Neutron anomaly in $\gamma N \to \eta N$ and the flavour SU(3) symmetry

Maxim V. Polyakov[1],★ and *Klaus* Goeke[1],★★

[1] *Institute for Theoretical Physics II, Ruhr-University Bochum, 44801 Bochum, Germany*

Abstract. We study the implications of the flavour SU(3) symmetry for various interpretations (existence of a narrow anti-decuplet resonance, interference of known resonances and a cusp effect) of the neutron anomaly in $\gamma N \to \eta N$ cross section. We show that the explanation of the neutron anomaly due to interference of known N(1535) and N(1650) resonances implies that N(1650) resonance should have a huge coupling to ϕ-meson – at least 5 times larger than the corresponding ρ^0 coupling. In terms of quark degrees of freedom that implies that the well-known N(1650) resonance must be a "cryptoexotic pentaquark"– its wave function should contain predominantly an $s\bar{s}$ component, implying that the N(1650) resonance is dominantly a pentaquark. The explanation of the neutron anomaly as a cusp effect implies very strong violation of the flavour SU(3) symmetry.

1 Introduction

The discovery of the neutron anomaly[1] in the $\gamma N \to \eta N$ cross section was reported in Ref. [1], in this paper the GRAAL data on the photon scattering off the deuteron were analysed. Presently three other collaborations (LNS [2],CBELSA/TAPS[3], and A2 [4]) confirmed the neutron anomaly beyond any doubts. For an illustration of the neutron anomaly in $\gamma N \to \eta N$ we show on Fig. 1 the most recent results of the A2 collaboration [4].

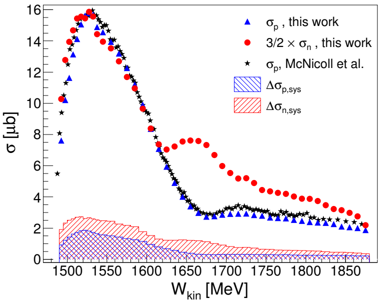

Figure 1. Figure from Ref. [4]. Total cross sections as a function of the final-state invariant mass $m(\eta N)$: Blue triangles: proton data. Red circles: neutron data scaled by 3/2. Black stars: free proton data from MAMI-C [6]. Hatched areas: total systematic uncertainties of proton (blue) and neutron (red) data.

Furthermore the neutron anomaly at the same invariant mass of $W \sim 1680$ MeV was also observed in the Compton scattering [5].

In our view the observation of the neutron anomaly is the most striking discovery in the field of the nucleon resonances spectroscopy during the last decade. It is important to figure out the physics nature of the phenomenon. In the present contribution we study the implications of the flavour SU(3) symmetry for various explanations of the neutron anomaly.

2 Flavour SU(3) decomposition of the $\gamma N \to \eta N$ amplitude

In the SU(3) symmetry limit the amplitudes $A\left(\gamma p \to \eta p\right)$ and $A\left(\gamma n \to \eta n\right)$ can be decomposed through the amplitudes corresponding to the irreducible representations of the SU(3) group in the s-channel. The photon and nucleon belong to the octet representation of the SU(3) group, therefore the possible representations in the s-channel are those which appear in the product $\mathbf{8}\times\mathbf{8} = \mathbf{1}+\mathbf{8}_{\mathrm{F}}+\mathbf{8}_{\mathrm{D}}+\mathbf{10}+\overline{\mathbf{10}}+\mathbf{27}$. Obviously, the $\mathbf{1}$ and $\mathbf{10}$ representations do not enter the decomposition of the $\gamma N \to \eta N$ amplitude. The SU(3) decomposition for the amplitudes has the following form:

$$\begin{aligned} A\left(\gamma p \to \eta p\right) &= \frac{1}{3}A_{\mathrm{D}}^{(8)} + A_{\mathrm{F}}^{(8)} + A^{(27)}, \\ A\left(\gamma n \to \eta n\right) &= \frac{2}{3}A_{\mathrm{D}}^{(8)} + A^{(\overline{10})} + \frac{1}{2}A^{(27)}. \end{aligned} \qquad (1)$$

We see that the anti-decuplet amplitude $A^{(\overline{10})}$ do not enter the γp channel, whereas the antisymmetric octet amplitude $A_{\mathrm{F}}^{(8)}$ do not enter the γn channel.

In order to describe the phenomenon of the neutron anomaly one needs that the amplitude $A\left(\gamma n \to \eta n\right)$ is very different (larger size and more rapid energy dependence) from $A\left(\gamma p \to \eta p\right)$ on a narrow invariant energy interval (several tens of MeV) around $W \sim 1680$ MeV. The decomposition (1) offers three possibilities to arrange such difference (ordered according to the *Prinzip der Denkökonomie*):

★e-mail: maxim.polyakov@tp2.rub.de

★★deceased

[1] Existence of the narrow ($\Gamma \sim$10-40 MeV) peak in the $\gamma n \to \eta n$ cross section around 1680 MeV and its absence in the $\gamma p \to \eta p$ process

(I) the anti-decuplet amplitude $A^{(\overline{10})}$ has large size and rapid energy dependence on a narrow energy interval around 1680 MeV,

(II) there is a conspiracy and a fine tuning among the SU(3) amplitudes $A_{\rm F}^{(8)}, A_{\rm D}^{(8)}$ and $A^{(27)}$ on that narrow energy interval,

(III) extraordinarily strong violation of the SU(3) symmetry on that narrow energy interval.

We emphasise that the option (II) can explain the neutron anomaly only in the η-photoproduction. In other channels, e.g. the Compton scattering [5], the assumed conspiracy and fine tuning are destroyed due to different from (1) SU(3) decomposition of the Compton amplitude. The anti-decuplet amplitude $A^{(\overline{10})}$ enters only the γn channel independently of the final state. Therefore the option (I) predicts the neutron anomaly for the Compton scattering as well.

Usually the approximate flavour SU(3) symmetry works pretty well. As a rule its predictions are satisfied with an accuracy of about 30% or better, see e.g. a review [7]. A very large violation of the SU(3) symmetry would be a serious challenge to our common wisdom about hadron dynamics. It seems that a possible realisation of the option (III) is provided by Ref. [8]. In this paper the neutron anomaly was explained by the threshold effect due to $K\Lambda$ and $K\Sigma$ intermediate states. It was argued in Ref. [8] that the intermediate $K^+\Sigma^-$ state in the γn channel produces the cusp effect at $W \sim 1685$ MeV which can explain the peak in that channel. In order to suppress the corresponding peak in the γp channel the authors of Ref. [8] fitted their model parameter in such a way that the cusp due to $K^+\Lambda$ intermediate state cancels the cusp effect due to $K^+\Sigma^0$ state (a kind of fine tuning). Again, the explanation of the neutron neutron anomaly of Ref. [8] is not universal, *i.e.* it works only for η-photoproduction and fails for Compton scattering, the same as for the option (II).

In the following sections we analyse the physics realisations of the two first possibilities discussed above.

3 (I) Dominance of the anti-decuplet amplitude

The simplest physics realisation of the option (I) is an existence of a narrow anti-decuplet of baryons. The existence of such narrow exotic baryon multiplet was predicted in Ref. [9]. Main properties of N* from the anti-deculpet which were predicted theoretically in years 1997-2004 (before the discovery of the neutron anomaly) are the following:

- quantum numbers are P_{11} ($J^P = \frac{1}{2}^+$, isospin=$\frac{1}{2}$) [9],
- narrow width of $\Gamma \leq 40$ MeV [9–11],
- mass of $M \sim 1650 - 1720$ MeV [10–12],
- strong suppression of the proton photocoupling relative to the neutron one [13] ,
- the πN coupling is suppressed, N* prefers to decay into ηN, $K\Lambda$ and $\pi\Delta$ [9–11].

It seems that the nucleon resonance with such properties can explain concisely the neutron anomaly in both η-photoproduction and the Compton scattering.

Detailed account for predictions and evidences for narrow anti-decuplet nucleon was presented at length previously in the literature (see e.g. [14, 19]). Not to dwell on this once again, we just give the Table 1 which summarises extracted properties of the putative anti-decuplet nucleon resonance.

Table 1. Our estimate of properties of the putative narrow antidecuplet N* extracted from the data.

observable	extracted value
mass (MeV)	1680 ± 15
$\Gamma_{\rm tot}$ (MeV)	≤ 40
$\Gamma_{\pi N}$ (MeV)	≤ 0.5
$\sqrt{{\rm Br}_{\eta N}}A^n_{1/2}$ (10^{-3} GeV$^{-1/2}$)	12-18
$\sqrt{{\rm Br}_{\eta N}}A^p_{1/2}$ (10^{-3} GeV$^{-1/2}$)	1-3

4 (II) Conspiracy and fine tuning among non-exotic SU(3) amplitudes

A physics realisation of the option (II) was suggested in Refs. [20–22] by the Bonn-Gatchina group (BnGa). In these papers the neutron anomaly was explained by the interference effect of well-known wide S_{11} resonances N(1535) and N(1650). In order to arrange a narrow structure in the neutron channel the photocouplings of these two resonances should be fine tuned. In particular, the proton and neutron photocouplings of N(1650) must have the same sign. To describe the most recent and the most precise data of the A2 collaboration on the neutron anomaly [4] BnGa obtained the following ratio of the proton to neutron photocouplings [22]:

$$R_{pn} \equiv \frac{A^p_{1/2}(1650)}{A^n_{1/2}(1650)} = 1.74 \pm 0.66\,. \qquad (2)$$

Employing the flavour SU(3) symmetry one can express the ratio of the F_V and D_V octet vector couplings in terms of the ratio R_{pn}:

$$\frac{F_V}{D_V} = -\frac{1}{3}\left(2R_{pn}+1\right) = -1.50 \pm 0.44\,. \qquad (3)$$

The resulting from the analysis [22] F_V to D_V ratio is negative and larger than 1 in the absolute value. To our best knowledge such values of F_V/D_V have been never obtained in any model of baryon resonances (variants of quark model, MIT bag model, soliton models, etc). Let us see what are physics implications of such unusual values of the F_V/D_V ratio.

The flavour SU(3) symmetry allows to express various flavour combinations of the vector current couplings in terms of F_V/D_V-ratio (and hence in terms of R_{pn} (2) owing Eq. (3)). One can easily derive the following relations for various vector couplings of N(1650) (valid also for any octet nucleon resonance N'):

$$R_\omega \equiv \frac{g_{\omega NN'}}{g_{\rho^0 NN'}} = \frac{R_{pn}+1}{R_{pn}-1} + \sqrt{\frac{2}{3}}\, r_0, \tag{4}$$

$$R_\phi \equiv \frac{g_{\phi NN'}}{g_{\rho^0 NN'}} = -\sqrt{2}\,\frac{R_{pn}+1}{R_{pn}-1} + \sqrt{\frac{1}{3}}\, r_0. \tag{5}$$

Here r_0 is the ratio of the flavour singlet $((\bar{u}\gamma_\mu u + \bar{d}\gamma_\mu d + \bar{s}\gamma_\mu s)/\sqrt{3})$ vector current coupling to the isovector $((\bar{u}\gamma_\mu u - \bar{d}\gamma_\mu d)/\sqrt{2})$ that. The value of r_0 is not fixed by the SU(3) symmetry, however with help of Eqs. (4,5) we can express ϕ-meson coupling R_ϕ in terms of the ω-meson coupling R_ω and the proton to neutron ratio of the photocoupling R_{pn}:

$$R_\phi = \frac{1}{\sqrt{2}}\left(R_\omega - 3\,\frac{R_{pn}+1}{R_{pn}-1}\right). \tag{6}$$

Additionally, from Eqs. (4,5) one can easily derive the following inequality:

$$R_\omega^2 + R_\phi^2 \geq 3\left(\frac{R_{pn}+1}{R_{pn}-1}\right)^2. \tag{7}$$

If we take the BnGa value (2) for R_{pn} we obtain from (7):

$$R_\omega^2 + R_\phi^2 \geq 27. \tag{8}$$

One sees that in the scenario of Refs. [20–22] the ω- and ϕ-meson couplings of N(1650) can not be small simultaneously[2].

Experimentally [24] the decay N(1650) → ρN is seen and sizable, however the decay N(1650) → ωN is not seen. If we conservatively assume that the yield of ω mesons does not exceed factor of four relative to the yield of ρ mesons, *i.e* $R_\omega^2 \leq 4$ [3] then from Eq. (6) with BnGa value for the p/n ratio of N(1650) photocouplings (2) we obtain:

$$\left|R_\phi\right| \geq 6. \tag{9}$$

We see that the explanation of the neutron anomaly by the interference of known N(1535) and N(1650) resonances advocated in [20–22] implies that the ϕ-meson (almost pure $s\bar{s}$ state) coupling to N(1650)→N transition should be huge. In terms of quark degrees of freedom it means that N(1650) has a large admixture of $s\bar{s}$ component, *i.e.* in the scenario of Refs. [20–22] N(1650) is dominantly "cryptoexotic pentaquark" . It turns out that the "conventional" interpretation of the neutron anomaly by the interference of known resonances [20–22] metamorphose into unconventional physics picture of N(1650).

5 (III) Very large violation of the flavour SU(3) symmetry

In Ref. [8] the neutron anomaly was explained[4] by the threshold effect due to $K\Lambda$ and $K\Sigma$ intermediate states. We shall see that this explanation implies an extraordinarily large violation of the SU(3) symmetry. Usually the approximate flavour SU(3) symmetry works pretty well. As a rule its predictions are satisfied with an accuracy of about 30% or better, see e.g. a review [7]. A very large violation of the SU(3) symmetry is a serious challenge to our common wisdom about hadron dynamics.

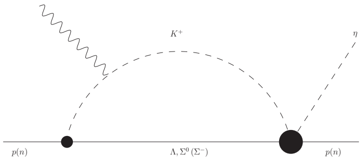

Figure 2. The diagram from [8] which contributes to the cusp at KY threshold.

The neutron anomaly was described in Ref. [8] by the diagram shown on Fig. 2. It was argued in Ref. [8] that the intermediate $K^+\Sigma^-$ state in the γn channel produces the cusp effect at $W \sim 1685$ MeV which can explain the peak in that channel. In order to suppress the corresponding peak in the γp channel the authors of Ref. [8] fitted their model parameter in such a way that the cusp due to $K^+\Lambda$ intermediate state cancels the cusp effect due to $K^+\Sigma^0$ state (a kind of fine tuning). Let us see how the assumed cancelation can be reconciled with SU(3) chiral dynamics.

The cusp contribution of the diagram on Fig. 2 to $\gamma N \to \eta N$ can be written as:

$$\begin{aligned} A_{\rm cusp}(\gamma p \to \eta p) &= D\left(A_\Sigma - \sqrt{\frac{1}{3}} A_\Lambda\right) \\ &- F\left(A_\Sigma + \sqrt{3} A_\Lambda\right), \\ A_{\rm cusp}(\gamma n \to \eta n) &= 2(D-F) A_\Sigma. \end{aligned} \tag{10}$$

Here A_Σ and A_Λ are (up to a common factor) $A(K^+\Sigma^0 \to \eta p)$ and $(K^+\Lambda \to \eta p)$ amplitudes at the corresponding KY thresholds (right blob on Fig. 2). In Eqs. (10,10) we expressed g_{KYN} coupling constants (left blob on Fig. 2) in terms of F and D pseudoscalar ground state octet couplings. To arrange the cancelation of the cusp effects suggested in Ref. [8] on sees from Eq. (10) that the amplitudes A_Σ and A_Λ should be related by:

$$\frac{A_\Lambda}{A_\Sigma} \simeq \sqrt{3}\,\frac{D-F}{D+3F} = \sqrt{3}\cdot 0.16. \tag{11}$$

Here the numerical value is obtained by taking the experimental value of $F = 0.46$, $D = 0.8$ [26]. The A_Λ/A_Σ ratio is predicted by the SU(3) chiral dynamics (see e.g [27]) as:

---

[2] Note that if we take N(1650) photocouplings from the SAID analysis [23], than $F_V/D_V = 0.6 \pm 0.6$ (range of values typical for all models of baryon resonances) and $R_\omega^2 + R_\phi^2 \geq 0.2$ (small values of ω and ϕ couplings are not excluded).

[3] If one combines the result of Ref. [33] for $g_{\rho NN'}$ with the result of Ref. [34] for $g_{\omega NN'}$ one obtains $R_\omega^2 \simeq 1$

[4] More precisely the authors were able to describe only the ratio of the neutron to proton cross section having a dozen of free adjustable parameters.

$$\frac{A_\Lambda}{A_\Sigma} \;=\; \sqrt{3}\left(1+O\left(\frac{m_K}{M_N}\right)\right), \tag{12}$$

where the symmetry breaking corrections $O(m_K/M_N)$ numerically can be rather sizable. The estimates of these corrections in Ref. [28] give $A_\Lambda/A_\Sigma = \sqrt{3}\cdot 0.8$, previous estimates in [29] give $A_\Lambda/A_\Sigma = \sqrt{3}\cdot(0.6 \div 0.7)$. We see that the result (11), which is needed for the explanation of the neutron anomaly by the cusp effect as in Ref. [8], is in a disagreement with the SU(3) chiral dynamics prediction (12), even if we take into account the $O(m_K/M_N)$ corrections of Refs. [28, 29]. We note, however, that the most recent analysis of the anti-kaon – baryon scattering [36–38] revealed that the NLO chiral corrections can be very large . It would be very interesting to see what is the resulting ratio in Eq. (12).

6 Conclusions

In summary, we analysed the implication of the flavour SU(3) symmetry for explanations of the neutron anomaly in the $\gamma N \to \eta N$ cross section. The SU(3) symmetry suggests three classes of scenarios: (A) dominance of the anti-decuplet channel at narrow energy interval (B) fine tuning of parameters of known wide resonances to arrange very specific interference pattern ([20–22]) or (C) fine tuning of parameters to arrange strong cusp effects in the neutron channel and their strong cancellation in the proton channel ([8]) .

The first two scenarios need exotic nucleon resonances – this can be either (A) a narrow anti-decuplet of baryons, or (B) well know N(1650) resonance with very large $s\bar{s}$ component, *i.e.* the well-known N(1650) resonance must be a "cryptoexotic pentaquark". In the scenario (C) it seems that one tunes parameters in such unnatural way that the flavour $SU(3)$ symmetry is very strongly violated. Also the scenario (C) assumes a fine tuning of a dozen of free adjustable parameters.

We stressed that the scenarious (B,C) (in contrast to the first scenario) can explain the neutron anomaly only in the $\gamma N \to \eta N$ process and it fails to explain the neutron anomaly in the Compton scattering. It seems that the simplest, universal (for both η-photoproduction and the Compton scattering) and concise way to explain the neutron anomaly is the existence of a narrow anti-decuplet of baryons. The most recent data [39] on double polarization observables for $\gamma n \to \eta n$ reaction strongly support our scenario (A) for explanation of the neutron anomaly. In that reference the authors came to the conclusion that "...the angular dependence to different model predictions favors a scenario with a contribution from a narrow P_{11} resonance."

7 Epilogue

The project **A.4** was funded over the first two periods of the SFB/TR 16. The PIs were Klaus Goeke and Maxim Polyakov and the project was called "Multiquark states of baryons". Apart from the neutron anomaly that was discussed in detail above, we briefly summarize here other pertinent work performed within this project.

7.1 Θ^+: puzzle of its existence

In 1997 the Diakonov, Petrov and Polyakov predicted in the Chiral Quark Soliton Model (χQSM) exotic baryons that have a particularly small decay width (<15 MeV) compared to usual resonances (about 100 MeV). Six years after the prediction the first positive indication of a baryon with positive strangeness (i.e. Θ^+) was provided by the LEPS collaboration at a mass of 1540 MeV. Experiments from DIANA, CLAS, SAPHIR and others found also positive evidence for the Θ^+. However in the last years several experiments were performed without evidence of Θ^+, such that presently the majority of physicists in the hadronic community doubts the existence of Θ^+. The main weakness is that one does not know the production mechanism of these exotic particles, if they exist. Therefore theoretical studies are needed and suggested and hence performed in the present project [40–42]. The studies are all performed assuming the predicted quantum numbers of Θ^+, the above mentioned energy, and a width below 1 MeV [43, 44].

7.2 Possibility to identify Θ^+ baryon from interference

In this work [45], we suggest to search for the narrow Θ^+ resonance in a non-standard way, exploiting the interference of the small Θ^+ production amplitude with the large production amplitude of a known resonance, yielding the same final state. Although the interference idea is very general, we apply it primarily to the CLAS experiment whose impressive amount of data can be used to look for the Θ^+ resonance in interference with the large ϕ photoproduction. Since the final state in both cases is the same, the two amplitudes *must* interfere unless forbidden kinematically. A simple account for kinematics shows that the two amplitudes interfere in the CLAS experiment.

The Θ^+ production amplitude *squared* has been estimated in Ref. [46] with the tiny result for the cross section in the sub-nanobarn range – too small to be observable even with the large CLAS statistics. However, the interference cross section is *linear* in the Θ^+ coupling and hence can be substantially larger. In the CLAS experiment studying the $\gamma p \to K^0\bar{K}^0 p$ reaction, the K_S (decaying into $\pi^+\pi^-$) and p have been detected. The second kaon was reconstructed from the missing mass of all detected particles. A large portion of events were due to the production of the ϕ meson decaying into $K_L K_S$. These events have been rejected in this analysis, however they are exactly what are needed now. The reanalysis of the CLAS data using the $K_L K_S$ pairs from the decay of ϕ-meson the was performed in Ref. [47]. The observation of a narrow peak structure at $\sim$ 1.54 GeV with a Gaussian width of $\sim$ 6 MeV in the missing mass of K_S was reported. The observed structure may be due to the interference between a strange (or anti-strange) baryon resonance in the pK_L system and the $\phi(K_S K_L)$ photoproduction leading to the same final state. The statistical significance of the observed excess of events estimated as the log likelihood ratio of the resonant signal+background hypothesis and the ϕ-production based background-only hypothesis corresponds to 5.3σ.

The method is directly applicable also to the $\bar{K}^0 K^+ n$ reactions at relatively low energies, where one should look for the $\Theta - \Lambda(1520)$ interference.

7.3 K^*-couplings for the anti-decuplet and photo-production of the Θ^+ on the nucleon

Current approaches to the theoretical description of Θ-production are often based on K and K^* meson or reggeon exchanges. The vertex for the $KN\Theta$-coupling may be considered as known, if one assumes the spin-parity and width of Θ^+ to be known (the corresponding form factor is still a problem, of course). Contrary to this, properties of the K^* exchange are totally unknown. However, they may be essential, *e.g.*, for comparisons of Θ^+-photoproduction off the proton and/or the neutron. In the works [43, 44, 46] we estimate the coupling of the K^* vector meson to the $N \to \Theta^+$ transition employing unitary symmetry, vector meson dominance, and results from the GRAAL Collaboration for η photo-production off the neutron. Our small numerical value for the coupling constant is consistent with the non-observation of the Θ^+ in recent CLAS searches for its photo-production. We also estimate the K^*-coupling for the $N \to \Sigma^*$ excitation, with Σ^* being the Σ-like anti-decuplet partner of the Θ^+ -baryon. As described in our paper ref. [43] we obtain the following estimates:

$$\begin{aligned} |f_2(K^{*0}\, p\, \Theta^+)| = |f_2(K^{*+}\, n\, \Theta^+)| &= \sqrt{6}\, |f_2(\rho^0\, n\, n^*)| \\ &= (1.10 - 3.14)\,, \\ |f_2(K^{*-}\; p\; \Sigma^{*0})| = (0.45 - 1.28)\,, \quad & |f_2(\overline{K}^{*0}\; p\; \Sigma^{*+})| \\ &= (0.64 - 1.81)\,. \end{aligned}$$

Incidentally, the value of 1.1 for $|f_2(K^{*+}\, n\, \Theta^+)| = |f_2(K^{*0}\, p\, \Theta^+)|$ was used earlier in Ref. [46] to estimate the production cross section of Θ^+ in photo-reactions. With a Θ^+-width of 1 MeV and the above value of $f_2(K^*\, N\, \Theta)$, calculations [46] find small cross sections $\sigma_{tot}(\gamma p \to \overline{K}^0 \Theta^+) < 0.22$ nb and $\sigma_{tot}(\gamma n \to K^- \Theta^+) < 1$ nb, which are below the limits given recently by the CLAS Collaboration.

Note also the difference between proton and neutron targets. To clarify the meaning of our numerical values for f_2, we consider in more detail the photo-production $\gamma + p \to \overline{K}^0 + \Theta^+$ with K^*-exchange as the main contribution. We can compare experimental limits for this reaction, obtained by the CLAS Collaboration, and the theoretical calculations in our model [46]. Our analysis shows that the CLAS analysis very likely is not sensitive enough to reveal the Θ^+ (if it exists).

7.4 SU(3) systematization of baryons

We studied the spectrum of all baryons with the mass less than approximately 2000-2200 MeV using the Gell-Mann–Okubo mass formulas and SU(3)-symmetric predictions for two-body hadronic decays [48–50]. We successfully placed almost all known baryons in twenty-one SU(3) multiplets and, thus, confirmed the prediction that the approximate SU(3) symmetry works remarkably well.

Our results are summarized in ref.[48]. In fact there are predictions of 17 new particles, which are absent in the Review of Particle Physics. Among the predicted baryons, the most remarkable is the Λ hyperon with $J^P = 3/2^-$, the mass around 1850 MeV, the total width $\approx$ 130 MeV, significant branching into the $\Sigma\pi$ and $\Sigma(1385)\pi$ states and a very small coupling to the $N\overline{K}$ state [51]. Our analysis gives a model-independent confirmation of the constituent quark model prediction that there should exist a new Λ baryon with the mass between 1775 MeV and 1880 MeV, which almost decouples from the $N\overline{K}$ state.

Methods of the approximate flavor SU(3) symmetry of the strong interactions are also applicable to the antidecuplet. Our analysis clearly demonstrates that, if the antidecuplet exists, it must mix with some other SU(3) multiplet [48–50]. We considered a scenario that the antidecuplet mixes with a non-exotic octet. This enables us to accommodate in a simple way all presently available experimental information on the antidecuplet decays and to predict the unmeasured $\overline{\mathbf{10}}$ decays. Ref. [48] summarizes our SU(3) predictions for the antidecuplet. Assuming $\Gamma_{\Theta^+} \leq 1$ MeV we obtain fkor all partial widths of the anti-decuplet of less than 2.5 MeV with the only exception of $\Gamma_{N_{\overline{10}} \to \Delta\pi} = (2.6 - 15.6)$MeV and $\Gamma_{\Sigma_{\overline{10}} \to \Sigma(1385)\pi} = (0.33 - 1.96)$MeV.

7.5 Baryons from the chiral quark-soliton picture

During the second funding period our work was also concentrated on studies of hadrons which emerge in the chiral quark-soliton picture of the baryons. Firstly, we worked out in Ref. [52] in detail the properties of possible anti-decuplet baryons. We have proposed a scenario in which the Roper octet can mix with the putative anti-decuplet of exotic baryons and predicted the properties of its cryptoexotic states. In our view, this is the best what one can do in the framework of the chiral-quark soliton model. It was found that the cryptoexotic anti-decuplet nucleon state must have a much larger photocoupling to the neutron than the proton. Also we found that the coupling of anti-decuplet N^* to the πN channel is strongly suppressed. As the byproduct of our studies of the ground state baryons in the chiral quark-soliton model, we developed a method to calculate the electromagnetic mass differences in the octet and decuplet of baryons [53]. In this work we showed that the electromagnetic mass differences in the octet and the decuplet are related to each other due to the hedgehog symmetry of the model. These relations are in a good agreement with the experimental data.

We appreciate very much fruitful collaboration with M. Amarian, Ya. I. Azimov, T. Boika, D.I Diakonov, V. Kuznetsov,

V. Petrov, M. Praszalowicz, and I. Strakovsky. We acknowledge important contributions from V. Guzey during the first funding period. The work reported here would not have been possible without the support from the Deutsche Forschungsgemeinschaft within the SFB/TR16.

References

[1] V. Kuznetsov [GRAAL Collaboration], "η photoproduction off the neutron at GRAAL: Evidence for a resonant structure at W = 1.67-GeV," arXiv:hep-ex/0409032,
V. Kuznetsov *et al.*, Phys. Lett. B **647**, 23 (2007) [arXiv:hep-ex/0606065].

[2] F. Miyahara *et al.*, Prog. Theor. Phys. Suppl. **168**, 90 (2007).

[3] I. Jaegle *et al.* [CBELSA Collaboration and TAPS Collaboration], Phys. Rev. Lett. **100** (2008) 252002 [arXiv:0804.4841 [nucl-ex]],
I. Jaegle, B. Krusche, A. V. Anisovich, J. C. S. Bacelar, B. Bantes, O. Bartholomy, D. E. Bayadilov and R. Beck *et al.*, Eur. Phys. J. A **47** (2011) 89 [arXiv:1107.2046 [nucl-ex]].

[4] D. Werthmuller *et al.* [A2 Collaboration], Phys. Rev. Lett. **111** (2013) 23, 232001 [arXiv:1311.2781 [nucl-ex]],
L. Witthauer *et al.* [A2 Collaboration], Eur. Phys. J. A **49** (2013) 154 [arXiv:1312.1571 [nucl-ex]],
D. Werthmuller *et al.* [A2 Collaboration], Phys. Rev. C **90** (2014) 015205 [arXiv:1407.6974 [nucl-ex]].

[5] V. Kuznetsov *et al.*, Phys. Rev. C **83** (2011) 022201(R) [arXiv:1003.4585 [hep-ex]].

[6] E. F. McNicoll *et al.*, Phys. Rev. C **82** (2010) 035208.

[7] N. P. Samios, M. Goldberg and B. T. Meadows, Rev. Mod. Phys. **46** (1974) 49.

[8] M. Doring and K. Nakayama, Phys. Lett. B **683**, 145 (2010) [arXiv:0909.3538 [nucl-th]].

[9] D. Diakonov, V. Petrov and M. V. Polyakov, Z. Phys. A **359** (1997) 305 [arXiv:hep-ph/9703373].

[10] R. A. Arndt *et al.*, Phys. Rev. C **69**, 035208 (2004) [arXiv:nucl-th/0312126].

[11] J. R. Ellis, M. Karliner and M. Praszalowicz, JHEP **0405** (2004) 002; M. Praszalowicz, Acta Phys. Polon. B **35** (2004) 1625 [arXiv:hep-ph/0402038].

[12] D. Diakonov and V. Petrov, Phys. Rev. D **69** (2004) 094011 [arXiv:hep-ph/0310212].

[13] M. V. Polyakov and A. Rathke, Eur. Phys. J. A **18**, 691 (2003) [arXiv:hep-ph/0303138].

[14] V. Kuznetsov *et al.*, Acta Phys. Polon. B **39**, 1949 (2008) [arXiv:0807.2316 [hep-ex]];

[15] V. Kuznetsov and M. V. Polyakov, JETP Lett. **88**, 347 (2008) [arXiv:0807.3217 [hep-ph]].

[16] V. Kuznetsov, M. V. Polyakov and M. Thurmann, arXiv:1102.5209 [hep-ph].

[17] A. V. Anisovich, E. Klempt, V. Kuznetsov, V. A. Nikonov, M. V. Polyakov, A. V. Sarantsev and U. Thoma, Phys. Lett. B **719** (2013) 89 [arXiv:1108.3010].

[18] Y. I. Azimov, *et al.*, Eur. Phys. J. A **25**, 325 (2005) [arXiv:hep-ph/0506236].

[19] K. Goeke, M. V. Polyakov and M. Praszalowicz, Acta Phys. Polon. B **42** (2011) 61 [arXiv:0912.0469 [hep-ph]],
M. Praszalowicz, Acta Phys. Polon. Supp. **3** (2010) 917 [arXiv:1005.1007 [hep-ph]].

[20] A. V. Anisovich *et al.*, Eur. Phys. J. A **41**, 13 (2009) [arXiv:0809.3340 [hep-ph]].

[21] A. V. Anisovich, V. Burkert, E. Klempt, V. A. Nikonov, A. V. Sarantsev and U. Thoma, Eur. Phys. J. A **49** (2013) 67 [arXiv:1304.2177 [nucl-ex]].

[22] A. V. Anisovich, E. Klempt, V. A. Nikonov, A. V. Sarantsev and U. Thoma, arXiv:1402.7164 [nucl-ex].

[23] W. Chen, H. Gao, W. J. Briscoe, D. Dutta, A. E. Kudryavtsev, M. Mirazita, M. W. Paris and P. Rossi *et al.*, Phys. Rev. C **86** (2012) 015206 [arXiv:1203.4412 [hep-ph]],
R. L. Workman, M. W. Paris, W. J. Briscoe and I. I. Strakovsky, Phys. Rev. C **86** (2012) 015202 [arXiv:1202.0845 [hep-ph]].

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

[25] V. Guzey and M. V. Polyakov, "SU(3) systematization of baryons," hep-ph/0512355.

[26] F. E. Close and R. G. Roberts, Phys. Lett. B **316** (1993) 165 [hep-ph/9306289],
B. Borasoy, Phys. Rev. D **59** (1999) 054021 [hep-ph/9811411].

[27] N. Kaiser, T. Waas and W. Weise, Nucl. Phys. A **612** (1997) 297 [hep-ph/9607459],
B. Borasoy, E. Marco and S. Wetzel, Phys. Rev. C **66** (2002) 055208 [hep-ph/0212256].

[28] Y. Ikeda, T. Hyodo and W. Weise, Nucl. Phys. A **881** (2012) 98 [arXiv:1201.6549 [nucl-th]].

[29] B. Borasoy, R. Nissler and W. Weise, Eur. Phys. J. A **25** (2005) 79 [hep-ph/0505239].

[30] A. Fix, L. Tiator and M. V. Polyakov, Eur. Phys. J. A **32**, 311 (2007) [arXiv:nucl-th/0702034].

[31] V. Shklyar, H. Lenske and U. Mosel, Phys. Lett. B **650**, 172 (2007) [arXiv:nucl-th/0611036].

[32] M. Praszalowicz, arXiv:1005.1007 [hep-ph].

[33] A. M. Gasparyan, J. Haidenbauer, C. Hanhart and J. Speth, Phys. Rev. C **68** (2003) 045207 [nucl-th/0307072].

[34] V. Shklyar, H. Lenske, U. Mosel and G. Penner, Phys. Rev. C **71** (2005) 055206 [Erratum-ibid. C **72** (2005) 019903] [nucl-th/0412029].

[35] T. M. Knasel *et al.*, Phys. Rev. **D11** (1975) 1-13;
B. Nelson *et al.*, Phys. Rev. Lett. **31** (1973) 901-904.

[36] M. Mai and U. G. Meissner, Nucl. Phys. A **900** (2013) 51 doi:10.1016/j.nuclphysa.2013.01.032 [arXiv:1202.2030 [nucl-th]].

[37] Z. H. Guo and J. A. Oller, Phys. Rev. C **87** (2013) no.3, 035202 doi:10.1103/PhysRevC.87.035202 [arXiv:1210.3485 [hep-ph]].

[38] A. Cieply, M. Mai, U. G. Meißner and J. Smejkal, Nucl. Phys. A **954** (2016) 17 doi:10.1016/j.nuclphysa.2016.04.031 [arXiv:1603.02531 [hep-ph]].

[39] L. Witthauer *et al.*, Phys. Rev. Lett. **117** (2016) no.13, 132502. doi:10.1103/PhysRevLett.117.132502

[40] K. Goeke, H. C. Kim, M. Praszalowicz and G. S. Yang, Prog. Part. Nucl. Phys. **55** (2005) 350 [arXiv:hep-ph/0411195].

[41] K. Goeke, H. C. Kim and M. Praszalowicz, Europhys. News **36** (2005) 151.

[42] M. Praszalowicz and K. Goeke, Acta Phys. Polon. B **36**, 2255 (2005) [arXiv:hep-ph/0506041].

[43] Y. Azimov, V. Kuznetsov, M. V. Polyakov and I. Strakovsky, Phys. Rev. D **75**, 054014 (2007) [arXiv:hep-ph/0611238].

[44] Y. Azimov, V. Kuznetsov, M. V. Polyakov and I. Strakovsky, Eur. Phys. J. A **25**, 325 (2005) [arXiv:hep-ph/0506236].

[45] M. Amarian, D. Diakonov and M. V. Polyakov, arXiv:hep-ph/0612150.

[46] H. Kwee, M. Guidal, M. V. Polyakov and M. Vanderhaeghen, Phys. Rev. D **72**, 054012 (2005) [arXiv:hep-ph/0507180].

[47] M. J. Amaryan *et al.*, Phys. Rev. C **85** (2012) 035209 doi:10.1103/PhysRevC.85.035209, 10.1103/PhysRevC.85.049901 [arXiv:1110.3325 [hep-ex]].

[48] V. Guzey and M. V. Polyakov, arXiv:hep-ph/0512355.

[49] V. Guzey, AIP Conf. Proc. **775**, 3 (2005).

[50] V. Guzey and M. V. Polyakov, Annalen Phys. **13**, 673 (2004).

[51] V. Guzey, arXiv:hep-ph/0512276.

[52] K. Goeke, M. V. Polyakov and M. Praszalowicz, Acta Phys. Polon. B **42**, 61 (2011)

[53] G.-S. Yang, H.-C. Kim and M. V. Polyakov, Phys. Lett. B **695**, 214 (2011)