Nucleon resonance production in the $\gamma p \to p\eta\phi$ reaction

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In this work, we perform a study of nucleon resonance production in the $\gamma p \to p\eta\phi$ reaction within an effective Lagrangian approach. In our model, we consider the excitation of the $N^*(1535)$, $N^*(1650)$, $N^*(1710)$, and $N^*(1720)$ in the intermediate state and the background term. We find that this reaction is dominated by the excitation of the $N^*(1535)$ in the near threshold region. Especially, we study the possible role of the scalar meson exchange in this reaction. It is found that the $f_0(980)$ exchange may give a significant contribution and the parity asymmetry can be used to identify its role in this reaction.

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I. INTRODUCTION

To study the properties of nucleon resonance is a central task in hadronic physics. Despite decades of studies of the nucleon resonances, there are still some controversies involving the nature and structure of some nucleon resonances. One outstanding example is the $N^*(1535)$. In addition to the conventional three quark picture, there are evidences that in the $N^*(1535)$ there may be a large mixture of the three-quark and the molecular or pentaquark components [1,2]. In the new picture, one can not only naturally explain why the $N^*(1535)$ has a strong coupling to $N\eta$ but also predict a large coupling of this resonance with other strange channels [3]. To verify these theoretical models and their predictions, it is necessary to study this resonance in various reactions.

In recent years, the photoproduction processes are widely employed to investigate the properties of nucleon resonance [4–8]. Until now, most of these studies concentrate on the single-meson production process. However, studying nucleon resonance in some multimeson production processes is also interesting and can benefit the understanding of the properties of nucleon resonances. For example, in Ref. [9] it was shown that, due to the special reaction mechanisms, the reaction $\gamma p \to \phi K^+\Lambda$ is suitable for studying the $N^*(1535)K\Lambda$ coupling which is difficult to be studied in the single-meson production process. Such example tells us, by inspecting the production mechanisms of nucleon resonance in multimeson production processes, it is possible to learn about their couplings with various channels [9,10]. Therefore, these studies are helpful for us to better understand the nature and properties of the N^*s.

In this paper, we present the results for the study of the $\gamma p \to \eta\phi p$ reaction using an effective Lagrangian approach. We consider the contributions from the $N^*(1535)$, $N^*(1650)$, $N^*(1710)$, and $N^*(1720)$ in the intermediate state, which then decay into the ηN in the final state. The resonance contribution in the $\phi\eta$ and ϕp channels is ignored in this work, because in the energy region under study no significant resonance signals are found in these two channels [11]. According to this assumption, it seems that the present reaction may be a good place to study the excitation mechanisms of the nucleon resonances in the $\gamma p \to \phi N^*$ process since the decay process of $N^* \to \eta N$ is relatively well known. Such studies are not only important for understanding the reaction mechanism itself but also helpful for learning about the coupling of nucleon resonances with the exchanged particles. In the $\gamma p \to \phi N^*$ process, due to the conservation of C parity, vector-meson exchange is forbidden in this reaction. Since the involved nucleon resonances in this work have relatively large decay branch ratios to $N\pi$ and $N\eta$ channels, it is natural to expect that the π and η exchanges play important roles for the excitation of the N^*s in this reaction. While, there are still some other possible contributions from such as scalar meson[σ, $f_0(980)$ and $a_0(980)$] and axial vector-meson [$a_1(1235)$] exchanges. These contributions were usually ignored in previous studies due to their relatively large mass or the ignorance of their couplings with N^*s. Certainly, these assumptions should be verified by the experiments. In this work, we hope to address the role of $f_0(980)$, which is denoted by f_0 in the rest of the paper, for the excitation of the $N^*(1535)$ in this reaction. To evaluate the f_0 exchange contribution, the knowledge of the $\phi f_0\gamma$ and $N^*(1535)Nf_0$ couplings is essential. The $\phi f_0\gamma$ coupling can be extracted from the ϕ radiative decay to γf_0 [12]. While the coupling of the $N^*(1535)$ with Nf_0 was rarely studied in previous works. However, if the $N^*(1535)$ has a significant strange component and tends to have a strong coupling with strange channel, then it is possible that the $N^*(1535)$ also has a large coupling with the Nf_0 channel since the f_0 is believed to be a $K\bar{K}$ molecular state. If so, then this means that the present reaction may be a good place to look for the evidence of the $N^*(1535)Nf_0$ coupling. As for the $a_0(980)$ and $a_1(1235)$, we choose to ignore their contributions at present partially because their couplings to

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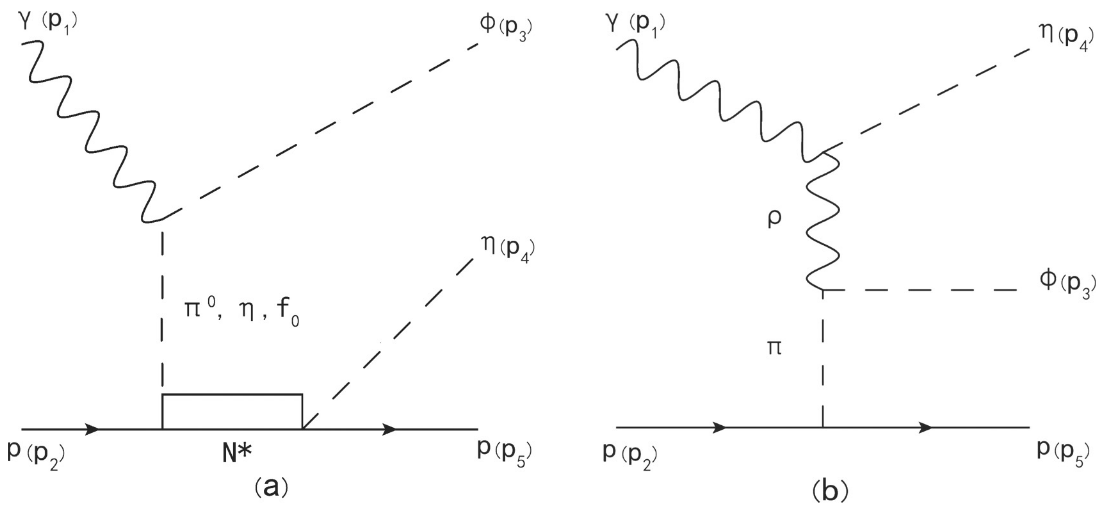

FIG. 1. Feynman diagrams for the $\gamma p \to \phi\eta p$ reaction.

the $N^*(1535)$ are totally unknown and partially because their couplings with $\phi\gamma$ are weak compared to the f_0 [11,13]. The other scalar meson σ is also ignored due to the weak coupling of the $\phi\gamma\sigma$ vertex [11,14]. The next important question is how to separate the scalar exchange contribution from the others. Inspired by some previous work [15,16], we find that the spin observable is very useful for this purpose. As we know, the spin density matrix elements (SDMEs) of the ϕ meson can be extracted from its decay angular distribution. By analyzing the SDMEs of the ϕ meson, it is possible to learn the information about the exchanged particles. Such a method was already used in Refs. [17,18] to identify the role of the scalar κ-meson exchange. In this work, we will show that the SDMEs may also offer useful information about the exchanged meson in the nucleon resonance production processes.

The rest of this paper is organized as follows. In Sec. II, we present the theoretical formalism used in the calculations. Numerical results and discussions are presented in Sec. III, followed by a summary in the last section.

II. MODEL

In our model, the Feynman diagrams for the $\gamma p \to \phi\eta p$ reaction can be depicted by Fig. 1. As mentioned in the Introduction, here we only consider the π, η, and f_0 exchanges for the excitation of nucleon resonances since other meson exchanges are either forbidden or expected to be unimportant.

To calculate the Feynman diagrams shown in Fig. 1, we need the Lagrangian densities for the various vertices. The following Lagrangian densities are employed in this work [9,19,20]:

$$\mathcal{L}_{\pi NN} = -\frac{g_{\pi NN}}{2m_N}\bar{N}\gamma_5\gamma_\mu\partial^\mu\pi N, \tag{1}$$

$$\mathcal{L}_{\gamma\pi\phi} = \frac{e}{m_\phi}g_{\phi\gamma\pi}\varepsilon^{\mu\nu\alpha\beta}\partial_\mu\phi_\nu\partial_\alpha A_\beta\pi, \tag{2}$$

$$\mathcal{L}_{\gamma\eta\phi} = \frac{e}{m_\phi}g_{\phi\gamma\eta}\varepsilon^{\mu\nu\alpha\beta}\partial_\mu\phi_\nu\partial_\alpha A_\beta\eta, \tag{3}$$

$$\mathcal{L}_{\rho_0\eta\gamma} = \frac{e}{m_\rho}g_{\rho\eta\gamma}\varepsilon^{\mu\nu\alpha\beta}\partial_\mu\rho_\nu\partial_\alpha A_\beta\eta, \tag{4}$$

$$\mathcal{L}_{\phi\rho_0\pi} = \frac{e}{m_\phi}g_{\phi\rho\pi}\varepsilon^{\mu\nu\alpha\beta}\partial_\mu\phi_\nu\partial_\alpha\rho_\beta\pi, \tag{5}$$

$$\mathcal{L}_{\phi f_0\gamma} = \frac{e}{m_\phi}g_{\phi f_0\gamma}\partial^\alpha\phi^\beta(\partial_\alpha A_\beta - \partial_\beta A_\alpha)f_0, \tag{6}$$

$$\mathcal{L}_{f_0NN^*_{1535}} = g_{f_0NN^*_{1535}}f_0\bar{N}\gamma_5N^* + \text{H.c.}, \tag{7}$$

$$\mathcal{L}_{MNN^*_{1535}} = ig_{MNN^*_{1535}}\bar{N}^*MN + \text{H.c.}, \tag{8}$$

$$\mathcal{L}_{MNN^*_{1650}} = ig_{MNN^*_{1650}}\bar{N}^*MN + \text{H.c.}, \tag{9}$$

$$\mathcal{L}_{MNN^*_{1710}} = -\frac{g_{MNN^*_{1710}}}{m_N + m_{N^*}}\bar{N}^*\gamma_5\gamma_\mu\partial^\mu MN + \text{H.c.}, \tag{10}$$

$$\mathcal{L}_{MNN^*_{1720}} = -\frac{g_{MNN^*_{1720}}}{m_M}\bar{N}^*_\mu\partial^\mu MN + \text{H.c.}, \tag{11}$$

where $e = \sqrt{4\pi/137}$, ϕ_μ is the ϕ-meson field, M denotes the π or η field, and A_μ is the photon field. The coupling constant $g_{\pi NN}$ is taken from Ref. [21,22] with $g_{\pi NN} = 13.45$. Other coupling constants can be determined through the following formulas:

$$\Gamma[V \to P\gamma] = \frac{e^2g^2_{VP\gamma}}{12\pi}\frac{|\vec{p}|^3}{m^2_\rho}, \tag{12}$$

$$\Gamma[\phi \to \rho_0\pi] = \frac{e^2g^2_{\phi\rho\pi}}{12\pi}\frac{|\vec{p}|^3}{m^2_\phi}, \tag{13}$$

$$\Gamma[\phi \to f_0\gamma] = \frac{e^2g^2_{\phi f_0\gamma}}{12\pi}\frac{|\vec{p}|^3}{m^2_\phi}, \tag{14}$$

$$\Gamma\left[N^*_{\frac{1}{2}^-} \to PN\right] = \frac{\kappa g^2_{PNN^*_{1/2-}}}{4\pi}\frac{(E_N + m_N)}{m_{N^*}}|\vec{p}|, \tag{15}$$

$$\Gamma[N^*_{1710} \to PN] = \frac{\kappa g^2_{PNN^*_{1710}}}{4\pi}\frac{(E_N - m_N)}{m_{N^*}}|\vec{p}|, \tag{16}$$

$$\Gamma[N^*_{1720} \to PN] = \frac{\kappa g^2_{PNN^*_{1720}}}{12\pi}\frac{(E_N + m_N)}{m_{N^*}m^2_P}|\vec{p}|^3, \tag{17}$$

where p denotes the magnitude of the momentum of final particles in the center-of-mass frame. P and V denote the

TABLE I. Coupling constants used in this work. The experimental decay branch ratios are taken from Ref. [11].

State	Width(MeV)	Decay channel	Adopt branching ratio	$g^2/4\pi$
ρ_0	147.8	$\eta\gamma$	3.0×10^{-4}	0.12
ϕ	4.25	$\pi\gamma$	1.3×10^{-3}	1.60×10^{-3}
		$\eta\gamma$	1.3×10^{-2}	3.97×10^{-2}
		$\rho\pi$	0.15	3.55
		$f_0\gamma$	3.2×10^{-4}	1.73
$N^*(1535)$	150	$N\pi$	0.42	3.43×10^{-2}
		$N\eta$	0.42	0.28
$N^*(1650)$	125	$N\pi$	0.60	3.73×10^{-2}
		$N\eta$	0.25	7.44×10^{-2}
$N^*(1710)$	140	$N\pi$	0.13	0.10
		$N\eta$	0.30	2.03
$N^*(1720)$	250	$N\pi$	0.11	2.04×10^{-3}
		$N\eta$	0.03	8.25×10^{-2}

pseudoscalar and vector meson, respectively. κ is a constant which equals 1 for the η exchange and 3 for the π exchange. The obtained coupling constants are listed in Table I.

As we are not dealing with pointlike particles here, the form factors are necessary to be introduced. In the present work, we choose the following form factor for the baryon exchange diagrams as in Refs. [23,24]:

$$F_B(q_{\rm ex}, m_{\rm ex}) = \frac{\Lambda_B^4}{\Lambda_B^4 + \left(q_{\rm ex}^2 - m_{\rm ex}^2\right)^2}. \tag{18}$$

For π-meson and η-meson exchange diagrams, we adopt [25]

$$F_M(q_{\rm ex}, m_{\rm ex}) = \left(\frac{\Lambda_M^2 - m_{\rm ex}^2}{\Lambda_M^2 - q_{\rm ex}^2}\right)^2. \tag{19}$$

While we use

$$F_V(q_{\rm ex}) = \left(\frac{\Lambda_V^2}{\Lambda_V^2 - q_{\rm ex}^2}\right)^2 \tag{20}$$

for ρ-meson exchange [26]. The $q_{\rm ex}$ and $m_{\rm ex}$ are the four-momentum and mass of the exchanged particle, respectively. As for the cutoff parameters, we take $\Lambda_\pi = \Lambda_\eta = 1.3$ GeV and $\Lambda_\rho = 1.2$ GeV for meson exchanges [10,21] and $\Lambda_B = 2.0$ GeV [9] for baryon exchanges.

The propagators for the exchanged particles are used as

$$G_0(q) = \frac{i}{q^2 - m^2} \tag{21}$$

for π and η,

$$G_1^{\mu\nu}(q) = -\frac{i(g^{\mu\nu} - q^\mu q^\nu/q^2)}{q^2 - m^2} \tag{22}$$

for ρ,

$$G_{\frac{1}{2}}(q) = \frac{i(\not{q} + m)}{q^2 - m^2 + im\Gamma} \tag{23}$$

for the spin-1/2 baryon, and

$$G^{\mu\nu}_{\frac{3}{2}}(q) = \frac{i(\not{q} + m)P^{\mu\nu}(q)}{q^2 - m^2 + im\Gamma} \tag{24}$$

for the spin-3/2 baryon with

$$P^{\mu\nu}(q) = -g^{\mu\nu} + \frac{1}{3}\gamma^\mu\gamma^\nu + \frac{1}{3m}(\gamma^\mu q^\nu - \gamma^\nu q^\mu) + \frac{2}{3m^2}q^\mu q^\nu. \tag{25}$$

Here q, m, and Γ are the four-momentum, mass and width of the exchanged particle.

By using the above effective Lagrangian densities and the propagators, we can get the scattering amplitude of the Feynman diagrams shown in Fig. 1. The corresponding amplitudes for Fig. 1(a) are

$$\begin{aligned} M_{N^*_{\frac{1}{2}^-}} = {}& \frac{e g_{\phi\gamma P} g_{NN^*P} g_{\eta N^*N}}{m_\phi\left[(p_3 - p_1)^2 - m_P^2\right]}\bar{u}(p_5, s_5) G_{\frac{1}{2}}(q_{N^*}) \\ & \times u(p_2, s_2)\varepsilon^{\mu\nu\alpha\beta} P_{3\mu}\varepsilon^*_\nu(p_3, s_3) p_{1\alpha}\varepsilon_\beta(p_1, s_1) \\ & \times F_B(q_{N^*}, m_{N^*}) F_M(q_P, m_P), \end{aligned} \tag{26}$$

$$\begin{aligned} M_{N^*_{\frac{1}{2}^+}} = {}& \frac{e g_{\phi\gamma P} g_{NN^*P} g_{\eta N^*N}}{m_\phi m_p + m_{N^*}{}^2}\bar{u}(p_5, s_5)\gamma_5 \not{p}_4 G_{\frac{1}{2}}(q_{N^*}) \\ & \times \gamma_5(\not{p}_3 - \not{p}_1) u(p_2, s_2)\frac{F_B(q_{N^*}, m_{N^*}) F_M(q_P, m_P)}{(p_3 - p_1)^2 - m_P^2} \\ & \times \varepsilon^{\mu\nu\alpha\beta} P_{3\mu}\varepsilon^*_\nu(p_3, s_3) p_{1\alpha}\varepsilon_\beta(p_1, s_1), \end{aligned} \tag{27}$$

$$\begin{aligned} M_{N^*_{\frac{3}{2}^+}} = {}& \frac{e g_{\phi\gamma P} g_{NN^*P} g_{\eta N^*N}}{m_\phi m_\eta m_P}\bar{u}(p_5, s_5) p_{4\mu} G^{\mu\nu}_{\frac{3}{2}}(q_{N^*}) \\ & \times (p_1 - p_3)_\nu u(p_2, s_2)\frac{F_B(q_{N^*}, m_{N^*}) F_M(q_P, m_P)}{(p_3 - p_1)^2 - m_P^2} \\ & \times \varepsilon^{\mu\nu\alpha\beta} p_{3\mu}\varepsilon^*_\nu(p_3, s_3) p_{1\alpha}\varepsilon_\beta(p_1, s_1), \end{aligned} \tag{28}$$

$$\begin{aligned} M_{f_0} = {}& \frac{-ie g_{\phi\gamma f_0} g_{NN^*f_0} g_{\eta N^*N}}{m_\phi\left[(p_3 - p_1)^2 - m_{f_0}^2\right]}\bar{u}(p_5, s_5) G_{\frac{1}{2}}(p_4 + p_5) \\ & \times \gamma_5 u(p_2, s_2)((p_3\cdot p_1)(\varepsilon_3^*\cdot\varepsilon_1) - (p_3\cdot\varepsilon_1)(p_1\cdot\varepsilon_3^*)) \\ & \times F_B(q_{N^*}, m_{N^*}) F_M(q_{f_0}, m_{f_0}), \end{aligned} \tag{29}$$

where P denotes the exchanged π or η and the momentum of individual particles is denoted as in Fig. 1. The corresponding amplitude for Fig. 1(b) can be written as

$$\begin{aligned} M_t = {}& -\frac{ie^2 g_{\phi\rho\pi} g_{\eta\rho\gamma} g_{\pi NN}}{2m_p m_\phi m_\rho}\bar{u}(p_5, s_5)\gamma_5(\not{p}_2 - \not{p}_5) u(p_2, s_2) \\ & \times \frac{F_V(q_\rho) F_M\left(q_P^2, m_P\right)}{(p_5 - p_2)^2 - m_\pi^2}\varepsilon^{\mu\nu\alpha\beta} P_{3\mu}\varepsilon^*_\nu(p_3, s_3) \\ & \times (p_1 - p_4)_\alpha G_1^{\beta\delta}(p_4 - p_1)\varepsilon^{\rho\sigma\gamma\delta} \\ & \times p_{1\rho}\varepsilon_\sigma(p_1, s_1)(p_1 - p_4)_\gamma. \end{aligned} \tag{30}$$

III. RESULTS AND DISCUSSION

With the formulas given in the last section, the total and differential cross sections can be calculated. First, we consider the case where the f_0 exchange contribution is not considered.

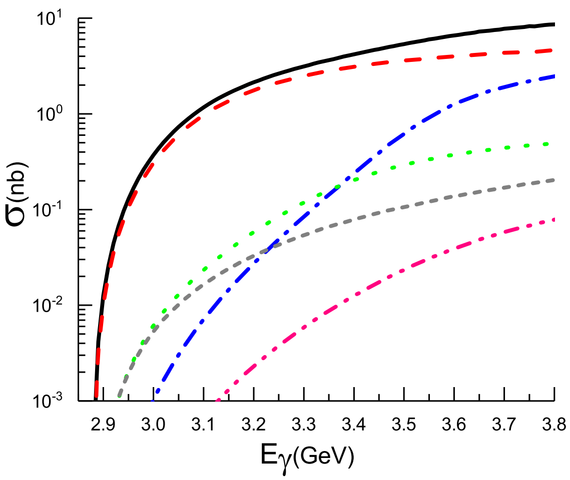

FIG. 2. Total cross section vs. the beam energy E_γ for the $\gamma p \to \phi\eta p$ reaction without considering the f_0 exchange. The red-dashed, green-dotted, blue-dash-dotted, and pink-dash-dot-dotted lines represent the contribution of the $N^*(1535)$, $N^*(1650)$, $N^*(1710)$, and $N^*(1720)$, respectively. The gray-short-dashed line denotes the t-channel background contribution. Their sum is shown by the solid black line.

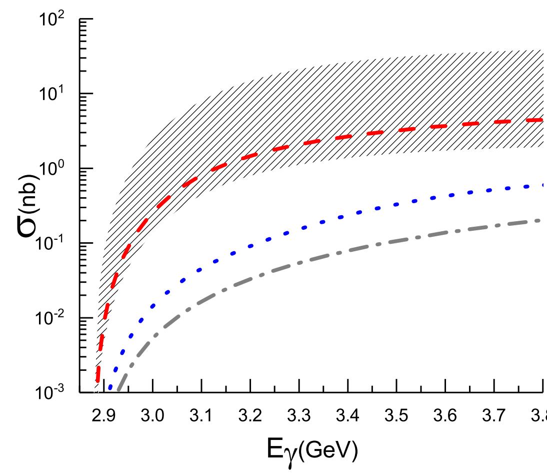

FIG. 3. Individual contributions of various meson exchanges. The red-dashed, blue-dotted, and gray-dash-dotted lines indicate the contributions of the η, π exchanges and background term, respectively. The shadow area represents the f_0 exchange contribution with Λ_{f_0} varying from 1.3 to 1.8 GeV.

In Fig. 2, we show the contributions of the various nucleon resonances and the background contribution. It is obvious that the $N^*(1535)$ plays a dominant role in this reaction near threshold. The dominant role of the $N^*(1535)$ is mainly attributed to its large coupling with the $N\eta$ channel. Other nucleon resonances and the background term only play minor roles in this reaction. While, with increasing energy, the $N^*(1710)$ will become important gradually. The interference terms among the individual amplitudes are usually important for understanding the experimental data. Most of the coupling constants used in our work are extracted from the decay width, in which way the relative phase of the couplings cannot be determined. Fortunately, due to the dominant role of the $N^*(1535)$ in the energy region under study, we do not expect the interference effects are very significant here. In fact, we have tried to alter the phase by multiplying a factor of -1 and no significant changes in the results have been found. It should also be noted that, to evaluate the $\phi\rho\pi$ coupling constant, we adopt the decay branch ratio of $\phi \to \rho\pi$ at the upper limit suggested by the Particle Data Group [11] which means the background contribution could be even smaller.

Now we come to discuss the role of the f_0 exchange in this reaction. To evaluate the contribution from the f_0 exchange, it is necessary to identify the coupling constant of the $N^*(1535)Nf_0$ vertex and the cutoff parameter in the form factor. Until now, these two parameters have been rarely known. Here we make the guess that $g_{N^*(1535)Nf_0}$ has a similar magnitude as the $g_{N^*(1535)N\sigma}$. For the latter, its value can be evaluated through the partial decay width $\Gamma(N^*(1535) \to N\sigma)$ and one can get $|g_{N^*(1535)N\sigma}| = 2.55$ [19]. As a rough estimate of the f_0 exchange contribution, we think this substitute is plausible since the $N^*(1535)$ is expected to have an even stronger coupling with final state containing significant strange component such as Nf_0. On the other hand, for the cutoff parameter Λ_{f_0}, we study the dependence of the results on this parameter explicitly by varying it from 1.3 to 1.8 GeV.

In Fig. 3, we show the individual contributions of various meson exchanges and the Λ_{f_0} dependence of the f_0 exchange contribution. It is found that the role of the η exchange is much more important than that of the π exchange in this reaction as expected, while the role of f_0 exchange is dependent on the adopted value of the Λ_{f_0}. However, even with a relatively small value of Λ_{f_0}, i.e., $\Lambda_{f_0} = 1.3$ GeV, the f_0 exchange contribution is still comparable to the η exchange contribution and larger than the contribution of the π exchange and the background term. The significant f_0 exchange contribution can be attributed to the relatively large $\phi f_0\gamma$ coupling and the p-wave nature of the $N^*(1535)Nf_0$ coupling. Compared to the s-wave coupling of the $N^*(1535)N\eta$ vertex, the p-wave $N^*(1535)Nf_0$ coupling is amplified due to the large threshold momentum of this reaction, which enhances the f_0 exchange contribution. Note that to extract the $\phi f_0\gamma$ coupling constant we use Eq. (14) and the decay branch ratio of $\phi \to \gamma f_0$, where the adopted value of the f_0 mass is essential in the calculation since ϕ lies near the $f_0\gamma$ threshold. In the above calculations, we take the mass of f_0 as 0.99 GeV [11,19]. If a smaller mass, such as $M_{f_0} = 0.98$ GeV, is adopted, then the $g^2_{\phi f_0\gamma}$ will become a factor of 2 to 3 smaller than the value used here.

Based on the results shown above, it seems that with the current parameters the f_0 exchange contribution is significant in the present reaction. To identify the role of f_0 exchange in this reaction, it is important to find some observable to separate the various meson exchange contributions. Inspired by the pioneer works [15,16], it is found that the parity asymmetry is suitable for this purpose. In Ref. [17], it has been shown that this observable can be used to identify the scalar exchange contribution. The parity asymmetry is defined by the SDMEs as

$$P_\sigma = 2\rho^1_{1-1} - \rho^1_{00}, \tag{31}$$

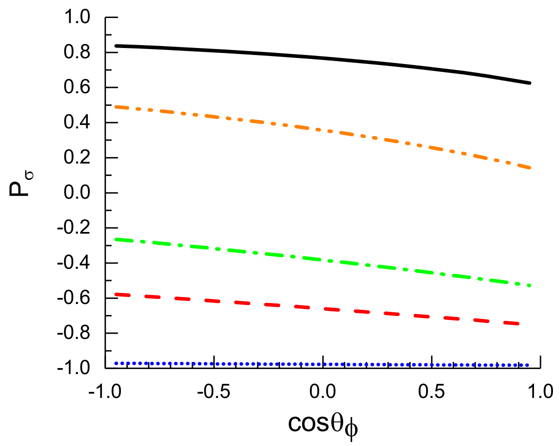

FIG. 4. Predictions for the P_σ at $P_\gamma = 3.0$ GeV. The black-solid, orange-dash-dot-dotted, and green-dash-dotted lines denote the results with $\Lambda_{f_0} = 1.8$, 1.5, and 1.3 GeV, respectively. The red-dashed line corresponds to the results using $\Lambda_{f_0} = 1.3$ GeV and a smaller mass of the f_0, i.e., $m_{f_0} = 0.98$ GeV, in the calculation. The blue-dotted line indicates the result without considering the f_0 exchange contribution.

In the γN $\rightarrow$VN reaction, it can be proven that for the natural and unnatural exchanges the parity asymmetry P_σ equals 1 and -1 respectively. Since the scalar meson f_0 has the natural parity and the pseudoscalar meson $\eta(\pi)$ has unnatural parity, it is possible to distinguish their contributions by measuring this observable. It should be pointed out that an important difference between our work and previous ones is that here we deal with nucleon resonance in the intermediate state. However, this difference is irrelevant to the purpose of the present work, since the P_σ is solely determined by the ϕ-γ-meson vertex if only scalar or pseudoscalar meson exchanges are concerned. Such an argument is supported by the numerical results shown in Fig. 4. In this figure, we present the predictions for the P_σ with $\Lambda_{f_0} = 1.3$, 1.5, and 1.8 GeV. When we take the $\Lambda_{f_0} = 1.8$ GeV, the f_0 exchange dominates this reaction and the P_σ is about 0.8. If we take $\Lambda_{f_0} = 1.3$ GeV, then the f_0 exchange contribution is smaller than that of the η exchange and the P_σ is about -0.4. When the f_0 exchange contribution is not considered at all, the P_σ approaches -1 in accordance with the expectations. Note that in this figure we also present the result using a smaller value, i.e., 0.98 GeV, for the mass of f_0 to check the dependence of the results on the mass of f_0. As shown in the figure, it seems even in this case the predictions for the P_σ is still distinct from the results without considering the f_0 exchange contribution. Therefore, we conclude that the parity asymmetry P_σ is suitable to identify the scalar exchange contribution in this reaction.

IV. SUMMARY

In this work, we investigate the $\gamma p \rightarrow p\eta\phi$ reaction within an effective Lagrangian approach. We consider the contribution of the $N^*(1535)$, $N^*(1650)$, $N^*(1710)$, and $N^*(1720)$ in the intermediate state and the background contribution. It is found that the production of the $N^*(1535)$ dominates this reaction in the near threshold region. In particular, we study the possible role of the scalar exchange for the excitation of $N^*(1535)$ and find that the f_0 may play an important role here. We also find the parity asymmetry P_σ is sensitive to the scalar exchange contribution and can be used to identify the role of the scalar exchange in this reaction.

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