

Search for supersymmetric sleptons and charginos with the ATLAS detector





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Supersymmetry

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

For each boson/fermion in the SM, a new fermionic/bosonic supersymmetric partner with spin differing by 1/2 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.

If *R*-parity is conserved, $\tilde{\chi}^0$ is the lightest SUSY particle and a potential candidate as **dark matter constituent**.

New searches target the **direct production of sleptons or chargino pairs** at \sqrt{s} = 13 TeV in proton-proton collisions collected by the ATLAS experiment during Run 2 (2015-2018) [1].

Supersymmetry and the g-2 anomaly

Smuons, sneutrinos, neutralinos and charginos couple to μ and γ and cause deviations to the anomalous magnetic moment of the muon, $a_{\mu} = (g-2)/2$.



The discrepancy Δa_{μ} is as large as the SM electroweak contribution to the muon g-2 [2] \rightarrow physics beyond the SM around the electroweak scale may be responsible for Δa_{μ} [3].

The slepton search

- Production of **sleptons** (a pair of selectrons or smuons) decaying into neutralinos through SM leptons [1].
- **Signature**: 2 Same Flavour (SF) leptons, 0/1 jets and E_{T}^{miss} .
- Targeting compressed mass splittings where $\Delta m(\tilde{\ell}, \tilde{\chi}_1^0) \preceq m_W$: existing gap between previous searches.
- Data-driven method for background estimation and cut-and-count approach to optimise the significance of the slepton signal.



Background estimation for sleptons

• Decays of SM particles in events from background processes such as $t\bar{t}$, single-top, WW and $Z(\rightarrow \tau\tau)$ +jets produce opposite-sign SF or DF leptons with the same probability (Flavour-Symmetric Backgrounds, FSB).

 \rightarrow Data events with DF leptons passing the SR selection ($N_{\rm DF}$) are used to predict the FSB contribution in the SF channel.

 Differences in trigger, reconstruction, isolation and identification efficiencies between electrons and muons are accounted for by the efficiency correction method

→ The number of expected FSB events in the SF channel, $N_{\text{SF}}^{\text{expected}}$, is computed as:

$$N_{ee}^{\text{expected}} = 0.5 \times \frac{1}{\kappa} \times \alpha \times N_{\text{DF}},$$
$$N_{\mu\mu}^{\text{expected}} = 0.5 \times \kappa \times \alpha \times N_{\text{DF}}$$
$$\square N_{\text{SF}}^{\text{expected}} = 0.5 \times \left(\kappa + \frac{1}{\kappa}\right) \times \alpha \times N_{\text{DF}}$$



 κ and α take into account the different acceptances and efficiencies for muons and electrons:

$$\kappa = \sqrt{\frac{N_{\mu^{+}\mu^{-}}}{N_{e^{+}e^{-}}}} \quad \alpha = \sqrt{\frac{\epsilon_{\mu\mu}^{\text{trig}}\epsilon_{ee}^{\text{trig}}}{\epsilon_{e\mu}^{\text{trig}}}}_{5}$$

Signal region for the slepton search

 Signal Region (SR) defined maximizing the signal significance with selections on a set of variables:

 $p_{\mathrm{T}}^{\ell_{1}}, p_{\mathrm{T}}^{\ell_{2}}, m_{\ell\ell}, p_{\mathrm{T},\mathrm{boost}}^{\ell\ell}, \Delta \phi_{p_{\mathrm{T}}^{\mathrm{miss}},\ell_{1}}, \Delta \phi_{\ell,\ell}, |\cos \theta_{\ell\ell}^{*}|$

• SRs for 0 or 1 jets with a shapefit in m_{T2}^{100} (binning is chosen to maximise the search sensitivity to the slepton model).



Exclusion limits for the slepton search

• Exclusion limits at 95% Confidence Level (CL) are set on the slepton pair production model.



 Slepton masses up to 150 GeV are excluded at 95% CL for the case of a mass-splitting between the slepton and the neutralino down to about 50 GeV.

Exclusion limits for the slepton search

• Sleptons exclusion limits are also set for the smuon pair production alone.

 \rightarrow Smuons excluded in regions compatible with the *g*-2 anomaly.



The chargino search

- Production of charginos decaying into neutralinos through SM W bosons [1].
- **Signature**: 2 leptons of Same Flavor (SF) or Different Flavor (DF), no jets and E_{T}^{miss} .
- Very challenging signature
 - low signal production cross section
 - leptonic decays of the W bosons
 - targeting compressed mass splittings where $\Delta m(\tilde{\chi}_1^{\pm}, \tilde{\chi}_1^0) \leq m_W$
 - \rightarrow signal similar to the WW background.
- Analysis strategy based on machine learning techniques:
 → Multi-class classification with 4 output scores that sum to 1.





Background estimation for charginos

- Main backgrounds: Diboson (VV with V=W/Z) and top-quark processes (*tt* and Wt).
- Background estimation: main backgrounds normalized to data in dedicated Control Regions (CRs).
 → 2 CRs: CR-VV and CR-Top.





- CR-VV in $n_{b-jets} = 0$ phase space close to the Signal Region (SR).
- CR-top in $n_{b-jets} = 1$ phase space to reach high purity of top backgrounds.

Signal region for the chargino search

- SR defined for high values of BDT-signal to maximise chargino signal significance:
 - SF and DF channels combined together in a likelihood fit.
 - Shape-fit in BDT-signal bins performed to increase sensitivity.
- No significant deviations from the SM observed in SR bins.



Exclusion limits for the chargino search

• Exclusion limits at 95% CL are set on the chargino pair production model.



 Chargino masses up to 140 GeV are excluded at 95% CL for the case of a mass-splitting between the chargino and the neutralino down to about 100 GeV.

Conclusions

Improved analysis strategies for the **slepton** and **chargino** searches allowed to reach **unprecedented sensitivities**:

- Slepton masses excluded in the gap region from previous searches, the new limits supersede the LEP ones and exclude regions compatible with the g-2 anomaly.
- Charginos excluded in regions with mass splittings close to the mass of the W boson where they could have hidden behind the looking alike VV background.



The SM is surviving our new ATLAS searches. However, **challenging regions** compatible with the *g-2* anomaly remain uncovered.

- Exploring these gaps requires larger datasets, improved data analysis techniques or even dedicated new searches.
- **Compressed searches** will continue to be a key target of these efforts in Run 3. Stay tuned to see if they lead to future discoveries!



References

- 1.ATLAS Collaboration, Search for direct pair production of sleptons and charginos decaying to two leptons and neutralinos with mass splittings near the W-boson mass in \sqrt{s} =13TeV pp collisions with the ATLAS detector, arXiv:2209.13935.
- 2. T. Aoyama et al., *The anomalous magnetic moment of the muon in the Standard Model*, Phys. Rept. 887 (2020) 1–166, arXiv:2006.04822.
- 3. M. Endo, K. Hamaguchi, S. Iwamoto, T. Kitahara, *Supersymmetric Interpretation of the Muon g-2 Anomaly*, JHEP 07 (2021) 075, arXiv:2104.03217.

Analysis variables

- $p_{\rm T}^{\ell_1}$: the magnitude of the transverse momentum of the leading lepton;
- $p_{\rm T}^{\ell_2}$: the magnitude of the transverse momentum of the subleading lepton;
- $E_{\rm T}^{\rm miss}$: the magnitude of the missing transverse momentum;
- E_T^{miss} significance: the significance of the E_T^{miss} as defined in <u>ATLAS-CONF-2018-038</u>;
- $m_{\ell\ell}$: the invariant mass of the two leptons;
- m_{T2} : the stransverse mass as defined in <u>Phys. Lett. B 463</u>, <u>Eur. Phys. J. C 80 (2020) 123</u>;
- $\Delta \phi_{\text{boost}}$: the azimuthal angular separation between $E_{\text{T}}^{\text{miss}}$ and the vectorial sum of the two leptons p_{T} and the $E_{\text{T}}^{\text{miss}}$;
- $\Delta \phi_{E_T^{\text{miss}},\ell_1}$: the azimuthal angular separation between E_T^{miss} and the leading lepton;
- $\Delta \phi_{E_T^{\text{miss}}, \ell_2}$: the azimuthal angular separation between E_T^{miss} and the sub-leading lepton;
- $p_{T,boost}^{\ell\ell}$: the module of the vectorial sum of the p_T of the two leptons and the E_T^{miss} ;
- $|\cos \theta_{\ell\ell}^*| = |\cos (2 \tan^{-1} e^{\frac{\Delta \eta_{\ell\ell}}{2}})| = |\tanh e^{\frac{\Delta \eta_{\ell\ell}}{2}}|$, sensitive to the spin of the particles <u>JHEP 0602</u>.

The g-2 anomaly

- Charged particles with spin have magnetic moment $\vec{\mu}_s = g \frac{q}{2m} \vec{S}$.
- Magnetic moment determines how strongly a particle couples to the electromagnetic field.
- SM prediction: at "tree-level" (no loops) \rightarrow g = 2 identically.
- Loops cause "anomalous magnetic moment" $a_{\mu} = (g 2)/2$.



SUSY contribution to g-2 (1/3)

• Assuming common mass scale M_{SUSY} for $\tilde{\mu}$, $\tilde{\nu}_{\mu}$, $\tilde{\chi}^{\pm}$, $\tilde{\chi}^{0}$, the SUSY one loop (1L) contributions to $a_{\mu} = (g-2)/2$ are [3]:

$$a_{\mu}^{\text{SUSY,1L}} = 13 \times 10^{-10} \left(\frac{100 \text{ GeV}}{M_{\text{SUSY}}}\right)^2 \tan\beta \operatorname{sign}(\mu)$$

- SUSY at electroweak scale can explain the observed g-2 deviation!
- Preferred mass range is well-matched to our direct SUSY searches.



SUSY contribution to g-2 (2/3)

- The SUSY contributions to the muon g 2 can be sizable when at least three SUSY multiplets are as light as O(100) GeV.
- They are classified into four types:

Туре	Ŵ	Ĩ	Ĥ	$\widetilde{\mu}_L/\widetilde{\upsilon}_L$	Ĩ
WHL	Х		Х	Х	
BHL		Х	Х	Х	
BHR		Х	Х		Х
BLR		Х		Х	Х

W = wino, B = bino, H = higgsino, L/R = left-handed/ right-handed smuon



SUSY contribution to g-2 (3/3)

• The four sizeable contributions are:

$$a_{\mu}^{\text{WHL}} = \frac{\alpha_2}{4\pi} \frac{m_{\mu}^2}{M_2 \mu} \tan \beta \cdot f_C \left(\frac{M_2^2}{m_{\tilde{\nu}_{\mu}}^2}, \frac{\mu^2}{m_{\tilde{\nu}_{\mu}}^2} \right) - \frac{\alpha_2}{8\pi} \frac{m_{\mu}^2}{M_2 \mu} \tan \beta \cdot f_N \left(\frac{M_2^2}{m_{\tilde{\mu}_{L}}^2}, \frac{\mu^2}{m_{\tilde{\mu}_{L}}^2} \right),$$

$$a_{\mu}^{\text{BHL}} = \frac{\alpha_Y}{8\pi} \frac{m_{\mu}^2}{M_1 \mu} \tan \beta \cdot f_N \left(\frac{M_1^2}{m_{\mu}^2}, \frac{\mu^2}{m_{\tilde{\mu}_{L}}^2} \right),$$

$$a_{\mu}^{\text{BHR}} = -\frac{\alpha_Y}{4\pi} \frac{m_{\mu}^2}{M_1 \mu} \tan \beta \cdot f_N \left(\frac{M_1^2}{m_{\mu}^2}, \frac{\mu^2}{m_{\tilde{\mu}_{R}}^2} \right),$$

$$a_{\mu}^{\text{BLR}} = \frac{\alpha_Y}{4\pi} \frac{m_{\mu}^2 M_1 \mu}{m_{\mu}^2} \tan \beta \cdot f_N \left(\frac{m_{\mu}^2}{M_1^2}, \frac{m_{\mu}^2}{M_1^2} \right),$$

$$M_1 = \text{bino soft mass, } M_2 = \text{wino soft masss}$$

$$\mu = \text{higgsino mass parameter}$$
Refs: Phys. Rev. D 53, 6565 (1996), Phys. Rev. D 56, 4424 (1997)
$$M_1 = \frac{1}{2} \sum_{\mu = 1}^{\infty} \frac{M_1^2}{M_1^2} \sum_{\mu = 1}^{\infty} \frac{M_1^2}{$$

 \widetilde{B}

20

 \widetilde{B}

 \widetilde{H}

Background validation for sleptons



Signal region for sleptons

Signal region (SR)	SR-0J	SR-1J
n _{b-tagged jets}	=	0
$E_{\rm T}^{\rm miss}$ significance	>	7
n _{non-b-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
$p_{\rm T, hoost}^{\ell\ell}$ [GeV]	< 5	-
$ \cos\theta_{\ell\ell}^* $	< 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		
	∈[100	,105)
	∈[105	,110)
	∈[110	,115)
m^{100} [GeV]	∈[115	,120)
	∈[120	,125)
	∈[125	,130)
	∈[130	,140)
	∈[140	,∞)

Background estimation for charginos (1/3)

Control region (CR)		CR-VV		CR-top
$E_{\rm T}^{\rm miss}$ significance			> 8	
$m_{\rm T2}$ [GeV]			> 50	
<i>n</i> _{non-<i>b</i>-tagged jets}			= 0	
Leptons flavour	DF	SF	DF	SF
$n_{b-\text{tagged jets}}$	= 0	= 0	= 1	= 1
BDT-other	-	< 0.01	-	< 0.01
BDT-signal	$\in (0.2, 0.65]$	€ (0.2, 0.65]	$\in (0.5, 0.7]$	∈ (0.7, 0.75]
BDT-VV	> 0.2	> 0.2	-	-
BDT-top	< 0.1	< 0.1	-	-

Background estimation for charginos (2/3)

Region	CR-VV	CR-top
Observed events	634	4468
Fitted backgrounds	634 ± 25	4470 ± 70
Fitted VV	520 ± 27	68 ± 12
Fitted $t\bar{t}$	69 ± 7	3240 ± 100
Fitted single-top	40 ± 6	1130 ± 90
Other backgrounds	$4.8^{+5.1}_{-4.8}$	29 ± 5
FNP leptons	$0.02^{+1.4}_{-0.02}$	$0.06^{+12}_{-0.06}$
Simulated VV	376	49
Simulated $t\bar{t}$	63	2974
Simulated single-top	37	1040

Background estimation for charginos (3/3)



25

<u>₩</u>SM

tī

200

\\`SM

tī

FNP

180

220

 E_{τ}^{miss} significance

240

m⁰_{T2} [GeV]

FNP

Background validation for charginos (1/3)

Validation region (VR)	VR-VV-DF	VR-VV-SF	VR-top-DF	VR-top-SF	VR-top0J-DF	VR-top0J-SF
$E_{\rm T}^{\rm miss}$ significance			>	8		
$m_{\rm T2}$ [GeV]			> 5	0		
$n_{\text{non-}b\text{-tagged jets}}$			= ()		
$n_{b-\text{tagged jets}}$	= 0	= 0	= 1	= 1	= 0	= 0
BDT-other	-	< 0.01	-	< 0.01	-	< 0.01
BDT-signal	$\in (0.65, 0.81]$	$\in (0.65, 0.77]$	$\in (0.7, 1]$	$\in (0.75, 1]$	€ (0.5, 0.81]	$\in (0.5, 0.77]$
BDT-VV	> 0.2	> 0.2	-	-	< 0.15	< 0.15
BDT-top	< 0.1	< 0.1	-	-	-	-

Background validation for charginos (2/3)

Regions	VR-VV-DF	VR-VV-SF	VR-top-DF	VR-top-SF	VR-top0J-DF	VR-top0J-SF
Observed events	972	596	1910	95	810	17
Fitted backgrounds	940 ± 60	670 ± 90	1900 ± 90	101 ± 10	880 ± 40	18 ± 4
Fitted VV	730 ± 50	400 ± 50	32 ± 13	2.2 ± 2.1	427 ± 30	8.1 ± 2.6
Fitted $t\bar{t}$	116 ± 12	111 ± 11	1350 ± 50	67 ± 7	260 ± 21	5.8 ± 1.8
Fitted single-top	94 ± 19	75 ± 11	500 ± 60	27 ± 7	168 ± 18	4 ± 1
Other backgrounds	3.1 ± 1.5	70 ± 70	13.6 ± 2.5	0.8 ± 0.4	5.2 ± 1.9	0.05 ± 0.05
FNP leptons	$0.02^{+2.3}_{-0.02}$	7 ± 4	$0.03^{+5}_{-0.03}$	4.2 ± 1.3	21 ± 8	$0.05^{+0.15}_{-0.05}$
Simulated VV	527	291	23	1.6	309	5.9
Simulated $t\bar{t}$	106	102	1240	61	239	5.3
Simulated single-top	87	69	460	25	154	3.2

Background validation for charginos (3/3)



Signal region for charginos

Signal region (SR)	SR-DF	SR-SF
n _{b-tagged jets}	=	= 0
<i>n</i> _{non-<i>b</i>-tagged jets}	=	= 0
$E_{\rm T}^{\rm miss}$ significance		>8
m_{T2} [GeV]		>50
BDT-other		< 0.01
Binned SRs		
	€(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]
DDT signal	€(0.8275,0.83]	€(0.81,1]
BD1-signal	€(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]	

Summary of ATLAS SUSY searches

March 2023							$\sqrt{s} = 13 \text{ TeV}$				
	Model	Si	gnature)£di	t [fb ⁻	¹] Mass	limit				Reference
SS	$\tilde{q}\tilde{q},\tilde{q}{ ightarrow}q\tilde{\chi}_{1}^{0}$	0 e,µ mono-jet	2-6 jets 1-3 jets	$\begin{array}{cc} E_T^{ m miss} & 1 \\ E_T^{ m miss} & 1 \end{array}$	39 39	 <i>q̃</i> [1×, 8× Degen.] <i>q̃</i> [8× Degen.] 	1. 0.9	0	1.85	m($ ilde{\chi}_1^0)$ <400 GeV m($ ilde{q}$)-m($ ilde{\chi}_1^0)$ =5 GeV	2010.14293 2102.10874
arche	$\tilde{g}\tilde{g}, \tilde{g} \rightarrow q \bar{q} \tilde{\chi}_1^0$	0 <i>e</i> , <i>µ</i>	2-6 jets	E_T^{miss} 1	39	ëg ëg	Forbidde	n	2.3 1.15-1.95	$m(\tilde{\chi}_{1}^{0})=0 \text{ GeV} \\ m(\tilde{\chi}_{1}^{0})=1000 \text{ GeV}$	2010.14293 2010.14293
Se	$\tilde{g}\tilde{g}, \tilde{g} \rightarrow q\bar{q}W\tilde{\chi}^0_{1}$	1 e,µ	2-6 jets	1	39	ĝ			2.2	m(𝔅1)<600 GeV	2101.01629
sive	$\tilde{g}\tilde{g}, \tilde{g} \rightarrow q\bar{q}(\ell\ell)\tilde{\chi}_1^0$ $\tilde{g}\tilde{g}, \tilde{g} \rightarrow q\bar{q}(\ell\ell)\tilde{\chi}_1^0$	ее, µµ 0 е. µ	2 jets 7-11 iets	E_T^{miss} 1 F^{miss} 1	39 39	ĝ ĝ			2.2	$m(\tilde{\chi}_1^0) < 700 \text{ GeV}$ $m(\tilde{\chi}_1^0) < 600 \text{ GeV}$	2204.13072
clus	$gg, g \rightarrow qq w 2\lambda_1$	SS <i>e</i> , <i>µ</i>	6 jets	2 _T 1	39	s ĝ		1.15	1.57	$m(\tilde{g})-m(\tilde{\chi}_{1}^{0})=200 \text{ GeV}$	1909.08457
Ч	$\tilde{g}\tilde{g}, \; \tilde{g} \rightarrow t t \tilde{\chi}_1^0$	0-1 <i>e</i> , μ SS <i>e</i> , μ	3 <i>b</i> 6 jets	E_T^{miss} 1	39 39	750 750		1.25	2.45	$m(\tilde{\chi}_{1}^{0}) < 500 \text{ GeV}$ $m(\tilde{g})-m(\tilde{\chi}_{1}^{0})=300 \text{ GeV}$	2211.08028 1909.08457
	$ ilde{b}_1 ilde{b}_1$	0 <i>e</i> , <i>µ</i>	2 <i>b</i>	E_T^{miss} 1	39	${ar b_1\ ar b_1}$	0.68	1.255		$m(\tilde{\chi}_{1}^{0}) < 400 \text{ GeV}$ 10 GeV $< \Delta m(\tilde{b}_{1}, \tilde{\chi}_{1}^{0}) < 20 \text{ GeV}$	2101.12527 2101.12527
arks	$\tilde{b}_1 \tilde{b}_1, \tilde{b}_1 \rightarrow b \tilde{\chi}_2^0 \rightarrow b h \tilde{\chi}_1^0$	0 e,μ 2 τ	6 <i>b</i> 2 <i>b</i>	E_T^{miss} 1 E_T^{miss} 1	39 39	\tilde{b}_1 Forbidden \tilde{b}_1 \tilde{b}_1	0.13-0.85	0.23-1.35	$\Delta m(\tilde{\chi}_2^0)$ $\Delta m(\tilde{\chi}_2^0)$	$(\tilde{\chi}_1^0)=130 \text{ GeV}, m(\tilde{\chi}_1^0)=100 \text{ GeV}$ $(\tilde{\chi}_2^0, \tilde{\chi}_1^0)=130 \text{ GeV}, m(\tilde{\chi}_1^0)=0 \text{ GeV}$	1908.03122 2103.08189
sque	$\tilde{t}_1 \tilde{t}_1, \tilde{t}_1 \rightarrow t \tilde{\chi}_1^0$	0-1 <i>e</i> , μ	≥ 1 jet	E_T^{miss} 1	39			1.25		$m(\tilde{\chi}_{1}^{0})=1 \text{ GeV}$	2004.14060, 2012.03799
en.	$\tilde{t}_1 \tilde{t}_1, \tilde{t}_1 \rightarrow W b \tilde{\chi}_1^0$ $\tilde{t}_1 \tilde{t}_1, \tilde{t}_1 \rightarrow \tilde{\tau}_1 b \chi, \tilde{\tau}_1 \rightarrow \tau \tilde{G}$	1 e,μ 1-2 τ	3 jets/1 b 2 jets/1 b	E_T^{miss} 1 E_T^{miss} 1	39 39	t_1 \tilde{t}_1	Forbidden 0.65	1	4	$m(\tilde{\chi}_{1}^{0})=500 \text{ GeV}$ $m(\tilde{\tau}_{1})=800 \text{ GeV}$	2012.03799 2108.07665
3 rd g direc	$\tilde{t}_1 \tilde{t}_1, \tilde{t}_1 \rightarrow c \tilde{\chi}_1^0 / \tilde{c} \tilde{c}, \tilde{c} \rightarrow c \tilde{\chi}_1^0$	0 e, μ 0 e, μ	2 c mono-jet	E_T^{miss} 36 E_T^{miss} 1	5.1 39		0.85		<i>a</i>	$m(\tilde{\chi}_1^0)=0 \text{ GeV}$ $m(\tilde{\chi}_1,\tilde{c})-m(\tilde{\chi}_1^0)=5 \text{ GeV}$	1805.01649 2102.10874
	$\tilde{t}_1 \tilde{t}_1, \tilde{t}_1 \rightarrow t \tilde{\chi}_2^0, \tilde{\chi}_2^0 \rightarrow Z/h \tilde{\chi}_1^0$	1-2 e, µ	1-4 b	E_T^{miss} 1	39	\tilde{t}_1	0.06	7-1.18		$m(\tilde{\chi}_2^0)=500 \text{ GeV}$	2006.05880
	$\tilde{t}_2 \tilde{t}_2, \tilde{t}_2 \rightarrow \tilde{t}_1 + Z$	3 e, µ	1 <i>b</i>	E_T^{miss} 1	39	ī ₂	Forbidden 0.86	_	$m(\tilde{\chi}_{1}^{0})=$	360 GeV, $m(\tilde{t}_1) - m(\tilde{\chi}_1^0) = 40 \text{ GeV}$	2006.05880
	$\tilde{\chi}_1^{\pm} \tilde{\chi}_2^0$ via <i>WZ</i>	Multiple ℓ/jets ee, μμ	≥ 1 jet	E_T^{miss} 1 E_T^{miss} 1	39 39		0.96			$m(\tilde{\chi}_1^0)=0$, wino-bino $m(\tilde{\chi}_1^{\pm})-m(\tilde{\chi}_1^0)=5$ GeV, wino-bino	2106.01676, 2108.07586 1911.12606
	$\tilde{\chi}_1^{\pm} \tilde{\chi}_1^{\mp}$ via WW	2 e,μ Multiplo ℓ/ioto		E_T^{miss} 1 E^{miss} 1	39	$\tilde{\chi}_1^{\pm}$	0.42	00		$m(\tilde{\chi}_1^0)=0$, wino-bino	1908.08215
	$\tilde{\chi}_1 \chi_2$ via wh $\tilde{\chi}_1^{\pm} \tilde{\chi}_1^{\pm}$ via $\tilde{\ell}_L / \tilde{\nu}$	$2 e, \mu$		E_T E_T^{miss} 1	39 39	$\tilde{\chi}_1^{\pm}$	1.	.00		$m(\tilde{\ell}_1)=70$ GeV, wino-bino $m(\tilde{\ell}_1\tilde{\chi})=0.5(m(\tilde{\chi}_1^{\pm})+m(\tilde{\chi}_1^{0}))$	1908.08215
N N	$\tilde{\tau}\tilde{\tau}, \tilde{\tau} \rightarrow \tau \tilde{\chi}_1^0$	2τ		E_T^{miss} 1	39	τ ¹ [τ̃ _L , τ̃ _{R,L}] 0.16-0.3 0.1	12-0.39			$m(\tilde{\chi}_1^0)=0$	1911.06660
шį	$\tilde{\ell}_{\mathrm{L,R}} \tilde{\ell}_{\mathrm{L,R}}, \tilde{\ell} \rightarrow \ell \tilde{\chi}_1^0$	2 e,μ ee,μμ	0 jets ≥ 1 jet	E_T^{miss} 1 E_T^{miss} 1	39 39	$\widetilde{\widetilde{\ell}}$ 0.256	0.7			$m(\tilde{\ell}_{1}^{0})=0$ $m(\tilde{\ell})-m(\tilde{\chi}_{1}^{0})=10 \text{ GeV}$	1908.08215 1911.12606
	$\tilde{H}\tilde{H}, \tilde{H} \rightarrow h\tilde{G}/Z\tilde{G}$	0 e, µ 4 e, µ	$\geq 3 b$ 0 jets	E_T^{miss} 36 E_T^{miss} 1	5.1 39	Й 0.13-0.23	0.29-0.88			$BR(\tilde{\chi}_{1}^{0} \rightarrow h\tilde{G})=1$ $BR(\tilde{\chi}_{1}^{0} \rightarrow Z\tilde{G})=1$	1806.04030 2103 11684
		$0 \ e, \mu \ge$	2 large jets	$E_T^{T_{miss}}$ 1	39	ĨI Ĥ	0.45-0.93			$BR(\tilde{\chi}_1^0 \rightarrow Z\tilde{G})=1$	2108.07586
		2 <i>e</i> ,µ	≥ 2 jets	E_T^{miss} 1	39	Ĥ	0.77		B	$R(\tilde{\chi}_1^0 \to Z\tilde{G}) = BR(\tilde{\chi}_1^0 \to h\tilde{G}) = 0.5$	2204.13072
<u>ر</u>	Direct $\tilde{\chi}_1^+ \tilde{\chi}_1^-$ prod., long-lived $\tilde{\chi}_1^\pm$	Disapp. trk	1 jet	E_T^{miss} 1	39	$ \tilde{\chi}_{1}^{\pm} \\ \tilde{\chi}_{1}^{\pm} $ 0.21	0.66			Pure Wino Pure higgsino	2201.02472 2201.02472
live	Stable g R-hadron	pixel dE/dx		E_T^{miss} 1	39	ĝ			2.05	-0	2205.06013
ng-	Metastable \tilde{g} R-hadron, $\tilde{g} \rightarrow qq\chi_1^{\vee}$	pixel dE/dx Displ lep		E_T^{miss} 1 E^{miss} 1	39 20	$\hat{g} [\tau(\hat{g}) = 10 \text{ ns}]$	0.7		2.2	$m(\tilde{k}_{1}^{0})=100 \text{ GeV}$	2205.06013
D Lo		pixel dE/dx		E_T E_T^{miss} 1	39	τ 0.34 τ 0.36	6			$\tau(\tilde{\ell}) = 0.1 \text{ ns}$ $\tau(\tilde{\ell}) = 0.1 \text{ ns}$ $\tau(\tilde{\ell}) = 10 \text{ ns}$	2011.07812 2205.06013
	$\tilde{\chi}_1^{\pm} \tilde{\chi}_1^{\mp} / \tilde{\chi}_1^0, \tilde{\chi}_1^{\pm} \rightarrow Z \ell \rightarrow \ell \ell \ell$	3 e,µ		1	39	$\tilde{\chi}_1^{\mp}/\tilde{\chi}_1^0$ [BR($Z\tau$)=1, BR(Ze)=1]	0.625 1	.05		Pure Wino	2011.10543
	$\tilde{\chi}_1^{\pm}\tilde{\chi}_1^{+}/\tilde{\chi}_2^{0} \rightarrow WW/Z\ell\ell\ell\ell\nu\nu$	4 e,μ	0 jets 5 large iete	$E_T^{\text{mass}} = 1$	39	$\tilde{\chi}_{1}^{\pi}/\tilde{\chi}_{2}^{0} [\lambda_{i33} \neq 0, \lambda_{12k} \neq 0]$	0.95	1.2	1.55	$m(\tilde{\chi}_{1}^{0})=200 \text{ GeV}$	2103.11684
	gg, $g \rightarrow qq\chi_1, \chi_1 \rightarrow qqq$ $\tilde{t}, \tilde{t} \rightarrow t\tilde{\chi}_1^0, \tilde{\chi}_1^0 \rightarrow ths$	4-	Multiple	, 36 36	5.1 5.1	$\tilde{t} = [\lambda_{222}''] = 200 \text{ GeV}, 1100 \text{ GeV}]^{-1}$ $\tilde{t} = [\lambda_{222}''] = 20-4, 10-2]$	0.55 1	.05	1.9	$m(\tilde{\chi}_{1}^{0})=200 \text{ GeV}, \text{ bino-like}$	ATLAS-CONF-2018-003
JP/	$\tilde{t}\tilde{t}, \tilde{t} \rightarrow b\tilde{\chi}_{1}^{\pm}, \tilde{\chi}_{1}^{\pm} \rightarrow bbs$		$\geq 4b$	1	39	ĩ	Forbidden 0.95			m($\tilde{\chi}_{1}^{\pm}$)=500 GeV	2010.01015
	$\tilde{t}_1 \tilde{t}_1, \tilde{t}_1 \rightarrow bs$	2	2 jets + 2 b	36	6.7	$\tilde{t}_1 [qq, bs]$	0.42 0.61				1710.07171
	$t_1t_1, t_1 \rightarrow q\ell$	2 e,μ 1 μ	2 <i>b</i> DV	36	5.1 36	$t_1 = t_1$ [1e-10< λ'_{22k} <1e-8, 3e-10< λ'_{22k} <3	e-9] 1.	0.4-1.	.45 1.6	$BR(\tilde{t}_1 \rightarrow be/b\mu) > 20\%$ $BR(\tilde{t}_1 \rightarrow q\mu) = 100\%, \cos\theta_t = 1$	1710.05544 2003.11956
	$\tilde{\chi}_1^{\pm}/\tilde{\chi}_2^0/\tilde{\chi}_1^0, \tilde{\chi}_{1,2}^0 \rightarrow tbs, \tilde{\chi}_1^+ \rightarrow bbs$	1-2 <i>e</i> , µ	≥6 jets	1	39	$\tilde{\chi}_{1}^{0}$ 0.2-0.32				Pure higgsino	2106.09609

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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. 10^{-1}

ATLAS SUSV Searches* - 95% CL Lower Limits

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ATI AS Preliminary