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Extracting the $f_0(980)$ signal from the photoproduced $\pi^+\pi^-$ spectrum

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Abstract. We present a phenomenological analysis of the $\pi^+\pi^-$ photoproduction data obtained by the CLAS collaboration at the Thomas Jefferson Laboratory. A special emphasis is put on the interference pattern observed in the moments of angular distribution for the $\pi^+\pi^-$ efective masses around 1 GeV. This pattern is attributed to the photoproduction of the scalar-isoscalar resonance $f_0(980)$. By fitting the model parameters to the data we obtain the strengths of the resonant and nonresonant parts of the S-wave photoproduction amplitude. We calculate the $f_0(980)$ photoproduction cross section which is smaller than previous estimations by a factor of about 5. A new estimation of the product of the σ meson couplings to nucleon and to the $\gamma\rho$ system $|g_{NN\sigma}g_{\gamma\rho\sigma}|$ is given.

1 Introduction

Reactions induced by electromagnetic probes are good sources of information on the inner structure of scalar mesons. In the radiative decays of the ρ mesons into $\gamma\pi^+\pi^-$ and the ϕ mesons into $\gamma K\overline{K}$ or into $\gamma\pi\eta$, the isoscalar mesons $f_0(500)$ and $f_0(980)$ or the isovector meson $a_0(980)$ play a substantial role. Photoproduction reactions like $\gamma p \to \pi^+\pi^- p$ [1] or $\gamma p \to K^+K^- p$ are valuable alternatives. These processes are, however, plagued by the relatively small values of the scalar meson photoproduction cross sections, thus making their observation in $\pi^+\pi^-$ and K^+K^- mass distributions very difficult. Nevertheless the strength of the $S-$ wave amplitude can be determined by analysing its interference with the dominant P-wave. Such an approach has been already successfully applied to determine the S-wave component in the $\gamma p \to K^+K^- p$ reaction [2].

2 Model description

We adopt the mechanisms commonly used to describe the $\pi^+\pi^-$ photoproduction like the diffractive $\rho(770)$ photoproduction, Fig. 1(a) and the photon dissociation into pair of pions with pion-nucleon rescattering (the Drell mechanism), Fig. 1(b) [3]. This standard approach is extended, however, by taking into account the photoproduction of the scalar-isoscalar mesons treated as resonances created dynamically through final state pion-pion interactions, Fig. 1(c). Our model includes also the ρ photoproduction amplitudes generated by the π, σ and f_2 exchanges which are important at low photon energies [4,5], Fig. 1(d).

We define the moments of the pion angular distribution in the s-channel helicity system as

$$\langle Y^L_M(t, M_{\pi\pi})\rangle = \int d\Omega\, Y^L_M(\Omega)\, |A^P + A^\pi + A^\sigma + A^{f_2} + A^D + A^{f_0}|^2, \quad (1)$$

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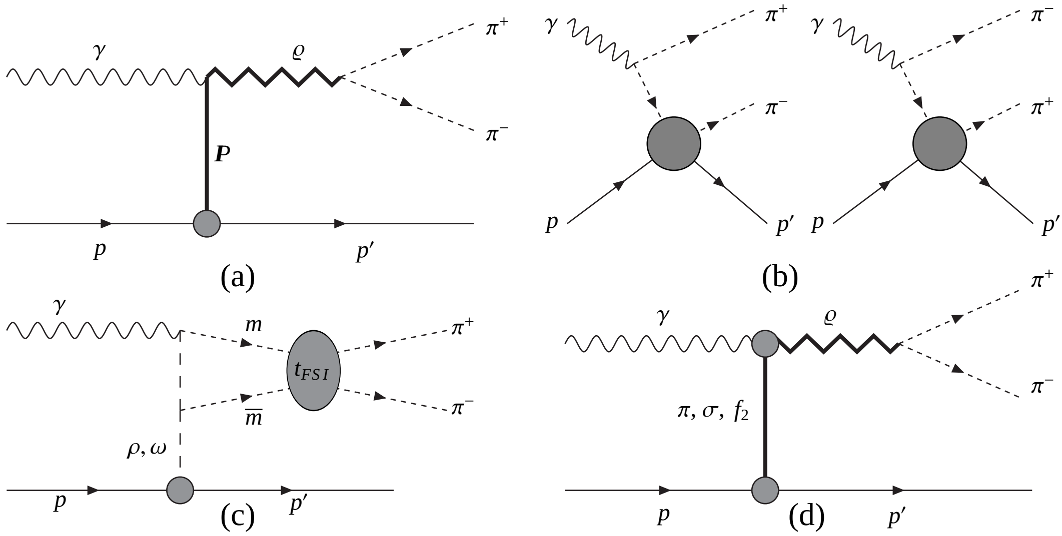

Fig. 1. Mechanisms of the $\pi^+\pi^-$ photoproduction used in the model.

where Ω is the π^+ solid angle, L and M are the angular momentum of the pion and its projection on the direction opposite to the recoil proton momentum, A^P, A^π, A^σ and A^{f_2} are the pomeron, π, σ and f_2 exchange amplitudes, respectively; A^D is the Drell amplitude in which the πp scattering amplitudes are parameterised using the phase shifts and inelasticities from the SAID database [6]. The form of the resonant S-wave amplitude A^{f_0} is

$$A^{f_0}_{\pi^+\pi^-} \;=\; \langle \pi^+\pi^- p'|\hat{V}|\gamma p\rangle \;+\; 4\pi \sum_{m\overline{m}} \int_0^\infty \frac{\kappa'^2 d\kappa'}{(2\pi)^3} F(\kappa,\kappa')\langle \pi^+\pi^-,\kappa|\,\hat{t}\,|m\overline{m},\kappa'\rangle G_{m\overline{m}}(\kappa')\langle m\overline{m}p'|\hat{V}|\gamma p\rangle, \quad (2)$$

where $\hat{V}$ is the Born amplitude, $\hat{t}$ is transition matrix between the intermediate $m\overline{m}$ states ($\pi\pi$ or $K\overline{K}$) and the final $\pi^+\pi^-$ state [7] and $\kappa'(\kappa)$ is CM momentum of the two-meson system in the intermediate (final) state. The $F(\kappa,\kappa')$ form factor is used to regularize the divergent mesonic loop of the diagram 1(c).

3 Main results

3.1 Moments

For the meson exchange amplitudes (Fig. 1(d)) we use the same values of the coupling constants and form factor range parameters as in Ref. [5]. However, due to substantial discrepancies concerning the σ meson couplings we treat the product $g_{\sigma\rho\gamma}g_{\sigma NN}$ as a free parameter which we fit to mass distributions obtained by CLAS for the photon energy E_γ=3.3 GeV [1]. Our result $|g_{\sigma\rho\gamma}g_{\sigma NN}|$=15.12±1.53 can be compared with the values between 2.55 and 35.9 calculated from the couplings given in Ref. [5].

In order to fit the moments $\langle Y_0^1\rangle$ and $\langle Y_1^1\rangle$ we introduced correction phases and scale parameters to individual partial waves. As seen in Fig. 2 a good description of these moments for the effective masses around 1 GeV is obtained. High L moments are not discussed here since in these moments the S-wave which is of interest to us interferes with higher partial waves of much smaller intensities than that of the dominant P-wave.

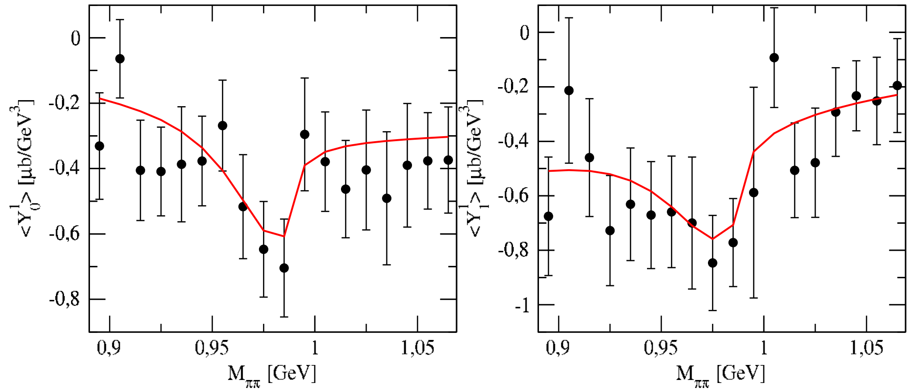

Fig. 2. Comparison of the moments $\langle Y_0^1 \rangle$ and $\langle Y_1^1 \rangle$ for t =-0.5 GeV^2 [1] with the present model.

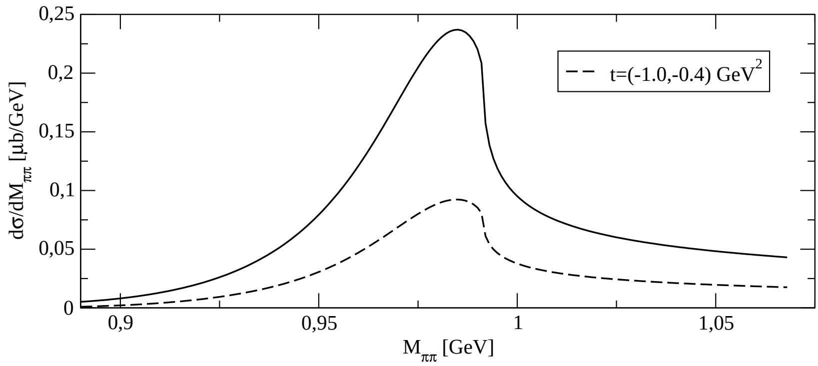

Fig. 3. Mass distribution for the S-wave in vicinity of the $f_0(980)$ resonance - solid line, mass distribution limited to the t range covered by CLAS - dashed line.

3.2 Mass distribution

By fitting the moments with $L \leqslant 1$ we have determined the absolute strength of the resonant ($f_0(980)$) S-wave amplitude and were able to calculate the corresponding mass distributions. The t-integrated mass distribution (Fig. 3) can be compared with previos calculations performed for the photon energies of 1.7 GeV [8] and 5 GeV [9], respectively. Assuming the ρ-type Regge energy dependence of the total S-wave cross section we find our result below those of [8] and [9] (Scenario II) by a factor of about 5.

4 Summary and outlook

The model provides a good description of the moments of the pion angular distribution in the reaction $\gamma p \to \pi^+\pi^- p$ for the $\pi^+\pi^-$ effective masses around the mass of the scalar-isoscalar resonance $f_0(980)$. We found the resonant S-wave cross section to be remarkably smaller than the values previously calculated using the chiral unitary model [8] and the quark model [9].

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