PROCEEDINGS OF SCIENCE

# $\Theta^+$, $\Xi^*$, and $\Omega$ coupling constants

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We review in this talk a series of recent works on the mass and width of the $\Theta^+$ within a framework of a chiral soliton model, all model parameters being determined by the experimental data unambiguously. We also discuss the results for the Yukawa coupling constants of the $\Xi^*$ and $\Omega$ baryons.

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## 1. Introduction

I am very honored to present a talk in the commemorative session to the late Dmitry Igorevich Diakonov. I have known Mitya for more than 20 years. I must say I am also one of the theorists who are greatly influenced by him. Mitya was indeed a unique and deep-thinking nuclear and particle theorist with broad interest. Since I am not in a position to review all he did, I would like to concentrate on some of applications using the chiral quark-soliton model [1], emphasizing the pentaquark $\Theta^+$ [2, 3].

Let me first summarize the present status of the pentaquarks:

- Since the CLAS null results [4, 5, 6, 7], the existence of the $\Theta^+$ was in doubt. The J-PARC E19 experiment also cast further doubt on the evidence of the $\Theta^+$ [8].
- Amaryan et al. observed a narrow peak corresponding to the $\Theta^+$ by analyzing the CLAS data through interference with $\phi$-meson production [9], though the CLAS collaboration did not agree on it [10].
- The existence of the $N^*(1685)$ [11] with narrow structure was reported and confirmed [12, 13, 14, 15, 16, 17]. This $N^*$ resonance might be interpreted as a member of the baryon antidecuplet, that is, one of the pentaquarks [18, 19].

If the $\Theta^+$ exists or not, we still need to understand the following points. If it exists, its width must be extremely small, possibly, smaller than 1 MeV. If it does not exist, what is then such a narrow peak seen from some of experiments? is it a fake or a murk?

In this talk, we would like to review recent works on the pentaquarks. The chiral quark-soliton model ($\chi$QSM) will be employed. Diakonov et al. [2] predicted the $\Theta^+$ but theoretical analyses partially relied on specific model calculations. Thus, some uncertainties are inherent in Ref. [2]. In a recent work [20], it was shown that we were able to fix unequivocally all the parameters of the $\chi$QSM, taking into account the SU(3) flavor and isospin symmetry breakings such that the experimental data of the masses of the baryon octet can be utilized as input. In order to consider the effects of isospin symmetry breaking consistently, one needs to include the electromagnetic effects on the baryon masses, which was already carried out within the same framework [21]. In addition, we will use the $\Omega$ and $\Theta^+$ masses as input. Both the $\Omega$ and $\Theta^+$ are the isosinglet, so that it is more convenient to use them as input. The Yukawa coupling constants can be determined by using the experimental data of the hyperon semileptonic decay (HSD) [22, 23]. In this talk, we will concentrate on the results from the $\chi$QSM in a model-independent approach rather than on the formalism. We refer to the recent works [20, 22, 23] for detailed formalisms.

## 2. Results and discussion

As shown in Ref. [20], the masses of the baryon decuplet were well reproduced. For example, the masses of the $\Xi^*$ are obtained as

$$M(\Xi^{*0}) = (1529.78 \pm 3.38)\,\mathrm{MeV}, \quad M(\Xi^{*-}) = (1533.33 \pm 3.37)\,\mathrm{MeV}, \tag{2.1}$$



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compared with the corresponding experimental data $M(\Xi^{*0}) = 1531.80 \pm 0.32,\mathrm{MeV}$ and $M(\Xi^{*-}) = 1535.0 \pm 0.6,\mathrm{MeV}$, respectively. On the other hand, we make use of the LEPS data for the $\Theta^+$ mass, $M(\Theta^+) = (1524 \pm 5)\,\mathrm{MeV}$, assuming that it exists. The masses of the $N^*$ is determined to be $M(p^*) = (1688.18 \pm 10.53)\,\mathrm{MeV}$ and $M(n^*) = (1692.16 \pm 10.53)\,\mathrm{MeV}$, which are in good agreement with the experimental data $M(N^*) = (1686 \pm 12)\,\mathrm{MeV}$ [14]. However, the $\Theta^+$ mass from the DIANA Collaboration is slightly larger than that of the LEPS data, i.e. $M(\Theta^+) = (1538 \pm 2)\,\mathrm{MeV}$. Thus, it is of interest to examine the dependence of the $N^*$ mass on $M(\Theta^+)$ [22].

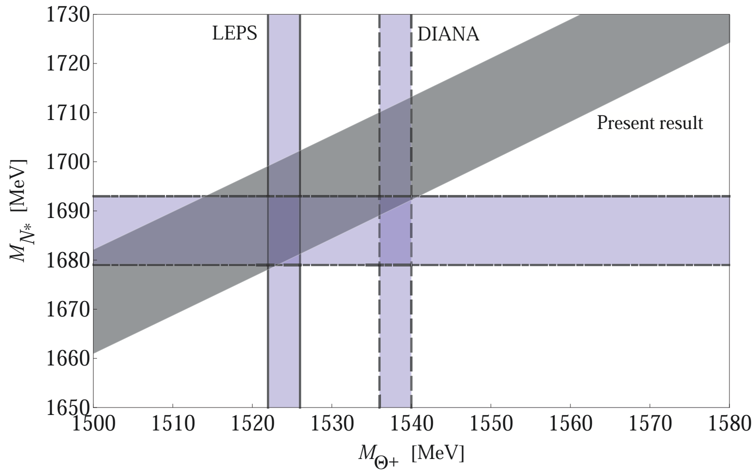


**Figure 1:** The dependence of the $N^*$ mass on $M_{\Theta^+}$.

Figure 1 shows the $N^*$ mass as a function of $M_{\Theta^+}$. The vertical shaded bars bounded with the solid and dashed lines stand for the values of the $\Theta^+$ mass with the experimental uncertainties by the LEPS and DIANA Collaborations, respectively. The horizontal shaded bar represents the values of the $N^*$ mass from Ref. [14]. The sloping shaded region indicates that the measured $N^*$ mass $M(N^*) = (1686 \pm 12)\,\mathrm{MeV}$ from Ref. [14] is compatible with the LEPS $\Theta^+$ mass.

To compute the decay width of $\Theta^+ \to K^+ n$, we have to calculate the coupling constant $g(\Theta^+ n K^+)$. This can be done by the following procedure: First, we fix six parameters of the collective operator for the axial-vector transition by using the experimental data of the HSD. However, only five decay constants are experimentally known. Thus, we also have to use the singlet axial-vector constant determined from polarized electron-proton deep inelastic scattering. Then the coupling constant $g(\Theta^+ n K^+)$ is determined to be $g(\Theta^+ n K^+)/\sqrt{4\pi} = -0.07 \pm 0.01$ that produces the $\Theta^+$ decay width $\Gamma(\Theta^+ \to K^+ n) = (0.52 \pm 0.1)\,\mathrm{MeV}$. This is a remarkable result. The smallness of the $\Theta^+$ decay width appears naturally because of the effects of SU(3) symmetry breaking.

The vector and tensor coupling constants for the $\Theta^+$ is even more interesting. As discussed already in Ref. [24], the values of these coupling constants should be small because of the generalized Ademollo-Gatto theorem for the electric transition form factor at the zero momentum transfer

$$G_E^{n\Theta}(0) = \sqrt{15}\, c_{\overline{10}}, \tag{2.2}$$

where $c_{\overline{10}}$ is a mixing parameter [1, 20]. Note that it is proportional to the strange quark mass. Using the experimental data of the baryon octet magnetic moments and employing the vector meson



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dominance, we are able to determine the vector and tensor coupling constants for the $K^*\Theta^+n$ vertex, respectively as

$$g(K^*\Theta^+n)/\sqrt{4\pi} = 0.27 \pm 0.05, \quad f(K^*\Theta^+n)/\sqrt{4\pi} = 0.813 \pm 0.257. \tag{2.3}$$

We can easily see that these values are much smaller than other coupling constants, for example, such as $g(K^*\Lambda p)/\sqrt{4\pi} = -1.97 \pm 0.02$ and $g(K^*\Lambda p)/\sqrt{4\pi} = -3.54 \pm 0.2$. These small values in Eq.(2.3) implies why it is so difficult to find the evidence of the $\Theta^+$ in photoproduction [25].

Finally, we want to discuss the Yukawa coupling constants for the $\Xi^*$ and $\Omega$ baryons. Lack of experimental information on hyperon-nucleon scattering makes it difficult to determine the Yukawa coupling constants for the baryon decuplet. Most often the coupling constants for the baryon decuplet are estimated by SU(3) symmetry and SU(6) quark models. Using the method we briefly mentioned above, we are also able to determine the Yukawa coupling constants for the $\Xi^*$ and $\Omega$ unambiguously. The results are given as follows:

$$\begin{aligned} f(\Xi^{*0}\Lambda K^-) &= 5.61 \pm 0.02, & f(\Xi^{*0}\Sigma^+ K^-) &= 3.97 \pm 0.02, \\ f(\Xi^{*0}\Sigma^0 K^-) &= 2.81 \pm 0.02, & f(\Omega^0\Xi^0 K^-) &= 7.15 \pm 0.03. \end{aligned} \tag{2.4}$$

One can compare them with those from the SU(6) quark model $f(\Xi^*\Lambda K) = 5.58$ and $f(\Xi^*\Sigma K) = 3.22$. The coupling constant for the $\Omega$ is the prediction. All results for the Yukawa coupling constants will appear elsewhere [23].

## 3. Summary and Conclusion

In this talk, we revisited the pentaquark analysis by Diakonov, Petrov and Polyakov [2] but fixed all parameters by using the experimental data. The analysis presented here is much more consistent to the existing *positive* experimental data, compared to the previous ones [2, 26]. Considering the experimental data of the $N^*(1685)$, we find that the LEPS value for the $\Theta^+$ mass is more preferable. The coupling constant for the $\Theta^+nK^+$ turns out to be small, which leads to the decay width $\Gamma(\Theta^+ \to K^+n) = (0.52 \pm 0.1)\,\mathrm{MeV}$. Note that this small value is determined by the experimental data of the semileptonic decay constants and the singlet axial-vector constants, which indicates that its smallness is a consequence of effects of SU(3) symmetry breaking. The vector and tensor coupling constants of the $\Theta^+$ turn out to be very small, which explains partially why it is so difficult to see the $\Theta^+$ in photoproduction. Finally, we briefly reported a recent investigation on the Yukawa coupling constants for the $\Xi^*$ and $\Omega$.

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## References

[1] D. Diakonov, V. Y. .Petrov and P. V. Pobylitsa, Nucl. Phys. B **306** (1988) 809.



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

[3] T. Nakano *et al.* [LEPS Collaboration], Phys. Rev. Lett. **91**(2003) 012002.

[4] M. Battaglieri *et al.* [CLAS Collaboration], Phys. Rev. Lett. **96** (2006) 042001.

[5] B. McKinnon *et al.* [CLAS Collaboration], Phys. Rev. Lett. **96** (2006) 212001.

[6] S. Niccolai *et al.* [CLAS Collaboration], Phys. Rev. Lett. **97** (2006) 032001.

[7] R. De Vita *et al.* [CLAS Collaboration], Phys. Rev. D **74** (2006) 032001.

[8] K. Shirotori, T. N. Takahashi, S. Adachi, M. Agnello, S. Ajimura, K. Aoki, H. C. Bhang and B. Bassalleck *et al.*, reaction at 1.92 GeV/*c*," Phys. Rev. Lett. **109** (2012) 132002.

[9] M. J. Amaryan, G. Gavalian, C. Nepali, M. V. Polyakov, Y. .Azimov, W. J. Briscoe, G. E. Dodge and C. E. Hyde *et al.*, interference with $\phi$-meson production," Phys. Rev. C **85** (2012) 035209.

[10] M. Anghinolfi *et al.* [CLAS Collaboration], arXiv:1204.1105 [hep-ex].

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

[12] V. Kuznetsov [GRAAL Collaboration], hep-ex/0409032.

[13] V. Kuznetsov *et al.*, Acta Phys. Polon. B **39** (2008) 1949.

[14] V. Kuznetsov and M. V. Polyakov, JETP Lett. **88** (2008) 347.

[15] D. Elsner and [CBELSA Collaboration], Eur. Phys. J. A**33** (2007) 147.

[16] 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.

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

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

[19] H.-Ch. Kim, M. Polyakov, M. Praszałowicz, G. S. Yang and K. Goeke, Phys. Rev. D **71** (2005) 094023.

[20] G. -S. Yang and H. -Ch. Kim, Prog. Theor. Phys. **128** (2012) 397.

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

[22] G. -S. Yang and H. -Ch. Kim, PTEP **2013** (2013) 013D01.

[23] G. -S. Yang and H. -Ch. Kim, in preparation.

[24] T. Ledwig, H. -Ch. Kim and K. Goeke, Nucl. Phys. A **811** (2008) 353.

[25] S. -i. Nam and H. -Ch. Kim, Phys. Rev. D **79** (2009) 034031 [arXiv:0901.0771 [hep-ph]].

[26] J. R. Ellis, M. Karliner and M. Praszalowicz, JHEP **0405** (2004) 002.


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