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

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Outline

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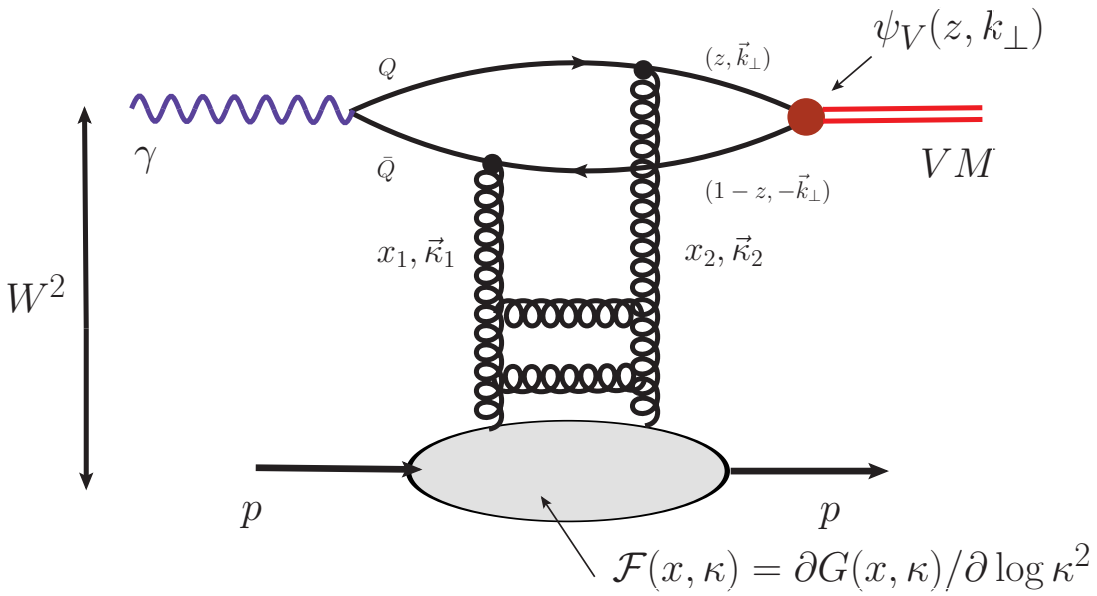
Introduction

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

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



- V $\longrightarrow$ Υ, J/Ψ, ϕ, ρ and ω
- $\psi_v(z, k)$ $\longrightarrow$ wave function of the vector meson
- $\mathcal{F}(x, \kappa)$ $\longrightarrow$ unintegrated gluon distribution function (Ivanov-Nikolaev)
- $x \sim (Q^2 + M_{VM}^2)/W^2$
- $\lambda_\gamma = \lambda_V$

The production amplitude for $\gamma p \longrightarrow Vp$

The imaginary part of the amplitude can be written as:

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

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

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

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

with: $\alpha'_{eff} = 0.25\ \mathrm{GeV}^{-2}$ (ϕ,ρ,ω); $\alpha'_{eff} = 0.164\ \mathrm{GeV}^{-2}$ (J/Ψ,Υ); $W_0 = 95$ 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 $\epsilon \approx 1$

I.P.Ivanov, N.N.Nikolaev, A.A.Savin: Phys.Part.Nucl.37 (2006)

Parameters of the vector meson wave functions

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

Leading Order approximation: $K_{NLO} = 1$

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

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

How to choose parameters of the wave function

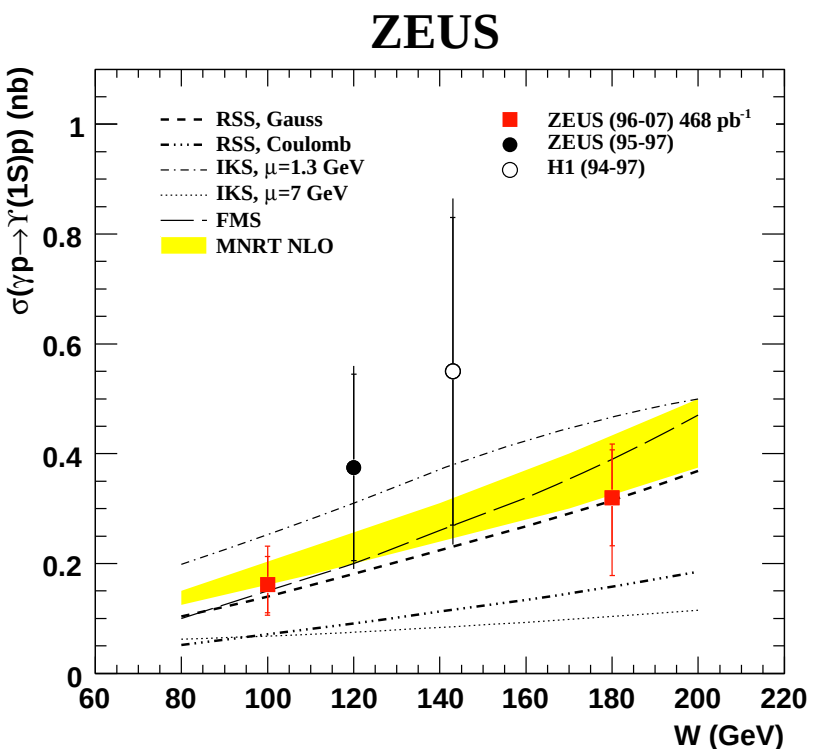
1) $\psi_v(z,k) \Rightarrow g_V$
2) we choose LO or NLO $\Rightarrow K_{NLO}$
3) $g_V, K_{NLO} \Rightarrow \Gamma(V \to e^+e^-)$

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

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

I.P.Ivanov, N.N.Nikolaev, A.A.Savin: Phys.Part.Nucl.37 (2006)

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

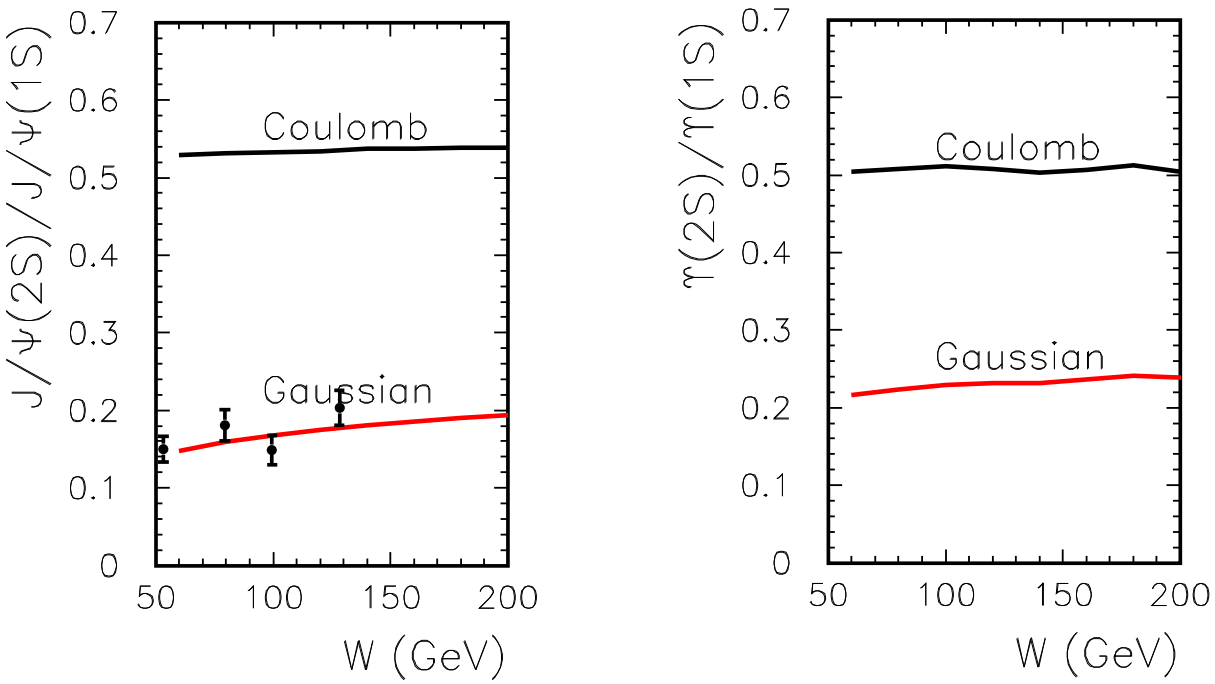


- FMS - Frankfurt, McDermott, Strikman (CTEQ4L)
- IKS - Ivanov, Krasnikov, Szymanowski
- MNRT NLO - Martin, Nockles, Ryskin, Teubner
- RSS - Rybarska, Schäfer, Szczurek

- experimental data $\rightarrow$ ZEUS Collaboration, Phys.Lett.B680:4-12 (2009)

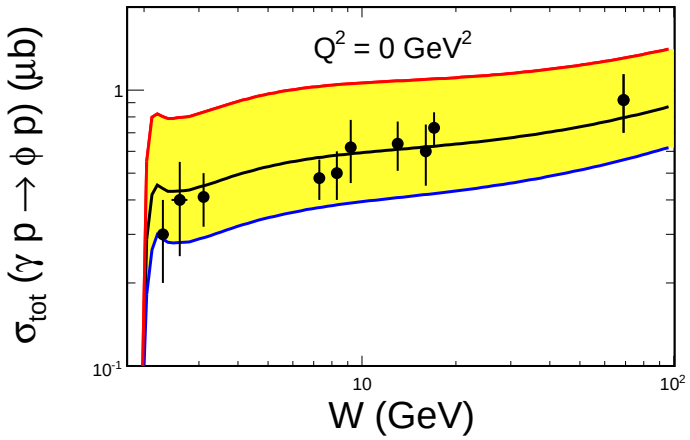
Radial excitations

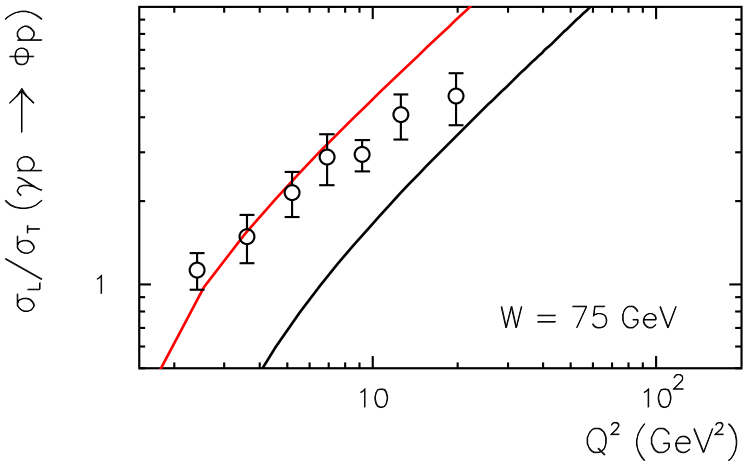
$$\sigma(\gamma p \to V(2S)p)/\sigma(\gamma p \to V(1S)p) :$$



- strong dependence on the wave function
- data $\longrightarrow$ H1 Collaboration, published in Phys.Lett.B541:251-264 (2002)

Total cross section for $\gamma p \longrightarrow \phi p$ and ratio σ_L/σ_T





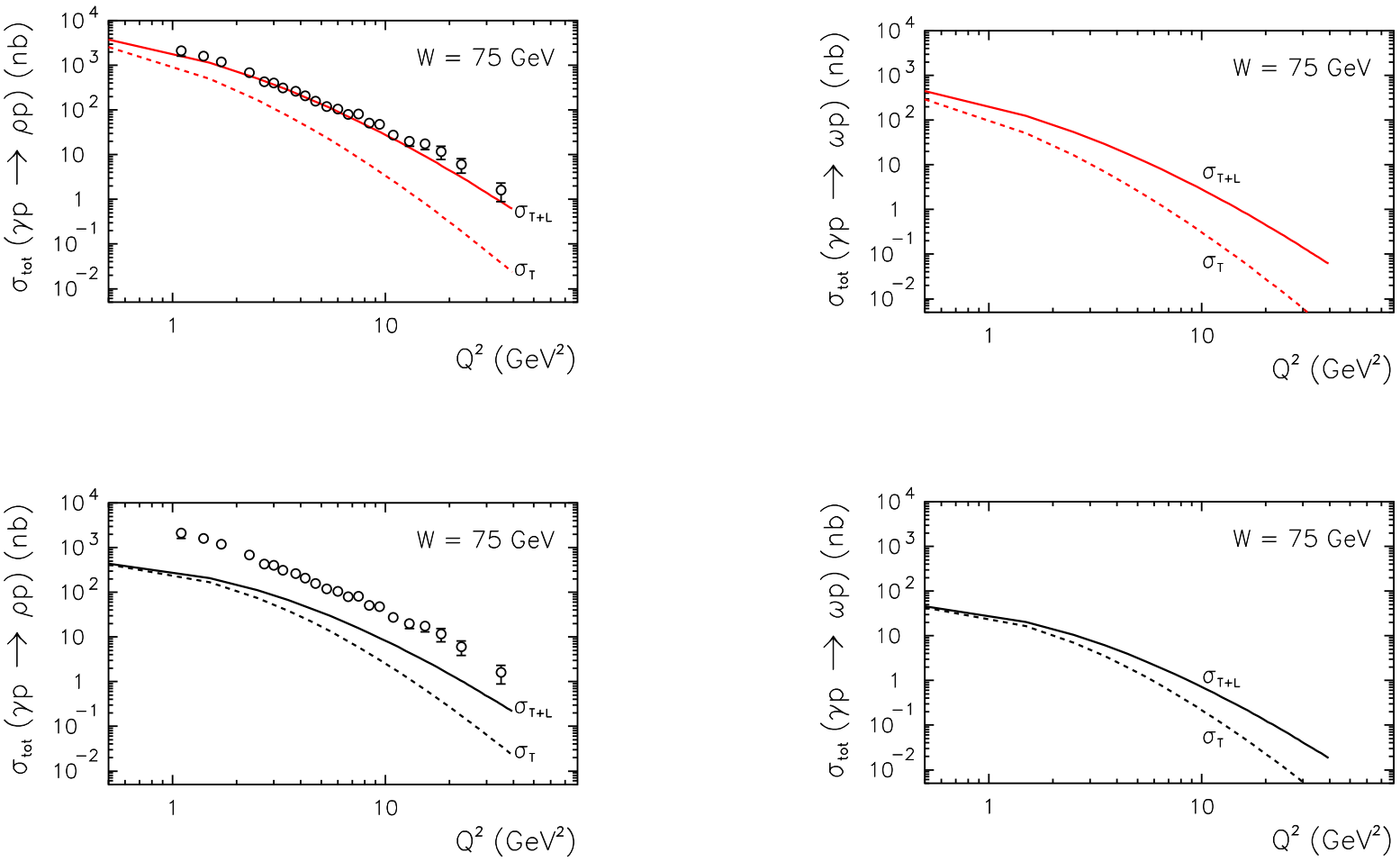
- $m_s = 0.37\ GeV$
- $m_s = 0.45\ GeV$
- $m_s = 0.5\ GeV$

- data $\longrightarrow$ Fermilab (E25,E401) Phys.Rev.D40 (1989) 1.
- data $\longrightarrow$ ZEUS Collaboration Phys.Lett.B377:259-272 (1996)

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

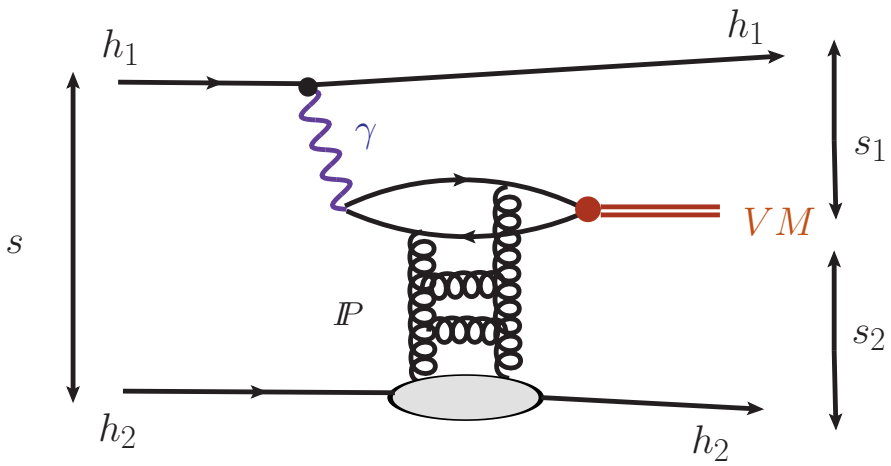
- data $\longrightarrow$ ZEUS Collaboration Phys.Lett.B377:259-272 (1996) Nucl.Phys.B718:3-31 (2005)

Q^2-dependence for energy $W = 75$ GeV, $\gamma p \longrightarrow \rho p$ and $\gamma p \longrightarrow \omega p$

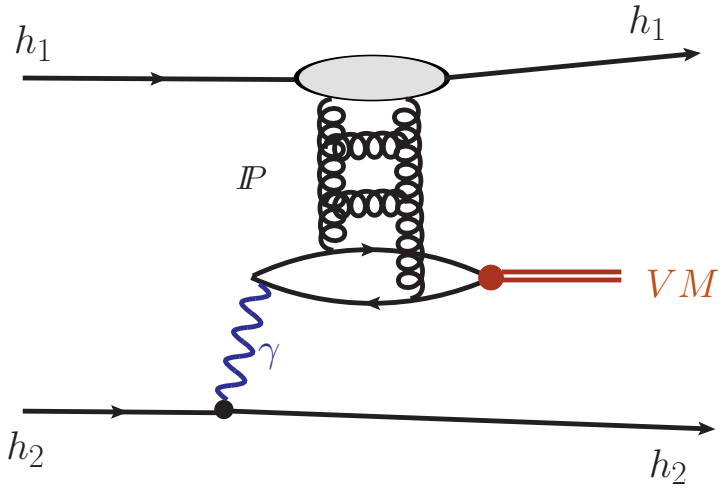


- experimental data → H1 Collaboration, Eur.Phys.J.C13: 371-396 (2000)

Dominant bare mechanism for $pp \longrightarrow pVp$

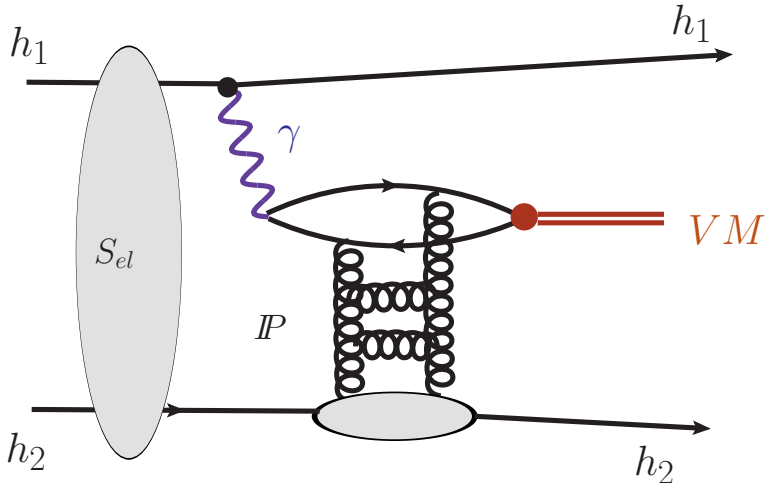


photon-pomeron

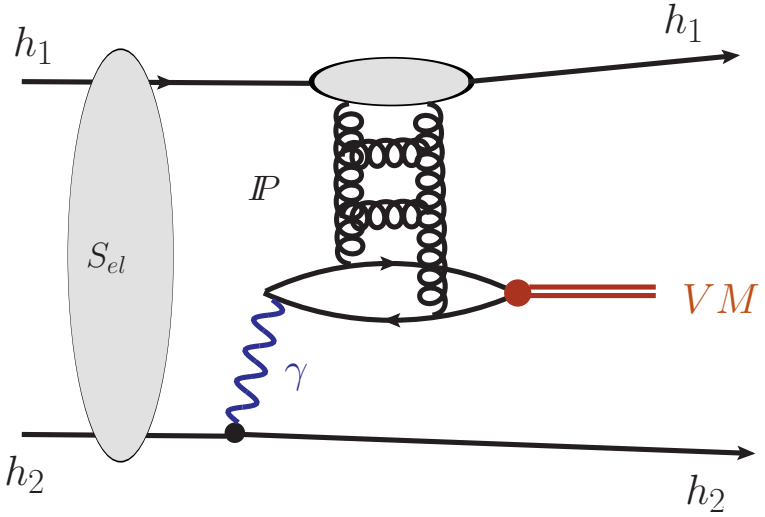


pomeron-photon

Diagram for $pp \to pVp$ with absorptive corrections



photon-pomeron



pomeron-photon

Amplitude for process $pp \to pVp$

Amplitude without absorption:

$$\boldsymbol{M}^{(0)}(\boldsymbol{p}_1,\boldsymbol{p}_2) = e_1 \frac{2}{z_1}\frac{\boldsymbol{p}_1}{t_1}\mathcal{F}_{\lambda_1'\lambda_1}(\boldsymbol{p}_1,t_1)\mathcal{M}_{\gamma h_2\to Vh_2}(s_2,t_2,Q_1^2) + e_2\frac{2}{z_2}\frac{\boldsymbol{p}_2}{t_2}\mathcal{F}_{\lambda_2'\lambda_2}(\boldsymbol{p}_2,t_2)\mathcal{M}_{\gamma h_1\to Vh_1}(s_1,t_1,Q_2^2)\,,$$

Full apmlitude for $pp \longrightarrow pVp$:

$$\boldsymbol{M}(\boldsymbol{p}_1,\boldsymbol{p}_2) = \int \frac{d^2\boldsymbol{k}}{(2\pi)^2} S_{el}(\boldsymbol{k})\, \boldsymbol{M}^{(0)}(\boldsymbol{p}_1-\boldsymbol{k},\boldsymbol{p}_2+\boldsymbol{k}) = \boldsymbol{M}^{(0)}(\boldsymbol{p}_1,\boldsymbol{p}_2) - \delta\boldsymbol{M}(\boldsymbol{p}_1,\boldsymbol{p}_2)\,,$$

where

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

$B_{el} = 21$ GeV^{-2}, $\sigma_{tot}^{pp}(s) = 100$ mb for LHC
$B_{el} = 17$ GeV^{-2}, $\sigma_{tot}^{pp}(s) = 76$ mb for Tevatron
$B_{el} = 14$ GeV^{-2}, $\sigma_{tot}^{pp}(s) = 52$ mb for RHIC

Cross section for exclusive photoproduction in pp and $p\bar{p}$ collisions

The absorptive corrections for amplitude:

$$\delta \boldsymbol{M}(\boldsymbol{p}_1, \boldsymbol{p}_2) = \int \frac{d^2\boldsymbol{k}}{2(2\pi)^2}\, T(\boldsymbol{k})\, \boldsymbol{M}^{(0)}(\boldsymbol{p}_1 - \boldsymbol{k}, \boldsymbol{p}_2 + \boldsymbol{k})\,.$$

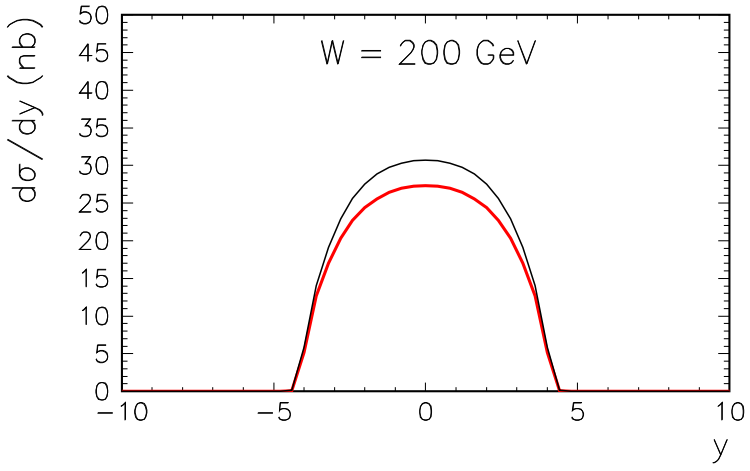
The differential cross section is given in terms of $\boldsymbol{M}$ as:

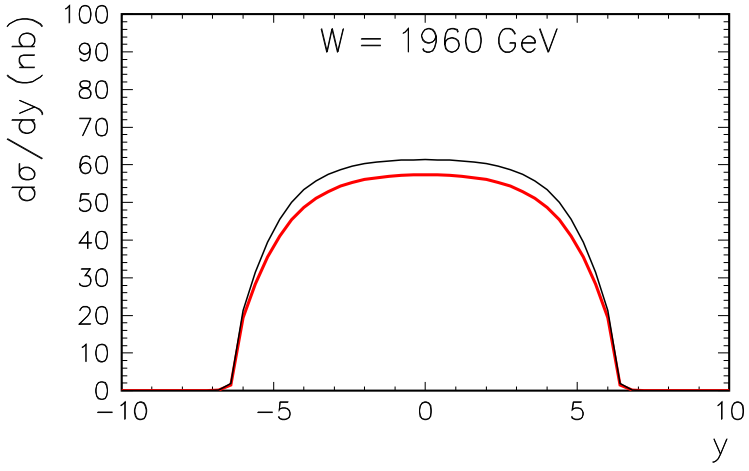
$$d\sigma = \frac{1}{512\pi^4 s^2} |\boldsymbol{M}|^2\, dy dt_1 dt_2 d\varphi\,,$$

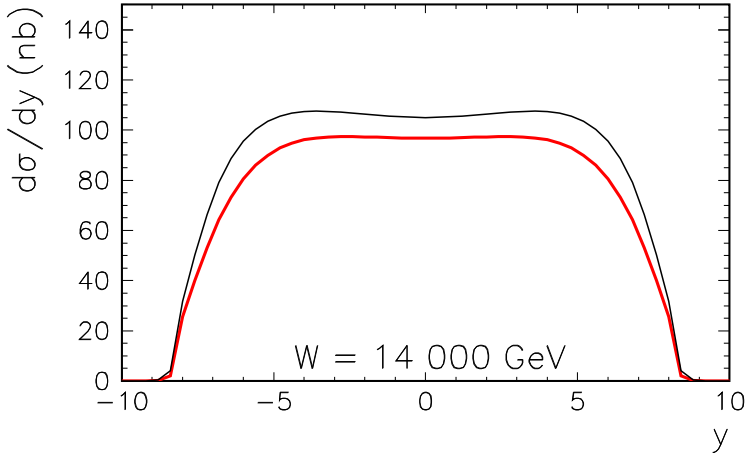
where

- y is rapidity of the vector meson
- φ is azimuthal angle between $\boldsymbol{p}_1$ and $\boldsymbol{p}_2$

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

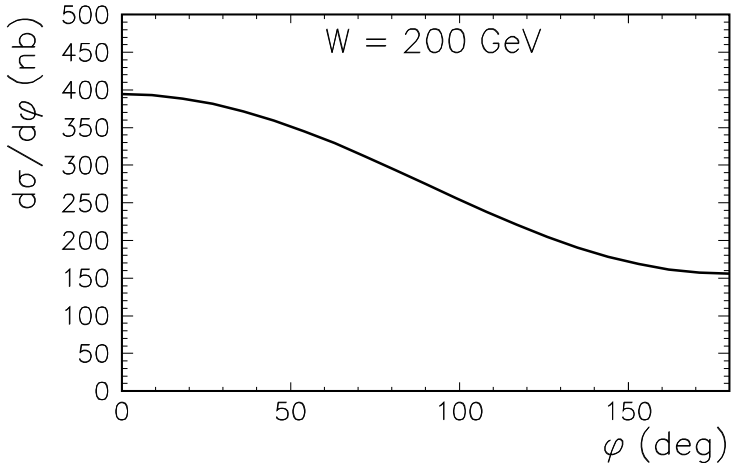


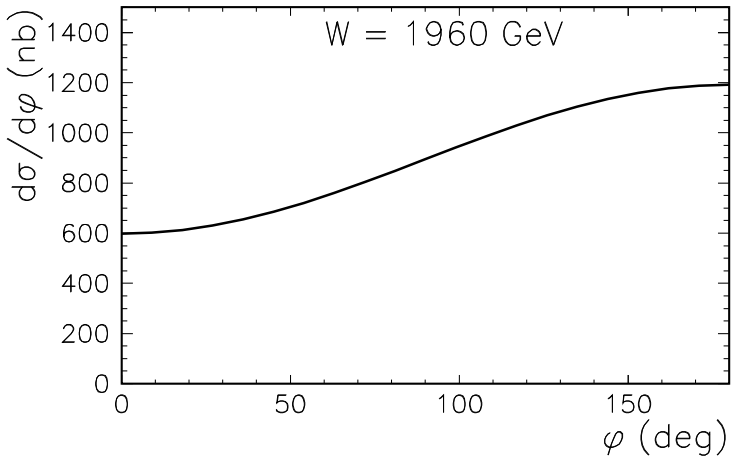


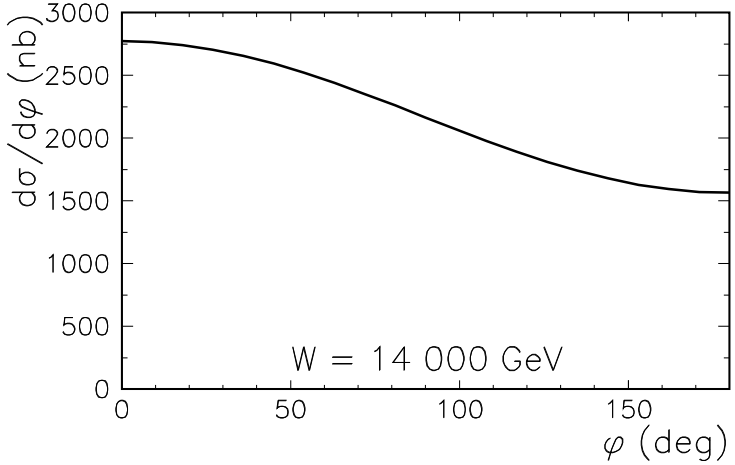


- results with absorption
- results without absorption

Distribution in φ for meson ρ

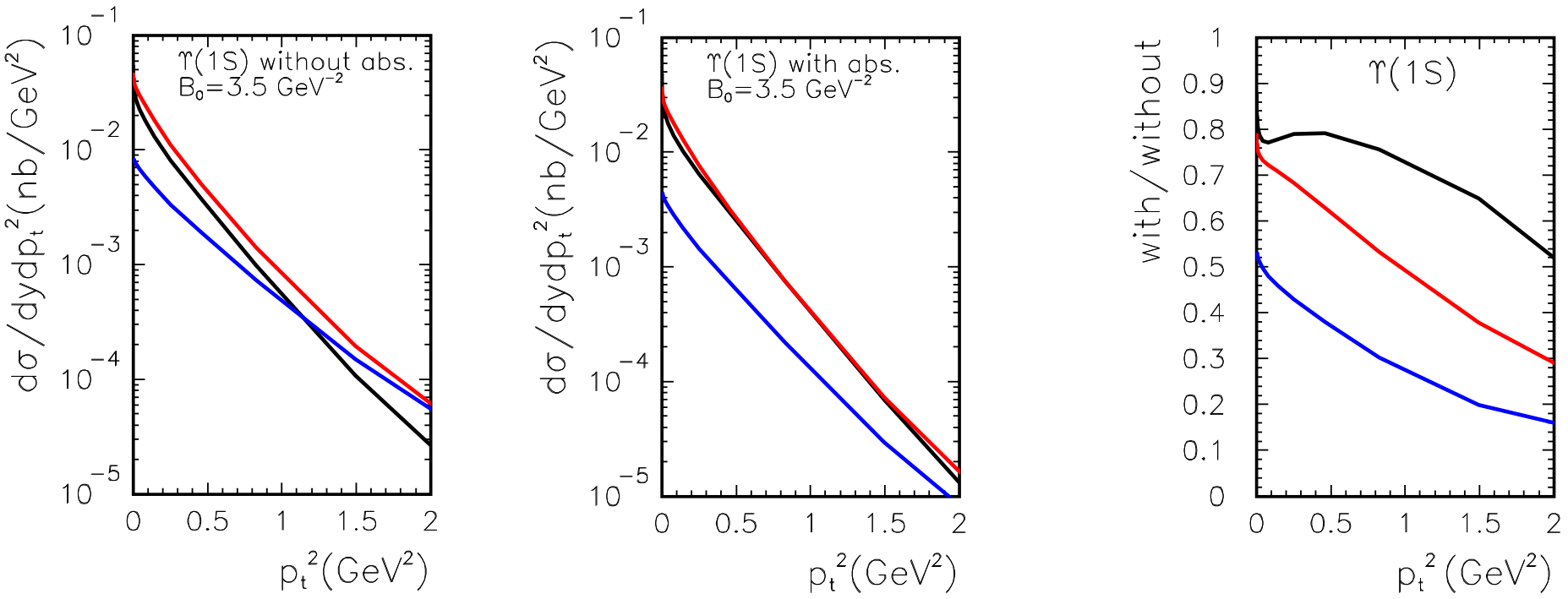






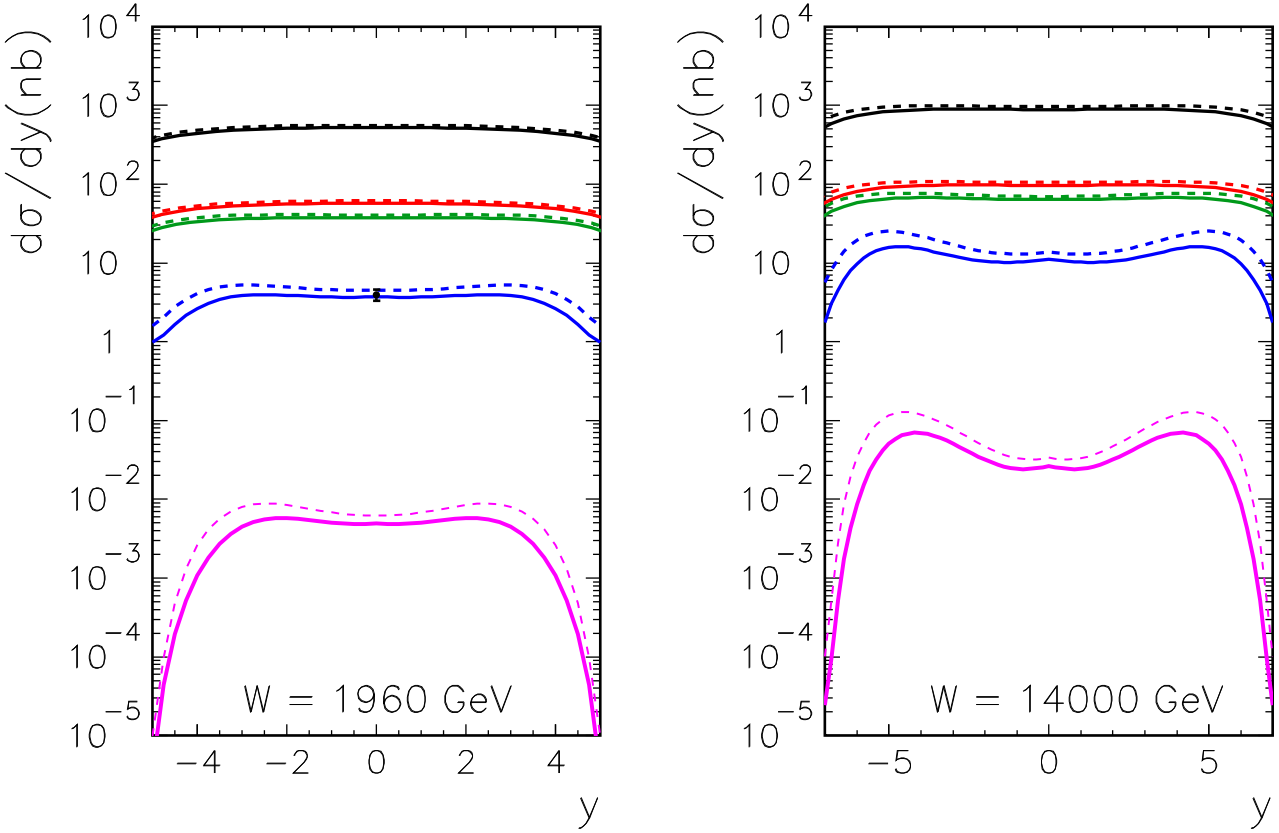
- φ - azimuthal angle between outgoing proton-proton and proton-antiproton
- results without absorption

$d\sigma/dydp_t^2$, absorption effect



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

Distribution in rapidity for Tevatron and LHC energy



- mezon ρ
- mezon ω
- mezon ϕ
- mezon J/Ψ
- mezon Υ

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

Conclusions

- We have compared our photoproduction results with recent HERA data.
- The results for $\gamma p \longrightarrow Vp$ 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.