Searches for electroweak production of supersymmetric particles with the ATLAS detector

Ben Hodkinson, on behalf of the ATLAS Collaboration
Department of Physics, Keble Road,
Oxford OX1 3RH, England

The direct production of electroweak SUSY particles, including sleptons, charginos, and neutralinos, is a particularly interesting area with connections to dark matter and the naturalness of the Higgs mass. The small production cross-sections and challenging experimental signatures, often involving compressed spectra, lead to difficult searches. This contribution highlights the most recent results of searches, performed by the ATLAS experiment at the LHC, for supersymmetric particles produced via electroweak processes, including analyses targeting small mass splittings between SUSY particles. Recent results involving the combination of searches and in the context of the pMSSM are also presented.

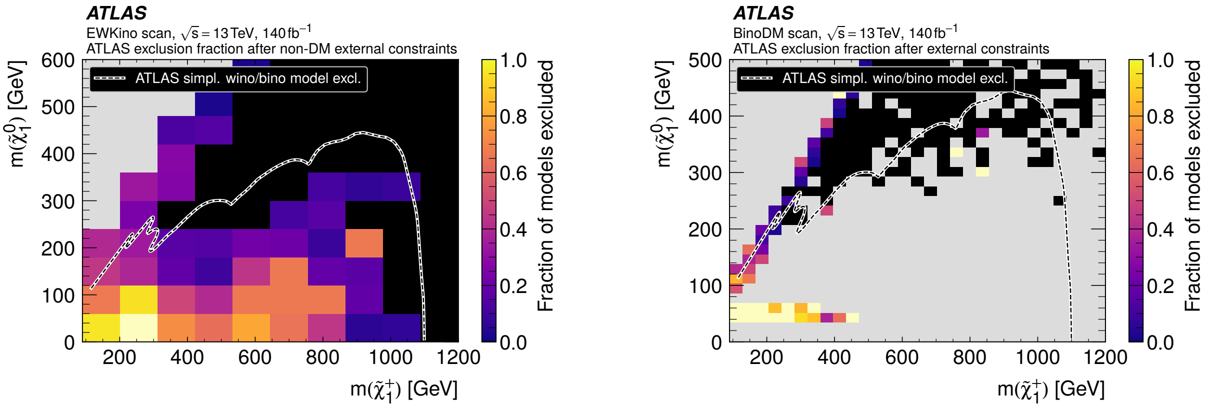
1 Introduction

Supersymmetry is an extension of the Standard Model (SM) that predicts a superpartner boson/fermion for each SM fermion/boson. In the electroweak sector, the superpartners of the SM Higgs boson and electroweak gauge bosons are the higgsinos, winos and binos, which mix to form chargino ($\tilde{\chi}_i^{\pm}, i = 1, 2$) and neutralino ($\tilde{\chi}_j^0, j = 1, 2, 3, 4$) mass eigenstates. These are collectively referred to as electroweakinos. In R-parity conserving scenarios, the lightest neutralino is expected to be the lightest SUSY particle (LSP) and a viable dark matter candidate. An LSP with mass at or below O(1 TeV) with a second electroweakino nearby in mass is favoured by dark matter constraints, naturalness and measurements of the anomalous magnetic moment of the muon. Additionally, the existing LHC limits on electroweak SUSY particles are far weaker than the coloured sparticles, due to their much smaller production cross-sections. Therefore, electroweak SUSY particles are a particularly promising avenue for new LHC searches.

The Minimal Supersymmetric Standard Model (MSSM) contains over 100 unknown parameters. Most of these are SUSY-breaking terms that parameterise our ignorance about the SUSY-breaking mechanism. The phenomenological MSSM (pMSSM) reduces this to 19 parameters by assuming no new CP-violation or flavour-changing neutral currents, 1st/2nd generation sfermion universality and R-parity conservation. ATLAS searches for supersymmetry are typically optimised for, and interpreted with, simplified models of supersymmetry which include a single SUSY production process and decay chain and pure bino/wino/higgsino states. Section 2 presents a recent pMSSM interpretation of ATLAS searches using the second data-taking run of the LHC ('Run 2'). In Section 3, several recent ATLAS searches for electroweak SUSY, which target remaining gaps in sensitivity, are presented.

2 pMSSM interpretation of early Run 2 ATLAS searches

ATLAS recently applied the suite of Run 2 electroweak SUSY searches to constrain the pMSSM[2]. This produced a global picture of ATLAS sensitivity and highlighted scenarios missed due to non-



(a)

(b)

Figure 1: Fraction of sampled pMSSM models excluded in the m($\tilde{\chi}_1^\pm$) − m($\tilde{\chi}_1^0$) plane for (a) a scan of bino-, wino- and higgsino-like LSP scenarios that satisfy flavour and electroweak precision constraints, (b) a dedicated scan of bino-like LSP scenarios that satisfy dark matter constraints [2].

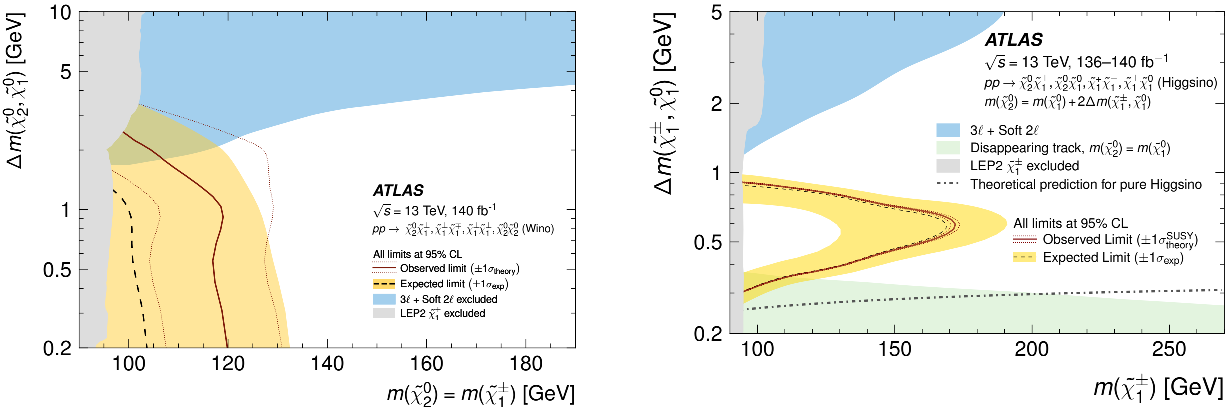
simplified phenomenology. The 19-dimensional pMSSM was randomly sampled to produce around 20,000 model points. For each point, SUSY spectra and observables were calculated and Monte-Carlo generation of LHC collision events performed. Eight searches for electroweak SUSY were evaluated, using SimpleAnalysis at truth-level and RECAST at detector-level.

Figure 1a shows the overall ATLAS sensitivity for a sample of models that satisfy flavour and electroweak precision constraints, including bino-, wino- and higgsino-like LSP scenarios. The results are shown in the m($\tilde{\chi}_1^\pm$)-m($\tilde{\chi}_1^0$) plane, with bin colours indicating the fraction of models excluded. The overlaid contour indicates the envelope of the ATLAS observed exclusion contours for simplified wino models in this plane. Notably, there is just a single bin with 100% exclusion, and viable models remain right up to the LEP limit at around m($\tilde{\chi}_1^\pm$) ≈ 100 GeV. This highlights the need to improve the depth of sensitivity in nominally ‘excluded’ mass regions. Some sensitivity to compressed scenarios is observed, partly from the disappearing track search [3] which strongly constrains wino-LSP scenarios, and partly through the production and decay of the heavier electroweakinos ($\tilde{\chi}_2^\pm$, $\tilde{\chi}_3^0$, $\tilde{\chi}_4^0$).

Figure 1b shows the same mass plane but restricting to models that satisfy dark matter constraints and have a bino-like LSP (a dedicated scan was performed for these scenarios). This restricts the parameter space to models in the Z/h funnel, with m($\tilde{\chi}_1^0$) ≈ m(Z, h)/2, and compressed region, such that LSP (co-)annihilation mechanisms are sufficient to reduce the dark matter relic density to (or below) the observed value. The Z/h funnel is well constrained by the searches considered, while many models with compressed spectra are not excluded. Additionally, complementarity is found between the sensitivity of ATLAS searches and direct detection experiments such as LZ.

3 Recent ATLAS searches

The pMSSM scan highlights the need to extend the sensitivity reach for scenarios with compressed mass-spectra and to improve the depth of sensitivity in scenarios with larger mass splittings. Several examples of recent ATLAS searches that target these gaps are highlighted here.



(a) (b)

Figure 2: Expected and observed 95% CL exclusion limits on simplified models from (a) the ATLAS VBF search[4], (b) the ATLAS mildly-displaced track search[5].

3.1 Compressed searches

VBF topologies

Electroweakinos can be produced through vector boson fusion (VBF) processes, providing a unique signature of large missing transverse momentum and two forward jets. Figure 2a shows the recent ATLAS exclusion limits on a simplified model of VBF production[4]. The visible decay products of the electroweakinos are too soft to be reconstructed, thus the analysis is agnostic to the branching ratios of the electroweakinos and provides generic sensitivity to models with mass splittings below 2 GeV and masses up to 120 GeV.

Mildly-displaced tracks

For $\tilde{\chi}_1^\pm$-$\tilde{\chi}_1^0$ mass splittings around 0.5 GeV, the chargino flight length reaches $0.1 - 1$ mm, producing a "mildly" displaced track. A recent ATLAS search[5] used the transverse impact parameter to identify this signature and target the gap in sensitivity between the previous soft-two-lepton and disappearing track searches. This unique signature significantly reduces backgrounds and provides the first sensitivity since LEP to higgsino mass splittings of 0.3 GeV to 0.9 GeV. Figure 2b shows the resulting ATLAS exclusion limits for a simplified higgsino model.

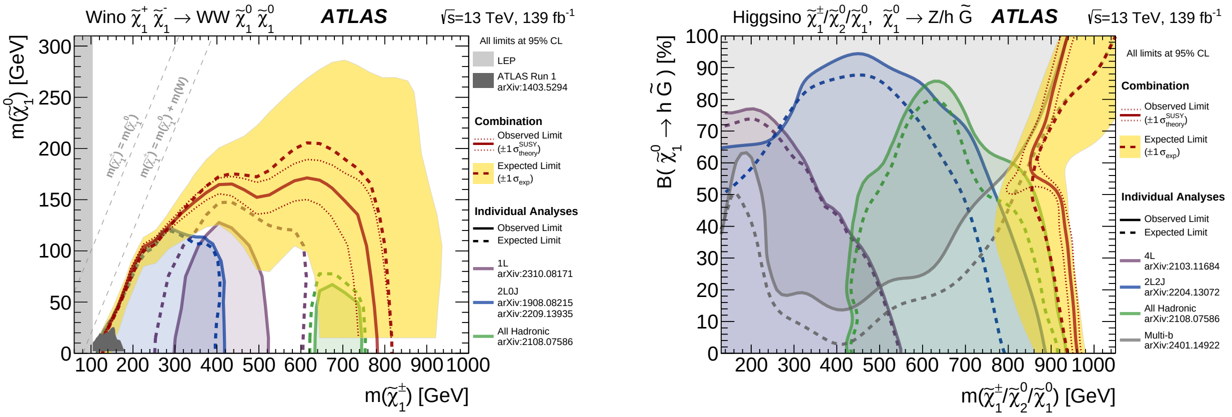
3.2 Hadronic final states

One lepton plus boosted jets

ATLAS is also targeting scenarios with larger mass splittings, including a recent search for electroweakino production with a final state of one lepton plus large missing transverse momentum plus one to three jets[6]. This targets scenarios where the charginos and neutralinos decay via on-shell $W/Z/h$ bosons. The resulting large radius W/Z- and b-jets are tagged using jet substructure information. Figure 3a shows the exclusion limits for a $\tilde{\chi}_1^\pm\tilde{\chi}_1^\pm \to WW\tilde{\chi}_1^0\tilde{\chi}_1^0$ simplified model from a statistical combination with previous searches in the two-lepton and zero-lepton channels[7]. The one-lepton search fills in the gap between the previous limits, and the combination extends the sensitivity to smaller mass splittings at higher $\tilde{\chi}_1^\pm$ mass.

Multiple b-jets

Beyond pMSSM-inspired wino/bino and higgsino scenarios, ATLAS is also targeting models of general gauge-mediation (GGM) and gauge-mediated SUSY-breaking (GMSB) which include a



(a) (b)

Figure 3: Reproduced expected and observed 95% CL exclusion limits, from a statistical combination [7] of several ATLAS searches, for a (a) $\tilde{\chi}_1^\pm \tilde{\chi}_1^\pm \rightarrow WW \tilde{\chi}_1^0 \tilde{\chi}_1^0$ simplified model, (b) higgsino GGM scenario.

gravitino. This includes a recent search for higgsinos decaying to the gravitino via a Higgs boson [8]. The targeted final state includes multiple b-jets which are paired using a new delta-R-based matching to reconstruct the Higgs boson(s). Improved jet reconstruction, b-tagging and machine learning-based discriminants are also employed to improve on the previous partial Run 2 search [9]. This analysis uses a data-driven background estimate by reweighting events with two b-jets to model the background contribution in the four b-jet signal region. Figure 3b shows the exclusion limits for a higgsino GGM simplified model, for a statistical combination with previous searches for four-lepton, two-lepton and zero-lepton final states.

4 Summary and outlook

Electroweak SUSY provides well-motivated but challenging scenarios which are being searched for by the ATLAS Collaboration at the LHC. Good coverage of the pMSSM has been provided by Run 2 searches, with room to improve the depth of sensitivity and coverage of compressed scenarios. Recent ATLAS searches are addressing these gaps, providing unique sensitivity to compressed and hadronic signatures using novel final states, new analysis techniques and improved reconstruction. The Run 3 programme is in active development and will leverage further innovations to improve sensitivity and target new signatures, including those identified in the pMSSM scans. A summary of the Run 2 ATLAS SUSY search programme can be found in Reference [10].

References

1. ATLAS Collaboration, *JINST* **3**, S08003 (2008).
2. ATLAS Collaboration, *JHEP* **05**, 106 (2024).
3. ATLAS Collaboration, *Eur. Phys. J. C* **82**, 606 (2022).
4. ATLAS Collaboration, arXiv:2409.18762 (2024).
5. ATLAS Collaboration, *Phys. Rev. Lett.* **132**, 221801 (2024).
6. ATLAS Collaboration, JHEP **12**, 167 (2023).
7. ATLAS Collaboration, *Phys. Rev. Lett.* **133**, 031802 (2024).
8. ATLAS Collaboration *Phys. Rev.* D **109**, 112011 (2024).
9. ATLAS Collaboration *Phys. Rev.* D **98**, 092002 (2018).
10. ATLAS Collaboration, arXiv:2403.02455 (2024).