Search for single top quarks via flavor-changing neutral currents (FCNC)

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• Introduction
  – Single top quarks at the Tevatron
• Status of FCNC searches (top quark sector)
• Details of the analysis
  – Signal modeling
• Event yields and kinematic distributions
• Neural network analysis
• Results: limits on FCNC couplings
• Conclusions
Single top quarks at the Tevatron

• In the Standard Model, production of single top quarks can occur through a $W$ boson exchange

$$\sigma_{\text{NLO}} = 0.88 \pm 0.07 \text{ pb}$$

• Additional single top events are also possible from non-SM interactions, for example, from \textit{flavor-changing neutral-currents} (FCNC)
Status of FCNC searches (top quark sector)

- **Exchange of a $Z/\gamma$:**
  
  - Limits from studies of the FCNC decays of the top quark

  \[
  B(t \to q\gamma) < 0.032, \quad \text{and} \quad B(t \to qZ) < 0.33
  \]

  \[
  (\kappa_\gamma < 0.4) \quad (\kappa_Z < 0.7)
  \]

  (CDF at Tevatron)


- Limits from studies of single top-quark production and decay

  \[
  \kappa_{\gamma, Z} < 0.4 \quad \text{(L3 at LEP)}
  \]


  \[
  \kappa_\gamma < 0.18 \quad \text{(ZEUS at HERA)}
  \]

Status of FCNC searches (top quark sector)

- Exchange of a gluon: focus of present search!

Representative 2->2 Feynman diagrams

- Phenomenological results using data from HERA
  \[ \kappa_{u,c} / \Lambda < 0.4 \text{ TeV}^{-1} \] (hep-ph/0604119)
Details of the analysis

**Data sample:** 230 pb$^{-1}$ of lepton+jets data
(lepton: electron or muon)

**Backgrounds:**
- W/Z+jets and diboson production (“W+jets”)
- Top-pair production (“ttbar”)
- Multi-jet events


**Selections:**
- Leptons: $p_T > 15$ GeV
  $|\eta_{\text{det}}| < 1.1$ (electron)
  $|\eta_{\text{det}}| < 2.0$ (muon)
- MET: 15 GeV $<$ MET $<$ 200 GeV
- Njets: $2 \leq \text{Njets} \leq 4$
- Jets: $E_T > 15$ GeV, $|\eta_{\text{det}}| < 3.4$
- Leading jet: $E_T > 25$ GeV, $|\eta_{\text{det}}| < 2.5$
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Include

SM single top production
(“tb” and “tqb”)

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Include
SM single top production
("tb" and "tqb")

Require
only one b-tagged jet
("SVT")

S. Jain
• Use LO CompHEP event generator

Effective Lagrangian:

\[ \frac{\kappa_f}{\Lambda} g_s \frac{1}{f} \sigma^{\mu\nu} \frac{\lambda^a}{2} t G^a_{\mu\nu} \]

where,

\( f \): u-quark, or c-quark

G: gauge field tensor of gluon

\( \kappa_f \): strength of tgu or tgc couplings

\( \Lambda \): scale of new physics

• We correct the LO cross section to NLO by a K-factor of 1.6

[Phys. Rev. D 72, 074018 (2005)]
Signal modeling

- Use LO CompHEP event generator

Effective Lagrangian:

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  [Phys. Rev. D 72, 074018 (2005)]

- The production cross sections scale up quadratically with \( \kappa_f / \Lambda \)
  
  (effect of FCNC couplings on top quark decay is negligible for \( \kappa_f / \Lambda < 0.2 \) TeV\(^{-1} \))

- Therefore, signal samples for any value of \( \kappa_f / \Lambda \) can be scaled quadratically to obtain the kinematic distributions at any other value of \( \kappa_f / \Lambda \)

- We choose that value to be \( \kappa_f / \Lambda = 0.03 \) TeV\(^{-1} \)
Event yields

- Event yields after full detector simulation, and same selections as in the SM single top search

<table>
<thead>
<tr>
<th></th>
<th>Electron channel</th>
<th>Muon channel</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Signals:</strong></td>
<td><strong>“tug”</strong></td>
<td>8.4 ± 2.1</td>
</tr>
<tr>
<td></td>
<td><strong>“tcg”</strong></td>
<td>0.6 ± 0.2</td>
</tr>
<tr>
<td><strong>Backgrounds</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>SM single top</td>
<td>6.4 ± 1.4</td>
<td>6.1 ± 1.4</td>
</tr>
<tr>
<td>ttbar</td>
<td>31.8 ± 6.9</td>
<td>31.4 ± 7.0</td>
</tr>
<tr>
<td>W+jets</td>
<td>84.6 ± 10.2</td>
<td>76.8 ± 8.5</td>
</tr>
<tr>
<td>multi-jets</td>
<td>13.7 ± 4.3</td>
<td>17.2 ± 1.5</td>
</tr>
<tr>
<td><strong>Sum of Backgrounds</strong></td>
<td><strong>136.5 ± 13.4</strong></td>
<td><strong>131.5 ± 12.7</strong></td>
</tr>
<tr>
<td><strong>Observed</strong></td>
<td><strong>134</strong></td>
<td><strong>118</strong></td>
</tr>
</tbody>
</table>
### Systematic Uncertainties

<table>
<thead>
<tr>
<th>Source</th>
<th>Uncertainty</th>
</tr>
</thead>
<tbody>
<tr>
<td>Integrated luminosity</td>
<td>6.5%</td>
</tr>
<tr>
<td>Lepton ID</td>
<td>4%</td>
</tr>
<tr>
<td>Theory cross sections</td>
<td>9 – 18%</td>
</tr>
<tr>
<td>Jet Fragmentation</td>
<td>5%</td>
</tr>
<tr>
<td>Jet ID</td>
<td>1 – 9%</td>
</tr>
<tr>
<td>Jet Energy Scale</td>
<td>1 – 16%</td>
</tr>
<tr>
<td>b-tag modeling</td>
<td>5 – 13%</td>
</tr>
<tr>
<td>Trigger Modeling</td>
<td>2 – 8%</td>
</tr>
</tbody>
</table>
Kinematic distributions
Neural network analysis

- We use neural networks to separate the FCNC signals from the backgrounds.
- When training, we consider:
  - Signal: sum of \( tgc \) and \( tgu \) processes
  - Background: sum of all SM processes
- We consider the following 10 input variables representing:

  **Individual object kinematics**
  - \( p_T(\text{jet1}) \), \( p_T(\text{tagged jet}) \), \( \eta(\text{lepton}) \), \( \text{Missing } E_T \)

  **Global event kinematics**
  - \( H_T(\text{jet1, jet2}) \), \( p_T(W) \), \( p_T(\text{jet1, jet2}) \), \( M(\text{all jets}) \),
  - Top Mass (using tagged jet)

  **Angular correlations**
  - \( \cos(\text{lepton, jet1}) \) in the lab frame
Neural network output

- For combined electron and muon channels

(a) normalized to unity

(b) normalized to data

DØ Run II preliminary
We use Bayesian statistics to extract limits on $\kappa_u / \Lambda$ and $\kappa_c / \Lambda$

- we assume priors flat in $(\kappa_u / \Lambda)^2$ and $(\kappa_c / \Lambda)^2$

We compute the posterior probability density in the 2-D plane of $(\kappa_u / \Lambda)^2$ versus $(\kappa_c / \Lambda)^2$, from which we extract

(a) 2-D limit contours, and (b) 1-D limits
Observed Limits (electron and muons combined)

\[ (\frac{\kappa_c}{\Lambda})^2 \leq (0.164 \text{ TeV})^{-1}, \]  
\[ (\frac{\kappa_u}{\Lambda})^2 \leq (0.046 \text{ TeV})^{-1}, \]  
\[ (\frac{\kappa_c}{\Lambda})^2 \leq (0.210 \text{ TeV})^{-1}, \]  
\[ (\frac{\kappa_u}{\Lambda})^2 \leq (0.049 \text{ TeV})^{-1}, \]  
\[ (\frac{\kappa}{\Lambda})^2 \leq (0.148 \text{ TeV})^{-1}, \]  
\[ (\frac{\kappa}{\Lambda})^2 \leq (0.037 \text{ TeV})^{-1}, \]  

DØ Run II preliminary

95% CL
90% CL
68% CL
### Summary of limits

<table>
<thead>
<tr>
<th></th>
<th>$\kappa_u/\Lambda$</th>
<th>$\kappa_c/\Lambda$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Electron channel</td>
<td>0.046 (0.052)</td>
<td>0.164 (0.190)</td>
</tr>
<tr>
<td>Muon channel</td>
<td>0.049 (0.050)</td>
<td>0.210 (0.205)</td>
</tr>
<tr>
<td>e+µ combined</td>
<td>0.037 (0.041)</td>
<td>0.148 (0.161)</td>
</tr>
</tbody>
</table>

(For expected limits, the data is set to the estimated background yield)

### Ensemble tests

- **e, µ combined channel, with all systematics**
  - Nensemble: 500
  - $\kappa_u/\Lambda$ (obs. limit) = 0.037 TeV$^{-1}$
  - $\kappa_c/\Lambda$ (obs. limit) = 0.148 TeV$^{-1}$
Conclusions

- We performed a first search at the Tevatron for FCNC interactions involving the top quark and a gluon
  - we looked for the production of single top quarks

- We found no evidence of an FCNC signal
  - limits, at 95% CL, on the FCNC couplings are
    $\kappa_u / \Lambda < 0.037 \text{ TeV}^{-1}$, $\kappa_c / \Lambda < 0.148 \text{ TeV}^{-1}$
    - these are much better than previous limits ($0.4 \text{ TeV}^{-1}$, hep-ph/0604119)
      - by a factor 11 for $\kappa_u / \Lambda$
      - by a factor 3 for $\kappa_c / \Lambda$

- Draft for publication is in preparation
Back-up slides
Single top production cross sections via FCNC

- The cross sections can be significantly enhanced depending on the value of the coupling $\kappa$

<table>
<thead>
<tr>
<th>NLO cross sections of single top production through FCNC interactions involving gluons</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\kappa/\Lambda$ [TeV$^{-1}$]</td>
</tr>
<tr>
<td>-----------------------------</td>
</tr>
<tr>
<td>0.01</td>
</tr>
<tr>
<td>0.03</td>
</tr>
<tr>
<td>0.07</td>
</tr>
<tr>
<td>0.11</td>
</tr>
<tr>
<td>0.19</td>
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</table>