"Search for Dibaryons with small energy excitation at SPD detector at NICA collider " - *accuracies and counting rates*

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1.1 SPD detector

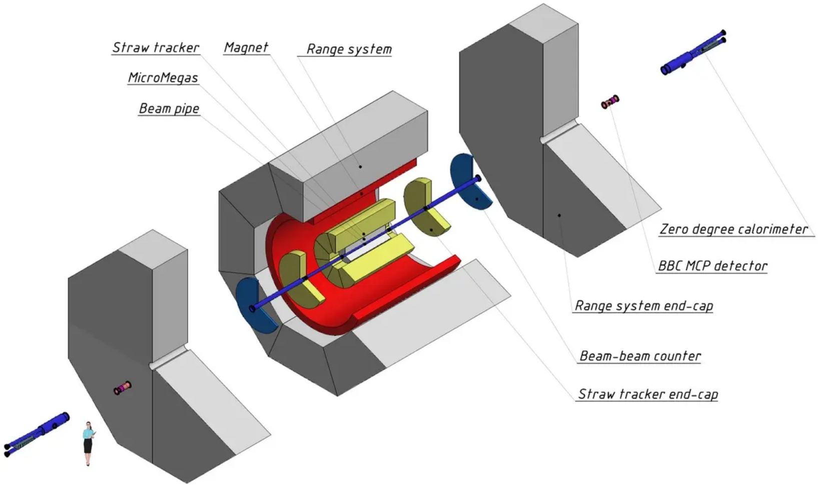

Figure 1: SPD, First phase

1.2 SPD detector

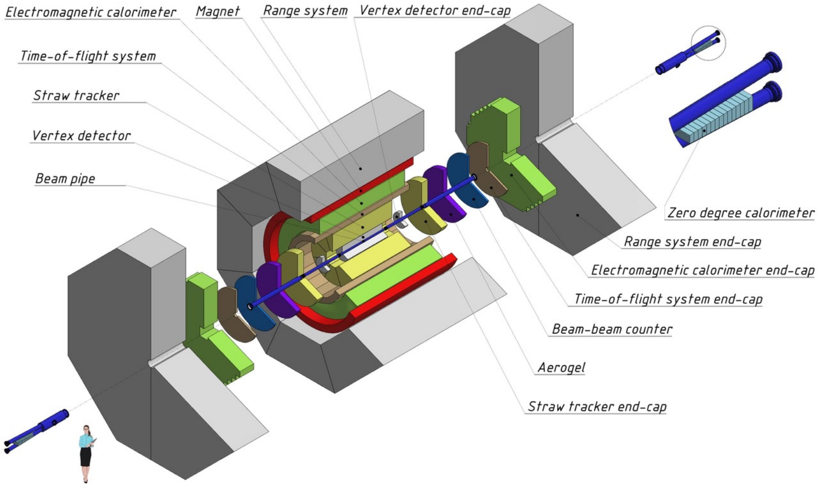

Figure 2: SPD, Full configuration

2.1 Elastic pn scattering

Most reliable and precise data

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>.

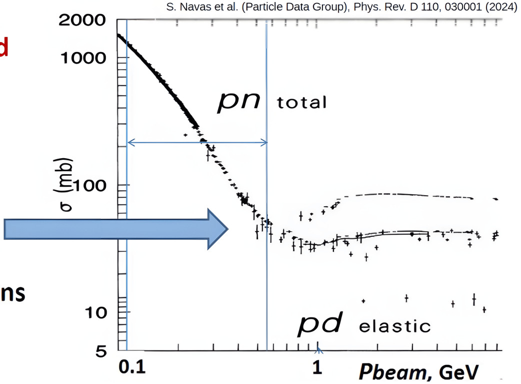

Figure 3: Cross section of *pn* interaction.

2.2 Remarks about elastic pn scattering

Natural remark :if Dibaryons existed the cross sections of $pn \to pn$ interactions would show some irregularities(or peaks) at some energies. No peaks are seen in a fig.3 in the region below pion threshold but it does not mean that the resonances do not exist!

$$a_l = (-m\Gamma_{el}/(s - m^2 + i \cdot m\Gamma_{tot})) \quad (1)$$

Formula (1) shows the expression for elastic amplitude in l partial wave for Breit-Wigner resonance. If partial width Γ_{el} is small, it may not be seen in principle!

In addition to this, the region near pion threshold is very scarce of data.

We think that future SPD detector could do more accurate search for Dibaryons in this area.

2.3 Extract from Troyan's review,Physics of Particles and Nuclei,**24**,3,1993

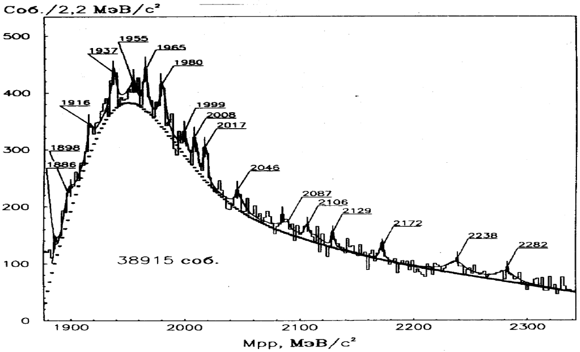

Figure 4: Effective mass of two protons from the reactions $np \to pp\pi^- m\pi^0$, m=0,1 for $P_n = 1.26; 1.33; 1.72; 2.23; 3.86 GeV/c$ and the reactions $np \to pp\pi^+\pi^-\pi^- m\pi^0$, m=0,1 for $P_n = 5.14; 5.18; 5.24; GeV/c$.Solid curve is the approximation by the sum of the background and 17 resonances

2.4 Remarks about Yu.Troyan's review

Comparatively long time ago Yu.Troyan,staff member of VBLHEP of JINR published the review on the search for diprotons(Yu.Troyan, Physics of Particles and Nuclei,**24**,3,1993) The author analyzed papers about search for diproton resonances, in different experiments(bubble chamber,electronics) published since 1986 till 1993. Diproton resonances were searched for both by effective mass and missing mass methods. At that time no experiment proved convincingly the existence of diproton resonance. Nevertheless in a fig 4 we show one of the pictures from this review due to its colorfulness.
Still, concluding his paper, Yu. Troyan says that"..Effects of narrow diproton esonances exist.."

2.5 Extract from Clement's review,arxiv:1610.05591v2

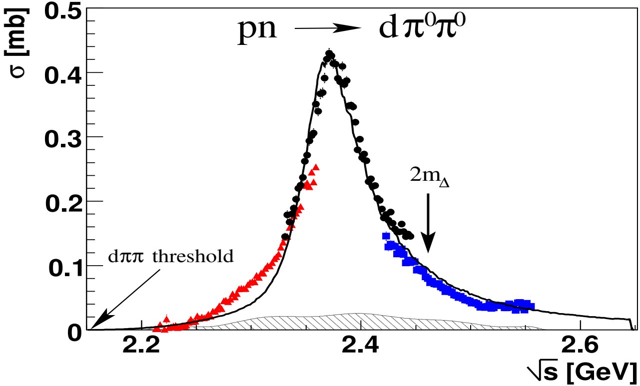

Figure 5: WASA collaboration claims that this is dibarion resonance with quantum numbers $I(J^P) = 0(3^+)$, $M = 2380 MeV, \Gamma \approx 80 MeV$,calls it as $d^*(2380)$.Triangles - for 1.0GeV,dots - for 1.2GeV,squares - for 1.4GeV

2.6 Remarks about Clement's review

Perhaps the latest and most complete review on the existence of dibarion resonances is a publication of Clement(WASA-at-COSY,H.Clement,arxiv:1610.05591v2 [nucl-ex];Progress in Particle and Nuclear Physics **93**,2017, Pp. 195-242)

Originally similar behavior of the reaction $pn \to d\pi^0\pi^0$ was observed when fixed deuteron target was used and the events were selected by detecting proton-spectator(with the momentum $p_{sp} <\approx 170 MeV/c$) together with deuteron and γ rays. Momentum of proton-spectator was being estimated by kinematical fit(Lagrange Multiplier Method).

To cover more angular range WASA group measured this process in reverse kinematics with deuteron beam and hydrogen as a target. The conclusion is :

H.Clement:"..a single firmly established non-trivial dibaryon state, the one with $I(J^P) = 0(3^+)$ at 2380 MeV..."

3. Baldin-Stavinsky experiment

In a figure 6 we show the results of Baldin-Stavinsky experiment(Baldin et al.,Communication of the JINR, Dubna 1979,1-12397) where on fixed target dd interaction at 8.9GeV/c was studied. .

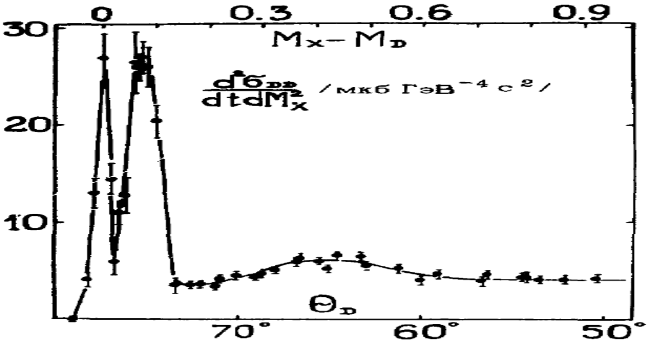

Figure 6: $d\sigma/(dtdM_X{}^2 \quad D + D \to M_X + D \qquad -t = 0.5(GeV/c)^2$

4. Proposal for the search for dibaryons with SPD

Our proposal is to do the similar experiment , aimed to investigate the reaction $D + D \to M_X + D$ **in the region of Missing Mass** $M_d < M_X < M_d + m_{\pi^0}$ **at collider deuteron momentum** $P_d = 2.6 GeV/c$**(equivalent to 8.9GeV/c on fixed target)**. Here M_d, M_X are masses of the deuteron and of the system broken deuteron turns to respectively, starting with the first version of SPD setup and continuing it in the process of improving it till full configuration. Remind that the first version of SPD is shown in a Fig. 1

In what follows we consequently show the accuracies(or resolutions) in dibaryon mass measurement, achievable in a suitable detector configuration, where under the resolution we understand a σ of the Gaussian function approximating peak region of the distribution(selected by eye!). In that we follow the practice acceptable in electronics where the width of any signal is characterized by so called FWHM(Full Width at Half Maximum) and if the signal is pure Gaussian, sigma of this Gauss is $\sigma = FWHM/2.35$.

4.1 Principal possibility of dibaryon detection

The most important question for the similar search - what is the accuracy of dibaryon mass measurement at SPD detector? In order to answer this question we performed the simulation under the following conditions

- The accelerator produces head-on dd collisions;the momenum of the colliding deuteron is 2.6GeV/c,equivalent to 8.9GeV/c on the fixed target
- The transferred momentum of the unbroken deuteron is $t = -0.5(GeV/c)^2$
- The mass of X system is taken to be $MX = M_d + E_{exc}$ and E_{exc} is as a fracton of the π^0 mass equal to 1/4,1/2,3/4(1.90935,1.94310,1.97685GeV respectively).Event Generator was done in such a way, that MX system decayed isotropically in its center of mass. It affected to the range of proton momentum in a Collider System and, finally to the mass resolution itself!
- All the collisions take place at the central point of the detector(coordinates $x = y = z = 0$),the deuteron and the proton tracks and the primary vertex are reconstructed and the dibaryon has zero decay width.Such condition for collision coordinates were selected at the very beginning of our studies in order to get maximal accuracy,achievable with SPD detector and to answer the question - is it poossible in principle to achieve reasonable resolution(few MeV)?
- Vertex Detector was in its MVD,DSSD,MAPS versions(see TRD-hep-ex arXiv:2404.08317),both End Cups were in full assembly: trackers and TOF systems

The details of data processing are set out in a publication V. Andreev et al , *Resolution of SPD Detector in the Search for Dibaryons with Small Energy Excitations*,Physics of Atomic Nuclei, **87**,3(2024),p.p. 220-223. Critical improvement in a resolution occurs due to the application of the kinemetical fit technique(see text).

4.1 Principal possibility of dibaryon detection,accuracies for different VD's

As is mentioned in a SPD technical design repot(arXiv:2404.08317) there may be three vesions of Vertex Detector(VD) in SPD setup:

- Micromegas-based Central Tracker(MVD)
- Double-Sided Silicon Detector(DSSD)
- MAPS-based vertex detector(MAPS)

depending on its cost,accuracy and construction time. In a Fig. 7 we show the resolution curves for different type of Vertex Detector. In this figure MX was taken only as equal maximal($MX = m_d + 3/4m_{\pi^0}$) from all three options.It was done specially to get more conservative estimates of dibaryon mass resolution(the bigger MX then the broader proton momentum spectrum fom dibaryon decay). All the other conditions were as mentioned before.
You may see that σ's are 4.4,2.8,2.5MeV for MVD,DSSD,MAPS types of Vetex Detector respectively.
You may see also that the resolutions for DSSD,MAPS are superior to MVD and sufficiently good. As for MVD version it may be considered as a candidate to do the experiment at the beginning of SPD operation.

4.1 Principal possibility of dibaryon detection,accuracies for different VD's, cont-ed

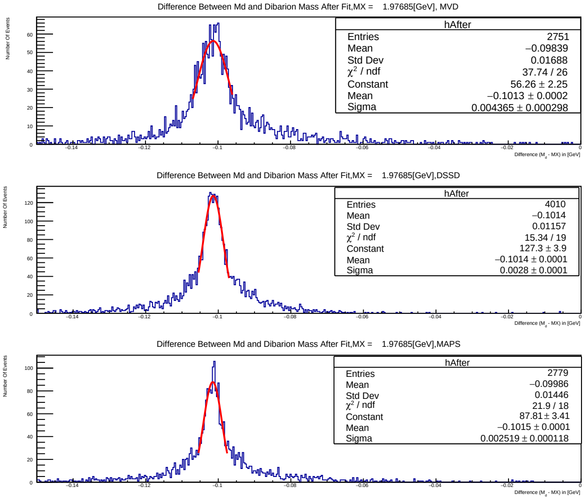

Figure 7: Resolution curves for $E_{exc} = 3/4 m_{\pi^0}$.Vertex detector is MVD,DSSD,MAPS from top to bottom

5. Accuracies in a "real" conditions

From what was said before it is seen that there is a possibility to searh for the dibaryons with the accuracy of a few MeV's under special conditions. It is natural to estimate these values in a conditions close to "real".They are:

- Mass of the dibarion X in the reaction $d + d \rightarrow d + X$ was taken again as $M_X = md + E_{exc}$,where md is deuteron mass, E_{exc} is the excitation energy equal to $E_{exc} = 3/4m_{\pi^0}$ and m_{π^0} is the π^0 mass
- The width of dibarion X was equal zero(this was done specially to estimate resolution)
- Momentum of deuteron in dd collisions 2.6GeV/c
- The distribution of Transfer momentum for unbroken deuteron is taken from Baldin-Stavinsky experiment obtained for dd elastic scattering , see fig. 8
- Cooridinates of primary vertex were generated by Gaus - for Z with $\sigma = 40cm$,for X,Y with $\sigma = 0.08cm$
- For the analysis only the events with $-35cm < Z < 35cm$ were selected
- Accuracies were estimated for two types of Vertex Detector - MVD and DSSD and SPD detector was in full assembly

t-dependence for the unbroken deuteron

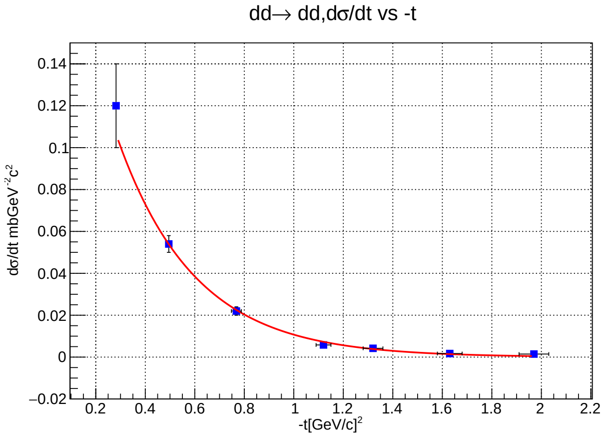

Figure 8: Transfer momentum distribution from Baldin-Stavinsky experiment

Resolution for MVD option

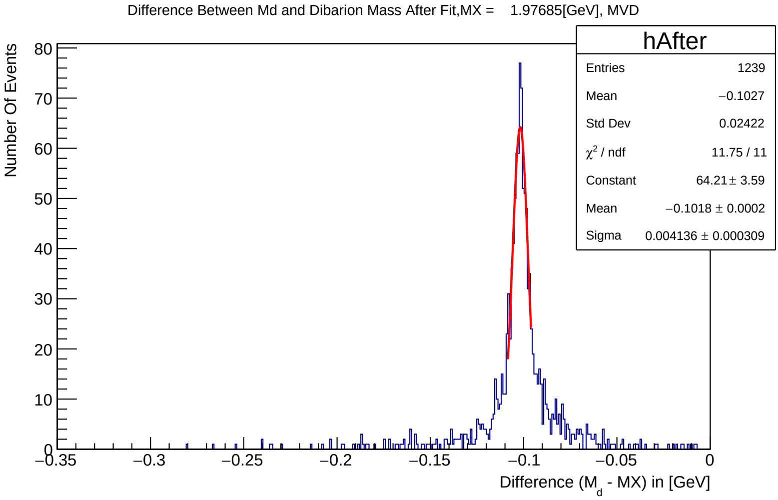

Figure 9: Difference $M_d - M_X$ in GeV, M_d, M_X are deuteron and dibarion masses respectively

Resolution for DSSD option

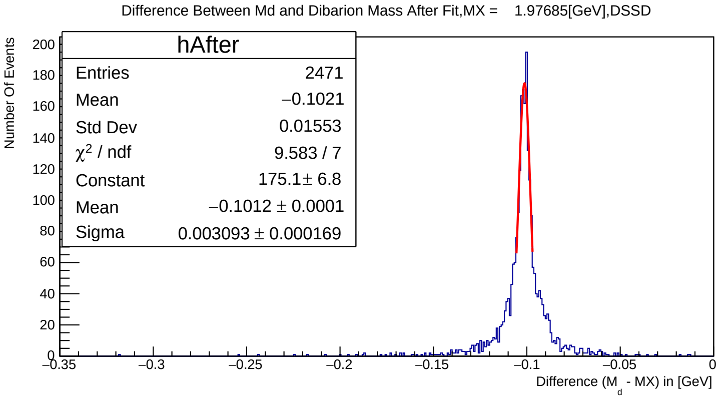

Figure 10: Difference $M_d - M_X$ in GeV, M_d, M_X are deuteron and dibarion masses respectively

6. Proposal for possible experiment with the first stage of SPD

Earlier we formulated our proposal for possible experiment; here we are citing the accuracies which would be obtained with the first stage of SPD.
To do such a study first version of SPD should include Vertex Detector(MVD version) and two End Cups, each of them containing only tracking system.
In a Fig. 11 we show the accuracy in a Missing Mass reconstruction in a SPD configuration mentioned above. It was obtained as the result of the simulation at the same conditions as before - for so-called "real" experiment As is seen the estimated resolution will be $\sigma \approx 4.8 MeV$. This time we used kinematical fit technique described in a publication *V.Kurbatov,Alternative to Lagrange Multuplier Method,"Physics of Particles and Nuclei, Letters"*, **22**, *number 1, 2025*
Remark: Adding TOF system in End Cups improves resolution to $\sigma \approx 4.1 MeV$; change Vertex Detector to DSSD option gives $\sigma \approx 3.1 MeV$

Proposal for possible experiment with the first version of SPD,cont-ed

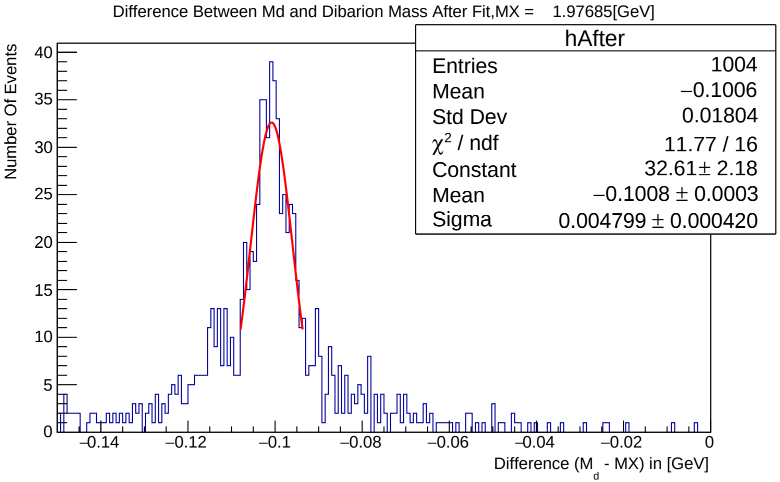

Figure 11: Difference $M_d - M_X$ in GeV,M_d, M_X are deuteron and dibarion masses respectively

Proposal for possible experiment with the first version of SPD,cont-ed, Counting rate.May this process be a candidate for first SPD experiments?

Factors for the estimation of Counting Rate:

- Luminosity of dd for Collider Momentum $2.6 GeV/c$ is $\approx 1.7 \cdot 10^{29} cm^{-2} sec^{-1}$
- Cross section of $d + d \to d + X$ for $(0.282 < -t < 1.97)(GeV/c)^2$ is $0.033 mb$.It was taken equal to elastic dd cross section; in fact it is bigger according to Baldin-Stavinsky experiment
- Fraction of the Luminosity corresponding to the probability of having primary vertex in the selected region is 0.382

Counting rate $\approx 2.1 sec^{-1}$

Luminosity of dd collisions

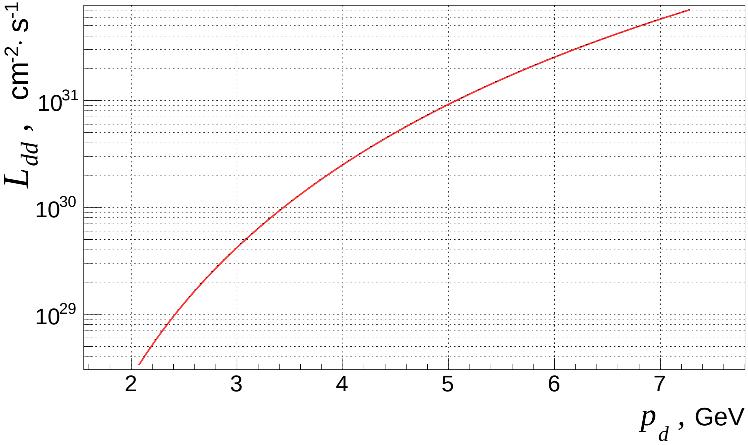

Figure 12: Luminosity of deuteron beam in a symmetric mode(prepared by A.Philippov, staff member of VBLHEP)

Conclusion

Creation of such a complicated detector requires a lot of time and human activity and now it seems very distant. Still the earlier we start the preparation of all the parts of stable running the SPD experiment the more qualitative physics results we will get.
Here we are talking about first possible experiment at the SPD, particularly about analysis of the primary data.
Having suitable support we are planning to start the necessary works to produce "embryo" of such an analysis.