Central Exclusive Production of J/ψ and ψ(2S) at 13 TeV in pp collisions at LHCb

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Signal: Central system with rapidity gaps down to proton

Background: Proton dissociation; finite detector acceptance
• Ability to trigger on low $p_T$ objects ($p_T > 400$ MeV)
• Low(er) number of visible interactions cf. ATLAS, CMS
• Forward coverage allows high $W$ and low gluon $x$ to be probed in photoproduction

(see also R. McNulty’s talk in this session)
Smaller uninstrumented region in Run 2
LHCb central exclusive measurements:

### Run 1:
- **J/ψ, ψ(2S) photoproduction**
  - Data: 7 TeV pp data
  - Reference: JPG 41 (2014) 055002
- **Upsilon photoproduction**
  - Data: 7 and 8 TeV pp data
  - Reference: JHEP 1509 (2015) 084
- **Double charmonium production**
  - Data: 7 and 8 TeV pp data
  - Reference: JPG 40 (2013) 045001
- **κc production**
  - Data: 7 TeV pp data
  - Reference: LHCb-CONF-2011-022
- **QED dimuon production**
  - Data: 7 TeV pp data
  - Reference: LHCb-CONF-2011-022

### Run 2:
- **J/ψ, ψ(2S) photoproduction**
  - Data: 13 TeV pp data
- **Coherent J/ψ production**
  - Data: 5 TeV PbPb data
  - Reference: LHCb-CONF-2018-003
Run 2 J/ψ and ψ(2S) photoproduction results

• Determining the exclusive fraction
• Selection
• Sample composition
• Production cross-section
• Photo-production cross-section
Run 2: Exclusive fraction (Herschel):

- CEP-enriched dimuons
- Inelastic-enriched $J/\psi$
- More than 4 tracks
Candidate selection:

2 muons: $2 < \eta < 4.5$
No other activity
(tracks, $\gamma$, Herschel)
$p_T^{2\mu\mu} < 0.8 \text{ GeV}^2$
$M_{\mu\mu}$ within 65 MeV of $J/\psi$
$M_{\mu\mu}$ within 65 MeV of $\psi(2s)$

~200 pb$^{-1}$ of 13 TeV pp data
Av. number of visible interactions = 1.1
Yields: $J/\psi$: 14753, $\psi(2S)$: 440
Sample composition:

- **Exclusive signal**
- QED
- Feed-down from $\psi(2S)$, $\chi_c$
- Inelastic production

Estimate composition from data by fitting $p_T^2$ of candidates.
Background subtract QED.
Background subtract feed-down.
Fit for exclusive (exp.) and inelastic components (data).
(same process for $\psi(2S)$ composition)
**J/ψ composition:**
- QED (0.9%)
- Feed-down of ψ(2S), χ_c (6.0%)
- Dissociation (17.5%)

**ψ(2S) composition:**
- QED (16.1%)
- Feed-down negligible
- Dissociation (11%)
Cross-section calculation:

\[
\frac{d\sigma_{\psi \rightarrow \mu^+\mu^-}}{dy} (2.0 < \eta_{\mu^+}, \eta_{\mu^-} < 4.5) = \frac{pN}{\epsilon_{\text{rec}}\epsilon_{\text{sel}} \Delta y \epsilon_{\text{single}} L}
\]

- **Poisson probability:** \(~33\%\)
- **Efficiencies from data**
- **Purity from data**
### Systematic errors:

<table>
<thead>
<tr>
<th>Source</th>
<th>$J/\psi$ analysis (%)</th>
<th>$\psi(2S)$ analysis (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>HERSCHEL veto</td>
<td>1.7</td>
<td>1.7</td>
</tr>
<tr>
<td>2 VELO track</td>
<td>0.2</td>
<td>0.2</td>
</tr>
<tr>
<td>0 photon veto</td>
<td>0.2</td>
<td>0.2</td>
</tr>
<tr>
<td>Mass window</td>
<td>0.6</td>
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<tr>
<td>$p_T^2$ veto</td>
<td>0.3</td>
<td>0.3</td>
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<tr>
<td>Proton dissociation</td>
<td>0.7</td>
<td>0.7</td>
</tr>
<tr>
<td>Feed-down</td>
<td>0.7</td>
<td>-</td>
</tr>
<tr>
<td>Nonresonant</td>
<td>0.1</td>
<td>1.5</td>
</tr>
<tr>
<td>Tracking efficiency</td>
<td>0.7</td>
<td>0.7</td>
</tr>
<tr>
<td>Muon ID efficiency</td>
<td>0.4</td>
<td>0.4</td>
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<tr>
<td>Trigger efficiency</td>
<td>0.2</td>
<td>0.2</td>
</tr>
<tr>
<td><strong>Total excluding luminosity</strong></td>
<td><strong>2.5 (5.5%)</strong></td>
<td><strong>2.7 (5.1%)</strong></td>
</tr>
<tr>
<td><strong>Luminosity</strong></td>
<td>3.9</td>
<td>3.9</td>
</tr>
</tbody>
</table>

Reduced systematic errors with respect to **Run 1 analysis**
pp → pJ/ψp and pp → pψ(2S)p differential cross-sections

Differential cross-section as a function of meson rapidity. Preference for NLO when compared to JMRT predictions.

Convert \( pp \rightarrow J/\psi p \) to \( \gamma p \rightarrow J/\psi p \)

\[
\frac{d\sigma}{dy_{pp \rightarrow pJ/\psi p}} = r_k^+ \frac{dn}{dk^+} \sigma_{\gamma p \rightarrow J/\psi p}(W^+) + r_k^- \frac{dn}{dk^-} \sigma_{\gamma p \rightarrow J/\psi p}(W^-)
\]
Convert pp $\rightarrow$ J/$\psi$ p to $\gamma$p $\rightarrow$ J/$\psi$ p

HERA measured power-law for J/$\psi$, $\psi$(2S) photoproduction:
use for W- solution (in previously measured region). **LHCb measures W+ solution**
Good agreement with Run 1 results
Run 2 measurements extend photoproduction points to $W \sim 10^3$
Indication of NLO preference at high $W$ in $J/\psi$ photoproduction
LHCb has a programme of central exclusive measurements.
  • Aided by low multiplicity data taking environment
  • Aided by ability to trigger on low transverse momentum objects

Herschel forward shower counters have improved our exclusivity measure for Run 2.

$J/\psi$ and $\psi(2s)$ exclusive and photoproduction measurements agree with NLO
Backup
**Purity of J/ψ:**

Signal slope:
\[ b_s = 5.93 \pm 0.08 \text{ GeV}^{-2} \] (6)

HERA measured \( b_s, b_d \) at lower W
Regge theory translates \( b_s, b_d \) from HERA to LHCb
Results agree with HERA parametrisation + Regge slope estimates
Purity of $\psi(2S)$:

Signal slope: $b_s = 5.06 \pm 0.45$ GeV$^{-2}$