What Next at LHC, TIFR

Jan 6-8, 2014

A theorist's wish list (?)

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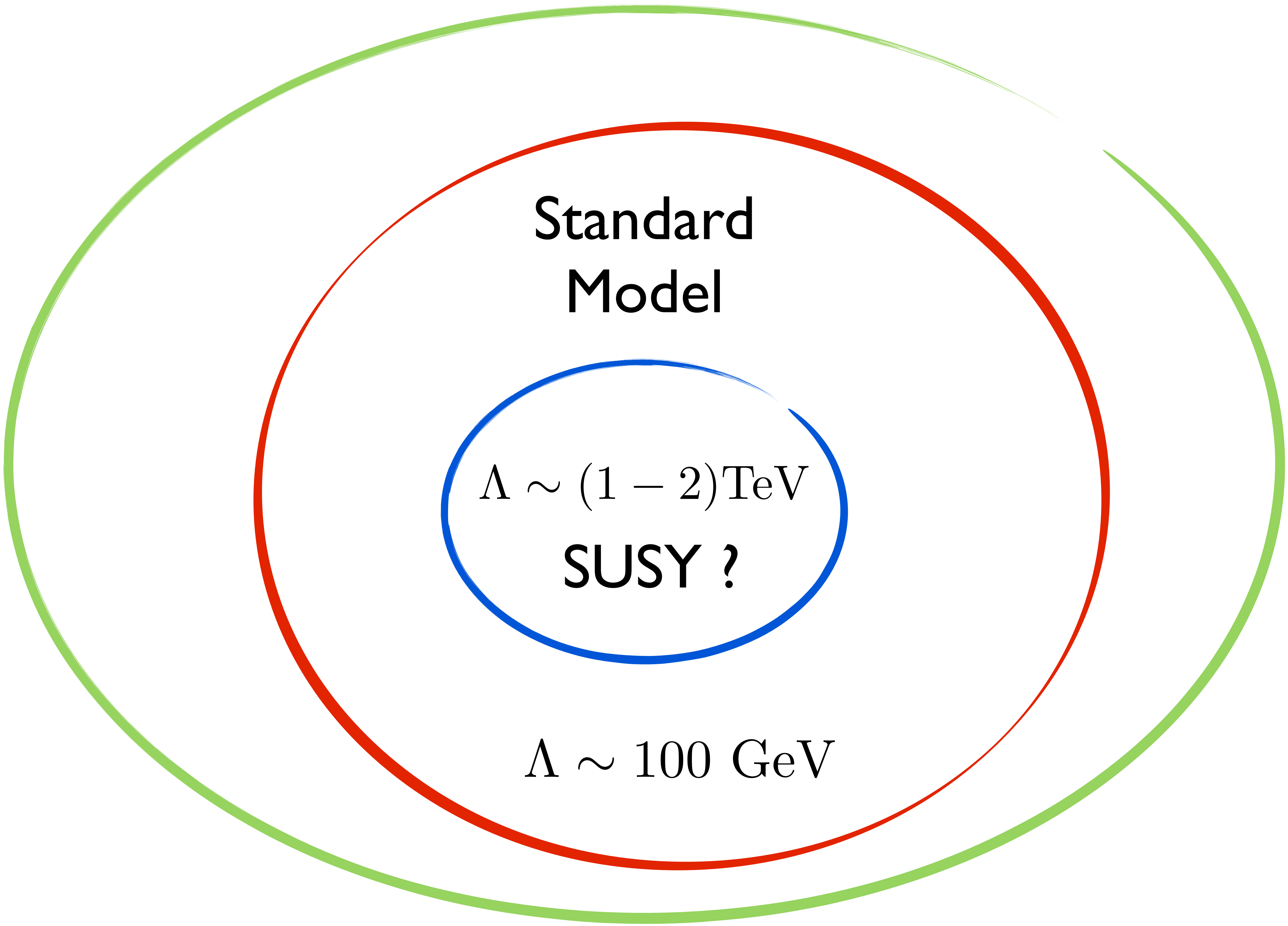
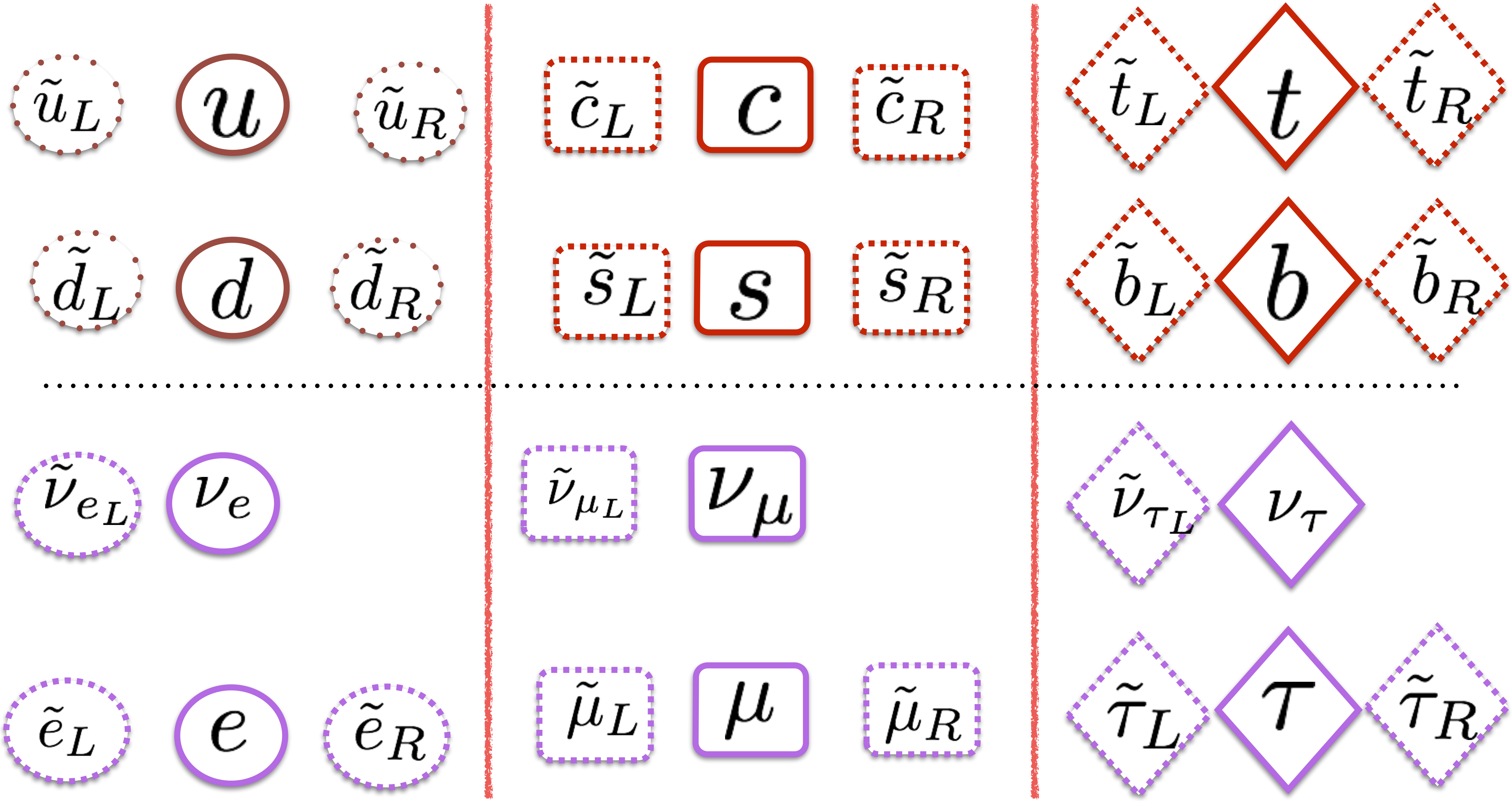
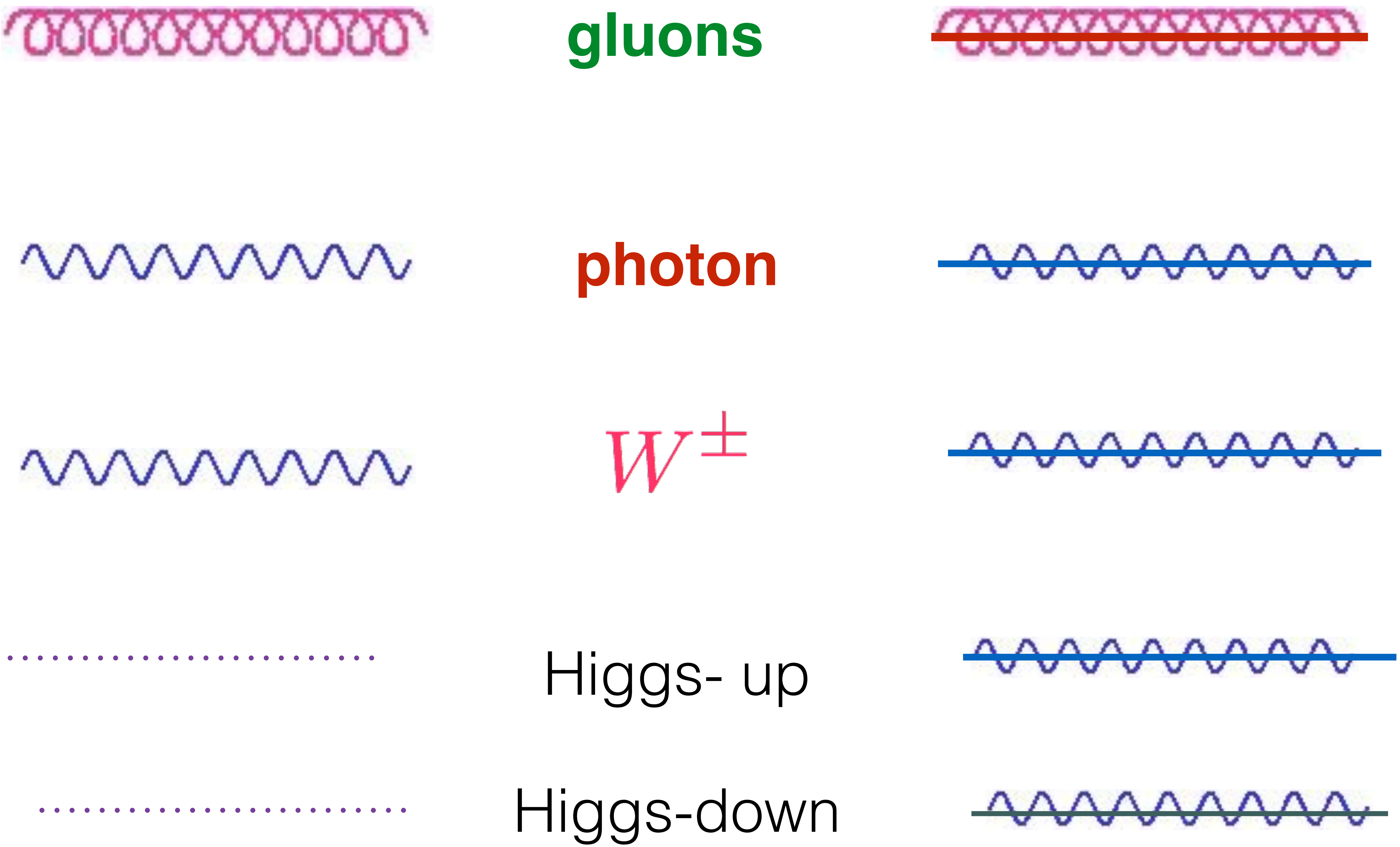
- Naturalness
- Dark Matter
- Flavour Issues (including Neutrino Masses)

As the LHC probes smaller length scales



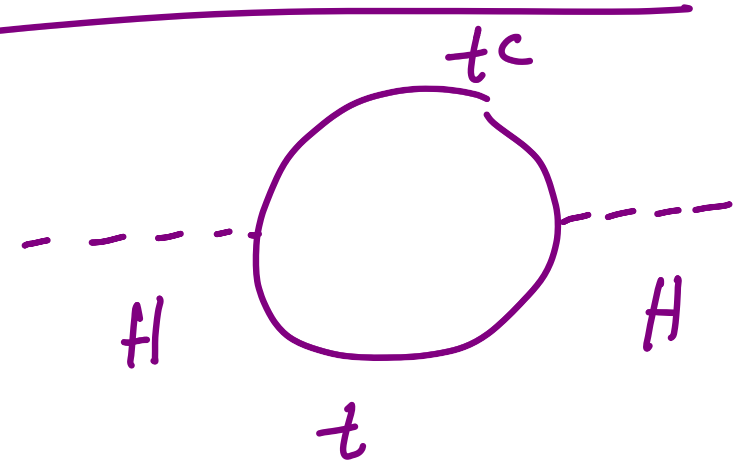


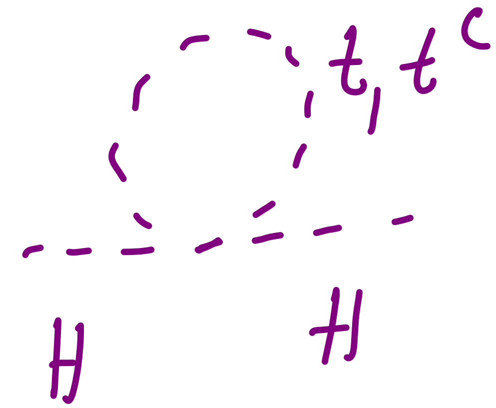
Supersymmetric Standard Model -1

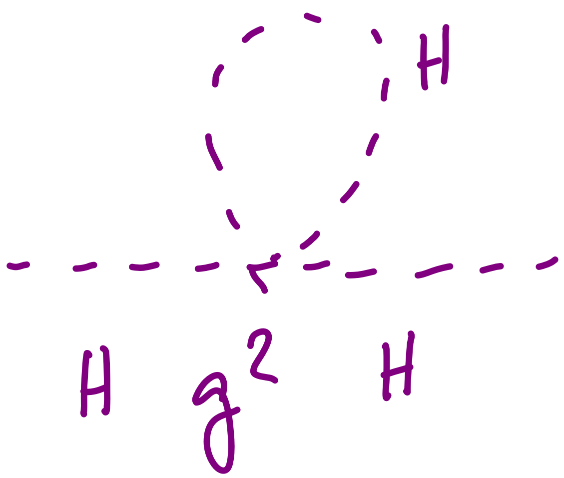


Supersymmetric Standard Model Spectrum -2

How SUSY works







quartic coupling replaced by gauge coupling

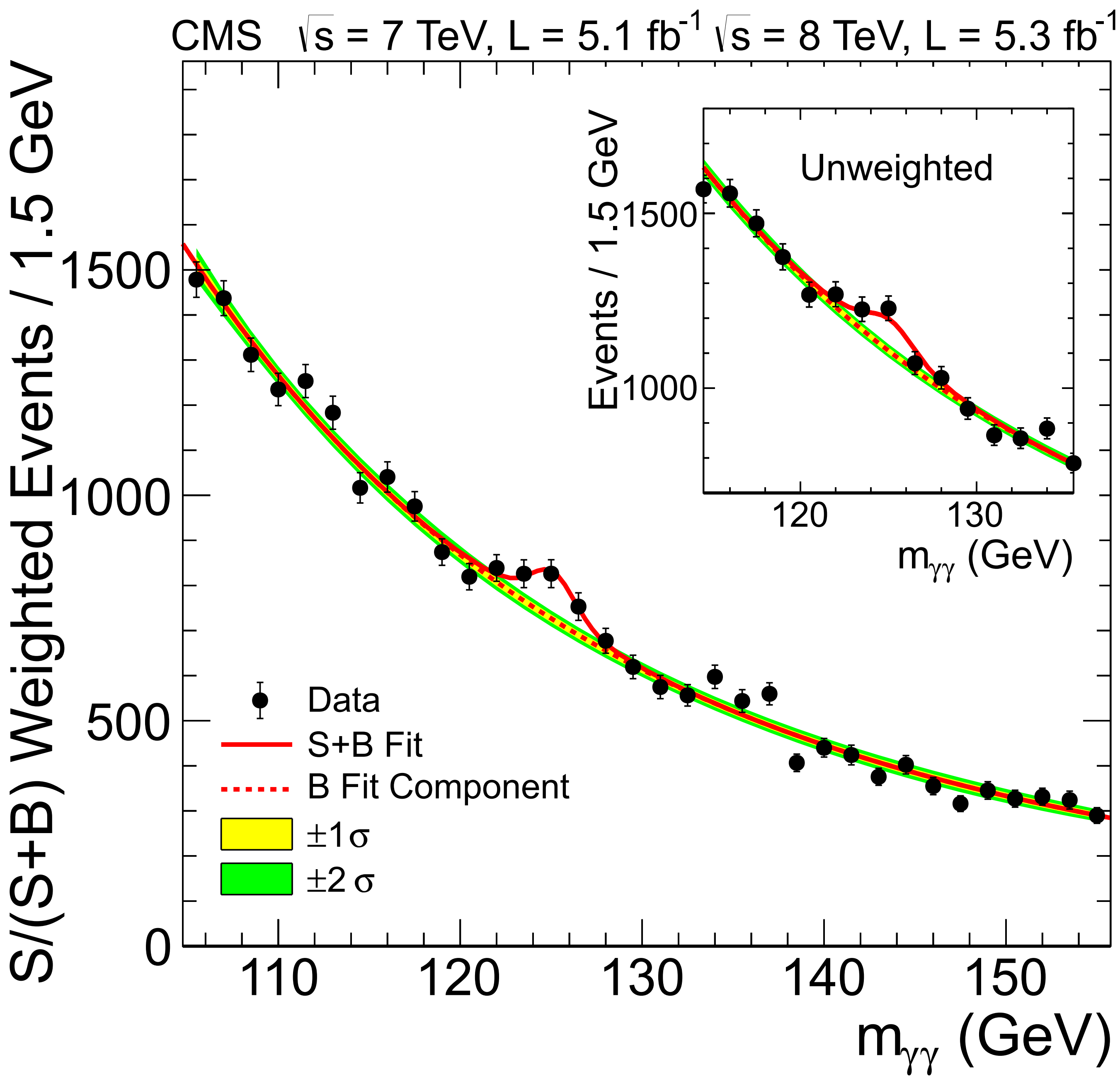
If $m_t \approx m_{\tilde{t}}$ quadratic divergences cancel from both the diagrams

Other advantages of SUSY

- Its calculable and thus in principle, predictable.
- Dark Matter candidate if R-parity is conserved.
- Gauge coupling unification (GUTs with neutrino masses and mixing)
- Lightest Higgs boson can be SM -like in regions of parameter space.

Higgs and stops

The Higgs bump at LHC



Speed breakers to Zero Stop mixing ??

Tree Level Mass

$$H_u = \begin{pmatrix} H_u^+ \\ H_u^0 \end{pmatrix} \qquad H_d = \begin{pmatrix} H_d^0 \\ H_d^- \end{pmatrix}$$

$$Y_{H_u} = +1 \qquad Y_{H_d} = -1$$

$$V_H = (|\mu|^2 + m_{H_d}^2)|H_d|^2 + (|\mu|^2 + m_{H_u}^2)|H_u|^2 - B_\mu \epsilon_{ij}(H_u^i H_d^j + \text{c.c.}) + \frac{g_2^2 + g_1^2}{8}(|H_d|^2 - |H_u|^2)^2 + \frac{1}{2}g_2^2 |H_d^\dagger H_u|^2$$

$$V_H = (|\mu|^2 + m_{H_d}^2)(|H_d^0|^2 + |H_d^-|^2) + (|\mu|^2 + m_{H_u}^2)(|H_u^0|^2 + |H_u^+|^2) - [B_\mu(H_d^- H_u^+ - H_d^0 H_u^0) + \text{c.c.}] + \frac{g_2^2 + g_1^2}{8}(|H_d^0|^2 + |H_d^-|^2 - |H_u^0|^2 - |H_u^+|^2)^2 + \frac{g_2^2}{2}|H_d^{-*} H_u^0 + H_d^{0*} H_u^+|^2$$

$$M_A^2 = \frac{2B_\mu}{\sin 2\beta} \qquad M_{H^\pm}^2 = M_A^2 + M_W^2$$

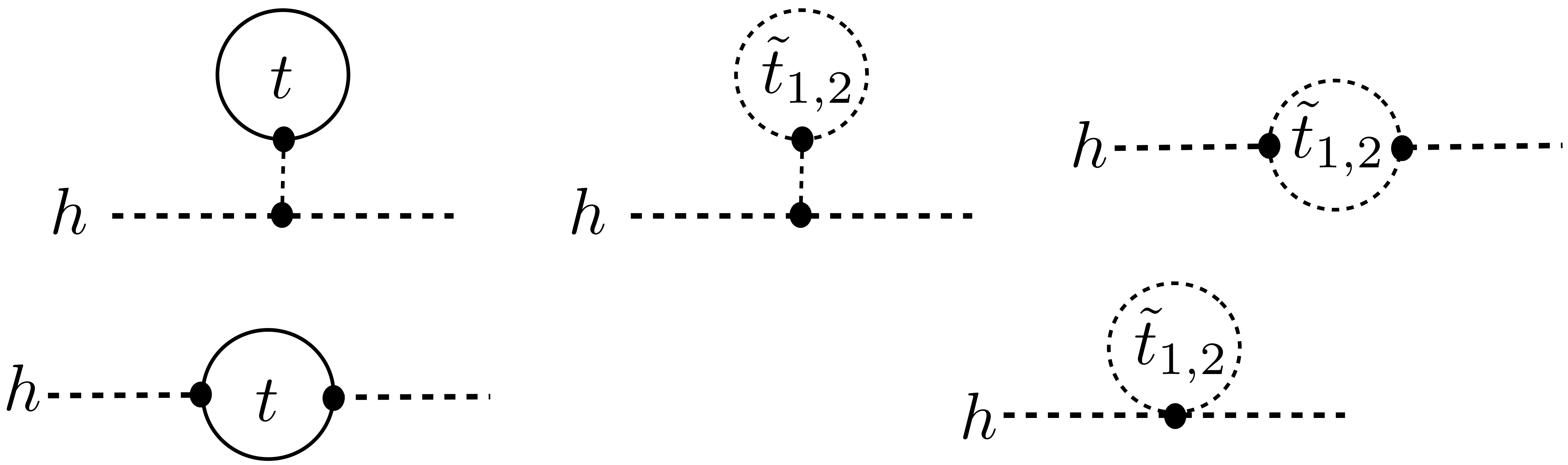
$$M_{h,H}^2 = \frac{1}{2}\left[M_A^2 + M_Z^2 \mp \sqrt{\left(M_A^2 + M_Z^2\right)^2 - 4M_A^2 M_Z^2 \cos^2 2\beta}\right]$$

$$\tan 2\alpha = \frac{M_A^2 + M_Z^2}{M_A^2 - M_Z^2}\tan 2\beta \qquad -\frac{\pi}{2} < \alpha < 0$$

at tree level the lightest Higgs mass upper limit is

$$M_h \le M_Z |\cos 2\beta| \le M_Z$$

Lightest Higgs mass @ 1-loop (top-stop enhanced)



in the limit of no-mixing

$$\Delta m_h^2 = \frac{3g_2^2}{8\pi^2 M_W^2} m_t^4 \log\left(\frac{M_S^2}{m_t^2}\right)$$

$$M_S \equiv \sqrt{m_{\tilde{t}_1} m_{\tilde{t}_2}}$$

in the case of non-zero mixing the correction is (but small)

$$\Delta m_h^2 \simeq \frac{3g_2^2 m_t^4}{8\pi^2 M_W^2}\left[\log\left(\frac{m_{\tilde{t}_1} m_{\tilde{t}_2}}{m_t^2}\right) + \frac{X_t^2}{m_{\tilde{t}_1} m_{\tilde{t}_2}}\left(1 - \frac{X_t^2}{12 m_{\tilde{t}_1} m_{\tilde{t}_2}}\right)\right]$$

where $X_t = A_t - \mu \cot\beta$

$$M_S \equiv \sqrt{m_{\tilde{t}_1} m_{\tilde{t}_2}}$$

Haber, Hempfling and Hoang,9609331

1-loop correction adds ~20 GeV to the tree-level, assuming the sparticles are < 1 TeV (in no-mixing scenario).

Upper bound on Light Higgs (one loop)

$$m_t(m_{SUSY}) \approx 157 \quad \text{GeV}$$

$$m_h^2 = m_Z^2 \cos^2 2\beta + \Delta m_h^2$$

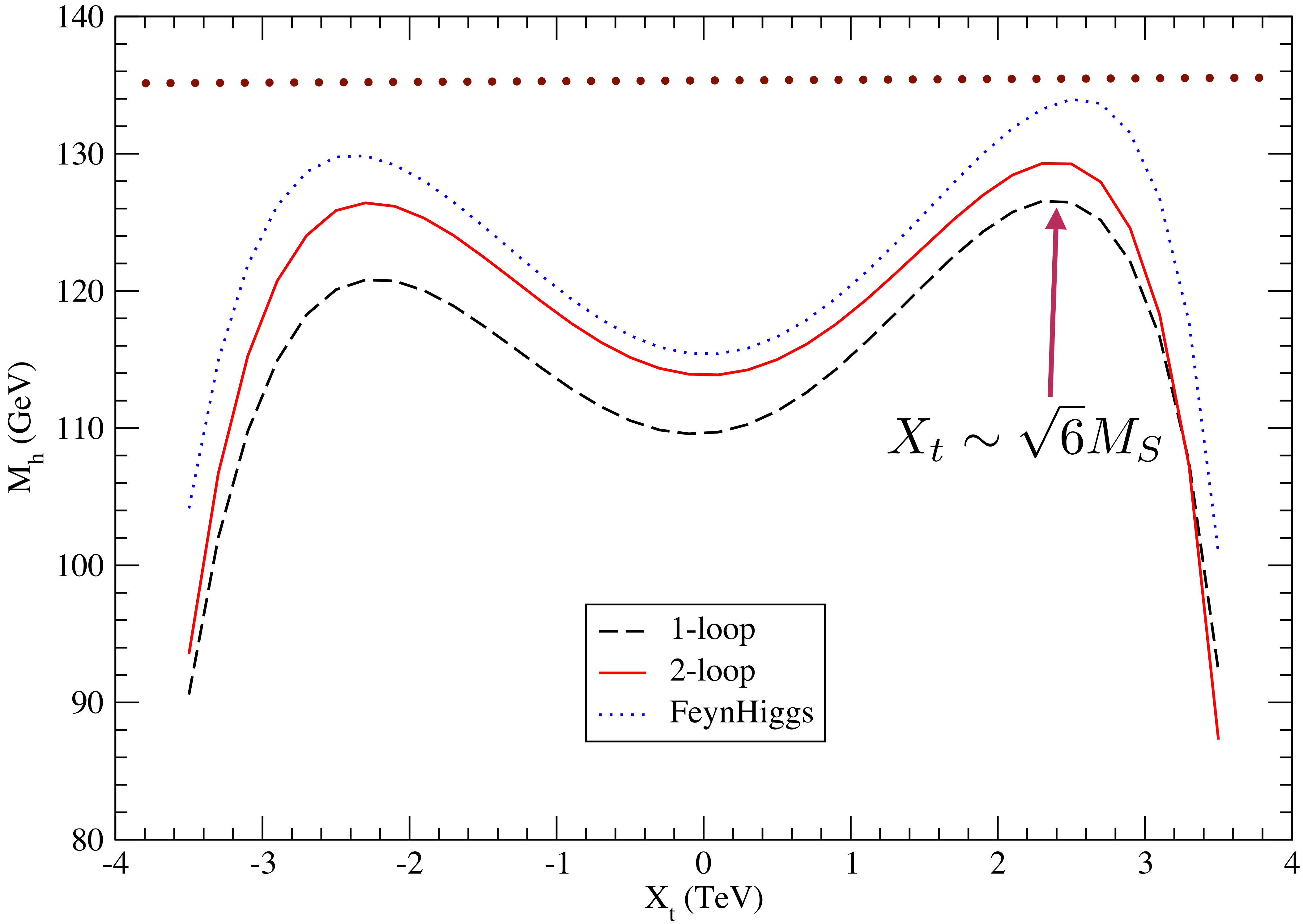
$$\Delta m_h^2 \simeq \frac{3g_2^2 m_t^4}{8\pi^2 M_W^2} \left[\log\left(\frac{m_{\tilde{t}_1} m_{\tilde{t}_2}}{m_t^2}\right) + \frac{X_t^2}{m_{\tilde{t}_1} m_{\tilde{t}_2}} \left(1 - \frac{X_t^2}{12 m_{\tilde{t}_1} m_{\tilde{t}_2}}\right)\right]$$

for m_{SUSY} = 1 TeV, we have an upper bound of 135 GeV

pretty robust prediction.

$\tan\beta = 10, M_A = M_S = 1$ TeV

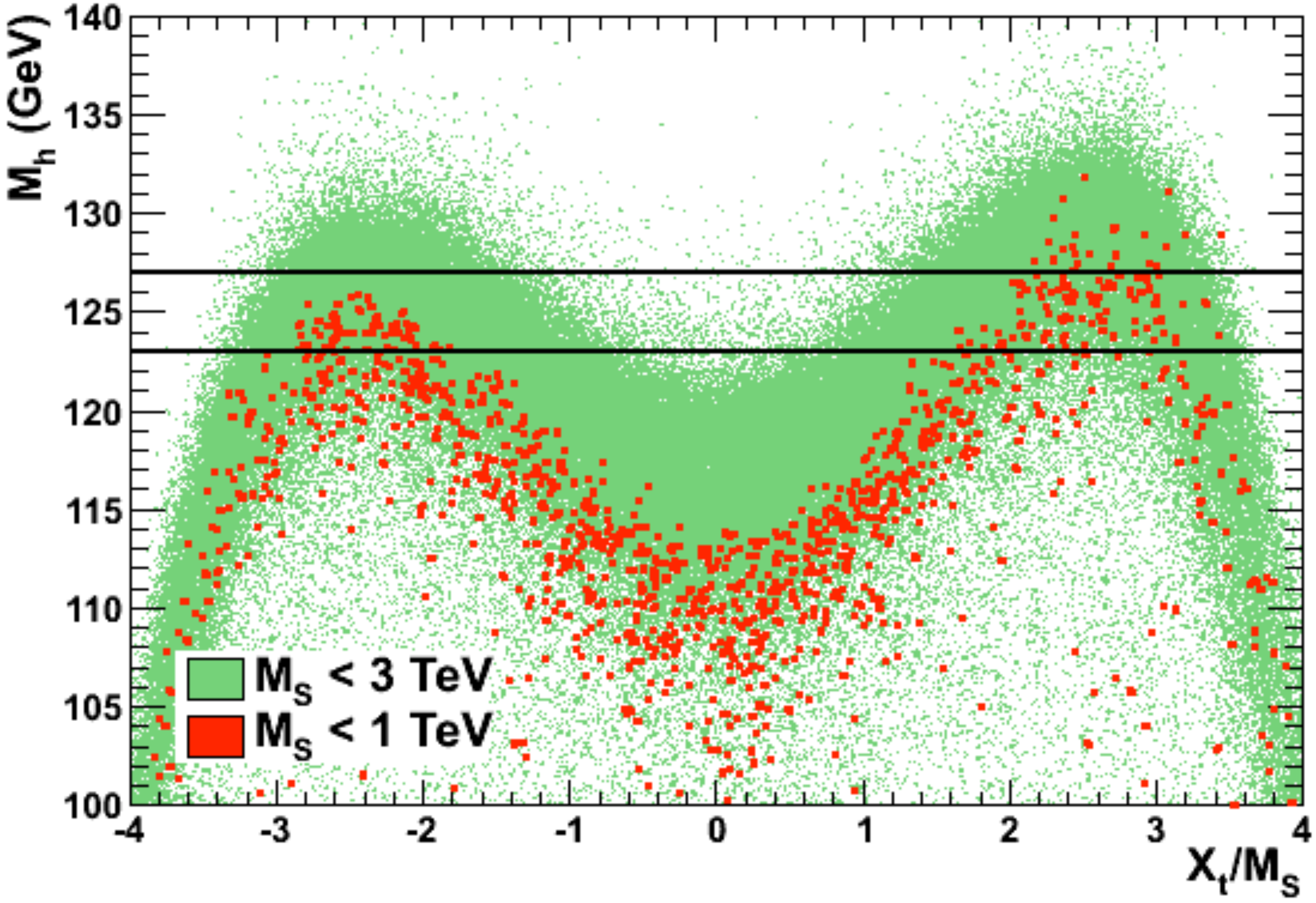
phenomenological models



Allanach et al. '04

Very close to the upper bound in MSSM

phenomenological models



Abrey et al. 1112.3028; 2012 updates

For zero mixing, we need multi TeV Stops !!!

Other option is to have maximal mixing : $|X_t| \sim \sqrt{6} M_S$

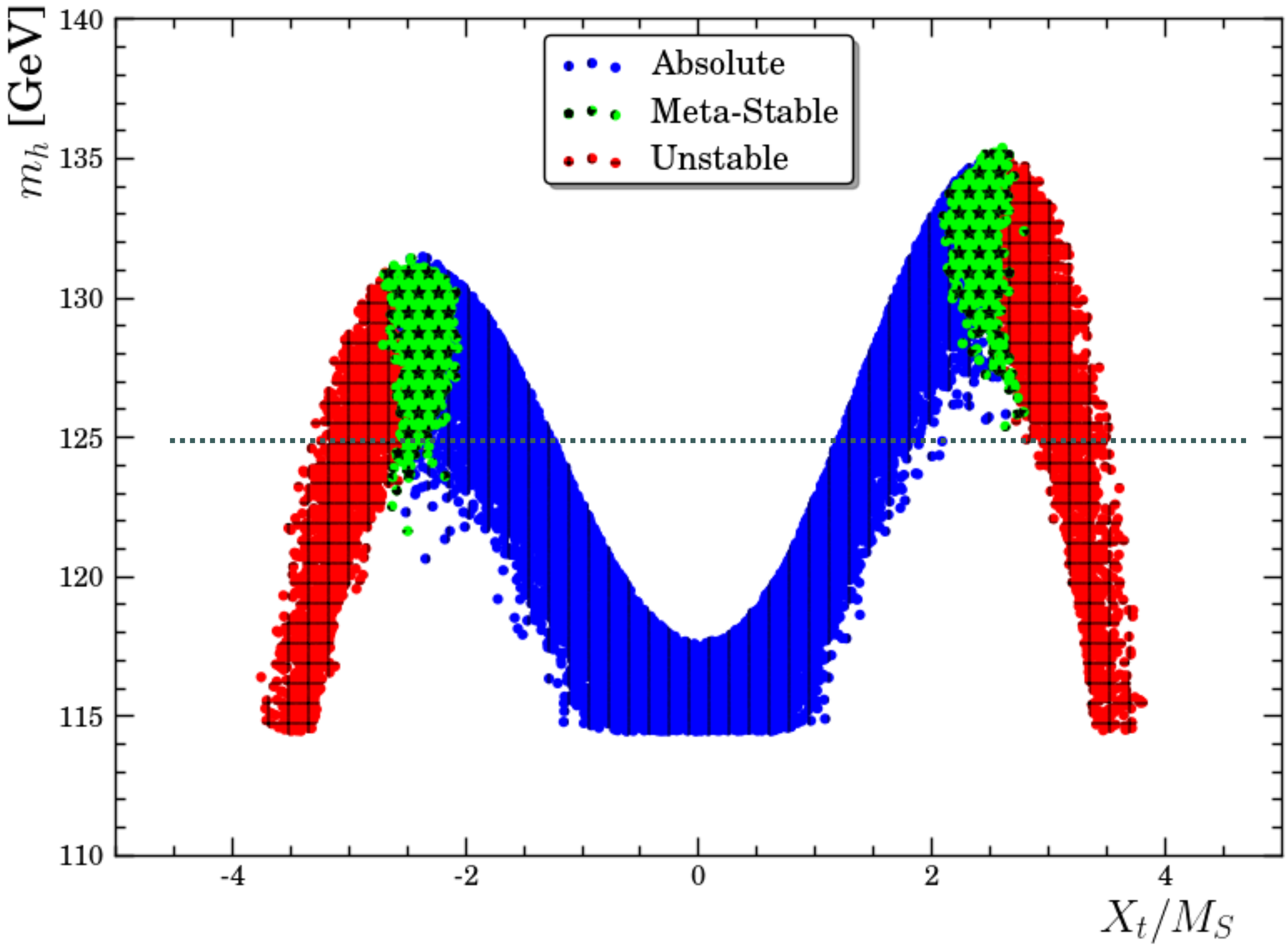
Theorem

- If LHC discovers light stops (less than TeV) and they are strongly mixed: then MSSM structure is true.

- If LHC discovers light stops and they have zero mixing, it points to structures beyond MSSM (like NMSSM , D-terms etc..)

Is the universe in a *critical* parameter SUSY parameter space ?

Stability of MSSM vacuum analysis with four fields, the two Higgs fields and the stop fields (considering they are light)



Chowdhury, Godbole, Mohan, Vempati, arXiv: 1310.1932

and other groups

SUSEFLAV with Cosmo Transitions etc.

Theoretical Status of the Higgs mass computation

One loop terms +

dominant 2-loop contribution due to top-stop loops

$$\Pi_{\phi_1}^{(2-\text{loop})}(0) = 0 \qquad \Pi_{\phi_1\phi_2}^{(2-\text{loop})}(0) = 0$$

$$\Pi_{\phi_2}^{(2-\text{loop})}(0) = \frac{G_F\sqrt{2}}{\pi^2}\frac{\alpha_s}{\pi}\frac{\bar{m}_t^4}{\sin^2\beta}\left[4 + 3\log^2\left(\frac{\bar{m}_t^4}{M_S^4}\right) + 2\log\left(\frac{\bar{m}_t^4}{M_S^4}\right) - 6\frac{X_t}{M_S} - \frac{X_t^2}{M_S^2}\left\{3\log\left(\frac{\bar{m}_t^2}{M_S^2}\right) + 8\right\} + \frac{17}{12}\frac{X_t^4}{M_S^4}\right]$$

$$\bar{m}_t = \bar{m}_t(m_t) \approx \frac{m_t^{\text{pole}}}{1 + \frac{4}{3\pi}\alpha_s(m_t)} \qquad +\mathcal{O}(G_F^2 m_t^6)$$

Heinemeyer et.al, 9812472

dominant 2-loop correction increases the lightest Higgs mass <10 GeV to the tree-level, assuming the sparticles are < 1 TeV (in no-mixing scenario).

3-loop correction

calculated up to $\mathcal{O}(\alpha_t \alpha_s^2)$

keeping only the leading terms $\sim m_t^4$

no mixing in the stop sector $\Rightarrow X_t = 0$

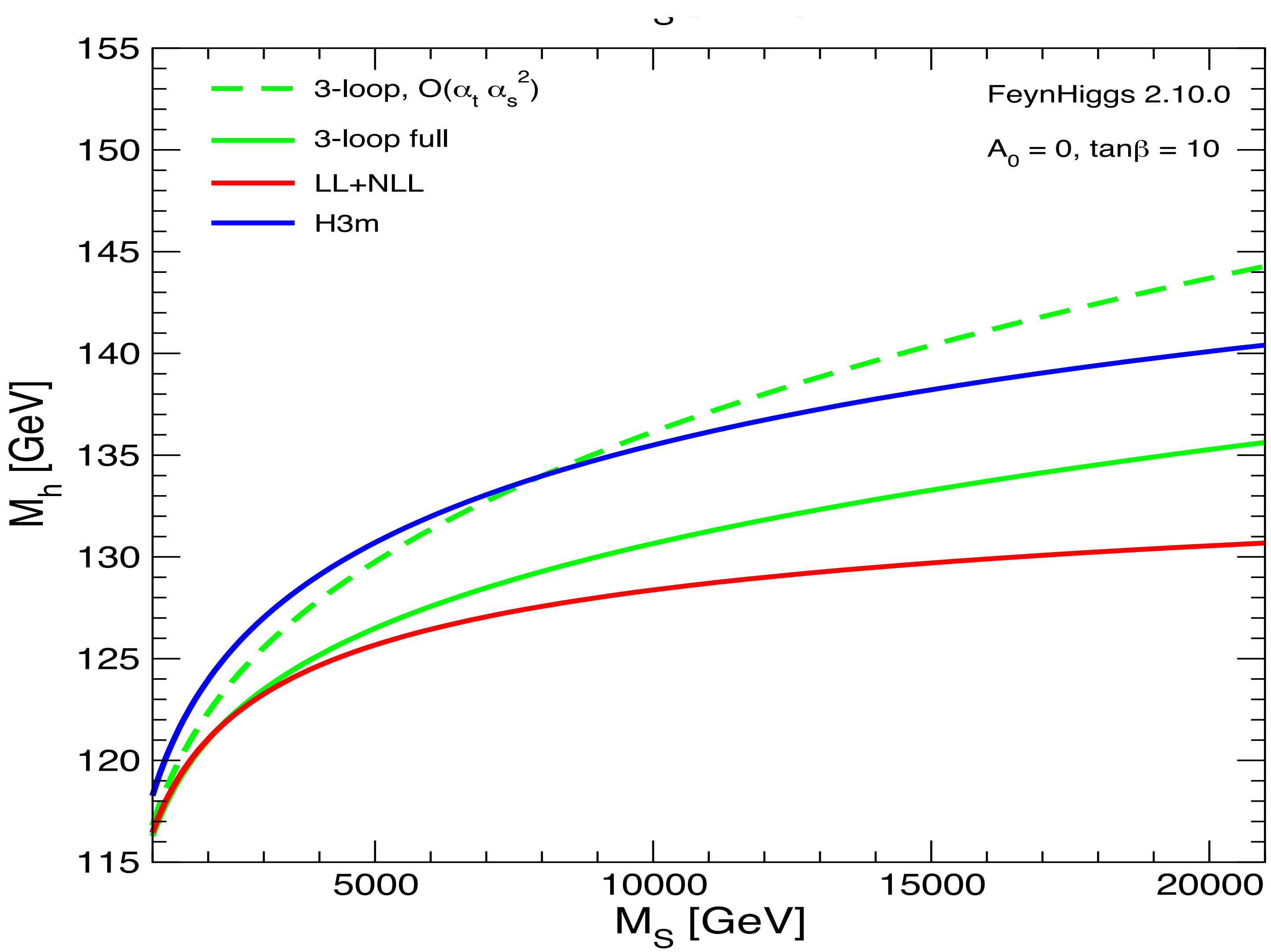
Harlander et al. '08
Martin '07

$$\Delta m_h^{3-\mathrm{loop}} \approx 500 \ \mathrm{MeV}$$

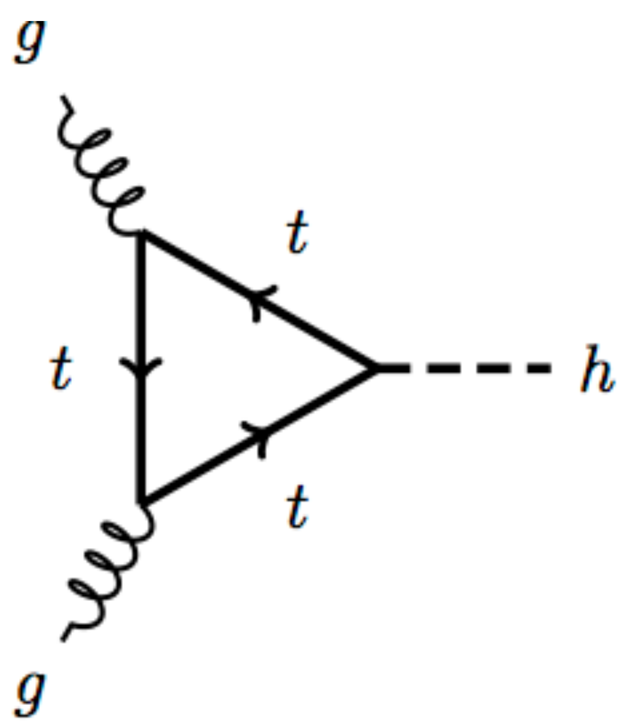
Most Publicly available spectrum generators calculate the CP-even Higgs spectrum at the 2-loop order.

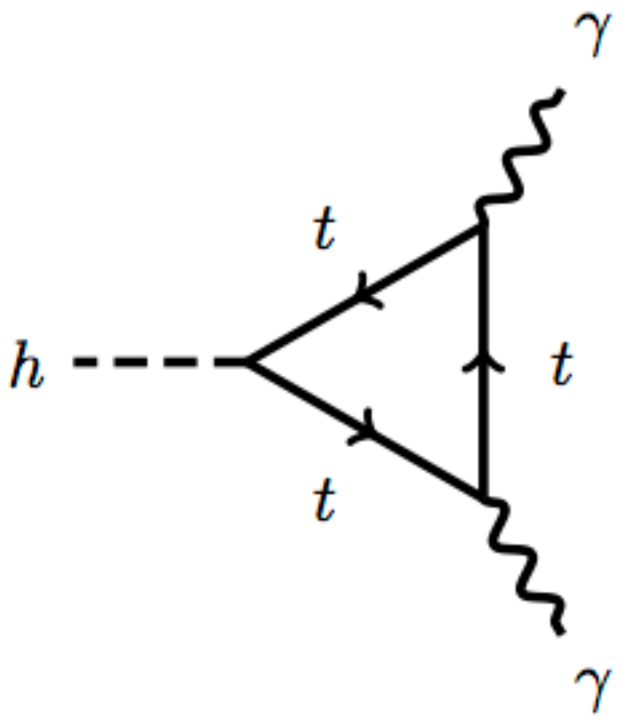
Theoretical Status of the Higgs mass computation

T.Hahn et. al, arXiv: 1312.4937.
Buchmueller et. al, arXiv:1312.5233
Draper et. al 1312.5743



Higgs productions, decays

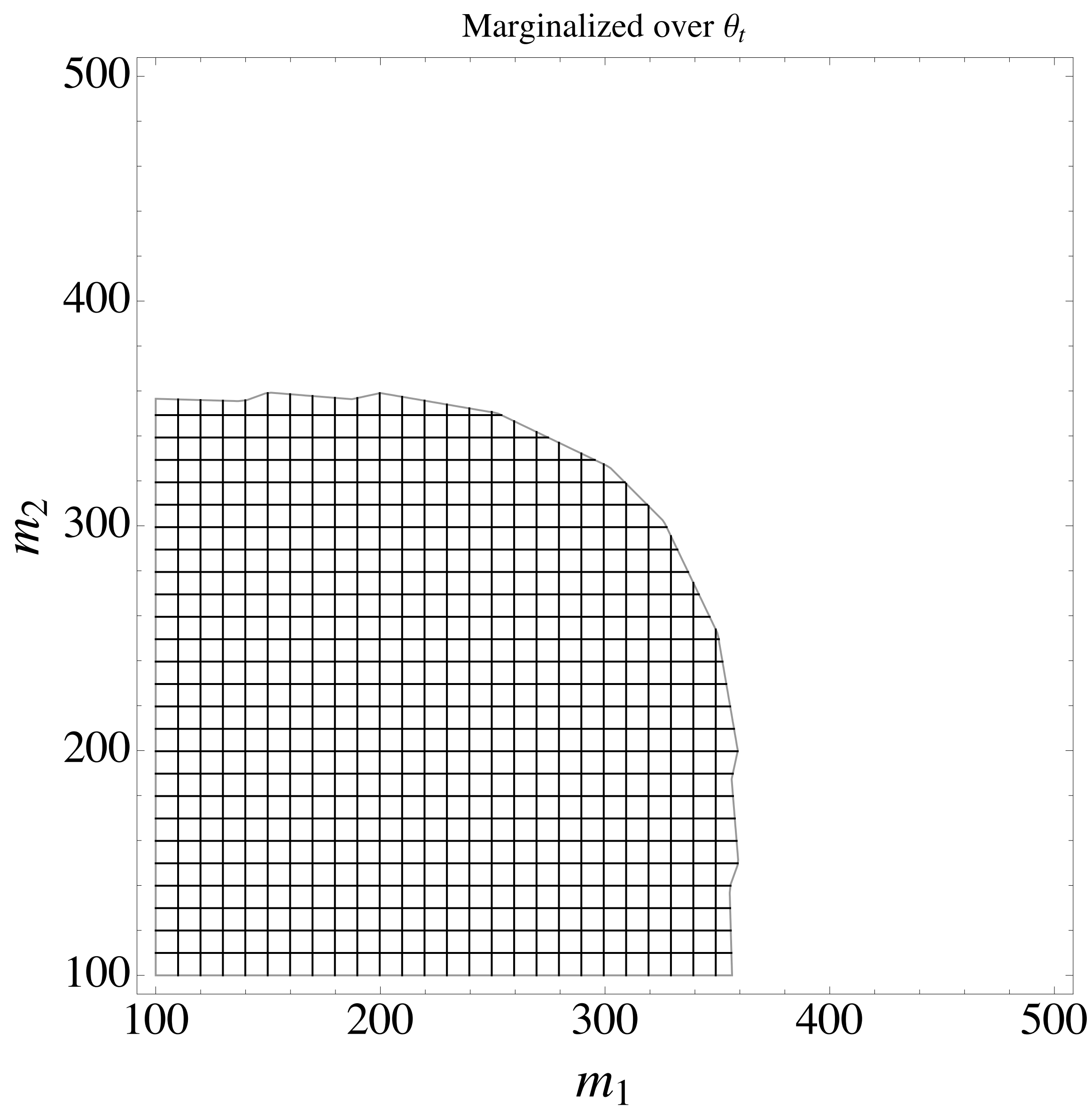


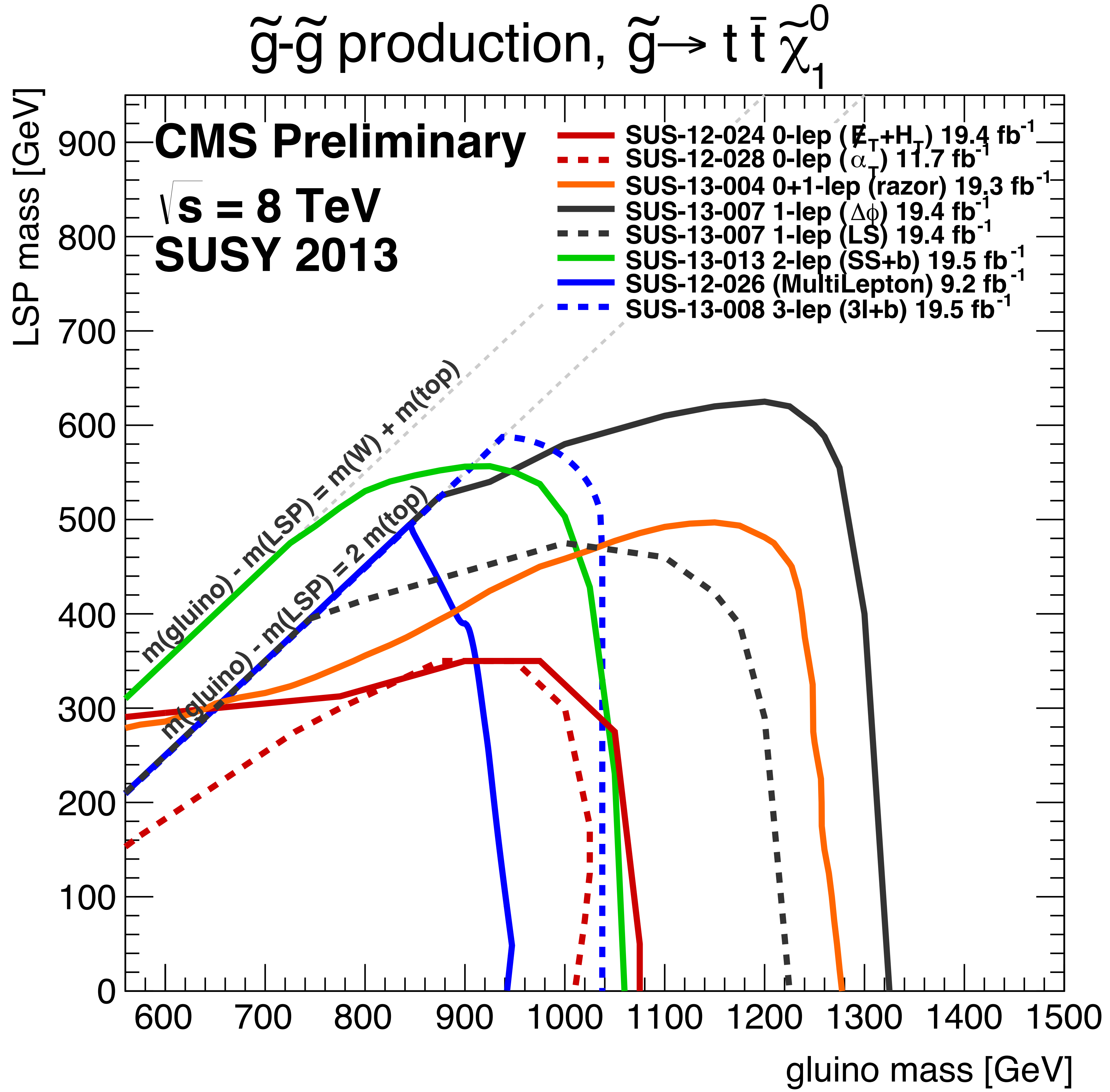


Light stops, light staus can significantly modify them…

Limits on Stop masses

Adam Falkowski et. al

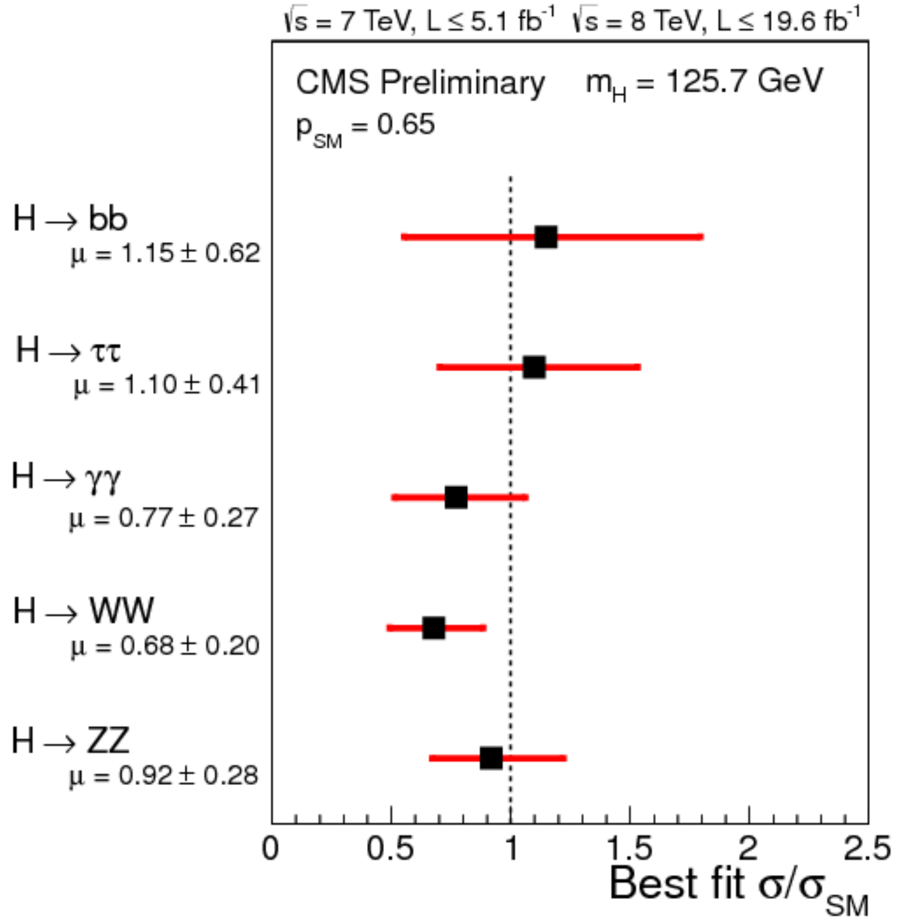


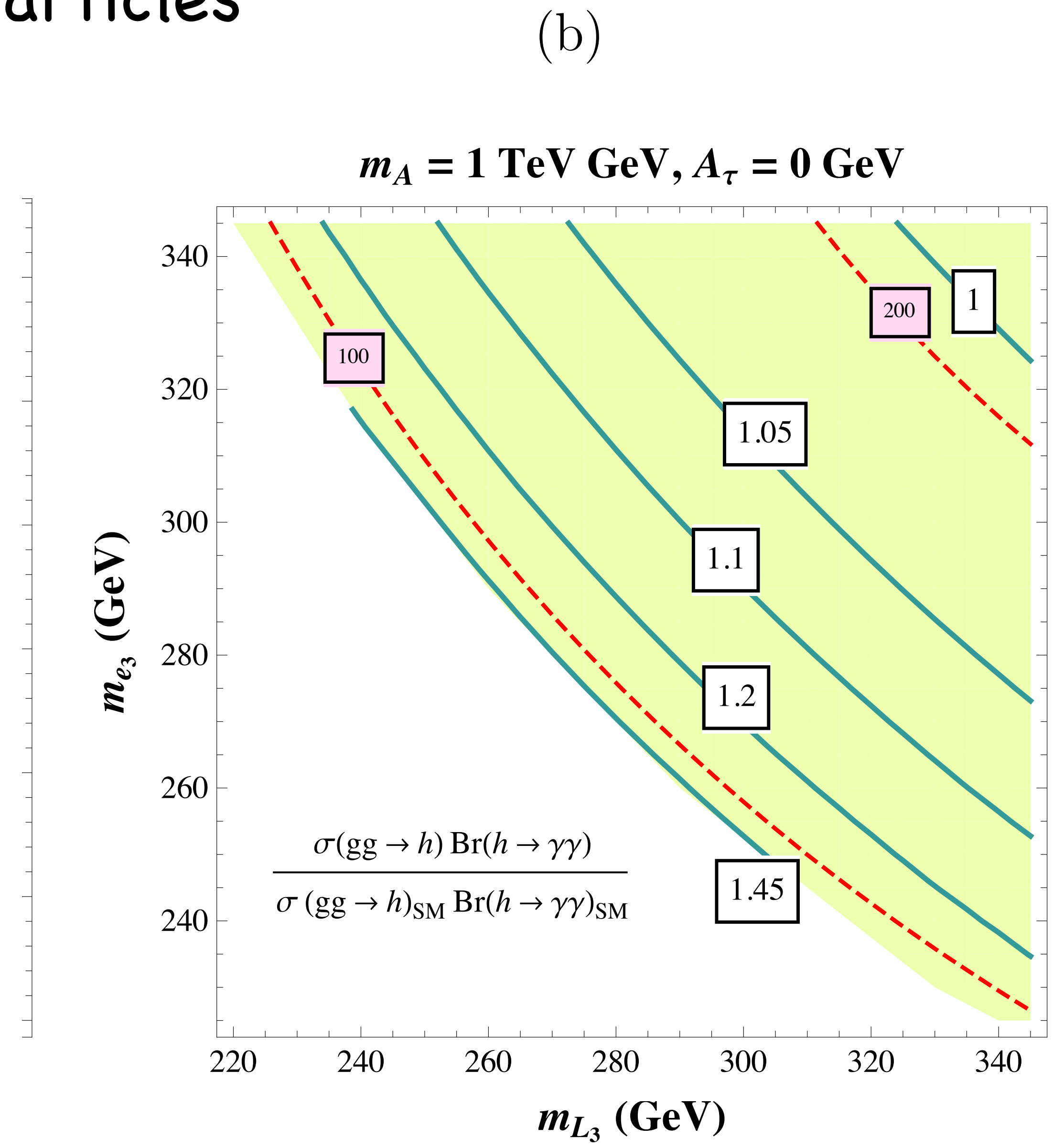


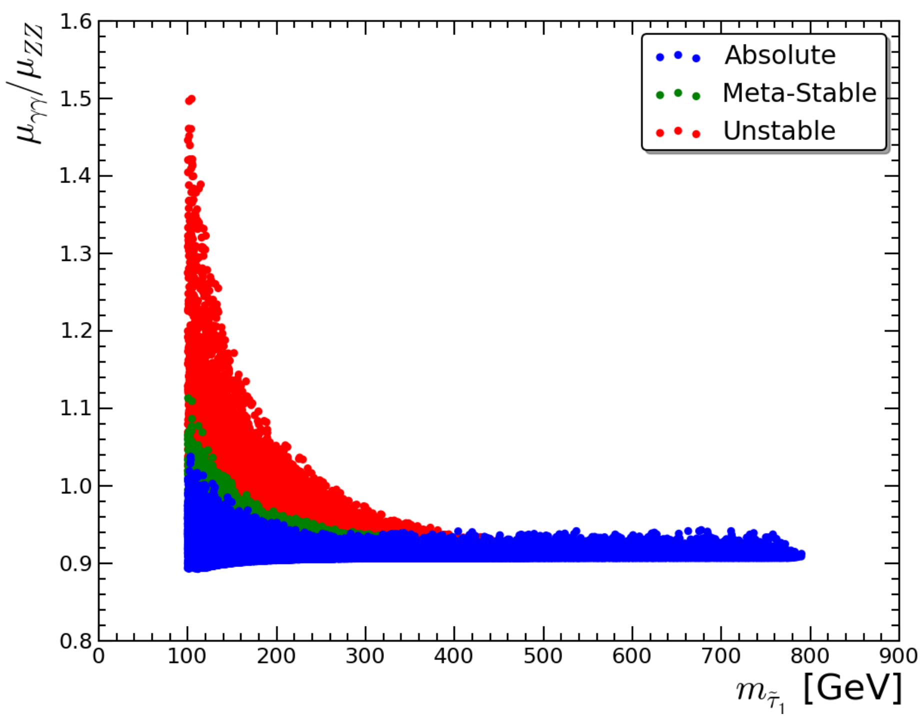
g̃-g̃ production, g̃→ t t̄ χ̃⁰₁
CMS Preliminary
√s = 8 TeV
SUSY 2013
SUS-12-024 0-lep (E̸T+HT) 19.4 fb-1
SUS-12-028 0-lep (αT) 11.7 fb-1
SUS-13-004 0+1-lep (razor) 19.3 fb-1
SUS-13-007 1-lep (Δφ) 19.4 fb-1
SUS-13-007 1-lep (LS) 19.4 fb-1
SUS-13-013 2-lep (SS+b) 19.5 fb-1
SUS-12-026 (MultiLepton) 9.2 fb-1
SUS-13-008 3-lep (3l+b) 19.5 fb-1
m(gluino) - m(LSP) = m(W) + m(top)
m(gluino) - m(LSP) = 2 m(top)
LSP mass [GeV]
gluino mass [GeV]
0
100
200
300
400
500
600
700
800
900
600
700
800
900
1000
1100
1200
1300
1400
1500

Carena et. al
1205.5842

Signal strengths can be used to constrain light particles

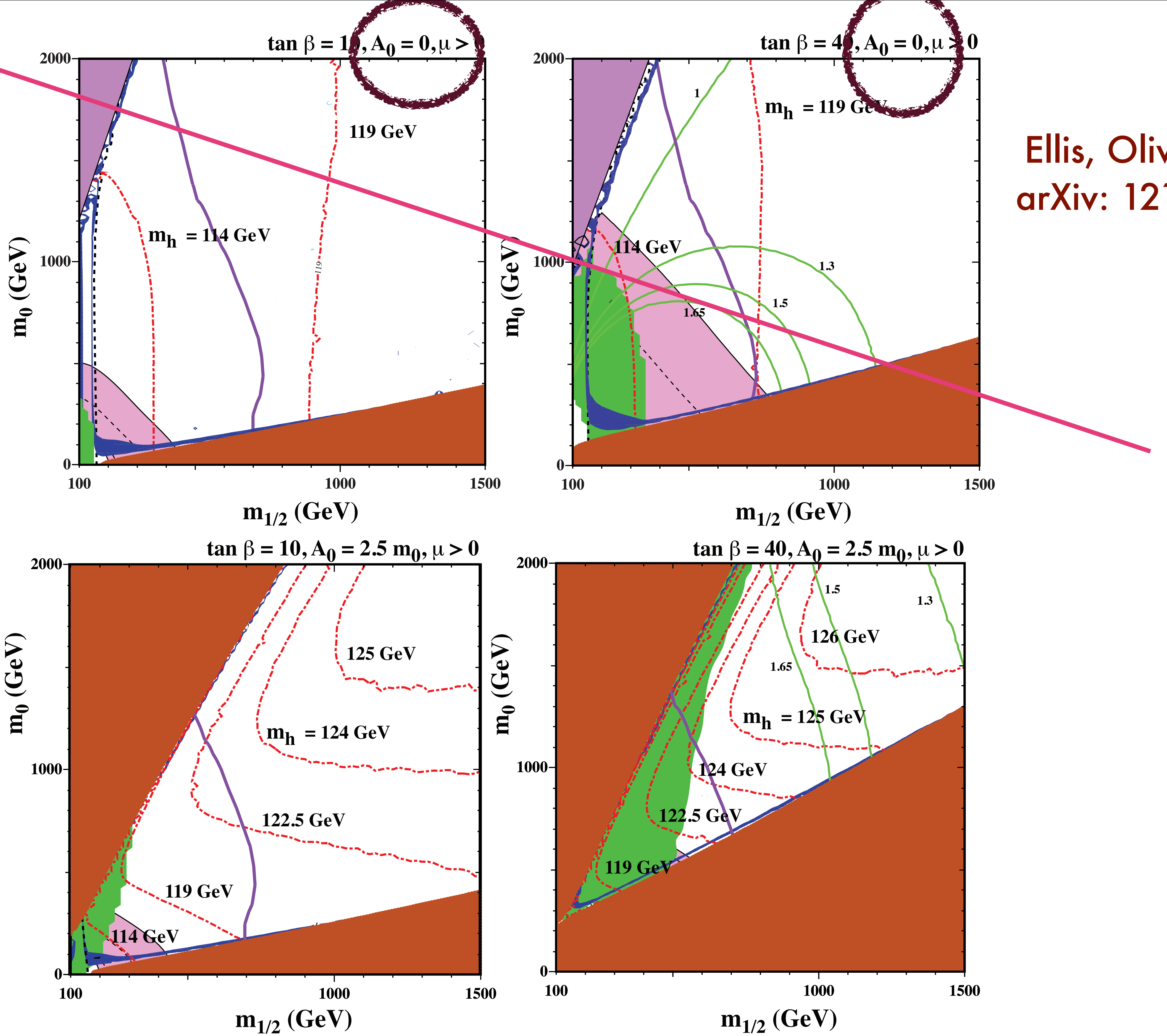






Chowdhury et. al

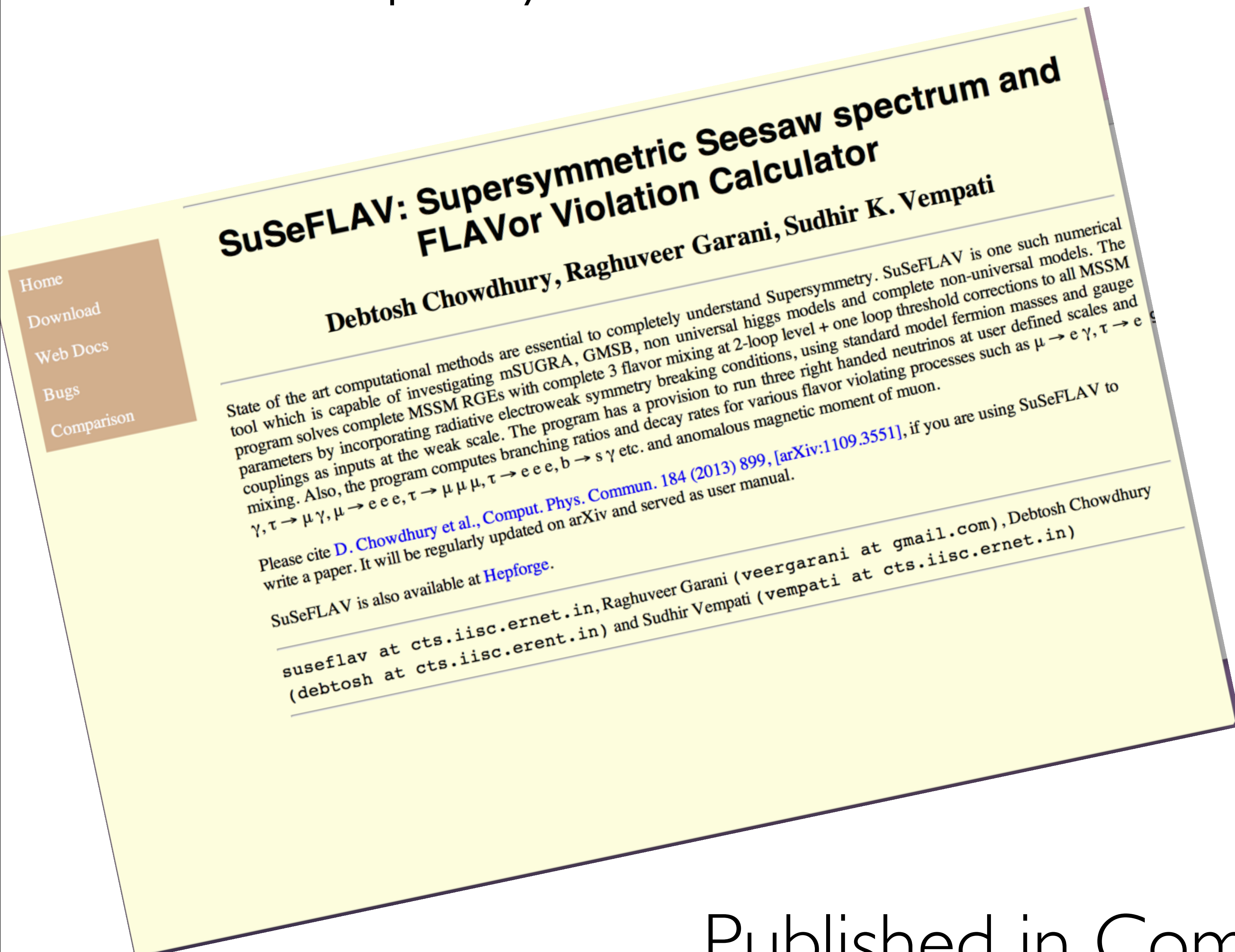
Implications on Models



Ellis, Olive et.al,
arXiv: 1212.4476

SuSeFLAV

SUpersymmetric SEesaw and Flavour Violation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Comparison

SuSeFLAV: Supersymmetric Seesaw spectrum and FLAVor Violation Calculator

Debtosh Chowdhury, Raghuveer Garani, Sudhir K. Vempati

State of the art computational methods are essential to completely understand Supersymmetry. SuSeFLAV is one such numerical tool which is capable of investigating mSUGRA, GMSB, non universal higgs models and complete non-universal models. The program solves complete MSSM RGEs with complete 3 flavor mixing at 2-loop level + one loop threshold corrections to all MSSM parameters by incorporating radiative electroweak symmetry breaking conditions, using standard model fermion masses and gauge couplings as inputs at the weak scale. The program has a provision to run three right handed neutrinos at user defined scales and mixing. Also, the program computes branching ratios and decay rates for various flavor violating processes such as $\mu \rightarrow e\,\gamma, \tau \rightarrow e\,\gamma, \tau \rightarrow \mu\,\gamma, \mu \rightarrow e\,e\,e, \tau \rightarrow \mu\,\mu\,\mu, \tau \rightarrow e\,e\,e, b \rightarrow s\,\gamma$ etc. and anomalous magnetic moment of muon.

Please cite D. Chowdhury et al., Comput. Phys. Commun. 184 (2013) 899, [arXiv:1109.3551], if you are using SuSeFLAV to write a paper. It will be regularly updated on arXiv and served as user manual.

SuSeFLAV is also available at Hepforge.

`suseflav at cts.iisc.ernet.in`, Raghuveer Garani (`veergarani at gmail.com`), Debtosh Chowdhury (`debtosh at cts.iisc.erent.in`) and Sudhir Vempati (`vempati at cts.iisc.ernet.in`)

Our Webpage

Published in Computer Physics Communications 184 (2013) 899

Range we chose

$$m_0 \in [0,\ 5]\ \mathrm{TeV}$$

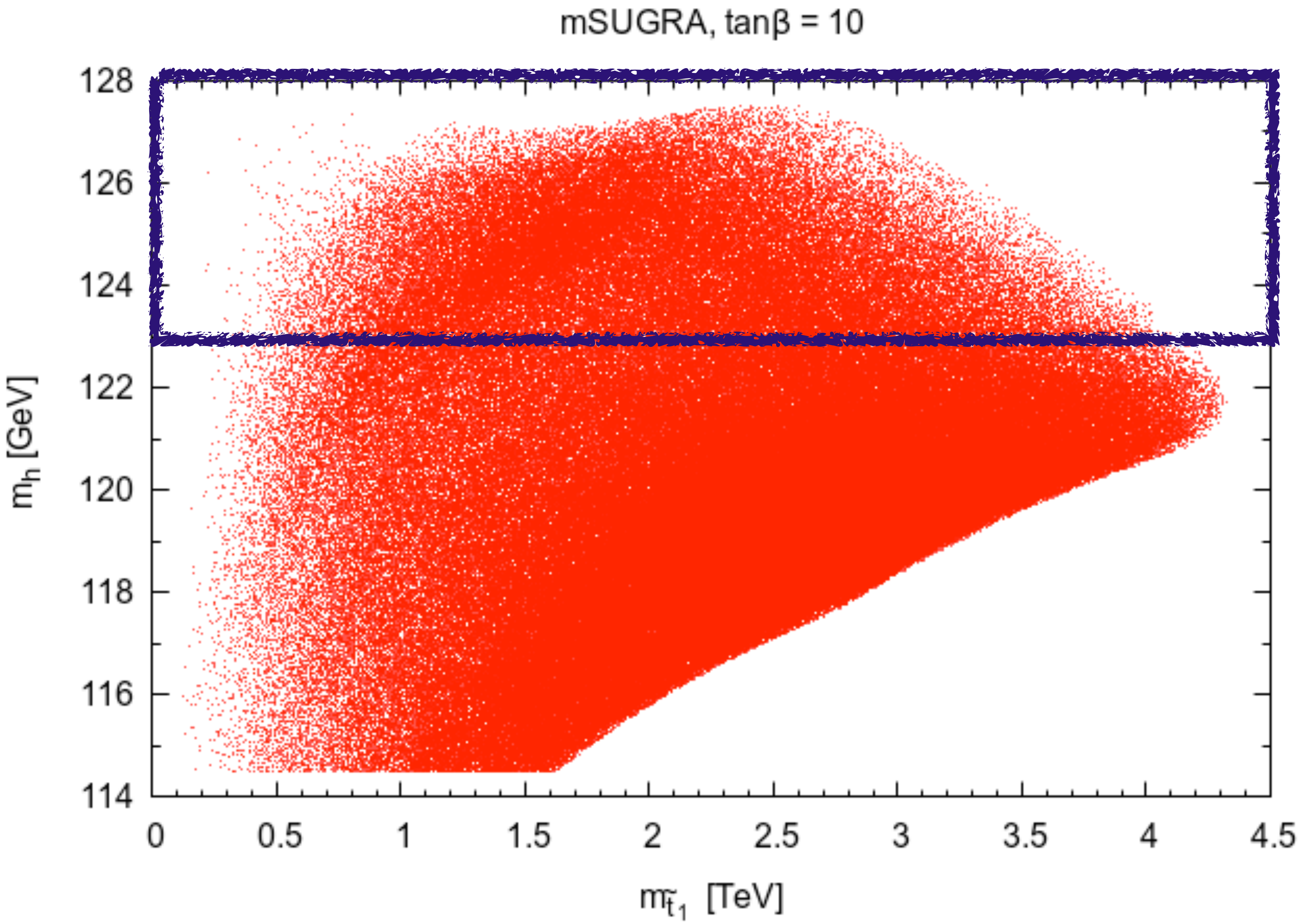
$$\Delta m_H \in \begin{cases} 0 & \text{for mSUGRA} \\ [0,\ 5] & \text{for NUHM1} \end{cases}$$

$$m_{1/2} \in [0.1,\ 2]\ \mathrm{TeV}$$

$$A_0 \in [-3m_0,\ +3m_0]$$

$$\mathrm{sgn}(\mu) \in \{-,+\}$$

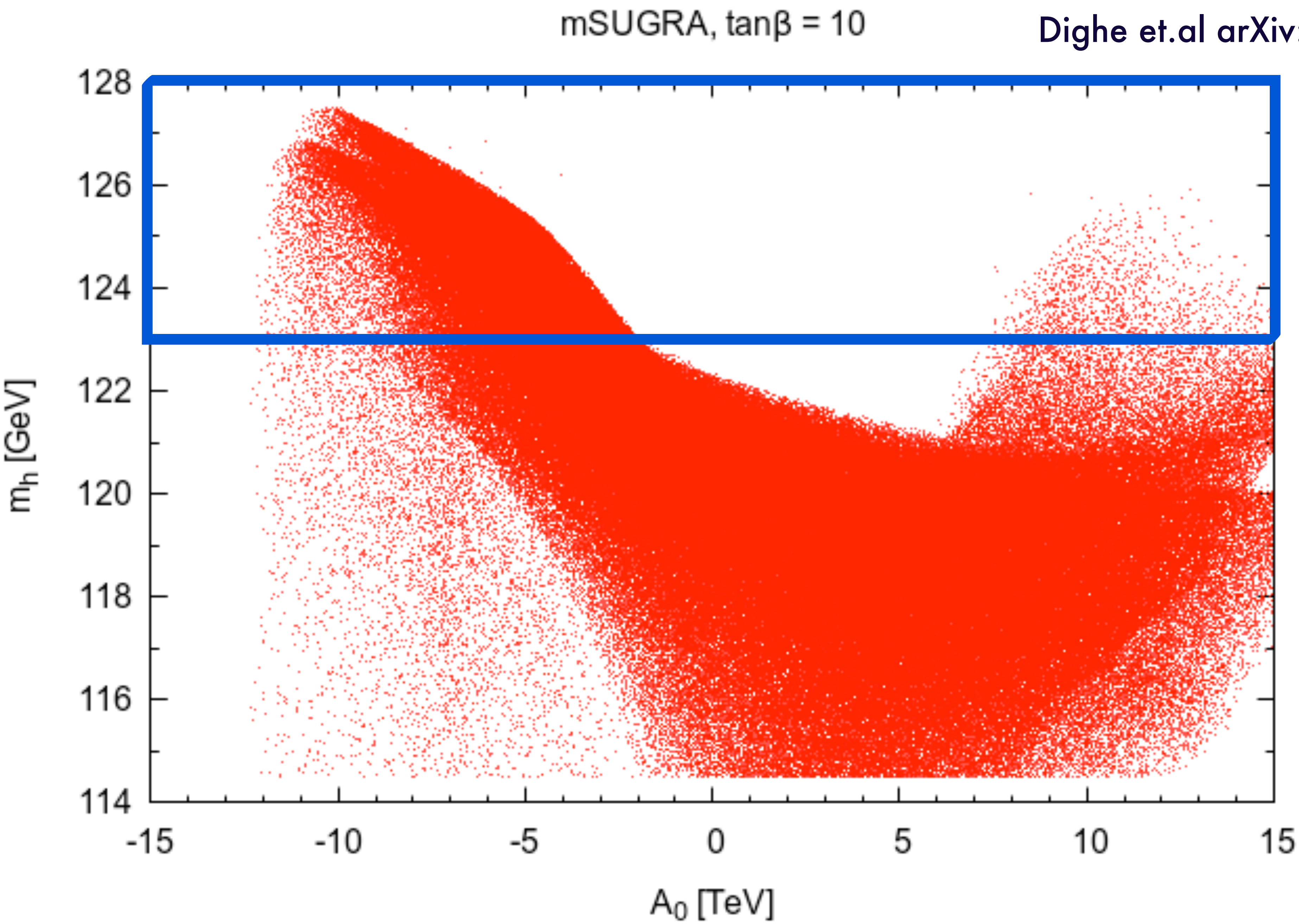
M Raidal et. al arxiv/1112.3647
P. Nath et.al and other groups
Baer et.al arXiv: 1112.3017



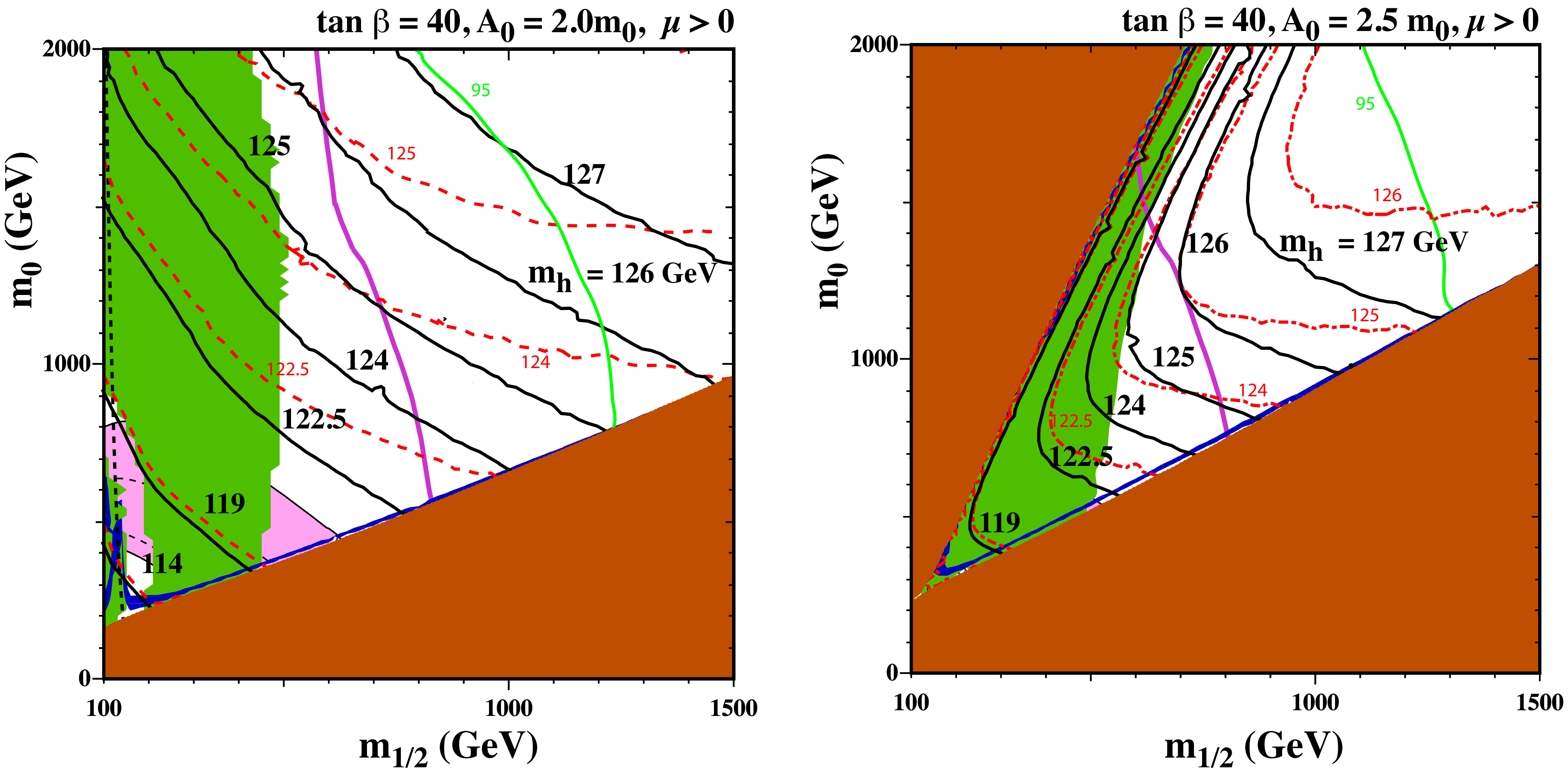
D. Chowdhury, S. Vempati, et. al

M Raidal et. al arxiv/1112.3647
P. Nath et.al and other groups
Baer et.al arXiv: 1112.3017

Dighe et.al arXiv: 1112.3017



D. Chowdhury, S. Vempati, et. al ,



latest update : 1312.5233

moving away from CMSSM- I

Non-Universal Higgs Models

Ellis, Olive et.al

$$m_{H_u}^2 \neq m_{H_d}^2 \neq m_0^2$$

Natural SUSY models

X. Tata et.al

$$(m_0^2)_{1,2} \gg m_{0\,3}^2$$

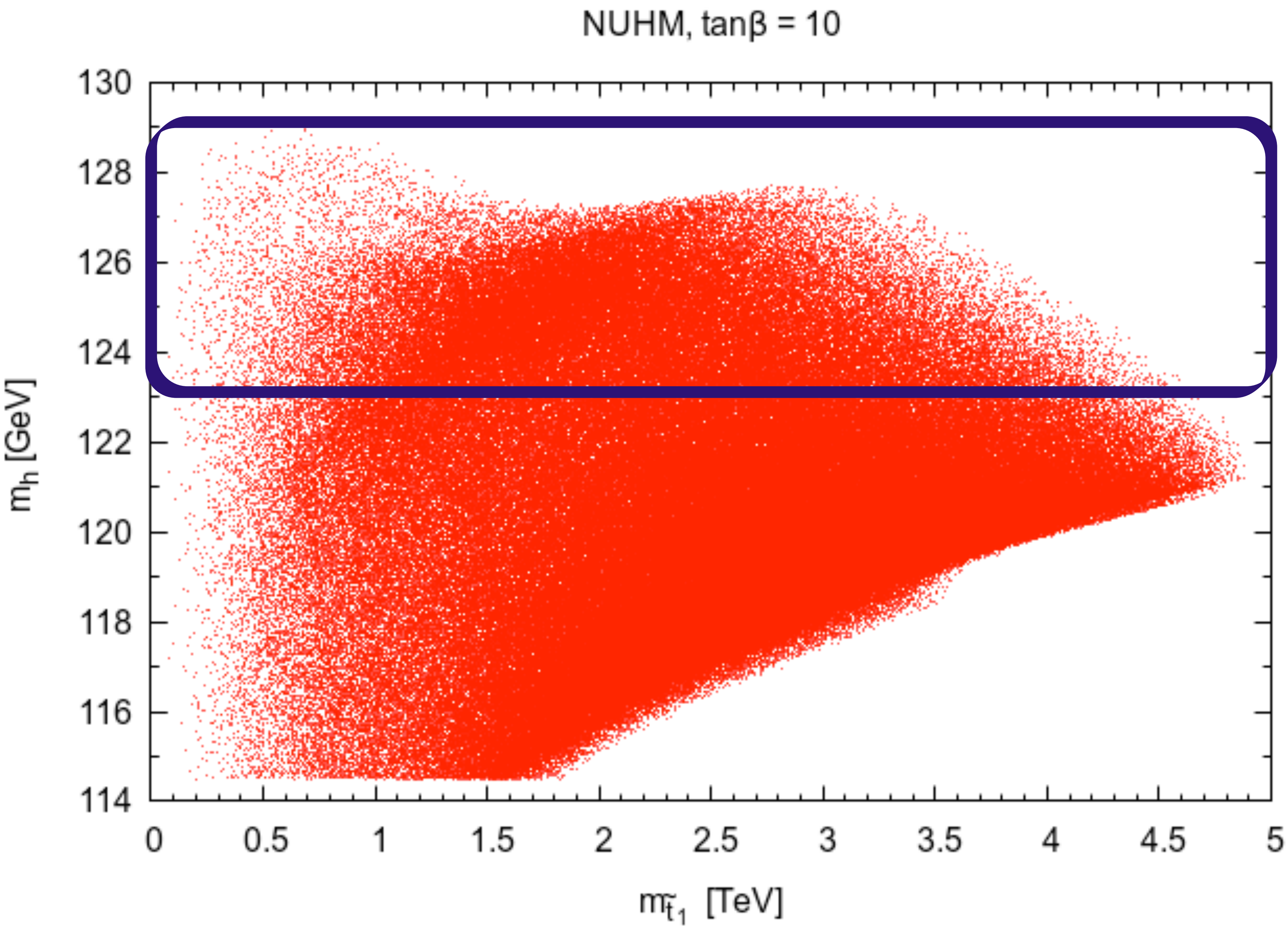
Non-Universal Gaugino models

P. Nath et. al

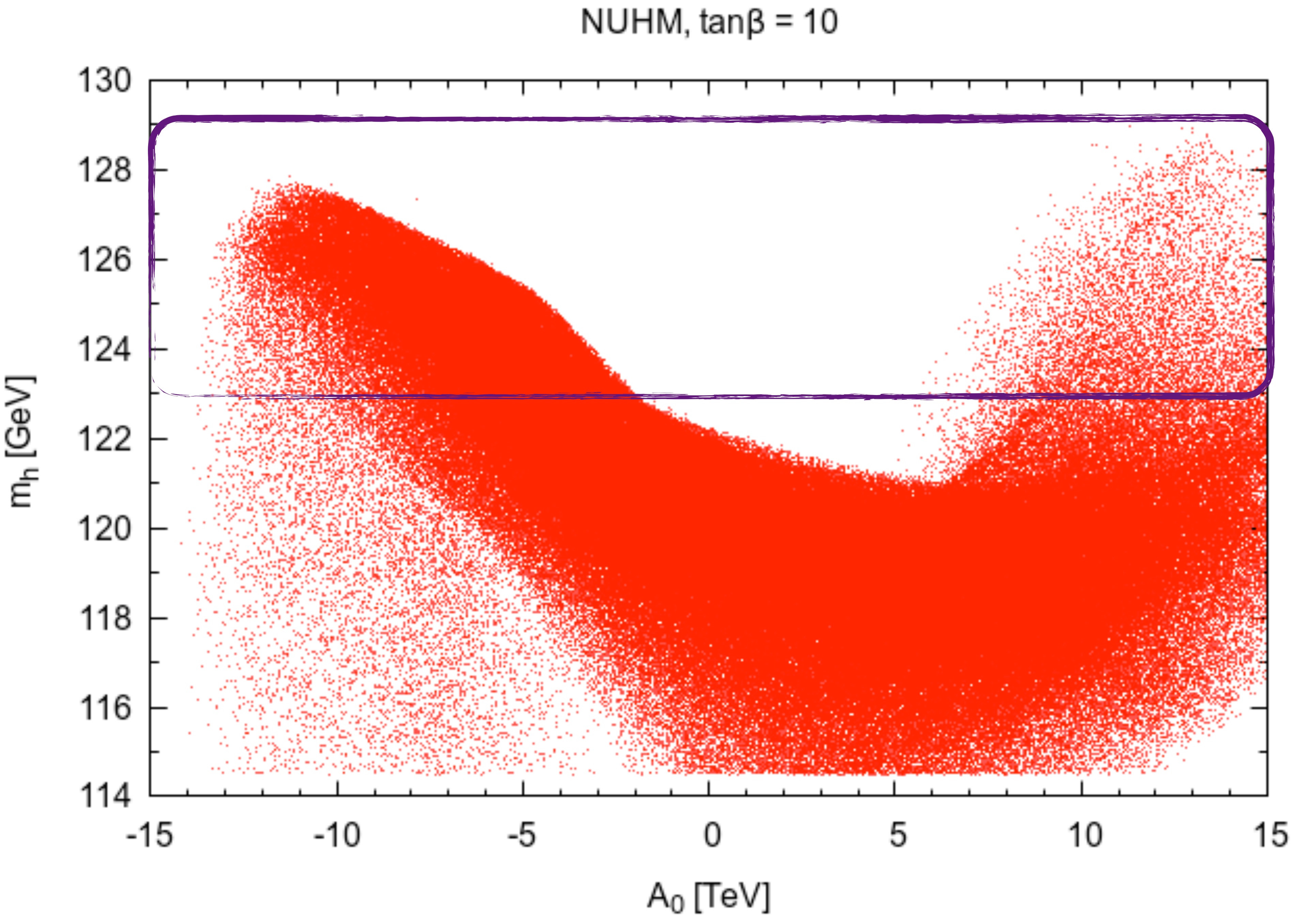
$$M_1 \neq M_2 \neq M_3$$

Non-Universal Scalar Mass models

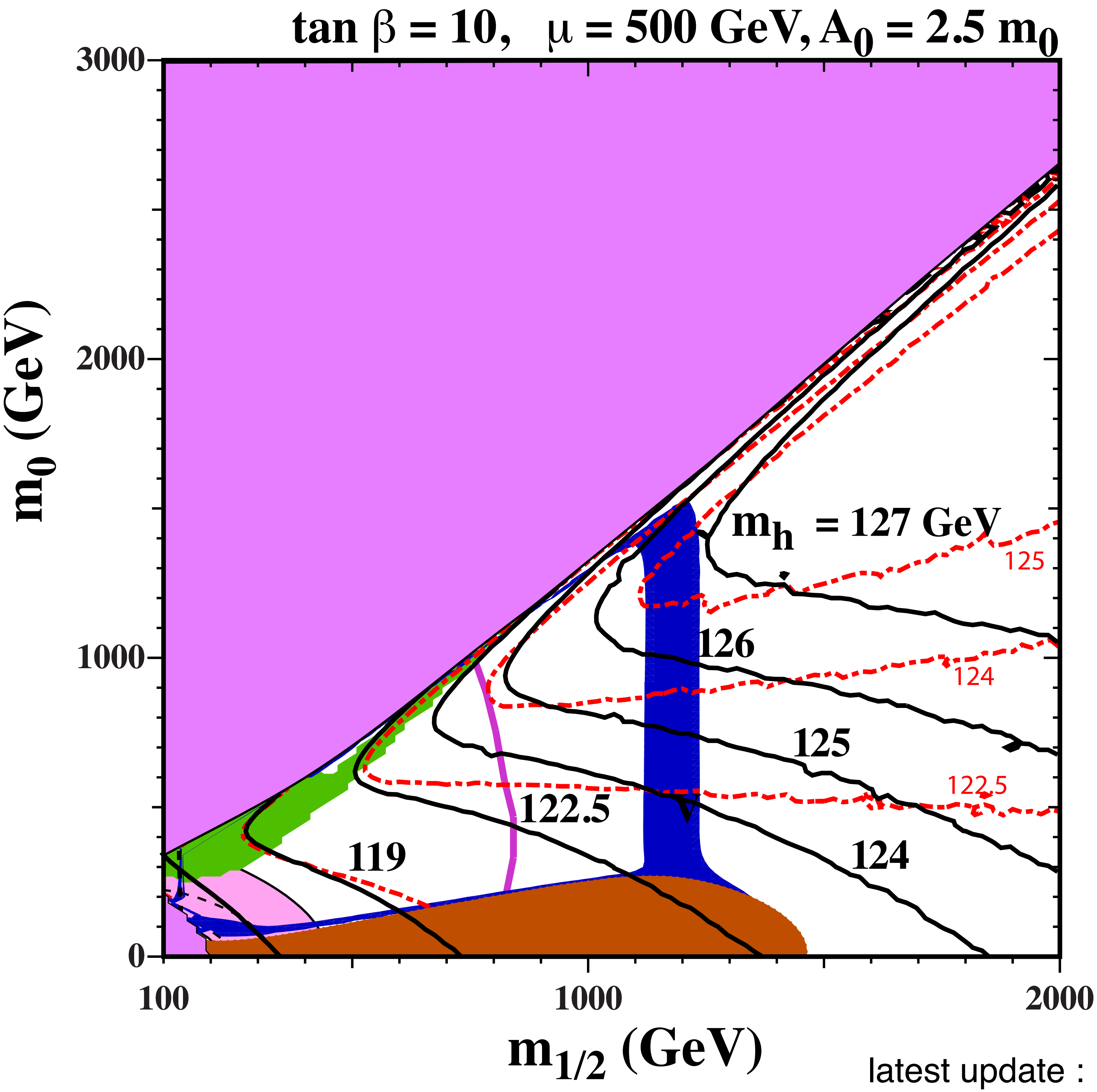
Chattopadhyaya et. al



D. Chowdhury, S. Vempati, et. al



D. Chowdhury, S. Vempati, et. al ,



latest update : 1312.5233

GUT [SO(10)] models

New Physics at Intermediate Scales

10^{18}GeV → M_{Pl} For simplification, neglect running above GUT

10^{16}GeV → M_{GUT} Gauge couplings unify

$(10^{14} - 10^{3})\text{GeV?}$ → M_{seesaw}

new running due to Intermediate scales

Three types of Seesaws,
Coloured Particles
Vector like particles
Strongly coupled sectors

10^{3}GeV → M_{SUSY}

→ M_{Z}

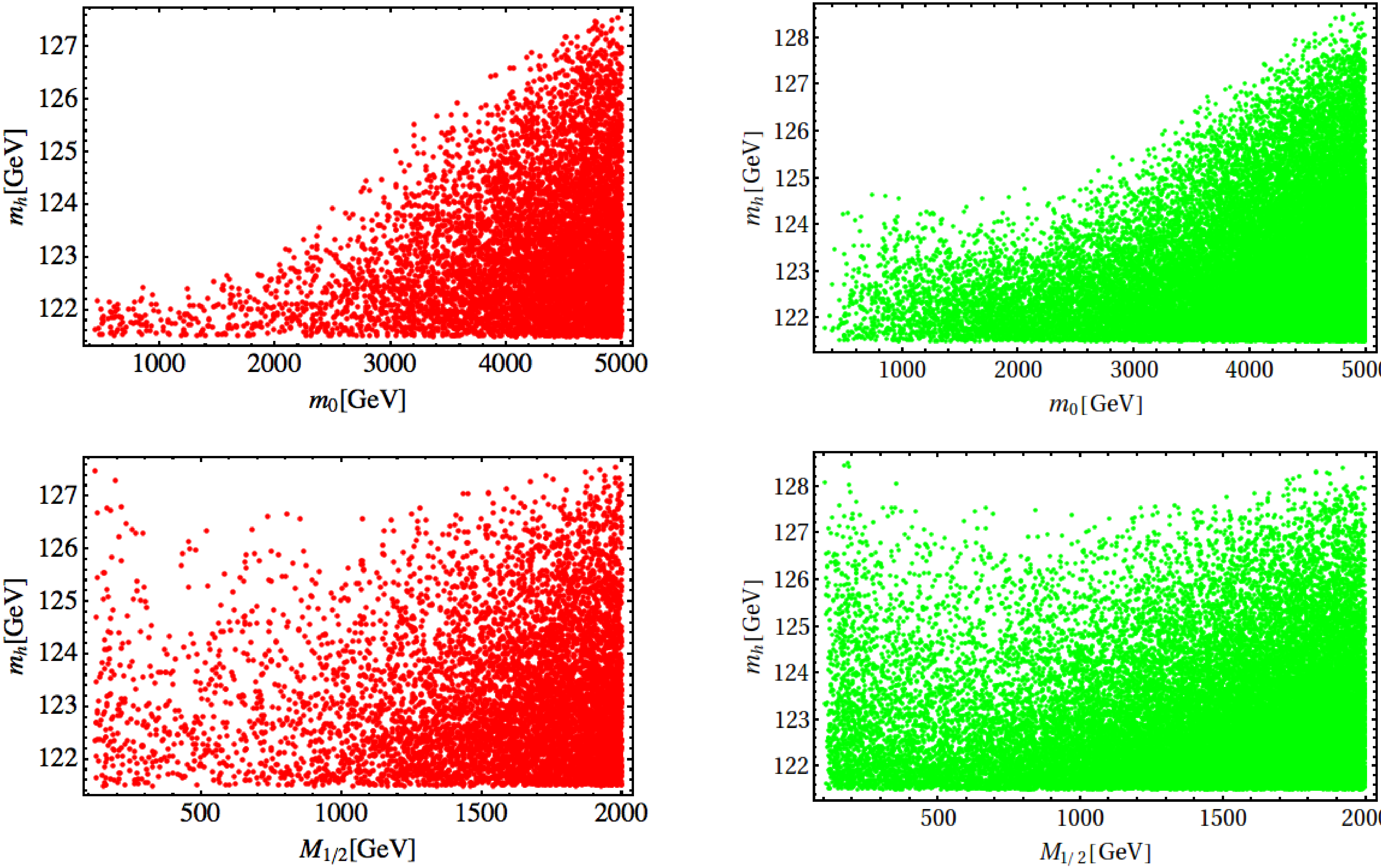
Model Dependent Results

Renormalisation of A_t is important

Chowdhury, Garg, Ibarra and Vempati , to appear

Present Constraints on mSUGRA + Seesaw

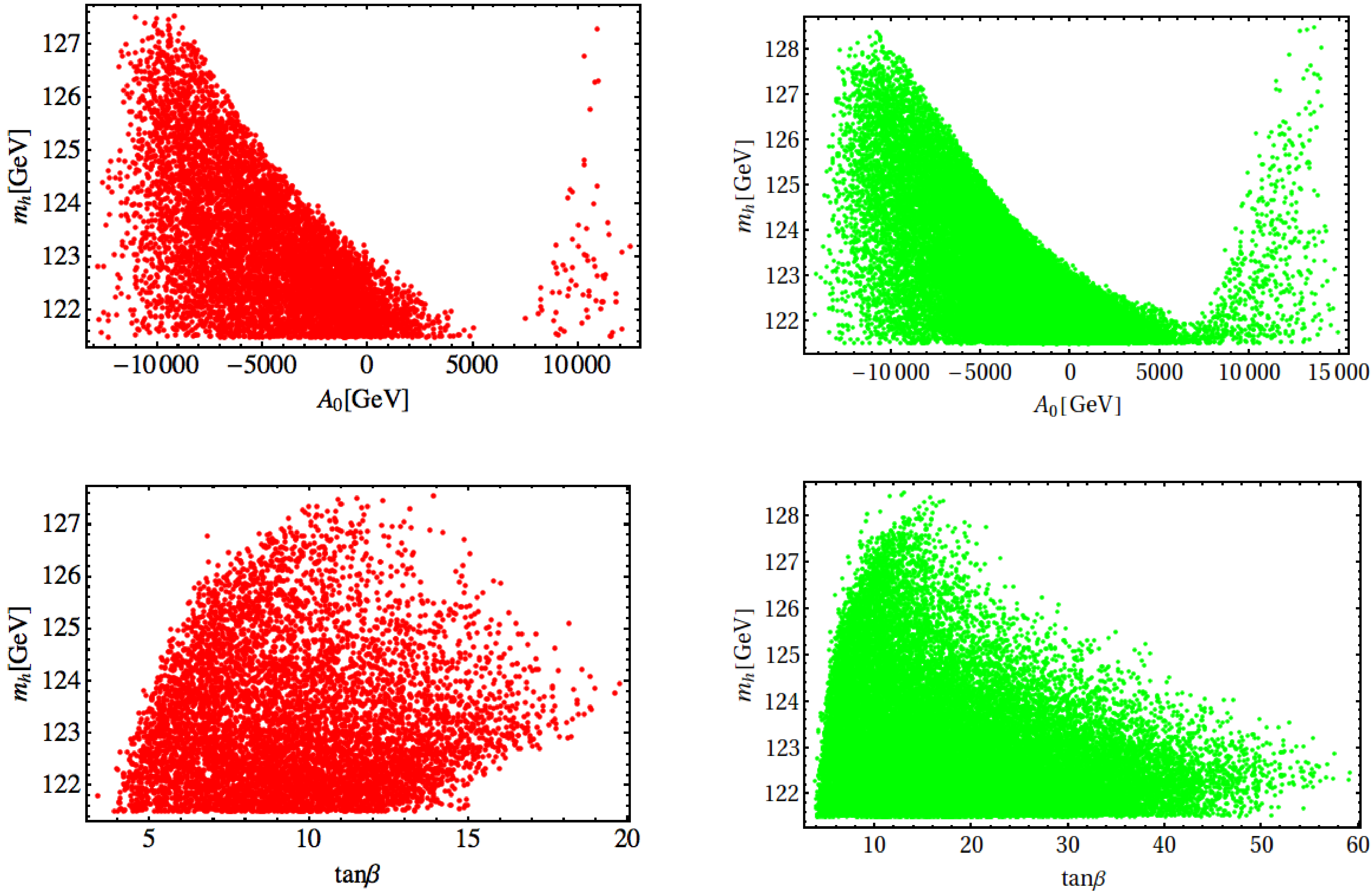
Calibbi, Chowdhury, Masiero, Patel,Vempati
JHEP 1211 (2012) 040



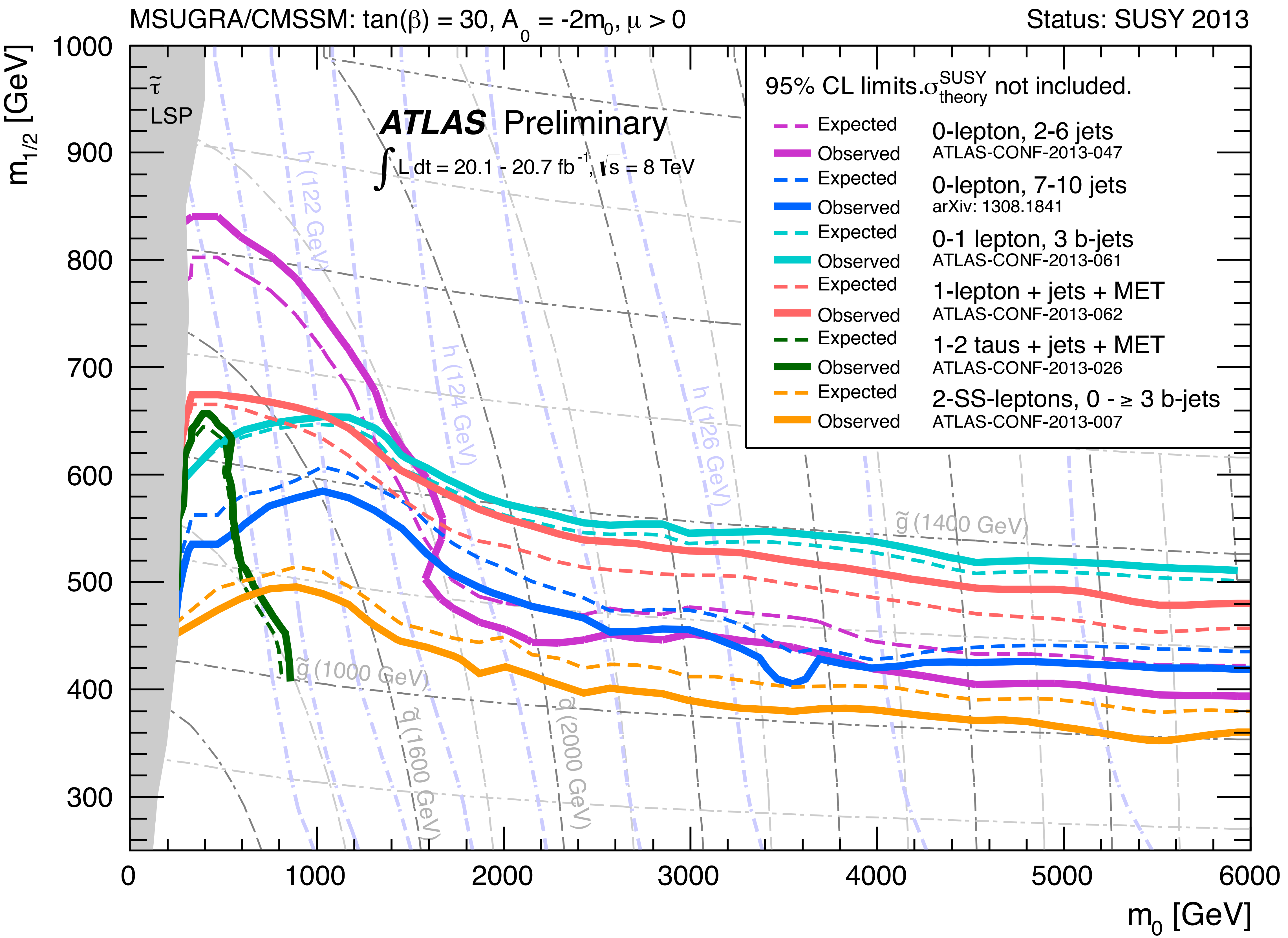
mSUGRA + seesaw

NUHM+ seesaw

Present Constraints on mSUGRA + Seesaw



Calibbi, Chowdhury, Masiero, Patel,Vempati
JHEP 1211 (2012) 040



MSUGRA/CMSSM: tan(β) = 30, A0 = -2m0, μ > 0
Status: SUSY 2013
ATLAS Preliminary
∫L dt = 20.1 - 20.7 fb-1, √s = 8 TeV
95% CL limits. σ SUSY theory not included.
Expected
Observed
0-lepton, 2-6 jets
ATLAS-CONF-2013-047
Expected
Observed
0-lepton, 7-10 jets
arXiv: 1308.1841
Expected
Observed
0-1 lepton, 3 b-jets
ATLAS-CONF-2013-061
Expected
Observed
1-lepton + jets + MET
ATLAS-CONF-2013-062
Expected
Observed
1-2 taus + jets + MET
ATLAS-CONF-2013-026
Expected
Observed
2-SS-leptons, 0 - ≥ 3 b-jets
ATLAS-CONF-2013-007
τ̃ LSP
h (122 GeV)
h (124 GeV)
h (126 GeV)
g̃ (1000 GeV)
g̃ (1400 GeV)
q̃ (1600 GeV)
q̃ (2000 GeV)
m1/2 [GeV]
m0 [GeV]
1000
900
800
700
600
500
400
300
0
1000
2000
3000
4000
5000
6000

minimal gauge mediation

Gauge Mediation

* Introduce a bunch of Matter superfields which are charged under gauge interactions but couple to the hidden sector.

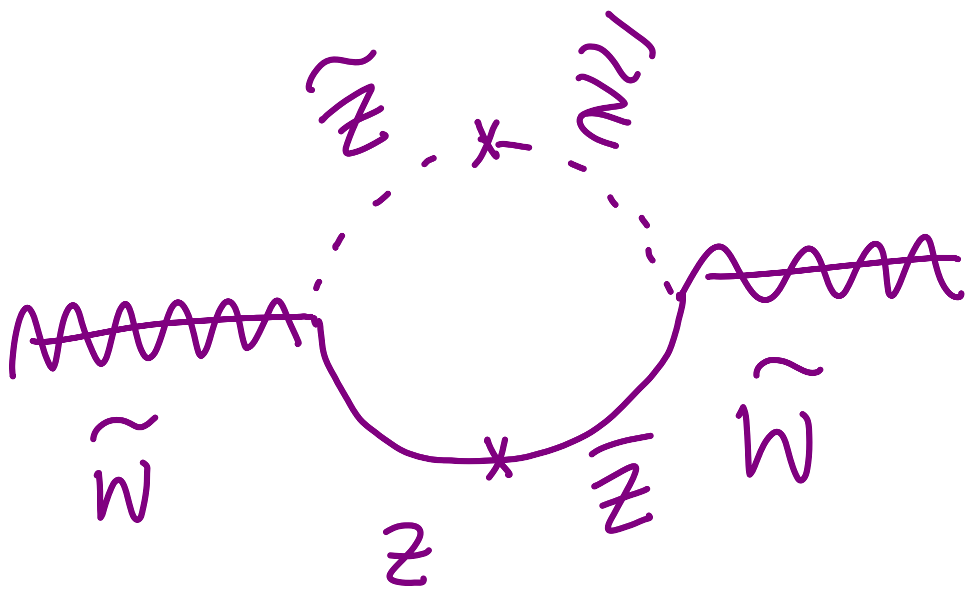
* $W \supset \lambda X Z \bar{Z}$

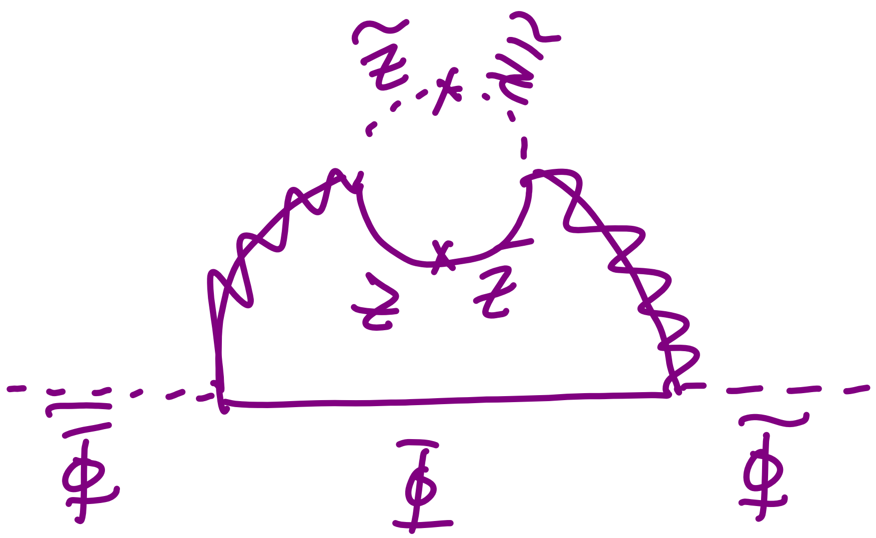
Hidden Sector (X) — Messenger sector (Z, $\bar{Z}$)

Giudice and Rattazzi, Phys. Reports Review

The Scale of SUSY breaking mediation is about 100 TeV or so

SUSY broken spontaneously by X

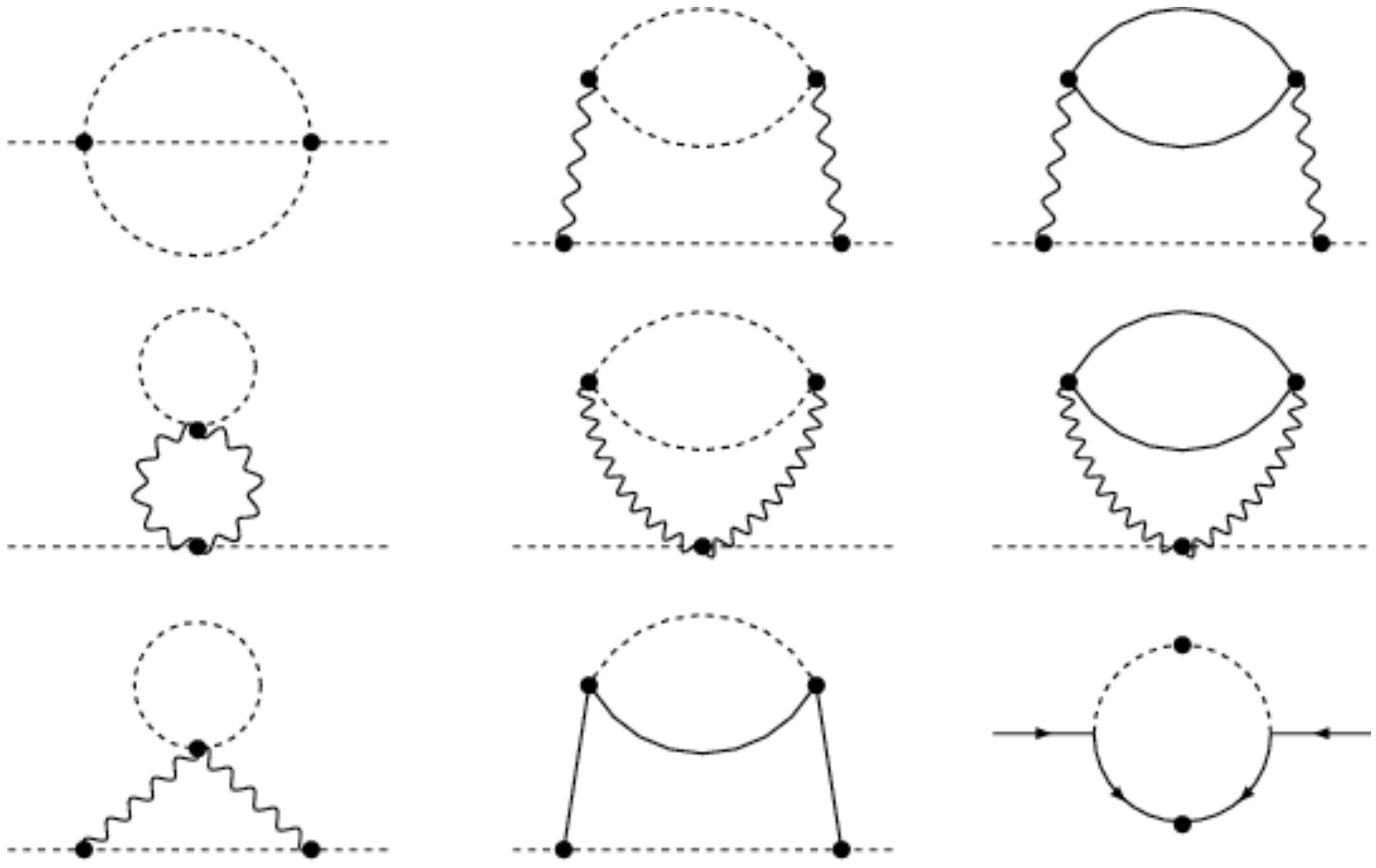




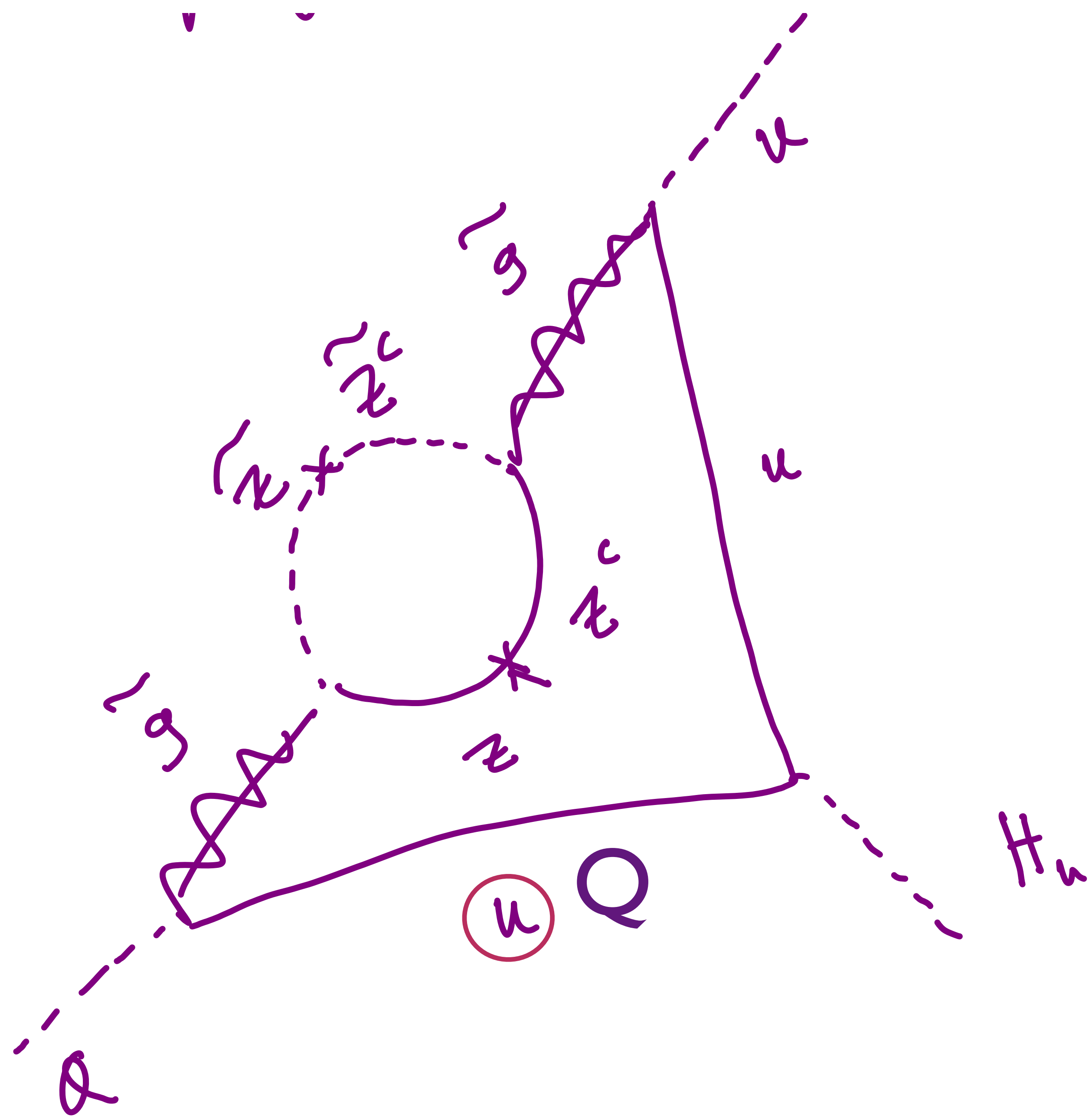
Soft masses in MSSM through loops

+ - - bunch of two loop diagrams

Two loop diagrams contributing to soft masses



Trilinear Couplings



additional coupling suppression

A-terms are essentially zero !!!

Draper, Meade, Shih et.al 1112.3068

Gauge Mediation and light higgs mass

the A-terms in the gauge mediation are very small !!

So a 125 GeV Higgs is very difficult unless we have a very heavy stop spectrum (beyond LHC)

Draper, Meade, Shih et.al 1112.3068

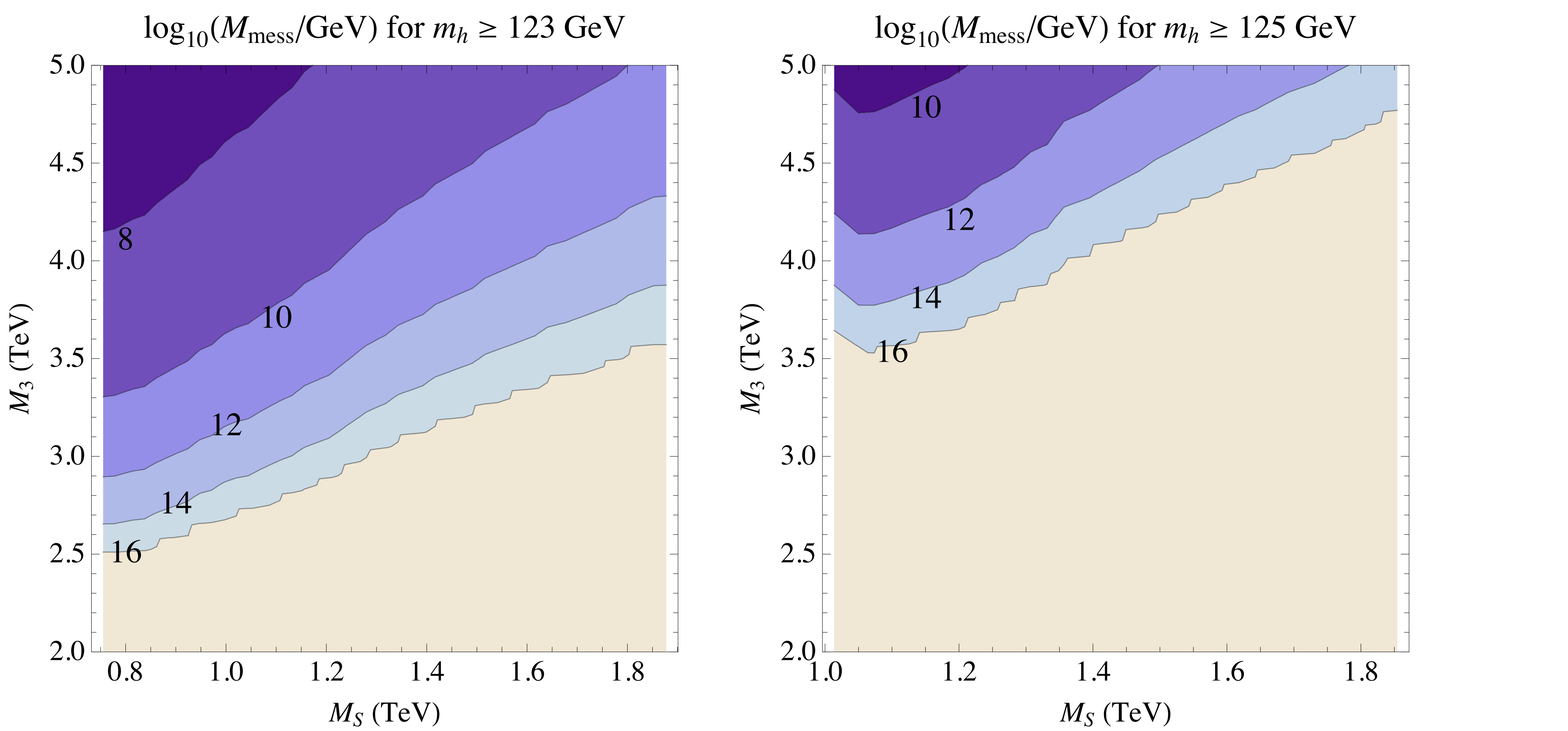


FIG. 5. Messenger scale required to produce sufficiently large $|A_t|$ for $m_h = 123$ GeV (left) and $m_h = 125$ GeV (right) through renormalization group evolution.

The change required in the messenger scale is a bit too large : almost up to GUT scale

Ways out for Gauge Mediation

(1) Have *Yukawa* mediation in addition to gauge mediation. This can be achieved by having matter-messenger fields mixing.

Delgado, Giudice, Rattazzi et. al, Yanagida et.al

review: Shih et.al, 1303.0228

(2) Have additional matter in the higgs sector.

Langacker et. al, Yanagida et. al

(3) Additional strongly coupled sectors

Yanagida et. al

NMSSM and gauge mediation

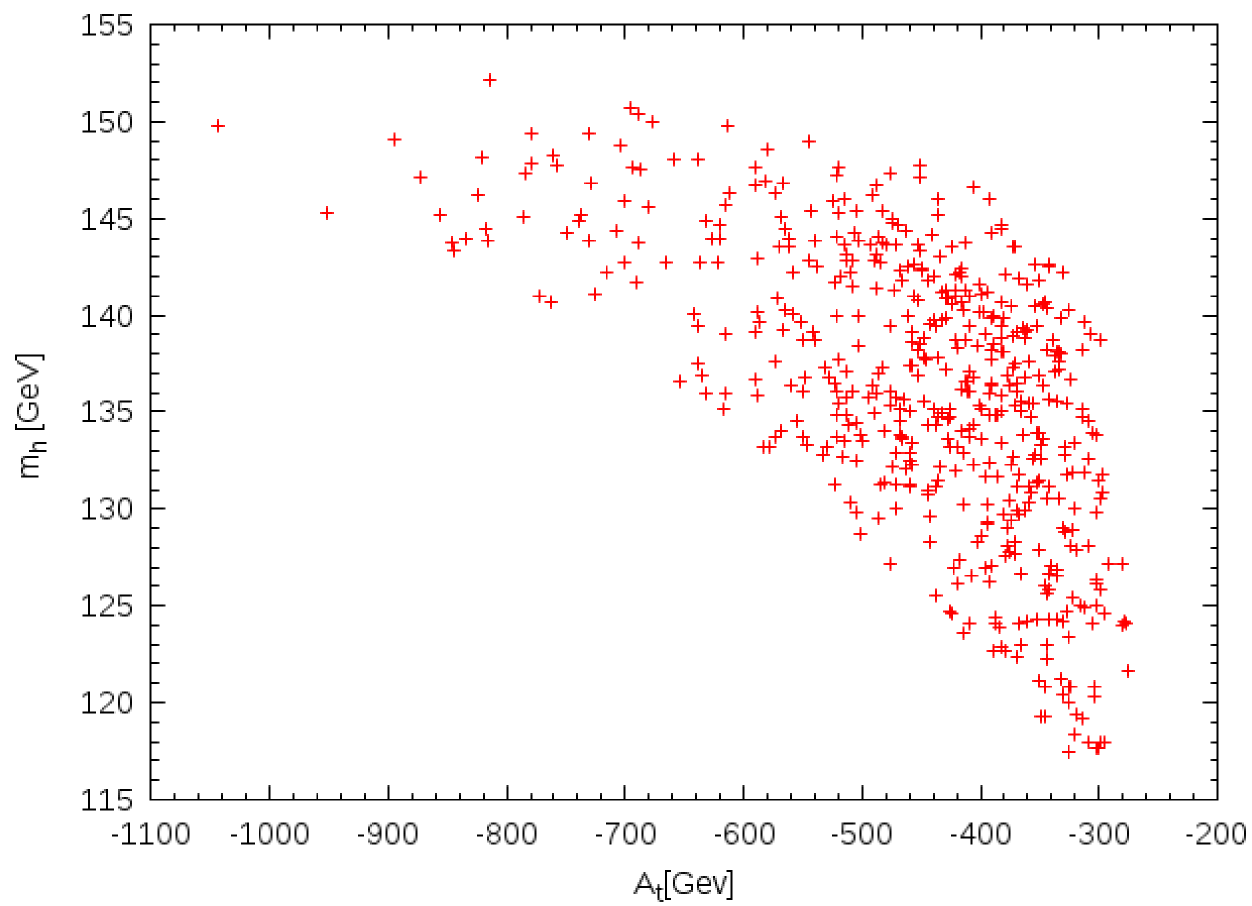
$$W = \lambda S H_u H_d + \kappa S^3 + h^u Q u^c H_2 + \ldots$$

Higgs Mass Matrix is a 3 x 3 mass matrix

A linear combination with the singlet can increase the light higgs mass

But the singlet is massless at the mediation scale !!!

Can be made to work with an extra gauge group !!



Sooryanarayana and Vempati, (to appear in NPB)

Rescuing Gauge Mediation has now several ways.
In this particular case Z' will be a signal along with SUSY..

In other cases, there could extra vector like fermions or
some other light matter along with SUSY..
which roughly follows the sum rules of minimal GMSB.

Direct LHC limits

ATLAS SUSY Searches* - 95% CL Lower Limits

Status: SUSY 2013

ATLAS Preliminary

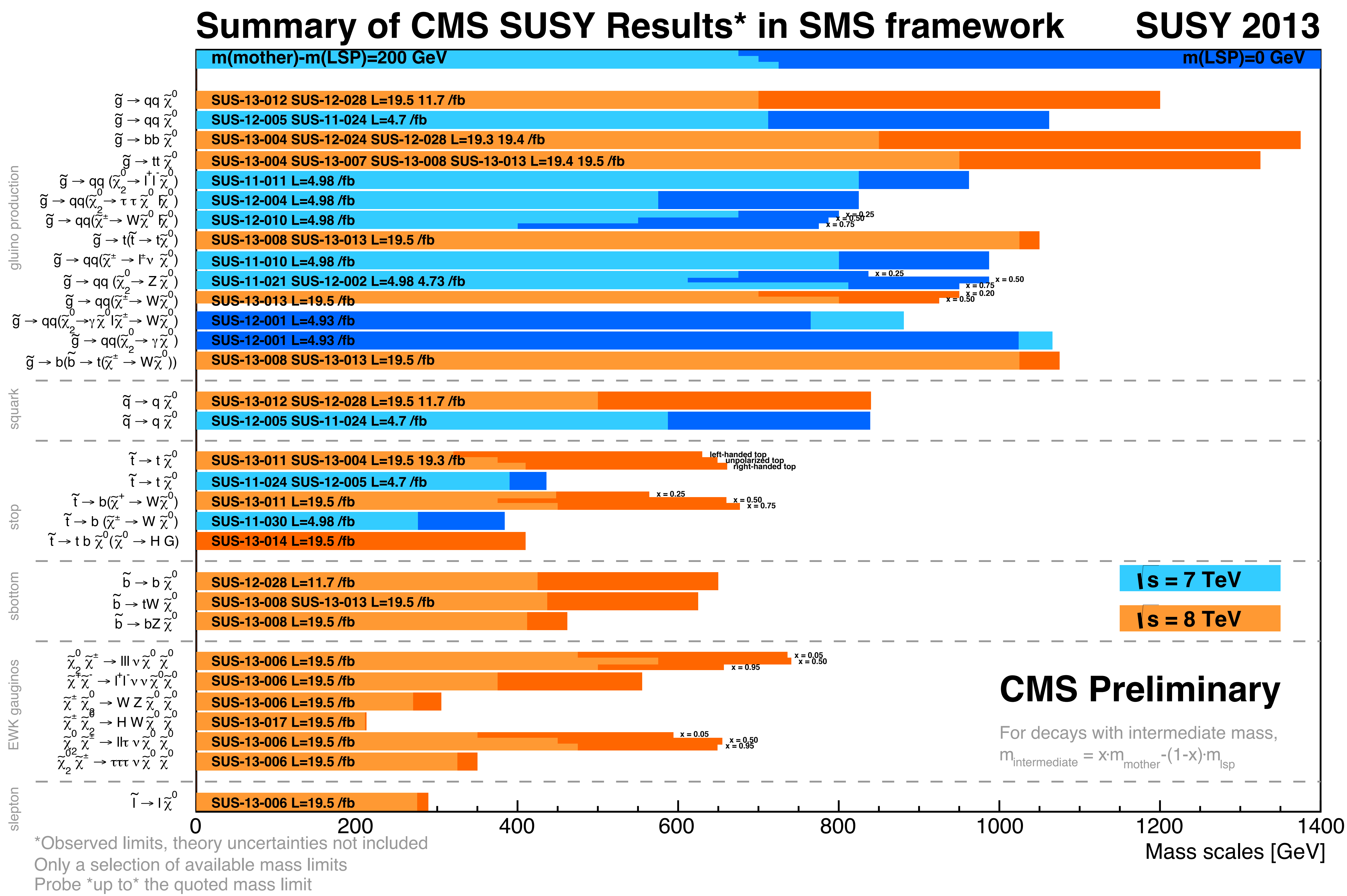
$\int \mathcal{L}\, dt = (4.6 - 22.9)\ \mathrm{fb}^{-1}$ $\sqrt{s}$ = 7, 8 TeV

	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	λ'_{311}=0.10, λ_{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	λ'_{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, λ_{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, λ_{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

10^{-1} 1   Mass scale [TeV]

*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.



Summary of CMS SUSY Results* in SMS framework
SUSY 2013
m(mother)-m(LSP)=200 GeV
m(LSP)=0 GeV
gluino production
SUS-13-012 SUS-12-028 L=19.5 11.7 /fb
SUS-12-005 SUS-11-024 L=4.7 /fb
SUS-13-004 SUS-12-024 SUS-12-028 L=19.3 19.4 /fb
SUS-13-004 SUS-13-007 SUS-13-008 SUS-13-013 L=19.4 19.5 /fb
SUS-11-011 L=4.98 /fb
SUS-12-004 L=4.98 /fb
SUS-12-010 L=4.98 /fb
x = 0.25
x = 0.50
x = 0.75
SUS-13-008 SUS-13-013 L=19.5 /fb
SUS-11-010 L=4.98 /fb
SUS-11-021 SUS-12-002 L=4.98 4.73 /fb
x = 0.25
x = 0.50
x = 0.75
SUS-13-013 L=19.5 /fb
x = 0.20
x = 0.50
SUS-12-001 L=4.93 /fb
SUS-12-001 L=4.93 /fb
SUS-13-008 SUS-13-013 L=19.5 /fb
squark
SUS-13-012 SUS-12-028 L=19.5 11.7 /fb
SUS-12-005 SUS-11-024 L=4.7 /fb
stop
SUS-13-011 SUS-13-004 L=19.5 19.3 /fb
left-handed top
unpolarized top
right-handed top
SUS-11-024 SUS-12-005 L=4.7 /fb
SUS-13-011 L=19.5 /fb
x = 0.25
x = 0.50
x = 0.75
SUS-11-030 L=4.98 /fb
SUS-13-014 L=19.5 /fb
sbottom
SUS-12-028 L=11.7 /fb
SUS-13-008 SUS-13-013 L=19.5 /fb
SUS-13-008 L=19.5 /fb
EWK gauginos
SUS-13-006 L=19.5 /fb
x = 0.05
x = 0.50
x = 0.95
SUS-13-006 L=19.5 /fb
SUS-13-006 L=19.5 /fb
SUS-13-017 L=19.5 /fb
SUS-13-006 L=19.5 /fb
x = 0.05
x = 0.50
x = 0.95
SUS-13-006 L=19.5 /fb
slepton
SUS-13-006 L=19.5 /fb
√s = 7 TeV
√s = 8 TeV
CMS Preliminary
For decays with intermediate mass,
m_intermediate = x·m_mother-(1-x)·m_lsp
0
200
400
600
800
1000
1200
1400
Mass scales [GeV]
*Observed limits, theory uncertainties not included
Only a selection of available mass limits
Probe *up to* the quoted mass limit

Summary of the data

Gluinos are ruled out up to masses 1- 1.25 TeV

Stops and sbottoms are ruled out up to masses 300-600 GeV

First two generations should be greater than 800 GeV -1.25 TeV

(especially if degenerate with the gluino mass)

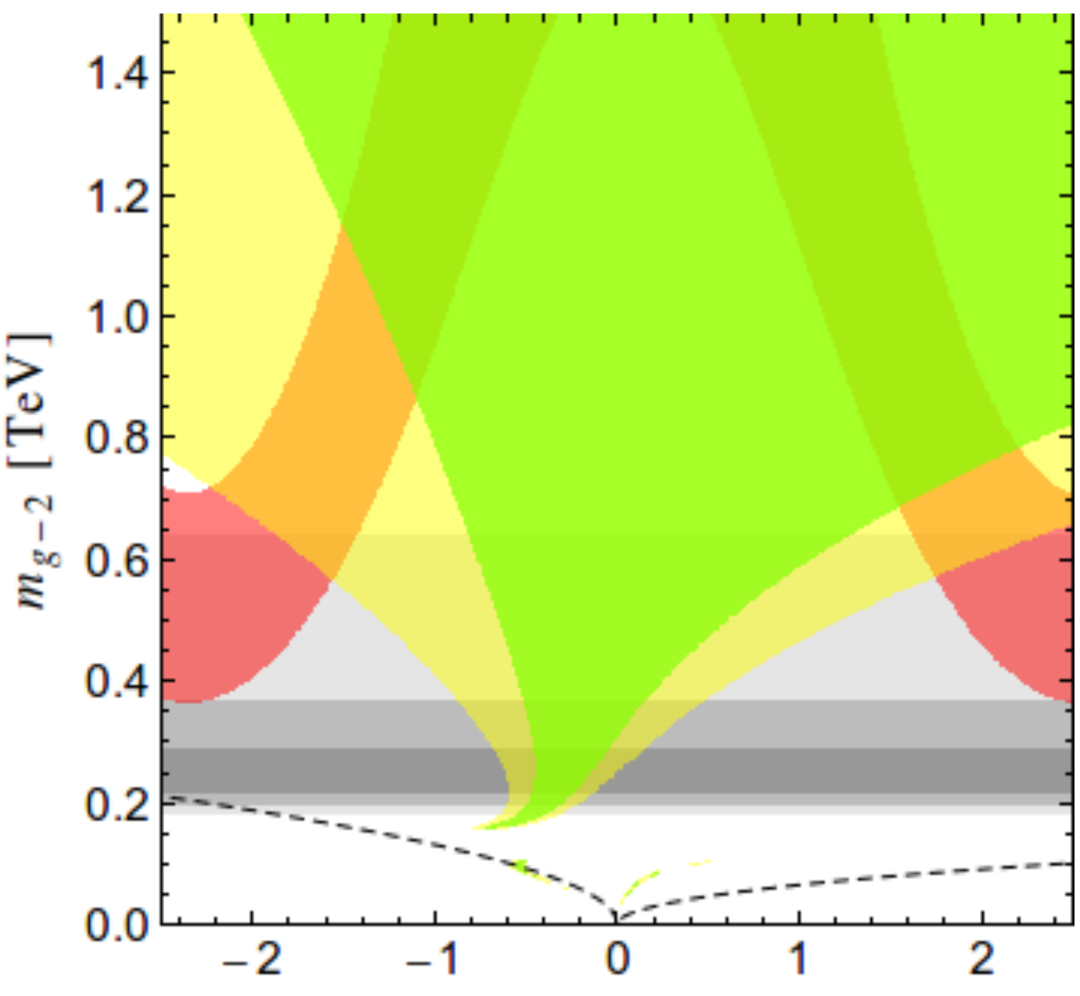
A closer look at degenerate MSSM

Martin, Nojiri, Bhattacherjee and Mohan, and several others

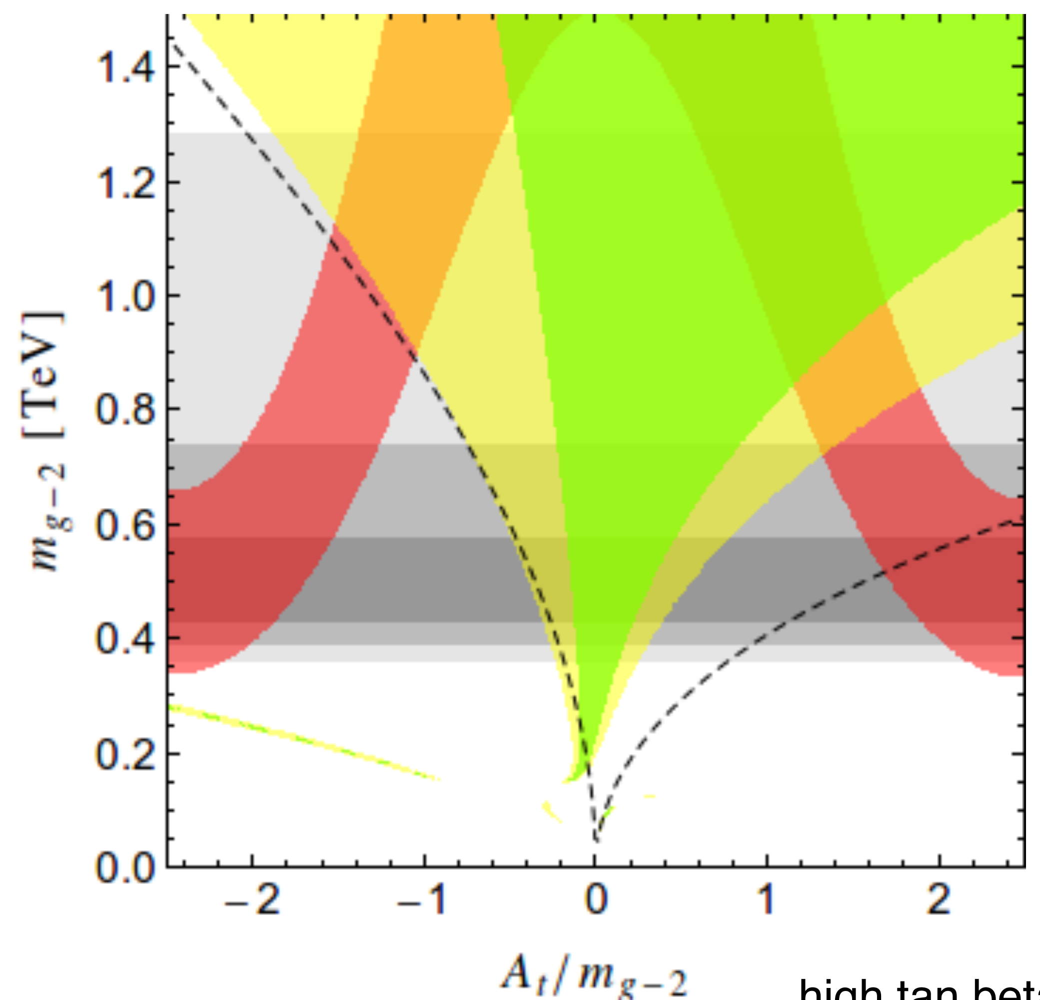
Degenerate gluino and neutralino mass can escape LHC constraints

Constraints from Monojets vs from other indirect results

Chowdhury, Patel, Tata, Vempati, in prep



low tan beta



high tan beta

flavour violation in charginos/neutralinos

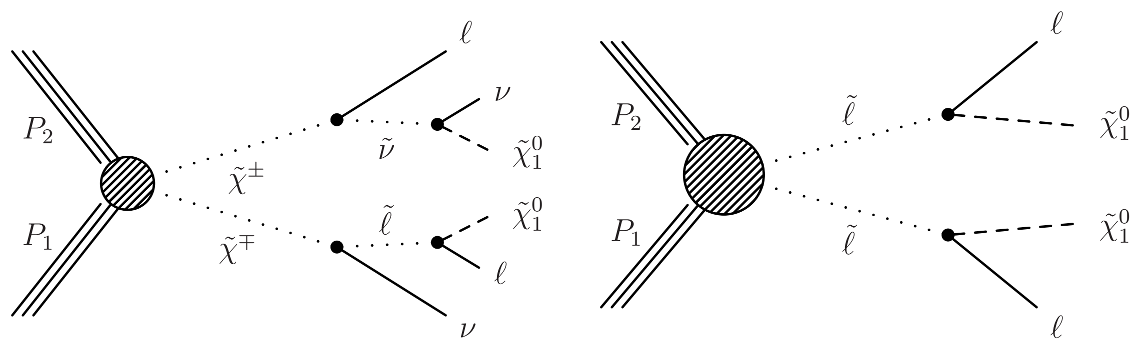


Figure 1: Production of pair of chargions (left) and sleptons (right) in the pp collision.

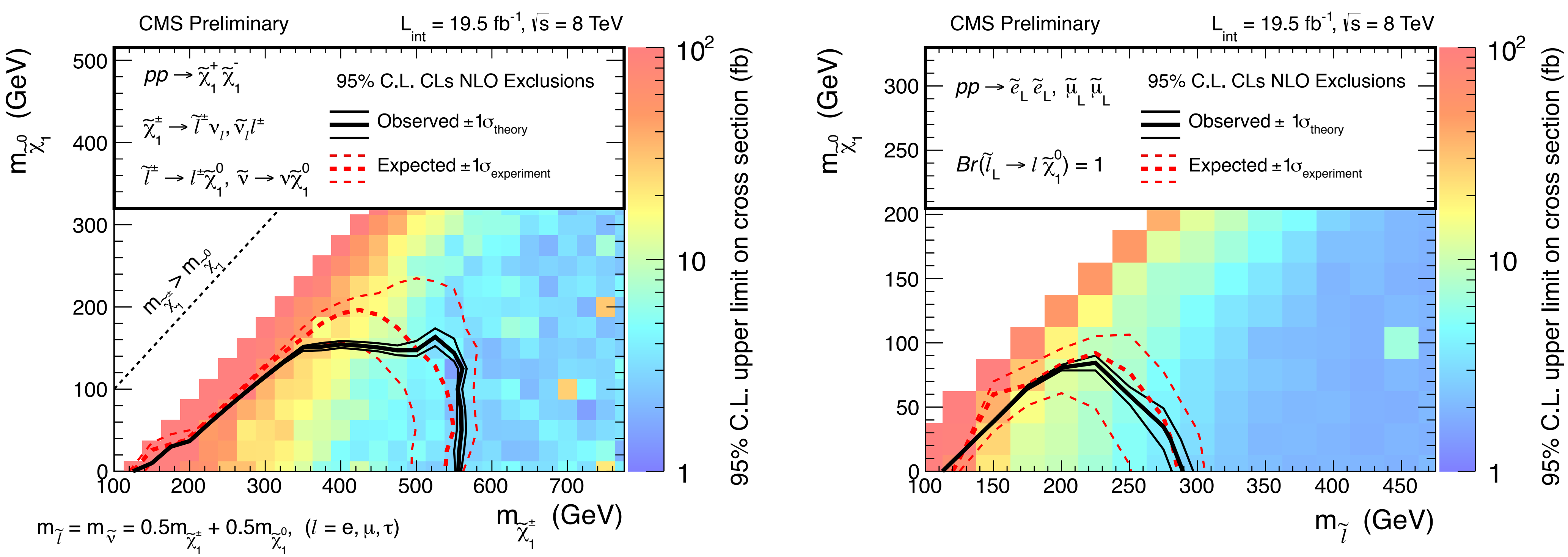


Figure 2: Limits on chargino (left) and slepton (right) pair production

wish list

- Higgs
- tops
- Z's
- flavour violation
- missing E_T
- Vector like particles
- stops with or without large mixing
- monojets
- …….
- something !