Electroweak Single Top Quark Production at Tevatron

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/ was pleasure to be at Fermilab /
Fermilab Tevatron & D0 detector
Top Quark Pair Production
D0 Event Display  (Single Top Jul 2006)
D0 Event Display (Single Top Jan 2007)
Representative Feynman Diagrams (t-channel, t, s-channel Processes)
CKM Matrix Element $V_{tb}$: does not assume 3 generations or unitarity.

\[
\Gamma_{W_{tb}}^{\mu} = -\frac{g}{\sqrt{2}} V_{tb} \left\{ \gamma^{\mu} \left[ f_1^L P_L + f_1^R P_R \right] - \frac{i\sigma^{\mu\nu}}{M_W} (p_t - p_b)_\nu \left[ f_2^L P_L + f_2^R P_R \right] \right\}
\]
New Physics – Exotic Processes - Influences t & s Single Top Cross Section
Relative Rates / Cross Sections of Processes
Variety of Multivariate Analyses

- Likelihood Function (LF)
- Matrix Element (ME)
- Neural Network (NN)
- Boosted Decision Tree (BDT)
- MET and jets (MJ) (nn based)

- as the signal is much smaller than the background (5-7%) and smaller than the uncertainty of the background
CDF and D0 Results

- Aaltonen et al. (CDF)
- Abazov et al. (D0)
Matrix Element Analysis

2-jet channels
- $tb$
- $tq$
- $Wbb$
- $Wcg$
- $Wgg$

3-jet channels
- $tbg$
- $tqb$
- $tqg$
- $Wbbg$

Added additional Matrix Elements since 2006
- 2jets: top pair, $WW$, $WZ$, $ggg$
- 3jets: top pair, $Wugg$
(Single) Decision Tree & Boosted (Forest of) Decision Trees
Expected Performances of Multivariate Techniques
Predicted Background & Single Top Events in 3.2/fb of CDF Run II Data ($\ell + \text{MET} + \text{jets}$, LF, ME, NN, BDT) and 2.1/fb (MET+jets, MJ) (March 4, 2009)

<table>
<thead>
<tr>
<th>Process</th>
<th>$\ell + \text{MET} + \text{jets}$</th>
<th>$\text{MET} + \text{jets}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>$s$-channel signal</td>
<td>77.3 ± 11.2</td>
<td>29.6 ± 3.7</td>
</tr>
<tr>
<td>$t$-channel signal</td>
<td>113.8 ± 16.9</td>
<td>34.5 ± 6.1</td>
</tr>
<tr>
<td>$W + HF$</td>
<td>1551.0 ± 472.3</td>
<td>304.4 ± 115.5</td>
</tr>
<tr>
<td>$t\bar{t}$</td>
<td>686.1 ± 99.4</td>
<td>184.5 ± 30.2</td>
</tr>
<tr>
<td>$Z + \text{jets}$</td>
<td>52.1 ± 8.0</td>
<td>128.6 ± 53.7</td>
</tr>
<tr>
<td>Diboson</td>
<td>118.4 ± 12.2</td>
<td>42.1 ± 6.7</td>
</tr>
<tr>
<td>QCD+mistags</td>
<td>777.9 ± 103.7</td>
<td>679.4 ± 27.9</td>
</tr>
<tr>
<td>Total prediction</td>
<td>3376.5 ± 504.9</td>
<td>1404 ± 172</td>
</tr>
<tr>
<td>Observed</td>
<td>3315</td>
<td>1411</td>
</tr>
</tbody>
</table>
Discriminant Distributions for $l+\text{MET}+\text{jets}$
Results (CDF, s+t channel, LFS: s only, SD: Super Discriminant)

<table>
<thead>
<tr>
<th>Analysis</th>
<th>Cross Section (pb)</th>
<th>Significance (Std. Dev.)</th>
<th>Sensitivity (Std. Dev.)</th>
</tr>
</thead>
<tbody>
<tr>
<td>LF</td>
<td>$1.6^{+0.8}_{-0.7}$</td>
<td>2.4</td>
<td>4.0</td>
</tr>
<tr>
<td>ME</td>
<td>$2.5^{+0.7}_{-0.6}$</td>
<td>4.3</td>
<td>4.9</td>
</tr>
<tr>
<td>NN</td>
<td>$1.8^{+0.6}_{-0.6}$</td>
<td>3.5</td>
<td>5.2</td>
</tr>
<tr>
<td>BDT</td>
<td>$2.1^{+0.7}_{-0.6}$</td>
<td>3.5</td>
<td>5.2</td>
</tr>
<tr>
<td>LFS</td>
<td>$1.5^{+0.9}_{-0.8}$</td>
<td>2.0</td>
<td>1.1</td>
</tr>
<tr>
<td>SD</td>
<td>$2.1^{+0.6}_{-0.5}$</td>
<td>4.8</td>
<td>&gt; 5.9</td>
</tr>
<tr>
<td>MJ</td>
<td>$4.9^{+2.5}_{-2.2}$</td>
<td>2.1</td>
<td>1.4</td>
</tr>
<tr>
<td>Combined</td>
<td>$2.3^{+0.6}_{-0.5}$</td>
<td>5.0</td>
<td>&gt; 5.9</td>
</tr>
</tbody>
</table>
Discriminants and Likelihood Ratio Test / CDF
Expected and Observed Events in 0.9/fb:
e & μ, 1 & 2 b-tagged – D0

<table>
<thead>
<tr>
<th>Source</th>
<th>2 jets</th>
<th>3 jets</th>
<th>4 jets</th>
</tr>
</thead>
<tbody>
<tr>
<td>tb</td>
<td>16 ± 3</td>
<td>8 ± 2</td>
<td>2 ± 1</td>
</tr>
<tr>
<td>tqb</td>
<td>20 ± 4</td>
<td>12 ± 3</td>
<td>4 ± 1</td>
</tr>
<tr>
<td>tt → ℓℓ</td>
<td>39 ± 9</td>
<td>32 ± 7</td>
<td>11 ± 3</td>
</tr>
<tr>
<td>tt → ℓ + jets</td>
<td>20 ± 5</td>
<td>103 ± 25</td>
<td>143 ± 33</td>
</tr>
<tr>
<td>Wb̅b</td>
<td>261 ± 55</td>
<td>120 ± 24</td>
<td>35 ± 7</td>
</tr>
<tr>
<td>Wc̅c</td>
<td>151 ± 31</td>
<td>85 ± 17</td>
<td>23 ± 5</td>
</tr>
<tr>
<td>Wjj</td>
<td>119 ± 25</td>
<td>43 ± 9</td>
<td>12 ± 2</td>
</tr>
<tr>
<td>Multijets</td>
<td>95 ± 19</td>
<td>77 ± 15</td>
<td>29 ± 6</td>
</tr>
<tr>
<td>Total background</td>
<td>686 ± 41</td>
<td>460 ± 39</td>
<td>253 ± 38</td>
</tr>
<tr>
<td>Data</td>
<td>697</td>
<td>455</td>
<td>246</td>
</tr>
</tbody>
</table>
BDT: W+jets (a) & tt (b) Control Sample, all tb+tqb (c); Invariant Mass of W & Highest-pT b-tagged Jet (d)
Expected Standard Model and Measured Probability Density for $tb+tbq$ Cross Section

![Graph showing the comparison between expected and measured probability densities for the $tb+tbq$ cross section. The measured value is $4.9 \pm 1.4 \text{ pb}$ and the expected value is $2.7 \pm 1.4 \text{ pb}$ for a data set of $0.9 \text{ pb}^{-1}$.](image)
Discriminants for Decision Tree, Matrix Element & Bayesian Neural Net – D0
Data/MC agreement (for all channels combined)
Combination of Results – D0 2.3/fb
D0 - 2.3/ fb

Distributions for BNNComb > 0.9

**OBJECT KINEMATICS**

- **D0**
  - Missing $E_T$ vs. $E_T$ [GeV]

**EVENT KINEMATICS**

- **D0**
  - $H_T$ (jets, $l$, $Y$) vs. Yield [fb]

**ANGULAR CORRELATIONS**

- **D0**
  - Cosine (lepton, untag1) vs. Yield [fb]

**JET RECONSTRUCTION**

- **D0**
  - Jet 2 $\eta$ Width vs. Yield [fb]

**TOP QUARK RECONSTRUCTION**

- **D0**
  - $m_{top}$ vs. Yield [fb]

**SINGLE TOP FINAL STATE**

- **D0**
  - $Q \times \eta$ vs. Yield [fb]
Combined Results

\( O' \ ( tb+X, tqb+X ) = 3.94 \pm 0.88 \text{ pb} \)

Significance: \( 5.03 \sigma \)

\( | V_{tb} | > 0.78 \)

at 95 % confidence level