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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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 QFT’s 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.

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 resonance 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 as

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$\kappa$, whose existence still requires definitive confirmation (for discussions, see e.g. Refs. \cite{2,3,4,5} and refs. therein). The inclusion of $\kappa$ 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. \cite{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 $K^\ast(892)$ and $K^*_0(1430)$ are standard quark-antiquark states, while $K^*_0(800)$ is a dynamically generated state.

2. The model(s) and results

In order to describe $K^\ast(892)$ and $K^*_0(1430)$ we introduce relativistic Lagrangians that couples them to one kaon and one pion:

$$
\mathcal{L}_v = cK^\ast(892)_\mu \partial^\mu K^- \pi^0 + \ldots, \quad \mathcal{L}_s = aK^+K^-\pi^0 + bK^*_0\partial_\mu K^-\partial^\mu \pi^0 + \ldots.
$$

(1)

The expressions above contain non-derivative and derivative interaction terms. 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. \cite{6}. According to our models, the decay widths of $K^\ast(892)$ and $K^*_0$ (as function of the running mass $m$) are:

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

(2)

$$
\Gamma_{K^*_0}(m) = 3\frac{\vec{k}_1}{8\pi m^2} \left[ a - b \frac{m^2 - M_K^2 - M^2}{2} \right]^2 F_\Lambda(m),
$$

(3)

where the form factor $F_\Lambda(m) = \exp(-2\vec{k}_1^2/\Lambda^2)$ has been introduced. $\Lambda$ is an energy scale, $\vec{k}_1$ the three-momentum of one outgoing particle, $M_K$ the kaon mass, and $M_\pi$ the pion mass. The on-shell decay widths are obtained by setting $m$ to the masses of $K^\ast(892)$ 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 $\Delta_{K^\ast/K^*_0}(p^2 = m^2) = [m^2 - M_0^2 + \Pi(m^2) + i\varepsilon]^{-1}$, where $M_0$ is the bare mass of $K^\ast(892)/K^*_0(1430)$ and $\Pi(m^2) = Re(m^2) + iIm(m^2)$ is the one-loop contribution. The spectral function which determines the probability that resonance has a mass between $m$ and $m + dm$ reads: $dK^\ast/K^*_0(m) = \frac{2m}{\pi} |\text{Im}\Delta_{K^\ast/K^*_0}(p^2 = m^2)|$. Spectral functions must be normalized to unity. For details of the used formalism, see Ref. \cite{7}.
Fig. 1. Spectral functions of $K^*(892)$ (left panel) and $K^*_0(1430)$ and of $K^*_0(800)$ (right panel) for different values of $\lambda = 3/N_c$.

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 $\kappa$ (there is only a broad enhancement in the low-energy regime). In this channel, it turns out that there are two poles: $(1.413\pm0.057) - i(0.127\pm0.011)$ GeV, which corresponds to the seed state $K^*_0(1430)$, and $(0.745\pm0.029) - i(0.263\pm0.027)$ 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.

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 $\kappa$ becomes smaller for increasing $N_c$.

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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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 $\lambda = 3/N_c$. 