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Analysis of $K_s^0 K_s^0$ and $\pi^+\pi^-\pi^0$ final states in two photon collisions at LEP

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Abstract. The $K_s^0 K_s^0$ and $\pi^+\pi^-\pi^0$ final states in two-photon collisions are studied with the L3 detector at LEP. A full energy dependent partial wave analysis demonstrates that the two-photon mass spectra are dominated by the formation of tensor mesons. Their masses, widths and two-photon partial widths are determined.

1 Introduction

An important step in the development of a nonperturbative approach in QCD at low and intermediate energies is an identification and classification of the strongly interacting particles - hadrons. An important tool for the investigation of hadronic states is provided by two-photon interactions.

Exclusive states are produced in two-photon collisions in clean conditions and with restricted quantum numbers. In the reaction

$$e^+e^- \to e^+e^-\gamma\gamma \to e^+e^-R$$

R denotes a neutral unflavoured meson with positive chage conjugation parity $C = +1$. Events, studied in this work, have small 4-momentum transfered squared ($Q^2 \approx 0$), the photons are quasi-real, odd spin states are forbidden. For $\gamma\gamma \to K_s^0 K_s^0$ allowed states are $J^{PC} = 0^{++}$, 2^{++}, 4^{++}, ... $(2n)^{++}$. In $\gamma\gamma \to \pi^+\pi^-\pi^0$ the 0^+ state is excluded by parity conservation, so that only isovector $q\bar{q}$ states can be produced ($I^G = 1^-$). Allowed states are $J^{PC} = 0^{-+}, 2^{++}, 2^{-+}, \ldots$.

The reactions are investigated with the L3 detector [1] at LEP in untagged two-photon events (final state electron and positron are not detected). Data are analysed with full energy dependent Partial Wave Analysis (PWA), based on the approach of [2,3,4]. In case of the $K_s^0 K_s^0$ channel an analysis is also done based on the SU(3) nonet classification, and SU(3) relations are imposed on parameters.

2 $\gamma\gamma \to K_s^0 K_s^0$

The $K_s^0 K_s^0$ final state is analysed at center of mass energies from 91 to 209 GeV and with total integrated luminosity L=806 pb^{-1} (LEPI: $\sqrt{s}$=91 GeV, L=143 pb^{-1}; LEP II: $\sqrt{s}$=183-209 GeV, L=663 pb^{-1}).

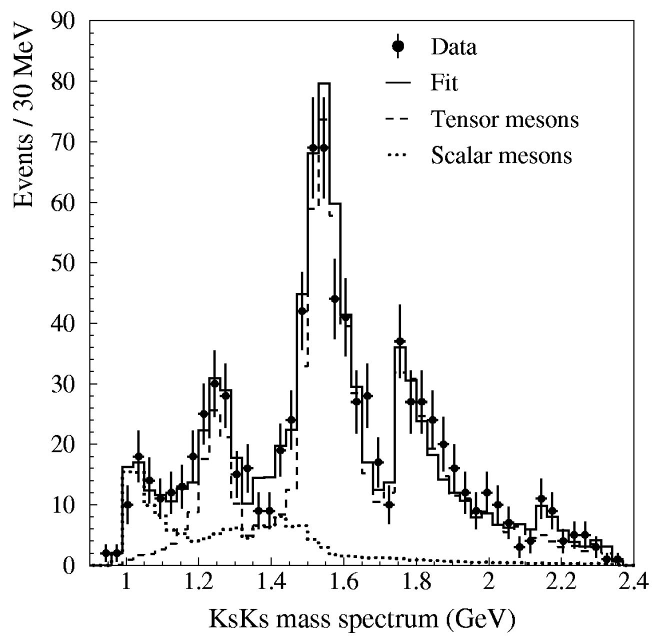

Fig. 1. $K_s^0 K_s^0$ mass distribution. Continuous histogram - fit of data with SU(3) relations imposed

Events with four charged tracks (two positive and two negative) are selected. Two opposite-pairs form secondary vertices with "invariant" distance from nominal interaction point $d_0 = d \cdot \frac{M_{K_S}}{P_{K_S}} > 1.5$ mm. To select kaon pairs, masses of two K_s^0 candidates, m_{+-}, are required to be inside a circle of 40 MeV radius around the central K_s^0 mass value indicating $K_s^0 K_s^0$ production. The total transverse momentum of all tracks $P_t = |\sum \mathbf{p}_t|$ has to be less than 0.3 GeV (to select an exclusive state). 870 events are selected.

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Table 1. Parameters obtained from SU(3) based fit of $K_s^0 K_s^0$ state

	First nonet			Second nonet		
	$a_2(1320)$	$f_2(1270)$	$f_2'(1525)$	$a_2(1700)$	$f_2(1560)$	$f_2(1750)$
Mass (MeV)	1304 ± 10	1277 ± 6	1523 ± 5	1730*	1570*	1755 ± 10
Width (MeV)	120 ± 15	195 ± 15	104 ± 10	340*	160*	67 ± 12
$K\bar{K}$ width (MeV)	$7.0^{+2.0}_{-1.5}$	7.5 ± 2	68*	5 ± 3	2 ± 1	23 ± 7
Radius (fm)	0.55*	0.55*	0.5*	0.55*	0.55*	0.5*
Nonet coupling (MeV)	0.8 ± 0.1	0.9 ± 0.1	1.05 ± 0.1	0.38 ± 0.05		
Mixing angle (degrees)	-1 ± 3			-10^{+5}_{-10}		
$\gamma\gamma$ width (KeV)	0.91*	2.55 ± 0.15	0.13 ± 0.03	0.18*	0.5 ± 0.1	0.11 ± 0.04
$\pi\pi$ width (MeV)		148 ± 8	$0.2^{+1.0}_{-0.2}$		30*	1.3 ± 1.0
$\pi\eta$ width (MeV)	18.5 ± 3			9.5 ± 2		
$\eta\eta$ width (MeV)		1.8 ± 0.4	5.0 ± 0.8		1.2 ± 0.3	2.0 ± 0.5

* fixed from other data

Figure 1 presents the mass distribution of selected $K_s^0 K_s^0-$ pairs (points), which shows rich resonance structure. The main contribution comes from tensor mesons. Resonances of the first tensor nonet are: $a_2(1320)$ and $f_2(1270)$ (a small signal due to a destructive interference) and $f_2'(1525)$, which dominates the spectrum. A signal from $a_0(980)$ is clearly seen near process threshold. Parameters of the scalar amplitudes (a_0 and f_0) are fixed (see [5],[6]). Angular distributions show that the 2150 MeV peak is most likely a 4^{++} state. The peak at 1700-1800 MeV (observed in a previous L3 analysis of the $K_s^0 K_s^0$ channel [7,8]) is well described by a tensor meson $f_2(1750)$. At the same time a dip is well reproduced between $f_2'(1525)$ and $f_2(1750)$ due to distructive interference of these states. If, instead, a scalar meson $f_0(1710)$ is introduced, the fit fails to reproduce both the dip and a slope above 1800 MeV. The $f_2(1560)$ and $a_2(1700)$ practically do not contribute to the cross section. Their parameters are fixed, respectively, from Crystal Barrel data [9, 10] and from the L3 analysis of $\pi^+\pi^-\pi^0$ state (see below).

A fit using SU(3) relations gives a very good description of the data (parameters obtained are shown in Table 1). A description of data in the nonet approach has a significant problem if the peak at 1750 MeV is assumed to be a scalar state. On the contrary as a tensor state it fits well into a second tensor nonet together with $f_2(1560)$ and $a_2(1700)$. The parameters, obtained here for $f_2(1750)$, are consistent with the previous L3 measurement [8].

As is seen from Table 1, the masses of the isoscalar tensor states are systematically lower than those of isovector states. This can be an indication of a tensor glueball in mass region 1800-2000 MeV.

3 $\gamma\gamma \to \pi^+\pi^-\pi^0$

$\pi^+\pi^-\pi^0$ final state is analysed at LEPII energies $\sqrt{s}$=183 - 209 GeV, L=609 pb^{-1}. Events have two tracks of opposite charge, originating from the interaction point, two isolated electromagnetic clusters, forming a π^0 ($0.065 < m_{\gamma\gamma} < 0.220$ GeV), and total transverse momentum $P_t = |\sum \mathbf{p}_t| < 0.1$ GeV. About 18 thousand events are selected.

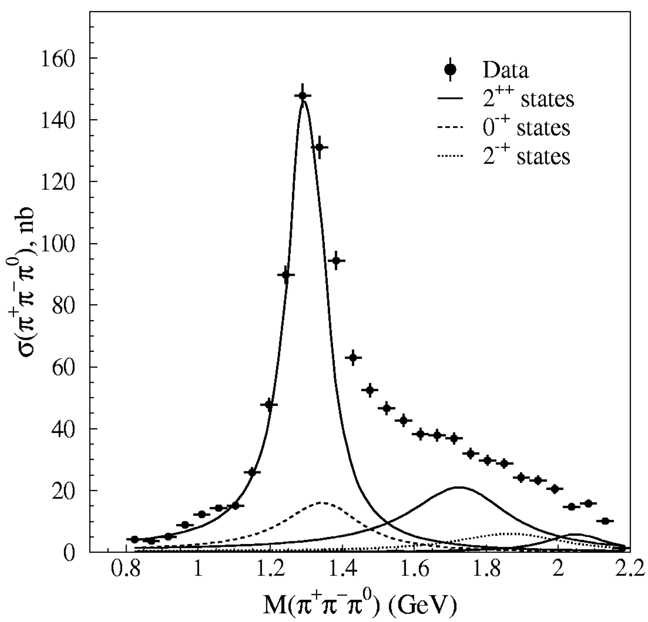

Fig. 2. Mass distribution of three pions and contribution of different states into cross section

The mass distribution for three pions is shown in Fig. 2. Possible states are 2^{++}: $a_2(1320)$, $a_2(1700)$, $a_2(2030)$; 2^{-+}: $\pi_2(1670)$; 0^{-+}: π (1300). The distribution is clearly dominated by production of the $a_2(1320)$ state. There is also a pronounced shoulder at masses higher than 1500 MeV. PWA is done in the mass range $1.1 < M(\pi^+\pi^-\pi^0) < 2.2$ GeV.

The model, used for PWA, supposes a cascade decay

$$\gamma\gamma \to R \to \pi R', \quad R' \to \pi\pi.$$

In the $\pi^\pm\pi^0$ mass spectrum $\rho(770)$ dominates, and $\rho(1450)$ is also seen. In the $\pi^+\pi^-$ system only f-states ($J^{PC} = 0^{++}, 2^{++}, ...$) are possible. $f_0(980)$ and $f_0(1500)$ give very

Table 2. Mass, width and the product of $\Gamma_{\gamma\gamma}$ times Br(3π) for observed resonances

Resonance	M (MeV)	Γ(MeV)	$\Gamma_{\gamma\gamma}$Br(3π) (KeV)
$a_2(1320)$	$1302 \pm 3 \pm 6$	$118 \pm 6 \pm 10$	0.65 ± 0.05
$a_2(1700)$	$1725 \pm 25 \pm 10$	340 ± 40	$0.37^{+0.12}_{-0.08}$
from [12]	$1752 \pm 21 \pm 4$	150 ± 115	0.29 ± 0.04
$a_2(2030)^*$	2030 ± 20	205 ± 25	0.11 ± 0.04
$\pi(1300)$	1350 ± 40	320 ± 50	≤ 0.8
2^{-+}	1870 ± 60	325 ± 40	0.15 ± 0.03
$\pi_2(1670)^*$	1670	260	≤ 0.1

* fixed from other data

small contributions and they are omitted. $f_2(1270)$ produces some signal. A $\pi\pi \to \pi\pi$ S-wave amplitude (from $\pi\pi$ threshold up to 2 GeV) was required. Background is described by a second order polynomial function depending on the 3π mass squared.

To reproduce the data (3π mass, 2π masses and all angular distributions) three tensor states are needed $a_2(1320)$, $a_2(1700)$ and $a_2(2030)$, a scalar, which can be identified as $\pi(1300)$, and a 2^{-+} state at high 3π masses. Masses and widths for resonances are listed in Table 2.

Tensor mesons are mainly produced from ${}^5S_2$ two-photon initial state. For $a_2(1320)$ the ratio with the ${}^1D_2$ wave is found to be:

$$\frac{\sigma(\gamma\gamma({}^5S_2) \to a_2(1320))}{\sigma(\gamma\gamma({}^1D_2) \to a_2(1320))} = 8.2 \pm 0.6$$

The corresponding value for the $a_2(1700)$ is 2.5 ± 1.0. The corresponding ratio of couplings is 0.60 ± 0.20, in good agreement with expectation [11] 0.54 ± 0.16 for the first recurrence of the $a_2(1320)$. The $a_2(1700)$ state was first observed in the previous L3 analysis [12] of $\pi^+\pi^-\pi^0$ with limited statistics. This state is confirmed by the present full energy analysis, and its paramaters are consistent with the previous measurement (see Table 2). The $a_2(1700)$ has a significant branching fraction into $f_2(1270)\pi$:

$$\frac{Br(a_2(1700) \to \rho(770)\pi)}{Br(a_2(1700) \to f_2(1270)\pi)} = 3.4 \pm 0.4$$

At higher 3π mass values a contribution from another isovector tensor state, $a_2(2030)$, is needed. The mass and width of this resonance can not be determined from present analysis, and they are fixed to values given in [13]. The $\pi(1300)$ state, when introduced in the analysis, appreciably improves the likelihood. But this state produces a uniform angular distribution and is similar to background, so only an upper limit is estimated for the $\gamma\gamma$ width of this state. A 2^{-+} signal is found at masses higher than $\pi_2(1670)$. If a mass of 2^{-+} is left free, it always moves to 1850-1900 mass region, giving indication of new 2^{-+} state (see Table 2). For $\pi_2(1670)$ an upper limit on the $\gamma\gamma$ width is defined (parameters of $\pi_2(1670)$ are fixed from [14]).

4 Conclusions

For $\gamma\gamma \to K_s^0 K_s^0$:

- PWA favors a description of the peak at 1750 MeV by a tensor state $f_2(1750)$.
- If nonet relations are applied this state fits naturally into a second tensor nonet together with $f_2(1560)$ and $a_2(1700)$ states.
- The data define very well the mixing angles for two tensor nonets: $(-1^o \pm 3^o)$ for the first and $(-10^{o}{}^{+5^o}_{-10^o})$ for the second.
- There is an indication for a 4^{++} state: M=(2150 ± 30) MeV, Γ=(50 ± 20) MeV.

For $\gamma\gamma \to \pi^+\pi^-\pi^0$:

- The characteristics of the dominant $a_2(1320)$ state are found. The measured mass is lower than the world average [14] since in the present fit it is the amplitude pole and not the central value of the mass spectrum.
- A strong signal is observed from the first radial excitation isovector tensor state $a_2(1700)$: M = $1725 \pm 25 \pm 10$ MeV, $\Gamma = 340 \pm 40$ MeV.
- Another isovector state with the mass 2030 MeV is found to be significant.
- There is also a signal from $\pi(1300)$ and an indication for a 2^{-+} signal in the region of 1870 MeV.

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