On possibility to observe chiral phase transition in separate fragments of dense baryon matter

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Density fluctuations of intranuclear matter suffering collisions with projectile particles are capable to turn into multiquark clusters with chiral symmetry restored. Theoretical analysis of these processes requires an additional taking account of finite size effects in the region of the chiral phase transition. From the experimental point of view, this method of observation of the chiral phase transition has its inherent advantages due to a relatively moderate number of secondary particles to be registered.

1. INTRODUCTION

Studies of the two- and three-nucleon short range correlations [1] afford us an opportunity to use the dense few-nucleon correlated systems of this type (SRC) as targets, which correspond to small fragments of nuclear matter in the dynamically broken chiral symmetry states. Collisions of SRC with bombarding particles can initiate the chiral phase transition ending in the creation of multibaryon (MB). Thus, its observation would be a direct evidence of the chiral condensate disappearance in the interaction area. Separation of a MB masses from the secondary particle background is possible, if the excitation energy of MB is small enough. We suggest to use the cumulative particle as a trigger for registration of MB decay products, since its appearance is a signature of "deep cooling" of the MB system.

2. KINEMATIC ANALYSIS OF MB PRODUCTION IN CUMULATIVE PROCESSES

Let us consider a cumulative particle, e.g. π-meson, outgoing under angle θ with respect to momentum $\mathbf{p}_0$ of the projectile proton. The law of conservation of energy-momentum

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gives:

$$E_p + M = E_\pi + (p_*^2 + M_*^2)^{1/2}, \tag{1}$$

where M is a value of mass of SRC, undergoing the collision, M_* is a value of mass of a total system in the final state aside from the cumulative meson, $\mathbf{p}_*$ is momentum of the system,

$$p_* = (p_\pi^2 - 2p_\pi \cos\theta + p_0^2)^{1/2}.$$

Relation (1) may be considered as a function

$$M_* = M_*(M), \tag{2}$$

since all the values it contains are known from the cumulative experiment arrangement. We use of $M_*(M)$ for estimation of production possibility of $(n+1)$-baryon from n-nucleon SRC in the cumulative process of this type. An interesting property of function (2), merely mathematical one, is its ability to demonstrate the inhibition of the process for values of M large enough. Therefore, the possibility of production is estimated at the minimal mass m_n of n-nucleon SRC. As is known, SRC have a continuous mass spectrum calculated at least for $2N$ and $3N$ SRC. In particular, $2N$ SRC dominate the nuclear wave function at $k_{\min} \geq$ 300 MeV [1]. Relying on this, and taking into account an approximate proportionality of SRC masses to their baryon numbers, n, we accept

$$m_n \geq n,$$

where n is taken in GeV/c^2 units. MB masses, M_n, are estimated here in the quark bag model framework [2]: $M_3 = 3.62$, $\qquad M_4 = 4.76$, $\qquad M_5 = 6.07$ GeV/c^2. The criterion of possibility of the transition n-nucleon SRC to $(n+1)$-MB is

$$M_* \geq M_{n+1}.$$

Excitation spectrum of MB may reach values up to $E_{\text{ex}} = (M_* - M_{n+1})c^2$.

In Tables 1 and 2 estimations of possible yield of MB in cumulative π-meson production from nuclear targets Be and Al for two angles $\theta = 119°$ and $\theta = 97°$ are shown. The first column encloses momenta of the registered cumulative mesons, the fourth column contains baryon numbers of resonances which production are possible. The invariant cross-sections, $f = A^{-1}E d\sigma/d^3p$, for corresponding cumulative processes in mb·GeV$^{-2} \cdot c^3$·sr^{-1}· per nucleon [3] are shown in the second and third columns. Here they only represent an upper

bound for production cross-section of corresponding MB. One can see that values of θ and momentum of cumulative π-meson should be maximal for observation of the chiral phase transition in fragments of nuclear matter large enough.

In the parton model framework, high momentum cumulative mesons hold SRC quarks, which had large momenta pointed at the opposite direction as compared to momentum of projectile. Escape of these quarks from the system results in deep cooling of MB. This circumstance is favorable for discrimination of MB mass from the secondary particle background, which production is stimulated by increasing phase volume of the system.

3. FINITE SIZE EFFECTS

Research of chiral phase transition in small fragments of nuclear matter calls for a careful analysis of finite size effects stipulated by shell structure of quark bag, its surface energy, and Coulomb forces at short distances. Quark bag models predict nearly constant value of M_n/n for $n = 3$, 4, 5, corresponding to its bulk value (see, e.g., [2, 4, 5]). A slight, on 2–3% accuracy level, deviation from this value is caused by shell effects. In accordance with [4], surface tension coefficient for quark bag is about $(70 \text{ MeV})^3 \approx 8.8 \text{ MeV}/\text{fm}^2$. This gives for M_3 a correction about 2–3% for radius of tribaryon estimated as radius of flucton, $R \approx 0.8 \text{ fm}$ [2]. Independent consideration of Casimir energy, which includes the contribution of surface tension energy, gives the same estimation within the bounds of the chiral bag model [6]. A compound (n+1)-baryon system, consisting of the projectile proton and n-baryon SRC, can acquire an additional mass increase due to the Coulomb repulsion of the charge of the projectile and a charge of SRC. This gives a correction to M_3 on 0.13 % level or less. Thus, our estimations indicate that the finite size effects have no sufficient effect on the chiral phase transition occurrence.

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Table 1. An upper bounds for production cross-section of MB by 10.14 GeV protons irradiating nuclear targets of Be and Al. Cumulative pion is registered at laboratory angle $\theta = 119°$.

P_π, ГэВ/c	f, Be	f, Al	B
0.873	1.65×10^{-4}	4.61×10^{-4}	
0.979	2.47×10^{-5}	8.62×10^{-5}	3
1.077	3.72×10^{-6}	1.72×10^{-5}	3
1.293	6.23×10^{-8}	3.56×10^{-7}	3
1.402	8.21×10^{-9}	5.32×10^{-8}	3, 4
1.512	7.94×10^{-10}	4.95×10^{-9}	3, 4
1.619		1.03×10^{-9}	3, 4, 5

Table 2. The same experiment as in Table I but $\theta = 97°$.

P_π, ГэВ/c	f, Be	f, Al	B
1.192	1.95×10^{-5}	7.09×10^{-5}	
1.370	1.20×10^{-6}	6.34×10^{-6}	3
1.523	9.36×10^{-8}	6.37×10^{-7}	3
1.635	1.40×10^{-8}	1.26×10^{-7}	3, 4
1.790	1.21×10^{-9}	1.42×10^{-8}	3, 4