Exclusive production of vector mesons in $\gamma p$ and $pp$ collisions.

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The dominant mechanism for the central exclusive production of vector meson in $pp$ and $p\bar{p}$ collisions is the $\gamma F^2$ fusion. As a building block for the $pp$ reaction, the amplitude for photoproduction $\gamma p \rightarrow V p$ is calculated in a pQCD $k_T$-factorization approach. We will present results for several vector mesons: $\rho$, $\omega$, $\phi$, $J/\Psi$ and $\Upsilon$. The total cross section for diffractive mesons production as a function of energy and photon virtuality is calculated.

We will present dependence on the mass of the quark for light mesons. The results for а pQCD command.

1. Introduction

Photoproduction of the vector mesons in photon-proton collisions is interesting from both experimental and theoretical side. It was studied intensively by many people. Photoproduction process $\gamma p \rightarrow V p$ has been measured at HERA. When calculating the cross section for photoproduction at high energies, the two main ingredients are the unintegrated gluon distribution function and the quark-antiquark wave function of the vector meson. Photoproduction of vector mesons can be also studied in proton-proton or proton-antiproton collisions, where it is the dominant mechanism for exclusive production of vector mesons at central rapidities. We refer to this production mechanism also as photon-Pomeron fusion. For an evaluation of differential distributions it is important to include the effect of absorptive corrections. The HERA data on photoproduction of vector mesons constrain the exclusive production at Tevatron for not too large rapidity of the vector meson.

2. Photoproduction $\gamma p \rightarrow V p$ at HERA

The amplitude for the reaction is shown schematically in Fig.1. The full amplitude for this process can be written as (see Refs. [123]):

$$B(W,\Delta^2) = (i + \rho_{L,T}) 3m \mathcal{M}_{L,T}(W, \Delta^2 = 0, Q^2) \times$$

$$\exp \left( - \frac{B(W) \Delta^2}{2} \right),$$

where $\rho_{L,T}$ is a ratio of real and imaginary part of the amplitude for longitudinal and transverse polarization of the photon and $B(W)$ is slope parameter which depends on energy: $B(W) = B_0 + 2\alpha_s \log \left( \frac{W^2}{\mu_0^2} \right)$. We have different $B_0$ for different mesons. This values can be found in Refs. [14567].

The imaginary part of the amplitude depends on the unintegrated gluon distribution function and on the wave function of the vector meson. The explicit form of the amplitude for longitudinal and transverse polarization can be found in Refs. [211].

Our amplitude is normalized to the cross section:

$$(\iota_{L,T}(\gamma p \rightarrow V p)) = \frac{1}{16\pi B(W)} \left| \mathcal{M}_{L,T}(W, \Delta^2) \right|^2. \quad (2)$$

We calculated separately cross section for transverse ($\iota_T$) and longitudinal ($\iota_L$) polarizations. The full cross section is a sum of these two components. In our calculation we used two types of model wave func-
tions, Gaussian:

\[
\psi_1S(p^2) = C_1 \exp \left( -\frac{p^2a_1^2}{2} \right),
\]

\[
\psi_2S(p^2) = C_2 \left( \xi_0 - p^2a_2^2 \right) \exp \left( -\frac{p^2a_2^2}{2} \right)
\]

(3)

and Coulomb–like wave functions:

\[
\psi_1S(p^2) = \frac{C_1}{\sqrt{M}} \frac{1}{(1 + a_1^2 p^2)^2},
\]

\[
\psi_2S(p^2) = \frac{C_2}{\sqrt{M}} \frac{\xi_0 - a_2^2 p^2}{(1 + a_2^2 p^2)^3}.
\]

(4)

The parameters of the wave function are obtained from fitting the decay widths into \(e^+ e^-\).

2.1. Numerical results and HERA data

In Fig. 2 the total cross section for photoproduction \(\gamma p \rightarrow \phi p\) is shown as a function of photon-proton center of mass energy for \(Q^2 = 0\). We present results for different models of UGDF function. The thick solid line is for the Ivanov-Nikolaev model, the dash-dotted line is for the Kutak-Stasto model, the solid line is for the BFKL, the dotted line is for the Kharzeev-Levin UGDF and the thin solid line is for the Golec-Biernat-Wüsthoff model. We can see that Ivanov-Nikolaev UGDF gives the best description of experimental data.

In Fig. 4 the total cross section as a function of energy \(W = 75\) GeV. This cross section is a function of \(Q^2\). The thick lines are for the Gaussian wave function and thin lines are for Coulomb wave function. The solid lines are for total cross section and the dashed lines are for transverse cross section. We compare our results with experimental data of the ZEUS Collaboration.

In Fig. 3 the cross section as a function of \(Q^2\) for photoproduction \((W = 75\) GeV) mesons rho. Experimental data are taken from Ref. [10].

Figure 2. Total cross section for \(\gamma p \rightarrow \phi p\) as a function of energy. Results for different models UDDF function. Experimental data can be found in Refs. [8,9].

Figure 3. Cross section as a function of \(Q^2\) for photoproduction \((W = 75\) GeV) mesons rho. Experimental data are taken from Ref. [10].

Figure 4. Total cross section for \(\gamma p \rightarrow \phi p\) as a function of energy. Different values of the strange quark mass. Experimental data can be found in Refs. [8,9].

In Fig. 4 the total cross section as a function of photon-proton center of mass energy for \(Q^2 = 0\). We show results for three different values of the strange quark mass. The red (upper) line is for \(m_s = 0.37\) GeV, blue (lower) line for \(m_s = 0.50\) GeV and the black line (which goes through the data points) for \(m_s = 0.45\) GeV. We can see that the results for \(m_s = 0.45\) GeV give the best description of the experimen-
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In Fig.5 we present total cross section for different mesons. This cross section is a function of energy. We can see that for higher energy ($> 5$ TeV) total cross sections for $J/\Psi$, $\phi$ and $\omega$ are very similar. The cross section for $\rho$ meson is much bigger in the energy range considered here. Here we have presented results for the Gaussian wave function.

3. Exclusive photoproduction in $pp$ collisions

The diagrams in (Fig.6) show schematically the amplitude with absorptive correction, including elastic rescattering. The full amplitude for $pp \to pVp$ or $p\bar{p} \to pV\bar{p}$ can be written as

$$M(p_1, p_2) = \int \frac{d^2k}{(2\pi)^2} S_{el}(k) M^{(0)}(p_1 - k, p_2 + k) =$$

In formula (5) $M^{(0)}(p_1, p_2)$ is the Born-amplitude (without absorption) for the process $pp \to pVp$ or $p\bar{p} \to pV\bar{p}$ which includes our amplitude for photoproduction and $\delta M(p_1, p_2)$ is the absorptive correction. We have calculated our amplitude for the Ivanov-Nikolaev unintegrated gluon distribution function and the Gaussian wave function. In formula (5) $p_1$ and $p_2$ are transverse momenta of outgoing protons. The differential cross section is given in terms $M$ as:

$$d\sigma = \frac{1}{512\pi s} |M|^2 dy dt_1 dt_2 d\varphi,$$

where $\varphi$ is azimuthal angle between outgoing $pp$ or $p\bar{p}$.

3.1. Numerical results for proton-proton and proton-antiproton collisions

In Fig.6 we show rapidity distribution for various vector meson in proton-antiproton collisions. Our results are compared with recent CDF data for $J/\Psi$. The solid lines are for the amplitude with absorptive corrections and the dashed lines are for the amplitude without absorption.

In Fig.7 we show distributions in transverse momentum for $\Upsilon$ at the Tevatron energy: $y = 0$ (solid), $y = 2$ (dashed) and $y = 4$ (dotted) for different values of rapidity. We present results for bare amplitudes (left - upper) and for the amplitudes with absorptive corrections (right - upper). We show the ratio of the...
4. Conclusions

We have calculated the total cross section for diffractive vector meson photoproduction $\gamma p \rightarrow V p$ in a pQCD-based model for $\rho$, $\omega$, $\phi$, $J/\Psi$ and $T$. The results for photoproduction $\gamma p \rightarrow V p$ depend on the model of the wave function and UGDFs function. The Gauss wave function better describes data than the Coulomb one. We can see that the Ivanov-Nikolaev unintegrated distribution the best describes experimental data. We have compared our results with a recent HERA data. Based on these photoproduction amplitudes, we have predicted cross sections for exclusive production of vector mesons in $pp$ and $p\bar{p}$ collisions. In our calculation of hadronic processes we have included explicitly absorption effects. This effect depends on rapidity and $p_t$.

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