Do $I = 0$ Scalar Mesons Couple to Two Photons?

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Abstract

We investigate the range of 2 photon couplings of $f_0(\varepsilon)$ and $f_2(1270)$ that are allowed by recent experiments on $\gamma\gamma \to \pi^+\pi^-$ and $\pi^0\pi^0$. Although our amplitude analysis enforces overriding theoretical constraints that are commonly overlooked, we find a much larger range of $f_0(\varepsilon)$ and $f_2(1270)$ 2 photon couplings than is usually reported. Our preferred solutions have $\Gamma_{f_0(\varepsilon)}/\Gamma_{f_2}$ in excess of 2. This augurs well for the programme to discriminate alternative types of scalars by their 2 photon couplings.

Two photon excitation should be a good way to probe meson composition ($\Gamma \sim< Q_c^4 >$). Accepted concepts explain the observed ratios of tensor partial widths, $f_2 : a_2 : f_2'$. Can we use them to diagnose what different scalars are made of? According to elementary quark model ideas, there should be a simple correspondence between 2 photon widths of $(q\bar{q})$ scalars and tensors:

$$\Gamma(0^{++} \to \gamma\gamma)/\Gamma(2^{++} \to \gamma\gamma) = (15/4)$$
$$* \text{ (phase space scaling)}$$
$$* \text{ (relativistic corrections)}$$

provided mixing is the same. This implies that there should be sizeable signals for the $(q\bar{q})f_0, a_0$ and f_0' states. For molecules and glueballs, we expect small widths. The question we address is; does all this work?

Experimentally there has been controversy; only a_0 (980) (I=1) shows an unambiguous signal ($\sim$ 0.2 to 0.3 KeV). The aim of the present work [1] is to investigate couplings of the corresponding I=0 scalars, $f_0(\varepsilon)$ (broad) and $f_0(S^*)$ (narrow), by analysing experiments on $\gamma\gamma \to \pi^+\pi^-$ [2] and $\pi^0\pi^0$ [3]. Amplitude analysis is necessary to separate the I=0 scalar signals of interest from the dominant $f_2(1270)$ peak and from I=2 components. The experimental signal comprises a mixture of partial waves 0,2,4 ... for I=0 and 2 with contributions from helicity $m = 0$ and 2. Angular and spin information is incomplete. To restrict ambiguities one must therefore devise a parameterisation that exploits the powerful theoretical constraints for this reaction to the full:

(a) Low energy theorem

$$F_{J\lambda} \longrightarrow B_{J\lambda} \quad \text{(OPE Born)}$$
$$\text{(at low energies)}$$

(b) Known final state interactions (I=0,2 $\pi\pi$ etc interactions are well-known)

Using (a) and (b), we can: (i) obtain I=0 amplitudes for the low energy region (and the I=2 waves throughout) by explicit calculation; (ii) in the resonance region, can parameterize the 2 photon amplitudes in terms of the corresponding strong interaction amplitudes (by unitarity and analyticity):

$$F_{J\lambda} = \alpha_\pi * T(\pi\pi \to \pi\pi) + \alpha_K * T(K\bar{K} \to \pi\pi)$$

with α_π and α_K smooth real functions of energy. As a result, resonance pole positions and the various phases entering are fixed by information on the strong interactions.

Fits incorporating the above constraints have been made to a pair of recent 2 photon experiments - that of the MKII group observing the $\pi^+\pi^-$ final state [2] and the corresponding $\pi^0\pi^0$ data from Crystal Ball [3]. To explore possibilities as to resonance couplings, we generated solutions with different cross-section ratios S/D and D_0/D at the f_2 mass ($D_{0(2)}$ denote the helicity $m = 0(2)$ D-wave cross-section and $D \equiv D_0 + D_2$).

Outcome

Despite enforcing constraints that are not usually demanded we find a much larger solution space than is customary, i.e. we find a large allowed region in the $S/D, D_0/D$ plane in contrast to the usual result $S/D \approx D_0/D \approx 0$. The more favoured solutions in terms of χ^2 have quite sizeable $f_0(\varepsilon)$ couplings (Fig. 1)

$$\Gamma_{f_0(\varepsilon)}/\Gamma_{f_2} \gtrsim 2$$

in agreement with the previously mentioned quark model predictions. The resulting fits to data which are excel-

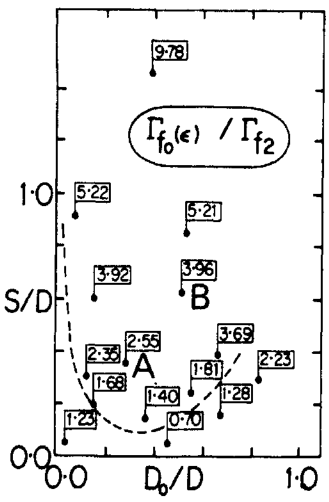

Fig. 1: Ratios of 2 photon couplings $\Gamma_{f_0(\epsilon)}/\Gamma_{f_2(1270)}$ from various fits (ref [1]). The better fits like A and B have appreciable S and D_0 contributions.

lent (for details and illustrations see ref (1)) prompt the following comments:

(i) The model gives an excellent parameter-free description of the low energy region for both $\pi^+\pi^-$ and $\pi^0\pi^0$. This vindicates the I=0 and 2 phase shifts used and demonstrates that there is no call in the new data for any extra low-mass enhancement.

(ii) The lack of experimental acceptance at forward and backward angles is a major cause for the spread of solution types.

(iii) Mostly the fits have no difficulty in accommodating both the $\pi^+\pi^-$ and $\pi^0\pi^0$ data. An exception is the $f_0(S^*)$ region where the $\pi^0\pi^0$ data indicates a larger S wave contribution than does $\pi^+\pi^-$.

Each fit entails corresponding I=0 partial wave cross-sections (see e.g. Fig. 2) from which one can extract the associated resonance signals $\Gamma(f_2(1270), f_0(\epsilon)$ and

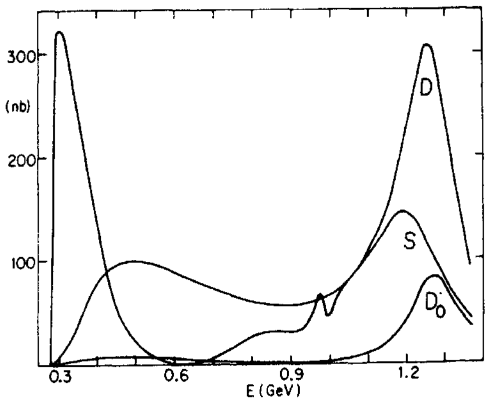

Fig. 2: $I = 0$ partial wave cross-sections from sol. A.

$f_0(S^*) \to \gamma\gamma)$. Results for the former two have already been mentioned. Our findings for $\Gamma(f_0(S^*))(\sim \mathbf{0.6}KeV)$ vary much less from solution to solution because the low-energy constraints have more purchase at 1 GeV than at say 1.25 GeV.

What our results entail for the scalars:

(i) Our finding $\Gamma_{f_0(\epsilon)}/\Gamma_{f_2} \gtrsim 2$ suggests that the quark model prediction [4] for $\gamma\gamma(0^{++}/2^{++})$ is roughly correct.

(ii) If so, we should see $(q\bar{q})$ scalar counterparts of $a_2(1320)$ and $f_2'(1520)$: $-\{\Gamma_{a_2} \sim 1KeV;\ \Gamma_{f_2'} \sim 0.1KeV$ (expt)$\}$ implies $\Gamma_{a_0} \approx$ 2-4 KeV and $\Gamma_{f_0'} \approx 0.2 - 0.4KeV$, both modulo '**phase space scaling**' and the latter **modulo** mixing, i.e. the extent to which f_0' is pure $(s\bar{s})$.

(iii) Our result $\Gamma(f_0(S^*)) \approx 0.6KeV$ is more like the molecule picture (or presumably a glueball) than $q\bar{q}$, unless S^* is predominantly $(s\bar{s})$ (not normally favoured on account of S^*'s low mass).

(iv) Given (i) above, knowing the relevant $\gamma\gamma$ widths should help resolve the identity of the I=1$(q\bar{q})$ scalar - $a_0(980)$ or $a_0(1300)$ of GAMS [5] or what? The empirical outcome is inconclusive. For $a_0(980)$, the measurement

$$\Gamma(a_0 \longrightarrow \gamma\gamma).BR(a_0 \longrightarrow \pi\eta) \approx 0.2, 0.3KeV$$

is more like the molecule picture than $(q\bar{q})$. Yet, according to Feindt (CELLO) [6], $\Gamma(a_0(1300) \to \gamma\gamma).BR(a_0 \to \eta\pi) < 0.44KeV$. So there is a problem.

Future:

$\gamma\gamma$ experiments provide a good extra probe for spectroscopy. More experiments are needed emphasizing better angular coverage, better statistics and other channels like $\eta\eta, K\bar{K}$. There is real scope for discoveries.

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