Searches for electroweak production of supersymmetric gauginos and sleptons with the ATLAS detector

Jeanette Lorenz (LMU Munich)

On behalf of the ATLAS Collaboration

Kobe, 18.4.2018
Most searches for Supersymmetry in LHC Run 2 so far for gluinos and squarks (including stop/sbottom).

Searches for charginos, neutralinos and sleptons challenging:

- Lower cross section (compared to gluino/squark production),
- Compressed final states for Higgsino signatures,
- Complex mixing structure.

Relatively light higgsinos/charginos/neutralinos well motivated by naturalness.
Typical production modes

Superpartners of $W^{\pm/-}/0$, $h/H$, $H^{\pm/-}$ and $A^0$ mix to charginos and neutralinos → cross sections and decay properties determined by mass and Higgsino/Wino/Bino fraction

Superpartners of leptons → sleptons
~ 0.5 fb (left-handed) @ 500 GeV

In comparison $t \bar{t}$ pair production: 818 pb
Possible decay modes

Decays of charginos/neutralinos/sleptons often studied in multi-lepton signatures + $E_T^{\text{miss}}$:

→ 2, 3 or 4 leptons
→ rather clean signatures

- Main backgrounds:
  - Irreducible: mainly diboson production, sometimes $t\bar{t}$ (+ $X$) → estimation using control and validation regions
  - Reducible: fakes → data-driven background estimation
- Often suppression of top backgrounds by (b-tagged) jet veto
2 or 3 leptons

Three categories:
- 2 leptons + 0 jets
  → *direct or indirect production of sleptons*
- 2 leptons + >= 2 jets
  → *chargino/neutralino decays mediated by gauge bosons*
- 3 leptons
  → *chargino/neutralino pair production*

Separation (depending on channel) via
\[ m_{T2} = \min_{q_T} \left[ \max \left( m_T(p_{T1}, q_T), m_T(p_{T2}, p_{T3}^\text{miss} - q_T) \right) \right], \]
\[ m_{ll}, E_T^\text{miss}, p_T \text{ (third lepton)} \]
2 or 3 leptons

No significant excess seen.

Signal regions fitted simultaneously to derive limits.

- Limits on sleptons reaching up to 500 GeV.
- Limits on charginos/neutralinos with gauge-mediated decays reaching up to 580 GeV.
4 leptons

Lightest neutralino decaying to SM particles in RPV scenarios → potentially high lepton multiplicity in final state → high lepton multiplicity also in certain RPC scenarios

- >=4 leptons, 0 - 2 hadronically decaying taus
- 6 different SRs to gain optimal sensitivity to different models
- Cutting on $m_{\text{eff}}$ or $E_T^{\text{miss}}$ and veto or requirement on Z bosons
- Main backgrounds: ZZ, $t\bar{t}Z$ and fakes

[arXiv:1804.03602]
4 leptons

No significant excess seen.

Example limits:

Gaugino production with RPV decay

General gauge mediated:
- Compressed Higgsino states
- 4 leptons from $\tilde{\chi}^0_1$ to gravitino

New!

[arXiv:1804.03602]
Final states with taus

Search for chargino/neutralino production with decays via staus or tau sneutrinos to the lightest neutralino

→ taus in the final state
→ light staus as NLSP could predict the right amount of relic DM density in coannihilation channel

Event selection for two SRs:
• >= two hadronical decaying taus, B-veto, Z-veto
• $M_{T2}^{\text{miss}}, E_T^{\text{miss}}, p_T$ of taus

\begin{align*}
\chi^+_1 & \rightarrow \tau^+ \nu_	au, \tau^+\nu\nu \rightarrow \tau^+\nu\nu \chi_1^0, \\
\chi^0_1 & \rightarrow 2 \times \bar{\nu}\nu \rightarrow 2 \times \nu\chi^0_1 \\
\chi_1^0 & \rightarrow \tau^+ \nu\nu \\
\chi^0_2 & \rightarrow \tau^+ \nu\nu
\end{align*}
Higgsinos searches

Naturalness arguments require light higgsinos with similar masses.

**Scenario 1:**
GMSB higgsino NLSP

**Scenario 2:**
higgsino LSP

**Scenario 3:**
ultra-compressed higgsino LSP

[B. Hooberman, SUSY17]
Higgsino searches with 4b

Final state with 4 b-jets
→ *key to separate from high hadronic background*

2 different sets of SRs: >= 4 jets of which >= 3 b-jets
+ $E_T^{\text{miss}}$

→ *low mass, targeting low $\mu$ with low $E_T^{\text{miss}}$*
→ *high mass, targeting high $\mu$ with high $E_T^{\text{miss}}$*
Compressed higgsinos/sleptons

Significant lower invariant mass $m_{ll}$ for models with higgsinos
→ analysis requiring extremely low energetic leptons and low $m_{ll}$
→ using electrons down to $p_T = 4.5$ GeV and muons down to $p_T = 4$ GeV and $m_{ll} = 1$ GeV
→ huge progress in reconstruction of low energetic leptons

Two searches:
- Direct production of higgsinos using $m_{ll}$
- Direct production of sleptons using $m_{T2}$

→ key is estimation of fake backgrounds!
Compressed higgsinos/sleptons

No significant excess seen.

ATLAS

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

ee/\mu\mu, m_{0} \text{ shape fit}

All limits at 95\% CL

pp \rightarrow \tilde{\chi}^{0}_{2} \tilde{\chi}^{0}_{1}, \tilde{\chi}^{0}_{2} \tilde{\chi}^{0}_{1} (Higgsino)

\tilde{\chi}^{0}_{2} \rightarrow Z^{\pm} \tilde{\chi}^{\mp}_{1}, \tilde{\chi}^{0}_{1} \rightarrow W^{\pm} \tilde{\chi}^{\mp}_{1}

m(\tilde{\chi}^{0}_{1}) = (m(\tilde{\chi}^{0}_{2}) + m(\tilde{\chi}^{0}_{1}))/2

\Delta m(\tilde{\chi}^{0}_{2}, \tilde{\chi}^{0}_{1}) \text{ [GeV]}

\Delta m(\tilde{\ell}_{L,R}^{0}, \tilde{\ell}^{0}) \text{ [GeV]}

18.04.2018  J. Lorenz, Searches for electroweak production of supersymmetric gauginos and sleptons at ATLAS
Disappearing tracks

Long-lived chargino decaying to invisible + pion
→ disappearing track

Addition of IBL in LS1 allowed reconstruction of smaller minimal track lengths down to 12 cm
→ pixel-only tracklets

Old LEP limits partially superseded first time at LHC.
Summary

- Starting to harvest the results of searches for charginos, neutralinos and sleptons in LHC Run 2.
- No significant excess seen yet.
- First time exceeding long-standing LEP limits in certain scenarios.
- All results available at:
  https://twiki.cern.ch/twiki/bin/view/AtlasPublic/SupersymmetryPublicResults
Backup
Summary

ATLAS SUSY Searches* - 95% CL Lower Limits
December 2017

<table>
<thead>
<tr>
<th>Model</th>
<th>$e, \mu, \tau, \gamma$</th>
<th>Jets</th>
<th>$F_{\text{miss}}^T$ [fb]</th>
<th>$\ell^T d(\Delta t) [\text{fb}]$</th>
<th>Mass limit</th>
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<tbody>
<tr>
<td>$\tilde{q}, \tilde{q}^\dagger, \tilde{q}^c_{\text{L}}$ (compressed)</td>
<td>0</td>
<td>2 - 6 jets</td>
<td>Yes</td>
<td>36.1</td>
<td>1.57 TeV</td>
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<td>36.1</td>
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<td>36.1</td>
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<td>$\tilde{g}^c_{\text{L}} + \text{photino}$</td>
<td>0</td>
<td>3 jets</td>
<td>Yes</td>
<td>28.3</td>
<td>1.57 TeV</td>
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Reference

1712.02232
1711.03501
1712.02232
1712.02232
1611.05791
1706.03731
1708.02794
1607.05979
ATLAS-CONF-2017-080
ATLAS-CONF-2017-080

*Only a selection of the available mass limits on new states or phenomena is shown. Many of the limits are based on simplified models, c.f. refs. for the assumptions made.
# 2 or 3 leptons – background estimation

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<thead>
<tr>
<th>Background estimation summary</th>
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<tbody>
<tr>
<td>Channel</td>
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<tr>
<td>Fake/non-prompt leptons</td>
</tr>
<tr>
<td>$tt+Wt$</td>
</tr>
<tr>
<td>$VV$</td>
</tr>
<tr>
<td>$Z+\text{jets}$</td>
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<td>Higgs/$VVV$/top+$V$</td>
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4 leptons – detailed results

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<tr>
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<th>SR0D</th>
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<th>SR2</th>
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<tr>
<td>Observed</td>
<td>13</td>
<td>2</td>
<td>47</td>
<td>10</td>
<td>8</td>
<td>2</td>
</tr>
<tr>
<td>SM Total</td>
<td>10.2 ± 2.1</td>
<td>1.31 ± 0.24</td>
<td>37 ± 9</td>
<td>4.1 ± 0.7</td>
<td>4.9 ± 1.6</td>
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<td>2.7 ± 0.7</td>
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<td>t\bar{t}Z</td>
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\(\langle\epsilon\sigma\rangle^{95}_{\text{obs}}\) fb

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Table 8: Expected and observed yields for 36.1 fb\(^{-1}\) in the signal regions. “Other” is the sum of the t\textit{W}Z, t\textit{t}\textit{W}W, and t\textit{t}\textit{t}\textit{t}\textit{t} backgrounds. Statistical and systematic uncertainties are included. Also shown are the model-independent limits calculated from the signal region observations; the 95% CL upper limit on (a) the visible cross section times efficiency \(\langle\epsilon\sigma\rangle^{95}_{\text{obs}}\), (b) the observed number of signal events\(S^{95}_{\text{obs}}\), and (c) the signal events given the expected number of background events \(S^{95}_{\text{exp}}\) \(\pm 1\sigma\) variations of the expected number) calculated by performing pseudo-experiments for each signal region. The last two rows report (d) the CL\(_b\) value for the background-only hypothesis, and finally (e) the one-sided \(p_0\)-value and the local significance \(Z\) (the number of equivalent Gaussian standard deviations).
4 leptons – which SRs are used
Supersymmetric models

Usually only look at a specific decay chain
Distinguish signal from background

Use kinematic variables to discriminate signal from background.

Most analyses try to use simple combination of cuts on kinematic variables → 'cut-and-count', but also more and more shape analyses or analyses using more sophisticated techniques, e.g. machine learning.

\[ m_{\text{eff}} = \sum_{\text{jets}} p_T + \sum_{\text{leptons}} p_T + E_T^{\text{miss}} \]
Essential to estimate the backgrounds

- **Reducible backgrounds**: backgrounds with another final state in comparison to the signal
- **Irreducible backgrounds**: backgrounds show the same final state as the signal