SEARCH FOR THE MIXED STATES OF STRONG INTERACTION MATTER-- PHASE TRANSITION AT LOW TEMPERATURE.

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Abstract

The experimental results on some centrality depending characteristics of hadron-nuclear and nuclear-nuclear interactions at high energies demonstrate the regime changes. Appearance of the strong interaction matter's mixed states is considered as a cause of the regime changes. These states are predicted by QCD for temperatures less than critical ones for deconfinement of strong interaction matter . These conditions could be obtained in the energy regions covered by the beams at GSI, Dubna and AGS facilities. The effects of a percolation cluster formation, apparition of the diquark condensate and critical nuclear transparency are considered as the phenomena connected with the mixed states. It is supposed that the results of the analysis of these effects depending on the centrality could give an information on 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 centrality of collisions (Q) at high energies. There are some results obtained in these experiments for the interactions of π -mesons, protons and nuclei with nuclei at energies less then SPS' energies which demonstrate the existing of the regime changes in these dependencies . We want to demonstrate some of them and before it is necessary to note that in the different experiments the values of Q are defined by the different ways. Therefore it is very difficult to compare the presented results on Q-dependencies in the different papers .

1.1. Experimental results on the centrality dependencies.

1.2 The interactions of the π^--mesons.

In fig. 1 is shown the Q-dependence of event number for π^- ^{12}C - interactions at the momentum 40 GeV/c. To determine the Q a number of protons with momentum less then 1.0 GeV/c was used. The figure was obtained from papers [1]. The point of regime change is observed in this dependence at the values of Q ~ 3-4 was used to select the events with total disintegration of nuclei(or central collisions).

1.3 The interactions of the protons.

In fig. 2 are shown the average values of pseudorapidity η = -log((tg(θ/2)) for s-particles (the particles with β > 0.7) depending on the number of g-particles (the particles with $\beta \leq 0.7$) for p+Em reactions at the moment P_0 = 4.5; 24.0; 50.0; 67.0 and 200.0 GeV/c. So in this work the Q was defined as the number of g-particles. This figure was obtained from the paper [2]. The dashed line in the figure corresponds to the cascade-evaporation model calculation . There are the points of regime change in these distributions. As we could see the cascade - evaporation model calculations can't numerically describe these distributions.

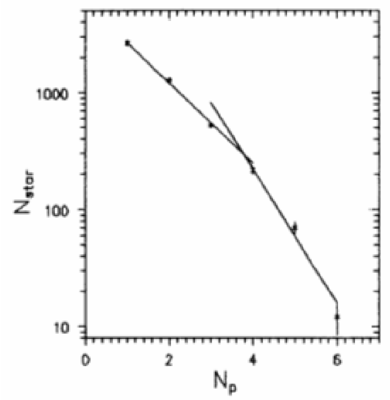

Fig.1.N_p–dependence of the events' number for π^- ^{12}C - interactions at the momentum 40 GeV/c.

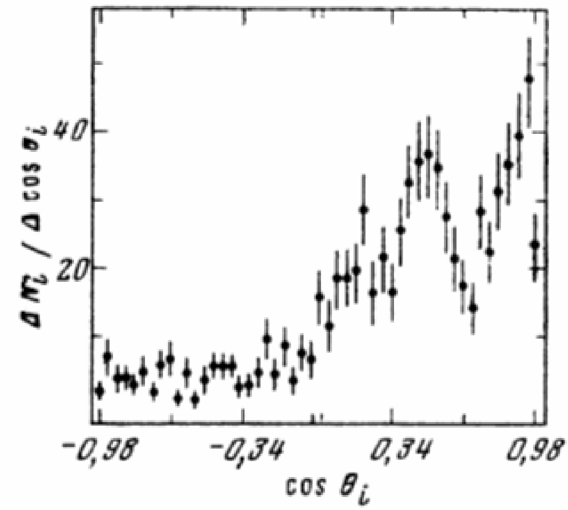

Fig.2 Average values of pseudorapidity η_c=-log(tan(θ/2)) for s-particles depending on the g-particles for pEm-reactions . The dashed line correspond to the cascade evaporation model calculation.

The preliminary integrated K^0_s yield in p+Au reactions at 18 GeV/c versus the number of slow particles emitted in the event is show in next figure (fig.3). The number of slow particles Q was used as the Q. We could also see the points of regime change in this figure. The figure was obtained from paper [3].

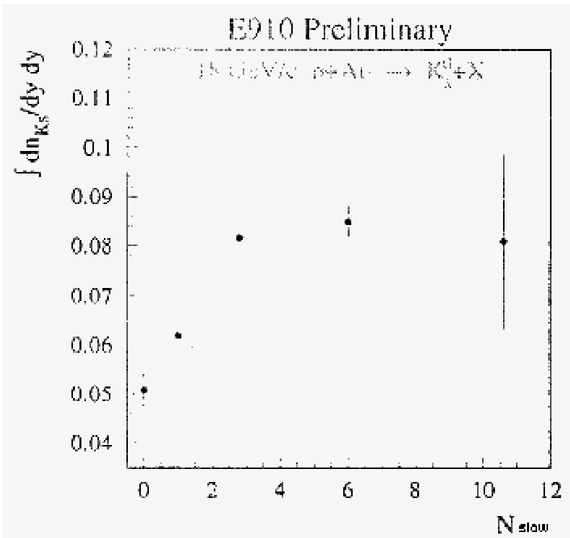

Fig.3. The preliminary integrated $K_S{}^0$ yield in p+Au reactions at 18 GeV/c versus the number of slow particles emitted in the event as measured by E910.

1.4 The interactions of the nuclei.

Fig . 4 shows the Q-dependencies of events' number for dC, ^{4}HeC and ^{12}CC interactions at the momentum 4.2 A GeV/c . The number of all protons in an event was used as the Q. We could see the points of regime changes in this figure. It is also seen that for all considered interactions the forms of distributions are nearly similar.

Fig.4. The Q-dependencies of events' number for dC, ^{4}HeC and ^{12}CC interactions at the momentum of 4.2 A GeV/c

In fig. 5 the average multiplicity of relativistic charged particles depending on Q are shown for the $^{28}S_{14}$ + Em -- reactions at the energies of 3.8 and 14.6 GeV per nucleon. To determine the Q a number of charged projectile fragments (Z_f) were used. The figures were obtained from the paper [4]. The points of regime change are observed in these dependencies. These points were used by the authors to select the central collisions events.

Fig.5. The average multiplicity of the relativistic charged particles depending on Q for the $^{28}S_{14}$ + Em -- reactions at the energies of 3.8(a) and

14.6 GeV(b) per nucleon.

The N_h^B-dedendences (N_h^B is a number of h-particles with emitted angle $\theta>90^0$) of the average multiplicity $<n_s^F>$ of s-particles (with emitted angle $\theta<90^0$) for C^{12}Em reactions at the momentum 4.5 GeV/c are shown in fig . 6. The figure was obtained from paper [5]. The number of N_h^B are used as the Q. We could also see the point of regime change in this distribution.

Fig.6. The N_h^B- dependencies of the average multiplicity $<n_s^F>$ of s-particles for C^{12}Em reactions at the momentum 4.5 GeV/c .

Thus the demonstrated figures show that there are the points of regime change for the behavior of the centrality dependencies for some characteristics of hadron -- nuclear and nuclear -- nuclear interactions . Prof. Zinovyev offered to us to consider the appearance of the mixed states of nuclear matter as a reason of these results. He directed our attention to the some predictions of QCD.

Before then to continue the discussion we want to note that in paper [6] it was found that the experimental results on transverse mass spectra of kaons produced in central Pb+Pb (Au+Au) interactions show an anomalous dependence on the collision energy. The inverse slopes of the spectra increase with energy in the low (AGS) and high (RHIC) energy domains, whereas they are constant in the intermediate (SPS) energy range. They argued that this anomaly is probably caused by a modification of the equation of state in the transition region between confined and deconfined matter and they were writeen that this observation may be considered as a new signal, in addition to the previously reported anomalies in the pion and strangeness production, of the onset of deconfinement located in the low SPS energy domain.

2. Prediction of QCD for mixed states.

QCD predicts that at high energy density, hadronic matter will turn into a plasma of deconfined quarks and gluons [7]. It is expected that the temperature of hadron mutter T will be
$T > T_c \cong$ 150-200 MeV and μ_B will be $\mu_B > \mu_{B\,c}$ (μ_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.

In fig. 7 are shown the dependence of the values of T on the values of μ_B for the simple QCD model -- the phase diagram (from review [8]). There are three phases in this diagram. The first phase correspond to the values of $T < T_c$ and $\mu_B < \mu_{Bc}$ which are named the phase of hadron matter. The second phase is the phase of diquark condensate at $T<T_c$ and $\mu_B > \mu_{Bc}$. The third phase is the quark gluon plasma one at $T>T_c$ and $\mu_B > \mu_{B\,c}$.

To explain the above mentioned results we consider the possibility of phase transition at $T<T_c$ in the system with high barion density (at high μ_B). In such systems the neighbouring nucleons could form the percolation cluster and neighbouring quarks could form the diquarks (fig.8). So these systems are a mixed system (MS) of pressed nucleons (clusters) and diquarks which could appearance at energies of GSI, Synchrophasotron (Nuclatron) and AGS.

Experimental information on the conditions of appearance of the MS could give the possibilities to fix the onset of the deconfinement which are important for forth separate the effects connected with deconfinement of strong interaction matter from another effects.

3. Experimental possibilities to search signal on mixed states.

The regime changes which were above shown could be better points to appearance of MS in the high energy interactions, but they are not enough to assert it. For full confirm the appearance and existing of the MS it is necessary to get the additional experimental information because to explain the appearance the regime changes could be used many another ideas which don't included the MS and the accompanied effects.

What could experimental information been got to confirm the appearance of MS?

Fig.7 The phase diagram.

Fig.8. Physical picture of MS formation.

Let us discuss the experimental possibilities to get the signal on the MS. First of all we have to answer on one question, what experimental observable effects could the MS be accompanied? It is been clear that the first effect is a cluster formation (in the result of percolation), the second effect could be the appearance of meson condensation (which could form as the result of hadronisation of diquarks). As we have already noted three phase of hadronic matter are consider in review [8] which would correspond to the succession of insulator, superconductor and conductor in atomic matter in the phase diagram. The succession of superconductor will correspond to the MS and therefore the MS appearance could be accompanied with high transparency of nuclear matter. Here it is necessary to note that above mentioned **effects would be had direct relation to the MS only in this case if they appearance as critical phenomena at some values of Q**. It is the more important request.

4. The main points of the proposal

1. The MS could be form at low temperature which could be reached at energies of building GSI's motions.
2.The MS could form and decay at the some critical values of Q, therefore it could be the reason of the appearance of regime changes in the behaviour of the events' characteristics depending on Q.
3.The processes of MS formation could be accompanied by the effects of percolation cluster formation , appearance of meson condensate and the high transparence of the nuclear mutter. These effects could be used as the signals on MS.

There are some experimental results which could be consider as the confirmations of the existing these effects and as a basis to their forth investigations in the new experimental possibility.

5. Percolation cluster production in interaction of high energy nuclei.

5.1 Percolation cluster as the sours of fragments.

There are many papers in which the processes of nuclear fragmentation [9] and the processes of central collisions [10] are considered as a critical phenomena and are offered to use the percolation approach to explain this phenomena. We have used some ideas from these works to experimental search a signal on percolation cluster. We suppose that in hadron-nucleus and nucleus-nucleus collisions the percolation cluster could appear on the some critical values of Q and would decay into fragments and free nucleons. The number of clusters and the number of fragments would increase with Q in the interval less then the critical values of Q (for MS formation) and then their values would decrease with the increasing Q into the central collisions. 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 percolation cluster exist and if it is a sours of fragments so the influences of nuclear fragments on the behaviour of the events' characteristics depending on Q could have a critical character.

To test this idea we the behaviors of the events' number depending on Q have been studied by us. The values of Q ware 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 second variant as a number of protons and fragments emitted in ones. We have used 20407 ^{12}CC events at the momentum of 4.2 A GeV/c [11]. The experimental data were compared with the simulation data coming from the quark-gluon string model (QGSM) without the nuclear fragments [12]. 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 not a percolation cluster and they would be differ if the percolation cluster is exist as a fragments source.

The distributions of events' number depending on Q are shown in fig. 9a,b . The empty starlets corresponds to first variant of Q-determination, the full starlets correspond to second ones(the fragments were included). It is seen that for the cases then the fragments numbers were included to determine Q the form of the distributions sharply changes and has two steps structure (full starlets in figure 9a).

In fig. 9b are shown the Q-dependencies of the events' number coming from the QGSM. The empty starlets correspond to the without the stripping protons cases and the full starlets correspond to the cases with the stripping protons. It is seen that the form of the distribution strongly differ from the experimental one in fig. 9a. There is no two steps structure in this figure. Therefore we could assure that observed difference connects with fragments influence. This result

Fig.9. The distributions of events' number depending on Q for the ^{12}CC events at the momentum of 4.2 A GeV/c ; a)the experimental data b) the simulation data.

demonstrate 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 could suppose that it could be connect with the existence of percolation cluster. It is possible that with increasing Q the probability of cluster formation grows but further increasing the Q (in the region of high Q) leads to the big cluster decay on nuclear fragments and then free nucleons. It could be reason of the observed the two step structure in the distributions. The first step connected with the formation of percolation cluster and second one with its decay(fig.10). The GSI results on multifragment production at high energy nucleus-nucleus interaction could give the additional confirmations for it [13]. So in fig. 11a,b are shown the mean multiplicity of intermediate mass fragments produced in nucleus-nucleus collisions at GSI energies as a function of Z_{bound} (the last fixes the centrality of collisions). It is seen that the mean multiplicity of fragments is maximum in the region of first step.

Fig.10 Physical picture of interaction.

Fig.11a Mean multiplicity of intermediate mass fragments

Fig.11b. Left panel: Mean multiplicity of intermediate mass fragments as a function as a function of Z_{bound} for the reaction Au+Au at E/A=400, 600,800 and 1000 MeV.

of Z_{bound} for the reaction ^{238}U on ^{197}Au (circles), ^{197}Au on ^{197}Au (squares) and ^{129}Xe On ^{197}Au(triangles) at E/A=600 MeV. Right panel: the same data after normalizing both quantities with respect to the atomic number Z_p of the projectile.

So the experimental results obtained in the interactions of π-mesons, protons and nuclei with nuclei at high energy demonstrate that the influence of nuclear fragmentation processes in the behavior of the event's number depending on Q has also a critical character. It could be explained with the existence of percolation cluster and with appearance of MS of nuclear matter.

5.2 Anomaly pick in angular distribution of protons.

The existing of percolation cluster could explain the experimental results on the angular distributions of emitted protons in $\pi^{-12}C$ -interactions at momentum 40 GeV/c[14]. In this experiments the angular distributions of protons (with the momentum less then 1.0 GeV/c) were

Fig.12 Angular distributions of protons emitted in $\pi^{-12}C$ -interactions at momentum 40 GeV/c.

studied in the events with total disintegration of nuclei (or central collisions). This distribution are shown in fig. 12. It is seen the anomalous peak in this distribution. The result on the angular distributions of protons emitted in $\pi^{-12}C$ -interactions at momentum 5 GeV/c [15] confirm the existing of anomalous peak (fig.13). Many years we could not explain this result. Now we think that it could connect with formation and decay of the percolation cluster.

6. Meson condensate in nucleus-nucleus collisions at high energies.

The another accompanied effect for the processes of MS formation could be the effect of meson condensate appearance as the result of diquark hadronisation. The idea on meson condensate formation was predicted [16] many years age. But up to now there are no the experimental results direct confirm this idea. It mainly connects by the absent the setup which could high accuracy measure the slow π^0 -mesons' characteristics a long time. Now there are setup TAPS [17] which can measure the slow π^0 -mesons' characteristics with high accuracy. When we analyzed some results from this setup [17] we found the results which could be interesting for the experimental search the meson condensate. In these papers the temperature of the slow π^0 -mesons were defined as a slop of the spectrums which are shown in the fig.14a-c. It were found one temperature for interactions of light nuclei and two temperature for the heavy ions' ones.

It is very interesting the result at low m_t the behavior of the spectrums differ from the exponential law(from these figures). We think that some part of these deviation could connect with the meson condensate . It increase with mass of the interactions nuclei and depend on centrality(fig.14a-c). The last is an main argument confirm that observed deviation could connect with the meson condensate.

We think to study the behaviour of the $f(m_{t,}y)$ depending on mass of colliding hadrons and nuclei and on the centrality of collisions and the number of fragments could give the information on the meson condensate.

Fig.13 Angular distributions of protons emitted in $\pi^{-12}C$ -interactions at the momentum 5 GeV/c.

7. Nuclear transparency at high energy hadron-nuclear and nuclear – nuclear interactions

The else one accompanying effect of the MS formation process could be high critical nuclear transparency which could connect with the appearance of the superconductor property of nuclear matter in MS. As we have noted (in section 3) when the MS appearance the conduction of nuclear environment sharply increase and matter is getting the superconductor properties because of that the nucleons mast be bound in the result of nucleon and quark percolation in this system. It could led critical violation of the angular correlations of particle production .

8. Conclusion.

Thus the experimental results obtained in the energies region less then SPS energy on hadron-nuclear and nuclear-nuclear interactions demonstrate the existing of regime changes in the behaviour of events' characteristics depending on centrality. The appearance of the stronginteraction matter mixed states are discussed as a reason of it. The percolation cluster formation , appearance of meson condensate and high critical nuclear transparency are considered as the accompanied effects of the mixed systems. Some experimental results obtained in different experimental groups could be considered as the confirmations on the being of percolation cluster and meson condensate. But for full confirm the formation of mixed systems it is necessary to forth investigation of these effects and their connections with mixed systems.

Fig.14a Transverse-mass spectra of π^0 and η-mesons in the covered rapidity intervals Δy near midrapidity.

Fig.14b Transverse-mass spectra of π^0 and η-mesons for Au+Au interactions at 0.8 A MeV.

Fig.14c. 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.

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