W Boson mass and width measurements at the Tevatron

Emily Nurse

University College London

MORIOND QCD, March 2007
Why measure the W mass/width?

\[ M_W^2 = \frac{\pi \alpha (M_Z^2)}{\sqrt{2} G_F} \left( \frac{1}{1 - (M_W^2 / M_Z^2)} \right) \frac{1}{1 - \Delta r} \]

\[ \Delta r: \text{O(3\%)} \text{ radiative corrections dominated by } tb \text{ and Higgs loops} \]

\[ \Delta M_W \propto M_{top}^2 \]

\[ \Delta M_W \propto \ln M_H \]

\[ \therefore \text{we can constrain } M_H \text{ by precisely measuring } M_W \text{ and } M_{top}: \]

Measuring W width (\( \Gamma_W \)) tests the SM.

\( \Gamma_W \) is an input to the \( M_W \) measurement: \( \Delta M_W \approx \Delta \Gamma_W / 7 \).
$m_T = \sqrt{2p_T^l p_T^\nu (1 - \cos \phi_{l\nu})}$

- $\mu$-channel: central tracker
- e-channel: EM calorimeter

The measurements are performed in the $\mu \nu \mu$ and $e\nu_e$ channels using 200pb$^{-1}$ (350pb$^{-1}$) for $M_W$ ($\Gamma_W$)

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**W production at the Tevatron**

The measurements are performed in the $\mu \nu \mu$ and $e\nu_e$ channels using 200pb$^{-1}$ (350pb$^{-1}$) for $M_W$ ($\Gamma_W$)
Analysis strategy

- Simulate $M_T$ distribution with a dedicated fast parameterised MC (using Breit-Wigner lineshape).
- MC simulates QCD (RESBOS) and QED (WGRAD) corrections.
- Utilise well understood data samples to calibrate detector to high precision.
- Fit templates (with $M_W/\Gamma_W$ varying) to the data:
  - $\Gamma_W$ fit range: 90-200 GeV
  - $M_W$ fit range: 65-90 GeV
Sources of systematic error

• The mass/width analyses are very similar with different dominant systematics:
  – Momentum scale/resolution
  – Calorimeter scale/resolution
  – Hadronic recoil
  – Backgrounds

• Current world average uncertainties:
  – $\Delta M_W = 29$ MeV
  – $\Delta \Gamma_W = 60$ MeV
Momentum scale set with di-muon resonance peaks in data:

\[ J/\Psi \rightarrow \mu\mu; \quad \Upsilon(1S) \rightarrow \mu\mu; \quad Z \rightarrow \mu\mu \]

\[ \Delta M_W (\mu) = 17 \text{ MeV} \]
\[ \Delta \Gamma_W (\mu) = 17 \text{ MeV} \]

\[ \Delta M_W (\mu) = 3 \text{ MeV} \]
\[ \Delta \Gamma_W (\mu) = 26 \text{ MeV} \]
Electron energy calibration ($p_T^e$)

Calorimeter scale and resolution set using:
- $E/p$ in $W\rightarrow e\nu$ data
- $M_{ee}$ in $Z\rightarrow ee$ data

$E$ scale known to 0.034%

Energy loss in tracker (bremsstrahlung)

scale: $E/p$
- $\Delta M_W(e) = 30$ MeV
- $\Delta \Gamma_W(e) = 17$ MeV

resolution:
- $\Delta M_W(e) = 3$ MeV
- $\Delta \Gamma_W(e) = 31$ MeV

$W$ mass and width

Emily Nurse, UCL
Hadronic Recoil: \( U (p_T^\nu) \)

- \( U = (U_x, U_y) = \sum_{\text{towers}} E \sin \theta (\cos \phi, \sin \phi) \)
- Vector sum over calorimeter towers
  - Excluding those surrounding lepton

\[
p_T^\nu = E_T^{\text{miss}} = -(U + p_T^{\text{lep}})
\]

- \( U \) split into components parallel (\( U_1 \)) and perpendicular (\( U_2 \)) to \( Z p_T \)
- 7 parameter model describes the recoil response and resolution: fit to \( Z \) data
Hadronic Recoil: $U (p_T^\gamma)$

**Data**

$Z \rightarrow ee$

**MC**

$Z \rightarrow ee$

$\Delta M_W (\mu) = 12 \, \text{MeV}$

$\Delta \Gamma_W (\mu) = 49 \, \text{MeV}$

$\Delta M_W (e) = 14 \, \text{MeV}$

$\Delta \Gamma_W (e) = 54 \, \text{MeV}$
Backgrounds

- Electroweak backgrounds ($Z \rightarrow l \bar{l}$, $W \rightarrow \tau \nu$) found from full GEANT MC samples.
- Data used to estimate:
  - multijet: Fit low $E_T^{\text{miss}}$ distribution.
  - kaons decaying-in-flight to $\mu$: Fit high $\chi^2_{\text{track}}$ distribution.

\[
\begin{align*}
\Delta M_W (\mu) &= 9 \text{ MeV} \\
\Delta \Gamma_W (\mu) &= 33 \text{ MeV} \\
\end{align*}
\]

\[
\begin{align*}
\Delta M_W (e) &= 8 \text{ MeV} \\
\Delta \Gamma_W (e) &= 32 \text{ MeV} \\
\end{align*}
\]
Results: $M_W$ fits

$M_W = (80417 \pm 48 \text{ (stat + syst)}) \text{ MeV}$

e + $\mu$ combination $P(\chi^2) = 7\%$

Include fits to $p_T^e$ and $p_T^\nu$:

$M_W = (80413 \pm 48 \text{ (stat + syst)}) \text{ MeV}$
Results: $\Gamma_W$ fits

$\Gamma_W = (1948 \pm 67)$ MeV
$\chi^2$/dof [fit range] = 17/21
$\chi^2$/dof [full range] = 21/29

CDF II Preliminary (350 pb$^{-1}$)

$\Gamma_W = 2032 \pm 71$ (stat + syst) MeV
$\chi^2$/dof [fit range] = 19/21
$\chi^2$/dof [full range] = 32/29

$\chi^2$/dof [fit range] = 19/21
$\chi^2$/dof [full range] = 32/29

$\Gamma_W = (2118 \pm 60)$ MeV
$\chi^2$/dof [fit range] = 19/21
$\chi^2$/dof [full range] = 32/29

$\chi^2$/dof [fit range] = 19/21
$\chi^2$/dof [full range] = 32/29

$\Gamma_W = 2032 \pm 71$ (stat + syst) MeV
$e + \mu$ combination $P(\chi^2) = 20\%$
# Systematic uncertainties

## $M_W$ uncertainties

<table>
<thead>
<tr>
<th>Source</th>
<th>Electrons</th>
<th>Muons</th>
<th>Common</th>
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<tr>
<td>Lepton Scale</td>
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<td><strong>Statistical</strong></td>
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<tr>
<td><strong>Total</strong></td>
<td>62</td>
<td>60</td>
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</table>

## $\Gamma_W$ uncertainties

**CDF Run II Preliminary (350 pb$^{-1}$)**

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<th>Source</th>
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<tr>
<td><strong>Total</strong></td>
<td>98</td>
<td>97</td>
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</table>
Results

World’s most precise single measurements!

Central value increases by 6 MeV:
80392 → 80398 MeV

Uncertainty reduced by 15%:
29 → 25 MeV

Central value decreases by 44 MeV:
2139 → 2095 MeV

Uncertainty reduced by 22%:
60 → 47 MeV
**Implications**

Previous World Data:

\[ m_H = 85^{+39}_{-28} \text{ GeV} \]

\[ m_H < 166 \text{ GeV @ 95\% C.L.} \]

Including New \( M_W \):

\[ m_H = 80^{+36}_{-26} \text{ GeV} \]

\[ m_H < 153 \text{ GeV @ 95\% C.L.} \]

Including New \( M_{\text{top}} \):

*Later this session…*(M. Wang)

Direct search from LEP II:

\[ m_H > 114.4 \text{ GeV @ 95\% C.L.} \]
Summary

- Two new measurements from CDF:
  - W mass: $80413 \pm 48$ MeV (stat + syst)
  - W width: $2032 \pm 71$ MeV (stat + syst)
- Both are the world’s most precise single measurements!!
- Getting to this point requires a “precision” level calibration of the detector.
- Continuing to squeeze the phase space available to the SM Higgs.
- Analyses utilised 200 pb\(^{-1}\) and 350 pb\(^{-1}\) respectively, both CDF and DØ already have \(\sim2\) fb\(^{-1}\) on tape.
- Expect improved mass/width measurements to further test the SM and constrain \(m_H\)