SEARCH FOR THE CRITERIA TO SELECT OF MULTINUCLEON COLLISIONS

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The experimental results on properties of multinucleon $\pi^{-12}C$ interactions at $p_{\pi-} = 40$ GeV/c are discussed. To select the multinucleon interactions the criteria was used that the number of identified protons (with momentum ρ_p<1 GeV/c) great or equal 2 for an event. To analyze the properties of the multinucleon events the variable R was used. The values of the R, were determined as a ratio between the inclusive spectra of $\pi^{\pm}$- mesons (protons) emitted in multinucleon events and in the all ones. We have studied the $\rho_{\perp}$-, β^0- and T- dependences of the R. It is shown that the main characteristics of pions for the multinucleon events do not differ from ones for all events. There is no correlation between the processes of pion production and the emission of protons for the chosen events. We obtained that the region of multinucleon processes could be fixed using the values 3-4 of a proton number.

Introduction

One of the main trends of the advancement of modern high-energy physics is the study of strongly interacting matter under extreme conditions (high temperatures and/or densities of the baryon charge). This scenario could have arisen at the early stages of the Universe evolution, in the process of formation of neutron stars, and they can be brought about under laboratory conditions in collisions of relativistic heavy nuclei. According to the currently available theoretical notions, strongly interacting matter may be subjected to a series of phase transitions with increasing temperature and/or density of the baryon charge, among which is the first-order phase transition of restoration of special symmetry of strong interactions - chiral symmetry that is strongly violated at low temperatures and/or densities of the baryon charge. These phases are determined by temperatures and baryon densities that can be achieved in the process of collision depending on energy and atomic number of accelerated nuclei.

Studying the characteristics behavior of the hadron-nuclear and nuclear-nuclear interactions as a function of collision centrality (Q) is an important experimental method to get information about changes in the nuclear matter phase, because the increasing Q could lead to the growth of the nuclear matter baryon density. In other words, the regime change in the behavior of some centrality depending characteristics of events is expected by variation of Q to be a signal on phase transition. This method is considered to be the best tool for reaching the quark-gluon plasma phase of strongly interacting matter. Some experimental results have already demonstrated the existence of the regime changes in the event characteristics behavior as a function of the collision centrality [1-8]. The regularity is observed for hadron-nuclear [1-2], heavy [3-7] and light nuclear [8] interactions in a large domain of nuclear masses and initial energies. It has also been observed for the behavior of some centrality characteristics of π-mesons, nucleons, fragments, strange particles and even for those of J/ψ. It is necessary to touch upon any other question which is very important for the centrality experiments. It is clear that the centrality of collisions Q can not be defined directly in the experiment. In different experiments the values of Q are defined as a number of identified protons , projectiles' and targets' fragments, slow particles, all particles, as the energy flow of particles with emission angles $\theta \cong 0^{\circ}$ or with $\theta \cong 90^{\circ}$. Apparently, it is not simple to compare quantitatively the results on Q-dependencies obtained in different papers; on the other hand the definition of Q could significantly influence the final results. So it is necessary to understand what centrality Q is. Usually for a chosen variable to fix Q it is supposed that its values have to increase linearly with a number of colliding nucleons or baryon density of the nuclear matter. The simplest possibility to fix the centrality is to use a number of proton emitted in reactions -- to consider the multinucleon processes. The physics of these processes serves as a bridge which joins the study of high energy mechanisms of particle production and that of new phases of strongly interacting matter. But there is one very important question what is the criteria to experimentally separate the multinucleon processes? What are boundary values of chosen variables after which new, multinucleon physics could start?

To answer the above questions is a main goal of this paper. To achieve this goal the $\pi^{-12}C$-interactions at $P_{\pi^-} = 40$ GeV/c were used. The events could give the unique possibility to study fragmentation of the nuclear target because the projectile fragments could be separated easily from target ones. Other important point of the interactions under consideration is that the interactions with light nuclei as well as ^{12}C could cleanly show a connection between the collisions of the free nucleon targets and with nucleon in nuclear medium to get further information on the states of nuclear matter.

Experimental results

Using the experimental data on $\pi^{-12}C$ - interactions at P_{π^-}=40 GeV/c obtained from the 2m propane bubble chamber of JINR (Dubna) [9] the relative inclusive spectra (R) of the $\pi^{\pm}$- mesons and protons (with momentum p_p <1 GeV/c) were analyzed separately as a function of the variables: the transverse momentum p_t , the $\beta^0 = (E_i - P_{Li})/m_N$ (E_i , P_{Li} and m_N are the total energy and longitudinal momentum of particles in lab. system and the mass of nucleon accordingly) [10] and the kinetic energy T of the particles in lab. system.

The chamber, placed in a magnetic field of 1.5 T, was exposed to beams of light relativistic nuclei at the Dubna Synchrophasotron [11]. Practically all secondaries, emitted at a 4π total solid angle, were detected in the chamber. All negative particles, except those identified as electrons, were considered as $\pi-$ mesons. The contaminations by misidentified electrons and negative strange particles do not exceed 5 and 1%, respectively. The minimum momentum for pion registration was about 70 MeV/c. The protons were selected by a statistical method applied to all positive particles with a momentum of $|p|$ > 500 MeV/c (slow protons were identified with $|p|$≤700 MeV/c by ionization in the chamber).

The N_{tot}=8791 $\pi^{-12}C$ events were used and the corresponding inelastic cross section was σ_{ine}= (87.5±1.0)mbn. [12] The interaction of the projectiles with "quasi-free" nucleons of the target were not taken into account.

The values of R were determined as a ratio of the spectrum of dN/dp_t; $dN/d\beta^0$ and dN/dT obtained in the events with $N_p \geq 2$ (multinucleon events - mn) to the similar ones in all events. The 3571 multinucleon events were found and analyzed by us.

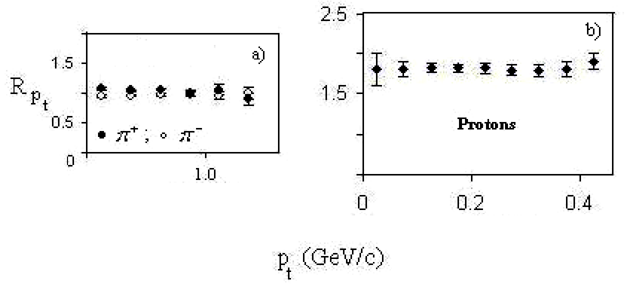

Fig.1a-b: The values of R_{pt} as a function of p_t for: *a)* $\pi^{\pm}$ -mesons and *b)* protons emitted in the $\pi^{-12}C$-interactions at P_{π^-}=40 GeV/c.

The obtained results are presented in Figs.1a, b-3a, b. It can be seen that the values of R do not depend on the values of the p_t for pions and protons (Fig.1a, b) –first result. There are some dependencies for the values of R (for protons at values of β^0 >1.0 and for pions and T for pions at lower values of β^0 (Fig.2a, b) –second result. It is also seen that the values of R for protons (Fig. 3b) and for negative pions (Fig. 3a) do not depend on T (third result) but there are some points at lower values of T for which the values of R for positive pions all more than 1.0 (fourth result).

The ratio of average values of the multiplicity for pions and protons produced in the multinucleon events and in all events are shown in following table. It is seen that values of average multiplicity are almost equal for both events and do not depend on the pion charge. In selected multinucleon events the average values of protons are 80% more than in all $\pi^{-12}C$-ones. So it can be said that almost double proton number does not lead to significant changes in the produced pion spectrum and their multiplicity in an event. It could be understood that there is no correlation between the processes of pion production and the emission of protons. One of the explanations of it could be that there are many protons among the chosen ones (for example see [13]), which become evaporated.

Table

The ratio of the average values of multiplicity.

Type of particles	$<n_{mn}>/<n_{tot}>$
π+ mesons	0.96 ± 0.03
π– mesons	1.05 ± 0.02
Protons	1.81 ± 0.02

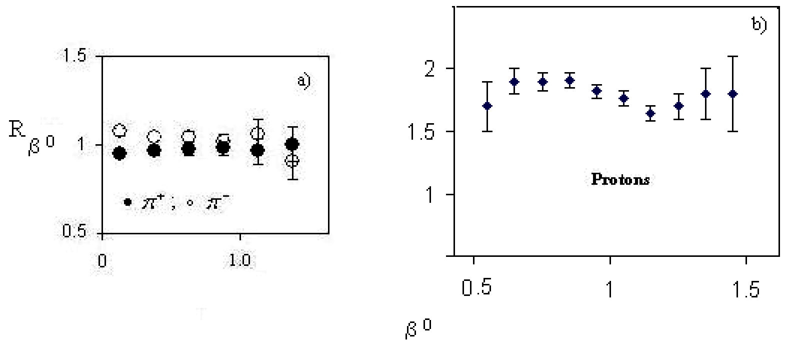

Fig.2a-b: The values of R_{β}^0 as a function of β^0 for : *a)* $\pi^{\pm}$ -mesons and *b)* protons emitted in the $\pi^{-12}C$-interactions at P_{π^-}=40 GeV/c.

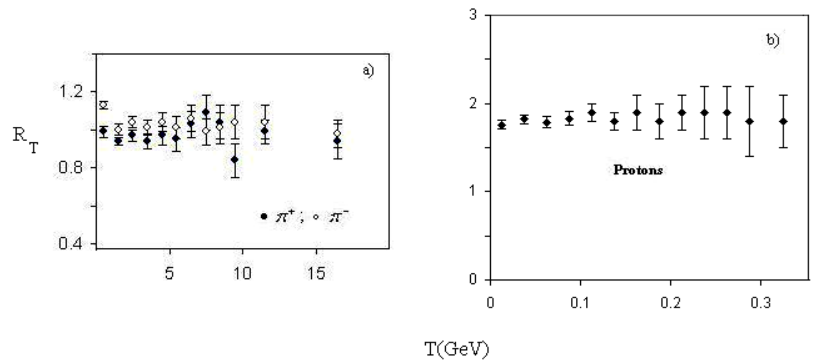

Fig.3a-b: The values of R_T as a function of T for : *a)* $\pi^{\pm}$ -mesons and *b)* protons emitted in the $\pi^{-12}C$-interactions at P_{π^-}=40 GeV/c.

What can one learn from these results? To answer this question it could be better to start from second and third results for pions which say that the number of pions at lower values of T and β^0 are greater than 1.0 that is their number in multinucleon collisions is more than for all ones. It could be connected with the effect of meson condensation. The idea of meson condensation formation was predicted [14] many years ago. But still now there are no experimental results to directly confirm this idea. It is due to the absence of a setup which could measure the slow π^0 -mesons' characteristics with high accuracy. Now there is a setup TAPS [15] which can measure the slow π^0 -mesons' characteristics with high accuracy. When some results from this setup [15] were analyzed few of them could be interesting for the experimental search of the meson condensate. In these papers [15] temperature of the slow π^0 -mesons was defined as slopes of the spectra which are shown in figs. 4-6. One temperature for interactions of light nuclei and two temperatures for the heavy ions ones were found. The result at low m_t is very interesting as the behavior of the spectra differ from the exponential law (from these figures). Some part of these deviations might be connected with the meson condensation. It increases with the mass of the interacting nuclei and depends on the centrality (Fig.4-6). The last is the main argument confirming that the observed deviation could be connected with the meson condensation.

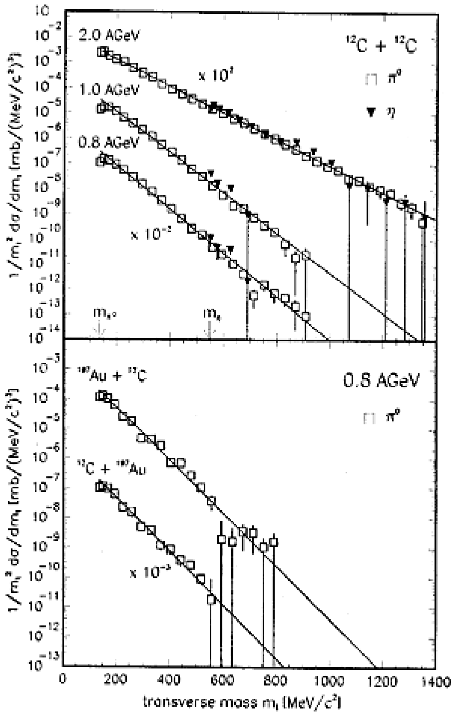

Fig.4 Transverse-mass spectra of π^0 and η-mesons for Au+Au interactions at intervals Δy near midrapidity.

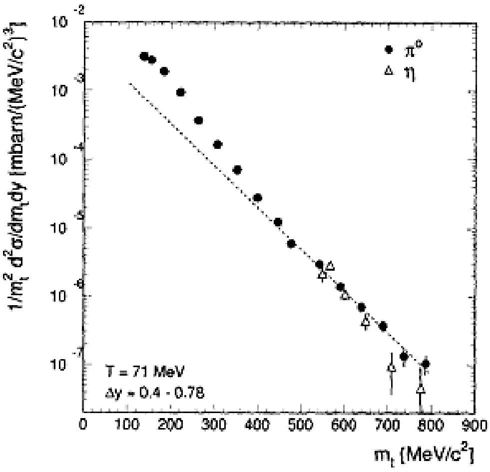

Fig.5. Transverse-mass spectra of π^0 and η-mesons for Au+Au interactions at 0.8 A MeV.

As mentioned above there are the dependences for the values of the *R* (for protons at the values of $\beta^0>1.0$ and for pions at the lower values of β^0) with increasing β^0 (Fig.2a, b)—second result. To explain the result let us consider the variable β^0 which is defined as $\beta^0 = (E_i - P_{Li})/m_N$ and it must be less than one for the protons produced in the nucleon-nucleon interaction and could be greater than one only in multinucleon collisions whether mass of the target is greater than m_N or the number of collisions great than one. So it is seen that in the region around the $\beta^0 \approx 1$, *R* as a function of β^0 starts to change for protons (Fig.2b). It could mean that the area of new physics – multinucleon physics begins at values of the $\beta^0>1.0$. Anoshin et al. [16] found that the probability of pion production with values of $\beta^0>1.0$ is (2.0 ± 0.2) % and certainly the probability of proton emission with values of $\beta^0>1.0$ in $\pi^{-12}C$-interactions at P_{π^-} = 40 GeV/c is much more than this values, it is (37.0± 1.0) % [17]. It explains why the regime change point could not be observed on the behavior of *R* as a function of β^0 pions.

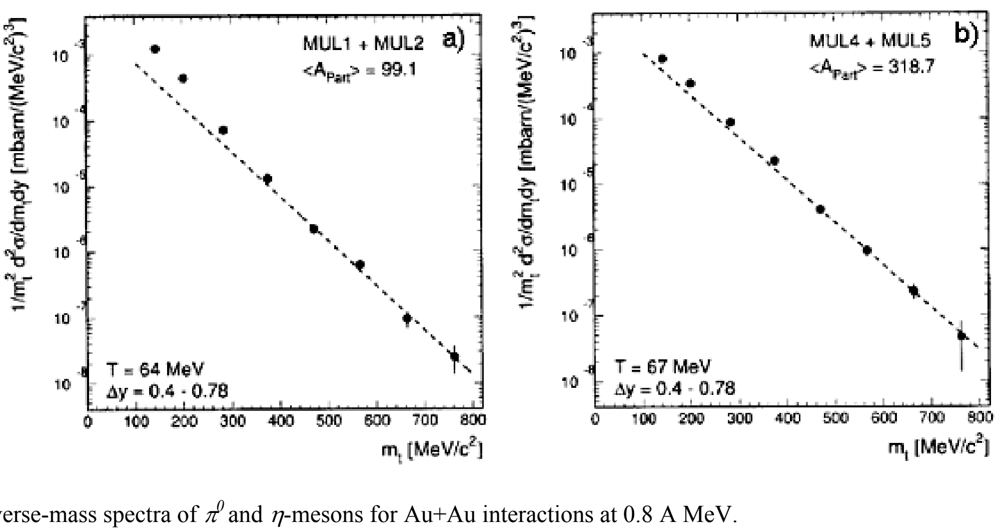

Fig. 6. Transverse-mass spectra of π^0 and η-mesons for Au+Au interactions at 0.8 A MeV.
a) in noncentral collisions; *b)* in central collisions.

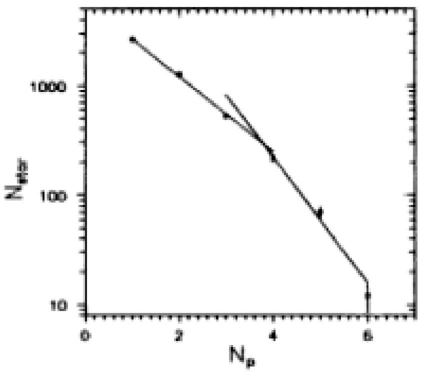

Fig. 7. The N_p-dependence of the $\pi^{-12}C$ reactions at 40 GeV/c.

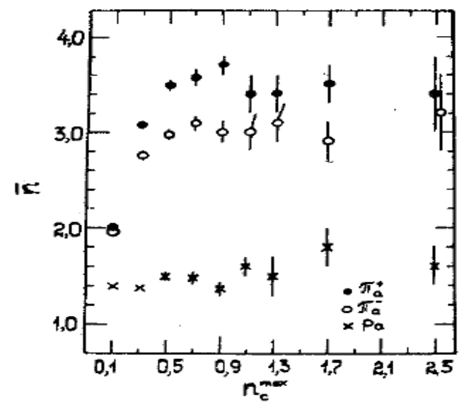

Fig. 8. The average multiplicity of pions produced in $\pi^{-12}C$-interactions at P_{π^-} = 40 GeV/c as a function of $n_c^{max}= \beta^0_{max}$. The β^0_{max} is the maximum values of β^0 in the event for the pions.

The result presented in fig.7 confirms the assumption. In this figure a number of $\pi^{-12}C$ events (at P_{π^-} = 40 GeV/c) is shown as a function of N_p [18]. The regime change point is seen at the values of $n_p \sim$ 3–4 which was used by the author to separate the central events. In this paper [18] it was shown that the probability of the processes of total disintegrated nuclei (or central collisions) in events with the particles having β^0>1.0 is almost 5 times more than in all events.

So it can said that the multinucleon physics could start at the values of N_p greater than 2, present results demonstrate that it could start at the values of $N_p \sim$ 3–4 for $\pi^{-12}C$-interactions at P_{π^-} = 40 GeV/c.

The results could also mean that only single variable, for example, N_p, is not enough to choose the multinucleon events and it is necessary to include other variables. For the events under consideration such variable could be β^0. In paper [12] it was shown that the new region on β^0 could be chosen using the values of β^0>0.6 for pions. In Fig.8 is shown the average multiplicity of the pions produced in $\pi^{-12}C$-interactions at P_{π^-} = 40 GeV/c as a function of the $n_c^{max}= \beta^0_{max}$.(the figure was taken from the paper [12].The β^0_{max} is the maximum values of β^0 in the event for the pions. It can be seen that the regime changes with the behavior of the the average values of pion multiplicity i.e. at the values of $\beta^0\approx$0.6.

Conclusion

It can be concluded that:
- the main characteristics of pions for the events with two or more protons do not differ from ones for all events;
- there is no strong correlation between the processes of pion production and the emission of protons for the events with two or more protons;
- the region of multinucleon processes begins from the values 3-4 of a proton number.

We believe that this result teaches us that the multinuclear events could be the correct selection using the criteria: a number of protons greater than 3-4 for protons and the values of β^0>0.6 for pions produced in $\pi^{-12}C$-interactions at P_{π^-} = 40 GeV/c.

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ÇOXNUKLONLU HADİSƏLƏRİN SEÇİLİB AYRILMASI ÜÇÜN LAZIM OLAN ŞƏRTLƏRİN AXTARILMASI

Bu məqalədə $\pi^{-12}C$ – qarşılıqlı təsirlərində əmələ gələn çoxnuklonlu hadisələrin xassələrinə dair təcrübi nəticələr müzakirə edilir. Bu cür hadisələri seçib ayırmaq üçün belə bir şərtdən istifadə edilir ki, hadisədə müşahidə edilmiş, impulsu 1 QeV/c –dən kiçik olan protonların sayı 2 –dən çox olsun. Çoxnuklonlu hadisələrin xassələrini tədqiq etmək üçün R kəmiyyətindən istifadə edilir ki, o, bu hadisələrdə əmələ gəlmiş $\pi^{\pm}$ -mezonların (protonların) inklyuziv spektrlərinin, bütün hadisələrdə əmələ gəlmiş $\pi^{\pm}$ -mezonların (protonların) uyğun inklyuziv spektrlərinə olan nisbəti kimi təyin edilir. Tədqiqatda *R* kəmiyyətinin $p_{\perp}$, β^{0} və *T* parametrlərindən asılılığından istifadə edilmişdir. Göstərilir ki: çoxnuklonlu hadisələrdə əmələ gələn π –mezonların xassələri bu zərrəciklərin uyğun bütün hadisələrdəki xassələrindən fərqlənmir; bu hadisələrdə əmələ gəlmiş π –mezon və protonlar arasında korrelyasiya yoxdur. Belə bir nəticəyə gəlinmişdir ki, çoxnuklonlu hadisələri seçib ayırmaq üçün hadisələrdə müşahidə edilən protonların sayının 3-4 -ə bərabər və çox olması şərtindən istifadə etmək lazımdır.

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ПОИСК КРИТЕРИЕВ ОТБОРА МНОГОНУКЛОННЫХ СОБЫТИЙ

В данной работе обсуждаются экспериментальные данные по рождению многонуклонных событий в $\pi^{-12}C$ – взаимодействиях. Выделялись события, в которых рождалось более 2 протонов с импульсом менее 1 GeV/c . Для исследования свойств многонуклонных событий использовалась величина *R* , которая определялась из отношения инклюзивных спектров $\pi^{\pm}$- мезонов (протонов), рождающихся в этих событиях, к инклюзивным спектрам $\pi^{\pm}$- мезонов (протонов), рождающихся во всех событиях. Исследовалось зависимость величины *R* от $p_{\perp}$, β^{0} и *T* . Показано что: свойства π – мезонов, рождающихся в многонуклонных событиях, отличаются от свойств этих частиц, рожденных во всех событиях; в многонуклонных событиях между π – мезонами и протонами нет корреляции. Проведенные исследования показали, что для выделения многонуклонных событий необходимо выделять события, в которых число протонов 3-4 и более.

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