

# Diffractive production of heavy vector mesons

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Diffraction for AFP meeting  
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# Outline

**Diffractive photoproduction of vector mesons**

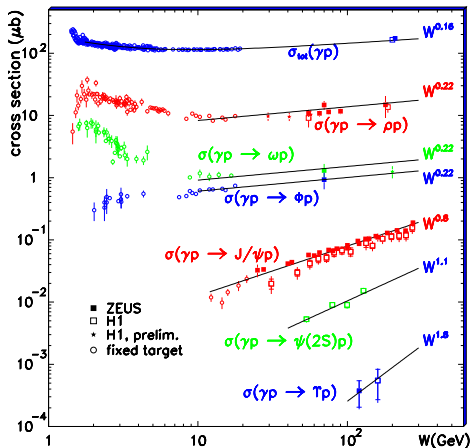
**Central Exclusive Production at Colliders (Tevatron/LHC)**

**Photoproduction on nuclei**

**Summary and outlook**

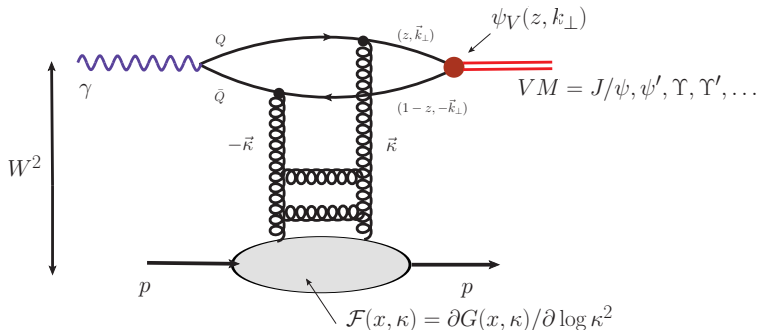
-  W.S. & Antoni Szczurek Phys. Rev. D **76**, 094014 (2007).
-  A. Rybarska, W.S. and A. Szczurek, Phys. Lett. B **668** (2008) 126.
-  A. Cisek, W.S. and A. Szczurek, Phys. Rev. D **80** (2009) 074013.
-  A. Cisek, W. S., A. Szczurek, Phys. Lett. **B690** (2010) 168-174.  
[arXiv:1004.0070 [hep-ph]].
-  A. Cisek, P. .Lebiedowicz, W. S., A. Szczurek, Phys. Rev. **D83** (2011) 114004.  
[arXiv:1101.4874 [hep-ph]].

# Total exclusive photoproduction cross sections



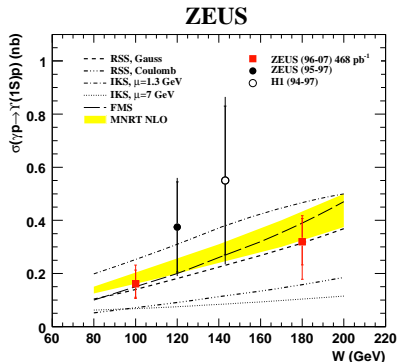
- VM photoproduction from light to heavy mesons
- the QCD Pomeron from soft to hard

# Diffractive Photoproduction $\gamma p \rightarrow Vp$



- $J/\psi = c\bar{c}$ ,  $\Upsilon = b\bar{b}$ : (almost) nonrelativistic bound states of heavy quarks. **Wavefunctions** constrained by their leptonic decay widths.
- Large quark mass  $\rightarrow$  **hard scale** necessary for (perturbative) QCD.
- $\mathcal{F}(x, \kappa) \equiv$  **unintegrated gluon density**,  $x \sim M_{VM}^2/W^2$ , constrained by HERA inclusive data.

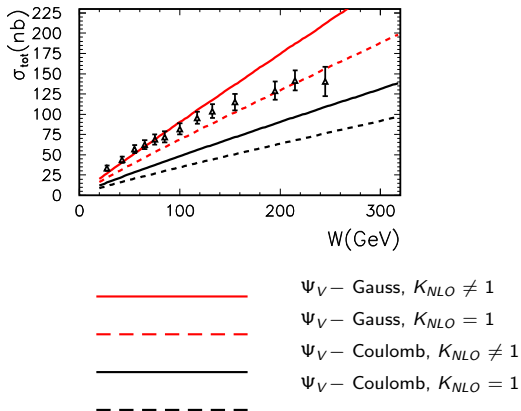
# Total cross section for $\gamma p \rightarrow \Upsilon p$



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

- experimental data → ZEUS Collaboration, Phys.Lett.B680:4-12 (2009)
- unintegrated glue from Ivanov & Nikolaev (2002).

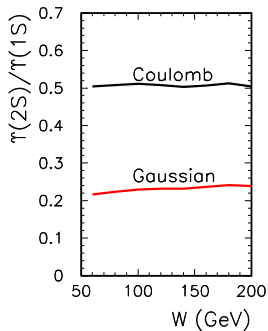
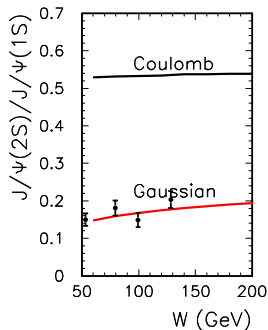
# $\gamma p \rightarrow J/\psi p$ vs ZEUS data



- dependence on wave function and LO/NLO treatment of decay width

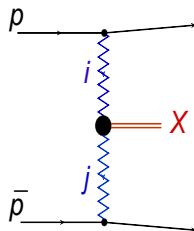
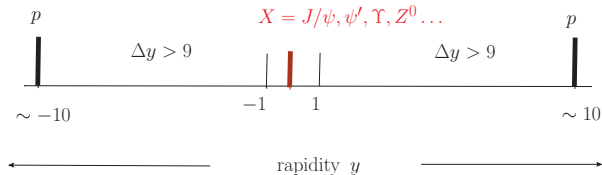
# Radial excitations

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



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

# Central Exclusive Production



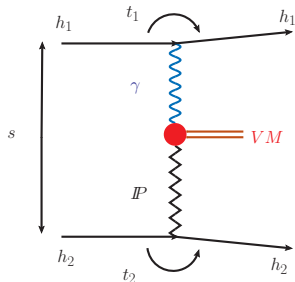
- central exclusive production  $\equiv$  very clean events.
- large rapidity gaps  $\rightarrow$  strong constraints on  $t$ -channel exchanges:
  - charge = 0, color singlet
  - spin  $J \geq 1$ : photon, Pomeron, Odderon(?).  $C_i \cdot C_j = C_X$



# Exclusive Production of $J/\psi$ , $\Upsilon$ in Hadronic Collisions

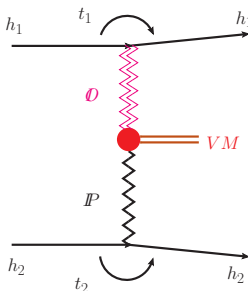
## Born Level Amplitudes

### Photoproduction



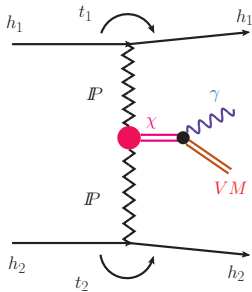
Khoze-Martin-Ryskin '02; Klein & Nystrand '04  
cross section  $\sim$  nanobarns

### Odderon-Pomeron fusion



A. Schäfer, Mankiewicz & Nachtmann '91  
cross section  $\sim 0.1 \div$  few nanobarns (??)

### Radiative Decay of $\chi$

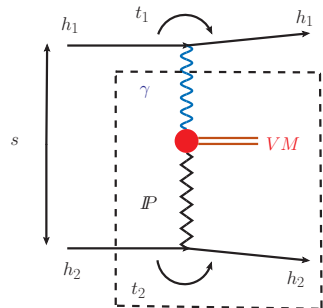


e.g. Szczurek, Pasechnik & Teryaev '07 find  
 $< 1$  nb.

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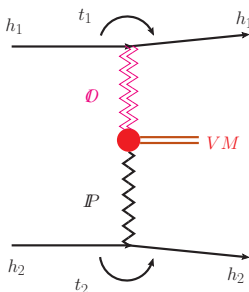
## Born Level Amplitudes

### Photoproduction



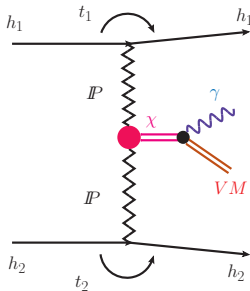
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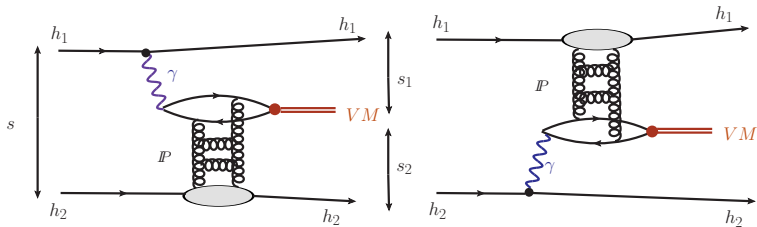
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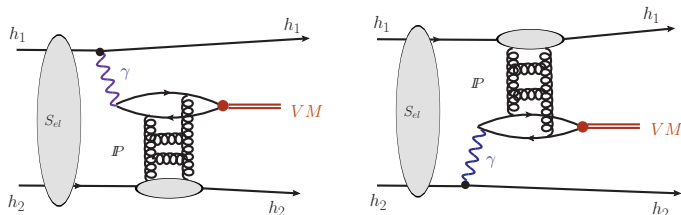
## Born Level Amplitude



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

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

# Absorptive Corrections



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

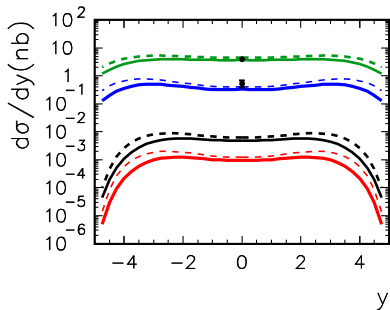
- Absorptive corrections depend on **elastic  $h_1 h_2$  Amplitude**  
→ taken from data.
- **photon pole** → **peripheral interactions** → Absorption at 20%–level.

# Rapidity distribution

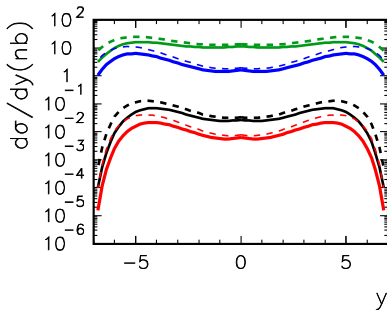
vs. data from CDF/Tevatron (2008)

dashed: no Absorption, solid: with Absorption

Tevatron:



LHC:

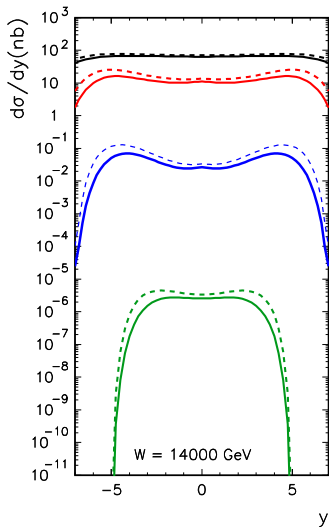
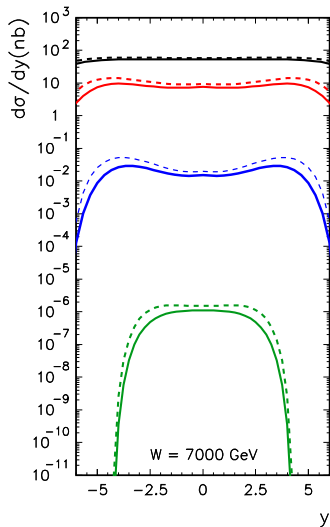


—  $J/\psi$     —  $\Psi'$     —  $\Upsilon(1S)$     —  $\Upsilon(2S)$

e.g.  $\Upsilon$  at LHC ( $\sqrt{s} = 14$  TeV):

- $y \sim 0$  probes the glue at  $x \sim 10^{-3} \div 10^{-4} \sim$  HERA
- $y \sim 5$  probes the glue at  $x \sim 10^{-5} \div 10^{-6}$

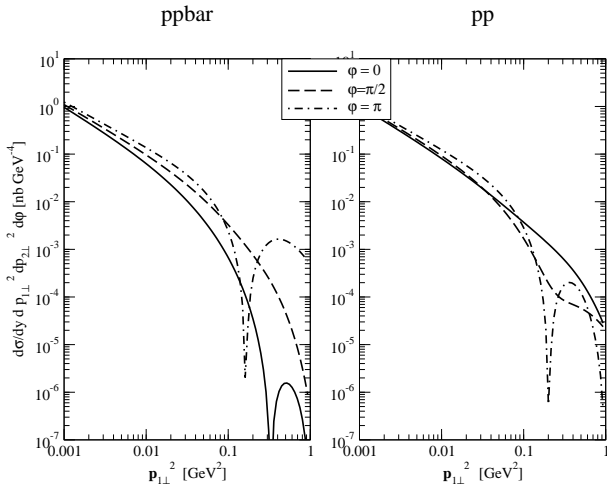
# Rapidity distributions at LHC energies



—  $\phi$       —  $J/\psi$       —  $\Upsilon$       —  $Z^0$

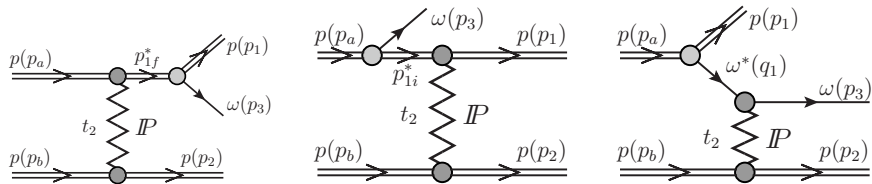
# Fully Differential Cross Section for $J/\psi$

Tevatron energy



- $y = 0$ ;  $p_2^2 = 1 \text{ GeV}^2$ . Absorptive corrections included.
- $\phi$  = azimuth between (anti-)protons → **interference effect**.
- The dip structure is **highly sensitive** to absorptive corrections.

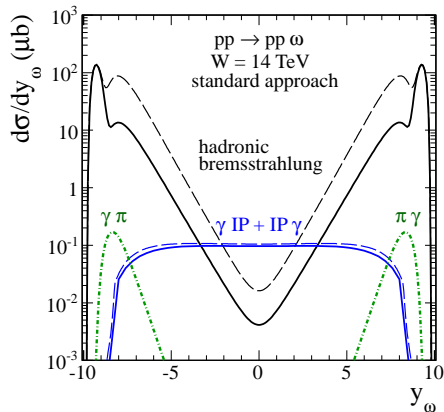
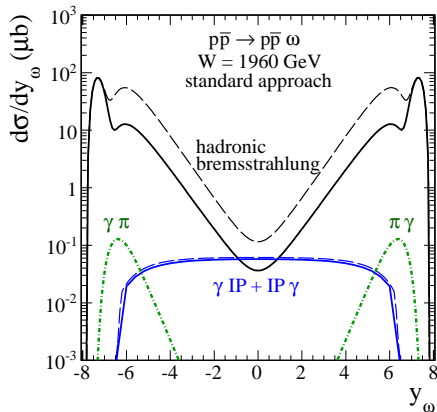
# A soft process: $pp \rightarrow pp\omega$



- "bremsstrahlung"-type mechanism contributes in proton fragmentation regions
- $t$ -channel exchange becomes reggeized
- subleading Regge pole, but **large**  $\omega NN$  coupling

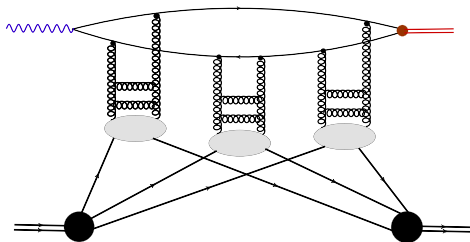
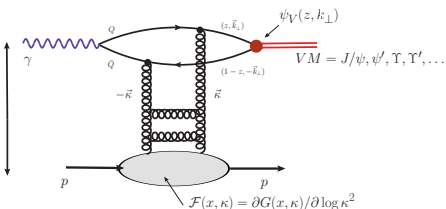


# A soft process: $pp \rightarrow pp\omega$



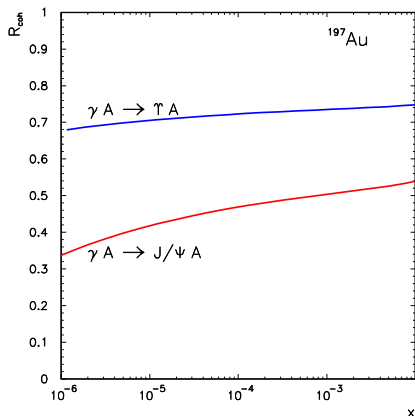
- dashed: without absorption, solid: with absorption
- need to go to very large energies to "dig out" photoproduction.

# VM photoproduction from nucleon to nucleus:



- large quark mass provides a hard scale for production of  $J/\Psi$ ,  $\Upsilon$
- for heavy nuclei rescattering/absorption effects are enhanced by the large nuclear size
- the final state might as well be a (virtual) photon (total photoabsorption cross section) or a  $q\bar{q}$ -pair (inclusive low-mass diffraction).

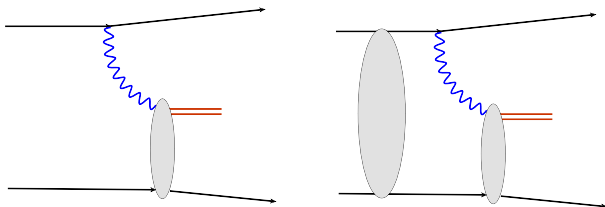
# Coherent diffractive production of $J/\psi$ , $\Upsilon$ on $^{208}\text{Pb}$



- Ratio of coherent production cross section to impulse approximation

$$R_{\text{coh}}(W) = \frac{\sigma(\gamma A \rightarrow VA; W)}{\sigma_{IA}(\gamma A \rightarrow VA; W)}, \quad \sigma_{IA} = 4\pi \int d^2\mathbf{b} T_A^2(\mathbf{b}) \frac{d\sigma(\gamma N \rightarrow VN)}{dt} \Big|_{t=0}$$

# Absorption corrected flux of photons



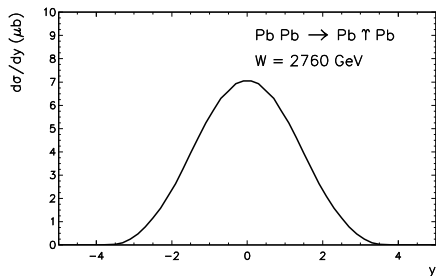
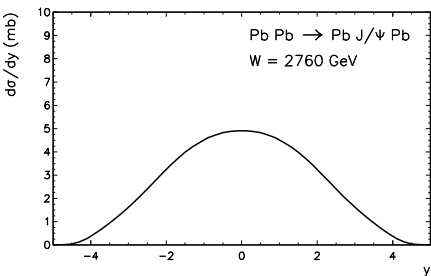
$$\sigma(A_1 A_2 \rightarrow A_1 A_2 f; s) = \int d\omega \frac{dN_{A_1}^{\text{eff}}(\omega)}{d\omega} \sigma(\gamma A_2 \rightarrow f A_2; 2\omega\sqrt{s}) + (1 \leftrightarrow 2)$$

$$dN^{\text{eff}} = \int d^2\mathbf{b} S_{el}^2(\mathbf{b}) dN(\omega, \mathbf{b})$$

- $dN(\omega)$  = Weizsäcker-Williams flux
- **survival probability:**

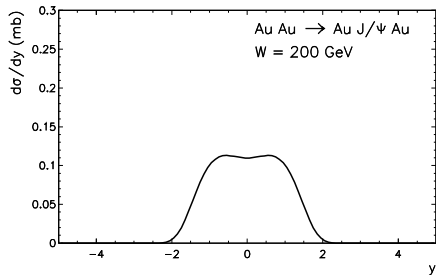
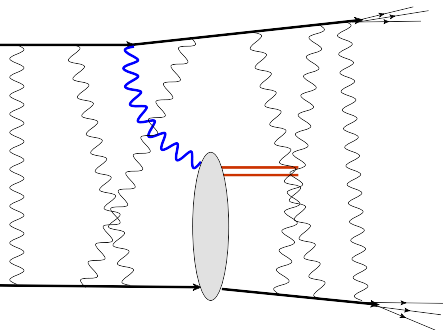
$$S_{el}^2(\mathbf{b}) = \exp\left(-\sigma_{NN} T_{A_1 A_2}(\mathbf{b})\right) \sim \theta(|\mathbf{b}| - (R_1 + R_2))$$

# Coherent exclusive production in AA: rapidity distributions



- left column:  $J/\psi$ , right column:  $\Upsilon$

# Few-neutron topological cross sections



$$d\sigma(AA \rightarrow V(Xn)(Yn)) = \int d^2\mathbf{b} d\sigma(AA \rightarrow VAA; \mathbf{b}) \times P(AA \rightarrow (Xn)(Yn); \mathbf{b})$$

- for the integrated case Klein and Nystrand estimate a suppression of 0.55
- exp. result: [PHENIX Collab. \(2009\)](#):

$$\frac{d\sigma(AuAu \rightarrow J/\psi Xn)}{dy}(y = 0) = 76 \pm 33 \pm 11 \mu b$$

# Summary

- In photoproduction of heavy quarkonia, the large quark mass ensures dominance of small dipoles.
- a sensitive probe of the (unintegrated) gluon distribution of the target.
- Odderon searches: measure  $t$  or  $p_{\perp}$ -distributions.
- Cross sections for exclusive photoproduction of Quarkonia at colliders are of measurable size. Theory works at Tevatron energies.
- At the LHC, a reach in energy beyond the HERA-domain possible.  
→ **Study the very small- $x$  gluon distribution.**
- heavy nuclei are of special interest in view of the scarcity of probes of the nuclear glue. Here saturation effects are enhanced by the nuclear size.