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DENSE COLD MATTER WITH CUMULATIVE TRIGGER

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New phase diagram sector at extremely large baryon density and low temperature is proposed for the laboratory study. High-p_t central rapidity double cumulative trigger for this study is proposed and tested experimentally at ITEP ion accelerator by FLINT Collaboration.

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INTRODUCTION

Chromodynamics of media is the subject of research in relativistic nuclear physics field. Different regions of the QCD phase diagram are an object of interest. One of the main goals for the experiments on heavy-ion beams is to find specific signatures in nuclear interactions indicating the phase transitions presence and study of new form of QCD matter — quark–gluon plasma (QGP). At present, the main experimentalists' efforts are bended on studying the phase diagram at high temperatures and low baryon densities (RHIC, LHC). This corresponds to the theory status ten years ago when the phase diagram consisted only of two regions: hadron phase and QGP. In the late years, advances in theory led to a significant complication of phase diagram, in particular, to the appearance of critical point widely discussed last years. Discovery of critical point at intermediate temperatures and densities is considered as one of the most important goals of FAIR and NICA projects. New phenomena are also predicted at high densities and low temperatures. In this phase space domain, first order phase transition and existence of new phenomena like color superconductivity [1] are expected. Low temperatures and extreme densities are probably realized in Nature within neutron stars. This region is hardly to be achieved in laboratory conditions by using standard experimental tools for moving on phase diagram like changing of the initial energy and masses of colliding nuclei, or selecting the impact parameters. Such tools do not provide possibility to study the whole phase diagram but specify some rather small area $T \pm dT$ vs. $(\rho \pm d\rho)$.

Cumulative effect has been discovered in 1970s [2] and considered in terms of local fluctuations of nuclear matter. Some properties of cumulative processes, such as strangeness enhancement, are similar to those expected for QGP. However interconnection of cumulative processes and QGP seems to be doubtful because of the next arguments. Firstly, if high densities could be realized in cumulative processes, then only in short-lived fluctuations (named by D. I. Blohintsev «fluctons» [3]). Secondly, particles in such fluctuations must be highly virtual and have large relative momentum. Thirdly, these are local few-nucleon fluctuations and it is inconsistently to consider it like a media (although existence of plasma droplets was already discussed, see for example [4]). Recognizing significance of these objections, we will confine ourselves to the following remark. By overcoming them we will obtain an effective trigger for extreme dense nuclear matter. Indeed, if we could select (e.g., kinematically) a process with ~ 10 nucleons being in volume of one nucleon, then the density of such formation would be tens times higher than the standard nuclear density ($\sim 1/6$).

1. GENERAL IDEA

We propose to make event selection (trigger) with a photon (pion, kaon) at midrapidity and maximal transverse momentum by colliding light nuclei (from Helium to Carbon). Due to kinematical restrictions such criterion selects mainly flucton–flucton (FF) interaction. We should stress that production of cumulative particle is neither necessary nor sufficient condition for selection of dense baryon system. However, we expect that such selection procedure would increase signal (dense cold matter production)-to-background (ordinary hadronic matter) ratio for several orders of magnitude. Interaction makes particles participation in both fluctons real. The closer the energy of trigger particle to maximal possible for present colliding nuclei, the lower should be internal energy of the secondary baryon system. Therefore the decay of this system will be slow. This weakens the objection of short lifetime and large relative momenta. And after all, at high density much smaller system size is enough to speak about medium because the smallness of free path in comparison with system sizes is the criterium, while the free path decreases with the density increasing.

After realization of proposed event selection, we suggest to proceed with a bright research program focused on properties of a system formed in final state. Theoretically predicted properties of dense baryon system (some of them are listed below) should be checked experimentally. This list will probably become longer in future but it seems already clear nowadays that spin (isospin) system's states, space-time characteristics, exotic particles search such as dibaryons, strangeness enhancement, etc., should be studied.

Reality of an effective trigger for the selection of flucton–flucton interaction was experimentally proven in FLINT (FLucton INTeraction) experiment in ITEP [5]. The trigger realization in FLINT is based on high-p_t photon registration in midrapidity range using lead glass electromagnetic calorimeter. Maximal order of cumulativeness $X_{\text{sum}} = X_1 + X_2$ (where X_i is the minimal number of participating nucleons from colliding nucleus i) achieved at the first stage of the experiment is ~ 5. Each additional unit step in X_{sum} value will result in event rarity increasing by 2–3 orders of magnitude. The value $X_{\text{sum}} \sim 7{-}8$ could be accessible experimentally with large acceptance detector at ion–ion interaction rate $\sim 10^8\ \text{s}^{-1}$. The nature of trigger photon (direct photons or photon from unstable particle decay (mostly from π^0)) is not important for the study because kinematical limits for photons and pions are approximately the same. Pion, kaon, or ϕ-meson trigger is also possible from physical point of view; possibility of practical realization should be discussed.

2. SPECIFIC FEATURES OF THE PROPOSED PROGRAM

Proposed trigger is only the tool to move us into phase diagram domain not studied yet. They need to realize wide experimental program of the study of dense baryonic system which is expected to be produced in the selected events. Each signature of dense cold matter should be checked experimentally and the total experimental program can be as wide as existing program for high temperature plasma study (RHIC, LHC, FAIR). A part of proposed experimental program is brifly mentioned below.

Clusterization. One of the expected consequences of the proposed event selection is the baryon's clusterization in momentum space in the final state. Well, refer below to phase space region where clusterization is expected as B2R3(recoil baryon rich bubble region). B2R3 position in momentum space is model-dependent. In quasi-binary model of flucton–flucton collision cluster momentum $P_c \sim P_{f1} + P_{f2} - P_{\rm trig}$.

In the model where one of the partons (e.g., quark) caries most of the flucton's momentum and trigger particle is produced as a result of hard interaction of these partons, $P_c \sim 0$ (in c.m.s.). In both cases (sure other models are possible, but we restrict our consideration with these ones) it is expected that B2R3 will be in midrapidities range; difference is in transverse momentum of the cluster. One can expect for baryons involved in the selected flucton–flucton interactions essentially more narrow relative momentum distribution in the final state than that for other ion–ion interaction participants. For a colliding system heavier than HeHe (e.g., CC), one can expect a bend in nucleon relative momentum spectrum. This bend is separating baryon pairs participating in dense and cold baryon system from other pairs. Spectators of colliding nuclei (those which clusterization is trivial) should be excluded from analysis. Thus to see the expected clusterization effect one should identify and measure baryon momenta at $y \sim 0$ and P_t beween 0 and $P_{\rm trig}$ with accuracy of the order of (or better than) typical Fermi momentum $\delta p \sim P_F$.

Femtoscopy. One can expect also a clusterization of baryons involved in selected flucton–flucton interactions in coordinate space and increase of cluster throw-out time in comparison with throw-out time of particles which are not in (the same) cluster. These predictions could be experimentally tested using correlation method (femtoscopy). Femtoscopy method, is based on the pair correlation function analysis at small relative momenta for different particle types [6]. Correlation functions can give information about size and possible form of source. The method is widely used in heavy-ion collisions.

Dividing secondary baryons into groups: participants of dense cluster formed in flucton–flucton interaction (N_c) and other participants (N_p) (spectators are not in consideration), one can expect hierarchy of sizes $r(N_{c1}, N_{c2}) < r(N_p, N_p) < r(N_c, N_p)$. Such measurements are needed to control the density and lifetime of the baryonic system.

Dense fermions rich system should cause a decrease of average distances between not identical baryons in comparison with identical ones, which is an interesting effect itself (see also article c). Secondary particles momentum space region where correlations are proposed to be studied is B2R3. $pp(np)$ correlations should be measured at relative momenta $q < 0.2$ GeV/c with resolution $dq \ll q$.

Isosymmetrization. If dense fermions rich system is created and selected with trigger (event selection) and this fact is ultimate (articles a, b), one can proceed with its properties study. All degrees of freedom in such a system which populating is not much energy consuming, should be brought into play. Therefore a list of broken symmetries should tend to restore. In particular, cross section ratios of particles production, which are components of one isomultiplet, should be near to unit [7]. This conclusion is trivial for isosymmetric nuclei collision and trigger, but becomes nontrivial for $^3\mathrm{He} + {}^3\mathrm{He}$ collisions and(or) asymmetric trigger (e.g., charged pion or kaon). The proposed measurements are p/n, π^+/π^- ratios for particles produced in selected flucton–flucton interactions within B2R3 (and for particles outside this kinematical region as the reference measurement). While yield ratios measurement for charged pions is a routine task for tracking detector, n/p ratio measurement needs special efforts. But ratios measurement of nucleons seems to be more informative. The «background» measurements of isosymmetric nuclei with isosymmetric trigger are needed to increase the measurement precision of isosymmetrization effects and to decrease systematical errors. Also at high secondaries multiplicity isosymmetrization is trivial therefore total multiplicity should be controlled.

Strangeness. Another broken symmetry ($SU(3)$) also should tend to restore in high baryon density conditions. This could cause the equalization of probabilities to produce different components of baryon octet. Since a strange-baryon (e.g., Λ baryon) production must be accompanied by production of additional kaons (strangeness conservation), it will result in noticeable increase of produced mass in the process with free energy shortage. At colliding nuclei energies of several GeV/nucleon, the energy shortage could be regulated by varying of minimal target mass — cumulative number [8]. By separating mass effects from other ones, strange baryon production within dense baryonic system would be more probable than that for not strange. Strangeness increase is also considered as one of the signatures of usual quark–gluon plasma.

The case when additional kaon makes cumulative number more than the sum of colliding nuclei mass is of special interest. In such a case the only visible way for Λ production is associative production with light pentaquarks, e.g., ($qqqqs$) or(and) dibaryons ($qqqqqqs$), in case the last one exists in the nature.

Vector mesons. An increased production of resonances and high-spin particles is expected in cumulative processes. In particular, the vector-to-scalar mesons ratio should increase with cumulative number increase (effect is predicted in [9]). An interesting effect can be seen due to free energy shortage in the process. Since kinematical restrictions become more important with the produced particles invariant mass increasing, the shape and width of peaks corresponding to wide resonances production (like ρ and Δ) are expected to be distorted with respect to PDG.

Exotic. When the possibilities of satisfying the requirements of Pauli principle using known degrees of freedom are exhausted, then the dense baryon reach system has to find new forms of existence. The role of exotic + states is expected to be increased in comparison to usual reactions in dense fermionic medium conditions. In particular, diquark medium will help in dibaryonic resonances production. Exotic states produced in these processes cannot be too heavy due to kinematical limits. Light (below the threshold with pions production) pentaquarks like ($qqqqs$) or(and) dibaryons like ($qqqqqqs$) will probably decay into nucleons and photons. Existing limits of exotics production are to several orders of magnitude higher than cross section of our proposed trigger hence there is no experimental exclusion for the exotics discussed in the subsection.

3. CONCLUDING REMARKS

The proposed program is partly realized or has status «in progress» within FLINT experimental program at ITEP [5]. The whole program can be realized at future facilities FAIR (SIS100) and(or) NICA (Nuclotron M). The author would like to thank his colleagues and collaborators from ITEP FLINT, NICA MPD, and FAIR CBM for helpful discussions on related subjects. This work was done with financial support by Federal Agency of Russia for Atomic Energy (Rosatom) and RFBR under grants № 08-02-00676-a, 08-02-92496-NCNIL-a, 10-02-00340-a,10-02-93111-NCNIL-a, 10-02-93118-NCNIL-a.

REFERENCES

1. *Alford M. et al.* // Rev. Mod. Phys. 2008. V. 80. P. 1455.
2. *Baldin A. M. et al.* // Sov. J. Nucl. Phys. 1973. V. 18. P. 79.
3. *Blohintsev D. I.* // Sov. J. Exp. & Theor. Phys. 1958. V. 6. P. 995.
4. *Seibert D.* // Phys. Rev. Lett. 1989. V. 63. P. 136.
5. *Alekseev I. G. et al.* // Phys. At. Nucl. 2008. V. 71. P. 1848.
6. *Kopylov G. I., Podgoretsky M. I.* // Yad. Fiz. 1972. V. 15. P. 392.
7. *Vorobiev L. S. et al.* // Yad. Fiz. 1996. V. 59. P. 694.
8. *Stavinskiy V. S.* JINR Commun. P2-80-767. Dubna, 1980.
9. *Baldin A. M., Gerasimov S. B.* JINR Commun. E2-11804. Dubna, 1978.