Searches for direct pair production of third generation squarks in final states with leptons with the ATLAS detector

Priscilla Pani (CERN) on behalf of the ATLAS Collaboration
Introduction and motivations

★ Stops and sbottoms are key ingredients for SUSY and hierarchy problem solutions

★ **Focus** of this talk: stop searches with leptons and *gauginos* in the final state.

★ **Question to be answered:** is the stop phase space really well excluded for realistic models?
# Outlook of the ATLAS stop searches

<table>
<thead>
<tr>
<th>Short Name</th>
<th>Reference</th>
<th>Target</th>
<th>Strategy</th>
</tr>
</thead>
</table>
| stop1L     | ATLAS-CONF-2017-037 | $\tilde{t}_1 \rightarrow b\tilde{\chi}_1^\pm / t\chi_1^0 / t\chi_2^0$
   $\tilde{t}_1 \rightarrow bff'\tilde{\chi}_1^0 / bW^\pm \tilde{\chi}_1^0$ | BDTs, multi-bin fits, multiple SR |
| stop2L     | ATLAS-CONF-2017-034 | $\tilde{t}_1 \rightarrow b\tilde{\chi}_1^\pm / t\chi_1^0 / t\chi_2^0$
   $\tilde{t}_1 \rightarrow bff'\tilde{\chi}_1^0 / bW^\pm \tilde{\chi}_1^0$ | multi-bin fits, multiple SR |
| stopZ/h    | arXiv: 1706.03986 | $\tilde{t}_1 \rightarrow t\tilde{\chi}_2^0$
   $\tilde{t}_2 \rightarrow \tilde{t}_1 h / \tilde{t}_1 Z$ | multiple single-bin SRs |
| RPV 1L     | arXiv: 1704.08493 | $\tilde{t}_1 \rightarrow t\chi_1^0 / t\chi_2^0$
   $\tilde{\chi}_{1,2}^0 \rightarrow tbs / sbb$ | multi-bin fits |
| RPV b-l    | ATLAS-CONF-2017-036 | $\tilde{t}_1 \rightarrow b\ell$ | multiple single-bin SRs |
Stop1L in a nutshell

Final state: 1L (soft or hard) + bjets + ETmiss

- Exploit the presence of 1 hadronic and 1 leptonic top decay (large R jet masses)
- Asymmetric stranverse mass to suppress di-lepton top in background
- Angular correlations between objects to enhance signal discrimination

shape-fits, BDT, cut-and-count
Details of the compressed analysis

### BDT inputs

**Recursive Jigsaw variables**

- Lab State
- Decay States
- Visible States
- Invisible States

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<table>
<thead>
<tr>
<th>tN_diag_low</th>
<th>Pure bino LSP ($\tilde{t}_1 \rightarrow t\tilde{\chi}^0_1$)</th>
<th>$m(\tilde{t}_1, \tilde{\chi}^0_1)$=(190,17)</th>
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**ATLAS Preliminary**

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

<table>
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<tr>
<th>Events</th>
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<tbody>
<tr>
<td>Data</td>
</tr>
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</table>

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**Graphical Representation**

- $\tilde{t}$
- $\tilde{\chi}^0$
- Lab State
- Decay States
- Visible States
- Invisible States
Stop2L in a nutshell

Final state: 2L (soft or hard) + ETmiss

★ Exploit kinematic end-point of stranverse mass (2-body)

★ jigsaw analysis for 3-body

★ Ratios of $E_T^{\text{miss}}$ and pTs to enhance soft topologies (4-body)
RPC quasi-simplified models

\[ \mathcal{BR}(\tilde{t}_1 \rightarrow t\tilde{\chi}_1^0) = 100\% \]

“standard” simplified model

more complex but also more realistic models than Run 1 benchmarks
Scenario a) Bino-LSP

Priscilla Panin (CERN)
Results along the diagonal

ATLAS Preliminary
\( \sqrt{s} = 13 \, \text{TeV}, \, 36.1 \, \text{fb}^{-1} \)
Limit at 95% CL

Pure Bino LSP model: \( \tilde{t}_1 \) production, \( \tilde{t}_1 \rightarrow bff'\chi_1^0, \tilde{t}_1 \rightarrow bW\chi_1^0, \tilde{t}_1 \rightarrow t\chi_1^0 \)
**Scenario b) Wino N-LSP**

- Good complementarity between 1L (left) and 2L (right) final states

<table>
<thead>
<tr>
<th>Parameter</th>
<th>M1, M2</th>
<th>M3</th>
<th>lμl</th>
<th>tan β</th>
<th>Ms</th>
<th>Xt</th>
</tr>
</thead>
<tbody>
<tr>
<td>Value</td>
<td>M2=2*M1</td>
<td>2.2 TeV</td>
<td>high</td>
<td>20</td>
<td>1.2 TeV</td>
<td>Xt=Ms*√6</td>
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</table>
Scenario c) Higgsino LSP

pMSSM-inspired Higgsino models: 1) $t_1 \sim t_L$, 2) $t_1 \sim t_R$, 3) $t_1 \sim t_L$ with large $\tan\beta$. $m_{t_1}$ up to 800 - 880 GeV is excluded.
Scenario d) Well tempered grid

\[ 0.10 < \Omega h^2 < 0.12 \]
Searches with higgs and Z

★ Simplified model targeting $\chi_2$ decaying via Higgs or Z-boson.

★ Final states:
  - 3L + 1b
  - 1L + 4b

★ Backgrounds:
  - ttZ in 3L+1b
  - ttbar in 1L+4b
RPV third generation summary

★ Multiple analyses dedicated to RPV in the 3rd generation sector:

- **2b2l** final states
- **1L** final states

Details in S. Mehlhase’s talk on Friday!
Conclusions and final remarks

- Many new results from ATLAS for 3rd generation squark searches based on full 2015+2016 data (36 fb-1)

- No significant excess found. Limits are significantly improved with respect to previous results

- Stringent limits obtained in pMSSM inspired models, yet some part of the parameter space is still uncovered.
Backup
Details of the compressed analysis (I)

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**BDT inputs**

$\Delta m_\alpha^\alpha (\text{SM, signal})$

$m_T, E_T^{\text{miss}}$

$m(t_\text{ISR})$ and $m(t_\text{lep}^\alpha)$

$\Delta \phi$ tt system, lepton, $E_T^{\text{miss}}$

*ATLAS Preliminary*

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

tN_diag_low

- Data
- Total SM
- $m(\tilde{t}_1, \tilde{\chi}_1^0) = (190,17) \text{ GeV}$
- $m(\tilde{t}_1, \tilde{\chi}_1^0) = (250,77) \text{ GeV}$
- Single top
- Diboson
- $t\bar{t}+V$

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Details of the compressed analysis (II)

Table 7

| tN_diag_low   | Pure bino LSP ($\tilde{t}_1 \rightarrow t\tilde{\chi}_1^0$) | $m(\tilde{t}_1, \tilde{\chi}_1^0)$=(190,17) | BDT cut-and-count | 7 |
| tN_diag_med   | Pure bino LSP ($\tilde{t}_1 \rightarrow t\tilde{\chi}_1^0$) | $m(\tilde{t}_1, \tilde{\chi}_1^0)$=(250,62) | BDT shape-fit      | 7 |
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**BDT inputs**

$m_T, E_T^{miss}, H_T^{sig}$

nJets, $p_T(j3, j4)$

$\Delta R(b, \ell), m_{top}$

$\Delta \phi(p_T^{miss}, t_{had}^\chi), \Delta \phi(t_{had}^\chi, t_{lep}^\chi)$

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Image: ATLAS Preliminary

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

tN_diag_med

- Data
- Total SM
- $t\bar{t}$ 2L
- $t\bar{t}$ 1L
- $t\bar{t}+V$
- W+jets
- Single top
- Diboson

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Image: $-m(\tilde{t}_1, \tilde{\chi}_1^0)$=(250,62) GeV

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Signal region distribution

Pure Bino LSP model: $\tilde{t}_1\tilde{t}_1$ production, $\tilde{t}_1 \rightarrow bff\tilde{\chi}_1^0$, $\tilde{t}_1 \rightarrow Wb\tilde{\chi}_1^0$, $\tilde{t}_1 \rightarrow t\tilde{\chi}_1^0$

**ATLAS** Preliminary

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

- Observed limit
- Expected limit

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Priscilla Pani (CERN)

**Bino LSP decays**

Illustration of the preferred stop decay modes in the plane spanned by the masses of the stop ($m_{\tilde{t}_1}$) and the lightest neutralino ($m_{\tilde{\chi}_1^0}$).

- $m_{\tilde{t}_1} < m_{\tilde{\chi}_1^0}$
- $\Delta m > 0$
- $\Delta m > m_W + m_b$
- $\Delta m > m_t$

The region of phase-space along the line $m_{\tilde{t}_1} = m_{\tilde{\chi}_1^0}$ is shaded. The decay process $\tilde{t}_1 \rightarrow c\tilde{\chi}_1^0$ is indicated, and the decay $\tilde{t}_1 \rightarrow bW\tilde{\chi}_1^0$ is also shown, with $\Delta m = m_{\tilde{t}_1} - m_{\tilde{\chi}_1^0}$.
## stop1L summary

<table>
<thead>
<tr>
<th>SR</th>
<th>Signal scenario</th>
<th>benchmark</th>
<th>Exclusion technique</th>
<th>Table</th>
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<td>Pure bino LSP ($\tilde{t}_1 \rightarrow t\tilde{x}_1^0$)</td>
<td>$m(\tilde{t}_1, \tilde{x}_1^0) = (600,300)$</td>
<td>shape-fit ($E_T^{miss}$)</td>
<td>6</td>
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<tr>
<td>tN_high</td>
<td>Pure bino LSP ($\tilde{t}_1 \rightarrow t\tilde{x}_1^0$)</td>
<td>$m(\tilde{t}_1, \tilde{x}_1^0) = (1000,1)$</td>
<td>cut-and-count</td>
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<td>bWN</td>
<td>Pure bino LSP ($\tilde{t}_1 \rightarrow bW\tilde{x}_1^0$)</td>
<td>$m(\tilde{t}_1, \tilde{x}_1^0) = (350,230)$</td>
<td>shape-fit ($am_{T2}$)</td>
<td>8</td>
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<tr>
<td>bffN</td>
<td>Pure bino LSP ($\tilde{t}_1 \rightarrow bff'\tilde{x}_1^0$)</td>
<td>$m(\tilde{t}_1, \tilde{x}_1^0) = (400,350)$</td>
<td>shape-fit ($p_T^{\ell}/E_T^{miss}$)</td>
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<td>bC2x_med</td>
<td>Wino NLSP ($\tilde{t}_1 \rightarrow b\tilde{x}_1^\pm, \tilde{t}_1 \rightarrow t\tilde{x}_2^0$)</td>
<td>$m(\tilde{t}_1, \tilde{x}_1^\pm, \tilde{x}_2^0) = (750,300,150)$</td>
<td>cut-and-count</td>
<td>9</td>
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<td>bC2x_diag</td>
<td>Wino NLSP ($\tilde{t}_1 \rightarrow b\tilde{x}_1^\pm, \tilde{t}_1 \rightarrow t\tilde{x}_2^0$)</td>
<td>$m(\tilde{t}_1, \tilde{x}_1^\pm, \tilde{x}_2^0) = (650,500,250)$</td>
<td>cut-and-count</td>
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<td>bC bv</td>
<td>Wino NLSP ($\tilde{t}_1 \rightarrow b\tilde{x}_1^\pm, \tilde{t}_1 \rightarrow t\tilde{x}_2^0$)</td>
<td>$m(\tilde{t}_1, \tilde{x}_1^\pm, \tilde{x}_2^0) = (700,690,1)$</td>
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<td>bCsoft_diag</td>
<td>Higgsino LSP ($\tilde{t}_1 \rightarrow t\tilde{x}_1^0, \tilde{t}_1 \rightarrow t\tilde{x}_2^0, \tilde{t}_1 \rightarrow b\tilde{x}_1^\pm$)</td>
<td>$m(\tilde{t}_1, \tilde{x}_1^0, \tilde{x}_2^0) = (400,355,350)$</td>
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<td>$m(\tilde{t}_1, \tilde{x}_1^0, \tilde{x}_2^0) = (600,205,200)$</td>
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<td>bCsoft_high</td>
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<td>$m(\tilde{t}_1, \tilde{x}_1^0, \tilde{x}_2^0) = (800,155,150)$</td>
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<td>DM_low_loose</td>
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Pure Bino LSP model: $\tilde{t}\tilde{t}$ production, $\tilde{t} \rightarrow bff\tilde{\chi}_1^0$, $\tilde{t} \rightarrow Wb\tilde{\chi}_1^0$, $\tilde{t} \rightarrow t\tilde{\chi}_1^0$

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

Limit at 95% CL

ATLAS Preliminary

- Observed limit ($\pm 1\sigma_{\text{th}}$)
- Expected limit ($\pm 1\sigma_{\text{exp}}$)
- ATLAS $t\bar{t}L$ 13 TeV, 3.2 fb$^{-1}$
- ATLAS 8 TeV, 20.3 fb$^{-1}$