Exclusive photoproduction of Υ: from HERA to Tevatron

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MESON 2008, 6-10 June, Kraków

In colaborations with Wolfgang Schäfer and Antoni Szczurek, hep-ph arXiv:0805.0717v1

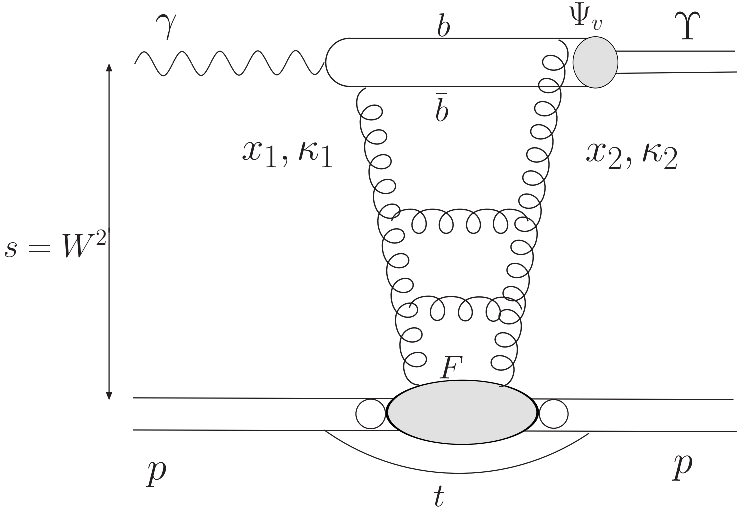
Outline

- Introduction
- Photoproduction $\gamma\mathrm{p} \longrightarrow \Upsilon\mathrm{p}$
  - Formalism
  - Results
- Exclusive photoproduction in $p\bar{p}$ collisions
  - Formalism
  - Results
- Conclusions

Introduction

- Exclusive production of heavy $Q\bar{Q}$ vector quarkonium states in hadronic interactions was never measured
- We restrict only to photon - Pomeron fusion mechanism
- The current experimental analyses at the Tevatron call for an calculation of differential distributions including the effect of absorptive corrections
- The HERA data cover energy range $W \sim$ 100 - 200 GeV
- This energy range is relevant to the exclusive production at Tevatron energies for not too large rapidities of the meson

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



Imaginary part of the production amplitude for $\gamma p \longrightarrow \Upsilon p$

$$\Im m\,\mathcal{M}(W,\Delta^2=0,Q^2=0) = W^2 \frac{c_\Upsilon \sqrt{4\pi\alpha_{em}}}{4\pi^2}\, 2\int_0^1 \frac{dz}{z(1-z)} \int_0^\infty \pi dk^2 \psi_V(z,k^2)$$
$$\int_0^\infty \frac{\pi d\kappa^2}{\kappa^4} \alpha_S(q^2) \mathcal{F}(x_{eff},\kappa^2) \Big(A_0(z,k^2)\; W_0(k^2,\kappa^2) + A_1(z,k^2)\; W_1(k^2,\kappa^2) \Big)\,,$$

where

$$A_0(z,k^2) = m_b^2 + \frac{k^2 m_b}{M+2m_b}$$
$$A_1(z,k^2) = \Big[z^2 + (1-z)^2 - (2z-1)^2 \frac{m_b}{M+2m_b} \Big] \frac{k^2}{k^2+m_b^2}\,,$$
$$W_0(k^2,\kappa^2) = \frac{1}{k^2+m_b^2} - \frac{1}{\sqrt{(k^2-m_b^2-\kappa^2)^2 + 4m_b^2 k^2}}$$
$$W_1(k^2,\kappa^2) = 1 - \frac{k^2+m_b^2}{2k^2} \Big(1 + \frac{k^2-m_b^2-\kappa^2}{\sqrt{(k^2-m_b^2-\kappa^2)^2 + 4m_b^2 k^2}} \Big)\,.$$

We choose the scale: $q^2 = \max\{\kappa^2, k^2+m_b^2\}$.

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

The full amplitude:

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

where

$$\rho = \frac{\Re e \mathcal{M}}{\Im m \mathcal{M}} = \frac{\pi}{2} \frac{\partial \log \left(\Im m \mathcal{M}/W^2\right)}{\partial \log W^2} = \frac{\pi}{2} \Delta_{\mathbb{P}}\,.$$

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

with: $\alpha'_{eff} = 0.164$ GeV^{-2}, $W_0 = 95$ GeV (H1 Collaboration 2006)

Total cross section can be write as:

$$\sigma_{tot}(\gamma p \rightarrow Vp) = \frac{1 + \rho^2}{16\pi B(W)} \left| \Im m \frac{\mathcal{M}(W, \Delta^2)}{W^2} \right|^2$$

Parameters of the Υ wave function

Υ decay electronic width:

$$\Gamma(V \to e^+e^-) = \frac{4\pi\alpha_{em}^2 c_\Upsilon}{3M_V^3} \cdot g_V^2 \cdot K_{NLO}$$

Leading order approximation:

$$K_{NLO} = 1$$

Next to leading order approximation:

$$K_{NLO} = 1 - \frac{16}{3\pi}\alpha_S(m_b^2)$$

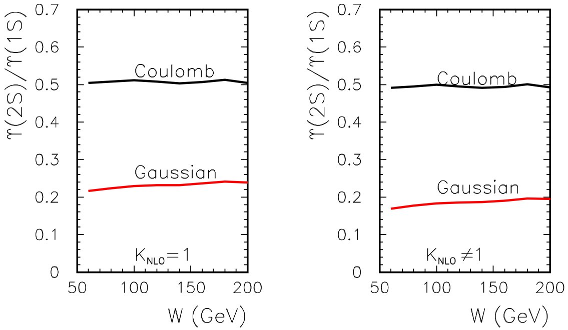
g_v -leptonic decay constant:

$$g_V = \frac{8N_c}{3}\int \frac{d^3\vec{p}}{(2\pi)^3}(M + m_b)\,\psi_V(p^2)$$

1) $\Gamma(V \to e^+e^-) \Rightarrow g_V$ and this depends on K_{NLO}

2) $g_V \Rightarrow$ parameters of $\psi_V(p^2)$

The ratio of the cross section for $\Upsilon(2S)/\Upsilon(1S)$



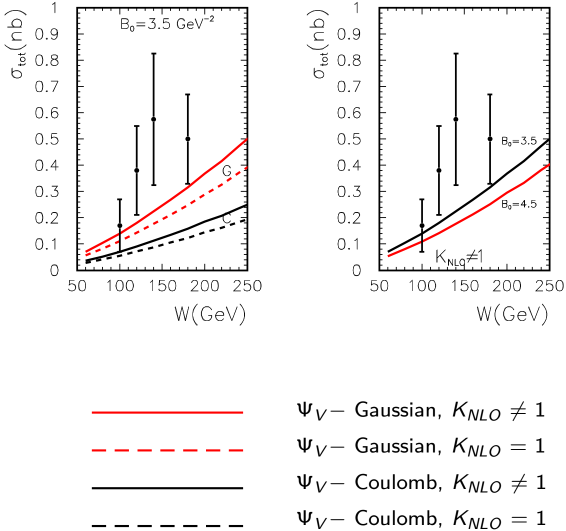
Gaussian wave function:

$$\psi_{1S}(p^2) = C_1 \exp\left(-\frac{p^2 a_1^2}{2}\right), \quad \psi_{2S}(p^2) = C_2(\xi_0 - p^2 a_2^2)\exp\left(-\frac{p^2 a_2^2}{2}\right),$$

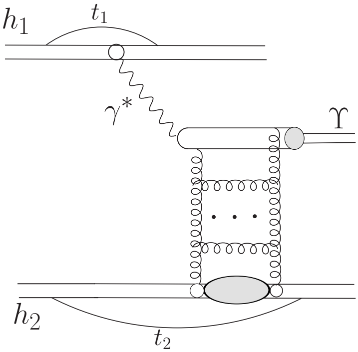
Coulomb wave function:

$$\psi_{1S}(p^2) = \frac{C_1}{\sqrt{M}} \frac{1}{(1+a_1^2 p^2)^2}, \quad \psi_{2S}(p^2) = \frac{C_2}{\sqrt{M}} \frac{\xi_0 - a_2^2 p^2}{(1+a_2^2 p^2)^3}.$$

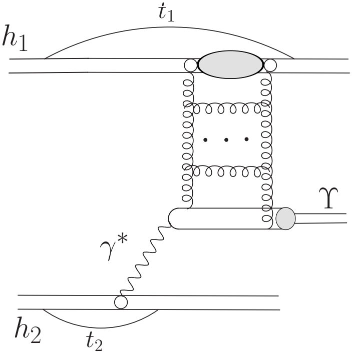
Total cross section for the $\gamma p \longrightarrow \Upsilon p$



Dominant bare mechanism for $p\bar{p} \longrightarrow p\bar{p}\ \Upsilon$

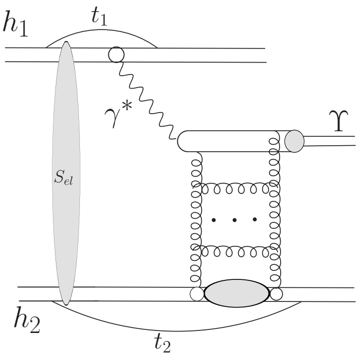


photon-pomeron

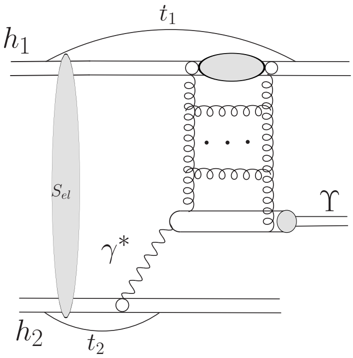


pomeron-photon

Diagram for $p\bar{p} \longrightarrow p\bar{p}\ \Upsilon$ with absorptive correction



photon-pomeron



pomeron-photon

Amplitude for $p\bar{p} \longrightarrow p\bar{p}\ \Upsilon$

Amplitude without absorption:

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

Full amplitude for $p\bar{p} \longrightarrow p\bar{p}\ \Upsilon$:

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

where

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

with $B_{el} = 17\ \mathrm{GeV}^{-2}$, $\sigma_{tot}^{pp}(s) = 76$ mb (CDF Collaboration 1994)

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

The absorptive correction for amplitude :

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

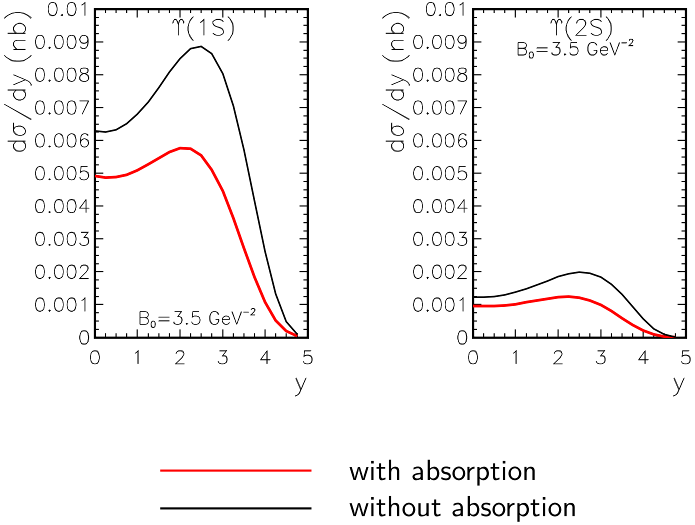
The differential cross section is given in terms of $\boldsymbol{M}$ as

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

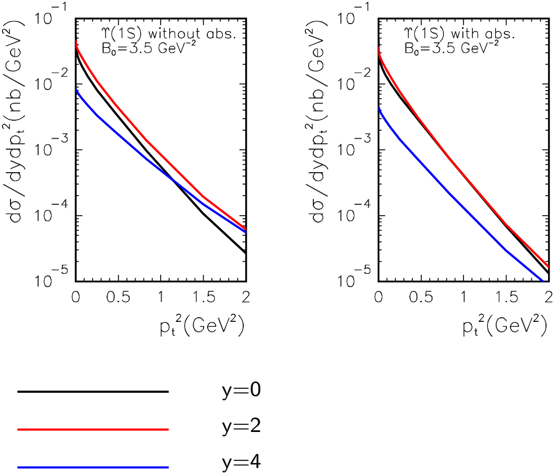
where:

- y is rapidity of the vector meson
- $t_1 \approx -\mathbf{p}_1^2$, $t_2 \approx -\mathbf{p}_2^2$
- ϕ is azimuthal angle between $\boldsymbol{p}_1$ and $\boldsymbol{p}_2$

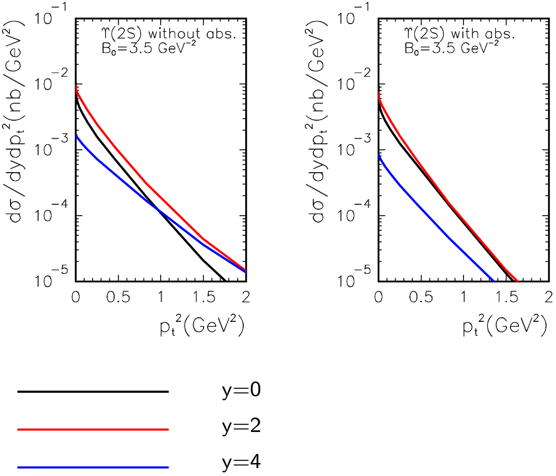
$d\sigma/dy$ for Υ(1S) and Υ(2S), W = 1960 GeV



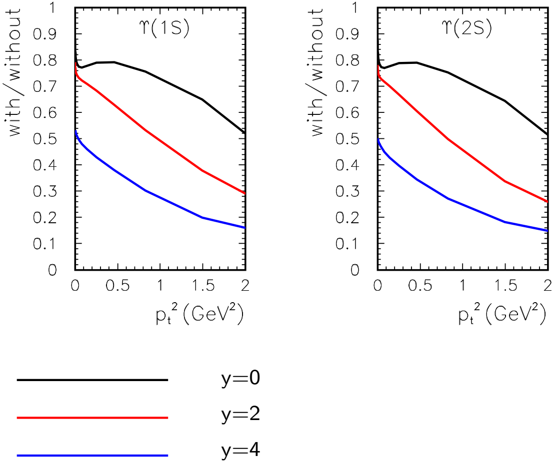
$d\sigma/dydp_t^2$ for as a function of p_t^2 for $\Upsilon(1S)$



$d\sigma/dydp_t^2$ for as a function of p_t^2 for $\Upsilon(2S)$

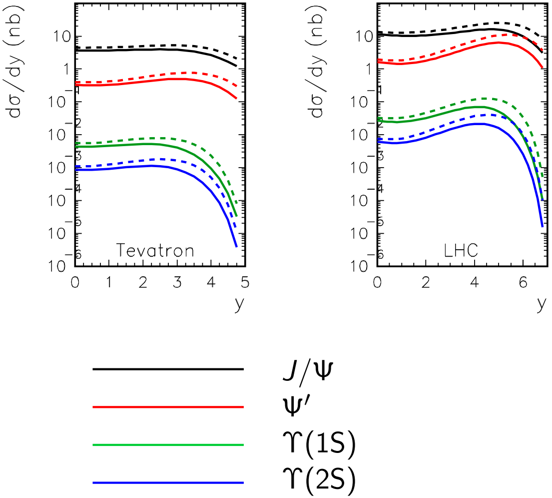


Absorption effects



The bigger rapidity $\longrightarrow$ the bigger absorption effect

$d\sigma/dy$ - J/Ψ,Ψ',Υ(1S) and Υ(2S) for Tevatron and LHC energy



Conclusions

- The results for $\gamma p \longrightarrow \Upsilon$ (1S) p production depend on the model of the wave function

- We have compared our results with a recent HERA data

- Our results are somewhat lower than the HERA data

- We have made predictions for $p\bar{p} \longrightarrow p\bar{p}\ \Upsilon$ for the Tevatron (and LHC)

- Absorptive corrections are included.Their effect depends not only total cross section, but also lead to distortions of p_t and y distributions