

LARGE- N_c POLE TRAJECTORIES OF THE VECTOR KAON $K^*(892)$ AND OF THE SCALAR KAONS $K_0^*(800)$ AND $K_0^*(1430)^*$

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(Received May 31, 2016)

We study the spectral functions, the poles and their trajectories for increasing N_c of the vector kaon state $K^*(892)$, characterized by $I(J^P) = \frac{1}{2}(1^-)$, and of the scalar kaons $K_0^*(800)$ and $K_0^*(1430)$, characterized by $I(J^P) = \frac{1}{2}(0^+)$. To this end, we use relativistic QFTs Lagrangians with both derivative and non-derivative terms. In the vector kaonic sector, the spectral function is well-approximated by a Breit–Wigner function: there is one single peak and, correspondingly, a single pole in the complex plane. On the contrary, in the scalar sector, although the Lagrangian contains only one scalar kaonic field, we find two poles, one corresponding to a standard quark–antiquark “seed” state $K_0^*(1430)$, and one to a “companion” dynamically generate pole $K_0^*(800)$. The latter does not correspond to any peak in the scalar kaonic spectral function, but only to an enhancement in the low-energy regime.

DOI:10.5506/APhysPolBSupp.9.321

1. Introduction

Understanding the nature of the mesonic resonances listed in Ref. [1] is an important topic of both experimental and theoretical hadron physics. In the vector kaonic sector with $I(J^P) = \frac{1}{2}(1^-)$ (I stands for isospin, J for total spin, and P for parity), the resonance $K^*(892)$ corresponds very well to the expected quark–antiquark states $u\bar{s}$, $d\bar{s}$, $s\bar{u}$, $s\bar{d}$; moreover, its spectral function is nicely described by a (relativistic) Breit–Wigner function. On the contrary, the scalar kaonic sector $I(J^P) = \frac{1}{2}(0^+)$ is much more complicated. Two resonances are listed in the PDG below 1.5 GeV: the broad but well-established $K_0^*(1430)$ and the very broad and light $K_0^*(800)$ (also known

* Presented at WPCF 2015: XI Workshop on Particle Correlations and Femtoscopy, Warszawa, Poland, November 3–7, 2015.

as κ), whose existence still requires definitive confirmation (for discussions, see *e.g.* Refs. [2–5] and references therein). The inclusion of κ in the summary table of PDG would allow to complete the nonet of light scalar states in the energy region below 1 GeV.

The aim of this work, based on Ref. [5], is to study the nature of the vector and scalar kaonic resonances. By using QFT Lagrangians, we determine the coordinates of the poles on the complex plane and study their nature by using the large- N_c limit. We confirm that $K^*(892)$ and $K_0^*(1430)$ are standard quark–antiquark states, while $K_0^*(800)$ is a dynamically generated state.

2. The model(s)

In order to describe $K^*(892)$ and $K_0^*(1430)$, we introduce relativistic Lagrangians that couples them to one kaon and one pion:

$$\mathcal{L}_v = cK^*(892)_\mu^+ \partial^\mu K^- \pi^0 + \dots, \quad \mathcal{L}_s = aK_0^{*+} K^- \pi^0 + bK_0^{*+} \partial_\mu K^- \partial^\mu \pi^0 + \dots \quad (1)$$

The expressions above contain non-derivative and derivative interaction term. The dots stay for the sum over isospin and Hermitian conjugation. The terms in Eq. (1) naturally emerge as a subset of more complete mesonic models, *e.g.* Ref. [6]. According to our models, the decay widths of $K^*(892)$ and K_0^* (as a function of the running mass m) are:

$$\Gamma_{K^*}(m) = 3 \frac{|\vec{k}_1|}{8\pi m^2} \frac{c^2}{3} \left[-M_\pi^2 + \frac{(m^2 + M_\pi^2 - M_K^2)^2}{4m^2} \right] F_\Lambda(m), \quad (2)$$

$$\Gamma_{K_0^*}(m) = 3 \frac{|\vec{k}_1|}{8\pi m^2} \left[a - b \frac{m^2 - M_K^2 - M_\pi^2}{2} \right]^2 F_\Lambda(m), \quad (3)$$

where the form factor $F_\Lambda(m) = \exp(-2\vec{k}_1^2/\Lambda^2)$ has been introduced. Λ is an energy scale, $\vec{k}_1$ the three-momentum of one outgoing particle, M_K the kaon mass and M_π the pion mass. The on-shell decay widths are obtained by setting m to the masses of $K^*(892)$ or $K_0^*(1430)$: this is accurate in the former case, but quite imprecise in the latter. The (scalar part of the) propagator of the resonances is given by $\Delta_{K^*/K_0^*}(p^2 = m^2) = [m^2 - M_0^2 + \Pi(m^2) + i\varepsilon]^{-1}$, where M_0 is the bare mass of $K^*(892)/K_0^*(1430)$ and $\Pi(m^2) = \text{Re}(m^2) + i\text{Im}(m^2)$ is the one-loop contribution. The spectral function which determines the probability that resonance has a mass between m and $m + dm$ reads: $d_{K^*/K_0^*}(m) = \frac{2m}{\pi} |\text{Im} \Delta_{K^*/K_0^*}(p^2 = m^2)|$. Spectral functions must be normalized to unity. For details of the used formalism, see Ref. [7].

The spectral functions of $K^*(892)$ and $K_0^*(1430)$ are shown in Fig. 1. For the vector kaon, we observe a single peak close to 0.9 GeV and a (unique!) pole at $0.89-i0.028$ GeV. In the scalar sector, there is a broad peak at about 1.4 GeV, but no peak corresponding to the light κ (there is only a broad enhancement in the low-energy regime). In this channel, it turns out that there are two poles: $(1.413 \pm 0.057) - i(0.127 \pm 0.011)$ GeV, which corresponds to the seed state $K_0^*(1430)$, and $(0.745 \pm 0.029) - i(0.263 \pm 0.027)$ GeV, which corresponds to $K_0^*(800)$ as an additional companion pole. The parameters for the scalar channel were determined via a fit to existing pion-kaon data, see Ref. [5] for details.

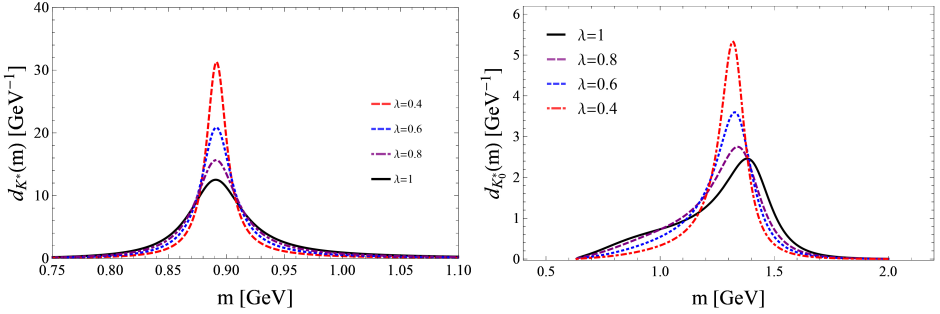


Fig. 1. Spectral functions of $K^*(892)$ (left panel) and $K_0^*(1430)$ and $K_0^*(800)$ (right panel), for different values of $\lambda = 3/N_c$.

We studied the change of the spectral function for different values of the number of colors N_c with the rescaling $a \rightarrow a\sqrt{3/N_c}$ (and so for b and c). When N_c increases, the interaction becomes smaller. In both channels, we observe that the peak becomes narrower and higher. However, in the scalar sector, the enhancement of the κ becomes smaller for increasing N_c .

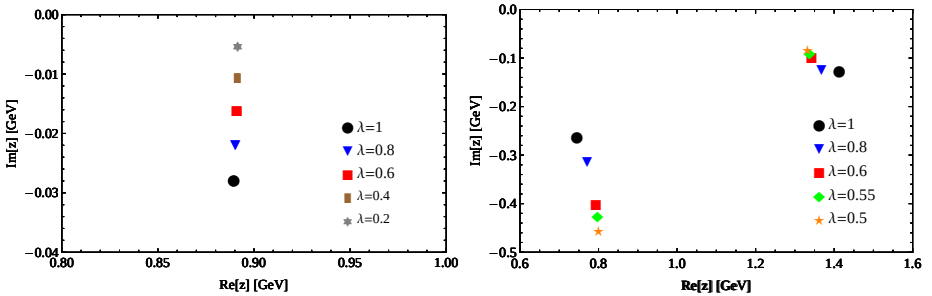


Fig. 2. Movement of the poles of $K^*(892)$ (left panel) and of $K_0^*(1430)$ and $K_0^*(800)$ (right panel) for different values of $\lambda = 3/N_c$.

In Fig. 2, we show the trajectories of the poles for increasing N_c . One sees that the poles of $K^*(892)$ and $K_0^*(1430)$ tend to the real axis, while that of $K_0^*(800)$ goes away from it and finally disappears for $N_c \simeq 13$. In conclusion, all these results, with special focus on Fig. 2 which is the main outcome of the present proceedings, confirm that $K_0^*(800)$ is a dynamically generated non-quarkonium meson.

3. Conclusions

We have discussed the nature of $K^*(892)$, $K_0^*(800)$, and $K_0^*(1430)$ by using QFT models presented in Ref. [5]. We find that $K^*(892)$ and $K_0^*(1430)$ are regular quark–antiquark mesons (see the quark-model review in [1]). In both cases, the spectral function has a well-pronounced peak; in the large- N_c limit, the positions of the poles tend to the real axis, as it should for conventional mesons. On the contrary, $K_0^*(800)$ does not correspond to a peak of the scalar spectral function, but there is a related pole in the complex plane. The original Lagrangian contains a single scalar field, which is associated to $K_0^*(1430)$, hence $K_0^*(800)$ emerges as a companion pole of $K_0^*(1430)$. In the large- N_c limit, the pole of $K_0^*(800)$ disappears, confirming its non-quarkonium nature.

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