Theoretical Study of the $\gamma\gamma \to$ Meson-Meson Reaction

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Abstract. We present a unified theoretical picture which studies simultaneously the $\gamma\gamma \to \pi^+\pi^-, \pi^0\pi^0, K^+K^-, K^0\bar{K}^0, \pi^0\eta$ reactions up to about $\sqrt{s} = 1.4$ GeV reproducing the experimental cross sections. The present work implements in an accurate way the final state interaction of the meson-meson system, which is shown to be essential in order to reproduce the data, particularly the $L = 0$ channel. This latter channel is treated here following a recent theoretical work in which the meson-meson amplitudes are well reproduced and the $f_0, a_0, \sigma$ resonances show up clearly as poles of the $t$ matrix. The present work, as done in earlier ones, also incorporates elements of chiral symmetry and exchange of vector and axial resonances in the crossed channels, as well as a direct coupling to the $f_2(1270)$ and $a_2(1320)$ resonances. We also evaluate the decay width of the $f_0(980)$ and $a_0(980)$ resonances into the $\gamma\gamma$ channel.

I INTRODUCTION

The $\gamma\gamma \to$ meson-meson reaction provides interesting information concerning the structure of hadrons, their spectroscopy and the meson-meson interaction, given the sensitivity of the reaction to the hadronic final state interaction (FSI) [2].

The chiral perturbation approach [5,6] is valid only for low energies. However, chiral symmetry is one of the important ingredients when dealing with the meson-meson interaction. In addition to the $f_0(980), a_0(980)$ and $\sigma$ resonances, which come up naturally in the approach of ref. [3], which we use here, we introduce phenomenologically the $f_2(1270)$ and $a_2(1320)$ resonances. Another relevant aspect of this reaction, which has been reported previously, is the role of the vector and axial resonance exchange in the $t, u$ channels.
II  FINAL STATE INTERACTION CORRECTIONS

The vertex contributions come from the Born term, only for charged particles, and the exchange in the \( t,u \) channels of axial and vector resonances, [5]. We now take into account their FSI corrections.

\( S \)-wave.

The one loop contribution generated from the Born terms with intermediate charged mesons can be directly taken from \( \chi PT \) calculations of the \( \gamma \gamma \rightarrow \pi^0\pi^0 \) amplitude to one loop. The important point is that the strong amplitude connecting the charge particles with the \( \pi^0\pi^0 \) factorizes. Our contribution beyond this point is to include all meson loops generated by the coupled channel Lippmann Schwinger equations of ref. [3], in which we also saw that the on shell meson-meson amplitude factorizes outside the loop integrals. Hence, the immediate consequence of introducing these loops is to substitute the on shell \( \pi\pi \) amplitude of order \( O(p^2) \) by our on shell meson-meson amplitude evaluated in ref. [3]. A similar procedure to account for FSI in the terms generated by vector and axial resonance exchange can be applied iterating the potential in the meson-meson amplitude.

\[
t_{R,M_3M_4} = \sum_{M_1M_2} \tilde{t}_{R,M_1M_2} t_{M_1M_2M_3M_4} \\
\tilde{t}_{R,M_1M_2} = i \frac{d^4q}{(2\pi)^4} \frac{1}{q^2-m_1^2+i\epsilon} \frac{1}{(P-q)^2-m_2^2+i\epsilon} \tag{1}
\]

In eq. (3) \( P = (\sqrt{s},0) \) is the total fourmomentum of the \( \gamma\gamma \) system and \( m_1, m_2 \) the masses of the intermediate \( M_1, M_2 \) mesons. In addition, and in analogy to the work of ref. [3], the integral over \( |\tilde{q}| \) in eq. (3) is cut at \( q_{\text{max}} = 0.9 \text{GeV} \). One can justify the accuracy of factorizing the strong amplitude for the loops with crossed exchange of resonances [?].

\( D \)-wave contribution

For the \((2,2)\) component we take the results of ref. [7], obtained using dispersion relations

\[
t^{(2,2)}_{BC} = \left[ \frac{2}{3} \chi_{22}^{T=0} e^{i\delta_{20}} + \frac{1}{3} \chi_{22}^{T=2} e^{i\delta_{22}} \right] t^{(2,2)}_{B} \tag{2}
\]

For the \( \gamma\gamma \rightarrow K^+K^- \) reaction the non resonant D-wave contribution is not needed because we are close to \( KK \) threshold and furthermore the functions \( \chi_{ij} \) are nearly zero close to the mass of the \( f_2 \) and \( a_2 \) resonances.

The resonance contribution in the \( D \)-wave coming form the \( f_2(1270) \) and \( a_2(1320) \) resonances is parametrised in the standard way of a Breit-Wigner as done in ref. [1]. The parameters of these resonances are completely compatible with the ones coming from the Particle Data Group [8].

III  RESULTS

Total and differential cross sections
Partial decay width to two photons of the $f_0(980)$ and $a_0(980)$. 
We follow the same scheme than in [3] in order to use directly our calculated strong and photo-production amplitudes. From our amplitudes in isospin $T = 1$ and for the isospin $T = 0$ part, taking the terms which involve the strong $M \bar{M} \to M \bar{M}$ amplitude, we isolate the part of the $\gamma \gamma \to M \bar{M}$ which proceeds via the resonances $a_0$ and $f_0$ respectively. In the vicinity of the resonance the amplitude proceeds as $M \bar{M} \to R \to M \bar{M}$. Then we eliminate the $R \to M \bar{M}$ part of the amplitude plus the $R$ propagator and remove the proper isospin Clebsch Gordan coefficients for the final states $(I = 1 \text{ or } \pi^0 \eta$ and $-1/\sqrt{2}$ for $K^+ K^-)$ and then we get the coupling of the resonances to the $\gamma \gamma$ channel.

$$
\Gamma^\gamma_\gamma a_0 = 0.78 \text{ KeV} \quad \Gamma^\gamma_\gamma f_0 = 0.49 \text{ KeV} \quad \Gamma^\gamma_\gamma f_0 = 0.20 \text{ KeV} \quad (3)
$$

IV CONCLUSIONS

1) The resonance $f_0(980)$ shows up weakly in $\gamma \gamma \to \pi^0 \pi^0$ and barely in $\gamma \gamma \to \pi^+ \pi^-$. 

2) In order to explain the angular distributions of the $\gamma \gamma \to \pi^+ \pi^-$ reaction we did not need the hypothetical $f_0(1100)$ broad resonance suggested in other works [7]. This also solves the puzzle of why it did not show up in the $\gamma \gamma \to \pi^0 \pi^0$ channel. Furthermore, such resonance does not appear in the theoretical work of ref. [3], while the $f_0(980)$ showed up clearly as a pole of the $t$ matrix in $T = 0$.

3) The resonance $a_0$ shows up clearly in the $\gamma \gamma \to \pi^0 \eta$ channel and we reproduce the experimental results without the need of an extra background from a hypothetical $a_0(1100 - 1300)$ resonance suggested in ref. [2].

4) We have found an explanation to the needed reduction of the Born term in the $\gamma \gamma \to K^+ K^-$ reaction in terms of final state interaction of the $K^+ K^-$ system.

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