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 $h_1 h_2 \to h_1 Vh_2$

Summary

W.S. & Antoni Szczurek

Anna Rybarska, W.S. & Antoni Szczurek,

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 $i = j = \text{Pomeron}$, we can have $X = \text{Higgs}$.
- FP420 proposes extensions to CMS, Atlas; also activity in ALICE collab.
  First results from CDF/Tevatron for $X = J/\psi, \psi'$. 

\[ X = J/\psi, \psi', \Upsilon, Z^0 \ldots \]

\[ \Delta y > 9 \]

\[ \sim -10 \quad -1 \quad 1 \quad \sim 10 \]

\[ \rho \]

\[ p \rightarrow i \quad X \quad j \quad p \]
Exclusive Production of $J/\psi$, $\Upsilon$ in Hadronic Collisions

Born Level Amplitudes

Photoproduction

$$s \quad h_1 \quad t_1 \quad h_1 \quad VM$$

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

Cross section $\sim$ nanobarns

Odderon–Pomeron fusion

$$s \quad h_1 \quad t_1 \quad h_1 \quad VM$$

(A. Schäfer, Mankiewicz & Nachtmann '91)

Cross section $\sim 0.1 \div$ few nanobarns (??)

Radiative Decay of $\chi$

$$s \quad h_1 \quad t_1 \quad h_1 \quad IP$$

(e.g. Szczurek, Pasechnik & Teryaev '07)

Find $< 1$ nb.
Exclusive Production of $J/\psi$, \( \Upsilon \) in Hadronic Collisions

Born Level Amplitudes

**Photoproduction**

Born level amplitudes have been examined for the exclusive production of $J/\psi$, $\Upsilon$ in hadronic collisions. The Born level amplitudes for photoproduction can be expressed as:

$$\gamma \rightarrow IP \rightarrow VM \rightarrow h_1 h_2$$

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

cross section $\sim$ nanobarns

**Odderon–Pomeron fusion**

Odderon–Pomeron fusion amplitudes have been studied as well. The fusion amplitudes can be expressed as:

$$IP \rightarrow VM \rightarrow h_1 h_2$$

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

cross section $\sim 0.1 \div \text{few nanobarns}$

**Radiative Decay of $\chi$**

The radiative decay of $\chi$ in hadronic collisions has also been considered. The decay amplitudes can be expressed as:

$$\chi \rightarrow IP \gamma \rightarrow VM \rightarrow h_1 h_2$$

e.g. Szczurek, Pasechnik & Teryaev '07

find $< 1$ nb.
Diffractive Photoproduction $\gamma p \rightarrow Vp$ 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 $\rightarrow$ hard scale necessary for (perturbative) QCD.
- $F(x, \kappa) \equiv$ unintegrated gluon density, $x \sim M_{VM}^2/W^2$, constrained by HERA inclusive data.
Total cross section for $\gamma p \rightarrow \Upsilon p$

Theory vs. ZEUS data (2009)

**Left panel:**
- Red: Gaussian type wavefunction
- Black: Coulomb type wavefunction (power-law tail).

**Right panel:**
Radial excitations

\[ \frac{\sigma(\gamma p \rightarrow V(2S)p)}{\sigma(\gamma p \rightarrow V(1S)p)} : \]

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

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

**Born Level Amplitude**

\[ \mathcal{M}(\mathbf{p}_1, \mathbf{p}_2) = e_1 \frac{2}{z_1} \frac{\mathbf{p}_1}{t_1} \mathcal{F}_{\lambda'_1 \lambda_1}(\mathbf{p}_1, t_1) \mathcal{M}_{\gamma^* h_2 \rightarrow \nu h_2}(s_2, t_2, Q^2_1) \]

\[ + e_2 \frac{2}{z_2} \frac{\mathbf{p}_2}{t_2} \mathcal{F}_{\lambda'_2 \lambda_2}(\mathbf{p}_2, t_2) \mathcal{M}_{\gamma^* h_1 \rightarrow \nu h_1}(s_1, t_1, Q^2_2). \]

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

\[ M(p_1, p_2) = \int \frac{d^2 k}{(2\pi)^2} S_{el}(k) M^{(0)}(p_1 - k, p_2 + k) \]

- 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

Tevatron:

LHC:

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 $x \sim 10^{-5} \div 10^{-6}$
$d\sigma / dy dp_t^2$ as a function of $p_t^2$ for $\Upsilon(1S)$

Tevatron energy

Right panel: $d\sigma_{\text{with Abs.}} / d\sigma_{\text{without Abs.}}$.

Absorption is a strong function of $y$ and $p_t$.
\[ \gamma p \rightarrow pZ^0 \]

\[ \mathcal{F}(x, \kappa) = \partial G(x, \kappa) / \partial \log \kappa^2 \]

- additional real part from cut through \( q\bar{q} \)-state.
- \( x = M_Z^2 / W^2 \) – small? → skewedness, \( q\bar{q} \) exchanges?
- right panel: total cross section for 3,4,5 flavors.
$pp \rightarrow pZ^0 p$

- tiny cross sections: CDF upper bound $\sim 1 \text{ pb}$.
- larger longitudinal momentum transfers $\rightarrow$ less peripheral collisions, stronger absorption.
- measurement possible at LHC?
- not the prime candidate for a calibration process.
Cross sections for exclusive photoproduction of Quarkonia at colliders are of measurable size.

Good agreement with first Tevatron data → promising reactions for momentum calibration of forward detectors.

Reach in energy far beyond HERA-domain possible. → Study the very small-x gluon distribution.

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