Direct Measurement of the $W$ Total Decay Width at DØ

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Outline

- Introduction
- Monte Carlo Simulation
- Event Selection
- Determination of the $W$ Width
- Conclusions
Introduction

- $\Gamma(W)$ is an important parameter in the Standard Model
- The Standard Model Prediction: $2.090 \pm 0.008$ GeV
- SM Prediction depends on:
  - Number of available decay modes
  - The coupling of $W$ to SU(2) doublets
  - QCD corrections
  - Electroweak radiative corrections
  - $W$ mass
- Measurement of $\Gamma(W)$:
  - A test of SM calculation
  - A probe for possible new physics
Direct Measurement

- $\Gamma(W)$ can be measured directly from the transverse mass distribution of $W \to e\nu$
  
  $M_T = \sqrt{2 p_T(e) p_T(\nu) [1 - \cos(\phi(e) - \phi(\nu))]}$

- Away from the Jacobian edge, the Breit-Wigner (width) component falls much more slowly than the Gaussian (detector resolution) component.

- The high tail region of $M_T$ spectrum is very sensitive to the $W$ decay width.

- **Measurement Strategy**: Generate MC $M_T$ templates with different $W$ width, compare with data and use a binned maximum likelihood method to extract the $W$ width.

- Same method used for $W$ mass measurement.

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$M_T$ Spectra from MC Simulation

- $M_T$ Sensitive Region
- $\Gamma_w$ Sensitive Region

High Tail Region
Monte Carlo Simulation

- Parameterizations of the detector response of the electron and recoil system
  - Electron simulation: electron energy scale and energy resolution
  - Recoil system simulation:
    - “Hard” component that models the $P_T$ of the W/Z boson
    - “Soft” component that models the underlying events and detector noise
- Detection efficiencies measured from data, applied in Monte Carlo
- Smearing parameters determined mostly from $Z \rightarrow ee$ data
- Main systematic uncertainties dominated by the size of $Z \rightarrow ee$ events
Event Selection

- Integrated Luminosity: 177 pb$^{-1}$

**Z → ee Selection**
- At least two isolated EM clusters in the calorimeter fiducial region with $|\eta| < 1.05$ and $p_T(e) > 25$ GeV;
- Each EM cluster has a matched track;
- $70 < M(ee) < 110$ GeV;
- 3,169 $Z \rightarrow ee$ candidates.

**W → ev Selection**
- At least one isolated EM cluster in the calorimeter fiducial region with $|\eta| < 1.05$ and $p_T(e) > 25$ GeV;
- EM cluster has a matched track;
- Missing Transverse Momentum > 25 GeV;
- $p_T(W) < 20$ GeV;
- 75,910 $W \rightarrow ev$ candidates;
- 625 candidates with $M_T$ between [100, 200] GeV ($\sim 0.8\%$).
Electron Simulation

- Electron Energy Scale: determined by varying energy scale in MC until it reproduces the peak position of $Z \rightarrow ee$ data
- Electron Energy Resolution: Determined by varying electron energy resolution in MC until it reproduces the width of $Z \rightarrow ee$ data
Recoil System Simulation (“Hard” component)

- $P_T^{\text{(recoil)}} = P_T$ of everything in the event except electron(s)
- Recoil response: comparing $P_T^{\text{(ee)}}$ with $P_T^{\text{(recoil)}}$ for $Z \rightarrow ee$ events
- Recoil resolution: determined from di-jet events and photon+jet events
Recoil System Simulation ("Soft" component)

- "Soft" component: use the transverse momentum balance measured from a minimum bias event recorded in the detector, then scale it to reflect the difference between the W underlying event with a real minimum bias event.

- Scale factor adjusted until $u_{\parallel}$ distribution from MC simulation agrees with data.

- $U_{\parallel}$ = the projection of the momentum of the recoil system along the electron.

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D0 Run II Preliminary

$u_{\parallel}$ distribution $W \rightarrow ev$
Data MC Comparison for $W \rightarrow e\nu$ Events

$\chi^2 / \text{d.o.f.} = 83.1 / 75$

$\chi^2 / \text{d.o.f.} = 82.5 / 75$
Determination of the W Width

- MC Templates are prepared for the W transverse mass using the detector simulation described above: W width from 1.6 to 3.6 GeV in step of 50 MeV
- Normalize data and MC+Background $M_T$ spectra in [50, 100] GeV region
- Calculate a binned log-likelihood for [100, 200] GeV region

$\Gamma(W) = 2.011 \pm 0.093$ GeV

$\chi^2 / \text{d.o.f} = 122.6 / 75$
Systematic Uncertainties

- The systematic uncertainties are due to effects that could alter the transverse mass spectrum.
- Vary each input parameter in the MC Simulation by one standard deviation.

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<thead>
<tr>
<th>Source</th>
<th>$\Delta \Gamma(W)$ (MeV)</th>
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<tbody>
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<td>HAD Energy Resolution</td>
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<td>W Underlying Event vs MB events</td>
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Conclusions

- First Direct Measurement of the W Width from DØ Run II
  \[ \Gamma(W) = 2.011 \pm 0.093 \text{ (stat.)} \pm 0.107 \text{ (syst.)} = 2.011 \pm 0.142 \text{ (GeV)} \]

Consistent with SM prediction

\[ \Gamma(W) = 2.090 \pm 0.008 \text{ (GeV)} \]

Consistent with the result from indirect measurement (W width extracted from the ratio of \( W \rightarrow l \nu \) and \( Z \rightarrow ll \) cross sections)

\[ \Gamma(W) = 2.079 \pm 0.041 \text{ (GeV)} \text{ (CDF)} \]

\[ \Gamma(W) = 2.101 \pm 0.064 \text{ (GeV)} \text{ (DØ)} \]
Monte Carlo Simulation

- Parameterizations of the detector response of the electron and recoil system

- Energy of the electron

\[ E(e) = R_{EM}(E_0) \otimes \sigma_{EM}(E_0) \]

- Recoil System (all particles recoiling against the W and Z bosons):
  'Hard Component' (models the pT of W and Z bosons) and
  'Soft Component' (models detector noise and underlying events)

\[ \bar{u}_T = -[R_{rec}(q_T) \otimes \sigma_{rec}(q_T)] \hat{q}_T - \Delta u_{||} \hat{p}_T(e) + \alpha_{mb} \bar{p}_T \]

- Smearing parameters determined mostly from Z → ee data

- Apply detection efficiencies measured from Data
Ratio Fit

\[ R = \frac{\text{Num of events with between [100, 200] GeV}}{\text{Num of events with between [50, 200] GeV}} \]

\[ \Gamma(W) = 2.004 \pm 0.091 \text{ GeV} \]
Residual Plots for Electron pT and MET Spectra

Electron pT Spectrum

MET Spectrum

$\chi^2 / \text{d.o.f} = 83.1 / 75$

$\chi^2 / \text{d.o.f} = 82.5 / 75$
Transverse Mass