Searches for electroweak production of SUSY particles with the ATLAS detector

SUSY 2016
Melbourne, Australia
July 3rd – 8th 2016

Matthew Gignac on behalf of the
ATLAS Collaboration
Overview of recent electro-weakino searches with ATLAS

- Analysis based on $\sqrt{s} = 8$ TeV of 20.3 fb$^{-1}$ from Run-1 of the LHC

1. Explored experimentally challenging SUSY scenarios
2. Interpretations of Run-1 searches in phenomenological models

Relevant papers:
- GGM Interpretations: CONF note to appear

All results available via ATLAS SUSY summary twiki:
https://twiki.cern.ch/twiki/bin/view/AtlasPublic/SupersymmetryPublicResults
Motivation

Strongly produced SUSY

- Largest cross section
- $\times$ TeV-scale mass limits
- $\times$ No signs yet...!

Motivation

Strongly produced SUSY
✓ Largest cross section
✗ TeV-scale mass limits
✗ No signs yet…!

Electroweak SUSY
✓ Small cross section but distinct leptonic signature
→ Topic of today’s talk!


July 4, 2016
Matthew Gignac (UBC)
Simplified SUSY scenarios

**Simplified models**
- Masses and decay modes are the only free parameters
- Assumed 100% BR of sparticles

\[ \tilde{\tau} \tilde{\tau} \text{ with taus} \]

\[ p \tilde{\tau} \tilde{\tau} \tilde{\tau} p \]

\rightarrow Di-hadronic tau
Simplified SUSY scenarios

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- Assumed 100% BR of sparticles

\[ \tilde{\tau}\tilde{\tau} \text{ with taus} \]
\[ \tilde{\chi}_1^\pm \tilde{\chi}_1^- \text{ with sleptons} \]

\[ \rightarrow \text{Di-hadronic tau} \]
\[ \rightarrow 2 \text{ OS light leptons} \]
Simplified SUSY scenarios

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\[ \tilde{\tau}\tilde{\tau} \text{ with taus} \]
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\[ \tilde{\chi}_1^0 \tilde{\chi}_2^0 \text{ with sleptons} \]

\rightarrow Di-hadronic tau \rightarrow 2 OS light leptons \rightarrow 3 light leptons 
\rightarrow 2 SS light leptons

\[ \tilde{\tau}\tilde{\tau} \rightarrow 2 \text{ OS light leptons} \]
\[ \tilde{\chi}_1^\pm \tilde{\chi}_1^\mp \rightarrow \ell/\bar{\nu} \]
\[ \tilde{\chi}_1^0 \tilde{\chi}_2^0 \rightarrow \nu/\ell \]

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→ Di-hadronic tau
→ 2 OS light leptons
→ 3 light leptons
→ 2 SS light leptons

\[ \tilde{\chi}_1^\pm \tilde{\chi}_1^\pm \text{ via VBF} \]
→ Forward jets

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Standard Model background modelling

Several SM backgrounds mimic the SUSY signatures
- Single/di-/tri-bosons, top-quark(s) and multi-jet
- Need to understand and accurately model these backgrounds!

1. **Irreducible backgrounds: MC simulation**
   - Sources of real, prompt leptons
   - Control regions (CRs) used to normalize dominant contributions
   - Shapes of kinematic variables taken from MC simulation

2. **Reducible backgrounds: Data-driven estimate**
   - One or more fake, non-prompt leptons
   - Non-prompt backgrounds estimated with the matrix method
   - Multi-jet production estimated with the ABCD method

![Real leptons and fake leptons diagrams](image)
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OS ditau channel

Di-hadronic tau final state, very challenging:
• Difficult to trigger and separate from SM backgrounds
• Previous ATLAS results\(^1\) not sensitive to stau production

Event selection:
• SR defined with a multivariate technique
• Z-veto: reduce \(Z \rightarrow \tau\tau\) events
• B-veto: reduce di-tau tt events

Background estimation:
• \(W \rightarrow \tau \nu +\) mis-identified tau \(\rightarrow\) normalized in CRs
• Diboson and top estimated using MC simulation
• Multi-jet background: data-driven ABCD method

Data consistent with background only predictions

Improved sensitivity compared previous ATLAS result

✓ Exclude one scenario where: $m_{\tau\tilde{R}} = 109$ GeV and $m_{\tilde{\chi}^0_1} = 0$ GeV

OS dilepton channel

Improve previous 2-lepton results\(^2\) for \(\tilde{\chi}_1^\pm - \tilde{\chi}_1^0 < 100\ \text{GeV}\)

Event selection

- Exactly two oppositely-charged leptons with \(p_T > 10\ \text{GeV}\)
- At least one hard ISR jet \(\rightarrow\) boosts the leptons
- Suppress top quark(s) background with b-jet veto

Data consistent with SM backgrounds only

\[m_{\tilde{\nu}, \tilde{\ell}} = \frac{(m_{\tilde{\chi}_1^\pm} + m_{\tilde{\chi}_1^0})}{2}\]

\([2]\) JHEP 1405 (2014) 071
3\ell channel

Improve previous 3-lepton results$^3$ for $\tilde{\chi}_2^0 - \tilde{\chi}_1^0 < 20$ GeV

**Event selection**
- Three leptons with muon (electron) $6(7) < p_T < 30$ GeV
- SRs to target ISR scenarios $\rightarrow$ jet with $p_T > 50$ GeV

**Background estimation:**
- WZ and ZZ estimated taken from MC $\rightarrow$ validated in VRs
- Reducible backgrounds: data driven matrix method

Data consistent with SM only predictions
SS dilepton channel

Target compressed scenarios when one lepton is lost

**Event selection:**
- Two light leptons with same charge: $e^\pm e^\pm$, $\mu^\pm \mu^\pm$, or $e^\pm \mu^\pm$
- BDTs trained and optimized for $\tilde{\chi}_1^\pm - \tilde{\chi}_1^0 < 100$ GeV

**Background estimation:**
- Charge flip ($Z, t\bar{t}, W^+ W^-$) estimated in $Z \rightarrow e^\pm e^\pm$
- $W^\pm W^\pm$, $WZ$ and $ZZ$ taken from MC simulation

Data consistent with SM only predictions
Chargino-pair production via VBF

Explore highly compressed SUSY with VBF
- Smaller cross section than direct production
- Forward jets give distinct signature from the SM

**Event Selection**
- Exactly two same sign leptons
- At least two jets with $m_{jj} > 350$ GeV & $|\Delta \eta_{jj}| > 1.6$

Data consistent with SM only predictions

\[ m(\tilde{\chi}_1^\pm) = 110 \text{ GeV} \]
\[ m_{\tilde{\nu}} = (m_{\tilde{\chi}_1^+} + m_{\tilde{\chi}_1^0})/2 \]
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Re-interpretation in the context of a pMSSM

- sfermions, gluinos and CP-odd Higgs are decoupled
- Four dimensional parameter space:
  - $M_1 = 50$ GeV to satisfy dark matter cosmological bounds; $\tan\beta = 10$
  - Interpretation in $M_2$ vs $\mu$ plane
- Direct production of charginos and neutralinos dominant
  - Decays through SM gauge bosons and the lightest higgs boson

$WZ \rightarrow 2\ell$ or $3\ell$

$Wh \rightarrow 1\ell + bb, XX, WW$

JHEP 1405 (2014) 071

Two-parameter NUHM model (NUHM2)

Radiatively-driven Natural SUSY
- Low-level of electroweak fine-tuning, allows SM h and Z-boson $\sim O(100)$ GeV
- Light higgsinos $|\mu| \sim 100 – 300$ GeV
- Squarks and gluinos all at the TeV-scale
- Production of heavier Wino-like gauginos
  - Distinct multi-lepton signature
  - Sensitivity with existing 2$\ell,3\ell$ and 4$\ell$ EW searches!

$\tilde{\chi}_1^0 \tilde{\chi}_2^\pm \tilde{\chi}_4^0 \tilde{\chi}_1^\pm$  

Compressed higgsinos

References

Gauge mediated SUSY breaking model with SM Higgs mass constraint

- Wino-higgsino electroweakino production
- Decays via W, Z, h and photons; gravitino LSP

\[ \tau \beta = 5, \mu = 150 \text{ GeV} \]
Gauge mediated SUSY breaking model with SM Higgs mass constraint

- Wino-higgsino electroweakino production
- Decays via W, Z, h and photons; gravitino LSP

Increasing $\mu$

$\tan \beta = 5$, $M_1 = 150$ GeV
Conclusions

ATLAS has a rich SUSY program to explore electroweak SUSY
• No evidence for electro-weak SUSY at 8 TeV
• Stay tuned for results at 13 TeV!

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Backup slides
Matrix method: overview

Relates tight (T) and loose (L) leptons to real (R) and fake (F) objects

• In 3ℓ events, leading lepton was shown to be real 99% of the time
• For 2ℓ events, we have a 4x4 matrix

\[
\begin{pmatrix}
N_{TT} \\
N_{TL}' \\
N_{LT}' \\
N_{LL}'
\end{pmatrix} = \begin{pmatrix}
\epsilon_1 \epsilon_2 & \epsilon_1 f_2 & f_1 \epsilon_2 & f_1 f_2 \\
\epsilon_1 (1 - \epsilon_2) & \epsilon_1 (1 - f_2) & f_1 (1 - \epsilon_2) & f_1 (1 - f_2) \\
(1 - \epsilon_1) \epsilon_2 & (1 - \epsilon_1) f_2 & (1 - f_1) \epsilon_2 & (1 - f_1) f_2 \\
(1 - \epsilon_1) (1 - \epsilon_2) & (1 - \epsilon_1) (1 - f_2) & (1 - f_1) (1 - \epsilon_2) & (1 - f_1) (1 - f_2)
\end{pmatrix} \cdot \begin{pmatrix}
N_{RR} \\
N_{RF} \\
N_{FR} \\
N_{FF}
\end{pmatrix}
\]

- \( \epsilon \): probability a real lepton passes signal loose to tight selection
- \( f \): probability a fake lepton passes signal loose to tight selection
- \( \epsilon \) and \( f \) measured in MC close to SR, corrected by data-driven measurements of \( \epsilon \) and \( f \) further from the SR

• Invert the matrix, solve for the number of fake leptons passing tight selection

\[
N_{Fake\rightarrow TT} = \epsilon_1 f_2 \times N_{RF} + f_1 \epsilon_2 \times N_{FR} + f_1 f_2 \times N_{FF}
\]
## Triggers

<table>
<thead>
<tr>
<th>Trigger</th>
<th>$p_T$ threshold [GeV]</th>
<th>Analysis</th>
</tr>
</thead>
<tbody>
<tr>
<td>Single $\tau$</td>
<td>150</td>
<td>Direct stau production</td>
</tr>
<tr>
<td>Double $\tau$</td>
<td>40, 25</td>
<td></td>
</tr>
<tr>
<td>Single Isolated $e$</td>
<td>25</td>
<td>Compressed spectra $\ell^+\ell^-$, $3\ell$</td>
</tr>
<tr>
<td>Single Isolated $\mu$</td>
<td>25</td>
<td></td>
</tr>
<tr>
<td>Double $e$</td>
<td>14, 14</td>
<td>Compressed spectra $\ell^+\ell^-$, $\ell^±\ell^±$, $3\ell$</td>
</tr>
<tr>
<td></td>
<td>25, 10</td>
<td></td>
</tr>
<tr>
<td>Double $\mu$</td>
<td>14, 14</td>
<td>Compressed spectra $\ell^+\ell^-$, $\ell^±\ell^±$, $3\ell$</td>
</tr>
<tr>
<td></td>
<td>18, 10</td>
<td></td>
</tr>
<tr>
<td>Triple $e$</td>
<td>20, 9, 9</td>
<td>Compressed spectra $3\ell$</td>
</tr>
<tr>
<td>Triple $\mu$</td>
<td>7, 7, 7</td>
<td>Compressed spectra $3\ell$</td>
</tr>
<tr>
<td></td>
<td>19, 5, 5</td>
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<tr>
<td>Combined $e\mu$</td>
<td>14(e), 10(\mu)</td>
<td>Compressed spectra $3\ell$</td>
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<td></td>
<td>18(\mu), 10(e)</td>
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<td></td>
<td>9(e), 9(e), 7(\mu)</td>
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<td></td>
<td>9(e), 7(\mu), 7(\mu)</td>
<td></td>
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<tr>
<td>$E_T^{\text{miss}}$</td>
<td>120</td>
<td>Chargino production via VBF</td>
</tr>
</tbody>
</table>
Heavier electroweakino states

Combination 3ℓ and 4ℓ analyses
- Overall improved sensitivity
- Limits robust against slepton mass
Two-parameter NUHM model (NUHM2)

\[ \frac{M_Z^2}{2} = \frac{m_{H_d}^2 + \Sigma_d^d - (m_{H_u}^2 + \Sigma_u^u) \tan^2 \beta}{\tan^2 \beta - 1} - \mu^2, \]

\[ \Delta_{EW} \equiv \max_i |C_i| / (M_Z^2/2). \]

Mechanism of SUSY breaking unknown

- SUSY particle masses arise from couplings to the messenger fields $\Phi$:

- Parameters of the theory:
  - Messenger mass scale ($M_{\text{mess}}$)
  - Number of SU(5) messenger fields ($N_5$)
  - SUSY-breaking mass scale ($\Lambda$)
  - $\tan\beta$ and $\mu$

High $\Lambda \rightarrow$ EW production of sparticles

- stau NLSP; gravitino LSP
- Final states with 2-4 tau-leptons
  - Sensitivity with 4$\ell$ EW search!