SUSY searches with ATLAS
new results for ICHEP

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Executive summary

We haven't found it

let me elaborate on that...
scope of the talk

- Focusing on new results released for ICHEP, that cover a large fraction (but not all) of ATLAS SUSY searches.

- All with 13 to 15 fb-1 of 13 TeV data. Many thanks for the LHC for the fantastic performances!

- All results can be found at https://twiki.cern.ch/twiki/bin/view/AtlasPublic/SupersymmetryPublicResults
**A typical ATLAS susy search**

- Signal selection targeting a specific production/decay mode (simplified model)
- Optimized for best discovery significance in a single 1-bin selection (SR). To cover different mass hierarchies, this typically results in a few overlapping SRs for each final state.
- Background estimate:
  - Irreducible backgrounds estimated using control region (CR) data as a constraint and MC to extrapolate from CR to SR in a likelihood fit.
  - Reducible background (fake/non isolated leptons, $E_T^{\text{Miss}}$ from jet mismeasurement) from data.
  - Use only well modelled variable in CR $\Rightarrow$ SR extrapolations! Validation regions (VR) used to check the assumptions in the background estimate and the CR $\Rightarrow$ SR variable modelling.

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**Diagram Description**

- The diagram illustrates an analysis strategy with multiple control, validation, and signal regions. All regions are orthogonal.
- For each region, define one CR to derive mini-datas from data as a constraint and MC to extrapolate from CR to SR in a likelihood fit.
- The fit to data is based on statistically independent CRs and SRs, which ensures that they can be analyzed independently.
- The analysis strategy flow is schematically shown in Fig. 2.2.
- Through the fit to data, the observed signal is compared with the extrapolation. The extrapolation to signal is verified in the validation regions that lie in the extrapolation phase space.
- An underlying assumption has been made in the previous sections, notably that extrapolations over different kinematic variables used to define signal-enriched regions (s), and tested in validation regions (s). If the dominant background processes are estimated with Monte Carlo (MC) event counts in CR(s) are used to coherently normalize background estimates in all regions, no-extra assumptions in the background estimate and the CR $\Rightarrow$ SR variable modelling.

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**Additional Information**

- The analysis strategy and framework are optimized for best discovery significance in a single 1-bin selection (SR).
- To cover different mass hierarchies, this typically results in a few overlapping SRs for each final state.
- The fit to data is based on statistically independent CRs and SRs, which ensures that they can be analyzed independently.
- The analysis strategy flow is shown in Fig. 2.2.
gluinos and squark searches

- Gluino direct
- Gluino 1-step (W)
- Gluino 1-step (Z)
- Gluino 2-step
- Gluino via b
- Gluino via t
- Squark direct
- Squark 1-step
- Gluino GMSB
- Gluino RPV
No electron or muon, 2-6 jets, MET > 200 GeV. Two sets of selections with similar sensitivity:

- Effective mass ($\sum p_T^{\text{jets}} + \text{MET}$)
- RJigsaw variables: decompose an event assuming a decay topology; compute invisible momenta by minimizing each hemisphere mass; all momenta of decay tree available for selection (mass-sensitive scale variables, angles for compressed topologies)

Main backgrounds normalized in 1 lepton, gamma+jets, and multijet control regions.

No excess, limits improve by a few hundred GeV.
1 lepton + 2-6 jets + MET

- 1L+jets+MET, targeting 1-step decays with a variety of mass hierarchies
- MET triggered, one soft (6-35 GeV) or hard (> 35 GeV) lepton, 2 to 6 jets
- Dominant W+jets and ttbar background normalized to control regions with low mT and aplanarity
- No excess, improved limits
0/1 leptons+3 b-jets+MET

- 0/1L+3 bjets+MET, targeting gluino decays via stop/sbottom
- tt+HF normalized to control selection with same b-jet multiplicity, robust against mismodelings of heavy flavor cross section
- No excess, improved limits (expected improves by 200 GeV, observed only a bit because of small 2015 deficit and 2016 excess)
SS/3 leptons

- Majorana gluinos or long cascade decays can give SS leptons, low SM background.
- Relax or remove MET cut: compressed spectra and RPV targets.
- Backgrounds: data driven charge flips and fake leptons, MC based rare SM processes (with validation region).

**Table:**

<table>
<thead>
<tr>
<th>Signal region</th>
<th>N_{\text{signal leptons}}</th>
<th>N_{\text{B-jets}}</th>
<th>N_{\text{jets}}</th>
<th>P_{\text{F-jets}} [GeV]</th>
<th>E_{\text{T}}^{\text{miss}} [GeV]</th>
<th>m_{\text{eff}} [GeV]</th>
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<tbody>
<tr>
<td>SR3L1</td>
<td>≥ 3</td>
<td>0</td>
<td>≥ 4</td>
<td>40</td>
<td>&gt; 150</td>
<td>-</td>
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<tr>
<td>SR3L2</td>
<td>≥ 3</td>
<td>0</td>
<td>≥ 4</td>
<td>40</td>
<td>&gt; 200</td>
<td>&gt; 1500</td>
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<tr>
<td>SR0b1</td>
<td>≥ 2</td>
<td>0</td>
<td>≥ 6</td>
<td>25</td>
<td>&gt; 150</td>
<td>&gt; 500</td>
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<tr>
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<td>0</td>
<td>≥ 6</td>
<td>40</td>
<td>&gt; 150</td>
<td>&gt; 900</td>
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<tr>
<td>SR1b</td>
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<td>1</td>
<td>≥ 6</td>
<td>25</td>
<td>&gt; 200</td>
<td>&gt; 650</td>
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<tr>
<td>SR3b</td>
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<td>≥ 3</td>
<td>≥ 6</td>
<td>25</td>
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<td>&gt; 600</td>
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<tr>
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<td>≥ 4</td>
<td>50</td>
<td>-</td>
<td>&gt; 1200</td>
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<tr>
<td>SR3b-DD</td>
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<td>≥ 3</td>
<td>≥ 4</td>
<td>50</td>
<td>-</td>
<td>&gt; 1000</td>
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<tr>
<td>SR1b-GG</td>
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<td>≥ 1</td>
<td>≥ 6</td>
<td>50</td>
<td>-</td>
<td>&gt; 1800</td>
</tr>
</tbody>
</table>
targeting neutralino NSLP decaying to gravitino and photons, with non-100% branching ratios

Low background signature. $W\gamma$, $t\bar{t}\gamma$, $\gamma+jets$ normalized in control regions.

No excess, limits (400 GeV improvement over run1)
RPV multijet

- no MET makes search more difficult
- key observable is sum of large-R jet masses
- background mass template built in data control regions, MC only used in closure tests
- Limits between 1000-1550 GeV depending on model
**third generation squarks**

Targets of ICHEP analyses
- heavy stop to top neutralino (boosted top, hard MET)
- stealth stop diagonal (ISR+tt+MET, MET/pTISR peaks at mc/mt)
- 3-body stop decays (bWχ₀)
- stop via chargino to bWχ₀
- stop via stau to gravitino
- stop2 to stop1 Z
- stop RPV decays in two jets
- sbottom via chargino (shown before)
not updated: sbottom direct decays

Channels
- 0L+bjets+MET
- 1L+bjets+MET
- 2L+bjets+MET
- Z+3rd lepton+b-jets+MET
- taus+bjets+MET
- 2x2 jets

Run 1 summary plot (stop direct decays)
stop O L channel

- 6 sets of SR, for heavy stop (direct and 1-step decays), stealth stop and Dark Matter + ttbar in fully hadronic channel
- Stealth stop selection: Jigsaw reconstruction
- Heavy stop with boosted top categories. Combine TT,TW,T) for discovery p-value assuming benchmark point signal ratios between categories

<table>
<thead>
<tr>
<th>Variable</th>
<th>SRD1</th>
<th>SRD2</th>
<th>SRD3</th>
<th>SRD4</th>
<th>SRD5</th>
<th>SRD6</th>
<th>SRD7</th>
<th>SRD8</th>
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<tbody>
<tr>
<td>min $R_{ISR}$</td>
<td>0.25</td>
<td>0.30</td>
<td>0.35</td>
<td>0.40</td>
<td>0.45</td>
<td>0.50</td>
<td>0.55</td>
<td>0.60</td>
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<tr>
<td>max $R_{ISR}$</td>
<td>0.40</td>
<td>0.45</td>
<td>0.50</td>
<td>0.55</td>
<td>0.60</td>
<td>0.65</td>
<td>0.70</td>
<td>0.75</td>
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<td>b-tagged jets</td>
<td>≥ 2</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

$R_{ISR} \equiv \frac{E_{T}^{miss}}{p_{T}^{ISR}} \sim \frac{m_{\tilde{\chi}^{0}_{1}}}{m_{\tilde{t}}}$

combined p-value = 0.10
stop 1L channel

- targeting DM, heavy stop (direct and 1-step decays)
- 1 lepton, 4 jets, b-jets, high MT and dedicated selections for each target
- W+jets, ttbar, single top normalized in low MT control regions. ttZ normalized with ttgamma control region.
Some excess in three (overlapping) signal regions, designed for chargino decays (bC2x_dia), direct decays (SR1) and DM+ttbar (DMlow) with relatively low mass scales/splitting.

3.3 sigma local is the largest excess

keep calm and wait for more data
limits...
Dark Matter interpretations

- The stop 0L, 1L, 2L notes also contain selections targeting DM production in the same final state (with comparable sensitivities).

- On-shell mediator lighter than 350 GeV excluded for maximum $g=3.5$ coupling. Probing couplings down to 1.7 at lower mass.

![Diagram](image)

Scalar or pseudo scalar mediator (similar sensitivity)
3-lepton and 2-tau stop

- fix stop1 mass to $m(\chi^0)+m(t)$
- Look for stop2

<table>
<thead>
<tr>
<th>Var/Region</th>
<th>SRL</th>
<th>SRH</th>
<th>SRE</th>
</tr>
</thead>
<tbody>
<tr>
<td>$m_{t\ell}$ [GeV]</td>
<td>76.2-106.2</td>
<td>76.2-106.2</td>
<td>76.2-106.2</td>
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<tr>
<td>Leading lepton $p_T$ [GeV]</td>
<td>&gt; 40</td>
<td>&gt; 40</td>
<td>&gt; 40</td>
</tr>
<tr>
<td>Leading jet $p_T$ [GeV]</td>
<td>&gt; 60</td>
<td>&gt; 100</td>
<td>&gt; 80</td>
</tr>
<tr>
<td>$n_{b\text{-jets}}$</td>
<td>≥ 1</td>
<td>≥ 1</td>
<td>≥ 1</td>
</tr>
<tr>
<td>$n_{jets}$</td>
<td>≥ 6</td>
<td>≥ 5</td>
<td>≥ 5</td>
</tr>
<tr>
<td>$E_T^{\text{miss}}$ [GeV]</td>
<td>&gt; 100</td>
<td>&gt; 100</td>
<td>&gt; 100</td>
</tr>
<tr>
<td>$p_T^{\ell}$ [GeV]</td>
<td>–</td>
<td>&gt; 200</td>
<td>&gt; 100</td>
</tr>
</tbody>
</table>

- 2$\ell$, 2$b$, MET, using lep-had channel

<table>
<thead>
<tr>
<th>Variable</th>
<th>SR requirement</th>
</tr>
</thead>
<tbody>
<tr>
<td>$N_{b\text{-jet}}$</td>
<td>≥ 1</td>
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<tr>
<td>$E_T^{\text{miss}}$</td>
<td>&gt; GeV180</td>
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<td>$p_T(\tau)$</td>
<td>&gt; GeV70</td>
</tr>
<tr>
<td>$m_{T2}(\ell,\tau)$</td>
<td>&gt; GeV100</td>
</tr>
</tbody>
</table>

ATLAS Preliminary
stop RPV (2x2 jets)

Target stop decay in two jets (no b-tagging, flavor agnostic)

Select 4 jets with $p_T>120$ GeV, forms 2 pairs according to $\Delta R$, cut on mass asymmetry and angle with beam line of the two resonances

ABCD method for background estimate (multijet)

ATLAS-CONF-2016-084
4 lepton search

- Four (off-Z) leptons and $M_{eff} > 600/900$ GeV
- Clean and relatively model independent selection, sensitive to many BSM. Interpreted in the context of leptonic RPV decay of EWKinos.
- Fake background from data loose lepton selection, scaled with tight/loose probabilities
conclusions/outlook

- 13 ATLAS analysis targeting SUSY released for ICHEP significantly improving sensitivity
- More searches in preparation – stay tuned!
- Looking forward to more data
For every point, the SR with the best expected sensitivity is used. DM\_low, which has the largest excess, is the best SR only for the (10,1) point. For most low mass region, SR1 and bC2c\_diag which have also a mild excess are best.
SUSY signatures

- R-parity conservation, pair production with two invisible particles in the final state
- Strong production of squarks and gluinos: high cross section/mass scale, jets and missing ET.
- Third generation squarks: same as above, but lower cross section/mass scale, b-tagging, focused effort/analysis techniques.
- Electroweak production: low cross section/mass scale, typical (but not only) signature many leptons, missing ET, no jets.
- RPV signatures: no MET but high jet multiplicity (jets or leptons depending on couplings) and resonances.

Focus of 2015 paper was heavy squarks to profit from center of mass energy.

With more luminosity, we are getting sensitive to electroweak production and compressed spectra.