QCD in W/Z/γ boson + jets events

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on behalf of ATLAS and CMS Collaborations

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Motivation

- Vector boson production associated with jets:
  - precise tests of perturbative quantum chromodynamics (pQCD)
  - sensitive to parton distribution functions (PDFs) in proton: gluon and sea-quarks PDF
    - presence of jets increases parton momentum fraction (x) and energy scale ($Q^2$) ranges
    - potential to improve the understanding of PDFs
  - important background for the Standard Model processes and for searches of new physics

$\bar{q}q \rightarrow Vg$

Dominant: $qg \rightarrow Vq$
Analyses overview

- Large production cross sections for vector boson
- Numerous measurements at different energies and conditions by ATLAS and CMS

March 2019

Today in the talk:

- **ATLAS**
  - W+jets at √s=8 TeV
    - JHEP 05 (2018) 077
  - Z+jets at √s=8 TeV
    - arXiv:1907.06728

- **CMS**
  - W+jet at √s=13 TeV
    - PRD 96 (2017) 072005
  - Z+jets at √s=13 TeV
  - γ+jets at √s=13 TeV

All results at: http://cern.ch/go/pNj7
Analyses overview

Vector Boson + X fid. Cross Section Measurements

\[
\begin{align*}
&\gamma
\quad -\gamma + \geq 1 j

&Z \rightarrow ee, \mu\mu
\quad -Z + \geq 1 j

&W \rightarrow ee, \mu\nu
\quad -W + \geq 1 j

&W, Z \rightarrow q\bar{q}
\quad \sigma(W)/\sigma(Z) \text{ (fid.)}
\quad -\geq 1 j

&\sigma(t\bar{t})/\sigma(Z) \text{ (tot.)}
\end{align*}
\]

\textbf{ATLAS Preliminary}
Run 1,2 \(\sqrt{s} = 5, 7, 8, 13\) TeV

\begin{itemize}
\item \textbf{Good agreement between data and predictions}
\end{itemize}
W+jets at 8 TeV

JHEP 05 (2018) 077

2012, 20.2 fb$^{-1}$
Analysis overview

Main backgrounds:
- Z+jets and multijet for $N_{\text{jets}} \leq 2$ jets
- $t\bar{t}$ at high jet multiplicities

Dominant systematic uncertainties:
- jet energy scale (8% to 55% for $N_{\text{jets}} \geq 1$ to $N_{\text{jets}} \geq 7$)
- jet energy resolution (9% to 20% for $N_{\text{jets}} \geq 1$ to $N_{\text{jets}} \geq 7$)

Theoretical predictions:
- Multi-parton MC LO or NLO (Alpgen, Sherpa)
- NLO: BlackHat+Sherpa (BH+S) up to 5 jets, CT10 NLO PDF set
- NLO: Sherpa 2.2.1 up to 2 jets + LO for 3rd jet, CT10 PDF set
- NNLO: N-jettiness subtraction technique ($N_{\text{jett}}$), CT14 NNLO PDF set

✓ Differential cross sections for $W$ production with one or two jets
✓ Cross-section ratios of $W^+/W^-$

Many observables are measured!
Jet multiplicity and ratio

- Comparison to the various theoretical predictions

agree with the predictions within the experimental uncertainties

agreement improved for the ratio
mismodelling related to jet emission cancels out
Differential cross section and ratio: $N_{\text{jets}} \geq 1$

- $H_T$: scalar sum of the jet, lepton $p_T$'s
  - higher values are sensitive to the higher jet multiplicities and topologies as $qq \rightarrow qq'W$

- best agreement with Sherpa and Alpgen (LO) predictions
Differential cross section and ratio: $N_{jets} \geq 1$

- Good agreement between the data and most LO predictions and NNLO
- NLO and LO Sherpa 2.2.1 predictions perform worse than LO Sherpa 1.4
- Improved experimental precision
- Most predictions (except $N_{jetti}$ NNLO and Sherpa 1.4) overestimate the data
QCD analysis of W+jets data

- W+jets probes higher x of partons than W and Z data
  - new input to PDF fits

- W⁻ and W⁺ data (8 TeV) are fitted with datasets used for the previous ATLASepWZ16 fit

- New PDF set: ATLASepWZWjets19 (using p_{W{T}} spectrum)

- PDFs obtained for sea quarks
  - improved determination of the high-x sea-quark densities

- confirming the unsuppressed strange-quark density at low x ≲ 0.02
- consistent with previous ATLAS fits
W/Z+jets at 13 TeV

PRD 96 (2017) 072005
Analyses overview

**W→μν + jets**
- muon channel
- main background: tt
- dominant systematic uncertainties:
  - jet energy scale (1–25% for N=1-6) and resolution (1%)
  - measured efficiency (1.2%)

**Z→μμ + jets**
- electron and muon channels (combined)
- main background: tt
- dominant systematic uncertainties:
  - jet energy scale (~5% for N=1) and resolution (1%)
  - measured efficiency (2%–4%)

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**Differential cross sections (up to 4 jets)**
- \( p_T, |y| \) of the leading jet
- \( \Delta \phi(\mu,j) \): azimuthal correlation between the muon and the leading jet
- \( \Delta R(\mu, \text{closest jet}) \): angular distance between the muon and the closest jet
- \( H_T \): the scalar \( p_T \) sum of the jets

**Differential cross sections**
- jet multiplicity (up to 6 jets)
- \( p_T \) of Z
- jet kinematics: \( p_T, y, H_T \) (up to 3 jets)
- \( p_T^{\text{bal}} \): balance between the Z boson and jet transverse momenta
- \( J_{ZB} \): jet-Z balance
Theoretical predictions for W/Z+jets

**MC multileg LO ME+PS**: MadGraph5_aMC@NLO generator
- $k_T$- MLM merging scheme
- interfaced with PYTHIA8 using NNPDF2.3 (LO) and NNPDF3 (LO) PDFs
- up to N = 0..4 jets in the final state

**MC multileg NLO ME+PS**: MadGraph5_aMC@NLO generator
- FXFX jet merging scheme
- interfaced with PYTHIA8 using NNPDF2.3 (LO) and NNPDF3 (NLO) PDFs
- NLO accuracy for N = 0,1,2 partons and LO accuracy for N = 3, 4

**NNLO+NNLL**: Geneva1.0-RC2 MC using PDF4LHC15 (for Z)
- combined with parton showering and hadronization provided by PYTHIA8

**Fixed-order NNLO** calculations for V+1jet
- N-jettiness subtraction scheme using CT14
  - non perturbative correction from MadGraph5_aMC@NLO+ PYTHIA8
W+jets at 13 TeV

- NLO MG_aMC FxFx: good agreement
- Njetti NNLO: best agreement for W ≥1jet
- LO MG_aMC: underestimates the data at low jet $p_T$

predictions are in good agreement with data
  - exception: underestimation at low $p_T$ by LO MG_aMC
W+jets at 13 TeV

predictions describe data within uncertainties

fairly good agreement with data within the uncertainties

LO MG_aMC: underestimates the data in the high-ΔR region
Z+jets at 13 TeV

- **NLO MG5_aMC and NNLO**: the best description
- **GENEVA**: good agreement for the 1st jet
- **LO MG5_aMC**: not describing well

CMS

\[
\frac{d^2}{dp_T} \sigma (j_1) \leq MG5_aMC + PY8 (4j LO + PS) \leq MG5_aMC + PY8 (NNLO + PS) \]

\[
\frac{d^2}{dp_T} \sigma (HT) \leq MG5_aMC + PY8 (4j LO + PS) \leq MG5_aMC + PY8 (NNLO + PS) \]

\[
\frac{d^2}{dp_T} \sigma (p_{T bal}) \leq MG5_aMC + PY8 (4j LO + PS) \leq MG5_aMC + PY8 (NNLO + PS) \]

Measurement

- MG5_aMC + PY8 (NLO + PS)
- MG5_aMC + PY8 (NNLO + PS)
- GE + PY8 (NNLO + NNLO)
- N_{NNLO} (1j NNLO)

\[
\frac{d^2}{dp_T} \sigma (HT) \leq MG5_aMC + PY8 (4j LO + PS) \leq MG5_aMC + PY8 (NNLO + PS) \]

\[
\frac{d^2}{dp_T} \sigma (p_{T bal}) \leq MG5_aMC + PY8 (4j LO + PS) \leq MG5_aMC + PY8 (NNLO + PS) \]

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\frac{d^2}{dp_T} \sigma (j_1) \leq MG5_aMC + PY8 (4j LO + PS) \leq MG5_aMC + PY8 (NNLO + PS) \]

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\frac{d^2}{dp_T} \sigma (HT) \leq MG5_aMC + PY8 (4j LO + PS) \leq MG5_aMC + PY8 (NNLO + PS) \]

\[
\frac{d^2}{dp_T} \sigma (p_{T bal}) \leq MG5_aMC + PY8 (4j LO + PS) \leq MG5_aMC + PY8 (NNLO + PS) \]

- **NLO MG5_aMC and NNLO**: the best description
- **GENEVA**: good agreement for the 1st jet
- **LO MG5_aMC**: not describing well

\[
\text{CMS} \quad \text{Measurement}
\]

\[
\text{NLO MG5_aMC} + \text{PY8 (NLO + PS)} \quad \text{and} \quad \text{NNLO} \quad \text{NNLO (1j NNLO)}
\]

\[
\text{GENEVA} \quad \text{good agreement for the 1st jet}
\]

\[
\text{LO MG5_aMC} \quad \text{not describing well}
\]
Z+jets at 8 TeV

arXiv:1907.06728
Analysis overview

- Based on the electron channel
- Main background: $t\bar{t}$ (within 3%)
- Dominant systematic uncertainties:
  - jet energy scale: 3–10% in the first bin of $p_T$ and reduces to 0.5–3% in larger bins
  - jet energy resolution in the first bin: ~6%
  - unfolding uncertainty: 2–5% in $p_T^{\text{jet}} < 100$ GeV

Fixed order predictions:

- **NLO**: calculated using MCFM interfaced to APPLgrid
  - different PDF sets
  - total uncertainty: 8–10%
- **NNLO**: provided by A. Gehrmann-De Ridder et al.
  - total uncertainty: 2–5%.
- QED radiation and non-perturbative corrections
  - total uncertainty includes: scale, PDF, $\alpha_S$, unc. from the non-perturbative and QED radiation effects

- ![Double differential cross sections](image)
  - as function of $|y_{\text{jet}}|$, $p_T^{\text{jet}}$

- **Total number of jets**
  - $2 \times 10^3$
  - $3 \times 10^3$
  - $4 \times 10^3$
  - $5 \times 10^3$

- **Pred./Data**
  - $0.8$
  - $1.0$
  - $1.2$

- **Relative uncertainty**
  - $0.1$
  - $0.05$
  - $0.15$

- **ATLAS** 
  - $\sqrt{s} = 8$ TeV, 19.9 fb$^{-1}$
  - anti-$k_t$, jets, $R=0.4$
  - $25$ GeV<$p_T^{\text{jet}}<$50 GeV
  - $Z(\rightarrow ee)$ + jets
  - Data
  - $Z(\rightarrow ee)$ (SHERPA 1.4)
  - $Z(\rightarrow ee)$ (ALPGEN+PY6)
  - $t\bar{t}$
  - Multijet, $W$ + jets
  - Diboson
  - Single top
  - $\tau\tau$

- **Relative uncertainty**
  - Scale uncertainty
  - Total pQCD uncertainty
  - PDF uncertainty
  - Total theory uncertainty
  - $\alpha_S$ uncertainty

- $s = 8$ TeV, $25$ GeV<$p_T^{\text{jet}}<$50 GeV
  - ATLAS
**Differential cross sections**

**ATLAS**

\(\sqrt{s}=8\) TeV, 19.9 fb\(^{-1}\)

Z(\(\rightarrow ee\)) + jets

anti-\(k_t\), \(R=0.4\)

- **Data**
- ME+PS
- SHERPA 1.4
- ALPGEN+PY6
- SHERPA 2.2

Fixed-order QCD

\(\times k_{NP} \times k_{QED}\)

CT14 PDF

- MCFM 6.8
- NNLOJET

\(d^2\sigma/dp_T^\text{jet}/dy\) [fb/GeV]

\(y_{\text{jet}}\) = 0, 0.5, 1, 1.5, 2

\(p_T^\text{jet}\) = 25 GeV - 1050 GeV

- **ATLAS**

\(\sqrt{s}=8\) TeV, 19.9 fb\(^{-1}\)

Z(\(\rightarrow ee\)) + jets

anti-\(k_t\), \(R=0.4\)

- **Data**
- ME+PS
- SHERPA 1.4
- ALPGEN+PY6
- SHERPA 2.2

Fixed-order QCD

\(\times k_{NP} \times k_{QED}\)

CT14 PDF

- MCFM 6.8
- NNLOJET

- **NLO** predictions: lower than data by \(~5–10\%)%
  - difference covered by the uncertainties
- **NNLO** predictions: better agreement
- **Sherpa 1.4**: lower than data by about 10\% in the low region and few \% in the high region
- **Alpgen+Pythia**: agree with data up to \(p_T^\text{jet}\) = 100 GeV
  - the biggest difference in the largest \(p_T^\text{jet}\) bin: \(~20\%)
Comparison between different PDF sets

NLO predictions with different PDFs:

- **MMHT2014 & NNPDF3.1:**
  - 1–2% larger cross-sections in comparison to those using the CT14 PDF.

- **ABMP16 & HERAPDF2.0:**
  - 3–5% are larger in the $|y_{\text{jet}}| < 2.0$ and $p_{T,\text{jet}} < 100$ GeV
  - up to 5% lower in other bins with respect to CT14

- Differences between the cross-sections calculated at NLO accuracy with various PDF sets:
  - covered by the theoretical uncertainties
γ+jets at 13 TeV


2015, 2.26 fb⁻¹
\(\gamma+\text{jets production at 13TeV}\)

**Signal extraction:**
- BDT based on photon (kinematic + shower shape) variables
- signal BDT template: \(\gamma+\text{jets MC (Pythia8), validated with } Z\rightarrow ee, Z\rightarrow \mu\mu\)

**Theoretical predictions:**
- NLO: JETPHOX 1.3.1 generator, NNPDF3.0 PDFs and the Bourhis-Fontannaz-Guillet (BFG) set II parton fragmentation functions
- photon \(E_T\) used as the scale
- total uncertainty includes:
  - the scale, PDF, \(\alpha_S\), and underlying event and parton shower uncertainties

\[\checkmark\] Differential cross sections as a function of the photon \(E_T\)

\(\Rightarrow\) Hugues LATTAUD’s talk

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\text{Theoretical predictions:}

- NLO: JETPHOX 1.3.1 generator, NNPDF3.0 PDFs and the Bourhis-Fontannaz-Guillet (BFG) set II parton fragmentation functions
- photon \(E_T\) used as the scale
- total uncertainty includes:
  - the scale, PDF, \(\alpha_S\), and underlying event and parton shower uncertainties

\(\checkmark\) Differential cross sections as a function of the photon \(E_T\)

\(\Rightarrow\) Hugues LATTAUD’s talk
**γ+jets production at 13TeV**

- Comparison between the cross sections and NLO pQCD calculations
  - in two photon rapidity and two jet rapidity bins
  - extended the photon $E_T$ range up to 1 TeV

- The ratio of the theoretical predictions to data
  - agreement within statistical and systematic uncertainties
  - low to middle range in photon $E_T$: the experimental uncertainties are smaller or comparable to theoretical uncertainties

✓ Experimental input to improve gluon PDF

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QCD in W/Z+jets events

QCD@LHC 2019
γ+jets production at 13TeV

- Comparison between data and predictions using different PDF sets:

- The ratio of the theoretical predictions to data:
  - differences are small
  - within the theoretical uncertainties estimated with NNPDF3.0
Summary

Plenty of measurements of differential cross sections provided by ATLAS and CMS collaborations

- covering different centre-of-mass energies
- many observables are studied
- compared to the theoretical predictions

Theoretical calculations reached (NNLO) QCD precision for V+1jet and (NLO) for four and five jets

- overall good agreement between predictions and data (NLO and NNLO)

Measurements provide valuable input for a better understanding of

- perturbative QCD
- SM predictions
- PDFs of the proton

Cross section ratios bring the high precision of the measurements

More V+jets measurements are available at:

- https://twiki.cern.ch/twiki/bin/view/AtlasPublic/StandardModelPublicResults
Backup
Standard Model Production Cross Section Measurements

**ATLAS Preliminary**
Run 1,2 $\sqrt{s} = 5,7,8,13$ TeV

**Status:** July 2019

### LHC pp $\sqrt{s} = 5$ TeV
- **Data:** 0.025 fb$^{-1}$

### LHC pp $\sqrt{s} = 7$ TeV
- **Data:** 4.5 – 4.9 fb$^{-1}$

### LHC pp $\sqrt{s} = 8$ TeV
- **Data:** 20.2 – 20.3 fb$^{-1}$

### LHC pp $\sqrt{s} = 13$ TeV
- **Data:** 3.2 – 79.8 fb$^{-1}$

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QCD in W/Z+jets events

QCD@LHC 2019

27
PFD sensitivity

- Including jet increases sensitivity at higher $x$ and $Q^2$

\[\text{ATLAS Simulation} \quad \sqrt{s} = 8 \text{ TeV}, 20.2 \text{ fb}^{-1} \]

- 0 - 10 jets

\[\text{ATLAS Simulation} \quad \sqrt{s} = 8 \text{ TeV}, 20.2 \text{ fb}^{-1} \]

- 1 - 10 jets

\[\text{Initial-state dominated by quark-gluon}\]
### W+jets at 8 TeV: theoretical predictions

<table>
<thead>
<tr>
<th>Program</th>
<th>Order in $\alpha_S$</th>
<th>$N_{\text{max partons}}$ at highest order</th>
<th>PDF set</th>
<th>NPC</th>
<th>PS</th>
</tr>
</thead>
<tbody>
<tr>
<td>$N_{\text{jetti}}$</td>
<td>NNLO</td>
<td>1</td>
<td>CT14</td>
<td>✓</td>
<td></td>
</tr>
<tr>
<td><strong>BlackHat+Sherpa</strong></td>
<td>NLO</td>
<td>1, 2 or 3</td>
<td>CT10</td>
<td>✓</td>
<td></td>
</tr>
<tr>
<td>MCFM 6.8</td>
<td>NLO</td>
<td>1</td>
<td>CT10 + 3 more</td>
<td>✓</td>
<td></td>
</tr>
<tr>
<td>Powheg+Pythia 8</td>
<td>NLO</td>
<td>1</td>
<td>CT14</td>
<td>✓</td>
<td></td>
</tr>
<tr>
<td>Sherpa 2.2.1</td>
<td>NLO</td>
<td>2</td>
<td>CT10</td>
<td>✓</td>
<td></td>
</tr>
<tr>
<td>Sherpa 2.2.1</td>
<td>LO</td>
<td>2 (3)</td>
<td>NNPDF 3.0</td>
<td>✓</td>
<td></td>
</tr>
<tr>
<td>ALPGEN+Pythia 6</td>
<td>LO</td>
<td>5</td>
<td>CTEQ6L1 (LO)</td>
<td>✓</td>
<td></td>
</tr>
<tr>
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<td>5</td>
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<td>Sherpa 1.4.1</td>
<td>LO</td>
<td>4</td>
<td>CT10</td>
<td>✓</td>
<td></td>
</tr>
</tbody>
</table>
W+jets at 8 TeV: uncertainties

ATLAS

\( \frac{W^+ + \text{jets}}{W^+ + \text{jets}} \) at \( \sqrt{s} = 8 \text{ TeV}, 20.2 \text{ fb}^{-1} \)

Relative uncertainty

0.2

0.4

0.6

0.8

1.0

1.2

1.4

0

1

N\_jets

\( \bar{\nu} = 8 \text{ TeV}, 20.2 \text{ fb}^{-1} \)

ATLAS

\( \frac{W^+ + 1 \text{ jets}}{W^+ + 1 \text{ jets}} \) at \( \sqrt{s} = 8 \text{ TeV}, 20.2 \text{ fb}^{-1} \)

Relative uncertainty

0.2

0.4

0.6

0.8

1.0

1.2

1.4

0

1

W boson \( p_T \) [GeV]

### Table 1: Relative uncertainties in the measured cross sections in percent as a function of the \( N\_\text{jets} \)

<table>
<thead>
<tr>
<th>Inclusive</th>
<th>( \geq 1 \text{ jet} )</th>
<th>( \geq 2 \text{ jets} )</th>
<th>( \geq 3 \text{ jets} )</th>
<th>( \geq 4 \text{ jets} )</th>
<th>( \geq 5 \text{ jets} )</th>
<th>( \geq 6 \text{ jets} )</th>
<th>( \geq 7 \text{ jets} )</th>
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<tr>
<td>Jet energy scale</td>
<td>0.1</td>
<td>7.5</td>
<td>10</td>
<td>14</td>
<td>18</td>
<td>27</td>
<td>38</td>
</tr>
<tr>
<td>Jet energy resolution</td>
<td>0.5</td>
<td>8.8</td>
<td>9.9</td>
<td>12</td>
<td>14</td>
<td>15</td>
<td>18</td>
</tr>
<tr>
<td>( b )-tagging</td>
<td>0.1</td>
<td>0.5</td>
<td>1.5</td>
<td>3.8</td>
<td>8.3</td>
<td>15</td>
<td>23</td>
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<td>Electron</td>
<td>1.1</td>
<td>1.4</td>
<td>1.4</td>
<td>1.5</td>
<td>1.8</td>
<td>2.1</td>
<td>2.1</td>
</tr>
<tr>
<td>( E_T^{\text{miss}} )</td>
<td>1.1</td>
<td>2.6</td>
<td>4.2</td>
<td>5.5</td>
<td>7.1</td>
<td>8.8</td>
<td>12</td>
</tr>
<tr>
<td>Multijet background</td>
<td>0.5</td>
<td>1.3</td>
<td>2.1</td>
<td>2.6</td>
<td>2.5</td>
<td>4.7</td>
<td>8.8</td>
</tr>
<tr>
<td>Top quark background</td>
<td>(&lt;0.1)</td>
<td>0.2</td>
<td>0.8</td>
<td>2.5</td>
<td>5.7</td>
<td>10</td>
<td>16</td>
</tr>
<tr>
<td>Other backgrounds</td>
<td>(&lt;0.1)</td>
<td>0.1</td>
<td>0.2</td>
<td>0.3</td>
<td>0.5</td>
<td>1.0</td>
<td>1.7</td>
</tr>
<tr>
<td>Unfolding</td>
<td>4.7</td>
<td>4.1</td>
<td>4.9</td>
<td>4.4</td>
<td>4.0</td>
<td>4.7</td>
<td>6.9</td>
</tr>
<tr>
<td>Other</td>
<td>0.3</td>
<td>0.8</td>
<td>1.0</td>
<td>2.1</td>
<td>4.6</td>
<td>8.7</td>
<td>14</td>
</tr>
<tr>
<td>Luminosity</td>
<td>0.1</td>
<td>0.2</td>
<td>0.4</td>
<td>0.7</td>
<td>1.2</td>
<td>2.0</td>
<td>2.9</td>
</tr>
<tr>
<td>Total systematic uncert.</td>
<td>5.0</td>
<td>13</td>
<td>16</td>
<td>20</td>
<td>27</td>
<td>38</td>
<td>55</td>
</tr>
</tbody>
</table>

Nataliia Zakharchuk

QCD in W/Z+jets events

QCD@LHC 2019
QCD analysis: $R_S$ distribution

- fitting the $W+\text{jets}$ data as a function of $p_T W$ in comparison to the similar fit without $W+\text{jets}$ data
- obtained ATLASepWZWjet19 fit corresponding to the fit with $W+\text{jets}$ data in the $p_T W$ spectrum
Z+jets at 8 TeV

Difference between CT14 PDF and NNPDF3.1: 2%–5%

› comparable to the size of the theoretical uncertainties
Systematics uncertainties on cross section

- excluding the highest photon $E_T$ bin in each $y$ range: $\sim 5$–$8\%$

| Source                     | $|y^\gamma| < 0.8$ | $0.8 < |y^\gamma| < 1.44$ | $1.57 < |y^\gamma| < 2.1$ | $2.1 < |y^\gamma| < 2.5$ |
|----------------------------|------------------|-----------------|-----------------|-----------------|
| Trigger efficiency         | 0.7–8.5          | 0.2–13.4        | 0.6–20.5        | 0.3–7.8         |
| Selection efficiency       | 0.1–1.3          | 0.1–1.3         | 0.1–5.3         | 0.1–1.1         |
| Data-to-MC scale factor    | 3.7              | 3.7             | 7.1             | 7.1             |
| Template shape             | 0.6–5.0          | 0.1–10.2        | 0.5–4.9         | 0.6–16.2        |
| Event migration            | 3.8–5.5          | 1.2–4.1         | 2.0–8.5         | 2.3–10.3        |
| Total w/o luminosity       | 5.4–12.0         | 5.9–18.2        | 8.2–26.9        | 8.6–21.7        |
| Integrated luminosity      |                  |                 |                 | 2.3             |