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CLUSTER-FLUCTON REVELATION IN NUCLEAR INTERACTIONS AT 4.2 (GeV/c)/N

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Total longitudinal momentum of all registered particles, their total energy and other summary kinematics variables are used for separation of the events with two- and three-quasi-nucleon collisions from the C + C, C + p, d + C, and p + C interactions at 4.2 (GeV/c)/N. The research results on charged particle multiplicity and their momentum spectra lead to the conclusion that nearly 60% of all three-quasi-nucleon events are due to collisions where two nucleons behave like a whole object, called flucton, which has been predicted by D. I. Blokhintsev. Mean values of one-particle longitudinal momenta of the products and their mean multiplicities for the subreactions in which fluctons take part are lower by $\sim 30\%$ compared to the subreactions where two nucleons interact not as a whole object, but in a successive way. Production of the cumulative particles is due to flucton interactions, especially when fluctons are used as a target.

С помощью анализа суммарного продольного импульса всех зарегистрированных частиц, их полной энергии в системе центра масс и других кинематических величин удается выделить среди всех C + C-, C + p-, d + C-, p + C-взаимодействий при 4,2 (ГэВ/c)/N такие, в которых в соударении участвуют два, а также три «квазинуклона». На основе исследования средних множественностей заряженных частиц и одночастичных спектров этих частиц показано, что в не менее 60 % всех рассматриваемых трехнуклонных взаимодействий два из трех нуклонов ведут себя как нечто целое — флуктон, существование которого было предсказано Д. И. Блохинцевым. Средние продольные импульсы и средние множественности продуктов подреакций, в которых участвуют флуктоны, на треть меньше тех значений, которые были бы в случае, если бы нуклоны взаимодействовали последовательно. Кумулятивные частицы образуются также за счет взаимодействия с флуктонами, особенно в том случае, когда флуктон является мишенью.

INTRODUCTION

The question about the correlations between nucleons in the nuclei and the conservation of their own individualities has always been an interesting puzzle for many researchers. As early as 1949 K. Brueckner et al. [1] reported about space nucleon correlations in nuclei. In 1950 J. Hadley et al. [2] studied forward emission of high-momentum deuterons in p + nucleus interactions. M. G. Meshcheryakov et al. [3], L. S. Azhgirei et al. [3] discovered the effect of deuteron knocking out from Li, Be, C... In 1956 H. Bethe [4] mentioned the short-range interactions between the pairs of nucleons in nuclei. Further, in 1957 D. I. Blokhintsev proposed [5] a very productive idea that high-momentum components of particles produced are connected with some clusters, consisting of nucleons, also called fluctons. In the 1970s many papers were published [6] on nuclear fragmentation, pion production in nuclear interactions, etc. Particularly, it was shown that pion spectra could not be reproduced by any model in which the pion generation is attributed to collisions between individual nucleons inside the nucleus only.

Cumulative particles, i.e., particles with moment greater than that allowed by nucleon–nucleon kinematics, began to be an object of intensive studies after the publications of G. A. Leksin et al. [7] and A. M. Baldin [8]. Strictly speaking, all products of the nuclear interactions are cumulative ones, just because of the existence of Fermi momentum. But in this case the particles are meant that have obtained an unusually great moment, and the total situation has become quite different. In this field a lot of experimental data were obtained by V. S. Stavinsky et al. [9]. Cumulative processes with high-momentum transfer enjoy nowadays a special interest. A review of the first experimental cumulative data and the analysis of these data from the point of view of the new hypotheses were made by V. K. Lukyanov and A. I. Titov [10]. It has been shown that hypotheses about the nuclear density fluctuations and quark–parton interaction mechanism existence could be the base of the large-momentum transfer, etc.

The study was undertaken in order to pick out and analyze the groups of events in which two, three or more nucleons had taken part in the interactions. Comparing them with collisions of elementary particles made the flucton interaction study. The quasi-nucleons and fluctons that may compose the nucleus are signed as F. One-nucleon flucton is N_F, two-nucleon is d_F. The type of the nucleus is signed by upper index.

In this situation experimental data of the proton, deuteron and carbon interactions with protons and carbons from propane ($\mathrm{C_3H_8}$), obtained in a propane bubble chamber at 4.2 (GeV/c)/N [11], were used. The collisions $p+\mathrm{C_3H_8}$, $d+\mathrm{C_3H_8}$, $\mathrm{C}+\mathrm{C_3H_8}$ were divided into $p+p$ and $p+\mathrm{C}$, $d+\mathrm{C}$ and $d+p$, and $\mathrm{C}+\mathrm{C}$ and $\mathrm{C}+p$ collisions correspondingly, as was done in [12].

1. DEFINITION OF REACTION PRODUCT

All charged particles and fragments were measured and identified. Possible losses of particles, as well as probability of separation of protons from π^+ mesons, were determined by special weights, put on for each particle [12]. Let us make a note that some particles were not the products of any specific reaction, but appeared as the result of reaction influence on residual nuclei. Such particles and fragments were not included in the event complement. These are

— recoil nuclei. It is accepted that the momenta which are taken away by recoil nuclei are so small that their contribution to the great part of analysis, especially to momentum spectra one, can be neglected;

— evaporated protons. The value of the constant for evaporated proton separation is accepted as equal to < 0.3 GeV/c. This value is determined on the basis of proton distribution in laboratory coordinate system. It must be isotropic for evaporated protons;

— stripping protons and fragments. The protons with polar angle $\theta_p < 4^\circ$ and moment $P_p > 3$ GeV/c, the deuterons with $\theta_d < 4^\circ$ and $P_d \geqslant 6$ GeV/c, α particles with $\theta_\alpha < 4^\circ$ and $P_\alpha/Z > 6$ GeV/c are regarded as stripping particles. Let us note that $A/Z = 2$ for deuterons and for α particles. The spectrum of stripping protons and fragments for $\mathrm{C}+\mathrm{C}$ collisions at 4.2 (GeV/c)/N is shown in Fig. 1.

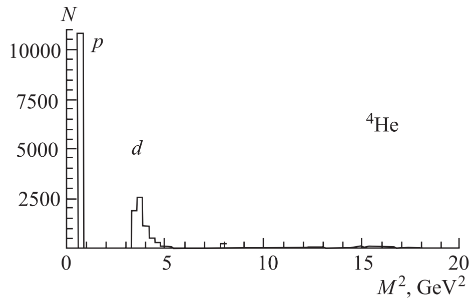

Fig. 1. Mass distribution of stripping protons and stripping nuclear fragments from C + C collisions at 4.2 (GeV/c)/N

The ratios of stripping protons, deuterons and α particles are determined as follows:

$$\begin{aligned} &\text{for C + C collisions } 0.54 : 0.34 : 0.10,\\ &\text{for C} + p \text{ collisions } 0.47 : 0.40 : 0.13. \end{aligned} \tag{1}$$

So, it turned out that the protons build the half of all stripping particles.

2. USED VALUES

The calculation and analysis of some total values for every event, based on charge particles registered inside the chamber, represent an important part of this study. These values are as follows:

$\sum P_t^i$, total transverse momentum of all registered particles, was calculated on the basis of the projections $\sum P_x^i$ and $\sum P_z^i$. The direction of the beam momentum coincides with the y axis. In this case it is obvious that within the error boundary $\sum P_t^i = 0$, provided all particles are taken into account. It may be applied to initial interactions only, because the secondary interactions in nucleus can give no uniform distribution of particles in the transverse plane. So, the application of the condition

$$\sum P_x^i, \ \sum P_z^i \leqslant \text{const}\, P_t \tag{2}$$

leads to strong suppression of the events with neutral particles, as well as with secondary interactions in nuclei. It may happen, of course, that many of the unregistered particles keep the balance between each other in the transverse plane. Nevertheless, the mixture of the events with neutral particles and with secondary interactions diminishes strongly, if $\text{const}\, P_t = 0.14$ GeV/c. The details of this part of our research do not belong to the content of this discussion, for the reason that they do not seem to be applicable for quantitative calculations.

Another value used in this analysis is $\sum P_y^i$, the total longitudinal momentum of all charged particles. As long as the beam particles run along the y axis, this value should be $\sum P_y^i = nP_0$, where P_0 is the beam nucleon momentum and $n = 1, 2, 3\ldots$, depending on the number of the beam nucleons that interacted. There is obviously no need to add that for

$p+\mathrm{C}$, $p+p$ collisions $n=1$, but for $d+\mathrm{C}$, $d+p$: $n \leqslant 2$. It is worth noting that for the latter reactions $n=2$ comes in a very small number of collisions. In most of such collisions one nucleon from the deuteron interacts only ($n=1$), the other one flying away without interaction.

The next value is the interaction energy (squared) $M^2_{\mathrm{tot},0} = \left(\sum E_0^{1,2}\right)^2 - \left(\sum P_0^{1,2}\right)^2$, where $E_0^{1,2}$ and $P_0^{1,2}$ are the energies and momenta of two initial particles. On the other hand, the value of interaction energy may be calculated using the reaction products:

$$M^2_{\mathrm{tot}} = \left(\sum E_i\right)^2 - \left(\sum P_i\right)^2, \tag{3}$$

where E_i, P_i are the energies and momenta of all particles produced. In the case when all products are registered, $M^2_{\mathrm{tot},0} = M^2_{\mathrm{tot}}$. The values of $M^2_{\mathrm{tot},0}$ calculated for some of the reactions are shown in Table 1.

Table 1. **Total energies calculated for the reactions with different number of nucleons participating in the collision**

Colliding particles (initial beam particle + target)	Secondary interactions (addition nucleon)	Total energy $M^2_{\mathrm{tot},0}$, GeV^2	Momentum of initial beam particle, GeV/c
$N+N$	—	9.86	4.2
$N+N$ or $N+d$	$+N$ —	≈ 20.49	4.2
$\{N+N$, $N+N\}$ (Double collision)	— —	39.18	8.4
$N+N$ $d+N$	N —	20.55	8.4
$d+d$ or $d+N$	N	39.33	8.4
$d+d$	$+N$	59.89	8.4

Some other values are used also. Among them is the mass target [13]

$$M_t = \sum \left(E^i - P_y^i\right) - e, \tag{4}$$

where $e = E_0^{1,2} - P_0^{1,2}$. At high energy this value depends almost not at all on the beam momentum and beam energy. It should be accepted just for estimation purposes.

The mass of the target may also be calculated in an ordinary way, by using (3):

$$M_{\mathrm{tg}} = \mathrm{sqrt}\left(M^2_{\mathrm{tot}} + (P_0^{1,2})^2\right) - E_0^{1,2}. \tag{5}$$

For the mass of initial beam particle the following formula is used:

$$M_{\mathrm{in}} = \mathrm{sqrt}\left(\left(\mathrm{sqrt}\left(M^2_{\mathrm{tot}} + (P_0^{1,2})^2\right) - m_N\right)^2 - P_0^{1,2}\right). \tag{6}$$

3. TOTAL SPECTRA

3.1. Distributions of the Total Longitudinal Particle Momenta $\sum P_y^i$ at 4.2 (GeV/c)/N. In case that only one initial nucleon takes part in the interaction ($n = 1$) at 4.2 GeV/c, only one maximum may be seen in the $\sum P_y^i$ spectrum. Observation of several peaks corresponds to a superposition of spectra having the following maximum values of total momentum: $R^k \approx 4.2, 8.4, 12.8$ GeV/$c\ldots$ This accords to the fact that $1, 2, 3\ldots$ nucleons from the beam nuclei interact with the target. For instance, the $\sum P_y^i$ total spectra for C + C and C + p interactions are shown in Fig. 2. Separate spectra on their right side are determined by the momenta measurement errors, corresponding to a narrow region of every maximum R^k. The left side of these spectra are eroded by the loss of neutral particles. For estimation of this erosion, let us suppose that momentum spectra of neutrons and π^0 mesons are similar to those of protons and π^+ mesons: $\sum P_y^{i,(p,\pi)}$. Then the separate spectra may be extended to the left side by subtracting the total missing longitudinal neutral particle momenta $\sum P_y^{i,(p,\pi)}$ from $\langle R^k \rangle$. The spectra calculated for $n = 1, 2$ and 3 are shown in Fig. 2, *a, b* as inside histograms. These histograms serve for approximate estimation only.

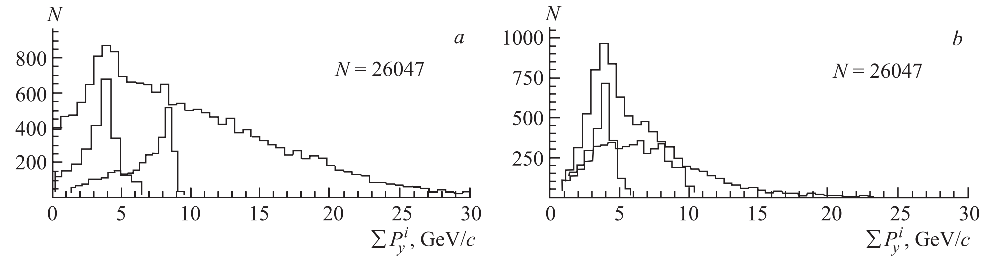

Fig. 2. Distributions of total longitudinal particle momenta $\sum P_y^i$ for C + C (*a*) and C + p collisions (*b*). The spectra for $n = 1, 2$ reactions with the target are shown by inside histograms. They are not normalized

Channel contributions for the reactions with $n = 1, 2, 3, 4$ extracted from C + C and C + p collisions are shown in Table 2. Channel separation was improved when rejection of the

Table 2. **Channel contributions for C + C and C + p interactions**

P_0, GeV/c	$n = 1$ 4.2	$n = 2$ 8.4	$n = 3$ 12.6	$n = 4$ 17.0
$\sum P_y^i$ interval, GeV/c	$3.0 < \sum P_y^i < 5.0$	$7.0 < \sum P_y^i < 9.0$	$11.5 < \sum P_y^i < 13$	$15.5 < \sum P_y^i < 18$
Ratio of channels with different n for C + C collisions	0.31 ± 0.04	0.24 ± 0.08	0.26 ± 0.12	0.19 ± 0.15
Ratio of channels with different n for C + p collisions	0.58 ± 0.04	0.26 ± 0.09	0.09 ± 0.06	0.07 ± 0.06

events with poor P_t^i compensation, i.e., the events with $\sum P_t^i < 0.14$ GeV/*c*, was applied. But the statistics decreased strongly.

3.2. Total Energy Distributions. First of all, let us discuss the events with $\sum P_y^i \approx 4.2$ GeV/*c*, i.e., $n = 1$. Note that the widths of the peaks here are determined by momenta errors and by neutral particle losses, the way it was for momenta distributions. So, in this case one peak at $M_{\text{tot}}^2 = 9.86$ GeV^2, corresponding to a number of interaction nucleons $n_{\text{part}} = 2$, or several peaks for $n_{\text{part}} = 2, 3, 4\ldots$ and $M_{\text{tot}}^2 = 9.86, 20.55$ GeV^2 and so on (see Table 1) will be observed. Further, due to small event statistics, two groups of events with $n_{\text{part}} = 2$ and 3 will be considered only.

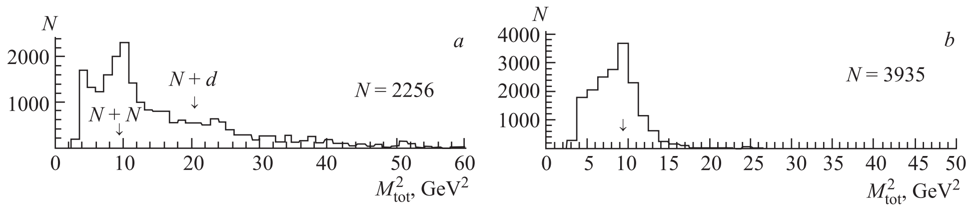

Fig. 3. Distributions of total particle energy (squared) M_{tot}^2 for $p + \text{C}$ (*a*) and $\text{C} + p$ collisions (*b*) for the events with total longitudinal momentum $\sum P_y^i \approx 4.2$ GeV/*c*

The events of proton–carbon interactions accord to the condition $n = 1$, basically. And, as seen from Fig. 3, *a*, two peaks at $M_{\text{tot}}^2 = 9.86$ and 20.55 GeV^2 were observed clearly. The first maximum corresponds to nucleon–nucleon interactions, the other one to interaction of one nucleon with two target nucleons ($n = 1$ and $n_{\text{part}} = 3$) successively or simultaneously. In the latter case two target nucleons are connected and might be considered as a flucton-cluster. As expected, in $\text{C} + p$ interactions the second group of events (near to $M_{\text{tot}}^2 = 20.55$ GeV^2) was completely absent (see Fig. 3, *b*).

Let us next consider C + C, $\text{C} + p$ interactions for which $\sum P_y^i \approx 8.4$ GeV/*c*. Here there are two nucleons from beam carbon that have taken part in the interaction: $n = 2$. If both nucleons interact with two target nucleons independently, or with one «quasi-deuteron» (that is $n_{\text{part}} = 4$), then such events will come to the region of $39 \div 40$ GeV^2 in M_{tot}^2 spectra. However, it does not seem to be the case: most of the events coming from the $\sum P_y^i \cong 8.4$ GeV/*c* interval settle down near $M_{\text{tot}}^2 \approx 20$ GeV^2, $n_{\text{part}} = 3$.

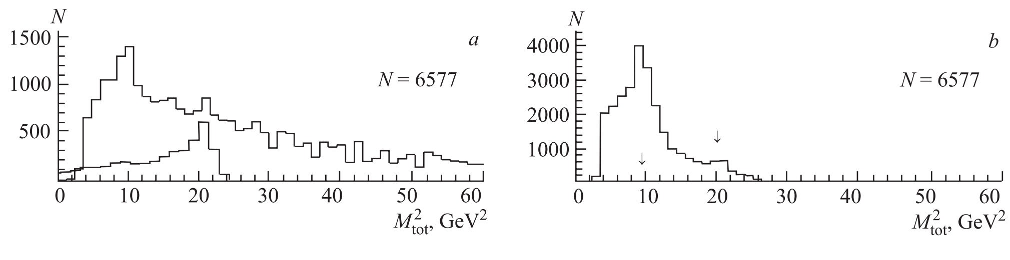

Fig. 4. Distributions of total energy M_{tot}^2 for C + C (*a*) and $\text{C} + p$ collisions (*b*) for both groups of events with total longitudinal particle momenta $\sum P_y^i \approx 4.2$ and 8.4 GeV/*c*. The inside histogram is the particle spectrum for $n = 2$ interaction with the nucleon target. It is not normalized

The $M^2_{\rm tot}$ distributions for $\rm C + C$, $\rm C + \mathit{p}$, and $d + \rm C$, $d + p$ collisions and for two $\sum P^i_y$ stripes: $\sum P^i_y \approx 4.2$ GeV/c, $n = 1$, and 8.4 GeV/c, $n = 2$ are shown in Figs. 4 and 5, correspondingly. As seen in these figures, the events are grouped near two $M^2_{\rm tot}$ values: $M^2_{\rm tot} \cong 9.8$ and 20 GeV^2 again. So, the events with $n = 1$ and $n_{\rm part} = 2$ according to nucleon–nucleon kinematics, obviously, are included in the first group. The second group of events corresponds to the interactions of two beam protons with one target's nucleon successively or simultaneously.

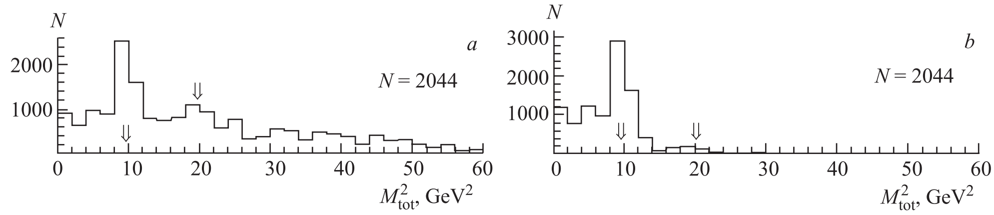

Fig. 5. Distributions of total particle energy $M^2_{\rm tot}$ for $d + \rm C$ (a) and $d + p$ collisions (b) for both groups of events with total longitudinal particle momenta $\sum P^i_y \approx 4.2$ and 8.4 GeV/c

4. MARKING OF SOME REACTIONS WITH $n = 1, 2$ AND WITH $n_{\rm part} = 2$ AND 3

Some reactions with definite $n = 1$ and $n_{\rm part} = 2, 3$ that have been picked out from the known $\rm C + C$, $\rm C + \mathit{p}$, and $d + \rm C$, $p + \rm C$ collisions are shown in Table 3. So, at $n = 1$, $n_{\rm part} = 2$, $\sum P^i_y \approx 4.2$ GeV/c and $M^2_{\rm tot} = 9.86$ GeV^2, the following reactions may go on:

• $p + N^{\rm C}_F$, $N^d_F + N^{\rm C}_F$, $N^{\rm C}_F + N^{\rm C}_F$ — collisions of free proton or deuteron's nucleon or carbon's nucleon with nucleon from the carbon target, correspondingly;

• $p + p$, $N^d_F + p$, $N^{\rm C}_F + p$ — collisions of free proton or deuteron's nucleon or carbon's nucleon with free protons as a target, correspondingly.

For $n = 1$ and $n_{\rm part} = 2$, $\sum P^i_y \approx 4.2$ GeV/c and $M^2_{\rm tot} = 20.55$ GeV^2, the following reactions may go on:

• $p + d^{\rm C}_F$, $N^d_F + d^{\rm C}_F$, $N^{\rm C}_F + d^{\rm C}_F$ — free proton or deuteron's nucleon or carbon's nucleon collisions with quasi-deuteron from the carbon target, correspondingly. Clearly, instead of $d^{\rm C}_F$ in some part of the collisions two nucleons from carbon will take part in the interaction independently.

At last, at $n = 2$ and $n_{\rm part} = 3$, $\sum P^i_y \approx 8.4$ GeV/c and $M^2_{\rm tot} = 20.55$ GeV^2, the following reactions may go on:

• $d^{\rm C}_F + p$, $d^{\rm C}_F + N^{\rm C}_F$ — quasi-deuteron from carbon nuclei interacts with a free proton or with a quasi-nucleon from the carbon target. Again here, two quasi-nucleons from the carbon target may interact in a consistent way or as d flucton;

• $d + p$, $d + N^{\rm C}_F$ — deuteron collisions with proton or with quasi-nucleon from carbon target, correspondingly.

Table 3. **Some specific reactions from the nucleus-nucleus interactions**

Initial collisions	Separation in [11]	$n = 1$, $n_{\rm part} = 2$	$n = 1$, $n_{\rm part} = 3$	$n = 2$, $n_{\rm part} = 3$
$p + {\rm C_3H_8}$	$p + {\rm C}$ $p + p$	$p + N_F^{\rm C}$ $p + p$	$p + d_F^{\rm C}$ —	— —
${\rm C} + {\rm C_3H_8}$	${\rm C} + {\rm C}$ ${\rm C} + p$	$N_F^{\rm C} + N_F^{\rm C}$ $N_F^{\rm C} + p$	$N_F^{\rm C} + d_F^{\rm C}$ —	$d_F^{\rm C} + N_F^{\rm C}$ $d_F^{\rm C} + p$
$d + {\rm C_3H_8}$	$d + {\rm C}$ $d + p$	$N_F^d + N_F^{\rm C}$ $N_F^d + p$	$N_F^d + d_F^{\rm C}$ —	$d + N_F^{\rm C}$ $d + p$

5. MASSES OF INTERACTING PARTICLES

On the basis of registered products the values of beam and target masses for some reactions have been calculated and the results are shown in Table 4. Let us mention that the values of masses calculated from formulae (4) and (5) coincide within the error limits.

As seen from Table 4, the masses of quasi-particles coincide within the error limits with the known ones. This gives us the confidence that we are dealing indeed with the reactions mentioned above. Besides, this helps in the correct choice of $\sum P_y^i$ intervals (see Table 2).

Table 4. **The interaction particle masses for some reactions from C + C and d + C collisions**

Reaction	Number of nucleons	Mass, GeV First calculation	Mass, GeV Second calculation
$N_F^{\rm C}$ ($M_{\rm in}$) + $N_F^{\rm C}$ ($M_{\rm tg}$)	$n = 1$, $n_{\rm part} = 2$	m_p 0.931 ± 0.066	0.892 ± 0.290 m_p
$N_F^{\rm C}$ ($M_{\rm in}$) + $d_F^{\rm C}$ ($M_{\rm tg}$, M_t)	$n = 1$, $n_{\rm part} = 3$	m_p 1.818 ± 0.098 1.989 ± 0.197	0.939 ± 0.291 M_d
$d_F^{\rm C}$ ($M_{\rm in}$) + $N_F^{\rm C}$ ($M_{\rm tg}$)	$n = 2$, $n_{\rm part} = 3$	1.783 ± 0.174 m_p	M_d 0.922 ± 0.038
d ($M_{\rm in}$) + $N_F^{\rm C}$ ($M_{\rm tg}$)	$n = 2$, $n_{\rm part} = 3$	1.680 ± 0.160 m_p	M_d 0.899 ± 0.025

6. ONE-PARTICLE LONGITUDINAL AND TRANSVERSE MOMENTUM SPECTRA FOR DIFFERENT $M^2_{\rm tot}$ REGIONS

The mean values of longitudinal $\langle P_y^{+,i}\rangle$ and transverse $\langle P_t^{+,i}\rangle$ momenta of all positive particles are shown in Tables 5–7.

Table 5. **Mean values of longitudinal and transverse momenta for the positively charged particles for the reactions with $n = 1$, $n_{\rm part} = 2$**

Beam particle	Target			
	$N_F^{\rm C}$		p	
	$\langle P_y^{+,i}\rangle$, GeV/c	$\langle P_t^{+,i}\rangle$, GeV/c	$\langle P_y^{+,i}\rangle$, GeV/c	$\langle P_t^{+,i}\rangle$, GeV/c
$N_F^{\rm C}$	1.782 ± 0.101	0.483 ± 0.025	1.819 ± 0.058	0.496 ± 0.014
N_F^d	1.742 ± 0.109	0.517 ± 0.044	1.813 ± 0.111	0.507 ± 0.030
p	1.842 ± 0.094	0.523 ± 0.024	1.508 ± 0.030	0.464 ± 0.009

Table 6. **Mean values of longitudinal and transverse momenta for the positively charged particles for the reactions with $n = 1$, $n_{\rm part} = 3$**

Beam particle	Target $d_F^{\rm C}$		$\langle \Delta P_y^{+,i}\rangle$, GeV/$c$	
	$\langle P_y^{+,i}\rangle$, GeV/c	$\langle P_t^{+,i}\rangle$, GeV/c	50%	15%
$N_F^{\rm C}$	1.176 ± 0.072	0.519 ± 0.029	0.530 ± 0.050	0.967 ± 0.059
N_F^d	1.102 ± 0.093	0.479 ± 0.030	0.586 ± 0.061	0.793 ± 0.066
p	1.189 ± 0.075	0.474 ± 0.025	0.683 ± 0.073	0.864 ± 0.065

Table 7. **Mean values of longitudinal and transverse momenta of the positively charged particles for the reactions with $n = 2$, $n_{\rm part} = 3$**

Beam particle	Target			
	$N_F^{\rm C}$		p	
	$\langle P_y^{+,i}\rangle$, GeV/c	$\langle P_t^{+,i}\rangle$, GeV/c	$\langle P_y^{+,i}\rangle$, GeV/c	$\langle P_t^{+,i}\rangle$, GeV/c
$d_F^{\rm C}$	2.392 ± 0.178	0.498 ± 0.037	2.479 ± 0.118	0.550 ± 0.024
d	2.265 ± 0.283	0.563 ± 0.070	2.350 ± 0.616 $\{1.525 \pm 0.033$	0.532 ± 0.093 $0.458 \pm 0.009\}$

As seen from Table 5, column 1, the values $\langle P_y^{+,i}\rangle$ and $\langle P_t^{+,i}\rangle$ depend on the initial beam nuclei type weakly, when one nucleon from the initial nuclei ($\sum P_y^i \cong 4.2$ GeV/c) interacts with one nucleon from the target nuclei (reactions $N_F^{\rm C} + N_F^{\rm C}$, $N_F^d + N_F^{\rm C}$ with $M^2_{\rm tot} = 9.86$ GeV^2) only. When a free proton is used as a target (see reactions $N_F^{\rm C} + p$,

$N_F^d + p$ (Table 5, column 2)), the values $\langle P_y^{+,i} \rangle$ and $\langle P_t^{+,i} \rangle$ do not depend on the initial beam nuclei type either, but they are greater than the ones for the above reactions. Besides, all mean momentum values for quasi-particle interactions exceed the ones typical for the nucleon–nucleon interactions (see Table 5).

One-quasi or free nucleon interaction with two carbon's nucleons ($N_F^{\rm C} + d_F^{\rm C}$, $N_F^d + d_F^{\rm C}$, $p + d_F^{\rm C}$ (see Table 6, column 1)) differ strongly from the foregoing ones, but there are no differences between them.

Further, let us suppose that all beam nucleons interact with the two target nucleons successively: one beam nucleon interacts with one target nucleon, and after this the target nucleon interacts with the particle-product from the first interaction. Afterwards the first interaction will give the $P_y^{+,i}$ spectrum, which will coincide with the spectrum obtained from free-proton or quasi-proton interactions (see Table 5). In this case the $\Delta P_y^{+,i}$ spectra of secondary particle interactions in the target nuclei may be obtained, if the $P_y^{+,i}$ spectra of $N_F^{\rm C}$, N_F^d, p interactions with p are subtracted from $N_F^{\rm C}$, N_F^d, p interactions with $d_F^{\rm C}$, correspondingly. The mean values of such «restored» spectra $\langle P_y^{+,i} \rangle$, calculated on the basis of two assumptions about secondary interaction contributions: 50 and 15%, are shown in Table 6, columns 2 and 3.

On the other hand, on the basis of the mean charge particle multiplicity of secondary interactions, known from [14], the mean momentum of secondary charged particles was evaluated, and it turned out to be no more than $0.75 \div 0.9$ GeV/c. In that case it is necessary to suppose that more than 85% of the particles produced in the first collision interact with the other nucleon from the target. But this is not possible, because this leads to strong increasing of charged particles multiplicity (see Sec. 7).

The mean values of positively charged particles, which are produced through interactions of two nucleons or deuterons with nuclear nucleons or with free nucleons are shown in Table 7. Let us remark here that the most of the deuteron–nucleon interactions ($> 90\%$) always follow the same order: only one nucleon of each deuteron interacts with the target, the other one passing with no interaction whatsoever. The spectra of such interactions coincide with those of quasi-particle collisions; the mean values $\langle P_y^+ \rangle$, $\langle P_t^+ \rangle$ for such interactions are shown in Table 7, in brackets. In the remaining part of the interactions both nucleons interact with the targets. Such collisions give the $\langle P_y^+ \rangle$, $\langle P_t^+ \rangle$ values which do not coincide with nucleon–nucleon interactions (see Table 7).

So, the events with both interacting nucleons were selected as $d_F^{\rm C} + N_F^{\rm C}$, $d + N_F^{\rm C}$ reactions only. The small events statistics do not allow the same procedure to be performed here. However, it seems obvious that deuterons behave in the interaction as separate objects. Indeed, in the mechanism of successive collisions all particles charged positively have $\langle P_y \rangle = 1.5 - 1.8$ GeV/c after their first interactions. The values of mean longitudinal momenta become twice as large ($3.0 \div 3.6$ GeV/c) after the second interaction of these products with second beam nucleon. But, as seen from Table 7, there is no such effect. All the values decrease by 30%, compared with the possible values.

7. CHARGED PARTICLE MULTIPLICITY IN SOME REACTIONS

Mean numbers $n_{\rm ch}$ of charged particles for some of the studied reactions are shown in Table 8.

Table 8. **Mean values of charged particle multiplicity**

Beam particle	Target		
	d_F^{C}	N_F^{C}	p
p [15]	4.05 ± 0.27	2.97 ± 0.12	2.86 ± 0.22 $2.37 \div 2.60$
N_F^{C}	3.73 ± 0.79	2.94 ± 0.46	2.73 ± 0.25
d_F^{C}	3.30 ± 0.20	3.82 ± 0.76	3.37 ± 0.58
d (both nucleons)	—	3.05 ± 0.14	2.95 ± 0.18
d (one nucleon)	—	2.78 ± 0.20	2.70 ± 0.21

As seen from Table 8, the ratio of the mean particle multiplicity observed in two-nucleon («flucton»)–nucleon interactions to the mean multiplicity of nucleon–nucleon collisions turns out to be $n_{\mathrm{ch}}(p+d_F^{\mathrm{C}})/n_{\mathrm{ch}}(p+p) = 1.26 \pm 0.10$, and $n_{\mathrm{ch}}(d_F^{\mathrm{C}}+p)/n_{\mathrm{ch}}(d(\text{one nucleon})+p) = 1.25 \pm 0.06$.

As seen from here, no more than $20 \div 30\%$ of all produced particles interact in the nuclei again.

So, the secondary interaction contributions, calculated on the basis of one-particle spectra and from mean values of charged particle multiplicities do not agree one with another. It is quite possible that the secondary interaction mechanism does not work here at all.

8. REMARKS ABOUT CUMULATIVITY

Let us consider two reactions of A and b particles with different type of kinematics, with $M_A > m_b$, where M_A and m_b are the masses of A and b particles.

1. Reaction $A + b \to$, where A is a beam particle with momentum 4.2 (GeV/c)/N.

Distributions of longitudinal proton momentum for the reaction $d_F^{\mathrm{C}} + N_F^{\mathrm{C}}$ are shown in Fig. 6. Note that the appearance of protons with momentum $P_y^{+,i} > 4.2$ GeV/c shows the maximum violation of nucleon–nucleon kinematics. As seen from Fig. 6, the number of such protons in the reaction $d_F^{\mathrm{C}} + N_F^{\mathrm{C}}$ is more than 12.5% of all protons produced. As was shown in Sec. 6, the secondary interaction mechanism is more preferable for production of such particles than the flucton ones.

Cumulative particles moving backward in the reaction $d_F^{\mathrm{C}} + N_F^{\mathrm{C}}$ are due to secondary interactions and to Fermi movement only. Therefore, the number of such particles is very small. For example, as seen from Fig. 6, it is less than 1.0% of all protons flying backward.

2. Reaction $b + A \to$, where the beam particle is a nucleon.

It has been proven in [10] that the abundant production of cumulative particles moving in beam direction or backward, especially the production of protons flying backward, can be explained neither by Fermi momentum nor by secondary interactions in nuclei.

Distribution of longitudinal proton momenta for the reaction $N_F^{\mathrm{C}} + d_F^{\mathrm{C}}$ ($n = 1$, $n_{\mathrm{part}} = 3$) is shown in Fig. 6, *a*. As seen from Fig. 6, more than 14% of all protons move in the direction opposite to the nucleon beam.

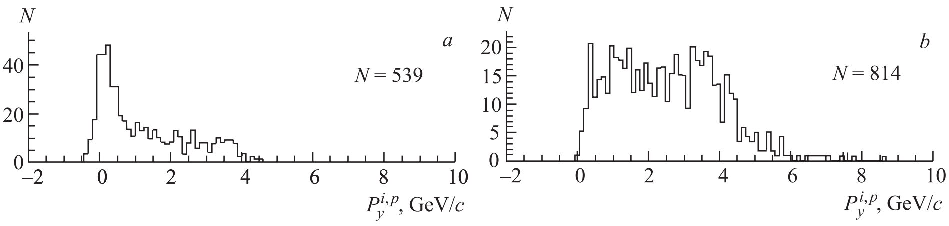

Fig. 6. Distribution of longitudinal momenta $P_y^{i,p}$ of protons for two reactions of $\mathrm{C}+\mathrm{C}$ interactions: $N_F^{\mathrm{C}} + d_F^{\mathrm{C}}$ (*a*) and $d_F^{\mathrm{C}} + N_F^{\mathrm{C}}$ (*b*)

So, in the reactions $d_F^{\mathrm{C}} + N_F^{\mathrm{C}}$ ($n = 2$, $n_{\mathrm{part}} = 3$) and $N_F^{\mathrm{C}} + d_F^{\mathrm{C}}$ ($n = 1$, $n_{\mathrm{part}} = 3$) this two-nucleon object A behaves as one whole particle-flucton. Thus, cumulative particles are produced abundantly in the fragmentation region of heavier particle A only [16].

CONCLUSIONS

The analysis of $\mathrm{C}+\mathrm{C}$, $\mathrm{C}+p$, $d+\mathrm{C}$ and $p+\mathrm{C}$ collisions with the help of some total values: total longitudinal momenta, total energy squared, etc., allows us to separate several reactions, in which three nucleons interact simultaneously.

The longitudinal momenta spectra and multiplicities of charged particle analysis and distinction of cumulative particle production in the $d_F^{\mathrm{C}} + p$ and $p + d_F^{\mathrm{C}}$ reactions suggest the reasonable assumption that two nucleons are combined as one flucton even before interaction. This has happened in more than 60% of all separated events. But the number of such separated events is not great.

Here, evidently, high momentum $P_t^{+,i}$ and $P_y^{+,i}$ appearance becomes more probable when a flucton with momentum 8.4 GeV/*c*, instead of a nucleon with momentum 4.2 GeV/*c*, interacts with the target. So, for example, the abundant production of cumulative protons flying backward may be explained easily if it is supposed that one nucleon interacts with two nucleons, i.e., with a flucton.

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REFERENCES

1. *Brueckner K., Eden R., Francis N.* // Phys. Rev. 1955. V. 98. P. 1445.

2. *Hadley J., York H.* // Phys. Rev. 1950. V. 80. P. 345.

3. *Meshcheryakov M. G. et al.* // Dokl. Akad. Nauk SSSR. 1956. V. 109. P. 499;
Azhgirei L. S. et al. // ZhETF. 1957. V. 33, No. 5(11).

4. *Bethe H.* // Phys. Rev. 1956. V. 103. P. 1354.

5. *Blokhintsev D. I.* // ZhETF. 1957. V. 33, No. 5(11).

6. See in *Heckman Harry H.* // Proc. of Intern. Conf. on High Energy Physics and Nuclear Structure, Uppsala, Sweden, June 18–22, 1973;
Steiner H. Lecture on Adriatic Meeting on Particle Physics, Rovinj, Yugoslavia, Sept. 23 – Oct. 5, 1973.

7. *Leksin G. A. et al.* // ZhETF. 1957. V. 32. P. 445; Nuclear Scaling. M.: MIFI, 1975.

8. *Baldin A. M.* // Part. Nucl. 1977. V. 8. P. 429.

9. *Stavinsky V. S.* // Part. Nucl. 1979. V. 10, No. 5.

10. *Lukyanov V. K., Titov A. I.* // Ibid. P. 815.

11. *Agakishiev G. N. et al.* // Yad. Fiz. 1984. V. 40. P. 1209;
Armutliiski D. et al. // Z. Physik A. 1987. V. 328. P. 455;
Simic L. J. et al. // Phys. Rev. D. 1986. V. 34. P. 692.

12. *Agakishiev T. N. et al.* JINR Commun. 1-83-662. Dubna, 1983;
Bondarenko A. I. et al. JINR Commun. P1-98-292. Dubna, 1998.

13. *Birger N. G., Smorodin Yu. A.* // ZhETF. 1959. V. 37, No. 5(11).

14. *Bugg D. V. et al.* // Phys. Rev. B. 1964. V. 133. P. 1017.

15. *Benary O. et al.* Particle Data Group. UCRL-200000 NN. 1970.

16. *Litvinenko A. G., Malakhov A. I., Zarubin P. I.* // Proc. of the XI Intern. Seminar on High Energy Physics Problems. Dubna, 1994. P. 228.

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