Study of the glueball candidate $f_0(1500)$ at LEP

The ALEPH Collaboration

Abstract

Data taken with the ALEPH detector at LEP have been used to study $\gamma\gamma$ production of the glueball candidate $f_0(1500)$ via its decay to $\pi^+\pi^-$. No signal is observed in excess of background and an upper limit to the $\gamma\gamma$ width of the $f_0(1500)$ has been calculated.

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1 Introduction

Lattice QCD has predicted the lightest scalar glueball to be in the 1500 MeV region [1], with the most recent calculations giving masses of $1600 \pm 85 \pm 100$ MeV [2] and 1740 ± 70 MeV [3]. However, these calculations have been performed in the quenched approximation, and the inclusion of quarks in the model would be expected to shift the mass of the glueball downwards, nearer the 1500 MeV mark [4].

The Crystal Barrel Collaboration has reported the observation of the $f_0(1500)$ resonance in the gluon–rich environment of $p\bar{p}$ interactions at rest [5]. This state, of mass 1503 ± 11 MeV and width 120 ± 19 MeV [6], decays predominantly to 4π, followed by the 2π decay mode. It does not fit well in the $q\bar{q}$ spectrum, but is considered a strong candidate to be the lightest scalar glueball, or rather, a manifestation of the glueball.

If it were a pure glue state, the $f_0(1500)$ would have negligible coupling to photons and so no signal for the process $\gamma\gamma \to f_0(1500)$ would be seen. But there are models for the mixing of the bare glueball with $q\bar{q}$ states [7], such that, in particular, the $f_0(1500)$ could be mostly glue but with some $q\bar{q}$ admixture, making coupling to photons possible. A measurement of the two-photon width, $\Gamma_{\gamma\gamma}$, of the $f_0(1500)$ would allow the determination of the quark content of the state and thus of a mixing angle between $q\bar{q}$ and the glueball in this scenario.

In this analysis, the process $\gamma\gamma \to f_0(1500) \to \pi^+\pi^-$ has been studied and an upper limit extracted for the two-photon width $\Gamma_{\gamma\gamma}$ of the $f_0(1500)$.

2 The ALEPH detector and event selection

This analysis uses 160.9pb^{-1}of data taken around the Z^0 peak with the ALEPH detector [8] at the e^+e^- collider, LEP, from 1990 to 1995. The key detector components are the time projection chamber (TPC), the electromagnetic calorimeter (ECAL) and the hadron calorimeter (HCAL) for reconstruction of charged tracks and particle identification; and the two luminosity monitors (LCAL and SiCAL), used to veto events with leptons tags.

Charged tracks are measured in the TPC with a momentum resolution $\Delta p/p^2 = 0.0012(\mathrm{GeV/c})^{-1}$ for $p = 45\mathrm{GeV/c}$. Electromagnetic showers are measured in ECAL with an energy resolution $\sigma(E)/E = 0.01 + 0.18/\sqrt{E(\mathrm{GeV}\ )}$. The energy resolution of the HCAL for pions at normal incidence is $\sigma(E)/E = 0.85/\sqrt{E(\mathrm{GeV}\ )}$. The LCAL and SiCAL have an energy resolution $\sigma(E)/E = 0.011 + 0.15/\sqrt{E(\mathrm{GeV}\ )}$ and $\sigma(E)/E = 0.23/\sqrt{E(\mathrm{GeV}\ )}$ respectively and together cover the low–angle region (0.024 – 0.155 radians) below the ECAL endcap.

Candidate events have been selected according to the following criteria:

- two good charged tracks ONLY in the event, of equal and opposite charge;
- a primary vertex is reconstructed;
- total energy observed in the event < 30 GeV and visible mass < 10 GeV , to exclude Z^0 events;
- tranverse momentum of the final state < 1.5 GeV/c and no energy deposited in the luminosity monitors LCAL and SiCAL as "anti-tagging" criteria to ensure (quasi–)real photon ($Q^2 = 0$) collisions.

To select pion pairs, first muons are identified and rejected using information from ECAL, HCAL and the muon chambers (with almost 100% efficiency for muons with momentum > 3 GeV/c). Then $\mathrm{d}E/\mathrm{d}x$ measured in the TPC is required to be consistent with a pion hypothesis: rejection of electrons is very efficient but there is some small kaon contamination of the final selection ($< 1\%$). Residual backgrounds from the processes $\gamma\gamma \to e^+e^-$, $\gamma\gamma \to \tau^+\tau^-$ and $Z^0 \to \tau^+\tau^-$ are negligible. The background to the resonances is dominated at low invariant mass by mis–identified, very low energy muons from the $\gamma\gamma \to \mu^+\mu^-$ process.

3 Fitting the mass spectrum

The $\pi^+\pi^-$ invariant mass spectrum obtained is shown in figure 1. The clear peak in the spectrum above 1 GeV can be identified with the known tensor resonance $f_2(1270)$. The experimental

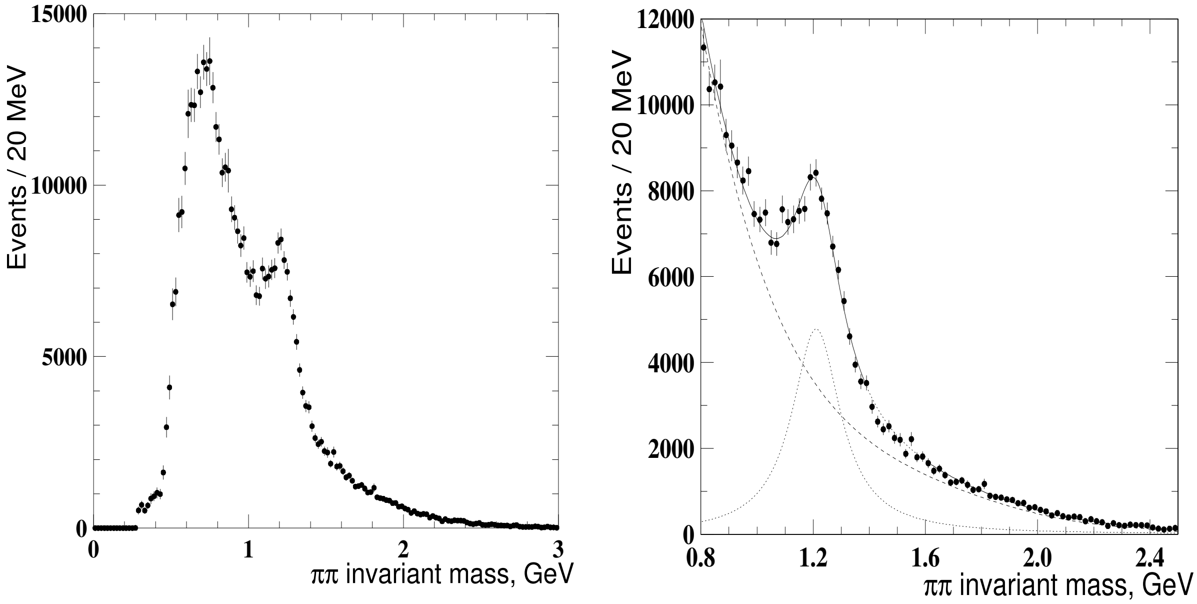

Figure 1: The invariant mass distribution for two-pion final states: data (left) and the fit to data (right) with the Breit-Wigner for the $f_2(1270)$ (dotted line), the polynomial for the background (dashed line) and the combination of these functions (solid line) are shown. The dotted line from 1.38 to 1.62 GeV indicates the exclusion of this region from the fit.

resolution of the masses of the $f_2(1270)$ and the $f_0(1500)$ resonances have been evaluated from Monte Carlo simulation (using the PHOT02 [9] program to generate Breit-Wigner resonances of appropriate mass, width and spin, with hadronisation performed by the JETSET program [10]). In both cases the resolution is of order 10 MeV , compared to full widths 185 MeV and 120 MeV for the $f_2(1270)$ and the $f_0(1500)$ respectively, and so Breit-Wigner shapes can be used to fit the resonances, avoiding convolution with Gaussian resolution functions.

The background spectrum, due to the $\pi\pi$ continuum process with contamination from $\gamma\gamma \to \mu\mu$, is fitted with a 5^{th} order polynomial.

The mass region 0.8 to 2.5 GeV is used in the fit, but with a window from 1.38 to 1.62 GeV excluded - the width of the window is chosen to be $2 \times \Gamma_{tot}$ of the $f_0(1500)$ and should adequately contain any signal from this resonance. The fit to the data is also shown in figure

1: the Breit-Wigner shape for the $f_2(1270)$, the polynomial for background processes and the combination of both these are indicated. The χ^2/d.o.f. for the fit is 1.1.

The parameters of the Breit-Wigner fitted for the $f_2(1270)$ are width 211 ± 18 MeV , in reasonable agreement with the PDG value [6] of 185 ± 20 MeV , and mass 1211 ± 4 MeV which is not consistent with the established value of 1275 ± 5 MeV : this, however, is expected as interference effects between the resonance and continuum have not been included in the fit, and the downward shift in mass is in line with observations from the MARKII and CELLO collaborations [11].

Around the 2 GeV region, there is no evidence of any signal that could be associated with the $f_J(2220)$ resonance (formerly the $\xi(2220)$) which is a candidate for the tensor glueball. A stringent limit on its two–photon width has recently been published by the CLEO collaboration [12].

4 The 1.5 GeV region

The background to the $f_0(1500)$ signal is defined by extrapolation of the fitted background spectrum through the excluded mass window of 1.38 to 162 GeV . A binned likelihood fit [13] is performed in this window to determine the upper limit on the number of events $\gamma\gamma \to f_0(1500) \to \pi^+\pi^-$. The likelihood for the spectrum to contain a given number of signal events was calculated according to the following formula:

$$\mathrm{L} = \prod_{i=1}^{\mathrm{N}} \frac{1}{\sqrt{2\pi\nu_i}}\, e^{\frac{-(n_i-\nu_i)^2}{2\nu_i}},$$

where n_i is the number of observed events in bin i, ν_i is the expected signal plus background for that bin and N is the number of bins in the mass window (N=12).The expected signal is taken to be a Breit-Wigner resonance of mass 1503 MeV and width 120 MeV (although this shape could be distorted by interference effects). The number of signal events was varied and the likelihood plotted as a function of this number, as shown in figure 2. The maximum likelihood is seen for the number of signal events equal to -905. The area under the graph is integrated above zero to obtain the 95% C.L. limit on the number of signal events: it is found here to be 128 events.

The limit on the number of signal events is used to calculate the upper limit on $\Gamma_{\gamma\gamma}(f_0(1500))$. The acceptance and selection efficiency for $\gamma\gamma \to f_0(1500) \to \pi^+\pi^-$ is 22%, while the trigger efficiency in the mass window is (64 ± 3)%. The branching ratio for $f_0(1500) \to \pi^+\pi^-$ is not yet firmly established: published data from the Crystal Barrel collaboration give $\mathcal{BR}(f_0(1500) \to \pi^+\pi^-) = 0.30 \pm 0.03$ [5] but a more recent calculation, taking all interference effects into account, gives $\mathcal{BR}(f_0(1500) \to \pi^+\pi^-) = 0.24 \pm 0.05$ [14]. Using the Crystal Barrel branching ratio, the limit on the two–photon width is $\Gamma_{\gamma\gamma} < 0.11$ keV , while the new calculation leads to a higher limit of $\Gamma_{\gamma\gamma} < 0.14$ keV . To be conservative, the limit on the two–photon width is set to the higher value plus one standard deviation (=0.03 keV , from the combination in quadrature of the uncertainty in the trigger efficiency and the uncertainty in the branching ratio, the latter being the dominant systematic error), *i.e.* the upper limit on the two-photon width of the $f_0(1500)$ is

$$\Gamma_{\gamma\gamma} \;<\; 0.17\,\mathrm{keV}\;,\quad 95\%\ \mathrm{C.L.}$$

This limit can be used to calculate the *stickiness* [15] of the resonance, by comparison of the two photon width with the width for $f_0(1500)$ production in the glue-rich environment of radiative J/ψ decay. Stickiness for a 0^{++} resonance X is defined

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

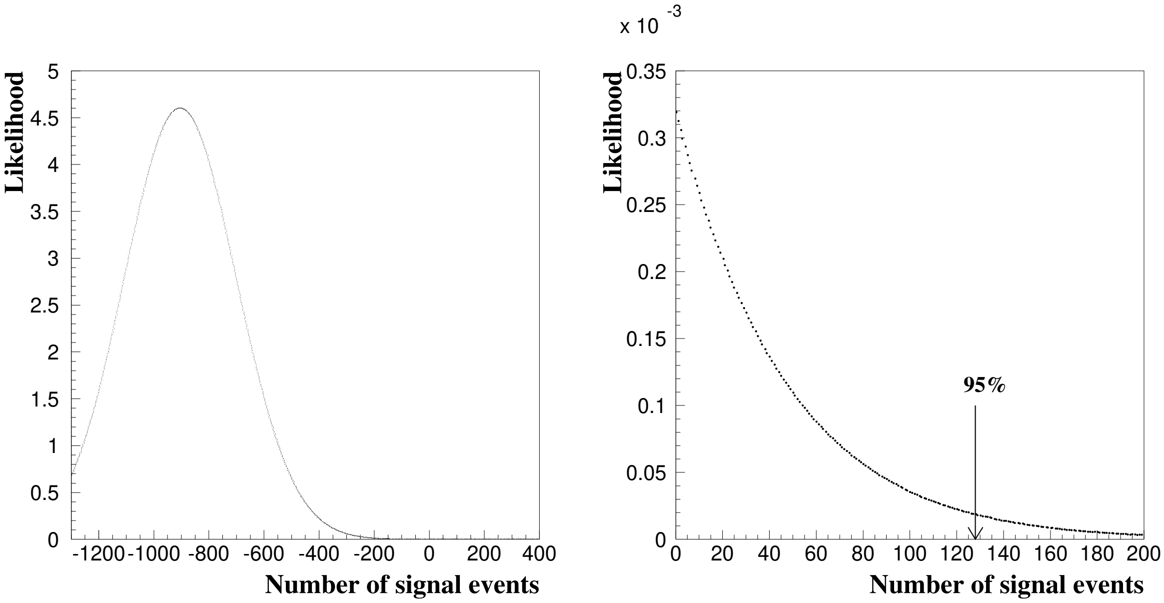

Figure 2: Likelihood for number of signal events $\gamma\gamma \to f_0(1500) \to \pi^+\pi^-$ in $\pi^+\pi^-$ mass spectrum (left), and detail of the plot for signal>0 showing the 95% C.L. limit (right).

where m_X is the mass of the resonance; $k_{\psi\to\gamma X} = (m_\psi^2 - m_X^2)/2m_\psi$ is the energy of the photon from a radiative J/ψ decay, measured in the J/ψ rest frame; $\Gamma(J/\psi \to \gamma X)$ is the width for production of the resonance in radiative J/ψ decay, which for the $f_0(1500)$ is 0.071 keV [6]; $\Gamma(X \to \gamma\gamma)$ for the $f_0(1500)$ is taken as 0.17 keV , in line with the upper limit measured in this analysis; and $\mathcal{N}$ is a normalisation factor chosen such that the $f_2(1270)$ resonance has stickiness of 1. The lower limit on the stickiness of the $f_0(1500)$ is then found to be 13, higher than would be expected for a $q\bar{q}$ state.

5 Conclusion

Production of the $f_0(1500)$ resonance in $\gamma\gamma$ collisions at LEP1 has been studied, via its decay to $\pi^+\pi^-$. No signal from this resonance can be seen, and the upper limit on its two–photon width has been calculated as $\Gamma_{\gamma\gamma} < 0.17$keV , at 95% C.L. . Although the lower limit on the stickiness of the resonance suggests it may not be a simple $q\bar{q}$ state, further study with LEP2 data and in other decay channels should help to establish more firmly the true nature of the $f_0(1500)$ resonance.

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