Studies of WW and WZ production at CDF

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on behalf of the CDF Collaboration

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Physics Motivation

- Direct probe into the gauge structure of the SM:
  1. S-channel probes triple gauge couplings (TGC)
  2. TeV with respect to LEP: explores higher energy range

- Cross sections can be enhanced by new physics

- Diboson final states close to higgs final states

- Benchmark for experimental capabilities towards Higgs

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WW/WZ at CDF

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CDF detector

- Proton-antiproton collision at $\sqrt{s} = 1.96$ TeV
- Peak luminosity $4.0 \cdot 10^{32}$ cm$^{-2}$ s$^{-1}$

- CDF $\rightarrow$ Multipurpose detector
- Data taking efficiency $\sim 85\%$
Heavy Diboson Production

Leptonic Decay Channels
Small branching fraction and low background
Clean signal but low yields
Key → increase lepton acceptance

Semileptonic Decay Channels
Larger branching fraction and much larger backgrounds
Signal / Background < 0.5%
**WW cross section using 3.6 fb⁻¹**

1. **WW → ℓν+ ℓν production**
   - Test SM predictions: x-section, TGC
   - Dominant background for H → WW (same analysis)
   - Can be enhanced by new physics or Higgs

2. **Two isolated leptons and large MET**

3. **Likelihood ratio formed from Matrix element probabilities**

\[ \sigma^{NLO}(p\bar{p} \rightarrow WW) = 11.7 \pm 0.7 \text{pb} \]
\[ \sigma(p\bar{p} \rightarrow WW) = 12.1^{+1.8}_{-1.6} \text{pb} \]


WW cross section with a precision of less than 15 %.
- Two diagrams producing WW: s-channel, and t-channel.

- s-channel is susceptible to anomalous triple gauge couplings: $\Delta K^z, \Delta K^\gamma, \Delta g_1^z, \Delta g_1^\gamma, \lambda^z, \lambda^\gamma$

- HISZ scheme (Phys. Rev. D 48 (1993) 2182) ties these together to make 3 independent parameters

- Fit lepton $p_T$ distribution

<table>
<thead>
<tr>
<th>$\Lambda$</th>
<th>$\lambda^Z$</th>
<th>$\Delta g_1^Z$</th>
<th>$\Delta K^\gamma$</th>
</tr>
</thead>
<tbody>
<tr>
<td>2.0 TeV</td>
<td>(-0.14, 0.15)</td>
<td>(-0.22, 0.30)</td>
<td>(-0.57, 0.65)</td>
</tr>
<tr>
<td>1.5 TeV</td>
<td>(-0.16, 0.16)</td>
<td>(-0.24, 0.34)</td>
<td>(-0.63, 0.72)</td>
</tr>
</tbody>
</table>
• Require 3 e or $\mu$ leptons and $E_T > 25$ GeV

• Lepton ID optimization
  1. Improved electron/muon isolation
  2. Recover central/plug transition
  3. Tight track quality
  4. Normalize to $Z \to \ell\ell$ to reduce the systematic uncertainties

$$\sigma(p\bar{p} \to WZ) = 4.1 \pm 0.6\text{(stat.)} \pm 0.4\text{(sys.)} \text{ pb}$$

$$\sigma(WZ)_{NLO} = 3.7\text{ pb}$$
Jet final states are more difficult → Resolution much worse

Select jj+MET events

- Acceptance to $\nu\nu$ and $l\nu$ events (WW, WZ, ZZ)
- Milestone for low mass Higgs searches
- Similar final state to $ZH \rightarrow \nu\nu + bb$

Analysis challenge:

1. Triggered data dominated by QCD multijet events with fake $E_T$
2. After trigger Signal/QCD $\sim 10^{-4}$

Reject QCD based on sophisticated $E_T$ resolution model [arXiv:0910.5170]

After QCD rejection: Signal/QCD $\sim 0.2$
**VV → met + jets**

- Fit $M_{jj}$ distribution
- EWK $M_{JJ}$ shape: checked with $\gamma + jj$ → significantly reduces systematics
- Fitted Jet Energy scale compatible with 1

$\sigma(WW + WZ + ZZ) = 18.0 \pm 2.8\text{(stat)} \pm 2.4\text{(syst)} \pm 1.1\text{(lumi)} \text{ pb}$

SM: $16.8 \pm 0.5pb$ (MCFM + CTEQ6M)

First observation in hadronic final state: 5.3 $\sigma$ significance

$WW/WZ \rightarrow l\nu + jets$

- Require high $p_T$ lepton, large $E_T$, and two jets
- Build $W$ or $Z$ from two-jet system:
  - Dijet mass resolution doesn’t allow to distinguish between $W$ and $Z$
- $WW$ is dominant ($WZ$ has lower cross section, branching ratio)

Two measurements of $WW/WZ \rightarrow l\nu jj$ have been carried out at CDF

- Matrix element analysis in 4.6 fb$^{-1}$ (2.7 fb$^{-1}$ published)
- Search for resonance in dijet invariant mass spectrum in 4.3 fb$^{-1}$ (3.9 fb$^{-1}$ published)

Two different approaches used:

1. First approach uses the shape of $M_{jj}$ of the two leading jet to look for a clear resonance

- Use $p_T > 40$ GeV/c cut to smoothen $m_{jj}$ distribution
- Fit to extract the signal:
  $$1582 \pm 275 \text{ (stat.)} \pm 107 \text{ (syst)}$$
  $WW/WZ \rightarrow l\nu jj$ events

\[ \sigma_{WW/WZ} = 18.1 \pm 3.3 \text{ (stat.)} \pm 2.5 \text{ (syst.) \, pb} \]

- Compatible with SM cross section:
  $$(15.9 \pm 0.9 \, pb)$$
  - Significance $5.2 \, \sigma$ (5.1 expected)
Second approach uses a multivariate technique to exploit all the information in the event.

- Use matrix element calculation to build discriminant (EPD) to separate signal and background

\[ EPD = \frac{P_{\text{sig}}}{(P_{\text{sig}} + P_{\text{BG}})} \]

- Likelihood fit to extract signal.

Significance 5.4 \( \sigma \) (5.1 expected)

$$\sigma_{WW/WZ} = 16.5^{+3.3}_{-3.0} (\text{stat.} + \text{syst.}) \text{pb}$$
Cross section $\sigma(WZ \rightarrow l\nu b\bar{b}) = 0.12 pb$.

Important benchmark toward higgs searches.

Event selected requiring one lepton (tight and central), $E_T > 20$ GeV and two jets.

The two b-jets identified with NN algorithm:

1. Uses both the lifetime information as well as the lepton information.
2. Per-jet output value $\rightarrow 1$ = more b-jet like.
3. Jet tagged if output $> 0.0$

Another is NN used to discriminate between WZ and other backgrounds.

Set a limit with $4.3 \text{ fb}^{-1}$:

$\sigma_{obs} < 3.9 \cdot \text{SM} (3.9 \text{ expected})$ at 95 % CL.
Combination of WZ and ZZ still unobserved:
- Expected cross section $5.0 \pm 0.4$ pb
- Branching ratio of $Z \rightarrow$ leptons small
- $Z$+jets background is very large
- Motivates new quark-gluon discriminant

Jet Likelihood Ratio: Quark/Gluon Discriminant
- Energy in $q$ jets less spatially spread than in $g$ jets $\rightarrow$ quantified as Jet LR: larger $= \text{more quark-like}$

Build NN discriminant
Fit of 4.8 fb$^{-1}$ data to S+B template yields:
- set a limit on $\sigma_{ZW+ZZ}$ of

$$\sigma_{ZZ+ZW} < 2.9 \cdot \text{SM at 95\% CL}$$
Conclusion

Diboson physics a rich and interesting place
- SM tests
- Higgs benchmark
- New physics searches

Larger Tevatron datasets allows for more targeted searches

Most interesting results are yet to come!!