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ANALYSIS OF CORRELATION EFFECTS IN MULTINUCLEON CC INTERACTIONS AT 4.2 GEV/C PER NUCLEON IN TERMS OF COLLECTIVE VARIABLES

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1. Introduction

Experimental studies of nuclear interactions with large momentum transfers in the region of limiting nuclear fragmentation /1-3/ have shown that nuclei are characterized by a universal quark-parton structure function which is different from a structure function of nucleons. Structure functions of nuclei similar to those determined in experiments on limiting nuclear fragmentation /4-6/ have been also obtained in NA-4 experiments on deep-inelastic scattering of muons and electrons on nuclei performed by the groups from SLAC, CERN and JINR-CERN collaboration.

The fact that nuclei have their quark-parton structure functions not reducible to one-nucleon ones shows evidence for a possible existence of multiquark configurations (6q and more) in nuclei. A direct manifestation of such states is to observe resonance features in effective mass spectra of baryons produced in hadron-nucleus and nucleus-nucleus collisions. The production of narrow dibaryon resonances in hadron-nucleus interactions for a mass range of 1.932-2.171 GeV has been investigated in papers /7,8/.

In this paper we study correlation effects in multinucleon CC interactions at 4.2 GeV/c per nucleon using collective variables. From results of such an analysis one can draw a conclusion of a possible production of dibaryon resonances in these interactions for $M_{eff.}$= 2.150-2.50 GeV. A review of experiments on a study of nucleon-nucleon interactions, in which indications of the existence of such resonances have been obtained, is presented in /9/.

2. Experiment

Experimental data have been obtained on the 2m propane bubble chamber (High Energy Laboratory, JINR) exposed to a beam of carbon nuclei with a momentum of 4.2 GeV/c per nucleon. Multinucleon CC interactions were selected according to the following criteria:

1. In an event there were no multicharged stripping fragments from the incident carbon nucleus.

2. The number of singly charged stripping particles with $P_{lab} \geqslant 3.0$ GeV/c emitted at an angle of $\theta \leq 4°$ relative to the primary beam was no larger than 2.

3. The total charge of all secondaries in an event was larger than +7.

In this selection the average number of nucleons involved in the interaction was $\langle \nu_n \rangle \simeq 16$. The number of CC events selected in this way was 1394. The mean relative error in measuring the momenta of secondary charged particles was ~ 12% and its most probable value ~ 6%. In our experiment the mean momentum, beginning from which protons were identified, was 150 MeV/c. Positive pions could be distinguished from protons by path and ionization at $P_{lab} \leq 700$ MeV/c. In other cases π^+ -mesons were classified as protons. The fraction of π^+ -mesons with $P_{lab} > 700$ MeV among positive particles was ~ 13%. Deuterons and tritium nuclei were visually identified by ionization for a momentum interval of 1÷2.5 GeV/c. In other cases these nuclei were assumed to be protons. Protons with $P_{lab} \leq 300$ MeV/c were not considered in the analysis as the fraction of spectator particles (protons, deuterons and so on) produced in target-nucleus fragmentation was very large.

A more detailed description of the experimental method can be found in papers /10,11/. The model of intranuclear cascade (Dubna version) was also used for data analysis /12/.

3. Collective Properties of Secondary Particles

Collective properties of secondary particles have been studied in the system of "principal axes" of an event by means of variables: "sphericity" S and $\langle P^2_{out} \rangle$ that determine the configuration of an event in momentum space. A more detailed analysis of the CC data by means of different collective variables can be found in paper /13/. Here we consider only the variables that are most significant for the analysis.

Sphericity S is determined as follows:

$$S = \frac{3}{2} min \left(\sum_i P^2_{\perp i} / \sum_i |\vec{P}_i|^2 \right) \qquad (1)$$

with $\vec{P}_i$ vectors of momenta of secondaries in the c.m.s. of colliding nuclei and $P_{\perp i}$ transverse momenta relative to some axis. The direction, relative to which the sum $\sum P^2_{\perp i}$ of all charged particles takes a minimal value, is commonly called an axis of jets. The tran-

sition of the system of principal axes is accomplished by diagonalization of the matrix consisting of components of momenta of secondary particles in the CC c.m.s.

$$M_{\alpha\beta} = \sum_i P_{i\alpha} P_{i\beta} \; ; \qquad \alpha, \beta = x, y, z . \qquad (2)$$

The diagonal elements of this matrix, arranged in increasing order of magnitude $Q_1 < Q_2 < Q_3$, are geometrically the main axes of an ellipsoid (fig.1), and the direction of the principal axes of an event is specified by single vectors $\vec{n}_1$, $\vec{n}_2$ and $\vec{n}_3$ corresponding to them. The direction of the largest elongation of an event is determined by vector $\vec{n}_3$ and the direction of its largest flattening by $\vec{n}_1$. The plane determined by vectors $\vec{n}_2$ and $\vec{n}_3$ is usually referred to as the plane of an event.

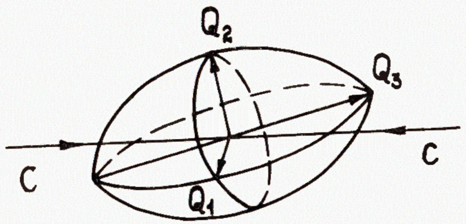

Fig.1. A scheme of the principal axes in an event.

The value of $\langle P^2_{out} \rangle$ can be found as

$$\langle P^2_{out} \rangle = \frac{Q_1}{n_\pm} \; , \qquad (3)$$

where $n_\pm$ is the multiplicity of the charged particles being considered. The smaller the value of $\langle P^2_{out} \rangle$ is in an event, the larger the coplanarity of the configuration of secondaries in momentum space.

Figure 2 shows the S distribution for CC interactions obtained in the experiment and for CC events simulated by the intranuclear cascade model*). One can see that CC interactions as a whole are characterized by a jet configuration of secondary particles in momentum space both in the experiment and in the model. However, as seen from fig.2, the simulated CC events do not agree with the experimental data: the CC interactions obtained in the experiment differ in larger sphericity.

In fig.3 is presented the $\langle P^2_{out} \rangle$ distribution of real and simulated CC events. It is seen that this distribution is broader than the theoretical one. For $\langle P^2_{out} \rangle > 0.08 (GeV/c)^2$ one can observe a "shoulder" which is not described by the intranuclear cascade model in question. The fraction of events with $\langle P^2_{out} \rangle > 0.1 (GeV/c)^2$ is

*) Selection criteria of multinucleon CC interactions in the experiment and in the model are the same; the features of particle identification are also taken into account.

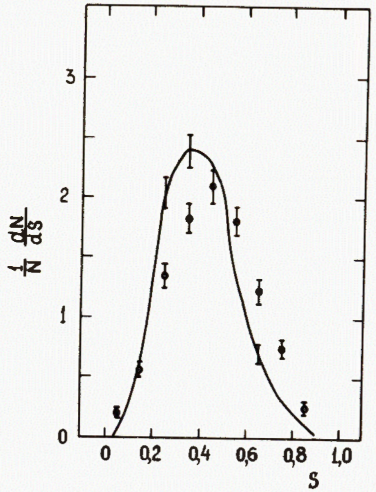

Fig.2. The S distribution of CC interactions. Solid curve - calculation by the intranuclear cascade model.

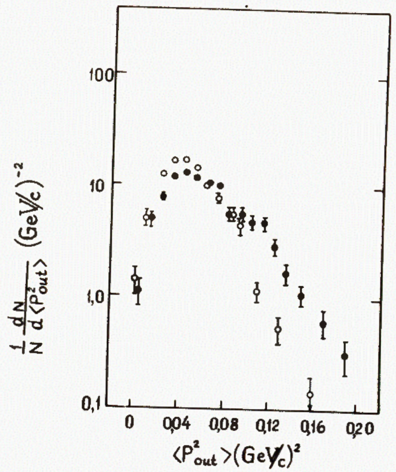

Fig.3. The $< P^2_{out} >$ distribution of CC interactions: (●) - experiment and (o) - cascade model.

~ 18% in the experiment and ~ 3% in the model. The results obtained indicate that the production of particles, emitted in the direction perpendicular to the event plane with relatively large momenta, is observed in the experiment for multinucleon CC interactions. The cross section of such processes in the cascade model of nucleus-nucleus collisions is smaller by a factor of several times.

4. Two-Particle Correlations

For a more detailed analysis we have considered azimuthal correlations of charged particle pairs in CC events with $< P^2_{out} > < 0.08(GeV/c)^2$ and $\geqslant 0.08(GeV/c)^2$. The fraction of CC interactions with $< P^2_{out} > \geqslant 0.08(GeV/c)^2$ was ~ 28%. The $\Delta\varphi$ distributions of particle pairs were investigated where $\Delta\varphi$ is the angle between their transverse momenta in the planes perpendicular to a) the direction of motion of colliding nuclei and b) the direction of the jet axis in an event

$$\Delta\varphi = \arccos \frac{\vec{P}_{\perp i} \cdot \vec{P}_{\perp j}}{|\vec{P}_{\perp i}|\,|\vec{P}_{\perp j}|} \qquad (4)$$

with $\vec{P}_{\perp i}$ and $\vec{P}_{\perp j}$ the transverse momenta of i-th and j-th particles in the azimuthal plane. Correlations were analyzed between a) protons, b) pions and c) protons and pions for different intervals of transverse momenta of the particles considered.

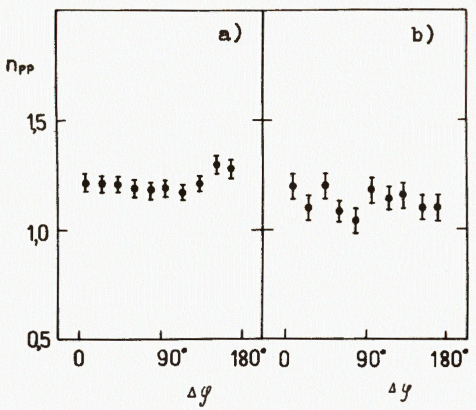

Fig.4. The $\Delta\varphi$ distribution of proton pairs: a) for the events with $< P^2_{out} > < 0.08(GeV/c)^2$ and b) for the events with $< P^2_{out} > \geqslant 0.08(GeV/c)^2$. One of the protons has $P_{\perp i} < 0.3$ GeV/c; the momentum of a second proton is unlimited.

Figure 4 a) and b) shows the $n_{pp} = \frac{N_{pair}}{N_{event}}$ distributions of proton pairs, one of which has $P_{\perp i} < 0.3$ GeV/c (the momentum of a second is unlimited), versus angle $\Delta\varphi$ between them for the two groups of events with $< P^2_{out} > < 0.08(GeV/c)^2$ and $\geqslant 0.08(GeV/c)^2$. As can be seen from the figure, the distributions of such pairs of protons are practically isotropic.

In fig.5 a) and b) are presented the azimuthal distributions of proton pairs with $P_{\perp i} \geqslant 0.7$ GeV/c and $\geqslant 0.85$ GeV/c relative to the direction of motion of colliding nuclei for the two groups of CC interactions. In the same figure are given results of a similar calculation for the simulated events. From the figure one can see that in CC interactions with small values of $< P^2_{out} >$ one can observe correlations of two protons emitted at angles approximate to 180° in the azimuthal plane. In CC events with $< P^2_{out} > \geqslant 0.08(GeV/c)^2$ there occurs a correlated emission of pion pairs at angles $\Delta\varphi$ of ~120° between their transverse momenta. If a similar distribution is constructed relative to the axis, the maximum of the n_{pp} dependence on $\Delta\varphi$ for the events with $< P^2_{out} > \geqslant 0.08(GeV/c)^2$ is shifted to the range of $\Delta\varphi$ values equal to 90°.

In both cases the observed correlations are not quantitatively described by the cascade model although correlated proton pairs with $\Delta\varphi$ approximate to 180° are also produced in the events with $< P^2_{out} > < 0.08(GeV/c)^2$ (this fact is probably due to proton elastic rescattering).

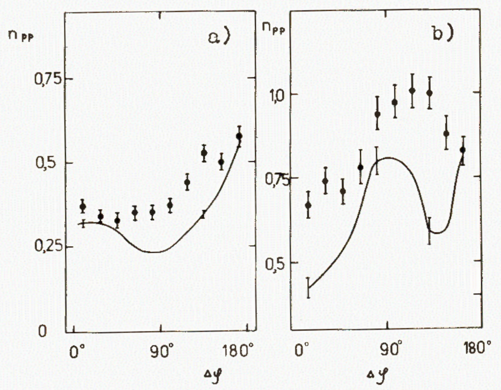

Fig.5. The $\Delta\varphi$ distribution of proton pairs with $P_{\perp i} \geqslant 0.7$ GeV/c and $P_{\perp j} \geqslant 0.85$ GeV/c : a) for the events with $\langle P^2_{out} \rangle < 0.08\ (GeV/c)^2$; b) for the events with $\langle P^2_{out} \rangle \geqslant 0.08\ (GeV/c)^2$. Solid curve - calculation by the intranuclear cascade model.

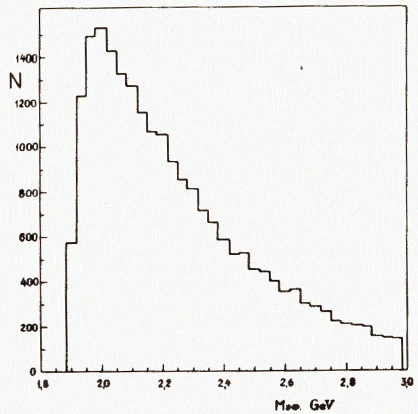

Fig.6. The effective mass distribution of proton pairs in multinucleon CC interactions.

The analysis has shown that pion and ($p\pi$) pairs have, within experimental errors, the isotropic $\Delta\varphi$ distribution between their transverse momenta for both groups of CC interactions.

For understanding the nature of these correlations, it is of interest to consider the M_{eff}(pp) distribution of proton pairs with large transverse momenta. Figure 6 shows the M_{eff}(pp) distribution of all proton pairs for multinucleon CC collisions and fig.7 the distribution of proton pairs with $P_{\perp i} \geqslant 0.5$ GeV/c and $P_{\perp j} \geqslant 0.7$ GeV/c relative to the jet axis. A similar distribution for the intranuclear cascade model is denoted by a solid line. The effective mass resolution for different M_{eff} intervals is presented in fig.8.

From fig.7 it is seen that in the effective mass spectrum of proton pairs there are maxima in the mass range $M_{eff} \simeq 2.15$, 2.23, 2.32, and 2.50 GeV although statistics is insufficient. At the same time no structure is observed in the M_{eff} distribution of all proton pairs. No structure is seen in the effective mass spectra of proton pairs with large transverse momenta constructed for the intranuclear cascade model.

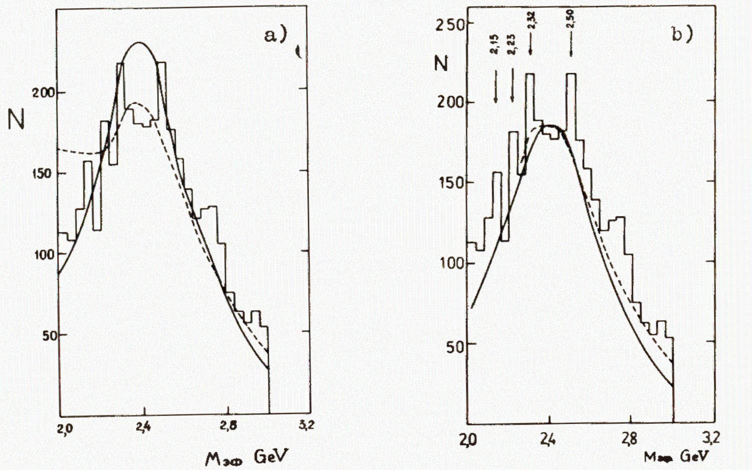

Fig.7. The effective mass distribution of proton pairs with $P_{\perp i} \geqslant 0.5$ GeV/c and $P_{\perp j} \geqslant 0.7$ GeV/c determined relative to the jet axis. Solid curve - calculation by the intranuclear cascade model. Dotted line - effective mass distribution of pairs of protons from different events.
a) The background is normalized to the histogram square.
b) The background is normalized to the mean value of Δ N of the histogram within the mass interval M_{eff}=2.32÷2.48 GeV.

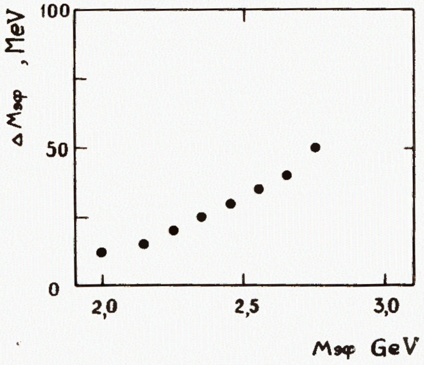

Fig.8. The average effective mass resolution $\Delta\ M_{eff}$ versus its value.

Figure 9 presents the effective mass distribution of correlated proton pairs with $P_{\perp i} \geqslant 0.5$ GeV/c and $P_{\perp j} \geqslant 0.7$ GeV/c (the proton pairs were selected with $\Delta\varphi \geqslant 45°$ in the events having $\langle P^2_{out} \rangle < 0.08 (GeV/c)^2$ and $\Delta\varphi = 45° \div 135°$ in the events with $\langle P^2_{out} \rangle \geqslant 0.08 (GeV/c)^2$). One can see that in this selection the background from noncorrelated proton pairs in the $\frac{dN}{dM_{eff}}$ spectra significantly decreases, and the resonance structure manifests itself more distinctly.

When constructing the M_{eff} distribution of the same proton pairs in the events with $\langle P^2_{out} \rangle \geqslant 0.08 (GeV/c)^2$ (fig.10), a larger decrease of the number of background combinations can be seen.

In all cases the experimental data are not described by the cascade model.

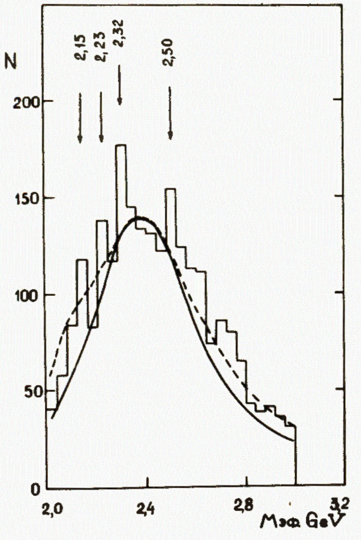

Fig.10. The effective mass distribution of proton pairs with $P_{\perp i} \geq 0.5$ GeV/c, $P_{\perp j} \geq 0.7$ GeV/c and $\Delta\varphi = 45° \div 135°$ for the events with $\langle P^2_{out} \rangle \geq 0.08$ GeV/c.
Solid line - calculation by the cascade model.
Dotted line - effective mass distribution of pairs of protons from different events.

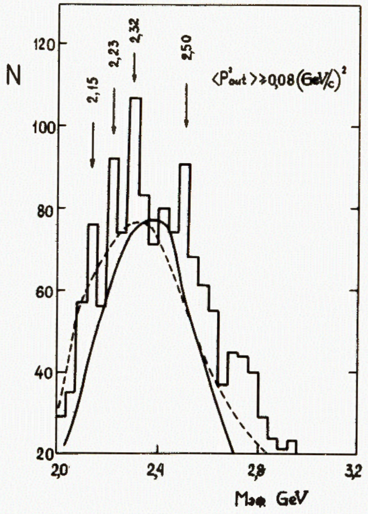

Fig.9. The effective mass distribution of proton pairs with $P_{\perp i} \geq 0.5$ GeV/c, $P_{\perp j} \geq 0.7$ GeV/c and $\Delta\varphi \geq 45°$ for the events with $\langle P^2_{out} \rangle < 0.08 (GeV/c)^2$ and $\Delta\varphi = 45° \div 135°$ for the events with $\langle P^2_{out} \rangle \geq 0.08 (GeV/c)^2$. Solid curve - calculation by the intranuclear cascade model. Dotted line - effective mass distribution of pairs of protons from different events.

5. Conclusion

Based on the analysis carried out, the conclusion can be drawn that the correlated emission of proton pairs with large transverse momenta is observed in multinucleon CC interactions. These correlations are likely to be due to the production of dibaryon resonances in these interactions. However, for a final conclusion it is required to significantly increase experimental material and to make its analysis in more detail.

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Агакишиев Г.Н. и др. E1-84-492
Анализ корреляционных явлений
в многонуклонных СС-столкновениях
при импульсе 4,2 ГэВ/с на нуклон
с помощью коллективных переменных

Проводится анализ корреляционных явлений в многонуклонных СС-столкновениях при импульсе 4,2 ГэВ/с на нуклон с помощью коллективных переменных "сферисити" и $<P^2_{out}>$. Показано, что в СС-столкновениях наблюдается коррелированное испускание пар протонов с большими поперечными импульсами, вылетающих под углами, близкими к 180 и 90° в плоскости, перепендикулярной оси струй. Модель внутриядерного каскада не описывает наблюдающиеся корреляции протонов. В спектре эффективных масс скоррелированных протонов имеются особенности в виде максимумов в районе масс $M_{эфф.}$= 2,15; 2,23; 2,32; 2,50 ГэВ, которые могут быть указанием на существование дибарионных резонансов.

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Analysis of Correlation Effects
in Multinucleon CC Interactions
at 4.2 GeV/c per Nucleon
in Terms of Collective Variables

An analysis of correlation effects in multinucleon CC interactions at 4.2 GeV/c per nucleon is being carried out in terms of collective variables. It is shown that the correlated emission of proton pairs with large transverse momenta is observed in CC interactions. In the effective mass spectrum of correlated protons there are maxima in the mass range $M_{eff.}$ = 2.15; 2.23; 2.32; and 2.50 GeV which can be an evidence for the existence of dibaryon resonances.

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

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