Searches for Electroweak Production of Supersymmetric Particles with the ATLAS Detector

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on behalf of the ATLAS Collaboration

Rencontres du Vietnam 2023 – 30th Anniversary – Windows on the Universe

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SUSY

ATLAS EXPERIMENT

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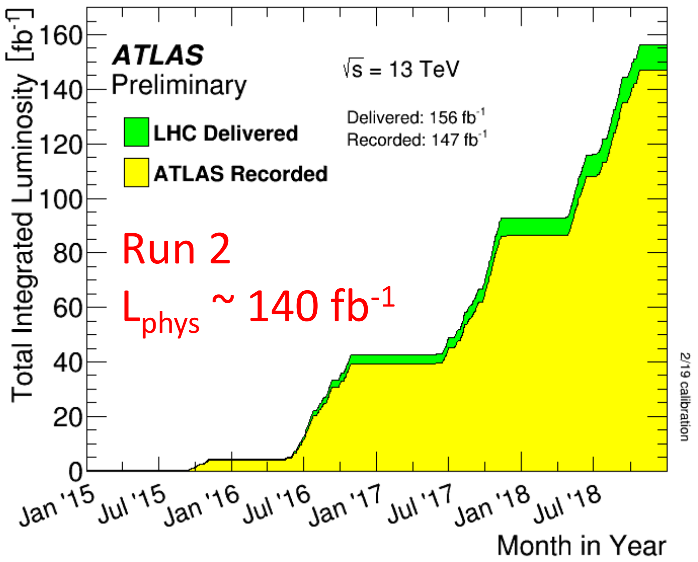
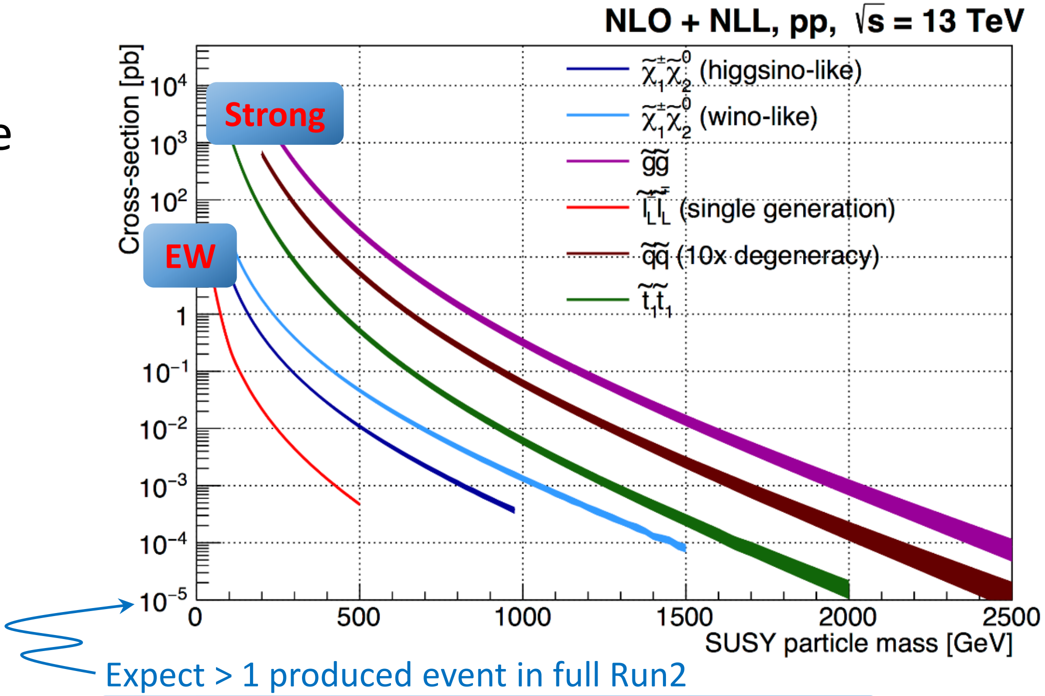
Outline

- Introduction
  - Why SUSY?
  - EW SUSY challenge
- Focus on recent ATLAS EW-SUSY search results, based on the full Run 2 statistics
  - Direct production of winos and higgsinos pairs
    - Final state: Multilepton (2L SS / 3L) + jets
  - Direct production of staus or charginos and neutralinos pairs
    - Final state: 2τ (hadronically decaying)
  - Pair production of sleptons and charginos decaying to two leptons and neutralinos with mass splittings near the W-boson mass
    - Final state: 2L0J
- Summary and perspectives

Introduction

- BSM: why SUSY?
  - Theoretically compelling
    ➡ Unique non-trivial extension of Poincaré algebra
  - Unites particles of integer and half-integer spin in common symmetry multiplets
    ➡ Relates bosons and fermions
  - If realized at weak scale, might naturally mitigate the hierarchy problems of the SM
  - Allows unification of the gauge couplings at GUT scale and a natural incorporation of gravity
  - If endowed with R-parity conservation, presents a natural cold dark matter candidate (LSP)
- Must be (spontaneously) broken
- LHC Run 2 is over ($L \sim 140\ fb^{-1}$), Run3 ongoing
  - Searches are actively in progress
  - In this talk: recent EW-SUSY results based on $L_{\text{Full Run 2}}$





EW SUSY searches are experimentally challenging

“Conventional” SUSY Searches

- R-parity conserving SUSY
- Search for signal pairs in decay final states
- Characterized by large E_T^{miss} from undetected LSP and hard objects (jets, leptons, tracks)
- Ad-hoc kinematic variables for SM bkg suppression in presence of several massive undetected objects in the final state; based on kinematics/topology in transverse plane
  - Stransverse Mass M_{T2}

$$M_{T2}^2 \equiv \min_{\not{\mathbf{p}}_1 + \not{\mathbf{p}}_2 = \not{\mathbf{p}}_T} \left[\max \left\{ m_T^2(\mathbf{p}_{Tl^-}, \not{\mathbf{p}}_1), m_T^2(\mathbf{p}_{Tl^+}, \not{\mathbf{p}}_2) \right\} \right]$$

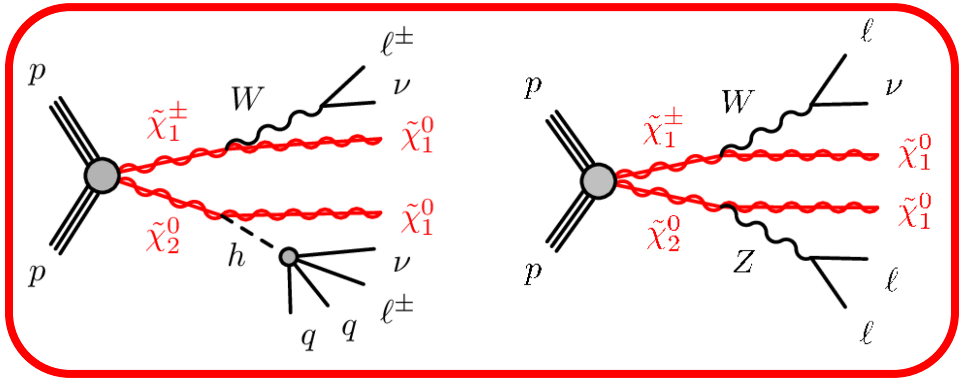
  - Effective Mass

$$m_{\rm eff} = \sum_{i \le N_{\rm jets}} (p_{\rm T}^{\rm jet})_i + E_{\rm T}^{\rm miss}$$

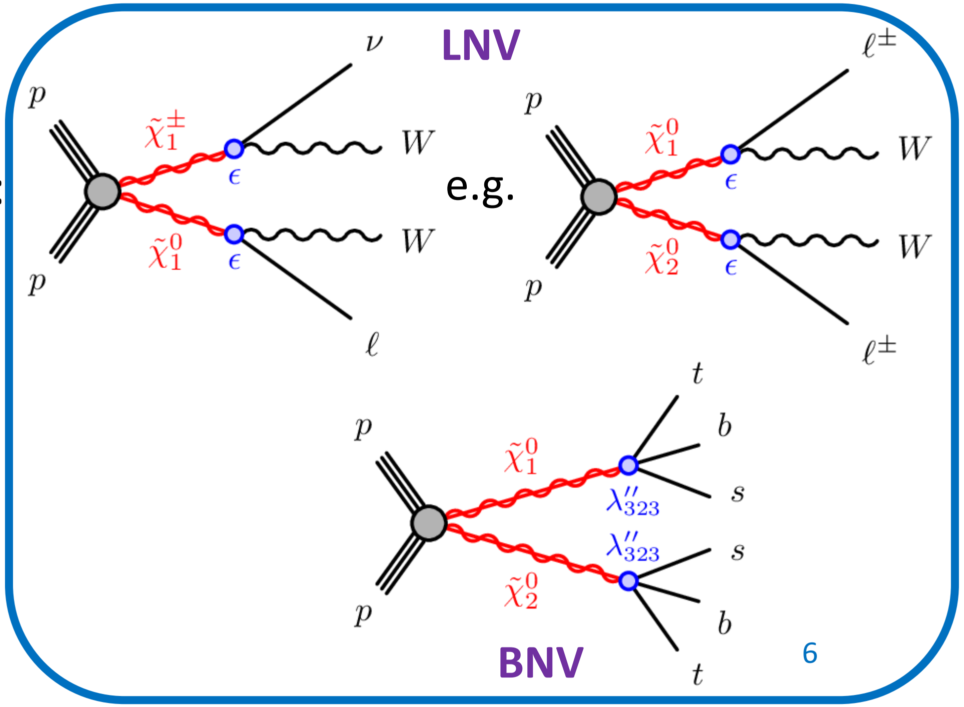
Ewkinos: two same-sign or three leptons

SS/3L: arXiv-2305.09322

- RPC scenarios
  - wino-like NLSP $\tilde{\chi}_1^{\pm}\tilde{\chi}_2^0$ pairs decaying to on-shell Wh/WZ bosons and bino-like LSP $\tilde{\chi}_1^0$
  - $W^{\pm} \rightarrow l^{\pm}\nu_l$, $Z \rightarrow l^{+}l^{-}$
  - In the Wh channel, all possible h decays that result in 1L final state are considered

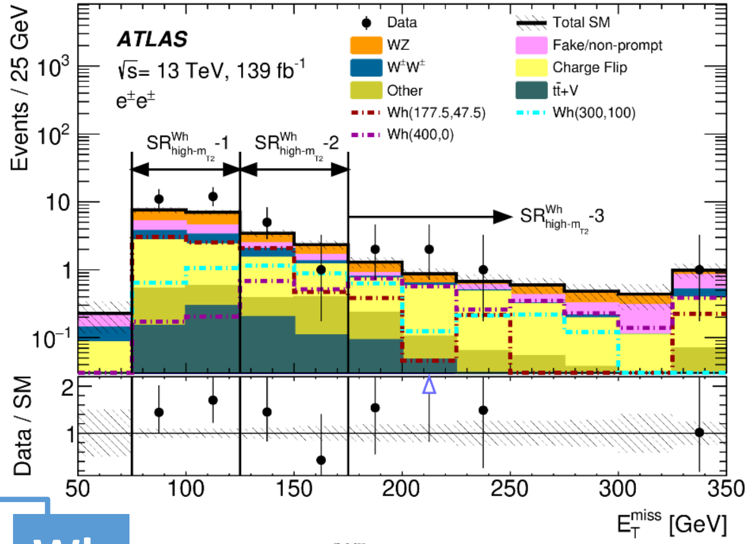


- RPV scenarios
  - Production of light higgsino-like $(\tilde{\chi}_1^{\pm}, \tilde{\chi}_1^0, \tilde{\chi}_2^0)$ pairs, with:
    - Bilinear (ϵ) RPV decays (inclusive): **LNV**
      - motivated by connection with neutrino physics (see-saw)
    - UDD trilinear (λ''_{323}) RPV decays: **BNV**
      - BNV featured in GUTs and models with black holes
      - necessary to describe the observed baryon asymmetry
  - Inclusive; dominant prods: $\tilde{\chi}_1^{\pm}\tilde{\chi}_1^0, \tilde{\chi}_1^{\pm}\tilde{\chi}_2^0, \tilde{\chi}_1^0\tilde{\chi}_2^0, \tilde{\chi}_1^{\pm}\tilde{\chi}_1^{\mp}$



Ewkinos: two same-sign or three leptons

- Signature
  - **Trigger**: 2 leptons ($p_T^{\mathrm{Thr}} \sim 20$ GeV) OR E_T^{miss}(> 250 GeV)
  - 2L SS (3L SR for bRPV model), ≥ 1 jet
- Optimized Signal Regions

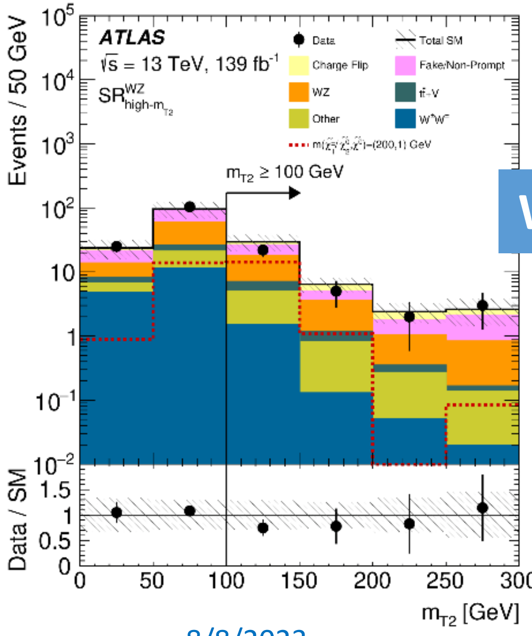


Wh

$e^{\pm}e^{\pm}$, $e^{\pm}\mu^{\pm}$, $\mu^{\pm}\mu^{\pm}$

Low and high m_{T2} (E_T^{miss} binned) scenarios

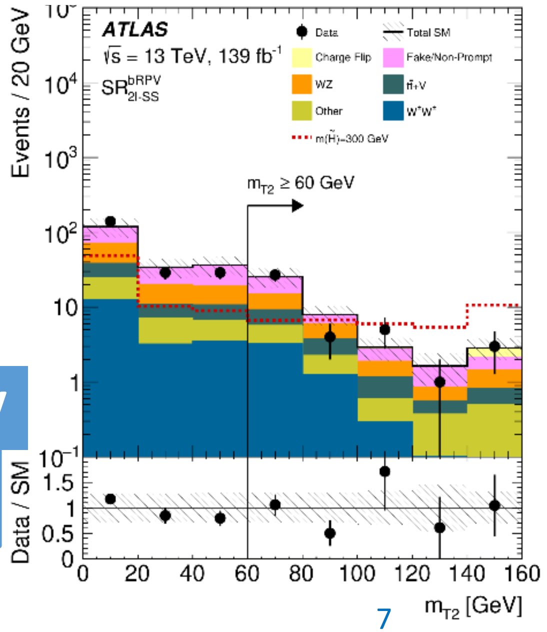
Using m_{jj}, m_{T2}, E_T^{miss}, E_T^{miss}significance, m_T^{min}



WZ

Low and high m_{T2} (E_T^{miss} significance binned) scenarios

Using m_{T2}, m_T^{min}, E_T^{miss}, m_{eff}, E_T^{miss}significance, ΔR_{ll}, Spread(ϕ)



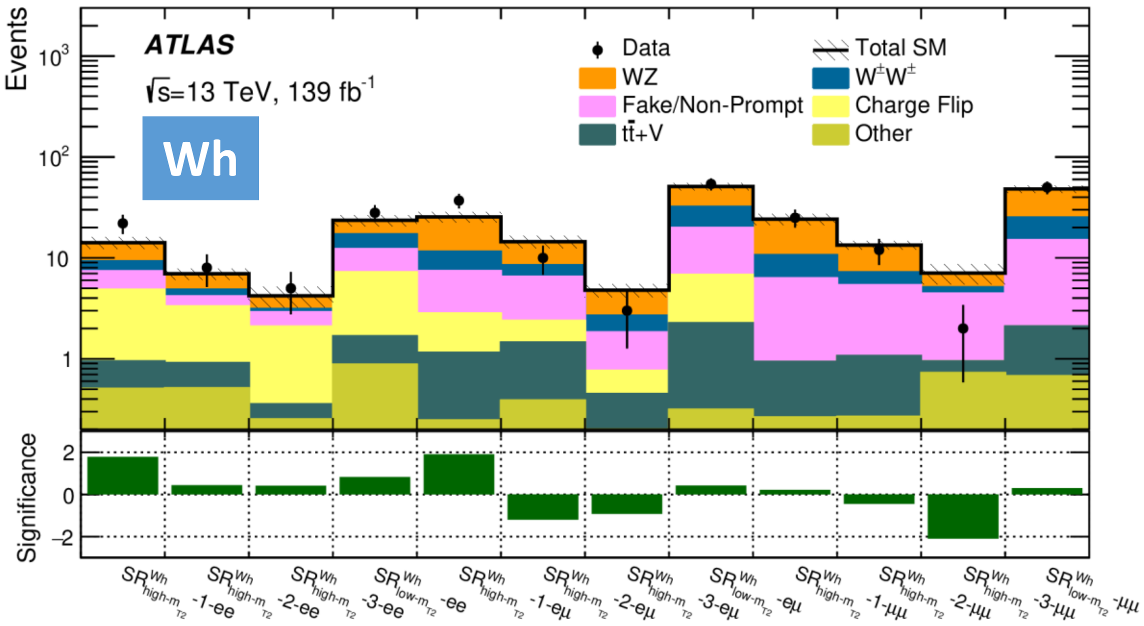
bRPV

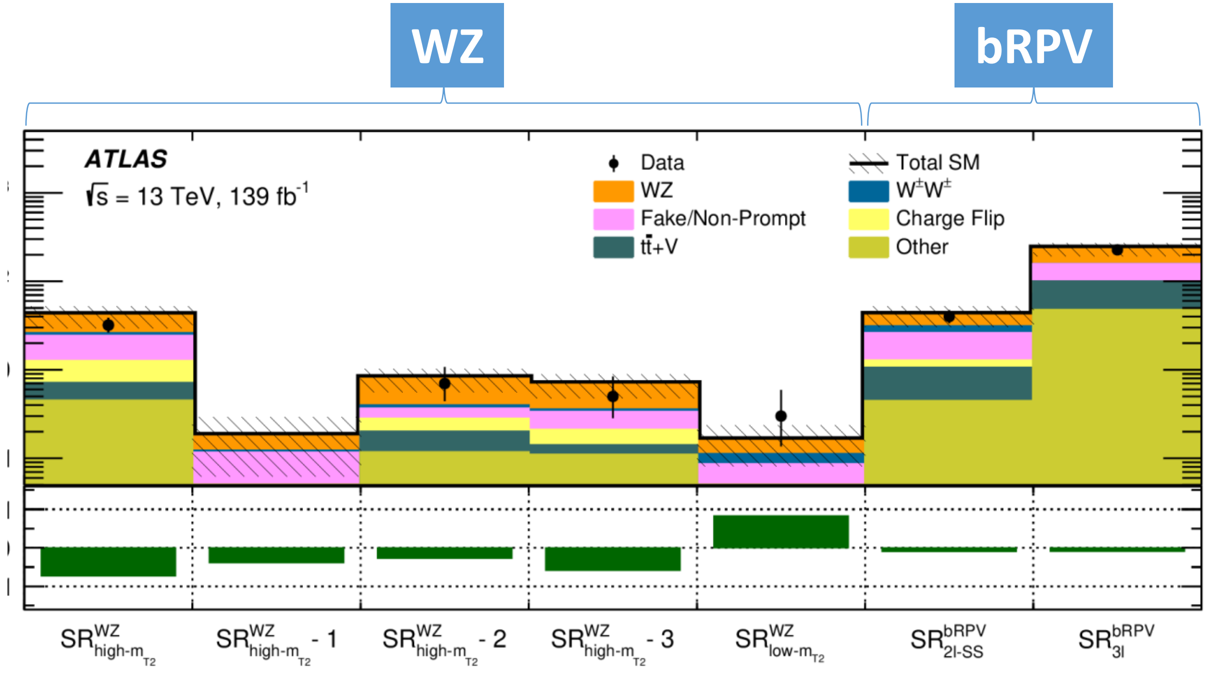
$\left.\begin{array}{l}\text{2L-SS: } \geq 4 \text{ jets} \\ \text{3L: Z veto}\end{array}\right\}$ High m_{T2}, E_T^{miss}

Ewkinos: two same-sign or three leptons

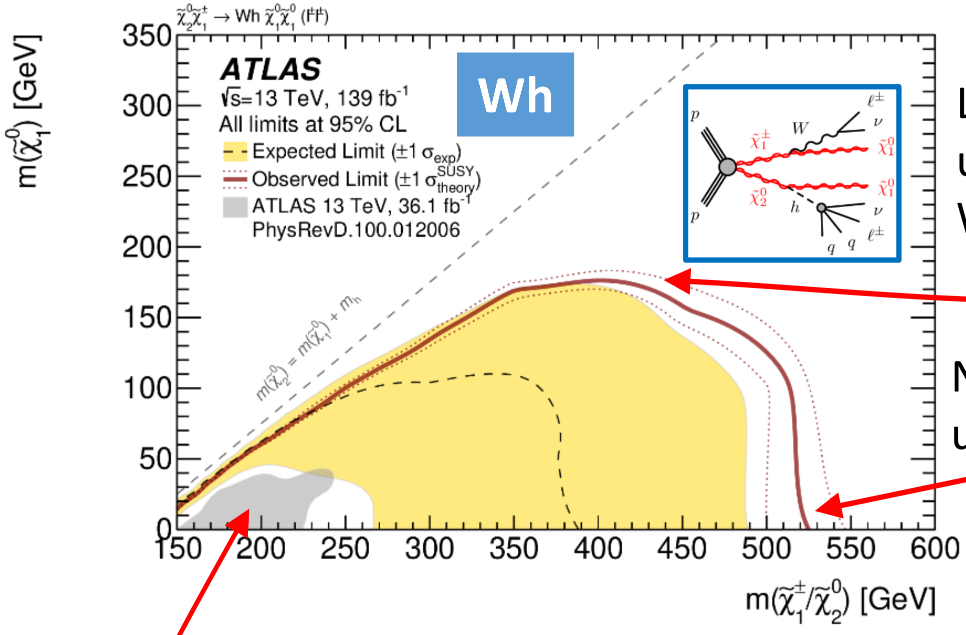
SS/3L: arXiv-2305.09322

- Irreducible bkgs: WZ, W^+W^-; normalised to data in dedicated CRs
  Other rare SM processes: MC simulation
- Reducible bkgs: fake/non-prompt lepton, charge flip (in electron case)
  typically dominant; measured by data-driven techniques
- No significant excess observed in any of the optimized SRs, for all targeted signals





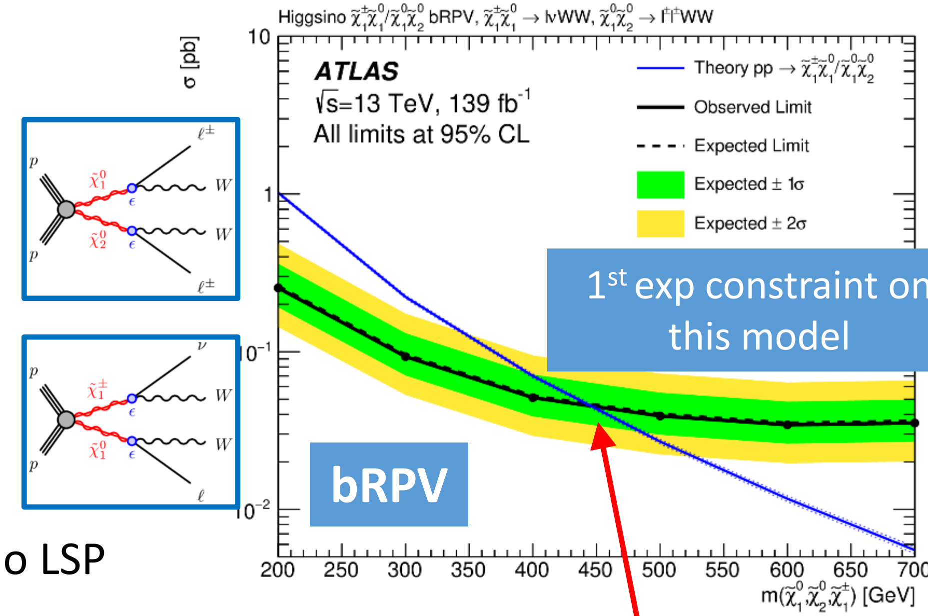
Ewkinos: two same-sign or three leptons



LSP bino mass excluded up to 180 GeV for NLSP Winos mass ~ 400 GeV

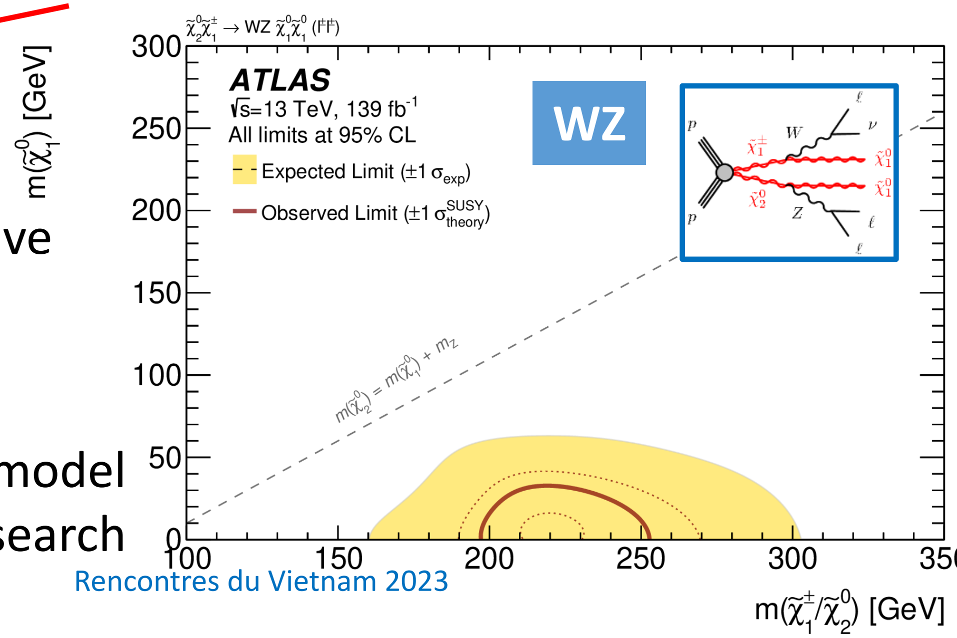
NLSP wino masses excluded up to 525 GeV for massless bino LSP

Large increase of exclusion zone relative to partial Run2 search (36 fb^{-1})



1st exp constraint on this model

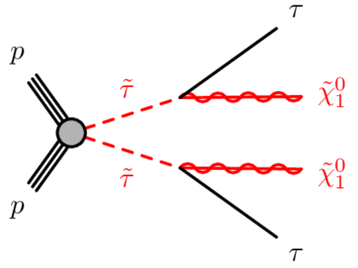
higgsino masses excluded below 440 GeV (assuming inclusive higgsino production and allowing all 1L sparticle decay modes)



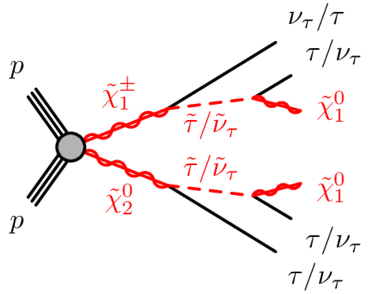
First sensitivity to this model using SS search

EWKinos and staus: two hadronic taus

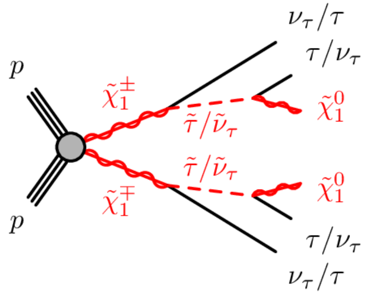
di-tau: ATLAS-CONF-2023-029



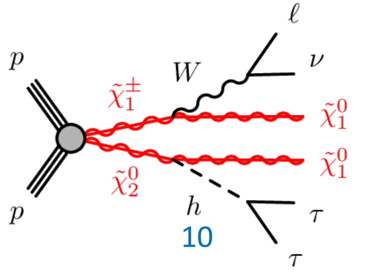
- Models
  - Direct stau
  - EWkinos (C1N2, C1C1) via intermediate stau decay
  - Ewkinos via Wh decay



- Event selection
  - BDTs to enhance sensitivity in “direct stau” search
  - In “intermediate stau decay”: treat separately SS/OS-lepton, low (LM) and high mass (HM)

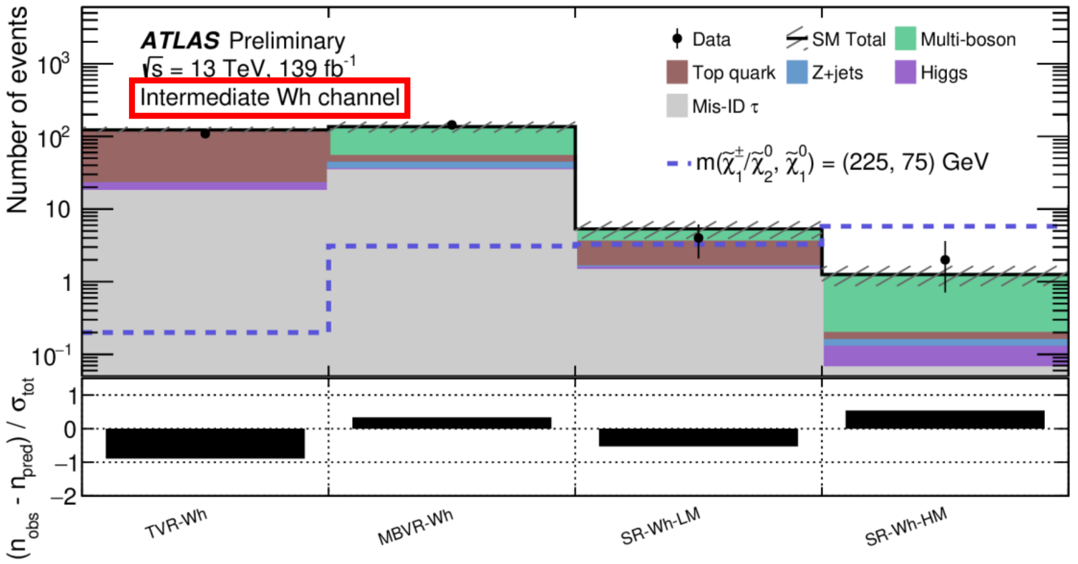


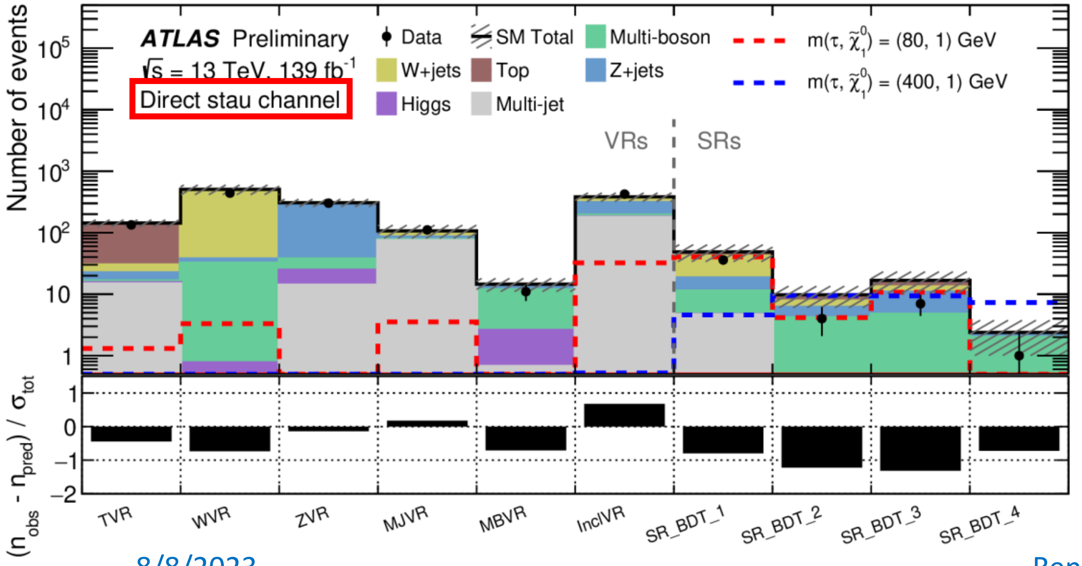
- Background estimation
  - Multi-jet background contributes to fake τ-leptons: data-driven approach
  - W/Z + jets, top: MC normalised to data in dedicated CRs
    - For Intermediate Wh channel, W/Z + jets bkg is estimated by data-driven technique
  - Multi-boson: dominant bkg in “Wh decay” channel, MC-estimated and checked in VRs

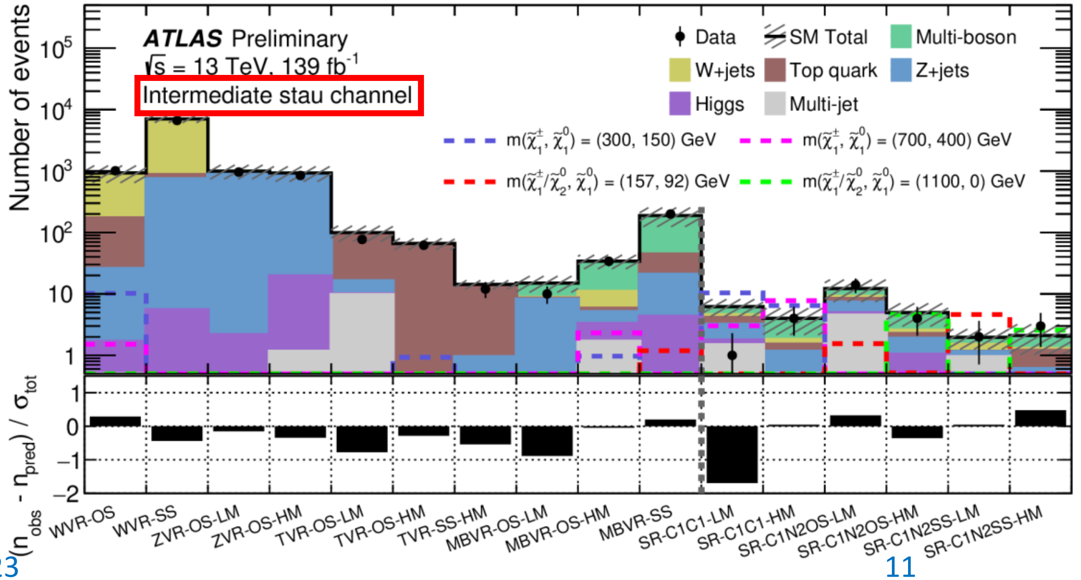


EWKinos and staus: two hadronic taus

- Data / SM expectation agreement within uncertainties in all SRs
- In "direct stau" channel, all BDT-SRs strongly overlap and show a common deficit (significance 0.7-1.3)
- In "intermediate stau / Wh" channels, the orthogonal SRs are statistically combined to get the best limits

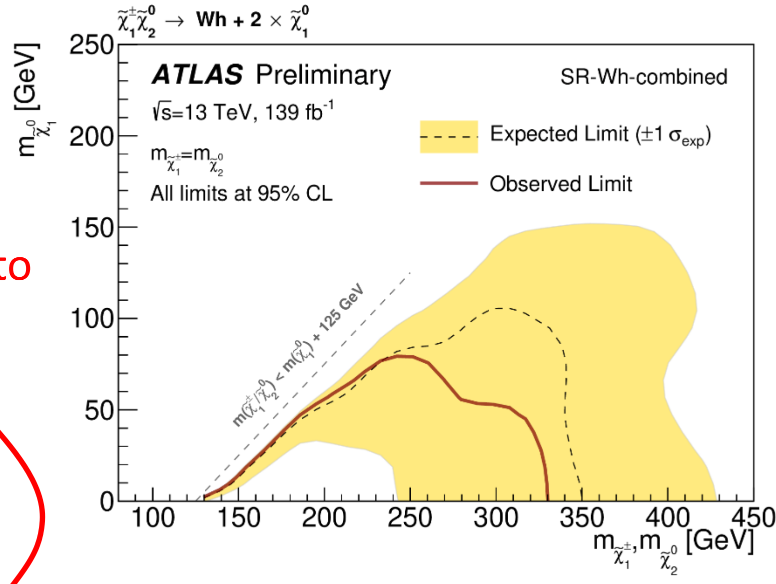


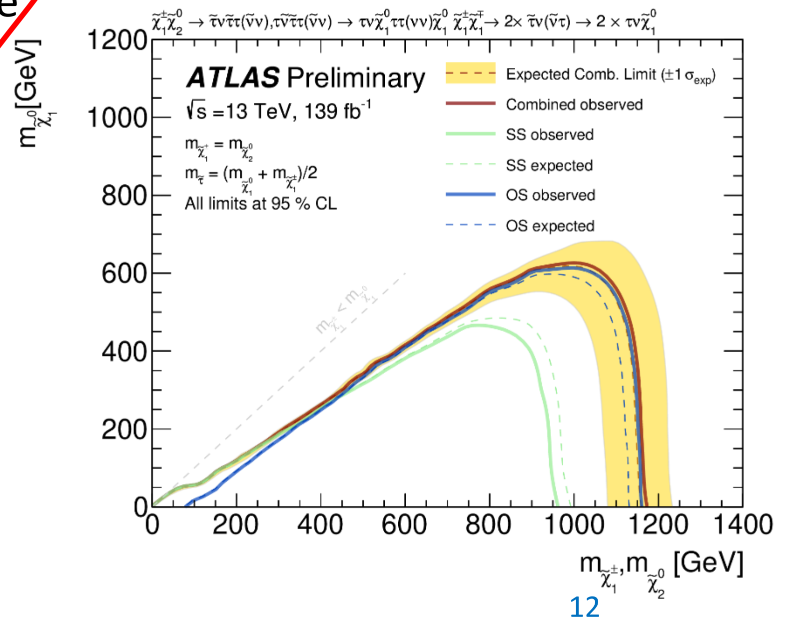


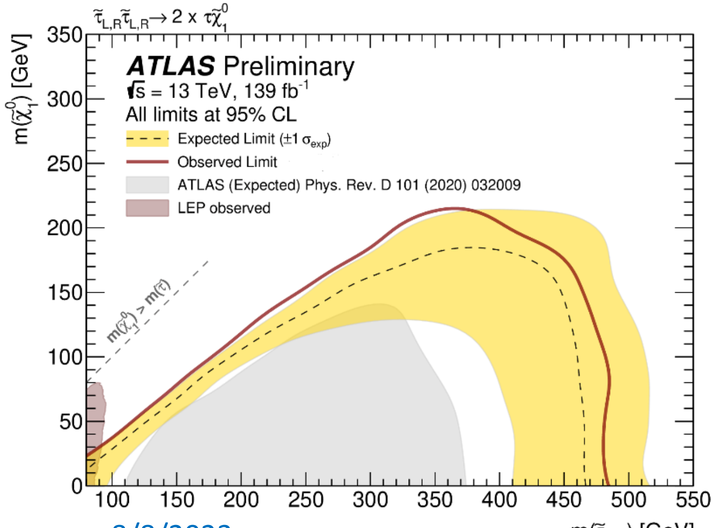


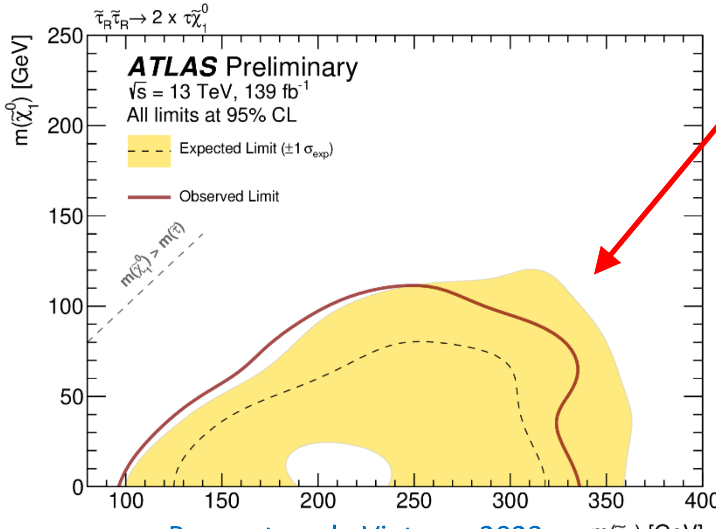
EWKinos and staus: two hadronic taus

- $\tilde{\tau}$ masses up to 480 GeV are excluded for mass-degenerate $\tilde{\tau}_{L,R}$ scenarios and up to 410 GeV for $\tilde{\tau}_L$-only scenarios
- The first sensitivity to $\tilde{\tau}_R$-only scenarios is presented, with $m(\tilde{\tau}_R)$ excluded up to 330 GeV
- Gauginos masses up to 1.16 TeV are excluded for a massless LSP in “intermediate stau” search
  - Improvements coming from recurrent neural network on τ identification
- Gauginos masses smaller than 330 GeV are excluded for a massless LSP for the “intermediate Wh” model





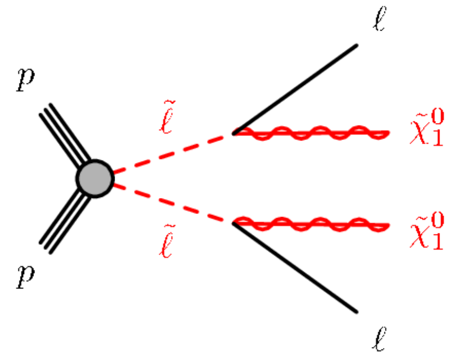


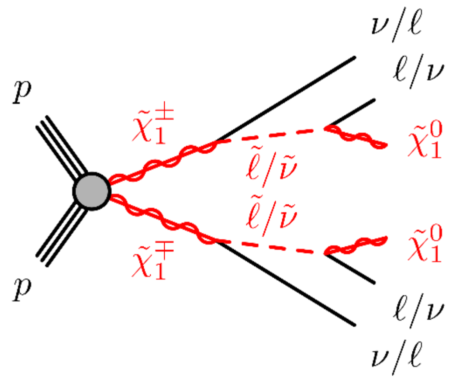


EWKinos and sleptons: two electrons or muons

2L0J: JHEP 06 (2023) 031

- Search for sleptons and charginos direct production with 2 OS leptons and $E_{\mathrm{T}}^{\mathrm{miss}}$
  - EW-scale SUSY with light smuons ($\tilde{\mu}$) and a light LSP ($\tilde{\chi}_1^0$) can explain the $(g-2)_\mu$ anomaly with additional loop corrections
  - For small $\tan\beta$, the $(g-2)_\mu$ anomaly favours the 'moderately compressed' or 'compressed' regions where $m(\tilde{\mu}) - m(\tilde{\chi}_1^0)$ is close to or smaller than W-boson mass
- Event selection
  - Separate same-flavour (SF) and different-flavour (DF) leptons in the final states
  - Slepton scenario: SRs binned in m_{T2} with SF leptons selections
  - Chargino scenario: SRs defined in bins of BDT output for both DF and SF events
- Background estimation
  - Data driven technique used to estimate flavour symmetric backgrounds (FSB) in slepton scenario
  - Dedicated CRs defined for top and diboson (VV) processes in chargino model



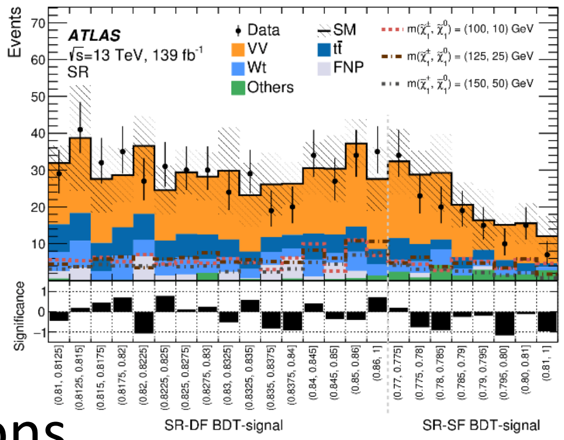


EWKinos and sleptons: two electrons or muons

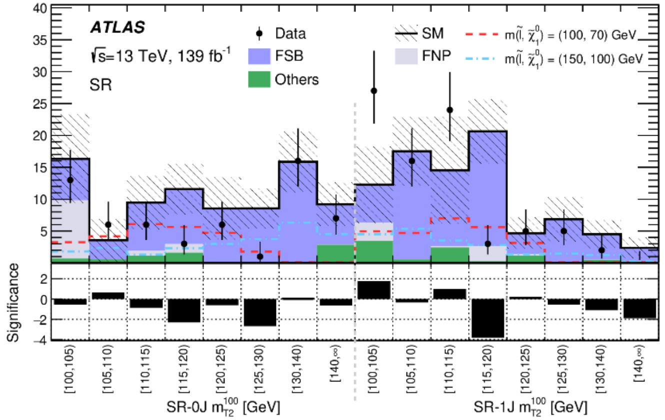
2L0J: JHEP 06 (2023) 031

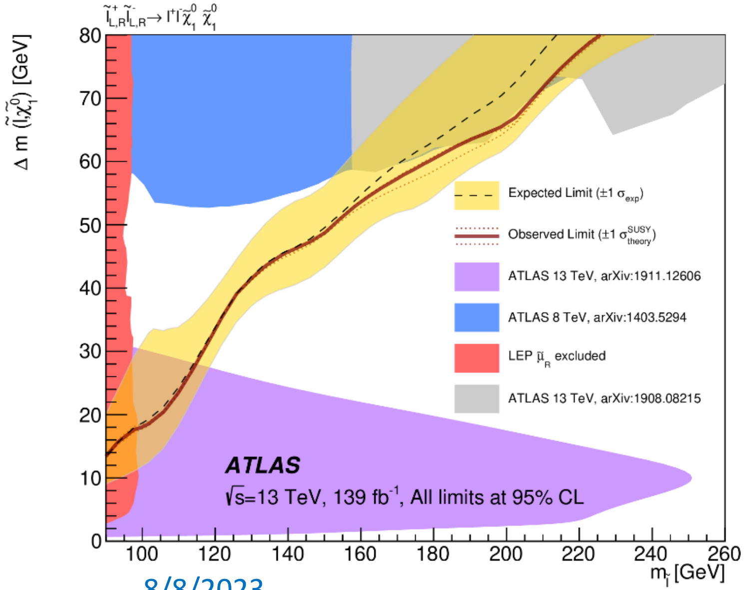
- Data are consistent with the SM predictions
  - 3.5 σ local data deficit in slepton SR is strictly correlated with statistical fluctuations
  - Extend the limits in low to moderate mass difference region between slepton or chargino and neutralino

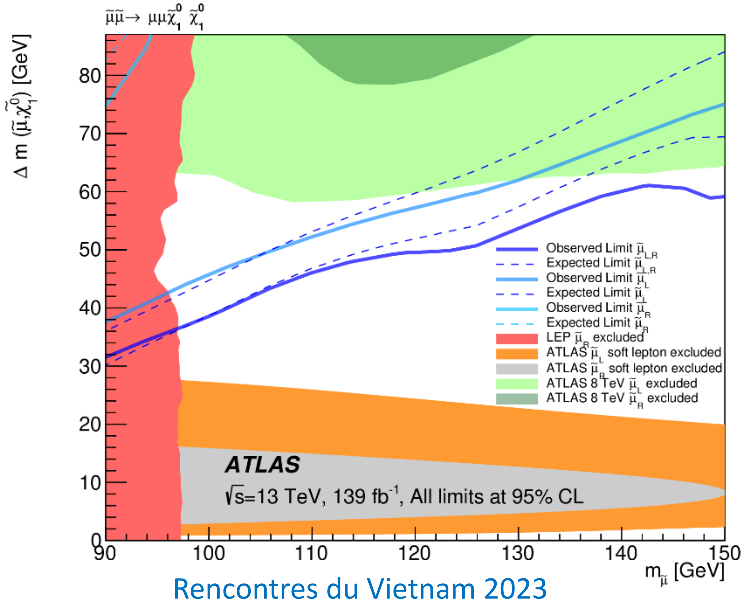
EWkinos

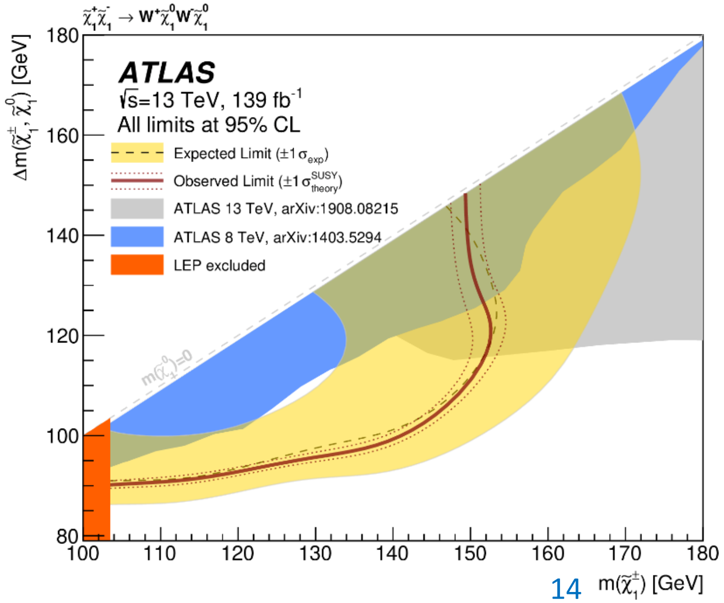


sleptons









Summary

- EWK SUSY searches are experimentally challenging
- No significant excess observed on top of SM predictions, stringent exclusion limits placed on the parameter space for sleptons and gauginos
  - First limits set on $m(\tilde{\tau}_R)$ at the LHC!
  - O(100) GeV - O(1) TeV slepton is still highly motivated
  - Chargino/neutralino mass excluded up to ~ 1TeV
- Looking forward to Run 3 results: Stay tuned!