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Exclusive production of hadron pairs in two-photon interactions

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Abstract. The knowledge of two-photon processes increased during the last years thanks to the large sample of $e^+e^- \to e^+e^-$ *hadrons* events collected at LEP. Non perturbative QCD phenomena are investigated through the study of exclusive meson and baryon pair production. The cross sections are measured as a function of the $\gamma\gamma$ center-of-mass energy, $W_{\gamma\gamma}$, and the center-of-mass production angle of the hadron, θ^*. Exclusive $\rho^0\rho^0$ and $\rho^+\rho^-$ production for quasi-real photons are investigated through a spin-parity-helicity analysis. Exclusive $\rho^0\rho^0$ production is also studied as a function of the photon virtuality Q^2 and compared to recent QCD predictions.

PACS. 13.66Bc Hadron production in e^+e^- interactions

1 Exclusive pion and kaon pair production

Based on the hard scattering approach developed by Brodsky and Lepage [1], predictions have been made for the production of meson pairs in two-photon interactions. In this formalism, the process is factorized into a perturbative $\gamma\gamma \to q\overline{q}$ amplitude and a non-perturbative part described by the quark distribution functions of the meson. The $\gamma\gamma \to \pi^+\pi^-$ and $\gamma\gamma \to K^+K^-$ reactions have been studied by the ALEPH Collaboration [2] for $|\cos\theta^*| < 0.6$. The shape of the cross sections are well reproduced by the theoretical predictions but the data have a significantly higher normalization, as shown in Fig. 1 for the $\gamma\gamma \to \pi^+\pi^-$ reaction. The QCD predictions are calculated using the hard scattering approach with a distribution amplitude set to its asymptotic form [2]. A fit to the data with a power law function AW^{-6} gives a value $A = 200 \pm 40$ for pions and $A = 220 \pm 40$ for kaons. The ratio $\sigma(\gamma\gamma \to K^+K^-)/\sigma(\gamma\gamma \to \pi^+\pi^-)$ is thus compatible with one, in complete disagreement with the theoretical prediction of 2.2. Another approach, the so called handbag model [4], has been recently proposed to describe meson pair production. In this model, the process amplitude is factorized into a hard $\gamma\gamma \to q\bar{q}$ subprocess and form factors describing the soft $q\bar{q} \to$ *meson antimeson* transition. Absolute prediction for the $\gamma\gamma \to \pi^+\pi^-$ and $\gamma\gamma \to K^+K^-$ cross sections are not available, since input data from other channels are needed. However, the ratio $\sigma(\gamma\gamma \to K^+K^-)/\sigma(\gamma\gamma \to \pi^+\pi^-)$ is predicted to be close to one, in agreement with the data. The observed angular distribution is also reproduced by these calculations.

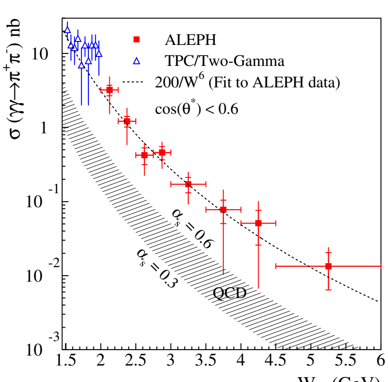

Fig. 1. The $\gamma\gamma \to \pi^+\pi^-$ cross section as a function of $W_{\gamma\gamma}$ with the previous measurement of TPC/2γ [3], the QCD prediction and the fit described in the text

2 Exclusive baryon pair production

Using the same hard scattering approach, predictions have been made for baryon pair production. However, such calculations with three-quark distribution functions [5,6] failed to reproduce early $\gamma\gamma \to p\overline{p}$ measurements [7]. The quark-diquark model [8] was proposed as a possible way to model non-perturbative effects through the use of diquarks, a bound state ot two quarks inside the baryon. The handbag model was also adapted to describe baryon pair production[9]. Using flavour symmetry, predictions for the members of the baryon octet can be obtained once the $\gamma\gamma \to p\overline{p}$ cross section is measured. The $\gamma\gamma \to p\overline{p}$ reaction has been measured as a function of $W_{\gamma\gamma}$ for $|\cos\theta^*| < 0.6$ by the L3 [10] and OPAL [11] Collaborations. The calculations of the three-quark model [5] are found to be about an order of magnitude below the measurement, whereas

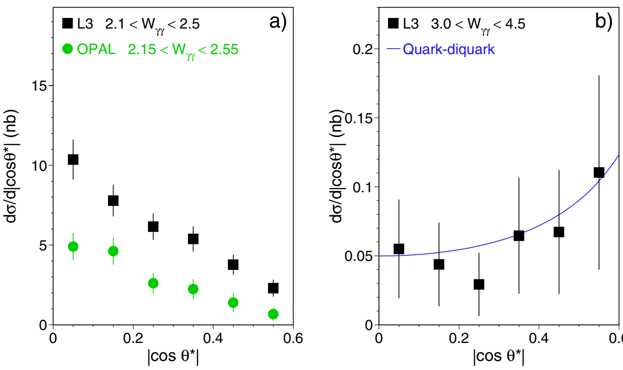

Fig. 2. a The differential $\gamma\gamma \to \mathrm{p\overline{p}}$ cross sections as a function of $|\cos\theta^*|$ for 2.1 GeV $< W_{\gamma\gamma} <$ 2.5 GeV and **b** for 3.0 GeV $< W_{\gamma\gamma} <$ 4.5 GeV with the diquark model prediction

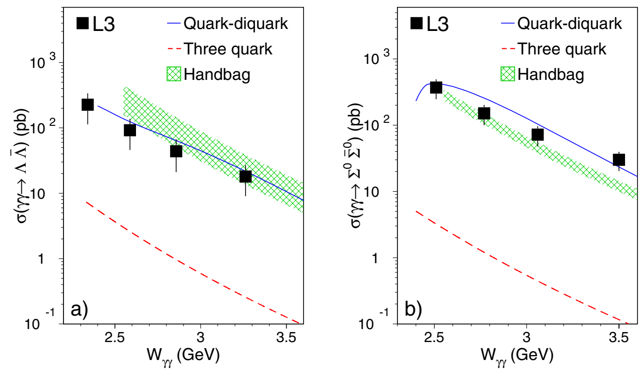

Fig. 3. a The $\gamma\gamma \to \Lambda\overline{\Lambda}$ and **b** the $\gamma\gamma \to \Sigma^0\overline{\Sigma}^0$ cross sections as a function of $W_{\gamma\gamma}$ compared to the three-quark [5], the quark-diquark [12] and the handbag model predictions [9]

the recent quark-diquark predictions [12] describe the data much better. The differential cross sections are also studied in three different mass intervals: 2.1 GeV $< W_{\gamma\gamma} <$2.5 GeV, 2.5 GeV $< W_{\gamma\gamma} <$ 3 GeV and 3 GeV $< W_{\gamma\gamma} <$4.5 GeV. The low mass and high mass distributions are displayed in Fig. 2 as example. A distinctive difference is observed between the three distributions. No prediction is available for the quark-diquark model below 2.5 GeV, but the data in this region have a qualitatively different behaviour to the diquark prediction above $W_{\gamma\gamma} = 3$ GeV, as it is strongly peaked at large angles. The intermediate region exhibits a rather flat dependence, which partially agrees with the model predictions. The forward peaking behaviour of the differential cross section in the high mass interval is well reproduced by the quark-diquark model.

The $\gamma\gamma \to \Lambda\overline{\Lambda}$, $\gamma\gamma \to \Lambda\overline{\Sigma}^0 + \Sigma^0\overline{\Lambda}$ and $\gamma\gamma \to \Sigma^0\overline{\Sigma}^0$ reactions have been studied by the L3 Collaboration [13] for $|\cos\theta^*| < 0.6$. These reactions are identified by first reconstructing the two decay vertices $\Lambda \to \mathrm{p}\pi^-$ and $\overline{\Lambda} \to \overline{\mathrm{p}}\pi^+$. The Σ^0 and $\overline{\Sigma}^0$ candidates are then reconstructed by combining the selected Λ and $\overline{\Lambda}$ with photons. A maximum likelihood fit, taking the misidentification probabilities between processes into account, is performed to separate the $\Lambda\overline{\Lambda}$, $\Lambda\overline{\Sigma}^0 + \overline{\Lambda}\Sigma^0$ and $\Sigma^0\overline{\Sigma}^0$ final states. As the $\Lambda\overline{\Sigma}^0 + \overline{\Lambda}\Sigma^0$ fraction is found to be negligible, the fit is repeated using only the $\Lambda\overline{\Lambda}$ and $\Sigma^0\overline{\Sigma}^0$ components. The $\gamma\gamma \to \Lambda\overline{\Lambda}$ and $\gamma\gamma \to \Sigma^0\overline{\Sigma}^0$ measurements are compared to different theoretical predictions in Fig. 3. Both measurements are well reproduced by the recent quark-diquark calculations [12], whereas the three-quark model [5] is clearly excluded. Our data are also in agreement with the handbag model predictions [9] inside the theoretical uncertainties.

3 Exclusive ρ meson pair production

Exclusive ρ meson pair production by quasi-real photons was studied by several experiments [14,15,16]. A prominent feature of the reaction $\gamma\gamma \to \rho^0\rho^0$ is the broad cross section enhancement near threshold, the origin of which is still not well understood. In contrast the cross section for the isospin related reaction $\rho^+\rho^-$ is shown to be small [17]. On the other hand few data involving highly off-shell virtual photons are available [16], since tagged two-photon processes have a considerably reduced rate. Recent theoretical predictions [18,19] have renewed interest for measuring $\rho\rho$ production at high Q^2.

3.1 Exclsuive $\rho^0\rho^0$ and $\rho^+\rho^-$ production at $Q^2 \simeq 0$

The $\gamma\gamma \to \rho^0\rho^0$ and $\gamma\gamma \to \rho^+\rho^-$ reactions at $Q^2 \simeq 0$ have been studied by the L3 Collaboration via the reactions $\gamma\gamma \to \pi^+\pi^-\pi^+\pi^-$ and $\gamma\gamma \to \pi^+\pi^0\pi^-\pi^0$. Following the model proposed by TASSO [14], the signal is modeled with $\rho\rho$ production in different spin-parity and helicity states (J^P, J_z) together with an isotropic production of four pions. All states are assumed to be produced incoherently. The allowed states of a $\rho\rho$ system in quasi-real $\gamma\gamma$ reactions are: $(J^P, J_z) = 0^+$, $(2^+, 0)$, $(2^+, \pm 2)$, 0^- and $(2^-, 0)$. A maximum likelihood fit is used to determine the contributions of the each amplitude. The preliminary results shows a dominance of the $(J^P, J_z) = (2^+, 2)$ state in both channels. The 0^+ and 0^- states give a smaller but non negligible contribution, whereas other states are found to be negligible. A broad enhancement near threshold of the $\gamma\gamma \to \rho^0\rho^0$ cross section is observed as in previous measurements and shown in Fig. 4. In contrast, no excess is observed in the $\rho^+\rho^-$ channel. The cross section ratio $\sigma(\gamma\gamma \to \rho^0\rho^0)/\sigma(\gamma\gamma \to \rho^+\rho^-)$ in the range 1.2 GeV $< W_{\gamma\gamma} <$1.6 GeV is thus incompatible with the hypothesis of a resonance with isospin I=0,1.

3.2 Exclusive $\rho^0\rho^0$ production at high Q^2

Exclusive $\rho^0\rho^0$ production at high Q^2 has been studied by the L3 Collaboration [20] through the reaction $\mathrm{e^+e^-} \to \gamma\gamma^* \to \mathrm{e^+e^-}\pi^+\pi^-\pi^+\pi^-$, where γ^* denotes a virtual photon. Events with four pions a first selected. A maximum likelihood fit using a box method [21] is then performed

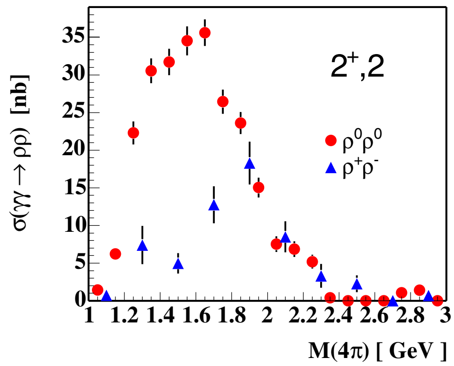

Fig. 4. The $(J^P, J_z) = (2^+, 2)$ composant of the $\gamma\gamma \to \rho^0\rho^0$ and $\gamma\gamma \to \rho^+\rho^-$ cross sections

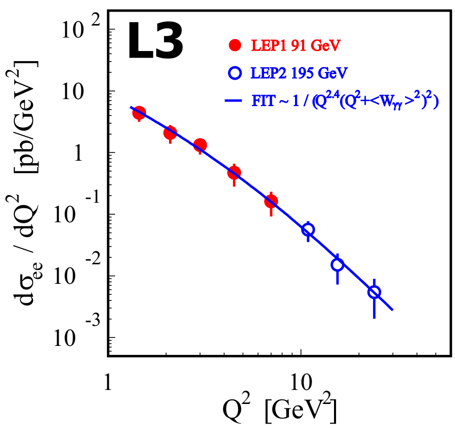

Fig. 5. The differential cross section $d\sigma(\mathrm{e^+e^-} \to \mathrm{e^+e^-}\rho^0\rho^0)/dQ^2$ with the fit described in text

for each $W_{\gamma\gamma}$ and Q^2 interval to determine the number of $\rho^0\rho^0$ events. The following non-interfering contributions are considered in the fit: $\gamma\gamma^* \to \rho^0\rho^0$, $\gamma\gamma^* \to \rho^0\pi^+\pi^-$ and $\gamma\gamma^* \to \pi^+\pi^-\pi^+\pi^-$. The broad enhancement in the $\rho^0\rho^0$ cross section near threshold at $Q^2 \simeq 0$ is also visible in the high Q^2 measurement. The differential cross section $d\sigma_{ee}/dQ^2$ is plotted in Fig. 5 together with the result of a fit to a form expected from QCD-based calculations:

$$d\sigma_{ee}/dQ^2 \propto Q^{-n}(Q^2 + \langle W_{\gamma\gamma}\rangle^2)^{-2})$$

with $\langle W_{\gamma\gamma}\rangle = 1.945$. The fit provides a good description of the Q^2 dependence of the data and gives an exponent $n = 2.4 \pm 0.3$, to be compared to the expected value $n = 2$. The Q^2 dependence, including the point at $Q^2 \simeq 0$, is also well described by a GVDM form factor [22] whereas a steeper decrease, excluded by the data, is expected for a simple ρ-pole form factor, as shown in Fig. 6.

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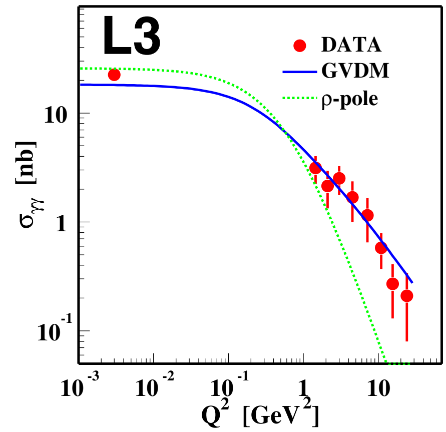

Fig. 6. The $\gamma\gamma^* \to \rho^0\rho^0$ cross section as a function of Q^2 fitted with a GDVM form factor (*solid line*) and a ρ-pole form factor (*dotted line*)

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