Central exclusive production at LHCb

Melody Ravonel Salzgeber
on behalf of the LHCb collaboration
### CEP at LHCb

<table>
<thead>
<tr>
<th>Run 1 (2011-2012)</th>
<th>$\sqrt{s}$</th>
<th>Collision</th>
<th>Reference paper</th>
</tr>
</thead>
<tbody>
<tr>
<td>$J/\psi, \psi(2S)$ photoproduction</td>
<td>7 TeV</td>
<td>$pp$</td>
<td>JPG 41(2014) 055002</td>
</tr>
<tr>
<td>$\Upsilon$ photoproduction</td>
<td>7-8 TeV</td>
<td>$pp$</td>
<td>JHEP 1509(2015) 084</td>
</tr>
<tr>
<td>Double charmonium production</td>
<td>7-8 TeV</td>
<td>$pp$</td>
<td>JPG 40(2013) 045001</td>
</tr>
<tr>
<td>$\chi_c$ production</td>
<td>7 TeV</td>
<td>$pp$</td>
<td>LHCb-CONF-2011-022</td>
</tr>
<tr>
<td>QED dimuon production</td>
<td>7 TeV</td>
<td>$pp$</td>
<td>LHCb-CONF-2011-022</td>
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</tbody>
</table>

### Run 2 (2015)

<table>
<thead>
<tr>
<th></th>
<th>$\sqrt{s}$</th>
<th>Collision</th>
<th>Reference paper</th>
</tr>
</thead>
<tbody>
<tr>
<td>$J/\psi, \psi(2S)$ photoproduction</td>
<td>13 TeV</td>
<td>$pp$</td>
<td>LHCb-PAPER-2018-011</td>
</tr>
<tr>
<td>$J/\psi$ photonuclear production</td>
<td>5 TeV</td>
<td>PbPb</td>
<td>LHCb-CONF-2018-003</td>
</tr>
</tbody>
</table>

*update of preliminary result: LHCb-CONF-2016-007 about to be released in a paper*

*in this talk*
**CEP elastic processes:**

\[ pp(\bar{p}, A) \rightarrow p + X + p(\bar{p}, A) \quad \text{or} \quad AA \rightarrow A + X + A \]

- t-channel exchange of a colourless object
- \( \gamma, \) pomeron \( \rightarrow X + \) rapidity gaps

---

**di-\( \gamma \) fusion**

- \( \mu^+ \mu^-, e^+e^-, \pi^+\pi^-, W^+W^- \ldots \)

**di-pomeron exchange**

- \( \chi_c, \chi_b, \pi^+\pi^-, gg, \) dijet, \ldots

**\( \gamma \)-pomeron fusion**

- \( \rho, J/\psi, \gamma, Z \ldots \)
Photonuclear production

(a) \( A \) \( \gamma \) \( W_{\gamma A} \) \( J/\psi \) \( t \) \( A \)

coherent photonuclear production
nucleus remain \(~\)intact

(b) \( A \) \( \gamma \) \( W_{\gamma A} \) \( J/\psi \) \( t \) \( A^{(t)} \)
incoherent photonuclear production
nucleus changes

The LHCb detector

**LHCb**: Single arm spectrometer optimised for precision flavour physics
The LHCb detector

optimal $\mu, p, K, \pi^\pm$ produced inside the VELO

good $K_S^0, \Lambda^0, \gamma, e, \pi^0$

challenging stable neutral hadrons: $n, K_L^0$

Excellent muon identification $\epsilon \approx 97\%$, mis-ID $\approx 0.7\%$ at high $p_T$

VELO Silicon Vertex Detector

MAGNET 4 Tm

RICH1

RICH2

$\Delta p/p = 0.4\%$ at 5 GeV/$c$
to 0.6\% at 100 GeV/$c$

JINST 3 (2008) S08005

LHCb: Single arm spectrometer optimised for precision flavour physics

fully instrumented in $2 < \eta < 5$, partial coverage for $-3.5 < \eta < -1.5$
Just to give an idea of “coverage” of various processes:

- Rich Physics: Photon-Pomeron, Double-Pomeron, Photoproduction, Glueballs, Exotica
- Colourless objects in QCD
- Very low PT objects
- Clean experimental environment

Central Exclusive Production can be done at LHCb. What do we look for?

- Elastic scattering
- Inelastic scattering
- Single diffraction
- Double diffraction
- CEP elastic
- CEP inelastic

LHCb coverage (approximate)

η of particle, primary protons

Example of LHCb events

- Inelastic event: many tracks, high p_T objects
- CEP event: rapidity gaps, low p_T objects

After D. d’Enterria arxiv 0806.0883

Melody Ravonel Salzgeber: Elba, 24.05.2018
- Increase pseudo-rapidity coverage
  - to reduce background in CEP analyses
- 5 retractable stations:
  - with 20 scintillating shower counters
- Detect showers from high rapidity particles interacting with the beam-pipe elements

JINST 13 (2018) P04017
• Clean pedestals

- Herschel can reject extra activity!

• Herschel activity above noise described by $\log(\chi^2_{\text{HRC}})$ (takes account of the correlations between counters)

• Response checked against 3 classes of events
• Clear signal/background enhancement
Exclusive event selection (\( pp \rightarrow p + \mu^+ \mu^- + p \))

- 2 reconstructed muons with 2 < \( \eta \) < 4.5
- No additional tracks or energy
- Within 65 MeV/c\(^2\) of the \( M_{J/\psi} \)
- HErSCHeL VETO
- \( p_T^2 < 0.8\) GeV\(^2\)

---

**Signal**

- CEP
- \( \gamma \)-prod. \( J/\psi \)
- CEP
- \( \gamma \)-prod. \( \psi(2S) \)
Examples of exclusive event selection ( \( pp \rightarrow p + \mu^+ \mu^- + p \) )

- 2 reconstructed muons with \( 2 < \eta < 4.5 \)
- No additional tracks or energy
- Within 65 MeV/c\(^2\) of the \( M_{J/\psi} \)
- H\(e\)RSCHeL VETO
- \( p_T^2 < 0.8 \) GeV\(^2\)

Continuum lepton pair production

- Non Resonant Background
- EM CEP(QED)

Feed-down Background

When remaining particles produced in association with the J/\(\psi\) remains undetected or goes outside detector

- Signal

CEP

\( \gamma \)-prod.

J/\(\psi\)

CEP

\( \gamma \)-prod.

\( \psi(2S) \)

\( \chi_c \)
Proton dissociation background for $pp \rightarrow p + J/\psi$ or $\psi(2S) + p$

- **Inelastic production of mesons**
  where one or more protons dissociate or emit a gluon

2 ways to extract the proton dissociation background:

- fit data with 2 exponential (one for the signal and one for the pr. diss. bkg)
- use the two independent sample below and above HERSCHEL veto to constrain the background (**new, more in backup**)

=> possible thanks to HERSCHEL!

No HERSCHEL veto applied

![Graph showing proton dissociation background](image-url)
• Inelastic production of mesons
  where one or more protons dissociate or emit a gluon

2 ways to extract the proton dissociation background:

- fit data with 2 exponential (one for the signal and one for the pr. diss. bkg)
- use the two independent sample below and above HERSCHEL veto to constrain the background (new, more in backup)

=> possible thanks to HERSCHEL!
Signal extracted with the second method and fit with a single exponential

Good agreement is found with expectation of


signal purity: $0.755 \pm 0.015$ for $J/\psi$ and $0.72 \pm 0.061$ for $\psi(2S)$
Exclusive event selection (PbPb → Pb + μ⁺ μ⁻ + Pb)

- 2 reconstructed muons
  - with 2 < η < 4.5
- No additional tracks or energy
- Within 65 MeV/c² of the $M_{J/\psi}$
- $J/\psi$ $p_T$ < 1 GeV/c
- Muon $p_T$ > 0.5 GeV/c

LHCb Preliminary
Pb-Pb $\sqrt{s_{NN}}$ = 5 TeV

LHCB-CONF-2018-003
PbPb → Pb + J/ψ + Pb

LHCb Preliminary
Pb-Pb $\sqrt{s_{NN}}$ = 5 TeV

- Nonresonant: STARlight template normalisation fixed to the result of the mass fit
- Incoherent production: STARlight template also account for feed-down from $\psi(2S) \rightarrow J/\psi$
- Coherent production: STARlight template

STARlight: A monte carlo simulation program for ultra-peripheral collisions of relativistic ions:
The use of HERSCHEL can help in reducing background and uncertainties.
High luminosity requires multiple interactions per beam-crossings

Number of interactions $n$ per beam crossings is distributed as:

$$P(n) = \frac{e^{-\mu} \mu^n}{n!}$$

- For $pp$ LHCb in 2015, $\mu = 1.08$ in average
- For PbPb LHCb in 2015, $\mu = 0.001$ in average
Cross-section calculation

\[
\frac{d\sigma_{\psi \to \mu^+ \mu^-}}{dy} (2.0 < \eta_\mu < 4.5) = \frac{\mathcal{P} N}{\epsilon_{\text{rec}} \epsilon_{\text{sel}} \Delta y \epsilon_{\text{single}} \mathcal{L}_{\text{tot}}},
\]

where the dimuon hardware trigger was fired by two objects having an absolute azimuthal veto.

The products of the cross-sections and the branching fractions of the decays to two muons, which is the product of the integrated luminosity, purity given in Sec. 3.2 and the total cross-section, summed over all bins, is also calculated. In Eq. 1, the efficiency for selecting signal events is the product of the reconstruction efficiency, rapidity window and gives a signal event.

The fits to the mass distributions in Fig. 1 determine the fraction of signal inside the mass window and gives a signal event. The e-activity is obtained from data.

The efficiency for the selection requirements on the mass and transverse momentum of the candidates, and the veto on additional tracks, photon activity, or log prob. to have one interaction i.e. \( P(1) \), is calibrated using a sample enriched in \( J/\psi \) events.

The different numbers entering the calculation are given in the backup slide for \( J/\psi \) and \( \psi(2S) \).
### Systematic uncertainties $pp \rightarrow p + J/\psi$ or $\psi(2S) + p$

<table>
<thead>
<tr>
<th>Source</th>
<th>$J/\psi$ analysis (%)</th>
<th>$\psi(2S)$ analysis (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Update</td>
<td>Previous</td>
</tr>
<tr>
<td>HERSCHEL veto</td>
<td>1.7</td>
<td>1.5</td>
</tr>
<tr>
<td>2 VELO track $^\text{new}$</td>
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<td></td>
</tr>
<tr>
<td>0 photon veto $^\text{new}$</td>
<td>0.2</td>
<td></td>
</tr>
<tr>
<td>Mass window</td>
<td>0.6</td>
<td>0.4</td>
</tr>
<tr>
<td>$p_T^2$ veto $^\text{new}$</td>
<td>0.3</td>
<td></td>
</tr>
<tr>
<td>Proton dissociation</td>
<td>0.7</td>
<td>4.0</td>
</tr>
<tr>
<td>Feed-down</td>
<td>0.7</td>
<td>0.1</td>
</tr>
<tr>
<td>Nonresonant</td>
<td>0.1</td>
<td>0.6</td>
</tr>
<tr>
<td>Tracking efficiency</td>
<td>0.7</td>
<td>4.0</td>
</tr>
<tr>
<td>Muon ID efficiency</td>
<td>0.4</td>
<td>0.4</td>
</tr>
<tr>
<td>Trigger efficiency</td>
<td>0.2</td>
<td>0.2</td>
</tr>
<tr>
<td>Total excluding luminosity</td>
<td>2.5</td>
<td>5.9</td>
</tr>
<tr>
<td>Luminosity</td>
<td>3.9</td>
<td>3.9</td>
</tr>
</tbody>
</table>

- Main uncertainties decreased with respect to previous analysis (LHCb-CONF-2016-007)
- Specially the proton dissociation background uncertainty thanks to the new method developed only possible with the new HERSCHEL detector!
- Better understanding of the tracking
Uncertainties relatively big: *work on-going*

<table>
<thead>
<tr>
<th>Source</th>
<th>Relative uncertainty (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Selection efficiency</td>
<td>3.2</td>
</tr>
<tr>
<td>Reconstruction efficiency</td>
<td>2.1 – 4.5</td>
</tr>
<tr>
<td>Hardware trigger efficiency</td>
<td>3.0</td>
</tr>
<tr>
<td>Software trigger efficiency</td>
<td>1.6 – 5.3</td>
</tr>
<tr>
<td>Momentum smearing model</td>
<td>3.3</td>
</tr>
<tr>
<td>Mass fit model</td>
<td>3.9</td>
</tr>
<tr>
<td>Feed-down background</td>
<td>5.8</td>
</tr>
<tr>
<td>Branching fraction</td>
<td>0.6</td>
</tr>
<tr>
<td>Luminosity</td>
<td><strong>13.0</strong></td>
</tr>
</tbody>
</table>

*Different ways of calculating the luminosity give big differences: work is ongoing to understand it well*
Cross-section results $pp \rightarrow p + J/\psi$ or $\psi(2S) + p$

$$
\begin{align*}
\sigma_{J/\psi \rightarrow \mu^+\mu^-}(2 < \eta_\mu < 4.5) &= 399 \pm 16 \pm 10 \pm 16 \text{ pb}, \\
\sigma_{\psi(2S) \rightarrow \mu^+\mu^-}(2 < \eta_\mu < 4.5) &= 10.2 \pm 1.0 \pm 0.3 \pm 0.4 \text{ pb}.
\end{align*}
$$

- Good agreement with JMRT NLO prediction J. Phys. G41 (2014) 055009
  \[ J/\psi: \chi^2/\text{ndf} = 8.5/10 \text{ compared to } 32.8/10 \text{ for JMRT LO prediction} \]
  \[ \psi(2S): \chi^2/\text{ndf} = 4.9/3 \text{ compared to } 15.4/3 \text{ for JMRT LO prediction} \]
Photo-production cross section $pp \rightarrow p + J/\psi$ or $\psi(2S) + p$

Photo-production to compare with fixed target experiments (HERA)

$$\Rightarrow \sigma_{\gamma p \rightarrow \psi p}(W_+) = \frac{\sigma_{pp \rightarrow p\psi p} - r(W_-) k_- \frac{dn}{dk_-} \sigma_{\gamma p \rightarrow \psi p}(W_-)}{r(W_+) k_+ \frac{dn}{dk_+}}$$

Our data

2-fold ambiguity contributing to one LHCb rapidity bin: $W^2 = 2k_+ \sqrt{s}$

Assume photon-production cross section for $W^-$ as the one from HERA as it contributes about 1/3 and already measured by HERA

$J/\psi$

$\psi(2S)$

$p p \rightarrow p + J/\psi$ or $\psi(2S) + p$

Preliminary

$\sigma_{\gamma p \rightarrow \psi p}$ (nb)

$W (GeV)$

$\sigma_{\gamma p \rightarrow \psi p}$ (nb)

$W (GeV)$

=centre-of-mass energy of the photon-proton system

Melody Ravonel Salzgeber: Elba, 24.05.2018
Cross-section result: PbPb → Pb + J/ψ + Pb

\[ \sigma(2 < y_{J/\psi} < 4.5) = 5.31 \pm 0.24 \pm 0.45 \pm 0.69 \text{ mb} \]

- Best description: Guzey et al.:
  - uses perturbative QCD with 3 different nuclear gluon distribution function
- Goncalves and Cepila use colour dipoles in the calculation.
- For Goncalves the plots shows the 2 extreme scenario over 6 different models
- Cepila applies different parametrisation of the dipole-proton cross-section
  - 2 different prescriptions to propagate it to the dipole-nucleus scattering which improved the description but breaks down at high rapidity
    - Glauber Gribov methodology (GG)
    - Geometrical Scaling (GS)
Conclusion and prospects

- $J/\psi$ and $\psi(2S)$ production cross-sections with 2015 dataset have been calculated in $pp$ data with $\sqrt{s} = 13$ TeV ⇒ better understanding of the backgrounds with respect to LHCb-CONF-2016-017 thanks to HeRSCHeL
- Preliminary $J/\psi$ production cross-section with 2015 dataset has been calculated in PbPb data with $\sqrt{s} = 5$ TeV ⇒ more improvements to be seen in this analysis using HeRSCHeL ⇒ looking forward to the larger dataset in fall 2018
- Other work ongoing in $pA$ data with 2016 dataset ⇒ more results to come in the near future
• THANK YOU
• BACK-UP
Angular coverage of the LHC experiments

**ALICE**
- Central
- Forward muon coverage

**ATLAS & CMS**
- Central detectors

**LHCb**
- Forward detector
- Tracking, particle-ID and calorimetry in full acceptance

**Diffraction Physics at LHCb - The LHCb Experiment**

M. Schmelling, Heidelberg, July 20, 2015

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**Angular coverage and pseudo-rapidity**

Pseudo-rapidity:

\[ \eta \equiv -\ln \left( \tan \left( \frac{\theta}{2} \right) \right) \]

where \( \theta \) is the angle between the particle momentum \( \vec{p} \) and the beam axis.
New method to get the dissociation background

\[ S_H \text{ if } \log(\chi^2_{HRC}) < 3.5 \]
\[ S_H^{-} \text{ if } \log(\chi^2_{HRC}) > 3.5 \]

\[ \beta = S_H - \left( (1 - \epsilon_H)/\epsilon_H \right) S_H \]
contains only background efficiency for \( \log(\chi^2_{HRC}) < 3.5 \)

\[ f(p_T^2) = a - b \cdot p_T^2 \]
no signal in this region

\[ f(p_T^2) = a \exp(-b \cdot p_T^2) \]
no signal in this region

\[ \Rightarrow \text{proton dissociation background} = \beta(p_T^2) \cdot f(p_T^2) \]
Use of backwards tracks

Clearly not exclusive

R. McNulty, CEP at LHCb
Table 2: Tabulation of numbers entering the cross-section calculation for the $J/\psi$ analysis with statistical and systematic uncertainties.

<table>
<thead>
<tr>
<th>$y$ bin</th>
<th>2.0–2.25</th>
<th>2.25–2.5</th>
<th>2.5–2.75</th>
<th>2.75–3.0</th>
<th>3.0–3.25</th>
</tr>
</thead>
<tbody>
<tr>
<td>$N$</td>
<td>259</td>
<td>1022</td>
<td>1644</td>
<td>2204</td>
<td>2482</td>
</tr>
<tr>
<td>Stat. unc. (%)</td>
<td>6.2</td>
<td>3.1</td>
<td>2.5</td>
<td>2.1</td>
<td>2.0</td>
</tr>
<tr>
<td>$\epsilon_{\text{rec}}$</td>
<td>0.410</td>
<td>0.525</td>
<td>0.555</td>
<td>0.565</td>
<td>0.563</td>
</tr>
<tr>
<td>Stat. unc. (%)</td>
<td>5.9</td>
<td>4.2</td>
<td>3.3</td>
<td>2.8</td>
<td>2.6</td>
</tr>
<tr>
<td>Syst. unc. (%)</td>
<td>3.1</td>
<td>0.8</td>
<td>1.7</td>
<td>1.0</td>
<td>0.5</td>
</tr>
<tr>
<td>$\epsilon_{\text{sel}}$</td>
<td>0.636</td>
<td>0.643</td>
<td>0.650</td>
<td>0.655</td>
<td>0.663</td>
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<tr>
<td>Stat. unc. (%)</td>
<td>1.2</td>
<td>1.2</td>
<td>1.2</td>
<td>1.2</td>
<td>1.2</td>
</tr>
<tr>
<td>Syst. unc. (%)</td>
<td>2.5</td>
<td>2.0</td>
<td>2.0</td>
<td>1.9</td>
<td>1.9</td>
</tr>
<tr>
<td>Purity</td>
<td>0.760</td>
<td>0.759</td>
<td>0.751</td>
<td>0.758</td>
<td>0.764</td>
</tr>
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<td>Stat. unc. (%)</td>
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<td>2.2</td>
<td>2.2</td>
<td>2.1</td>
<td>2.1</td>
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<tr>
<td>Syst. unc. (%)</td>
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<td>1.0</td>
<td>1.0</td>
<td>1.0</td>
<td>1.0</td>
</tr>
<tr>
<td>$L_{\text{tot}}$</td>
<td>204 pb$^{-1}$</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>$\epsilon_{\text{single}}$</td>
<td>0.3662</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>$\frac{d\sigma}{dy}$ (pb)</td>
<td>40</td>
<td>123</td>
<td>183</td>
<td>242</td>
<td>272</td>
</tr>
<tr>
<td>Stat. unc. (%)</td>
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<td>6.0</td>
<td>5.0</td>
<td>4.5</td>
<td>4.3</td>
</tr>
<tr>
<td>Syst. unc. (%)</td>
<td>4.3</td>
<td>2.7</td>
<td>3.1</td>
<td>2.7</td>
<td>2.6</td>
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<td>Lumi. unc. (%)</td>
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<td>3.9</td>
<td>3.9</td>
<td>3.9</td>
<td>3.9</td>
</tr>
</tbody>
</table>
## Values entering the cross-section calculation

<table>
<thead>
<tr>
<th>$y$ bin</th>
<th>3.25–3.50</th>
<th>3.50–3.75</th>
<th>3.75–4.0</th>
<th>4.0–4.25</th>
<th>4.25–4.5</th>
</tr>
</thead>
<tbody>
<tr>
<td>$N$</td>
<td>2522</td>
<td>2112</td>
<td>1433</td>
<td>829</td>
<td>246</td>
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<tr>
<td>Stat. unc. (%)</td>
<td>2.0</td>
<td>2.2</td>
<td>2.6</td>
<td>3.5</td>
<td>6.4</td>
</tr>
<tr>
<td>$\epsilon_{\text{rec}}$</td>
<td>0.587</td>
<td>0.599</td>
<td>0.588</td>
<td>0.551</td>
<td>0.518</td>
</tr>
<tr>
<td>Stat. unc. (%)</td>
<td>2.5</td>
<td>2.6</td>
<td>2.8</td>
<td>3.3</td>
<td>4.1</td>
</tr>
<tr>
<td>Syst. unc. (%)</td>
<td>0.6</td>
<td>0.6</td>
<td>0.5</td>
<td>0.8</td>
<td>0.9</td>
</tr>
<tr>
<td>$\epsilon_{\text{sel}}$</td>
<td>0.665</td>
<td>0.670</td>
<td>0.670</td>
<td>0.676</td>
<td>0.667</td>
</tr>
<tr>
<td>Stat. unc. (%)</td>
<td>1.2</td>
<td>1.2</td>
<td>1.2</td>
<td>1.2</td>
<td>1.2</td>
</tr>
<tr>
<td>Syst. unc. (%)</td>
<td>1.9</td>
<td>1.9</td>
<td>1.9</td>
<td>1.9</td>
<td>2.0</td>
</tr>
<tr>
<td>Purity</td>
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<td>0.749</td>
<td>0.748</td>
<td>0.732</td>
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<tr>
<td>Stat. unc. (%)</td>
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<td>2.1</td>
<td>2.2</td>
<td>2.4</td>
<td>3.1</td>
</tr>
<tr>
<td>Syst. unc. (%)</td>
<td>1.0</td>
<td>1.0</td>
<td>1.0</td>
<td>1.0</td>
<td>1.0</td>
</tr>
<tr>
<td>$\mathcal{L}_{\text{tot}}$</td>
<td>204 pb$^{-1}$</td>
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<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>$d\sigma/dy$(pb)</td>
<td>264</td>
<td>211</td>
<td>146</td>
<td>87</td>
<td>28</td>
</tr>
<tr>
<td>Stat. unc. (%)</td>
<td>4.3</td>
<td>4.4</td>
<td>4.8</td>
<td>5.7</td>
<td>8.5</td>
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<td>Syst. unc. (%)</td>
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<td>2.6</td>
<td>2.7</td>
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<td>Lumi. unc. (%)</td>
<td>3.9</td>
<td>3.9</td>
<td>3.9</td>
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</table>
### $\psi(2S)$ analysis

<table>
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<tr>
<th>$y$ bin</th>
<th>2.0–3.0</th>
<th>3.0–3.5</th>
<th>3.5–4.5</th>
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<tbody>
<tr>
<td>$N$</td>
<td>170</td>
<td>134</td>
<td>136</td>
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<tr>
<td>Stat. unc. (%)</td>
<td>7.7</td>
<td>8.6</td>
<td>8.6</td>
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<tr>
<td>$\epsilon_{\text{rec}}$</td>
<td>0.633</td>
<td>0.644</td>
<td>0.622</td>
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<td>3.4</td>
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<tr>
<td>Syst. unc. (%)</td>
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<tr>
<td>$\epsilon_{\text{sel}}$</td>
<td>0.650</td>
<td>0.664</td>
<td>0.671</td>
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<td>Purity</td>
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<tr>
<td>Syst. unc. (%)</td>
<td>1.7</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

$\mathcal{L}_{\text{tot}}$ = 204 pb$^{-1}$

| $\epsilon_{\text{single}}$ | 0.3662 |

| $d\sigma/dy$(pb) | 4.0 | 6.1 | 3.2 |
| Stat. unc. (%) | 12.0 | 12.4 | 12.4 |
| Syst. unc. (%) | 2.9 | 2.7 | 2.7 |
| Lumi. unc. (%) | 3.9 | 3.9 | 3.9 |