Helicity-flip transitions and the t-dependence of exclusive photoproduction of rho meson

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Abstract. We calculate the differential cross section $d\sigma/dt$ for the diffractive photoproduction process $\gamma p \to \rho p$ and compare our results with experimental data. Our model is based on two-gluon exchange in the nonperturbative domain. We take into account both helicity conserving and often neglected helicity-flip amplitudes in the $\gamma \to V$ transition, which can contribute at finite t. The shape of the differential cross section as well as the role of helicity-flip processes is strongly related to the dependence of the unintegrated gluon distribution on transverse momenta in the nonperturbative region.

1 Introduction

The exclusive photoproduction of vector mesons is one of the intensively studied processes at high energies. Our work was motivated by a recent measurement of the differential cross section $d\sigma/dt$ for diffractive ρ^0 production [1]. The t-dependence of the cross section was advocated as a probe of gluon saturation effects. These calculations, which are formulated in the color dipole approach, also restrict themselves to the helicity conserving part of the amplitude. We compare results of our calculations for a variety of unintegrated gluon distributions available in the literature.

2 Formalism for the exclusive production of vector meson in photon-proton collisions

The amplitude for the exclusive production of vector meson is shown schematically in Fig.1.

The imaginary part of this amplitude can be written as:

$$\Im m\, \mathcal{M}_{\lambda_V,\lambda_\gamma}(W,\boldsymbol{\Delta}) = W^2 \frac{c_v\sqrt{4\pi\alpha_{em}}}{4\pi^2} \int \frac{d\kappa^2}{\kappa^4}\alpha_S(q^2)\mathcal{F}(x,\frac{\boldsymbol{\Delta}}{2}+\boldsymbol{\kappa},\frac{\boldsymbol{\Delta}}{2}-\boldsymbol{\kappa}) \\ \times \int \frac{dz d^2\boldsymbol{k}}{z(1-z)} I(\lambda_V,\lambda_\gamma;z,\boldsymbol{\kappa},\boldsymbol{k},\boldsymbol{\Delta})\psi_V(z,k)\,. \quad (1)$$

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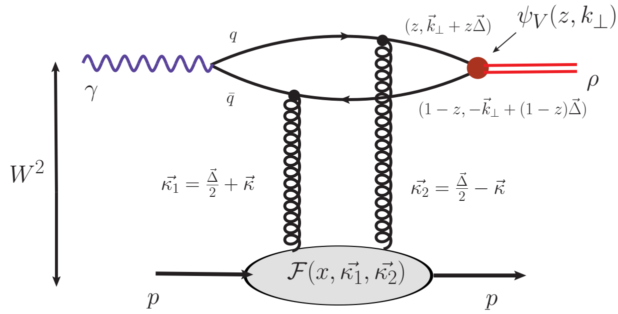

Figure 1. Feynman diagram for the $\gamma p \to \rho p$ diffractive amplitude.

The ρ–meson is treated as the pure s-wave bound state of light quarks with the constituent quark mass taken as $m_q = 0.22$ GeV. As to the vector meson radial light-front wave function (LFWF), we use the Gaussian parametrization [2].

The s-channel helicity conserving $T \to T$ transition, where $\lambda_\gamma = \lambda_V$ is given by the formula:

$$I(T,T)_{(\lambda_V=\lambda_\gamma)} = m_q^2\Phi_2 + \Big[z^2 + (1-z)^2\Big](\boldsymbol{k}\boldsymbol{\Phi}_1) + \frac{m_q}{M+2m_q}\Big[\boldsymbol{k}^2\Phi_2 - (2z-1)^2(\boldsymbol{k}\boldsymbol{\Phi}_1)\Big]\,. \quad (2)$$

The helicity-flip by one unit, i.e. from the transverse photon $\lambda_\gamma = \pm 1$ to the longitudinally polarized meson, $\lambda_V = 0$:

$$I(L,T) = -2Mz(1-z)(2z-1)(\boldsymbol{e}\boldsymbol{\Phi}_1)\Big[1 + \frac{(1-2z)^2}{4z(1-z)}\frac{2m_q}{M+2m_q}\Big] + \frac{Mm_q}{M+2m_q}(2z-1)(\boldsymbol{e}\boldsymbol{k})\Phi_2\,. \quad (3)$$

The helicity-flip by two units, from the transverse photon $\lambda_\gamma = \pm 1$ to the transversely polarized meson with $\lambda_V = \mp 1$:

$$I(T,T)_{(\lambda_V=-\lambda_\gamma)} = 2z(1-z)(\Phi_{1x}k_x - \Phi_{1y}k_y) - \frac{m_q}{M+2m_q}\Big[(k_x^2 - k_y^2)\Phi_2 - (2z-1)^2(k_x\Phi_{1x} - k_y\Phi_{1y})\Big]\,. \quad (4)$$

For the function $G(\boldsymbol{\Delta}^2)$ we considered two options: an exponential parametrization

$$G(\boldsymbol{\Delta}^2) = \exp\Big[-\frac{1}{2}B\boldsymbol{\Delta}^2\Big] \quad (5)$$

and a dipole form factor parametrization often used in nonperturbative Pomeron models [2]

$$G(\boldsymbol{\Delta}^2) = \frac{4m_p^2 + 2.79\boldsymbol{\Delta}^2}{4m_p^2 + \boldsymbol{\Delta}^2} \times \frac{1}{\Big(1 + \frac{\boldsymbol{\Delta}^2}{\Lambda^2}\Big)^2}\,. \quad (6)$$

3 Results

In Fig. 2, we show our results for different values of energy and the Ivanov-Nikolaev UGD (Unintegrated Gluon Distribution)[3] using the exponential parametrization for $G(\boldsymbol{\Delta}^2)$. We show the $T \to T$ helicity conserving contribution by the long dashed line. The dotted line shows the $T \to L$ transition and the dash-dotted line shown the $T \to T'$ transition. We observe, that the $T \to T$ contribution has a dip at $-t \sim 0.5 \div 0.7\,\mathrm{GeV}^{-2}$. The position

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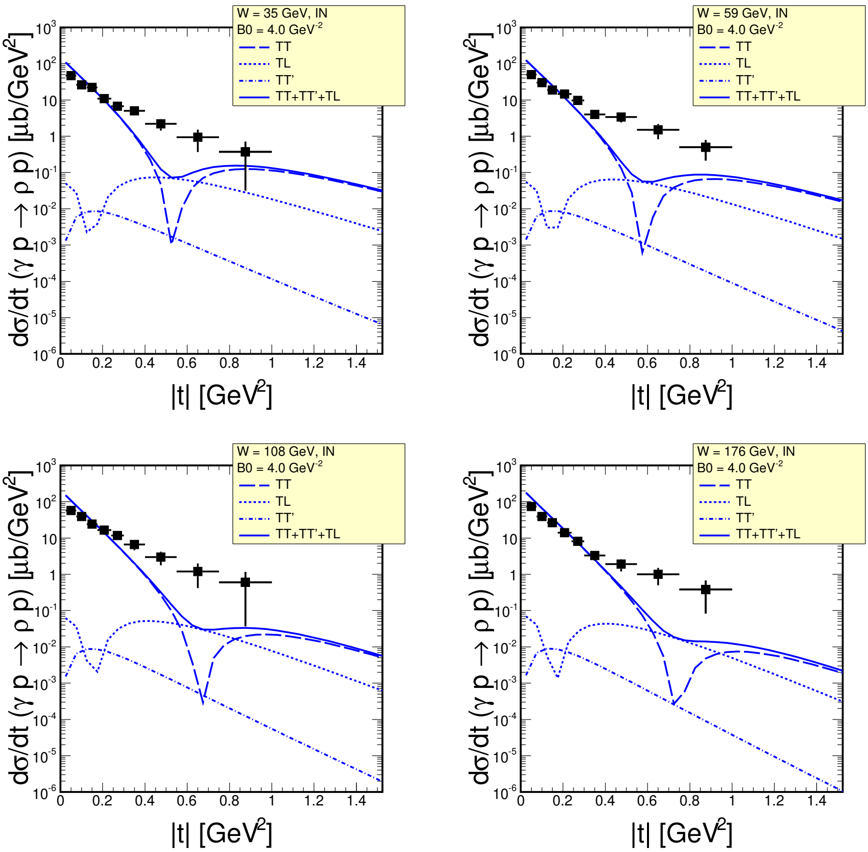

Figure 2. Distribution in t, the four-momentum transfer squared in the $\gamma p \to \rho p$ reaction, for different energies and the Ivanov-Nikolaev UGD. Here the exponential parametrization of the form factor $G(\mathbf{\Delta}^2)$ was used.

is slightly dependent on collisions energy. The $T \to L$ transition itself possesses a dip at $-t \sim 0.2\,\mathrm{GeV}^{-2}$ but in this region the $T \to T$ transition vastly dominates. The double helicity-flip contribution is very small throughout the whole kinematic region.

In Fig. 3 we show the results for all UGDs summed over all helicity combinations. Here we use the dipole parametrization for $G(\mathbf{\Delta}^2)$. For the KMR UGD [4] the helicity conserving part dominates throughout. In this case, there is no dip in the differential cross section. The description of data is very good except for the highest energy, where the t-dependence is too hard. For the Kutak-Staśto UGD [5] we observe no dip and a complete dominance of the helicity conserving process. Also the results for the GBW UGD [6] have no dip within the measured region, and again helicity-flip transitions are negligible. The results for MPM UDG [7] give a very good description of data.

4 Conclusions

We have studied the role played by the often neglected helicity-flip amplitudes, which can contribute at finite t. The large $|t|$-behaviour $d\sigma/dt$ depends on the form factor describing

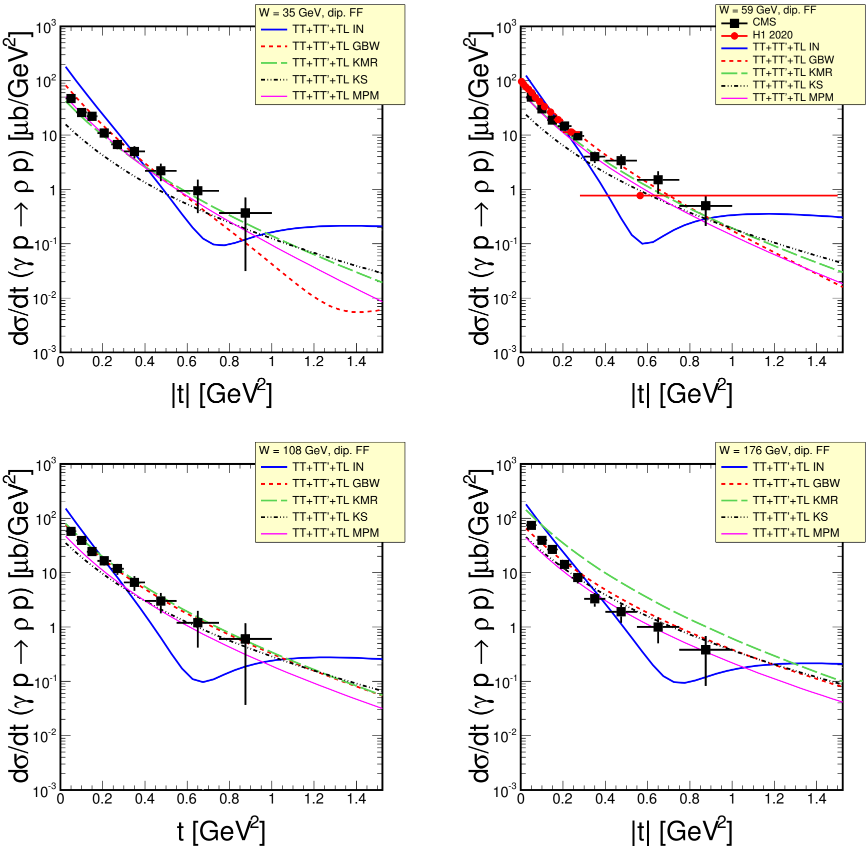

Figure 3. Distribution in t for different energies for the different UGDs. Here the dipole parametrization of the form factor $G(\mathbf{\Delta}^2)$ was used.

the coupling of the pomeron to the $p \to p$ transition, while the dip-bump structure depends rather on the UGD used. We have included traditional $T \to T$ contribution and also $T \to L$ and $T \to T'$ (double spin-flip) contributions. The relative amount and differential shape of the subleading contributions depend on the UGD used. All UGDs generate dips for $T \to L$ transition and some of them generate dips for $T \to T$ transition. More resuts can be found in our recent paper [2].

References

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