Study of the $a_1(1260)$ resonance in the $\gamma p \to \pi^+\pi^+\pi^- n$ reaction*

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Abstract: Within an effective Lagrangian approach and resonance model, we study the $\gamma p \to a_1(1260)^+ n$ and $\gamma p \to \pi^+\pi^+\pi^- n$ reactions via the π-exchange mechanism. For the $\gamma p \to \pi^+\pi^+\pi^- n$ reaction, we perform a calculation of the differential and total cross-sections by considering the contributions of the $a_1(1260)$ intermediate resonance decaying into $\rho\pi$ and then into $\pi^+\pi^+\pi^-$. Besides, the non-resonance process is also considered. With a lower mass of $a_1(1260)$, the experimental data for the invariant $\pi^+\pi^+\pi^-$ mass distributions can be fairly well reproduced. For the $\gamma p \to a_1(1260)^+ n$ reaction, with the model parameters, the total cross-section is of the order of 10 μb at the photon beam energy E_γ~2.5 GeV. It is expected that the model calculations in this work could be tested by future experiments.

Keywords: photoproduction, mass distributions, total cross-section, $a_1(1260)$

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1 Introduction

The $a_1(1260)$ resonance with quantum numbers $J^{PC} = 1^{++}$ is a candidate for the chiral partner of ρ meson [1-3]. It is also described as a $q\bar{q}$ state in the Numbu-Jona-Lasino model [4, 5]. Apart from the quark model, it is considered as a gauge boson of the local hidden symmetry [6, 7]. By using the chiral unitary approach, $a_1(1260)$ is a state arising from the interactions of pairs of hadrons in coupled channels [8, 9]. In addition, the nature of $a_1(1260)$ has also been investigated using the τ decay spectrum into three pions [10-12], and multi-pion decays of light vector mesons [13, 14]. Recently, the $a_1(1260)$ resonance was studied in Ref. [15] in the decay of $\tau \to \nu_\tau \pi^- a_1(1260)$ through a triangle mechanism.

The dynamically generated nature of $a_1(1260)$ has been tested in the radiative decay process. The decay of $a_1(1260)$ into $\pi\gamma$ in Ref. [16] was also studied in Refs. [17, 18] and found to be in agreement with the experimental data if $a_1(1260)$ is associated with the dynamically generated picture. In Ref. [19], the lattice result for the coupling constant of $a_1(1260)$ into the $\rho\pi$ channel is similar to the one obtained in Ref. [8]. Recently, the production of $a_1(1260)$ in the $\pi^- p \to a_1(1260)^- p$ reaction within the effective Lagrangian approach was studied in Ref. [20] based on the results of [8]. Besides, it was found that the elementary $q\bar{q}$ component of $a_1(1260)$ is comparable to the hadronic composite [21-23]. Using the chiral unitary approach, the large N_c behavior of the $a_1(1260)$ state was investigated in Ref. [22], and it was found that $q\bar{q}$ is not the main component of $a_1(1260)$.

Based on the values obtained by two different experimental groups [24, 25], it is estimated that the mass and Breit-Wigner width of $a_1(1260)$ is $M_{a_1(1260)} = 1230 \pm 40$ MeV and $\Gamma_{a_1(1260)} = (250-600)$ MeV, respectively [26][2)]. The large uncertainties of the mass and width of $a_1(1260)$ in the Particle Data Group (PDG) [26] show that the knowledge of $a_1(1260)$ is very limited. Therefore, a study of $a_1(1260)$ photoproduction could be helpful to determine the mass and width of this resonance.

Meson photoproduction off a proton provides one of the most direct platforms to extract information about the hadronic structure [27, 28]. We should point out that in the experiments, no signal representing $a_1(1260)^+ n$ photo-

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2) The result reported by COMPASS provides the mass $M_{a_1(1260)} = 1255 \pm 6^{+7}_{-17}$ MeV and width $\Gamma_{a_1(1260)} = 367 \pm 9^{+28}_{-25}$ MeV [24], while the analysis results of Ref. [25] are $M_{a_1(1260)} = 1225 \pm 9 \pm 20$ MeV and $\Gamma_{a_1(1260)} = 430 \pm 24 \pm 31$ MeV.

production [29-33] could be isolated even though the $\pi\gamma$ radiative width of $a_1(1260)$ very likely exceeds that of $a_2(1320)$ [16, 34-36]. The absence of the $J^{PC}=1^{++}$ state in charge exchange photoproduction is puzzling. In this paper, by investigating the $\gamma p \to a_1(1260)^+ n$ process within the π-exchange mechanism, we calculate its total cross-section. The $\pi^+\pi^+\pi^-$ mass distribution and the total cross-section of $\gamma p \to \pi^+\pi^+\pi^- n$ are studied. In addition, we consider the non-resonance contributions to the $\gamma p \to \pi^+\pi^+\pi^- n$ resonance, which involve nucleon pole terms. Other contributions, which involve $\Delta(1232)$ and nucleon excited states, can be removed based on the $\pi^+ n$ invariant mass spectrum from the experiments [33].

The article is organized as follows. After the introduction, we present the reaction mechanism of $a_1(1260)$ photoproduction. The possible background relevant to the production of $a_1(1260)$ is discussed and the $\pi^+\pi^+\pi^-$ mass distribution is presented in Sec. 3. This work ends with a discussion and conclusion.

2 $\gamma p \to a_1(1260)^+ n$ reaction

In this section, we discuss the $a_1(1260)$ production mechanism. Fig. 1 shows the basic tree-level Feynman diagram for the $a_1(1260)$ production in the $\gamma p \to a_1(1260)^+ n$ reaction via the π-exchange process.

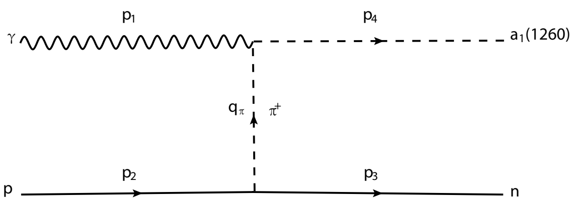

Fig. 1. Feynman diagram for the $\gamma p \to a_1(1260)^+ n$ reaction via π-exchange.

For the πNN vertex, we adopt the commonly used effective Lagrangian

$$\mathcal{L} = -\mathrm{i}g_{\pi NN}\bar{N}\gamma_5(\vec{\tau}\cdot\vec{\pi})N = -\mathrm{i}g_{\pi NN}(\bar{p}\gamma_5 p\pi^0 + \sqrt{2}\bar{p}\gamma_5 n\pi^+ + \sqrt{2}\bar{n}\gamma_5 p\pi^- - \bar{n}\gamma_5 n\pi^0), \tag{1}$$

where the standard value, $g^2_{\pi NN}/4\pi = 14.4$, is adopted as in Refs. [37, 38]. In addition, the form factor is introduced for suppressing the vertex coupling when one or two interacting particles go off-shell. For the πNN vertex, the form factor satisfies the relation

$$F_{\pi NN}(q_\pi) = \frac{\Lambda_\pi^2 - m_\pi^2}{\Lambda_\pi^2 - q_\pi^2}, \tag{2}$$

where Λ_π is a cut-off parameter [39, 40], which will be discussed in the following. q_π is the momentum of the exchanged π meson.

The vertex depicting the interaction of $a_1(1260)$ and $\pi\gamma$ is [17, 18]

$$t_{a_1^+\to\pi^+\gamma} = g_{a_1\pi\gamma}\left(g^{\mu\nu} - \frac{p_\gamma^\mu p_{a_1}^\nu}{p_\gamma\cdot p_{a_1}}\right)\varepsilon_\mu(p_{a_1})\varepsilon_\nu(p_\gamma), \tag{3}$$

where $\varepsilon_\mu(p_{a_1})$ and $\varepsilon_\nu(p_\gamma)$ are the polarization vectors corresponding to $a_1(1260)$ and photon, respectively.

With the vertex above, we can easily get the partial decay width of $a_1 \to \pi\gamma$,

$$\Gamma_{a_1\to\pi\gamma} = \frac{g^2_{a_1\pi\gamma}}{24\pi M^3_{a_1}}(M^2_{a_1} - m^2_\pi), \tag{4}$$

where $M_{a_1} = 1230$ MeV is the nominal mass of $a_1(1260)$. Using the partial decay width $\Gamma_{a_1\to\pi\gamma} = 640\pm246$ keV of $a_1(1260)$ as listed in PDG [26], we get $g_{a_1\pi\gamma} = 244\pm94$ MeV, where the error is from the uncertainties of $\Gamma_{a_1\to\pi\gamma}$ and the mass of $a_1(1260)$. In the following calculations, we take the average value $g_{a_1\pi\gamma} = 244$ MeV.

With the above integrants, one can get the scattering amplitude of the $\gamma(p_1)p(p_2) \to a_1(1260)^+(p_4) + n(p_3)$ process as

$$\mathcal{M} = \frac{-\sqrt{2}\mathrm{i}g_{\pi NN}g_{a_1\pi\gamma}}{q_\pi^2 - m_\pi^2}\bar{u}(p_3)\gamma_5 u(p_2) \times\left(g^{\mu\nu} - \frac{p_1^\mu p_4^\nu}{p_1\cdot p_4}\right)\varepsilon_\mu(p_4)\varepsilon_\nu(p_1)F_{\pi NN}(q_\pi). \tag{5}$$

By defining $s=(p_1+p_2)^2$, the corresponding unpolarized differential cross-section reads

$$\frac{\mathrm{d}\sigma}{\mathrm{d}\cos\theta} = \frac{1}{32\pi s}\frac{|\vec{p}_4^{\,\mathrm{c.m.}}|}{|\vec{p}_1^{\,\mathrm{c.m.}}|}\left(\frac{1}{4}\sum_{\mathrm{spins}}|\mathcal{M}|^2\right), \tag{6}$$

where θ is the scattering angle of a_1^+ meson relative to the beam direction in the c.m. frame, while $\vec{p}_1^{\,\mathrm{c.m.}}$ and $\vec{p}_4^{\,\mathrm{c.m.}}$ are the three-momenta of the initial photon and the final a_1^+, respectively.

In Fig. 2, the solid, dashed and dotted lines are obtained with $\Lambda_\pi = 1.0$, 1.3 and 1.6 GeV, respectively. From Fig. 2 one can see that the total cross-section via π exchange increases very rapidly close to the threshold, and

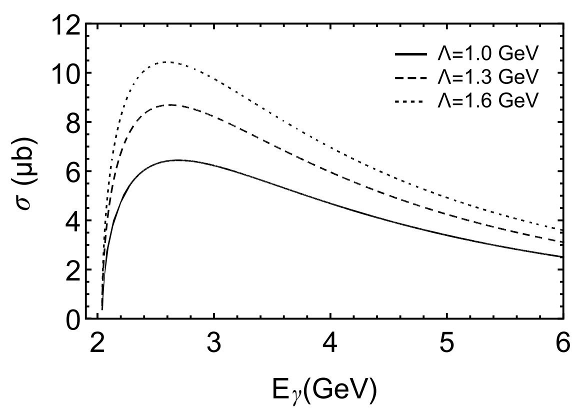

Fig. 2. Dependence of the total cross-section of $\gamma p \to a_1(1260)^+ n$ as a function of E_γ.

the peak position of the total cross-section is $E_\gamma \sim 2.6$ GeV. The total cross-section is proportional to $g^2_{a_1\pi\gamma}$, which indicates that the cross-section is proportional to the partial decay width $\Gamma_{a_1\to\pi\gamma}$. Since the exact value of $\Gamma_{a_1\to\pi\gamma}$ is not determined by theory or experiment, in this work we take $\Gamma_{a_1\to\pi\gamma} = 640$ keV. The result is comparable with the cross-section of $a_2(1320)$ photoproduction [41].

3 $\gamma p \to \pi^+\pi^+\pi^- n$ reaction

Next, we consider the $\gamma p \to a_1(1260)^+ n \to \rho^0\pi^+ n \to \pi^+\pi^+\pi^- n$ and $\gamma p \to \rho^0 p \to \pi^+\pi^+\pi^- n$ processes. Here $\gamma p \to \rho^0 p \to \pi^+\pi^+\pi^- n$ can occur via the nucleon pole term [42].

3.1 $\gamma p \to a_1(1260)^+ n \to \rho^0\pi^+ n \to \pi^+\pi^+\pi^- n$ reaction

The $\gamma p \to a_1(1260)^+ n \to \rho^0\pi^+ n \to \pi^+\pi^+\pi^- n$ reaction with π exchange is shown in Fig. 3, where the relevant kinematic variables are shown. As discussed in the introduction, we take the coupling of $a_1(1260)$ to the $\rho\pi$ channel as obtained in Ref. [8].

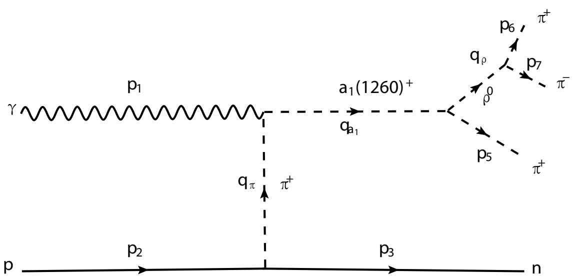

Fig. 3. Feynman diagram for the $\gamma p \to a_1(1260)^+ n \to \rho^0\pi^+ n \to \pi^+\pi^+\pi^- n$ reaction via π exchange.

The $a_1^+\rho^0\pi^+$ vertex can be written as

$$-\mathrm{i}t_1 = -\mathrm{i}\frac{g_{a_1\rho\pi}}{\sqrt{2}}\varepsilon^\mu_{a_1}\varepsilon_\mu, \tag{7}$$

where ε_{a_1} and ε are the polarization vectors of $a_1(1260)$ and ρ, respectively. $g_{a_1\rho\pi}$ is the coupling of $a_1(1260)$ to $\rho\pi$. We take $g_{a_1\rho\pi} = (-3795+\mathrm{i}2330)$ MeV as obtained in Ref. [8], where only the S-wave interaction was considered. Note that there is also a D-wave contribution to the $a_1\rho\pi$ vertex as investigated in Ref. [43], where the D-wave contribution was found to be small.

For the vertex of $a_1(1260)^+$ interacting with $\rho^0\pi^+$, we also introduce a form factor $F_{a_1\rho\pi}$, which is

$$F_{a_1\rho\pi}(q_{a_1}) = \frac{\Lambda^4_{a_1}}{\Lambda^4_{a_1} + (q^2_{a_1} - M^2_{a_1})^2}, \tag{8}$$

with a typical value of $\Lambda_{a_1} = 1.5$ GeV as in Refs. [20, 44].

The $a_1(1260)$ propagator is

$$G^{\alpha\beta}_{a_1}(q_{a_1}) = \mathrm{i}\frac{-g^{\alpha\beta} + q^\alpha_{a_1}q^\beta_{a_1}/M^2_{a_1}}{q^2_{a_1} - M^2_{a_1} + iM_{a_1}\Gamma_{a_1}}, \tag{9}$$

where the width Γ_{a_1} is dependent on its four-momentum squared, and we can take the form as in Refs. [45, 46],

$$\Gamma_{a_1} = \Gamma_0 + \Gamma_{3\pi}, \tag{10}$$

where $\Gamma_{3\pi}$ is the decay width for the process $a_1(1260) \to \rho\pi \to 3\pi$ [44], and Γ_0 is the decay width for the other processes. Following the experimental result in Ref. [24] for the total decay width of $a_1(1260)$, we take $\Gamma_0 = 201$ MeV for $\Gamma_{a_1} = 367$ MeV at $\sqrt{q^2_{a_1}} = 1230$ MeV.

For the structure of the $\rho\pi\pi$ vertex, we use the general interaction as,

$$\mathcal{L}_{PPV} = -\mathrm{i}g < V^\mu[P, \partial_\mu P] >, \tag{11}$$

where $<>$ stands for the trace in $SU(3)$, and $g = \frac{m_V}{2f}$, with $m_V = m_\rho$, and $f = 93$ MeV is the pion decay constant. The $\rho\pi\pi$ vertex can then be written as

$$-\mathrm{i}t = -\mathrm{i}\sqrt{2}g(p_7 - p_6)_\lambda\varepsilon^\lambda(p_4). \tag{12}$$

For the vertex of ρ interacting with $\pi\pi$, we also introduce a form factor $F_{\rho\pi\pi}$, which satisfies the relation

$$F_{\rho\pi\pi}(q_\rho) = \frac{\Lambda^4_\rho}{\Lambda^4_\rho + (q^2_\rho - m^2_\rho)^2}, \tag{13}$$

with a typical value of $\Lambda_\rho = 1.5$ GeV as used in Ref. [44].

The ρ propagator is

$$G^{\sigma\lambda}_\rho(q_\rho) = \mathrm{i}\frac{-g^{\sigma\lambda} + q^\sigma_\rho q^\lambda_\rho/m^2_\rho}{q^2_\rho - m^2_\rho + im_\rho\Gamma_\rho}, \tag{14}$$

where Γ_ρ is energy dependent. Because the dominant decay channel of ρ is $\pi\pi$, we take

$$\Gamma_\rho(M^2_{\rm inv}) = \Gamma_{\rm on}\left(\frac{q_{\rm off}}{q_{\rm on}}\right)^3\frac{m_\rho}{M_{\rm inv}}, \tag{15}$$

with $\Gamma_{\rm on} = 149.1$ MeV, and

$$q_{\rm on} = \frac{\sqrt{m^2_\rho - 4m^2_\pi}}{2}, \tag{16}$$

$$q_{\rm off} = \frac{\sqrt{M^2_{\rm inv} - 4m^2_\pi}}{2}, \tag{17}$$

where $M^2_{\rm inv} = q^2_\rho = (p_6+p_7)^2$ or $(p_5+p_7)^2$ is the invariant mass squared of the $\pi^+\pi^-$ system. We take $m_\rho = 775.26$ MeV in this work.

It is worth to mention that the parametrization of the width of ρ meson shown in Eq. (15) is meant to take into account the phase space of each decay mode as a function of the energy [40, 47, 48]. In the present work we take explicitly the phase space for the P-wave decay of the ρ into two pions.

We finally obtain the scattering amplitude for the diagram shown in Fig. 3,

$$\mathcal{M}_I = \frac{\sqrt{2}ig_{\pi NN}g_{a_1\pi\gamma}}{q_\pi^2 - m_\pi^2}\bar{u}(p_3)\gamma_5 u(p_2)\left(g^{\mu\nu} - \frac{p_1^\mu q_{a_1}^\nu}{p_1\cdot q_{a_1}}\right)$$
$$\times \varepsilon_\nu(p_1)G^{a_1}_{\mu\sigma}(q_{a_1})F_{\pi NN}(q_\pi)F_{a_1\rho\pi}(q_{a_1})(g_{\rho\pi}g)$$
$$\times\Big(G^{\sigma\lambda}_\rho(p_6+p_7)(p_7-p_6)_\lambda F_{\rho\pi\pi}(p_6+p_7)$$
$$+(G^{\sigma\lambda}_\rho(p_5+p_7)(p_7-p_5)_\lambda F_{\rho\pi\pi}(p_5+p_7)\Big). \quad (18)$$

3.2 $\gamma p\to\rho^0 p\to\pi^-\pi^+p\to\pi^+\pi^+\pi^-n$ reaction

Besides the resonance contribution of the $a_1(1260)$ resonance, we study another kind of reaction mechanism for the $\gamma p\to\pi^+\pi^+\pi^-n$ reaction, which is depicted in Fig. 4, where we have considered the contribution from $\gamma p\to\rho^0 p\to\pi^+\pi^-\pi^+n$. In Fig. 4, the relevant kinematic variables are also shown.

To compute the contribution of Fig. 4, we take the interaction density for $\rho\gamma\pi$ as [49, 50],

$$\mathcal{L}_{\rho\gamma\pi} = \frac{eg_{\rho\gamma\pi}}{m_\rho}\epsilon^{\mu\nu\alpha\beta}\partial_\mu\rho_\nu\partial_\alpha A_\beta\pi, \quad (19)$$

where A_β,π and ρ_ν denote the fields of the photon, π and ρ, respectively. The coupling constant $g_{\rho\gamma\pi}$ can be obtained from the experimental decay width $\Gamma_{\rho^0\to\pi^0\gamma}$ [26] , which leads to $g_{\rho\gamma\pi}=0.76$.

Other vertexes are the same as given above. With the above preparation, we get the transition amplitude for the diagram shown in Fig. 4,

$$\mathcal{M}_{II} = \frac{-\sqrt{2}g_{\pi NN}g_{\pi NN}}{q_\pi^2-m_\pi^2}\frac{eg_{\rho\gamma\pi}}{m_\rho}gF_{\pi NN}(q_\pi)\bar{u}(p_3)\gamma_5$$
$$\times\Bigg(\frac{(\not{p}_3+\not{p}_5)+m_p}{(p_3+p_5)^2-m_p^2}\gamma_5 u(p_2)F_N(p_3+p_5)\epsilon^{\mu\nu\alpha\beta}$$
$$\times(p_6+p_7)_\alpha p_{1\beta}\epsilon_\nu G^{\mu\sigma}_\rho(p_6+p_7)(p_7-p_6)_\sigma F_{\rho\pi\pi}(p_6+p_7)$$
$$+\frac{(\not{p}_3+\not{p}_6)+m_p}{(p_3+p_6)^2-m_p^2}\gamma_5 u(p_2)F_N(p_3+p_6)\epsilon^{\mu\nu\alpha\beta}(p_5+p_7)_\alpha$$
$$\times p_{1\beta}\epsilon_\nu G^{\mu\sigma}_\rho(p_5+p_7)(p_7-p_5)_\sigma F_{\rho\pi\pi}(p_5+p_7)\Bigg), \quad (20)$$

with

$$F_N(q_p) = \frac{\Lambda_N^4}{\Lambda_N^4+(q_p^2-m_p^2)^2}, \quad (21)$$

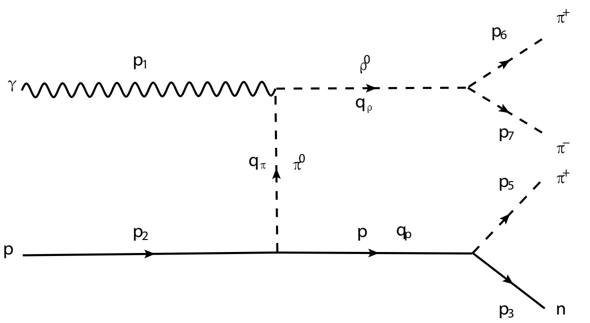

Fig. 4. Feynman diagram for the $\gamma p\to\rho^0\pi^+n\to\pi^+\pi^+\pi^-n$ reaction via π exchange.

where $\Lambda_\pi=0.6$ GeV and $\Lambda_N=0.5$ GeV are taken from Refs. [49, 50, 51]. This choice of the cut-off leads to a satisfactory explanation of the ρ^0 photoproduction at low energies. Note that the value of Λ_π is different from the one we used for the $\gamma p\to na_1(1260)^+$ production. Other cut-off parameters are the same as given above.

3.3 Numerical results

The total cross-section of the $\gamma p\to\pi^+\pi^+\pi^-n$ reaction can be obtained by integrating the invariant amplitude in the four-body phase space:

$$d\sigma(\gamma p\to\pi^+\pi^+\pi^-n) = \frac{1}{2!}\frac{2m_p\cdot 2m_n}{4|p_1\cdot p_2|}\left(\frac{1}{4}\sum_{\rm spins}|\mathcal{M}|^2\right)$$
$$\times(2\pi)^4 d\phi_4(p_1+p_2;p_3;p_5,p_6,p_7), \quad (22)$$

with

$$\mathcal{M} = \mathcal{M}_I+\mathcal{M}_{II}, \quad (23)$$

where 2! is a statistical factor for the final two π^+ mesons, and the four-body phase space is defined as [26]

$$d\phi_4(p_1+p_2;p_3;p_5,p_6,p_7) =$$
$$-\frac{1}{16(2\pi)^8\sqrt{s}}|\vec{p}_6^{\,*a}||\vec{p}_5^{\,*b}||\vec{p}_3|d\Omega_6^{*a}d\Omega_5^{*b}d\Omega_3 dM_{\pi^+\pi^-}dM_{\pi^+\pi^+\pi^-}, \quad (24)$$

where $|\vec{p}_6^{\,*a}|$ and Ω_6^{*a} are the three-momentum and solid angle of the out-going π^+ in the c.m. frame of the final $\pi^+\pi^-$ system, $|\vec{p}_5^{\,*b}|$ and Ω_5^{*b} are the three-momentum and solid angle of the out-going π^+ in the c.m. frame of the final $\pi^+\pi^+\pi^-$ system, and $|\vec{p}_3|$ and Ω_3 are the three-momentum and solid angle of the out-going n in the c.m. frame of the initial γp system. In the above equation, $M_{\pi^+\pi^-}$ is the invariant mass of the $\pi^+\pi^-$ two body system, and $M_{\pi^+\pi^+\pi^-}$ is the invariant mass of the $\pi^+\pi^+\pi^-$ three body system, and $s=(p_1+p_2)^2$ is the invariant mass squared of the initial γp system.

In Ref. [33], the $\gamma p\to\pi^+\pi^+\pi^-n$ reaction was studied in the photon energy range 4.8 – 5.4 GeV. The 3π mass distributions are measured from the $1^{++}(\rho\pi)_S$ partial wave. In Fig. 5, we show the theoretical results, $c_1 d\sigma/dM_{\pi^+\pi^+\pi^-}$, for the $\pi^+\pi^+\pi^-$ invariant mass distributions for the $\gamma p\to\pi^+\pi^+\pi^-n$ reaction at $E_\gamma=5.1$ GeV, compared with the experimental measurements of Ref. [33]. The theoretical results are obtained with $c_1=21.5$ and $c_1=18$ for $M_{a_1}=1080$ and 1230 MeV, respectively, which have been adjusted to the experimental data reported by the CLAS collaboration [33]. From Fig. 5, it is seen that the bump structure around 1.4 – 1.6 GeV may account for the nuclear pole contribution. If we use $M_{a_1}=1080$ MeV, the $\pi^+\pi^+\pi^-$ invariant mass distributions agree well with the experimental data. On the other hand, the theoretical results with $M_{a_1}=1230$ MeV can not describe the bump structure around 1.1 GeV.

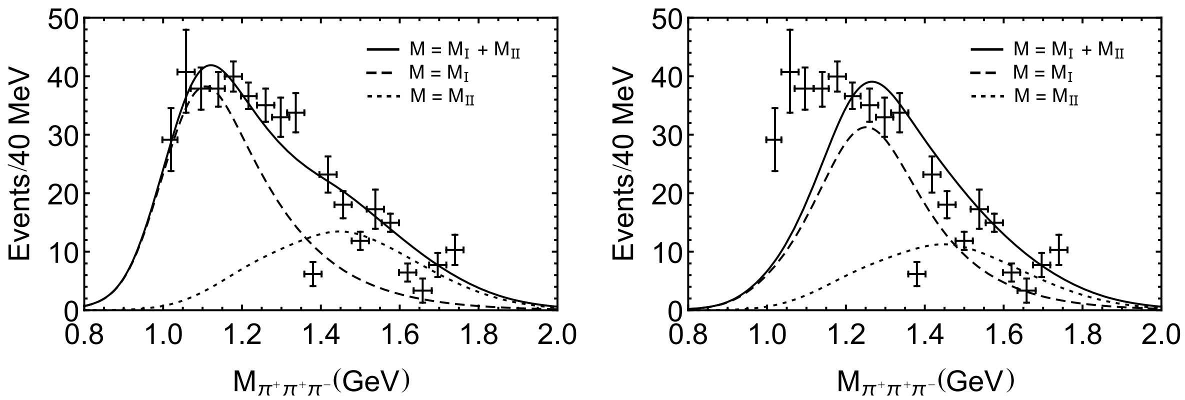

Fig. 5. The 3 π invariant mass spectrum for the $\gamma p \to \pi^+\pi^+\pi^- n$ process compared with the data obtained by the CLAS collaboration from the $1^{++}(\rho\pi)_S$ partial wave [33]. Left and right plots correspond to M_{a_1} = 1080 and 1230 MeV , respectively.

In addition to the differential cross-section, we also calculated the total cross-section for the $\gamma p \to \pi^+\pi^+\pi^- n$ process as a function of the photon beam energy E_γ. The results are shown in Fig. 6, where one can see that the total cross-section increases rapidly near the threshold, and the peak of the total cross-section is at $E_\gamma = 2.5$ and 2.9 GeV corresponding to M_{a_1} = 1080 and 1230 MeV, respectively. The differential and total cross-sections could be checked in future experiments, such as those at CLAS.

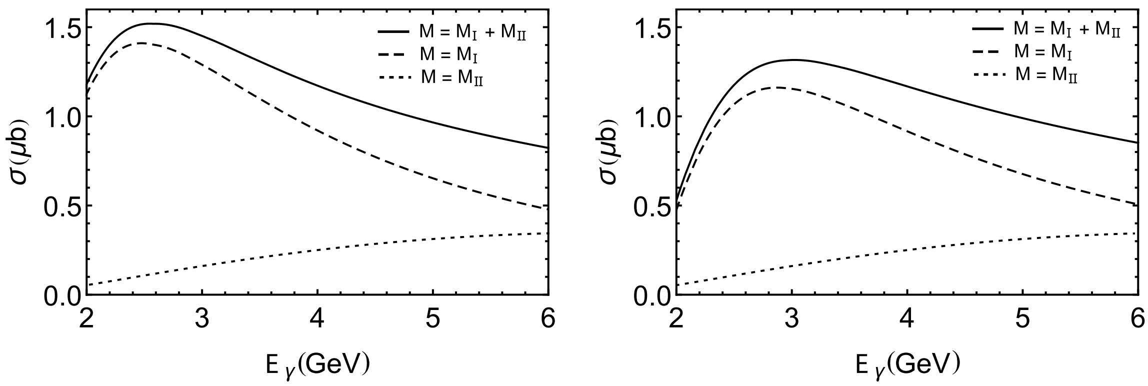

Fig. 6. Total cross-section for the $\gamma p \to \pi^+\pi^+\pi^- n$ process. Left and right plots correspond to M_{a_1} = 1080 and 1230 MeV , respectively.

4 Conclusion and discussion

In recent years, it has been found that the $a_1(1260)$ resonance, although long accepted as an ordinary $q\bar{q}$ state, can be dynamically generated from the pseudoscalar-meson-vector-meson interaction, and therefore qualify as a pseudoscalar-vector molecule. In this work, we have proposed to study the $a_1(1260)$ resonance in the photoproduction process. Since $a_1(1260)$ was observed in the radiative decay of $a_1(1260)^+ \to \pi^+\gamma$, the $\gamma p \to a_1(1260)^+ n$ reaction by π meson exchange is the main process for producing $a_1(1260)$. Our numerical results show that the total cross-section of $\gamma p \to a_1(1260)^+ n$ is of the order of 10 μb, which is comparable with the cross-section for photoproduction of $a_2(1320)$.

In addition, taking the coupling constant obtained from the picture where the $a_1(1260)$ resonance is a dynamically generated state from pseudoscalar-meson-vector-meson interaction, the $\pi^+\pi^+\pi^-$ invariant mass distributions from the $\gamma p \to \pi^+\pi^+\pi^- n$ reaction were studied. With M_{a_1} = 1080 MeV, we can describe the experimental data for the $\pi^+\pi^+\pi^-$ invariant mass distributions fairly well. The total cross-section of the $\gamma p \to \pi^+\pi^+\pi^- n$ reaction was also studied using the model parameters determined from a comparison with the experimental data for the $\pi^+\pi^+\pi^-$ invariant mass distributions. It is expected that our model calculations could be tested by future experiments with the $\gamma p \to \pi^+\pi^+\pi^- n$ reaction at the photon beam energy E_γ around 2.5~2.9 GeV.

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