Searches for electroweak production of supersymmetric particles with ATLAS

Da XU (IHEP, CAS)
Qingdao Online, 2021

ATLAS EXPERIMENT

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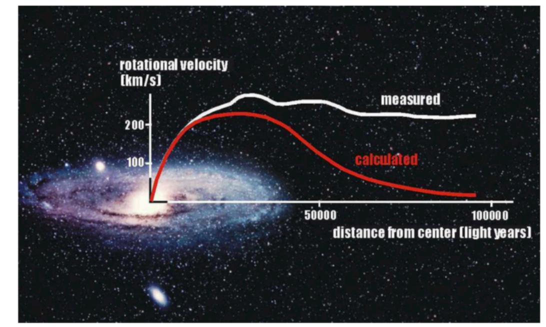
Supersymmetry

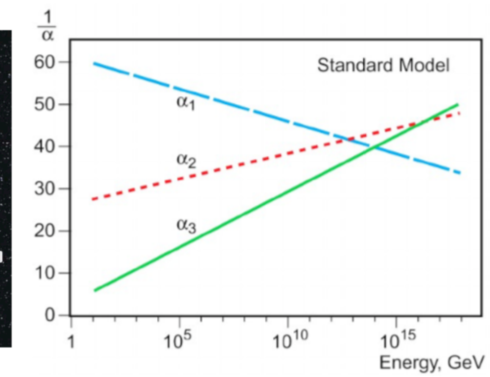
A theory to describe physics beyond *Standard Model*

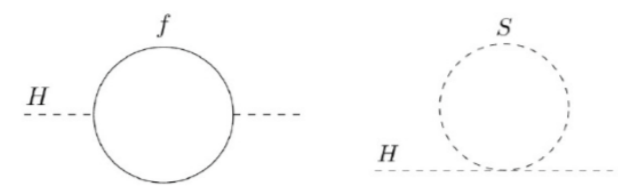
- Introduce an additional symmetry: fermions ~ bosons

It can

- Offer a Dark Matter candidate
- Possible unification of inverse gauge coupling
- Solve the fine-tuning problem of the Higgs mass







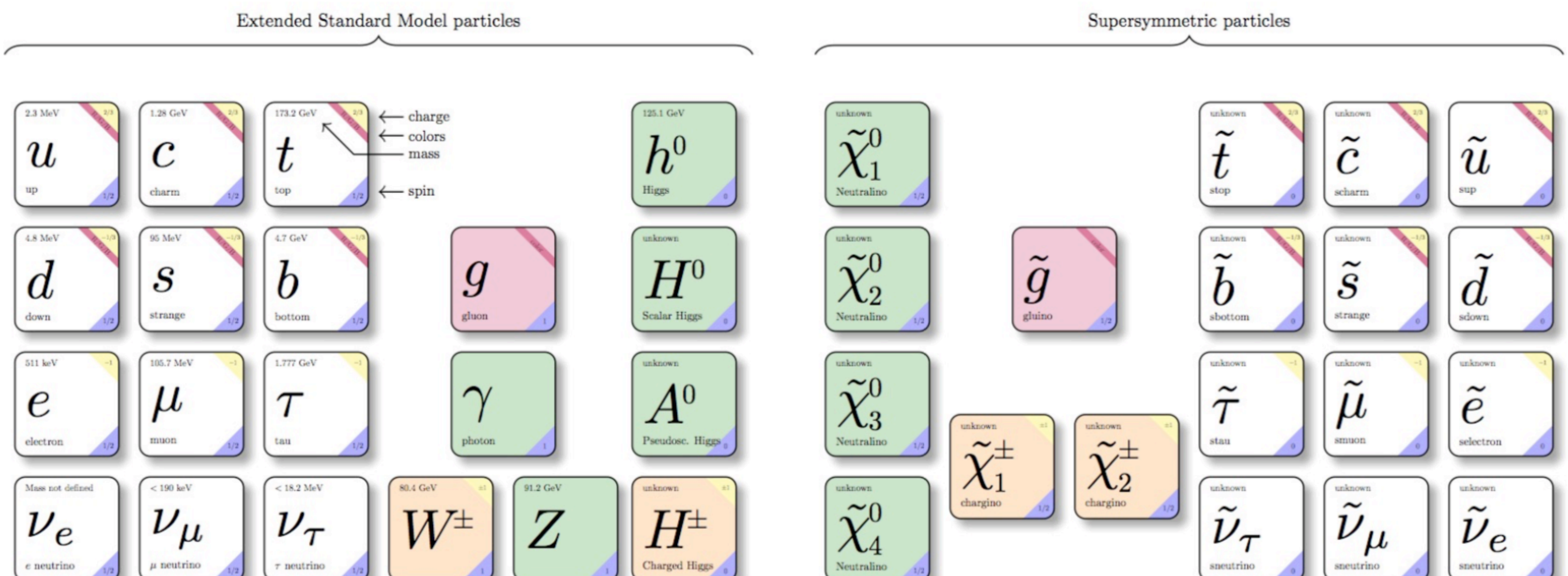
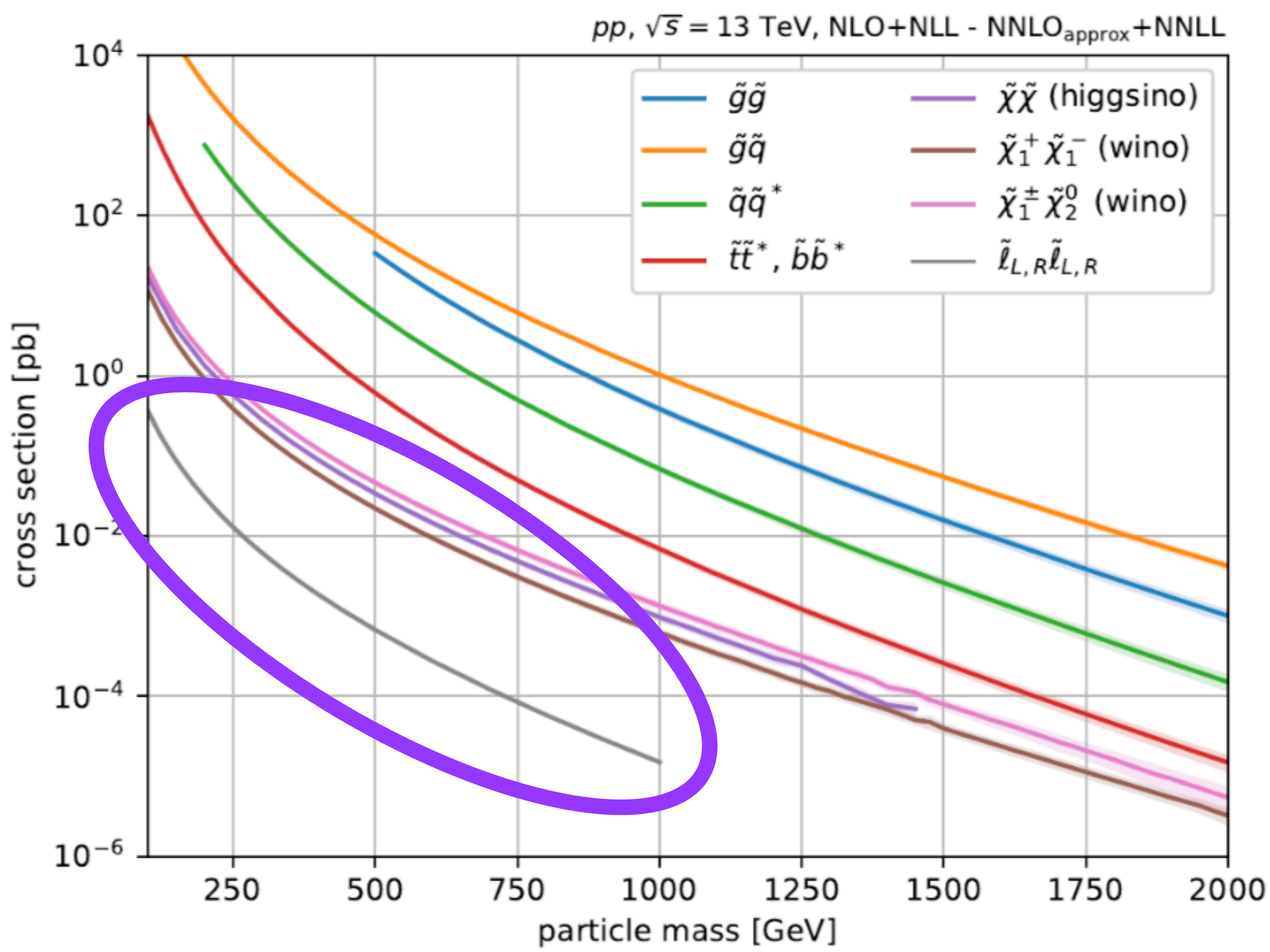


Image credit: M. Rimoldi

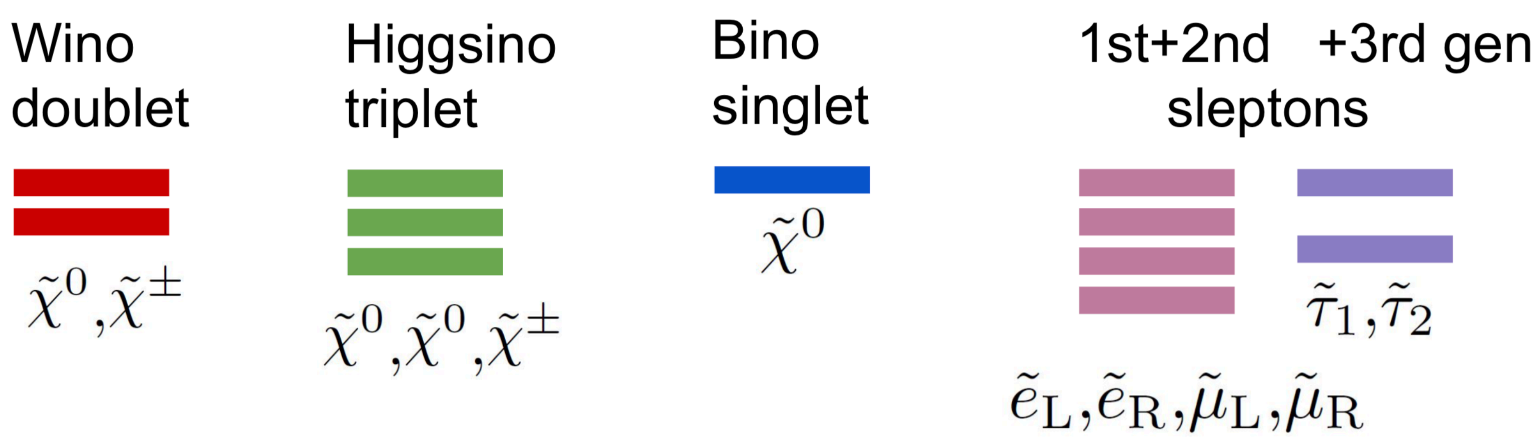
The SUSY production @ 13TeV

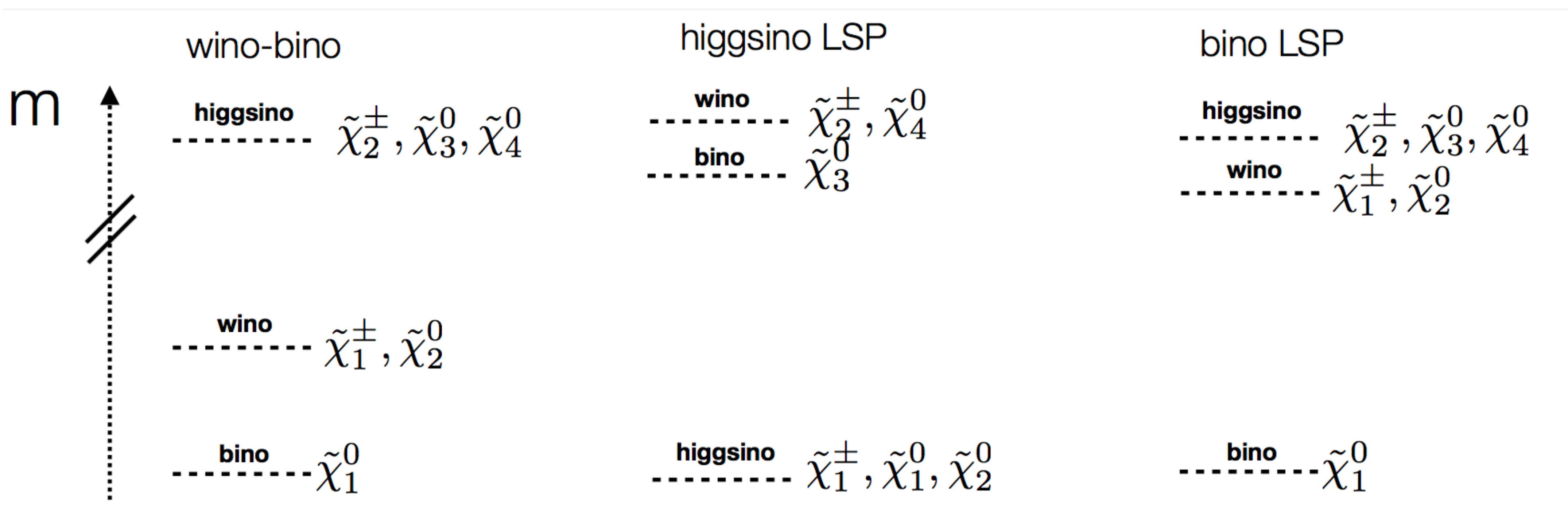


Electroweak SUSY:
smaller cross-section; less jet activity —> cleaner signature.

The electroweak SUSY search

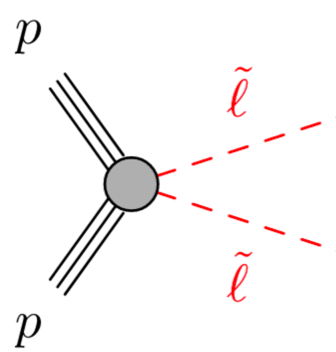
- **Production of Charginos/Neutralinos/sLeptons**

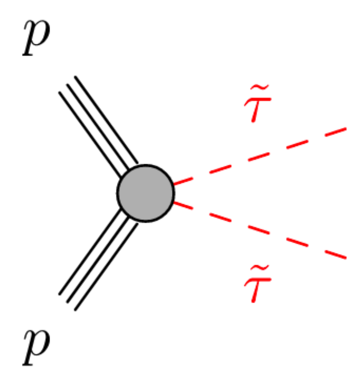


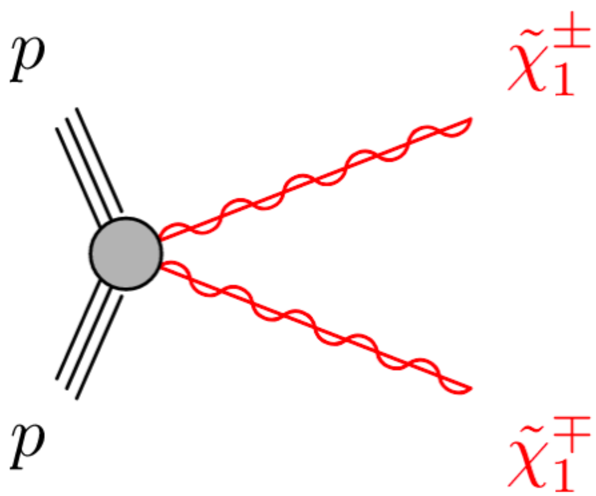


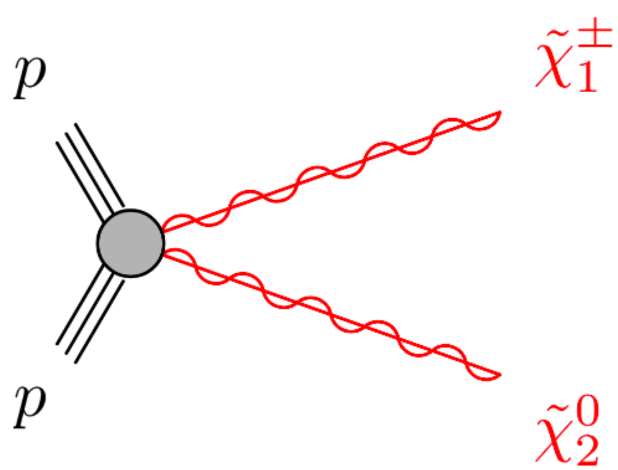
Phenomenology depends on wino-bino-higgsino mixing, mass hierarchy, and decay channels.

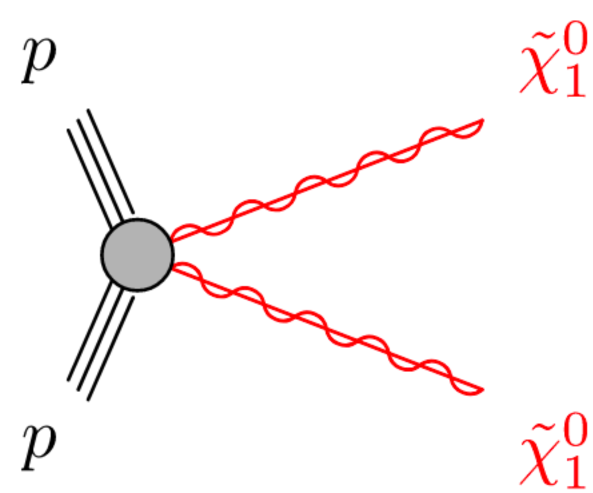
Benchmark EWK scenarios











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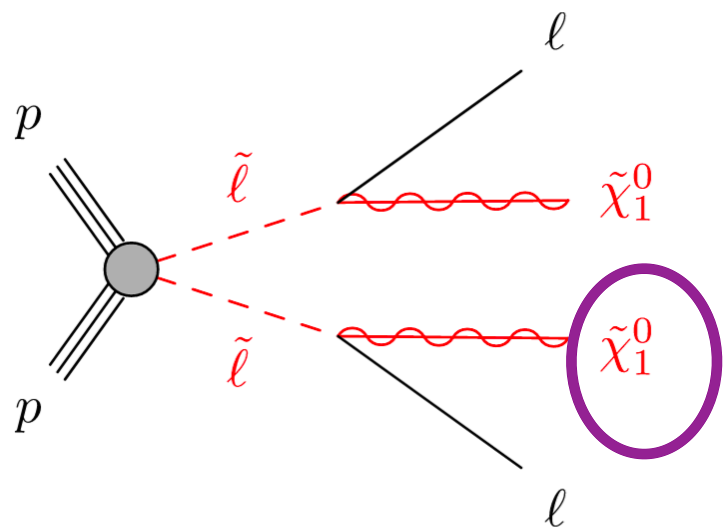
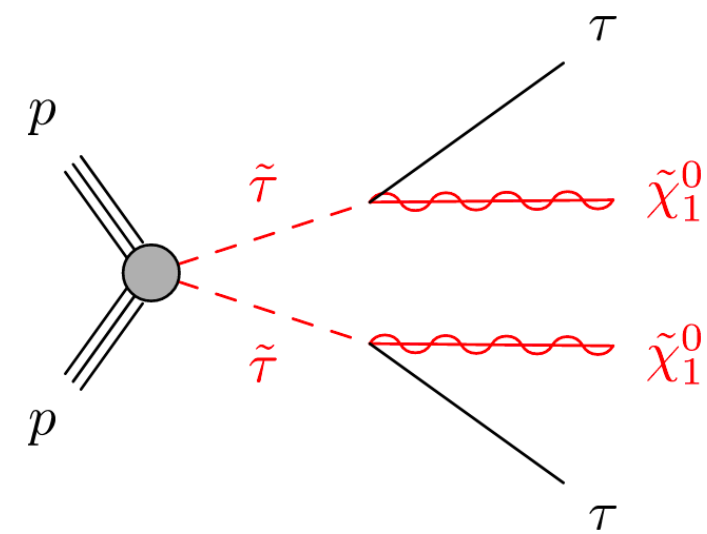
Benchmark EWK scenarios

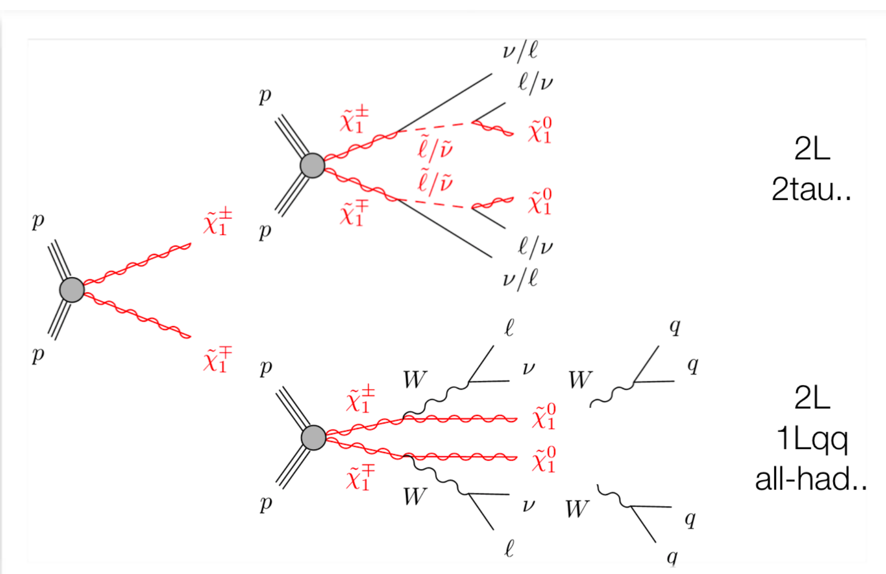


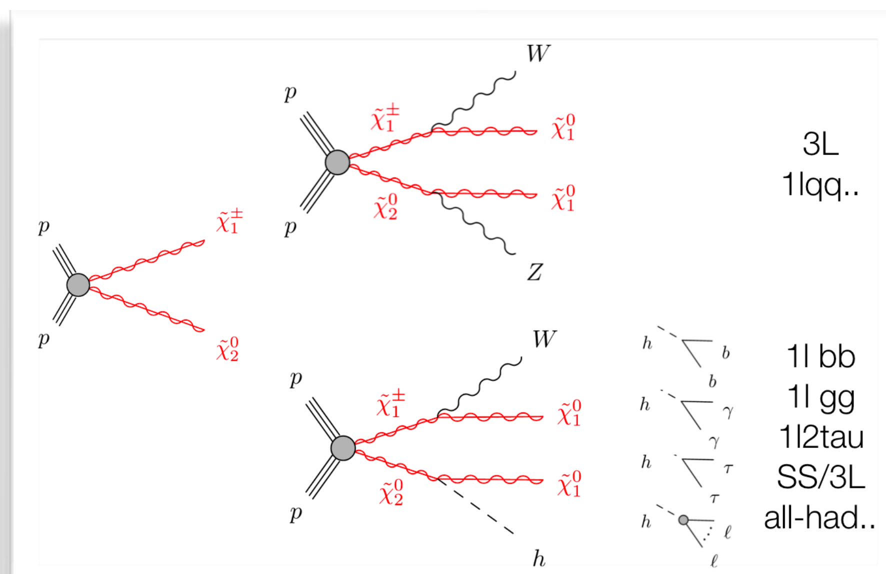
2L



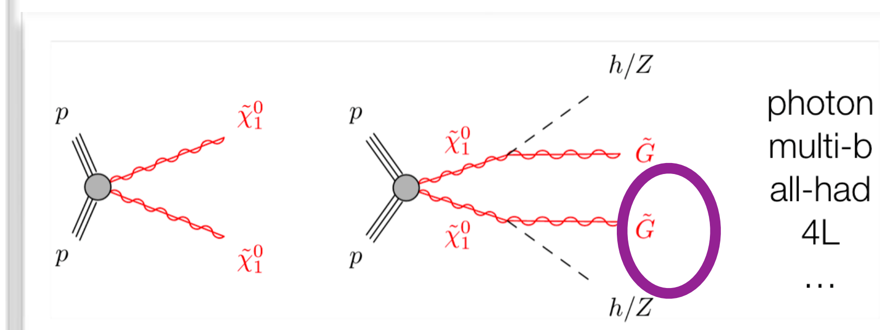
2tau

Lightest SUSY particle — Etmiss





Gravitino LSP



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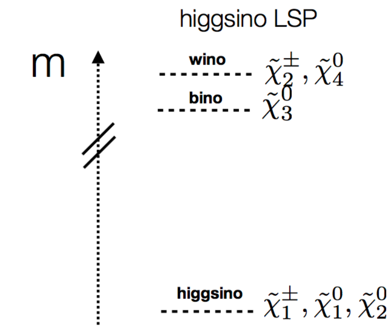
The EWK SUSY program in ATLAS

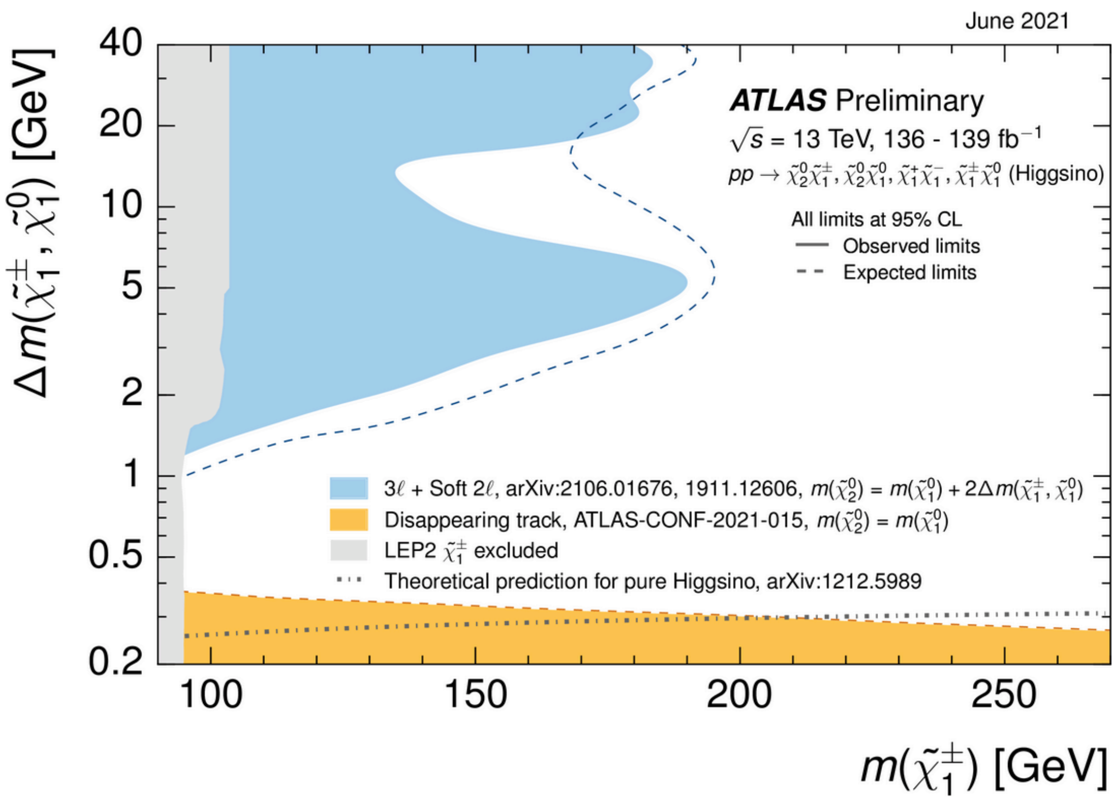
Published Signature	Scenario	Publication
2L0J	C1C1-WW/slepton; Slepton pair	arXiv:1908.08215
1lbb	C1N2-Wh	arXiv:1909.09226
Stau	Stau pair	arXiv:1911.0666
Compressed	C1N2-WZ; Slepton pair	arXiv:1911.12606
3LeRJR	C1N2-WZ	arXiv:1912.08479
Photon	C1N2-Wh; GGM	arXiv:2004.10894
3L RPV	C1C1/C1N1 via RPV coupling	arXiv:2011.10543
4L	C1N2/C1C1; Slepton pair; GGM	arXiv:2103.11684
3L conv/RJ	C1N2-WZ/Wh	arXiv:2106.01676
All hadronic	C1N2/C1C1-WZ/Wh/WW; GGM	ATLAS-CONF-2021-022

New since 2021

Each benchmark scenario will be discussed and the fresh results are preferred in this talk.
Reminder: more signatures are still in processing: 💡 2L2J; multi-b; SS; bbyy... More to come!

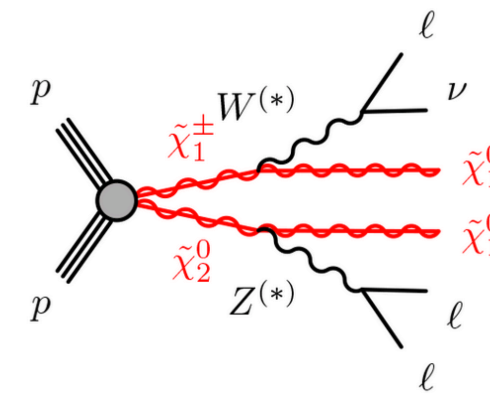


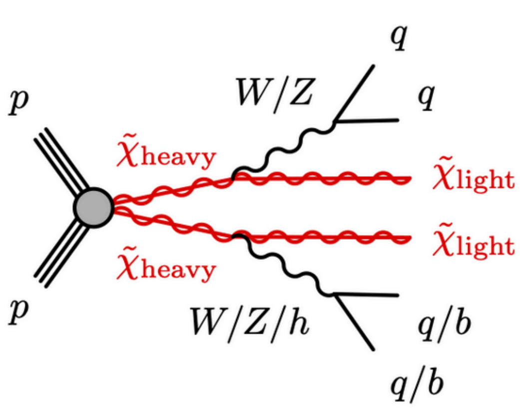
Higgsino search



Standard Higgsino search, where

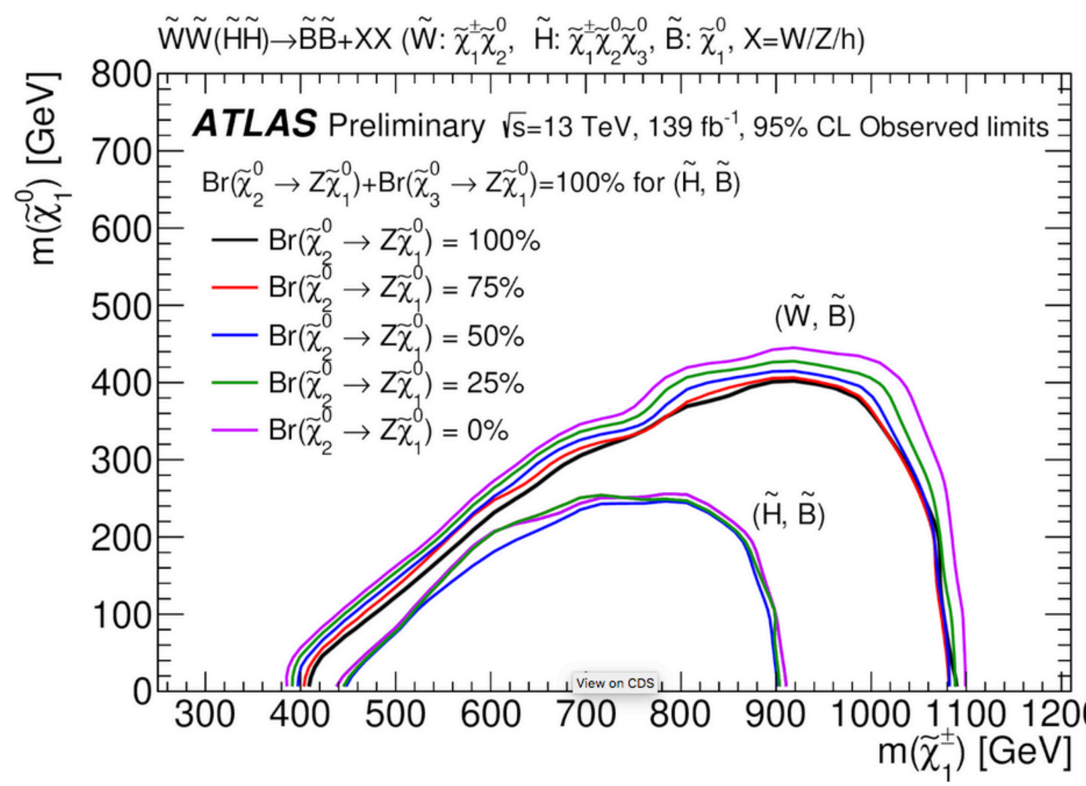
- **Mass splitting is very small**
- **Off-shell W/Z bosons emitted**
- **Final states with three el/mu or ISR+two soft el/mu**
- **Introduced a new machine-learning identification for soft el/mu**
- **Explore dM down to ~1-2GeV**



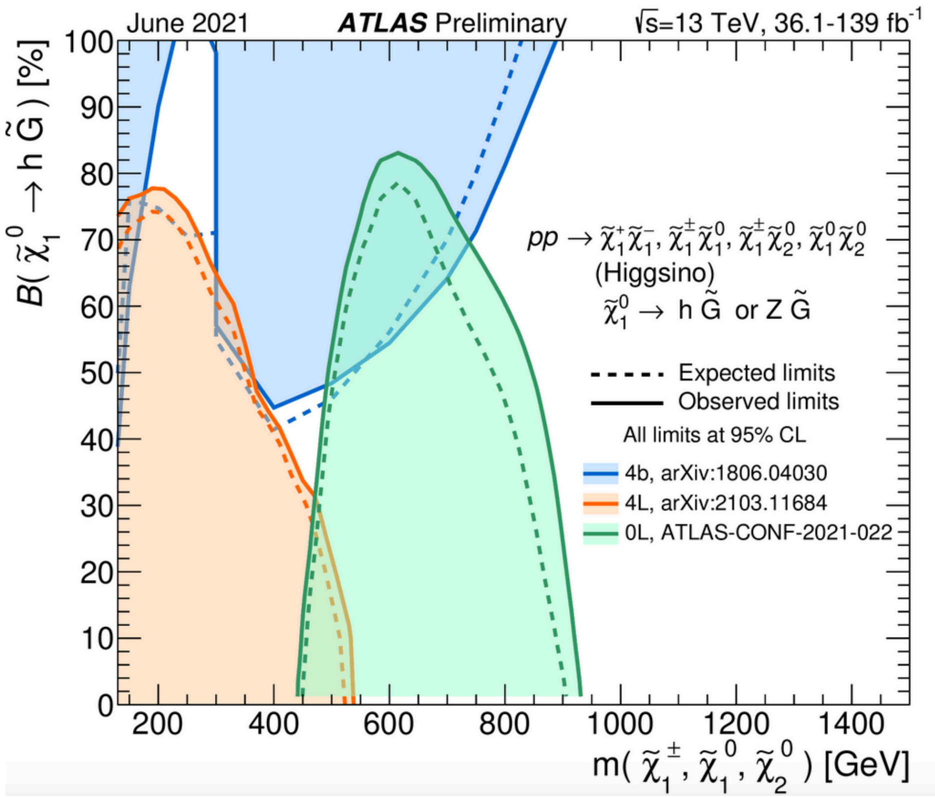


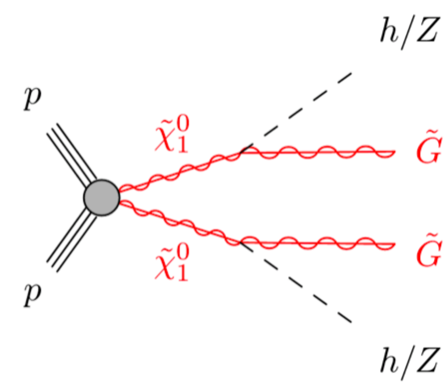
NEW! Heavier Higgsino decays into lighter one

- **Boosting the sensitivity using all hadronic decays (0L)**
- **Study the highly-boosted SM bosons with jet substructure info. —> Effective boson reconstruction and bkg suppression**
- **Probe the higgsinos high mass region unprecedentedly –> 900 GeV**



Higgsino search



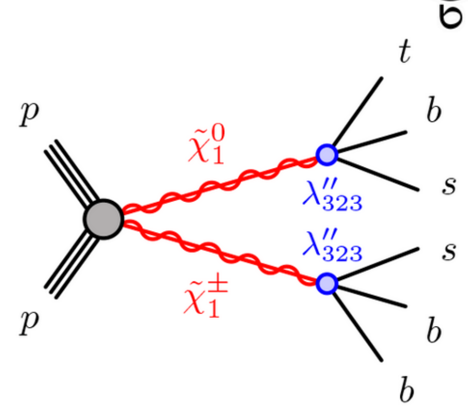


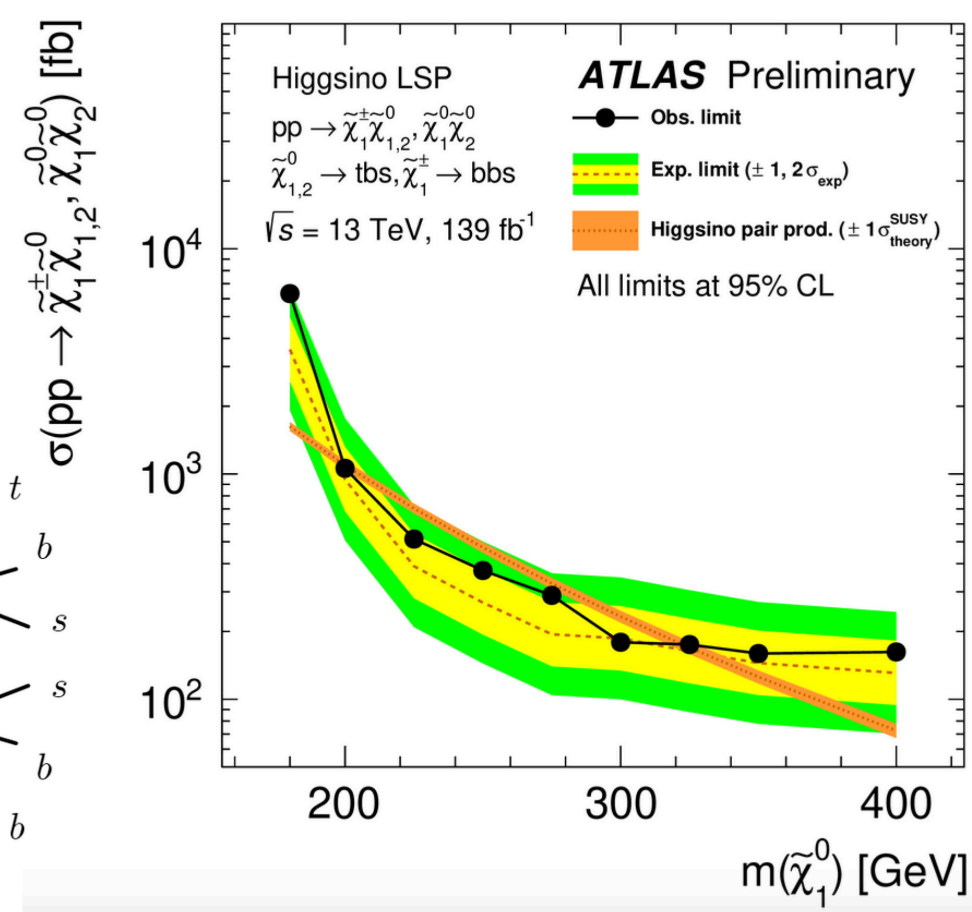
NEW! Higgsino NLSP decays into Z/H and Gravitino LSP

- **For Higgs dominant decay mode, 4b channel wins**
- **For Z dominant decay mode**
  - **Low mass region: 4L channel wins**
  - **High mass region: 0L wins (w/ boost strategy)**

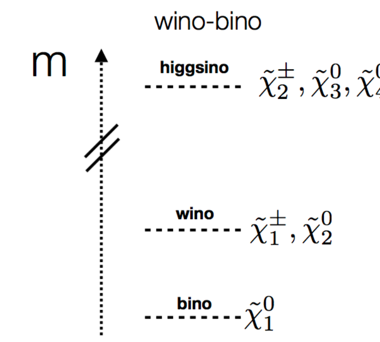
Higgsino decays into SM quarks via RPV coupling

- **Final states with 6-8 jets, at least three bjets**
- **Extreme topologies studied with data-driven approach**
- **Neural-net classifier to distinguish signal**
- **Excluded higgsino masses 200-320 GeV**
- **<— first since LEP result in 2004**

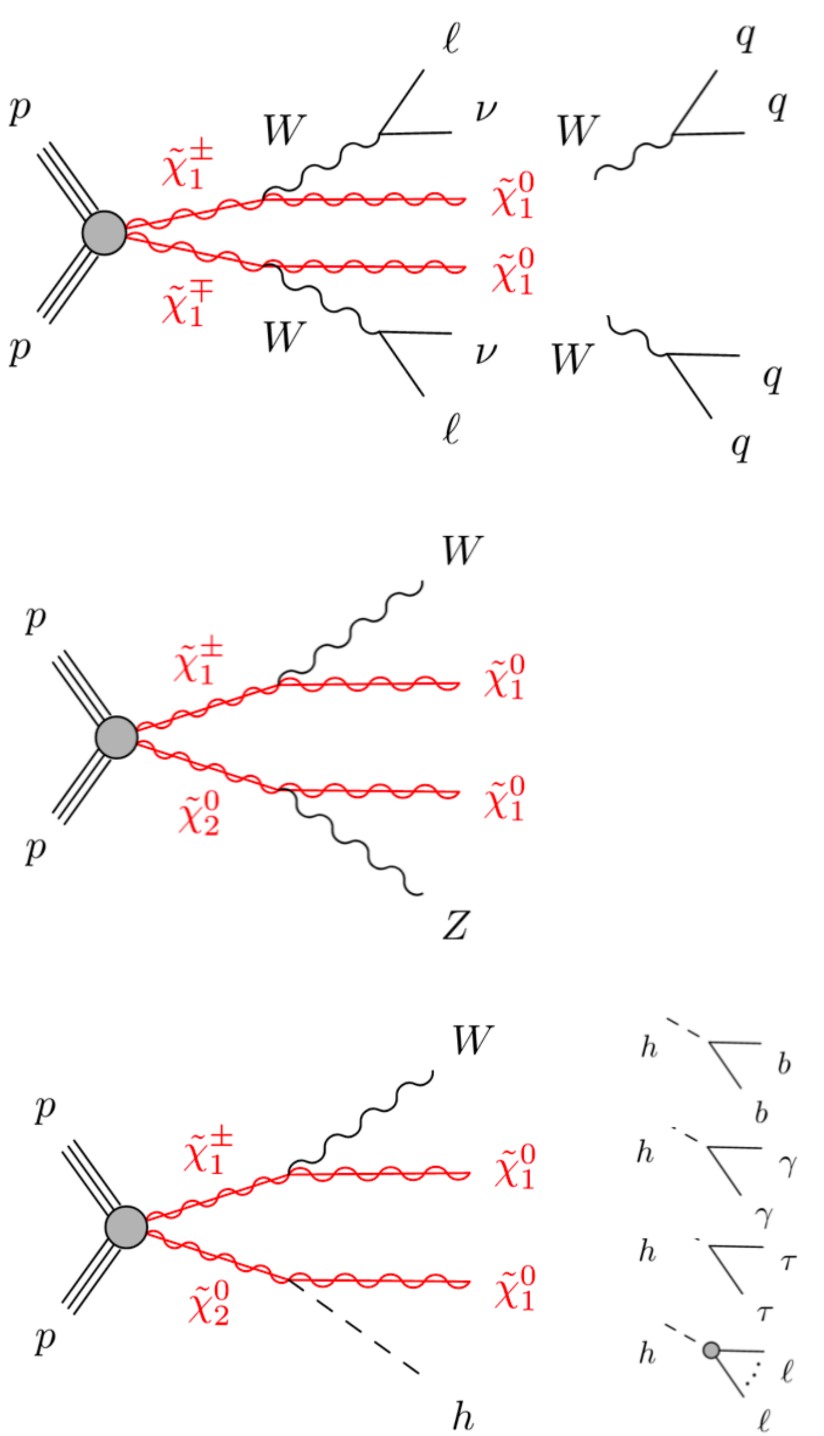


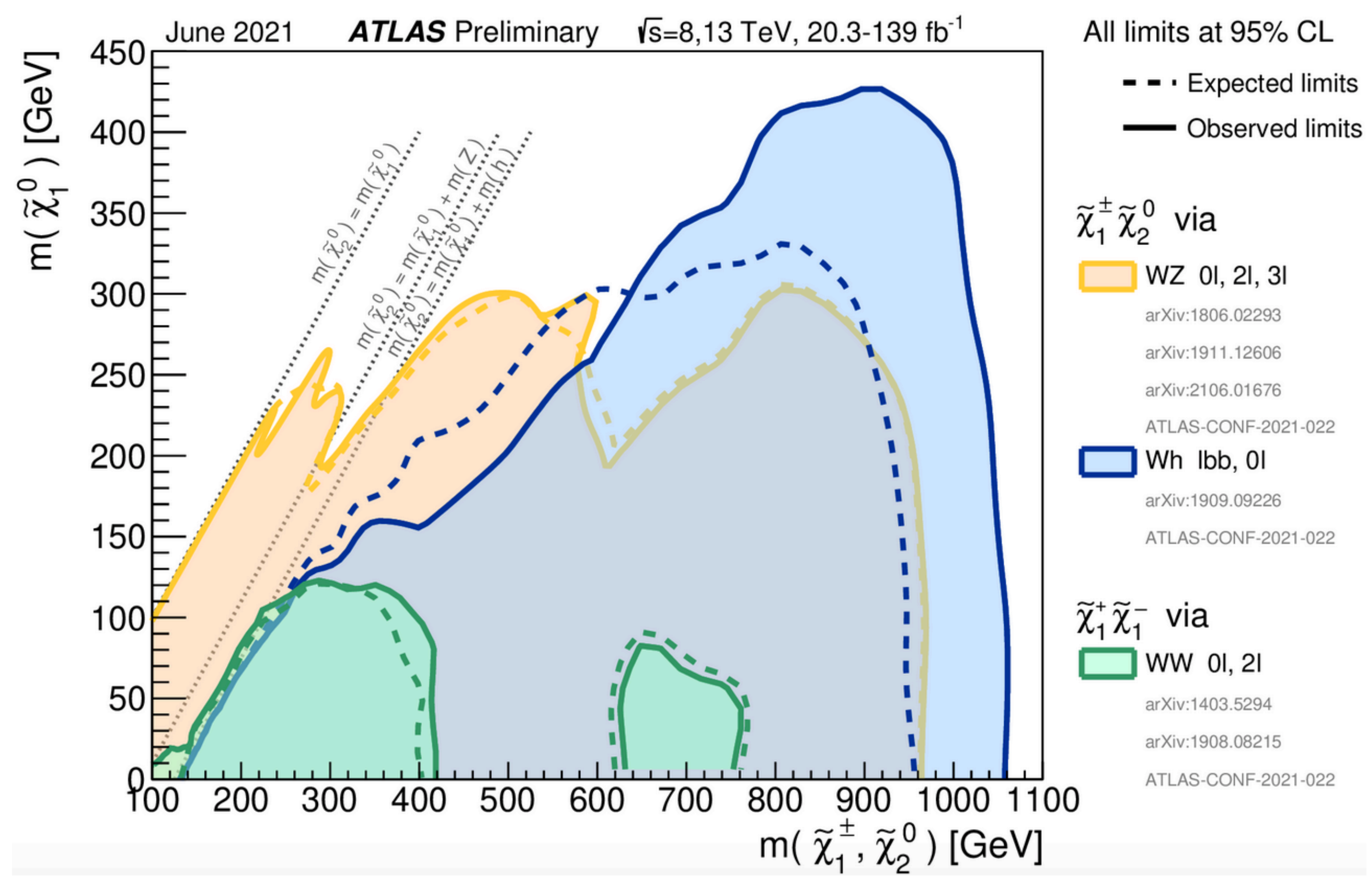


Wino-bino search

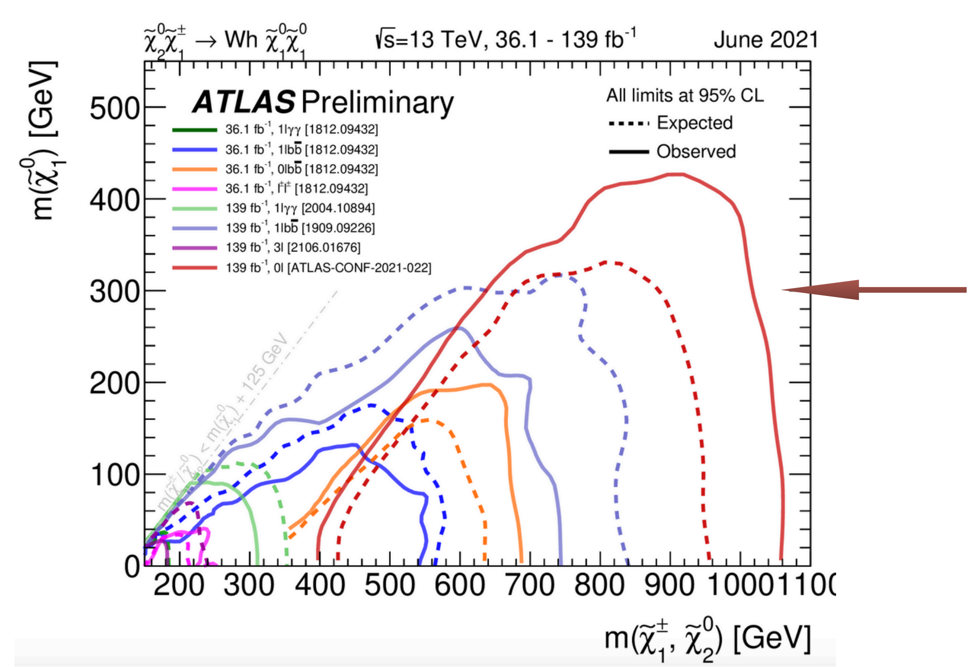


"Traditional Summary Plot"



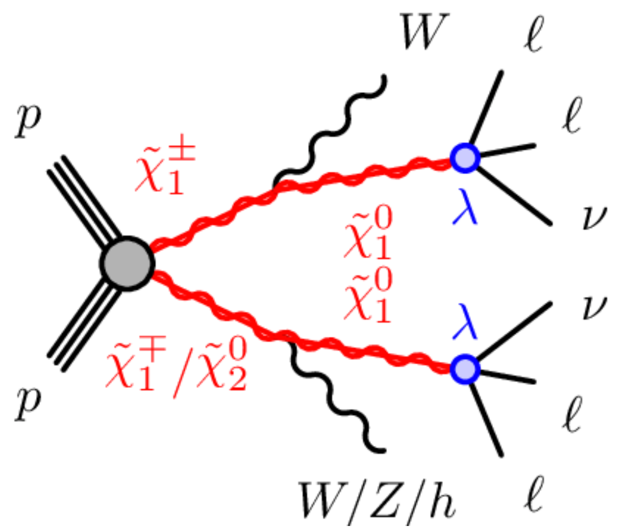


WW via 1L to come.



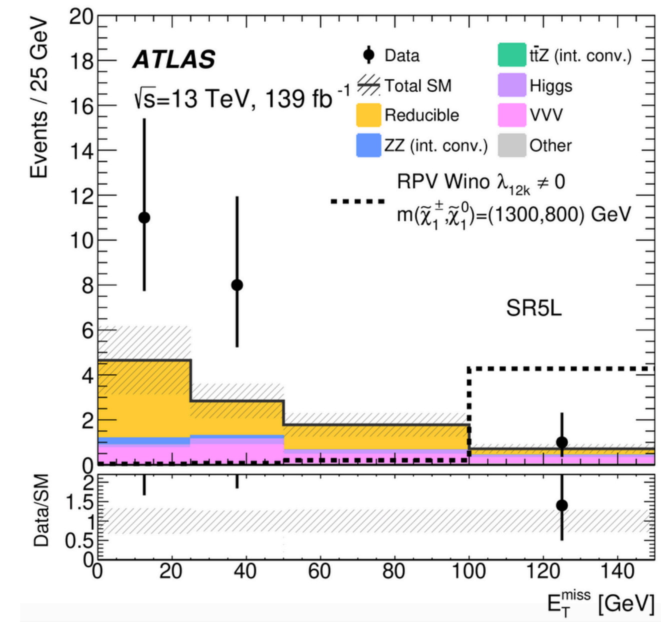
Channel breakdown for "C1N2-Wh only"

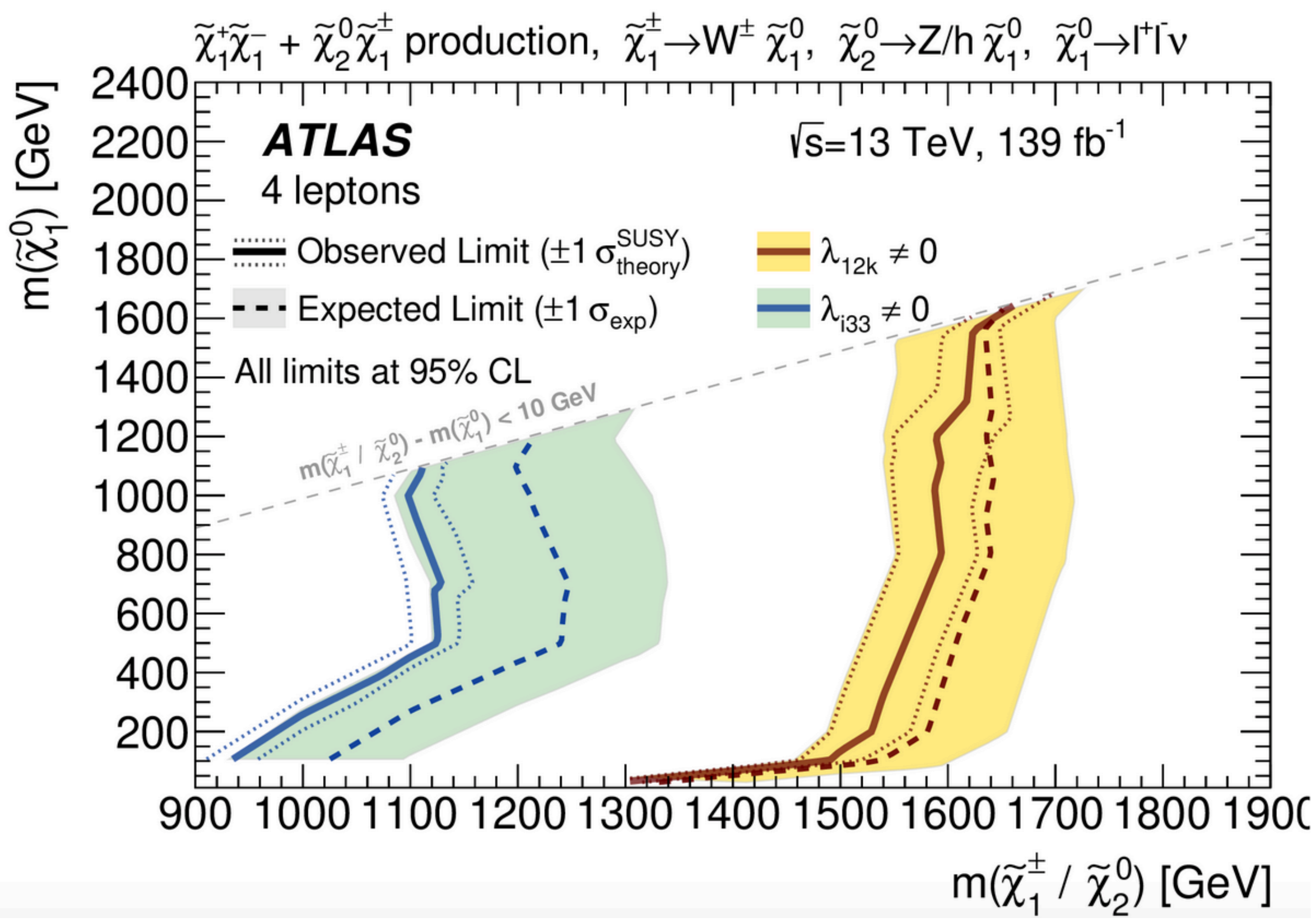
Wino-bino search



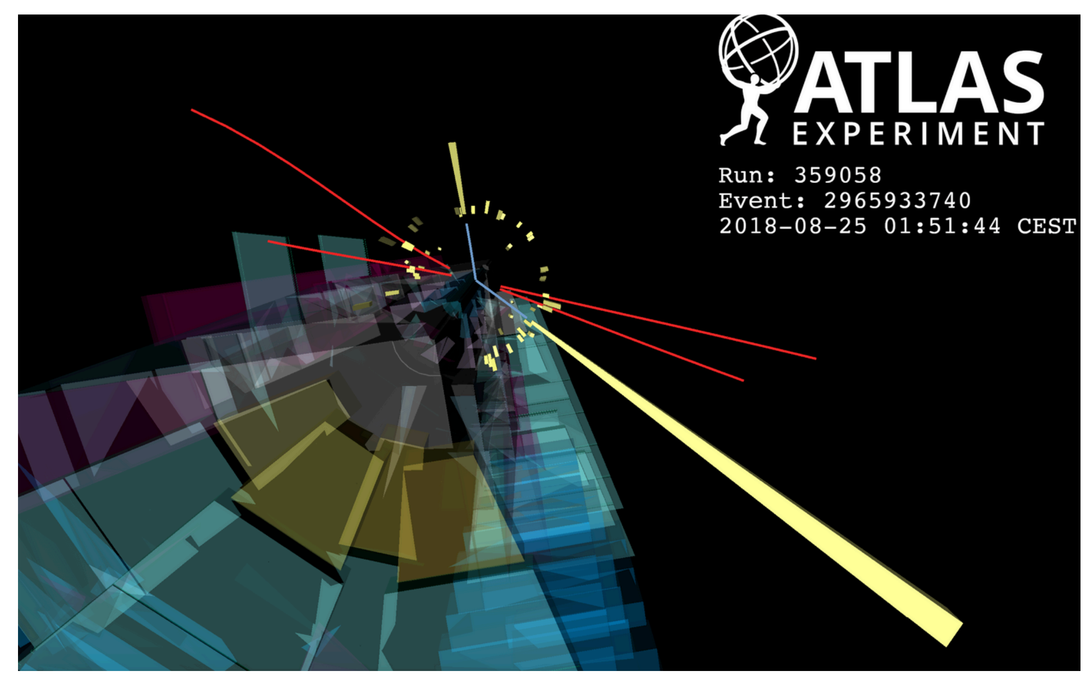
NEW! "4L Analysis"

- RPC wino production, followed by the RPV decay of the χ_1^0 LSP
- SR with at least 4L with up to two hadronically decaying τ
- First look of SR5L

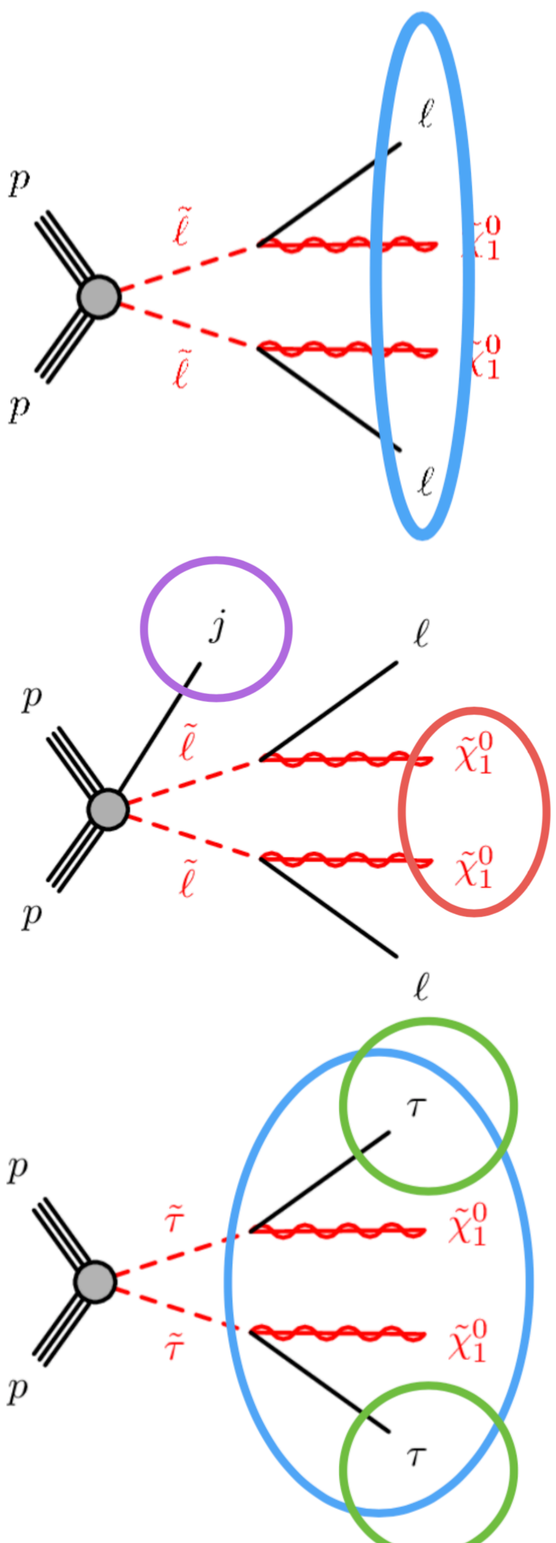


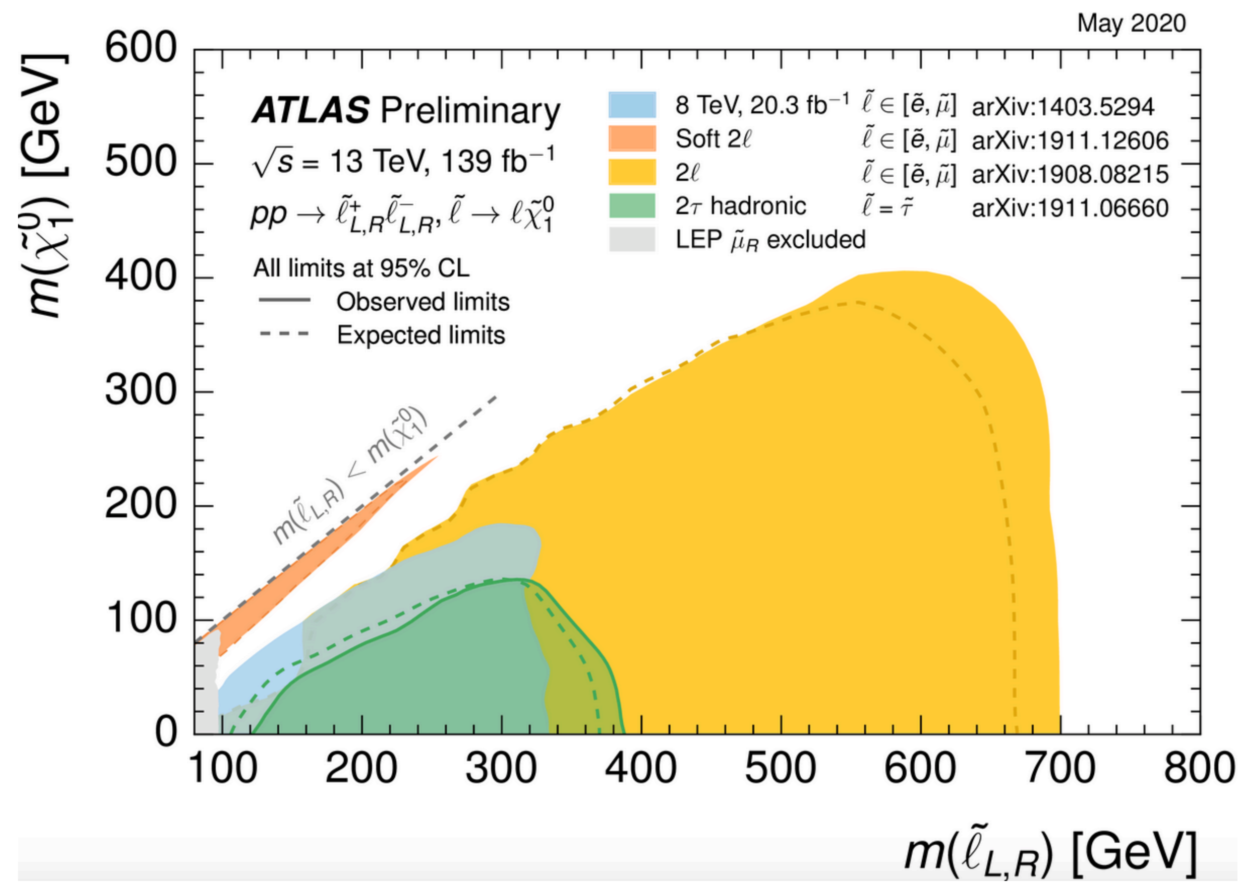


Visualisation of a 6-lepton event which falls within SR5L. The event consisted of 4 muons+ 2 electrons.



Slepton search

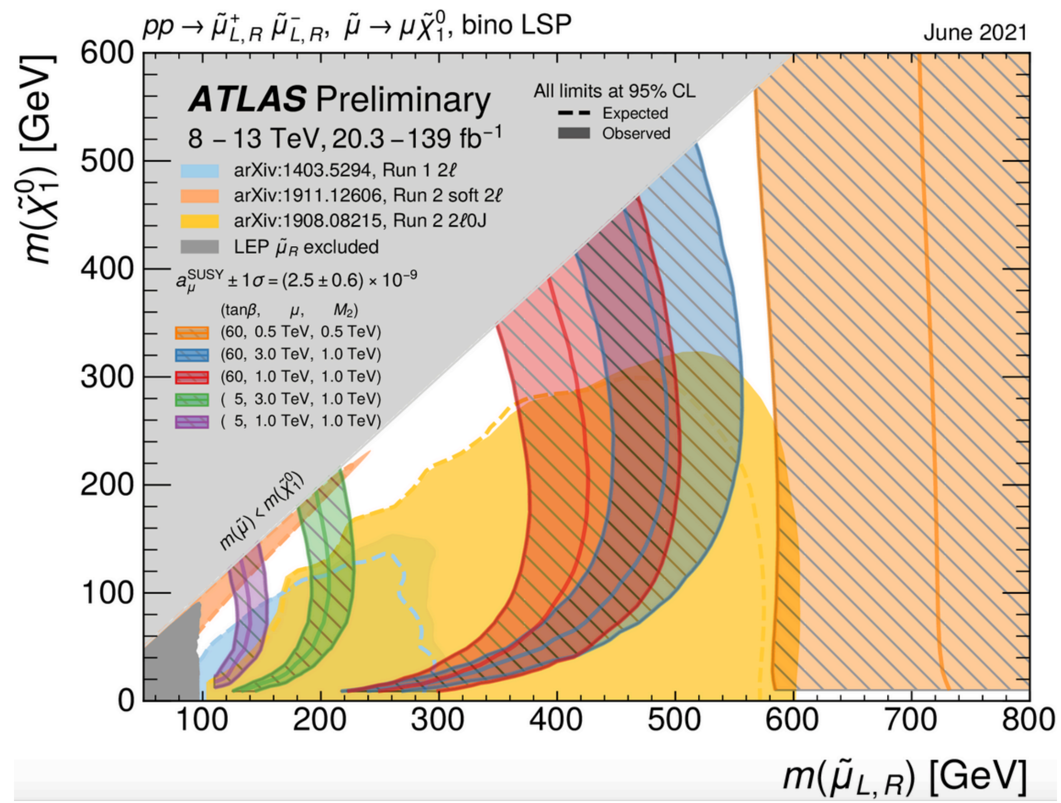


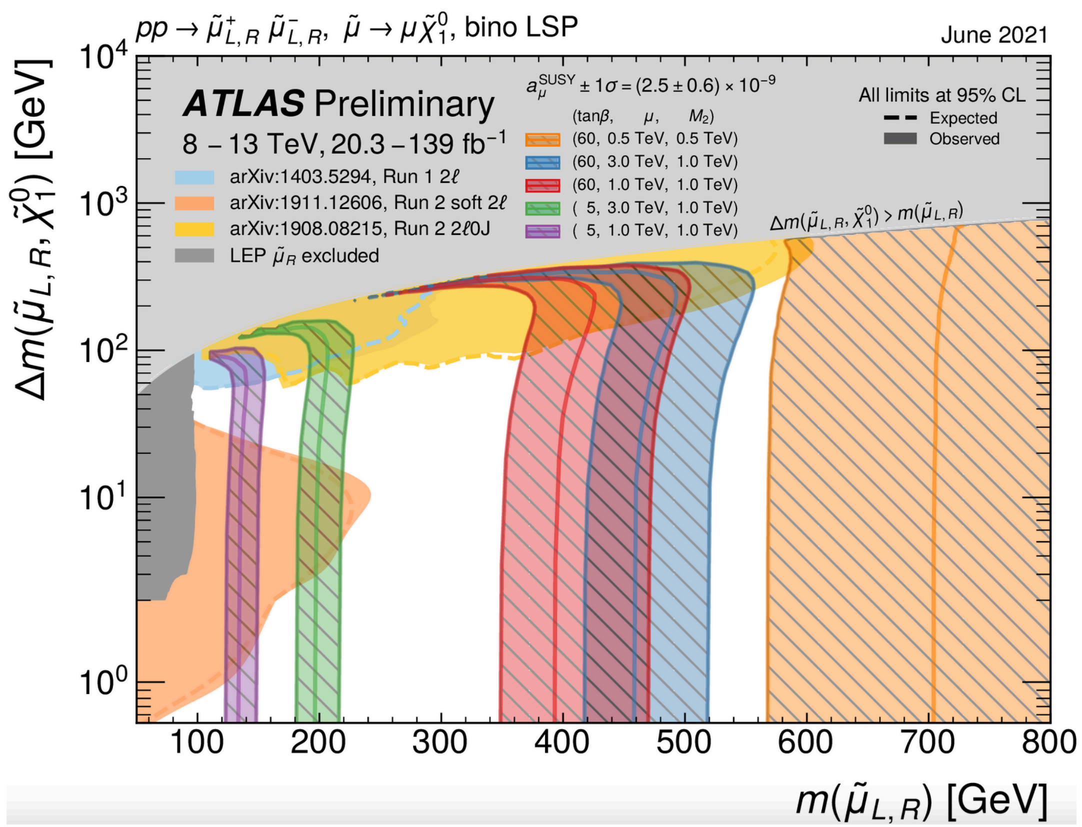


- Search 1: Final states with 2 hard el/mu (pT>25GeV) —> target high mass region!
- Search 2: Compressed analysis — 2 soft el/mu (pT_e>4.5GeV and pT_mu>3GeV) + ISR-jet —> target small mass splitting region!
- Search 3: 2 hadronic tau analysis — improvement in tau trigger with improved tau ID.

Smuon search

“New Smuon Summary”





- Shaded bands indicate regions compatible with the observed g-2 anomaly
- Low/High mass smuon region is favored for small/large tan β
- Uncovered space in the small dM region
- Need to ensure that our searches cover the full mass plane!

Summary

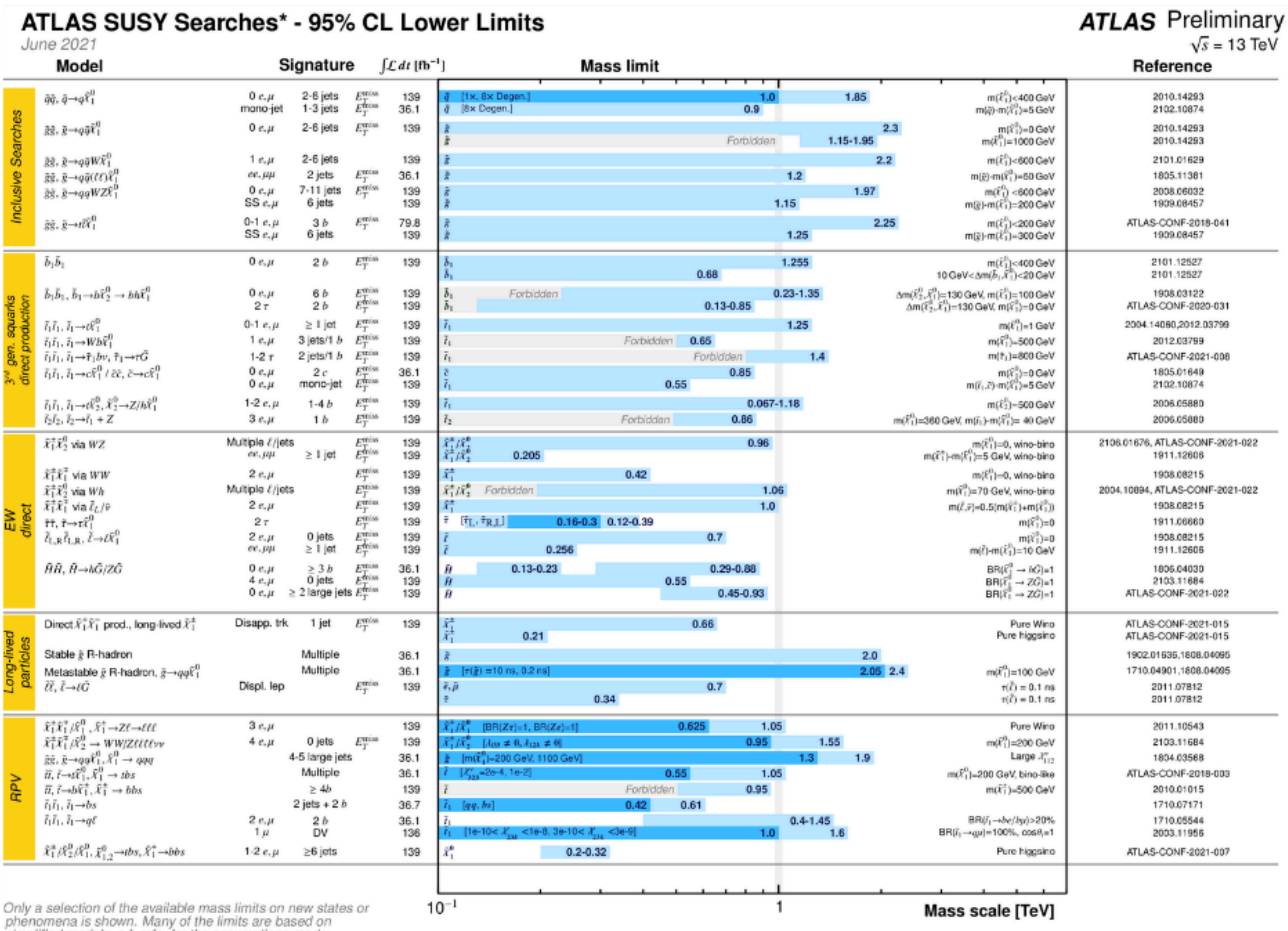
* A short overview on the recent ATLAS Electroweak Supersymmetry results is presented with full Run2 data analyzed.

* No discovery yet, the limits are probed in new/challenge scenarios. Various novel techniques are developed/under development.

* More challenge signatures to come.

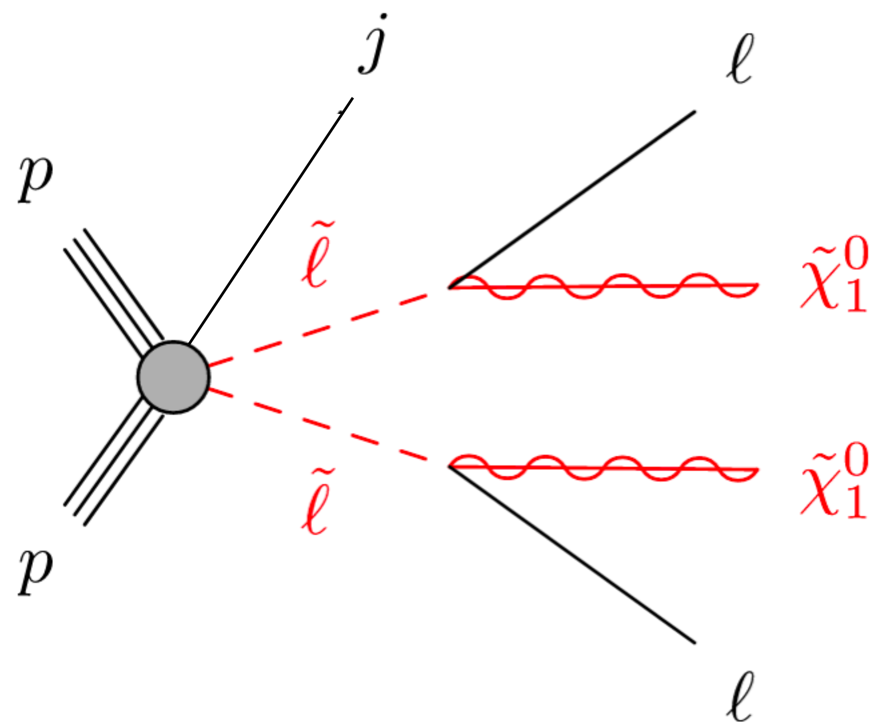
* More excitingly, the EWK combination & the pMSSM interpretation are in process & to come next year. Hopefully more new ideas will be inspired! 💡🔑

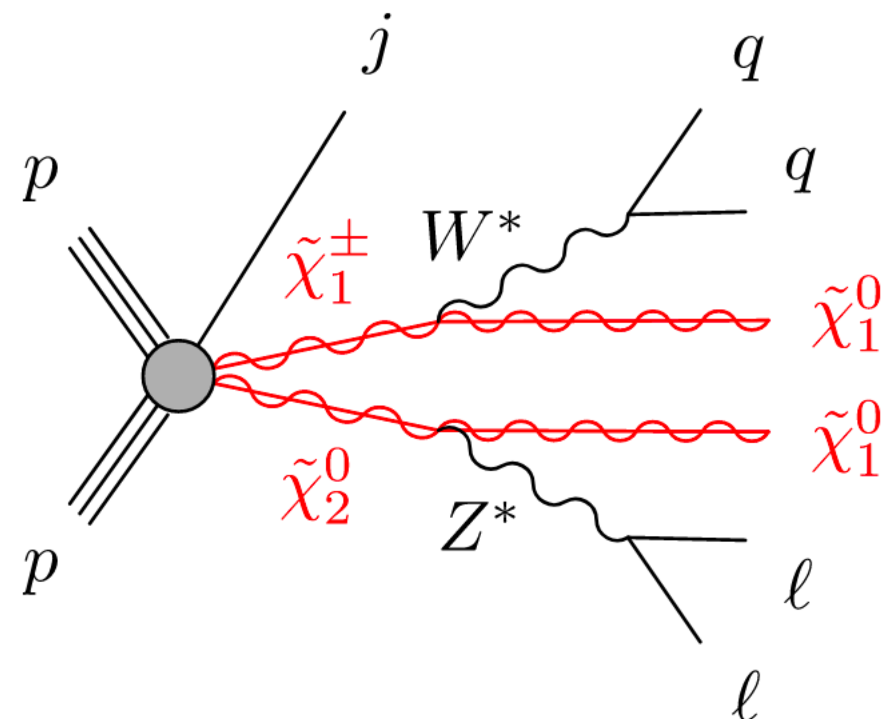
Extra slides



ATLAS SUSY Searches* - 95% CL Lower Limits
June 2021
ATLAS Preliminary
√s = 13 TeV
Model
Signature
∫ℒ dt [fb⁻¹]
Mass limit
Reference
Inclusive Searches
q̃q̃, q̃→qχ̃⁰₁ | 0 e,μ 2-6 jets E_T^miss 139 | q̃ [1×, 8× Degen.] 1.0 1.85 | m(χ̃⁰₁)<400 GeV | 2010.14293
mono-jet 1-3 jets E_T^miss 36.1 | q̃ [8× Degen.] 0.9 | m(q̃)-m(χ̃⁰₁)=5 GeV | 2102.10874
g̃g̃, g̃→qq̄χ̃⁰₁ | 0 e,μ 2-6 jets E_T^miss 139 | g̃ 2.3 | m(χ̃⁰₁)=0 GeV | 2010.14293
g̃ Forbidden 1.15-1.95 | m(χ̃⁰₁)=1000 GeV | 2010.14293
g̃g̃, g̃→qq̄Wχ̃⁰₁ | 1 e,μ 2-6 jets 139 | g̃ 2.2 | m(χ̃⁰₁)<600 GeV | 2101.01629
g̃g̃, g̃→qq̄(ℓℓ)χ̃⁰₁ | ee,μμ 2 jets E_T^miss 36.1 | g̃ 1.2 | m(g̃)-m(χ̃⁰₁)=50 GeV | 1805.11381
g̃g̃, g̃→qqWZχ̃⁰₁ | 0 e,μ 7-11 jets E_T^miss 139 | g̃ 1.97 | m(χ̃⁰₁) <600 GeV | 2008.06032
SS e,μ 6 jets 139 | g̃ 1.15 | m(g̃)-m(χ̃⁰₁)=200 GeV | 1909.08457
g̃g̃, g̃→tt̄χ̃⁰₁ | 0-1 e,μ 3 b E_T^miss 79.8 | g̃ 2.25 | m(χ̃⁰₁)<200 GeV | ATLAS-CONF-2018-041
SS e,μ 6 jets 139 | g̃ 1.25 | m(g̃)-m(χ̃⁰₁)=300 GeV | 1909.08457
3rd gen. squarks direct production
b̃₁b̃₁ | 0 e,μ 2 b E_T^miss 139 | b̃₁ 1.255 | m(χ̃⁰₁)<400 GeV | 2101.12527
b̃₁ 0.68 | 10 GeV<Δm(b̃₁,χ̃⁰₁)<20 GeV | 2101.12527
b̃₁b̃₁, b̃₁→bχ̃⁰₂→bhχ̃⁰₁ | 0 e,μ 6 b E_T^miss 139 | b̃₁ Forbidden 0.23-1.35 | Δm(χ̃⁰₂,χ̃⁰₁)=130 GeV, m(χ̃⁰₁)=100 GeV | 1908.03122
2 τ 2 b E_T^miss 139 | b̃₁ 0.13-0.85 | Δm(χ̃⁰₂,χ̃⁰₁)=130 GeV, m(χ̃⁰₁)=0 GeV | ATLAS-CONF-2020-031
t̃₁t̃₁, t̃₁→tχ̃⁰₁ | 0-1 e,μ ≥ 1 jet E_T^miss 139 | t̃₁ 1.25 | m(χ̃⁰₁)=1 GeV | 2004.14060,2012.03799
t̃₁t̃₁, t̃₁→Wbχ̃⁰₁ | 1 e,μ 3 jets/1 b E_T^miss 139 | t̃₁ Forbidden 0.65 | m(χ̃⁰₁)=500 GeV | 2012.03799
t̃₁t̃₁, t̃₁→τ̃₁bν, τ̃₁→τG̃ | 1-2 τ 2 jets/1 b E_T^miss 139 | t̃₁ Forbidden 1.4 | m(τ̃₁)=800 GeV | ATLAS-CONF-2021-008
t̃₁t̃₁, t̃₁→cχ̃⁰₁ / c̃c̃, c̃→cχ̃⁰₁ | 0 e,μ 2 c E_T^miss 36.1 | c̃ 0.85 | m(χ̃⁰₁)=0 GeV | 1805.01649
0 e,μ mono-jet E_T^miss 139 | t̃₁ 0.55 | m(t̃₁,c̃)-m(χ̃⁰₁)=5 GeV | 2102.10874
t̃₁t̃₁, t̃₁→tχ̃⁰₂, χ̃⁰₂→Z/hχ̃⁰₁ | 1-2 e,μ 1-4 b E_T^miss 139 | t̃₁ 0.067-1.18 | m(χ̃⁰₂)=500 GeV | 2006.05880
t̃₂t̃₂, t̃₂→t̃₁+Z | 3 e,μ 1 b E_T^miss 139 | t̃₂ Forbidden 0.86 | m(χ̃⁰₁)=360 GeV, m(t̃₁)-m(χ̃⁰₁)= 40 GeV | 2006.05880
EW direct
χ̃±₁χ̃⁰₂ via WZ | Multiple ℓ/jets E_T^miss 139 | χ̃±₁/χ̃⁰₂ 0.96 | m(χ̃⁰₁)=0, wino-bino | 2106.01676, ATLAS-CONF-2021-022
ee,μμ ≥ 1 jet E_T^miss 139 | χ̃±₁/χ̃⁰₂ 0.205 | m(χ̃±₁)-m(χ̃⁰₁)=5 GeV, wino-bino | 1911.12606
χ̃±₁χ̃∓₁ via WW | 2 e,μ E_T^miss 139 | χ̃±₁ 0.42 | m(χ̃⁰₁)=0, wino-bino | 1908.08215
χ̃±₁χ̃⁰₂ via Wh | Multiple ℓ/jets E_T^miss 139 | χ̃±₁/χ̃⁰₂ Forbidden 1.06 | m(χ̃⁰₁)=70 GeV, wino-bino | 2004.10894, ATLAS-CONF-2021-022
χ̃±₁χ̃∓₁ via ℓ̃_L/ν̃ | 2 e,μ E_T^miss 139 | χ̃±₁ 1.0 | m(ℓ̃,ν̃)=0.5(m(χ̃±₁)+m(χ̃⁰₁)) | 1908.08215
τ̃τ̃, τ̃→τχ̃⁰₁ | 2 τ E_T^miss 139 | τ̃ [τ̃_L, τ̃_R,L] 0.16-0.3 0.12-0.39 | m(χ̃⁰₁)=0 | 1911.06660
ℓ̃_L,Rℓ̃_L,R, ℓ̃→ℓχ̃⁰₁ | 2 e,μ 0 jets E_T^miss 139 | ℓ̃ 0.7 | m(χ̃⁰₁)=0 | 1908.08215
ee,μμ ≥ 1 jet E_T^miss 139 | ℓ̃ 0.256 | m(ℓ̃)-m(χ̃⁰₁)=10 GeV | 1911.12606
H̃H̃, H̃→hG̃/ZG̃ | 0 e,μ ≥ 3 b E_T^miss 36.1 | H̃ 0.13-0.23 0.29-0.88 | BR(χ̃⁰₁ → hG̃)=1 | 1806.04030
4 e,μ 0 jets E_T^miss 139 | H̃ 0.55 | BR(χ̃⁰₁ → ZG̃)=1 | 2103.11684
0 e,μ ≥ 2 large jets E_T^miss 139 | H̃ 0.45-0.93 | BR(χ̃⁰₁ → ZG̃)=1 | ATLAS-CONF-2021-022
Long-lived particles
Direct χ̃⁺₁χ̃⁻₁ prod., long-lived χ̃±₁ | Disapp. trk 1 jet E_T^miss 139 | χ̃±₁ 0.66 | Pure Wino | ATLAS-CONF-2021-015
χ̃±₁ 0.21 | Pure higgsino | ATLAS-CONF-2021-015
Stable g̃ R-hadron | Multiple 36.1 | g̃ 2.0 | 1902.01636,1808.04095
Metastable g̃ R-hadron, g̃→qqχ̃⁰₁ | Multiple 36.1 | g̃ [τ(g̃) =10 ns, 0.2 ns] 2.05 2.4 | m(χ̃⁰₁)=100 GeV | 1710.04901,1808.04095
ℓ̃ℓ̃, ℓ̃→ℓG̃ | Displ. lep E_T^miss 139 | ẽ,μ̃ 0.7 | τ(ℓ̃) = 0.1 ns | 2011.07812
τ̃ 0.34 | τ(ℓ̃) = 0.1 ns | 2011.07812
RPV
χ̃±₁χ̃∓₁/χ̃⁰₂, χ̃±₁→Zℓ→ℓℓℓ | 3 e,μ 139 | χ̃±₁/χ̃⁰₂ [BR(Zτ)=1, BR(Ze)=1] 0.625 1.05 | Pure Wino | 2011.10543
χ̃±₁χ̃∓₁/χ̃⁰₂ → WW/Zℓℓℓℓνν | 4 e,μ 0 jets E_T^miss 139 | χ̃±₁/χ̃⁰₂ [λ_i33 ≠ 0, λ_12k ≠ 0] 0.95 1.55 | m(χ̃⁰₁)=200 GeV | 2103.11684
g̃g̃, g̃→qqχ̃⁰₁, χ̃⁰₁ → qqq | 4-5 large jets 36.1 | g̃ [m(χ̃⁰₁)=200 GeV, 1100 GeV] 1.3 1.9 | Large λ''₁₁₂ | 1804.03568
t̃t̃, t̃→tχ̃⁰₁, χ̃⁰₁ → tbs | Multiple 36.1 | t̃ [λ''₃₂₃=2e-4, 1e-2] 0.55 1.05 | m(χ̃⁰₁)=200 GeV, bino-like | ATLAS-CONF-2018-003
t̃t̃, t̃→bχ̃±₁, χ̃±₁ → bbs | ≥ 4b 139 | t̃ Forbidden 0.95 | m(χ̃±₁)=500 GeV | 2010.01015
t̃₁t̃₁, t̃₁→bs | 2 jets + 2 b 36.7 | t̃₁ [qq, bs] 0.42 0.61 | 1710.07171
t̃₁t̃₁, t̃₁→qℓ | 2 e,μ 2 b 36.1 | t̃₁ 0.4-1.45 | BR(t̃₁→be/bμ)>20% | 1710.05544
1 μ DV 136 | t̃₁ [1e-10< λ'₂₃k <1e-8, 3e-10< λ'₂₃k <3e-9] 1.0 1.6 | BR(t̃₁→qμ)=100%, cosθ_t=1 | 2003.11956
χ̃±₁/χ̃⁰₂/χ̃⁰₁, χ̃⁰₁,₂→tbs, χ̃⁺₁→bbs | 1-2 e,μ ≥6 jets 139 | χ̃⁰₁ 0.2-0.32 | Pure higgsino | ATLAS-CONF-2021-007
10⁻¹
1
Mass scale [TeV]
*Only a selection of the available mass limits on new states or phenomena is shown. Many of the limits are based on simplified models, c.f. refs. for the assumptions made.

EWK signatures — "Compressed"





Compressed scenario targets very small mass splittings dM(sl/C1/N2, N1);
Taking advantage of softer leptons, ISR jets, VBF jets etc.