Higgs Boson Mass in GMSB with Messenger-Matter Mixing

K.S. Babu

Oklahoma State University

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Based on:

Higgs boson of mass 125 GeV in GMSB models with messenger–matter mixing

A. Albaid and K.S. Babu, arXiv: 1207.1014 [hep-ph]
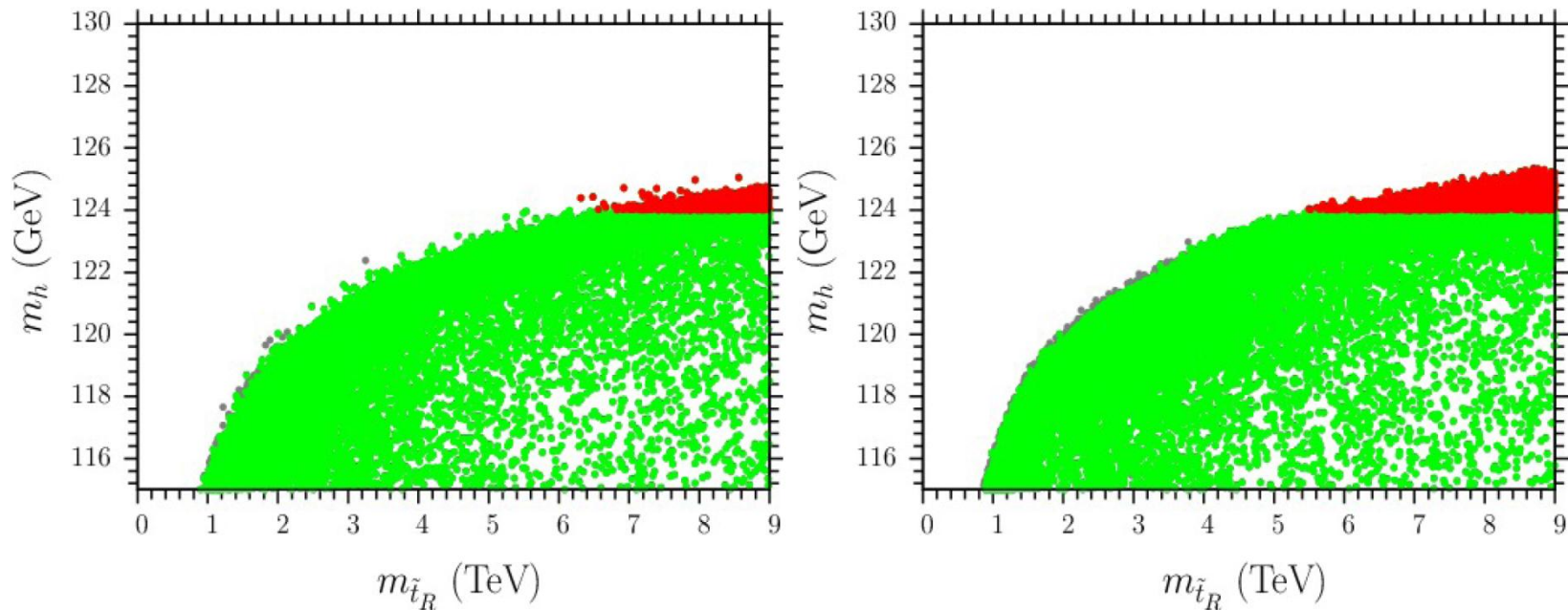
Higgs boson mass in GMSB models

Observation of Standard Model–like Higgs particle severely strains minimal gauge mediation models

$$m_h^2 \;=\; M_Z^2 \cos^2 2\beta \left(1 - \frac{3}{8\pi^2} \frac{m_t^2}{v^2} t \right)$$

$$+ \;\; \frac{3}{4\pi^2} \frac{m_t^4}{v^2} \left[\frac{1}{2} X_t + t + \frac{1}{16\pi^2} \left(\frac{3}{2} \frac{m_t^2}{v^2} - 32\pi\alpha_3 \right) \left(X_t t + t^2 \right) \right],$$

$$v^2 = v_d^2 + v_u^2, \;\; t = \log\left(\frac{M_s^2}{M_t^2} \right), \;\; X_t = \frac{2\tilde{A}_t^2}{M_s^2} \left(1 - \frac{\tilde{A}_t^2}{12M_s^2} \right), \;\; \tilde{A}_t = A_t - \mu \cot\beta$$

To obtain $m_h \simeq 125$ GeV, $X_t \simeq 6$ needed

GMSB models typically have $X_t \ll 6$, since $A_t = 0$ at M_{mess}

$m_h = 125$ GeV requires stop mass larger than 6 TeV!

Higgs boson mass in GMSB models

Stop mass versus Higgs mass in GMSB with $n = 1(5)$

Ajaib, Gogoladze, Nasir, Shafi (2012)

If stop masses < 2 TeV, $m_h < 118$ GeV

SUSY Spectrum in GMSB Models

Messenger fields $\Phi_i + \overline{\Phi}_i$ belonging to complete vector–like multiplets of $SU(5)$ introduced

They couple to a singlet Z which has VEVs along scalar and F–components

$$W = \lambda_i Z \Phi_i \overline{\Phi}_i$$

$$M_a = \frac{\alpha_a}{4\pi} \Lambda\, n_a(i)\, g(x_i) \quad (a = 1 - 3),$$

$$\tilde{m}^2 = 2\Lambda^2 \sum_{a=1}^{3} \left(\frac{\alpha_a}{4\pi}\right)^2 C_a n_a(i) f(x_i) \ .$$

$\Lambda \equiv \langle F_Z \rangle / \langle Z \rangle$, $n_a(i) = 1$ for $N + \overline{N}$, $C_a(N) = (N^2 - 1)/(2N)$

$$A_f = 0 \ \text{ for all } f$$
$$B = 0$$

Degneracy of scalars solves SUSY flavor problem

Messenger-Matter Mixing

Consider $5 + \bar{5}$ messenger fields

$$5 = (\overline{d^c}_m + \overline{L}_m) \text{ and } \bar{5} = (d^c_m + L_m)$$

Normally these fileds are assumed not to mix with MSSM fields

($\Rightarrow$ Messenger number conservation!)
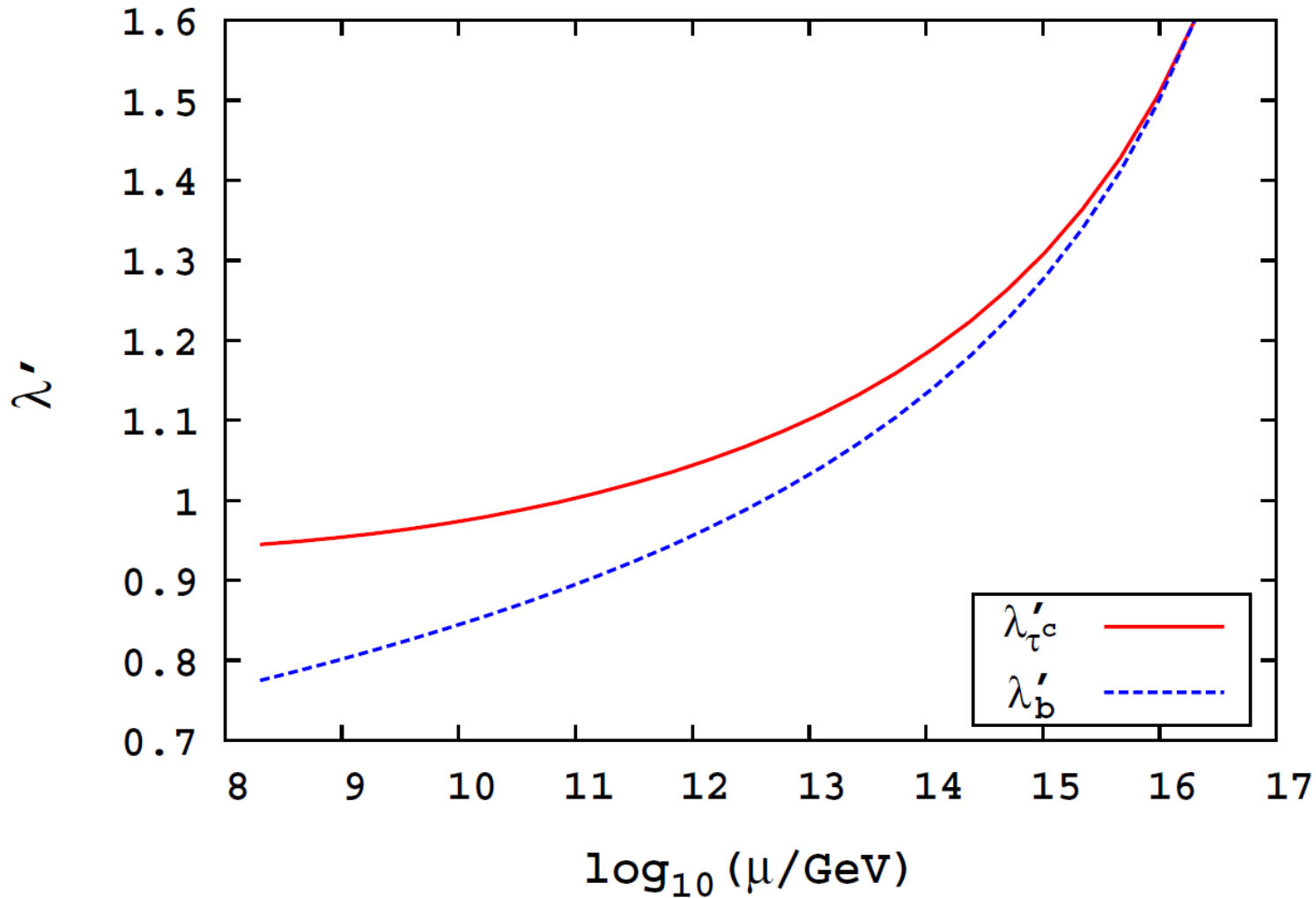
Messengers can mix with MSSM fields, however

$$W_{5+\bar{5}} = f_d \overline{d^c}_m d^c_m Z + f_e \overline{L}_m L_m Z + \lambda'_b Q_3 d^c_m H_d + \lambda'_{\tau^c} L_m e^c_3 H_d$$

Only 3rd family mixing is assumed

In $SU(5)$, $W = f_0 5_m \bar{5}_m Z + \lambda'_0 10_3 \bar{5}_m \bar{5}_H$

$(f_0, \ \lambda'_0)$ at GUT scale

Evolution of Mixed Yukawas

New contributions to soft SUSY breaking parameters:

$$\delta\tilde{m}_{Q_3}^2 = \frac{\alpha_b'\Lambda^2}{8\pi^2}\left(3\alpha_b' + \frac{1}{2}\alpha_{\tau^c}' - \frac{8}{3}\alpha_3 - \frac{3}{2}\alpha_2 - \frac{7}{30}\alpha_1\right),$$

$$\delta\tilde{m}_{\tau^c}^2 = \frac{2\alpha_{\tau^c}'\Lambda^2}{8\pi^2}\left(2\alpha_{\tau^c}' + \frac{3}{2}\alpha_b' - \frac{3}{2}\alpha_2 - \frac{9}{10}\alpha_1\right),$$
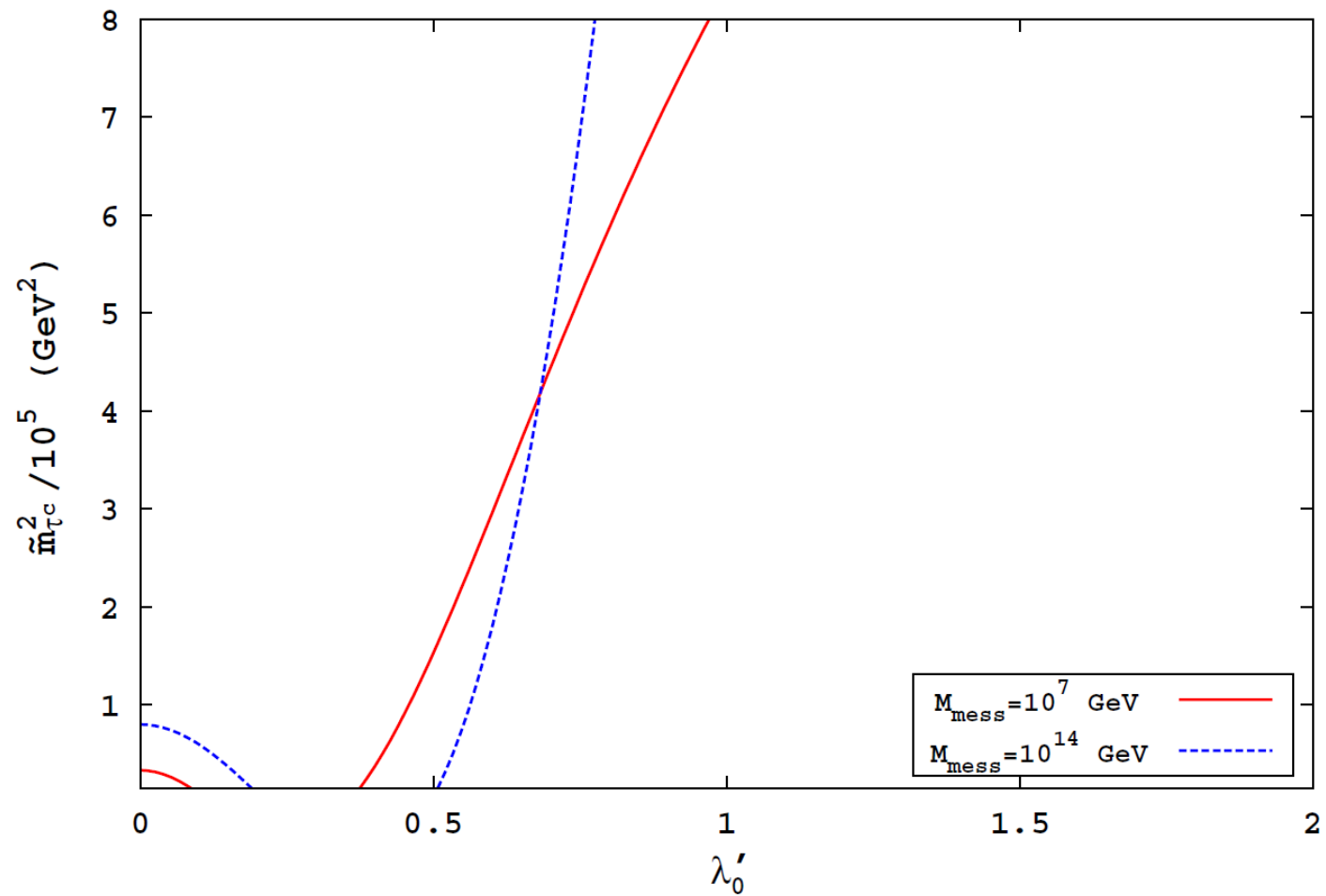
$$\delta\tilde{m}_{H_d}^2 = \frac{\delta\tilde{m}_{\tau^c}^2}{2} + 3\delta\tilde{m}_{Q_3}^2 + \frac{3\Lambda^2\alpha_b'\alpha_t}{16\pi^2}$$

$$\delta A_t = -\frac{1}{4\pi}\alpha_b'\Lambda,$$

$$\delta A_b = -\left(\frac{4\alpha_b' + \alpha_{\tau^c}'}{4\pi}\right)\Lambda, \qquad \alpha_b' = \frac{\lambda_b'^2}{4\pi}, \ \alpha_{\tau^c}' = \frac{\lambda_{\tau^c}'^2}{4\pi}$$

$$\delta A_\tau = -\left(\frac{3\alpha_b' + 3\alpha_{\tau^c}'}{4\pi}\right)\Lambda,$$

Constraints on Yukawa from positivity of stau mass–squared

Improved Higgs boson mass

λ_0'	$m_h(\text{GeV})$	$\Lambda(10^5\text{GeV})$	$M(10^{13}\,\text{GeV})$	$\tilde{m}_{t_1}(\text{GeV})$	$\tilde{m}_{t_2}(\text{GeV})$
0	114	2	1.78	1249	1695
0.8	116	2	10	1212	1583
1.2	119	2	10	384	2613

Messenger–matter mixing increases m_h by 5 GeV

$m_h \simeq 121$ GeV can be realized with light SUSY spectrum

Messenger-Matter Mixing with 10+10*

Consider $10 + \overline{10}$ messenger fields

$$10 + \overline{10} = (Q_m + \overline{Q}_m) + (u_m^c + \overline{u^c}_m) + (e_m^c + \overline{e^c}_m)$$

$$
\begin{aligned}
W_{10+\overline{10}} \;=\; & \lambda'_{t^c} Q_3 u_m^c H_u + \lambda'_t Q_m u_3^c H_u + \lambda'_m Q_m u_m^c H_u \\
+ \; & f_{e^c} \overline{e^c}_m e_m^c Z + f_{u^c} \overline{u^c}_m u_m^c Z + f_Q \overline{Q}_m Q_m Z.
\end{aligned}
$$

Only 3rd family mixing is assumed

In $SU(5)$, $W \supset \lambda'_0 10_3 10_m 5_H + \lambda'_{m0} 10_m 10_m 5_H + f_0 10_m \overline{10}_m Z$

$(f_0, \; \lambda'_0, \lambda'_{m0})$ at GUT scale

Evolution of mixed Yukawas in 10+10*
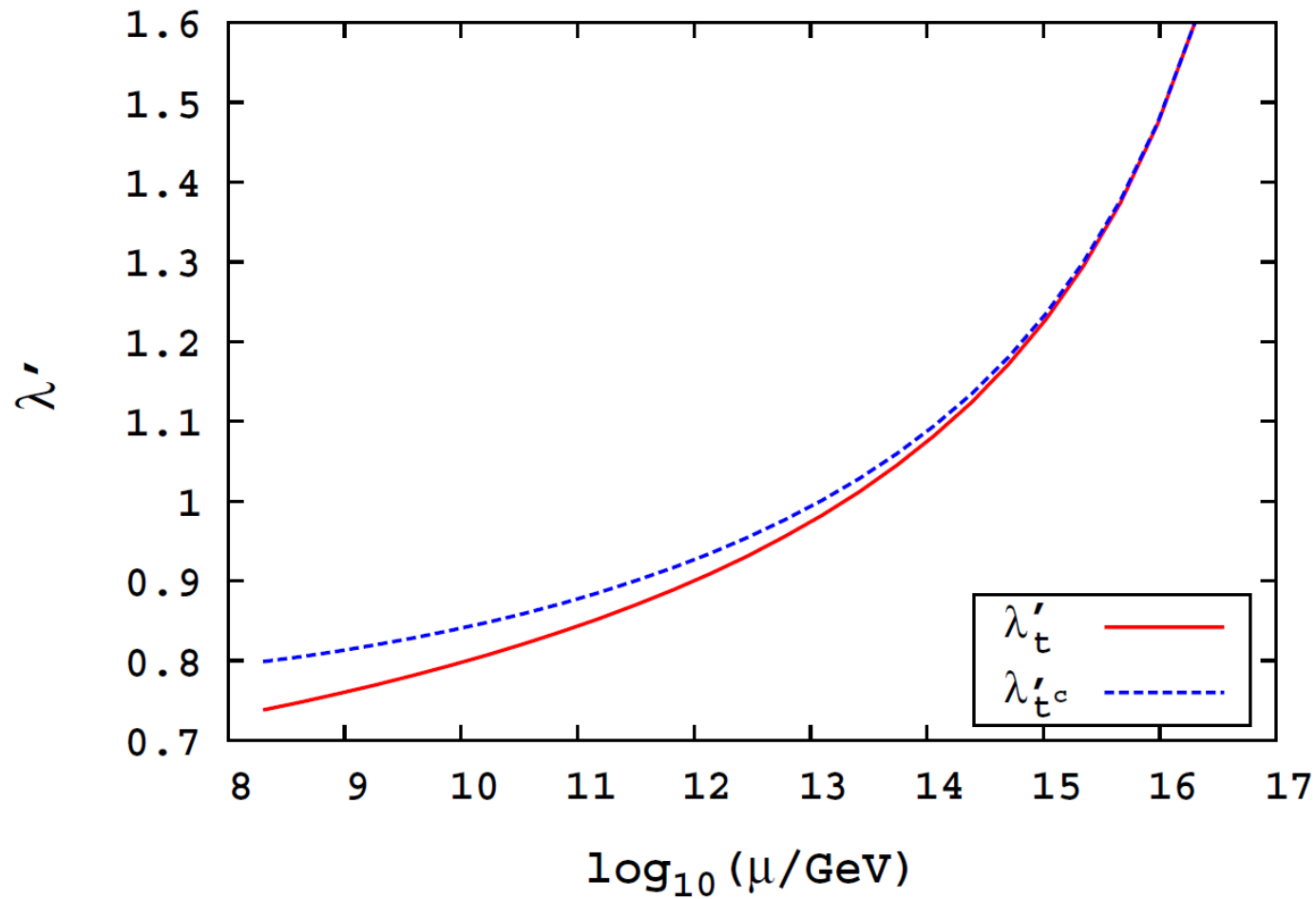
Messenger-Matter Mixing in 10+10*

New contributions to soft SUSY breaking parameters:
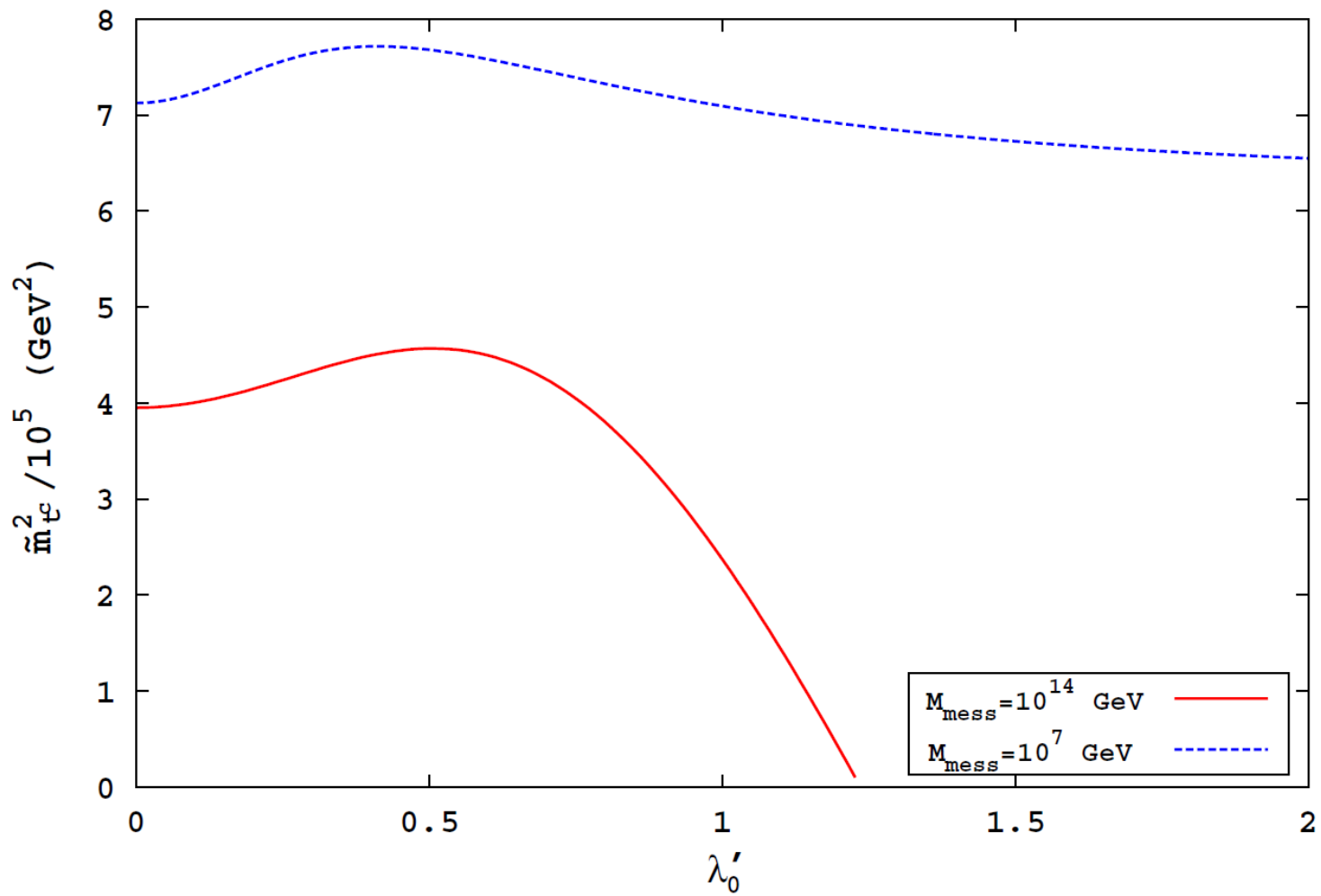
$$\delta\tilde{m}_{Q_3}^2 = \frac{\Lambda^2}{8\pi^2}\left[\alpha'_{t^c}\left(3\alpha'_{t^c} + \frac{3}{2}\alpha'_t + \frac{5}{2}\alpha'_m - \frac{8}{3}\alpha_3 - \frac{3}{2}\alpha_2 - \frac{13}{30}\alpha_1\right)\right.$$
$$\left. - \alpha_t\left(\frac{5}{2}\alpha'_t + \frac{3}{2}\alpha'_m\right)\right],$$

$$\delta\tilde{m}_{t^c}^2 = \frac{2\Lambda^2}{8\pi^2}\left[\alpha'_t\left(3\alpha'_t + \frac{3}{2}\alpha'_{t^c} + 2\alpha'_m - \frac{8}{3}\alpha_3 - \frac{3}{2}\alpha_2 - \frac{13}{30}\alpha_1\right)\right.$$
$$\left. - \alpha_t\left(2\alpha'_{t^c} + \frac{3}{2}\alpha'_m\right)\right],$$

$$\delta\tilde{m}_{H_u}^2 = \frac{3\Lambda^2}{8\pi^2}\left[\alpha'_{t^c}\left(3\alpha'_{t^c} + \frac{3}{2}\alpha'_t + \frac{5}{2}\alpha'_m - \frac{8}{3}\alpha_3 - \frac{3}{2}\alpha_2 - \frac{13}{30}\alpha_1\right)\right.$$
$$+ \alpha'_t\left(3\alpha'_t + \frac{3}{2}\alpha'_{t^c} + 2\alpha'_m - \frac{8}{3}\alpha_3 - \frac{3}{2}\alpha_2 - \frac{13}{30}\alpha_1\right)$$
$$\left. + \alpha'_m\left(3\alpha'_m + 2\alpha'_t + \frac{5}{2}\alpha'_{t^c} - \frac{8}{3}\alpha_3 - \frac{3}{2}\alpha_2 - \frac{13}{30}\alpha_1\right)\right]$$

$$\delta A_t = -\left[\frac{5\alpha'_t + 4\alpha'_{t^c} + 3\alpha'_m}{4\pi}\right]\Lambda,$$

$$\delta A_b = -\frac{\alpha'_{t^c}}{4\pi}\Lambda \qquad \alpha'_{t^c} = \frac{\lambda'^2_{t^c}}{4\pi}, \ \alpha'_t = \frac{\lambda'^2_t}{4\pi}, \ \alpha'_m = \frac{\lambda'^2_m}{4\pi}$$

No major constraint from positivity of stop mass–squared

Improved Higgs boson mass

λ_0'	$m_h(\text{GeV})$	$\Lambda(10^5\text{GeV})$	$M_{\text{mess}}(\text{GeV})$	$\tilde{m}_{t_1}(\text{GeV})$	$\tilde{m}_{t_2}(\text{GeV})$	A_t/M_s
0	121	0.97	2×10^{13}	928	1636	-1.8
0.4	123	0.91	3×10^{13}	656	1612	-2.3
0.6	123	0.848	10^{12}	673	1512	-2.3
0.8	123	0.784	10^{11}	682	1509	-2.3
2	123	0.784	10^8	753	1425	-2.2

$m_h \simeq 125$ GeV can be realized with light SUSY spectrum

Sample SUSY Spectrum

Particle		$10 + \overline{10}$	$10 + \overline{10}$	$5 + \overline{5}$
Inputs	M_{mess}	10^8	4×10^5	10^8
	N_{mess}	3	3	1
	$\Lambda(10^5\,\mathrm{GeV})$	0.45	0.3	1.5
	$\tan\beta$	10	6.1	15.6
	f_0	0.25	0.25	0.25
	λ_0	1.3	1.2	1.2
Higgs:	m_h	122	118	114.5
	m_H^0	858	592	1690
	m_A	858	591	1690
	$m_{H^\pm}$	862	597	1689
Gluino:	$\tilde{m}_g$	980	667	1041
Neutralinos:	m_{χ_1}	186	124	208
	m_{χ_2}	346	225	408
	m_{χ_3}	800	557	781
	m_{χ_4}	807	569	790
Charginos:	χ_1^+	347	227	409
	χ_2^+	807	569	790
Squarks:	$\tilde{m}_{u_L, c_L}$	972	657	1480
	$\tilde{m}_{u_R, c_R}$	929	632	1377
	$\tilde{m}_{d_L, s_L}$	971	657	1480
	$\tilde{m}_{d_R, s_R}$	922	630	1365
	$\tilde{m}_{b_L}$	800	555	1315
	$\tilde{m}_{b_R}$	919	629	1294
	$\tilde{m}_{t_L}$	853	621	1315
	$\tilde{m}_{t_R}$	412	270	1123
Sleptons:	$\tilde{m}_{e_L, \mu_L}$	323	200	596
	$\tilde{m}_{\nu_{eL}, \nu_{\mu L}}$	323	200	596
	$\tilde{m}_{e_R, \mu_R}$	152	92	290
	$\tilde{m}_{\tau_L}$	322	197	539
	$\tilde{m}_{\tau_R}$	151	92	1543

SUSY Flavor Violation

$10 + \overline{10}$ model embedded in a $U(1)$ flavor symmetry:

SU(5)	10_1	10_2	10_3	$\overline{5}_1$	$\overline{5}_2, \overline{5}_3$	$5_u, \overline{5}_d$	S	10_m	$\overline{10}_m$	Z
$U(1)$	4	2	0	1+p	p	0	-1	0	$-\alpha$	α

$$
\begin{aligned}
W_{10+\overline{10}} \;=\; & (\lambda'_{u^c}\epsilon^4 Q_1 + \lambda'_{c^c}\epsilon^2 Q_2 + \lambda'_{t^c}Q_3)u^c_m H_u + Q_m(\lambda'_u\epsilon^4 u^c_1 + \lambda'_c\epsilon^2 u^c_2 \\
+ \;& \lambda'_t u^c_3)H_u + \lambda'_m Q_m u^c_m H_u + \lambda'_b\epsilon^p Q_m d^c_3 H_d + \lambda'_\tau \epsilon^p L_3 e^c_m H_d \\
+ \;& f_{e^c}\overline{e^c}_m e^c_m Z + f_{u^c}\overline{u^c}_m u^c_m Z + f_Q \overline{Q}_m Q_m Z.
\end{aligned}
$$

With $\epsilon \simeq 0.2$, SUSY FCNC suppressed sufficiently

Flavor Symmetry and Neutrino Mixing

$$M^u = Y^u v_u = \begin{pmatrix} y_{11}^u \epsilon^8 & y_{12}^u \epsilon^6 & y_{13}^u \epsilon^4 \\ y_{21}^u \epsilon^6 & y_{22}^u \epsilon^4 & y_{23}^u \epsilon^2 \\ y_{31}^u \epsilon^4 & y_{32}^u \epsilon^2 & y_{33}^u \end{pmatrix} v_u \ ,$$

$$M^d = Y^d v_d = \epsilon^p \begin{pmatrix} y_{11}^d \epsilon^5 & y_{12}^d \epsilon^3 & y_{13}^d \epsilon \\ y_{21}^d \epsilon^4 & y_{22}^d \epsilon^2 & y_{23}^d \\ y_{31}^d \epsilon^4 & y_{32}^d \epsilon^2 & y_{33}^d \end{pmatrix} v_d \ ,$$

$$M^e = Y^e v_d = \epsilon^p \begin{pmatrix} y_{11}^e \epsilon^5 & y_{12}^e \epsilon^4 & y_{13}^e \epsilon^4 \\ y_{21}^e \epsilon^3 & y_{22}^e \epsilon^2 & y_{23}^e \epsilon^2 \\ y_{31}^e \epsilon & y_{32}^e & y_{33}^e \end{pmatrix} v_d \ .$$

Lopsided mass matrices explain small quark mixings and large neutrino mixings

Babu, Barr (1996)
Albright, Babu, Barr (1998)
Elwood, Irges, Ramond (1998)
Sato, Yanagida (1998)

SUSY Flavor Violation

Mass Insertion (δ)	$5 + \bar{5}$	$10 + \overline{10}$	Process	Exp. Bounds
$(\delta^l_{12})_{LL}$	-	ϵ^{1+2p}		0.00028
$(\delta^l_{12})_{RR}$	$r\ \epsilon^6$	-	$\mu \to e\gamma$	0.0004
$(\delta^l_{12})_{RL,LR}$	$r\ \kappa^l_5(\epsilon^4,\ \epsilon^3)$	$\kappa^l_{10}\ (\epsilon^{4+2p}, \epsilon^{3+2p})$		1.3×10^{-6}
$(\delta^l_{13})_{LL}$	-	ϵ^{1+2p}		0.026
$(\delta^l_{13})_{RR}$	$r\ \epsilon^4$	-	$\tau \to e\gamma$	0.04
$(\delta^l_{13})_{RL,LR}$	$r\ \kappa^l_5(\epsilon^4,\ \epsilon^1)$	$\kappa^l_{10}(\epsilon^{4+2p}, \epsilon^{1+2p})$		0.002
$(\delta^l_{23})_{LL}$	-	ϵ^{2p}		0.02
$(\delta^l_{23})_{RR}$	$r\ \epsilon^2$	-	$\tau \to \mu\gamma$	0.03
$(\delta^l_{23})_{RL,LR}$	$r\ \kappa^l_5(\epsilon^2,\ 1)$	$\kappa^l_{10}(\epsilon^{2+2p}, \epsilon^{2p})$		0.0015
$\left(\sqrt{\|\mathrm{Re}(\delta^d_{12})^2_{LL}\|}, \sqrt{\|\mathrm{Im}(\delta^d_{12})^2_{LL}\|}\right)$	ϵ^6	ϵ^6		$(0.065, 0.0052)$
$\left(\sqrt{\|\mathrm{Re}(\delta^d_{12})^2_{RR}\|}, \sqrt{\|\mathrm{Im}(\delta^d_{12})^2_{RR}\|}\right)$	-	ϵ^{1+2p}		$(0.065, 0.0052)$
$\left(\sqrt{\|\mathrm{Re}(\delta^d_{12})^2_{LR}\|}, \sqrt{\|\mathrm{Im}(\delta^d_{12})^2_{LR}\|}\right)$	$\kappa^d_5\epsilon^3$	$\kappa^d_{10}\epsilon^3$	$K - \overline{K}$	$(0.007, 5.2 \times 10^{-5})$
$\left(\sqrt{\|\mathrm{Re}(\delta^d_{12})^2_{RL}\|}, \sqrt{\|\mathrm{Im}(\delta^d_{12})^2_{RL}\|}\right)$	$\kappa^d_5\epsilon^4$	$\kappa^d_{10}\epsilon^4$		$(0.007, 5.2 \times 10^{-5})$
$\sqrt{\|\mathrm{Re}(\delta^d_{12})_{LL}(\delta^d_{12})_{RR}\|}$	-	$\epsilon^{3.5+p}$		0.00453
$\sqrt{\|\mathrm{Im}(\delta^d_{12})_{LL}(\delta^d_{12})_{RR}\|}$	-	$\epsilon^{3.5+p}$		0.00057
$(\mathrm{Re}\delta^d_{13}, \mathrm{Im}\delta^d_{13})_{LL}$	ϵ^4	ϵ^4		$(0.238, 0.51)$
$(\mathrm{Re}\delta^d_{13}, \mathrm{Im}\delta^d_{13})_{RR}$	-	ϵ^{1+2p}	$B_d - \overline{B}_d$	$(0.238, 0.51)$
$(\mathrm{Re}\delta^d_{13}, \mathrm{Im}\delta^d_{13})_{LR,RL}$	$\kappa^d_5(\epsilon^4, \epsilon)$	$\kappa^d_{10}(\epsilon, \epsilon^4)$		$(0.0557, 0.125)$
$(\delta^d_{23})_{LL}$	ϵ^2	ϵ^2		1.19
$(\delta^d_{23})_{RR}$	-	ϵ^{2p}	$B_s - \overline{B}_s$	1.19
$(\delta^d_{23})_{LR,RL}$	$\kappa^d_5(1, \epsilon^2)$	$\kappa^d_{10}(1, \epsilon^2)$	$b \to s\gamma$	0.04

Summary

- $m_h = 125$ GeV can be naturally realized in minimal GMSB models with messenger–matter mixing

- Relatively light SUSY spectrum obtained