# HELICITY-FLIP TRANSITIONS AND THE $t$-DEPENDENCE OF EXCLUSIVE PHOTOPRODUCTION OF RHO MESON*

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We calculate the differential cross section $\mathrm{d}\sigma/\mathrm{d}t$ for the diffractive photoproduction process $\gamma p \to \rho p$ and compare it to recent experimental data extracted by the CMS Collaboration. Our model is based on two-gluon exchange in the non-perturbative domain. We take into account both the helicity-conserving and the often neglected helicity-flip amplitudes in the $\gamma \to V$ transition, which can contribute at finite $t$. The shape of the differential crosssection as well as the role of helicity-flip processes is strongly related to the dependence of the unintegrated gluon distribution on the transverse momenta in the non-perturbative region. Results for different unintegrated gluon distribution are shown.

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## 1. Introduction

The exclusive photoproduction of vector mesons is one of the intensively studied processes at high energies. For the light vector mesons, the energy dependence displays a "soft Pomeron" behaviour and follows one of the total $\gamma p$ photoabsorption cross section. Our work was motivated by a recent

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measurement of the differential cross section $\mathrm{d}\sigma/\mathrm{d}t$ for diffractive $\rho^0$ 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 colour dipole approach, also restrict themselves to the helicity-conserving part of the amplitude. We compare our results obtained using 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 a vector meson is shown schematically in Fig. 1. The imaginary part of this amplitude can be written as

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

The $\rho$-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].

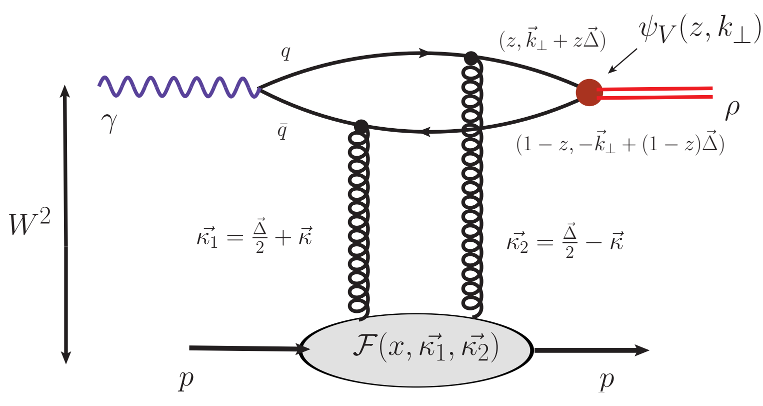


Fig. 1. Feynman diagram for the $\gamma p \to \rho p$ diffractive amplitude.

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

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

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

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

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

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

For the function $G(\boldsymbol{\Delta}^2)$, we have considered two options: an exponential parametrization and a dipole form factor parametrization often used in non-perturbative Pomeron models [2].

## 3. Results

In Fig. 2, we show our results for the Ivanov–Nikolaev UGD [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, where the helicity is changed by one unit. Finally, by the dash-dotted line, we display the $T \to T'$ transition, where $|\lambda_\gamma - \lambda_V| = 2$. We observe that the $T \to T$ contribution has a dip at $-t \sim 0.5 \div 0.7$ GeV$^{-2}$, which position is slightly dependent on the collisions energy. The $T \to L$ transition itself possesses a dip at $-t \sim 0.2$ 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.

We show for convenience the results for all UGDs summed over all helicity combinations in Fig. 3. Here, we use the dipole parametrization for $G(\boldsymbol{\Delta}^2)$. We observe that some qualitative features, like the position of the dip, are very similar to the previous case, however, the cross section develops a much harder tail at large $-t$. 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 the helicity-flip transitions are negligible. The results for MPM UDG [7] give a very good description of data. Also here, the helicity-flip transitions are negligible, and the general behaviour is close to that for the GBW UGD.

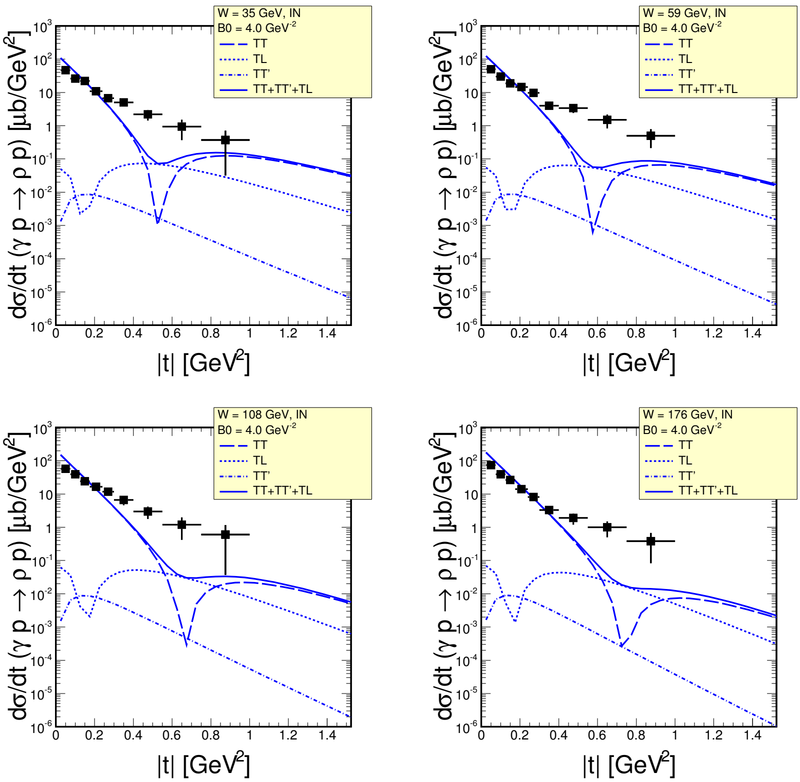

Fig. 2. Distribution in $t$, the four-momentum transfer squared in the $\gamma p \to \rho p$ reaction, for different energies and the Ivanov–Nikolaev UGD. Here, the exponential parametrization of the form factor $G(\boldsymbol{\Delta}^2)$ was used.

## 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 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 as well as somewhat smaller subleading $T \to L$ 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 also for $T \to L$ transition and some of them generate dips for $T \to T$ transition. More results can be found in our recent paper [2].

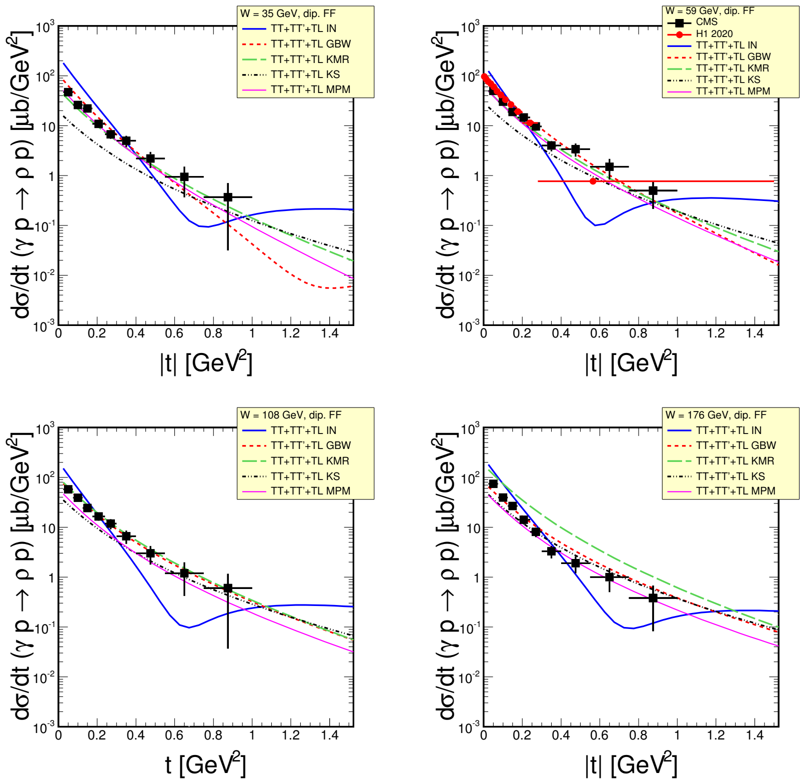


Fig. 3. Distribution in $|t|$ for different energies for the different UGDs. Here, the dipole parametrization of the form factor $G(\boldsymbol{\Delta}^2)$ was used.

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