Searches for supersymmetric particles with prompt decays with the ATLAS detector

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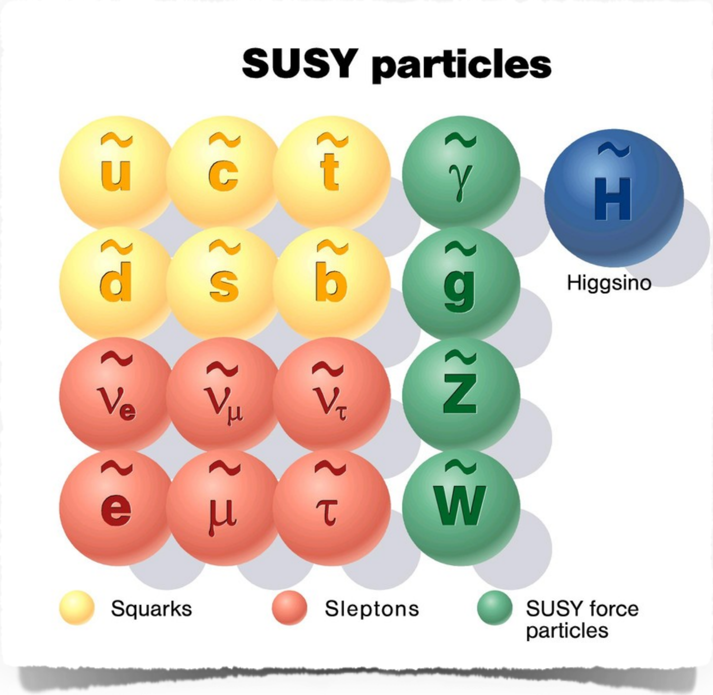
SUSY

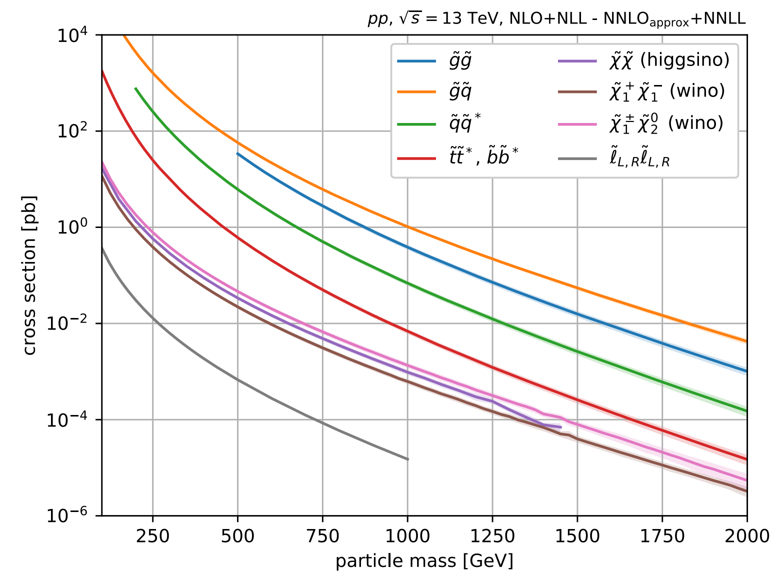
- **Supersymmetry (SUSY)** is one of the most elegant theories beyond the Standard Model
    - solves the hierarchy problem
    - achieves grand unification
    - provides Dark Matter candidate
- introduces supersymmetric partners

- No evidence for SUSY at LHC Run1 and Run2 so far
- Why is there no clue yet?
    - SUSY exists beyond the limit → Run 3 and beyond
    - We have, but missed it
- Exploiting the large amount of data
    - New techniques allow us to tackle challenging signatures
    - New scenarios and models



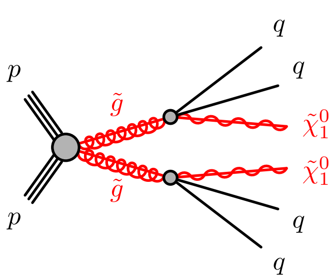
SUSY Production at LHC

- **140 fb^{-1} data** recorded at $\sqrt{s}$=13 TeV in Run 2
  - 140 gluino (2 TeV) pairs
  - 960 stop (1 TeV) pairs
  - 6400 $\tilde{\chi}_1^{\pm}\tilde{\chi}_2^0$ (500 GeV) wino pairs
  - 1500 $\tilde{\chi}_1^{\pm}\tilde{\chi}_2^0$ (500 GeV) higgsino pairs



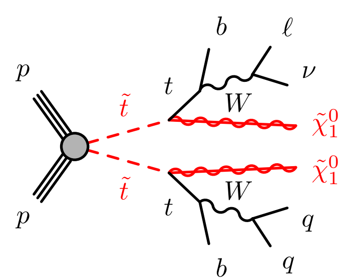
- Stable Lightest Supersymmetric Particle (LSP) in R-parity conserved models
  - → **large E_T^{miss}** is the key signature

Gluino



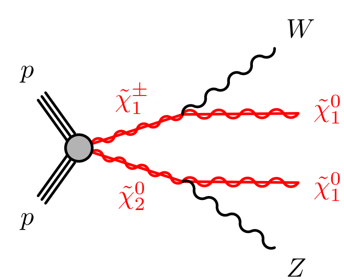
E_T^{miss} + jets

Stop



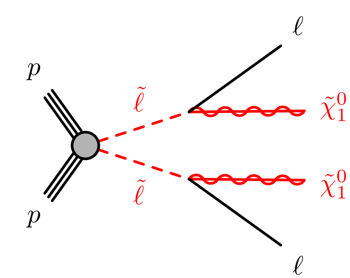
E_T^{miss} + b-jets

Chargino, Neutralino



E_T^{miss} + Bosons

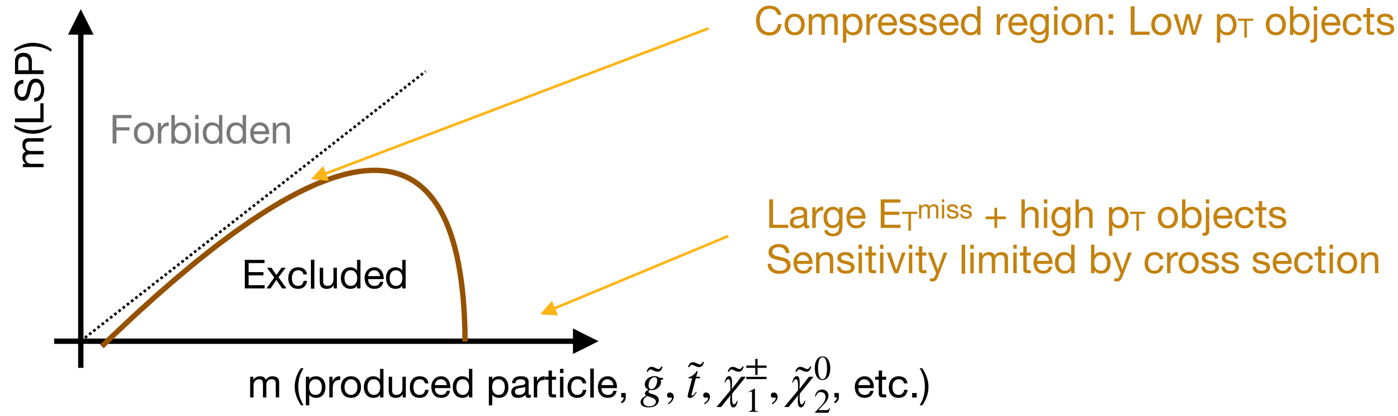
Slepton



E_T^{miss} + leptons

SUSY Search Strategy

- **Signal model building**
  - Simplified model — 100% branching ratio, decoupled other SUSY particles
- **Event selection:** E_T^{miss} + something (jets, leptons, etc.) for R-parity conserving SUSY
  - E_T^{miss} trigger in many analyses
- **Background estimation**
  - Normalize MC in control regions. Normalization checked in validation regions
- **Uncertainty evaluation**
  - Experimental syst.: Jet energy scale/resolution, b-tagging, lepton ID, etc.
  - Theoretical syst.: scale uncertainties, parton shower, etc.
  - Statistical uncertainty is dominant in most SUSY analyses
- **Discover SUSY! … or exclude models**



New Techniques

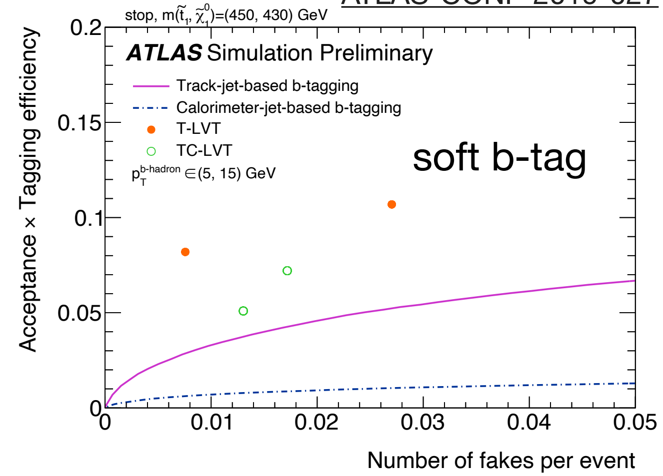
Dedicated object reconstruction for challenging signatures

- Low pt objects for compressed region

  Soft muon and electron for compressed region
  - Fake lepton background
  - → data-driven background estimation

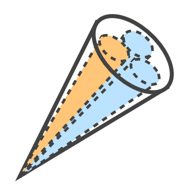
  Soft b-tagging for compressed stop and sbottom
  - p_T below jet reconstruction threshold (20 GeV)
  - Dedicated SV-based algorithm

ATLAS-CONF-2019-027



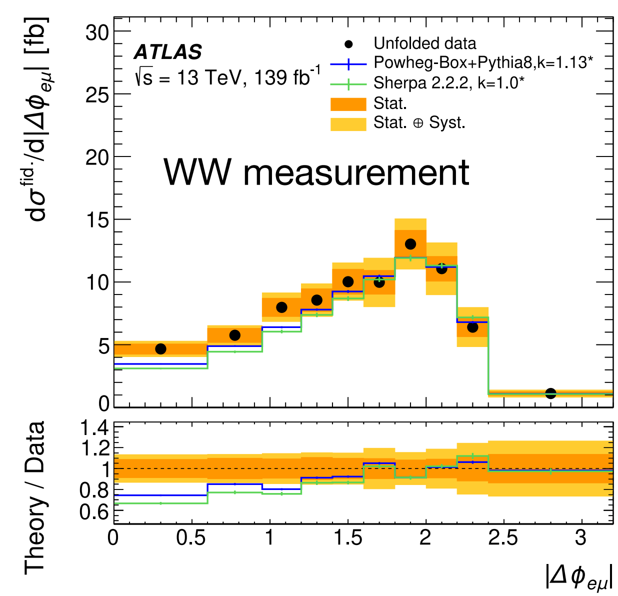
- High pt objects for high mass region

  Boosted top and boson tagging for large radius jet using jet substructure variables (2108.07586)



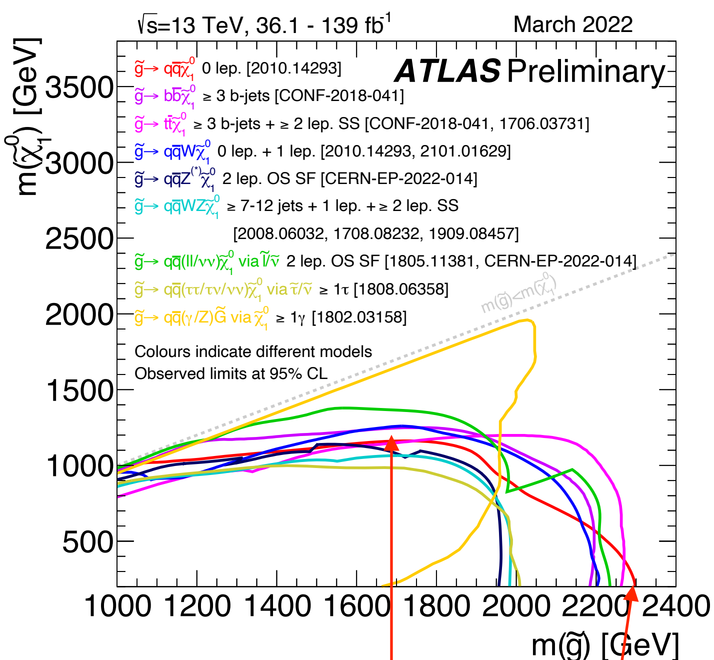
Background measurement for SUSY searches

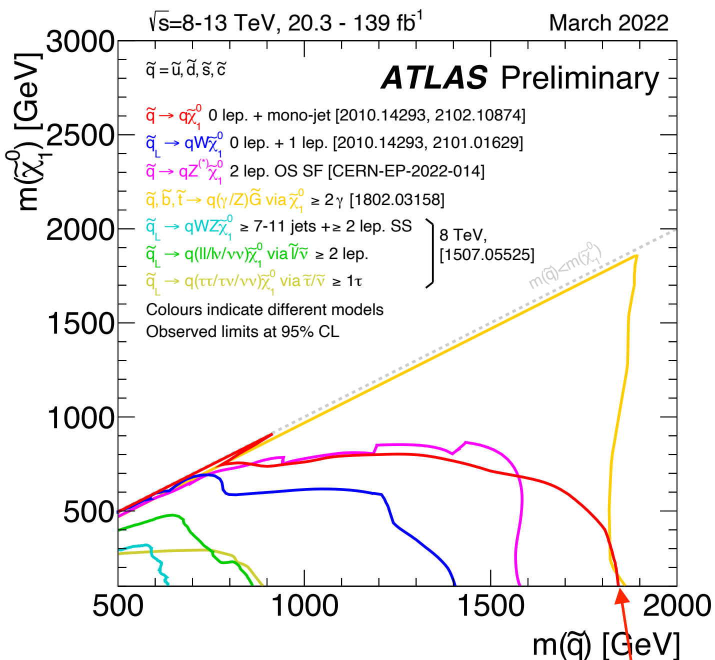
Measurement of WW production in decay topology inspired by EW SUSY searches (2206.15231)
→ improved background modeling in control regions

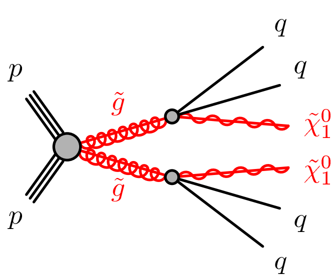


Gluino, Squark

- E_T^{miss} + jets **signatures**
- Excluded up to around 2 TeV thanks to the large cross sections

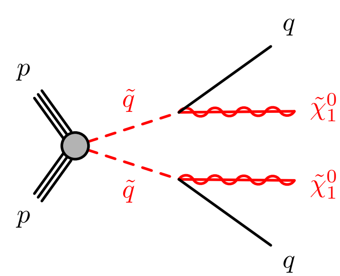






LSP 1.2 TeV

gluino 2.3 TeV



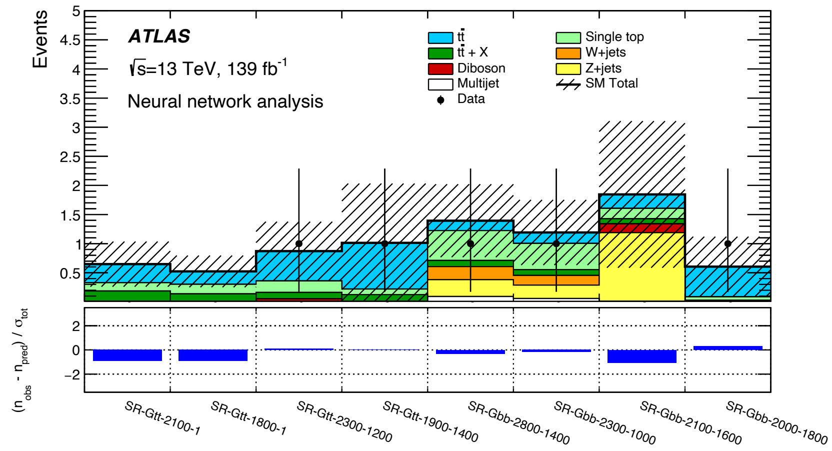
squark 1.85 TeV

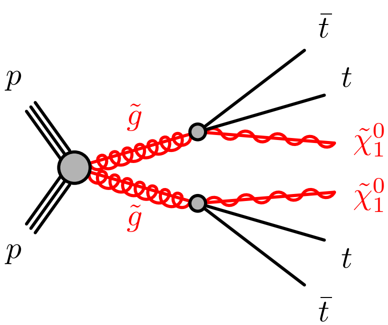
Gluino → tt, bb, tb

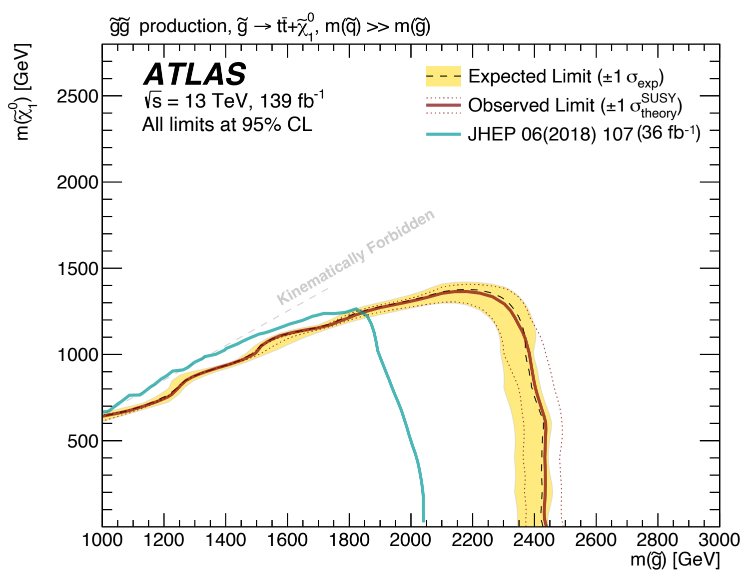
New result
2211.08028

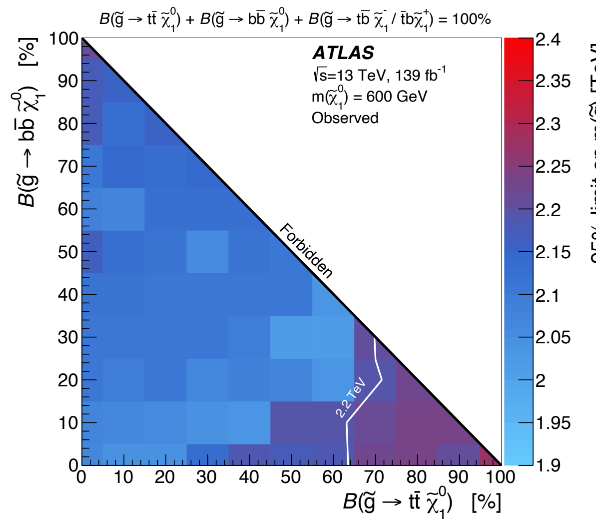
Gluino decay via off-shell stop or sbottom

- ≥ 3 b-jets + 0/1L + E_T^{miss}
- Neural network in event selection
  - Input: 4 vectors of jets and leptons, E_T^{miss}
  - $m(\tilde{g})$ and $m(\tilde{\chi}_1^0)$ added as parameters
- Interpretation for 3 mixed decay modes
  - $\tilde{g} \to tt\tilde{\chi}_1^0, bb\tilde{\chi}_1^0$, or $tb\tilde{\chi}_1^{\pm}$

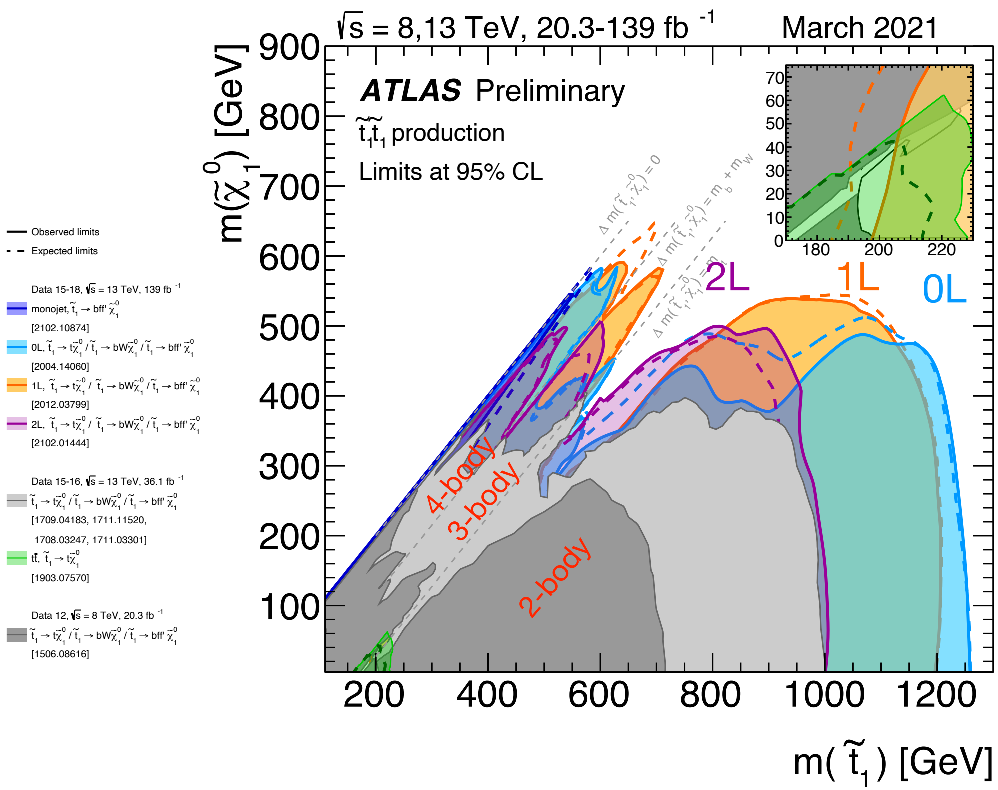








Stop Searches

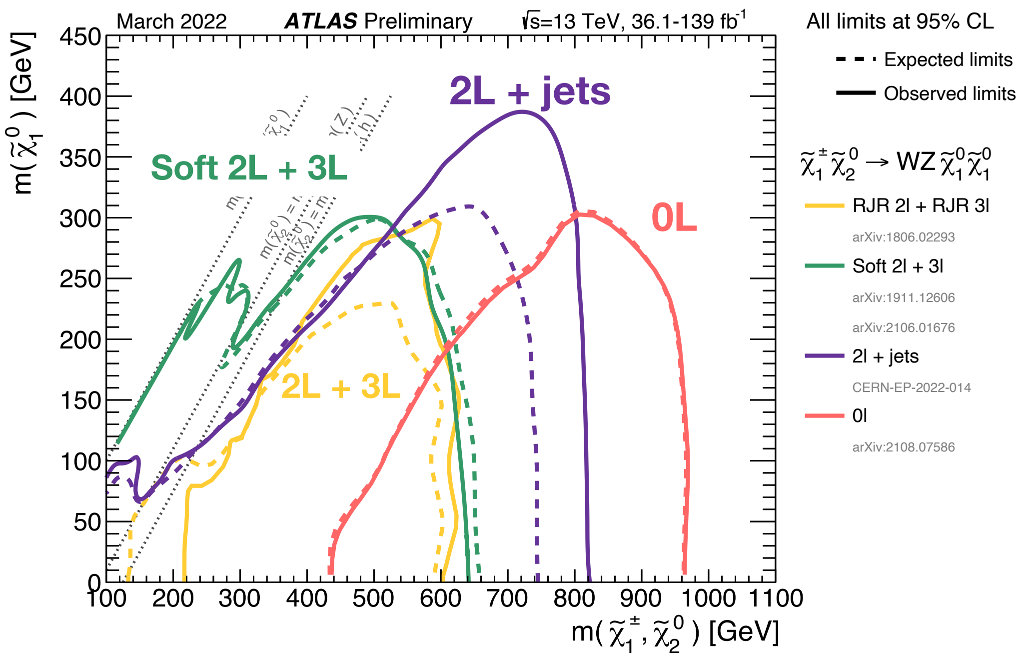


- Stop → $t^{(*)}$ + LSP
- Low Δm $(\tilde{t}, \tilde{\chi}_1^0)$ — compressed region
  - Soft b-tagging
- High Δm $(\tilde{t}, \tilde{\chi}_1^0)$
  - Boosted top reconstruction
- 0, 1, 2 lepton searches have compatible sensitivities
  - Combination will improve the limit

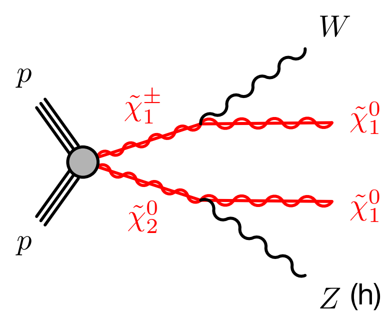
- Excluded up to 1.25 TeV for the simplest stop model
- However, m(stop) < 1 TeV is still allowed in the compressed region and complicated scenarios (e.g. higgsino LSP, $\tilde{t} \to t\tilde{\chi}_1^0/b\tilde{\chi}_1^\pm$ mixed scenarios)

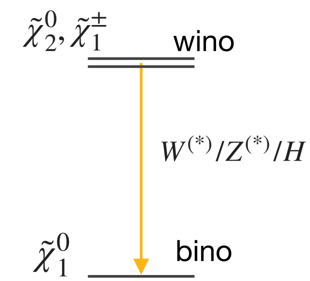
Electroweak production

Chargino/Neutralino → WZ + LSP



Wino production cross section for $\tilde{\chi}_2^0, \tilde{\chi}_1^{\pm}$





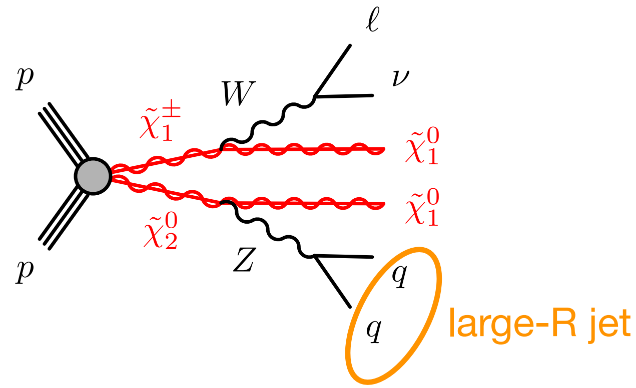
New results for electroweak production

- 1lepton + large-R jet for WZ and WW channels (ATLAS-CONF-2022-059)
- 2 same-sign or 3 leptons for WZ and Wh, and RPV higgsino (ATLAS-CONF-2022-057)
- 2 taus for electroweakino to stau decays (ATLAS-CONF-2022-042)

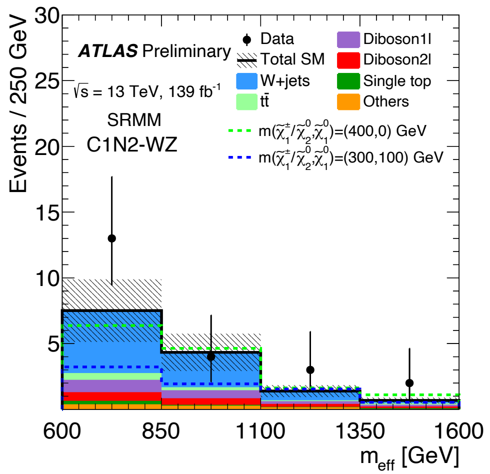
1L + large-R jet

ATLAS-CONF-2022-059

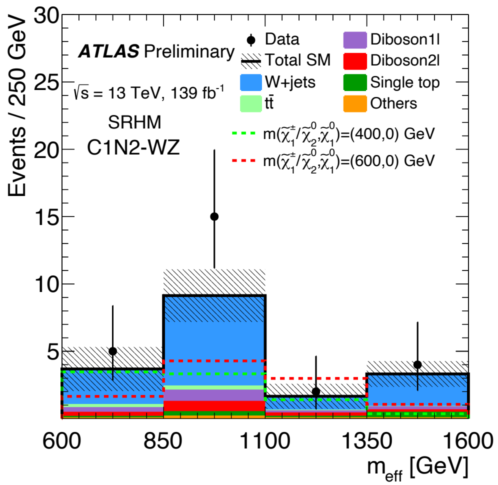
- Targeting WZ and WW channels
- For large Δm(wino, bino)
- W/Z boson tagging for large-R jet
- Large E_T^{miss} significance, m_T, m_{eff}
- Consistent with SM prediction (1.1σ, 1.5σ)

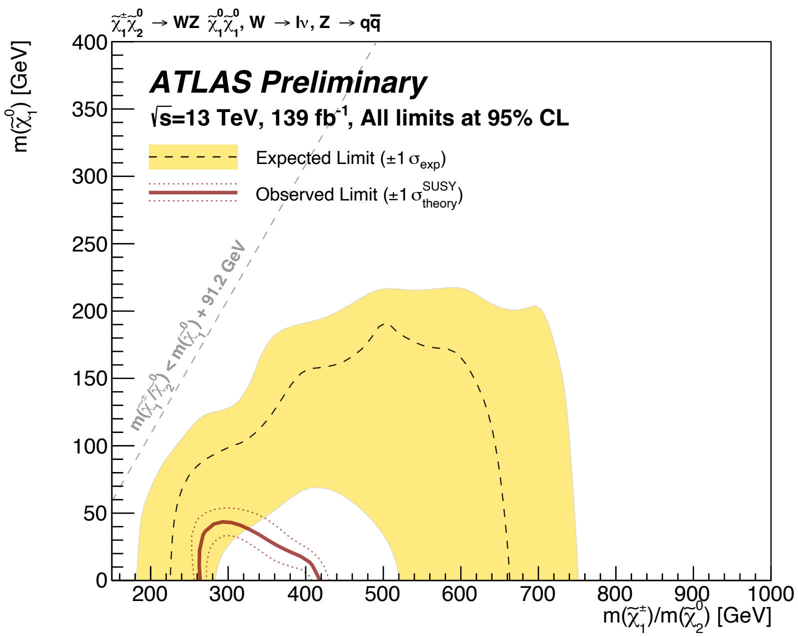


200 GeV < m_T < 300 GeV



m_T>300 GeV

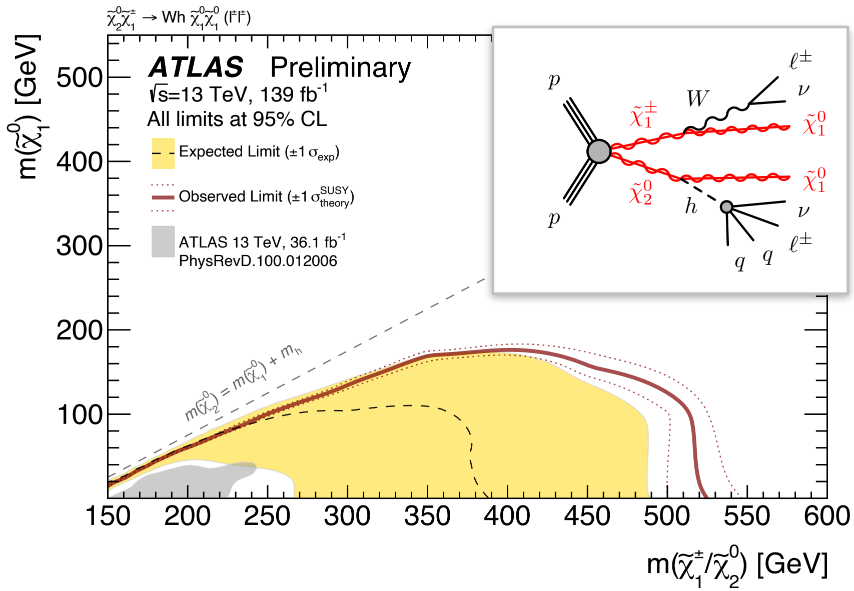


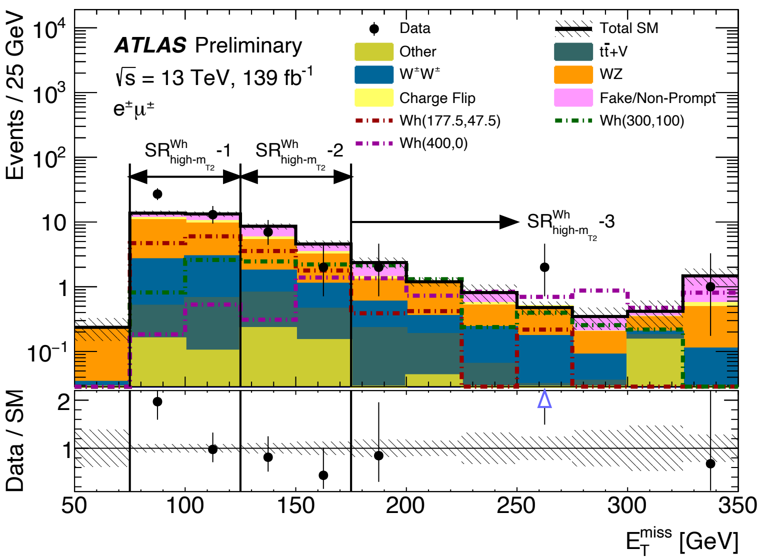


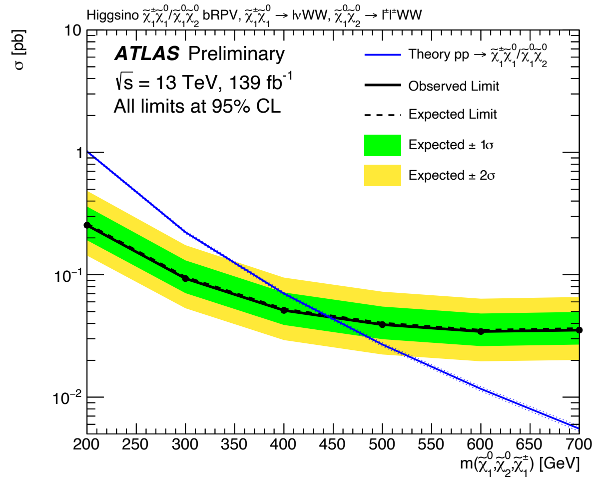
2 same-sign or 3 leptons

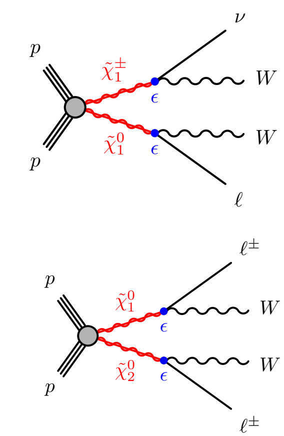
ATLAS-CONF-2022-057

- 2 same-sign or 3 leptons, ≥ 1 jets
- No significant excess observed
- wino-bino Wh channel
  - m($\tilde{\chi}_1^\pm/\tilde{\chi}_2^0$) excluded up to 520 GeV
- Higgsino-like electroweakino in RPV scenario
  - bilinear lepton-number violating term considered
  - higgsino excluded up to 440 GeV





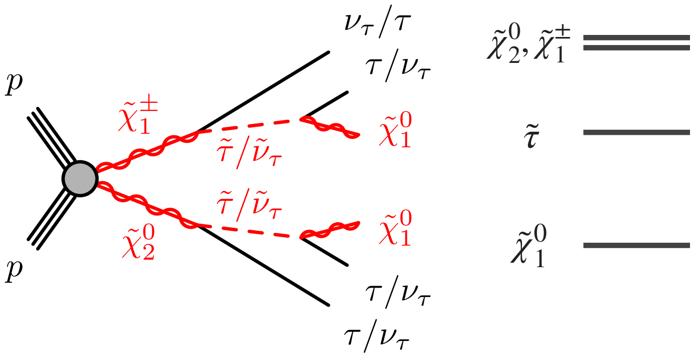


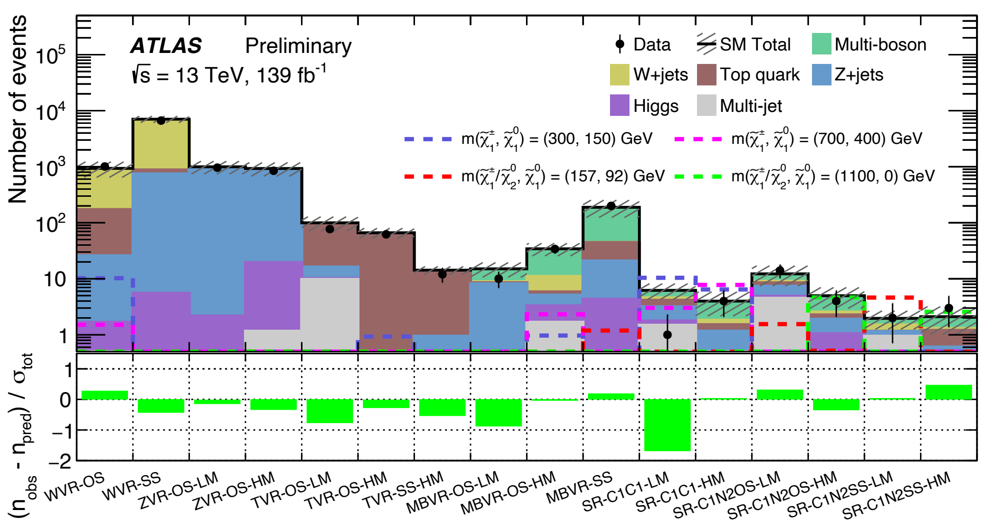


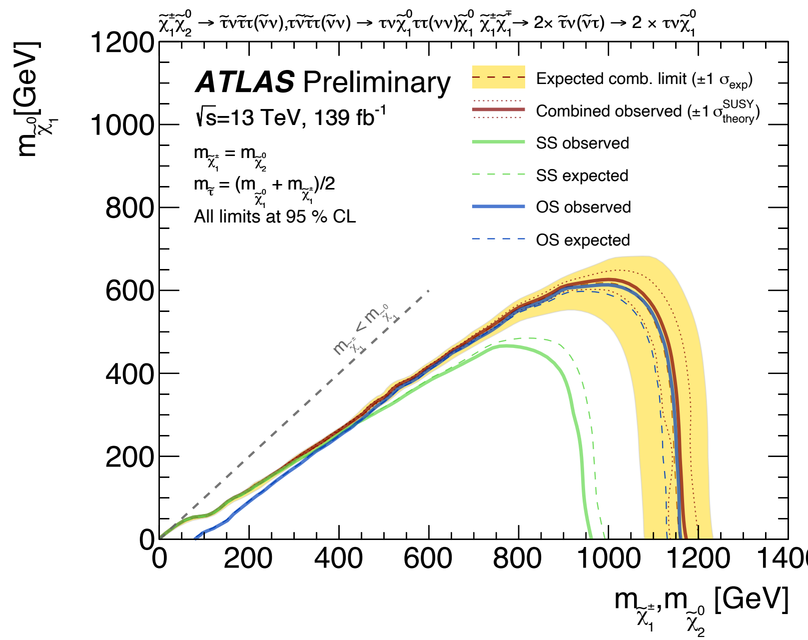
2 taus

ATLAS-CONF-2022-042

- Chargino/Neutralino decaying into stau in light stau scenario
  - $m_{\tilde{\tau}} = (m_{\tilde{\chi}_1^\pm} + m_{\tilde{\chi}_1^0})/2$
- 2 hadronically decaying taus
- di-tau + E_T^{miss} trigger
- RNN-based hadronic tau ID
- High E_T^{miss}, m_T, m_{T2} required

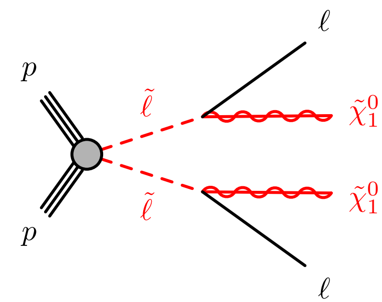


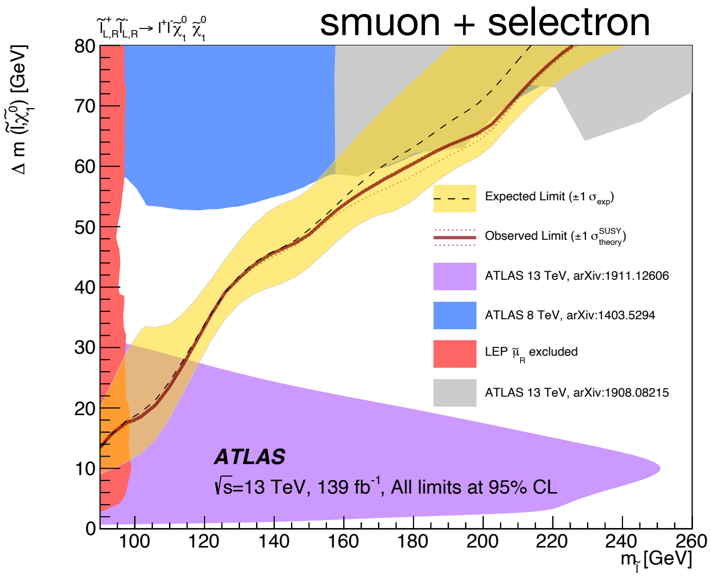


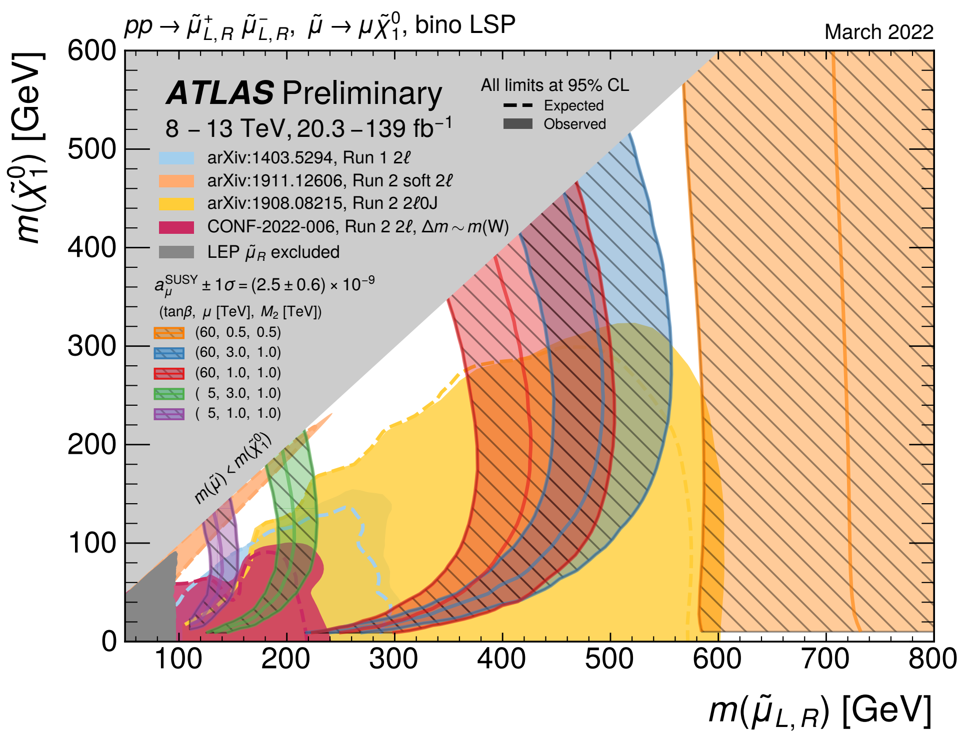


Slepton Searches

- Motivated by the **g-2 anomaly**
- 2L + E_T^{miss} searches
- Our slepton searches are exploring the preferred phase space
- New analysis targeting $\Delta m \sim m_W$ (2209.13935)
- The gap region still needs to be searched using more data in Run3







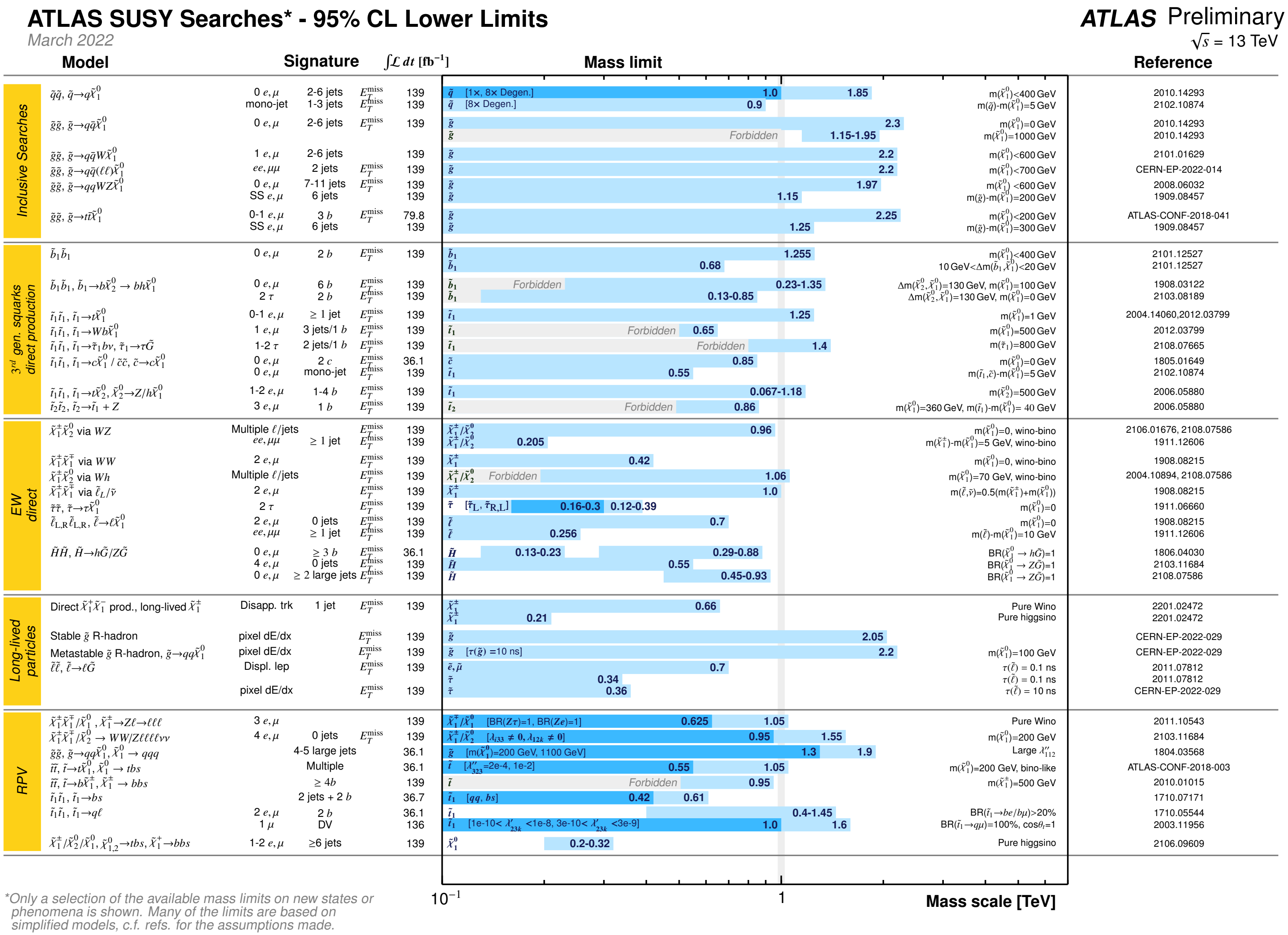
Hatched regions motivated by muon g-2

Conclusion

- Searches for various SUSY scenarios at Run-2
  - All ATLAS SUSY results are available [here]
  - No evidence found so far
- SUSY might be
  - a little bit heavier than the current limits.
  - not simple (e.g. low E_T^{miss}, SM-like signal)
  - uncovered models, e.g. mixed decay branching ratios
- Final Run2 analyses to tackle those challenging scenarios are ongoing
- We already have Run3 data!
- **Stay tuned for final Run2 and fresh Run3 results**

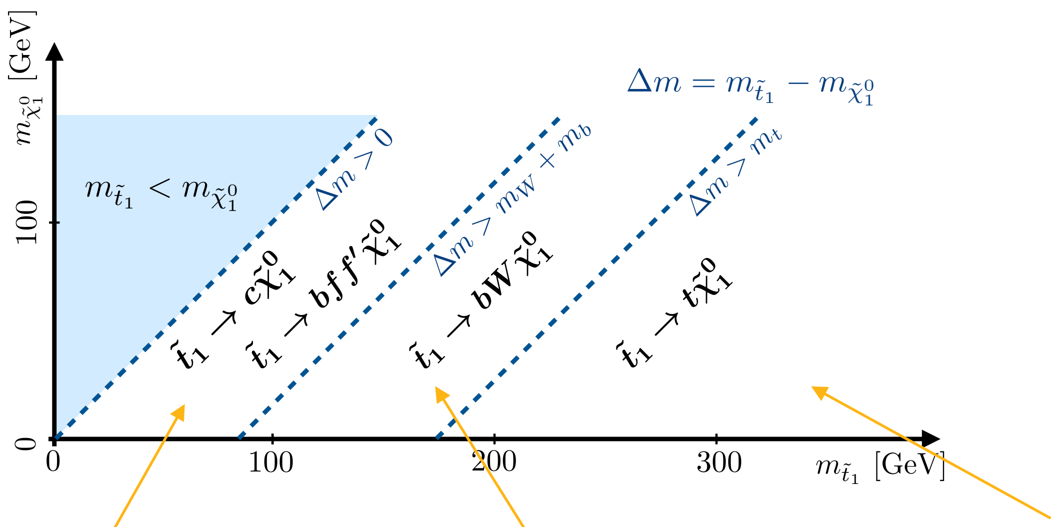
Backup

SUSY Summary

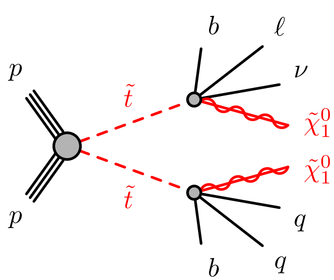


Stop Searches

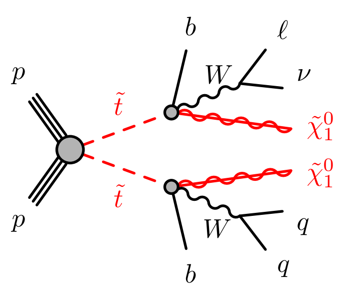
- Light stop favored by naturalness
- Decay modes depend on Δm(stop, LSP)
- stop simplified model : stop → t(*) + LSP
  - stop → $b\tilde{\chi}_1^{\pm}$ is not considered in this model



4-body (off-shell W)



3-body (off-shell top)



2-body (on-shell top)