

An alternative explanation for the dibaryon suggested by experiments at the WASA facility at Julich.

D V Bugg ¹

Queen Mary, University of London, London E1 4NS, UK

Abstract

A series of publications of the WASA collaboration culminates in a recent paper of Pricking, Bashkanov and Clement [1] claiming a $\Delta\Delta$ dibaryon resonance at 2370 MeV. However, as explained here, there are logical flaws in this result. A natural alternative arises from the reaction $pd \rightarrow NN^*(1440)p_s$, where p_s is a spectator proton. There is supporting evidence from a recent experiment of Mielke et al. on $dp \rightarrow {}^3He\pi^+\pi^-$.

PACS 13.75.Cs, 14.20.Gk.

There has been a series of publications by the WASA collaboration working first at CELSIUS, then at Julich, over the years 1997 to the present. The most relevant will be referenced here. They have located a signal at 2370 MeV which they claim to be a “hidden” dibaryon. They have studied many reactions using a variety of kinematics to locate this signal. The dibaryon is claimed to exist in pd scattering to 5-body final states: $pd \rightarrow \Delta\Delta p_s$, where Δ refers to $\Delta(1232)$. At 2370 MeV, the average Δ mass is 1185 MeV. At this mass, the average phase of each Δ is just below 45° . Why should two subliminal Δ produce a dibaryon resonance?

In Ref. [1], WASA claim a 0.8 mb $I = 0$ signal in the final state $np\pi^+\pi^-$. This is a factor ~ 14 smaller than the peak cross section observed in $I = 0$ total cross sections at Rutherford Lab [2]. These total cross sections had a statistical accuracy of $\pm 0.1\%$ and point to point errors of $\pm 0.2\%$. There was a possible overall normalisation error of 2 mb but varying slowly with momenta over the entire range up to 8 GeV/c; the systematic uncertainty over the $\Delta\Delta$ peak is < 0.4 mb. There was no sign of a dibaryon in total cross sections near the $\Delta\Delta$ peak. One would expect such a resonance to lie close to the peak of the $\Delta\Delta$ cross section, but there is no sign of any such effect in the total cross sections of Ref. [2].

1 An alternative explanation

There is an obvious alternative explanation for the peak at 2370 MeV from the production of the final state $NN^*(1440)$, whose masses add to 2379 MeV, well within errors of the $N^*(1440)$ mass. Fig. 1 sketches the kinematics of this process, which generates 5 particles in the final state from 3 in the initial state. Subscripts f and s in the figure identify fast and slow particles in the lab frame. The top of the figure displays the production of a neutral $N^*(1440)$ and the lower part shows production of a charged $N^*(1440)$. Interchanging the π^- and π^+ in the final state generates Δ^- and Δ^0 intermediate states. So there are 4 configurations of Δ whose Clebsch-Gordan coefficients are taken into account in fitting experimental data. The $\Delta(1232)\pi$ branching ratio of $N^*(1440)$ is 20 – 30% according to Particle Data Tables [3].

A prominent effect in WASA data is the ABC effect of Abashian, Booth and Crowe [4] [5]. Fäldt and Wilkin first outlined this effect [6]; Gardestig, Fäldt and Wilkin [7] extended it to the

¹email: david.bugg@stfc.ac.uk

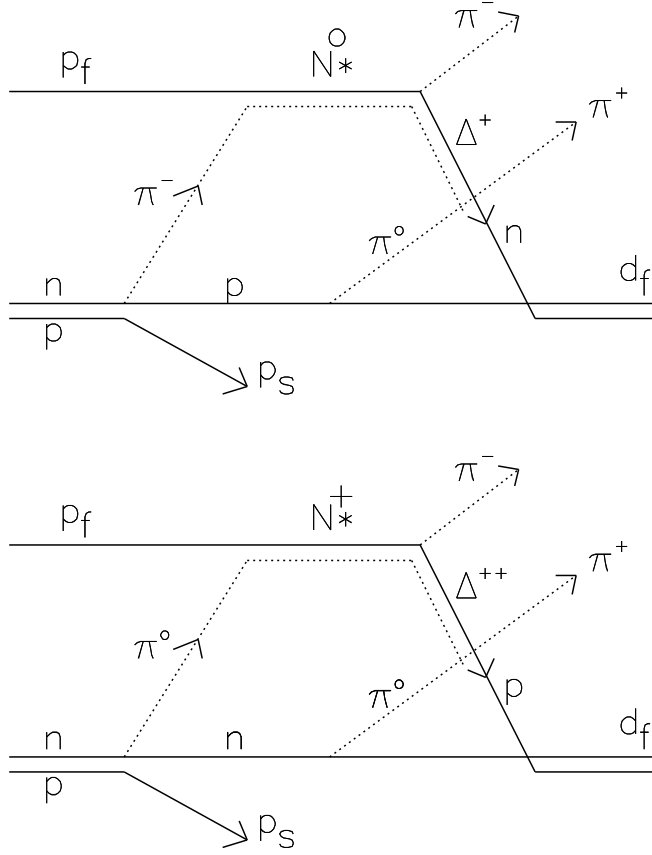


Figure 1: The kinematics of the reaction $pd \rightarrow NN^* \rightarrow \pi^+\pi^-dp_s$

reaction $pd \rightarrow \pi^3He$ to explain an early result from WASA at CELSIUS. Production of 3He is favoured if the pion has a low momentum; otherwise production of a low momentum pion would be strongly suppressed by Chiral Symmetry Breaking. The end result is that there are 3 coupled channels: $^3He\pi$ from the ABC effect, together with production of $d\pi^+$ and $d\pi^-$ pairs in Fig. 1.

The recent paper of Mielke et al. [8] presents new data using the inverse kinematics to the COSY-WASA experiment: $dp \rightarrow ^3He\pi^+\pi^-$ rather than $pd \rightarrow \Delta\Delta\pi$. They detect the well known ABC enhancement in the $^3He\pi^+$ and $^3He\pi^-$ spectra, but differences between data for these two channels require some interfering $\pi\pi$ production at low excess energies. They model these differences in terms of $N^*(1440) \rightarrow [\Delta(1232)\pi]_{L=1} \rightarrow N\pi\pi$, where L is the orbital angular momentum between Δ and π .

Readers are referred to a paper of Bashkanov *et al* on $pp \rightarrow nn\pi^+\pi^-$ at 1.1 GeV [9]. These data reveal a definite peak in the fourth panel of their Fig. 3 at ~ 1400 MeV, appearing slightly lower than 1440 MeV because of limited phase space. One would expect a similar peak in $np \rightarrow NN^*(1440)$. WASA instead attributed the peak to $\Delta(1600)$. However, $\Delta\pi$ decays of $S_{11}(1640)$ have orbital angular momentum $L = 2$. The centrifugal barrier factor already suppresses this decay mode near threshold. In fact, this $L = 2$ barrier distinguishes $S_{11}(1640)$ from $S_{11}(1535)$ distinctively. So its low momentum tail cannot be as narrow as the peak seen in WASA data.

Why is the peak at 2370 MeV so narrow? WASA find a width of 70 MeV. This is much

narrower than the width quoted for $N^*(1440)$ in Particle Data tables [3]. However, there is a straightforward origin of this effect. Readers are referred to a paper of Nakamura [10] which provides a figure showing the variation of the real and imaginary parts of the $N^*(1440)$ amplitude. The real part of the amplitude peaks at 1370 MeV and the imaginary part peaks at 1460 MeV. Accordingly, there is a 45° change in the phase of $N^*(1440)$ over this mass range. This phase variation will introduce structure into the interference between $NN^*(1440)$ and $\Delta\Delta$ over a narrow range of 90 MeV using Nakamura's estimate of the mass, or 70 MeV using the PDG mass. This phase variation cannot be calculated a priori because of the three isobar model phases for the three coupled channels from the ABC effect and production of $d\pi^+$ and $d\pi^-$. These phases arise from multiple scattering amongst the 5 particles in the final state. It is therefore necessary to fit phases to the WASA data.

An early paper of Bashkanov *et al* shows in their Fig. 4 a blue curve for $pn \rightarrow d\pi^0\pi^0$ with a long tail extending to > 3 GeV [11]. This tail can arise from interference between the $NN^*(1440)$ signal and the remains of a $\Delta\Delta$ signal. Their red curve shows the cross section for $pn \rightarrow d\pi^+\pi^-$. A later paper of Adlarson *et al* [12] revises the result for $pn \rightarrow d\pi^+\pi^-$. In Fig. 1 of this paper, the peak at 2370 MeV of $pn \rightarrow d\pi^0\pi^0$ moves down slightly and a rising tail appears, joining on to the earlier results of Bashkanov *et al*. The difference between $d\pi^0\pi^0$ and $d\pi^+\pi^-$ can arise from different isobar model phases for the three coupled channels ${}^3He\pi$ of the ABC effect and production of $d\pi^0$ or $d\pi^+ + d\pi^-$. These effects are capable of explaining the 0.8 mb cross section evaluated for the peak at 2370 MeV in the latest paper of Pricking *et al* [1].

Consider next decays of $N^*(1440)$. Below a mass of 1204 MeV, phase shifts of Carter *et al* [13] are negative; this arises from the level repulsion between the nucleon and $N^*(1440)$ which have the same quantum numbers. The phase shift then rises rapidly and reaches 20° at 1320 MeV and the analysis of Nakamura shows that it reaches 45° at 1370 MeV; over this mass range, decays to $N\sigma$ are dominant. Then decays to $\Delta(1232)\pi$ rise rapidly as its phase space increases. This channel accounts for the rapid rise of the imaginary part of the $N^*(1440)$ amplitude.

There is a corollary concerning the figure of Nakamura [10]. The decay of $N^*(1440) \rightarrow \Delta(1232)\pi$ produces a P-wave pion. The real and imaginary parts of amplitudes shown in his figure resemble a broad P-wave cusp in the $\Delta(1232)\pi$ channel. The real part of the amplitude peaks first, followed by a peak in the imaginary part of the amplitude; this is characteristic of a cusp in the P-wave, where the centrifugal barrier delays the peak in the imaginary part [14].

In the late 1970's there were claims for the existence of several dibaryons in the reaction $pp \rightarrow d\pi^+$ over lab kinetic energies of 600–800 MeV in 1D_2 , 3F_3 and 3P_2 partial waves. However, these claims were eventually disproved by a partial wave analysis which included many sets of spin dependent data produced by the Geneva group working at PSI [15] and by several groups at LAMPF in the range of lab kinetic energies 500-800 MeV. In addition, many spin dependent measurements were made at LAMPF using a polarised proton beam whose spin could be rotated to three orientations: the N direction, normal to the plane of scattering, the S (sideways) direction in the plane of scattering and normal to the beam, and the L direction (Longitudinal) along the beam. These protons scattered from a longitudinally polarised target [16]. The data determined magnitudes and phases of all partial waves up to 3F_3 [17], except that the phase of one small partial wave, 3F_2 , needed to be constrained to a calculation done by Blankleider [18], and extended later by Blankleider and Afnan [19]. Earlier than this, Hoenig and Rinat predicted in 1974 that loops would appear on the Argand diagrams for $\pi d \rightarrow NN$ amplitudes from projection of the $\pi N P_{33}$ resonance when πd kinematics and Fermi motion are

folded in [20]; that was precisely how it turned out eventually.

An extension of the LAMPF experiment determined the spin dependence of $pp \rightarrow np\pi^+$ from 492 to 796 MeV lab kinetic energy [21]. Spin correlation parameters $A_{LL}, A_{SL}, A_{NL}, A_{NO}, A_{SO}, A_{L0}$ and A_{0L} were measured. The parameter A_{N0} alone is not sufficient to determine the full Argand plot of amplitudes and their interferences. In the representations popularly used, it measures the imaginary part of the interferences between amplitudes. The parameter A_{S0} measures the real part of the same interferences. There is a general theorem for all final states that A_{SL} measures the imaginary part of exactly the same amplitudes and is therefore a very powerful constraint. There is limited sensitivity in the parameter A_{NL} because of the longitudinal orientation of the target polarisation.

Results from this experiment ruled out broad dibaryons in this mass range in the dominant NN 3P_2 and 3F_3 partial waves and smaller partial waves were negligibly small [22]. In the 1D_2 amplitude, a phase variation of 33° was observed. The conclusion was that the 360° phase variation required for a dibaryon resonance was definitely ruled out. A further remark is that there is presently no evidence for the existence of the H dibaryon.

It would be very important if $\Delta\Delta$ dibaryons exist. However, this needs to be proved. The WASA data presently contain only one phase sensitive measurement, A_{N0} . This is inadequate for a full determination of all partial waves. The key point is that a claim for the existence of a dibaryon resonance must map out the phase variation in the Argand diagram and prove the existence of a pole. There are data for A_{xx} and A_{yy} , but these depend only on intensities. So there is insufficient data at present to map out Argand diagrams for individual partial waves. Without these Argand diagrams, there is no proof of the existence of a dibaryon. What is needed is to use a polarised proton beam to study the same set of parameters as were measured at LAMPF. It would require the use of a solenoid to rotate the beam polarisation and a polarised target. This would extend enormously the physics content of the data. From such an experiment it should be possible to establish in a single run whether the $NN^*(1440)$ channel accounts for the present WASA data and how it interferes with $\Delta\Delta$ final states. This should hopefully complete the WASA experiments on this topic.

References

- [1] A. Pricking, M. Bashkanov and H. Clement arXiv: 1310.5532.
- [2] D.V. Bugg *et al.* Phys. Rev. **146** 980 (1966).
- [3] J. Beringer *et al.* (Particle Data Group), Phys. Rev. D **86** 010001 (2012).
- [4] A. Abashian, N.E. Booth and K.M. Crowe, Phys. Rev. Lett. **6** 258 (1960).
- [5] N.E. Booth, A. Abashian and K.M. Crowe, Phys. Rev. C **132** 2296 (1963).
- [6] A. Fäldt and C. Wilkin, Phys. Rev. C **56** 2067 (1997), arXiv: nucl-th/970144.
- [7] A. Gardestig, A. Fäldt and C. Wilkin, Phys. Lett. B **421** 41 (1998).
- [8] M. Mielke *et al.* arXiv: 1404.2066.

- [9] M. Bashkanov *et al.* arXiv: 1012.1463.
- [10] S.X. Nakamura, arXiv: 1106.3599, AIP Con. Proc. **1432** 301 (2012).
- [11] M. Bashkanov *et al.* Phys. Rev. Lett. **102** 052301 (2009), arXiv: 0806.4942.
- [12] P. Adlarson *et al.*, Phys. Lett. B **721** 229 (2013), arXiv: 1212.2881.
- [13] J.R. Carter, D.V. Bugg and A.A. Carter, Nucl. Phys. B **58** 378 (1973).
- [14] D.V. Bugg, J. Phys. G **35** 075003 (2008), arXiv: 0802.0934.
- [15] G.M.N. Cantale *et al.*, Helv. Phys. Acta **60** 398 (1987).
- [16] R. L. Shypit *et al.*, Nucl. Phys. A **477** 541 (1988).
- [17] D.V. Bugg, A. Hasan and R.L. Shypit, Nucl. Phys. A **477** 546 (1988).
- [18] B. Blankleider, Flinders Univ. report FLAS-R-72 (1980).
- [19] B. Blankleider and I.R. Afnan, Phys Rev. C **31** 1380 (1985).
- [20] M.M. Hoenig and A.S. Rinat, Phys. Rev. C **10** 2102 (1974).
- [21] W.M. Kloet and R.R. Silbar, Phys. Rev. Lett. **45**, 970 (1980).
- [22] R.L. Shypit *et al.* Phys. Rev. C **40** 2203 (1989).