Analysis of photoproduction data on $\gamma p \to p f_1 (1285)$ and $\gamma p \to \eta p(958)$ from the reaction $\gamma p \to p \eta \pi^+ \pi^-$

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We investigate the reaction $\gamma p \to p f_1 (1285)$ in a simple $\rho + \omega$ Reggeon exchanges. As the decay mode $\eta (1295) \to \eta \pi^+ \pi^-$ is potentially overlapped with the former reaction, a combined analysis of $\gamma p \to p f_1 (1285)$ is performed to find that the measured cross sections for $f_1$ and $f_1$ are well explained by the vector meson exchanges with a correction by the branching fraction to $f_1 \to \eta \pi^+ \pi^-$, respectively. The numerical consequences show that $f_1 (1295)$ cross section is negligible in the reconstruction of $f_1$ cross section from $\gamma p \to p \eta \pi^+ \pi^-$. 

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I. INTRODUCTION

Understanding the structure of hadrons on the basis of QCD has become current topics in the study of hadron reactions by electromagnetic and mesonic probes [1, 2]. Ideas of measuring the soft gluon contribution in addition to valence quarks in hadrons are suggested for finding evidences of quark and gluon dynamics in these reactions. The Lattice QCD predicts for the existence of exotic meson states $|q \bar{q} G >$ which have the quantum numbers of $J^{PC} = 0^+, 1^-$, and $2^-$ by the known excitation $\eta$. Therefore, searching for the exotic mesons of such quantum numbers in experiments could offer a chance to study the gluon dynamics in the meson structure more than the conventional picture of the $|q \bar{q} >$ state.

Recent report of the differential cross sections for $\gamma p \to p f_1 (1285)$ measured from the reaction $\gamma p \to p \eta \pi^+ \pi^-$ by the CLAS collaboration at the Jefferson Lab [4] draw attention, not only because it is the first time measurement of cross sections in experiment, but also because it could provide a physical ground on which a new state of hadrons, $\pi_1$ is investigated with the expected decay mode to $\pi_1 \to \eta \pi$ via the reaction $\gamma p \to \pi_1 \Delta \to p \eta \pi^+ \pi^-$ [4], though the process may requires a different kinematical channel to trace. From the theoretical point of view, the axial vector meson $f_1 (1285) 0^+(1^{++})$ itself is, of course, an interesting object because it is related with the QCD gluon anomaly as discussed in Ref. [2]. The special feature of the $f_1$ trajectory plays the role similar to Pomeron exchange at high energies in photoproductions of lighter vector mesons $\omega$ and $\phi$ [2, 3]. Nevertheless, in this work we would rather regard the reaction $\gamma p \to p f_1$ emerging from the final state $p \eta \pi^+ \pi^-$ to be of value for testing such a possibility of finding the exotic meson $\pi_1$ of $1^{++}$. 

With this in mind, it is, thus, of significance to study photoproduction of $f_1$ based on the CLAS data, prior to initiate investigation of exotic $\pi_1$ in the aforementioned reaction process. We recall that the $f_1 (1285)$ data were extracted in experiment by assuming the negligence of interference between $f_1 (1285)$ and $\eta (1295)$ photoproductions. From the Particle Data Group (PDG) the sort of $\eta$ and $\eta (1295)$ is another source of the decay mode to $\eta \pi^+ \pi^-$ as well as $f_1 (1285)$ the reactions $\gamma p \to \eta f_1$ and $\eta (1295)$ could be involved through the channel, $\gamma p \to p f_1 \to p \pi^+ \pi^-$ and $\eta (1295)$, likewise. Thus, we begin with a review of photoproductions of these $\eta$’s in the framework where $\rho + \omega$ exchanges are known to play a role. We then apply them to an analysis of $f_1$ photoproduction within the same framework, while the reliability of model predictions confirmed by the numerical consequences from the previous reaction processes.

As the threshold energies of the exclusive processes $\gamma p \to \eta p(1295)$ and $\gamma p \to p f_1 (1285)$ are over the region $\sqrt{s}_{\text{thres}} \approx 2.2$ GeV, the contribution of nucleon resonances in the direct and crossed channels are less significant to these reactions, and hence, it is good to consider only the $t$-channel meson exchange for the description of these reactions. The C-parity even property of $\eta$ as well as $f_1$ meson allows the mesons of C-parity odd to exchange and, in order to compare with existing model predictions [8] we consider only the $\rho + \omega$ exchanges, but exclude exchanges of axial vector mesons $b_1$ and Primakoff effect. In actual, inclusion of the $b_1$ meson leads to a large uncertainty in the model prediction, because of their unknown coupling constants. The primakoff effect is highly suppressed in comparison to $\rho$ and $\omega$ exchanges with $\gamma \gamma f_1$ coupling constant from PDG.

This paper is organized as follows: In Section II, photoproduction of $\eta$, $\eta'$ and $\eta (1295)$ on proton target are investigated in the Reggeized model for $\rho + \omega$ exchanges. Sec. III devotes to an analysis of the exclusive $f_1$ photoproduction on proton from the photoproduction reaction $\gamma p \to p \eta \pi^+ \pi^-$ within the same approach as in Sec. II. Predictions for the energy dependence of differential cross section and the beam polarization asymmetry are presented to distinguish between the reactions aforementioned for future experiment. Summary and conclusions are given in the Section IV.
II. PHOTOPRODUCTIONS OF $\eta(548)$, $\eta'(958)$, AND OF $\eta(1295)$ ON PROTON

In this section we treat the photoproduction of $\eta'$ and $\eta(1295)$ in a single framework where the vector meson exchange is reggeized with vector meson nucleon coupling constants common in these reactions. For consistency, let us start from $\gamma p \rightarrow p\eta(548)$ to provide a basic formalism with a discussion about the respective radiative decay constants for the different masses of $\eta$'s estimated from the respective decay widths.

For the exclusive $\eta$ photoproduction on nucleon,

$$\gamma(k) + N(p) \rightarrow \eta(q) + N(p')$$  \hspace{1cm} (1)

we denote the particle momenta $k$, $q$, $p$ and $p'$ to stand for the incident photon, outgoing $\eta$ meson, and the initial and final nucleons, respectively. $s = (p + k)^2$ and $t = (q - k)^2$ are the Mandelstam variables in the reaction kinematics. We restrict our discussion only to the production mechanism by the meson exchanges, as depicted in Fig. 1 for our purpose here is to see how the meson exchanges work well in the kinematical region of $\eta(1295)$ and $J_1 (1285)$ photoproductions.

By $C$-parity even property of $\eta$, the exchanges of $C$-odd vector mesons are allowed and the production amplitude is written as,

$$M(N \rightarrow \eta N) = \pm \rho + \omega,$$  \hspace{1cm} (2)

with the sign of $\rho$ for proton and neutron, respectively.

The effective Lagrangians for the vector meson exchange is written as

$$\mathcal{L}_{VNN} = \bar{N} \left( g_{VNN}^\rho \gamma^\mu + \frac{g_{VNN}^{\omega}}{2M} \gamma^{\mu\nu} \partial_{\nu} \right) V_{\mu} N$$  \hspace{1cm} (3)

and the corresponding production amplitude is given by

$$\mathcal{M}_V = \frac{g_{VNN}}{m_0} \epsilon_{\mu
u\alpha\beta} F^{\mu
u} \gamma^{\alpha\beta} \eta + \text{H.c.},$$  \hspace{1cm} (4)

where $\alpha$ is the incident photon polarization and $Q = q - k$ is the momentum in the $t$-channel.

The Regge pole for spin-1 vector meson is given by

$$\mathcal{R}^V(s,t) = \frac{\pi \alpha'_V \times \text{phase}}{\Gamma_{\alpha V}(t) \sin \pi \alpha_V(t)} \left( \frac{s}{s_0} \right)^{-\alpha_V(t) - 1}$$  \hspace{1cm} (5)

which is written collectively for $V = (\rho, \omega)$.

The choice of $\rho$ trajectory is unambiguous. From the reactions [12, 13] where the single $\rho$ exchange is involved to test its role, we take $\rho$ trajectory given below with the coupling constants $g_{\rho NN}^{\rho} = 2.6$ and $g_{\rho NN}^{\omega} = 9.62$. We use

$$\alpha_{\rho}(t) = 0.9t + 0.46,$$  \hspace{1cm} (7)

$$\alpha_{\omega}(t) = 0.9t + 0.44,$$  \hspace{1cm} (8)

for $\omega$ trajectory as well throughout the present calculation.

The radiative decay constant $g_{\gamma \eta V}$ is normalized by the parameter $m_0$ of the mass dimension chosen to be 1 GeV. The constants $g_{\gamma \eta V}$ is determined from the measured decay width,

$$\Gamma_{\gamma \rightarrow \eta V} = \frac{1}{96\pi} \frac{g_{\gamma \eta V}^2}{m_0} \left( \frac{m_0}{m_V} \right)^3.$$  \hspace{1cm} (9)

For the process $\gamma p \rightarrow p\eta'$ and $\gamma p \rightarrow p\eta(1295)$ in which cases the $\eta'$ ($\eta(1295)$) decays to vector meson the decay width in Eq. (9) is modified by changing $m_V$ to $m_{\eta'} (m_{\eta(1295)})$ and vice versa with the factor of 3 multiplied for the recovery of $\eta'$ ($\eta(1295)$) spin degrees of freedom.

Given the similar trajectories in Eqs. (7) and (8) with the ratio of decay widths, $\sqrt{\frac{\Gamma_{\gamma \rightarrow \eta V}}{\Gamma_{\gamma \rightarrow \eta' V}}} \propto \frac{g_{\gamma \eta V}}{g_{\gamma \eta'} V}$, with the ratio between $2g_{\rho NN}^{\rho}/g_{\omega NN}^{\rho}$ $\simeq$ 3, and the ratio between $2g_{\rho NN}^{\rho}/g_{\omega NN}^{\rho}$ $\simeq$ 1/3, the contributions of $\rho$ and $\omega$ are quite the same with each other, if the same phase is taken. This is similar to $\eta'$ and $\eta(1295)$. We choose the complex phase $e^{-i\alpha_{\eta V}(t)}$ for both $\rho$ and $\omega$ Reggeons, which agrees with the general features of differential cross sections and keep these phases in photoproductions of all $\eta$'s on proton target for consistency. For the reaction $\gamma n \rightarrow n\eta$, we take the constant phase 1 for $\rho$, and $-1$ for $\omega$ Reggeons for a better description of the total cross section.

In Fig. 2 we present the scaled differential, beam polarization, and total cross sections for $\gamma p \rightarrow p\eta$, and total

![FIG. 1. $\rho$ and $\omega$ exchanges in the exclusive $\eta$ photoproduction. $t$-channel momentum $Q = q - k$.](image-url)

| Table I: Coupling constants $g_{\gamma \eta V}/m_0$ used for the eta-maid [20] and Regge model [9] for $\eta$ photoproduction are listed for comparison. |
|-----------------|-----------------|-----------------|
| $g_{\eta \rho}$ | 0.448 | 0.448 |
| $g_{\eta' \rho}$ | 0.392 | 0.36 |
| $g_{\eta(1295) \rho}$ | - | 0.0566 | 0.0566 |
| $g_{\eta \omega}$ | 2.4 | 3.9 | 2.6 |
| $g_{\eta' \omega}$ | 8.88 | 23.79 | 9.62 |
| $g_{\eta(1295) \omega}$ | - | 0.0189 | 0.0189 |
| $g_{\rho NN}^{\omega}$ | 9 | 15.6 |
| $g_{\rho NN}^{\omega}$ | 0 | 0 |
| $g_{\rho NN}^{\omega}$ | 0 | 0 |

For the process $\gamma p \rightarrow p\eta'$ and $\gamma p \rightarrow p\eta(1295)$ in which cases the $\eta'$ ($\eta(1295)$) decays to vector meson the decay width in Eq. (9) is modified by changing $m_V$ to $m_{\eta'} (m_{\eta(1295)})$ and vice versa with the factor of 3 multiplied for the recovery of $\eta'$ ($\eta(1295)$) spin degrees of freedom.
In practice, the determination of the radiative coupling constant is crucial to agree with the overall size of cross sections. On the other hand, most of Regge calculations for η photoproduction introduce hadron form factors at γηV and VNN coupling vertices to fit the Reggeon contributions to experimental data. However, it is natural to apply the Reggeon exchange without hadron form factors, because it contains the gamma function F(αV(t)) in Eq. (6) to suppress the singularity from the sequential zeros of sin παV(t). Thus, avoiding such a model dependence from the cutoff masses, we do without form factors and this will turn out to be more beneficial, when we deal with the models of Refs. [9, 10] with hadron form factors which are hard to predict a consistent result with the CLAS data. This point will be illustrated in Figs. 5 and 6.

In the next we calculate the exclusive γp → pη′ and η(1295) within the same framework. However, in order to compare with the CLAS data on γp → η(958)p → pηπ+π−, we consider the branching ratio Γ_{η′→ηπ+π−}/Γ_{η→ηπ+π−} ≈ 43%, from PDG which implements a reduction by an overall factor of 0.43 to the exclusive production cross section. In Table II we list the coupling constants compiled for the η′ and η(1295) in addition to η photoproduction above. For the physical status of η(1295) only the mass m_η(1295) = 1294 ± 4 MeV and decay width Γ_{η(1295)} = 55 ± 5 MeV are known. Thus, we follow the coupling constants those deduced from Ref. [9] to calculate total cross section with the same ratio of the
reduction as in the case of $\eta'$. Figures 3 and 4 show the differential and total cross section for $\eta'$ and total cross section for $\eta(1295)$ for comparison. The data on differential cross sections are from the CLAS measurement and the corresponding data are integrated out to obtain total cross section without error bars. These reaction cross sections are scaled, as discussed above. The shape of angular distribution is reproduced to a degree. Nevertheless, the underestimation of differential data below $\sqrt{s} \approx 2.55$ GeV implies that the $t$-channel exchanges are insufficient and the backward rise of the cross section below the energy region needs the contribution of baryon resonances in the $u$-channel, as shown in Fig. 4.

As for the total cross sections in Fig. 4, we first note that the slope of the CLAS cross section is not consistent with the model prediction, apart from the deviation of the cross section below $E_\gamma \approx 2$ GeV due to the absence of $N^*$ resonances. Rather, our model prediction is consistent with the AHMM cross section 16 as shown by the dashed curve which is uncorrected. Within the present framework the $\eta(1295)$ cross section is much smaller than the $\eta'$ by two orders of magnitude by the coupling constants deduced from Ref. 4. Thus, it seems reasonable to assume the negligence of the $\eta(1295)$ production in the data analysis for $f_1$ production from the reaction $\gamma p \rightarrow p\eta\pi^+\pi^-$, as performed by the CLAS Collaboration.

III. $f_1(1285)$ PHOTOPRODUCTION ON PROTON

From the study of the $f_1(1285)$ in $\gamma p \rightarrow p\eta\pi^+\pi^-$ at CLAS, the structure of $f_1(1285)$ at $m_\pi \approx 1280$ MeV was observed in the $\gamma p$ missing mass spectrum with a great statistic $\approx 1.5 \times 10^5 \times (1280)$ events. As the $\eta(1295)$ as well as $f_1(1285)$ are decaying to $\pi\pi\pi$, care must be taken for the potential overlap with each other to extract the structure associated with the $f_1(1285)$ with $p$-wave decay and positive parity from the Dalitz analysis of $x \rightarrow \eta\pi^+\pi^-$. The CLAS experiment leads to a conclusion on $f_1$ with mass $m_{f_1} = 1281.0 \pm 0.8$ MeV and width $\Gamma_{f_1} = 18.4 \pm 1.4$ MeV narrower than PDG value 24.2$\pm$1.1 MeV.

In theoretical sides, Kochelev 3 and Domokos 10 calculated the reaction cross section for the exclusive $\gamma p \rightarrow pf_1$ by using the Reggeized model where the $\rho$ and $\omega$ vector meson exchanges are considered in the $t$-channel. The $\rho$ and $\omega$ exchanges in the $t$-channel is depicted in Fig. 4 with the produced $f_1$ meson instead of $\eta$. However, due to the large decay width $\Gamma_{f_1} = 1.33$ MeV from PDG, and the large coupling constant $g_{\rho\rho f_1} = 0.94$ GeV$^{-2}$ as a result leads to a difficulty from these models to reproduce the experimental cross sections. For this reason, they employed hadron form factors to suppress overestimation of model calculations. Avoiding model dependence such as the cutoff mass with form factors, we, here, consider the decay width to be 453 keV recently listed in the PDG as well. We then demonstrate how the production mechanism is explained to accommodate the CLAS data, while comparing our results with those of Kochelev’s. It is legitimate to consider the $t$-channel meson exchange as in Fig. 1 for the description of the features of production mechanism, because the threshold energy of the reaction is $\sqrt{s}_{\text{thres}} \approx 2.2$ GeV, high enough to neglect the nucleon resonances. (This might be a contradiction to a conclusive remark that there contributes nucleon resonances based on the lack of Kochelev’s and other hadron model predictions in the analysis by the CLAS Collaboration.)

The photon-axial vector meson-vector meson coupling vertex is given by

$$\Gamma_{\gamma V A} = \frac{g_{\gamma V A}}{m_\rho^2} Q^2 \epsilon_{\mu\nu\alpha\beta} \xi'(q) \epsilon^\nu(k) k^\alpha q^\beta(Q), \quad (10)$$

where $\xi'(q)$, $\eta'(Q)$ are spin polarizations of axial vector meson and vector meson of momenta, $q$, and $Q$, respectively. $m_\rho^2 = 1$ GeV$^2$ is the dimensionful parameter for the normalization of the radiative decay constant. Given the $VNN$ coupling vertex in Eq. 3, the vector meson exchange is now written as

$$\mathcal{M}_V = \frac{g_{\gamma V NN}}{m_\rho^2} Q^2 \epsilon_{\mu\nu\alpha\beta} \xi'(q) (-g^{\alpha\lambda} + Q^\beta Q^\lambda/m_\rho^2) \times \pi(p') \left( g_{VNN} \gamma^\lambda + \frac{g_{\gamma V NN}(\gamma, Q)}{4M} \right) R^V(s,t) u(p). \quad (11)$$

The decay width from the coupling vertex Eq. (10) is given by

$$\Gamma_{A \rightarrow V \gamma} = \frac{1}{96\pi} \frac{g_{\gamma V A}^2 m_\rho^2}{m_A^2} (m_A^2 + m_V^2)(m_A^2 - m_V^2)^3. \quad (12)$$

The empirical width $f_1 \rightarrow \rho^0 \gamma$ is currently at large. Theoretical estimate based on the QCD inspired models such as the Constituent quark model 21 and the Four quark model 21 suggests half the values reduced to the current PDG fit. Moreover, the width 453 $\pm$ 177 keV extracted from the CLAS experiment supporting these smaller values as shown in Table III. Keeping the ratio of $g_{\gamma \rho f_1}/g_{\gamma \omega f_1}$ as 3 as from the relevant decay width in the Table, we take the CLAS width for $\rho$ and the Relativistic quark model width for $\omega$, which is close to the CLAS width. Given the decay widths aforementioned, the angular distribution of the CLAS differential data favors $e^{-1^{*\omega}(s)}$ for $\rho$ and $1/2(-1 + e^{-1^{*\rho}(s)})$, for $\omega$, respectively. Hence, the dominance of $\rho^0$ exchange is expected in the $f_1$ photoproduction.

The differential cross sections for $\gamma p \rightarrow pf_1 \rightarrow p\eta\pi^+\pi^-$ are presented in Fig. 5 which are not corrected by the fraction $\Gamma_{f_1 \rightarrow \pi^+\pi^-}/\Gamma_{f_1 \rightarrow \text{all}}$ in the measurement, because of the insensitivity of the CLAS detector to $4\pi$ and charged neutral decay modes. Nevertheless, in order to describe the single $\gamma p \rightarrow pf_1$ from the data with such $\eta\pi^+\pi^-$ mesons in the final state, we have to consider a scaling of the cross section by the fraction $\Gamma_{f_1 \rightarrow \pi^+\pi^-}/\Gamma_{f_1 \rightarrow \text{all}} \approx 0.35$, similar to the case of $\eta'$ photoproduction in the previous section. The roles of $\rho$ and
TABLE II. Estimates for $\gamma AV$ coupling constants from decay widths given in unit of keV in Ref. [4], Ref. [21], Ref. [22], and PDG. $g_{\gamma f_1} = 0.59^a, 0.45^b$ and $0.94^c$. $g_{\gamma \omega f_1} = 0.152^d$.

| $g_{\gamma AV}$ | CLAS [4] | CQM [21] | 4quark [22] | PDG |
|------------------|-----------|-----------|--------------|-----|
| $f_1 \rightarrow \rho \gamma$ | 0.54$^a$ | 453$^a$ | 509$^b$ | 311$^c$ | 1330$^d$ |
| $f_1 \rightarrow \omega \gamma$ | 0.18$^b$ | - | 48$^b$ | 34.3$^c$ | - |

FIG. 5. Differential cross section for $\gamma p \rightarrow f_1 p \rightarrow \eta(1295)$ for reference. The cross section is scaled by a factor of 0.35 which is the ratio $\Gamma_{f_1 \rightarrow \eta(1295)} / \Gamma_{f_1 \rightarrow \eta'}$. The dashed and dotted curves at $\sqrt{s} = 2.55$ GeV are the contributions of $\rho$ and $\omega$ exchanges, respectively. Data are taken from Ref. [4]. From the angular distribution of the cross sections, the complex phase for the $\rho$ Reggeon is mandatory. The Green dash-dotted is from Kochelev with $\Lambda_2 = 1.2$ and $\Lambda_2 = 1.4$ GeV and $n = 1$ for $\gamma V f_1$ form factor.

FIG. 6. Total cross section for $\gamma p \rightarrow f_1 p \rightarrow \eta(1295)$. The data are obtained by integrating out the differential cross sections given in Fig. 5 for reference. The cross section is scaled by the same factor of scaling as in Fig. 4. The total cross section for $\gamma p \rightarrow \eta(1295)$ scaled by 43% is presented for comparison. The interference between $f_1$ and $\eta(1295)$ reactions is insignificant, even though the latter cross section is corrected.

FIG. 7. Energy dependence of differential cross sections for $\gamma p \rightarrow f_1 p$, $\gamma p \rightarrow \eta'$, and $\gamma p \rightarrow \eta(1295)$ from $\gamma p \rightarrow \eta \eta(1295)$. The cross sections versus $\sqrt{s}$ are predicted at the production angle $\theta = 40^\circ$ in the center of mass system.

$\omega$ are displayed at $\sqrt{s} = 2.55$ GeV. As expected from the complex phase for $\rho$, it plays the role over the $\omega$ with no oscillatory behavior of the differential cross section $d\sigma/d\Omega$ consistent with the absence of nonsense zeros of $\omega$ trajectory. The original model of Kochelev makes a poor prediction for the CLAS data. To appreciate this model we introduce the form factors

$$\left(\frac{\Lambda_1^2 - m_2^2}{\Lambda_1^2 - t}\right)\left(\frac{\Lambda_2^2 - m_2^2}{\Lambda_2^2 - t}\right)^n$$

(13)

to the production amplitude in Eq. (11) with the trajectories and coupling constants following Kochelev. The (green) dash-dotted curve results from the model modified to be compatible with data by taking the cutoff masses $\Lambda_1 = 1.2$ and $\Lambda_2 = 1.4$ GeV with $n = 1$ for the form factor at the $\gamma V f_1$ vertex. It is found that angle dependence is too much suppressed due to the form factors and the reaction mechanism shows the complete dominance of $\rho$ exchange over the $\omega$, which is quite different from the present approach without form factors.

We show the total cross section in Fig. 6 where the data points are obtained by integrating out the differential data. The respective contributions of $\rho$ and $\omega$ exchanges are shown with the same notations. The cross sections of modified model of Kochelev yields the smaller cross section. The cross section for $\eta(1295)$ photoproduction with the size 43% reduced is shown for comparison. From these cross sections we agree with the negligence of $\eta(1295)$ component in the analysis of $f_1(1285)$ cross section.

For future studies on the search of exotic $\pi_1$ meson in the photoproductions with the multimesons $\eta \pi \pi$ in the final state, we present the energy dependence of differential cross section at the forward angle $\theta = 40^\circ$ (corresponding to a forward peak at $\cos \theta \approx 0.75$ and $\sqrt{s} = 2.75$ GeV in Fig. 6 in Fig. 7 to discern the $\pi_1(1400)$ cross sections from $\eta(958)$, $\eta(1295)$, and $f_1(1285)$ cross sections.
involved in the overlapped potential region. The discrimination between these reactions is more apparent in the beam polarization $\Sigma$ as can be seen in Fig. 8. As the present model includes only the natural parity exchanges of $\rho$ and $\omega$, the $\Sigma$ is positive definiteness for all the reactions. This trend would unaltered, even if the $b_1$ of the unnatural parity is considered. The difference of the $\Sigma$ between pseudoscalar and axial vector meson photoproduction reveals the different scheme for the interference between $\rho$ and $\omega$ Reggeons.

IV. SUMMARY

In summary we have investigated the $\eta'$ and $f_1(1285)$ photoproductions measured at the CLAS Collaboration based on the $\rho+\omega$ Reggeon exchanges. The observables of $\eta$ photoproduction is reproduced to confirm the validity of these vector meson contributions prior to an application to the $\eta'$ and $\eta(1295)$ photoproductions. To meet with the conditions from the $\eta\pi^+\pi^-$ final state off the proton target the reaction cross sections are corrected by the branching fraction to such a final decay mode. The Regge calculation of axial vector meson $f_1(1285)$ photoproduction was performed within the similar approach. It is found that the $\eta(1295)$ photoproduction is small enough to be neglected in the extraction of data points for the $f_1$ photoproduction from the multimeson reactions. Our model could reproduce the differential cross section to a good degree, if the 35% of branching ratio for $\eta\pi^+\pi^-$ and the decay width 453 keV are admissible for use. To demonstrate the analyzing capability to discern the photoproductions between pseudoscalar and axial vector mesons, energy dependence of differential cross sections and the beam polarization asymmetry were predicted. The difference of reaction mechanism between them yields a contrasting features to each other. These results shed light on the possibility of searching exotic mesons via multimeson photoproductions on nucleon target as planned at the CLAS 12 upgrade for future experiments.

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