Searches for electroweak production of supersymmetric particles with ATLAS

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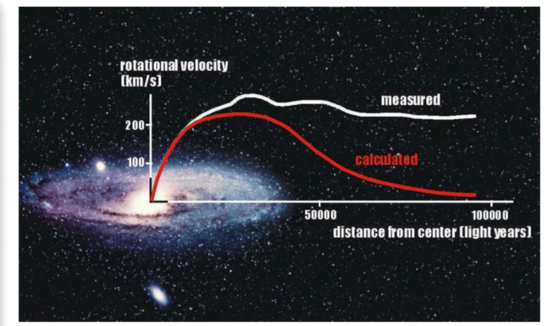
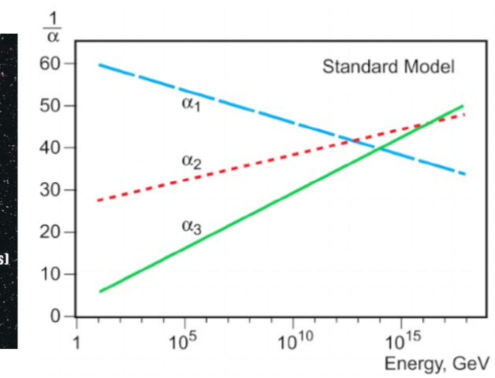
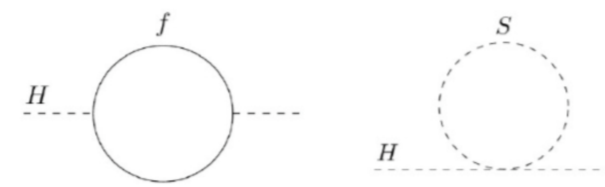
Supersymmetry

A theory to describe physics beyond *Standard Model*
- Introduce an additional symmetry: fermions ~ bosons

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







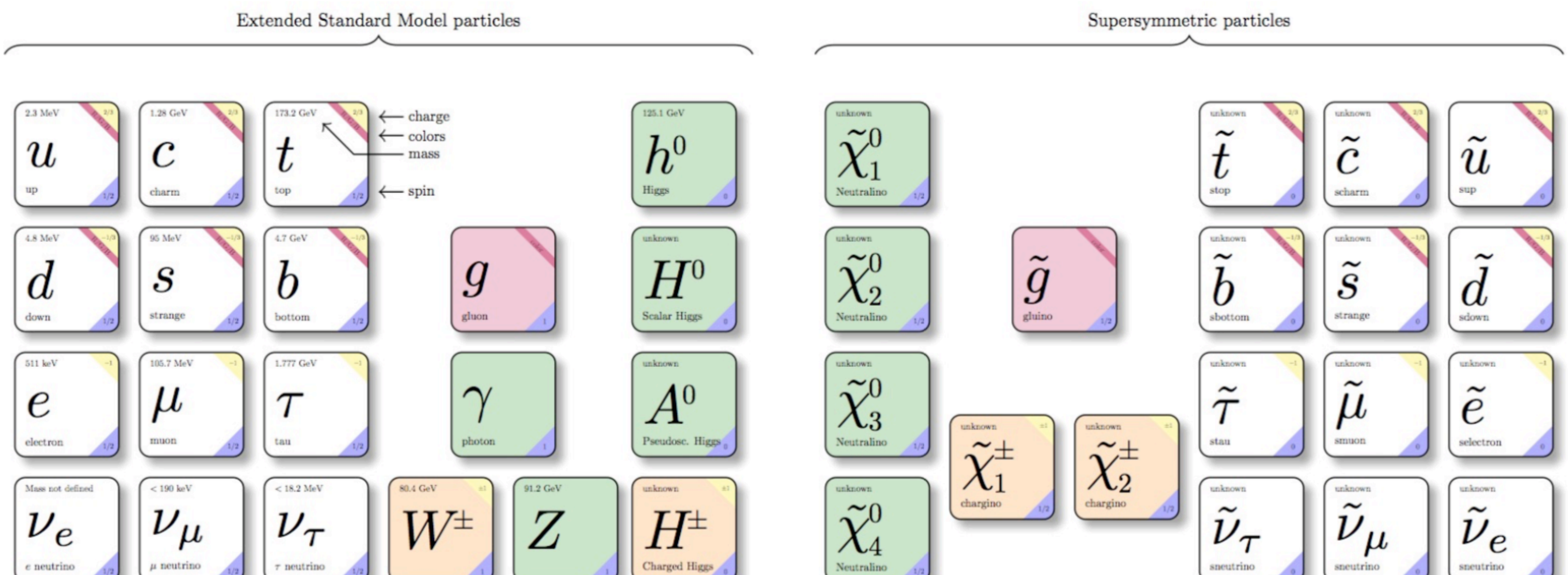
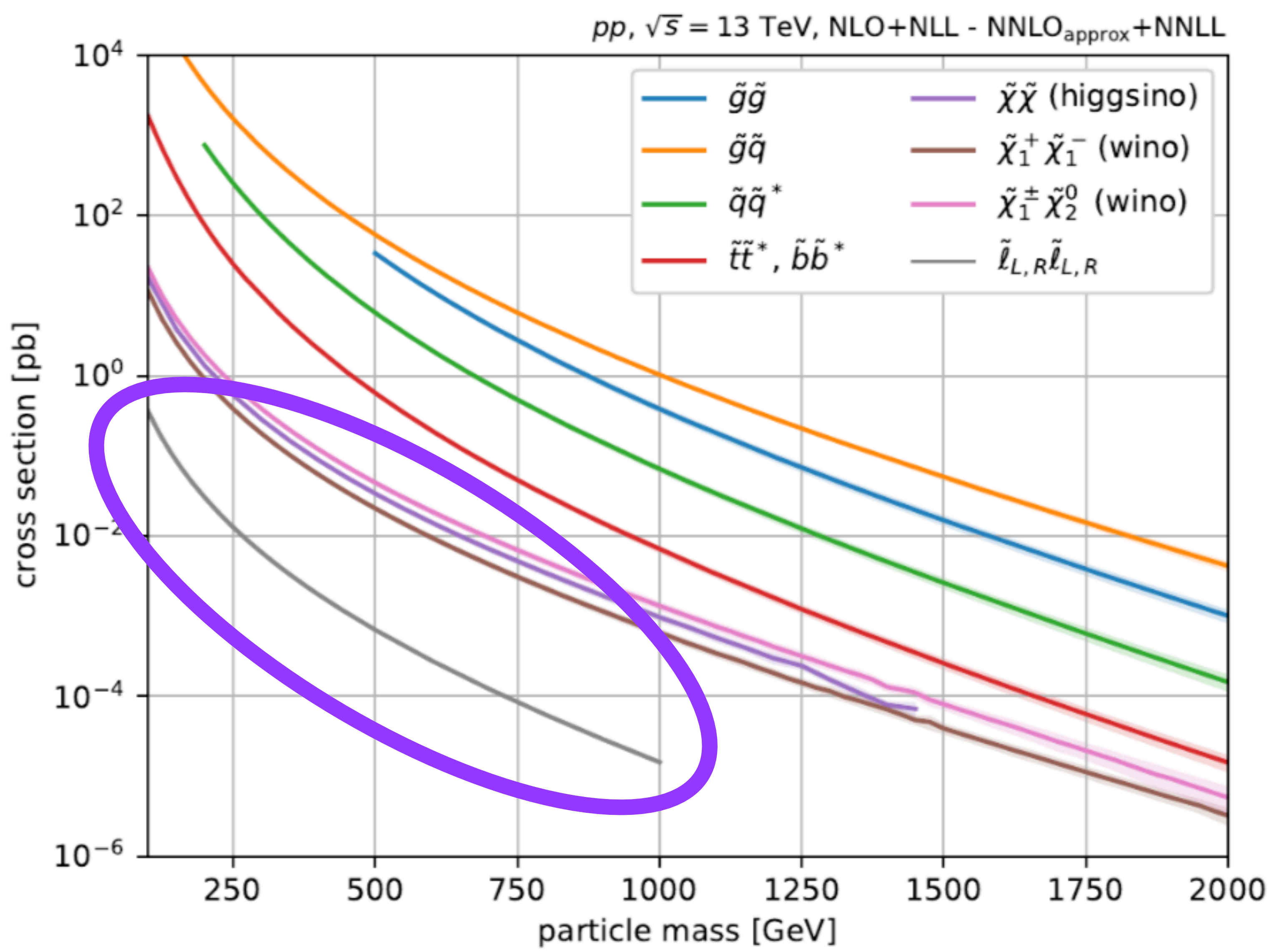


Image credit: M. Rimoldi

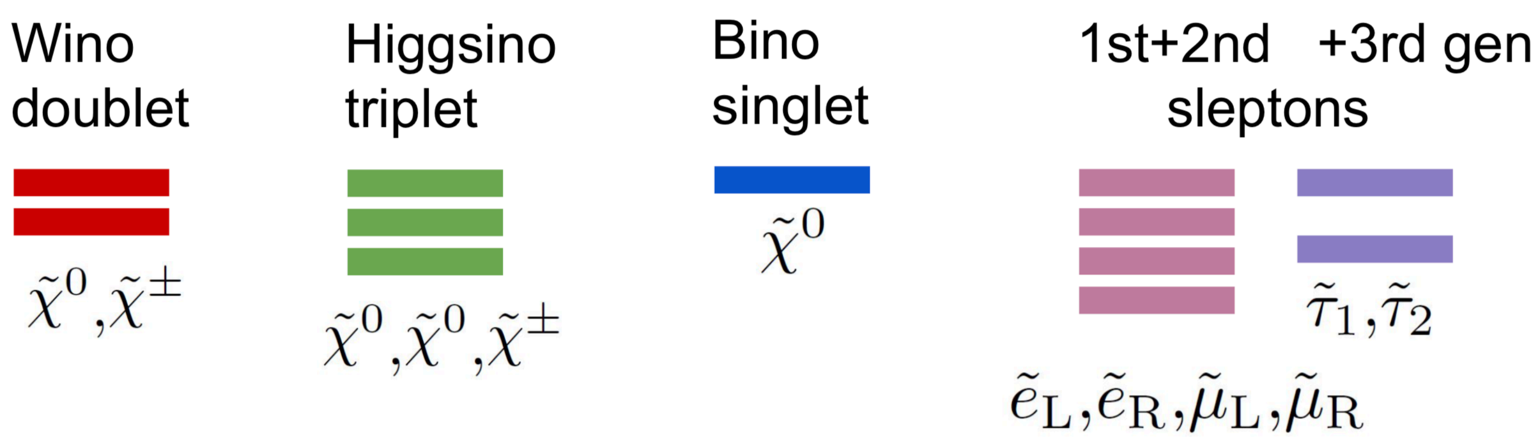
The SUSY production @ 13TeV

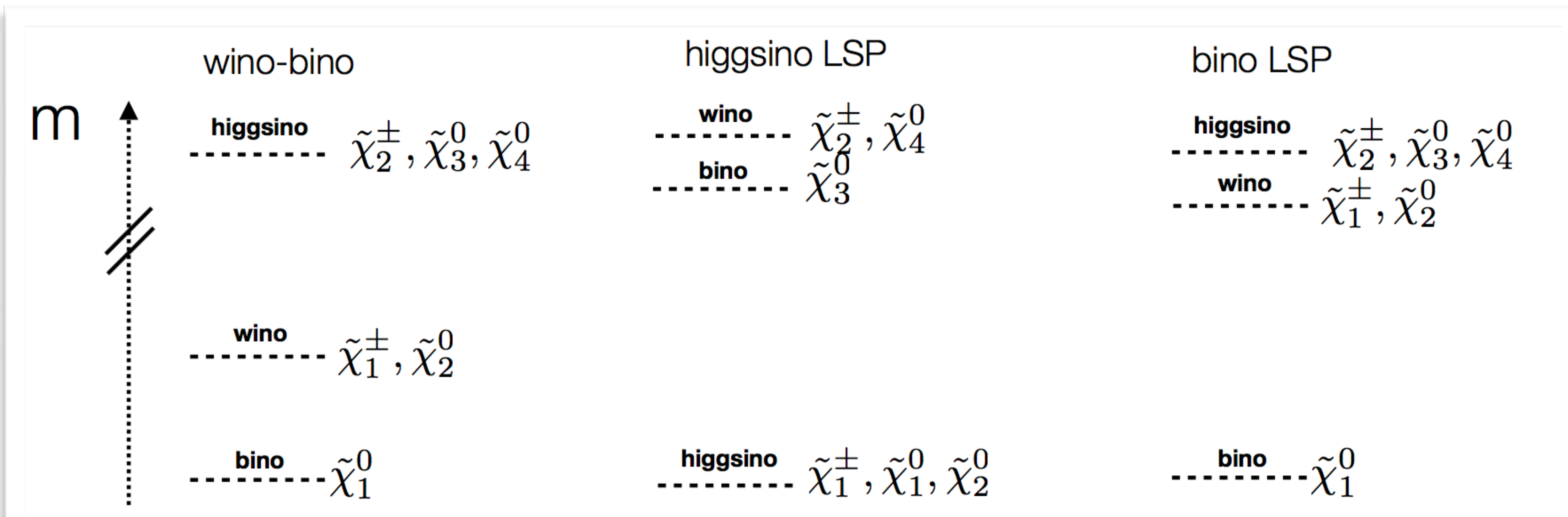


Electroweak SUSY:
smaller cross-section; less jet activity —> cleaner signature.

The electroweak SUSY search

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





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

The EWK SUSY program in ATLAS

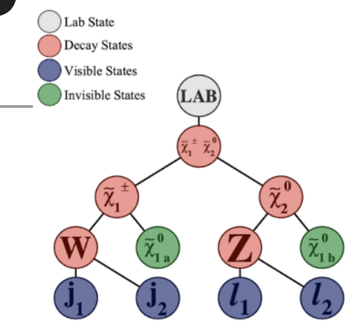
With Full Run2 Data

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
Full hadronic	C1N2/C1C1-WZ/Wh/WW; GGM	arXiv: 2108.07586
NEW 2L2J	C1N2-WZ; GGM	arXiv: 2204.13072
NEW 2L0J	C1C1-WW; Slepton pair	ATLAS-CONF-2022-006
NEW Tau	C1N2/C1C1-WZ/Wh/WW	ATLAS-CONF-2022-042

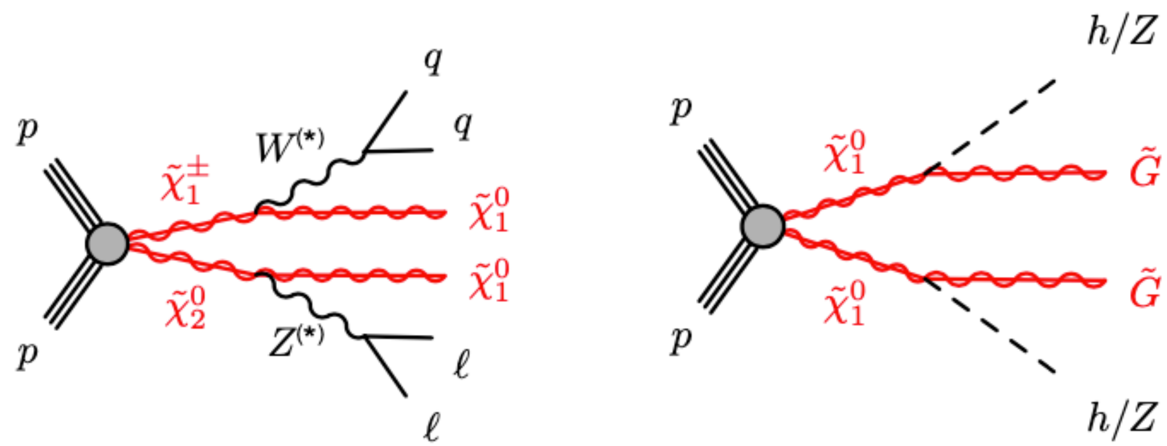
Each benchmark scenario will be discussed and the fresh results are preferred in this talk.
Reminder: more signatures are still in processing: 💡 1L; SS; multi-b; bbyy… More to come!

NEW

Wino-bino/Higgsino search with 2L2J



Follow up on excesses in previous analysis (2.0σ / 1.4σ in 36.1 ifb).

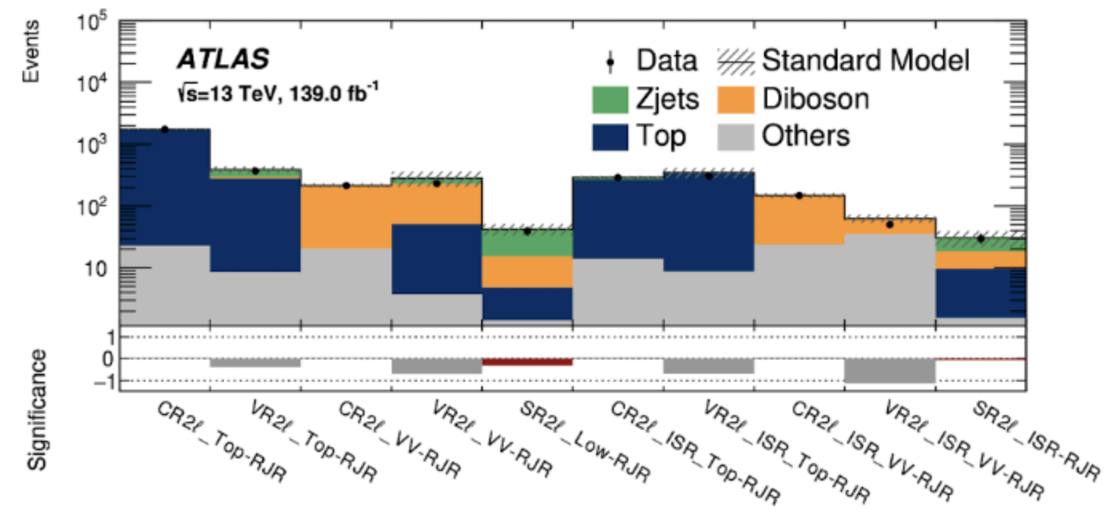


Recursive Jigsaw Reconstruction (RJR)

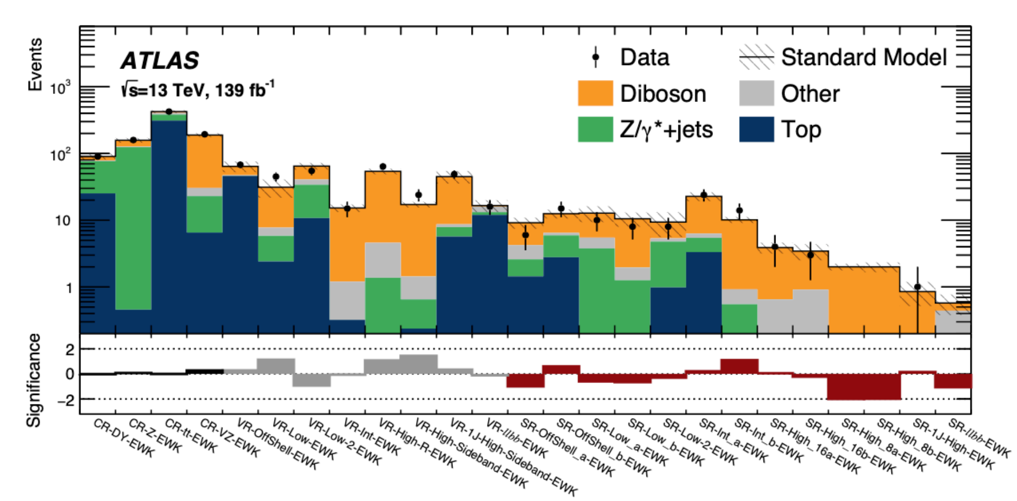
- Selection as in 36.1 ifb analysis
- 2 leptons, same flavour opposite sign, jets
- ABCD method for gamma/Z + jets background
- No excess with full 139 ifb dataset

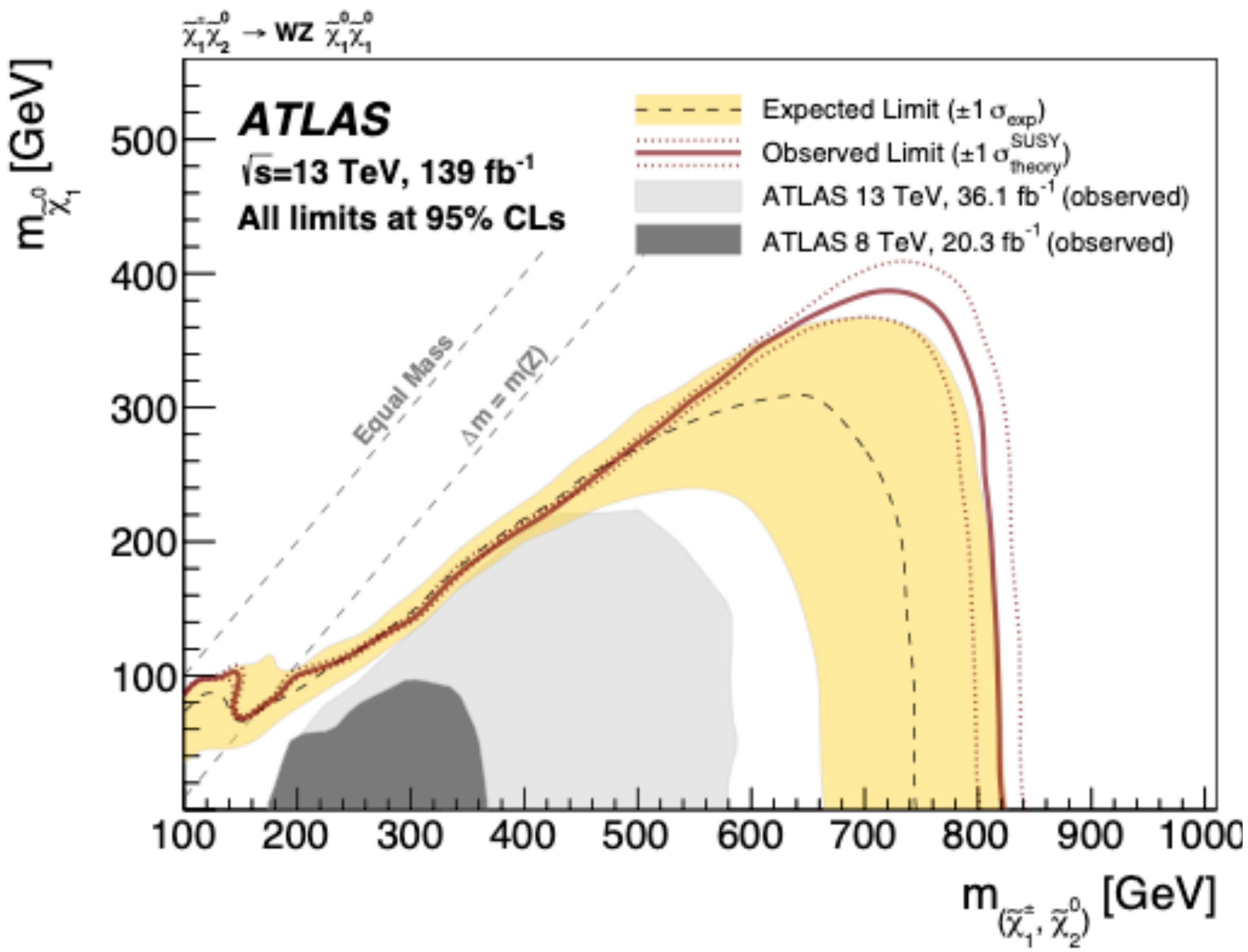
New regions targeting off-shell W/Z and GMSB

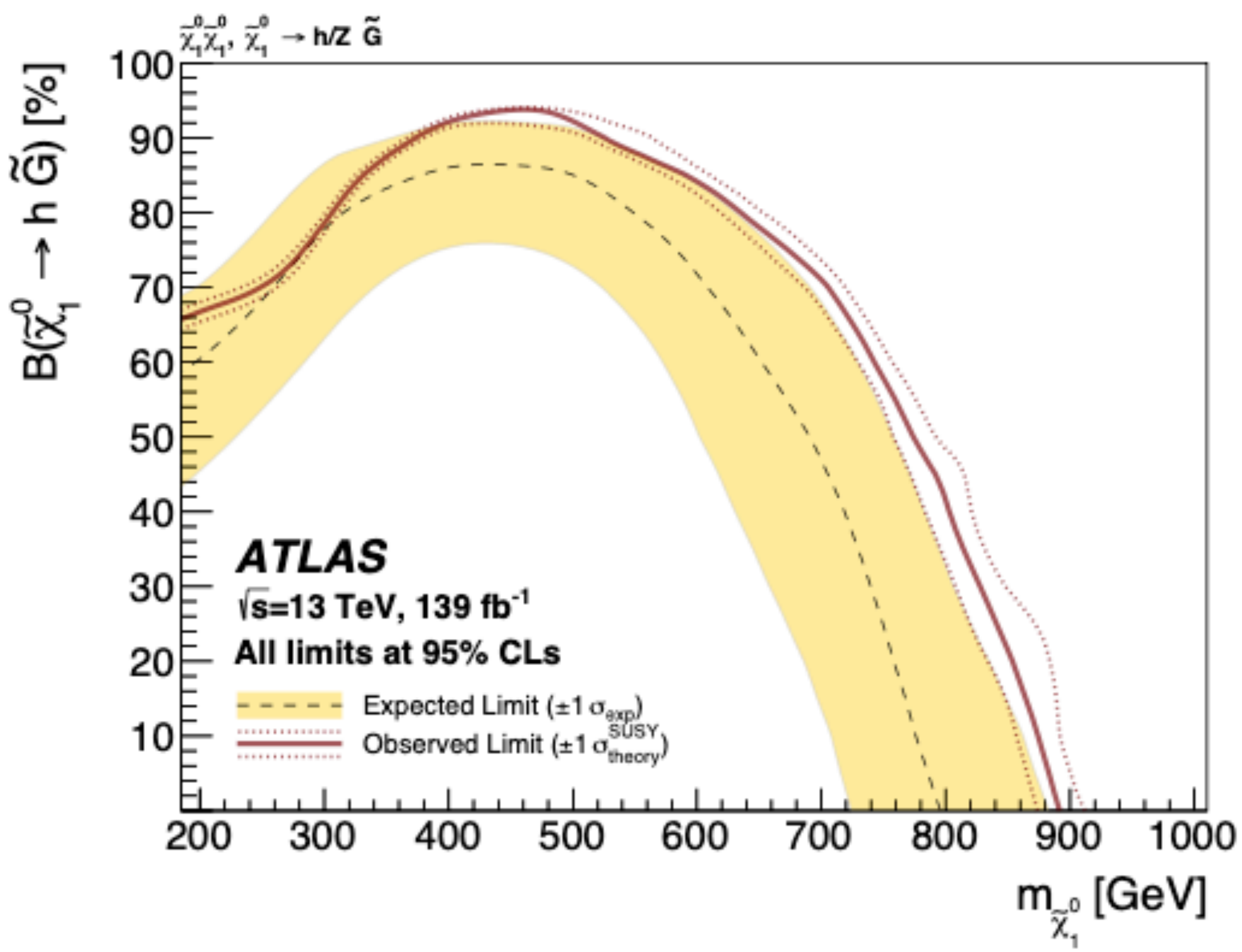
- 13 orthogonal SRs
- fake leptons estimated through matrix method



	SR2ℓ-Low-RJR	SR2ℓ-ISR-RJR
Observed events	39	30
Total expected background events	42 ± 9	31 ± 9
Diboson events	10.6 ± 3.4	8.9 ± 2.5
Top events	3.5 ± 1.7	8.2 ± 2.3
Z/γ^* + jets events	27 ± 8	12 ± 9
Other events	$0.3^{+0.5}_{-0.3}$	0.11 ± 0.04







C1N2: extending partial Run2 limit by ~200 GeV.

GMSB: large range of low BR region is covered.

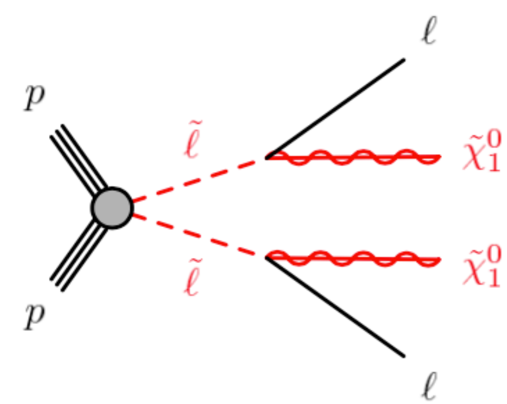
NEW

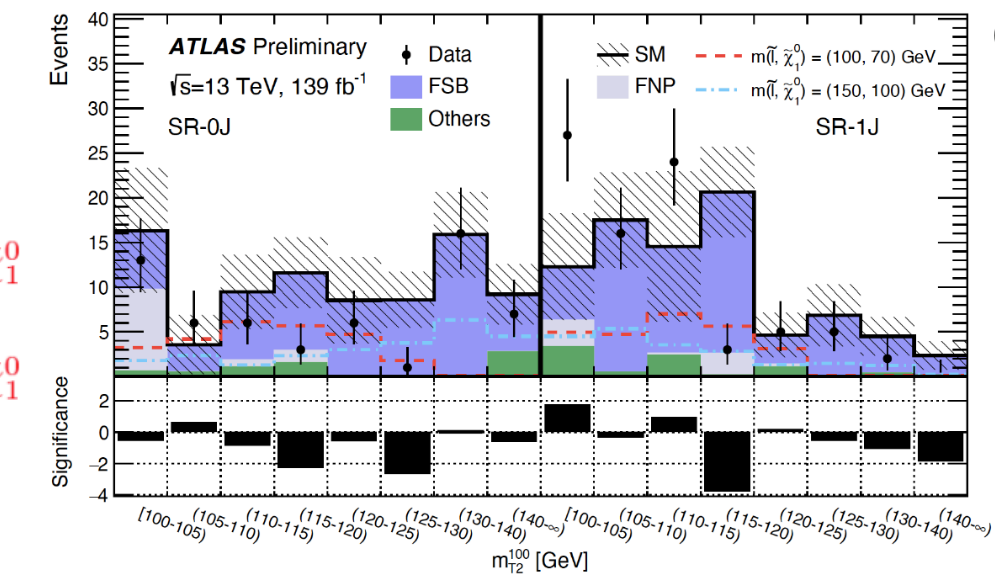
Wino-bino/Slepton search with 2L0J

Targeting moderately compressed regions, mass splitting close to W boson mass.

Slepton production

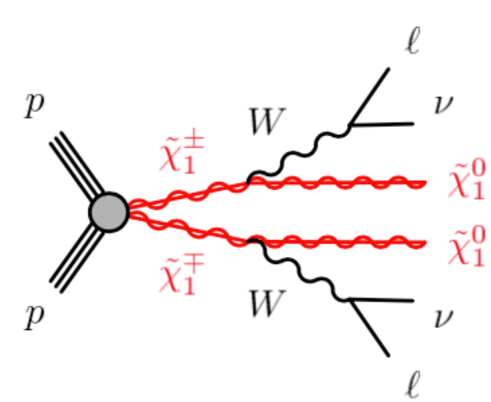
- Light smuon and light LSP could explain g-2 anomaly through loop corrections
- Same-flavour opposite sign final state, 0 or 1 jet SR
- Estimation of flavour symmetric backgrounds (FSB) through different flavour opposite sign final state

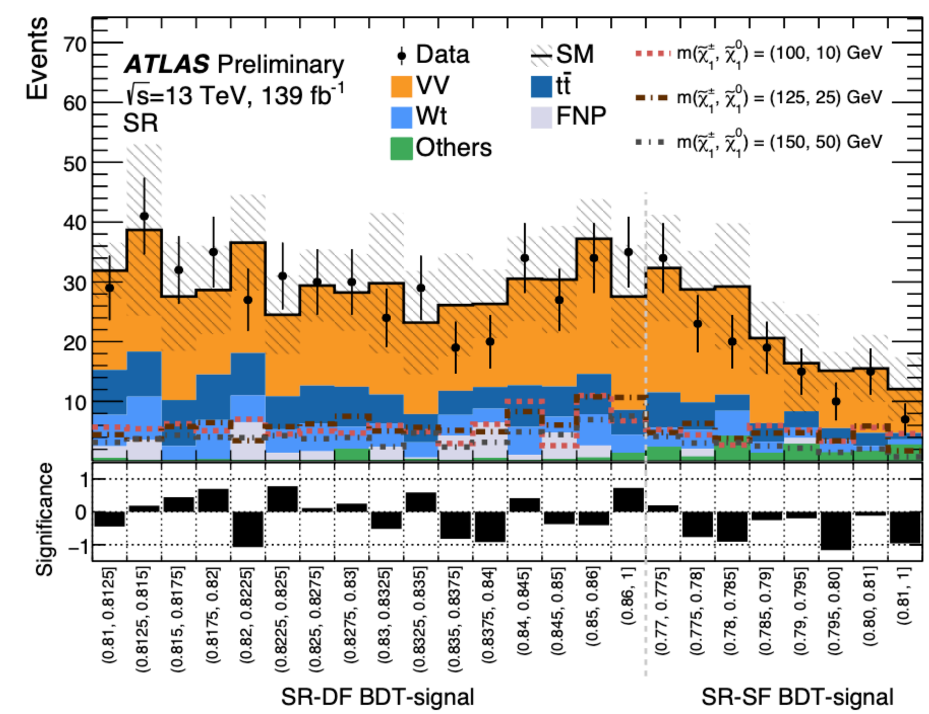


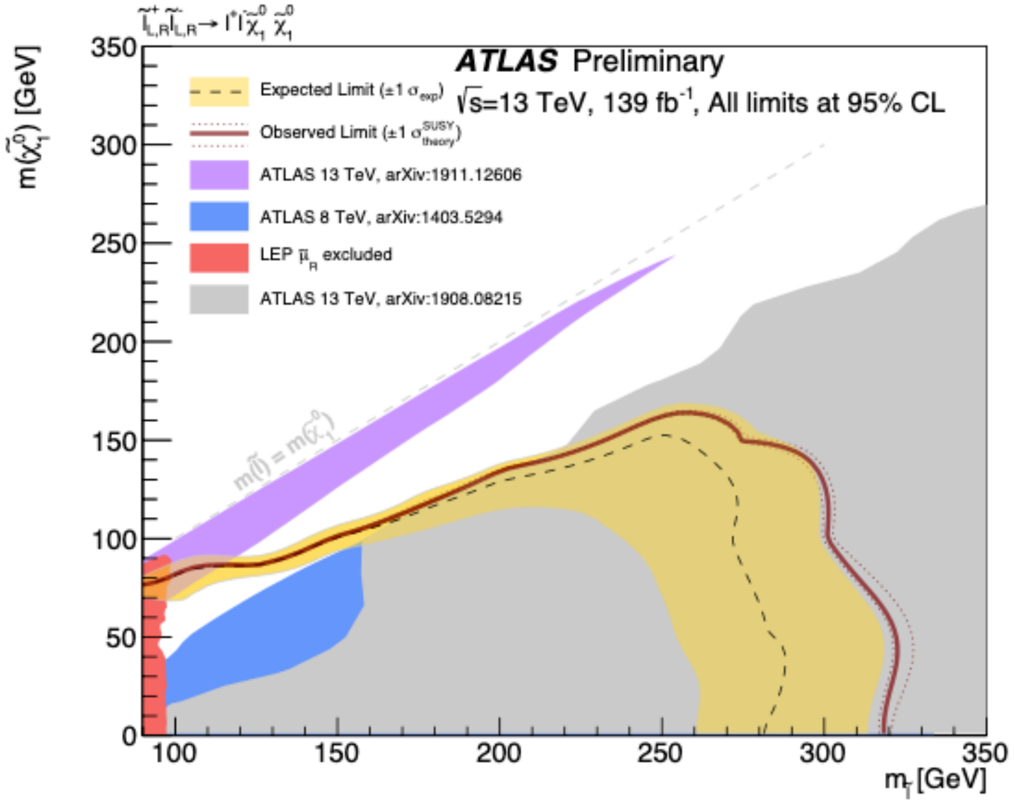


Chargino pair production

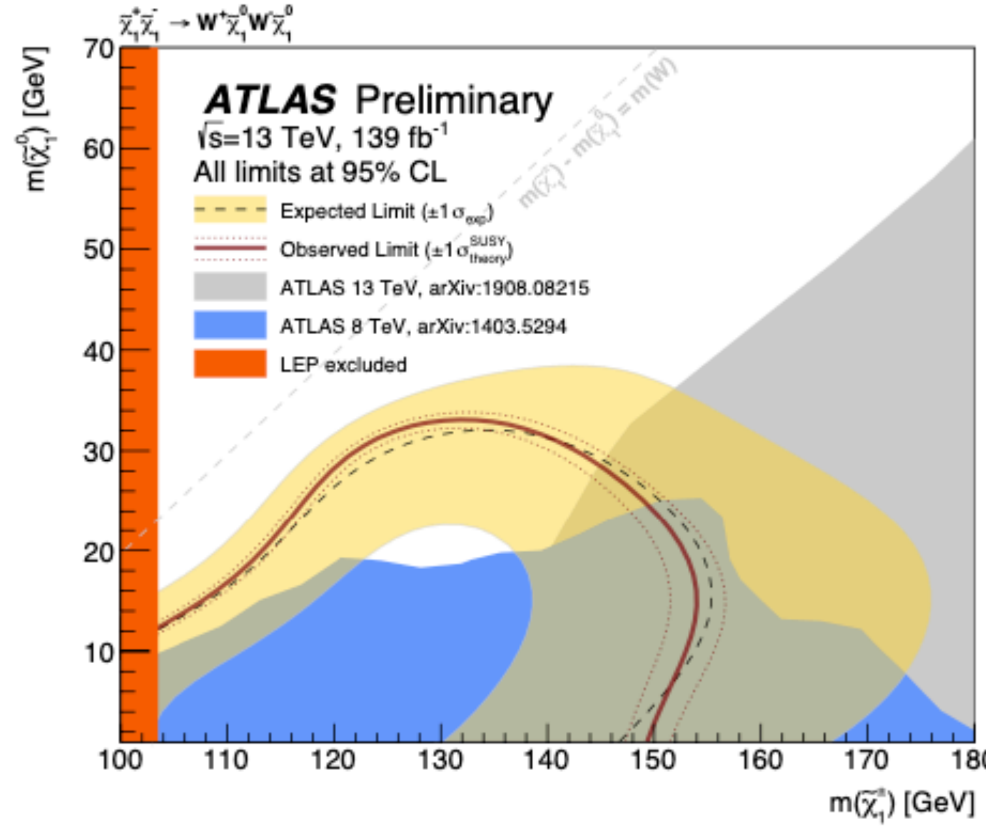
- Same-flavour and different flavour opposite sign final state
- Boosted Decision Tree approach, SR's binned in BDT output
- VV Control regions, fake leptons through matrix method



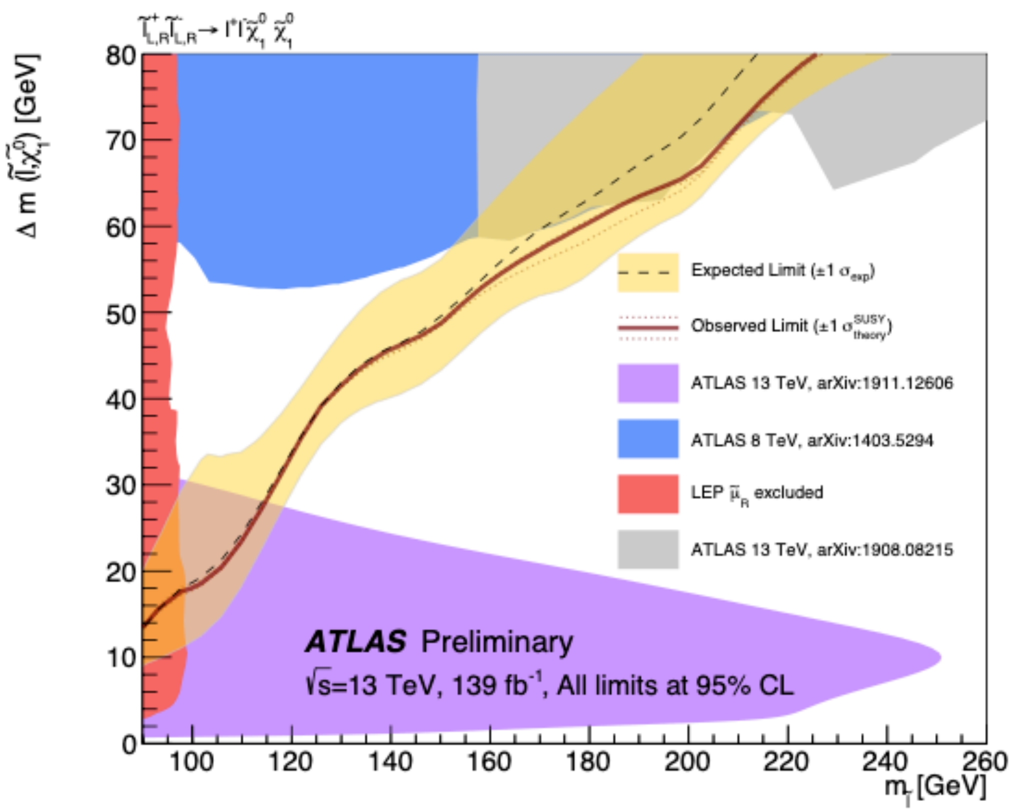


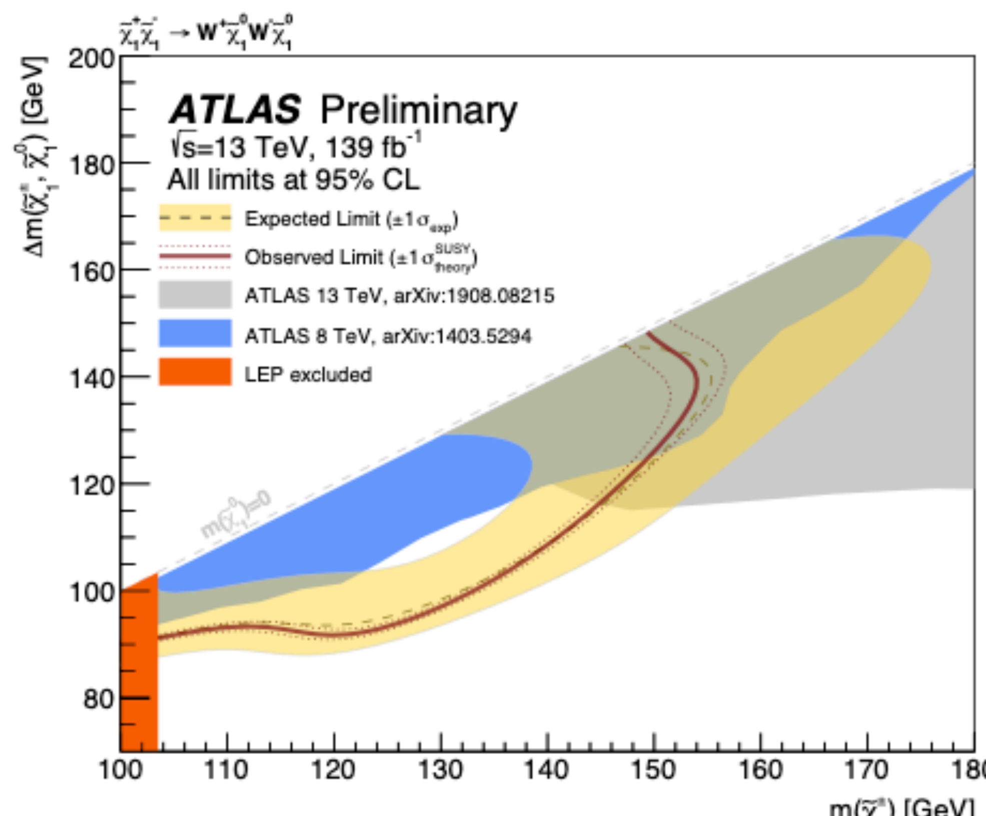


(a)



(a)



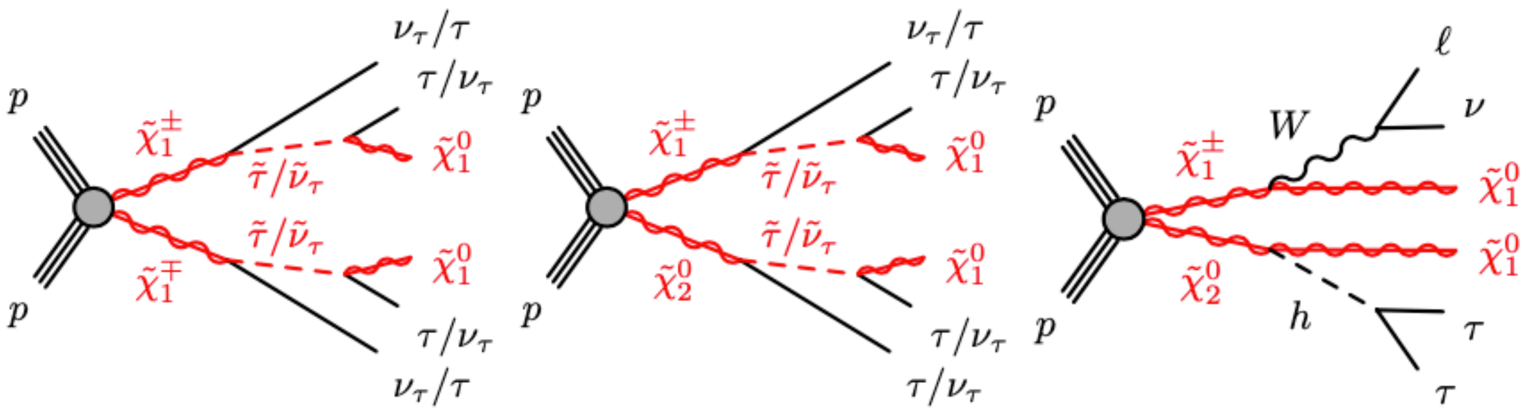


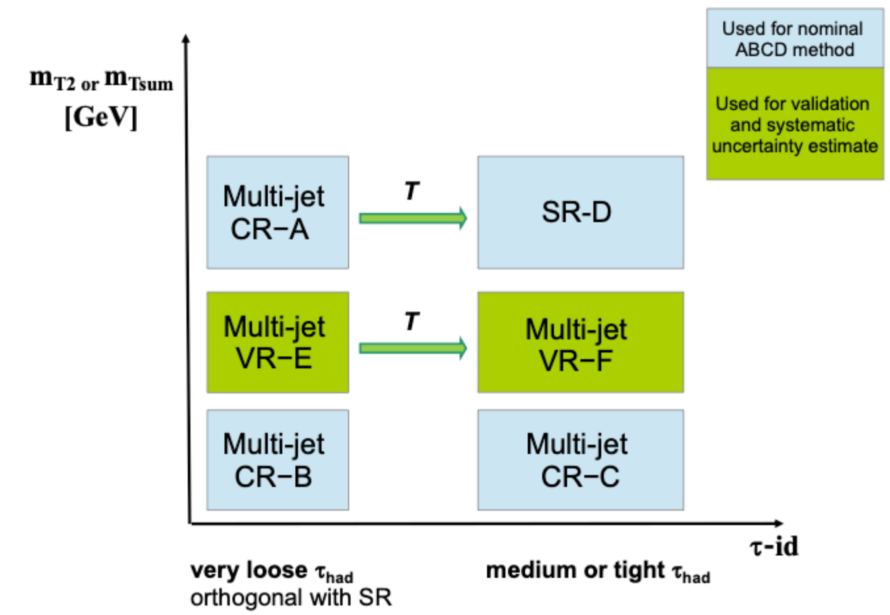
Slepton: 3.5 sigma local data deficit -> observed limit excluded more than expected.
C1C1: Closing gaps towards diagonal.

NEW

Wino-bino search with hadronic taus

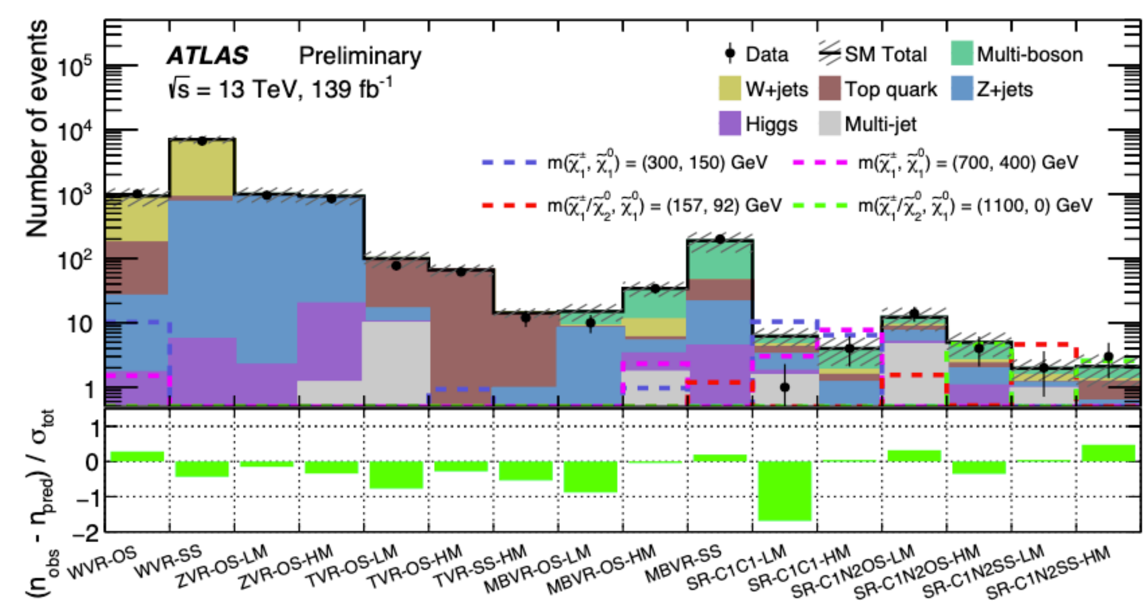
Chargino/neutralino pair production decaying to LSP via stau using >=2 tau final states

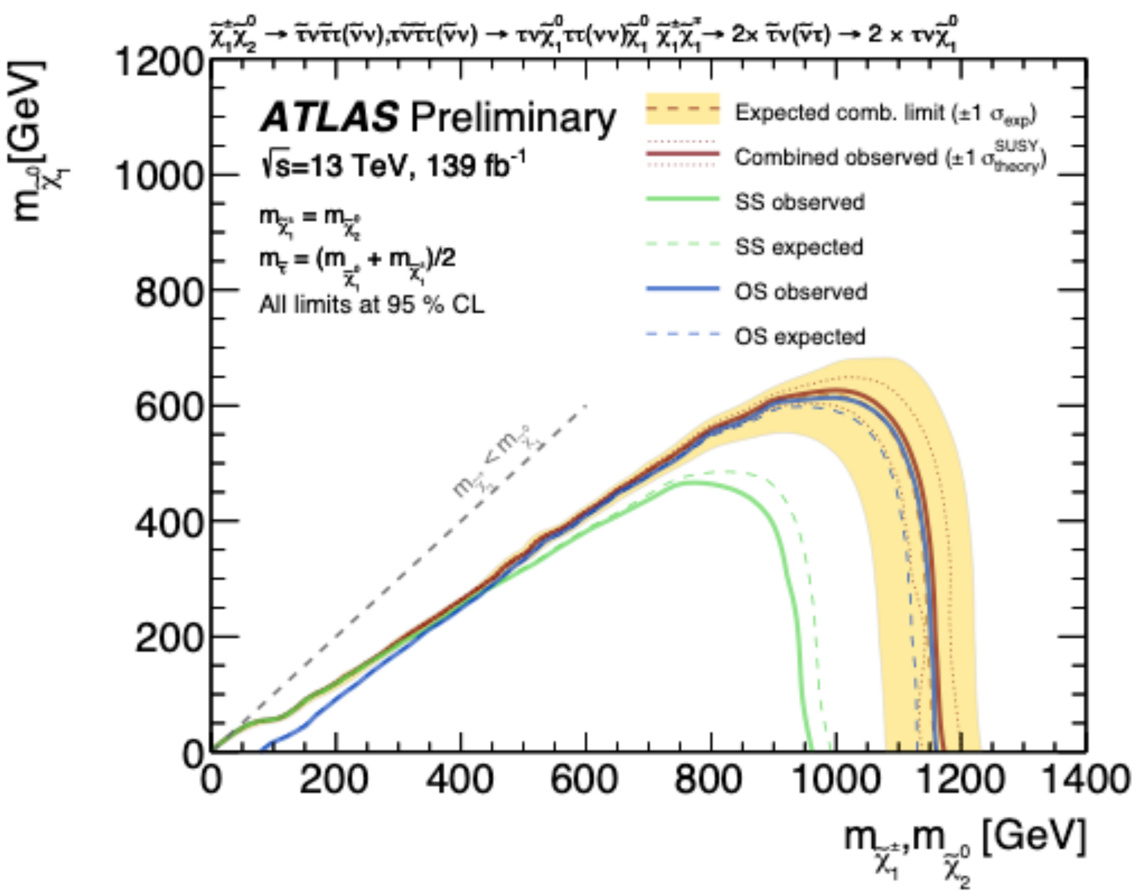


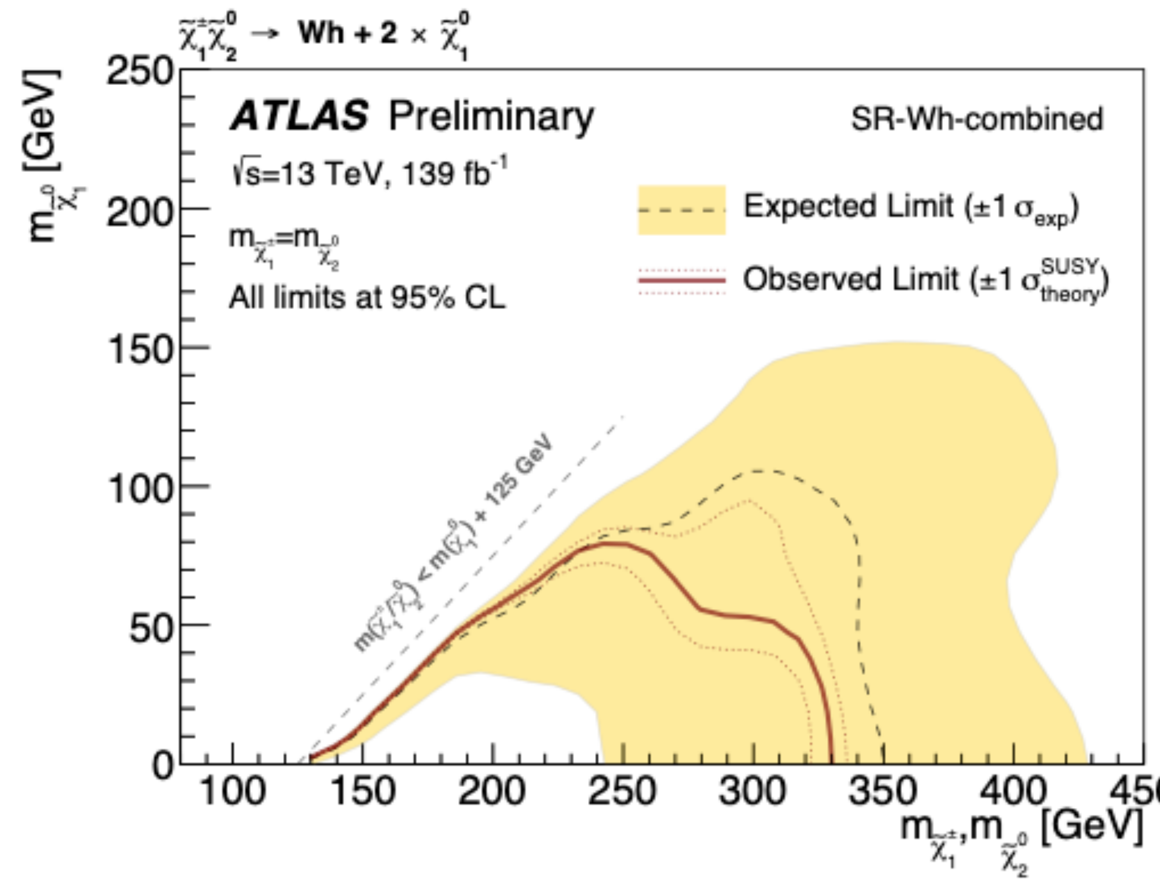


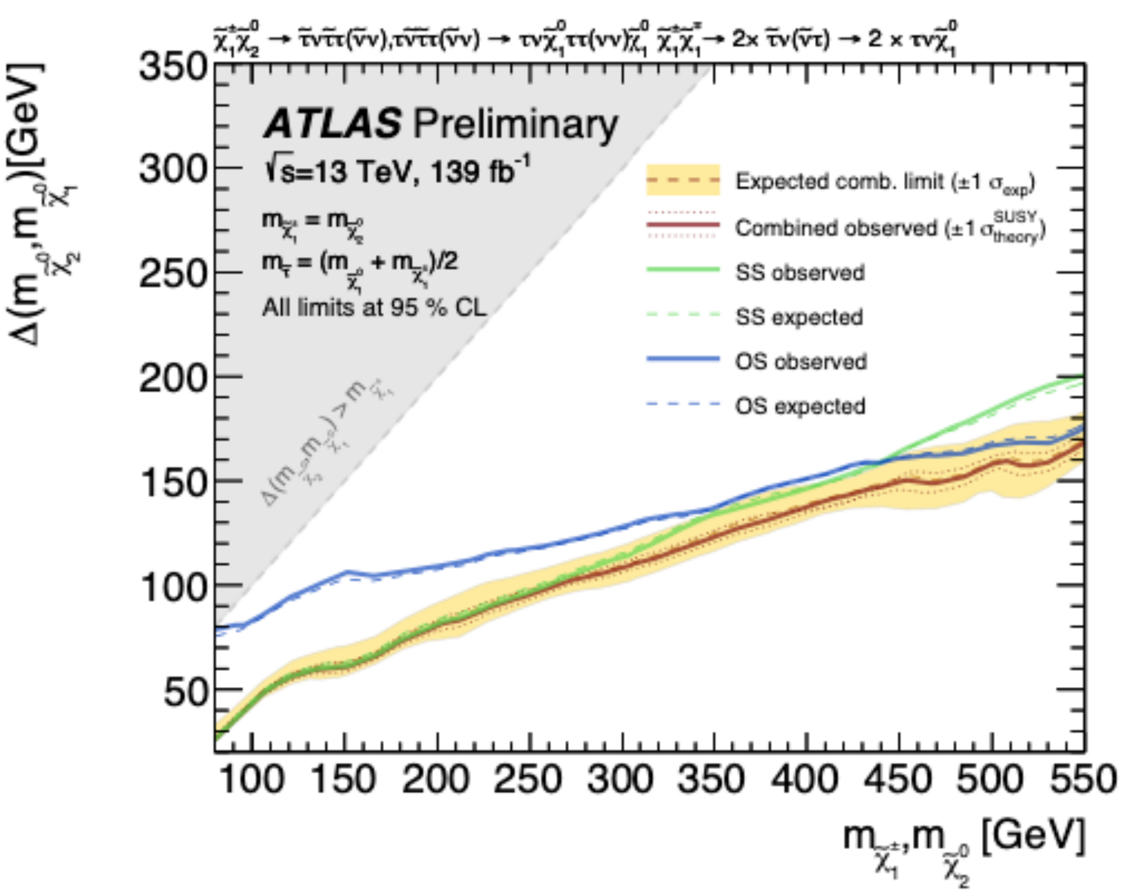
Considering muon g-2 and W-mass anomalies, light stau is also preferable

- **Hadronically-decaying taus are identified by RNN (+ BDT for e/τ separation for 1-prong τ); calibrated in Z→ττ events**
- **Categorized into SS/OS and HM/LM channels**
- **mT2: reconstructed chargino/neutralino transverse mass using 2 taus and mET, assuming a pair of symmetric decays into visible (tau) and invisible particles (LSP and ν)**
- **Dominant background: Multiboson (MC, VR); Fake (ABCD)**



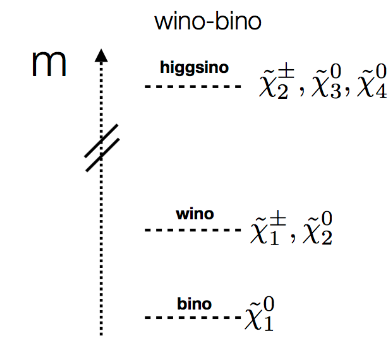




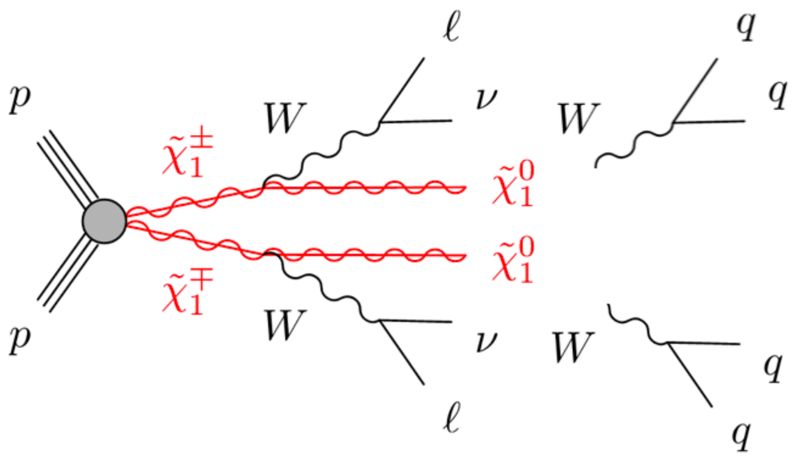


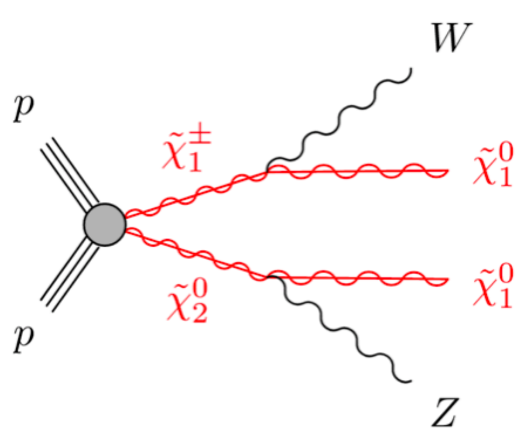
C1C1/C1N2 channels: Chargino/neutralino mass < ~1TeV is excluded

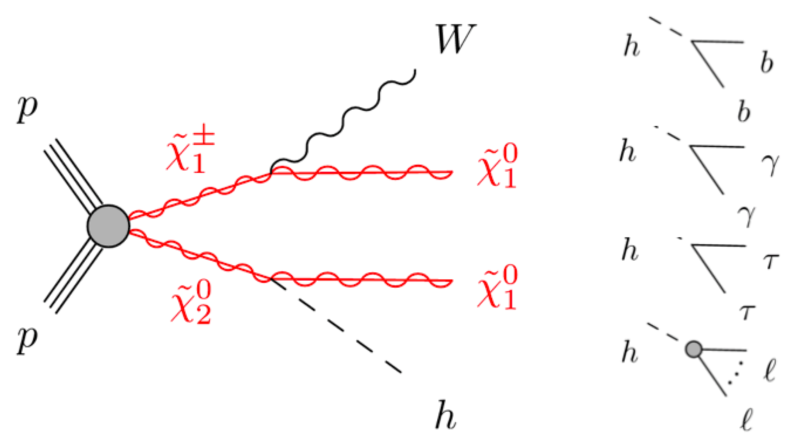
Wh channel: chargino/neutralino mass < ~300GeV is excluded

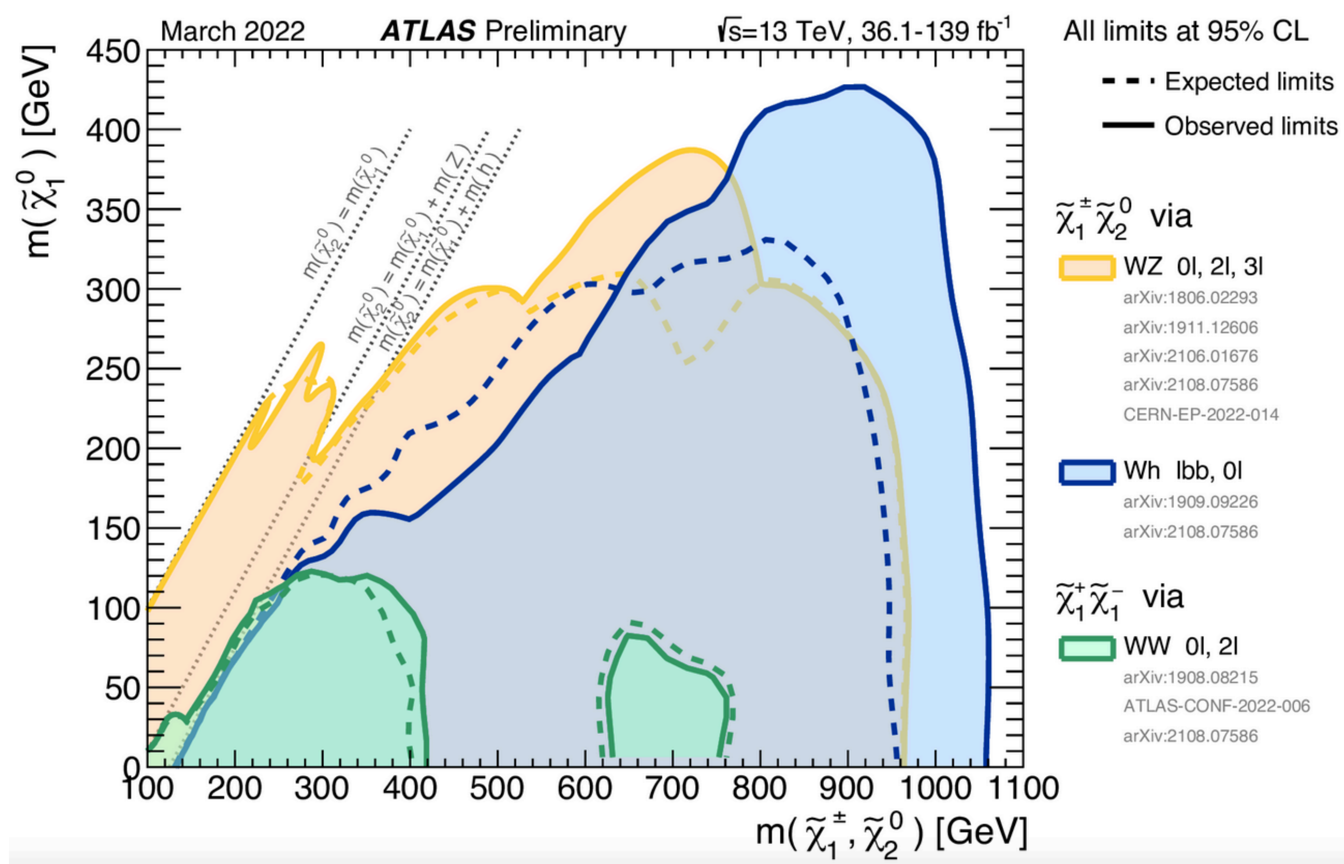


Wino-bino summary

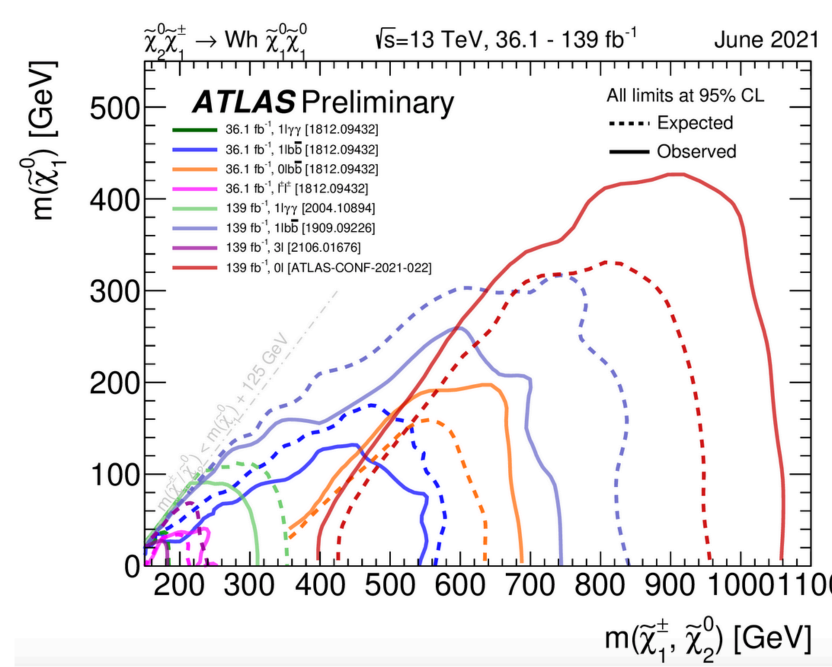




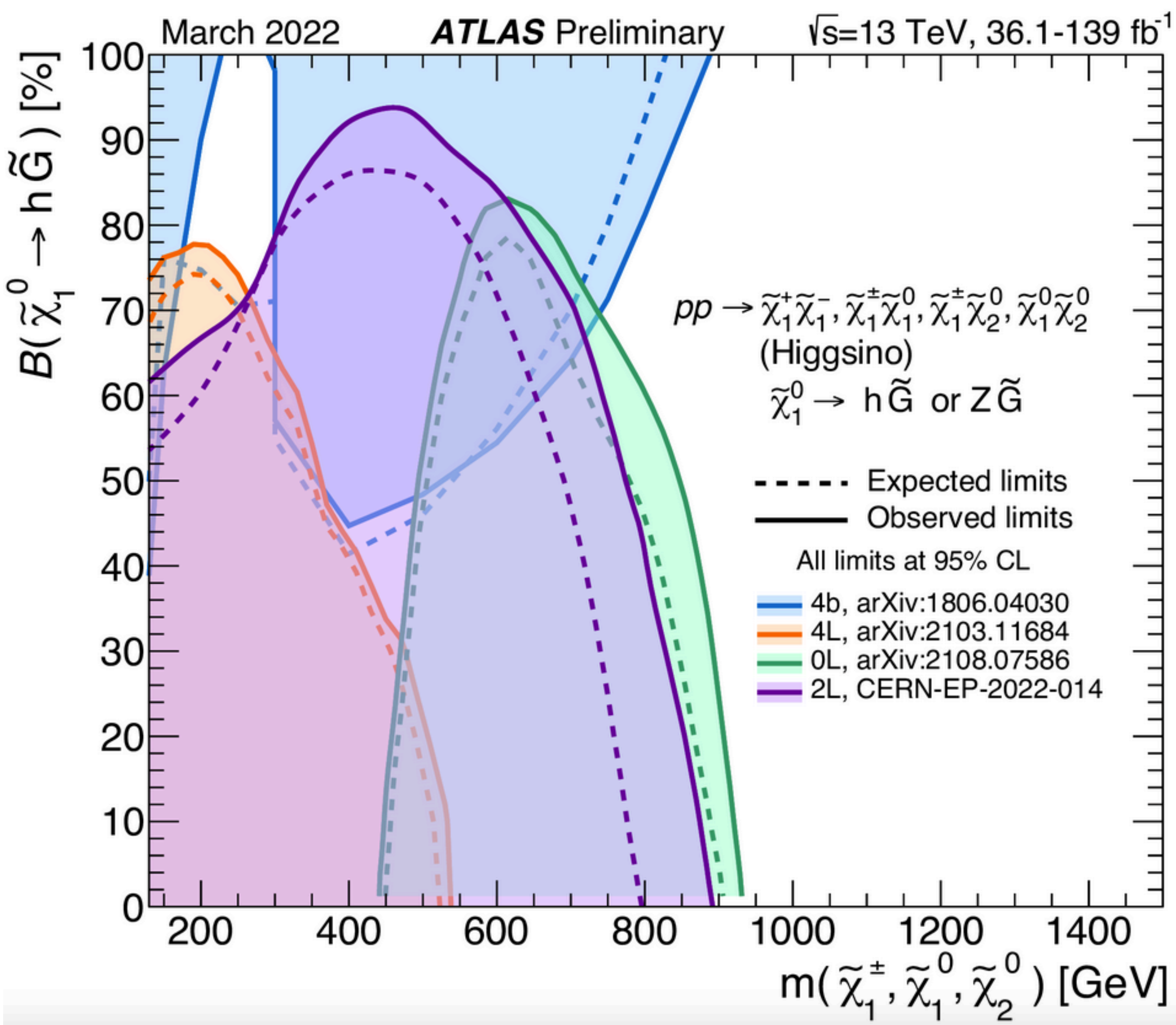


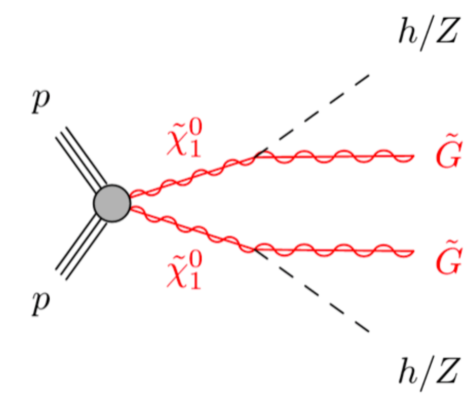


C1C1 via 1L to cover gap.



Higgsino summary

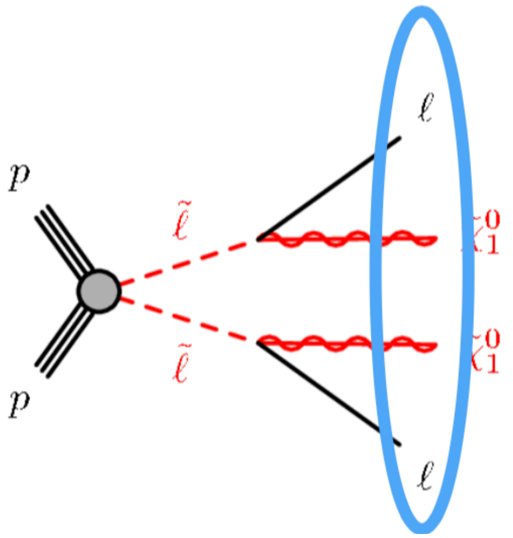


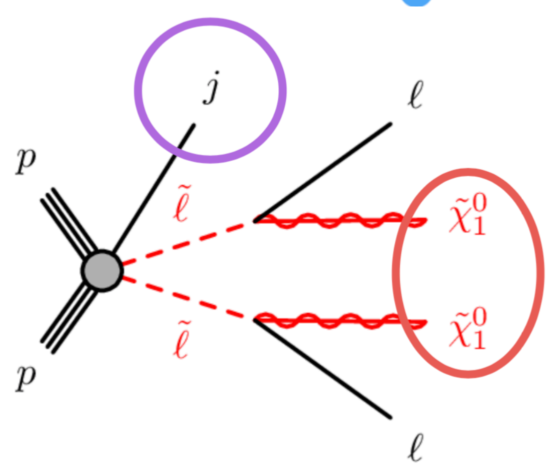


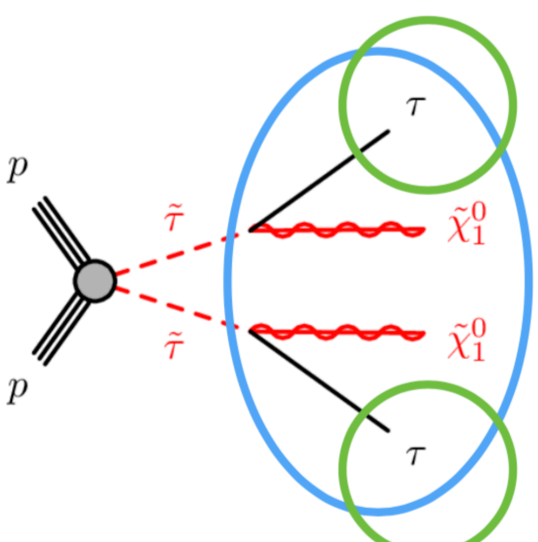
- For Higgs dominant decay mode, 4b channel wins

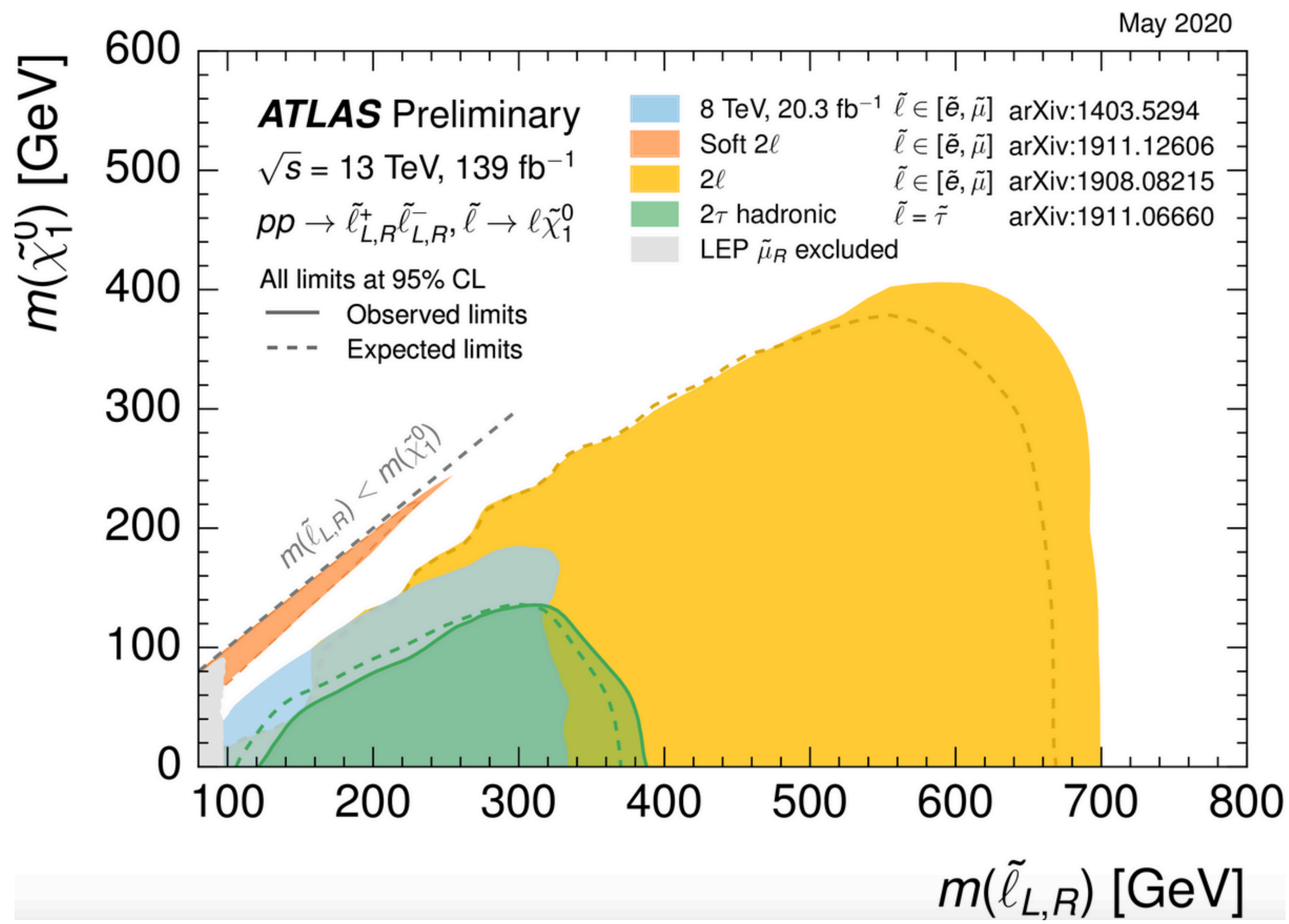
- For Z dominant decay mode
  - Low mass region: 4L channel
  - High mass region: 0L wins (w/ boost strategy)
  - Overall region: 2L2J channel wins!

Slepton summary



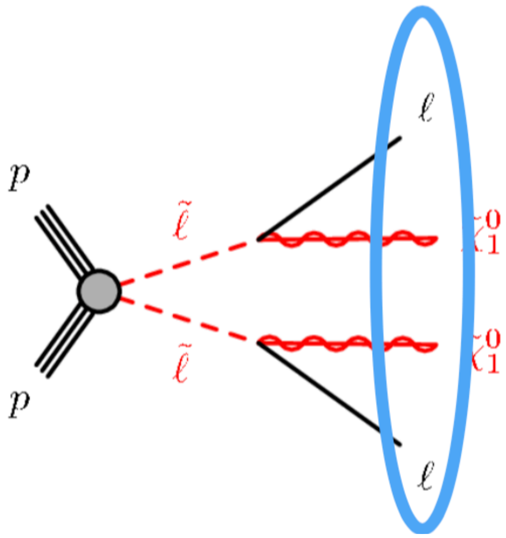


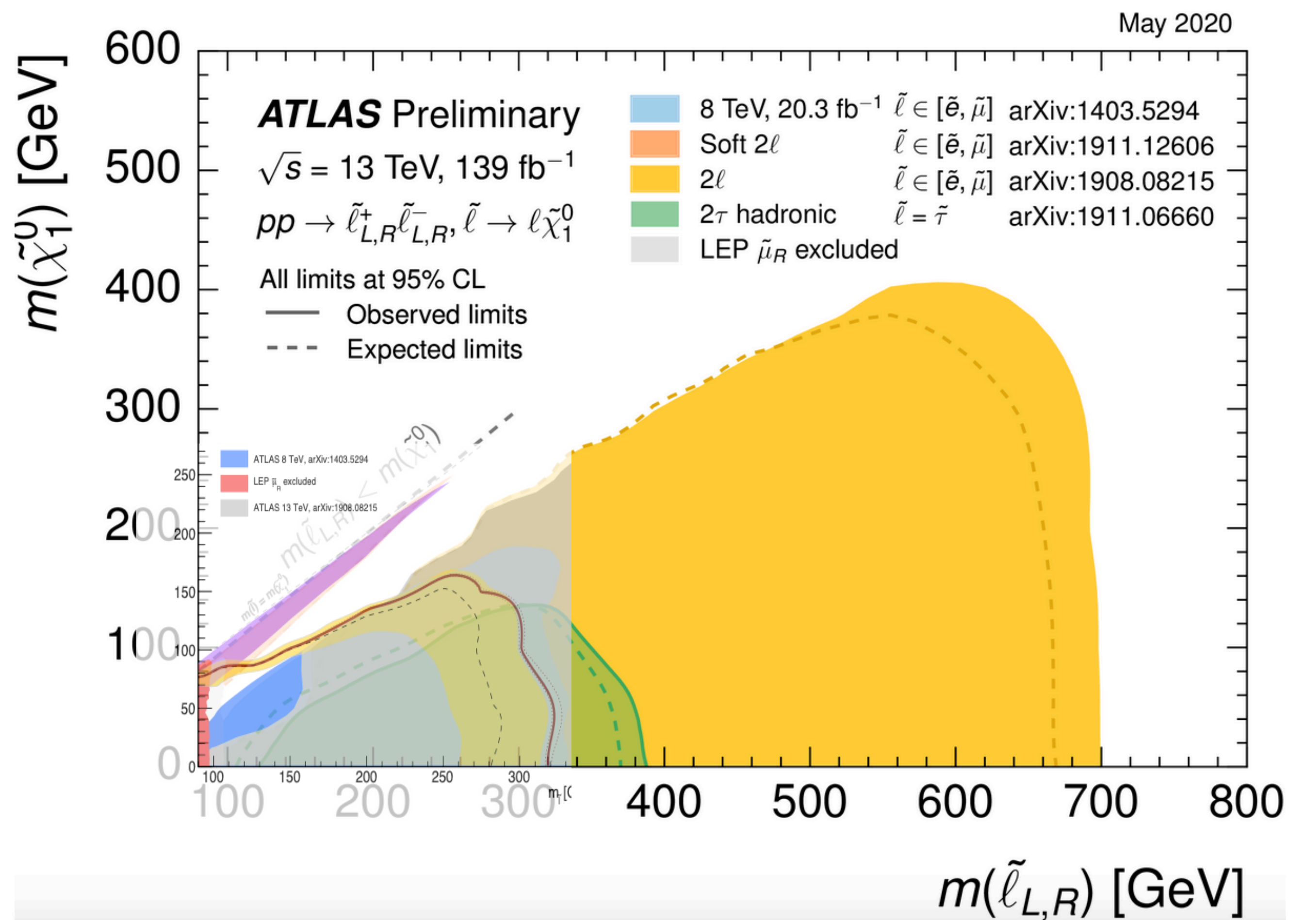


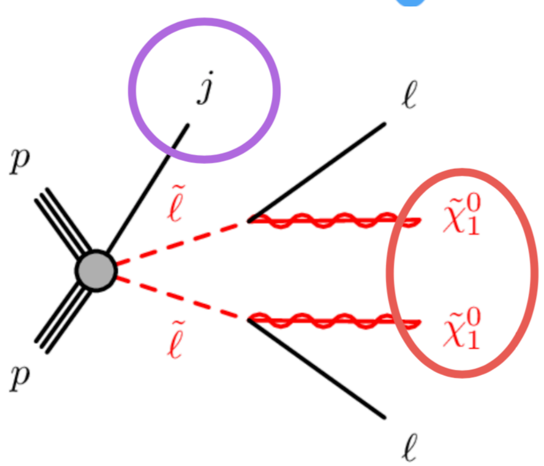


- Search 1: Final states with 2 hard el/mu (pT>25GeV) —> target high mass region!
- Search 2: Compressed analysis — 2 soft el/mu (pT_e>4.5GeV and pT_mu>3GeV) + ISR-jet —> target small mass splitting region!
- Search 3: 2 hadronic tau analysis — improvement in tau trigger with improved tau ID.

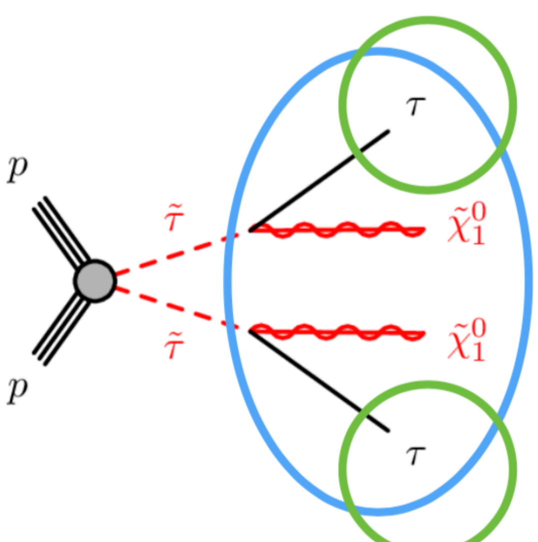
Slepton summary







- **Advanced Search 1**: Final states with 2 hard el/mu (pT>25GeV) —> target *moderate* 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.

Summary

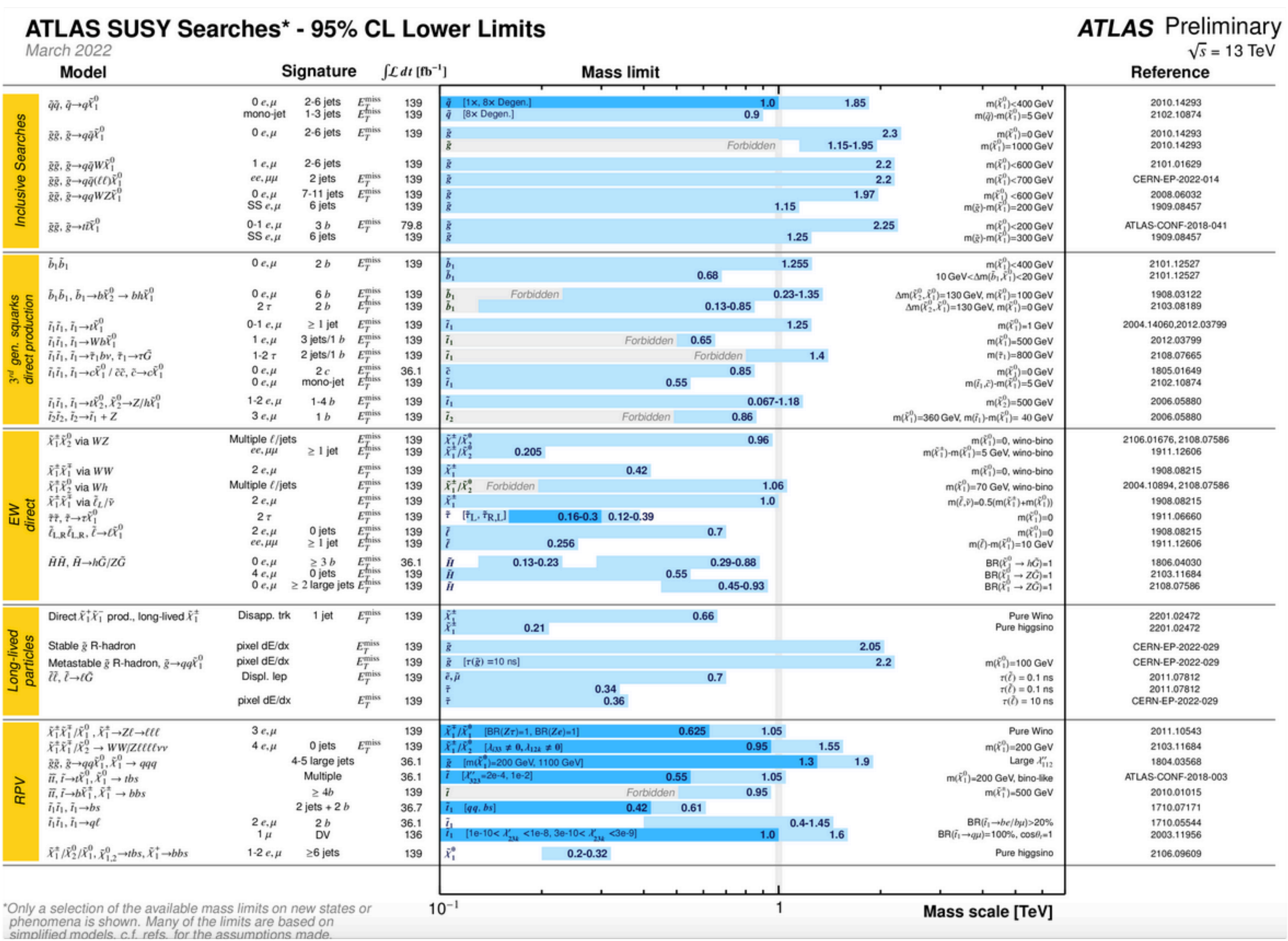
* A short overview on the recent ATLAS Electroweak Supersymmetry results is presented with full Run2 data analyzed.

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

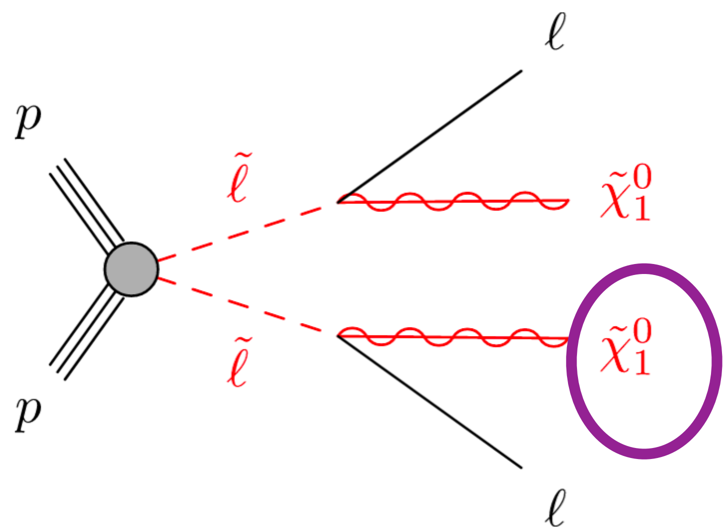
* More challenge signatures to come.

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

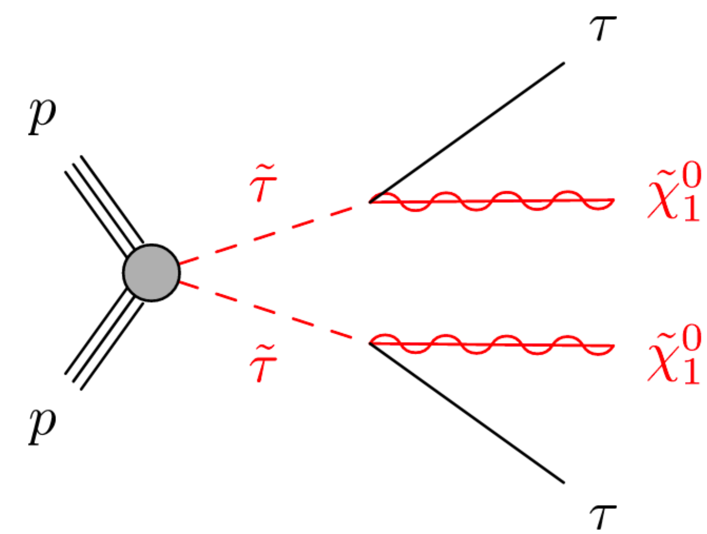
Extra slides


ATLAS SUSY Searches* - 95% CL Lower Limits
March 2022
ATLAS Preliminary
$\sqrt{s}$ = 13 TeV
Model
Signature
$\int \mathcal{L}\, dt\ [\mathrm{fb}^{-1}]$
Mass limit
Reference
Inclusive Searches
$\tilde{q}\tilde{q}, \tilde{q}\to q\tilde{\chi}^0_1$ | 0 e,μ 2-6 jets E_T^{miss} 139 | $\tilde{q}$ [1×, 8× Degen.] 1.0 1.85 | $m(\tilde{\chi}^0_1)$<400 GeV | 2010.14293
mono-jet 1-3 jets E_T^{miss} 139 | $\tilde{q}$ [8× Degen.] 0.9 | $m(\tilde{q})$-$m(\tilde{\chi}^0_1)$=5 GeV | 2102.10874
$\tilde{g}\tilde{g}, \tilde{g}\to q\bar{q}\tilde{\chi}^0_1$ | 0 e,μ 2-6 jets E_T^{miss} 139 | $\tilde{g}$ 2.3 | $m(\tilde{\chi}^0_1)$=0 GeV | 2010.14293
$\tilde{g}$ Forbidden 1.15-1.95 | $m(\tilde{\chi}^0_1)$=1000 GeV | 2010.14293
$\tilde{g}\tilde{g}, \tilde{g}\to q\bar{q}W\tilde{\chi}^0_1$ | 1 e,μ 2-6 jets 139 | $\tilde{g}$ 2.2 | $m(\tilde{\chi}^0_1)$<600 GeV | 2101.01629
$\tilde{g}\tilde{g}, \tilde{g}\to q\bar{q}(\ell\ell)\tilde{\chi}^0_1$ | $ee,\mu\mu$ 2 jets E_T^{miss} 139 | $\tilde{g}$ 2.2 | $m(\tilde{\chi}^0_1)$<700 GeV | CERN-EP-2022-014
$\tilde{g}\tilde{g}, \tilde{g}\to qqWZ\tilde{\chi}^0_1$ | 0 e,μ 7-11 jets E_T^{miss} 139 | $\tilde{g}$ 1.97 | $m(\tilde{\chi}^0_1)$ <600 GeV | 2008.06032
SS e,μ 6 jets 139 | $\tilde{g}$ 1.15 | $m(\tilde{g})$-$m(\tilde{\chi}^0_1)$=200 GeV | 1909.08457
$\tilde{g}\tilde{g}, \tilde{g}\to t\bar{t}\tilde{\chi}^0_1$ | 0-1 e,μ 3 b E_T^{miss} 79.8 | $\tilde{g}$ 2.25 | $m(\tilde{\chi}^0_1)$<200 GeV | ATLAS-CONF-2018-041
SS e,μ 6 jets 139 | $\tilde{g}$ 1.25 | $m(\tilde{g})$-$m(\tilde{\chi}^0_1)$=300 GeV | 1909.08457
3rd gen. squarks direct production
$\tilde{b}_1\tilde{b}_1$ | 0 e,μ 2 b E_T^{miss} 139 | $\tilde{b}_1$ 1.255 | $m(\tilde{\chi}^0_1)$<400 GeV | 2101.12527
$\tilde{b}_1$ 0.68 | 10 GeV<$\Delta m(\tilde{b}_1,\tilde{\chi}^0_1)$<20 GeV | 2101.12527
$\tilde{b}_1\tilde{b}_1, \tilde{b}_1\to b\tilde{\chi}^0_2\to bh\tilde{\chi}^0_1$ | 0 e,μ 6 b E_T^{miss} 139 | $\tilde{b}_1$ Forbidden 0.23-1.35 | $\Delta m(\tilde{\chi}^0_2,\tilde{\chi}^0_1)$=130 GeV, $m(\tilde{\chi}^0_1)$=100 GeV | 1908.03122
2 τ 2 b E_T^{miss} 139 | $\tilde{b}_1$ 0.13-0.85 | $\Delta m(\tilde{\chi}^0_2,\tilde{\chi}^0_1)$=130 GeV, $m(\tilde{\chi}^0_1)$=0 GeV | 2103.08189
$\tilde{t}_1\tilde{t}_1, \tilde{t}_1\to t\tilde{\chi}^0_1$ | 0-1 e,μ ≥ 1 jet E_T^{miss} 139 | $\tilde{t}_1$ 1.25 | $m(\tilde{\chi}^0_1)$=1 GeV | 2004.14060,2012.03799
$\tilde{t}_1\tilde{t}_1, \tilde{t}_1\to Wb\tilde{\chi}^0_1$ | 1 e,μ 3 jets/1 b E_T^{miss} 139 | $\tilde{t}_1$ Forbidden 0.65 | $m(\tilde{\chi}^0_1)$=500 GeV | 2012.03799
$\tilde{t}_1\tilde{t}_1, \tilde{t}_1\to\tilde{\tau}_1 b\nu, \tilde{\tau}_1\to\tau\tilde{G}$ | 1-2 τ 2 jets/1 b E_T^{miss} 139 | $\tilde{t}_1$ Forbidden 1.4 | $m(\tilde{\tau}_1)$=800 GeV | 2108.07665
$\tilde{t}_1\tilde{t}_1, \tilde{t}_1\to c\tilde{\chi}^0_1$ / $\tilde{c}\tilde{c}, \tilde{c}\to c\tilde{\chi}^0_1$ | 0 e,μ 2 c E_T^{miss} 36.1 | $\tilde{c}$ 0.85 | $m(\tilde{\chi}^0_1)$=0 GeV | 1805.01649
0 e,μ mono-jet E_T^{miss} 139 | $\tilde{t}_1$ 0.55 | $m(\tilde{t}_1,\tilde{c})$-$m(\tilde{\chi}^0_1)$=5 GeV | 2102.10874
$\tilde{t}_1\tilde{t}_1, \tilde{t}_1\to t\tilde{\chi}^0_2, \tilde{\chi}^0_2\to Z/h\tilde{\chi}^0_1$ | 1-2 e,μ 1-4 b E_T^{miss} 139 | $\tilde{t}_1$ 0.067-1.18 | $m(\tilde{\chi}^0_2)$=500 GeV | 2006.05880
$\tilde{t}_2\tilde{t}_2, \tilde{t}_2\to\tilde{t}_1+Z$ | 3 e,μ 1 b E_T^{miss} 139 | $\tilde{t}_2$ Forbidden 0.86 | $m(\tilde{\chi}^0_1)$=360 GeV, $m(\tilde{t}_1)$-$m(\tilde{\chi}^0_1)$= 40 GeV | 2006.05880
EW direct
$\tilde{\chi}^\pm_1\tilde{\chi}^0_2$ via WZ | Multiple ℓ/jets E_T^{miss} 139 | $\tilde{\chi}^\pm_1/\tilde{\chi}^0_2$ 0.96 | $m(\tilde{\chi}^0_1)$=0, wino-bino | 2106.01676, 2108.07586
$ee,\mu\mu$ ≥ 1 jet E_T^{miss} 139 | $\tilde{\chi}^\pm_1/\tilde{\chi}^0_2$ 0.205 | $m(\tilde{\chi}^\pm_1)$-$m(\tilde{\chi}^0_1)$=5 GeV, wino-bino | 1911.12606
$\tilde{\chi}^\pm_1\tilde{\chi}^\mp_1$ via WW | 2 e,μ E_T^{miss} 139 | $\tilde{\chi}^\pm_1$ 0.42 | $m(\tilde{\chi}^0_1)$=0, wino-bino | 1908.08215
$\tilde{\chi}^\pm_1\tilde{\chi}^0_2$ via Wh | Multiple ℓ/jets E_T^{miss} 139 | $\tilde{\chi}^\pm_1/\tilde{\chi}^0_2$ Forbidden 1.06 | $m(\tilde{\chi}^0_1)$=70 GeV, wino-bino | 2004.10894, 2108.07586
$\tilde{\chi}^\pm_1\tilde{\chi}^\mp_1$ via $\tilde{\ell}_L/\tilde{\nu}$ | 2 e,μ E_T^{miss} 139 | $\tilde{\chi}^\pm_1$ 1.0 | $m(\tilde{\ell},\tilde{\nu})$=0.5($m(\tilde{\chi}^\pm_1)$+$m(\tilde{\chi}^0_1)$) | 1908.08215
$\tilde{\tau}\tilde{\tau}, \tilde{\tau}\to\tau\tilde{\chi}^0_1$ | 2 τ E_T^{miss} 139 | $\tilde{\tau}$ [$\tilde{\tau}_L$, $\tilde{\tau}_{R,L}$] 0.16-0.3 0.12-0.39 | $m(\tilde{\chi}^0_1)$=0 | 1911.06660
$\tilde{\ell}_{L,R}\tilde{\ell}_{L,R}, \tilde{\ell}\to\ell\tilde{\chi}^0_1$ | 2 e,μ 0 jets E_T^{miss} 139 | $\tilde{\ell}$ 0.7 | $m(\tilde{\chi}^0_1)$=0 | 1908.08215
$ee,\mu\mu$ ≥ 1 jet E_T^{miss} 139 | $\tilde{\ell}$ 0.256 | $m(\tilde{\ell})$-$m(\tilde{\chi}^0_1)$=10 GeV | 1911.12606
$\tilde{H}\tilde{H}, \tilde{H}\to h\tilde{G}/Z\tilde{G}$ | 0 e,μ ≥ 3 b E_T^{miss} 36.1 | $\tilde{H}$ 0.13-0.23 0.29-0.88 | BR($\tilde{\chi}^0_1\to h\tilde{G}$)=1 | 1806.04030
4 e,μ 0 jets E_T^{miss} 139 | $\tilde{H}$ 0.55 | BR($\tilde{\chi}^0_1\to Z\tilde{G}$)=1 | 2103.11684
0 e,μ ≥ 2 large jets E_T^{miss} 139 | $\tilde{H}$ 0.45-0.93 | BR($\tilde{\chi}^0_1\to Z\tilde{G}$)=1 | 2108.07586
Long-lived particles
Direct $\tilde{\chi}^+_1\tilde{\chi}^-_1$ prod., long-lived $\tilde{\chi}^\pm_1$ | Disapp. trk 1 jet E_T^{miss} 139 | $\tilde{\chi}^\pm_1$ 0.66 | Pure Wino | 2201.02472
$\tilde{\chi}^\pm_1$ 0.21 | Pure higgsino | 2201.02472
Stable $\tilde{g}$ R-hadron | pixel dE/dx E_T^{miss} 139 | $\tilde{g}$ 2.05 | CERN-EP-2022-029
Metastable $\tilde{g}$ R-hadron, $\tilde{g}\to qq\tilde{\chi}^0_1$ | pixel dE/dx E_T^{miss} 139 | $\tilde{g}$ [$\tau(\tilde{g})$ =10 ns] 2.2 | $m(\tilde{\chi}^0_1)$=100 GeV | CERN-EP-2022-029
$\tilde{\ell}\tilde{\ell}, \tilde{\ell}\to\ell\tilde{G}$ | Displ. lep E_T^{miss} 139 | $\tilde{e},\tilde{\mu}$ 0.7 | $\tau(\tilde{\ell})$ = 0.1 ns | 2011.07812
$\tilde{\tau}$ 0.34 | $\tau(\tilde{\ell})$ = 0.1 ns | 2011.07812
pixel dE/dx E_T^{miss} 139 | $\tilde{\tau}$ 0.36 | $\tau(\tilde{\ell})$ = 10 ns | CERN-EP-2022-029
RPV
$\tilde{\chi}^\pm_1\tilde{\chi}^\mp_1/\tilde{\chi}^0_1, \tilde{\chi}^\pm_1\to Z\ell\to\ell\ell\ell$ | 3 e,μ 139 | $\tilde{\chi}^\pm_1/\tilde{\chi}^0_1$ [BR($Z\tau$)=1, BR(Ze)=1] 0.625 1.05 | Pure Wino | 2011.10543
$\tilde{\chi}^\pm_1\tilde{\chi}^\mp_1/\tilde{\chi}^0_2\to WW/Z\ell\ell\ell\ell\nu\nu$ | 4 e,μ 0 jets E_T^{miss} 139 | $\tilde{\chi}^\pm_1/\tilde{\chi}^0_2$ [$\lambda_{i33}\neq 0, \lambda_{12k}\neq 0$] 0.95 1.55 | $m(\tilde{\chi}^0_1)$=200 GeV | 2103.11684
$\tilde{g}\tilde{g}, \tilde{g}\to qq\tilde{\chi}^0_1, \tilde{\chi}^0_1\to qqq$ | 4-5 large jets 36.1 | $\tilde{g}$ [$m(\tilde{\chi}^0_1)$=200 GeV, 1100 GeV] 1.3 1.9 | Large λ''_{112} | 1804.03568
$\tilde{t}\tilde{t}, \tilde{t}\to t\tilde{\chi}^0_1, \tilde{\chi}^0_1\to tbs$ | Multiple 36.1 | $\tilde{t}$ [λ''_{323}=2e-4, 1e-2] 0.55 1.05 | $m(\tilde{\chi}^0_1)$=200 GeV, bino-like | ATLAS-CONF-2018-003
$\tilde{t}\tilde{t}, \tilde{t}\to b\tilde{\chi}^\pm_1, \tilde{\chi}^\pm_1\to bbs$ | ≥ 4b 139 | $\tilde{t}$ Forbidden 0.95 | $m(\tilde{\chi}^\pm_1)$=500 GeV | 2010.01015
$\tilde{t}_1\tilde{t}_1, \tilde{t}_1\to bs$ | 2 jets + 2 b 36.7 | $\tilde{t}_1$ [qq, bs] 0.42 0.61 | 1710.07171
$\tilde{t}_1\tilde{t}_1, \tilde{t}_1\to q\ell$ | 2 e,μ 2 b 36.1 | $\tilde{t}_1$ 0.4-1.45 | BR($\tilde{t}_1\to be/b\mu$)>20% | 1710.05544
1 μ DV 136 | $\tilde{t}_1$ [1e-10< λ'_{23k} <1e-8, 3e-10< λ'_{23k} <3e-9] 1.0 1.6 | BR($\tilde{t}_1\to q\mu$)=100%, $\cos\theta_t$=1 | 2003.11956
$\tilde{\chi}^\pm_1/\tilde{\chi}^0_2/\tilde{\chi}^0_1, \tilde{\chi}^0_{1,2}\to tbs, \tilde{\chi}^+_1\to bbs$ | 1-2 e,μ ≥6 jets 139 | $\tilde{\chi}^0_1$ 0.2-0.32 | Pure higgsino | 2106.09609
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.

Benchmark EWK scenarios

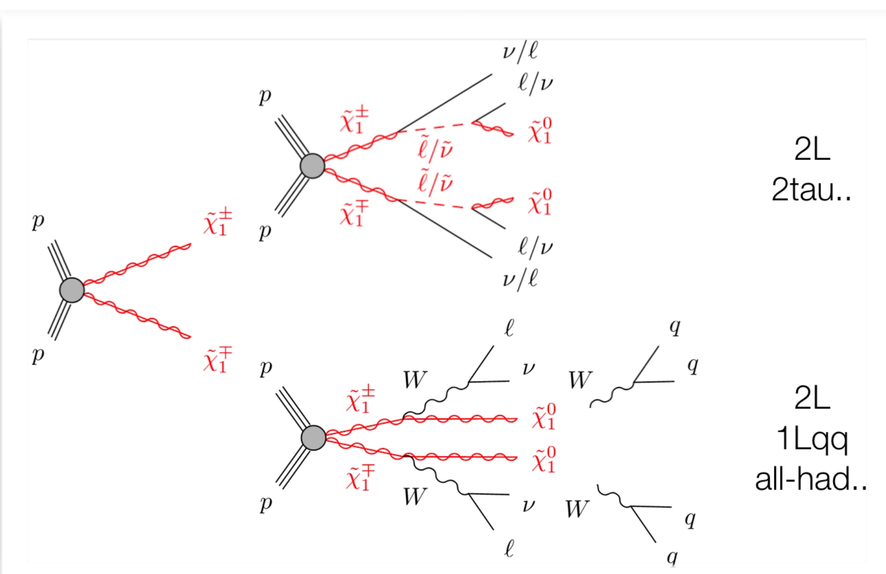


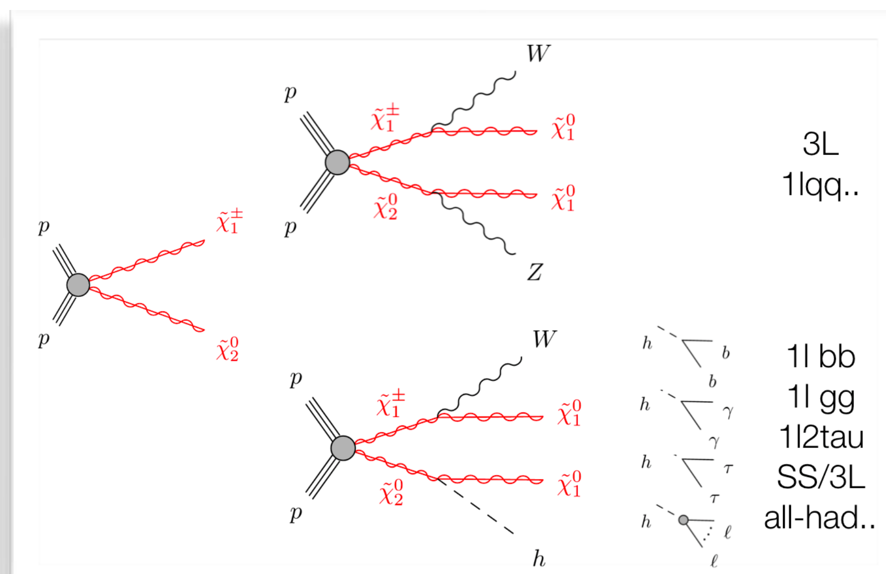
2L



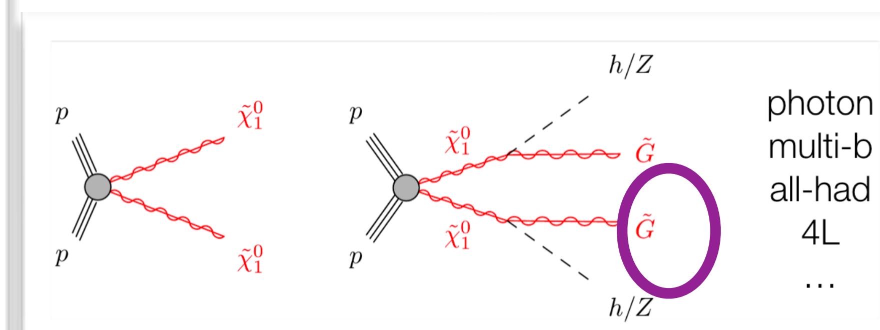
2tau

Lightest SUSY particle — Etmiss





Gravitino LSP



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