Measurement of the \( W \rightarrow \ell\nu \) and \( Z \rightarrow \ell\ell \)
production cross section in proton-proton collisions at \( \sqrt{s} = 7 \text{ TeV} \)
with the ATLAS detector

ATLAS-CONF-2010-051, ATLAS-CONF-2010-076

Jan Kretzschmar

University of Liverpool

On behalf of the ATLAS collaboration

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Inclusive production of $W^\pm$ and $Z$ bosons is a high cross section process, total $\sigma$ known to $\sim 4\%$, dominated by PDF uncertainties

$$
\sigma_{W^+\rightarrow\ell^+\nu}^{NNLO} = 6.16 \text{ nb} \quad \sigma_{W^-\rightarrow\ell^-\bar{\nu}}^{NNLO} = 4.30 \text{ nb} \quad \sigma_{Z/\gamma^*\rightarrow\ell\ell}^{NNLO} = 0.96 \text{ nb}
$$

$\sqrt{s} = 7$ TeV, calculated with FEWZ using MSTW2008NNLO PDFs

Measurements in the electron and muon channels are important:

- Precise tests of QCD in unexplored regions of low parton momentum fraction at large scales; eventually constrain PDFs
- Detector commissioning and calibration especially using $Z/\gamma^*\rightarrow\ell\ell$ — Paving the road to precision measurements and new Physics!
Data and MC Samples

- $W$ cross sections: $\mathcal{L} \approx 17 \text{ nb}^{-1}$ taken until June
- $Z$ cross sections: $\mathcal{L} \approx 225 \text{ nb}^{-1}$
- Preview: $\mathcal{L} \approx 300 - 330 \text{ nb}^{-1}$
- Luminosity calibrated to 11% using van-der-Meer scans
- Recorded using single electron and muon hardware triggers with low thresholds

- MC signal and background with many $10^6$ events per sample, fully simulated with GEANT4
- Pythia signal MC generated with MRST LO* PDFs, norm. to $\sigma^{NNLO}$
- Cross checks and acceptance calculations with latest MC@NLO version and CTEQ6.6 and HERAPDF1.0 PDFs
- QCD background is determined mostly directly from the data
Electron Reconstruction and Identification

Central $|\eta| < 2.47$: Calorimeter Cluster + Track

- **Loose Preselection**: Calorimeter 2$^{nd}$ sampling shapes and leakage
- **Medium** for $Z \rightarrow ee$: add Calorimeter 1$^{st}$ sampling shapes, Si tracker hits and impact parameter, track-cluster matching
- **Tight** for $W \rightarrow e\nu$: add b-layer hits and TRT high threshold hits, conversion rejection, $E/p$ matching

Forward $2.5 < |\eta| < 4.9$: Only Calorimeter Cluster

- **forward Loose** Preselection
- **forward Tight** for $Z \rightarrow ee$ with one central + one forward electron
Muon Reconstruction

*Combined muon* $|\eta| < 2.4$:
- muon spectrometer (MS) + inner detector (ID) track
- Decays in flight, cosmics and other background reduced by $p_T$ and spatial matching cuts between MS and ID
Towards \( W: \) Lepton Preselection

- Largely dominated by QCD background, \( W \) signal at large \( \mathbb{E}_T \)

**Electron channel**
- \(|\eta| < 1.37\) or \(|\eta| < 2.47\)
- \( E_T > 20 \text{ GeV} \)
- Loose identification
- QCD scaled \( \times 0.4 \)

**Muon channel**
- \(|\eta| < 2.4\)
- \( p_T > 15 \text{ GeV} \)
- QCD scaled \( \times 0.6 \)

\( \mathbb{E}_T \) calibrated for different EM/hadronic response
Towards $W$: Final Lepton Selection

$W$ signal emerging clearly after further cuts to reduce fake leptons

Electron channel
- Using *tight* identification
- Calorimetric isolation in $\Delta R = 0.3$ cone used for QCD background estimation

Muon channel
- Cut on rel. Track isolation $< 0.2$ in $\Delta R = 0.4$ cone for lepton selection
Final W Signal and Background

- Requires $H_T > 25$ GeV and transverse mass
  \[ m_T = \sqrt{2p_T^\ell p_T^\nu (1 - \cos(\phi^\ell - \phi^\nu))} > 40 \text{ GeV} \]
- Observe 46 $e^\pm$ and 72 $\mu^\pm$ candidates
- Electroweak backgrounds (mainly $W \to \tau\nu$ in electron, $Z \to \mu\mu$ in muon channel) largest, taken from MC with $\lesssim 10\%$ syst. uncertainty
- QCD small, estimated with data driven techniques with $\approx 50\%$ syst. uncertainty

<table>
<thead>
<tr>
<th></th>
<th>Observed</th>
<th>EW Bkg.</th>
<th>QCD Bkg.</th>
</tr>
</thead>
<tbody>
<tr>
<td>$e^+$</td>
<td>27</td>
<td>0.9</td>
<td>0.6</td>
</tr>
<tr>
<td>$e^-$</td>
<td>19</td>
<td>0.6</td>
<td>0.6</td>
</tr>
<tr>
<td>$e^\pm$</td>
<td>46</td>
<td>1.5</td>
<td>1.1</td>
</tr>
<tr>
<td>$\mu^+$</td>
<td>47</td>
<td>2.4</td>
<td>0.7</td>
</tr>
<tr>
<td>$\mu^-$</td>
<td>25</td>
<td>2.0</td>
<td>0.2</td>
</tr>
<tr>
<td>$\mu^\pm$</td>
<td>72</td>
<td>4.4</td>
<td>0.9</td>
</tr>
</tbody>
</table>
Lepton Kinematics with Full W Selection

Good description of lepton kinematics, also separated by charges.
Measurement of the W Cross Sections

- Fiducial cross section inside the acceptance defined by geometrical and kinematic cuts

\[ \sigma_{W}^{\text{fid}} \times \text{BR}(W \rightarrow \ell\nu) = \frac{N_{\text{obs}} - N_{\text{bkg}}}{C_{W}L_{\text{int}}} \]

- Correction for reconstruction, identification, trigger efficiencies and radiative effects performed with a single factor \( C_{W} \) taken from MC

- Total cross section is obtained using the geometrical acceptance \( A_{W} \)

\[ \sigma_{W}^{\text{tot}} \times \text{BR}(W \rightarrow \ell\nu) = \frac{\sigma_{W}^{\text{fid}}}{A_{W}} \text{ where } A_{W} = \left( \frac{N_{\text{acc}}}{N_{\text{all}}} \right)_{\text{gen}} \]

<table>
<thead>
<tr>
<th>Generator</th>
<th>( A_{W} ) ( W^{+} \rightarrow e^{+}\nu )</th>
<th>( A_{W} ) ( W^{+} \rightarrow \mu^{+}\nu )</th>
<th>( A_{W} ) ( W^{-} \rightarrow e^{-}\bar{\nu} )</th>
<th>( A_{W} ) ( W^{-} \rightarrow \mu^{-}\bar{\nu} )</th>
</tr>
</thead>
<tbody>
<tr>
<td>PYTHIA MRSTLO*</td>
<td>0.466</td>
<td>0.484</td>
<td>0.457</td>
<td>0.475</td>
</tr>
<tr>
<td>MC@NLO HERAPDF1.0</td>
<td>0.475</td>
<td>0.494</td>
<td>0.454</td>
<td>0.472</td>
</tr>
<tr>
<td>MC@NLO CTEQ6.6</td>
<td>0.478</td>
<td>0.496</td>
<td>0.452</td>
<td>0.470</td>
</tr>
</tbody>
</table>

- Also \( W^{+} + W^{-} \) averaged; systematics from different generators \( \approx 3\% \)
Contributions and Uncertainties to $C_W$

- Much work has been invested to determine corrections and uncertainties to the MC derived $C_W$ factors.
- Done using data as far as possible with current statistics, partially using other channels like $\pi^0 \rightarrow \gamma\gamma$, $J/\psi$ or QCD dijets: e.g. trigger, $\mu$ reconstruction.
- Employ special MC samples with additional material or misalignments.
- $Z \rightarrow \ell\ell$ will soon become basis for systematic studies.

<table>
<thead>
<tr>
<th></th>
<th>$W \rightarrow e\nu$</th>
<th>$W \rightarrow \mu\nu$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Trigger</td>
<td>$99.9 \pm 0.1%$</td>
<td>$88% \pm 4%$</td>
</tr>
<tr>
<td>Lepton reconstruction</td>
<td>$78 \pm 6%$</td>
<td>$97% \pm 4%$</td>
</tr>
<tr>
<td>+ identification</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Material + dead regions</td>
<td>$\pm 4%$</td>
<td>—</td>
</tr>
<tr>
<td>Lepton scale &amp; resolution</td>
<td>$\pm 3%$</td>
<td>$\pm 4%$</td>
</tr>
<tr>
<td>$E_T$ scale &amp; resolution</td>
<td></td>
<td>$\pm 2%$</td>
</tr>
<tr>
<td>charge averaged $C_W$</td>
<td>$66 \pm 8%$</td>
<td>$81 \pm 7%$</td>
</tr>
</tbody>
</table>

Jan Kretzschmar, 23.7.2010 – p.11
**W Cross Section Results** $\mathcal{L} = 17 \text{ nb}^{-1}$

<table>
<thead>
<tr>
<th></th>
<th>$W^+$</th>
<th>$W^-$</th>
<th>$W^\pm$</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Electron channel</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>$\sigma_{\text{fid}} [\text{nb}]$</td>
<td>$2.3 \pm 0.5 \pm 0.2 \pm 0.3$</td>
<td>$1.6 \pm 0.4 \pm 0.1 \pm 0.2$</td>
<td>$3.9 \pm 0.6 \pm 0.3 \pm 0.4$</td>
</tr>
<tr>
<td>$\sigma_{\text{tot}} [\text{nb}]$</td>
<td>$5.0 \pm 1.0 \pm 0.4 \pm 0.5$</td>
<td>$3.5 \pm 0.9 \pm 0.3 \pm 0.4$</td>
<td>$8.5 \pm 1.3 \pm 0.7 \pm 0.9$</td>
</tr>
<tr>
<td><strong>Muon channel</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>$\sigma_{\text{fid}} [\text{nb}]$</td>
<td>$3.2 \pm 0.5 \pm 0.2 \pm 0.4$</td>
<td>$1.7 \pm 0.4 \pm 0.1 \pm 0.2$</td>
<td>$4.9 \pm 0.6 \pm 0.4 \pm 0.5$</td>
</tr>
<tr>
<td>$\sigma_{\text{tot}} [\text{nb}]$</td>
<td>$6.6 \pm 1.0 \pm 0.5 \pm 0.7$</td>
<td>$3.6 \pm 0.8 \pm 0.3 \pm 0.4$</td>
<td>$10.3 \pm 1.3 \pm 0.8 \pm 1.1$</td>
</tr>
<tr>
<td><strong>Theory Expectations</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>$\sigma_{\text{tot}} [\text{nb}]$</td>
<td>$6.16 \pm 0.25$</td>
<td>$4.30 \pm 0.17$</td>
<td>$10.46 \pm 0.42$</td>
</tr>
</tbody>
</table>

- The limited data statistics is (still) dominating the result
- Good agreement with theory expectation within uncertainties so far
Inclusive $W \rightarrow \ell \nu$ at Hadron Colliders

\[ \sigma_W \times \text{Br}(W \rightarrow \ell \nu) \text{[nb]} \]

ATLAS Preliminary

NNLO QCD (FEWZ)

ATLAS data 2010 ($\sqrt{s} = 7 \text{ TeV}$)

$\int L = 17 \text{ nb}^{-1}$

\[ W \rightarrow (e/\mu)\nu \]
\[ W^+ \rightarrow (e^+/\mu^+)\nu \]
\[ W^- \rightarrow (e^-/\mu^-)\nu \]

CDF $W \rightarrow \ell \nu$

D0 $W \rightarrow (e/\mu)\nu$

UA1 $W \rightarrow \ell \nu$

UA2 $W \rightarrow e \nu$

Jan Kretzschmar, 23.7.2010 – p.13
Lepton Charge Asymmetry

- Difference of $W^+$ and $W^-$ production can be measured via the lepton charge asymmetry
  \[ A = \frac{\sigma^{l^+} - \sigma^{l^-}}{\sigma^{l^+} + \sigma^{l^-}} \]

- Constrains $u/d$ quark ratio in proton, perform as function of $\eta_l$ (correlated to parton momentum fraction $x$)

- Many uncertainties cancel fully (luminosity) or partially (lepton efficiencies)
**Z → ℓℓ Selection**

- Relaxed cuts compared to $W$ analysis, but same preselection
- Measurement in invariant mass window $66 < m_{\ell\ell} < 116 \text{ GeV}$

**Electron channel**
- *Medium* cuts, opposite charge
- 46 candidates for background of $0.5 \pm 0.1$ events (dominated by QCD)

**Muon channel**
- Track isolation, opposite charge
- 79 candidates for background of $0.17 \pm 0.02$ events ($t\bar{t}$, $Z \rightarrow \tau\tau$, $b\bar{b}$)
Measurement of the $Z/\gamma^*$ Cross Section

Same Procedure as for the $W$ is used to determine $\sigma_{\text{fid}}$ and $\sigma_{\text{tot}}$:

$$\sigma_{\text{fid}}^Z \times \text{BR} = \frac{N_{\text{obs}} - N_{\text{bkg}}}{C_Z \mathcal{L}_{\text{int}}}$$

$$\sigma_{\text{tot}}^Z \times \text{BR} = \frac{\sigma_{\text{fid}}^Z}{A_Z}$$

Uncertainties on $C_Z$ correction factor

<table>
<thead>
<tr>
<th></th>
<th>$Z \rightarrow ee$</th>
<th>$Z \rightarrow \mu\mu$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Trigger</td>
<td>±0.2%</td>
<td>±2%</td>
</tr>
<tr>
<td>Effect of Lepton reconstruction + identification</td>
<td>±14%</td>
<td>±7%</td>
</tr>
<tr>
<td>Lepton scale &amp; resolution</td>
<td>±2%</td>
<td>±1%</td>
</tr>
<tr>
<td>$C_Z$</td>
<td>65 ± 14%</td>
<td>80 ± 7%</td>
</tr>
</tbody>
</table>

Geometrical acceptance values $A_Z$ known to at least $\approx 3\%$

<table>
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<td>0.485</td>
</tr>
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### Z/γ* Cross Section Results

<table>
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<th>Muon channel</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>σ ± stat ± sys ± lumi</td>
<td></td>
</tr>
<tr>
<td>$\sigma_{\text{fid}}$ [nb]</td>
<td>0.32 ± 0.05 ± 0.05 ± 0.04</td>
<td>0.43 ± 0.05 ± 0.03 ± 0.05</td>
</tr>
<tr>
<td>$\sigma_{\text{tot}}$ [nb]</td>
<td>0.72 ± 0.11 ± 0.10 ± 0.08</td>
<td>0.89 ± 0.10 ± 0.07 ± 0.10</td>
</tr>
</tbody>
</table>

- Agreement with theory expectation of $\sigma_{\text{tot}} = 0.96 \pm 0.04$ nb

![Graph showing the cross-section results](attachment:image.png)
Summary

A large rate of $W$ and $Z$ are expected to be recorded with the ATLAS in the electron and muon channels: important to calibrate the detector, precision tests of QCD and constraining PDFs.

Using the first $17 \text{ nb}^{-1}$ of data
- $46 \ W \rightarrow e\nu$ candidates over $2.6$ background events
  $\sigma_{\text{tot}} = 8.5 \pm 1.3(\text{stat}) \pm 0.7(\text{sys}) \pm 0.9(\text{lumi}) \text{ nb}$
- $72 \ W \rightarrow \mu\nu$ candidates over $5.3$ background events
  $\sigma_{\text{tot}} = 10.3 \pm 1.3(\text{stat}) \pm 0.8(\text{sys}) \pm 1.1(\text{lumi}) \text{ nb}$
- Agrees with SM expectation $\sigma_{\text{tot}}^{NNLO} = 10.46 \pm 0.42 \text{ nb}$

Using the first $225 \text{ nb}^{-1}$ of data
- $46 \ Z \rightarrow ee$ candidates over $0.5$ background events
  $\sigma_{\text{tot}} = 0.72 \pm 0.11(\text{stat}) \pm 0.10(\text{sys}) \pm 0.08(\text{lumi}) \text{ nb}$
- $79 \ Z \rightarrow \mu\mu$ candidates over $0.2$ background events
  $\sigma_{\text{tot}} = 0.89 \pm 0.10(\text{stat}) \pm 0.07(\text{sys}) \pm 0.10(\text{lumi}) \text{ nb}$
- Agrees with SM expectation $\sigma_{\text{tot}}^{NNLO} = 0.96 \pm 0.04 \text{ nb}$
An exciting start with much more to come...

815 $W \rightarrow e\nu$

56 $Z \rightarrow ee$

1111 $W \rightarrow \mu\nu$

106 $Z \rightarrow \mu\mu$

\[ L = 296 \text{ nb}^{-1} \]

\[ L = 297 \text{ nb}^{-1} \]

\[ L = 291 \text{ nb}^{-1} \]

\[ L = 331 \text{ nb}^{-1} \]