Search for the glueball candidates $f_0(1500)$ and $f_J(1710)$ in $\gamma\gamma$ collisions with the ALEPH detector

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Abstract

Data taken with the ALEPH detector at LEP1 have been used to search for $\gamma\gamma$ production of the glueball candidates $f_0(1500)$ and $f_J(1710)$ via their decay to $\pi^+\pi^-$. No signal is observed and upper limits to the product of $\gamma\gamma$ width and $\pi^+\pi^-$ branching ratio of the $f_0(1500)$ and the $f_J(1710)$ have been measured to be

$$\Gamma(\gamma\gamma \to f_0(1500)) \cdot \mathcal{BR}(f_0(1500) \to \pi^+\pi^-) < 0.31 \text{ keV}$$

$$\Gamma(\gamma\gamma \to f_J(1710)) \cdot \mathcal{BR}(f_J(1710) \to \pi^+\pi^-) < 0.55 \text{ keV}$$

at 95% confidence level.

1. Introduction

QCD lattice calculations have predicted the lightest scalar glueball to be a scalar resonance with mass 1600 ± 150 MeV/c^2 [1, 2] with tensor and pseudoscalar glueballs in the $2000 - 2500$ MeV/c^2 region [3].

Experimentally two principal candidates for the scalar glueball have been observed, the $f_0(1500)$ and the $f_J(1710)$. Both are seen in gluon-rich reactions such as $p\bar{p}$ annihilation, central production and radiative J/ψ decay. The $f_0(1500)$ does not fit naturally in the $q\bar{q}$ spectrum but could be due to a glueball mixed with $q\bar{q}$ states in that mass region [4]. The spin of the $f_J(1710)$ is not yet confirmed, indications for both spin 2 and spin 0 have been reported [7, 5]. If the $f_J(1710)$ is indeed spin 0 it becomes a candidate for the $^3P_0(s\bar{s})$-like state in the $1600-2000$ MeV/c^2 region, but also for the lightest scalar glueball [2].

In $\gamma\gamma$ interactions, production of a pure gluon state is suppressed. Measuring the two-photon width $\Gamma_{\gamma\gamma}$ of the $f_0(1500)$ and the $f_J(1710)$, or setting an upper limit on $\Gamma_{\gamma\gamma}$, should indicate whether either is likely to be a pure glueball or has quark content.

In this analysis, the processes $\gamma\gamma \to f_0(1500) \to \pi^+\pi^-$ and $\gamma\gamma \to f_J(1710) \to \pi^+\pi^-$ have been studied and upper limits extracted for $\Gamma_{\gamma\gamma} \cdot \mathcal{BR}(\pi^+\pi^-)$ of both resonances.

2. Selection of $\pi^+\pi^-$ events

This analysis uses 160.9 pb^{-1} of data at $\sqrt{s} = 91$ GeV. Candidate events must contain only two good tracks of equal and opposite charge. The total energy observed in the event must be less than 30 GeV and visible mass less than 10 GeV to exclude Z events with the transverse momentum of the final state with respect to the beam axis not exceeding 0.1 GeV/c and no 'tagged' lepton. The absolute value of the cosine of the angle θ^* between the two tracks in their centre-of-mass system and the boost direction is required to be less than 0.9.

The dominant background is the $\gamma\gamma \to \mu^+\mu^-$ process. To reduce this, events containing identified muons are rejected. The rejection efficiency is close to 100% for pair invariant masses $W > 3$ GeV/c^2 but falls off rapidly, being only ~20% for $W = 1$ GeV/c^2. No attempt is made to remove the residual background using Monte Carlo subtraction since the trigger efficiency is not well understood. Rejection of electrons using dE/dx is almost 100% efficient and the residue of kaon contamination is estimated to be ~0.05% from Monte Carlo.

A sample of 294141 $\pi^+\pi^-$ candidate events is selected.

3. Fitting the mass spectrum

The $\pi^+\pi^-$ invariant mass spectrum obtained shows a steep rise around 0.5 GeV/c^2 which is an artefact of the triggers which depend on the observation of at least two charged tracks. The clear peak in the spectrum above 1 GeV/c^2 can be identified as the known tensor resonance $f_2(1270)$. No other clear structure is observed. A fit to this invariant mass spectrum is performed. For the resonances $f_2(1270)$, $f_0(1500)$ and $f_J(1710)$, a Breit-Wigner function of the form

$$\frac{m m_0 \Gamma(m)}{(m_0^2 - m^2)^2 + m^2\Gamma^2(m)} \quad (1)$$

is used, where the mass-dependent width $\Gamma(m)$ is given by

$$\Gamma(m) = \Gamma_0 \left(\frac{m}{m_0}\right)^{(l+1/2)} \exp\left[\frac{-(m^2 - m_0^2)}{48\beta^2}\right] \quad (2)$$

and $\beta = 0.4$ GeV/c^2 [6]. For the $f_2(1270)$ the mass m_0, total width Γ_0 and overall normalisation are free parameters. For the $f_0(1500)$ and the $f_J(1710)$ the normalisation is a free parameter, while the mass and width are fixed to 1500 MeV/c^2 and 112 MeV/c^2 for the $f_0(1500)$ and 1712 MeV/c^2 and 133 MeV/c^2 for the $f_J(1710)$ [7]. The $f_J(1710)$ is considered here as a $J = 0$ state. The background spectrum, due to $\gamma\gamma \to \mu\mu$ events and the $\pi\pi$ continuum process, is fitted on the data with a 5^{th} order Chebyshev polynomial.

The mass region 0.8 to 2.5 GeV/c^2 is used in the fit. Four fits are performed (i) with the Breit-Wigner for the $f_2(1270)$ and the polynomial background alone; then in turn adding (ii) the $f_0(1500)$, (iii) the $f_J(1710)$ and (iv) the $f_0(1500)$ and $f_J(1710)$ simultaneously.

The parameters of the combined fit (iv) are summarised in Table 1, including the number of events fitted for the glueball candidate signals. For the fit including the $f_2(1270)$ alone, the χ^2 of 75 for 76 degrees of freedom is already very good. The χ^2 per degree of freedom hardly changes with the addition of glueball signals.

The width of the Breit-Wigner function fitted for the $f_2(1270)$ is in all cases in agreement with the world average value of $185.5^{+3.8}_{-2.7}$ MeV/c^2 [7]. However, the fitted mass of $\sim$1214 MeV/c^2 in each case is not consistent with the established value of 1275.0 ± 1.2 MeV/c^2 [7]. This has been previously observed by the MARKII and CELLO collaborations [9] and is thought to be caused by interference of the spin 2 resonant amplitude with other components in the background.

Limited knowledge of the trigger efficiency for this topology prevents an investigation of interference effects using the measured angular distribution. The number of events fitted for the $f_0(1500)$ signal is negative, but consistent with zero. Data from the WA76 and WA102 collaborations [10] suggest interference effects in this region can cause the $f_0(1500)$ to appear as a dip in the spectrum. However, here limits are set assuming no interference.

The CELLO collaboration has reported possible structure in the $\pi^+\pi^-$ invariant mass spectrum around 1.1 GeV/c^2 [11]. If the fit of case (i) is repeated but excluding a region around 1.1 GeV/c^2, a clear excess of data over the fitted curve extrapolated through that region can be seen. The excess can be described by the introduction of another spin 0 resonance of apparent mass $\sim$1.1 GeV/c^2 and total width $\sim$250 MeV/c^2.

4. $\Gamma_{\gamma\gamma}\cdot\mathcal{BR}(\pi^+\pi^-)$ for $f_0(1500)$ and $f_J(1710)$

The fitted numbers of signal events from the processes $\gamma\gamma \to f_0(1500) \to \pi^+\pi^-$ and $\gamma\gamma \to f_J(1710) \to \pi^+\pi^-$ are used to calculate upper limits on $\Gamma_{\gamma\gamma}\cdot\mathcal{BR}(\pi^+\pi^-)$ for both resonances.

The trigger efficiency is calculated as a function of invariant mass by comparing rates of independent triggers for $\pi^+\pi^-$ selected data. In the 1500 MeV/c^2 mass region the average trigger efficiency is $(66 \pm 7)\%$, while for the 1700 MeV/c^2 mass region it is $(77 \pm 7)\%$.

The acceptance and selection efficiency for $\gamma\gamma \to f_0(1500) \to \pi^+\pi^-$ and for $\gamma\gamma \to f_J(1710) \to \pi^+\pi^-$ are determined from Monte Carlo to be $(17.5 \pm 0.4)\%$ and $(16.3 \pm 0.4)\%$, where the quoted errors include the systematic error due to the simulation of the detector and the error due to Monte Carlo statistics.

The product branching ratio, $\Gamma_{\gamma\gamma}\cdot\mathcal{BR}(\pi^+\pi^-)$, of each resonance is calculated directly from the fitted number of signal events in each of the cases (ii)–(iv). The fitted value of $\Gamma_{\gamma\gamma}\cdot\mathcal{BR}(\pi^+\pi^-)$ (which may be negative) and its error are used to define the mean and width of a Gaussian distribution: the area under the Gaussian is integrated above zero to obtain the 95% C.L. limit on $\Gamma_{\gamma\gamma}\cdot\mathcal{BR}(\pi^+\pi^-)$.

The upper limits on the product branching ratios at 95% C.L. for the combined fit are $\Gamma_{\gamma\gamma}\cdot\mathcal{BR}(\pi^+\pi^-) < 0.31$ keV and $\Gamma_{\gamma\gamma}\cdot\mathcal{BR}(\pi^+\pi^-) < 0.55$ keV for the $f_0(1500)$ and $f_J(1710)$ respectively.

5. Stickiness

From the limits on $\Gamma_{\gamma\gamma}$ the *stickiness* [12] of each resonance can be calculated, by comparison of the two photon width with the particle's width for production in the glue-rich environment of radiative J/ψ decay. The ratio is normalised such that the $q\bar{q}$ resonance $f_2(1270)$ has stickiness equal to 1. Then for a glueball a higher value of stickiness is expected.

Table 1. Table of parameters from the combined fit to both candidates using the Breit-Wigner form of Eqn.1 for resonances.

	(iv) Fit for $f_2(1270) + f_0(1500) + f_J(1710)$
χ^2	73.21
Degrees of freedom	74
Fitted mass of $f_2(1270)$ (MeV/c^2)	1214.2 ± 3.8
Fitted width of $f_2(1270)$ (MeV/c^2)	175.5 ± 14.2
No. of $f_0(1500)$ signal events	-671.0 ± 690.0
No. of $f_J(1710)$ signal events	198.6 ± 541.9

Stickiness for a 0^{++} resonance X is defined as

$$S_X(0^{++}) = \mathcal{N}\,\frac{m_X}{k_{\mathrm{J}/\psi\to\gamma X}}\,\frac{\Gamma(\mathrm{J}/\psi\ \to \gamma X)}{\Gamma(X\to\gamma\gamma)}$$

where m_X is the mass of the resonance; $k_{\mathrm{J}/\psi\to\gamma X} = (m^2_{\mathrm{J}/\psi} - m^2_X)/2m_{\mathrm{J}/\psi}$ is the energy of the photon from the radiative J/ψ decay, measured in the J/ψ rest frame; $\Gamma(\mathrm{J}/\psi\ \to \gamma X)$ is the width for production of the resonance in radiative J/ψ decay; and $\mathcal{N}$ is the normalisation factor. The branching ratio for $f_0(1500) \to \pi^+\pi^-$ is taken as 0.30 ± 0.07, while the branching ratio for $f_J(1710) \to \pi^+\pi^-$ is $0.026^{+0.001}_{-0.016}$ [7], giving, from the fit for both resonances, $\Gamma(f_0(1500) \to \gamma\gamma) = 1.08$ keV and $\Gamma(f_J(1710) \to \gamma\gamma) = 21.25$ keV. The lower limits on stickiness are then 1.4 and 0.3 for the $f_0(1500)$ and the $f_J(1710)$ respectively.

6. Conclusion

Production of the glueball candidates $f_0(1500)$ and $f_J(1710)$ in $\gamma\gamma$ collisions at LEP1 has been studied via decay to $\pi^+\pi^-$. No signal from either resonance is seen, and the upper limits on the product of two-photon width and $\pi^+\pi^-$ branching ratio have been calculated as $\Gamma_{\gamma\gamma} \cdot \mathcal{BR}(\pi^+\pi^-) < 0.31$ keV for the $f_0(1500)$ and $\Gamma_{\gamma\gamma} \cdot \mathcal{BR}(\pi^+\pi^-) < 0.55$ keV for the $f_J(1710)$, both at 95% C.L., from a simultaneous fit for both resonances.

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