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E1-87-472

PARTICULARITIES OF NEON-22 NUCLEI INELASTIC INTERACTIONS WITH EMULSION AT 4,1 A GeV/c

Alma-Ata - Bucharest - Dubna - Dushanbe -
Gatchina - Kosice - Krakow - Leningrad -
Moscow - Rzez - Tashkent - Tbilisi -
Ulhan-Bator - Yerevan Collaboration

Submitted to International Conference
on Ultrarelativistic Nucleus-Nucleus Collisions.
Quark Matter - 1987, GFR, August 1987

1987

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Introduction. The goal of this report is to search for effects in collisions of relativistic nuclei with nuclei, which are unordinary in the framework of a nucleon-nucleon superposition picture of these collisions. 4309 inelastic interactions of neon-22 nuclei with emulsion measured in the experiment at 4.1 A GeV/c and 4976 events simulated by the cascade-evaporation model/1/ (CEM), taking into account the experimental conditions, have been analysed.

During the investigation, charged secondaries were separated, in accordance with their energetic characteristics, into different groups using traditional criteria of the emulsion method:

a) particles with $\beta < 0.23$ having a "black" track (b-particles);
b) particles with $0.23 \leq \beta \leq 0.7$ having a "grey" track (g-particles);
c) singly-charged particles with $\beta > 0.7$, particles - nonfragments of the projectile ("shower", s-particles);
d) projectile fragments with $\beta \simeq 0.97$ (fr).

The following variables were used in our analysis:

1. Transverse momenta of projectile fragments, P_T. In the case of singly-charged fragments P_T was determined from measurements of $p\beta$ by the multiple Coulomb scattering method. For multicharged fragments $P_T = 2P_o z \sin\Theta$. Here $P_o = 4.1$ GeV/c, z is the fragment charge and Θ the polar angle of emission of this fragment.
2. Azimuthal angle characteristics:
   a) the azimuthal asymmetry coefficient of k-type particles
   $$\alpha_k = \sum_{i \neq j} \cos \varepsilon_{ij} / \sqrt{n_k(n_k - 1)},$$
   b) the azimuthal collinearity coefficient
   $$\beta_k = \sum_{i \neq j} \cos 2\varepsilon_{ij} / \sqrt{n_k(n_k - 1)},$$

c) the angle between the pronounced directions of emission of two group particles (i and j) in the azimuthal plane

$$\Phi_{i,j} = \arccos \left\{ (a_l a_m + b_l b_m) \left[(a_l^2 + b_l^2)(a_m^2 + b_m^2) \right]^{-1/2} \right\},$$

$a_l = \sum_i \cos\varphi_i$; $b_l = \sum_i \sin\varphi_i$; $a_m = \sum_j \cos\varphi_j$; $b_m = \sum_j \sin\varphi_j$.
Here φ is an azimuthal angle of particle emission; $\varepsilon_{ij} = \varphi_i - \varphi_j$, an angle between the directions of i- and j-particle emission.

3. The polar angle of a resultant vector of k-type particles.

$$\Theta_{R_k} = \arccos (X/|R|),$$

where $|R| = (X^2 + Y^2 + Z^2)^{1/2}$.

We have investigated the dependence of the above variable distributions on the impact parameter, that is the centrality degree of nuclear collisions connected with the disintegration degree of both nuclei, i.e. the number of target-nucleus fragments, the number of h-particles per event ($n_h = n_g + n_b$) and the summary charge of neon-22 fragments $Q = \sum_i z_i^{fr}$. Experimental conditions and some results of carrying out the investigations are described in more detail in our papers/2-5/.

Projectile-nucleus fragments. The analysis of transverse momentum and azimuthal angle characteristics α_{fr}, β_{fr} and $\Phi_{fr,h}$ distributions has shown that:

1. The P_T distributions cannot be described by a single Rayleih's distribution as it follows from the statistical theory of fast fragmentation/6/

$$f(P_T) \sim P_T \exp(-P_T^2 / 2\sigma^2),$$

due to an abundant yield of fragments with large P_T.

2. The fragments with large P_T (for example, α-particles) do not correlate with those having small transverse momenta. Consequently, other mechanisms incompatible with the single centre emission hypothesis are responsible for their formation, e.g., cascade decays of heavier fragments, rescattering and so on.

3. A strong asymmetry of fragment emission is observed in the azimuthal plane (Fig.1). As a result of the fitting the experimental data by the simplest model of fragmentation/4/ taking into account a transverse motion of the residual neon-22 nucleus, we obtain that this remainder acquires a large transverse momentum q_T (the so-called bounce off effect) and, probably, an angular momentum (Fig.1). The average value of $\langle q_T \rangle$ for the full ensemble is equal to 0.4 GeV/c. The estimation of the bounce off value made from the distribution of the resultant vectors of the projectile charged fragment momenta gives the value close to that obtained above. The $\langle q_T \rangle$ as a function of the mass of the residual nucleus (Q) reaches its maximum for the mass equal to one half the projectile mass.

4. The tendency to the emission of colliding nuclear fragments in the opposite directions in the azimuthal plane (analysis of $\Phi_{fr,h}$ in Table 1) is reinforced with decreasing the impact parameter (decrease of Q).

Table 1.

Q	≤ 2	3÷6	≥ 7
$(\langle \Phi_{fr,g} \rangle - \pi/2) \cdot 10^2$	32±10	12±3	7±3
$(\langle \Phi_{fr,b} \rangle - \pi/2) \cdot 10^2$	12±11	4±3	5±2

The observed bounce off of the projectile remainder for peripheral collisions might be explained in the framework of quasi-elastic scattering of the projectile by nuclear forces of a target. However, the reinforcement of the tendency to the emission colliding nuclei fragments in the opposite directions with decreasing the impact parameter finds a more natural explanation in the framework of hydrodynamics. The $\langle q_T \rangle$ dependence on the fragmenting remainder mass (Q) in terms of hydrodynamics is the dependence on the size of the surface which divides the hot and cold parts of colliding nuclei.

Target-nucleus fragments, produced particles. The analysis of the distributions over azimuthal characteristics α and β for produced (s) particles and target-nucleus fragments (h-particles) and over the angle between the pronounced emission of these particles in the azimuthal plane ($\Phi_{s,h}$) has shown that

1. The emission asymmetry of s- and h-particles in the azimuthal plane increases with increasing the centrality degree of nuclear collisions (with increasing n_h and decreasing Q) (Table 2).
2. Decreasing the impact parameter (Table 2 and Fig. 2) reinforces the tendency to the emission of s- and h-particles in the opposite directions in the azimuthal plane.

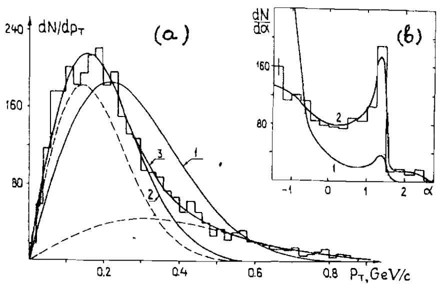
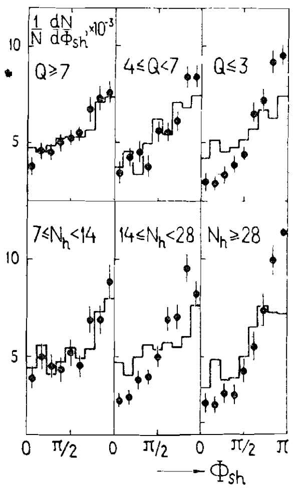


Fig. 1. The transverse momentum distribution (a) for projectile-nucleus fragments with z=2: 1 - fitting of the experimental data by a single Rayleigh's distribution with $\sigma = \sigma_{exp}$, 2 - by a single Rayleigh's distribution for $P_T \leq 0.4$ GeV/c, 3 - by a double Rayleigh's distribution.
The distribution over the azimuthal asymmetry coefficient (b) for neon-22 nucleus fragments: 1 - average transverse momentum of the residual nucleus $< q_T > =0$; 2 - $< q_T > =0.4$GeV/c.

Fig. 2. The distribution over the angle between the pronounced emission of s- and h-particles in the azimuthal plane, $\Phi_{s,h}$. Histogram - CEM, points - experiment.



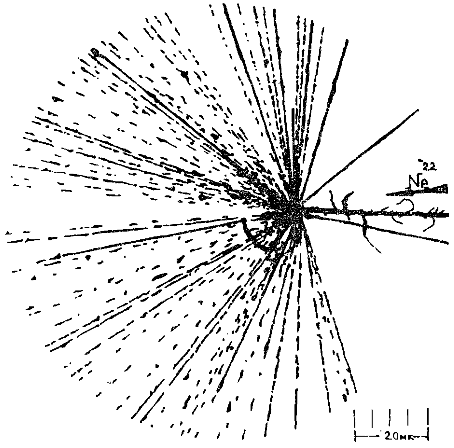


Fig. 3. Scheme of a peculiar event.

Table 2

Ensemble of interactions	$<\alpha_s>$	$<\alpha_h>$	$<\Phi_{s,h}> - \pi/2$
$0 \leq Q < 2$	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±0.05 (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)

3. The cascade-evaporation model does not describe the values of α, β and $\Phi_{s,h}$ (shown in the parentheses) for the most central collisions (Table 2 and Fig.2).

Thus, the side-splash of produced particles and target-nucleus fragments is observed. This effect is more prominent for the central collisions. The observation of events with large azimuthal asymmetry ($\alpha_s \geq 3.5$) in the experiment is a striking illustration of the side-splash of these particles. 44 out of 1959 events with $n_s \geq 8$ have been selected. The CEM does not give a single event with such a strong asymmetry.

The most significant disagreement of the experiment with the CEM for the events with the smallest impact parameter is observed in the region of pseudorapidities $1 \leq \eta \leq 3$ ($\eta = -\ln tg(\theta/2)$) for s-particles and at angles of $45° \leq \theta \leq 135°$ for h-particles.

The comparison of the experimental distributions over the polar angles of the resultant vectors for all particles from the central collisions ($Q=0$, $n_h \geq 7$) with the CEM ones shows a systematic underestimation of the average values of these angles by the model (Table 3). In this table $< \theta^{\pi}_{R_s} >$ is shown for the s-particles considered as pions. The s-particles left after substraction of ten particles with the smallest angles, considered as interacting protons of projectile, from all s-particles are attributed to pions. This procedure can be used for events with $Q = 0$. The average values of the difference pseudorapidities between neighbouring particles, $< \Delta \eta_{\pi} >$, are also presented in this table. The

Table 3.

Interactions	N_{ev}	$<\Theta_{R_b}>$	$<\Theta_{R_g}>$	$<\Theta^{\pi}_{R_s}>$	$<\Delta \eta_{\pi}>$
Central	218	76.4±2.5	24.8±1.2	12.4±0.5	0.126±0.003
	(116)	(67.0±2.7)	(17.9±1.2)	(9.1±0.4)	(0.163±0.004)
Peculiar	18	81.4±6.7	25.3±3.6	13.6±1.8	0.116±0.008
	(6)	(63.6±7.8)	(13.8±1.6)	(8.0±1.0)	(0.142±0.017)

last data indicate that pions with $\beta > 0.7$ tend to stronger grouping (clusterization) than in CEM.

Peculiar events. The events called by us "peculiar" were found in the analysis of central interactions. There are no particles with $\beta > 0.7$ observed in these events at angles greater than (6-12)° relative to the projectile direction. 18 out of 218 events of central collisions have been registered using the selection criterion $\Theta_{min} \geq 7°$. CEM gives 11 events by normalizing both samples (experiment and model) to the same number of central collision events and 5 events by normalizing to the number of all inelastic interactions. The probability of common appurtenance to the same Poisson distribution for 18 and 11(5) events for an average of 11(5) is equal to 10^{-2} $(4 \cdot 10^{-6})$. It is obvious that the experimental probabilities are not reproduced by CEM. Let us consider the characteristics of peculiar events as compared with the events of central collisions. The multiplicities of s-particles and h-particles do not practically change (see Table 4).

Table 4

Interactions	$<n_s>$	$<n_h>$	$<\alpha_s> \cdot 10^2$	$<\beta_s> \cdot 10^2$	$\left(<\Phi_{s,g}> - \frac{\pi}{2}\right) \cdot 10^2$
Central	33.4±0.6	31.8±0.6	85± 8	6±4	24±6
	(34.9±0.6)	(38.4±0.7)	(7± 5)	(-6±4)	(9±8)
Peculiar	31.8±2.5	31.3±1.6	90±29	32±12	22±23
	(34.8±2.9)	(45.0±3.9)	(-20±13)	(-26±8)	(12±41)

The average angles of the resultant vectors for all particles increase although the statistics is insufficient (see Table 3). The same tendency is observed for the coefficients of azimuthal asymmetry and collinearity (Table 4). The emission of pions with $\beta > 0.7$ becomes more combined (decrease of $<\Delta \eta_{\pi}>$). The large value of the collinearity coefficient for all s-particles may be connected with a considerable angular momentum for a system decaying into given s-particles. The CEM describes neither the observed values quantitatevely nor the tendency of their change. The values of $<\Theta_{R_k}>$, $<\alpha_s>$ and $<\beta_s>$ in the model decrease when passing to the peculiar events. The reverse tendency is observed in the experiment.

If the peculiar events are assumed to be connected with a smaller impact parameter than central collision events, then the experimental tendency of changing $<\Theta_{R_k}>$, $<\alpha_s>$ and $<\beta_s>$ shows evidence for the hydrodynamic approach.

Conclusion. As a result of the investigation of interactions of neon-22 nuclei with emulsion the following effects not described by CEM have been observed:

1. The remainder neon-22 nucleus acquires a considerable transverse momentum (bounce off effect) and, probably, some angular momentum.
2. Azimuthal asymmetry for all particles is observed in the central collisions with heavy emulsion nuclei (side-splash of produced particles and target-nucleus fragments).
3. The tendency to the emission of projectile-nucleus and target-nucleus fragments, produced particles and target-nucleus fragments in the opposite directions in the azimuthal plane is reinforced with increasing the degree of collision centrality.
4. The peculiar events have been found among the central interactions There are no particles with $\beta > 0.7$ registered in these events at angles greater than (6-12)° relative to the projectile.

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Received by Publishing Department
on June 24, 1987.

Эль-Наги А. и др. E1-87-472
Особенности неупругих взаимодействий ядер неона-22
с ядрами фотоэмульсии при импульсе 4,1 А ГэВ/с

На основе анализа распределений по поперечным импульсам фрагментов ядра-снаряда и корреляций по азимутальным углам вылета этих фрагментов показано, что в результате взаимодействий ядер неона-22 с ядрами фотоэмульсии остаточное ядро-снаряда приобретает значительный ~0,4 ГэВ/с поперечный импульс. В центральных соударениях с тяжелыми ядрами эмульсии обнаружена азимутальная асимметрия всех типов частиц /боковое выплескивание/. В этих же взаимодействиях обнаружен класс событий, названных особыми, где под углами /6-12/$^{\circ}$ по направлению первичного ядра нет частиц с $\beta > 0,7$. Наблюдается тенденция к испусканию в противоположные стороны в азимутальной плоскости фрагментов сталкивающихся ядер, фрагментов ядра-мишени и рожденных частиц, усиливающаяся с уменьшением параметра удара. Показано, что каскадно-испарительная модель не описывает наблюдаемых явлений.

Работа выполнена в Лаборатории высоких энергий ОИЯИ.

Препринт Объединенного института ядерных исследований. Дубна 1987

El-Naghy A. et al. E1-87-[illegible]
Particularities of Neon-22 Nuclei Inelastic
Interactions with Emulsion at 4.1 A GeV/c

From the analysis of the transverse momentum distributions and azimuthal angle correlations for fragments of the projectile nucleus, a residual nucleus of the projectile is shown to acquire a large ~0.4 GeV/c transverse momentum in collisions of neon-22 nuclei with emulsion. The azimuthal asymmetry for all particles (side-splash) is observed in central collisions with heavy emulsion nuclei. The class of events called particular events, where the particles with $\beta > 0.7$ are not observed at angle less than (6-12)$^{\circ}$ relative to the direction of flight of the projectile, has been also found among the central collision events. The tendency to emission in the opposite direction in the azimuthal plane of colliding nuclear fragments, target nucleus fragments and produce particles is observed. This tendency increases with decreasing an impact parameter. These effects are not described by the cascade-evaporation model.

The investigation has been performed at the Laboratory of High Energies, JINR.

Preprint of the Joint Institute for Nuclear Research. Dubna 1987