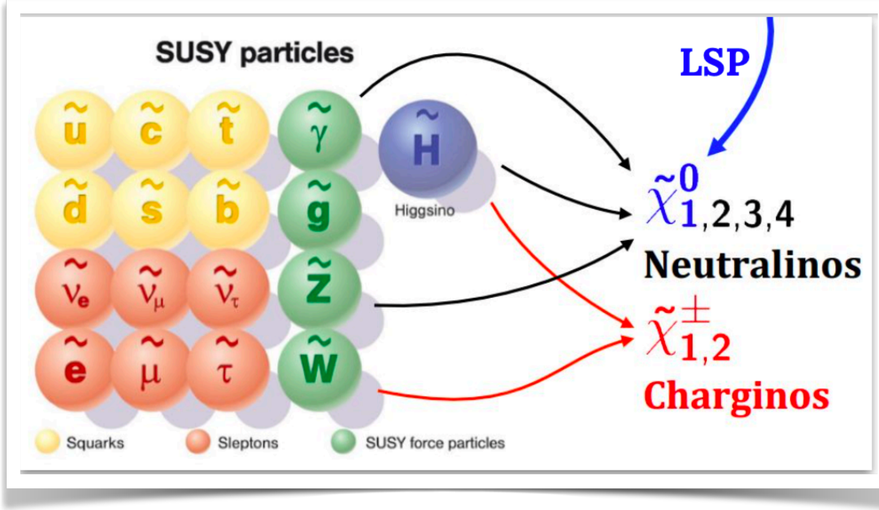
Electroweak SUSY Searches in ATLAS

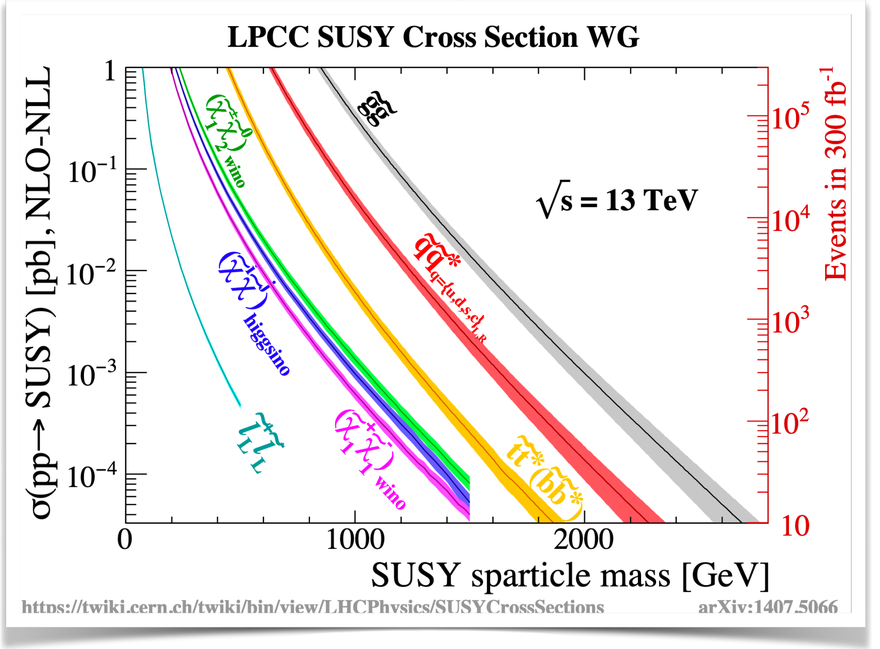
Phenomenology 2021 (24-27 May 2021, University of Pittsburgh)

Batool Safarzadeh (University of Sussex)

Supersymmetry

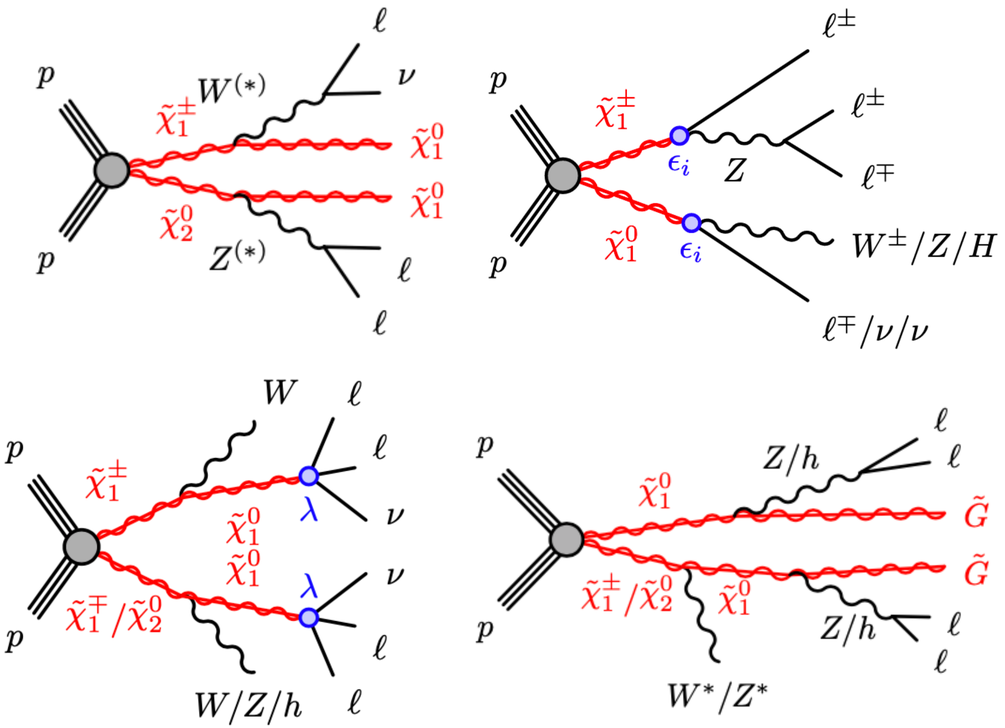
- Supersymmetry (SUSY) predicts a super-partner for every SM particle, spin differs by 1/2
- Why Supersymmetry?
  - Lightest SUSY particle in R-parity conserving models:
    - **viable dark matter candidate**
  - Can solve hierarchy problem, …
- Mass reach for strong production higher than for electroweak production but current limits have pushed them beyond the TeV scale
  - Naturalness requires electroweakino mass near the EW scale
  - the EWK sector can account for the long-standing discrepancy of muon g-2
  - EWK searches could be the key in finding SUSY



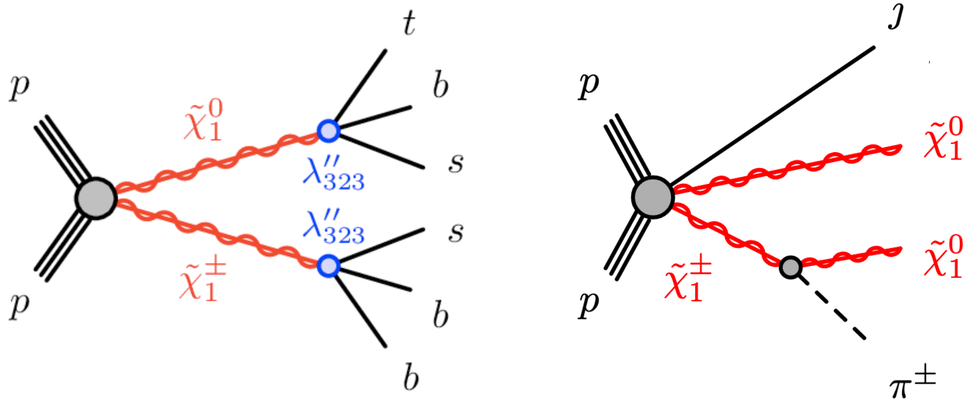


Search Strategy

- Systematic approach to cover all possible production and decay modes including dedicated searches targeting special scenarios
  - Compressed spectra, long- lived particles
- Address both R-parity conserving and violating models
- Main backgrounds are estimated from data in CRs
- Search results interpreted in context on the “Simplified Models”
  - A reduction of the complexity of full SUSY models

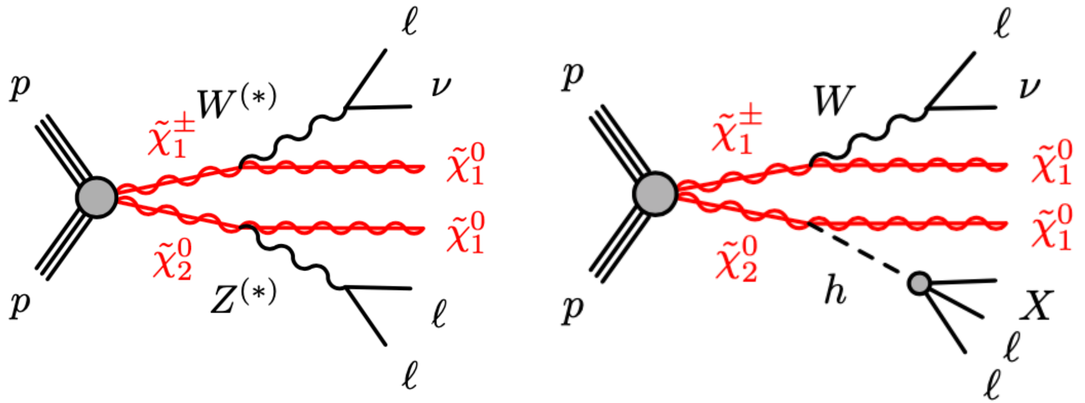


- RPC/RPV Scenarios:Covered in this talk:
  - 3L: CONF-2020-015
  - 4L: arxiv-2103.11684 (sub to JHEP)
  - 3/4 L RPV: arxiv-2011.10543 (Acc by PRD)
  - 1L/2LSS + Jets : CONF-2021-007
  - Disappearing track : CONF-2021-015

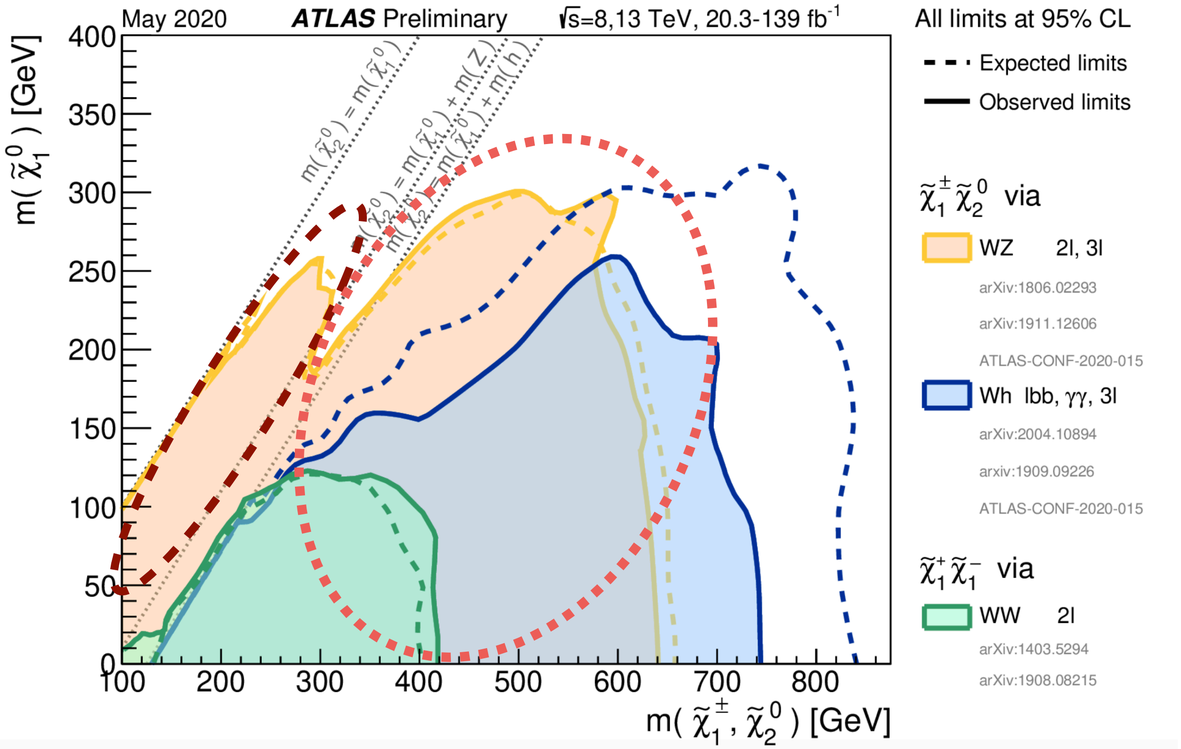


3 Leptons search (RPC)

- Chargino-neutralino pair production
  - intermediate *WZ* or *W*h (SM Higgs)
  - bino-like LSP, wino-like NSLP
- On-shell *WZ*
  - Covering high/moderate $\Delta m(C\,1, N\,1) \geq mZ$
  - OSSF pair with mll ∈[75,105] GeV
  - SR binning in m_T (W decay) & E_T^{miss}
- **Off-shell *WZ***
  - Expanding analysis to low $\Delta m(C\,1, N\,1) <$ mZ
  - kinematic edge at $m_{ll}^{min} = \Delta m$ & in m_{T2}^{100}
  - SR binning in E_T^{miss} and jet multiplicity
- ***W*h**
  - SFOS pair with mll∉[75,105] GeV
  - DFOS pair, selecting events with close-by leptons

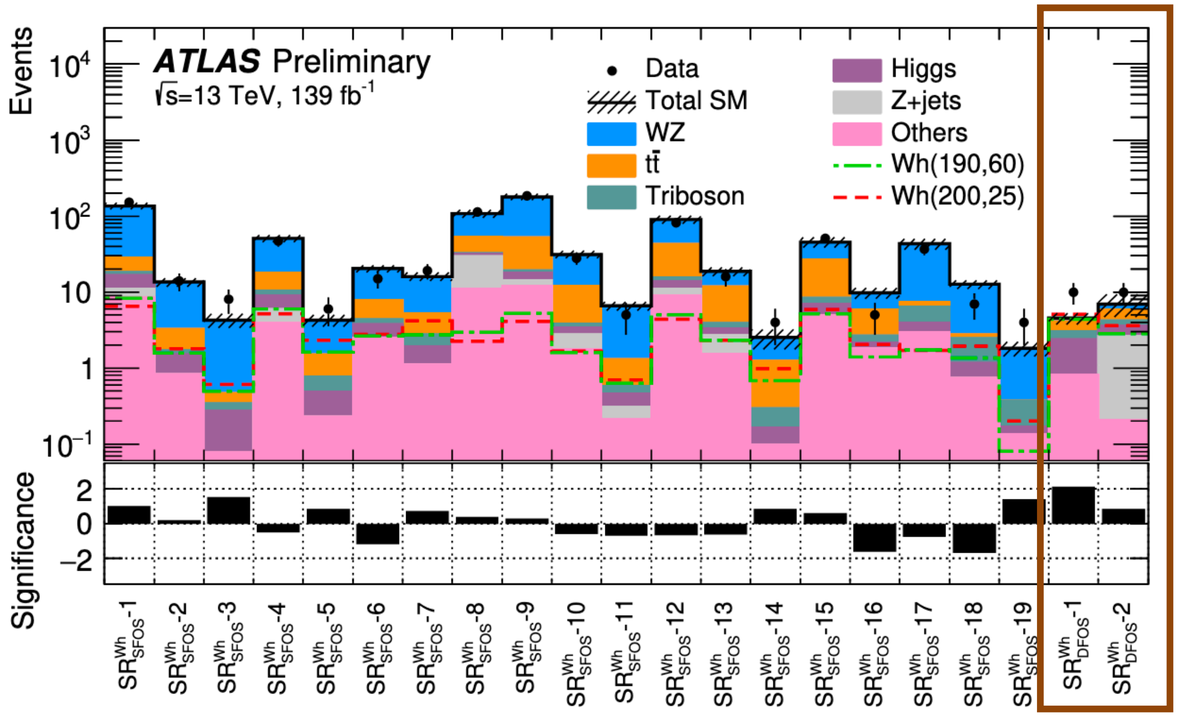


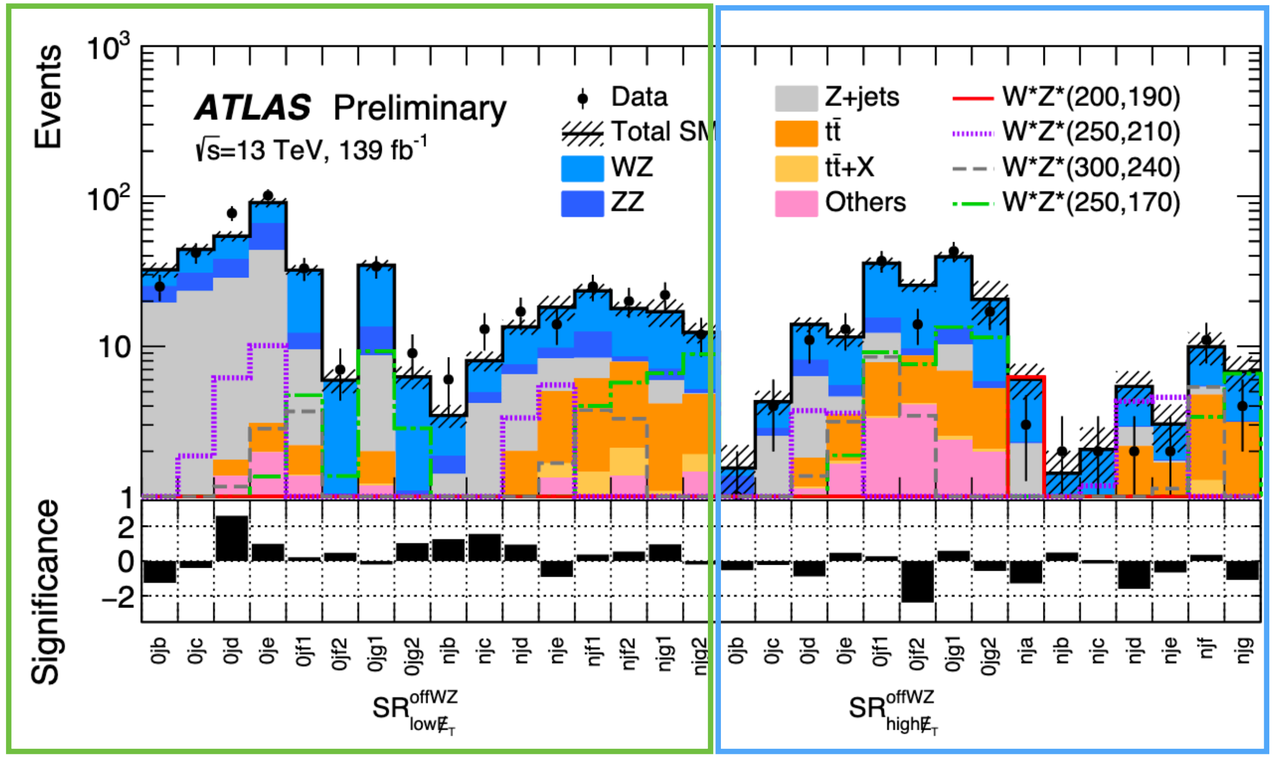
3l (e, μ) + MET final state



3 Leptons Search (RPC)

- Diboson WZ:
  - dominant background, estimated using MC normalised to data in the CRs
- Z/γ+jets:
  - non-prompt lepton background, estimated using data-driven method



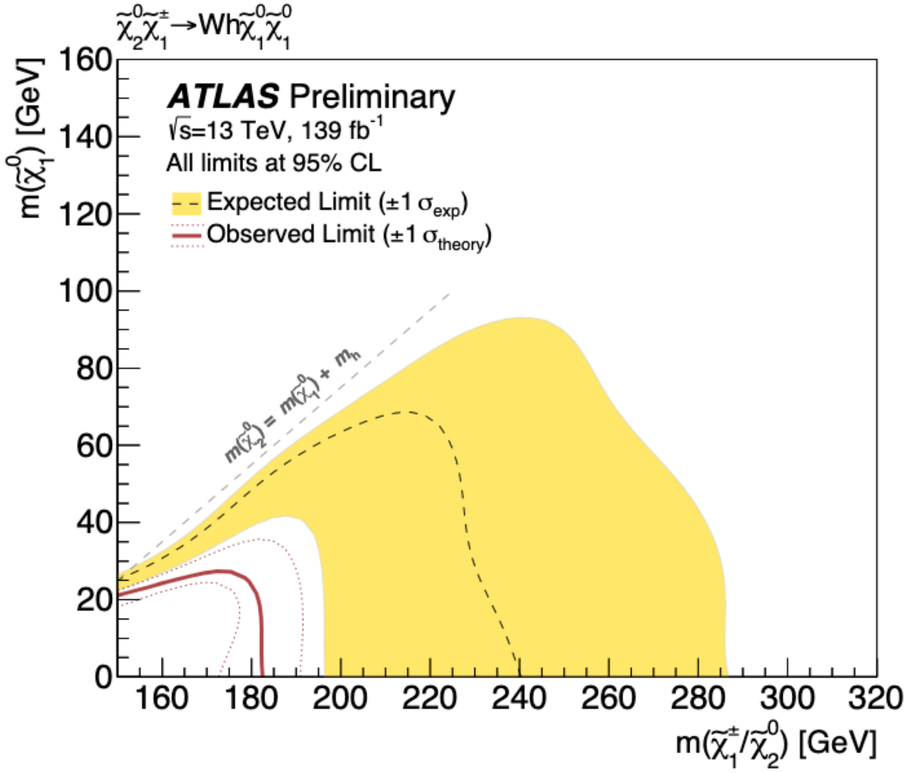


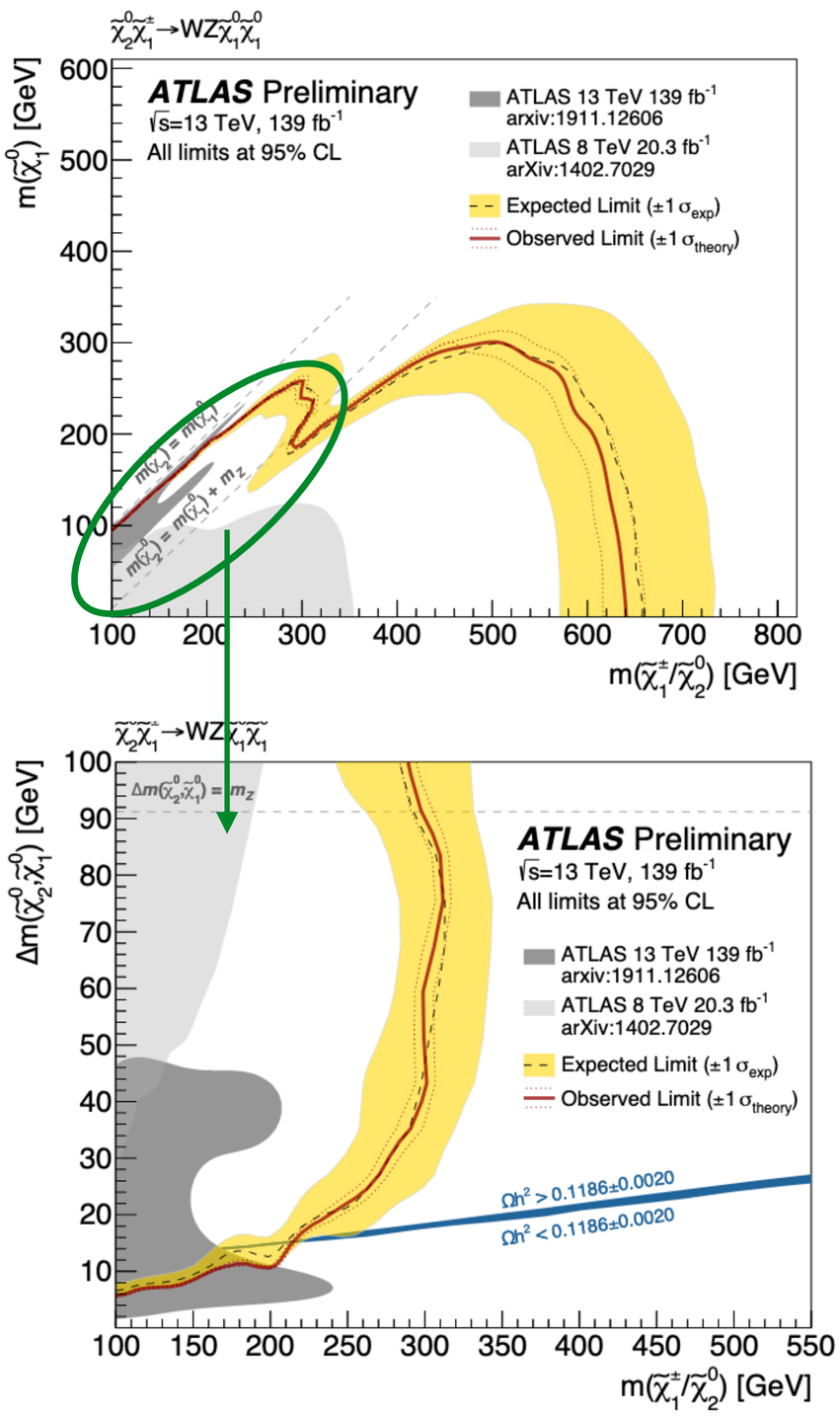
- SRs targeting moderate mass splittings, Δm = 40 - 90 GeV
- High E_T^{miss} SR : highly compressed mass spectra, Δm < 40 GeV

- DFOS:
  - Strong signal sensitivity, main backgrounds from tt^-, VVV, and Higgs processes

3 Leptons Search (Interpretation)

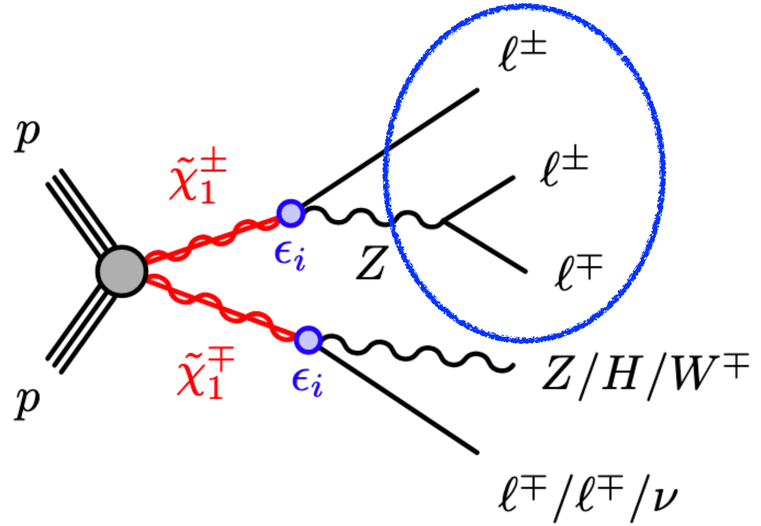
- No significant excess
  - **WZ Scenario**
    - constraints are calculated in the bino-wino co-annihilation dark-matter scenario where $\Omega_{DM}h^2 \leq$ the observed value
  - **Wh Scenario**
    - weaker observed exclusion limit due to 2 σ in DFOS SR

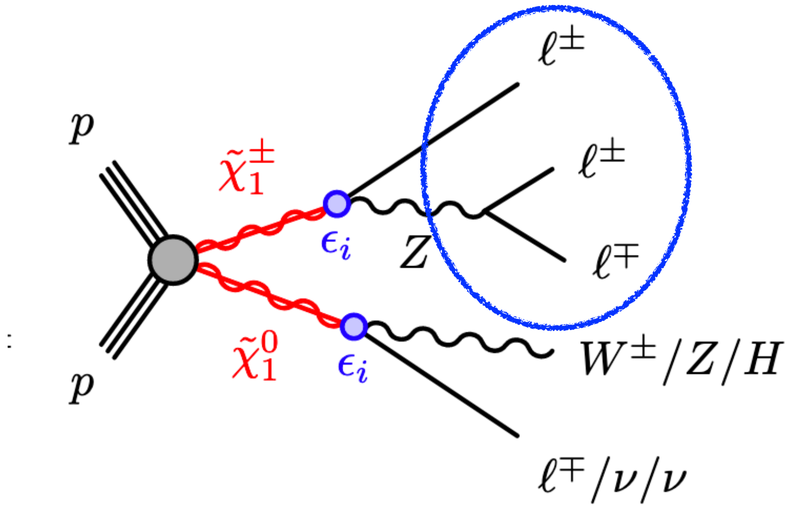




3/4 Leptons Serach (RPV)

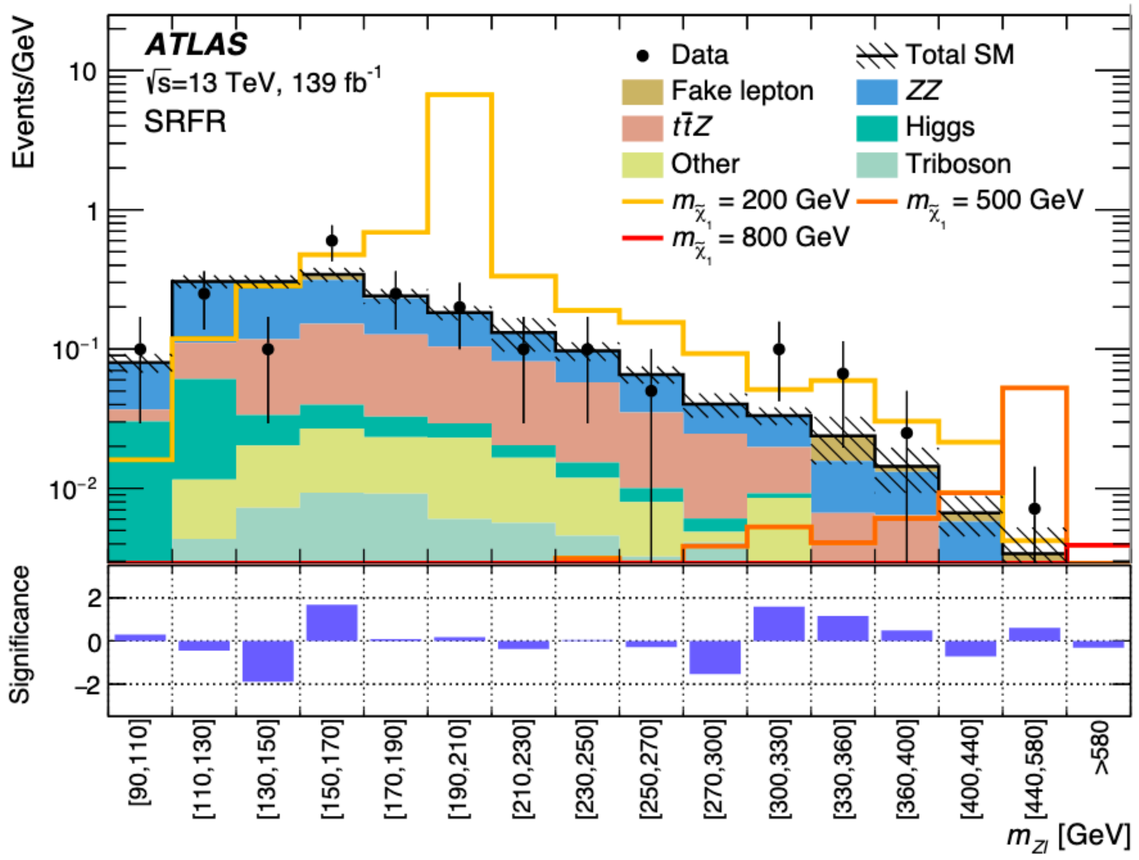
- SUSY MSSM with $U(1)_{B-L}$ symmetry & 3 RH (s) neutrinos
  - R-parity via sneutrino VEV
  - wino-type $\tilde{\chi}^{\pm}_1$ /$\tilde{\chi}^{0}_1$ are likely LSPs
  - C1/N1 Mass-degenerated, both RPV decay
- **Analysis Strategy**
  - Tri-lepton (l+Z(ll)) to identify chargino decays
  - Primary discriminates: m_T^{min}, E_T^{miss}
  - **SR**
    - SRFR : event is fully reconstructed (2nd C1—>lZ(qq))
    - SR4L : 4 Leptons (2nd $\tilde{\chi}^{\pm}_1$—> vW(lv))
    - SR3L : 3 Leptons (2nd $\tilde{\chi}^{\pm}_1$—> vW(qq))
  - **BKG**
    - WZ, ZZ & ttZ : estimated using MC normalised to data in the CRs
    - Non-prompt leptons: using the data-driven method





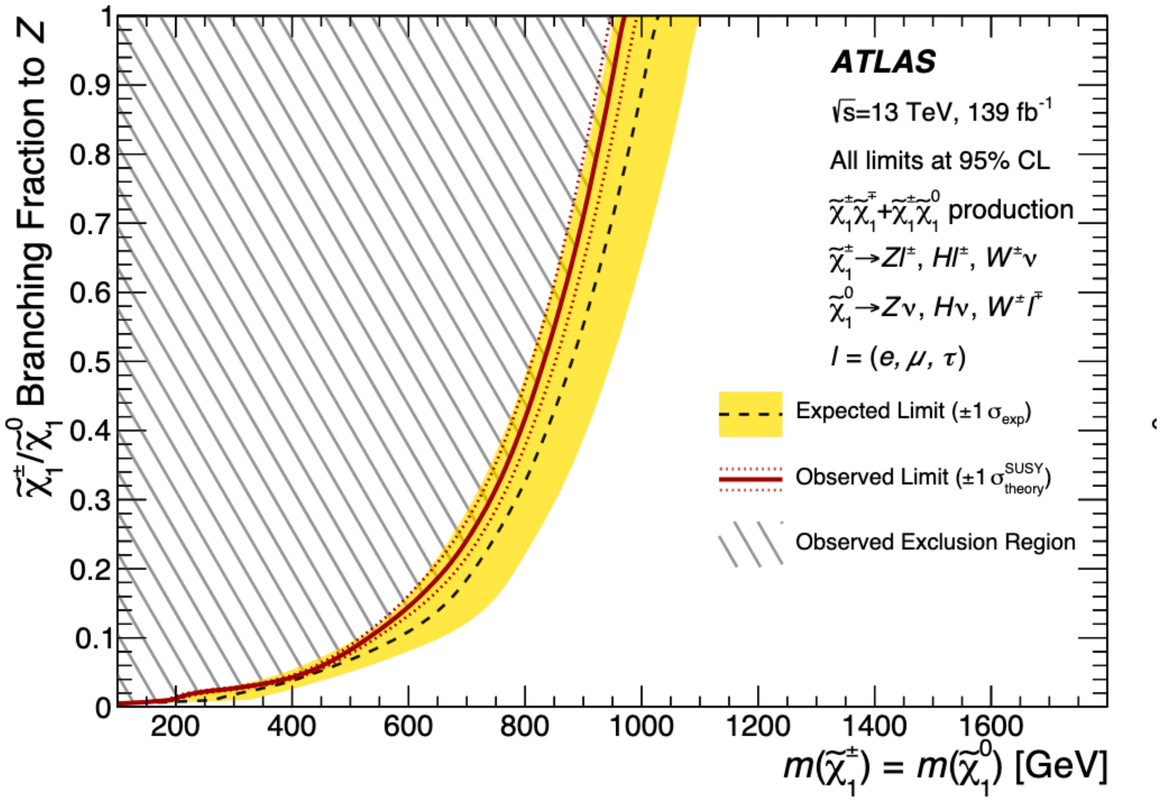
3/4 Leptons Search (Results & Interpretation)

- good data-prediction agreement across m_{Zl}



Limits on

mass × Br(Z) × Br(e,μ,τ)

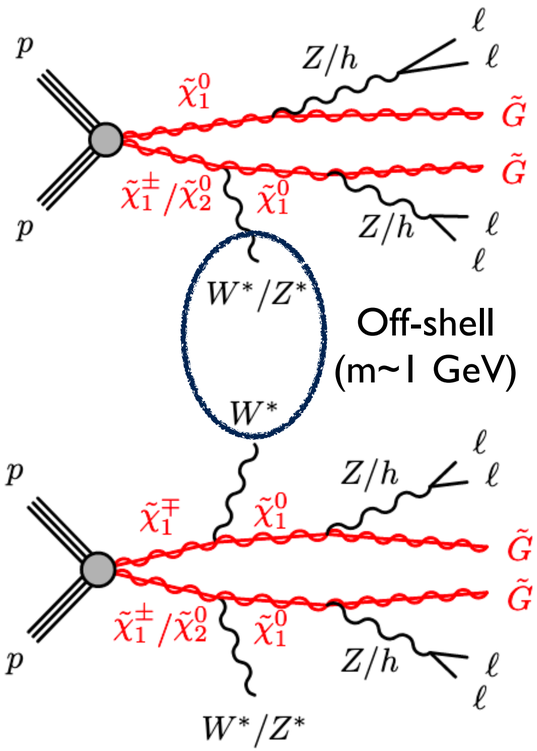


- $\tilde{\chi_1}^{\pm,0}$ → Z/W/H BR are scanned, no significant difference in sensitivity in relative W & H BR
- $\tilde{\chi_1}^{\pm,0}$ → e only, μ only, τ only (Back up) and equal e, μ & τ decays

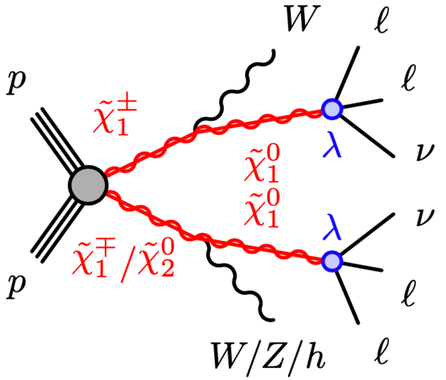
4 Leptons Search (RPC/RPV)

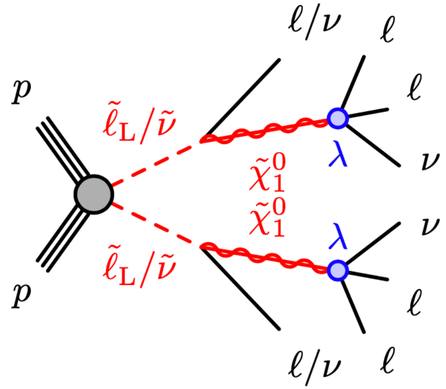
- **RPC**
  - Pure Higgsino $\tilde{\chi}^{\pm}_1, \tilde{\chi}^0_2, \tilde{\chi}^0_1$
    $m(\tilde{\chi}^{\pm}_1) = m(\tilde{\chi}^0_2) = m(\tilde{\chi}^0_1) + 1$ GeV
  - $\tilde{\chi}_1 \rightarrow Z/h\ \tilde{G}$
  - Vary $m(\tilde{\chi}^0_1)$ and $B(\tilde{\chi}^0_1 \rightarrow Z\tilde{\chi}^0_1)$
  - ≥ 4 Leptons (e, u, τ_{had}), ≥5 Leptons (new !)
- **RPV**
  - Pure Bino LSP $\tilde{\chi}^0_1$
    NLSP pair production: wino $\tilde{\chi}^{\pm}_1, \tilde{\chi}^0_1$, L/$\tilde{\nu}$, or $\tilde{g}$

RPC



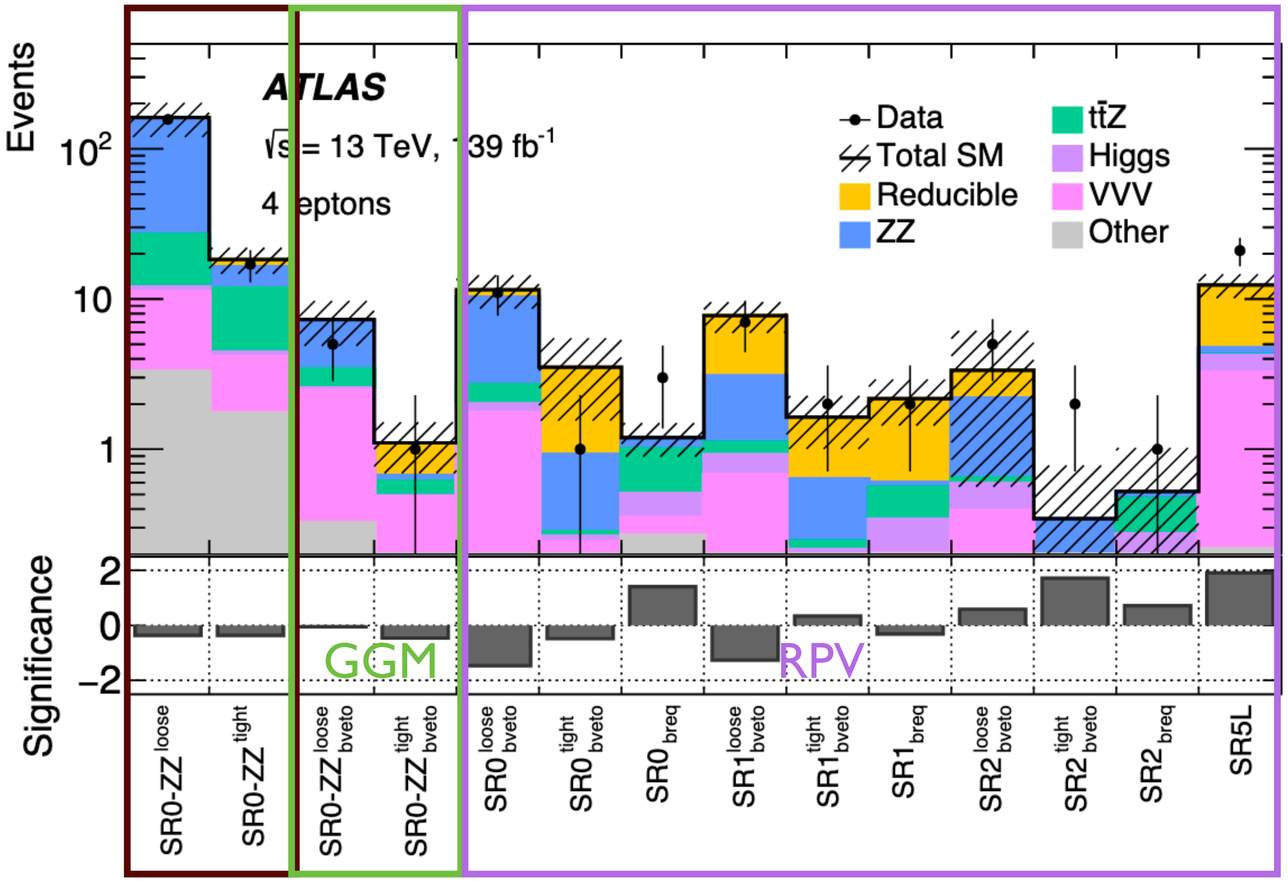
RPV

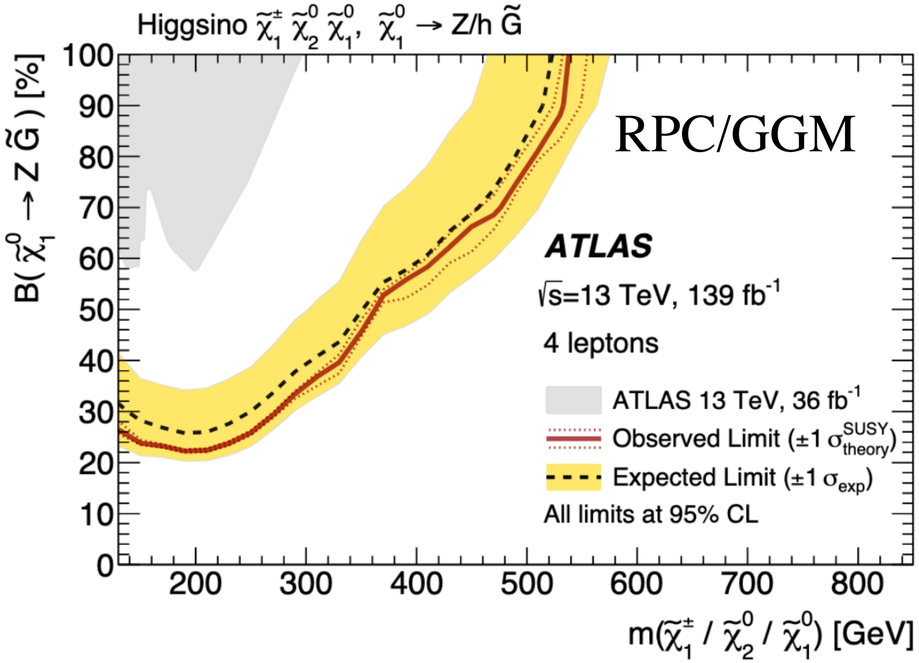


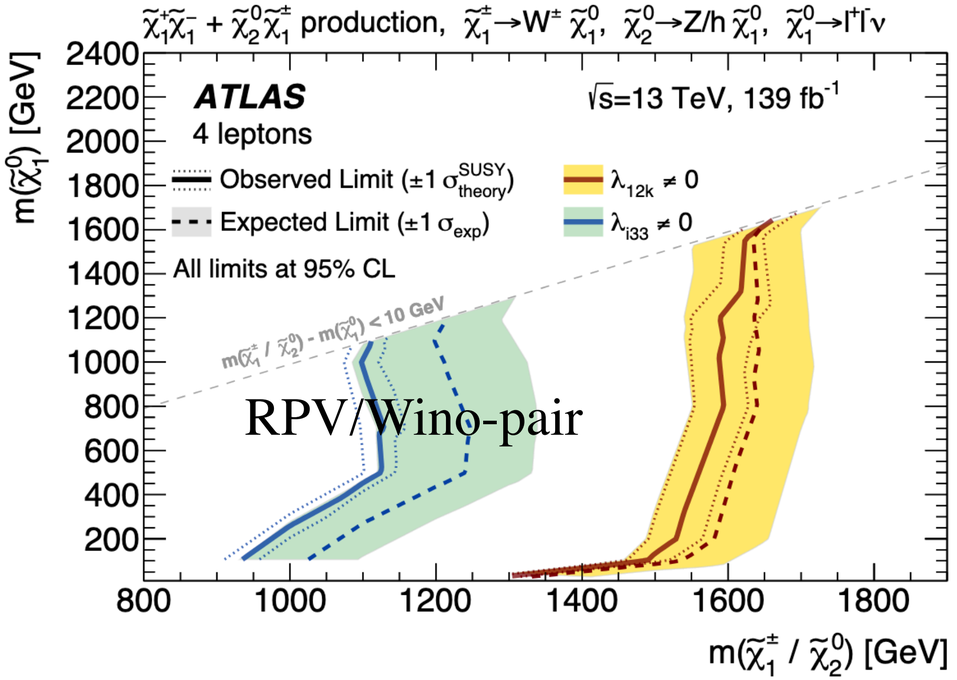


- Primary discriminates :Z-requirement, Number of τ_{had}, meff, loose/signal leptons
- **BKG**
  - *ZZ*, $t\bar{t}Z$: estimated from MC normalised to data
  - Non-prompt lepton background: estimated using data-driven method

4 Leptons Search (PRC/RPV)



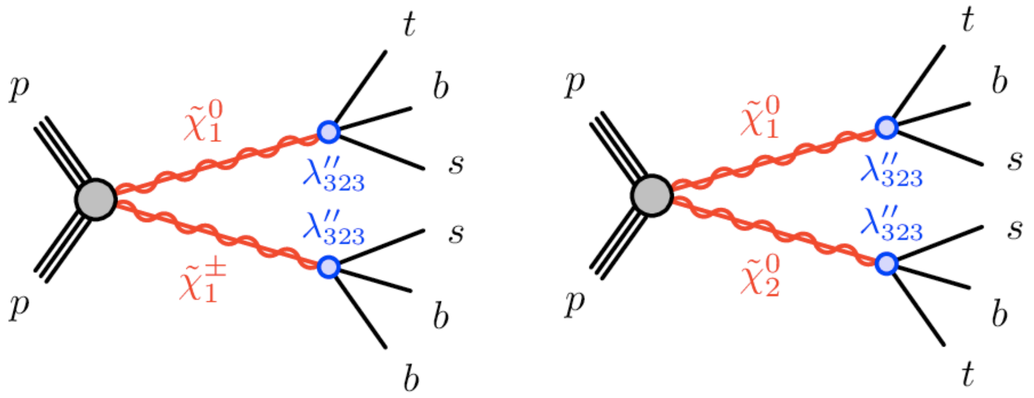


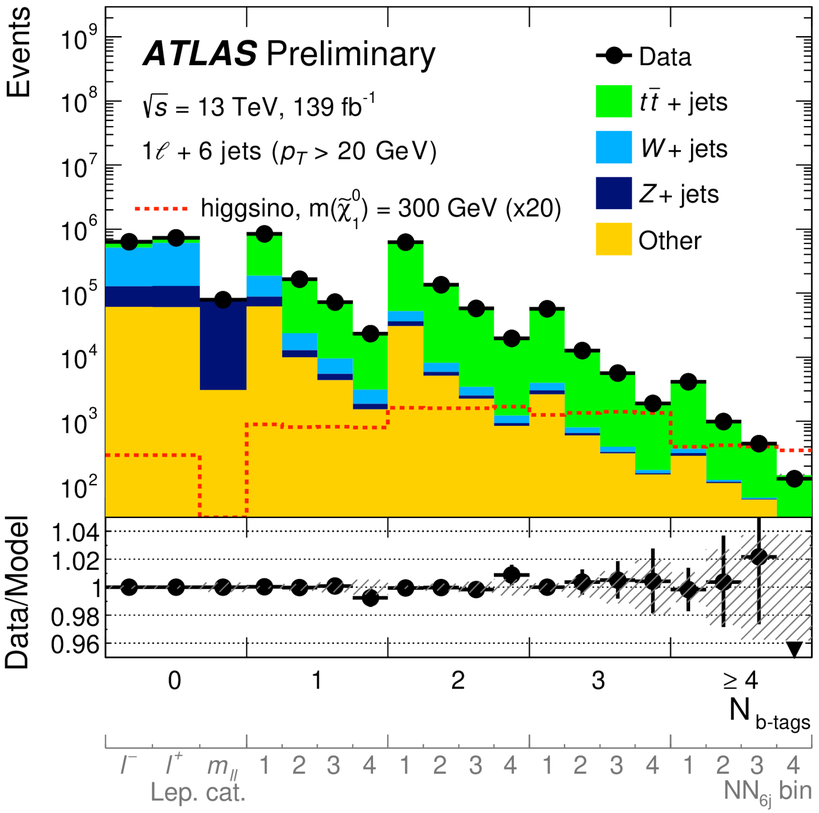


- SR0-ZZ^{loose}, SR0-ZZ^{tight} : follow up the excess observed in the analysis with 36^{-1} fb data (arxiv-1804.03602)
- No significant excess in SRs

Leptons + Jets (RPV)

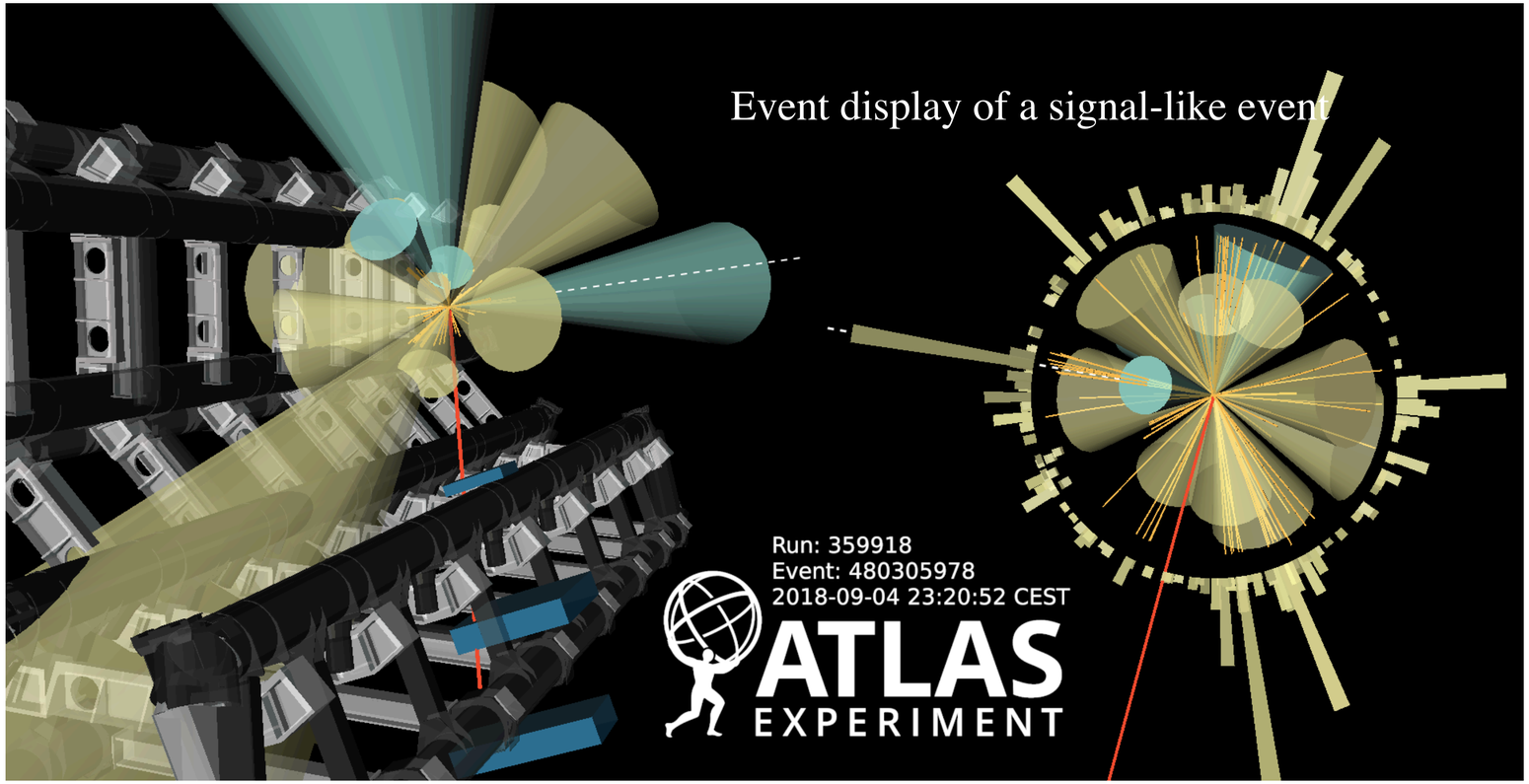
- **Signature & Strategy**
  - ≥1/SS Leptons + many (b-tag) jets
  - Cut & Count and NN-based SRs
    - NN SRs :
      - Essential to reach the sensitivity to higgsino signals
      - Designed to get similar output for different b-jet selections
- **BKG**
  - W+jets in 0 b-tag SRs, $t\bar{t}$ in ≥1 b-tag SRs, estimated using data-driven method
  - Main challenge : BKG estimation in the extreme N/b-jets regions
    - Jet multiplicity estimated using a parametrisation of the jet scaling
    - b-jet multiplicity extracted at low number of jets, and parametrised the evolution up to arbitrary jet multiplicity





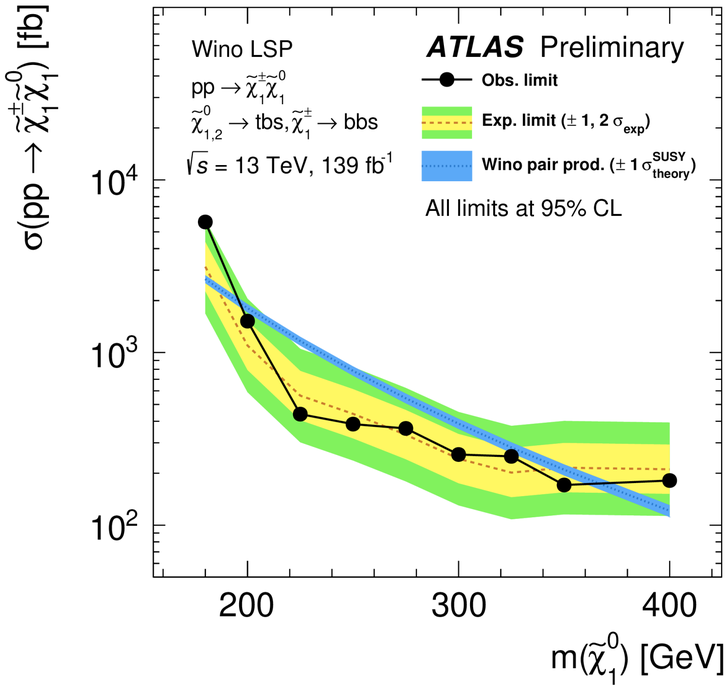
Leptons + Jets (Interpretation)

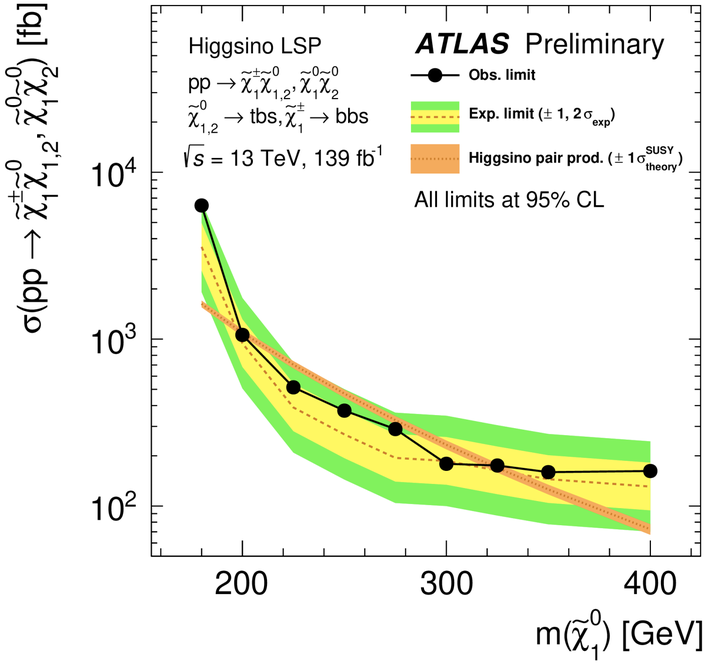
- No significant excess
  - Limits on EWK production with prompt RPV decay to quarks



Leptons +Jets (RPV) :

- 1 μ (p_T = 53 GeV)
- 15 jets (p_T = [21-182] GeV, 4 b-jets
- MET : 67 GeV

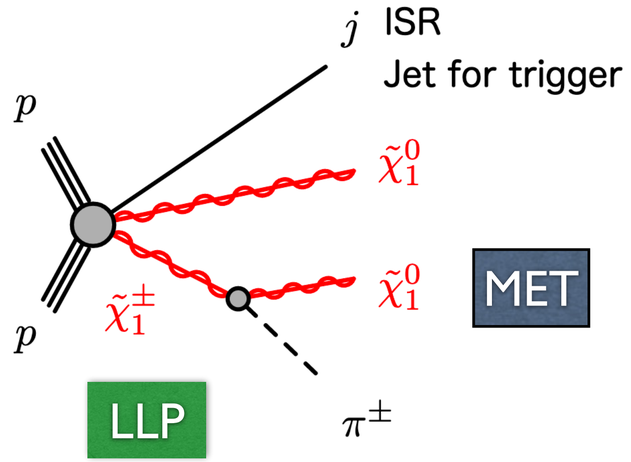


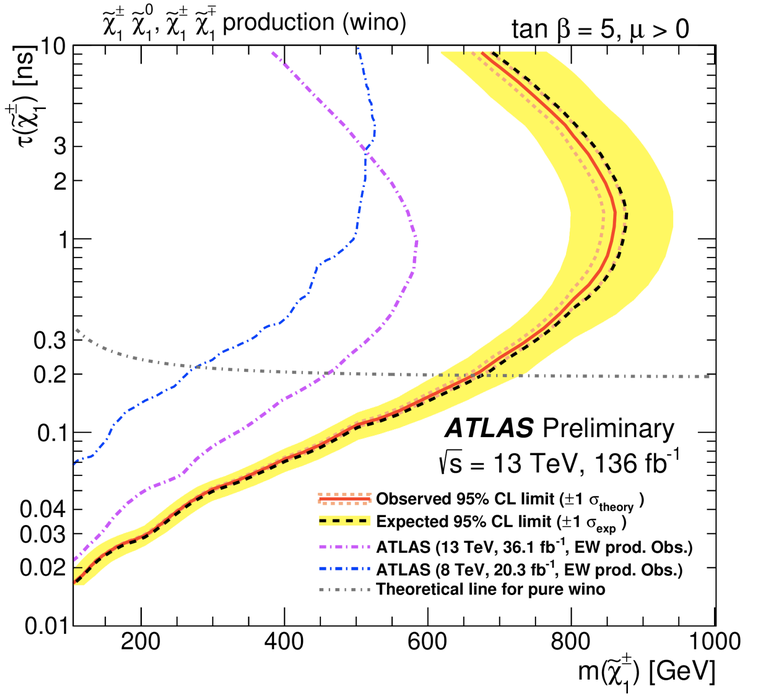


Disappearing track

more details in presentation by Jackson Burzynski

- Anomaly-Mediated Supersymmetry Breaking (AMSB)
  - $\Delta m(\tilde{\chi}^{\pm}_1, \tilde{\chi}^{0}_1) = O(100\ \text{MeV})$
  - wino LSP scenario, $\tilde{\chi}^{\pm}_1$ is LLP
- **Signature :**
  - large E_T^{miss} + single jet + disappearing track
  - Disappearing track :
    - tracklet with short track with only pixel hits, $p_T > 20$ GeV
- **BKG :**
  - Arising from scattering electrons, hadrons and muons, and fake tracks
    - Estimated using template methods
    - Good agreement between the estimated BKG and data in the SR



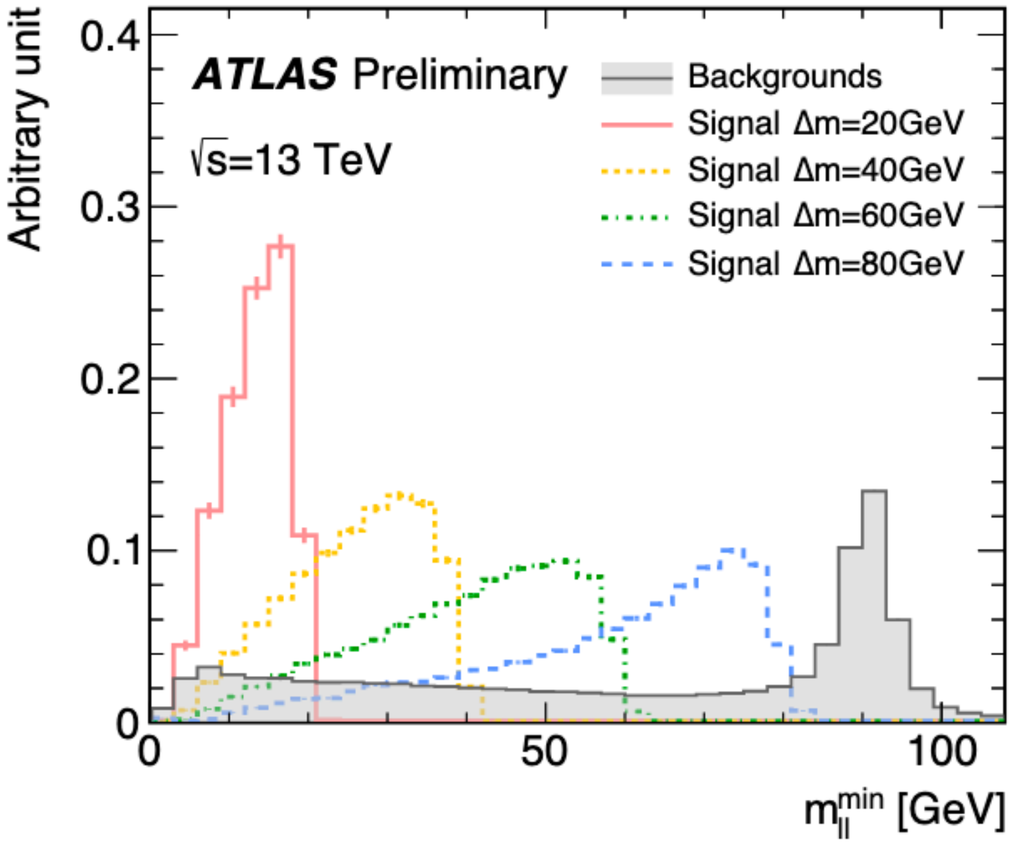


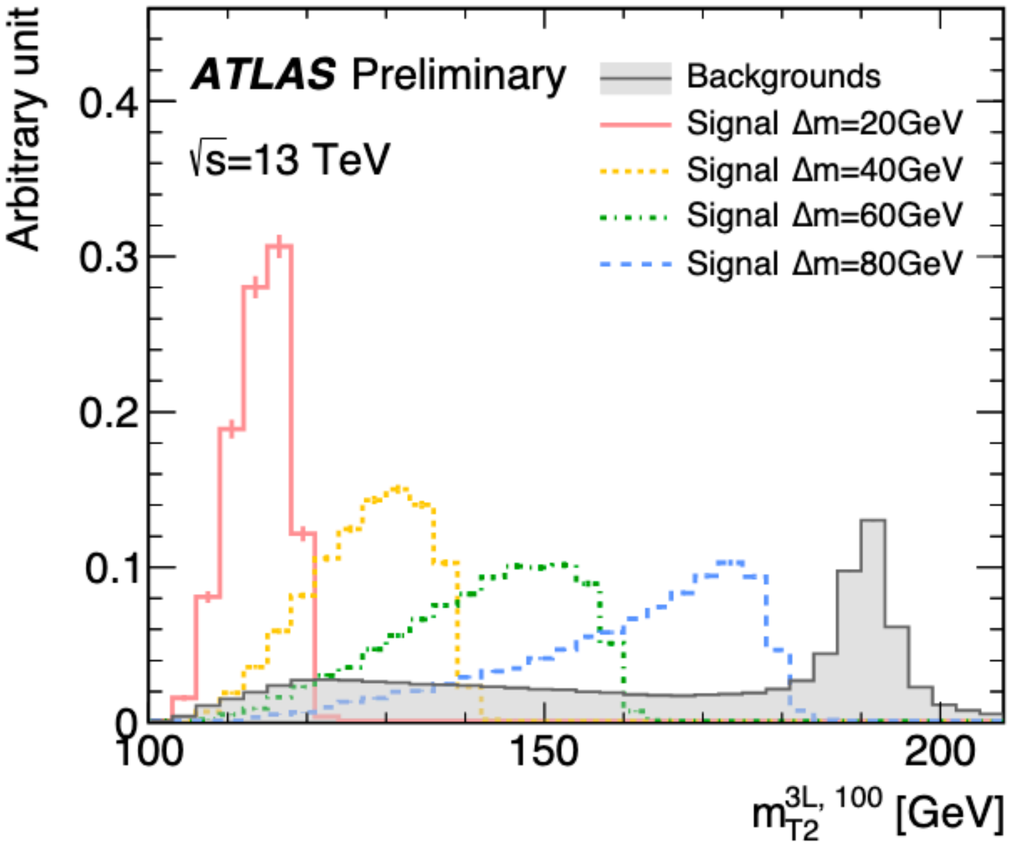
Summary

- Electroweak SUSY is a thriving field of research, pushing the boundaries of search for new physics
  - Compressed regions, LLPs,…
- No signal observed yet
  - Need to look everywhere
  - Still more to come forward with the statistical power of the Run 2 luminosity and Run 3
- Stay tuned for new and exciting news

Back up

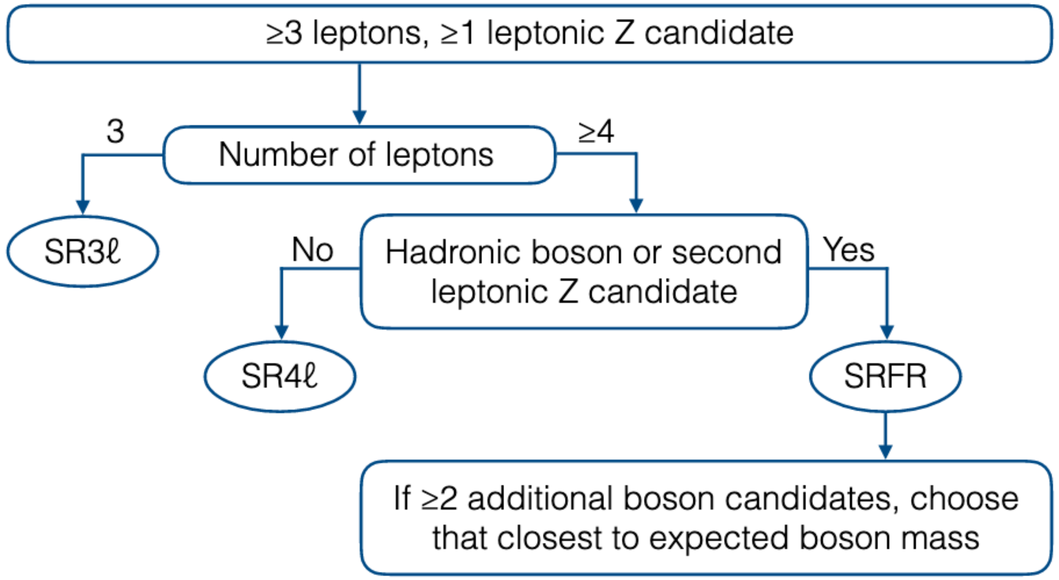
3 Leptons (RPC)

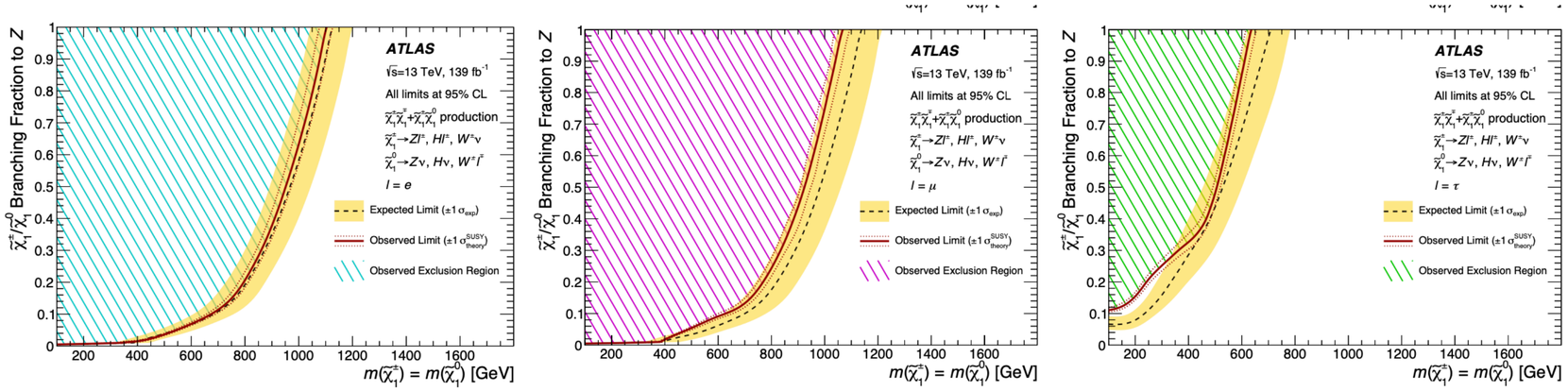


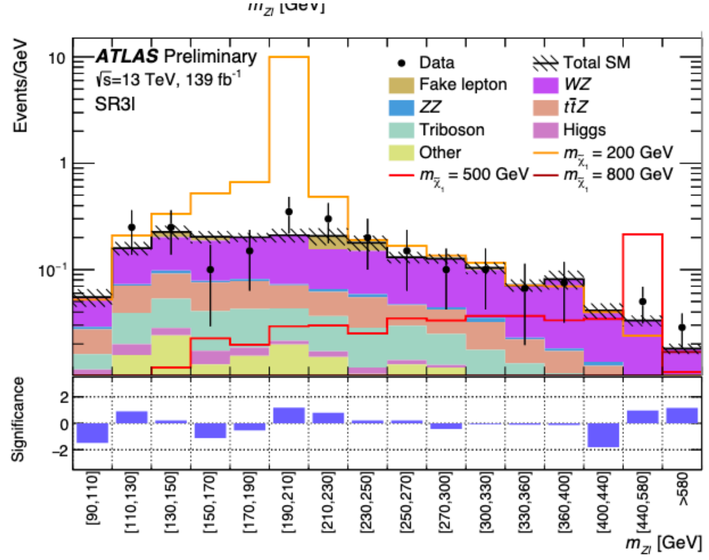


3/4 Leptons (RPV)

- 3rd Lepton assignments
- Use LT (∑pTlep) as proxy for C1/N1 mass
- Assignment algorithm is optimised using HistFitter, accounting for signal & background behaviour
- For high mass C1/N1 :
  - Maximising m_{Zl}
- For low mass C1/N1 :
  - Select pairing closest in ΔR

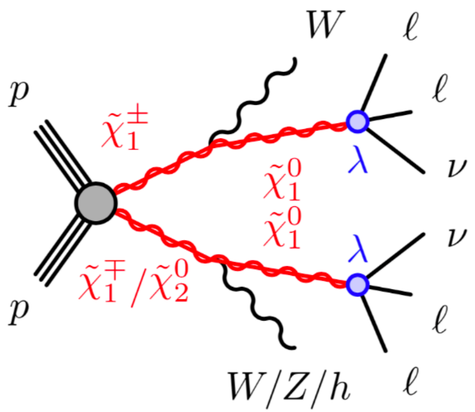




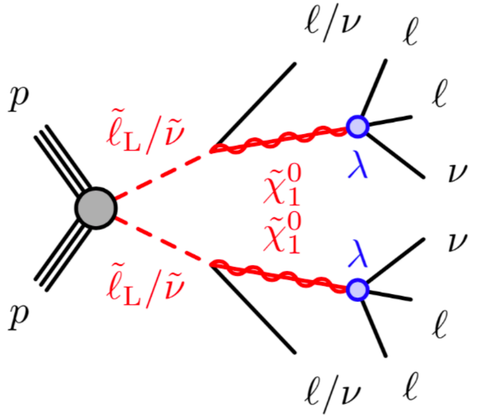


RPV (>= 4 Leptons)

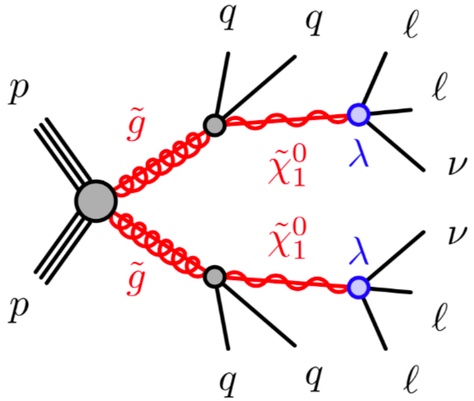
Scenario	Non-zero couplings	$\tilde{\chi}_1^0$ branching ratios		
LLE12k	λ_{12k}, $k \in \{1,2\}$	$e^+e^-\nu$ (1/4)	$e^\pm\mu^\mp\nu$ (1/2)	$\mu^+\mu^-\nu$ (1/4)
LLEi33	λ_{i33}, $i \in \{1,2\}$	$e^\pm\tau^\mp\nu$ (1/4)	$\tau^+\tau^-\nu$ (1/2)	$\mu^\pm\tau^\mp\nu$ (1/4)



(a) Wino NLSP



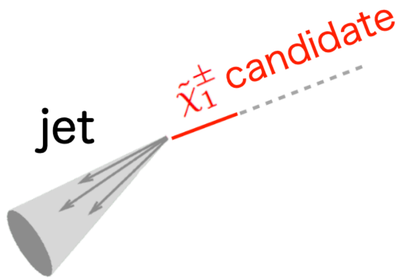
(b) $\tilde{\ell}_L/\tilde{\nu}$ NLSP



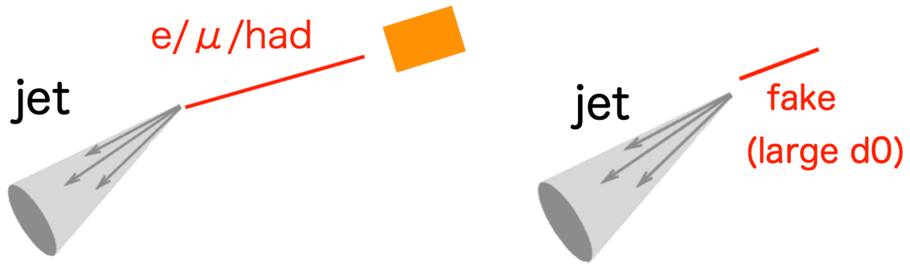
(c) $\tilde{g}$ NLSP

Disparaging Tracks

Signal topology

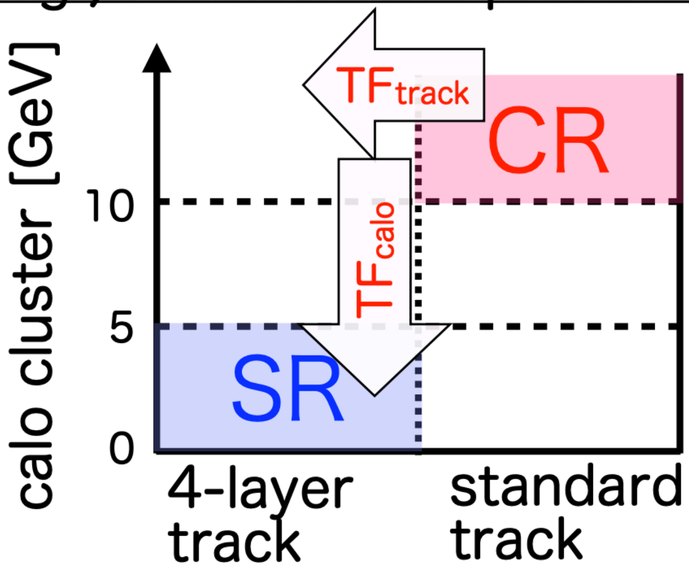


CRs for each BG



Obtain BG pT-shape of tracklet from each CRs

e.g.) electron BG spectrum



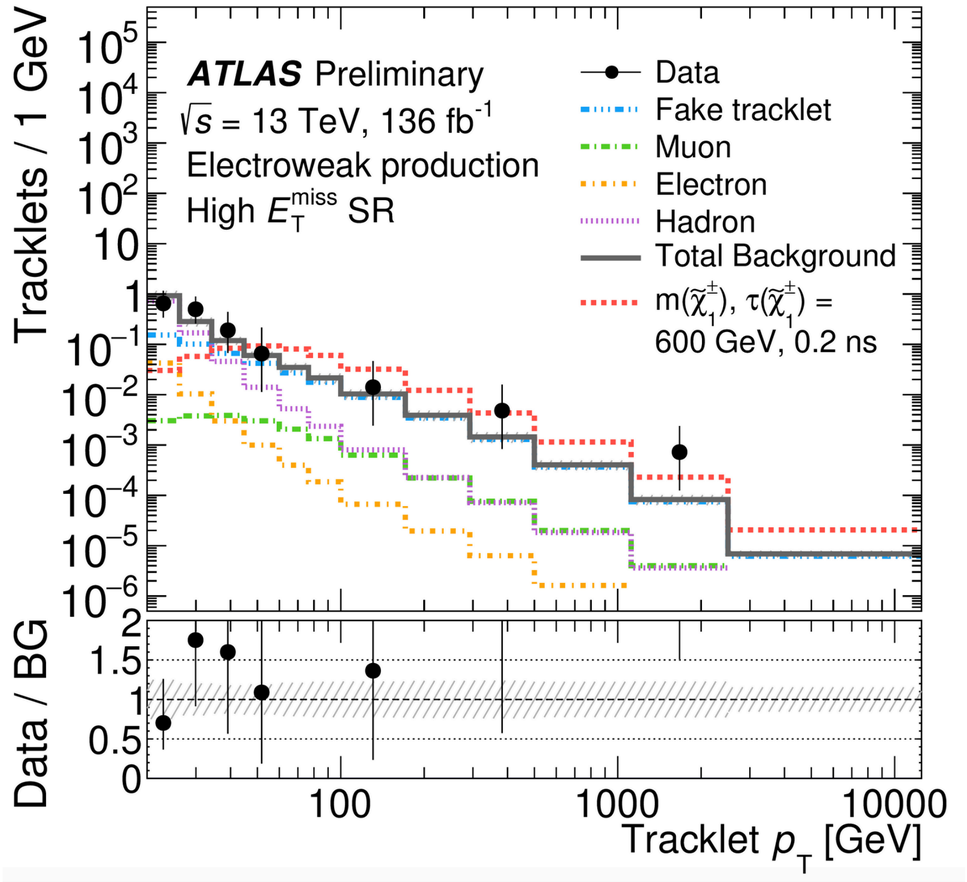
The fake shape is directly obtained from fake CR.
The pT spectra for other BG are obtained
by applying transfer factor(TF) and smearing function
to the events in CR.

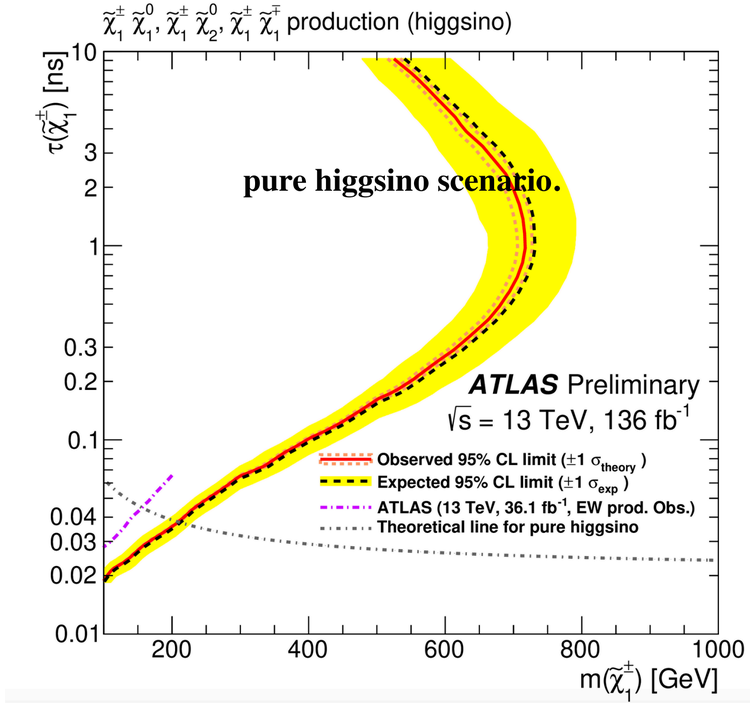
$$f^{e}_{SR}(p_{\mathrm{T}},\eta) = N^{\mathrm{CR}}_{e,\mathrm{signal}}(p_{\mathrm{T}},\eta) \times \mathrm{TF}^{e}_{\mathrm{pixel-only}}(p_{\mathrm{T}},\eta) \times \mathrm{TF}^{e}_{\mathrm{calo-veto}}(p_{\mathrm{T}},\eta)$$

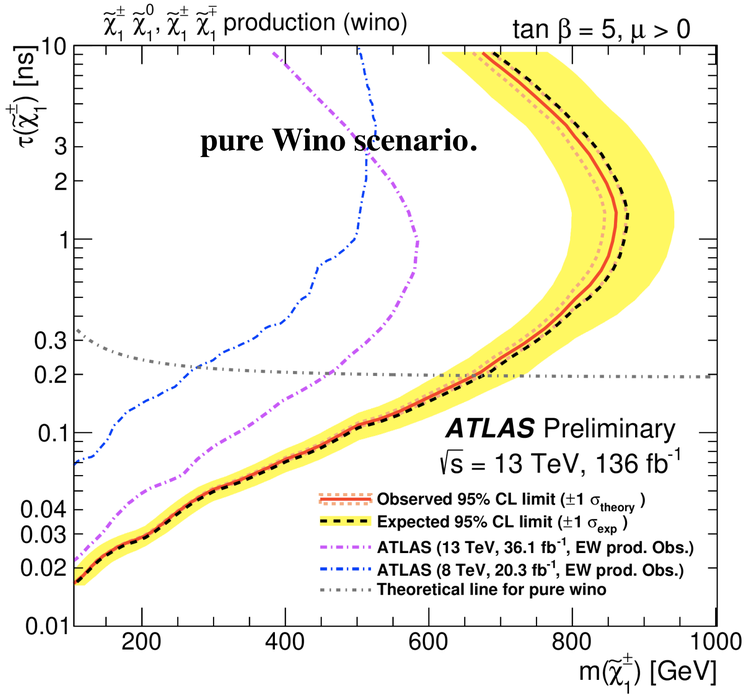
$$f^{\mu}_{SR}(p_{\mathrm{T}},\eta,\phi) = N^{\mathrm{CR}}_{\mu,\mathrm{signal}}(p_{\mathrm{T}},\eta,\phi) \times \mathrm{TF}^{\mu}_{\mathrm{pixel-only}}(p_{\mathrm{T}},\eta) \times \mathrm{TF}^{\mu}_{\mathrm{noMStrack}}(\eta,\phi)$$

$$f^{\mathrm{had}}_{SR}(p_{\mathrm{T}},\eta) = N^{\mathrm{CR}}_{\mathrm{had}}(p_{\mathrm{T}},\eta) \times \mathrm{TF}^{e}_{\mathrm{calo-veto}}(p_{\mathrm{T}},\eta)$$

Disappearing track (Results & Interpretation)







- Good agreement between the estimated BKG and data in the SR
- Significant improvement over previous results due to additional track quality criteria —> more BKG rejection

Event Display

3,4 Leptons (RPV) :

- 2 μ+ 1 ele
- mZ : 87 GeV
- mZl : 742 GeV
- MET : 172 GeV