Potential possibility to search for dibaryons in pp collisions

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Recent progress in experimental search for dibaryons

The first recognized experimental result regarding the observation of the dibaryon
with mass of 2.38 GeV, width of $\Gamma = 70 MeV$,
and quantum numbers $I(J^P) = 0(3^+)$, which is formed as a result of the fusion of a neutron and a proton, were published by the WASA-at COSY Collaboration in 2011: PRL 106, 242302 (2011). What came as a surprise was that the cross-section of the processes $\mathbf{pn \rightarrow dibaryon \rightarrow d + \pi^0 + \pi^0}$, in which the dibaryon was produced in an intermediate state, turned out to be very small. This refuted the previously popular argument against the possibility of dibaryon formation in neutron-proton interactions due to the absence of observed resonant peaks in the cross-section of elastic neutron-proton scattering. Currently, it is believed that the resonant peaks corresponding to the dibaryon with a mass of 2.38 GeV are not visible due to large statistical errors in the experimental data on the cross-sections of elastic n p scattering

M.Bashkanov, D.P. Watts,
PoS(Hadron2017)122:
"In elastic np
scattering the
$d^*(2380)$ resonance
contribution is about
**0.17mb, which is
more than two orders
below the total elastic
cross section"**

Another lesson we learned from the experiments conducted by the WASA-at-COSY collaboration:

We should do exclusive experiments

Heinz Clement,Erice School, Sep 16 - 24, 2015

In the first stage of the experiments, there will be no photon detectors at NICA SPD when photons are formed from the decay of neutral pions. Therefore, we will not be able to carry out experiments on the production of d*(2380) in the reactions $d + d \rightarrow d + d^*(2380)$, which have not yet been observed in dd collisions. However, later, when photon detectors become available at SPD, such experiments will need to be carried out.

By now, sufficiently convincing experimental evidence has emerged in favor of the existence of other isoscalar dibaryons with masses of **2.47** and **2.63GeV**; see [Phys. Lett. B832 (2022)137277].

Japan ELPH Facility,PL B789(2019)413

The reaction $\gamma d \rightarrow d + \pi^0 + \pi^0$, γ energy range (0.75-1.15)GeV.Peaks at $\approx 2.47 and \approx 2.63 GeV$

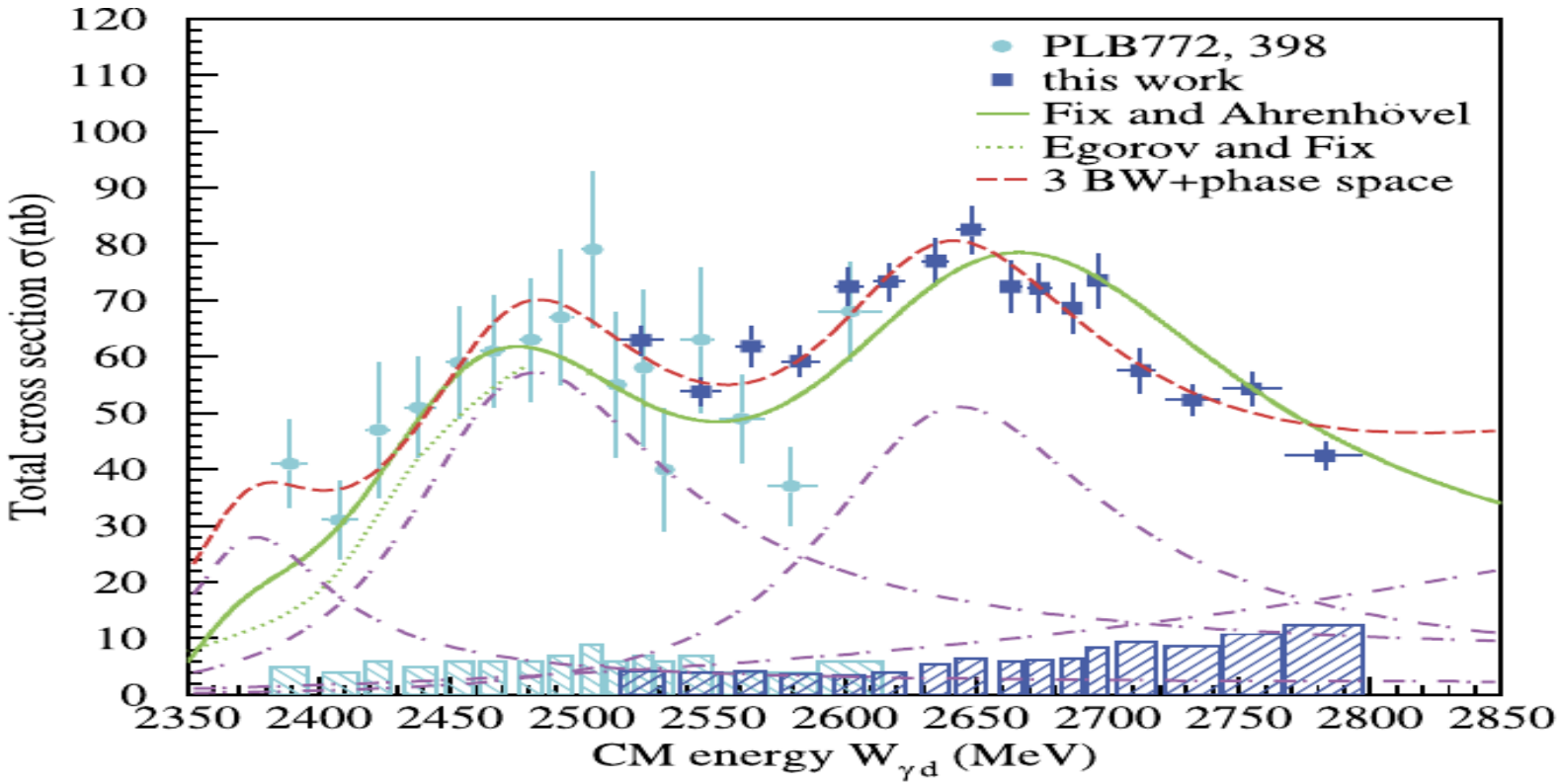


Fig. 1. Total cross section σ as a function of $W_{\gamma d}$. The squares (blue) show σ obtained in this work, while the circles (cyan) show that presented in Ref. [6]. The horizontal error of each data point corresponds to the coverage of the incident photon energy, and the vertical error shows the statistical error of σ. The solid and dotted curves (green) show theoretical calculations given in Ref. [31] and [32], respectively. The dashed curve (red) shows the fitted function in Eq. (1): a sum of three BW peaks and phase-space contributions. Each contribution to it is shown in a dash-dotted curve (magenta). The lower hatched histograms (blue and cyan) show the systematic errors of σ in this work and in Ref. [6], respectively.

Germany ELSA Facility,PL**832**,137277

The same reaction $\gamma d \to d + \pi^0\pi^0$, from threshold($\approx 2.145 GeV$) to cms energy 2850MeV

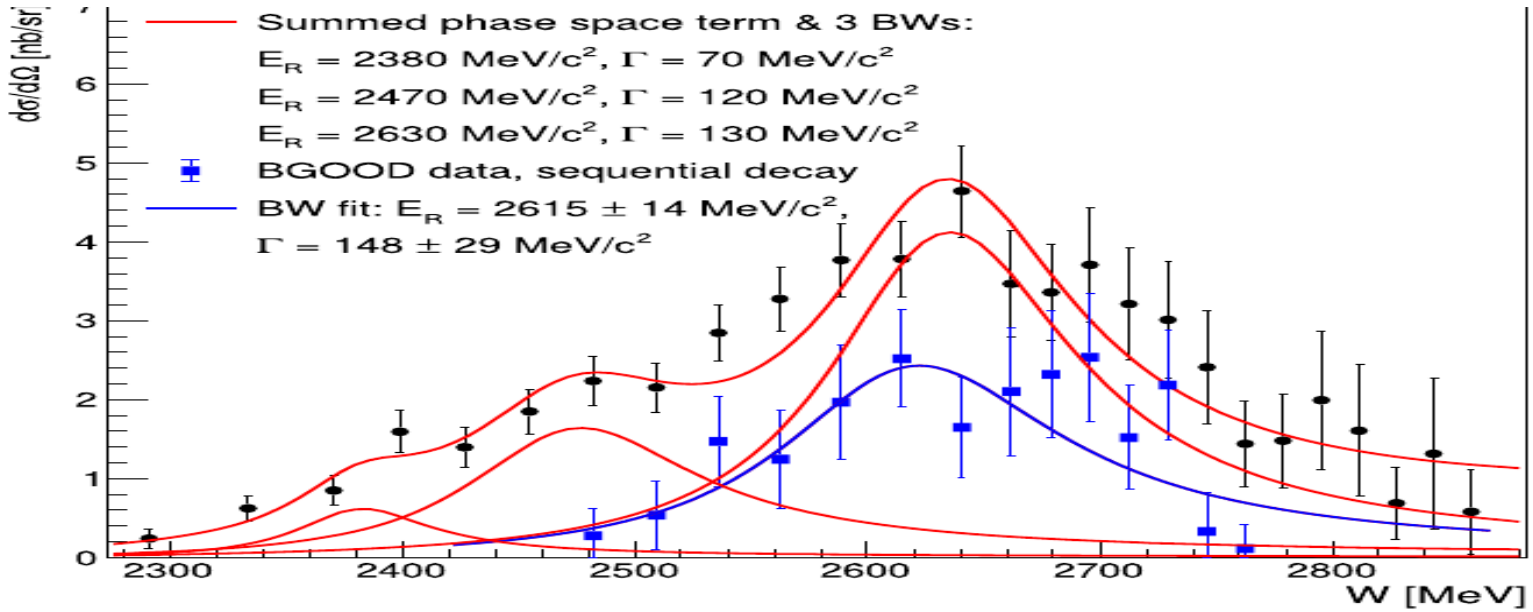


Fig. 7. $\gamma d \to \pi^0\pi^0 d$ differential cross section for $\cos\theta^d_{CM} > 0.8$ (the same as in Fig. 5). A fit including three Breit-Wigner functions (BW) are shown as the red lines, with the fixed masses and widths labelled inset. The additional small centre-of-mass momentum term described in the text is not shown. The blue square data points are the differential cross section for the first of the sequential dibaryon candidate determined from the $\pi^0 d$ invariant mass distributions shown in Fig. 9 with a Breit-Wigner function fitted and the mass and width labelled inset. Only the statistical uncertainties are shown.

Possibility of observing light dibaryons in proton proton collisions

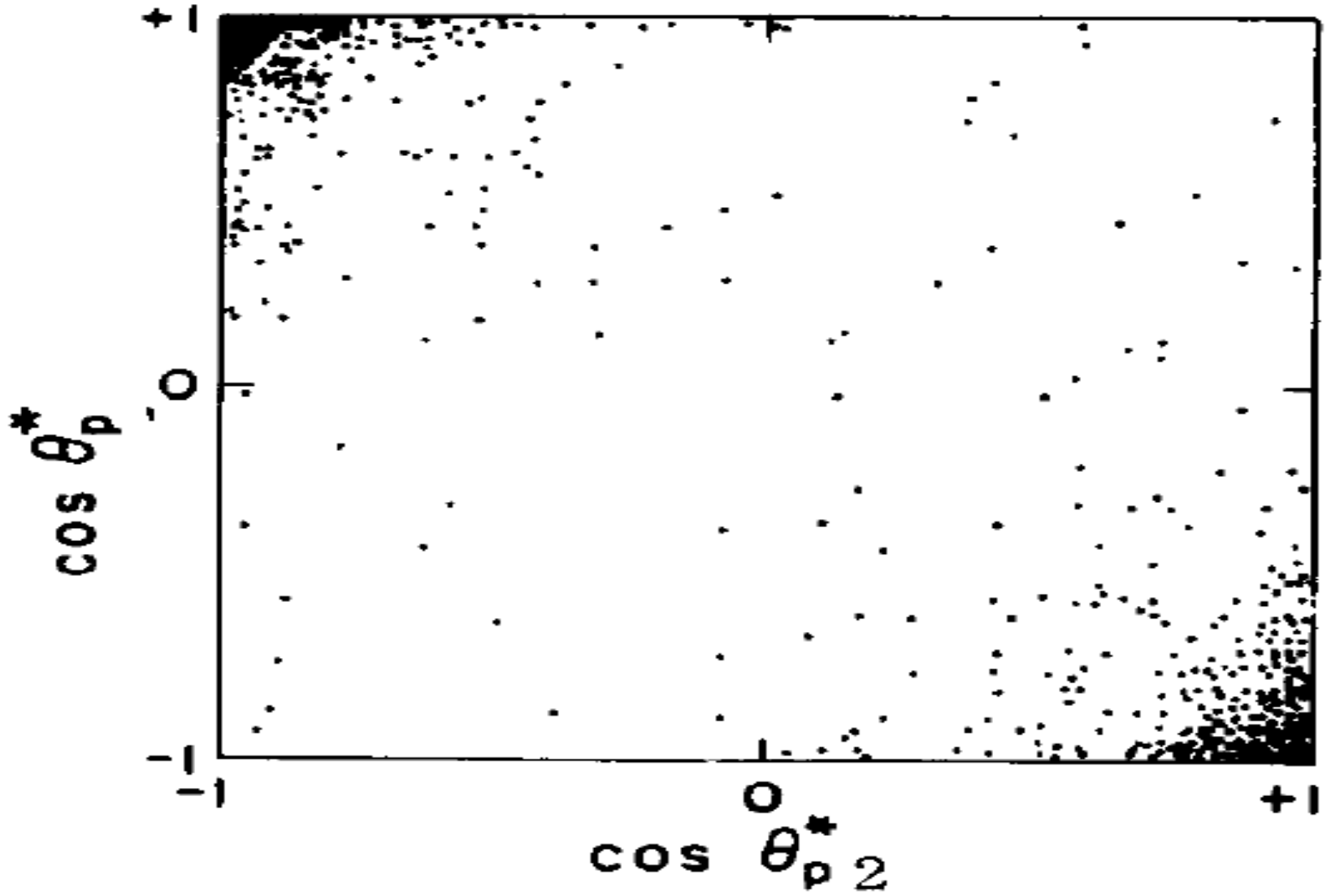
In a paper by G.Yekutielli et al. [Nucl. Phys. B18(1970)301] cross section of reaction $pp \to pp + \pi^+ + \pi^-$ was measured in a kinematical range close to that studied in a paper by Yu.A. Troyan[Particles and Nuclei,vol 24,294] in which indications were obtained for the existence of isovector dibaryons.The cross sections most of the processes in the paper of by G.Yekutielli et al. had been well explained by the models of proton resonance excitations or soft peripheral interactions. A relatively small number of events $(4-5)\%$ could not be explained in this way. They correspond to rows (C),(D) and (E) in the table, where particles that exit in the same hemisphere(front or back relative to beam direction) are grouped in parentheses

Clusters.

Combinations	Number of events	Percentage
(A) $(p\pi^+)$ + $(p\pi^-)$	719	47%
(B) $(p\pi^+\pi^-)$ + p	740	49%
(C) (pp) + $(\pi^+\pi^-)$	47	3%
(D) $(pp\pi^+)$ + π^-	12	1%
(E) $(pp\pi^-)$ + π^+	6	$\frac{1}{2}$%

From a physical point of view, it is clear that in the cases (C),(D), and (E), the proton pair in the final state had very small internal energy as a result of its deep "cooling" by one or two secondary pions
It is very plausible to assume that in case (C), the pions in the final state were formed after the proton pair emitted a heavier meson,such as $\rho \to \pi^+ + \pi^-$.It is also plausible to assume that in cases (D) and (E),most of the excitation energy was carried away by a single high-energy pion, while the second pion provided a small additional cooling of proton pair, converting it into a light dibaryon. The total cross section of all the processes presented in the table is equal to $3.0 \pm 0.3 mb$. The total cross sections of the processes of interest (C),(D), and (E) can be easily found using their percentage in the table. They are approximately equal to 0.12mb in the energy region used by Yu. A.Troyan to detect them. This allows us to estimate the time required to use the collider to generate the desired number of events.

Using the results of the paper by G.Yekutielli et al.,it is also possible to adjust the kinematics of event selection already at the proton registration stage so that they contain almost nothing extra, only light dibaryons. So, in this paper, a 2-D graph is shown on which the angles of departure of both outgoing protons relative to the beam axis in the cms are plotted. They match the angles of protons departure in the laboratory coordinate system at NICA SPD The two high density clusters of points in the upper left and low right corners of the figure correspond to soft scattering processes that do not contain protons produced by the decay of dibaryons. The most interesting events are those in which the final state protons are travelling at approximately the same angle to the axis of the colliding beams. There are very few of such events, but they do exist. Among them, we should look for evidence of the existence of light dibaryons. If successful, this will allow us to estimate the effective masses of the outgoing proton pairs and compare them with the masses of the light dibaryons that Yu.A. Troyan could observe earlier[Particles and Nuclei,vol 24,294]


+1
0
−1
−1
0
+1
cos θ*p 1
cos θ*p 2

In which mass region should we look for a light isovector dibaryon that decays into two protons?

Among the recent publications in which observation of isovector dibaryons were announced, papers of **collaborations ELPH** and **BGOOD** should be mentioned.

Observation of dibaryon with mass **of 2140 ± 11** MeV was reported in **ELPH Collab. [Phys. Lett. B 789 (2019) 413**.

Observation of an isovector dibaryon with mass of **2117 MeV**, which was produced after the emission of a neutral pion by one of the heavier isoscalar dibaryons observed in these experiments too was reported in **BGOOD, Phys. Lett. B832 (2022) 137277; J. Phys. Conf. Ser. 2586 (2023) 012003** .

In which mass region should we look for a light isovector dibaryon that decays into two protons?

In an earlier paper by **JLab Hall A Collaboration, PRL 99, 072501 (2007),** which studied the knocking out of pairs of high-momenta nucleons from the *12C* nucleus, the complete kinematic analysis of the process of knocking out two protons was performed, the results of which are presented in the following figure

PRL 99, 072501 (2007)

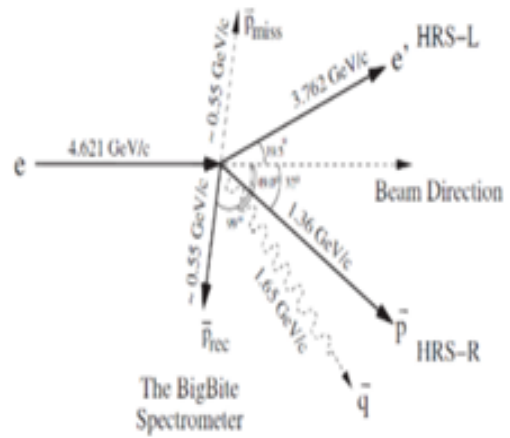


FIG. 1. A vector diagram of the layout of the $^{12}C(e, e'pp)$ experiment shown for the largest p_{miss} kinematics of 0.55 GeV/c.

Using this data, it is easy to determine that approximately 290 MeV of accelerated electron energy was spent for knocking out the protons with the momenta shown in the figure. One of the possible interpretations of this calculation is the assumption that protons, before they were knocked out, were inside the nucleus in the form of a **dibaryon with a mass of 2167 MeV**, which could occur in the nucleus in virtual form for a short time τ ~ 2 10^-21 seconds.

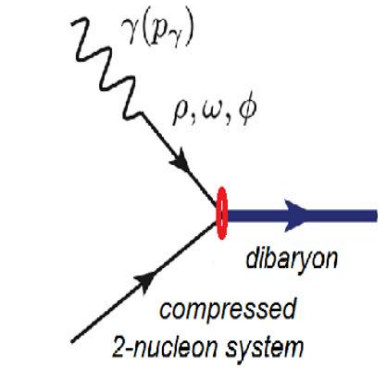
In which mass region should we look for a light isovector dibaryon that decays into two protons?

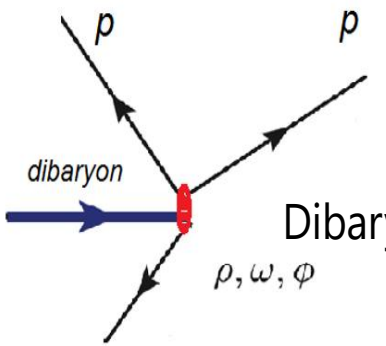
The possibility of the existence of an isovector dibaryon decaying into two protons, with a mass close to all of the above values, is also indicated by the data of **Yu. A. Troyan, ECHAYA 24 (1993) 683**, which even earlier reported the observation of a dibaryon with a mass of **2172 ± 5 MeV**.

Conclusion. The available experimental data, including those obtained recently, allow us to hope that at the first stage of experiments at NICA SPD there is a real opportunity to detect an **isovector dibaryon with a mass in the range of 2117-2177 MeV**, which is produced in reaction **pp → dibaryon π+ π -**

(C) (pp) + (π^+ π^-)

Vector dominance model





Dibaryon decay

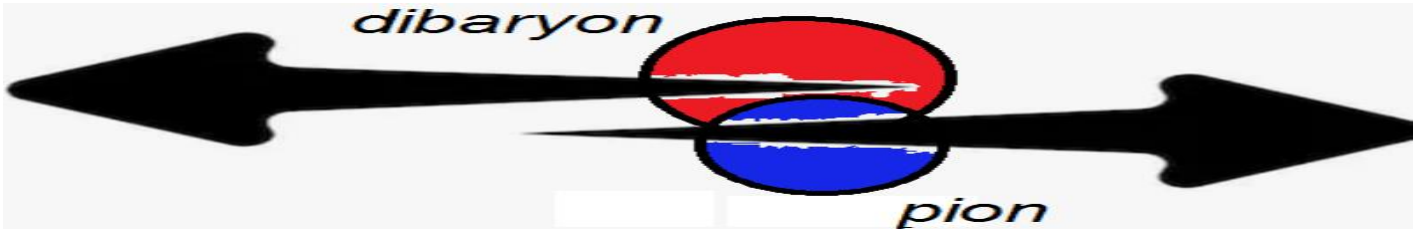
In the BGOOD experiment dibaryons were excited in deuteron by bremsstranhlung photons which, according to the vector dominance model, turn into vector mesons before collissions.

It is reasonable to suppose that deexcitation of the initially excited dibaryons is realized by means of the inverse process, i. e. via a vector meson radiation.

The ρ meson has a high branching fraction for the $\pi^+\pi^-$ decay mode, while the ω meson decays almost entirely into $\pi^0\pi^+\pi^-$. Although these events were omitted from the table in Yekutieli et al., they should naturally be included in row C. Even without π^0 detectors during the initial phase of the NICA SPD experiments, neutral meson identification will be feasible via the missing mass method.

Lines D and E of the Table

are naturally described by a model of cumulative pion, which is flying in the direction opposite to the direction of the dibaryon.



Line D: (p p π+)π–

Here, the hypothetical dibaryon has an electric charge of 3. At the quark level, it should consist of of five u quarks and one d quark.
There are also models describing the internal structure of this dibaryon as a bound state of proton and Delta++, see [A Valcarce et al, Rep. Prog. Phys. 68 (2005) 965].

Line E: (p p π–) π+

Here, the dibaryon has the same quark content as the deuteron. However, it can be not only an isoscalar but also an isovector. They can be distinguished by the effective mass of the $(pp\pi^-)$system.

Unlike the processes of dibaryon production, which are accompanied by the formation of vector mesons, rows D and E from the table in the paper by Yekutieli et al. may correspond to cascade decay processes of two dibaryons. In this case, the first, heavier dibaryon may be produced immediately after the emission of a cumulative meson, which carries away a significant part of the energy of the colliding protons. In turn, the dibaryon formed after this may itself decay into a pion and a lighter dibaryon, breaking into two protons

Our proposal

Hypothesis **is** $pp \rightarrow R^* + \pi^+ + \pi^-$, where R^* - dibaryon decaying into two protons. Our aim is to simulate this reaction in the framework SPD setup, to see anticipated accuracies, counting rates,etc. We took one of the resonances from paper Yu. A. Troyan, Particles and Nuclei 24, 294, namely dibaryon with mass equal to 1980 MeV and width $\Gamma = 6MeV$. Momentum of Collider proton was equal to 2GeV/c. The dynamics of reaction was simulated according to phase space.In a fig. 1 we show momenta of all the particles in a final state.

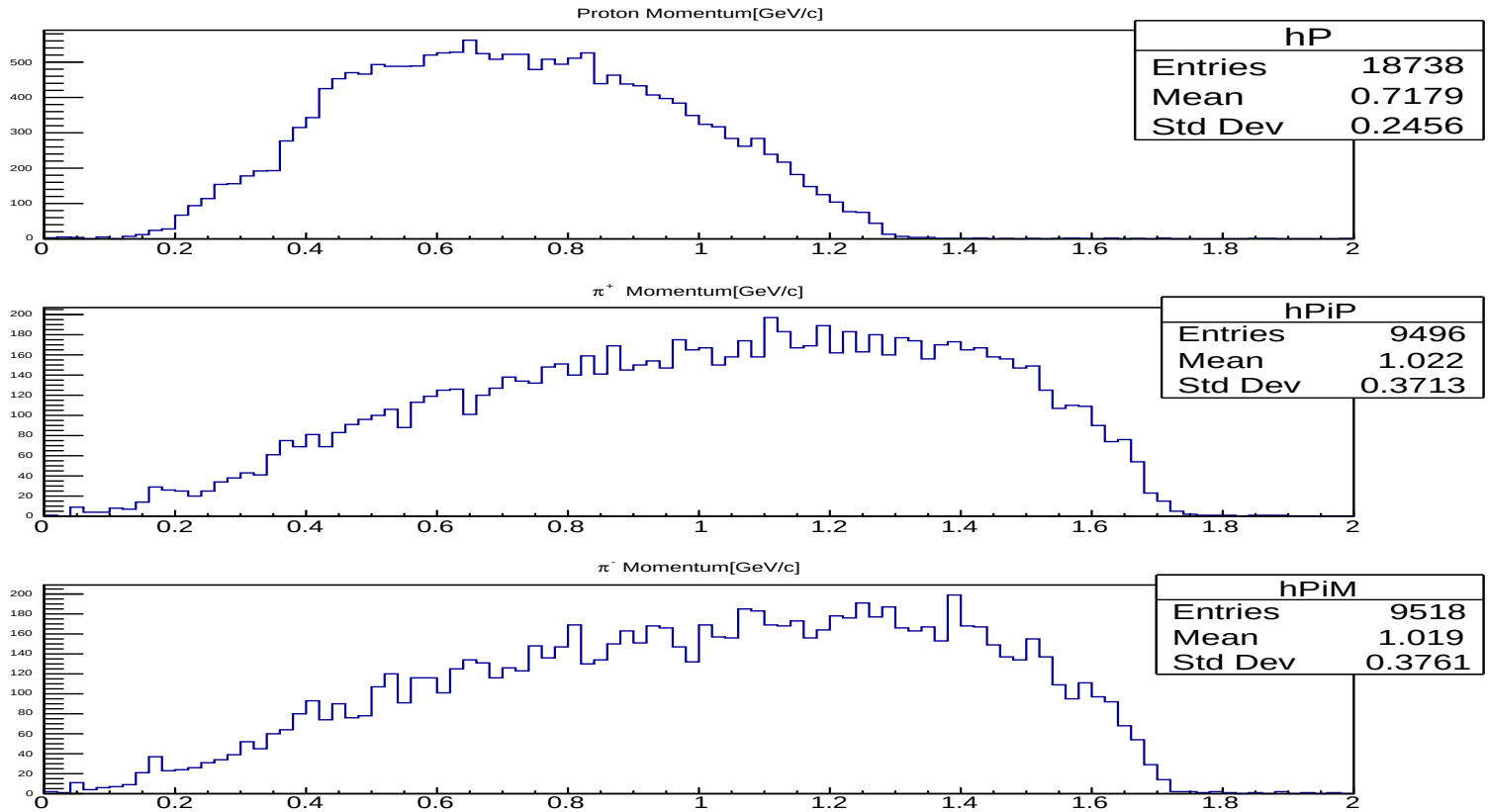


Figure 1: Momentum Spectra[GeV/c] of the particles in a final state

Accuracy of proton reconstruction

We generated 10000 events of the reaction using as Vertex Detector DSSD option and then applying all standard cuts of SpdRoot.We selected only events when all four particles were successfully reconstructed and at the end we had $\approx$ a little less than 8 thousand events(7960). During the reconstruction we used kinematical fitting technique in the version of the method published V.I. Moroz, Preprint JINR, P-1958, Dubna (1965). In fig. 2 we show the accuracies without(upper picture) and with(low picture) kinematical fit in the reconstruction of momentum.

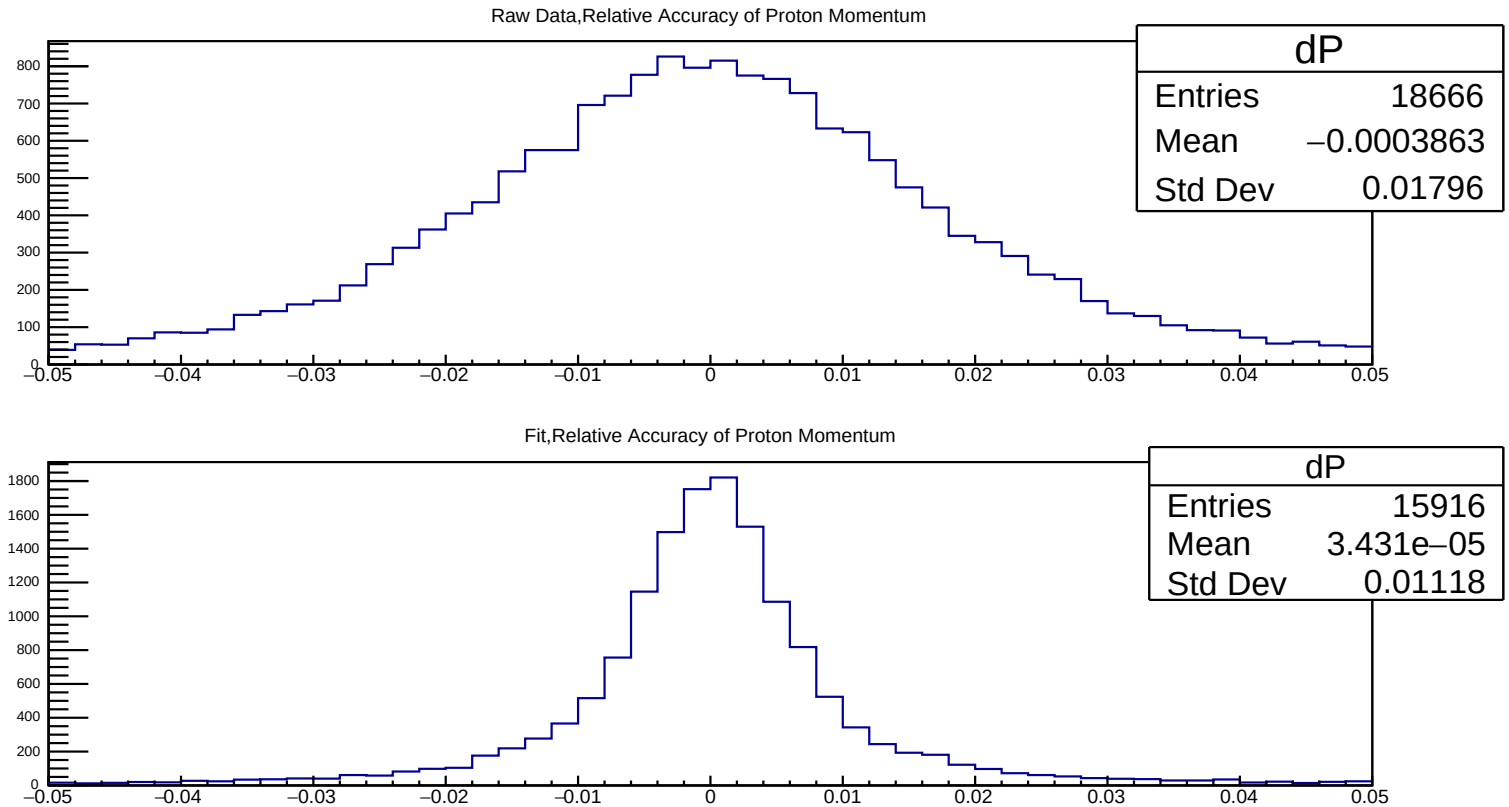


Figure 2: $(|P_{rec}| - |P_{true}|)/|P_{true}|)$,Relative Accuracy in the reconstruction of proton momentum

Angular Accuracies

Here we demonstrate only accuracies, obtained with applying kinematical fitting. All the values shown are in degrees

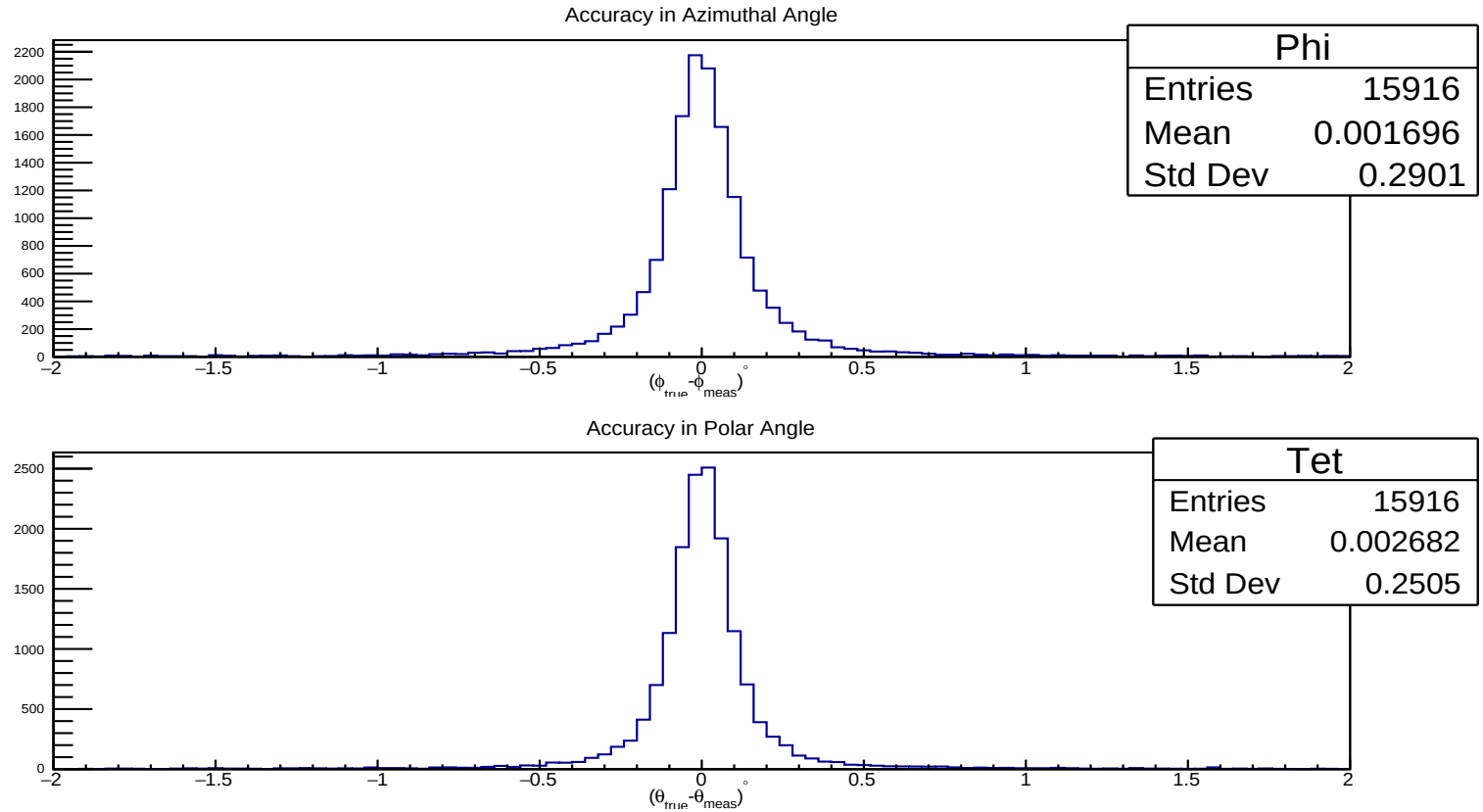


Figure 3: Angular Accuracies(applying kinematical fit) in the reconstruction of proton momentum in the degrees,upper picture for azimuthal angle,low one for polar

Accuracies in Dibaryon masses reconstruction

In a fig. 4 we show distribution, having rather methodical character. It demostrates how to process data to get better accuracy in the dibaryon mass reconstruction

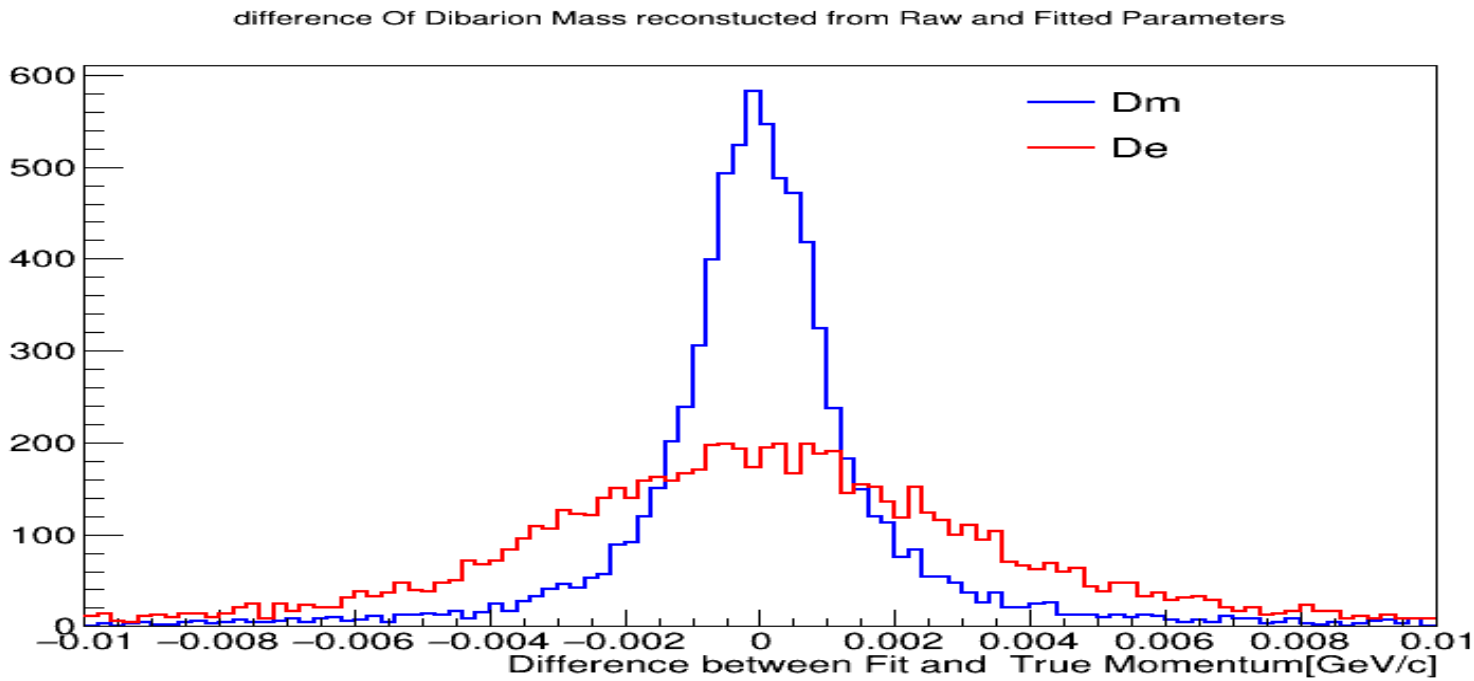


Figure 4: Histogram showing distribution of differencies between generated dibaryon mass and reconstructed ones : blue - for the values after kinematical fit ,red - for the values from raw data in [GeV]

Few commentaries about minimizing method

In a fig. 5 we show histogram illustrating the results of the method of kinematical fit proposed by V.Moroz. Briefly the estimates of parameters is being found by minimizing the function, which is usual χ^2 plus so called Heavy Term. Heavy Term is the sum of the constraints divided by its error formally calculated; The ratio constraint to its error is taken in square. Here we will not explain how errors are calculated(see original paper). This sum is multiplied by big number- that is why this minimization is called as Method With Heavy Term. By the picture you may see that Heavy Term turns to zero at the minimum

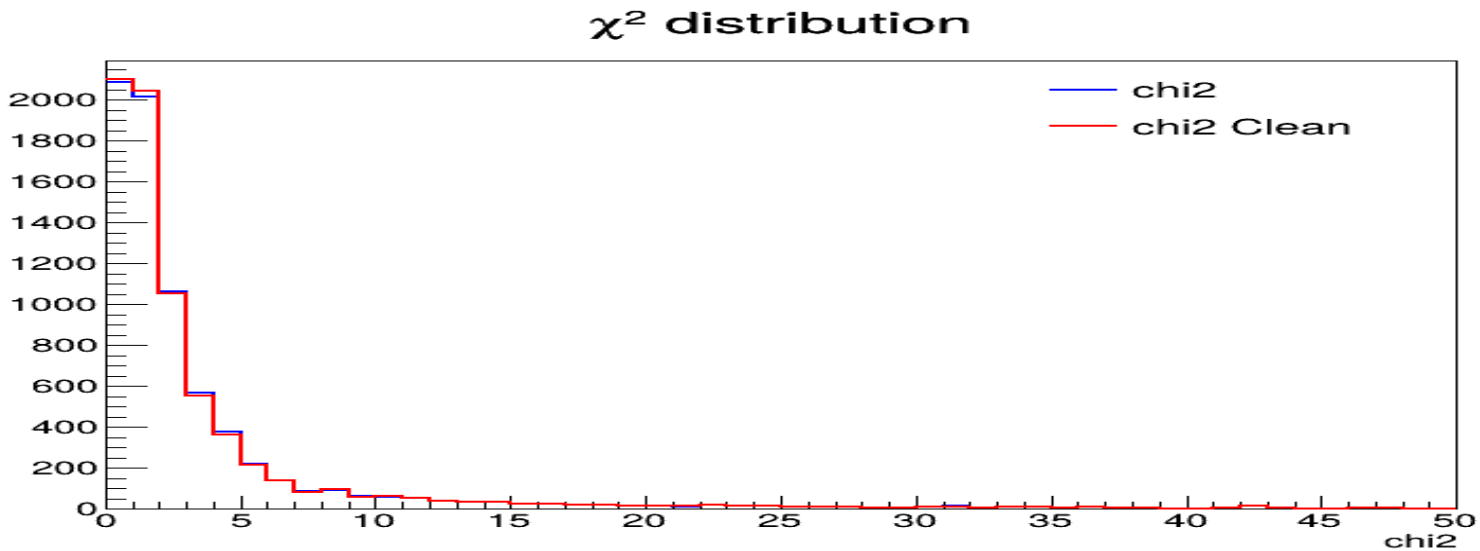


Figure 5: chi2Clean - is just pure χ^2, chi2 - full function

Dibaryon masses

In a fig. 6 we show dibaryon mass distribution, where blue histogram shows the distribution produced by the generator and red one is the the distribution built from reconstructed values using kinematical fitting.We may see that Breight- Wigner distribution form, describing the decay of resonance is reproduced by the parameters, found during estimation

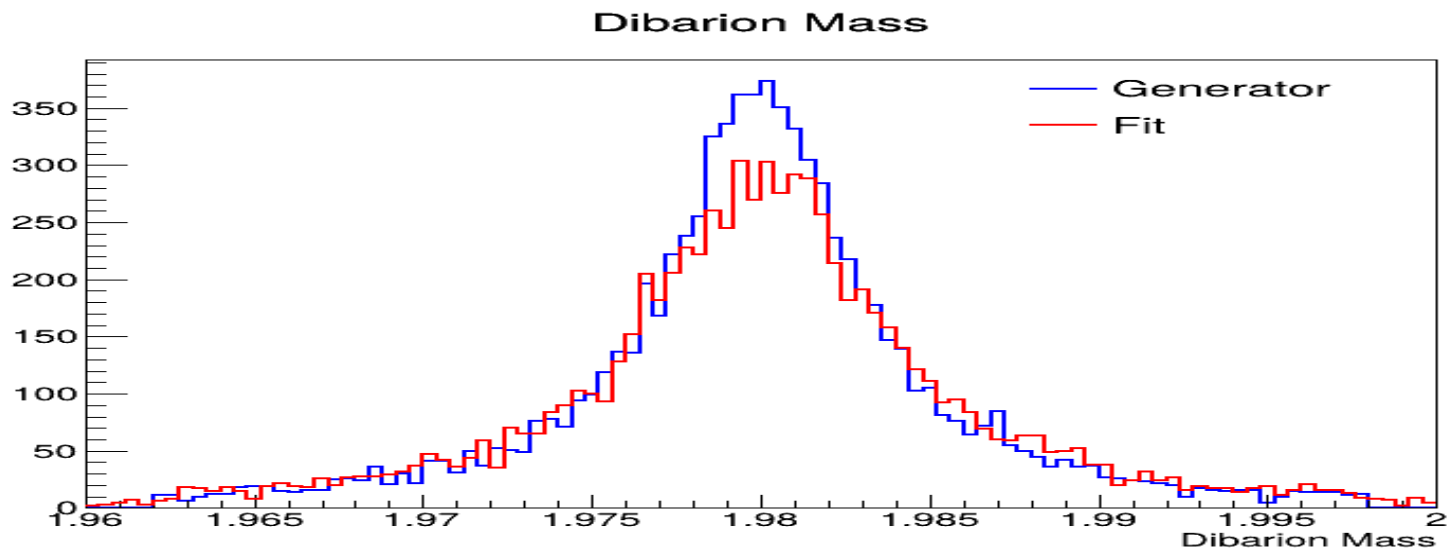


Figure 6: Histograms showing dibaryon mass[GeV] distribution, generated(blue) and reconstructed(red)

Counting rate

It is very interesting to estimate hypothetical counting rate, if we assume that all the events of the reaction 1C(see table 4 in YEKUTIELI et al.) are delivered with the production of dibaryon. If we take cross section equal to $0.09mb$(see table 4 in YEKUTIELI et al.),for the luminosity of pp interaction at 2GeV/c $\approx 2 \cdot 10^{28} cm^2 \cdot sec^{-1}$ we obtain about ≈ 2 evnts/sec. Of course it is too optimistic, still it shows the perspective of such type investigation.