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Evidence for a negative-parity spin-doublet of nucleon resonances at 1.88 GeV

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ABSTRACT

Evidence is reported for two nucleon resonances with spin-parity $J^P = 1/2^-$ and $J^P = 3/2^-$ at a mass just below 1.9 GeV. The evidence is derived from a coupled-channel analysis of a large number of pion and photo-produced reactions. The two resonances are nearly degenerate in mass with two resonances of the same spin but positive parity. Such parity doublets are predicted in models claiming restoration of chiral symmetry in high-mass excitations of the nucleon. Further examples of spin parity doublets are found in addition. Alternatively, the spin doublet can be interpreted as member of the 56-plet expected in the third excitation band of the nucleon. Implications for the problem of the *missing resonances* are discussed.

SU(3) symmetry was the prerequisite for the interpretation of mesons and baryons [1] as systems composed of quarks and antiquarks or of three quarks, respectively, and is the basis of quark models. As three-particle systems, nucleons – protons and neutrons – are expected to exhibit a rich spectrum of rotational and vibrational energy levels. The excitation levels of the nucleon are extremely short-lived and decay in a variety of different decay modes. Many states are predicted which overlap and are very difficult to resolve. Only a fraction of the expected states has been found experimentally; the absence of many states is called the problem of the *missing resonances*. It is still unclear if the *missing resonances* do not exist or if they escaped detection due to the limitations of experiments performed so far. Most information on the spectrum of excited nucleons is derived from pion–nucleon (πN) elastic scattering experiments which are incapable to identify resonances with weak coupling to πN. Indeed, model calculations suggest that the *missing resonances* do have weak $N\pi$ couplings [2].

New experimental techniques and new data are obviously required. Photoproduction of mesons offers distinctive advantages. The use of photon beams and inelastic reactions avoid πN in the entrance and exit channel; polarized photon beams, polarized hydrogen targets, and measurements of the polarization of outgoing baryons – best accessible in the case of hyperon production – are important to separate contributions with different quantum numbers. Different final states are sensitive to different resonances; hence it is important to combine different channels into a common analysis and to search for new resonances in a variety of different reactions. In this Letter we present the results of a multichannel partial wave analysis (PWA) of a large body of reactions, in particular of the large database which exists on hyperon production. From hyperon production experiments we expect a high sensitivity to low-spin resonances above – and close to – the ΛK and ΣK thresholds which range from 1610 to 1690 MeV. This is an interesting mass region since so far all established low-spin negative-parity nucleon resonances have masses below 1700 MeV.

A large database was fitted within the Bonn–Gatchina multichannel partial wave analysis. The data include nearly the complete available database on pion-induced reactions and of photoproduction off protons. In particular, data of single pion or η production, with hyperon production with recoiling charged and neutral kaons, and photoproduction of $2\pi^0$ and $\pi^0\eta$ are included in the analysis. Recent results are presented in two longer papers [3,4] where references are given to papers in which the PWA method is fully described. Newly added were recent data on $\gamma p \to \Sigma^+ K^0$ [5]. A longer article summarizes our results on nucleon and Δ resonances and provides a list of references to all data used in the fits [6]. In this Letter we give a brief account of the experimental findings and focus on possible interpretations of the results.

Table 1 lists the positive-parity nucleon resonances below 2.3 GeV used in the analysis. Nucleon resonances are characterized by the letter N, by their nominal mass from [7] or from us, and by

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Table 1
List of positive-parity nucleon resonances used in the coupled channel analysis. The Δ excitations quoted in [7] are used in addition. For resonances with a $*$, alternative solutions exist yielding different mass values. These are discussed in [8]. New resonances not quoted by the PDG are underlined. $N(2100)1/2^+$ improves the fit but is not required.

$N(1440)1/2^+$	$N(1710)1/2^+$	$N(1720)3/2^+$	$N(1680)5/2^+$
$\underline{N(1880)1/2^+}$	$N(1900)3/2^+$	$\underline{N(1860)5/2^{+*}}$	$N(1990)7/2^{+*}$
$N(2000)5/2^{+*}$	$N(2100)1/2^+$	$N(2220)9/2^+$	

their spin and parity J^P. Here, we concentrate on resonances with negative parity. A discussion of positive-parity nucleon resonances in the 2 GeV mass range can be found in a separate letter [8].

We first give a short outline of the analysis method. The transition amplitude for a pion-produced reaction from the initial state a to a final state b is described by a sum of a K matrix amplitude

$$A_{ab} = K_{ac}(I - i\rho K)^{-1}_{cb}, \tag{1}$$

containing resonances and direct couplings from the initial to final states, and amplitudes for reggeized exchanges in the t- and u-channel. In Eq. (1), I is the identity operator and ρ the phase space. The angular momentum barrier q^L – with q being the decay momentum and L the orbital angular momentum – is modified by form factors as suggested by Blatt and Weisskopf [9]. The explicit forms for t- and u-channel amplitudes and form factors can be found, respectively, in Section 8 and Appendix C of [10].

The K matrix parameterizes resonances and background contributions,

$$K_{ab} = \sum_\alpha \frac{g_a^\alpha g_b^\alpha}{M_\alpha^2 - s} + f_{ab}, \tag{2}$$

where $g^\alpha_{a,b}$ are coupling constants of the pole α to the initial and the final state. The background terms f_{ab} describe non-resonant transitions from the initial to the final state. We tested f_{ab} as constant or a parameterization in the form

$$f_{ab} = \frac{(c_{ab} + d_{ab}\sqrt{s})}{(s - s_{0ab})}, \tag{3}$$

where c_{ab} and d_{ab} are real numbers, and where s_{0ab} parameterizes left-hand singularities. In most partial waves, a constant background term is sufficient to achieve a good fit. The fit to the $(I)J^P = (1/2)1/2^-$ wave required the form (3). For the $(I)J^P = (3/2)1/2^-$ wave and for the P-wave amplitudes, the background form (3) led to a slight improvement, and some fits were done with, others without this term. Both types of solutions were included in the error analysis. Below we give sometimes the pole position $(M_{\text{pole}} - i\frac{1}{2}\Gamma_{\text{pole}})$, but often only the Breit–Wigner mass and width. The latter quantities are determined by

$$A_{ab} = \frac{f^2 g_a^r g_b^r}{M_{\text{BW}}^2 - s - if^2 \sum_c |g_c^r|^2 \rho_c(s)}, \tag{4}$$

where M_{BW} and scaling factor f are calculated to reproduce exactly the pole position of the resonance.

The helicity-dependent amplitude for photoproduction of the final state b is calculated in the framework of P-vector approach [11]:

$$a_b^h = P_a^h (I - i\rho K)^{-1}_{ab} \tag{5}$$

where

$$P_a^h = \sum_\alpha \frac{A_\alpha^h g_a^\alpha}{M_\alpha^2 - s} + F_a. \tag{6}$$

Table 2
The quintet of low-mass negative-parity nucleon resonances.

$N(1535)1/2^-$	$N(1520)3/2^-$	
$N(1650)1/2^-$	$N(1700)3/2^-$	$N(1675)5/2^-$

A_α^h is the photo-coupling of the K-matrix pole α and F_a a non-resonant transition. The photo-couplings are defined as residuum of the helicity-dependent amplitude in the pole position

$$A^h g_b^r = \int\limits_o \frac{ds}{2\pi i} a_b^h(s). \tag{7}$$

The helicity amplitudes $A^{1/2}$, $A^{3/2}$ are complex numbers. They become real and coincide with the conventional helicity amplitudes $A^{1/2}_{\text{BW}}$, $A^{3/2}_{\text{BW}}$, if a Breit–Wigner amplitude with constant width is used.

The $I(J^P) = \frac{1}{2}(\frac{1}{2}^-)$ and $I(J^P) = \frac{1}{2}(\frac{3}{2}^-)$ partial waves are described by two-pole K-matrices, the $I(J^P) = \frac{1}{2}(\frac{5}{2}^-)$ partial wave by one pole, with couplings to $N\pi$, $N\eta$, ΛK^+, ΣK, $N(\pi\pi)_{\text{S-wave}}$, $\Delta\pi$, and one unconstrained channel (parameterized as $N\rho$), representing the well-known resonances listed in Table 2.

With these amplitudes, several data sets were only moderately well described unless two further resonances were introduced, called $N(1895)1/2^-$ and $N(1875)3/2^-$. In a first step, the new resonances were represented by coupled-channel relativistic Breit–Wigner amplitudes. With the new resonances, data and fit agreed very well. Figs. 1 and 2 show a few examples, selected data on $\gamma p \to \Sigma^+ K^0_S$ [5], $\gamma p \to n\pi^+$ [12], $\gamma p \to \Lambda K^+$ [13], and $\gamma p \to p\eta$ [14]. The solid lines represent the full fit, the dashed lines in Fig. 1 our fit when $N(1875)3/2^-$ is removed from the fit; in Fig. 2 $N(1895)1/2^-$ was removed.

Introduction of $N(1875)3/2^-$ improved the fit also to other data which are not shown here. Significant improvements were found in the description of the many observables in $\gamma p \to \Lambda K^+$: in the fit to differential cross sections and recoil polarization [13], to photon beam asymmetry [15], target asymmetry, and to the observables $O_{x'}$, $O_{z'}$ [16] and C_x, C_z [17]. The latter quantities describe, respectively, the polarization transfer from linearly and circularly polarized photons to the final-state hyperons. Introduction of $N(1895)1/2^-$ gave major improvements in the description of the data on $\gamma p \to \Lambda K^+$ [13,15–17], and for $\gamma p \to N\pi$ from different sources [3, Table 3].

The need to introduce $N(1895)1/2^-$ and $N(1875)3/2^-$ can be seen in mass scans. The mass of one of the two resonances was stepped through the resonance region, a new fit was made with all parameters released, except the mass of the resonance. The quality of the fit – expressed as χ^2 as a function of the imposed mass – was monitored. Fig. 3a shows a mass scan for the $N_{1/2^-}$ resonance, Fig. 3b, c for $N_{3/2^-}$. The scans show very clear and highly significant minima. Formally, the statistical significance for $N(1895)1/2^-$ corresponds to 25 standard deviations, the significance for $N(1875)3/2^-$ is even higher. The widths of the minima in Fig. 3 reflects the natural width of the resonance. We believe that the minima in Fig. 3 constitute solid evidence for the existence of these two resonances.

In a second scan, the new resonances were included as third K-matrix poles in the two partial waves and a search was made for higher-mass resonances. In the $N_{3/2^-}$ wave, a clear minimum was observed at 2125 MeV which we identify with the known two-star $N(2200)3/2^-$ [7] (see Fig. 3d). A scan for a further $N_{1/2^-}$ resonance – known as one-star $N(2090)1/2^-$ [7] – showed no significant additional minimum. We searched for other high-spin nucleon resonances; the results, summarized in Table 3, confirm established particles.

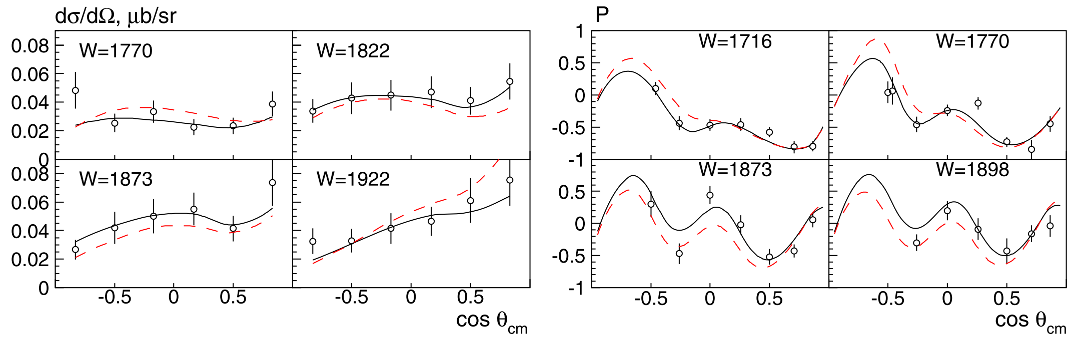

Fig. 1. Differential cross section for $\gamma p \to \Sigma^+ K^0$ [5] (left) and recoil asymmetry for $\gamma p \to n\pi^+$ (right) [12]. The full curves show our best fit, the dashed curves this fit without resonant contributions above 1.7 GeV in the $I(J^P) = \frac{1}{2}(\frac{3}{2}^-)$ wave.

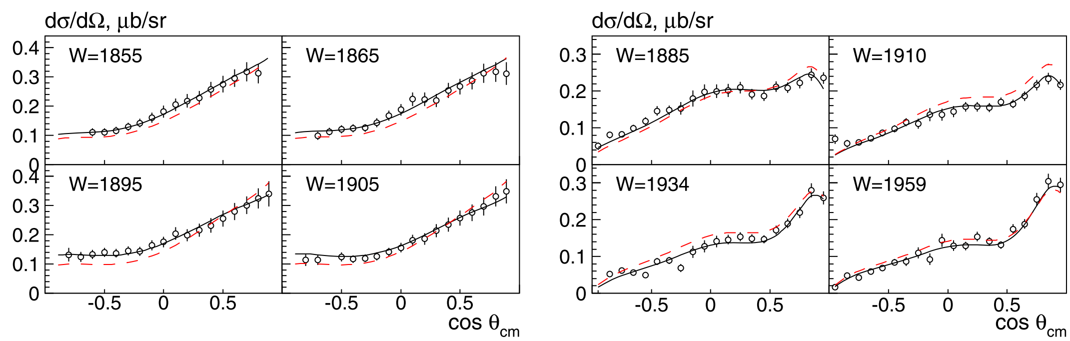

Fig. 2. Differential cross section for $\gamma p \to \Lambda K^+$ (left) [13] and $\gamma p \to p\eta$ [14] (right). The full curves show our best fit, the dashed curves this fit without resonant contributions above 1.7 GeV in the $I(J^P) = \frac{1}{2}(\frac{1}{2}^-)$ wave.

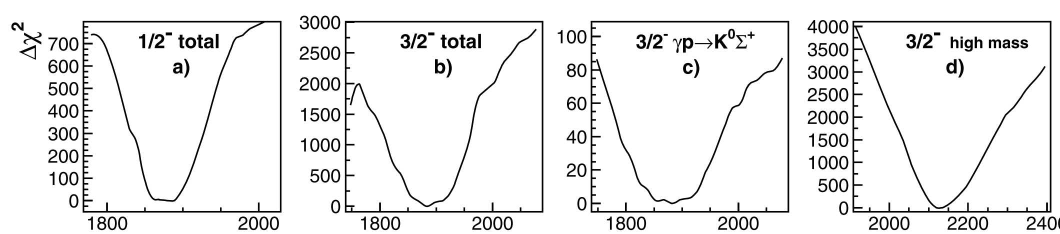

Fig. 3. a) Mass scan for an $N_{1/2^-}$ resonance; change of the total χ^2 of the fit as a function of the assumed mass. b), c) Mass scan for an $N_{3/2^-}$ resonance; χ^2 of the fit as a function of the assumed mass for an assumed width of 100 MeV. b) Total χ^2. c) χ^2 contribution from $\gamma p \to \Sigma^+ K^0_S$ [5]. d) Mass scan for a fourth $N_{3/2^-}$ resonance when $N(1875)3/2^-$ is included in the K-matrix.

Table 3
Masses and widths of selected negative-parity resonances. The mass values are from [6]. The second column gives the PDG [7] star rating, ranging from 4-star (established) to 1-star (poor evidence).

$N(1895)1/2^-$:	new	$M_{BW} = 1895 \pm 15$	$\Gamma_{BW} = 90^{+30}_{-15}$	[MeV]
$N(2090)1/2^-$:	1*	no evidence		
$N(1875)3/2^-$:	new	$M_{BW} = 1880 \pm 20$	$\Gamma_{BW} = 200 \pm 25$	[MeV]
$N(2150)3/2^-$:	new	$M_{BW} = 2150 \pm 60$	$\Gamma_{BW} = 330 \pm 45$	[MeV]
$N(2060)5/2^-$:	new	$M_{BW} = 2060 \pm 15$	$\Gamma_{BW} = 375 \pm 25$	[MeV]
$N(2190)7/2^-$:	4*	$M_{BW} = 2180 \pm 20$	$\Gamma_{BW} = 335 \pm 40$	[MeV]
$N(2250)9/2^-$:	4*	$M_{BW} = 2200 \pm 40$	$\Gamma_{BW} = 480 \pm 60$	[MeV]

Evidence for the two resonances $N(1895)1/2^-$ and $N(1875)3/2^-$ has been reported before. From πN scattering, Höhler et al. [18] gave Breit–Wigner parameters of $M = 1880 \pm 20$, $\Gamma = 95 \pm 30$ MeV for a pole in the $I(J^P) = \frac{1}{2}(\frac{1}{2}^-)$ wave. Manley et al. [19] found a broad state, $M = 1928 \pm 59$, $\Gamma = 414 \pm 157$ MeV which is possibly related to the resonance discussed here. Vrana et al. [20] reported a pole at $M_{pole} = 1795$, $\Gamma_{pole} = 220$ MeV. A third and a fourth pole in the $I(J^P) = \frac{1}{2}(\frac{1}{2}^-)$ wave was suggested in [21]. The third pole was given with mass and width of $M_{pole} = 1733$ MeV; $\Gamma_{pole} = 180$ MeV, and in [22] with $M_{pole} = 1745 \pm 80$; $\Gamma_{pole} = 220 \pm 95$ MeV. A fourth pole in this partial wave may have been seen by Cutkosky et al. [23] at $M_{pole} = 2150 \pm 70$, $\Gamma_{pole} = 350 \pm 100$ MeV and at 2191 ± 241; 392 ± 301 MeV in [22].

In the $\frac{1}{2}(\frac{3}{2}^-)$ wave, Cutkosky et al. [23] reported two resonances, the lower mass state at $M_{pole} = 1880 \pm 100$, $\Gamma_{pole} = 160 \pm 80$ MeV, the higher mass pole at $M_{pole} = 2050 \pm 70$, $\Gamma_{pole} = 200 \pm 80$ MeV. A few further suggestions exist, partly supporting the lower mass, partly the higher mass [7]. Based on SAPHIR data on $\gamma p \to \Lambda K^+$ [24], Mart and Bennhold claimed evidence for a $\frac{1}{2}(\frac{3}{2}^-)$ resonance at 1895 MeV [25] which was confirmed by us on a richer database in [26,27], with mass and width of 1875 ± 25 and 80 ± 20 MeV, respectively. The high-mass $N_{3/2^-}$ was also seen in [26,27] with $M = 2166^{+25}_{-50}$; $\Gamma = 300 \pm 65$ MeV and in [28] with of $M = 2100 \pm 20$ MeV and $\Gamma = 200 \pm 50$ MeV.

We now discuss possible interpretations. Hadron resonances often appear in parity doublets [29]. Table 4 shows a striking consistency with this conjecture. In particular, the new negative-parity

Table 4
Nucleon resonances as parity doublets. For an easier comparison we give our mass values and not the nominal values from PDG [7]. A star* denotes values which are not uniquely defined, a second solution exists with a different mass.

$N(1895)1/2^-$	$N(1875)3/2^-$	$N(2060)5/2^-$	$N(2190)7/2^-$	$N(2250)9/2^-$
$N(1880)1/2^+$	$N(1900)3/2^+$	$N(2095)5/2^{+*}$	$N(2110)7/2^{+*}$	$N(2220)9/2^+$

Table 5
Nucleon and Δ resonances assigned to the third excitation shell. The masses of nucleon resonances are from our work, most Δ resonances from [7], one* from [31]. The two resonances $N(2060)5/2^-$ and $N(2190)7/2^-$ could belong to the $S = 3/2$ quartet or to an $S = 1/2$ doublet. Two resonances are missing. $N(2060)5/2^-$ and $N(2190)7/2^-$ may both consist of two unresolved resonances, one belonging to the quartet, the other one to the doublet.

$L = 1$, $N = 1$	$S = \frac{1}{2}$	$N(1895)1/2^-$	$N(1875)3/2^-$		
	$S = \frac{3}{2}$	$\Delta(1900)1/2^-$	$\Delta(1940)3/2^-$	$\Delta(1930)5/2^-$	
$L = 3$, $N = 0$	$S = \frac{3}{2}$	$N(2150)3/2^-$	$N(2060)5/2^-$	$N(2190)7/2^-$	$N(2250)9/2^-$
	$S = \frac{1}{2}$				
	$S = \frac{1}{2}$		$\Delta(2223)5/2^{-*}$	$\Delta(2200)7/2^-$	

spin-doublet $N(1895)1/2^-$, $N(1875)3/2^-$ is mass degenerate with $N(1880)1/2^+$ and $N(1900)3/2^+$. Also the masses of the higher-spin resonances of opposite parity are consistent. There is, however, one caveat. $N(2000)5/2^+$, with 2000 MeV nominal mass [7], is not well defined. The $I(J^P) = \frac{1}{2}(\frac{5}{2}^+)$ wave can be described by one resonance above $N(1680)5/2^+$. In this case, mass and width are determined to $M = 2090 \pm 20$, $\Gamma = 450 \pm 40$ MeV. (In Table 4 we list this resonance as $N(2095)5/2^+$ to avoid confusion with $N(2090)3/2^-$.) If the wave is described by three poles, the (Breit–Wigner) mass and width of the highest pole is found at $(2090 \pm 120), (460 \pm 100)$ MeV, and a further lower-mass pole shows up. Its position cannot be defined precisely; any mass between 1800 and 1950 MeV gives a good description of the data. We call it $N(1860)5/2^+$ and assign a Breit–Wigner mass of $1860^{+120}{}_{-60}$ and a width of $270^{+140}{}_{-50}$ MeV. Also for $N(1990)7/2^+$ there are different solutions. In one class of solution, its mass and width are determined to $(2105 \pm 15), (260 \pm 25)$ MeV; this mass which is consistent with parity doubling. A second class of solution yields $(1990 \pm 10), (225 \pm 25)$ MeV. In the latter case, $N(2190)7/2^-$ stands alone, so far with no parity partner.

In quark models, baryon resonances are organized in SU(6) multiplets combining spin and flavor according to the decomposition $6 \otimes 6 \otimes 6 = 56_S \oplus 70_M \oplus 70_M \oplus 20_A$ [30]. The multiplets are characterized by the SU(6) dimensionality D, the leading orbital angular momentum L, the shell number $\mathtt{N}$ and the parity P in the form $(D, L^P_{\mathtt{N}})$. Instead of $\mathtt{N}$, we often use the radial excitation quantum number N, with $\mathtt{N} = L + 2N$. Restricted to non-strange baryons, the 56-plet decomposes into a spin-doublet of nucleon resonances and a spin quartet of Δ resonances, $56 = {}^4 10 \oplus {}^2 8$. A 70-plet is formed by a spin quartet and a spin doublet of nucleon resonances and a spin doublet of Δ resonances.

The two resonances $N(1895)1/2^-$ and $N(1875)3/2^-$ could form a spin doublet like the one in the upper line of Table 2 or be members of a spin triplet like in the lower line. In the latter case, a close-by resonance with $I(J^P) = \frac{1}{2}(\frac{5}{2}^-)$ should be expected. A scan gives a minimum – with a gain in χ^2 of 2500 units – at 2075 MeV, seemingly unrelated to $N(1895)1/2^-$ and $N(1875)3/2^-$. Hence we interpret these two resonances as spin doublet. The spin doublet is not accompanied by a close-by spin triplet like in Table 2. Hence the doublet must belong to a 56-plet. A spin triplet of Δ resonances is then expected at about this mass. Indeed, such a triplet seems to exist. The Particle Data Group [7] lists $\Delta(1900)1/2^-$, $\Delta(1940)3/2^-$, $\Delta(1930)5/2^-$. These five states and their quantum number assignment are listed in Table 5. They can be assigned naturally to a 56-plet, and exhaust the non-strange sector of this multiplet. Note that a 56-plet is symmetric in its spin-flavor wave function. Hence the spatial wave function must be symmetric, too, in spite of the odd angular momentum. In three-particle systems, odd angular momenta with a symmetric spatial wave function can indeed be constructed, except for $L = 1$ and $N = 0$. With $N = 2$, the resonances would belong to the fifth excitation shell and should have a mass well above 2 GeV. Because of their low mass, they have very likely $N = 1$. The five resonances belong to the $(56, 1^-_3)$ multiplet in the third excitation shell.

In the mass range from 2000 to 2300 MeV, four further nucleon and two further Δ resonances are known which have negative parity. In the harmonic oscillator approximation, these resonances can be assigned to the third excitation shell, they are listed in the lower part of Table 5. The $N(2250)9/2^-$ resonance must have $L = 3$, $S = 3/2$ coupling to $J^P = \frac{9}{2}^-$ as dominant angular momentum configuration; there could be a small $L = 5$ component in the wave function but resonances with $L = 5$ as leading orbital angular momentum are expected at much higher masses. With $L = 3$, $S = 3/2$ coupling to $\frac{9}{2}^-$ as anchor, we expect a full quartet with $J^P = \frac{3}{2}^-, \frac{5}{2}^-, \frac{7}{2}^-, \frac{9}{2}^-$. SU(6) symmetry then demands the existence of an additional $J^P = \frac{5}{2}^-, \frac{7}{2}^-$ doublet, i.e. six states in total. Instead of six resonances, only four are observed. Possibly, the two expected resonances with $\frac{5}{2}^-$ are unresolved, and both hide in the one observed $N(2060)5/2^-$. Likewise, two resonances may hide within $N(2190)7/2^-$. Thus only four resonances instead of six are observed or observable. In the Δ sector, the Particle Data Group lists one negative-parity resonance in this mass range, $\Delta(2200)7/2^-$, and a second one, $\Delta(2223)5/2^-$, is reported by SAID [31]. These two resonances form a natural spin doublet with $L = 3$, $S = 1/2$ coupling to $J^P = \frac{5}{2}^-, \frac{7}{2}^-$. In SU(6), this group of nucleon and Δ resonances can all be assigned to one multiplet $(70, 3^-_3)$. Apart from the problem that two pairs of nucleon resonances may hide in one observed spin doublet, the $(70, 3^-_3)$ is completely filled.

Quark models predict six further multiplets which are completely empty, $(56, 3^-_3)$, $(20, 3^-_3)$, $(70, 2^-_3)$, $(70, 1^-_3)$, $(70, 1^-_3)$, $(20, 1^-_3)$. There is not one additional resonance which may hint at the possibility that one of these multiplets may be required. Some of these resonances would have noticeable features. From the $(56, 3^-_3)$ multiplet, a Δ resonance with $J^P = \frac{9}{2}^-$ is expected. A resonance with these quantum numbers is observed, but at 2400 MeV [7], too high in mass to fall into the third excitation shell. We speculate that it may have an additional unit of radial excitation and may belong to the $(56, 3^-_5)$ multiplet. The $(70, 2^-_3)$

multiplet predicts a quartet of states with $J^P = \frac{1}{2}^-, \frac{3}{2}^-, \frac{5}{2}^-, \frac{7}{2}^-$, all with even angular momentum and odd parity. These are just absent in the spectrum. Out of eight multiplets, six are completely empty, two are fully equipped.

This is a remarkable observation: in two of the eight expected SU(6) multiplets, all members seem to be identified experimentally. In contrast, the other six multiplets remain completely empty. At present, one thus should have to conclude that *missing resonances* are not just voids which might be filled when new data become available. It seems, instead, that whole multiplets are unobserved and are possibly unobservable. If this conjecture should be confirmed in future experiments and analyses, there must be a dynamical reason which prohibits formation of certain SU(6) multiplets.

In summary, we have reported evidence for a spin doublet of nucleon resonances, $N(1895)1/2^-$ and $N(1875)3/2^-$. The spectrum of negative parity resonances in this mass range shows remarkable features. The resonances can be grouped, jointly with positive parity states, into parity doublets. Within a quark-model classification, the negative parity resonances around 2.1 GeV can be assigned to two multiplets while six multiplets remain completely empty. It will be important to see whether indeed entire multiplets are missing as opposed to individual states within multiplets. This observation may hint to new features of intra-baryon dynamics.

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References

[1] M. Gell-mann, Y. Ne'eman, The Eightfold Way, Benjamin, New York, 1964.
[2] R. Koniuk, N. Isgur, Phys. Rev. Lett. 44 (1980) 845.
[3] A.V. Anisovich, et al., Eur. Phys. J. A 47 (2011) 27.
[4] A.V. Anisovich, et al., Eur. Phys. J. A 47 (2011) 153.
[5] R. Ewald, et al., Anomaly of the $K^0\Sigma^+$ photoproduction cross section off the proton at the K^* threshold, arXiv:1112.0811 [nucl-ex].
[6] A.V. Anisovich, et al., Eur. Phys. J. A 48 (2012) 15.
[7] K. Nakamura, et al., J. Phys. G 37 (2010) 075021.
[8] A.V. Anisovich, et al., Phys. Lett. B 711 (2012) 167, in this issue.
[9] J. Blatt, V. Weisskopf, Theoretical Nuclear Physics, John & Sons, New York, 1952.
[10] A. Anisovich, et al., Eur. Phys. J. A 24 (2005) 111.
[11] S.U. Chung, et al., Annalen Phys. 4 (1995) 404.
[12] P.J. Bussey, et al., Nucl. Phys. B 154 (1979) 205.
[13] M.E. McCracken, et al., Phys. Rev. C 81 (2010) 025201.
[14] V. Crede, et al., Phys. Rev. C 80 (2009) 055202.
[15] A. Lleres, et al., Eur. Phys. J. A 31 (2007) 79.
[16] A. Lleres, et al., Eur. Phys. J. A 39 (2009) 149.
[17] R. Bradford, et al., Phys. Rev. C 75 (2007) 035205.
[18] G. Höhler, H. Schopper, Numerical Data and Functional Relationships in Science and Technology. Group I: Nuclear and Particle Physics. Vol. 9: Elastic and Charge Exchange Scattering of Elementary Particles. B: Pion Nucleon Scattering. Pt. 2: Methods and Results, Landolt-Boernstein, New Series, I, vol. 9B2, Springer, Berlin, Germany, 1983, 601 pp.
[19] D.M. Manley, E.M. Saleski, Phys. Rev. D 45 (1992) 4002.
[20] T.P. Vrana, S.A. Dytman, T.S.H. Lee, Phys. Rept. 328 (2000) 181.
[21] L. Tiator, et al., Phys. Rev. C 82 (2010) 055203.
[22] M. Hadzimehmedovic, et al., Phys. Rev. C 84 (2011) 035204.
[23] R.E. Cutkosky, et al., Pion–nucleon partial wave analysis, in: 4th Int. Conf. on Baryon Resonances, Toronto, Canada, July 14–16, 1980, published in: Baryon 19 (1980) (QCD161:C45:1980).
[24] K.H. Glander, et al., Eur. Phys. J. A 19 (2004) 251.
[25] T. Mart, C. Bennhold, Phys. Rev. C 61 (2000) 012201.
[26] A.V. Anisovich, et al., Eur. Phys. J. A 25 (2005) 427.
[27] A.V. Sarantsev, et al., Eur. Phys. J. A 25 (2005) 441.
[28] R.A. Schumacher, M.M. Sargsian, Phys. Rev. C 83 (2011) 025207.
[29] L.Y. Glozman, Phys. Rept. 444 (2007) 1.
[30] A.J.G. Hey, R.L. Kelly, Phys. Rept. 96 (1983) 71.
[31] R.A. Arndt, et al., Phys. Rev. C 74 (2006) 045205.