Searches for New Physics in Top Events at the Tevatron

Andreas Jung (Fermilab) for the CDF & DØ collaboration

Rencontres de Moriond QCD and High Energy Interactions
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Searches for New Physics in Top Events at Tevatron

A. Jung

Thanks to the Accelerator Division!

- DØ Run II Integrated Luminosity:
- Initial luminosities: $3 - 4 \times 10^{32} \text{ cm}^{-2}\text{s}^{-1}$
- Data taking ended 30th September 2011

The Tevatron

Main Injector & Recycler

p $\rightarrow$ 1.96 TeV $\rightarrow \bar{p}$

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Searches for New Physics in Top Events at Tevatron
Top is the heaviest fundamental particle discovered so far (Fermilab 1995):
\[ m_{\text{top}} = 173.2 \pm 0.9 \text{ GeV/c}^2 \]
- Lifetime: \( \tau \approx 5 \times 10^{-25} \text{ s} \), bare quark
- Charge: \( +\frac{2}{3}e \)
- SM top quark: \( \sim 100\% \) decay into Wb
- Yukawa coupling close to 1
  - Special role in EWSB?
- Top sector is expected to be sensitive to many new physics processes

More talks on top at Tevatron:
See talks by: O.Brandt (top mass), D.Mietlicki (top properties) and B.Wu (single top)
Introduction

- $t\bar{t}$ production and decay:
  - $q\bar{q} \sim 85\%$ and $gg \sim 15\%$
  - Sample classified according to $W$-decay:
    - dilepton ($\ell\ell$), lepton+jets ($l$+jets), all jets
  - Compromise between S/B and BR:
    - $\ell\ell$: Small BR $\sim 4\%$, very good S/B
    - $l$+jets: Large BR $\sim 30\%$, good S/B
    - all jets: Large BR $\sim 46\%$, challenging S/B

Top Pair Branching Fractions

- "alljets" 46\%
- $\tau$+jets 15\%
- $\mu$+jets 15\%
- $e$+jets 15\%

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Searches for New Physics in Top Events at Tevatron
Search for heavy new particle in association with a top quark using 8.7 fb⁻¹:

\[ p\bar{p} \rightarrow t + M \rightarrow t + tj \]

\( A_{FB} \) measured at CDF/\( D\bar{\Omega} \) significantly larger than SM, many models explain this by adding a new heavy particle M

Final state: \( e/\mu, \geq 5 \text{ jets, } \geq 1 \text{ b-jet and } E_T \)

Control region: exactly 4 jets (\( \geq 1 \text{ b-jet} \))

Control region: \( \geq 5 \text{ jets (0 b-jet)} \)

Data 8.7 fb⁻¹

Full CDF RunII data set!
top+jet resonances

- Resonance mass $m_{tj}$ is reconstructed using top kinematic reconstruction.
- Likelihood scan for best match to $t\bar{t}$ topology, remaining jets are paired with the $t/\bar{t}$: $m_{tj}$ is the combination with highest mass.

Limits on $t\bar{t} + j$ production as a function of resonance mass $M$:

Data are consistent with SM.

Cross-section upper limits: 0.61 pb to 0.02 pb as a function of the mass.
Resonance mass $m_{tj}$ is reconstructed using top kinematic reconstruction.

Likelihood scan for best match to $t\bar{t}$ topology, remaining jets are paired with
the $t/\bar{t}$: $m_{tj}$ is the combination with highest mass.

Convert limits on top+jet resonance to exclusion of specific models.

Excluded region in mass-coupling space for two specific models
(M part of a new singlet or triplet)
Search for a narrow $t\bar{t}$ resonance decaying into lepton+jets final state
Many models (KK excitations of gluons/Z bosons, axigluons, strong dynamics, etc.) predict heavy neutral gauge bosons
Final state: $e/\mu$, $\geq 3$ jets, $\geq 1$ b-jet and $E_T$

No observation of narrow resonance, but slight excess (2 s.d.) of events around 950 GeV/c$^2$, best fit yields $\sigma \cdot BR(M_X) = 0.10 \pm 0.05$ pb
Absence of narrow resonance allows limits for the NLO production cross section of a topcolor $Z'$ boson.

Intrinsic width set to:

$$\Gamma_X = 0.012 M_X$$

Assume $\text{BR}(Z' \rightarrow t\bar{t}) = 100\%$
Studies show that dark matter candidate can be produced in association with a single top: $p\bar{p} \rightarrow t + D \rightarrow q\bar{q}'b + \not{E}_T$ [Phys. Rev. D 84, 074025 (2011)]

- Final state: 3 jets, ≥1 b-jet and $\not{E}_T$
- Dark matter signal is expected to contribute significantly at high $\not{E}_T$

Control region (identified lepton):

Signal region:
First search for the production of DM in association with a single top quark
95% C.L. upper cross-section limit is about 0.5 pb for DM mass of 0 – 150 GeV/c²

Data are consistent with SM
Search for boosted tops in a sample of high transverse momentum jets using 6 fb$^{-1}$
Substructure of high transverse momentum objects (jets) has not been studied extensively at Tevatron
Decay products of top collimated into one single massive jet
Estimate background by data-driven methods
Predicted top cross-section (MSTW2008NNLO): $p_T > 400$ GeV/c of $4.55^{+0.50}_{-0.41}$ fb

$E_T$ significance with at least one jet with $p_T > 400$ GeV/c$^2$

Top cross-section limit (95% C.L.) for $p_T > 400$ GeV/c: 38 fb
Search for pair production of massive object, upper limit of 20 fb (95% C.L.)
Search for a time dependent $tt$ cross section

Standard Model Extension (SME): adds terms for Lorentz Invariance violation (LIV) to the matrix element:

$$ |\mathcal{M}_{\text{SME}}|^2 = PFF + (\delta P_p)FFF + (\delta P_v)FFF + P(\delta F)\bar{F} + P\bar{F}(\delta F). $$

$$ \sigma(t) \approx \sigma_{\text{ave}} [1 + f_{\text{SME}}(t)] $$

Reference:

[D. Colladay and V.A. Kostelecky, Phys. Rev. D 58, 116002 (1998)]
[V.A. Kostelecky, Phys. Rev. D 69, 105009 (2004)]

1 Solar day $\approx 0.997$ sidereal days

SME predicts cross section dependence on sidereal time (relative to fixed stars) as the orientation of the detector changes with the rotation of the earth.

c_{L(R)} are different components of SME matrices.
Searches for New Physics in Top Events at Tevatron

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No indication for time dependence of $t\bar{t}$ cross-section.
First constraints on LIV in top sector (and for a bare quark)
Lorentz Invariance Violation

- Use lepton+jets $tt$ selection with: $\geq 4$ jets, exactly one b-tag and $\not{E}_T$
- Other ingredients: 'Timestamp' of data at production, signal fraction $f_s$
- Ratio $R_i$ expected to be flat in SM, i.e. no time dependence
- $c_U$ (right-handed) and $c_Q$ (left-handed)

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**TABLE IV:** Limits on SME coefficients at the 95% C.L., assuming $(c_{Q})_{\mu\nu} \equiv 0$.

<table>
<thead>
<tr>
<th>Coefficient</th>
<th>Value ± Stat. ± Sys.</th>
<th>95% C.L. Interval</th>
</tr>
</thead>
<tbody>
<tr>
<td>$(c_U)_{XX33}$</td>
<td>0.10 ± 0.09 ± 0.02</td>
<td>[-0.08, +0.27]</td>
</tr>
<tr>
<td>$(c_U)_{YY33}$</td>
<td>-0.10 ± 0.09 ± 0.02</td>
<td>[-0.27, +0.08]</td>
</tr>
<tr>
<td>$(c_U)_{XY33}$</td>
<td>0.04 ± 0.09 ± 0.01</td>
<td>[-1.14, +0.22]</td>
</tr>
<tr>
<td>$(c_U)_{XZ33}$</td>
<td>-0.14 ± 0.07 ± 0.02</td>
<td>[-0.28, +0.01]</td>
</tr>
<tr>
<td>$(c_U)_{YZ33}$</td>
<td>0.01 ± 0.07 ± &lt;0.01</td>
<td>[-0.13, +0.14]</td>
</tr>
</tbody>
</table>

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**TABLE III:** Limits on SME coefficients at the 95% C.L., assuming $(c_{Q})_{\mu\nu} \equiv 0$.

<table>
<thead>
<tr>
<th>Coefficient</th>
<th>Value ± Stat. ± Sys.</th>
<th>95% C.L. Interval</th>
</tr>
</thead>
<tbody>
<tr>
<td>$(c_Q)_{XX33}$</td>
<td>-0.12 ± 0.11 ± 0.02</td>
<td>[-0.34, +0.11]</td>
</tr>
<tr>
<td>$(c_Q)_{YY33}$</td>
<td>0.12 ± 0.11 ± 0.02</td>
<td>[-0.11, +0.34]</td>
</tr>
<tr>
<td>$(c_Q)_{XY33}$</td>
<td>-0.04 ± 0.11 ± 0.01</td>
<td>[-0.26, +0.18]</td>
</tr>
<tr>
<td>$(c_Q)_{XZ33}$</td>
<td>0.15 ± 0.08 ± 0.02</td>
<td>[-0.01, +0.31]</td>
</tr>
<tr>
<td>$(c_Q)_{YZ33}$</td>
<td>-0.03 ± 0.08 ± 0.01</td>
<td>[-0.19, +0.12]</td>
</tr>
</tbody>
</table>

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No indication for time dependence of $tt$ cross-section. First constraints on LIV in top sector (and for a bare quark)
Presented searches in top events at the Tevatron:

- CDF and DØ continue to provide unique results in top sector
- More analyses using final data sample will come soon
- Stay tuned...

More results in the top sector:

- Search for new physics in top+MET in all-hadronic tops (5.7 fb⁻¹)
  (arxiv:1107.3574 PRL107 191803 )

- Search for a Fourth Generation t' Quark (5.3 fb⁻¹)

- Search for Anomalous Wtb Couplings in Single Top Quark Production (5.4 fb⁻¹)
  see Talk on Friday by B. Wu
Summary

• Top results by CDF:
  http://www-cdf.fnal.gov/physics/new/top/top.html

• Top results by DØ:
  http://www-d0.fnal.gov/Run2Physics/top/top_public_web_pages/top_public.html

Thank you!
Questions?
The Experiments: CDF & DØ

- **General purpose $4\pi$ detectors:**
  - **Tracker:** Detection and momentum measurement for charged particles
  - **Calorimeter:** Identification and energy measurement of jets and electrons
  - **Muon system:** Identification and momentum measurement of muons
ttbar cross section

- tt pair production tests QCD while the decaying system properties can be used as an electro-weak laboratory to search for new physics.

A recipe:
- \( l + 1,2 \) jets as control, 3 and \( \geq 4 \) jet bins for measurement.
- Require at least one jet as a b-jet using a NN-based tagger.
- Require an isolated lepton and large missing transverse energy.
- Largest physics background: W/Z+jets; include di-boson, single-top.
- Simulate most of SM backgrounds, include NLO/LO scale factors.
- Multi-jet background from data
**top+jet resonances**

- Control region (≥ 5jets, 0b-jets):

![Control region graph]

**TABLE I: Impact of systematic uncertainties on each background source and an example signal of 500 GeV in the signal region.**

<table>
<thead>
<tr>
<th>Systematic</th>
<th>$t\bar{t}$</th>
<th>W+jets</th>
<th>Total</th>
<th>$M$ (500 GeV)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Nominal</td>
<td>550.55</td>
<td>78.64</td>
<td>669.17</td>
<td>339.69</td>
</tr>
<tr>
<td>JES</td>
<td>17%</td>
<td>15%</td>
<td>16%</td>
<td>9%</td>
</tr>
<tr>
<td>Radiation</td>
<td>6%</td>
<td>-</td>
<td>5%</td>
<td>4%</td>
</tr>
<tr>
<td>$Q^2$</td>
<td>-</td>
<td>19%</td>
<td>2%</td>
<td>-</td>
</tr>
<tr>
<td>Nvtx</td>
<td>3%</td>
<td>2%</td>
<td>3%</td>
<td>2%</td>
</tr>
<tr>
<td>$t\bar{t}$ Generator</td>
<td>6%</td>
<td>-</td>
<td>5%</td>
<td>-</td>
</tr>
<tr>
<td>Normalization</td>
<td>10%</td>
<td>30%</td>
<td>12%</td>
<td>-</td>
</tr>
<tr>
<td>Total Uncertainty</td>
<td>22%</td>
<td>38%</td>
<td>21%</td>
<td>10%</td>
</tr>
</tbody>
</table>
Event selection for LIV based on cross section measurement in lepton+jets:

- Isolated lepton $p_T > 20\text{GeV/c}$
- $E_T(e) > 20\text{ GeV}, E_T(\mu) > 25\text{ GeV}$
- 4 jets $p_T > 20\text{ GeV/c}, p_T^{\text{lead.jet}} > 40\text{ GeV/c}$
- $|\eta(\text{jet})| < 2.5$ and at least 1 $b$-tag
Search for a fourth generation $t'$ quark in lepton+jets channel

Exclude at 95% C.L. $t't'$ production for masses below 285 GeV