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CENTRALITY OF COLLISIONS AND TOTAL DISINTEGRATION OF NUCLEI

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1 Introduction

The search for signals connected with superdense states of nuclear matter is one of the basic trends of research in experiments on relativistic nuclear physics [1]. The best conditions of research of such states are the studies of events with a maximum number of nucleons - participants in the interaction or events connected with central collisions of nuclei. To select such events, the following criteria are usually used: events with maximum multiplicities of secondary particles or events with a minimum flow of energy of secondary particles emitted at a zero angle (see Refs. [2], the results presented in these papers show much importance of studying the central collisions for a full understanding of the processes of interactions of relativistic nuclei). Theoretically, both of these conditions correspond to the value of impact parameter $b \to 0$. The centrality of nucleus - nucleus collisions is really the best condition for arising superdense states of nuclear matter. However, this condition is not sufficient as there are processes with a high degree of centrality of collisions, but they do not result in arising superdense states of nuclear matter [4] (besides,the b-dependence of the production cross section of superdense states of nuclear matter can be of a resonance character). In this cases,it is necessary to introduce an additional condition of selection of such a type of events to observe a signal from superdense states of nuclear matter. We think that such conditions can be from the research of processes with total disintegration of nuclei in interactions of relativistic nuclei [4]. For this, it is necessary to relate processes with total disintegration of nuclei to cases with a minimum flow of energy of particles emitted at a zero angle as the condition of a minimum flow of energy of particles emitted at a zero angle is now in use as a basic trigger for central collision selection .

The research of the processes with total disintegration of nuclei started long ago in experiments with emulsion nuclei [5]. Interest in them was primarily connected with that anomalously high densities of nuclear matter could be realized in these processes and the effects, related to collective properties of nuclear matter, could be observed. However, contrary to the expectations, one could not receive in the experiment an unequivocal answer to the question on the realization of these states. To our mind, the reasons of this are the following: 1) the absence of an adequats insight into the kind of signals of superdense states of nuclear matter; 2) in the above experiments there was no opportunity to take into account the cases, in which large momenta were transferred to fragments in interactions; the energy characteristics of secondary particles were not practically determined, and the statistical material, as a rule, did not exceed some hundred events.

Taking into account all this and also the importance of the problem, the processes with total disintegration of nuclei were studied in our experiment [6-8] according to a new experimental statement. It included the following:

(a) The bubble chamber technique was used that allowed the energy and the charge sings of all secondary particles to be determine.

(b) The development of new selection criteria of events with total disintegration of nuclei. For this purpose, the idea is used that the processes with total disintegration of nuclei correspond to qualitatively new states of nuclear matter and the transition to these states occurs in nuclear interactions when the number of protons emitted from nuclei, Q, reaches a critical value of Q^*, at which the regime change happens in the behaviour of the characteristics of secondary particles in Q-dependences . Hence one can use the following condition as a selection criterion for events with total disintegration of nuclei :

$$Q \geq Q^* \qquad (1)$$

This method of selection of reactions with total disintegration of nuclei is experimentally realized by studying the behaviour of different characteristics of secondary particles in nucleus - nucleus interactions depending on Q. So, the Q-dependences of the following characteristics are considered [6-8] : probabilities to observe events, the average characteristics and inclusive spectra of secondary particles, and also one-particle correlation functions for π - mesons and protons. The results, obtained in these papers , have confirmed the assumption of the existence a certain boundary value of Q^* (which excess leads to the processes with total disintegration of nuclei). The experimental data on the dependence of the average multiplicity of relativistic charged particles of the sum of charges of projectail fragments for $^{28}Si_{14} + Em$ (at 14.6 A GeV) and $Si + Em$ (at 3.7 A GeV) reactions are presented in paper [9]. The regime change was observed in these dependences at the transition from the region of large values of the sum of charges of projectile fragments the region of small values - to the region of central collisions. The values of the sum of charges of projectile fragments corresponding to the points of regime change in these dependences were used to select the central collisions. We believe that at our energies this result can mean the existence of the transition of nuclear matter from nucleon states to its non-nucleon and mixed states. At RICH or LHC energies , a similar result can mean the detection of "critical" points of phase transition to nuclear matter, and it can be used to develop adequate representations of the kind of a signal from superdense states of nuclear matter.

2 Methods of the experiment

The experimental data, obtained in an exposure of the 2-m propane bubble chamber to relativistic nuclei at a momentum of 4.2 A GeV/c, were used in the analysis. The total statistics of events are: 8130 events - pC , 6945 - dC , 11248 - ^4HeC and 20407 - ^{12}CC interactions. Methodical details are described in [9]. It should be noted, that protons in this experiment are reliably identified by ionization and path only over a momentum interval of 0.15-0.50 GeV/c. Protons with a momentum of $p < 0.15$ GeV/c have a path shorter than 2 mm and most of them are not seen in the photograph. The weights, determining the probability that the given particle is a proton or a π^+ - meson, are assigned to all positive particles having a momentum higher than 0.5 GeV/c . The characteristics of π^- - mesons were used to determine the weights. The minimum momentum for the detection of π^- -mesons was 0.07 GeV/c. The fraction of electrons and negative strange particles did not exceed 5 % and 1 %, respectively. To determine the number of protons (as well as in ref. [6-8]), the variable Q was used. The value of Q for each event was determined as

$$Q = N_+ - N_{\pi^-}. \tag{2}$$

Here N_+ and N_{π^-} are the numbers of positive particles and π^- -mesons,respectively (assuming that $N_{\pi^+} = N_{\pi^-}$). The experimental losses of particles and errors in identifying secondary particles and fragments affect the accuracy of determining the values of Q. A bad accuracy in determining Q can result in the appearance of "false" Q^* and extension of the regions of regime changes. For this reason we cannot determine precisely the number of regions of regime change and the values of Q^* corresponding to them. To decrease the influence of this factor, we consider not groups of events with definite values of Q and groups of events with Q larger than a certain value, i.e. the integral spectrum. Under such consideration, the influence of accidents of all kinds decreases. Therefore, the experimental material was divided into groups of events with the following values of Q:

$$Q \geq 1; 2; 3; ..Q^{max}. \tag{3}$$

For example, we took 11 for Q^{max} for ^{12}CC interactions and $Q^{max} = 7$ for the other types of interactions .

3 Results

As already noted, the basic aim of the present work is to relate events with total disintegration of nuclei to cases with a minimum flow of energy of particles emitted at a zero angle. To achieve this aim in the experiment, it was supposed that if these events correlated, with increasing Q the average values of

$$K = \frac{\sum_{i=1}^{n} p_i^2}{\sum_{i=j}^{N} p_j^2} \tag{4}$$

(Here p_i^2 is the momentum squared of the charged particles with an emission angle $\theta \leq 5^0$ in the laboratory system of coordinates and n

is the number of these particles; p_j^2 is the momentum squared of all charged particles and N is their number in the event) must decrease sharply and reach a minimum value for the events with a minimum flow of energy at emission angles close to 0^0. In this case, if the value of $< b >$ decreases with increasing Q, this means an approach to the condition of central collision (to define the values of $< b >$ we uced the calculation data by the quark-gluon string model (QGSM) [10]).

Fig. 1 shows the Q-dependences of $< K >$. It is seen that the values of $< K >$ decreasing with increase Q : for ^{12}CC interactions in the interval $Q \geq 6$, for ^4HeC - $Q \geq 4$, and for dC, pC - interactions in the interval $Q \geq 3$. Thus, one can conclude that in the interval of large Q, i.e. in area of total disintegration of nuclei, $< K >$ decreases with increasing Q and reaches its minimum at a maximum value of Q. From here it follows that the events with total disintegration of nuclei correspond to the cases with a minimum flow of energy of charged particles at an emission angle of $\theta \leq 5^0$.

One can also see (fig. 2) that with increasing Q, $< b >$ decreases (calculated data on QGSM) and reaches its minimum at a maximum value of Q. This means that the processes with total disintegration of nuclei, selected with the help of the condition $Q \geq Q^*$ in the framework of QGSM, correspond to events with the highest centrality of collisions. One can also see that the values of $< b >$ increase with growing A. Thus, the events with total disintegration of nuclei, selected with the help of the condition $Q \geq Q^*$, correspond to the cases with the largest centrality or the cases with a minimum flow of energy at an angle of 0^0. In so doing, the determined values of $< K^* >$ correspond to the values of Q^*.

From the data in fig. 1, one can see that there is a strong A - dependence for the distributions $< K >= f(Q)$. A similar result has been obtained in [7]. As was noticed there, one-partial correlations weaken with increasing A, and they become minimum for ^{12}CC interactions. As it follows from [7] and the present data, the character of dependence of correlation functions on Q also changes simultaneously with weakering correlations in the region $Q \geq Q^*$ (total disintegration of nuclei). In the [8], it has also been found that there are two regions in the behaviours of back slopes of invariant inclusive spectra in Q-dependences . We have interpeted this fact as an indication of a probable growth of the density (or " temperature ") of nuclear matter in the area of total disintegration of nuclei. Thus, the results, obtained in this paper, come the conclusion that the condition $< K > << K^* >$ (corresponding to the condition $Q \geq Q^*$) can be used (as an additional one) in the experiments, studying the reactions with a minimum flow of energy of secondary particles at a zero angle, for experimental detection of a signal from superdense states of nuclear matter. For this, the opportunity of an application of event-by-event analysis is discussed [12]. We have no opportunity for direct application of the event-by-event analysis, as in our experiment the multiplicity of secondary particles is much smaller than it is necessary for the event-by-event analysis. But we believe that the method of event analysis used by us in the present work and the obtained results will bee important in the event-by-event analysis (to receive a signal from quark- gluon plasma) in collisions of heavy nuclei at high energies. The event-by-event analysis must give more full information on the dynamics of nuclear collisions than the inclusive analysis. To search for fluctuations with the event-by-event analysis, it is necessary to exclude changes of collision geometry. Event selection with fixed values of b is assumed to be the best way for it . The values of b can be estimated through the values of a flow of energy in fragmentation regions, in particular through a flow of energy at an angle 0^0. Thus, information on the energy and volume dependence of the obtained experimental results is needed for an unambiguous interpretation of the obtained data. The energy dependence can be taken into account by comparison of the data obtained at different energies of colliding nuclei. The volume dependence of results can be taken into account by comparison of the data obtained for collisions of nuclei with different masses. It is expected that in the event-by-event analysis the cases with quark gluon plasma will differ from those without plasma in the point of regime change in the corresponding dependences. The first results of the NA49 Collaboration [13] in the event-by-event analysis for Pb + Pb collisions at SPS energies were reported.

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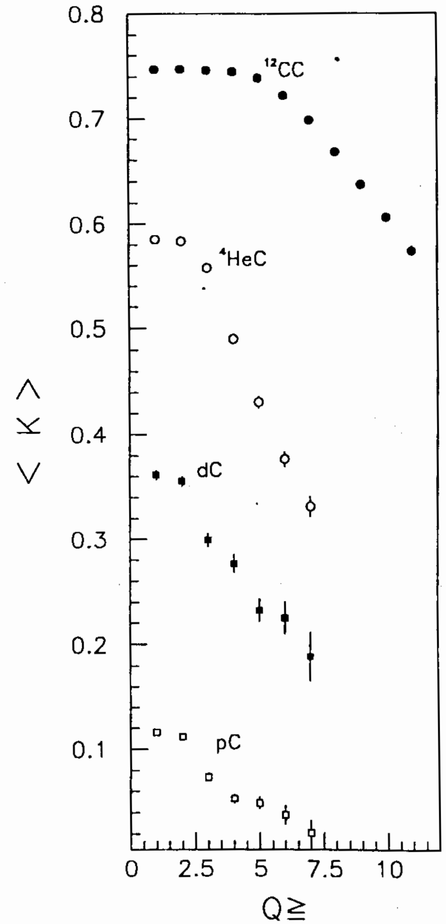

Figure 1: Q - dependence of the values of $< K >$ for ^{12}CC, ^4HeC, dC and pC interactions.

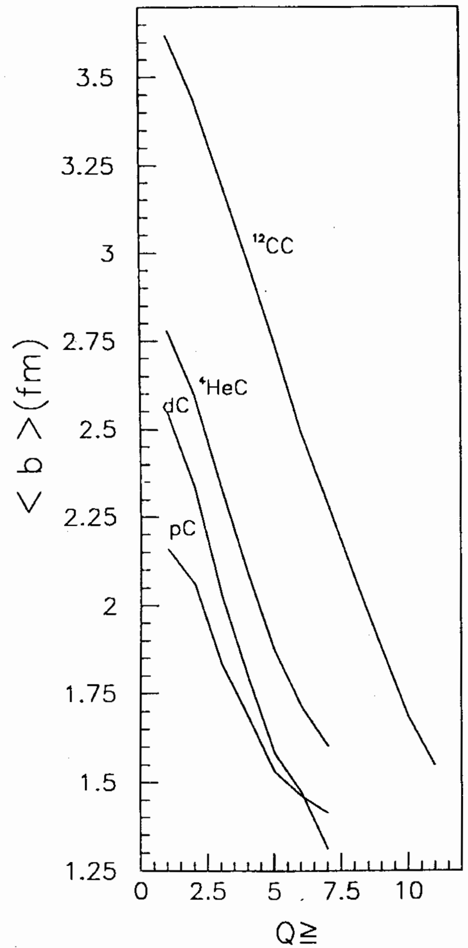

Figure 2: Q - dependence of the values of $< b >$ for ^{12}CC, ^4HeC, dC and pC interactions.

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