ρ MESON PRODUCTION IN TWO PHOTON COLLISION AT LEP WITH L3 DETECTOR*

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The reaction $\gamma\gamma \to \pi^+\pi^-\pi^+\pi^-$ has been studied with the L3 detector at LEP. The data sample was collected by L3 at centre-of-mass energies from 160 GeV to 202 GeV with a total integrated luminosity of 466.2 pb^{-1}. The process is dominated by $\rho^0\rho^0$ production. A spin-parity analysis of the $\rho^0\rho^0$ system for $W_{\gamma\gamma} < 3$ GeV shows a dominance of $J^P = 2^+$ and helicity 2. A contribution of $J^P = 0^+$ is also observed whereas contributions of negative parity states are found to be negligible.

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1. Introduction

A large cross section for the two-photons reaction $\gamma\gamma \to \rho^0\rho^0$ near threshold has been observed in several experiment [1–7].

For the first time a spin-parity-helicity analysis for the reaction $\gamma\gamma \to \pi^+\pi^-\pi^+\pi^-$ was carried out by the TASSO Collaboration [3] by studying angular correlations in the four pion final state. The data sample consisted of 1722 events in the region $1.2 < M_{4\pi} < 2.0$ GeV. A spin-parity-helicity analysis with higher statistics was done by ARGUS Collaboration [7]: 5181 events were analysed in the four pion mass region between 1.1 and 2.3 GeV. Both groups used similar models and found the dominance of the $\rho^0\rho^0$ state $(J^p, J_z) = (2^+, 2)$ with a small contribution from the 0^+ state. The contribution of the negative parity states is found to be negligible.

In this paper the results of the spin-parity-helicity analysis of the reaction $\gamma\gamma \to \pi^+\pi^-\pi^+\pi^-$ for the data collected by the L3 detector at LEP are presented using the same model as TASSO and ARGUS.

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2. The mass spectra

Data have been collected during the 1996-1999 at the e^+e^- centre of mass energy $\sqrt{s}$=160 – 202 GeV with a total integrated luminosity of $\mathcal{L}$ = 466.2 pb^{-1}. The L3 detector has been described elsewhere [8, 9].

In order to select $\gamma\gamma \to \pi^+\pi^-\pi^+\pi^-$ events, we require four charged tracks with a net charge of zero and a common vertex. Events with photons are rejected. The measured energy loss dE/dx correspond to the hypotheses of four pions with a confidence level CL(4π) > 6%. To suppress the background from non-exclusive four-track events we required the net transverse momentum $(\Sigma\vec{p}_T)^2$ to be smaller than 0.02 GeV^2. A sample of 56359 events was obtained, 55120 events lie in the mass region between 1.0 and 3.0 GeV. The mass distribution of the four pions final states is shown in Fig. 1 The mass distribution of the unlike-sign combinations for $M_{4\pi}$ higher than $\rho^0\rho^0$ threshold exhibit a clear ρ^0 signal (Fig. 2).

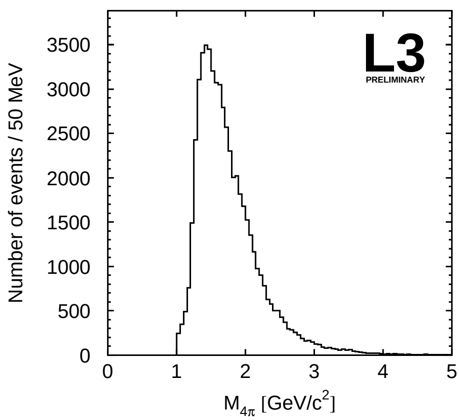

Fig. 1. Mass distribution of the four pions for $e^+e^- \to e^+e^-\pi^+\pi^-\pi^+\pi^-$ events after the selection cut $(\Sigma\vec{p}_T)^2 < 0.02$ GeV.

We divide our data sample in two parts on low mass data 2($W_{\gamma\gamma}$ < 3 GeV) and high mass data ($W_{\gamma\gamma}$ > 3 GeV). The spin-parity and helicity analysis is performed only on the low mass data. For the high mass data we used like-sign $\pi^\pm\pi^\pm$ mass combinations to estimate the level of combinatorial background under the unlike-sign $\pi^+\pi^-$ distribution. The $\pi^+\pi^-$ mass spectrum after subtraction of the $\pi^\pm\pi^\pm$ combinatorial background, presented in Fig 3, shows that for $W_{\gamma\gamma}$ > 3 GeV there is still a strong production of the ρ^0 meson but the $f_2(1270)$ meson is also seen. We fitted this spectra by three Breit–Wigner functions with the following fit results: $m_\rho = 765 \pm 3$ MeV $\Gamma_\rho = 129 \pm 7$ MeV and $m_{f_2} = 1261 \pm 9$ MeV $\Gamma_{f_2} = 217 \pm 28$ MeV which is in good agreement with PDG values.

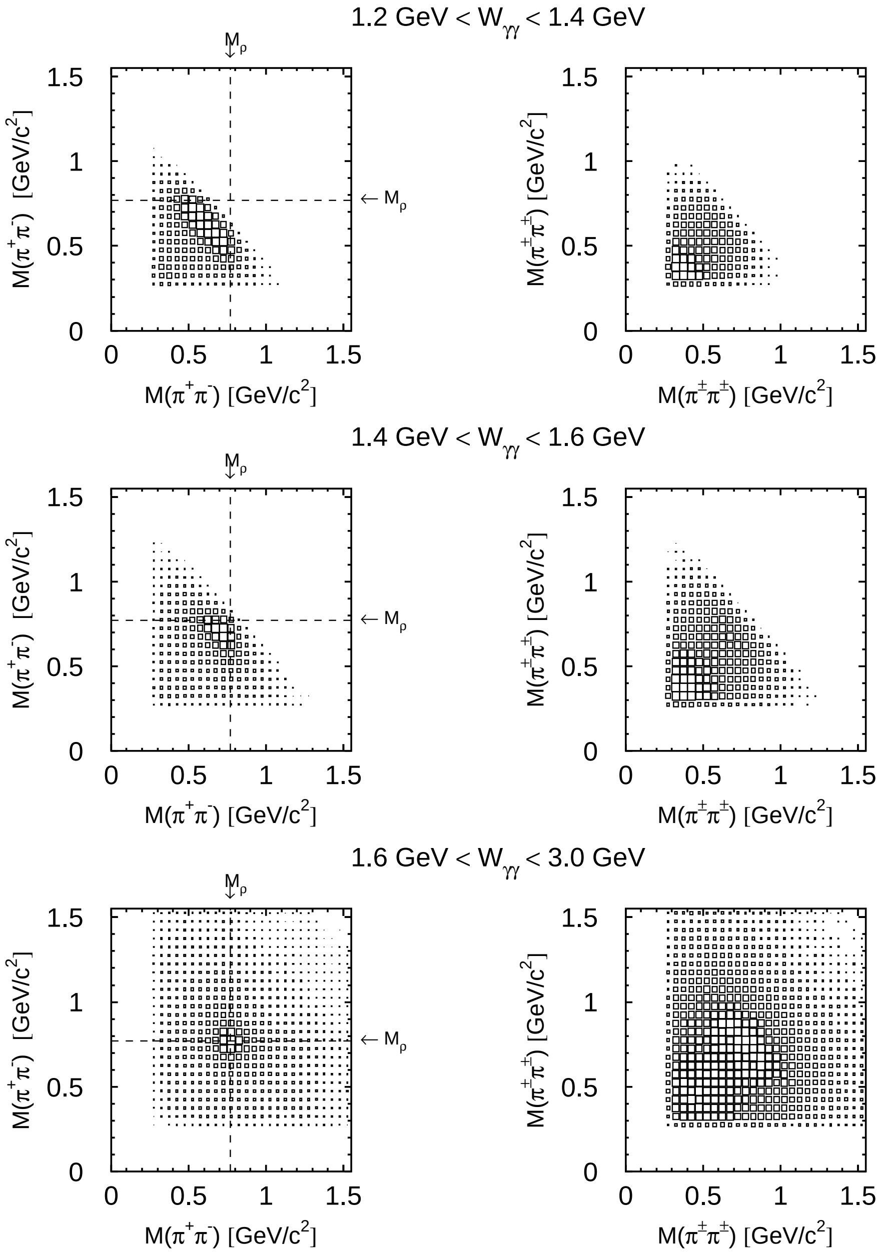

Fig. 2. Scatter plots of two pion mass distribution, on the left for unlike-charge ($\pi^+\pi^-$) combinations (four entries per event) and on the right for the like-charge ($\pi^\pm\pi^\pm$) mass combinations (two entries per event).

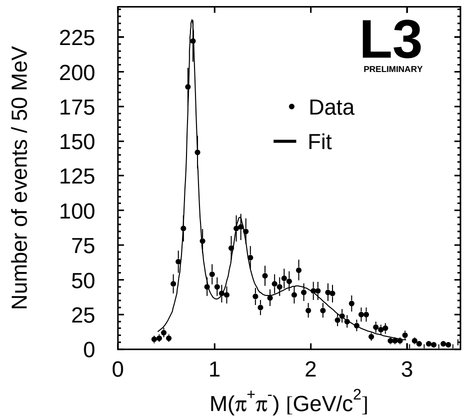

Fig. 3. The two-pion mass after combinatorial background subtraction for the high mass data $W_{\gamma\gamma} > 3$ GeV

3. Spin-parity-helicity analysis

We consider the $\rho^0\rho^0$ production in different spin-parity and helicity states (J^P, J_z) and an isotropic production of $\rho^0\pi^+\pi^-$ and $\pi^+\pi^-\pi^+\pi^-$. All states are assumed to be produced incoherently. The analysis is performed in intervals of $W_{\gamma\gamma}$ of 50 MeV. Since pions are bosons the amplitude which describes the process must be symmetric under interchange of two pions with the same charge. The appropriate amplitude satisfying these requirements are [3]:

$$\begin{aligned} g_{\rho^0\rho^0} &= \mathrm{BW}(m_{\rho^0_1})\mathrm{BW}(m_{\rho^0_2})\Psi_{J^P J_z}(1,2) + \mathrm{permutations}\,, \\ g_{\rho^0\pi^+\pi^-} &= \mathrm{BW}(m_{\rho^0_1}) + \mathrm{permutations}\,, \\ g_{4\pi} &= 1\,, \end{aligned}$$

where $\mathrm{BW}(m_{\rho^0})$ is the relativistic Breit–Wigner amplitude for the ρ^0 meson [10] and Ψ_{J^P,J_z} is the angular part of amplitude which describe the rotational properties of the $\rho^0\rho^0$ state with definite spin-parity J^P and helicity J_z. It is constructed by combining the spin of the two ρ^0 mesons $\vec{S} = \vec{s}_1 + \vec{s}_2$ and by adding the orbital angular momentum $\vec{L}$ to obtain the state with total spin $\vec{J}$:

$$\Psi_{J^p J_z LS} = \sum_{M,m_1} C^{J^p J_z}_{LMSM_s} C^{SM_s}_{s_1 m_1 s_2 m_2} Y_{LM}(\xi_1) Y_{s_1 m_1}(\xi_2) Y_{s_2 m_2}(\xi_3)\,,$$

where $\xi_1 = (\vartheta_\rho, \varphi_\rho), \xi_2 = (\vartheta_{\pi_1^+}, \varphi_{\pi_1^+})$ and $\xi_3 = (\vartheta_{\pi_2^+}, \varphi_{\pi_2^+})$. $\vartheta_\rho, \varphi_\rho$ are the polar and the azimuthal angles of the ρ^0 meson in the $\gamma\gamma$ helicity system.

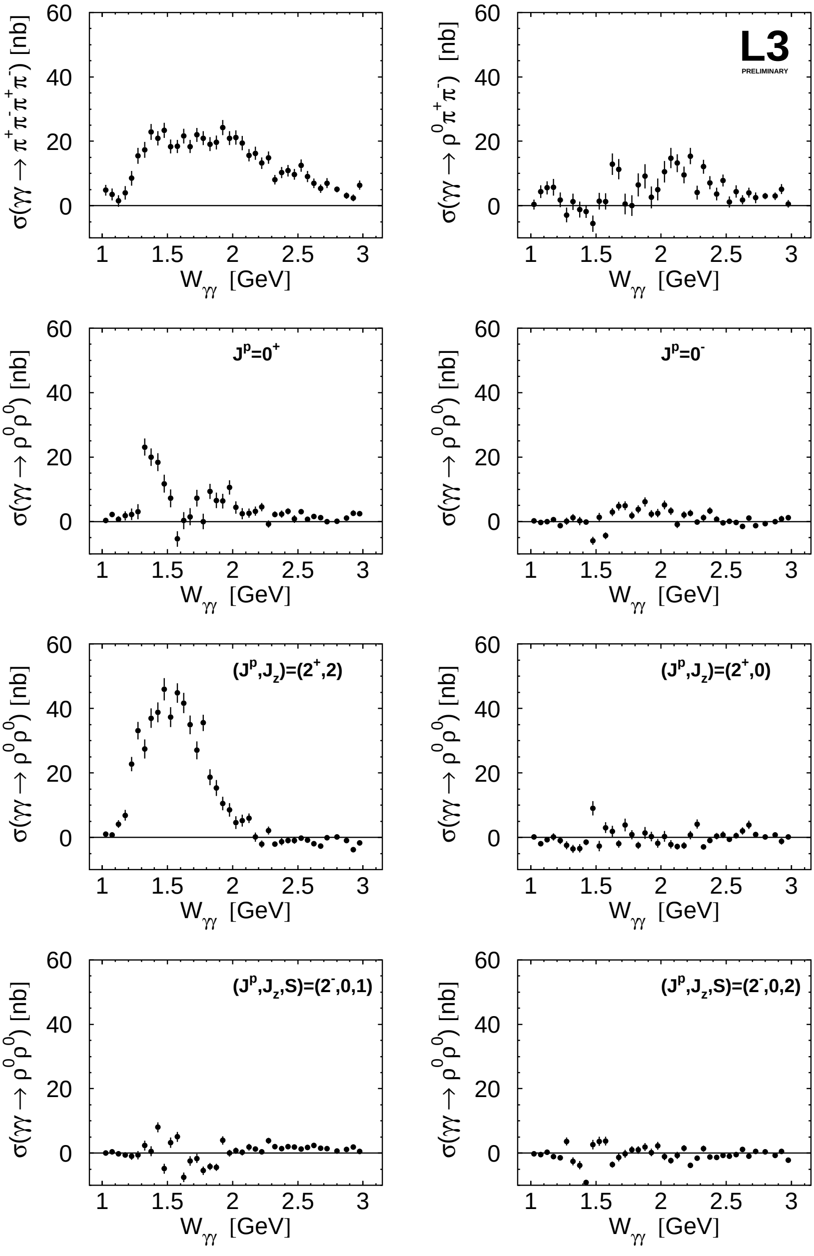

Fig. 4. Cross sections for different spin-parity and helicity states (J^P, J_z) of $\rho^0\rho^0$ and for the isotropic $\rho^0\pi^+\pi^-$ and $\pi^+\pi^-\pi^+\pi^-$ srates as determined by the eight parameter fit.

The z axis is chosen parallel to the beam direction, which in good approximation, is parallel to the $\gamma\gamma$ helicity axis. The angles $\vartheta_{\pi_1^+}, \varphi_{\pi_1^+}$ $(\vartheta_{\pi_2^+}, \varphi_{\pi_2^+})$ are the polar and azimuthal angles of positive pions in the center-of-mass of the first (second) ρ^0 meson with z axis parallel to the beam axis. Since the analysis is performed close to threshold the orbital angular momenta are restricted to $L = 0, 1$. The allowed spin-parity-helicity final states of the $\rho^0\rho^0$ system in quasi-real $\gamma\gamma$ reactions are : $(J^P, J_z) = 0^+, (2^+, 0), (2^+, 0), 0^-$ and $(2^-, 0)$ with total spin of $\rho^0\rho^0$ meson system $S = 1$ or $S = 2$. Other states are forbidden by helicity conservation or by the Landau-Yang theorem.

In each $W_{\gamma\gamma}$ bin a maximum likelihood fit is used to determine the contribution λ_j of the eight amplitudes to the data sample. The fitting procedure takes into account the detector acceptance, trigger efficiency and selection efficiency.

The result of fit are shown on Fig. 4. It is clearly seen that the $\rho^0\rho^0$ state with spin-parity 2^+ and helicity 2 dominates. There is a contribution of the $J^P = 0^+$ state in the $\gamma\gamma$ mass region below 2 GeV. The contribution of the negative parity states and the state $(2^+, 0)$ are found to be negligible.

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