Higgs Boson from t-b-tau Yukawa Unification

Ilia Gogoladze

Bartol Research Institute
Department Physics and Astronomy
University of Delaware, USA

in collaboration with Qaisar Shafi and Cem Salih Ün
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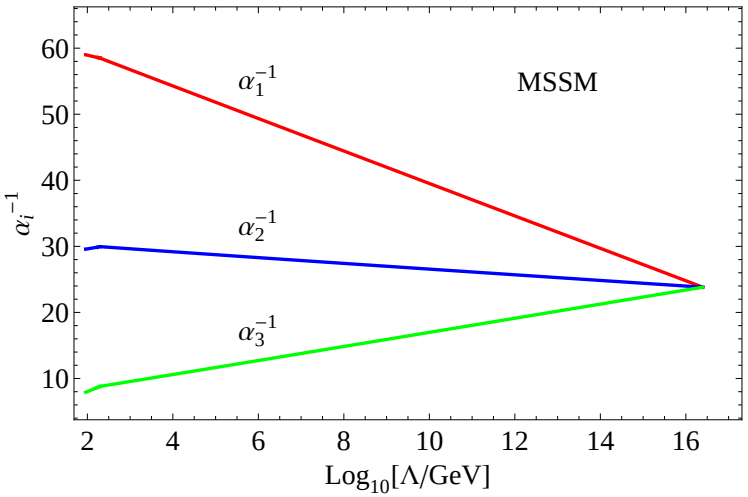
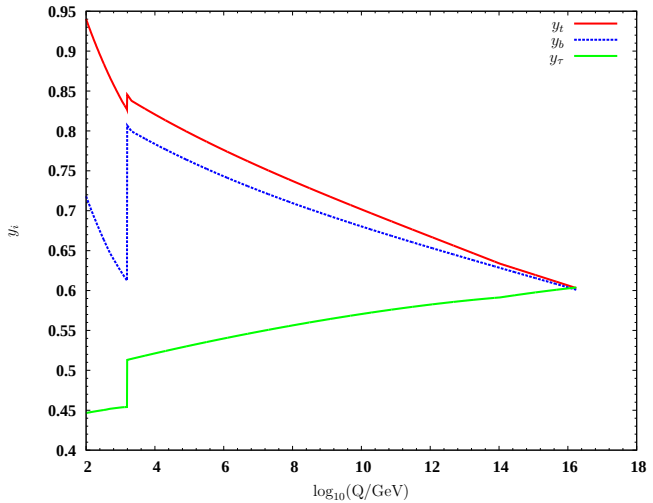
SUSY SO(10) GUT

- Unification of matter/ quark-lepton in one multiplet
  Fermion families reside in 16_i (i=1-3) and MSSM Higgs in 10.
- predicts 'right handed' neutrino $\Rightarrow$ non-zero neutrino masses through seesaw mechanism.
- Z_2 'matter' parity can be obtain.
- $SO(10)$ is automatically anomaly free.
- Explains electric charge quantization.
- Baryon asymmetry of the universe via leptogenesis.

SUSY SO(10) GUT

- Unification of gauge and $t - b - \tau$ Yukawa couplings. But **non-universal** Higgs SSB ($m_{H_u} \neq m_{H_d}$) or **non-universal** gaugino masses are needed for Yukawa unification
- Predicts light CP even Higgs boson mass???





SO(10) GUT

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- $m_{16},\ m_{10},\ M_{1/2},\ A_0,\ \tan\beta,\ sign(\mu).$
- $m_{16} \equiv$ Universal soft SUSY breaking (SSB) sfermion mass.
- $m_{10} \equiv$ Universal SSB MSSM Higgs mass.
- $M_i \equiv$ SSB gaugino masses. $M_1 : M_2 : M_3 = 1 : 3 : -2$ at M_{GUT} comes from $\frac{F_{\Phi_{ab}}}{M_P}\lambda^a\lambda^b$
- $A_0 \equiv$ Universal SSB trilinear interaction.
- $\tan\beta = \frac{v_u}{v_d}$.
- $\mu \equiv$ bilinear Higgs mixing term, $\mu > 0$.

We performed random scans for the following parameter range

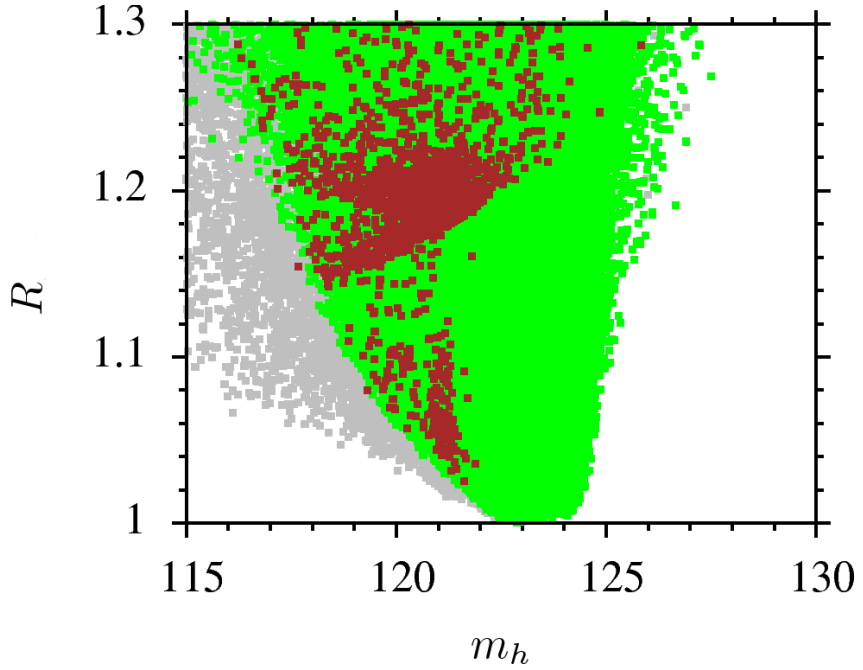
$$
\begin{aligned}
0 &\leq m_{16} \leq 5\,\mathrm{TeV}, \\
0 &\leq m_{10} \leq 5\,\mathrm{TeV} \\
0 &\leq M_{1/2} \leq 2\,\mathrm{TeV}, \\
-3 &\leq A_0/m_{16} \leq 3, \\
35 &\leq \tan\beta \leq 55, \\
\mu &> 0, \qquad\qquad m_t = 173.3\,\mathrm{GeV}.
\end{aligned}
$$

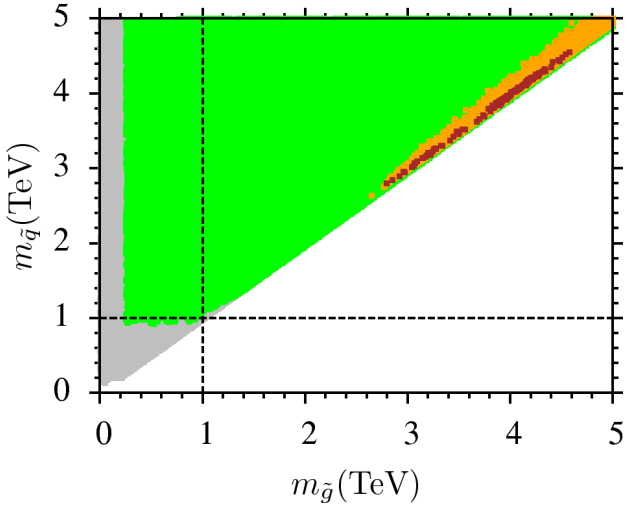
Quantify Yukawa unification by

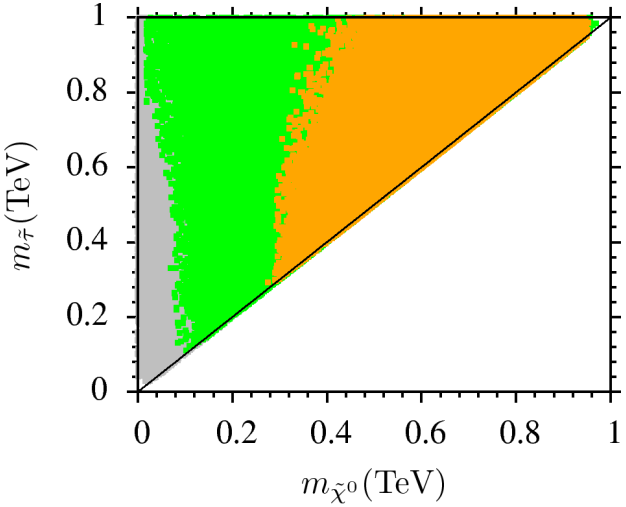
$$R_{tb\tau} = \frac{\max(y_t, y_b, y_\tau)}{\min(y_t, y_b, y_\tau)}$$

Constraints

$$115 \leq m_h \text{ (lightest Higgs mass)},$$
$$BR(B_s \to \mu^+\mu^-) < 4.5 \times 10^{-9},$$
$$0.15 < \frac{BR(B_u \to \tau\nu_\tau)MSSM}{BR(B_u \to \tau\nu_\tau)SM} < 2.03 \ (2\sigma),$$
$$2.85 \times 10^{-4} \leq BR(b \to s\gamma) \leq 4.24 \times 10^{-4} \ (2\sigma),$$
$$\Omega_{\text{CDM}}h^2 = 0.111^{+0.028}_{-0.037} \ (5\sigma),$$
$$0 < \Delta a_\mu \leq 55.6 \times 10^{-10}.$$


1.3
1.2
1.1
1
R
115
120
125
130
m_h


5
4
3
2
1
0
$m_{\tilde{q}}$(TeV)
0
1
2
3
4
5
$m_{\tilde{g}}$(TeV)


1
0.8
0.6
0.4
0.2
0
$m_{\tilde{\tau}}$(TeV)
0
0.2
0.4
0.6
0.8
1
$m_{\tilde{\chi}^0}$(TeV)

	Point 1	Point 2	Point 3
m_{16}	1277	1296	1920
M_1	1302	1174	1768
M_2	3906	3522	5304
M_3	-2604	-2248	-3536
m_{10}	613.7	1296	240.2
$\tan\beta$	47.2	47.3	46.9
A_0/m_{16}	1.41	1.61	2.73
μ	2216	1919.7	3478.7
m_h	**122.3**	**122.1**	**124**
m_H	408.7	392.5	559.5
m_A	406	390	555.8
$m_{H^\pm}$	420.5	404.7	568.3
$m_{\tilde{\chi}^0_{1,2}}$	**609.3**, 2227.3	**546.7** , 1930.4	**833.4**, 3487.6
$m_{\tilde{\chi}^\pm_{1,2}}$	2260.4, 3281.1	1959.8, 2956	3533.3, 4458.5
$m_{\tilde{g}}$	5413.9	4919.5	7217.9
$m_{\tilde{u}_{L,R}}$	5251.4, 4766.1	4895.8, 4375.4	7176.2, 6386
$m_{\tilde{t}_{1,2}}$	3839.2, 4665.7	3453.1, 4211.6	4967.6, 6120.1
$m_{\tilde{d}_{L,R}}$	5352, 4759.7	4896.5, 4369.9	7176.7, 6378.7
$m_{\tilde{b}_{1,2}}$	3969.3, 4640.1	3589.8, 4188	5168.1, 6088.1
$m_{\tilde{\nu}_1}$	2784.8	2585	3844.3
$m_{\tilde{\nu}_3}$	2639.9	2421.7	3605.8
$m_{\tilde{e}_{L,R}}$	2789.5, 1355.5	2589.3, 1359.5	3849.1, 2016.8
$m_{\tilde{\tau}_{1,2}}$	**609.4**, 2650.7	**548.9**, 2431.6	**842.4**, 3621.2
$\Omega_{CDM}h^2$	0.176	0.189	0.55
R	1.01	1.02	1.01

Yukawa Unification and Neutralino DM in $\mathbf{SU(4)_c \times SU(2)_L \times SU(2)_R}$ (4-2-2)

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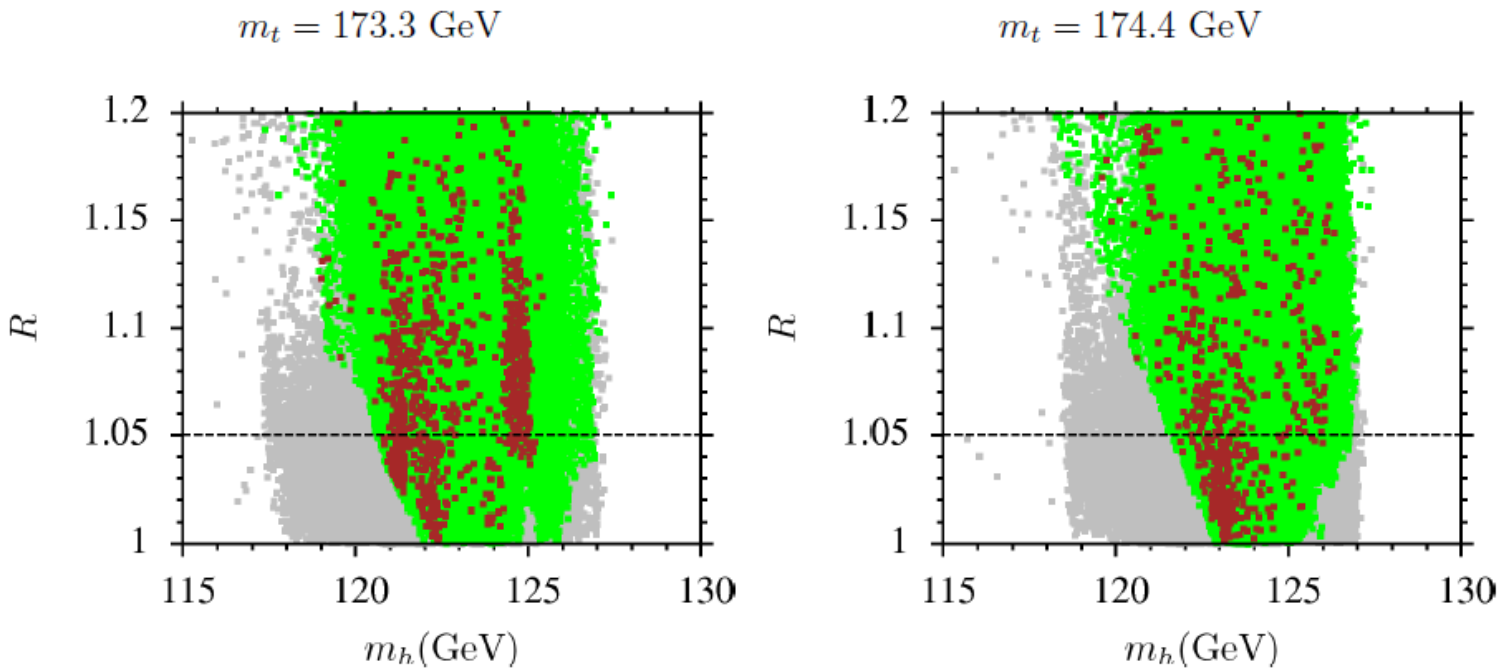
- SM fermions: $\psi_{\mathbf{i}} = (\mathbf{4}, \mathbf{2}, \mathbf{1})$ and $\psi_{\mathbf{i}}^{\mathbf{c}} = (\bar{\mathbf{4}}, \mathbf{1}, \mathbf{2})$
- MSSM Higgs: $\mathbf{H} = (\mathbf{1}, \mathbf{2}, \mathbf{2})$
- Third family Yukawa coupling $\psi\, \psi^{\mathbf{c}}\, \mathbf{H}$ yields

$$Y_t = Y_b = Y_\tau = Y_\nu$$

- Asymptotic relation between the three MSSM gaugino masses with left-right symmetry

$$M_1 = \tfrac{3}{5} M_2 + \tfrac{2}{5} M_3$$

- One additional parameter (from gaugino non-universality) compared to the SO(10) model


$m_t = 173.3$ GeV
$m_t = 174.4$ GeV
R
1.2
1.15
1.1
1.05
1
115
120
125
130
m_h(GeV)

	Point 1	Point 2	Point 3	Point 4
m_{16}	1729	2777	2406	**2016**
M_1	-809	1262	**1177**	-1046
M_2	-4180	-685	**-633**	-4867
M_3	4247	4183	3892	4686
m_{10}	965	640	227	**2016**
$\tan\beta$	49.2	48.6	48.2	48.2
A_0/m_0	1.04	-2.74	-2.82	-2.81
μ	-3762	-5765	-5305	-4539
m_h	**125**	**125**	**125**	**125**
m_H	949	1160	1197	1048
m_A	943	**1152**	1190	**1042**
$m_{H^\pm}$	954	1164	1201	1053
$m_{\tilde{\chi}^0_{1,2}}$	**405**, 3608	**556**, 663	**515, 614**	**508**, 4188
$m_{\tilde{\chi}^\pm_{1,2}}$	3605, 3812	666, 5738	616, 5282	4193, 4555
$m_{\tilde{g}}$	8496	8455	7891	9340
$m_{\tilde{u}_{L,R}}$	7828, 7386	7691, 7705	7128, 7140	8674, 8138
$m_{\tilde{t}_{1,2}}$	6265, 6943	5978, 6209	5579, 5800	6541, 7387
$m_{\tilde{d}_{L,R}}$	7828, 7388	7692, 7706	7128, 7141	8675, 8139
$m_{\tilde{b}_{1,2}}$	6430, 6903	6128, 6225	5716, 5813	6743, 7346
$m_{\tilde{\nu}_1}$	3147	2807	2435	3650
$m_{\tilde{\nu}_3}$	2909	2344	2037	3376
$m_{\tilde{e}_{L,R}}$	3155, 1743	2810, 2810	2439, 2439	3658, 2040
$m_{\tilde{\tau}_{1,2}}$	**426**, 2925	1617, 2330	1388, 2028	710, 3402
$\Omega_{CDM}h^2$	**0.26**	**0.11**	**0.11**	**1.22**
R	**1.03**	**1.02**	**1.04**	**1.03**

Summary

- We identify a class of supersymmetric SO(10) and $\mathbf{SU(4)_c \times SU(2)_L \times SU(2)_R}$ models in which imposing essentially perfect t-b-τ Yukawa coupling unification at $M_{\rm GUT}$ yields a mass close to 122-126 GeV for the lightest CP-even (SM-like) Higgs boson.

- The squark and gluino masses in these models exceed 3 TeV, but the stau and charginos in some cases can be considerably lighter.