Search for non-standard production of single top quarks at DØ

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For the DØ collaboration

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Outline

• Introduction
  – Single top quark production
  – New Physics

• Search for flavor changing neutral currents

• Search for new heavy boson W'

• Conclusions
Single Top Quark Production

- Evidence for single top quark production with 1 fb$^{-1}$

  - See other talks in this session
  - Observe excess above SM expectation → new Physics?

$\sigma$(NLO):

<table>
<thead>
<tr>
<th>Process</th>
<th>Cross Section (pb)</th>
<th>Uncertainty (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>s-channel</td>
<td>0.88 ± 8%</td>
<td></td>
</tr>
<tr>
<td>t-channel</td>
<td>1.98 ± 11%</td>
<td></td>
</tr>
</tbody>
</table>

\[ q \rightarrow W + t \rightarrow q'b \]
\[ \bar{q}' \rightarrow W + t \rightarrow \bar{b} \]
\[ u \rightarrow W + t \rightarrow d \]
\[ b \rightarrow W + t \rightarrow t \]
New Physics in Single Top Quark Production

s-channel: new boson $W'$

- Heavy resonance decaying to top quark
- Focus on $W'$ decay to $t\bar{b}$
- Include right-handed and left-handed interactions
- Assume SM-like $W'$ couplings

$t$-channel: FCNC

- Additional top quark coupling to light quarks
- $Z$ or $\gamma$ coupling
  \[ \rightarrow \text{excellent limits from top decay, Hera, LEP} \]
- Focus on gluon coupling
Flavor Changing Neutral Currents and the top quark

- **Exchange of a Z/γ:**
  - Searches for top quark FCNC decays
    \[ B(t \to q\gamma) < 0.032 \ (\kappa_\gamma < 0.4) \]
    \[ B(t \to qZ) < 0.33 \ (\kappa_Z < 0.7) \]
  - Single top quark production searches
    - \( \kappa_\gamma, Z < 0.4 \) (L3 at LEP)
    - \( \kappa_\gamma < 0.18 \) (ZEUS at HERA)

- **Exchange of a gluon:**
  - Phenomenological results based on single top quark searches at HERA
    \[ \kappa_{u,c} / \Lambda < 0.4 \text{ TeV}^{-1} \]
    (hep-ph/0604119)
Gluon FCNC coupling to top quarks

- Cross section is proportional to FCNC top quark coupling to up or charm quarks

\[ \sigma \propto (\kappa_{u,c} / \Lambda)^2 \]

- \( \Lambda \) is the scale of the new physics
- \( \kappa_{u,c} \) is the strength of the tgu (tgc) coupling

- Same final state as t-channel single top quark
  - Modification of overall single top quark production rate
  - Different matrix element \( \rightarrow \) different kinematics
  - Form multivariate classifier to maximize signal sensitivity
New heavy boson $W'$

- Many extensions of the SM involve heavy gauge bosons
  - Typically called $W'$ and $Z'$
  - Current limit: $M(W'\rightarrow\text{leptons}) > 786\text{ GeV}$
  - If $W'$ only couples to hadrons: $M(W'\rightarrow qq') > 800\text{ GeV}$

- Single top quark production is the ideal place to search for hadronic decays of a $W'$
  - New physics coupling to heavy quark
  - Current limit (CDF Run I): $M(W') > 566\text{ GeV}$

- $W'$ model used here: $W'\rightarrow tb$ with SM-like couplings
  - Include interference with SM $W$ boson in event generation
Tevatron and DØ Experiment

Tevatron
Proton-Antiproton Collider
CM Energy 1.96 TeV
→ Energy Frontier

DØ experiment
230 pb\(^{-1}\) of data for this analysis
Data sample: \(230 \text{ pb}^{-1}\) of lepton+jets data (lepton: electron or muon)

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

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

Separate into single tags and double tags for W' search

Require exactly one b-tagged jet for FCNC search
Gluon FCNC coupling to top quarks

- Use neural networks to separate the FCNC signals from the backgrounds
  - Signal: sum of both $tgc$ and $tgu$
  - Background: sum of all SM processes

- 10 discriminating variables
  - Individual object kinematics
    - $p_T(jet1)$, $p_T$(tagged jet),
    - $\eta$(lepton), Missing $E_T$
  - Global event kinematics
    - $H_T(jet1, jet2)$, $p_T(W)$,
    - $p_T(jet1, jet2)$, $M$(all jets),
  - Top Mass (using tagged jet)
  - Angular correlations
    - $\cos$(lepton, jet1) in the lab frame

\[ P_T(jet1) [\text{GeV}] \]

\[ \text{arbitrary units} \]
FCNC result

95% C.L. Coupling limit:

\[
\kappa_u / \Lambda < 0.037 \text{ TeV}^{-1}
\]

\[
\kappa_c / \Lambda < 0.148 \text{ TeV}^{-1}
\]

Submitted to PRL

APS 2007
**W' analysis procedure**

- Use final state invariant mass ($\sqrt{S}$) distribution to set limits
  - For several masses between 550 GeV and 800 GeV
- Bayesian limit setting approach
- Including all systematic uncertainties

<table>
<thead>
<tr>
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<th>signal</th>
<th>backgrounds</th>
</tr>
</thead>
<tbody>
<tr>
<td>b-tag modeling</td>
<td>4 – 16%</td>
<td>5 – 20%</td>
</tr>
<tr>
<td>Jet energy calibration</td>
<td>1 – 2%</td>
<td>15 – 30%</td>
</tr>
<tr>
<td>Others (trigger, ID, ...)</td>
<td>1 – 5%</td>
<td>1 – 5%</td>
</tr>
</tbody>
</table>
\textbf{W' Results}

At the 95\% C.L.: $M(W'_{L}) > 610$ GeV

$M(W'_{R} \rightarrow l \text{ or } q) > 630$ GeV

$M(W'_{R} \rightarrow q \text{ only}) > 670$ GeV

\textit{PLB 641, 423 (2006)}
Conclusions/Outlook

• Search for new physics in 230 pb$^{-1}$ of DØ data
• No evidence for flavor-changing neutral currents
  – Improve limits on FCNC gluon couplings by factor 4-10
• No evidence for a W' boson
  – Set mass limit for several different W' coupling scenarios
    • Improved limits for $W'_L$ and $W'_R$
• Outlook:
  – Repeat searches with larger datasets
    • Currently analyzing 1 fb$^{-1}$ sample
      – “Evidence” dataset
    • Expect to accumulate 4 fb$^{-1}$ to 8 fb$^{-1}$
  – Extend searches to other new single top physics signals