Exclusive photoproduction of J/Ψ in pp and $p\bar{p}$ collisions

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Workshop on Hard Diffraction at LHC, 18 - 19 October 2007, Kraków, Poland

Outline

Exclusive production of heavy vector mesons

Results for J/Ψ

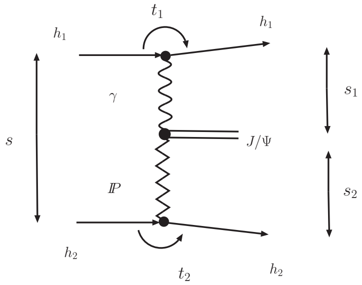
A Glimpse at Υ

Summary

W.S. & Antoni Szczurek
Exclusive Photoproduction of J/Ψ in proton–proton and proton–antiproton scattering.
Phys. Rev. D, to appear, 2007.

Exclusive Production of J/Ψ in Hadronic Collisions
Born Level Amplitudes

Photoproduction



Khoze-Martin-Ryskin '02; Klein & Nystrand '04

cross section $\sim$ nanobarns

Exclusive Production of J/Ψ in Hadronic Collisions
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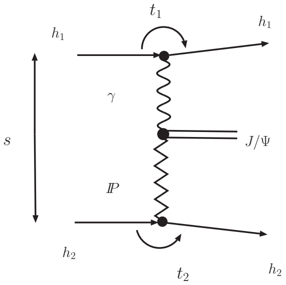

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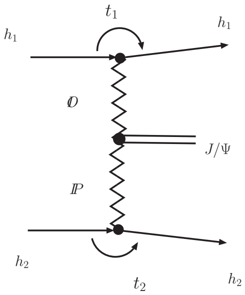
Odderon–Pomeron fusion



A. Schäfer, Mankiewicz & Nachtmann '91; Bzdak et al. '07

cross section $\sim$ 0.1÷few nanobarns (??)

Exclusive Production of J/Ψ in Hadronic Collisions
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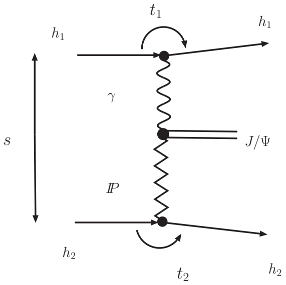

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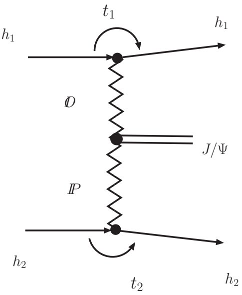

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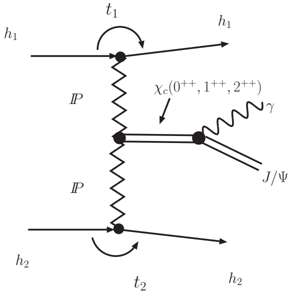
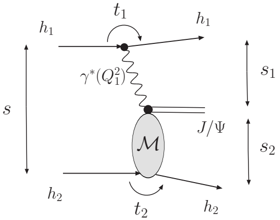
Radiative Decay of χ_c

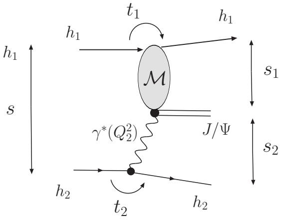


e.g. Szczurek, Pasechnik & Teryaev '07 find < 1 nb.

Exclusive Photoproduction in Hadronic Collisions

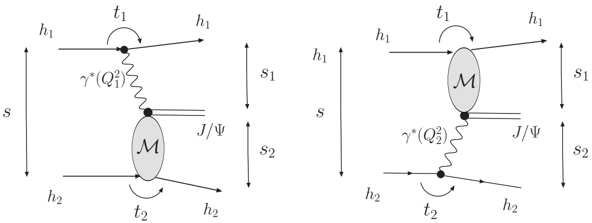
Born Level Amplitude





Exclusive Photoproduction in Hadronic Collisions

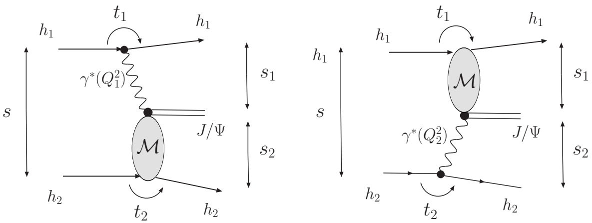
Born Level Amplitude



- $p \to \gamma p$ transition given in terms of e.m. formfactors.

Exclusive Photoproduction in Hadronic Collisions

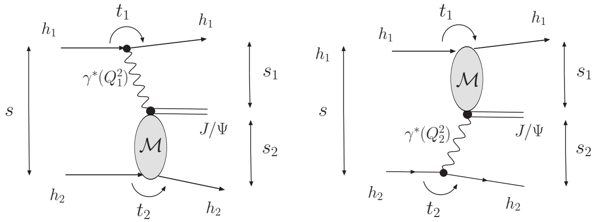
Born Level Amplitude



- $p \to \gamma p$ transition given in terms of e.m. formfactors.
- $\gamma p \to J/\Psi p$ amplitude adjusted to HERA data.
  $\mathcal{M} = (i+\rho)s\sqrt{16\pi d\sigma/dt|_{t=0}}(s/s_0)^{\alpha(t)-1}\exp(B_0 t/2)$.

Exclusive Photoproduction in Hadronic Collisions

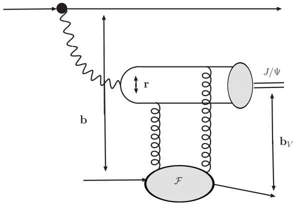
Born Level Amplitude



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

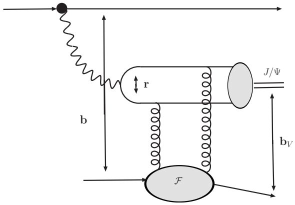
- $\boldsymbol{p}_1, \boldsymbol{p}_2 =$ transverse momenta of outgoing (anti–) protons.
- Interference induces azimuthal correlation $e_1 e_2 (\boldsymbol{p}_1 \cdot \boldsymbol{p}_2)$.

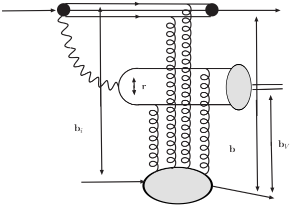
Absorptive Corrections



- Born: $\Gamma^{(0)}(\boldsymbol{r}, \boldsymbol{b}_V) = \frac{1}{2}\,\sigma(\boldsymbol{r})\,t_N(\boldsymbol{b}_V)$

Absorptive Corrections





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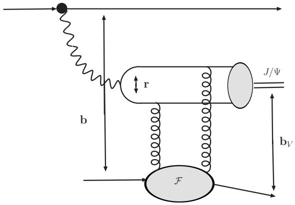
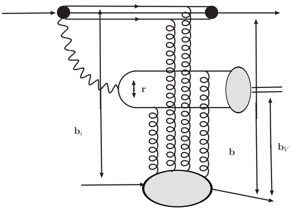
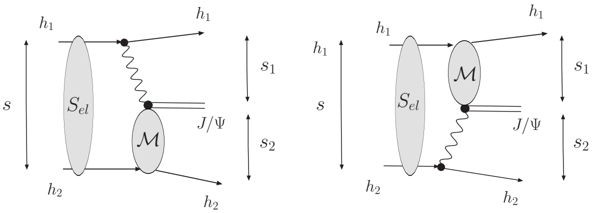




- Born: $\Gamma^{(0)}(\boldsymbol{r}, \boldsymbol{b}_V) = \frac{1}{2}\,\sigma(\boldsymbol{r})\,t_N(\boldsymbol{b}_V)$
- Absorbed:

$$
\begin{aligned}
\Gamma(\boldsymbol{r}, \boldsymbol{b}_V, \boldsymbol{b}) &= \Gamma^{(0)}(\boldsymbol{r}, \boldsymbol{b}_V) - \frac{1}{4}\sigma(\boldsymbol{r})\sigma_{qqq}(\{\boldsymbol{b}_i\})t_N(\boldsymbol{b}_V)t_N(\boldsymbol{b}) \\
&= \Gamma^{(0)}(\boldsymbol{r}, \boldsymbol{b}_V)\left(1 - \frac{1}{2}\sigma_{qqq}(\{\boldsymbol{b}_i\})t_N(\boldsymbol{b})\right) \\
&\to \Gamma^{(0)}(\boldsymbol{r}, \boldsymbol{b}_V) \cdot S_{el}(\boldsymbol{b})
\end{aligned}
$$

Absorptive Corrections



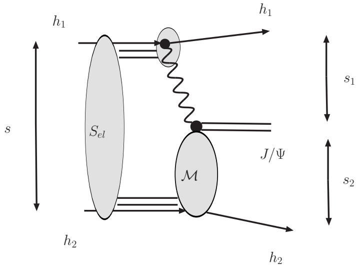
$$\begin{aligned} \boldsymbol{M}(\boldsymbol{p}_1,\boldsymbol{p}_2) &= \int \frac{d^2\boldsymbol{k}}{(2\pi)^2}\, S_{el}(\boldsymbol{k})\, \boldsymbol{M}^{(0)}(\boldsymbol{p}_1-\boldsymbol{k},\boldsymbol{p}_2+\boldsymbol{k}) \\ &= \boldsymbol{M}^{(0)}(\boldsymbol{p}_1,\boldsymbol{p}_2) - \delta\boldsymbol{M}(\boldsymbol{p}_1,\boldsymbol{p}_2)\,,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

with

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

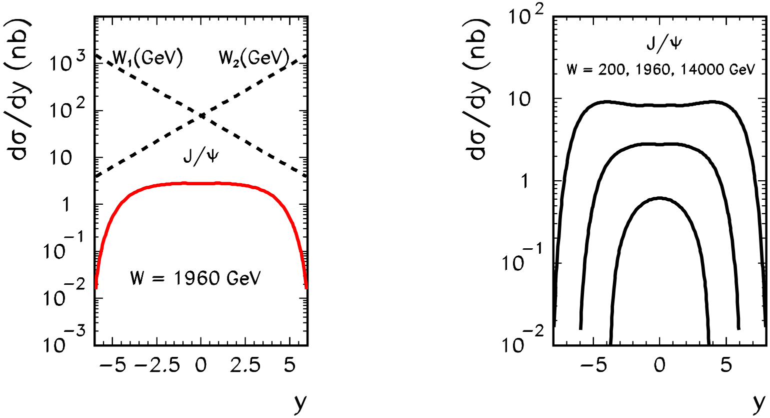
$$\delta\boldsymbol{M}(\boldsymbol{p}_1,\boldsymbol{p}_2) = \int \frac{d^2\boldsymbol{k}}{2(2\pi)^2}\, T(\boldsymbol{k})\, \boldsymbol{M}^{(0)}(\boldsymbol{p}_1-\boldsymbol{k},\boldsymbol{p}_2+\boldsymbol{k})$$

Absorptive Corrections

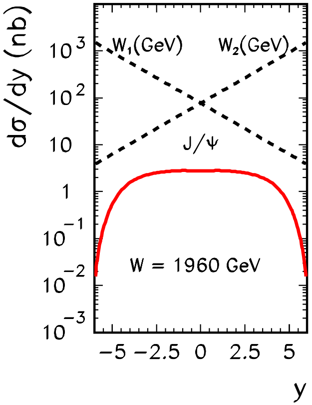


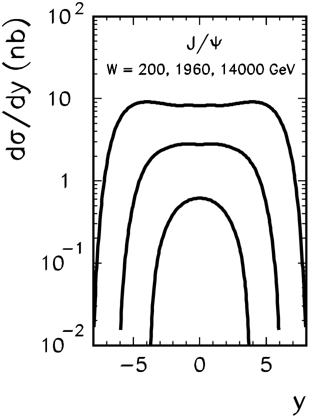
- A poor man's recipe to account for other than elastic rescatterings:
- multiply rescattering amplitude by $\lambda \sim (\sigma_{el} + \sigma_D)/\sigma_{el}$
- $\sigma_D = 2\sigma(pp \to pX) + \sigma(pp \to XY)$.

Rapidity Distribution



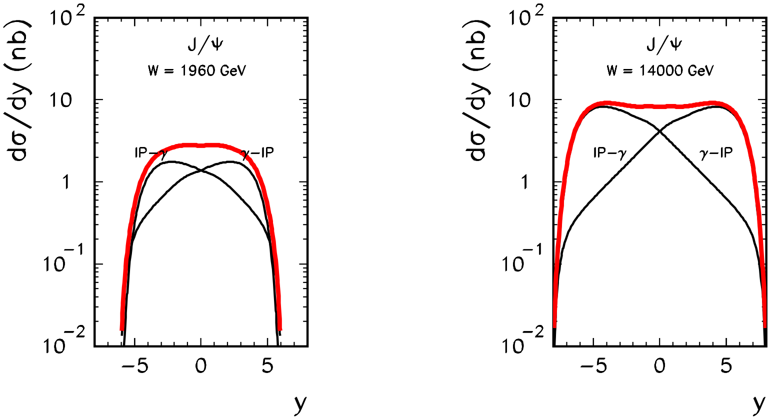
Rapidity Distribution





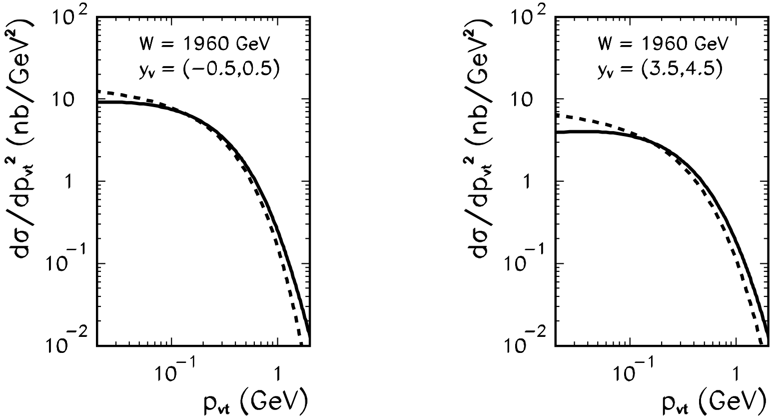
- sizeable cross sections, energy reach beyond the HERA regime

Rapidity Distribution



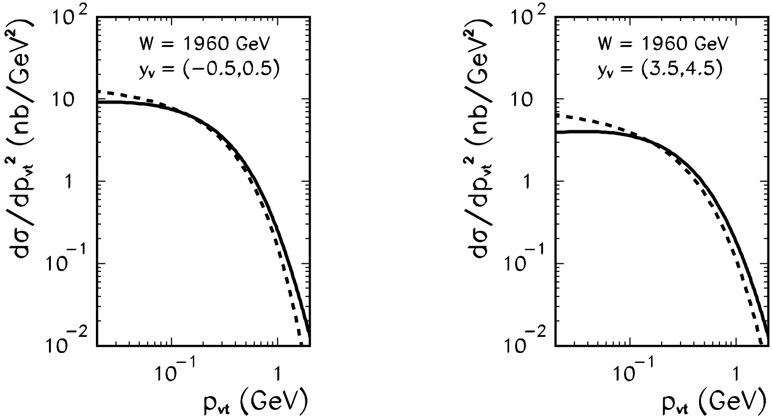
- No Absorption included → Interference cancels out.
- Separation of the two mechanisms: ***P*** propagates the larger distance in rapidity.

Transverse Momentum Distribution of J/Ψ's



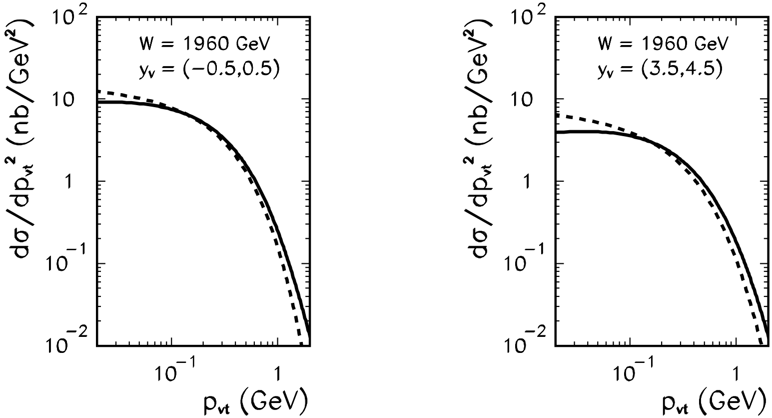
- Solid lines ↔ pp collisions. Dashed lines ↔ $p\bar{p}$ collisions.

Transverse Momentum Distribution of J/Ψ's



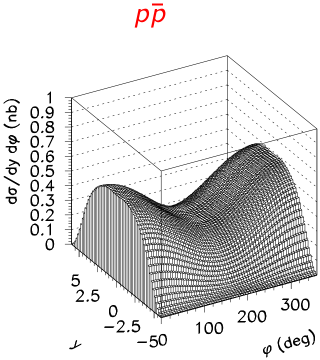
- Solid lines $\leftrightarrow$ pp collisions. Dashed lines $\leftrightarrow$ $p\bar{p}$ collisions.
- J/Ψ's are produced with very small $\boldsymbol{p}_\perp$.

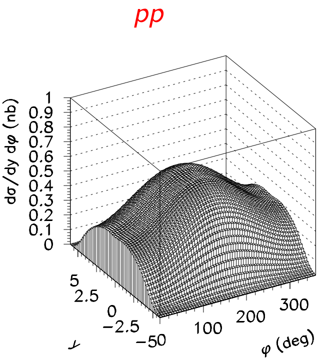
Transverse Momentum Distribution of J/Ψ's



- Solid lines ↔ pp collisions. Dashed lines ↔ $p\bar{p}$ collisions.
- J/Ψ's are produced with very small $\boldsymbol{p}_\perp$.
- Interference of $\gamma \boldsymbol{P}$ and $\boldsymbol{P}\gamma \rightarrow$ different shapes in pp and $p\bar{p}$.

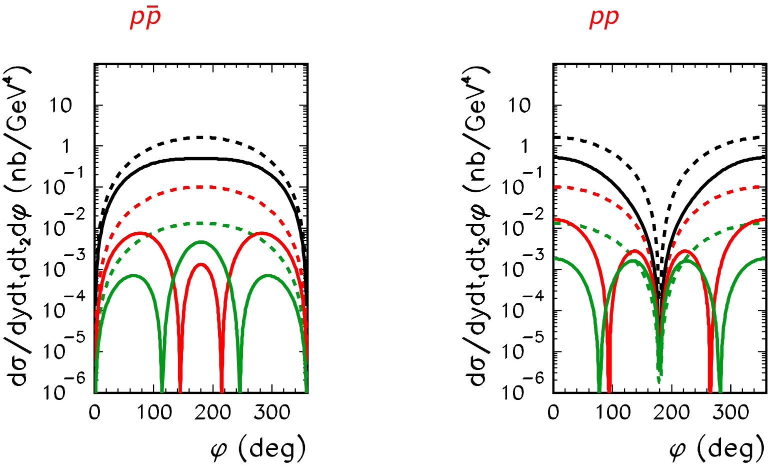
Azimuthal Angle Between Outgoing (Anti-)Protons





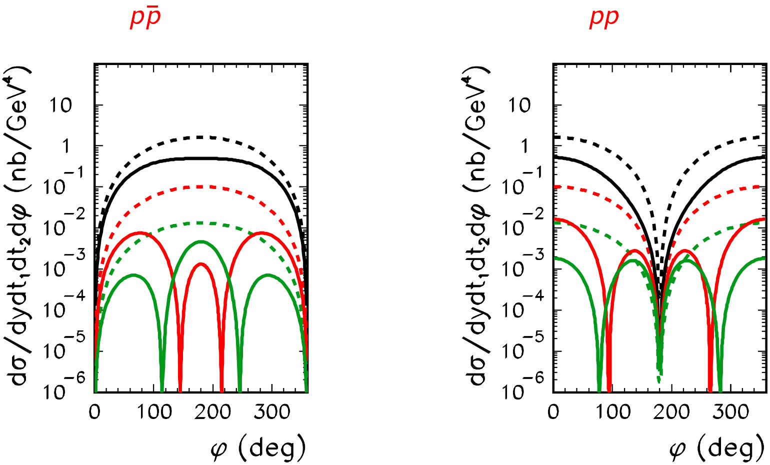
- Interference of $\gamma \boldsymbol{P}$ and $\boldsymbol{P}\gamma$ induces dependence on azimuth.
- It works in a broad range of rapidities.

Azimuthal Angle Between Outgoing (Anti-)Protons



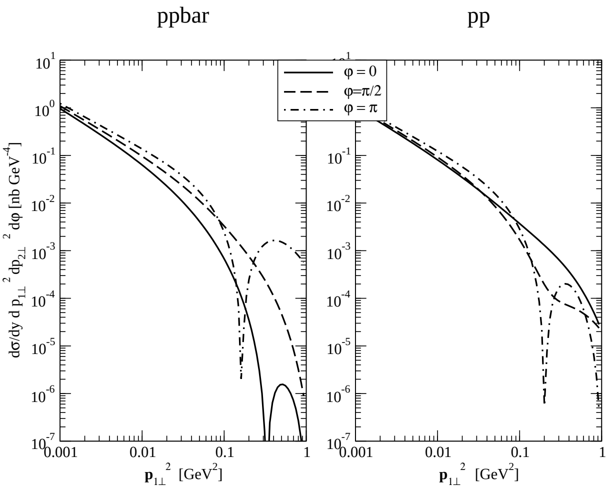
- Dashed Lines → Born Level. Solid Lines: Absorption included.

Azimuthal Angle Between Outgoing (Anti-)Protons



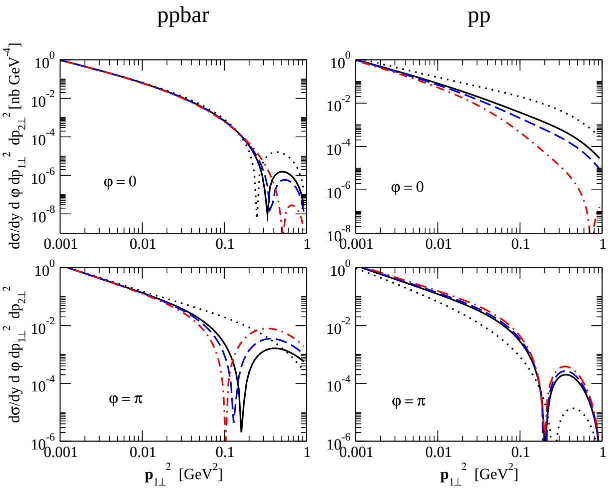
- Dashed Lines → Born Level. Solid Lines: Absorption included.
- Absorption induces a rich structure of "diffractive dips".

Fully Differential Cross Section



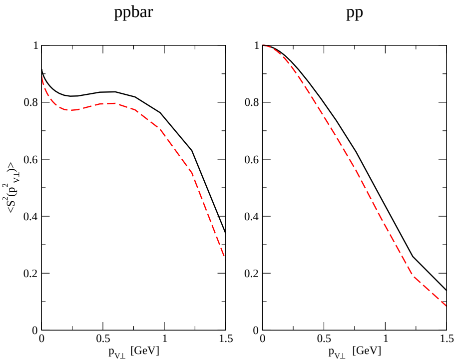
- $y = 0$; $\boldsymbol{p}_2^2 = 1$ GeV^2. Absorptive corrections included.

Varying the Strength of Absorption



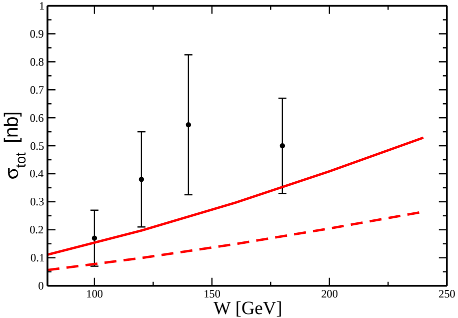
- $y = 0$; $\boldsymbol{p}_2^2 = 1$ GeV^2. Dotted: Born level.
- solid:elastic rescattering; dashed/dash-dotted: enhanced rescattering.

$p_\perp$–dependence of Absorption $< S^2(p_v) >$, y=0



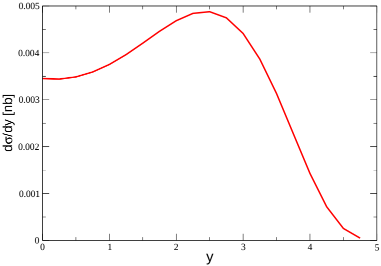
- Solid: elastic rescattering, Dashed: enhanced rescattering $\lambda = 1.5$.
- Absorptive Suppression is a strong function of $\boldsymbol{p}_{J/\Psi}$.
- Absorption leads to a small $2 \div 3\%$ charge asymmetry in rapidity distributions.

A Glimpse at Υ

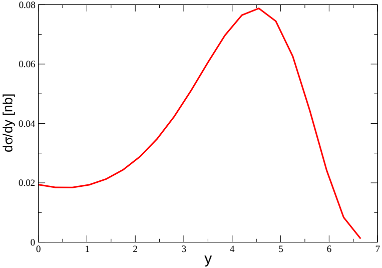


- Calculation following Ivanov-Nikolaev $k_\perp$ factorisation formalism. Data:ZEUS.
- Uncertainty due to wave–function of Υ: solid=harmonic oscillator; dashed=Coulomb–like
- effective $\Delta_{\boldsymbol{P}} \sim 0.4$

Rapidity Distributions of Υ's



$W = 1960$ GeV



$W = 14$ TeV

- No Absorptive corrections included.

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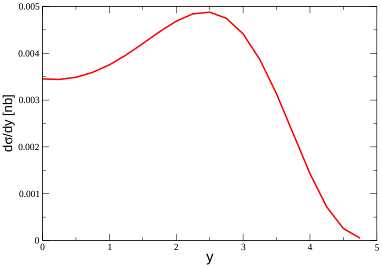
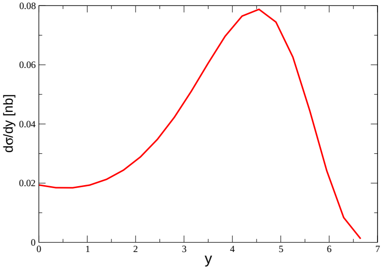


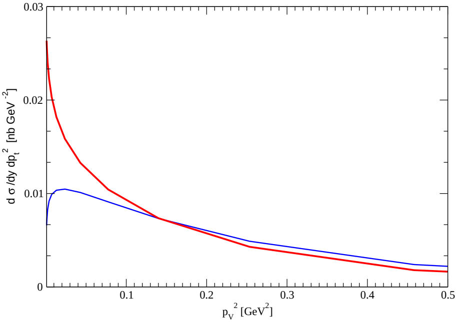
$W = 1960$ GeV



$W = 14$ TeV

- No Absorptive corrections included.
- Large effective Pomeron intercept $\longrightarrow$ peak in rapidity distribution.

Transverse Momentum of Υ's



- No Absorptive corrections included.
- Blue=pp; Red = $p\bar{p}$
- Interference rules behaviour at low momenta.

Summary

- Cross sections for exclusive photoproduction of Quarkonia at colliders are of measurable size.
- Reach in energy far beyond HERA-domain possible.
- Absorptive corrections: rich structure in distributions.

- Outlook
  - Extend to radial excitations $\psi(2S), \Upsilon(2S, 3S)$.
  - Absorptive corrections at LHC energies remain a challenge.
  - Include other 'backgrounds', feeddown from p-waves, Odderon.