Bottom-Tau Unification in SUSY Model with Heavy Sfermions

Takeo Moroi (Tokyo)

Ref:

Chigusa & TM, arXiv:1604.02156

PASCOS 2016, Quy Nhon, Vietnam
1. Introduction
Subject today: SU(5)-based SUSY GUT (with heavy scalars)

- Successful unification of the SM gauge groups is possible

The SUSY particles may be as heavy as $\sim 10$ TeV

- No SUSY particle has been observed yet
- $m_h \approx 125$ GeV
$b$ and $\tau$ are (usually) in a same GUT multiplet

$\Rightarrow$ In simple GUT models: $y_b(\mathcal{M}_{\text{GUT}}) = y_\tau(\mathcal{M}_{\text{GUT}})$

In my talk, I will discuss:

- $b$-$\tau$ unification in models with heavy SUSY particles
  [Tobe & Wells; Ross & Serna; Antusch & Spinrath; Antusch & Spinrath; Baer et al.; Badziak; Joshipura & Patel; Elor, Hall, Pinner & Ruderman; Anandakrishnan, Raby & Wingerter; Ajaib, Gogoladze, Shafi & Un; Miller & Morais]

- I pay particular attention to “pure gravity mediation” (PGM) model, which naturally predicts heavy scalars

I study $b$-$\tau$ unification in PGM model, taking into account:

- Mass splittings among SUSY particles
- Threshold corrections due to SUSY particles
2. Analysis
Pure gravity mediation model
[Ibe, Moroi & Yanagida; Ibe & Yanagida; Arkani-Hamed et al.]

- Scalar masses originates from a direct coupling in the Kähler potential to the SUSY breaking sector
- Gaugino masses are from anomaly-mediation
  [Giudice, Luty, Murayama & Rattazzi; Randall & Sundrum]

Mass spectrum:

- Sfermion masses are relatively heavy $\sim O(10) \, \text{TeV}$
- Gaugino masses are one-loop suppressed relative to the scalar masses
- Higgsinos are as heavy as sfermions
Effective theories

- SM for $m_t < Q < M_{\tilde{G}}$: SM particles
- $\tilde{G}$SM for $M_{\tilde{G}} < Q < M_S$: SM particles and gauginos
- MSSM for $M_S < Q < M_{\text{GUT}}$: MSSM particles
Boundary conditions of SUSY breaking scalar masses

\[ m_Q^2(M_{\text{GUT}}) = m_U^2(M_{\text{GUT}}) = m_E^2(M_{\text{GUT}}) \equiv m_{10}^2 \]
\[ m_D^2(M_{\text{GUT}}) = m_L^2(M_{\text{GUT}}) \equiv m_5^2 \]
\[ m_{H_u}^2(M_{\text{GUT}}) \equiv m_{H5}^2 \]
\[ m_{H_d}^2(M_{\text{GUT}}) \equiv m_{H\bar{5}}^2 \]

Gaugino masses

\[ M_1(M_{\text{GUT}}) = \frac{11g_1^2(M_{\text{GUT}})}{16\pi^2} m_3^{3/2} \]
\[ M_2(M_{\text{GUT}}) = \frac{g_2^2(M_{\text{GUT}})}{16\pi^2} m_3^{3/2} \]
\[ M_3(M_{\text{GUT}}) = -\frac{3g_3^2(M_{\text{GUT}})}{16\pi^2} m_3^{3/2} \]
We have calculated $y_b(M_{\text{GUT}})$ and $y_\tau(M_{\text{GUT}})$

- 2-loop RGEs for the MSSM with SOFTSUSY [Allanach]
- 3-loop RGEs for the SM and $\tilde{G}\text{SM}$
- Threshold correction at $M_{\tilde{G}}$ and $M_S$

We fix the Higgs mass with RG analysis of Higgs coupling:

- $m_h = 125$ GeV

We calculate:

$$R_{b\tau} = \frac{y_b(M_{\text{GUT}})}{y_\tau(M_{\text{GUT}})}$$
3. Results
Proper choice of the effective theory below the MSSM scale is important for the precise calculation of $R_{b\tau}$.
$R_{b\tau}$, assuming universal sfermion masses: $\mu > 0$

Scalar mass is determined to realize $m_h = 125.09$ GeV

- $R_{b\tau}$ is typically $\sim 0.7$, if all the scalars are as heavy as gravitino
Threshold correction to $m_b$ from the MSSM particles

[Hall, Rattazzi & Sarid; Hempfling; Carena, Olechowski, Pokorski & Wagner]

\[ \Delta m_b \approx \left[ \frac{2\alpha_s}{3\pi} M_3 \mu I(m_{b_1}^2, m_{b_2}^2, M_3^2) + \frac{y_t^2}{16\pi^2} \mu A_t I(m_{t_1}^2, m_{t_2}^2, \mu^2) \right] \tan \beta \]

Threshold correction to $m_b$ should be sizable for $R_{b\tau} \approx 1$

$\Leftrightarrow |\Delta m_b|$ is suppressed when the sfermions masses are very high (because $\tan \beta$ is not large for $m_h \approx 125$ GeV)
$R_{b\tau}$, as a result of parameter scan

- **Red**: $(m_{10}^2/m_{3/2}^2) > 0.1$
- **Green**: $0.1 < (m_{10}^2/m_{3/2}^2) < 1$
- **Blue**: $(m_{10}^2/m_{3/2}^2) < 0.01$
4. Summary
Today, I discussed:

- $b-\tau$ unification in SUSY model with heavy sfermions
  \[ \Rightarrow \text{Pure gravity mediation (in which gaugino masses obey anomaly-mediation relation)} \]
- Detailed RG analysis has been performed

We found:

- $R_{b\tau} \approx 0.7$, if the threshold correction is negligible
- In pure gravity mediation model, a large threshold correction at the GUT scale is suggested
  \[ W \sim \frac{c}{M_{\text{GUT}}} \Sigma(24) H(\bar{5}) T(10) F(\bar{5}) \]
- If $M_i \sim m_{\tilde{q}}$, $R_{b\tau} \approx 1$ is possible with large $\tan \beta$
Back Up
$R_{b\tau}$, assuming universal sfermion masses: $\mu < 0$

![Graph showing $R_{b\tau}$ dependency on $m_{3/2}$ for different values of $\mu$ and $\tan\beta$.](image)

- $\star (m_{10}^2 / m_{3/2}^2) = 1$
- $\blacktriangledown (m_{10}^2 / m_{3/2}^2) = 0.1$
- $\bullet (m_{10}^2 / m_{3/2}^2) = 0.03$
- $\blacksquare (m_{10}^2 / m_{3/2}^2) = 0.01$
- $\blacktriangle (m_{10}^2 / m_{3/2}^2) = 0.003$
Higgs properties are sensitive to $A_t$ parameter

$$\mathcal{L}_{\text{soft}} = -y_t A_t \tilde{Q}_L \tilde{t}_R^c H_u + \text{h.c.}$$

Radiative correction to the lightest Higgs mass

[Okada, Yamaguchi & Yanagida, Ellis, Ridolfi & Zwirner, Haber & Hempfling]

$$m_h^2 \simeq m_Z^2 \cos^2 2\beta + \frac{3m_t^4}{2\pi^2 v^2} \left[ \log \frac{m_t^2}{m_t^2} + \frac{A_t^2}{m_t^2} \left( 1 - \frac{A_t^2}{12m_t^2} \right) \right]$$