International Journal of Modern Physics A

STRUCTURE OF Λ*(1405) AND THE Λ*-MESON-BARYON COUPLING CONSTANTS

C. S. AN, B. SAGHAI

CEA, Centre de Saclay, IRFU/Service de Physique Nuclaire, F-91191 Gif-sur-Yvette, France
chunsheng.an@cea.fr ; bijan.saghai@cea.fr

Received (Day Month Year)
Revised (Day Month Year)

Within an extended chiral constituent quark model, three- and five-quark structure of the S_{01} resonance $\Lambda(1405)$ is investigated with respect to the coupling constants $g^2_{\Lambda^*\pi\Sigma}$ and $g^2_{\Lambda^*\bar{K}N}$. Our findings corroborate with about 50% of five-quark admixture in the $\Lambda(1405)$ needed in reproducing the strong decay width, $\Gamma_{\Lambda(1405)\to(\Sigma\pi)^\circ}$.

Keywords: Phenomenological quark models; Hyperons; Strong coupling constants.

1. Introduction and Theoretical Frame

The nature of the $\Lambda^*(1405)$-resonance, investigated since half a century, still bears puzzling features. Its well established couplings to $\bar{K}N$ and $\pi\Sigma$ states have offered guidance to various theoretical approaches in improving our understanding of it.

Recent achievements[1] in describing non-strange baryons such as the nucleon, Δ-, $P_{11}(1440)$ and $S_{11}(1535)$-resonances as a superposition of three- and five-quark states bring in new insights into the structure of baryons.

In a recent work[2] a chiral constituent quark model approach was extended to the strangeness sector, studying the $\Lambda^*(1405)$ in a truncated Fock space, which includes three- and five-quark components, as well as configuration mixings among them, namely, $qqq \leftrightarrow qqqq\bar{q}$ transitions. That formalism allowed us to calculate the helicity amplitudes for the electromagnetic decays ($\Lambda^* \to \Lambda(1116)\gamma$, $\Sigma(1194)\gamma$), and transition amplitudes for strong decays ($\Lambda^* \to \Sigma(1194)\pi$, K^-p), as well as the relevant decay widths, namely, $\Gamma_{\Lambda^*\to\Lambda(1116)\gamma}$, $\Gamma_{\Lambda^*\to\Sigma(1193)\gamma}$, and $\Gamma_{\Lambda(1405)\to\Sigma(1194)\pi}$. The only available experimental value[3], for the strong decay width $\Gamma_{\Lambda^*\to(\Sigma\pi)^\circ}$, was well reproduced with about 50% of five-quark admixture in Λ^*.

In this contribution we concentrate on the coupling constants $g_{\Lambda^*\bar{K}N}$ and $g_{\Lambda^*\pi\Sigma}$ allowing us to put further constraints on the percentage of the five-quark component within the Λ^*. The starting point is the hadronic level Lagrangian for the $\Lambda(1405)BM$ coupling, with $B \equiv \Sigma,\ N$ and $M \equiv \pi,\ K$

$$\mathcal{L}_{\Lambda(1405)BM} = i\frac{f_{\Lambda(1405)BM}}{m_M}\bar{\psi}_B\gamma_\mu\partial^\mu\phi_M X_M\psi_{\Lambda(1405)} + h.c., \tag{1}$$

where the transition coupling amplitude reads

$$\frac{f_{\Lambda(1405)BM}}{m_M} = \frac{\langle [\hat{T}_d^M + \hat{T}_{35}^M + \hat{T}_{53}^M] \rangle}{m_{\Lambda(1405)} - m_B}, \tag{2}$$

with the diagonal ($\hat{T}_d^M$) and non diagonal ($\hat{T}_{53}^M$ and $\hat{T}_{35}^M$) transition amplitudes calculated within the nonrelativistic chiral constituent quark model[2]. The Λ^*-Baryon-Meson coupling constant is given by

$$g_{\Lambda^* BM} = \frac{m_B - m_{\Lambda^*}}{m_M} f_{\Lambda^* BM}. \tag{3}$$

2. Results and Discussion

The coupling constants $g_{\Lambda^*\bar{K}N}$ and $g_{\Lambda^*\pi\Sigma}$, as well as the ratio $R = g_{\Lambda^*\bar{K}N}/g_{\Lambda^*\pi\Sigma}$ have been investigated both experimentally[4] and within various theoretical approaches[5,6,7,8,9,10,11], but none of them relying on the internal quark structure of the Λ^*-resonance. Here we report on the results obtained within our chiral constituent quark approach, and investigate the dependence of the coupling constants on the percentage of genuine five-quark admixture in the Λ^* wave function.

Values for those entities, extracted through a T-matrix effective-range expansion[6] are

$$g^2_{\Lambda^*\pi\Sigma}/4\pi = 0.047 \pm 0.007 \ ; \ g^2_{\Lambda^*\bar{K}N}/4\pi = 0.32 \pm 0.02 \ ; \ R = \frac{g^2_{\Lambda^*\bar{K}N}}{g^2_{\Lambda^*\pi\Sigma}} = 6.8 \pm 1.0 \ .$$

Several authors report results for the ratio R and not always for individual coupling constants. The ratio R, given above, comes out to be about one order of magnitude larger than its value (2/3) if it were a pure $SU(3)$ singlet. It is also significantly different from values obtained by various approaches, such as current algebra[7,8]: 3.2, potential models[7,9]: 4.8, dispersion relations[10]: 4.0, or still asymptotic $SU(3)$ symmetry approach[11]: 4.8.

In Fig. 1 our results are shown. In the Left panel coupling constants as a function of five-quark component percentage (P_{5q}) in the Λ^* wave function are depicted. As known from other sources, the $\bar{K}N$ coupling to Λ^* is (much) larger than coupling to $\pi\Sigma$. The latter, within our approach, shows no significant sensitivity to P_{5q}. Actually, the predicted value for $g^2_{\Lambda^*\pi\Sigma}$ starts and ends at 0.031, after having gone through a maximum around 0.065 at P_{5q} ≈46%. This smooth dependence on P_{5q} does not impose significant constraints on the P_{5q} range. On the contrary, the $g^2_{\Lambda^*\bar{K}N}$ varies, at least up to $P_{5q} \lesssim 60\%$, rather drastically. The horizontal line corresponds to the central value in $g^2_{\Lambda^*\bar{K}N}/4\pi = 0.32 \pm 0.02$ and dotted lines to $\pm\sigma$, intercepting the prediction curve at $P_{5q} = (55 \pm 1)\%$.

In the Right panel, Fig. 1, our results for the ratio R as a function of P_{5q} are shown. The horizontal lines correspond to $R = 6.8 \pm 1.0$. We notice that the smooth variation of $g^2_{\Lambda^*\pi\Sigma}$ affects nevertheless the shape of R and the intersection values. Actually, from that figure we deduce $P_{5q} = (48 \pm 3)\%$, in agreement with

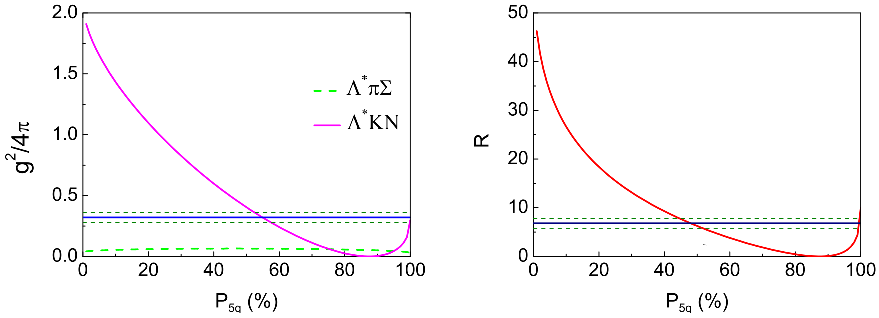

Fig. 1. **Left**: Coupling constants $g_{\Lambda^*\bar{K}N}$ and $g_{\Lambda^*\pi\Sigma}$ as a function of the five-quark component (P_{5q}) in $\Lambda^*(1405)$ **Right**: ratio $R = g_{\Lambda^*\bar{K}N}/g_{\Lambda^*\pi\Sigma}$ as a function of P_{5q}. For explanations of horizontal lines see the text.

the $P_{5q} \approx 50\%$ found to reproduce the strong decay width $\Gamma_{\Lambda(1405)\to(\Sigma\pi)^\circ} = 50 \pm 2$ MeV.

In conclusion, our recent[2] and present studies strongly suggest an admixture of five-quark components in Λ^* at the level of $P_{5q} \approx 50\%$. Extensive ongoing theoretical investigations (see e.g. Refs.[2,12] and references therein) will greatly benefit from current experimental programmes on the K^--nucleon interactions in $DA\Phi NE$[13] and electromagnetic production of $\Lambda^*(1405)$ in JLab[14].

References

1. Q. B. Li and D. O. Riska, **Phys. Rev. C 73**, 035201 (2006); *ibid* **C 74**, 015202 (2006); **Nucl. Phys. A 766**, 172 (2006); B. Julia-Diaz and D. O. Riska, *ibid* **A 780**, 175 (2006); C. S. An and B. S. Zou, **Eur. Phys. J. A 39**, 195 (2009).
2. C. S. An, B. Saghai, S. G. Yuan and J. He, **Phys. Rev. C 81**, 045203 (2010).
3. C. Amsler *et al.* [Particle Data Group], **Phys. Lett. B 667**, 1 (2008).
4. R. D. Tripp *et al.*, **Phys. Rev. Lett. 21**, 1721 (1968); O. Braun *et al.*, **Nucl. Phys. B 129**, 1 (1977).
5. J. Soln, **Phys. Rev. D 2**, 2404 (1970); D. L. Katyal and A. N. Mitra, *ibid* **D 1**, 338 (1970); G. Rajasekaran, *ibid* **D 5**, 610 (1972); G. C. Oades and G. Rasche, **Nuovo Cim. A 42**, 462 (1977).
6. J. K. Kim and F. Von Hippel, **Phys. Rev. 184**, 1961 (1969).
7. C. Weil, **Phys. Rev. 161**, 1617 (1967).
8. M. Gell-Mann R. J. Ookes and B. Renner, **Phys. Rev. 175**, 2195 (1968).
9. R. H. Dalitz, T. C. Wong and G. Rajasekaran, **Phys. Rev. 153**, 1617 (1967).
10. A. D. Martin, **Phys. Lett. B 65**, 346 (1976).
11. S. Oneda and S. Matsuda, **Phys. Rev. D 2**, 887 (1970).
12. D. Jido, J. A. Oller, E. Oset, A. Ramos and U. G. Meissner, **Nucl. Phys. A 725**, 181 (2003); D. Jido, T. Sekihara, Y. Ikeda, T. Hyodo, Y. Kanada-En'yo and E. Oset, *ibid* **A 835**, 59 (2010).
13. M. Cargnelli *et al.*, **Nucl. Phys. A 835**, 27 (2010).
14. K. Moriya and R. Schumacher [CLAS Collaboration], **Nucl. Phys. A 835**, 325 (2010).