Search for compressed SUSY scenarios with the ATLAS detector

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Compressed mass spectra?

- Specific well-motivated scenarios can lead to such configurations.
- For ex. if $\mu \ll M_1 \ll M_2 \rightarrow$ lightest $\tilde{\chi}$'s almost mass-degenerate
  $\tilde{t}_1, \tilde{b}_1, \tilde{\ell}_1, \tilde{\ell}_2, \tilde{\ell}_3$

- Or more coincidental, since we try to probe the whole phase space with simplified models:

Both lead to the same experimental challenges though!
In ATLAS searches

- Only “at the beginning” of Run 2, but ATLAS SUSY searches — thanks to Run 1 experience — are mature enough to already include various tools to target specifically these corners

Overview:

- selection of ISR topologies
- sophisticate discriminants: Recursive jigsaw reconstruction, tagging of hadronically-decaying top/\(W\) bosons...
- increased acceptance by reconstructing low-\(p_T\) leptons
- a particularly scrutinized scenario: \(\tilde{t}_1\) searches
Explicit selection of ISR topologies (1)

- Monojet + $E_T^{\text{miss}}$ search when SUSY decays too soft to be identified

- Signal regions with $E_T^{\text{miss}}$ from $> 250$ to $> 1000$ GeV

- Limits on $\tilde{q}\tilde{q}^*$, $\tilde{t}_1\tilde{t}_1^*$ and $\tilde{b}_1\tilde{b}_1^*$ production with direct decays to $\tilde{\chi}_1^0$

(source: ATLAS-CONF-2017-060)
Explicit selection of ISR topologies (2)

- Search for $\tilde{b}_1 \tilde{b}_1^*$ production in events with $b$-tagged jets and $E_T^{\text{miss}}$ ⇒ add information (presence of soft $b$-jets) to reject background

- Signal region $b0L$-SRC targets small $\Delta m(\tilde{b}_1, \tilde{\chi}_1^0)$

- One ISR jet back-to-back with $E_T^{\text{miss}}$, both $> 500$ GeV (transverse plane)

- Non-ISR jets required to be rather soft comparatively, especially those beyond tree level

(source: ATLAS-CONF-2017-038)
≥ 3 sparticles → several “compressed” corners (1)

1) small $\Delta m(\tilde{g}, \tilde{\chi}_1^0)$

2) small $\Delta m(\tilde{g}, \tilde{\chi}_1^\pm)$, large $\Delta m(\tilde{g}, \tilde{\chi}_1^0)$

- 0L + jets: $m_{\text{eff}}$-based selection complemented by Recursive Jigsaw to reconstruct events with ISR jets:

- Once “decay products” distinguished from ISR, cuts on $\sum p_T$, $S \rightarrow l$ boost transfer, $n_{\text{jets}}, m_T, \Delta \varphi(\text{ISR}, l)$...

(source: ATLAS-CONF-2017-022)
\( \geq 3 \) sparticles \( \rightarrow \) several “compressed” corners (2)

1) small \( \Delta m(\tilde{g}, \tilde{\chi}^0_1) \)
2) small \( \Delta m(\tilde{g}, \tilde{\chi}^\pm_1) \), large \( \Delta m(\tilde{g}, \tilde{\chi}^0_1) \)

\[\begin{align*}
\tilde{g} &\rightarrow q\tilde{q}W^\pm, m_{\tilde{\chi}^0_1} = 60 \text{ GeV} \\
\tilde{g} &\rightarrow q\tilde{q}W^\pm, m_{\tilde{\chi}^0_1} = 60 \text{ GeV}
\end{align*}\]

\( \text{NEW!} \)

(source: SUSY-2016-12)

- 1L + jets: large \( m_T \) and \( E_T^{\text{miss}}/m_{\text{eff}} \) but only 4 – 5 jets (versus \( \geq 6 \) for \( x \sim 0.5 \))
- 0L + jets: \( W \)-tagging of large-radius jets to nicely recover acceptance as \( x \rightarrow 1 \)
**Soft leptons**

- Searches with leptons: acceptance gains when reconstructing low $p_T$ leptons ⇒ also allow to tag intermediate sparticles (useful to characterize observed signal!)
- Upper bound on lepton $p_T$ to veto SM production of $t\bar{t}/W/Z$

**Same-sign leptons+jets:** $10(20) < p_T^{\ell_2(\ell_1)} < 100$ GeV for $1L + \geq 2$ jets: $6(7) < p_T^{\ell_1(e)} < n_{jets} \times 5$ GeV for $\tilde{q}(\tilde{g}) \rightarrow q(q)W^*\tilde{\chi}_1^0$
Even softer leptons

- Lepton performances (reconstruction, identification, calibration, isolation) now assessed (2016 data) down to $p_T = 4.5$ GeV (electrons) or $p_T = 4$ GeV (muons)

- Crucial to probe e.g. direct $\tilde{\chi}\tilde{\chi}$ production for small $\Delta m(\tilde{\chi}, \tilde{\chi}_1)$

- But already put to good use in recent SUSY searches (see next slide)
Mixing all ingredients: $\tilde{t}_1 \rightarrow bff' \tilde{\chi}_1^0$ (1)

Stop 1L (ATLAS-CONF-2017-037) combines many of these tools:
- ISR: $p_T^{\text{jet}_1} (E_T^{\text{miss}}) > 400 (300)$ GeV
- Lepton $p_T > 4–5$ GeV
- Anti-$t\bar{t}$: reclustered hadronic top mass veto, $m_T$ upper bound

Stop 2L (ATLAS-CONF-2017-034) complementary, looser requirements:
- $7 < p_T^{\ell_2(\ell_1)} < 35(80)$ GeV,
- $p_T^{\text{jet}_1} (E_T^{\text{miss}}) > 150 (200)$ GeV
\( \tilde{t}_1 \rightarrow bff' \tilde{\chi}_1^0 \) (2)

- Complemented by monojet+\( E_T^{\text{miss}} \) search for very small mass gaps:

(source: ATLAS-CONF-2017-060)

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ATLAS – Compressed SUSY

2017, July 6th
Stealth stop: $\Delta m(\tilde{t}_1, \tilde{\chi}_1^0) \sim m_t$

- Stop 1L: BDTs using kinematics of reconstructed hadronic and leptonic top quarks as input
- Stop 0L (ATLAS-CONF-2017-020): Recursive Jigsaw, fit of $E_T^{\text{miss}} / p_T^{\text{ISR}}$ shape $\sim m_{\tilde{\chi}_1^0} / m_{\tilde{t}_1}$
- $t\bar{t}$ cross-section (EPJC 74 (2014) 3109), spin correlations in $t\bar{t}$ system (PRL 114 (2015) 142001)
- Closed the gap left by Run 1 searches!

- Same-sign leptons+jets: constraints on $\tilde{t}_1 \rightarrow tW^{\pm} \tilde{\chi}_1^{\mp}$ for $\Delta m(\tilde{\chi}_1^\pm, \tilde{\chi}_1^0) \sim 0$, using events with $\ell^\pm \ell^\pm \ell^\pm + 1b$-jet
  $\Rightarrow$ extremely low SM background!
Conclusion

- ATLAS SUSY searches have deployed an arsenal of tools to probe scenarios with compressed mass spectra
- No significant excess observed so far! Analysis details in the other ATLAS SUSY talks / posters
- More results to come, in particular in the SUSY-electroweak sector
Additional material
\[ \tilde{q}\tilde{q} \text{ production, } B(\tilde{q} \rightarrow q \tilde{\chi}_1^0)=100\% \]

\[ m_{\tilde{\chi}}^0 \text{ vs. } m_{\tilde{q}} \text{ (GeV)} \]

- **ATLAS Preliminary**
- \( \sqrt{s} = 13 \text{ TeV}, 36.1 \text{ fb}^{-1} \)
- 0-leptons, 2-6 jets
- MEff or RJR (Best Expected)
- All limits at 95% CL.

(source: ATLAS-CONF-2017-022)
\[ \tilde{g}\tilde{g} \text{ production, } B(\tilde{g} \rightarrow \text{qq} \tilde{\chi}_1^0) = 100\% \]

*ATLAS* Preliminary

\[ \sqrt{s} = 13 \text{ TeV}, 36.1 \text{ fb}^{-1} \]

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(source: *ATLAS-CONF-2017-022*)
## Recursive Jigsaw in the 0L+jets search

Targeted signal: \( \tilde{g} \tilde{g}, \tilde{g} \rightarrow q \tilde{\chi}_0^0 \)

### Requirement Signal Region

<table>
<thead>
<tr>
<th>Requirement</th>
<th>RJR-C1</th>
<th>RJR-C2</th>
<th>RJR-C3</th>
<th>RJR-C4</th>
<th>RJR-C5</th>
</tr>
</thead>
<tbody>
<tr>
<td>( R_{\text{ISR}} \geq )</td>
<td>0.95</td>
<td>0.9</td>
<td>0.8</td>
<td>0.7</td>
<td>0.7</td>
</tr>
<tr>
<td>( p_{\text{TS}}^{\text{CM}} ) ,[GeV] \geq</td>
<td>1000</td>
<td>1000</td>
<td>800</td>
<td>700</td>
<td>700</td>
</tr>
<tr>
<td>( \Delta \phi_{\text{ISR}, \ 1/\pi} \geq )</td>
<td>0.95</td>
<td>0.97</td>
<td>0.98</td>
<td>0.95</td>
<td>0.95</td>
</tr>
<tr>
<td>( \Delta \phi(\text{jet}<em>{1,2}, E</em>{\text{T}}^{\text{miss}})_{\text{min}} \geq )</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>0.4</td>
<td>0.4</td>
</tr>
<tr>
<td>( M_{\text{TS}} ) ,[GeV] \geq</td>
<td>-</td>
<td>100</td>
<td>200</td>
<td>450</td>
<td>450</td>
</tr>
<tr>
<td>( N_{\text{jet}} \geq )</td>
<td>1</td>
<td>1</td>
<td>2</td>
<td>2</td>
<td>3</td>
</tr>
<tr>
<td>(</td>
<td>\eta_{jV}</td>
<td>\leq )</td>
<td>2.8</td>
<td>1.2</td>
<td>1.4</td>
</tr>
</tbody>
</table>
Additional discriminants built from kinematic/angular variables after separating ISR and decay systems

$$R_{\text{ISR}} = \frac{E_T^{\text{miss}}}{p_T^{\text{ISR}}} \sim \frac{m_{\tilde{t}_1}}{m_{\tilde{\chi}_1^0}}$$

(source: ATLAS-CONF-2017-020)
$\tilde{b}_1\tilde{b}_1$ production, $\tilde{b}_1 \rightarrow b\tilde{\chi}^0_1$

**ATLAS** Preliminary

$\sqrt{s}=13$ TeV, 36.1 fb$^{-1}$

All limits at 95% CL

- **Observed limit** ($\pm 1\sigma_{\text{theory}}$)
- **Expected limit** ($\pm 1\sigma_{\text{exp}}$)
- **Expected limit** $\pm 2\sigma_{\text{exp}}$

(source: ATLAS-CONF-2017-060)