

Non-diffractive mechanisms in the ϕ meson photoproduction on nucleons

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(February 11, 2002)

Abstract

We examine the non-diffractive mechanisms in the ϕ meson photoproduction from threshold up to a few GeV using an effective Lagrangian in a constituent quark model. The new data from CLAS at large angles can be consistently accounted for in terms of s - and u -channel processes. Isotopic effects arising from the reactions $\gamma p \rightarrow \phi p$ and $\gamma n \rightarrow \phi n$, are investigated by comparing the cross sections and polarized beam asymmetries. Our result highlights an experimental means of studying non-diffractive mechanisms in ϕ meson photoproduction.

PACS numbers: 12.39.-x, 25.20.Lj, 13.60.Le

Keywords: Phenomenological quark model, Photoproduction reactions, Meson production

For a long time, the study of ϕ meson photoproduction has been concentrated at high energies where the diffractive process is the dominant source, and a Pomeron exchange model based on the Regge phenomenology explains the elastic ϕ production at small momentum transfers [1]. In contrast with the high energy reactions, data for the photoproduction of the ϕ meson near threshold are still very sparse, and were available only for small momentum transfers [2]. The new data from the CLAS collaboration at JLAB [3] cover for the first time momentum transfers above 1.5 (GeV/c)^2 with $2.66 \leq W \leq 2.86 \text{ GeV}$, and provide important information about mechanisms leading to non-diffractive processes at large angles.

Initiated by the possible existence of strangeness in nucleons, Henley *et al.* [4] showed that 10-20% of strange quark admixture in the nucleon would result in an $s\bar{s}$ knockout cross section compatible with the diffractive one near threshold. More recently, it has been shown by Titov *et al.* [5–8] using a relativistic harmonic oscillator quark model that an even smaller fraction of $s\bar{s}$ of about 5% would produce detectable effects in some polarization observables. In Ref. [9], Williams studied the effect of an OZI evading ϕNN interaction by including the Born term with an effective ϕNN coupling. Quite different conclusions were drawn from the above approaches, since the descriptions of the diffractive process were

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significantly model-dependent, and would influence not only the fraction of a possible $s\bar{s}$ component in the nucleon, but also the OZI evading ϕNN coupling. As shown in Ref. [9], the $|g_{\phi NN}|$ could have a range of 0.3-0.8, depending on the model for the diffractive process. Therefore, a reliable description of the diffractive contribution, which determines what scope remains for other non-diffractive mechanisms, is vital. Near threshold, another question arising from non-diffractive ϕ meson production is what the dominant process in the large angle ϕ production might be? In Ref. [10], we showed that OZI suppressed s - and u -channel contributions should be a dominant source for large angle ϕ production in $\gamma p \rightarrow \phi p$.

Concerning the two points noted above, we study here, within a quark model, the non-diffractive ϕ meson photoproduction in two isotopic channels, $\gamma p \rightarrow \phi p$ and $\gamma n \rightarrow \phi n$, from threshold to a few GeV of c.m. energy. A Pomeron exchange model, which was determined at higher energies, was then extrapolated to the low energy limit with the same parameter. In this way, we believe the diffractive contribution has been reliably evaluated and should be a prerequisite for study of non-diffractive mechanisms in both reactions. Pion exchange was also included but found to be small. Moreover, its forward peaking character suggests that some other non-diffractive process is necessary at large angles. An effective ϕ - qq interaction was proposed for the s - and u -channel ϕ meson production, which will account for the large angle non-diffractive contributions up to $W \approx 3$ GeV. In the quark model framework, the nucleon pole terms (Born term), as well as a complete set of resonance contributions can be consistently included. Our attention will be focused on the large angle s - and u -channel processes in this work. We do not take into account the strangeness component, although the effective ϕ - qq coupling might have included effects from an OZI evading process. A comparison with the new data from the CLAS Collaboration should highlight the roles played by the s - and u -channel ϕ production, and the isotopic study will provide insight into any non-diffractive mechanism.

The question of whether a non-diffractive process can play a role at a few GeV of c.m. energy, is still an open one. As pointed out by Donnachie and Landshoff [11], contributions from two-gluon exchanges should be small at a few GeV, and a Pomeron exchange would be enough. Laget [12] showed that a two-gluon exchange mechanism might start to play a role at large $|t|$ with $W \approx 3$ GeV. A relatively large contribution was found from correlation processes. However, it was also shown that two-gluon exchange could not account for the increase in the cross sections at large angles. A u -channel process, which violated the s -channel helicity conservation (SCHC), was then employed to explain the large angle behavior. Interestingly, newly submitted results from the CLAS Collaboration for the ϕ electroproduction at $0.7 \leq Q^2 \leq 2.2$ (GeV/c)² and $2.0 \leq W \leq 2.6$ GeV suggest that some non-diffractive mechanism plays a role at large t [13]. Such results cannot generally be explained by the SCHC Pomeron exchange and the soft two-gluon-exchange model, but strongly imply that some non-perturbative process might still compete against the progressively more important perturbative QCD processes at a few GeV. To disentangle these mechanisms near threshold, one should start with those SCHC violated processes, in particular, the s - and u -channel ϕ productions. Their energy evolution to a few GeV as well as a measurable effect arising from their isotopic reaction should be seriously considered.

Our model consists of three processes: (i) s - and u -channel ϕ production with an effective Lagrangian; (ii) t -channel Pomeron exchange; (iii) t -channel pion exchange.

At quark level, the ϕ - qq coupling is described by the effective Lagrangian [14,15]:

$$L_{eff} = \bar{\psi}(a\gamma_\mu + \frac{ib\sigma_{\mu\nu}q^\nu}{2m_q})\phi_m^\mu\psi, \quad (1)$$

where the quark field ψ can be u , d , or s for the light-quark baryon system, while ϕ_m^μ represents the vector ϕ meson field. The 3-quark baryon system is described by the nonrelativistic constituent quark model (NRCQM) in the $SU(6) \otimes O(3)$ symmetry limit. The vector meson is treated as an elementary point-like particle which couples to the constituent quark through the effective interaction. Two parameters, a and b , are introduced for the vector and tensor coupling of the ϕ - qq in the s - and u -channels.

At tree level, the transition amplitude from the effective Lagrangian can be expressed as the contributions from the s -, u - and t -channel processes:

$$M_{fi} = M_{fi}^s + M_{fi}^u + M_{fi}^t. \quad (2)$$

In $\gamma N \rightarrow \phi N$, M_{fi}^t vanishes since it is proportional to the charge of the final state ϕ meson. Introducing intermediate states, the s - and u -channel amplitudes can be written as:

$$\begin{aligned} M_{fi}^{s+u} = & i\omega_\gamma \sum_j \langle N_f | H_m | N_j \rangle \langle N_j | \frac{1}{E_i + \omega_\gamma - E_j} h_e | N_i \rangle \\ & + i\omega_\gamma \sum_j \langle N_f | h_e \frac{1}{E_i - \omega_\phi - E_j} | N_j \rangle \langle N_j | H_m | N_i \rangle, \end{aligned} \quad (3)$$

with $H_m = -\bar{\psi}(a\gamma_\mu + \frac{ib\sigma_{\mu\nu}q^\nu}{2m_q})\phi_m^\mu\psi$ for the quark-meson coupling vertex, and

$$h_e = \sum_l e_l \mathbf{r}_l \cdot \boldsymbol{\epsilon}_\gamma (1 - \boldsymbol{\alpha} \cdot \hat{\mathbf{k}}) e^{i\mathbf{k} \cdot \mathbf{r}_l}, \quad \hat{\mathbf{k}} = \frac{\mathbf{k}}{\omega_\gamma}, \quad (4)$$

where \mathbf{k} and ω_γ are the three-momentum and energy of the incident photon, respectively. $|N_j\rangle$ represents the complete set of intermediate states. In the NRCQM, those low-lying states ($n \leq 2$) have been successfully related to the resonances and can be taken into account explicitly in the formula. Higher excited states can be treated as degenerate in the main quantum number n of the harmonic oscillator basis. A detailed description of this approach can be found in Refs. [14] and [15]. It should be noted that resonances belonging to quark model representation [70, 48] do not contribute in $\gamma p \rightarrow \phi p$ due to the Moorhouse selection rule at the electromagnetic interaction vertex [16]. Therefore, eight low-lying resonances will explicitly appear in $\gamma p \rightarrow \phi p$, while there are 16 in $\gamma n \rightarrow \phi n$.

The t -channel diffractive process is accounted for by the Pomeron exchange model of Donnachie and Landshoff [1,17,18]. In this model, the Pomeron mediates the long range interaction between two confined quarks, and behaves rather like a $C = +1$ isoscalar photon. We summarize the vertices as follows:

(i) Pomeron-nucleon coupling:

$$F_\mu(t) = 3\beta_0\gamma_\mu f(t), \quad f(t) = \frac{(4M_N^2 - 2.8t)}{(4M_N^2 - t)(1 - t/0.7)^2}, \quad (5)$$

where β_0 is the coupling of the Pomeron to one light constituent quark; $f(t)$ is the isoscalar nucleon electromagnetic form factor with four-momentum transfer t ; the factor 3 comes from the ‘‘quark-counting rule’’.

(ii) Quark- ϕ -meson coupling:

$$V_\nu(p - \frac{1}{2}q, p + \frac{1}{2}q) = f_\phi M_\phi \gamma_\nu , \quad (6)$$

where $f_\phi = 164.76$ MeV is the decay constant of the ϕ meson in $\phi \rightarrow e^+e^-$, which is determined by $\Gamma_{\phi \rightarrow e^+e^-} = 8\pi\alpha_e^2 e_Q^2 f_\phi^2 / 3M_\phi = 1.32$ keV [19].

A form factor $\mu_0^2/(\mu_0^2 + p^2)$ is adopted for the Pomeron-off-shell-quark vertex, where $\mu_0 = 1.2$ GeV is the cut-off energy, and p is the four-momentum of the quark. The Pomeron trajectory is $\alpha(t) = 1 + \epsilon + \alpha't$, with $\epsilon = 0.08$ and $\alpha' = 0.25$ GeV⁻².

The π^0 exchange is introduced via the Lagrangian for the πNN coupling and $\phi\pi\gamma$ coupling as

$$L_{\pi NN} = -ig_{\pi NN} \bar{\psi} \gamma_5 (\boldsymbol{\tau} \cdot \boldsymbol{\pi}) \psi , \quad (7)$$

and

$$L_{\phi\pi^0\gamma} = e_N \frac{g_{\phi\pi\gamma}}{M_\phi} \epsilon_{\alpha\beta\gamma\delta} \partial^\alpha A^\beta \partial^\gamma \phi^\delta \pi^0 . \quad (8)$$

Then the amplitude for the π^0 exchange can be derived in the NRCQM. The commonly used couplings, $g_{\pi NN}^2/4\pi = 14$, $g_{\phi\pi\gamma}^2 = 0.143$, are adopted. A sign exists between the two pion exchange amplitudes for $\gamma p \rightarrow \phi p$ and $\gamma n \rightarrow \phi n$, i.e. $g_{\pi pp} = -g_{\pi nn}$, due to the isospin symmetry.

In the pion exchange, the only parameter $\alpha_\pi = 300$ MeV comes from the quark model form factor $e^{-(\mathbf{q}-\mathbf{k})^2/6\alpha_\pi^2}$ given by the spatial integral over the nucleon wavefunctions. The η meson exchange has not been included due to its even smaller contribution compared to the pion exchange. A recent study [20] showed that the $g_{\eta NN}$ coupling could be as small as 1.1, which means that η exchange can be neglected safely in ϕ meson production.

A criticism of the application of a NRCQM to $W \approx 3$ GeV is that relativistic effects become important due to the high momentum transfer between the incoming photon and the constituent quarks. In principle, one needs a relativistic version of the quark model to take into account the time axis. However, a self-consistent relativistic quark model is not available yet. On the other hand, the NRCQM has made impressive success in hadron spectroscopy as well as most photo-excitation helicity amplitudes for baryons [21]. In our approach, uncertainties arising from NRCQM's shortcoming can be regarded as being efficiently taken into account in two ways: (i) The masses as well as total decay widths of those low-lying resonances come from the experimental output. Therefore, one need not fit the baryon spectroscopy. (ii) A Lorentz boost factor for each momentum in the spatial integrals is employed to take into account the Lorentz contraction effects up to $W \approx 3$ GeV. In fact, it shows that energy evolution of those s - and u -channel terms is very important in relating a Pomeron exchange model to the effective Lagrangian model.

In the range of the CLAS measurements, the value $|t| = 2$ (GeV/c)² corresponds to a scattering angle of $\theta \approx 90^\circ$ in the c.m. system. For larger values of $|t|$, the cross section will reflect features from a non-diffractive mechanism, which in our model is described by the s - and u -channel ϕ meson production. The energy evolution as well as the large angle cross sections provide a direct constraint on the parameters in our model. A numerical fit of the old data [2] at $E_\gamma = 2.0$ GeV and the new ones [3] at 3.6 GeV gives $a = 0.241 \pm 0.105$ and

$b' = -0.458 \pm 0.091$, which are consistent with previous work [10]. Qualitatively, the ratio of parameter a for the ϕ and ω meson (see Ref. [22]) can be related to the ratio $g_{\phi NN}/g_{\omega NN}$, namely $g_{\phi NN}/g_{\omega NN} = a(\phi)/a(\omega)$. In Ref. [22], $a(\omega) = -2.5$ accounted for the differential and total cross sections reasonably. In Ref. [23], the best value $a(\omega) = -2.72$ was derived. It shows that $a(\phi)/a(\omega) = -0.096 \sim -0.087$ covers a range very close to the value determined by SU(3) symmetry, i.e. $g_{\phi NN}/g_{\omega NN} = -\tan 3.7^\circ = -0.065$, where the angle 3.7° is the deviation from the ideal ω - ϕ mixing [19]. This feature is strongly related to the effective quark-vector-meson coupling and quark model phenomenology which perhaps need to be seriously considered in future investigation. In this work, we just treat the couplings as parameters and leave them determined by the data. The signs of the parameters reflect the relative phases between the Pomeron exchange terms and the s - and u -channel transition amplitudes. We assume that the quark-photon vertices and quark- ϕ -meson vertices in both the Pomeron exchange and s - and u -channel processes have the same signs, even though the quark flavors are different. Then we leave the relative phases determined by the signs of the parameters. The sign for pion exchange is fixed by Eqs. 7 and 8.

In Fig. 1, the differential cross section is calculated at $E_\gamma = 3.6$ GeV for $\gamma p \rightarrow \phi p$. The dot-dashed and dotted curves denote the results for exclusive pion exchange and pion plus Pomeron exchange, respectively. Clearly, the Pomeron exchange is the dominant mechanism at small momentum transfers. It can be seen that above $|t| = 2$ (GeV/c)², the Pomeron plus pion exchange cannot reproduce the flattened feature of the cross section. With the s - and u -channel contributions taken into account, the full model calculation is presented by the solid curve. It is also found that the u -channel has a relatively stronger contribution to the cross sections above the resonance energy region. Meanwhile, the u -channel nucleon pole term is dominant over other u -channel contributions. This feature is in agreement with the findings of Ref. [12]. The dotted curve denotes the result excluding the u -channel from contributing. It should be noted that the s - and u -channel contributions might be slightly over-estimated since the small two-gluon-exchange contributions are overlooked here.

Next, we show that an isotopic ϕ meson photoproduction on the neutron will be able to provide us with information about the large angle ϕ meson production mechanism.

The ϕ - qq coupling in $\gamma n \rightarrow \phi n$ can be described in the same way as in $\gamma p \rightarrow \phi p$. But the isospin degrees of freedom distinguish between proton and neutron via different g -factors defined for the meson-baryon couplings [15]. Significant changes occur due to the disappearance of the electro-interaction in the nucleon pole terms. The anomalous magnetic moment of the neutron will result in phase change effects in the s - and u -channel amplitudes. The nucleon pole terms in $\gamma n \rightarrow \phi n$ can be written as

$$\begin{aligned}
M_n^s(T) &= g_A \mu_n \frac{b'}{2m_q} \frac{M_n}{P_i \cdot k} e^{-(\mathbf{q}^2 + \mathbf{k}^2)/6\alpha^2} \\
&\quad \times \langle \chi_f | [(\boldsymbol{\epsilon}_\phi \times \mathbf{q}) \cdot (\boldsymbol{\epsilon}_\gamma \times \mathbf{k}) \\
&\quad + i\boldsymbol{\sigma} \cdot (\boldsymbol{\epsilon}_\phi \times \mathbf{q}) \times (\boldsymbol{\epsilon}_\gamma \times \mathbf{k})] | \chi_i \rangle, \tag{9}
\end{aligned}$$

for the transverse ϕ production in the s -channel, and

$$\begin{aligned}
M_n^s(L) &= -i a g_v^t \mu_n \frac{M_\phi (W + M_n)}{|\mathbf{q}|} \frac{1}{2P_i \cdot k} e^{-(\mathbf{q}^2 + \mathbf{k}^2)/6\alpha^2} \\
&\quad \times \langle \chi_f | \boldsymbol{\sigma} \cdot (\boldsymbol{\epsilon}_\gamma \times \mathbf{k}) | \chi_i \rangle, \tag{10}
\end{aligned}$$

for the longitudinal ϕ production. The corresponding u -channel amplitudes are

$$\begin{aligned}
M_n^u(T) &= g_A \mu_n \frac{b'}{2m_q} \frac{M_n}{P_f \cdot k} e^{-(\mathbf{q}^2 + \mathbf{k}^2)/6\alpha^2} \\
&\quad \times \langle \chi_f | [(\boldsymbol{\epsilon}_\phi \times \mathbf{q}) \cdot (\boldsymbol{\epsilon}_\gamma \times \mathbf{k}) \\
&\quad - i\boldsymbol{\sigma} \cdot (\boldsymbol{\epsilon}_\phi \times \mathbf{q}) \times (\boldsymbol{\epsilon}_\gamma \times \mathbf{k})] | \chi_i \rangle,
\end{aligned} \tag{11}$$

for the transverse ϕ production, and

$$\begin{aligned}
M_n^u(L) &= i a g_v^t \mu_n \frac{M_\phi (W + M_n)}{|\mathbf{q}|} \frac{M_n}{2W} \frac{M_n}{P_f \cdot k} e^{-(\mathbf{q}^2 + \mathbf{k}^2)/6\alpha^2} \\
&\quad \times \langle \chi_f | \boldsymbol{\sigma} \cdot (\boldsymbol{\epsilon}_\gamma \times \mathbf{k}) | \chi_i \rangle,
\end{aligned} \tag{12}$$

for the longitudinal ϕ production. In the above equations, $\mu_n = -1/3m_q$ is the neutron's magnetic moment, and $m_q = 330$ MeV is the constituent quark mass; M_n and M_ϕ are the neutron and ϕ meson, respectively; \mathbf{k} and \mathbf{q} are the momenta of the incoming photon and outgoing meson, respectively, while $\boldsymbol{\epsilon}_\gamma$ and $\boldsymbol{\epsilon}_\phi$ are the polarization vectors of the photon and meson. Two parameters, a and $b \equiv b' + a$, denote the vector and tensor coupling of the ϕ - qq interaction, and are determined in $\gamma p \rightarrow \phi p$.

An interesting feature related to the gauge invariance condition and arising from the longitudinal ϕ production terms is that the separate calculation of the s - and u -channel nucleon pole terms will result in divergence at threshold $|\mathbf{q}| \rightarrow 0$. To get rid of such a problem, we need to add the s - and u -channel terms together. Notice that $|\mathbf{k}| = \omega_\gamma$ in the real photon reaction, we obtain $P_i \cdot k = |\mathbf{k}|W$. Thus, $M_n^{s+u}(L)$ can be written as

$$\begin{aligned}
M_n^{s+u}(L) &= i a g_v^t \mu_n \frac{M_\phi (W + M_n)}{|\mathbf{q}|} \frac{M_n}{2W} e^{-(\mathbf{q}^2 + \mathbf{k}^2)/6\alpha^2} \\
&\quad \times \left[-\frac{W}{\omega_\gamma (E_i + \omega_\gamma)} + \frac{M_n}{\omega_\gamma (E_f + |\mathbf{q}| \cos \theta)} \right] \\
&\quad \times \langle \chi_f | \boldsymbol{\sigma} \cdot (\boldsymbol{\epsilon}_\gamma \times \mathbf{k}) | \chi_i \rangle \\
&= -i a g_v^t \mu_n \frac{M_\phi (W + M_n)}{|\mathbf{q}|} \frac{M_n}{2W} e^{-(\mathbf{q}^2 + \mathbf{k}^2)/6\alpha^2} \\
&\quad \times \frac{1}{P_f \cdot k} \left[\frac{|\mathbf{q}|^2}{E_f + M_n} + |\mathbf{q}| \cos \theta \right] \\
&\quad \times \langle \chi_f | \boldsymbol{\sigma} \cdot (\boldsymbol{\epsilon}_\gamma \times \mathbf{k}) | \chi_i \rangle,
\end{aligned} \tag{13}$$

where $g_v^t = 3$ is derived in the quark model. In the last equation, the factor $|\mathbf{q}|$ in the denominator will be cancelled by a corresponding one in the square-bracket, and the divergence at threshold ($|\mathbf{q}| \rightarrow 0$) is avoided. Meanwhile, the u -channel propagator $(P_f \cdot k)^{-1}$ partly explains why the u -channel plays an important role in the isoscalar vector meson (ω , ϕ) photoproduction.

Using the parameters derived in $\gamma p \rightarrow \phi p$, the cross sections for both $\gamma p \rightarrow \phi p$ and $\gamma n \rightarrow \phi n$ are calculated at $E_\gamma = 2.0$ GeV (Fig. 2). An obvious feature is that the large angle cross sections are significantly smaller for $\gamma n \rightarrow \phi n$ than for $\gamma p \rightarrow \phi p$. Meanwhile, a relatively stronger backward peaking is found from the u -channel nucleon pole term. We

also present the results without the u -channel contributions in Fig. 2 (see the dotted curves). Comparing the dashed curves (Pomeron plus pion exchange) to the dotted ones, we find that the u -channel contributions play a dominant role in both reactions. In another word, the s -channel resonance contributions are significantly smaller than the u -channel contributions in the ϕ meson photoproduction. This feature, which has not been seen in the ω meson photoproduction, might make it difficult to filter signals for individual s -channel resonances in the ϕ photoproductions. This result might be regarded as a negative result in the context of searching for “missing resonances” in various reaction channels, however it has a positive side in that the forward angle kinematics might be an ideal region for studying the strangeness component in nucleons. The dot-dashed curves in Fig. 2 denote results for the s - and u -channel processes.

In Fig. 3, the isotopic effects of these two reactions are shown for the polarized beam asymmetry $\check{\Sigma}$ at $E_\gamma = 2.0$ GeV. Here, $\check{\Sigma}$ is defined as

$$\check{\Sigma} = \frac{\sigma_{\parallel} - \sigma_{\perp}}{\sigma_{\parallel} + \sigma_{\perp}}, \quad (14)$$

where σ_{\parallel} and σ_{\perp} denote the cross sections for $\phi \rightarrow K^+K^-$ when the decay plane is parallel or perpendicular to the photon polarization vector. The dashed curves represent results for the Pomeron plus pion exchange, which deviate from +1 due to the presence of the *unnatural* parity pion exchange. With the s - and u -channel contributions, the full model calculations are denoted by the solid curves. Explicitly, the large angle asymmetry is strongly influenced by the presence of the s - and u -channel processes, while the forward angles are not sensitive to them. Interferences between the Pomeron exchange s - and u -channel processes can be seen by excluding the pion exchanges (see the dot-dashed curves). It shows that asymmetries produced by the s - and u -channel processes at forward angles are negligible. Since the pion exchange becomes very small at large angles, we conclude that the large angle asymmetry is determined by the s - and u -channel processes and reflects the isotopic effects. The role played by the s -channel resonances in the two reactions are presented by excluding the u -channel contributions. As shown by the dotted curves, the interferences from the s -channel resonances are much weaker than that from the u -channel. However, they are still an important non-diffractive source at large angles.

It should be noted that no isotopic effects can be seen if only the Pomeron and pion exchange contribute to the cross section. This is because the transition amplitude of the Pomeron is purely imaginary, while that of pion exchange is purely real. In $\check{\Sigma}$, the sign arising from the $g_{\pi NN}$ will disappear, which is why the dashed curves in Fig. 3 are the same. We also point out that our results for the $\check{\Sigma}$ are quite similar to findings of Ref. [24] at small angles, but very different at large angles. This is because only the nucleon pole terms for the s - and u -channel processes were included in Ref. [24].

To show our model can be smoothly extended to a few GeV, we present the total cross sections in Fig. 4 for both isotopic channels. The solid and dotted curve denote the full calculations for the proton and neutron reaction, respectively, while the dashed and dot-dashed curve denote the exclusive calculations of the s - and u -channel contributions for these two reactions, respectively. Although significant difference exists between the exclusive s - and u -channel isotopic reactions, the total cross section is not sensitive to such an effect due to the dominance of Pomeron exchange. This feature explains why such a mechanism has in the past been neglected.

In summary, we studied the non-diffractive mechanisms in the ϕ meson photoproductions using a quark model with an effective Lagrangian in two isotopic channels. The diffractive process is accounted for by a Pomeron exchange model. The pion exchange is also included and found to be small. The newly published data from CLAS provides a good test of our model and highlights the mechanisms of non-diffractive ϕ production through the direct s -channel and crossing u -channel processes. The result shows that, up to a few GeV, these two channels might still play a role at large angles, although their cross sections become small. Isotopic effects arising from the proton and neutron reaction provide a means of study the s - and u -channel processes in experiment. The measurement of the polarized beam asymmetry at large angles can provide detectable effects between these two isotopic reactions.

Concerning the search for signals of $s\bar{s}$ component in the nucleon, the forward angle kinematics might be selective if the findings of Refs. [6,7] are true, since at forward angles the s - and u -channel only play a negligible role. Certainly, since a possible strangeness content has not been explicitly included in this model, the effective ϕ - qq coupling cannot distinguish between an OZI evading ϕNN coupling and a strangeness component in the nucleon. In future study, a more complex approach including the possible strangeness component in the nucleon will be explored. To disentangle all the possible non-diffractive mechanisms in ϕ meson photoproduction, a measurement of the isotopic reactions covering the full angle range would be also required.

Useful comments from Z.-P. Li are gratefully acknowledged. Q.Z. thanks M. Guidal and J.-M. Laget for valuable communications. We thank J.-P. Didelez, and E. Hourany for their interest in this work. The CLAS data from G. Audit are gratefully acknowledged.

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FIGURES

FIG. 1. Differential cross section for $\gamma p \rightarrow \phi p$ at $E_\gamma = 3.6$ GeV. The dot-dashed, dashed, and solid curves denote the pion exchange, Pomeron plus pion, and full model calculations, respectively, while the dotted curve represents full model calculation excluding the u -channel contribution. Data come from [2] (dot), [3] (square), and [25] (diamond).

FIG. 2. Differential cross section for $\gamma p \rightarrow \phi p$ and $\gamma n \rightarrow \phi n$ at $E_\gamma = 2.0$ GeV. The dot-dashed, dashed, and solid curves denote the s - and u -channel, Pomeron plus pion, and full model calculations, respectively, while the dotted curve represents full model calculation excluding the u -channel contribution. Data come from Ref. [2].

FIG. 3. Polarized beam symmetry for the proton and neutron reactions at $E_\gamma = 2.0$ GeV. The dashed, and solid curves denote the Pomeron plus pion, and full model calculations, respectively, while the dotted curve represents full model calculation excluding the u -channel contribution. The dot-dashed curves denote full model calculation excluding the pion exchange.

FIG. 4. Total cross section for $\gamma p \rightarrow \phi p$ and $\gamma n \rightarrow \phi n$. The solid (dotted) and dashed (dot-dashed) curves denote the full model calculation and exclusive s - and u -channel cross section for the proton (neutron) reaction, respectively. Data come from Refs. [26–31]. See text for curve notations.







