Search for gluinos in their decays through third generation quarks at LHC

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**Introduction**

- $m_{\text{sparticle}} > O(1 \text{ TeV})$ disfavored from Naturalness and Fine-tuning. However, $m_{\text{sparticle}} \gtrsim O(1 \text{ TeV})$ (1st and 2nd gen.) cures: SUSY FCNC, SUSY CP, suppress proton decay rates and etc.
- Therefore, models with $m_{\text{sparticle}} \sim O(1 \text{ TeV})$ without sacrificing naturalness, *if viable*, are indeed pretty good.
- These attractive features are realized in Focus point or Hyperbolic Branch of mSUGRA model. **Ref:** Feng and Wilczek, hep-ph/0507032; Feng etal. hep-ph/9909334; Chan etal. hep-ph/9710473.
- REWSB criterion:

\[
\frac{1}{2} M_Z^2 = \frac{m_{H_d}^2 - m_{H_u}^2 \tan^2 \beta}{\tan^2 \beta - 1} - \mu^2.
\]

- For all $\tan \beta$, $m_{H_u}^2 \gg M_Z^2$ is disfavored by the naturalness criterion, as in that case, a large cancellation between $m_{H_u}^2$ and $\mu^2$ is needed to arrive at the physical value of the weak scale. For moderate and large values of $\tan \beta$, however, $m_{H_d}^2 \gg M_Z^2$ does not necessarily lead to fine-tuning.
- At moderate to large $\tan \beta$, $\mu^2 \sim m_{H_u}^2$; $m_{H_u}^2 \sim O(M_Z^2)$ ($m_{1/2}$ or $A_0$ is not too large ($\sim 1 \text{ TeV}$)); $\mu \sim O(M_Z)$.
Figure 1: For $m_{1/2} = 300$ GeV, $A_0 = 0$, and $\tilde{\chi}_1^\pm = 174$ GeV. Ref: Feng et al. hep-ph/9909334

- low $\mu$ important phenomenological implication:
  $\tilde{\chi}_1^0, \tilde{\chi}_2^0, \tilde{\chi}_1^{\pm}$ Higgsino dominated and are also mass degenerate ($\sim \mu$).
  A higgsino dominated gaugino couples to a light fermion and its super-partner with suppressed couplings → important for collider and dark matter phenomenology. Ref: H. Baer et al. hep-ph/0507282
Neutralino relic density

- The properties of the Universe: density of baryons, matter, vacuum energy and the Hubble expansion rate.
- From WMAP $\Omega_{CDM} h^2 = 0.1126^{+0.0161}_{-0.0181}$ at 95% CL
- $\tilde{\chi}_1^0$ can be CDM candidate and only certain regions give rise to relatively low $\Omega_{\chi_1^0} h^2$ consistent with WMAP where $\tilde{\chi}_1^0 \tilde{\chi}_1^0 \rightarrow$ SM particles is large.
- $0.094 < \Omega_{\chi_1^0} h^2 < 0.129$

Figure 2: Regions of Neutralino relic density for $A_0 = 0$ and $\tan \beta = 30$ (55).

Figure 3: Parameter space of mSUGRA model for $\tan\beta = 30$ showing the reach of different colliders for supersymmetry discovery in the jets+ $E_T$ channel from $\tilde{q}$ and $\tilde{g}$ pair production.

Signal and Backgrounds

In addition the $\tilde{g}$ is light and $\tilde{t}_1, \tilde{b}_1$ are also light compared to the 1st and 2nd generation squarks.

Gluino can decay: $\tilde{g} \rightarrow tb\tilde{\chi}_i^\pm; t\tilde{t}\tilde{\chi}^0_j; b\bar{b}\tilde{\chi}_i^0$

$\Rightarrow$

(I) $2W + 4b + \text{jets} + \not{E}_T$

(II) $4W + 4b + \text{jets} + \not{E}_T$

Backgrounds: $t\bar{t}t\bar{t}$, $t\bar{t}b\bar{b}$, $b\bar{b}b\bar{b}$, $t\bar{t}qq$, $b\bar{b}qq$, $Wtb$, $QCD$....

Events generated with ALPGEN and then interfaced with PYTHIA (We also checked using CalcHEP and Madgraph).


Present work (in preparation): with backgrounds. eg. $tt\bar{t}\bar{t}$, $t\bar{t}b\bar{b}$ and $b\bar{b}b\bar{b}$, W and top quark reconstruction.
Selection of events

1) Lepton selection: Leptons are identified by using its particle identity at the generator level $p_T^\ell > 20$ GeV and $|\eta|^\ell < 2.5$.

2) Jet reconstruction: jets are constructed using the default subroutine PYCELL in PYTHIA: $|\eta|_j < 4.5$; $\Delta R(j, j) > 0.5$; $p_T^j > 30$ GeV

Cuts used: $p_T^{j,1-4} > 350$, 250, 150, 100. GeV

3) $b$-tagging: If a jet ($j^b$) matches with a decayed B-hadron within a cone with $\Delta R < 0.3$ of the jet axis and if $|\eta|_j^b < 2.5$ and the decay length of the B-hadron $> 3.0$ mm.

4) $E_T$: 300 GeV

5) Effective mass: $M_{eff} = \sum p_T^j + \sum p_T^\ell + E_T$

Benchmark Point: $m_0, m_{1/2}, A_0, \tan \beta, sgn(\mu) =$ 3712 GeV, 700 GeV, 0.0, 30.0, +1 and $m_t =$ 175 GeV and $\Omega h^2 = 0.124$ (using micrOMEGA v2.0)

ALPGEN except $tt$ with $p_T^j(j, b) > 10$ GeV and $\Delta R(j, b) > 0.3$, $\eta(j, b) < 5.0$.

Table 1: Mass spectrum for given mSUGRA parameter

<table>
<thead>
<tr>
<th>$\tilde{g}$</th>
<th>$\tilde{q}_L$</th>
<th>$\tilde{q}_R$</th>
<th>$\tilde{t}_1$</th>
<th>$\tilde{\chi}_1^\pm$</th>
<th>$\tilde{\chi}_2^\pm$</th>
<th>$\tilde{\chi}_1^0$</th>
<th>$\tilde{\chi}_2^0$</th>
<th>$\tilde{\chi}_3^0$</th>
<th>$\tilde{\chi}_4^0$</th>
<th>$h$</th>
</tr>
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<tbody>
<tr>
<td>1751</td>
<td>3912</td>
<td>3907</td>
<td>2469</td>
<td>397</td>
<td>599</td>
<td>287</td>
<td>393</td>
<td>404</td>
<td>612</td>
<td>121</td>
</tr>
<tr>
<td>Cuts</td>
<td>$t\bar{t}t\bar{t}$</td>
<td>$t\bar{t}b\bar{b}$</td>
<td>$t\bar{t}$ $p_T &lt; 500$</td>
<td>$t\bar{t}$ $p_T &gt; 500$</td>
<td>$b\bar{b}b\bar{b}$</td>
<td>Signal ($g\bar{g}$)</td>
<td>Signal ($g\bar{q}$)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>-----------------------</td>
<td>---------------------</td>
<td>---------------------</td>
<td>-------------------------</td>
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<td>---------------------</td>
<td>---------------------</td>
<td>---------------------</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>No cuts</td>
<td>287616</td>
<td>118680</td>
<td>1000000</td>
<td>1000000</td>
<td>87621</td>
<td>100000</td>
<td>100000</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>$N_j \geq 6$</td>
<td>273977</td>
<td>62138</td>
<td>185574</td>
<td>255840</td>
<td>1122</td>
<td>97557</td>
<td>97764</td>
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<td>$N_{j+l} \geq 9$</td>
<td>208565</td>
<td>12725</td>
<td>12599</td>
<td>43947</td>
<td>33</td>
<td>86013</td>
<td>88712</td>
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<tr>
<td>$N_b \geq 2$</td>
<td>123472</td>
<td>6909</td>
<td>3351</td>
<td>13004</td>
<td>13</td>
<td>52595</td>
<td>50228</td>
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<tr>
<td>$P_{T1}^{b1} \geq .3$</td>
<td>18963</td>
<td>486</td>
<td>270</td>
<td>8086</td>
<td>1</td>
<td>37614</td>
<td>38742</td>
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<tr>
<td>$E_T \geq .3$</td>
<td>1591</td>
<td>17</td>
<td>9</td>
<td>814</td>
<td>0</td>
<td>27870</td>
<td>32340</td>
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<tr>
<td>$M_{eff} \geq 2.2$</td>
<td>719</td>
<td>11</td>
<td>5</td>
<td>292</td>
<td>0</td>
<td>25269</td>
<td>32298</td>
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<tr>
<td>$\sigma(fb)$</td>
<td>2.9</td>
<td>190</td>
<td>$4.3 \times 10^5$</td>
<td>$1.4 \times 10^3$</td>
<td>$8.0 \times 10^6$</td>
<td>1.64</td>
<td>0.11</td>
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<tr>
<td>$\sigma \times \epsilon_{ac}(fb)$</td>
<td>0.0073</td>
<td>0.0176</td>
<td>2.1</td>
<td>0.4</td>
<td>&lt;1</td>
<td>0.41</td>
<td>0.036</td>
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</tbody>
</table>

Total cross sections, Background: 2.52 fb, signal:0.446fb
So, for 100 fb$^{-1}$ Significance $\simeq 2.8$

Other backgrounds, Optimization
Figure 4: $E_T$ distribution: Normalized to Unity; Signal: yellow; $t\bar{t}$ ($p_T > 500$): blue; $t\bar{t}t\bar{t}$: green; $t\bar{t}b\bar{b}$: red.
Figure 5: $M_{eff}$ distribution: Normalized to Unity; Signal: yellow; $t\bar{t}$ ($p_T > 500$): blue; $t\bar{t}t\bar{t}$: green; $t\bar{t}bb$: red.
Conclusion

- In the Focus point regions, lighter neutralino and chargino are higgsino dominated.
- Neutralino may be the CDM candidates from WMAP.
- Gluino is light (since $m_{1/2}$ is not so large); 3rd generation squarks are also light compare to first two generations.
- Gluino pair production and Squark-Gluino production and their subsequent decay contains more number of b-jets; b-tagging helps.
- Considered the heavy flavour background, e.g., $ttt$, $ttbb$, $bbbb$, $ttqq$...
- $E_T$ and $M_{eff}$ reject large fraction of backgrounds.
- Optimization.