From charged-particle multiplicities to the top quark

W. H. Bell

Université de Genève
Overview

• Introduction
• Charged-particle multiplicities
• Inclusive W cross-section
• W + jets cross-section
• Top cross-section
• Conclusions
• Analyses for 2011
Objectives

- The LHC is a discovery machine
- Study standard model properties
- Search for the Higgs boson.
- Look for sources of new physics.
The ATLAS detector
Charged-particle multiplicity distributions

- Basic underlying physics of $pp$ interactions.
- MC attempt to describe low-$p_T$ processes using 2-to-2 scatters and phenomenological models.
  - Multiple-parton scattering
  - Partonic matter distributions
  - Scattering between unresolved protons
  - Colour reconnection.
- Phenomenological models tuned using measurements.
  - Measurements needed to constrain behaviour at different centre-of-mass energies.
Making a measurement

• Select inelastic $pp$ interactions using minimal bias.
  – Trigger scintillators with a large coverage overlapping with track-reconstruction volume.
  – The tracking detector itself.
  – Beam bunch requirement.

• Reconstruct charged particles using silicon or gas tracking detectors.
  – Magnetic field surrounding tracking volume needed for momentum measurements.

• Reconstruct the primary vertex or use the beam position to select primary tracks.

• Correct for event and track selection and provide a particle level result.
Experimental issues

• Additional $pp$ interactions.
• Multiple scattering within tracking detector.
• Nuclear interactions, which result in badly measured tracks.
• $p_T$ resolution as $p_T$ becomes large.
Types of measurement

• No corrections
  – Easy to produce this result, hard for someone else outside the experiment to understand.

• Non-single-diffractive
  – Removal of single-diffractive events within acceptance.
  – Addition of double-diffractive and non-diffractive events with $n_{\text{ch}} = 0$ using MC generator.

• Fully corrected within kinematic range.
  – Data used for trigger and vertex corrections.
  – Only events with $n_{\text{ch}} \geq 1$ included in distributions.
Correction factors

• Trigger selection is sensitive to physics processes.
  – Trigger correction with MC model folds in physics assumptions from MC into data distribution.

• Extrapolation back to $p_T = 0$.
  – Fold in model based assumptions about distribution.

• Correction of tracking acceptance using MC.
  – Folds in $n_{ch}$ distribution from MC for low multiplicity bins.

• Need to avoid sources of model dependence and present results within acceptance.
Additional in $n_{ch}=0$ events effects normalisation of distribution.

Removing single diffractive diffractive component implies $p_T$ spectrum of generator removed from measured distribution.

Corrections typically made using PYTHIA 6.4.21 i.e. poor diffractive model.

These corrections are not made on the ATLAS data and this Figure is used for illustrative purposes only.
Distributions

\[
\frac{1}{N_{ev}} \cdot \frac{dN_{ch}}{d\eta}
\]

\[
\frac{1}{N_{ev}} \cdot \frac{1}{2\pi p_T} \cdot \frac{d^2N_{ch}}{d\eta dp_T}
\]

\[
\frac{1}{N_{ev}} \cdot \frac{dN_{ev}}{dn_{ch}}
\]

\[\langle p_T \rangle \text{ vs. } n_{Ch}\]

\[N_{ev}\]

(1) Events with \(n_{ch} \geq 1\) (\(|\eta| < 2.5 \& p_T > 500\text{MeV}\))

(2) Events with \(n_{ch} \geq 2\) (\(|\eta| < 2.5 \& p_T > 100\text{MeV}\))

Discussion will follow (2) and \(\sqrt{s} = 7\text{TeV}\) measurements
Charged-particle multiplicities: summary

• Measure charged particle multiplicity distributions from inelastic events within $|\eta|<2.5$ & $p_T > 100\text{MeV}$
  – Require $n_{\text{ch}} \geq 2$ ($|\eta|<2.5$ & $p_T > 100\text{MeV}$)
    • Removes model dependence from trigger and vertex corrections.
  – No removal of single-diffractive-component.
  – No removal of Dalitz decays.
  – No extrapolation to $p_T = 0$ or correction for acceptance using models.

• Correct reconstructed-track distributions back to particle level for all detector effects.
  – Measure trigger and vertex corrections from data.
\[ \frac{dN_{\text{ch}}}{d\eta} \]

\[ \frac{1}{(2\pi p_T)} \frac{d^2N_{\text{ch}}}{d\eta dp_T} \]

\[ n_{\text{ch}} \geq 2, p_T > 100 \text{ MeV}, |\eta| < 2.5 \]

ATLAS \( \sqrt{s} = 7 \text{ TeV} \)

Plot showing the ratio of data to MC for different models (Data 2010, PYTHIA ATLAS AMBT1, PYTHIA ATLAS MC09, PYTHIA DW, PYTHIA 8, PHOJET) for the range \(-2.5 < \eta < 2.5\).
\[ \frac{dN_{\text{ev}}}{dn_{\text{ch}}} \]

\[ \langle p_T \rangle \text{ vs } n_{\text{ch}} \]

\[ n_{\text{ch}} \geq 2, \ p_T > 100 \text{ MeV, } |\eta| < 2.5 \]

ATLAS \( \sqrt{s} = 7 \text{ TeV} \)

DPNC Genève - 2011/03/09
$dN_{\text{ch}}/d\eta$ at $\eta = 0$ vs $\sqrt{s}$

ATLAS
- Data
- PYTHIA 6 AMBT1
- PYTHIA 6 MC09
- PYTHIA 6 DW
- PYTHIA 8
- PHOJET

$p_T > 100$ MeV, $n_{\text{ch}} \geq 2$

$p_T > 500$ MeV, $n_{\text{ch}} \geq 6$

$p_T > 500$ MeV, $n_{\text{ch}} \geq 1$
W production

• The W (and Z) boson production expected from the Standard Model is an important background for top quark production and for searches beyond the standard model.

• W (and Z) bosons provide a source of high $p_T$ isolated leptons.
  – Used to understand detector and trigger performance, lepton identification and MET resolution.

• Inclusive and associated jets analyses have been carried out.
Electron identification

- Electrons are selected with three levels of selection, each tighter than the first.
- The definition of these selection criteria depends on ongoing optimisation.
- Typically:
  - The loosest selection is based on transverse and longitudinal shower shape in the second layer of the calorimeter, with a requirement on the hadronic leakage.
  - A slightly more robust selection is given by using shower shape measurements in the first layer of the calorimeter and track quality and impact parameter.
  - The most robust requirement uses cluster-track energy vs momentum, transition radiation in the TRT, at least one pixel b-layer hit.
Muon identification

• Stand-alone muon-spectrometer track associated to an inner-detector track.
  – association found from best $\chi^2$
  – combine tracks or refit.
  – W+jets and Top analysis use additional track quality, matching and impact parameter requirements.
  • Further reduce QCD background.
QCD background

- All other source of background not included in another term.
  - Jets which deposit a lot of energy in the electromagnetic calorimeter.
  - Conversions in material before first pixel layer.
  - Muons produced from long lived weakly decaying particles.

- Tightly coupled to the detector description and the result of fluctuations.
  - Create templates from adjacent control regions, where signal is \( \approx 0 \).
  - Use looser selection and calculate:

\[
N_{\text{loose}} = N_{\text{nonQCD}} + N_{\text{QCD}} \\
N_{\text{iso}} = \varepsilon_{\text{nonQCD}} N_{\text{nonQCD}} + \varepsilon_{\text{QCD}} N_{\text{QCD}}
\]

Solving for \( N_{\text{QCD}} \) given the two efficiency factors.
W inclusive: event selection

- Presence of a primary vertex
- Electron ET > 20 GeV or combined muon $p_T > 20$ GeV
- Muon isolation $\Sigma p_T^{ID}/p_T < 0.2$ within $\Delta R < 0.2$
  \[
  \Delta R = \sqrt{\Delta \phi^2 + \Delta \eta^2}
  \]
- $ET_{miss} > 25$ GeV
- $m_T > 40$ GeV, where the transverse mass is:
  \[
  m_T = \sqrt{2 \ p_T^\ell \ E_T^{miss} \ (1 - \cos \Delta \phi)}
  \]
  and $\Delta \phi$ is the azimuthal separation between $ET_{miss}$ and the lepton.
W inclusive: fiducial limits

- \( W \rightarrow e\nu \)
  - \( E_{T e} > 20 \text{ GeV} \)
  - \( |\eta_e| < 2.47 \), excluding \( 1.37 < |\eta_e| < 1.52 \)
  - \( p_T^\nu > 25 \text{ GeV} \)
  - \( m_T > 40 \text{ GeV} \)
- \( W \rightarrow \mu\nu \)
  - \( p_T^\mu > 20 \text{ GeV} \)
  - \( |\eta_\mu| < 2.4 \)
  - \( p_T^\nu > 25 \text{ GeV} \)
  - \( m_T > 40 \text{ GeV} \)
\[ W \rightarrow \mu \nu_{\mu} \text{ inclusive: } p_{T} \text{ & } m_{T} \]

Muon candidate events and backgrounds before ETmiss requirement
$W \rightarrow \mu \nu_\mu$ inclusive: $m_T$ & $p_T$

Muon candidate events and backgrounds

After $E_T^{miss} > 25$GeV

**ATLAS**

$\int L \, dt = 310 \, nb^{-1}$

Entries / 5 GeV

- Data 2010 ($\sqrt{s} = 7$ TeV)
- $W \rightarrow \mu \nu$
- QCD
- $W \rightarrow \tau \nu$
- $Z \rightarrow \mu \mu$
- $Z \rightarrow \tau \tau$
- $t\bar{t}$

After $E_T^{miss} > 25$GeV & $m_T > 40$GeV

**ATLAS**

$\int L \, dt = 310 \, nb^{-1}$

Entries / 2.5 GeV

- Data 2010 ($\sqrt{s} = 7$ TeV)
- $W \rightarrow \mu \nu$
- QCD
- $W \rightarrow \tau \nu$
- $Z \rightarrow \mu \mu$
- $Z \rightarrow \tau \tau$
- $t\bar{t}$
$W \rightarrow \mu \nu \mu$ inclusive: candidates and backgrounds

<table>
<thead>
<tr>
<th>$\ell$</th>
<th>Observed candidates</th>
<th>Background (EW+$t\bar{t}$)</th>
<th>Background (QCD)</th>
<th>Background-subtracted signal $N_{W}^{\text{sig}}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>$e^+$</td>
<td>637</td>
<td>$18.8 \pm 0.2 \pm 1.7$</td>
<td>$14.0 \pm 2.1 \pm 7.1$</td>
<td>$604.2 \pm 25.2 \pm 7.6$</td>
</tr>
<tr>
<td>$e^-$</td>
<td>432</td>
<td>$14.7 \pm 0.2 \pm 1.3$</td>
<td>$14.0 \pm 2.1 \pm 7.1$</td>
<td>$403.2 \pm 20.8 \pm 7.5$</td>
</tr>
<tr>
<td>$e^\pm$</td>
<td>1069</td>
<td>$33.5 \pm 0.2 \pm 3.0$</td>
<td>$28.0 \pm 3.0 \pm 10.0$</td>
<td>$1007.5 \pm 32.7 \pm 10.8$</td>
</tr>
<tr>
<td>$\mu^+$</td>
<td>710</td>
<td>$42.5 \pm 0.2 \pm 2.9$</td>
<td>$12.0 \pm 3.0 \pm 4.6$</td>
<td>$655.6 \pm 26.6 \pm 6.2$</td>
</tr>
<tr>
<td>$\mu^-$</td>
<td>471</td>
<td>$35.1 \pm 0.2 \pm 2.4$</td>
<td>$10.9 \pm 2.4 \pm 4.1$</td>
<td>$425.0 \pm 21.7 \pm 5.4$</td>
</tr>
<tr>
<td>$\mu^\pm$</td>
<td>1181</td>
<td>$77.6 \pm 0.3 \pm 5.4$</td>
<td>$22.8 \pm 4.6 \pm 8.7$</td>
<td>$1080.6 \pm 34.4 \pm 11.2$</td>
</tr>
</tbody>
</table>

Electroweak backgrounds ($W \rightarrow \tau \nu$, $Z \rightarrow ll$, $Z \rightarrow \tau\tau$)

The background-subtracted signal events are used to calculate fiducial cross sections.
MC derived acceptance factors are used to convert the fiducial cross-section results into cross sections for the full phase space. The $W^+/W^-$ production asymmetry is expected from the $u$ and $d$ quark distributions in the proton.
W production asymmetry

\[
A_\ell = \frac{\sigma_{\text{fid}}^{W^+} - \sigma_{\text{fid}}^{W^-}}{\sigma_{\text{fid}}^{W^+} + \sigma_{\text{fid}}^{W^-}}
\]

Used to constrain parton distribution functions.

Expected from u and d valence quark distributions in the proton.

Uncertainty bounds correspond to 90% CL on PDF sets.
Experimental and theoretical uncertainties partially cancel to provide a more powerful test of the standard model.
W+jets production cross-section

• Test QCD as a function of the number of jets and the leading jet $p_T$.
• Important background for $t\bar{t}$bar, Higgs and BSM physics.

• Very similar selection to the inclusive W analysis.
  – Some additional requirements were made in the muon identification to reduce the QCD background.
W+jets: associated jet multiplicities

\[ \int L dt = 1.3 \text{ pb}^{-1} \]

Events

Inclusive Jet Multiplicity, \(N_{\text{jet}}\)

\(N_{\text{jet}}\)

\(\geq 0\)

\(\geq 1\)

\(\geq 2\)

\(\geq 3\)

\(\geq 4\)

ATLAS

Uncorrected

Data 2010, \(\sqrt{s} = 7 \text{ TeV}\)

\(W \rightarrow e\nu\)

QCD

\(W \rightarrow \tau\nu\)

\(Z \rightarrow e\bar{e}\)

\(t\bar{t}\)
W+jets: fiducial limits

• In a similar manner to the inclusive W measurements the cross-section is quoted within a fiducial limit corresponding to the detector acceptance and event selection at the particle-level.

  - $E_T^j > 20$ GeV, $|\eta_j| < 2.8$,
  - $E_T^l > 20$ GeV
  - $|\eta_e| < 2.47$ (excluding $1.37 < |\eta_e| < 1.52$)
  - $|\eta_\mu| < 2.4$
  - $p_T^{\nu} > 25$ GeV, $m_T > 40$ GeV, $\Delta R_{lj} > 0.5$
W+jets: inclusive jet multiplicity

Measurements at the particle-level, within the selected fiducial volume.
Measurements at the particle-level, within the selected fiducial volume.
The top quark

• The heaviest fundamental particle observed.
  – Expect large coupling to the mediator of electroweak symmetry breaking.
  – Possible new physics may couple to the top quark.
    • Therefore, seek to test Standard Model predictions of properties and production.
b-tagging

- Tracks associated with a jet are used to determine the decay length of the particle which fragmented into a jet.
  - Tracks are chosen that fulfill minimal quality requirements.
  - A secondary vertex fit is formed iteratively removing tracks with large $\chi^2$ contributions until the $\chi^2$ of the fit is below a selected threshold.
  - Two track vertices which originate from a material layer are discarded.

The signed decay length significance $L/\sigma(L)$ for the SV0 $b$-tagging algorithm for simulated QCD jets.
Top (l+jets): event selection

- Similar lepton identification to the W+jets analysis.
- Exclusively one lepton with $p_T > 20 \text{ GeV}$
- $E_T^{\text{miss}} > 20 \text{ GeV}$
- $E_T^{\text{miss}} + m_T > 60 \text{ GeV}$
- Jet $p_T > 25 \text{ GeV}$
- One or more b-tagged jet. ("tagged")
Jet multiplicity distributions

For jets with $p_T > 25$ GeV & $|\eta| < 2.5$

Hatched area represents total uncertainty on background.
$M_{jjj}$ invariant mass

Hardest three jets are combined without b-tagging weight. The combination is $\sim 25\%$ correct. There is good agreement between predicted and observed $t\bar{t}$ shapes.

Hatched area represents total uncertainty on background.
Forming a final result

- The number of events in the inclusive 4 jet bin after background subtraction was used together with acceptance factors derived from MC and the branching ratios.
- The result of the l+jets analysis was combined with the di-lepton analysis to form a final result.
First \( t\bar{t} \) cross-section comparison

ATLAS result is from a combination of \( l+jets \) and dilepton channels.

CMS result is from just the dilepton channels.
Conclusions

• Charged-particle multiplicity studies have lead to better MC tunes.
  – Diffractive models could still be improved.

• Inclusive W and W with associated jet production cross-sections have been measured.
  – Perturbative QCD calculations agree with these measurements.

• An initial ttbar cross-section measurement has been made.
  – CMS and ATLAS results are in agreement.
  – NNLO QCD measurements agree with these measurements.
Analyses for 2011/12

• Production cross-section of ttbar + jets
  – Experimental measurements of 0 and 1 jet at the Tevatron.
  – Theoretical calculations are difficult.
    • Large number of diagrams and the presence of massive particles.
  – Background to Higgs boson production in vector boson fusion, BSM processes involving lepton + jets.

• t’ – Heavy top like 4\textsuperscript{th} generation searches.

• ttbar production asymmetry
  – 2\sigma excess observed at the Tevatron.

• Vector boson scattering (W+jets, Z+jets)
  – Discriminate between Higgs and dynamic symmetry breaking models.
ttbar, associated jets and asymmetry

Expected and observed number of events as a function of jet multiplicity for events with at least one b-tag and additional selection

$H_T > 220 \text{ GeV}$, and $\text{MET} > 20 \text{ GeV}$

Inclusive forward-backward asymmetry in tt production in the dilepton channel using 334 dilepton candidates
References for further reading

arXiv:1012.5104 Charged-particle multiplicities
arXiv:1010.2130 Inclusive W cross-section
arXiv:1012.5382 W+jets cross-section
arXiv:1012.1792 Top cross-section
Additional slides
Charged-particle multiplicities

<table>
<thead>
<tr>
<th>Systematic Uncertainty</th>
<th>Size</th>
<th>Region</th>
</tr>
</thead>
<tbody>
<tr>
<td>Material</td>
<td>±2 – 15%</td>
<td>decreases with $p_T$, increases with $</td>
</tr>
<tr>
<td>$\chi^2$ prob. cut</td>
<td>±10%</td>
<td>flat, only for $p_T &gt; 10$ GeV</td>
</tr>
<tr>
<td>Resolution</td>
<td>±5%</td>
<td>$100 &lt; p_T &lt; 150$ MeV</td>
</tr>
<tr>
<td></td>
<td>negligible</td>
<td>$0.15 &lt; p_T &lt; 10$ GeV</td>
</tr>
<tr>
<td></td>
<td>−7%</td>
<td>$p_T &gt; 10$ GeV</td>
</tr>
<tr>
<td>Track Selection</td>
<td>±1%</td>
<td>flat in $p_T$ and $\eta$</td>
</tr>
<tr>
<td>Truth Matching</td>
<td>±1%</td>
<td>only for $\sqrt{s} = 2.36$ TeV Pixel Tracks</td>
</tr>
<tr>
<td>Efficiency correction factor</td>
<td>±4%</td>
<td>only for $\sqrt{s} = 2.36$ TeV ID Track</td>
</tr>
<tr>
<td>Alignment and other high $p_T$</td>
<td>-3% to -30%</td>
<td>only for $p_T &gt; 10$ GeV, averaged over $\eta$, increases with increasing $p_T$</td>
</tr>
</tbody>
</table>

Table 5: The systematic uncertainties on the track reconstruction efficiency for $\sqrt{s} = 0.9$ TeV, $\sqrt{s} = 7$ TeV and $\sqrt{s} = 2.36$ TeV Pixel Track and ID Track methods. Unless otherwise stated, the systematic is similar for all energies and phase-space regions. All uncertainties are quoted relative to the track reconstruction efficiency.
LAr calorimeter module

Sketch of a barrel module
$\sigma_W \times \text{BR}(W \rightarrow l\nu)$ for $W^+$, $W^-$

\[
\begin{align*}
\sigma_{W^+}^{\text{tot}} \cdot \text{BR}(W \rightarrow l\nu) &= 5.93 \pm 0.17 \text{ (stat)} \pm 0.30 \text{ (syst)} \pm 0.65 \text{ (lumi) nb}, \\
\sigma_{W^-}^{\text{tot}} \cdot \text{BR}(W \rightarrow l\nu) &= 4.00 \pm 0.15 \text{ (stat)} \pm 0.20 \text{ (syst)} \pm 0.44 \text{ (lumi) nb}, \\
\sigma_{W}^{\text{tot}} \cdot \text{BR}(W \rightarrow l\nu) &= 9.96 \pm 0.23(\text{stat}) \pm 0.50(\text{syst}) \pm 1.10(\text{lumi}) \text{ nb}.
\end{align*}
\]
## W+jets systematic uncertainties

<table>
<thead>
<tr>
<th>Effect</th>
<th>Range</th>
<th>Cross Section Uncertainty (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Jet energy scale and $E_T^{miss}$</td>
<td>±10% (dependent on jet $\eta$ and $p_T$) $\oplus$ 5%</td>
<td>+11, -9</td>
</tr>
<tr>
<td>Jet energy resolution</td>
<td>14% on each jet</td>
<td>±1.0</td>
</tr>
<tr>
<td>Electron trigger</td>
<td>±0.5%</td>
<td>±0.7</td>
</tr>
<tr>
<td>Electron identification</td>
<td>±5.2%</td>
<td>±5.5</td>
</tr>
<tr>
<td>Electron energy scale</td>
<td>±3%</td>
<td>+3.9, -4.7</td>
</tr>
<tr>
<td>Pile-up removal cut</td>
<td>4 – 7% in lowest jet $p_T$ bin</td>
<td>±1.9</td>
</tr>
<tr>
<td>Residual pile-up effects</td>
<td>from simulation</td>
<td>±2.2</td>
</tr>
<tr>
<td>QCD background shape</td>
<td>from template variation</td>
<td>-1.5, +5.2</td>
</tr>
<tr>
<td>Luminosity</td>
<td>±11%</td>
<td>-10, +13</td>
</tr>
</tbody>
</table>

### $\mu$ channel

<table>
<thead>
<tr>
<th>Effect</th>
<th>Range</th>
<th>Cross Section Uncertainty (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Jet energy scale and $E_T^{miss}$</td>
<td>±10% (dependent on jet $\eta$ and $p_T$) $\oplus$ 5%</td>
<td>+11, -9</td>
</tr>
<tr>
<td>Jet energy resolution</td>
<td>14% on each jet</td>
<td>±1.8</td>
</tr>
<tr>
<td>Muon trigger</td>
<td>±2.5% in barrel, ±2.0% in endcap</td>
<td>±1.6</td>
</tr>
<tr>
<td>Muon reconstruction</td>
<td>±5.6%</td>
<td>-5.4, +5.9</td>
</tr>
<tr>
<td>Muon momentum scale</td>
<td>±1%</td>
<td>+2, -0.9</td>
</tr>
<tr>
<td>Muon momentum resolution</td>
<td>±5% in barrel, ±9% in endcap</td>
<td>±1.4</td>
</tr>
<tr>
<td>Pile-up removal cut</td>
<td>4 – 7% in lowest jet $p_T$ bin</td>
<td>±1.7</td>
</tr>
<tr>
<td>Residual pile-up effects</td>
<td>from simulation</td>
<td>±1.4</td>
</tr>
<tr>
<td>Luminosity</td>
<td>±11%</td>
<td>-11, +13</td>
</tr>
</tbody>
</table>

Table 3: Summary of the systematic uncertainties in the cross section. The uncertainties are shown only for $N_{\text{jet}} \geq 1$. The sign convention for the JES and lepton energy scale uncertainties is such that a positive change in the energy scale results in an increase in the jet or lepton energy observed in the data.
b-tagging
ttbar cross-section: uncertainties

<table>
<thead>
<tr>
<th>Source</th>
<th>Relative cross-section uncertainty [%]</th>
<th>$e+$jets</th>
<th>$\mu+$jets</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Statistical uncertainty</strong></td>
<td></td>
<td>±43</td>
<td>±29</td>
</tr>
<tr>
<td><strong>Object selection</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Lepton reconstruction, identification, trigger</td>
<td></td>
<td>±3</td>
<td>±2</td>
</tr>
<tr>
<td>Jet energy reconstruction</td>
<td></td>
<td>±13</td>
<td>±11</td>
</tr>
<tr>
<td>$b$-tagging</td>
<td></td>
<td>-10 / +15</td>
<td>-10 / +14</td>
</tr>
<tr>
<td><strong>Background rates</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>QCD normalisation</td>
<td></td>
<td>±30</td>
<td>±2</td>
</tr>
<tr>
<td>$W$+jets normalisation</td>
<td></td>
<td>±11</td>
<td>±11</td>
</tr>
<tr>
<td>Other backgrounds normalisation</td>
<td></td>
<td>±1</td>
<td>±1</td>
</tr>
<tr>
<td><strong>Signal simulation</strong></td>
<td></td>
<td>-6 / +13</td>
<td>±8</td>
</tr>
<tr>
<td>Initial/final state radiation</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Parton distribution functions</td>
<td></td>
<td>±2</td>
<td>±2</td>
</tr>
<tr>
<td>Parton shower and hadronisation</td>
<td></td>
<td>±1</td>
<td>±3</td>
</tr>
<tr>
<td>Next-to-leading-order generator</td>
<td></td>
<td>±4</td>
<td>±6</td>
</tr>
<tr>
<td>Integrated luminosity</td>
<td></td>
<td>-11 / +14</td>
<td>-10 / +13</td>
</tr>
<tr>
<td><strong>Total systematic uncertainty</strong></td>
<td></td>
<td>-38 / +43</td>
<td>-23 / +27</td>
</tr>
<tr>
<td><strong>Statistical + systematic uncertainty</strong></td>
<td></td>
<td>-58 / +61</td>
<td>-37 / +40</td>
</tr>
</tbody>
</table>

DPNC Genève - 2011/03/09