Light stop from b-τ Yukawa Unification

Shabbar Raza

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

in collaboration with Ilia Gogoladze and Qaisar Shafi
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Motivation

- 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
- In past decades a lot of work has been done to study the implications of b-τ Yukawa Unification(YU)

- It was know that in the case of CMSSM, because of tension between finite SUSY threshold corrections(need $\mu < 0$ to have correct bottom quark mass) and muon anomalous magnetic moment(needs $\mu > 0$), it was very hard to have ‘good’ b-τ YU
- With finite SUSY threshold corrections(with $\mu < 0$), one needs heavy SUSY particle spectrum to survive the experimental constraints such as $BR(b \to s\gamma)$
- In this project we explore the low energy consequences of implementing b-τ YU in CMSSM framework with $\mu > 0$
- We refer to b-τ YU and CMSSM as YCMSSM
- Among other things, we require that YCMSSM delivers a viable cold dark matter(DM) candidate (lightest stable neutralino) whose relic energy density is compatible with the WMAP measured value

- We find that the LSP neutralino is bino, the spin 1/2 SUSY partner of the $U(1)_y$ gauge boson
- The NLSP, which is slightly heavier (10-20%) than the neutralino, is stop, the SUSY partner of the top quark
- The desired relic abundance is achieved via stop-neutralino co-annihilation
- The stop-neutralino co-annihilation channel is the only channel we found consistent with 10% or better YU and satisfying all experimental bounds

CMSSM parameters

- $m_0 \equiv$ Universal soft SUSY breaking (SSB) scalar mass
- $M_{1/2} \equiv$ Universal SSB gaugino mass
- $A_0 \equiv$ Universal SSB trilinear interaction term
- $\tan\beta = \frac{v_u}{v_d}$
- $sign(\mu)$ is sign of SUSY bilinear Higgs parameter > 0

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

$$\begin{aligned} 0 \leq & \; m_0 \leq 25\,\mathrm{TeV}, \\ 0 \leq & \; M_{1/2} \leq 2\,\mathrm{TeV}, \\ -3 \leq & \; A_0/m_0 \leq 3, \\ 1.1 \leq & \; \tan\beta \leq 60, \\ \mu > 0, & \quad m_t = 173.3\,\mathrm{GeV}. \end{aligned}$$

Quantify b-τ Yukawa unification(YU) by

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

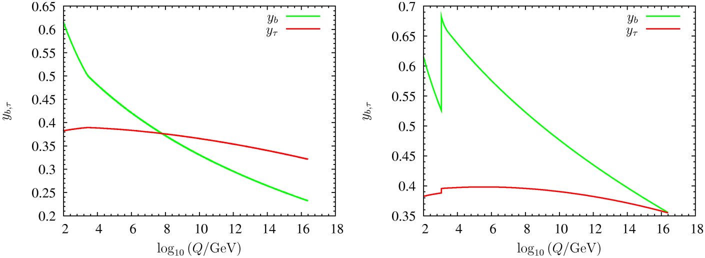
Constraints

All the collected data points satisfy the requirement of REWSB, with the neutralino in each case being the LSP.
After collecting data we impose experimental mass bounds.
We use the IsaTools package to implement the following phenomenological constraints:

$$\begin{aligned} BR(B_s \to \mu^+\mu^-) < 4.3 \times 10^{-8}, \\ 0.53 < \frac{BR(B_u \to \tau\nu_\tau)MSSM}{BR(B_u \to \tau\nu_\tau)SM} < 2.03\ (3\sigma), \\ 2.85 \times 10^{-4} \leq BR(b \to s\gamma) \leq 4.24 \times 10^{-4}\ (2\sigma), \\ \Omega_{\mathrm{CDM}} h^2 = 0.111^{+0.028}_{-0.037}\ (5\sigma). \end{aligned}$$

For muon anomalous magnetic moment, we only require that YCMSSM does no worse than SM

Importance of finite SUSY threshold corrections
($3 \le \tan\beta \le 60$)



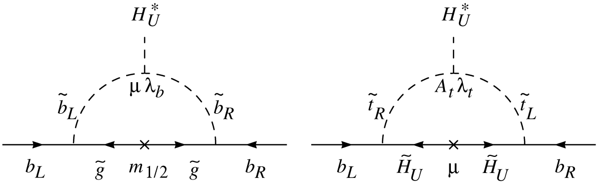
Evolution of bottom (green) and τ (red) Yukawa couplings without (left) and with (right) finite SUSY threshold corrections

b-τ YU and finite threshold corrections [1] [2]

Dominant contributions to the bottom quark mass come from the gluino and chargino loops

$$\delta y_b^{\mathrm{finite}} \approx \frac{\mu}{4\pi^2}\left(\frac{g_3^2}{3}\frac{m_{\tilde{g}}}{m_1^2} + \frac{y_t^2}{8}\frac{A_t}{m_2^2}\right)\tan\beta + \ldots$$

where $m_1 \approx (m_{\tilde{b}_1} + m_{\tilde{b}_2})/2$ and $m_2 \approx (m_{\tilde{t}_2} + \mu)/2$



where $\lambda_b = y_b$ and $\lambda_t = y_t$

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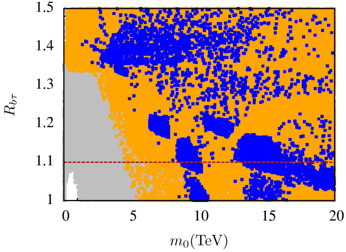
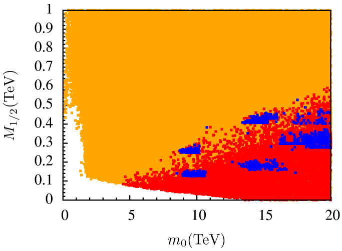
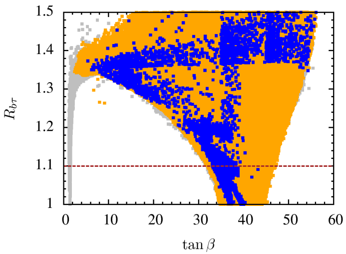
[1] L. J. Hall, R. Rattazzi and U. Sarid, Phys. Rev.D 50, 7048 (1994)

[2] D. M. Pierce, J. A. Bagger, K. T. Matchev, and R.-j. Zhang, Nucl. Phys. **B491** (1997) 3

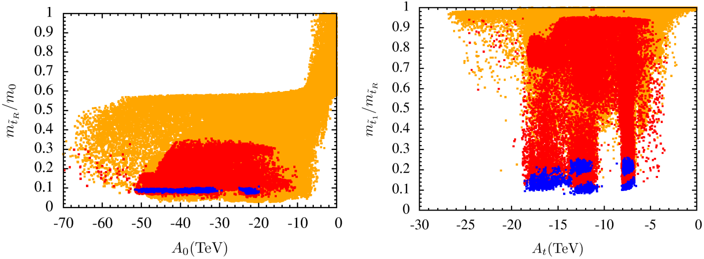




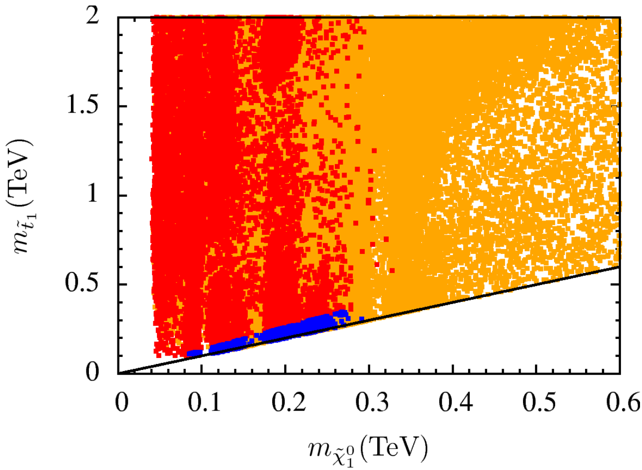
In $R_{b,\tau} - m_0$ plane gray points are consistent with REWSB and $\tilde{\chi}_1^0$ LSP. Orange points satisfy collider bounds and the blue points are subset of orange points that satisfy WMAP bounds on $\tilde{\chi}_1^0$ DM abundance. In $M_{1/2} - m_0$ plane gray and orange points have the same meaning as in $R_{b,\tau} - m_0$ plane, red points are subset of orange points with $R_{b,\tau} \leq 1.1$, and its subset (blue points) represent solutions satisfy WMAP bounds on $\tilde{\chi}_1^0$ DM abundance



The gray points are consistent with REWSB and $\tilde{\chi}_1^0$ LSP. Orange points satisfy collider bounds and the blue points are subset of orange points that satisfy WMAP bounds on $\tilde{\chi}_1^0$ DM abundance



Orange points satisfy all collider bounds.The red points are subset of orange points and represent $R_{b,\tau} \leq 1.1$. Points in blue color show neutralino-stop co-annihilation solutions



Orange points satisfy all collider bounds. The red points are subset of orange points and represent $R_{b,\tau} \leq 1.1$. Points in blue color show neutralino-stop co-annihilation solutions

	'Perfect" $R_{b,\tau}$	NLSP $\tilde{t}$	$NLSP\tilde{t}$
m_0	15220	10040	17920
$M_{1/2}$	177	152	521
$\tan\beta$	37	39	37
A_0/m_0	-2.36	-2.32	-2.33
$sgn(\mu)$	$+$	$+$	$+$
m_h	115	120	115
m_H	6036	4566	9752
m_A	5997	4537	9688
$m_{H^\pm}$	6037	4568	9753
$m_{\tilde{\chi}^0_{1,2}}$	124,272	97,209	290,592
$m_{\tilde{\chi}^0_{3,4}}$	10379,10379	6836,6836	12347,12347
$m_{\tilde{\chi}^\pm_{1,2}}$	275,10406	211,6840	598,1239
$m_{\tilde{g}}$	796	640	1680
$m_{\tilde{u}_{L,R}}$	15170,15214	10000,10030	17892,17942
$m_{\tilde{t}_{1,2}}$	153,5930	114,4076	328,7894
$m_{\tilde{d}_{L,R}}$	15170,15222	10000,10036	17892,17951
$m_{\tilde{b}_{1,2}}$	6060,8357	4152,5752	8097,11159
$m_{\tilde{\nu}_1}$	15223	10041	17929
$m_{\tilde{\nu}_3}$	12744	8453	15082
$m_{\tilde{e}_{L,R}}$	15211,15208	10032,10032	17911,17909
$m_{\tilde{\tau}_{1,2}}$	9843,12771	6619,8474	11801,15130
$\sigma_{SI}(\mathrm{pb})$	3.28×10^{-12}	5.85×10^{-12}	7.93×10^{-13}
$\sigma_{SD}(\mathrm{pb})$	3.90×10^{-12}	2.39×10^{-11}	1.77×10^{-12}
$\Omega_{CDM}h^2$	0.11	0.09	0.1
$R_{b\tau}$	1.00	1.02	1.09

Summary of b-τ Yukawa Unification

- We have investigated b-τ Yukawa unification in the mSUGRA/CMSSM (YCMSSM) framework and find that it is consistent with the NLSP stop scenario and also yields the desired LSP neutralino relic abundance.
- YCMSSM predicts that there are just two ‘light’ (LHC accessible) colored sparticles, namely the NLSP stop with mass $\sim 100-330\,\mathrm{GeV}$, and the gluino which is $\sim 600-1700\,\mathrm{GeV}$
- The Chargino and a second neutralino are about a factor 2-3 lighter than the gluino. The remaining squarks as well as all sleptons have masses in the multi-TeV range.
- Regarding the fundamental CMSSM parameters, we find that $5\,\mathrm{TeV} \lesssim m_0 \lesssim 20\,\mathrm{TeV}$, $m_0/M_{1/2} \sim 30-50$ or so, $\tan\beta \approx 35-40$, $|\mu| \sim 3-15\,\mathrm{TeV}$ and $|A_0/m_0| \sim 2.2-2.4$.