Search for Flavor Changing Neutral Currents in Single Top Quark Production using 2.3 fb\(^{-1}\) at DØ

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on behalf of the D0 Collaboration

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- 396 ns between bunches
- has delivered about 9.2 fb$^{-1}$ since 2002
Flavor Changing Neutral Currents
change flavor of quarks without changing the charge

models with soliton structure of the top quark
models with new dynamical interactions of the top quark
models with top quark as a composite object
models with multiple Higgs doublets, such as SUSY
FCNC: exchange photons and Z-bosons

- FCNC through photons and Z-bosons:
  
  - CDF constraints (95% CL):
    \[ B(t \to q\gamma) < 0.032 \quad B(t \to qZ) < 0.33 \]
    
    \((Phys.\ Rev.\ Lett.\ 80,\ 2525\ (1998))\)

  - L3 (LEP) direct constraints on FCNC parameters: \( k_{\gamma,Z} < 0.4\)
    
    \((Phys.\ Lett.\ B459,\ 290\ (2002))\)

  - ZEUS (HERA) constraints (95% CL):
    \[ k_{\gamma} < 0.174 \]
    
    \((Phys.\ Lett.\ B559,\ 153\ (2004))\)

  - CDF recent constraints (95% CL):
    \[ \beta(t \to Zq) < 3.7\% \]
    
    \((Phys.\ Rev.\ Lett.\ 101,\ 192002\ (2008))\)
FCNC: exchange of gluons

- Vertex $tgc$ ($tgu$)

\[
\frac{\kappa_f}{\Lambda} g_s \bar{f} \sigma^{\mu\nu} \frac{\lambda^a}{2} tG^a_{\mu\nu}
\]

where, $f$: $u$-quark, or $c$-quark

- $G$: gauge field tensor of gluon
- $\kappa_f$: strength of $tug$ or $tcg$ couplings
- $\Lambda$: scale of new physics

- TEVATRON searches for FCNC through gluons:

  - previous D0 results ($230 \text{ pb}^{-1}$; 2006)
    \[
    \frac{k^c_g}{\Lambda} < 0.15 \text{ TeV}^{-1} \quad \frac{k^u_g}{\Lambda} < 0.037 \text{ TeV}^{-1}
    \]

  - CDF results ($2.2 \text{ fb}^{-1}$; 2008)
    \[
    (k^c_g/\Lambda) < 0.105 \text{ TeV}^{-1}, (k^u_g/\Lambda) < 0.025 \text{ TeV}^{-1}
    \]
    (Phys. Rev. Lett. 102, 151801 (2009))
For this search we used our experience of D0 FCNC search analysis, 2006

We generated CompHEP MC signal FCNC samples

for $p, \bar{p} \rightarrow t\bar{q} + t\bar{q}$ with subsequent top decays

We consider the following four processes:

$q\bar{q} \rightarrow t\bar{c}$, $gg \rightarrow t\bar{c}$, $cq(\bar{q}) \rightarrow tq(\bar{q})$, $cg \rightarrow tg$,

and, also $t$ replaced with $t$

and, also $c$ replaced by $u$.

Samples: $tgc$, $tgu$

$K_c = 0.03$, $K_u = 0.0 \rightarrow (K_c/\Lambda)^2 = 0.0009 \text{ TeV}^{-2}$

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FCNC search: selection and S/B

- Event selection
  - is identical to the D0 Observation Single Top Analysis
    - W from top decays leptonically
    - exactly one of the jet is required to be b-tagged (in contrast with SM)

- Signal modeling
  - we model the signal kinematics and obtain the acceptance for the signal sample at only one value of the FCNC coupling (0.03); then we scale the CS correspondingly

- Background modeling
  - SM single top processes considered as background
  - double top production, W+jets...
FCNC search: multivariate analysis

- Bayesian Neural Networks
- Discriminating variables

- Variables considered for the observation analysis:
  18 - 28 per channel

- Variables used in the previous FCNC analysis in each analysis channel:
  10 variables

- Stable list of final variables: ~24 per channel
  - «Event Kinematics», «Top Quark Reconstruction»
FCNC analysis: discriminating variables

Plots compare the observed data to the background for some discriminating variables.
Kinematics of the FCNC processes are similar

- Two FCNC signal processes (tgc, tgu) combined into a single signal for training the BNN
- Separate BNNs are trained for each choice of lepton flavor (e or mu), jet multiplicity (2, 3 or 4) and data-taking period (RunIIa and RunIIb) — 12 in total
Comparison between background and data for all twelve BNN discriminant combined for (left) whole discriminant range and (right) high discriminant region.
FCNC search: systematics and setting limits

- Systematic uncertainties
  - mainly from JES, b-tagging, normalization
  - when setting limits on FCNC coupling additional signal CS uncertainty is included

(D0 Collaboration, Phys. Rev. D 78, 012005 (2008))

- The observed data are consistent with the background expectation
  - we proceed to set limits on the FCNC couplings

Relative Systematic Uncertainties

<table>
<thead>
<tr>
<th>Components for Normalization</th>
<th>Uncertainties</th>
</tr>
</thead>
<tbody>
<tr>
<td>Integrated luminosity</td>
<td>6.1%</td>
</tr>
<tr>
<td>cross section top pair</td>
<td>12.7%</td>
</tr>
<tr>
<td>single top cross section</td>
<td>8.4%</td>
</tr>
<tr>
<td>Z+jets cross section</td>
<td>5.8%</td>
</tr>
<tr>
<td>Diboson cross sections</td>
<td>5.8%</td>
</tr>
<tr>
<td>Branching fractions</td>
<td>1.5%</td>
</tr>
<tr>
<td>Parton distribution functions (signal acceptances only)</td>
<td>3.0%</td>
</tr>
<tr>
<td>Triggers</td>
<td>5.0%</td>
</tr>
</tbody>
</table>

...
We determine the FCNC limits for up and charm quark couplings using a Bayesian approach. First we obtain a 2D posterior as a function of both cross sections and as a function of both couplings, using the BNN distribution for data, background and signals.

The 2-dimensional posterior probability density as a function of (left) FCNC cross sections and (right) the squared FCNC couplings.
FCNC search: limits

- One-dimensional posterior densities as a function of CS are derived from the general 2-dimensional posterior by integrating over the axes.

![Graph showing 1-dimensional posterior probability as a function of squared tgu coupling and tgc coupling](image)

- The 1-dimensional posterior probability as a function of (left) squared tgu coupling (right) squared tgc coupling

- Limits on the couplings can be translated into decay branching fraction limits.
FCNC search: results

- Observed 95% C.L. limits on cross sections, couplings and branching fractions:

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<td>$\kappa_{tqg}/\Lambda$</td>
<td>0.013 TeV$^{-1}$</td>
<td>0.057 TeV$^{-1}$</td>
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<td>$\mathcal{B}(t \to qg)$</td>
<td>$2.0 \times 10^{-4}$</td>
<td>$3.9 \times 10^{-3}$</td>
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- for comparison
  - previous D0 results (2006): $k_g^u/\Lambda < 0.037$ TeV$^{-1}$, $k_g^c/\Lambda < 0.15$ TeV$^{-1}$
  - CDF results (2008): $\mathcal{B}(t \to u+g) < 3.9 \times 10^{-4}$, $\mathcal{B}(t \to c+g) < 5.7 \times 10^{-3}$, $\kappa_{tug}/\Lambda < 0.018$ TeV$^{-1}$, $\kappa_{tcg}/\Lambda < 0.069$ TeV$^{-1}$
FCNC search: conclusion

- We presented a search for FCNC interactions through gluons
- Using $2.3 \text{ fb}^{-1}$ of integrated luminosity recorded by the D0 detector at Fermilab we set limits on the couplings, branching fractions and cross sections

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- This branching fraction and FCNC couplings limits are the most stringent at the moment
- The paper: arXiv:1006.3575
- We could set stronger limits with new D0 data