Searches for electroweak production of supersymmetric particles with the ATLAS detector

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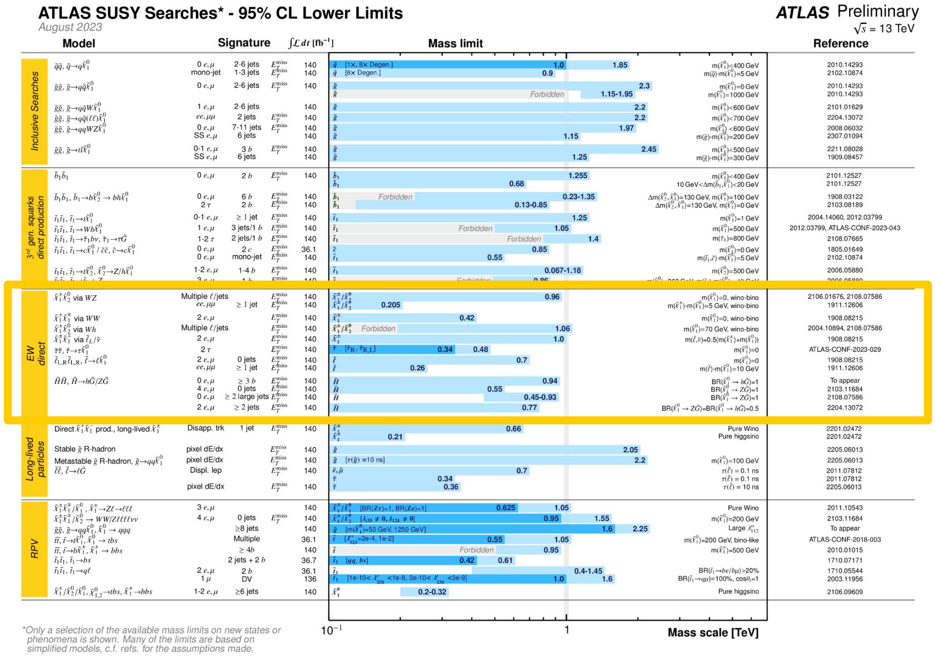
Introduction

- ATLAS has a large search program for electroweak SUSY - but so far haven't discovered any Beyond the SM Physics yet
- Full Run 3 data set will only bring small improvement to significance
- We need to make good use of both Run 2 and Run 3 data
  - Employ new techniques/ideas for future and already ongoing analyses
- This talk will cover a subset of results with the complete Run 2 data set (140 fb^{-1}):
  - 1L + MET – SUSY-2023-01
  - Multi-b-jets – SUSY-2020-16
  - Photons + two b-jets – SUSY-2020-17
  - Compressed spectra with soft displaced tracks – SUSY-2020-04
  - Simplified model combination – SUSY-2020-05
  - pMSSM scan – SUSY-2020-15

See also the other ATLAS SUSY talks at ICHEP!

Electroweak SUSY

- SUSY postulates a superpartner with spin altered by 1/2 for each SM particle
- Offers solutions to open questions of the SM
  - hierarchy problem
  - fine-tuning of the Higgs mass
  - unification of fundamental interactions
- Provides good candidate for dark matter
  - R-parity conserving models ⟶ SUSY particles produced in pairs
  - in many models, the lightest stable particle (LSP) is the neutralino
  - model dependent limit on DM candidate

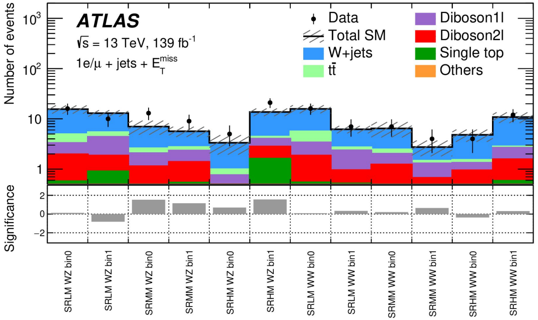


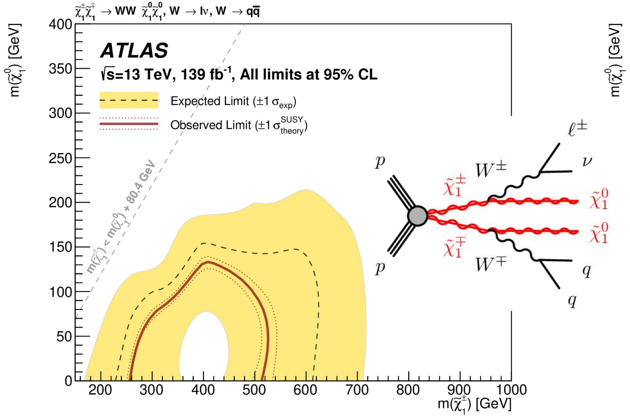
- Electroweak SUSY (EWK-SUSY) well motivated by naturalness arguments and with many possible signatures at colliders
  - Less constrained than strong production, especially in mass degenerate regimes
  - Really challenging to probe due to small cross-sections and signatures similar to SM processes

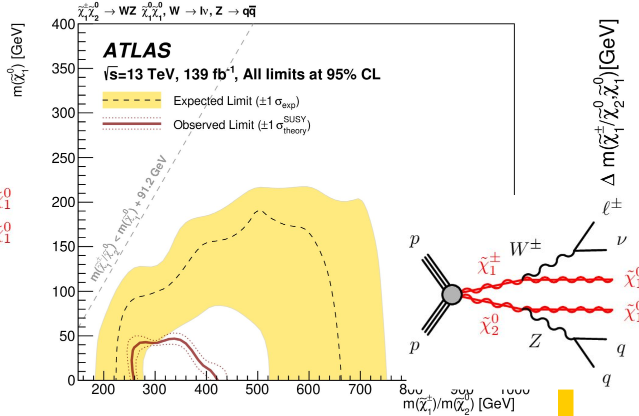
EWK 1L

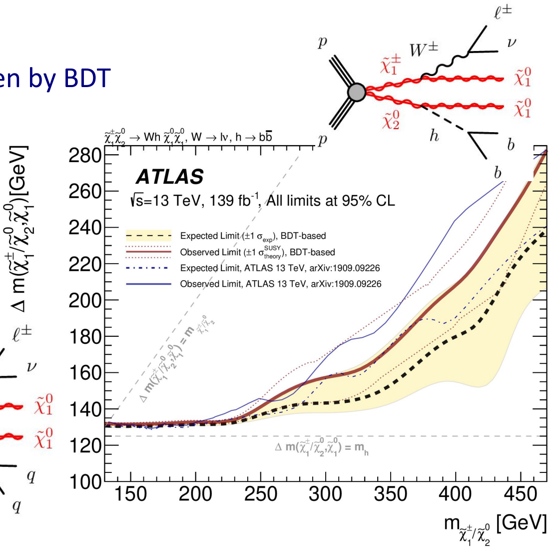
SUSY-2023-01

- First 1L + jets search using jet-substructure information + BDT to improve sensitivity
- Wino-like mass degenerate Chargino-Neutralino pairs decaying to bino-like LSPs via SM ***V,h*** boson
- Three sets of SRs all requiring one isolated lepton + max. three jets. Additionally:
  - C1C1-WW, C1N2-WZ SRs binned in mass with MET > 200 GeV + at least one large-R boson-tagged jet
  - C1N2-Wh SRs with exactly two b-jets and binned in output score of Boosted Decision Tree (BDT)
- Results:
  - Weak observed limits due to 2.1σ excess in SRMM-WZ bins
  - Similar weak observed limits in Wh channel due to small data excess, improvements driven by BDT



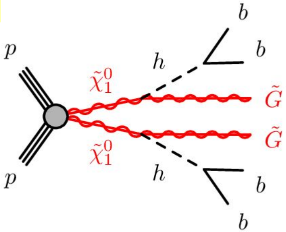






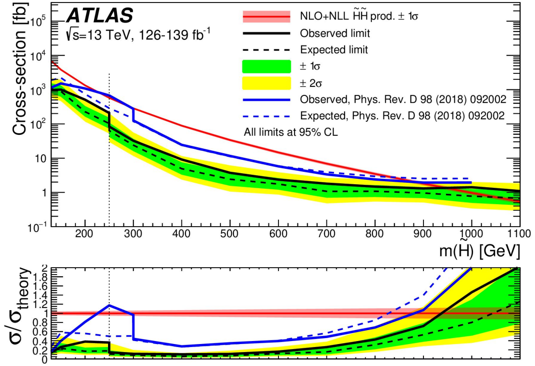
Multi-b

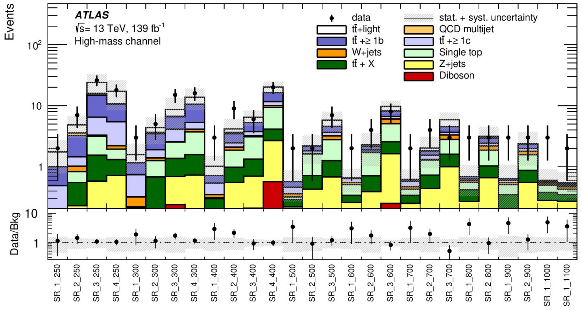
SUSY-2020-16



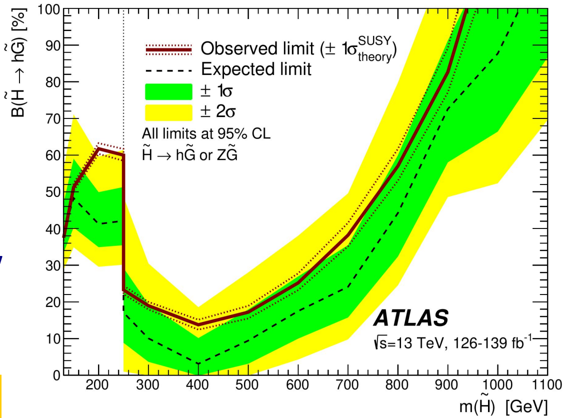
- GMSB scenario with neutralino decaying to nearly massless Ğ via SM ***h***(→bb) boson
- Search performed in two channels
  - High-mass (m($\check{H}$) > 250 GeV): large MET+ MET trigger + at most 7 jets, at least 3 b-tagged
  - Low-mass (m($\check{H}$)<250 GeV): low MET+ b-jet triggers + at least four b-jets
- Relying on new techniques w.r.t. partial Run-2 analysis
  - Improved jet reconstruction and b-tagging
  - New b-jets pairing to Higgs boson
  - SRs of High-mass channel binned (x4) in BDTs output score to better discriminate signal from backgrounds

→ Full Run-2 update using new techniques to achieve highest sensitivity to date





- Largest excess of 1.9σ (2.6σ) local significance in High-Mass (Low-Mass) channel
- Most sensitive limits to date to GMSB simplified models in 130 GeV < m($\check{H}$) <800 GeV mass window

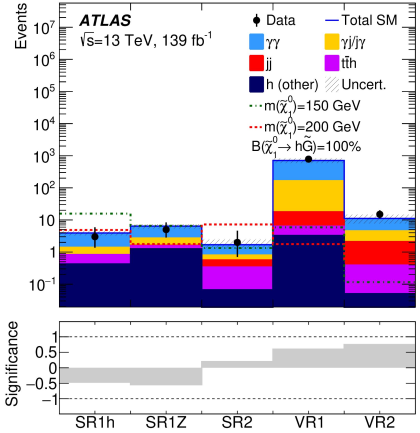


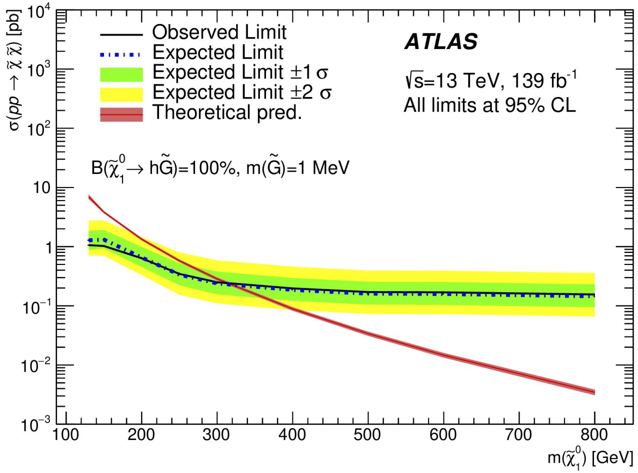
EWK photons + b-jets

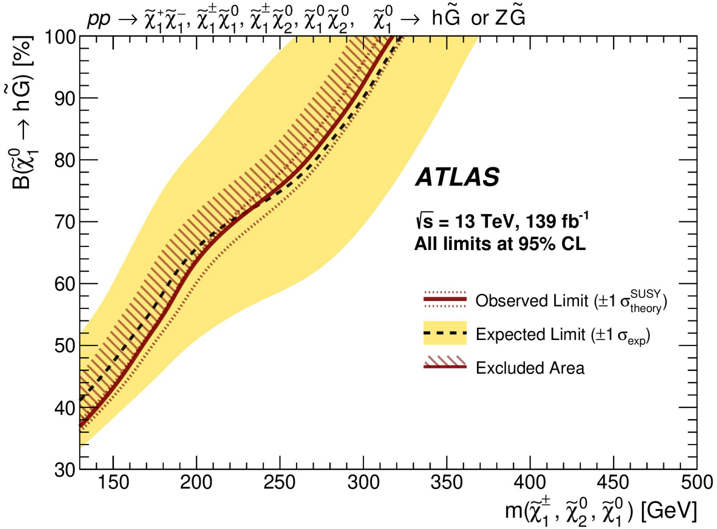
SUSY-2020-17

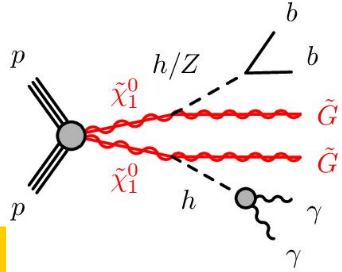
- Provides complementary results to multi-b search by targeting different SM boson decays
- GMSB scenario complementary to previous one, targeting N1 decays via SM ***h***(→ɣɣ/bb) or ***Z***(→bb) bosons
- Events selected vetoing leptons and requiring exactly 2ɣ + 2b-jets in the ***h*** or ***Z*** mass windows
- Three non-overlapping signal regions defined to be sensitive to different masses and decay modes

→ Very good agreement with SM







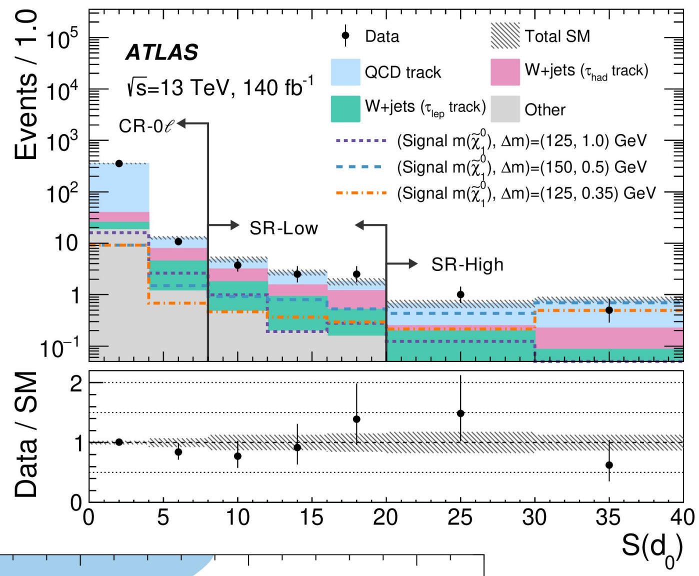


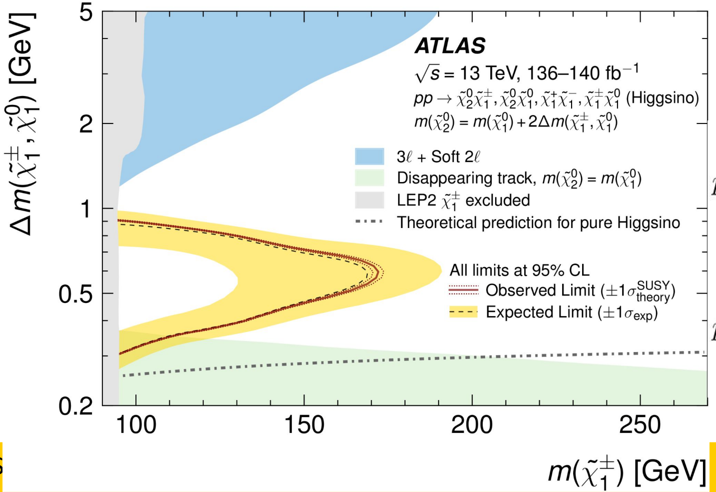
Compressed spectra

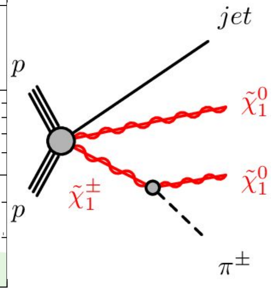
SUSY-2020-04

- Higgsinos production, much lighter than gauginos, Higgsinos, Δm ≃0.4-1 GeV, c_τ ≃0.1-1mm
- Targeting final state with
  - ISR leading jet (p_T> 250 GeV)
  - Large MET(> 600 GeV)
  - 1 track with 2<p_T<5 GeV, large d_0 significance ($S(d_0)$ > 8)
- Backgrounds:
  - τ decay tracks ($W(\to \tau\nu)$):
    - MC scaled to data at higher track p_T
  - Non-prompt QCD tracks ($Z(\to \nu\nu)$, $W(\to \ell\nu)$)
  - Data-driven - $S(d_0)$shape is the same in 0L and 1L ($W\to\mu\nu$ events) control selection
- Two SR in $S(d_0)$ (sensitive to lower/ higher Δm)

Observed limit excludes higgsino gap up to ~170 GeV





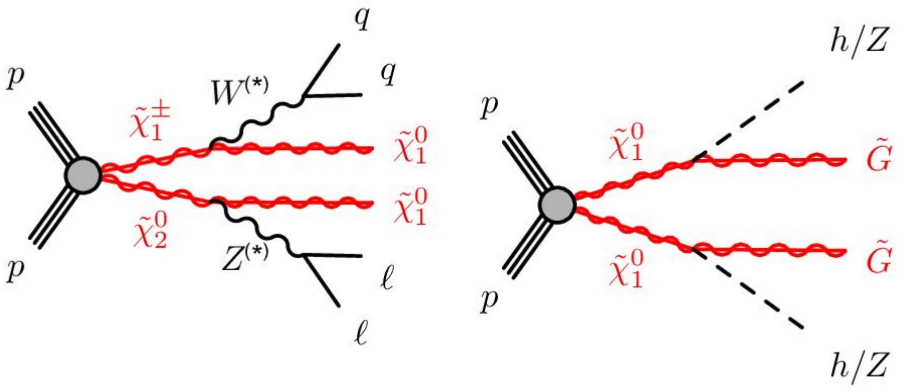


Simplified models combination

SUSY-2020-05

- Generally extends sensitivity to NLSP/LSP masses by 100 GeV, improves cross-section upper limits by 15%-40%
- Simplified models of pure-wino or pure- higgsino NLSPs pair production decaying to LSPs via SM ***V,h*** bosons
- Using all available EW searches with 139 fb−1

Production mode	Wino $\tilde{\chi}_1^+\tilde{\chi}_1^-$	Wino $\tilde{\chi}_1^\pm\tilde{\chi}_2^0$	Wino $\tilde{\chi}_1^\pm\tilde{\chi}_2^0$	Higgsino GGM $\tilde{\chi}_1^+\tilde{\chi}_1^-, \tilde{\chi}_1^\pm\tilde{\chi}_{1,2}^0, \tilde{\chi}_1^0\tilde{\chi}_2^0$
Decay mode	$\tilde{\chi}_1^\pm \to W^\pm\tilde{\chi}_1^0$	$\tilde{\chi}_1^\pm \to W^\pm\tilde{\chi}_1^0$ $\tilde{\chi}_2^0 \to Z\tilde{\chi}_1^0$	$\tilde{\chi}_1^\pm \to W^\pm\tilde{\chi}_1^0$ $\tilde{\chi}_2^0 \to h\tilde{\chi}_1^0$	$\tilde{\chi}_1^0 \to Z/h\tilde{G}$
Searches				
All Hadronic	✓	✓	✓	✓
1L	✓	✓		
1Lbb			✓	
2L Compressed		✓		
2L0J $\Delta m > m(W)$	✓			
2L0J $\Delta m \sim m(W)$	✓			
2L2J		✓		✓
2τ			✓	
3L		✓	✓	
SS/3L		✓	✓	
4L				✓
Multi-b				✓

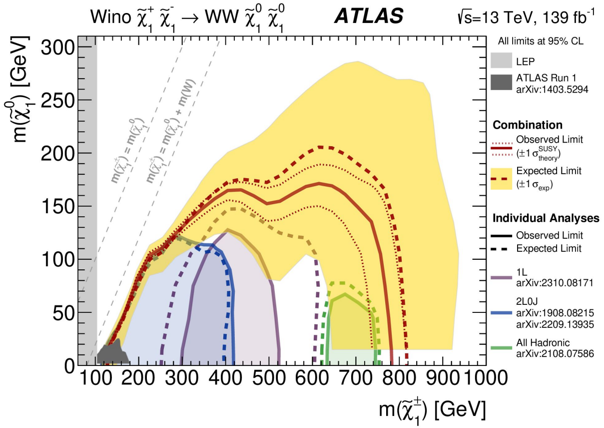


- Statistical independence checked by inspecting yields on data and simulations in SRs + CRs
- Combination performed for searches with overlap < 10%, otherwise search with best expected sensitivity is used
- Experimental systematics and theory uncertainties left uncorrelated

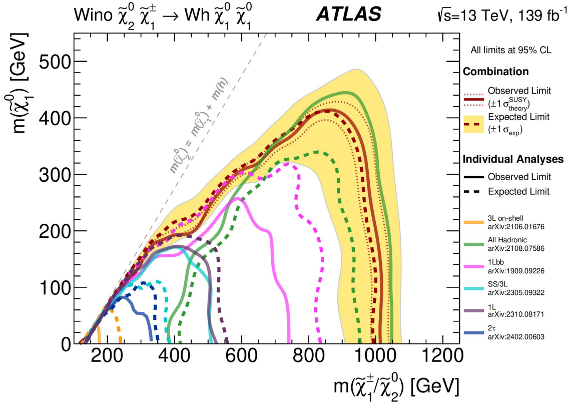
Simplified models combination

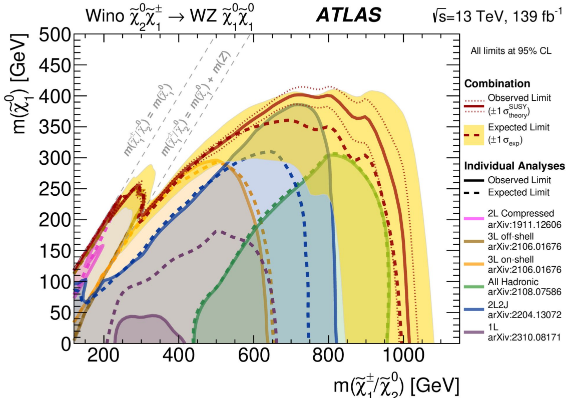
SUSY-2020-05

- Overall improvements in cross-section upper limits from 15%to 40%

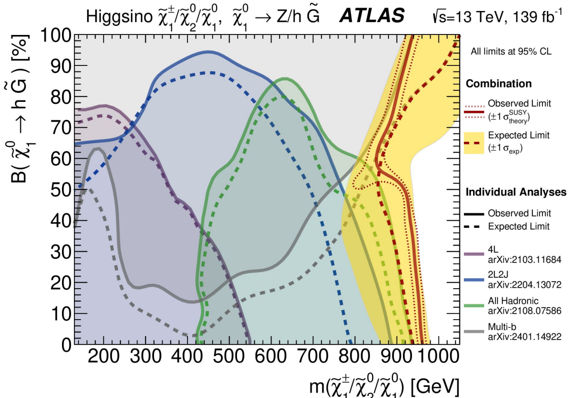


- Closes gap between individual searches, improves sensitivity to high mass
- Smooths out deficit/excess effects of individual searches





- Extends limits everywhere besides compressed region
- Fully covers all branching ratio possibilities in gauge-mediatedSUSY-breaking (GMSB) scenarios



EWK pMSSM

[SUSY-2020-15]

Exclusion limits on "simplified models" (very small portion of the MSSM)

- If we think of using the Phenomenological MSSM:
  - "Only" 19 free parameters (thanks to CP-conserved, RPC, minimal flavour violation)
- Evaluate sensitivity of ATLAS EWK SUSY searches in broader SUSY parameter space
  - Randomly sample pMSSM parameters
  - Re-interpret 8 Run-2 analyses on pMSSM models
  - EWK scan targets electroweakinos (other sparticles decoupled)
  - Highlight areas to be targeted with future searches
- Two scans performed:
  - General EWKino scan (squarks and slepton decoupled)
  - Bino-DM scan
  - A total of ~20000 models to study (after applying all constraints)
- Considering external constraints from:
  - Flavour, precision EWK and DM related measurements

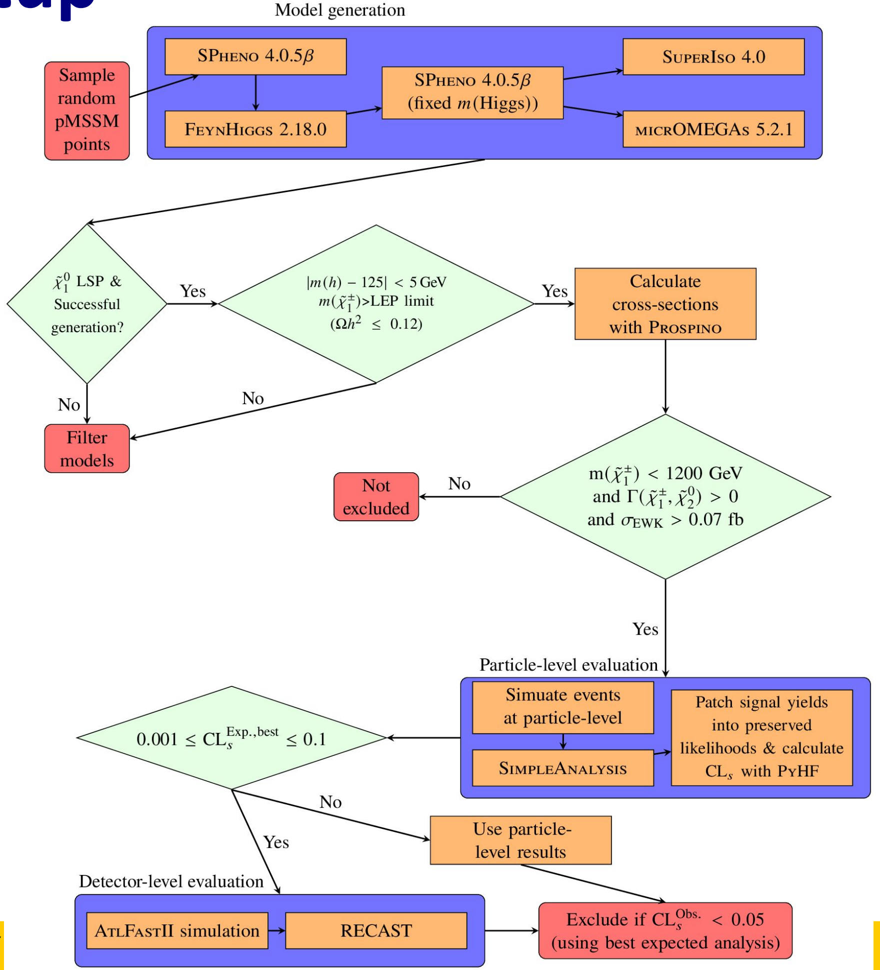
Analysis	Relevant simplified models targeted
FullHad	Wino $\tilde{\chi}_1^\pm\tilde{\chi}_2^0$ via WZ, Wino $\tilde{\chi}_1^\pm\tilde{\chi}_2^0$ via Wh, Wino $\tilde{\chi}_1^+\tilde{\chi}_1^-$ via WW
1Lbb	Wino $\tilde{\chi}_1^\pm\tilde{\chi}_2^0$ via Wh
2L0J	Wino $\tilde{\chi}_1^+\tilde{\chi}_1^-$ via WW, slepton pairs
2L2J	Wino $\tilde{\chi}_1^\pm\tilde{\chi}_2^0$ via WZ
3L	Wino $\tilde{\chi}_1^\pm\tilde{\chi}_2^0$ via WZ, Wino $\tilde{\chi}_1^\pm\tilde{\chi}_2^0$ via Wh, higgsino $\tilde{\chi}_1^\pm\tilde{\chi}_2^0\tilde{\chi}_1^0$
4L	Higgsino GGM
Compressed	Wino $\tilde{\chi}_1^\pm\tilde{\chi}_2^0$ via WZ, higgsino $\tilde{\chi}_1^\pm\tilde{\chi}_2^0\tilde{\chi}_1^0$
Disappearing-track	Wino $\tilde{\chi}_1^+\tilde{\chi}_1^-$ and $\tilde{\chi}_1^\pm\tilde{\chi}_1^0$

Parameter	Min	Max	Note
$M_{\tilde{L}_1}$ $(=M_{\tilde{L}_2})$	10 TeV	10 TeV	Left-handed slepton (first two gens.) mass
$M_{\tilde{e}_1}$ $(=M_{\tilde{e}_2})$	10 TeV	10 TeV	Right-handed slepton (first two gens.) mass
$M_{\tilde{L}_3}$	10 TeV	10 TeV	Left-handed stau doublet mass
$M_{\tilde{e}_3}$	10 TeV	10 TeV	Right-handed stau mass
$M_{\tilde{Q}_1}$ $(=M_{\tilde{Q}_2})$	10 TeV	10 TeV	Left-handed squark (first two gens.) mass
$M_{\tilde{u}_1}$ $(=M_{\tilde{u}_2})$	10 TeV	10 TeV	Right-handed up-type squark (first two gens.) mass
$M_{\tilde{d}_1}$ $(=M_{\tilde{d}_2})$	10 TeV	10 TeV	Right-handed down-type squark (first two gens.) mass
$M_{\tilde{Q}_3}$	2 TeV	5 TeV	Left-handed squark (third gen.) mass
$M_{\tilde{u}_3}$	2 TeV	5 TeV	Right-handed top squark mass
$M_{\tilde{d}_3}$	2 TeV	5 TeV	Right-handed bottom squark mass
M_1	−2 TeV	2 TeV	Bino mass parameter
M_2	−2 TeV	2 TeV	Wino mass parameter
μ	−2 TeV	2 TeV	Bilinear Higgs boson mass parameter
M_3	1 TeV	5 TeV	Gluino mass parameter
A_t	−8 TeV	8 TeV	Trilinear top coupling
A_b	−2 TeV	2 TeV	Trilinear bottom coupling
A_τ	−2 TeV	2 TeV	Trilinear τ-lepton coupling
M_A	0 TeV	5 TeV	Pseudoscalar Higgs boson mass
$\tan\beta$	1	60	Ratio of the Higgs vacuum expectation values

EWK pMSSM - Technical setup

SUSY-2020-15

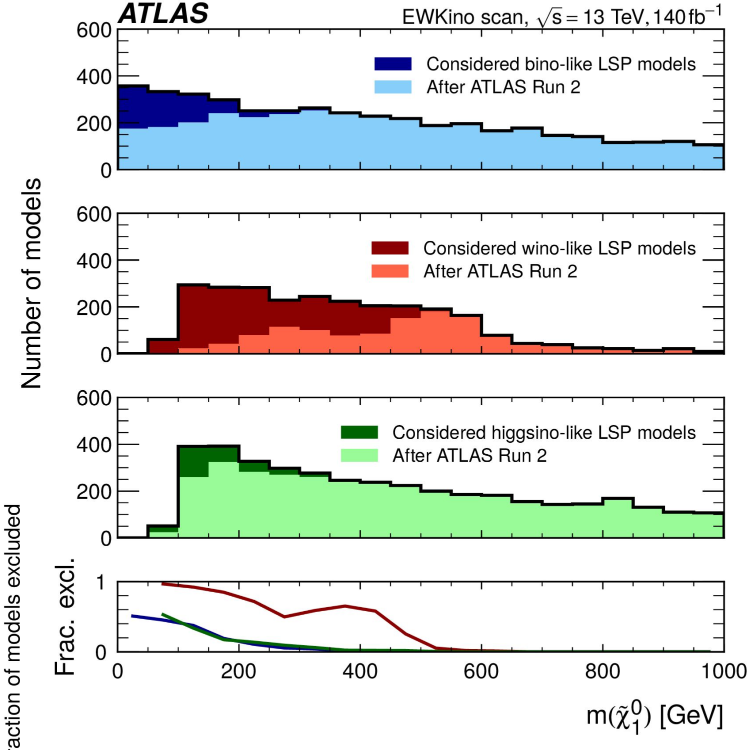
- First generate pMSSM models and apply initial filters
- Perform particle-level categorization of models using SimpleAnalysis and pyhf
- For models deemed “ambiguous” detector-level MC samples are produced and processed using RECAST.

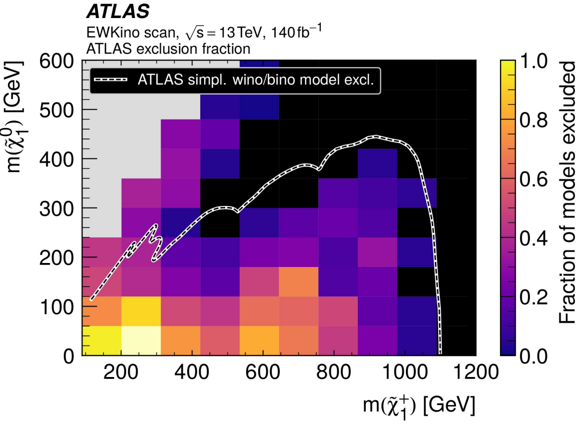


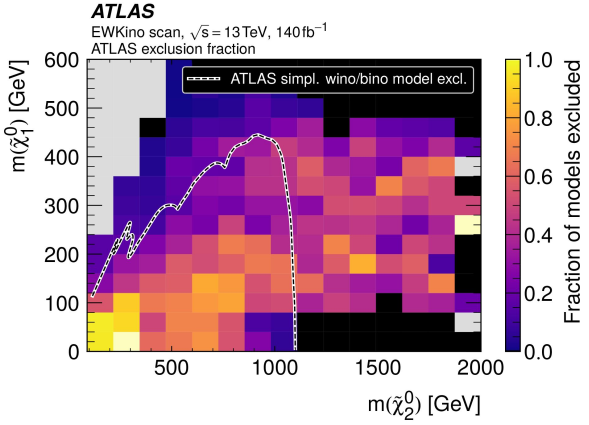
EWK pMSSM - general scan

SUSY-2020-15

- For $m(\tilde{\chi}_1^0) \leq 100$ GeV, almost all are Bino-like LSP models
  - And ~50% are excluded by ATLAS
- For LSP mass ≤ 400 GeV, more than 50% excluded for Wino-like LSP models
  - Driven by disappearing track analysis.
- ATLAS exclude at least 50% of models with up to $m(\tilde{\chi}_1^{\pm})$=400 GeV
- There are unexcluded models even at low LSP masses

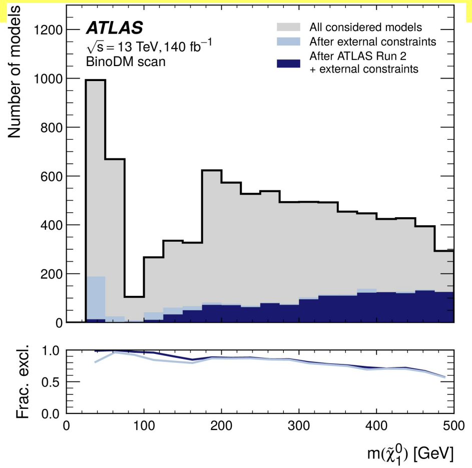




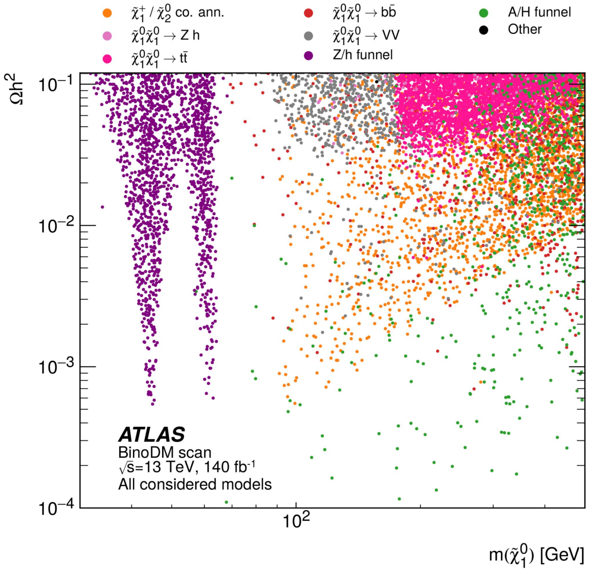


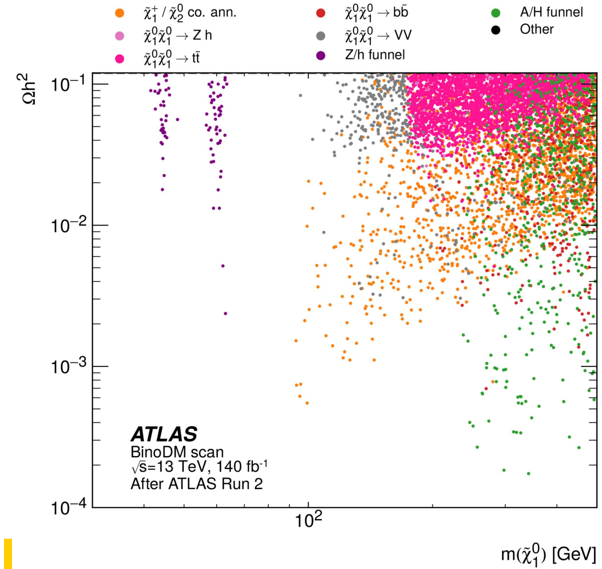
EWK pMSSM - Bino scan

SUSY-2020-15



- Models with Bino-like LSP typically overestimate the dark matter relic density, unless additional annihilation mechanisms are present:
  - compressed mass splitting between LSP and $\tilde{\chi}_2^0/\tilde{\chi}_1^{\pm}$
  - ***Z/h*** "funnel regions"
- Scan oversampling region with |M1| < 500 GeV (low-mass bino)





- ***Z/h*** "funnel region" almost completely excluded by ATLAS Run-2 data.
- Weaker ATLAS constraints at higher LSP masses.
- $\tilde{\chi}_2^0/\tilde{\chi}_1^{\pm}$ co-annihilation: dominant mode still viable

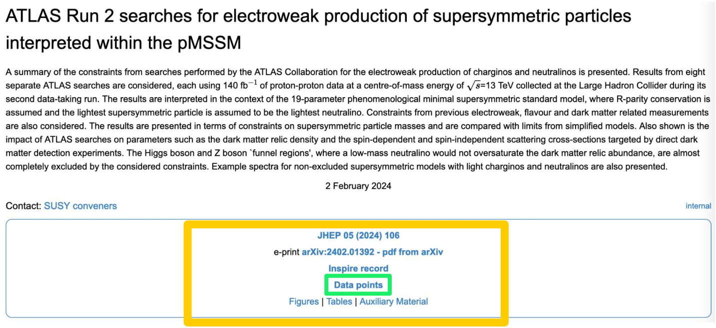
Outlook

- For simplified SUSY models most interesting phase space regions are challenging to probe
- Motivates to use new techniques and explore different ideas

  → Great results and improvements already with the full Run 2 data set - more to come with Run 3

- Combining results to improve reach
- Scanning vast parameter space to find currently non-excluded signatures

- All analyses also providing results in various formats to make them more accessible to the whole HEP community


ATLAS Run 2 searches for electroweak production of supersymmetric particles interpreted within the pMSSM

A summary of the constraints from searches performed by the ATLAS Collaboration for the electroweak production of charginos and neutralinos is presented. Results from eight separate ATLAS searches are considered, each using 140 fb^{-1} of proton-proton data at a centre-of-mass energy of $\sqrt{s}$=13 TeV collected at the Large Hadron Collider during its second data-taking run. The results are interpreted in the context of the 19-parameter phenomenological minimal supersymmetric standard model, where R-parity conservation is assumed and the lightest supersymmetric particle is assumed to be the lightest neutralino. Constraints from previous electroweak, flavour and dark matter related measurements are also considered. The results are presented in terms of constraints on supersymmetric particle masses and are compared with limits from simplified models. Also shown is the impact of ATLAS searches on parameters such as the dark matter relic density and the spin-dependent and spin-independent scattering cross-sections targeted by direct dark matter detection experiments. The Higgs boson and Z boson `funnel regions', where a low-mass neutralino would not oversaturate the dark matter relic abundance, are almost completely excluded by the considered constraints. Example spectra for non-excluded supersymmetric models with light charginos and neutralinos are also presented.

2 February 2024

Contact: SUSY conveners internal

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