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Nuclear Physics B 909 (2016) 418–428

NUCLEAR PHYSICS B

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$K_0^*(800)$ as a companion pole of $K_0^*(1430)$

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Received 4 March 2016; received in revised form 18 May 2016; accepted 28 May 2016

Available online 2 June 2016

Editor: Hong-Jian He

Abstract

We study the light scalar sector up to 1.8 GeV by using a quantum field theoretical approach which includes a single kaonic state in a Lagrangian with both derivative and non-derivative interactions. By performing a fit to πK phase shift data in the $I = 1/2$, $J = 0$ channel, we show that $K_0^*(800)$ (or κ) emerges as a dynamically generated companion pole of $K_0^*(1430)$. This is a result of investigating quantum fluctuations with one kaon and one pion circulating in the loops dressing $K_0^*(1430)$. We determine the position of the poles on the complex plane in the context of our approach: for $K_0^*(1430)$ we get $(1.413 \pm 0.002) - i\,(0.127 \pm 0.003)$ (in GeV), while for κ we get $(0.746 \pm 0.019) - i\,(0.262 \pm 0.014)$ (in GeV). The model-dependence of these results and related uncertainties are discussed in the paper. A large-N_c study confirms that $K_0^*(1430)$ is predominantly a quarkonium and that $K_0^*(800)$ is a molecular-like dynamically generated state.

1. Introduction

The lightest scalar resonance with isospin $I = 1/2$ is the state $K_0^*(800)$, also denoted as κ. This state is not yet listed in the summary table of the Particle Data Group (PDG) [1]. The con-

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http://dx.doi.org/10.1016/j.nuclphysb.2016.05.025
0550-3213/

firmation of κ is important, since it would complete the nonet of light scalar states below 1 GeV. Namely, besides the putative κ state, the broad but by now established $f_0(500)$ (see Ref. [2] and references therein) as well as the narrow resonances $a_0(980)$ and $f_0(980)$ are well-established mesons [1]. These light scalar mesons are excellent candidates to be non-conventional states, *i.e.*, four-quark objects, realized as diquark–antidiquark states [3–13] and/or as dynamically generated molecular-like states [14–30] (for review, see also Refs. [31,32]).

The aim of this work is to apply a quantum field theoretical approach in order to investigate the existence of the κ as well as its nature. Within our approach a *single* (quark–antiquark) seed state, roughly corresponding to the well-known resonance $K_0^*(1430)$, is described by an effective Lagrangian. In particular, we shall use a Lagrangian that contains – in agreement with chiral perturbation theory (chPT) and chiral models – both derivative and non-derivative interaction terms. As we shall see, the simultaneous presence of both of them ensures a good description of scattering data. Indeed, as expected from chPT the derivative interaction gives the largest contribution. After computing the full one-loop resummed propagator we perform a fit to experimental πK phase shift data from Ref. [33]. The fit depends on four parameters of the model: two coupling constants, one bare mass, and one cutoff entering a Gaussian form factor. We find that, besides the expected resonance pole of $K_0^*(1430)$, a pole corresponding to the light κ naturally emerges on the unphysical Riemann sheet. In this situation the κ is established as a dynamically generated companion pole of the conventional quark–antiquark meson $K_0^*(1430)$. We determine the position of the poles for both states including errors. For previous determinations of the pole position of κ see *e.g.* Refs. [16,17,34–41], as well as the experimental observation by BES [42] and the lattice study of Ref. [43].

Moreover, (i) it turns out that the light κ does not correspond to any peak in the scalar kaonic spectral function but only to an enhancement in the low-energy region at about 750 MeV. A large-N_c study shows that its pole disappears when N_c is large enough ($N_c \simeq 13$). As a consequence, this state is *not* predominantly a quarkonium but rather a dynamically generated meson. (ii) On the other hand, the pole of the corresponding state above 1 GeV tends to the real energy axis in the large-N_c, as expected for a predominantly quark–antiquark state.

For completeness, we also investigate the statistical significance of our results: we find that both derivative and non-derivative interactions are needed for a satisfactory fit. On the contrary, variations of the models with only derivative or non-derivative interactions or with other form factors different from the Gaussian turn out not to be in agreement with the experimental results.

2. The model

Our model consists of an interaction Lagrangian describing the interaction/decay of a single scalar kaonic seed state, denoted as K_0^*, into one pion and one kaon. In agreement with effective approaches of low-energy QCD (both chPT [44–46] and effective chiral models [47–49], based on the nonlinear and linear realization of chiral symmetry, respectively), it consists of two types of terms, *i.e.*, one without and one involving derivatives:

$$\mathcal{L}_{\text{int}} = aK_0^{*-}\pi^0K^+ + bK_0^{*-}\partial_\mu\pi^0\partial^\mu K^+ + \sqrt{2}aK_0^{*-}\pi^+K^0 + \sqrt{2}bK_0^{*-}\partial_\mu\pi^+\partial^\mu K^0 + \ldots, \tag{1}$$

where dots represent analogous interaction terms for the other members of the isospin multiplets, as well as Hermitian conjugation. The decay width as function of the (running) mass m of the unstable K_0^* reads