Scrutinizing the evidence for N(1685)

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The helicity-dependent observable E for the reaction $\gamma d \to \eta n(p)$ with a spectator proton was recently measured by the A2 Collaboration at MAMI in Mainz. The data were interpreted as further evidence for a narrow resonance with spin and parity $J^P = 1/2^+$ (P_{11} wave). However, a full partial wave analysis without any narrow resonance leads to an excellent description of the data; imposing a narrow resonance with the properties suggested by the A2 Collaboration leads to a significant deterioration of the fit quality: there is no need for a narrow resonance.

A narrow structure was observed at a mass of about 1685 MeV in the $\gamma d \to \eta n(p)$ excitation function [1–7]. The structure was interpreted [8, 9] as the non-strange member of the antidecuplet of pentaquarks with spin-parity $J^P = 1/2^+$ predicted by Diakonov, Petrov, and Polyakov [10]. In 2012, the observations reported in [1, 3, 6] were introduced into the Review of Particle Properties (RPP) under the heading of a new one-star nucleon resonance $N(1685)$ [11] but was removed from the listings in the most recent issue of RPP [12]. The interpretation of the structure as narrow resonance was supported by further studies [13–16], the results reported in [17] were ambiguous. In a study of the helicity asymmetry of the reaction $\gamma p \to \eta p$, no evidence for $N(1685)$ was found [18].

However, also coupled-channel and interference effects of known nucleon resonances have been discussed in the literature to explain the narrow structure. The Gießen group interpreted the narrow dip in the $\gamma d \to \eta n(p)$ excitation function as $N(1650)1/2^-$ and $N(1710)1/2^+$ coupled-channel effect [19], Shyam and Scholten assign the dip to interference effects between the $N(1650)1/2^-$, $N(1710)1/2^+$, and $N(1720)3/2^+$ resonances [20]; alternatively, the dip could be produced to effects from strangeness threshold openings [21].

The narrow dip can, however, also be explained naturally by interference effects in the $J^P = 1/2^-$ wave [17, 22–24]. In [24], the precise data reported by the A2 Collaboration at MAMI [4, 5] were used to study the structure. It was found that it can be explained quantitatively by interference of the two nucleon resonances $N(1535)1/2^-$ and $N(1650)1/2^-$ within the $J^P = 1/2^-$ partial wave. Fits which included a narrow $J^P = 1/2^+$ resonance returned a zero production strength. If the properties of the narrow $J^P = 1/2^+$ resonance as reported in [4, 5] were imposed, the fit deteriorated significantly.

Recently, the A2 Collaboration at MAMI reported a measurement of the helicity-dependent double polarization variable E of the $\gamma d \to \eta n(p)$ reaction [25] where $E = (\sigma_{1/2} - \sigma_{3/2})/(\sigma_{1/2} + \sigma_{3/2})$, with σ_h being the cross section for $\gamma d \to \eta n(p)$ with neutron and photon spins aligned (helicity $h = 3/2$) or opposite ($h = 1/2$). Ex-

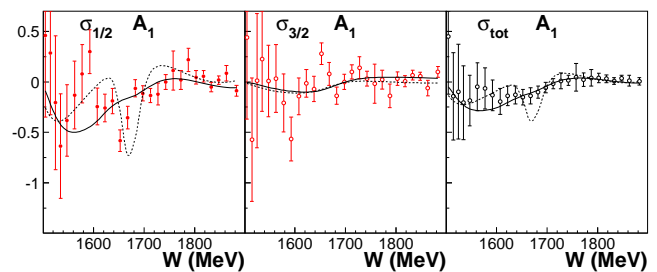FIG. 1: Legendre coefficients A_1 of the angular distributions of $\sigma_{1/2}$, $\sigma_{3/2}$ [25], and σ_{tot} for the reaction $\gamma d \to \eta n(p)$ where σ_{tot} is calculated as $(\sigma_{1/2} + \sigma_{3/2})/2$ as functions of the invariant mass W. The experimental results (red circles) are compared to a BnGa fit to the data of [4, 5] without a narrow resonance (solid curve) or a fit imposing a narrow resonance (dotted curve).

ploiting the data on the differential cross sections from [4, 5], the two helicity components were determined. The data show clearly that the structure originates from the $h = 1/2$ contribution. The authors fitted the angular distributions (five data points per energy interval) with third-order Legendre polynomial functions and found a narrow dip at 1650 MeV in the first order Legendre coefficient. They concluded: *The extracted Legendre coefficients of the angular distributions for $\sigma_{1/2}$ are in good agreement with recent reaction model predictions assuming a narrow resonance in the P_{11} wave as the origin of this structure.* In this paper we will show that their conclusions are incompatible with the data.

As a first step, we repeated the fit with Legendre polynomials. Figure 1 shows the first-order Legendre coefficients $A_1^{\sigma_{1/2}}$, $A_1^{\sigma_{3/2}}$, and $A_1^{\sigma_{\text{tot}}}$ as functions of the invariant mass W for fits to the angular distributions of $\sigma_{1/2}$, $\sigma_{3/2}$, and $\sigma_{\text{tot}} = (\sigma_{1/2} + \sigma_{3/2})/2$. The coefficients $A_0^{\sigma_{1/2}}$, $A_0^{\sigma_{3/2}}$, and $A_0^{\sigma_{\text{tot}}}$ are similar to the corresponding total cross sections, the coefficients A_2 and A_3 for the cross sections $\sigma_{1/2}$ and $\sigma_{3/2}$ are shown in [25]. In the coefficient $A_1^{\sigma_{1/2}}$ there is indeed a narrow dip at about 1650 MeV. Since the $J^P = 1/2^-$ partial wave dominates the reaction, significant contributions to $A_1^{\sigma_{1/2}}$ have to come from the interference between the $J^P = 1/2^-$ partial wave and P-
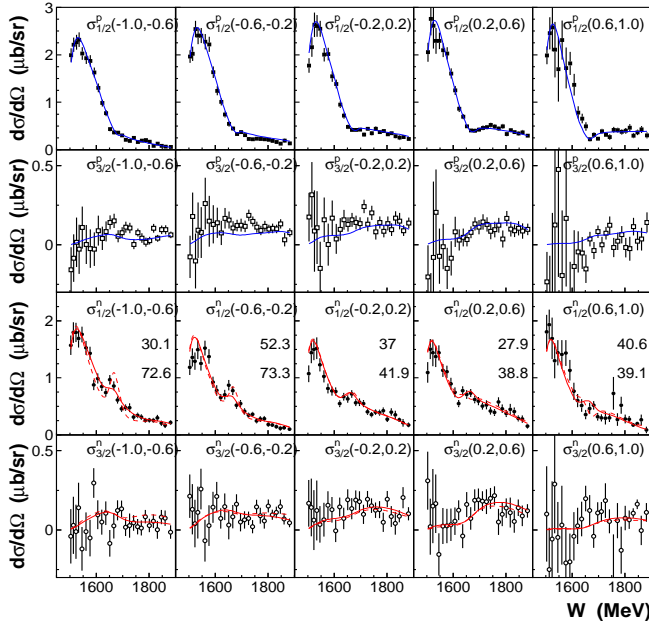
FIG. 2: Excitation functions $\sigma_{1/2}$ and $\sigma_{3/2}$ for 5 bins in $\cos\theta_\eta^*$ for the reaction $\gamma d \to \eta p(n)$ (top 2 rows) and $\gamma d \to \eta n(p)$ (bottom 2 rows), statistical and systematic errors are added quadratically. The solid curves represent the new BnGa fit (which include the data from [25]) without an additional narrow resonance, the dashed lines a fit in which a narrow resonance is imposed with the properties given in [4]. The two numbers give the χ^2 contribution of the bin, the upper number without, the lower number including the narrow resonance.

wave contributions. Indeed, a comparison of $A_1^{\sigma_{1/2}}$ with results from BnGa fits to the data of [4, 5] shows that a model assuming no $N(1685)$ (Fig. 1, solid curve) does not reproduce the narrow dip while a model which includes a narrow $N(1685)$ (Fig. 1, dotted curve) gives qualitative agreement between data and prediction. These observations are the basis for the conjecture in [25] that a narrow resonance has been observed. There are, however, a few arguments which disagree with this conjecture.

The dip in $A_1^{\sigma_{1/2}}$ is – with a few standard deviations – statistically significant. Relative to the solid line (representing the fit with no $N(1685)$), the dip in $A_1^{\sigma_{1/2}}$ has a mean deviation -0.24 ± 0.04 and contributes $\chi^2 = 15.9$ for two data points. There are, however, arguments which imply that the dip cannot be a real effect. The dip could be caused by a small systematic deviation of the observable E from its true value. In this case, the dip in $A_1^{\sigma_{1/2}}$ would be accompanied by a peak in $A_1^{\sigma_{3/2}}$.

Indeed, there is an unexpected peak in $A_1^{\sigma_{3/2}}$ as well, at the same mass and of similar size and shape as the dip in $A_1^{\sigma_{1/2}}$. The peak deviates from the solid line by $+0.25 \pm 0.04$, contributes $\chi^2 = 12.7$, and is thus of similar importance as the dip. This peak cannot originate from the same narrow resonance as the dip: the interference of any partial wave with the dominant $J^P = 1/2^-$ wave produces effects in $h = 1/2$ only. If the dip in $A_1^{\sigma_{1/2}}$ had
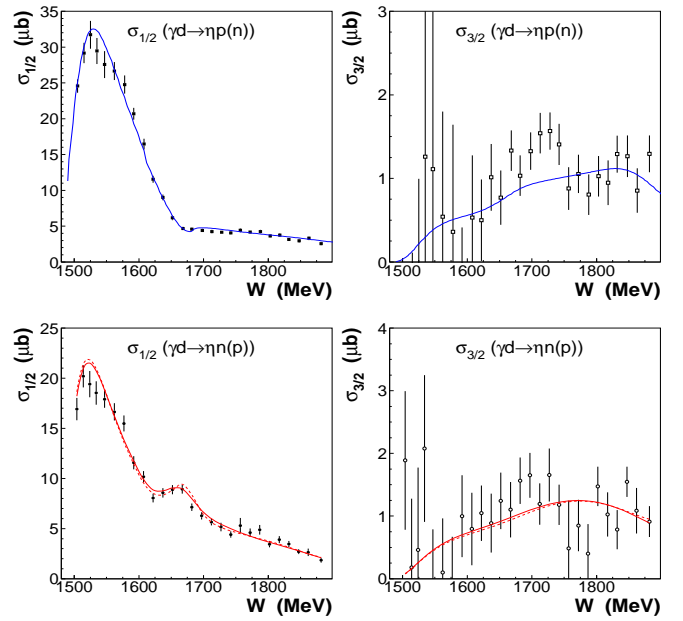

FIG. 3: The total cross sections $\sigma_{1/2}$, $\sigma_{3/2}$ for the reactions $\gamma d \to \eta p(n)$ (top) and $\gamma d \to \eta n(p)$ (bottom) and new BnGa fits. The solid lines represent a fit without a narrow resonance, the dashed lines in the bottom figure represent a fit in which a narrow resonance is imposed with the properties given in [4].

a physical significance, there would be no peak in $A_1^{\sigma_{3/2}}$, and the dip should be seen in $A_1^{\sigma_{tot}}$ with a strength as given by the dotted line in Fig. 1. But it is not. The coefficient $A_1^{\sigma_{tot}}$ follows precisely the fit with no $N(1685)$, the data are compatible with the fit with $\chi^2 = 2.1$ for the two data points. There is hence the strong suspicion that the dip is false and does not represent real physics.

To scrutinize the possibility further that there could be a narrow resonance with $J^P = 1/2^+$ we performed new fits. In these fits most particle properties are frozen to the values derived from fits to pion and photo-induced reactions off protons. For γn reactions we use the data listed in [24] and, in addition, the new MAMI data [25]. The latter data are shown in Fig. 2 and Fig. 3, the solid line is our fit without introduction of a narrow resonance. For the differential cross sections from [4, 5] and [25], the fit returns a $\chi^2_{\rm MAMI} = 1205$ for 1150 data points. Obviously, there is no need to introduce $N(1685)$. When $N(1685)$ was enforced in the fit with properties as given in [4], i.e. with $M = 1670$ MeV, width $\Gamma = 30$ MeV, and $\sqrt{Br(\eta n)}A_n^{1/2} = \tilde{a} = 12.3$ GeV$^{-\frac{1}{2}}$ 10^{-3}, the fit returned $\chi^2_{\rm MAMI} = 1834$. The χ^2's for the new data from [25] are shown in Fig. 2 for each angular bin of $\sigma_{1/2}$ for $\gamma d \to \eta n(p)$, the sum is $\chi^2 = 187.9$ for the fit without narrow resonance and 265.8 when it is imposed.

If the production strength is fitted freely, it reduced to 1.2 [GeV$^{-\frac{1}{2}}$ 10^{-3}] and the total χ^2 improved by 12 units to 1193. This production strength corresponds to a contribution which is about 100 times smaller than the con-

TABLE I: Helicity amplitudes determined from a fit without a narrow $N(1685)$ resonance. The T-matrix couplings are the quantities which are listed in the RPP; K-matrix couplings are given in addition. The new results are compared to those obtained in [24] which are listed in small numbers. The comparison shows the impact of the new data from [25] and [26].

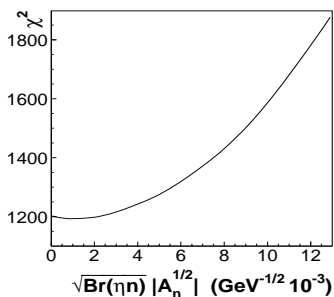|		$N(1535)1/2^-$	$N(1650)1/2^-$				$N(1535)1/2^-$	$N(1650)1/2^-$	
p	T-matrix	0.093 ± 0.009	0.032 ± 0.006	$\text{GeV}^{-1/2}$	**n**	T-matrix	-0.088 ± 0.004	0.016 ± 0.004	$\text{GeV}^{-1/2}$
	[24]	0.114 ± 0.008	0.032 ± 0.007	$\text{GeV}^{-1/2}$		[24]	-0.095 ± 0.006	0.019 ± 0.006	$\text{GeV}^{-1/2}$
	Phase	$8 \pm 4^\circ$	$7 \pm 7^\circ$			Phase	$5 \pm 4^\circ$	$-28 \pm 10^\circ$	
	[24]	$10 \pm 5^\circ$	$-2 \pm 11^\circ$			[24]	$8 \pm 5^\circ$	$0 \pm 15^\circ$	
	K-matrix	0.112 ± 0.008	0.075 ± 0.006			K-matrix	-0.160 ± 0.030	-0.052 ± 0.005	
	[24]	0.096 ± 0.007	0.075 ± 0.007			[24]	-0.120 ± 0.006	-0.052 ± 0.006	

FIG. 4: Increase of χ^2 when a narrow resonance with mass $M = 1670$ MeV, width $\Gamma = 30$ MeV, and $J^P = 1/2^+$ is imposed as a function of the signal strength $\tilde{a} = \sqrt{Br(\eta n)}A_n^{1/2}$. The number of data points is 1150.

tribution claimed in [4, 5]. Figure 4 shows how the χ^2 increases with the strength of an imposed narrow $N(1670)$.

The new data on E for the reaction $\gamma d \to \eta p(n)$ in [25] – with a spectator neutron – differ significantly from first BnGa fits which were performed before the data on double-polarization observables on $\gamma p \to \eta p$ on protons became available [18, 26]. To explore this discrepancy, we included the new MAMI data for η production off protons (bound in deuterons) [25] in the fits. The data are very similar to data for η production off free protons showing that effects due to final-state interactions with the spectator nucleon are small. Figures 2 and 3 show that the new data can be included in the fit without any problems, after a slight tuning of the parameters. In Table I, we show the helicity amplitudes obtained in the new fit in comparison to the fit presented in [24].

The changes in the photocouplings of $N(1535)1/2^-$ and $N(1650)1/2^-$ for protons are likely due to the inclusion of the new data on $\gamma p \to \eta p$ [26].

In [27] it is argued that the T-matrix photocouplings of $N(1650)1/2^-$ for protons and neutrons imply that $N(1650)1/2^-$ must have a very large ϕN coupling. The photocouplings of $N(1650)1/2^-$ are strongly influenced by the ΛK and ΣK thresholds, it may hence be more appropriate to use the "undressed" K-matrix photocoupling. Using the formulae given in [27] we find from the K-matrix couplings that the branching ratio for $N(1650)1/2^- \to \phi N$ vanishes when the $N\omega$ coupling has about half the strength of the $N\rho$ coupling.

Summarizing, we have studied the new data on the helicity dependence of the reaction $\gamma d \to \eta n(p)$ with a spectator proton measured by the A2 Collaboration at MAMI in Mainz [25]. We cannot confirm the conclusions of the authors that the dip in the first-order Legendre coefficient in an expansion of the angular distributions of $\sigma_{1/2}$ is due to a narrow $J^P = 1/2^+$ resonance. First, the dip is accompanied by a peak in the first-order Legendre coefficient of $\sigma_{3/2}$ of the same shape suggesting that the dip is due to a statistical fluctuation in the measurement of E. Second, a partial wave analysis without a narrow $J^P = 1/2^+$ resonance is excellent, the inclusion of it with the reported properties leads to a significantly worse description of the data.

[1] V. Kuznetsov *et al.*, Phys. Lett. B **647**, 23 (2007).

[2] I. Jaegle *et al.* [CBELSA/TAPS Collaboration], Phys. Rev. Lett. **100**, 252002 (2008).

[3] I. Jaegle *et al.* [CBELSA/TAPS Collaboration], Eur. Phys. J. A **47**, 89 (2011).

[4] D. Werthmüller *et al.* [A2 Collaboration], Phys. Rev. Lett. **111**, 232001 (2013).

[5] D. Werthmüller *et al.* [A2 Collaboration], Phys. Rev. C **90**, 015205 (2014).

[6] V. Kuznetsov *et al.*, Phys. Rev. C **83**, 022201 (2011).

[7] V. Kuznetsov *et al.*, Phys. Rev. C **91**, 042201 (2015).

[8] M. V. Polyakov and A. Rathke, Eur. Phys. J. A **18**, 691 (2003).

[9] V. Kuznetsov and M. V. Polyakov, JETP Lett. **88**, 347

(2008).

[10] D. Diakonov, V. Petrov, and M. V. Polyakov, Z. Phys. A **359**, 305 (1997).

[11] J. Beringer *et al.* [Particle Data Group], Phys. Rev. D **86**, 010001 (2012).

[12] C. Patrignani *et al.* [Particle Data Group], Chin. Phys. C **40**, no. 10, 100001 (2016).

[13] R.A. Arndt *et al.*, Phys Rev. C **69**, 035208 (2004).

[14] Ki-Seok Choi *et al.*, Phys. Lett. B **636** 253 (2006) 253.

[15] A. Fix, L. Tiator, and M.V. Polyakov, Eur. Phys. J. A **32**, 311 (2007).

[16] M. Shrestha and D.M. Manley, Phys. Rev. C **86** 045204 (2012), *idem* **86** 055203 (2012).

[17] A. V. Anisovich *et al.*, Eur. Phys. J. A **41**, 13 (2009).

[18] I. Senderovich *et al.* [CLAS Collaboration], Phys. Lett. B **755**, 64 (2016).

[19] V. Shklyar, H. Lenske, and U. Mosel, Phys. Lett. B **650**, 172 (2007).

[20] R. Shyam and O. Scholten, Phys. Rev. C **78** 065201 (2008).

[21] M. Döring and K. Nakayama, Phys. Lett. B **683**, 145 (2010).

[22] X. -H. Zhong and Q. Zhao, Phys. Rev. C **84**, 045207 (2011).

[23] A. V. Anisovich *et al.*, Eur. Phys. J. A **49**, 67 (2013).

[24] A. V. Anisovich *et al.*, Eur. Phys. J. A **51**, 72 (2015).

[25] L. Witthauer *et al.*, Phys. Rev. Lett. **117**, 132502 (2016).

[26] J. Müller *et al.*, New data on $\vec{\gamma}\vec{p} \to \eta p$ with polarized photons and protons, $N^* \to N\eta$ decays revisted, submitted to Phys. Lett. B.

[27] M. V. Polyakov and K. Goeke, EPJ Web Conf. **134**, 02004 (2017).