Further evidence for $N(1900)P_{13}$ from photoproduction of hyperons

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Abstract

We report further evidence for $N(1900)P_{13}$ from an analysis of a large variety of photo- and pion-induced reactions, in particular from the new CLAS measurements of double polarization observables for photoproduction of hyperons. The data are consistent with two classes of solutions both requiring contributions from $N(1900)P_{13}$ but giving different $N(1900)P_{13}$ pole positions. $(M - i\Gamma/2) = (1915 \pm 50) - i(90 \pm 25)$ MeV covers both solutions. The small elasticity of 10% or less explains why it was difficult to observe the state in $\pi N$ elastic scattering.

$N(1900)P_{13}$ is a 2-star resonance which is predicted by symmetric three-quark models. In diquark-quark models, the existence of the state is not expected.

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The flavour structure of baryons and of their resonances is well described in quark models which assume that baryons can be build from three constituent quarks. The spatial and spin-orbital wave functions can be derived using a confinement potential and some residual interactions between constituent quarks. The best known example is the Karl-Isgur model [1], at that time a breakthrough in the understanding of baryons. Later refinements differed by the choice of the residual interactions: Capstick and Isgur continued to use an effective one gluon exchange interaction [2], Plessas and his collaborators used exchanges of Goldstone bosons between the quarks [3], while Löring, Metsch and Petry exploited instanton induced interactions [4]. A group theoretical analysis by Bijker, Iachello and Leviatan gave the same complexity of the spectrum of baryon resonances [5]. Quark models, including a discussion of different decay modes, were reviewed recently by Capstick and Roberts [6].

A common feature of these models is the large number of predicted states: the
dynamics of three quarks leads to a rich spectrum, much richer than observed experimentally. The reason for the apparent absence of many predicted states could be that the dynamics of three quark interactions is not understood well enough. It is often assumed for instance that, within the nucleon, two quarks may form a diquark of defined spin and isospin, and that the diquark is a ‘stable’ object within the baryon. There is a long discussion on the nature and relevance of the diquark concept; we quote here a few recent papers [7,8,9,10]. Applied to baryon spectroscopy, the diquark model helps to solve the problem of the missing baryon resonances. Santopinto, e.g., calculated the $N^*$ and $\Delta^*$ excitation spectrum [11] with the assumption that the baryon is made up from a point-like diquark and a quark. The results match data perfectly, provided $N^*$- and $\Delta^*$-resonances are omitted from the comparison that have an one- or two-star PDG [12] ranking only.

Of course, there is also the possibility that symmetric quark models treating all three quarks on the same footing are right, and that the large number of predicted but unobserved states reflects an experimental problem. In the region between 1900 and 2000 MeV, there are 3 two-star resonances, $N(1900)P_{13}$, $N(2000)F_{15}$, $N(1990)F_{17}$. According to diquark models, these states should not exist but they are firmly predicted in symmetric three-quark models. An independent confirmation of the states is therefore highly desirable.

For long time, the main source of information on $N^*$ and $\Delta^*$ resonances was derived from pion nucleon elastic scattering. If a resonance couples weakly to this channel, it could thus escape identification. This effect may be the reason for the non-observation of the missing resonances or for the weak evidence with which they are observed. Important information is hence expected from experiments studying photoproduction of resonances off nucleons, decaying into complex final states. Such experiments are being carried out at several places. In this letter we report on further evidence for the $N(1900)P_{13}$ derived from photoproduction, in particular from recent CLAS data on the spin transfer coefficients $C_x$ and $C_z$ from circularly polarized photons to final-state hyperons in the reaction $\gamma p \rightarrow \Lambda K^+$ and $\Sigma K^+$ [13].

The analysis of photoproduction data is not straightforward. Due to the spin of the initial particles and of the final-state baryon, an unambiguous solution cannot be obtained without polarization observables. Moreover, even in the simplest case of single meson photoproduction a ‘complete’ experiment from which the full amplitude can be constructed in an energy independent analysis requires the measurements of at least 8 observables [14]. Not only single polarization observables are required but also double polarization variables need to be measured. Photoproduction of hyperons is very well suited to measure double polarization observables since the self-analyzing decay of the hyperon provides access to the hyperon ‘induced’ polarization, and only one further observable needs to be determined, e.g. by using a polarized photon beam.
Recently, the CLAS collaboration measured the spin transfer coefficients $C_x$ and $C_z$ from circularly polarized photons to final-state hyperons in the reactions $\gamma p \to \Lambda K^+$ and $\gamma p \to \Sigma^0 K^+$, in the invariant mass region from threshold to $W = 2.454$ GeV \cite{13}. These measurements have yielded the first data expected from a series of double polarization photoproduction experiments which are presently planned and carried out at Bonn, JLab, and Mainz. Even though the new CLAS data provide an important step into the direction of a complete experiment, we are still far from being able to reconstruct fully complex amplitudes in a model independent way. An alternative approach is therefore to include many reactions in a coupled channel analysis. This direction is followed by EBAC, the JLab Excited Baryon Analysis Center \cite{15}, by the Giessen group \cite{16} and by the Bonn-Gatchina group \cite{17,18}.

The main input into the new analysis presented here are the new data on hyperon photoproduction \cite{13} in combination with the analysis of a large number of other reactions. It will be shown that the data can be described well under an assumption that a further baryon resonance exists in the 1800-2000 MeV mass region which had not been taken into account in our previous fits \cite{19,20}. Identification of the new state with the $N(1900)P_{13}$ is plausible.

Apart from the data on polarization transfer \cite{13}, the following data sets were included in the analysis: differential cross sections $\sigma(\gamma p \to \Lambda K^+)$, $\sigma(\gamma p \to \Sigma^0 K^+)$, and $\sigma(\gamma p \to \Sigma^+ K^0)$, recoil polarization, and photon beam asymmetry \cite{21,22,23,24,25,26,27}; photoproduction of $\pi^0$ and $\eta$ with measurements of differential cross sections, beam and target asymmetries and recoil polarization from the SAID data base \cite{28,29,30,31,32,33,34,35}. Amplitudes for $\pi N$ elastic scattering from \cite{36} were included for the low-spin partial waves. The data include about 16.000 data points on two-body reactions; acceptable fits give a total $\chi^2$ of less than 20.000. A more detailed description of the analysis method and comparison of the fit with further data can be found elsewhere \cite{37}.

Photoproduction of $2\pi^0$ \cite{38,39} off protons and the recent BNL data on $\pi^- p \to n\pi^0\pi^0$ \cite{40} were also included. These data sets were taken into account in an event-based likelihood fit; at present this data is restricted to the low-mass region ($M<1.8$ GeV). The data define isobar contributions like $\Delta\pi$ and $N\sigma$ \cite{38} and help to disentangle the properties of the Roper resonance \cite{39} but have little influence on states in the 2 GeV region. The reaction $\gamma p \to p\pi^0\eta$ was included as well; it provides access to $\Delta P_{33}$ and $\Delta D_{33}$ partial waves which make the largest contributions to the latter reaction \cite{41}.

The partial wave analysis presented here is based on relativistically invariant amplitudes constructed from the four-momenta of particles involved in the process \cite{17}. High-spin resonances were described by relativistic multi-channel Breit-Wigner amplitudes, partial waves with low total spin ($J < 5/2$) were
Table 1

The four strongest resonant contributions (in decreasing importance) to the reactions included in this analysis. Resonances contributing less than 1% to a reaction are not listed. The contributions are determined for the energy range where data (see text) exist. Note that the ordering of the states is sometimes not well defined: it is, e.g., different for solution 1 (chosen here) and solution 2 discussed below. In some reactions, $t$- and $u$-channel exchanges provide a significant contribution to the cross section, too.

| Reaction                  | Resonances                      |
|---------------------------|---------------------------------|
| $\gamma p \to N\pi$      | $\Delta(1232)P_{33}$ $N(1520)D_{13}$ $N(1680)F_{15}$ $N(1535)S_{11}$ |
| $\gamma p \to p\eta$     | $N(1535)S_{11}$ $N(1720)P_{13}$ $N(2070)D_{15}$ $N(1650)S_{11}$ |
| $\gamma p \to p\pi^0\pi^0$ | $\Delta(1700)D_{33}$ $N(1520)D_{13}$ $N(1680)F_{15}$ |
| $\gamma p \to p\pi^0\eta$ | $\Delta(1940)D_{33}$ $\Delta(1920)P_{33}$ $N(2200)P_{13}$ $\Delta(1700)D_{33}$ |
| $\gamma p \to \Lambda K^+$ | $S_{11}$-wave $N(1720)P_{13}$ $N(1900)P_{13}$ $N(1840)P_{11}$ |
| $\gamma p \to \Sigma K$  | $S_{11}$-wave $N(1900)P_{13}$ $N(1840)P_{11}$ |
| $\pi^- p \to n\pi^0\pi^0$ | $N(1440)P_{11}$ $N(1520)D_{13}$ $S_{11}$-wave |

Resonances may make large contributions to one reaction and smaller contributions to other reactions. This property helps considerably in the identification of resonances and in the determination of their properties. Table 1 lists the strongest contributions in the various reactions which are used in the fits. Further resonances ($N(1675)D_{15}$, $N(1710)P_{11}$, $N(1875)D_{13}$, $N(2000)F_{15}$, $N(2170)D_{13}$, $N(2200)P_{13}$, $\Delta(1620)S_{31}$, $\Delta(1905)F_{35}$) were required to get a good description of the data. Although these states do not contribute strongly to the differential cross sections, they are needed for the description of the polarization variables. In most cases the properties of these states are compatible with the PDG listings. A few additional high-mass resonances were added to describe the intensity. However, spins, parities, masses and widths remained uncertain, and we do not discuss them here.

In the first attempt, the data were fitted using one low-mass Breit-Wigner amplitude to describe the $P_{13}$ wave. A second $P_{13}$ resonance at $M=2200$ MeV was needed to fit the data on $\gamma p \to p\pi^0\eta$ [41]. No good description of the data
was reached. As example, data on $C_x, C_z$ for $\gamma p \rightarrow \Lambda K^+$ are compared to the fit in Fig. 1a. Systematic discrepancies are observed demonstrating the need to introduce further amplitudes. In a second step we added to our solutions, one by one, Breit-Wigner resonances with different quantum numbers. The largest improvement was observed introducing a second $P_{13}$ state. The fit optimized at $1885 \pm 25$ MeV mass and $180 \pm 30$ MeV width, with improvement of $\chi^2$ for the reactions with two-body final states, $\Delta \chi^2_{2b} = 1540$ where $\chi^2_{2b}$ is defined as the (normalized) sum of the $\chi^2$ contributions of all two-body reactions, including their weights (see eq. (15) in [37]). Adding a $S_{11}$ or $D_{15}$ state instead, improved the description by 950 units. Replacing the $P_{13}$ by a $P_{11}$ state resulted in a much smaller improvement, $\Delta \chi^2_{2b} = 205$, probably due to the fact that the fit included already a $P_{11}$ resonance in this mass region. A $F_{15}$ state produced a marginal change in $\chi^2_{2b}$ as well; introducing $F_{17}$ and $G_{17}$ did not improve the fit. A resonance with $P_{33}$ quantum numbers state provided a better description of the $\Sigma_0^0 K^+$ channel and gave some additional freedom to the fit of the $\Lambda K^+$ reaction. However, the change in $\chi^2_{2b}$ was again smaller by a factor 2 than the one found for a $P_{13}$ state.

In a final step, the $P_{13}$ was introduced as 3-pole 8-channel K-matrix with $\pi N$, $\eta N$, $\Delta(1232)\pi$ ($P$ and $F$-waves), $N\sigma$, $D_{13}(1520)\pi$ ($S$-wave), $K\Lambda$, and $K\Sigma$ channels. A satisfactory description of the $C_x$ and $C_z$ distributions was obtained for both, the $\Lambda K^+$ (see Fig. 1b) and the $\Sigma_0^0 K^+$ channel (not shown). The inclusion of the $N(1900)P_{13}$ resonance was essential to achieve a good quality of the fit, not only for the new $C_x, C_z$ but also for other data. The $\chi^2/N_F$ for the differential $\Lambda K^+$ ($\Sigma_0^0 K^+$) cross section reduced from 2.35 to 2.0 (2.4 to 2.1) when the $N(1900)P_{13}$ resonance was introduced. Fig. 1 shows the best fit without (a) and with (b) $N(1900)P_{13}$ included. When the $P_{13}$-wave was treated as K-matrix, introduction of a third resonance (representing $N(1900)P_{13}$) improved $\chi^2$ for $\Lambda K^+$ and $\Sigma K$ data by 1650 units, a significant number. Overall, the fit proved to be marginally better than the fit using Breit-Wigner amplitudes.

The $\chi^2$ change as a function of the $N(1900)P_{13}$ mass is shown in Fig. 2. The $\Lambda K^+$ data exhibit two minima, corresponding to solution 1 and solution 2, discussed below; the $\Sigma K$ prefer the lower mass for $N(1900)P_{13}$. Note the different definitions of the unweighted $\chi^2$ shown in Fig. 2 and the weighted $\chi^2_{2b}$ used in the fits.

The data set used in this analysis, even though comprising nearly all available information, is still not yet sufficient to determine a unique solution. For different start values, the fit can converge to different minima. As a rule, we accepted all fits which gave a reasonable description of all data sets and did not show a significant problem in one of the reactions included. Fits were rejected, when we found that the trend of the data was inconsistent with the fit curve even if the increase in $\chi^2$ in some low-statistics data was counterbalanced by
Fig. 1. Double polarization observables $C_x$ (black circle) and $C_z$ (open circle) for $\gamma p \rightarrow \Lambda K^+$ [13]. The solid ($C_x$) and dashed ($C_z$) curves are our result obtained without (left panel) and with the $N(1900)^+P_{13}$ state (right panel) included in the fit.
Fig. 2. The change of $\chi^2$ for the fit to photoproduction of $\Lambda K^+$ and $\Sigma K$ as a function of the assumed $N(1900)P_{13}$ mass.

an improved description of some high-statistics data. When the trend of some data was inconsistent with the fit curve, we increased the weight of that data until reasonable consistency was obtained. The variety of different solutions was used to define the final errors.

All solutions considered from now on include the $P_{13}$ state and give a reasonable description of all data. However the contributions of the different isobars to the fitted channels are not uniquely defined. We observed two classes of solutions which we call the first and second solution. Both solutions yield a similar overall $\chi^2_{2b}$. In the first solution, the pole of the $P_{13}$ partial wave is situated at about 1870 MeV and provides a noticeable contribution to the $\Lambda K^+$ and $\Sigma^0 K^+$ total cross sections. It is responsible for the double peak structure in the $\Lambda K^+$ total cross section and helps to describe the peak in the $\Sigma^0 K^+$ total cross section. In the $\gamma p \rightarrow K^0 \Sigma^+$ channel, the contribution of the $P_{13}$ state has a similar strength as the $N(1840)P_{11}$ state reported in [20] where the possible presence of an additional $P_{13}$ state was already discussed even though it could not yet be identified unambiguously. In this first solution, the $P_{11}$ pole moved to 1880 MeV and became broader. Interference of this pole with the pole at the region 1700 MeV generated a comparatively narrow structure in the $\gamma p \rightarrow K^0 \Sigma^+$ total cross section.

In the second type of the solutions (the second solution) the $P_{13}$ pole is found at about 1950 MeV. It provides rather small contributions to the $\Lambda K^+$ and $\Sigma^0 K^+$ total cross sections while the main contribution to the $\gamma p \rightarrow K^0 \Sigma^+$ cross section now comes from a $P_{11}$ state. The new impact of the $P_{13}$ state is an improvement of the description of double polarization variables due to interferences. The data are described reasonably well in both solutions, including those on $C_x$ and $C_z$, see Fig. 1 except perhaps in two slices in the 2.15 GeV mass region.
A few regions show small but systematic deviations. The first solution does not describe well the $\Lambda K^+$ recoil polarization at backward angles in the 1700 MeV region. The description can be improved by the introduction of an additional state in the 1800 MeV region, with quantum numbers $P_{33}$, $D_{15}$ or $S_{11}$. In the latter case, the data might demand a more sophisticated parameterization of the $S_{11}$ wave by, for example, taking into account the $\rho(770)N$ threshold. Thus it is not clear if an additional resonance is really needed. Furthermore, we are not sure that, with the present quality of the data, these additional states or threshold effects can be identified with reasonable confidence. We therefore decided to postpone attempts to identify weaker signals until new data are available. The main result of the present analysis is that a satisfactory description of the fitted data can be obtained by introduction of just one new resonance, a relatively narrow $P_{13}$ state at about 1885 MeV or 1975 MeV.

The new $P_{13}$ state also improves the description of the $\gamma p \to K^+\Sigma^0$ reaction, even though its effect is much less visible here. The double polarization data in this channel were already described reasonably well in our previous analysis (see the figures in [13]); and a slight readjustment of the fit parameters gave a good representation of the data. The main contribution to $\gamma p \to K^+\Sigma^0$ data is now due to $K$-exchange. In [20], the larger contribution was assigned to $K^*$ exchange. A dominance of $K$ exchange explains naturally the small $\gamma p \to K^0\Sigma^+$ cross section which is forbidden for $K$ exchange. The $P_{13}$ partial wave provides a moderate contribution to the cross section but helps to achieve a good fit.

To check whether elastic data are compatible with the new state, we introduced it as an additional K-matrix pole and fitted the $\pi N \to \pi N P_{13}$ partial wave for invariant masses up to 2.4 GeV. A satisfactory description of all fitted observables was obtained; as example we show the elastic scattering data in Fig. 3.

![Fig. 3. Real (a) and imaginary (b) part of the $\pi N P_{13}$ elastic scattering amplitude and the result of our fit. Solution 1: solid curve, solution 2: dashed curve.](image)

Most masses and widths obtained in the fits are compatible with the numbers given in [19][20]. Here we comment only on the $P_{13}$ partial wave. The param-
eters of the two lowest $P_{13}$ poles are given in Table 2. For both solutions, the first $P_{13}$ state was found to be a rather broad state. Most previous analyses gave much narrower Breit-Wigner widths [12].

However, Manley and Saleski [43], the only earlier analysis which includes $N2\pi$ decays, reported a width of $380 \pm 180$ MeV. The most recent $\pi N \rightarrow N\pi$ plus $N\eta$ analysis of Arndt et al. [36] gave a pole position at $M = 1666, \Gamma = 355$ MeV with no error, not too far from our pole position at $M = 1640 \pm 80, \Gamma = 480 \pm 60$ or (2nd solution) $M = 1630 \pm 80, \Gamma = 440 \pm 60$. Only, the Breit-Wigner masses differ substantially. Arndt et al. gave $M = 1763.8 \pm 4.6, \Gamma = 210 \pm 22$ MeV while we find $1800 \pm 100$ (1780 $\pm 80$) MeV mass and $700 \pm 100$ (680 $\pm 80$) MeV width where the numbers correspond to the first, those in parentheses to the second solution.

The difference in the Breit-Wigner width could indicate a problem. Attempts to find solutions with a narrower $N(1720)P_{11}$ (with widths in the 150-250 MeV range) failed. Yet, Breit-Wigner parameters are certainly model dependent. It looks strange that in [36] the Breit-Wigner width is narrower than the pole width. We assume that interference between the two $P_{13}$ resonances leads to an apparent narrowing of the $N(1720)P_{13}$ and $N(1900)P_{13}$ peaks. If these are fitted using Breit-Wigner amplitudes, the widths become too narrow. Taking both $P_{13}$ resonances into account in a K-matrix reveals the true $N(1720)P_{13}$ width. The Breit-Wigner parameters we quote are derived in a different way: our Breit-Wigner amplitude has exactly the same pole position as the T-matrix derived from a K-matrix fit. The state couples strongly to $\Delta(1232)\pi$ and, in the second solution, also to the $D_{13}(1520)\pi$ channel. The $D_{13}(1520)\pi$ threshold is close to the resonance mass and creates a double pole structure. The two poles are hidden under a Riemann sheet created by a cut at the $D_{13}(1520)\pi$ threshold; the closest physical region for them is situated above the $D_{13}(1520)\pi$ threshold. The pole structure renders the definition of helicity amplitudes and of decay partial widths complicated; here these quantities are calculated in a procedure described in [37] as residues of the poles of the scattering matrix (T-matrix).

The pole of the second $P_{13}$ state is situated in the region 1850-2000 MeV; it has a smaller coupling to the $\pi N$ channel. In the first class of solutions, this coupling can be a positive or a negative value. The helicity couplings are, however, defined under the assumption that the coupling to the $\pi N$ channel is a positive number. Thus the sign of the helicity coupling is ambiguous. In the analysis [19], only one $P_{13}$ state below 2.0 GeV was needed to describe the data. This state was found to be rather broad and to couple to the $\eta n$ channel with branching ratio 8-12%. The present analysis reproduces the $P_{13}$ partial wave in the $\gamma p \rightarrow \eta N$ reaction even though the broad structure is produced now due to an interference of two poles.
Table 2
Properties of the two lowest $P_{13}$ resonances for both solutions. The masses, widths are given in MeV, the branching ratios in % and helicity couplings in $10^{-3}$ GeV$^{-1/2}$. The helicity couplings and phases were calculated as residues in the pole position.

|            | Solution 1 | Solution 2 |
|------------|------------|------------|
| $M_{pole}$ | $1640 \pm 80$ | $1870 \pm 15$ | $1630 \pm 60$ | $1960 \pm 15$ |
| $\Gamma_{pole}^{tot}$ | $480 \pm 80$ | $170 \pm 30$ | $440 \pm 60$ | $195 \pm 25$ |
| $A_{1/2}$  | $140 \pm 80$ | $- (10 \pm 15)$ | $160 \pm 40$ | $- (18 \pm 8)$ |
| $\varphi_{1/2}$ | $-(10 \pm 15) ^\circ$ | $-(10 \pm 15) ^\circ$ | $-(40 \pm 15) ^\circ$ |
| $A_{3/2}$  | $150 \pm 80$ | $- (40 \pm 15)$ | $70 \pm 30$ | $- (35 \pm 12)$ |
| $\varphi_{3/2}$ | $-(40 \pm 30) ^\circ$ | $(30 \pm 25) ^\circ$ | $(0 \pm 20) ^\circ$ | $-(40 \pm 15) ^\circ$ |
| $\text{Br}_{N\pi}$ | $8 \pm 4$ | $5 \pm 3$ | $18 \pm 5$ | $6 \pm 3$ |
| $\text{Br}_{N\eta}$ | $14 \pm 4$ | $20 \pm 8$ | $10 \pm 2$ | $15 \pm 3$ |
| $\text{Br}_{K\Lambda}$ | $16 \pm 6$ | $15 \pm 5$ | $7 \pm 2$ | $12 \pm 3$ |
| $\text{Br}_{K\Sigma}$ | $< 2$ | $22 \pm 8$ | $< 1$ | $8 \pm 2$ |
| $\text{Br}_{\Delta\pi(P)}$ | $54 \pm 10$ | $36 \pm 6$ |
| $\text{Br}_{\Delta\pi(F)}$ | $2 \pm 2$ | $18 \pm 5$ |
| $\text{Br}_{D_{13}\pi}$ | $2 \pm 2$ | $5 \pm 3$ |
| $\text{Br}_{N\sigma}$ | $4 \pm 2$ | $4 \pm 2$ |
| $\text{Br}_{Add}$ | $< 2$ | $38 \pm 12$ | $2 \pm 2$ | $60 \pm 6$ |

In summary, we have analyzed the new CLAS data on spin transfer from circularly polarized photons to $\Lambda$ and $\Sigma$ hyperons in the final state. Included in the analysis are other data on photo- and pion-induced reactions. One additional resonance (compared to previous fits) is needed to achieve a good description of all data. Quantum numbers $P_{13}$ are preferred. In spite of the large data set which includes differential distributions, beam, target and recoil asymmetries, and some double polarization data, no unique solution was found. But all solutions require a $P_{13}$ state. The two classes of solutions from this analysis optimize for masses (and widths) of 1870 (170) or 1960 (195) MeV, respectively. We assign mass and width of $M = 1915 \pm 60$ MeV and $\Gamma = 180 \pm 40$ MeV which covers the large majority of all solutions we have obtained. The elastic widths is about 2-9%, the branching fraction to $\Lambda K^+$, 5-15%.

The Particle Data Group lists two entries for $N(1900)P_{13}$; Manley and Saleski find mass and width of $1879 \pm 17$ (498 $\pm 78$) MeV, the elastic widths is determined to $0.26 \pm 0.06$ [13]. Penner and Mosel find $1951 \pm 53$ (622 $\pm 42$) MeV and an elastic width of $0.16 \pm 0.02$ [14,15]. The $\Lambda K^+$ branching fraction was determined to $2.4 \pm 0.3$% by Shklyar and Mosel [16].
Even though there are considerable inconsistencies between the four analyses, it seems most likely that the observations are traces of one resonance. Given its mass and quantum numbers, it can be ascribed to a quark model state which requires excitation of both oscillators in the 3-body system. The $N(1900)P_{13}$ is unlikely to be explainable in a picture where a quark is bound by a “good” diquark.

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References

[1] N. Isgur and G. Karl, Phys. Rev. D 19 (1979) 2653 [Erratum-ibid. D 23 (1981) 817].
[2] S. Capstick and N. Isgur, Phys. Rev. D 34 (1986) 2809.
[3] L. Y. Glozman et al., Phys. Rev. D 58 (1998) 094030.
[4] U. Löring et al., Eur. Phys. J. A 10 (2001) 395, 447.
[5] R. Bijker, F. Iachello and A. Leviatan, Annals Phys. 236 (1994) 69.
[6] S. Capstick and W. Roberts, Prog. Part. Nucl. Phys. 45 (2000) 241.
[7] M. Anselmino, E. Predazzi, S. Ekelin, S. Fredriksson and D. B. Lichtenberg, Rev. Mod. Phys. 65 (1993) 1199.
[8] M. Kirchbach, M. Moshinsky and Yu. F. Smirnov, Phys. Rev. D 64 (2001) 114005.
[9] R. L. Jaffe and F. Wilczek, Phys. Rev. Lett. 91 (2003) 232003.
[10] R. L. Jaffe, Phys. Rept. 409 (2005) 1 [Nucl. Phys. Proc. Suppl. 142 (2005) 343.
[11] E. Santopinto, Phys. Rev. C 72 (2005) 022201.
[12] W. M. Yao et al. [Particle Data Group], J. Phys. G 33 (2006) 1.
[13] R. Bradford et al. [CLAS Collaboration], Phys. Rev. C 75 (2007) 035205.
[14] W. T. Chiang and F. Tabakin, Phys. Rev. C 55, (1997) 2054.
[15] A. Matsuyama, T. Sato and T. S. Lee, Phys. Rept. 439 (2007) 193.
[16] V. Shklyar, H. Lenske and U. Mosel, Phys. Rev. C 72 (2005) 015210.
[17] A.V. Anisovich et al., Eur. Phys. J. A 24 (2005) 111.
[18] A.V. Anisovich and A.V. Sarantsev, Eur. Phys. J. A 30 (2006) 427.
[19] A.V. Anisovich et al., Eur. Phys. J. A 25 (2005) 427.
[20] A.V. Sarantsev et al., Eur. Phys. J. A 25 (2005) 441.
[21] K. H. Glander et al., Eur. Phys. J. A 19 (2004) 251.
[22] J. W. C. McNabb et al., Phys. Rev. C 69 (2004) 042201.
[23] R. G. T. Zegers et al., Phys. Rev. Lett. 91 (2003) 092001.
[24] R. Lawall et al., Eur. Phys. J. A 24 (2005) 275.
[25] R. Bradford et al., Phys. Rev. C 73 (2006) 035202.
[26] A. Lleres et al., Eur. Phys. J. A 31, 79 (2007).
[27] R. Castelijns et al., “Nucleon resonance decay by the $K^0\Sigma^+$ channel,” [arXiv:nucl-ex/0702033].
[28] R.A. Arndt et al., [http://gwdac.phys.gwu.edu](http://gwdac.phys.gwu.edu)
[29] A. A. Belyaev et al., Nucl. Phys. B 213 (1983) 201.
R. Beck et al., Phys. Rev. Lett. 78 (1997) 606.
D. Rebreyend et al., Nucl. Phys. A 663 (2000) 436.
[30] K. H. Althoff et al., Z. Phys. C 18 (1983) 199.
E. J. Durwen, BONN-IR-80-7 (1980).
K. Buechler et al., Nucl. Phys. A 570 (1994) 580.
[31] B. Krusche et al., Phys. Rev. Lett. 74 (1995) 3736.
[32] J. Ajaka et al., Phys. Rev. Lett. 81 (1998) 1797.
[33] O. Bartholomy et al., Phys. Rev. Lett. 94 (2005) 012003.
[34] V. Crede et al., Phys. Rev. Lett. 94 (2005) 012004.
[35] O. Bartalini et al., Eur. Phys. J. A 26 (2005) 399.
[36] R. A. Arndt, W. J. Briscoe, I. I. Strakovsky and R. L. Workman, Phys. Rev. C 74, 045205 (2006) [arXiv:nucl-th/0605082].
[37] A.V. Anisovich, V. Kleber, E. Klempt, V.A. Nikonov, A.V. Sarantsev, and U. Thoma, “Baryon resonances and polarization transfer in hyperon photoproduction” [arXiv:0707.3596].
[38] U. Thoma et al., ”$N^*$ and $\Delta^*$ decays into $N\pi^0\pi^0$”, [arXiv:0707.3592].
[39] A.V. Sarantsev et al., ”New results on the Roper resonance and of the $P_{11}$ partial wave”, [arXiv:0707.3591].
[40] S. Prakhov et al., Phys. Rev. C 69 (2004) 045202.
[41] I. Horn et al., "Evidence for the $\Delta D_{33}(1940)$ resonance from $\gamma p \rightarrow p\pi^0\eta$ photoproduction", arXiv:0711.1138.

[42] I.J.R.Aitchison, Nucl.Phys.A 189 (1972) 417.

[43] D. M. Manley and E. M. Saleski, Phys. Rev. D 45 (1992) 4002.

[44] G. Penner and U. Mosel, Phys. Rev. C 66 (2002) 055211.

[45] G. Penner and U. Mosel, Phys. Rev. C 66 (2002) 055212.