PROCEEDINGS OF SCIENCE

Searches for electroweak production of supersymmetric gauginos and sleptons with the ATLAS detector

Jeanette Miriam Lorenz[*†]
Ludwig-Maximilians-Universität München, Am Coloumbwall 1, D-85748 Garching, Germany
E-mail: jeanette.miriam.lorenz@cern.ch

Analyzing 36.1 fb^{-1} of proton-proton collision data at $\sqrt{s}$ = 13 TeV, delivered by the LHC and recorded by the ATLAS detector in 2015 and 2016 during Run 2, various SUSY searches for the electroweak production of gauginos and sleptons were pursued. More challenging than searches for strongly produced supersymmetric particles, many of these searches show their first results with data of Run 2. In particular, searches for higgsinos are able to reach sensitivities that surpass LEP limits for the first time using LHC data.

XXVI International Workshop on Deep-Inelastic Scattering and Related Subjects (DIS2018)
16-20 April 2018
Kobe, Japan

[*] Speaker.
[†] on behalf of the ATLAS Collaboration

PoS(DIS2018)080

1. Introduction

Supersymmetry (SUSY) is a well motivated theory beyond the Standard Model (SM), proposing supersymmetric partner particles to all existing SM particles. If realized in nature, SUSY could provide a solution to the hierarchy problem and could offer a candidate particle for Dark Matter.

Most searches for supersymmetric particles using LHC Run 2 data at $\sqrt{s}$ = 13 TeV have concentrated on the production of gluinos and squarks. Searches for gauginos and sleptons produced in electroweak production are more challenging, as the cross sections are considerably lower. Gauginos summarize the supersymmetric partners of the photon and the W-, Z- and higgs-bosons which mix to neutral mass eigenstates (neutralinos) and charged mass eigenstates (charginos). The production cross sections and the decay properties of charginos and neutralinos depend on the precise fraction of higgsino, bino and wino contributions.

Apart from lower cross sections, the potential signatures from decays of gauginos might also be more to difficult to analyze. Decays of charginos and neutralinos with a high higgsino component may result in so-called compressed mass hierarchies. In this case the mass difference between charginos and neutralinos is small and thus only low energetic SM particles, which are difficult to reconstruct, emerge from the decays. Improved reconstruction techniques allow to probe these challenging scenarios for the first time at the LHC.

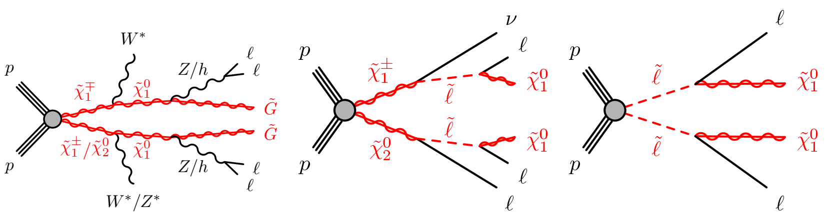

Figure 1: Different decay possibilities of pair-produced charginos and neutralinos in RPC SUSY.

Possible decays of gauginos and of sleptons are depicted in Figure 1. Often, these decays result in final states with many leptons. The lightest supersymmetric particle (LSP) is stable in R-parity conserving (RPC) SUSY and thus leaves the detector without signal, but results in missing transverse energy, $E_{\mathrm{T}}^{\mathrm{miss}}$. The rather clean signature of two or more leptons, no jets and $E_{\mathrm{T}}^{\mathrm{miss}}$ helps suppressing SM backgrounds. The remaining SM backgrounds are estimated using data-driven methods if they are reducible ('fakes'). Irreducible backgrounds like diboson production or $t\bar{t}+X$ processes are typically estimated by using Monte Carlo simulation scaled to data in control regions.

All searches presented in these proceedings use 36.1 fb^{-1} proton-proton collision data recorded by the ATLAS detector [1] in 2015 and 2016 at $\sqrt{s}$ = 13 TeV.

2. Search in signatures with two or three leptons

The *2- or 3-lepton* analysis [2] targets gaugino and slepton decays resulting in final states with at least two or three leptons (electron or muons, but no taus) and possibly jets, as well as $E_{\mathrm{T}}^{\mathrm{miss}}$.

To reach optimal sensitivity the analysis considers three different analysis categories. The category requiring two leptons and imposing a veto on jets ($2l0j$ channel) searches for the direct pair production of sleptons with decays $\tilde{l} \rightarrow l\tilde{\chi}_1^0$ and for the indirect production of sleptons in decays of charginos ($\tilde{\chi}_1^\pm \rightarrow \nu\tilde{l} \rightarrow l\tilde{\chi}_1^0$). Separation of the signal from the SM background is reached by e.g. criteria on the invariant mass between both leptons m_{ll} (Figure 2) and on the stransverse mass $m_{\mathrm{T2}} = \min_{\mathbf{q}_T}[\max(m_{\mathrm{T}}(\mathbf{p}_{\mathrm{T}}^{l1}, \mathbf{q}_{\mathrm{T}}), m_{\mathrm{T}}(\mathbf{p}_{\mathrm{T}}^{l2}, \mathbf{p}_{\mathrm{T}}^{\mathrm{miss}} - \mathbf{q}_{\mathrm{T}}))]$ with $m_{\mathrm{T}}(\mathbf{p}_{\mathrm{T}}, \mathbf{q}_{\mathrm{T}}) = \sqrt{2(p_{\mathrm{T}}q_{\mathrm{T}} - \mathbf{p}_{\mathrm{T}}\mathbf{q}_{\mathrm{T}})}$, resulting in multiple exclusive signal regions, which are combined statistically.

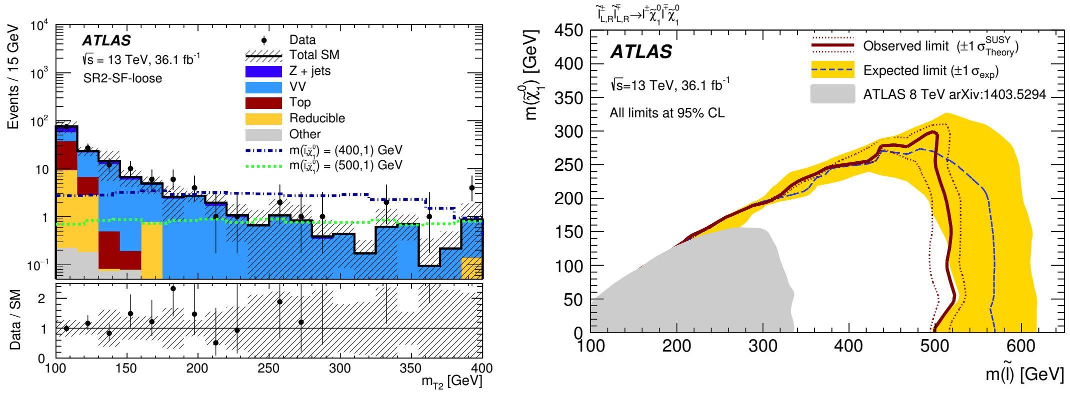

Figure 2: m_{ll} distribution for one of the signal regions in the $2l0j$ channels (left) and the exclusion limits at 95 % CL on the direct pair production of sleptons (right) [2].

The second category addresses the pair-production of charginos and neutralinos which decay into the LSP via emission of W and Z-bosons ($2l2j$ channel). These decays may result in final states with two isolated leptons from a Z-boson decay and jets from a W-boson decay. Sensitivity is reached by imposing additional criteria on various kinematic variables, including $E_{\mathrm{T}}^{\mathrm{miss}}$ and m_{T2}.

The third category considers final states with three isolated leptons ($3l$) and targets decays of charginos and neutralinos via intermediate sleptons or gauge bosons. Criteria on the p_{T} of the lowest energetic lepton are used in addition to other kinematic variables to define signal regions.

None of the categories observes a significant excess. Limits at 95 % CL are derived, e.g. on direct slepton production (Figure 2), excluding slepton masses up to 500 GeV assuming three mass-degenerate generations of sleptons, or on chargino and neutralino masses with gauge-mediated decays reaching up to 580 GeV in specific simplified models.

3. Search in signatures with four leptons

The *4-lepton analysis* [3] targets both supersymmetric models with R-parity conservation and violation (RPV). In RPV models the lightest supersymmetric particle (in this case the $\tilde{\chi}_1^0$) decays to SM particles. Consequently, decays of charginos and neutralinos will result in busy final states that can show a high lepton multiplicity. Such final states can also be obtained in RPC models as displayed in Figure 1, left. In this general gauge-mediated model (GGM), the pair-produced $\tilde{\chi}_1^\pm/\tilde{\chi}_2^0$ are higgsino-like and thus the mass difference between the $\tilde{\chi}_1^\pm/\tilde{\chi}_2^0$ and the $\tilde{\chi}_1^0$ is small. Decay products of this step are too soft to be reconstructed. However, in the decay of the $\tilde{\chi}_1^0$ to the gravitino ($\tilde{G}$), Z and h bosons are emitted which may result in a final state with four leptons.

Different signal regions are defined requiring at least four leptons with zero, one or two hadronically decaying taus. Requiring the presence of four leptons leaves little data statistics for further selection criteria. Thus, the analysis only requires a further cut on the $E_{\mathrm{T}}^{\mathrm{miss}}$ or $m_{\mathrm{eff}} = \sum p_{\mathrm{T}}^{l} + \sum p_{\mathrm{T}}^{\mathrm{jets}} + E_{\mathrm{T}}^{\mathrm{miss}}$. Depending on the signal region, a veto on Z bosons is imposed or not. Important backgrounds are the ZZ diboson background, $t\bar{t}+Z$ production and fakes. No significant excess is observed in any of the signal regions, although one of the two signal regions targeting the GGM model features a small excess of about 2.3σ, see Figure 3. Consequently, the observed limit in this model, shown in Figure 3, is weaker than the expected one and excludes mostly Z-dominated decays for $\tilde{\chi}_1^{\pm}/\tilde{\chi}_2^0$ masses up to 295 GeV.

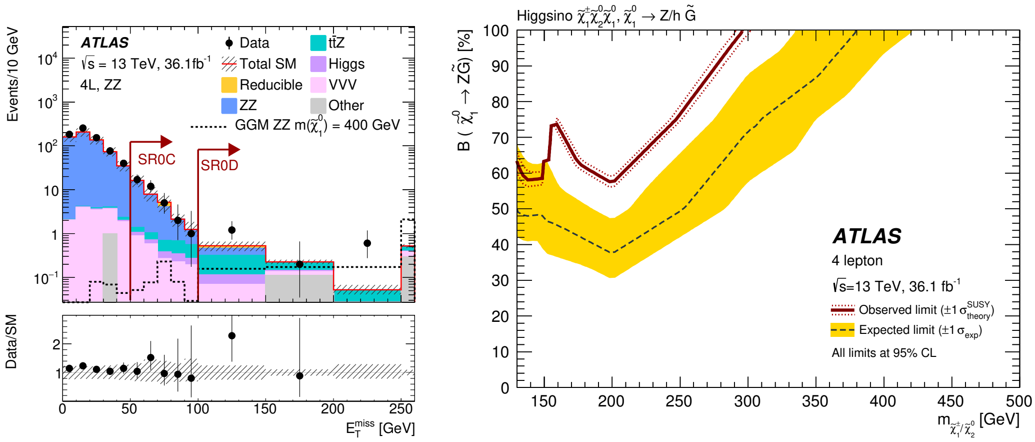

Figure 3: Yields (left) in the two GGM signal regions and the corresponding limits (right) [3].

4. Searches for higgsinos

Searches for light higgsinos are well motivated by naturalness arguments. Experimentally, it is challenging to detect the low-energetic particles emitted in decays of higgsino-dominated charginos and neutralinos with small mass differences between $\tilde{\chi}_1^{\pm}/\tilde{\chi}_2^0$ and $\tilde{\chi}_1^0$. Example diagrams are shown in Figure 4. In the first scenario, which is motivated by GMSB SUSY, the low-energetic particles from transitions between $\tilde{\chi}_i^{\pm}$ and $\tilde{\chi}_j^0$ cannot be reconstructed (and are thus not shown in Figure 4, left), instead analyses exploit the high-energetic particles emerging from decays of $\tilde{H}$ to $\tilde{G}$. In this particular case, the decay products include h and Z bosons which is exploited by the *4b* analysis [4].

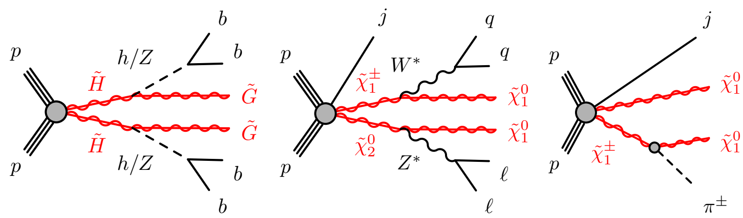

Figure 4: Different models involving higgsinos pair production: a GMSB model (left), a model resulting in low p_{T} leptons (middle) and a model with a ultra-compressed spectrum and a disappearing track (right).

Requring a fully hadronic signature, a good separation from the high hadronic background needs to be ensured. Two different sets of signal regions are defined, either targeting a low mass of the higgsino and requesting low $E_{\mathrm{T}}^{\mathrm{miss}}$ or a high mass of the higgsinos and requiring high $E_{\mathrm{T}}^{\mathrm{miss}}$. Both of them require the presence of at least four jets, among these at least three b-tagged jets. The main discriminating variable between signal and backgrounds is the m_{eff}. No significant excess over the background expectation was found, and higgsino masses between 130 and 230 GeV and between 290 and 880 GeV can be excluded at 95 % CL, see Figure 5.

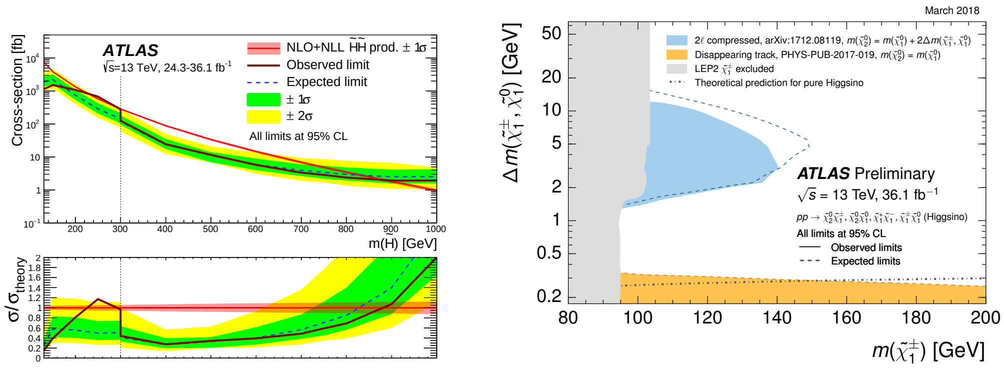

Figure 5: Limits at 95 % CL on the higgsino mass obtained by the *4b* analysis [4] (left). Limits on the higgsino mass obtained by the *soft 2-lepton* analysis [5] and the *disappearing track analysis* [6] (right).

In the second scenario, analyses reconstruct the low energetic decay products of chargino and neutralino decays (compressed scenario). The *soft 2-lepton* [5] analysis searches both for higgsino and slepton pair production, e.g. the model shown in Figure 4 in the middle, in signatures with two leptons (electrons or muons) with a low p_{T} and an additional jet from initial state radiation. In case of higgsino pair production the signal shows very low m_{ll} values, as shown in Figure 6. Various signal regions with different requirements on m_{ll} between 1 and 60 GeV are defined. For slepton pair-production, signal regions binned in m_{T2} provide an optimal sensitivity. Requiring very low p_{T} leptons in the signal regions enhances the fake background which is estimated by a fake factor method. The analysis does not observe a significant excess in any of the signal regions. Limits are set on Higgsino pair production (Figure 5) and on slepton pair-production (Figure 6). Higgsino masses up to 130 GeV and slepton masses up to 180 GeV are excluded in certain scenarios.

The third scenario considers the possibility that the mass difference between $\tilde{\chi}_i^{\pm}$ and $\tilde{\chi}_j^0$ is as small as 300 MeV (ultra-compressed scenario) so that any decay products are too low-energetic to be detected. Instead, the signature consists of a disappearing track from a decay of a $\tilde{\chi}_1^{\pm}$ into a $\tilde{\chi}_1^0$ and a very low-energetic pion which does not leave a track as shown in Figure 7. The addition of the insertable b-layer during the shut-down between LHC Run 1 and 2 allows the reconstruction of tracks down to a length of 12 cm. The *disappearing track* analysis [6] exploits this to reconstruct so-called pixel-only tracklets. Seeing no significant excess, the analysis sets limits on the higgsino mass as shown in Figure 5, surpassing – together with the *soft 2-lepton* analysis – the LEP limits on similar scenarios for the first time at the LHC.

5. Conclusions

Searches for gauginos and sleptons are more challenging than searches for strongly produced

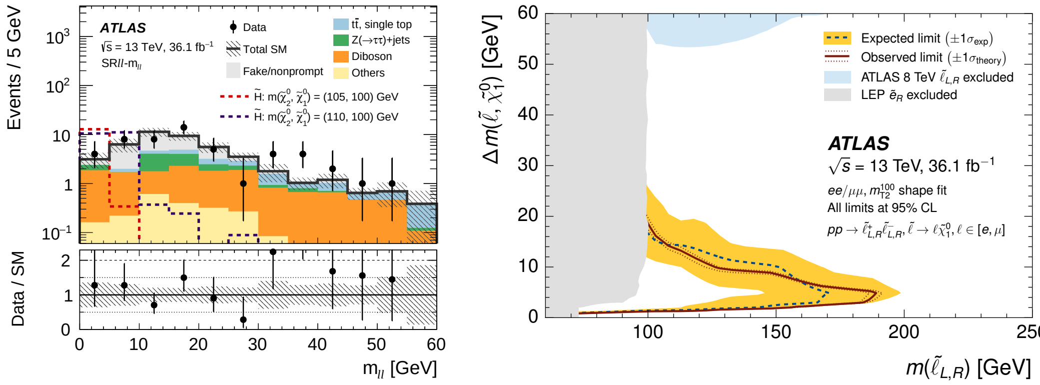

Figure 6: $m_{\rm ll}$ distribution (left) in the *soft 2-lepton* analysis, where the signal is peaking at lower values. Limits on slepton pair-production (right) as derived from the slepton signal regions [5].

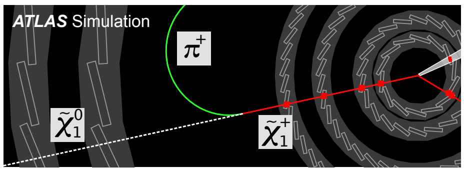

Figure 7: Sketch of the chargino decay resulting in a disappearing track and a low energetic pion [6].

supersymmetric particles due to the lower cross sections, the more complicated mixing patterns and the sometimes extremely compressed mass hierarchies. First searches using LHC Run 2 data at the ATLAS detector show an excellent sensitivity, albeit not yet seeing any significant deviation from SM expectations. Limits on the challenging Higgsino scenarios are set using improved reconstruction techniques on low $p_{\rm T}$ leptons and the insertable b-layer newly installed in the detector.

References

[1] ATLAS Collaboration, *The ATLAS Experiment at the CERN Large Hadron Collider*, **JINST** 3 S08003 (2008).

[2] ATLAS Collaboration, *Search for electroweak production of supersymmetric particles in final states with two or three leptons at $\sqrt{s}$=13TeV with the ATLAS detector*, `arXiv:1803.02762 [hep-ex]`.

[3] ATLAS Collaboration, *Search for supersymmetry in events with four or more leptons in $\sqrt{s}$=13 TeV pp collisions with ATLAS*, `arXiv:1804.03602 [hep-ex]`.

[4] ATLAS Collaboration, *Search for higgsino pair production in the hh topology in final states with $\geq$ 3b-jets using the ATLAS detector in $\sqrt{s}$ =13 TeV pp collisions*, `arXiv:1806.04030 [hep-ex]`.

[5] ATLAS Collaboration, *Search for electroweak production of supersymmetric states in scenarios with compressed mass spectra at $\sqrt{s}$=13 TeV with the ATLAS detector*, Phys. Rev. D 97 (2018) 052010.

[6] ATLAS Collaboration, *Search for long-lived charginos based on a disappearing-track signature in pp collisions at $\sqrt{s}$ = 13 TeV with the ATLAS detector*, JHEP 06 (2018) 022.