PBC-500 პროპანის ბუშტოვანი კამერის მეშვეობით.

$^-$ მეზონების მრავალნაწილაკოვანი აზიმუტური კორელაციები შესწავლილია პ. დანიელევიჩისა და გ. ოდინიეცის სტანდარტული განივი იმპულსებით ანალიზის მეთოდის გამოყენებით. ფაზურ სივრცეში გამოყოფილია ღერძი, რომლის მიმართაც დამზერილია პიონების კორელაციები. კორელაციის პარამეტრი წრფივად იზრდება დამჯახებელი ბირთვების მასების ზრდასთან ერთად.

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