Available online at www.sciencedirect.com

ScienceDirect

Progress in Particle and Nuclear Physics 61 (2008) 133–139

Progress in Particle and Nuclear Physics

www.elsevier.com/locate/ppnp

Review

Light scalars as tetraquarks: Decays and mixing with quarkonia

Francesco Giacosa

Institut für Theoretische Physik, Universität Frankfurt, Johann Wolfgang Goethe - Universität, Max von Laue–Str. 1, 60438 Frankfurt, Germany

Abstract

The tetraquark assignment for light scalar states below 1 GeV is discussed on the light of strong decays. The next-to-leading order in the large-N expansion for the strong decays is considered. Mixing with quarkonia states above 1 GeV is investigated within a chiral approach and the inclusion of finite-width effects is taken into account.

Keywords: Light scalar mesons; Tetraquark; Mixing; Strong decays

1. Introduction

The nature of scalar states, under debate for over 30 years, represents one of the major problems of low energy QCD, see [1] for reviews. In this review, based on the works [2–4], the tetraquark hypothesis for the light scalar mesons is discussed.

The resonances $a_0(980)$, $f_0(980)$ and $f_0(600)$ are well established [5] and evidence for the state $k(800)$, although not yet decisive, is mounting. Thus, a full nonet emerges below 1 GeV. Why not interpret it as a quarkonium scalar nonet? Some serious problems are well known: (a) the mass degeneracy of $a_0^0(980)$ and $f_0(980)$, which would be $\sqrt{1/2}(\overline{u}u - \overline{d}d)$ and $\overline{s}s$ in the $\overline{q}q$ assignment, is unexplained. (b) The coupling of $a_0(980)$ to $\overline{K}K$ is large and points to a hidden s-quark component. (c) Scalar quarkonia are p-wave (and spin 1) states, therefore expected to lie above 1 GeV as the tensor and axial-vector mesons. (d) Quenched lattice results [6] find a quarkonium isospin 1 mass $M_{u\overline{d}} = 1.4 - 1.5$ GeV, thus showing that $a_0(1450)$, rather than $a_0(980)$, is the lowest scalar $I = 1$ quarkonium; recent unquenched results of Ref. [7] which find in addition to $a_0(1450)$ also $a_0(980)$, are discussed in the conclusions. (e) In the large-N_c study of Ref. [8] it is shown that the resonance $f_0(600)$ does *not* behave as a quarkonium or a glueball state: the width does not scale as $1/N_c$ and the mass is not constant.

These problems can be solved in the framework of the tetraquark assignment of the light scalars: as shown by Jaffe 30 years ago [9], when composing scalar diquarks in the color and flavor antitriplet configuration (good diquarks) instead of quarks, the resonance $f_0(980)$ is dominantly "$\overline{s}s(\overline{u}u + \overline{d}d)$" and the neutral isovector $a_0(980)$ as "$\overline{s}s(\overline{u}u - \overline{d}d)$", thus neatly explaining the problem (a) mentioned above. The $f_0(600)$ is the lightest state with dominant contribution of "$\overline{u}u\overline{d}d$", in between one has the kaonic state $k(800)$ (k^+ interpreted as "$\overline{d}d\overline{s}u$"): the mass pattern is nicely reproduced. This is still one of the most appealing properties of the tetraquark assignment. Support

E-mail address: giacosa@th.physik.uni-frankfurt.de.

0146-6410/$ - see front matter © 2008 Published by Elsevier B.V.
doi:10.1016/j.ppnp.2007.12.004

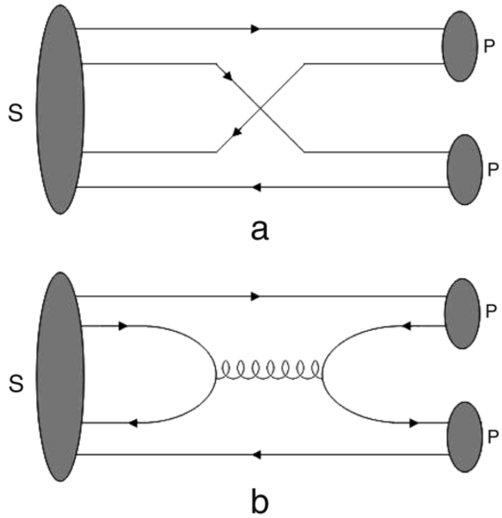

Fig. 1. Dominant (a) and subdominant (b) contributions to the transition amplitudes of a scalar tetraquark state into two pseudoscalar mesons.

for the existence of Jaffe's states below 1 GeV is also in agreement with the Lattice studies of Ref. [10]. Concerning the other problems mentioned above: (b) is solved because $a_0(980)$ has a hidden s-quark content. Points (c) and (d) are solved setting the quarkonia states above 1 GeV: $a_0(1450)$ and $K(1430)$ are the isovector and isodoublet respectively, $f_0(1370)$, $f_0(1500)$ and $f_0(1710)$ are the isoscalar states with glueball's intrusion (with $f_0(1500)$ being a hot candidate) [11]. Point (e) is solved in virtue of the large-N_c counting for tetraquarks: width and mass increase for increasing N_c [12].

In the following we concentrate on quantitative aspects of the tetraquark assignment: in Section 2 the Clebsch–Gordan coefficients for the strong decays are studied, in Section 3 the inclusion of mixing with quarkonia states is investigated within a chiral approach; subsequently, the inclusion of mesonic loops and finite-width effects is analyzed. Finally, in Section 4 the conclusions are presented.

2. Strong decays in a $SU_V(3)$-invariant approach

In the original work of Jaffe [9] the decay of tetraquark states takes place via the so-called superallowed OZI-mechanism (Fig. 1(a)): the switch of a quark and an antiquark generates the fall-apart of the tetraquark into two mesons. This mechanism is dominant in the large-N_c counting. Already in [9] the possibility that a quark and an antiquark annihilate is mentioned in relation to isoscalar mixing but is not explicitly evaluated for the decay rates. The fact that only one intermediate transverse gluon is present, see Fig. 1(b), may indicate that this mechanism, although suppressed of a factor $1/N_c$, is relevant. In [13] the discussion of strong decays of tetraquarks is revisited. Mechanism of Fig. 1(b) is mentioned at the end of the work but is not systematically evaluated for all decay modes. This has been the motivation of [2], where the inclusions of both decay modes of Fig. 1(a) and (b) in a $SU_V(3)$-invariant interaction Lagrangian parameterized by two coupling constants c_1 and c_2, is performed in all decay channels.

The nonet of scalar tetraquark is described by the matrix [2]:

$$\mathcal{S}^{[4q]} \equiv \frac{1}{2}\begin{pmatrix} [\overline{d},\overline{s}][d,s] & -[\overline{d},\overline{s}][u,s] & [\overline{d},\overline{s}][u,d] \\ -[\overline{u},\overline{s}][d,s] & [\overline{u},\overline{s}][u,s] & -[\overline{u},\overline{s}][u,d] \\ [\overline{u},\overline{d}][d,s] & -[\overline{u},\overline{d}][u,s] & [\overline{u},\overline{d}][u,d] \end{pmatrix} \tag{1}$$

$$= \begin{pmatrix} \sqrt{\frac{1}{2}}(f_B - a_0^0(980)) & -a_0^+(980) & k^+ \\ -a_0^-(980) & \sqrt{\frac{1}{2}}(f_B + a_0^0(980)) & -k^0 \\ k^- & -\overline{k}^0 & \sigma_B \end{pmatrix} \tag{2}$$