Checkmating Natural SUSY

IBS, Daejeon, 2016

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IFT Madrid

Outline

- Motivation
- Natural Supersymmetry
- Setup
- CheckMATE
- Numerical Results
- Conclusion

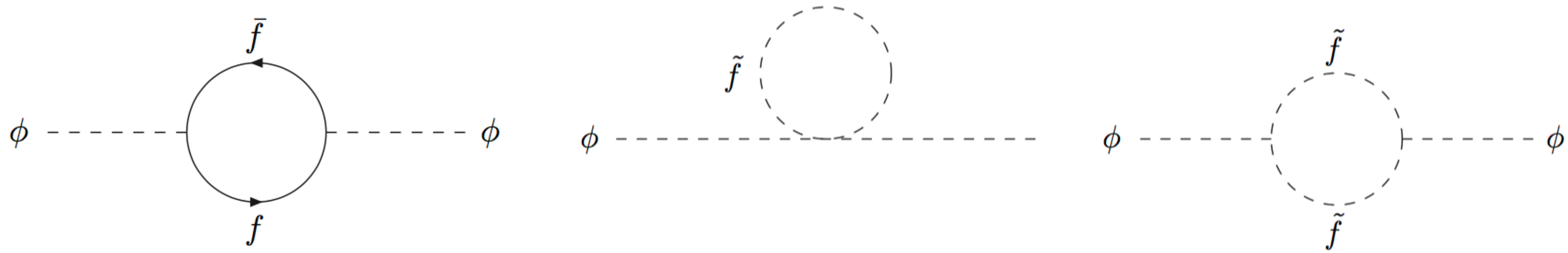
Motivation

Hierarchy Problem I

- One loop corrections contribute to mass renormalization of the Higgs
- Contributions diverge quadratically

$$M_H^2(M_W) \approx M_H^2(M_X) - Cg^2 M_X^2$$

- A Higgs with mass at EW scale requires large cancellations!
- Solution 1: introduce a cut off @O(1) TeV
- Solution 2: for exact boson-fermion symmetry, loop corrections do not affect the Higgs mass!



Supersymmetry I

- SUSY relates bosons and fermions
- SUSY partners have same gauge numbers and masses
- SUSY removes quadratic divergencies
- SUSY fields allows for gauge coupling unification
- It provides a natural candidate for DM
- Supersymmetrization of the SM -> MSSM

Supersymmetry II

- The MSSM is the simplest supersymmetric extension of the SM
- Each SM particle has a superpartner, e.g. electron -> selection
- Anomaly cancellation requires additional Higgs doublet

Names		spin 0	spin 1/2	$SU(3)_C, SU(2)_L, U(1)_Y$
squarks, quarks	Q	$(\widetilde{u}_L \;\; \widetilde{d}_L)$	$(u_L \;\; d_L)$	$(\mathbf{3}, \mathbf{2}, \frac{1}{6})$
(×3 families)	$\overline{u}$	$\widetilde{u}^*_R$	$u^\dagger_R$	$(\overline{\mathbf{3}}, \mathbf{1}, -\frac{2}{3})$
	$\overline{d}$	$\widetilde{d}^*_R$	$d^\dagger_R$	$(\overline{\mathbf{3}}, \mathbf{1}, \frac{1}{3})$
sleptons, leptons	L	$(\widetilde{\nu} \;\; \widetilde{e}_L)$	$(\nu \;\; e_L)$	$(\mathbf{1}, \mathbf{2}, -\frac{1}{2})$
(×3 families)	$\overline{e}$	$\widetilde{e}^*_R$	$e^\dagger_R$	$(\mathbf{1}, \mathbf{1}, 1)$
Higgs, higgsinos	H_u	$(H^+_u \;\; H^0_u)$	$(\widetilde{H}^+_u \;\; \widetilde{H}^0_u)$	$(\mathbf{1}, \mathbf{2}, +\frac{1}{2})$
	H_d	$(H^0_d \;\; H^-_d)$	$(\widetilde{H}^0_d \;\; \widetilde{H}^-_d)$	$(\mathbf{1}, \mathbf{2}, -\frac{1}{2})$

Table 1.1: Chiral supermultiplets in the Minimal Supersymmetric Standard Model. The spin-0 fields are complex scalars, and the spin-1/2 fields are left-handed two-component Weyl fermions.

Names	spin 1/2	spin 1	$SU(3)_C, SU(2)_L, U(1)_Y$
gluino, gluon	$\widetilde{g}$	g	$(\mathbf{8}, \mathbf{1}, 0)$
winos, W bosons	$\widetilde{W}^\pm \;\; \widetilde{W}^0$	$W^\pm \;\; W^0$	$(\mathbf{1}, \mathbf{3}, 0)$
bino, B boson	$\widetilde{B}^0$	B^0	$(\mathbf{1}, \mathbf{1}, 0)$

Table 1.2: Gauge supermultiplets in the Minimal Supersymmetric Standard Model.

Supersymmetry III

- Superpotential uniquely defines all interactions

$$W_R = \epsilon_{ij}\left[h_\tau \widehat{H}_1^i \widehat{L}^j \widehat{E} + h_b \widehat{H}_1^i \widehat{Q}^j \widehat{D} - h_t \widehat{H}_2^i \widehat{Q}^j \widehat{U} - \mu \widehat{H}_1^i \widehat{H}_2^j\right]$$

- Since no scalar partner of the electron with the same mass has been observed, SUSY must be "softly" broken

$$\begin{aligned}
V_{\text{soft}} = {} & m_1^2|H_1|^2 + m_2^2|H_2|^2 - m_{12}^2(\epsilon_{ij}H_1^i H_2^j + \text{h.c.}) \\
& + M_{\widetilde{Q}}^2\left[\tilde{t}_L^*\tilde{t}_L + \tilde{b}_L^*\tilde{b}_L\right] + M_{\widetilde{U}}^2\,\tilde{t}_R^*\tilde{t}_R + M_{\widetilde{D}}^2\,\tilde{b}_R^*\tilde{b}_R \\
& + M_{\widetilde{L}}^2\left[\tilde{\nu}^*\tilde{\nu} + \tilde{\tau}_L^*\tilde{\tau}_L\right] + M_{\widetilde{E}}^2\,\tilde{\tau}_R^*\tilde{\tau}_R \\
& + \frac{g}{\sqrt{2}m_W}\epsilon_{ij}\left[\frac{m_\tau A_\tau}{\cos\beta}H_1^i\,\tilde{\ell}_L^j\tau_R^* + \frac{m_b A_b}{\cos\beta}H_1^i\,\tilde{q}_L^j\tilde{b}_R^* - \frac{m_t A_t}{\sin\beta}H_2^i\,\tilde{q}^j t_R^*\right] \\
& + \tfrac{1}{2}\left[M_3\,\overline{\tilde{g}}\,\tilde{g} + M_2\overline{\widetilde{W}^a}\widetilde{W}^a + M_1\overline{\widetilde{B}}\widetilde{B}\right],
\end{aligned}$$

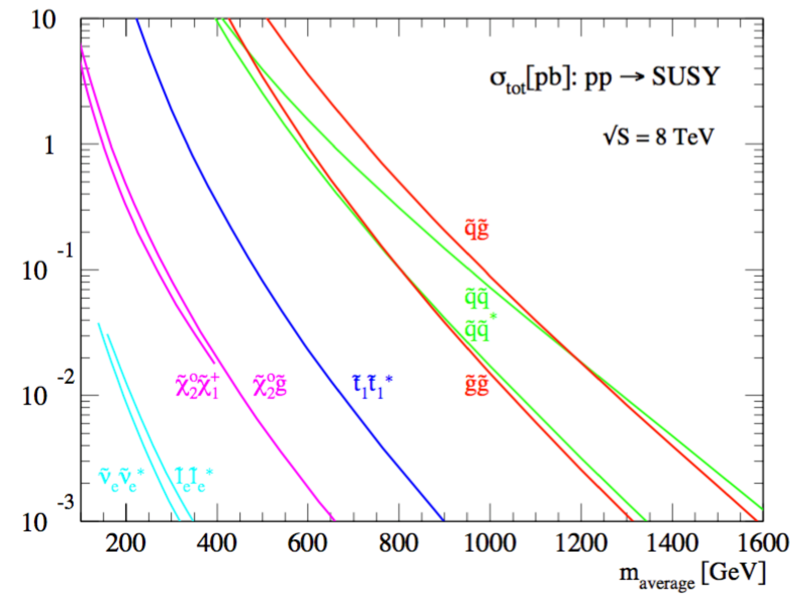
Supersymmetry IV

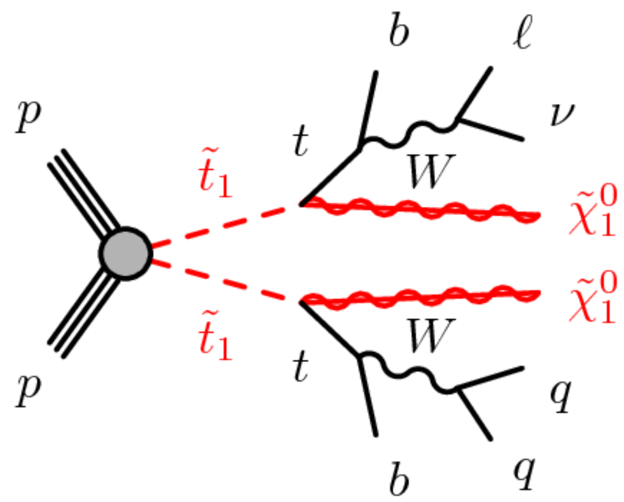
- Lightest supersymmetric particle (LSP) is neutral and stable in most common scenarios

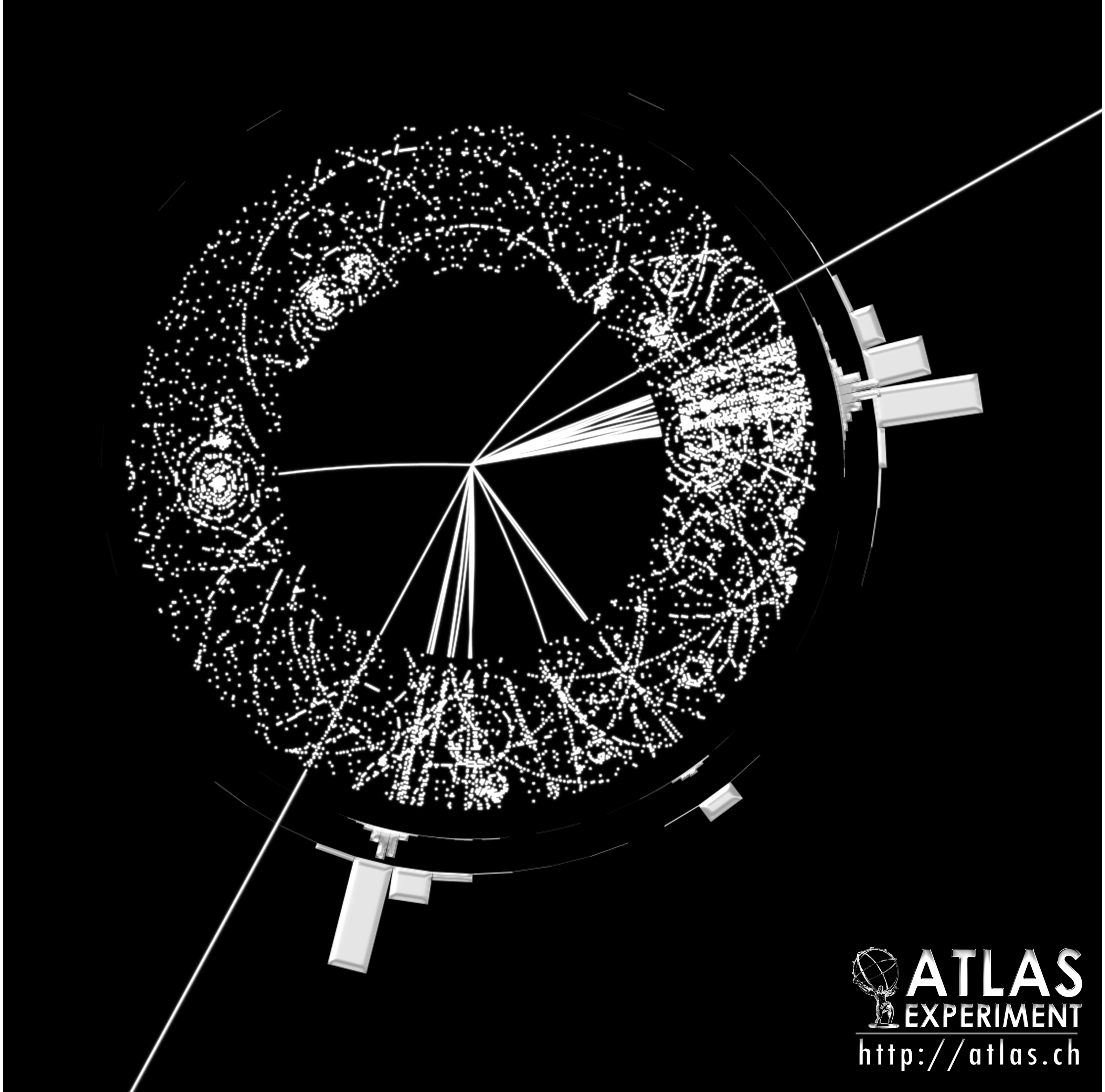
- Large missing transverse momentum expected

- Hadroproduction of squarks and gluinos are dominant

- Third generation production cross section is subdominant






ATLAS
EXPERIMENT
http://atlas.ch

ATLAS SUSY Searches* - 95% CL Lower Limits

Status: March 2016

ATLAS Preliminary

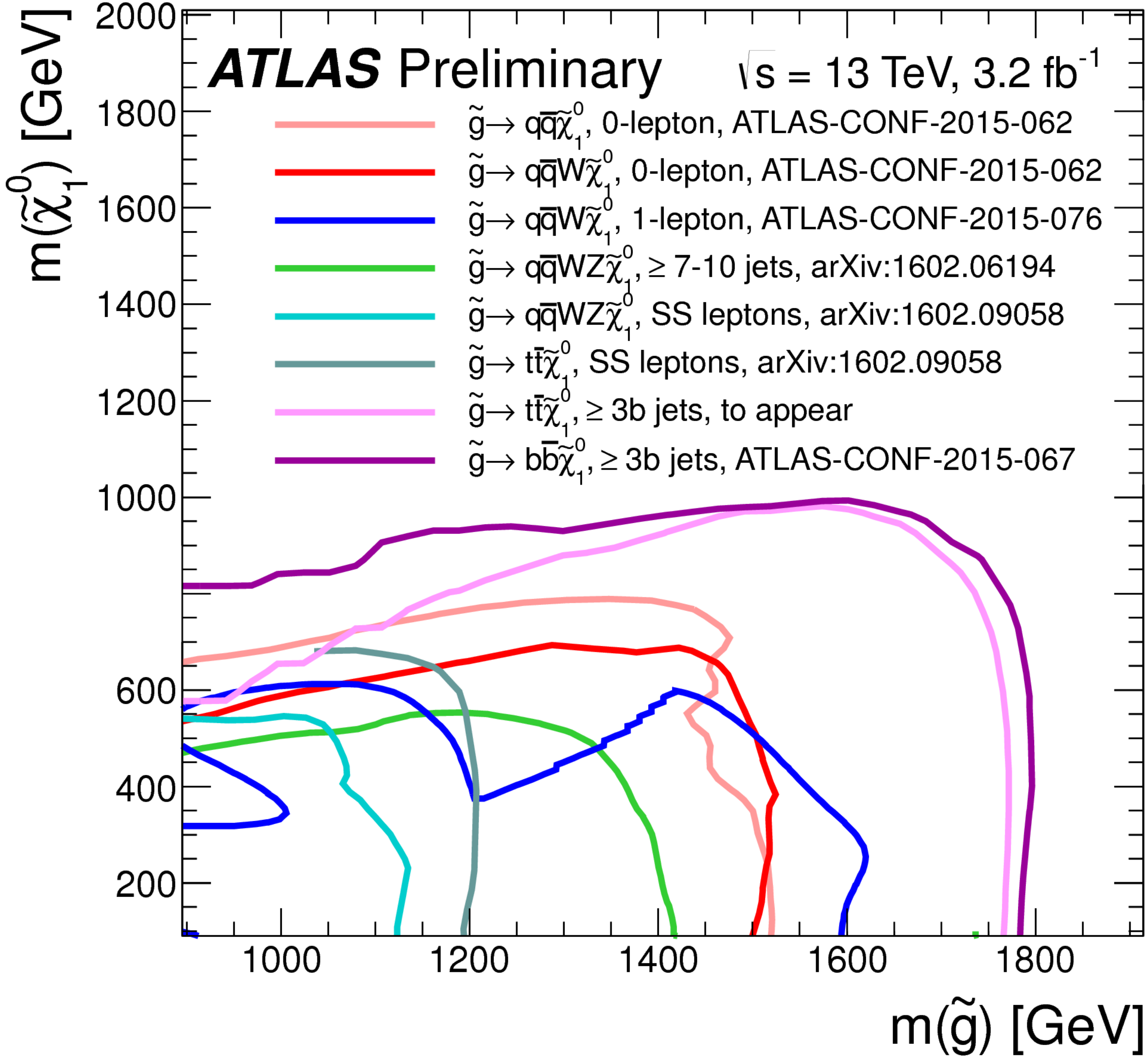
$\sqrt{s}$ = 7, 8, 13 TeV

$\sqrt{s}$ = 7, 8 TeV | $\sqrt{s}$ = 13 TeV

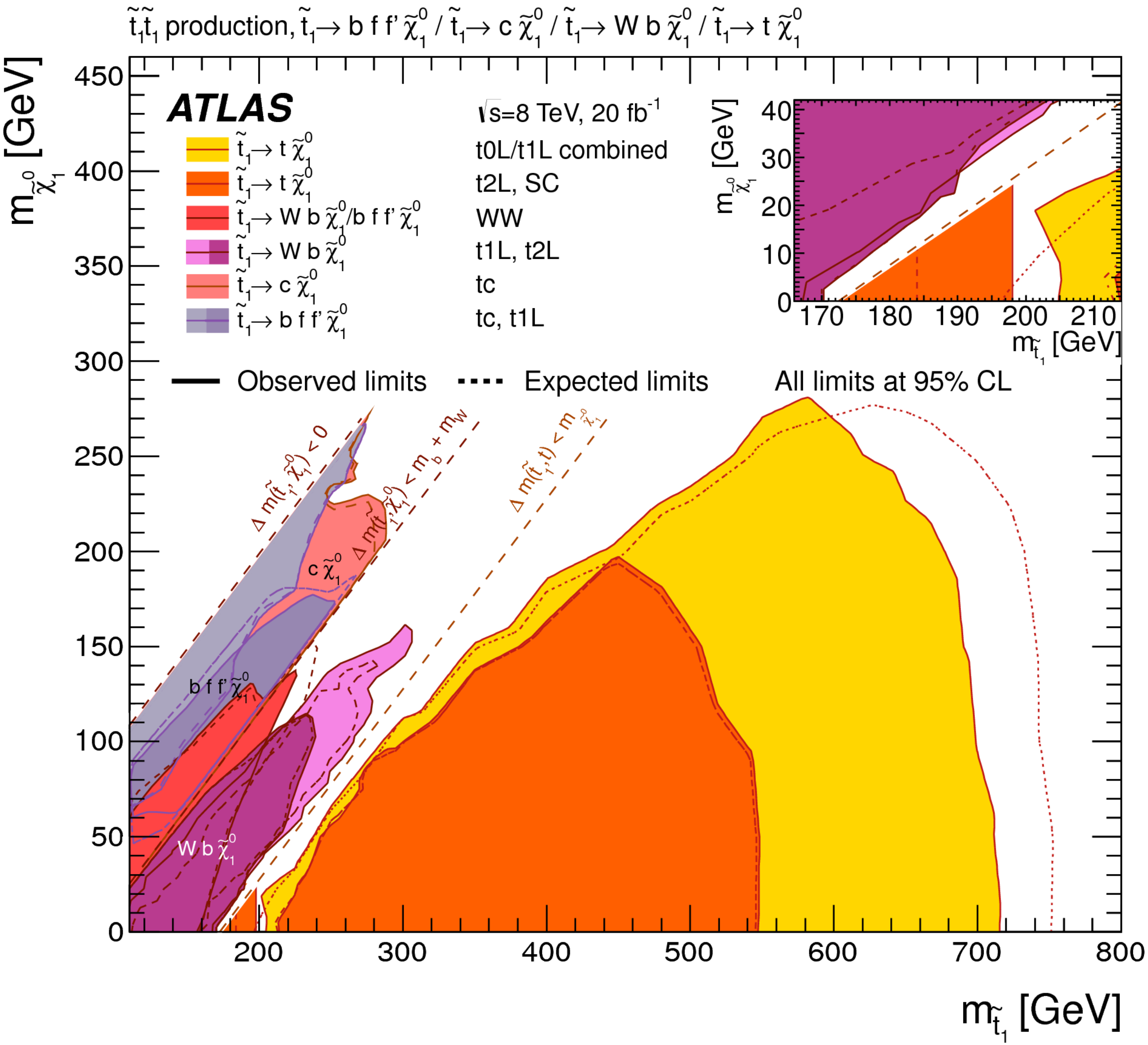
	Model	e, μ, τ, γ	Jets	E_T^{miss}	$\int \mathcal{L}\, dt[fb^{-1}]$	Mass limit		Reference
Inclusive Searches	MSUGRA/CMSSM	0-3 e,μ/1-2 τ	2-10 jets/3 b	Yes	20.3	$\tilde{q}, \tilde{g}$ 1.85 TeV	$m(\tilde{q})$=$m(\tilde{g})$	1507.05525
	$\tilde{q}\tilde{q}$, $\tilde{q}\to q\tilde{\chi}^0_1$	0	2-6 jets	Yes	3.2	$\tilde{q}$ 980 GeV	$m(\tilde{\chi}^0_1)$=0 GeV, m(1st gen. $\tilde{q}$)=m(2nd gen. $\tilde{q}$)	ATLAS-CONF-2015-062
	$\tilde{q}\tilde{q}$, $\tilde{q}\to q\tilde{\chi}^0_1$ (compressed)	mono-jet	1-3 jets	Yes	3.2	$\tilde{q}$ 610 GeV	$m(\tilde{q})$-$m(\tilde{\chi}^0_1)$<5 GeV	To appear
	$\tilde{q}\tilde{q}$, $\tilde{q}\to q(\ell\ell/\ell\nu/\nu\nu)\tilde{\chi}^0_1$	2 e,μ (off-Z)	2 jets	Yes	20.3	$\tilde{q}$ 820 GeV	$m(\tilde{\chi}^0_1)$=0 GeV	1503.03290
	$\tilde{g}\tilde{g}$, $\tilde{g}\to q\bar{q}\tilde{\chi}^0_1$	0	2-6 jets	Yes	3.2	$\tilde{g}$ 1.52 TeV	$m(\tilde{\chi}^0_1)$=0 GeV	ATLAS-CONF-2015-062
	$\tilde{g}\tilde{g}$, $\tilde{g}\to qq\tilde{\chi}^\pm_1\to qqW^\pm\tilde{\chi}^0_1$	1 e,μ	2-6 jets	Yes	3.3	$\tilde{g}$ 1.6 TeV	$m(\tilde{\chi}^0_1)$<350 GeV, $m(\tilde{\chi}^\pm)$=0.5($m(\tilde{\chi}^0_1)$+$m(\tilde{g})$)	ATLAS-CONF-2015-076
	$\tilde{g}\tilde{g}$, $\tilde{g}\to qq(\ell\ell/\ell\nu/\nu\nu)\tilde{\chi}^0_1$	2 e,μ	0-3 jets	-	20	$\tilde{g}$ 1.38 TeV	$m(\tilde{\chi}^0_1)$=0 GeV	1501.03555
	$\tilde{g}\tilde{g}$, $\tilde{g}\to qqWZ\tilde{\chi}^0_1$	0	7-10 jets	Yes	3.2	$\tilde{g}$ 1.4 TeV	$m(\tilde{\chi}^0_1)$ =100 GeV	1602.06194
	GMSB ($\tilde{\ell}$ NLSP)	1-2 τ + 0-1 ℓ	0-2 jets	Yes	20.3	$\tilde{g}$ 1.63 TeV	$\tan\beta$ >20	1407.0603
	GGM (bino NLSP)	2 γ	-	Yes	20.3	$\tilde{g}$ 1.34 TeV	$c\tau$(NLSP)<0.1 mm	1507.05493
	GGM (higgsino-bino NLSP)	γ	1 b	Yes	20.3	$\tilde{g}$ 1.37 TeV	$m(\tilde{\chi}^0_1)$<950 GeV, $c\tau$(NLSP)<0.1 mm, μ<0	1507.05493
	GGM (higgsino-bino NLSP)	γ	2 jets	Yes	20.3	$\tilde{g}$ 1.3 TeV	$m(\tilde{\chi}^0_1)$<850 GeV, $c\tau$(NLSP)<0.1 mm, μ>0	1507.05493
	GGM (higgsino NLSP)	2 e,μ (Z)	2 jets	Yes	20.3	$\tilde{g}$ 900 GeV	m(NLSP)>430 GeV	1503.03290
	Gravitino LSP	0	mono-jet	Yes	20.3	$F^{1/2}$ scale 865 GeV	$m(\tilde{G})$>1.8×10^{-4} eV, $m(\tilde{g})$=$m(\tilde{q})$=1.5 TeV	1502.01518
3^{rd} gen. $\tilde{g}$ med.	$\tilde{g}\tilde{g}$, $\tilde{g}\to b\bar{b}\tilde{\chi}^0_1$	0	3 b	Yes	3.3	$\tilde{g}$ 1.78 TeV	$m(\tilde{\chi}^0_1)$<800 GeV	ATLAS-CONF-2015-067
	$\tilde{g}\tilde{g}$, $\tilde{g}\to t\bar{t}\tilde{\chi}^0_1$	0-1 e,μ	3 b	Yes	3.3	$\tilde{g}$ 1.76 TeV	$m(\tilde{\chi}^0_1)$=0 GeV	To appear
	$\tilde{g}\tilde{g}$, $\tilde{g}\to b\bar{t}\tilde{\chi}^+_1$	0-1 e,μ	3 b	Yes	20.1	$\tilde{g}$ 1.37 TeV	$m(\tilde{\chi}^0_1)$<300 GeV	1407.0600
3^{rd} gen. squarks direct production	$\tilde{b}_1\tilde{b}_1$, $\tilde{b}_1\to b\tilde{\chi}^0_1$	0	2 b	Yes	3.2	$\tilde{b}_1$ 840 GeV	$m(\tilde{\chi}^0_1)$<100 GeV	ATLAS-CONF-2015-066
	$\tilde{b}_1\tilde{b}_1$, $\tilde{b}_1\to t\tilde{\chi}^\pm_1$	2 e,μ (SS)	0-3 b	Yes	3.2	$\tilde{b}_1$ 325-540 GeV	$m(\tilde{\chi}^0_1)$=50 GeV, $m(\tilde{\chi}^\pm_1)$= $m(\tilde{\chi}^0_1)$+100 GeV	1602.09058
	$\tilde{t}_1\tilde{t}_1$, $\tilde{t}_1\to b\tilde{\chi}^\pm_1$	1-2 e,μ	1-2 b	Yes	4.7/20.3	$\tilde{t}_1$ 117-170 GeV; 200-500 GeV	$m(\tilde{\chi}^\pm_1)$ = 2$m(\tilde{\chi}^0_1)$, $m(\tilde{\chi}^0_1)$=55 GeV	1209.2102, 1407.0583
	$\tilde{t}_1\tilde{t}_1$, $\tilde{t}_1\to Wb\tilde{\chi}^0_1$ or $t\tilde{\chi}^0_1$	0-2 e,μ	0-2 jets/1-2 b	Yes	20.3	$\tilde{t}_1$ 90-198 GeV; 205-715 GeV; 745-785 GeV	$m(\tilde{\chi}^0_1)$=1 GeV	1506.08616, ATLAS-CONF-2016-007
	$\tilde{t}_1\tilde{t}_1$, $\tilde{t}_1\to c\tilde{\chi}^0_1$	0	mono-jet/c-tag	Yes	20.3	$\tilde{t}_1$ 90-245 GeV	$m(\tilde{t}_1)$-$m(\tilde{\chi}^0_1)$<85 GeV	1407.0608
	$\tilde{t}_1\tilde{t}_1$(natural GMSB)	2 e,μ (Z)	1 b	Yes	20.3	$\tilde{t}_1$ 150-600 GeV	$m(\tilde{\chi}^0_1)$>150 GeV	1403.5222
	$\tilde{t}_2\tilde{t}_2$, $\tilde{t}_2\to\tilde{t}_1+Z$	3 e,μ (Z)	1 b	Yes	20.3	$\tilde{t}_2$ 290-610 GeV	$m(\tilde{\chi}^0_1)$<200 GeV	1403.5222
	$\tilde{t}_2\tilde{t}_2$, $\tilde{t}_2\to\tilde{t}_1+h$	1 e,μ	6 jets + 2 b	Yes	20.3	$\tilde{t}_2$ 320-620 GeV	$m(\tilde{\chi}^0_1)$=0 GeV	1506.08616
EW direct	$\tilde{\ell}_{L,R}\tilde{\ell}_{L,R}$, $\tilde{\ell}\to\ell\tilde{\chi}^0_1$	2 e,μ	0	Yes	20.3	$\tilde{\ell}$ 90-335 GeV	$m(\tilde{\chi}^0_1)$=0 GeV	1403.5294
	$\tilde{\chi}^+_1\tilde{\chi}^-_1$, $\tilde{\chi}^+_1\to\tilde{\ell}\nu(\ell\tilde{\nu})$	2 e,μ	0	Yes	20.3	$\tilde{\chi}^\pm_1$ 140-475 GeV	$m(\tilde{\chi}^0_1)$=0 GeV, $m(\tilde{\ell},\tilde{\nu})$=0.5($m(\tilde{\chi}^\pm_1)$+$m(\tilde{\chi}^0_1)$)	1403.5294
	$\tilde{\chi}^+_1\tilde{\chi}^-_1$, $\tilde{\chi}^+_1\to\tilde{\tau}\nu(\tau\tilde{\nu})$	2 τ	-	Yes	20.3	$\tilde{\chi}^\pm_1$ 355 GeV	$m(\tilde{\chi}^0_1)$=0 GeV, $m(\tilde{\tau},\tilde{\nu})$=0.5($m(\tilde{\chi}^\pm_1)$+$m(\tilde{\chi}^0_1)$)	1407.0350
	$\tilde{\chi}^\pm_1\tilde{\chi}^0_2\to\tilde{\ell}_L\nu\tilde{\ell}_L\ell(\tilde{\nu}\nu)$, $\ell\tilde{\nu}\tilde{\ell}_L\ell(\tilde{\nu}\nu)$	3 e,μ	0	Yes	20.3	$\tilde{\chi}^\pm_1,\tilde{\chi}^0_2$ 715 GeV	$m(\tilde{\chi}^\pm_1)$=$m(\tilde{\chi}^0_2)$, $m(\tilde{\chi}^0_1)$=0, $m(\tilde{\ell},\tilde{\nu})$=0.5($m(\tilde{\chi}^\pm_1)$+$m(\tilde{\chi}^0_1)$)	1402.7029
	$\tilde{\chi}^\pm_1\tilde{\chi}^0_2\to W\tilde{\chi}^0_1 Z\tilde{\chi}^0_1$	2-3 e,μ	0-2 jets	Yes	20.3	$\tilde{\chi}^\pm_1,\tilde{\chi}^0_2$ 425 GeV	$m(\tilde{\chi}^\pm_1)$=$m(\tilde{\chi}^0_2)$, $m(\tilde{\chi}^0_1)$=0, sleptons decoupled	1403.5294, 1402.7029
	$\tilde{\chi}^\pm_1\tilde{\chi}^0_2\to W\tilde{\chi}^0_1 h\tilde{\chi}^0_1$, $h\to b\bar{b}/WW/\tau\tau/\gamma\gamma$	e,μ,γ	0-2 b	Yes	20.3	$\tilde{\chi}^\pm_1,\tilde{\chi}^0_2$ 270 GeV	$m(\tilde{\chi}^\pm_1)$=$m(\tilde{\chi}^0_2)$, $m(\tilde{\chi}^0_1)$=0, sleptons decoupled	1501.07110
	$\tilde{\chi}^0_2\tilde{\chi}^0_3$, $\tilde{\chi}^0_{2,3}\to\tilde{\ell}_R\ell$	4 e,μ	0	Yes	20.3	$\tilde{\chi}^0_{2,3}$ 635 GeV	$m(\tilde{\chi}^0_2)$=$m(\tilde{\chi}^0_3)$, $m(\tilde{\chi}^0_1)$=0, $m(\tilde{\ell},\tilde{\nu})$=0.5($m(\tilde{\chi}^0_2)$+$m(\tilde{\chi}^0_1)$)	1405.5086
	GGM (wino NLSP) weak prod.	1 e,μ + γ	-	Yes	20.3	$\tilde{W}$ 115-370 GeV	$c\tau$<1 mm	1507.05493
Long-lived particles	Direct $\tilde{\chi}^+_1\tilde{\chi}^-_1$ prod., long-lived $\tilde{\chi}^\pm_1$	Disapp. trk	1 jet	Yes	20.3	$\tilde{\chi}^\pm_1$ 270 GeV	$m(\tilde{\chi}^\pm_1)$-$m(\tilde{\chi}^0_1)$~160 MeV, $\tau(\tilde{\chi}^\pm_1)$=0.2 ns	1310.3675
	Direct $\tilde{\chi}^+_1\tilde{\chi}^-_1$ prod., long-lived $\tilde{\chi}^\pm_1$	dE/dx trk	-	Yes	18.4	$\tilde{\chi}^\pm_1$ 495 GeV	$m(\tilde{\chi}^\pm_1)$-$m(\tilde{\chi}^0_1)$~160 MeV, $\tau(\tilde{\chi}^\pm_1)$<15 ns	1506.05332
	Stable, stopped $\tilde{g}$ R-hadron	0	1-5 jets	Yes	27.9	$\tilde{g}$ 850 GeV	$m(\tilde{\chi}^0_1)$=100 GeV, 10 μs<$\tau(\tilde{g})$<1000 s	1310.6584
	Metastable $\tilde{g}$ R-hadron	dE/dx trk	-	-	3.2	$\tilde{g}$ 1.54 TeV	$m(\tilde{\chi}^0_1)$=100 GeV, τ>10 ns	To appear
	GMSB, stable $\tilde{\tau}$, $\tilde{\chi}^0_1\to\tilde{\tau}(\tilde{e},\tilde{\mu})+\tau(e,\mu)$	1-2 μ	-	-	19.1	$\tilde{\chi}^0_1$ 537 GeV	10<$\tan\beta$<50	1411.6795
	GMSB, $\tilde{\chi}^0_1\to\gamma\tilde{G}$, long-lived $\tilde{\chi}^0_1$	2 γ	-	Yes	20.3	$\tilde{\chi}^0_1$ 440 GeV	1<$\tau(\tilde{\chi}^0_1)$<3 ns, SPS8 model	1409.5542
	$\tilde{g}\tilde{g}$, $\tilde{\chi}^0_1\to ee\nu/e\mu\nu/\mu\mu\nu$	displ. $ee/e\mu/\mu\mu$	-	-	20.3	$\tilde{\chi}^0_1$ 1.0 TeV	7 <$c\tau(\tilde{\chi}^0_1)$< 740 mm, $m(\tilde{g})$=1.3 TeV	1504.05162
	GGM $\tilde{g}\tilde{g}$, $\tilde{\chi}^0_1\to Z\tilde{G}$	displ. vtx + jets	-	-	20.3	$\tilde{\chi}^0_1$ 1.0 TeV	6 <$c\tau(\tilde{\chi}^0_1)$< 480 mm, $m(\tilde{g})$=1.1 TeV	1504.05162
RPV	LFV $pp\to\tilde{\nu}_\tau+X$, $\tilde{\nu}_\tau\to e\mu/e\tau/\mu\tau$	$e\mu,e\tau,\mu\tau$	-	-	20.3	$\tilde{\nu}_\tau$ 1.7 TeV	λ'_{311}=0.11, $\lambda_{132/133/233}$=0.07	1503.04430
	Bilinear RPV CMSSM	2 e,μ (SS)	0-3 b	Yes	20.3	$\tilde{q},\tilde{g}$ 1.45 TeV	$m(\tilde{q})$=$m(\tilde{g})$, $c\tau_{LSP}$<1 mm	1404.2500
	$\tilde{\chi}^+_1\tilde{\chi}^-_1$, $\tilde{\chi}^+_1\to W\tilde{\chi}^0_1$, $\tilde{\chi}^0_1\to ee\tilde{\nu}_\mu, e\mu\tilde{\nu}_e$	4 e,μ	-	Yes	20.3	$\tilde{\chi}^\pm_1$ 760 GeV	$m(\tilde{\chi}^0_1)$>0.2×$m(\tilde{\chi}^\pm_1)$, $\lambda_{121}\neq0$	1405.5086
	$\tilde{\chi}^+_1\tilde{\chi}^-_1$, $\tilde{\chi}^+_1\to W\tilde{\chi}^0_1$, $\tilde{\chi}^0_1\to\tau\tau\tilde{\nu}_e, e\tau\tilde{\nu}_\tau$	3 e,μ + τ	-	Yes	20.3	$\tilde{\chi}^\pm_1$ 450 GeV	$m(\tilde{\chi}^0_1)$>0.2×$m(\tilde{\chi}^\pm_1)$, $\lambda_{133}\neq0$	1405.5086
	$\tilde{g}\tilde{g}$, $\tilde{g}\to qqq$	0	6-7 jets	-	20.3	$\tilde{g}$ 917 GeV	BR(t)=BR(b)=BR(c)=0%	1502.05686
	$\tilde{g}\tilde{g}$, $\tilde{g}\to qq\tilde{\chi}^0_1$, $\tilde{\chi}^0_1\to qqq$	0	6-7 jets	-	20.3	$\tilde{g}$ 980 GeV	$m(\tilde{\chi}^0_1)$=600 GeV	1502.05686
	$\tilde{g}\tilde{g}$, $\tilde{g}\to\tilde{t}_1 t$, $\tilde{t}_1\to bs$	2 e,μ (SS)	0-3 b	Yes	20.3	$\tilde{g}$ 880 GeV		1404.2500
	$\tilde{t}_1\tilde{t}_1$, $\tilde{t}_1\to bs$	0	2 jets + 2 b	-	20.3	$\tilde{t}_1$ 320 GeV		1601.07453
	$\tilde{t}_1\tilde{t}_1$, $\tilde{t}_1\to b\ell$	2 e,μ	2 b	-	20.3	$\tilde{t}_1$ 0.4-1.0 TeV	BR($\tilde{t}_1\to be/\mu$)>20%	ATLAS-CONF-2015-015
Other	Scalar charm, $\tilde{c}\to c\tilde{\chi}^0_1$	0	2 c	Yes	20.3	$\tilde{c}$ 510 GeV	$m(\tilde{\chi}^0_1)$<200 GeV	1501.01325

10^{-1} — 1 — Mass scale [TeV]

*Only a selection of the available mass limits on new states or phenomena is shown.



ATLAS Preliminary
√s = 13 TeV, 3.2 fb-1
g̃→ qq̄χ̃10, 0-lepton, ATLAS-CONF-2015-062
g̃→ qq̄Wχ̃10, 0-lepton, ATLAS-CONF-2015-062
g̃→ qq̄Wχ̃10, 1-lepton, ATLAS-CONF-2015-076
g̃→ qq̄WZχ̃10, ≥ 7-10 jets, arXiv:1602.06194
g̃→ qq̄WZχ̃10, SS leptons, arXiv:1602.09058
g̃→ tt̄χ̃10, SS leptons, arXiv:1602.09058
g̃→ tt̄χ̃10, ≥ 3b jets, to appear
g̃→ bb̄χ̃10, ≥ 3b jets, ATLAS-CONF-2015-067
m(χ̃10) [GeV]
m(g̃) [GeV]
2000
1800
1600
1400
1200
1000
600
400
200
1000
1200
1400
1600
1800



$\tilde{t}_1\tilde{t}_1$ production, $\tilde{t}_1 \to b f f' \tilde{\chi}^0_1$ / $\tilde{t}_1 \to c \tilde{\chi}^0_1$ / $\tilde{t}_1 \to W b \tilde{\chi}^0_1$ / $\tilde{t}_1 \to t \tilde{\chi}^0_1$
ATLAS
$\sqrt{s}$=8 TeV, 20 fb^{-1}
$\tilde{t}_1 \to t \tilde{\chi}^0_1$ t0L/t1L combined
$\tilde{t}_1 \to t \tilde{\chi}^0_1$ t2L, SC
$\tilde{t}_1 \to W b \tilde{\chi}^0_1$/b f f' $\tilde{\chi}^0_1$ WW
$\tilde{t}_1 \to W b \tilde{\chi}^0_1$ t1L, t2L
$\tilde{t}_1 \to c \tilde{\chi}^0_1$ tc
$\tilde{t}_1 \to b f f' \tilde{\chi}^0_1$ tc, t1L
Observed limits
Expected limits
All limits at 95% CL
$\Delta m(\tilde{t}_1,\tilde{\chi}^0_1) < 0$
$\Delta m(\tilde{t}_1,\tilde{\chi}^0_1) < m_b + m_W$
$\Delta m(\tilde{t}_1,t) < m_{\tilde{\chi}^0_1}$
c $\tilde{\chi}^0_1$
b f f' $\tilde{\chi}^0_1$
W b $\tilde{\chi}^0_1$
$m_{\tilde{\chi}^0_1}$ [GeV]
$m_{\tilde{t}_1}$ [GeV]

Natural Supersymmetry

Hierarchy Problem II

- For exact boson-fermion symmetry, loop corrections do not change the Higgs mass!
- Soft breaking terms do not affect the cancellation of quadratic divergencies
- However, corrections to squared Higgs mass parameter scale with squares of soft breaking parameters!
- @tree level: mHiggz < mZ with mHiggs=125 GeV!
- Large loop corrections needed
- mHiggs(loop)≈log(mt1 mt2/mtop^2)
- Heavy stops needed, which induces large corrections to Lagrangian parameters

Natural SUSY I

- What is natural? How to quantify fine-tuning?
- First answer:

$$\left| \frac{a}{M_Z^2} \frac{\partial M_Z^2}{\partial a} \right| \leq \Delta$$

- Finetuning increases quadratically with μ as well as with stop mass (@1loop) and with gluino mass (@2loop)

Natural SUSY II

- The minimization of the EW scalar potential yields

$$\frac{M_Z^2}{2} = -(m_{H_u}^2 + \Sigma_u^u) - \mu^2$$

- Naturalness requires no large cancellations on RHS
- Higgsino parameter should be small
- Loop corrections should not blow up hence no large stop masses (@1 loop) & gluino masses (@ 2 loop)
- All other particles are decoupled

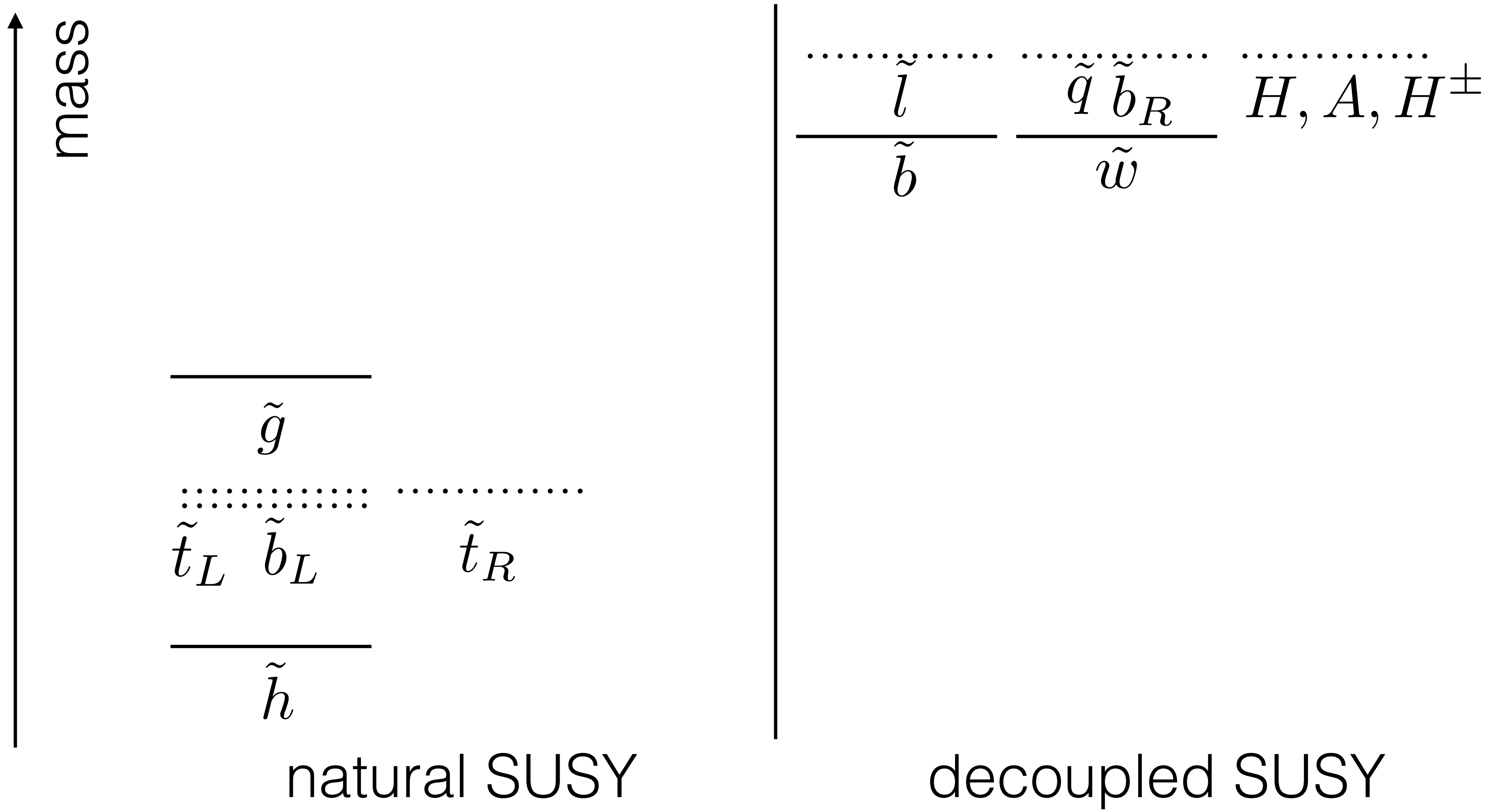
SUSY under attack?

- Observed Higgs is SM like & relatively heavy
- Large Higgs mass needs highly mixed TeV scale stops
- No supersymmetric particles observed, m(gluino)>1.8 TeV and m(squark)>1.8 TeV
- Too strict direct constraints on SUSY particles jeopardize naturalness!
- Higgs **and** direct searches put SUSY under pressure
- Thus does SUSY have a little hierarchy problem?
- Limits are generally put on simplified/constrained models
- However, third generation limits are much weaker!
- Tree level Higgs mass can be increased in non minimal models

Natural SUSY III

- A <u>minimal</u> natural SUSY scenario consists of light higgsinos, TeV scale stops and multi TeV gluinos
- A left-handed sbottom is in the same SU(2) doublet as the stop and hence a light SU(2) doublet sbottom is required
- The right handed sbottoms do not couple strongly to the Higgs for small tan(β) and can be decoupled
- The trilinear coupling Ab has only little impact

Natural SUSY IV



Natural SUSY V

- Gluinos and third generation scalar production are dominant

$$pp \to \tilde{g}\tilde{g}, \quad pp \to \tilde{t}_i \tilde{t}_i^*, \quad pp \to \tilde{b}_i \tilde{b}_i^*$$

- In general, we expect large b-jet multiplicities from gluino decays

$$\tilde{g} \to \tilde{t}_i \bar{t}, \quad \tilde{t}_i^* t, \quad \tilde{b}_i \bar{b}, \quad \tilde{b}_i^* b$$
$$\tilde{g} \to g \tilde{\chi}_1^0$$

- Stop decay modes depend on model parameters

$$\tilde{t}_i \to t\tilde{g}, \quad \tilde{b}_i \to b\tilde{g},$$
$$\tilde{t}_i \to t\tilde{\chi}_l^0, \quad b\tilde{\chi}_1^\pm,$$
$$\tilde{b}_i \to b\tilde{\chi}_l^0, \quad t\tilde{\chi}_1^\pm,$$
$$\tilde{t}_i \to \tilde{b}_j W^\pm, \quad \tilde{b}_i \to \tilde{t}_j W^\pm,$$
$$\tilde{t}_2 \to \tilde{t}_1 Z, \quad \tilde{t}_2 \to \tilde{t}_1 h$$

Setup

Scan Procedure I

- We randomly vary the soft breaking parameter of the natural SUSY parameters
- We demand a SM like Higgs and assume a decoupled MSSM Higgs sector
- LEP2 and low energy constraints must be satisfied

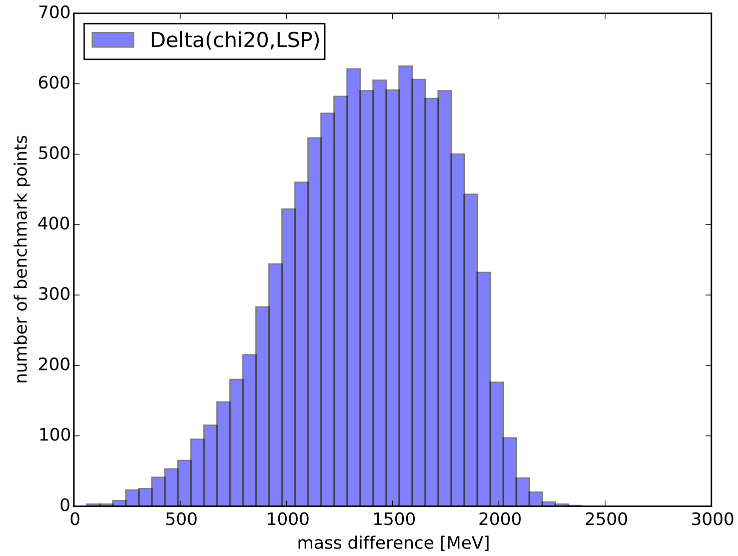
Parameter	Description	Scanned range
$m_{\tilde{Q}_t}$	3^{rd} generation $SU(2)$ doublet soft breaking squark mass	[0.1 TeV, 1.5 TeV]
$m_{\tilde{t}_R}$	3^{rd} generation $SU(2)$ singlet soft breaking squark mass	[0.1 TeV, 1.5 TeV]
M_3	Gluino mass parameter	[0.1 TeV, 3.0 TeV]
A_t	Stop trilinear coupling	[−3.0 TeV, 3.0 TeV]
μ	Higgsino mass parameter	[0.1 TeV, 0.5 TeV]
$\tan\beta$	Ratio of vacuum expectation values	[1, 20]

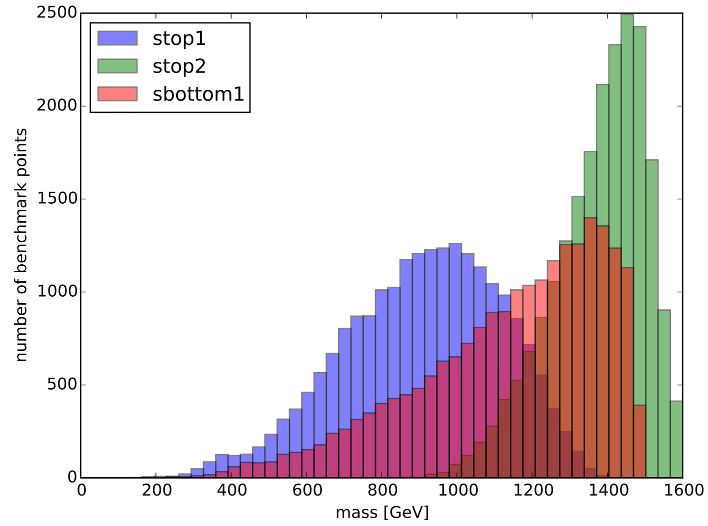
Scan Procedure II

- We use SPheno for the generation of the spectrum and decay tables
- We randomly generate 22000 benchmark point assuming flat priors
- Since higgsino mass eigenstates are nearly mass degenerate, we demand short lived higgsinos!
- Take care that the decay modes are correctly implemented for NLSP higgsino decays, e.g. higgsino->pion LSP

Mass Spectrum

- The mass between the NLSP and the LSP must be at least above the pion mass
- The heavier stop mass eigenstate is kinematically not accessible at the LHC run 1
- The sbottom mass eigenstate is slightly heavier





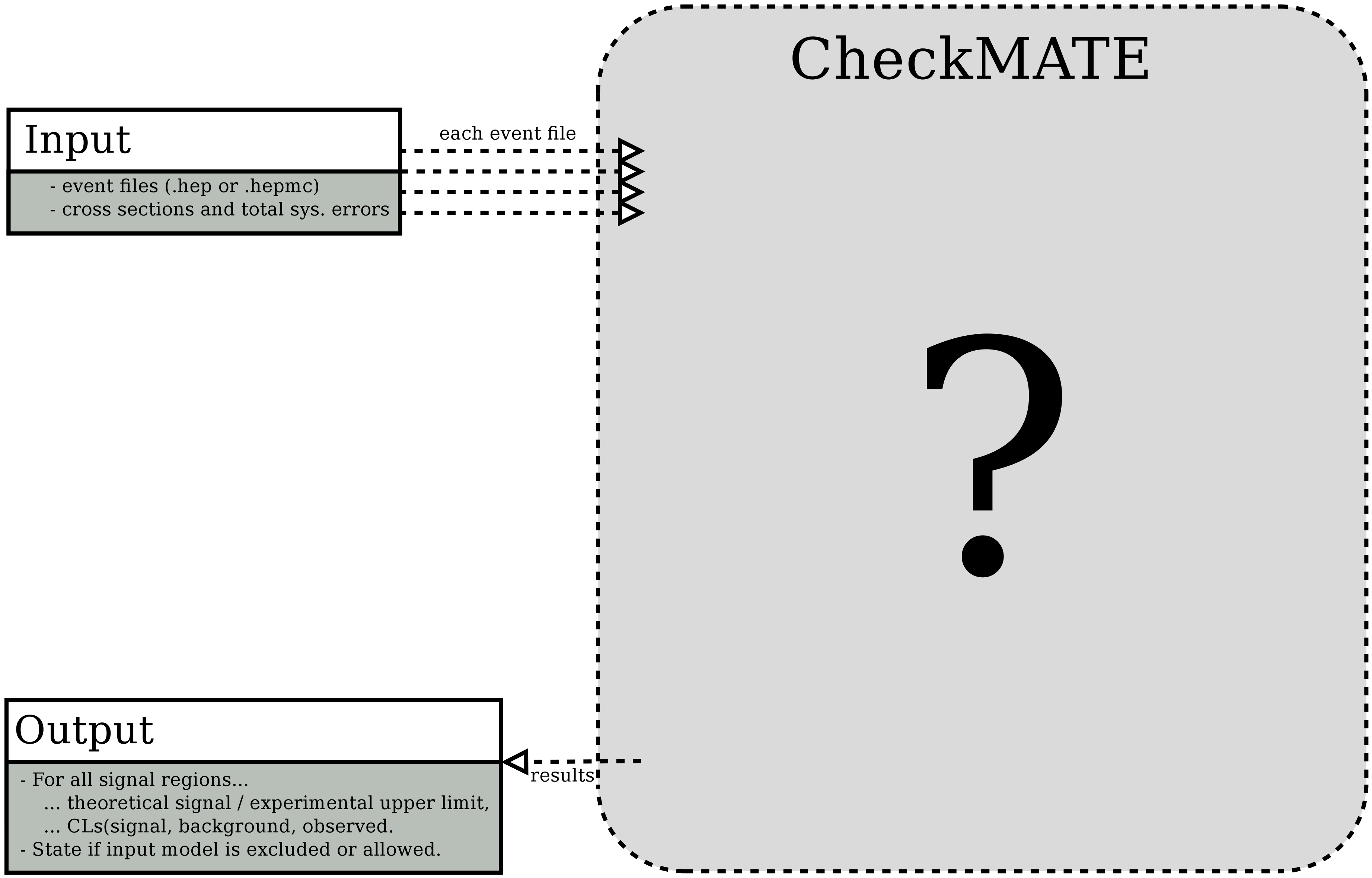
Numerical Tools

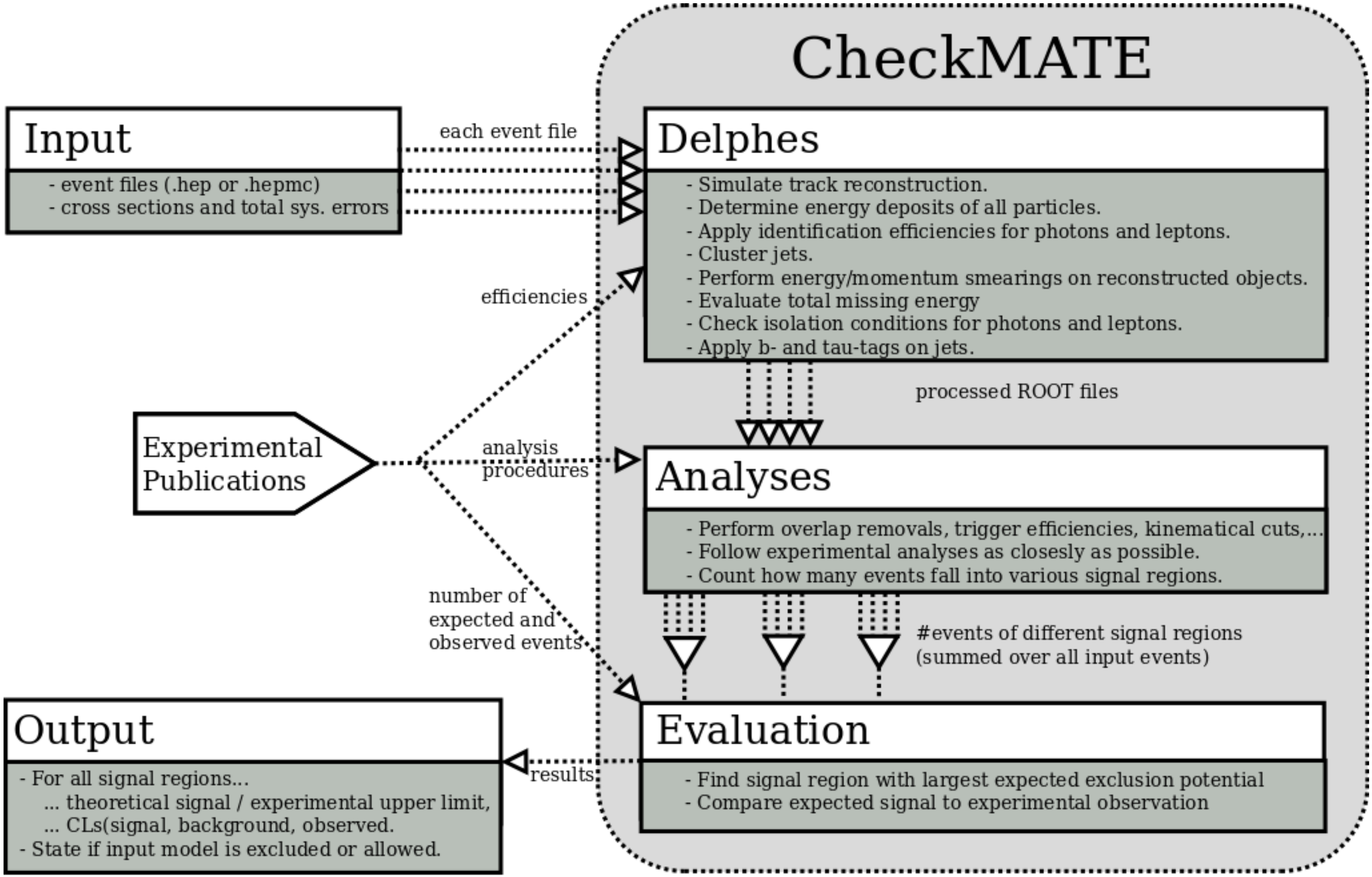
- We generate gluino, stop and sbottom pair production
- Higgsino pair production is negligible & is invisible
- MC Events are generated with Pythia 8
- For degenerate mass spectra, we generate matched events with Madgraph/Pythia 6
- LHC constraints are tested with CheckMATE

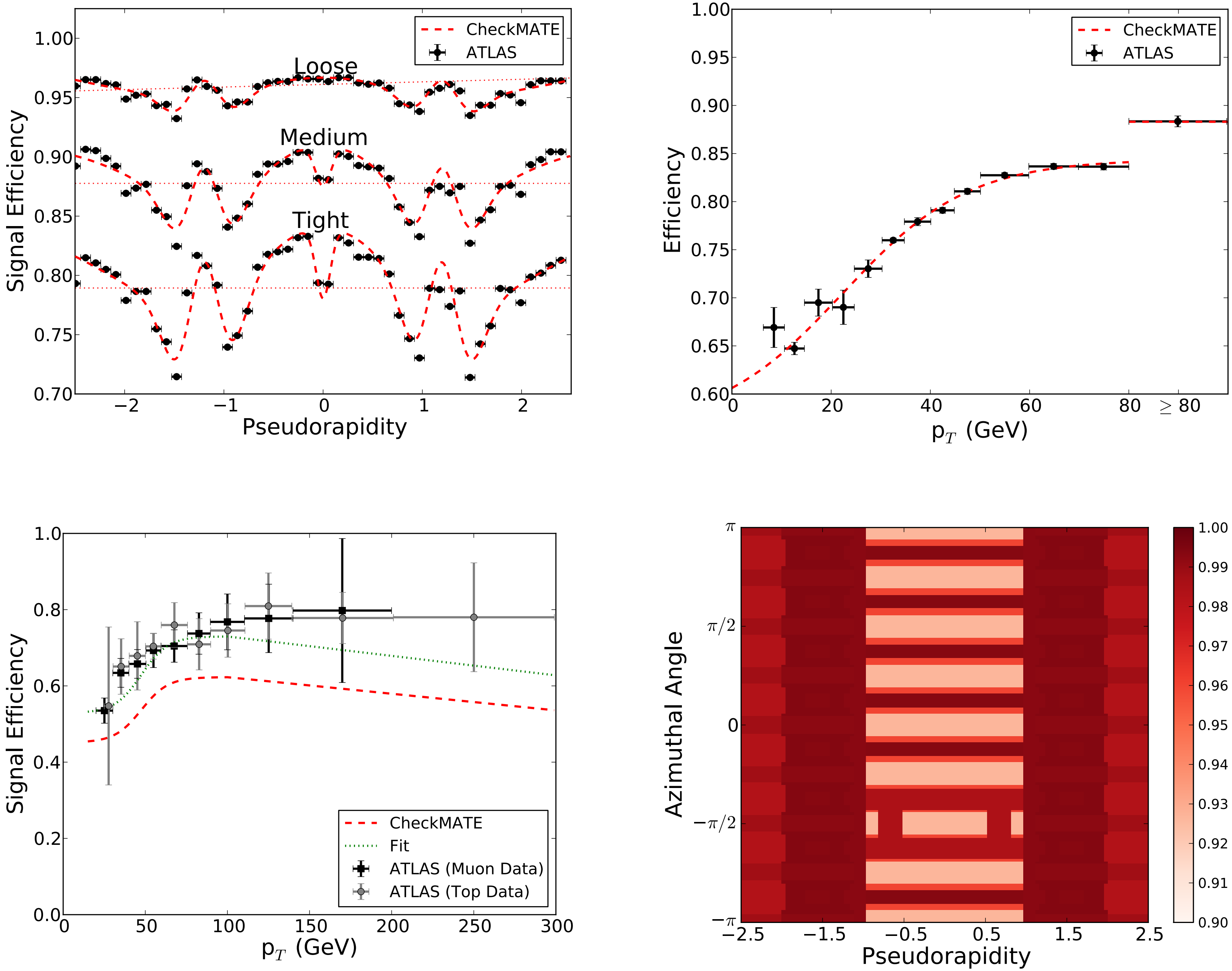
CheckMATE

N. Desai, M. Drees, H. Dreiner, J.S. Kim, D. Schmeier, J. Tattersall, K. Rolbiecki

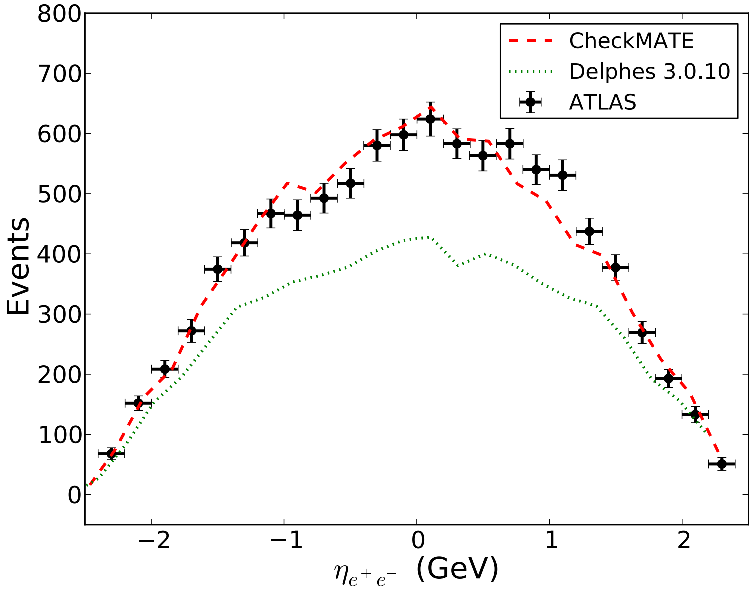
Our idea


CheckMATE
Input
- event files (.hep or .hepmc)
- cross sections and total sys. errors
each event file
?
Output
- For all signal regions...
... theoretical signal / experimental upper limit,
... CLs(signal, background, observed.
- State if input model is excluded or allowed.
results

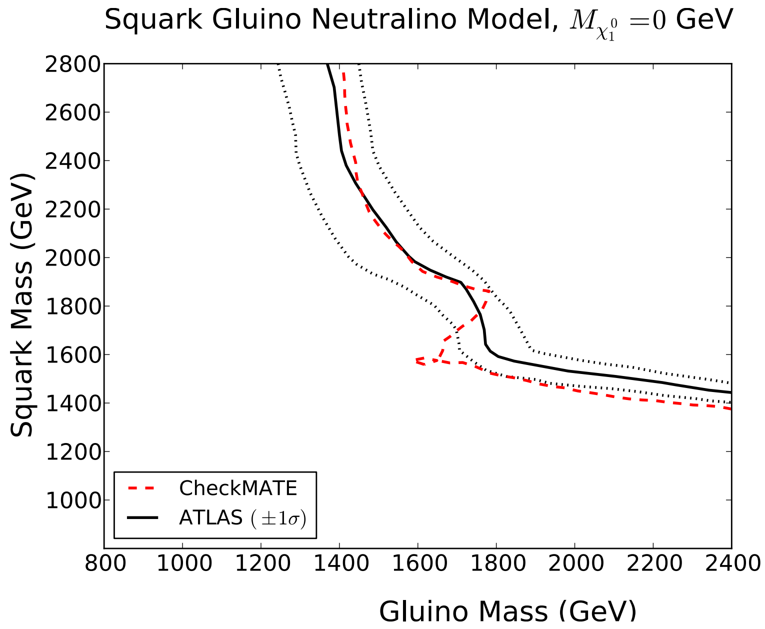

CheckMATE
Input
- event files (.hep or .hepmc)
- cross sections and total sys. errors
each event file
Delphes
- Simulate track reconstruction.
- Determine energy deposits of all particles.
- Apply identification efficiencies for photons and leptons.
- Cluster jets.
- Perform energy/momentum smearings on reconstructed objects.
- Evaluate total missing energy
- Check isolation conditions for photons and leptons.
- Apply b- and tau-tags on jets.
efficiencies
processed ROOT files
Experimental Publications
analysis procedures
Analyses
- Perform overlap removals, trigger efficiencies, kinematical cuts,...
- Follow experimental analyses as closesly as possible.
- Count how many events fall into various signal regions.
number of expected and observed events
#events of different signal regions (summed over all input events)
Output
- For all signal regions...
... theoretical signal / experimental upper limit,
... CLs(signal, background, observed).
- State if input model is excluded or allowed.
results
Evaluation
- Find signal region with largest expected exclusion potential
- Compare expected signal to experimental observation



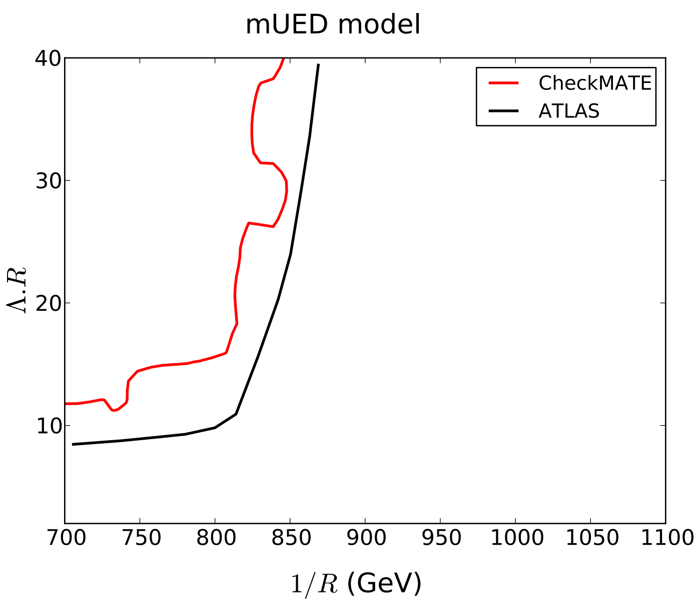
CheckMATE
ATLAS
Loose
Medium
Tight
Signal Efficiency
Pseudorapidity
Efficiency
p_T (GeV)
≥ 80
Fit
ATLAS (Muon Data)
ATLAS (Top Data)
Azimuthal Angle



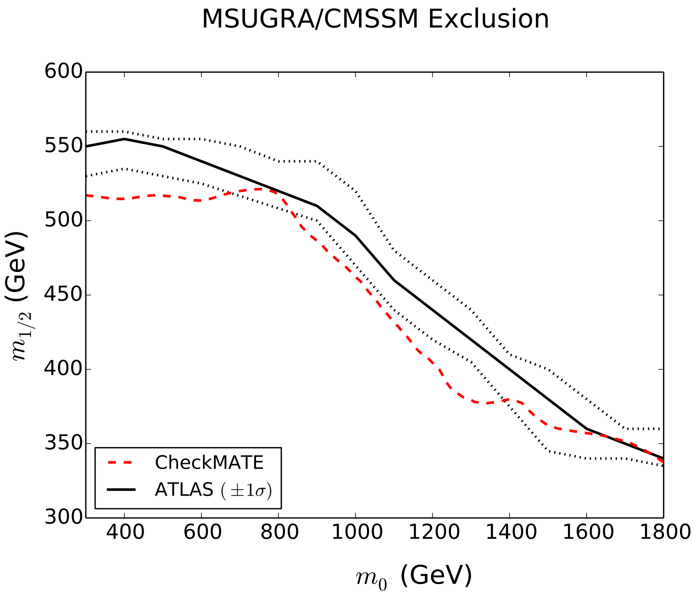
Events
CheckMATE
Delphes 3.0.10
ATLAS
800
700
600
500
400
300
200
100
0
−2
−1
0
1
2
$\eta_{e^+e^-}$ (GeV)



Squark Gluino Neutralino Model, $M_{\chi_1^0}=0$ GeV
Squark Mass (GeV)
Gluino Mass (GeV)
CheckMATE
ATLAS ($\pm 1\sigma$)
2800
2600
2400
2200
2000
1800
1600
1400
1200
1000
800
1000
1200
1400
1600
1800
2000
2200
2400



mUED model
CheckMATE
ATLAS
$\Lambda.R$
40
30
20
10
700
750
800
850
900
950
1000
1050
1100
$1/R$ (GeV)



MSUGRA/CMSSM Exclusion
$m_{1/2}$ (GeV)
CheckMATE
ATLAS ($\pm 1\sigma$)
600
550
500
450
400
350
300
400
600
800
1000
1200
1400
1600
1800
m_0 (GeV)

Setting limits

- Many searches provides O, B, uncertainty on B, upper limits on signal S95
- Directly compare S to 95% upper limit on signal S95
- Calculate the ratio r=S/S95. If r>1: Excluded!
- Choose signal region with strongest expected exclusion
- Use its observed result to state “excluded” or “allowed”
- Alternatively, calculate CL. If CL < 0.05: Excluded!

Numerical Results

General Results I

- We employ 12 searches with 159 SR
- We want to be conservative and claim that a model point is excluded (allowed) if *r*>1.5 (*r*<0.67) with r=S/S95

Reference	Final State	$\mathcal{L}$ [fb^{-1}]
1308.2631 (ATLAS) [51]	0ℓ+$2b$ jets+$\not{E}_T$	20.1
1403.4853 (ATLAS) [52]	2ℓ+$\not{E}_T$	20.3
1404.2500 (ATLAS) [54]	SS 2ℓ or 3ℓ	20.3
1407.0583 (ATLAS) [55]	1ℓ+(b) jets+$\not{E}_T$	20.0
1407.0608 (ATLAS) [56]	monojet+$\not{E}_T$	20.3
1303.2985 (CMS) [57]	α_T+b jets	11.7
ATLAS-CONF-2012-104 [58]	1ℓ+$\geq$ 4 jets+$\not{E}_T$	5.8
ATLAS-CONF-2013-024 [59]	0ℓ+6 ($2b$) jets+$\not{E}_T$	20.5
ATLAS-CONF-2013-047 [60]	0ℓ+2-6 jets+$\not{E}_T$	20.3
ATLAS-CONF-2013-061 [61]	0-1ℓ+$\geq$ $3b$ jets+$\not{E}_T$	20.1
ATLAS-CONF-2013-062 [62]	1-2ℓ+3-6 jets+$\not{E}_T$	20.0
CMS-SUS-13-016 [63]	OS 2ℓ+$\geq$$3b$ jets	19.7

General Results II

Experiment	Final State	Best Sensitivity				Excludes
		all	excluded	ambiguous	allowed	
ATLAS [61]	0-1ℓ+$\geq$ 3b jets+$\not{E}_T$	0.22	0.37	0.56	0.13	0.57
ATLAS [60]	0ℓ+2-6 jets+$\not{E}_T$	0.37	0.25	0.056	0.44	0.69
CMS [57]	α_T+b jets	0.088	0.11	0.14	0.075	0.66
ATLAS [59]	0ℓ+6 (2b) jets+$\not{E}_T$	0.044	0.12	0.041	0.016	0.58
ATLAS [55]	1ℓ+(b) jets+$\not{E}_T$	0.14	0.078	0.10	0.16	0.45
ATLAS [56]	monojet+$\not{E}_T$	0.013	0.042	0.018	0.002	0.23
ATLAS [51]	0ℓ+2b jets+$\not{E}_T$	0.10	0.019	0.085	0.13	0.051
ATLAS [62]	1-2ℓ+3-6 jets+$\not{E}_T$	0.024	0.002	0.001	0.034	0.50
ATLAS [54]	SS 2ℓ or 3ℓ	0.0	0.0	0.0	0.0	0.070
ATLAS [58]	1ℓ+$\geq$ 4 jets+$\not{E}_T$	0.0	0.0	0.0	0.0	0.12
CMS [63]	OS 2ℓ+$\geq$3b jets	0.0	0.0	0.0	0.0	0.043
ATLAS [52]	2ℓ+$\not{E}_T$	0.0	0.0	0.0	0.0	0.0

General Results III

Experiment	Final State	Best Sensitivity				Excludes
		all	excluded	ambiguous	allowed	
ATLAS [61]	0-1ℓ+$\geq$ 3b jets+$\not{E}_T$	0.22	0.37	0.56	0.13	0.57
ATLAS [60]	0ℓ+2-6 jets+$\not{E}_T$	0.37	0.25	0.056	0.44	0.69
CMS [57]	α_T+b jets	0.088	0.11	0.14	0.075	0.66
ATLAS [59]	0ℓ+6 (2b) jets+$\not{E}_T$	0.044	0.12	0.041	0.016	0.58
ATLAS [55]	1ℓ+(b) jets+$\not{E}_T$	0.14	0.078	0.10	0.16	0.45
ATLAS [56]	monojet+$\not{E}_T$	0.013	0.042	0.018	0.002	0.23
ATLAS [51]	0ℓ+2b jets+$\not{E}_T$	0.10	0.019	0.085	0.13	0.051
ATLAS [62]	1-2ℓ+3-6 jets+$\not{E}_T$	0.024	0.002	0.001	0.034	0.50
ATLAS [54]	SS 2ℓ or 3ℓ	0.0	0.0	0.0	0.0	0.070
ATLAS [58]	1ℓ+$\geq$ 4 jets+$\not{E}_T$	0.0	0.0	0.0	0.0	0.12
CMS [63]	OS 2ℓ+$\geq$3b jets	0.0	0.0	0.0	0.0	0.043
ATLAS [52]	2ℓ+$\not{E}_T$	0.0	0.0	0.0	0.0	0.0

General Results IV

Experiment	Final State	Best Sensitivity				Excludes
		all	excluded	ambiguous	allowed	
ATLAS [61]	0-1ℓ+$\geq$ 3b jets+$\not{E}_T$	0.22	0.37	0.56	0.13	0.57
ATLAS [60]	0ℓ+2-6 jets+$\not{E}_T$	0.37	0.25	0.056	0.44	0.69
CMS [57]	α_T+b jets	0.088	0.11	0.14	0.075	0.66
ATLAS [59]	0ℓ+6 (2b) jets+$\not{E}_T$	0.044	0.12	0.041	0.016	0.58
ATLAS [55]	1ℓ+(b) jets+$\not{E}_T$	0.14	0.078	0.10	0.16	0.45
ATLAS [56]	monojet+$\not{E}_T$	0.013	0.042	0.018	0.002	0.23
ATLAS [51]	0ℓ+2b jets+$\not{E}_T$	0.10	0.019	0.085	0.13	0.051
ATLAS [62]	1-2ℓ+3-6 jets+$\not{E}_T$	0.024	0.002	0.001	0.034	0.50
ATLAS [54]	SS 2ℓ or 3ℓ	0.0	0.0	0.0	0.0	0.070
ATLAS [58]	1ℓ+$\geq$ 4 jets+$\not{E}_T$	0.0	0.0	0.0	0.0	0.12
CMS [63]	OS 2ℓ+$\geq$3b jets	0.0	0.0	0.0	0.0	0.043
ATLAS [52]	2ℓ+$\not{E}_T$	0.0	0.0	0.0	0.0	0.0

General Results V

Experiment	Final State	Best Sensitivity				Excludes
		all	excluded	ambiguous	allowed	
ATLAS [61]	0-1ℓ+$\geq$ 3b jets+$\not{E}_T$	0.22	0.37	0.56	0.13	0.57
ATLAS [60]	0ℓ+2-6 jets+$\not{E}_T$	0.37	0.25	0.056	0.44	0.69
CMS [57]	α_T+b jets	0.088	0.11	0.14	0.075	0.66
ATLAS [59]	0ℓ+6 (2b) jets+$\not{E}_T$	0.044	0.12	0.041	0.016	0.58
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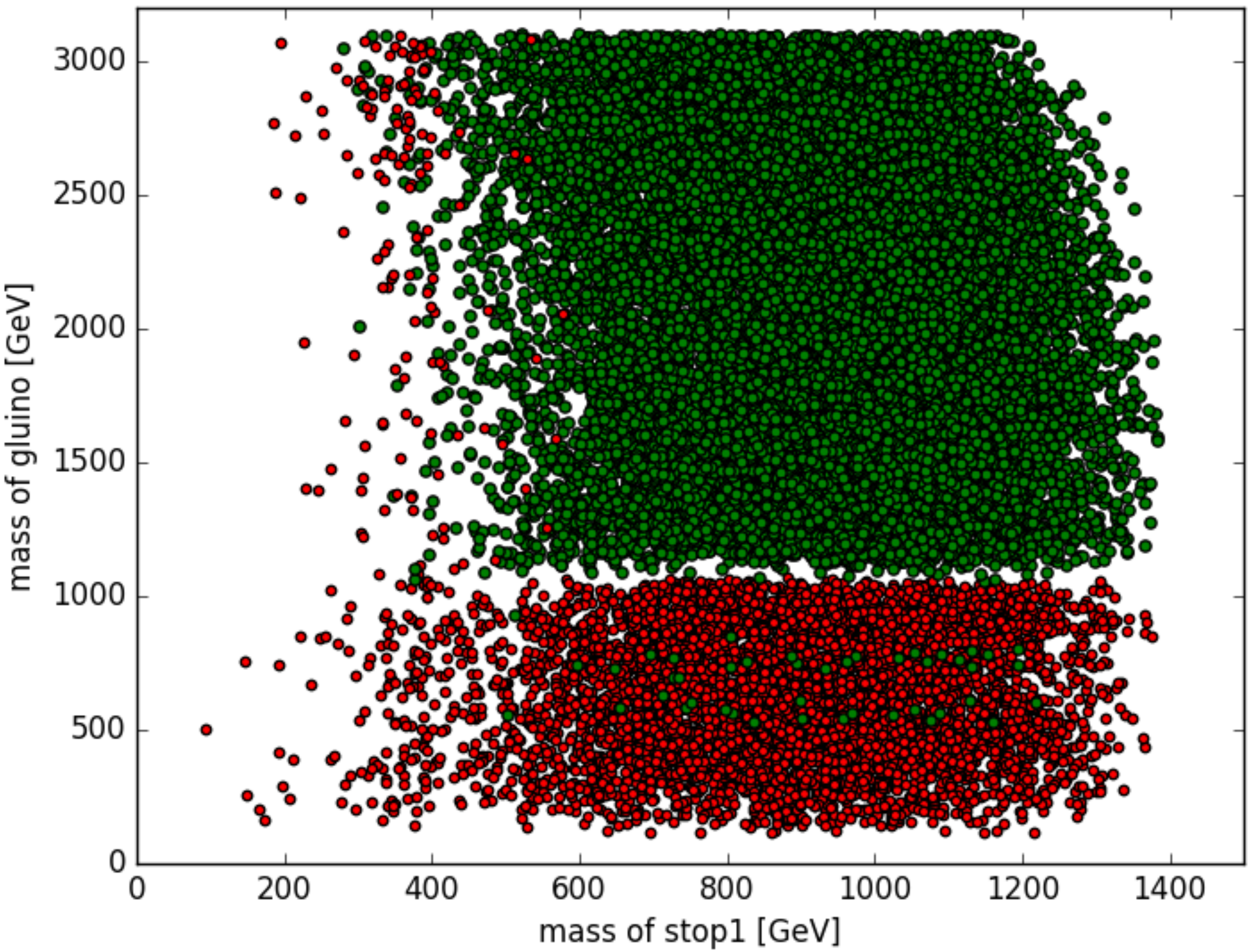
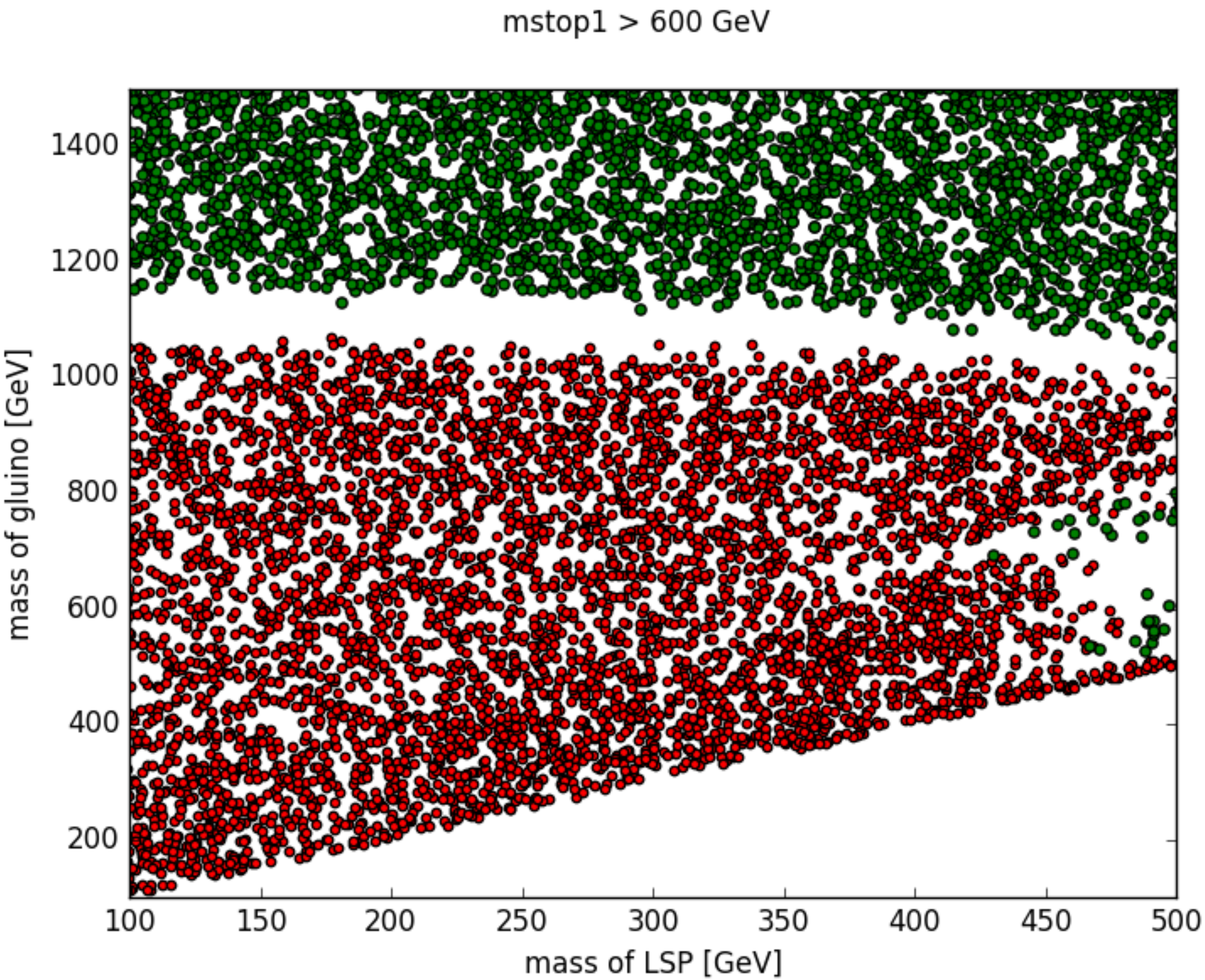
ATLAS [56]	monojet+$\not{E}_T$	0.013	0.042	0.018	0.002	0.23
ATLAS [51]	0ℓ+2b jets+$\not{E}_T$	0.10	0.019	0.085	0.13	0.051
ATLAS [62]	1-2ℓ+3-6 jets+$\not{E}_T$	0.024	0.002	0.001	0.034	0.50
ATLAS [54]	SS 2ℓ or 3ℓ	0.0	0.0	0.0	0.0	0.070
ATLAS [58]	1ℓ+$\geq$ 4 jets+$\not{E}_T$	0.0	0.0	0.0	0.0	0.12
CMS [63]	OS 2ℓ+$\geq$3b jets	0.0	0.0	0.0	0.0	0.043
ATLAS [52]	2ℓ+$\not{E}_T$	0.0	0.0	0.0	0.0	0.0

General Results VI

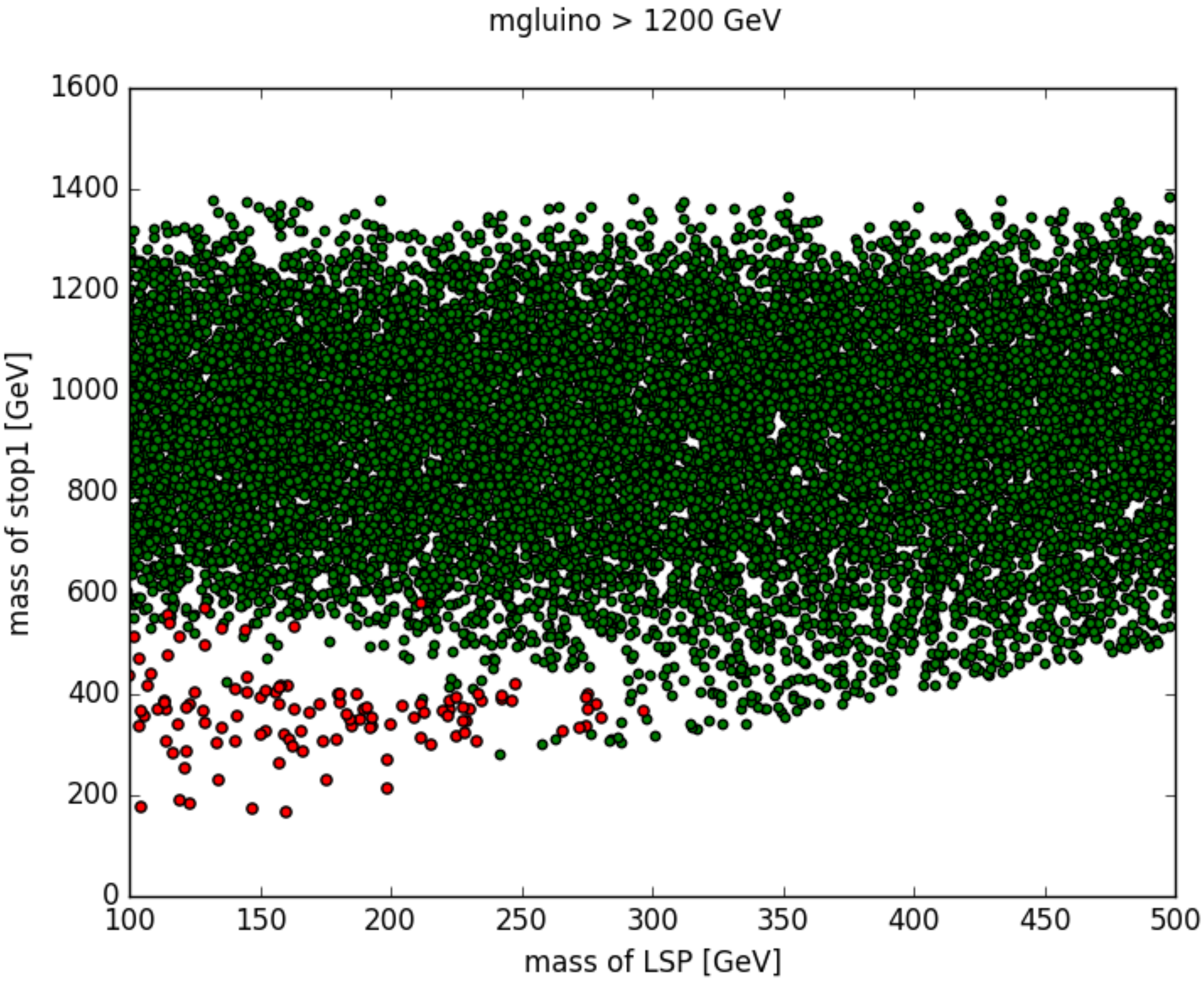
Experiment	Final State	Best Sensitivity				Excludes
		all	excluded	ambiguous	allowed	
ATLAS [61]	0-1ℓ+$\geq$ 3b jets+$\not{E}_T$	0.22	0.37	0.56	0.13	0.57
ATLAS [60]	0ℓ+2-6 jets+$\not{E}_T$	0.37	0.25	0.056	0.44	0.69
CMS [57]	α_T+b jets	0.088	0.11	0.14	0.075	0.66
ATLAS [59]	0ℓ+6 (2b) jets+$\not{E}_T$	0.044	0.12	0.041	0.016	0.58
ATLAS [55]	1ℓ+(b) jets+$\not{E}_T$	0.14	0.078	0.10	0.16	0.45
ATLAS [56]	monojet+$\not{E}_T$	0.013	0.042	0.018	0.002	0.23
ATLAS [51]	0ℓ+2b jets+$\not{E}_T$	0.10	0.019	0.085	0.13	0.051
ATLAS [62]	1-2ℓ+3-6 jets+$\not{E}_T$	0.024	0.002	0.001	0.034	0.50
ATLAS [54]	SS 2ℓ or 3ℓ	0.0	0.0	0.0	0.0	0.070
ATLAS [58]	1ℓ+$\geq$ 4 jets+$\not{E}_T$	0.0	0.0	0.0	0.0	0.12
CMS [63]	OS 2ℓ+$\geq$3b jets	0.0	0.0	0.0	0.0	0.043
ATLAS [52]	2ℓ+$\not{E}_T$	0.0	0.0	0.0	0.0	0.0



green (red) points are allowed (excluded)



gluinos up to ~1100 GeV can be excluded



stop masses up to 600 GeV can be excluded

Type	Boundaries
Allowed	$m_{\tilde{t}_1} > 660$ GeV and $m_{\tilde{g}} > 1180$ GeV $m_{\tilde{g}} > 1150$ GeV and $m_{\tilde{\chi}_1^0} > 370$ GeV
Not excluded	$m_{\tilde{t}_1} > 580$ GeV and $m_{\tilde{g}} > 1070$ GeV $m_{\tilde{g}} > 1060$ GeV and $m_{\tilde{\chi}_1^0} > 300$ GeV $m_{\tilde{t}_1} > 550$ GeV, $m_{\tilde{\chi}_1^0} > 470$ GeV and $m_{\tilde{g}} \in [600$ GeV, 760 GeV$]$
Excluded	$m_{\tilde{t}_1} < 230$ GeV or $m_{\tilde{g}} < 440$ GeV $m_{\tilde{g}} < 990$ GeV and $m_{\tilde{\chi}_1^0} < 340$ GeV $m_{\tilde{g}} < 1040$ GeV and $m_{\tilde{\chi}_1^0} < 200$ GeV $m_{\tilde{t}_1} < 300$ GeV and $m_{\tilde{\chi}_1^0} < 210$ GeV

Type	Boundaries
Allowed	$m_{\tilde{t}_1} > 660$ GeV and $m_{\tilde{g}} > 1180$ GeV $m_{\tilde{g}} > 1150$ GeV and $m_{\tilde{\chi}_1^0} > 370$ GeV
Not excluded	$m_{\tilde{t}_1} > 580$ GeV and $m_{\tilde{g}} > 1070$ GeV $m_{\tilde{g}} > 1060$ GeV and $m_{\tilde{\chi}_1^0} > 300$ GeV $m_{\tilde{t}_1} > 550$ GeV, $m_{\tilde{\chi}_1^0} > 470$ GeV and $m_{\tilde{g}} \in [600$ GeV, 760 GeV$]$
Excluded	$m_{\tilde{t}_1} < 230$ GeV or $m_{\tilde{g}} < 440$ GeV $m_{\tilde{g}} < 990$ GeV and $m_{\tilde{\chi}_1^0} < 340$ GeV $m_{\tilde{g}} < 1040$ GeV and $m_{\tilde{\chi}_1^0} < 200$ GeV $m_{\tilde{t}_1} < 300$ GeV and $m_{\tilde{\chi}_1^0} < 210$ GeV

Hidden scenarios

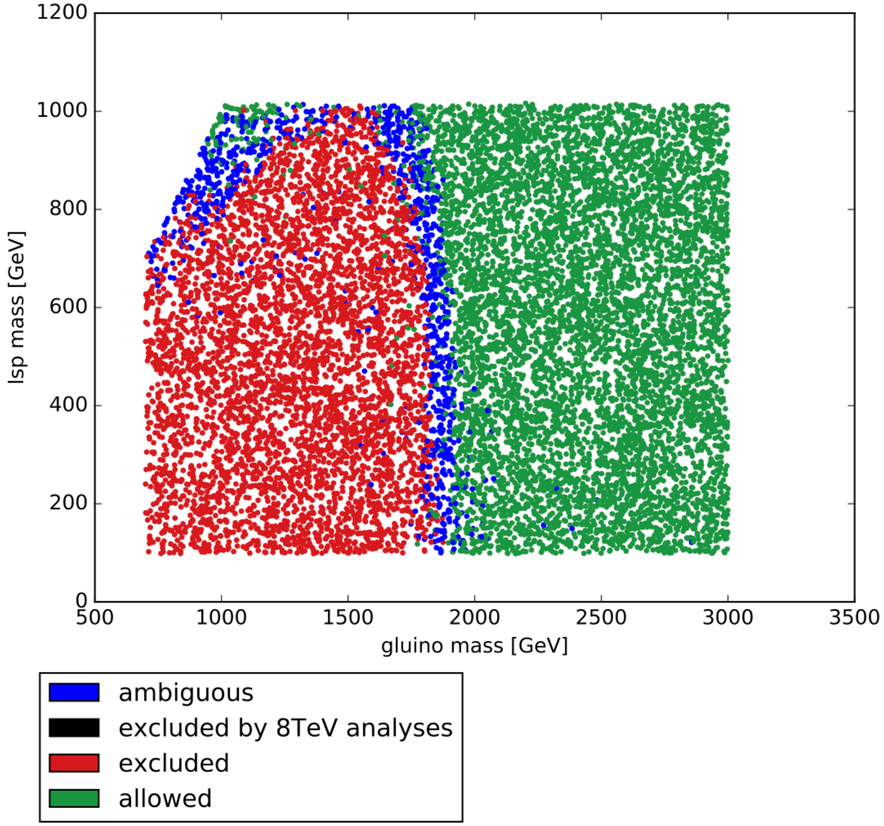
- The simplest (and most obvious) reason is a very small production cross section for heavy SUSY particles
- Compressed spectra where the mass difference between the gluino/third generation scalar and the LSP is very small
- Signal looks very similar to the top pair production process
- Is the stop1 dominantly SU(2) singlet or doublet?
- Asymmetric final states, e.g. one stop decays into top and the other to a b quark

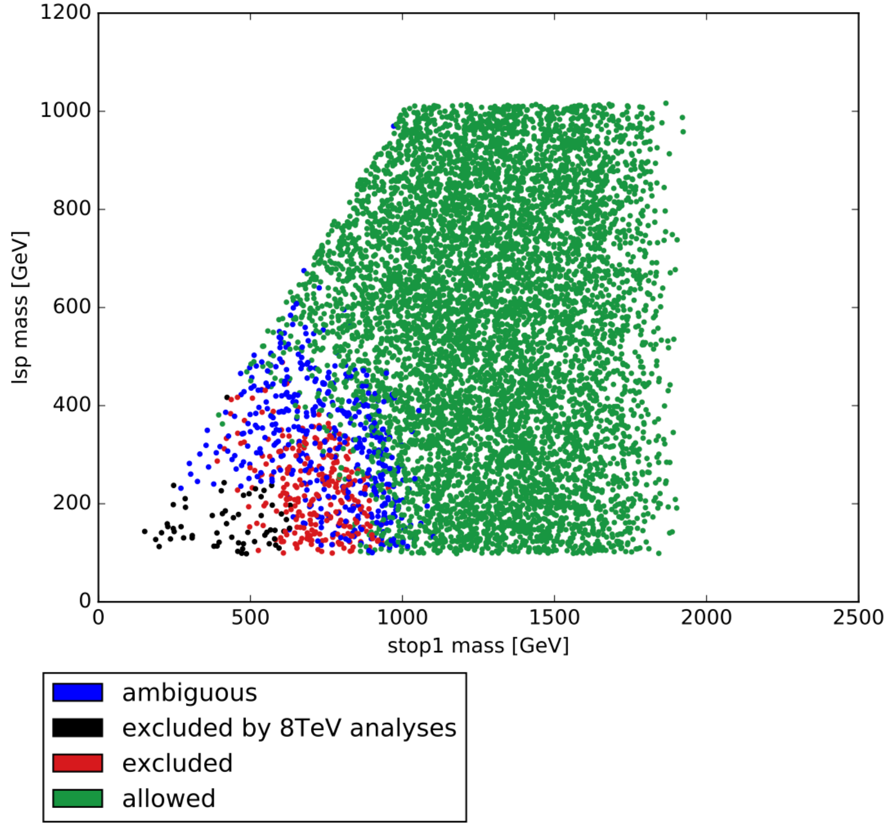
A glimpse at 14 TeV

- In collaboration with K. Rolbiecki, R. Ruiz, T. Weber and J. Tattersall
- we implemented official ATLAS high luminosity searches

Analysis	Description	ECM [TeV]	lumi [fb^-1]
atlas_conf_2015_067	≥3 bjets+MET	13	3.3
atlas_phys_2014_010_300	2-6 jets+MET	14	300
atlas_phys_2014_010_sq_hl	2-6 jets+MET	14	3000
atlas_phys_pub_2013_011	hadr. & lep. stop search	14	3000
atlas_phys_pub_2014_010_sbottom	2b-jets+MET	14	3000

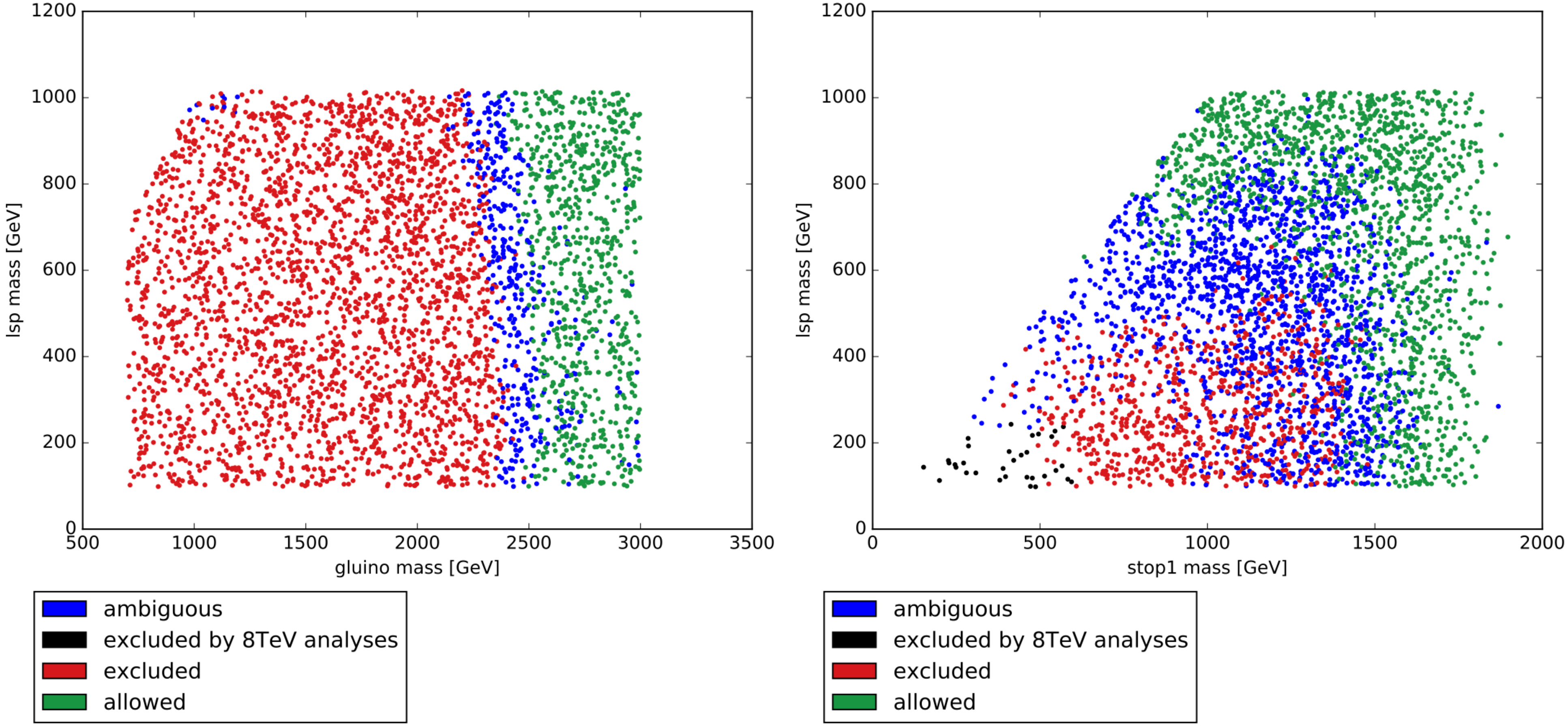
A glimpse at ~~14~~ 13 TeV





assuming 20 inverse fb

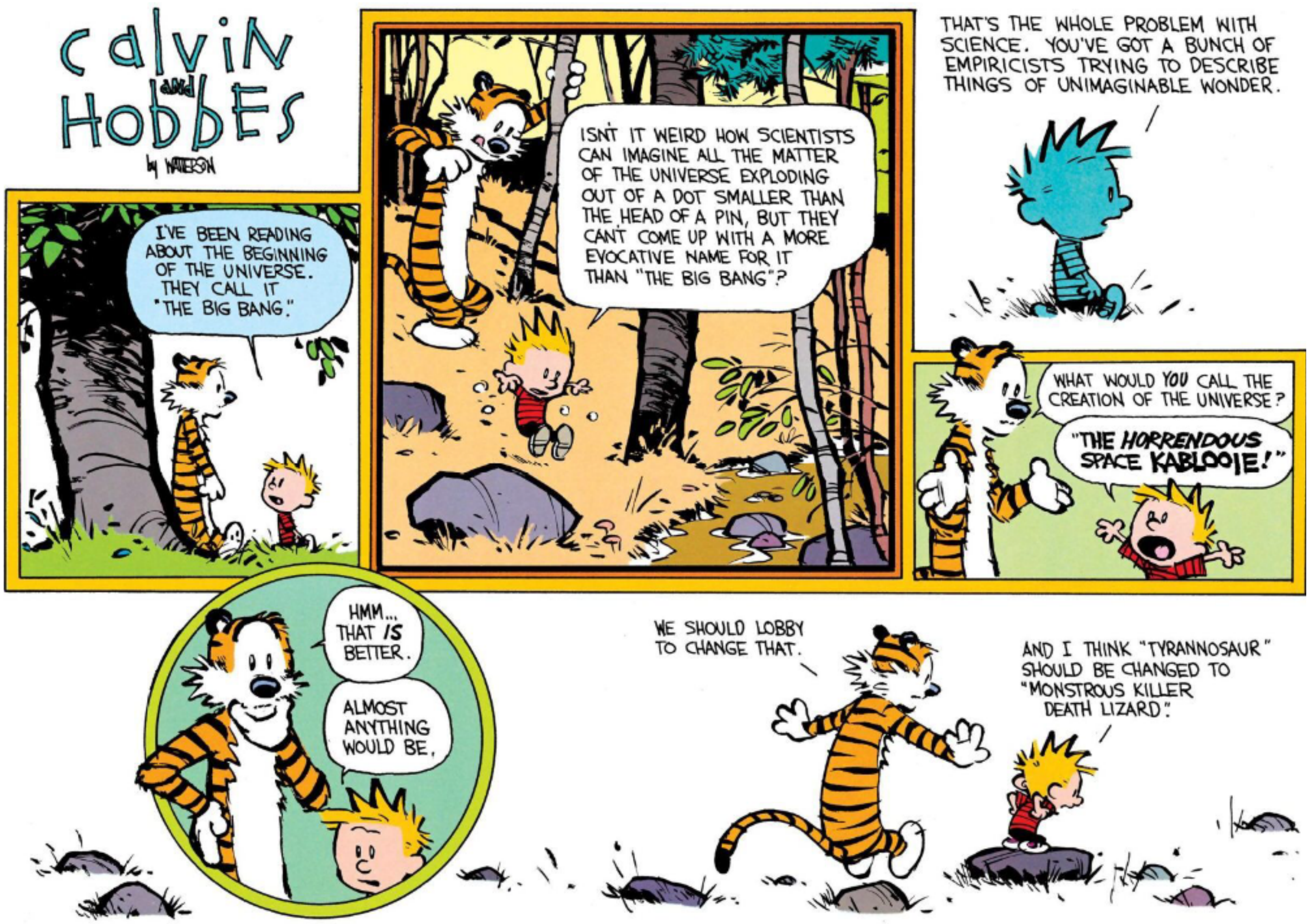
A glimpse at 14 TeV



assuming 3000 inverse fb

Summary

- Natural SUSY satisfies the direct LHC constraints and can still be a solution of the little hierarchy problem
- We have generated 22k model points
- We derived “universal” limits @8TeV: mstop<230 GeV & mlguino<440 GeV excluded
- We have performed a projection of the high luminosity phase (work in progress)


Calvin and Hobbes
by WATTERSON
I'VE BEEN READING ABOUT THE BEGINNING OF THE UNIVERSE. THEY CALL IT "THE BIG BANG."
ISN'T IT WEIRD HOW SCIENTISTS CAN IMAGINE ALL THE MATTER OF THE UNIVERSE EXPLODING OUT OF A DOT SMALLER THAN THE HEAD OF A PIN, BUT THEY CAN'T COME UP WITH A MORE EVOCATIVE NAME FOR IT THAN "THE BIG BANG"?
THAT'S THE WHOLE PROBLEM WITH SCIENCE. YOU'VE GOT A BUNCH OF EMPIRICISTS TRYING TO DESCRIBE THINGS OF UNIMAGINABLE WONDER.
WHAT WOULD *YOU* CALL THE CREATION OF THE UNIVERSE?
"THE *HORRENDOUS* SPACE **KABLOOIE!**"
HMM... THAT *IS* BETTER.
ALMOST ANYTHING WOULD BE.
WE SHOULD LOBBY TO CHANGE THAT.
AND I THINK "TYRANNOSAUR" SHOULD BE CHANGED TO "MONSTROUS KILLER DEATH LIZARD."