Searches for WZ and ZZ Diboson Production in Final States with Jets and Charged Leptons or Missing Transverse Energy at CDF

Wesley Ketchum (University of Chicago) on behalf of the CDF Collaboration
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Motivation

• Semi-hadronic diboson decays important step to Higgs
  – Share similar final state for $m_H < 135$ GeV/c$^2$
  – Testing ground for new tools

• Previous observations all involve WW
  – Larger $\sigma$
  – Large $W\rightarrow l, \nu$ branching ratio

• In this talk
  – $WZ/ZZ \rightarrow l\nu, \nu\nu + qq'$: MET (Missing transverse energy) + jets
    • $b$ tagging to separate from WW
  – $ZW/ZZ \rightarrow l^+l^- + qq/qq'$: Charged leptons + jets
    • New quark-gluon discriminant to combat large $Z + (gluon)$ jets background

<table>
<thead>
<tr>
<th>Process</th>
<th>Cross Section (pb)</th>
</tr>
</thead>
<tbody>
<tr>
<td>WW</td>
<td>11.70 ± 0.7</td>
</tr>
<tr>
<td>WZ</td>
<td>3.60 ± 0.3</td>
</tr>
<tr>
<td>ZZ</td>
<td>1.49 ± 0.2</td>
</tr>
</tbody>
</table>
# Previous Tevatron WZ/ZZ Measurements

<table>
<thead>
<tr>
<th>Process</th>
<th>SM $\sigma$ (pb)</th>
<th>Decay Channel</th>
<th>$\sigma$ (pb)</th>
<th>$\int L$ (Year Pub.)</th>
<th>Exp.</th>
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</thead>
<tbody>
<tr>
<td>WZ</td>
<td>3.6</td>
<td>$l^+\nu$, $l^+\ell^-$</td>
<td>$3.89^{+1.07}_{-0.90}$</td>
<td>4.1 fb$^{-1}$ (2010)</td>
<td>D0</td>
</tr>
<tr>
<td></td>
<td></td>
<td>$l^+\ell^-$</td>
<td>$3.9^{+0.8}_{-0.7}$</td>
<td>7.1 fb$^{-1}$ (2011)</td>
<td>CDF</td>
</tr>
<tr>
<td>ZZ</td>
<td>1.5</td>
<td>$l^+\ell^-$, $l^+\ell^-$</td>
<td>$1.26^{+0.49}_{-0.40}$</td>
<td>6.4 fb$^{-1}$ (2011)</td>
<td>D0</td>
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<tr>
<td></td>
<td></td>
<td>$l^+\ell^-$, $\nu\nu$</td>
<td>$2.01 \pm 0.97$</td>
<td>2.7 fb$^{-1}$ (2008)</td>
<td>D0</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>$1.45^{+0.60}_{-0.51}$</td>
<td>5.9 fb$^{-1}$ (2010)</td>
<td>CDF</td>
</tr>
</tbody>
</table>

| WZ      | 3.6             | $l\nu, jj$ & $l^+\ell^-, jj$ | ? |  |
| ZZ      | 1.5             | $\nu\nu, jj$ & $l^+\ell^-, jj$ | ? |  |
## Other New Tevatron Measurements

<table>
<thead>
<tr>
<th>Process</th>
<th>Experiment</th>
<th>URL</th>
</tr>
</thead>
<tbody>
<tr>
<td>$W\gamma$</td>
<td>D0</td>
<td><a href="http://www-d0.fnal.gov/Run2Physics/WWW/results/prelim/EW/E36/">http://www-d0.fnal.gov/Run2Physics/WWW/results/prelim/EW/E36/</a></td>
</tr>
<tr>
<td>$W + jj$</td>
<td>D0</td>
<td><a href="http://www-d0.fnal.gov/Run2Physics/WWW/results/final/HIGGS/H11B/">http://www-d0.fnal.gov/Run2Physics/WWW/results/final/HIGGS/H11B/</a></td>
</tr>
<tr>
<td>$W \rightarrow l\nu + h.f.$</td>
<td>CDF</td>
<td><a href="http://www-cdf.fnal.gov/physics/new/hdg/Results_files/results/wzlubb_071911/">http://www-cdf.fnal.gov/physics/new/hdg/Results_files/results/wzlubb_071911/</a></td>
</tr>
</tbody>
</table>
About the Tevatron and CDF

- **Fermilab Tevatron**
  - Collide p-pbar at $\sqrt{s} = 1.96$ TeV
  - $11.6$ fb$^{-1}$ delivered to experiments

- **Collider Detector at Fermilab (CDF)**
  - Silicon detectors and “outer” drift chamber for particle tracking
  - Electromagnetic and hadronic calorimeters
  - Muon systems outside calorimeters
**Event Selection**

**MET + Jets**
- Data from MET triggers
  - MET > 50 GeV
  - Quality cuts to reduce “fake” MET from multijet production
  - Determine trigger efficiency from $Z \rightarrow \mu^+\mu^-$ sample
- Two (or more) jets
  - Jets’ $E_T > 20$ GeV, $|\eta| < 2.0$
  - Fit to Dijet Mass to extract Diboson signal

**$e^+e^-,\mu^+\mu^- + Jets$**
- Data from high-\(p_T\) lepton triggers
  - Leptons’ $p_T > 20$ GeV/c
  - $76$ GeV/$c^2 < $ Dilepton Mass $< 106$ GeV/$c^2$
  - Determine trigger efficiency by comparing data and MC in $Z + 1$ jet sample
Artificial Neural-Network Based Jet bness Tagger

• Multivariate algorithm to separate $b$ jets from non-$b$ jets
  – Long $B$ hadron lifetimes
  – Large $B$ hadron mass compared to decay products

• Focus on properties of individual tracks
  – Train NN to assign “track bness” to each track in a jet
    • Consider $d_0$, $z_0$, $p_T$, rapidity and $p_T$ w.r.t. jet axis ($p_\perp$)
    – Combine with jet-level information to assign overall “jet bness”
    • Decay length in xy-plane ($L_{xy}$), existence of $K_S$ or $\mu$’s in jet

Tracks Inside Jet

Jet-Level Info

Jet bness NN

Jet bness Value

Tracks Inside Jet

Jet bness NN
Jet bness Tagger

- Train using ZZ Pythia MC
  - Jets from $Z \rightarrow bb$ decays for $b$ jet samples
  - Jets from $Z \rightarrow qq$ (no $b$’s present) for non-$b$ samples

- “Tag”: Place cut on minimum bness value for jets
  - Optimize cut location
  - Calculate efficiency of cut in data from $b$-rich $tt$ selection
  - Get mistag rate from $Z$ or $W$ + jets samples
  - Correct MC efficiency/mistag rate to match data

CDF Run II Preliminary

$\int L = 4.8 \text{ fb}^{-1}$

- Data
- $W^+Z/ZZ$
- $W^+W$
- $tt$
- $Z \rightarrow \gamma\gamma + b\bar{b}$
- $Z \rightarrow \gamma\gamma$
- $W^+ \rightarrow \tau^+\nu$, $b\bar{b}$
- $W^+ \rightarrow \mu^+\nu$, $b\bar{b}$
- $W^+ \rightarrow \mu^+\nu$
- $W^+ \rightarrow e^+\nu_e$
- $W^+ \rightarrow e^+\nu_e$

Events / 0.05 units

Highest jet bness
Artificial Neural-Network Based Jet Quark-Gluon Discriminant

- **WZ/ZZ signal is entirely quark jets**
  - W/Z + jets background has significant gluon contribution
- **Gluon jets more spatially spread than quark jets**
  - Gluons have more color charge than quarks
- **Construct distribution of distances between pairs of towers and tracks in a jet**
  - \[ \Delta R = \sqrt{(\Delta \eta)^2 + (\Delta \phi)^2} \]
  - Weight towers/tracks by their energy/momentum content

A wedge of the CDF central calorimeter. Towers’ size ~ 0.1 in \( \eta \) and 15° in \( \phi \).
Jet QG Discriminant

- Content in bins of $\Delta R$ are inputs into NN discriminant
  - Separate NNs for tower and track distributions
Jet QG Discriminant

- Use third neural network to combine tower and track information, and other relevant jet variables
  - Tower and Track NN values
  - Ratios of Energy and Momentum in Cone 0.4 to 0.7 around jet
  - Jet EM Fraction
  - Number of Tracks and Towers in jet
  - Jet $E_T$, $\eta$
    - Gluon distribution normalized to match quarks
  - Number of interaction vertices

- Calibrate MC response by comparing data and MC in $W + 1$ jet selection region

- Determine efficiency of cut on QG value
  - $tt \rightarrow Wb$, $Wb \rightarrow lvb$, $qq'b$ for quark-jet signal
  - $W +$ jets for background-like regions
Backgrounds To Diboson Searches: W/Z + Jets

- Dominant background for both analyses
- Two different approaches

**MET + Jets:**

Photon + 2 jet data used to correct MC modeling of dijet mass

**Charged Leptons + Jets:**

Use MC, but scale JES of gluon jets down based on Z + 1 jet balancing studies

**Z-Jet Balancing: Jet QG Value**

CDF Run II Preliminary, $\langle L \rangle = 6.6$ fb$^{-1}$

- No-Tag Electroweak MC Template
- No-Tag +Jets Data Template

CDF Run II Preliminary, $\langle L \rangle = 6.6$ fb$^{-1}$

- Data - Fakes
- MC, JES 0
- MC, JES -2 ($\gamma$)
- MC, JES -1 ($\gamma$)

More Quark-Like
Backgrounds To Diboson Searches: Jets Faking Charged Leptons/Neutrinos

• MET + Jets:
  – Multijet production with mismeasured jet energies can fake MET
  – To model…
    • Construct missing $P_T$ from tracks ($MET_{Trk}$)
    • $\Delta \phi (MET, MET_{Trk}) > 1$ → “QCD-Enhanced” region

• Lepton + Jets
  – $W + 1$ jet faking a lepton may pass dilepton cuts
    • Use like-sign objects to model muon fakes
    • Calculate probability of jet to fake electron from jet triggered data
MET + Jets Results

- Perform $\chi^2$ fit to dijet mass in two channels
  - Heavy-flavor enriched “2-tag” region
  - Remaining events in “no-tag” region
- Best fit: $N_{WZ/ZZ} \sim$ SM prediction
- Use Feldman-Cousins method to extract sensitivity

<table>
<thead>
<tr>
<th>Process(es)</th>
<th>Fit $N_{\text{events}}$ (no-tag)</th>
<th>Fit $N_{\text{events}}$ (2-tag)</th>
</tr>
</thead>
<tbody>
<tr>
<td>EWK</td>
<td>153300 ± 3000</td>
<td>694 ± 48</td>
</tr>
<tr>
<td>$t\bar{t}$ and single $t$</td>
<td>1700 ± 140</td>
<td>313 $^{+24}_{-26}$</td>
</tr>
<tr>
<td>QCD</td>
<td>72300 ± 2800</td>
<td>54.6 ± 7.3</td>
</tr>
<tr>
<td>WW</td>
<td>2720 ± 190</td>
<td>8.3 $^{+1.8}_{-1.9}$</td>
</tr>
<tr>
<td>WZ/ZZ</td>
<td>1160 ± 620</td>
<td>39.9 ± 20</td>
</tr>
</tbody>
</table>

$\sigma_{WZ/ZZ} = 5.0^{+3.6}_{-2.5}$ pb
$< 13$ pb at 95% CL
Charged Leptons + Jets Results

CDF Run II Preliminary, \( \int L = 6.6 \text{ fb}^{-1} \)

- Perform \( \chi^2 \) fit to dijet mass in three channels
  - Heavy-flavor tag region using jet bness
  - Light-flavor tag region using jet QG
  - Remaining events in no-tag region
- Best Fit: \( N_{WZ/ZZ} = 0 \)
- Use Feldman-Cousins method to get limit
  - \( \sigma_{SM} \) consistent with no observed signal

\[ \sigma_{WZ/ZZ} < 1.3 \times \sigma_{SM} \text{ (Exp: 2.3)} < 6.6 \text{ pb at 95% CL} \]

<table>
<thead>
<tr>
<th>Process</th>
<th>( N_{events} ) (HF Tag)</th>
<th>( N_{events} ) (LF Tag)</th>
<th>( N_{events} ) (No Tag)</th>
</tr>
</thead>
<tbody>
<tr>
<td>( Z + \text{jets} )</td>
<td>660( ^{+110}_{-150} )</td>
<td>3900( ^{+1920}_{-1800} )</td>
<td>5800( ^{+1300}_{-1800} )</td>
</tr>
<tr>
<td>( t\bar{t} )</td>
<td>4.26( ^{+0.56}_{-0.59} )</td>
<td>0.86( ^{+0.19}_{-0.23} )</td>
<td>2.51( ^{+0.42}_{-0.36} )</td>
</tr>
<tr>
<td>( WW )</td>
<td>0.025 ( \pm 0.002 )</td>
<td>0.26( ^{+0.07}_{-0.04} )</td>
<td>0.56( ^{+0.07}_{-0.19} )</td>
</tr>
<tr>
<td>Fakes</td>
<td>18.3 ( \pm 4.7 )</td>
<td>80 ( \pm 21 )</td>
<td>190 ( \pm 49 )</td>
</tr>
<tr>
<td>( WZ/ZZ ) at limit</td>
<td>0( ^{+3.3}_{-4} )</td>
<td>0( ^{+17}_{-10} ) at limit</td>
<td>0( ^{+16}_{-10} ) at limit</td>
</tr>
<tr>
<td>Data</td>
<td>685 ( \pm 26 )</td>
<td>3942 ( \pm 63 )</td>
<td>5976 ( \pm 77 )</td>
</tr>
</tbody>
</table>

WZ/ZZ \( \rightarrow l^+l^-jj \) Search
Conclusions

• Have conducted searches for WZ/ZZ production in semi-hadronic final states
  – Similar final state to Higgs searches with $m_H < 135$ GeV/$c^2$
• Using new multivariate algorithms to increase sensitivity
  – Jet $b$-ness tagger picks out heavy-flavor jets
  – Jet QG discriminant separates light-flavor quark jets from gluon jets
• Extract signal through fit to dijet mass distribution
  – MET + jets: $\sigma_{WZ/ZZ} < 13$ pb at 95% CL (5.5 fb$^{-1}$)
  – Charged leptons + jets: $\sigma_{WZ/ZZ} < 6.6$ pb at 95% CL (6.6 fb$^{-1}$)
    • Standard model: $\sigma_{WZ/ZZ} = 5.1$ pb
• Looking ahead
  – Further studies of W/Z + jets modeling using jet QG value
    • Reduce systematic uncertainties on modeling
  – Implement new tools in Higgs searches
Jet *b*ness Tagger: Efficiency and Mistag Rates

CDF Run II Preliminary, $\mathcal{L} = 4.8$ fb$^{-1}$

**Z + 1 jet Selection**

- **Data**
- *W*Z/ZZ
- *W*W
- tt
- Z$\rightarrow$ $\tau^+\tau^-$+b$b$
- Z$\rightarrow$$\mu^+\mu^-+b$b
- Z$\rightarrow$ e$^+e^-+b$b
- Z$\rightarrow$ $\tau^+\tau^-$
- Z$\rightarrow$$\mu^+\mu^-$
- Z$\rightarrow$ e$^+e^-$

**Highest jet bness**

- **Data**
- W$^+$Z/ZZ
- W$^+W$
- tt
- Z$\rightarrow$ $l^+l^-$+b$b$
- Z$\rightarrow$l$^+l^-$
- W$^+\rightarrow$ $\tau^+\nu_\tau+b$b$
- W$^+\rightarrow$$\mu^+\nu_\mu+b$b
- W$^+\rightarrow$ e$^+\nu_e+b$b
- W$^+\rightarrow$$\mu^+\nu_\mu$
- W$^+\rightarrow$ e$^+\nu_e$

CDF Run II Preliminary, $\mathcal{L} = 4.8$ fb$^{-1}$

**Z + 1 jet Selection**

- **Data**
- All MC
- b jet MC

**Highest jet bness**

- **Data**
- All MC
- b jet MC
Jet $b$ness Tagger: Efficiency and Mistag Rates

CDF Run II Preliminary, $L = 4.8$ fb$^{-1}$

- Data
- $W/ZZZ$
- $W/W$
- $t\bar{t}$
- $Z\rightarrow t\bar{t}+b\bar{b}$
- $Z\rightarrow t\bar{t}$
- $W\rightarrow \tau\nu_e+b\bar{b}$
- $W\rightarrow \tau\nu_e$ + $b\bar{b}$
- $W\rightarrow e\nu_e+b\bar{b}$
- $W\rightarrow e\nu_e$ + $b\bar{b}$
- $W\rightarrow \mu\nu_e$
- $W\rightarrow \mu\nu_e$ + $b\bar{b}$

Events / 0.05 units

2nd highest jet bness
Jet bness Tagger: Efficiency and Mistag Rates

CDF Run II Preliminary, $\int L = 4.8$ fb$^{-1}$

**Efficiency**

- Data
- Uncertainties
- Monte Carlo

**Mistag Rate**

- Data
- Uncertainties
- Monte Carlo

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Jet QG Discriminant: Flow Chart

- Distribution of Towers
  - Tower Neural Network (NN)
- Distribution of Tracks
  - Track NN
- Other Jet Information

Final QG NN Discriminant
Z-Jet Balancing: Jet QG Value

CDF Run II Preliminary, $\int L = 6.6$ fb$^{-1}$

- **Data - Fakes**
- **MC, JES 0**
- **MC, JES -2\sigma (Gluons)**
- **MC, JES -1\sigma (All)**

- **Jet** $E_T / Z P_T$
- **Jet QG Value**
Z-Jet Balancing: Jet $\eta$

CDF Run II Preliminary, $\int L = 6.6$ fb$^{-1}$

- **Data - Fakes**
- **MC, JES 0**
- **MC, JES -2$\sigma$ (Gluons)**
- **MC, JES -1$\sigma$ (All)**
Z-Jet Balancing: Jet $E_T$

CDF Run II Preliminary, $\int L = 6.6$ fb$^{-1}$

- Data - Fakes
- MC, JES 0
- MC, JES -2$\sigma$ (Gluons)
- MC, JES -1$\sigma$ (All)
Flow Chart for Analysis

Z + 2 Jet Selection

- Pass HF Tag?
  - YES: HF-Tag Channel
  - NO: Pass QG Tag?
    - YES: LF-Tag Channel
    - NO: No-Tag Channel
Z + 2 Jet Selection: Tagging Variables

Z + 2 Jet Selection: Sum Jet bness

Z + 2 Jet Selection: Sum Jet QG Value

CDF Run II Preliminary $L = 6.6 \text{ fb}^{-1}$
Charged Leptons + Jets: Expected Events

CDF Run II Preliminary, $\int L = 6.6 \text{ fb}^{-1}$

<table>
<thead>
<tr>
<th>Process</th>
<th>$N_{\text{events}}$ (HF Tag)</th>
<th>$N_{\text{events}}$ (LF Tag)</th>
<th>$N_{\text{events}}$ (No Tag)</th>
</tr>
</thead>
<tbody>
<tr>
<td>$Z + \text{jets}$</td>
<td>$730 \pm 120$</td>
<td>$3510_{-630}^{+550}$</td>
<td>$5490_{-1120}^{+970}$</td>
</tr>
<tr>
<td>$t\bar{t}$</td>
<td>$4.26_{-0.59}^{+0.56}$</td>
<td>$0.86_{-0.23}^{+0.19}$</td>
<td>$2.51_{-0.36}^{+0.42}$</td>
</tr>
<tr>
<td>$WW$</td>
<td>$0.025 \pm 0.002$</td>
<td>$0.26_{-0.04}^{+0.07}$</td>
<td>$0.56_{-0.19}^{+0.07}$</td>
</tr>
<tr>
<td>Fakes</td>
<td>$18.9 \pm 4.7$</td>
<td>$82 \pm 21$</td>
<td>$196 \pm 49$</td>
</tr>
<tr>
<td>Total Background</td>
<td>$760_{-130}^{+120}$</td>
<td>$3600_{-620}^{+550}$</td>
<td>$5690_{-1120}^{+970}$</td>
</tr>
<tr>
<td>$WZ/ZZ$</td>
<td>$15.9_{-2.1}^{+2.0}$</td>
<td>$87.2_{-9.4}^{+9.7}$</td>
<td>$80.3_{-9.2}^{+9.6}$</td>
</tr>
<tr>
<td>Total Predicted</td>
<td>$770_{-130}^{+120}$</td>
<td>$3690_{-630}^{+560}$</td>
<td>$5770_{-1120}^{+980}$</td>
</tr>
<tr>
<td>Data</td>
<td>$685 \pm 26$</td>
<td>$3942 \pm 63$</td>
<td>$5976 \pm 77$</td>
</tr>
</tbody>
</table>

$WZ/ZZ \rightarrow l^+l^-jj$ Search
Z + 2 Jet Selection: Dijet Mass Fit Templates

Z + 2 Jet Selection: Dijet Mass (HF Tag Region)

Z + 2 Jet Selection: Dijet Mass (LF Tag Region)

CDF Run II Preliminary
L = 6.6 fb^{-1}

Data
Fakes
WZ+ZZ
WW
tt
Z + b jets
Z + jets

Z + 2 Jet Selection: Dijet Mass (HF Tag Region)

Z + 2 Jet Selection: Dijet Mass (LF Tag Region)

CDF Run II Preliminary
L = 6.6 fb^{-1}

Data
Fakes
WZ+ZZ
WW
tt
Z + b jets
Z + jets

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Z + 2 Jet Selection: Dijet Mass Fit Templates
Remaining Backgrounds

• Backgrounds
  – Top quark production
    • Add cuts to reduce top-pair production background
      – MET + jets: cuts on jet and lepton multiplicity
      – Leptons + jets: Require MET < 25 GeV
  – WW diboson production (MET + jets)
    • Indistinguishable from signal (WZ/ZZ) from dijet mass
    • Use $b$ tagging to pick out events with $Z \rightarrow bb$
MET + Jets: Multijet Production Modeling

MET Quality Cuts in MET + Jets Analysis

QCD dijet mass distribution in MET + Jets Analysis

CDF Run II Preliminary, <L>=5.5 fb⁻¹
Systematic Uncertainties:
Charged Leptons + Jets

CDF Run II Preliminary, $\int L = 6.6 \text{ fb}^{-1}$

<table>
<thead>
<tr>
<th></th>
<th>Normalization</th>
<th>JES</th>
<th>$b$-tag</th>
<th>QG-Tag</th>
<th>$Q^2$</th>
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</thead>
<tbody>
<tr>
<td>$Z + \text{jets}$</td>
<td></td>
<td></td>
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<td></td>
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</tr>
<tr>
<td>HF Tag Region</td>
<td>$\pm 12%$</td>
<td>$+10%,-8.3%$</td>
<td>$-$</td>
<td>$-$</td>
<td>Shape Only</td>
</tr>
<tr>
<td>LF Tag Region</td>
<td>$+14%,-16%$</td>
<td>$-0.5%,+0.4%$</td>
<td>$+1.0%,-1.9%$</td>
<td></td>
<td>Shape Only</td>
</tr>
<tr>
<td>No Tag Region</td>
<td>$+16%,-19%$</td>
<td>$-1.0%,+0.9%$</td>
<td>$-0.6%,-1.2%$</td>
<td></td>
<td>Shape Only</td>
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<tr>
<td>$t\bar{t}$</td>
<td>$\pm 6.45%$</td>
<td>$+0.4%,-0.1%$</td>
<td>$+8.9%,-9.8%$</td>
<td>$-$</td>
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<tr>
<td>HF Tag Region</td>
<td>$\pm 6.45%$</td>
<td>$+0.3%,-0.4%$</td>
<td>$-17%,+16%$</td>
<td>$+11%,-19%$</td>
<td>$-$</td>
</tr>
<tr>
<td>LF Tag Region</td>
<td>$\pm 6.45%$</td>
<td>$+4.4%,-2.4%$</td>
<td>$-9.5%,+11%$</td>
<td>$-3.8%,6.6%$</td>
<td>$-$</td>
</tr>
<tr>
<td>No Tag Region</td>
<td>$\pm 6.45%$</td>
<td>$+32%,-8.4%$</td>
<td>$-$</td>
<td>$-9.6%,-0%$</td>
<td>$-$</td>
</tr>
<tr>
<td>WW</td>
<td>$\pm 6%$</td>
<td>$-$</td>
<td>$-$</td>
<td>$+$ $20%,-0%$</td>
<td>$-$</td>
</tr>
<tr>
<td>HF Tag Region</td>
<td>$\pm 6%$</td>
<td>$-$</td>
<td>$-$</td>
<td>$-$</td>
<td></td>
</tr>
<tr>
<td>LF Tag Region</td>
<td>$\pm 6%$</td>
<td>$+12%,-9.4%$</td>
<td>$-$</td>
<td>$+$ $20%,-0%$</td>
<td>$-$</td>
</tr>
<tr>
<td>No Tag Region</td>
<td>$\pm 6%$</td>
<td>$+32%,-8.4%$</td>
<td>$-$</td>
<td>$-9.6%,-0%$</td>
<td>$-$</td>
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<tr>
<td>Signal</td>
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<tr>
<td>HF Tag Region</td>
<td>$-$</td>
<td>$+4.2%,-4.3%$</td>
<td>$+9.7%,-10%$</td>
<td>$-$</td>
<td>$-$</td>
</tr>
<tr>
<td>LF Tag Region</td>
<td>$-$</td>
<td>$+5.5%,-4.4%$</td>
<td>$-0.7%,+0.6%$</td>
<td>$+6.3%,-6.6%$</td>
<td>$-$</td>
</tr>
<tr>
<td>No Tag Region</td>
<td>$-$</td>
<td>$+6.0%,-5.4%$</td>
<td>$-1.2%,+1.4%$</td>
<td>$-6.9%,+7.2%$</td>
<td>$-$</td>
</tr>
<tr>
<td>Fakes (All Regions)</td>
<td>$\pm 25%$</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

$WZ/ZZ \rightarrow l^+l^-jj$ Search

7/25/11
# Systematic Uncertainties: Charged Leptons + Jets

*CDF Run II Preliminary, $\int L = 6.6 \text{ fb}^{-1}$*

<table>
<thead>
<tr>
<th>Acceptance Uncertainty</th>
<th>±0.7%</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lepton Energy Scale</td>
<td>±0.7%</td>
</tr>
<tr>
<td>Lepton Energy Resolution</td>
<td>±0.14%</td>
</tr>
<tr>
<td>Trigger/Lepton Reconstruction Efficiency</td>
<td>±2.2%</td>
</tr>
<tr>
<td>Jet Resolution</td>
<td>±2.5%</td>
</tr>
<tr>
<td>ISR/FSR</td>
<td>±1.2%</td>
</tr>
<tr>
<td>PDF</td>
<td>±2%</td>
</tr>
<tr>
<td>Luminosity</td>
<td>±6%</td>
</tr>
</tbody>
</table>

$WZ/ZZ \rightarrow l^+l^-jj$ Search
## Systematic Uncertainties: MET + Jets

<table>
<thead>
<tr>
<th>Systematic</th>
<th>channel</th>
<th>WZ/ZZ</th>
<th>WW</th>
<th>$t\bar{t}$ &amp; single $t$</th>
<th>EWK</th>
<th>QCD</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cross Section (Norm.)</td>
<td>no-tag</td>
<td>± 6%</td>
<td>± 7.9%</td>
<td>± 7%</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>2-tag</td>
<td>± 6%</td>
<td>± 6.9%</td>
<td>± 13.5%</td>
<td></td>
<td></td>
</tr>
<tr>
<td>EWK Shape</td>
<td>both</td>
<td></td>
<td></td>
<td></td>
<td>✓</td>
<td></td>
</tr>
<tr>
<td>QCD Shape</td>
<td>both</td>
<td></td>
<td></td>
<td></td>
<td>✓</td>
<td></td>
</tr>
<tr>
<td>JES Shape/Rate</td>
<td>no-tag</td>
<td>yes/± 7.1%</td>
<td>yes/± 7.6%</td>
<td>no/± 3.7%</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>2-tag</td>
<td>yes/± 6.9%</td>
<td>yes/± 7.6%</td>
<td>no/± 3.2%</td>
<td></td>
<td></td>
</tr>
<tr>
<td>$b$ness cuts (up)</td>
<td>no-tag</td>
<td>+0.46%</td>
<td>+0.08%</td>
<td>+2.3%</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>2-tag</td>
<td>−13.2%</td>
<td>−23.9%</td>
<td>−12.1%</td>
<td></td>
<td></td>
</tr>
<tr>
<td>$b$ness cuts (down)</td>
<td>no-tag</td>
<td>−0.51%</td>
<td>−0.08%</td>
<td>−2.7%</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>2-tag</td>
<td>+14.4%</td>
<td>+25.8%</td>
<td>+14.5%</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

### Acceptance

<p>| | | | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>JER</td>
<td>± 0.7%</td>
<td>± 0.7%</td>
<td>± 0.7%</td>
</tr>
<tr>
<td>$E_T$ Model</td>
<td>± 1.0%</td>
<td>± 1.0%</td>
<td>± 1.0%</td>
</tr>
<tr>
<td>ISR/FSR</td>
<td>± 2.5%</td>
<td>± 2.5%</td>
<td>± 2.5%</td>
</tr>
<tr>
<td>PDF</td>
<td>± 2%</td>
<td>± 2%</td>
<td>± 2%</td>
</tr>
<tr>
<td>Lumi/Trigger $e$</td>
<td>± 6.4%</td>
<td>± 6.4%</td>
<td>± 6.4%</td>
</tr>
</tbody>
</table>
Feldman-Cousins Bands for MET+ Jets

CDF Run II Preliminary, $\int L = 5.5$ fb$^{-1}$

- Measured Result
- 68% Coverage Bands
- 95% Coverage Bands

$\sigma_{\text{Measured}} / \sigma_{\text{SM}}$
Feldman-Cousins Bands for Charged Leptons + Jets

Feldman-Cousins Bands for Limit Calculation

CDF Run II Preliminary, $\mathcal{L} = 6.6$ fb$^{-1}$

- Measured Result
- 68% Coverage Bands
- 95% Coverage Bands