Search for a Fourth Generation t’ Quark via Wb Decays into a Lepton Plus Jets Final State

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for CMS

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CMS Detector

- CMS is a multi-purpose detector located at the Large Hadron Collider (LHC) at CERN
- Currently observing 7 TeV center of mass pp collisions.
- Searching for
  - Higgs
  - SUSY
  - Compositeness
  - Extra dimensions
  - Extensions to Standard Model
  - etc.

- Si Tracker
- EM Calorimeter
- Hadronic Calorimeter
- Muon Detection
  - 21 m long, 15 m Diameter
  - 3.8 T Solenoid
Motivation

- Search for massive top-like quarks (t'): 4th Generation.
- Current number of generations set by $Z^0 \rightarrow \nu \bar{\nu}$ width.
- Extra generations allowed if $m_{\nu(4)} > m_Z/2$
  - $m_{t'} - m_{b'} < m_W$
  - So $t' \rightarrow Wb$
  - This analysis is sensitive to chiral or vector $t'$.
- $pp \rightarrow t't' \rightarrow (Wb)(Wb) \rightarrow (l \nu b) (q q' b)$
  - $pp \rightarrow l \nu + 4$ jets
    - Electron + 4 jets +MET final state: 537 pb$^{-1}$
    - Muon + 4 jets +MET final state: 821 pb$^{-1}$

Event Selection

- **Number of good interaction vertices \( \geq 1 \)**
  - \( e + \) jets:
    - \( P_T \) > 30, 35, 45 GeV
      - match trigger threshold
    - |\( \eta \)| < 2.1
  - \( \mu + \) jets:
    - \( P_T \) > 35 GeV
      - match trigger threshold
    - |\( \eta \)| < 2.5

- **Missing \( E_T \) > 20 GeV**
- **Number of Jets \( \geq 4 \)**
- **\( P_T \) for leading jets > 120, 90 GeV, 35 GeV, 35 GeV**
- |\( \eta \)| < 2.5
- **Lepton-jet separation: \( \Delta R (l,\text{jet}) > 0.3 \)**
Event Yields (lumi)

- Observed and expected yields for standard model.
- Efficiencies for t’t’ signals including branching ratio into lepton+jets final state.

<table>
<thead>
<tr>
<th>Process</th>
<th>Cross</th>
<th>e+jets events</th>
<th>µ+jets events</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>section</td>
<td></td>
<td></td>
</tr>
<tr>
<td>$\mathcal{L}$</td>
<td></td>
<td>537 pb$^{-1}$</td>
<td>821 pb$^{-1}$</td>
</tr>
<tr>
<td>Data</td>
<td></td>
<td>520</td>
<td>1054</td>
</tr>
<tr>
<td>$t\bar{t}$</td>
<td>158 pb</td>
<td>456 ± 91</td>
<td>907 ± 114</td>
</tr>
<tr>
<td>Single t</td>
<td>33 pb</td>
<td>14.5 ± 3.5</td>
<td>30 ± 6</td>
</tr>
<tr>
<td>W+jets</td>
<td>30 $\mu$b</td>
<td>33.3± 8.2</td>
<td>106 ± 25</td>
</tr>
<tr>
<td>Z+jets</td>
<td>2.9 $\mu$b</td>
<td>4.5 ± 1.2</td>
<td>2.6 ± 2.6</td>
</tr>
<tr>
<td>WW, WZ, ZZ</td>
<td>67 pb</td>
<td></td>
<td>2.1 ± 0.6</td>
</tr>
<tr>
<td>multijets</td>
<td></td>
<td>2.5 ± 1.2</td>
<td>5.7 ± 5.5</td>
</tr>
<tr>
<td>Total background</td>
<td></td>
<td>510 ± 103</td>
<td>1054 ± 145</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Process</th>
<th>Cross Section</th>
<th>e+jets eff</th>
<th>µ+jets eff</th>
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</thead>
<tbody>
<tr>
<td></td>
<td>t’t’</td>
<td></td>
<td></td>
</tr>
<tr>
<td>$m_{t'} = 350$ GeV</td>
<td>3.20 pb</td>
<td>3.7 ± 0.4 %</td>
<td>4.5 ± 0.3 %</td>
</tr>
<tr>
<td>$m_{t'} = 400$ GeV</td>
<td>1.41 pb</td>
<td>4.3 ± 0.4 %</td>
<td>5.2 ± 0.4 %</td>
</tr>
<tr>
<td>$m_{t'} = 450$ GeV</td>
<td>0.66 pb</td>
<td>4.8 ± 0.4 %</td>
<td>5.6 ± 0.4 %</td>
</tr>
<tr>
<td>$m_{t'} = 500$ GeV</td>
<td>0.33 pb</td>
<td>5.0 ± 0.4 %</td>
<td>5.8 ± 0.4 %</td>
</tr>
</tbody>
</table>

CMS Simulation

- Errors include uncertainties in the jet energy scale, lepton trigger selection, b-tagging, MC statistics.
- No uncertainties for cross section or integrated luminosity.

- The background totals in agreement with observed number of events.

CMS Preliminary
Scalar Transverse Energy

\[ H_T = \sum P_T(Jets) + P_T(Lepton) + E_T \]

- \( H_T \): scalar sum of transverse energy for e+jets
- Include backgrounds.
- Monte Carlo: \( \sigma(t'\bar{t}') \times 3: m_{t'} = 400 \text{ GeV} \) (dotted line)

- \( H_T \): scalar sum of transverse energy for \( \mu \) + jets
- Include backgrounds.
- Monte Carlo: \( \sigma(t'\bar{t}') \times 3: m_{t'} = 400 \text{ GeV} \) (dotted line)
Mass Reconstruction ($m_{\text{fit}}$)

- Assign final state particles from decay to reconstructed objects
- Reconstructed objects: lepton, missing $P_T$, jets.
  - Constraints:
    - $m(l\nu) = M_W$
    - $m(q \bar{q}) = M_W$
    - $m(l\nu b) = m(q \bar{q} b) = m_{\text{fit}}$
  - Perform kinematic fit to improve mass resolution.

- **$e + \text{jets channel}$**
  - Fit all 4 jet combinations from leading 5 jets
  - Choose combination with smallest $\chi^2$

- **$\mu + \text{jets channel}$**
  - Fit leading 4 jets unless 5th leading jet is $b$ tagged.
  - Instead use 5th leading jet.
Reconstructed Mass

- e + jets data with backgrounds:
  - $t\bar{t}$, Single t, W + jets, Z + jets, QCD
  - Monte Carlo: $\sigma(t'\bar{t}') \times 3$: $m_{t'} = 400$ GeV

- $\mu$ + jets data with backgrounds:
  - $t\bar{t}$, Single t, VV, W + jets, Z + jets, QCD
  - Monte Carlo: $\sigma(t'\bar{t}') \times 3$: $m_{t'} = 400$ GeV
Isolate $t\bar{t}$ and $W + \text{Jet}$ Background

- $t\bar{t}$ background irreducible from $t'\bar{t}'$ events.
- Mass difference of $t$ and $t'$ produce different kinematical distributions.
- Statistical separation of $t\bar{t}$ background.
- Also isolate events $t'\bar{t}'$ from $W+$jets background.
- Plot scalar transverse energy ($H_T$) vs. fitted mass ($m_{\text{fit}}$).

$H_T$ vs. reconstructed mass for $e + \text{jets}$

$H_T$ vs. reconstructed mass for $\mu + \text{jets}$
Systematic Uncertainties

- $\sigma_{tt} = 158 \text{ pb} \pm 11\%$

- Number of electroweak background events
  - W+jets constrained to 1.5 times predicted value.
  - Other processes constrained to predicted values
  - 50% uncertainty to the sum of all electroweak backgrounds

- $\alpha_{jes}$ – jet energy scale calibration:
  - Affects $H_T$ vs $m_{fit}$ distributions
  - determined from jet-energy scale $\pm$ standard deviation.
  - Distributions for other values of $\alpha_{jes}$ determined from vertical morphing of $H_T$ vs $m_{fit}$ distributions

- $\varepsilon_e$: selection efficiency of e+jets events: 3%
- $\varepsilon_{\mu}$: selection efficiency of $\mu$+jets events: 3%
- $\varepsilon_b$: b-tagging efficiency: 5% in yield of $t\bar{t}$ and $t't'\bar{t}$ events.
- $L_{int} = \pm 6\%$

Systematic uncertainties small.
Limits for $t^-' t'$ Production

- Use $CL_s$ method to establish the limit on the $t'$ cross section.
- Probability calculated for likelihood $L$ larger than observed likelihood $L_{obs}$
  - Generated 1000 pseudo experiments with background: probability: $CL_b$
  - Generated 1000 pseudo experiments with background and $t^-' t'$ signal with
    cross section $\sigma$: probability: $CL_{s+b}$

• $e + jets$: 573 pb$^{-1}$
  • Exclude: $m_{t'} < 430$ GeV

• $\mu + jets$: 821 pb$^{-1}$
  • Exclude $m_{t'} < 420$ GeV

Conclusions

Combined channels
\( t'^{-}t'^{-} \rightarrow WbWb \rightarrow l\nu + 4 \text{ jet} \)

Exclude \( m_{t'} < 450 \text{ GeV} \) (95 CL)

Future Plans

• Collect and analyze more data.
• CMS current delivered luminosity is 5 fb\(^{-1}\).
• Search for other signals
  – \( b' \rightarrow Wt \) Search
  – Third generation leptoquark.
  – Other searches.