A mechanism for the Double-Spin Asymmetry in Electromagnetic ρ Production at HERMES

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Abstract

We calculate the contribution of meson and pomeron exchanges to the double-spin asymmetry in ρ-meson electromagnetic production at HERMES energies. We show that the observed double-spin asymmetries, which are large, can be explained by the interference between the natural parity f_2-secondary Reggeon and the unnatural parity anomalous f_1 exchanges.

1 Introduction

The measurement of spin observables gives very important information on the structure of the strong interactions [1]. Recently, the HERMES Collaboration has found a significant ($\approx 20\%$) double-spin asymmetry in elastic vector meson electroproduction at energy $< E_\gamma > \approx 13$ GeV [2]. This result is quite intriguing since it was not expected within models of the vector meson production processes based on convenient mesonic and pomeron exchanges.

There are two different approaches to describe the electromagnetic production of light vector mesons at intermediate energies [3] and [4]. The first assumes that only $\pi-$ and $\sigma-$ exchanges are relevant for explaining the ρ and ω cross sections and their relation. The second involves the pomeron, and the $\pi-$, $\sigma-$ and f_2-secondary reggeon exchanges. In both of the approaches the main contribution to the ρ production cross section comes from the natural parity exchanges, e.g. pomeron, σ and f_2.

In spite of the fact that the πNN coupling constant is very large, the contribution of unnatural parity $\pi-$meson exchange to the elastic cross-section is small and falls off rapidly with energy. At HERMES energies its value is negligible in both models.

For spin observables the parity of the exchanges plays a crucial role. For example, the double-spin asymmetry will not vanish only if there is a considerable interference between the exchanges with natural and unnatural parities. It turns out, that the HERMES data are impossible to describe by interference of the pion exchange with any existing natural parity exchanges.

Recently we suggested a new unnatural parity anomalous f_1 trajectory, with a very high intercept $\alpha_{f_1} \approx 1$ and a small slope $\alpha_{f_1} \approx 0$, to explain the behavior of the elastic proton-proton, proton-antiproton and vector meson photoproduction cross-sections at large energies and momentum transfers [5]. The connection of this new trajectory with spin physics has been stressed, and its importance for the low $x-$ behavior of the nucleon spin-dependent structure

function $g_1(x, Q^2)$ and the double spin asymmetries in diffractive reactions at large energies has been shown [6].

In here we analyze the contributions of the f_1 exchange to the double-spin asymmetries in ρ-meson electromagnetic production at intermediate energies [1].

2 The pomeron, f_1 and secondary Regge exchange contributions to ρ-meson production

The kinematics of the ρ-meson electromagnetic production off the nucleon is shown in Fig.1. The invariant variables of the reaction are $s = (q + p_1)^2 = (p_V + p_2)^2$ and $t = (q - p_V)^2 = (p_1 - p_2)^2$, where q and p_1 are the momenta of the initial photon and proton, p_V and p_2 are the momenta of the final ρ-meson and proton. At HERMES energies the mechanism for vector meson production is rather complicated. We will take into account the contributions to the amplitude related to the $t-$ channel pomeron and the anomalous f_1- exchanges [5], with a weak energy dependence, together with the secondary Regge $\pi-$, $\sigma-$ and f_2- exchanges, which have a rather strong energy dependence [2] .
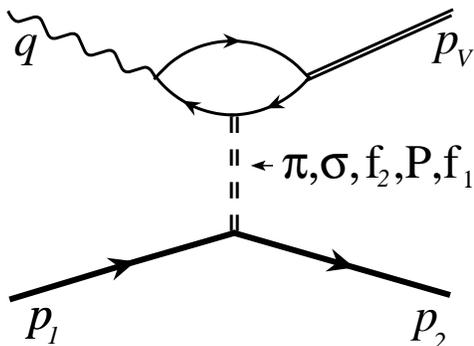
Figure 1: The diagram describing ρ-meson electromagnetic production.

For the pomeron exchange we use the Donnachie-Landshoff model [11]. The pomeron exchange amplitude is

$$T^P = 12 i m_V \beta_P^2 \sqrt{\frac{3 m_V \Gamma_{e^+ e^-}}{\alpha_{em}}} \cdot \frac{(g_{\mu\nu} q^\alpha - g_{\nu,\alpha} p_V^\mu - g_{\mu\alpha} q^\nu) \varepsilon_\gamma^m u \varepsilon_V^\nu}{q^2 + t - m_V^2} \bar{u}(p_2) \gamma_\alpha u(p_1) \times$$
$$\times \left(\frac{s}{s_P}\right)^{\alpha_P(t)-1} exp\{-\frac{i\pi}{2}(\alpha_P(t) - 1)\} F_P(t), \qquad (1)$$

where m_V is the mass of the ρ meson and $\Gamma_{e^+ e^-}$ is its leptonic width. The quark-pomeron coupling β_P can be fixed from fits [12] to total hadron-hadron cross sections. For the mass scale $s_P = 4$ GeV^2 one obtains $\beta_P = 2.0$ GeV^{-1}. The pomeron trajectory is given by [11]

$$\alpha_P(t) = 1.08 + 0.25t. \qquad (2)$$

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[1] The generalization of our model to ω and ϕ-meson production is straightforward.

[2] We will not include the contribution from the gluonic G-pole exchange related to axial anomaly [8]. Its contribution is important at rather large $-t \geq 1 GeV^2$. HERMES only measures elastic vector meson production cross section at low $-t \leq 0.6 GeV^2$.

The form factor of the pomeron-NN vertex is [11]

$$F_P = \frac{4m_p^2 - 2.8t}{(4m_p^2 - t)(1 - t/0.71)^2}.$$ (3)

It is also necessary to include an additional factor which takes into account the nonlocality of the pomeron vertex [11],

$$\frac{2\mu_0^2}{2\mu_0^2 + m_V^2 - t},$$ (4)

where $\mu_0^2 = 1.1$ GeV^2. This formula was obtained under the assumption that the effective quark-quark scattering amplitude induced by the pomeron has the following form

$$T_{Pqq} = i\beta_P^2 \bar{q}\gamma_\mu q \bar{q}\gamma_\mu q \left(\frac{s}{s_P}\right)^{\alpha_P(t)-1} exp\{-\frac{i\pi}{2}(\alpha_P(t) - 1)\},$$ (5)

which is supported by the Landshoff-Nachtmann two-gluon model of the pomeron [13].

Since at HERMES the energy is not very high, it is also necessary to take into account the contribution from secondary reggeons. The most important reggeons in the reaction under consideration are the π, σ and f_2-trajectories. The usual approach to estimate their contribution to vector meson production is to fix their parameters from some low energy decay amplitudes and from fitting the total and differential elastic cross sections for vector meson production [3] and [4]. Therefore the predictive power of such approaches is rather low.

To avoid this problem, we calculate the contribution from secondary Regge exchanges using only information extracted from proton-proton and proton-antiproton scattering in analogy to the Donnachie-Landshoff approach to the calculation of the pomeron contribution to vector meson production [11]. Within our approach one determines the parameters of the secondary Regge exchanges between two quarks from the hadron-hadron cross-sections. Then by using the assumption on a nonrelativistic shape for the vector meson wave function, normalized to the leptonic decay width $\Gamma_{e^+e^-}$, one calculates the contribution of any exchanges to the vector meson production amplitude free of parameters.

Within this model, using the following forms for effective π-quark and σ-quark interactions

$$L_{\pi qq} = ig_{\pi qq}\bar{q}\gamma_5 q\pi^0, \quad L_{\sigma qq} = g_{\sigma qq}\bar{q}q\sigma,$$ (6)

we obtain for the amplitudes

$$T^\pi = 4i\sqrt{\frac{m_V\Gamma_{\rho\rightarrow e^+e^-}}{3\alpha_{em}}} \frac{g_{\pi qq}g_{\pi NN}\epsilon_{\mu\nu\alpha\beta}q^\alpha p_V^\beta \varepsilon_\gamma^\mu \varepsilon_V^\nu}{(q^2 + t - m_V^2)(t - m_\pi^2)} \bar{u}(p_2)\gamma_5 u(p_1)$$ (7)

where $g_{\pi qq} = 3/5g_{\pi NN}$ is the value of the coupling of the π^0 meson to quarks, and we use for the pion-nucleon coupling $g_{\pi NN} = 13.28$ [9]. The π-meson form factor of the nucleon is given by [10]

$$F_\pi = \frac{\Lambda_\pi^2 - m_\pi^2}{\Lambda_\pi^2 - t},$$ (8)

with $\Lambda = 1.05 GeV$. For the σ exchange one has

$$T^\sigma = 2g_{\sigma qq}g_{\sigma NN}\sqrt{\frac{3m_V\Gamma_{e^+e^-}}{\alpha_{em}}} \frac{(2q_\nu p_{V\mu} - g_{\mu\nu}(m_V^2 - t))}{(q^2 + t - m_V^2)(t - m_\sigma)} \times$$
$$\times \varepsilon_\gamma^\mu \varepsilon_V^\nu \bar{u}(p_2)u(p_1)R_\sigma(s,t)F_\sigma(t).$$ (9)

The parameters of the σ exchange are taken from [10]: m_σ=0.55 GeV, $g_{\sigma qq} = 1/3 g_{\sigma NN}$, $g_{\sigma NN}$ = 10.2,

$$F_\sigma(t) = \frac{\Lambda_\sigma^2 - m_\sigma^2}{\Lambda_\sigma^2 - t}, \tag{10}$$

with $\Lambda_\sigma = 2.0 GeV^2$. In (7) and (9) the Regge factor $R_{\pi,\sigma}(s,t)$ is [7]

$$R(s,t) = \left(\frac{s}{s_0}\right)^{\alpha(t)} \Gamma(1 - \alpha(t)) \frac{1 + e^{-i\pi\alpha(t)}}{2}, \tag{11}$$

where $s_0 = 1 GeV^2$ and $\alpha(t)$ is the mesonic Regge trajectory

$$\alpha(t)_{\pi,\sigma} = \alpha'(t - m_{\pi,\sigma}^2), \tag{12}$$

with slope $\alpha' \approx 0.9 GeV^{-2}$.

We will assume with refs. [4] and [12] that the coupling of f_2 to the quarks has the same form as that of the pomeron (5). Therefore the formula for the f_2 amplitude is similar to (1) changing the parameters to : $\beta_R = 3.5$ GeV^{-1}, $s_0 = 1$ GeV^2, and the trajectory is now $\alpha_R(t) = 0.55 + 0.9t$. The values of parameters have been obtained from a fit to the total hadron-hadron cross-sections [12].

In a similar manner one can obtain the unnatural parity f_1−trajectory contribution to the ρ-meson production amplitude. The f_1 interaction with the quarks is

$$L_{f_1 qq} = i g_{f_1 qq} \bar{q} \gamma_\mu \gamma_5 q. \tag{13}$$

By using this coupling we have for the amplitude,

$$T^{f_1} = 4 i m_V g_{f_1 qq} g_{f_1 NN} \sqrt{\frac{3 m_V \Gamma_{e^+ e^-}}{\alpha_{em}}} \frac{\epsilon_{\mu\nu\alpha\beta} q^\beta \varepsilon_\gamma^\mu \varepsilon_V^\nu \bar{u}(p_2) \gamma_5 \gamma_\delta u(p_1)}{(q^2 + t - m_V^2)(t - m_{f_1}^2)} \times$$
$$\times (-g^{\alpha\delta} + (q - p_V)^\alpha (q - p_V)^\delta / m_{f_1}) F_{f_1}(t). \tag{14}$$

In (14) the coupling of f_1 to the quarks, $g_{f_1 qq} = g_{f_1 NN} = 2.5$, is fixed by using a constituent quark model and the result of the analysis of the proton spin problem within f_1 anomalous exchange model [5]. The form factor is given by

$$F_{f_1}(t) = \frac{1}{(1 - t/m_{f_1}^2)^2}, \tag{15}$$

with $m_{f_1} = 1.285 GeV$.

3   The double-spin asymmetry

The result of the calculation of π-, σ-, f_2-, f_1- contributions to the total elastic ρ photoproduction cross-section as a function of the photon energy

$$\sigma_{\pi,\sigma,f_2,f_1,P} = \frac{1}{64\pi s |p_{cm}|^2} \int dt |M_{\pi,\sigma,f_2,f_1,P}|^2 \tag{16}$$

are shown in Fig.(2). Our model describes the experimental data well without tuning the parameters. It is evident that for HERMES kinematics, $E_\gamma \approx 10 \div 18 GeV$ [2], the main contribution to the cross section comes from the pomeron and f_2 exchange and the contributions from π and σ exchanges are very small and therefore can be neglected. The contribution of the f_1

exchange near the ρ meson production threshold is smaller then the π and σ contributions. But due to the very high intercept, the f_1 anomalous trajectory, has a non vanishing contribution at HERMES energies. Due to its unnatural parity and negative signature, the corresponding amplitude is proportional to the product of helicities of the photon and the proton. Therefore the interference of the f_1 amplitude with the natural parity amplitudes leads to a nonzero double spin asymmetry,

$$A_1 = \frac{\sigma_{1/2} - \sigma_{3/2}}{\sigma_{1/2} + \sigma_{3/2}}, \qquad (17)$$

where $\sigma_{1/2,3/2}$ are the cross-sections for ρ-meson production from different photon-proton helicity states. Due to the large intercept $\alpha_{f_1} \approx 1$ and negative signature, the amplitude of the f_1 exchange is real with high accuracy. Therefore one can expect that its interference with the nearly imaginary pomeron amplitude is very small and its contribution to the double-spin asymmetry is also small. At the same time the f_2 amplitude contains a significant real part and, as consequence, the main contribution to the double-spin asymmetry should come from the interference between the f_2 and the f_1 exchanges.

Within our model all amplitudes have the same Q^2 dependence and therefore the double-spin asymmetry does not depend on the value of Q^2. In Fig.3 we compare the contribution to the asymmetry from the f_1-pomeron (dotted line), f_1-f_2 (dashed-dot line) interferences and the total result (solid line) with HERMES data for an average photon virtuality $<Q^2> = 1.7\,\mathrm{GeV}^2$. In the same figure we show the result for a slightly different set of f_2 trajectory parameters [14] by a dashed line. As one can see, the contribution of the f_1-pomeron interference is negative and rather small. The main contribution comes, as it was to be expected, from the f_2-f_1 interference and the total contribution explains the HERMES data within error bars.
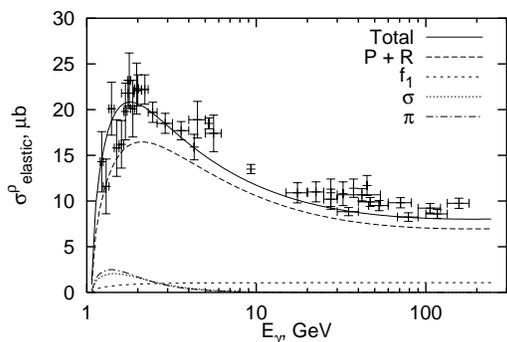
Figure 2: Contributions of hadronic exchanges to the total elastic cross section of ρ meson photoproduction. The experimental data are taken from [15].
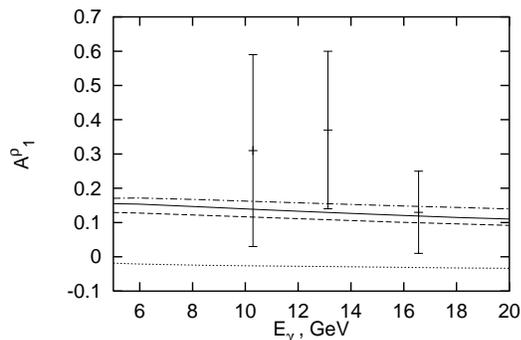
Figure 3: The calculated transverse double-spin asymmetry for ρ-meson electromagnetic production compared with the experimental data from HERMES. The solid line corresponds to pomeron-reggeon fit of [12]; the dashed line is for the fit of ref.[14]. The dotted line shows the contribution of the f_1-pomeron interference for the parameters from first fit [12].

4   Conclusion

We propose a new mechanism to explain the double-spin asymmetry in ρ-meson electromagnetic production off the nucleon at intermediate energies. This mechanism is related to the existence of a new anomalous unnatural parity, negative signature f_1 Regge trajectory which was introduced recently in [5] to explain features of diffractive reactions at large momentum transfers and the anomalous behavior of the spin-dependent structure function $g_1(x, Q^2)$. The interference of the f_1 exchange with the natural parity f_2 secondary reggeon exchange gives the very large contribution to the double spin asymmetry. The calculated value for the total asymmetry is $A_1 \approx 10 - 15\%$, which is compatible with the measured value $24\pm11\%$. For ϕ- and $J/\Psi-$ mesons the main contribution to the double-spin asymmetry should come from interference of pomeron and the f_1 trajectory, because the f_2 couplings with these mesons vanish in OZI limit. Therefore one can expect small and negative double-spin asymmetries for both mesons.

We have shown that the f_1 anomalous exchange gives the biggest contribution to the spin-dependent cross sections of vector meson production, not only at very large energies [6], but also in intermediate energy range.

Acknowledgements

References

[1] R.L.Jaffe, hep-ph/0101280.

[2] A. Airapetian *et al.* [HERMES Collaboration], Phys. Lett. **B513**, 301 (2001).

[3] B. Friman and M. Soyeur, Nucl. Phys. **A600**, 477 (1996). Y. Oh, A. I. Titov and T. S. Lee, nucl-th/0004055.

[4] J. M. Laget and R. Mendez-Galain, Nucl. Phys. **A581**, 397 (1995),
J. M. Laget, Phys. Lett. **B489**, 313 (2000).

[5] N. I. Kochelev, D. P. Min, Y. Oh, V. Vento and A. V. Vinnikov, Phys. Rev. **D61**, 094008 (2000).

[6] Y. Oh, N. I. Kochelev, D. P. Min, V. Vento and A. V. Vinnikov, Phys. Rev. **D62**, 017504 (2000).

[7] M. Guidal, J. M. Laget and M. Vanderhaeghen, Nucl. Phys. **A627**, 645 (1997).

[8] N. I. Kochelev and V. Vento, Phys. Lett. **B515**, 375 (2001);
hep-ph/0110268.

[9] V. G. Stoks, R. Timmermans and J. J. de Swart, Phys. Rev. **C47**, 512 (1993).

[10] R. Machleidt, Adv. Nucl. Phys. **19**, 189 (1989).

[11] A. Donnachie and P. V. Landshoff, Phys. Lett. **B185**, 403 (1987).

[12] A. Donnachie and P. V. Landshoff, Phys. Lett. **B296**, 227 (1992)

[13] P. V. Landshoff and O. Nachtmann, Z. Phys. **C35** (1987) 405.

[14] D. E. Groom *et al.* [Particle Data Group Collaboration], Eur. Phys. J. **C15**, 231 (2000).

[15] W. Struczinski *et al.* [Aachen-Hamburg-Heidelberg-Munich Collaboration], Nucl. Phys. **B108**, 45 (1976),
Y. Eisenberg *et al.*, Nucl. Phys. **B42**, 349 (1972),
J. Breitweg *et al.* [ZEUS Collaboration], Eur. Phys. J. **B2**, 247 (1998);
Y. A. Aleksandrov *et al.*, Yad. Fiz. **32**, 651 (1980);
R. M. Egloff *et al.*, Phys. Rev. Lett. **43**, 657 (1979);
J. Barth *et al.* [SAPHIR Collaboration], Acta Phys. Polon. **B29**, 3321 (1998).