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New Narrow Nucleon N*(1685)

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We argue that the existence of a new narrow ($\Gamma \leq 25$ MeV) nucleon resonance N*(1685) is strongly supported by recent data on η photoproduction off the nucleon. The resonance has much stronger photo-coupling to the neutron than to the proton. This nucleon resonance is a good candidate for the non-strange member of the exotic anti-decouplet of baryons – the partner of the pentaquark Θ^+. All known to the date properties of new N*(1685) are summarized.

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Secondly, the exotic Θ^+ baryon always has to be accompanied by its siblings. A multiplet containing pentaquarks should also contain baryons with non-exotic "3-quark" quantum numbers. The minimal $SU_{fl}(3)$ multiplet containing pentaquarks is the anti-decouplet of baryons. In the anti-decouplet [1] there are two types of baryons with non-exotic quantum numbers: the isodoublet of non-strange nucleons (N*) and the isotriplet of $S = -1$ Σ^*'s. In the Chiral Quark-Soliton model (χQSM) the spin-parity quantum numbers of the anti-decouplet members are unambiguously predicted to be $J^P = \frac{1}{2}^+$ [1], so that the N* from the anti-decouplet is predicted to be a P_{11} nucleon resonance. One of the striking properties of N* is that it can be excited by an electromagnetic probe from the neutron target much stronger than from the proton one [2]. The photoexcitation of the charged isocomponent of N* is possible only due to $SU_{fl}(3)$ violation, therefore it is suppressed by a factor $\sim 1/10$ in the amplitude. The mass of the anti-decouplet N* was predicted to be around 1680 MeV in Refs. [3, 4]. Its width is predicted to be in the range of tens of MeV ($\Gamma \leq 30$ MeV) with a very small coupling to the πN channel [4]. The preferred decay channels are predicted to be ηN, $\pi\Delta$ and $K\Lambda$ [1, 4 – 9].

Predictions of Refs. [2 – 4] encouraged one of the authors (V. K.) to push forward the study of the η photoproduction on the neutron at GRAAL. In 2004 these efforts led to the observation of a narrow peak in the quasi-free neutron cross section and in the ηn invariant mass spectrum [10, 11], see Fig.1.

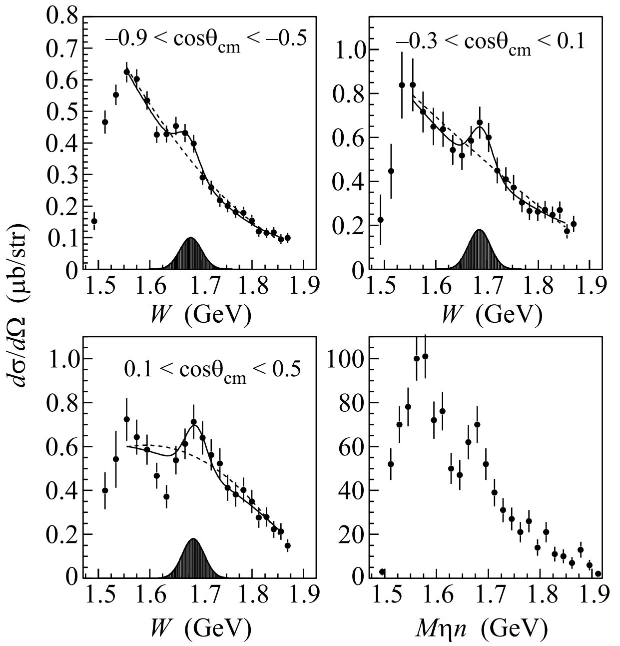

Fig.1. Quasi-free cross sections and ηn invariant mass spectrum (low right panel) for the $\gamma n \to \eta n$ reaction (data from [11]). Solid lines are the fit by the sum of 3-order polynomial and narrow state. Dashed lines are the fit by 3-order polynomial only. Dark areas show the simulated signal of a narrow state

The original observation of Refs. [10, 11] has been recently confirmed by two other groups: CBELSA/TAPS [12] and LNS-Sendai [13]. In all three experiments an enhancement in the quasi-free cross-section1) on the neutron has been found. More-

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1) For brevity we call this enhancement "neutron anomaly".

over, the GRAAL and CBELSA/TAPS groups have observed narrow peaks in the ηn invariant mass spectrum at 1680 – 1685 MeV. The position of the peaks are ~ 1680 MeV at GRAAL data (see low-right panel of Fig.1) and ~ 1683 MeV at CBELSA/TAPS data (see Fig.2). The width of the peaks is 40 MeV in the GRAAL data and 60 ± 20 MeV in the CBELSA/TAPS data. In both experiments the width is dominated by the instrumental resolution. We note that the cross section in the proton channel does not exhibit any strong enhancement around $W \sim 1680{-}1685$ MeV (see e.g. Fig.2).

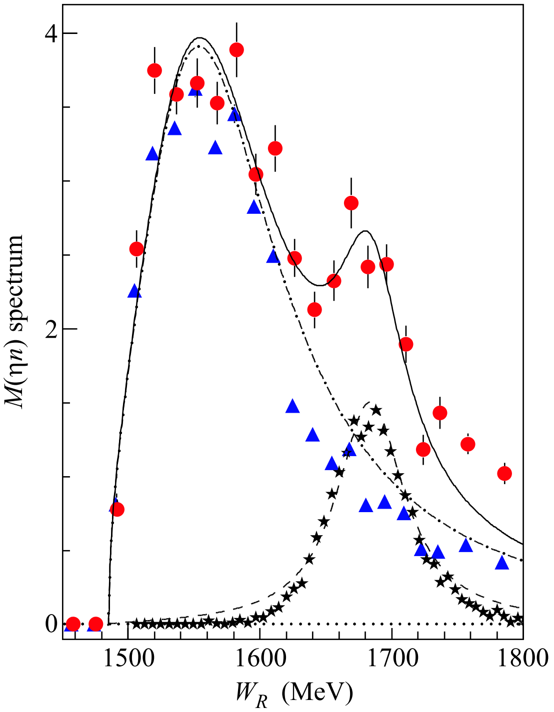

Fig.2. $M(\eta n)$ spectrum from CBELSA/TAPS [12] (filled circle) in comparison with $M(\eta p)$ spectrum (filled triangles) Stars show the simulated signal of a narrow state

A simple and concise explanation of the "neutron anomaly" and of the peak in the ηn invariant mass is the existence of a new narrow nucleon resonance with much stronger photocoupling to the neutron than to the proton predicted in Refs. [2 – 4]. Due to the weak photocoupling to the proton, the expected signal of N* in the proton channel requires high precision and high resolution of the data.

Alternative theoretical explanations of the "neutron anomaly" were suggested in Refs. [14, 15]. The authors demonstrated that the bump in the $\gamma n \to \eta n$ cross section could be explained in terms of photoexcitation of the known $S_{11}(1650)$ and $P_{11}(1710)$ (or $S_{11}(1535)$ and $S_{11}(1650)$) resonances. The authors of Refs. [14, 15] tuned the neutron photocouplings of these known resonances in order to obtain a bump in the $\gamma n \to \eta n$ quasi-free cross section. The proton photocouplings were not touched. This implies that all observables in the proton channel, predicted by these models, do not possess any irregularities at $W \sim 1680 - 1690$ MeV. In other words, the models of Refs. [14, 15] predict the absence of any narrow structures in the proton observables, whereas the existence of the new N* should lead to the presence of a narrow structure[2)] in observables for η photoproduction on the free proton.

One can put the two qualitatively different explanations of the "neutron anomaly" to the test. If photoexcitation of a nucleon resonance occurs on the neutron, its isospin partner must materialize itself in the proton channel as well. Thus, *experimentum crucis* lies in the studies of η photoproduction on the free proton. The observables in this case are not affected by the nuclear effects.

In order to clarify the interpretation of the "neutron anomaly" we have undertaken in Ref. [16][3)] a reanalysis of the GRAAL data [18, 19] on the Σ beam asymmetry for the η photoproduction off the free proton. We have extracted the beam asymmetry using narrow energy bins, in order to reveal in details the dependence of the beam asymmetry on the photon energy in the region of $E_\gamma = 0.85 - 1.15$ GeV (or $W = 1.55 - 1.75$ GeV).

The results of Ref. [16] are presented in Fig.3. We see that the peak at forward angles and the oscillating structure at central angles form a pattern similar to the interference of a narrow resonance with a smooth background. In order to examine this assumption, we employ the multipoles of the recent E429 solution of the SAID partial-wave analysis [20] for η photoproduction as the model for the smooth part of the observables. We see on Fig.3 that the SAID multipoles provide a good description of the data on Σ beam asymmetry. However, in the narrow photon energy interval of $E_\gamma = 1.015 - 1.095$ the considerable deviation of the data from the smooth curve provided by the SAID multipoles takes place. The χ^2 value for the points in this energy interval [6×4 points – 6 energy bins in 4 angular bins] for the SAID solution is rather sizeable $\chi^2/dof = 74/24$. For the nearby energy bins the SAID solution gives a good description of the data. A natural way to describe the deviation of the data from the smooth SAID solution is an addition

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[2)] In order to reveal such suppressed narrow structures one has to consider observables with fine binning in energy and with high enough statistics.

[3)] See this Ref. for comments on the analysis of analogous data in Ref.[17]

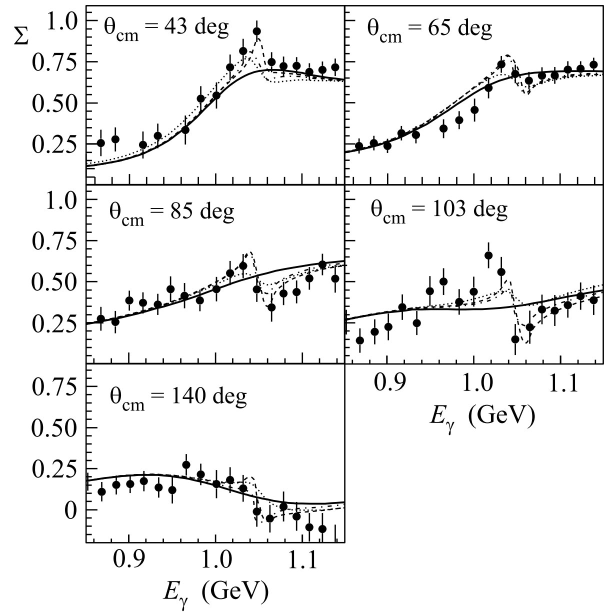

Fig.3. Fit of experimental data (filled circles data obtained in the analysis of Ref. [16]). Solid lines show our calculations [16] based on the SAID multipoles only, dotted lines include the P_{11} resonance with the width $\Gamma = 19$ MeV; dashed lines are calculations with the P_{13} resonance ($\Gamma =$ 8 MeV), while the dash-dotted lines use the resonance D_{13}, also with $\Gamma = 8$ MeV

of a narrow resonance in the Breit-Wigner form (see e.g. [21]) to the SAID multipoles. The contribution of a resonance is parameterized by the mass, width, photocouplings (multiplied by square root of ηN branching), and the phase. These parameters are varied in order to achieve the minimization of χ^2.

The mass of the included resonances is strongly constrained by the experimental data. The mass values belong to the range of $M_R = 1.685 - 1.690$ GeV. The best agreement with the data is obtained with the width of $\Gamma \sim 8$ MeV for P_{13} and D_{13}, and $\Gamma \sim 19$ MeV for P_{11}. However, the reasonable reproduction of the data is achieved for the width up to $\Gamma \leq 25$ MeV.

We tried various quantum numbers of the resonance. The S_{11} resonance generates a dip at 43° in the entire variation range of its photocoupling and its phase. It does not lead to improvement of χ^2 in the photon energy interval $E_\gamma = 1.015 - 1.095$. This indicates that most probably the observed structures can not be attributed to a narrow S_{11} resonance. The inclusion of the narrow P_{11}, P_{13} and D_{13} resonances improves the description of the data. The corresponding values of χ^2 are the following: $\chi^2/dof = 56/22$ for the P_{11}; $\chi^2/dof = 25/20$ for the P_{13}; and $\chi^2/dof = 39/20$ for the D_{13} resonances.

The curves shown in Fig.3 correspond to the following values of the photocouplings:

- for the P_{11} resonance:

$$\sqrt{Br_{\eta N}}A^p_{1/2} \sim 1 \cdot 10^{-3}\ \text{GeV}^{-1/2}; \qquad (1)$$

- for the P_{13} resonance:

$$\sqrt{Br_{\eta N}}A^p_{1/2} \sim -0.3 \cdot 10^{-3}\ \text{GeV}^{-1/2}, \qquad (2)$$

$$\sqrt{Br_{\eta N}}A^p_{3/2} \sim 1.7 \cdot 10^{-3}\ \text{GeV}^{-1/2}; \qquad (3)$$

- for the D_{13} resonance:

$$\sqrt{Br_{\eta N}}A^p_{1/2} \sim -0.1 \cdot 10^{-3}\ \text{GeV}^{-1/2}, \qquad (4)$$

$$\sqrt{Br_{\eta N}}A^p_{3/2} \sim 0.9 \cdot 10^{-3}\ \text{GeV}^{-1/2}. \qquad (5)$$

The neutron photocoupling is considerably larger than the above values for the proton. On the basis of the data from Refs. [10, 11], the photocoupling of N* was estimated in Ref. [22] as[4]:

$$\sqrt{\mathrm{Br}_{\eta N}}A^n_{1/2} \sim 15 \cdot 10^{-3}\ \text{GeV}^{-1/2}. \qquad (6)$$

The value (1) of $\sqrt{Br_{\eta N}}A^p_{1/2}$ and the value (6) of $\sqrt{\mathrm{Br}_{\eta N}}A^n_{1/2}$ are in a good agreement with the estimates for the non-strange pentaquark from the anti-decouplet performed in Chiral Quark-Soliton Model [2, 23].

In summary, we have demonstrated here that the existence of a new narrow nucleon resonance N*(1685) has sprouted from the experimental results of Refs. [10 – 13, 16]. We have educed its properties from the data of Refs. [10 – 12, 16] as follows:

- The mass is [10 – 12, 16]

$$M = 1.685 \pm 0.005 \pm 0.007\ \text{GeV}.$$

- The width is estimated as [16]

$$\Gamma \leq 25\ \text{MeV}.$$

- The neutron photocoupling is much stronger than that of the proton [22, 16]

$$\frac{\Gamma(n^* \to n\gamma)}{\Gamma(p^* \to p\gamma)} \sim 50 - 250.$$

- Most probably the S_{11} quantum numbers are excluded [16].

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[4] Possible theoretical errors of this analysis are up to a factor of two.

Employing additional information on elastic πN scattering [4] and broken $\mathrm{SU}_{\mathrm{fl}}(3)$ [8] we can obtain further properties of N*(1685):

- The πN branching is estimated as [4]

$$\mathrm{Br}_{\pi N} \leq 5\%.$$

- The most probable quantum numbers are P_{11} [4].
- Mixing angles between N*(1685) and ground state nucleon, $P_{11}(1440)$, and $P_{11}(1710)$ are small [8]:

$$|\theta_{1,2,3}| \leq 12^{\circ}.$$

It seems that for many years we have been overlooking a *narrow* nucleon resonance with a mass around 1685 MeV! Indeed, searches for new baryon resonances have been focusing on the states with a width in the range of hundreds of MeV. Such "missing" resonances have been copiously predicted by variants of the 3-quark models of baryons. The existence of an excited nucleon state with a width in the range of tens of MeV has been unthinkable.

The new narrow nucleon N*(1685) discussed here, being a very good candidate for the non-strange member of the exotic anti-decouplet, provides us with strong circumstantial evidence for the existence of *Ultima Thule* of hadronic physics – the exotic Θ^+ baryon.

There are several experiments that support the existence of Θ^+ baryon. We mention only two collaborations, that first explored Θ^+. The LEPS and DIANA collaborations not only announced the pioneering signals in 2003 [24, 25] but also confirmed their signals on the higher statistics after a careful and critical analysis [26, 27]. Yet, the existence of Θ^+ has not been widely accepted (see e.g. [28]). One of the most influential negative results on Θ^+ comes from the report [29] by the CLAS collaboration, in which the previous CLAS announcement [30] of the evidence for Θ^+ is renounced. The presented in Refs. [30] evidences for Θ^+ were based on noncritical estimates of the background and statistical significance of the announced signal, as it has been shown by the most recent CLAS analysis[5] [31]. The reports of the CLAS collaboration in no way diminish the evidences for Θ^+ provided by the LEPS, DIANA and other collaborations.

Firstly, the direct and indirect evidences for the existence of Θ^+ are strong and can not be simply brushed away.

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1. D. Diakonov, V. Petrov, and M. V. Polyakov, Z. Phys. A **359**, 305 (1997) [arXiv:hep-ph/9703373].
2. M. V. Polyakov and A. Rathke, Eur. Phys. J. A **18**, 691 (2003) [arXiv:hep-ph/0303138].
3. D. Diakonov and V. Petrov, Phys. Rev. D **69**, 094011 (2004) [arXiv:hep-ph/0310212].
4. R. A. Arndt, Y. I. Azimov, M. V. Polyakov et al., Phys. Rev. C **69**, 035208 (2004) [arXiv:nucl-th/0312126].
5. J. R. Ellis, M. Karliner, and M. Praszalowicz, JHEP **0405**, 002 (2004) [arXiv:hep-ph/0401127].
6. M. Praszalowicz, Acta Phys. Polon. B **35**, 1625 (2004) [arXiv:hep-ph/0402038].
7. M. Praszalowicz, Ann. Phys. **13**, 709 (2004) [arXiv:hep-ph/0410086].
8. V. Guzey and M. V. Polyakov, arXiv:hep-ph/0501010; Ann. Phys. **13**, 673 (2004); arXiv:hep-ph/0512355.
9. T. Ledwig, H. C. Kim, and K. Goeke, arXiv:0805.4063 [hep-ph].
10. V. Kuznetsov et al. [GRAAL Collaboration], *Proc. of Workshop on the Physics of Excited Nucleons NSTAR2004*, March, 2004, Grenoble, France, Eds. J.-P. Bocquet, V. Kuznetsov, D. Rebreyend, World Scientific, p. 197; arXiv:hep-ex/0409032.
11. V. Kuznetsov et al., Phys. Lett. B **647**, 23 (2007); [hep-ex/0606065].
12. I. Jaegle et al., arXiv:0804.4841 [nucl-ex].
13. F. Miyahara et al., Prog. Theor. Phys. Suppl. **168**, 90 (2007).
14. V. Shklyar, H. Lenske, and U. Mosel, Phys. Lett. B **650**, 172 (2007) [arXiv:nucl-th/0611036].
15. A. V. Anisovich, talk at the NSTAR07, Bonn, September, 2007, http://nstar2007.uni-bonn.de/talks.
16. V. Kuznetsov et al., arXiv:hep-ex/0703003; V. Kuznetsov et al., arXiv:0801.0778 [hep-ex]; V. Kuznetsov et al., arXiv:0807.2316 [hep-ex], to appear in Acta Physica Polonica B **39**, No. 8, 1949 (2008). http://durpdg.dur.ac.uk/cgi-hepdata/hepreac/7091516
17. O. Bartalini et al. [The GRAAL collaboration], Eur. Phys. J. A **33**, 169 (2007) [arXiv:0707.1385 [nucl-ex]].
18. J. Ajaka et al., Phys. Rev. Lett. **81**, 1797 (1998).
19. V. Kuznetsov et al., πN News Letters **16**, 160 (2002), http://gwdac.phys.gwu.edu.
20. R. A. Arndt, W. J. Briscoe, I. I. Strakovsky, and R. L. Workman, in progress, http://gwdac.phys.gwu.edu.

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[5] Note, however, that this analysis is not flawless [32]

21. W. T. Chiang, S. N. Yang, L. Tiator, and D. Drechsel, Nucl. Phys. A **700**, 429 (2002) [arXiv:nucl-th/0110034].
22. Y. Azimov, V. Kuznetsov, M. V. Polyakov, and I. Strakovsky, Eur. Phys. J. A **25**, 325 (2005) [arXiv:hep-ph/0506236].
23. H. C. Kim, M. Polyakov, M. Praszalowicz et al., Phys. Rev. D **71**, 094023 (2005) [arXiv:hep-ph/0503237].
24. T. Nakano et al. [LEPS Collaboration], Phys. Rev. Lett. **91**, 012002 (2003) [arXiv:hep-ex/0301020].
25. V. V. Barmin et al. [DIANA Collaboration], Phys. Atom. Nucl. **66**, 1715 (2003) [Yad. Fiz. **66**, 1763 (2003)] [arXiv:hep-ex/0304040].
26. V. V. Barmin et al. [DIANA Collaboration], Phys. Atom. Nucl. **70**, 35 (2007) [arXiv:hep-ex/0603017].
27. T. Nakano, talk at MENU 2007, September 12, 2007: http://www.fz-juelich.de/ikp/menu2007/Talks/talk-Nakano.pdf.
28. F. Close, Nature **435**, 287 (2005); R. L. Jaffe, AIP Conf. Proc. **792**, 97 (2005); The present common feelings towards Θ^+ are touchingly reflected on the first slide of R.L. Jaffe's talk at DIS05, Madison, April 27, 2005; http://agenda.hep.wisc.edu/conference.
29. B. McKinnon et al. [CLAS Collaboration], Phys. Rev. Lett. **96**, 212001 (2006) [arXiv:hep-ex/0603028].
30. S. Stepanyan et al. [CLAS Collaboration], Phys. Rev. Lett. **91**, 252001 (2003) [arXiv:hep-ex/0307018].
31. D. G. Ireland et al. [CLAS Collaboration], Phys. Rev. Lett. **100**, 052001 (2008) [arXiv:0709.3154 [hep-ph]].
32. R. D. Cousins, arXiv:0807.1330 [hep-ph].