Electroweak SUSY searches in ATLAS and CMS

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Motivation

→ Still no direct hints of BSM physics in the LHC… but we are not done yet!

→ Strongly charged SUSY partners are preferred when they have similar masses to electroweak ones but current limits have pushed them beyond the TeV scale.

→ The electroweak sector could be the key in finding SUSY.

→ Spectacular effort with 2016 data already being surpassed by full Run II analysis: introducing new exciting strategies!

→ Nearly covered the TeV scale, but SUSY might be hiding in the most challenging regions yet.
Electroweak SUSY at LHC, a simplified overview

→ Typical treatment of SUSY modelling at LHC relies on “simplified” models.
→ A reduction of the complexity of full SUSY models let us focus on quite defined final state signatures for several possible parameter configurations assuming RPC:

Direct slepton pair production
Decoupled high mass gauginos

Decay chains involving several SUSY particles (i.e. gaugino through slepton)

Gaugino pair production
Decoupled high mass sleptons

ATLAS, 2τₜ
CMS, 2τₜ, 1τₜ
ATLAS, 2l

Check Mateusz talk in soft SUSY!
Slepton pair production
Highlight - Stau production

SUSY models with light staus can predict some cosmological observations (DM relic density).

Searches for direct stau pair production carried on by both the ATLAS (2$\tau_h$, 139 fb$^{-1}$) and CMS (both 2$\tau_h$, 1l + 1$\tau_h$, 77 fb$^{-1}$) collaborations.

- 1 light lepton + 1$\tau_h$ “simplifies” triggering and selection strategy. MisID of jet-$\rightarrow$\(\tau_h\) constitutes a dominant background, along with Z + jets production.

- Several BDT discriminants trained to define signal regions that optimally separate the stau signal from the backgrounds using high level kinematics.
Highlight - Stau production

A search performed both by ATLAS and CMS, heavily dominated by the misID $\tau_h$ in either W+jets or multijet production.

Similar selection criteria:

<table>
<thead>
<tr>
<th>CMS</th>
<th>ATLAS</th>
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</table>
| $\Delta \phi(\tau_h, \tau_h) > 1.5$ | $\Delta \phi(\tau_h, \tau_h) > 0.8$ | MJet
| $\Delta R(\tau_h, \tau_h) < 3.2$ | $p_T^{miss} > 75 \text{ GeV}$ |DY
| $p_T^{miss} > 50 \text{ GeV}$ | $m(\tau_h, \tau_h) > 120 \text{ GeV}$ |
| $N_{b \text{ tag}} = 0$ | $N_{b \text{ tag}} = 0$ | tt
| $M_{T2}(\tau_h, \tau_h) > 70 \text{ GeV}$ | |

And background estimation: using data driven techniques for the mis ID $\tau_h$ in multijet (ATLAS) and multijet/W (CMS)

ATLAS relies on 2 extra tight SRs (low/high mass) + background CRs for the signal extraction fit.

CMS uses an extended fit to regions defined by a three variable binning. Low $m_T$, low $m_{T2}$ act as "background regions".

Highlight - Stau production

Interpretations in both terms of left-handed only (here) and degenerated left/right (back up):

- ATLAS profits from higher statistics in the bulk $m_{\text{NLSP}} \sim 150$-300 GeV
- CMS usage of light leptons (lower $p_T$) provides higher sensitivity in the $m_{\text{NLSP}} \sim 100$-150 GeV.

Searches reach result complementary:

- ATLAS
- CMS

A thorough publication by ATLAS looking into final states with two leptons plus significant \( p_T^{\text{miss}} \).

Includes also sensitivity to chargino pair production (backup)

Updated results on chargino pair production (great improvements since Run II!).

\[ \mathbf{ATLAS}, \, 2\ell: \quad \text{Eur. Phys. J. C 80 (2020) 123} \]
Chargino+neutralino production
A very recent ATLAS search with 139 fb^{-1} worth of data focusing on three light lepton final states with a selection based on several high level observables.

Select three moderate $p_T$ (>25,20,10 GeV) light leptons with different topologies:

- **WZ-like**: OSSF pair with $m_{ll} \in [75,105]$ GeV.
- **WH-like**: OSSF pair with $m_{ll} \notin [75,105]$ GeV or no OSSF pair.

Careful estimation of the WZ background is needed: control regions included in the fit to constrain the WZ behavior. Validation regions used to check this approach outside the fitted regions:

Great overall agreement!
Highlight - 3l searches

- WZ-like regions categorized in ISR jet presence:
  - 0 jet: $2 m_T \times 4 p_T^{miss}$ bins.
  - Low $H_T$: $2 m_T \times 4 p_T^{miss}$ bins.
  - High $H_T$: $4 p_T^{miss}$ bins. High jet multiplicity means quite relevant (~30%) theoretical uncertainties.

- WH-like regions include a much more complex $t\bar{t}$-enhanced SM background.

- Similar signal region strategy to the on-Z case but with:
  - DSOF: selecting events with close-by leptons targeting the Higgs decay. Strong signal sensitivity, but also prone to high fake lepton background.
Current exclusion reach dominated by the more “traditional” analysis over the eRJR approach.

Both analysis statistically limited, but different sources of systematics provide different ways of evolution in the future. Stay tuned for the higher statistics cases!
Highlight - 2γ final states

→ A set of new results targeting the $H\rightarrow 2\gamma$ decay from ATLAS (139 fb$^{-1}$) and CMS (79 fb$^{-1}$).

→ Usually produced in association with other massive boson and neutralinos. Both collaborations look at multiple final states:

- ATLAS: $W\rightarrow l\nu$, $W\rightarrow qq'$
- CMS: $H\rightarrow bb$, inclusive
- CMS: $Z\rightarrow bb, Z\rightarrow ll$

→ Both signal extraction strategy relying on precise fits to analytic forms for the signal and background contributions.
**WHχχ (+ other new searches!)**

→ Quite interesting set of new interpretations in the WHχχ production.
→ Same model is targeted by 1l+2b and the 2γ searches:
→ Check more information in the back-up and public results.

Core of the sensitivity comes from high statistics given by the H → bb decay.
→ High purity of the H → 2γ decay provides a handle in the most compressed scenarios.
→ Theoretical uncertainties (Scale/QCD) still relevant for the reach of the H → 2γ searches.
→ 3l can be a handle in the mixed WZ/WH models (not here) → Depends on bino/higgsino mixing.

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ATLAS 1l2b arXiv:1909.0926 (sub. to EPJ C)


Conclusions

- Great quantity of new high quality results in SUSY searches during the last year (...)

- (... but still more to come forward with the statistical power of the Run II luminosity.

- Electroweak SUSY is a thriving field of research, pushing the boundaries of new physics.

- Stay tuned for new and exciting news!

- For the (over a coffee!) post-talk discussion, follow this zoom link during the break (same pass).
Thanks for your attention!
Back-Up
Stau pair production - $1\ell 1\tau_h$

Same BDT distributions as in slide 4 but for the 2017 year data:

Stau pair production-$2\tau_h$ ATLAS

Distributions in the high mass search region and validation regions

Stau pair production-$2\tau_h$ CMS

Search regions with data taken during the 2017 year.
Interpretations in terms of degenerated left/right staus:

- As in the left handed interpretation, both searches limited by:
  - MisID $\tau_h$ background: ATLAS $\sim$15% (multijet inclusive), CMS $\sim$5-50% (multijet/W+jets per region).
  - $\tau_h$ selection and identification criteria: ATLAS $\sim$10-30% (depend on process and region), CMS $\sim$5-50% (depends on process and region).
A search for SUSY targeting scenarios of heavy sleptons in which gauginos decay to a WH+2LSP final state. Select the leptonic W decay (1l) and the b quark decay of the Higgs (2b).

Extremely tight selection motivated by trigger requisites and reduction of W+jets/tt background:

\[ p_T^{miss} > 240 \text{ GeV} \quad N_{jets} = 2 \text{ or } 3 \]
\[ m_{bb} \in [100, 140] \text{ GeV} \]

Main backgrounds are estimated through several control regions included in the signal extraction fit (...).

And validated in additional intermediate validation regions used to check the final normalization/unc. results of the background fit.

Several signal sensitive regions defined with moderate (100-160GeV) to high (> 240GeV) \(m_T(l)\) criteria and binned on \(m_{CT}(b_1,b_2)\) for the signal extraction fit.

Aggregated (disc.) signal regions built with looser model-independent criteria, not included in the signal extraction.
ATLAS search with 139 fb\(^{-1}\) worth of data focusing on three light lepton final states.

Based on the Recursive Jigsaw Reconstruction (RJR) technique to “get back to” the chargino/neutralino kinematics from the laboratory frame measurements.

Use of high level variables to emulate the RJR quantities (eRJR) and select different configuration topologies (what is boosted and where):

In this example:

\[ m_{\text{eff}}^{3l} \sim \text{Scalar sum of } p_T^{\text{lep}} + p_T^{\text{miss}} \]

\[ H^{\text{boost}} \sim \text{Scalar sum of } p_T^{\text{lep}} + p_T^{\text{miss}} \text{ in the p-p frame} \]

(rec. \( p_T^{\text{miss}} \) from lepton p + mass constrain).

Boosting back to the p-p system using the 3l+\( \nu \) 4-momenta.

Signal models peaking at high value quotients: most of the original available energy retained by the leptonic system in the transverse plane.
3l searches (RJR)

Final event selection targeting two main topologies:

- Events in which leptons include most of the final system energy (SR low).
- Events with energetic ISR jets, well separated from $p_T^{miss}$ (SR ISR).

Some small excesses in the tails (integrated to define the signal regions) but not extremely significant.
2γ final states

→ Searches by both ATLAS (137 fb⁻¹) and CMS (77 fb⁻¹) in the double photon final state.

→ Selecting a pair of photons with high invariant mass $m_{\gamma\gamma} \in [105,160]$ GeV (> 100 GeV) for ATLAS (CMS) and -in consequence- high $p_T$ photons:

→ Classify phase space of VH+2LSP based on different decays of the other massive boson:

<table>
<thead>
<tr>
<th>Channel</th>
<th>ATLAS selection</th>
<th>CMS Selection</th>
<th>Target</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dileptonic</td>
<td>-</td>
<td>$N_{\ell} \geq 2;</td>
<td>m_{ll} - m_Z</td>
</tr>
<tr>
<td>Leptonic</td>
<td>$N_{\ell} \geq 1$</td>
<td>$N_{\ell} \geq 1$; !Dileptonic</td>
<td>WH$\chi_1^0\chi_1^0$(leptonic W)</td>
</tr>
<tr>
<td>Hadronic</td>
<td>$N_{jets} \geq 2; m_{jj} \in [40, 120]$ GeV; $N_{\ell} = 0$</td>
<td>-</td>
<td>WH$\chi_1^0\chi_1^0$(hadronic W)</td>
</tr>
<tr>
<td>b tagged</td>
<td>-</td>
<td>$N_b \geq 2; m_{bb} \in [60, 95]</td>
<td>[95, 140]$ GeV</td>
</tr>
<tr>
<td>“Rest”</td>
<td>!(Leptonic or hadronic)</td>
<td>!(Di)Leptonic or b tagged</td>
<td>All</td>
</tr>
</tbody>
</table>

Look at Mark’s talk for the sbottom interpretation!

2γ final states

Signal extraction follows quite a similar approach, fitting the 2γ invariant mass distribution to an analytic form including:

- Non resonant background: compare several functional forms, choose according to minimal bias.
- Resonant (Higgs) background: double sided crystal ball.
- Resonant signal: double sided crystal ball.

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**ATLAS**

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

**CMS**

Data, Non-resonant Bkg, Fitted Signal, SM Higgs, Total

- Signal plus background
- Total background
- Signal

77.5 fb$^{-1}$ (13 TeV)
Diphoton HH interpretation

Interpretations from both ATLAS and CMS in terms of gauge mediated symmetry breaking (GMSB). General assumption is near degenerate set of neutralinos that, effectively, can be summed up into lightest neutralino pair production (+soft non detected particles) which decay to near massless gravitinos:

CMS 2\gamma: JHEP 11 (2019) 109
ATLAS 2\gamma: arXiv:2004.10894 (sub. to JHEP)
A search for SUSY in dileptonic final states (off-Z, $m_\ell > 100$ GeV) performed with 139 fb$^{-1}$ of data by ATLAS.

Simple selection to avoid the top-enriched and Z+jets backgrounds:

$$N_{b \text{ tag}} = 0 \quad p_T^{miss} > 100 \text{ GeV}$$

Main background sources controlled in several control regions included in the signal extraction fit:

<table>
<thead>
<tr>
<th>Region</th>
<th>CR-WW</th>
<th>CR-VZ</th>
<th>CR-top</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lepton flavour</td>
<td>DF</td>
<td>SF</td>
<td>DF</td>
</tr>
<tr>
<td>$n_{h-h\text{-tagged}}$</td>
<td>0</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td>$n_{h\text{-non-h\text{-tagged}}}$</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>$m_{T2}$ [GeV]</td>
<td>$[60,65]$</td>
<td>$&gt; 120$</td>
<td>$&gt; 80$</td>
</tr>
<tr>
<td>$E_T^{miss}$ [GeV]</td>
<td>$[60,100]$</td>
<td>$&gt; 110$</td>
<td>$&gt; 110$</td>
</tr>
<tr>
<td>$E_T^{miss}$ significance</td>
<td>$[5,10]$</td>
<td>$&gt; 10$</td>
<td>$&gt; 10$</td>
</tr>
<tr>
<td>$m_{4\ell}$ [GeV]</td>
<td>$&gt; 100$</td>
<td>$[61.2,121.2]$</td>
<td>$&gt; 100$</td>
</tr>
</tbody>
</table>
Dilepton final states

Top enriched control region of the dilepton analysis and exclusion region in the chargino pair production decaying through sleptons model.
Dilepton final states

Interpretations performed for direct slepton pair production and direct chargino pair production with direct SM/slepton mediated (back-up) decays:

- Dominant source of uncertainty is data statistics, but several notable sources of systematics in terms of background normalization uncertainties: WW (3-7%), tt (3-8%) and jet energy scale (2-3%).