Search for electroweak SUSY at ATLAS and CMS

Moriond QCD 2022 - March 19th-26th

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INFN Sezione di Milano
Introduction

Search for Electroweak SUSY at LHC

Direct production of **sleptons**, leptons superpartners

- \( \tilde{u}, \tilde{c}, \tilde{\tau} \)
- \( \tilde{d}, \tilde{s}, \tilde{b} \)
- \( \tilde{e}^-, \tilde{\mu}^-, \tilde{\tau}^- \)
- \( \tilde{\nu}_e, \tilde{\nu}_\mu, \tilde{\nu}_\tau \)

**Masses are free parameters**

Direct production of **charginos** and **neutralino**, mixed states of W, Z e H bosons superpartners (different mixes are possible)

- \( \tilde{\chi}_1^\pm, \tilde{\chi}_2^\pm \)
- \( \tilde{\chi}_1^0, \tilde{\chi}_2^0, \tilde{\chi}_3^0, \tilde{\chi}_4^0 \)

**Small cross section** compared to strong production, portion of the phase space with **challenging signature** not explore yet

→ **using advanced analysis techniques to exploit full LHC Run 2 data**

Lightest neutralino is the lightest SUSY particles (LSP) in many models
**Outline**

**Highlights from recent results** by ATLAS and CMS  

**ATLAS:**
- charginos/neutralinos with 2 leptons and hadronic activity
- charginos and sleptons with 2 leptons (no hadronic activity) + mention of related SM cross section measurement for WW

**CMS:**
- stau production with all hadronic final state
- charginos/neutralinos with hadronic decays of WW/WZ/WH
- higgsinos decaying to two Higgs bosons

More EWK SUSY searches will be covered in the talks by Julia Goski (ATLAS) and Lisa Benato (CMS)
ATLAS results
Charginos/neutralinos with 2 leptons and jets

Signature: 2 leptons, at least 2 jets and missing transverse energy ($E_T^{miss}$)

Using kinematic variable to select the SUSY signal (cut-and-count strategy)

Events selection to target different supersymmetric particle mass

Data compatible with SM prediction → not observation of a signal is translate in limits on SUSY particles masses

New model! Gauge-mediated SUSY breaking

Gravitino is the LSP

Higgsinos

Neutralino is the LSP
Charginos/neutralinos with 2 leptons and jets

95% CL limits on SUSY particles masses

Exclusion as a function of the branching ratio of $\tilde{\chi}_1^0 \rightarrow h/Z + \tilde{G}$

Gravitino assumed to be massless

Large improvement compared to previous result
Charginos/sleptons with 2 leptons and no jets

- Signature is 2 leptons, no hadronic activity and large $E_T^{miss}$
- Region with large slepton and chargino mass excluded by previous searches
- **Now focusing on region with slepton-neutralino and chargino-neutralino mass difference of the order of W boson mass**
- Challenging signature, very similar to WW
- **Dedicated search strategy for each model**
Sleptons with 2 leptons and no jets

Considering only **smuon** and **selectron**

- **Data driven background estimate**, looking for excess in same flavor events compared to different flavor ones
- Data compatible with SM background
- Search relevant also in the contest of the **muon (g-2) measurement**, light smuon could explain the anomaly

[ATLAS-CONF-2022-006]
Charginos with 2 leptons and no jets

- Signature is both same flavor and different flavor leptons, different analysis technique used
- Using machine learning techniques for signal selection, boosted decision tree (BDT) with multiclass classification
- Data compatible with SM background
Cross-sections measurement of WW process in SUSY “control region” from 2 leptons and no jets search
→ kinematically similar to the search regions but enriched in WW

Motivation:
- improve background modelling for future searches
- produce constraints on new physics using the unfolded data distribution
CMS results
Staus search in all-hadronic final state

- **Hadronic decay of tau**
  → reconstructing **tau candidates** using deep neural network (CMS “DeepTau”)
- Tau candidates used to built kinematic variables for events selection
- **Data compatible with SM expectation**
- Largely improvement of the previous result that considered only massless LSP
Data compatible with SM prediction, new limits on SUSY particles masses

[CMS-SUS-21-002]
Chargino/neutralino decaying via WW/WZ/WH

Data compatible with SM prediction, new limits on SUSY particles masses

Comparison with ATLAS result from slide 5 for WZ:

\[ \text{CMS-SUS-21-002} \]
Chargino/neutralino decaying via WW/WZ/WH

**Signature:** hadronically decaying bosons and high $E_T^{\text{miss}}$

First result with fully hadronic signature for these models at CMS

- Machine learning algorithms to **identify hadronically-decaying W, Z and H bosons** reconstructed as large-radius jets
- Taggers to classify the large-radius jets:
  - **bb tagger** to identify $Z\rightarrow bb$ or $H\rightarrow bb$ decay
  - **W and V tagger** to identify jets consistent with a $W\rightarrow qq$ and $Z\rightarrow qq$

[CMS-SUS-21-002]
Chargino/neutralino decaying via WW/WZ/WH

Complementary to ATLAS result for low masses shown in slide 11 with 2 leptons signature [ATLAS-CONF-2022-006]

CMS Preliminary


pp → ± ± ± ± ± ± → NLO+NLL Exclusion
 Observed ± 1 σ

Expected ± 1, 2 σ

All limits at 95% CL

CMS-SUS-21-002
Higgsinos decaying via Higgs bosons

- **Higgsinos decaying to H boson and LSP** (neutralino or goldstino)
- Considering $H \rightarrow bb$ for both the H and large missing transverse momentum
- Targeting both events containing pairs of $H \rightarrow bb$ with resolved b-tagged jet and events with jets merged together in a wider jet

[arXiv:2201.04206]
Higgsinos decaying via Higgs bosons

Over-fluctuation in data compared to SM prediction

Small observed limit

Considering only massless Goldstino

Previous CMS result: excluded 230-770 GeV

Excluding 175-1025 GeV higgsino

[arXiv:2201.04206]
Conclusion

Searches for electroweak SUSY at LHC:

- **challenging scenarios** due to small production cross section
- exploiting large Run 2 dataset and using **new analysis techniques**

- Thank to these, ATLAS and CMS are **improving previous limits** and exploring portion of the phase space not covered before
- **Continuing to explore new ideas and improving our results!**
Art: Schinako
Back-up
List of ATLAS and CMS new results

**ATLAS:**

✔ charginos/neutralinos with 2 leptons and 2 jets [ATLAS-SUSY-2018-05]
✔ charginos and sleptons with 2 leptons and zero jets [ATLAS-CONF-2022-006]
✔ unfolding and cross section measurement of WW [ATLAS-CONF-2022-011]
  ◦ long-lived charginos/sleptons with dE/dx [ATLAS-SUSY-2018-42]
  ◦ long-lived charginos with disappearing track [ATLAS-SUSY-2018-19]
  ◦ charginos/neutralinos with full hadronic signature [ATLAS-SUSY-2018-41]
  ◦ charginos/neutralinos with 3 leptons [ATLAS-SUSY-2019-09]

CMS:

✔ stau with all hadronic final state [CMS-SUS-21-001]
✔ charginos/neutralinos with hadronic decaying WW/WZ/WH [CMS-SUS-21-002]
✔ higgsinos decaying to Higgs bosons [CMS-SUS-20-004]
  ◦ charginos/neutralinos decaying to WH with 1 lepton [CMS-SUS-20-003]
  ◦ charginos/neutralinos with multileptons [CMS-SUS-19-012]
  ◦ charginos/neutralinos with soft leptons [CMS-SUS-18-004]
Muon g-2 anomaly
Charginos/neutrinos with 2 leptons and jets

Recursive-Jigsaw Reconstruction decay trees (RJR)

Follow up un 36 ifb excess
Data compatible with SM prediction

<table>
<thead>
<tr>
<th></th>
<th>SR2\ell-Low-RJR</th>
<th>SR2\ell-ISR-RJR</th>
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<tbody>
<tr>
<td>Observed events</td>
<td>39</td>
<td>30</td>
</tr>
<tr>
<td>Total expected background events</td>
<td>42 ± 9</td>
<td>31 ± 9</td>
</tr>
<tr>
<td>Diboson events</td>
<td>10.6 ± 3.4</td>
<td>8.9 ± 2.5</td>
</tr>
<tr>
<td>Top events</td>
<td>3.5 ± 1.7</td>
<td>8.2 ± 2.3</td>
</tr>
<tr>
<td>Z/γ* + jets events</td>
<td>27 ± 8</td>
<td>12 ± 9</td>
</tr>
<tr>
<td>Other events</td>
<td>0.3^{+0.5}_{-0.3}</td>
<td>0.11 ± 0.04</td>
</tr>
</tbody>
</table>
Charginos with 2 leptons and no jets

- BDT trained on $p_T^\ell_1$, $p_T^\ell_2$, $E_T^{\text{miss}}$, $m_{T2}$, $m_{\ell\ell}$, $\Delta\phi_{\text{boost}}$, $\Delta\phi_{p_T^{\ell_1}, \ell_1}, \Delta\phi_{p_T^{\ell_2}, \ell_2}$, $\cos \theta^*_\ell\ell$ and $E_T^{\text{miss}}$ significance.
- Multi-classifier:
  - event → BDT
    - BDT-signal
    - BDT-top
    - BDT-VV
    - BDT-other
Sleptons with 2 leptons and no jets

Considering only smuon and selectron

- Flavor symmetric background estimated with different flavor events: WW, top and $Z \rightarrow \tau\tau$
- Other background estimated from Monte Carlo simulation

2 leptons of same flavor

[ATLAS-CONF-2022-006]