W and Z boson production at CMS in pp collisions at $\sqrt{s}=7$ TeV

Jeremiah Mans
University of Minnesota
On behalf of the CMS Collaboration

ICHEP 2010
Paris, France :::: July 22, 2010
Outline

- **Motivations and Physics Reach**
- **CMS Performance**
- **Inclusive measurements**
  - $W \rightarrow e\nu / W \rightarrow \mu\nu$
  - $Z \rightarrow e\nu / Z \rightarrow \mu\nu$
- **Differential Measurements**
  - $W$ charge asymmetry
  - $Z$ rapidity
  - $Z/W +$ jets
- **Outlook**

This talk has a broad view of the W/Z, including both new data and near-term prospects. For all the details on the W/Z extraction from first data, see Maria Cepeda’s talk tomorrow in Session 1 (11am)
Properties of W/Z well-established
- Masses and Widths
- Decay Products
- Theoretical understanding of production processes

Use W/Z as tools to study:
- Detector effects/performance
- Luminosity
- Collision environment (PDFs)
- Analysis Techniques
- W/Z define a hard scale for many physics measurements

First Steps
- Isolation of W/Z signals
- Understand efficiencies and acceptance
- Measure cross-sections
Data and Monte Carlo Samples

- Data collected at $\sqrt{s}=7$ TeV from March 30 through July 15 2010
  - $\int L dt=198$ nb$^{-1}$ analyzed
    (out of 303 nb$^{-1}$ collected by CMS)

- Large samples of Monte Carlo simulated data used for
  - Validation of analysis techniques
  - Evaluation of signal acceptance and for input to signal and background shapes

- EWK ($W\rightarrow lv$, $Z\rightarrow ll$) processes generated with NLO Monte Carlo (POWHEG)

- QCD and some minor backgrounds (ttbar) generated at LO (PYTHIA)
Missing Transverse Energy

- Missing transverse energy reconstructed using “particle flow” objects which combine calorimeter and track measurements to provide the highest possible resolution
  - Events are also cleaned to remove calorimeter instrumental noise
Muons

- Kinematics
  - For W, $p_T > 9$ GeV, $|\eta| < 2.1$
  - For Z, $p_T > 20$ GeV, one $|\eta| < 2.4$

- Good quality muon track
  - Hits in pixels, strip tracker, muon system)
  - $\chi^2$/dof $< 10$

- Z measurement requires only track isolation of 3 GeV in a cone
- For W measurement, use a relative isolation in a cone of $\Delta R < 0.3$:

$$I_{\text{rel,comb}} = \left\{ \sum (p_T(\text{tracks}) + E_T(\text{em}) + E_T(\text{had})) \right\} / p_T(\mu)$$
Electrons

- Kinematics
  \[ p_T > 20 \text{ GeV} \]
  \[ 0.0 < |\eta| < 1.442 \]
  \[ 1.566 < |\eta| < 2.5 \]

- Specialized track reconstruction to deal with potential large bremsstrahlung

- Electron identification requirements on shower shape variables

- Isolation requirements in tracker, ECAL, HCAL
W Signal Extraction

- Yield of W bosons determined using simultaneous fits to background and signal contributions.
- QCD background shapes obtained using data, electroweak background and signal shapes from Monte Carlo simulation.
Systematic Errors for \(W\)

- Efficiencies and scales studied in \(Z\) events and recoil studies
- Background uncertainties from cut inversion studies and control samples
- PDF uncertainties evaluated via CTEQ66, MSTW08NLO, NNPDF2.0 sets

<table>
<thead>
<tr>
<th>Source</th>
<th>(W \rightarrow \mu \nu) (%)</th>
<th>(W \rightarrow e\nu) (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lepton reconstruction</td>
<td>3.0</td>
<td>6.1</td>
</tr>
<tr>
<td>Trigger Efficiency</td>
<td>3.2</td>
<td>0.6</td>
</tr>
<tr>
<td>Isolation Efficiency</td>
<td>0.5</td>
<td>1.1</td>
</tr>
<tr>
<td>Momentum/energy scale</td>
<td>1.0</td>
<td>2.7</td>
</tr>
<tr>
<td>MET scale and resolution</td>
<td>1.0</td>
<td>1.4</td>
</tr>
<tr>
<td>Background subtraction</td>
<td>3.5</td>
<td>2.2</td>
</tr>
<tr>
<td>PDF uncertainty in acceptance</td>
<td>2.0</td>
<td>2.0</td>
</tr>
<tr>
<td>Other theoretical uncertainties</td>
<td>1.4</td>
<td>1.3</td>
</tr>
<tr>
<td>Total systematic error</td>
<td>6.3</td>
<td>7.7</td>
</tr>
<tr>
<td>Luminosity uncertainty</td>
<td>11.0</td>
<td>11.0</td>
</tr>
</tbody>
</table>
Z Signal Extraction

Observed: 77 $Z \rightarrow \mu\mu$ candidates with $60 \text{ GeV} < m_{\mu\mu} < 120 \text{ GeV}$

Observed: 61 $Z \rightarrow ee$ candidates with $60 \text{ GeV} < m_{ee} < 120 \text{ GeV}$
## Systematic Errors for Z

<table>
<thead>
<tr>
<th>Source</th>
<th>$Z \rightarrow \mu\mu$ (%)</th>
<th>$Z \rightarrow ee$ (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lepton reconstruction</td>
<td>2.5</td>
<td>7.2</td>
</tr>
<tr>
<td>Trigger Efficiency</td>
<td>0.7</td>
<td>-</td>
</tr>
<tr>
<td>Isolation Efficiency</td>
<td>1.0</td>
<td>1.2</td>
</tr>
<tr>
<td>Momentum/energy scale</td>
<td>0.5</td>
<td>-</td>
</tr>
<tr>
<td>PDF uncertainty in acceptance</td>
<td>2.0</td>
<td>2.0</td>
</tr>
<tr>
<td>Other theoretical uncertainties</td>
<td>1.6</td>
<td>1.3</td>
</tr>
<tr>
<td>Total systematic error</td>
<td>3.8</td>
<td>7.7</td>
</tr>
<tr>
<td>Luminosity uncertainty</td>
<td>11.0</td>
<td>11.0</td>
</tr>
</tbody>
</table>
Full Results

\[ \int L \, dt = 198 \text{ nb}^{-1} \]

**W → μν**
9.14 ± 0.33 \text{ stat} ± 0.58 \text{ syst} ± 1.00 \text{ lumi nb}

**W → ev**
9.34 ± 0.36 \text{ stat} ± 0.70 \text{ syst} ± 1.03 \text{ lumi nb}

**W → lv (combined)**
9.22 ± 0.24 \text{ stat} ± 0.47 \text{ syst} ± 1.01 \text{ lumi nb}

\[ \sigma( pp \rightarrow W+X \rightarrow lv+X ) \text{ [nb]} \]

**Z/γ* → μμ**
0.88 ± 0.10 \text{ stat} ± 0.04 \text{ syst} ± 0.10 \text{ lumi nb}

**Z/γ* → ee**
0.88 ± 0.12 \text{ stat} ± 0.08 \text{ syst} ± 0.10 \text{ lumi nb}

**Z/γ* → ll (combined)**
0.88 ± 0.08 \text{ stat} ± 0.04 \text{ syst} ± 0.10 \text{ lumi nb}

\[ \sigma( pp \rightarrow Z/γ^*+X \rightarrow ll+X ) \text{ [nb]} \]

**W → μν, Z/γ* → μμ**
10.36 ± 1.34 \text{ stat} ± 0.78 \text{ syst}

**W → ev, Z/γ* → ee**
10.57 ± 1.54 \text{ stat} ± 1.20 \text{ syst}

**W → lv, Z/γ* → ll (combined)**
10.46 ± 0.99 \text{ stat} ± 0.65 \text{ syst}

\[ R_{W/Z} = \sigma( pp \rightarrow W+X \rightarrow lv+X )/\sigma( pp \rightarrow Z/γ^*+X \rightarrow ll+X ) \]

**NNLO, MSTW08 68% CL prediction**

\[ \sqrt{s} = 7 \text{ TeV} \]

\[ 10.44 ± 0.52 \text{ nb} \]

\[ 0.97 ± 0.04 \text{ nb} \]

\[ 10.74 ± 0.04 \]

\[ 10.46 ± 0.99 \text{ stat} ± 0.65 \text{ syst} \]

July 22, 2010

W/Z at CMS :::: J. Mans :::: ICHEP
Slicing up the Vector Bosons

-- or --

Differential Measurements of the Z and W
W charge Asymmetry

\[ A(\eta) = \frac{\frac{d\sigma}{d\eta} (W^+ \to \mu^+\nu) - \frac{d\sigma}{d\eta} (W^- \to \mu^-\nu)}{\frac{d\sigma}{d\eta} (W^+ \to \mu^+\nu) + \frac{d\sigma}{d\eta} (W^- \to \mu^-\nu)}. \]
Both electron and muon channels produce separate fit measurements for $W^+$ and $W^-$

- Some kinematic differences between $W^+$ and $W^-$ result in slightly different total efficiencies for $W^-$ and $W^+$

$$\int L \, dt = 198 \text{ nb}^{-1}$$

- $W \rightarrow \mu\nu$
  $$1.69 \pm 0.12 \text{ stat} \pm 0.04 \text{ syst}$$

- $W \rightarrow e\nu$
  $$1.26 \pm 0.10 \text{ stat} \pm 0.05 \text{ syst}$$

- $W \rightarrow l\nu$ (combined)
  $$1.51 \pm 0.08 \text{ stat} \pm 0.04 \text{ syst}$$
Initial W Asymmetry Results

CMS preliminary 2010

$\int L \, dt = 198 \text{ nb}^{-1}$

lepton charge asymmetry

W → $\mu\nu$ data

W → $e\nu$ data

NLO+NNLL (ResBos+CTEQ6.6)

lepton pseudorapidity, $|\eta|$
Z Differential Distributions (Uncorrected)

Many powerful differential measurements possible for dileptons

\[
\frac{d\sigma(Z \rightarrow l^+ l^-)}{d\cos \theta_{CS}}
\]

\[
\frac{d\sigma(Z \rightarrow l^+ l^-)}{d q_T}
\]

\[
\frac{d\sigma(Z \rightarrow l^+ l^-)}{dY}
\]

Even more Z results in the poster
“Forward-backward Charge Asymmetry for Muon Pairs via Z/gamma* at 7 TeV in CMS”
**W/Z + Jets**

- Crucial background to many new physics searches
  - Also an interesting measurement tool for QCD dynamics
- Measurement follows same selection as for inclusive analysis, but adds a focus on jet production
- Algorithm used: Anti-$k_t$ ($\Delta R = 0.5$) using Particle Flow Objects in $|\eta| < 2.5$
**W/Z + Jets**

See the poster "A Study of the Production of Vector Bosons and Jets at 7 TeV" for even more information on the V+jets results from CMS.
Outlook

- CMS is now making measurements with significant precision for EWK processes, filling in our understanding of EWK physics.
- The next 1-2 months should provide sufficient data for inclusive measurements and the full year dataset will be sufficient for precise differential measurements.