New theoretical and experimental indications of the existence of light dibaryons

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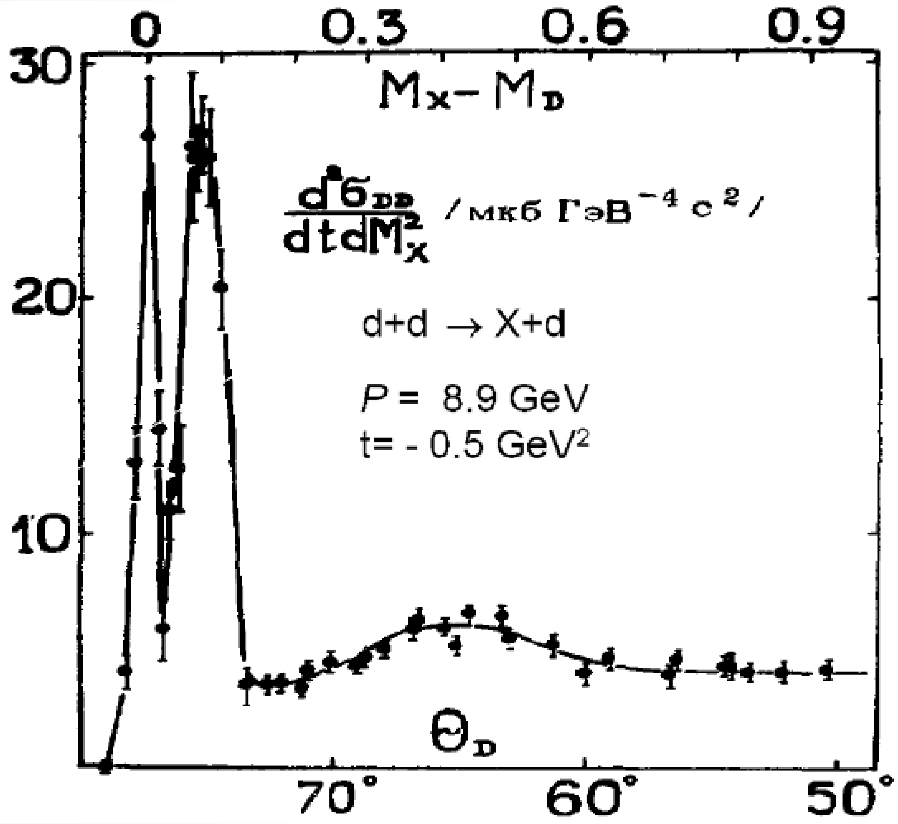
As an additional justification for the need to search for light dibaryons at the NICA SPD facility, which was formulated in the author's previous report on 31 August 2020, new theoretical and experimental indications in favor of their existence are given.

6 October 2020

Data from Baldin-Stavinskiy et al.*)

d+d → X+d

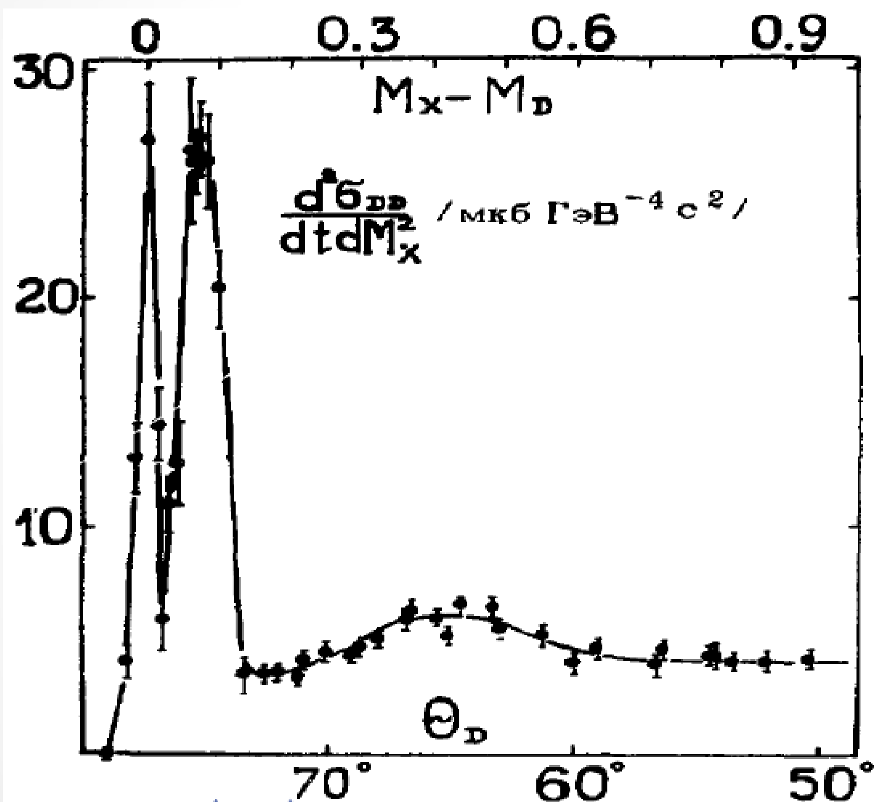
P = 8.9 GeV
t= - 0.5 GeV^2



Interpretation: the peak corresponding to angle of emission of the recoil deuteron equal to 77.45° is **elastic deuteron-deuteron scattering**. The emission angle at 75.35° is the processes of **quasi-free knockout of a nucleon from the incident deuteron by the recoil deuteron.**

*) A.M. Baldin et al. Differential Elastic Proton-Proton, Nucleon-Deuteron and Deuteron-Deuteron Scatterings at Big Transfer Momenta, JINR Communication, 1-12397, 1979

Could there be light dibaryons in the second peak region?



$\pi 0$ $2\pi 0$

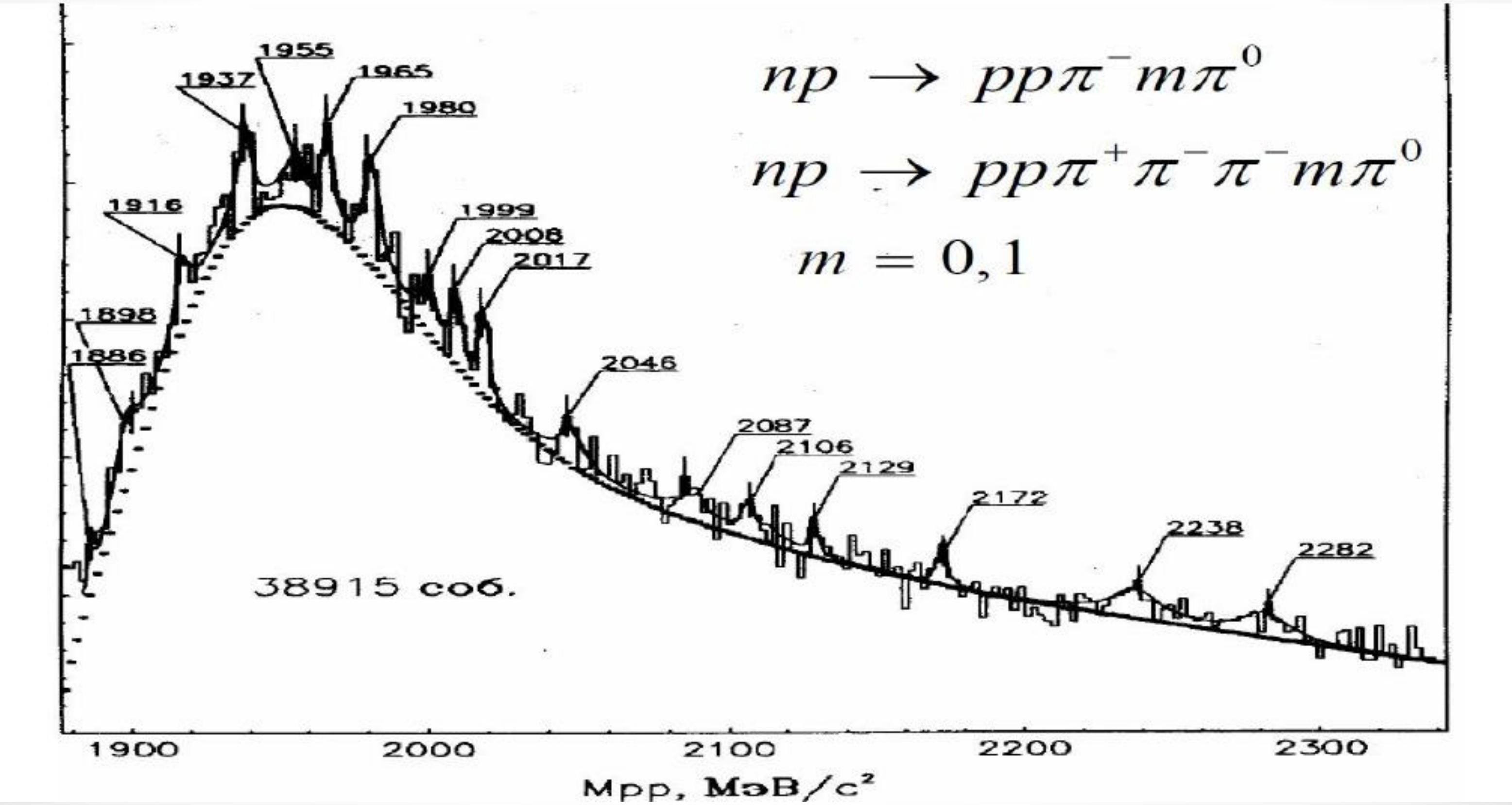
<u>Single scale</u> for all peaks as an invitation to ask the question.

Threshold for the production of $\pi 0$ corresponds to the emission angle of the recoil deuteron ≈74.4°, and for $2\pi 0$ ≈71.7°.

Dibaryons below pion production threshold?

An experiment with dibaryons below pion production threshold

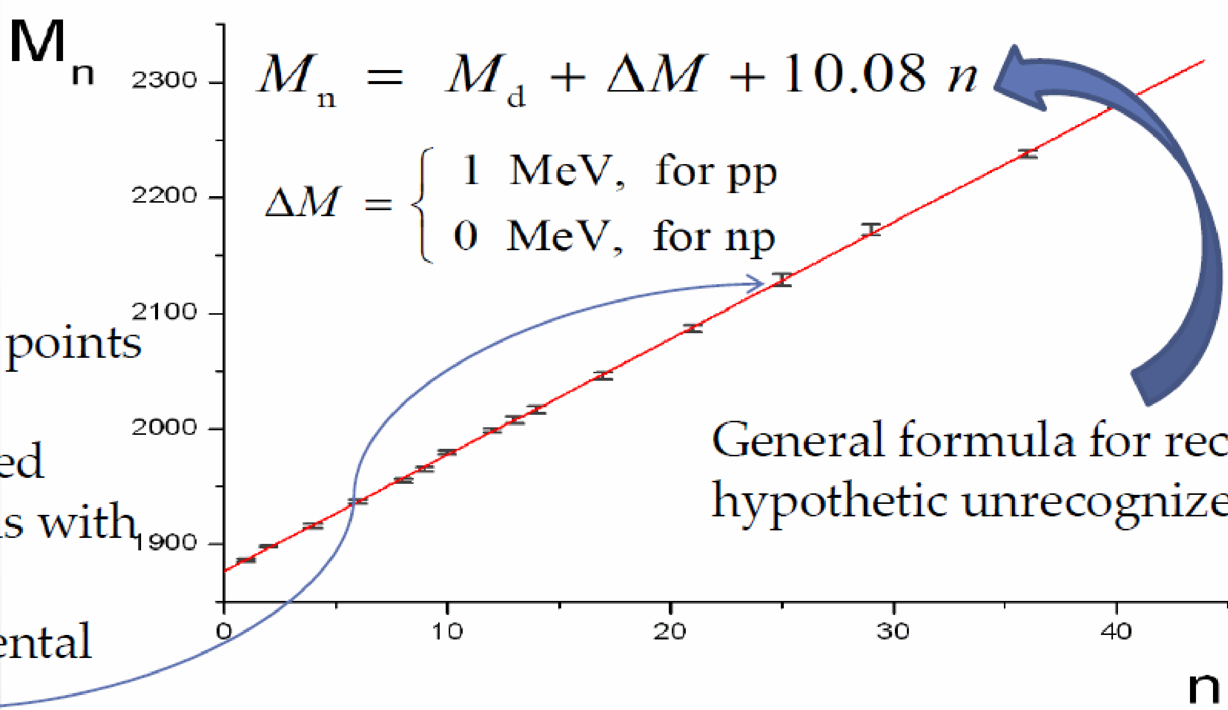
Yu.A. Troyan, Fiz. Elem. Chastits At. Yadra 24, 683 (1993)



Assumption:

Some dibaryons could be **unrecognized** due to a large background of extraneous events

Mass spectrum



Separate points are the recognized dibaryons with their experimental errors

General formula for recognized and hypothetic unrecognized dibaryons

A mysterious connection of Baldin-Stavinskiy's and Troyan's papers

Reaction	KAM	dibaryon masses
X+D→Y+D	1886→1966	1886, 1966
	1896→1977	1896, 1976
	1916→1998	1916, 1997
	1926→2009	1926, 2007
	1936→2019	1936, 2017
	1946→2030	1946, 2027
	1997→2084	1997, 2087
	2007→2095	2007, 2097
	2017→2105	2017, 2107
	2027→2116	2027, 2118
	2037→2127	2037, 2128
	2047→2137	2047, 2138
	2057→2148	2057, 2148
	2067→2158	2067, 2158
	2077→2169	2077, 2168
	2087→2179	2087, 2178
	2097→2190	2097, 2188
	2107→2200	2107, 2198

See details in B.F.K.,J. Pribish, Baldin ISHEPP XXII, 2014

The second peak

All dibaryons in the range from 1886 to 2198 MeV/c^2 may be met in deuteron

A mysterious connection of Baldin-Stavinskiy's and Troyan's papers

Reaction	KAM	dibaryon masses
X+D→Y+D	1916→1884	1916, 1886
	1926→1895	1926, 1896
	1936→1905	1936, 1906
	1946→1916	1946, 1916
	1956→1927	1956, 1926
	1966→1938	1966, 1936
	1976→1948	1976, 1946
	1986→1959	1986, 1956
	2047→2024	2047, 2027
	2057→2034	2057, 2037
	2067→2045	2067, 2047
	2077→2056	2077, 2057
	2087→2066	2087, 2067
	2097→2078	2097, 2077
	2107→2087	2107, 2087
	2118→2099	2118, 2097
	2128→2109	2128, 2107
	2138→2120	2138, 2118
	2148→2131	2148, 2128
	2158→2141	2158, 2138

Total correspondence Between Troyan's and Baldin's group data!

The first peak

KAM – kinematically allowed masses,
dibaryon masses – according to

$$M_n = M_d + 10.08\, n$$

Can this be considered as a confirmation of the existence of Troyan's dibaryons?

Violation of the quark counting rules and appearance of $q\bar{q}$ pairs on the shell

Participation of particles on the mass shell in hard processes leads to violation of 1/s scaling and an increase in their cross sections. This fact explains the **effect of attenuation of color transparency** *(Ralston and Pire, Phys. Rev. Lett. 61 (1988)1823;*

Brodsky and de Teramond, Phys. Rev. Lett. 60 (1988)1924)

Excitations of quark-antiquark pairs $|6q(q\bar{q})\rangle, |6q2(q\bar{q})\rangle$ ... on the shell as a specific mechanism of color transparency violation.

Could such quark-antiquark pairs be seen in the Baldin-Stavinsky and Troyan experiments at m_{pair}=10 MeV?

For a **large number** of excitations (n can be **more than 20** in the Baldin-Stavinsky experiment) this is **unlikely** due to the Pauli exclusion principle.

⇩

In the case of large n, the **quark-antiquark pairs must unite into bosons !**

Bosonization of quark-antiquark pairs

The **vector dominance model** also leads to violation of the quark counting rules and the creation of **vector particles on the mass shell**, *see S. Brodsky et al, Phys. Rev. D 97 (2018) 034009* .

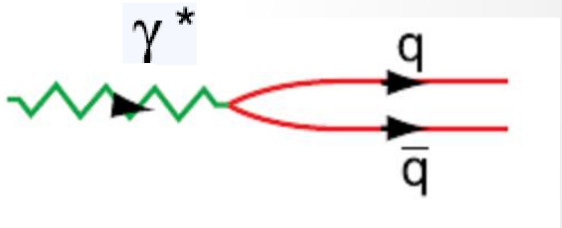
Expected combinations of quark-antiquark pairs:

A la ρ^0-meson:

$$|\rho^0,\uparrow\rangle = (u\uparrow\bar{u}\uparrow - d\uparrow\bar{d}\uparrow)/\sqrt{2},$$

A la ω-meson:

$$|\omega,\uparrow\rangle = (u\uparrow\bar{u}\uparrow + d\uparrow\bar{d}\uparrow)/\sqrt{2}.$$



$m_{\gamma*} = m_{q\bar{q}} = 10$ MeV.

They have the **same quantum numbers** as mesons but are **lighter**.

ϕ –"meson" was not seen in the experiments under consideration as it should be **significantly heavier**, $|\phi\rangle = s\bar{s}$.

Physical properties of pseudo mesons

It is possible to use a theory which successfully described a large amount of light-quark meson experimental data:
[1] M.S. Bhagwat, P. Maris, Phys. Rev. C 77 (2008) 025203

According to the Baldin-Stavinskiy and Troyan experiments, we take $\boldsymbol{m_{q\bar{q}}}$**= 10 MeV.** In that case $\boldsymbol{m_{u/d}}$ **≈ 5 MeV**. In pQCD, such a mass of light quarksis arrived at a renormalization point ζ = 2 GeV (at the one-loop level of RG equation). This means that: 1) **pQCD is applicable** for description of pseudo meson production, 2) a **characteristic size** of pseudo mesons is of order $\hbar/\zeta$ = **0.1 fm**. For comparison, the radius of the usual ϱ^0 is calculated to be 0.74 fm.
According to [1], **magnetic dipole moment** of ϱ^0 is almost independent on the current quark mass, so that its value should be **almost the same** for pseudo and real vector mesons.

Other experimental indications for light dibaryons?

Measurements of the **electromagnetic form factors** of the nucleons in electron scattering experiments were interpreted once as empirical evidence for mesons ω and ρ^0 appearing near the nucleon core, see

Y. Nambu, Phys. Rev. 106, 1366 (1957);
W.R. Frazer, J. Fulco, Phys. Rev. Lett. 2, 365 (1959).

It would be strange if until now there were no experiments on hard **electron-deuteron** scattering near the deuteron breakup threshold indicating the existence of pseudo mesonic states of the ρ and ω type.

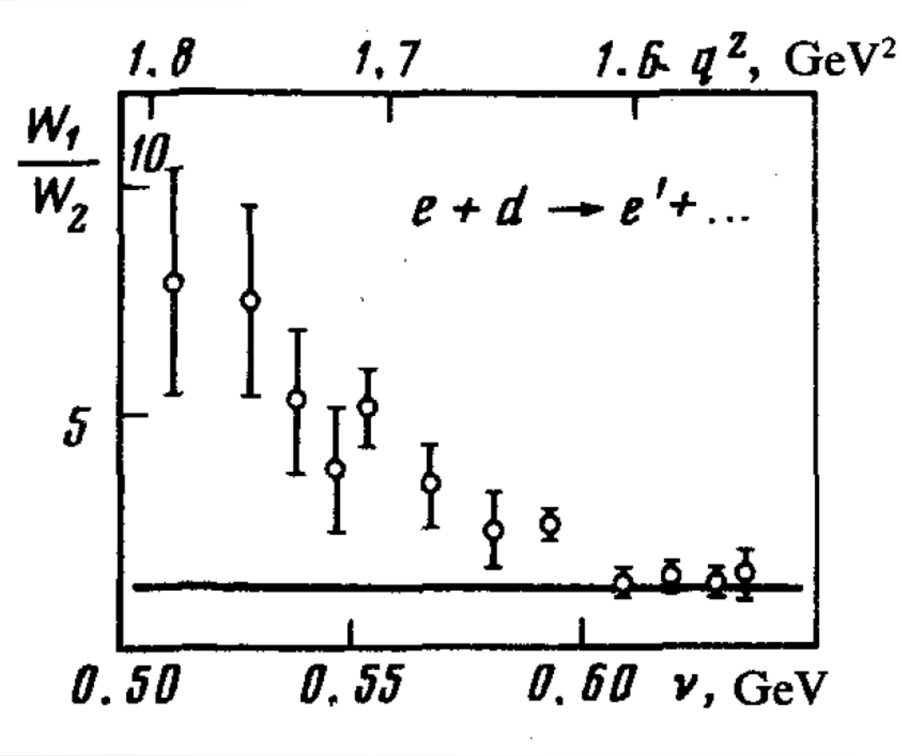
Experiments like this may actually exist

Structure functions for the electrodisintegration of the deuteron at a momentum transfer of 1.8 GeV²

Yu. I. Titov, A. S. Esaulov, E. V. Inopin, R. V. Akhmerov, and E. M. Smelov
Physicotechnical Institute, Academy of Sciences of the Ukrainian SSR

(Submitted 24 July 1982)
Pis'ma Zh. Eksp. Teor. Fiz. **36**, No. 7, 262–265 (5 October 1982)

FIG. 3. Ratio of the structure functions for the electrodisintegration of the deuteron. The curve shows the ratio W_1/W_2 for elastic scattering of electrons by the proton and the neutron.

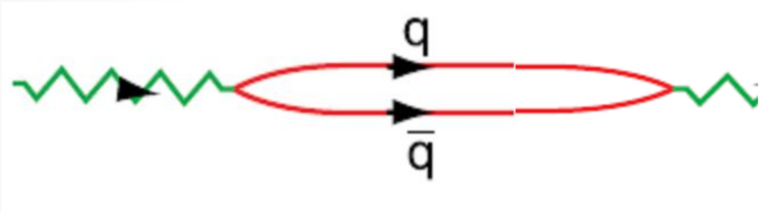


$$\nu = E_e - E_{e'}$$

The authors assume that the increase in the W_1 / W_2 ratio at small ν is due to the appearance of **additional** meson currents in a highly compressed deuteron, which **were not present** in the individual nucleons. Indeed, according FIG.3, the deuteron consists of the usual nucleons only in events with $\boldsymbol{\nu} > 0.6$ GeV. **Hypothetic meson currents** increase strongly the contribution of the magnetic interaction with the projectile electron in the region $\boldsymbol{\nu} < 0.6$ GeV.

Possible excitations of the deuteron

1) **The vector dominance model?**

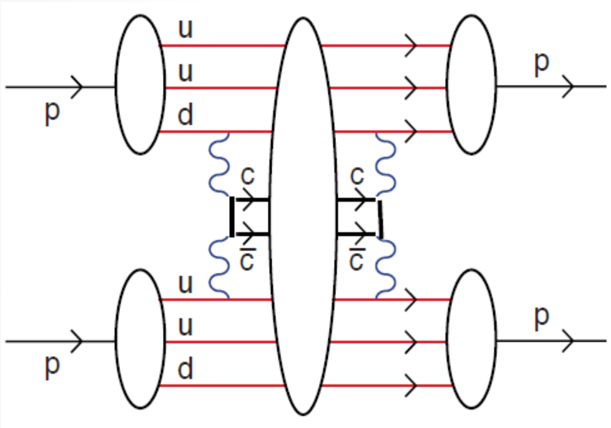


<u>This is unlikely</u>:

It is **difficult to understand why photons with energy of 5 MeV are emitted in large quantities inside a compressed deuteron and why they are <u>all</u> absorbed in it.**

States with **light** quarks on the **shell** through four-gluon exchange?

*S. Brodsky, **Novel Features of QCD Phenomenology at the LHC,***
LHC Working-Group Workshop on Forward Physics and Diffraction,
Madrid, March 22, 2018.



2) Generalization of the mechanism of **formation of Brodsky's multiquark states** to light u and d quarks?

This is more realistic. An attempt can be made to explain the discrete spectrum by the peculiarities of multiquark states, while the confinement of soft gluons does not need to be explained. However, it will be **difficult to explain the formation of states with a large number (up to 20) of light quarks**.

Final state interactions

Another explanation for the magnetic form factor enhancement mentioned in the work [1] is an **interaction in the final state**. This means that the electron first excites some currents in the deuteron, and then interacts with them. The multiquark excitations shown in the previous slide are just one of the possible manifestations of this mechanism.

A similar model can be based on the **possibility of excitation inside a highly compressed deuteron of vibrations of a 2-D oscillator describing a strongly coupled Δ-Δ pair.** Indeed, paper [2] showed that when one of the nucleons in an SRC pair is knocked out in the hard collision, it **can** transfer part of its momentum to another nucleon (contrary to the assumption of quasi-free knockout in the SRC model). If the last collision allows a **semi-classical description**, and the potential of the Δ-Δ interaction is deep enough to be approximated near the bottom by a quadratic parabola, then the excitations in the Δ-Δ system are described by the coherent states [2]. The excitation **spectrum of such a system is equidistant**, which should be expected for the quantum oscillator. The **circular semiclassical motion** of nucleons in the final state can **create a magnetic dipole moment** sufficient to explain the significant increase in the value of W_1 measured in [1].

[1] Yu. I. Titov et al., Pis'ma Zh. Eksp. Theor. Fiz. 7 (1982) 262

[2] B.F.K. arXiv:1902.05252v5[nucl-th]

Where should we look for light dibaryons?

Let's consider an elastic scattering $a+b \rightarrow a'+b'$.
The **energy losses** ν = $\mathbf{E_a}$ **-** $\mathbf{E_{a'}}$ of particle *a* in the rest frame of particle *b* are ν **= -t/(2 m_b).** For the Baldin-Stavinskiy experiment **t= - 0.5 GeV^2**, and ν **= 0.1333 GeV for d-d**, ν **= 0.2664 GeV for d-p** elastic scatterings.
Light dibaryons should be visible at **large | t |**, but **very small** values of **deuteron excitations** *) **:**

$$\nu - 133.3\ \text{MeV} = 10, 20, 30\ldots\ \text{MeV}.$$

This means that in order to detect light dibaryons, it is **enough** to measure the change in the energy of the scattered deuteron with an **accuracy** of the order of 1 MeV. **But this difficult!**

*) The exact kinematics corresponding to the excitation of the dibaryon reads: $-t = 2 m_d \nu - m^2_{d^*} + m^2_d \approx 2 m_d(\nu - \Delta E_{exc})$, where $\Delta E_{exc} = m_{d^*} - m_d$ is the deuteron excitation energy.

Feasibility

The completely controlled process of measuring the mass of light dibaryons requires a very precise measurement of change in the energy of a projectile which excites light dibaryon at large momentum transfer. This may be very difficult to do.

In fact, for recognition of the dibaryons, we should know only momenta of neutron and proton formed after the breakup of dibaryons at the 1 MeV level. A very precise knowledge of a value of the momentum transfer squared $Q^2 = -t$ is not necessary.

It is better to use a fixed target to reduce the energy of detected nucleons. The angles at which such nucleons are recorded at coincidence and their momenta should correspond to the kinematics of decay of dibaryons with masses of 5, 10, 15, ... MeV (or any other dibaryons if you want). For example, for $Q^2 \approx 0.5$ GeV^2 and the target deuteron excitation energy of 10 MeV, the momenta of one of the nucleons (emitted in a direction of motion of the center of mass of the disintegrated deuteron) and of the other (emitted in the opposite direction) should be equal to 466 MeV and - 258 MeV, accordingly. For the deuteron excitation of 50 MeV, these values should be equal to 0.712 and – 0.047 MeV.

All the dibaryons can be recognized due to an increase in the probability of events falling into a kinematic regions corresponding to their masses which are found using momenta travel directions of secondary nucleons.

What should be done

It is necessary to develop an algorithm and a program for the recognition of light dibaryons formed at large values of momentum transfer to the target deuteron.

It is also necessary to carry out a mathematical simulation proving the effectiveness of the program in case of measurement errors expected at the NICA SPD installation.

Thank you for your attention!