Exclusive production of vector mesons in $pp$ and $p\bar{p}$ collisions.

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Introduction

- Exclusive production of vector meson in high energy hadronic reaction was measured only for $J/\Psi$.

- We have one point for Tevatron at $y = 0$

- In our analysis we restrict only to photon-pomeron fusion mechanism

- Photoproduction of vector meson has been studied in the energy range $W \sim 2 - 300$ GeV (recently at HERA)

- This energy range is relevant for the exclusive production at Tevatron energies for not too large rapidities of the meson

- We include the absorption effects in hadronic reaction
Formalism

Diagram for exclusive photoproduction $\gamma p \rightarrow Vp$

- $V \rightarrow \Upsilon, J/\Psi, \phi, \rho$ and $\omega$
- $\psi_V(z, k) \rightarrow$ wave function of the vector meson
- $F(x, \kappa) \rightarrow$ unintegrated gluon distribution function (Ivanov-Nikolaev)
- $x \sim (Q^2 + M_{VM}^2)/W^2$
- $\lambda_\gamma = \lambda_V$
The production amplitude for $\gamma p \to Vp$

The imaginary part of the amplitude can be written as:

$$\Im m \mathcal{M} = W^2 \frac{c_v \sqrt{4\pi \alpha_{em}}}{4\pi^2} \int \frac{d\kappa^2}{\kappa^4} \alpha_s(q^2) \mathcal{F}(x_{\text{eff}}, \kappa^2) \int \frac{dz d^2k}{z(1-z)} I(\lambda_V, \lambda_\gamma),$$

where $I(\lambda_V, \lambda_\gamma)$ have the form:

$$I(L, L) = 4QMz^2(1 - z)^2 \left[1 + \frac{(1 - 2z)^2}{4z(1 - z)} \frac{2m_q}{M + 2m_q}\right] \psi_v(z, k) \Phi_2$$

$$I(T, T) = m_q^2 \psi_v(z, k) \Phi_2 + \left[z^2 + (1 - z)^2\right] (\psi_v(z, k) \Phi_1) +$$

$$\frac{m_q}{M + 2m_q} \left[(k^2 \psi_v(z, k)) \Phi_2 - (2z - 1)^2 (k \Phi_1) \psi_v(z, k)\right]$$
Cross section for $\gamma p \to Vp$

The full amplitude:

$$\mathcal{M}_{L,T}(W, \Delta^2) = (i + \rho_{L,T}) \Im m \mathcal{M}_{L,T}(W, \Delta^2 = 0) \exp(-B(W)\Delta^2).$$

where

$$\rho_{L,T} = \frac{\Re e \mathcal{M}_{L,T}}{\Im m \mathcal{M}_{L,T}} = \frac{\pi}{2} \frac{\partial \log \left(\frac{\Im m \mathcal{M}_{L,T}}{W^2}\right)}{\partial \log W^2} = \frac{\pi}{2} \Delta_P.$$

$$B(W) = B_0 + 2\alpha'_\text{eff} \log \left(\frac{W^2}{W_0^2}\right),$$

with: $\alpha'_\text{eff} = 0.25 \text{ GeV}^{-2} (\phi, \rho, \omega); \ \alpha'_\text{eff} = 0.164 \text{ GeV}^{-2} (J/\Psi, \Upsilon); \ W_0 = 95 \text{ GeV}$

Total cross section can be written as:

$$\sigma_{L,T}(\gamma p \to Vp) = \frac{1 + \rho_{L,T}^2}{16\pi B(W)} \left|\frac{\Im m \mathcal{M}_{L,T}(W, \Delta^2)}{W^2}\right|^2$$

$$\sigma_{tot}(\gamma p \to Vp) = \sigma_T(\gamma p \to Vp) + \epsilon \sigma_L(\gamma p \to Vp)$$

where $\epsilon \approx 1$

Formalism

Parameters of the vector meson wave functions

Decay electronic width: \( \Gamma(V \to e^+e^-) = \frac{4\pi\alpha_{em}^2 c_V^2}{3M_V^3} \cdot g_V^2 \cdot K_{NLO} \)

Leading Order approximation: \( K_{NLO} = 1 \)

Next to Leading Order approximation: \( K_{NLO} = 1 - \frac{16}{3\pi}\alpha_S(m_q^2) \)

\( g_V \) -leptonic decay constant: \( g_V = \frac{8N_c}{3} \int \frac{d^3\vec{p}}{(2\pi)^3} (M + m_q) \psi_v(z,k) \)

How to choose parameters of the wave function

1. \( \psi_v(z,k) \Rightarrow g_V \)
2. we choose LO or NLO \( \Rightarrow K_{NLO} \)
3. \( g_V, K_{NLO} \Rightarrow \Gamma(V \to e^+e^-) \)

Gauss: \( \psi_{1S}(k^2) = C_1 \exp\left(-\frac{k^2a_1^2}{2}\right), \psi_{2S}(K^2) = C_2(\xi_0 - p^2a_2^2) \exp\left(-\frac{k^2a_2^2}{2}\right) \)

Coulomb: \( \psi_{1S}(k^2) = \frac{C_1}{\sqrt{M}} \frac{1}{(1 + a_1^2k^2)^2}, \psi_{2S}(k^2) = \frac{C_2}{\sqrt{M}} \frac{\xi_0 - a_2^2k^2}{(1 + a_2^2k^2)^3} \)

Total cross section for $\gamma p \rightarrow \Upsilon p$

- FMS - Frankfurt, McDermott, Strikman (CTEQ4L)
- IKS - Ivanov, Krasnikov, Szymanowski
- MNRT NLO - Martin, Nockles, Ryskin, Teubner
- RSS - Rybarska, Schäfer, Szczurek
Radial excitations

\[ \frac{\sigma(\gamma p \rightarrow V(2S)p)}{\sigma(\gamma p \rightarrow V(1S)p)} : \]

- strong dependence on the wave function
Total cross section for $\gamma p \rightarrow \phi p$ and ratio $\sigma_L/\sigma_T$

- $m_s = 0.37 \text{ GeV}$
- $m_s = 0.45 \text{ GeV}$
- $m_s = 0.5 \text{ GeV}$

- Left panel: Gauss
- Right panel: Gauss and Coulomb

**Results**

\( Q^2 \)-dependence for energy \( W = 75 \text{ GeV} \), \( \gamma p \rightarrow \rho p \) and \( \gamma p \rightarrow \omega p \)

**Dominant bare mechanism for** $pp \rightarrow pVp$

**Formalism**

- **photon-pomeron**
- **pomeron-photon**
Diagram for $pp \rightarrow pVp$ with absorptive corrections

- photon-pomeron
- pomeron-photon
Amplitude for process $pp \rightarrow pVp$

Amplitude without absorption:

$$M^{(0)}(p_1, p_2) = e_1 \frac{2}{z_1} \frac{p_1}{t_1} F_{\lambda'_1 \lambda_1}(p_1, t_1) M_{\gamma h_2 \rightarrow vh_2}(s_2, t_2, Q^2_2)$$

$$+ e_2 \frac{2}{z_2} \frac{p_2}{t_2} F_{\lambda'_2 \lambda_2}(p_2, t_2) M_{\gamma h_1 \rightarrow vh_1}(s_1, t_1, Q^2_2),$$

Full amplitude for $pp \rightarrow pVp$:

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

$$= M^{(0)}(p_1, p_2) - \delta M(p_1, p_2),$$

where

$$S_{el}(k) = (2\pi)^2 \delta^{(2)}(k) - \frac{1}{2} T(k), \quad T(k) = \sigma_{tot}^{pp}(s) \exp \left( - \frac{1}{2} B_{el}k^2 \right),$$

$$B_{el} = 21 \text{ GeV}^{-2}, \quad \sigma_{tot}^{pp}(s) = 100 \text{ mb for LHC}$$

$$B_{el} = 17 \text{ GeV}^{-2}, \quad \sigma_{tot}^{pp}(s) = 76 \text{ mb for Tevatron}$$

$$B_{el} = 14 \text{ GeV}^{-2}, \quad \sigma_{tot}^{pp}(s) = 52 \text{ mb for RHIC}$$
Cross section for exclusive photoproduction in $pp$ and $p\bar{p}$ collisions

The absorptive corrections for amplitude:

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

The differential cross section is given in terms of $M$ as:

$$d\sigma = \frac{1}{512\pi^4 s^2} |M|^2 dy dt_1 dt_2 d\varphi,$$

where

- $y$ is rapidity of the vector meson
- $\varphi$ is azimuthal angle between $p_1$ and $p_2$
Results

Distribution in rapidity for $pp \rightarrow p\omega p$ and $pp \rightarrow p\omega\bar{p}$

- results with absorption
- results without absorption
Results

**Distribution in $\varphi$ for meson $\rho$**

- $\varphi$ - azimuthal angle between outgoing proton-proton and proton-antiproton
- Results without absorption
$d\sigma/dydp_t^2$, absorption effect

- Left panel: results without absorption
- Middle panel: results with absorption
- Right panel: absorption effect

$\gamma p \to Vp$
Results

**Distribution in rapidity for Tevatron and LHC energy**

- solid line: results with absorption
- dashed line: results without absorption

- mezon $\rho$
- mezon $\omega$
- mezon $\phi$
- mezon $J/\Psi$
- mezon $\Upsilon$
Conclusions

- We have compared our photoproduction results with recent HERA data.

- The results for $\gamma p \rightarrow Vp$ production depend on the model of the wave function.

- Cross sections for exclusive photoproduction of Quarkonia at colliders are of measurable size.

- Absorptive corrections have been included. Their effect depends on $p_t$ and $y$. 