SUSY searches at ATLAS

SUSY 2024

Theory meets Experiment

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on behalf of the ATLAS Collaboration

SUSY24, Madrid - 10/06/24

Outline

- Brief introduction on how we search for SUSY at ATLAS
  - Simplified models, analysis strategy, and relaxed assumptions
- Status of the simplified model searches done so far
- Overview of the latest results

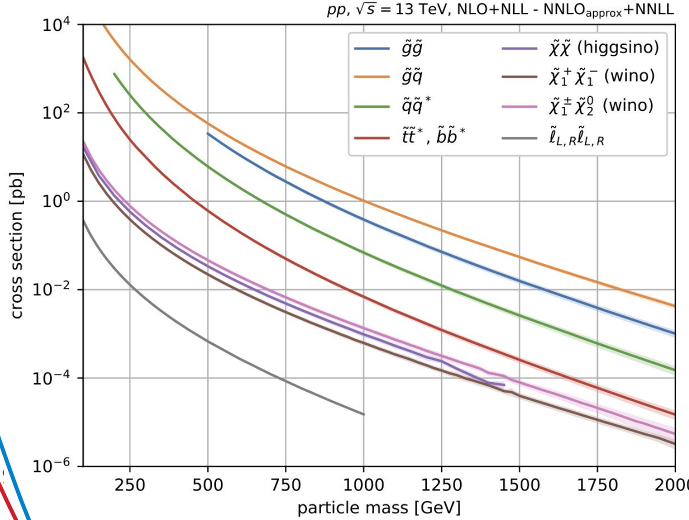
- Several ATLAS SUSY dedicated talks this week:
  - EWK SUSY by Alessandro Sala
  - Strong SUSY by Edmund Ting
  - Compressed EWK SUSY by Jeff Shahinian
  - Non-minimal models by Yvonne Ng
  - SUSY on LLPs by Vasiliki Mitsou

Supersymmetry in ATLAS

- Supersymmetry is a promising extension of the SM
- SUSY parameter space is huge (MSSM with 105 new parameters)
  - Phenomenological MSSM (pMSSM) with 19 parameters
- Focus on “simplified models” to reduce the number of parameters
  - **Limits are on simplified models, not on SUSY**

SUSY searches in ATLAS
- Exhaustive search programme
- Final state oriented, driven by cross-section and event topology
  - Strong-production: $\tilde{g}$ and $\tilde{q}$ ~2.4 TeV
    → Many light(b-tag) jets, 0 or many leptons, large $E_{\mathrm{T}}^{\mathrm{miss}}$
  - Third generation squarks: stop & sbottom ~1.3 TeV
    → masses around TeV for Natural SUSY
  - Ewkinos pair production ~1 TeV
    → main production if $\tilde{g}$ and $\tilde{q}$ are too heavy
    → direct gaugino/higgsino production

- Naturalness favours light stop, gluino and Higgsino



Sensitivity with Run-2 data (up to)

How do we look for SUSY?

- Usually we look for:
  - **Simplified models** (few production/decay modes, 2-3 free parameters)
  - with **R-parity conservation** (RPC) and prompt decays
  - and **minimal flavour violations**

- But we can relax these assumptions and:
  - have unconventional searches including RPV and long-lived particles (LLP)
  - non-minimal flavour violations
  - and phase space scans
    - More realistic model pMSSM

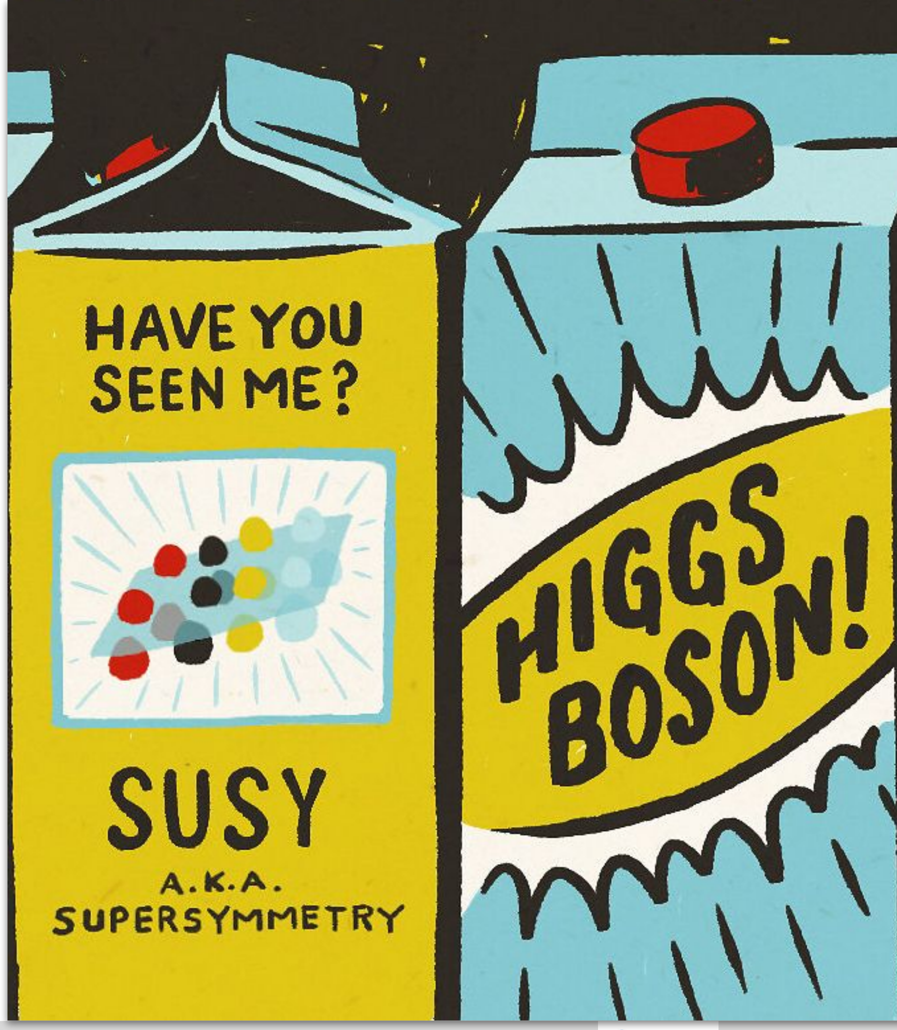


Illustration by Sandbox Studio, Chicago with Steve Shanabruch

How do we look for SUSY?

Simplified models

- SUSY is not one model
  - It's a principle that can produce a large number of models.
- In a simplified model:
  - Consider as free parameters only the masses of the **initial** sparticle and **lightest** SUSY particle (LSP), and the **associated BRs.**
  - The remaining particles are "decoupled".
  - Interpreting/predicting the kinematics from a simplified model is easier.

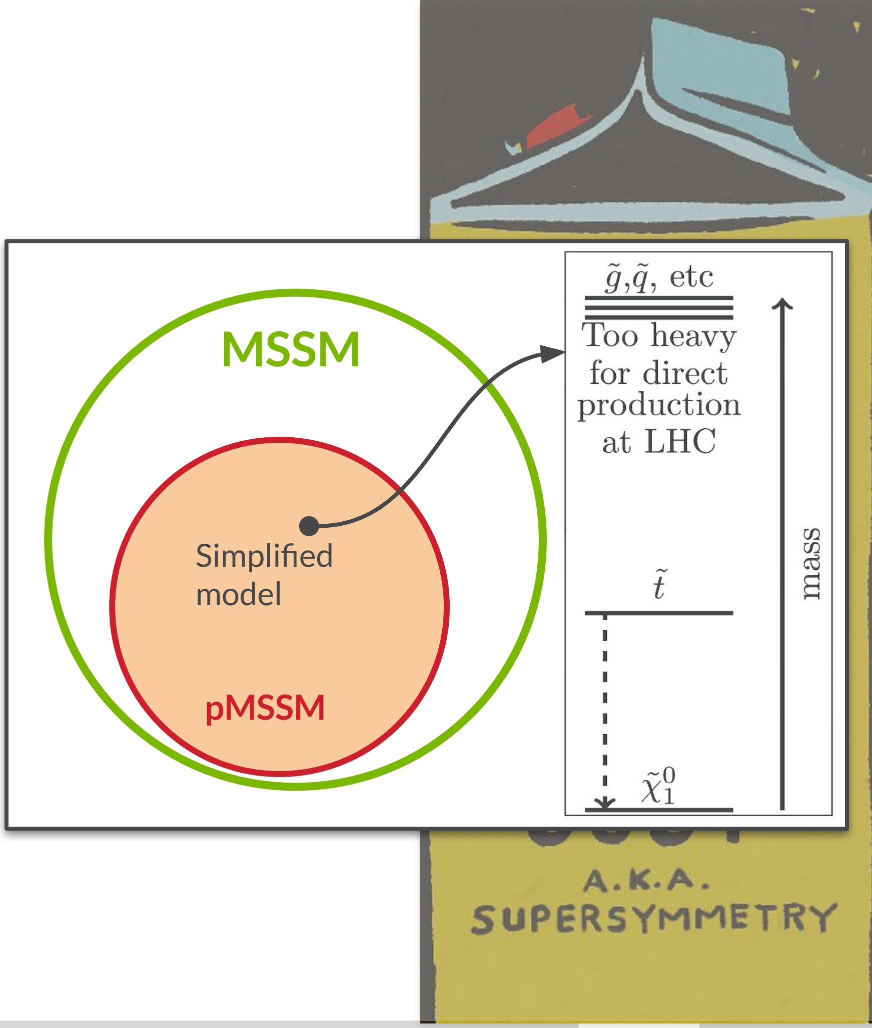
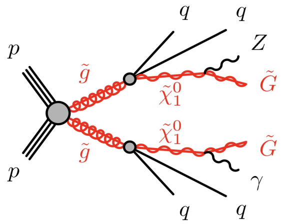
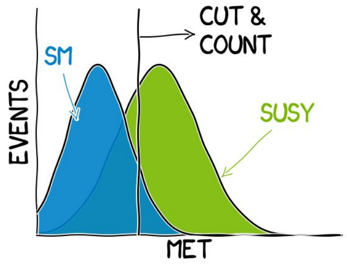


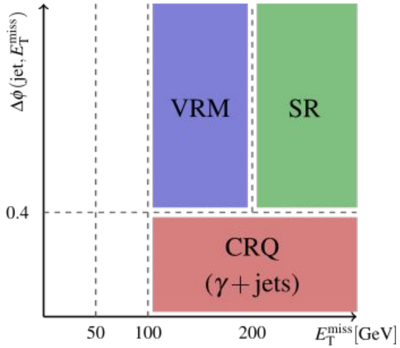
Illustration by Sandbox Studio, Chicago with Steve Shanabruch

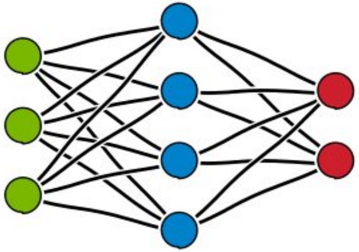
General analysis strategy

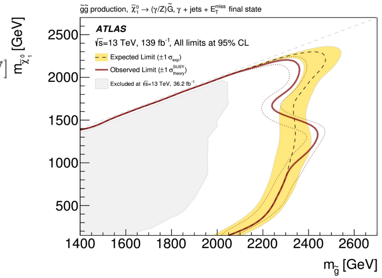
- **Choose a simplified model**
- **Design Signal Regions (SR)**
  - Where the signal strength is expected to be high.
- **Estimate SM background**
  - Data-driven estimation for fake backgrounds
  - MC simulation normalized in dedicated Control Regions (CR)
  - Validation regions (VR) to cross-check estimation in between CR/SR
- **Estimate systematic uncertainties**
- **Statistical interpretation**
  - Test the compatibility between <u>data</u> and <u>bkg</u> in the SR, using simultaneous likelihood fit.
  - If no excess, set limits:
    - Exclusion limits at 95% CL using CR+SR combined fit for specific SUSY model.
    - Model independent limits on visible cross section.





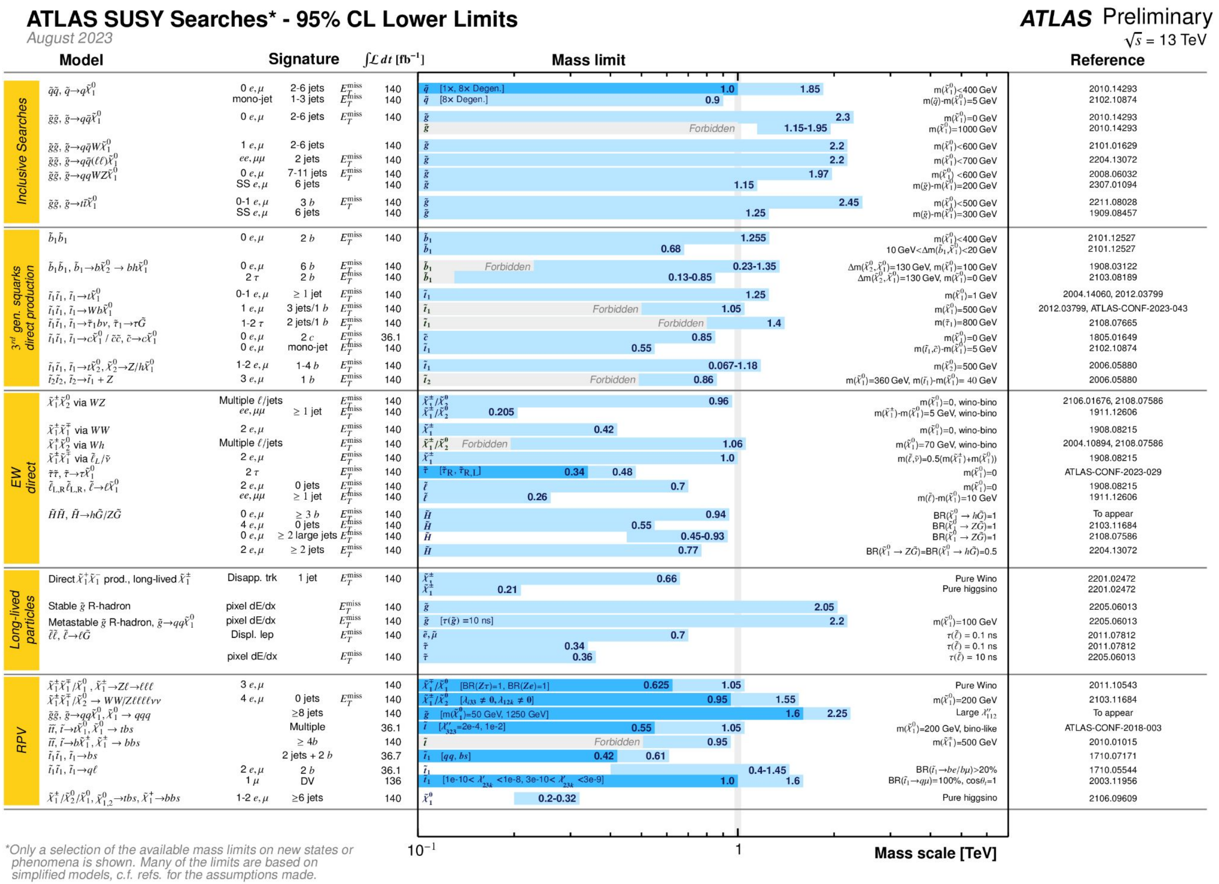






SUSY Searches - Status

SupersymmetryPublicResults



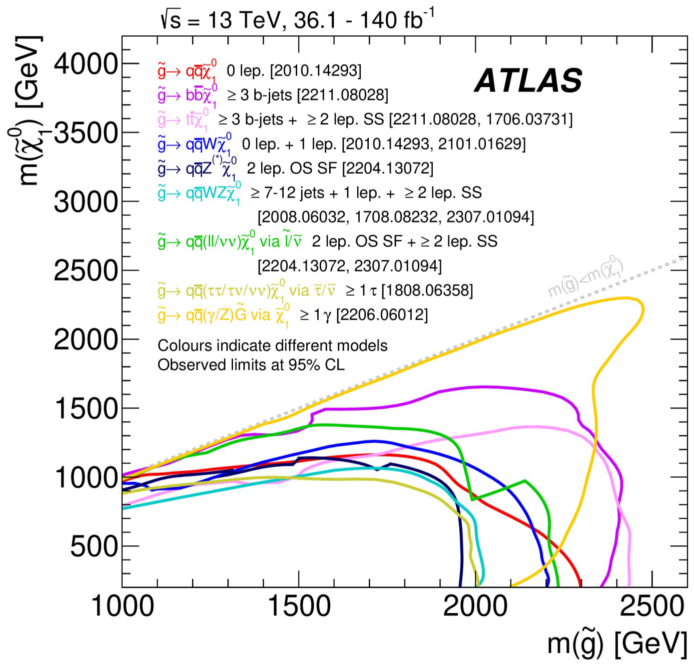
Huge effort covering vast regions of SUSY phase space

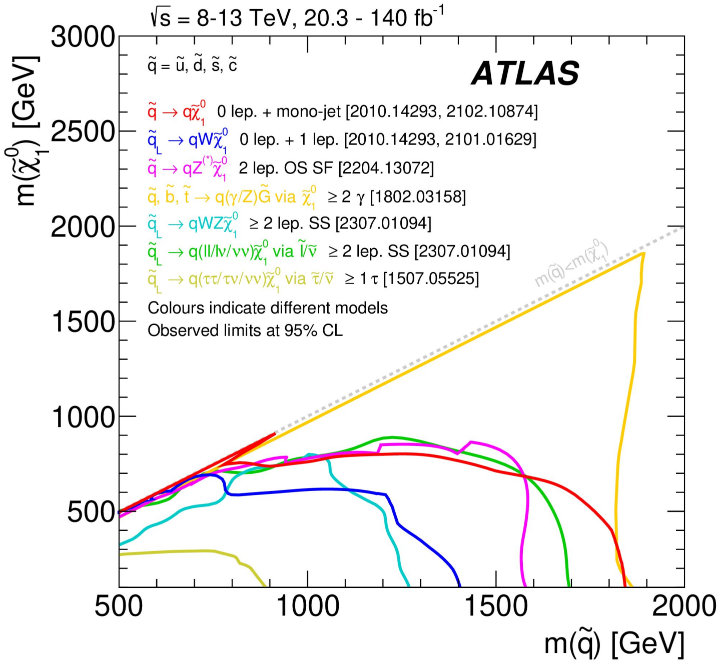
Gluinos and Squark searches

SUSY-2023-10

"The quest to discover supersymmetry at the ATLAS experiment"

Many analyses covering most of the phase space for different gluino/squark decay modes.

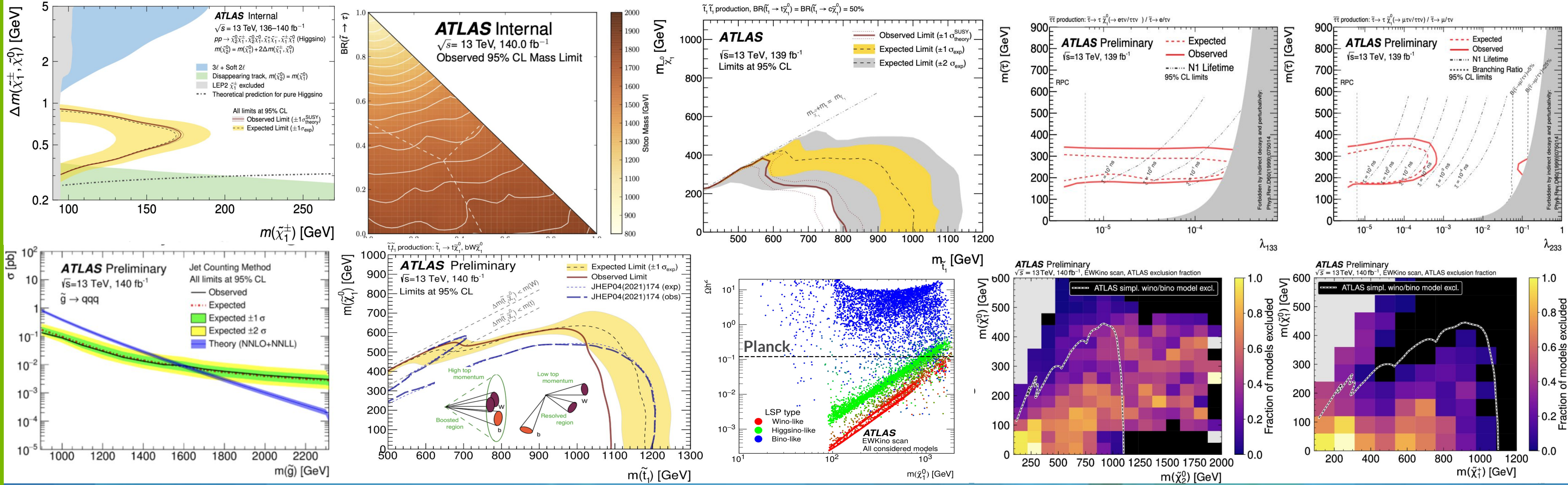




Masses excluded up to 1-2 TeV
(depending on the model)

Weaker limits in the compressed region for χ^0_1

work ongoing to improve this **with ML**



Latest ATLAS SUSY results

EWK compressed Displaced Track

1910.08065

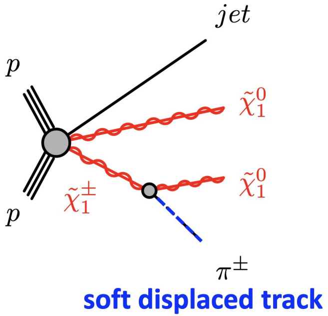
SUSY-2020-04

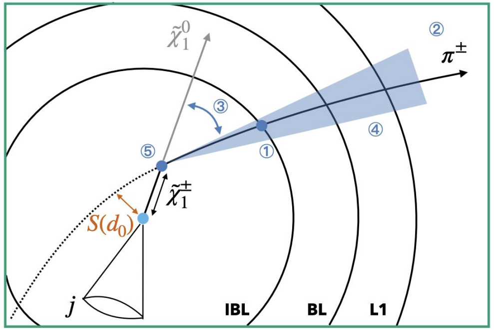
Target:

- Higgsinos production, much lighter than gauginos
  $(\tilde{\chi}_2^0, \tilde{\chi}_1^\pm, \tilde{\chi}_1^0)$ Higgsinos, Δm ≃0.4-1 GeV, $c\tau$ ≃0.1-1mm

Final state:

- ISR leading jet (p_T> 250 GeV)
- Large $E_{\mathrm{T}}^{\mathrm{miss}}$ (> 600 GeV)
- 1 track with 2<p_T<5 GeV, large d_0 significance $(S(d_0) > 8)$



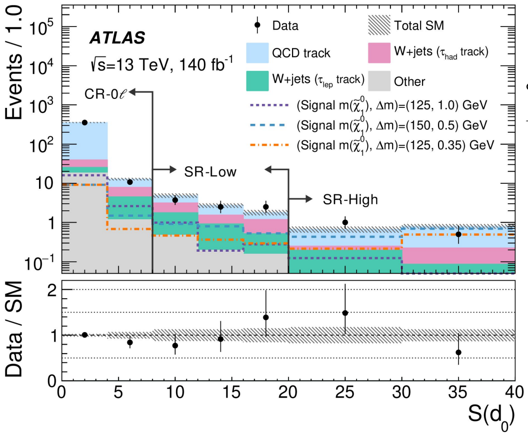


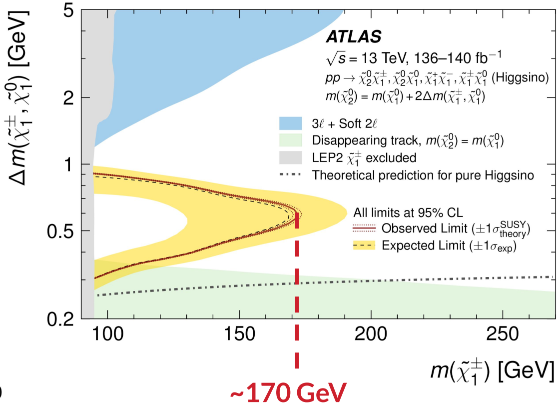
Backgrounds:

- τ decay tracks (W($\rightarrow \tau\nu$)):
  - MC scaled to data at higher track p_T
- Non-prompt QCD tracks (Z(→ νν), W(→ ℓν))
  - Data-driven.
  - $S(d_0)$ shape is the same in 0L and 1L (W→μν events) control selection

Strategy:

- Two SR in $S(d_0)$
  (sensitive to lower/ higher Δm)



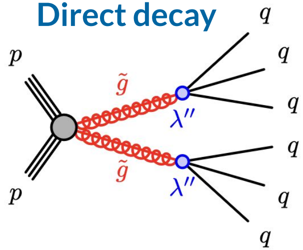


Model-dependent limits exclude higgsino gap up to ~170 GeV

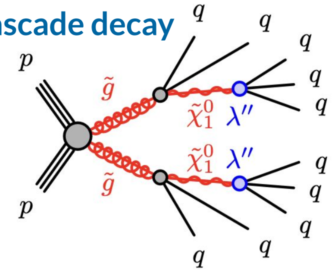
RPV all-hadronic multijets

SUSY-2019-24

Direct decay



Cascade decay



Target:

- Dropping R-parity conservation assumptions.
- UDD couplings $\lambda''_{112}, \lambda''_{113}$ violating baryon number, leads to decays to quarks

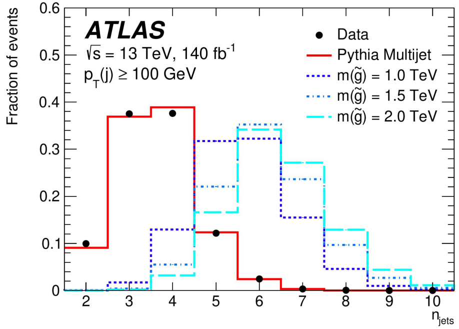
Final state: Pure multijet.

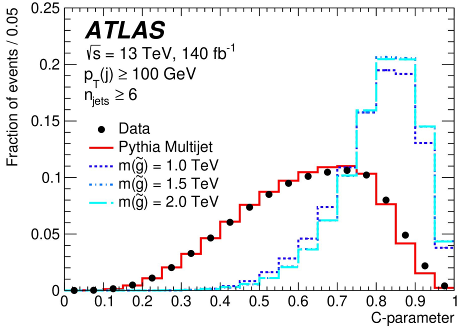
Backgrounds:

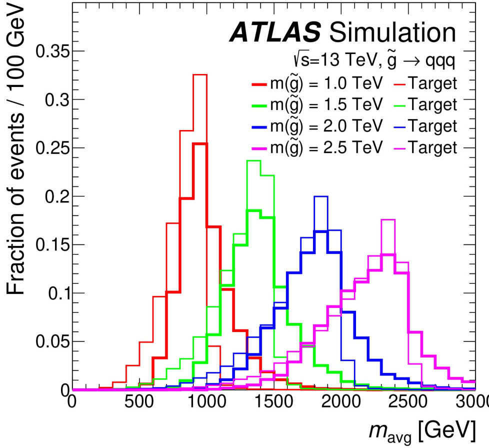
- Massive QCD multi jet background.
- Hard combinatorics for event reconstruction.

Strategy:

- **Jet counting analysis (both decays)**
  - SRs depending on number of jets, energy isotropy and number of b-tags
  - SRs with ≥7 high-p_T jets
  - Bkg from data with 4 jets, extrapolation to high N_{jet} and p_T using MC
- **Mass resonance analysis (Direct decay only)**
  - NN model to reconstruct gluino mass
  - NN assigns each jet to $\tilde{g}_1/\tilde{g}_2$/other
  - Look for bump in average $\tilde{g}$ mass, 3-param function describing multijet





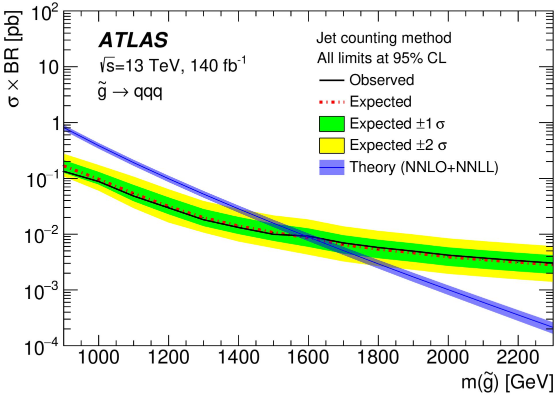


Trained on all signal models simultaneously (different $m(\tilde{g})$)

RPV all-hadronic multijets - cont.

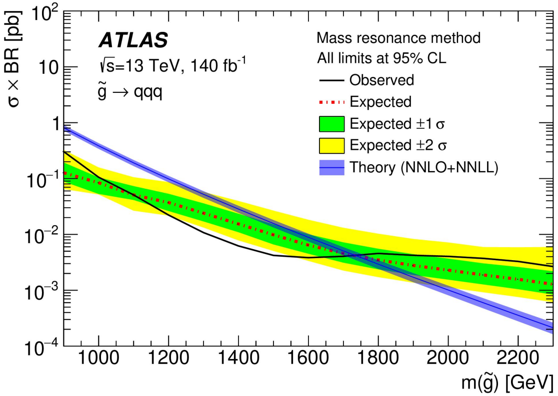
SUSY-2019-24

Direct decay (Jet counting)

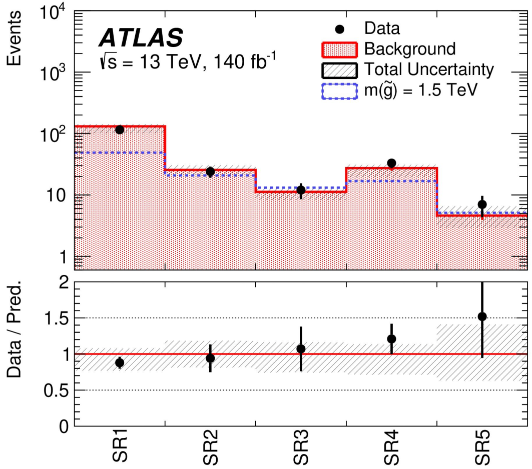


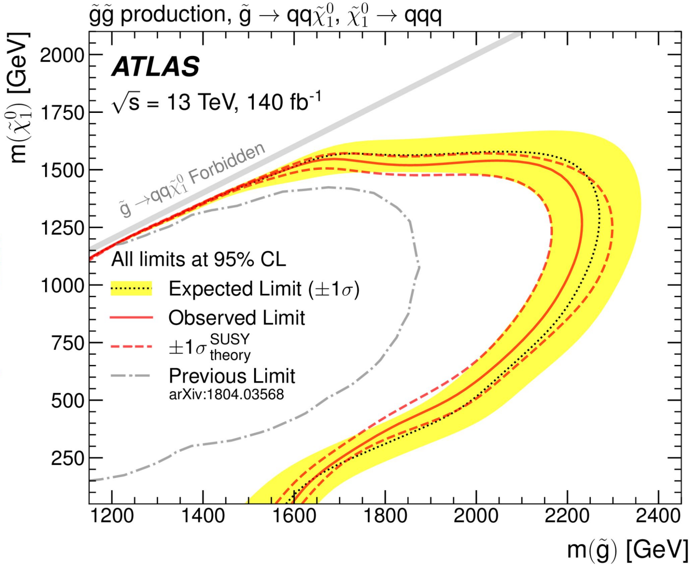
- Good agreement between Data and Background in all SRs.
- Mass resonance method extending by ~200 GeV the limits compared to the jet counting method.

Direct decay (Mass resonance)



Cascade decay (Jet counting)





RPV Stop B-L

SUSY-2018-37

1401.7989

Target:

- R-parity violating SUSY with stop as LSP.
- $\tilde{t}$ and anti-$\tilde{t}$ ($\tilde{t}^*$) decay to charged lepton and b-quark through RPV coupling (λ).

Final state:

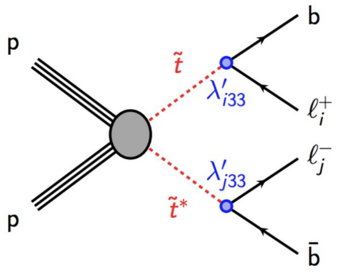
- 2 opposite sign leptons and 2 jets (≥1 b-tag)
- No significant source of $E_{\mathrm{T}}^{\mathrm{miss}}$.

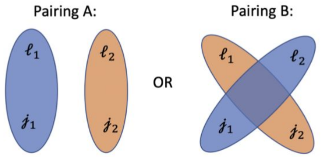
Backgrounds:

- $t\bar{t}$, Single-top, and Z+jets

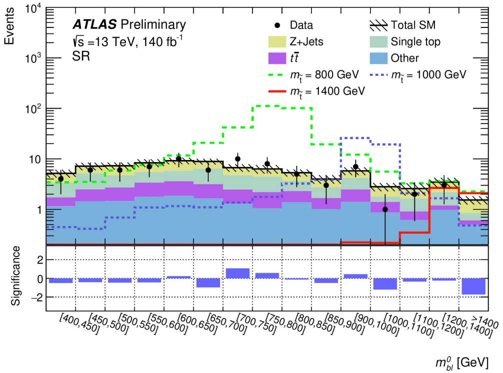
Strategy:

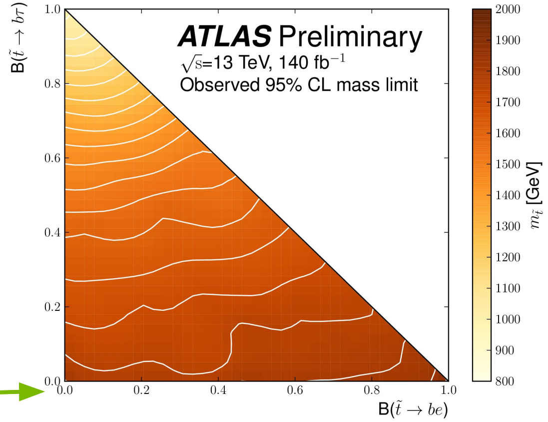
- Search for resonance in combined jet + lepton invariant mass distribution m_{bl}^{0}
- Two possible jet-lepton pairing
  - Pick pairing with lowest mass asymmetry
  - Stop pair production → Low mass asymmetry
  - Backgrounds are flat in mass asymmetry
- SR bins optimized over m_{bl}^{0} with variable bin widths.
- Limits (BR choice):
  - Lepton-flavour agnostic
  - Lepton-flavour aware





$$\frac{|m_1 - m_2|}{m_1 + m_2}$$





Strictest limits used for final results

Comparing to Early Run-2 (excluded stop mass):

- 1400 → 1800 GeV for $BR\mu$ = 100%
- 1500 → 1900 GeV for BRe = 100%
- 600 → 1100 GeV for $BR\tau$ = 90%

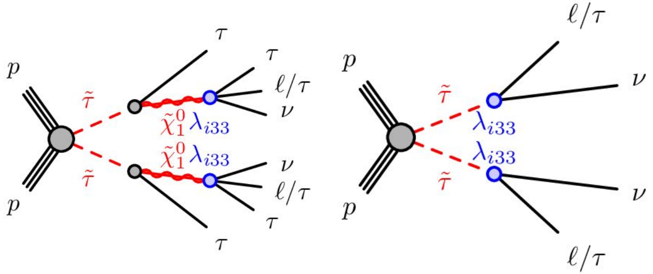
ATLAS EXPERIMENT Argonne NATIONAL LABORATORY

RPC-to-RPV LLP: di-τ & 4L re-interpretation

ATL-PHYS-PUB-2024-007

Re-interpretation of the *di-*τ [2402.00603] and *4L* [JHEP07(2021)167] analyses in models with variable lepton-number-violating RPV $\lambda_{133}/\lambda_{233}$

- **Stau pair-production** with bino-like LSP and production of mass-degenerate **higgsino pairs** (see back-up).
- RPV SUSY can mimic RPC if:
  - LSP decays beyond the detector
  - displaced particles ($\tau_{\text{LSP}} \sim O(10^{-3} - 1)\text{ns}$)
  - mother particle decays to SM particles (large RPV coupling)

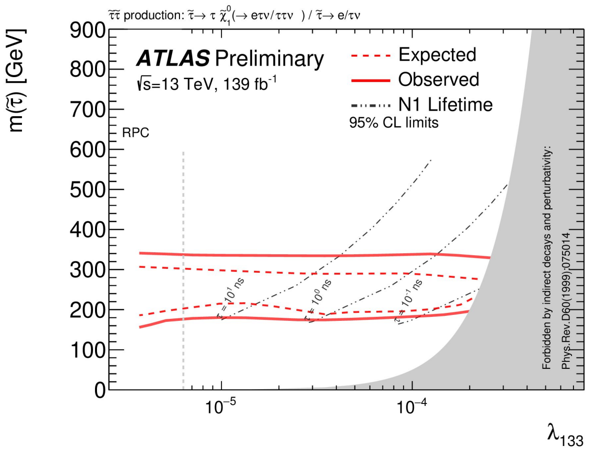


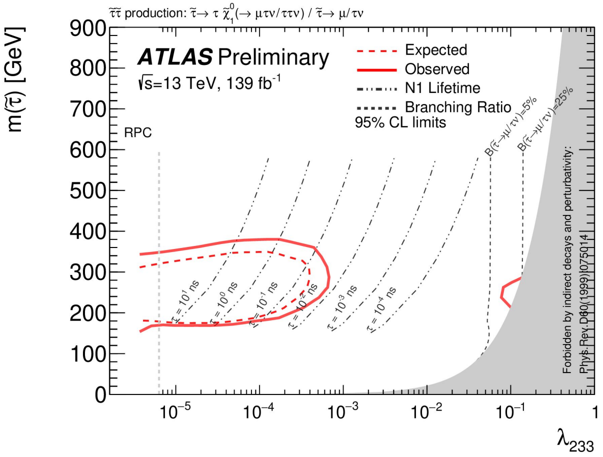
Stau pair production

- The LSP mass is fixed to 50 GeV
- Stau mass ranges from 100 to 500 GeV

Stau masses between **180 GeV** and **340 GeV** are excluded for neutralino lifetimes exceeding 10^{-1} ns.

The exclusion power drops considerably for $10^{-3} \geq \lambda_{i33} \geq 10^{-1}$.



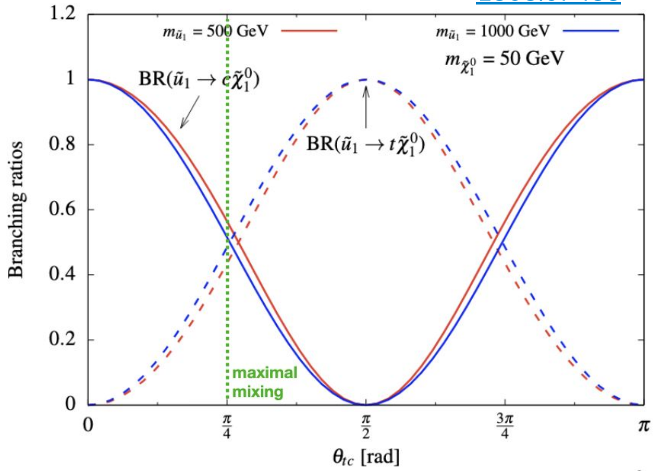


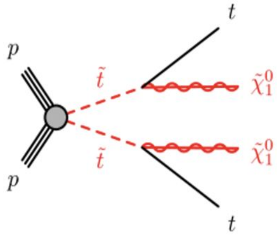
Additional flavour mixing terms

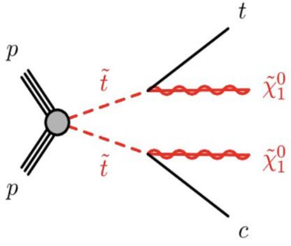
[1808.07488](1808.07488)

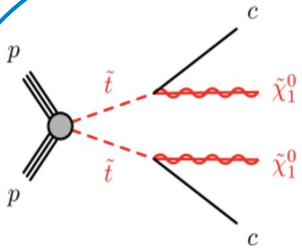
- Usually, assume minimal flavour violation in the SUSY models
- If allow additional flavour-mixing terms in the SUSY Lagrangian:
  - Mixing of 2nd and 3rd generation squarks
  - $\tilde{t}_1$ can decay to *(t or c)* + $\tilde{\chi}_1^0$ (linked via θ_{tc})
  - Maximal mixing implies our signals are:

    $50\%\ tc + E_{\mathrm{T}}^{\mathrm{miss}}, 25\%\ cc + E_{\mathrm{T}}^{\mathrm{miss}}$ and $25\%\ tt + E_{\mathrm{T}}^{\mathrm{miss}}$









New Full Run-2 result in preparation!

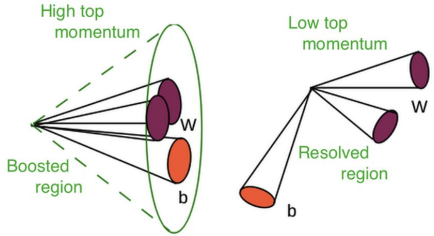
Previous results:

tt+ E_T^{miss}
- 2L channel - JHEP 04 (2021) 165
- 1L channel - JHEP 04 (2021) 174
- 0L channel - Eur. Phys. J. C 80 (2020) 737

cc+ E_T^{miss}
- JHEP 09 (2018) 050 (36fb^{-1})

$\tilde{t}\,\tilde{t} \rightarrow t\bar{t} + E_{\mathrm{T}}^{\mathrm{miss}}$ (1L)

SUSY-2023-22

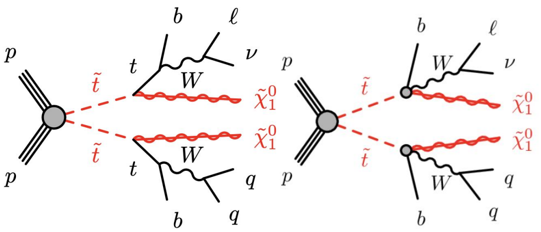


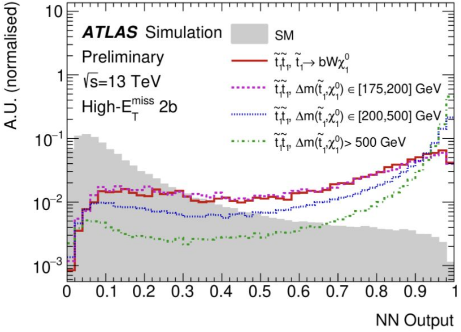
Target: Search for direct stop pair production.
Final state: One lepton, jets (possible large-R jet and b-tagged) and high $E_{\mathrm{T}}^{\mathrm{miss}}$.

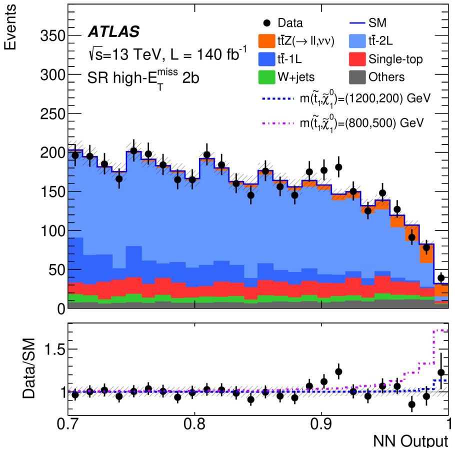
Backgrounds: $t\bar{t}$, W+jets and Single top.

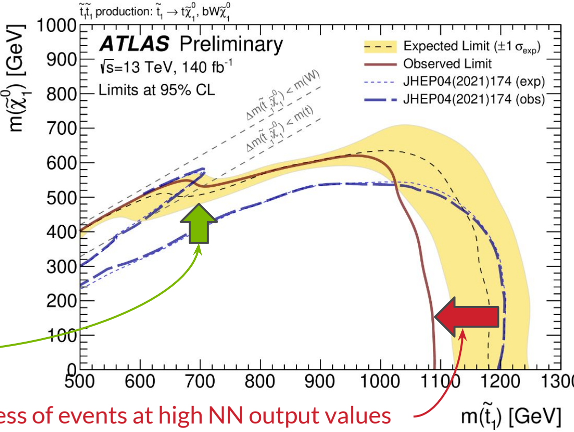
Strategy:

- **Hadronic top quark reconstruction with DNN**
  - **Boosted** (high p_T): large-R jet tagging.
  - **Resolved** (low-p_T & high $E_{\mathrm{T}}^{\mathrm{miss}}$): DNN combining b-/light-jets.
- **Event classification with NN**
  - Exploit the full kinematic properties of the events.
  - Low-/high-p_T top, # b-jets (in/out large-R jet).
  - NN discriminates sig/bkg in each category.
  - The NN score is also used to define control, validation and signal regions.







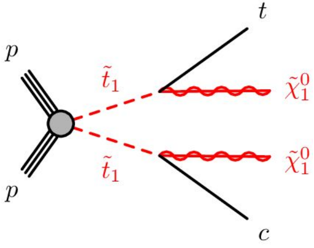


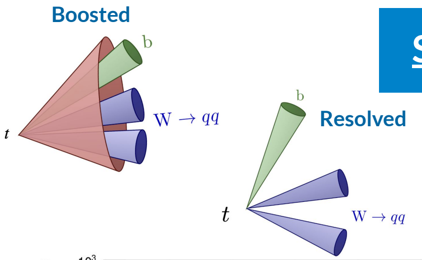
Able to exclude the valley!

Mild excess of events at high NN output values

$\tilde{t}_1\tilde{t}_1 \to tc + E_{\mathrm{T}}^{\mathrm{miss}}$

SUSY-2019-23





Target: Dropping assumption of minimal flavor violation allow stop and scharm mixing

- Maximal mixing: $\theta_{tc} = \pi/4 \rightarrow BR(tc) = 50\%$
- 0L channel with Boosted and Resolved topologies.

Final state: Many jets, high $E_{\mathrm{T}}^{\mathrm{miss}}$ and c-jet.

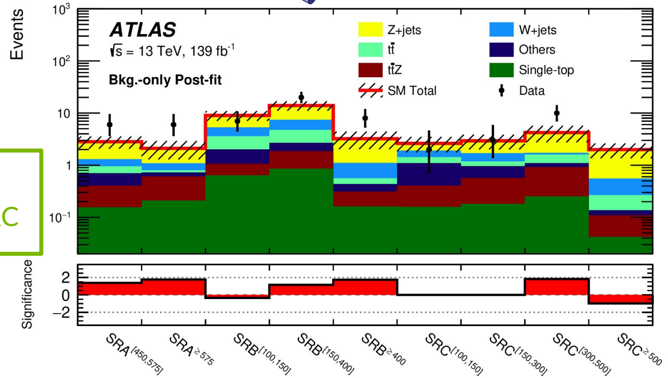
Backgrounds: Z+jets,W+jets, $t\bar{t}$.
Normalised in dedicated control regions.

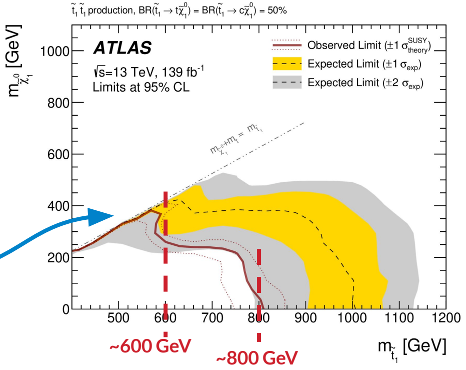
Strategy:

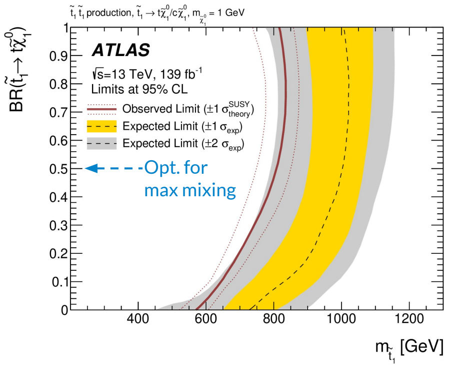
- Scan of $BR(\tilde{t}_1 \rightarrow c\tilde{\chi}_1^0/t\tilde{\chi}_1^0)$
- Dedicated charm tagger with 20% c-tag efficiency
- DNN top tagger: large-R jets from top decays
- Large $\Delta m(\tilde{t}_1, \tilde{\chi}_1^0)$: Boosted - large-R jet top-tagged.
- Small Δm: Resolved - ISR jet, NN to separate sig/bkg.
- 2 Intermediate orthogonal regions.

Weak observed limit reach due to the observed excesses.

Mild ~**2σ** excesses regions SRA, SRB, SRC







More realistic SUSY model approach

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)

Not a combination!

Check EWK Combination and A. Salas talk

Idea: 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.

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 $\tilde{\chi}_1^\pm\tilde{\chi}_1^0$

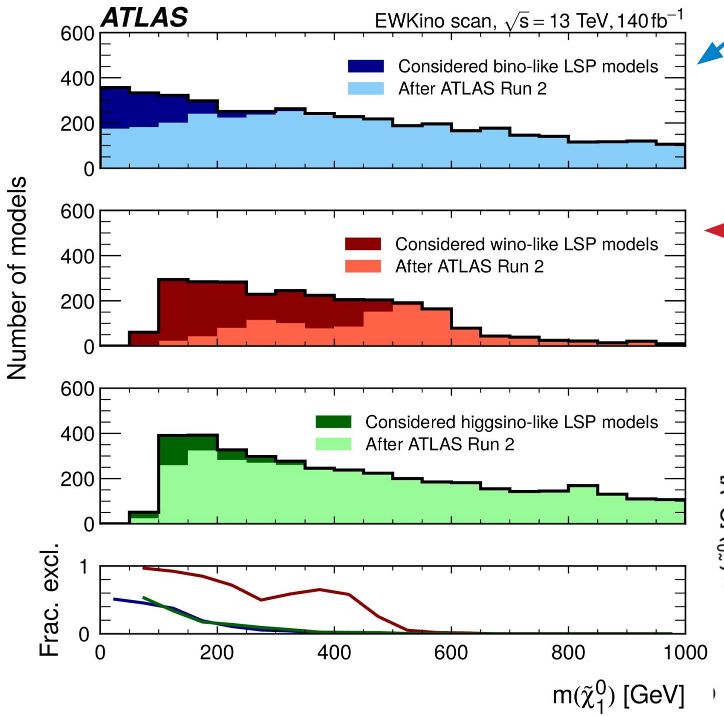
- Two scans performed:
  - **General EWKino** scan (squarks and slepton decoupled)
  - **Bino-DM** scan
  - A total of **~20000** models to study (after applying all constraints)
- Considering external constraints from:
  - Flavour, precision EWK and DM related measurements.

pMSSM Parameter	Meaning
$\tan\beta$	Ratio of the Higgs vacuum expectation values for the two doublets
M_A	Pseudoscalar (CP-odd) Higgs boson mass parameter
μ	Higgsino mass parameter
M_1, M_2, M_3	Bino, wino and gluino mass parameters
A_t, A_b, A_τ	Third generation trilinear couplings
$M_{\tilde{q}}, M_{\tilde{u}_R}, M_{\tilde{d}_R}, M_{\tilde{l}}, M_{\tilde{e}_R}$	First/second generation sfermion mass parameters
$M_{\tilde{Q}}, M_{\tilde{t}_R}, M_{\tilde{b}_R}, M_{\tilde{L}}, M_{\tilde{\tau}_R}$	Third generation sfermion mass parameters

Most relevant for EWKino sector

Electroweak pMSSM General Scan

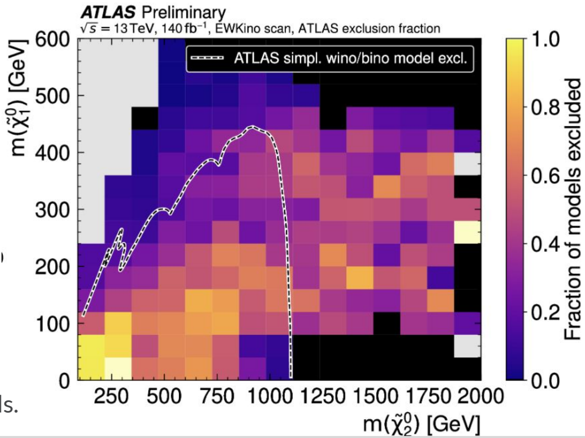
SUSY-2020-15

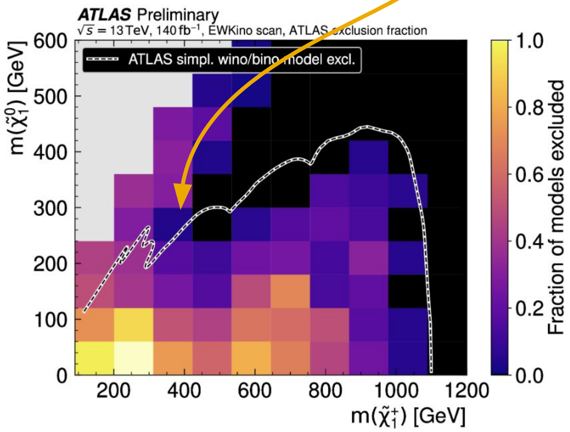


- For $m(\tilde{\chi}_1^0) \leq 100$ GeV, almost all are Bino-like LSP models.
  - And ~50% are excluded by ATLAS.
- For LSP mass ≤ 400 GeV, more than 50% excluded for Wino-like LSP models
  - Driven by disappearing track analysis.

- ATLAS exclude at least 50% of models with up to $m(\tilde{\chi}_1^{\pm}) = 400\text{GeV}$

- There are unexcluded models even at low LSP masses.



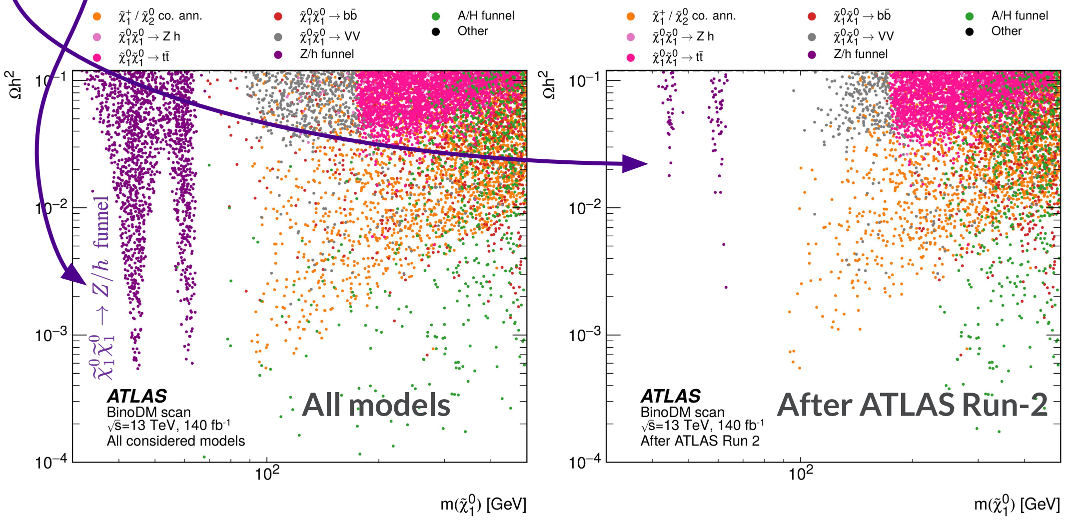


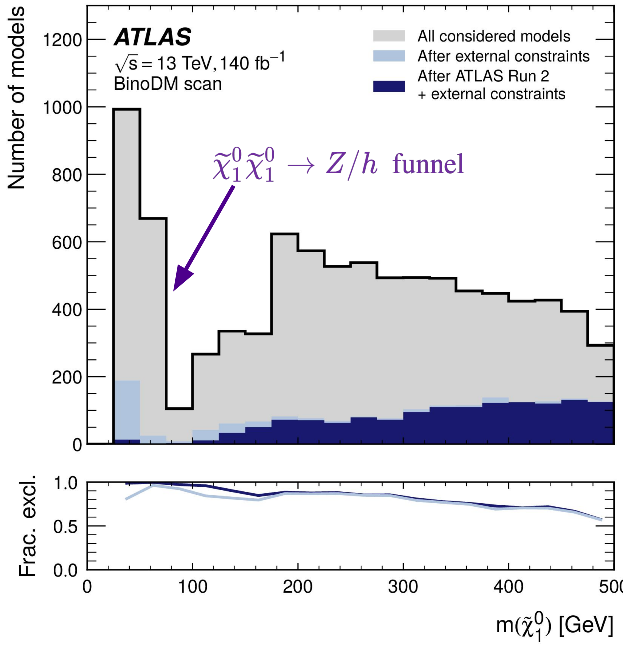
Grey indicates no models.

Electroweak pMSSM Bino-DM 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 $|M_1| < 500\ \mathrm{GeV}$ (low-mass bino)
- **Z/h "funnel region"** almost completely excluded by ATLAS Run-2 data.
- Weaker ATLAS constraints at higher LSP masses.
- $\tilde{\chi}_1^\pm/\tilde{\chi}_2^0$ **co-annihilation**: dominant mode still viable.





ATLAS EXPERIMENT Argonne NATIONAL LABORATORY

Outlook

- Huge effort covering vast regions of SUSY phase space, mostly using simplified models, RPC and minimal flavor violation
  - But also:
    - unconventional searches including RPV, long-lived particles (LLP), displaced tracks
    - non-minimal flavour violations
    - and phase space scans on more realistic model pMSSM

- **LHC Run-3** is on-going and the extra data will improve sensitivity
- Looking beyond:
  - High-Luminosity LHC (2029+)
    Many more opportunities, with increased sample size, improved detector and trigger.
    - Already working on this:
      tt+MET projections for HL-LHC ATL-PHYS-PUB-2024-001

tt+MET

EWK Compressed Displaced Track

RPV Multijets

RPV Stop B-L

tc+MET

RPC-to-RPV re-interpretation

EWK pMSSM scan

ATLAS_SupersymmetryPublicResults | Run-2 SUSY physics report

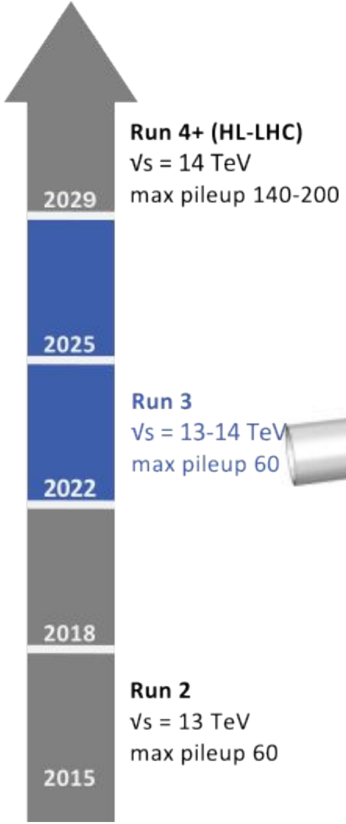
Backup Slides

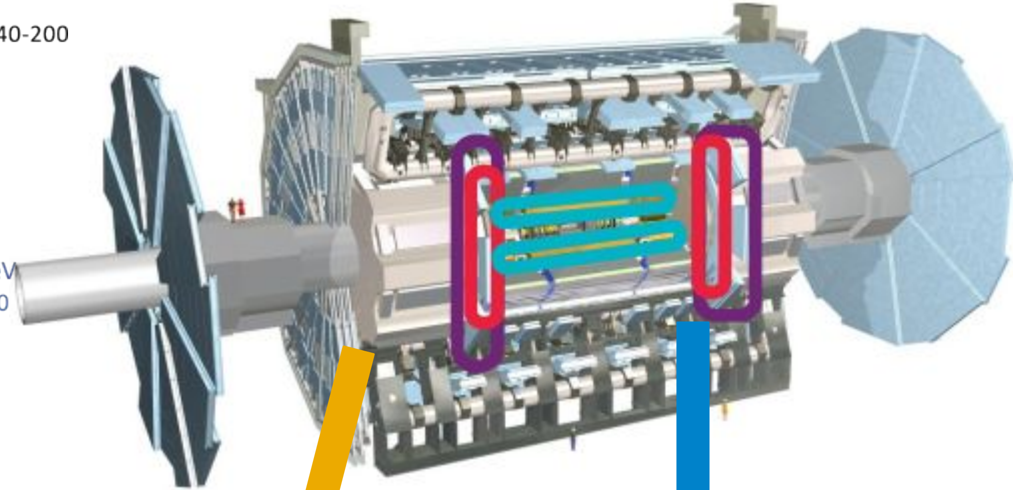
ATLAS

ATLAS upgrades for the LHC Run 3

The Large Hadron Collider (LHC) collides proton bunches at a **40MHz** rate.

- **ATLAS** detects the collision products and selects (trigger) physics events of interest. The **Run 3** expected avg. event data rate for permanent storage is ~3 kHz.
- New detector and trigger systems installed for Run 3 to improve background rejection.





New in Run 3

Muon System
- New Small Wheels (NSW)
- Inner Barrel RPCs (BIS7/8)

Calorimeters
- Liquid Argon (LAr) digital readout

Trigger and DAQ
- L1Calorimeter Trigger (L1Calo)
- FELIX & Software Readout Driver (SWROD)

40MHz rate

Level-1 (L1) Trigger

Accept signal
max latency 2.5 μs
max rate 100 kHz

DAQ → 100kHz → High-Level Trigger (HLT) → 3kHz → Permanent Storage

Pileup = number of interactions per LHC bunch crossing

How do we look for SUSY?

R-parity

Most general superpotential: $W_{\text{RPV}} = \frac{\lambda_{ijk}}{2} L_i L_j \bar{E}_k + \lambda'_{ijk} L_i Q_j \bar{D}_k + \frac{\lambda''_{ijk}}{2} \bar{U}_i \bar{D}_j \bar{D}_k + k_i L_i H_u$

- Terms allowing baryon- and lepton-number violation.
- Non-zero values of both these couplings lead to rapid proton decay.
- Impose an ad-hoc symmetry (R-parity) to forbid these couplings:
    - **+1 for SM** and **-1 for SUSY** particles

If **RPC** :

$\rightarrow$ SUSY particles produced in pairs

$\rightarrow$ LSP can be stable and weakly interacting (good candidate for DM)

$\rightarrow$ Large missing transverse momentum ($E_{\mathrm{T}}^{\mathrm{miss}}$) in the final state.

If **RPV** (other theoretical alternatives can prevent proton decay):

$\rightarrow$ LSP unstable and decays into SM particles

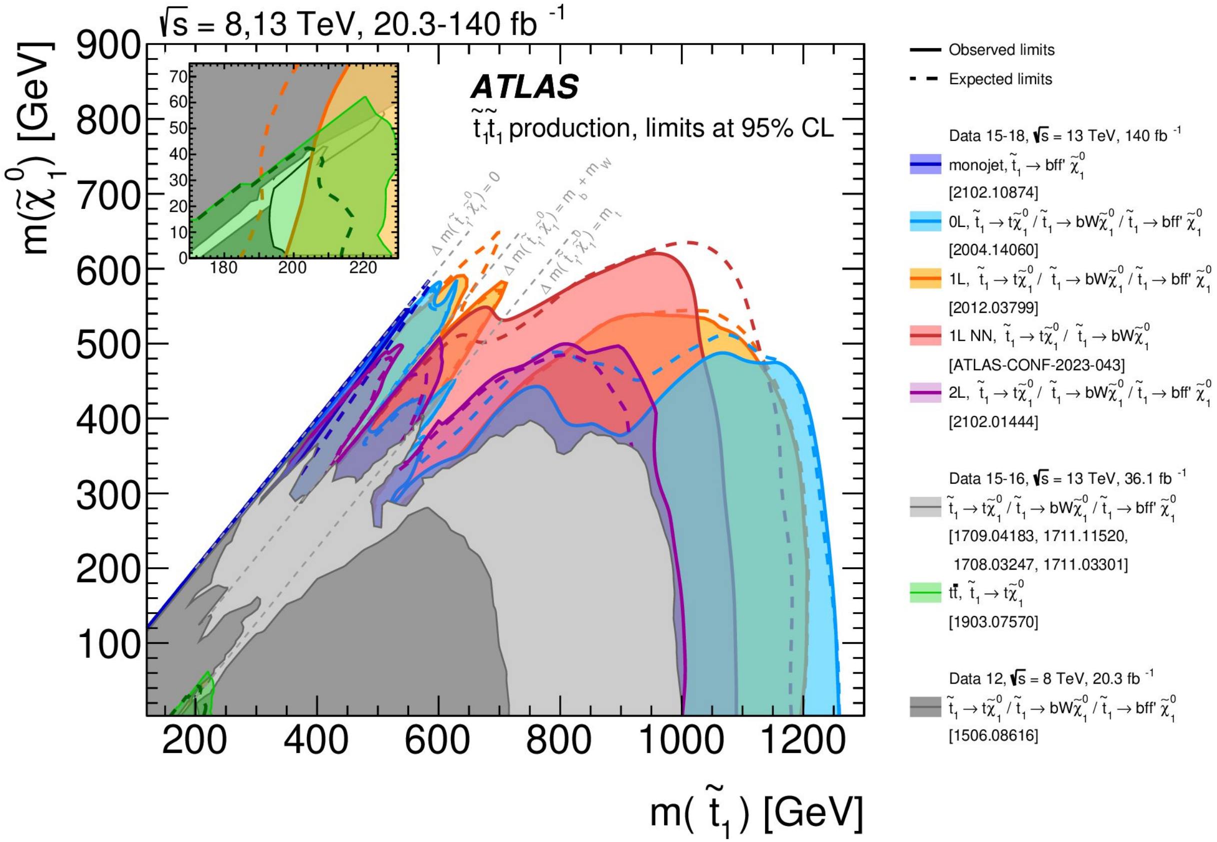
$\rightarrow$ Low $E_{\mathrm{T}}^{\mathrm{miss}}$ in the final state (or coming from neutrinos)

Illustration by Sandbox Studio, Chicago with Steve Shanabruch

Stop searches summary

SUSY-2023-10

"The quest to discover supersymmetry at the ATLAS experiment"



Sensitivity driven by 0L+1L combination

Uncertainties

Statistical uncertainty

- Source: data and simulation (you only have X events in your SR or CR).
- We are performing counting experiments: stat uncertainty is Poisson → relative uncertainty ~ $\frac{1}{\sqrt{N}}$
  - You need a lot of data to reduce this uncertainty.

Systematic uncertainties

- Quantify how good your measurements are.
- Detector calibration (scale/resolution) effects: your measurement may only be accurate/precise at X%.
- More data and cleverness can reduce these.
  - Measure $\frac{X}{Y}$ where both X and Y change in a similar way → "canceling" the syst. effect.

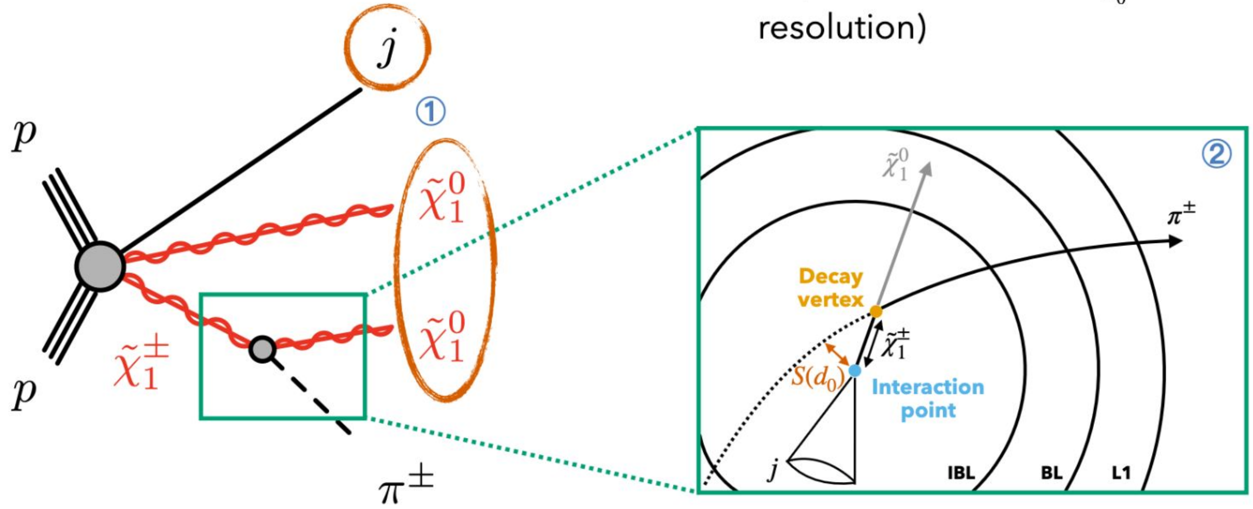
From Walter Hopkins

EWK compressed Displaced Track

SUSY-2020-04

① **Monojet**: exploit energetic ISR jet to boost SUSY system and generate enough $E_{\mathrm{T}}^{\mathrm{miss}}$ to trigger the events

② **Tracks**: apply track quality selections and require large $S(d_0) = d_0/\sigma_{d_0}$ to select candidate displaced track (here σ_{d_0} is the impact parameter resolution)



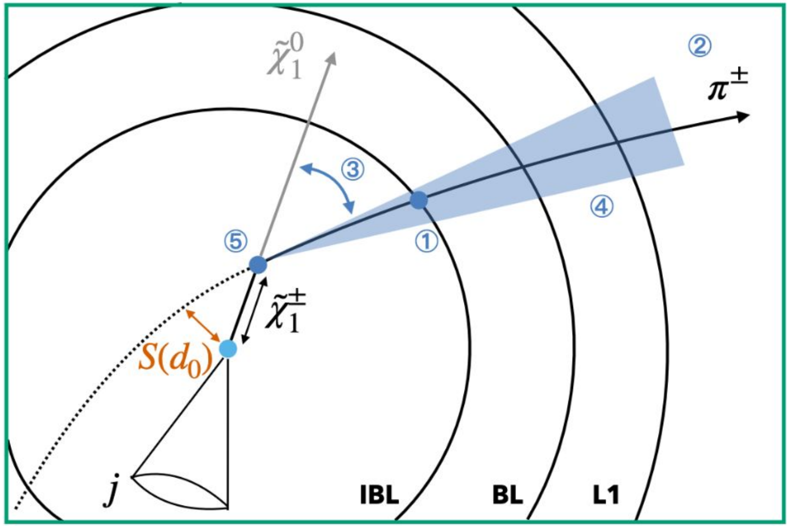
From Alessandro Sala

EWK compressed Displaced Track

SUSY-2020-04

- **Track-level selections**
  - ① $N_{IBL} > 0$: select only tracks with origin within the beam pipe
  - ② **Track p_T**: lower (upper) limit to reduce QCD (τ decay) tracks
  - ③ **Track-MET alignment**: due to ISR boost, $\tilde{\chi}_1^0$ and $\pi^{\pm}$ tracks are oriented in same direction
  - ④ **Track isolation**: suppress background tracks from B and strange hadrons
  - ⑤ **Secondary vertex veto**: suppression of K_S^0 and Λ^0 backgrounds

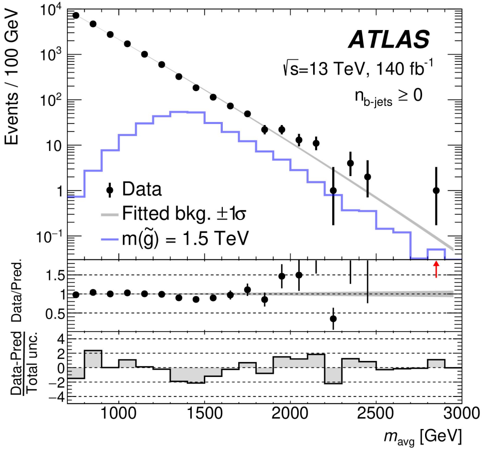
	Variable	Requirement
	Track quality	*Tight Primary*
①	N_{IBL}	> 0
②	p_T [GeV]	[1:5]
	η	< 1.5
	d_0 [mm]	< 10
	$\|\Delta z_0 \sin\theta\|$ [mm]	< 3
③	$\|\Delta\phi(p_T^{track}, E_T^{miss})\|$	< 0.4
④	Track-based isolation	No tracks with $p_T > 1$ GeV within a $\Delta R < 0.4$ cone
⑤	Secondary vertex veto	Veto tracks assigned to secondary vertex by `InDetV0FinderTool`
	Leading $S(d_0)$ selection	Select track with largest $S(d_0)$

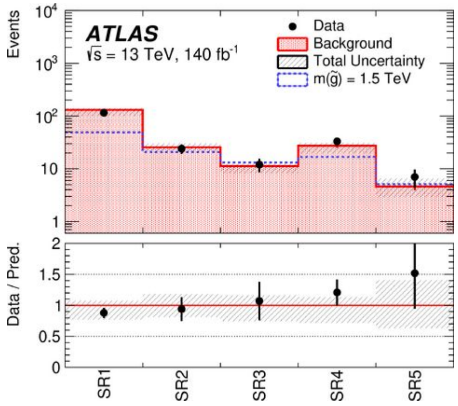


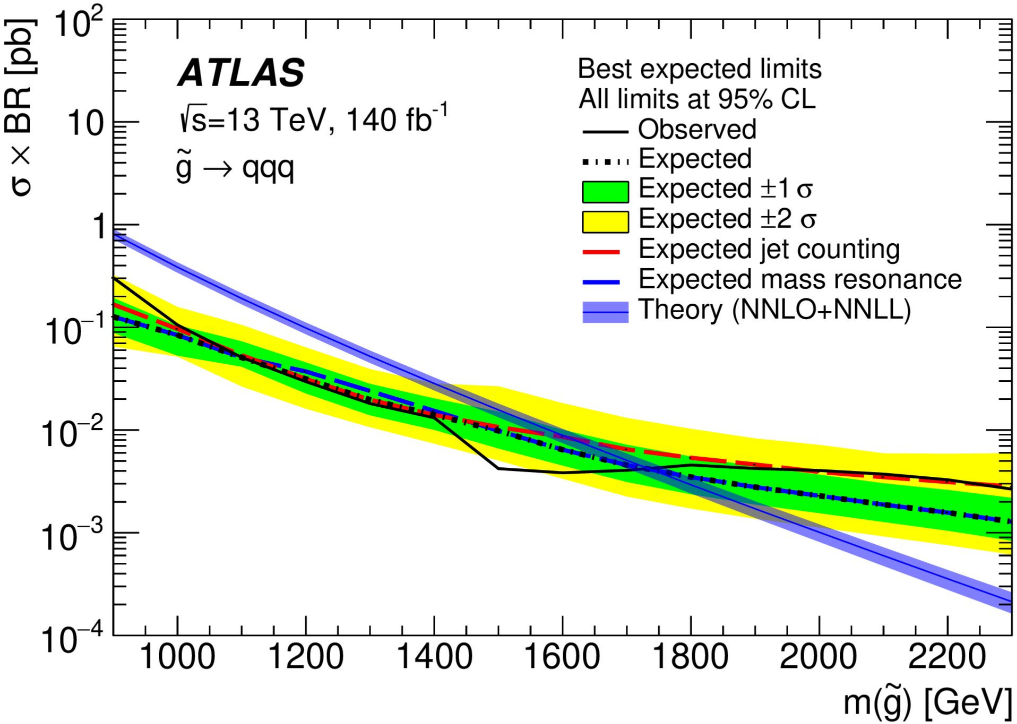
From Alessandro Sala

RPV all-hadronic multijets

SUSY-2019-24



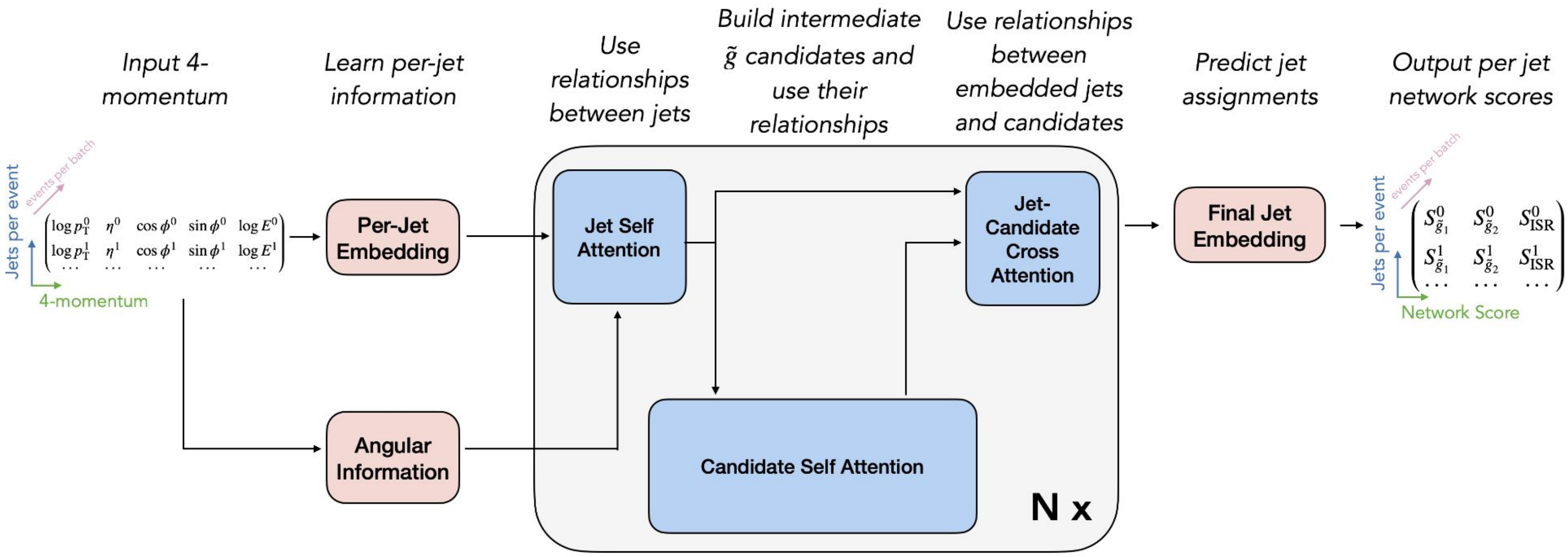




RPV all-hadronic multijets

SUSY-2019-24

Jet $p_\mu \rightarrow$ Gluino p_μ Procedure



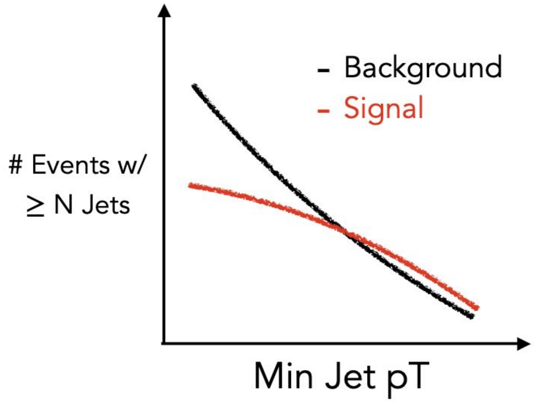
From Anthony Badea

RPV all-hadronic multijets - cont.

SUSY-2019-24

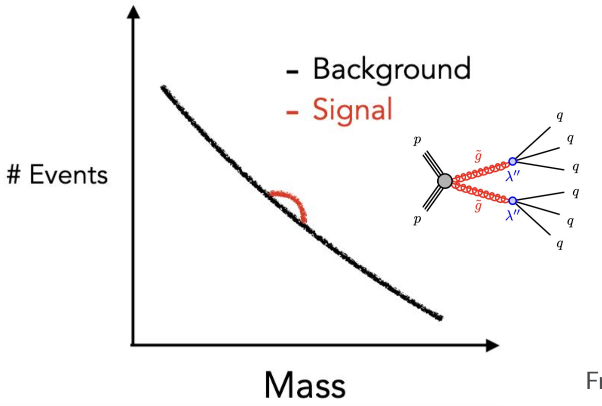
1. Jet Counting Method

Definition of SRs with selections on many jets with high pT and "C" variable (a measure of the isotropic-ness of the decay), to isolate signal on top of the SM background. Main background is multi-jet production, estimated in a semi-data-driven way, extrapolating from low jet multiplicities to high jet multiplicities. Targets both the direct and cascade models



2. Mass Resonance Method

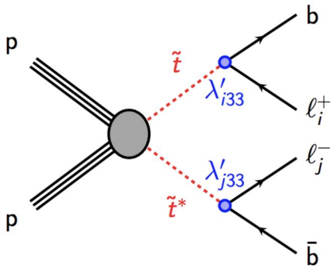
Uses ML method to correctly group the 3 jets from the direct gluino decay and reconstruct the gluino mass from the grouped jets. Selection again using high jet multiplicity and C. Background is again multi-jets but is estimated in a fully-data driven way using a fit to the falling gluino mass distribution. Targets only the direct decay model

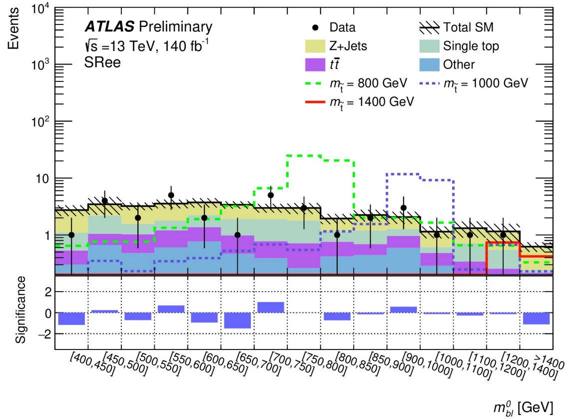


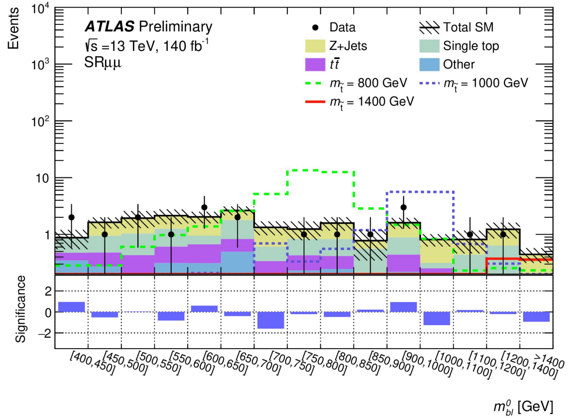
From Anthony Badea

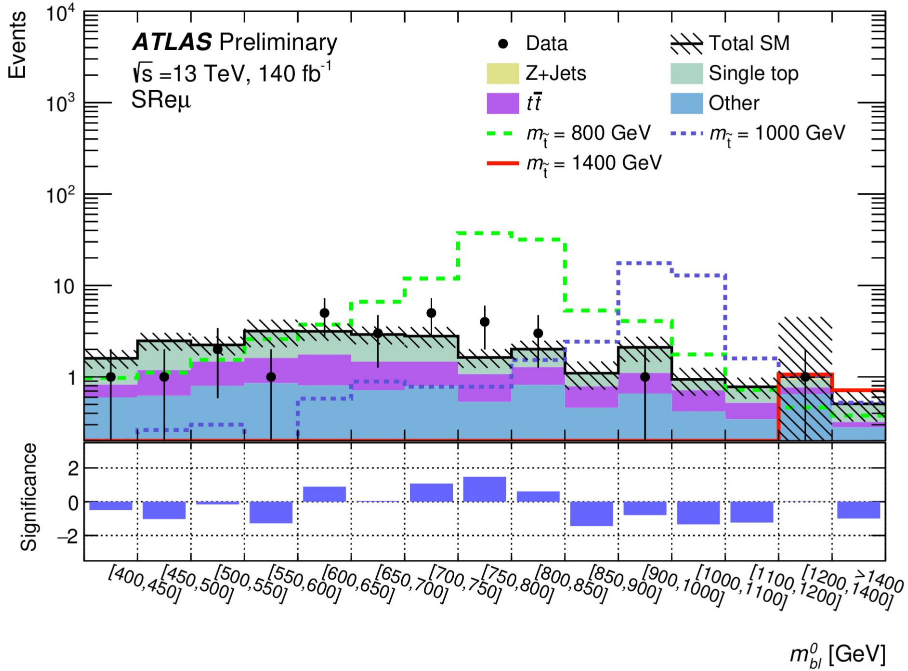
RPV Stop B-L

SUSY-2018-37



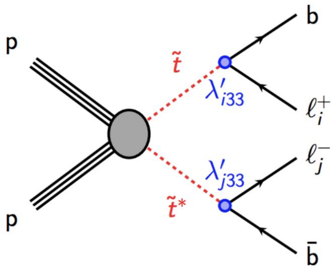


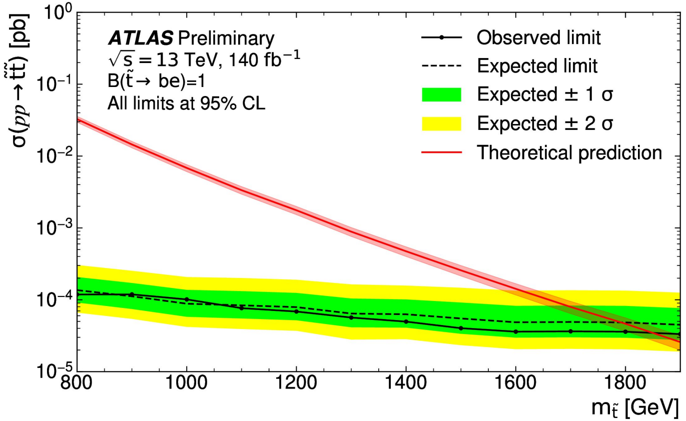


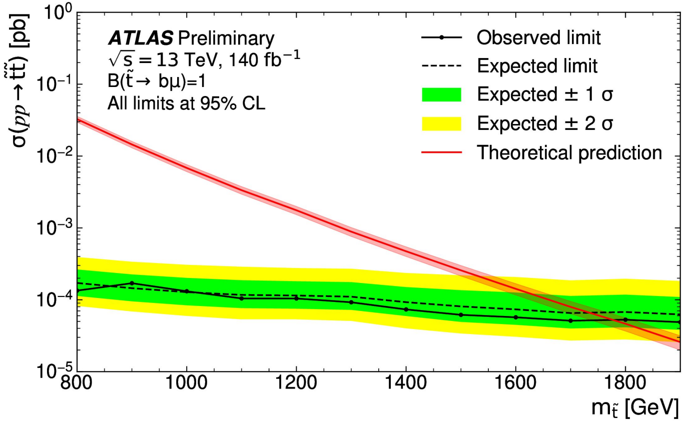


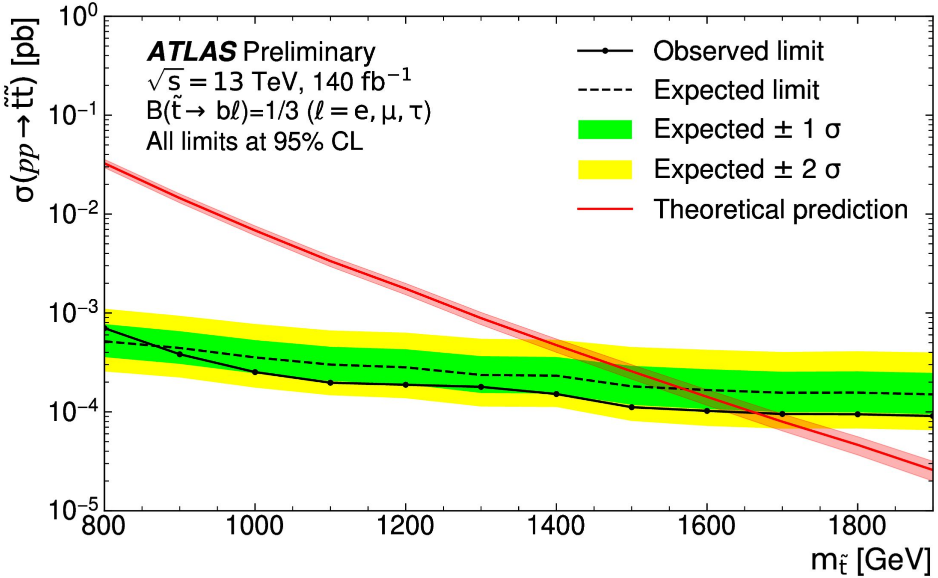
RPV Stop B-L

SUSY-2018-37



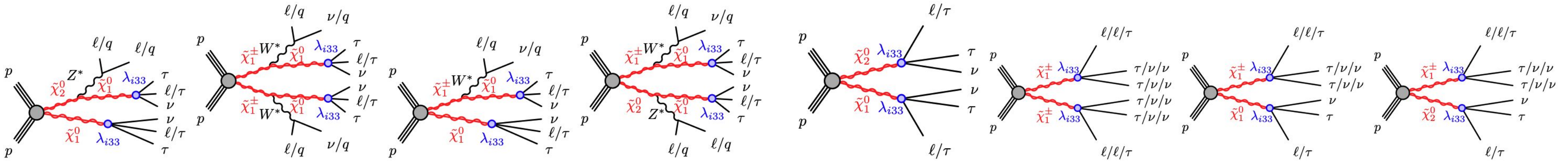




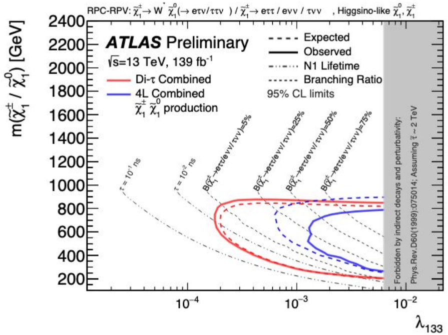


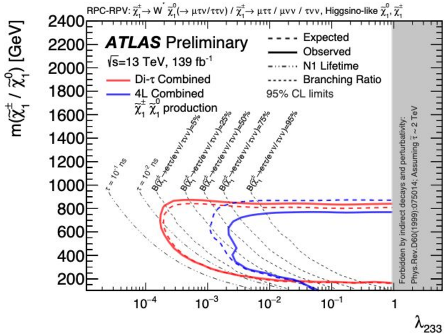
RPC-to-RPV LLP: di-τ & 4L re-interpretation

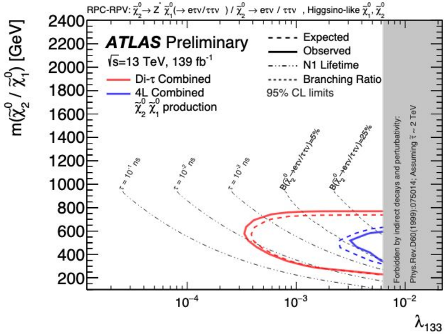
ATL-PHYS-PUB-2024-007

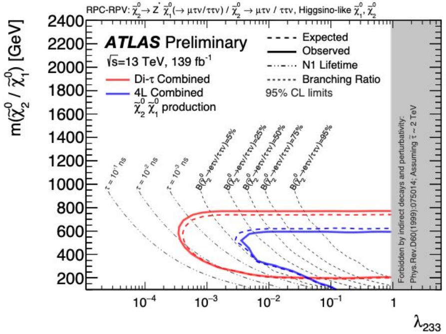


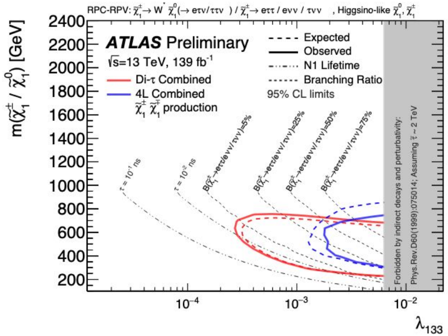
In scenarios with large coupling, where the higgsinos decay mainly via RPV couplings into SM particles, masses up to **800 GeV** are excluded across all production channels.
For the higgsino model no exclusion limits can be established for values of λ_{i33} larger than 10^{-4}.

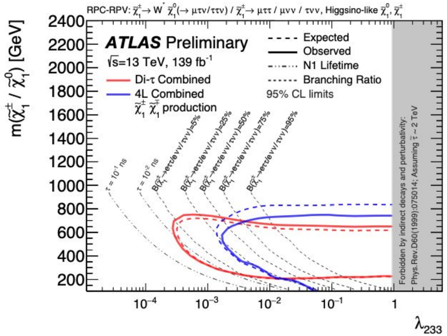












tc + MET - Discriminant variables

SUSY-2019-23

$$S = \frac{|\mathbf{E}_{\mathrm{T}}^{\mathrm{miss}}|}{\sqrt{\sigma_{\mathrm{L}}^2(1-\rho_{\mathrm{LT}}^2)}}$$

Object-based E_T^{miss} significance (S)
Discriminates events where E_T^{miss} arises from poorly measured particles & jets, from events with invisible particles in the final state.

min[Δϕ(j, E_T^{miss})]
Min. angular distance between the four (three in compressed) leading jets and E_T^{miss}. Reduce QCD multijet mis-measured E_T^{miss}.

m_T(j, E_T^{miss})$_{close}$
Transverse mass between the closest jet to E_T^{miss} and the E_T^{miss}, reject ttbar.

min[m_T(b/c, E_T^{miss})], max[m_T(b/c, E_T^{miss})]
Minimum and maximum transverse mass between b-tagged and c-tagged jets and the E_T^{miss}. In the case of ttbar, these variables are bound at truth level by the mass of the top while signals tend to present higher values.

Number of identified top
Reduction of the V +jets background after requiring at least one tagged-top.

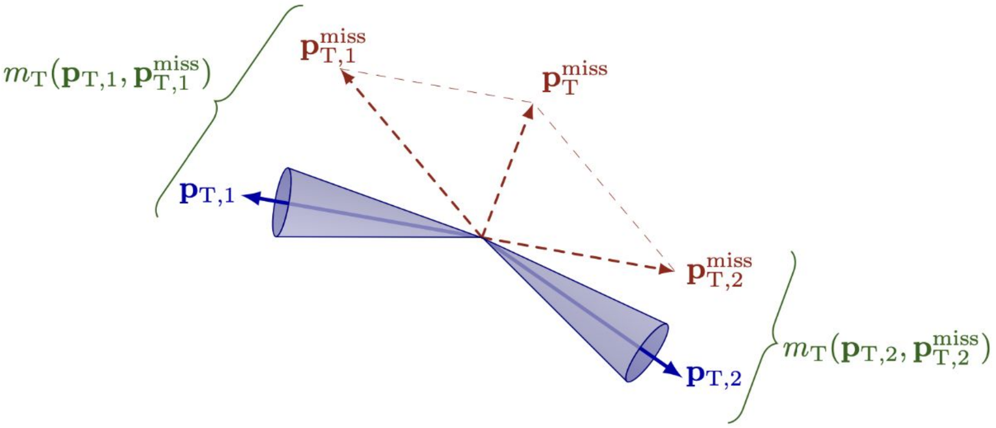
Stransverse mass m_{T2} (lead b-tagged fat-jet, lead c-jet)
Reduces the ttbar and the V+jets backgrounds by profiting of the asymmetric decays of the signals considered in this analysis.

Effective mass
Scalar sum of the transverse momenta of all reconstructed objects. Discriminates between SUSY signal events and background processes, it is expected to be higher for events with new massive particles.

$$m_{eff} = \sum_{objects} p_T + E_T^{miss}$$

tc + MET

mT2



$$m_{T2}(\mathrm{p}_{T,1}, \mathrm{p}_{T,2}, \mathrm{p}_T^{miss}) = \min_{\mathrm{p}_{T,1}^{miss} + \mathrm{p}_{T,2}^{miss} = \mathrm{p}_T^{miss}} \left[\max(m_T(\mathrm{p}_{T,1}, \mathrm{p}_{T,1}^{miss}), m_T(\mathrm{p}_{T,2}, \mathrm{p}_{T,2}^{miss}))\right].$$

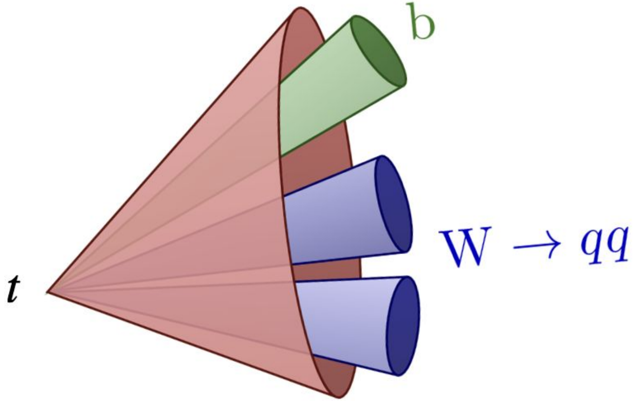
If the two jets are coming from ttbar decays then the distribution of mT2 is bounded sharply from above by the mass of the top quark

From Marawan Barakat

tc + MET

top-tagger

DNN top tagging for large-R jets

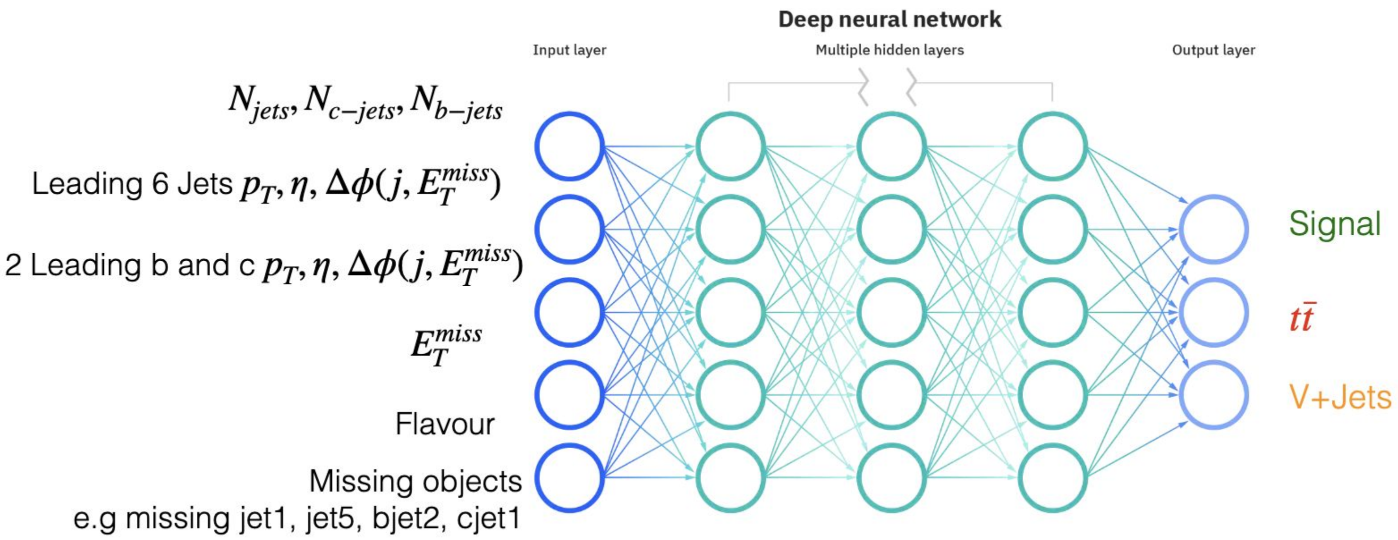


80% efficiency WP
$p_T \in [350, 2500]$ GeV
$m \in [40, 600]$ GeV

In topologies where **high-mass quarks** are produced with high-pT, their decay products maybe **collimated** along the direction of the mother particle. In such case, these final particles might be close enough to be **reconstructed as large-R** jets instead of separated small-R jets

From Marawan Barakat

tc + MET

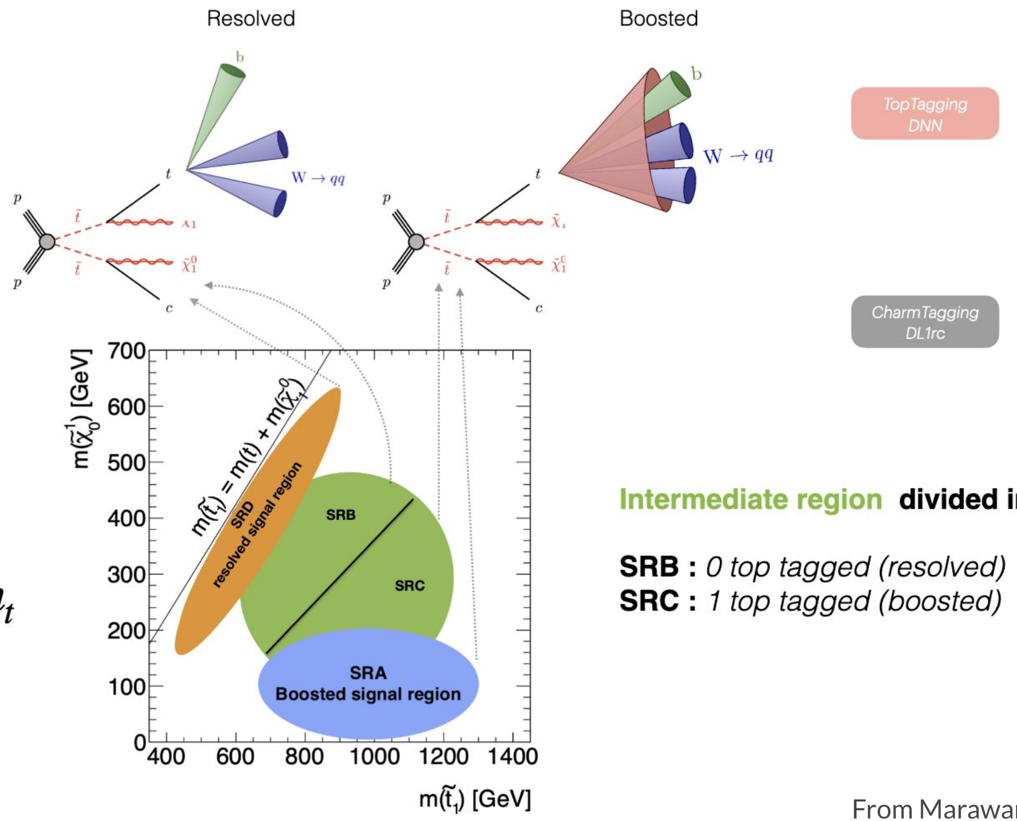


Deep Neural Network with fully connected layers using as input the jets, E_T^{miss}, FTAG information

3 Output Probabilities per event to be :
Signal or V+jets or $t\bar{t}$

From Marawan Barakat

tc + MET



Search regions :

Boosted : $\Delta m(\tilde{t}_1, \tilde{\chi}_0^1) \gg m_t$

Intermediate : $\Delta m(\tilde{t}_1, \tilde{\chi}_0^1) > m_t$

Resolved : $\Delta m(\tilde{t}_1, \tilde{\chi}_0^1) \simeq m_t$

Intermediate region divided into :

SRB : *0 top tagged (resolved)*
SRC : *1 top tagged (boosted)*

From Marawan Barakat

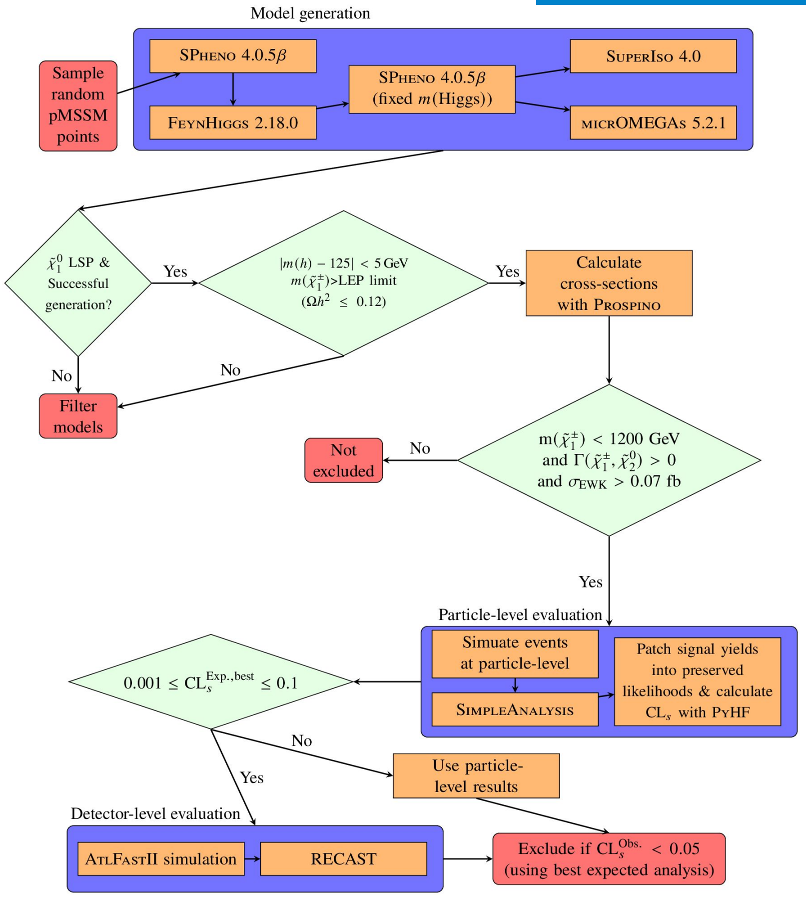
Electroweak pMSSM Scan

SUSY-2020-15

1. Generate pMSSM models and apply initial filters.

2. Perform particle-level categorization of models using SimpleAnalysis and pyhf.

3. For models deemed "ambiguous" detector-level MC samples are produced and processed using RECAST.



Electroweak pMSSM

SUSY-2020-15

External constraints

Category	Constraint	Lower bound	Upper bound	Notes
Flavour	$\mathcal{B}(b \to s\gamma)$	3.11×10^{-4}	3.87×10^{-4}	2022 PDG average (2σ window)
	$\mathcal{B}(B_s \to \mu\mu)$	1.87×10^{-9}	4.31×10^{-9}	Most recent LHCb result (2σ window)
	$\mathcal{B}(B^+ \to \tau\nu)$	6.10×10^{-5}	1.57×10^{-4}	2022 PDG average (2σ window)
Precision electroweak	$\Delta\rho$	-0.0004	0.0018	Updated global electroweak fit by GFITTER group (not including CDF W mass measurement)
	$\Gamma_{\text{inv}}^{\text{BSM}}(Z)$	–	2 MeV	Beyond-the-Standard Model contributions to precision electroweak measurements on the Z-resonance from experiments at the SLC and LEP colliders .
	$m(W)$	80.347 GeV	80.407 GeV	2022 PDG result (excluding CDF W mass measurement) but with the 2σ window expanded by 6 MeV to allow for uncertainty due to the top-quark mass in the MSSM Higgs calculation
DM	Relic density	–	0.12	Latest bound from Planck
	Direct detection $\sigma_{\text{Spin-independent}}$			Exclusion contour on direct detection of DM from the LZ Collaboration
	Direct detection $\sigma_{\text{Spin-dependent}}$			Exclusion contour on direct detection of DM from PICO-60

Electroweak pMSSM

SUSY-2020-15

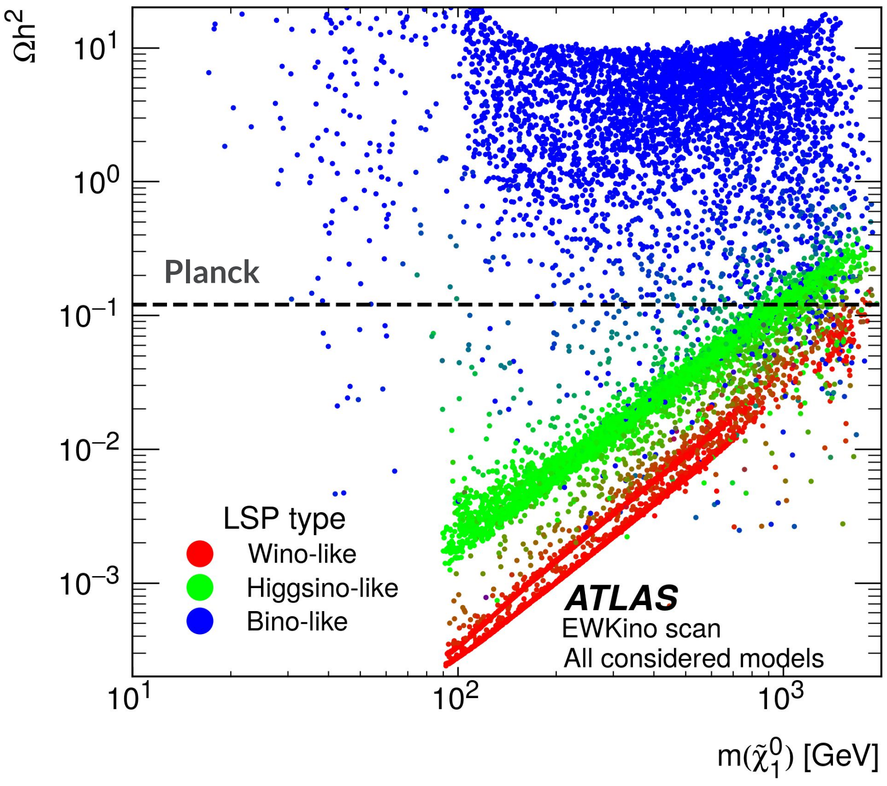
Scan configurations and models generated

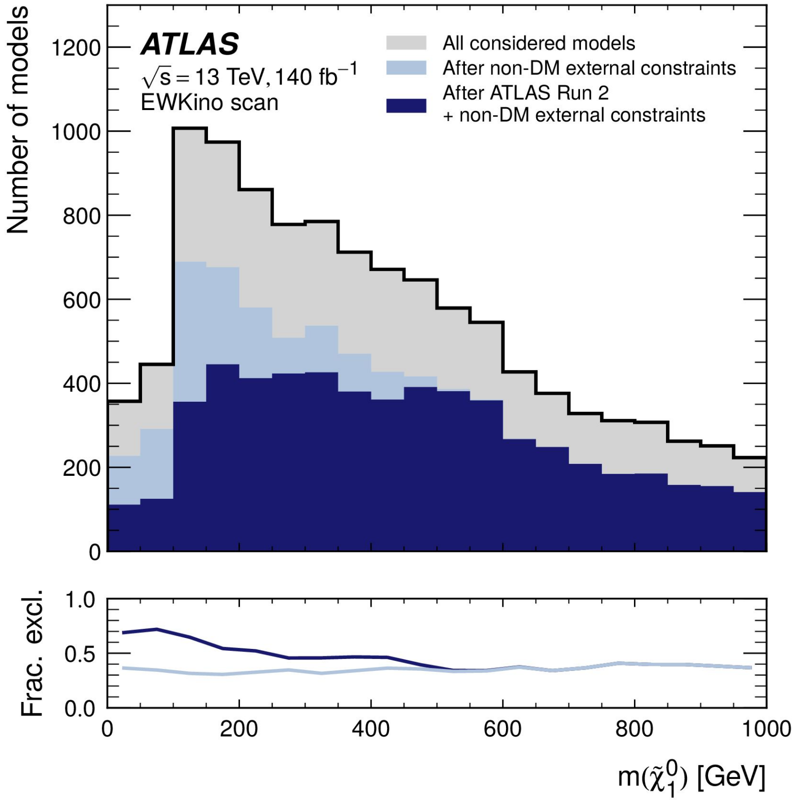
Parameter	Min	Max	Note
$M_{\tilde{L}_1}$ $(=M_{\tilde{L}_2})$	10 TeV	10 TeV	Left-handed slepton (first two gens.) mass
$M_{\tilde{e}_1}$ $(=M_{\tilde{e}_2})$	10 TeV	10 TeV	Right-handed slepton (first two gens.) mass
$M_{\tilde{L}_3}$	10 TeV	10 TeV	Left-handed stau doublet mass
$M_{\tilde{e}_3}$	10 TeV	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

Scan name	EWKino	BinoDM
$\lvert M_1 \rvert$ range	0 – 2 TeV	0 – 500 GeV
LSP type	Neutralino	Bino-like neutralino
Number of models generated:		
Sampled	20 000	437 500
Successful generation	16 667	370 017
Correct LSP type	15 321	286 267
Satisfy DM relic density constraint $\Omega h^2 \leq 0.12$	N/A	11 122
Satisfy LEP chargino mass constraint	13 969	10 174
120 GeV $<$ m(h) $<$ 130 GeV	12 280	8 897
Satisfy non-DM external constraints	7 956	5 752
Satisfy all external constraints	2 460	1 769

Electroweak pMSSM General Scan

[SUSY-2020-15]

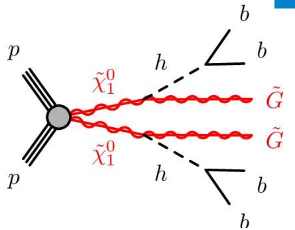




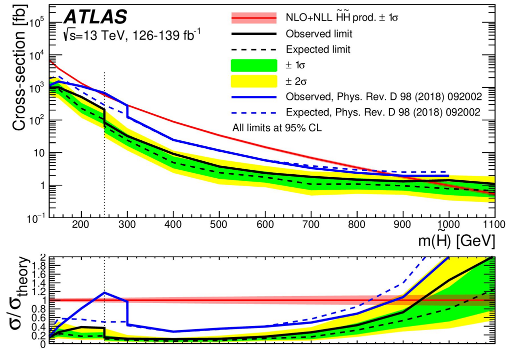
Other ATLAS SUSY results

EWK higgsinos with multi b-jets

SUSY-2020-16



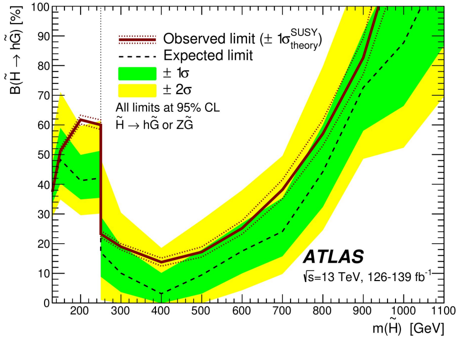
- Higgsino production in GGM/GMSB model
  - Decaying to h(bb)h(bb) + MET (Nearly massless gravitino LSP)
- New method for pairing b-jets into Higgs boson candidates, improved jet reconstruction and b-tagging, MVA techniques



- Two analysis strategies:

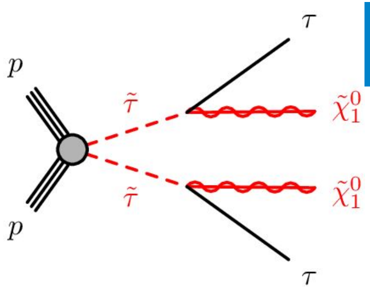
  Low higgsino mass (<250 GeV)
  - Low MET and using b-jet triggers (126 fb^{-1})
  - Four or more b-jets to reconstruct Higgs bosons
  - QCD multijet estimated using data-driven ABCD method

  High higgsino mass (>250 GeV)
  - High MET (MET based triggers)
  - At least 3 b-jets
  - Z+jets and ttbar CR and QCD multijet data-driven
  - BDT signal/background discrimination
- Higgsino masses excluded up to 940 GeV for 100% BR($\rightarrow h\tilde{G}$)

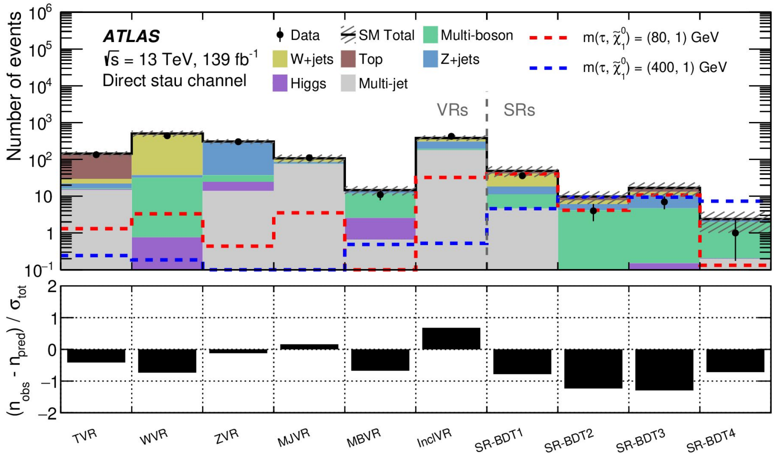


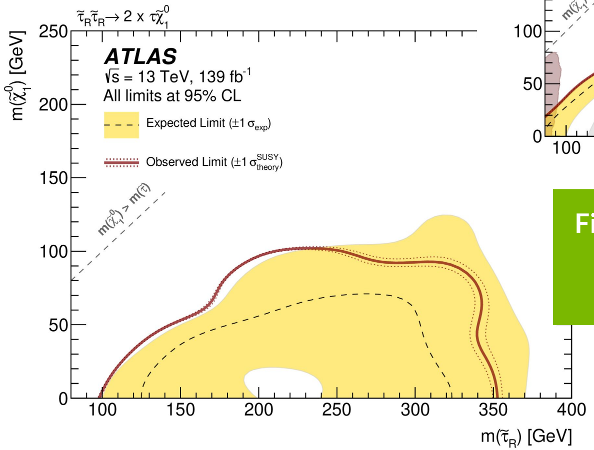
EWK di-taus: direct $\tilde{\tau}$

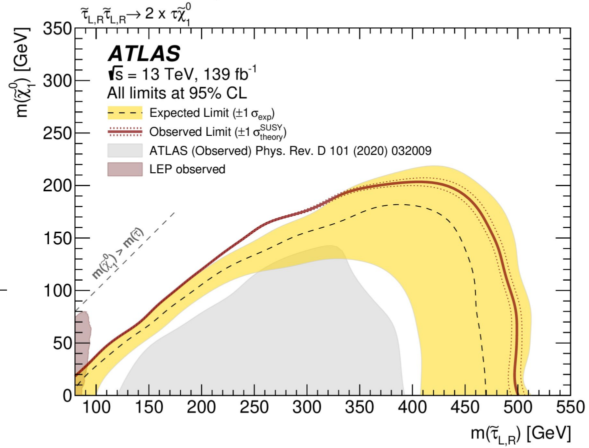
SUSY-2023-03



- Search for direct stau production decaying to tau and LSP
- BDT define SR for different signal masses
- Backgrounds
  - Data-driven method for QCD multijets (fake taus).
  - MC normalized in CRs for W/Z+jets, top, multi-boson.
- Interpret results for left-handed and right-handed only scenarios
- Extended sensitivity to 480 GeV for $\tau_{L,R}$





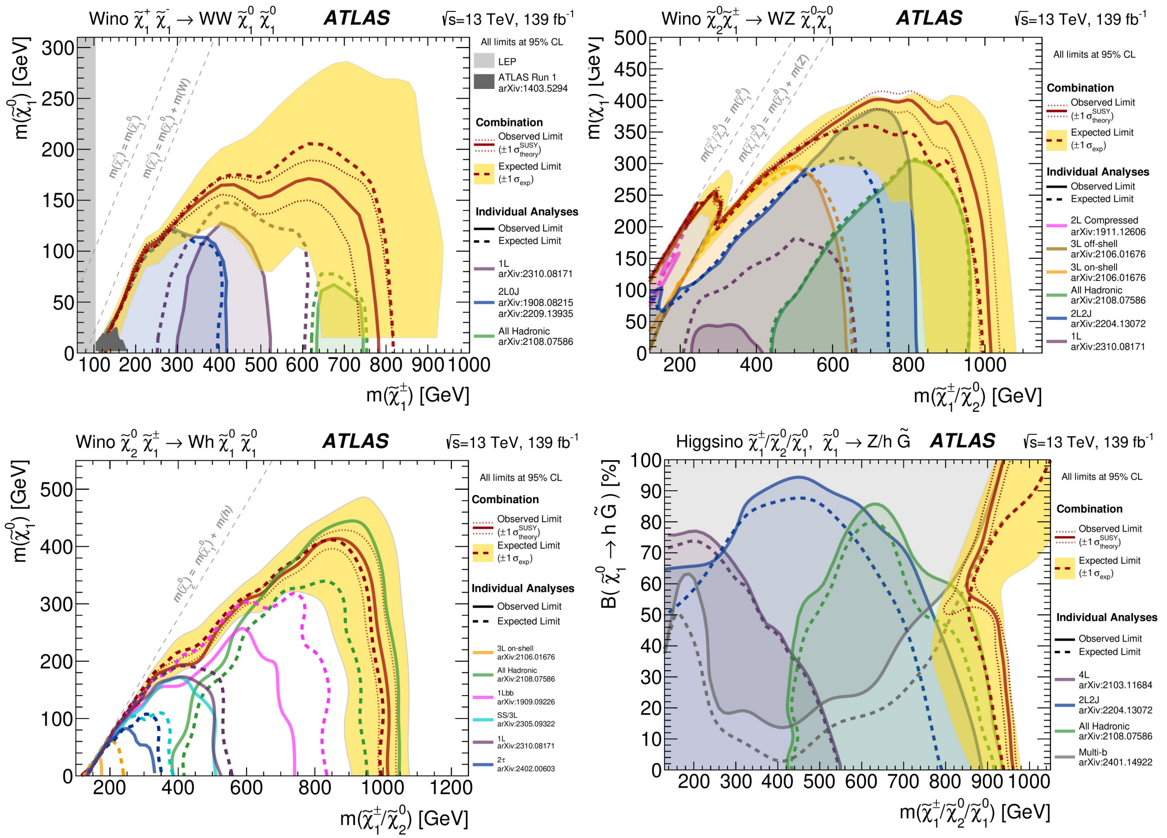


First LHC sensitivity to $\tilde{\tau}_r$ → up to 330 GeV

Electroweak combination

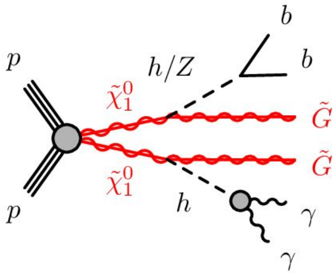
SUSY-2020-05

- Statistical combination of 12 Run-2 results on electroweakly produced charginos and neutralinos
- Focus on pure-wino or pure-higgsino NLSP decaying via W, Z and h SM bosons
- Searches harmonized to allow for the statistical combination
    - Each analysis requiring an exclusive lepton multiplicity
- Combined results connects the gap between the individual analysis.
- Mass reach extended 30-100 GeV
- Cross section upper limit improved between 20 to 40%

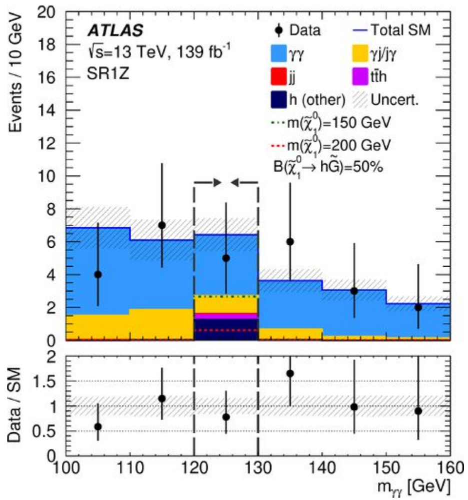


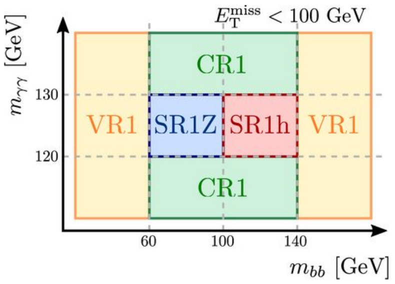
Electroweak bbγγ

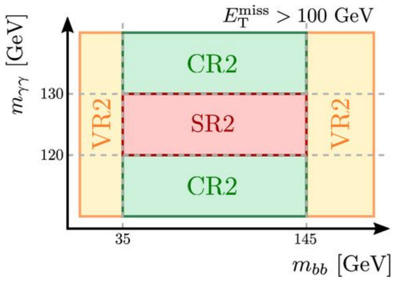
[SUSY-2020-17]

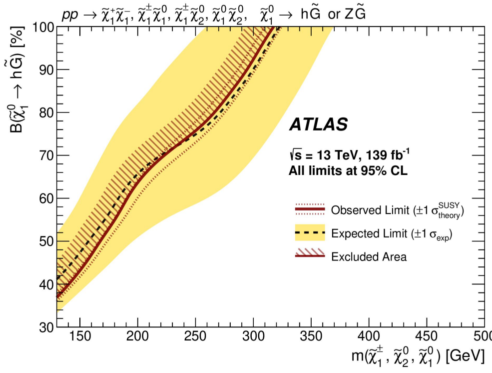


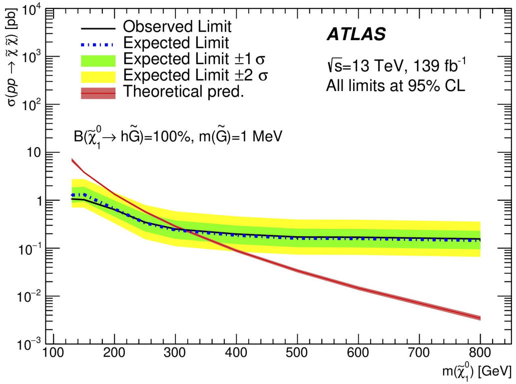
- Gauge-Mediated SUSY breaking
- Pair produced neutralinos decay to SM (photon, Z or Higgs) and near massless gravitino.
- Final State: Two γ's compatible with h, 2 b-jets compatible with h or Z and MET.
- SRs defined on the Higgs/Z peaks.
  - Low- and high-MET requirements depending on m_{N1}.
- Data driven method for non-resonant di-photon backgrounds.
- No excess found.
  - Great sensitivity at low neutralino mass (100 GeV - 200 GeV).
  - Increased coverage in a challenging and previously uncovered region.









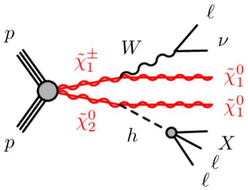


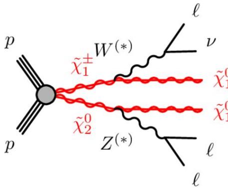
EWK 3L+MET

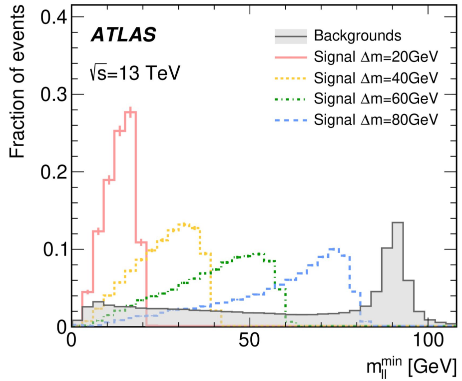
SUSY-2019-09

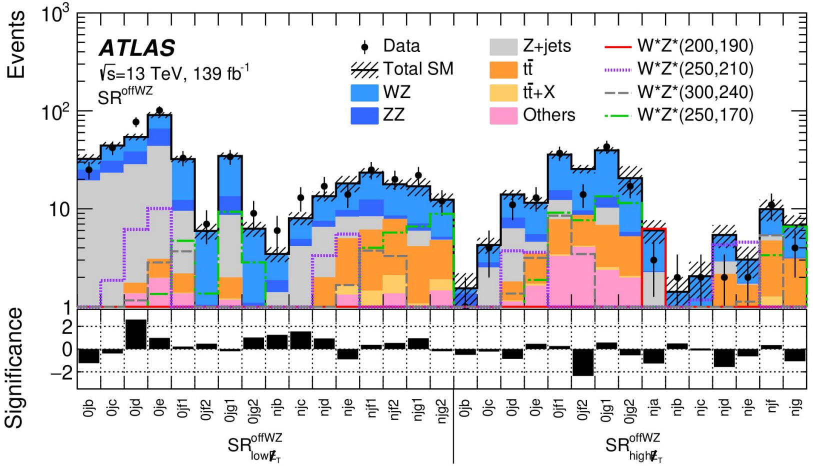
- SUSY chargino-neutralino direct production with R-parity conserving decay to stable LSP
- Final states with exactly three leptons, light jets and MET
- Simplified models considered:
  - On-shell WZ: $\Delta m(\tilde{\chi}_1^{\pm}/\tilde{\chi}_2^0, \tilde{\chi}_1^0) \geq m_Z$
  - Off-shell WZ: $\Delta m(\tilde{\chi}_1^{\pm}/\tilde{\chi}_2^0, \tilde{\chi}_1^0) < m_Z$
  - On-shell Wh: $\Delta m(\tilde{\chi}_1^{\pm}/\tilde{\chi}_2^0, \tilde{\chi}_1^0) > m_h$

- SRs optimised to the wino/bino(+) scenario, but wino/bino(-) and higgsino reinterpretations also considered.
  - Two SR selection optimisations:
    1) On-shell WZ and Wh phase space:
      - Binned selection in m_{ll}, MET, m_T and n_{jets}
    2) Off-shell WZ phase space:
      - Binned selection in m_{ll}^{min}, n_{jets} and MET
      - Low-p_T leptons are used. PLV is used to suppress the fakes
- Background estimation:
  - SM *WZ* background normalisation in dedicated control regions
  - *Z+jets* estimation using data-driven fake factor method
  - *ttbar* background validation in dedicated validation regions





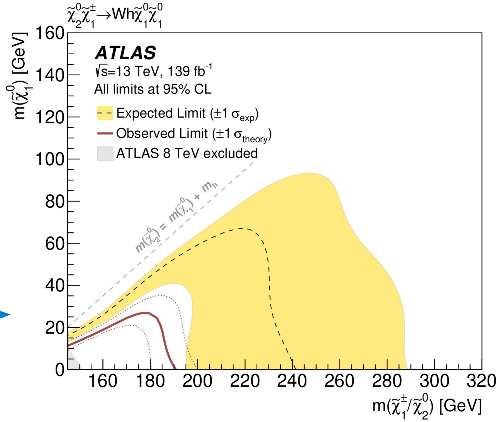


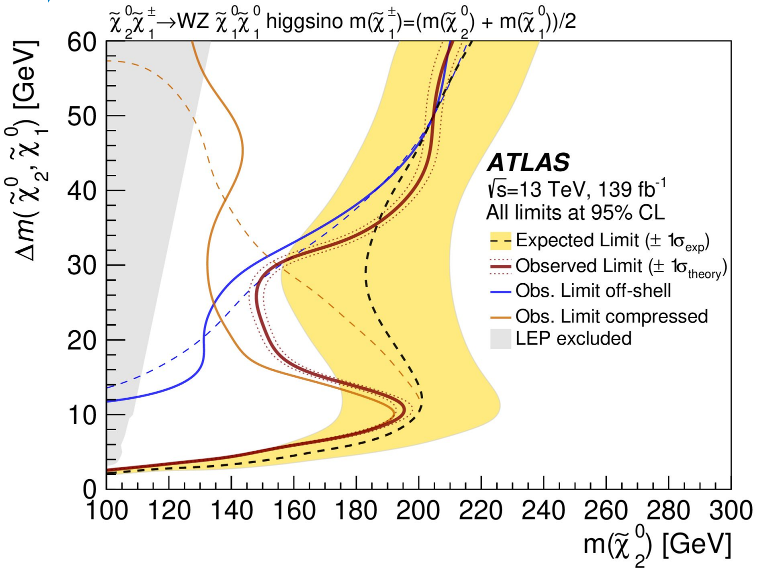


EWK 3L+MET - cont.

[SUSY-2019-09]

- Statistical combination with existing compressed 2L results.
- Setting limits:
  - For WZ model: wino/bino(+), wino/bino(-) and higgsino interpretations, making the combination with the 2L compressed result ([2019 paper])
  - For Wh model in 3L final states





Summary Plot!