Top Quark Properties
at the Tevatron

Aspen 2008 Winter Conference
"Revealing the Nature of
Electroweak Symmetry Breaking"
January 18, 2008

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For the CDF and D∅ Collaborations
How is Top Produced at the Tevatron?

**Strongly**
- Large theoretical uncertainties
- As QCD predicts?
- Only SM top?
- By heavy particles?

\[ \sigma(\bar{p}p \rightarrow t\bar{t} @ M_{\text{top}} = 175 \text{GeV}) \approx 6.7 \text{ pb} \]

**Weakly**
- Rate \( \propto |V_{tb}|^2 \) in SM
- Sensitive to H\(^+\), 4\(^{\text{th}}\) gen, W\('\), FCNC, ...
- Signature \( \sim \) SM Higgs

\[ \sigma \approx 1 \text{ pb} \]

s-channel

\[ \sigma \approx 2 \text{ pb} \]

t-channel
How Does Top Decay?

lepton + jets is the "golden channel"
Identifying Top

leptons (e, μ and τ)  
ν (missing E_T)  
quarks (jets)  
b-quarks (“b-tag” jet)

Jet 1

Jet 2

A real event!
Top Pair Cross Section

\[ \sigma(p\bar{p} \to t\bar{t}) = \frac{N_{\text{obs}} - N_{\text{bkg}}}{\mathcal{A} \cdot \mathcal{E} \cdot \int \mathcal{L}} \]

For example, in \(~1\; fb^{-1}\) of integrated luminosity:

- \(~60\) dilepton
- \(~200\) lepton + jets (with b-tag)
- \(~300\) all-hadronic (with b-tag)

S/B ~ 2-3:1
S/B ~ 3:1
S/B ~ 1:5

Main backgrounds:
- W+jets, WW, WZ, DY
- mistag, W+hf, V V, non-W
- QCD multijets
Summary of Top Pairs Cross Sections

Measurements in all channels using different methods are found to be consistent

Good agreement with SM prediction

Sample composition well understood → use it to look for new physics!
Single Top Production

Very rare! First evidence of single top production! Working towards observation.

Use many different techniques to extract signal from large backgrounds

Multivariate techniques: boosted decision trees, matrix element reconstruction, bayesian neural networks, likelihood discrimnnts

$d\sigma$ is the differential cross section (Matrix Element)

$W(x,y)$ is the probability that a parton level set of variables $y$ will be measured as a set of variables $x$ (parton level corrections)

$f(q)$ is the probability distribution than a parton will have a momentum $q$

Matrix Element Techniques

Also see talk by R. Demina

Neural Network Techniques

January 18, 2008

Top Properties at the Tevatron
First Evidence for Single Top!

**Boosted Decision Trees**

- **s-channel**: $\sigma(p\bar{p} \rightarrow tb + X) = 1.0 \pm 0.9$ pb
- **t-channel**: $\sigma(p\bar{p} \rightarrow tqb + X) = 4.2^{+1.8}_{-1.4}$ pb
- **s+t channels**: $\sigma(p\bar{p} \rightarrow tb + X, tqb + X) = 4.9 \pm 1.4$ pb

Significance of result: **3.4$\sigma$**! (expected 2.1$\sigma$)

**Input 49 variables: object kinematics, event kinematics, angular correlations**

**0.9 fb$^{-1}$ single top**

**PRL 98 18102 (2007)**

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**Significance: 3.6$\sigma$ ! (expected 2.3$\sigma$)**

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First Evidence for Single Top!

**Multivariate Likelihood Function**

CDF Run II Preliminary, $L=1.5$ fb$^{-1}$

- Data
- $Wb\bar{b}$
- $W+LF$
- $W+LF$
- $ttbar$
- $Wc+Wc$
- $Syst. Error$

1.5 fb$^{-1}$ single top

**Matrix Element Technique**

CDF Run II Preliminary, $L=1.51$ fb$^{-1}$

Input 7 variables (different for s-, t- channels):
- kinematics
- kinematic solver and ANN b-tag outputs

**s-channel**
- $\sigma(p\bar{p} \rightarrow tb + X) = 1.1^{+1.4}_{-1.1} \text{ pb}$

**t-channel**
- $\sigma(p\bar{p} \rightarrow tqb + X) = 1.3^{+1.2}_{-1.0} \text{ pb}$

**s+t channels**
- $\sigma(p\bar{p} \rightarrow tb + X, tqb + X) = 2.7^{+1.3}_{-1.1} \text{ pb}$

Significance of result: **2.7$\sigma$** (expected 2.9$\sigma$)

Significance of result: **3.1$\sigma$** (expected 3.0$\sigma$)
$|V_{tb}|$ is CKM matrix element describing strength of $Wtb$ vertex

$\sigma_{\text{single top}} \propto |V_{tb}|^2$

**Measurement:**

Made with $\sigma_{\text{single top}}$

Assumes $|V_{td}|^2 + |V_{ts}|^2 \ll |V_{tb}|^2$

**Theory uncertainties:**

Arise from the cross-section dependence on the top quark mass, the factorization and renormalization scales, PDFs and $\alpha_s$


**Using Boosted Decision Trees**

$0.68 < |V_{tb}| < 1$ @ 95% CL or $|V_{tb}| = 1.3 \pm 0.2$

$|V_{tb}| = 1.02 \pm 0.18^{\text{experiment}} \pm 0.07^{\text{theory}}$
Simultaneous Measurement of $\sigma_{ttbar}$ and $R$

In SM, $\sigma_{ttbar} \propto |V_{tq}|^2$, where $q = d,s,b$

$$R = \frac{B(t \to Wb)}{B(t \to Wq)} = \frac{|V_{tb}|^2}{|V_{tb}|^2 + |V_{ts}|^2 + |V_{td}|^2} \approx 1$$

A simultaneous measurement of $\sigma_{ttbar}$ and $R$:  
extract $\sigma_{ttbar}$ without assuming $B(t \to Wb) = 1$
higher precision on both quantities

$R = 0.97^{+0.09}_{-0.08} (stat + syst)$

$\sigma_{tt} = 8.18^{+0.90}_{-0.84} (stat + syst) \pm 0.50 (lumi) \text{ pb}$

for $M_{top} = 175 GeV$

A $\sim 10\%$ measurement of $\sigma_{ttbar}$

Use this to extract limits:

$R > 0.88 @ 68\% \text{ C.L.}$ and

$|V_{tb}| > 0.89 @ 95\% \text{ C.L.}$
Is Top Pair Produced as Expected?

How much \( gg \rightarrow \bar{t}t \) vs. \( q\bar{q} \rightarrow t\bar{t} \)? Large theoretical uncertainties (~10%)

Measure fraction of gg vs. qq top production

May reveal existence of unknown tt production and top quark decay mechanisms (top quark from gluino decays, and decays to stops)

Two complementary approaches, both statistics limited

Use kinematics of production and decay

\[
\frac{\sigma(gg \rightarrow \bar{t}t)}{\sigma(pp \rightarrow \bar{t}t)} < 0.33 @ 68\% C.L.
\]

Combination of two methods gives \( \sim 6\% \) improvement (a posteriori).

Use track multiplicity distribution

\[
\frac{\sigma(gg \rightarrow \bar{t}t)}{\sigma(pp \rightarrow \bar{t}t)} = 0.07 \pm 0.16
\]

\[
\frac{\sigma(gg \rightarrow \bar{t}t)}{\sigma(pp \rightarrow \bar{t}t)} = 0.07^{+0.15}_{-0.07} \text{ (New!)}
\]

1 fb\(^{-1}\) \( \ell^+\text{jets} \)

Submitted to PRL
Differential Cross Section $d\sigma/dM_{ttbar}$

Measure $d\sigma/dM_{ttbar}$ and test consistency with SM

Possible non-SM contributions

$Z'$, MSSM Higgs, colorons, axigluons, ....

Sensitive to interference effects as well as resonances

$$\frac{d\sigma^i}{dM_{tt}} = \frac{N_i - N_i^{bkg}}{A_i \int L\Delta^i_{M_{tt}}}$$

Reconstruct $M_{ttbar}$

Remove background and unfold

Calculate cross section

Consistent with SM

p-value $= 0.45$
NLO calculations predict forward-backward asymmetry of 4-6% (none at LO)
Asymmetry arises from interference between LO and higher order diagrams
Measurements in both parton rest frame and lab frame

\[ A_{fb}(\text{parton rest frame}) = 1.3 \times A_{fb}(\text{lab frame}) \]

In lab frame:

\[ A_{fb} = \frac{N(-Q \cdot \cos \theta > 0) - N(-Q \cdot \cos \theta < 0)}{N(-Q \cdot \cos \theta > 0) + N(-Q \cdot \cos \theta < 0)} \]

In the pp\overline{p} (lab) frame for \( M_{\text{top}} = 175.0 \) GeV, after corrections

\[ A_{fb} = 0.17 \pm (0.07)_{\text{stat}} \pm (0.04)_{\text{syst}} \]

\[ A_{fb}^{\text{Theory NLO}} = 0.03 - 0.05 \]
Forward Backward Production Asymmetry $A_{fb}$

Measured in parton (t-tbar) rest frame:

$$A_{fb} = \frac{N_{\Delta y>0} - N_{\Delta y<0}}{N_{\Delta y>0} + N_{\Delta y<0}}$$

$\Delta y \equiv y_t - y_\bar{t}$

$A_{fb}^{Theory\ NLO} = 0.04 - 0.06$

Uncorrected for reconstruction, but provide geometric dilution function to be applied to any model

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Two different approaches

- **New!** Submitted to PRL

Two different approaches

- Fully corrected for reconstruction

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January 18, 2008
Top Properties at the Tevatron, E. Halkiadakis
Searching For New Physics In $A_{FB}$

Several models suggest new particles coupled to the 3rd generation.

For example, models with a “leptophobic” $Z'$ that decays dominantly to quarks.

Results in $t\bar{t}$ production via a heavy narrow (or wide) resonance.

(e.g. Harris, Hill, Parke hep-ph/9911288)

$\frac{f}{2}$: fraction of top pair events produced via a wide $Z'$ resonance

For $M_{Z'} = 750$ GeV:

$f < 0.81$ @95% C.L. (observed)

$f < 0.44$ @95% C.L. (expected)
Search for a $t\bar{t}b\bar{b}$ Resonance

Direct search for narrow-width heavy resonance
Analyze reconstructed $M_{t\bar{t}b\bar{b}}$ distribution

Within a topcolor-assisted technicolor model, exclude leptophobic $Z'$:
$M_{Z'}<680$ GeV ($\Gamma=0.012 M_{Z'}$)
excluded at 95% C.L.
Search for a Massive Gluon

Search for heavy gluon-like particle, $G \rightarrow t\bar{t}b\bar{b}$

Analyze reconstructed $M_{t\bar{t}b\bar{b}}$ distribution with a Matrix Element technique (DLM)

Set upper and lower limits on coupling strength, $\lambda = \lambda_q \lambda_Q$, for $\Gamma_G = 5\% - 50\% M_G$ and $M_G = 400\text{ - }800\text{GeV}$

$\Gamma_G = 0.1 M_G$, $M_G = 800\text{ GeV}$

95% C.L. Lower Limit = $-0.02$

95% C.L. Upper Limit = $0.26$

CDF Run II Preliminary 1.9 fb$^{-1}$

CDF Run II Preliminary 1.9 fb$^{-1}$
Search for a $W'$ Resonance

Search for resonances in $tb$ channel using $M_{WJJ}$

Use massive $W$ boson, or $W'$, to model such a resonance

$W'$ with SM couplings has a large branching fraction to $tb$

Many new theories include new gauge bosons:
- Extensions to the Standard Model (GUT)
- Extra dimensions (Kaluza-Klein)

New! 1.9fb$^{-1}$ single-top

CDF Run II Preliminary, L=1.9 fb$^{-1}$ (Monte Carlo Scaled to Data)

95% C.L. Observed Limit - CDF Run II Preliminary: 1.9 fb$^{-1}$

@95% C.L.

$M_{W'} > 800 \text{ GeV}/c^2 \ (M_{W'} > M_{\nu_R})$

$M_{W'} > 825 \text{ GeV}/c^2 \ (M_{W'} < M_{\nu_R})$

(Branching ratio depends whether $W' \rightarrow l\nu_R$ is kinematically allowed)
Search for Scalar Top

What about SUSY? Search for superpartner of top quark

Consider stop quark masses equal to or lighter than the top quark mass

$\tilde{t} \rightarrow b\tilde{\chi}_1^+ (\tilde{\chi}_1^+ \rightarrow W^+\tilde{\chi}_1^0)$ can be important

**Likelihood Discriminant**

Input subset of 11 kinematic variables, depending on stop quark mass point

First time search done in this channel in Run II.

Obtain upper cross section limits @ 95% C.L.

for stop (chargino) masses of 145-175 (105-135) GeV.

Observed limits are a factor of ~7-12 above the theoretical predictions
Charged Higgs Limits

In SM, cross section ratio expectation:

\[ \frac{\sigma(\bar{p}p \rightarrow \bar{t}t)_{\ell+ \text{jets}}}{\sigma(\bar{p}p \rightarrow \bar{t}t)_{\ell\ell}} = 1 \]

Measurement in agreement with SM:

\[ \frac{\sigma(\bar{p}p \rightarrow \bar{t}t)_{\ell+ \text{jets}}}{\sigma(\bar{p}p \rightarrow \bar{t}t)_{\ell\ell}} = 1.21^{+0.27}_{-0.26} \text{(stat + syst)} \]

Confidence Intervals

Interpret \( R_\sigma \) into upper limit on:

\[ B(t \rightarrow Hb) < 0.35@95\% \text{C.L.} \]

With SM expectation of:

\[ B(t \rightarrow Hb) < 0.25@95\% \text{C.L.} \]

Assumptions:

- \( M_{H^\pm} = 80 \text{GeV} \) (not ruled out by LEP)
- \( H^\pm \) and decays exclusively to \( H^\pm(-) \rightarrow c\bar{s}(\bar{c}s) \).
The V-A character of the decay makes the helicity of the W only 
\[ F_0 = 0.70, \quad F_- = 0.30, \quad F_+ = 0 \]
(longitudinal, left-handed, right-handed)

\[ \cos \theta^* = \text{angle between lepton and top in } W \text{ rest frame} \]
$F_0 = 0.425 \pm 0.166 \text{ stat} \pm 0.102 \text{ syst}$

$F_+ = 0.119 \pm 0.090 \text{ stat} \pm 0.053 \text{ syst}$

If $F_+$ fixed to 0:
$F_0 = 0.619 \pm 0.090 \text{ stat} \pm 0.052 \text{ syst}$

If $F_0$ fixed to 0.7:
$F_+ = -0.002 \pm 0.047 \text{ stat} \pm 0.047 \text{ syst}$

If $F_+$ fixed to 0:
$F_0 = 0.66 \pm 0.10 \text{ stat} \pm 0.06 \text{ syst}$

If $F_0$ fixed to 0.7:
$F_+ = 0.01 \pm 0.05 \text{ stat} \pm 0.03 \text{ syst}$
**W Helicity Matrix Element Technique**

Likelihood based on differential cross sections for ttbar and W+jets

\[
\mathcal{L} = (F_0, C_s) = \prod_{i=1}^{N} C_s P_{t\bar{t}}(\bar{x}_i; F_0) + (1-C_s) P_{W+jets}(\bar{x}_i)
\]

\[
d\sigma \propto |M|^2, |M|^2 \propto w_{lep}(\cos \theta^*) \times w_{had}(\cos \theta^*)
\]

\[
w(\cos \theta^*) = F_+ \frac{3}{8} (1 - \cos \theta^*)^2 + F_0 \frac{3}{4} (1 - \cos^2 \theta^*) + (1 - F_0 - F_+) \frac{3}{8} (1 + \cos \theta^*)^2
\]

**New!**

CDF Run II Preliminary (1.9 fb⁻¹)

-\ln(L/L_{\text{max}})

\[
F_0 = 0.637 \pm 0.084_{\text{stat}} \pm 0.069_{\text{syst}}
\]

for \( M_{\text{top}} = 175 \text{ GeV/c}^2 \)

and \( F_+ = 0 \)

~20% improvement in sensitivity!
The top quark is the least known quark, and the most interesting for new physics.

Lots of exciting top physics happening at the Tevatron! (Many topics I didn’t have time to cover: $t'$, FCNC, Top Charge, Top Width, …)

We are unraveling the true nature of the top quark.

Beginning to have sensitivity to the unexpected in particle properties and new phenomena in the data.

Frustratingly consistent with standard model, so far.

For more info go to:

http://www-cdf.fnal.gov/physics/new/top/top.html
http://www-d0.fnal.gov/Run2Physics/top/top_public_web_pages/top_public.html
Single Top
Single Top DØ

Summary table

<table>
<thead>
<tr>
<th></th>
<th>Exp p-value (std.dev.)</th>
<th>Obs p-value (std.dev.)</th>
<th>p-value SM (std.dev.)</th>
<th>Frequency</th>
</tr>
</thead>
<tbody>
<tr>
<td>DT</td>
<td>0.019 (2.1)</td>
<td>0.00035 (3.4)</td>
<td>0.11 (1.2)</td>
<td>60%</td>
</tr>
<tr>
<td>ME</td>
<td>0.037 (1.8)</td>
<td>0.0021 (2.9)</td>
<td>0.21 (0.8)</td>
<td>62%</td>
</tr>
<tr>
<td>BNN</td>
<td>0.097 (1.3)</td>
<td>0.0089 (2.4)</td>
<td>0.175 (0.9)</td>
<td>59%</td>
</tr>
</tbody>
</table>

- Expected p-value: Fraction of zero-signal pseudo-datasets above SM cross section (2.9 pb)
- Observed p-value: Fraction of zero-signal pseudo-datasets above measured cross section
- p-value SM: Fraction of SM-signal pseudo-datasets (including 16% uncertainty on the signal cross section) above measured cross section
- Frequency: Fraction of measured-cross-section signal pseudo-datasets (including 16% uncertainty on the signal cross section) that fall within the 1 standard deviation error bands of the observed value
## Single Top $D\emptyset$

### Percentage of single top $tb+tqb$ selected events and S:B ratio

(white squares = no plans to analyze)

<table>
<thead>
<tr>
<th>Electron + Muon</th>
<th>1 jet</th>
<th>2 jets</th>
<th>3 jets</th>
<th>4 jets</th>
<th>≥ 5 jets</th>
</tr>
</thead>
<tbody>
<tr>
<td>0 tags</td>
<td>10%</td>
<td>25%</td>
<td>12%</td>
<td>3%</td>
<td>1%</td>
</tr>
<tr>
<td></td>
<td>1 : 3,200</td>
<td>1 : 390</td>
<td>1 : 300</td>
<td>1 : 270</td>
<td>1 : 230</td>
</tr>
<tr>
<td>1 tag</td>
<td>6%</td>
<td>21%</td>
<td>11%</td>
<td>3%</td>
<td>1%</td>
</tr>
<tr>
<td></td>
<td>1 : 100</td>
<td>1 : 20</td>
<td>1 : 25</td>
<td>1 : 40</td>
<td>1 : 53</td>
</tr>
<tr>
<td>2 tags</td>
<td>3%</td>
<td>2%</td>
<td>1%</td>
<td>0%</td>
<td></td>
</tr>
<tr>
<td></td>
<td>1 : 11</td>
<td>1 : 15</td>
<td>1 : 38</td>
<td>1 : 43</td>
<td></td>
</tr>
</tbody>
</table>
### Single Top $D\emptyset$

<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>$16 \pm 3$</td>
<td>$8 \pm 2$</td>
<td>$2 \pm 1$</td>
</tr>
<tr>
<td>$tqb$</td>
<td>$20 \pm 4$</td>
<td>$12 \pm 3$</td>
<td>$4 \pm 1$</td>
</tr>
<tr>
<td>$t\bar{t} \rightarrow ll$</td>
<td>$39 \pm 9$</td>
<td>$32 \pm 7$</td>
<td>$11 \pm 3$</td>
</tr>
<tr>
<td>$t\bar{t} \rightarrow l+\text{jets}$</td>
<td>$20 \pm 5$</td>
<td>$103 \pm 25$</td>
<td>$143 \pm 33$</td>
</tr>
<tr>
<td>$W+b\bar{b}$</td>
<td>$261 \pm 55$</td>
<td>$120 \pm 24$</td>
<td>$35 \pm 7$</td>
</tr>
<tr>
<td>$W+c\bar{c}$</td>
<td>$151 \pm 31$</td>
<td>$85 \pm 17$</td>
<td>$23 \pm 5$</td>
</tr>
<tr>
<td>$W+jj$</td>
<td>$119 \pm 25$</td>
<td>$43 \pm 9$</td>
<td>$12 \pm 2$</td>
</tr>
<tr>
<td>Multijets</td>
<td>$95 \pm 19$</td>
<td>$77 \pm 15$</td>
<td>$29 \pm 6$</td>
</tr>
<tr>
<td>Total background</td>
<td>$686 \pm 41$</td>
<td>$460 \pm 39$</td>
<td>$253 \pm 38$</td>
</tr>
<tr>
<td>Data</td>
<td>$697$</td>
<td>$455$</td>
<td>$246$</td>
</tr>
</tbody>
</table>

Event Yields in 0.9 fb$^{-1}$ Data

Electron+muon, 1tag+2tags combined
### Single Top DØ

#### Decision Tree Input Variables

<table>
<thead>
<tr>
<th>Object Kinematics</th>
<th>Event Kinematics</th>
</tr>
</thead>
<tbody>
<tr>
<td>( p_T(\text{jet1}) )</td>
<td>Aplanarity(alljets,W)</td>
</tr>
<tr>
<td>( p_T(\text{jet2}) )</td>
<td>( M(\text{W,best1}) ) (“best” top mass)</td>
</tr>
<tr>
<td>( p_T(\text{jet3}) )</td>
<td>( M(\text{W,tag1}) ) (“b-tagged” top mass)</td>
</tr>
<tr>
<td>( p_T(\text{jet4}) )</td>
<td>( H_T(\text{alljets}) )</td>
</tr>
<tr>
<td>( p_T(\text{best1}) )</td>
<td>( H_T(\text{alljets, best1}) )</td>
</tr>
<tr>
<td>( p_T(\text{notbest1}) )</td>
<td>( H_T(\text{alljets, tag1}) )</td>
</tr>
<tr>
<td>( p_T(\text{notbest2}) )</td>
<td>( H_T(\text{alljets,W}) )</td>
</tr>
<tr>
<td>( p_T(\text{tag1}) )</td>
<td>( H_T(\text{jet1,jet2}) )</td>
</tr>
<tr>
<td>( p_T(\text{untag1}) )</td>
<td>( H_T(\text{jet1,jet2,W}) )</td>
</tr>
<tr>
<td>( p_T(\text{untag2}) )</td>
<td>( M(\text{alljets}) )</td>
</tr>
</tbody>
</table>

#### Angular Correlations

\( \Delta R(\text{jet1,jet2}) \)

\( \cos(\text{best1,lepton}_{\text{besttop}}) \)

\( \cos(\text{best1,not best1}_{\text{besttop}}) \)

\( \cos(\text{tag1,alljets}_{\text{alljets}}) \)

\( \cos(\text{tag1,lepton}_{\text{btaggedtop}}) \)

\( \cos(\text{jet1,alljets}_{\text{alljets}}) \)

\( \cos(\text{jet1,lepton}_{\text{btaggedtop}}) \)

\( \cos(\text{jet2,alljets}_{\text{alljets}}) \)

\( \cos(\text{jet2,lepton}_{\text{btaggedtop}}) \)

\( \cos(\text{lepton,Q(lepton)\times z}_{\text{besttop}}) \)

\( \cos(\text{lepton}_{\text{besttop,btaggedtop CMframe}}) \)

\( \cos(\text{lepton}_{\text{btaggedtop,btaggedtop CMframe}}) \)

\( \cos(\text{not best, alljets}_{\text{alljets}}) \)

\( \cos(\text{not best, lepton}_{\text{btaggedtop}}) \)

\( \cos(\text{untag1, alljets}_{\text{alljets}}) \)

\( \cos(\text{untag1,lepton}_{\text{btaggedtop}}) \)

For angular variables, the subscript indicates the reference frame.
### Single Top CDF

<table>
<thead>
<tr>
<th>Process</th>
<th>Number of Events in 1.51 fb$^{-1}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>s-channel</td>
<td>23.9±5.4</td>
</tr>
<tr>
<td>t-channel</td>
<td>37.0±9.3</td>
</tr>
<tr>
<td>$W\bar{b}$</td>
<td>319.6±112.3</td>
</tr>
<tr>
<td>$Wc\bar{c}, Wc\bar{j}$</td>
<td>324.2±115.8</td>
</tr>
<tr>
<td>Mistags</td>
<td>214.6±27.3</td>
</tr>
<tr>
<td>$t\bar{t}$</td>
<td>85.3±17.3</td>
</tr>
<tr>
<td>Diboson/$Z + jets$</td>
<td>54.5±6.0</td>
</tr>
<tr>
<td>non – $W$</td>
<td>44.5±17.8</td>
</tr>
<tr>
<td>Total signal</td>
<td>60.9±15.3</td>
</tr>
<tr>
<td>Total background</td>
<td>1042.8±218.2</td>
</tr>
<tr>
<td>Total prediction</td>
<td>1103.7±230.9</td>
</tr>
<tr>
<td>Observed in data</td>
<td>1078</td>
</tr>
</tbody>
</table>

$W+2$jets bin
($\geq 1$ bjet)
FIG. 7: The best fit value for $\sigma_s$ and $\sigma_t$ obtained from fitting the 2-dimensional $\mathcal{L}_s$ vs. $\mathcal{L}_t$ distribution. A $\Delta \chi^2$ is computed, comparing the $\chi^2(\sigma_s, \sigma_t)$ against that of best-fit corresponding to $(\sigma_s, \sigma_t) = (0.1 \text{ pb}, 0.2 \text{ pb})$. The 1$\sigma$ fit region and the region allowed at the 95% C.L. are shown, along with the Standard Model prediction.
FIG. 3: Left: Evaluation of the event probability discriminant in the high statistics taggable but untagged $W + 2$ jets control sample. The hatched band accounts for the Monte Carlo statistical uncertainty. The error bars on the data points are Gaussian errors. Right: Evaluation of the event probability discriminant in the tagged $W + 4$ jets sample using only the two jets with the highest transverse momentum as input to the discriminant calculation. This control sample is enriched in $t\bar{t}$ events ($\sim 85\%$).
FIG. 9: Data and Monte Carlo comparison of the $Q_{\text{lepton}} \cdot \eta_{\text{untagged jet}}$ and $m_{Wb}$ distributions for increasing cuts on the EPD discriminant. The top row includes the last three bins of the EPD discriminant (EPD>0.9) and the bottom row includes the last bin of the EPD discriminant (EPD>0.965).
Projections for Single Top Sensitivity

CDF II preliminary

significance $S/\sqrt{B}$

integrated luminosity [ 1/fb ]

January 18, 2008  Top Properties at the Tevatron, E. Halkiadakis
TABLE II: Summary of uncertainties on $\sigma_{tt}$ and $R$. 

<table>
<thead>
<tr>
<th>Source</th>
<th>$\Delta \sigma_{tt}$ (pb)</th>
<th>$\Delta R$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Statistical</td>
<td>$+0.67$ $-0.64$</td>
<td>$+0.067$ $-0.065$</td>
</tr>
<tr>
<td>Lepton identification</td>
<td>$+0.32$ $-0.27$</td>
<td>n/a</td>
</tr>
<tr>
<td>Jet energy scale</td>
<td>$+0.32$ $-0.23$</td>
<td>n/a</td>
</tr>
<tr>
<td>$W$+jets background</td>
<td>$+0.21$ $-0.23$</td>
<td>n/a</td>
</tr>
<tr>
<td>Multijet background</td>
<td>$+0.17$ $-0.17$</td>
<td>$+0.016$ $-0.016$</td>
</tr>
<tr>
<td>Signal modeling</td>
<td>$+0.12$ $-0.25$</td>
<td>n/a</td>
</tr>
<tr>
<td>$b$-tagging efficiency</td>
<td>$+0.10$ $-0.09$</td>
<td>$+0.059$ $-0.047$</td>
</tr>
<tr>
<td>Other</td>
<td>$+0.24$ $-0.13$</td>
<td>$+0.015$ $-0.014$</td>
</tr>
<tr>
<td>Total uncertainty</td>
<td>$+0.90$ $-0.84$</td>
<td>$+0.092$ $-0.083$</td>
</tr>
</tbody>
</table>
An example unfolded $M_{ttbar}$ distribution compared with the true and a simulated measured distribution.
$A_{FB}$ CDF

CDF II Preliminary

$L=1.9\text{fb}^{-1}$

- CDF Data
- Pythia
- Herwig
- MC@NLO

$A_{bg\ subtracted}$

$N_{jets}$

4

$\geq 5$
The top quark is the heaviest elementary particle, which could be sensitive to the physics beyond standard model [1]. The search for the new color-singlet particle decaying the top pair have been performed at both CDF and DØ [2, 3]. In this analysis we search for the new color-octet particle, “massive gluon (G),” based on the generic assumption. The top quark pairs are produced coherently in $q\bar{q}$ annihilation process in this case. The production matrix element can be written as,

$$|\mathcal{M}_{\text{prod.}}|^2 = \frac{9}{2}g_s^4\hat{s}^2(2 - \beta^2 + \beta^2 \cos^2 \theta)(\Pi_g + \lambda \Pi_{\text{int.}} + \lambda^2 \Pi_G)$$ \hspace{1cm} (1)

where the propagator factors are

$$\Pi_g = \frac{1}{\hat{s}^2}, \quad \Pi_G = \frac{1}{(\hat{s} - M^2)^2 + M^2 \Gamma^2}, \quad \Pi_{\text{int.}} = \frac{2}{\hat{s}} \frac{\hat{s} - M^2}{(\hat{s} - M^2)^2 + M^2 \Gamma^2}$$ \hspace{1cm} (2)

$\lambda \equiv \lambda_q \lambda_Q$. $\lambda_f$ and $\lambda_Q$ are the coupling strength of massive gluon to the light quark and heavy quark, relative to the strong coupling as shown in the figure1. There are 3 modeling parameters, $\lambda$ (strength of coupling), mass, and the decay width. $\lambda$ can be both positive and negative. We assume no parity violation.
Massive Gluon

Example of systematics
IV. \( W' \) SIGNAL

A. \( R \) and \( L \)-Handed \( W' \) Models

The Lagrangian describing the \( W' \) coupling to fermions can be written as [9]:

\[
\mathcal{L} = g f_i \gamma_{\mu} \left( C_{ij}^{R} P_R + C_{ij}^{L} P_L \right) W' f_j
\]  

(1)

where \( P_{L,R} = (1 \pm \gamma_5)/2 \) are the projection operators, \( g \) is the gauge coupling, and the \( C_{ij}^{L,R} \) are arbitrary coupling that differ for quarks and leptons. We assume that the \( W' \) has purely right-handed or left-handed couplings. Figure 2 shows the dominant s-channel diagram for \( W' \) production. Contributions from the \( t- \) and \( u- \) channels are suppressed by the large \( W' \) mass.
W’ Coupling Limits

For a given mass $M_{W'}$ we can adjust $g$ until the cross-section of the model calculated via scaling by $g^4/g_{SM}^4$ equals the experimentally excluded cross-section. This is precisely how the $M_{W'}$-$g$ graph is constructed.

We exclude gauge couplings down to $0.4g_{SM}$ for low $W'$ masses and $M_{W'}<M(\nu)$.
Scalar Top

$A_t = 1 \text{ TeV}$
$M_A = 250 \text{ GeV}$
$m_H = 280 \text{ GeV}$
$M_Z = 250 \text{ GeV}$
III. MONTE CARLO SIMULATION

The $\tilde{t}_1 \tilde{t}_1$ signal events in the lepton+jets topology were generated using PYTHIA v6.323 [13] in its general MSSM mode. The neutralino $\tilde{\chi}_1^0$ is the LSP and the MSSM parameters are chosen as follows:

- $\tan \beta = 20$, $\mu = 225$ GeV, $M_A = 800$ GeV, $M_1 = 53$ GeV, $M_3 = 500$ GeV,
- Trilinear couplings $A_b = A_{\tau} = 200$ GeV,
- Scalar lepton masses $M_{\tilde{l}_L} = M_{\tilde{l}_R} = M_{\tilde{\tau}_L} = M_{\tilde{\tau}_R} = 200$ GeV,
- Scalar quark masses $M_{\tilde{q}_L} = M_{\tilde{q}_R} = M_{\tilde{t}_L} = M_{\tilde{t}_R} = 250$ GeV.

For this set of SUSY parameters the branching ratio for $\tilde{t}_1 \rightarrow \tilde{\chi}_1^+ b$ is 100% according to PYTHIA. The masses of the stop quark, the lightest chargino, and the lightest neutralino are determined essentially by the top trilinear coupling $A_t$ and the gaugino masses $M_2$ and $M_1$, respectively. These were chosen to produce the specific mass points given in Table I. The table also shows the corresponding cross section for $\tilde{t}_1 \tilde{t}_1$ production for each mass point as calculated in PROSPINO. The mass difference between the chargino and the neutralino determines if the chargino will decay to a neutralino and a real $W$ boson or to a neutralino and a lepton with a neutrino or quarks via a virtual $W$ boson. For the produced mass points a real $W$ boson is only possible for the mass point with a chargino mass of 135 GeV (and a stop quark mass of 175 GeV).

<table>
<thead>
<tr>
<th>Mass point</th>
<th>$\sigma_{\tilde{t}_1 \tilde{t}_1}$</th>
<th>$A_t$</th>
<th>$m_{\tilde{t}_1}$</th>
<th>$M_2$</th>
<th>$m_{\tilde{\chi}_1^+}$</th>
<th>$M_1$</th>
<th>$m_{\tilde{\chi}_1^0}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Stop 175/135</td>
<td>0.579 pb</td>
<td>357 GeV</td>
<td>175 GeV</td>
<td>164 GeV</td>
<td>135 GeV</td>
<td>53 GeV</td>
<td>50 GeV</td>
</tr>
<tr>
<td>Stop 175/120</td>
<td>0.579 pb</td>
<td>357 GeV</td>
<td>175 GeV</td>
<td>144 GeV</td>
<td>120 GeV</td>
<td>53 GeV</td>
<td>50 GeV</td>
</tr>
<tr>
<td>Stop 175/105</td>
<td>0.579 pb</td>
<td>357 GeV</td>
<td>175 GeV</td>
<td>125 GeV</td>
<td>105 GeV</td>
<td>53 GeV</td>
<td>50 GeV</td>
</tr>
<tr>
<td>Stop 160/120</td>
<td>1.00 pb</td>
<td>387 GeV</td>
<td>160 GeV</td>
<td>144 GeV</td>
<td>120 GeV</td>
<td>53 GeV</td>
<td>50 GeV</td>
</tr>
<tr>
<td>Stop 160/105</td>
<td>1.00 pb</td>
<td>387 GeV</td>
<td>160 GeV</td>
<td>125 GeV</td>
<td>105 GeV</td>
<td>53 GeV</td>
<td>50 GeV</td>
</tr>
<tr>
<td>Stop 145/105</td>
<td>1.80 pb</td>
<td>414 GeV</td>
<td>148 GeV</td>
<td>125 GeV</td>
<td>105 GeV</td>
<td>53 GeV</td>
<td>50 GeV</td>
</tr>
</tbody>
</table>

Table I: Stop/Chargino mass points used in this analysis with their $\tilde{t}_1 \tilde{t}_1$ cross section, SUSY parameters and particle masses.