W and Z Cross Section Measurements at CDF

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Canada
Why W&Z cross section?

- Precise Electroweak measurements
  -> constrain Standard Model (or)
  suggest Physics beyond SM
- W,Z signal well established
  -> base of detector performance studies
- Cross section measurements
  -> ensure good understanding of $e, \mu, \tau$ identification
  -> common cross-check for other analyses

- New data available
  -> first measurements based on 72 pb$^{-1}$ of data collected during 2002-2003
  -> ~300 pb$^{-1}$ of additional data collected 2003-2004
W and Z cross section at CDF

Tevatron \rightarrow W and Z hadronic decay overwhelmed by QCD background
\rightarrow bosons identified by leptonic decay

\[ \sigma \cdot \text{Br} = \frac{N_{\text{EVENTS}} - N_{\text{BACKGROUND}}}{A \times \varepsilon \times \int L \, dt} \]

\[ N_{\text{EVENTS}} = \# \text{ of observed events} \]
\[ N_{\text{BACKGROUND}} = \# \text{ of expected background} \]
\[ \varepsilon = \text{efficiency (trigger,reconstruction,ID)} \]
\[ A = \text{geometrical and kinematical efficiency} \]

(usually based on Monte Carlo)

\[ \int L \, dt = \text{integrated luminosity} \rightarrow \text{dominant uncertainty of all cross section measurement (6%)} \]

Measurement strategy:
1. identify clean signal and estimate background contamination
2. evaluate efficiencies
3. estimate systematics

Talk Overview:
New results from CDF

\[ \Rightarrow \sigma_w \cdot \text{Br}(W \rightarrow e\nu) \quad \int L \, dt \sim 223 \text{pb}^{-1} \]
\[ \Rightarrow \sigma_z \cdot \text{Br}(Z \rightarrow \mu\mu) \quad \int L \, dt \sim 337 \text{pb}^{-1} \]
\[ \Rightarrow \sigma_z \cdot \text{Br}(Z \rightarrow \tau\tau) \quad \int L \, dt \sim 349 \text{pb}^{-1} \]
**W boson signatures at CDF**

**W→ev signatures**
- Large missing energy in transverse plane
- Isolated electron:
  -> combination of calorimeter signal and high $p_T$ track

**W analysis for first 72 ± 4.4 pb$^{-1}$ @ CDFII**
- Cross section measurements
- $W$ branching ratio
- $W$ width $\Gamma_W$
- $V_{CS}$
- $g_\mu/g_e$

CDF: PRL 94, 091803 (2005)

$\sigma.BF(W→ev) = 2.780 \pm 0.014$ (stat) $\pm 0.063$(syst) $\pm 0.166$(lum) nb

$\sigma.BF(W→lv) = 2.775 \pm 0.010$ (stat) $\pm 0.053$(syst) $\pm 0.166$(lum) nb
W boson in forward region of CDF

Extension of electron ID to forward region of detector -> $1.2 < |\eta| < 2.8$

Used combined information from forward EM calorimeters and extended tracking system (ISL)

$\eta = -\ln ( \tan \frac{\Theta}{2} )$

Increases sample size at given luminosity for many analyses:

$tt\bar{t}$ sample increase by $\sim 15\%$ with forward region included
**W boson in forward region of CDF**

1.2 < |\eta| < 2.8

**W->ev in numbers:**
- 48144 W candidates with ~4.5% background contaminations
- acceptance \times efficiency of signal selection ~7%
- largest source of systematics coming from acceptance ~2% (PDF)

CDF RUN 2 Preliminary — 223 pb\(^{-1}\)

Forward CDF W cross section measurement with 223 pb\(^{-1}\)

\[ \sigma_{BF}(W->ev) = 2.815 \pm 0.013 \text{ (stat)} + 0.094 \text{ (syst)} - 0.089 \text{ (syst)} \pm 0.169 \text{ (lum)} \text{ nb} \]

\[ \sigma(pp\rightarrow W)_{Th} @\sqrt{1.96} \text{ TeV} = 2.687 \pm 0.054 \text{ (Th) nb(NNLO), (Stirling, van Neerven)} \]
W boson in forward region of CDF

$1.2 < |\eta| < 2.8$

Next steps:

- Comparison of experimental measurements of central and forward W production (ratio of cross sections)
- Test of theoretical predictions in different lepton pseudorapidity range -> different sensitivity to PDF source of uncertainty (hep-ph/0405130)

Looking at the future -> luminosity measurement at LHC collider based on process with high production cross section, clean signature and well known theoretical uncertainties

$$\sigma(W)_{\text{th}} = \frac{1}{\int L \, dt} \frac{N_{\text{obs}}}{A_W}$$
Z→μμ signatures at CDF

**Muon signatures:**
- Signal in muon detectors (|η|<1)
- Isolated high p_T tracks

- Measurement using first 72 pb^{-1} showed good agreement with NNLO
- Results combined with W cross section measurement to extract Γ_W

\[ \sigma_Z \cdot B(Z/γ^*→μμ) = 248.0 \pm 5.9_{stat} \pm 8.0_{syst} \pm 7.2_{syst} \pm 15.1_{lum} \text{ pb} \]

combined \[ \sigma_Z \cdot B(Z/γ^*→ll) = 254.9 \pm 3.3_{stat} \pm 4.6_{syst} \pm 15.2_{lum} \text{ pb} \]
Z$\rightarrow$μμ cross section using 337 pb$^{-1}$

The new result -> first step towards Z boson $d\sigma/dp_T$ measurement

Changes:
- new generation of reconstruction software and Monte Carlo samples
- Modified selection criteria
  -> optimized for Z boson $p_T$ distribution measurement

Z$\rightarrow$μμ in number:
- 9620 Z candidates with 8 background events
- Overall efficiency ~ 10%
- Luminosity is dominant uncertainty

NNLO @ $\sqrt{1.96}$ TeV (Stirling,van Neerven)

$\sigma(pp\rightarrow Z)_{\text{Th}} = 251.3 \pm 5.0_{(\text{Th})}$ pb

$\sigma(pp\rightarrow Z/\gamma^*)B(Z/\gamma^*\rightarrow\mu\mu) = 261.2 \pm 2.7_{\text{stat}} + 5.8_{\text{syst}} - 6.9_{\text{syst}} \pm 15.1_{\text{lum}}$ pb
**τ identification and Z-→ττ cross section**

Taus -> difficult to reconstruct at hadron colliders

Z-→ττ -> exploit event topology to suppress backgrounds (QCD & W+jet)

-> measurement of cross section important for Higgs and SUSY analyses

CDF strategy of hadronic τ reconstruction:

1. Charged tracks -> define signal and isolation cone (10°)
   - isolation: require no tracks in isolation cone

2. Hadronic calorimeter clusters (to suppress e background)

3. π⁰ identified by shower maximum detector (CES)
   -> π⁰ required to be isolated in signal cone

CES
-> resolution
2-3mm

-> proportional strip/wire drift chamber at 6X₀

of EM calorimeter

Channel for Z-→ττ: e +isolated track

τ→e (E_T>10GeV)

τ→h (p_T>15GeV/c)

+ remove DY(ee) and apply event topology cuts for non-Z background
$Z \rightarrow \tau\tau$ cross section using 349pb$^{-1}$

$Z \rightarrow \tau\tau$ in numbers:
- 316 Z boson candidates
- Most systematic uncertainties data-driven
  - will be reduced with more luminosity
- $\tau$ identification eff $\sim$60% with uncertainty about 3%

$$\sigma_{Z} \cdot B(Z \rightarrow \tau e \tau \mu) = 265 \pm 20 \text{ (stat)} \pm 21 \text{ (syst)} \pm 15 \text{ (lum)} \text{ pb}$$

**NEW result**

CDF Run II Preliminary ($\mathcal{L}$=350 pb$^{-1}$)

**NEW result**

CDF Run II Preliminary ($\mathcal{L}$=350 pb$^{-1}$)

<table>
<thead>
<tr>
<th>Number of $\tau$ tracks</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
</tr>
<tr>
<td>0</td>
</tr>
</tbody>
</table>

**same sign**

**opposite sign**

<table>
<thead>
<tr>
<th>Invariant mass (e, $\tau$, MET) GeV/c$^2$</th>
</tr>
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<tbody>
<tr>
<td>0</td>
</tr>
<tr>
<td>0</td>
</tr>
</tbody>
</table>

1 and 3 tracks, opposite sign
20 years of W & Z cross section measurements at hadron colliders

\[ \sigma \times \text{Br}(W \rightarrow \ell \nu) \]

\[ \sigma \times \text{Br}(Z \rightarrow \ell^+ \ell^-) \]

NNLO theory curves:
Martin, Roberts, Stirling, Thorne

CDF II (e, 1.2 < |y| < 2.8)
CDF II (e+\mu)
CDF I (e)
CDF II Z(\mu)
CDF II Z(\tau)

CDF (630)
UA1 (\mu)
UA2 (e)
DO I (e)

E_{cm} (TeV)

In red NEW measurements at CDF
Summary

New cross section measurements from CDF

- $W \rightarrow e\nu$ in forward region ($1.2 < |\eta| < 2.8$) using 223 pb$^{-1}$
- $Z \rightarrow \mu\mu$ using 337 pb$^{-1}$
- $Z \rightarrow \tau_e\tau_h$ using 349 pb$^{-1}$

Excellent base for next set of analyses
- $d\sigma/dy_e$ for $W \rightarrow e\nu$
- $d\sigma/dp_T$ for $Z \rightarrow \mu\mu$
- Tau widely used in SM measurements and SUSY, H boson searches

New generation of W&Z measurements (R, WW, WZ, W charge asymmetry...) on the way -> stay tuned!
From now on backup
Tevatron

$s_{\text{RunI}} = 1.8$ TeV
Now $s_{\text{RunII}} = 1.96$ TeV
Tevatron

Start of physics-quality data

March 2002
CES detector

**CES**
- resolution
  2-3mm
- proportional strip/wire drift chamber at $6X_0$
of EM calorimeter
### W boson in forward region of CDF

<table>
<thead>
<tr>
<th>Description</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>N. candidate events</td>
<td>48144</td>
</tr>
<tr>
<td>N. background QCD events</td>
<td>87759 (stat)</td>
</tr>
<tr>
<td></td>
<td>438 (sys)</td>
</tr>
<tr>
<td>N. background Z events</td>
<td>2333 (stat)</td>
</tr>
<tr>
<td>N. background $W \rightarrow \tau \nu$ events</td>
<td>107312 (stat)</td>
</tr>
<tr>
<td>Lumin (pb$^{-1}$)</td>
<td>223</td>
</tr>
<tr>
<td></td>
<td>13 (sys)</td>
</tr>
<tr>
<td>$\varepsilon$</td>
<td>0.07320.0011 (stat)</td>
</tr>
</tbody>
</table>
W boson in forward region of CDF

CDF RUN 2 Preliminary — 223 pb⁻¹

Events per 1.0 GeV

W → e ν Candidates
electrons in 1.2 < |η| < 2.8

CDF RUN 2 Preliminary — 223 pb⁻¹

Events per 1.0 GeV

W → e ν Candidates
electrons in 1.2 < |η| < 2.8
**Z$\rightarrow$μμ cross section**

$Z/\gamma^* \rightarrow \mu\mu$ with mass between 66 and 116 GeV/c$^2$

CDF Run 2 Preliminary

<table>
<thead>
<tr>
<th>Number of $Z/\gamma^*$ Candidates</th>
<th>9620</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Background</strong></td>
<td></td>
</tr>
<tr>
<td>$Z \rightarrow \tau\tau$</td>
<td>8 ± 2</td>
</tr>
<tr>
<td>WW, Cosmic, Top, QCD</td>
<td>Smaller and neglected</td>
</tr>
<tr>
<td><strong>Acceptance (Including Efficiencies)</strong></td>
<td>0.1091 ± 0.0024 − 0.0029</td>
</tr>
<tr>
<td><strong>Luminosity</strong></td>
<td>337 ± 20 pb$^{-1}$</td>
</tr>
<tr>
<td><strong>Cross Section × Branching Ratio</strong></td>
<td>261.2 ± 2.7 (stat) + 5.8 − 6.9 (syst) ± 15.1 (lum) pb</td>
</tr>
</tbody>
</table>
# \(Z \rightarrow \tau \tau\) cross section

<table>
<thead>
<tr>
<th>Process</th>
<th>Yield (in number of events)</th>
</tr>
</thead>
<tbody>
<tr>
<td>(Z \rightarrow ee)</td>
<td>(34.8 \pm 1.4 \pm 7.0)</td>
</tr>
<tr>
<td>(W+\text{jets})</td>
<td>(36.6 \pm 3.5 \pm 4.9)</td>
</tr>
<tr>
<td>(\gamma+\text{jets})</td>
<td>(47.8 \pm 2.2 \pm 12.0)</td>
</tr>
<tr>
<td>(\text{QCD di-jets})</td>
<td>(68.6 \pm 3.6)</td>
</tr>
<tr>
<td>Total:</td>
<td>(187.7 \pm 5.7 \pm 15.0^*)</td>
</tr>
<tr>
<td>Data</td>
<td>504</td>
</tr>
</tbody>
</table>

\[Z \rightarrow \tau \tau\] = \(316 \pm 23 \pm 15\)

<table>
<thead>
<tr>
<th>Systematic Uncertainty [%]</th>
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<tbody>
<tr>
<td>Geometrical and kinematical acceptance (incl. PDFs)</td>
</tr>
<tr>
<td>Electron ID</td>
</tr>
<tr>
<td>Tau ID</td>
</tr>
<tr>
<td>Electron Trigger Efficiency</td>
</tr>
<tr>
<td>Tau Trigger Efficiency</td>
</tr>
<tr>
<td>Topology cuts</td>
</tr>
<tr>
<td>Background estimation</td>
</tr>
<tr>
<td>Total:</td>
</tr>
</tbody>
</table>

Cross-Section \(\sigma(pp \rightarrow Z) Br(Z \rightarrow \tau \tau) = 265 \pm 20(\text{stat}) \pm 21(\text{syst}) \pm 15(\text{lumi})\) pb
$Z\rightarrow \tau\tau$ cross section