Available online at www.sciencedirect.com

ScienceDirect

Nuclear and Particle Physics Proceedings 273–275 (2016) 570–576

www.elsevier.com/locate/nppp

Searches for electroweak production of supersymmetric charginos, neutralinos and sleptons with the ATLAS detector

Andrée Robichaud-Véronneau[a]

[a] *On behalf of the ATLAS Collaboration*
McGill University - Department of Physics
3600 University Street, Montréal, Québec, H3A 2T8

Abstract

Many supersymmetry models feature charginos, neutralinos and also sleptons with masses less than a few hundred GeV. These can give rise to direct pair production rates at the LHC that can be observed in the data sample recorded by the ATLAS detector. This article presents results from searches for charginos, neutralinos and slepton production in final state events characterized by the presence of leptons, missing transverse momentum and possibly jets.

Keywords: electroweak, chargino, neutralino, slepton, supersymmetry

1. Introduction

Supersymmetry (SUSY) constitutes a proposed solution to the shortcomings of the Standard Model (SM) at the TeV scale. It introduces a space-time symmetry that predicts the existence of a superpartner for each SM particle with a spin differing by ½. In R-parity conserving models, the SUSY particles are produced in pairs and the lightest supersymmetric particle (LSP) is a stable dark matter candidate.

Charginos ($\tilde{\chi}^{\pm}_{1,2}$) and neutralinos ($\tilde{\chi}^{0}_{1,2,3,4}$) are mass eigenstates formed by the superposition of the higgsino, wino and bino fields, which are superpartners of the SM Higgs and electroweak bosons. They are collectively referred to as electroweakinos, classified by their index with increasing mass. The superpartners of the SM leptons are known as the sleptons ($\tilde{\ell}$). Electroweakinos and sleptons form the sparticle content of the electroweak production in SUSY. Naturalness arguments suggests that the electroweakinos should have masses of the order of 100 GeV and therefore should be accessible at LHC energies.

Results for searches for direct production of electroweakinos and sleptons using the ATLAS detector [1] at the LHC are presented here. Benchmark searches are used to look for a variety of decays, involving electroweakinos decaying through SM bosons ($W/Z/h$) or sleptons. Specific searches are designed to look for electroweakinos decay through a Higgs boson. Finally, searches aiming at the production of electroweakinos in a General Gauge Mediation framework are presented.

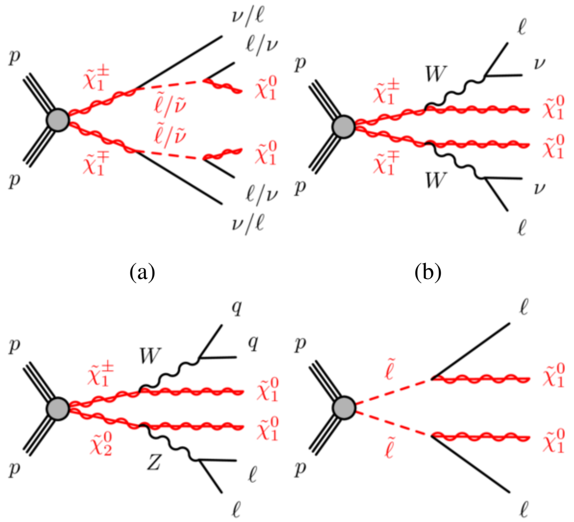
2. Benchmark searches

In the search for electroweak production, SUSY simplified models sharing common features are used throughout all the analyses presented in this section: the $\tilde{\chi}^{0}_{1}$ is the LSP and is of pure bino nature, while the $\tilde{\chi}^{\pm}_{1}$ and $\tilde{\chi}^{0}_{2}$ are mass degenerate and are pure wino.

Four searches, classified by the number of leptons in their signature (2, 3, ≥4), form the benchmark searches used to target a large range of charginos, neutralinos and sleptons decays. The 2-lepton search, as shown in Fig. 1, targets the $\tilde{\chi}^{\pm}_{1}$-$\tilde{\chi}^{\mp}_{1}$ and $\tilde{\chi}^{\pm}_{1}$-$\tilde{\chi}^{0}_{2}$ production decaying to diboson (WW/WZ) which decay semi-leptonically ($WW \to \ell\nu\ell\nu$ and $WZ \to qq\ell\ell$), as well as $\tilde{\chi}^{\pm}_{1}$-$\tilde{\chi}^{\mp}_{1}$ decaying

Email address: andree.robichaud-veronneau@cern.ch (Andrée Robichaud-Véronneau)

http://dx.doi.org/10.1016/j.nuclphysbps.2015.09.085
2405-6014/



(a) (b) (c) (d)

Figure 1: Direct production of SUSY electroweak particles targetted by 2-lepton search [2].

through intermediate sleptons and direct slepton production [2]. In this search, the leptons are electrons and muons only.

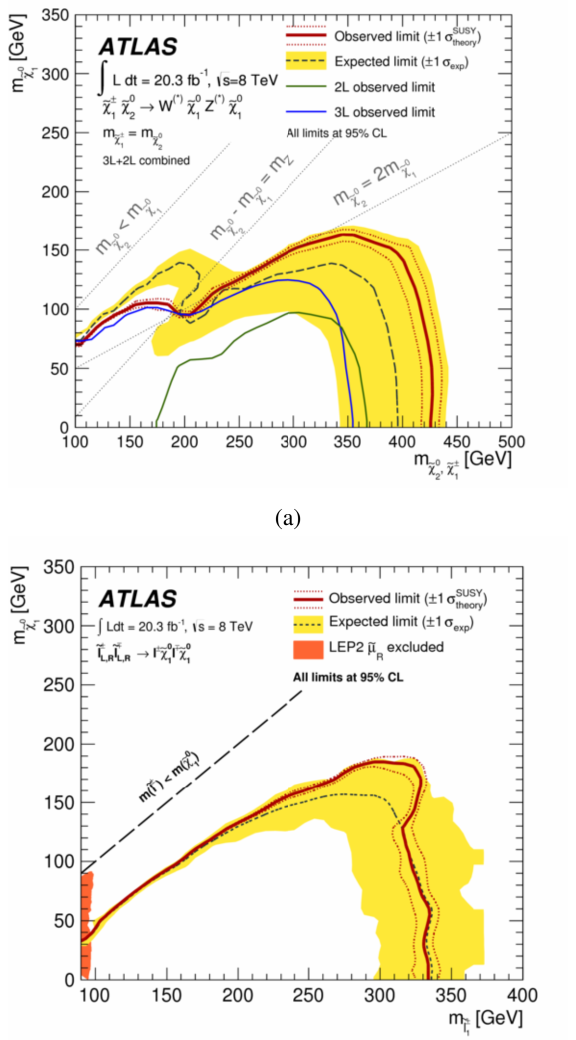
Using the m_{T2} and $E_{\mathrm{T}}^{\mathrm{miss,rel}}$ variables,

$$m_{\mathrm{T2}} = \min_{q_{\mathrm{T}}}[\max(m_{\mathrm{T}}(p_{\mathrm{T}}^{\ell 1}, q_{\mathrm{T}}), m_{\mathrm{T}}(p_{\mathrm{T}}^{\ell 2}, p_{\mathrm{T}}^{miss} - q_{\mathrm{T}}))],$$

$$E_{\mathrm{T}}^{\mathrm{miss,rel}} = \begin{cases} E_{\mathrm{T}}^{\mathrm{miss}} & \text{if } \Delta\phi_{\ell,j} \geq \pi/2 \\ E_{\mathrm{T}}^{\mathrm{miss}} \times \sin\Delta\phi_{\ell,j} & \text{if } \Delta\phi_{\ell,j} < \pi/2 \end{cases},$$

where $\Delta\phi_{\ell,j}$ is the azimuthal angle between the direction of $E_{\mathrm{T}}^{\mathrm{miss}}$ and that of the nearest lepton or central jet, this search can target sleptons decays (intermediate or direct). Seven signal regions (SR) are defined using cuts on m_{T2}, $m_{\ell\ell}$, $E_{\mathrm{T}}^{\mathrm{miss,rel}}$, and lepton flavour. A veto on Z production using an $m_{\ell\ell}$ window cut is applies to same-flavour channels only. A specific SR is defined to target the Z+jets channel. Dominant backgrounds for this search are WW and top (ZV) production in opposite flavour (same flavour) channel. Systematic uncertainties are dominated by the Monte Carlo (MC) modelling. No excess compared to the SM expectations is observed and limits are set, in particular for simplified models of $\tilde{\chi}_1^{\pm}$-$\tilde{\chi}_2^0$ and $\tilde{\ell}_{\mathrm{L,R}}$-$\tilde{\ell}_{\mathrm{L,R}}$, as shown in Fig. 2.

A new dedicated search using the 2012 ATLAS dataset is optimised for signatures with 2-τ decaying hadronically [3], as shown in Fig. 3. The dominant backgrounds are processes involving τ or hadronic



(a)

(b)

Figure 2: Exclusion limits for (a) $\tilde{\chi}_1^{\pm}$-$\tilde{\chi}_2^0$ production from the combination of the 2 and 3-lepton searches and for (b) slepton production obtained by the 2-lepton search [2].

production, such as $Z(\to\tau\tau)$+jets, QCD multijets and W+jets.

A data-driven method is used to determine the QCD multijet background since the τ misidentification rate from jets is poorly modeled in MC. Three control regions (CR) are defined around each SR in a plane of two uncorrelated discriminating variable (one kinematic variable and the τ identification variable) and are used to determine transfer factors (TF) to estimate the amount of background events in the SR. Fig. 4a illustrates how

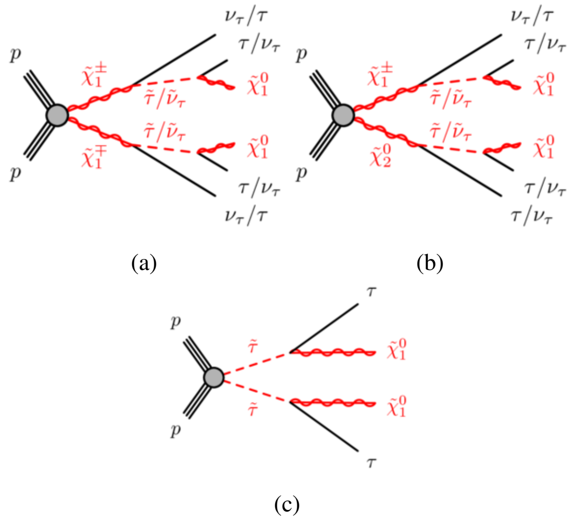


Figure 3: Direct production of SUSY electroweak particles targetted by 2-τ search [3].

the TF are obtained and applied. Four SRs are used (one for each electroweakino production, and two for the direct $\tilde{\tau}$ production in different mass ranges), each using their particular kinematic variable in the TF plane. For example, for the SR aiming at direct $\tilde{\tau}$ production with high mass (labelled SR-DS-highMass), the effective mass is used and its distribution is shown in Fig. 4b.

Since no significant departure from the SM prediction is observed, limits are set on $\tilde{\tau}_L$ production cross-section (see Fig. 5c) as well as on simplified models, shown in Fig. 5a for $\tilde{\chi}_1^{\pm}$ production and in Fig. 5b for combined $\tilde{\chi}$ production.

Production of $\tilde{\chi}_1^{\pm}$-$\tilde{\chi}_2^0$ decaying through WZ decaying leptonically or through sleptons is targetted by a 3-lepton search [4]. Intermediate sleptons could be $\tilde{e}$, $\tilde{\mu}$ or $\tilde{\tau}$, as shown in Fig. 6. The event selection used to target these decays requires that at least one of the three requested leptons be an e or a μ. Five SRs are then defined, each for a specific combination of flavours and charges of the final state leptons. One SR targetted at e/μ signatures only, called $SR\tau 0a$, is further subdivided into 20 bins of $m_{\ell\ell}$ and m_{T}, hence performing a 2D scan in these variables. The $m_{\ell\ell}$ quantity in this case is computed from one pair of leptons of the same flavour and opposite sign (SFOS). The transverse mass m_{T} is defined as:

$$m_{\mathrm{T}} = \sqrt{2p_{\mathrm{T}}^{\ell}E_{\mathrm{T}}^{\mathrm{miss}} - 2\vec{p}_{\mathrm{T}}^{\,\ell} \cdot \vec{E}_{\mathrm{T}}^{\mathrm{miss}}}.$$

The backgrounds to this search are composed of SM diboson production and reducible backgrounds, such as

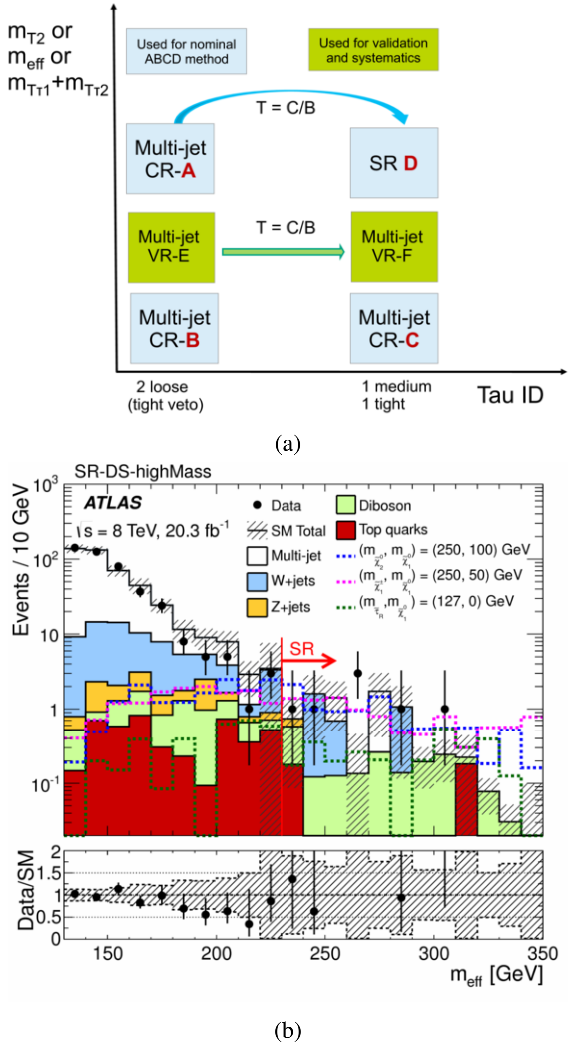
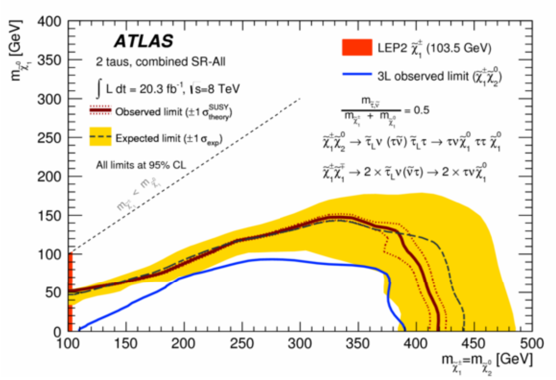


Figure 4: (a) Signal, Control and Validation Regions definition and (b) effective mass distribution in the SR-DS-highMass region for the 2-τ search [3].

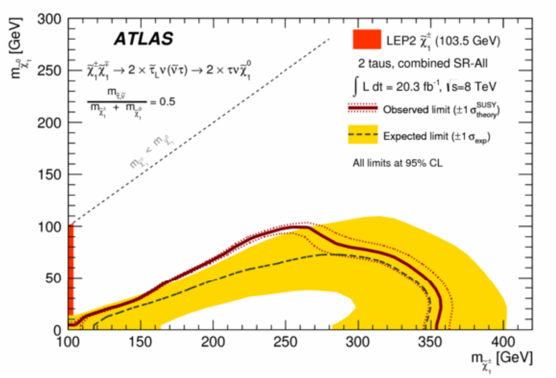
W+jets and $t\bar{t}$. Since no significant excess is found in data events over the SM prediction, exclusion limits are set in simplified models for for $\tilde{\ell}_L$ in Fig. 7a and for $\tilde{\tau}_L$ production in Fig. 7b.

The last benchmark search looks for production mechanisms of electroweakinos involving their decay into four or more leptons [5]. In this search the production of $\tilde{\chi}_2^0$-$\tilde{\chi}_3^0$ is considered, with intermediate decays to either sleptons or ZZ, both decaying fully leptonically, as shown in Fig. 8. Events are classified according to the light lepton flavour content in nine SRs. A Z veto or window is applied on these SRs to reject or target the intermediate Z decays using the invariant mass of at least of pair of SFOS leptons.

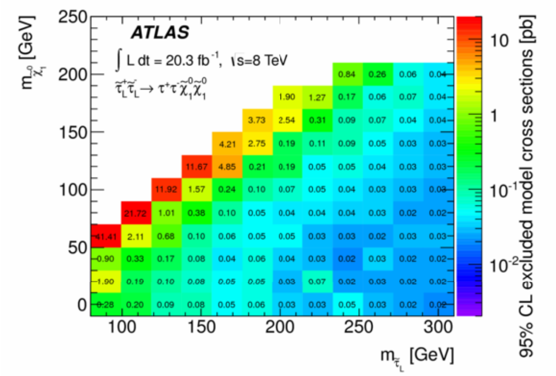
In the absence of any departure from the SM prediction, exclusion limits are obtained for the simplified models corresponding to the three production diagrams. A selection of results are shown in Fig. 9. The exclusion limit for right-handed sleptons (Fig. 9a) shows excellent



(a)

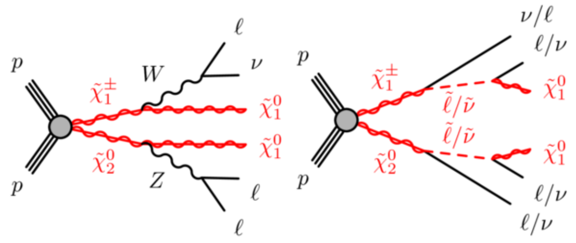


(b)



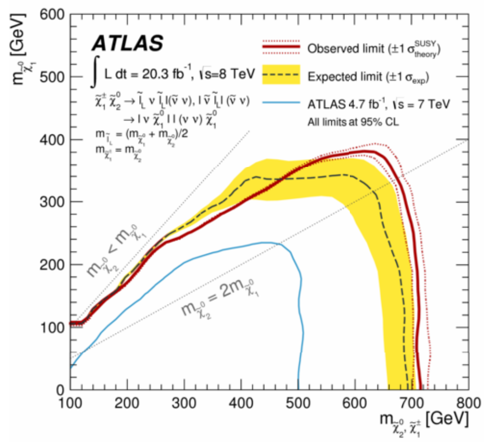
(c)

Figure 5: Exclusion limits for (a) $\tilde{\mathcal{X}}_1^\pm$-$\tilde{\mathcal{X}}_1^\pm$ and (b) $\tilde{\mathcal{X}}$-$\tilde{\mathcal{X}}$ production, as well as (c) $\tilde{\tau}_L$-$\tilde{\tau}_L$ cross section as obtained by the 2-τ search [3].

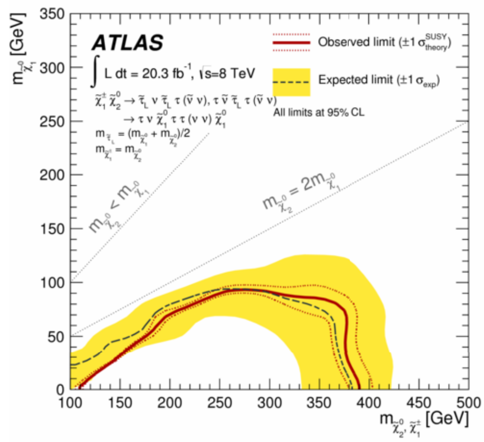


(a) (b)

Figure 6: Direct production of SUSY electroweak particles targetted by 3-lepton search [4]. The term $\tilde{\ell}$ designates all three flavours: $\tilde{e}$, $\tilde{\mu}$ and $\tilde{\tau}$.

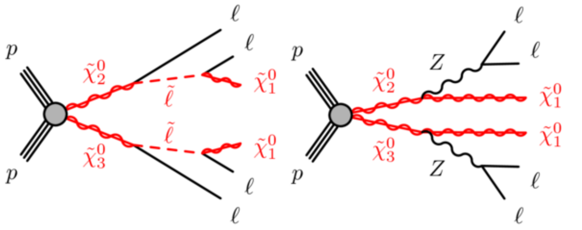


(a)



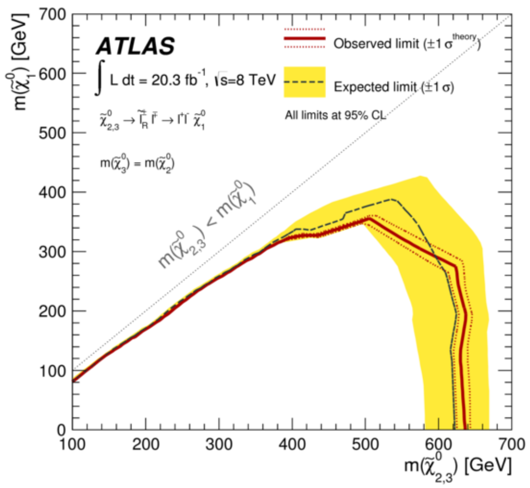
(b)

Figure 7: Exclusion limits for (a) $\tilde{\ell}_L$ production and (b) $\tilde{\tau}_L$ obtained by the 3-lepton search [4].

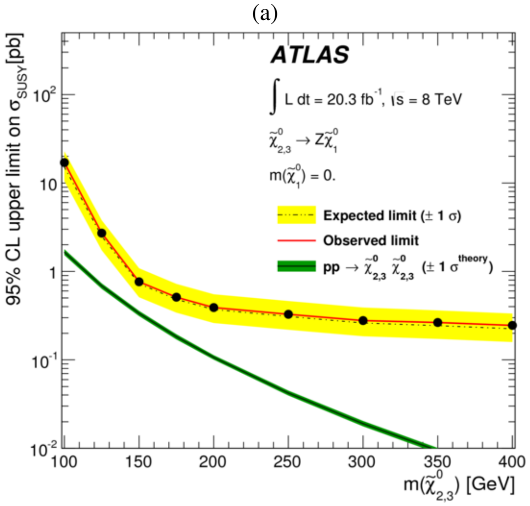


(a) (b)

Figure 8: Direct production of SUSY electroweak particles targetted by 4-lepton search [5]. The term $\tilde{\ell}$ designates all three flavours: $\tilde{e}$, $\tilde{\mu}$ and $\tilde{\tau}$.

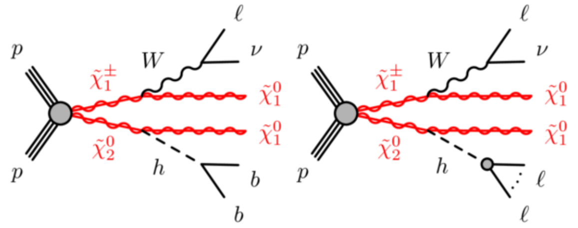


(a)



(b)

Figure 9: Exclusion limits for (a) $\tilde{\ell}_R$ mass and (b) Z decay model obtained by the 4-lepton search [5].



(a) (b)

Figure 10: Production of $\tilde{\chi}_1^{\pm}$-$\tilde{\chi}_2^0$ with decays to a Wh final state [8, 4].

agreement with the corresponding limit for the 2-lepton search, in the $\tilde{\chi}_1^0$-$\tilde{\chi}_2^0/\tilde{\chi}_1^{\pm}$ plane.

3. Higgs-aware searches

The discovery of a Higgs-boson with a mass of 125 GeV [6, 7] opens up new channels to look for decays of SUSY electroweak production into Higgs. In particular, the searches presented here consider the decay of the directly produced $\tilde{\chi}_1^{\pm}$ and $\tilde{\chi}_2^0$ into Wh, the Higgs boson decaying to either a pair of leptons or a pair of b-quarks, as shown in Fig. 10.

A dedicated search is performed for the channel in which the Higgs decays to b-quarks [8]. Assuming SM branching ratios, this channel would be favoured. Only e/μ leptons are considered to define two SRs, and a binning in m_{T} and m_{CT} is used to determine the $t\bar{t}$ and W+jets background. The contransverse mass m_{CT} is defined as:

$$m_{\mathrm{CT}}^2 = \left(E_{\mathrm{T}}^{b_1} + E_{\mathrm{T}}^{b_2}\right)^2 - \left|\vec{p}_{\mathrm{T}}^{\,b_1} - \vec{p}_{\mathrm{T}}^{\,b_2}\right|^2,$$

where b_1 and b_2 are the two b-quarks in the decay.

After observing no excess compared to the SM, the exclusion limit on a simplified model shown in Fig. 11a is obtained.

The 3-lepton search described in Section 2 is used to search for Wh production. Three SRs can be used to look for this channel, using all three flavours of leptons, as τ should dominate. A veto on SFOS pairs is applied to reduce the Z background. No excedent of events being observed compared to the SM expectation, an exclusion limit is set, as shown in Fig. 11b.

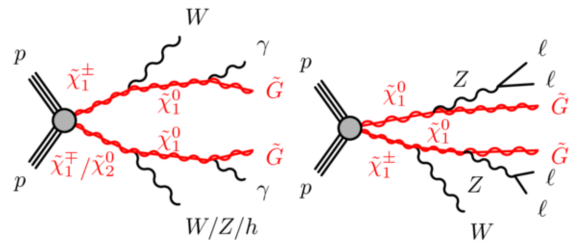
4. General Gauge Mediation searches

The direct production of SUSY electroweak particles can also be probed in the General Gauge Mediation

(GGM) framework, which is an extension of the more familiar Gauge Mediated Symmetry Breaking (GMSB) family of models. The most notable difference between GGM and simplified models is the presence of the Gravitino ($\tilde{G}$) as the LSP. The decays of $\tilde{\chi}_1^0$ in leptons and photons, shown in Fig. 12, are considered in the searches presented here.

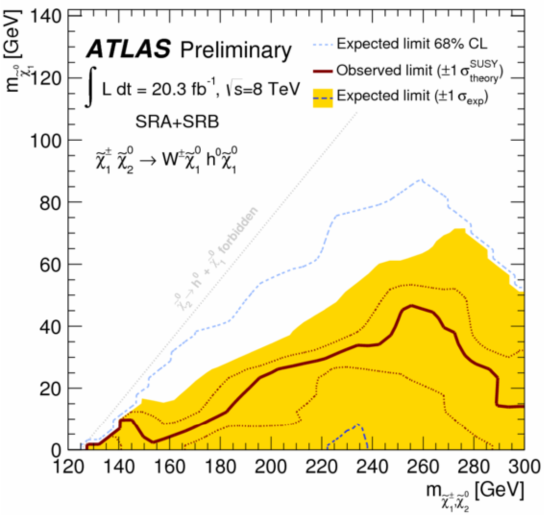
A search for di-photon signatures [9] is used to probe for the decay shown in Fig. 12a. A scenario with wino-bino production is assumed in this model and the exclusion limit shown in their mass plane is shown in Fig. 13a.

The 4-lepton search presented in Section 2 is also used to search for the process shown in Fig. 12b, in a scenario with higgsino-like co-NLSPs (next LSP). The resulting exclusion limit contour is shown in Fig. 13b.

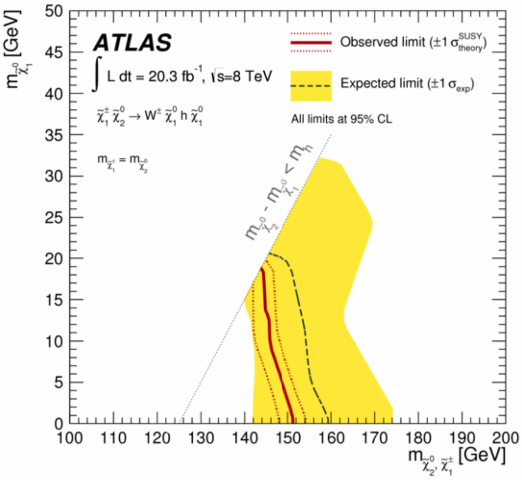


(a) (b)

Figure 12: Direct production of SUSY electroweak particles in the GGM framework [9, 5].

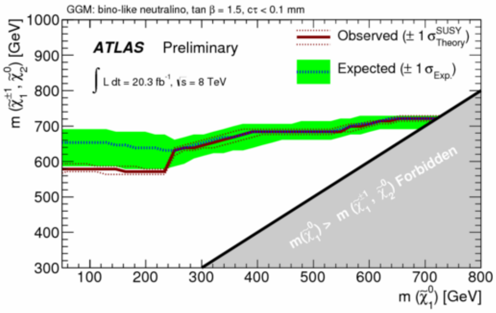


(a)

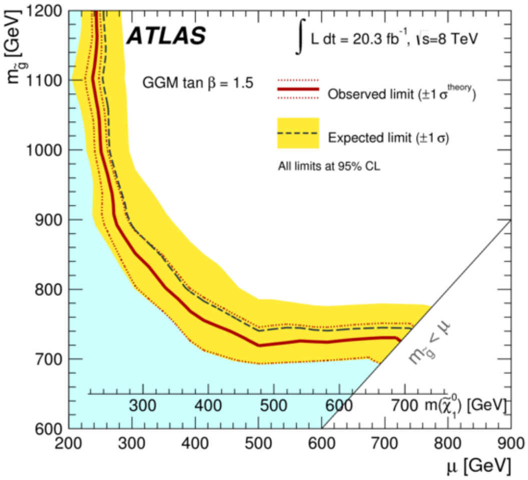


(b)

Figure 11: Exclusion limits for Wh in the (a) $b\bar{b}$ [8] and (b) 3-lepton [4] searches.



(a)



(b)

Figure 13: Exclusion limits for GGM models for (a) the di-photon [9] and (b) the 4-lepton [5] channels.

5. Conclusion

The production of electroweak sparticles is actively searched for in ATLAS using various methods. Naturalness arguments used in SUSY models suggest that electroweakinos should have low masses. By combining the exclusion limits obtained for $\tilde{\chi}_1^{\pm}$-$\tilde{\chi}_2^0$ production in a chargino-LSP grid by the searches presented in Section 2 and Section 3, which all assume degenerate masses for these two sparticles, masses for the $\tilde{\chi}_1^{\pm}$ are excluded up to 700 GeV.

Electroweak SUSY searches are looking at a variety of production and intermediate decays. The data from the Run I ATLAS dataset used in these many searches shows an excellent agreement with the SM expectation. As new LHC data with increased energy is expected for 2015, the search for SUSY electroweak production using the ATLAS detector is only starting.

References

[1] The ATLAS Collaboration, The ATLAS Experiment at the CERN Large Hadron Collider, JINST 3 (2008) S08003. doi:10.1088/1748-0221/3/08/S08003.
[2] The ATLAS Collaboration, Search for direct production of charginos, neutralinos and sleptons in final states with two leptons and missing transverse momentum in *pp* collisions at $\sqrt{s}$ = 8 TeV with the ATLAS detector, JHEP 1405 (2014) 071, arXiv:1403.5294 [hep-ex].
[3] The ATLAS Collaboration, Search for the direct production of charginos, neutralinos and staus in final states with at least two hadronically decaying taus and missing transverse momentum in *pp* collisions at $\sqrt{s}$ = 8 TeV with the ATLAS detector, Accepted for publication by JHEP, arXiv:1407.0350 [hep-ex].
[4] The ATLAS Collaboration, Search for direct production of charginos and neutralinos in events with three leptons and missing transverse momentum in $\sqrt{s}$ = 8TeV *pp* collisions with the ATLAS detector, JHEP 1404 (2014) 169, arXiv:1402.7029 [hep-ex].
[5] The ATLAS Collaboration, Search for supersymmetry in events with four or more leptons in $\sqrt{s}$ = 8 TeV *pp* collisions with the ATLAS detector, Phys. Rev. D 90 (2014) 052001, arXiv:1405.5086 [hep-ex].
[6] The ATLAS Collaboration, Observation of a new particle in the search for the Standard Model Higgs boson with the ATLAS detector at the LHC, Physics Letters B 716 (1) (2012) 1–29.
[7] The CMS Collaboration, Observation of a new boson at a mass of 125 GeV with the CMS experiment at the LHC, Physics Letters B 716 (1) (2012) 30–61.
[8] The ATLAS Collaboration, Search for chargino and neutralino production in final states with one lepton, two b-jets consistent with a Higgs boson, and missing transverse momentum with the ATLAS detector in 20.3 fb^{-1} of $\sqrt{s}$ = 8 TeV *pp* collisions, Tech. Rep. ATLAS-CONF-2013-093, CERN, Geneva, https://cds.cern.ch/record/1595756 (Aug 2013).
[9] The ATLAS Collaboration, Search for Diphoton Events with Large Missing Transverse Momentum in 8 TeV *pp* Collision Data with the ATLAS Detector, Tech. Rep. ATLAS-CONF-2014-001, CERN, Geneva, https://cds.cern.ch/record/1641169 (Jan 2014).