On the Existence of Light-Scalar Mesons κ(800) and κ'(1150): The U˜(12) Scheme and BES II Data

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I. INTRODUCTION

Recently, the existence of the light-scalar mesons, $\sigma(600)$ and $\kappa(800)$, has been confirmed by showing the presence of respective poles in the $\pi\pi$ [Caprini et al. (2006)] and $K\pi$ [Descotes-Genon et al. (2006)] scattering amplitudes, in addition to results of Breit-Wigner fits to D- and J/ψ-decay data, respectively, from the E791 [Aitala et al. (2002)] and BES [Ablikim et al. (2006)] collaborations.

However, the nature of these resonances, together with the $f_0(980)$ and $a_0(980)$, has been a long-standing problem in controversy, where it is not obvious how these light-scalar mesons are understood in terms of quarks and gluons in QCD.

In this talk we focus on the strange scalar mesons and discuss the existence of an extra κ' meson, in addition to the normal $\kappa(800)$, and their strong decay properties.

II. Existence of the Extra κ' Meson

- **The $\tilde{U}(12)$ scheme**

The covariant $\tilde{U}(12)$-classification scheme of hadrons with $\tilde{U}(12)_{SF}$ x $O(3,1)_L$ [Ishida et al. (2000)] gives covariant quark representations for composite hadrons with definite Lorentz and chiral transformation properties. The $\tilde{U}(12)$ scheme has a “static” unitary $U(12)_{SF}$ spin-flavor symmetry in the rest frame of hadrons, embedded in the covariant $\tilde{U}(12)$-representation space, which includes subgroups as $\tilde{U}(4)_D \times U(3)_F$ ($\tilde{U}(4)_D$ being the pseudounitary homogeneous Lorentz group for Dirac spinors). The static $U(12)_{SF}$ symmetry includes as its subgroup both the nonrelativistic $SU(6)_{SF}$ spin-flavor and $U(3)_L \times U(3)_R$ chiral symmetry, as $SU(6)_{SF} \times SU(2)_\rho$ and $U(3)_L \times U(3)_R \times SU(2)_\sigma$, where $SU(2)_\rho$ and $SU(2)_\sigma$ are the Pauli-spin groups concerning the boosting and intrinsic spin rotation, respectively, of constituent quarks, being connected with decomposition of Dirac γ-matrices, $\gamma = \rho \times \sigma$.

This implies that the $\tilde{U}(12)$-classification scheme is able to incorporate effectively the effects of chiral symmetry and its spontaneous breaking, essential for understanding of properties of the low-lying hadrons, into what is called a constituent quark model.

In the $\tilde{U}(12)$ scheme there exist two light-scalar meson multiplets, $S^{(N)}(0^{++})$ and $S^{(E)}(0^{+-})$, in the ground level (L=0). These normal (N) and extra (E) scalar multiplets are the chiral partners, respectively, of the N and E pseudoscalar multiplets and they form linear representations of the $U(3)_L \times U(3)_R$ chiral symmetry.

Concerning the strange scalar mesons, now we have two κ mesons, $\kappa^{(N)}(0^{++})$ and $\kappa^{(E)}(0^{+-})$. Note that the observed $\kappa(800)$ and missing κ' are generally mixtures of them.

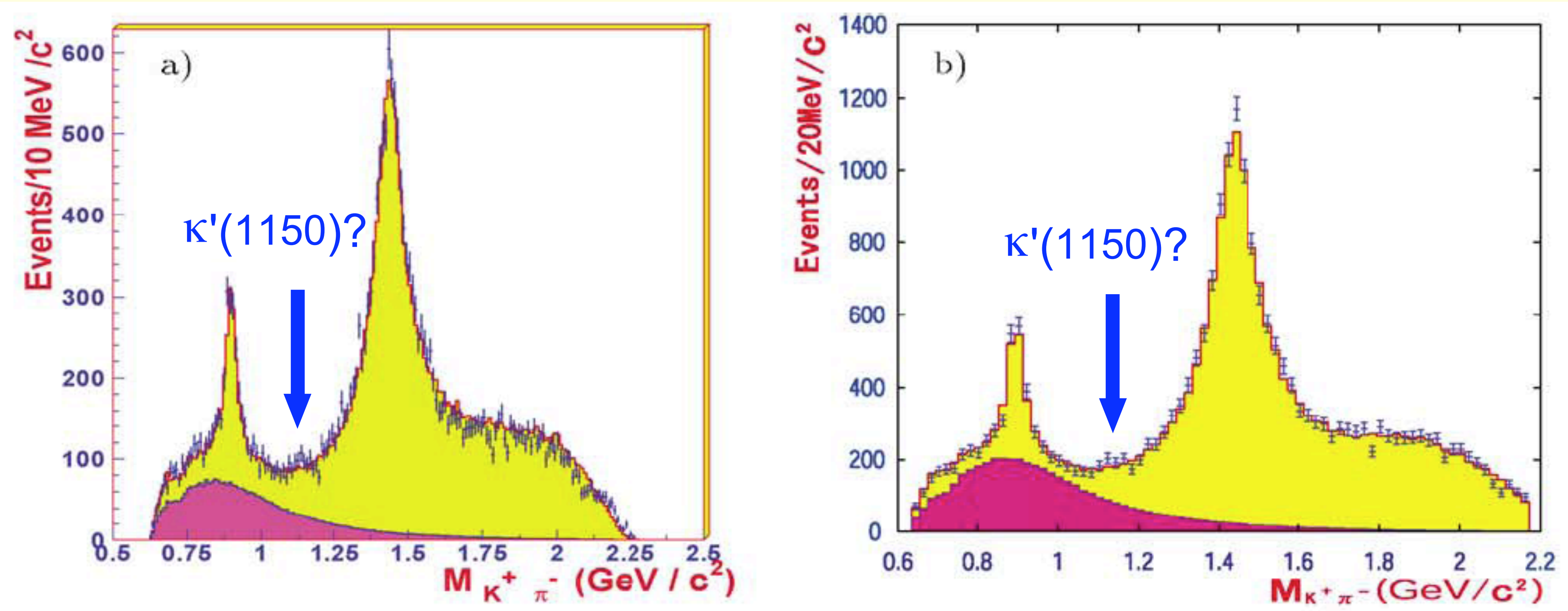
- **Lattice-QCD results**

A recent lattice-QCD study on light-scalar mesons by the UKQCD collaboration [McNeile et al. (2006)] suggests that the $a_0(980)$ is predominantly a conventional $q\bar{q}$ state, while the $\kappa(800)$ is too light to be assigned to the $q\bar{q}$ state, which is expected to have a mass about 100-130 MeV heavier than the $a_0(980)$.

- **BES II data**

In the BES II data on the $K^+\pi^-$ mass spectrum in $J/\psi \to \bar{K}^*(892)^0 K^+\pi^-$ [Ablikim et al. (2006)] there seems to me to be a visible bump structure at 1.1-1.2 GeV. If this structure is attributed to the existence of a new $K\pi$ resonance, its spin-parity will likely be 0^+ or 1^-, since higher spins are unfavorable for such a low-mass state, and also its width is supposed to be narrow, judging from the data structure.

- **The $K^+\pi^-$ invariant mass spectrum in $J/\psi \to \bar{K}^*(892)^0 K^+\pi^-$** [BES collaboration, Phys. Lett. B 633 (2006) 681]



We hereafter refer to the strange scalar meson mentioned above as the $\kappa'(1150)$.

III. Strong Decays of the κ(800) and κ'(1150) Mesons

We examine strong two-body decays of the κ(800) and κ'(1150) as mixtures of the $\kappa^{(N)}$ and $\kappa^{(E)}$ in the $\tilde{U}$(12)-scheme as follows:

κ(800) –> K + π

κ'(1150) –> K + π, K + η,

κ(800) + σ(600) [–> K$\pi\pi\pi$]

In the actual calculations of decay matrix elements we treat the strange mesons K, κ and κ' mesons as quark-composite $n\bar{s}$ states, while π, η and σ as external local fields.

- Quark-pseudoscalar and quark-scalar couplings

For the effective qqP coupling we assume the two independent interactions of the forms

pseudoscalar type: $g_{ps}\,\bar{q}(-i\gamma_5)q\phi_p$,

pseudovector type: $g_{pv}\,\bar{q}(-i\gamma_5\gamma_\mu)q\,\partial_\mu\phi_p$.

The effective qqσ coupling is simply related to the qqP coupling, assuming the σ meson is a chiral partner of the π meson in the linear representation of chiral symmetry, and given as

$$g_{ps}\,\bar{q}q\phi_\sigma,$$

$$g_{pv}\,\bar{q}\gamma_\mu q\,\partial_\mu\phi_\sigma.$$

Then the matrix elements for the pseudoscalar-emitted processes are generally given by

$T = T_{ps} + T_{pv}$,

$T_{ps}=g_{ps}<\bar{W}(v')(-i\gamma_5\phi_p)W(v)\, iv_\mu\gamma_\mu> + c.c.$,

$T_{pv}=g_{pv}<\bar{W}(v')(-\gamma_5\gamma_\mu q_\mu\phi_p)W(v)\, iv_\mu\gamma_\mu> + c.c.$,

where $W(v)$ and $\bar{W}(v')$ are the spin wave functions of initial- and final-state mesons, v and v' the 4-velocities, and q_μ is the momentum of emitted pseudoscalar mesons.

The matrix elements for the σ-emitted processes are given likewise by

$$T = T_{ps} + T_{pv},$$

$$T_{ps}=g_{ps}\langle \overline{W}(v')(\phi_\sigma)W(v)\, iv_\mu\gamma_\mu\rangle + \text{c.c.},$$

$$T_{pv}=g_{pv}\langle \overline{W}(v')(-i\gamma_\mu q_\mu\phi_\sigma)W(v)\, iv_\mu\gamma_\mu\rangle + \text{c.c.},$$

<…> means the trace taken over the spinor and flavor indices.

- Evaluation of the coupling constants

The coupling constants g_{ps} and g_{pv} are evaluated by Maeda [Maeda's talk, this conference]. He calculated the D-wave/S-wave amplitude ratio and width of the decay $b_1(1235) \to \omega + \pi$, and using their experimental values D/S=0.277(± 0.027) and $\Gamma[\omega\pi] \approx \Gamma^{tot}$=142(±9) MeV [PDG 2006] as input, he obtained g_{ps}=2.07 GeV and g_{pv}=14.0.

We now calculate the decay width of K*(892) $\to$ K + π to see the validity of the present decay model and obtain a reasonable value of $\Gamma[K\pi]=58$ MeV, compared with the experimental value $\Gamma[K\pi]\approx\Gamma^{tot}=50.8(\pm0.9)$ MeV [PDG 2006].

- Strong decay widths of the $\kappa(800)$ and $\kappa'(1150)$

Since the $\kappa(800)$ and $\kappa'(1150)$ are generally mixtures of $\kappa^{(N)}$ and $\kappa^{(E)}$, we introduce the mixing angle, which is the only free parameter in the present analysis, by

$$\kappa(800) \quad = \quad \cos\theta\, \kappa^{(E)} + \sin\theta\, \kappa^{(N)},$$

$$\kappa'(1150) = -\sin\theta\, \kappa^{(E)} + \cos\theta\, \kappa^{(N)}.$$

Here we take the mixing angle θ to be around –65º so that the κ(800) has a width of several hundred MeV and the κ'(1150) a rather narrow width, in conformity with their observed properties, $\Gamma[\kappa(800)]=550\pm34$ MeV [PDG 2007 partial update] and the BESII data mentioned above for the κ'(1150).

Using the mixing angle θ=–65º, we evaluate the partial decay widths of the κ(800) and κ'(1150) for respective channels as follows:

- **Decay of the κ(800)**

If we take a mass of the κ(800) to be 800 MeV, we obtain

Γ[Kπ] = 354 MeV for $\kappa(800) \to K + \pi$.

This is consistent, though somewhat small, with the experimental value $\Gamma^{tot} \approx \Gamma$[K$\pi$] = 550±34 MeV [PDG 2007 partial update].

- **Decays of the $\kappa'(1150)$**

Here we take tentatively 1150 MeV for a mass of the missing state $\kappa'(1150)$ and then obtain

$\Gamma[K\pi]$ = 18 MeV for $\kappa'(1150) \to K + \pi$,

$\Gamma[K\eta]$ = 2 MeV for $\kappa'(1150) \to K + \eta$,

$\Gamma[\kappa\sigma]$ = 30 MeV for $\kappa'(1150) \to \kappa + \sigma$, and for the total width

$$\Gamma^{tot} \approx \Gamma[K\pi] + \Gamma[K\eta] + \Gamma[\kappa\sigma] = 50 \text{ MeV},$$

where mass values of the κ and σ are taken tentatively to be 600 MeV and 350 MeV, respectively. It may be worthwhile to mention that the dominant decay mode of the $\kappa'(1150)$ is not $K\pi$ but $\kappa\sigma$ ($K\pi\pi\pi$), $\Gamma[K\pi]/\Gamma^{tot} \approx 0.36$ and therefore the $\kappa'(1150)$ is supposed not to be seen in the $K\pi$ scattering processes.

It goes without saying that the present treatment of the κ and σ as narrow resonances is quite a rough approximation and the evaluated decay width to $\kappa\sigma$ does not really make sense. In practice we should perform a dynamical calculation of the decay chain $\kappa'(1150) \to \kappa + \sigma \to K\pi\pi\pi$, taking into account the effects of the broad κ and σ widths.

IV. Concluding Remarks

- It is suggested that there exists an extra κ' meson which has a mass around 1.1-1.2 GeV, a rather narrow width, and couples strongly to $\kappa(800)\sigma(600)$ ($\rightarrow K\pi\pi\pi$) but weakly to $K\pi$, based upon the $\tilde{U}(12)$-scheme and the BESII data.

- In a future study it is necessary to calculate dynamically the decay κ' –> $\kappa(800)\sigma(600)$ –> $K\pi\pi\pi$ in order to obtain a more realistic decay width and also to make the present decay model more effective.