Measuring the W Mass at DØ

Mandy Rominsky on behalf of the DØ Collaboration
Why is precisely measuring the W mass important?

- In the Standard Model, the $M_W$ can be calculated from other EW parameters:

$$M_W = \sqrt{\frac{\pi \alpha}{\sqrt{2} G_F}} \frac{1}{\sin \theta_W \sqrt{1 - \Delta r}}$$

- And through radiative corrections ($\Delta r$) is related to $M_{\text{top}}$ and $M_H$

- Unknown particles in these loops will change the form of $\Delta r$

Precisely measuring $M_W$ limits couplings to new particles
Why is precisely measuring the W mass important?

- Prior to July 2012: Use $M_W$ to constrain $M_H$
- Now can also use $M_H$ to constrain $M_W$

Any deviation would be new physics
- Limited by the precision in $\Delta M_W$
  - Direct measurement: 15 MeV
  - Indirect measurement: 11 MeV
What are we measuring?

- $M_W$ is measured using the kinematic distributions in $W \rightarrow ev$ events:
  - Transverse mass
  - Lepton momentum
  - Missing transverse energy
- $Z \rightarrow ee$ events are used for detector calibration

$$M_T^W = \sqrt{2 \vec{P}_T \cdot \vec{E}_T (1 - \cos \Delta \phi)}$$
And where are we measuring it?

- Use the D0 calorimeter
- Central electron energy resolution is 4.2% averaged over electron E and $\eta$ spectra in W-$\nu$ events
- Use central electrons: $|\eta_{\text{det}}| < 1.05$

- Results presented here are based on 5.3 fb$^{-1}$ of data
- Another 5 fb$^{-1}$ are on tape and being analyzed
Analysis Strategy

• Measure distributions of 3 variables: $M_T^W$, $MeT$, $p_T^e$
• Compare data to parameterized detector model templates with different mass hypotheses
• Templates made with:
  • Generator level done with ResBos (W/Z production and decay), Photos (FSR)
  • Parameterized detector model built using Z->ee data samples
• Blinded Analysis
  • Central value hidden by an unknown offset.
• Use binned likelihood fits to extract mass from templates fit to data
• Combine results across observables
• Full MC closure test was performed to study the method
Electron Energy Response

- Calibrate the calorimeter for electron response
  - Use Z-ee data events
  - Use the Z peak to fit the parameters (precisely measured by LEP)
- First correct for nonlinear effects like underlying events and dead material
- Then assume a linear response
  - Use 4 luminosity bins

\[ R_{EM}(E) = \alpha(E - \bar{E}) + \beta + \bar{E} \]

\[ L = 36 \times 10^{30} \text{ cm}^{-2} \text{ s}^{-1} \]
Electron Energy Response

- Closure test using Z→ee data

\[ M_Z = 91.193 \pm 0.017 \text{ (stat) GeV} \]

World Average \( M_Z = 91.188 \pm 0.002 \text{ GeV} \)
Hadronic Recoil Response

\[ \vec{u}_T = \vec{u}_T^{HARD} + \vec{u}_T^{SOFT} + \vec{u}_T^{ELEC} + \vec{u}_T^{FSR} \]

- \( u_T^{Hard} \): Recoil against W/Z
- \( u_T^{Soft} \): Recoil from pileup and spectator partons
- \( u_T^{electron} \): Hadronic energy in cone or electron shower leakage out of cone
- \( u_T^{FSR} \): Final state radiation photons
Hadronic Recoil Response

- The $u_T^{Hard}$ component is derived from $Z \rightarrow \nu\nu$ events
- $u_T^{Soft}$ comes from zero bias and min bias data look up tables
- $u_T^{Elec}$ and $u_T^{FSR}$ are determined from dedicated simulations
- Final response and resolution taken from fits to momentum imbalance $\vec{p}_T(ee) + \vec{u}_T$
Systematic Uncertainties

- Experimental systematic uncertainties are driven by the statistics of the Z sample
- Electron Energy scale and PDF are the largest uncertainties

<table>
<thead>
<tr>
<th>Source</th>
<th>$\sigma(m_W)$ MeV</th>
<th>$m_T$</th>
<th>$\sigma(m_W)$ MeV $p_T(e)$</th>
<th>$\sigma(m_W)$ MeV $E_T$</th>
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<tbody>
<tr>
<td><strong>Experimental</strong></td>
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<tr>
<td>Electron Energy Scale</td>
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<td>Electron Energy Nonlinearity</td>
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<td>W and Z Electron energy loss differences</td>
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<td>Recoil Model</td>
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<td><strong>W production and decay model</strong></td>
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<td>Boson $p_T$</td>
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<td><strong>Total</strong></td>
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Results

<table>
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<tr>
<th>Method (4.3 $fb^{-1}$)</th>
<th>$M_W$ (MeV)</th>
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<tbody>
<tr>
<td>$m_T(e, \nu)$</td>
<td>$80371 \pm 13$ (stat)</td>
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<tr>
<td>$p_T(e)$</td>
<td>$80343 \pm 14$ (stat)</td>
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<tr>
<td>$E_T(e, \nu)$</td>
<td>$80355 \pm 15$ (stat)</td>
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<tr>
<td>Combination $m_T \oplus p_T$ (4.3 $fb^{-1}$)</td>
<td>$80367 \pm 26$ (syst + stat)</td>
</tr>
<tr>
<td>Combination (5.3 $fb^{-1}$)</td>
<td>$80375 \pm 23$ (syst + stat)</td>
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</tbody>
</table>
Conclusions

- D0 measured the W mass to $\Delta M_W = 23$ MeV
  - Same as previous world average
- Current world average is $\Delta M_W = 15$ MeV
  - Includes latest CDF result
- By including the full data set and end calorimeter electrons, we should reach $\Delta M_W = 15$ MeV with D0 alone
Backups
Event Selection

Event selection
• Single EM trigger
• Vertex $|z| < 60$ cm

Electron Selection
• $p_T > 25$ GeV
• $\text{HMatrix}_7 < 12$, $\text{emf} > 0.9$, $\text{iso} < 0.15$
• $|\eta_{\text{det}}| < 1.05$ (calorimeter fiducial region)
• In the calorimeter $\phi$ fiducial region, as determined by track
• Spatial track match, track $p_T > 10$ GeV and at least 1 SMT hit

Z-\text{ee} Selection
• At least 2 good electrons
• Hadronic recoil transverse moment $u_T < 15$ GeV
• Invariant mass: $70 < m_{ee} < 110$ GeV

W-\text{ev} Selection
• At least one good electron
• Hadronic recoil transverse moment $u_T < 15$ GeV
• Invariant mass: $50 < m_T < 200$ GeV
• $\text{MeT} > 25$ GeV

Forward electron Requirements: $\text{Hmatrix}_8 < 20$, $1.5 < |\eta_{\text{det}}| < 2.5$