3rd generation SUSY searches at CMS

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(on behalf of the CMS collaboration)

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Introduction

- **Heirarchy problem of the light Higgs solved by natural SUSY**
  - Interesting given discovery of the 125 GeV boson
  - Requires light gluinos, stops and sbottoms
  - Strong program for 3rd generation SUSY at CMS
    - Hadronic and leptonic final states
    - R-Parity violating scenarios

- **Gluino induced top or bottom squark production**
  - Relatively high cross-sections and high multiplicity signatures.

- **Direct top or bottom squark production**
  - Cross sections lower than gluino induced
  - Decays dependant on $\Delta M(M_{STOP/SBOTTOM}, M_{LSP})$
  - **This talk will cover direct production**
Hadronic stops

Search: Top-squark pair production in multi-jet events

Main bkgs: TTbar (with W → l ν), Z + jets (with Z → ν ν)

1) Tag two top quarks per event: One full-reconstruction and one partial-reconstruction → increase signal efficiency (slide 14)

2) Then utilize topological variables ($m_{T2}$, $m_{T3j}$, $m_{T_{Rsys}}$) to increase S/B

### Variable | Cut
--- | ---
$N_{jets}$ | $\geq 5 \ (p_T>30 \text{ GeV} \ & \ |\eta|<2.4)$
$N_{bjets}$ | $\geq 1, \geq 2$
$E_T^{miss}$ | $\geq 200, \geq 350 \text{ GeV}$
$m_{T2}$ | $\geq 300 \text{ GeV}$
$0.5 \cdot m_{T3j} + m_{T_{Rsys}}$ | $\geq 500 \text{ GeV}$
The production of top squarks with mass less than 535 GeV is excluded at 95% confidence-level for small LSP masses less than 10 GeV.

Assume 100% BF

Results based on assumption that search has no acceptance if one stop decays in a different mode
1-lepton stops

Search: Top-squark pair production in single lepton channel

Main bkgs: TTbar (di-lepton), W + jets, Drell-Yan, QCD, single top, di/tri-boson

1) Use a multivariate (BDT) approach to search for an excess over SM bkg. and cross check results with cut and count method

Variable | Cut
--- | ---
$N_{\text{jets}}$ | $\geq 4$ ($p_T > 30$ GeV, $|\eta| < 2.4$)
$N_{\text{bjets}}$ | $\geq 1$
$E_T^{\text{miss}}$ | $\geq 100$
$m_T$ | $\geq 120$ GeV
1-lepton stops

18 BDT-based SRs and 16 cut-based SRs according to $\Delta M(M_{\text{STOP}}, M_{\text{LSP}})$

Bkg estimation: Normalize MC to data in $m_T$-peak region (50-80 GeV) and extrapolate to tail
Top-squark mass values up to around 650 GeV for small mass values of the LSP are excluded at the 95% confidence level.

Future studies to focus on closing gap at $\Delta M(M_{\text{STOP}}, M_{\text{LSP}}) = m_{\text{top}}$ possibly with with special ISR sensitive SRs or better designed BDTs.
**Search: Top-squark (t₂) pair production decaying with:**

\[ t₂ \rightarrow H \, t₁ \text{ or } t₂ \rightarrow Z \, t₁ \]

**Main bkgs: TTbar**

1) \( t₁ \) and \( t₂ \) are eigenstates of \( t_{L/R} \) \( \rightarrow \) usually search for lighter \( t₁ \) eigenstate (*see earlier slides*)

2i) Analysis targets the region: \( m(t₁) - m(χ₁^0) \sim m(\text{top}) \)

2ii) Region not currently covered by CMS stops searches

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<table>
<thead>
<tr>
<th>( N_ℓ )</th>
<th>Veto</th>
<th>( N_b ) jets</th>
<th>( N_j ) jets</th>
<th>( E^\text{miss}_T ) [GeV]</th>
<th>Additional requirements [GeV]</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>track or ( τ_h )</td>
<td>( = 3 \geq 4 )</td>
<td>( \geq 5 \geq 4 )</td>
<td>( \geq 50 )</td>
<td>( m_T &gt; 150 ) ( m_T &gt; 120 )</td>
</tr>
<tr>
<td>2 OS</td>
<td>extra e/( µ )</td>
<td>( = 3 \geq 4 )</td>
<td>( \geq 5 \geq 4 )</td>
<td>( \geq 50 )</td>
<td>( (N_{bb} = 1 \text{ with } 100 \leq m_{bb} \leq 150), N_{bb} \geq 2 )</td>
</tr>
<tr>
<td>2 SS</td>
<td>extra e/( µ )</td>
<td>( \geq 2 ) ( [2,3] \geq 4 ) ( [50,120] ) ( \geq 120 )</td>
<td>for low/high-( p_T ): ( H_T \in [200,400] ), ( \geq 400 )</td>
<td></td>
<td></td>
</tr>
<tr>
<td>( \geq 3 )</td>
<td>—</td>
<td>( = 2 ) ( [2,3] \geq 4 ) ( [50,100], [100,200] ) ( \geq 200 )</td>
<td>for on/off-Z: ( H_T \in [60,200] ), ( \geq 200 )</td>
<td></td>
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</tr>
</tbody>
</table>
Top-squarks with masses $M(\tilde{t}_2)$ up to around 575 GeV for $M(\tilde{t}_1)$ masses up to around 400 GeV are excluded at the 95% confidence level.

$t_2 \rightarrow H t_1$ with $t_1$ decaying to top plus LSP

Driving force in limit plot is 3 lepton SR
Direct sbottoms

Search: Direct sbottom squark pair production decaying to $b$-quark + LSP

Main bkgs: $Z \to \nu \nu + \text{jets}$, $TT\text{bar} + \text{jets}$, $W \to l \nu$

1) Construct 2D analysis in 8 bins of $N_{\text{bjet}}$ and $m_{\text{CT}}^2$ where:

$$m_{\text{CT}}^2(jet_1, jet_2) = [E_T(jet_1) + E_T(jet_2)]^2 - [p_T(jet_1) - p_T(jet_2)]^2$$

<table>
<thead>
<tr>
<th>Variable</th>
<th>Cut</th>
</tr>
</thead>
<tbody>
<tr>
<td>$N_{\text{jets}}$</td>
<td>2 ($p_T &gt; 70$ GeV &amp; $</td>
</tr>
<tr>
<td>$N_{\text{bjets}}$</td>
<td>[1, 2]</td>
</tr>
<tr>
<td>$E_T^{\text{miss}}$</td>
<td>$\geq 175$ GeV</td>
</tr>
<tr>
<td>$H_T$</td>
<td>$\geq 250$ GeV</td>
</tr>
<tr>
<td>$m_{\text{CT}}^2$</td>
<td>$[0, 250, 350, 450, \infty]$ GeV</td>
</tr>
</tbody>
</table>
Direct sbottoms

Bottom-squark mass values up to around 700 GeV for LSP masses less than 50 GeV are excluded at the 95% confidence level.

With new search bins (with one ISR + 1 or 2 b-jets) expect the analysis to become more sensitive to the compressed region (near the diagonal).
Summary

• **Wide range of SUSY searches for 3rd generation particles covered at CMS**
  - Collected around 20 fb-1 of pp data at $\sqrt{s}=8$ TeV in 2012 and performed searches for third generation squarks.

• **No significant excess over expected SM bkgs observed so far**
  - Have set top-squark lower limits at around 700 GeV
  - Have set bottom-squark lower limits at around 750 GeV
  - Have only covered direct production in this talk, can see here: [https://twiki.cern.ch/twiki/bin/view/CMSPublic/PhysicsResultsSUS](https://twiki.cern.ch/twiki/bin/view/CMSPublic/PhysicsResultsSUS) for full range of CMS 3G SUSY public material

• **LHC Run2 will start soon at $\sqrt{s}=13$TeV**
  - Discovery potential for top-squark masses will be at around 1 TeV with 300 fb$^{-1}$ at $\sqrt{s}=14$ TeV
Thank You
SUS-13-015: Top-tagger references


Kinematic variable definitions

\[ M_{T}^{3\text{-jet}} \] is the transverse mass of the fully reconstructed top quark tri-jet system and the \( \vec{p}_{T}^{\text{miss}} \) vector given by

\[
(M_{T}^{3\text{-jet}})^2 = (m^{3\text{-jet}})^2 + 2(E_T^{3\text{-jet}} \vec{p}_{T}^{\text{miss}} - p_T^{3\text{-jet}} \vec{p}_{T}^{\text{miss}} \cos \Delta \phi),
\] (2)

\( m_{T}^{\text{R_syst}} \) is the transverse mass of the identified partial top decay products in the Rsys and the \( p_{T}^{\text{miss}} \) vector

(3)
SUS-13-015: Topological variable correlation plots
### SUS-13-015: Event yields (MC)

<table>
<thead>
<tr>
<th></th>
<th>$p_T^{\text{miss}} &gt; 200,\text{GeV}$, $N_{b\text{-jets}} \geq 1$</th>
<th>$p_T^{\text{miss}} &gt; 350,\text{GeV}$, $N_{b\text{-jets}} \geq 1$</th>
<th>$p_T^{\text{miss}} &gt; 200,\text{GeV}$, $N_{b\text{-jets}} \geq 2$</th>
<th>$p_T^{\text{miss}} &gt; 350,\text{GeV}$, $N_{b\text{-jets}} \geq 2$</th>
</tr>
</thead>
<tbody>
<tr>
<td>$t\bar{t}$</td>
<td>153.8 ± 5.7</td>
<td>18.9 ± 2.0</td>
<td>63.4 ± 3.7</td>
<td>6.3 ± 1.2</td>
</tr>
<tr>
<td>$W \rightarrow \ell\nu$</td>
<td>22.9 ± 2.9</td>
<td>5.8 ± 1.4</td>
<td>3.9 ± 1.2</td>
<td>1.1 ± 0.6</td>
</tr>
<tr>
<td>$Z \rightarrow \nu\bar{\nu}$</td>
<td>25.0 ± 1.2</td>
<td>8.4 ± 0.6</td>
<td>4.6 ± 0.5</td>
<td>1.3 ± 0.2</td>
</tr>
<tr>
<td>QCD</td>
<td>1.1 ± 0.6</td>
<td>0.0^{+0.5}_{-0.0}</td>
<td>0.0^{+0.5}_{-0.0}</td>
<td>0.0^{+0.5}_{-0.0}</td>
</tr>
<tr>
<td>single top</td>
<td>17.5 ± 3.9</td>
<td>5.2 ± 2.1</td>
<td>7.0 ± 2.5</td>
<td>1.8 ± 1.2</td>
</tr>
<tr>
<td>$t\bar{t}Z$</td>
<td>7.8 ± 0.4</td>
<td>2.3 ± 0.2</td>
<td>4.2 ± 0.3</td>
<td>1.4 ± 0.2</td>
</tr>
<tr>
<td>$t\bar{t}W$</td>
<td>2.4 ± 0.2</td>
<td>0.3 ± 0.1</td>
<td>1.1 ± 0.2</td>
<td>0.1 ± 0.1</td>
</tr>
<tr>
<td>ZZ</td>
<td>0.8 ± 0.2</td>
<td>0.3 ± 0.1</td>
<td>0.2 ± 0.1</td>
<td>0.0^{+0.1}_{-0.0}</td>
</tr>
<tr>
<td>WZ</td>
<td>0.5 ± 0.2</td>
<td>0.1 ± 0.1</td>
<td>0.1 ± 0.1</td>
<td>0.0^{+0.1}_{-0.0}</td>
</tr>
<tr>
<td>WW</td>
<td>0.8 ± 0.3</td>
<td>0.1 ± 0.1</td>
<td>0.3 ± 0.2</td>
<td>0.0^{+0.2}_{-0.0}</td>
</tr>
<tr>
<td>Total (no QCD)</td>
<td>231.5 ± 7.6</td>
<td>41.2 ± 3.3</td>
<td>84.7 ± 4.6</td>
<td>12.0 ± 1.8</td>
</tr>
<tr>
<td>Data</td>
<td>254</td>
<td>45</td>
<td>83</td>
<td>15</td>
</tr>
<tr>
<td>Signal (350, 0)</td>
<td>162.8 ± 7.2</td>
<td>11.3 ± 1.9</td>
<td>84.4 ± 5.2</td>
<td>7.5 ± 1.5</td>
</tr>
<tr>
<td>Signal (500, 100)</td>
<td>83.2 ± 1.7</td>
<td>33.7 ± 1.1</td>
<td>48.1 ± 1.3</td>
<td>19.8 ± 0.8</td>
</tr>
<tr>
<td>Signal (650, 50)</td>
<td>22.4 ± 0.4</td>
<td>15.8 ± 0.3</td>
<td>13.1 ± 0.3</td>
<td>9.3 ± 0.2</td>
</tr>
</tbody>
</table>
SUS-13-011:
Kinematic variables used in event selection

<table>
<thead>
<tr>
<th>Selection</th>
<th>BDT</th>
<th>Cut-based</th>
<th>BDT</th>
<th>Cut-based</th>
</tr>
</thead>
<tbody>
<tr>
<td>$E_T^{\text{miss}}$ (GeV)</td>
<td>yes</td>
<td>&gt; 150, 200, 250, 300</td>
<td>yes</td>
<td>&gt; 100, 150, 200, 250</td>
</tr>
<tr>
<td>$M_W^T$ (GeV)</td>
<td>yes</td>
<td>&gt; 0.8</td>
<td>yes</td>
<td>&gt; 0.8</td>
</tr>
<tr>
<td>$\Delta \phi$</td>
<td>yes</td>
<td>&lt; 5</td>
<td>yes</td>
<td>&gt; 100</td>
</tr>
<tr>
<td>$H_T^\text{ratio}$</td>
<td>yes</td>
<td>(on-shell top)</td>
<td>yes</td>
<td>(off-shell top)</td>
</tr>
<tr>
<td>Hadronic top $\chi^2$</td>
<td></td>
<td>&lt; 5</td>
<td></td>
<td>&gt; 0.8</td>
</tr>
<tr>
<td>Leading b-tagged jet $p_T$ (GeV)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>$\Delta R(\ell, \text{leading b-tagged jet})$</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Lepton $p_T$ (GeV)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Figure 2: The stop-chargino-neutralino mass spectra for the three choices of the parameter $x$ considered in this work.
SUS-13-024: Kinematic variables (3 lepton SR)

Figure 4: Observed data events and predicted SM background for the event sample with at least three leptons as a function of the number of jets, number of b jets and $E_T^{miss}$ are shown for events that do not contain (off-Z), top row, or contain (on-Z), bottom row, an opposite-sign-same-flavor pair that is a Z boson candidate. The distribution for the models $\tilde{t}_2 \rightarrow H\tilde{t}_1$ where $m_{\tilde{t}_2} = 450$ GeV and $m_{\tilde{t}_1} = 200$ GeV and $\tilde{t}_2 \rightarrow Z\tilde{t}_1$ where $m_{\tilde{t}_2} = 600$ GeV and $m_{\tilde{t}_1} = 200$ GeV are stacked on top of the backgrounds in the top and bottom rows respectively. The last bin in the histograms includes overflow events. The shaded bands correspond to the estimated uncertainties on the background which are calculated on the per bin basis.