Three possible experiments in the search for dibaryons at NICA SPD

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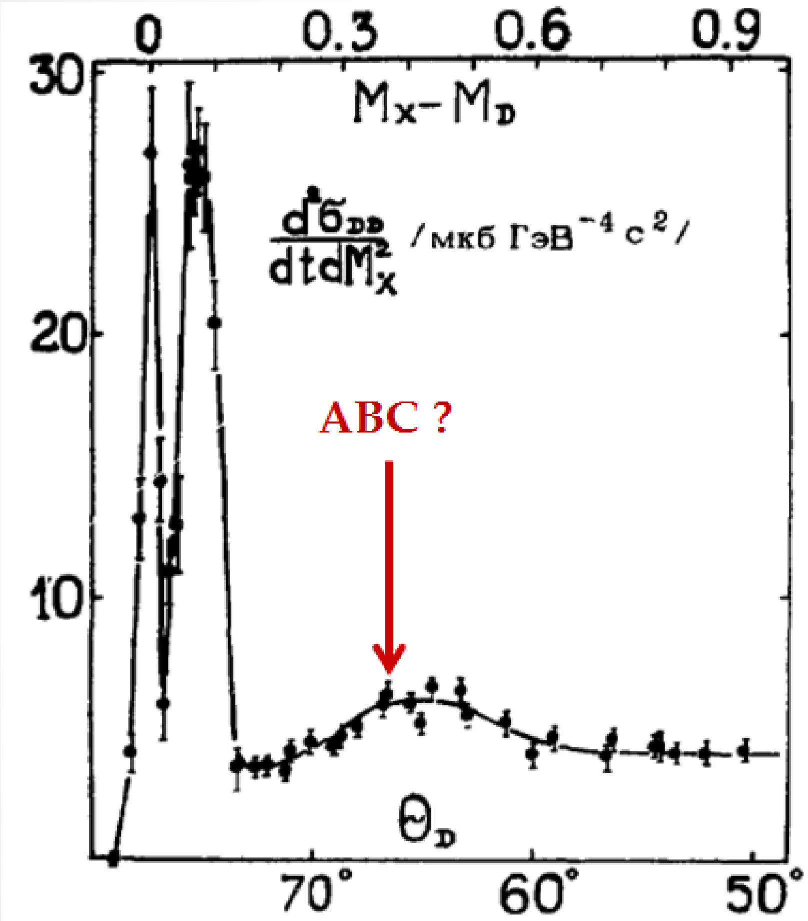
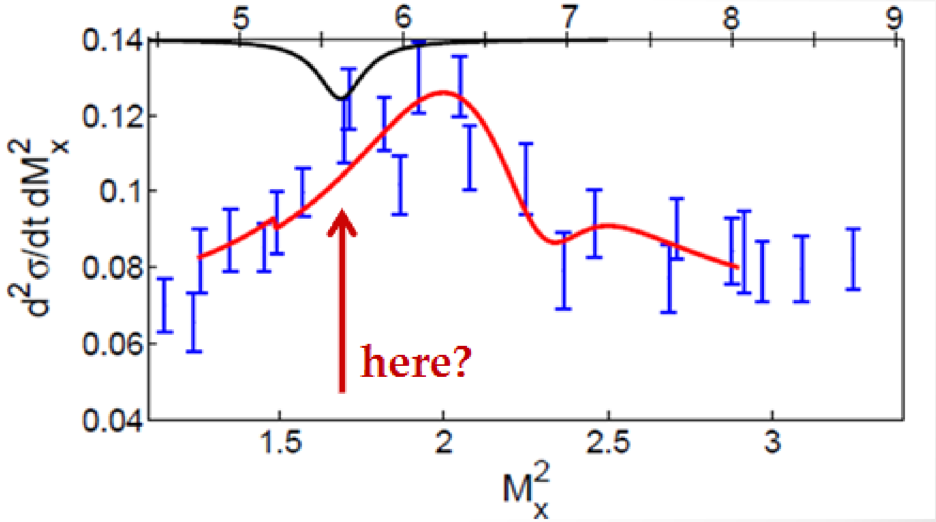
1. Observation of ABC dibaryon

d*(2380), $IJ^P = 03^+$



A.M. Baldin et al., JINR Communication 1-12397, 1979

$d + d \rightarrow M_x + d$



B.Kostenko, J. Pribis, PoS (Baldin ISHEPP XXII) 122

N(1440)+N(1520)+N(1535)

+ ABC dibaryon?

Two new candidates should be checked

The BGOOD experiment at the ELSA electron accelerator facility

T.C. Jude et al., arXiv:2202.08594v3 [nucl-ex] 29 Oct 2024

Electromagnetic production of ABC dibaryon directly from the deuteron ground state

$\gamma\, d \rightarrow d^*(2380) \rightarrow \pi^0 \pi^0 d, \quad \pi^0 \rightarrow 2\gamma$

In addition to the ABC dibaryon, experimental indications have been obtained for the existence of two new dibaryons

1) $\gamma\, d \rightarrow d^*(2470) \rightarrow \pi^0 \pi^0 d$, 2) $\gamma\, d \rightarrow d^*(2630) \rightarrow \pi^0 \pi^0 d$

Experimental proposal # 1

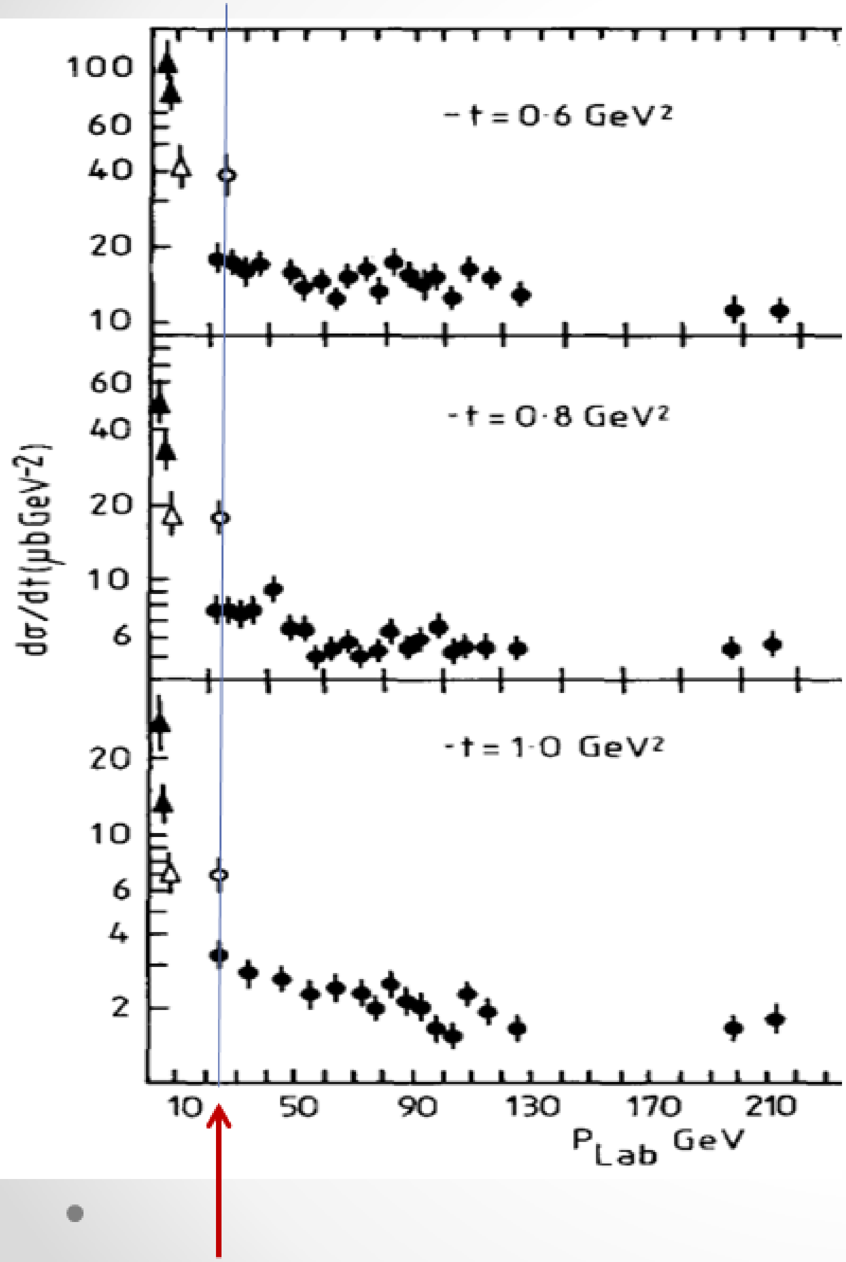
We can try to produce these hypothetic dibaryons in reactions

$d\, d \rightarrow d^*\, d$ at energy $\sqrt{s} = 6.16 \in [4.76\ ,\ 15.26]$ GeV

If we do not see $d^*(2380)$ in dd reaction, we can synthesize it in reaction pd –> pd*(2380) –>d $\pi^0\pi^0$, as it was done in the WASA experiment.

After that we can proceed to verify the existence of $d^*(2470)$ and $d^*(2630)$ in pd reaction.

2. CERN – FNAL puzzle



Nucl. Phys. B39 (1972) 39,
Nucl. Phys. B207(1982)365

$p + d \rightarrow p + d$

P_{Lab} = 24 GeV/c, d was a fixed target.

The cross sections in the two experiments differ by a factor of two.

Possible explanation of the difference.

In the first experiment, the deuteron was identified by the kinematics of elastic p-d scattering (missing mass method).
In the second experiment, the recognition of deuterons hitting the detector after scattering was performed explicitly. If this is the reason, then in the first experiment the detector could record particles with masses close to the deuteron mass – light dibaryons.

Experimental proposal #2

To investigate the deuteron breakup reaction

$$p+d \rightarrow p+(p+n)$$

at intermediate for NICA SPD energies

$$\sqrt{s} = 9.72 \in [4.76\ ,\ 15.26]\ \text{GeV}$$

and select events for which the effective mass of the (p+n) system that appeared after the deuteron disintegration does not exceed $M_d + M_\pi$.

It is clear that **dibaryons with such small masses might be identified as deuterons,** if in an experiment the presence of a deuteron in the final state was determined using the missing mass method (as it had been in the CERN experiment).

Simplified experiment setup

We can try to observe such light dibaryons already in dd collisions.

But if we will not see them, it will not be a proof of the impossibility to observe them in pd collisions under the same t and s as in the experiments had been done at CERN and FNAL.

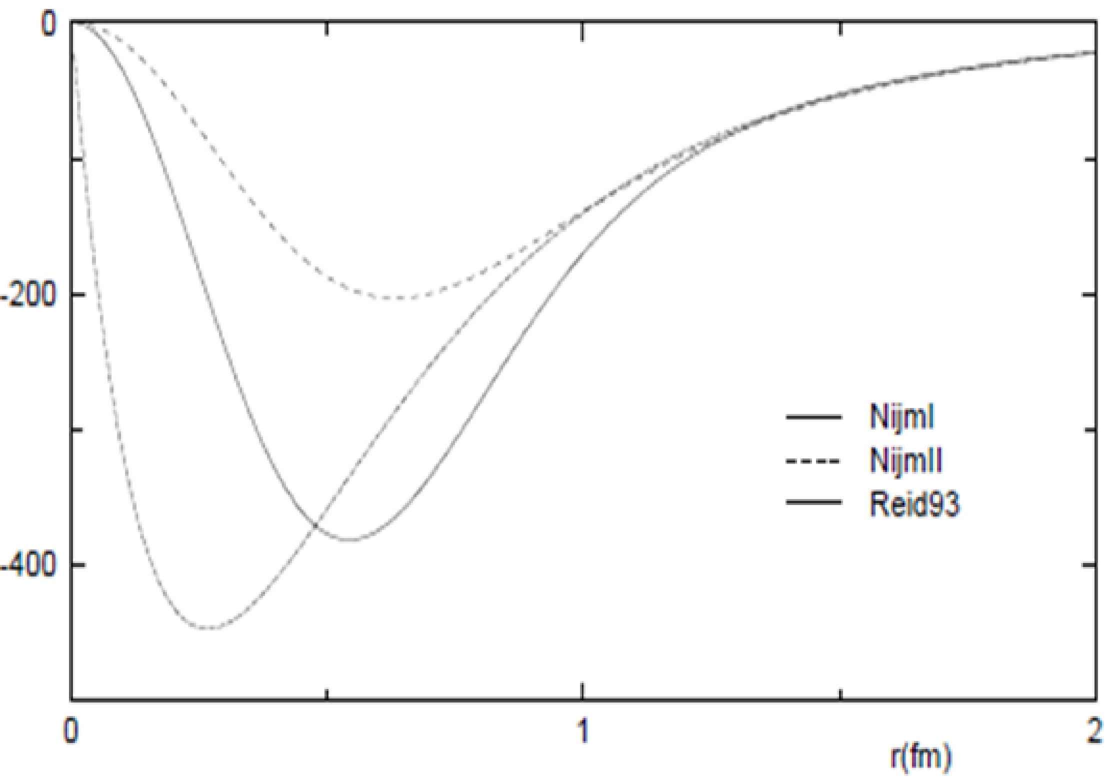
3. Admixture of 6q systems in deuteron

V. A. Matveev, P. Sorba, Lett Nuovo Cim. (1977) 435 – Is Deuteron a Six-Quark System?

J.J. de Swart, R.A.M.M. Klomp, M.C.M. Rentmeester, Th.A. Rijken, Few-Body Systems Suppl. 99, 1–10 (2018)

The Nijmegen tensor potentials

connecting the $^3S_1$ and $^3D_1$ partial waves



Main features of the potentials

1. They are very deep.
2. They allow the proton and neutron centers to approach each other at a distance of 0.25 - 0.6 fm.
3. They connect the $^3S_1$ and $^3D_1$ partial waves of the deuteron wave function.

At such a strong compression of neutron and proton it is possible to form 6q-systems - collectivization of their quarks. Analogy with collectivization of electrons, which was observed in metal atoms at their strong compression (famous I. K. Kikoin group experiments).

6q system or Blokhintsev's flucton?

The experimental detection of a deep potential binding neutrons and protons at very short distances, would be a strong indication of the possibility of the pre-sence of a 6-q system in the deuterium nucleus, as had been assumed by V. A. Matveev and P. Sorba. But it would also confirm the D. I. Blokhintsev's hypothesis about the existence of nuclear density fluctuations. Indeed, the Nijmegen potential, according to the interpretation given by its developers, describes the transitions from the sparse S-state into the denser D-state and back. Here the flucton should be considered as a system of two strongly coupled states, one of which occupies a relatively large spatial volume, and the other is localized much better. This construction allows to harmonize D.I. Blokhintsev's dynamical idea of fluctuations of the of nuclear density with the quantum mechanics of stationary states, which is used now for description of unexcited states of atomic nuclei.

I don't know how D.I. would feel about this interpretation, but it's very plausible to assume that he would agree with it.

Jlab experiment supporting such a picture

PRL **99**, 072501 (2007)

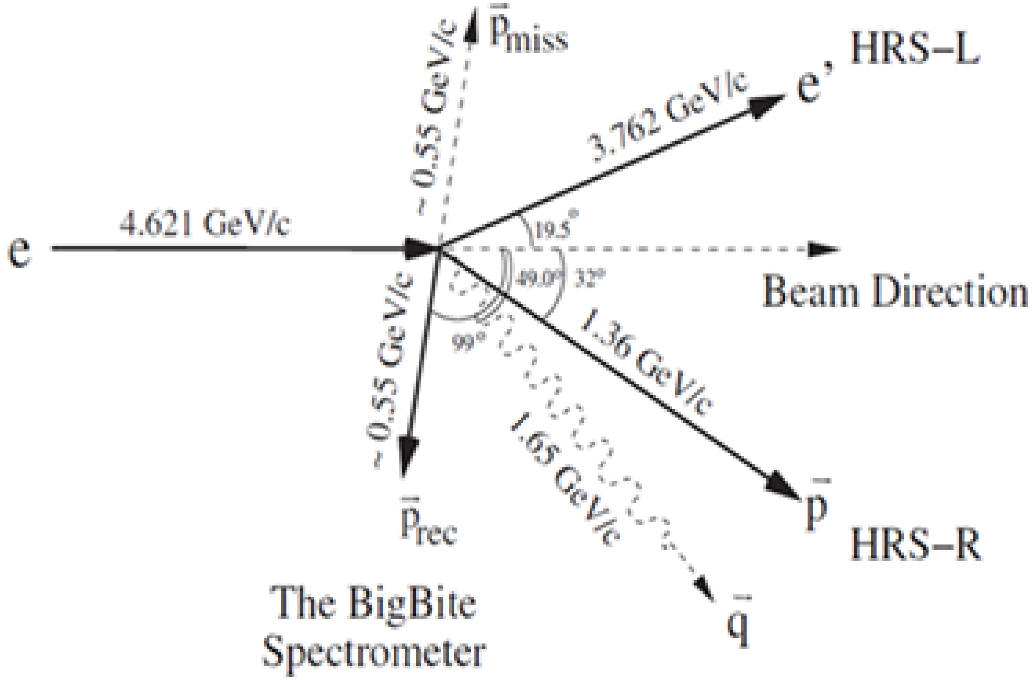


FIG. 1. A vector diagram of the layout of the $^{12}C(e, e'pp)$ experiment shown for the largest p_{miss} kinematics of 0.55 GeV/c.

The law of conservation of energy is satisfied only if the neutron-proton pair was in a deep potential well with a binding energy of 290 MeV. Such conclusion is in a good agreement with potentials of the Nijmegen group.

However, this conclusion cannot be considered definitive because the description of the reaction contains two uncertain parameters: the mass of the residual nucleus and its excitation energy. These parameters are not only unknown, but are unlikely to have a definite value for all observed events.

Proposal #3 at NICA SPD

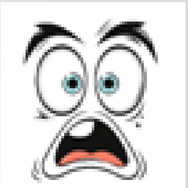
In this respect, the possibility of setting up

p + d --> p + (p + n)

experiment at the NICA SPD offers obvious advantages. In this reaction, the final state, in addition to the neutron, contains only two protons and the measurement of momenta of which allows us to reconstruct the whole kinematics without any additional assumptions.

This opens the way to a direct measurement of the neutron-proton binding energy in a hypothetical deep potential well in deuteron that may be responsible for formation of 6q systems in more heavy atomic nuclei too.

The challenge



In the JLab experiment, the energy homogeneity of the colliding electron beam was **0.02 %**, as well as the accuracy of the momentum measurement of the scattered electrons was approximately the same. This is what allowed us to calculate with the necessary accuracy the energy expended to knock nucleons out of the deep potential well, and thus to know the energy of their binding in this well. Such measurement accuracies of proton momentum are not available in commonly used proton detectors, where they are about two orders of magnitude worse.

Nevertheless, close accuracies are, in principle, achievable for protons too. For example, in a **paper**

X. Altuna et al., A MOMENTUM CALIBRATION OF THE SPS PROTON BEAM, CERN SL/92-32 (EA)

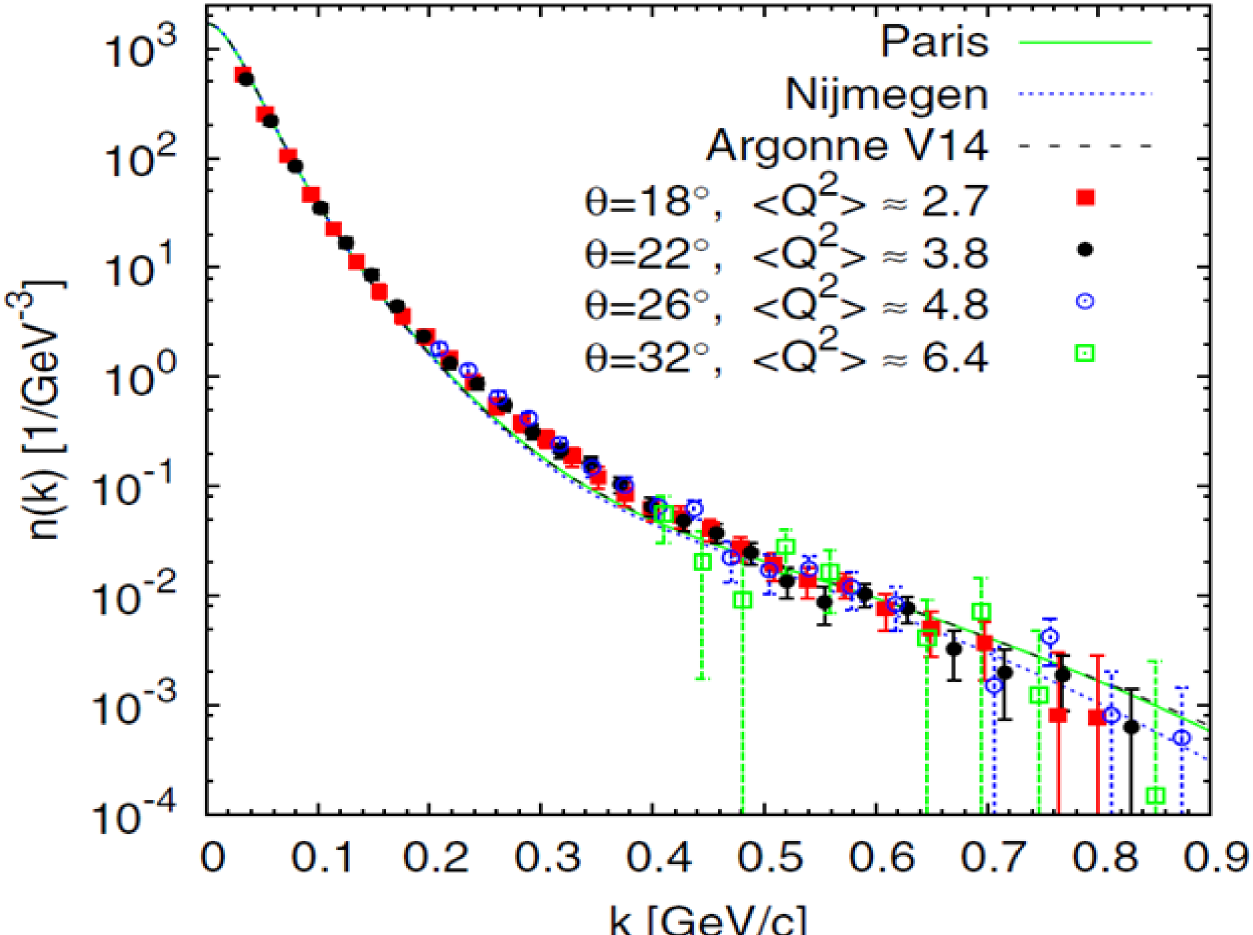
the momentum of the SPS proton beam had been measured. The resolution obtained in the experiment **was 0.034 %** and the momentum of the beams was deduced to be p = 270.55 +- 0.095 GeV/c. In addition, just as in the JLab experiment, the energy homogeneity of the proton and deuteron beams at the NICA collider should also be in our experiment of the same order.

Thank you for your attention

Accessory materials

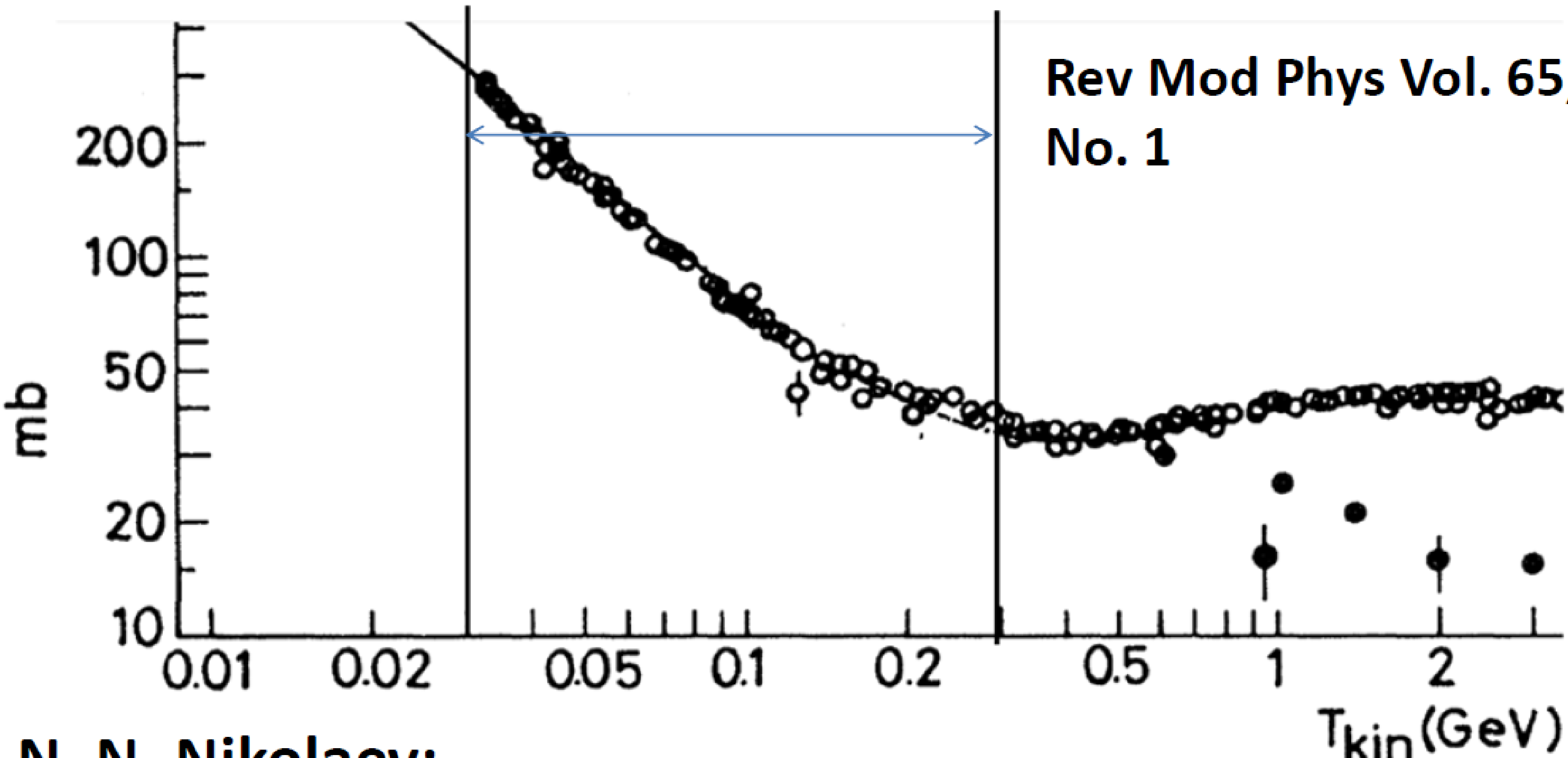
N. Fomin et al., PRL 108, 092502 (2012)

New Measurements of High-Momentum Nucleons and Short-Range Structures in Nuclei.



Extracted nucleon momentum distribution (points) and calculated (curves) using three different N-N potentials.

Is it possible: n+p -> d*->n+p?



Rev Mod Phys Vol. 65, No. 1

N. N. Nikolaev:
"No resonance n-p peaks are seen in the dibaryon excitation region"

at DSPIN-23

Counter-evidence: "It is difficult to assess the <u>accuracy and reliability</u> of the data"

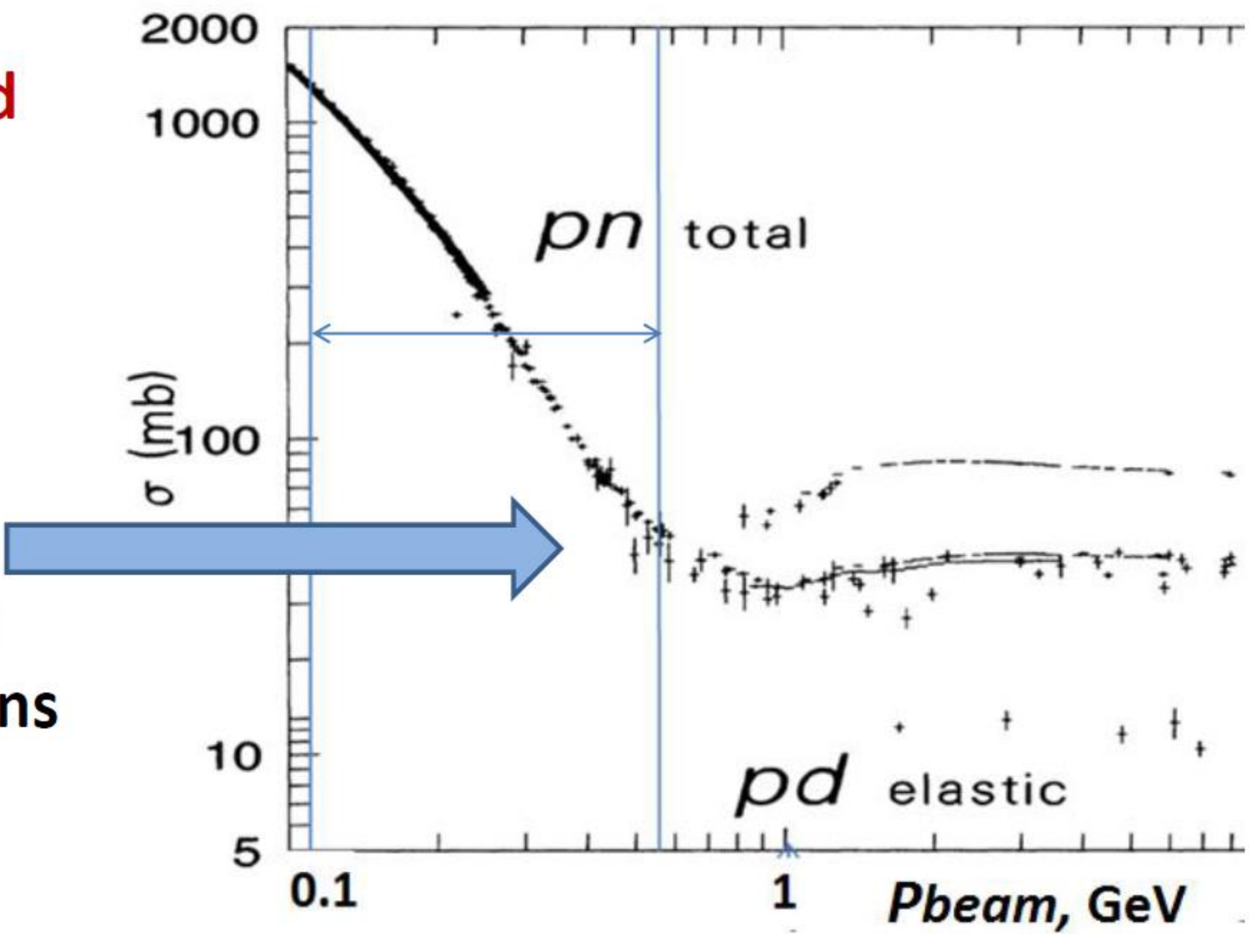
The answer (at Baldin ISHEP2023):

Most reliable and precise data
recommended for use by PDG in 2023

https://pdg.lbl.gov/rpp-archive/files/PhysRevD.45.S1.pdf

From gold-bearing sand to gold

For the upper energy part of spectrum some chances for the existence of light resonant dibaryons <u>still remain</u>.



EMC effect, Nature, 566(2019)354

Basic statement: the EMC effect on a specific atomic nucleus is determined by the abundance of SRC pairs in it. This statement can be expressed by the equality

$$\frac{n^d_{SRC}(\Delta F_2^p + \Delta F_2^n)}{F_2^d} = \frac{\frac{F_2^A}{F_2^d} - (Z-N)\frac{F_2^p}{F_2^d} - N}{(A/2)a_2 - N}\,, \quad (1)$$

where $n^d{}_{SRC}$ is a number of SRC pairs in the deuteron. However, modern experimental data are consistent with the statement that $n_d{}^{SRC} = 1$ within the accuracy of the model in Nature (see Appendix). Thus, the EMC effect should be connected not with the abundance of SRC pairs in the atomic nuclei, but with the amount of the quasi-deuterons in them.

⇩

Then EMC effect itself can be explained by the admixture of the 6-q states in quasi-deutrons in atomic nuclei.

Appendix

Results of structure function ratio $R^d_{EMC} = \frac{F^d_2}{F^p_2 + F^n_2}$ measurement were reported in [PRC 92 (2015) 015211]. Using it, one can estimate the coefficient n^d_{SRC} in (1)as follows. First, let us write

$$\frac{\Delta F^p_2 + \Delta F^n_2}{F^d_2} = 1 - \frac{1}{R^d_{EMC}}, \tag{2}$$

where, according to [PRC 92 (2015) 015211], $R^d_{EMC} = 1 + C(x_B - 0.35)$, and $C \approx -0.10$ for $0.35 \leq x_B \leq 0.70$. One finds from Fig. 2b in [Nature, 566(2019)354] for $x_B = 0.5$

$$n^d_{SRC} \frac{\Delta F^p_2 + \Delta F^n_2}{F^d_2} = -0.015 \pm 0.007,$$

where -0.015 is the arithmetical mean of maximal and minimal values in the graph at $x_B = 0.5$. The value of 0.007 displays uncertainties of the right side of (1) due to its residual dependence on nuclei. On the other hand, it is easy to check that left side of equation (2) is equal to -0.015 too at $x_b = 0.5$. It immediately follows from this that $n^d_{SRC} = 1$. Similarly, for $x_B = 0.7$, where right side of equation (1) is equal to -0.033 ± 0.007, left side of (2) is equal to -0.036. This value is also consistent with the statement that $n^d_{SRC} = 1$ within the accuracy of the model.