4 The Scalar Glueball

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The Crystal Barrel experiment which ran at CERN's Low Energy Antiproton Ring until 1996 discovered several new mesons, among them the J^{PC} = 0^{++} isoscalar meson $f_0(1500)$ and the 0^{++} isovector $a_0(1450)$ (for a review see ref. [1]). We have shown several years ago that the $f_0(1500)$ was an excellent candidate for the ground state glueball expected by lattice gauge theories around this mass [2]. In the present report we argue that recent results from LEP indicate that $f_0(1500)$ couples only weakly to photons. This strengthens the evidence that $f_0(1500)$ contains a large fraction of glue. On the other hand, a reasonable $q\overline{q}$ nonet for the scalar mesons can be built with the other known mesons, among them the $f_0(1710)$ which appears to be the $s\overline{s}$ state in the nonet [3].

The $f_0(1370)$ and $f_0(1500)$ mesons were established by Crystal Barrel, first in their $\eta\eta$ and $\pi^0\pi^0$ decay modes [4]. The $f_0(1370)$ is broad ($\sim$ 400 MeV) while the $f_0(1500)$ is rather narrow ($\sim$ 100 MeV). Their $K\bar{K}$ decay rates were measured by Crystal Barrel [5]. They are small compared to $\pi\pi$, indicating that neither state can have a large $s\overline{s}$ component [3].

The WA102 Collaboration at CERN observed the f_0(1370), $f_0(1500)$ and $f_0(1710)$ decaying to $K\bar{K}$ and $\pi\pi$ in pp central production at 450 GeV [6]. For f_0(1370) and $f_0(1500)$, the $\pi\pi$ decay mode was favoured over $K\overline{K}$. Hence both $f_0(1370)$ and $f_0(1500)$ do not have large $s\bar{s}$ components, in agreement with Crystal Barrel results. However, for $f_0(1710)$, $K\bar{K}$ decay dominates $\pi\pi$ by a large factor, suggesting that this state must be dominantly $s\overline{s}$.

The $f_0(1710)$ was also searched for in $\overline{p}p$ annihilation into three pseudoscalar mesons with 900 MeV/c antiprotons [7]. For example, in $\overline{p}p \to \pi^0\eta\eta$ the $f_0(1710) \to \eta\eta$ is not observed, while $f_0(1500)$ is clearly seen. This is prima facie evidence that $f_0(1710)$ cannot have a large $u\overline{u} + d\overline{d}$ component.

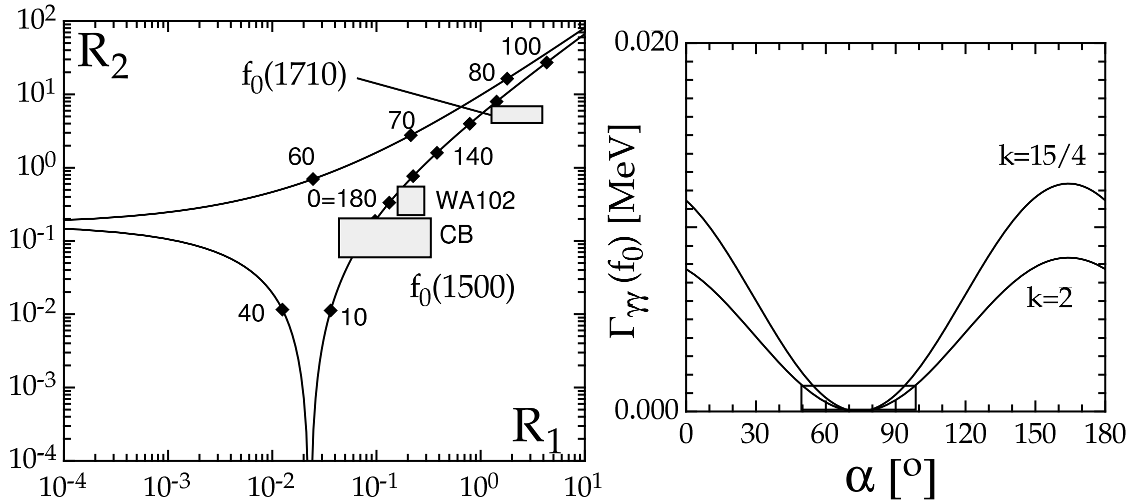

Figure 4.1: *Left: relative decay branching ratio R_2 = $B(K\overline{K})/B(\pi\pi)$ vs. R_1 = $B(\eta\eta)/B(\pi\pi)$ as a function of mixing angle α (in deg.); right: predicted $\gamma\gamma$-width for the $f_0(1500)$. The experimental upper limit is shown by the box (from ref.[3]).*

For a more quantitative statement, look at fig. 4.1 (left) which shows the ratio of branching ratios R_2 = $B(K\overline{K})/B(\pi\pi)$ vs. R_1 = $B(\eta\eta)/B(\pi\pi)$ for scalar mesons, apart from phase space factors. Data from Crystal Barrel and WA102 (2σ boundaries) on the $f_0(1500)$ and $f_0(1710)$ are compared with predictions from SU(3). The angle α describes the mixing of the two nonet isoscalar mesons,

$$|f_0\rangle = \cos\alpha\,|n\overline{n}\rangle - \sin\alpha\,|s\overline{s}\rangle \quad \text{with} \quad |n\overline{n}\rangle \equiv \frac{u\overline{u}+d\overline{d}}{\sqrt{2}}\ . \tag{4.2}$$

Hence for α = 0, f_0 is pure $n\overline{n}$ and for α = 90°, pure $s\overline{s}$. Assuming that $f_0(1500)$ and $f_0(1710)$ are $q\overline{q}$ states, we conclude from fig. 4.1 (left) that the former is mainly $n\overline{n}$ (-10° $\leq \alpha \leq 5°$) and the latter mainly $s\overline{s}$ ($\alpha \simeq 117°$).

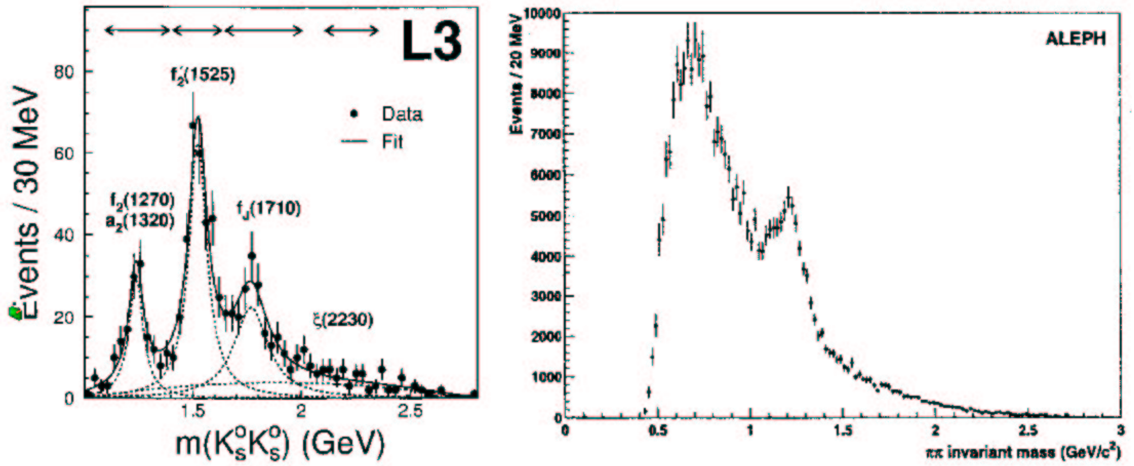

Figure 4.2: *Left: K_SK_S mass distribution in $\gamma\gamma$-collisions at LEP/L3 (from ref. [8]); right: $\pi^+\pi^-$ mass distribution from LEP/ALEPH showing only the $f_2(1270)$ (from ref.[9]).*

Let us now deal with two-photon processes which are useful to probe the charge content of mesons through their electromagnetic couplings. Glueballs do not couple directly to photons and their production should therefore be suppressed in $\gamma\gamma$-processes. New data in $\gamma\gamma$-collisions have been presented by the LEP collaborations. L3 observes three peaks below 2 GeV in the K_SK_S mass distribution [8] (fig. 4.2, left), but the spin 0 $f_0(1500)$ is not seen. Since $f_0(1500)$ does not couple strongly to $K\bar{K}$, this is perhaps not surprising. However, ALEPH studying the reaction $\gamma\gamma \to \pi^+\pi^-$, does not observe $f_0(1500)$ either [9] (see fig. 4.2, right). An upper limit of 1.4 keV (95 % CL) can be derived for its $\gamma\gamma$-width from the ALEPH result [9], using the known $\pi\pi$ decay branching ratio of the $f_0(1500)$.

The $\gamma\gamma$-width of a $q\overline{q}$ state can be predicted from SU(3). Apart from an unknown nonet constant C and for a meson of mass m:

$$\Gamma_{\gamma\gamma} = C(5\cos\alpha - \sqrt{2}\sin\alpha)^2 m^3\ . \tag{4.3}$$

The $\gamma\gamma$-width of a scalar meson is related to that of the corresponding tensor by

$$\Gamma_{\gamma\gamma}(0^{++}) = k\left(\frac{m_0}{m_2}\right)^3 \Gamma_{\gamma\gamma}(2^{++})\ , \tag{4.4}$$

with obvious notations. Here the factor $k = 15/4$ arises from spin multiplicities in a non-relativistic calculation, while relativistically $k \simeq 2$. Figure 4.1 (right) shows the prediction for the $\gamma\gamma$ partial width of the $f_0(1500)$ as a function of α, together with the ALEPH upper limit [3]. Assuming a $q\overline{q}$ structure, one concludes that $f_0(1500)$ is dominantly $s\overline{s}$ (50° $\leq \alpha \leq$ 100°), at variance with the hadronic results discussed above.

This contradiction indicates that $f_0(1500)$ is not $q\overline{q}$ and the lack of $\gamma\gamma$-coupling points to a large gluonic content. Obviously, some mixing with nearby $q\overline{q}$ states is possible [2] but more accurate

Table 4.1: *Classification of the low-mass scalar mesons showing the scattering resonances below 1 GeV and the ground state $q\overline{q}$ nonet (1^3P_0).*

State	Γ [MeV]	Isospin	Nature
$a_0(980)$	~ 50	1	$K\overline{K}, qq\bar{q}\bar{q}$
$f_0(980)$	~ 50	0	$K\overline{K}, qq\bar{q}\bar{q}$
$f_0(600)$	~ 800	0	meson-meson
$\kappa(800)$?	~ 600	1/2	resonances
$a_0(1450)$	265	1	$u\bar{d}, d\bar{u}, d\bar{d} - u\bar{u}$
$f_0(1370)$	~ 400	0	$d\bar{d} + u\bar{u}$
$f_0(1710)$	125	0	$s\bar{s}$
$K_0^*(1430)$	294	1/2	$u\bar{s}, d\bar{s}, s\bar{u}, s\bar{d}$

data in $\gamma\gamma$-collisions and theoretical guidance on the strength of $\gamma\gamma$-couplings to glueballs are needed for a more quantitative statement on mixing. Table 4.1 shows an increasingly popular classification scheme for the low lying scalar nonets [10]. The lower mass nonet is made of four-quark states and/or meson-meson resonances. The ground state (1^3P_0 or 0^{++}) $q\overline{q}$ nonet lies in the 1400 MeV region. The supernumerary $f_0(1500)$ (not shown) is dominantly glue.

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see also F.E. Close and A. Kirk, Eur. Phys. J **C 21** (2001) 531.

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