

Status of supersymmetric models with GAMBIT

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on behalf of the GAMBIT collaboration

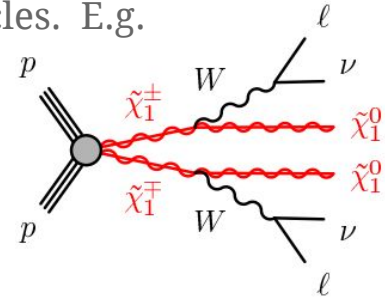
ALPS2019 - Fourth Alpine LHC Physics Summit

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1. Motivation

- No clear evidence of supersymmetry at LHC
 - ...so set limits on SUSY models
- But, the general MSSM has many free parameters
 - -> very difficult to explore thoroughly
- ATLAS and CMS have opted for a search strategy optimised around “simplified models”;
 - simple SUSY-like models where one or two SUSY particles added, with certain assumptions about how they decay to SM particles. E.g.
- What might these searches miss?



Model	Signature	$\int \mathcal{L} dt$ [fb $^{-1}$]	Mass limit	Reference					
Inclusive Searches	$q\bar{q}, \bar{q} \rightarrow q\bar{q}_1^0$	0 e, μ mono-jet	2-6 jets E_T^{miss}	36.1	\bar{q} [2x, 8x Degen] \bar{q} [1x, 8x Degen]	0.9 0.71	1.55	$m(\tilde{q}_1^0) < 100$ GeV $m(\tilde{g}) - m(\tilde{q}_1^0) = 5$ GeV	1712.02332 1711.03301
	$\bar{g}\bar{g}, \bar{g} \rightarrow q\bar{q}\tilde{q}_1^0$	0 e, μ	2-6 jets E_T^{miss}	36.1	\bar{g} \bar{g}	2.0 Forbidden	0.95-1.6	$m(\tilde{q}_1^0) < 200$ GeV $m(\tilde{q}_1^0) = 900$ GeV	1712.02332 1712.02332
	$\bar{g}\bar{g}, \bar{g} \rightarrow q\bar{q}(\ell\ell)\tilde{q}_1^0$	3 e, μ $e\ell, \mu\mu$	4 jets 2 jets E_T^{miss}	36.1 36.1	\bar{g} \bar{g}	1.85 1.2		$m(\tilde{q}_1^0) < 800$ GeV $m(\tilde{g}) - m(\tilde{q}_1^0) = 50$ GeV	1706.03731 1805.11381
	$\bar{g}\bar{g}, \bar{g} \rightarrow qqWZ\tilde{q}_1^0$	0 e, μ 3 e, μ	7-11 jets 4 jets E_T^{miss}	36.1 36.1	\bar{g} \bar{g}	1.8 0.98		$m(\tilde{q}_1^0) < 400$ GeV $m(\tilde{g}) - m(\tilde{q}_1^0) = 200$ GeV	1708.02794 1706.03731
	$\bar{g}\bar{g}, \bar{g} \rightarrow t\bar{t}\tilde{q}_1^0$	0-1 e, μ 3 e, μ	3 b 4 jets E_T^{miss}	79.8 36.1	\bar{g} \bar{g}	2.25 1.25		$m(\tilde{q}_1^0) < 200$ GeV $m(\tilde{g}) - m(\tilde{q}_1^0) = 300$ GeV	ATLAS-CONF-2018-041 1706.03731
	3 rd gen. squarks direct production	$\bar{b}_1\bar{b}_1, \bar{b}_1 \rightarrow b\tilde{q}_1^0 / \bar{t}\tilde{q}_1^+$	Multiple Multiple Multiple	36.1 36.1 36.1	\bar{b}_1 \bar{b}_1 \bar{b}_1	Forbidden Forbidden Forbidden	0.9 0.58-0.82 0.7		$m(\tilde{q}_1^0) = 300$ GeV, $\text{BR}(\tilde{b}_1^0) = 1$ $m(\tilde{q}_1^0) = 300$ GeV, $\text{BR}(\tilde{b}_1^0) = \text{BR}(\tilde{t}_1^+) = 0.5$ $m(\tilde{q}_1^0) = 200$ GeV, $m(\tilde{q}_1^0) = 300$ GeV, $\text{BR}(\tilde{q}_1^+) = 1$
$\bar{b}_1\bar{b}_1, \bar{b}_1 \rightarrow b\tilde{t}_2^0 \rightarrow b\tilde{b}\tilde{t}_1^0$		0 e, μ	6 b E_T^{miss}	139	\bar{b}_1 \bar{b}_1	Forbidden 0.23-0.48	0.23-1.35	$\Delta m(\tilde{t}_2^0, \tilde{t}_1^0) = 130$ GeV, $m(\tilde{q}_1^0) = 100$ GeV $\Delta m(\tilde{t}_2^0, \tilde{t}_1^0) = 130$ GeV, $m(\tilde{q}_1^0) = 0$ GeV	SUSY-2018-31 SUSY-2018-31
$\bar{t}_1\bar{t}_1, \bar{t}_1 \rightarrow Wb\tilde{q}_1^0$ or $\bar{t}_1\tilde{q}_1^0$		0-2 e, μ	0-2 jets/1-2 b E_T^{miss}	36.1	\bar{t}_1		1.0	$m(\tilde{q}_1^0) = 1$ GeV	1506.08616, 1709.04183, 1711.11520
$\bar{t}_1\bar{t}_1$, Well-Tempered LSP		Multiple	36.1	\bar{t}_1		0.48-0.84		$m(\tilde{q}_1^0) = 150$ GeV, $m(\tilde{q}_1^0) - m(\tilde{q}_2^0) = 5$ GeV, $\tilde{t}_1 \approx \tilde{t}_2$	1709.04183, 1711.11520
$\bar{t}_1\bar{t}_1, \bar{t}_1 \rightarrow \tau b, \tau \rightarrow \tau\tilde{G}$		1 $\tau + 1 e, \mu, \tau$	2 jets/1 b E_T^{miss}	36.1	\bar{t}_1		1.16	$m(\tilde{q}_1^0) = 800$ GeV	1803.10178
$\bar{t}_1\bar{t}_1, \bar{t}_1 \rightarrow c\tilde{q}_1^0 / \tilde{c}\tilde{q}_1^+$		0 e, μ	2 c E_T^{miss}	36.1	\bar{t}_1 \bar{t}_1	0.46 0.43	0.85	$m(\tilde{q}_1^0) = 0$ GeV $m(\tilde{t}_1, \tilde{c}) - m(\tilde{q}_1^0) = 50$ GeV $m(\tilde{t}_1, \tilde{c}) - m(\tilde{q}_1^0) = 5$ GeV	1805.01649 1805.01649 1711.03301
$\bar{t}_2\bar{t}_2, \bar{t}_2 \rightarrow \tilde{t}_1 + h$		1-2 e, μ	4 b E_T^{miss}	36.1	\bar{t}_2		0.32-0.88	$m(\tilde{q}_1^0) = 0$ GeV, $m(\tilde{t}_1) - m(\tilde{q}_1^0) = 180$ GeV	1706.03986
EW direct	$\tilde{\chi}_1^{\pm}\tilde{\chi}_2^0$ via WZ	2-3 e, μ $e\ell, \mu\mu$	≥ 1 E_T^{miss}	36.1 36.1	$\tilde{\chi}_1^{\pm}\tilde{\chi}_2^0$ $\tilde{\chi}_1^{\pm}\tilde{\chi}_2^0$	0.17	0.6	$m(\tilde{q}_1^0) = 0$ $m(\tilde{q}_1^0) - m(\tilde{q}_2^0) = 10$ GeV	1403.5294, 1806.02293 1712.08119
	$\tilde{\chi}_1^{\pm}\tilde{\chi}_1^{\mp}$ via WW	2 e, μ	E_T^{miss}	139	$\tilde{\chi}_1^{\pm}$	0.42		$m(\tilde{q}_1^0) = 0$	ATLAS-CONF-2019-008
	$\tilde{\chi}_1^{\pm}\tilde{\chi}_2^0$ via Wh	0-1 e, μ	2 b E_T^{miss}	36.1	$\tilde{\chi}_1^{\pm}\tilde{\chi}_2^0$	0.68		$m(\tilde{q}_1^0) = 0$	1812.09432
	$\tilde{\chi}_1^{\pm}\tilde{\chi}_1^{\mp}$ via $\tilde{t}_1/\bar{\nu}$	2 e, μ	E_T^{miss}	139	$\tilde{\chi}_1^{\pm}$		1.0	$m(\tilde{q}_1^0) = 0$	ATLAS-CONF-2019-008
	$\tilde{\chi}_1^{\pm}\tilde{\chi}_1^{\mp}/\tilde{\chi}_2^0, \tilde{\chi}_1^{\pm} \rightarrow \tilde{\tau}_1\nu(\tilde{\tau}\bar{\nu}), \tilde{\chi}_2^0 \rightarrow \tilde{\tau}_1\tau(\tilde{\nu}\bar{\tau})$	2 τ	E_T^{miss}	36.1	$\tilde{\chi}_1^{\pm}\tilde{\chi}_2^0$ $\tilde{\chi}_1^{\pm}\tilde{\chi}_2^0$	0.22	0.76	$m(\tilde{q}_1^0) = 0, m(\tilde{q}_1^0) = 0.5(m(\tilde{q}_1^0) + m(\tilde{q}_2^0))$ $m(\tilde{q}_1^0) - m(\tilde{q}_2^0) = 100$ GeV, $m(\tilde{q}_1^0) = 0.5(m(\tilde{q}_1^0) + m(\tilde{q}_2^0))$	1708.07875 1708.07875
	$\tilde{t}_{1,R}\tilde{t}_{1,L}, \tilde{t} \rightarrow \ell\tilde{q}_1^0$	2 e, μ ≥ 1	0 jets E_T^{miss}	139 36.1	\tilde{t} \tilde{t}	0.18	0.7	$m(\tilde{q}_1^0) = 0$ $m(\tilde{q}_1^0) - m(\tilde{q}_2^0) = 5$ GeV	ATLAS-CONF-2019-008 1712.08119
	$\tilde{H}\tilde{H}, \tilde{H} \rightarrow h\tilde{C}/Z\tilde{G}$	0 e, μ 4 e, μ	≥ 3 b 0 jets E_T^{miss}	36.1 36.1	\tilde{H} \tilde{H}	0.13-0.23 0.3	0.29-0.88	$\text{BR}(\tilde{q}_1^0 \rightarrow h\tilde{C}) = 1$ $\text{BR}(\tilde{q}_1^0 \rightarrow Z\tilde{G}) = 1$	1806.04030 1804.03602
Long-lived particles	Direct $\tilde{\chi}_1^{\pm}\tilde{\chi}_1^{\mp}$ prod., long-lived $\tilde{\chi}_1^{\pm}$	Disapp. trk	1 jet E_T^{miss}	36.1	$\tilde{\chi}_1^{\pm}$ $\tilde{\chi}_1^{\pm}$	0.15	0.46	Pure Wino Pure Higgsino	1712.02118 ATL-PHYS-PUB-2017-019
	Stable \tilde{g} R-hadron Metastable \tilde{g} R-hadron, $\tilde{g} \rightarrow qq\tilde{q}_1^0$	Multiple Multiple	36.1 36.1	\tilde{g} \tilde{g} [$\tau(\tilde{g}) = 10$ ns, 0.2 ns]		2.0 2.05 2.4		$m(\tilde{q}_1^0) = 100$ GeV	1902.01636, 1808.04095 1710.04901, 1808.04095
RPV	LFV $pp \rightarrow \tilde{\nu}_i + X, \tilde{\nu}_i \rightarrow e\mu/\tau/\mu\tau$	$e\mu, e\tau, \mu\tau$	3.2	$\tilde{\nu}_i$		1.9		$\lambda'_{111} = 0.11, \lambda'_{132}/\lambda'_{133}/\lambda'_{233} = 0.07$	1607.08079 1804.03602
	$\tilde{\chi}_1^{\pm}\tilde{\chi}_1^{\mp}/\tilde{\chi}_2^0 \rightarrow WW/Z\ell\ell\nu\nu$	4 e, μ	0 jets E_T^{miss}	36.1	$\tilde{\chi}_1^{\pm}\tilde{\chi}_2^0$ [$\lambda_{33} \neq 0, \lambda_{32} \neq 0$]	0.82	1.33	$m(\tilde{q}_1^0) = 100$ GeV	1804.03602
	$\bar{g}\bar{g}, \bar{g} \rightarrow qq\tilde{q}_1^0, \tilde{q}_1^0 \rightarrow qq\tilde{q}$	4-5 large-R jets Multiple	36.1 36.1	\bar{g} [$m(\tilde{q}_1^0) = 200$ GeV, 1100 GeV] \bar{g} [$\lambda'_{112} = 2e-4, 2e-5$]		1.05 1.3	1.9 2.0	Large λ'_{112}	1804.03568
	$\tilde{u}, \tilde{t} \rightarrow t\tilde{q}_1^0, \tilde{q}_1^0 \rightarrow tbs$	Multiple	36.1	\tilde{g} [$\lambda'_{333} = 2e-4, 1e-2$]		0.55	1.05	$m(\tilde{q}_1^0) = 200$ GeV, bino-like	ATLAS-CONF-2018-003
	$\tilde{t}_1\bar{t}_1, \tilde{t}_1 \rightarrow bs$	2 jets + 2 b	36.7	\tilde{t}_1 [qq, hq]		0.42	0.61		1710.07171
	$\tilde{t}_1\bar{t}_1, \tilde{t}_1 \rightarrow q\ell$	2 e, μ 1 μ	2 b DV	36.1 136	\tilde{t}_1 \tilde{t}_1		1.0	$\text{BR}(\tilde{t}_1 \rightarrow b\ell/hq) > 20\%$ $\text{BR}(\tilde{t}_1 \rightarrow q\mu) = 100\%, \cos\theta_{\tilde{t}_1} = 1$	1710.05544 ATLAS-CONF-2019-006

*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 1 Mass scale [TeV]

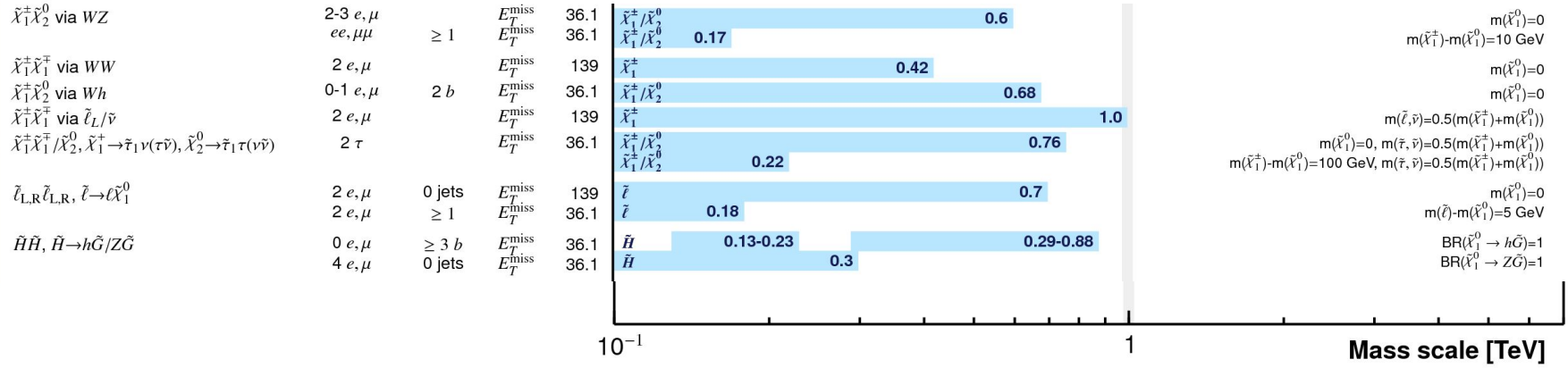
Model	Signature	$\int \mathcal{L} dt$ [fb ⁻¹]	Mass limit	Reference				
Inclusive Searches	$q\bar{q}, \bar{q} \rightarrow q\bar{t}_1^0$	0 e, μ mono-jet	2-6 jets E_T^{miss}	36.1	\bar{q} [2x, 8x Degen] \bar{q} [1x, 8x Degen]	0.9 1.55	$m(\tilde{t}_1^0) < 100$ GeV $m(\tilde{g}) - m(\tilde{t}_1^0) = 5$ GeV	1712.02332 1711.03301
	$\bar{g}\bar{g}, \bar{g} \rightarrow q\bar{q}\tilde{t}_1^0$	0 e, μ	2-6 jets E_T^{miss}	36.1	\bar{g}	0.43 0.71 2.0	$m(\tilde{t}_1^0) < 200$ GeV $m(\tilde{t}_1^0) = 900$ GeV	1712.02332 1712.02332
	$\bar{g}\bar{g}, \bar{g} \rightarrow q\bar{q}(\ell\ell)\tilde{t}_1^0$	3 e, μ $e\ell, \mu\mu$	4 jets 2 jets E_T^{miss}	36.1 36.1	\bar{g}	Forbidden 0.95-1.6	$m(\tilde{t}_1^0) < 800$ GeV $m(\tilde{g}) - m(\tilde{t}_1^0) = 50$ GeV	1706.03731 1805.11381
	$\bar{g}\bar{g}, \bar{g} \rightarrow q\bar{q}WZ\tilde{t}_1^0$	0 e, μ 3 e, μ	7-11 jets 4 jets E_T^{miss}	36.1 36.1	\bar{g}	1.2 1.8	$m(\tilde{t}_1^0) < 400$ GeV $m(\tilde{g}) - m(\tilde{t}_1^0) = 200$ GeV	1708.02794 1706.03731
	$\bar{g}\bar{g}, \bar{g} \rightarrow t\bar{t}\tilde{t}_1^0$	0-1 e, μ 3 e, μ	3 b 4 jets E_T^{miss}	79.8 36.1	\bar{g}	0.98 2.25	$m(\tilde{t}_1^0) < 200$ GeV $m(\tilde{g}) - m(\tilde{t}_1^0) = 300$ GeV	ATLAS-CONF-2018-041 1706.03731
	3 rd gen. squarks direct production	$\bar{b}_1\bar{b}_1, \bar{b}_1 \rightarrow b\tilde{t}_1^0 / \tilde{t}_1^0\tilde{t}_1^+$	Multiple Multiple Multiple	36.1 36.1 36.1	\bar{b}_1 \bar{b}_1 \bar{b}_1	Forbidden Forbidden Forbidden	0.9 0.58-0.82 0.7	$m(\tilde{t}_1^0) = 300$ GeV, $\text{BR}(\tilde{t}_1^0) = 1$ $m(\tilde{t}_1^0) = 300$ GeV, $\text{BR}(\tilde{t}_1^0) = \text{BR}(\tilde{t}_1^+) = 0.5$ $m(\tilde{t}_1^0) = 200$ GeV, $m(\tilde{t}_1^+) = 300$ GeV, $\text{BR}(\tilde{t}_1^+) = 1$
$\bar{b}_1\bar{b}_1, \bar{b}_1 \rightarrow b\tilde{t}_2^0 \rightarrow b\tilde{t}_1^0$		0 e, μ	6 b E_T^{miss}	139	\bar{b}_1 \bar{b}_1	Forbidden 0.23-0.48	$\Delta m(\tilde{t}_2^0, \tilde{t}_1^0) = 130$ GeV, $m(\tilde{t}_1^0) = 100$ GeV $\Delta m(\tilde{t}_2^0, \tilde{t}_1^0) = 130$ GeV, $m(\tilde{t}_1^0) = 0$ GeV	SUSY-2018-31 SUSY-2018-31
$\tilde{t}_1\tilde{t}_1, \tilde{t}_1 \rightarrow Wb\tilde{t}_1^0$ or $\tilde{t}_1^0\tilde{t}_1^0$		0-2 e, μ	0-2 jets/1-2 b E_T^{miss}	36.1	\tilde{t}_1	1.0	$m(\tilde{t}_1^0) = 1$ GeV	1506.08616, 1709.04183, 1711.11520
$\tilde{t}_1\tilde{t}_1, \tilde{t}_1 \rightarrow \tilde{t}_1 b\tilde{\nu}$, $\tilde{t}_1 \rightarrow \tau\tilde{G}$		Multiple	36.1	\tilde{t}_1	0.48-0.84	$m(\tilde{t}_1^0) = 150$ GeV, $m(\tilde{t}_1^+) - m(\tilde{t}_1^0) = 5$ GeV, $\tilde{t}_1 \approx \tilde{t}_2$	1709.04183, 1711.11520	
$\tilde{t}_1\tilde{t}_1, \tilde{t}_1 \rightarrow c\tilde{t}_1^0 / \tilde{c}\tilde{\nu}, \tilde{c} \rightarrow c\tilde{t}_1^0$		1 $\tau + 1 e, \mu, \tau$	2 jets/1 b E_T^{miss}	36.1	\tilde{t}_1	1.16	$m(\tilde{t}_1^0) = 800$ GeV	1803.10178
$\tilde{t}_2\tilde{t}_2, \tilde{t}_2 \rightarrow \tilde{t}_1 + h$								
EW direct	$\tilde{\chi}_1^{\pm}\tilde{\chi}_2^0$ via WZ							
	$\tilde{\chi}_1^{\pm}\tilde{\chi}_1^{\mp}$ via WW							
	$\tilde{\chi}_1^{\pm}\tilde{\chi}_2^0$ via Wh							
	$\tilde{\chi}_1^{\pm}\tilde{\chi}_1^{\mp}$ via $\tilde{t}_1/\tilde{\nu}$	2 e, μ	E_T^{miss}	139	$\tilde{\chi}_1^{\pm}$	0.76	$m(\tilde{\nu}_\tau) = 0, m(\tilde{t}_1) = m(\tilde{t}_1^+)$ $m(\tilde{t}_1^0) = 0, m(\tilde{\nu}_\tau) = 0.5(m(\tilde{t}_1^+) + m(\tilde{t}_1^0))$ $m(\tilde{t}_1^+) - m(\tilde{t}_1^0) = 100$ GeV, $m(\tilde{\nu}_\tau) = 0.5(m(\tilde{t}_1^+) + m(\tilde{t}_1^0))$	ATLAS-CONF-2019-006 1708.07875 1708.07875
	$\tilde{\chi}_1^{\pm}\tilde{\chi}_1^{\mp} / \tilde{\chi}_2^0, \tilde{\chi}_1^{\pm} \rightarrow \tilde{\tau}_1(\nu\tilde{\nu}), \tilde{\chi}_2^0 \rightarrow \tilde{\tau}_1\tau(\nu\tilde{\nu})$	2 τ	E_T^{miss}	36.1	$\tilde{\chi}_1^{\pm}$ $\tilde{\chi}_1^{\pm}$ $\tilde{\chi}_2^0$	0.22 0.76	$m(\tilde{\tau}_1) = 0$ $m(\tilde{\tau}_1) - m(\tilde{\chi}_1^0) = 100$ GeV, $m(\tilde{\tau}_1) = 0.5(m(\tilde{\chi}_1^+) + m(\tilde{\chi}_1^0))$	ATLAS-CONF-2019-008 1712.08119
	$\tilde{t}_1\tilde{t}_1, \tilde{t}_1 \rightarrow \tilde{t}_1\tilde{\nu}$	2 e, μ ≥ 1	0 jets E_T^{miss}	139 36.1	\tilde{t}_1	0.18	$m(\tilde{\nu}_\tau) = 0$ $m(\tilde{\nu}_\tau) - m(\tilde{t}_1^0) = 5$ GeV	ATLAS-CONF-2019-008
$\tilde{H}\tilde{H}, \tilde{H} \rightarrow h\tilde{G}$	0 e, μ 4 e, μ	≥ 3 b 0 jets E_T^{miss}	36.1 36.1	\tilde{H} \tilde{H}	0.13-0.23 0.3	$\text{BR}(\tilde{H}^0 \rightarrow h\tilde{G}) = 1$ $\text{BR}(\tilde{H}^0 \rightarrow Z\tilde{G}) = 1$	1806.04030 1804.03602	
Long-lived particles	Direct $\tilde{\chi}_1^{\pm}\tilde{\chi}_1^{\mp}$ prod., long-lived $\tilde{\chi}_1^{\pm}$	Disapp. trk	1 jet E_T^{miss}	36.1	$\tilde{\chi}_1^{\pm}$ $\tilde{\chi}_1^{\pm}$	0.15 0.46	Pure Wino Pure Higgsino	1712.02118 ATL-PHYS-PUB-2017-019
	Stable R-hadron	Multiple	36.1	\tilde{g}	2.0	$m(\tilde{t}_1^0) = 100$ GeV	1902.01636, 1808.04095	
	Metastable \tilde{g} R-hadron, $\tilde{g} \rightarrow q\bar{q}\tilde{t}_1^0$	Multiple	36.1	\tilde{g}	\tilde{g} [$\tau(\tilde{g}) = 10$ ns, 0.2 ns]	2.05 2.4		1710.04901, 1808.04095
RPV	LFV $pp \rightarrow \tilde{\nu}_\tau + X, \tilde{\nu}_\tau \rightarrow e\mu/\tau/\mu\tau$	$e\mu, e\tau, \mu\tau$	3.2	$\tilde{\nu}_\tau$	1.9	$\lambda'_{111} = 0.11, \lambda'_{132}/\lambda'_{133}/\lambda'_{233} = 0.07$	1607.08079	
	$\tilde{\chi}_1^{\pm}\tilde{\chi}_1^{\mp} / \tilde{\chi}_2^0 \rightarrow WW/Z\ell\ell\nu\nu$	4 e, μ	0 jets E_T^{miss}	36.1	$\tilde{\chi}_1^{\pm} / \tilde{\chi}_2^0$ [$\lambda_{333} \neq 0, \lambda_{323} \neq 0$]	0.82 1.33	$m(\tilde{t}_1^0) = 100$ GeV	1804.03602
	$\tilde{g}, \tilde{g} \rightarrow q\bar{q}\tilde{t}_1^0, \tilde{t}_1^0 \rightarrow q\bar{q}q$	4-5 large-R jets	36.1	\tilde{g}	[$m(\tilde{t}_1^0) = 200$ GeV, 1100 GeV] [$\lambda'_{112} = 2e-4, 2e-5$]	1.05 1.8 1.9 2.0	Large λ'_{112}	1804.03568
	$\tilde{u}, \tilde{t} \rightarrow t\tilde{t}_1^0, \tilde{t}_1^0 \rightarrow tbs$	Multiple	36.1	\tilde{g}	[$\lambda'_{333} = 2e-4, 1e-2$]	0.55	$m(\tilde{t}_1^0) = 200$ GeV, bino-like	ATLAS-CONF-2018-003
	$\tilde{t}_1\tilde{t}_1, \tilde{t}_1 \rightarrow bs$	2 jets + 2 b	36.7	\tilde{t}_1	[qq, \tilde{g}]	0.42	$m(\tilde{t}_1^0) = 200$ GeV, bino-like	1710.07171
	$\tilde{t}_1\tilde{t}_1, \tilde{t}_1 \rightarrow q\ell$	2 e, μ 1 μ	2 b DV	36.1 136	\tilde{t}_1 \tilde{t}_1	0.61 1.0	$\text{BR}(\tilde{t}_1 \rightarrow b\ell) > 20\%$ $\text{BR}(\tilde{t}_1 \rightarrow q\mu) = 100\%, \cos\theta = 1$	1710.05544 ATLAS-CONF-2019-006

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How light could the electroweak sector of the MSSM still be?

EW direct



$m(\tilde{\chi}_1^0)=0$
 $m(\tilde{\chi}_1^\pm)-m(\tilde{\chi}_1^0)=10$ GeV
 $m(\tilde{\chi}_1^0)=0$
 $m(\tilde{\chi}_1^0)=0$
 $m(\tilde{\ell}, \tilde{\nu})=0.5(m(\tilde{\chi}_1^\pm)+m(\tilde{\chi}_1^0))$
 $m(\tilde{\chi}_1^0)=0, m(\tilde{\tau}, \tilde{\nu})=0.5(m(\tilde{\chi}_1^\pm)+m(\tilde{\chi}_1^0))$
 $m(\tilde{\chi}_1^\pm)-m(\tilde{\chi}_1^0)=100$ GeV, $m(\tilde{\tau}, \tilde{\nu})=0.5(m(\tilde{\chi}_1^\pm)+m(\tilde{\chi}_1^0))$
 $m(\tilde{\chi}_1^0)=0$
 $m(\tilde{\ell})-m(\tilde{\chi}_1^0)=5$ GeV
 $BR(\tilde{\chi}_1^0 \rightarrow h\tilde{G})=1$
 $BR(\tilde{\chi}_1^0 \rightarrow Z\tilde{G})=1$

- Limits from EW direct production pushing to TeV scale?



2. Analysis

Light SUSY is alive!



Theory: MSSM particle content

Slide credit:
Anders
Kvellestad

Name	Spin	P_R	Gauge Eigenstates	Mass Eigenstates
Higgs bosons	0	+1	H_u^0 H_d^0 H_u^+ H_d^-	h^0 H^0 A^0 H^\pm
squarks	0	-1	\tilde{u}_L \tilde{u}_R \tilde{d}_L \tilde{d}_R \tilde{s}_L \tilde{s}_R \tilde{c}_L \tilde{c}_R \tilde{t}_1 \tilde{t}_2 \tilde{b}_L \tilde{b}_R	(same)
sleptons	0	-1	\tilde{e}_L \tilde{e}_R $\tilde{\nu}_e$ $\tilde{\mu}_L$ $\tilde{\mu}_R$ $\tilde{\nu}_\mu$ $\tilde{\tau}_L$ $\tilde{\tau}_R$ $\tilde{\nu}_\tau$	(same)
neutralinos	1/2	-1	\tilde{B}^0 \tilde{W}^0 \tilde{H}_u^0 \tilde{H}_d^0	$\tilde{\chi}_1^0$ $\tilde{\chi}_2^0$ $\tilde{\chi}_3^0$ $\tilde{\chi}_4^0$
charginos	1/2	-1	\tilde{W}^\pm \tilde{H}_u^+ \tilde{H}_d^-	$\tilde{\chi}_1^\pm$ $\tilde{\chi}_2^\pm$
gluino	1/2	-1	\tilde{g}	(same)

Decoupled



Theory: parameter space

$$M_1 \quad M_2 \quad \mu \quad \tan \beta$$

Slide credit:
Anders
Kvellestad

Neutralinos

$$\psi^0 = (\tilde{B}, \tilde{W}^0, \tilde{H}_d^0, \tilde{H}_u^0)$$

$$M_N = \begin{pmatrix} M_1 & 0 & -\frac{1}{2}g'vc_\beta & \frac{1}{2}g'vs_\beta \\ 0 & M_2 & \frac{1}{2}gvc_\beta & -\frac{1}{2}gvs_\beta \\ -\frac{1}{2}g'vc_\beta & \frac{1}{2}gvc_\beta & 0 & -\mu \\ \frac{1}{2}g'vs_\beta & -\frac{1}{2}gvs_\beta & -\mu & 0 \end{pmatrix}$$

Charginos

$$\psi^\pm = (\tilde{W}^\pm, \tilde{H}_u^\pm, \tilde{W}^\mp, \tilde{H}_d^\mp)$$

$$M_C = \begin{pmatrix} 0 & X^T \\ X & 0 \end{pmatrix}, \quad \text{where } X = \begin{pmatrix} M_2 & \frac{gvs_\beta}{\sqrt{2}} \\ \frac{gvc_\beta}{\sqrt{2}} & \mu \end{pmatrix}.$$



Theory: parameter space

M_1 M_2 μ $\tan \beta$

Slide credit:
Anders
Kvellestad

Neutralinos

$$\psi^0 = (\tilde{B}, \tilde{W}^0, \tilde{H}_d^0, \tilde{H}_u^0)$$

$M_N =$

Rough summary:

- M_1 controls the mass of **one neutralino**
- M_2 controls the mass of **one neutralino** and **one chargino**
- μ controls the mass of **two neutralinos** and **one chargino**

inos

(\tilde{I}_d^-)

$$M_C = \begin{pmatrix} 0 & X^T \\ X & 0 \end{pmatrix}, \text{ where } X = \begin{pmatrix} M_2 & \frac{gvs_\beta}{\sqrt{2}} \\ \frac{gvc_\beta}{\sqrt{2}} & \mu \end{pmatrix}$$



“EWMSSM”

- Only electroweak sector of MSSM kept light
- Everything else decoupled
- 4 parameters: $M_1, M_2, \mu, \tan \beta$
 - Manageable! But still a lot of non-trivial physics beyond what simplified models can capture.
 - 6 new particles: 4 neutralinos + 2 charginos



Strategy

- Focus on 13 TeV searches
- Scan 4D EWMSSM parameter space
- *At every point*: Run MC simulations of 13 TeV searches
- Compute joint likelihood function for all searches

How? -> GAMBIT



GAMBIT



The Global And Modular BSM Inference Tool

- An international community with 40+ collaborators (10 experiments, 14 major theory codes)
- A new software framework for global fits developed over the past six years



- First public code release in May 2017, [arXiv:1705.07908](https://arxiv.org/abs/1705.07908) (gambit.hepforge.org)
- So far 7 physics studies:
[arXiv:1705.07917](https://arxiv.org/abs/1705.07917), [arXiv:1705.07935](https://arxiv.org/abs/1705.07935)
[arXiv:1705.07931](https://arxiv.org/abs/1705.07931), [arXiv:1806.11281](https://arxiv.org/abs/1806.11281)
[arXiv:1808.10465](https://arxiv.org/abs/1808.10465), [arXiv:1809.02097](https://arxiv.org/abs/1809.02097),
[arXiv:1810.07192](https://arxiv.org/abs/1810.07192)
+ many more in preparation

GAMBIT



- Apply **wide ranges of constraints** to a given model
 - Construction of composite likelihoods
 - Efficient scans of multi-dimensional parameter space
 - Consistent treatment of uncertainties and nuisance parameters
- Maximum of **flexibility and modularity** in terms of
 - Fast definition of new data sets and models
 - Plug and play of many popular theory tools* (dynamical adaptation to user's system)
 - Large database of models and observables (+ more to come)
 - Many statistical methods (frequentist & Bayesian)
- **Optimized** for parallel computing & fully open source

* GAMBIT supports backend codes in C/C++, Fortran, Python and Mathematica

GAMBIT



Modules

A module provides GAMBIT with a range of capabilities (the ability to calculate a certain quantity)

- **DarkBit** (arXiv:1705.07920) – dark matter observables
- **ColliderBit** (arXiv:1705.07919) – collider observables (Higgs + SUSY searches from ATLAS, CMS, LEP)
- **FlavBit** (arXiv:1705.07933) – flavour physics ($g - 2$, $b \rightarrow s\gamma$, B decays)
- **SpecBit** (arXiv:1705.07936) – RGE running, masses, mixings, ...
- **DecayBit** (arXiv:1705.07936) – decay widths for all relevant particles
- **PrecisionBit** (arXiv:1705.07936) – SM likelihoods, electroweak precision tests
- **ScannerBit** (arXiv:1705.07959) – manages statistics, sampling and optimisation

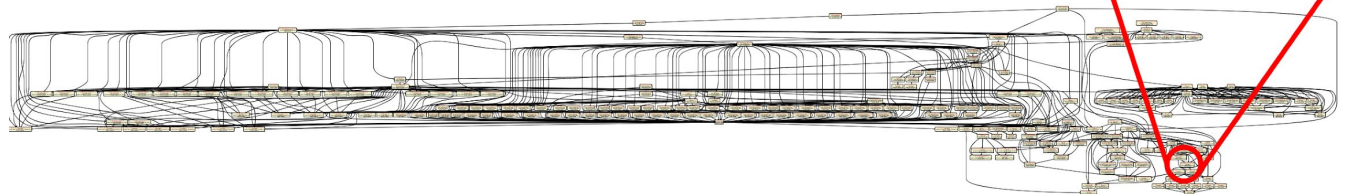
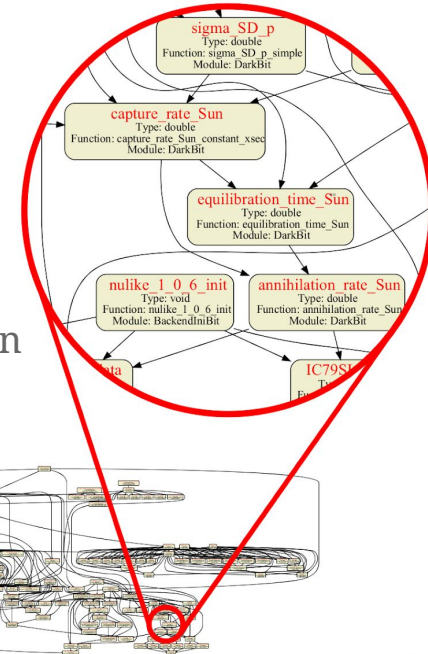
- Coming soon: NeutrinoBit & CosmoBit

GAMBIT



How does GAMBIT work?

- User specifies the model, parameter space, observables and scanning technique
- GAMBIT then performs the **dependency resolution**
 - Identification of all functions necessary to calculate requested observables
 - Determination of the required inputs for each function
 - Construction of the optimum order of function evaluation
- A scan then consists of calling all necessary modules and external libraries in the required order for each parameter point



Global fits of GUT-scale SUSY models with GAMBIT

The GAMBIT Collaboration: Peter Athron^{1,2,a}, Csaba Balázs^{1,2}, Torsten Bringmann³, Andy Buckley⁴, Marcin Chrzęszcz^{5,6}, Jan Conrad^{7,8}, Jonathan M. Cornell⁹, Lars A. Dal³, Joakim Edsjö^{7,8}, Ben Farmer^{7,8,b}, Paul Jackson^{10,2}, Abram Krislock³, Anders Kvellestad^{11,c}, Farvah Mahmoudi^{12,13,*}, Gregory D. Martinez¹⁴, Antje Putze¹⁵, Are Raklev¹⁶, Christopher Rogan¹⁶, Roberto Ruiz de Austri¹⁷, Aldo Saavedra^{18,2}, Christopher Savage¹¹, Pat Scott^{19,d}, Nicola Serra⁵, Christoph Wenig^{10,2,e}, Martin White^{10,2,e}

arXiv: 1809.02097

EPJC 77 (2017) no.12, 879

arXiv: 1705.07935

EPJC 77 (2017) no.12, 824

A global fit of the MSSM with GAMBIT

The GAMBIT Collaboration: Peter Athron^{1,2,a}, Csaba Balázs^{1,2}, Torsten Bringmann³, Andy Buckley⁴, Marcin Chrzęszcz^{5,6}, Jan Conrad^{7,8}, Jonathan M. Cornell⁹, Lars A. Dal³, Joakim Edsjö^{7,8}, Ben Farmer^{7,8}, Paul Jackson^{10,2}, Abram Krislock³, Anders Kvellestad^{11,b}, Farvah Mahmoudi^{12,13,*}, Gregory D. Martinez¹⁴, Antje Putze¹⁵, Are Raklev³, Christopher Rogan¹⁶, Aldo Saavedra^{17,2}, Christopher Savage¹¹, Pat Scott^{18,c}, Nicola Serra⁵, Christoph Wenig¹⁹, Martin White^{10,2,d}

Combined collider constraints on neutralinos and charginos

The GAMBIT Collaboration: Peter Athron^{1,2}, Csaba Balázs^{1,2}, Andy Buckley³, Jonathan M. Cornell⁴, Matthias Danninger⁵, Ben Farmer⁶, Andrew Fowlie^{1,2,9}, Tomás E. Gonzalo¹⁰, Julia Harz¹¹, Paul Jackson^{2,12}, Rose Kudzman-Blais⁵, Anders Kvellestad^{6,10,a}, Gregory D. Martinez¹³, Andreas Petridis^{2,12}, Are Raklev¹⁰, Christopher Rogan¹⁴, Pat Scott⁶, Abhishek Sharma^{2,12}, Martin White^{2,12,b}, Yang Zhang^{1,2}

arXiv: 1809.02097

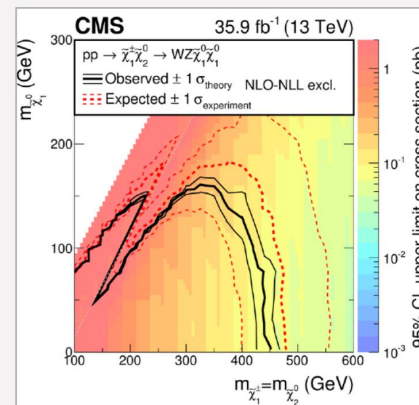
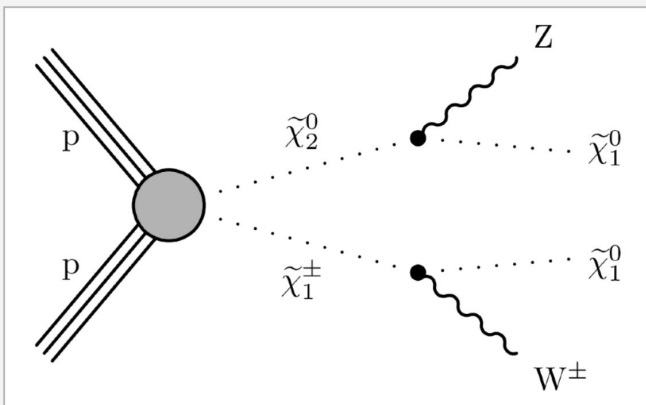
Accepted at EPJC, 3 April 2019



13 TeV, 36 fb⁻¹

Analysis: EW SUSY searches

- ATLAS Higgsino search: **ATLAS_4b**
- ATLAS ≥ 4 lepton search: **ATLAS_4lep**
- ATLAS multilepton EW search: **ATLAS_MultiLep_* (2lep_0jet, 2lep_jet, 3lep)**
- ATLAS recursive jigsaw EW search: **ATLAS_RJ_* (2lep_2jet, 3lep)**
- CMS Wh search: **CMS_1lep_2b**
- CMS 2 soft opposite-sign lepton search: **CMS_2lep_soft** (including SR correlations)
- CMS 2 opposite-sign lepton search: **CMS_2OSlep** (including SR correlations)
- CMS multilepton EW search: **CMS_MultiLep_* (2SSlep, 3lep)**



Included likelihoods

- Z and Higgs invisible decays

$$\Gamma(Z \rightarrow \text{inv.}) = 499.0 \pm 1.5 \text{ MeV}$$

$$\text{BF}(h \rightarrow \text{inv.}) \leq 0.19$$

- LEP cross-section limits

Production	Signature	Experiment
$\tilde{\chi}_i^0 \tilde{\chi}_1^0$	$\tilde{\chi}_i^0 \rightarrow q\bar{q}\tilde{\chi}_1^0$	OPAL [53]
$(i = 2, 3, 4)$	$\tilde{\chi}_i^0 \rightarrow \ell\bar{\ell}\tilde{\chi}_1^0$	L3 [98]
$\tilde{\chi}_i^+ \tilde{\chi}_i^-$	$\tilde{\chi}_i^+ \tilde{\chi}_i^- \rightarrow q\bar{q}' q\bar{q}' \tilde{\chi}_1^0 \tilde{\chi}_1^0$	OPAL [53]
$(i = 1, 2)$	$\tilde{\chi}_i^+ \tilde{\chi}_i^- \rightarrow q\bar{q}' \ell\nu \tilde{\chi}_1^0 \tilde{\chi}_1^0$	OPAL [53]
	$\tilde{\chi}_i^+ \tilde{\chi}_i^- \rightarrow \ell\nu\ell\nu \tilde{\chi}_1^0 \tilde{\chi}_1^0$	OPAL [53], L3 [98]
	ISR γ + missing energy	OPAL [99]

- 13 TeV searches for EW SUSY

Likelihood label	Source
ATLAS_4b	ATLAS Higgsino search [104]
ATLAS_4lep	ATLAS 4ℓ search [105]
ATLAS_MultiLep_2lep_0jet	ATLAS multilepton EW search [100]
ATLAS_MultiLep_2lep_jet	ATLAS multilepton EW search [100]
ATLAS_MultiLep_3lep	ATLAS multilepton EW search [100]
ATLAS_RJ_2lep_2jet	ATLAS recursive jigsaw EW search [101]
ATLAS_RJ_3lep	ATLAS recursive jigsaw EW search [101]
CMS_1lep_2b	CMS Wh search [106]
CMS_2lep_soft	CMS 2 soft opposite-charge lepton search [109]
CMS_2OSlep	CMS 2 opposite-charge lepton search [110]
CMS_MultiLep_2SSlep	CMS multilepton EW search [111]
CMS_MultiLep_3lep	CMS multilepton EW search [111]

Joint likelihood

$$L(\mu) = \prod_i L_i(\mu)$$

- Different analyses assumed to be statistically independent
 - (no search region event overlap)
 - Also assumed signal regions with different final states to be independent

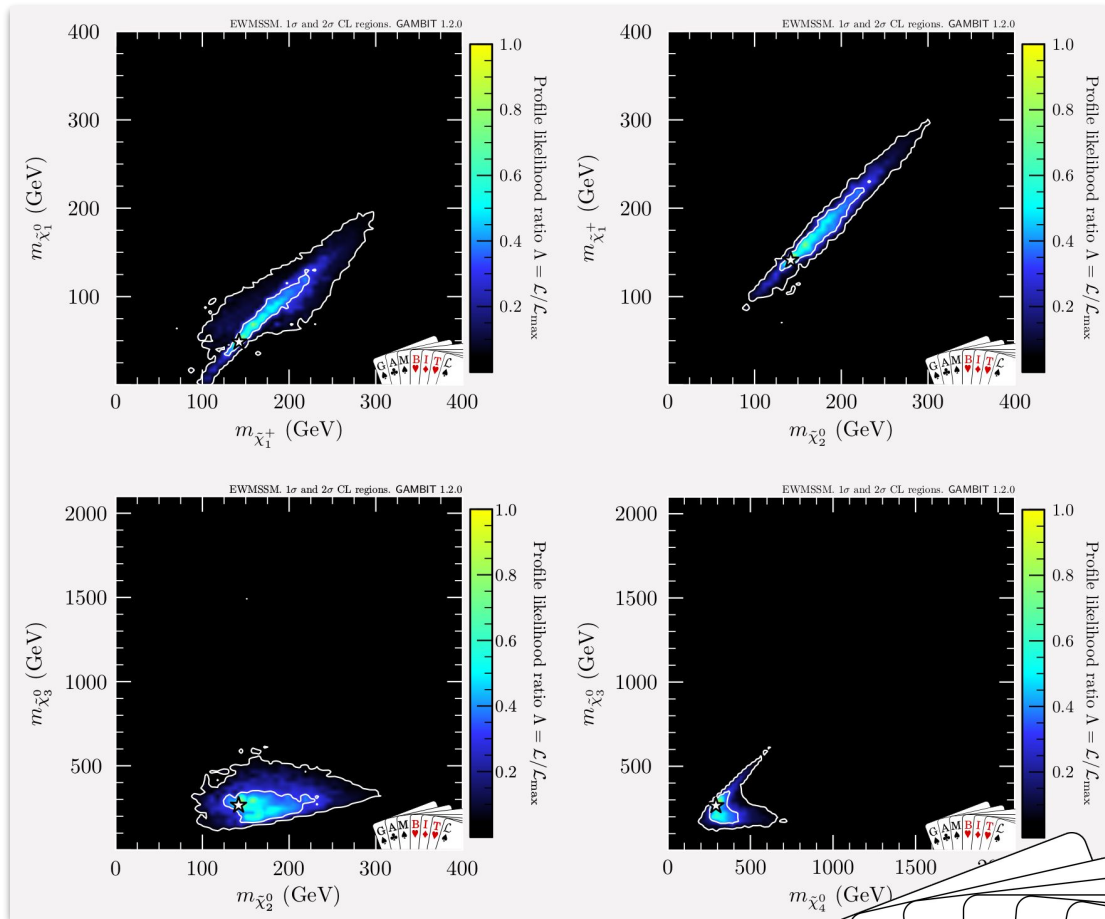
- CMS simplified likelihoods used where available
 - ...but when they aren't, “Best expected” signal region is used*
 - --> reduced exclusion power but not much choice without correlation information.

$$\mathcal{L}(\mathbf{s}, \boldsymbol{\gamma}) = \prod_i^{N_{\text{bin}}} \left[\frac{(s_i + b_i + \gamma_i)^{n_i} e^{-(s_i + b_i + \gamma_i)}}{n_i!} \right] \\ \times \frac{1}{\sqrt{\det 2\pi \boldsymbol{\Sigma}}} e^{-\frac{1}{2} \boldsymbol{\gamma}^T \boldsymbol{\Sigma}^{-1} \boldsymbol{\gamma}} .$$

*for p-value tests of best fit point we also combined all signal regions as if they were independent, to check potential impact of un-chosen signal regions.

Results

- Full profile likelihood
- All electroweakinos preferred light
- Prefers scenarios with **two large steps** $\gtrsim m_Z$ in neutralino mass hierarchy



Results

Local significance tests

+

“Goodness of fit” tests

Analysis	Best expected SRs				All SRs; neglect correlations			
	Local signif. (σ)	SM fit (σ)	EWMSSM fit (σ)	#SRs	Local signif. (σ)	SM fit (σ)	EWMSSM fit (σ)	#SRs
Higgs invisible width	0	0	0	1	0	0	0	1
Z invisible width	0	1.3	1.3	1	0	1.3	1.3	1
ATLAS_4b	0.7	0	0	1	1.5	0	0	2*
ATLAS_4lep	2.3	1.9	0	1	2.5	1.0	0	4
ATLAS_MultiLep_2lep_0jet	0.9	0.3	0.1	1	1.3	0	0	6
ATLAS_MultiLep_2lep_jet	0	0	0.5	1	0.8	0.5	0.2	3
ATLAS_MultiLep_3lep	1.8	1.5	0.7	1	1.2	0.4	0.3	11
ATLAS_RJ_2lep_2jet	0	0.3	0.5	1	1.5	1.8	1.5	4
ATLAS_RJ_3lep	2.7	2.5	1.1	1	3.4	2.5	0.7	4
CMS_1lep_2b	0.8	0.3	0.3	1	0	0	0	2
CMS_2lep_soft	0.1	0.2	0.2	12	0.1	0.2	0.2	12
CMS_2OSlep	0.1	0.5	0.5	7	0	0.4	0.5	7
CMS_MultiLep_2SSlep	0.2	0	0	1	0.2	0	0	2
CMS_MultiLep_3lep	0	0	0.4	1	0	0	0	6
Combined	3.3	1.4	0.2	31	4.1	1.2	0	65

- Est. local significance $\sim 3.3\sigma$ (reduced to $\sim 2.9\sigma$ with 8 TeV analyses)
- **Optimistic summary:** Early hint of signal in multilepton final states? (not necessarily SUSY/MSSM)
- **Cool-headed summary:** Very light electroweakinos still allowed in MSSM
- Need to go **beyond simplified models** with one-step decay chains
- Look forward to updates on ATLAS/CMS multilepton searches!



Results

A few caveats:

- Only L0+LL cross-sections
 - *Why?* Speed.
- For most analyses can only use one SR per point
 - *Why?* Missing correlation information
- Too weak constraints from CMS multilepton search
 - *Why?* Too many SRs - had to use aggregated SRs
 - CMS have recently provided covariance information - **thanks!**

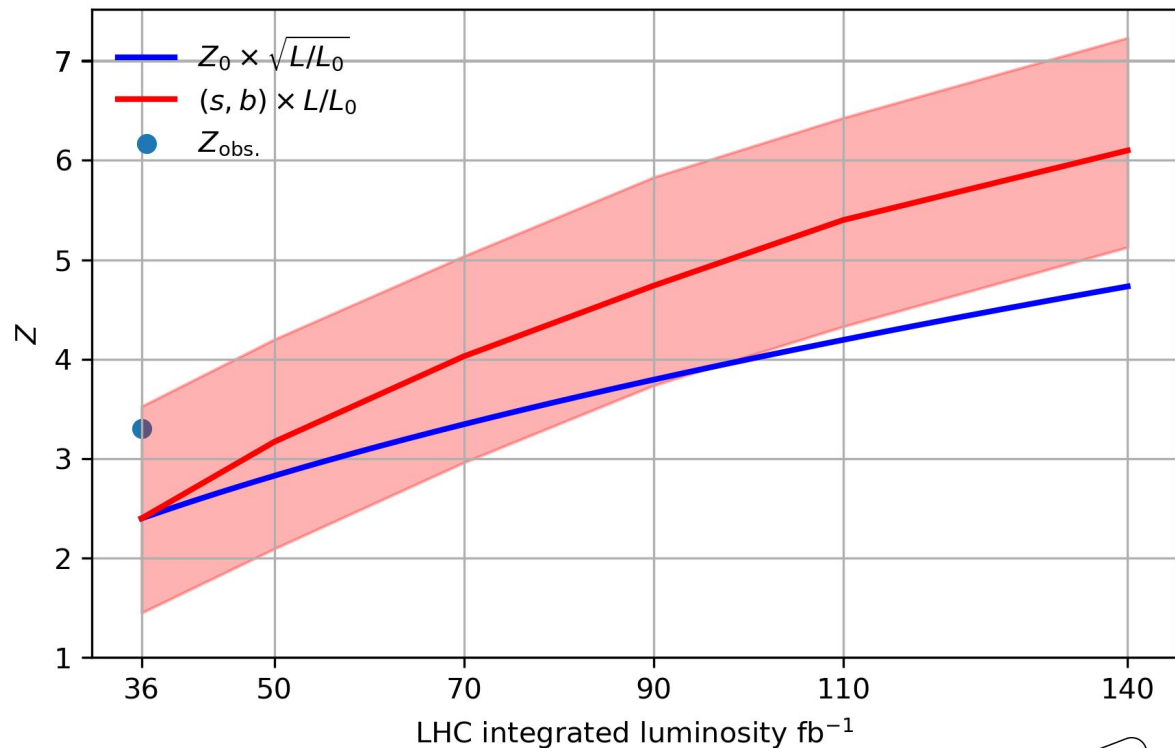


Predictions for full Run 2 data!

ATLAS and CMS now have $\sim 140 \text{ fb}^{-1}$ of data on disk.

What can we expect under the assumption that our EWMSSM BF point is True?

-> Simple scaling of 36 fb^{-1} 13 TeV analyses. Take with a grain of salt.



Predictions for full Run 2 data!

36 fb^{-1}



Scaled to



140 fb^{-1}

Analysis	Best expected SRs				All SRs; neglect correlations				24
	Local signif. (σ)	SM fit (σ)	EWMSSM fit (σ)	#SRs	Local signif. (σ)	SM fit (σ)	EWMSSM fit (σ)	#SRs	
Higgs invisible width	0	0	0	1	0	0	0	1	
Z invisible width	0	1.3	1.3	1	0	1.3	1.3	1	
ATLAS_4b	0.7	0	0	1	1.5	0	0	2*	
ATLAS_4lep	2.3	1.9	0	1	2.5	1.0	0	4	
ATLAS_MultiLep_2lep_0jet	0.9	0.3	0.1	1	1.3	0	0	6	
ATLAS_MultiLep_2lep_jet	0	0	0.5	1	0.8	0.5	0.2	3	
ATLAS_MultiLep_3lep	1.8	1.5	0.7	1	1.2	0.4	0.3	11	
ATLAS_RJ_2lep_2jet	0	0.3	0.5	1	1.5	1.8	1.5	4	
ATLAS_RJ_3lep	2.7	2.5	1.1	1	3.4	2.5	0.7	4	
CMS_1lep_2b	0.8	0.3	0.3	1	0	0	0	2	
CMS_2lep_soft	0.1	0.2	0.2	12	0.1	0.2	0.2	12	
CMS_2OSlep	0.1	0.5	0.5	7	0	0.4	0.5	7	
CMS_MultiLep_2SSlep	0.2	0	0	1	0.2	0	0	2	
CMS_MultiLep_3lep	0	0	0.4	1	0	0	0	6	
Combined	3.3	1.4	0.2	31	4.1	1.2	0	65	

Analysis	Best expected SRs				All SRs; neglect correlations				24
	Local signif. (σ)	SM fit (σ)	EWMSSM fit (σ)	#SRs	Local signif. (σ)	SM fit (σ)	EWMSSM fit (σ)	#SRs	
ATLAS_4b	0	0	0	1	0.1	0	0	2	
ATLAS_4lep	3.3	3.1	0	1	3.9	2.6	0	4	
ATLAS_MultiLep_2lep_0jet	0.4	0	0	1	0.4	0	0	6	
ATLAS_MultiLep_2lep_jet	2.0	1.7	0	1	2.2	0.9	0	3	
ATLAS_MultiLep_3lep	2.0	1.7	0	1	3.8	0.8	0	11	
ATLAS_RJ_2lep_2jet	1.6	1.2	0	1	1.6	0	0	4	
ATLAS_RJ_3lep	2.8	2.6	0	1	3.6	2.2	0	4	
CMS_1lep_2b	0	0	0	1	0	0	0	2	
CMS_2lep_soft	0.1	0	0	12	0.1	0	0	12	
CMS_2OSlep	1.6	0	0	7	1.6	0	0	7	
CMS_MultiLep_2SSlep	0.7	0	0	1	0.9	0	0	2	
CMS_MultiLep_3lep	2.2	1.9	0	1	2.8	0.7	0	6	
Combined	6.1	1.1	0	29	7.8	0	0	63	

Summary

- We have performed a large global fit of the MSSM electroweak sector using GAMBIT
- **Light neutralinos and charginos still allowed** in MSSM
- No necessary tension between ATLAS RJ and conventional multilepton searches
- Combined LHC results prefer scenarios with **all neutralinos and charginos below ~500 GeV**
- Predicts **multi-W/Z/h** final states
- Subset of best-fit regions compatible with dark matter results
- **Interesting times for EW SUSY searches!**

Benchmark points

Parameter	#1 Best fit	#2 Heavy winos	#3 Highest mass	#4 DM
$M_1(Q)$	-50.6 GeV	-79.2 GeV	133.4 GeV	-45.6 GeV
$M_2(Q)$	149.3 GeV	263.0 GeV	243.5 GeV	143.7 GeV
$\mu(Q)$	252.7 GeV	-187.3 GeV	-293.2 GeV	260.8 GeV
$\tan\beta(m_Z)$	28.7	40.4	41.5	16.4
$m_{\tilde{\chi}_1^0}$	-49.4 GeV	-73.9 GeV	129.4 GeV	-45.1 GeV
$m_{\tilde{\chi}_2^0}$	141.6 GeV	165.7 GeV	230.6 GeV	136.5 GeV
$m_{\tilde{\chi}_3^0}$	-270.3 GeV	-208.5 GeV	-308.8 GeV	-277.8 GeV
$m_{\tilde{\chi}_4^0}$	290.2 GeV	292.6 GeV	344.6 GeV	297.2 GeV
$m_{\tilde{\chi}_1^\pm}$	142.1 GeV	168.7 GeV	230.2 GeV	136.8 GeV
$m_{\tilde{\chi}_2^\pm}$	293.9 GeV	294.2 GeV	345.8 GeV	300.5 GeV
Collider log-likelihood	10.8	10.3	9.7	10.4



All results are publically available

- Results available on zenodo.cern.ch
 - Parameter point samples and signal predictions (hdf5 files)
 - GAMBIT input files for all scans
 - SLHA files for benchmark points
- Links at gambit.hepforge.org/pubs

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GAMBIT (Collaboration)

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October 18, 2018 (v2) Dataset Open Access View

Supplementary Data: Axion global fits with Peccei-Quinn symmetry breaking before inflation using GAMBIT

The GAMBIT Collaboration;

Description of Supplementary Data This record contains the samples used to create the figures (excluding validation and prior dependence plots) and to derive most of the results in Hoof et al., "Axion global fits with Peccei-Quinn symmetry breaking before inflation using GAMBIT" (availa

Uploaded on April 3, 2019

1 more version(s) exist for this record

September 7, 2018 (v1) Dataset Open Access View

Supplementary Data: Combined collider constraints on neutralinos and charginos using GAMBIT

The GAMBIT Collaboration;

Supplementary Data Combined collider constraints on neutralinos and charginos. The files in this record contain data for the EWMSSM model considered in the GAMBIT paper on constraints on electroweakinos.

Uploaded on September 7, 2018

September 3, 2018 (v1) Dataset Open Access View

Supplementary Data: Global analyses of Higgs portal singlet dark matter models using GAMBIT

The GAMBIT Collaboration;

The files in this record contain data for the effective Higgs portal dark matter models considered in the GAMBIT "Higgs portal" paper.

Uploaded on September 3, 2018

June 29, 2018 (v1) Dataset Open Access View

Supplementary Data: Impact of vacuum stability, perturbativity and XENON1T on global fits of Z2 and Z3 scalar singlet dark matter (arXiv:1806.11281)

The GAMBIT Collaboration;

Supplementary Data Impact of vacuum stability, perturbativity and XENON1T on global fits of Z2 and Z3 scalar singlet dark matter arXiv:1806.11281 The files in this record contain data for the scalar singlet dark matter models considered in the GAMBIT "Scalar singlet Mark II&qu

New upload

Community

GAMBIT (Collaboration)

Datasets, code snippets and other supplementary material created with or for GAMBIT, the Global and Modular Beyond-the-Standard-Model Inference Tool.

Curated by: patscott

Curation policy: This community is for official GAMBIT Collaboration data products. Please see gambit-community for equivalent data products relating to GAMBIT but not issued by the GAMBIT Collaboration.

Created: May 31, 2017

Harvesting API: OAI-PMH Interface

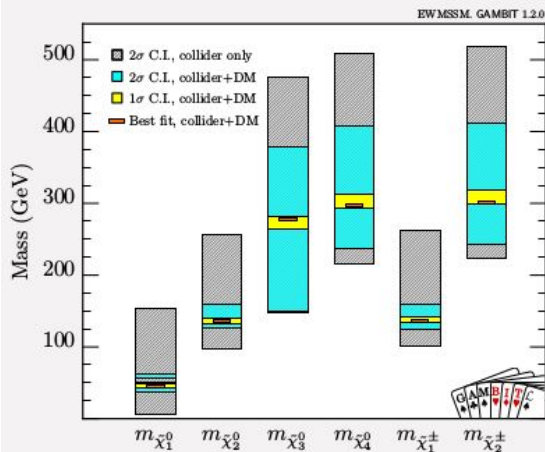
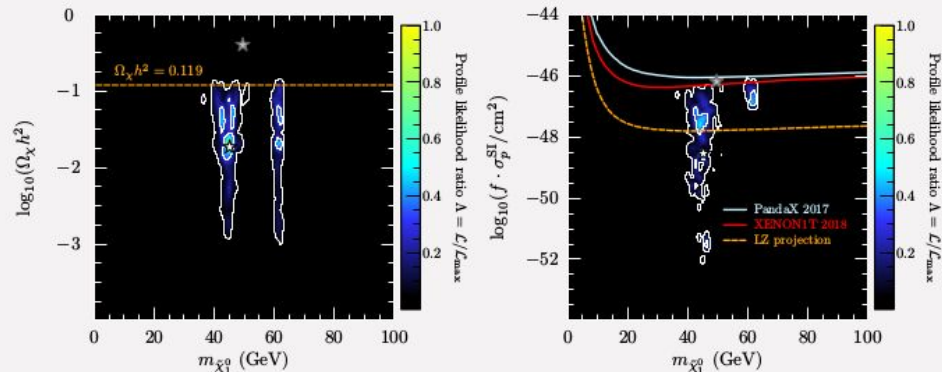
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- The community curator is notified, and will

Backup slides

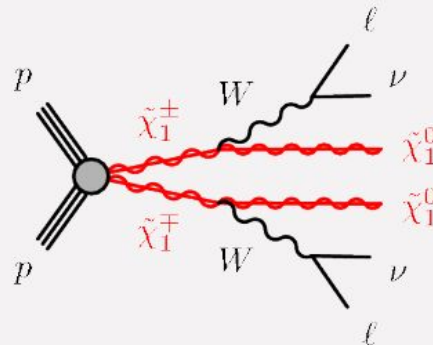
Bonus result: dark matter

- Scan did **not** include DM constraints
- LHC likelihood prefers **light bino LSP** (with non-zero higgsino component)
- **Z/Higgs resonances** can give acceptable relic density
- We post-process all samples with DM likelihoods: **relic density, direct detection** and **indirect detection**

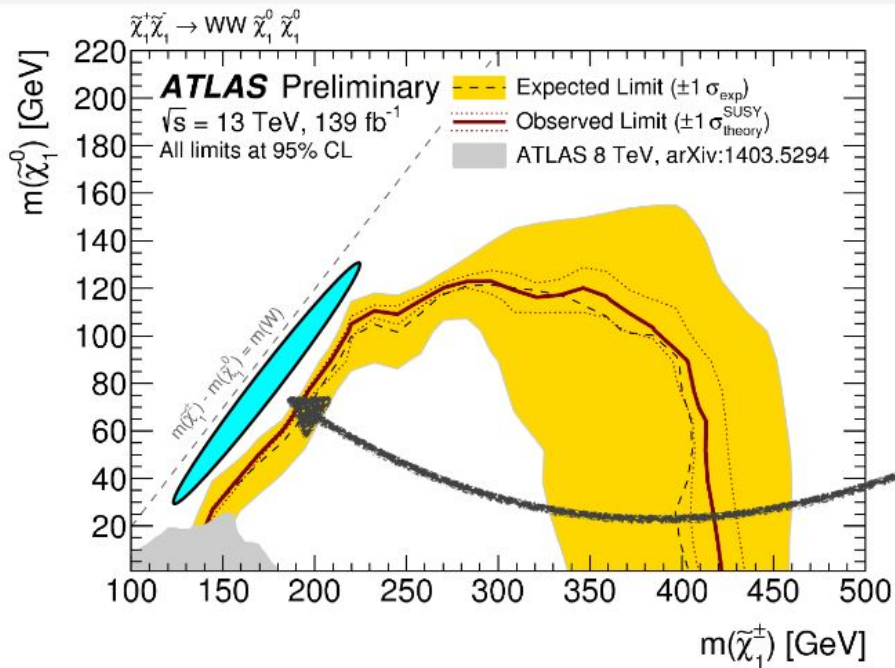


- Subset of our «collider-only» best-fit region also gives acceptable relic density and avoids DD and ID constraints.
- Part of best-fit region accessible to next generation of DD experiments
- *This is only a rough check: A dedicated scan with both collider and DM likelihoods is needed for complete picture*

EW SUSY results with $\sim 140 \text{ fb}^{-1}$ starting to appear:
ATLAS search for production of chargino pairs



[ATLAS-CONF-2019-008]



Naive comparison:
 Not sensitive to the $\sim M_Z$ mass
 splitting in our best-fit region

Analysis: scan and post-processing

Parameter	Minimum	Maximum	Priors
$M_1(Q)$	-2 TeV	2 TeV	hybrid, flat
$M_2(Q)$	0 TeV	2 TeV	hybrid, flat
$\mu(Q)$	-2 TeV	2 TeV	hybrid, flat
$\tan\beta(m_Z)$	1	70	flat
Q		3 TeV	fixed
$\alpha_s^{\overline{MS}}(m_Z)$		0.1181	fixed
Top quark pole mass		171.06 GeV	fixed

Scans

- Diver (differential evolution)
- 100k/500k Pythia events per point for LHC simulations
- ~2.4M parameter point samples (large uncertainty in LHC likelihood)

Post-processing

- Re-run points in preferred parameter regions with higher MC statistics
- $2\sigma/3\sigma$ regions: $\geq 4M$ events, 1σ region: $\geq 16M$ events, 500 best points: 64M events
- ~240k parameter point samples

~3 hours per point, using
68 CPUs x4 hyperthreading

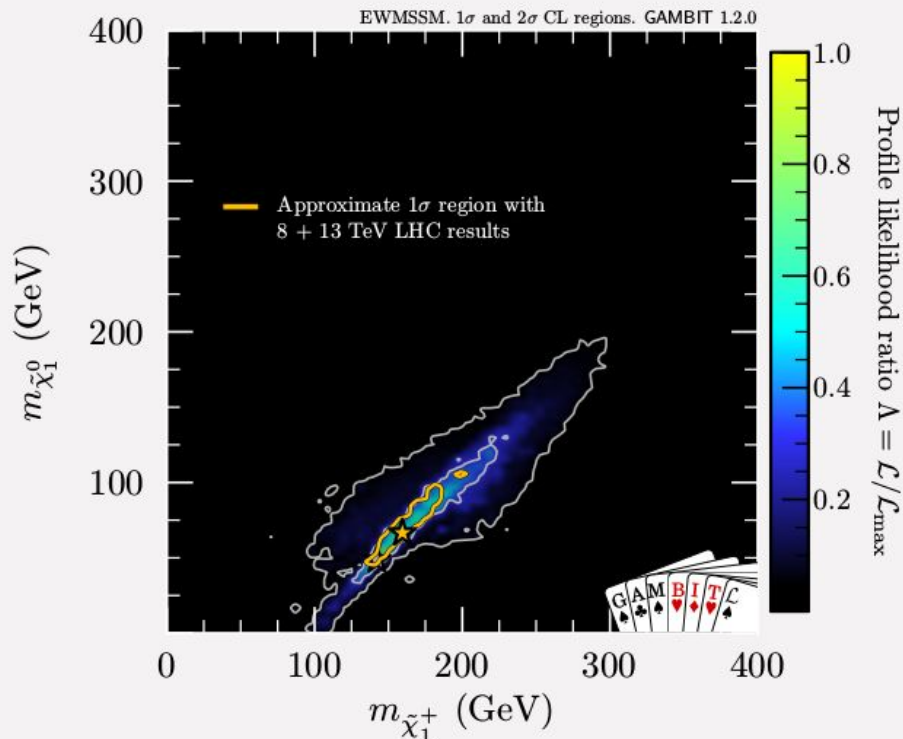
Analysis: impact of 8 TeV searches

Post-processed all samples within the 1-sigma preferred region from 13 TeV.

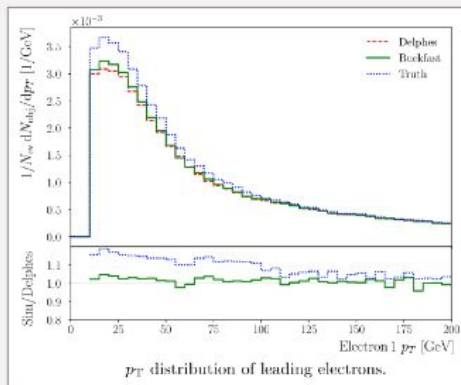
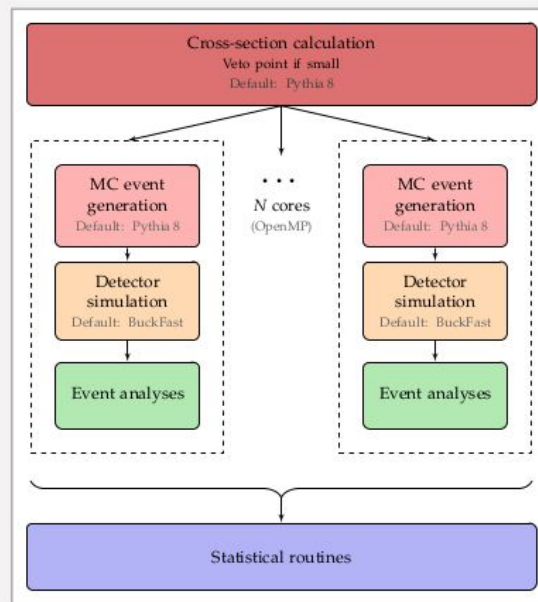
Included 8 TeV analyses:

- ATLAS 2 lepton search
- ATLAS 3 lepton search
- ATLAS Wh search (1lep + 2b)
- CMS 3 lepton search
- CMS 4 lepton search

Bino < higgsinos < winos
generally less constrained than
bino < winos < higgsinos

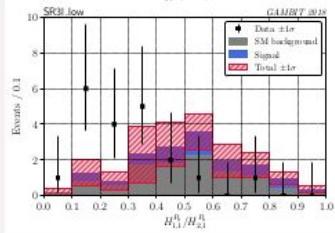
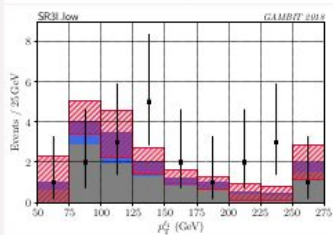
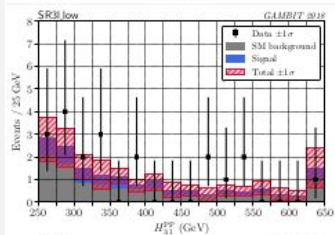
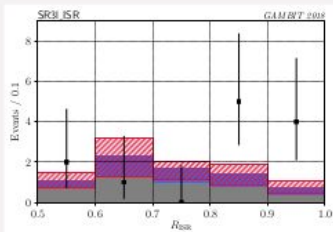
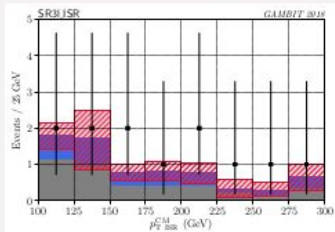


- The collider physics module of GAMBIT
- **LEP limits (SUSY):** Calculate $\sigma \times BR$ and check against published limits
- **LHC particle searches:** Full Poisson likelihood from fast MC simulation of LHC searches
 - Parallellized MC event generation and analysis loop inside ColliderBit
 - Event generation with Pythia 8
 - Fast detector simulator: BuckFast (4-vector smearing)
- **Focus on speed**, as required for use in global fits

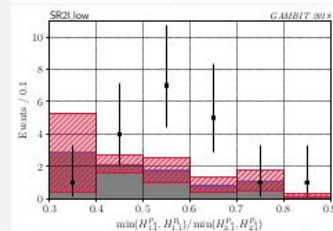
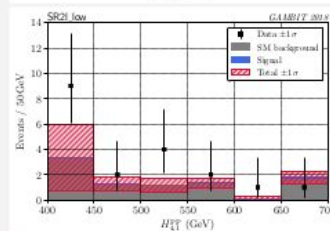
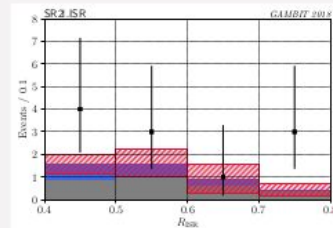
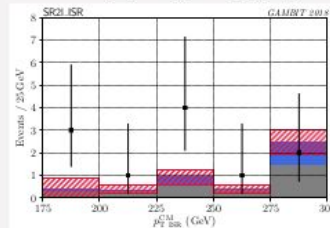


Analysis: best-fit point distributions

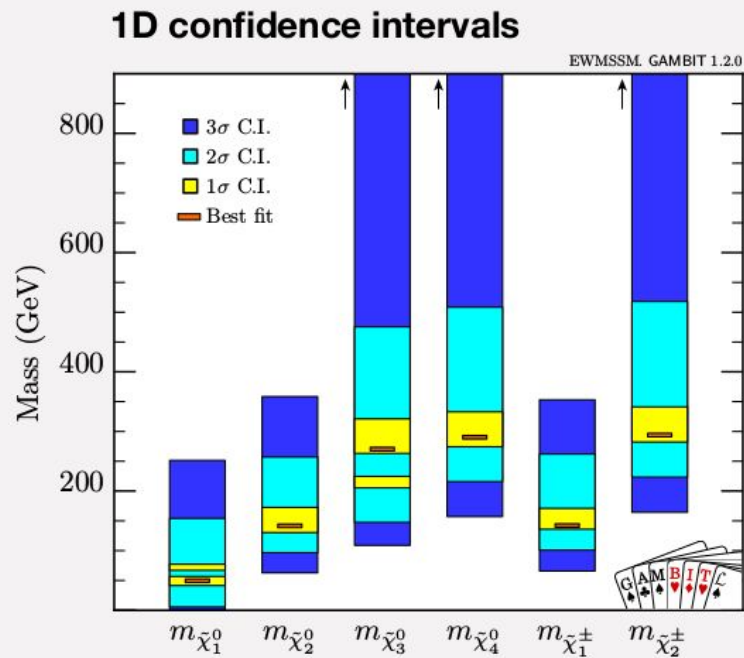
ATLAS_RJ_3lep



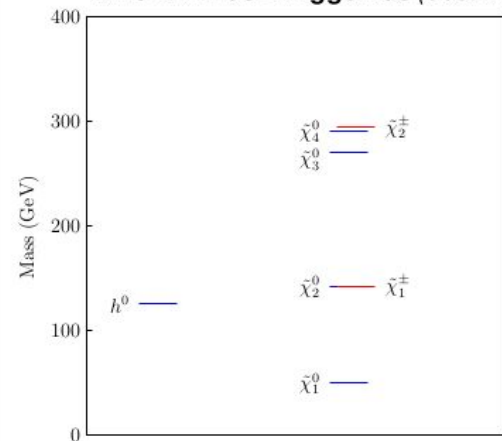
ATLAS_RJ_2lep_2jet



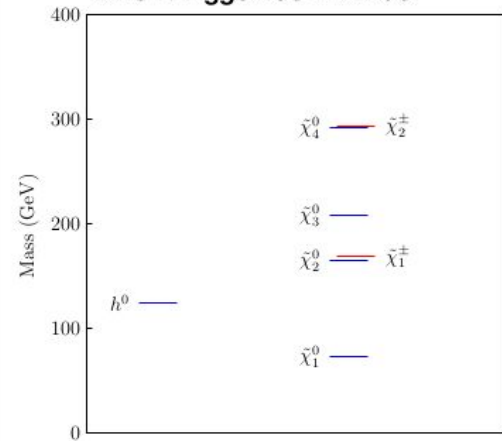
Analysis: results

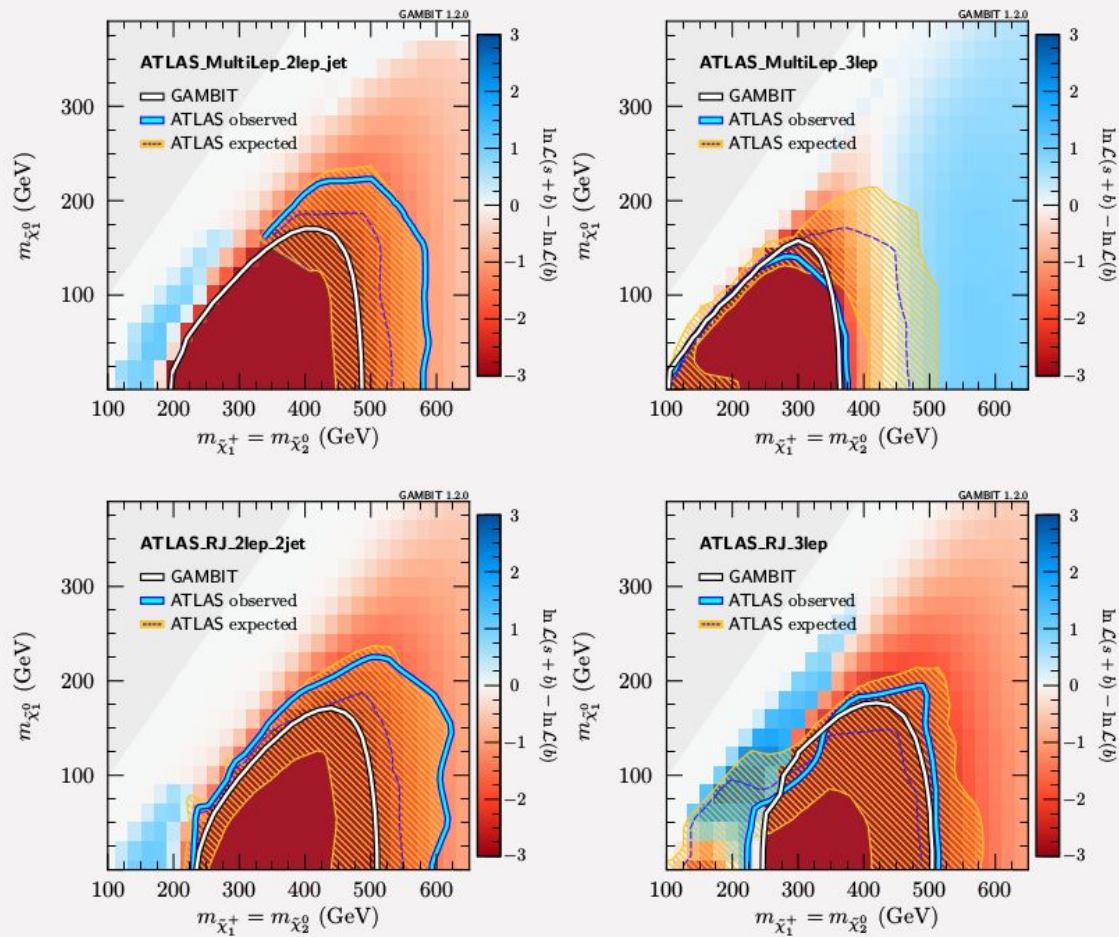


Bino < winos < higgsinos (best fit)



Bino < higgsinos < winos





ColliderBit: validation

Cut	ATLAS	GAMBIT	Ratio
All events	14028	14028	1.00
Trigger, 4 jets ($p_T > 40$ GeV, 2 b -tags)	1455	1906	1.31
≥ 4 b -tags	163.0	161.0	0.99
≥ 2 Higgses	126.4	140.8	1.11
Lepton veto	126.1	140.3	1.11
$X_{W\tau} > 1.8$	108.4	132.8	1.23
$X_{hh}^{SR} < 1.6$	53.4	52.47	0.98
SR1: $m_{\text{meff}} > 440$ GeV	37.0	43.58	1.18
SR2: $m_{\text{meff}} > 440$ GeV + $E_T^{\text{miss}} > 150$ GeV	14.2	16.27	1.15

Table 4: Example comparison of GAMBIT and ATLAS [120] cutflows for two signal regions targeting low-mass Higgsinos in a search for new physics in events with two Higgs bosons decaying into $b\bar{b}$. Shown are the numbers of events expected in 24.3 fb^{-1} of 13 TeV ATLAS data for Higgsino pair production with a signal cross-section of 0.577 pb , $m_{\tilde{H}} = 250 \text{ GeV}$ and a massless gravitino, assuming 100% branching fraction for $\tilde{H} \rightarrow h\tilde{G}$.

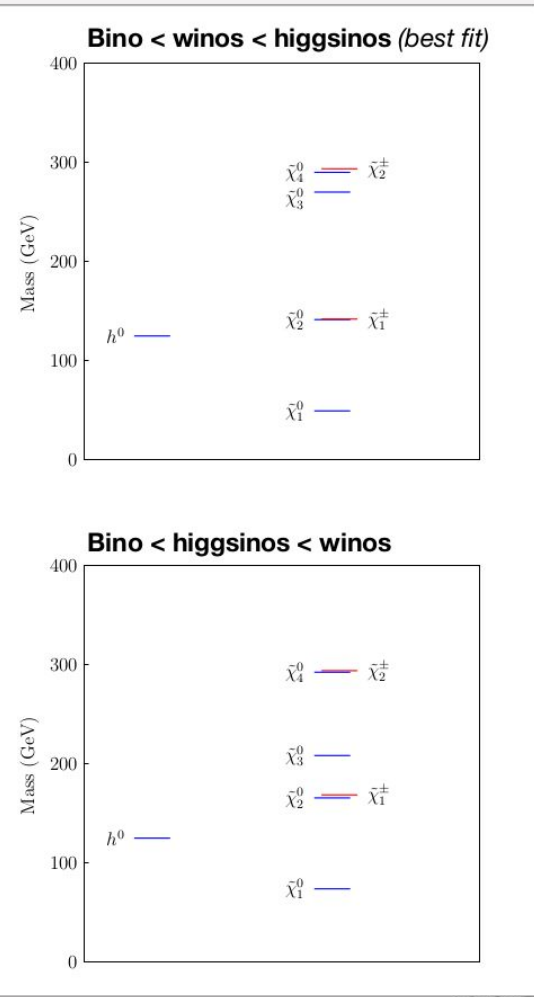
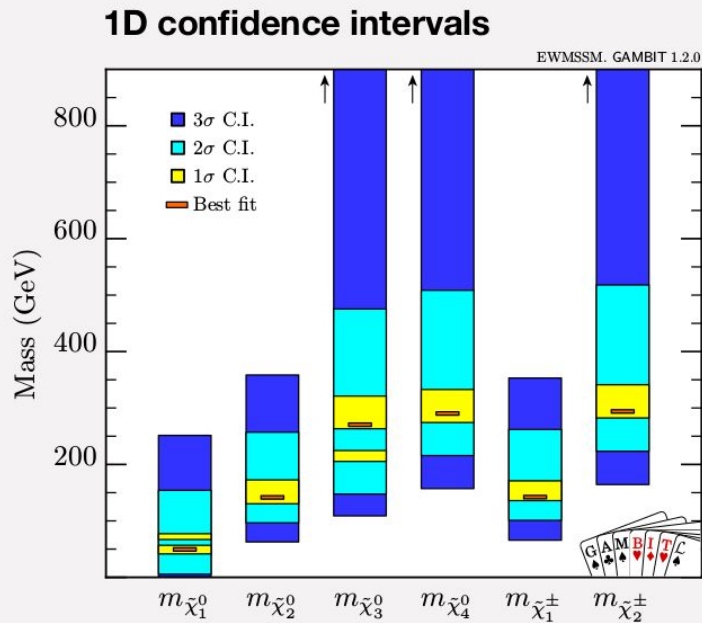
Cut	CMS	GAMBIT	Ratio
All events	172000	172000	1.00
2 reconstructed muons with $5 < p_T < 30$ GeV	1250	1212	0.97
muons oppositely charged	1200	1099	0.91
$p_T(\mu\mu) > 3$ GeV	1176	1067	0.97
$M(\mu\mu) \in [4, 50]$ GeV	1095	1062	1.02
$M(\mu\mu) \in [9, 10.5]$ GeV veto	988.5	1011	0.99
$125 < p_T^{\text{miss}} < 200$ GeV	46.8	46.4	0.98
Trigger efficiency	30.7	30.2	1.07
ISR jet	27.9	29.9	1.17
$H_T > 100$ GeV	23.6	27.7	1.40
$0.6 < p_T^{\text{miss}}/H_T < 1.4$	17.2	24.0	1.42
b -tag veto	14.0	19.8	1.25
$M(\tau\tau)$ veto	12.3	15.4	1.25
$M_T(\mu\tau, p_T^{\text{miss}}) < 70$ GeV	9.3	10.3	1.11

Table 5: Comparison of the GAMBIT and CMS [125] cutflows for a WZ signal model ($m_{\tilde{\chi}_1^\pm} = 150 \text{ GeV}$, $m_{\tilde{\chi}_1^0} = 130 \text{ GeV}$) in a search for new physics in events with two low-momentum opposite-sign leptons and missing transverse momentum. Shown are the numbers of events expected in 33.2 fb^{-1} of 13 TeV CMS data for a signal cross-section of 5.18 pb [129]. Both the CMS cutflow and GAMBIT cutflow are generated for production of $\tilde{\chi}_1^\pm \tilde{\chi}_2^0$ in a simplified model with decays via off-shell W/Z .

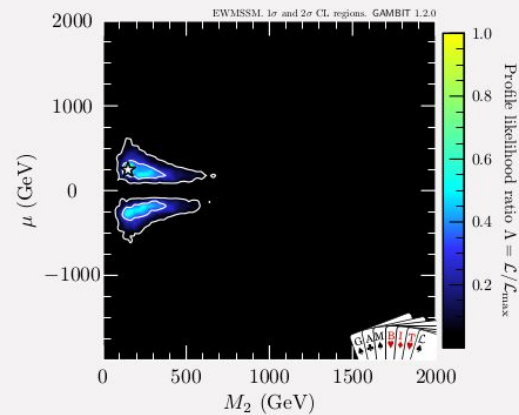
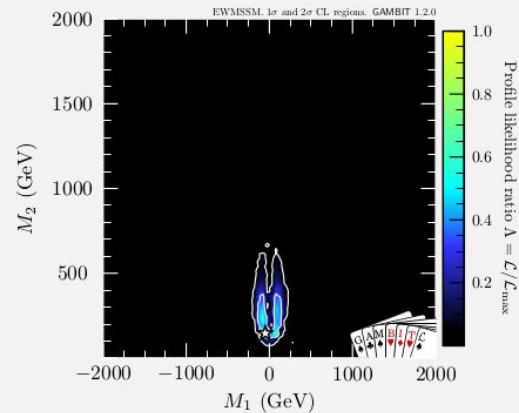
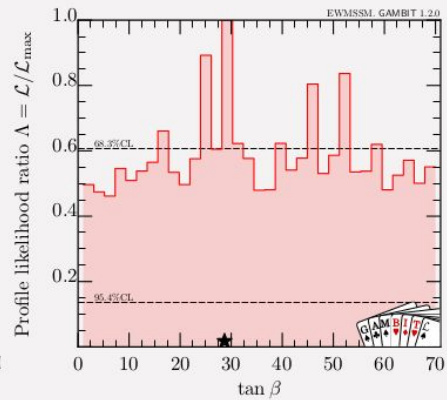
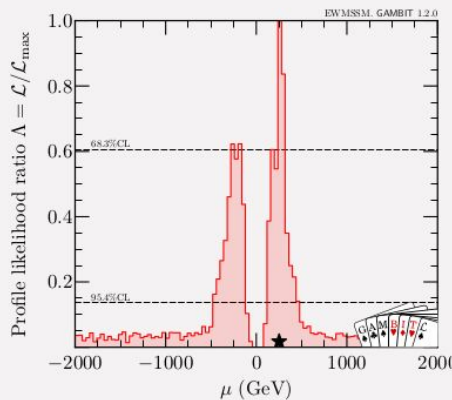
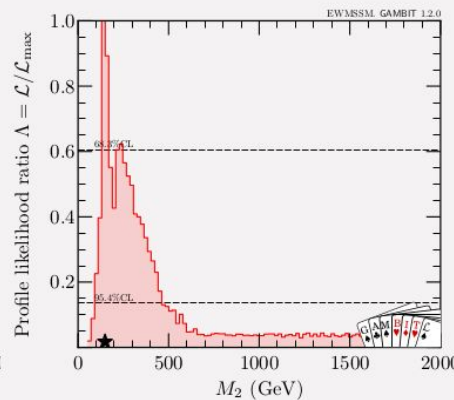
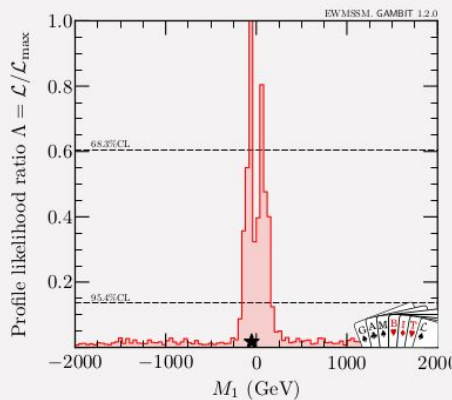
Cut	CMS	GAMBIT	Ratio
All events	109.35	1084.18	9.91
2 SFOS leptons	24.21	30.00	1.24
Extra lepton vetoes	18.37	25.07	1.36
$m_{\ell\ell} \in [86, 96]$ GeV	14.13	15.97	1.13
2-3 Jets	11.98	9.83	0.82
$\Delta\Phi(E_T^{\text{miss}}, j_{1,2}) > 0.4$	10.95	9.07	0.83
B -tag veto	9.92	8.86	0.89
$M_{T2}(\ell\ell) > 80$ GeV	8.04	7.27	0.90
$M_{\ell\ell} < 150$ GeV	5.62	5.26	0.94
SR1: $E_T^{\text{miss}} > 100$ GeV	5.41	5.05	0.93
SR2: $E_T^{\text{miss}} > 150$ GeV	4.96	4.76	0.96
SR3: $E_T^{\text{miss}} > 250$ GeV	3.59	3.49	0.97
SR4: $E_T^{\text{miss}} > 350$ GeV	1.94	1.95	0.96

Table 6: Comparison of the GAMBIT and published CMS cutflows [126] in four signal regions of a search for new physics in events with two opposite-charge same-flavor leptons and missing transverse momentum, for a WZ signal model ($m_{\tilde{\chi}_1^\pm} = 550 \text{ GeV}$, $m_{\tilde{\chi}_1^0} = 200 \text{ GeV}$). Shown are the numbers of events expected in 35.9 fb^{-1} of 13 TeV CMS data, and the ratio of the GAMBIT and CMS numbers. Note that the CMS cutflow is generated for a $\tilde{\chi}_1^\pm \tilde{\chi}_2^0$ simplified model decaying via W/Z where the Z boson decays leptonically, while the GAMBIT cutflow is generated without specifying Z boson decay mode. This explains the discrepancy at the “All events” cut.

Analysis: results

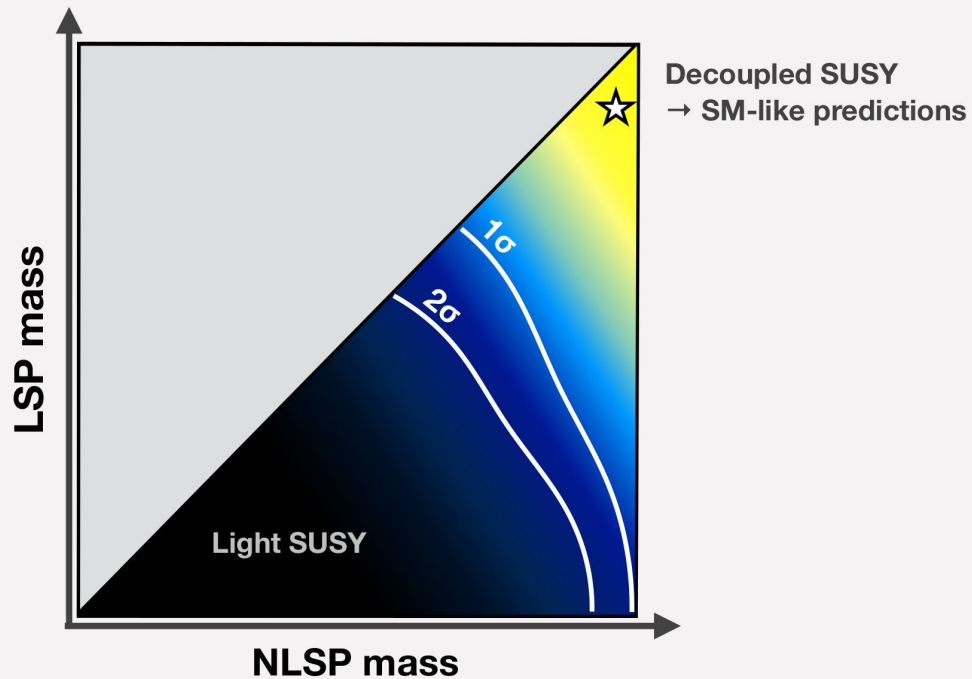


Analysis: Lagrangian parameters



Analysis: profile likelihood maps

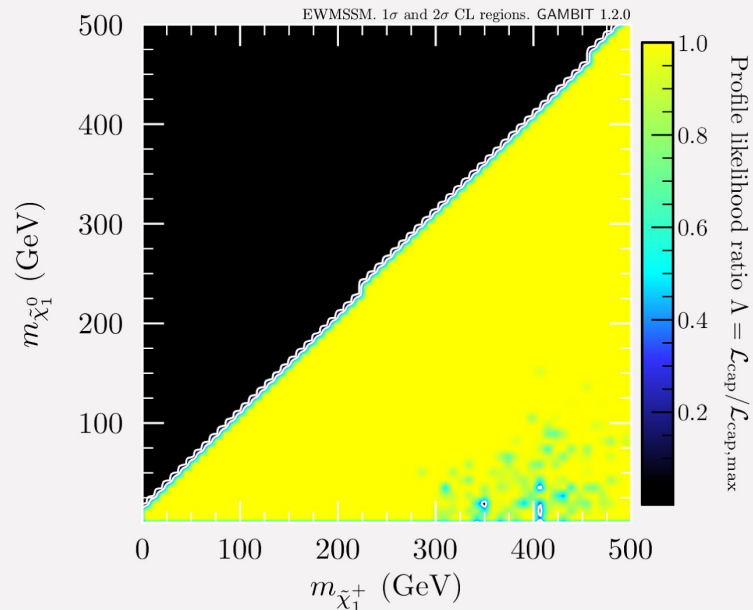
Naive «*light SUSY is dead*» expectation:



Analysis: results

- First: «**capped**» LHC likelihood
- How much **worse** does a point in the MSSM fit the data compared to the SM?
- Capping done on **combined** likelihood for all analyses
- If **profile likelihood ratio = 1**:
found a point with *either*
 - no sensitivity; *or*
 - all bad fits offset by other good fits
- **No general constraint** on the lightest EWinos

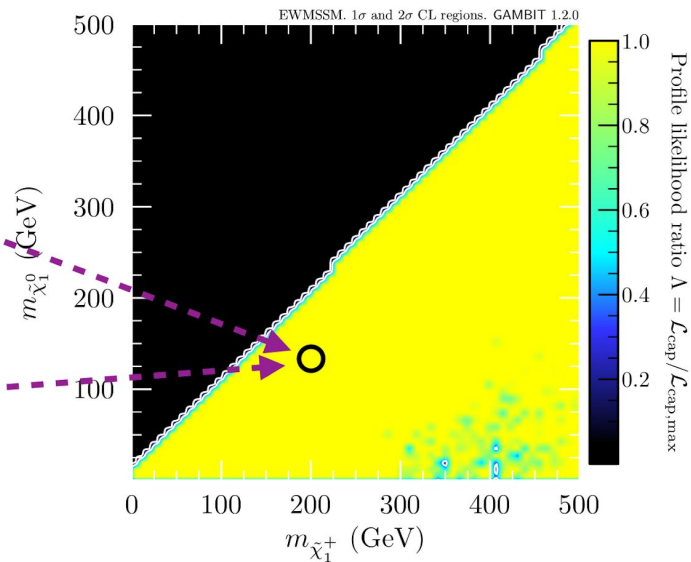
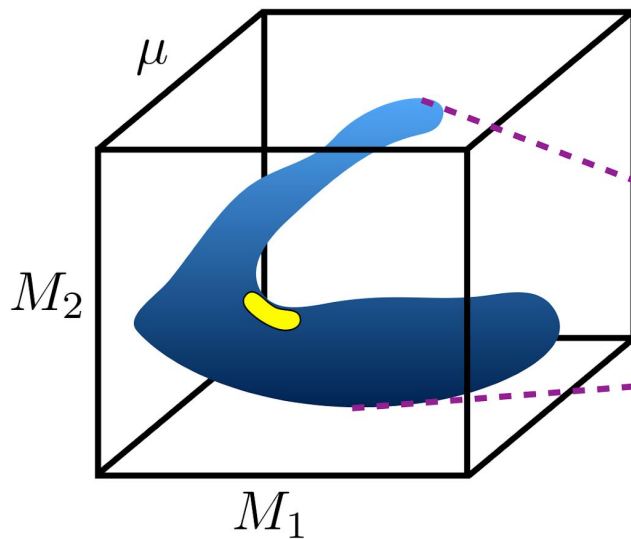
$$\mathcal{L}_{\text{cap}} = \min[\mathcal{L}_{\text{LHC}}(\mathbf{s} + \mathbf{b}), \mathcal{L}_{\text{LHC}}(\mathbf{b})]$$



Analysis: results

Interpretation: For every point in the mass plane, there is *at least one point* in the MSSM parameter space that fits the data as well as (or better than) the SM expectation.

This does not tell us anything about *the size* of the viable parameter space...



Analysis: results

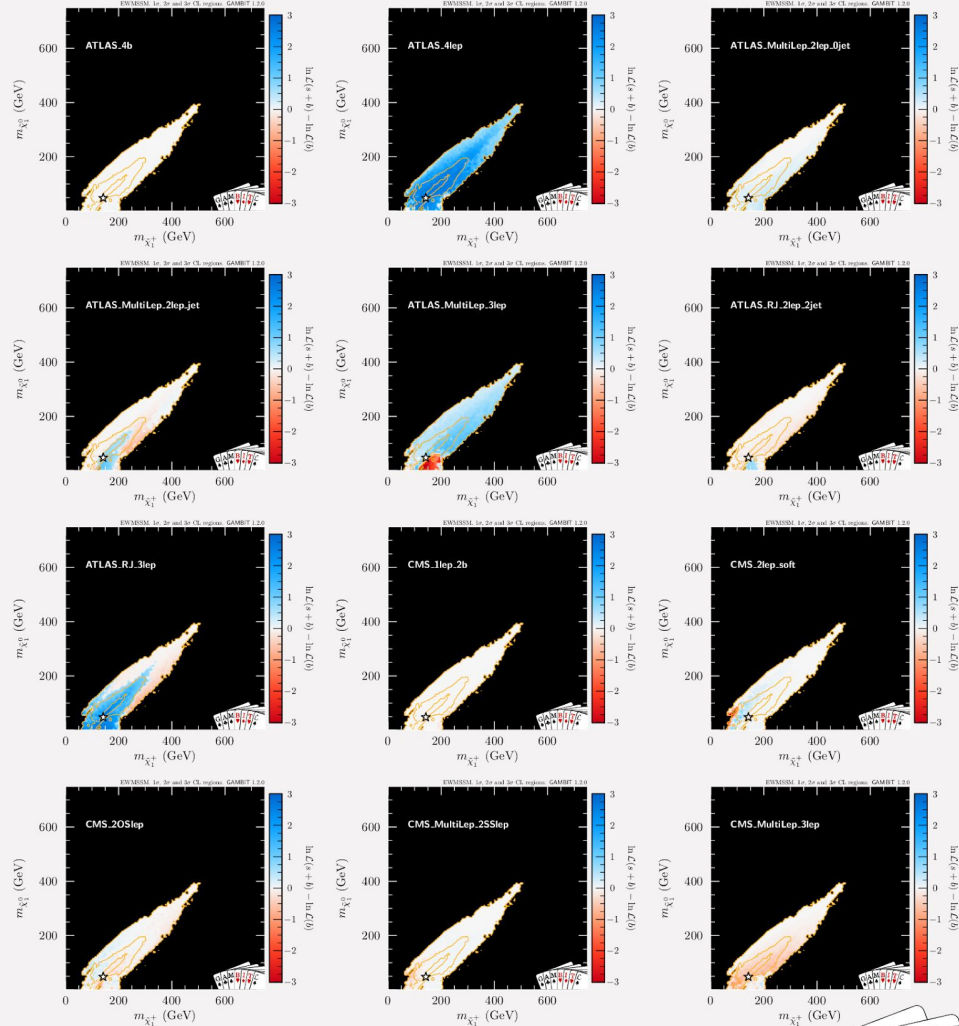
- Contribution from each analysis to the 1σ , 2σ and 3σ best-fit regions

$$\ln \mathcal{L}(s + b) - \ln \mathcal{L}(b)$$

- Blue:** better than background-only
- Red:** worse than background-only

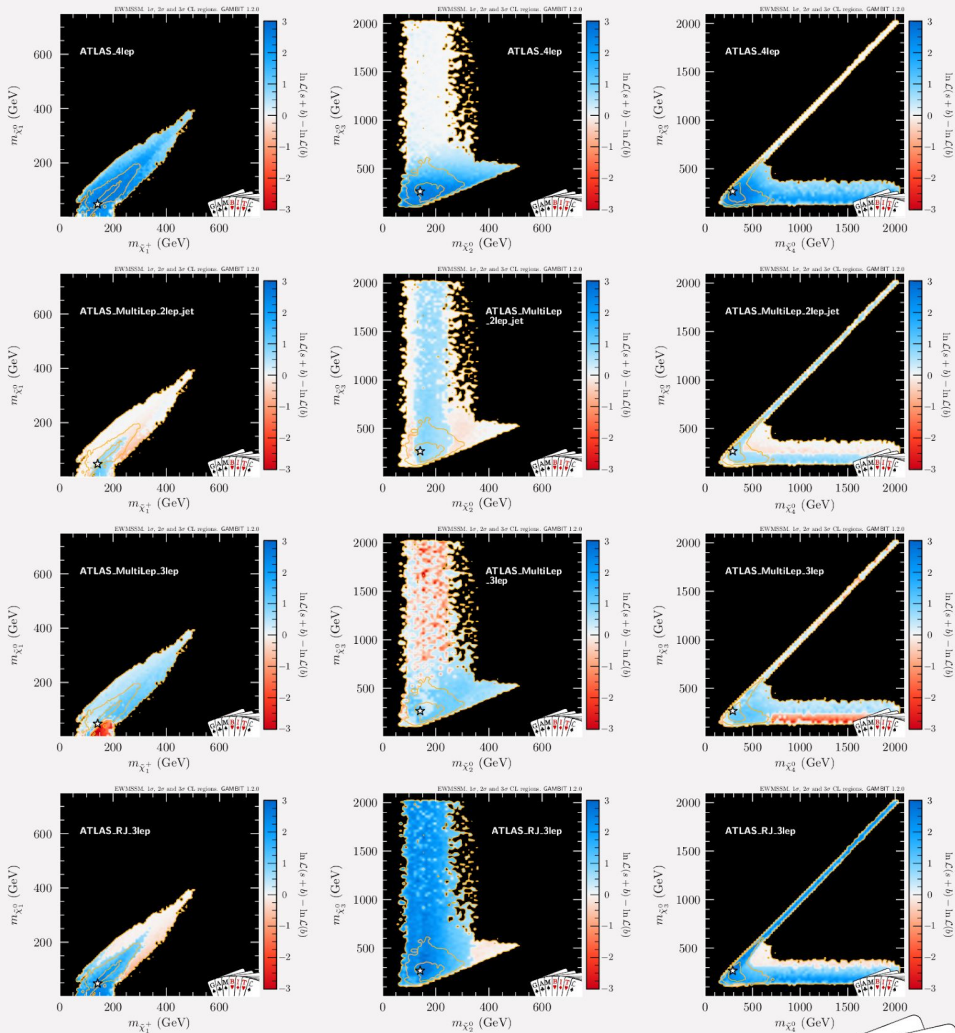
- Most important contributions to best-fit region:

- ATLAS_4lep
- ATLAS_RJ_3lep
- ATLAS_MultiLep_2lep_jet
- ATLAS_MultiLep_3lep
- CMS_MultiLep_3lep



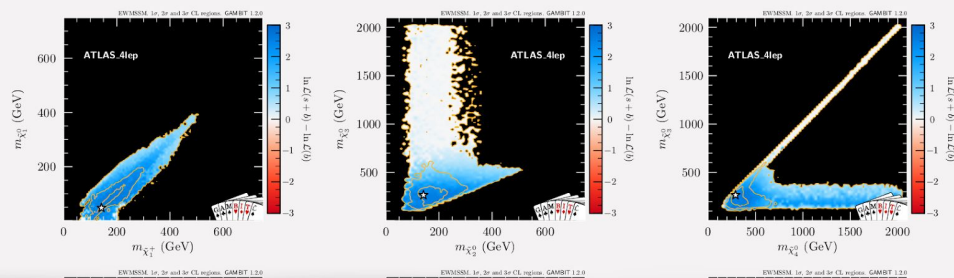
Analysis: results

- More detailed look on
 - **ATLAS_4lep**
 - **ATLAS_RJ_3lep**
 - **ATLAS_MultiLep_2lep_jet**
 - **ATLAS_MultiLep_3lep**
- Sudden changes in likelihood due to changes in most sensitive SR
- Light $\tilde{\chi}_3^0$ preferred by **ATLAS_4lep** and **ATLAS_MultiLep_3Lep**
- Heavy $\tilde{\chi}_4^0$ disfavoured by **ATLAS_MultiLep_2lep_jet** and **ATLAS_MultiLep_3Lep**
- The «expected» tension between **ATLAS_MultiLep_3Lep** and **ATLAS_RJ_3lep** observed for heavy $\tilde{\chi}_4^0$ (production of higgsino $\tilde{\chi}_2^0, \tilde{\chi}_3^0, \tilde{\chi}_1^\pm$)



Analysis: results

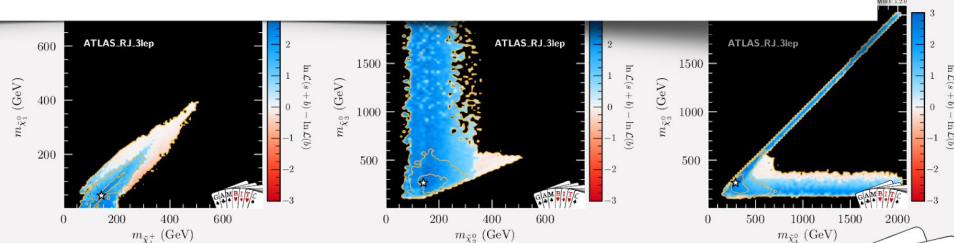
- More detailed look on
 - ATLAS_4lep
 - ATLAS RJ 3lep



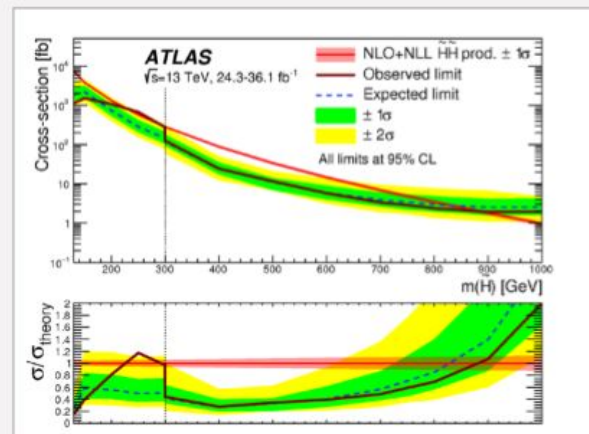
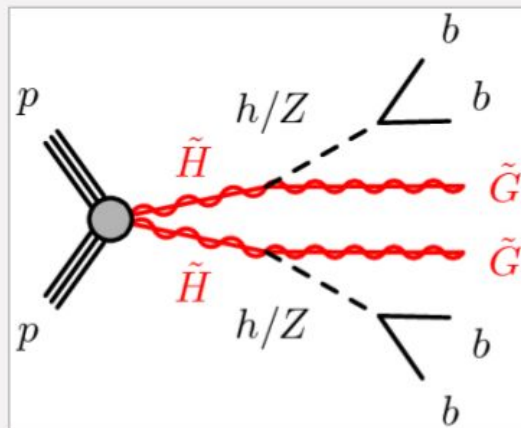
Lots of processes relevant for the best-fit point:

- $\tilde{\chi}_2^{\pm} \tilde{\chi}_3^0$ production, with e.g.
 - $\tilde{\chi}_2^0 \rightarrow Z + \tilde{\chi}_1^0, \tilde{\chi}_3^0 \rightarrow W^- + \tilde{\chi}_1^+ \rightarrow W^- + W^+ + \tilde{\chi}_1^0$
 - $\tilde{\chi}_2^{\pm} \tilde{\chi}_2^{\mp}$ production, with e.g.
 - $\tilde{\chi}_2^{\pm} \rightarrow W^{\pm} + \tilde{\chi}_2^0 \rightarrow W^{\pm} + Z + \tilde{\chi}_1^0$
 - $\tilde{\chi}_2^{\pm} \tilde{\chi}_3^0$ production, with e.g.
 - $\tilde{\chi}_2^{\pm} \rightarrow W^{\pm} + \tilde{\chi}_1^0, \tilde{\chi}_3^0 \rightarrow Z + \tilde{\chi}_2^0 \rightarrow Z + Z + \tilde{\chi}_1^0$
 - $\tilde{\chi}_2^{\pm} \tilde{\chi}_3^0$ production, with e.g.
 - $\tilde{\chi}_2^{\pm} \rightarrow W^{\pm} + \tilde{\chi}_2^0 \rightarrow W^{\pm} + Z + \tilde{\chi}_1^0,$
 - $\tilde{\chi}_3^0 \rightarrow W^- + \tilde{\chi}_1^+ \rightarrow W^- + W^+ + \tilde{\chi}_1^0$
- $\tilde{\chi}_2^{\pm} \tilde{\chi}_4^0$ production, with e.g.
 - $\tilde{\chi}_2^{\pm} \rightarrow W^{\pm} + \tilde{\chi}_2^0 \rightarrow W^{\pm} + Z + \tilde{\chi}_1^0, \tilde{\chi}_4^0 \rightarrow Z + \tilde{\chi}_1^0$
 - $\tilde{\chi}_2^{\pm} \tilde{\chi}_2^0$ production, with e.g.
 - $\tilde{\chi}_2^{\pm} \rightarrow h + \tilde{\chi}_1^{\pm} \rightarrow h + W^{\pm} + \tilde{\chi}_1^0, \tilde{\chi}_2^0 \rightarrow Z + \tilde{\chi}_1^0$
 - $\tilde{\chi}_1^{\pm} \tilde{\chi}_3^0$ production, with e.g.
 - $\tilde{\chi}_1^{\pm} \rightarrow W^{\pm} + \tilde{\chi}_1^0, \tilde{\chi}_3^0 \rightarrow W^- + \tilde{\chi}_1^+ \rightarrow W^+ + W^- + \tilde{\chi}_1^0$
 - $\tilde{\chi}_2^{\pm} \tilde{\chi}_4^0$ production, with e.g.
 - $\tilde{\chi}_2^{\pm} \rightarrow Z + \tilde{\chi}_1^{\pm} \rightarrow Z + W^{\pm} + \tilde{\chi}_1^0,$
 - $\tilde{\chi}_4^0 \rightarrow h + \tilde{\chi}_2^0 \rightarrow h + Z + \tilde{\chi}_1^0$

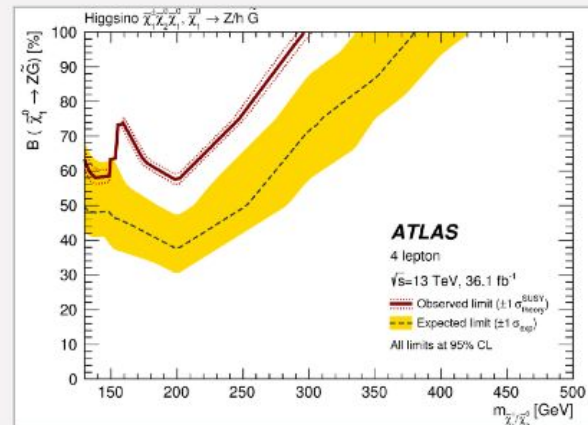
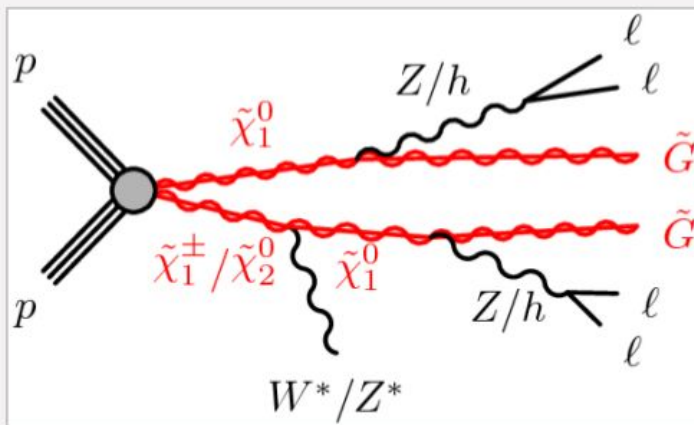
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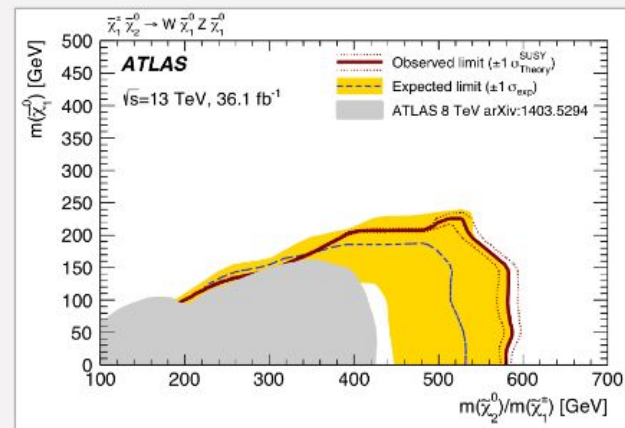
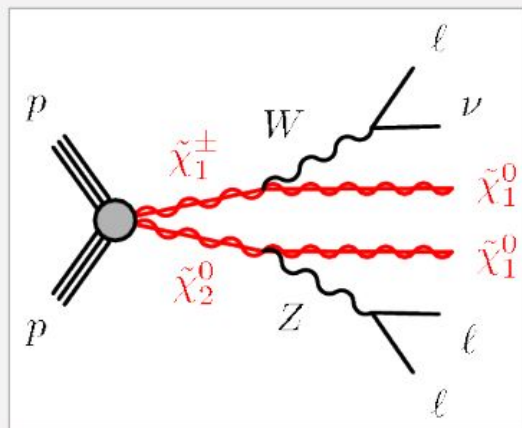
- ATLAS Higgsino search: **ATLAS_4b**
- ATLAS ≥ 4 lepton search: **ATLAS_4lep**
- ATLAS multilepton EW search: **ATLAS_MultiLep_*** (2lep_0jet, 2lep_jet, 3lep)
- ATLAS recursive jigsaw EW search: **ATLAS_RJ_*** (2lep_2jet, 3lep)
- CMS Wh search: **CMS_1lep_2b**
- CMS 2 soft opposite-sign lepton search: **CMS_2lep_soft** (including SR correlations)
- CMS 2 opposite-sign lepton search: **CMS_2OSlep** (including SR correlations)
- CMS multilepton EW search: **CMS_MultiLep_*** (2SSlep, 3lep)



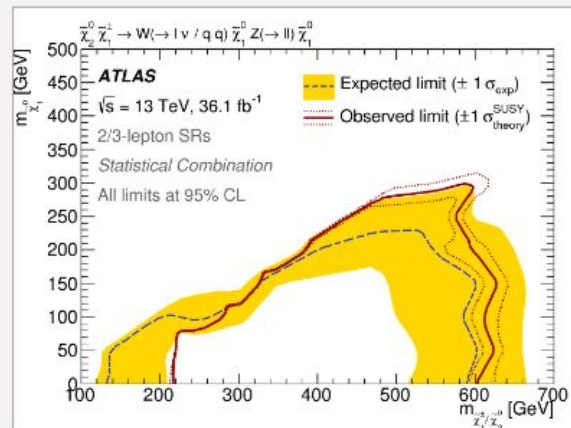
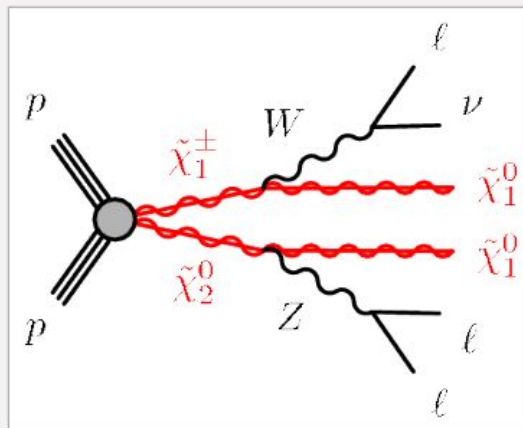
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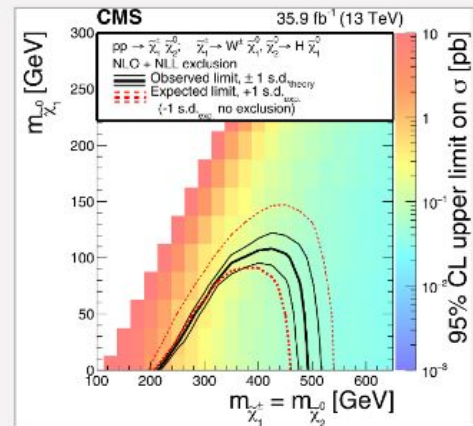
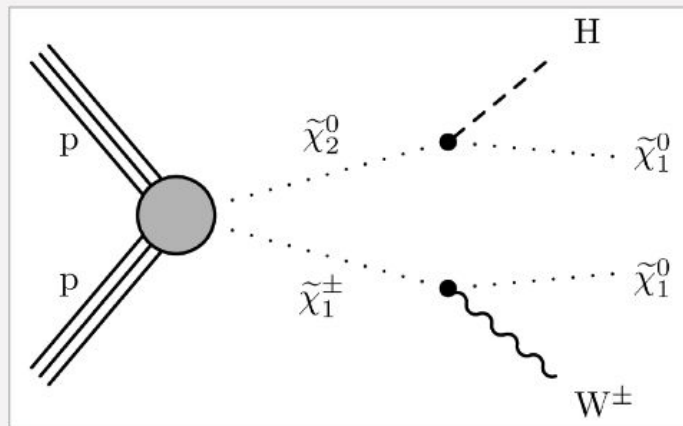
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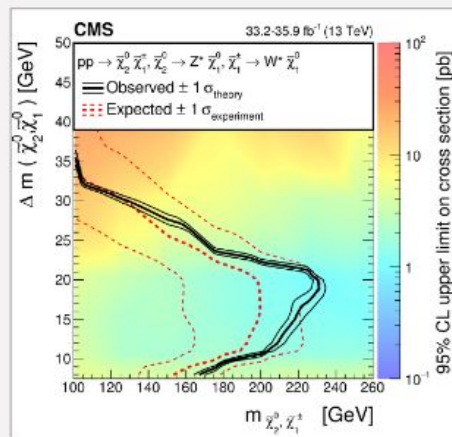
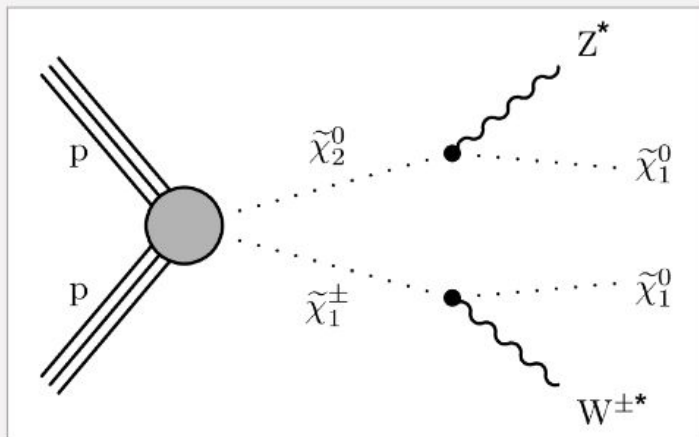
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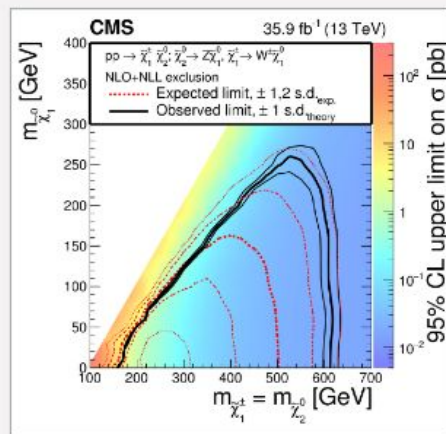
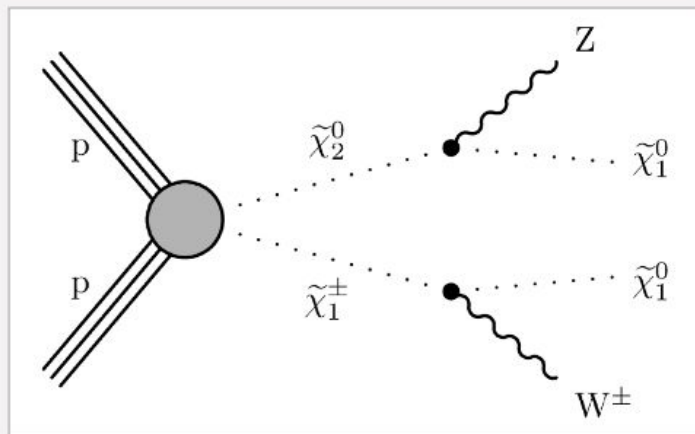
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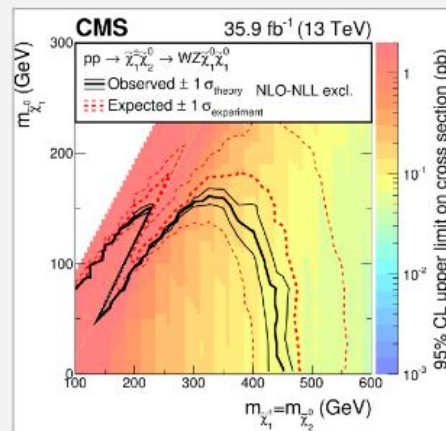
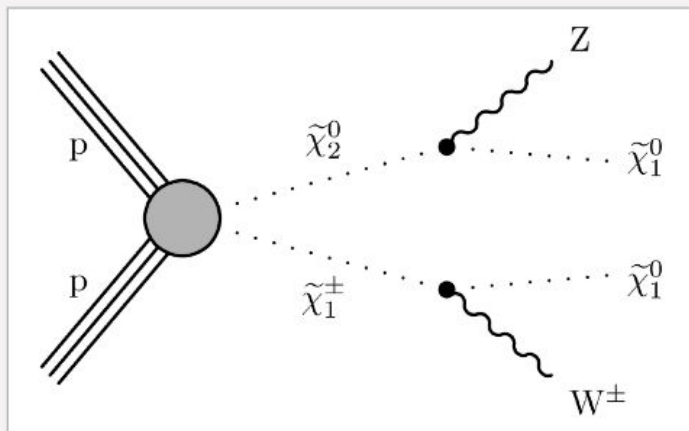
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- CMS 2 soft opposite-sign lepton search: **CMS_2lep_soft** (including SR correlations)
- CMS 2 opposite-sign lepton search: **CMS_2OSlep** (including SR correlations)
- CMS multilepton EW search: **CMS_MultiLep_*** (2SSlep, 3lep)



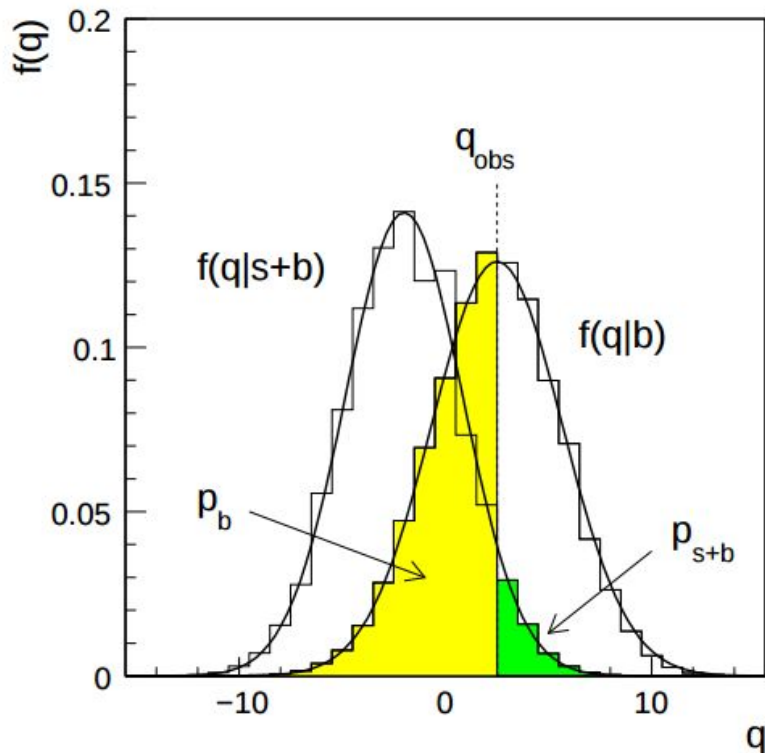
- ATLAS Higgsino search: **ATLAS_4b**
- ATLAS ≥ 4 lepton search: **ATLAS_4lep**
- ATLAS multilepton EW search: **ATLAS_MultiLep_* (2lep_0jet, 2lep_jet, 3lep)**
- ATLAS recursive jigsaw EW search: **ATLAS_RJ_* (2lep_2jet, 3lep)**
- CMS Wh search: **CMS_1lep_2b**
- CMS 2 soft opposite-sign lepton search: **CMS_2lep_soft** (including SR correlations)
- CMS 2 opposite-sign lepton search: **CMS_2OSlep** (including SR correlations)
- CMS multilepton EW search: **CMS_MultiLep_* (2SSlep, 3lep)**



- ATLAS Higgsino search: **ATLAS_4b**
- ATLAS ≥ 4 lepton search: **ATLAS_4lep**
- ATLAS multilepton EW search: **ATLAS_MultiLep_* (2lep_0jet, 2lep_jet, 3lep)**
- ATLAS recursive jigsaw EW search: **ATLAS_RJ_* (2lep_2jet, 3lep)**
- CMS Wh search: **CMS_1lep_2b**
- CMS 2 soft opposite-sign lepton search: **CMS_2lep_soft** (including SR correlations)
- CMS 2 opposite-sign lepton search: **CMS_2OSlep** (including SR correlations)
- CMS multilepton EW search: **CMS_MultiLep_* (2SSlep, 3lep)**



Local p-values



$$q = -2 \ln \frac{L_{s+b}}{L_b}, \quad \lambda_i = \mu s_i(\phi) + b_i + \theta_i$$

$$q = -2 \ln \frac{L(\mu = 1, \hat{\theta}(1))}{L(\mu = 0, \hat{\theta}(0))}$$

Note: this is where combination comes in! Same whether combining signal regions or whole analyses:

$$L(\mu) = \prod_i L_i(\mu)$$

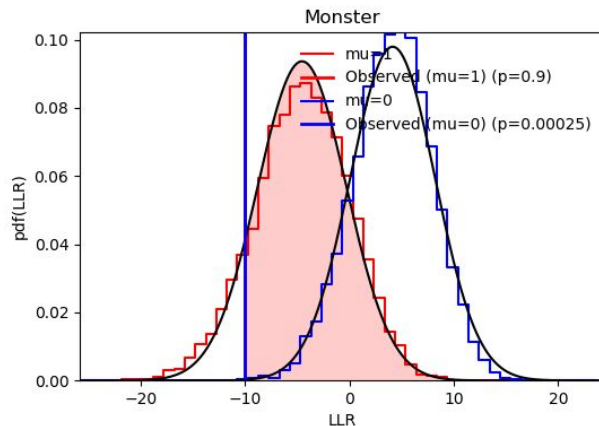
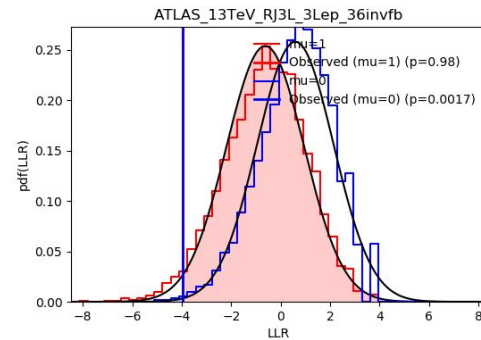
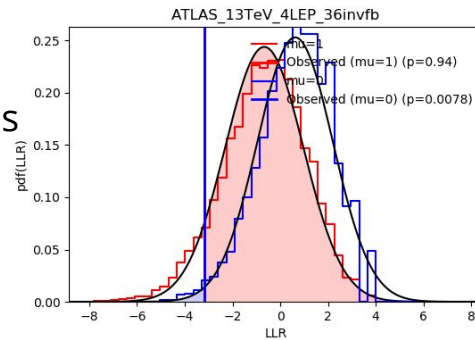
Figure 6: The distribution of the statistic $q = -2 \ln(L_{s+b}/L_b)$ under the hypotheses of $\mu = 0$ and $\mu = 1$ (see text).

*Note: for simple vs simple hypothesis testing, the likelihood ratio gives the best discrimination (power, **Neyman-Pearson Lemma**)

Local p-values

No correlations

Analysis	Local signif. (σ)
Higgs invisible width	0
Z invisible width	0
ATLAS_4b	0.7
ATLAS_4lep	2.3
ATLAS_MultiLep_2lep_0jet	0.9
ATLAS_MultiLep_2lep_jet	0
ATLAS_MultiLep_3lep	1.8
ATLAS_RJ_2lep_2jet	0
ATLAS_RJ_3lep	2.7
CMS_1lep_2b	0.8
CMS_2lep_soft	0.1
CMS_2OSlep	0.1
CMS_MultiLep_2SSlep	0.2
CMS_MultiLep_3lep	0
Combined	3.3



$$q = -2 \ln \frac{L_{s+b}}{L_b},$$

$$q = -2 \ln \frac{L(\mu = 1, \hat{\theta}(1))}{L(\mu = 0, \hat{\theta}(0))}$$

Goodness of fit

$$q_{\text{GOF}} = -2 \log \frac{\mathcal{L}_{\text{joint}}(\mathbf{s}(\theta), \hat{\eta})}{\mathcal{L}_{\text{joint}}(\hat{\mathbf{s}}, \hat{\eta})}$$

Asymptotic distribution is chi-squared with $\text{DOF} = \#\text{SR}$

(to test background-only hypothesis, set $\mathbf{s}(\theta) = 0$)

No look-elsewhere effect*, but test is not very powerful for discovery due to large DOF.

Goodness of fit

Analysis	Best expected SRs				All SRs; neglect correlations			
	Local signif. (σ)	SM fit (σ)	EWMSSM fit (σ)	#SRs	Local signif. (σ)	SM fit (σ)	EWMSSM fit (σ)	#SRs
Higgs invisible width	0	0	0	1	0	0	0	1
Z invisible width	0	1.3	1.3	1	0	1.3	1.3	1
ATLAS_4b	0.7	0	0	1	1.5	0	0	2*
ATLAS_4lep	2.3	1.9	0	1	2.5	1.0	0	4
ATLAS_MultiLep_2lep_0jet	0.9	0.3	0.1	1	1.3	0	0	6
ATLAS_MultiLep_2lep_jet	0	0	0.5	1	0.8	0.5	0.2	3
ATLAS_MultiLep_3lep	1.8	1.5	0.7	1	1.2	0.4	0.3	11
ATLAS_RJ_2lep_2jet	0	0.3	0.5	1	1.5	1.8	1.5	4
ATLAS_RJ_3lep	2.7	2.5	1.1	1	3.4	2.5	0.7	4
CMS_1lep_2b	0.8	0.3	0.3	1	0	0	0	2
CMS_2lep_soft	0.1	0.2	0.2	12	0.1	0.2	0.2	12
CMS_2OSlep	0.1	0.5	0.5	7	0	0.4	0.5	7
CMS_MultiLep_2SSlep	0.2	0	0	1	0.2	0	0	2
CMS_MultiLep_3lep	0	0	0.4	1	0	0	0	6
Combined	3.3	1.4	0.2	31	4.1	1.2	0	65

