Search for Supernarrow Dibaryons in $pd$ Interactions

L.V. Fil’kov1, V.L. Kashevarov1, E.S. Konobeevski2, M.V. Mordovskoy2, S.I. Potashev2 and V.M. Skorkin2

1Lebedev Physical Institute, Moscow, Russia
2Institute for Nuclear Research, Moscow, Russia

(November 4, 2021)

The reaction $pd \rightarrow pX$ at 305 MeV is studied with the aim to search for supernarrow dibaryons, the decay of which into two nucleons is forbidden by the Pauli exclusion principle. The experiment was carried out at the Moscow Meson Factory using the spectrometer TAMS, which detected the scattered proton and another charged particle (either $p$ or $d$) from the decay of $X$. Narrow peaks in missing mass spectra have been observed at 1905 and 1924 MeV. Comparison of the obtained data with theoretical predictions leads to the conclusion that the peak found at 1905 MeV most likely corresponds to a supernarrow dibaryon with the isotopic spin equal to 1. The possible origin of the peak at 1924 MeV is also discussed.

PACS number(s): 14.20.Pt, 12.39.Mk, 13.75.Cs

I. INTRODUCTION

The possibility of the existence of multiquark states was predicted by QCD inspired models [1,2]. These works initiated a lot of experimental searches for six-quark states (dibaryons). Usually one looked for dibaryons in the NN channel. In the present work we will consider supernarrow dibaryons (SNDs), the decay of which into two nucleons is forbidden by the Pauli exclusion principle [3–8]. In the NN channel such dibaryon states correspond to even singlets and odd triplets at the isotopic spin $T = 0$, and odd singlets and even triplets at $T = 1$. These dibaryons with the mass $M < 2m_N + m_\pi$ ($m_N(m_\pi)$ is the nucleon (pion) mass) can decay into two nucleons, mainly emitting a photon. This is a new class of dibaryons with decay widths $\leq 1$keV. The contribution of such dibaryons to strong interaction processes of hadrons is small. However, their contribution to electromagnetic processes on light nuclei may exceed the cross section for the process under study out of range of the dibaryon resonance by several orders of magnitude [5,7,8]. The experimental discovery of such states would have important consequences for particle and nuclear physics.

In the frame of the MIT bag model, Mulders et al. [2] calculated the masses of different dibaryons, in particular, NN-decoupled dibaryons. They predicted dibaryons $D(T = 0; J^P = 0^-, 1^-, 2^-; M = 2.11$ GeV) and $D(1; 1^-; 2.2$ GeV) corresponding to the forbidden NN states $^{13}P_J$ and $^{31}P_1$. However, the dibaryon masses obtained exceed the pion production threshold. Therefore, these dibaryons can decay into the $\pi NN$ channel. The possibility of the existence of dibaryons with masses $M < 2m_N + m_\pi$ was discussed by Kondratyuk et al. [8] in the model of stretched rotating bags, taking account of spin-orbital quark interactions. In the frame of the chiral soliton model, Kopeliovich [10] predicted that the masses of $D(T = 1, J^P = 1^+)$ and $D(0, 2^+)$ dibaryons exceeded the two-nucleon mass by 60 and 90 MeV, respectively. These values are lower than the pion production threshold.

Unfortunately, all results obtained for the dibaryon masses are model dependent. Therefore, only an experiment could answer the question about the existence of SNDs and their masses.

In the work [1] the existence of a dibaryon, called $d'$, with quantum numbers $T = even$ and $J^P = 0^-$ which forbid its decay into two nucleons, and with the mass $M = 2.06$ GeV, and the decay width $\Gamma_{\pi NN} = 0.5$ MeV, has been postulated to explain the observed resonance-like behavior in the energy dependence of the pionic double charge exchange on nuclei at an energy below the $\Delta$-resonance. However, there is a more conventional interpretation of these data. It was shown [12] in the frame of the distorted-wave impulse approximation that such a peak arises naturally because of the pion propagation in the sequential process, in which pion double charge exchange occurs through two successive $\pi N$ charge exchange reactions on two neutrons.

In the work [13] dibaryons with exotic quantum numbers were searched for in the process $pp \rightarrow pp\gamma\gamma$. The experiment was performed with a proton beam from the JINR phasotron at the energy of 198 MeV. Two photons were detected in the energy range between 10 and 100 MeV. Some structure was observed in the photon energy spectrum, which was attributed to the exotic dibaryon with the mass $M \approx 1920$ MeV. The statistical significance of the effect is about 8$\sigma$. However, a big width (FWHM=31.3$\pm$5.0 MeV) of the observed structure was obtained, and an additional careful experimental study of this reaction is needed in order to understand the nature of this structure. It is necessary to measure the photon energy spectrum with a higher energy resolution and a higher statistical precision. Moreover, measurements at two different incident proton energies are needed to check whether the structure observed is a SND.
On the other hand, an analysis of the Uppsala proton-proton bremsstrahlung data looking for the presence of a dibaryon in the mass range from 1900 to 1960 MeV only gave the upper limits of 10 and 3 nb for the dibaryon production cross section at proton beam energies of 200 and 310 MeV, respectively. This result disagrees with the data [13].

Earlier we have carried out measurements of missing mass spectra in the reaction \(pd \rightarrow pX\) using a double-arm spectrometer at the Moscow Meson Factory. The narrow peak in the missing mass spectrum at 1905 MeV with a width equal to the experimental resolution of 7 MeV has been observed in this experiment.

As will be shown below, the nucleons and the deuteron from the decay of the dibaryons under consideration into \(\gamma NN\) and \(\gamma d\) have to be emitted in a narrow angular cone with respect to the direction of motion of the dibaryon. The size of this cone depends also on the quantum numbers of the dibaryon. So a detection of the scattered proton in coincidence with the proton (or the deuteron) from dibaryon decay at correlated angles gives a good possibility to separate the SNDs from the background and to determine their quantum numbers.

In the present paper we give a more detailed study of the reactions \(pd \rightarrow p + pX\) and \(pd \rightarrow p + dX\) (where \(X_1\) and \(X_2\) are undetected particles in this experiment) with the aim to search for SNDs at the Moscow Meson Factory using an improved facility. We will consider the following dibaryons: \(D(T=0, J^P=0^+)\), \(D(0,0^-)\), \(D(1,1^+)\), and \(D(1,1^-)\).

It is worth noting that the state \((T=1, J^P=1^-)\) corresponds to the states \(31P_1\) and \(33P_1\) in the NN channel. The former is forbidden and the latter is allowed for a two-nucleon state. In our work we will study the dibaryon \(D(1,1^-)\), a decay of which into two nucleons is forbidden by the Pauli principle (i.e. \(31P_1\) state).

The contents of the paper are the following. In Sec. II the decay widths of SNDs are given and the cross sections of these dibaryon production in the processes \(pd \rightarrow pD\) are calculated. A description of the experimental setup is in Sec. III. In Sec. IV the results of the measurements are presented. The results of a Monte Carlo calculation and an analysis of the experimental data obtained are presented in Sec. V. The main conclusions are given in Sec. VI.

II. CROSS SECTIONS OF THE SUPERNARROW DIBARYON PRODUCTION IN THE REACTION \(pd \rightarrow pD\)

In the process \(pd \rightarrow pD\), SNDs can be produced only if the nucleons in the deuteron overlap sufficiently, such that a six-quark state with deuteron quantum numbers can be formed. In this case, an interaction of a photon or a meson with this state can change its quantum numbers so that a metastable state is formed. Therefore, the probability of the production of such dibaryons is proportional to the probability \(\eta\) of the six-quark state existing in the deuteron.

The magnitude of \(\eta\) can be estimated from the deuteron form factor at large \(Q^2\) (see, for example, [13]). However, the values obtained depend strongly on the model of the form factor of the six-quark state over a broad region of \(Q^2\). Another way to estimate this parameter is to use the discrepancy between the theoretical and experimental values of the deuteron magnetic moment [17,18]. This method is free from the restrictions quoted above and gives \(\eta \leq 0.03\) [18]. We assume here that \(\eta\) and the probability of the full overlap of nucleons in the virtual singlet state \(31S_0\) are equal to 0.01.

Since the energy of nucleons, produced in the decay of the dibaryons under study with \(m < 2m_N + m_\pi\), is small, it may be expected that the main contribution to a two-nucleon system should come from \(13S_1\) (deuteron) and \(31S_0\) (virtual singlet) states. The results of calculations of the decay widths of the dibaryons into \(\gamma d\) and \(\gamma NN\) on the basis of such assumptions are listed in Table I.

As shown in [13] the main contribution to the dibaryon photoproduction from the deuteron is given by the one-pion exchange diagram. Therefore, we will describe the production of SNDs in the process \(pd \rightarrow pD\) using the one meson exchange diagram also.

The production of the isoscalar dibaryons \(D(0,0^+)\) and \(D(0,0^-)\) will be calculated with the help of the pole diagram with \(\omega\)-meson exchange between the incident proton and the deuteron. The vertices \(D(0,0^+) \rightarrow \omega d\) and \(D(0,0^-) \rightarrow \omega d\) can be written as

\[
\Gamma_{D(0,0^+) \rightarrow \omega d} = \frac{f_1}{M} \sqrt{\eta} \epsilon_{\mu \nu \lambda \sigma} G^{\mu \nu} \Phi_1^{\lambda \sigma},
\]

\[
\Gamma_{D(0,0^-) \rightarrow \omega d} = \frac{f_2}{M} \sqrt{\eta} G^{\mu \nu} \Phi_1^{\mu \nu},
\]

where \(G^{\mu \nu} = v_\mu r_\nu - r_\mu v_\nu, \Phi_1^{\mu \nu} = w_\mu p_\nu - p_\mu w_\nu\). Here \(v\) and \(w\) are the four-vectors of the deuteron and \(\omega\) meson polarization, \(r\) and \(p\) are their four-momenta.

As a result of the calculations we have
\[
\frac{d\sigma_{pd\rightarrow pD(0^+)}}{d\Omega} = \frac{f_1^2}{4\pi} F_0 R_{(+)},
\]

(3)

\[
\frac{d\sigma_{pd\rightarrow pD(0^-)}}{d\Omega} = \frac{1}{4\pi} F_0 R_{(-)},
\]

(4)

where

\[
F_0 = \frac{g_{2NN}^2}{4\pi} \frac{F}{(t-m_d^2)^2},
\]

\[
F = \frac{8}{3} \frac{p_d^2}{M^2} \frac{1}{m_d p_1 [(m_d + E_1)p_2 - p_1 E_2 \cos \theta]},
\]

\[
R_{(-)} = -\frac{1}{4} \{2t[(s-m_d^2-m_N^2)(s+t-M^2-m_N^2)+tm_d^2]
\]

\[
+ (M^2-m_d^2-t)^2(2m_N^2+t)},
\]

\[
R_{(+)} = R_{(-)} + tm_d^2(2m_N^2+t),
\]

\[
t = 2(m_N^2 - E_1 E_2 + p_1 p_2 \cos \theta),
\]

\[
E_1, p_1(E_2, p_2) \text{ are the energy and momentum of the initial (final) proton, } \theta \text{ is the angle of the scattered proton emission, } m_d \text{ is the deuteron mass, } g_{2NN}^2 \text{ is the constant of the } \omega N \text{ interaction}, f_1^2/4\pi \text{ are the coupling constants in the vertices } D(0,1^+) + \omega \rightarrow D(0,0^+) \text{ and } D(0,1^+) + \omega \rightarrow D(0,0^-), \text{ respectively, and } D(0,1^+) \text{ is the six-quark state with quantum numbers of the deuteron.}
\]

The isovector dibaryons \( D(1,1^+) \) and \( D(1,1^-) \) can be formed mainly as a result of pion exchange between the incident proton and the deuteron. The vertices \( D(1,1^+) \rightarrow \pi + d \) and \( D(1,1^-) \rightarrow \pi + d \) are written as

\[
\Gamma_{D(1,1^+)\rightarrow \pi d} = \frac{g_1}{M} \sqrt{\epsilon_{\mu\nu}\omega} G^{\mu\nu} \Phi_2^{\pi},
\]

(5)

\[
\Gamma_{D(1,1^-)\rightarrow \pi d} = \frac{g_2}{M} \sqrt{\epsilon_{\mu\nu}\omega} G^{\mu\nu} \Phi_3^{\pi},
\]

(6)

where \( \Phi_2^{\pi} = \epsilon_{1\mu}q_{1\nu} - \epsilon_{1\nu}q_{1\mu}, \Phi_3^{\pi} = \epsilon_{2\mu}q_{2\nu} - \epsilon_{2\nu}q_{2\mu}, \) and \( \epsilon_{1(2)} \) and \( q_{1(2)} \) are the four-vectors of polarization and four-momenta of the \( D(1,1^+) \) \( (D(1,1^-)) \) respectively.

The calculations yield the following expressions for the cross section of these dibaryon production

\[
\frac{d\sigma_{pd\rightarrow pD(1^+)}}{d\Omega} = \frac{g_1^2}{4\pi} F_1 [M^2 + m_d^2 - t]^2 - 4m_d^2 M^2],
\]

(7)

\[
\frac{d\sigma_{pd\rightarrow pD(1^-)}}{d\Omega} = \frac{1}{4\pi} g_2^2 F_1 [M^2 + m_d^2 - t]^2 + 2m_d^2 M^2],
\]

(8)

where

\[
F_1 = -\frac{1}{4} \frac{g_{2NN}^2}{4\pi} \frac{tF}{(t-m_d^2)^2},
\]

and \( g_{1,2}^2/(4\pi) \) are the coupling constants in the vertex for the transition of the six-quark state \( D(0,1^+) \) into the dibaryons under consideration via the pion exchange.

For a numerical calculation of the dibaryon contribution let us assume that \( g_{2NN}^2/4\pi = 14.6, g_{2NN}^2/4\pi = 19.2, \eta = 0.01 \). The constants \( g_{1,2}^2/4\pi \) and \( f_1^2/4\pi \) are unknown. They are strong interaction constants. In order not to overestimate the contributions of the dibaryons we put these constants equal to 1. The results of the calculation of the SND production cross sections in the process \( pd \rightarrow pD \) at the kinetic energy of the incident proton \( T_1 = E_1 - m = 305 \) MeV and the emission angle of the scattered proton \( \theta = 70^\circ \) as a function of the dibaryon mass \( M \) are shown in Fig. [1] Here the solid, dashed, dotted and dash-dotted lines correspond to \( D(0,0^+), D(0,0^-), D(1,1^+), \) and \( D(1,1^-) \) dibaryon production, respectively.

As indicated above, the SNDs decay mainly emitting a photon. Therefore, if we limit ourselves to the investigation of \( pd \) interactions with the photon in the final state, then the contribution of such dibaryons will essentially exceed the cross sections of the background processes. On the other hand, the special choice of the \( pd \rightarrow pX \) kinematics allows us to allocate the area where the contribution of the SNDs domnates, even without detection of the final photon.
III. EXPERIMENTAL SETUP

The reaction $p + d \to p + X$ was studied at the proton accelerator of the Moscow Meson Factory at 305 MeV. A proton beam with an average effective intensity $\sim 0.1$ nA bombarded alternatively CD$_2$ and $^{12}$C targets of 0.14 and 0.18 g/cm$^2$, respectively. The $pd$ reaction contribution was determined by subtracting the $^{12}$C spectrum from the CD$_2$ spectrum. The exposition time of the experiment using CD$_2$ as a target was 100 hours. This period consisted of two runs corresponding to two different kinematic conditions in order to avoid a systematic error. The charged particles produced in the reaction in question were detected at different correlated angles by the Two Arms Mass Spectrometer (TAMS).

Our layout is shown schematically in Fig. 2. The left movable spectrometer arm, which is a single telescope $\Delta E - \Delta E - E$, was used to measure the energy and the time of flight of the scattered proton at a fixed emission angle $\theta_L \equiv \theta$. A remote control drive allowed to place this arm at various angles between 65° and 85°. In the present experiment TAMS detected the scattered proton at the angle $\theta_L = 72.5°$ (and 70° in another run) in coincidence with the second charged particle (either $p$ or $d$) from the decay of the particle $X$ during 55 (and 45) hours.

The detection of the second charged particle in the right arm at angles close to the emission angle of particle $X$ with mass $M$ allows to suppress essentially the contribution of background processes and increase the relative contribution of a possible SND production. The right arm consisted of three telescopes which were located at $\theta_R = 33°$, 35° and 37°. These angles correspond to directions of the emission of the dibaryons with a certain mass.

Each telescope included two thin plastic scintillation $\Delta E$ detectors ($4 \times 4 \times 0.5$ cm$^3$) and one $E$ detector of thick plastic ($5 \times 5 \times 20$ cm$^3$, used in the right arm) or BGO crystal ($5 \times 5 \times 8$ cm$^3$, used in the left arm). Each detector was viewed by a PMT-143 phototube coupled to specially developed fast electronic modules. A trigger was generated by 4-fold coincidence of the two $\Delta E$ detector signals of the left arm combined with those of any telescope of the right arm. A time resolution better than 0.5 ns was achieved, which allowed to suppress essentially an accidental coincidence background. The scattered proton $E$ signals, selected in the coincidence, formed the energy spectrum and accordingly the missing mass spectrum. Each useful event including two time of flights and two energies were stored event by event and then analyzed off line.

The elastic $pd$ scattering was measured at various angles of the spectrometer arms. The proton energy spectra obtained were used to calibrate the spectrometer in the proton energy and, accordingly, in the missing mass. The missing mass resolution of the spectrometer was $\Delta M \approx 3$ MeV, the angular resolution was 1°.

IV. RESULTS OF THE MEASUREMENTS

The experimental missing mass spectra obtained with the deuterated polyethylene target are shown in Figs. 3(a,b,c). Each spectrum corresponds to a certain combination of outgoing angles of the scattered proton and the second charged particle. These combinations in Figs. 3(b,c) are consistent with the shift of the emission angle $\theta_R$ of the dibaryon with the given mass when the angle $\theta_L$ changes from 70° to 72.5°. As is evident from Figs. 3(a) and 3(b), a resonance-like behavior of the spectra is observed for the CD$_2$ target in two mass regions at 1905 ± 2 MeV and 1924 ± 2 MeV. On the other hand, the experiment with the carbon target resulted in a rather smooth spectra [13]. This smoothness is caused by an essential increase of the contribution of background reactions in the interaction of the proton with the carbon.

It is worth noting that the resonance structure at 1905 MeV is observed in both runs at $\theta_L = 70°$ and $\theta_L = 72.5°$ and at different setup modifications. This essentially decreases the possibility of a random origin of the observed structure. The results obtained at different $\theta_L$ were summed up to improve statistics.

The mass spectra obtained in Figs. 3(a,b,c) were interpolated by second order polynomials (for the background) plus Gaussians (for the peaks in Figs. 3(a) and 3(b)). Let us regard Fig. 3(b). In this case the interpolation gave $\chi^2/(n - 5) = 0.81$. We determine the number of standard deviations (SD) as

$$\frac{N_{eff}}{\sqrt{N_{eff} + N_b}},$$

where $N_{eff}$ is the number of events above the background curve and $N_b$ is the number of events below this curve. Taking 5 points for the peak at $M = 1905$ MeV, we have $65/\sqrt{185} = 4.8$ SD. That corresponds to the probability of statistic fluctuations $P$ equal to $2.7 \times 10^{-5}$ [20].

Using the same procedure for the peak at $M = 1924$ MeV in Fig. 3(a) results in 4.9 SD and $P = 1.6 \times 10^{-5}$. If, for the number of SD, we use the expression [21]
\[ \sum_{i=1}^{n=5} \frac{(N_{i1} - N_{i2})/\sigma_i}{\sqrt{\sum_{i=1}^{n=5} 1/\sigma_i^2}} \]

where \( N_{i1}, N_{i2}, \) and \( \sigma_i \) correspond, respectively, to total, background, and error bar data, then we obtain 4.2 S.D. for the peak at \( M = 1905 \text{ MeV} \) and 4.4 S.D. for the peak at \( M = 1924 \text{ MeV} \).

The widths of both observed peaks correspond to the experimental resolution (3 MeV).

The peak at 1924 MeV was obtained only for one spectrum close to the upper limit of the missing mass. In the other cases this mass position was beyond the range of measurement. Therefore, in the present work we analyze in more detail the peak at 1905 MeV only.

The experimental missing mass spectra in the range of 1872–1914 MeV, after subtracting the carbon contributions, are shown in Figs. 3(a,b,c).

As seen from Figs. 3 and 4, the resonance behaviour of the cross section exhibits itself in a limited angular region.

V. ANALYSIS OF THE EXPERIMENTAL DATA

If the observed structure at \( M = 1905 \text{ MeV} \) corresponds to a dibaryon decaying mainly into two nucleons, then the expected angular cone size of emitted nucleons would be about 50°. Moreover, the angular distributions of the emitted nucleons are expected to be very smooth in the angular region under consideration. Thus, even assuming that the dibaryon production cross section is equal to that of elastic scattering \( (40 \, \mu \text{b}/\text{sr}) \) its contribution to the missing mass spectra in Figs. 3(a,b,c) would be nearly the same and would not exceed 1–2 events. Hence, the peaks found are hardly interpreted as a manifestation of the formation and decay of such states.

It was shown in [3] that the decay of the SND into \( \gamma N N \) had to be characterized in the rest frame by a narrow peak near the maximum photon energy in the probability distribution of the dibaryon decay over an emitted photon energy. It leads to an essential limitation of the outgoing nucleon angles. On the other hand, if such a dibaryon decays into \( \gamma d \), the emitted deuteron angles are limited by the following condition: \( \sin \theta_d \leq M_{p_d}^2/(m_d p_D) \), where \( p_D \) is the momentum (in the lab. syst.) of the dibaryon and \( p_d^2 \) is the momentum (in the c.m.s.) of the deuteron.

Using the Monte Carlo simulation we estimated the contribution of the SNDs with different quantum numbers and \( M=1905 \text{ MeV} \) to the mass spectra at various angles of the left and right arms of our setup. The production cross section and branching ratio of these states were taken according to the calculations presented in Sec. II and the proton beam current was assumed to be equal to 0.1 nA. The results obtained for different quantum numbers and decay modes of the dibaryons are listed in Table I.

This calculation showed that the angular cone of protons and deuterons emitted from a certain dibaryonic state can be rather narrow. The axis of this cone is lined up with the direction of the dibaryon emission. Therefore, placing the right spectrometer arm at the expected angle of the dibaryon emission we increase essentially the signal-to-background ratio.

Figs. 3(a,b) exhibit the angular distributions of charged particles (either \( p \) or \( d \)) from the decay of the dibaryon \( D(1,1^+) \) (Fig. 3(a)) and \( D(0,0^+) \) (Fig. 3(b)). The solid and dashed curves correspond to the emission angles of the scattered proton equal to 70° and 72.5°, respectively. The solid vertical lines show the location of the right arm detectors. These figures demonstrate the dependence of the angular distribution of the charged particles under consideration on the quantum numbers of the dibaryons.

In Figs. 3(a,b,c), the experimental spectra are compared with the predicted yields normalized to the maximum of the measured signal in Fig. 3(b). The solid and dashed curves in these figures correspond to the states with the isospin \( T=1 \) and \( T=0 \), respectively. The background is described by a second order polynomial.

As is seen from these figures and Table I, the ratios of the calculated yields to the given spectra are expected to be \( 0.3 : 1 : 0.7 \), if the state at 1905 MeV is interpreted as an isovector dibaryon \( (D(T=1, J^P=1^+) \text{ or } D(1,1^-)) \). This is in agreement with our experimental data within the errors. On the other hand, the signals from isoscalar dibaryons \( (D(0,0^+) \text{ or } D(0,0^-)) \) could be observed in Figs. 3(b,c) with the same probability. So, the dibaryon with \( M = 1905 \text{ MeV} \) is most likely to have the isospin equal to 1.

In order to estimate the dibaryon production cross section, we use normalization to the elastic \( pd \) scattering and then, comparing the theoretical predictions for the yields of one of the isovector dibaryons with the experimental data, find that the differential cross section of this dibaryon production is equal to \( 8 \pm 4 \, \mu \text{b}/\text{sr} \). That allows us to evaluate the product of unknown constants in Eqs. (7) and (8). If it is a dibaryon \( D(1,1^+) \), then \( \eta q_1^2/4\pi = (0.44 \pm 0.22) \times 10^{-2} \). But if it is a dibaryon \( D(1,1^-) \), we have \( \eta q_2^2/4\pi = (0.2 \pm 0.1) \times 10^{-2} \). The quantum numbers \( J^P \) of the observed state could be found, for example, by a search for such dibaryons in the processes of charged pion photoproduction by polarized photons from the deuteron [8].
As for the structure at 1924 MeV, the number of events in this peak exceeds the expected yields of the usual dibaryons (decaying into two nucleons) by almost two orders, even when produced with the rather big cross section of $40 \mu b/sr$. So this state, probably, could be a supernarrow dibaryon, too.

It should be noted that the reaction $pd \rightarrow NX$ was investigated in other works, too (see, for example, [22]). However, in contrast to the present work, the authors of these works did not study either the correlation between the parameters of the scattered nucleon and the second detected particle or the emission of the photon from the dibaryon decay. Therefore, in these works the relative contribution of the dibaryons under consideration was small, which hampered their observation.

VI. CONCLUSIONS

The following conclusions can be made.
1) As a result of the study of the reactions $pd \rightarrow ppX_1$ and $pd \rightarrow pdX_2$ two narrow peaks at 1905 and 1924 MeV with widths less than 3 MeV have been observed in the missing mass spectra.
2) The analysis of the angular distributions of the protons and the deuterons from decay of particle $X$, produced in the reaction $pd \rightarrow pX$, showed that the peak found at 1905 MeV can be explained as a manifestation of the SND with isospin equal to 1, the decay of which into two nucleons is forbidden by the Pauli exclusion principle.
3) Probably, the observed state at 1924 MeV can be interpreted as the SND, too.

ACKNOWLEDGMENTS

We thank T.E. Grigorieva and Yu.M. Burmistrov for their active participation in the creation of the setup and in the experimental runs.

[1] R.L. Jaffe, Phys.Rev.Lett. 38, 195 (1977); P.J.G. Mulders, A.T. Aerts, and J.J. de Swart, Phys.Rev.Lett. 40, 1543 (1978); D.B. Lichtenberg, E. Predazzi, D.H. Weingarten, and J.G. Wills, Phys.Rev. D18, 2569 (1978); V. Matveev and P. Sorba, Lett.Nuovo Cim. 20, 435 (1977).
[2] P.J.G. Mulders, A.T.M. Aerts, and J.J. de Swart, Phys. Rev. D 21, 2653 (1980).
[3] L.V. Fil’klov, Sov.Physics–Lebedev Inst. Reports No.11, 49 (1986); Sov.J.Nucl.Phys. 47, 437 (1988).
[4] D.M. Akhmedov et al., in Proceed. of the 8th Seminar ”Electromagnetic interactions of nuclei at low and medium energies”, Moscow, 1991, p.228 and p.252.
[5] D.M. Akhmedov and L.V. Fil’klov, Nucl.Phys. A544, 692 (1992).
[6] S.B. Gerasimov, S.N. Ershov, and A.S. Khrykin, Phys.At.Nucl. 58, 844 (1995).
[7] V.M. Alekseyev, S.N. Cherepnya, L.V. Fil’klov, and V.L. Kashevarov, Preprint of Lebedev Phys.Inst., No 52, 1996.
[8] V.M. Alekseyev, S.N. Cherepnya, L.V. Fil’klov, and V.L. Kashevarov, Kratk. Soobsch. Fiz., FIAN, No.1, 28 (1998); nucl-th/9812041.
[9] E.S. Konobeevski, M.V. Mordovskoy, S.I. Potashev, V.M. Skorkin, Sov.J.Nucl.Phys. 45, 776 (1987).
[10] B.V. Kopeliovich, Phys.At.Nucl. 58, 1237 (1995).
[11] B.V.Martem’yanov and M.G. Shchepkin, JETP Lett. 53, 139 (1991); R.Bilger, H.A.Clement, and M.G.Shchepkin, Phys.Rev.Lett. 71, 42 (1993); G.Wagner, L.Ya. Glozman, A.J. Buchmann, and A. Faessler, Nucl.Phys. A594, 263 (1995).
[12] M. Nuseirat, M.A.K. Lodhi, M.O. El-Ghossain, W.R. Gibbs, and W.B. Kaufmann, Phys.Rev. C58, 2292 (1998).
[13] A.S. Khrykin, in Proc. VII International Conference on Meson-Nucleon Physics and the Structure of the Nucleon, TRIUMF, Vancouver, 1997.
[14] H. Calén et al., Phys.Lett. B427, 248 (1998).
[15] L.V. Fil’klov, E.S. Konobeevski, M.V. Mordovskoy, S.I. Potashev, and V.M. Skorkin, Preprint of INR, No. 0923/96, 1996.
[16] V.V. Burov, S.M. Dorkin, V.K. Lukyanov, and A.I. Titov, Z.Phys. A306, 149 (1982); I.L. Grash and L.A. Kondratyuk, Sov.J.Nucl.Phys. 39, 198 (1984).
[17] Y.E. Kim and M. Orłowski, Phys.Lett. 140B, 275 (1984); R.K. Bhadury and Y. Negami, Phys.Lett. 152B, 35 (1985).
[18] L.A. Kondratyuk, M.I. Krivoruchenko, and M.G. Shchepkin, Sov.J.Nucl.Phys. 43, 899 (1986).
[19] E.S. Konobeevski, M.V. Mordovskoy, S.I. Potashev, V.M. Skorkin, S.K. Zuev, V.A. Simonov, and L.V. Fil’klov, Izv.Ross.Akad.Nauk., Ser. Fiz. 62, 2171 (1998).
[20] V.B. Vinogradov, M.E. Dohtmanov, V.G. Odinsov and A. Pazman, JINR preprint P1-7155, Dubna, 1973.
[21] B. Tatischeff, M.P. Combes-Comets, P. Courtat, R. Gacougnolle, Y. Le Bornec, E. Loireloup, F. Reide, and N. Willis, Phys.
Rev. C45, 2005 (1992).

[22] K.K. Set, in Proc. XII Int. Conf. on Few Body Problems in Physics, Vancouver, Canada, TRIUMF, TR-89-2, C35; L.C.
Bland, T.W. Bowyer, D.S. Carman, V. Derenchuk, D.L. Friesel, C.D. Goodman, A.H. Smith, J. Sowinski, S.E. Vigdor,
and G. Xu, IUCF Scientific and Technical Report, 1989-1990, p.14.
### TABLE I. Decay widths of the dibaryons $D(0,0^+)$, $D(0,0^-)$, $D(1,1^+)$ and $D(1,1^-)$ at various dibaryon masses $M$.

| $M$ (GeV) | $\Gamma_{\gamma d}$ (keV) | $\Gamma_{\gamma pn}$ (keV) | $\Gamma_t$ (keV) | $\Gamma_{\gamma d}$ (keV) | $\Gamma_{\gamma pn}$ (keV) | $\Gamma_t$ (keV) | $\Gamma_t \approx \Gamma_{\gamma NN}$ (eV) | $\Gamma_t \approx \Gamma_{\gamma NN}$ (eV) |
|-----------|----------------|----------------|----------------|----------------|----------------|----------------|----------------|----------------|
| 1.90      | 0.005           | 0.010          | 0.015          | 0.001          | 0.002          | 0.003          | 0.51           | 0.13           |
| 1.91      | 0.01            | 0.05           | 0.06           | 0.003          | 0.007          | 0.010          | 1.57           | 0.39           |
| 1.93      | 0.05            | 0.18           | 0.23           | 0.012          | 0.033          | 0.045          | 6.7            | 1.67           |
| 1.96      | 0.17            | 0.80           | 0.97           | 0.04           | 0.14           | 0.18           | 25.6           | 6.4            |
| 1.98      | 0.3             | 1.6            | 1.9            | 0.08           | 0.27           | 0.35           | 48             | 12             |
| 2.00      | 0.5             | 2.7            | 3.2            | 0.13           | 0.47           | 0.60           | 81             | 20             |
| 2.013     | 0.7             | 3.6            | 4.3            | 0.17           | 0.64           | 0.81           | 109            | 27             |

### TABLE II. The expected contributions of the SNDs with $M=1905$ MeV and different quantum numbers to the spectra of mass at various angles of the left and right arms of the setup.

| $\theta_L$ | $\theta_R$ |
|------------|------------|
| $\theta_L$ | $\theta_R$ | $70^\circ$ | $72.5^\circ$ |
| $T, J^P$   | $31^\circ$ | $33^\circ$ | $35^\circ$ | $37^\circ$ | $39^\circ$ | $31^\circ$ | $33^\circ$ | $35^\circ$ | $37^\circ$ | $39^\circ$ |
| $0,0^+$    | $\gamma pn$ | 5         | 8          | 8          | 7          | 5          | 9          | 10         | 10         | 6          | 3          |
| $0,0^+$    | $\gamma d$  | 0         | 38         | 17         | 32         | 0          | 4          | 23         | 34         | 0          | 0          |
| $0,0^-$    | $\gamma pn$ | 3         | 4          | 5          | 4          | 2          | 4          | 6          | 5          | 2          | 2          |
| $0,0^-$    | $\gamma d$  | 0         | 19         | 10         | 17         | 0          | 2          | 12         | 17         | 0          | 0          |
| $1,1^+$    | $\gamma pn$ | 14        | 55         | 81         | 50         | 12         | 47         | 97         | 79         | 23         | 5          |
| $1,1^-$    | $\gamma pn$ | 30        | 120        | 180        | 110        | 27         | 103        | 213        | 174        | 50         | 12         |
FIG. 1. The cross section of the supernarrow dibaryon production in the process \( pd \rightarrow pD \) at \( T_1 = 305 \) MeV and \( \theta = 70^\circ \) as a function of the dibaryon mass \( M \). The solid, dashed, dotted and dash-dotted lines correspond to the production of the dibaryons \( D(0, 0^+), D(0, 0^-), D(1, 1^+) \) and \( D(1, 1^-) \), respectively.
FIG. 2. The Two Arm Mass Spectrometer TAMS. $S_0$, $S_1$, $S_2$ and $S_3$ are start detectors; $F_0$, $F_1$, $F_2$ and $F_3$ are stop $\Delta E$ detectors; $D_0$ is a BGO detector; $D_1$, $D_2$ and $D_3$ are full absorption $E$ detectors.
FIG. 3. The missing mass spectra of the reaction on CD$_2$: (a) from the run data at $\theta_L = 70^\circ$ and $\theta_R = 33^\circ$, b) from the run data at $70^\circ$ and $35^\circ$, summarized with the run data at $72.5^\circ$ and $33^\circ$, c) from the run data at $70^\circ$ and $37^\circ$, summarized with the run data at $72.5^\circ$ and $35^\circ$. 
FIG. 4. The missing mass spectra of the reaction on deuteron. Areas marked by letters a), b), c) correspond to the same experimental conditions as in Fig.3. The solid and dashed curves are normalized theoretical predictions of the yields of the supernarrow dibaryon with isotopic spin equal to 1 and 0, respectively.
FIG. 5. The angular distribution of protons emitted by the dibaryon $D(1, 1^+)$ (a), and the sum of the angular distributions of protons and deuterons emitted by the dibaryon $D(0, 0^+)$ (b). The solid and dashed curves correspond to the scattered proton angles $70^\circ$ and $72.5^\circ$, respectively. The solid vertical lines show the location of the right arm detectors.