Probing Compressed Top Squarks at the LHC at 14 TeV

Sean Wu
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Motivations for Physics Beyond the Standard Model

Gravitational lensing and galactic rotation curves suggest “missing mass” that is not part of the standard model. What is it? What particle is it?
Motivations for Supersymmetry

In R-Parity conserving models, the lightest neutralino is stable and is a good candidate for Dark Matter.

Supersymmetry has other attractive features such as the cancellation of the Higgs Boson quadratic mass renormalization.
The Experiment

The LHC provides a natural laboratory for searches beyond the standard model.
Particle Decay and the Compressed Scenario
Experimental Bounds

\( \tilde{t} \tilde{t} \) production, \( \tilde{t} \rightarrow t \tilde{\chi}_1^0 / c \tilde{\chi}_1^0 \)

**CMS Preliminary**

\( \sqrt{s} = 8 \text{ TeV} \)

**ICHEP 2014**

- **Observed**
  - SUS-13-011 1-lep (MVA) 19.5 fb\(^{-1}\)
  - SUS-14-011 0-lep + 1-lep + 2-lep (Razor) 19.3 fb\(^{-1}\)
  - SUS-14-011 0-lep (Razor) + 1-lep (MVA) 19.3 fb\(^{-1}\)
  - SUS-13-009 (monojet stop) 19.7 fb\(^{-1}\) (\( \tilde{t} \rightarrow c \tilde{\chi}_1^0 \))
  - SUS-13-015 (hadronic stop) 19.4 fb\(^{-1}\)

- **Expected**
Vector Boson Fusion (VBF) Topology

- High $p_T$ jets in opposite hemispheres
- Significantly reduces background
- Allows for probing of the compressed region
Simulation Work Flow and Cut Flow

Simulation Work Flow
1. Suspect2 (Mass Spectrum Calculation)
2. MadGraph (Parton Level Calculation)
3. Pythia 6 (Hadronization and Parton Showering)
4. PGS4 (Event Reconstruction)
5. Analysis Code
6. Root

Analysis Cut Flow
1. VBF Cuts (at least two jets satisfying)
   i. \( p_T \geq 75 \text{ GeV}; \ p_T \geq 50 \text{ GeV} \) with \(|\eta| \leq 4\)
   ii. \(|\Delta \eta(j_1, j_2)| > 3.5\);
   iii. \((\eta_1 \cdot \eta_2) < 0\)
   iv. \(M_{jj_1j_2} > 500 \text{ GeV}\)
2. 1 lepton
3. 2 b-jets
4. MET Cut (Varied)
Results: MET Shape

\[ \Delta M = m_t - (m_t + m_{\chi_i}) = \pm 7 \text{ GeV} \]

Fraction of Events / 20 GeV

\[ \mathcal{E}_T \text{ (GeV)} \]

- \( m_t = 200 \text{ GeV} \)
- \( m_t = 300 \text{ GeV} \)
- \( t \bar{t} + \text{jets} \)
Results: Cut Summary

<table>
<thead>
<tr>
<th>$(m_{\ell}, m_{\chi^0})$ Selection</th>
<th>Signal</th>
<th>$tt+\text{jets}$</th>
<th>S/B</th>
</tr>
</thead>
<tbody>
<tr>
<td>(200, 20) Pre cut</td>
<td>5.4 x $10^4$</td>
<td>6.9 x $10^5$</td>
<td>—</td>
</tr>
<tr>
<td>$\Delta M = 7$ VBF</td>
<td>1.8 x $10^3$</td>
<td>3.8 x $10^4$</td>
<td>—</td>
</tr>
<tr>
<td>1 lepton</td>
<td>390</td>
<td>8.1 x $10^3$</td>
<td>—</td>
</tr>
<tr>
<td>2 b-jets</td>
<td>170</td>
<td>3.1 x $10^3$</td>
<td>5.6 x $10^{-2}$</td>
</tr>
<tr>
<td>$E_T &gt; 100$</td>
<td>44</td>
<td>680</td>
<td>6.5 x $10^{-2}$</td>
</tr>
<tr>
<td>(300, 120) Pre cut</td>
<td>7.4 x $10^3$</td>
<td>6.9 x $10^5$</td>
<td>—</td>
</tr>
<tr>
<td>$\Delta M = 7$ VBF</td>
<td>250</td>
<td>3.8 x $10^4$</td>
<td>—</td>
</tr>
<tr>
<td>1 lepton</td>
<td>56</td>
<td>8.1 x $10^3$</td>
<td>—</td>
</tr>
<tr>
<td>2 b-jets</td>
<td>32</td>
<td>3.1 x $10^3$</td>
<td>1.0 x $10^{-2}$</td>
</tr>
<tr>
<td>$E_T &gt; 100$</td>
<td>8.9</td>
<td>680</td>
<td>1.3 x $10^{-2}$</td>
</tr>
<tr>
<td>(400, 220) Pre cut</td>
<td>1.6 x $10^3$</td>
<td>6.9 x $10^5$</td>
<td>—</td>
</tr>
<tr>
<td>$\Delta M = 7$ VBF</td>
<td>62</td>
<td>3.8 x $10^4$</td>
<td>—</td>
</tr>
<tr>
<td>1 lepton</td>
<td>14</td>
<td>8.1 x $10^3$</td>
<td>—</td>
</tr>
<tr>
<td>2 b-jets</td>
<td>8.4</td>
<td>3.1 x $10^3$</td>
<td>2.7 x $10^{-3}$</td>
</tr>
<tr>
<td>$E_T &gt; 100$</td>
<td>4.8</td>
<td>680</td>
<td>7.0 x $10^{-3}$</td>
</tr>
<tr>
<td>(500, 320) Pre cut</td>
<td>460</td>
<td>6.9 x $10^5$</td>
<td>—</td>
</tr>
<tr>
<td>$\Delta M = 7$ VBF</td>
<td>19</td>
<td>3.8 x $10^4$</td>
<td>—</td>
</tr>
<tr>
<td>1 lepton</td>
<td>4.2</td>
<td>8.1 x $10^3$</td>
<td>—</td>
</tr>
<tr>
<td>2 b-jets</td>
<td>2.4</td>
<td>3.1 x $10^3$</td>
<td>7.9 x $10^{-4}$</td>
</tr>
<tr>
<td>$E_T &gt; 150$</td>
<td>1.5</td>
<td>250</td>
<td>6.0 x $10^{-3}$</td>
</tr>
</tbody>
</table>

Cross section summaries for 3 and 2 body decays respectively. Cross sections are in fb$^{-1}$. 
Results: Significance vs Mass

\[ \Delta M = m_t - (m_{t_l} + m_{\chi_1}) = 7 \text{ GeV} \]

\[ \Delta M = m_t - (m_{t_l} + m_{\chi_1}) = -7 \text{ GeV} \]
Results: Significance with Systematics

\[ \Delta M = m_t - (m_t + m_{\tilde{\chi}_1}) = 7 \text{ GeV} \]

\[ \Delta M = m_t - (m_t + m_{\tilde{\chi}_1}) = -7 \text{ GeV} \]
Summary

- Physics beyond the standard model is well motivated.
- Supersymmetry is an advantageous model to describe it.
- The experimental bounds can make the search for the top squark difficult.
- Using VBF topology cuts we can investigate the compressed region.
- We can see discovery reach up to 450 GeV and 390 GeV for the two and three body scenarios for 3000 fb$^{-1}$ luminosity.
- This reach is degraded when systematic uncertainty is considered.
- VBF cuts are helpful in other SUSY searches as well.
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