Associative Photoproduction of Roper Resonance and $\omega$-Meson

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Abstract

Associative photoproduction of $\omega$-meson and $N^*(1440)$ on nucleons, $\gamma + N \rightarrow \omega + N^*(1440)$, in the near threshold region is investigated in a framework employing effective Lagrangians. Besides $\pi$-exchange in t-channel, baryon exchanges, i.e. N- and $N^*$-exchanges, in the s- and u-channels are also taken into account in calculations of differential cross-section and beam asymmetry. Important inputs of this model are the vector and tensor coupling constants of $\omega NN^*(1440)$-vertex, which are assumed to be equal to the values of these couplings for $\omega NN$ vertex. Using our previous estimation of $\omega NN$ coupling constants obtained from a fit to available experimental data on photoproduction of $\omega$ meson in the near threshold region, we produce the necessary numerical predictions for different observables in $\gamma + N \rightarrow \omega + N^*(1440)$. Numerical results shows that at low $|t|$ dominant contribution comes from t-channel $\pi$-exchange while effects of nucleon and $N^*(1440)$ pole terms can be seen at large $|t|$. Our predictions for the differential cross section and beam asymmetry for the processes $\gamma + N \rightarrow \omega + N^*(1440)$, where N is proton and neutron at $E_\gamma = 2.5$ GeV are presented with zero width approximation and also with the inclusion of width effects of $N^*(1440)$. 
I. INTRODUCTION

Baryon resonances, in particular the Roper resonance $N^*_1(1440)$, have a special interest at the moment from the theoretical and experimental point of view. $N^*(1440)$ is the first excited state of nucleon with a broad full width of $350 \pm 100$ MeV which is twice as compared to those of the neighboring resonances $N^*(1520)$ and $N^*(1535)$\cite{1}. Although the Roper resonance was discovered first during the phase shift analysis of $\pi$-N scattering\cite{2}, it has not observed directly yet. Some quark\cite{3–7} and bag models\cite{8,9} try to explain its nature, but it is still not well known. Photoproduction of vector mesons in particular channel, where the target nucleon is excited to Roper resonance, $\gamma + N \rightarrow V + N^*(1440)$, might provide supplementary knowledge about this resonance and its couplings to meson-nucleon channels.

In order to extract information on Roper resonance from associative production of vector meson and $N^*(1440)$ it is essential to understand the production mechanisms. Since Roper resonance has similar quantum numbers (spin 1/2, isospin 1/2 and positive parity) with nucleon the corresponding dynamics of the associative photoproduction of vector meson and $N^*(1440)$, $\gamma + N \rightarrow V + N^*(1440)$, can be studied analogously to that of ”elastic” vector meson photoproduction, $\gamma + N \rightarrow V + N$. Theoretical studies on photoproduction of neutral vector meson\cite{10–19} involve the different combination of the following mechanisms: (i) pseudoscalar ($\pi, \eta$) and scalar ($\sigma$)- meson exchanges in t-channel; (ii) One-nucleon exchange in (s+u)-channel; (iii) the Pomeron exchange in t-channel.

In Ref.\cite{20}, associative neutral vector meson ($\rho$ and $\omega$) and $N^*(1440)$ production near threshold in $\gamma p$ interaction has been analyzed within an approach based on the tree level diagrams of t- channel $\pi$- and $\sigma$- exchanges and effective Lagrangians. For such exchanges although it is possible to obtain some constraints on $\pi NN^*(1440)$ and $\sigma NN^*(1440)$ couplings, measurement of above reactions with linearly polarized photon will be more decisive. Considering these both mechanisms alone will also result in trivial polarization phenomena which can be predicted without knowledge of exact values of coupling constants and phe-
nomenological form factors. For example, the beam asymmetry $\Sigma$ induced by the linear polarization of the photon beam, and all possible T-odd polarization observables as such, for example, target asymmetry or polarization of final proton produced in collisions of unpolarized particles will be zero identically for any kinematical conditions of the considered reaction. Analogously, it is possible to predict that $\rho_{11} = 1$, and all other elements of the $\rho$-meson density matrix must be zero. Evidently contributions other than above mechanisms should be estimated to assess the relevance of the proposed measurement.

In consideration of other mechanisms one problem that must be stressed is the applicability of Pomeron exchange in the near threshold region. In accordance with resonance-Reggeon duality [21], at low energies sum of the resonance contributions in s-channel can be effectively described by the different t-channel Reggeon (but not by the Pomeron). Thus we face with double counting problem when s-channel resonance contributions and t-channel exchanges are considered simultaneously [22], and therefore division of threshold amplitude into resonance and background cannot be done in a unique way. In this respect, Born contributions to $\gamma + N \rightarrow V + N^*(1440)$ must be considered as background.

Complex spin structure in matrix elements of the reaction $\gamma + N \rightarrow \omega + N^*(1440)$ as compared with the pseudoscalar meson photoproduction on nucleon have been a barrier to go further to include the resonances. For example for spin $J \geq 3/2$ case, there are six independent multipole amplitudes with six unknown coupling constants different from zero and large number of nucleon resonances $N^*$ in the considered reaction. Therefore, the effects of each resonance cannot be considered with good accuracy. Determination of $VN^*N^*$ is also another problem in consideration of resonance mechanisms of these reactions because there is no information directly available from experiments. Without having the polarization data with polarized beam, polarized target and of measurements on polarization properties of final vector meson for the $\gamma + N \rightarrow \omega + N^*(1440)$ reaction, inclusion of resonance mechanisms do not seem as suitable for the analysis of these reactions.

In the present work, we investigate the role played by (s+u)-channel $(N+N^*(1440))$-exchanges in, $\gamma + N \rightarrow \omega + N^*(1440)$, associative photoproduction of $\omega$-meson and Roper
resonance in the near threshold region \( (E_\gamma < 3 \text{ GeV}) \). Our model contains \((N+N^*(1440))\)-exchange mechanisms together with the \(\pi\)-exchange but without Pomeron exchange. Advantage of this model compared to the over simplified \(\pi\)-exchange model is that it allows to find nonzero values for the polarization observables, which are in T-even character, such as beam asymmetry \(\Sigma\) induced by linear photon polarization, and density matrix elements of the vector meson produced in polarized and unpolarized particles. In the proposed model it is also possible to discriminate the isotopic spin effects in observables on proton and neutron targets due to \(\pi \otimes N\)-interference and different \(N\)-contributions.

The paper is organized as follows: In Sec. II we give the model independent formalism for calculation of differential cross-section and beam asymmetry and describe our model in the framework of exchange mechanisms. Results of our calculations for the differential cross-section and beam asymmetry are presented and are discussed in Sec. III. In the last section conclusions extracted from the discussion of our results are given with a few remarks.

II. FORMALISM AND MODEL

Calculations of different observables for the associative photoproduction \(\gamma + N \rightarrow N^* + \omega\) are performed by using the formalism of so called transversal amplitudes in the center of mass system (CMS) of the considered reaction. Advantage of this formalism is that it is effective for the analysis of polarization phenomena in photoproduction reactions.

Matrix element of any photoproduction mechanism can be written in terms of 12 independent transversal amplitudes as

\[
\mathcal{M} = \varphi_2^\dagger \mathcal{F} \varphi_1 ,
\]

\[
\mathcal{F} = if_1(\hat{\varepsilon} . \hat{m})(\hat{U} . \hat{m}) + if_2(\hat{\varepsilon} . \hat{m})(\hat{U} . \hat{k}) + if_3(\hat{\varepsilon} . \hat{n})(\hat{U} . \hat{n})
+ (\hat{\sigma} . \hat{m})[f_4(\hat{\varepsilon} . \hat{m})(\hat{U} . \hat{m}) + f_5(\hat{\varepsilon} . \hat{m})(\hat{U} . \hat{k}) + f_6(\hat{\varepsilon} . \hat{n})(\hat{U} . \hat{n})]
+ (\hat{\sigma} . \hat{n})[f_7(\hat{\varepsilon} . \hat{m})(\hat{U} . \hat{m}) + f_8(\hat{\varepsilon} . \hat{n})(\hat{U} . \hat{m}) + f_9(\hat{\varepsilon} . \hat{n})(\hat{U} . \hat{k})]
+ (\hat{\sigma} . \hat{k})[f_{10}(\hat{\varepsilon} . \hat{m})(\hat{U} . \hat{m}) + f_{11}(\hat{\varepsilon} . \hat{n})(\hat{U} . \hat{m}) + f_{12}(\hat{\varepsilon} . \hat{n})(\hat{U} . \hat{k})] ,
\] (1)
where \( \hat{m}, \hat{n}, \) and \( \hat{k} \) are defined as \( \hat{k} = \vec{k}/|\vec{k}|, \hat{n} = \vec{k} \times \vec{q}/|\vec{k} \times \vec{q}|, \) \( \hat{m} = \hat{n} \times \hat{k} \). \( \vec{k} \) and \( \vec{q} \) are the three-momentum of the photon and the vector meson in CMS, \( \varphi_1(\varphi_2) \) is the two-component spinor for initial nucleon and final Roper resonance, and transversal amplitudes \( f_i, i = 1, ..., 12, \) are complex functions of \( s \) and \( t, f_i = f_i(s,t). \)

Differential cross section and beam asymmetry are given by

\[
\frac{d\sigma}{d\Omega} = \frac{1}{2}N\overline{\mathcal{F}\mathcal{F}^\dagger}
\]

and

\[
\Sigma = \frac{d\sigma_\parallel/d\Omega - d\sigma_\perp/d\Omega}{d\sigma_\parallel/d\Omega + d\sigma_\perp/d\Omega} ,
\]

where \( N = |\vec{q}|/64\pi^2s|\vec{k}| \) and \( d\sigma_\parallel/d\Omega \) \( (d\sigma_\perp/d\Omega) \) is the differential cross section induced by photon whose polarization is parallel (perpendicular) to reaction plane in which all other particles in the initial and final state are unpolarized. The corresponding differential cross section and beam asymmetry which are obtained by using Eq. (1), (2), and (3) can be written in terms of transversal amplitudes \( f_i \)

\[
\frac{d\sigma}{d\Omega} = N(h_1 + h_2) ,
\]

\[
\Sigma = \frac{(h_1 - h_2)}{(h_1 + h_2)} ,
\]

\[
h_1 = \frac{1}{2}\left\{ |f_1|^2 + |f_2|^2 + |f_4|^2 + |f_5|^2 + |f_7|^2 + |f_{10}|^2 \right\}
\]

\[
+ \left[ \frac{|\vec{q}|^2 \sin^2 \theta}{m_v^2} \right] \left[ |f_1|^2 + |f_4|^2 \right] + \left[ \frac{|\vec{q}|^2 \cos^2 \theta}{m_v^2} \right] \left[ |f_2|^2 + |f_5|^2 \right]
\]

\[
+ \left[ \frac{|\vec{q}|^2 \sin \theta \cos \theta}{m_v^2} \right] Re \left[ (f_1f_2^*) + (f_4f_5^*) \right] ,
\]

\[
h_2 = \frac{1}{2}\left\{ |f_2|^2 + |f_6|^2 + |f_{11}|^2 + |f_{12}|^2 \right\}
\]

\[
+ \left[ \frac{|\vec{q}|^2 \sin^2 \theta}{m_v^2} \right] \left[ |f_8|^2 + |f_{11}|^2 \right] + \left[ \frac{|\vec{q}|^2 \cos^2 \theta}{m_v^2} \right] \left[ |f_9|^2 + |f_{12}|^2 \right]
\]

\[
+ \left[ \frac{|\vec{q}|^2 \sin \theta \cos \theta}{m_v^2} \right] Re \left[ (f_8f_9^*) + (f_{11}f_{12}^*) \right] ,
\]

where \( m_v \) is the mass of vector meson, \( \theta \) is the angle between \( \vec{k} \) and \( \vec{q} \) in CMS, \( h_1 \) and \( h_2 \) are the structure functions of the considered reaction.
Due to large width of Roper resonance, width effects must be included in the calculation of $\gamma p \rightarrow \omega N^* (1440)$ reaction near threshold. We introduce these effects by the Breit-Wigner parametrization as

$$\frac{d\sigma}{d\Omega}(\gamma p \rightarrow \omega N^* (1440) \rightarrow \omega \pi^0 p) = \int_{M_{\omega} + m_p}^{M_{\omega} + m_p} \frac{d\sigma}{dt}(\gamma p \rightarrow \omega N^* (1440)) B(M_{N^*}) dM_{N^*}$$

in which $M_{\omega}^{max}$ is the maximum mass of the Roper resonance for fixed $s$ and $t$, and $B(M_{N^*})$ is the Breit-Wigner function in the form

$$B(M_{N^*}) = \frac{2}{\pi} \frac{M_{N^*} M_{\omega} \Gamma_{\omega N^* (1440) \rightarrow \pi^0 p}(M_{N^*})}{(M_{N^*}^2 - M_{\omega}^2)^2 + M_{\omega}^2 \Gamma_{\omega N^* (1440) \rightarrow \pi^0 p}(M_{N^*})^2}.$$

Energy dependent partial and total widths are given by

$$\Gamma_{\omega N^* (1440) \rightarrow \pi^0 p}(M_{N^*}) = \Gamma_{\omega N^* (1440) \rightarrow \pi^0 p}(M_{N^*}^0)$$

$$= \frac{M_{\omega}^0}{M_{N^*}} \left[ \frac{E(M_{N^*} - M_N)}{E(M_{N^*}^0 - M_N)} \right] \frac{p[E(M_{N^*})]}{p[E(M_{N^*}^0)]},$$

and

$$\Gamma_{\omega N^* (1440) \rightarrow \pi^0 p}(M_{N^*}) = \Gamma_{\omega N^* (1440) \rightarrow \pi^0 p}(M_{N^*}^0)$$

$$= \frac{M_{\omega}^0}{M_{N^*}} \left[ \frac{E(M_{N^*} - M_N)}{E(M_{N^*}^0 - M_N)} \right] \frac{p[E(M_{N^*})]}{p[E(M_{N^*}^0)]},$$

where $E(M_{N^*}(p(E(M_{N^*})))$ is the energy(three momentum) of $M_{N^*}^0$. We use the values for $\Gamma_{\omega N^* (1440) \rightarrow \pi^0 p}(M_{N^*}^0) = 76$ MeV and $\Gamma_{\omega N^* (1440) \rightarrow \pi^0 p}(M_{N^*}^0) = 350$ MeV $[1]$.

The suggested model for the reaction $\gamma + N \rightarrow N^* (1440) + \omega$ contains $t$-, $s$-, and $u$-channel exchange mechanisms, which are shown in Fig. 1. Following discussion of Ref $[19]$ we consider only $\pi$-exchange mechanism in $t$-channel. The matrix element for this exchange mechanism can be written as

$$\mathcal{M}_t = e \frac{g_{\omega \pi}}{m_{\omega}} \frac{g_{\pi NN^*}}{t - m_{\pi}^2} F_{\pi NN^*}(t) F_{\omega \pi \gamma}(t) \left( \bar{u}(p_2) \gamma_5 u(p_1) \right) \left( \epsilon^{\alpha \beta} \right) \left( \bar{u}(p_2) \gamma_5 u(p_1) \right) \left( \epsilon^{\alpha \beta} \right),$$

where $t = (k - q)^2$, $m_{\omega}(m_{\pi})$ is the mass of the $\omega$-($\pi$-) meson, $\epsilon^{\alpha \beta}$, $U_{\alpha}$, $q_{\beta}$, $p_{\alpha}$ is Dirac spinor for initial nucleon (final Roper
resonance), $g_{\pi NN^*}$ and $g_{\omega \pi \gamma}$ are the strong and electromagnetic coupling constants of the $\pi NN^*$ and $\omega \pi \gamma$ vertices, respectively. Notation of particle four momenta is given in Fig. 1.

Form factors which appear in the above matrix element are in the form

$$F_{\pi NN^*}(t) = \frac{\Lambda_{\pi NN^*}^2 - m_{\pi}^2}{\Lambda_{\pi NN^*}^2 - t}, F_{\omega \pi \gamma}(t) = \frac{\Lambda_{\omega \pi \gamma}^2 - m_{\pi}^2}{\Lambda_{\omega \pi \gamma}^2 - t},$$

where $\Lambda_{\pi NN^*}(\Lambda_{\omega \pi \gamma})$ is the cut-off parameter of the considered vertices in pole diagrams.

The nucleon $s$-channel contribution is described by the following amplitude

$$\mathcal{M}_s = \frac{e}{s - M^2}\pi(p_2)(g_{V_{NN^*}}^V \hat{U} + \frac{g_{V_{NN^*}}^T}{(M + M^*)}\hat{U} \hat{q})(\hat{p}_1 + \hat{k} + M)(Q_N \hat{\varepsilon} - \frac{\kappa_N}{2M^2} \hat{k})u(p_1)$$

where $\varepsilon \cdot k = U \cdot q = 0$, $\hat{a} = \gamma^\mu a_\mu$, $M(M^*)$ is the mass of initial nucleon (final Roper resonance), $Q_N = 1(0)$ is the electric charge for proton (neutron), $\kappa_N = 1.79(-1.91)$ is the anomalous magnetic moment for proton (neutron). Different from the nucleon exchange in $s$-channel amplitude, Roper resonance exchange in $u$-channel amplitude is considered which is given by

$$\mathcal{M}_u = \frac{e}{u - M^*2}\pi(p_2)(Q_N \hat{\varepsilon} - \frac{\kappa_N^*}{2M^*} \hat{k})(\hat{p}_2 - \hat{k} + M^*)(g_{\omega_{NN^*}}^V \hat{U} + \frac{g_{\omega_{NN^*}}^T}{(M + M^*)}\hat{U} \hat{q})u(p_1)$$

where $u = (k - p_2)^2$, $\kappa_N^*$ is the anomalous magnetic moment of Roper resonance $N^*(1440)$. Neglecting their possible dependence on the virtuality in $s$ and $u$ of the intermediate nucleon and Roper resonance, $g_{\omega_{NN^*}}^V$ and $g_{\omega_{NN^*}}^T$ (vector and tensor coupling constants) are chosen to be the same in both channel matrix elements.

For $s$- and $u$-channel amplitudes it is possible to dress the form factors with $s$ and $u$ dependencies either in the form of $F(s)$ and $F(u)$ or $F(s,u)$. Use of the form factor as in the first case causes the violation of the gauge invariance. Even if the latter form preserve the gauge invariance this type of phenomenological form factor $[23]$, being the function of both Mandelstam variables, behaves like an amplitude rather than form factor. Therefore, following the prescription of the Ref. $[24]$, we use the constant form factors $F(s) = F(u) = 1$. In this case the effects are absorbed by the coupling constants $g_{\omega_{NN^*}}^V$ and $g_{\omega_{NN^*}}^T$ of $\omega NN^*$ vertices.
Let us note that these couplings are free parameters of our model and their values must be different from the values in space-like region of the vector meson momentum. In literature the values of the $g_{\omega NN^*}^V$ and $g_{\omega NN^*}^T$ coupling constants are obtained from the reactions $N^* + N \rightarrow N + N^*$ following arguments of Ref. [23]. However, the values of such coupling constants obtained from the NN- and $NN^*$- potentials will be different from that of coupling constants used in the associative photoproduction of $\omega$-meson and Roper resonance because they are considered in different regimes, space-like in the first case whereas time-like in the latter case. Another approach in calculation of transition couplings for virtual meson is suggested in the framework of constituent quark model [27], but the values obtained are suggestive rather than being definite quantitative predictions. At this stage determining the values of $\omega NN^*(1440)$ coupling constants is also not possible due to the fact that there is no direct experimental data on these coupling strengths. To overcome this problem we assume that the values of $\omega NN^*(1440)$ coupling constants are equal to that of $\omega NN$ coupling constants. With this assumption it is possible to determine the values of these constants from the fit to experimental data on the differential cross-section for the photoproduction of $\omega$ meson [28].

\section*{III. RESULTS AND DISCUSSION}

In the previous section, we have defined all the necessary parameters in t-, s-, and u-channel amplitudes of our model for the process, $\gamma + N \rightarrow \omega + N^*(1440)$. Let us specify here in more detail the coupling strengths and cut-off parameters of the considered model. For the coupling constant $g_{\omega \pi \gamma}$ we take the most commonly used value 1.82 obtained from the experimental partial decay width of $\omega \rightarrow \pi \gamma$ decay. The situation is however not clear for coupling strength of $\pi NN^*(1440)$-vertex. Because of the large uncertainty in the partial decay width of the $N^*(1440)$ into $N\pi$ channel ($228 \pm 82 MeV$) the coupling constant $g_{\pi NN^*(1440)}$ cannot be determined precisely. Following [20] we will use the value 3.4 for the $g_{\pi NN^*(1440)}$. 

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The remaining inputs of our model are the $\omega NN^*(1440)$ coupling constants and cut-off parameters $\Lambda_i$. In consideration of the coupling constants not only their absolute values but also their relative signs are important because of the essential interference effects. Cut-off parameters are in any case positive and by convention $g_{\omega \pi \gamma} g_{\pi NN^*(1440)}$ is chosen as positive. Therefore, the signs of $g^V_{\omega NN^*(1440)}$ and $g^T_{\omega NN^*(1440)}$ that appear in our results are their relative signs with respect to the $\pi$-contribution, and not their absolute signs. Since applicability of the same form factors for different processes is not proved rigorously we can fixed absolute values of cut-off parameters at some plausible values. Consequently, we are left with two fitting parameters $g^V_{\omega NN^*}$ and $g^T_{\omega NN^*}$.

For our calculations, the following three different sets with almost the same value of $\chi^2$, which are obtained from the fit to the experimental data about $d\sigma(\gamma p \rightarrow p\omega)/dt$ in the near threshold region [28], are chosen for the coupling constants $g^V,T_{\omega NN^*}$:

**Set 1:**

$$g^V_{\omega NN^*} = -1.4, \quad g^T_{\omega NN^*} = 0.4, \quad \chi^2 = 2.2 \quad (13)$$

**Set 2:**

$$g^V_{\omega NN^*} = 0.5, \quad g^T_{\omega NN^*} = 0.1, \quad \chi^2 = 1.6 \quad (14)$$

**Set 3:**

$$g^V_{\omega NN^*} = -0.01, \quad g^T_{\omega NN^*} = 0.6, \quad \chi^2 = 1.9 \quad (15)$$

To obtain set 1, we use the standard values of cut-off parameters $\Lambda_{\pi NN^*} = \Lambda_{\pi NN} = 0.7$ GeV and $\Lambda_{\omega \pi \gamma} = 0.77$ GeV. In analyzing the sensitivity of the best fit to $\Lambda_{\pi NN^*}$ and $\Lambda_{\omega \pi \gamma}$, we discover that the standard values of $\Lambda_i$ do not give the best solution. If the values of $\Lambda_{\pi NN^*}$ and $\Lambda_{\omega \pi \gamma}$ are changed to 0.5 GeV and 1.0 GeV, respectively, we find better sets for the coupling constants $g^V,T_{\omega NN^*}$, namely set 2 and set 3. We follow the same minimization procedure used in Ref. [29] for the determination of vector and tensor coupling constant values.
Differential cross section for $\gamma p \to \omega N^*(1440)$ reaction at $E_\gamma = 2.5$ GeV using the above sets of coupling constants of our model and zero-width approximation is shown in the left panel of Fig. 2. All these sets give different cross section for $\gamma p \to \omega N^*(1440)$. We also consider the width effects of Roper resonance on differential cross section, assuming that $N^*(1440)$ decays subsequently into the $\pi^0 p$ channel. These effects are presented in the right panel of Fig. 2. At $-t = 0.36 \text{ GeV}^2$, differential cross section for the process $\gamma p \to \omega N^*(1440) \to \omega \pi^0 p$ is about 20 times smaller than differential cross section for $\gamma p \to \omega N^*(1440)$ in the zero-width approximation. This difference comes from the partial decay width of $N^*(1440)$ into $\pi^0 p$ channel which is nearly 20% and interval of the $M_{N^*}$ appear in the integral of Eq. (5) reduces the strength of Roper resonance excitation by a factor of about 4 compared to case where all strength is concentrated at $M_{N^*} = 1.44$ GeV. Progress on the width effects directly is linked to the availability of new experimental data providing constraints on the couplings of $N^*(1440)$ to the $\pi N$ and $\omega N$ channels.

The contributions of different amplitudes to $d\sigma(\gamma p \to \omega N^*(1440))/dt$ and $d\sigma(\gamma n \to \omega N^*(1440))/dt$ are presented in Fig. 3 and 4. Set 1 and set 3 for the coupling constants produce negative $\pi \otimes (N + N^*(1440))$-interference while set 2 has a positive interference in the differential cross section for the associative photoproduction of Roper resonance and $\omega$-meson on proton and neutron targets. For all these cases up to $-t = 0.5$ our predictions for differential cross section does not differ significantly from the one-pion exchange results, but beyond this value of $t$ predictions of both model are different. Predicted behaviour of differential cross section for $\gamma n \to \omega N^*(1440)$ as compared with $\gamma p \to \omega N^*(1440)$ indicates that differential cross section on proton and neutron targets can have differences by a factor of 2 or more, i.e. we can predict definite isotopic effects.

Another prediction of our model is the $t$-dependence of beam asymmetry $\Sigma(\gamma p \to \omega N^*(1440))$ and $\Sigma(\gamma n \to \omega N^*(1440))$ at $E_\gamma = 2.5$ GeV, shown in Fig. 5 and Fig. 6. For the proton target, all three sets of coupling constants produce negative $\Sigma$, but although absolute value of $\Sigma$ is small for set 1 and set 2, being $|\Sigma| \leq 0.1$, it is nearly 0.25 at $|t| = 1.2$ GeV$^2$. However, in the neutron case, especially for set 1, beam asymmetry shows different
behaviour, i.e positive in sign for $|t| \leq 0.6 \, GeV^2$ and negative in the rest of the interval of $|t|$. Moreover, our model results show that beam asymmetry is sensitive to the sets of coupling constants in our model.

At present time, there is no systematic investigation of the role played by the $(s+u)$-contribution in associative photoproduction of the Roper resonance and $\omega$ meson in near threshold region. In fact, the unknown $\omega NN^*(1440)$ couplings have been the barrier to go further to include this contributions. However, our approach to determine these couplings make detail analysis possible for the description differential cross section and beam asymmetry. At this stage, of course, it is very difficult to say that our results are decisive because of the absence of the any differential cross section and polarization data about the processes $\gamma N \rightarrow N^*(1440)\omega$, but we can test our model by comparing it with the proposed one-boson exchange model, which include only $\pi$-contribution and is valid in the region $|t| \leq 0.5 - 0.6 \, GeV^2$. In this region our predictions of the differential cross section for $\gamma p \rightarrow \omega N^*(1440)$ are consistent with the predictions of Ref. [20] obtained from $\pi$-exchange model. This indicates that if the simple $\pi$-exchange model make sense our assumption about coupling strengths of $\omega NN^*(1440)$ is reasonable. Therefore, this model seems appropriate to perform the calculations on the boundary of the modern approaches to these processes and it should be considered as a first approach.

IV. CONCLUSIONS

The analysis done in the previous section results in the following conclusions:

• The relatively simple model $(\pi + N + N^*)$ is proposed to describe the associative photoproduction of Roper resonance and $\omega$ meson on proton and neutron targets near threshold region $(E_\gamma < 3GeV)$ for the whole t region. Comparison of this model with one-pion calculations demonstrates the definite difference in behaviour of differential cross section.

• The different solutions for the coupling constants and the cut-off parameters obtained from the fitting procedure result in the constructive and destructive $\pi \otimes (N + N^*)$-
interference contributions to $d\sigma(\gamma p \rightarrow N^*(1440))/dt$.

- $\Sigma$-asymmetry is different from zero and its $t$-behaviour is sensitive to our model parameters, namely $g^{V,T}_{\omega NN^*(1440)}$ coupling constants, which are obtained in the time-like region of vector meson four momentum.

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FIG. 1. Mechanisms of the model for associative photoproduction of Roper resonance and \( \omega \)-photoproduction: (a) t-channel exchanges, (b) and (c) s- and u-channel nucleon exchanges.
FIG. 2. Differential cross section for the processes, (a) $\gamma p \to \omega N^*(1440)$ in the zero-width approximation (b) $\gamma p \to \omega N^*(1440) \to \omega \pi^0 p$, at $E_\gamma = 2.5$ GeV. Solid, dashed and dot-dashed lines correspond to $g_{\omega NN}^V = 0.5$ and $g_{\omega NN}^T = 0.1$; $g_{\omega NN}^V = -0.01$ and $g_{\omega NN}^T = 0.6$; $g_{\omega NN}^V = -1.4$, $g_{\omega NN}^T = 0.4$, respectively.
FIG. 3. Different contributions to $d\sigma(\gamma p \to \omega N^*(1440))/dt$ at $E_\gamma = 2.5$ GeV for three different fitted parameter values: (a) $g_{\omega NN}^{V} = 0.5, \ g_{\omega NN}^{T} = 0.1$, (b) $g_{\omega NN}^{V} = -0.01, \ g_{\omega NN}^{T} = 0.6$, and (c) $g_{\omega NN}^{V} = -1.4, \ g_{\omega NN}^{T} = 0.4$. Solid, dashed and dot-dashed lines correspond to total, $\pi$-, and $(s+u)$-contribution, respectively.
FIG. 4. Different contributions to $d\sigma(\gamma n \rightarrow \omega N^*(1440))/dt$ at $E_\gamma = 2.5$ GeV for three different fitted parameter values: (a) $g_{\omega NN}^V = 0.5$, $g_{\omega NN}^T = 0.1$, (b) $g_{\omega NN}^V = -0.01$, $g_{\omega NN}^T = 0.6$, and (c) $g_{\omega NN}^V = -1.4$, $g_{\omega NN}^T = 0.4$. Notations are same as in Fig. 3.
FIG. 5. Different contributions to $\Sigma(\gamma p \rightarrow \omega N^*(1440))$ at $E_\gamma = 2.5$ GeV for three different fitted parameter values: (a) $g^V_{\omega NN} = 0.5$, $g^T_{\omega NN} = 0.1$, (b) $g^V_{\omega NN} = -0.01$, $g^T_{\omega NN} = 0.6$, and (c) $g^V_{\omega NN} = -1.4$, $g^T_{\omega NN} = 0.4$. Notations are same as in Fig. 3.
FIG. 6. Different contributions to $\Sigma(\gamma n \rightarrow \omega N^*(1440))$ at $E_\gamma = 2.5$ GeV for three different fitted parameter values: (a) $g^V_{\omega NN} = 0.5$, $g^T_{\omega NN} = 0.1$, (b) $g^V_{\omega NN} = -0.01$, $g^T_{\omega NN} = 0.6$, and (c) $g^V_{\omega NN} = -1.4$, $g^T_{\omega NN} = 0.4$. Notations are same as in Fig. 3.