Electroweak Measurements at the Tevatron

Kristian Harder

for the CDF and DØ Collaborations

Les Rencontres de Physique de La Vallée d’Aoste, La Thuile, 7 March 2007
Precision Measurement of the W Boson Mass with CDF

Chris Hays, University of Oxford

Les Rencontres de Physique de la Vallee d’Aoste
March 7, 2007
On the Brink of Revelation and Revolution: Electroweak Symmetry Breaking in 2009

Dr. Richard St. Denis
Glasgow University
La Thuile
March 4-10, 2007
Where the fb$^{-1}$ are coming from

Fermilab’s Tevatron: 2 km diameter $p\bar{p}$ collider

centre of mass energy 1.96 TeV
Tevatron performance: peak lumi

very close to the (revised) design luminosity!

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Tevatron performance: integrated lumi

integrated lumi still falling short of 55 pb$^{-1}$ per week expectation.
still problems with antiproton stacking rate!

BUT: delivered lumi per experiment growing quickly

Kristian Harder, 7 March 2007
Tevatron performance: integrated lumi

Delivered luminosity per experiment: currently $\approx 2.4 \text{ fb}^{-1}$

Lumi used in analyses presented today: typically $\approx 1 \text{ fb}^{-1}$

Difference explained by:
- $\approx 1 \text{ year delay in preparing data for analysis}$
  (understanding detector effects etc)
- Losses due to hardware and data quality problems

Integrated lumi still falling short of $55 \text{ pb}^{-1}$ per week expectation.

Still problems with antiproton stacking rate!

**BUT:** Delivered lumi per experiment growing quickly
Each experiment has collected $>2 \text{ fb}^{-1}$ of 1.96 TeV $\sqrt{s}$ pp collisions. Current Run II: $>15 \times$ Run I data set.
\[ \eta = -\ln(tan(\Theta/2)) \]

- \( \eta = 0 \): central muon
- \( \eta = 1.7 \): central tracker
- \( \eta = 2 \): forward muon
- \( \eta = 3 \): forward tracker
- \( \eta = 4.2 \): calorimeter

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DØ tracking detectors

- **8 (+1) layers of silicon strips**
- **16 (-2) silicon disks**
- **16 scintillating fiber layers**
- **$\approx 2$ T solenoid**

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CDF Detector

High-precision tracking drift chamber
\[ \delta p_T/p_T = 0.05\% \quad p_T : 2\% \text{ for } 40\text{ GeV } \mu \]

High-precision electromagnetic calorimeter
\[ \delta E_T/E_T = 13.5\%/\sqrt{E_T} \oplus 1.7\% : \quad 3\% \text{ for } 40\text{ GeV } e \]
CDF inner detectors

- 6–7 layer silicon
- COT: 96 layer
- 1.4 T solenoid

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SM cross-section predictions

**reconstructed events:**
- O(100k) per fb$^{-1}$ per final state
- O(1) per fb$^{-1}$ per final state

**Cross-section [pb]**

- W
- Z
- Wγ
- Zγ
- WW
- WZ
- ZZ
- H → WW

**Tevatron Run II pp at $\sqrt{s} = 1.96$ TeV/c$^2$**

**SM Expectation**

**note:** this is $\sigma$, not $\sigma \times \text{BR}$
Electroweak physics 101

Simplest tree-level diagrams to study at hadron colliders:

\[
\begin{align*}
    Z &\rightarrow \ell\ell, \quad W &\rightarrow \ell\nu
\end{align*}
\]

- Reconstruction can be studied very well:
  - clean signature (high \( p_T \) leptons)
  - high rate (for single W,Z production)

Electroweak physics = excellent laboratory for precision studies!

- testing the SM beyond leading order
- detecting non-SM contributions
- constraining PDFs

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Total $W$, $Z$ production cross-sections: good agreement with Standard Model (at current precision!)

**BUT:** not the most sensitive observable to look at for SM checks!
Electroweak topics of the day

Analyses presented in this talk:

- differential Z cross sections (rapidity, transverse momentum)
- better distinction of production mechanisms
- diboson production (WW, WZ, ZZ, Wγ, Zγ)
- unknown loop contributions?
- anomalous triple gauge couplings?
- high mass particles decaying to two bosons? (Higgs?)

All these require a lot more integrated luminosity to study than
\[ \sigma_{tot}(p\bar{p} \rightarrow W+X) \text{ and } \sigma_{tot}(p\bar{p} \rightarrow Z+X) \]
lepton identification

**electrons**
- $E_t$ above $\approx 20$ GeV
- shower shape criteria
- isolation requirement
- $|\eta|$ coverage CDF $< 1.1$ (central), $1.2$–$2.0$ (forward)
  DØ $< 1.1$ (central), $1.5$–$2.5$ (forward)

**muons**
- $p_t$ above $\approx 20$ GeV
- isolation requirement
- $|\eta|$ coverage CDF $< 1.1/1.2$ (central)
  DØ $< 1$ (central), $1$–$2$ (forward)

**tau** not treated separately. $\tau \rightarrow e$, $\tau \rightarrow \mu$ included in $e, \mu$ channels

**neutrinos**
- missing $E_t$ above $\approx 20$ GeV
- CDF: isolation requirement (angular distance)
forward region probes PDF at low $x$ + large $Q^2$, and at large $x$ use $Z \rightarrow e^+e^-$ events: best $\eta$ range —

DØ: $|\eta| < 3.2$, CDF: $|\eta| < 2.8$

submitted to PRD, 1 fb$^{-1}$ analysis in progress
**Z transverse momentum**

- Boson $p_T$ can be non-zero for NLO
- $p_T$ shape predicted by resummation
- $>1$ model for small $x$ (=large rapidity)
  → forward region very interesting!

\begin{align*}
Z \text{ boson } p_T \text{ after unfolding} & \\
\frac{1}{\sigma} \frac{d\sigma}{dp_T} \cdot Br(Z^0 \rightarrow e^+e^-) & \\
\text{Resbos+PHOTOS CTEQ6.1m, no small-x corr} & \\
\text{Resbos+PHOTOS CTEQ6.1m, with small-x corr} & \\
\text{D0 Run II data} & \\
\end{align*}

**tricky analysis:**
- sensitive to electron energy scale
- $p_T$ dependence of lepton ID

**improving model sensitivity:**
- more data
- plot in bins of Z rapidity
  → updated version due soon

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no LO ZZγ and Zγγ vertices in SM → Zγ production only as ISR or FSR

new physics could be found as additional ZZγ or Zγγ contribution potentially with high $E_t$ photons

CDF and DØ analyses: $Z \rightarrow ee$ selection photon with $E_t > 7$ GeV (angular separation)

two-body vs three-body mass

CDF Run II Preliminary, 1.1fb$^{-1}$

DØ Run II Preliminary

Kristian Harder, 7 March 2007
**Zγ results**

<table>
<thead>
<tr>
<th>candidates</th>
<th>Zγ cross section $\times$ BR</th>
<th>SM prediction</th>
</tr>
</thead>
<tbody>
<tr>
<td>DØ 387</td>
<td>$4.51 \pm 0.37$ (stat+syst) $\pm 0.27$ (lum) pb</td>
<td>$4.2 \pm 0.2$ pb</td>
</tr>
<tr>
<td>CDF 390</td>
<td>$4.9 \pm 0.3$ (stat) $\pm 0.3$ (syst) $\pm 0.3$ (lum) pb</td>
<td>$4.7 \pm 0.4$ pb</td>
</tr>
</tbody>
</table>

NB: different SM predictions due to different kinematic region
good agreement with Standard Model!

two-body vs three-body mass

![Two-body vs three-body mass](image1)

photon $E_T$ spectrum

![Photon $E_T$ spectrum](image2)
Now with LO diagrams:

similar analysis to $Z\gamma$, but $W\rightarrow \mu\nu$ (CDF+DØ), $W\rightarrow e\nu$ (DØ)

---

**CDF RunII Preliminary 1/fb**

<table>
<thead>
<tr>
<th>Process</th>
<th>Number</th>
<th>$Z\gamma$ cross section $\times$ BR</th>
<th>SM prediction</th>
</tr>
</thead>
<tbody>
<tr>
<td>CDF $\mu$</td>
<td>855</td>
<td>$19.11\pm1.04$ (stat) $\pm2.40$ (syst) $\pm1.11$ (lum) pb</td>
<td>$19.3\pm1.4$ pb</td>
</tr>
<tr>
<td>DØ $\mu$</td>
<td>245</td>
<td>$3.21\pm0.49$ (stat+syst) $\pm0.20$ (lum) pb</td>
<td>$3.21\pm0.08$ pb</td>
</tr>
<tr>
<td>DØ $e$</td>
<td>389</td>
<td>$3.12\pm0.49$ (stat+syst) $\pm0.19$ (lum) pb</td>
<td>$3.21\pm0.08$ pb</td>
</tr>
</tbody>
</table>

DØ uses tight FSR veto: $M_t(W\gamma) > 110$ GeV
increased sensitivity to anomalous couplings through charge-signed rapidity difference:

interference between tree-level diagrams

\[ \text{dip in } Q_\ell \times [y(\gamma) - y(\ell)] \]

prediction (SM vs example anom TGC) data

good agreement with Standard Model...and with many other scenarios...clearly need more data for this measurement!
WW
(SM: $12.4\pm0.8$ pb)

WZ
(SM: $3.7\pm0.3$ pb)

ZZ
(SM: $1.4\pm0.1$ pb)
CDF WW with 0.8 fb$^{-1}$

$WW \rightarrow \ell\ell\nu\nu$ with $\ell\ell = ee, e\mu, \mu\mu$

$\approx$ std lepton selection, missing $E_t$, jet veto, opposite charge, $|\Delta z| < \pm 4$ cm

95 events, cross section $13.6 \pm 2.3$(stat)$\pm 1.6$(syst)$\pm 1.2$(lumi) pb,

SM prediction $12.4 \pm 0.8$ pb
WZ → ℓℓν, with eee, eem, emm, mmm (total BR ≈ 1.5%) again, standard lepton and missing $E_t$ selection.
require two leptons in Z mass window.

**Selection results:**

<table>
<thead>
<tr>
<th></th>
<th>Candidates</th>
<th>Background</th>
<th>Signal Significance</th>
</tr>
</thead>
<tbody>
<tr>
<td>DØ:</td>
<td>12</td>
<td>3.61±0.20</td>
<td>3.34σ</td>
</tr>
<tr>
<td>CDF:</td>
<td>16</td>
<td>2.65±0.28±0.33±0.09</td>
<td>6.0σ</td>
</tr>
</tbody>
</table>

**Z mass**

background composition similar, just overall worse S/B ratio for DØ
<table>
<thead>
<tr>
<th></th>
<th>measured</th>
<th>predicted</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>CDF</td>
<td>5.0^{+1.8}_{-1.4} (stat) ± 0.4 (syst) pb</td>
<td>3.7 ± 0.3 pb</td>
<td></td>
</tr>
<tr>
<td>DØ</td>
<td>4.0^{+1.9}_{-1.5} (stat+syst) pb</td>
<td>3.7 ± 0.3 pb</td>
<td></td>
</tr>
</tbody>
</table>

Events / 2.5 GeV

CDF Run II Preliminary

\[ \int L \, dt = 1.1 \, fb^{-1} \]
How about events with 4 leptons? SM predicts \( \approx 2 \) events in 1 fb\(^{-1} \)...

Here is a candidate. The only one so far.

\[ \sigma(ZZ) < 3.8 \text{ pb} \]
(95% C.L.)

(SM: 1.4 \pm 0.1 \text{ pb})

With 4–8 fb\(^{-1} \), this could become another first observation.
DØ + CDF data samples increase quickly
understanding of detector response improving as well
bringing electroweak precision physics to the next next-to-next level!

precise measurements

precision physics playground

established signals —
more data should help to improve those!

promising searches

acts of desperation → LHC?
Given precise measurements of $m_Z$ and $\alpha_{EM}(m_Z)$, we can predict $m_W$:

$$m_W^2 = \frac{\pi \alpha_{EM}}{\sqrt{2} G_F (1 - m_W^2/m_Z^2)(1 - \Delta r)}$$

($"on-shell scheme"$)

$\Delta r$: O(3%) radiative corrections dominated by $tb$ and Higgs loops

$$\Delta m_W \propto m_t^2$$

$$\Delta m_W \propto \ln \left( \frac{m_H}{m_Z} \right)$$
Predicted Higgs mass from global electroweak data:

\[ m_H = 85^{+39}_{-28} \text{ GeV} \ (< 166 \text{ GeV at 95\% CL}) \]

Direct search from LEP II: \[ m_H > 114.4 \text{ GeV at 95\% CL} \]

C. Hays, University of Oxford
W Mass Prediction and Measurement

W mass uncertainty from input parameters:

<table>
<thead>
<tr>
<th>Parameter Shift</th>
<th>$m_W$ Shift (MeV/c^2)</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\Delta m_H = +100$ GeV/c^2</td>
<td>-41.3</td>
</tr>
<tr>
<td>$\Delta m_t = +2.1$ GeV/c^2</td>
<td>12.8</td>
</tr>
<tr>
<td>$\Delta m_Z = +2.1$ MeV/c^2</td>
<td>2.6</td>
</tr>
<tr>
<td>$\Delta\alpha_{EM} = +0.00013$</td>
<td>-2.3</td>
</tr>
</tbody>
</table>

Direct W mass measurement

W-Boson Mass [GeV]

<table>
<thead>
<tr>
<th>Experiment</th>
<th>Mass</th>
</tr>
</thead>
<tbody>
<tr>
<td>TEVATRON</td>
<td>80.452 ± 0.059</td>
</tr>
<tr>
<td>LEP2</td>
<td>80.376 ± 0.033</td>
</tr>
<tr>
<td>Average</td>
<td>80.392 ± 0.029</td>
</tr>
</tbody>
</table>

$\chi^2$/DoF: 1.3 / 1

W mass predicted much more precisely (13 MeV) than measured (29 MeV)
Need to reduce $\delta m_W$ to further constrain $m_H$ and other new physics

C. Hays, University of Oxford
Weak Boson Physics

Z boson parameters measured precisely by LEP:

* 17 million measured Z candidates: $\delta m_Z = 2.1$ MeV, $\delta \Gamma_Z = 2.3$ MeV

Tevatron goal:

* World's most precise W boson measurements
* Expect 15 million measured W candidates
W & Z Boson Production and Decay

Dominant production mechanism: $q\bar{q}(\gamma)$ annihilation

\[ \sigma(W \rightarrow l\nu) = 2775 \text{ pb} \]

After event selection
\[(l, \nu E_T > 30 \text{ GeV}):\]
51,128 $W \rightarrow \mu\nu$ candidates
63,964 $W \rightarrow e\nu$ candidates

\[ \sigma(Z \rightarrow ll) = 254.9 \text{ pb} \]

After event selection
\[(l E_T > 30 \text{ GeV}):\]
4,960 $Z \rightarrow \mu\mu$ candidates
2,919 $Z \rightarrow ee$ candidates
Measurement Strategy

Calibrate $l^\pm$ track momentum with mass measurements of $J/\psi$ and $Y$ decays to $\mu$

Calibrate calorimeter energy using track momentum of $e$ from $W$ decays

**Cross-check with $Z$ mass measurement, then add $Z$'s as a calibration point**

Calibrate recoil measurement with $Z$ decays to $e, \mu$

**Cross-check with $W$ recoil distributions**

Combine information into transverse mass:

$$m_T = \sqrt{E_T^e E_T^\nu (1 - \cos \Delta \phi)}$$

**Statistically most powerful quantity for $m_W$ fit**

C. Hays, University of Oxford
Momentum Scale Calibration

Magnetic field along z-axis causes curvature in transverse plane:

\[ \frac{mv^2}{R} = evB, \]
\[ p_T = eBR \]

CDF: Insufficient precision on \( B \) and \( R \) for \( W \) mass measurement

**In-situ calibration:**

1. Apply relative alignment of drift chamber wires
2. Determine momentum scales such that \( J/\psi, Y, \) and \( Z \) mass measurements result in the world-average values

Combine results to obtain scale for \( m_W \) measurement
Alignment and Corrections

Align tracker using cosmic-ray data
Determine track-level corrections from electron-positron differences

Use ratio of calorimeter energy to track momentum

Curvature biases affect $e^+$, $e^-$ differently, but calorimeter measurement independent of charge

Statistical uncertainty of track-level corrections leads to $\delta m_W = 6$ MeV

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Tracker Alignment

Central Outer Tracker: Open-cell drift chamber
Wires strung under tension between two endplates

Model endplate distortions and constructional variations using a cell-to-cell endplate alignment

Determine individual cell tilts & shifts using cosmic-ray data
Fit a single 'dicosmic' to track segments on opposite sides of the chamber
Measure cell displacement

C. Hays, University of Oxford

(Kotwal, Gerberich, Hays, NIM A 506, 110 (2003))
Alignment Example

Inner 'Superlayer:'

Before alignment

Cell Shift (microns)

After alignment

CDF Run II preliminary

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Wire Alignment

Wire shape along z-axis determined by:
- Gravitational sag
- Electrostatic effects

Apply additional correction based on cosmic ray study
- Compare parameters of incoming and outgoing tracks from a cosmic ray muon

Final correction removes $z$-dependent curvature biases
Mass Measurements

Template mass fits to $J/\psi$, $Y$, $Z$ resonances in muon decay channels

Fast detector simulation models relevant physical processes
  - internal bremsstrahlung
  - ionization energy loss
  - multiple scattering

Simulation includes event reconstruction and selection

Detector material model
  - Map energy loss and radiation lengths in each detector layer

One material parameter determined from data:
  - Overall material scale
Y Mass Measurement

$\mathcal{L} = 200 \text{ pb}^{-1}$  
CDF Run II Preliminary

$\Delta p / p = (-1.38 \pm 0.06) \times 10^3$

$\chi^2 / \text{dof} = 26 / 18$

Tracks with beam constraint

34,618 $Y \rightarrow \mu \mu$ candidates

Short lifetime allows a track constraint to the beam line

Improves resolution by a factor of $\approx 3$

Test beam constraint by measuring mass using unconstrained tracks

Correct by half the difference between fits

Take correction as a systematic uncertainty

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Momentum Scale Calibration

Constrain tracks to originate from the beam line
Improves resolution by a factor of $\approx 3$

606,701 $J/\psi \rightarrow \mu \mu$ candidates

Fit mass as a function of mean inverse $p_T$

Slope affected by energy loss modelling
Scale detector material by 0.94 to remove slope

Use calibrated momentum scale to measure Z mass

Constrain tracks to originate from the beam line
Improves resolution by a factor of $\approx 3$

$M_Z = (91184 \pm 43)$ MeV

$\chi^2$/dof = 32 / 30

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Electron Track Model Validation

Fit Z mass reconstructed from electron track momenta

\[ \mathcal{L} = 200 \text{ pb}^{-1} \quad \text{CDF Run II Preliminary} \]

Measured value consistent with world average value (91188 MeV)
Calorimeter Energy Calibration

*Calibrate electron energy using electron track momentum*
First step: validate model of electrons in tracker

Additional physical effects beyond those associated with muons:
*Photon radiation and conversion in tracker*
Full Electron Simulation

- Response and resolution in EM calorimeter
- Energy loss into hadronic calorimeter
- Track reconstruction in outer tracker
- Energy loss in solenoid
- Bremstrahlung and conversions in silicon
- EM Calorimeter
- SOLENOID
- END WALL HADRON CAL
- END PLUG EM CALORIMETER
- END PLUG HADRON CALORIMETER

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Energy Loss Model

Use GEANT to parametrize energy loss in solenoid and hadronic calorimeter

Energy loss in hadronic calorimeter:
Energy Scale Calibration

Calibrate calorimeter energy with peak of $W$ electron $E/p$ distribution

One free parameter for $X_0$ scale (set with high $E/p$ region)

Material scale: $1.004 \pm 0.009$

Energy scale uncertainty: 0.034%

CDF Run II Preliminary

$\chi^2$/dof = 17 / 16

Calorimeter Energy < Track Momentum:
Energy loss in hadronic calorimeter

Calorimeter Energy > Track Momentum:
Energy loss in tracker
Apply energy-dependent scale to each simulated electron and photon

Determine energy dependence from $E/p$ fits as functions of electron $E_T$

Scale: $1 + (6 \pm 7) \times 10^{-5} \left[ \frac{E_T}{\text{GeV}} - 39 \right]$ 

$\delta m_W = 23 \text{ MeV}$

Most energy dependence implicitly accounted for by detector model
Fit Z mass using scale from E/p calibration

\[ \mathcal{L} = 200 \text{ pb}^{-1} \]

CDF Run II Preliminary

Measured value consistent with world average value (91188 MeV)

Incorporate mass fit into calibration to reduce scale uncertainty

\[ \delta m_W = 30 \text{ MeV} \]

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Boson $p_T$ Model

Model boson $p_T$ using RESBOS generator with tunable non-perturbative parameters

"$g_2$" parameter determines position of peak in $p_T$ distribution

Measure $g_2$ with Z boson data (other parameters have negligible effect on $W$ mass)

$$g_2 = 0.685 \pm 0.048: \delta m_W = 3 \text{ MeV}$$

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Recoil Measurement

Calculate recoil by summing over calorimeter towers, excluding:
- Towers with lepton energy deposits
- Towers near the beam line

Electron: Remove 7 towers (shower)
Muon: Remove 3 towers (MIP)

Model tower removal in simulation
\[ \delta m_W = 8 \ (5) \text{ MeV for } e \ (\mu) \]
Recoil Model

Components:
- **Recoil scale** \( R = \frac{u_{\text{meas}}}{u_{\text{true}}} \)
- **Recoil resolution**
- **Spectator and additional interactions** (contribute to resolution)

Calibrate scale with momentum balance along bisector axis (\( \eta \))

Calibrate models of recoil resolution and spectator interactions using momentum resolution along both axes

\[ \delta m_W = 11 \text{ MeV} \]
Recoil Model Checks

Apply model to $W$ boson sample, test consistency with data

Recoil distribution

*Sensitive to scale, resolution, boson $p_T$*

$u_{||}$ distribution

*Sensitive to lepton removal, efficiency model, scale, resolution, $W$ decay*

*Directly affects $m_T$, fit result*
Production, Decay, Background

Boson $p_z$ determined by
parton distribution functions
$Vary\ PDFs\ according\ to\ uncertainties$
$\delta m_W = 11\ MeV$

Bremšrahlung reduces charged lepton $p_T$

Predict using NLO QED calculation,
apply NNLO correction
$\delta m_W = 11\ (12)\ MeV\ for\ e\ (\mu)$

Background affects fit distributions

QCD: Measure with data
Electroweak: Predict with MC
$\delta m_W = 8\ (9)\ MeV\ for\ e\ (\mu)$

<table>
<thead>
<tr>
<th>Background</th>
<th>$%\ (\mu)$</th>
<th>$%\ (e)$</th>
</tr>
</thead>
<tbody>
<tr>
<td>HadronJet</td>
<td>$0.1 \pm 0.1$</td>
<td>$0.25 \pm 0.15$</td>
</tr>
<tr>
<td>Decays in Flight</td>
<td>$0.3 \pm 0.2$</td>
<td>-</td>
</tr>
<tr>
<td>Cosmic Rays</td>
<td>$0.05 \pm 0.05$</td>
<td>-</td>
</tr>
<tr>
<td>$Z \rightarrow ll$</td>
<td>$6.6 \pm 0.3$</td>
<td>$0.24 \pm 0.04$</td>
</tr>
<tr>
<td>$W \rightarrow \tau\nu$</td>
<td>$0.89 \pm 0.02$</td>
<td>$0.93 \pm 0.03$</td>
</tr>
</tbody>
</table>

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Transverse Mass Distribution

Distribution peaks just below $m_W$ and falls sharply just above $m_W$
Mass fit results blinded with [-100,100] MeV offset throughout analysis
Upon completion, offset removed to determine final result

**Transverse mass fits:**

- **muon channel**
  - $M_W = (80349 \pm 54_{stat})$ MeV
  - $\chi^2$/dof = 59 / 48

- **electron channel**
  - $M_W = (80493 \pm 48_{stat})$ MeV
  - $\chi^2$/dof = 86 / 48

$m_W = 80417 \pm 48$ MeV (stat + sys)
for $e + \mu$ combination ($P(\chi^2) = 7\%$)
Fit $E_T$, $\not{E}_T$ distributions and combine with $m_T$ to extract most precise result

**Electron $E_T$ fit:**

$$m_W = (80451 \pm 58_{\text{stat}}) \text{ MeV}$$

$\chi^2/\text{dof} = 63 / 62$

**Muon $p_T$ fit:**

$$m_W = (80321 \pm 66_{\text{stat}}) \text{ MeV}$$

$\chi^2/\text{dof} = 72 / 62$

$m_W = 80388 \pm 59 \text{ MeV (stat + sys)}$

for lepton $p_T e + \mu$ combination ($P(\chi^2) = 18\%$)

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$m_W = 80434 \pm 65$ MeV (stat + sys) for neutrino $p_T e + \mu$ combination ($P(\chi^2) = 43\%$)

Electron $E_T$ fit:

CDF II preliminary

$M_W = (80473 \pm 57_{\text{stat}})$ MeV

$\chi^2/\text{dof} = 63 / 62$

Muon $E_T$ fit:

CDF II preliminary

$M_W = (80396 \pm 66_{\text{stat}})$ MeV

$\chi^2/\text{dof} = 44 / 62$

$m_W = 80413 \pm 48$ MeV (stat + sys) for six-fit combination ($P(\chi^2) = 44\%$)
### W Mass Uncertainties

<table>
<thead>
<tr>
<th>$m_T$ Uncertainty [MeV]</th>
<th>Electrons</th>
<th>Muons</th>
<th>Common</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lepton Scale</td>
<td>30</td>
<td>17</td>
<td>17</td>
</tr>
<tr>
<td>Lepton Resolution</td>
<td>9</td>
<td>3</td>
<td>0</td>
</tr>
<tr>
<td>Recoil Scale</td>
<td>9</td>
<td>9</td>
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</tr>
<tr>
<td>Recoil Resolution</td>
<td>7</td>
<td>7</td>
<td>7</td>
</tr>
<tr>
<td>$u_\parallel$ Efficiency</td>
<td>3</td>
<td>1</td>
<td>0</td>
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<td>26</td>
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<tr>
<td><strong>Statistical</strong></td>
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<tr>
<td><strong>Total</strong></td>
<td>62</td>
<td>60</td>
<td>26</td>
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CDF II preliminary

$L = 200 \text{ pb}^{-1}$

C. Hays, University of Oxford
W Mass Result

New CDF result is world's most precise single measurement

Central value increases: 80392 to 80398 MeV
World average uncertainty reduced ~15% (29 to 25 MeV)
**Previous Higgs Mass Prediction**

**Predicted Higgs mass from global electroweak data:**

\[ m_H = 85^{+39}_{-28} \text{ GeV} \ (< 166 \text{ GeV at 95\% CL}) \]

Direct search from LEP II: \( m_H > 114.4 \text{ GeV at 95\% CL} \)

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C. Hays, University of Oxford
Predicted Higgs mass from global electroweak data:

\[ m_H = 80^{+36}_{-26} \text{ GeV} \quad (< 153 \text{ GeV at 95\% CL}) \]

Direct search from LEP II: \( m_H > 114.4 \text{ GeV at 95\% CL} \)

C. Hays, University of Oxford
Effect on New Physics Models

Additional space-time symmetry (Supersymmetry) would affect the $W$ mass

Previous world average:

![Graph showing the effect of supersymmetry on the $W$ mass](image-url)
Effect on New Physics Models

Supersymmetry now preferred at 1σ level...

New world average:

- Experimental errors 68% CL:
  - LEP2/Tevatron (today)

- Masses:
  - $M_W = 114$ GeV
  - $M_H = 400$ GeV

- Models:
  - Light SUSY
  - Heavy SUSY

- Both models

Heinemeyer, Hollik, Stockinger, Weber, Weiglein '06

C. Hays, University of Oxford
Effect on New Physics Models

Supersymmetry now preferred at 1σ level...

New world average:

![Graph showing experimental errors: LEP2/Tevatron (today) with confidence levels of 68%, 95%, and 99.7%. The graph includes regions for light SUSY, MSSM, heavy SUSY, SM, and both models. The graph is labeled with different confidence levels and mass values.](image)
Previous $W$ Mass Projections

Previously projected Tevatron precision as a function of luminosity:

**Projection with $2 \text{ fb}^{-1}$ of data:**

$\delta m_W = 40 \text{ MeV per experiment}$

C. Hays, University of Oxford
New W Mass Projections

New projected Tevatron precision as a function of luminosity:

New projection with 1.5 fb⁻¹ of data: \( \delta m_W < 25 \text{ MeV} \) with CDF

C. Hays, University of Oxford
Filling in the Pieces

Precision electroweak data will continue to guide us to the next physics

**Today:** \( \delta m_{W} = 25 \text{ MeV}, m_{H} < 153 \text{ GeV} \text{ at } 95\% \text{ CL} \)

\[ \text{SM} \quad \xrightarrow{\text{measurement}} \quad m_{W} \]

**After Higgs:** \( \delta m_{W} = 15 \text{ MeV}, \text{SUSY predicted at } 95\% \text{ CL?} \)

\[ \text{SM} \quad \times \quad \xrightarrow{\text{measurement}} \quad m_{W} \]

**After SUSY:** \( \delta m_{W} = 10 \text{ MeV}, \text{more new physics?} \)

\[ m_{W} \quad \xrightarrow{\text{measurement}} \quad \text{MSSM} \]
Summary

$W$ mass excellent probe for new particles coupling to the electroweak sector

CDF has made the single most precise $W$ mass measurement

$$m_W = 80413 \pm 34 \text{ MeV (stat)} \pm 34 \text{ MeV (sys)}$$
$$= 80413 \pm 48 \text{ MeV (stat + sys)}$$

New SM Higgs mass prediction: $m_H = 80^{+36}_{-26}$ GeV

Mass has moved further into LEP-excluded region

Expect CDF $\delta m_W < 25$ MeV with $1.5 \text{ fb}^{-1}$ already collected

Will squeeze SM in conjunction with Tevatron Higgs results

Electroweak data will probe more new physics after the Higgs
\[ \delta M_t = 1.2 \text{ GeV}, \]
\[ \delta M_W = 24 \text{ MeV, world avg} \]

\((\text{LEP2} + \delta M_W = 30 \text{ MeV (Tevatron), no LEP/TeV correlations})\)