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Vector-Vector Production in Photon-Photon Interactions

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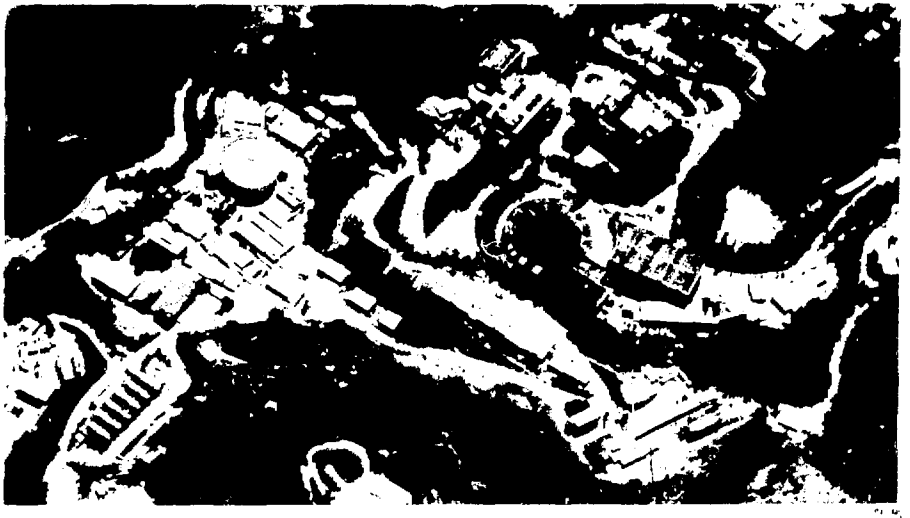

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VECTOR-VECTOR PRODUCTION IN PHOTON-PHOTON INTERACTIONS[1]

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VECTOR-VECTOR PRODUCTION IN PHOTON-PHOTON INTERACTIONS†

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ABSTRACT

Measurements of exclusive untagged $\rho^0\rho^0$,$\rho\phi$,$K^*\overline{K^*}$, and $\rho\omega$ production and tagged $\rho^0\rho^0$ production in photon-photon interactions by the TPC/Two-Gamma experiment are reviewed. Comparisons to the results of other experiments and to models of vector-vector production are made. Fits to the data following a four quark model prescription for vector meson pair production are also presented.

INTRODUCTION

As experiments for the PETRA and PEP e^+e^- machines were being prepared, studies of photon-photon interactions such as resonance formation measurements of $\gamma\gamma$ widths and jet production at large p_T from hard photon-quark scattering were being planned in addition to the annihilation physics program. Based on the success of diffractive models in explaining high energy hadron production in fixed target machines, it was assumed that low transverse momentum hadron production in photon-photon interactions would have the characteristics of diffractive vector meson scattering as illustrated in Fig. 1a. Given the standard photon vector-meson couplings of

$$g_{\rho\gamma} : g_{\omega\gamma} : g_{\phi\gamma} = 1 : 1/3 : \sqrt{2}/3,$$

$\rho^0\rho^0$ scattering was expected to have a relatively large cross section.

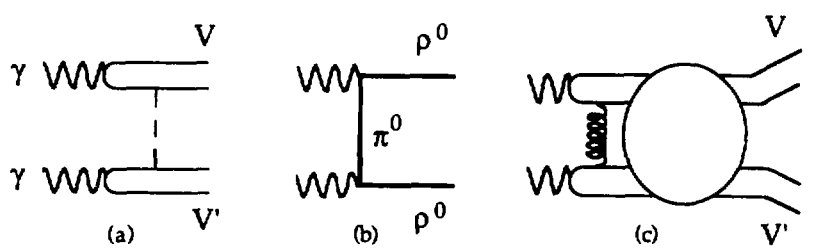

Figure 1. Models of vector meson pair production in photon-photon interactions: a.) diffractive scattering with Pomeron exchange, b.) $\rho^0\rho^0$ production by π^0 exchange and c.) four quark resonance production and "fall-apart" decay into vector meson pairs.

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In measurements of the reaction $\gamma\gamma \to \pi^+\pi^-\pi^+\pi^-$ production by the TASSO collaboration in 1980, the cross section for $\rho^0\rho^0$ production was found to peak near threshold more than an order of magnitude larger than vector meson dominance model (VDM) predictions.[1] Nearly isotropic $\rho^0\rho^0$ angular distributions[1] argued against diffractive production. Measuring the $\rho^+\rho^-$ yield, subsequent experiments demonstrated that single isospin-0 or 2 resonance production could not explain the observed $\rho^0\rho^0$ cross section.[2] Models of $\rho^0\rho^0$ production in terms of simple exchange processes, e.q. π^0 exchange as shown in Fig. 1b, which predicted sizable $\rho^0\omega$ and $\omega\omega$ yields were excluded by early upper limit measurements.[2]

Four quark models of vector-vector production, as shown in Fig. 1c, with isoscalar and isotensor resonances interfering constructively in the $\rho^0\rho^0$ channel and destructively in the $\rho^+\rho^-$ channel[3,4] as well as t-channel factorization models[5] explained the experimental results and made detailed predictions for other vector-vector channels. In this report, a comparison of these models to measurements of $\rho^0\rho^0$, $\rho\phi$, $K^{*}\overline{K^{*}}$ and $\rho^0\omega$ production by the TPC/Two-Gamma experiment is discussed.

TPC/TWO-GAMMA DATA SAMPLES

For the past several years, the PEP storage ring at SLAC has been operated at a e^+e^-center-of-mass energy of 29 GeV for studies of annihilation and two-photon physics. The TPC/Two-Gamma facility has collected data samples of 73 pb^{-1} and 64 pb^{-1} with a low-field conventional coil and a high-field (13.2 kG) superconducting coil, respectively. The tracking and dE/dx particle identification of the Time Projection Chamber for small angle tracks, the good low energy photon detection and nearly 85% of 4π coverage of the gas sampling calorimetry and the precision NaI tagging from 22 to 90 mrad provide excellent two-photon physics capabilities.

For the study of untagged two-photon reactions (where the final state e^+ and e^- are not detected), events were triggered by the standard central detector trigger which required two charged tracks in the TPC originating from the interaction point or neutral energy deposition in the calorimeters. Tagged data samples of 50 and 42 pb^{-1} for the low and high field running were obtained with a separate trigger requiring only one track or low energy deposition in addition to a e^+ or e^- tag.

Studies of $\rho^0\rho^0$,$\rho\phi$,$K^{*}\overline{K^{*}}$ and $\rho^0\omega$ production have been made using the following reactions:

Table 1. Reactions used to measure vector meson pair production.

Vector-Vector final state	Reaction
$\rho^0\rho^0$	$\gamma\gamma \to \pi^+\pi^-\pi^+\pi^-$
$\rho\phi$	$\gamma\gamma \to K^+K^-\pi^+\pi^-$
$K^{*}\overline{K^{*}}$	"
$\rho^0\omega$	$\gamma\gamma \to \pi^+\pi^-\pi^+\pi^-\pi^0$

The published results for $\rho^0\rho^0$,$\rho\phi$ and $K^{*}\overline{K^{*}}$ analysis were based on the low field untagged samples[6], while the untagged $\rho^0\omega$ analysis demanded the more precise high field sample.[7] The analysis of the tagged data was performed on both the low and high field samples.[6]

EVENT SELECTION

Using standard selection criteria for untagged two-photon events, beam gas scattering events and events with tracks back-scattering in the detector were eliminated by requiring that all of the charged prongs originated from the interaction region (15 cm along the beam line and 5 cm in radius). In addition, annihilation events within the fiducial volume were rejected by a visible energy cut of 12 GeV; while, transverse momentum ($\vec{p}_T$) cuts described below were used to select the final samples of exclusive two-photon events.

For the untagged $\rho^0\rho^0$, $\rho\phi$ and $K^*\overline{K^*}$ measurements, exclusive four prong events with no undetected charged tracks or photons were selected by requiring that the $\mid \Sigma\vec{p}_T \mid$ be less than 200 MeV. To select a four pion sample, all particles were required to be compatible with pions with at least one unambiguously identified as a pion. $K^+K^-\pi^+\pi^-$ events were selected by requiring two particles compatible with a kaon hypothesis with the remaining two compatible with being pions, and at least one unambiguous kaon and pion. These requirements led to a final sample of 4637 $\pi^+\pi^-\pi^+\pi^-$ and 175 $K^+K^-\pi^+\pi^-$ events.

Events with four charged pions and exactly two photons detected after distinguishable fake photons had been eliminated were used to obtain a $\pi^+\pi^-\pi^+\pi^-\pi^0$ sample for studying $\rho^0\omega$ production. Non-exclusive background was eliminated by subjecting the events to a 3C fit with $\vec{p}_T$ and π^0 mass constraints. Requiring the kinematically fitted photon energies to be greater than 50 Mev resulted in a final sample of 107 $\pi^+\pi^-\pi^+\pi^-\pi^0$ events with $W_{\gamma\gamma}$ <3.0 GeV.

For events tagged by the NaI and shower counters, a requirement that there be less than 200 MeV transverse momentum perpendicular to the lepton scattering plane was imposed in addition to total transverse momentum cuts of 400 MeV and 800 MeV, respectively. A sample of 1034 tagged four-prongs events was thus obtained.

EXPERIMENTAL RESULTS

$\rho^0\rho^0$ production - Our measured $\pi^+\pi^-\pi^+\pi^-$ cross section[6], shown in Fig. 2, is seen to be in good agreement with results from other experiments.[2,3] The $\pi^+\pi^-$ mass combinations show a large $\rho^0\rho^0$ contribution for $W_{\gamma\gamma}$ <2.0 GeV persisting below nominal $\rho^0\rho^0$ threshold with contributions from $\rho\pi^+\pi^-$ and $f_2\pi^+\pi^-$ production at larger $W_{\gamma\gamma}$.

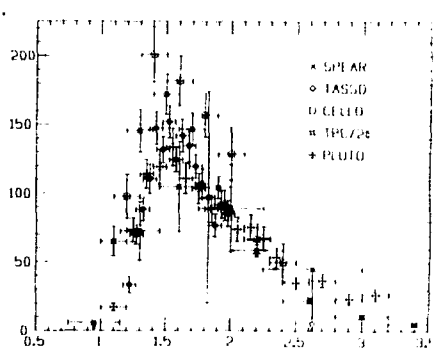

Figure 2. Cross section in nanobarns versus $W_{\gamma\gamma}$ in GeV for $\pi^+\pi^-\pi^+\pi^-$ production in photon-photon interactions from several experiments at PETRA, SPEAR and PEP.

The contributions from different processes were determined from a 3-component maximum likelihood fit to pion pair masses with the following matrix elements:

$$g_{2\pi^+2\pi^-} = \text{const},$$

$$g_{\rho^0\pi^+\pi^-} = \frac{1}{2}[B_\rho(m_{12})+B_\rho(m_{34})+B_\rho(m_{14})+B_\rho(m_{23})]$$

$$g_{\rho^0\rho^0} = \frac{1}{\sqrt{2}}[B_\rho(m_{12})B_\rho(m_{34}) + B_\rho(m_{14})B_\rho(m_{23})]$$

where B_ρ is a Breit-Wigner amplitude with an energy dependent width. The fractions obtained from the fit, shown in Fig. 3, agree with TASSO measurements.

A spin-parity analysis was performed in a 6-component fit including spin-0 and 2 $\rho^0\rho^0$ contributions with negative and positive parity. Both 0^+ and 2^+ $\rho^0\rho^0$ contributions with no significant contribution from negative parity states, and a larger fraction of $\rho\pi^+\pi^-$ than found in the 3-component fits was obtained. Comparisons of Monte Carlo simulations to production and decay angular distributions clearly favor 2^+; however, isotropic $\rho^0\rho^0$ production is similar in shape to 2^+ and is also in good agreement with the data.

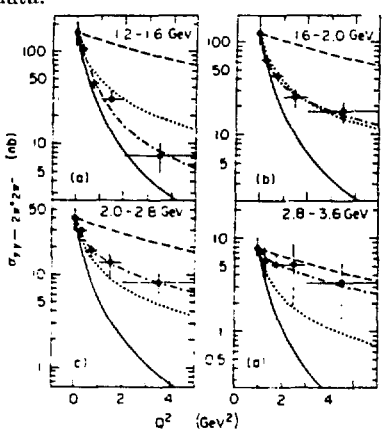

Figure 4. Cross section for $\pi^+\pi^-\pi^+\pi^-$ production as a function of Q^2 in bins of $W_{\gamma\gamma}$. The solid and dashed lines represent ρ and ψ-pole form factor normalized to the data.

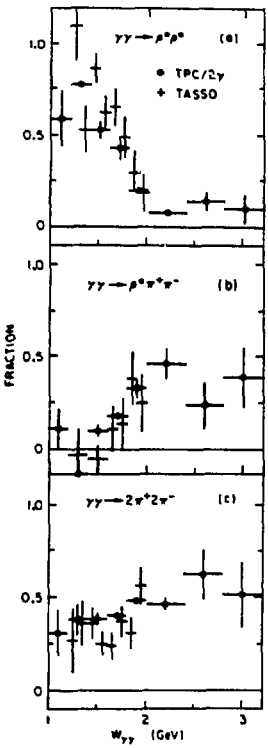

Figure 3. Fractions of the observed $\pi^+\pi^-\pi^+\pi^-$ events contributed by the processes $\rho^0\rho^0$, $\rho\pi^+\pi^-$ and $2\pi^+2\pi^-$ as a function of $W_{\gamma\gamma}$.

From our analysis of the tagged data we find that the fractional contributions of $\rho^0\rho^0$, $\rho\pi^+\pi^-$ and $\pi^+\pi^-\pi^+\pi^-$ are roughly the same at higher Q^2. In Fig. 4 we observe that the topological $\pi^+\pi^-\pi^+\pi^-$ cross section deviates markedly from a simple ρ-pole form factor especially at larger $W_{\gamma\gamma}$. At $W_{\gamma\gamma}$ ~3 GeV, the data approach a ψ-pole form factor description.

Search for $\rho\phi$ and $K^{*}\overline{K}^{*}$ production - Clear signals of $\phi\pi^+\pi^-$ and $K^{*0}K^{\pm}\pi^{\mp}$ production were observed in the analysis of our $K^+K^-\pi^+\pi^-$ sample but no evidence for $\rho\phi$ or $K^{*}\overline{K}^{*}$ production was found.[6] Upper limits determined for $\rho\phi$ production as described below appear to rule out the four-quark model predictions[3,4]. The topological cross section for $\gamma\gamma \to K^+K^-\pi^+\pi^-$ with the contribution from $\phi\pi^+\pi^-$ subtracted as measured by the TPC/$\gamma\gamma$ and TASSO[9] collaborations are in good agreement as seen in Fig. 5.

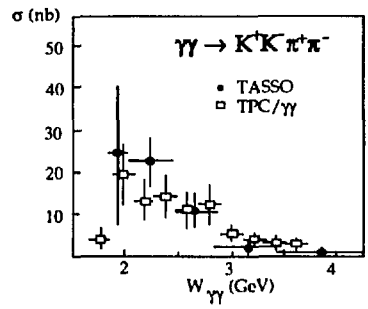

Figure 5. Topological cross section for $K^+K^-\pi^+\pi^-$ production from the TPC/$\gamma\gamma$ and TASSO collaborations.

$\rho^0\omega$ production - The analysis of our $\pi^+\pi^-\pi^+\pi^-\pi^0$ sample[7] shows a clear ω signal in the $\pi^+\pi^-\pi^0$ mass combinations having a recoil $\pi^+\pi^-$ mass in the ρ mass band, Fig. 6a; while, a strong ρ^0 contribution is observed in the $\pi^+\pi^-$ mass spectra with a selection of recoil $\pi^+\pi^-\pi^0$ mass combinations in the ω mass range, Fig. 6b. To obtain the contribution from $\rho^0\omega$ production we have performed a maximum likelihood fit to the two dimensional scatter plot of $\pi^+\pi^-$ vs. $\pi^+\pi^-\pi^0$ using Monte Carlo distributions for the processes: $\rho^0\omega$, $\rho^0\pi^+\pi^-\pi^0$, $\omega\pi^+\pi^-$ and $\pi^+\pi^-\pi^+\pi^-\pi^0$ phase space. The curves shown in Fig. 6 were obtained by combining Monte Carlo events according to the fractions obtained in a four region fit and the observed $W_{\gamma\gamma}$ distribution. Unfortunately, the large width of the ρ combined with the limited statistics of our data make a definitive separation of the $\rho^0\omega$ and $\omega\pi^+\pi^-$ channels impossible. From a two region fit (inside or outside the ω mass band) we estimate the fraction of events containing an ω to be over 40% of the events with $1.25 \leq W_{\gamma\gamma} < 2.25$ Gev. We estimate that (75^{+25}_{-15})% of the inclusive $\omega\pi^+\pi^-$ events are actually $\rho^0\omega$ events.

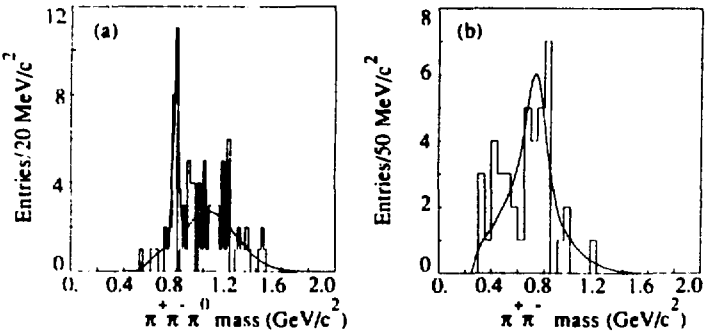

Figure 6. Mass spectra for: a) $\pi^+\pi^-\pi^0$ and b) $\pi^+\pi^-$ combinations with a recoil mass in the ρ or ω mass band, respectively.

The measured cross section for $\omega\pi^+\pi^-$ (including $\rho^0\omega$) production, shown in Fig. 7, is in good agreement with the recent result from the ARGUS collaboration.[10] A prediction for the $\rho^0\omega$ cross section from the t-channel factorization model of Alexander et al.[5], shown as a shaded band in Fig. 7, falls considerably below the measured $\omega\pi^+\pi^-$ cross section. Predictions of the four quark model for $\rho^0\omega$ production[4] with m_0= 1.55-1.65 GeV/c^2 also do not fit our data.

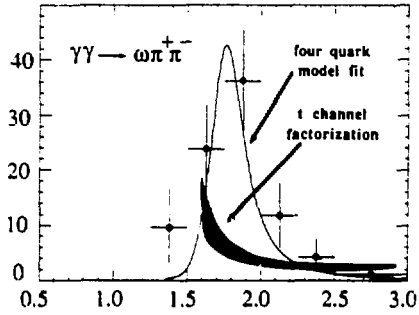

Figure 7. Cross section in nanobarns for $\omega\pi^+\pi^-$ production as a function of $W_{\gamma\gamma}$. The fitted curve was obtained from a four quark model prescription.[4]

FOUR QUARK MODEL FITS

In an attempt to reproduce the observed $\omega\pi^+\pi^-$ cross section using the prescription of for four quark resonance production,[4] we have performed fits in which the model parameters m_0 (the mass of the resonance) and a_0 (used to account for non-calculable contributions) were varied while Y (the dissociation coupling constant) was fixed at 1.0 GeV^2. An acceptable fit ($\chi^2/d.f.$ of 0.88) was obtained using this model with $m_0 = 1.80 \pm 0.05$ GeV/c^2 and $a_0 = 0.0 \pm 0.08$, as shown in Fig. 7. The mass obtained from the fit is significantly higher than expected from the peak in the $\rho^0\rho^0$ cross section, while the a_0 parameter agrees with the expected dominance of the "fall-apart" decay of a four-quark state.

Pursuing the possibility of different mass values for the four quark states, we calculated the cross section for $\rho^0\rho^0$ production with the mass of the state in the same multiplet as the $\rho^0\omega$ state fixed at 1.8 GeV, while varying the remaining parameters. One of the examples considered, shown in Fig. 8, has resonance mass values of m_3=1.2, m_4=1.8 and m_5=1.25 GeV/c^2 with acceptable values for the remaining parameters. However, due to the large systematic errors in obtaining the fraction of $\rho^0\rho^0$ production from the measured $\pi^+\pi^-\pi^+\pi^-$ cross section, our results are equally compatible with four quark model predictions[3,4] of three resonances states with masses between 1.4 and 1.5 GeV.

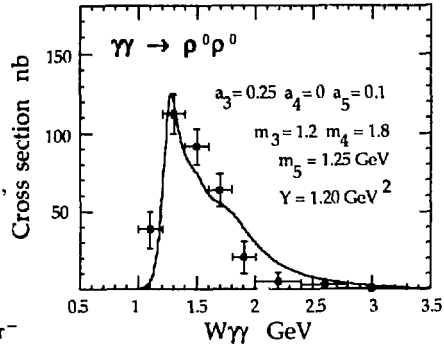

Figure 8. A variation of the four-quark model (with parameters shown) compared to a measurement of the $\rho^0\rho^0$ cross section.

In the case of $\rho\phi$ production, the four quark model predictions[3,4] are ruled out by the measured upper limits[6] as seen in Fig. 9 for the prediction of Ref. 4 (dashed curve). To force the calculated cross section to fall below the upper limit measured from $W_{\gamma\gamma}$=2.0 to 2.5 GeV, the masses of the two resonances contributing to this process had to be lowered to ~1.7 GeV/c^2 while the a parameters were increased to 0.8 resulting in the dashed curve shown in Fig. 9. Clearly, unexpectedly large mass shifts and contributions from other decays would be required to explain the absence of $\rho\phi$ production within the four quark model.

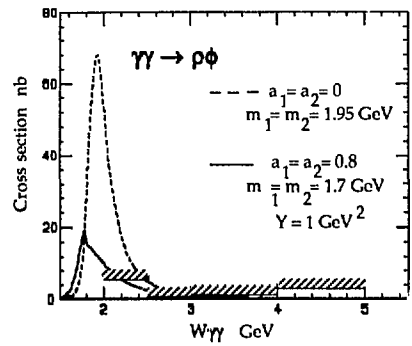

Figure 9. Measured upper limits for $\rho\phi$ production and four quark model estimates with m_1=m_2=1.95 GeV/c^2 (dashed) and m_1=m_2=1.7 GeV/c^2 (solid).

CONCLUSION

At this time there is no model which can explain the large $\rho^0\rho^0$ yield, peaked $\rho^0\omega$ cross section and absence of $\rho\phi$ production in photon-photon interactions. Although the four quark model parameters can be adjusted to fit the measurements of vector-vector production in several channels, the resulting resonance mass splittings are quite large and, if true, would then need to be understood from the dynamics of four quark states.

I would like to thank my collaborators on the TPC/Two-Gamma experiment especially A. Bay, K. Derby, A. Nicol and R. Ross.

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