Higgs and Sparticle Spectroscopy in Yukawa Unified Models

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b-τ Yukawa Unification in SUSY $SU(5)$

- The apparent unification at $M_{GUT} \approx 10^{16}\mathrm{GeV}$ of the three SM gauge couplings, assuming TeV scale SUSY, strongly suggests the existence of an underlying GUT with a single coupling constant

- The minimal SUSY $SU(5)$ and $SO(10)$ models, in addition to unifying gauge couplings, also predict at M_{GUT} of the third family bottom (b) quark and tau (τ) lepton Yukawa couplings unification $(y(10\bar{5}\bar{5}_H))$

- In recent years it has become clear that imposing b-τ and t-b-τ YU has important consequences for the sparticle and Higgs mass spectrum of the MSSM (for example please see Gogoladze talk)

We performed random scans using ISAJET7.80 [1] for the following parameter range

$$\begin{array}{ll} m_{10}: & 0 \rightarrow 20\ \mathrm{TeV} \\ m_{\bar{5}}: & 0 \rightarrow 20\ \mathrm{TeV} \\ M_{1/2}: & 0 \rightarrow 2\ \mathrm{TeV} \\ A_t: & -60 \rightarrow 60\ \mathrm{TeV} \\ A_b = A_\tau: & -60 \rightarrow 60\ \mathrm{TeV} \\ m_{H_u}: & 0 \rightarrow 20\ \mathrm{TeV} \\ m_{H_d}: & 0 \rightarrow 20\ \mathrm{TeV} \\ \tan\beta: & 1.1 \rightarrow 60 \\ \mu > 0, & m_t = 173.3(GeV) \end{array}$$

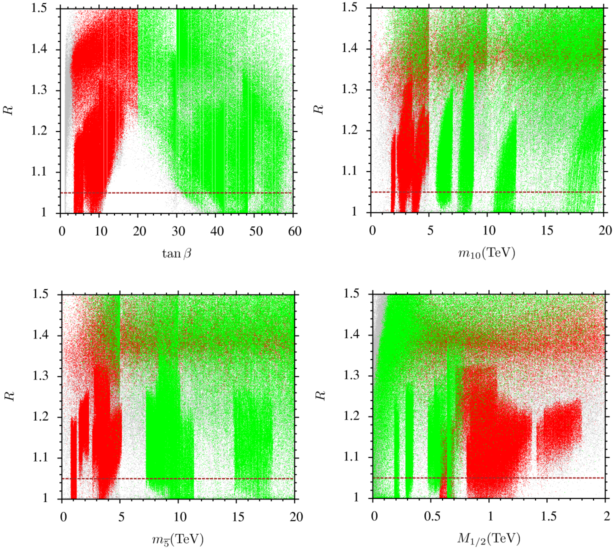
Quantify b-τ Yukawa unification(YU) by

$$R \equiv \frac{\max(y_b, y_\tau)}{\min(y_b, y_\tau)}$$

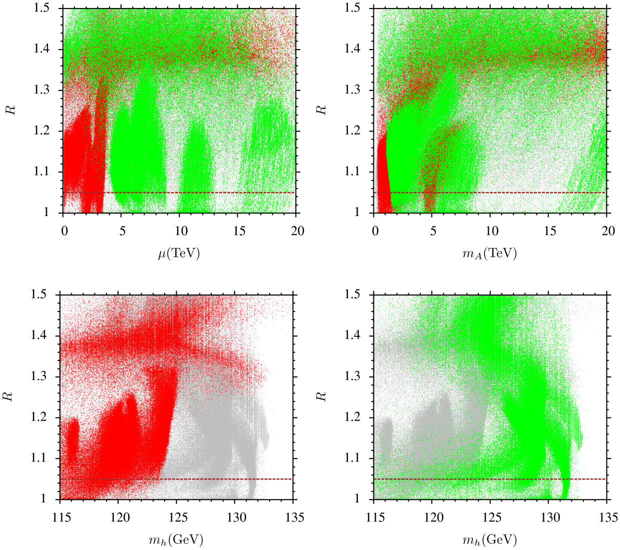
[1] F. E. Paige, S. D. Protopopescu, H. Baer and X. Tata, arXiv:0312045 [hep-ph]

Constraints

$$m_h \text{ (lightest Higgs mass)} \geq 115 \text{ GeV},$$
$$BR(B_s \to \mu^+\mu^-) < 4.5 \times 10^{-9},$$
$$0.15 < \frac{BR(B_u \to \tau\nu_\tau)MSSM}{BR(B_u \to \tau\nu_\tau)SM} < 2.03 \ (2\sigma),$$
$$2.85 \times 10^{-4} \leq BR(b \to s\gamma) \leq 4.24 \times 10^{-4} \ (2\sigma),$$
$$\Omega_{\rm CDM} h^2 = 0.111^{+0.028}_{-0.037} \ (5\sigma),$$
$$3.4 \times 10^{-10} \leq \Delta a_\mu \leq 55.6 \times 10^{-10} \ (3\sigma).$$



Gray points satisfy REWSB and neutralino as LSP conditions. Red and green points satisfy additional spartcile mass and B-physics bounds and have $\tan\beta < 20$ and $\tan\beta > 20$, respectively. The horizontal dashed line indicates the 5% b-τ Yukawa unification.



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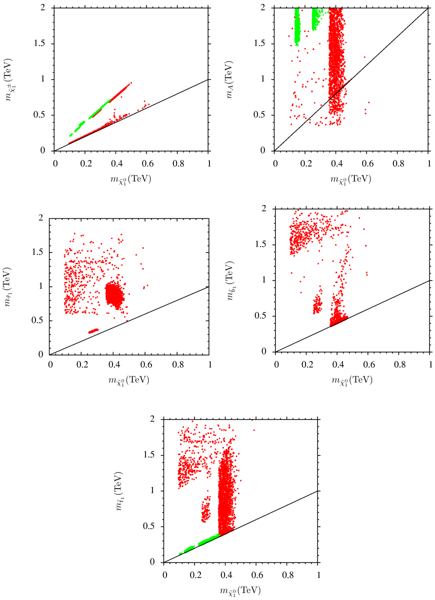


All points satisfy mass bounds, B-physics bounds, WMAP bounds and have $R < 1.05$. Red and green points satisfy additional spartcile mass and B-physics bounds and have $\tan\beta < 20$ and $\tan\beta \geqslant 20$, respectively.

	Point 1	Point 2	Point 3	Point 4
m_{10}	2604	3849	18380	16800
$m_{\overline{5}}$	3443	900.1	16450	18960
$m_{1/2}$	1049	1056	292.6	358.6
$\tan\beta$	8.3	4.77	42.4	45
A_t	-5140	-7455	-44840	-39510
$A_b = A_\tau$	41070	40830	-8170	23640
m_{H_d}	3424	905	18500	17340
m_{H_u}	1380	4700	14150	10410
$sign(\mu)$	+	+	+	+
m_h	120.9	119.6	125.1	125.2
m_A	929	797	18781	13544
μ	2934	2345	17562	17394
$m_{\tilde{\chi}^0_{1,2}}$	461, 882	467, 887	179, 362	179, 354
$m_{\tilde{\chi}^0_{3,4}}$	2857, 2859	2291, 2295	16905, 16905	16406, 16406
$m_{\tilde{\chi}^\pm_{1,2}}$	881, 2857	887, 2311	368, 17075	357, 16429
$m_{\tilde{g}}$	2385	2431	1089	1165
$m_{\tilde{u}_{L,R}}$	3314, 3211	4336, 4405	18374, 18265	16788, 16608
$m_{\tilde{t}_{1,2}}$	1211, 1798	1007, 2825	215, 10165	3289, 7153
$m_{\tilde{d}_{L,R}}$	3315, 3984	4337, 2033	18374, 16488	16788, 19095
$m_{\tilde{b}_{1,2}}$	1375, 2082	489, 2841	10198, 11734	7139, 12709
$m_{\tilde{e}_{L,R}}$	3479, 2719	1321, 3731	16319, 18556	18850, 17052
$m_{\tilde{\tau}_{1,2}}$	876, 2939	803, 341	14263, 14864	11256, 16464
Ωh^2	0.113	0.074	0.11	$2269 \gg 1$
$\langle\sigma v\rangle(v \to 0)$ $[cm^3/s]$	3.886×10^{-27}	9.512×10^{-29}	1.684×10^{-26}	4.385×10^{-31}
$\sigma^{SI}(p) \times 10^{12}$ [pb]	5.639	9.689	1.640	0.127
R	1.02	1.02	1.02	1.0

t-b-τ Yukawa Unification in SUSY $SU(4)_c \times SU(2)_L \times SU(2)_R$ (4-2-2)

- SM fermions: $\psi_{\mathbf{i}} = (\mathbf{4}, \mathbf{2}, \mathbf{1})$ and $\psi^{\mathbf{c}}_{\mathbf{i}} = (\bar{\mathbf{4}}, \mathbf{1}, \mathbf{2})$
- 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

- This model was first studied by Gogoladze,Khalid, Shafi(Phys.Rev. D79 (2009) 115004). We are revisiting this model to see that if we can still have solutions consistent with new limits set by LHC results.
- The main result of this study is that with 10% or better t-b-τ YU, we have NLSP gluino solutions
- Yukawa unified and NLSP gluino solutions are mostly in heavier Higgs mass range ($m_h \sim 123 - 130$ GeV)

We quantify t-b-τ Yukawa unification(YU) by

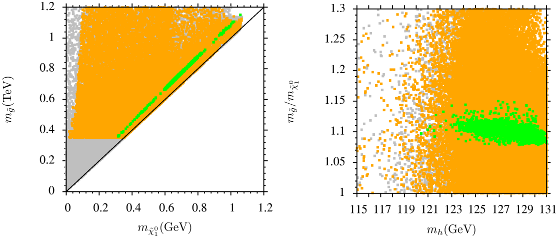
$$R_{tb\tau} \equiv \frac{\max(y_t, y_b, y_\tau)}{\min(y_t, y_b, y_\tau)}$$

We performed random scans for the following parameter range:

$$\begin{aligned} 0 &\leq m_{16} \leq 30\,\mathrm{TeV}, \\ 0 &\leq M_2 \leq 2\,\mathrm{TeV}, \\ 0 &\leq M_3 \leq 2\,\mathrm{TeV}, \\ -3 &\leq A_0/m_{16} \leq 3, \\ 0 &\leq M_D/m_{10} \leq 1, \\ 0 &\leq m_{10} \leq 45\,\mathrm{TeV} \\ 40 &\leq \tan\beta \leq 60, \\ \mu > 0&, \quad m_t = 173.3\,\mathrm{GeV}. \end{aligned}$$

$$m_{Hd,Hu} = m_{10}\sqrt{1 \pm 2(M_D/m_{10})^2}$$

S. Raza and Q. Shafi (in preparation) .



Gray points are consistent with REWSB and neutralino LSP. Orange points satisfy mass bounds (including m_h in the range 115-131 GeV and $m_{\tilde{g}} \geq 0.35\,TeV$) constraints from B-physics. Green point solutions belong to a subset of orange points and satisfy WMAP bounds and $R_{tb\tau} \leq 1.05$

	Point 1	Point 2	Point 3
m_{16}	27620	27530	29050
M_1	917.9	1315	1801.56
M_2	1526	2135	2882
M_3	5.75	85.29	180.9
m_{10}/m_{16}	0.705	0.991	0.783
m_D/m_{10}	0.498	0.425	0.891
A_0/m_0	-2.5	-2.4	-2.3
$\tan\beta$	53.8	52.5	52.6
m_h	126.6	125.0	125.2
m_H	11077	14611	11680
m_A	11005	14515	11604
$m_{H^\pm}$	11078	14611	11681
$m_{\tilde{\chi}^0_{1,2}}$	543,1660	732, 2197	973, 2875
$m_{\tilde{\chi}^0_{3,4}}$	28040,28040	23540,23540	19225 ,19225
$m_{\tilde{\chi}^\pm_{1,2}}$	1666 ,28015	2203 ,23520	2880,19200
$m_{\tilde{g}}$	609	802	1066
$m_{\tilde{u}_{L,R}}$	27650,27424	27600,27249	29137,28824
$m_{\tilde{t}_{1,2}}$	11193,11653	9382 ,9748	8066,8540
$m_{\tilde{d}_{L,R}}$	27650,27757	27600,27721	29137 ,29233
$m_{\tilde{b}_{1,2}}$	11162,11574	8685,9515	7394 ,8490
$m_{\tilde{\nu}_1}$	27502	27352	28925
$m_{\tilde{\nu}_3}$	18847	17952	18732
$m_{\tilde{e}_{L,R}}$	27501 ,27921	27350,27968	28923 ,29429
$m_{\tilde{\tau}_{1,2}}$	13298,18778	11322,17946	10615,18746
$\sigma_{SI}(\mathrm{pb})$	9.46×10^{-14}	6.23×10^{-14}	3.19×10^{-14}
$\sigma_{SD}(\mathrm{pb})$	2.59×10^{-14}	1.40×10^{-14}	3.27×10^{-14}
$\Omega_{CDM}h^2$	0.11	0.076	0.132
$R_{tb\tau}$	1.00	1.02	1.05

Summary

b-τ YU in SU(5)

- YU solutions breakdown into two classes namely low $\tan\beta \sim 3-11$ and high $\tan\beta \sim 30-60$
- Solutions with low $\tan\beta$ have $m_{\tilde{g}} \sim 1-4$ TeV, $m_{\tilde{q}} \sim 1-5$TeV (many of them beyond LHC reach) and $m_h < 123$ GeV(may be rule out by ATLAS/CMS)
- Large $\tan\beta$ solutions favors a light gluino with $m_{\tilde{g}} \sim 0.5-2$ TeV (should be accessible to LHC searches), $m_h \gtrsim 120$ GeV and stop-coannihilation as a characteristic feature of this scenario

t-b-τ YU in 4-2-2

- with 10% or better t-b-τ YU, we only have gluino-cannihilation
- Yukawa unified and NLSP gluino ($m_{\tilde{g}} \sim 0.4-1$ TeV) solutions are mostly in heavier Higgs mass range $m_h \sim 123-130$ GeV