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КОМПЬЮТЕРНЫЕ ТЕХНОЛОГИИ В ФИЗИКЕ

# ON DIBARYON PRODUCTION IN $D + D \to X + D$ REACTION

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Analysis of experimental data taken at the JINR synchrophasotron has revealed that quasiresonant peaks (dibaryons) observed in the two-proton effective mass distribution from reactions $np \to pp\pi^-m\pi^0$ and $np \to pp\pi^+\pi^-\pi^-m\pi^0$, $m = 0, 1$, were also detected in $D + D \to X + D$ reaction by other experimental group. Besides, the data on $D + D \to X + D$ hint at a possibility of existence of dibaryons with $I = 0$ and masses in the vicinity of 2.4 and 2.5 GeV, which were predicted in the framework of the MIT 6-q bag model.

Анализ экспериментальных данных, полученных на синхрофазотроне ОИЯИ, показал, что квазирезонансные пики (дибарионы), наблюдавшиеся в двухпротонных спектрах эффективных масс из реакций $np \to pp\pi^-m\pi^0$ и $np \to pp\pi^+\pi^-\pi^-m\pi^0$, $m = 0, 1$, были также зарегистрированы в реакции $D + D \to X + D$ другой экспериментальной группой. Кроме того, данные по $D + D \to X + D$ указывают на возможность существования дибарионов с $I = 0$ и массами в окрестности 2,4 и 2,5 ГэВ, которые были предсказаны в рамках 6-q MIT мешка.

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## INTRODUCTION

Recently, a proposal of QCD investigation at high density and low temperature complementary to the high-energy heavy nuclear collisions was suggested [1]. The proposal is based on the fact that a large number of nucleons in the interaction region is not necessary for phase transition to occur, and only a change of the vacuum state should be initiated in some experimental environment. Detection of two- and three-nucleon short range correlations (SRC) [2] affords 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 a multibaryon (MB). Thus, the observation of MB would be a direct evidence of the chiral condensate disappearance and the chiral symmetry restoration in the interaction area. Separation of the MB mass from the secondary particle background is feasible if the MB decay width is narrow enough. That requires excitation energy of produced MB to be low. For this purpose, it is reasonable to select only those experimental events, in which the MB production is accompanied with a high momentum particle taking away an essential part of energy from the interaction region (cooling effect). In this paper, we focus on new developments in this direction outlined in [1] and put them in context with some of older experimental data taken at the JINR synchrophasotron [3–5].

Experiment [3] was designed for measurement of the cross sections of elastic $pp$, $ND$, and $DD$ scatterings at 8.9 GeV momentum of primary protons and deuterons. Particularly, three peaks were observed in the spectrum of missing masses of the reaction $D + D \to M_X + D$ at $t = -0.495$ GeV$^2$. Till now, the first of them, corresponding to the most heavy $M_X$, was estimated to cover the elastic $DD$ scattering; the second one was interpreted as a manifestation of the scattering of a projectile deuteron's nucleon by the target deuteron; in regard to the third peak, it was suggested to appear because of 1) a contribution of the constituent quark scattering, 2) a contribution of a 6-q bag, and 3) a kinematic manifestation of a baryon $N^*$ with a value of mass in the neighborhood of 1400 MeV. Recent analysis has revealed that the treatment of the first two peaks is definitely inconsistent (see below), and we devote the major portion of the article to it. The interpretations of the third peak promise detection of the $D \to$ 6-q bag phase transition, so that we begin with them.

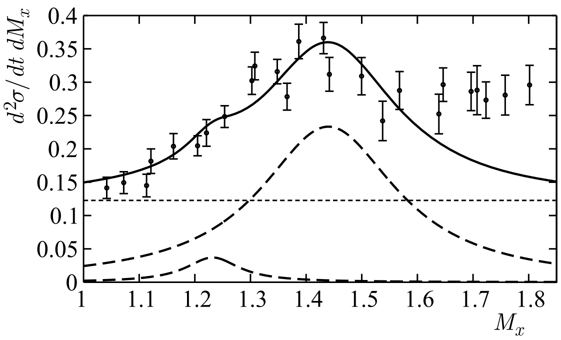
## 1. POSSIBLE TRANSITION $D \to$ 6-q BAG

In the Figure, an attempt to explain the experimental data in the range of the third peak by the sum of contributions of reactions $N+D \to X+D$, where $X = N+\pi$, $\Delta(1232)$, $N(1440)$, and $N(1520)$ is shown. Data on baryon resonances are taken from [6]; a contribution of the reaction with $X = N + \pi$ is approximated by the straight line; weights of each line are found to obtain the best description of the data, according to the global optimization procedure. Kinematics reads

$$M_X^2 = M_N^2 + t + \frac{1}{2}\,\frac{\sqrt{P_1^2 + 4M_N^2}\,t + P_1\sqrt{t(-4M_D^2 + t)}\cos\theta}{M_D}, \qquad (1)$$

where $P_1$ is momentum of the primary deuteron, $P_1 = 8.9$, and $M_N = 0.94$, $M_D = 1.8756$ GeV. It is seen that Roper's resonance plays here the most important role, and $N(1520)$ is invisible. Such a description explains a general structure of the third peak, but it does not describe a fine structure at $M_X = 1250{-}1450$ MeV.

The elastic scattering of a constituent quark by the target deutron may be considered in the framework of a model, in which values of momentum and mass of the projectile quark



The experimental data in the range of the third peak and their explanation in the framework of the $N + D \to X + D$ model are taken in the form

$$P_q = xP_1, \quad M_q = xM_D,$$

where $x$ is determined from kinematics of the reaction. The model gives

$$M_q = \frac{-M_D^2 t}{E_1 t + P_1 \sqrt{t(-4M_D^2 + t)}\cos\theta} = 0.311 \text{ GeV}$$

for $\theta = 65°$, in good agreement with the constituent quark models; see, e.g., [7], in which $M_q = 0.318$ GeV. Thus, a contribution of this process to the third peak is also admissible.

For the dibaryon production in the reaction $D + D \to 2B + D$, the isospin conservation leads to $I_{2B} = 0$. Kinematics,

$$M_X^2 = M_D^2 + t + \frac{E_1 t + P_1 \sqrt{t(-4M_D^2 + t)}\cos\theta}{M_D}, \tag{2}$$

states that the fine structure near $\theta = 65°$ is described if one supposes existence of two dibaryons at $M_{2B} \approx 2.4$ and 2.5 GeV. Dibaryons with close masses were predicted in the framework of the MIT bag model in [8]. Similar masses were found in $pp\pi^+$ system in [5]. Therefore, it is plausible to expect that these hypothetic dibaryons decay into two nucleons and one pion.

## 2. DIBARYONS WITH AN EQUIDISTANT MASS SPECTRUM

In [3], the angle between the projectile and the recoil deuteron was a measurable value. Estimations of the first two peaks' form revealed that they are approximated much better by the Gauss distribution than by the Breit–Wigner function. This allows one to conclude that the experimental errors are dominant in the elastic scattering peaks' form, and that an occurrence of resonances is hardly possible in the region. The Gaussian two-peak approximation results in $\cos\theta_1 = 0.2154$ and $\cos\theta_2 = 0.2539$ for the location of the first two peaks' maxima.

It was very unexpected to find that elastic $DD$ scattering gives the angle distribution with a maximum at 0.2272, i.e., between $\cos\theta_1$ and $\cos\theta_2$, see (2) for $M_X = M_D$. Similarly, elastic $ND$ scattering described by (1) with $M_X = M_N$ has a maximum at 0.2661, clearly shifted from the second peak location. Thus, the explanation of the first two peaks by means of contributions of the elastic $DD$ and $ND$ scatterings fails and their origin remains unclear. At first glance, the discrepancy may be attributed to systematic errors committed in the experiment, but a subsequent calculations found out that another astonishing explanation is more plausible.

In fact, the Gauss distribution can also arise from superposition of many resonances observed. To explain positions of the first two peaks, different models have been tried out. The models were based on the fact that only the recoil deuteron was unambiguously identified in [3], but masses of all other participants were unknown. Therefore, any transitions $X+Y \to Z + D$ are allowed to be taken into account. For example, the scattering $X + D$ to $D + D$ explains the first peak location if to assign to $X$ a value of mass of about 1913 MeV, which turns out to be close to $(1916 \pm 2)$ MeV, observed in a $pp$ dibaryon spectrum by Yu. A. Troyan [4]. Analysis of other models ($D + D \to X + D$, $D + X \to D + D$,

$D + X \to X + D$, $X + X \to X + D$, $X + X \to Y + D$, $X + D \to Y + D$) showed that almost each dibaryon observed in [4] can give a contribution to the first two peaks observed in [3], under the assumption that masses of dibaryons detected in the $np$ system are 1 MeV less than the corresponding masses in the $pp$ system.

This finding brought us to scrutinize the data on $pp$-dibaryon production too. In [4], the dibaryons were registered as quasiresonant peaks in the two-proton effective mass distribution from reactions $np \to pp\pi^- m\pi^0$ and $np \to pp\pi^+\pi^-\pi^- m\pi^0$, $m = 0, 1$. Thus, deep cooling of the interaction region was achieved here without a high-energy secondary particle, by means of sufficient number of secondary pions. Also, in contrast to [3], the dibaryon production was realized in this case by compression of two separate nucleons, not a nucleus. With the assumption that some of dibaryons were unrecognized in the experiments [4], it is possible to approximate the $pp$-dibaryon mass spectrum within rather small, at 1–2 MeV level, experimental errors by the formula

$$M_n = M_{NN} + 10.08m, \tag{3}$$

where $m = 0, 1, 2, \ldots, 40$, all values are taken in MeV, $M_{NN}$ is equal to the value of mass of two protons. The quality of this assumption is seen, e.g., from the fact that only four dibaryons might be unrecognized in [4] among the first 14 ones predicted by (3).

To test the suggestion of similarity of $pp$- and $np$-dibaryon mass spectrum, we accepted relation (3) for $np$ dibaryons too, only changing $M_{NN}$ with the deuteron value of mass. Using kinematics of the $X + D \to Y + D$ reaction,

$$M_Y^2 = M_X^2 + t + M_X P_1 \frac{\sqrt{t(-4M_D^2 + t)}}{M_D^2} \cos\theta + \frac{M_X E_1 t}{M_D^2},$$

one can make sure that each of dibaryons described by (3) in the range from 1886 to 2198 MeV can contribute, within the accuracy of observation, to the first or second peaks found in [3]. Thus, new dibaryons predicted by the equidistant spectrum (3) taken as an assumption on basis of [4] are also confirmed by the data [3]. Moreover, quality of description definitely improves, since no dibaryon mass calculated using (3) is now lost in the description of the data from [3].

## CONCLUSION

Consideration of the data on the hard deuteron–deuteron scattering [3] meets, to some degree, the expectation to observe the transition of nucleon matter into weakly excited quark–gluon plasma using the method of deep cooling, which allows one to recognize quasiresonant peaks in the reaction cross section. Meanwhile, a further verification of this preliminary conclusion is necessary. As concerns the dibaryons, obeying the equidistant spectrum regularity observed in [3, 4], they can hardly be interpreted in the framework of the 6-q bag model. Maybe, the most realistic description is to assign them to production of pion pairs strongly bound to compressed nucleon matter (the pion Bose condensate) [9].

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