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 $\pi^+\pi^-$ effective 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 $\sigma$ meson couplings to nucleon and to the $\gamma\rho$ system $|\sigma_{NN}\sigma_{\gamma\rho}|$ 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 $\rho$ mesons into $\gamma\pi^+\pi^-$ and the $\phi$ mesons into $\gamma K\bar{K}$ or into $\gamma\eta\eta$, the isoscalar mesons $f_0(500)$ and $f_0(980)$ or the isovector meson $a_0(980)$ play a substantial role. Photoproduction reactions like $\gamma p \rightarrow \pi^+\pi^- p$ [1] or $\gamma p \rightarrow K^+K^- p$ 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 component 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 $\gamma p \rightarrow K^+K^- p$ 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 $\rho$ photoproduction amplitudes generated by the $\pi$, $\sigma$ 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

$$\langle Y_M^L(t, M_{\pi\pi}) \rangle = \int d\Omega \; Y_M^L(\Omega) |A^P + A^{\pi} + A^{\sigma} + A^{f_2} + A^{D} + A^{h_0}|^2,$$  

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

$$A_{\pi^+\pi^-}^{f_0} = \langle \pi^+\pi^- p' | \hat{V} | \gamma p \rangle + 4\pi \sum_{m\bar{m}} \int_0^{\infty} \frac{k'^2 dk'}{(2\pi)^3} F(k, k') \langle \pi^+\pi^- , k | \hat{t} | m\bar{m}, k' \rangle \langle m\bar{m} p' | \hat{V} | \gamma p \rangle,$$

where $\hat{V}$ is the Born amplitude, $\hat{t}$ is transition matrix between the intermediate $m\bar{m}$ states ($\pi\pi$ or $K\bar{K}$) and the final $\pi^+\pi^-$ state [7] and $k'(k)$ is CM momentum of the two-meson system in the intermediate (final) state. The $F(k, k')$ 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 $\sigma$ meson couplings we treat the product $g_{\sigma\gamma\gamma} g_{\sigma NN}$ as a free parameter which we fit to mass distributions obtained by CLAS for the photon energy $E_{\gamma}=3.3$ GeV [1]. Our result $|g_{\sigma\gamma\gamma} g_{\sigma NN}|=15.12\pm1.53$ 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 $\langle Y_1^1 \rangle$ 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.
3.2 Mass distribution

By fitting the moments with $L \leq 1$ 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 previous calculations performed for the photon energies of 1.7 GeV [8] and 5 GeV [9], respectively. Assuming the $\rho$-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 $\gamma p \rightarrow \pi^+\pi^- p$ 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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