Searches for Supersymmetry with the ATLAS detector

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On behalf of ATLAS Collaboration

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**SUSY**: Additional symmetry on top of the SM

→ *SUSY particles expected to have a mass above 1 TeV*

- LHC is the only place for direct searches for new heavy particles

- ATLAS has a very rich program in SUSY searches

→ *Generally based on final states with jets, $E_T^{\text{miss}}$ and high $p_T$ objects.*

Today we will focus on the latest results:

1. Photon + jets + $E_T^{\text{miss}}$: [ATLAS-CONF-2021-028](#)

2. Fully Hadronic: [ATLAS-CONF-2021-022](#)

Latest results long-lived particles: see Melisa’s talk!
Final State: Photon + Jets + $E_T^{\text{miss}}$

**Experimental signature:** one high $p_T$ photon, many jets and $E_T^{\text{miss}}$

**Model interpretation:**
- Based on General Gauge Mediation (GGM) models
  - Allow decoupled mass scales for strongly interacting SUSY particles: NLSP $\tilde{\chi}_0$ has large $\tilde{H}$ or $\tilde{B}$ components:
    - $\tilde{\chi}_1^0 \rightarrow (\gamma/Z)\tilde{G}$
    - $\tilde{\chi}_1^0 \rightarrow (\gamma/h)\tilde{G}$
- LSP is the ultra light $\tilde{G}$.
- R-parity is conserved.

**Signal Regions:** Target different mass splitting
- **SRL:** $\tilde{g} \gg \tilde{\chi}_1^0$
- **SRH:** $\tilde{g} \sim \tilde{\chi}_1^0$
- **SRM:** $\tilde{g} > \tilde{\chi}_1^0$
Final State: Photon + Jets + $E_T^{miss}$

**Background estimation:**

- $W\gamma, t\bar{t}\gamma, \gamma+$jets: *normalised to data in dedicated CRs.*
- $W\gamma\gamma, Z\gamma, Z\gamma\gamma, \gamma\gamma$: *taken from MC.*
- $\gamma$ fakes: *data-driven techniques used independently for jets and electrons faking photons*
No significant excess above the SM background is observed
Final State: Photon + Jets + $E_T^{miss}$

<table>
<thead>
<tr>
<th>Signal Region</th>
<th>$N_{\text{obs}}$</th>
<th>$N_{\text{exp}}$</th>
<th>$\langle \epsilon \sigma \rangle^{95}_{\text{obs}}$ [fb]</th>
<th>$\langle \epsilon \sigma \rangle^{95}_{\text{exp}}$ [fb]</th>
<th>$S^{95}_{\text{obs}}$</th>
<th>$S^{95}_{\text{exp}}$</th>
<th>$p_0(Z)$</th>
</tr>
</thead>
<tbody>
<tr>
<td>SRL</td>
<td>2</td>
<td>2.67 ± 0.75</td>
<td>0.030</td>
<td>0.034±0.019</td>
<td>4.12</td>
<td>4.7±2.6</td>
<td>0.50 (0.00)</td>
</tr>
<tr>
<td>SRM</td>
<td>0</td>
<td>2.55 ± 0.64</td>
<td>0.018</td>
<td>0.032±0.018</td>
<td>2.56</td>
<td>4.4±2.6</td>
<td>0.50 (0.00)</td>
</tr>
<tr>
<td>SRH</td>
<td>5</td>
<td>2.55 ± 0.44</td>
<td>0.054</td>
<td>0.034±0.011</td>
<td>7.43</td>
<td>4.7±2.6</td>
<td>0.09 (1.36)</td>
</tr>
</tbody>
</table>

Model independent limits

ATLAS Preliminary
$\sqrt{s}=13$ TeV, 139 fb$^{-1}$, All limits at 95% CL

- Expected Limit ($\pm 1 \sigma_{\text{exp}}$)
- Observed Limit ($\pm 1 \sigma_{\text{exp}}$)
- Excluded at $\sqrt{s}=13$ TeV, 36.2 fb$^{-1}$

$\gamma/Z$ model

$\gamma/h$ model
Final State: Fully Hadronic

**Experimental signature:** 2 boosted hadronically-decaying heavy SM bosons ($W$, $Z$, or $h$) + $E_T^{\text{miss}}$

Model interpretation based on 3 scenarios:

1. **A baseline MSSM with $\tilde{B}/\tilde{H}/\tilde{W}$ LSP**
   
   $\rightarrow (\tilde{\chi}_{\text{heavy}}, \tilde{\chi}_{\text{light}}) : (\tilde{W}, \tilde{B}), (\tilde{W}, \tilde{H}), (\tilde{H}, \tilde{B}), (\tilde{H}, \tilde{W})$

   *Typical electroweakino searches at the LHC target only ($\tilde{W}, \tilde{B}$).

2. **GGM/Naturalness-driven $\tilde{G}$ LSP model**
   
   $\rightarrow (\tilde{\chi}_{\text{heavy}}, \tilde{\chi}_{\text{light}}) : (\tilde{H}, \tilde{G})$

3. **Naturalness-driven $\tilde{a}$ LSP model**
   
   $\rightarrow (\tilde{\chi}_{\text{heavy}}, \tilde{\chi}_{\text{light}}) : (\tilde{H}, \tilde{a})$

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SUSY searches in ATLAS 7/19
**Final State: Fully Hadronic**

Large-R jets (J) are used to capture two collimated energetic jets from each SM boson decay

“Boson tagging” is used to identify the decays of $W$, $Z$, and $h$:

- $W, Z \rightarrow qq$: Use $m_J$, energy correlation function $D_2$ and $n_{trk}$.
- $Z, h \rightarrow bb$: Use $m_J(bb)$.

**Signal Regions:** Two categories: 4Q and 2B2Q

→ Every category splits to target the different final states of the signal processes.
Final State: Fully Hadronic

Background estimation:

- **Irreducible**: $VVV, ttX \rightarrow$ taken from MC.

- **Reducible**: Mainly from $Z(\nu\nu)+\text{jets}, W(\ell\nu)+\text{jets} \rightarrow$ Normalised in a CR with no lepton (0L)

$\rightarrow$ Validation done in regions with one lepton (1L) or one photon (1Y)

### Events

<table>
<thead>
<tr>
<th></th>
<th>Data</th>
<th>Total SM</th>
<th>W+jets</th>
<th>VV</th>
<th>Top</th>
<th>$\gamma+\text{jets}$</th>
<th>$\gamma$</th>
<th>V+$\gamma$</th>
<th>Other</th>
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</thead>
<tbody>
<tr>
<td><strong>ATLAS</strong> Preliminary $\sqrt{s}=13$ TeV, 139 fb$^{-1}$ Post-fit</td>
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### Significance

- VR1L-4Q
- VR1Y-4Q
- VR1L-2B2Q
- VR1Y-2B2Q

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SUSY searches in ATLAS 9/19
No significance excess above SM background is observed
Exclusion limits: $(\tilde{W}, \tilde{B}), (\tilde{H}, \tilde{B}), (\tilde{W}, \tilde{H}), (\tilde{H}, \tilde{W})$

\[ \begin{array}{c}
\mathcal{L}^{\tilde{B}}(\tilde{W}_i, \tilde{H}_i) \rightarrow \tilde{B}
\end{array} \]

\[ \begin{array}{c}
\mathcal{L}^{\tilde{W}}(\tilde{H}_i, \tilde{W}_i) \rightarrow \tilde{W}
\end{array} \]

\[ \begin{array}{c}
\mathcal{L}^{\tilde{H}}(\tilde{W}_i, \tilde{H}_i) \rightarrow \tilde{H}
\end{array} \]

\[ \begin{array}{c}
\mathcal{L}^{\tilde{B}}(\tilde{W}_i, \tilde{H}_i) \rightarrow \tilde{B}
\end{array} \]

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\mathcal{L}^{\tilde{W}}(\tilde{B}_i, \tilde{H}_i) \rightarrow \tilde{W}
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\[ \begin{array}{c}
\mathcal{L}^{\tilde{H}}(\tilde{B}_i, \tilde{W}_i) \rightarrow \tilde{H}
\end{array} \]
Exclusion limits: comparison with other searches

ATLAS Preliminary

June 2021

All limits at 95% CL

- Expected
- Observed

ATL-PHYS-PUB-2021-019
Exclusion limits: \((\tilde{H}, \tilde{G}), (\tilde{H}, \tilde{a})\)

\[ \begin{align*}
\tilde{H}, \tilde{G} & \quad \text{or} \quad \tilde{h} \tilde{G} \\
\tilde{H}, \tilde{a} & \quad \text{or} \quad \tilde{h} \tilde{a} \\
\tilde{H}, \tilde{a} & \quad : \quad \tilde{H}^\pm (\tilde{G}^\pm \text{ or } \tilde{h} \tilde{a})
\end{align*} \]

ATLAS Preliminary \(\sqrt{s}=13\,\text{TeV}, 139\,\text{fb}^{-1}\)
All limits at 95% CL

- Expected Limit \((\pm 1\,\sigma_{\text{exp}})\)
- Observed Limit \((\pm 1\,\sigma_{\text{SUSY}})\)
- Observed 95% CL

\[ \begin{align*}
&\text{Observed 95% CL} \\
&\text{arXiv:2103.11684 (4L, 139fb^{-1})} \\
&\text{arXiv:1806.04030 (multi-b, 36.1fb^{-1})}
\end{align*} \]

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SUSY searches in ATLAS 13/19
Searches for $\tilde{t}_1$ and $\tilde{b}_1$

ATLAS Preliminary

Limits at 95% CL

$\sqrt{s} = 8, 13$ TeV, 20.3-139 fb$^{-1}$

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Searches for $\tilde{g}$ and $\tilde{q}$

$\sqrt{s} = 13$ TeV, 36.1 - 139 fb$^{-1}$

**ATLAS Preliminary**

- $\tilde{g} \rightarrow q\tilde{\chi}_1^0$ 0 lep. [2010.14293]
- $\tilde{g} \rightarrow t\bar{t}\tilde{\chi}_1^0 \geq 3$ b-jets [CONF-2018-041]
- $\tilde{g} \rightarrow t\bar{t}\tilde{\chi}_1^0 \geq 3$ b-jets + $\geq 2$ lep. SS [CONF-2018-041, 1706.03731]
- $\tilde{g} \rightarrow qW\tilde{\chi}_1^0$ 0 lep. + 1 lep. [2010.14293, 2101.01629]
- $\tilde{g} \rightarrow qW\tilde{\chi}_1^0 \geq 7-12$ jets + 1 lep. + $\geq 2$ lep. SS [2008.06032, 1708.08232, 1909.08457]
- $\tilde{g} \rightarrow q(\ell\ell/\nu\nu)\tilde{\chi}_1^0$ via $\tilde{\nu}\tilde{\nu}$ 2 lep. OS SF + $\geq 3$ lep. [1805.11381, 1706.03731]
- $\tilde{g} \rightarrow q(\tau\tau/\tau\nu)\tilde{\chi}_1^0$ via $\tau/\nu$ $\geq 1\tau$ [1808.06358]
- $\tilde{g} \rightarrow q(\gamma/Z)\tilde{G}$ via $\tilde{\chi}_1^0 \geq 1\gamma$ [1802.03158]

Colours indicate different models

Observed limits at 95% CL

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$\sqrt{s} = 8-13$ TeV, 20.3 - 139 fb$^{-1}$

**ATLAS Preliminary**

- $\tilde{q} \rightarrow q\tilde{\chi}_1^0$ 0 lep. + mono-jet [2010.14293, 2102.10874]
- $\tilde{q} \rightarrow qW\tilde{\chi}_1^0$ 0 lep. + 1 lep. [2010.14293, 2101.01629]
- $\tilde{q}, \tilde{b}, \tilde{t} \rightarrow q(\ell/\nu)\tilde{G}$ via $\tilde{\chi}_1^0 \geq 2\gamma$ [1802.03158]
- $\tilde{q} \rightarrow qW\tilde{\chi}_1^0 \geq 7-11$ jets + $\geq 2$ lep. SS
- $\tilde{q} \rightarrow q(\ell\ell/\nu\nu)\tilde{\chi}_1^0$ via $\tilde{\nu}\tilde{\nu} \geq 2$ lep. [1507.05525]
- $\tilde{q} \rightarrow q(\tau\tau/\tau\nu)\tilde{\chi}_1^0$ via $\tau/\nu \geq 1\tau$

Colours indicate different models

Observed limits at 95% CL

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ATLAS Preliminary

\( \lambda''', \tilde{g} \rightarrow q\bar{q}\tilde{\chi}_0^0, \tilde{\chi}_1^0 \rightarrow q\bar{q}, \) RPV Multijet, SUSY-2016-22

\( \lambda''', \tilde{g} \rightarrow t\bar{t}\tilde{\chi}_0^0, \tilde{\chi}_1^0 \rightarrow \text{tbs}, \) RPV 1L+Jets, CONF-2021-007

\( \lambda'', \tilde{g} \rightarrow t\bar{t}\tilde{\chi}_0^0, \tilde{\chi}_1^0 \rightarrow u\bar{d}s, \) SS/3L, arXiv:1706.03731

\( \sqrt{s} = 13 \text{ TeV}, 36 - 139 \text{ fb}^{-1} \)

All limits at 95% CL

Observed Limit

Expected Limit

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SUSY searches in ATLAS
Parameters compatible with the muon g-2 anomaly
ATLAS SUSY searches cover a wide range of scenarios.

No excess above SM background has been observed.

Exclusion limits have been set for model dependent and model independent scenarios.

A good portion of parameter space is still unexplored!

*Waiting for more data from the LHC Run 3!*