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Physics prospects for Susy / BSM

(Theory)

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Outline

- pp collisions: where we stand today
- guiding principles to go Beyond Standard Model
- SUSY : present status

  lastest fits on CMSSM and NUHM
- extending mono-jet and VBF potential

  to Natural Compressed scenarios
- Outlook

benefitted a lot from discussions with Giacomo Polesello and Tommaso Lari

pp collisions: where we stand today

- LHC run at 7-8 TeV completed [∫ L ~ 5 + 20 fb^{-1}/ exp]

  (just initial LHC phase !)

  amazing performance → results well above expectations...
- SM tested at high accuracy in a new √s range :
  QCD (many regimes), top physics, EW processes, flavor
- "direct" exploration of SM EWSB sector started up with observation of a (quite light) Higgs resonance !!!
- still a lot of room for a non-SM EWSB sector
- bounds on new heavy states predicted by many BSM models widely extended wrt pre-LHC era
- no real hint of BSM physics !
- SM Hierarchy-Problem solution getting harder...

guiding principles to go BSM

- SM not enough !
  beautifully successful at E < 1 TeV,
  but has some "messy features" (flavour sector...),
  and does not explain a number of things
  (strong CP, neutrino sector, baryogenesis, Dark Matter...)

- crucial issue for Collider Physics (and LHC !) :

what is the expected
Energy Threshold (E_{TH}) to go BSM ???

What is expected E_{TH} to go BSM ?

- given by requirement of Naturalness of EWSB scale !
  quadratic divergences on mass parameters of fundamental scalars drive Higgs mass to the next energy threshold E_{TH}
  (because of absence of symmetry protecting m_H in SM)
  ➜ to avoid Fine-Tuning of parameters, one expects roughly

$$E_{TH} \sim m_H / g_{coupling} \sim 1 \text{ TeV}$$

- this was (before LHC start-up), and still is (!),
  a ROBUST statement !!!

- WARNING : the way E_{TH} materializes (enters theory) depends on actual SM extension (nobody presently knows !)

how has LHC Run I affected this statement ?

how LHC Run I has affected the statement $E_{TH} \sim m_H / g_{coupling} \sim 1$ TeV

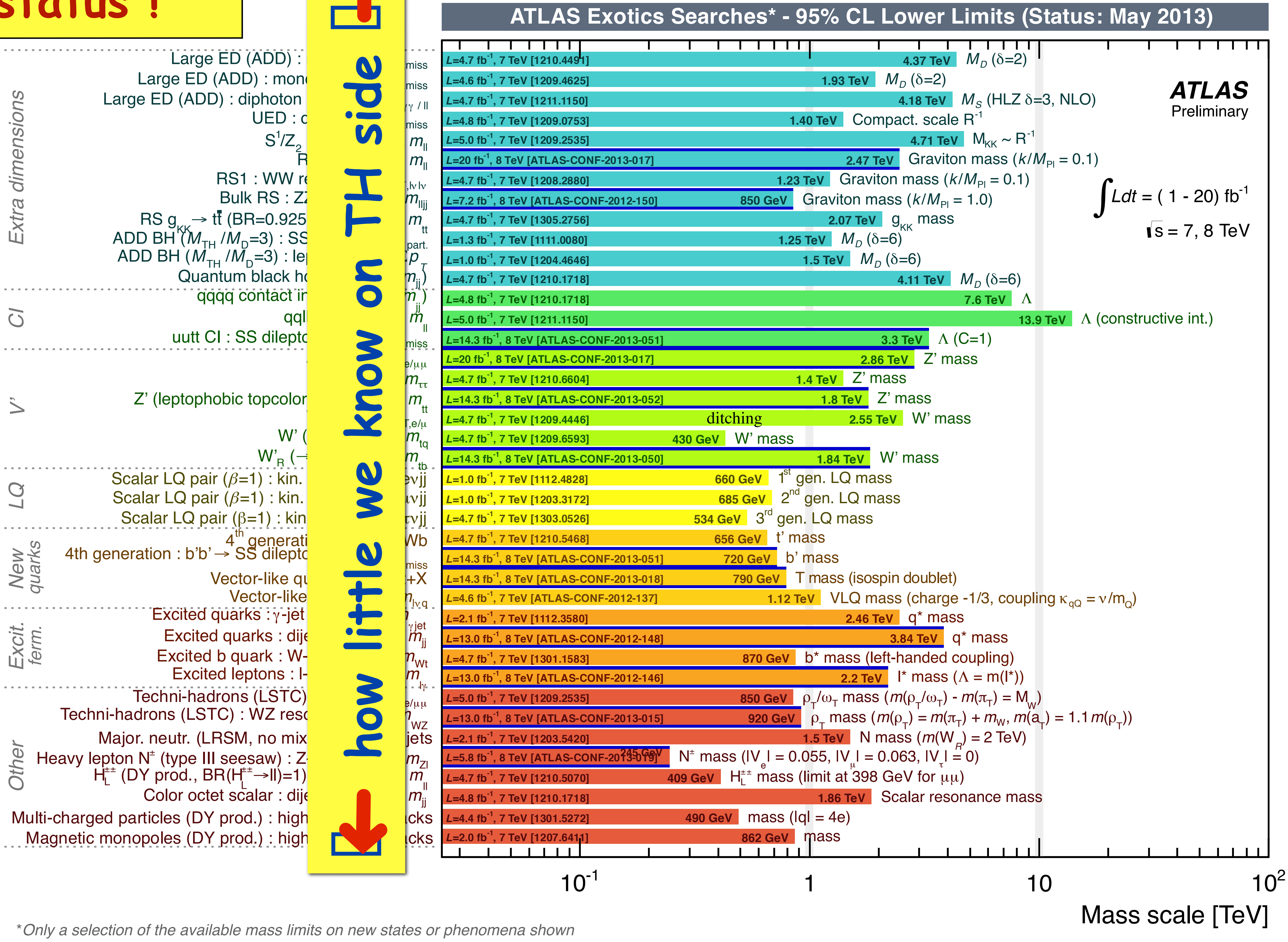
- in the last few decades a lot of theoretical speculations to build models satisfying this criterium
  (SuSy, Compositeness, Extra Dim.'s, Little Higgs, ...)
- in general good features are introduced at the expenses of quite a number of UNPREDICTED new parameters
- in PHENO studies at colliders, most emphasis given to SIMPLE versions of models (preserving basic features)
  (→ less free parameters)
- after LHC Run I, Simplest Versions of different models look quite Fine-Tuned !

theories must build up on experimental facts ....

BSM present status !

how much we learned on EXP side

how little we know on TH side



ATLAS Exotics Searches* - 95% CL Lower Limits (Status: May 2013)

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

today, SuSy is still the best candidate (among the ones we have thought of) to solve all problems connected to the TeV scale (and beyond !)

- predicts a light (fundamental) Higgs boson; radiat. EWSB
- stabilizes mass hierarchy;
- weakly coupled theory (coupl.s are known !) : allows accurate and consistent TH predictions even at scales >>TeV
  - can in principle be extended up to M_{GUT}, M_{Pl}, and support the desert hypothesis ➜ consistent with GUT
  - delicate impact on EWPT's and FCNC's (as needed by exp's)
- Dark Matter origin as a WIMP

actually.... two weak points in SuSy

- one on the exp side :

  no susy partner observed in > 30 years of searches;
  present LHC mass bounds on
  squarks and gluinos ~ 1-1,7 TeV (in CMSSM !)

- one on the theory side : →

makes implications
of previous issue
less dramatic !

vast arbitrariness in construction
of theoretical models for SuSy breaking
on which spectrum of SuSy partners
is crucially based !

a few robust constraints on mass spectrum :

- in order to stabilize SM mass hierarchy, (a few) SuSy-partner masses should be in the o(TeV) range

- (SuSy breaking) mass terms in SuSy Lagrangian should not spoil the good convergence properties of SuSy (➜soft)!

  ➜>100 new parameters in MSSM (cf. ~ 10 SM mass param's)

  - FCNC's imply squarks and sleptons with same quantum #'s be either almost degenerate in mass or almost diagonal in Yukawa matrices !

    ➜ constrains # of free parameters

- many SuSy-breaking models proposed with reduced # of parameters (CMSSM, SuGra, NUHM, GMSB, pMSSM....)

  (none meets all challenges !)

warning on “fashionable” SUSY models !

- simplicity (➔few parameters) not always a good guiding principle !

  [ex: simplicity in the SM would never lead to the observed fermion mass spectrum !]

- changing model (and # of parameter) in general affects pheno at LHC in a non-trivial way (different classes of signatures) !

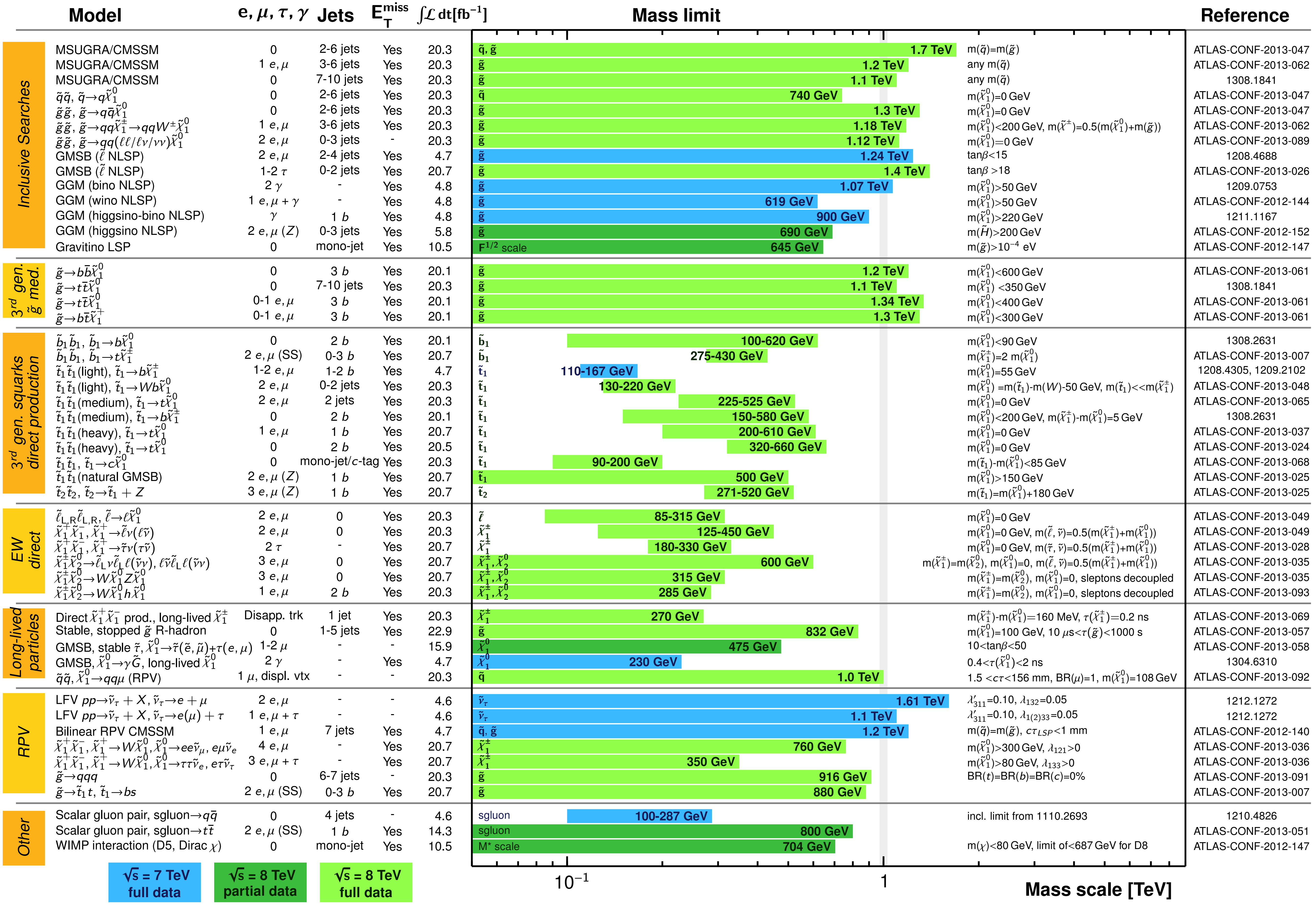
(nicely illustrated by the ATLAS SUSY Summary plot ➔)

ATLAS SUSY Searches* - 95% CL Lower Limits

Status: SUSY 2013

ATLAS Preliminary

$\int \mathcal{L} dt = (4.6 - 22.9)$ fb^{-1} $\sqrt{s}$ = 7, 8 TeV



	Model	e, μ, τ, γ	Jets	E_T^{miss}	$\int \mathcal{L} dt[fb^{-1}]$	Mass limit			Reference
Inclusive Searches	MSUGRA/CMSSM	0	2-6 jets	Yes	20.3	$\tilde{q}, \tilde{g}$	1.7 TeV	$m(\tilde{q})=m(\tilde{g})$	ATLAS-CONF-2013-047
	MSUGRA/CMSSM	1 e, μ	3-6 jets	Yes	20.3	$\tilde{g}$	1.2 TeV	any $m(\tilde{q})$	ATLAS-CONF-2013-062
	MSUGRA/CMSSM	0	7-10 jets	Yes	20.3	$\tilde{g}$	1.1 TeV	any $m(\tilde{q})$	1308.1841
	$\tilde{q}\tilde{q}, \tilde{q}\to q\tilde{\chi}_1^0$	0	2-6 jets	Yes	20.3	$\tilde{q}$	740 GeV	$m(\tilde{\chi}_1^0)=0$ GeV	ATLAS-CONF-2013-047
	$\tilde{g}\tilde{g}, \tilde{g}\to q\bar{q}\tilde{\chi}_1^0$	0	2-6 jets	Yes	20.3	$\tilde{g}$	1.3 TeV	$m(\tilde{\chi}_1^0)=0$ GeV	ATLAS-CONF-2013-047
	$\tilde{g}\tilde{g}, \tilde{g}\to qq\tilde{\chi}_1^\pm\to qqW^\pm\tilde{\chi}_1^0$	1 e, μ	3-6 jets	Yes	20.3	$\tilde{g}$	1.18 TeV	$m(\tilde{\chi}_1^0)<200$ GeV, $m(\tilde{\chi}^\pm)=0.5(m(\tilde{\chi}_1^0)+m(\tilde{g}))$	ATLAS-CONF-2013-062
	$\tilde{g}\tilde{g}, \tilde{g}\to qq(\ell\ell/\ell\nu/\nu\nu)\tilde{\chi}_1^0$	2 e, μ	0-3 jets	-	20.3	$\tilde{g}$	1.12 TeV	$m(\tilde{\chi}_1^0)=0$ GeV	ATLAS-CONF-2013-089
	GMSB ($\tilde{\ell}$ NLSP)	2 e, μ	2-4 jets	Yes	4.7	$\tilde{g}$	1.24 TeV	$\tan\beta<15$	1208.4688
	GMSB ($\tilde{\ell}$ NLSP)	1-2 τ	0-2 jets	Yes	20.7	$\tilde{g}$	1.4 TeV	$\tan\beta>18$	ATLAS-CONF-2013-026
	GGM (bino NLSP)	2 γ	-	Yes	4.8	$\tilde{g}$	1.07 TeV	$m(\tilde{\chi}_1^0)>50$ GeV	1209.0753
	GGM (wino NLSP)	1 $e, \mu + \gamma$	-	Yes	4.8	$\tilde{g}$	619 GeV	$m(\tilde{\chi}_1^0)>50$ GeV	ATLAS-CONF-2012-144
	GGM (higgsino-bino NLSP)	γ	1 b	Yes	4.8	$\tilde{g}$	900 GeV	$m(\tilde{\chi}_1^0)>220$ GeV	1211.1167
	GGM (higgsino NLSP)	2 e, μ (Z)	0-3 jets	Yes	5.8	$\tilde{g}$	690 GeV	$m(\tilde{H})>200$ GeV	ATLAS-CONF-2012-152
	Gravitino LSP	0	mono-jet	Yes	10.5	$F^{1/2}$ scale	645 GeV	$m(\tilde{g})>10^{-4}$ eV	ATLAS-CONF-2012-147
3^{rd} gen. $\tilde{g}$ med.	$\tilde{g}\to b\bar{b}\tilde{\chi}_1^0$	0	3 b	Yes	20.1	$\tilde{g}$	1.2 TeV	$m(\tilde{\chi}_1^0)<600$ GeV	ATLAS-CONF-2013-061
	$\tilde{g}\to t\bar{t}\tilde{\chi}_1^0$	0	7-10 jets	Yes	20.3	$\tilde{g}$	1.1 TeV	$m(\tilde{\chi}_1^0) <350$ GeV	1308.1841
	$\tilde{g}\to t\bar{t}\tilde{\chi}_1^0$	0-1 e, μ	3 b	Yes	20.1	$\tilde{g}$	1.34 TeV	$m(\tilde{\chi}_1^0)<400$ GeV	ATLAS-CONF-2013-061
	$\tilde{g}\to b\bar{t}\tilde{\chi}_1^+$	0-1 e, μ	3 b	Yes	20.1	$\tilde{g}$	1.3 TeV	$m(\tilde{\chi}_1^0)<300$ GeV	ATLAS-CONF-2013-061
3^{rd} gen. squarks direct production	$\tilde{b}_1\tilde{b}_1, \tilde{b}_1\to b\tilde{\chi}_1^0$	0	2 b	Yes	20.1	$\tilde{b}_1$	100-620 GeV	$m(\tilde{\chi}_1^0)<90$ GeV	1308.2631
	$\tilde{b}_1\tilde{b}_1, \tilde{b}_1\to t\tilde{\chi}_1^\pm$	2 e, μ (SS)	0-3 b	Yes	20.7	$\tilde{b}_1$	275-430 GeV	$m(\tilde{\chi}_1^\pm)=2\ m(\tilde{\chi}_1^0)$	ATLAS-CONF-2013-007
	$\tilde{t}_1\tilde{t}_1$(light), $\tilde{t}_1\to b\tilde{\chi}_1^\pm$	1-2 e, μ	1-2 b	Yes	4.7	$\tilde{t}_1$	110-167 GeV	$m(\tilde{\chi}_1^0)=55$ GeV	1208.4305, 1209.2102
	$\tilde{t}_1\tilde{t}_1$(light), $\tilde{t}_1\to Wb\tilde{\chi}_1^0$	2 e, μ	0-2 jets	Yes	20.3	$\tilde{t}_1$	130-220 GeV	$m(\tilde{\chi}_1^0) =m(\tilde{t}_1)$-$m(W)$-50 GeV, $m(\tilde{t}_1)<<m(\tilde{\chi}_1^\pm)$	ATLAS-CONF-2013-048
	$\tilde{t}_1\tilde{t}_1$(medium), $\tilde{t}_1\to t\tilde{\chi}_1^0$	2 e, μ	2 jets	Yes	20.3	$\tilde{t}_1$	225-525 GeV	$m(\tilde{\chi}_1^0)=0$ GeV	ATLAS-CONF-2013-065
	$\tilde{t}_1\tilde{t}_1$(medium), $\tilde{t}_1\to b\tilde{\chi}_1^\pm$	0	2 b	Yes	20.1	$\tilde{t}_1$	150-580 GeV	$m(\tilde{\chi}_1^0)<200$ GeV, $m(\tilde{\chi}_1^\pm)$-$m(\tilde{\chi}_1^0)=5$ GeV	1308.2631
	$\tilde{t}_1\tilde{t}_1$(heavy), $\tilde{t}_1\to t\tilde{\chi}_1^0$	1 e, μ	1 b	Yes	20.7	$\tilde{t}_1$	200-610 GeV	$m(\tilde{\chi}_1^0)=0$ GeV	ATLAS-CONF-2013-037
	$\tilde{t}_1\tilde{t}_1$(heavy), $\tilde{t}_1\to t\tilde{\chi}_1^0$	0	2 b	Yes	20.5	$\tilde{t}_1$	320-660 GeV	$m(\tilde{\chi}_1^0)=0$ GeV	ATLAS-CONF-2013-024
	$\tilde{t}_1\tilde{t}_1, \tilde{t}_1\to c\tilde{\chi}_1^0$	0	mono-jet/c-tag	Yes	20.3	$\tilde{t}_1$	90-200 GeV	$m(\tilde{t}_1)$-$m(\tilde{\chi}_1^0)<85$ GeV	ATLAS-CONF-2013-068
	$\tilde{t}_1\tilde{t}_1$(natural GMSB)	2 e, μ (Z)	1 b	Yes	20.7	$\tilde{t}_1$	500 GeV	$m(\tilde{\chi}_1^0)>150$ GeV	ATLAS-CONF-2013-025
	$\tilde{t}_2\tilde{t}_2, \tilde{t}_2\to\tilde{t}_1 + Z$	3 e, μ (Z)	1 b	Yes	20.7	$\tilde{t}_2$	271-520 GeV	$m(\tilde{t}_1)=m(\tilde{\chi}_1^0)+180$ GeV	ATLAS-CONF-2013-025
EW direct	$\tilde{\ell}_{L,R}\tilde{\ell}_{L,R}, \tilde{\ell}\to\ell\tilde{\chi}_1^0$	2 e, μ	0	Yes	20.3	$\tilde{\ell}$	85-315 GeV	$m(\tilde{\chi}_1^0)=0$ GeV	ATLAS-CONF-2013-049
	$\tilde{\chi}_1^+\tilde{\chi}_1^-, \tilde{\chi}_1^+\to\tilde{\ell}\nu(\ell\tilde{\nu})$	2 e, μ	0	Yes	20.3	$\tilde{\chi}_1^\pm$	125-450 GeV	$m(\tilde{\chi}_1^0)=0$ GeV, $m(\tilde{\ell}, \tilde{\nu})=0.5(m(\tilde{\chi}_1^\pm)+m(\tilde{\chi}_1^0))$	ATLAS-CONF-2013-049
	$\tilde{\chi}_1^+\tilde{\chi}_1^-, \tilde{\chi}_1^+\to\tilde{\tau}\nu(\tau\tilde{\nu})$	2 τ	-	Yes	20.7	$\tilde{\chi}_1^\pm$	180-330 GeV	$m(\tilde{\chi}_1^0)=0$ GeV, $m(\tilde{\tau}, \tilde{\nu})=0.5(m(\tilde{\chi}_1^\pm)+m(\tilde{\chi}_1^0))$	ATLAS-CONF-2013-028
	$\tilde{\chi}_1^\pm\tilde{\chi}_2^0\to\tilde{\ell}_L\nu\tilde{\ell}_L\ell(\tilde{\nu}\nu), \ell\tilde{\nu}\tilde{\ell}_L\ell(\tilde{\nu}\nu)$	3 e, μ	0	Yes	20.7	$\tilde{\chi}_1^\pm, \tilde{\chi}_2^0$	600 GeV	$m(\tilde{\chi}_1^\pm)=m(\tilde{\chi}_2^0)$, $m(\tilde{\chi}_1^0)=0$, $m(\tilde{\ell}, \tilde{\nu})=0.5(m(\tilde{\chi}_1^\pm)+m(\tilde{\chi}_1^0))$	ATLAS-CONF-2013-035
	$\tilde{\chi}_1^\pm\tilde{\chi}_2^0\to W\tilde{\chi}_1^0 Z\tilde{\chi}_1^0$	3 e, μ	0	Yes	20.7	$\tilde{\chi}_1^\pm, \tilde{\chi}_2^0$	315 GeV	$m(\tilde{\chi}_1^\pm)=m(\tilde{\chi}_2^0)$, $m(\tilde{\chi}_1^0)=0$, sleptons decoupled	ATLAS-CONF-2013-035
	$\tilde{\chi}_1^\pm\tilde{\chi}_2^0\to W\tilde{\chi}_1^0 h\tilde{\chi}_1^0$	1 e, μ	2 b	Yes	20.3	$\tilde{\chi}_1^\pm, \tilde{\chi}_2^0$	285 GeV	$m(\tilde{\chi}_1^\pm)=m(\tilde{\chi}_2^0)$, $m(\tilde{\chi}_1^0)=0$, sleptons decoupled	ATLAS-CONF-2013-093
Long-lived particles	Direct $\tilde{\chi}_1^+\tilde{\chi}_1^-$ prod., long-lived $\tilde{\chi}_1^\pm$	Disapp. trk	1 jet	Yes	20.3	$\tilde{\chi}_1^\pm$	270 GeV	$m(\tilde{\chi}_1^\pm)$-$m(\tilde{\chi}_1^0)=160$ MeV, $\tau(\tilde{\chi}_1^\pm)=0.2$ ns	ATLAS-CONF-2013-069
	Stable, stopped $\tilde{g}$ R-hadron	0	1-5 jets	Yes	22.9	$\tilde{g}$	832 GeV	$m(\tilde{\chi}_1^0)=100$ GeV, 10 μs$<\tau(\tilde{g})<1000$ s	ATLAS-CONF-2013-057
	GMSB, stable $\tilde{\tau}, \tilde{\chi}_1^0\to\tilde{\tau}(\tilde{e}, \tilde{\mu})+\tau(e, \mu)$	1-2 μ	-	-	15.9	$\tilde{\chi}_1^0$	475 GeV	$10<\tan\beta<50$	ATLAS-CONF-2013-058
	GMSB, $\tilde{\chi}_1^0\to\gamma\tilde{G}$, long-lived $\tilde{\chi}_1^0$	2 γ	-	Yes	4.7	$\tilde{\chi}_1^0$	230 GeV	$0.4<\tau(\tilde{\chi}_1^0)<2$ ns	1304.6310
	$\tilde{q}\tilde{q}, \tilde{\chi}_1^0\to qq\mu$ (RPV)	1 μ, displ. vtx	-	-	20.3	$\tilde{q}$	1.0 TeV	$1.5 <c\tau<156$ mm, BR(μ)=1, $m(\tilde{\chi}_1^0)=108$ GeV	ATLAS-CONF-2013-092
RPV	LFV $pp\to\tilde{\nu}_\tau + X, \tilde{\nu}_\tau\to e + \mu$	2 e, μ	-	-	4.6	$\tilde{\nu}_\tau$	1.61 TeV	$\lambda'_{311}=0.10$, $\lambda_{132}=0.05$	1212.1272
	LFV $pp\to\tilde{\nu}_\tau + X, \tilde{\nu}_\tau\to e(\mu) + \tau$	1 $e, \mu + \tau$	-	-	4.6	$\tilde{\nu}_\tau$	1.1 TeV	$\lambda'_{311}=0.10$, $\lambda_{1(2)33}=0.05$	1212.1272
	Bilinear RPV CMSSM	1 e, μ	7 jets	Yes	4.7	$\tilde{q}, \tilde{g}$	1.2 TeV	$m(\tilde{q})=m(\tilde{g})$, $c\tau_{LSP}<1$ mm	ATLAS-CONF-2012-140
	$\tilde{\chi}_1^+\tilde{\chi}_1^-, \tilde{\chi}_1^+\to W\tilde{\chi}_1^0, \tilde{\chi}_1^0\to ee\tilde{\nu}_\mu, e\mu\tilde{\nu}_e$	4 e, μ	-	Yes	20.7	$\tilde{\chi}_1^\pm$	760 GeV	$m(\tilde{\chi}_1^0)>300$ GeV, $\lambda_{121}>0$	ATLAS-CONF-2013-036
	$\tilde{\chi}_1^+\tilde{\chi}_1^-, \tilde{\chi}_1^+\to W\tilde{\chi}_1^0, \tilde{\chi}_1^0\to\tau\tau\tilde{\nu}_e, e\tau\tilde{\nu}_\tau$	3 $e, \mu + \tau$	-	Yes	20.7	$\tilde{\chi}_1^\pm$	350 GeV	$m(\tilde{\chi}_1^0)>80$ GeV, $\lambda_{133}>0$	ATLAS-CONF-2013-036
	$\tilde{g}\to qqq$	0	6-7 jets	-	20.3	$\tilde{g}$	916 GeV	BR(t)=BR(b)=BR(c)=0%	ATLAS-CONF-2013-091
	$\tilde{g}\to\tilde{t}_1 t, \tilde{t}_1\to bs$	2 e, μ (SS)	0-3 b	Yes	20.7	$\tilde{g}$	880 GeV		ATLAS-CONF-2013-007
Other	Scalar gluon pair, sgluon$\to q\bar{q}$	0	4 jets	-	4.6	sgluon	100-287 GeV	incl. limit from 1110.2693	1210.4826
	Scalar gluon pair, sgluon$\to t\bar{t}$	2 e, μ (SS)	1 b	Yes	14.3	sgluon	800 GeV		ATLAS-CONF-2013-051
	WIMP interaction (D5, Dirac χ)	0	mono-jet	Yes	10.5	M* scale	704 GeV	$m(\chi)<80$ GeV, limit of<687 GeV for D8	ATLAS-CONF-2012-147

$\sqrt{s}$ = 7 TeV full data **$\sqrt{s}$ = 8 TeV partial data** **$\sqrt{s}$ = 8 TeV full data**

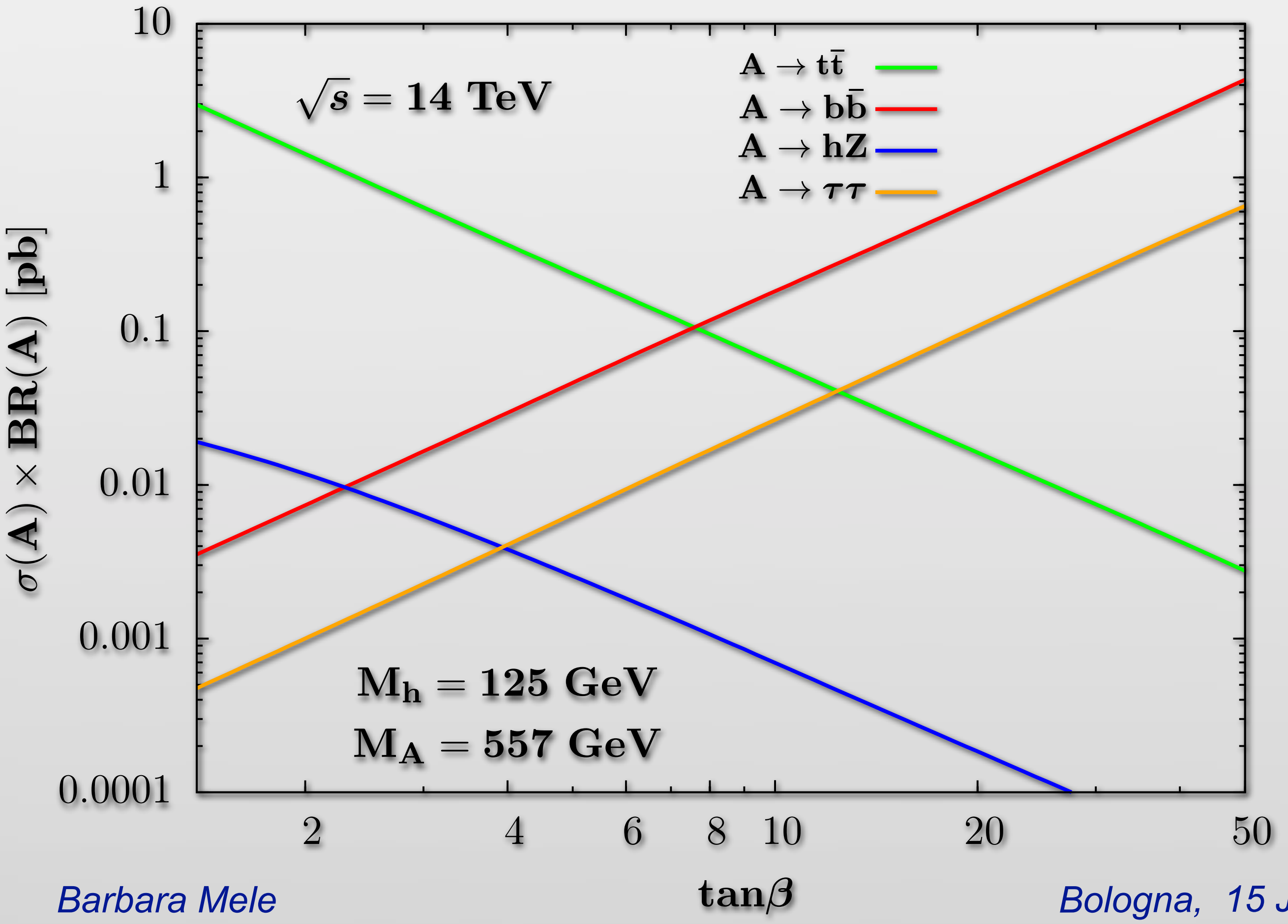
**Only a selection of the available mass limits on new states or phenomena is shown. All limits quoted are observed minus 1σ theoretical signal cross section uncertainty.*

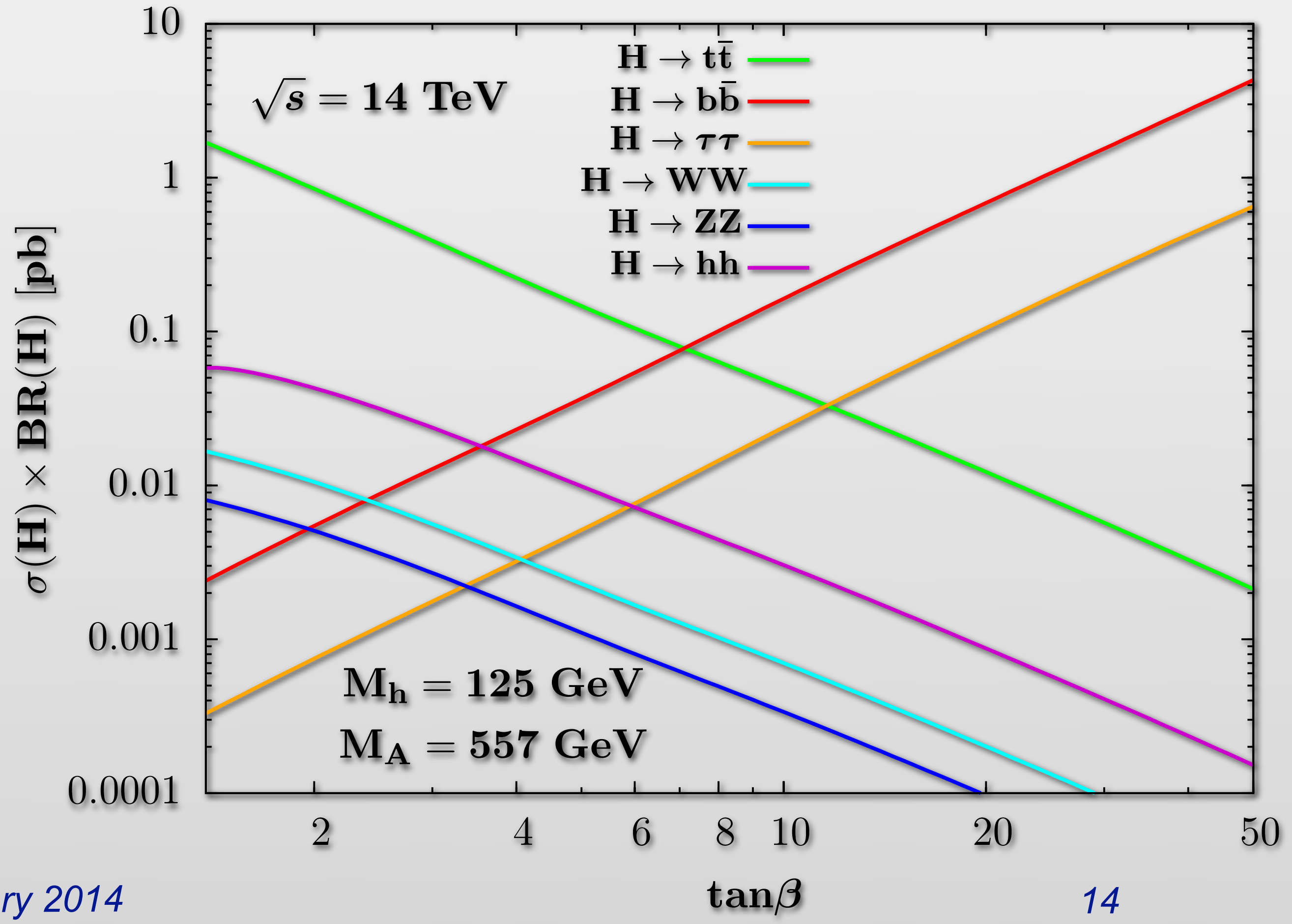
Susy predicts extended Higgs sector !

- 2 Higgs doublets in MSSM ➜ 5 physical fields
  h, H, A, H^+,H^-
- best fit for m_h~125 GeV and measured h signal strengths :
  M_H ~ 580 GeV, M_A~M_{H+}~ 560 GeV, tanβ~1

Djouadi et al, arxiv:1307.5205

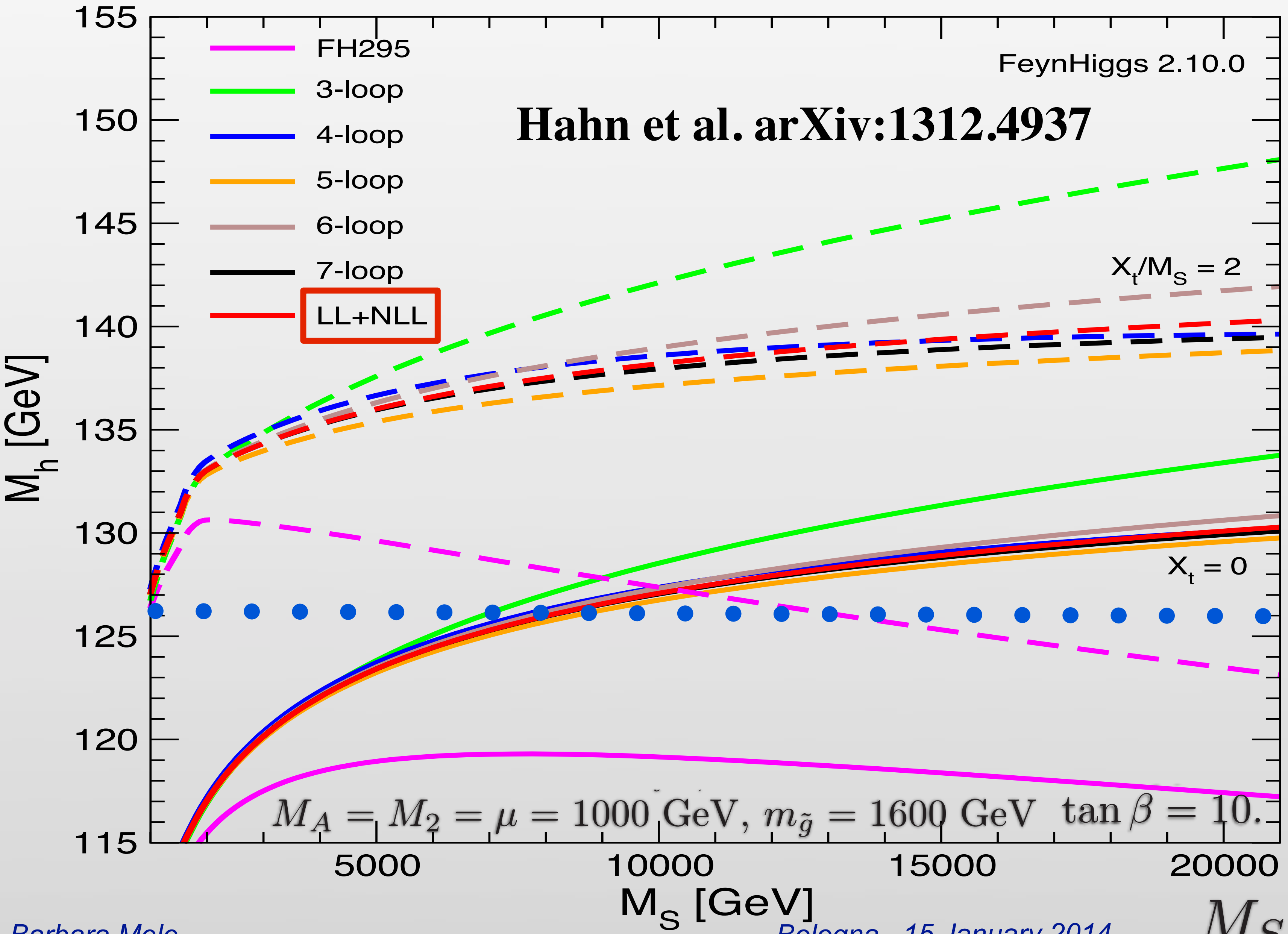
- gg,bb ➜ A,H ➜ t t could be accessible in next run !





news on Susy Higgs-mass calculators

- new version of FeynHiggs (2.10.0) including resummation of LL and NLL in log(m_{stop}/m_{top}) through 2-loop RGEs
- achieves higher accuracy at large m_{stop}



$\Delta M_h \sim + 2$ (5) GeV at $m_{stop} \sim 2$ (5) TeV !

FeynHiggs 2.10.0

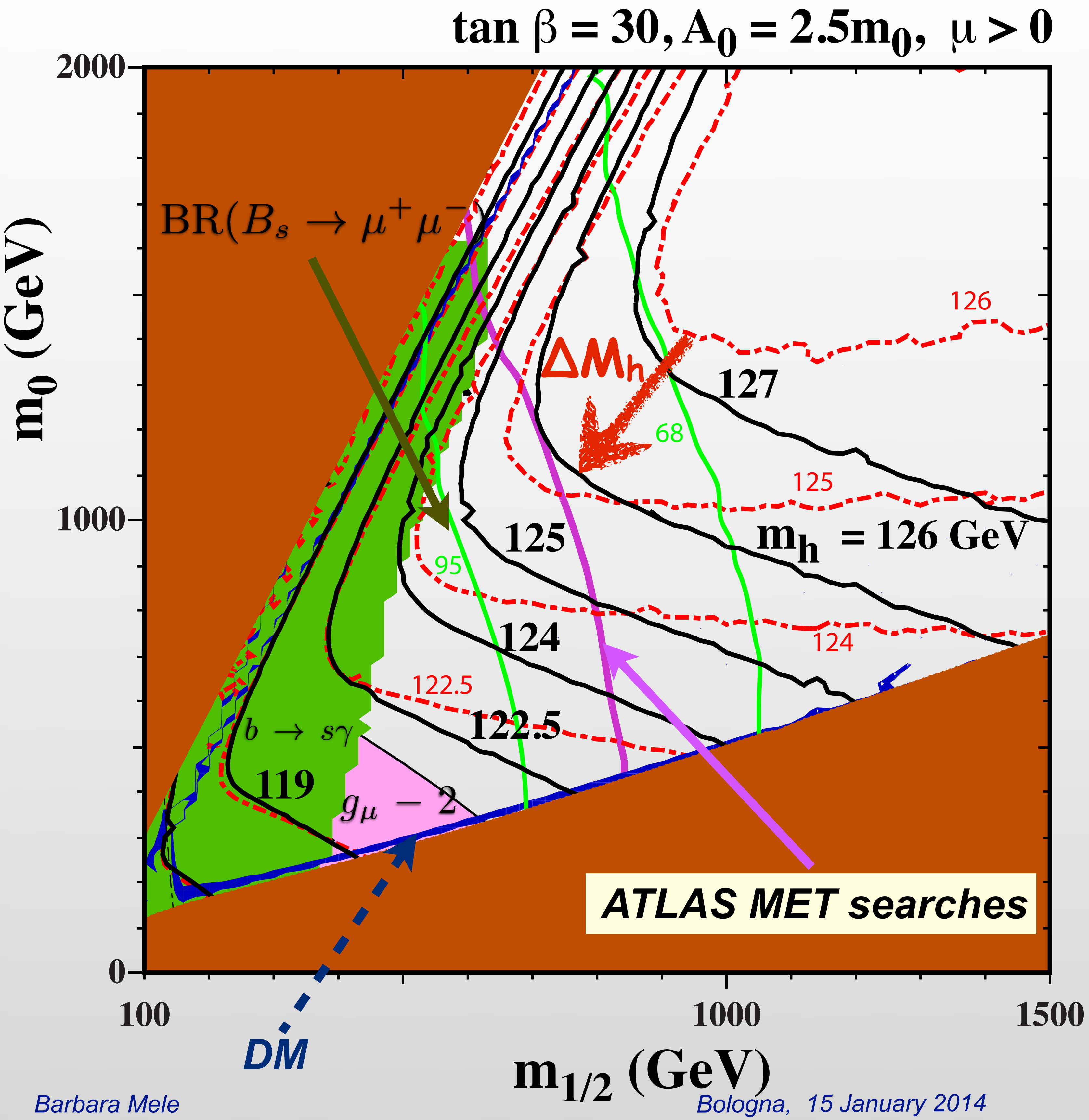
M_h(max) ➔ m_{stop}(max)

fixed order up to 2-loops

$$M_S \equiv \sqrt{m_{\tilde t_1} m_{\tilde t_2}}$$

upward shift in M_h relaxes constraints on CMSSM (and NUHM1)

Buchmueller et al. arXiv:1312.5233



improved consistency with all constraints !

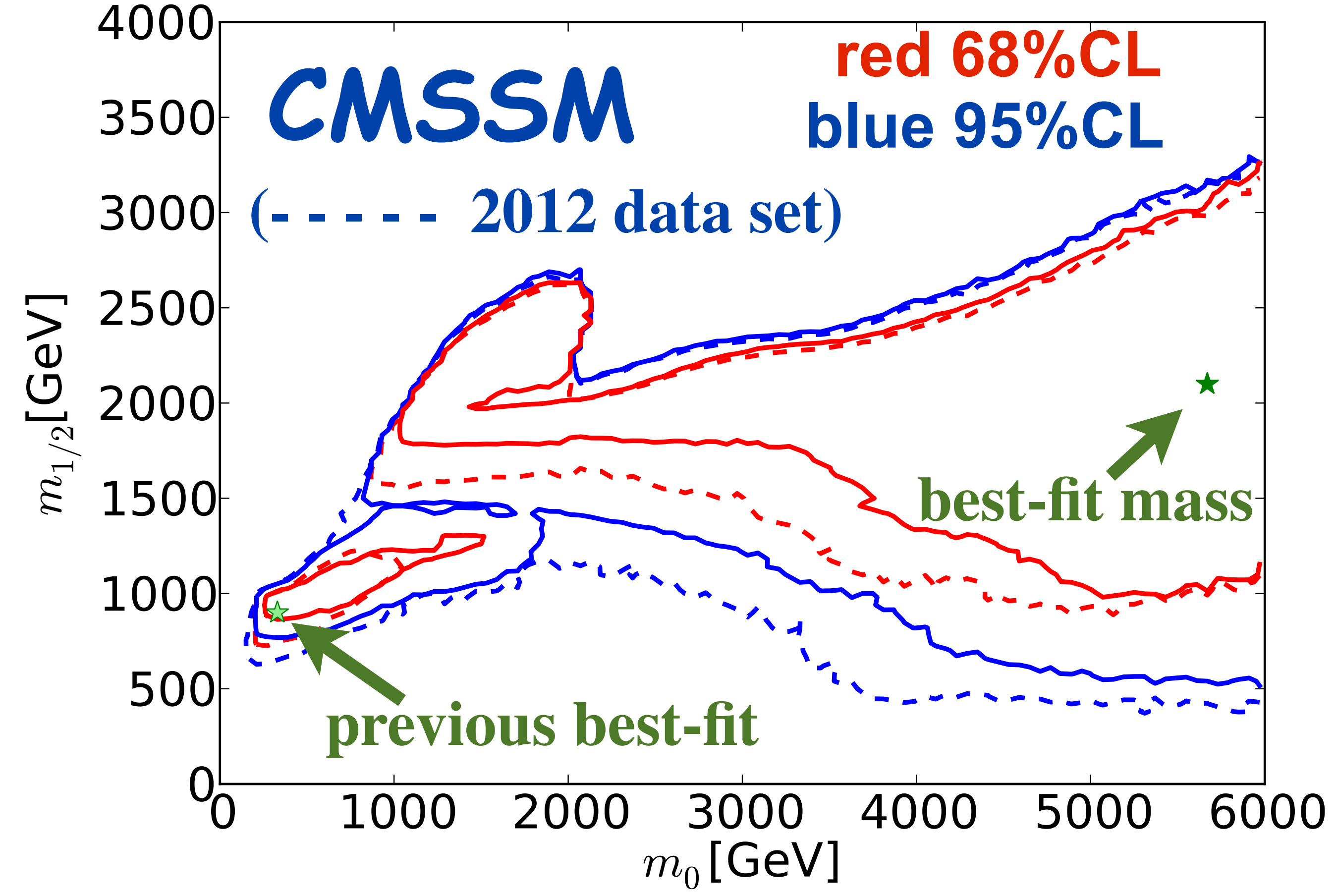
large M_h contour differences at high $m_{1/2}$

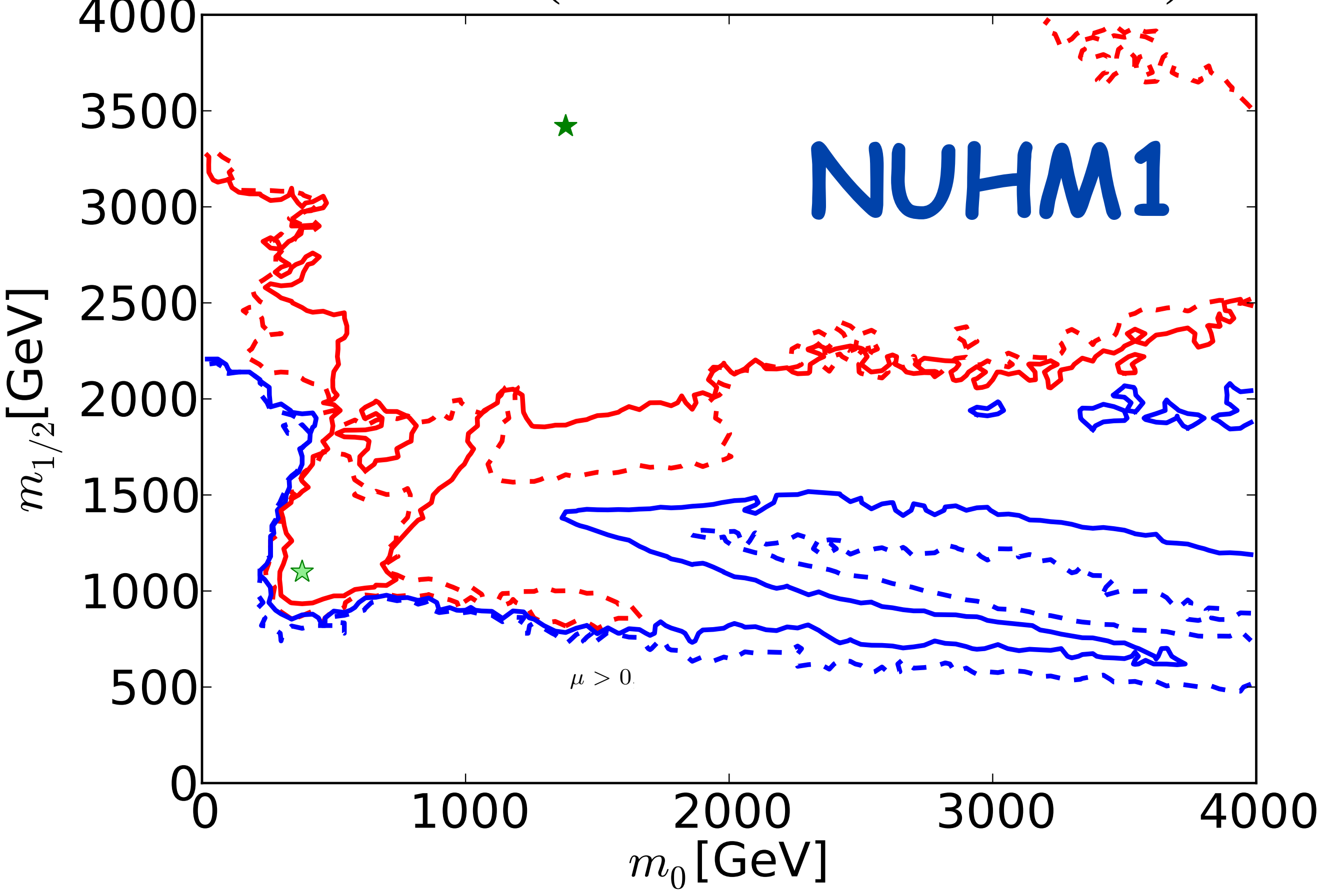
tanβ<10 disfavored by M_h in CMSSM (not in NUHM) !

new global fits in CMSSM and NUHM1

ATLAS E^T_{miss}, BR(B)'s, Mh, EWPT, DM density, LUX, gμ-2

Buchmueller et al. arXiv:1312.5250 (MasterCode framework)





best-fit points

overall likelihood function quite flat and precise location not very significant

Model $\mu > 0$	Region	Minimum χ^2	m_0 (GeV)	$m_{1/2}$ (GeV)	$\tan\beta$
CMSSM	Low-mass	35.8	670	1040	21
	High-mass	35.1	5650	2100	51
NUHM1	Low-mass	33.3	470	1270	11
	High-mass	32.7	1380	3420	39

arXiv:1312.5426

see also: Bechtle et al arXiv:1310.3045 FITTINO framework

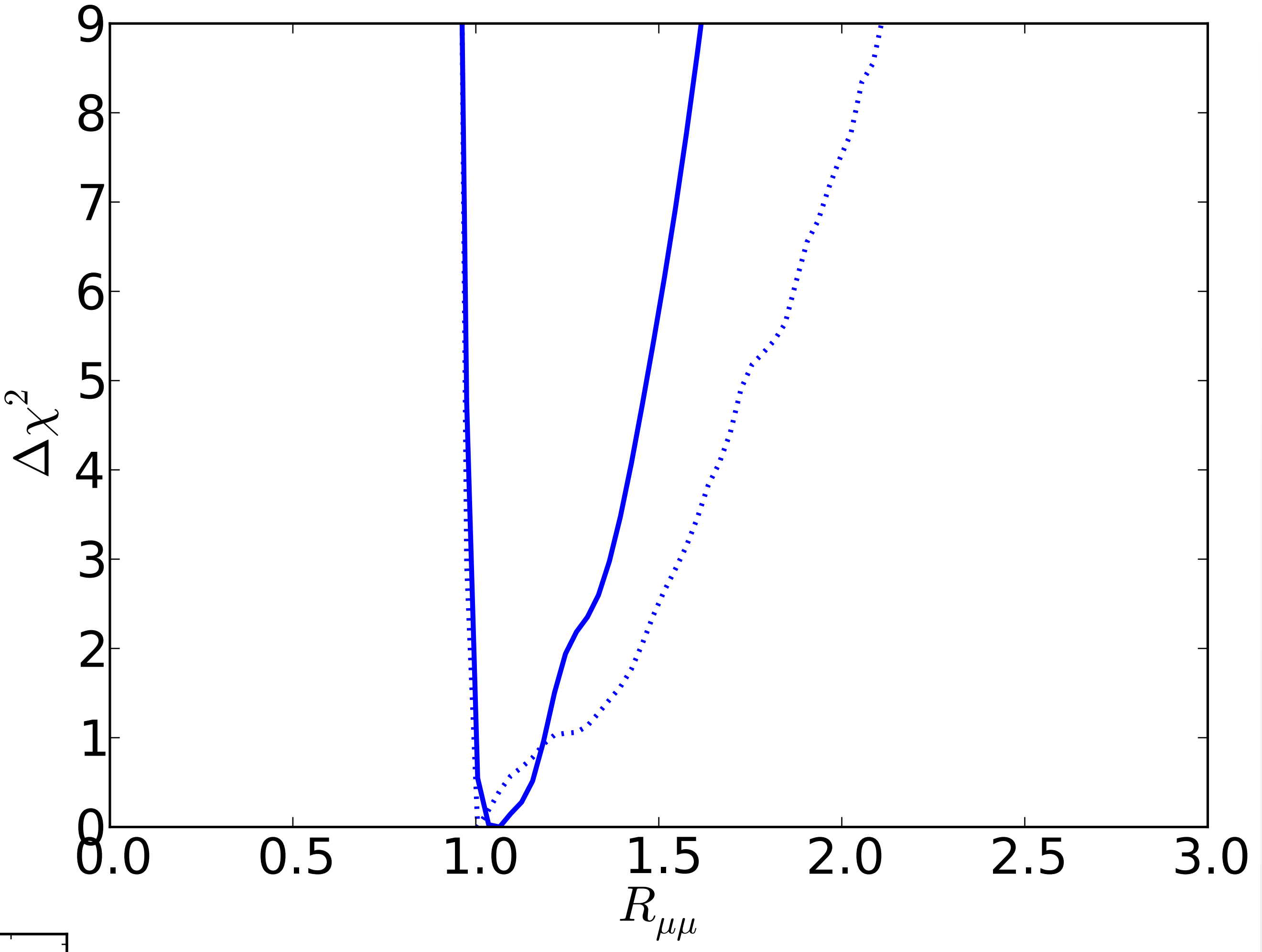
contribution of most relevant observables to global X^2 at best-fit points at high and low masses

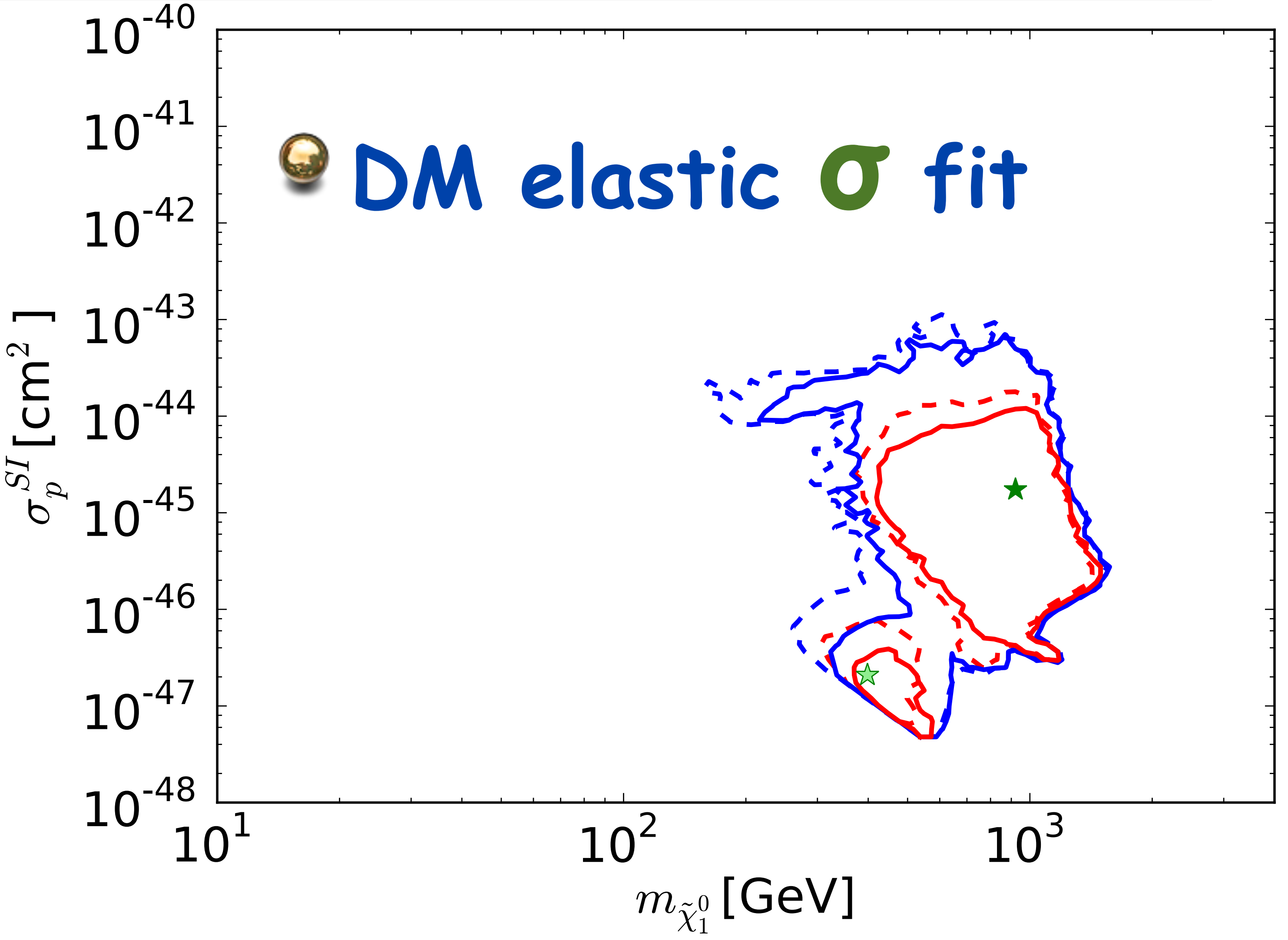
arXiv:1312.5250
(MasterCode framework)

Observable	$\Delta\chi^2$ CMSSM $\mu > 0$ (high)	$\Delta\chi^2$ CMSSM $\mu > 0$ (low)	$\Delta\chi^2$ CMSSM $\mu < 0$ (high)	$\Delta\chi^2$ CMSSM $\mu < 0$ (low)	$\Delta\chi^2$ NUHM1 $\mu > 0$ (high)	$\Delta\chi^2$ NUHM1 $\mu > 0$ (low)	$\Delta\chi^2$ Standard Model
Global	35.1	35.8	36.6	38.9	32.7	33.3	36.5
$\mathrm{BR}_{b\to s\gamma}^{\mathrm{exp/SM}}$	0.52	1.58	0.37	0.00	0.54	0.02	0.57
$\mathrm{BR}_{B\to\tau\nu}^{\mathrm{exp/SM}}$	1.77	1.63	1.63	1.61	1.65	1.66	1.60
ϵ_K	1.94	1.88	1.94	1.87	1.94	1.94	1.96
$a_\mu^{\mathrm{exp}} - a_\mu^{\mathrm{SM}}$	10.71	9.34	11.42	12.65	10.50	9.63	11.19
M_W	1.35	0.22	2.15	0.04	0.00	0.11	1.38
M_h	0.00	0.04	0.03	0.53	0.00	0.22	(1.5)
R_ℓ	1.10	1.04	1.10	1.00	1.07	1.00	1.09
$A_{\mathrm{fb}}(b)$	6.56	6.79	6.05	7.61	5.45	6.93	6.58
$A_\ell(\mathrm{SLD})$	3.59	3.40	3.99	2.81	4.59	3.30	3.55
σ_{had}^0	2.52	2.55	2.56	2.51	2.59	2.56	2.54
LUX	0.03	0.07	0.66	0.07	0.00	0.07	-
ATLAS 20/fb	0.04	2.52	0.02	3.35	0.02	1.15	-
$B_{s,d} \to \mu^+\mu^-$	0.51	0.46	0.13	0.11	0.22	0.35	0.15

global X^2 functions vary slowly over most of param. space allowed by M_h and E^T_{miss}+jets searches, with best-fit X^2/dof comparable to SM one !

CMSSM $\mu > 0$





- DM elastic σ fit

- BR($B_{s,d} \to \mu\mu$)/SM fit

Buchmueller et al., arXiv:1312.5250
(MasterCode framework)

95% CL lower limits on masses

Buchmueller et al., arXiv:1312.5250
(MasterCode framework)

Sparticle	CMSSM $\mu > 0$	CMSSM $\mu < 0$	NUHM $\mu > 0$
$\tilde{g}$	1810	(2100) (3200) 3540	1920
$\tilde{q}_R$	1620	(1900) 6300	1710
$\tilde{t}_1$	750	(950) 4100	(650) 1120
$\tilde{\tau}_1$	340	(400) 4930	380
M_A	690	(1900) 3930	450

- large part of the preferred CMSSM and NUHM1 parameter regions accessible at future LHC runs !

E_t^{miss} searches strongly constrain universal soft Susy-breaking masses !

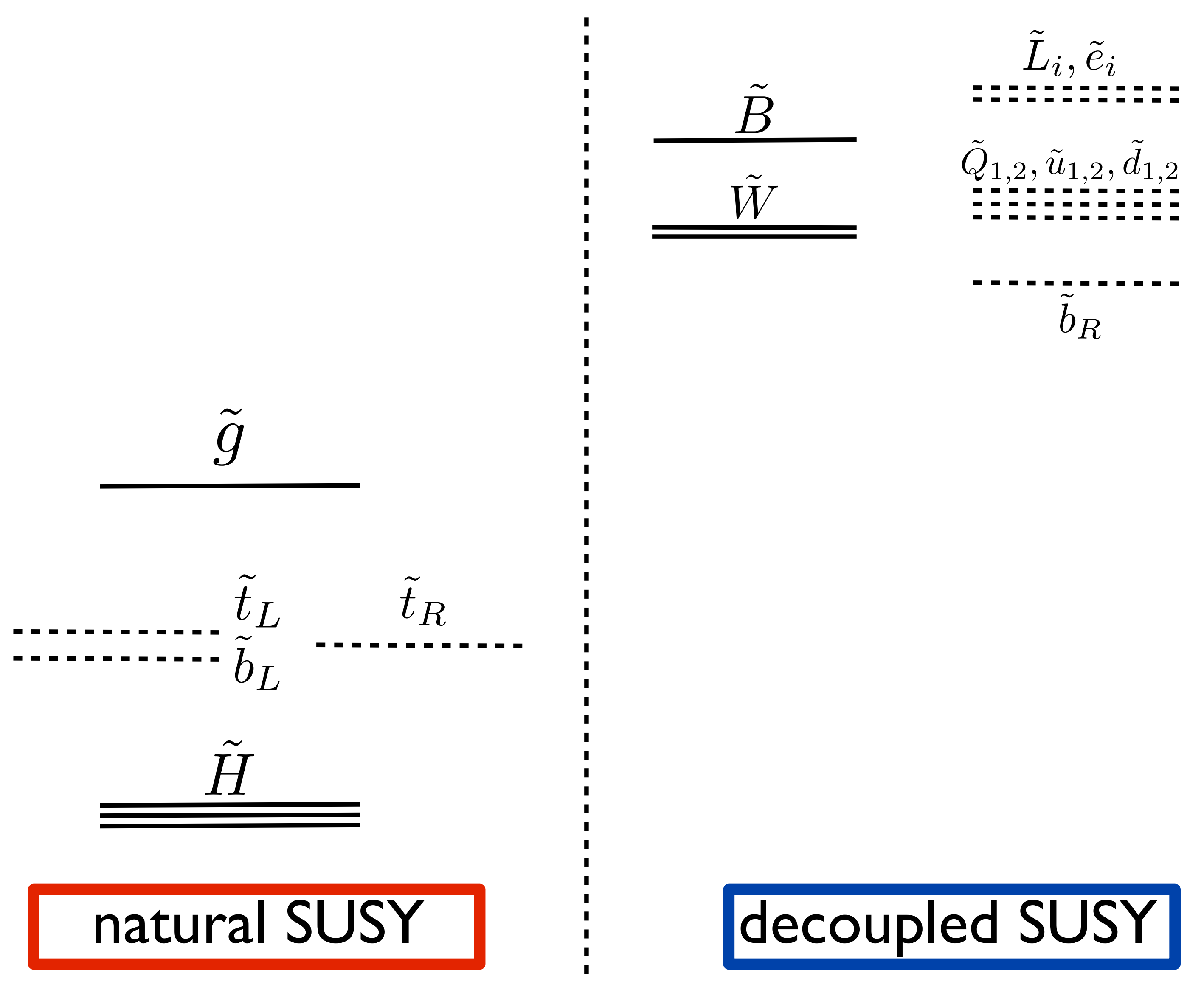
- high priority to Natural Scenarios' searches !
- light stop quarks (but also light higgsinos and gluinos) have a privileged role in stabilizing the Higgs mass
- bounds on m_{stop} much softer than ones on $m_{light\text{-}flavor}$

"Natural Scenario"

m_{stop}, $m_{sbottom}$ < 1 TeV

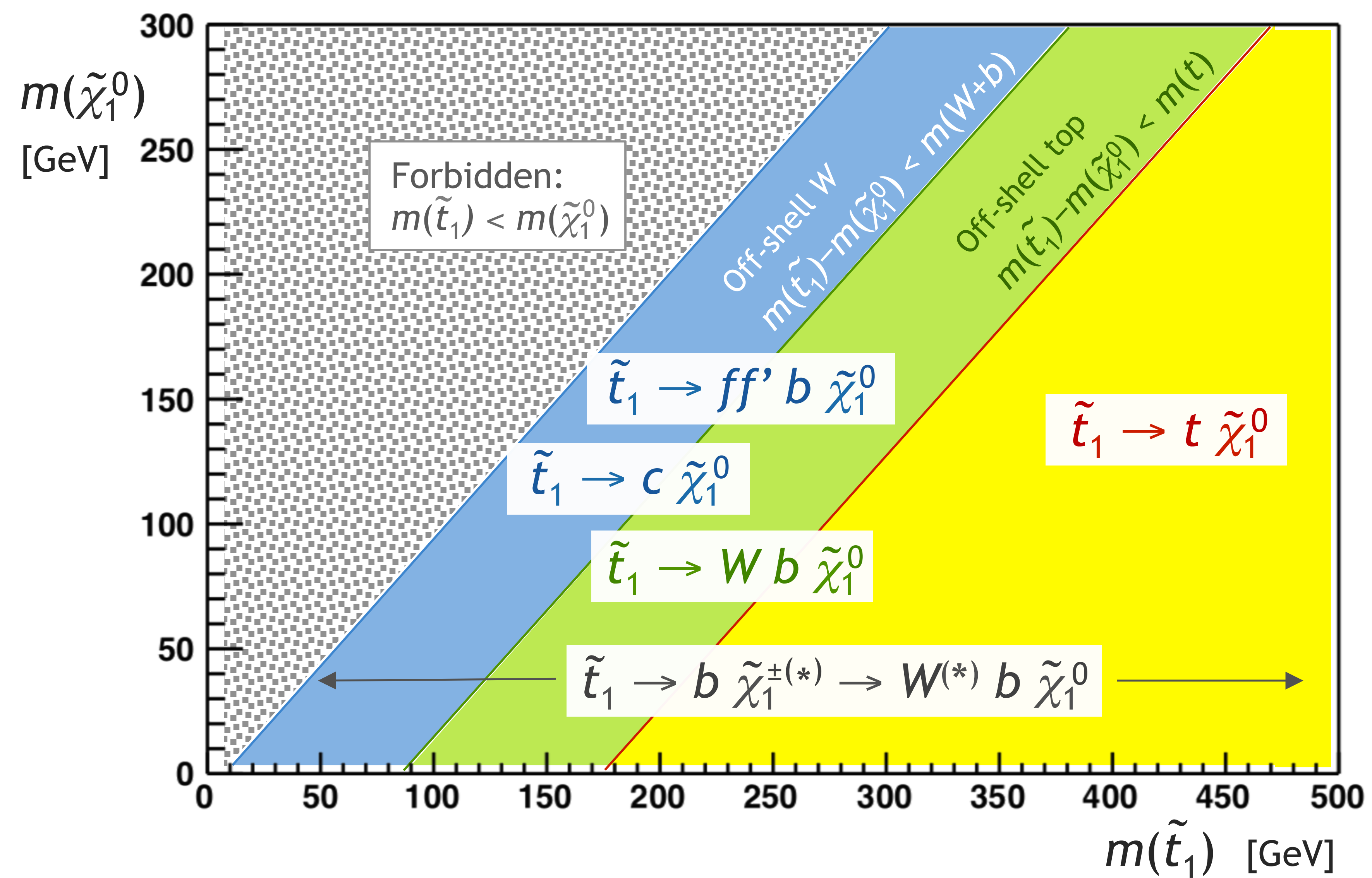
m_{gluino} < 2 TeV

$m_{higgsino}$~ 100-300 GeV



focus on stop pair production

- for **light** stop, **large** cross sections
  but $E_{visible}$ and $E_{invisible}$ released tends to be **smaller** ➜
  signal can be **missed** in searches tailored to more generic spectra
- huge background from **top pairs**
- different **mass hierarchies** require different search strategies
- **small mass gaps** can give **soft (untriggered)** $E_{(in)visible}$!!!



also :

$\tilde{b}_1 \to b \, \tilde{\chi}_1^0$

$\tilde{b}_1 \to t \, \tilde{\chi}_1^{\pm}$

$\tilde{b}_1 \to b \, \tilde{\chi}_2^0 \to b \, h(Z) \, \tilde{\chi}_1$

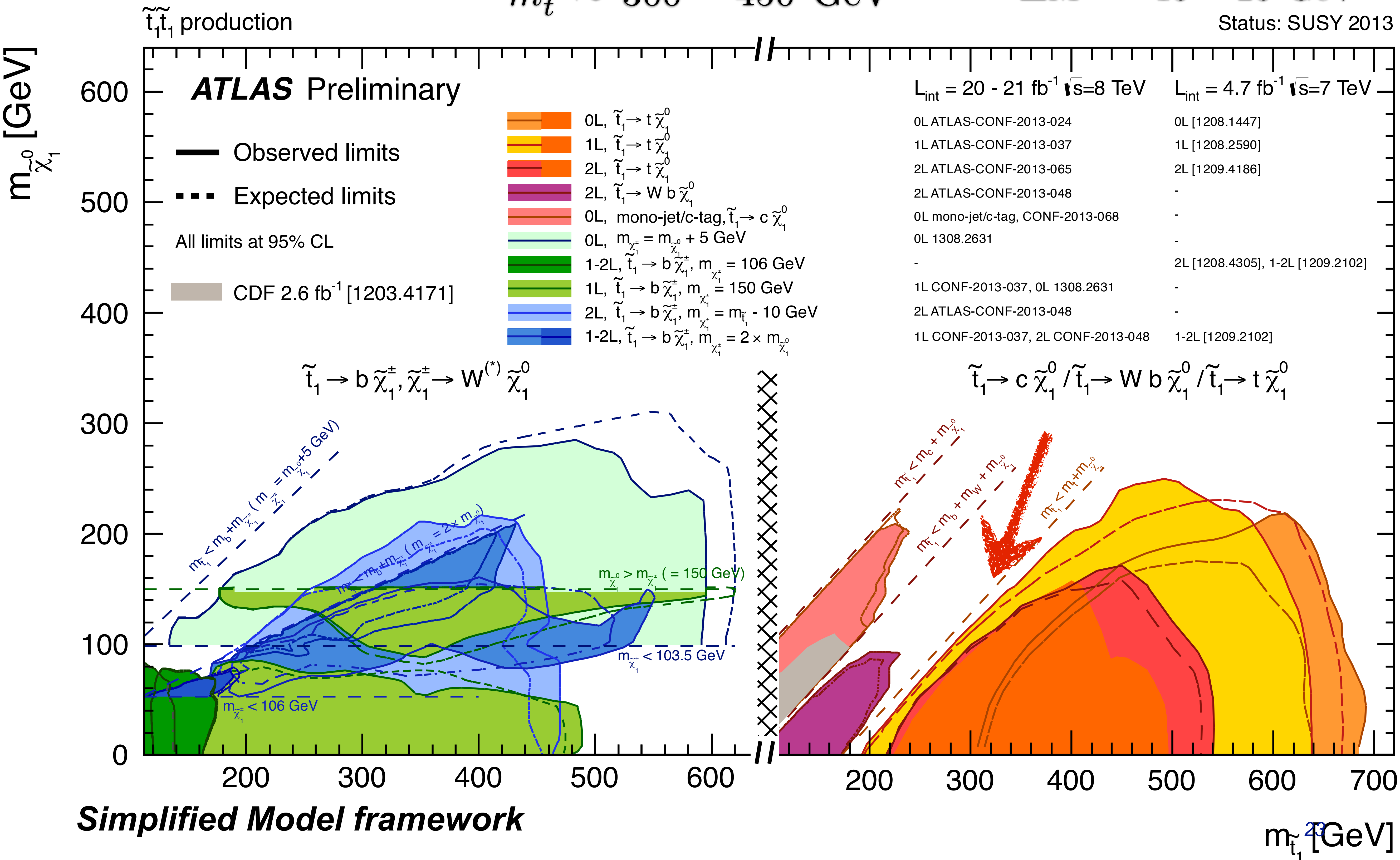
bounds tend to evaporate for compressed spectra

$$m_{\tilde t} \simeq m_t + m_{\tilde\chi_1^0}$$

$$m_{\tilde t} \sim 190-300 \text{ GeV}$$

$$\Delta M = m_{\tilde t} - (m_t + m_{\tilde\chi_1^0}) \sim 5-10 \text{ GeV}$$

$$m_{\tilde t} \sim 300-450 \text{ GeV} \qquad \Delta M \sim 15-20 \text{ GeV}$$



Simplified Model framework

compressed spectra : recent developments

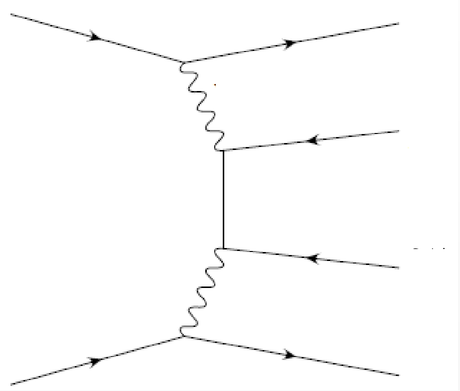
- small mass gaps give softer E_T^{miss} and $E_T^{\ell,j}$, reducing search sensitivity
  → boost typical E_T^i above the reconstruction threshold by considering same final state
  either in VBF topology or in mono-jet (mono-γ) events
  → trigger on extra jets (photon)
- two examples :
  - compressed-stop pairs with VBF tagging

    Dutta et al., arXiv:1312.1348 (1304.7779 , 1210.0964)
  - compressed charginos/neutralinos in mono-jet (mono-γ) events

    Schwaller and Zurita, arXiv:1312.7350
    Baer, Mustafayev, Tata, arXiv:1401.1162
    Han et al., arXiv:1310.4274

compressed stop in VBF topology

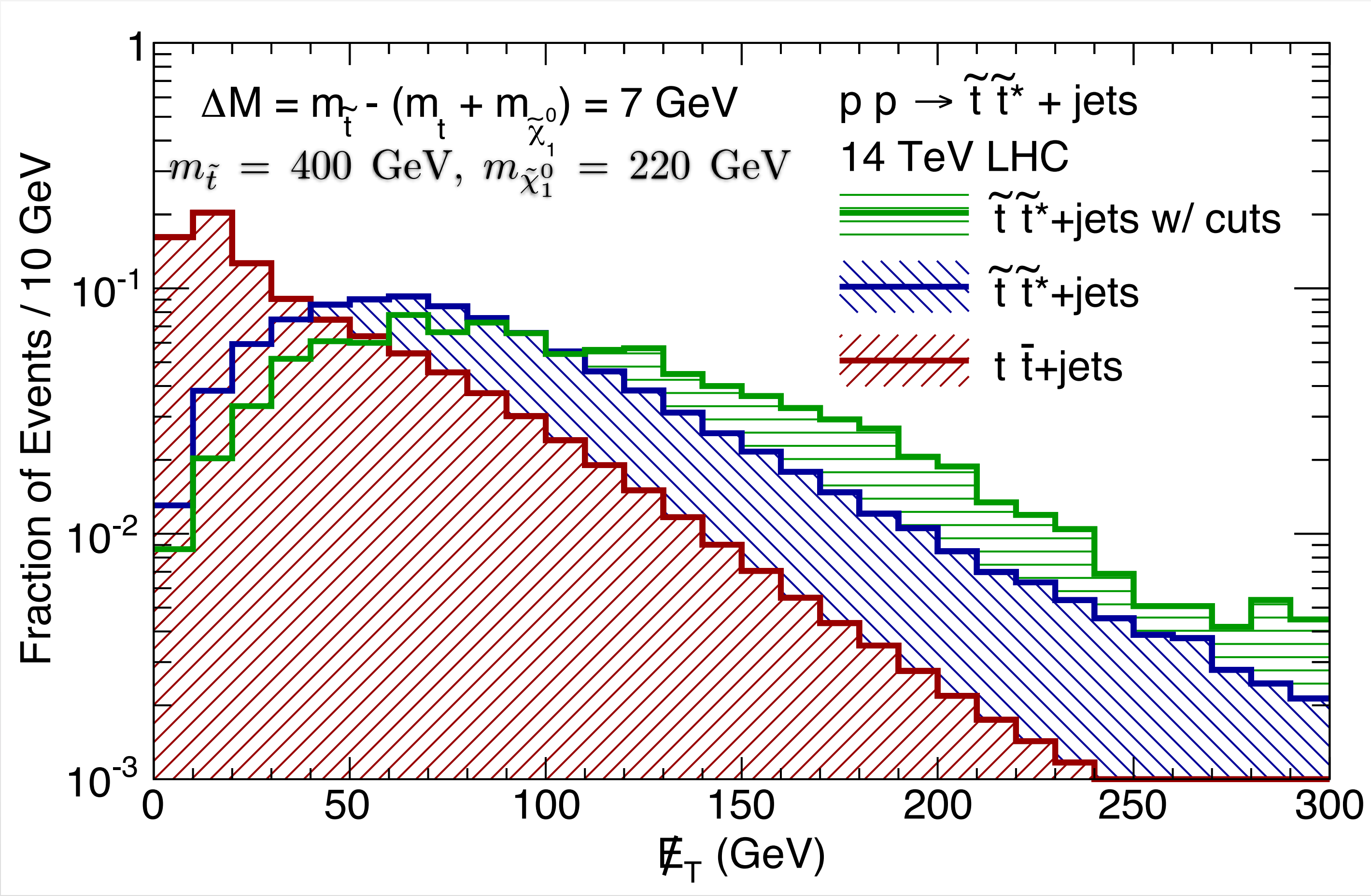
- in inclusive $\tilde t \tilde t^* +$ jets production, ask for **2 forward jets with large $M_{inv}(JJ)$**



$(m_{\tilde t}, m_{\tilde\chi_1^0})$	Selection	Signal	$t\bar t$+jets
		fb	fb
$(300, 120)$	VBF	95.7	16774
	1 lepton	22.1	3587
	2 b-jets	9.70	1612
	$\not\!\!E_T > 50$	8.00	924
$(400, 220)$	VBF	25.2	16774
	1 lepton	5.93	3587
	2 b-jets	2.84	1612
	$\not\!\!E_T > 100$	1.48	337
$(500, 320)$	VBF	7.50	16774
	1 lepton	1.69	3587
	2 b-jets	0.74	1612
	$\not\!\!E_T > 150$	0.27	123

$$m_{\tilde t} \Rightarrow m_t + m_{\tilde\chi_1^0}$$

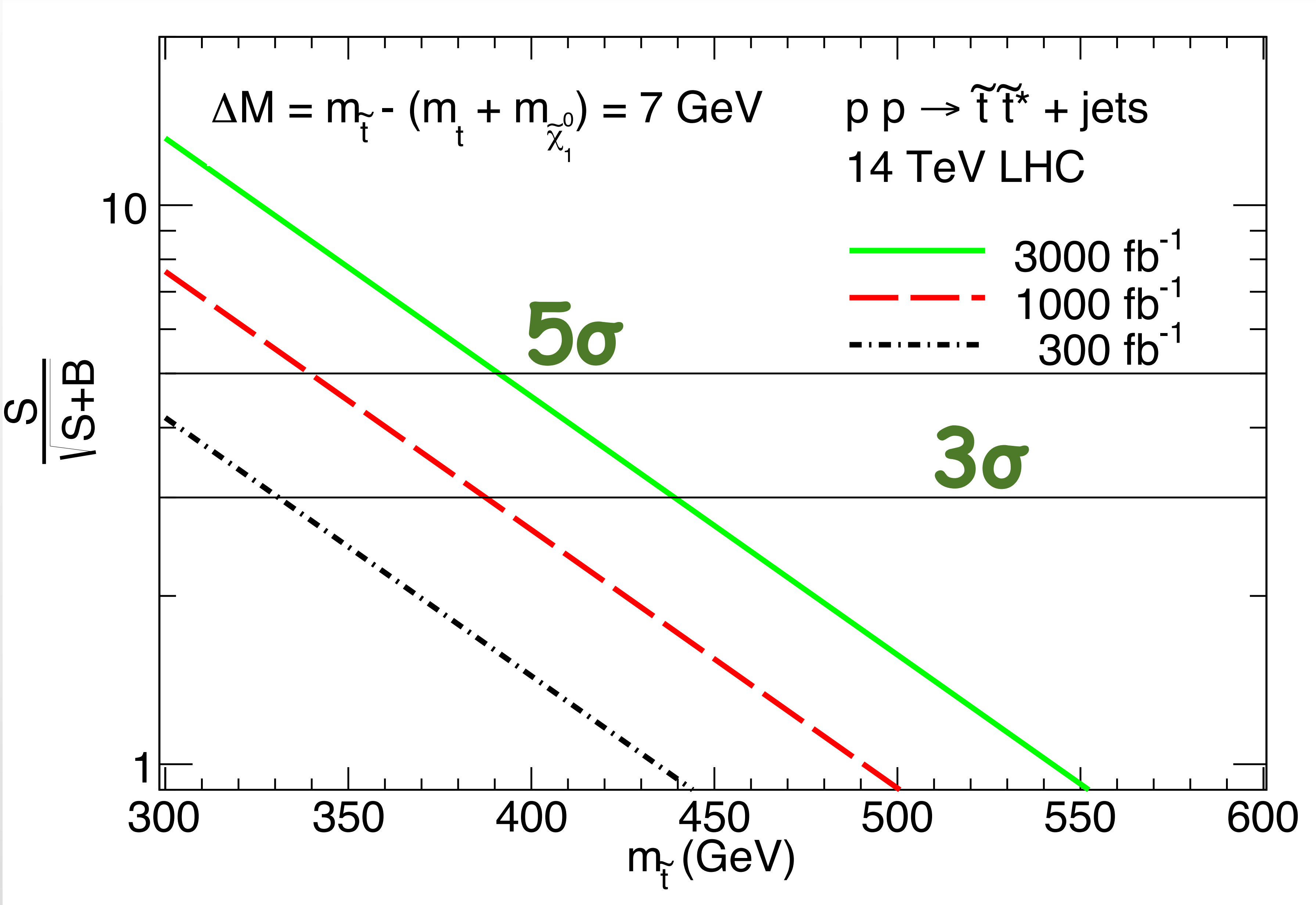
Dutta et al., arXiv:1312.1348



E_T^{miss} cut very effective in enhancing S/B

- for ΔM ~ 7 GeV
  LHC discovery potential up to
  m_{stop} ~ 340 (390) GeV with 1000 (3000) fb^{-1}

Dutta et al., arXiv:1312.1348



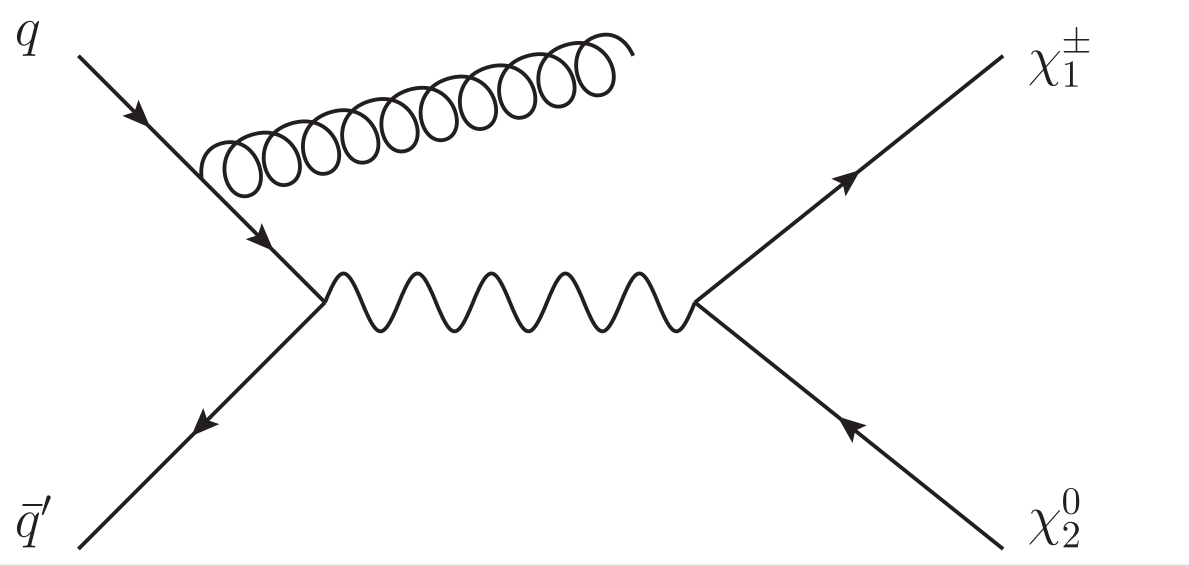
- for stealthy stop (m_{χ^0}~ 0), E_T^{miss} cut looses performance

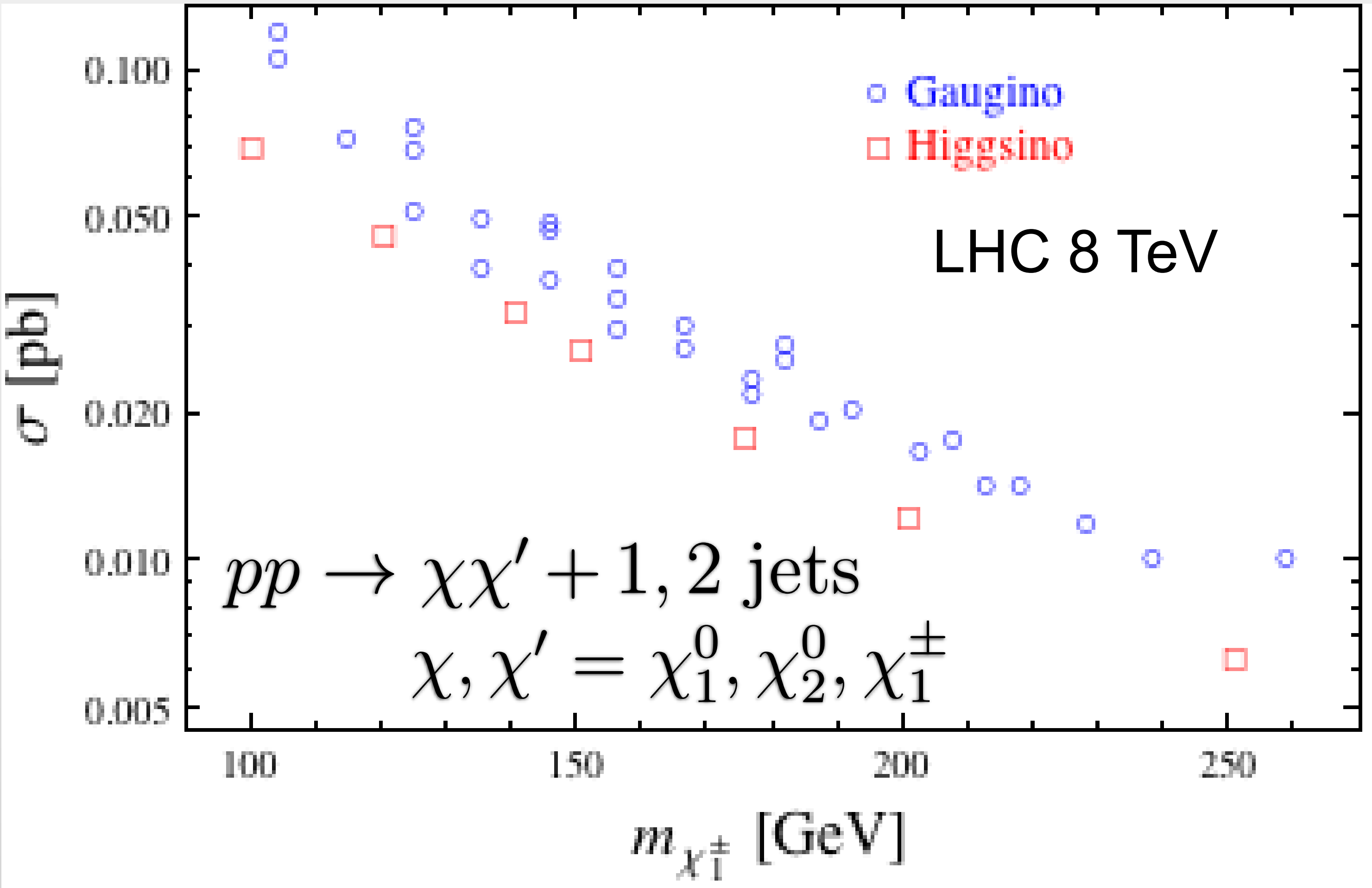
compressed X^+/X^0 in mono-jet

Schwaller and Zurita, arXiv:1312.7350

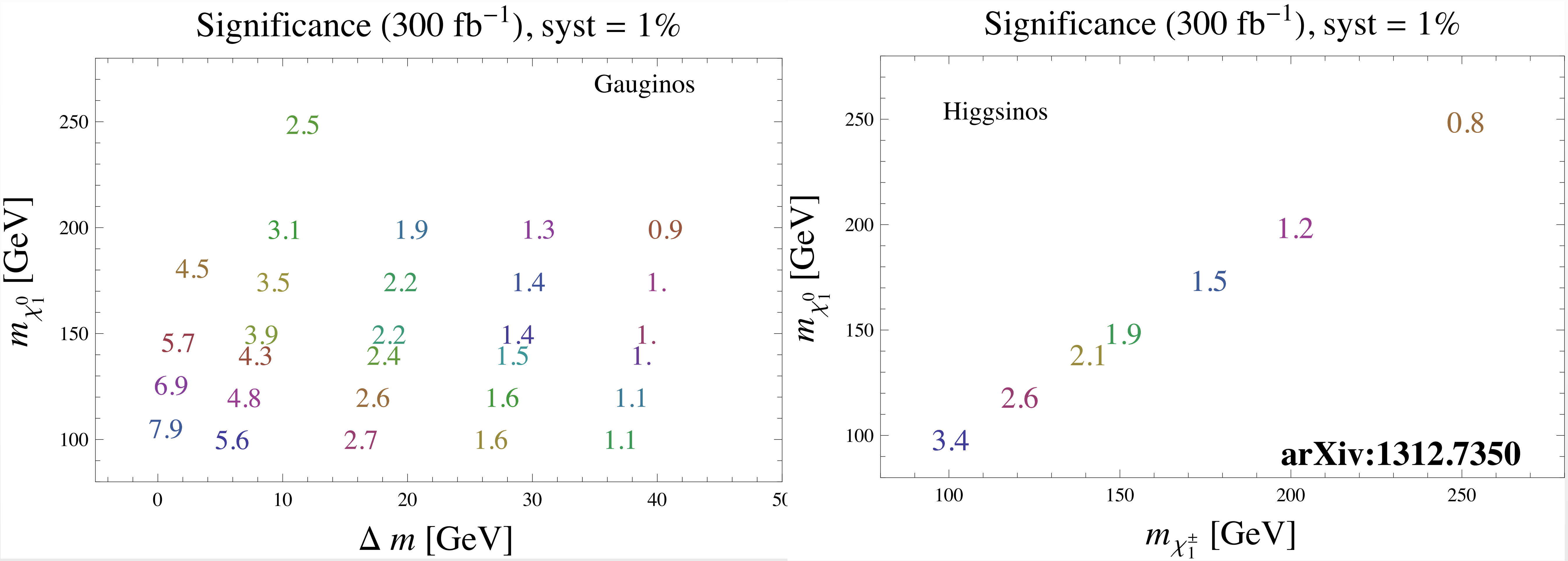
- extend strategies for DM searches to degenerate X^+/X^0 whose $\chi' \to \ell\ell'\chi_1^0$ products are too soft to pass trigger requirements
- two possibilities studied:

$\mu \gg M_1, M_2 \sim M_Z$ degenerate gauginos
$M_1, M_2 \gg \mu \sim M_Z$ " higgsinos (Natural Scen.)





addition of soft leptons crucial to reach sensitivity at 14 TeV (for ΔM ~ 10-30 GeV)



arXiv:1312.7350

- at 14 TeV for 300 (3000) fb^{-1} can exclude up to 250 GeV gauginos, for ΔM < 10-(40) GeV, and up to 150 (200) GeV higgsinos

what if a BSM signal comes out at LHC ?

- a Great Breakthrough in particle physics,
although not a confirmation of any single theory model ! ! !

- just the start-up of
exploration of the "next layer of theory"

- considerable degeneracy in the expected phenomenology
for quite a number of BSM models
(eg. missing P_T from many models with a WIMP candidate)

- for any single TH model to be credited, it will have to
overcome the "anomaly-fitting phase"
and enter the "prediction phase" !

- it will take time and a lot of effort to advance in theory !

Outlook (1)

- SM built up on decades of unexplained experimental facts... By early 70's it was a complete framework whose many crucial predictions had to be checked out in following 40 years, guaranteeing a tremendous outcome for collider physics (and proving the model an extraordinary success !)
- today no BSM framework is as mature as SM in 70's ! just a number of theoretical suggestions ... (with no guarantee of success for anyone !)
- nevertheless, the statement that "new phenomena at the TeV scale are needed to make the EWSB scale Natural" is still robust after LHC Run 1
- in which format ?

Outlook (2)

- many alternatives open: new resonances, but also deviations in inclusive cross sections / decay rates / Kinem. distributions / correlations
- use theory suggestions as "benchmark frameworks" for search strategies !
- crucial also to extend "signature-driven" studies, as unbiased as possible by theoretical prejudice !
- today exp data definitely needed to advance in theory
- we are now in a thrilling phase: LHC is an extraordinary (and highly complex) tool that has still to develop its full potential ... (lot of effort and inventiveness will be needed)

big advances in the exploration of TeV scale
in next few years "guaranteed" !