EXCLUSIVE $\pi^+\pi^-\pi^+\pi^-$ AND $\pi^+\pi^0\pi^-\pi^0$ PRODUCTION IN TWO PHOTON COLLISIONS AT L3*

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Exclusive $\rho^0\rho^0$ and $\rho^+\rho^-$ production in two-photon collisions for quasi-real photons and $\rho^0\rho^0$ production, involving highly virtual photons, was measured by the L3 experiment at LEP. The spin-parity-helicity analysis of $\rho^0\rho^0$ and $\rho^+\rho^-$ systems at $Q^2 \approx 0$ was performed. A dominance of $J^P = 2^+$ and helicity 2 is observed. The cross sections of the process $\gamma\gamma^* \to \rho^0\rho^0$ for $1.2 < Q^2 < 30$ GeV^2 and for $1.1 < W_{\gamma\gamma} < 3.0$ GeV are determined as a function of photon virtuality Q^2 and as a function of the two-photon center-of-mass energy $W_{\gamma\gamma}$.

1 Introduction

We present preliminary results on $\rho^0\rho^0$ and $\rho^+\rho^-$ production in untagged two-photon interactions at $Q^2 \approx 0$ and results on $\rho^0\rho^0$ in single-tagged two-photon interactions for $1.2 < Q^2 < 30$ GeV^2 [1]. The data was collected by the L3 detector [2] at LEP.

A large cross section for the two quasi-real photon reaction $\gamma\gamma \to \rho^0\rho^0$ near threshold has been observed in several experiments [3]. The first spin-parity-helicity analysis for the reaction $\gamma\gamma \to \pi^+\pi^-\pi^+\pi^-$ and $\gamma\gamma \to \pi^+\pi^0\pi^-\pi^0$ was

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carried out by the TASSO Collaboration [4] by studying angular correlations. In contrast the available data on $\rho^0\rho^0$ production in interactions involving highly off-shell virtual photons are poor, since tagged two-photon processes have considerably reduced event rate resulting into limited data statistics of high Q^2 events.

Exclusive production of hadronic final states have been generated by the Monte-Carlo generator EGPC [5] according to the $\gamma\gamma$ luminosity function [6]. The generated events are passed through the full L3 detector simulation programs and are reconstructed following the same procedure used for the data.

2 Exclusive $\rho\rho$ production at $Q^2 \approx 0$

2.1 Data selection

The data was collected in the years 1996–2000 with a total integrated luminosity of 697 pb^{-1} and average center-of-mass energy $\sqrt{s} = 197.9$ GeV. Detection of the scattered e^+ or e^- is not required in this analysis. The event selection is based mainly on the central tracking system and electromagnetic calorimeter. The events are collected by triggers based on the central tracking chamber. The absolute value of the transverse momentum for each charged particle, $|\vec{p}_t|$, should be greater than 100 MeV. To select $e^+e^- \to e^+e^-\pi^+\pi^-\pi^+\pi^-$ events we require: four charged tracks with a common vertex; no photons in the final state, where a photon is defined as an isolated energy cluster in the electromagnetic calorimeter with $E > 100$ MeV. To select $e^+e^- \to e^+e^-\pi^+\pi^0\pi^-\pi^0$ events we require: two charged tracks with a common vertex and two neutral pions determined from a constraint fit. Identification of a charged pion is based on dE/dx information. We require the confidence level for four charged pion hypothesis CL$(4\pi) > 6\%$ as well as for two charged pion hypothesis CL$(2\pi) > 6\%$. To reduce non-exclusive background a cut on the total transverse momentum was applied: $P_T^2 \equiv (\Sigma\vec{p}_T)^2 < 0.02$ GeV^2.

After selection we obtain a $2\pi^+2\pi^-$ sample of 74859 events and a $\pi^+\pi^-2\pi^0$ sample of 7535 events. The two pion mass spectra in $\gamma\gamma$-mass region $1.5 < W_{\gamma\gamma} < 2.2$ GeV show clean $\rho\rho$ signal in both channels.

2.2 Spin-Parity-Helicity analysis

According to the model proposed by TASSO [4] we consider the $\rho\rho$ production in different spin-parity and helicity states (J^P, J_z) and an isotropic production of $\pi\pi\pi\pi$. The allowed spin-parity-helicity final states of the $\rho\rho$ system in quasi-real $\gamma\gamma$ reactions are : $(J^P, J_z) = 0^+, (2^+, 0), (2^+, \pm 2), 0^-$ and $(2^-, 0)$ with total spin of the $\rho\rho$ meson system $S = 1$ or $S = 2$. The isotropic four pion state in the analysis acts as an effective background.

In each $W_{\gamma\gamma}$ bin a maximum likelihood fit to the data sample is used to determine the contribution λ_j of the four amplitudes. The fit is performed in the region $1.0 < W_{\gamma\gamma} < 3.0$ GeV.

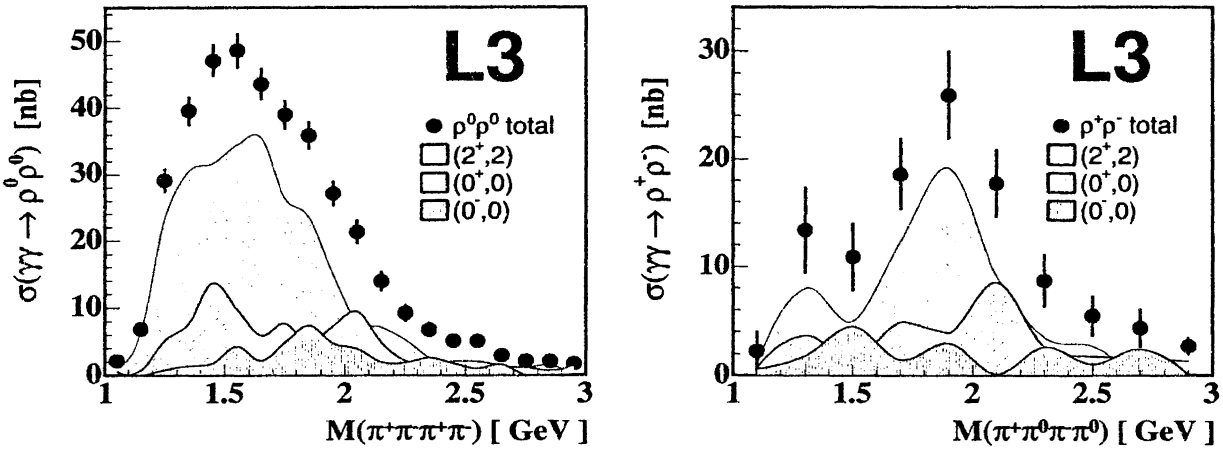

Figure 1: Results on total $\gamma\gamma \to \rho\rho$ cross section and dominant partial waves cross sections of (left) $\sigma(\gamma\gamma \to \rho^0\rho^0)$ (right) $\sigma(\gamma\gamma \to \rho^+\rho^-)$.

The acceptance and selection efficiencies depend on the model and on the $\gamma\gamma$-mass. They are computed by means of Monte Carlo, re-weighting the events with the matrix elements of the corresponding processes. For the $\rho^0\rho^0$ channel the average selection efficiency varies from 7% to 10%. Whereas for the $\rho^+\rho^-$ channel it varies from 1.5% to 2%. The average trigger efficiency for the $\pi^+\pi^-\pi^+\pi^-$ final state is 96% and for the $\pi^+\pi^0\pi^-\pi^0$ finals state is 69%.

The results on the cross sections for the dominant waves and total $\rho^0\rho^0$ and $\rho^+\rho^-$ cross sections are shown in Figure 1. A broad enhancement near threshold of $\gamma\gamma \to \rho^0\rho^0$ is seen for the $1.2 < W_{\gamma\gamma} < 1.6$ GeV like in the previous measurements. The dominance of the $(J^P, J_z) = (2^+, 2)$ spin-parity state is observed in both channels. The cross section ratio $\sigma(\rho^0\rho^0)/\sigma(\rho^+\rho^-)$ for

the $1.2 < W_{\gamma\gamma} < 1.6$ GeV is incompatible with the hypothesis of a resonance with isospin $I = 0, 1$.

3 High Q^2 region

All the data, collected in the years 1991–2000 with a total integrated luminosity of 854.7 pb^{-1} are used in this analysis. Out of this sample, 149 pb^{-1} are at center-of-mass energies around the Z peak (LEP1 run) and 706 pb^{-1} center-of-mass energies in the range $161 < \sqrt{s} < 208$ GeV (LEP2 run). Events are collected by the central tracker and energy triggers demanding a large energy deposition in the luminosity monitor (single-tag).

As in the previous analysis, strict requirements on the track quility are applied. The scattered electron is detected as an electromagnetic cluster in the luminosity monitor covering a polar angle 25 mrad $< \theta <$ 68 mrad, and larger than 80% of the beam energy. Double-tagged events are excluded.

To ensure that an exclusive final state is detected we require that the total transverse momentum, $P_t = |\vec{p}_t(e_{\rm tag}\pi^+\pi^-\pi^+\pi^-)|$, should be smaller than 0.45 GeV. After selection we obtain a sample of 851 events (498 events from the LEP1 run and 353 events from the LEP2 run). The detection efficiency for the considered processes is in the range of 10%–25%.

To estimate the number of $\rho^0\rho^0$ events in the selected four pion data sample, we consider non-interfering contributions from three isotropic processes $\gamma\gamma^* \to \rho^0\rho^0$, $\gamma\gamma^* \to \rho^0\pi^+\pi^-$, $\gamma\gamma^* \to \pi^+\pi^-\pi^+\pi^-$. A maximum likelihood fit of the selected events to a sum of the three processes is performed in intervals of Q^2 and $W_{\gamma\gamma}$ using a box method [7].

The $\rho^0\rho^0$ cross section as function of Q^2 is determined by integrating over $W_{\gamma\gamma}$ for $1.1 < W_{\gamma\gamma} < 3.0$ GeV and fitting the LEP1 data in 5 bins of Q^2 in the region: $1.2 < Q^2 < 8.5$ GeV^2 and fitting the LEP2 data in 3 bins of Q^2 in the region: $8.8 < Q^2 < 30$ GeV^2.

The differential cross section $d\sigma_{ee}/dQ^2$ of the process $e^+e^- \to e^+e^-\rho^0\rho^0$ is plotted in Figure 2(left) where is also shown the result of a fit to a form expected from QCD-based calculations [8]. The fit provides a good description of the Q^2-dependence of the data and gives an exponent $n = 2.4 \pm 0.31$, to be compared with the expected value $n = 2$. A common fit of the data sets taken at LEP1 and LEP2 energies.

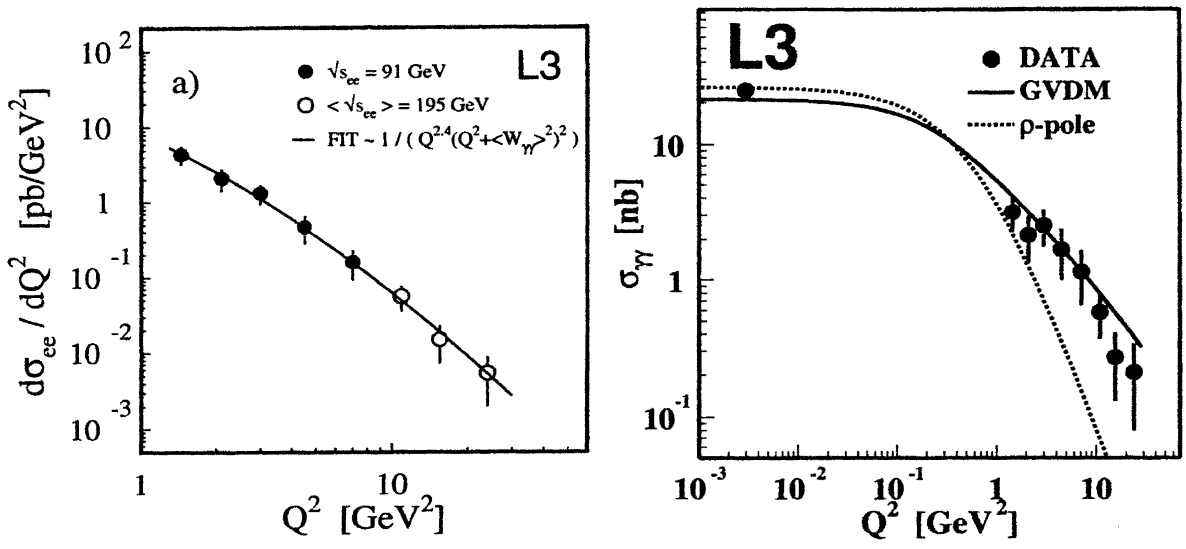

Figure 2: (left) Differential cross section of the process $e^+e^- \to e^+e^-\rho^0\rho^0$. The line represent the fit result of a fit to a form expected from QCD-based calculation [8] ($\langle W_{\gamma\gamma}\rangle$ = 1.945 GeV).(right) The Q^2-dependence of the cross section $\sigma_{\gamma\gamma^* \to \rho^0\rho^0}(Q^2)$ for $1.1 < W_{\gamma\gamma} < 3.0$ GeV. GVDM [9] and ρ-pole form-factor fits are performed.

In Figure 2(right) is shown the result of a fit of $\sigma_{\gamma\gamma}(Q^2)$ to a form suggested in [9], based on the generalized vector dominance model (GVDM) [10]. The fit also includes the point at $Q^2 \approx 0$, an independent measurement. In the fit the normalization is the only free parameter. It gives a good description of the Q^2-dependence of our data, whereas a steeper Q^2-decrease is expected by a simple ρ-pole form-factor. This fit also proves the consistency of our measurements in different Q^2 regions.

4 High $W_{\gamma\gamma}$ region at $Q^2 \approx 0$

The two pion mass spectra of reaction $\gamma\gamma \to \pi^+\pi^-\pi^+\pi^-$ for $W_{\gamma\gamma} > 2.4$ GeV show not only the $\rho^0\rho^0$ production but also the formation of the $f_2(1270)$ and $\rho'(1700)$. The Breit-Wigner fit of the two pion mass spectrum is performed for $W_{\gamma\gamma} > 2.4$ GeV after combinatorial background subtraction, estimated by like-sign two pion mass combinations. Fit gives the values: $M_\rho = 758 \pm 3$ MeV, $\Gamma_\rho = 141 \pm 8$ MeV, $M_{f_2} = 1252 \pm 8$ MeV, $\Gamma_{f_2} = 162 \pm 30$ MeV.

5 Summary

We have measured the $\gamma\gamma$ cross section of the exclusive $\rho\rho$ production at $Q^2 \approx 0$. The measurement shows the dominance of $(J^P, J_z) = (2^+, 2)$ spin-parity state as a broad enhancement near $\rho\rho$ threshold. The cross section ratio $\sigma(\rho^0\rho^0)/\sigma(\rho^+\rho^-)$ for the $1.2 < W_{\gamma\gamma} < 1.6$ GeV is incompatible with the hypothesis of a resonance with isospin $I = 0, 1$.

The measurement of the differential cross section of the $\rho^0\rho^0$ production as a function of Q^2 is also performed. The Q^2-dependence of the data including the measurement at $Q^2 \approx 0$ is in a good agreement with the GVDM model form-factor. Recent QCD-based calculations also reproduce well the Q^2-dependence of the $\rho^0\rho^0$ differential cross section.

For the $W_{\gamma\gamma} > 2.4$ GeV not only the ρ^0 is produced, but also the $f_2(1270)$ gives a significant signal in the two pion mass spectra.

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