Search for direct top squark pair production in events with a Higgs or Z boson

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SPS Annual Meeting

LHEP-AEC, University of Bern

August 29th 2018
SUSY and the top squark

For decades the **Standard Model** has been subject to experimental scrutiny and has been found to be in agreement with experimental measurements.

Still, some open questions:

- Higgs mass not natural,
- Dark Matter...

**Supersymmetry** can solve these problems by adding a new set of particles one for each of the Standard Model’s ones.

We haven’t seen these particles yet → the symmetry must be broken

→ comprehensive program of top squark searches at the LHC
Exclusion limits often presented through simplified models:
most popular $\tilde{t}_1 \rightarrow t\tilde{\chi}_1^0$
Complex decay chains: $\tilde{t}_2$ pair production

When the $\tilde{t}_1 \rightarrow t + \tilde{\chi}_1^0$ becomes difficult to tackle it can be convenient to pass through the $\tilde{t}_2$

Two main selections, to target the two different bosons
- 3 leptons + 1 $b$ jet ($Z \rightarrow \ell^+\ell^-$)
- 1 or 2 leptons + 4 $b$ jets ($h \rightarrow b\bar{b}$)

Pros:
- busy final state
- reduce the most common SM backgrounds
- no need to rely on the $\tilde{t}_1$ decays products

Cons:
- higher masses
- lower cross sections
- more free parameters
  $\Delta m(\tilde{t}_1, \tilde{\chi}_1^0) = m(t)$
First results with 2015/16 dataset

No significant excess has been found

Results used to put limits on \( \tilde{t}_1, \tilde{t}_2 \) and \( \tilde{\chi}_1^0 \) masses

\[ \bar{t}_1 \bar{t}_2 \text{ production, } \bar{t}_1 \rightarrow \tilde{t}_1 + Z, \tilde{t}_1 \rightarrow t + \tilde{\chi}_1^0, m(\bar{t}_1) \cdot m(\tilde{\chi}_1^0) = 180 \text{ GeV} \]

\[ \bar{t}_2 \text{ production, } \bar{t}_2 \rightarrow \tilde{t}_2 + h, \tilde{t}_2 \rightarrow t + \tilde{\chi}_2^0, m(\bar{t}_2) \cdot m(\tilde{\chi}_2^0) = 180 \text{ GeV} \]

\[ m_{\tilde{t}_1} = 650 \text{ GeV} \]
\[ m_{\tilde{t}_2} = 200 \text{ GeV} \]
\[ m_{\tilde{\chi}_1^0} = m_{\tilde{t}_1} + 180 \text{ GeV} \]

arxiv:1706.03986
Compress scenarios

Plan to target also the compressed scenarios with the **full datasets**

- a different phase space results in different kinematic distributions
- softer leptons and $b$-jets
- a new selection will be developed
The new selections will come with new challenges

- events with non-prompt leptons become dominant at low $p_T$
  - coming from $b$ decays
- re-definition of candidate leptons
- isolation is the key!
Conclusions

Long decay chains can be considered to target more realistic models and experimentally complex phase space regions

- pair production of heavy stops allows to investigate such regions
- $Z$ or $h$ boson are present in the decay chain
  - $3\ell + 1b$ selection
  - $1/2\ell + 4b$ selection
- the ATLAS search with the intermediate Run 2 dataset allows to exclude up to 800-900 GeV of $\tilde{t}_2$ mass (depending on mass splitting and BR assumptions)
- plan to cover also very small $\Delta m(\tilde{t}_1, \tilde{\chi}_1^0)$ with the full dataset

Stay tuned for the new results!
Backup slides
Decay chains with the $Z$: $3\ell + 1b$ selection

3 signal regions targeting different mass splitting

<table>
<thead>
<tr>
<th>Requirement / Region</th>
<th>$SR^A_{3\ell 1b}$</th>
<th>$SR^B_{3\ell 1b}$</th>
<th>$SR^C_{3\ell 1b}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>$</td>
<td>m_{\ell\ell} - m_Z</td>
<td>$ [GeV]</td>
<td>$&lt; 15$</td>
</tr>
<tr>
<td>Leading jet $p_T$ [GeV]</td>
<td>$&gt; 250$</td>
<td>$&gt; 80$</td>
<td>$&gt; 60$</td>
</tr>
<tr>
<td>Leading $b$-tagged jet $p_T$ [GeV]</td>
<td>$&gt; 40$</td>
<td>$&gt; 40$</td>
<td>$&gt; 30$</td>
</tr>
<tr>
<td>$n_{jets}$ ($p_T &gt; 30$ GeV)</td>
<td>$\geq 6$</td>
<td>$\geq 6$</td>
<td>$\geq 5$</td>
</tr>
<tr>
<td>$E^{miss}_T$ [GeV]</td>
<td>$&gt; 100$</td>
<td>$&gt; 180$</td>
<td>$&gt; 140$</td>
</tr>
<tr>
<td>$p_{\ell\ell}$ [GeV]</td>
<td>$&gt; 150$</td>
<td>$-$</td>
<td>$&lt; 80$</td>
</tr>
</tbody>
</table>

Main backgrounds:

$ttZ$ and diboson (Monte Carlo normalised in control regions)
fakes and non prompt lepton (data-driven estimation)
Decay chains with the $h: 1/2\ell + b$ selection

3 signal regions targeting different mass splitting

<table>
<thead>
<tr>
<th>Requirement / Region</th>
<th>$\text{SR}_{A}^{1\ell 4b}$</th>
<th>$\text{SR}_{B}^{1\ell 4b}$</th>
<th>$\text{SR}_{C}^{1\ell 4b}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>$m_T$ [GeV]</td>
<td>–</td>
<td>&gt;150</td>
<td>&gt;125</td>
</tr>
<tr>
<td>$H_T$ [GeV]</td>
<td>&gt;1000</td>
<td>–</td>
<td>–</td>
</tr>
<tr>
<td>$E_{\text{miss}}$ [GeV]</td>
<td>&gt;120</td>
<td>&gt;150</td>
<td>&gt;150</td>
</tr>
<tr>
<td>Leading $b$-tagged jet $p_T$ [GeV]</td>
<td>–</td>
<td>–</td>
<td>&lt;140</td>
</tr>
<tr>
<td>$m_{bb}$ [GeV]</td>
<td>95–155</td>
<td>–</td>
<td>–</td>
</tr>
<tr>
<td>$p_T^{bb}$ [GeV]</td>
<td>&gt;300</td>
<td>–</td>
<td>–</td>
</tr>
<tr>
<td>$n_{\text{jets}}$ ($p_T &gt; 60$ GeV)</td>
<td>$\geq 6$</td>
<td>$\geq 5$</td>
<td>–</td>
</tr>
<tr>
<td>$n_{\text{jets}}$ ($p_T &gt; 30$ GeV)</td>
<td>–</td>
<td>–</td>
<td>$\geq 7$</td>
</tr>
</tbody>
</table>

Main background:
$t\bar{t} + b\bar{b}$ production
Monte Carlo normalised in 3 control regions kinematically close to the signal regions