Analysis of the characteristics of nucleus-nucleus collisions depending on the centrality

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The experimental results on some centrality depending characteristics of hadron-nuclear and nuclear-nuclear interactions at high energies demonstrate the regime changes. Appearance of strong interaction matter’s mixed states is considered as a cause of it and the effect of a cluster formation is discussed as one of the phenomena connected with the mixed states.

1. INTRODUCTION

One of the important experimental methods to get the information on the changes of states of nuclear matter with increasing its baryon density is to study the characteristics of hadron-nuclear and nuclear-nuclear interactions depending on the centrality of collisions \( Q \) at high energies. There are some results obtained in these experiments for the interactions of \( \pi \)-mesons, protons and nuclei with nuclei at energies less than SPS’ energies which demonstrate existence of the regime changes in these dependencies [1]-[5]. It is necessary to note that in different experiments the values of \( Q \) are defined in different ways. Therefore it is very difficult to compare the obtained results on \( Q \)-dependencies in different papers.

QCD predicts that at high energy density, hadronic matter will turn into plasma of deconfined quarks and gluons [6]. It is expected that the temperature of hadron matter \( T \) will be \( T > T_c \approx 150 - 200 MeV \) and \( \mu_B \) will be \( \mu_B > \mu_{B_c} \) (\( \mu_B \) increases with the barion
charge). It is a new phase of nuclear matter. The $T_c$ could be reached at energies of SPS, RICH and LHC.

To explain the above mentioned results we consider the possibility of the phase transition at $T < T_c$ in the system with high barion density (at high $\mu_B$). In such systems the neighbouring nucleons could form the cluster and neighbouring quarks could form the diquarks (for example in the result of percolation). So these systems are a mixed system (MS) of compressed nucleons (clusters) and diquarks which could appear at energies of GSI, Synchrophasotron (Nuclatron) and AGS.

Experimental information on the conditions of the MS appearance could give the possibilities to fix the onset of the deconfinement. It is important for further separate on of the effects connected with deconfinement of strong interaction matter from the other ones.

The regime changes which were shown above could be a better indication of the MS appearance in high energy interactions, but they are not enough to assert it. For further confirmation of the appearance and existence of the MS it is necessary to obtain an additional experimental information because the regime changes under consideration can be explained by some other approaches without the MS.

Let us discuss experimental possibilities to get a signal on the MS. First of all we have to answer a question, by what experimental observable effects the MS could be accompanied. It is clear that the first effect is a cluster formation (for example in the result of percolation), the second effect could be the appearance of meson condensation (which could be formed in the result of hadronisation of diquarks).

There are many papers in which the processes of nuclear fragmentation [7] and the processes of central collisions [8] are considered as critical phenomena and percolation approach is suggested to be used to explain these phenomena. We have used some ideas from these works to experimental search of a signal on a cluster formation. We suppose that in hadron-nucleus and nucleus-nucleus collisions the cluster could appear on some critical values of $Q$ and would decay into fragments and free nucleons. The number of clusters and fragments would increase with $Q$ in the interval less than the critical values of $Q$ (for MS formation) and then their values would decrease with the increase of $Q$ to the boundary of the central collisions region. It could lead to the regime change in the behavior of different characteristics of events depending on $Q$ and the number of fragments. We believed that if the cluster exists and if it is a source of fragments then the influences of nuclear fragments on the behaviour of the events’ characteristics depending on $Q$ could have a critical character.

1.1. EXPERIMENT

To test this idea the behaviors of the events’ number depending on $Q$ have been studied by us [9]. The values of $Q$ were determined in two variants. In the first variant the values of $Q$ were determined as a number of protons emitted in a event and in the second variant – as a number of protons and fragments emitted in the events. We have used 20407 $^{12}CC$ events at the momentum of 4.2 A GeV/c [10]. The experimental data were compared with the simulation data coming from the quark-gluon string model (QGSM) without nuclear fragments [11]. We want to note that the behavior of the events’ number depending on $Q$ determined for both variants have to be similar if there are no cluster and they would differ
if the cluster exists as a source of fragments. The distributions of the events’ number as a function of $Q$ are shown in fig. 1a,b. The open symbols correspond to the first variant of $Q$-determination, the black symbols correspond to the second ones (the fragments were included). It is seen that for the cases when the fragments numbers were included to determine $Q$ the form of the distributions sharply changes and has two steps structure (black symbols in fig. 1a). The $Q$-dependencies of the events’ number coming from the QGSM are shown in fig. 1b. The open symbols correspond to the cases without stripping protons and the black symbols correspond to the cases with the stripping protons. It is seen that the form of the distribution strongly differs from the experimental one in fig. 1a. There is no two steps structure in this figure. Therefore we could assure that the observed difference is connected with the fragment influence. This result demonstrates that the influence of nuclear fragmentation processes in the behavior of the events’ number depending on $Q$ has a critical character. To explain this result we can suppose that it could be connected with the existence of a cluster. It is possible that with the increase of $Q$ the probability of cluster formation grows but further increasing of the $Q$ (in the region of high $Q$) leads to a cluster decay on nuclear fragments and then on free nucleons. It could be the reason of the observed two step structure in the distributions. The first step connected with the formation of a cluster and the second one with its decay. The obtained results on multifragment production at high energy nucleus-nucleus interaction could give additional confirmations for it (for example see [12]).

Figure 1. The distributions of events’ number as a function of $Q$ for the $^{12}CC$ events at the momentum of 4.2 A GeV/c; a) the experimental data b) the simulation data.

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