Searches for Diboson production in final states with heavy flavor jets at CDF

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on behalf of the CDF collaboration

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Outline

• Motivations
• Experimental Environment
• Milestones on diboson searches at CDF
• b-tagging
• Diboson searches as:
  ✴ benchmarks for Higgs analyses
  ✴ validation of the SM
Motivation

- Important test of the EWK sector of the SM
  - deviations from the SM would hint to:
    - anomalous gauge couplings
    - new physics

- Important background to Top, Higgs, SUSY searches

- “Known” territory to test analysis techniques used for the CDF (low mass) Higgs analyses
Experimental Environment

Tevatron

- proton-antiproton collisions at $\sqrt{s} = 1.96\ TeV$
- delivered $\sim 12/fb$
  - $\sim 10/fb$ for analyzers

CDF

- Accurate tracking system with silicon
- Projective-towers calorimeters to measure $e, \gamma, \text{jet energy}$
- Muon detection system
Diboson at CDF: history

• Observation in fully leptonic states
  • $WZ \rightarrow ll\nu l\nu$, $ZZ \rightarrow llll$, $WW \rightarrow l\nu l\nu$

• Observation in semileptonic states
  • MET+jets, lepton+MET+jets

cannot separate $WW$ and $WZ$ due to dijet mass resolution
b-tagging

- **Goal:** separate jets containing B hadrons from other jets
  - key to separate WZ/ZZ from WW

- **Solution:** brand new multivariate tagger (HOBIT)
  - continuous output
    - operation points can be optimized upon search sensitivity
  - trained on Higgs and W+jets MC
  - built upon the strength of previous CDF taggers
    - using the most powerful inputs
b-tagging

- Higher performances than previous CDF b-taggers
- For identical u,d,s,g-jet accept rate (mistag rate), b-jet efficiency:
  - Tight: 38.6% → 53.6% (mistag rate: 1.4%)
  - Loose: 47.1 → 59.3% (mistag rate: 2.8%)

- Calibrated on two orthogonal samples
- Results combined to improve the precision
- Corrections for:
  - b-jet efficiency: 0.95 +/- 0.04 (tight), 0.96 +/- 0.04 (loose)
  - mistag-rate: 1.52 +/- 0.23 (tight), 1.48 +/- 0.17 (loose)
Diboson with heavy flavor jets as Higgs benchmark

<table>
<thead>
<tr>
<th>Process</th>
<th>$\sigma \times \text{BR} \ (\text{fb})$</th>
</tr>
</thead>
<tbody>
<tr>
<td>$WH \to l\nu bb$</td>
<td>27</td>
</tr>
<tr>
<td>$ZH \to llbb$</td>
<td>5</td>
</tr>
<tr>
<td>$ZH \to vvbb$</td>
<td>15</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>46</strong></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Process</th>
<th>$\sigma \times \text{BR} \ (\text{fb})$</th>
</tr>
</thead>
<tbody>
<tr>
<td>$WZ \to l\nu bb$</td>
<td>105</td>
</tr>
<tr>
<td>$ZZ \to llbb$</td>
<td>24</td>
</tr>
<tr>
<td>$ZZ \to vvbb$</td>
<td>73</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>202</strong></td>
</tr>
</tbody>
</table>

- Diboson searches share the same final states as low mass Higgs analyses
- 4-5 times larger cross-sections
Diboson with heavy flavor jets

- Replicate low-mass Higgs analyses

★ 3 main final states:

- 2,3 jets (>=1 b-tagged jet) and
  - 2 identified leptons (“llbb”) or
  - 1 identified lepton and large MET (“lvbb”) or
  - large MET (“vbbb”)

- Re-train multivariate discriminants to extract VZ=WZ+ZZ signal

- Some signal contribution from $W \rightarrow cs, \ Z \rightarrow cc$
llbb

- Cleaner sample, lowest signal rate
- **Selection:**
  - 2 High $P_T$ electrons/muons
    - $75<M_{ll}/GeV<105$
  - 2,3 large $E_T$ jets
    - $\geq 1$ b-tagged jet
- **Analysis strategy:**
  - 16 orthogonal channels examined simultaneously
    - channels divided upon lepton flavor, number of jets, heavy flavor content
  - multivariate discriminant for extracting the signal
    - full reconstruction of the final state
    - improved sensitivity compared to using dijet invariant mass
• Highest signal yield
• Selection:
  ➡ =1 High $P_T$ electron/muon
  ✓ extended lepton acceptance due to a more inclusive triggers
  ➡ large MET
  ➡ 2,3 large $E_T$ jets
  ➡ multivariate techniques to reject multi-jet background

Analysis strategy:
  ➡ 7 orthogonal channels depending on the flavor content, number of jets
    - sensitivity improved thanks to HOBIT
  ➡ Bayesian neural network to discriminate signal from background
    ▶ different optimization in 2 and 3 jets channels
Selection:
- lepton veto
- large MET
- 2,3 large $E_T$ jets
- NN-based discriminant to reject the large instrumental background
- NN to parameterize trigger efficiency curve
  - allows for more relaxed kinematic cuts

Analysis strategy:
- 3 orthogonal channels depending on the flavor content
  - still using “pre-HOBIT” CDF taggers
- Final neural network to discriminate signal from background
  - trained separately in 2 and 3 jet sample
CDF combination

- Simultaneous fit on the discriminant distributions of all (26) sub-channels
- Systematic uncertainties either fully correlated or uncorrelated
  - b-tagging efficiency, jet energy scale correlated
  - multi-jet rate uncorrelated
  - uncertainties on background rates do not contribute much
    - heavily constrained across different channels

\[ \sigma(VZ) = 4.08^{+1.38}_{-1.26} \text{ pb} \]

- Significance \( \sim 3.2 \sigma \)
- Result compatible with SM
  - \( \sigma^{SM}(VZ) = 4.42 \text{ pb} \)
Diboson with heavy flavor jets as test of the SM

- Optimized analysis to isolate $WZ/ZZ$ from $WW$
- Uses the same tools and signature of $l\nu bb$ analysis
  - multivariate techniques to reject multi-jet background
  - at least 1 b-tagged jet
- 2-D fit to extract $\sigma(WZ/ZZ), \sigma(WW)$
  1. dijet invariant mass
  2. NN-based jet flavor separator

\[ \sigma(WW) = 5.10^{+3.97}_{-3.63} \text{ pb} \quad (\sigma^{SM} = 11.34 \text{ pb}) \]
\[ \sigma(WZ + ZZ) = 7.25^{+3.67}_{-3.40} \text{ pb} \quad (\sigma^{SM} = 4.42 \text{ pb}) \]

Consistent with SM
CDF is sensitive to diboson in final states with heavy-flavor jets

- paving the way for (low mass) Higgs analyses
- but also as a sanity check of the SM / search for new physics

\[ \sigma(VZ) = 4.08^{+1.38}_{-1.26} \text{ pb} \]
- compatible with SM expectations

\[ 3.2 \sigma \text{ evidence for } WZ+ZZ \]
- assuming SM \( \sigma(WZ)/\sigma(ZZ) \)

More details at http://www-cdf.fnal.gov/physics/new/hdg/Results.html
• backup
llbb: NN for jet corrections

<table>
<thead>
<tr>
<th>Inputs to the NN jet-energy correction algorithm</th>
</tr>
</thead>
<tbody>
<tr>
<td>lead jet $E_T$</td>
</tr>
<tr>
<td>lead jet $\eta$</td>
</tr>
<tr>
<td>$\Delta \phi(\vec{E}_T, \text{lead jet})$</td>
</tr>
<tr>
<td>$Z$ projection onto the lead jet</td>
</tr>
<tr>
<td>$\vec{E}_T$ projection onto the lead jet</td>
</tr>
<tr>
<td>second jet $E_T$</td>
</tr>
<tr>
<td>second jet $\eta$</td>
</tr>
<tr>
<td>$\Delta \phi(\vec{E}_T, \text{second jet})$</td>
</tr>
<tr>
<td>$Z$ projection onto the second jet</td>
</tr>
<tr>
<td>$\vec{E}_T$ projection onto the second jet</td>
</tr>
<tr>
<td>$\vec{E}_T$</td>
</tr>
<tr>
<td>$\Delta \phi(\text{lead jet, second jet})$</td>
</tr>
<tr>
<td>number of jets</td>
</tr>
</tbody>
</table>

TABLE I: Inputs to the jet-energy correction neural network.

**FIG. 1:** The dijet invariant mass distribution for all $b$-tagged candidates before (left) and after (right) NN correction. The bin at 400 GeV/c$^2$ contains the histogram overflow.
llbb: Final discriminant

<table>
<thead>
<tr>
<th>Inputs to the expert neural networks</th>
<th>$t\bar{t}$ Expert</th>
<th>$Z + l \ell_1 + Z + c\bar{c}$ Expert</th>
<th>$WZ/ZZ$ Expert</th>
</tr>
</thead>
<tbody>
<tr>
<td>$E_T$</td>
<td>NN Corrected $M_{jj}$</td>
<td>2nd jet $E_T$</td>
<td>2nd jet $E_T$</td>
</tr>
<tr>
<td>$E_T$ projection onto the all jets</td>
<td>$H_T$ [23]</td>
<td>$\Delta R(Z, \text{jet 1})$</td>
<td>$\cos(\theta^*)$ [24]</td>
</tr>
<tr>
<td>$E_T$ of $Z + \text{all jets}$</td>
<td>combined mass of $Z$ and all jets</td>
<td>$\Delta R(Z, \text{jet 1})$</td>
<td>$\Delta R(Z, H)$</td>
</tr>
<tr>
<td>$R_T$ projection onto the lead jet</td>
<td>combined mass of $Z$ and $H$ candidates</td>
<td>$H_T$</td>
<td>$Z$ projection onto all jets</td>
</tr>
<tr>
<td>$E_T$ of $Z + H$ candidates</td>
<td>$\Delta R(\text{lepton 1, lepton 2})$</td>
<td>$Z$ projection onto all jets</td>
<td>$\Delta R(\text{lepton 1, lepton 2})$</td>
</tr>
<tr>
<td>$\Delta R(Z, \text{all jets})$ [22]</td>
<td>$Z p_T$</td>
<td>$Z p_T$</td>
<td></td>
</tr>
<tr>
<td>NN Corrected $M_{jj}$</td>
<td>jet 1 $E_T$</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

TABLE II: Inputs to the expert neural networks, listed in descending order of importance.
llbb: modeling of the final discriminant - pretag

FIG. 3: Output of the expert discriminants in the PreTag (defined in text) sample. The bin at zero (one) contains the histogram underflow (overflow).
### llbb: event yields

<table>
<thead>
<tr>
<th>Process</th>
<th>TT</th>
<th>TL</th>
<th>Tx</th>
<th>LL</th>
<th>TT</th>
<th>TL</th>
<th>Tx</th>
<th>LL</th>
</tr>
</thead>
<tbody>
<tr>
<td>$t\bar{t}$</td>
<td>20.1 ± 2.8</td>
<td>21.5 ± 2.8</td>
<td>36.1 ± 4.7</td>
<td>6.1 ± 0.8</td>
<td>7.5 ± 1.2</td>
<td>9.3 ± 1.4</td>
<td>13.5 ± 1.9</td>
<td>2.9 ± 0.5</td>
</tr>
<tr>
<td>Diboson</td>
<td>4.7 ± 0.6</td>
<td>6.5 ± 0.9</td>
<td>19.6 ± 1.8</td>
<td>3.9 ± 0.4</td>
<td>0.7 ± 0.1</td>
<td>1.3 ± 0.2</td>
<td>3.0 ± 0.4</td>
<td>1.0 ± 0.1</td>
</tr>
<tr>
<td>$Z + bb$</td>
<td>19.1 ± 8.0</td>
<td>26.8 ± 11.3</td>
<td>81.5 ± 34.2</td>
<td>10.2 ± 4.4</td>
<td>4.5 ± 2.0</td>
<td>6.5 ± 2.9</td>
<td>14.1 ± 6.2</td>
<td>2.5 ± 1.1</td>
</tr>
<tr>
<td>$Z + cc$</td>
<td>1.5 ± 0.6</td>
<td>6.9 ± 2.9</td>
<td>39.0 ± 16.8</td>
<td>7.3 ± 3.1</td>
<td>0.5 ± 0.2</td>
<td>1.7 ± 0.8</td>
<td>7.4 ± 3.3</td>
<td>2.4 ± 1.1</td>
</tr>
<tr>
<td>$Z + t.f.$</td>
<td>0.7 ± 0.3</td>
<td>8.3 ± 2.0</td>
<td>124.9 ± 27.5</td>
<td>27.5 ± 6.6</td>
<td>0.3 ± 0.1</td>
<td>2.8 ± 0.8</td>
<td>20.3 ± 5.5</td>
<td>8.1 ± 2.3</td>
</tr>
<tr>
<td>mis-ID Z</td>
<td>0.1 ± 0.0</td>
<td>5.1 ± 2.6</td>
<td>7.7 ± 3.9</td>
<td>1.1 ± 0.6</td>
<td>0.0 ± 0.0</td>
<td>2.1 ± 1.0</td>
<td>5.2 ± 2.6</td>
<td>3.0 ± 1.5</td>
</tr>
</tbody>
</table>

| Total Bkg. | 46.2 ± 8.6 | 75.2 ± 12.4| 309.2 ± 47.4| 56.1 ± 8.6 | 13.6 ± 2.3 | 23.6 ± 3.5 | 63.5 ± 9.5 | 19.9 ± 3.2 |
| $ZH(120)$ GeV/c² | 1.1 ± 0.1 | 1.1 ± 0.1 | 1.6 ± 0.2 | 0.3 ± 0.03 | 0.2 ± 0.04 | 0.2 ± 0.04 | 0.3 ± 0.1 | 0.1 ± 0.01 |
| Data      | 45         | 83         | 352        | 66         | 16         | 23         | 59         | 23         |

**TABLE IV:** Comparison of the expected mean event totals for background and $ZH$ signal with the observed number of data events for the $ZH \rightarrow e^+e^- + bb$ channels. The totals are for full event selection, and uncertainties are systematic.

<table>
<thead>
<tr>
<th>Process</th>
<th>TT</th>
<th>TL</th>
<th>Tx</th>
<th>LL</th>
<th>TT</th>
<th>TL</th>
<th>Tx</th>
<th>LL</th>
</tr>
</thead>
<tbody>
<tr>
<td>$t\bar{t}$</td>
<td>20.8 ± 3.1</td>
<td>22.1 ± 3.1</td>
<td>30.4 ± 3.9</td>
<td>5.7 ± 0.8</td>
<td>6.4 ± 1.2</td>
<td>7.4 ± 1.2</td>
<td>10.4 ± 1.5</td>
<td>2.4 ± 0.4</td>
</tr>
<tr>
<td>Diboson</td>
<td>3.8 ± 0.6</td>
<td>5.1 ± 0.7</td>
<td>15.1 ± 1.5</td>
<td>3.0 ± 0.4</td>
<td>0.6 ± 0.1</td>
<td>0.9 ± 0.2</td>
<td>2.3 ± 0.3</td>
<td>0.8 ± 0.1</td>
</tr>
<tr>
<td>$Z + bb$</td>
<td>15.0 ± 6.3</td>
<td>21.0 ± 8.8</td>
<td>64.4 ± 27.0</td>
<td>7.7 ± 3.2</td>
<td>3.5 ± 1.5</td>
<td>5.2 ± 2.4</td>
<td>11.3 ± 5.0</td>
<td>2.3 ± 1.1</td>
</tr>
<tr>
<td>$Z + cc$</td>
<td>1.0 ± 0.4</td>
<td>4.6 ± 2.0</td>
<td>30.0 ± 12.6</td>
<td>6.3 ± 2.6</td>
<td>0.4 ± 0.2</td>
<td>1.5 ± 0.7</td>
<td>5.8 ± 2.5</td>
<td>1.9 ± 0.8</td>
</tr>
<tr>
<td>$Z + t.f.$</td>
<td>0.6 ± 0.3</td>
<td>6.2 ± 1.5</td>
<td>91.7 ± 20.2</td>
<td>19.4 ± 4.5</td>
<td>0.3 ± 0.1</td>
<td>2.2 ± 0.6</td>
<td>15.3 ± 4.0</td>
<td>6.3 ± 1.7</td>
</tr>
<tr>
<td>mis-ID Z</td>
<td>1.0 ± 0.1</td>
<td>0.0 ± 0.0</td>
<td>10.0 ± 0.5</td>
<td>1.0 ± 0.1</td>
<td>1.0 ± 0.1</td>
<td>8.0 ± 0.4</td>
<td>8.0 ± 0.4</td>
<td>5.0 ± 0.3</td>
</tr>
</tbody>
</table>

| Total Bkg. | 42.3 ± 7.1 | 58.9 ± 9.7 | 241.5 ± 36.3| 43.0 ± 6.2 | 12.2 ± 1.9 | 25.2 ± 2.8 | 53.0 ± 7.0 | 18.8 ± 2.2 |
| $ZH(120)$ GeV/c² | 0.9 ± 0.1 | 0.9 ± 0.1 | 1.4 ± 0.1 | 0.3 ± 0.03 | 0.2 ± 0.03 | 0.2 ± 0.04 | 0.2 ± 0.04 | 0.1 ± 0.01 |
| Data      | 41         | 69         | 273        | 51         | 15         | 24         | 46         | 25         |

**TABLE V:** Comparison of the expected mean event totals for background and $ZH$ signal with the observed number of data events for the $ZH \rightarrow \mu^+ \mu^- + bb$ channels. The totals are for full event selection, and uncertainties are systematic.
• Cleaner sample, lowest signal rate

• Selection:
  ➡ 2 High PT electrons/muons
    ➢ $75 < M_{ll}/\text{GeV} < 105$
  ➡ 2,3 large ET jets
    ➢ $\geq 1$ b-tagged jet

• Analysis strategy:
  ➡ 16 orthogonal channels examined simultaneously
    ➢ channels divided upon lepton flavor, number of jets, heavy flavor content
  ➡ multivariate discriminant for extracting the signal
    ➢ full reconstruction of the final state
    ➢ improved sensitivity wrt using dijet invariant mass

$\sigma(VZ) = 0.79^{+1.68}_{-0.70} \text{ pb}$
• Highest signal yield

• Selection:
  ➡ 1 High PT electron/muon
  ✓ extended lepton acceptance due to a more inclusive triggers
  ➡ large MET
  ➡ 2,3 large ET jets
  ➡ multivariate techniques to reject multi-jet background

■ Analysis strategy:
  ➡ 7 orthogonal channels depending on the flavor content, number of jets
  - sensitivity improved thanks to HOBIT
  ➡ Bayesian neural network to discriminate signal from background
  ▶ different optimization in 2 and 3 jets channels

\[ \sigma(VZ) = 7.78^{+2.47}_{-2.25} \text{ pb} \]
**lvbb: even yield**

<table>
<thead>
<tr>
<th>Number of Jets</th>
<th>2 jets</th>
<th>3 jets</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tagging categories</td>
<td>TT</td>
<td>TL</td>
</tr>
<tr>
<td>DiTop</td>
<td>177.49±22.17</td>
<td>211.19±19.8</td>
</tr>
<tr>
<td>STopS</td>
<td>59.1±7.06</td>
<td>66.39±5.85</td>
</tr>
<tr>
<td>STopT</td>
<td>17.4±2.48</td>
<td>32.45±3.98</td>
</tr>
<tr>
<td>WW</td>
<td>1.9±0.48</td>
<td>15.54±3.13</td>
</tr>
<tr>
<td>WZ</td>
<td>21.86±2.63</td>
<td>25.97±2.28</td>
</tr>
<tr>
<td>ZZ</td>
<td>2.6±0.3</td>
<td>2.73±0.24</td>
</tr>
<tr>
<td>Zjets</td>
<td>11.94±1.29</td>
<td>23.24±2.47</td>
</tr>
<tr>
<td>Wbb</td>
<td>284.99±116.78</td>
<td>382.43±155.86</td>
</tr>
<tr>
<td>Wcc</td>
<td>22.54±9.39</td>
<td>141.43±58.32</td>
</tr>
<tr>
<td>WIf</td>
<td>5.17±1.54</td>
<td>73.93±16.53</td>
</tr>
<tr>
<td>QCD</td>
<td>12.35±7.94</td>
<td>101.82±41.71</td>
</tr>
<tr>
<td>Bkg</td>
<td>617.34±172.05</td>
<td>1077.12±309.74</td>
</tr>
<tr>
<td>Obs</td>
<td>556</td>
<td>907</td>
</tr>
<tr>
<td>WH115</td>
<td>9.57±0.98</td>
<td>9.98±0.62</td>
</tr>
</tbody>
</table>

**TABLE I:** Background summary, signal expectation and data yield for the events with two jets in all $b$-tagging categories for central leptons.
lvbb: Mj1 j2
$\nu\nu bb$: BNN 3 jets

All Leptons, 3 jets, "TT" b-tags

WH-$\nu b\bar{b}$

CDF Run II Preliminary (9.4fb⁻¹)

Number of events

$10^3$

$10^2$

$10$

$10^1$

$1$

$0.2$, $0.4$, $0.6$, $0.8$, $1$, $1.2$, $1.4$, $1.6$, $1.8$, $2$

BNN output ($M_H = 115$ GeV/c²)

643 Data Events

Friday, July 6, 2012
$\nu\nu bb$

<table>
<thead>
<tr>
<th>Variable</th>
</tr>
</thead>
<tbody>
<tr>
<td>Magnitude of $\vec{E}_T$</td>
</tr>
<tr>
<td>Magnitude of $\vec{p}_T$</td>
</tr>
<tr>
<td>$\vec{E}_T$ / $\sqrt{\sum E_T}$</td>
</tr>
<tr>
<td>$\vec{E}_T$ / $H_T$</td>
</tr>
<tr>
<td>$H_T$ / $\vec{E}_T$</td>
</tr>
<tr>
<td>$M(\vec{E}_T, \vec{j}_1, \vec{j}_2)$</td>
</tr>
<tr>
<td>$\Delta \varphi$ between $\vec{E}_T$ and $\vec{p}_T$</td>
</tr>
<tr>
<td>Maximum of $\Delta \varphi$ between any two jets</td>
</tr>
<tr>
<td>Maximum of $\Delta R$ between any two jets</td>
</tr>
<tr>
<td>Minimum of $\Delta \varphi$ between the $\vec{E}_T$ and $\vec{j}_i$</td>
</tr>
<tr>
<td>Minimum of $\Delta \varphi$ between the $\vec{p}_T$ and $\vec{j}_i$</td>
</tr>
<tr>
<td>$\Delta \varphi(\vec{j}_1, \vec{j}_2)$ in the 2-jet rest frame</td>
</tr>
<tr>
<td>Sphericity</td>
</tr>
<tr>
<td>Centrality</td>
</tr>
</tbody>
</table>

**TABLE III:** Input variables to the neural network devised to suppress the QCD background, and the background coming from production of light flavor jets.

(a) Exclusive SecVtx

(b) Exclusive SecVtx
\textbf{\textit{\nu\nu}bb: inputs NN to correct jet ET}

\begin{table}[h]
\begin{center}
\begin{tabular}{|l|p{15cm}|}
\hline
Variable & Description \\
\hline
Raw $E_T$ & Uncorrected transverse jet energy \\
$L_5$ $m_T$ & Transverse jet mass corrected to hadronic level \\
$H_1$ $E_T$ & H1-corrected transverse jet energy \\
$\pi^0$ Energy & CES detector energies of $\pi^0$ candidates within jet cone \\
EM Fraction & Fraction of jet energy collected in EM calorimeter \\
Jet $\eta$ & Jet pseudorapidity \\
Maximum Track $p_T$ & Maximum transverse momentum of track within jet cone \\
Sum Track $p_T$ & Linear sum of transverse momenta of tracks within jet cone \\
\hline
\end{tabular}
\end{center}
\end{table}

\textbf{TABLE II: Description of the $NN_{JER}$ input variables.}


\textbf{\texttt{vVbb: inputs final discriminant}}

\begin{table}
\centering
\begin{tabular}{ll}
\hline
\textbf{Variable} & \\
\text{Invariant mass of the two leading jets in the event ($M_{jj}$)} & \\
\text{Invariant mass of $E_T$, $j_1^-$ and $j_2^-$} & \\
\text{Difference between the scalar sum of transverse energy of the jets ($H_T$) and $E_T$} & \\
\text{Difference between the vector sum of transverse energy of the jets ($\vec{H}_T$) and $\vec{E}_T$} & \\
\text{The output of the TRACKMET neural network} & \\
\text{Maximum of the difference in the $\eta - \phi$ space between the directions of two jets, taking two jets at the time} & \\
\text{The output of $NN_{QCD}$} & \\
\hline
\end{tabular}
\caption{Input variables to the final discriminant neural network.}
\end{table}
**ννbb: event yields**

<table>
<thead>
<tr>
<th></th>
<th>1S</th>
<th></th>
<th>SS</th>
<th></th>
<th>SJ</th>
<th></th>
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<tbody>
<tr>
<td>$E_T + b$-jets 9.45 fb$^{-1}$</td>
<td></td>
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<td></td>
<td></td>
</tr>
<tr>
<td>$WW$</td>
<td>158.8</td>
<td>± 17.2</td>
<td>0.8</td>
<td>± 0.1</td>
<td>2.5</td>
<td>± 0.3</td>
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<tr>
<td>$WZ/ZZ$</td>
<td>133.9</td>
<td>± 14.3</td>
<td>31.3</td>
<td>± 3.9</td>
<td>27.6</td>
<td>± 3.2</td>
</tr>
<tr>
<td>Single Top</td>
<td>273.6</td>
<td>± 35.2</td>
<td>48.3</td>
<td>± 7</td>
<td>41</td>
<td>± 5.6</td>
</tr>
<tr>
<td>Top Pair</td>
<td>741.5</td>
<td>± 93.1</td>
<td>147.2</td>
<td>± 21.1</td>
<td>133.3</td>
<td>± 18</td>
</tr>
<tr>
<td>$Z + h.f.$</td>
<td>812.2</td>
<td>± 146.2</td>
<td>73.6</td>
<td>± 14.2</td>
<td>72.4</td>
<td>± 13.5</td>
</tr>
<tr>
<td>$W + h.f.$</td>
<td>2868.1</td>
<td>± 528.8</td>
<td>123.5</td>
<td>± 23.9</td>
<td>154.4</td>
<td>± 29.3</td>
</tr>
<tr>
<td>QCD Multijet</td>
<td>10824.6</td>
<td>± 177.3</td>
<td>376.9</td>
<td>± 11.9</td>
<td>923.1</td>
<td>± 19.2</td>
</tr>
<tr>
<td>EWK Mistags</td>
<td>2287.8</td>
<td>± 283</td>
<td>16.5</td>
<td>± 5.4</td>
<td>38.4</td>
<td>± 20.3</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td>18100.6</td>
<td>± 1295.1</td>
<td>818</td>
<td>± 87.5</td>
<td>1392.7</td>
<td>± 109.5</td>
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<tr>
<td><strong>Data</strong></td>
<td>18165</td>
<td></td>
<td>807</td>
<td></td>
<td>1310</td>
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</tr>
</tbody>
</table>
Selection:

- lepton veto
- large MET
- 2,3 large ET jets
- NN-based discriminant to reject the large instrumental background
- NN to parameterize trigger efficiency curve
  - allows for more relaxed kinematic cuts

Analysis strategy:

- 3 orthogonal channels depending on the flavor content
  - still using "pre-HOBIT" CDF taggers
- Final neural network to discriminate signal from background
  - trained separately in 2 and 3 jet sample

\[ \sigma(VZ) = 3.09^{+2.21}_{-1.77} \, \text{pb} \]
Diboson at CDF: history

- Observation in fully leptonic states
  - $WZ \rightarrow l\nu ll$, $ZZ \rightarrow llll$, $WW \rightarrow l\nu l\nu$

- Observation in semileptonic states
  - MET+jets, lepton+MET+jets

cannot separate $WW$ and $WZ$ due to dijet mass resolution
b-tagging

• **Goal:** separate jets containing B hadrons from other jets
  - key to separate WZ/ZZ from WW

• **Solution:** brand new multivariate tagger (HOBIT)
  - continuous output
    - operation points can be optimized upon search sensitivity
  - trained on Higgs and W+jets MC
  - built upon the strength of previous CDF taggers
    - using the most powerful inputs

Some HOBIT inputs

- b-jets
- others
KIT input variables
KIT input variables