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EXPERIMENTAL STUDY OF NUCLEAR FLOW IN $^{22}Ne + (Ag, Br)$ INELASTIC INTERACTIONS AT 4.1 AGeV/c[1]

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Azimuthal correlations in angles between charged secondary particles from inelastic interactions of 4.1A GeV/c ^{22}Ne nuclei with heavy emulsion nuclei are studied. We observe that the degree of azimuthal asymmetry increases with a decreasing impact parameter. We present an experimental evidence for the same-side (opposite-side) emission of charged secondaries in the transversal plane for particles belonging to the same (different) fragmentation regions of nucleus-nucleus collisions. The observed effect is not confirmed by the intranuclear-cascade model calculations and points towards a possible presence of hydrodynamical bounce-off.

I. INTRODUCTION

Macroscopic aspects of high energy nuclear collisions are certainly one of the most attractive subjects of experiments seeking signals of high temperature and density. A low sensitivity of data on multiplicities and single-particle spectra when discriminating between different models of multiparticle production and nuclear fragmentation makes approaches based on multiparticle correlations or the analysis of event shapes and emission patterns on an event by event basis highly preferable [1—3]. Both the streamer chamber and the plastic ball groups claimed to have found an evidence for the collective flow of nuclear matter in high multiplicity events in nucleus-nucleus collisions at 0.4 A GeV/c [4]. First hints for a hydrodynamical bounce-off were observed in photoemulsion studies in central ^{12}C+Pb [5] and ^{56}Fe+(Ag, Br) [3] collisions.

Here we report new experimental data on azimuthal correlations between charged secondaries produced in interactions of ^{22}Ne nuclei at 4.1 A GeV/c.

II. EXPERIMENTAL DETAILS

The experimental material comes from an exposure of a BR-2 emulsion by a 4.1 AGeV/c beam of ^{22}Ne nuclei at the Dubna Synchrophasotron. Detailed information on experimental procedures is in our previous paper [6]. Here we only briefly recall a classification of charged secondary particles, which is relevant for our present study:

i) h-particles: heavily ionizing particles with $v < 0.7$ c (or $p/m < 1$).

ii) s-particles: singly charged relativistic particles with $p/m > 1$ without contribution of singly charged spectator fragments of the incident ^{22}Ne nucleus (using a polar angle cut $\Theta = 3°$)

iii) f-particles: spectator fragments of ^{22}Ne.

Let us recall that the h-particles consist mainly of the target nucleus fragments (p, d, ...) with ofly a very small admixture of slow mesons. On the other hand our previous analysis [7] of momentum spectra of the s-particles, which was carried out separately on a 10% subsample of all 4307 inelastic ^{22}Ne+Em interactions, has shown that both the relativistic mesons and the wounded nucleons of the projectile contribute this group with a comparable strength.

In the present study we are analysing only events in which at least seven charged fragment of the target nucleus have been emitted. By this criterion we exclude practically all interactions with emulsion light nuclei as well as very peripheral ^{22}Ne+(Ag, Br) collisions. Condition $N_h \geq 7$ selects 1824 events, i.e. $\simeq 75$ % of all ^{22}Ne+(Ag, Br) inelastic interactions.

III. CHARACTERISTICS OF AZIMUTHAL CORRELATIONS

To study the azimuthal correlations in angles between charged particles we use the following collective variables [3, 5]:

1. Coefficient of azimuthal asymmetry

$$\beta_1 = \sum_{i \neq j}^{n_k} \cos \varepsilon_{ij} / \sqrt{n_k(n_k - 1)}$$

where $n_k \geq 2$ is the multiplicity of particle of the considered type in the k-th event and ε_{ij} is the relative azimuthal angle between transverse momenta of the i-th and j-th particles from an event.

2. While discussing the azimuthal correlations between particles belonging to different types (intergroup correlations) we use the distribution of the angle Φ_{IJ} between vectors composed of the unit vectors directed along the transverse momenta of particles belonging to two groups of particles (I and J)

$$\Phi_{IJ} = \arcos \{(a_I a_J + b_I b_J) [(a_I^2 + b_I^2)(a_J^2 + b_J^2)]^{-1/2}\}$$

where $a_L = \sum_{i=1}^{n_{k,L}} \cos \varphi_i$, $b_L = \sum_{i=1}^{n_{k,L}} \sin \varphi_i$, $L = I$ or J are the sums of Cartesian components of the unit vectors in a transverse plane and $n_{k,L} > 1$ is the number of tracks in the k-th event of group I or J.

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Table 1

Ensemble of events	$\langle\beta_1^S\rangle$	$\langle\Phi_{sh}\rangle - \pi/2$	$\beta_1^S > 0$	
			$\langle\beta_1^h\rangle$	$\langle\Phi_{sh}\rangle - \pi/2$
$7 < N_h < 14$	-0.03 ± 0.20 (-0.13)	0.21 ± 0.04 (0.15)	0.02 ± 0.04 (-0.03)	0.34 ± 0.06 (0.27)
$14 \leq N_h < 28$	0.07 ± 0.02 (-0.05)	0.37 ± 0.03 (0.14)	0.10 ± 0.03 (-0.03)	0.39 ± 0.05 (0.28)
$N_h \geq 28$	0.19 ± 0.03 (0.04)	0.48 ± 0.04 (0.23)	0.23 ± 0.05 (0.02)	0.65 ± 0.05 (0.35)

Our unit-vector approach has been dictated by the fact that we have no experimental information on that 4-momenta of particles. Only their polar and azimuthal angles are known. However, one can show (see [3]) that this underestimates the magnitude of true intergroup correlations only, and the character of these correlations remains unchanged.

IV. EXPERIMENTAL RESULTS

In Tables 1 and 2 we present our results concerning the impact parameter dependence of azimuthal correlations between particles belonging to the same group, characterized by β_1^S or β_1^h as well as to the different groups (Φ_{IJ}). While in Table 1 the centrality of the ^{22}Ne+(Ag, Br) collision is measured by the multiplicity of target-nucleus fragments (by N_h), in Table 2 we use the number of interacting nucleons of the projectile nucleus for the same purpose:

$$v_p = A_p - (A_p/Z_p).Q,$$

where $Q = \sum_f Z_f$ is the sum of charges of projectile spectator fragments.

The general trend observed is that both the intragroup and intergroup correlations increase with the decreasing impact parameter: with the increasing number of nucleous participating in a collision the s- and the h-particles are more likely to be emitted into two distinct regions in the transverse plane: $\beta_1^S > 0$, $\beta_1^h > 0$ and $\Phi_{sh} > \pi/2$. The observed effect of the preferred direction flow is even more pronounced if we select events with an asymmetrical emission of particles of one type (e.g. the s-particles) and look for the intergroup correlations of the fragmentation products of the other nucleus (see the two last columns of Table 1).

The dependence of azimuthal correlations on the polar emission angle Θ is shown in Fig. 1. For the s-particles $\eta_S = -\ln(\mathrm{tg}(\Theta_S/2))$ is used. According to

Table 2

Ensemble of events	$\langle\beta_1^S\rangle$	$\langle\beta_1^h\rangle$	$\langle\Phi_{sh}\rangle - \pi/2$
$0 \leq Q < 2$	0.13 ± 0.03 (-0.02)	0.10 ± 0.03 (-0.03)	0.40 ± 0.04 (0.17)
$2 \leq Q < 4$	0.08 ± 0.03 (-0.02)	0.15 ± 0.03 (-0.01)	0.39 ± 0.04 (0.13)
$4 \leq Q < 7$	-0.02 ± 0.02 (-0.10)	0.03 ± 0.02 (-0.03)	0.27 ± 0.03 (0.21)
$7 \leq Q < 9$	-0.01 ± 0.02 (-0.11)	-0.05 ± 0.02 (-0.01)	0.22 ± 0.04 (0.15)
$Q \geq 9$	-0.07 ± 0.02 (-0.12)	-0.02 ± 0.02 (0.03)	0.19 ± 0.04 (0.12)

our results above, the smaller the impact parameter is, the stronger is the angular dependence of the correlations. It is maximal for the h-particles emitted at polar angles of $45° < \Theta < 135°$ and minimal at $\Theta \simeq 0°$ and $\Theta \simeq 180°$. For the s-particles the correlations are larger for pseudorapidities $\eta_S > 1$ and they are small at $\eta_S < 1$.

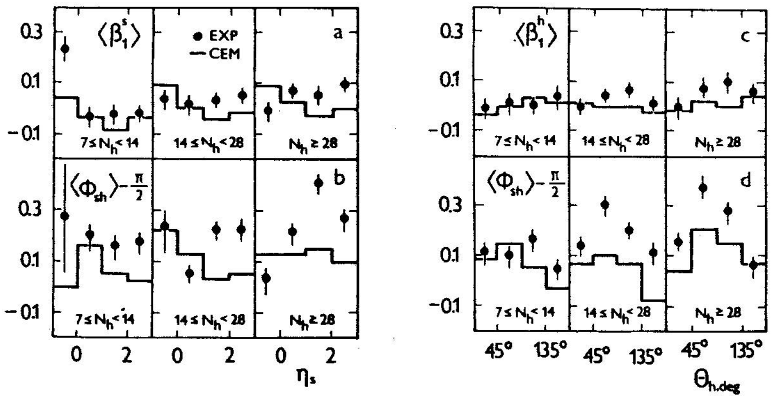

Fig. 1. Dependence of the coefficient of azimuthal asymmetry $\langle\beta_1\rangle$ (a, c) and of $\langle\Phi_{sh}\rangle - \pi/2$ (b, d) on polar emission angles of s(a, b) and h particles (c, d) in different ensembles of ^{22}Ne + (Ag, Br) interactions.

V. DISCUSSION

Is the observed collective flow a genuine manifestation of hydrodynamical bounce-off [8] or can it be explained by approaches with no collectivity explicitly built-in [2, 9]? We shall try to answer this question by comparing our experimental results with predictions of an intranuclear cascade model [2, 10]. A satisfactory description of our ^{22}Ne + Em data on multiplicities and single-particle spectra (see ref [6]) makes the cascade code [10] a suitable candidate for the present analysis. Model predictions are given in the tables in brackets, in Fig. 1 by histograms. Let us summarize the main results of this comparison.

1. Our data on azimuthal correlations confirm the general expectation [2] that the cascade model is less justified for central collisions than for peripheral ones. The model predicts a too slow increase of these correlations with increasing N_h or v_p.

2. The model fails to reproduce the angular dependence of the observed correlations. Let us note that an asymmetric development of a intranuclear cascade may contribute to the observed opposite-side emission of fast and slow particles for large impact parameters and in the region of small η_s (for our most central collisions having $N_h \geq 28$ the model gives $\langle b \rangle = 4.1$ fm).

3. If we trigger on "bounce-off" events by demanding that $\beta_1^f > 0$ (see Table 1) we slightly increase the intergroup correlations between fast and slow particles but contrary to the experiment we do not produce any noticeable "opposite-side jet" of the h-particles within the model.

In conclusion, we do not think that we have shown an unambiguous presence of the hydrodynamical flow within our data, but we hope to have shown some noticeable deviations from the standard picture of nucleus-nucleus interaction proceeding via a two-body successive collisions. Whether these deviations may be related to signals of the hydrodynamics compression effects remains an open question. We hope that our data on nuclear flow obtained at much higher energies than in the LBL experiments represent a real challenge both to the macro- and the microscopic approaches to high energy nuclear collisions.

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ЭКСПЕРИМЕНТАЛЬНОЕ ИЗУЧЕНИЕ ЯДЕРНОГО ПОТОКА В НЕУПРУГИХ ВЗАИМОДЕЙСТВИЯХ ^{22}Ne + (Ag, Br) ПРИ 4,1 АГэВ/с

В работе изучаются азимутальные корреляции в углах между заряженными вторичными частицами, бозникающими ВППХ неупруги взаимодействия ядер ^{22}Ne с тяжелыми ядрами эмульсии. Обнаружено, что степень азимутальной асимметрии увеличивается с уменшеньем параметра столкновения. Представлены также экспериментальные доказательства для испускания заряженных вротичных частиц на той же (противоположной) стороне в поперечной плоскости для частиц, принадлежащих той же самой (другой) области фрагментации в ядерно-ядерных столкновениях. Наблюдаемое явление не подтверждено расчетами на основе модели внутриядерного каскада, что указывает на возможное присутствие гидродинамического эффекта отскока.