Exclusive Production of $J/\psi$ and double $J/\psi$

Tevatron and LHCb Results

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on behalf of the LHCb collaboration

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ECT* - New Observables in Quarkonium Production
Central Exclusive Production

It is a process defined as $pp \rightarrow p + X + p$ where $X$ is a *colourless central object* with the protons remaining *intact* after the interaction. Examples of mechanisms that produce pairs of *charm* quarks with the overall process being colour neutral:

- **General**
- **Photo production**
- **Double pomeron exchange**
- **QED (BG)**

Colour neutral object diagrams creating muon pairs and charmonium resonances. Note: $J/\psi \rightarrow \mu^+\mu^-$ and $\chi_c \rightarrow J/\psi\gamma$. See arXiv:1401.3288v2
Motivation

- Understanding of vacuum
- Understanding diffraction phenomena
- Good environment to search for exotica
- Gluon density function
  Photo production cross section is proportional to the gluon’s cross-section squared (currently a high uncertainty at small fractional momentum x)
The LHCb

Interaction point

Vertex detector

Beam

Tracking

Calo

Muon

300 mrad

Fully instrumented: \(2 < \eta < 5\)

Some sensitivity: \(-3.5 < \eta < -1.5\)
CEP at the LHCb
Event Selection

Use VELO information to veto non-exclusive processes:
- Precisely two forward muons.
- No backwards tracks.
- No photons.
Event Displays
For low multiplicity muon triggered events...

non-CEP

CEP

Where the coordinates \((R, \phi)\) corresponds to \(z\) and the azimuthal angle respectively. The transverse energy (in GeV) for ECAL and HCAL coloured in yellow and cyan.
$J/\psi$ and $\psi(2S)$ signal and non-resonant BG regions. The data are fitted (solid curve) with crystal ball functions for the signals and an exponential function for the non-resonant background.
$J/\psi$ and $\psi(2S)$ Inelastic Background

Signal (blue) candidates and different sources of inelastic BG (red) for $X = J/\psi$ plot (a) and $\psi(2S)$, plot (b). Feed-down (green) $\chi_c \rightarrow J/\psi \gamma$ if photon outside acceptance or undetected.
Integrated Cross-sections
See JPG 41 (2014) 055002, Table 4

LHCb measurement of integrated cross-sections, with a BR for muons in the pseudo rapidity range $2.0 < \eta < 4.5$, compared with different theory predictions.

CDF Cross-section results at $\sqrt{s} = 1.96$ TeV

\[
\left. \frac{d\sigma(J/\psi)}{dy} \right|_{y=0} = 3.92 \pm 0.25(\text{stat}) \pm 0.52(\text{syst}) \text{ nb}
\]
\[
\left. \frac{d\sigma(\psi(2S))}{dy} \right|_{y=0} = 0.53 \pm 0.09(\text{stat}) \pm 0.10(\text{syst}) \text{ nb}
\]

Differential Cross-sections

For $J/\psi$ and $\psi(2S)$

NLO agrees better than LO.
Upsilon Results

Observation of $\Upsilon(1S)$, $\Upsilon(2S)$, $\Upsilon(3S)$

NLO agrees better than LO (again).
Results of $J/\psi$ photo-production across wide range of energies and colliders. The $W_+$ and $W_-$ solutions allow to compare LHCb results to HERA.
Double $J/\psi$ production through Double Pomeron Exchange
Double $J/\psi$ production through Double Pomeron Exchange

Why is it important?

▶ Study the role of the Pomeron
▶ Presents an opportunity to search for exotic states in a low-background experimental environment
▶ Compare mass spectrum of exclusive production where DPS is almost negligible

**Note:** The case of $\gamma\gamma \rightarrow J/\psi J/\psi$ It’s been widely studied, see A. Cisek, W. Schäfer, and A. Szczurek, Phys. Rev. C86 (2012) 014905, arXiv:1204.5381.
Exclusive Double $J/\psi$ Results

Invariant mass of the four-muon (left) and di-muon systems (right).
Double $J/\psi$ Cross-section

Differential cross-sections of exclusive (left) and inclusive (right) double $J/\psi$.

Integrated (Exclusive) cross-section LHCb results in $2 < \eta < 4.5$ range:

\[
\sigma^{J/\psi J/\psi} = 58 \pm 10^{\text{(stat)}} \pm 6^{\text{(syst)}} \text{ pb}
\]

\[
\sigma^{J/\psi \psi(2S)} = 63^{+27}_{-18}^{\text{(stat)}} \pm 10^{\text{(syst)}} \text{ pb}
\]

\[
\sigma^{\psi(2S) \psi(2S)} < 247 \text{ pb}
\]
CEP of $\pi^+\pi^-$ at Tevatron CDF

Phys. Rev. D91 (2015) 9, 091101  
arXiv:1502.01391

The $\pi^+\pi^-$ production is dominated by double pomeron exchange.

Invariant mass of a pion pion system. The peak in the 1000-1500 MeV/$c^2$ region could be associated with the $f_2(1270)$ ($2^{++}$) and $f_0(1370)$ ($0^{++}$) resonances.
Prospects
HeRSCheL: High Rapidity Shower Counters for LHCb

- Extension of the upstream and downstream coverage LHCb in a very forward region $5 < \eta < 8$.
- Additionally the low pileup in Run II favours CEP studies.
- On 21 May, 13 TeV centre-of-mass energy collisions were performed for the first time.

https://twiki.cern.ch/twiki/bin/view/LHCb/LHCbHerschel
Prospects
HERSCHEL Extra Rapidity Coverage

LHCb coverage (approximate) + Herschel extension

Single Diffraction
Double Diffraction
Central Exclusive (elastic)
Central Exclusive (inelastic)
Elastic Scattering

CEP events: Trigger on and reconstruct a handful of particles (muons, hadrons, photons..)

CEP backgrounds: reject events with additional particles, usually very forward

After D. d’Enterria arxiv 0806.0883 and http://cern.ch/dde
Prospects

\(X(3872)\) studies

- Study of other charmonium resonances, i.e. \(X(3872)\) already observed inclusively, \(J^{PC}\) shown to be \(1^{++}\) by LHCb (arXiv:1302.6269). Is it possible to produce it exclusively?

Prospects

$D\bar{D}$ studies

- Studies on inclusive charm pair production have been performed by LHCb and its results compared with different QCD theoretical frameworks (DGLAP, CCFM).

![Graph showing comparison of $1/N dN/d(\phi)$ for different models: LHCb, PYTHIA, CASCADE, CASCADEnk, POWHEG.]

- Exclusive $D\bar{D}$ production studies are already taking place but combinatoric backgrounds are still large.

- CEP complements the standard QCD production mechanism. However, relative rates between CEP/no-CEP processes are expected to be different.
Summary

▶ CEP provides a clean (controlled) environment to test QCD predictions and search for complex effects i.e. exotica.

▶ Several CEP measurements performed by the LHCb:
  ▶ $J/\psi$ and $\psi(2S)$
  ▶ $\Upsilon(1S), \Upsilon(2S), \Upsilon(3S)$
  ▶ $J/\psi, \psi(2S)$ and $J/\psi, J/\psi$

▶ And by Tevatron experiments (D0, CDF)
  ▶ $J/\psi$ and $\psi(2S) \rightarrow$ fist (CEP) observation in hadron collisions (arXiv:0902.1271v4 2009)
  ▶ $\pi^+\pi^-$

▶ Herschel will allow us to significantly reduce inelastic backgrounds in future CEP studies
Thank you