Prospects for electroweakinos at the HL-LHC

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Based on collaboration with Jiu Liu, Carlos Wagner, and Xiaoping Wang

arXiv:2008.11847 [hep-ph] arXiv:2006.07389 [hep-ph]



Motivation







Scalars & in particular strongly interacting superpartners studied in great detail so far, stringent limits



Plenty of room to explore weakly interacting sfermions

<u>Current status</u>

https://twiki.cern.ch/twiki/bin/view/AtlasPublic/SupersymmetryPublicResults

ATLAS SUSY Searches* - 95% CL Lower Limits July 2020

ATLAS Preliminary $\sqrt{s} = 13 \text{ TeV}$

	Model	Signat	ture	∫ <i>L dt</i> [fb ⁻	¹] Ma	ss limit		Reference
Inclusive Searches	$\tilde{q}\tilde{q},\tilde{q}{ ightarrow}q\tilde{\chi}_1^0$	0 <i>e</i> , μ 2-6 je mono-jet 1-3 je	ets E_T^{miss} ets E_T^{miss}	139 36.1	 <i>q</i> [10× Degen.] <i>q</i> [1×, 8× Degen.] 	0.43 0.71	1.9 m($\tilde{\chi}_1^0$)<400 GeV m(\tilde{q})-m($\tilde{\chi}_1^0$)=5 GeV	ATLAS-CONF-2019-040 1711.03301
	$\tilde{g}\tilde{g},\tilde{g}{ ightarrow} q \tilde{q} \tilde{\chi}^0_1$	0 <i>e</i> , <i>µ</i> 2-6 je	ets E_T^{miss}	139	e e e	Forbidden	2.35 $m(\tilde{k}_1^0)=0 \text{ GeV}$ 1.15-1.95 $m(\tilde{k}_1^0)=1000 \text{ GeV}$	ATLAS-CONF-2019-040 ATLAS-CONF-2019-040
	$\tilde{g}\tilde{g}, \tilde{g} \rightarrow q\bar{q}W\tilde{\chi}_1^0$	1 <i>e</i> , <i>µ</i> 2-6 je	ets	139	Ĩ		2.2 m($\tilde{\chi}_1^0$)<600 GeV	ATLAS-CONF-2020-047
	$\tilde{g}\tilde{g}, \tilde{g} \rightarrow q\bar{q}(\ell\ell)\tilde{\chi}_1^0$	<i>ee</i> ,μμ 2 jei	ts E_T^{miss}	36.1	ğ Ξ		1.2 $m(\tilde{g})-m(\tilde{\chi}_{1}^{0})=50 \text{ GeV}$	1805.11381
	$gg, g \rightarrow qqWZX_1$	$SS e, \mu$ 6 je	is E _T	139	ŝ		1.15 $m(\tilde{x}_1) < 600 \text{ GeV}$ $m(\tilde{y}_1) = 200 \text{ GeV}$	1909.08457
	$\tilde{g}\tilde{g}, \tilde{g} \rightarrow t t \tilde{\chi}_1^0$	0-1 <i>e</i> ,μ 3 <i>b</i> SS <i>e</i> ,μ 6 je	E_T^{miss}	79.8 139	ο σ σ σ σ σ		2.25 m(\tilde{k}_1^0)<200 GeV 1.25 m(\tilde{g})-m(\tilde{k}_1^0)=300 GeV	ATLAS-CONF-2018-041 1909.08457
ks Dn	$\tilde{b}_1 \tilde{b}_1, \tilde{b}_1 \rightarrow b \tilde{\chi}_1^0 / t \tilde{\chi}_1^{\pm}$	Multi Multi	ole ole	36.1 139	<i>b</i> ₁ Forbidden <i>b</i> ₁	0.9 Forbidden 0.74	$m(\tilde{\chi}_1^0)$ =300 GeV, BR($b\tilde{\chi}_1^0$)=1 $m(\tilde{\chi}_1^0)$ =200 GeV, m($\tilde{\chi}_1^\pm$)=300 GeV, BR($b\tilde{\chi}_1^\pm$)=1	1708.09266, 1711.03301 1909.08457
	$\tilde{b}_1 \tilde{b}_1, \tilde{b}_1 \rightarrow b \tilde{\chi}_2^0 \rightarrow b h \tilde{\chi}_1^0$	0 e, μ 6 b 2 τ 2 b	E_T^{miss} E_T^{miss}	139 139	$ ilde{b}_1$ Forbidden $ ilde{b}_1$	0.13-0.85	$\begin{array}{llllllllllllllllllllllllllllllllllll$	1908.03122 ATLAS-CONF-2020-031
luar ucti	$\tilde{t}_1 \tilde{t}_1, \tilde{t}_1 \rightarrow t \tilde{\chi}_1^0$	0-1 $e, \mu \ge 1$ j	et E_T^{miss}	139	\tilde{t}_1		1.25 $m(\tilde{\chi}_1^0)=1 \text{ GeV}$	ATLAS-CONF-2020-003, 2004.14060
rod	$\tilde{t}_1 \tilde{t}_1, \tilde{t}_1 \rightarrow W b \tilde{\chi}_1^0$	$1 e, \mu$ 3 jets/	$1b E_T^{\text{miss}}$	139	<i>t</i> ₁	0.44-0.59	$m(\tilde{\chi}_1^0)=400 \text{ GeV}$	ATLAS-CONF-2019-017
3 rd gen direct p	$t_1t_1, t_1 \rightarrow \tau_1 b \nu, \tau_1 \rightarrow \tau G$ $\tilde{t}_1 \tilde{t}_1, \tilde{t}_1 \rightarrow \tilde{t}_2 \tilde{\tilde{t}}_1^0 / \tilde{c} \tilde{c} \rightarrow \tilde{c} \tilde{\tilde{t}}_1^0$	$0e, \mu$ 2 jets	E_T^{miss}	36.1	r ₁ č	0.85	$m(\tilde{\tau}_1) = 000 \text{ GeV}$ $m(\tilde{\chi}_1^0) = 0 \text{ GeV}$	1805.01649
		0 <i>e</i> , μ mono	-jet E_T^{miss}	36.1	\tilde{t}_1 \tilde{t}_1	0.46 0.43	$\begin{array}{c} m(\tilde{r}_1,\tilde{c})-m(\tilde{x}_1^0)=\!$	1805.01649 1711.03301
	$\tilde{t}_1\tilde{t}_1, \tilde{t}_1 \rightarrow t\tilde{\chi}_2^0, \tilde{\chi}_2^0 \rightarrow Z/h\tilde{\chi}_1^0$	1-2 <i>e</i> , <i>µ</i> 1-4	$b = E_T^{miss}$	139	\tilde{t}_1	0.067	-1.18 $m(\tilde{\chi}_2^0) = 500 \text{ GeV}$	SUSY-2018-09
	$\tilde{t}_2 \tilde{t}_2, \tilde{t}_2 \rightarrow \tilde{t}_1 + Z$	3 e,μ 1 b	E_T^{miss}	139	\tilde{t}_2	Forbidden 0.86	$m(\tilde{\chi}_1^0)$ =360 GeV, $m(\tilde{t}_1)$ - $m(\tilde{\chi}_1^0)$ = 40 GeV	SUSY-2018-09
	${ ilde \chi}_1^\pm { ilde \chi}_2^0$ via WZ	$\begin{array}{c} 3 \ e, \mu \\ e e, \mu \mu \\ \end{array} \ge 1 \ j$	et E_T^{miss}	139 139	$egin{array}{c} { ilde \chi}_1^{\pm}/{ ilde \chi}_2^0 \ { ilde \chi}_1^{\pm}/{ ilde \chi}_2^0 \ 0.205 \end{array}$	0.64	$\begin{array}{c} m(\tilde{\chi}_1^0) {=} 0 \\ m(\tilde{\chi}_1^{\pm}) {-} m(\tilde{\chi}_1^0) {=} 5 \ \mathrm{GeV} \end{array}$	ATLAS-CONF-2020-015 1911.12606
	$ ilde{\chi}_1^{\pm} ilde{\chi}_1^{\mp}$ via WW	2 <i>e</i> , <i>µ</i>	$E_T^{\rm miss}$	139	$\tilde{\chi}_1^{\pm}$	0.42	$m(\tilde{\chi}_1^0)=0$	1908.08215
	$\tilde{\chi}_1^{\pm}\tilde{\chi}_2^0$ via Wh	0-1 <i>e</i> , μ 2 <i>b</i> /2	γE_T^{miss}	139	$\tilde{\chi}_1^{\pm}/\tilde{\chi}_2^0$ Forbidden	0.74	$m(\tilde{\chi}_1^0)=70 \text{ GeV}$	2004.10894, 1909.09226
irec	$\chi_1 \chi_1$ via $\ell_L / \tilde{\nu}$	2 e, µ	Emiss Emiss	139	χ_1^2	0.12.0.20	$m(\tilde{\ell},\tilde{v})=0.5(m(\tilde{\ell}_1^+)+m(\tilde{\ell}_1^0))$	1908.08215
ס־	$\tilde{\tau}\tau, \tau \to \tau \chi_1$ $\tilde{\ell}_1 p \tilde{\ell}_1 p \tilde{\ell} \to \ell \tilde{\chi}_1^0$	2 <i>e</i> ,μ 0 je	ts E_T^{miss}	139	Ĩ	0.12-0.39	$m(\tilde{x}_1) = 0$ $m(\tilde{\chi}_1^0) = 0$	1908.08215
	L, K ⁰ L, K ¹ , C ¹ , O	$ee, \mu\mu \ge 1$ j	et E_T^{miss}	139	τ̃ 0.256		$m(\tilde{\ell})-m(\tilde{\chi}_1^0)=10 \text{ GeV}$	1911.12606
	$\tilde{H}\tilde{H},\tilde{H}{ ightarrow}h\tilde{G}/Z\tilde{G}$	$\begin{array}{ll} 0 \ e, \mu & \geq 3 \\ 4 \ e, \mu & 0 \ {\rm jet} \end{array}$	$\begin{array}{ll} b & E_T^{\rm miss} \\ {\rm is} & E_T^{\rm miss} \end{array}$	36.1 139	<u>Й</u> 0.13-0.23 <u>Й</u>	0.29-0.88 0.55	$\begin{array}{l} BR(\tilde{\chi}_1^0 \to h\tilde{G}){=}1\\ BR(\tilde{\chi}_1^0 \to Z\tilde{G}){=}1 \end{array}$	1806.04030 ATLAS-CONF-2020-040
-lived cles	$\text{Direct}\tilde{\chi}_1^{+}\tilde{\chi}_1^{-}\text{prod.},\text{long-lived}\tilde{\chi}_1^{\pm}$	Disapp. trk 1 je	t E_T^{miss}	36.1	$ \tilde{x}_{1}^{\pm} \\ \tilde{x}_{1}^{\pm} 0.15 $	0.46	Pure Wino Pure higgsino	1712.02118 ATL-PHYS-PUB-2017-019
arti	Stable § R-hadron	Multi	ole	36.1	Ĩ		2.0	1902.01636,1808.04095
D C	Metastable \tilde{g} R-hadron, $\tilde{g} \rightarrow qq \tilde{\chi}_1^0$	Multi	ole	36.1	$\tilde{g} [\tau(\tilde{g}) = 10 \text{ ns}, 0.2 \text{ ns}]$		2.05 2.4 m($\tilde{\chi}_1^0$)=100 GeV	1710.04901,1808.04095
	$\tilde{\chi}_1^{\pm} \tilde{\chi}_1^{\mp} / \tilde{\chi}_1^0 , \tilde{\chi}_1^{\pm} {\rightarrow} Z\ell {\rightarrow} \ell\ell\ell$	3 e, µ		139	$\tilde{\chi}_1^{\mp}/\tilde{\chi}_1^0$ [BR($Z\tau$)=1, BR(Ze)=1]	0.625 1.0	95 Pure Wino	ATLAS-CONF-2020-009
	$LFV \ pp \to \tilde{v}_{\tau} + X, \tilde{v}_{\tau} \to e\mu/e\tau/\mu\tau$	<i>eµ,eτ,μτ</i>	remiss	3.2	$\tilde{\gamma}_{\tau}$	0.00	1.9 $\lambda'_{311}=0.11, \lambda_{132/133/233}=0.07$	1607.08079
	$\chi_1^-\chi_1^-/\chi_2^- \to WW/Z\ell\ell\ell\ell\nu\nu$	4 e, μ 0 je 4-5 large	-R iets	36.1	$\chi_1^-/\chi_2^- [\lambda_{i33} \neq 0, \lambda_{12k} \neq 0]$ $\tilde{\alpha} = [m(\tilde{\chi}^0) - 200 \text{ GeV}/(1100 \text{ GeV})]$	0.82	1.33 m(X ₁)=100 GeV	1804.03602
>	$gg, g \rightarrow qq\chi_1, \chi_1 \rightarrow qqq$	Multi	ple	36.1	$\tilde{g} = [\mathcal{M}(\mathcal{X}_1) = 200 \text{ GeV}, 1100 \text{ GeV}]$ $\tilde{g} = [\mathcal{X}''_{112} = 2e-4, 2e-5]$	1.0	1.5 1.9 $m(\tilde{\chi}_1^0)$ =200 GeV, bino-like	ATLAS-CONF-2018-003
R	$\tilde{t}\tilde{t}, \tilde{t} \rightarrow t \tilde{\chi}_1^0, \tilde{\chi}_1^0 \rightarrow t b s$	Multi	ole	36.1	\tilde{t} [λ''_{323} =2e-4, 1e-2]	0.55 1.0	$m(\tilde{\chi}_1^0)$ =200 GeV, bino-like	ATLAS-CONF-2018-003
	$\tilde{t}\tilde{t}, \tilde{t} \rightarrow b\tilde{\chi}_{1}^{\pm}, \tilde{\chi}_{1}^{\pm} \rightarrow bbs$	≥ 4	b	139	ĩ	Forbidden 0.95	$m(\tilde{\chi}_1^{\pm})$ =500 GeV	ATLAS-CONF-2020-016
	$\tilde{t}_1 \tilde{t}_1, \tilde{t}_1 \rightarrow bs$	2 jets -	- 2 b	36.7	$\tilde{t}_1 [qq, bs]$	0.42 0.61		1710.07171
	$\iota_1\iota_1, \iota_1 \rightarrow q\iota$	1μ DV		136.1	$t_1 \\ \tilde{t}_1 $ [1e-10< λ'_{23k} <1e-8, 3e-10< λ'_{23k}	<3e-9] 1.0	U.4-1.45 BR $(t_1 \rightarrow be/b\mu) > 20\%$ BR $(\bar{t}_1 \rightarrow q\mu) = 100\%$, $\cos\theta_t = 1$	1/10.05544 2003.11956
*0 '					Li ∩−1		1	I
"Only a selection of the available mass limits on new states or 10 to 1 Mass scale [TeV]								

simplified models, c.f. refs. for the assumptions made.

For my talk: EWino direct channels *without* sleptons. Looking at final states resulting from W +Z/h decays: bounds ranging ~200-700 GeV

<u>Current status</u>

https://twiki.cern.ch/twiki/bin/view/AtlasPublic/SupersymmetryPublicResults

ATLAS SUSY Searches* - 95% CL Lower Limits

ATLAS Preliminary $\sqrt{s} = 13$ TeV

	Model	Signature	$\int \mathcal{L} dt [\mathbf{f} \mathbf{b}^{-1}]$	Mass limit		Reference
Inclusive Searches	$\tilde{q}\tilde{q},\tilde{q}{ ightarrow}q\tilde{\chi}_{1}^{0}$	$0 e, \mu$ 2-6 jets E_{Tis}^{mis} mono-jet 1-3 jets E_{Ts}^{mis}	^{ss} 139 ^{ss} 36.1	<i>q</i> [10x Degen.] <i>q</i> [1x, 8x Degen.] 0.43 0.71	1.9 m($\tilde{\chi}_1^0$)<400 GeV m(\tilde{g})-m($\tilde{\chi}_1^0$)=5 GeV	ATLAS-CONF-2019-040 1711.03301
	$\tilde{g}\tilde{g},\tilde{g}{ ightarrow}q\bar{q}\tilde{\chi}_{1}^{0}$	$0 e, \mu$ 2-6 jets E_T^{mis}	^{ss} 139	ğ ğ Forbidder	2.35 m(\tilde{k}_1^0)=0 GeV 1.15-1.95 m(\tilde{k}_1^0)=1000 GeV	ATLAS-CONF-2019-040 ATLAS-CONF-2019-040
	$\begin{split} \tilde{g}\tilde{g}, \tilde{g} \to q\bar{q}W\tilde{\chi}_1^0 \\ \tilde{g}\tilde{g}, \tilde{g} \to q\bar{q}(\ell\ell)\tilde{\chi}_1^0 \\ \tilde{g}\tilde{g}, \tilde{g} \to qqWZ\tilde{\chi}_1^0 \end{split}$	1 e, μ 2-6 jets $ee, \mu\mu$ 2 jets E_T^{mis} 0 e, μ 7-11 jets E_T^{mis}	139 ³⁵ 36.1 ³⁵ 139	762 762 762	$\begin{array}{ccc} \textbf{2.2} & m(\tilde{\chi}_1^0) {<} 600 \ \text{GeV} \\ \textbf{1.2} & m(\tilde{g}){-}m(\tilde{\chi}_1^0) {=} 50 \ \text{GeV} \\ \textbf{1.97} & m(\tilde{\chi}_1^0) {<} 600 \ \text{GeV} \end{array}$	ATLAS-CONF-2020-047 1805.11381 ATLAS-CONF-2020-002
	$\tilde{g}\tilde{g}, \tilde{g} {\rightarrow} t t \tilde{\chi}_1^0$	$\begin{array}{rcl} \text{SS } e, \mu & \text{6 jets} \\ \text{0-1 } e, \mu & \text{3 } b & E_T^{\text{mis}} \\ \text{SS } e, \mu & \text{6 jets} \end{array}$	139 ⁵⁵ 79.8 139	Gai Gai Cari		1909.08457 ATLAS-CONF-2018-041 1909.08457
3 rd gen. squarks direct production	$\tilde{b}_1 \tilde{b}_1, \tilde{b}_1 \rightarrow b \tilde{\chi}_1^0 / t \tilde{\chi}_1^{\pm}$	Multiple Multiple	36.1 139	b1 Forbidden 0.9 b1 Forbidden 0.74	$\begin{array}{c} m(\tilde{\chi}_{1}^{0}){=}300~\text{GeV},~\text{BR}(b\tilde{\chi}_{1}^{0}){=}1\\ m(\tilde{\chi}_{1}^{0}){=}200~\text{GeV},~m(\tilde{\chi}_{1}^{+}){=}300~\text{GeV},~\text{BR}(t\tilde{\chi}_{1}^{+}){=}1 \end{array}$	1708.09266, 1711.03301 1909.08457
	$\tilde{b}_1 \tilde{b}_1, \tilde{b}_1 \rightarrow b \tilde{\chi}_2^0 \rightarrow b h \tilde{\chi}_1^0$	$\begin{array}{ccc} 0 \ e, \mu & 6 \ b & E_T^{\text{mis}} \\ 2 \ \tau & 2 \ b & E_T^{\text{mis}} \end{array}$	^{ss} 139 ^{ss} 139	b1 Forbidden b1 0.13-0.85	$\begin{array}{llllllllllllllllllllllllllllllllllll$	1908.03122 ATLAS-CONF-2020-031
	$ \tilde{t}_1 \tilde{t}_1, \tilde{t}_1 \rightarrow t \tilde{\chi}_1^0 $ $ \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 \nu, \tilde{\tau}_1 \rightarrow \tau \tilde{G} $ $ \tilde{\tau}_1 \tilde{\tau}_1, \tilde{\tau}_1 \rightarrow \tilde{\tau}_1 b \nu, \tilde{\tau}_1 \rightarrow \tau \tilde{G} $	$\begin{array}{lll} 0\text{-1} e, \mu &\geq 1 \text{ jet } & E_T^{\text{mis}} \\ 1 e, \mu & 3 \text{ jets}/1 \ b & E_T^{\text{mis}} \\ 1 \tau + 1 e, \mu, \tau & 2 \text{ jets}/1 \ b & E_T^{\text{mis}} \end{array}$	⁵⁵ 139 ⁵⁵ 139 ⁵⁵ 36.1	<i>ī</i> ₁ <i>ī</i> ₁ 0.44-0.59 <i>ī</i> ₁ 0.00	1.25 m(ξ₁₀)=1 GeV m(ξ₁₀)=400 GeV m(テ₁)=800 GeV 1.16 m(テ₁)=800 GeV	ATLAS-CONF-2020-003, 2004.14060 ATLAS-CONF-2019-017 1803.10178
	$\hat{t}_1\hat{t}_1, \hat{t}_1 \rightarrow \mathcal{X}_1^{\vee} / \tilde{c}\tilde{c}, \tilde{c} \rightarrow \mathcal{X}_1^{\vee}$	$0 e, \mu$ $2 c$ E_T^{min} $0 e, \mu$ mono-jet E_T^{min}	~ 36.1 * 36.1	$\vec{t}_1 = 0.46$ $\vec{t}_1 = 0.43$	$m(\tilde{x}_{1}^{*})=0 \text{ GeV}$ $m(\tilde{r}_{1},\tilde{c})-m(\tilde{x}_{1}^{0})=50 \text{ GeV}$ $m(\tilde{r}_{1},\tilde{c})-m(\tilde{x}_{1}^{0})=5 \text{ GeV}$	1805.01649 1805.01649 1711.03301
	$ \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 \tilde{t}_2 \tilde{t}_2, \tilde{t}_2 \rightarrow \tilde{t}_1 + Z $	$\begin{array}{cccc} 1-2 \ e, \mu & 1-4 \ b & E_T^{\rm mis} \\ 3 \ e, \mu & 1 \ b & E_T^{\rm mis} \end{array}$	^{ss} 139 ^{ss} 139	ī1 0.067 ī2 Forbidden 0.86	-1.18 $m(\tilde{\chi}_1^0)$ =500 GeV $m(\tilde{\chi}_1^0)$ =360 GeV, $m(\tilde{\chi}_1)$ =0 GeV	SUSY-2018-09 SUSY-2018-09
	$ ilde{\chi}_1^{\pm} ilde{\chi}_2^0$ via WZ	$\begin{array}{ccc} 3 \ e, \mu & E_T^{\text{mis}} \\ e e, \mu \mu & \geq 1 \ \text{jet} & E_T^{\text{mis}} \end{array}$	^{ss} 139 ^{ss} 139	$egin{array}{ccc} & \tilde{\chi}_1^{\pm}/ ilde{\chi}_2^0 & & 0.64 \ & \tilde{\chi}_1^{\pm}/ ilde{\chi}_2^0 & & 0.205 \end{array} \end{array}$	$\begin{array}{c} m(\tilde{\chi}_1^0){=}0\\ m(\tilde{\chi}_1^\pm){\cdot}m(\tilde{\chi}_1^0){=}5~\mathrm{GeV} \end{array}$	ATLAS-CONF-2020-015 1911.12606
t	$ ilde{\chi}_1^{\pm} ilde{\chi}_1^{\mp}$ via WW $ ilde{\chi}_1^{\pm} ilde{\chi}_2^0$ via Wh	$\begin{array}{ccc} 2 \ e, \mu & E_T^{\text{mis}} \\ 0\text{-}1 \ e, \mu & 2 \ b/2 \ \gamma & E_T^{\text{mis}} \end{array}$	^{is} 139 ^{is} 139	\$\tilde{x}_1^{+}\$ 0.42 \$\tilde{x}_1^{+} \tilde{x}_2^{0}\$ Forbidden 0.74 0.74	$m(\tilde{\chi}_{1}^{0})=0$ $m(\tilde{\chi}_{1}^{0})=70$ GeV	1908.08215 2004.10894, 1909.09226
EW direct	$\begin{split} \tilde{\chi}_{1}^{\dagger} \tilde{\chi}_{1}^{\dagger} & \text{via } \tilde{\ell}_{L} / \tilde{\nu} \\ \tilde{\tau} \tilde{\tau}, \tilde{\tau} \rightarrow \tau \tilde{\chi}_{1}^{0} \\ \tilde{\ell}_{L,R} \tilde{\ell}_{L,R}, \tilde{\ell} \rightarrow \ell \tilde{\chi}_{1}^{0} \end{split}$	$\begin{array}{ccc} 2 \ e, \mu & E_T^{\text{mis}} \\ 2 \ \tau & E_T^{\text{mis}} \\ 2 \ e, \mu & 0 \ \text{jets} & E_T^{\text{mis}} \end{array}$	⁵⁵ 139 ⁵⁵ 139 ⁵⁵ 139	$\tilde{\chi}_{1}^{+}$ 1.0 $\tilde{\tau}$ [$\tilde{\tau}_{L}, \tilde{\tau}_{R,L}$] 0.16-0.3 0.12-0.39 $\tilde{\ell}$ 0.7	$m(\tilde{\ell}_{1}, 0, 5(m(\tilde{k}_{1}^{+}) + m(\tilde{k}_{1}^{+})))$ $m(x_{1})=0$ $= 0 m(\tilde{k}_{1}^{0})=0$	1908.08215 1911.06660 1908.08215
	$\tilde{H}\tilde{H}, \tilde{H} { ightarrow} h\tilde{G}/Z\tilde{G}$	$\begin{array}{rcl} ee, \mu\mu & \geq 1 \text{ jet} & E_T^{\text{mis}} \\ 0 e, \mu & \geq 3 b & E_T^{\text{mis}} \\ 4 e, \mu & 0 \text{ jets} & E_T^{\text{mis}} \end{array}$	^{ss} 139 ^{ss} 36.1 ^{ss} 139	I 0.256 H 0.13-0.23 0.29-0.88 H 0.55	$ \begin{array}{c} m(\ell) \cdot m(\mathcal{X}_1^*) = 10 \text{ GeV} \\ BR(\tilde{\chi}_1^0 \to h\tilde{G}) = 1 \\ BR(\tilde{\mathcal{X}}_1^0 \to Z\tilde{G}) = 1 \end{array} $	1911.12606 1806.04030 ATLAS-CONF-2020-040
lived cles	$\operatorname{Direct} \tilde{\chi}_1^{+} \tilde{\chi}_1^{-}$ prod., long-lived $\tilde{\chi}_1^{\pm}$	Disapp. trk 1 jet E_T^{mis}	^{is} 36.1	$\tilde{\vec{x}}^{\pm}_{1}$ 0.46 $\tilde{\vec{x}}^{\pm}_{1}$ 0.15	Pure Wino Pure higgsino	1712.02118 ATL-PHYS-PUB-2017-019
Long- parti	Stable \tilde{g} R-hadron Metastable \tilde{g} R-hadron, $\tilde{g} \rightarrow qq \tilde{\chi}_1^0$	Multiple Multiple	36.1 36.1	\tilde{g} \tilde{g} [$\tau(\tilde{g})$ =10 ns, 0.2 ns]	2.0 2.05 2.4 m($\tilde{\chi}_1^0$)=100 GeV	1902.01636,1808.04095 1710.04901,1808.04095
RPV	$\begin{split} \tilde{\chi}_{1}^{\pm} \tilde{\chi}_{1}^{\mp} / \tilde{\chi}_{1}^{0} , \tilde{\chi}_{1}^{\pm} \rightarrow \mathcal{Z}\ell \rightarrow \ell\ell\ell \\ \text{LFV } pp \rightarrow \tilde{\nu}_{\tau} + X, \tilde{\nu}_{\tau} \rightarrow e\mu/e\tau/\mu\tau \\ \tilde{\chi}_{1}^{\pm} \tilde{\chi}_{2}^{0} \rightarrow WW/Z\ell\ell\ell\ell\nu\nu \\ \tilde{g}\tilde{g}, \tilde{g} \rightarrow qq\tilde{\chi}_{1}^{0}, \tilde{\chi}_{1}^{0} \rightarrow qqq \\ \tilde{t}, \tilde{t} \rightarrow t\tilde{\chi}_{1}^{0}, \tilde{\chi}_{1}^{0} \rightarrow tbs \\ \tilde{t}, \tilde{t} \rightarrow b\tilde{\chi}_{1}^{\pm}, \tilde{\chi}_{1}^{\pm} \rightarrow bbs \\ \tilde{t}_{1}\tilde{t}_{1}, \tilde{t}_{1} \rightarrow bs \\ \tilde{t}, \tilde{t}, \tilde{t}, \varphi \neq \ell \end{split}$	$\begin{array}{c} 3 \ e, \mu \\ e\mu, e\tau, \mu\tau \\ 4 \ e, \mu \\ 4 \ 5 \ \text{large-}R \ \text{jets} \\ Multiple \\ \geq 4b \\ 2 \ \text{jets} + 2 \ b \\ 2 \ x \mu \\ p \ b \end{array}$	139 3.2 36.1 36.1 36.1 36.1 139 36.7 26.1	$ \begin{array}{c ccccccccccccccccccccccccccccccccccc$	5 Pure Wino 1.9 λ'_{311} =0.11, $\lambda_{132/133/233}$ =0.07 1.33 m($\tilde{\chi}_1^0)$ =100 GeV 1.3 1.9 Large λ''_{112} 15 2.0 m($\tilde{\chi}_1^0)$ =200 GeV, bino-like 15 m($\tilde{\chi}_1^0)$ =200 GeV	ATLAS-CONF-2020-009 1607.08079 1804.03602 1804.03568 ATLAS-CONF-2018-003 ATLAS-CONF-2018-003 ATLAS-CONF-2020-016 1710.07171 1110.05544
*Oņly	a selection of the available ma	$\frac{1}{\mu} \frac{2}{DV}$ ss limits on new states or	136	$\frac{1}{t_1} [1e-10 < \lambda'_{23k} < 1e-8, 3e-10 < \lambda'_{23k} < 3e-9] \qquad 1.0$	Interpretent BR(i_1 - 4re/ph/) > 20 % 1.6 BR(i_1 - 4q \mu) = 100%, cos \theta_i = 1 1 Mass scale [TeV]	2003.11956

phenomena is shown. Many of the limits on new states of simplified models, c.f. refs. for the assumptions made.

Fine print: simplified models with specific spectrum and/or BRs=100% MSSM dynamics: spectrum *and* BRs determined by same parameters. Different channels give complementary information

Search channels

Looking at EW direct production without sleptons, decaying through W + Z/h

Wino scenario

 $M_1 \lesssim M_2 \ll \mid \mu \mid$



Higgsino-Bino scenario

 $M_1 \lesssim |\mu| \ll M_2$





- Wino scenario (large components of \tilde{W}):
 - Traditional search channel considered by ATLAS and CMS collaborations
 - Cross sections actually connected to SUSY strong sector major implications for EWino bounds!



 M_{SUSY} = overall scale of scalar super partners. 1 - 10 TeV suggested by measured value of Higgs mass

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- Wino scenario (large components of \tilde{W}):
 - Sign of μ matters



Take away: trilepton searches good for compressed region or special region of parameters. Fairly robust ultimate reach for m_1^{\pm} from W+h channels



<u>Wino summary</u>

 $M_1 \lesssim M_2 \ll \mid \mu \mid$

- Direct EW searches gives indirect info on squark sector through prod x-section
- Sign of μ can have drastic consequences in branching ratios

Assuming the optimal case for the HL-LHC, when $M_{SUSY} \rightarrow 10$ TeV, projection of current analyses gives reach of $m_{\chi_1^\pm} \simeq 1$ TeV, $m_{\chi_1^0} \simeq 400$ GeV

 $M_1 \lesssim |\mu| \ll M_2$



 $\chi_2^0 \& \chi_3^0$ give comparable contributions now, $m_{\chi_1^{\pm}} \simeq m_{\chi_2^0} \simeq m_{\chi_3^0}$



Simple pattern of overall branching ratio to Z or h

Complementary channel





arXiv:2006.07389 [hep-ph]

 $\sigma(H/A \rightarrow \chi^0_{2,3} + \chi^0_1 \rightarrow Z + 2\chi^0_1), M_A = 600 \text{ GeV}$ Complementary channel fb 500 $\tan\beta = 2$ $\tan\beta = 5$ 400 - 55 $m^0_{\chi_1}$ [GeV] 300 - 50 χ^0_1 999999 - 45 200 - 40 100 - 35 H/A- 30 500 $\tan\beta = 8$ $\tan\beta = 10$ 25 000000 400 20 002 x^x 200 200 x - 15 - 10 - 5 100 Bino 600 200 400 600 800 200 400 800 $m_{\chi_1}^{\pm}$ [GeV] $m_{\chi_1}^{\pm}$ [GeV] Higgs Higgsino

 $\mathcal{O}(1-10)$ fb size x-section

Very different kinematics due to heavy resonance

- Higgsino-Bino scenario (large components of \tilde{H}):
 - Alternative search channel NOT yet explored (in detail) by ATLAS and CMS



Not only relevant for EWinos, but gives additional handle on the heavy Higgs sector in the MSSM



<u>Higgsino-Bino summary</u>

 $M_1 \lesssim |\mu| \ll M_2$

- Weaker direct production (no squark channel) than in Wino case
- Pattern of mixing allows alternative search channel with complementary region to explore decays. Additionally probes Higgs sector

Optimal case of $m_A = 700$ GeV, gives significant reach in compressed region $m_{\chi_1^\pm} \simeq 400$ GeV, $m_{\chi_1^0} \simeq 300$ GeV



ATLAS SUSY Searches* - 95% CL Lower Limits

A ال	TLAS SUSY Sea	5% CL I	-0V				ATLAS Preliminary $\sqrt{s} = 13$ TeV		
	Model	Signat	ure ∫£ d	t [fb ⁻¹	Mass limit				Reference
S	$\tilde{q}\tilde{q},\tilde{q}\! ightarrow\!q\tilde{\chi}_{1}^{0}$	0 <i>e</i> , μ 2-6 je mono-jet 1-3 je	ts E_T^{miss} 1 ts E_T^{miss} 3	39 6.1	$ \vec{q} $ [10× Degen.] $ \vec{q} $ [1×, 8× Degen.] 0.43		1.9	${f m}(ilde{\chi}_1^0){<}400{f GeV}$ ${f m}(ilde{q}){-}{f m}(ilde{\chi}_1^0){=}5{f GeV}$	ATLAS-CONF-2019-040 1711.03301
Inclusive Searche	$\tilde{g}\tilde{g}, \tilde{g} \rightarrow q \bar{q} \tilde{\chi}_1^0$	0 <i>e</i> , <i>µ</i> 2-6 je	ts E_T^{miss} 1	39	lag B	For	2.35 1.15-1.95	${f m}(ilde{\chi}_1^0)$ =0 GeV ${f m}(ilde{\chi}_1^0)$ =1000 GeV	ATLAS-CONF-2019-040 ATLAS-CONF-2019-040
	$\tilde{g}\tilde{g}, \tilde{g} \rightarrow q\bar{q}W\tilde{\chi}_1^0$	1 <i>e</i> , μ 2-6 je	ts 1	39	б г		2.2	$m(\tilde{\chi}_1^0) < 600 \text{ GeV}$	ATLAS-CONF-2020-047
	$gg, g \to qq(\ell\ell)\chi_1$ $\tilde{g}\tilde{g}, \tilde{g} \to qqWZ\tilde{\chi}_1^0$	$0 e, \mu$ 7-11 je	ets E_T^{miss} 1	39	ğ.		1.2	$m(g)-m(\chi_1)=50 \text{ GeV}$ $m(\chi_1^0) < 600 \text{ GeV}$	ATLAS-CONF-2020-002
	22 2 v ⁺ v ⁰	$SS e, \mu$ 6 jets	Fmiss 7	39 3.8	ig a		.15	$m(\tilde{g})-m(\tilde{\chi}_1^0)=200 \text{ GeV}$	1909.08457 ATLAS.CONE.2018.041
	$gg, g \rightarrow u \chi_1$	$SS e, \mu$ 6 jets	s 1	39	8 7 7		1.25	$m(\tilde{g})-m(\tilde{\chi}_1^0)=300 \text{ GeV}$	1909.08457
	$\tilde{b}_1 \tilde{b}_1, \tilde{b}_1 \rightarrow b \tilde{\chi}_1^0 / t \tilde{\chi}_1^{\pm}$	Multip Multip	le 30 le 1	6.1 39	\$\vec{b}_1\$ Forbidden \$\vec{b}_1\$ Forbidden 0.1	,	$m(\tilde{\chi}_{1}^{0})=2000$	$m(\tilde{\chi}_{1}^{0})$ =300 GeV, BR($b\tilde{\chi}_{1}^{0}$)=1 GeV, $m(\tilde{\chi}_{1}^{+})$ =300 GeV, BR($t\tilde{\chi}_{1}^{+}$)=1	1708.09266, 1711.03301 1909.08457
s) U	$\tilde{b}_1 \tilde{b}_1, \tilde{b}_1 \rightarrow b \tilde{\chi}_2^0 \rightarrow b h \tilde{\chi}_1^0$	0 e,μ 6 b 2 τ 2 b	E_T^{miss} 1 E_T^{miss} 1	39 39	b1 Forbidden b1 0.1	3 0.8	.23-1.35 Δm(ž Δn	$\tilde{\chi}_{2}^{0}, \tilde{\chi}_{1}^{0}$)=130 GeV, m($\tilde{\chi}_{1}^{0}$)=100 GeV n($\tilde{\chi}_{2}^{0}, \tilde{\chi}_{1}^{0}$)=130 GeV, m($\tilde{\chi}_{1}^{0}$)=0 GeV	1908.03122 ATLAS-CONF-2020-031
juark luctio	$\tilde{t}_1 \tilde{t}_1, \tilde{t}_1 \rightarrow t \tilde{\chi}_1^0$	$0-1 \ e, \mu \ge 1 \ je$	et E_T^{miss} 1	39	Ĩ,		1.25	$m(\tilde{\chi}_1^0)=1 \text{ GeV}$	ATLAS-CONF-2020-003, 2004.14060
n. sı proc	$\tilde{t}_1 \tilde{t}_1, \tilde{t}_1 \rightarrow Wb\chi_1^\circ$ $\tilde{t}_1 \tilde{t}_1, \tilde{t}_1 \rightarrow \tilde{\tau}_1 by, \tilde{\tau}_1 \rightarrow \tau \tilde{G}$	$1 e, \mu$ 3 jets/ $1 \tau + 1 e, \mu, \tau$ 2 jets/	$b E_T^{\text{miss}} = 1$ $b E_T^{\text{miss}} = 30$	39 5.1	t ₁ 0.44-0.59		.16	m(𝑋₁)=400 GeV m(𝑣₁)=800 GeV	AI LAS-CONF-2019-017 1803.10178
^d ge rect	$\tilde{t}_1 \tilde{t}_1, \tilde{t}_1 \rightarrow c \tilde{\chi}_1^0 / \tilde{c} \tilde{c}, \tilde{c} \rightarrow c \tilde{\chi}_1^0$	0 <i>e</i> , <i>µ</i> 2 <i>c</i>	E_T^{miss} 30	6.1	č	8.0		$m(\tilde{\chi}_1^0)=0 \text{ GeV}$	1805.01649
3 ^r di		0 <i>e</i> , <i>µ</i> mono-	jet E_T^{miss} 30	6.1					1805.01649 1711.03301
	$\tilde{t}_1\tilde{t}_1, \tilde{t}_1 \rightarrow t\tilde{\chi}_2^0, \tilde{\chi}_2^0 \rightarrow Z/h\tilde{\chi}_1^0$	1-2 <i>e</i> , μ 1-4 <i>l</i>	E_T^{miss} 1	39	<i>ī</i> ₁		I.18	$m(\tilde{\chi}_2^0)=500 \text{ GeV}$	SUSY-2018-09
	$t_2 t_2, t_2 \rightarrow t_1 + Z$	3 e, µ 1 b	E_T^{mass} 1	39	t ₂ Forbidden	0.8	m(\mathcal{X}_1°)	=360 GeV, m(\tilde{t}_1)-m(\mathcal{X}_1)= 40 GeV	SUSY-2018-09
	$ ilde{\chi}_1^{\pm} ilde{\chi}_2^0$ via WZ	$\begin{array}{ll} 3 \ e, \mu \\ ee, \mu \mu & \geq 1 \ je \end{array}$	E_T^{miss} 1 et E_T^{miss} 1	39 39				$m(\tilde{\chi}_{1}^{t})=0$ $m(\tilde{\chi}_{1}^{t})-m(\tilde{\chi}_{1}^{0})=5 \text{ GeV}$	ATLAS-CONF-2020-015 1911.12606
	$\tilde{\chi}_1^{\pm} \tilde{\chi}_1^{\mp}$ via WW	2 <i>e</i> , <i>µ</i>	E_T^{miss} 1	39	$\tilde{\chi}_1^{\pm}$ 0.42			$m(\tilde{\chi}_1^0)=0$	1908.08215
st <	$\hat{\chi}_1^+ \hat{\chi}_2^0$ via Wh	0-1 <i>e</i> , μ 2 <i>b</i> /2	$\gamma = E_T^{\text{mass}} = 1$	39	χ_1^*/χ_2^* Forbidden 0.1			$m(\tilde{\chi}_1^\circ)=70 \text{ GeV}$	2004.10894, 1909.09226 1908.08215
dire		0 0							1911.06660
	$H/A \rightarrow T$	$\gamma_{1}^{0} + \gamma_{1}^{0}$					п	$i_{\Lambda} = 700 \ GeV$	1908.08215 1911.12606
		$a_h \cdot x_1$						A	1806.04030 ATLAS-CONF-2020-040
pe sd	Direct $\tilde{\chi}_{1}^{+}\tilde{\chi}_{1}^{-}$ prod., long-lived $\tilde{\chi}_{1}^{\pm}$	Disapp. trk 1 jet	E_T^{miss} 30	6.1	ž [‡] 0.46			Pure Wino	1712.02118
-live			1	-	$\tilde{\chi}_{1}^{\pm}$ 0.15			Pure higgsino	ATL-PHYS-PUB-2017-019
ong	Stable \tilde{g} R-hadron	Multip	le 31	6.1 S 1	\tilde{g} $\tilde{\sigma} = [\tau(\tilde{\sigma}) = 10 \text{ ns} = 0.2 \text{ ns}]$		2.0	$m(\tilde{v}^{0}) = 100 \text{ GeV}$	1902.01636,1808.04095 1710.04901.1808.04095
	$\tilde{v}^{\pm}\tilde{v}^{\mp}/\tilde{v}^{0} \tilde{v}^{\pm} \mathcal{R} \mathcal{R} $	3 e u	10 01	30	$\tilde{v}^{\mp}/\tilde{v}^{0}$ [BB(7_{\pm})_1 BB(7_{\pm})_1 0.625	1.0	5	Pure Wino	ATLAS_CONE_2020_009
	$LFV \ pp \to \tilde{\nu}_{\tau} + X, \tilde{\nu}_{\tau} \to e\mu/e\tau/\mu\tau$	<i>e</i> μ, <i>e</i> τ,μτ	:	3.2	$\tilde{\gamma}_{\rm T}$	1.0	1.9	λ'_{311} =0.11, $\lambda_{132/133/233}$ =0.07	1607.08079
	$\tilde{\chi}_1^{\pm} \tilde{\chi}_1^{\mp} / \tilde{\chi}_2^0 \rightarrow WW/Z\ell\ell\ell\ell\nu\nu$	4 <i>e</i> , μ 0 jets	E_T^{miss} 30	6.1	$\tilde{\chi}_1^{\pm}/\tilde{\chi}_2^0 [\lambda_{i33} \neq 0, \lambda_{12k} \neq 0]$	0.82	1.33	$m(\tilde{\chi}_1^0)=100 \text{ GeV}$	1804.03602
>	$\tilde{g}\tilde{g}, \tilde{g} \rightarrow qq\tilde{\chi}_1^0, \tilde{\chi}_1^0 \rightarrow qqq$	4-5 large- Multip	R jets 30 le 30	5.1 5.1	$ \begin{array}{l} \widetilde{g} & [m(\widetilde{X}_{1}^{u})=200 \; \text{GeV}, 1100 \; \text{GeV}] \\ \widetilde{g} & [\widetilde{X}_{112}^{u}=2e{-}4, 2e{-}5] \end{array} $	1.0	1.3 1.9 5 2.0	Large λ_{112}'' m($\tilde{\chi}_1^0$)=200 GeV, bino-like	1804.03568 ATLAS-CONF-2018-003
RP	$\tilde{t}\tilde{t}, \tilde{t} \rightarrow t \tilde{\chi}_1^0, \tilde{\chi}_1^0 \rightarrow tbs$	Multip	le 30	6.1	\tilde{t} [λ''_{323} =2e-4, 1e-2] 0.55	1.0	5	m($\tilde{\chi}_1^0$)=200 GeV, bino-like	ATLAS-CONF-2018-003
	$\tilde{t}\tilde{t}, \tilde{t} \rightarrow b\tilde{\chi}_1^{\pm}, \tilde{\chi}_1^{\pm} \rightarrow bbs$	$\geq 4b$	1	39	ĩ Forbidden	0.95		$m(\tilde{\chi}_1^{\pm})$ =500 GeV	ATLAS-CONF-2020-016
	$t_1 t_1, t_1 \rightarrow bs$ $\tilde{t}_1 \tilde{t}_1, \tilde{t}_1 \rightarrow a\ell$	2 jets +	2 <i>0</i> 31	5./ 5.1	$t_1 \ [qq, bs]$ 0.42 0.61 \tilde{t}_1		0 4-1 45	$BB(\tilde{t}_1 \rightarrow he/hu) > 20\%$	1/10.07171 1710.05544
	·1·1, ·1 /40	1μ DV	1	36	\vec{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
*Only	*Only a selection of the available mass limits on new states or 10^{-1}						1		1
nhor	a solection of the available III	limite are hased on	1105 01	1	J			wass scale [rev]	

simplified models, c.f. refs. for the assumptions made.

*Current bounds highly relaxed in H-B scenario

<u>Summary</u>

- Traditional EW search channels can probe different mixing scenarios btw a Wino/ bino-like spectrum and Higgsino/Bino-like spectrum
- Each case requires different kind of search strategy (branching ratios, production channels, kinematics)
- HL-LHC has strong potential to explore all of these regions, probing multiple aspects of SUSY models: Higgs sector, EWino mixings, squarks (indirectly)

We will learn a lot about EWinos at the HL-LHC :)