INCLUSIVE SEARCHES FOR SQUARKS AND GLUINOS AT ATLAS

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on behalf of the ATLAS Collaboration
SUSY @ LHC

- Strong production: gluino pair, squark pair, gluino with associated squark
- Many possible decays => multiple search strategies:
  - Interpretation of these in both specific susy-breaking scenarios:
    - mSUGRA (minimal Supergravity)
    - NUHM (Non-Universal Higgs masses)
    - GMSB (Gauge Mediated Symmetry breaking)
    - GGM (General Gauge Mediation)
- And generic scenarios:
  - Simplified Models
  - phenomenological MSSM

What is important?
- Powerful discriminating variables
- Well-understood simulation
- Background under control
- Interpret results in multiple scenarios
### IN THIS TALK:

<table>
<thead>
<tr>
<th>Event Description</th>
<th>Reference</th>
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<tbody>
<tr>
<td>0 lepton, 2-6 jets, EtMiss</td>
<td>arXiv: 1405.7875 (submitted to JHEP)</td>
</tr>
<tr>
<td>0 lepton, 7-10 jets, EtMiss</td>
<td>arXiv: 1308.1841 (JHEP 10 (2013) 130)</td>
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<tr>
<td>0-1 lepton, 3 b-jets, EtMiss</td>
<td>ATLAS-CONF-2013-061</td>
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<td>1-2 lepton, 3-6 jets, EtMiss</td>
<td>ATLAS-CONF-2013-062</td>
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<tr>
<td>2 SS leptons / 3 leptons</td>
<td>arXiv: 1404.2500 (accepted by JHEP)</td>
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<tr>
<td>taus, jets, EtMiss</td>
<td>ATLAS-CONF-2013-026</td>
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<tr>
<td>diphoton, EtMiss</td>
<td>ATLAS-CONF-2014-001</td>
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<tr>
<td>multijets (RPV)</td>
<td>ATLAS-CONF-2013-091</td>
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</table>
SEARCH FOR SUSY: STRATEGY

SM BACKGROUND ESTIMATION - CONTROL REGIONS
(ttbar/t, W/Z+jets, Multi-jets, Diboson)

Check bkg estimate in validation regions (closer to signal regions then control regions)

Look for the excess in signal regions

MAIN BACKGROUNDS: (determination methods)

- (semi)data-driven using control regions kinematically close to signal regions
  - transfer factors (minimize systematics)
- fully data-driven:
  - jet smearing method
  - matrix method
  - templates

Interpretation:
Set model dependent / independent limits
Target: Large number of RPC models containing final states with jets and missing energy originating from the decays of \( \tilde{q} \) and \( \tilde{g} \).

- \( Z(\rightarrow \nu\nu) + \) jets bkg estimated using a sample of \( \gamma + \) jets events using a data-driven normalisation procedure.

- Multi-jets bkg estimated using data-driven technique (normalized using reversed \( \text{EtMiss}/m_{\text{eff}} \) or \( \text{EtMiss}/\sqrt{\text{HT}} \) cuts)

- Inclusive signal regions defined for increased jet multiplicity (2-6 jets) and with loose, medium and tight selections on \( m_{\text{eff}}(\text{incl}) \), \( \text{EtMiss}/m_{\text{eff}} \) or \( \text{EtMiss}/\sqrt{\text{HT}} \)

- Two dedicated SRs (2jW and 4jW) place additional requirements on the invariant masses of candidate W bosons decaying to hadrons \( \Rightarrow \) designed to improve sensitivity to models predicting \( \tilde{q}/\tilde{g} \) decays to W (via \( \tilde{\chi}^{\pm} \)), in case where \( \tilde{\chi}^{\pm} \) is nearly degenerate in mass with \( \tilde{q}/\tilde{g} \).
Lower limit of 1650 GeV for equal mass light-flavour squarks and gluinos is found for phenoMSSM models with a massless LSP. Squark masses below 850 GeV (440 GeV) are excluded, assuming mass degenerate (single light-flavour) squarks. Gluino masses below 1330 GeV are excluded in a simplified model with only gluinos and the lightest neutralino for a light LSP.
**Target:** High jet multiplicity scenarios from long decay chains ($\tilde{g} \rightarrow \tilde{t} \tilde{t}$, $\tilde{g} \rightarrow \tilde{q}$ (via $\tilde{\chi}^\pm$ or $\tilde{\chi}^\pm$ and $\tilde{\chi}^0_2$), $\tilde{g} \rightarrow \tilde{t} \tilde{t}$ (RPV))

Template method used to estimate background from mismeasured MET

2 streams of selection criteria:
- #jets + flavour (0,1,>=2 b-jets)
- #jets + composite jets’ mass

Composite (fat) jets are formed from reclustered anti-kt R=0.4 jets to R=1.0 jets. Mass of those jets used to isolate signal:

$$M_{\Sigma}^J = \Sigma m_j^{R=1.0}$$
\( g \rightarrow \tilde{t} \tilde{t} \) model: Gluino masses smaller than 1.1 TeV are excluded for neutralino masses below 350 GeV.
Target: various SUSY models where top or bottom quarks are produced in gluino decay chains

- Reducible bkg: $tt\bar{t}$ events in association with additional non-$b$ jets, $tt\bar{t}+W/Z$, single top, $W/Z$+heavy flavour jets; irreducible bkg: $tt\bar{t}+b/\bar{b}$, $tt\bar{t}+Z/h(Z/h\to bb)$

- Reducible bkg sources estimated simultaneously using the matrix method (MM) based on number of $b$-tagged and non $b$-tagged jets including efficiencies and mistag rates.
- MC used for irreducible bkg

<table>
<thead>
<tr>
<th>baseline selection: baseline lepton veto, $p_T^{3j} &gt; 90$ GeV, $E_T^{miss} &gt; 150$ GeV, $\geq 4$ jets with $p_T &gt; 30$ GeV, $\Delta R_{min} &gt; 0.5, E_T^{miss}/m^{jj}_{cut} &gt; 0.2$, $\geq 3 b$-jets with $p_T &gt; 30$ GeV</th>
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<tbody>
<tr>
<td>SR-01-4j-A $\geq 4$ $&gt; 30$ $&gt; 200$ $m^{jj}_{cut} &gt; 1000$</td>
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<tr>
<td>SR-01-4j-B $\geq 4$ $&gt; 50$ $&gt; 350$ $m^{jj}_{cut} &gt; 1100$</td>
</tr>
<tr>
<td>SR-01-4j-C $\geq 4$ $&gt; 50$ $&gt; 250$ $m^{jj}_{cut} &gt; 1300$</td>
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</tbody>
</table>

<table>
<thead>
<tr>
<th>baseline selection: $\geq 1$ signal lepton ($e, \mu$), $p_T^{3j} &gt; 90$ GeV, $E_T^{miss} &gt; 150$ GeV, $\geq 4$ jets with $p_T &gt; 30$ GeV, $\geq 3 b$-jets with $p_T &gt; 30$ GeV</th>
</tr>
</thead>
<tbody>
<tr>
<td>SR-1l-6j-A $\geq 6$ $&gt; 175$ $&gt; 140$ $&gt; 700$ $&gt; 5$</td>
</tr>
<tr>
<td>SR-1l-6j-B $\geq 6$ $&gt; 225$ $&gt; 140$ $&gt; 800$ $&gt; 5$</td>
</tr>
<tr>
<td>SR-1l-6j-C $\geq 6$ $&gt; 275$ $&gt; 160$ $&gt; 900$ $&gt; 5$</td>
</tr>
</tbody>
</table>
- $\tilde{g} \to \tilde{t}t$ model: gluino masses below 1340 GeV are excluded for $m(\text{LSP}) < 400$ GeV while neutralino masses below 620 GeV are excluded for $m(\text{gluino}) = 1000$ GeV
- $\tilde{g} \to \tilde{t}b$ model, gluino masses below 1300 GeV are excluded for $m(\text{LSP}) < 300$ GeV while neutralino masses below 580 GeV are excluded for $m(\text{gluino}) = 1100$ GeV.
**Target:** pair production of gluinos or squarks (assuming degenerate first and second generation squarks) considering three different simplified models: the “one-step” models, “two-step” models with sleptons and “two-step” models without sleptons.

- Signal regions defined to target both soft and hard leptons
- Fake leptons from matrix method

**- SOFT SINGLE LEPTON (optimized for compressed spectra)**
  - one electron or muon $10(6)\text{GeV} < p_T < 25 \text{ GeV}$
    - 3 jets ($\text{EtMiss} > 400 \text{ GeV}$) OR 5 jets ($\text{EtMiss} > 300 \text{ GeV}$)

**- HARD SINGLE LEPTON**
  - one electron or muon $p_T > 25 \text{ GeV}$
    - 3 jets ($\text{EtMiss} > 500 \text{ GeV}$) OR 5 jets ($\text{EtMiss} > 300 \text{ GeV}$) OR 6 jets ($\text{EtMiss} > 350 \text{ GeV}$)
Gluino mass up to 1.1-1.2 TeV excluded in the one-step and two-step gluino simplified models. First and second generation squark masses up to 700-750 GeV are also excluded in the one-step and two-step squark simplified models.
2 SAME SIGN LEPTONS OR 3 LEPTONS

Target: \( \tilde{g} \tilde{g} / \tilde{q} \tilde{q} / \tilde{g} \tilde{q} \) pairs production leading to same-sign or 3-lepton signatures when decaying to any final state that includes leptons;
- Scenarios with small mass differences between SUSY particles (compressed scenarios) or in RPV scenarios.

- very low background for same-sign lepton modes

- 3L signal regions increase sensitivity to longer cascades

- Data-driven estimation of charge-flip and fake lepton bkg.
Gluino-mediated top squark scenarios, favoured by naturalness arguments, are excluded for $m(gl) < [600–1000]$ GeV.
**Target:** GMSB, nGM (tuned version of GGM to avoid fine tuning in Higgs sector) models

- Signal regions with either 1 tau or at least 2 tau leptons
- Fake tau contribution estimated with data-driven method (ABCD)

<table>
<thead>
<tr>
<th>Signal cuts</th>
<th>1τ SR</th>
<th>2τ GMSB SR</th>
<th>2τ nGM SR</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>$m^{\tau_1}_T &gt; 140$ GeV</td>
<td>$m^{\tau_1}_T + m^{\tau_2}_T \geq 150$ GeV</td>
<td>$m^{\tau_1}_T + m^{\tau_2}_T \geq 250$ GeV</td>
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<tr>
<td></td>
<td>$H_T &gt; 800$ GeV</td>
<td>$H_T &gt; 900$ GeV</td>
<td>$H_T &gt; 600$ GeV</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>$N_{jet} \geq 4$</td>
</tr>
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</table>

The result of the 2τ analysis in an optimised signal region can be translated into a limit on the gluino mass of 1140 GeV, independent of the $\tilde{\tau}$ mass, provided the $\tilde{\tau}$ is the NLSP.
**Target:** GGM models ($\tilde{\chi}^0_1$ decay to photon and gravitino)

- All backgrounds except $Z\rightarrow\nu\nu + \gamma\gamma$ estimated from data.
- Bkgd largely jets/electrons faking photons
- Here focus on strong production signal regions

Under the GGM hypothesis, lower limits on the gluino masses of 1280 GeV are set for bino masses above 50 GeV.
**Target:** Gluino production through all possible $R$-parity violating branching fractions of gluino decays to various quark flavours (6-quark final states)

- Limits are also set for decay modes through an intermediary neutralino, which leads to 10-quark final states

- A single systematic uncertainty on the background yield is determined by comparing the background prediction to the data in a wide variety of control regions

Example: extrapolation of data events from the low-jet multiplicity (3J, 4J, 5J) control regions to $\geq 6$ jets signal regions

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6-quark model

10-quark model
SUMMARY

ATLAS SUSY Searches* - 95% CL Lower Limits
Status: Moriond 2014

\[ \int L dt = (4.6 - 22.9) \text{ fb}^{-1} \quad \sqrt{s} = 7, 8 \text{ TeV} \]

<table>
<thead>
<tr>
<th>Model</th>
<th>$e, \mu, \tau, \gamma$</th>
<th>Jets</th>
<th>$E_{T}^{\text{miss}}$</th>
<th>Mass limit</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>MSUGRA/CMS</td>
<td>0</td>
<td>2-6 jets</td>
<td>Yes</td>
<td>20.3</td>
<td>1.2 TeV</td>
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<tr>
<td>MSUGRA/CMS</td>
<td>0</td>
<td>2-6 jets</td>
<td>Yes</td>
<td>20.3</td>
<td>1.1 TeV</td>
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<tr>
<td>MSUGRA/CMS</td>
<td>0</td>
<td>2-6 jets</td>
<td>Yes</td>
<td>20.3</td>
<td>1.3 TeV</td>
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<tr>
<td>MSUGRA/CMS</td>
<td>0</td>
<td>2-6 jets</td>
<td>Yes</td>
<td>20.3</td>
<td>1.24 TeV</td>
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<tr>
<td>MSUGRA/CMS</td>
<td>0</td>
<td>2-6 jets</td>
<td>Yes</td>
<td>20.3</td>
<td>1.2 TeV</td>
</tr>
<tr>
<td>MSUGRA/CMS</td>
<td>0</td>
<td>2-6 jets</td>
<td>Yes</td>
<td>20.3</td>
<td>1.28 TeV</td>
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<tr>
<td>GMSB (f NLS)</td>
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<td>2-4 jets</td>
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<td>4.7</td>
<td>1.4 TeV</td>
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<tr>
<td>GMSB (f NLS)</td>
<td>2</td>
<td>2-4 jets</td>
<td>Yes</td>
<td>4.7</td>
<td>1.4 TeV</td>
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<tr>
<td>GMSB (f NLS)</td>
<td>2</td>
<td>2-4 jets</td>
<td>Yes</td>
<td>4.7</td>
<td>1.28 TeV</td>
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<tr>
<td>LSP</td>
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<td>mono-jet</td>
<td>Yes</td>
<td>10.5</td>
<td>0.5 (\text{ TeV})</td>
</tr>
</tbody>
</table>

Inclusive Searches

\[ \int L dt = (10.8 - 18.3) \text{ fb}^{-1} \quad \sqrt{s} = 7, 8 \text{ TeV} \]

Looking forward to Run 2 data!

No indications for SUSY particles in a large variety of search channels