

A THEORETICAL STUDY OF ρ^0 -PHOTOPRODUCTION ON NUCLEONS NEAR THRESHOLD

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We investigate the possibility that the process of ρ^0 -meson photoproduction on proton, $\gamma + p \rightarrow p + \rho^0$, in the near threshold region $E_\gamma < 2$ GeV, can be considered in the framework of model with π -, σ - and N -exchanges. This suggestion is based on a study of the t -dependence of differential cross section, $d\sigma(\gamma p \rightarrow p\rho^0)/dt$, which has been measured by SAPHIR Collaboration. We find that the suggested model provides a good description of the experimental data with new values of ρNN -coupling constants in the region of the time-like ρ^0 -meson momentum. Our results suggest that such model can be considered as a suitable nonresonant background mechanism for the future discussion of possible role of nucleon resonance contributions. Our predictions for ρ^0 -meson photoproduction on neutron target and for beam asymmetry on both proton and neutron targets are presented.

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1. Introduction

The photoproduction of ρ - and ω -mesons on nucleons, $\gamma + N \rightarrow N + V$, near threshold $E_\gamma < 2$ GeV, is considered typically as a possible way for the study of the physics of nucleon resonances N^* in the interesting dense region of its masses, $M_{N^*} > M + m_v = 1.7$ GeV, where $M(m_v)$ is the nucleon (vector meson) mass. Especially, such experiments could be interesting for the search and subsequent study of the so-called missing resonances [1, 2]. Typical opinion here is that due to possible large width of the decay $N^* \rightarrow N + V(\rho, \omega)$, the reactions of vector meson photoproduction on nucleons will be sensitive to these resonances. Therefore, the future intensive flux of new data from JLAB will be effective for the solution of this problem. Multipole analysis of experimental data on different observables in processes $\gamma + N \rightarrow N + V$ can be realized only in the case of an appropriate and a realistic model for the nonresonant mechanisms for $\gamma + N \rightarrow N + V$. This

is especially important for the photoproduction of neutral vector mesons, where N^* contributions do not seem as the main ones [2–4].

In the literature [1–10] the following nonresonant mechanisms are discussed: the pseudoscalar (π, η) and scalar (σ) exchanges in t -channel, one nucleon exchanges in s - and u -channels, and the Pomeron exchange. This introduces a large enough set of unknown parameters, characterizing different contributions, such as the coupling constants, their relative phases, and the cut-off parameters of numerous phenomenological form factors, as well. In principle different combinations of these ingredients are presented in the literature. For example, in Ref. [5] the model for $\gamma + N \rightarrow N + \rho(\omega)$ contains the following two contributions: $(\pi + \sigma)$ -exchanges in t -channel; with specific form factors in electromagnetic and strong vertices of pole diagrams. The same nonresonant background, *i.e.* $(\pi + \sigma)$ -exchanges, is also considered in Ref. [2], with the same coupling constants but with different form factors. The corresponding model in Ref. [3] contains three ingredients: $(\pi + \sigma)$ -exchanges in t -channel, $(s + u)$ -channel one-nucleon contribution and the Pomeron exchange.

Our aim here is to suggest a simple enough model for the process $\gamma + N \rightarrow N + \rho^0$ in the near threshold region which will describe relatively well the existing experimental data [11] on differential cross sections for $\gamma + p \rightarrow p + \rho^0$ and will produce nontrivial polarization phenomena, more rich, for example, than in the case of $(\pi + \sigma)$ -exchange. For such exchanges almost all polarization phenomena are trivial and can be predicted without knowledge of exact values of the coupling constants and phenomenological form factors. For example, the beam asymmetry Σ induced by the linear polarization of the photon beam, and all possible T -odd polarization observables such as, 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 ρ -meson density matrix must be zero. Let us note also that $(\pi + \sigma)$ -model will not produce any difference in cross section on proton and neutron targets due to the absence of σ - and π -interference.

But the model suggested in this work will be more rich and more flexible, allowing to predict nontrivial polarization phenomena. Such model $(\pi + \sigma + N)$ will be suitable enough as starting point for the discussion of possible contribution of nucleon resonances. And presence of different interference contributions such as $\sigma \otimes N$ and $\pi \otimes N$ in the differential cross section even with unpolarized particles will be important for establishing relative signs of coupling constants. That will be crucial for more complete information about these constants, which is necessary for prediction of polarization phenomena.

2. Exchange mechanisms and amplitudes

For t -channel, we consider the pseudoscalar (π), and scalar (σ) exchanges, shown in Fig. 1(a). The pseudoscalar exchange amplitudes can be obtained from the Lagrangian,

$$\mathcal{L}_\pi = \frac{e}{m_\rho} g_{\rho\pi\gamma} \epsilon^{\mu\nu\alpha\beta} \partial_\mu V_\nu \partial_\alpha A_\beta \pi - i g_{\pi NN} \bar{N} \gamma_5 N \pi, \quad (1)$$

and where $A_\mu (V_\mu)$ is the photon (vector meson) field. Then one-pion exchange amplitude takes the form

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

where $t = (k - q)^2$, m_ρ is the mass of ρ^0 -meson, $\varepsilon_\mu (U_\mu)$ is the polarization four vector of photon (vector meson). Notation of particle four momenta is presented in Fig. 1. We shall use the coupling constants as $g_{\rho\pi\gamma} = 0.54$ and $g_{\pi NN}^2/4\pi = 14.0$. The coupling constant $g_{\rho\pi\gamma}$ is obtained from the experimental partial width of ρ^0 radiative decay $\rho^0 \rightarrow \pi^0 + \gamma$ [12]. The form factors used in our calculations are

$$F_{\pi NN}(t) = \frac{A_\pi^2 - m_\pi^2}{A_\pi^2 - t}, \quad F_{\rho\pi\gamma}(t) = \frac{A_{\rho\pi\gamma}^2 - m_\pi^2}{A_{\rho\pi\gamma}^2 - t}, \quad (3)$$

where $A_\pi = 0.7$ GeV and $A_{\rho\pi\gamma} = 0.77$ GeV [5].

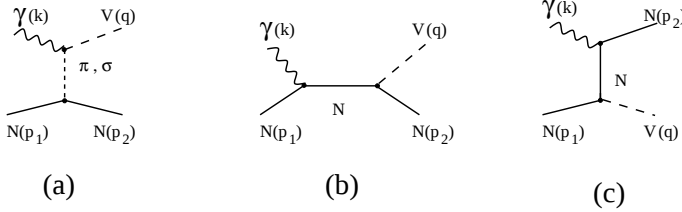


Fig. 1. Mechanisms of the model for ρ^0 -photoproduction: (a) t -channel exchanges, (b) and (c) s - and u -channel nucleon exchanges.

The scalar (σ) exchange amplitude can be obtained from the Lagrangian,

$$\mathcal{L}_\sigma = \frac{e}{m_\rho} g_{\rho\sigma\gamma} (\partial^\alpha V^\beta \partial_\alpha A_\beta - \partial^\alpha V^\beta \partial_\beta A_\alpha) \sigma + g_{\sigma NN} \bar{N} N \sigma. \quad (4)$$

The above Lagrangian leads to the following expression for scalar exchange amplitude:

$$\mathcal{M}_\sigma = e \frac{g_{\rho\gamma\sigma}}{m_\rho} \frac{g_{\sigma NN}}{t - m_\sigma^2} F_{\sigma NN}(t) F_{\rho\sigma\gamma}(t) (\bar{u}(p_2) \gamma_5 u(p_1)) (\varepsilon \cdot U k \cdot q - \varepsilon \cdot q U \cdot k), \quad (5)$$

where $g_{\rho\gamma\sigma}$ and $g_{\sigma NN}$ are the coupling constants for the vertices $\rho\gamma\sigma$ and σNN . Following Ref. [5], they are taken as $g_{\sigma NN}^2/4\pi = 8.0$, and $g_{\rho\gamma\sigma} = 2.7$. The form factors for this exchange mechanism are given by

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

where $\Lambda_\sigma = 1.0$ GeV and $\Lambda_{\rho\sigma\gamma} = 0.9$ GeV [5].

The Lagrangian for VNN and γNN interactions can be written in the following way:

$$\mathcal{L}_N = \overline{N} \left(g_{\rho NN}^V \hat{V} - \frac{g_{\rho NN}^T}{2M} \sigma_{\mu\nu} \partial^\nu V^\mu \right) N + e \overline{N} (Q_N \hat{A} - \frac{\kappa_N}{2M} \sigma_{\mu\nu} \partial^\nu A^\mu) N, \quad (7)$$

where we use the notation $\hat{a} = a_\mu \gamma^\mu$, and $\sigma_\mu = (\gamma_\mu \gamma_\nu - \gamma_\nu \gamma_\mu)/2$. The s - and u -channel amplitudes can then be obtained by using the above Lagrangian as

$$\mathcal{M}_s = e \frac{g_{\rho NN}^V}{s - M^2} \bar{u}(p_2) \left(\hat{U} + \frac{\kappa_\rho}{2M} \hat{U} \hat{q} \right) (\hat{p} + M) \left(Q_N \hat{\varepsilon} - \frac{\kappa_N}{2M} \hat{\varepsilon} \hat{k} \right) u(p_1), \quad (8)$$

$$\mathcal{M}_u = e \frac{g_{\rho NN}^V}{u - M^2} \bar{u}(p_2) \left(Q_N \hat{\varepsilon} - \frac{\kappa_N}{2M} \hat{\varepsilon} \hat{k} \right) (\hat{f} + M) \left(\hat{U} + \frac{\kappa_\rho}{2M} \hat{U} \hat{q} \right) u(p_1), \quad (9)$$

where $s = (k + p_1)^2$, $u = (k - p_2)^2$, $f = p_1 - q$, $p = p_2 + q$, $g_{\rho NN}^V$ and $g_{\rho NN}^T$ are the vector and tensor coupling constants for ρNN -vertex, $Q_N = 1(0)$ is the electric charge for proton(neutron), $\kappa_N = 1.79(-1.91)$ is the anomalous magnetic moment of proton(neutron), and κ_ρ is defined as $\kappa_\rho = g_{\rho NN}^T/g_{\rho NN}^V$. The values of the coupling constants $g_{\rho NN}^V$ and $g_{\rho NN}^T$ will be given in the next section.

Let us note that the suggested model for the matrix element of the process $\gamma + N \rightarrow N + V$ namely $\mathcal{M} = \mathcal{M}_\pi + \mathcal{M}_\sigma + \mathcal{M}_s + \mathcal{M}_u$ satisfies the gauge invariance of hadron electromagnetic interaction at any values of the coupling constants and form factors in the whole region of kinematical variables s and t . Furthermore, we would like to mention that we do not introduce any form factor in $\mathcal{M}_s$ and $\mathcal{M}_u$. Problem here is that in general the form factors for $\mathcal{M}_s$ and $\mathcal{M}_u$ must be different, having s - or u -dependences, respectively. But this "natural" form factors will destroy the gauge invariance of $s + u$ contribution to the total matrix element for $\gamma + p \rightarrow p + V$. In

principle, it is possible to introduce some common phenomenological form factor in front of $\mathcal{M}_s + \mathcal{M}_u$ [13] with s - and u -dependences simultaneously as $F(s, u)$. Such a “form factor” $F(s, u)$, depending on two variables seems more like as some amplitude, but not as form factor which typically depends on one variable. So this dependence differs from the case of t -channel where the corresponding form factors are the functions of t -variable only.

Another point which must be stressed here concerns the values of the coupling constants, g_{VNN}^V and g_{VNN}^T for the vertex VNN . Typical way in the literature is to use for these constants from NN -interaction [14, 15] or pion photoproduction processes, $\gamma + N \rightarrow N + \pi$ [16], where vector meson exchange plays a role. But the case we consider, $\gamma + N \rightarrow N + V$, on one hand, and $N + N \rightarrow N + N$, for example, on the other hand, are controlled by the VNN -constants in the different regimes of vector meson momentum: space-like in the case of NN -interaction or $\gamma + N \rightarrow N + \pi$ and time-like for $\gamma + N \rightarrow N + V$. Therefore, to connect $N + N \rightarrow N + N$ and $\gamma + N \rightarrow N + V$, a long extrapolation in momentum transfer must be done. So VNN -coupling constants for these cases could be essentially different. And another important difference in VNN -constants for different processes, which must be mentioned here, concerns the high virtuality of one of the nucleons for the VNN -vertex in the case of the processes $\gamma + N \rightarrow N + V$.

These comments could be considered as a justification of our strategy in the consideration of these coupling constants: namely, we shall consider these constants as free parameters, whose values must be adjusted by some fit to the existing experimental data on differential cross sections for process $\gamma + p \rightarrow p + \rho^0$ in the near threshold region.

Moreover, in our consideration here we will neglect the Pomeron contribution to the matrix element for $\gamma + N \rightarrow N + V$ in the near threshold region, $E_\gamma < 2$ GeV. It is possible to justify such an approach by observation that the Pomeron, being an effective high energy phenomenological phenomenon, does not seem to be the adequate production mechanism in the near threshold region. For example, in another processes, where the Pomeron exchange is definitely allowed, such as the elastic $\pi + N$, $K + N$ or $N + N$ -scattering [17], its contribution is considered typically at higher values of invariant variable s in comparison with the near threshold values of s for $\gamma + N \rightarrow N + V$. For example, $W_{\text{th}}(NN \rightarrow NN) = 2M > W_{\text{th}}(\gamma N \rightarrow NV) = M + m_v$, where $s = W^2$, but it is evident that in $N + N \rightarrow N + N$ the Pomeron exchange is taken into account at higher W -values. Therefore, it is difficult to find some specific theoretical reasons to justify the Pomeron exchange in the threshold region for processes $\gamma + N \rightarrow N + V$. This region can be considered as the transition regime from the contributions of s -channel nucleon resonances to the Regge approach in accordance with the duality hypothesis [17–19]. Namely, in this region there is the delicate problem of double counting if

both above mentioned contributions are considered simultaneously. Therefore, to avoid this problem we will not consider the Pomeron contribution in the near threshold region $E_\gamma \leq 2$ GeV for $\gamma + p \rightarrow p + \rho(\omega)$.

We do not consider in our work the nucleon resonances as well. Diffractive-like behaviour of the differential cross sections for $\gamma + p \rightarrow p + V$ processes even very near to the threshold can be considered as some indication that this mechanism cannot be the main one here. For example, the analysis in the quark model of the contribution of large number of nucleon resonances demonstrated that they cannot reproduce such diffractive t -dependence [2].

Let us note that the contribution of nucleon resonance N^* with the definite value of spin J and parity P , J^P , to the amplitude of $\gamma + N \rightarrow N + V$ process is complicated generally, being characterized by six independent constants or partial amplitudes, for $J \geq 3/2$. These amplitudes correspond to two possible initial $(\gamma + N)$ -states with the electric and magnetic multipolarities of real photons in the chain of the transitions: $\gamma + N \rightarrow N^*(J^P) \rightarrow N + V$ and three different final $(V + N)$ -states with definite combinations of total VN spin, $S_f = 1/2$ and $3/2$, and the orbital angular momentum of the vector meson. Even for $J^P = (1/2)^\pm$ there are two independent transitions, *i.e.* the situation with N^* in processes $\gamma + N \rightarrow N + V$ is more complicated in comparison with $\gamma + N \rightarrow N + \pi$ or $\gamma + N \rightarrow N + \eta$, where the N^* contribution with some J^P is characterized by two multipole amplitudes only.

In the case of the Breit–Wigner parametrization of the N^* contribution to the matrix element for $\gamma + N \rightarrow N + V$ process, each such contribution is characterized by five constants: two electromagnetic ones, magnetic and electric, and three strong constants for the decay $N^* \rightarrow N + V$. In principle, it is possible to use information about the electromagnetic vertex, $N^* \rightarrow N + \gamma$, from the multipole analysis of processes $\gamma + N \rightarrow N + \pi(\eta)$. So, the processes $\gamma + N \rightarrow N + V$ will be used for the study of the spin structure of strong vertices: $N^* \rightarrow N + V$. But it is not the case for the missing resonances, with the small $N^* \rightarrow N + \pi$ branching ratio, *i.e.* with a weak signal in $\gamma + N \rightarrow N + \pi$, with unknown electromagnetic constants.

It is evident that the successful solution of the missing resonance problem, using the processes $\gamma + N \rightarrow N + \rho(\omega)$, needs a large amount of polarization data with polarized beam, polarized target, with measurements of polarization properties of produced vector mesons. Only in that case the corresponding multipole analysis can be done more or less uniquely.

We would like to note that the model suggested here produces real amplitudes and as a result all possible T -odd polarization observables must be identically zero, independently on the relative role of the considered mechanisms. But N^* -contribution in s -channel will change the situation qualitatively, introducing a new essential property, namely complexity of

amplitudes with a rich T -odd polarization phenomena. Therefore, these observables will be especially sensitive to possible N^* -contribution to the matrix element for $\gamma + p \rightarrow p + \rho^0$. Even not so intensive N^* -contribution, through its interference with large σ -contribution, can produce a detectable signal in target asymmetry, for example. But before that the following problem must be solved: are there some other sources of amplitude complexity in the near threshold region for $\gamma + p \rightarrow p + \rho^0$? Evidently the complex Pomeron exchange through its specific signature cannot be considered as a good mechanism near threshold. Of course, it is necessary to keep in mind final VN -interaction, which will modify the real π and σ contributions. This way we will not meet the delicate problem of double counting in the case of additional N^* -contributions.

In any case, the problem of missing resonances in $\gamma + N \rightarrow N + V^0$, being very interesting, will introduce necessity of solution of some serious problems. And one such problem is the choice of the adequate model for the nonresonant mechanism in $\gamma + N \rightarrow N + V^0$ (ρ^0, ω), where this nonresonant background is the main mechanism in the near threshold region. Intensive study of polarization phenomena in $\gamma + p \rightarrow p + V^0$ will be very important for a successful solution of this and other related problems.

And we must repeat here once more, that the construction of an adequate model for the nonresonant contributions to the matrix element for $\gamma + p \rightarrow p + \rho(\omega)$ in the near threshold region is an important task, especially taking into account the large number of possible N^* with many free parameters. Interference of different mechanisms must be intensive enough, and that will introduce additional problem of relative phases of different contributions.

3. Results and discussion

Even such relatively simple model contains large number of unknown parameters: $A_\pi, A_\sigma, A_{\rho\sigma\gamma}, A_{\rho\pi\gamma}, g_{\rho\sigma\gamma}, g_{\sigma NN}, g_{\rho NN}^V, g_{\rho NN}^T$. The σ -meson mass in principle can also be considered as a parameter, being limited in the wide interval: $400 \leq m_\sigma \leq 1200$ MeV [12]. Only two coupling constants, namely $g_{\pi NN}$ and $g_{\rho\pi\gamma}$ can be considered as well known. Evidently any attempt to find all these parameters by fitting the limited set of experimental data concerning only differential cross section for process $\gamma + p \rightarrow p + \rho^0$, with unpolarized particles, cannot be successful. Therefore we follow the literature [5], and we will fix all four cut-off parameters, A_i , choosing their values as it was indicated in Sec. 2.

After this we have only three parameters, $g_{\rho NN}^V, g_{\rho NN}^T$, and $g_{\rho\sigma\gamma}$, assuming $g_{\sigma NN}^2/4\pi = 8.0$, as it follows from NN -interaction [14]. We fit our model with all the $d\sigma/dt$ data from SAPHIR Collaboration at three energy intervals: $1.45 < E_\gamma < 1.64$ GeV, $1.64 < E_\gamma < 1.82$ GeV, $1.82 < E_\gamma < 2.03$ GeV. Note that we choose the "standard value" for σ -mass: $m_\sigma = 500$ MeV, evi-

dently another value of m_σ from allowed wide interval can change the results of fitting.

We choose specially only the above mentioned three energy intervals for $d\sigma/dt$ ones from existing six measured by SAPHIR Collaboration [11], to have the possibility to predict $d\sigma/dt$ for another three energy intervals, and to test in some sense the validity of the suggested model.

The best results for the fitted coupling constants are the following two sets of coupling constants: $g_{\rho NN}^V = 0.4$, $g_{\rho NN}^T = 1.0$ for the fixed value of coupling constant $g_{\rho\sigma\gamma}$, namely, $g_{\rho\sigma\gamma} = 2.7$, following Ref. [5] and $g_{\rho NN}^V = 1.0$, $g_{\rho NN}^T = -1.2$, $g_{\rho\sigma\gamma} = -3.0$. In the last case we consider $g_{\rho\sigma\gamma}$ as a fitting parameter, as well.

This allows to obtain some conclusions, concerning the proposed model.

- (1) First of all, we can see that $|g_{\rho\sigma\gamma}|_{\text{fit}} \approx g_{\rho\sigma\gamma}$ of Ref. [5]. Note that the sign of $g_{\rho\sigma\gamma}$ cannot be determined in the model of Ref. [5] because in that model $d\sigma(\gamma p \rightarrow p\rho^0)/dt = |\pi|^2 + |\sigma|^2$, *i.e.* there is no $\pi \otimes \sigma$ -interference contribution. But in the model we consider it is possible in principle to determine relative signs of coupling constants, for example, to the sign of π -contribution, *i.e.* choosing the positive value for the product $g_{\rho\pi\gamma}g_{\rho NN} > 0$.
- (2) The resulting values for the coupling constants, $g_{\rho NN}^V$ and $g_{\rho NN}^T$, are different from their standard values, which have been found early from NN -potential [14, 15], where typically, they are ranging from 2.97 to 3.16 for $g_{\rho NN}^V$ and 12.5 to 20.8 for $g_{\rho NN}^T$. We must repeat here once more that such a difference could be considered as natural due to the large difference in momentum transfer.

Relatively small values for the coupling constant $g_{\rho NN}^V$, which we found in our analysis, can be understood as being some indication of the importance of the phenomenological form factors $F(s, u)$ [13], which must be introduced for the $s + u$ contribution to the matrix element for the reaction $\gamma + N \rightarrow N + \rho$. Thus, our coupling constant $g_{\rho NN}^V$ is not the “real” ρNN -coupling constant, but it is the result of the modification of this constant by the form factor $F(s, u)$, which is evidently less than unity in the physical region of the considered reaction. However, any phenomenological form factor $F(s, u)$ cannot change the ratio of the both ρNN -coupling constants. Ratios of tensor and vector ρNN -coupling constants, $\kappa_{1,2} = g_{\rho NN}^T/g_{\rho NN}^V$, for which we found two different values, namely $\kappa_1 = 2.5$ and $\kappa_2 = -1.2$, have opposite signs and different values. Let us note in this connection that our κ_1 -value is near to the so called standard values, which have been obtained previously from NN -potentials, πN -scattering, nucleon form factors or pion photoproduction in the space-like region of t . We also note furthermore that these κ values are concentrated near the VDM result, $\kappa = 3.7$, which follows from the values of electromagnetic characteristics, that is electric charges

and magnetic moments, of nucleons, therefore for $t = 0$. In the literature there is only one attempt [20] to determine $g_{\rho NN}$ -coupling constants directly in the time-like region, using the data about the process $N\bar{N} \rightarrow \pi\pi$, where the value $\kappa = 6.6$ was obtained which is near to the κ values determined for space-like t . So, our solution κ_1 can be considered as the almost standard value, but we have another allowed solution κ_2 which differs in sign and value. Meanwhile we did not exclude this solution from our consideration.

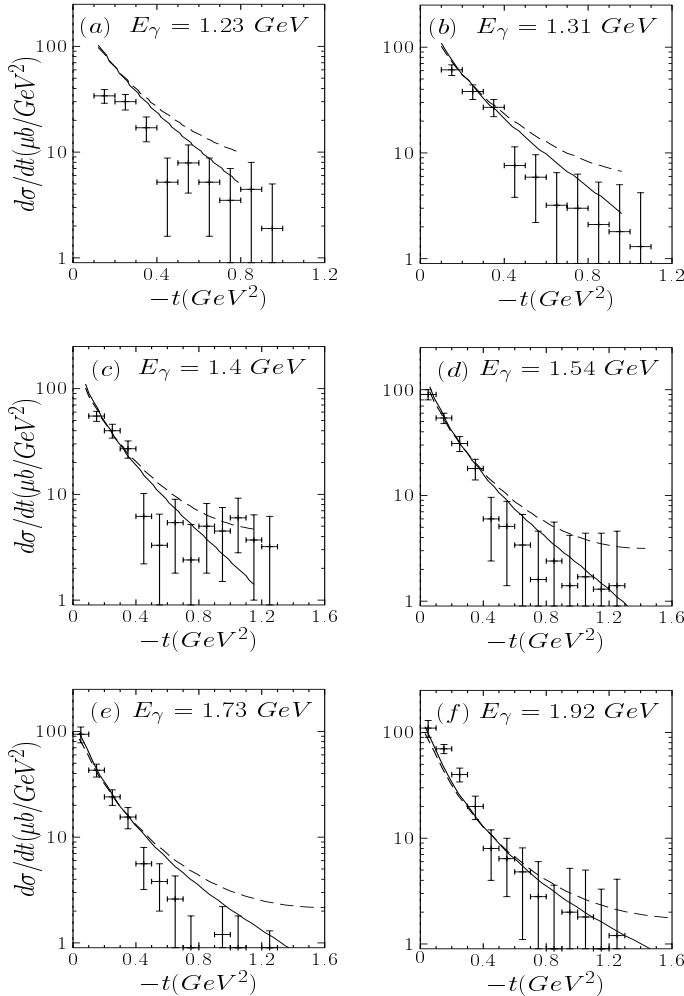


Fig. 2. Comparison of experimental differential cross section data for $\gamma + p \rightarrow p + \rho^0$ at $E_\gamma = 1.23, 1.31, 1.4, 1.54, 1.73$ and 1.92 GeV from [11] with the calculation of suggested model. Solid and dashed lines correspond to $g_{\rho NN}^V = 1.0$, $g_{\rho NN}^T = -1.2$, $g_{\rho\sigma\gamma} = -3.0$, and $g_{\rho NN}^V = 0.4$, $g_{\rho NN}^T = 1.0$, $g_{\rho\sigma\gamma} = 2.7$, respectively.

The problem we face is therefore that while s - and u -diagrams for the reaction $\gamma + N \rightarrow N + \rho$ are determined by ρNN -coupling constants, that is different from the previous analysis in the time-like region [20], because in our case one nucleon in the ρNN -vertex is characterized by large virtuality. For the s -channel diagram even at threshold the corresponding virtuality is very large; $s - m^2 = 2E_\gamma m \geq 2m^2$. Therefore we cannot exclude the essential dependence of the ρNN -coupling constants on the nucleon virtuality in such a way that the ratio κ may change sign if the virtuality of nucleon is changed from 0 to $2m^2$. This is really large extrapolation. In this sense the polarization phenomena in $\gamma + N \rightarrow N + \rho$ reaction, in the near threshold region, being so sensitive to different values of κ , could be especially interesting.

To characterize the quality of our fit, let us mention that the χ^2 -value for the set of constants given above is $\chi^2/\text{ndf} = 2.1$ for the second set and 2.5 for the first set. We note that in the interval $2.1 < \chi^2/\text{ndf} < 2.5$ there are a lot of comparable minima in χ^2 as a function of the three coupling constants. This means a large correlation between these constants, due to not so large sensitivity of $d\sigma/dt$ to the details of the considered model.

Using both these fits we predict the t -dependence of $d\sigma(\gamma p \rightarrow p\rho^0)/dt$ for three another energy intervals $1.19 < E_\gamma < 1.26$ GeV, $1.26 < E_\gamma < 1.35$ GeV, $1.35 < E_\gamma < 1.45$ GeV which were not used in our fits, and we compare them with the experimental results in Fig. 2 for two sets of ρNN and $\rho\sigma\gamma$ -coupling constants. In the same figure, we also show our fits for the other three energy intervals. One can see that both fits are good enough for all measured differential cross sections for $E_\gamma < 2$ GeV. Only for the smallest energy with central value $E_\gamma = 1.23$ GeV the predicted cross sections are larger than the experimental values, such discrepancy could be

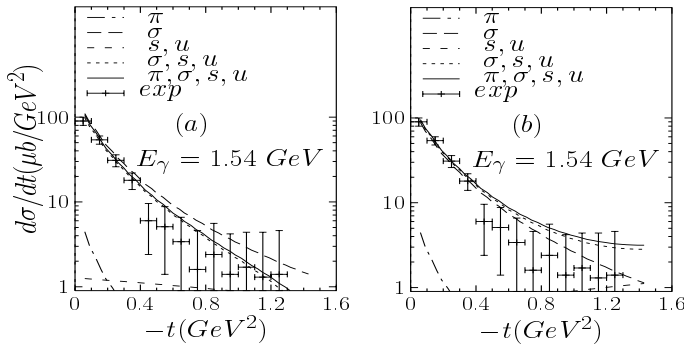


Fig. 3. Different contributions to the differential cross sections of $\gamma + p \rightarrow p + \rho^0$ at $E_\gamma = 1.54$ GeV for two different fitted parameter values: (a) $g_{\rho NN}^V = 1.0$, $g_{\rho NN}^T = -1.2$, $g_{\rho\sigma\gamma} = -3.0$ (b) $g_{\rho NN}^V = 0.4$, $g_{\rho NN}^T = 1.0$, $g_{\rho\sigma\gamma} = 2.7$.

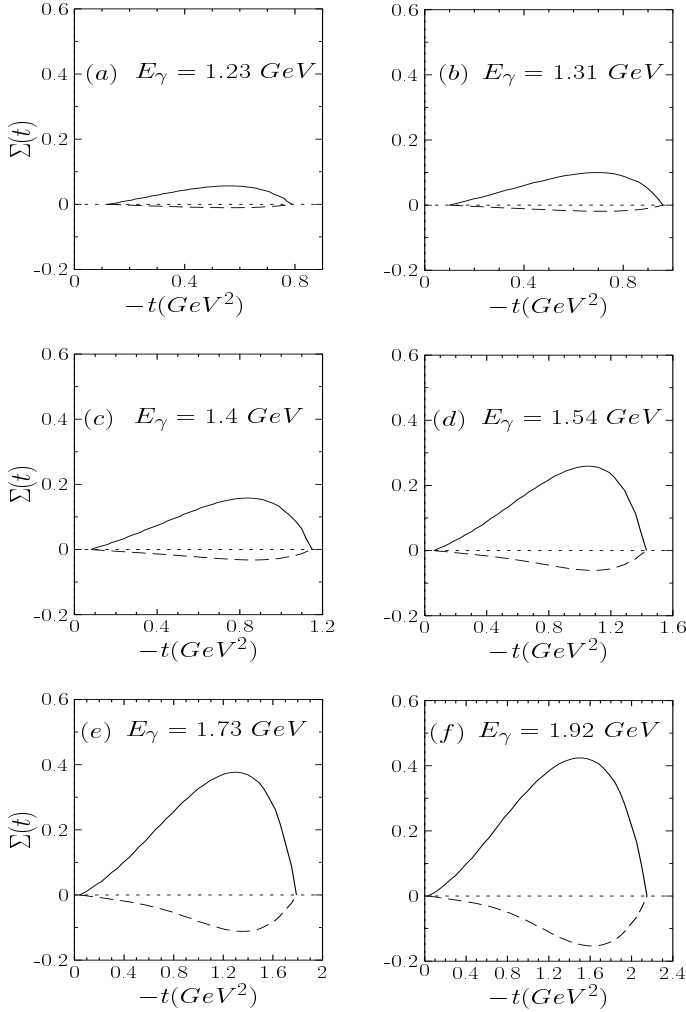


Fig. 4. Predicted behaviour of beam asymmetry for $\gamma + p \rightarrow p + \rho^0$ at $E_\gamma = 1.23, 1.31, 1.4, 1.54, 1.73$ and 1.92 GeV. Solid and dashed lines correspond to $g_{\rho NN}^V = 1.0$, $g_{\rho NN}^T = -1.2$, $g_{\rho\sigma\gamma} = -3.0$, and $g_{\rho NN}^V = 0.4$, $g_{\rho NN}^T = 1.0$, $g_{\rho\sigma\gamma} = 2.7$, respectively.

considered as some indication of possible contribution of nucleon resonances. The contributions of different amplitudes to $d\sigma(\gamma p \rightarrow p\rho^0)/dt$ at $E_\gamma = 1.54$ GeV are shown in Fig. 3.

In any case, one can state that in the considered energy region $E_\gamma < 2$ GeV the existing experimental data on differential cross sections can be described relatively well in the framework of a simple model with small

number of adjustable parameters. And the quality of the existing experimental data allows different models without strong preference of some of them as compared to many another possible models. Even our simplified $(\pi + \sigma + N)$ model can be realized with at least by two different possibilities with different values of $g_{\rho NN}$ and $g_{\rho\sigma\gamma}$ coupling constants.

So, the available experimental data on $d\sigma(\gamma p \rightarrow p\rho^0)/dt$ is consistently well described in $(\pi + \sigma + N)$ approach, and these data are not sensitive to the details of different possible models. Another case is the polarization phenomena, even the simplest of them, for example, the beam asymmetry Σ induced by linear photon polarization

$$\Sigma = \frac{\sigma_{\parallel} - \sigma_{\perp}}{\sigma_{\parallel} + \sigma_{\perp}} \quad (10)$$

with $\sigma_{\perp}(\sigma_{\parallel})$, induced by photon with polarization orthogonal (parallel) to reaction plane, is sensitive to reaction mechanism. Being equal to zero identically for $(\pi + \sigma)$ -exchange, this T -even polarization observable must be sensitive to the relative value of other contributions. And this is demonstrated in Fig. 4 for the proton target, where we present the predicted values of Σ for the SAPHIR energies. We see that two sets of coupling constants result in Σ which are different in sign for the whole interval of t , demonstrating the importance of the N -contribution, and especially $\sigma \otimes N$ -interference. So the future measurement of Σ -asymmetry even at one energy and at one angle will be very decisive in the choice of the correct reaction mechanism or in the set of nonresonant background mechanisms.

Photoproduction of ρ^0 -mesons on the neutron target, $\gamma + n \rightarrow n + \rho^0$, will be interesting also, especially in the near threshold region. Point here is that the N -contribution, being controlled by the coupling constants, $g_{\rho pp}^V$ and $g_{\rho pp}^T$, will be different due to different electromagnetic characteristics of neutron and proton. This also results in different interference $\sigma \otimes N$ contribution to all observables for processes, $\gamma + p \rightarrow p + \rho^0$ and $\gamma + n \rightarrow n + \rho^0$, such as the differential cross section and beam asymmetry. The predicted behaviour of beam asymmetry for $\gamma + n \rightarrow n + \rho^0$ is presented in Fig. 5.

We also note that the ratio of differential cross sections $R = d\sigma(\gamma n \rightarrow n\rho^0)/d\sigma(\gamma p \rightarrow p\rho^0)$ is sensitive to the set of vector coupling constants, especially at large value of momentum transfer $|t|$, with evident deviation of R from unity, in contrary directions for the considered sets of coupling constants, as shown in Fig. 6.

Although we found good fit in our model, even two fits with different sets of coupling constants, to the existing data on differential cross sections for the process, $\gamma + p \rightarrow p + \rho^0$, in the near threshold region $E_{\gamma} < 2$ GeV, we do not consider our results to be decisive. Indeed, we miss here some

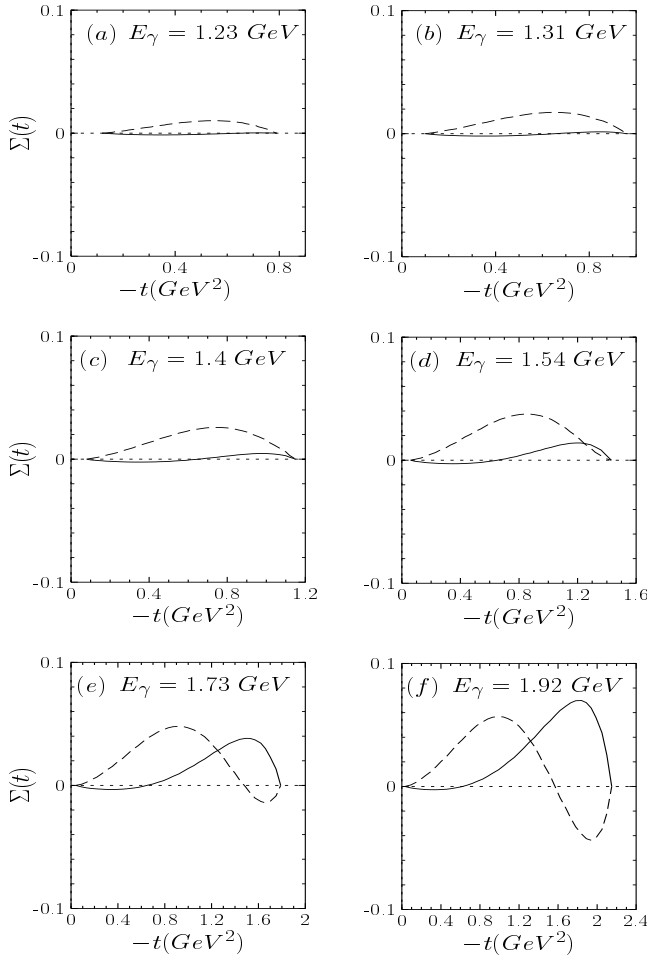


Fig. 5. Predicted behaviour of beam asymmetry for $\gamma + n \rightarrow n + \rho^0$ at $E_\gamma = 1.23, 1.31, 1.4, 1.54, 1.73$ and 1.92 GeV. Notation for different graphs is the same as in Fig. 4.

“traditional” contributions, such as for example the nucleon resonances in the s -channel. There is no any strong proof that the suggested model for the nonresonant background is more suitable in comparison with another possible approaches [1–5]. We can only say that our model is relatively simple, being free from consideration of such high-energy ingredients as the Pomeron exchange. In any case the suggested model produces nontrivial polarization phenomena. We note that the value of coupling constants $g_{\rho NN}^{T,V}$ which are controlled by N -contribution to the matrix element of $\gamma + N \rightarrow N + \rho^0$ proces must be different generally from the values for these constants

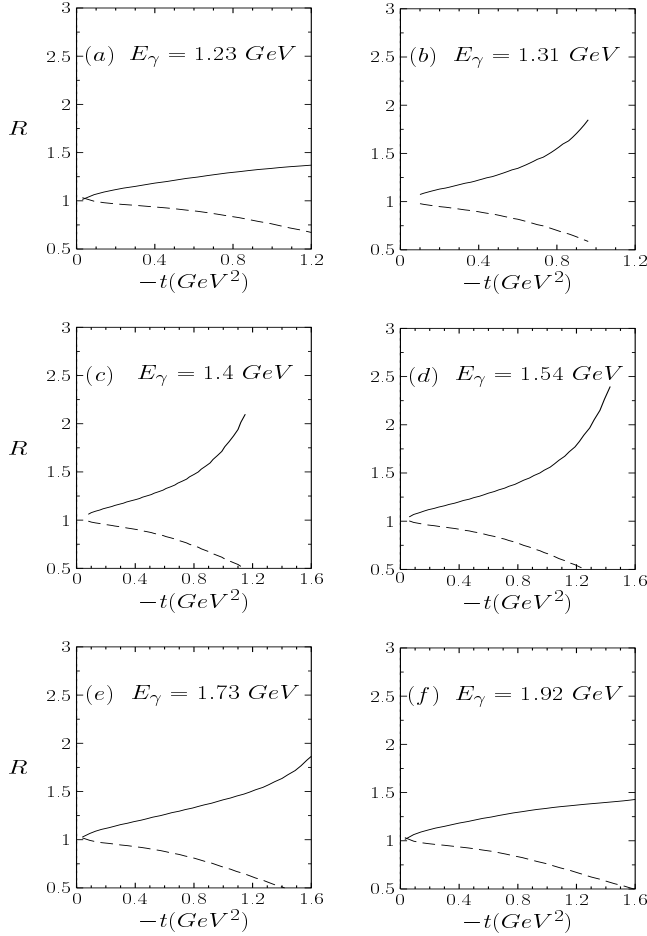


Fig. 6. Ratio of differential cross section on neutron and proton target ($R = d\sigma(\gamma n \rightarrow n\rho^0)/d\sigma(\gamma p \rightarrow p\rho^0)$) at $E_\gamma = 1.23, 1.31, 1.4, 1.54, 1.73$ and 1.92 GeV with the total contributions of exchange mechanisms (π, σ, s, u). Notation for different graphs is the same as in Fig. 4.

that follow from NN -interaction. And the values of $g_{\rho NN}$ -coupling constants in the time-like region of ρ^0 -momentum can find a lot of applications in consideration of another process with vector meson production. Clearly, and not only for our analysis, additional polarization data, about asymmetry Σ for example, will help to establish more uniquely the models for $\gamma + N \rightarrow N + \rho^0$. And this is unavoidable as a way in the solution of missing resonance problem.

4. Conclusions

Following are the main conclusions of our study and some general remarks.

- It is shown that the relatively simple model ($\sigma + \pi + N$) can explain the SAPHIR data about the differential cross section for $\gamma + p \rightarrow p + \rho^0$, $E_\gamma < 2$ GeV, and therefore could be considered as a good nonresonant background mechanism for searching the missing nucleon resonances.

- Results for the VNN -coupling constants, their absolute values and the signs as well, $g_{\rho NN}^{T,V}$, considered in our work as a fitting parameters, depend on the value of $g_{\rho\sigma\gamma}$ -coupling constant.

- The simplest polarization observable, namely the beam asymmetry Σ , is especially sensitive to possible variation of parameters of our models in some limits, for which the differential cross section is not so discriminative.

- The ratio of differential cross sections of ρ^0 -photoproduction on proton and neutron targets are sensitive to the discussed variants of the suggested model.

In any case, the VNN -coupling constants from the fit to $d\sigma(\gamma p \rightarrow p\rho^0)/dt$ in the near threshold region could be different in absolute values and in signs from the so called “standard” values of these constants, which have been extracted from the data about NN -interaction or pion photoproduction, $\gamma + N \rightarrow N + \pi$, due to essential difference in momentum transfer.

In principle our estimation for the coupling constants $g_{\rho NN}^V$ and $g_{\rho NN}^T$ will be useful for analysis of another processes of vector meson production, such as for example, $\pi + N \rightarrow N + V$, $N + N \rightarrow N + N + V$, $e^- + N \rightarrow e^- + N + V$, $\bar{N} + N \rightarrow \pi + V$, $\bar{N} + N \rightarrow \gamma + V$, $\bar{N} + N \rightarrow V + V$ etc., in the framework of the Effective Lagrangian approach.

- Our fitting procedure demonstrates that even the differential cross sections are sensitive to the relative sign of the different contributions to the matrix element of the process, $\gamma + p \rightarrow p + \rho^0$.

- Cut-off parameters A_i of above mentioned phenomenological form factors, which typically must be introduced in electromagnetic and strong vertices of the considered pole diagrams, must be object of special consideration, because such universality *i.e.*, applicability of the same form factors for different process is not proved rigorously. It is only a very simplified procedure.

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