Searches for electroweak production of supersymmetric particles with the ATLAS detector

2022 Phenomenology Symposium, Pittsburgh (US)

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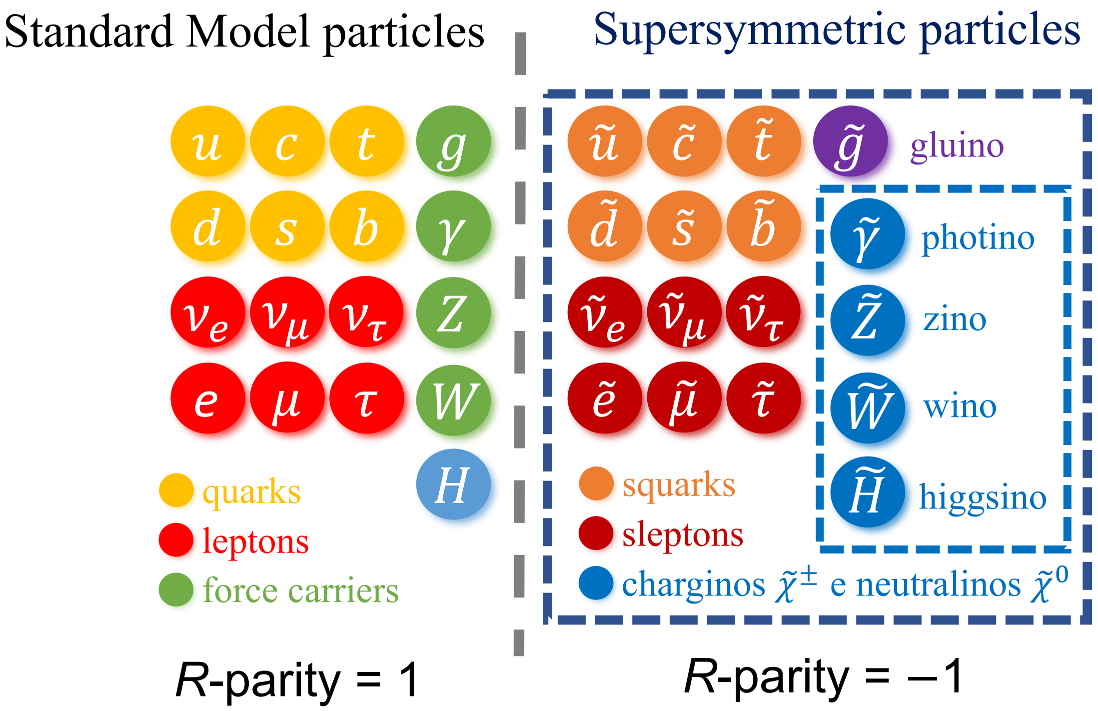
Introduction

Supersymmetry (SUSY) is an extension of the Standard Model (SM)



R-parity distinguishes between SM and SUSY particles.

A new fermionic/bosonic supersymmetric partner to each boson/fermion in the SM with spin differing by ½ unit is introduced.

The superpartners of the SM Higgs and the electroweak gauge bosons, known as *electroweakinos*, mix to form chargino $\tilde{\chi}^{\pm}$ and neutralino $\tilde{\chi}^{0}$ mass eigenstates.

***R*-parity conservation (RPC):** SUSY particles are produced in pairs and the lightest supersymmetric particle (LSP) is stable and weakly interacting, thus a candidate for dark matter.

***R*-parity violation (RPV):** Additional terms in the Lagrangian potential W_{RPV} allow for *RPV* interactions, including the decay of the lightest neutralino into softer particles.

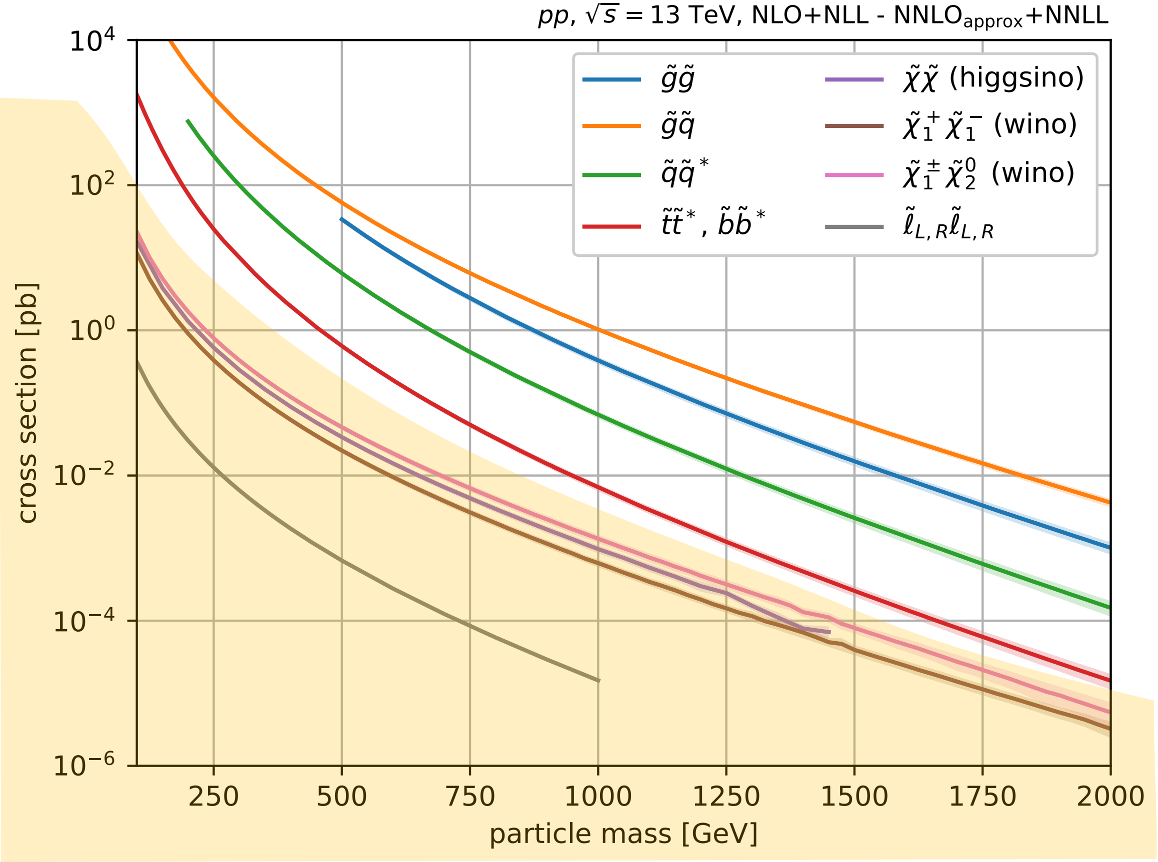
Introduction

Wide program of SUSY searches in ATLAS with *R*-parity conserving or violating models

- Strong
- 3rd generation → see *B. Martin's talk*
- **Electroweak** → focus of *this talk*

Electroweak production has a relatively small cross section compared to strong production

Challenging signatures
Many uncovered regions in the exclusion contours
Advanced analysis techniques and large dataset needed to gain sensitivity



Outline

Covering **new results** by the ATLAS collaboration!

All results targeting electroweak production of SUSY particles using the full Run 2 dataset collected at $\sqrt{s} = 13$ TeV:

- All hadronic [Phys.Rev.D 104, 112010]
- 2 leptons and $\geq$ 2 jets analysis [CERN-EP-2022-014]
- 2 leptons and 0 jets analysis [ATLAS-CONF-2022-006]
- RPV with leptons and many jets [EPJC 81 (2021) 1023]

Other new analyses I won't have time to cover:

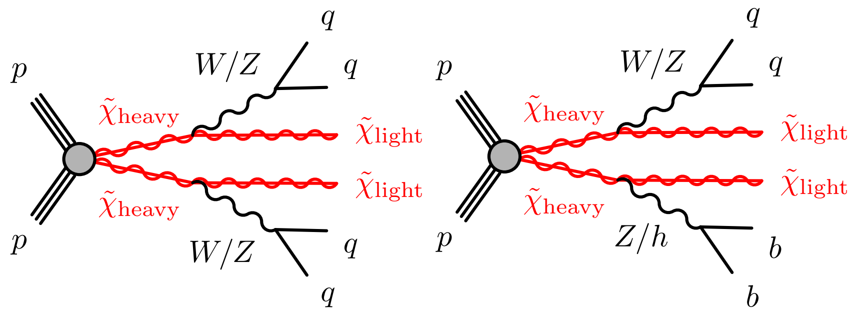
- WW unfolding for 2L0J analysis [ATLAS-CONF-2022-011, backup slide]
- 3 leptons search [Eur. Phys. J. C 81 (2021) 1118, backup slide]
- Long lived particles with large *d*E/*d*x [SUSY-2018-42, *see M. Proffitt's talk*]

All hadronic

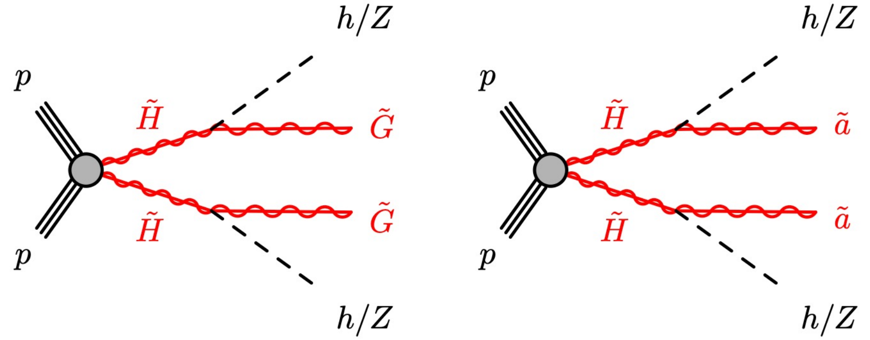
[Phys.Rev.D 104, 112010]

Targeted models:

- Production of heavy charginos/neutralinos in different bino/wino/higgsino mass hierarchies.



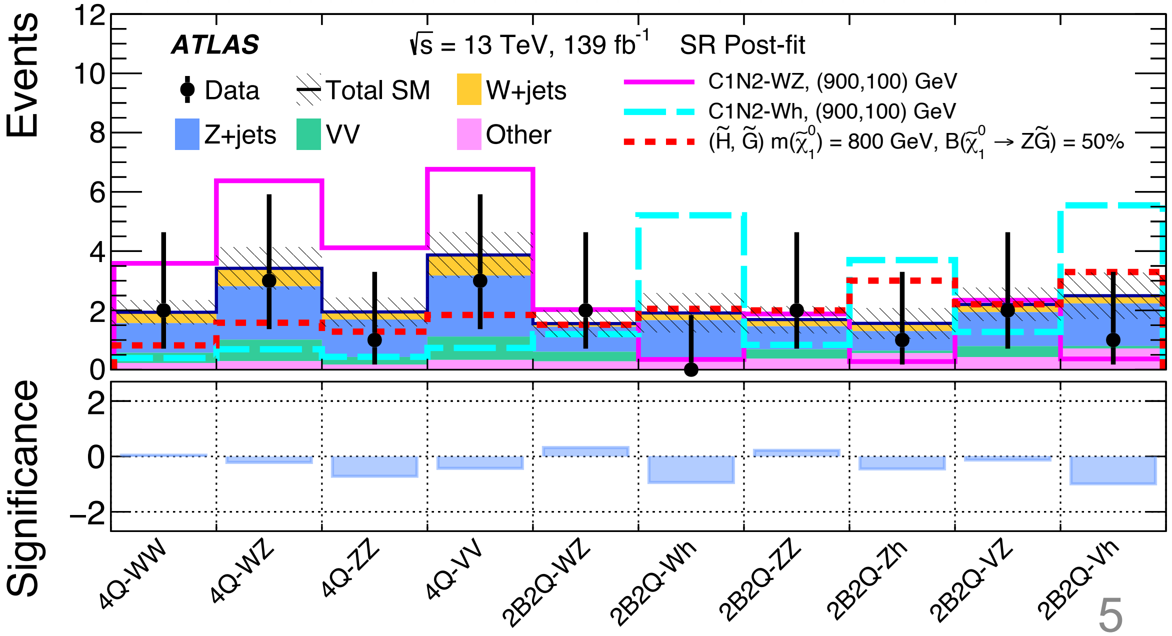
- Production of light higgsinos decaying into gravitinos ($\tilde{G}$) in general gauge mediation (GGM) or decaying into axinos ($\tilde{a}$) assuming the SM extension with a QCD axion (**new model**)



Signature: Large radius jets for the hadronic decays of *W*, *Z* and Higgs bosons, ≤ 2 *b*-jets and missing transverse energy ($E_{\mathrm{T}}^{\mathrm{miss}}$) .

Background estimation: *Z*+jets, *W*+jets, $t\bar{t}$, and *Wt* backgrounds normalized to data in Control Regions (CRs).

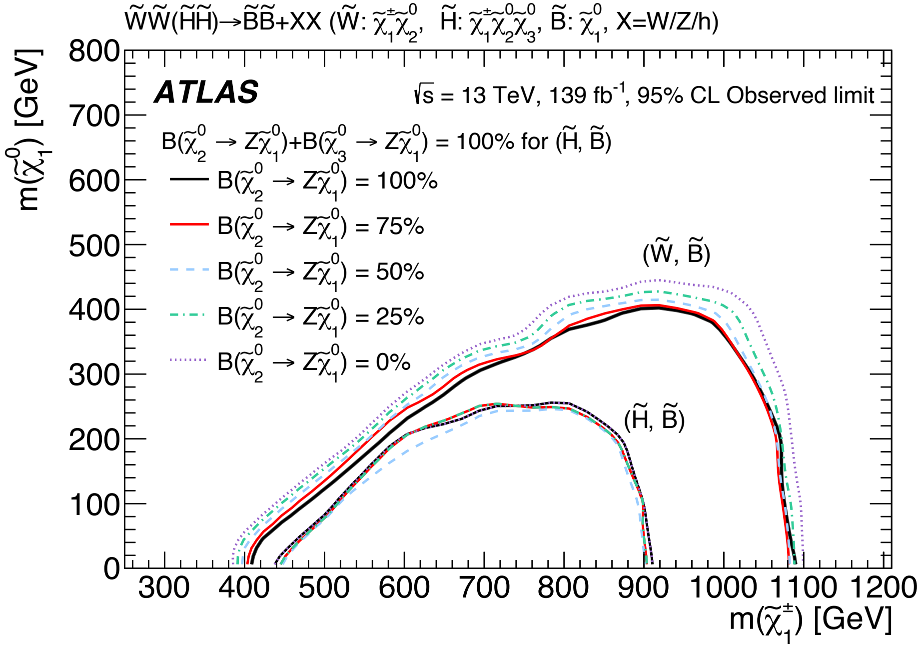
Signal region (SR): events selected with hard kinematics using the effective mass of the two leading large radius jets and $E_{\mathrm{T}}^{\mathrm{miss}}$. 4Q and 2B2Q SRs to target *qqqq* and *bbqq* final states, respectively.



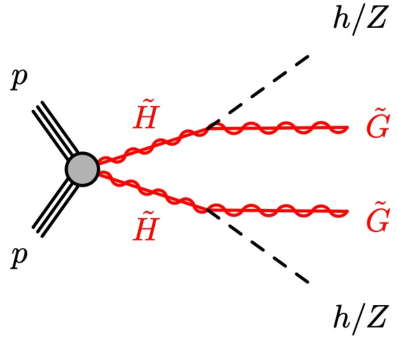
All hadronic

[Phys.Rev.D 104, 112010]

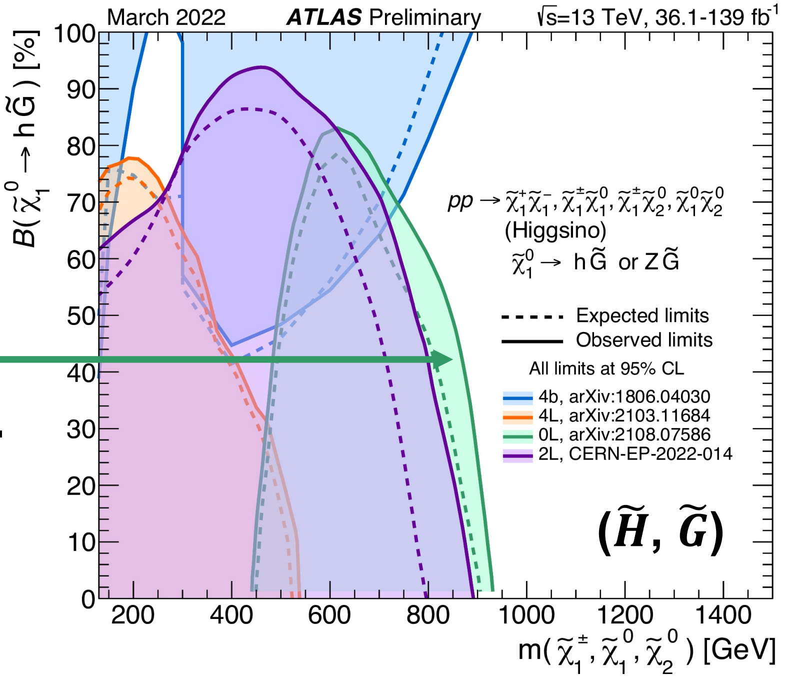
Data compatible with SM → exclusion limits set on SUSY particles masses at 95% confidence level (CL).

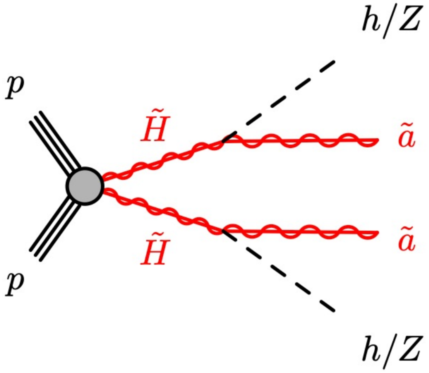


Observed limits for the $(\widetilde{W}, \widetilde{B})$ and $(\widetilde{H}, \widetilde{B})$ models for various $B(\tilde{\chi}_2^0 \to Z\tilde{\chi}_1^0)$.
The $(\widetilde{H}, \widetilde{B})$ hierarchy well motivated when the mass of a bino-like $\tilde{\chi}_1^0$ is half the Z/H boson mass and the LSP dark matter can annihilate via the Z/H resonance (*"Z/H-funnel" dark matter*).

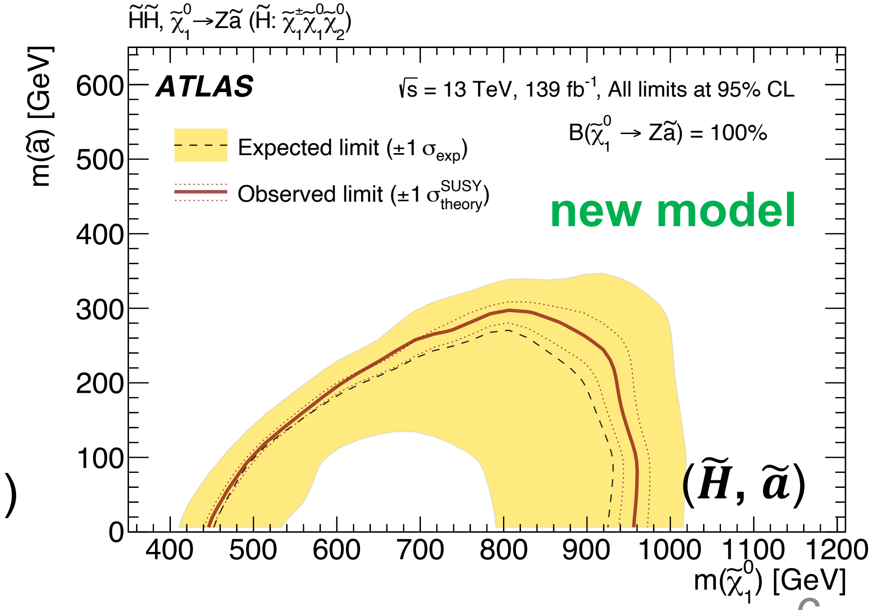


Observed limits for the $(\widetilde{H}, \widetilde{G})$ model as a function of $B(\tilde{\chi}_1^0 \to h\,\widetilde{G})$.
Results extend the sensitivity achieved by other ATLAS searches.





A higgsino mass between 450 and 940 GeV excluded for m(ã) < 300 GeV in $(\widetilde{H}, \tilde{a})$ model.

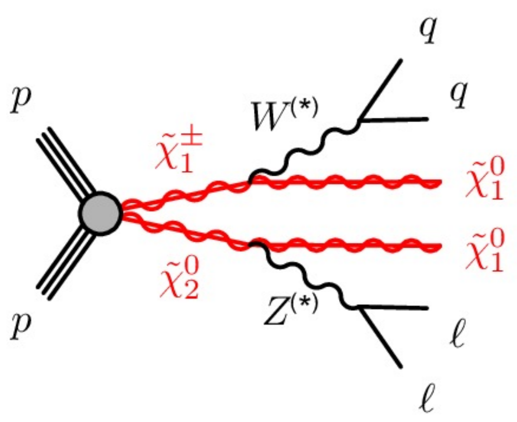


2 leptons and 2 jets

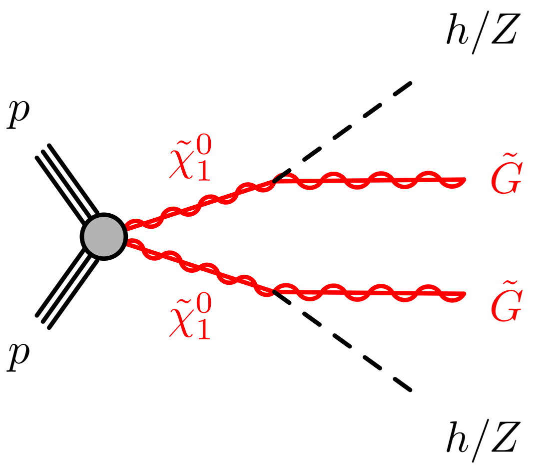
[CERN-EP-2022-014]

Targeted models:

- Production of charginos and neutralinos decaying into LSP neutralinos.



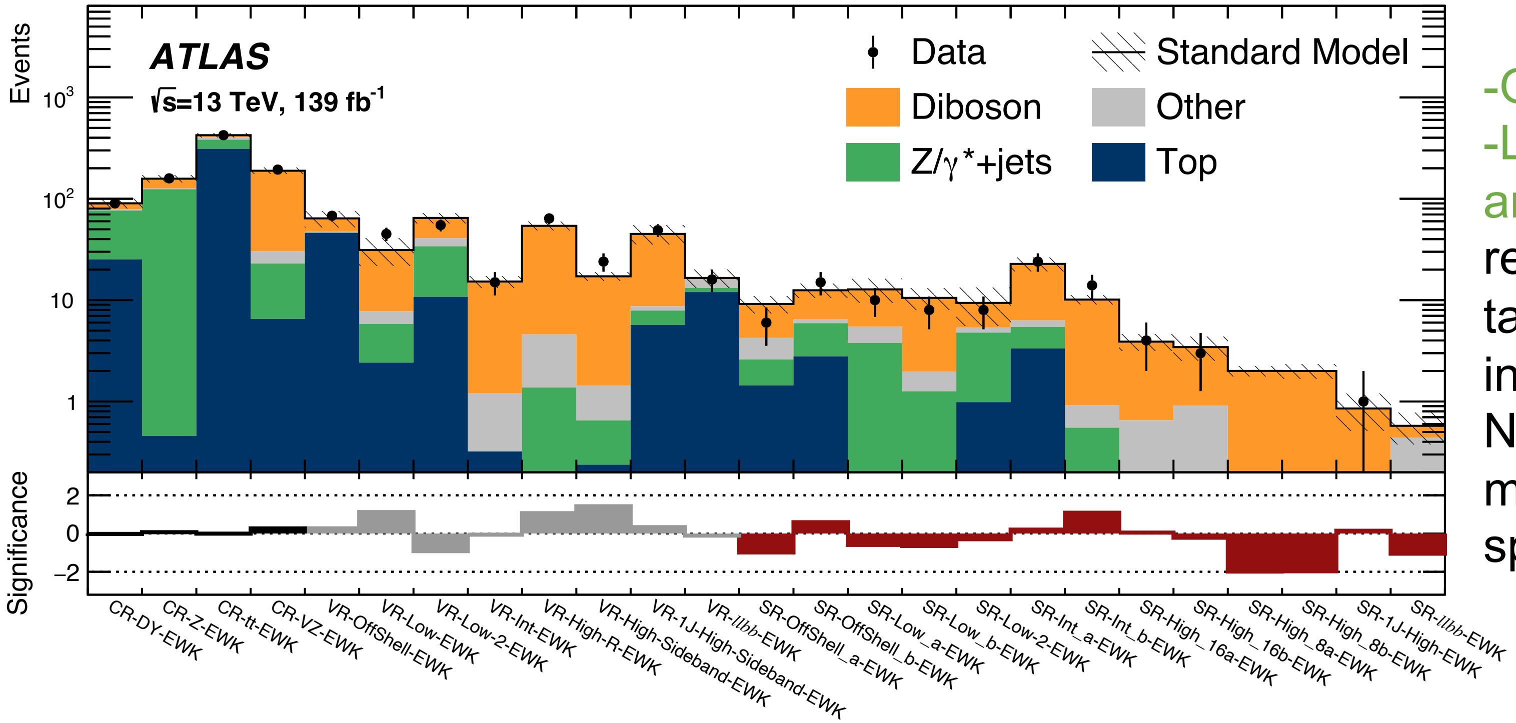
- Production of neutralinos decaying into a nearly massless gravitino through a Higgs/Z boson assuming gauge-mediated SUSY breaking (GMSB).



Signature: 2 Same Flavour (SF) leptons, ≥ 2 jets and $E_{\mathrm{T}}^{\mathrm{miss}}$.

Background estimation: Drell-Yann (DY), Z+jets, $t\bar{t}$, and VZ (with V = W or Z) backgrounds normalized to data in CRs.

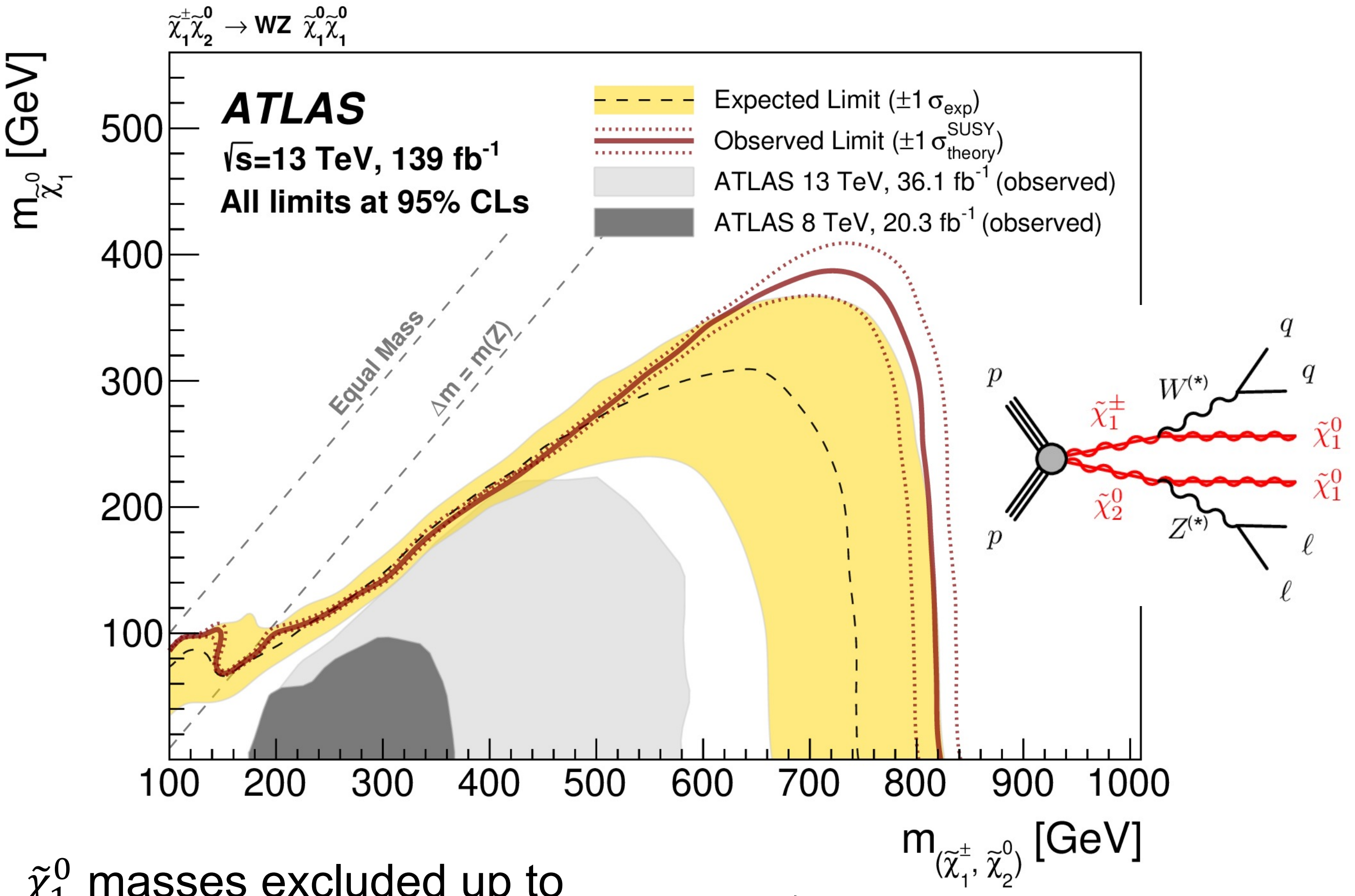
SR: Cut-and-count event selection to target different SUSY particle masses.

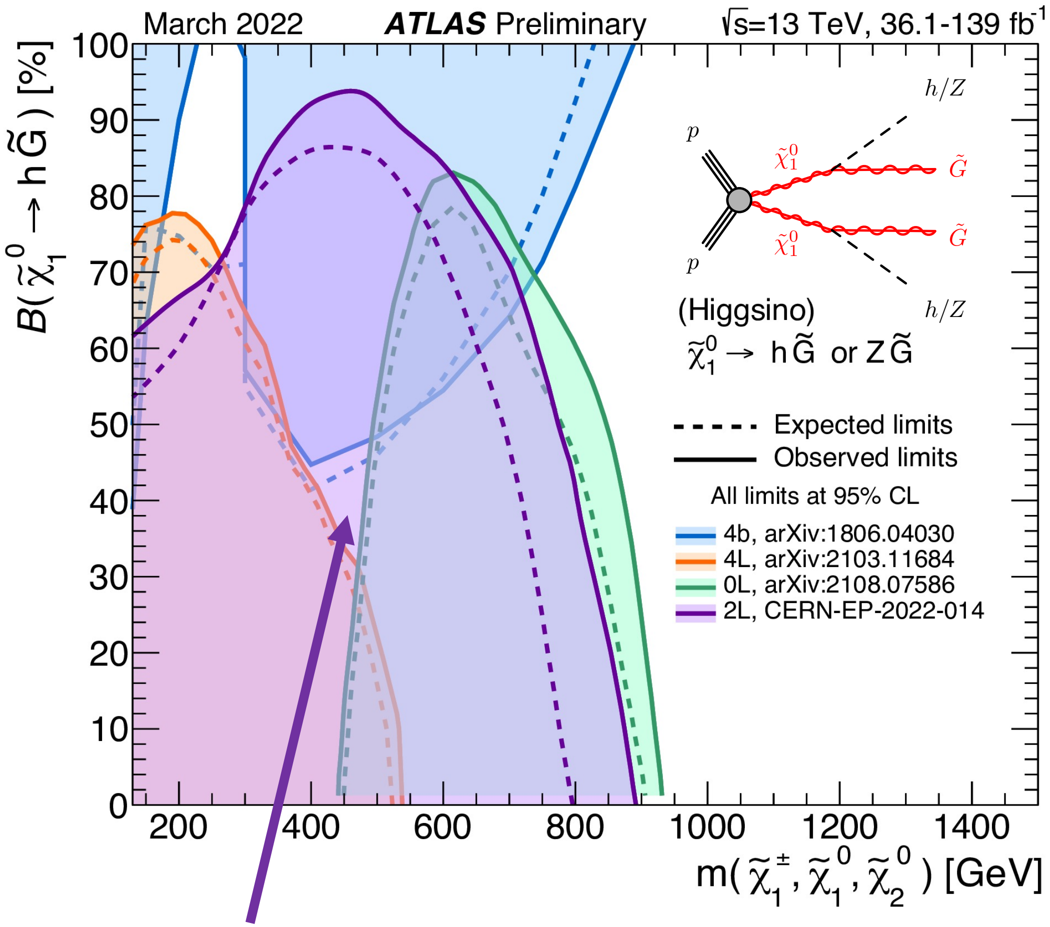


-OffShell, -Low, -Int, and -High regions target increasing NLSP–LSP mass splittings.

2 leptons and 2 jets

[CERN-EP-2022-014]





$\tilde{\chi}_1^0$ masses excluded up to 100 GeV for off-shell decays of the *W/Z* bosons.

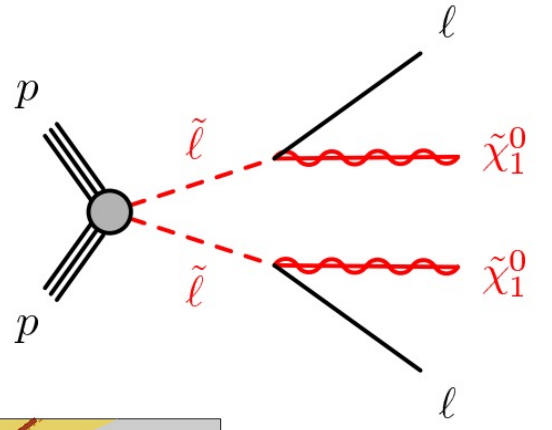
$\tilde{\chi}_1^{\pm}$ / $\tilde{\chi}_2^0$ masses excluded up to 820 GeV for large Δm.

Large improvement compared to the previous results.

Excluded branching fractions $B(\tilde{\chi}_1^0 \rightarrow h\,\tilde{G})$ complement the sensitivity reached by previous searches and fully exclude the model for masses between 300 and 800 GeV.

[ATLAS-CONF-2022-006]

2 leptons and no jets



Targeted models:
- Production of sleptons (selectrons+smuons) decaying into neutralinos through leptons

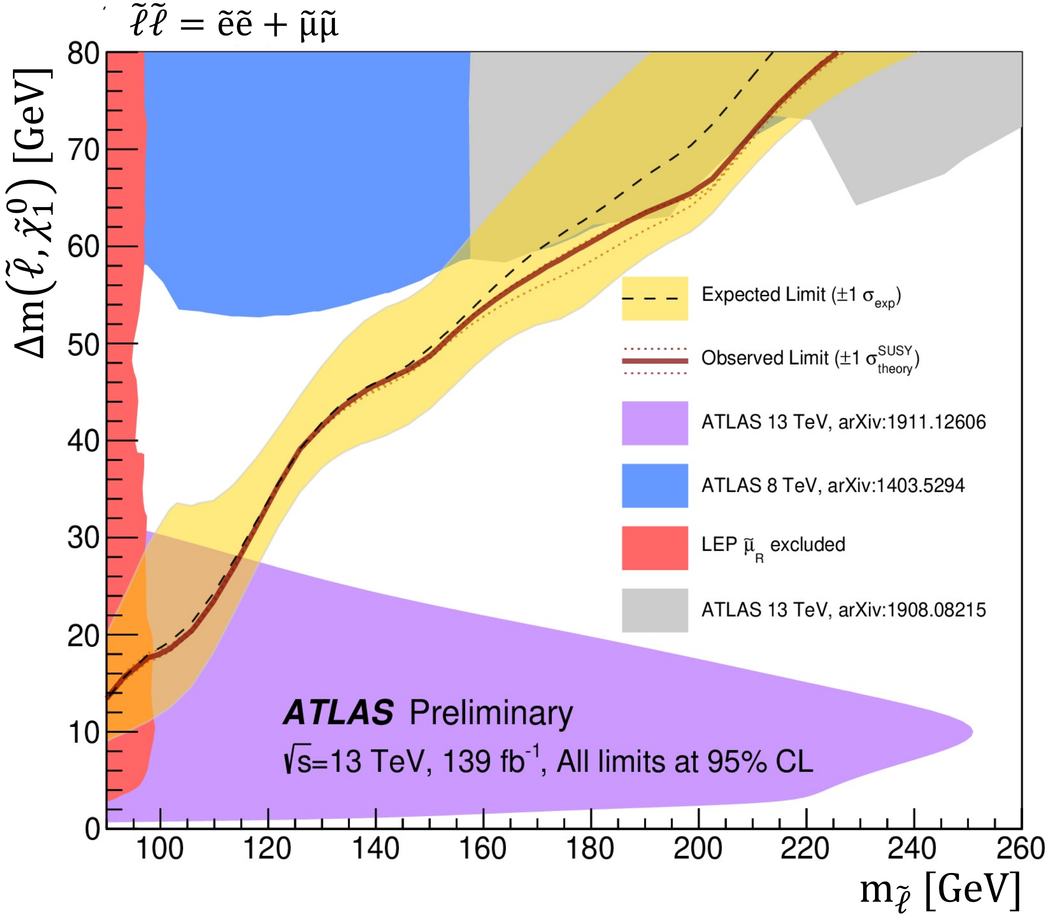
Signature: 2 SF leptons, 0/1 jets and $E_{\mathrm{T}}^{\mathrm{miss}}$.

Background estimation: SF events of flavour symmetric backgrounds from Different Flavour (DF) events in data.

SR: Cut-and-count event selection.
Different SRs in m_{T2}^{100} to target different SUSY particle masses in **compressed mass splittings**.

Data compatible with SM prediction.
Slepton masses excluded up to 150 GeV at 95% CL for mass splittings $\Delta m(\tilde{\ell}, \tilde{\chi}_1^0)$ up to 50 GeV.

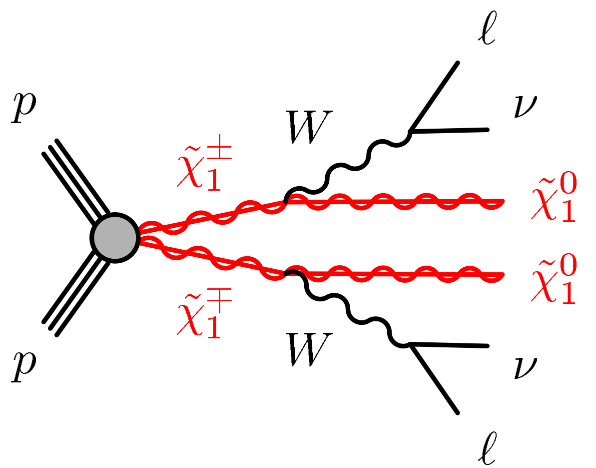
Limits also set for smuons separately!
Excluded portions of the region expected to be compatible with the *g* − 2 anomaly for small tanβ [see backup slide].



New results extend LEP exclusion limits and cover the gap between previous results.

[ATLAS-CONF-2022-006]

2 leptons and no jets



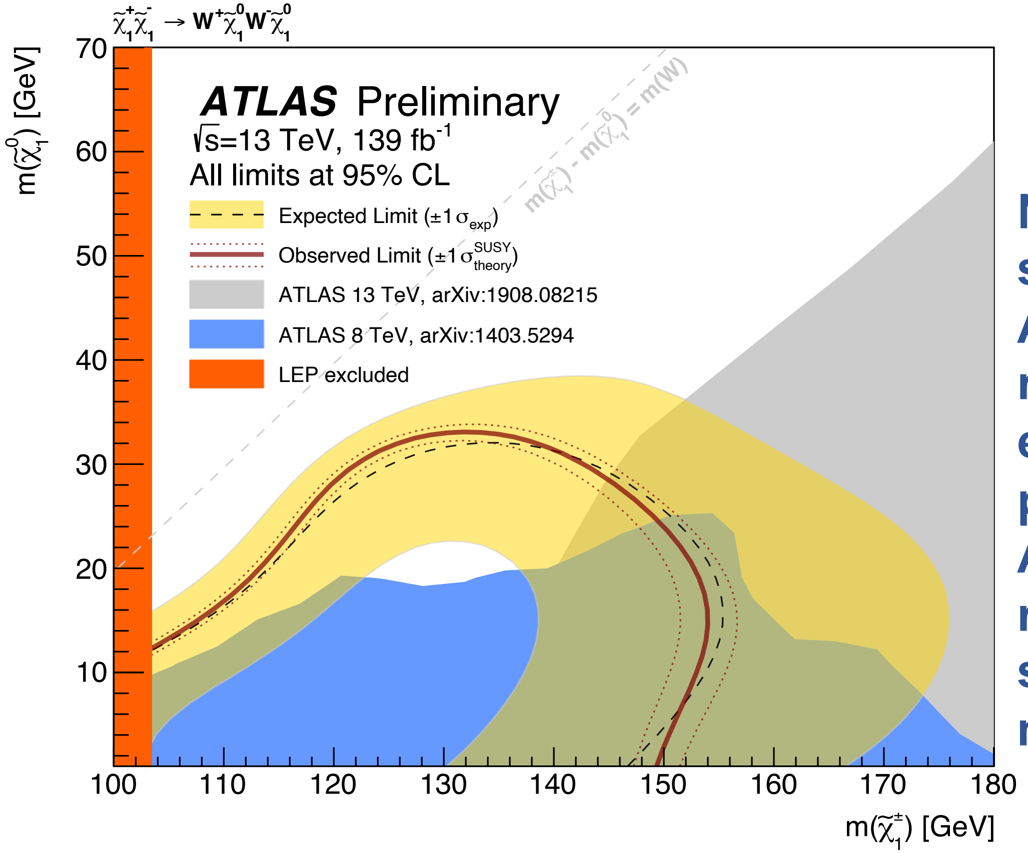
Targeted models:
- Production of charginos decaying into neutralinos through *W* bosons

Signature: 2 SF or DF leptons, no jets and $E_{\mathrm{T}}^{\mathrm{miss}}$.
Very **challenging signature**
- low signal production cross section
- signal similar to the *WW* background
- targeting **compressed mass splittings**

Background estimation: *VV* and top ($t\bar{t}$ and *Wt*) backgrounds normalized to data in CRs.

SR: Event selection based on BDTs. Multi-class classification with 4 ouput scores: *BDT-signal*, *BDT-VV*, *BDT-top*, *BDT-others*.
SR defined for high values of *BDT-signal*.

Data compatible with SM prediction
Chargino masses excluded up to 135 GeV at 95% CL for $\Delta m(\tilde{\chi}_1^{\pm}, \tilde{\chi}_1^0)$ up to 100 GeV.



New results supersede the ATLAS 8 TeV results and extend the previous ATLAS 13 TeV results for small chargino masses.

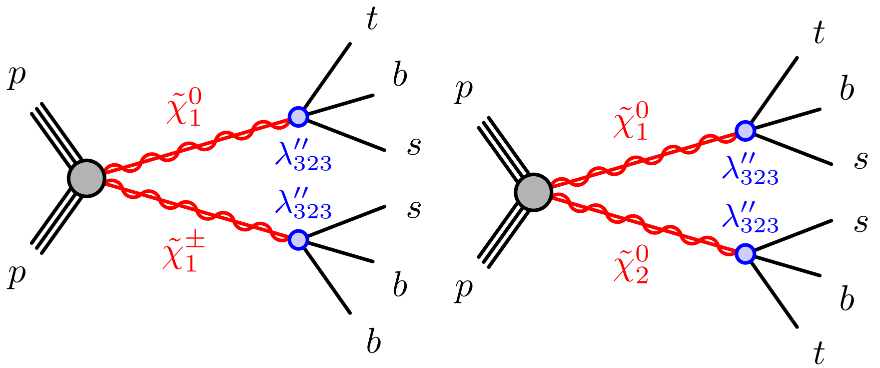
RPV with leptons and many jets

[EPJC 81 (2021) 1023]

Targeted models: Production of charginos and neutralinos in RPV models

$$W_{RPV} = \lambda_{ijk} L_i L_j e^c_k + \lambda'_{ijk} Q_i L_j d^c_k + \lambda''_{ijk} u^c_i d^c_j \, d^c_k + m_i L_i H_u$$

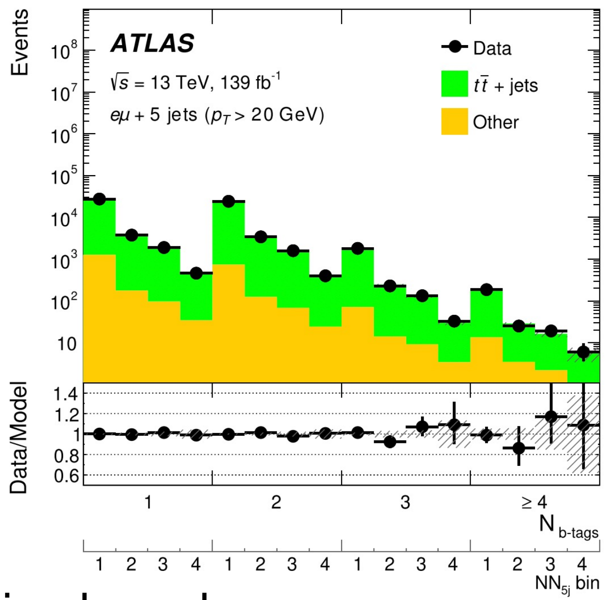
$\lambda''_{321} \neq 0$ allows $\tilde{\chi}^0_{1/2} \rightarrow tbs$ and $\tilde{\chi}^\pm_1 \rightarrow bbs$ decays



Signature: 1ℓ or 2ℓ with same charge and high jet multiplicity

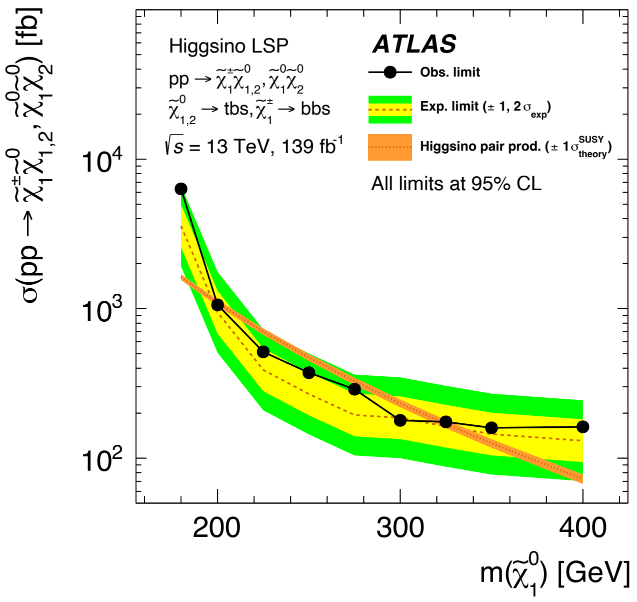
Background estimation:

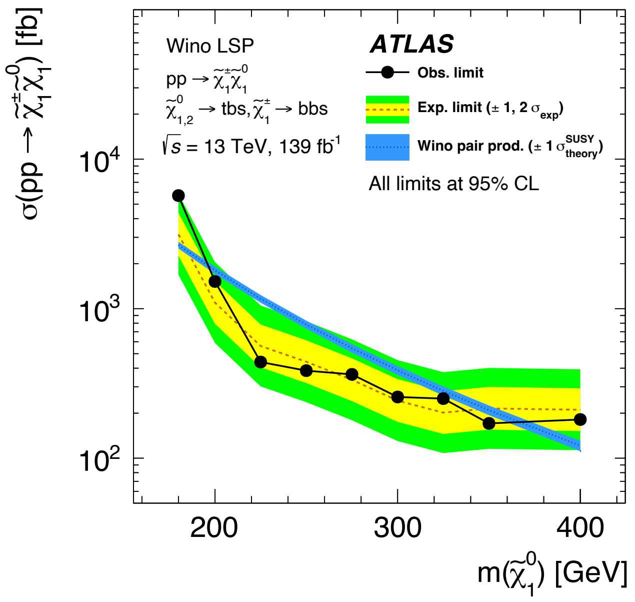
- data driven, based on predicting the high jet multiplicity (up to 10/15 jets) from the medium one.
- A NN trained using distance correlation training to ensure invariance under $n_{b-\text{jets}}$.



SR: Event selection based on n_{jets}.

First limits on direct production of electroweakinos with fully hadronic RPV decays since LEP!





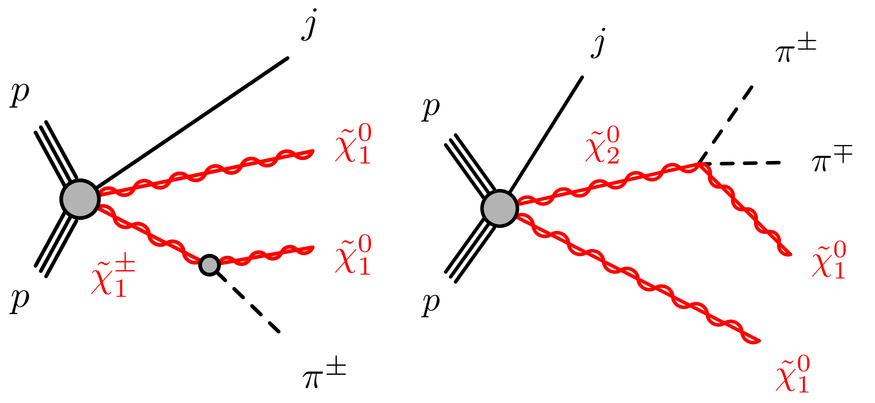
Electroweakinos with higgsino (wino) masses between 200 (197) GeV and 320 (365) GeV excluded at 95% CL.

Higgsino constraints

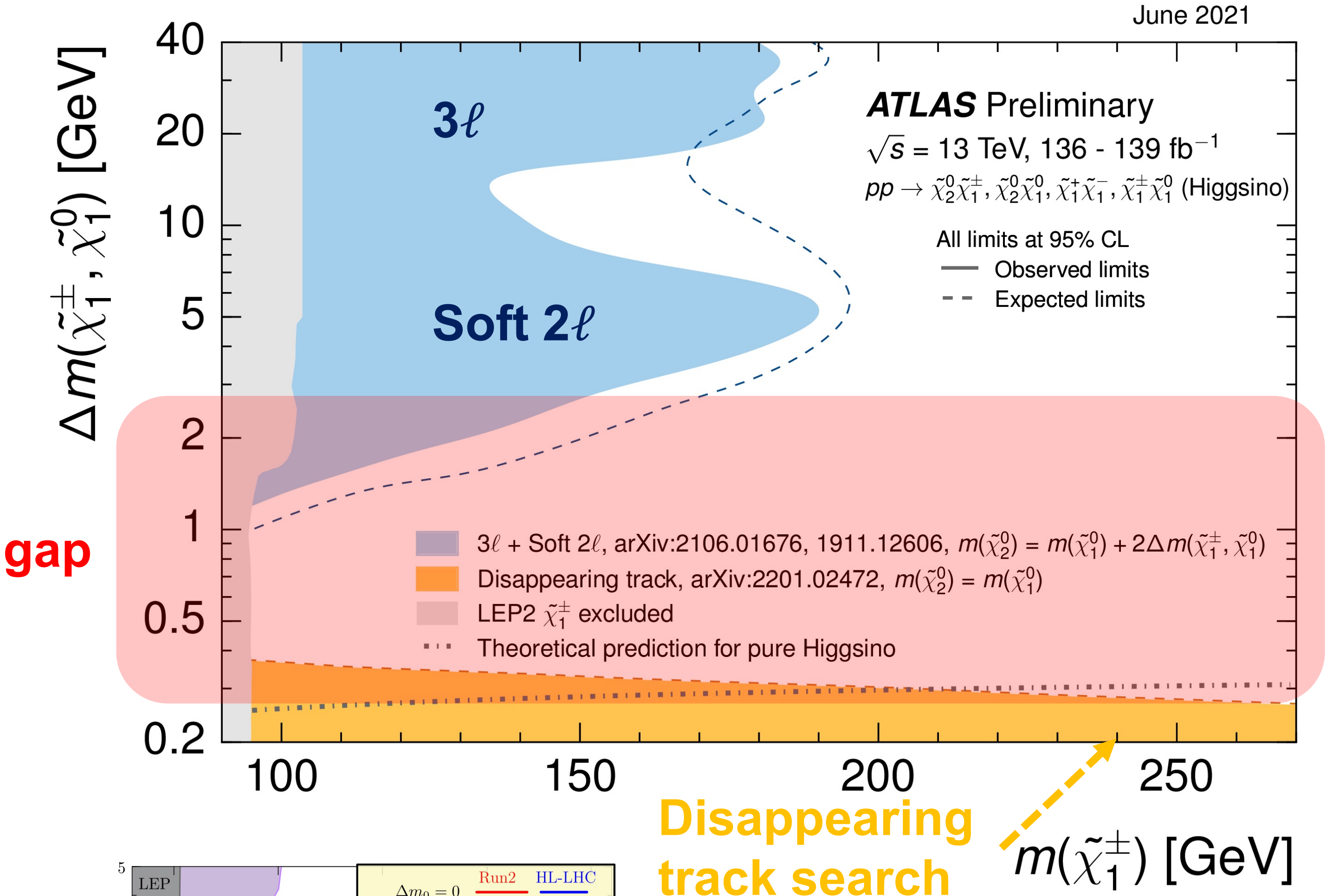
Higgsino searches very well motivated
- Higgsino mass connected to the scale of the electroweak symmetry breaking.
- The naturalness argument requires it to be around the electroweak scale.

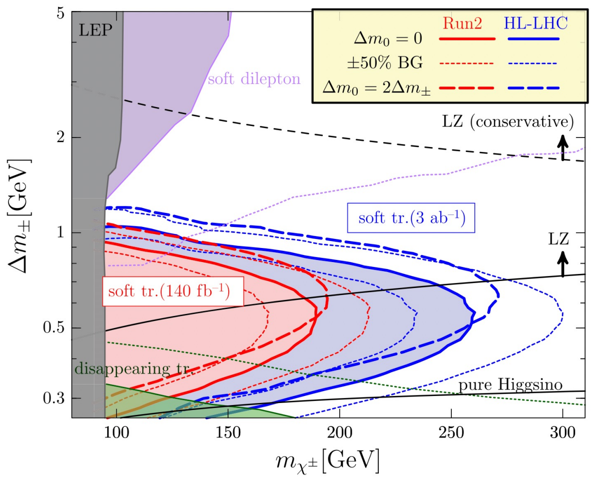
Existing gap between soft lepton searches and the disappearing track search.

A search for soft displaced tracks arising from chargino/neutralino decays into pions could cover the gap!



Novel approach using a soft displaced track, never performed before at LHC.





Expected exclusion limits for Run2 and HL-LHC

PRL 124 (2020) 101801

Conclusions

New set of compelling results published by the ATLAS collaboration.

- **Tighter** constraints set on the masses of SUSY particles.
- **New** signal models considered.
- Regions with **compressed mass splittings** excluded.

No SUSY found yet, the SM is surviving our new ATLAS searches...

- Many models and phase space regions not explored yet!
- Larger datasets, improved data analysis techniques or even dedicated new searches needed.
- Run3 is due to start this year – STAY TUNED for future discoveries!

Thank you for your attention!
Any questions?

Backup

WW unfolding for 2L0J analysis

[SUSY-2018-42]

Motivation: *WW* background was the main background process in the 2ℓ+0jets analysis. *WW* background was estimated with a scale factor in CR-WW, which resulted to be $\mu_{WW} = 1.25 \pm 0.11$.

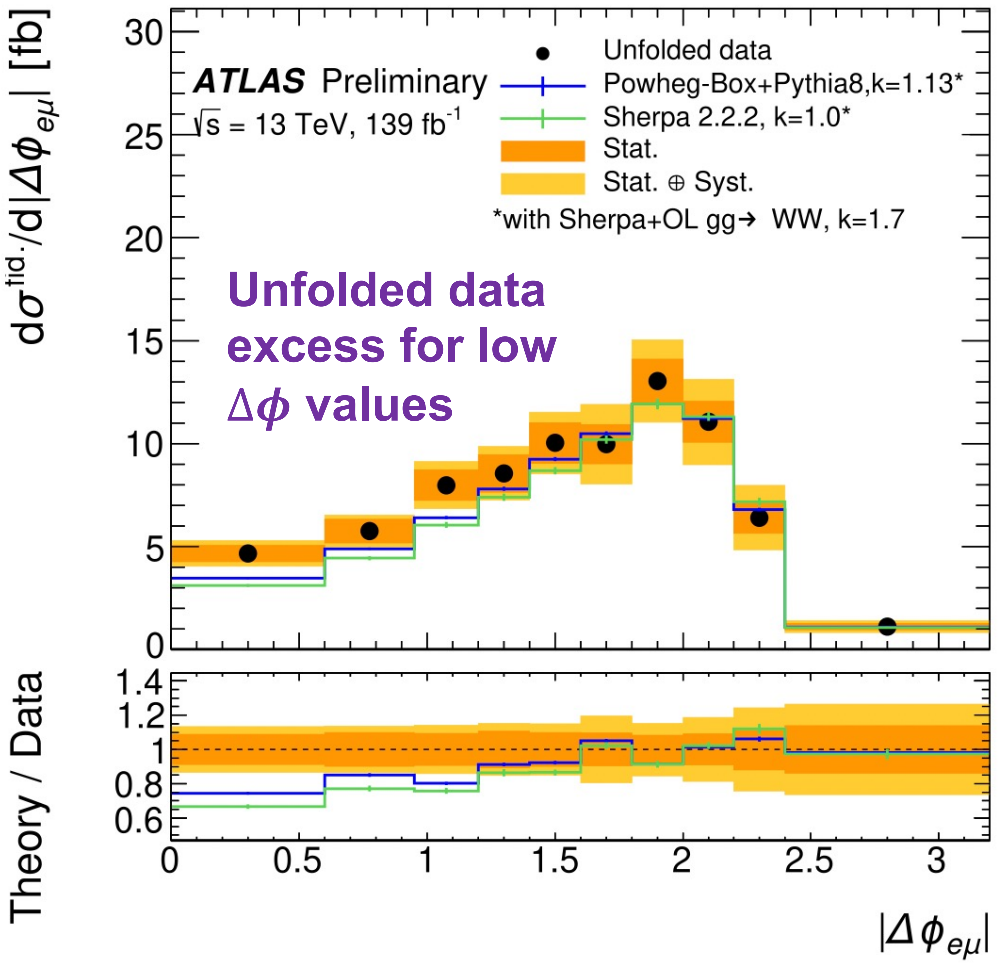
- **Differences from unity of scaling factors suggest mismodelling in the phase space targeted by the search.**
- **Fiducial and differential measurement of *WW* background.**

Unfolded fiducial cross section: $\sigma_{WW} = 19.2 \pm 2.6$ fb, with largest systematic uncertainty coming from jet measurements (12%).

Unfolded scale factor $\mu_{WW}^{unfolded} = 1.22$ compatible with the result from 2ℓ+0jets analysis.

Validation of the SM in a particularly interesting region for supersymmetric searches.

Unfolded differential cross section as a function of $\Delta\phi$ between the two leptons

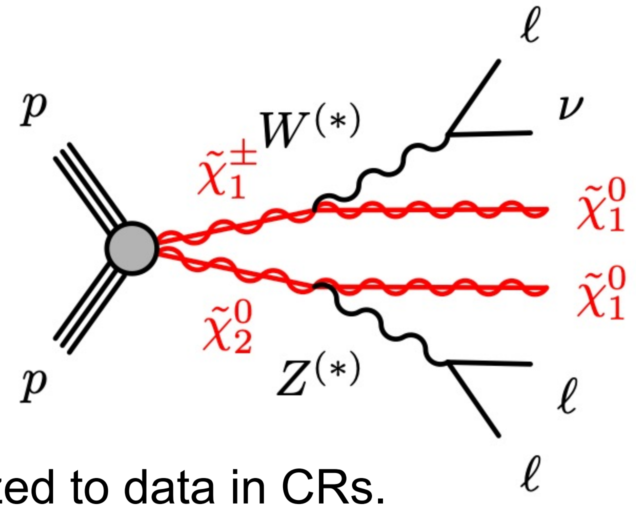


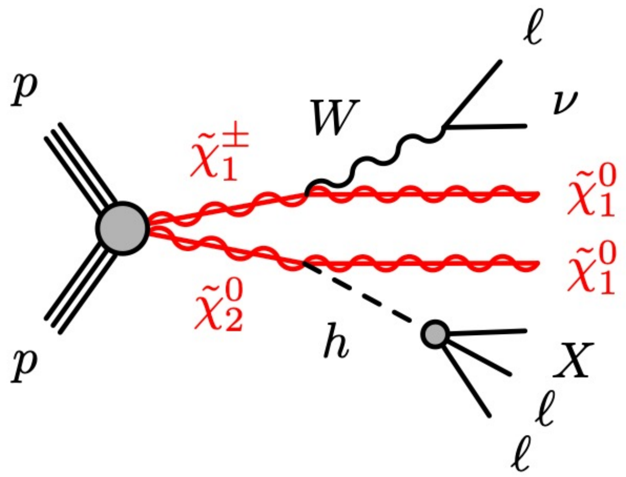
3 leptons search

[Eur. Phys. J. C 81 (2021) 1118]

Targeted models: Charginos and neutralinos

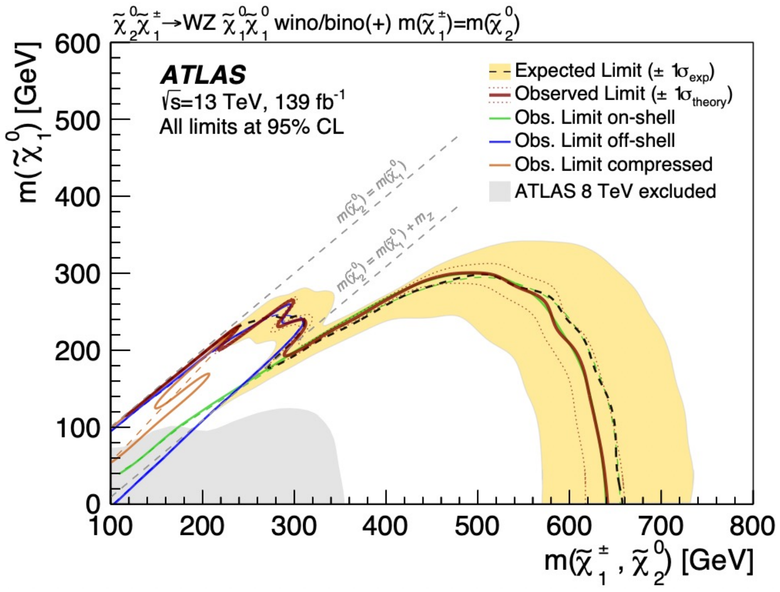
Signature: Leptonic decays of W, Z and SM Higgs bosons (Higgs boson decaying into leptons+X via WW, ZZ, or $\tau\tau$).



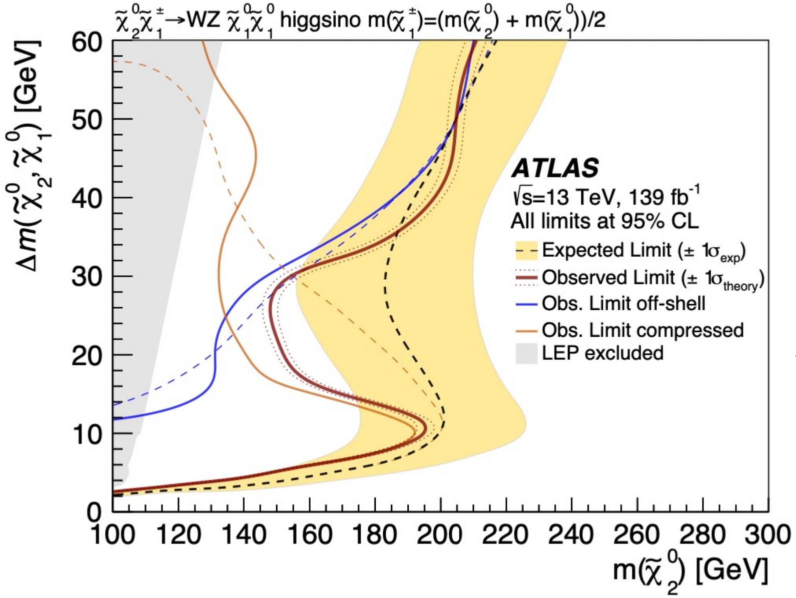


Background estimation: *WZ* background normalized to data in CRs.

SR: Independent optimisation for the on-shell WZ, off-shell WZ, and Wh selections.



Wino/bino limits set at 640 GeV for the WZ-mediated signal model in the limit of massless $\tilde{\chi}_1^0$, at 300 GeV for mass splittings between $\tilde{\chi}_1^\pm$ / $\tilde{\chi}_2^0$ and $\tilde{\chi}_1^0$ close to m_Z.



Higgsino limits combined with the 2ℓ analysis targeting compressed mass spectra.
$\tilde{\chi}_2^0$ masses excluded up to 210 GeV for WZ-mediated signal models with a mass splitting of 2–60 GeV.

Long lived particles with large *d*E/*d*x

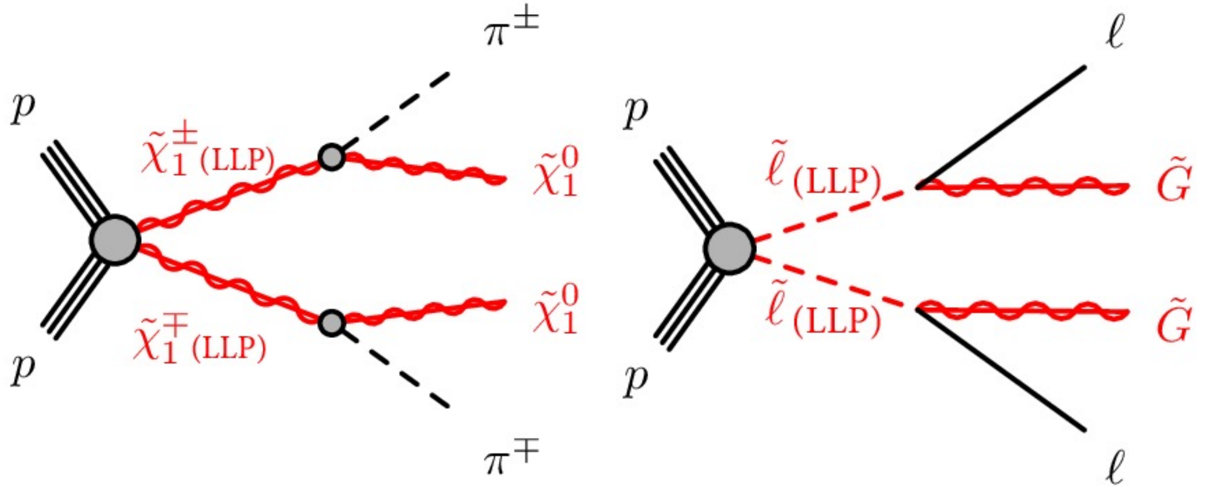
[SUSY-2018-42]

Targeted models: Charginos and sleptons as Long Lived Particles (LLPs)

Signature: isolated tracks with high p_T and large specific ionisation.

Reconstruction of the mass for each track from the Bethe-Bloch relation:

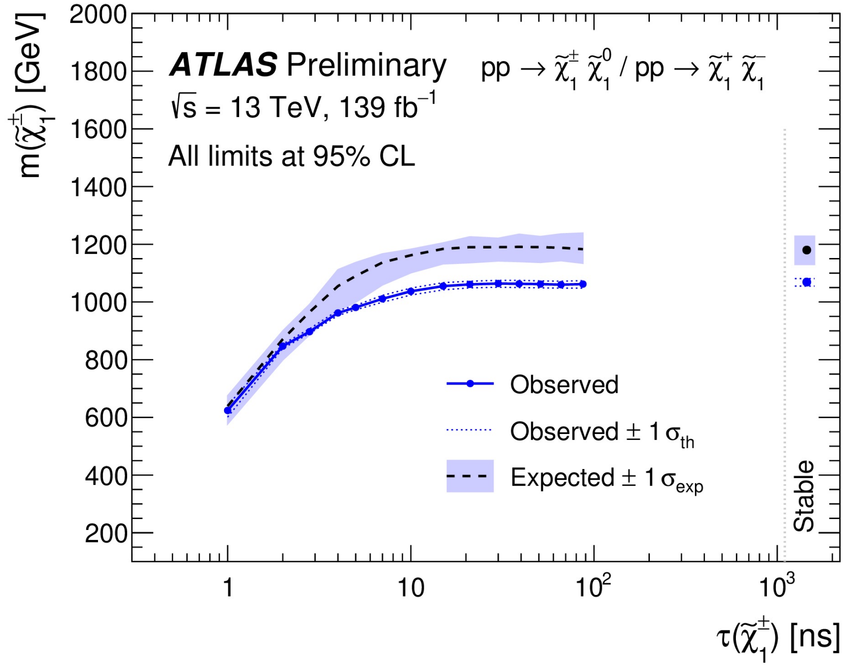
$$m_{\mathrm{d}E/\mathrm{d}x} \equiv \frac{p_{\mathrm{reco}}}{\beta\gamma(\langle \mathrm{d}E/\mathrm{d}x \rangle_{\mathrm{corr}})}$$



Background estimation: mass distribution of SM tracks estimated in CRs close to the SRs.

Signal region: *d*E/*d*x larger than 1.8 MeV $\mathrm{g}^{-1}\mathrm{cm}^2$. Different SRs in *d*E/*d*x to target different LLPs.

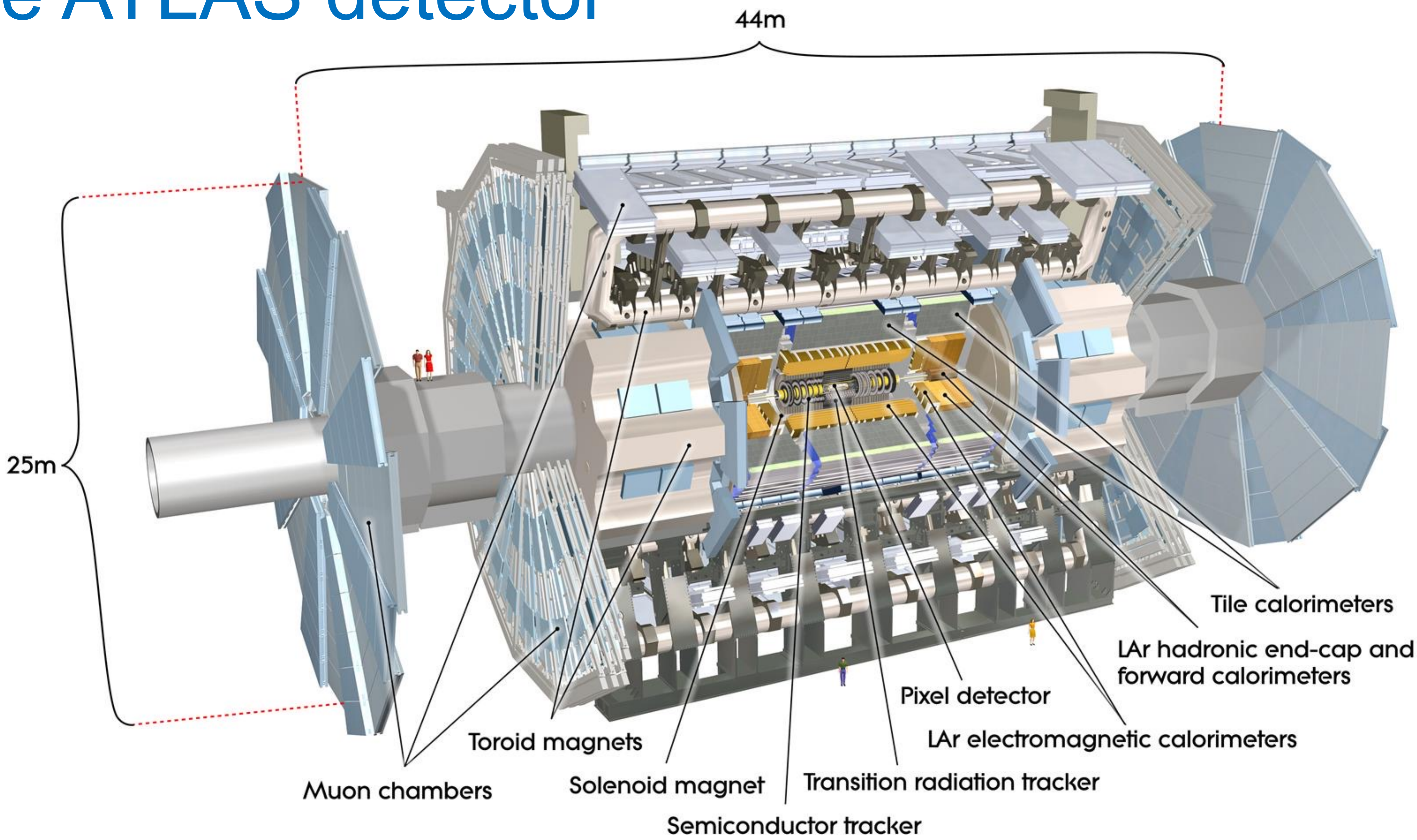
Observed data excess with **global significance 3.6σ** in an high mass inclusive SR → calls for further investigation.



Exclusion limits set as a function of LLP lifetime τ.

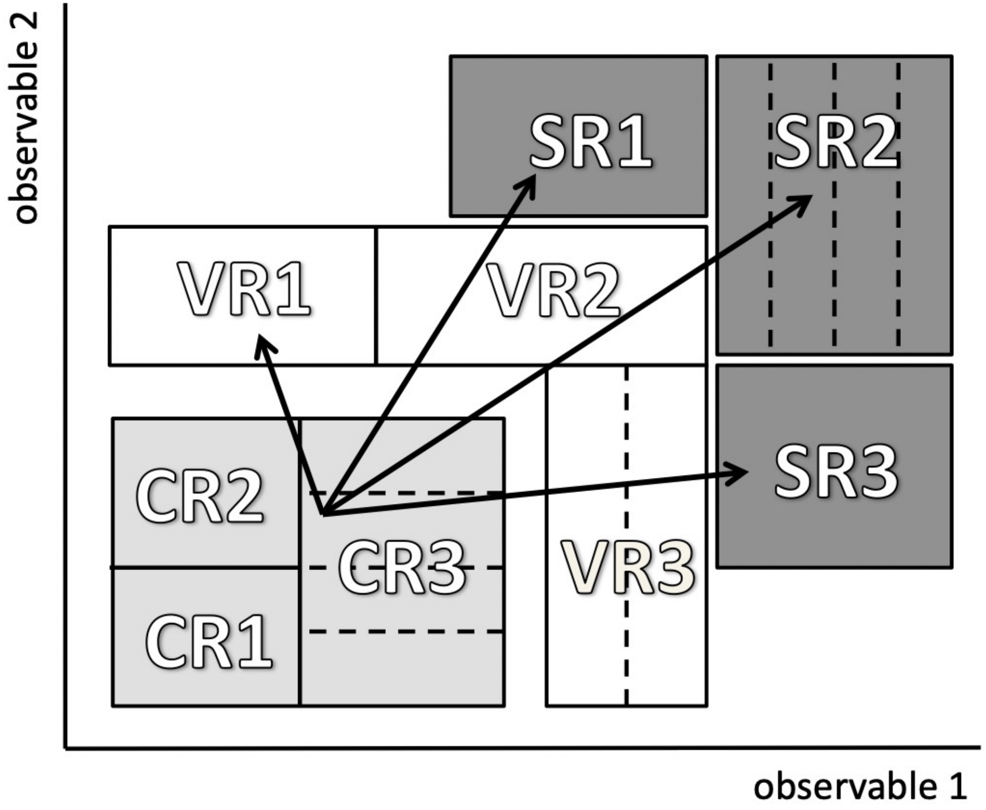
LLP chargino masses excluded up to 2.2 TeV, LLP tau masses excluded up to 1.07 TeV at 95% CL.

The ATLAS detector

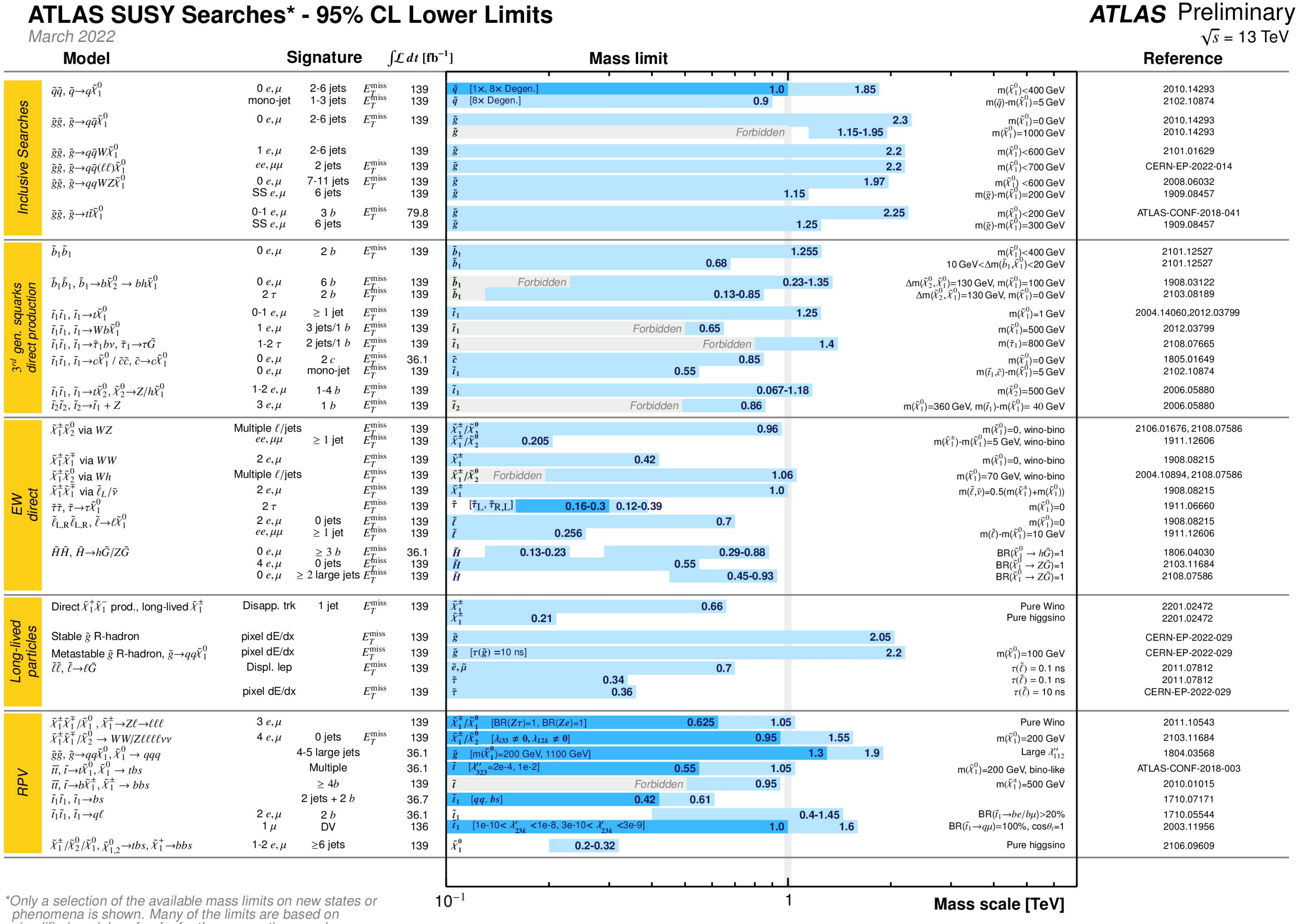


SUSY search strategy

- Signal regions (SRs) are defined where the excesses of data would be expected over the SM if there was a signal present.
- Control regions (CRs) are kinematically similar to the SRs but with suppressed signal. They are used to extract data-driven normalisation factors for dominant background components using simultaneous likelihood fit.
- Validation regions (VRs) are used to check that background estimates provide accurate normalisation and shape of the distributions before unblinding the SRs.



Summary of ATLAS searches



*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.

All hadronic

[Phys.Rev.D 104, 112010]

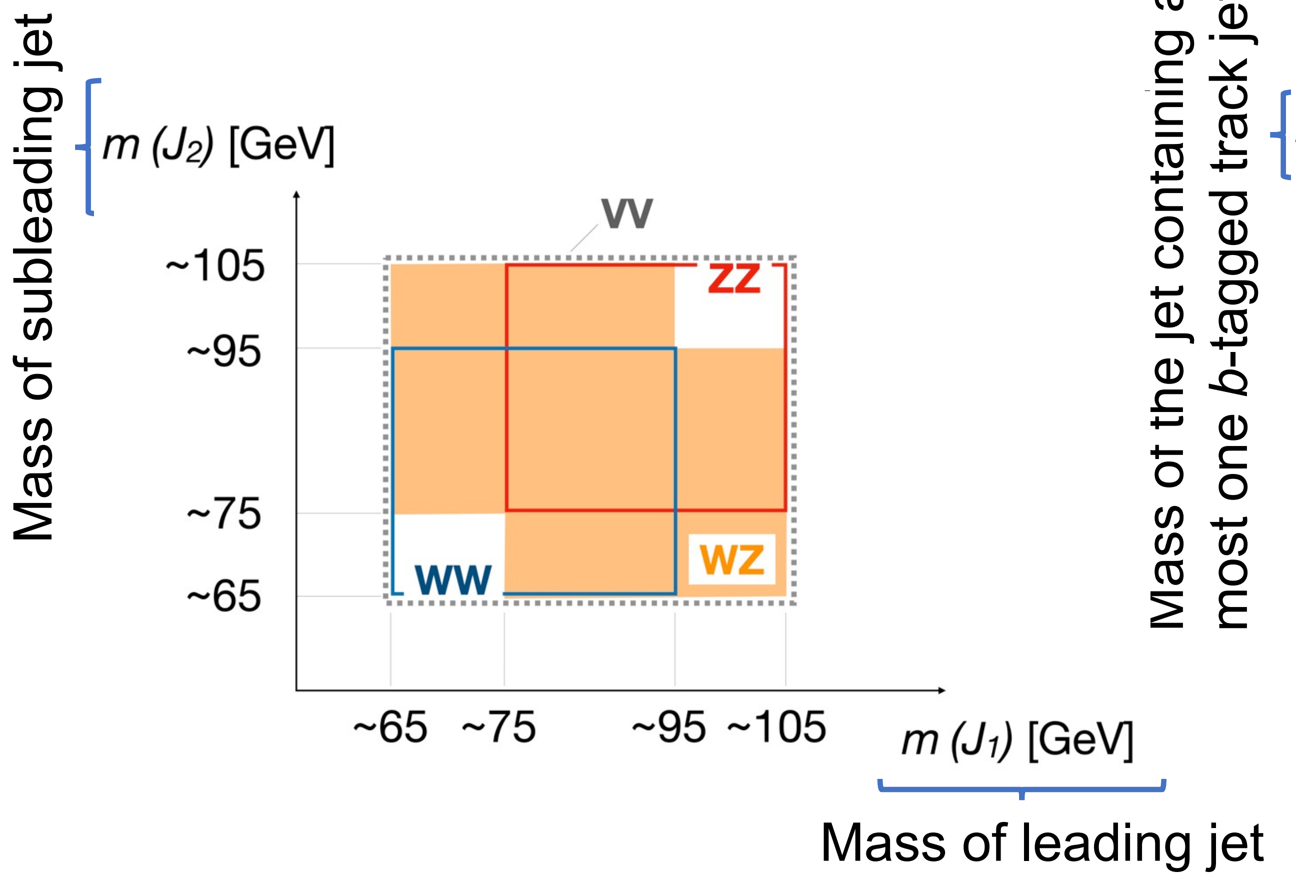
SR selection

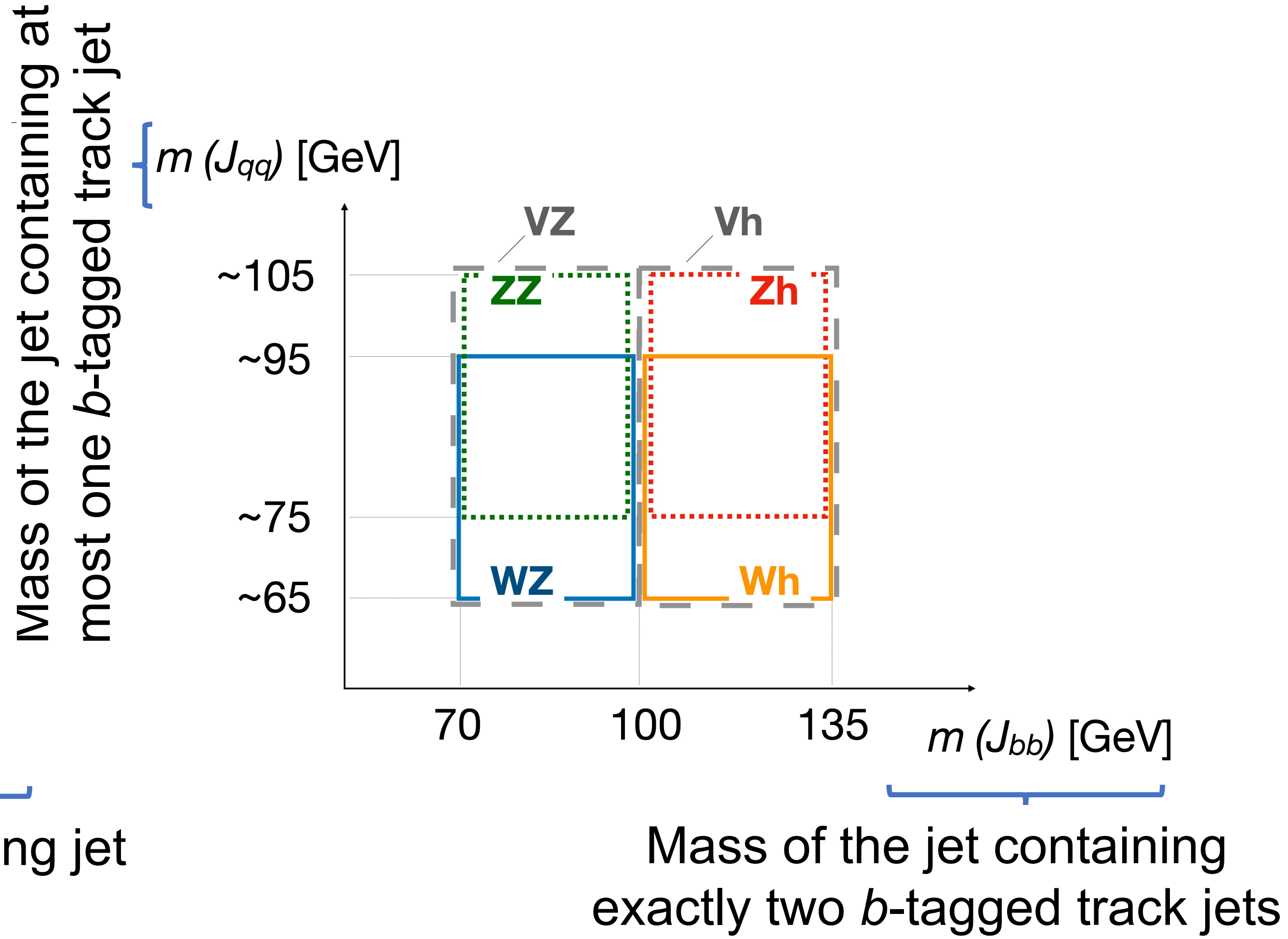
		$n(W_{qq})$	$n(Z_{qq})$	$n(V_{qq})$	$n(Z_{bb})$	$n(h_{bb})$
4Q SR	4Q-WW	$= 2$	$\cdots$	$= 2$	$= 0$	$= 0$
	4Q-WZ	≥ 1	≥ 1	$= 2$	$= 0$	$= 0$
	4Q-ZZ	$\cdots$	$= 2$	$= 2$	$= 0$	$= 0$
	4Q-VV	$\cdots$	$\cdots$	$= 2$	$= 0$	$= 0$
2B2Q SR	2B2Q-WZ	$= 1$	$\cdots$	$= 1$	$= 1$	$= 0$
	2B2Q-ZZ	$\cdots$	$= 1$	$= 1$	$= 1$	$= 0$
	2B2Q-Wh	$= 1$	$\cdots$	$= 1$	$= 0$	$= 1$
	2B2Q-Zh	$\cdots$	$= 1$	$= 1$	$= 0$	$= 1$
	2B2Q-VZ	$\cdots$	$\cdots$	$= 1$	$= 1$	$= 0$
	2B2Q-Vh	$\cdots$	$\cdots$	$= 1$	$= 0$	$= 1$

All hadronic

[Phys.Rev.D 104, 112010]

SR selection





All hadronic

[Phys.Rev.D 104, 112010]

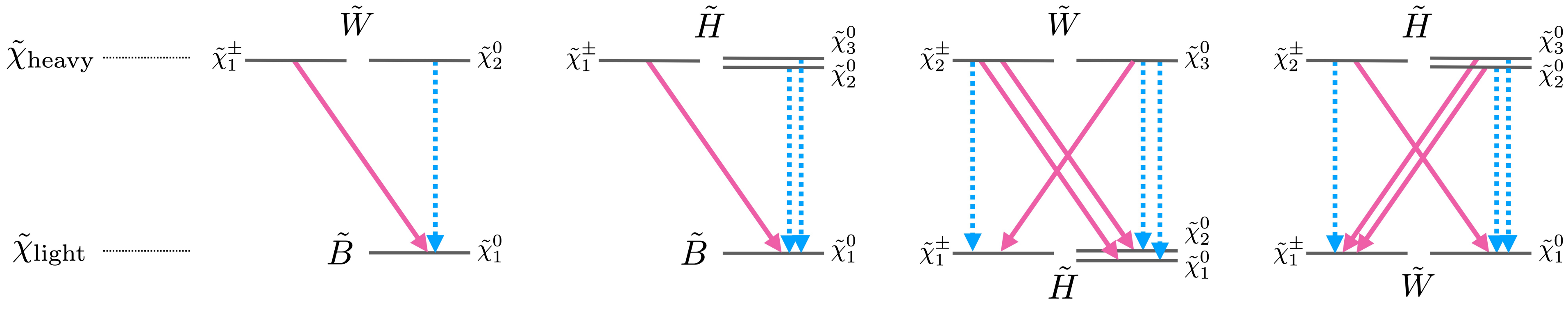
SR selection

	SR(CR0L)		VR(CR)1L		VR(CR)1Y		
	4Q	2B2Q	4Q	2B2Q	4Q	2B2Q	VRTTX
$n_{\text{Large-}R\text{ jets}}$	≥ 2		≥ 2		≥ 2		$=1$
n_{lepton}	$=0$		$=1$		$=0$		$=3$
$p_{\mathrm{T}}(\ell_1)$ [GeV]	$\cdots$		>30		$\cdots$		>30
n_{photon}	$\cdots$		$\cdots$		$=1$		$\cdots$
$n(V_{qq})$	$=2(=1)$	$=1(=0)$	$=2(=1)$	$=1(=0)$	$=2(=1)$	$=1(=0)$	$\cdots$
$n(!V_{qq})$	$=0(=1)$	$=0(=1)$	$=0(=1)$	$=0(=1)$	$=0(=1)$	$=0(=1)$	$\cdots$
$n(J_{bb})$	$=0$	$=1$	$=0$	$=1$	$=0$	$=1$	$=1$
$m(J_{bb})$ [GeV]	$\cdots$	$\in[70, 135(150)]$	$\cdots$	$\in[70, 150]$	$\cdots$	$\in[70, 150]$	$\cdots$
$n_{b\text{-jet}}^{\text{unmatched}}$	$=0$		$=0$		$=0$		$\cdots$
$n_{b\text{-jet}}$	≤ 1	$\cdots$	$=0$	$\cdots$	≤ 1	$\cdots$	$\cdots$
$E_{\mathrm{T}}^{\text{miss}}$	>300	>200	>50		<200		$\cdots$
$p_{\mathrm{T}}(W)$	$\cdots$		>200		$\cdots$		$\cdots$
$p_{\mathrm{T}}(\gamma)$	$\cdots$		$\cdots$		>200		$\cdots$
m_{eff}	>1300	$>1000(>900)$	>1000	>900	>1000	>900	$\cdots$
$\min \Delta\phi(E_{\mathrm{T}}^{\text{miss}}, j)$	>1.0		>1.0		>1.0		$\cdots$
m_{T2}	$\cdots$	>250	$\cdots$	>250	$\cdots$	>250	$\cdots$

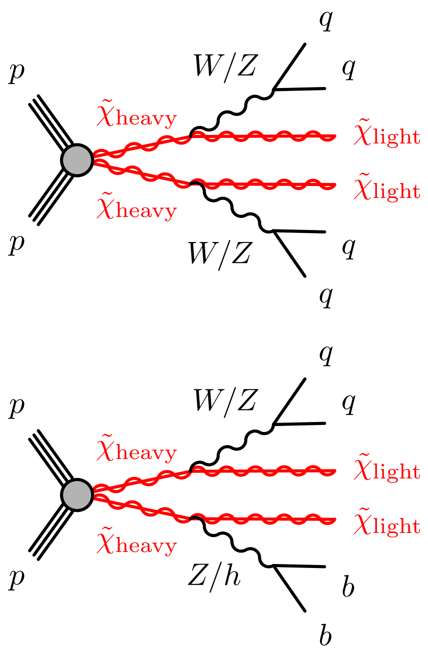
All hadronic

[Phys.Rev.D 104, 112010]

Mass hierarchies



(a) $(\tilde{W}, \tilde{B})$ (b) $(\tilde{H}, \tilde{B})$ (c) $(\tilde{W}, \tilde{H})$ (d) $(\tilde{H}, \tilde{W})$



SRs fitted

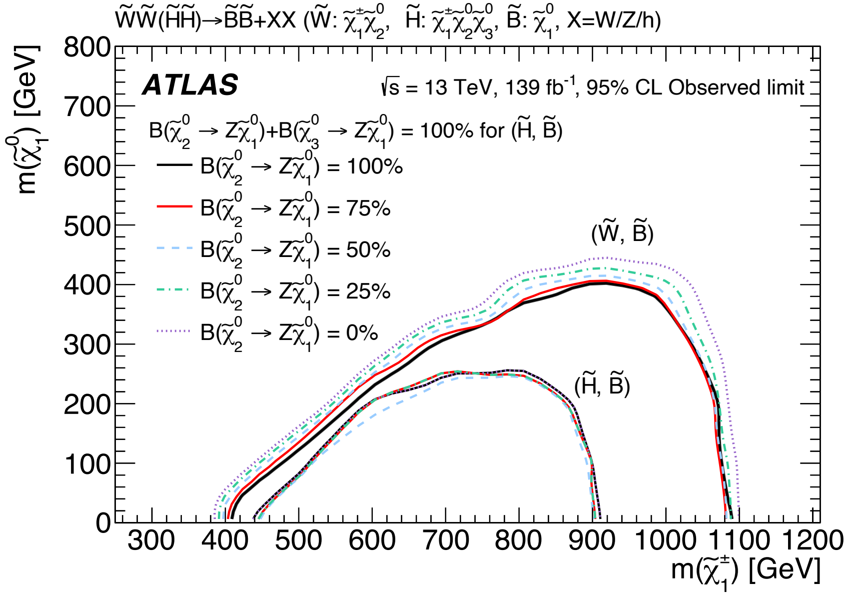
Model	Production	Final states	SRs simultaneously fitted	Branching ratio
$(\tilde{W}, \tilde{B})$	$\tilde{\chi}_1^{\pm}\tilde{\chi}_1^{\mp}$, $\tilde{\chi}_1^{\pm}\tilde{\chi}_2^0$	WW, WZ, Wh	4Q-VV, 2B2Q-WZ, 2B2Q-Wh	$\mathcal{B}(\tilde{\chi}_1^{\pm} \to W\tilde{\chi}_1^0) = 1$ $\mathcal{B}(\tilde{\chi}_2^0 \to Z\tilde{\chi}_1^0)$ scanned
$(\tilde{H}, \tilde{B})$	$\tilde{\chi}_1^{\pm}\tilde{\chi}_1^{\mp}$, $\tilde{\chi}_1^{\pm}\tilde{\chi}_2^0$, $\tilde{\chi}_1^{\pm}\tilde{\chi}_3^0$, $\tilde{\chi}_2^0\tilde{\chi}_3^0$	$WW, WZ, Wh,$ ZZ, Zh, hh	4Q-VV, 2B2Q-VZ, 2B2Q-Vh	$\mathcal{B}(\tilde{\chi}_1^{\pm} \to W\tilde{\chi}_1^0) = 1$ $\mathcal{B}(\tilde{\chi}_2^0 \to Z\tilde{\chi}_1^0)$ scanned $\mathcal{B}(\tilde{\chi}_3^0 \to Z\tilde{\chi}_1^0) = 1 - \mathcal{B}(\tilde{\chi}_2^0 \to Z\tilde{\chi}_1^0)$
$(\tilde{W}, \tilde{H})$	$\tilde{\chi}_2^{\pm}\tilde{\chi}_2^{\mp}$, $\tilde{\chi}_2^{\pm}\tilde{\chi}_3^0$	$WW, WZ, Wh,$ ZZ, Zh, hh	4Q-VV, 2B2Q-VZ, 2B2Q-Vh	Determined from $(M_2, \mu, \tan\beta)$
$(\tilde{H}, \tilde{W})$	$\tilde{\chi}_2^{\pm}\tilde{\chi}_2^{\mp}$, $\tilde{\chi}_2^{\pm}\tilde{\chi}_2^0$, $\tilde{\chi}_2^{\pm}\tilde{\chi}_3^0$, $\tilde{\chi}_2^0\tilde{\chi}_3^0$	$WW, WZ, Wh,$ ZZ, Zh, hh	4Q-VV, 2B2Q-VZ, 2B2Q-Vh	Determined from $(M_2, \mu, \tan\beta)$

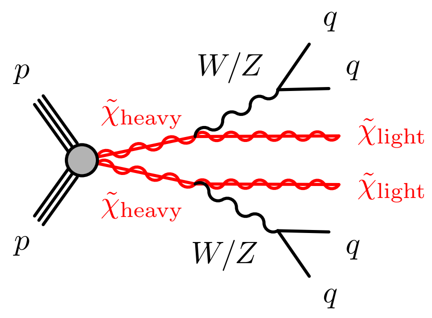
All hadronic

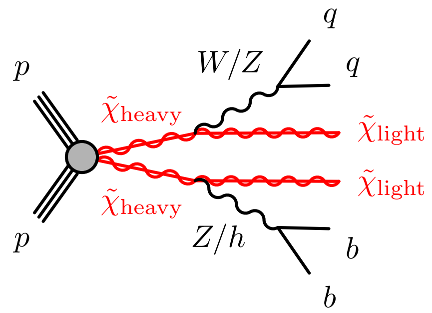
[[Phys.Rev.D 104, 112010](#)]

Exclusion limits

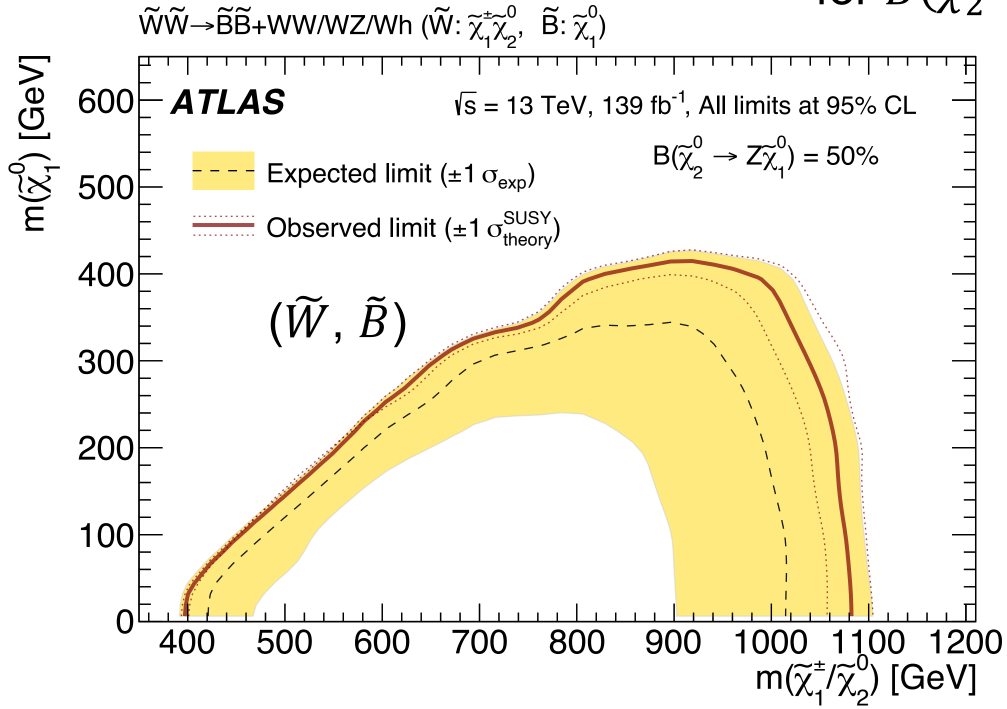
for various $B(\tilde{\chi}_2^0 \to Z\tilde{\chi}_1^0)$

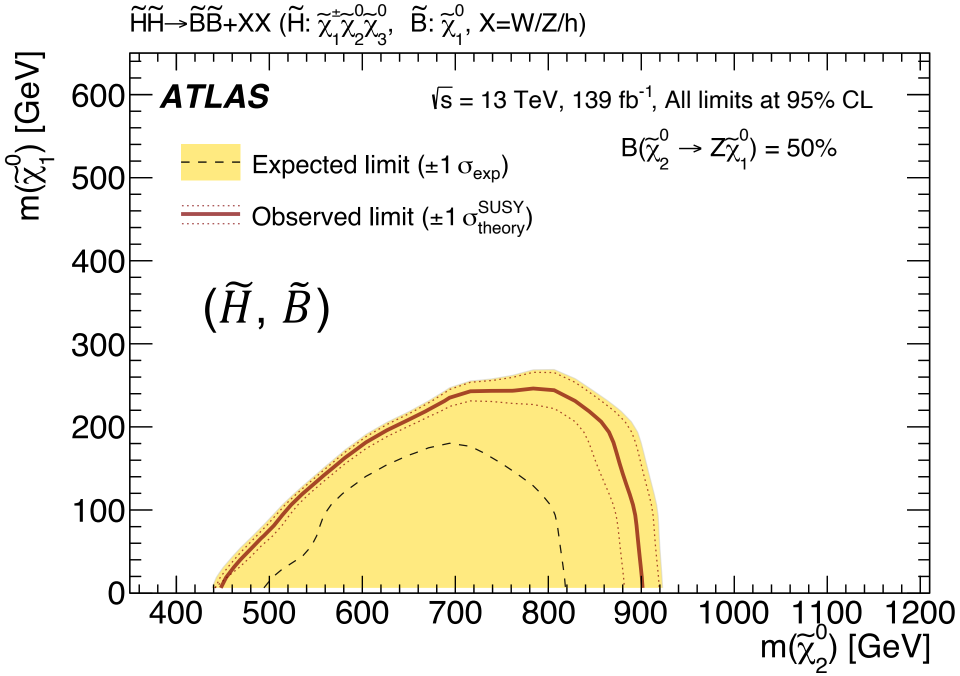






for $B(\tilde{\chi}_2^0 \to Z\tilde{\chi}_1^0) = 50\%$



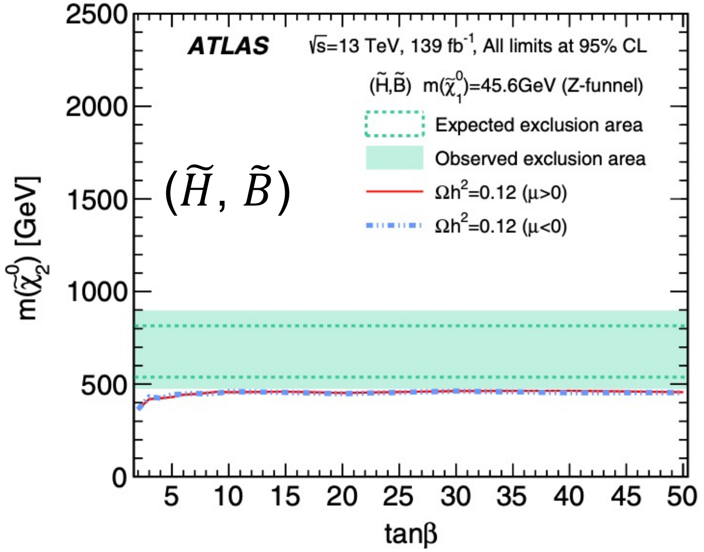


All hadronic

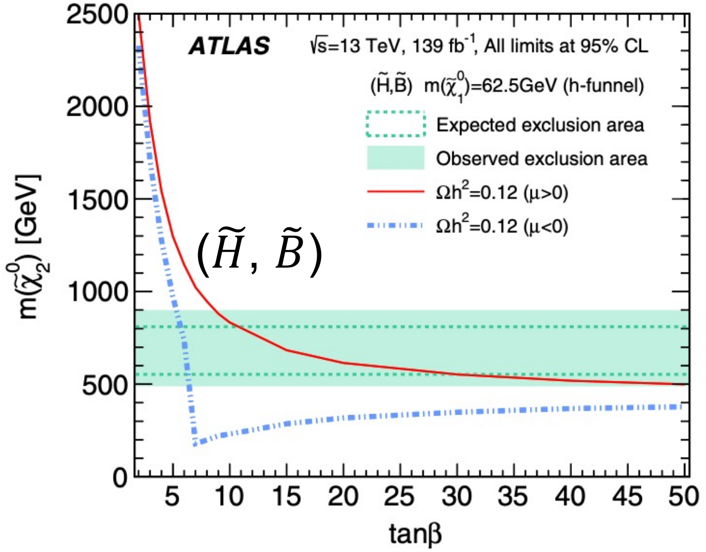
[Phys.Rev.D 104, 112010]

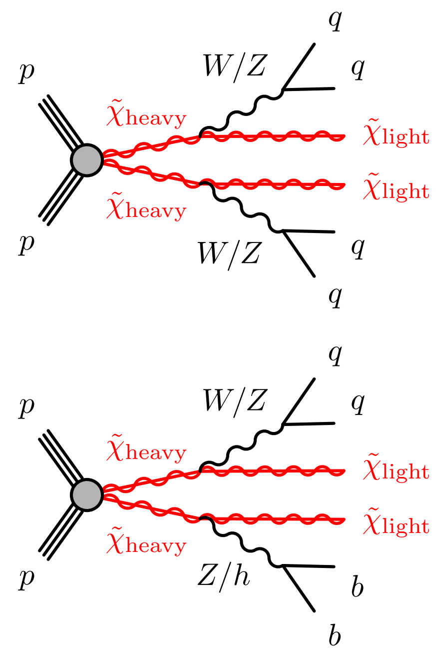
Exclusion limits

Z-funnel

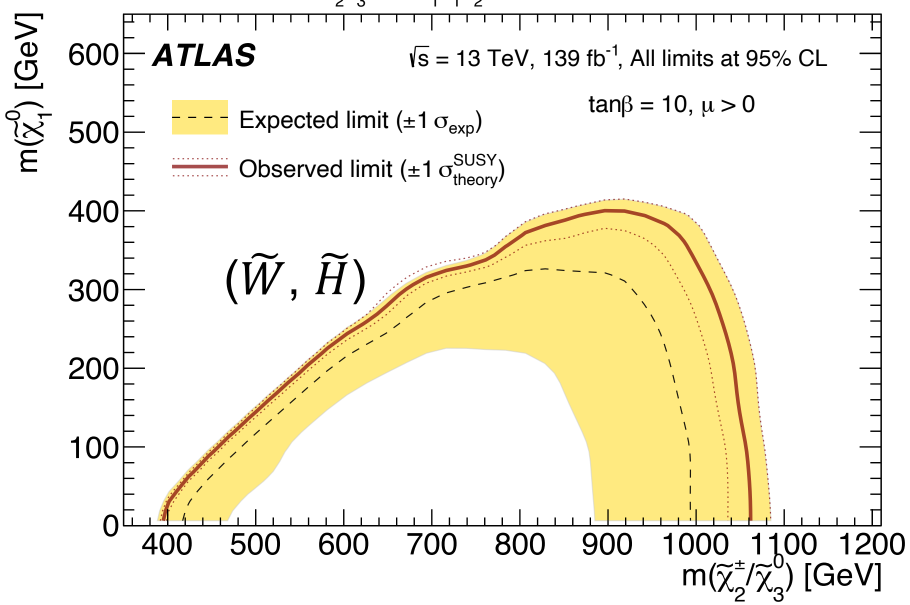


H-funnel

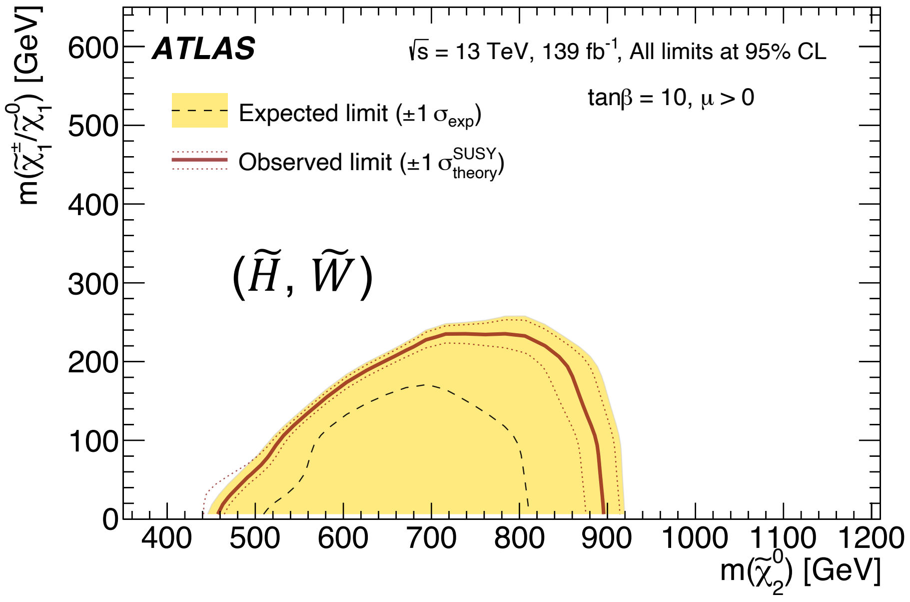




$\tilde{W}\tilde{W} \to \tilde{H}\tilde{H}$+XX ($\tilde{W}$: $\tilde{\chi}_2^\pm\tilde{\chi}_3^0$, $\tilde{H}$: $\tilde{\chi}_1^\pm\tilde{\chi}_1^0\tilde{\chi}_2^0$, X=W/Z/h)

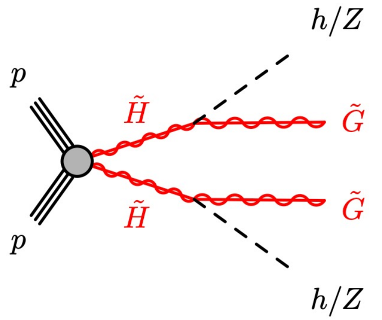


$\tilde{H}\tilde{H} \to \tilde{W}\tilde{W}$+XX ($\tilde{H}$: $\tilde{\chi}_2^\pm\tilde{\chi}_2^0\tilde{\chi}_3^0$, $\tilde{W}$: $\tilde{\chi}_1^\pm\tilde{\chi}_1^0$, X=W/Z/h)



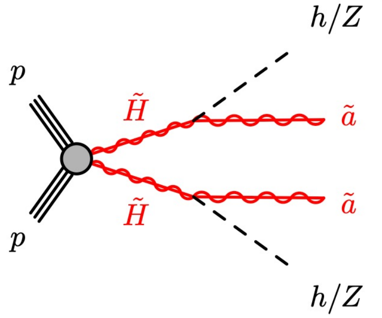
All hadronic

[Phys.Rev.D 104, 112010]

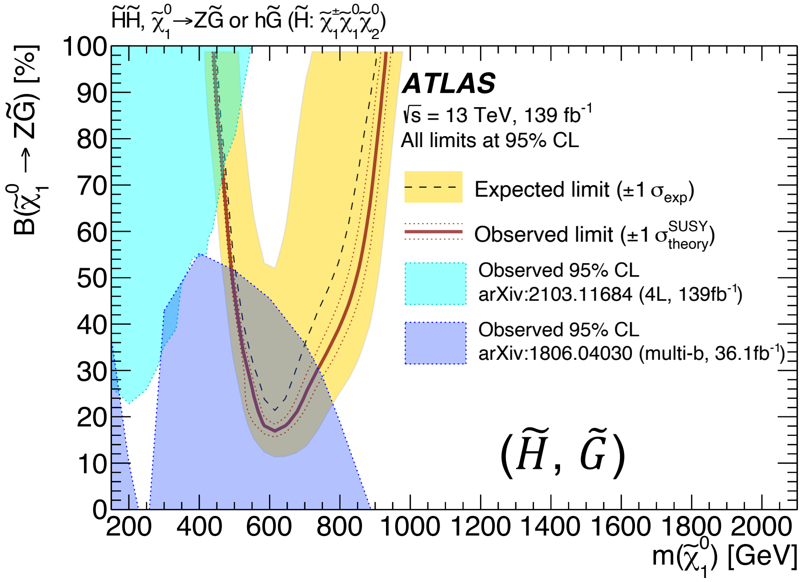


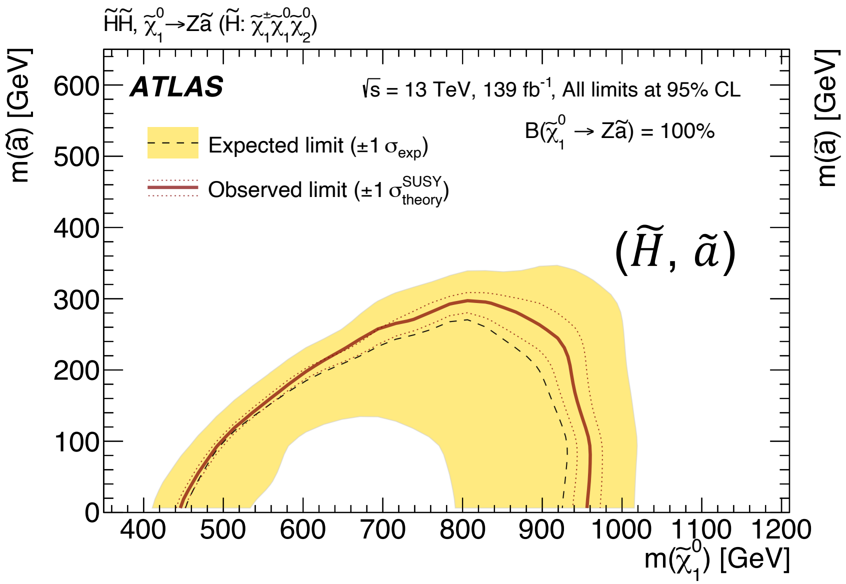
SRs fitted

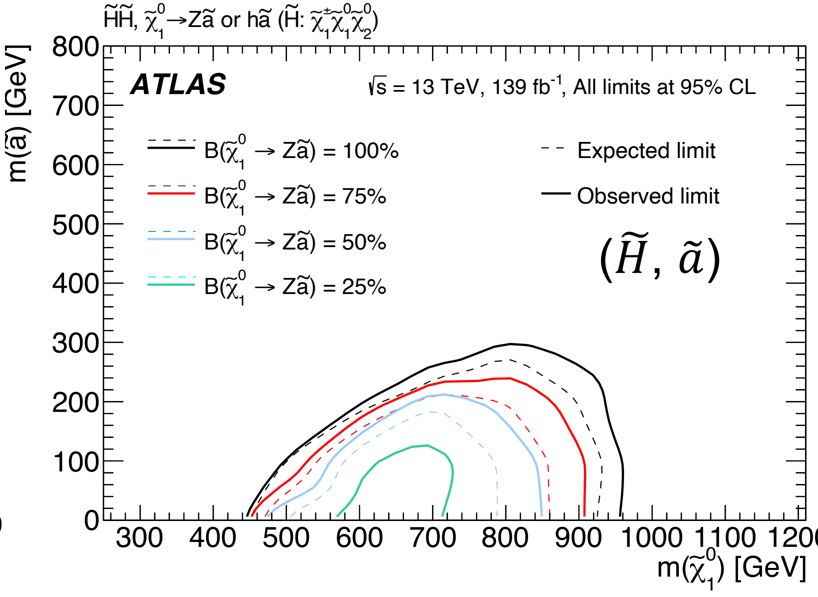
Model	Production	Final states	SRs simultaneously fitted	Branching ratio
$(\tilde{H},\, \tilde{G})$	$\tilde{\chi}_1^{\pm}\tilde{\chi}_1^{\mp}$, $\tilde{\chi}_1^{\pm}\tilde{\chi}_1^{0}$, $\tilde{\chi}_1^{\pm}\tilde{\chi}_2^{0}$, $\tilde{\chi}_1^{0}\tilde{\chi}_2^{0}$	ZZ, Zh, hh	4Q-ZZ, 2B2Q-ZZ, 2B2Q-Zh	$\mathcal{B}(\tilde{\chi}_1^0 \to Z\tilde{G})$ scanned
$(\tilde{H},\, \tilde{a})$	$\tilde{\chi}_1^{\pm}\tilde{\chi}_1^{\mp}$, $\tilde{\chi}_1^{\pm}\tilde{\chi}_1^{0}$, $\tilde{\chi}_1^{\pm}\tilde{\chi}_2^{0}$, $\tilde{\chi}_1^{0}\tilde{\chi}_2^{0}$	ZZ, Zh, hh	4Q-ZZ, 2B2Q-ZZ, 2B2Q-Zh	$\mathcal{B}(\tilde{\chi}_1^0 \to Z\tilde{a})$ scanned



Exclusion limits







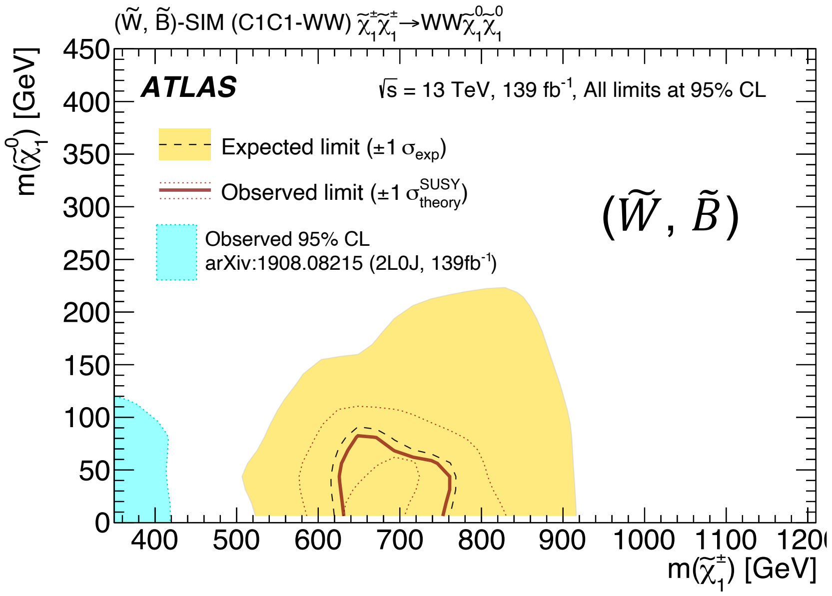
All hadronic

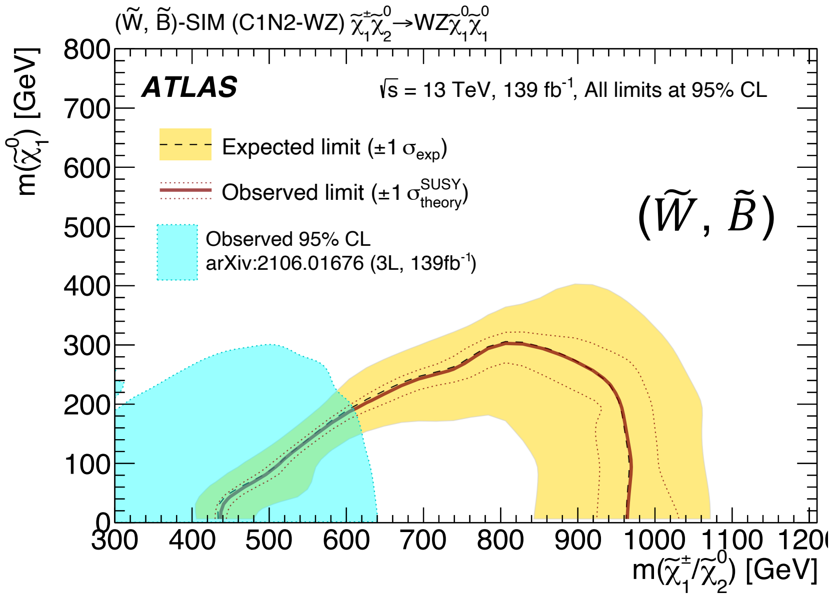
[Phys.Rev.D 104, 112010]

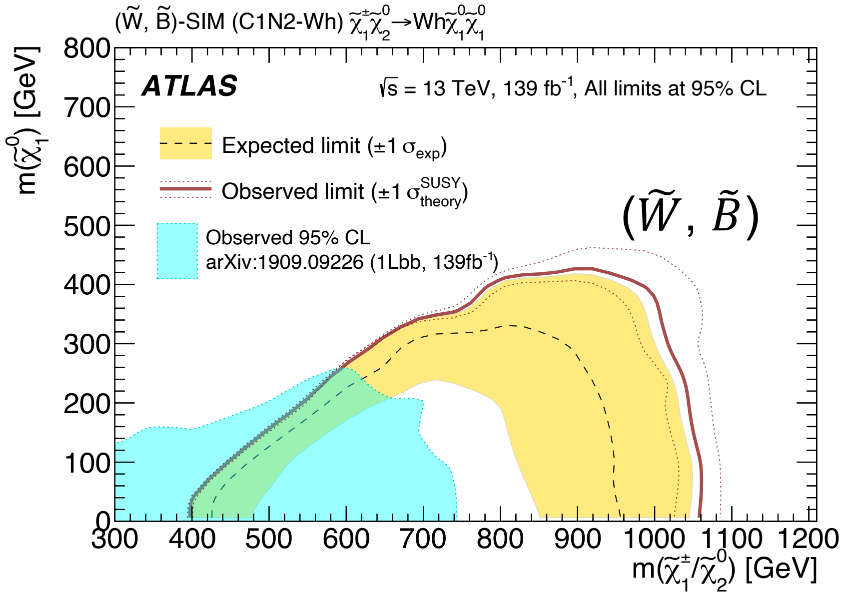
SRs fitted

Model	Production	Final states	SRs simultaneously fitted	Branching ratio
		$(\tilde{W}, \tilde{B})$ simplified models: $(\tilde{W}, \tilde{B})$-SIM		
C1C1-WW	$\tilde{\chi}_1^{\pm}\tilde{\chi}_1^{\mp}$	WW	4Q-WW	$\mathcal{B}(\tilde{\chi}_1^{\pm} \to W\tilde{\chi}_1^0) = 1$
C1N2-WZ	$\tilde{\chi}_1^{\pm}\tilde{\chi}_2^0$	WZ	4Q-WZ, 2B2Q-WZ	$\mathcal{B}(\tilde{\chi}_1^{\pm} \to W\tilde{\chi}_1^0) = \mathcal{B}(\tilde{\chi}_2^0 \to Z\tilde{\chi}_1^0) = 1$
C1N2-Wh	$\tilde{\chi}_1^{\pm}\tilde{\chi}_2^0$	Wh	2B2Q-Wh	$\mathcal{B}(\tilde{\chi}_1^{\pm} \to W\tilde{\chi}_1^0) = \mathcal{B}(\tilde{\chi}_2^0 \to h\tilde{\chi}_1^0) = 1$

Exclusion limits







2 leptons and 2 jets

[CERN-EP-2022-014]

Analysis selection

Region	n_{jets}	$n_{\text{jets}}^{b\text{-tag}}$	$\mathcal{S}(E_{\text{T}}^{\text{miss}})$	$m_{\ell\ell}$ [GeV]	m_X [GeV]	m_{T2} [GeV]	ΔR_X	$p_{\text{T}}^{j_1}$ [GeV]
SR-High-EWK	≥ 2	≤ 1	$(18, 21, \infty)$	71–111	$60 < m_{jj} < 110$	> 80	$\Delta R_{jj} \in (0, 0.8, 1.6)$	–
VR-High-Sideband-EWK	≥ 2	≤ 1	> 18	71–111	$\mathbf{20 < m_{jj} < 60 \cup m_{jj} > 110}$	> 80	$\Delta R_{jj} < 1.6$	–
VR-High-R-EWK	≥ 2	≤ 1	> 18	71–111	$\mathbf{m_{jj} > 20}$	> 80	$\mathbf{\Delta R_{jj} > 1.6}$	–
SR-1J-High-EWK	1	≤ 1	> 12	71–111	$60 < m_{j_1} < 110$	> 80	–	–
VR-1J-High-Sideband-EWK	1	≤ 1	> 12	71–111	$\mathbf{20 < m_{j_1} < 60 \cup m_{j_1} > 110}$	> 80	–	–
SR-$\ell\ell bb$-EWK	≥ 2	≥ 2	> 18	71–111	$60 < m_{bb} < 150$	> 80	–	–
VR-$\ell\ell bb$-EWK	≥ 2	≥ 2	**12–18**	71–111	$60 < m_{bb} < 150$	> 80	–	–
SR-Int-EWK	≥ 2	0	$(12, 15, 18)$	81–101	$60 < m_{jj} < 110$	> 80	–	> 60
VR-Int-EWK	≥ 2	0	12–18	81–101	$60 < m_{jj} < 110$	> 80	–	$\mathbf{< 60}$
CR-VZ-EWK	≥ 2	0	12–18	81–101	$\mathbf{20 < m_{jj} < 60 \cup m_{jj} > 110}$	> 80	–	**–**
CR-tt-EWK	≥ 2	$\mathbf{\geq 1}$	**9–12**	81–101	$\mathbf{m_{jj} > 20}$	> 80	–	> 60

Region	n_{jets}	$n_{\text{jets}}^{b\text{-tag}}$	$\mathcal{S}(E_{\text{T}}^{\text{miss}})$	$m_{\ell\ell}$ [GeV]	m_X [GeV]	m_{T2} [GeV]	ΔR_X	$\Delta\phi(p_{\text{T}}^{\ell\ell}, \vec{p}_{\text{T}}^{\text{miss}})$
SR-Low-EWK	2	0	$(6, 9, 12)$	81–101	$60 < m_{jj} < 110$	> 80	$\Delta R_{\ell\ell} < 1$	–
VR-Low-EWK	2	0	6–12	81–101	$60 < m_{jj} < 110$	> 80	$\mathbf{1 < \Delta R_{\ell\ell} < 1.4}$	–
SR-Low-2-EWK	2	0	6–9	81–101	$60 < m_{jj} < 110$	< 80	$\Delta R_{\ell\ell} < 1.6$	< 0.6
VR-Low-2-EWK	2	0	6–9	81–101	$\mathbf{20 < m_{jj} < 60 \cup m_{jj} > 110}$	< 80	$\Delta R_{\ell\ell} < 1.6$	< 0.6
CR-Z-EWK	2	0	6–9	81–101	$\mathbf{20 < m_{jj} < 60 \cup m_{jj} > 110}$	$\mathbf{> 80}$	**–**	**–**

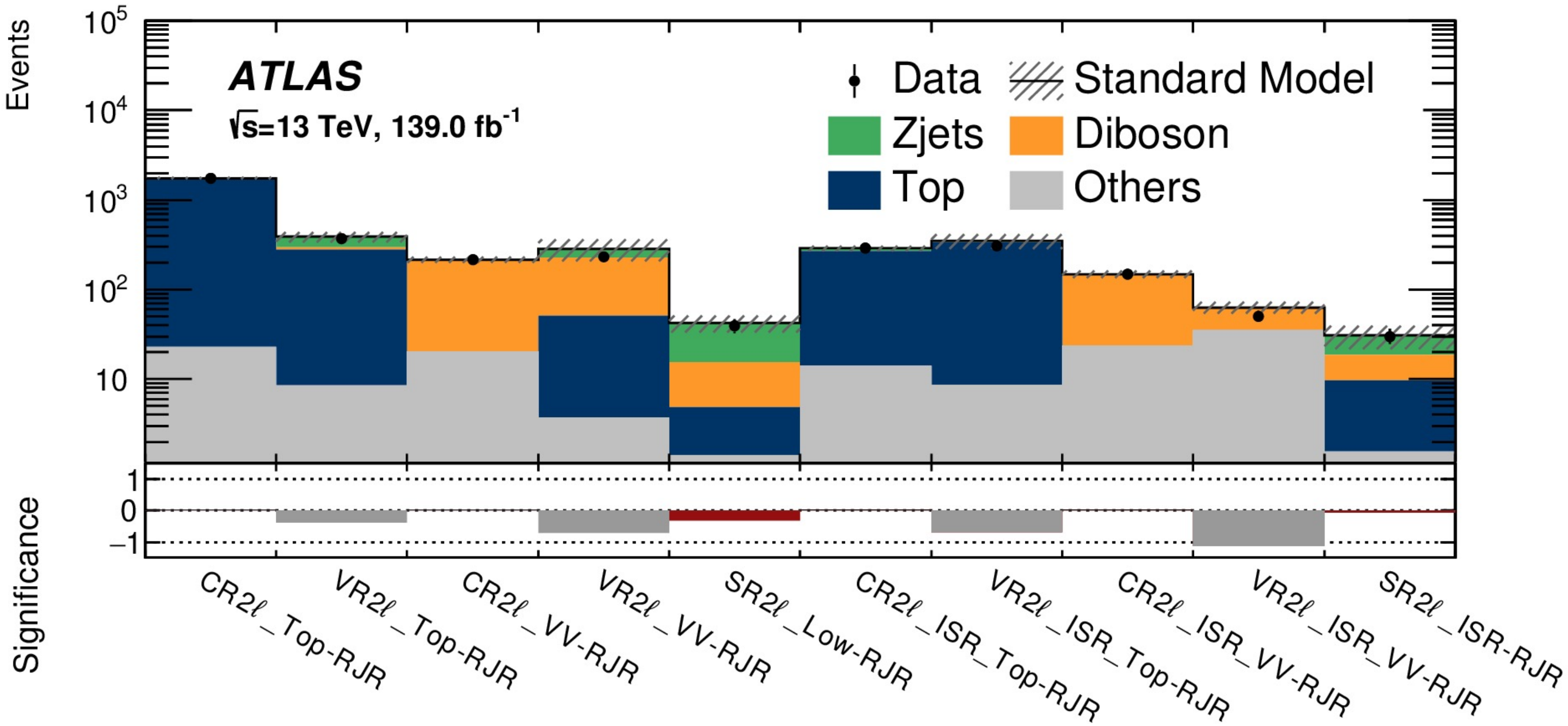
Region	n_{jets}	$n_{\text{jets}}^{b\text{-tag}}$	$\mathcal{S}(E_{\text{T}}^{\text{miss}})$	$m_{\ell\ell}$ [GeV]	m_{T2} [GeV]	$p_{\text{T}}^{j_1}$ [GeV]	$\Delta\phi(p_{\text{T}}^{j_1}, \vec{p}_{\text{T}}^{\text{miss}})$
SR-OffShell-EWK	≥ 2	0	> 9	$(12, 40, 71)$	> 100	> 100	> 2
VR-OffShell-EWK	≥ 2	0	> 9	12–71	**80–100**	> 100	> 2
CR-DY-EWK	≥ 2	0	**6–9**	12–71	> 100	**–**	**–**

2 leptons and 2 jets

[CERN-EP-2022-014]

RJR search

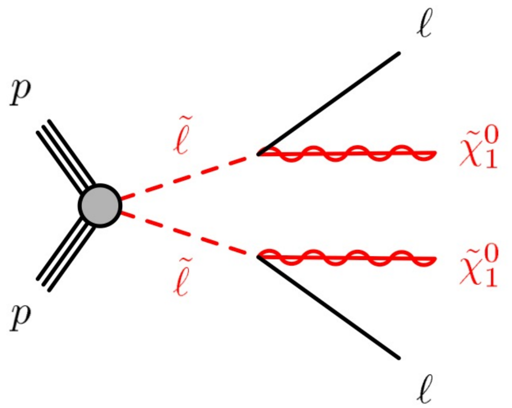
- Search motivated by the 2.0σ and 1.4σ excesses in the previous search using 36 fb^{-1}.
- Two SRs, using recursive-jigsaw reconstruction (RJR) variables + a new analysis strategy for the same topology, optimized for full Run 2 dataset.
- SRs designated to target $\Delta m(\tilde{\chi}_1^{\pm}, \tilde{\chi}_1^0) \sim 100$ GeV.



No more excess in the 2 RJR search SRs

2 leptons and no jets

[ATLAS-CONF-2022-006]



Data driven background estimation for the slepton search

- Data events with DF leptons surviving the SR selection (N_{DF}) are used to predict the **Flavour Symmetric Background** (FSB) in the SF channel.
- Since electrons and muons have different trigger, reconstruction, isolation and identification efficiencies, these differences must be taken into account.
- The efficiency correction method is applied. The number of expected FSB events in the SF channel is computed as:

$$N_{ee}^{FSB} = 0.5 \times \frac{1}{\kappa} \times \alpha \times N_{DF}$$
$$N_{\mu\mu}^{FSB} = 0.5 \times \kappa \times \alpha \times N_{DF}$$
$$\Rightarrow \quad N_{SF}^{FSB} = 0.5 \times \left(\kappa + \frac{1}{\kappa}\right) \times \alpha \times N_{DF}$$

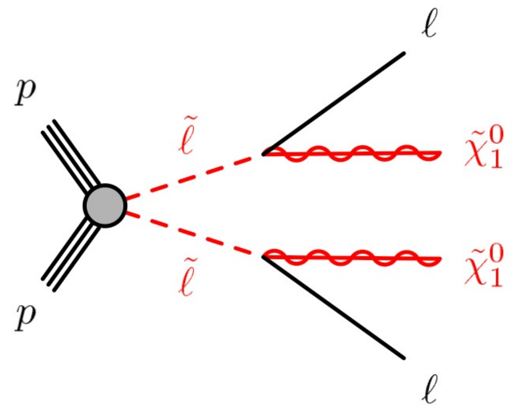
  where the factor 0.5 assumes that the production rate of the DF events is twice that of the dimuon and dielectron events.

- κ and α take into account the difference in reconstruction, identification and trigger efficiencies for muons and electrons, respectively.
  They are defined as:

$$\kappa = \sqrt{\frac{N_{\mu^+\mu^-}}{N_{e^+e^-}}} \qquad \alpha = \sqrt{\frac{\epsilon_{\mu\mu}^{trig}\epsilon_{ee}^{trig}}{\epsilon_{e\mu}^{trig}}}$$

2 leptons and no jets

[ATLAS-CONF-2022-006]



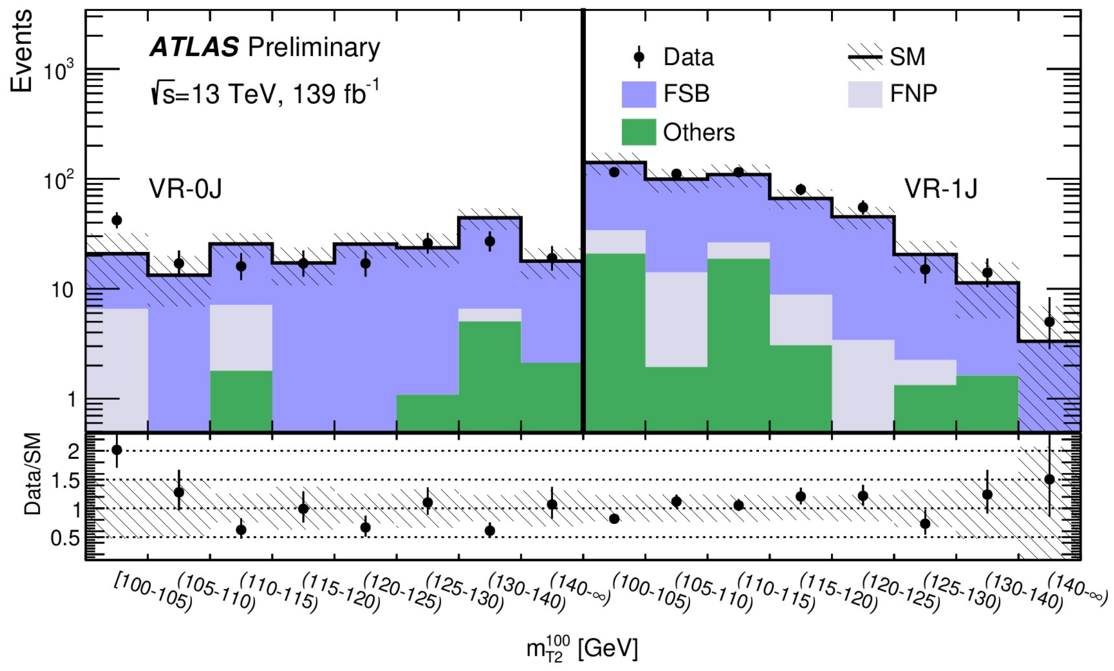
Data driven background estimation for the slepton search

- κ and α take into account the difference in reconstruction, identification and trigger efficiencies for muons and electrons, respectively.
  They are defined as:

$$\kappa = \sqrt{\frac{N_{\mu^+\mu^-}}{N_{e^+e^-}}} \qquad \alpha = \sqrt{\frac{\epsilon_{\mu\mu}^{trig}\epsilon_{ee}^{trig}}{\epsilon_{e\mu}^{trig}}}$$

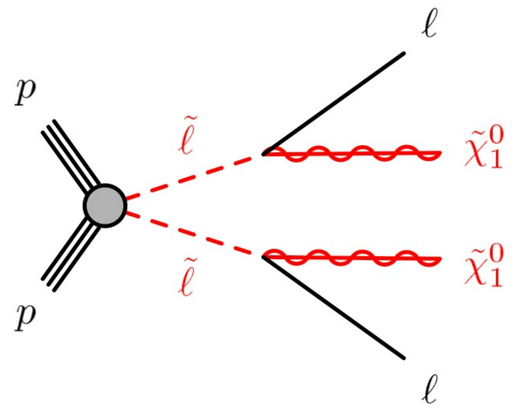
- The factor κ is extracted from data in a control sample, obtained relaxing the cuts on $p_{\mathrm{T}}^{\ell_1}$ and parametrised as a function of that variable, $E_{\mathrm{T}}^{\mathrm{miss}}$ significance and inverting the cut on $|\cos\theta_{\ell\ell}^*|$ to make it orthogonal to the SRs.

- The factor α is computed from the global efficiencies of the trigger selection applied in the analysis, evaluated on a control sample of data triggered with an independent selection.



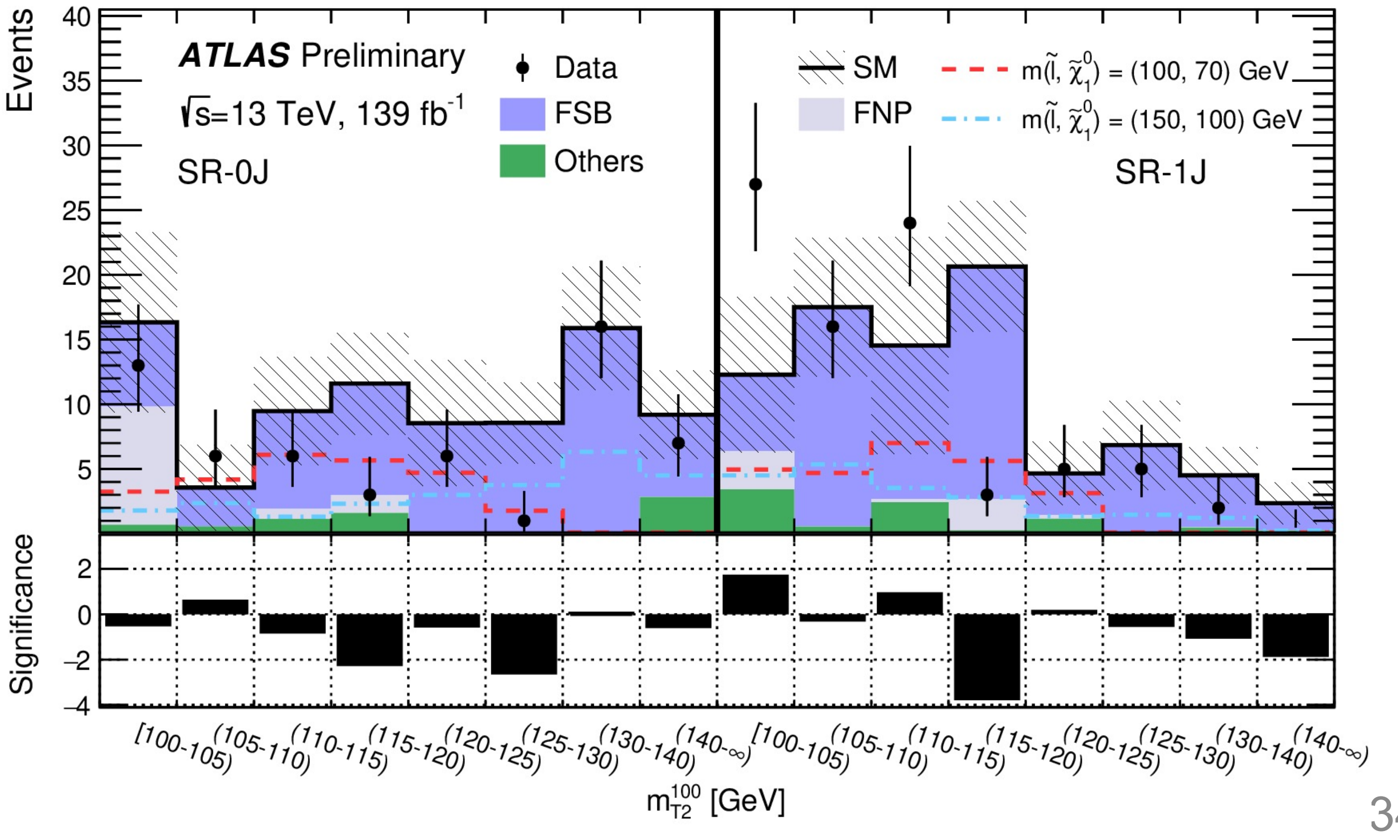
2 leptons and no jets

[ATLAS-CONF-2022-006]



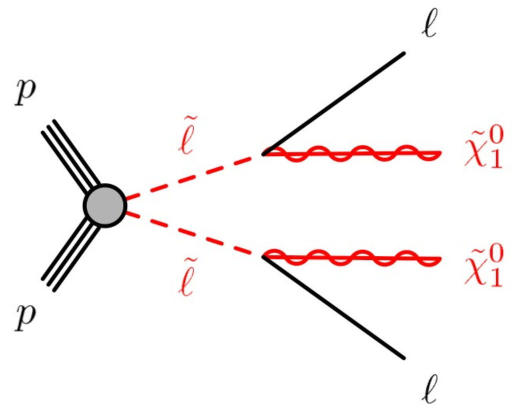
SR selection and yields for the slepton search

Signal region (SR)	SR-0J	SR-1J
$n_{b\text{-tagged jets}}$	= 0	
$E_{\mathrm{T}}^{\mathrm{miss}}$ significance	>7	
$n_{\text{non-}b\text{-tagged jets}}$	= 0	= 1
$p_{\mathrm{T}}^{\ell_1}$ [GeV]	> 140	> 100
$p_{\mathrm{T}}^{\ell_2}$ [GeV]	> 20	> 50
$m_{\ell\ell}$ [GeV]	> 11	> 60
$p_{\mathrm{T,boost}}^{\ell\ell}$ [GeV]	< 5	-
$\lvert\cos\theta^*_{\ell\ell}\rvert$	< 0.2	< 0.1
$\Delta\phi_{\ell,\ell}$	> 2.2	> 2.8
$\Delta\phi_{p_{\mathrm{T}}^{\mathrm{miss}},\ell_1}$	> 2.2	-
Binned SRs		
m_{T2}^{100}[GeV]	∈[100,105) ∈[105,110) ∈[110,115) ∈[115,120) ∈[120,125) ∈[125,130) ∈[130,140) ∈[140,∞)	

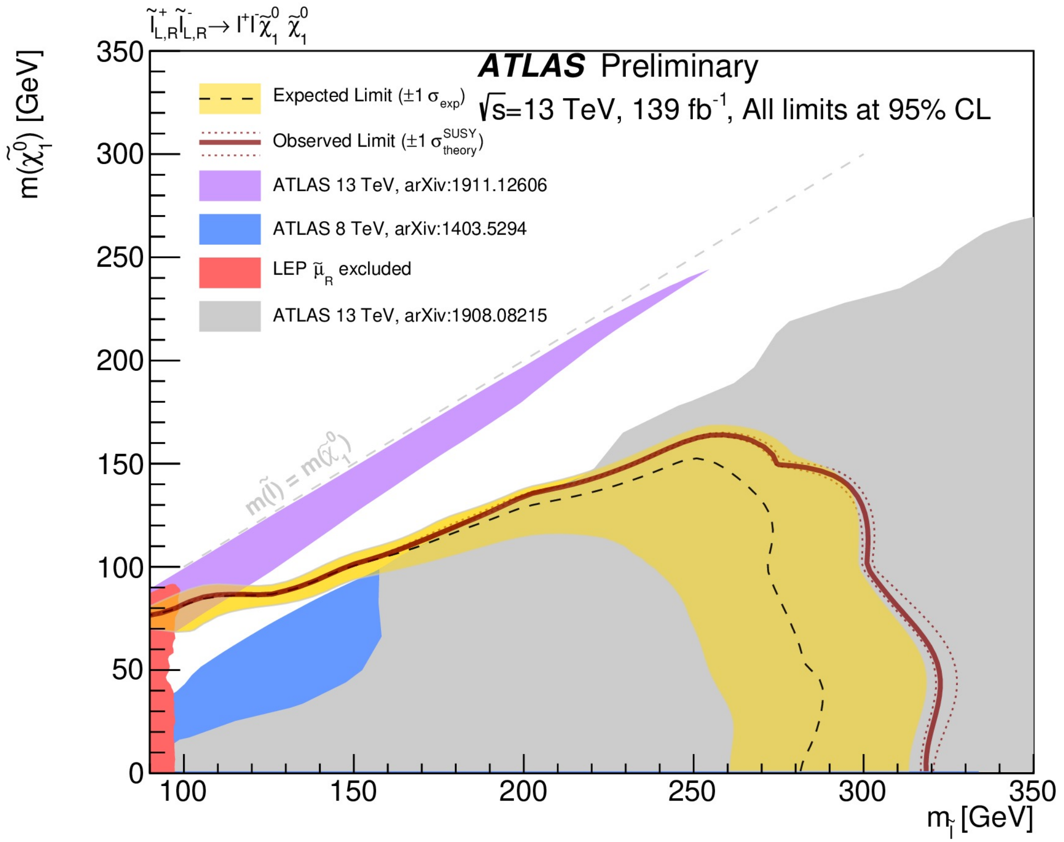


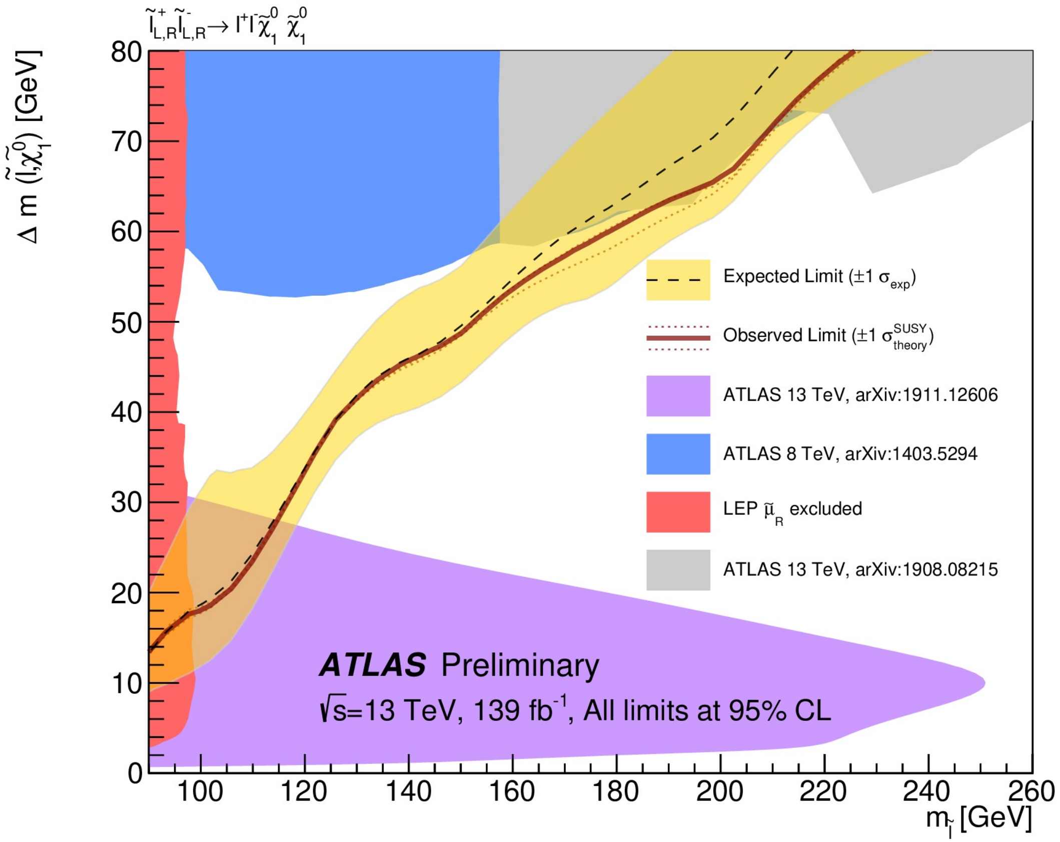
2 leptons and no jets

[ATLAS-CONF-2022-006]



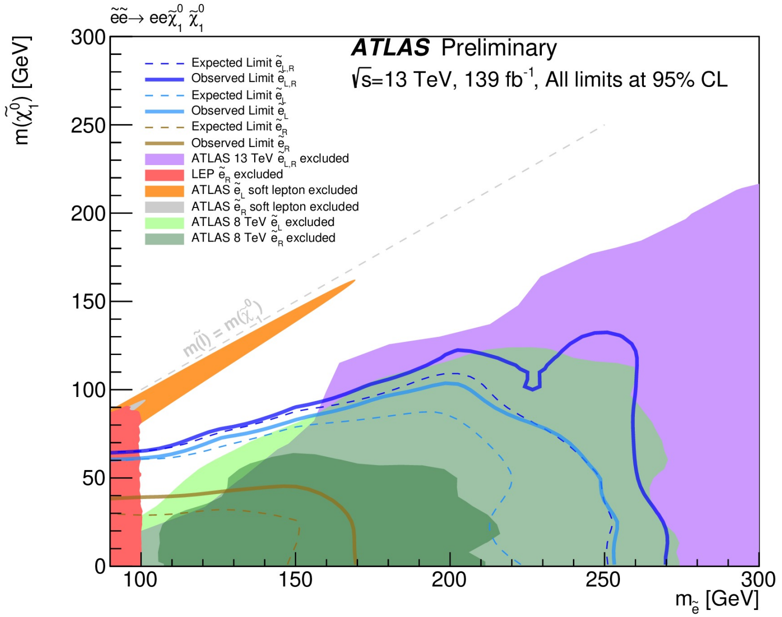
Exclusion limits for the slepton search

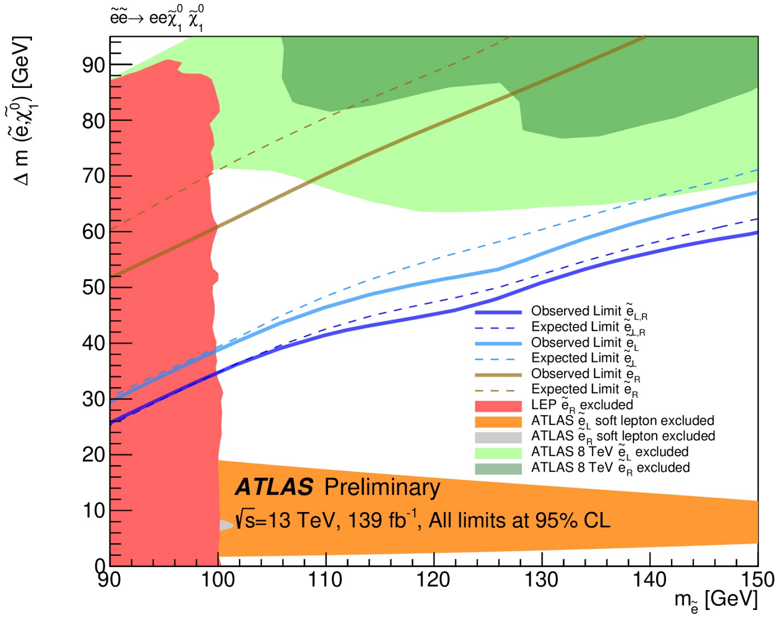


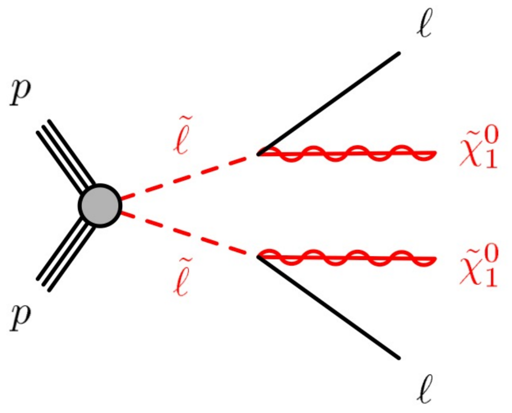


2 leptons and no jets

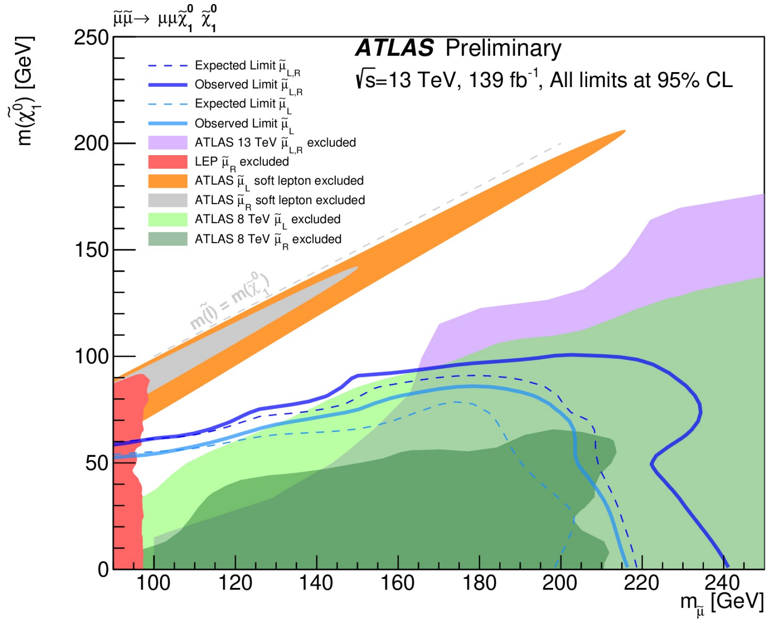
[ATLAS-CONF-2022-006]

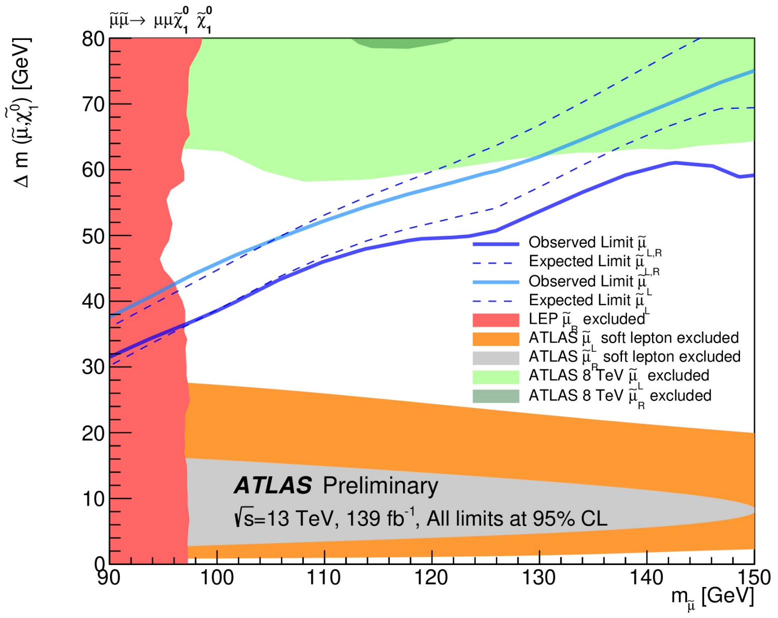






Exclusion limits for selectron pair production



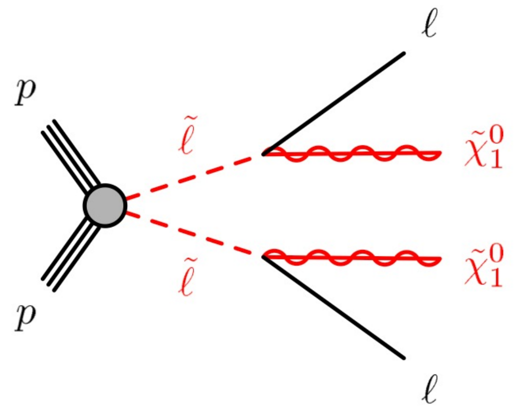


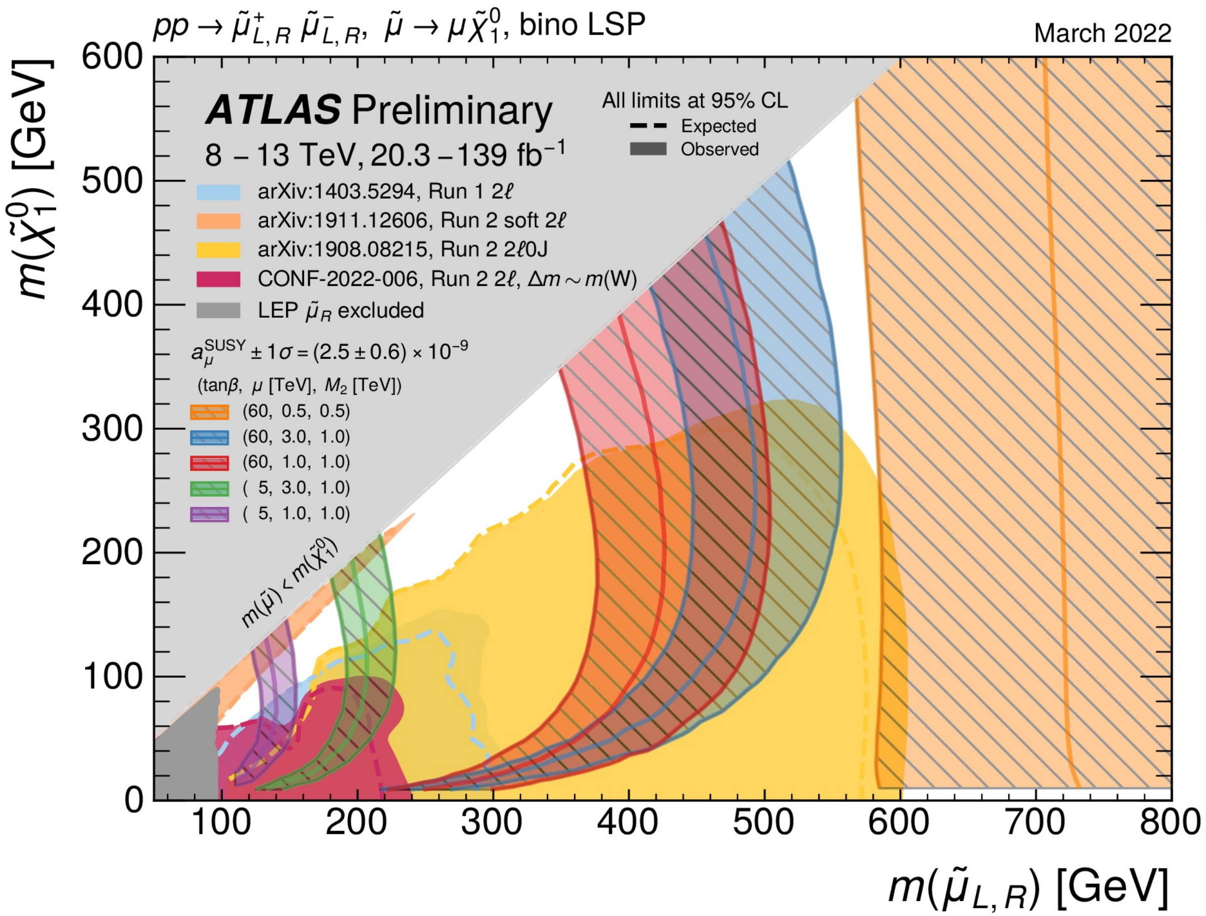
Exclusion limits for smuon pair production

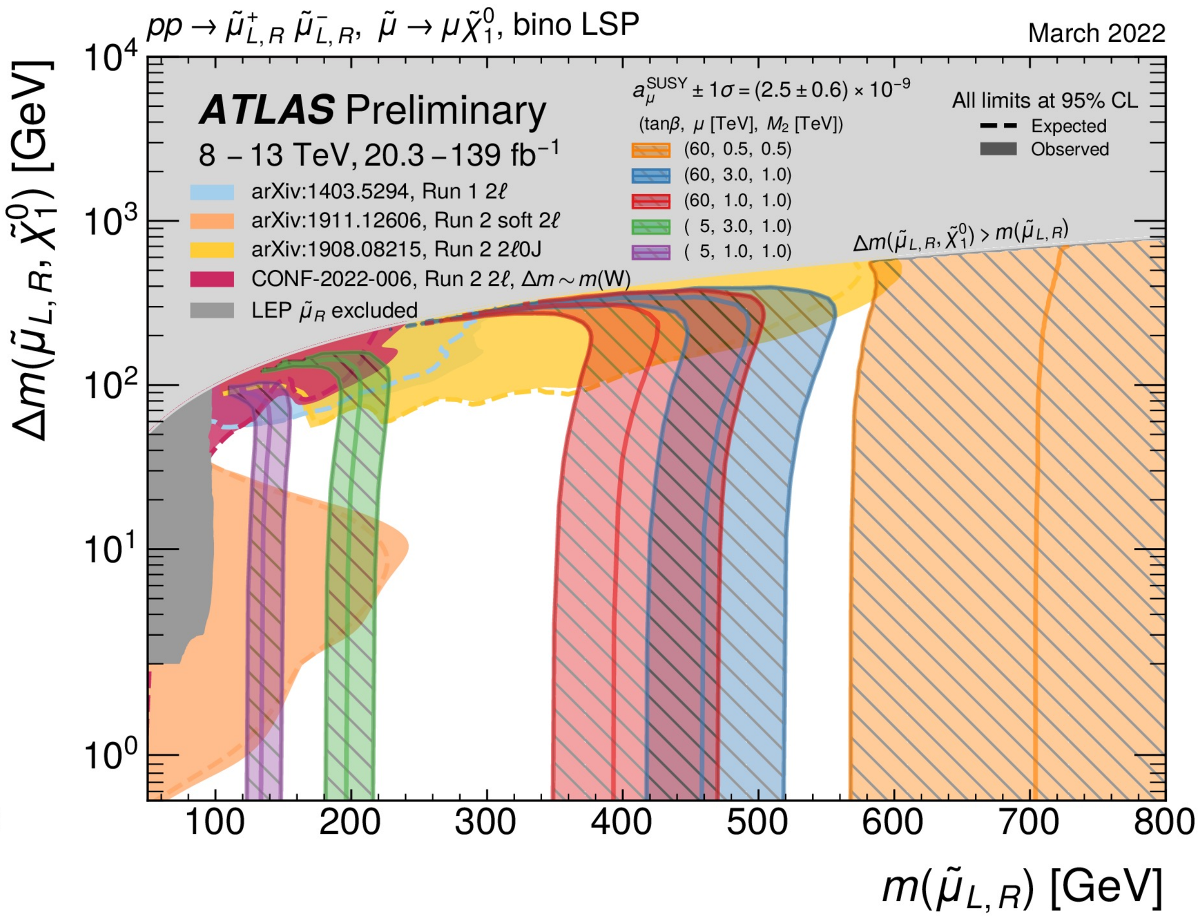
[ATLAS-CONF-2022-006]

2 leptons and no jets

Exclusion limits in the phase space region relevant for the *g-2* anomaly

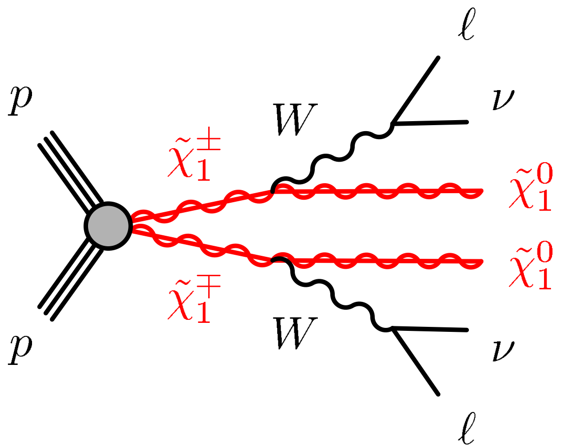






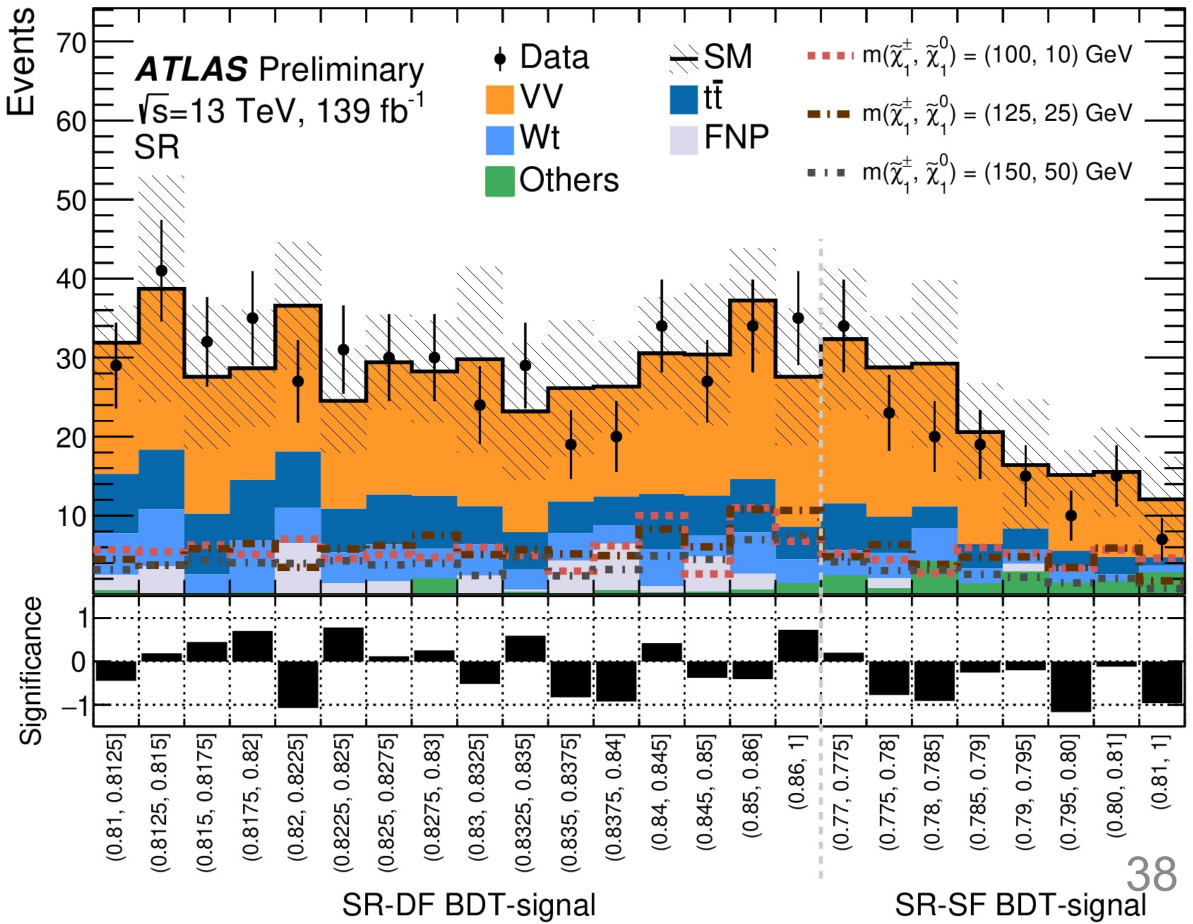
2 leptons and no jets

[ATLAS-CONF-2022-006]



SR selection and yields for the chargino search

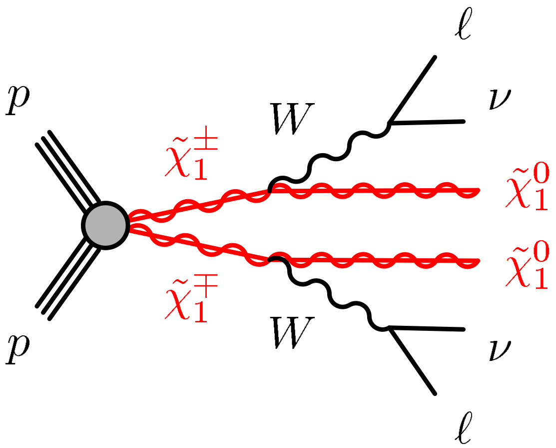
Signal region (SR)	SR-DF	SR-SF
$n_{b\text{-tagged jets}}$	= 0	
$n_{\text{non-}b\text{-tagged jets}}$	= 0	
E_T^{miss} significance	>8	
m_{T2} [GeV]	>50	
BDT-other		< 0.01
Inclusive SRs	BDT-signal	
BDT-signal	∈(0.81 ,0.8125]	∈(0.77 ,0.775]
	∈(0.8125 ,0.815]	∈(0.775 ,0.78]
	∈(0.815 ,0.8175]	∈(0.78 ,0.785]
	∈(0.8175 ,0.82]	∈(0.785 ,0.79]
	∈(0.82 ,0.8225]	∈(0.79 ,0.795]
	∈(0.8225 ,0.825]	∈(0.795 ,0.80]
	∈(0.825 ,0.8275]	∈(0.80 ,0.81]
	∈(0.8275 ,0.83]	∈(0.81 ,1]
	∈(0.83 ,0.8325]	
	∈(0.8325 ,0.835]	
	∈(0.835 ,0.8375]	
	∈(0.8375 ,0.84]	
	∈(0.84 ,0.845]	
	∈(0.845 ,0.85]	
	∈(0.85 ,0.86]	
	∈(0.86,1]	

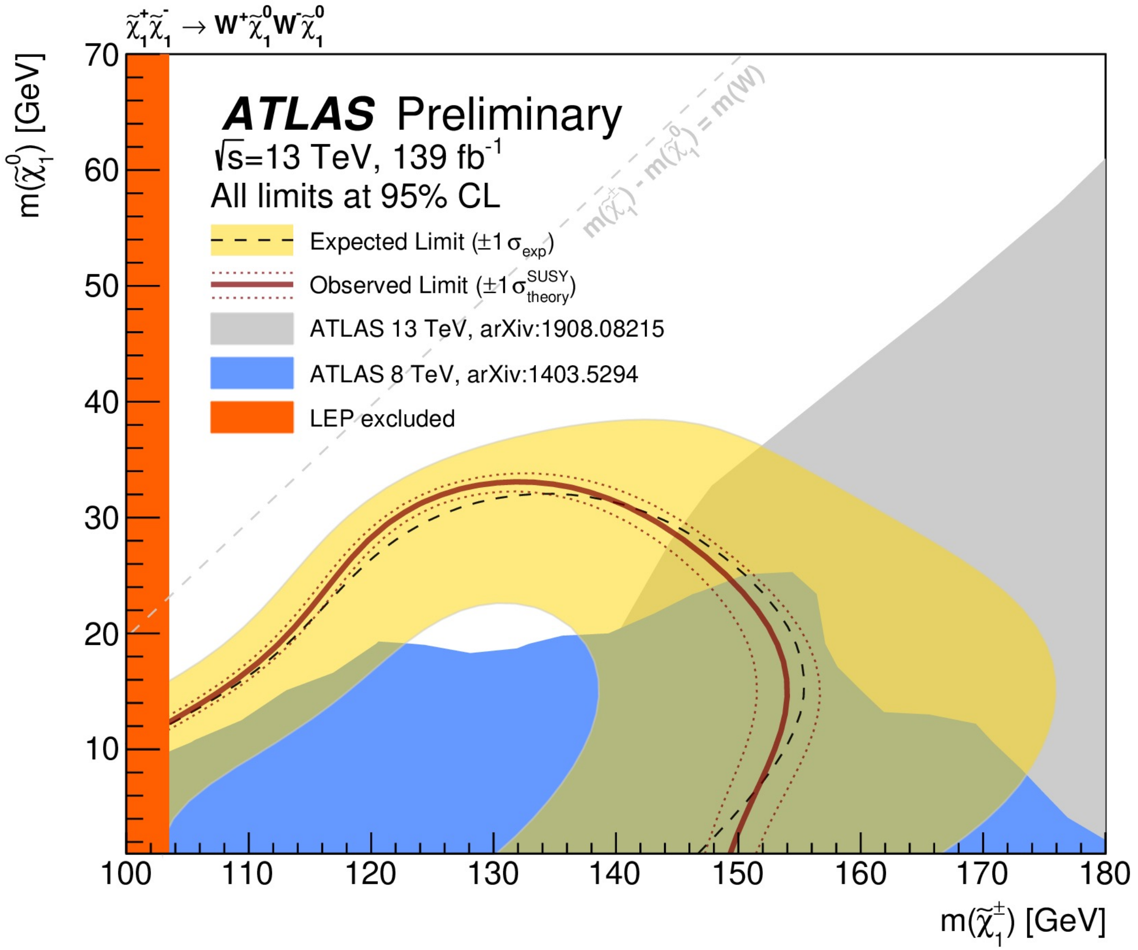


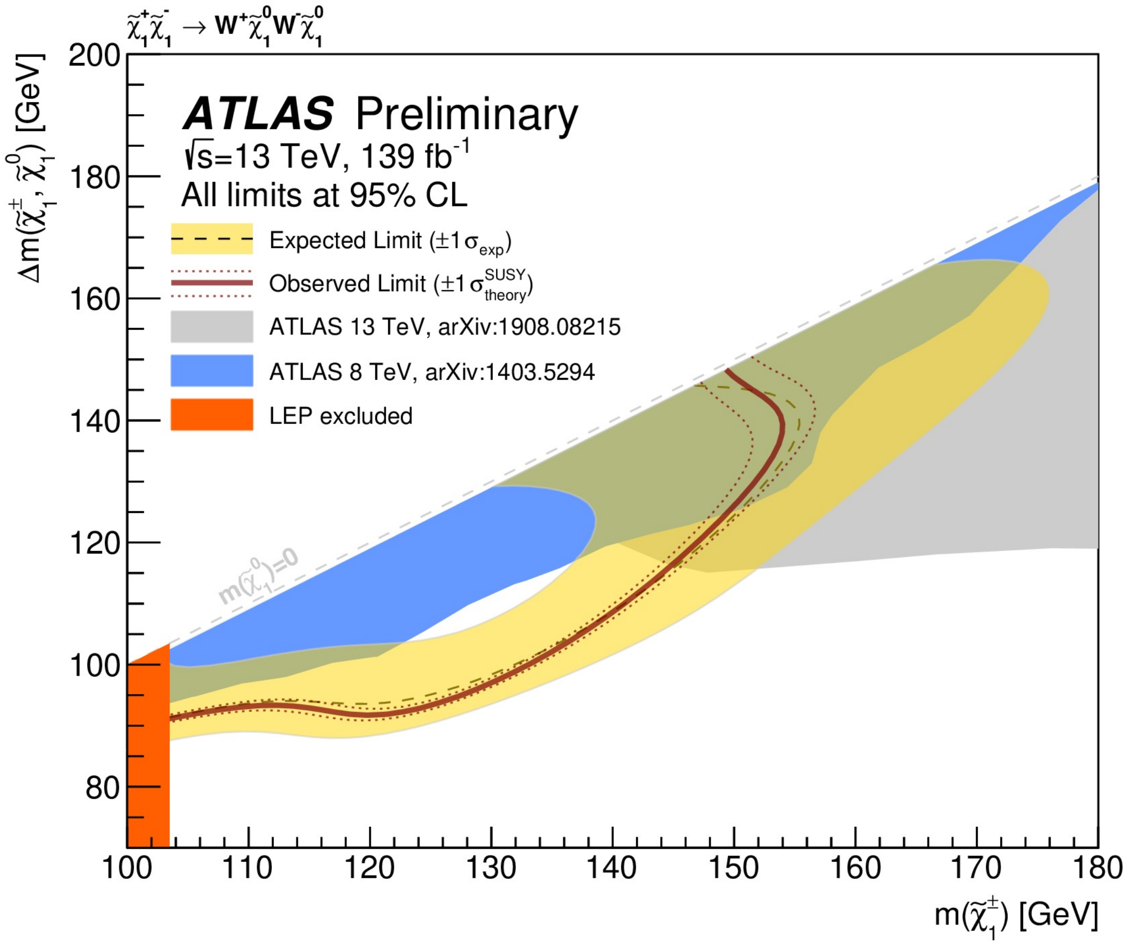
2 leptons and no jets

[ATLAS-CONF-2022-006]

Exclusion limits for the chargino search

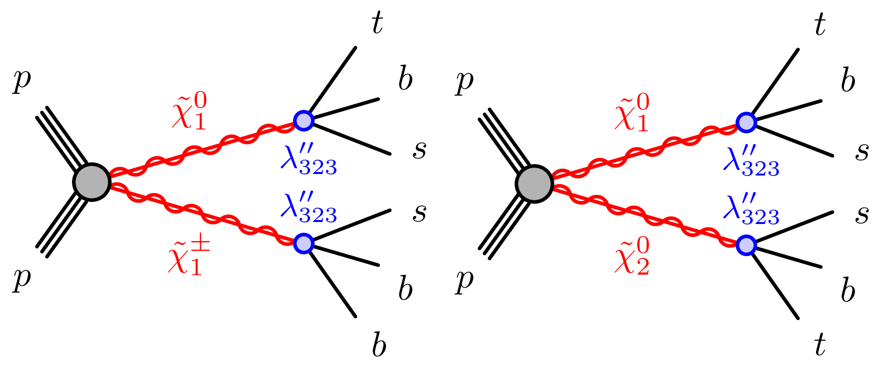






RPV with leptons and many jets

[EPJC 81 (2021) 1023]



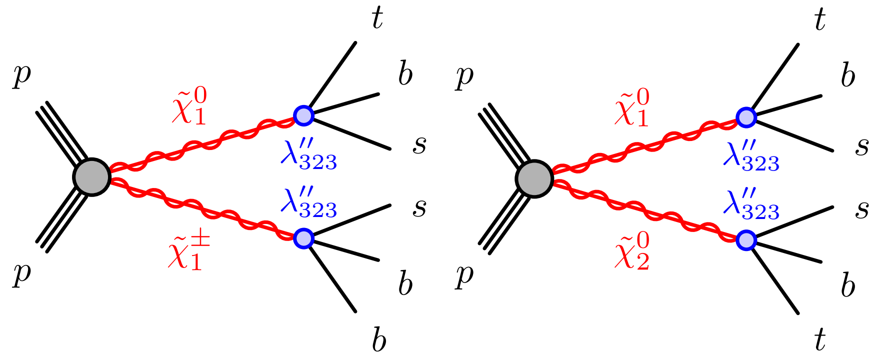
SR selection (jet counting analysis).

- The highest jet multiplicity considered (N_{last}) depends on the jet p_{T} threshold and the lepton category.
- In the 1ℓ category it corresponds to 15, 12, 11, 10, and 8 jets for the different jet p_{T} thresholds in increasing order. In the $2\ell^{\mathrm{sc}}$ category it corresponds to 10, 8, 7, 7, and 6 jets respectively.

Lepton category	Jet multiplicity	Analysis regions
1ℓ category	$4\ldots7$ jets	$0b\ \ell^-$, $0b\ \ell^+$, $0b\ m_{\ell\ell}$, $1b$, $2b$, $3b$, $\geq 4b$
	$8\ldots\geq N_{\mathrm{last}}^{1\ell}$ jets	$0b$, $1b$, $2b$, $3b$, $\geq 4b$
$2\ell^{\mathrm{sc}}$ category	$4\ldots\geq N_{\mathrm{last}}^{2\ell^{\mathrm{sc}}}$ jets	$0b\ 3\ell$, $0b$, $1b$, $2b$, $3b$, $\geq 4b$

RPV with leptons and many jets

[EPJC 81 (2021) 1023]



Jet multiplicity prediction

A data-driven approach is used to estimate the contribution of the main backgrounds in each jet multiplicity slice.

- Above a certain number of jets, the estimate of the normalization relies on assuming a functional form to describe the evolution of the number of background events for process *X* as a function of the jet multiplicity $r^X(j) \equiv N^X_{j+1}/N^X_j$.
  $r^X(j)$ is assumed to be constant, implying a fixed probability of additional jet radiation, referred to as '**staircase scaling**' [Ref. 1, 2, 3, 4]. This behaviour has been observed in *W*/*Z*+jets by the ATLAS [Ref. 5, 6] and CMS [Ref. 7] collaborations.

- For lower jet multiplicities, a different scaling is expected with $r(j)$=k/(j+1) where *k* is a constant, referred to as '**Poisson scaling**' [Ref. 8]. The transition point between these scaling behaviours depends on the jet kinematic selections.

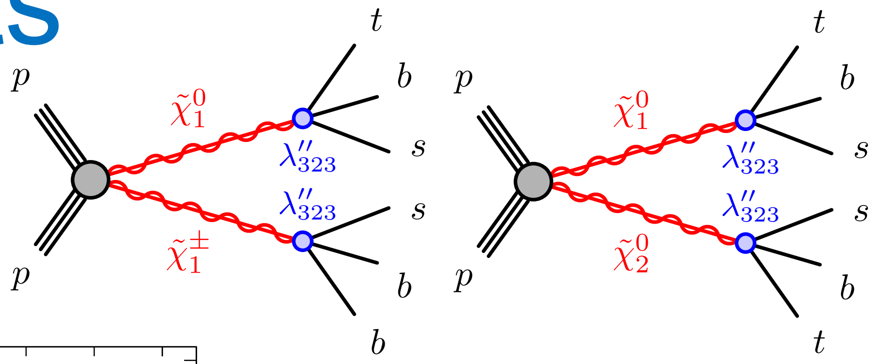
A combination of the two scalings is used for the kinematic phase space relevant for this search.

$$r^X(j) \equiv c_0^X + c_1^X(j + c_2^X)$$

where c_0^X, c_1^X and c_2^X are process-dependent constants that are extracted from the data.

RPV with leptons and many jets

[EPJC 81 (2021) 1023]



Validation of the multiplicity prediction