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STUDY OF COLLECTIVE FLOW EFFECTS IN *CC*-COLLISIONS AT A MOMENTUM OF 4.2 GeV/c PER NUCLEON

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1 Introduction

The multiparticle azimuthal correlations are investigated very intensively with the goal to study the dynamics of relativistic nuclei collisions. The study of this effect in terms of the collective flow variables with respect to the reaction plane turned out to be especially fruitful. The collective emission of the particles occurs at the expansion stage of the nuclear matter through the short-range repulsion between the nucleons at the expense of the compressional energy concentrated in the high density and temperature overlap region of colliding nuclei. The collective effects lead to characteristic, azimuthally asymmetric sideward emission of the reaction products. The analysis of the main characteristics of the collective flow allows one to obtain the information about the fundamental properties of nuclear matter, connected particularly to the equation of state (EOS) [1].

Two different signatures of the collective flow have been studied:

a) the bounce-off of compressed matter in the reaction plane (a sideward deflection of the spectator fragments - "bounce-off", as well as directed flow of nucleons from the overlap region between the colliding nuclei (participants) in the reaction plane - "side splash"), called the sideward or directed flow.

b) the squeeze-out of the participant matter out of the reaction plane – the elliptic flow.

The method proposed by P. Danielewicz and G.Odyniec [2] turned out to be the most convenient and fruitful for the investigation of collective flow phenomena, which allows one to determine the reaction plane by using the transverse momenta of participating protons. Lately the method of Fourier expansion of azimuthal particle distributions has been widely used [3].

At present the collective flow effects are investigated in the wide range of energies from several hundreds of MeV up to hundreds of GeV. The most part of the experiments are carried out using the electronic technique in the 4π geometry and only in the first experiments at Berkley and lately at Dubna, the streamer chamber served as the detector.

The collective flow of charged particles has been observed experimentally for the first time at BEVALAC by the Plastic Ball [4] and Streamer Chamber [7] collaborations. It has been studied intensively at Berkeley and GSI [4-12], at AGS [13-15] and CERN/SPS [16].

At Dubna (JINR) in the 2 meter Propane Bubble Chamber the shape of the individual events of C-Ta collisions at a momentum of 4.2 GeV/c/nucleon has been studied in terms of the tensor of kinetic energy (sphericity) [17]. It has been shown that the angle between the axis of the ellipsoid and the beam direction $\Theta_{flow} = 12^0$ for the high-multiplicity events.

The flow of protons and π^- mesons has been observed at Dubna by the SKM-200-GIBS collaboration [18,19] in central CNe and CCu collisions at a momentum of 4.5 GeV/c/nucleon. In inelastic CC collisions at a momentum of 4.2 GeV/c/nucleon registered in the 2 meter Propane Bubble Chamber, the flow of protons has been obtained only on the part of statistics [20]. The most complete experimental data of collective flow effects are presented in the review article [21].

2 Experimental data

In this paper the collective flow of protons, π^- mesons and projectile light fragments (d, t, ^3He, ^4He) in CC collisions at a momentum of 4.2 GeV/c/nucleon registered in the 2 meter Propane Bubble Chamber at JINR are studied.

The chamber was placed in a magnetic field of 1.5 Tesla. The method of separation of CC collisions in propane, the processing of the data, identification of particles and discussion of corrections is described in detail in Ref.[22]. The experimental data, apart from the unambiguously identified CC collisions with the probability of ωc=1, contains the sample of CC events with ωc=0.21. When studying the inclusive characteristics of CC collisions the distributions are obtained for the whole ensemble of C-propane collisions, taking into account the weight factor ωc.

For the analysis of the collective flow of particles, the experimental data contained 15692 unambiguously identified CC.

The study of collective flow phenomenon needs "event-by-event" analysis, which requires the exclusive analysis of each individual collision. In this connection there has been a necessity to perform an additional identification of π^+ mesons, since in the propane chamber the π^+ mesons have been identified in the narrow interval of momenta (up to 0.5 GeV/c). The weight (probability) is defined statistically for the particles with the momentum $p > 0.5$ GeV/c with which the particle satisfies the hypothesis of π^+ meson or proton for the whole ensemble of CC collisions. However the group of particles has remained with unseparated hypothesis (p, π^+), the most part of which form the protons. The separation of the group of CC collisions with ωc=1 and the necessity of unambiguous separation of protons and π^+ mesons have led to the difference, in the momentum distributions of π^- and π^+ mesons. To remove this difference, the correction of the π^+ mesons identification has been carried out. The procedure has been performed statistically, based on the well founded assumption that for symmetric nuclear collisions the distributions of π^- and π^+ mesons are similar.

In Fig. 1 the momentum and transverse momentum distributions of π^- and π^+ mesons are presented with the previous and additional identifications. One can see from Fig.1 that a small difference in the momentum distribution of π^+ mesons is removed.

Only participant protons have been selected for the analysis. With this purpose, from the whole ensemble of particles the fragments of the target ($p < 0.3$ GeV/c), projectile stripping ($p > 3$ GeV/c and angle $\Theta < 4^0$) fragments and also the light fragments of the projectile with $Z > 1$ (^3He, ^4He) identified by ionization visually and $Z = 1$ (d, t) with $p > 5$ GeV/c have been excluded.

The following restriction - the choice of the events with the number of participant protons $N_{part} \geq 4$, is caused by the necessity to obtain reliable results at low multiplicity. In consequence, from the inelastic CC collisions the group of 9490 semicentral collisions (58078 participant protons) have been selected.

3 Transverse flow analysis method

The method of P.Danielewicz and G.Odyniec has been used for study of collective flow of protons, based on the summation of the transverse momenta of selected particles [2]. The most of experimental data at energies below 4 GeV/nucleon has been analysed by this method. It gives satisfactory results even at a small available statistics obtained by the film detectors.

The reaction plane vector $\overrightarrow{Q}$ in each individual event is defined only by the participant protons in the center-of-mass system:

$$\overrightarrow{Q} = \sum_{i=1}^{n} \omega_i \overrightarrow{p_{\perp i}}, \qquad (1)$$

where $p_{\perp i}$ is the transverse momentum of particle i; the weight factor ω_i is taken as 1; for $y_i > 0$ and -1 for $y_i < 0$, where y_i is the rapidity of particle i, and n is the number of participant protons in the event. This choice leads to the result that the forward and backward moving particles, which are azimuthal anticorrelated if there is a collective transverse flow, will contribute equally to $\overrightarrow{Q}$.

The reaction plane is the plane containing the impact parameter $\overrightarrow{b}$ and beam axis. Taking into account that the definition of $\overrightarrow{b}$ experimentally is not possible, in the transverse momentum analysis method of Danielewicz and Odyniec the vector $\overrightarrow{b}$ is replaced by $\vec{Q}$. If one projects the transverse momentum of each particle $p_{\perp i}$ onto the summary momentum, the autocorrelations will arise, from which it will be very difficult to extract true dynamic correlations. To remove the autocorrelations, Danielewicz and Odyniec [2] supposed to estimate the reaction plane for each particle j, i.e., to project $p_{\perp i}$ onto the summary vector of all other particles in the same event:

$$\vec{Q}_j = \sum_{i \neq j}^{n} \omega_i \vec{p_{\perp i}}. \tag{2}$$

The transverse momentum of each particle in the estimated reaction plane is calculated as

$$p_{xj}' = \{\vec{Q}_j \cdot \vec{p}_{\perp j} / |\vec{Q}_j|\}. \tag{3}$$

The dependence of the mean transverse momentum of each particle in the reaction plane $< p_x >$ on the rapidity y is constructed. The average transverse momentum $< p_x'(y) >$ is obtained by averaging over all events in the corresponding intervals of rapidity.

It is known [4] that the estimated reaction plane differs from the true one, due to the finite number of particles in each event. The component p_x in the true reaction plane is systematically larger than the component p_x' in the estimated plane, hence:

$$< p_x > = < p_x' > / < cos\varphi >, \tag{4}$$

where φ is the angle between the estimated and true planes. The correction factor k=1 / $< cos\varphi >$ is the subject of a large uncertainty, especially for low multiplicity. In Ref. [2] the method for the definition of the correction factor has been proposed. Each event is randomly divided into two almost equal subevents, the vectors $\vec{Q_1}$ and $\vec{Q_2}$ are constructed and then the distribution of the azimuthal angle between these two vectors is plotted. The dispersion of this angular distribution determines the discrepancy between the true and estimated reaction planes. The coefficient k depends on the multiplicity in the event and naturally the correction is larger at low multiplicity. It is desirable to group the events by the multiplicity intervals. Due to the limited statistics the coefficient in this paper has been defined for the whole ensemble, averaged over all the multiplicities: k=1.43±0.8.

Fig. 2 shows the dependence of the corrected $< p_x(y) >$ on y for protons in CC collisions at a momentum of 4.2 GeV/c/nucleon. The data exhibits S-shape behaviour which demonstrates the collective transverse momentum transfer between the backward and forward hemispheres.

From the mean transverse momentum distributions one can extract two main observables sensitive to the EOS. One of them is the mean transverse momentum in the reaction plane in the forward rapidity region $< p_x >_{y>0}$. Another equivalent observable is the transverse flow F, i.e., the slope of the momentum distribution at midrapidity (in the intersection point y=0), which was introduced by the Plastic Ball team [5]:

$$F = \frac{\partial [p_x]}{\partial y} |_{y_{cms}=0}. \tag{5}$$

F is a measure of the amount of collective transverse momentum transfer in the reaction plane, i.e., intensity of nuclear interactions.

This quantity was the subject of less experimental bias than the maximum of p_x, and it enabled one to compare different reactions and results of different experimental set-ups to each other. The straight line in Fig.2 is the result of the fit of experimental data in the rapidity y interval (-0.75 $\div$ 0.75). The protons flow $F = (136 \pm 11)$ MeV/c. The value of F is very similar to the result obtained at SKM-200-GIBS set-up at JINR in central C-Ne collisions at a momentum of 4.5 GeV/c/nucleon [18,19]. One can see from Fig.2 that the $< p_x >$ distribution for CC collisions is more symmetric than for CNe interactions [18,19]. It is worth emphasizing that CC is the lightest system of colliding nuclei in which the transverse (directed) flow of protons has been observed.

To be convinced that the observed effect is due to the manifestation of the dynamics of collisions, the following check-up has been carried out. The events have been composed by mixing of the randomly selected tracks from different events (within the same multiplicity range) and then the flow has been defined for this "mixed" events. One can see from Fig.2 that in these events there is no correlation with the reaction plane and particles are emitted isotropically in the "mixed" events.

The mean transverse momentum in the reaction plane in the forward rapidity region $< p_x >_{y>0}$ has been calculated for protons and the value of $< p_x >_{y>0} = (104 \pm 9)$ MeV/c has been obtained. In CC collisions, selected for the flow analysis, 4464 identified light fragments with $Z > 1$ (^3He, ^4He) and 4857 single charged particles with the momentum $p > 5$ GeV/c have been registered, which are deuterons and tritons with a large probability. The $< p_x >_{y>0}$ has been estimated for these particles, assuming that the fraction of ^3He and ^4He and also d and t is the same. The value of $< p_x >_{y>0}$ has been obtained: $< p_x >_{y>0} = (140 \pm 20)$ MeV/c. Thus the value of $< p_x >_{y>0}$ for light fragments is 20-30 % larger than those for participant protons.

The experimental data of different particle flows formed in heavy ion collisions contains the whole interval of available energies and a large set of colliding nuclei A_p and A_t (ArKCl, CaCa, NbNb, CNe, CCu, NiCu, CPb, $ArBaI_2$, ArPb, AuAu, PbPb etc.). For the investigation of energy dependence of flow values for different projectile/target mass combinations the scaled variable F_s has been introduced, which does not depend on the mass numbers of colliding nuclei

$$F_s = F/(A_p^{1/3} + A_t^{1/3}). \tag{6}$$

In Fig. 3 the energy dependence of scaled flow F_s of protons from different experiments is presented. The point $F_s = (29.7 \pm 2.4)$ MeV/c is obtained in this article. One can see that the scaled flow F_s follows, within the uncertainties, a common trend with initial step rise and then a gradual decrease.

In view of the strong coupling between the nucleon and pion, it is interesting to know if pions also have a collective flow behaviour and if yes, how the pion flow is related to the nucleon flow.

For this purpose, the reaction plane has been defined for the participant protons and the transverse momentum of each π^- meson has been projected onto this reaction plane. Fig. 4 shows the dependence of $< p_x >$ on rapidity y in the c.m.s. for π^- mesons in CC collisions. This dependence has the same behaviour as for the protons. The value of flow F for π^- mesons is $F = (22.2 \pm 6.1)$ MeV/c. The straight line in Fig. 4 shows the result of the fitting. The fit was done in the interval of y: -0.6 $\div$ 0.6. This result is very close to the F of pions obtained at SKM-200-GIBS [19] in CNe collisions at 4.5 GeV/c/nucleon.

The dependence of flow of pions F on the transverse momentum has been investigated. In Table 2 the flows of pions with $p_T > 0.1$, 0.15 and 0.2 GeV/c are presented. The flow increases with p_T from 22.2 up to 43.7 MeV/c. The flow of π^- mesons in CC collisions has been observed for the first time.

One can see from Fig.4 that for CC collisions flows of protons and pions are correlated similarly as in CNe interactions.

Several theoretical models of nucleus-nucleus collisions at high energy have been proposed for the description of the collective flow effects. The Relativistic Transport Model (ART 1.0) [23] and Quark-Gluon String Model (QGSM) are widely used. A detailed description and comparison of the QGSM with collective flow effects observed in different experiments over a wide energy range can be found in Refs. [24,25]. It is worth mentioning that the QGSM satisfactorily describes the spectra of secondary protons and π^- mesons in CC [26] and MgMg [27] collisions at momenta of 4.2 and 4.3 GeV/c/nucleon, respectively. The model also well reproduces the flow of protons and π^- mesons in CNe and CCu collisions at $p = 4.5$ GeV/c/nucleon [18,19]. In the present paper the QGSM was used for a comparison with experimental data. We have generated CC inelastic collisions using the COLLI Monte Carlo generator. At the first step, the version of the generation program with unfixed impact parameter b has been used. 50000 inelastic CC collisions at a momentum of 4.2 GeV/c have been generated . From the b distribution we obtained the mean value $< b >$=3.8 fm. Then similarly as for the experimental data, the selection criteria of participant protons have been applied on these events, namely, the fragments of the target ($p < 0.3$ GeV/c) and stripping fragments of the projectile ($p > 3$ GeV/c and angle $\Theta < 4^0$) have been excluded. From the analysis of generated events the protons with deep angles greater than 60^0 have been excluded additionally, because such vertical tracks are registered with less efficiency in the experiment. After selection of events with the number of participant protons not less than 4, for the analysis of the flow of protons the group of semicentral collisions with $< b >= 2.65$ fm survived.

At the second step, 50000 of semicentral CC collisions have been generated at a fixed impact parameter $< b >$=2.65 fm with superimposing the above-mentioned criteria during the generation of the collisions. The both samples of generated events have been used for the comparison with experimental distributions.

In Fig. 2 the result of the analysis of the group of generated events with $< b >$=2.65 is presented with experimental data. One can see that the model describes quite well the experimental data of protons in the central region and $F_{mod} = (145 \pm 9)$ MeV/c (196942 participant protons). From QGSM the value of mean transverse momentum of protons in the reaction plane in the forward rapidity region $< p_x >_{y>0}$ has been obtained $< p_x >_{y>0} = (114 \pm 7)$ MeV/c.

The QGSM has been also used for the comparison with the pion flow in CC collisions. One can see from Fig. 4 that the QGSM yields flow signature similar to the experimental data. The value of F, obtained from the QGSM, is $F_{mod} = (23.2 \pm 3.0)$ MeV/c.

4 Azimuthal anisotropic emission of protons and pions

The preferential emission of particles in the direction perpendicular to the reaction plane (i.e., "squeeze-out") is particularly interesting, since it is the only way where nuclear matter might escape without being rescattered by spectator remnants of the projectile and target and is expected to provide direct information on the hot and dense participant region formed in high energy nucleus-nucleus interactions. This phenomenon, predicted by hydrodynamical calculations [2], was clearly identified by the Plastic Ball collaboration.

In order to extend these investigations, we have studied the azimuthal ϕ ($cos\phi = P_x/P_t$) distributions of the pions and protons with respect to the reaction plane. The angle ϕ is the angle of the transverse momentum of each particle in the event with respect to the reaction plane. The analysis was restricted only to the mid-rapidity region by applying a cut around the center-of-mass rapidity. Fig.5 shows respective distribution for protons in CC collisions obtained in central rapidity region $|y| \leq 1$. The azimuthal angular distribution shows maxima at ϕ=90^0 and 270^0 with respect to the event plane. These maxima are associated with preferential particle emission perpendicular to the reaction plane (squeeze-out, or elliptic flow). Thus a clear signature of an out-of-plane signal (elliptic flow) is evidenced.

To treat the data in a quantitative way, the azimuthal distributions have been fitted by a polynomial:

$$dN/d\phi = a_0(1 + a_1 cos\phi + a_2 cos2\phi). \quad (7)$$

The anisotropy factor a_2 is negative for out-of-plane enhancement (squeeze-out) and is the measure of the strength of the anisotropic emission. The value of the coefficient a_2 extracted from the azimuthal distribution of protons is $a_2 = -0.044 \pm 0.006$ (Table 1) and of pions is $a_2 = -0.037 \pm 0.011$ (Table 2). The fitted curves are superimposed on the experimental distributions (Fig. 5). The Quark Gluon String Model (QGSM) has been used for the comparison with the experimental results. The QGSM data for protons and pions at fixed impact parameter b=2.65 fm is also plotted in Fig. 5 and corresponding values of a_2 extracted from the QGSM data are listed in Tables 1 and 2. One can see that the model describes the experimental azimuthal distributions.

The values of a_2 are used to quantify the ratio R of the number of particles emitted in the perpendicular direction to the number of particles emitted in the reaction plane, which represents the magnitude of the out-of-plane emission signal:

$$R = \frac{1 - a_2}{1 + a_2}. \quad (8)$$

A ratio R, larger than unity, implies a preferred out-of-plane emission. The values of R for protons and pions are listed in Tables 1 and 2. The dependence of the azimuthal anisotropy on the transverse momentum has been investigated. One can see that a_2 and R increase for both protons and π^- mesons with increasing cutting limit applied to the transverse momentum. The squeeze-out effect is more pronounced for protons than for π^- mesons. Our results on transverse momentum dependence of the azimuthal anisotropy in

CC semicentral collisions are consistent with the results of SKM-200-GIBS [19] for CNe and CCu central collisions.

In experiments (E-895 [29], E-877 [30]) at AGS and at SPS (CERN) (NA49) [32], the elliptic flow is typically studied at midrapidity and quantified in terms of the second Fourier coefficient $v_2 =< cos2\phi >$. The Fourier coefficient v_2 is related to a_2 via the equation $v_2 = a_2/2$.

5 Conclusions

The flow effects of protons, π^- mesons and projectile light fragments (d, t, ^3He, ^4He) have been investigated in semicentral CC collisions at a momentum of 4.2 GeV/c/nucleon. *The transverse momentum technique of P. Danielewicz and G.Odyniec was used for data* analysis. Clear evidence of directed (in-plane) and elliptic (out-of-plane, squeeze-out) flow effects for protons and π^- mesons has been obtained.

1. From the transverse momentum distributions of protons and π^- mesons with respect to the reaction plane, the flow F (the measure of the collective transverse momentum transfer in the reaction plane) has been extracted. For participant protons the value of F has been obtained: $F = (136 \pm 11)$ MeV/c. The mean transverse momentum of protons in the reaction plane in the forward rapidity region $y > 0 < p_x >_{y>0}$ has been estimated: $< p_x >_{y>0} = (104 \pm 9)$ MeV/c.

2. The comparison of our results on the protons directed (in-plane) flow with flow data for various projectile/target combinations was made using the scaled flow $F_s = F/(A_p^{1/3} + A_t^{1/3})$. F_s demonstrates a common scaling behaviour for flow values from different systems.

3. The value of π^- mesons flow F is equal to (22.2 ± 6) MeV/c and increases up to (43.7 ± 10.2) MeV/c with increasing transverse momentum of pions from 0 to 0.2 GeV/c. The flow of π^- mesons is obtained for the first time for such a light system as CC. In-plane flow of π^- mesons is in the same direction as for the protons.

4. The mean transverse momentum in the reaction plane in the forward rapidity region $y > 0 < p_x >_{y>0}$ has been estimated for projectile light fragments (d, t, ^3He, ^4He), assuming that the fraction of ^3He and ^4He, and d and t is the same: $< p_x >_{y>0} = (140 \pm 20)$ MeV/c.

5. From the azimuthal distributions of protons and π^- mesons with respect to the re-

action plane the parameter a_2 (the measure of the anisotropic emission strength) has been extracted. The value of the azimuthal anisotropy coefficient a_2 of protons is $a_2 = -0.044 \pm 0.006$ and of pions is $a_2 = -0.037 \pm 0.011$. The anisotropy of π^- mesons increases with rise of the cut applied to the transverse momentum. The a_2 was defined for light CC system also for the first time.

6. All experimental results have been compared with the predictions of the Quark Gluon String Model. The model reproduces all data quite well.

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Table 1. The number of protons N_P, the values of the parameters a_2, χ^2/N and R for experimental and QGSM (*) events

p_T (GeV/c)	N_P	a_2	χ^2/N	R
all p_T	55752	-0.044±0.006	28/30	1.092±0.050
(*)	189676	-0.046±0.003	37/30	1.096±0.025
$p_T > 0.1$	53197	-0.059±0.007	35/30	1.125±0.045
(*)	180416	-0.068±0.003	34/30	1.146±0.013
$p_T > 0.2$	48442	-0.067±0.007	33/30	1.144±0.040
(*)	169667	-0.072±0.003	36/30	1.155±0.016
$p_T > 0.3$	40057	-0.079±0.007	32/30	1.171±0.034
(*)	151257	-0.079±0.004	35/30	1.171±0.020

Table 2. The number of π^- mesons, the values of the parameters F, a_2, χ^2/N and R for experimental and QGSM (*) events

p_T (GeV/c)	N_p	F (MeV/c)	a_2	χ^2/N	R
all p_T	20310	22.2±6.1	-0.037±0.011	20/24	1.077±0.106
(*)	71014	23.2±3.0	-0.034±0.006	22/24	1.070±0.063
$p_T > 0.1$	16898	27.0±7.1	-0.051±0.012	21/24	1.107±0.086
(*)	58963	29.1±3.5	-0.042±0.006	20/24	1.088±0.052
$p_T > 0.15$	13415	33.5±8.6	-0.067±0.013	14/24	1.144±0.074
(*)	47410	34.4±4.1	-0.052±0.007	26/24	1.110±0.050
$p_T > 0.2$	10208	43.7±10.2	-0.083±0.015	12/24	1.181±0.071
(*)	36218	45.0±5.1	-0.062±0.008	27/24	1.132±0.050

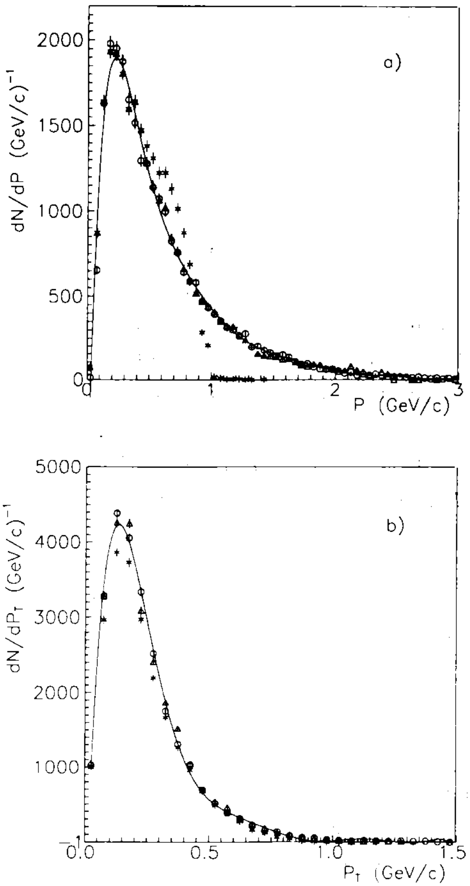

Fig.1 The momentum (a) and transverse momentum (b) distributions of π^- and π^+ mesons in CC collisions: o - π^- mesons, $*$ π^+ mesons, identified by ionization, $\triangle$ - π^+ mesons, additional identification

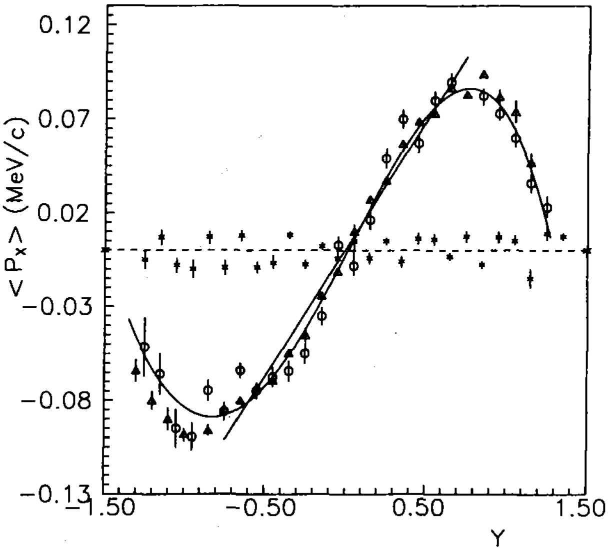

Fig.2 The dependence of $< p_x(y) >$ on y for protons in CC collisions in c.m.s. o – the experimental data, Δ – QGSM generated data for fixed b= 2.65 fm, $*$ – events composed by randomly selected tracks from different events (within the same multiplicity range). The solid line is the result of the linear approximation of experimental data in the interval of y - 0.75 $\div$ 0.75. The solid curve for visual presentation of experimental events - result of approxomation by 4-th order polynomial

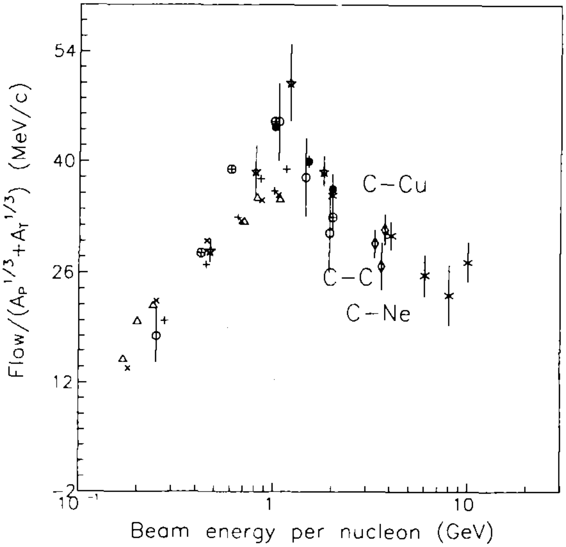

Fig.3 Scaled flow values versus beam energy per nucleon for different projectile/target systems. △ – AuAu Plastic Ball, ○ – NiNi FOPI, • – NiCu EOS, + – AuAu EOS, ⊕ NiAu EOS, ⋆ – ArPb Streamer Chamber, the value at E=1.08 AGeV represents ArKCl Streamer Chamber, ◇ – CC, CNe and CCu, ∗ – AuAu E-895, the value at E=10 AGeV represents AuAu from E-877. To improve the distinction between data points at the same beam energy, some of the beam energy values have been shifted

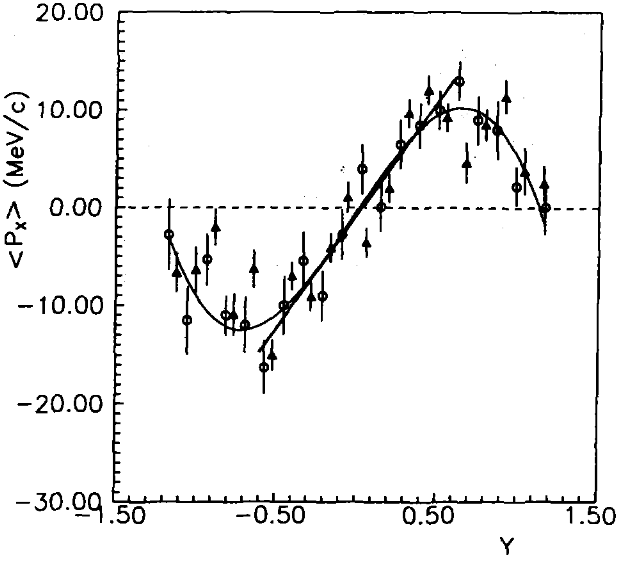

Fig.4 The dependence of $< P_x(y) >$ on y for π^- mesons in CC collisions in c.m.s. o – the experimental data, Δ – QGSM generated data for fixed b= 2.65 fm. The solid line is the result of the linear approximation of experimental data in the interval of y - 0.6 ÷ 0.6. The solid curve for visual presentation of experimental events - result of approxomation by 4-th order polynomial function

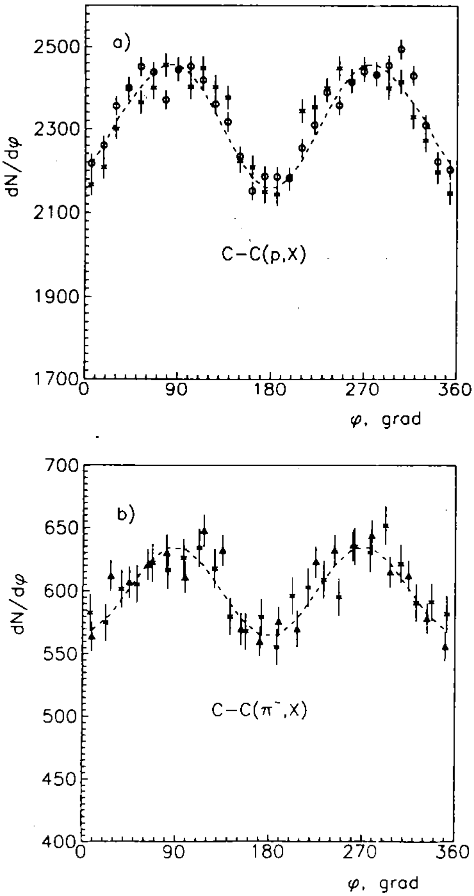

Fig.5 The azimuthal distributions with respect to the reaction plane of midrapidity protons dN/dϕ and π^- mesons. o – protons, △ π^- mesons, × – QGSM generated data. respectively. The curves — result of approximation by $dN/d\phi = a_0(1 + a_1 cos\phi + a_2 cos2\phi)$

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Чхаидзе Л. В. и др. E1-2002-255

Изучение коллективного эффекта в CC-соударениях с импульсом 4,2 ГэВ/с на нуклон

Определены направленные потоки протонов, π^--мезонов и легких фрагментов (d, t, ^{3}He, ^{4}He) путем исследования в системе центра масс зависимости среднего поперечного импульса в плоскости реакции $\langle p_x \rangle$ от y-быстроты. Установлено, что величина полученного скейлингового потока протонов $F_s = F/(A_p^{1/3} + A_t^{1/3})$ согласуется с результатами других экспериментов для различных пар сталкивающихся ядер. Из анализа азимутальных угловых распределений протонов и π^--мезонов получена составляющая потока, перпендикулярная к плоскости реакции (squeeze-out). Определен параметр a_2, который является мерой интенсивности анизотропного испускания. Экспериментальные результаты хорошо описываются кварк-глюонной струнной моделью.

Работа выполнена в Лаборатории высоких энергий им. В. И. Векслера и А. М. Балдина ОИЯИ и Институте физики высоких энергий Тбилисского государственного университета.

Препринт Объединенного института ядерных исследований. Дубна, 2002

Chkhaidze L. V. et al. **E1-2002-255**

Study of Collective Flow Effects in CC-Collisions at a Momentum of 4.2 GeV/c per Nucleon

The directed (in-plane) flows of protons, pions and projectile light fragments (d, t, ^{3}He, ^{4}He) have been observed by investigating the dependence of the mean transverse momentum in the reaction plane $\langle p_x \rangle$ on the rapidity y in the center-of-mass system. The comparison of our in-plane flow results of protons with flow data for various projectile/target configurations was made using the scaled flow $F_s = F/(A_p^{1/3} + A_t^{1/3})$. F_s demonstrates a common scaling behaviour for flow values from different systems. From azimuthal distributions of protons and π^- mesons the out-of-plane (squeeze-out) flow effects have been observed and the parameter a_2 (the measure of the anisotropic emission strength) has been extracted. The Quark-Gluon String Model reproduces quite well the experimental results.

The investigation has been performed at the Veksler-Baldin Laboratory of High Energies, JINR and High Energy Physics Institute of Tbilisi State University.

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