Search for Single Top Production

Reinhard Schwienhorst on behalf of the DØ and CDF Collaborations

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Outline

• Introduction
  – Standard Model Single Top Production
  – Backgrounds
• Search for Single Top Quark Production at DØ
• Search for Single Top Quark Production at CDF
• Conclusions/Outlook
Standard Model Single Top Quark Production

- **Electroweak (charged current) production of top quarks**
  - NLO cross-sections: $0.88\text{pb} \pm 8\%$ \quad $1.98\text{pb} \pm 11\%$
  - Run I 95\% CL limits, DØ: $<17\text{pb}$ \quad $<22\text{pb}$
    - CDF: $<18\text{pb}$ \quad $<13\text{pb}$ \quad $<14\text{pb}$
  - Measure CKM matrix element $V_{tb}$ (test CKM unitarity)
  - Discover new Physics
  - Observe top polarization

- **Event Signature:** 1 high-$E_T$ lepton, MET, $\geq 2$ jets ($\geq 1$ b-tagged jets)

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**Backgrounds**

- **W/Z+jets production (real-\(l\))**
  - \(Wjj, Wcc, Wbb, Zjj, Zcc, Zbb, \ldots\)
  - Estimated from **data** (D\(\Phi\))
  - Estimated from **MC/data** (CDF)

- **Mis-reconstructed multi-jet events (fake-\(l\))**
  - Jet mis-identified as isolated electron or muon
  - Estimated from **data**

- **Top-pair production**
  - Estimated from **MC**

- **Other (WZ, WW, Z\(\tau\tau\), cosmic rays,\ldots)**
  - Estimated from **MC** (CDF)
  - Included in **data** W/Z+jets estimate (D\(\Phi\))
Search for Single Top Quark Production

- **Dataset:** 156-168pb⁻¹ DØ Run II data

- **Preselection**
  - 1 high-pt lepton (Eₜ > 15GeV)
    - |η| < 1.1 (e); |η| < 2.0 (μ)
  - Missing Eₜ > 15GeV
  - 2 Jets, Eₜ > 15GeV, |η| < 3.4
  - Leading jet Eₜ > 25GeV, |η| < 2.5

- **Split Analysis into orthogonal channels**
  - Study separately, then combine results
  - ≥1 b-tagged jet
    - Soft-lepton-tag (SLT)
    - Secondary vertex tag (SVT)
    - Jet-lifetime probability tag (JLIP)
  - Reject mis-reconstructed events
Data – Background Model Comparison

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**Final Event Selection**

- Simple cut to remove largest background (W/Z+jets)
  
  \[ H_T = E_T(\text{lepton}) + \text{MET} + \sum_{i=1,2} E_T(\text{jet}_i) > 150\text{GeV} \]

- Systematic Uncertainties
  
  - MC signal: dominated by jet energy scale, trigger and tagger modeling, \( \sim 20\% \)
  - MC backgrounds: also normalization, \( \sim 25\% \)
  - Data backgrounds: dominated by tagging probability estimate, \( \sim 20\% \)
**Result and Cross Section Limit**

**Electron+muon yield**

<table>
<thead>
<tr>
<th></th>
<th>SLT</th>
<th>SVT</th>
<th>JLIP</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Signals</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>(s)-channel</td>
<td>1.3±0.3</td>
<td>3.1±0.8</td>
<td>3.2±0.7</td>
</tr>
<tr>
<td>(t)-channel</td>
<td>1.7±0.4</td>
<td>5.1±1.3</td>
<td>5.3±1.3</td>
</tr>
<tr>
<td><strong>Backgrounds</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>(\bar{t}\bar{t})</td>
<td>17.8±4.1</td>
<td>43.2±10.4</td>
<td>43.7±10.9</td>
</tr>
<tr>
<td>(W/Z+\text{jets} + \text{fake-}l)</td>
<td>58.4±11.5</td>
<td>94.2±17.7</td>
<td>122.2±23.9</td>
</tr>
</tbody>
</table>

**Sum of backgrounds**

<table>
<thead>
<tr>
<th></th>
<th>SLT</th>
<th>SVT</th>
<th>JLIP</th>
</tr>
</thead>
<tbody>
<tr>
<td>76±11</td>
<td>137±21</td>
<td>166±26</td>
<td></td>
</tr>
</tbody>
</table>

**Observed**

<p>| | | | |</p>
<table>
<thead>
<tr>
<th></th>
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</thead>
<tbody>
<tr>
<td>97</td>
<td>138</td>
<td>148</td>
<td></td>
</tr>
</tbody>
</table>

- **Cross section limit with Bayesian approach**
  - Include systematic uncertainties and correlations
  - Also computed CLs method limits
    - Similar result, different interpretation
  - Most sensitive Channel: e+\(\mu\), SVT+SLT

**Observed/Expected limit at 95%CL:**

\[ \sigma_s < 19 / 16 \text{ pb} \]
\[ \sigma_{s+t} < 23/20 \text{ pb} \]
\[ \sigma_t < 25 / 23 \text{ pb} \]
Search for Single Top Quark Production

• Dataset: 162pb\(^{-1}\) CDF Run II data

• Preselection
  – 1 lepton, \(E_T > 15\text{GeV}, |\eta| < 1.0\)
  – Missing \(E_T > 20\text{GeV}\)
  – 2 Jets, \(E_T > 15\text{GeV}, |\eta| < 2.8\)
  – \( \geq 1 \) b-tagged jet (SecVtx)

• Event yield:

<table>
<thead>
<tr>
<th></th>
<th>Combined search</th>
<th>t-channel search</th>
</tr>
</thead>
<tbody>
<tr>
<td>s-channel</td>
<td>1.19± 0.25</td>
<td>1.16± 0.24</td>
</tr>
<tr>
<td>t-channel</td>
<td>2.39± 0.56</td>
<td>2.34± 0.54</td>
</tr>
<tr>
<td>tt pairs</td>
<td>3.47± 1.04</td>
<td>3.39± 1.02</td>
</tr>
<tr>
<td>non-top</td>
<td>20.7± 4.1</td>
<td>17.4± 3.3</td>
</tr>
<tr>
<td>Total Predicted</td>
<td>27.8± 4.3</td>
<td>24.3± 3.5</td>
</tr>
<tr>
<td>Observed</td>
<td>28</td>
<td>25</td>
</tr>
</tbody>
</table>

• Topological selection
  – 140GeV < \(M_{lvb}\) < 210GeV
  – \(E_T\) (jet 1) > 30GeV (t-channel only)
Analysis Strategy

- Combined search:
  - Near term, aimed at discovery of single top production
- Separate searches for s- and t-channel
  - Long term, needed to study underlying Physics

Combined search

\[ H_T = E_T(\text{lepton}) + \text{MET} + \sum_i E_T(\text{jet}_i) \]

\[ Q(\text{lepton}) \times \eta(\text{untagged jet}) \]
Likelihood Fit to Data

- Maximum likelihood fit to $H_T$ or $Q\times\eta$ data distributions
  - Using MC templates: single top (Pythia), $tt$ (Herwig), non-top: Wbb (Alpgen)
  - Backgrounds are allowed to float within uncertainty on expected yield
  - For each signal and background, define fit parameter $\beta_i = \frac{\mu_i}{\mu_i^{SM}} = \frac{\sigma_i}{\sigma_i^{SM}}$

<table>
<thead>
<tr>
<th>Process</th>
<th>$\beta_{\text{fit}}$</th>
<th>Poisson $\mu$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Single Top</td>
<td>0.64 $\pm$ 1.55</td>
<td>2.30 $\pm$ 5.55</td>
</tr>
<tr>
<td>$tt$</td>
<td>0.98 $\pm$ 0.30</td>
<td>3.40 $\pm$ 1.03</td>
</tr>
<tr>
<td>Non-top</td>
<td>1.04 $\pm$ 0.19</td>
<td>21.46 $\pm$ 3.81</td>
</tr>
<tr>
<td>$\sum \mu$</td>
<td>$-$</td>
<td>27.16</td>
</tr>
</tbody>
</table>

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<th>Process</th>
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<th>Poisson $\mu$</th>
</tr>
</thead>
<tbody>
<tr>
<td>t-channel</td>
<td>0.0 $\pm$ 1.39</td>
<td>0.0 $\pm$ 3.3</td>
</tr>
<tr>
<td>s-channel</td>
<td>1.01 $\pm$ 0.21</td>
<td>1.2 $\pm$ 0.24</td>
</tr>
<tr>
<td>$tt$</td>
<td>1.06 $\pm$ 0.29</td>
<td>3.6 $\pm$ 1.0</td>
</tr>
<tr>
<td>non-top</td>
<td>1.04 $\pm$ 0.16</td>
<td>18.1 $\pm$ 2.7</td>
</tr>
<tr>
<td>$\sum \mu$</td>
<td>$-$</td>
<td>22.8</td>
</tr>
</tbody>
</table>
Cross Section Limit

- Bayesian approach to set cross section limit
- Systematic uncertainties included by convoluting likelihood:

$$L_{sm}(\beta) = \int_{-\infty}^{+\infty} L(\beta') \cdot \frac{1}{\sigma(\beta) \sqrt{2\pi}} \exp \left( -\frac{1}{2} \left( \frac{\beta - \beta'}{\sigma(\beta)} \right)^2 \right) d\beta'$$

**Result:**

CDF Run II Preliminary

- Observed/Expected limit at 95% CL:
  - $\sigma_{s+t} < 13.7/14.1$ pb
  - $\sigma_t < 8.5/11.3$ pb

- $\sigma^2(\beta) = \Delta^2_{\text{Norm}} + \Delta^2_{\text{Shape}}$
- **Normalization:** $\Delta_{\text{Norm}} \sim 20\%$
- **Shape:** $\Delta_{\text{Shape}} \sim 22\%$ (combined) 
  - $\sim 54\%$ (t-channel)

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Conclusions/Outlook

• Searches for Single Top Quark Production have started in Run II
  – Focus on understanding of data
  – Current result improvement over Run I limit

• Work towards observation of Single Top
  – Keep acceptance as high as possible
    • Selection cuts, b-tagging
  – Improve detector understanding and background modeling
    • Reduce systematic uncertainties
  – Employ advanced analysis techniques
    • Both DØ and CDF working on several methods
    • Likelihood ratio, Multivariate analysis (AIDA), Neural Networks, Matrix Element,...

STAY TUNED...