Central exclusive photoproduction at the LHC

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Outline

Central Exclusive Production at Colliders (Tevatron/LHC)

Results for $J/\psi, \psi', \Upsilon, \Upsilon', Z^0$ in $\gamma p \to Vp$ and $h_1 h_2 \to h_1 V h_2$

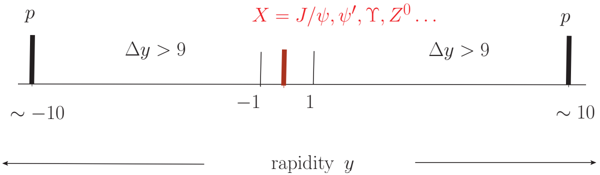
Summary

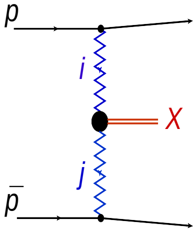
W.S. & Antoni Szczurek
Phys. Rev. D **76***:094014 (2007)*

Anna Rybarska, W.S. & Antoni Szczurek,
Phys. Lett. B **668***, 126 (2008)*

Anna Cisek, W.S. & Antoni Szczurek,
arXiv:0906.1739

Central Exclusive Production



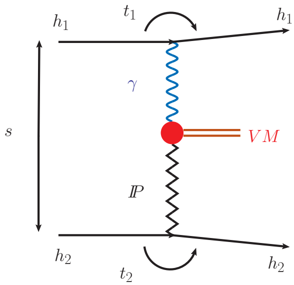


- central exclusive production $\equiv$ very clean events.
- large rapidity gaps $\rightarrow$ strong constraints on t–channel exchanges: charge $= 0$, color singlet, spin $J \geq 1$: photon,Pomeron,Odderon(?). $C_i \cdot C_j = C_X$
- for $i = j =$ Pomeron, we can have X=Higgs.
- FP420 proposes extensions to CMS,Atlas; also activity in ALICE collab. First results from CDF/Tevatron for $X = J/\psi, \psi'$.

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

Born Level Amplitudes

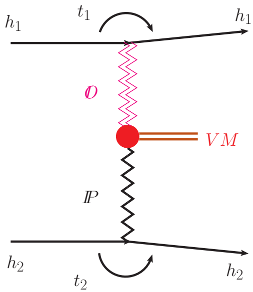
Photoproduction



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

cross section $\sim$ nanobarns

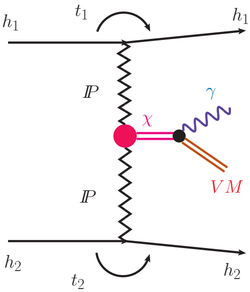
Odderon–Pomeron fusion



A. Schäfer, Mankiewicz & Nachtmann '91

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

Radiative Decay of χ



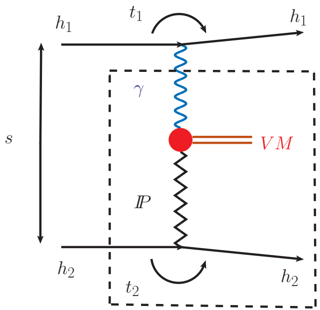
e.g. Szczurek, Pasechnik & Teryaev '07

find < 1 nb.

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

Born Level Amplitudes

Photoproduction



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

cross section $\sim$ nanobarns

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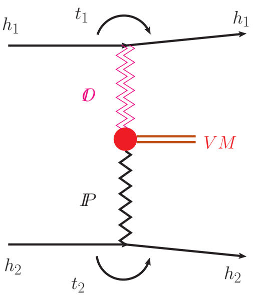

A. Schäfer, Mankiewicz & Nachtmann '91; Bzdak et al. '07

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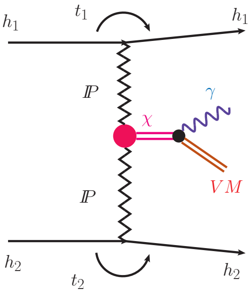
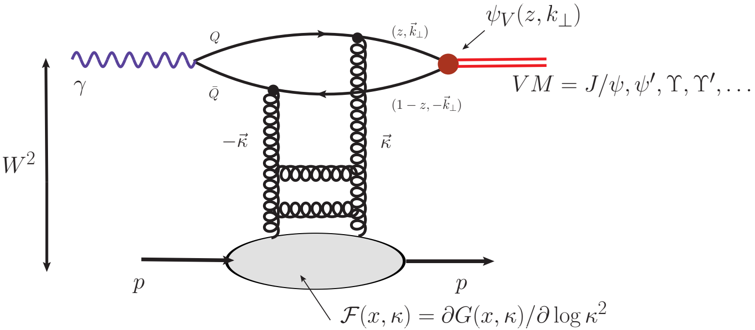
Radiative Decay of χ



e.g. Szczurek, Pasechnik & Teryaev '07

find < 1 nb.

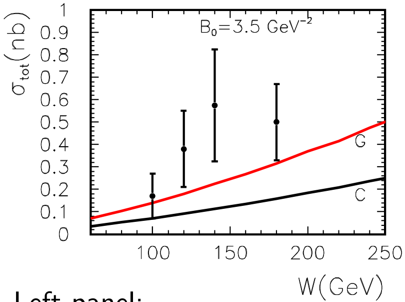
Diffractive Photoproduction $\gamma p \to Vp$ in QCD

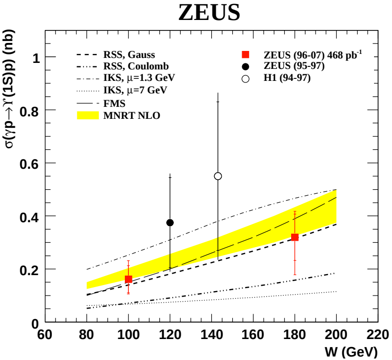


- $J/\psi = c\bar{c}$, $\Upsilon = b\bar{b}$: (almost) nonrelativistic bound states of heavy quarks. Wavefunctions constrained by their leptonic decay widths.
- Large quark mass $\to$ hard scale necessary for (perturbative) QCD.
- $\mathcal{F}(x, \kappa) \equiv$ unintegrated gluon density, $x \sim M_{VM}^2/W^2$,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

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

Theory vs. ZEUS data (2009)



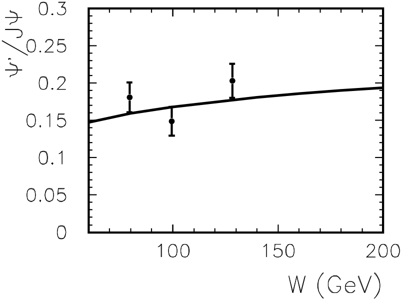


- Left panel:
  - Red: Gaussian type wavefunction
  - Black: Coulomb type wavefunction (power-law tail).
- Right panel:
  - data released by ZEUS (arXiv:0903.4205).

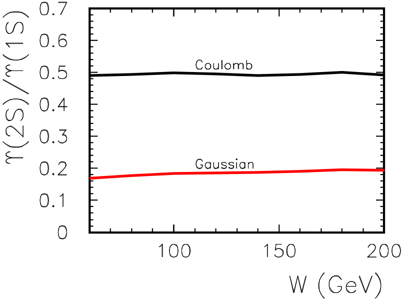
Radial excitations

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

$HERA(H1, 2002), \psi'(2S)/J/\psi$



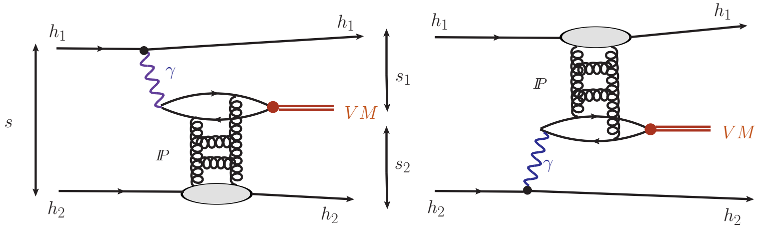
$\Upsilon(2S)/\Upsilon(1S)$



- suppression of 2S/1S due to node in the 2S wavefunction.
- strong dependence on the wavefunction.

Exclusive Photoproduction in Hadronic Collisions

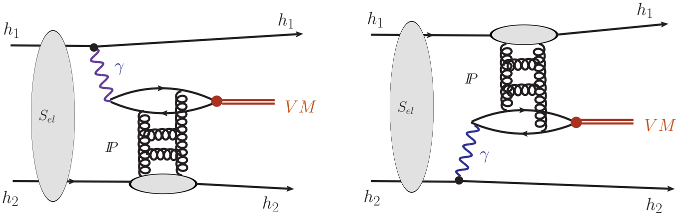
Born Level Amplitude



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

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

Absorptive Corrections



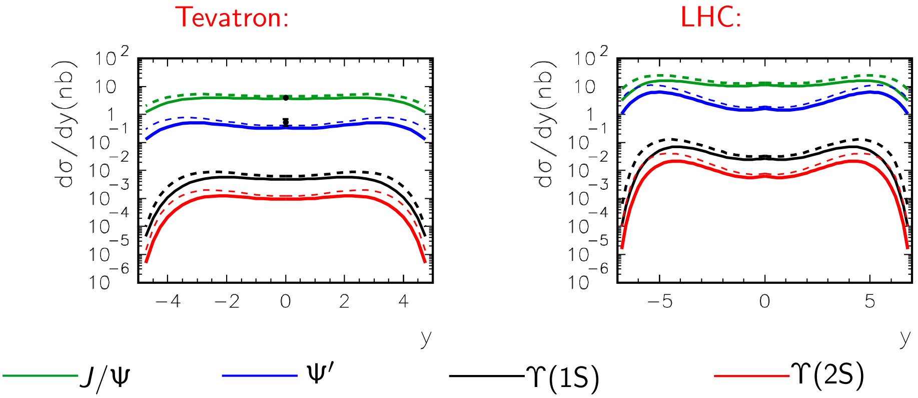
$$\boldsymbol{M}(\boldsymbol{p}_1, \boldsymbol{p}_2) = \int \frac{d^2\boldsymbol{k}}{(2\pi)^2} S_{el}(\boldsymbol{k}) \, \boldsymbol{M}^{(0)}(\boldsymbol{p}_1 - \boldsymbol{k}, \boldsymbol{p}_2 + \boldsymbol{k})$$

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

Rapidity distribution

vs. data from CDF/Tevatron (2008)

dashed: no Absorption, solid: with Absorption



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

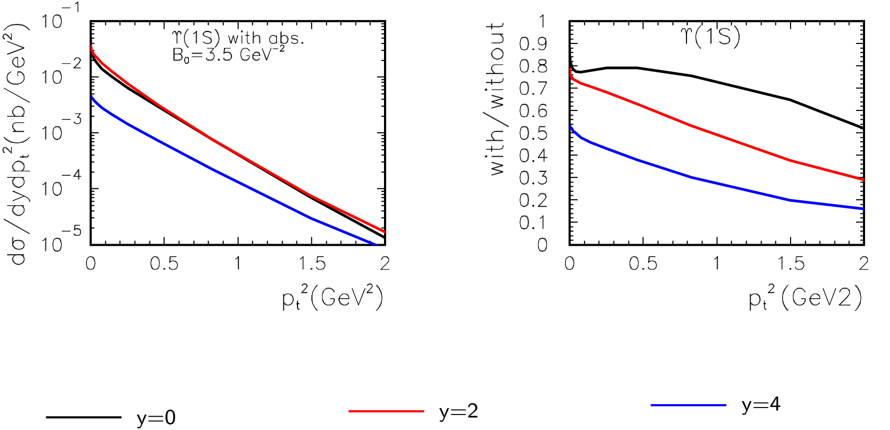
- $y \sim 0$ probes the glue at $x \sim 10^{-3} \div 10^{-4}$ $\sim$ HERA
- $y \sim 5$ probes the glue at $x \sim 10^{-5} \div 10^{-6}$

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

Tevatron energy

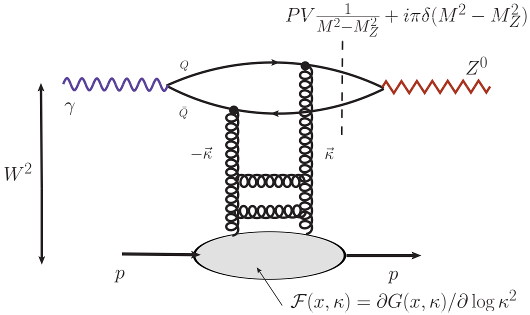
Tevatron energy

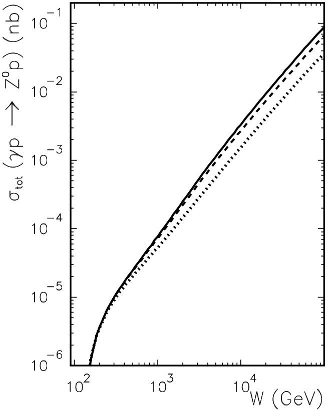
Absorption effect:



- Right panel: $d\sigma$(with Abs.)/ $d\sigma$(without Abs.).
- Absorption is a strong function of y and p_t.

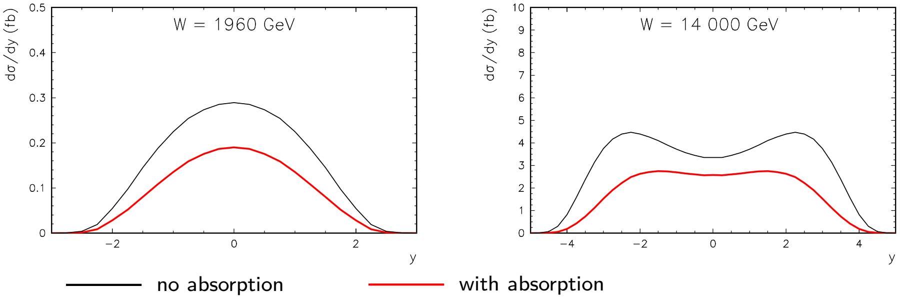
$\gamma p \longrightarrow pZ^0$





- additional real part from cut through $q\bar{q}$–state.
- $x = M_Z^2/W^2$ – small ? $\rightarrow$ skewedness, $q\bar{q}$ exchanges?
- right panel: total cross section for 3,4,5 flavors.

$pp \longrightarrow pZ^0p$



- tiny cross sections: CDF upper bound $\sim 1\,\text{pb}$.
- larger longitudinal momentum transfers $\longrightarrow$ less peripheral collisions, stronger absorption.
- measurement possible at LHC ?
- not the prime candidate for a calibration process.

Summary/Outlook

- Cross sections for exclusive photoproduction of Quarkonia at colliders are of measurable size.
- Good agreement with first Tevatron data $\rightarrow$ promising reactions for momentum calibration of forward detectors.
- Reach in energy far beyond HERA-domain possible.
  $\rightarrow$ Study the very small-x gluon distribution.

- *Outlook:*
  - Extension to pA and/or AA collisions
    $\rightarrow$ the small–x gluon distribution in nuclei.
  - related physics in AA collisions: $\gamma\gamma$–physics.