ω-meson photoproduction on nucleons in the near-threshold region

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Abstract. The ω-meson photoproduction, $\gamma + p \rightarrow p + \omega$, is studied in the framework of a model, containing π-meson exchange in t-channel and nucleon-exchange in s- and u-channels. Considering both ωNN coupling constants in the region of time-like meson four-momenta as the free parameters, we find different sets of solutions for these constants from the existing data on the t-dependence of the differential cross-sections, $d\sigma(\gamma + p \rightarrow p + \omega)/dt$, in the near-threshold region $E_\gamma \leq 2$ GeV. These sets of ωNN coupling constants, corresponding to destructive and constructive $\pi \otimes N$-interference contributions to $d\sigma/dt$ can be well distinguished by measurements of beam asymmetry, induced by linear photon polarization.

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1 Introduction

The vector meson photoproduction on nucleons, $\gamma + p \rightarrow p + V$, $V = \rho$ or ω, in the near-threshold region $E_\gamma < 2$ GeV, can be considered as a source of important information concerning interesting problems of hadron electrodynamics, such as for example the values of different electromagnetic and strong-coupling constants and the properties of the so-called "missing" resonances [1,2]. To solve these and other similar problems a suitable model for $\gamma + p \rightarrow p + V$ must be formulated. This is especially important for the study of the physics of missing resonances. It is a well-known fact that in the N^*-resonance physics for the successful extraction of adequate resonance information, the correct theoretical description of nonresonant mechanisms must be at hand. This is not a simple task and it has been an actual problem up to now even for the case of the "oldest" $\Delta(1232)$-resonance, where for the exact value of the small quadrupole ($E2$) multipole amplitude for the decay $\Delta \rightarrow N + \gamma$, the correct knowledge of the corresponding nonresonant background is needed [3–5]. Evidently, this statement is correct for any N^*-resonance.

The theoretical study of the nonresonant mechanisms for the processes of vector meson photoproduction on nucleons, $\gamma + N \rightarrow N + V$, in the near-threshold region $E_\gamma < 2$ GeV, is at its beginnings, there is no unique and well-proved solution of this task. The following mechanisms are considered in the literature [1,2,6–13]: pseudoscalar (π, η) and scalar (σ)-meson exchanges in the t-channel,

one-nucleon exchanges in $(s + u)$-channels, and pomeron exchange for the case of neutral vector meson photoproduction. Typically, different combinations of these contributions are analyzed by different authors. All these ingredients are characterized by a relatively large number of coupling constants and cut-off parameters which determine the phenomenological form factors for the electromagnetic and strong vertices of the considered pole diagrams. Some of these parameters can be determined from other processes, such as for example, the radiative decays of vector mesons $V \rightarrow \pi(\eta) + \gamma$, with good enough accuracy. The same is correct for the πNN coupling constant, which has been determined with the highest accuracy among different strong-coupling constants. However, another situation exits for VNN coupling constants which determine the nucleon pole diagrams for processes $\gamma + N \rightarrow N + V$ in the time-like region of the vector meson momentum, $q^2 = m_V^2$. In general, therefore, these values can be very different from their values in the space-like region of the vector meson momentum, which is the case of the pion photoproduction, $\gamma + N \rightarrow N + \pi$, the vector meson exchange in t-channel, or NN-potential [14,15].

Another important question concerns the applicability of the pomeron exchange in the near-threshold region, where the validity of the Regge regime seems not so evident. It is enough to remember that, typically, the kinematic region of application of the Regge theory is determined by the following conditions: $s \gg M^2, s \gg t$, where s and t are the standard Mandelstam variables, M is the nucleon mass. Evidently, such conditions cannot be realized in the near-threshold region for $\gamma + N \rightarrow N + V$.

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In consideration of s-channel N^*-contributions and t-channel exchanges simultaneously, the so-called interference model [16], it is necessary to keep in mind a dangerous problem of double counting [17]. Due to the classic duality hypothesis [18], a Regge amplitude, when extrapolated into the low-energy region, provides an average description of s-channel N^*-resonances. In this connection we must note the pecularities of the pomeron exchange in high-energy processes, because in duality approach it occupies a special position, that is if the normal reggeons (ρ, ω, A_2 ...) are associated with s-resonances alone, the pomeron is associated only with background [19]. So the main problem here is in the division of the threshold amplitude into the resonance and background parts. Evidently, the Born contribution to $\gamma + N \rightarrow N + V$ must be considered as some background piece.

In this work, we attempt to consider these questions for the ω-meson photoproduction, $\gamma + N \rightarrow N + \omega$, which have some special properties, different from the ρ^0-meson photoproduction, $\gamma + N \rightarrow N + \rho^0$. First of all, due to the relatively large $\omega\pi\gamma$ coupling constant in comparison with $\rho\pi\gamma$ coupling constant, one-pion contribution can be considered as the main mechanism in the near-threshold region for $\gamma + N \rightarrow N + \omega$ processes. That is an important point because this contribution is determined by the product of the well-known coupling constants, $g_{\omega\pi\gamma}g_{\pi NN}$. So here we have a situation, different from the case of ρ^0-photoproduction, where another t-exchange is important, namely, the σ-exchange. But the properties of the σ-meson are not well established now, even its mass is inside a wide interval: 400–1200 MeV [20], the same is also true for the σ-width: $\Gamma = 600$–1000 MeV. Moreover, the product of necessary coupling constants, namely, $g_{\rho\sigma\gamma}g_{\sigma NN}$, cannot be considered as well known. For example, the "standard" assumption [13] that $\rho\sigma\gamma$ coupling constant is essentially larger in comparison with $\omega\sigma\gamma$ coupling constant must be revised now after the experiment of Novosibirsk group [21], which proved definitely that the width of the radiative decays $\omega \rightarrow \pi^0 + \pi^0 + \gamma$ and $\rho \rightarrow \pi^0 + \pi^0 + \gamma$ are comparable. Let us note in this connection the previous conclusion about the large enough $\rho\sigma\gamma$ coupling constant that was obtained on the basis of the relatively large measured branching ratio for $\rho \rightarrow \pi^+ + \pi^- + \gamma$ in comparison with the $\omega \rightarrow \pi^0 + \pi^0 + \gamma$ branching ratio [22]. However, the main contribution to $\rho \rightarrow \pi^+ + \pi^- + \gamma$ must be not due to the σ-mechanism ($\rho^0 \rightarrow \gamma + \sigma^0 \rightarrow \gamma + \pi^+ + \pi^-$) but due to γ-radiation of final charged pions.

Therefore, the situation with the σ-exchange in the process $\gamma + p \rightarrow p + \rho^0$ becomes more complicated now. In principle it is possible to "save" the σ-exchange in $\gamma + p \rightarrow p + \rho^0$: the decrease in the value of the $g_{\rho\sigma\gamma}$ coupling constant, which follows from the Novosibirsk experiment, can be compensated by correspondingly increasing the value of the $g_{\sigma NN}$ coupling constant. By such a manipulation it is possible to conserve the substantial σ-contribution to the matrix element for the process $\gamma + p \rightarrow p + \rho^0$ in the near-threshold region, but as a result, we will obtain a quadratically increasing σ-contribution to

the NN-potential. Therefore, this problem must be studied independently.

And another point connected with increasing the σNN coupling constant is that this will also increase, correspondingly, the σ-contribution to the matrix element of the process $\gamma + p \rightarrow p + \omega$ making this contribution comparable with that of the process $\gamma + p \rightarrow p + \rho^0$. Thus, in such a situation, we will have large and comparable contributions, namely, σ and π, to the matrix element of $\gamma + p \rightarrow p + \omega$ which evidently contradicts the existing explanation of the experimental data about differential cross-sections for this process. In order to remove this contradiction, these two large contributions must be essentially compensated by some destructive interference with other possible contributions to the matrix element of the $\gamma + p \rightarrow p + \omega$ process. But a pure imaginary pomeron contribution cannot interfere with the real amplitudes of π- and σ-exchange. So the best candidate for such interference could be the N-contribution considered in $(s+u)$-channels to satisfy gauge invariance, or N^*-contributions.

We like to note that in the general case each N^*-resonance, with spin $J \geq 3/2$, produces a complicated enough spin structure in the matrix element due to the possible six independent multipole amplitudes, which must be nonzero. In any case, the situation with resonance physics in $\gamma + N \rightarrow N + V$ processes is evidently more complicated in comparison with the pseudoscalar meson photoproduction on nucleon: $\gamma + N \rightarrow N + \pi$ or $\gamma + N \rightarrow N + \eta$. This means that the polarization phenomena in processes $\gamma + N \rightarrow N + V$ are especially important to realize more or less unique multipole analysis.

The specific property of N^*-contributions in the s-channel is the generation of the complex amplitudes. This new property of the corresponding model will result in rich and specific T-odd polarization effects in $\gamma + N \rightarrow N + V$, such as the analyzing power induced by the polarized nucleon target, or the polarization of produced nucleon. So, namely, the T-odd polarization phenomena in $\gamma + N \rightarrow N + V$ will be the most decisive for the estimation of N^*-contributions in a more definite way. Being the simplest among all vector meson photoproduction processes, the reaction $\gamma + N \rightarrow N + \omega$ seems as the most suitable for the identification of the adequate nonresonant mechanisms for such processes in the near-threshold region.

From the duality point of view, we can conclude that in the case of the importance of N^*-contributions in $\gamma + N \rightarrow N + \omega$, the nonpomeron Regge contributions must be considered at high energy. But all existing models are neglecting such contributions.

In this paper, we try to estimate the role of nucleon-exchange contribution in $(s + u)$-channels to the matrix element of the processes $\gamma + N \rightarrow N + \omega$. Instead of the standard and oversimplified model for $\gamma + p \rightarrow p + \omega$ with π-exchange only, we consider here the more complicated $(\pi + N)$ model, but without pomeron exchange in the near-threshold region. To estimate the possible strong dependence of ωNN coupling constants on the vector meson four-momentum, going from the region of space-like to time-like vector meson momentum, we consider in our

approach both possible ωNN coupling constants, tensor and vector types, as free parameters to be determined by performing a fit to the existing experimental data on the differential cross-section $d\sigma(\gamma + p \rightarrow p + \omega)/dt$ in the near-threshold region. Such a model will produce non-trivial and relatively intensive polarization phenomena in $\gamma + N \rightarrow N + \omega$. Of course, all these polarization effects have T-even character. But instead of trivial polarization effects of the π-exchange model, the $(\pi + N)$ model will produce specific t-behaviour of such observables, such as the asymmetry Σ induced the by the photon linear polarization, the elements of density matrix for the vector mesons produced in collisions of polarized and unpolarized particles. Among the possible two spin polarization observables of T-even nature, let us note the asymmetry in collisions of circularly polarized photons with polarized targets. High-energy photon beams with high degree of circular polarization are available at JLAB now. Note also that the suggested model with $(\pi + N)$-contributions will produce also essential difference in observables on proton and neutron targets due to the $\pi \otimes N$-interference and due to different N-contributions.

Thus, our main aim in this work is to find a special simple $(\pi + N)$ model with relatively large N-contribution, which is cancelled in differential cross-section with unpolarized particles by the essential $\pi \otimes N$-interference, as a result imitating the differential cross-section $d\sigma(\gamma + p \rightarrow p + \omega)/dt$ of the pure π-exchange model. Evidently such $(\pi + N)$ model and simple π-exchange model will differ essentially in isotopic effects and in polarization phenomena.

2 Description of the model

We begin here by discussing the main properties of the suggested model for the process $\gamma + N \rightarrow N + \omega$ in the near-threshold region. The nucleon s-channel contribution is described by the following amplitude:

$$\mathcal{M}_s = \frac{e}{s - M^2} \overline{u}(p_2) \left(g_{\omega NN}^V \hat{U} + \frac{g_{\omega NN}^T}{2M} \hat{U} \ \hat{q} \right)$$
$$\times (\hat{p_1} + \hat{k} + M) \left(Q_N \hat{\varepsilon} - \frac{\kappa_N}{2M} \hat{\varepsilon} \ \hat{k} \right) u(p_1) , \qquad (1)$$

where ε_μ and k (U_μ and q) are the polarization four-vector and four-momentum of the photon (ω-meson), $\varepsilon \cdot k = U \cdot q = 0$, $\hat{a} = \gamma^\mu a_\mu$, M is the nucleon mass, Q_N is the nucleon electric charge, *i.e.* $Q_N = 1(0)$ for proton (neutron), κ_N is the nucleonic anomalous magnetic moment, $\kappa_N = 1.79(-1.91)$ for proton (neutron); $g_{\omega NN}^V$ and $g_{\omega NN}^T$ are the vector (Dirac) and tensor (Pauli) coupling constants of the ωNN-vertex. The notation of particle four-momenta is presented in fig. 1. We consider here the quantities $g_{\omega NN}^V$ and $g_{\omega NN}^T$ as constants, neglecting their possible dependence on the virtuality s of the intermediate nucleon. Therefore, the same coupling constants $g_{\omega NN}^V$ and $g_{\omega NN}^T$ determine the matrix element of the nucleon exchange in the u-channel as
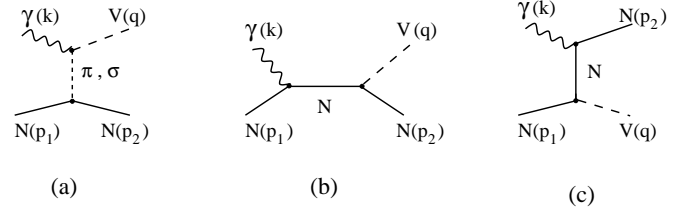

Fig. 1. Mechanisms of the model for ω-photoproduction: (a) t-channel exchanges, (b) and (c) s- and u-channel nucleon exchanges.

$$\mathcal{M}_u = \frac{e}{u - M^2} \overline{u}(p_2) \left(Q_N \hat{\varepsilon} - \frac{\kappa_N}{2M} \hat{\varepsilon} \ \hat{k} \right) (\hat{p_2} - \hat{k} + M)$$
$$\times \left(g_{\omega NN}^V \hat{U} + \frac{g_{\omega NN}^T}{2M} \hat{U} \ \hat{q} \right) u(p_1) , \qquad (2)$$

where $u = (k - p_2)^2$.

We like to repeat here once more that, in the general case the quantities $g_{\omega NN}^V$ and $g_{\omega NN}^T$ in eq. (2) must be considered as some form factors, $g_i = g_i(u)$, but to preserve gauge invariance of the sum $\mathcal{M}_s + \mathcal{M}_u$, we will neglect the possible s- or u-dependence of g_i. In any case, we consider here the very probable possibility that the $g_{\omega NN}^V$ and $g_{\omega NN}^T$ in eqs. (1) and (2) are different from their values in the space-like region of vector meson momentum, *i.e.* we will consider the coupling constants $g_{\omega NN}^V$ and $g_{\omega NN}^T$ as the fitting parameters of the suggested model.

The matrix element for t-channel π-meson exchange can be written straightforwardly in the following way:

$$\mathcal{M}_t = e \frac{g_{\omega \pi \gamma}}{m_\omega} \frac{g_{\pi NN}}{t - m_\pi^2} F_{\pi NN}(t) \ F_{\omega \pi \gamma}(t)$$
$$\times (\overline{u}(p_2) \ \gamma_5 \ u(p_1)) \ (\epsilon^{\mu\nu\alpha\beta} \ \varepsilon_\mu \ k_\nu \ U_\alpha \ q_\beta) , \qquad (3)$$

where $t = (k - q)^2$, m_π is the pion mass, m_ω is the ω-meson mass, $g_{\omega \pi \gamma}$ and $F_{\omega \pi \gamma}(t)$ ($g_{\pi NN}$ and $F_{\pi NN}(t)$) are the coupling constant and the corresponding form factor for the electromagnetic-$\omega \pi \gamma$ (strong-πNN) vertex of the considered diagram.

We like to note that, in our analysis we avoid using any form factor in $\mathcal{M}_s + \mathcal{M}_u$, again to preserve gauge invariance of $\mathcal{M}_s + \mathcal{M}_u$. Evidently, a s-dependent form factor for $\mathcal{M}_s$ and a u-dependent form factor for $\mathcal{M}_u$, which seems as the most natural way to introduce form factors, will destroy the coherence of both of these contributions with respect to the conservation of the electromagnetic current for the considered process.

We prefer in our treatment to include the possible form factor effects and also the effects of the transition from space-like to time-like region in ω-meson four-momentum in the effective values of the coupling constants $g_{\omega NN}^V$ and $g_{\omega NN}^T$. If the above-mentioned effects are important, the resulting values of the fitted coupling constants $g_{\omega NN}^V$ and $g_{\omega NN}^T$, which are to be obtained by a fit to the existing experimental data about the differential cross-section for $\gamma + p \rightarrow p + \omega$ [23], will be different from their values obtained in the space-like region. Therefore, these new values for the coupling constants $g_{\omega NN}^V$ and $g_{\omega NN}^T$ can also be used in similar analysis of the nucleon contribution to
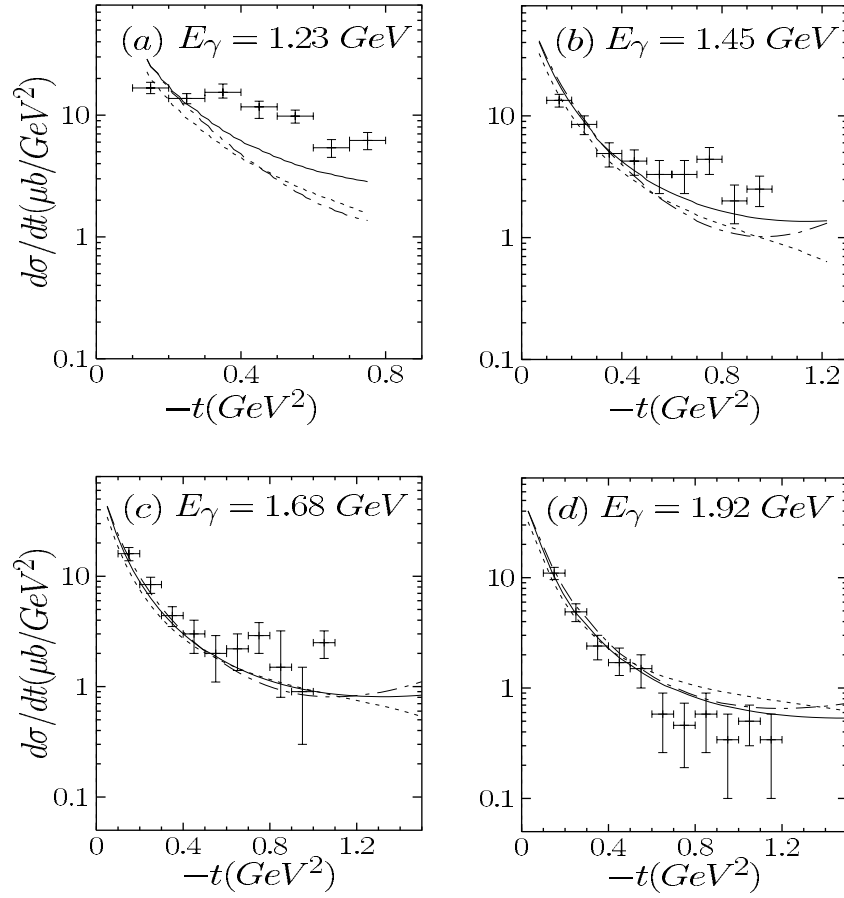
Fig. 2. Comparison of experimental differential cross-section data for $\gamma + p \rightarrow p + \omega$ at $E_\gamma = 1.23$, 1.45, 1.68 and 1.92 GeV from [19] with the calculation of the suggested model. Solid, dashed and dot-dashed lines correspond to $g_{\omega NN}^V = 0.5$, $g_{\omega NN}^T = 0.1$; $g_{\omega NN}^V = -0.4$, $g_{\omega NN}^T = 1.0$; and $g_{\omega NN}^V = -1.4$, $g_{\omega NN}^T = 0.4$, respectively.

many other processes with ω-meson production, such as, $\pi + N \rightarrow N + \omega$, $e^- + N \rightarrow e^- + N + \omega$, $\pi + N \rightarrow \pi + \omega$ etc.

In our calculation of different observables for $\gamma + N \rightarrow N + \omega$ we use the formalism of the so-called transversal amplitudes in the center-of-mass system (CMS) of the considered reaction. This formalism is effective for the analysis of polarization phenomena in the processes of the vector meson photoproduction, and especially useful in the analysis of the problem of the full reconstruction of the spin structure of the matrix element for $\gamma + N \rightarrow N + V$ from the complete experimental data.

The corresponding parametrization of the general matrix element of any photoproduction process $\gamma + N \rightarrow N + V$, which is valid for any model, can be written in terms of 12 independent transversal spin structures in the following way:

$$\mathcal{M} = \varphi_2^\dagger \mathcal{F} \varphi_1 \,,$$
$$\mathcal{F} = i f_1 (\vec{\varepsilon} \cdot \hat{\vec{m}})(\vec{U} \cdot \hat{\vec{m}}) + i f_2 (\vec{\varepsilon} \cdot \hat{\vec{m}})(\vec{U} \cdot \hat{\vec{k}})$$
$$+ i f_3 (\vec{\varepsilon} \cdot \hat{\vec{n}})(\vec{U} \cdot \hat{\vec{n}}) + (\vec{\sigma} \cdot \hat{\vec{n}})[f_4 (\vec{\varepsilon} \cdot \hat{\vec{m}})(\vec{U} \cdot \hat{\vec{m}})$$

$$+ f_5 (\vec{\varepsilon} \cdot \hat{\vec{m}})(\vec{U} \cdot \hat{\vec{k}}) + f_6 (\vec{\varepsilon} \cdot \hat{\vec{n}})(\vec{U} \cdot \hat{\vec{n}})]$$
$$+ (\vec{\sigma} \cdot \hat{\vec{m}})[f_7 (\vec{\varepsilon} \cdot \hat{\vec{m}})(\vec{U} \cdot \hat{\vec{n}})$$
$$+ f_8 (\vec{\varepsilon} \cdot \hat{\vec{n}})(\vec{U} \cdot \hat{\vec{m}}) + f_9 (\vec{\varepsilon} \cdot \hat{\vec{n}})(\vec{U} \cdot \hat{\vec{k}})]$$
$$+ (\vec{\sigma} \cdot \hat{\vec{k}})[f_{10}(\vec{\varepsilon} \cdot \hat{\vec{m}})(\vec{U} \cdot \hat{\vec{n}})$$
$$+ f_{11}(\vec{\varepsilon} \cdot \hat{\vec{n}})(\vec{U} \cdot \hat{\vec{m}}) + f_{12}(\vec{\varepsilon} \cdot \hat{\vec{n}})(\vec{U} \cdot \hat{\vec{k}})] \,, \qquad (4)$$

where the set of unit orthogonal 3-vectors $\hat{\vec{m}}$, $\hat{\vec{n}}$, and $\hat{\vec{k}}$ are defined as: $\hat{\vec{k}} = \vec{k}/|\vec{k}|, \hat{\vec{n}} = \vec{k} \times \vec{q}/|\vec{k} \times \vec{q}|, \hat{\vec{m}} = \hat{\vec{n}} \times \hat{\vec{k}}$ and $\vec{k}$ and $\vec{q}$ are the three-momentum of the photon and the vector meson in the CMS, φ_1 and φ_2 are the two-component spinors for initial and final nucleons; f_i, $i = 1, ..., 12$, are the so-called transversal amplitudes, which are complex functions of two independent invariant variables, s and t, $f_i = f_i(s,t)$.

The differential cross-section $d\sigma/d\Omega$ with all the particles in the initial and final states unpolarized, and the beam asymmetry Σ which is defined as

$$\Sigma = \frac{d\sigma_\parallel/d\Omega - d\sigma_\perp/d\Omega}{d\sigma_\parallel/d\Omega + d\sigma_\perp/d\Omega} \,, \qquad (5)$$

can be expressed as quadratic combinations of the transversal amplitudes f_i in a straightforward manner.

3 Numerical results and discussion

In the suggested model there are two different sets of parameters, namely, the coupling constants, and the cut-off parameters Λ_i which characterize the t-dependence of the phenomenological form factors $F_{\omega\pi\gamma}(t)$ and $F_{\pi NN}(t)$ for the two vertices of the one-pion diagram:

$$F_{\omega\pi\gamma}(t) = \frac{\Lambda_{\omega\pi\gamma}^2 - m_\pi^2}{\Lambda_{\omega\pi\gamma}^2 - t}, \quad F_{\pi NN}(t) = \frac{\Lambda_{\pi NN}^2 - m_\pi^2}{\Lambda_{\pi NN}^2 - t}, \quad (6)$$

Evidently, these two sets have different physical content and different physical meaning. First of all, the parameters Λ_i are positive, whereas for the coupling constants $g_{\omega NN}^V$ and $g_{\omega NN}^T$ not only their absolute values are important but their signs as well, because of the essential interference effects. So, on the level of differential cross-section with unpolarized particles there is a strong $\pi \otimes N$-interference, and the interference of type $g_{\omega NN}^V g_{\omega NN}^T$, as well. As a result, the fitting procedure can produce not only the absolute values of both constants $g_{\omega NN}^V$ and $g_{\omega NN}^T$ but their signs also. Of course, it is not the absolute signs we can speak here, but only about the relative signs of coupling constants $g_{\omega NN}^V$ and $g_{\omega NN}$ with respect to the π-contribution. Therefore, it is possible to assume that the product $g_{\omega\pi\gamma}g_{\pi NN}$ must be positive, thus fixing by this agreement some system for relative signs. In any case, the cut-off parameters Λ_i must be positive and can be fixed at some plausible values.

So, in our model we have two fitting parameters, namely, the ωNN coupling constants $g_{\omega NN}^V$ and $g_{\omega NN}^T$. To find these constants we use the "new" experimental data about $\mathrm{d}\sigma(\gamma p \rightarrow p\omega)/\mathrm{d}t$ in the near-threshold region [23], namely, for $E_\gamma = 1.23$, 1.45, 1.68, and 1.92 GeV corresponding to four energy intervals, $1.1 < E_\gamma < 1.35$ GeV, $1.35 < E_\gamma < 1.55$ GeV, $1.55 < E_\gamma < 1.8$ GeV, and $1.8 < E_\gamma < 2.03$ GeV, and in our fit we use all the experimental data in these energy intervals. Minimizing procedure demonstrates that $(s+u)$-contribution, being very important, cannot be fixed uniquely on the basis of the existing experimental data about $\mathrm{d}\sigma(\gamma p \rightarrow p\omega)/\mathrm{d}t$. There are two sets of different pair $g_{\omega NN}^V$ and $g_{\omega NN}^T$, which are equivalently good for the description of the differential cross-section $\mathrm{d}\sigma(\gamma p \rightarrow p\omega)/\mathrm{d}t$ with almost the same value of χ^2. For example, if one uses the "standard" values for the cut-off parameters, namely, $\Lambda_{\pi NN} = 0.7$ GeV and $\Lambda_{\omega\pi\gamma} = 0.77$ GeV, the best solution with $\chi^2/\text{ndf} = 2.2$ corresponds to the following values of $g_{\omega NN}^V$ and $g_{\omega NN}^T$:

(a) $\qquad g_{\omega NN}^V = -1.4, \qquad g_{\omega NN}^T = 0.4.$

To analyze the sensitivity of the "best" fit to $\Lambda_{\pi NN}$, and $\Lambda_{\omega\pi\gamma}$, we produce fitting with variable values of Λ_i, and discover that the "standard" values of Λ_i are not the best ones. For example for $\Lambda_{\pi NN} = 0.5$ GeV, $\Lambda_{\omega\pi\gamma} = 1.0$ GeV we find a better solution, namely,

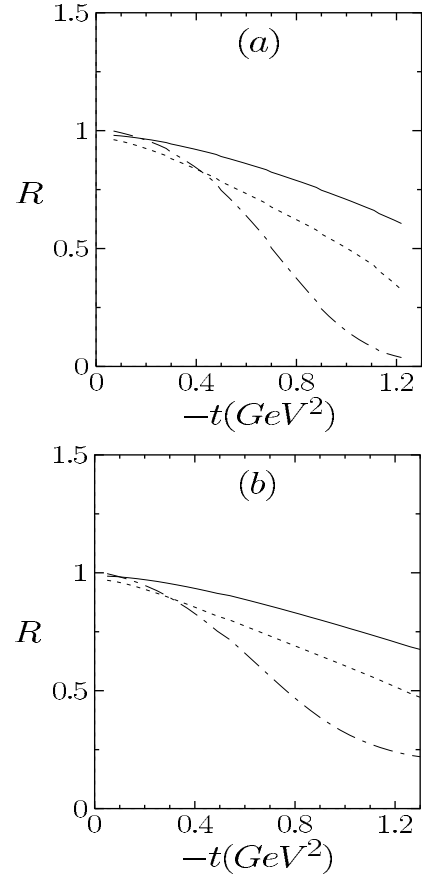(b) $\qquad g_{\omega NN}^V = 0.5, \qquad g_{\omega NN}^T = 0.1$

Fig. 3. Ratio of the differential cross-section on neutron and proton target ($R = \mathrm{d}\sigma(\gamma n \rightarrow n\omega)/\mathrm{d}\sigma(\gamma p \rightarrow p\omega)$) at (a) $E_\gamma = 1.45$ GeV and (b) $E_\gamma = 1.68$ GeV with the total contributions of exchange mechanisms (π, s, u). Notation for different graphs is the same as in fig. 2.

with $\chi^2/\text{ndf} = 1.6$. For these values of the parameter Λ_i, the solution with negative value of the coupling constant $g_{\omega NN}^V$, namely,

(c) $\qquad g_{\omega NN}^V = -0.4, \qquad g_{\omega NN}^T = 1.0$

can also be found, but not with the best value of $\chi^2/\text{ndf} = 2.5$, which is near to the solution (a). The resulting differential cross-sections obtained using the above solutions of the coupling constants in the model considered for $\gamma + p \rightarrow p + \omega$ at $E_\gamma = 1.23$, 1.45, 1.68, and 1.92 GeV are shown in fig. 2. All these solutions are good enough to reproduce the t-dependence of $\mathrm{d}\sigma/\mathrm{d}t$, but they are different in physical content: fit (b) produces positive $\pi \otimes N$-interference contribution to $\mathrm{d}\sigma/\mathrm{d}t$, whereas fits (a) and (c) produce negative interference contribution. But in all cases we are evidently improving in the description of the t-behaviour for $-t > 0.5$ GeV^2, in comparison with the one-pion exchange only. As we can see from fig. 3, the different sets result in different cross-section for $\gamma n \rightarrow n\omega$. So from the point of view of the suggested model the future data about $\gamma n \rightarrow n\omega$ will be very interesting.

In this respect the beam asymmetry Σ, which is very sensitive to the considered variants of the model here, is
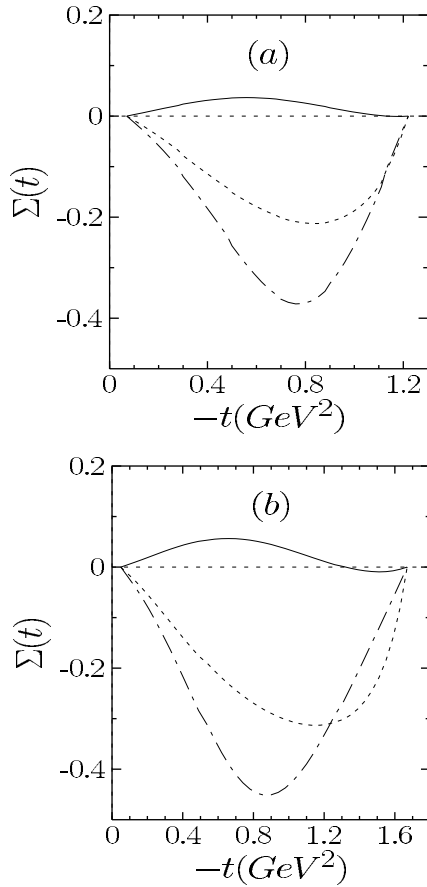
Fig. 4. Predicted behaviour of beam asymmetry for $\gamma + p \rightarrow p + \omega$ at (a) $E_\gamma = 1.45$ GeV and (b) $E_\gamma = 1.68$ GeV. Notation for different graphs is the same as in fig. 2.
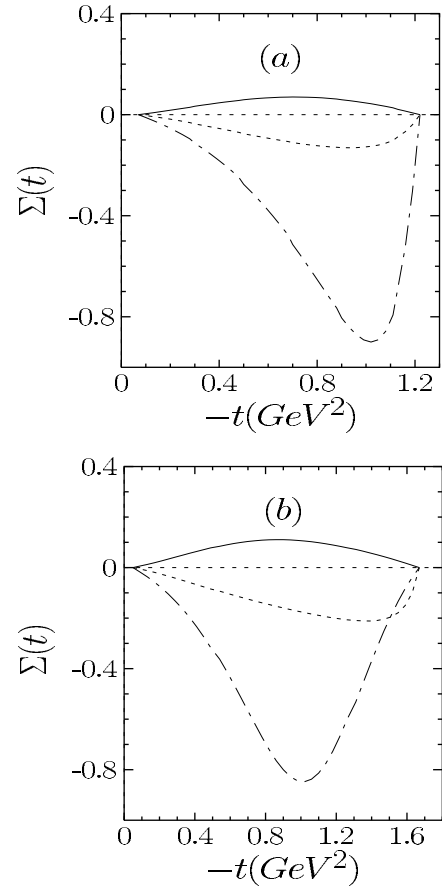

Fig. 5. Predicted behaviour of beam asymmetry for $\gamma + n \rightarrow n + \omega$ at (a) $E_\gamma = 1.45$ GeV and (b) $E_\gamma = 1.68$ GeV. Notation for different graphs is the same as in fig. 2.

also important. Predicted behaviours of the beam asymmetry Σ for $\gamma + p \rightarrow p + \omega$ and $\gamma + n \rightarrow n + \omega$ are presented in fig. 4 and fig. 5, respectively. In the case of the (b) model, the one-nucleon contribution produces in absolute value a large, in sign a negative value of Σ, but the contribution of the $\pi \otimes N$-interference term to Σ is cancelling this value. Therefore, we have here some "imitation" of pure one-pion exchange, for which $\Sigma = 0$, exactly, but for this set of values of corresponding coupling constants and cut-off parameters in this model $\Sigma \neq 0$, being $\Sigma \leq 0.1$. In some sense, the contrary situation appears for model (a) and (c), where the one-nucleon contribution generates small values of Σ, but the $\pi \otimes N$-interference is very important, especially for the neutron target, producing even the maximal value $|\Sigma| = 1$ at $t \simeq 1.0$ GeV^2.

Another prediction of our model is the ratio of differential cross-sections $R = \mathrm{d}\sigma(\gamma n \rightarrow n\omega)/\mathrm{d}\sigma(\gamma p \rightarrow p\omega)$, which is shown in fig. 6. In this figure, different contributions of exchange mechanisms to $\mathrm{d}\sigma(\gamma p \rightarrow p\omega)/\mathrm{d}t$, R, $\Sigma(\gamma p \rightarrow p\omega)$ and $\Sigma(\gamma n \rightarrow n\omega)$ at $E_\gamma = 1.45$ GeV are shown for the values of the ωNN coupling constants $g_{\omega NN}^V = 0.5$ and $g_{\omega NN}^T = 0.1$.

In principle the σ-contribution can be estimated here on the basis of the coupling constant $g_{\omega\sigma\gamma}$ obtained from the branching ratio $\omega \rightarrow \pi^0 + \pi^0 + \gamma$. Considering two

mechanisms for this decay, namely, the σ-exchange: $\omega \rightarrow \sigma + \gamma \rightarrow \pi^0 + \pi^0 + \gamma$, and the ρ-exchange: $\omega \rightarrow \pi^0 + \rho^0 \rightarrow \pi^0 + \pi^0 + \gamma$, then utilizing the experimental value of the branching ratio it is possible to find two solutions for $g_{\omega\sigma\gamma}$[24]. But these possible solutions for $g_{\omega\sigma\gamma}$ with different signs will result however, in very small contribution to $\mathrm{d}\sigma/\mathrm{d}t$ and Σ, on proton and neutron targets.

Of course, our investigation is succeptible to both experimental and theoretical uncertainties. Experimentally, a systematic study of the differential cross-section $\mathrm{d}\sigma(\gamma p \rightarrow p\omega)/\mathrm{d}t$ with high enough accuracy is not available. And the absence of any polarization data about the process $\gamma + p \rightarrow p + \omega$ seems as a serious defect at the moment. This, combined with the overall poor quality of the reported data, may make a detailed analysis nonconclusive at this stage. Therefore, our calculations are performed on the boundary of the modern approaches to these processes, and as such should be considered as a first approach.

Although our $\mathrm{d}\sigma/\mathrm{d}t$ fit demonstrates our point that the existing data about real ω-photoproduction in the near-threshold region can be explained in the framework of the $(\pi + N)$ model, we do not consider our success to be decisive. Indeed, we obtained a fit in which only the nucleon exchange in s- and u-channels is taken into ac-
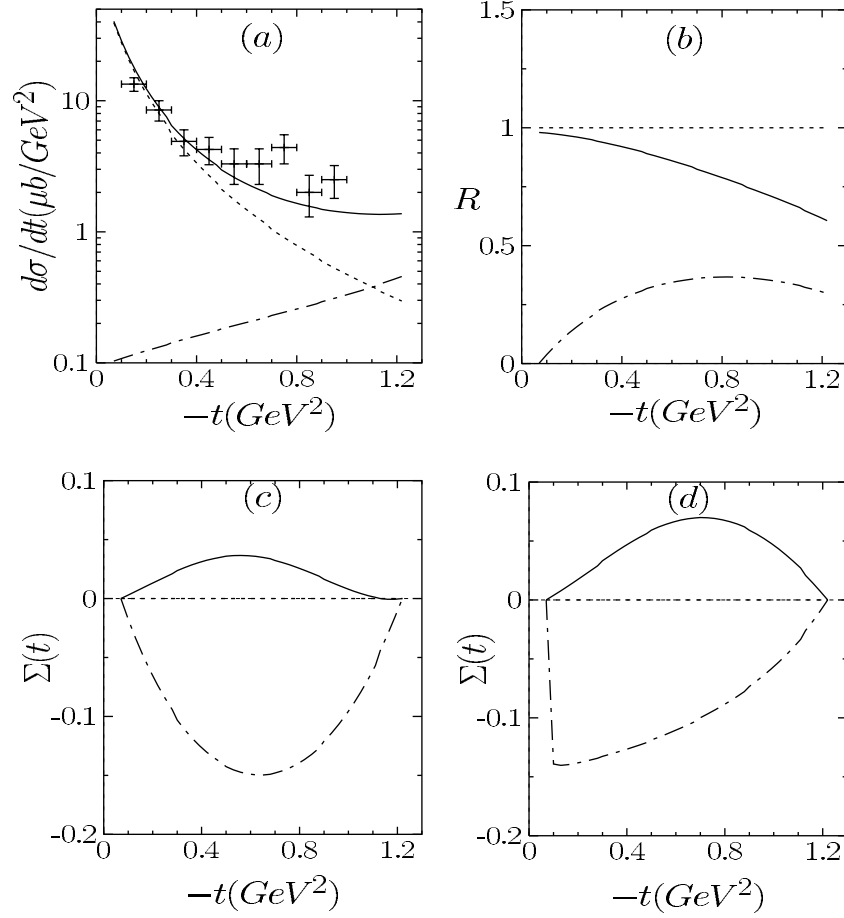
Fig. 6. Different contributions of exchange mechanisms to: (a) $\mathrm{d}\sigma(\gamma p \to p\omega)/\mathrm{d}t$, (b) $R = \mathrm{d}\sigma(\gamma n \to n\omega)/\mathrm{d}\sigma(\gamma p \to p\omega)$, (c) $\Sigma(\gamma p \to p\omega)$, (d) $\Sigma(\gamma n \to n\omega)$ at $E_\gamma = 1.45$ GeV for $g_{\omega NN}^V = 0.5$, $g_{\omega NN}^T = 0.1$. Solid, dashed and dot-dashed lines correspond to total, π-exhange and $(s + u)$-nucleon contributions, respectively.

count. In principle a fit of better quality can be done in a model with N^*-contributions. But we must repeat once more that the quality of existing data is not so good for a more refined analysis. In any case it is demonstrated here that the proposed model in this work provides not only an explanation of the existing data about $\mathrm{d}\sigma(\gamma p \to p\omega)/\mathrm{d}t$ in the near-threshold region in the whole t region, but our analysis also proves that information about polarization observables in $\gamma p \to p\omega$ will help in clarifying the picture of the ω-meson photoproduction mechanism.

4 Conclusions

So, our previous analysis allows us to obtain the following conclusions:

– The existing experimental data about the t-dependence of the differential cross-section $\mathrm{d}\sigma(\gamma p \to p\omega)/\mathrm{d}t$ in the near-threshold region ($E_\gamma \leq 2.0$ GeV) can be described in the framework of the model with π- and N-exchanges, only.
– For the coupling constants $g_{\omega NN}^V$ and $g_{\omega NN}^T$ of the ωNN-vertex different solutions have been obtained,

corresponding to positive and negative values of $g_{\omega NN}^V$ and $g_{\omega NN}^T$, respectively, with constructive and destructive $\pi \otimes N$-interference contributions to the differential cross-section $\mathrm{d}\sigma(\gamma p \to p\omega)/\mathrm{d}t$. Let us note that all these sets of coupling constants $g_{\omega NN}^V$ and $g_{\omega NN}^T$ are different from the "standard" values of these constants for the space-like values of the vector meson four-momentum.
– It is demonstrated that the t-behaviour of the beam asymmetry Σ is especially sensitive to the above-mentioned sets of ωNN coupling constants obtained in the time-like region of the vector meson four-momentum.

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