Bottom-Tau Unification in SUSY Model with Heavy Sfermions

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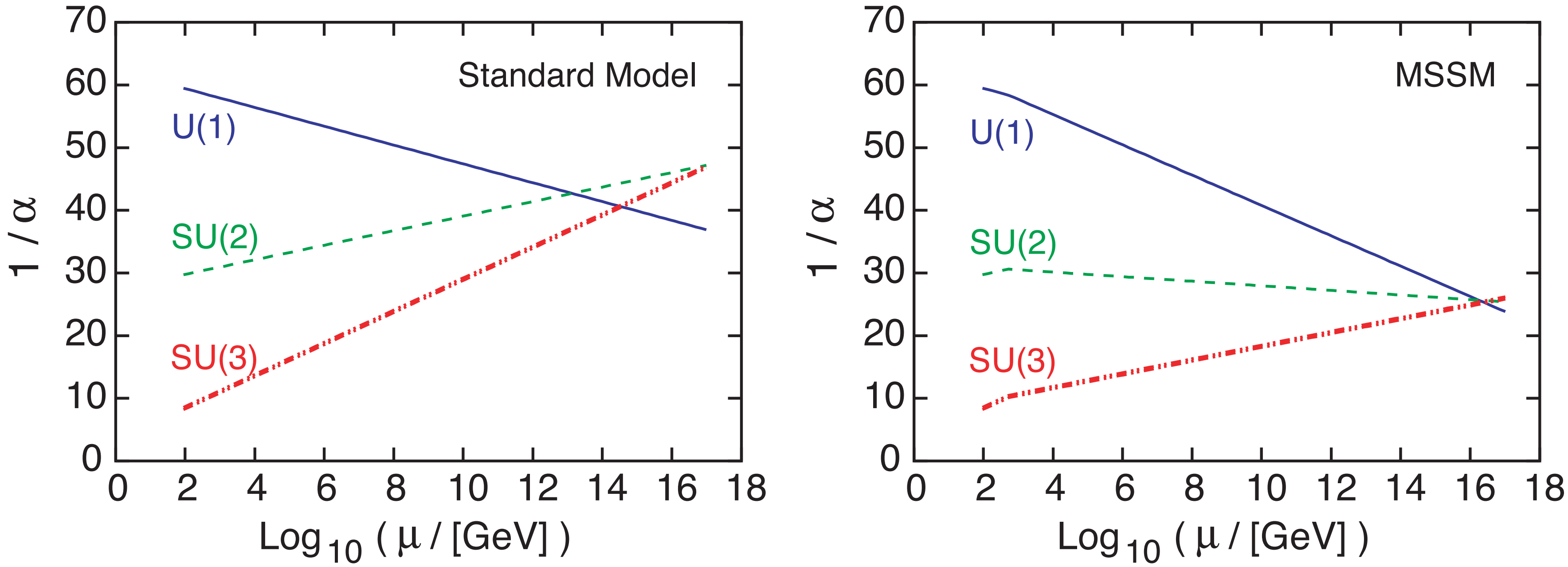
1. Introduction

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 ~ 10 TeV
  - No SUSY particle has been observed yet
  - $m_h \simeq 125$ GeV

b and τ are (usually) in a same GUT multiplet

$\Rightarrow$ In simple GUT models: $y_b(M_{\mathsf{GUT}}) = y_\tau(M_{\mathsf{GUT}})$

In my talk, I will discuss:

- b-τ 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-τ 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.]

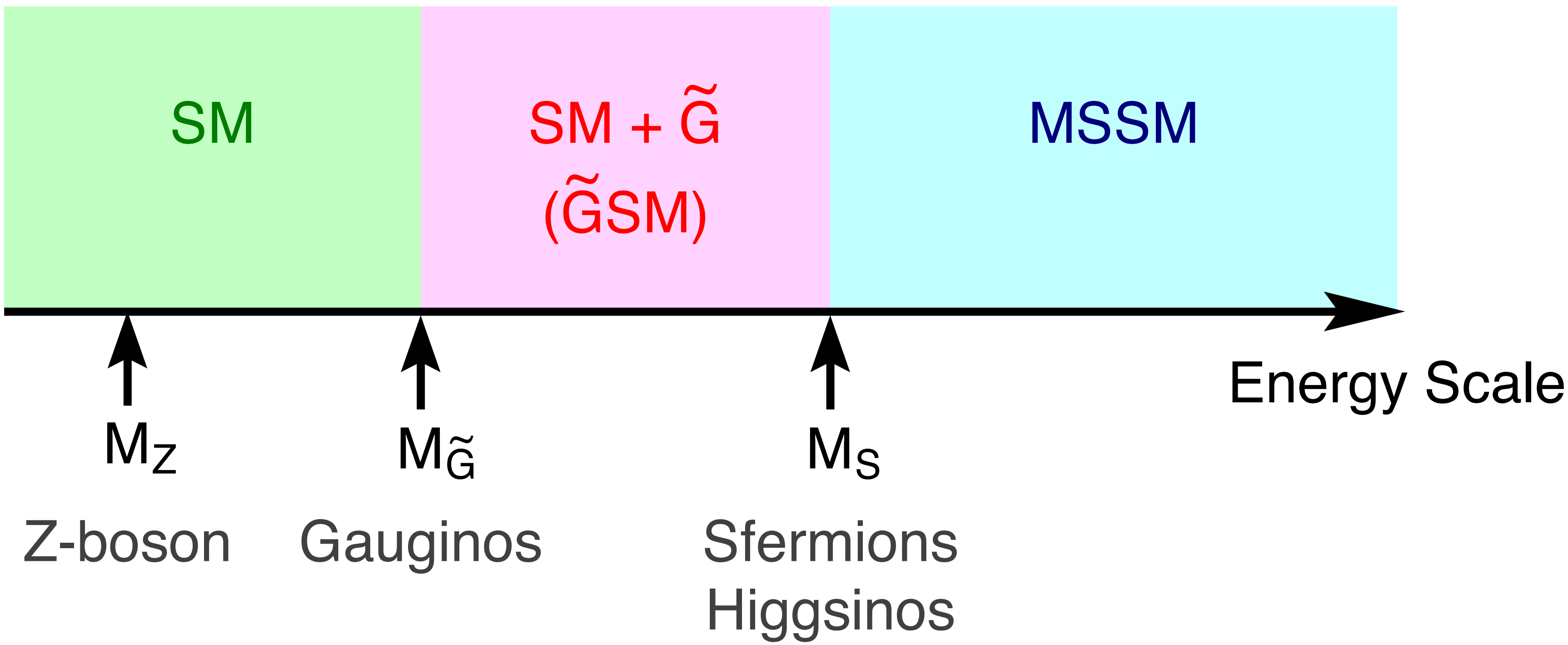
- Scalar masses originates from a direct coupling in the Kähler potential to the SUSY breaking sector
- Gaugino masses are from anomaly-mediation
  [Giudice, Luty, Murayama & Rattazzi; Randall & Sundrum]

Mass spectrum:

- Sfermion masses are relatively heavy $\sim O(10)$ 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 $M_{\tilde{G}} < Q < M_{\text{S}}$: SM particles and gauginos
- MSSM for $M_{\text{S}} < Q < M_{\text{GUT}}$: MSSM particles



Boundary conditions of SUSY breaking scalar masses

- $m^2_{\tilde{Q}}(M_{\mathsf{GUT}}) = m^2_{\tilde{U}}(M_{\mathsf{GUT}}) = m^2_{\tilde{E}}(M_{\mathsf{GUT}}) \equiv m^2_{\mathbf{10}}$
- $m^2_{\tilde{D}}(M_{\mathsf{GUT}}) = m^2_{\tilde{L}}(M_{\mathsf{GUT}}) \equiv m^2_{\bar{\mathbf{5}}}$
- $m^2_{H_u}(M_{\mathsf{GUT}}) \equiv m^2_{H\mathbf{5}}$
- $m^2_{H_d}(M_{\mathsf{GUT}}) \equiv m^2_{H\bar{\mathbf{5}}}$

Gaugino masses

- $M_1(M_{\mathsf{GUT}}) = \dfrac{11 g_1^2(M_{\mathsf{GUT}})}{16\pi^2} m_{3/2}$
- $M_2(M_{\mathsf{GUT}}) = \dfrac{g_2^2(M_{\mathsf{GUT}})}{16\pi^2} m_{3/2}$
- $M_3(M_{\mathsf{GUT}}) = -\dfrac{3 g_3^2(M_{\mathsf{GUT}})}{16\pi^2} m_{3/2}$

We have calculated $y_b(M_{\mathsf{GUT}})$ and $y_\tau(M_{\mathsf{GUT}})$

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

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

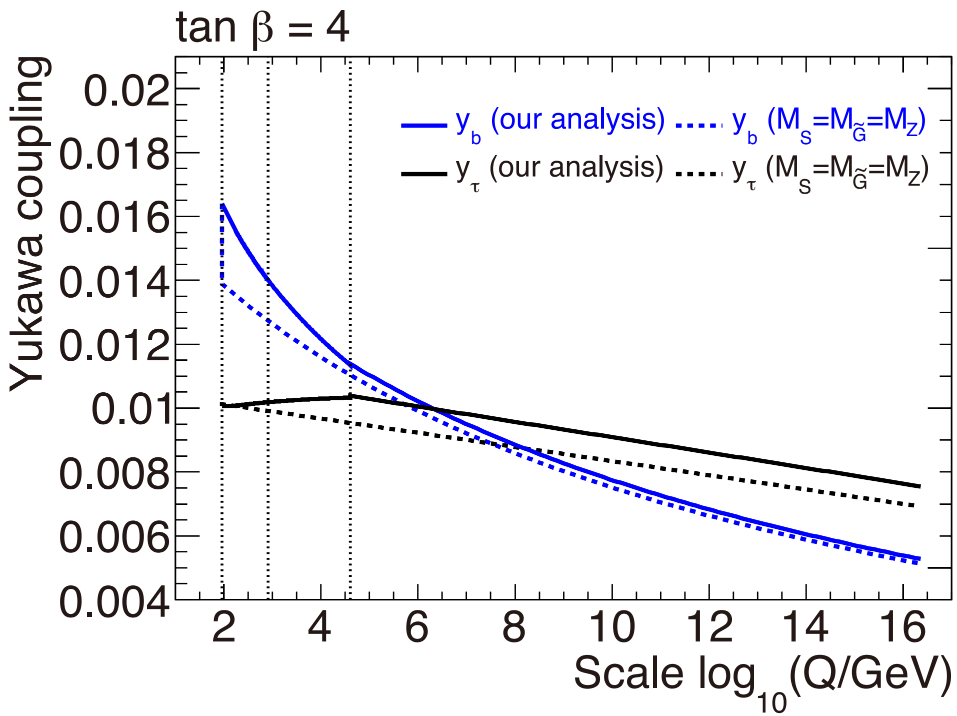
- $m_h = 125$ GeV

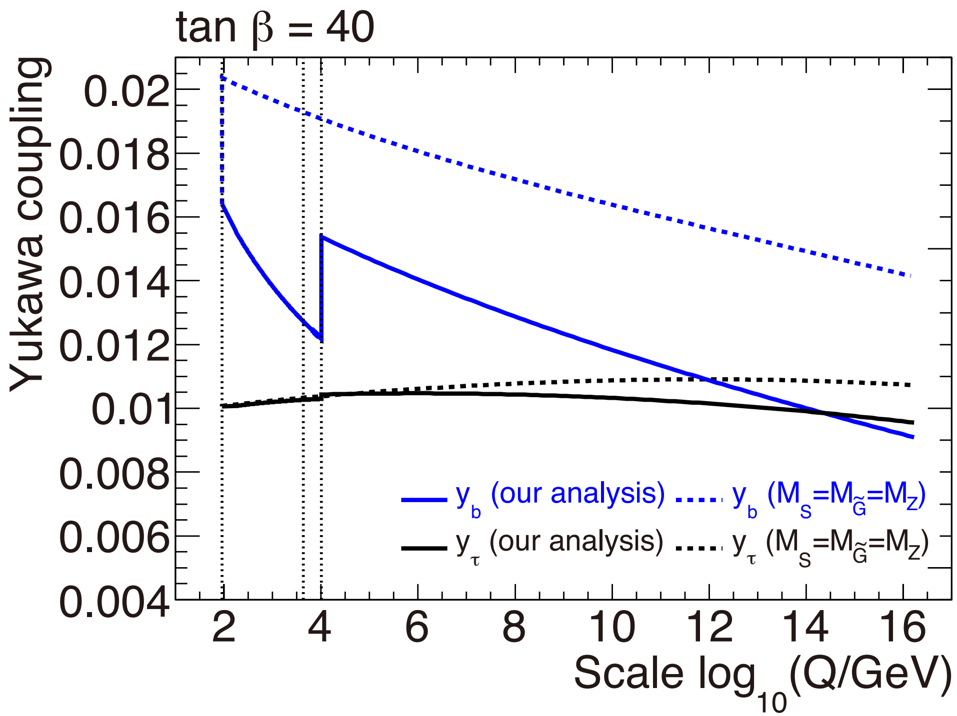
We calculate:

$$R_{b\tau} = \frac{y_b(M_{\mathsf{GUT}})}{y_\tau(M_{\mathsf{GUT}})}$$

3. Results

RG runnings of y_b and y_τ (for the MSSM, rescaled by $\cos\beta$)

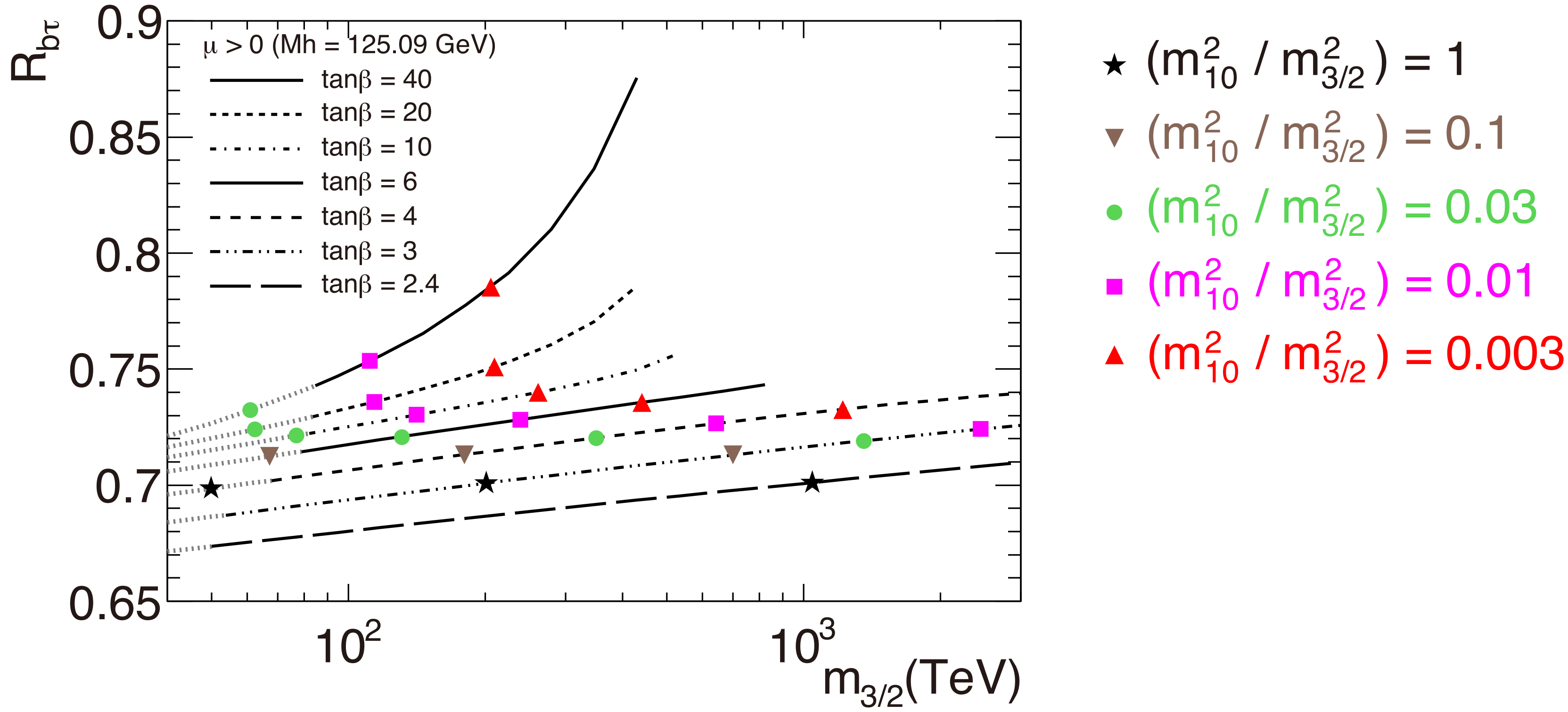




- Proper choice of the effective theory below the MSSM scale is important for the precise calculation of $R_{b\tau}$

$R_{b\tau}$, assuming universal sfermion masses: $\mu > 0$

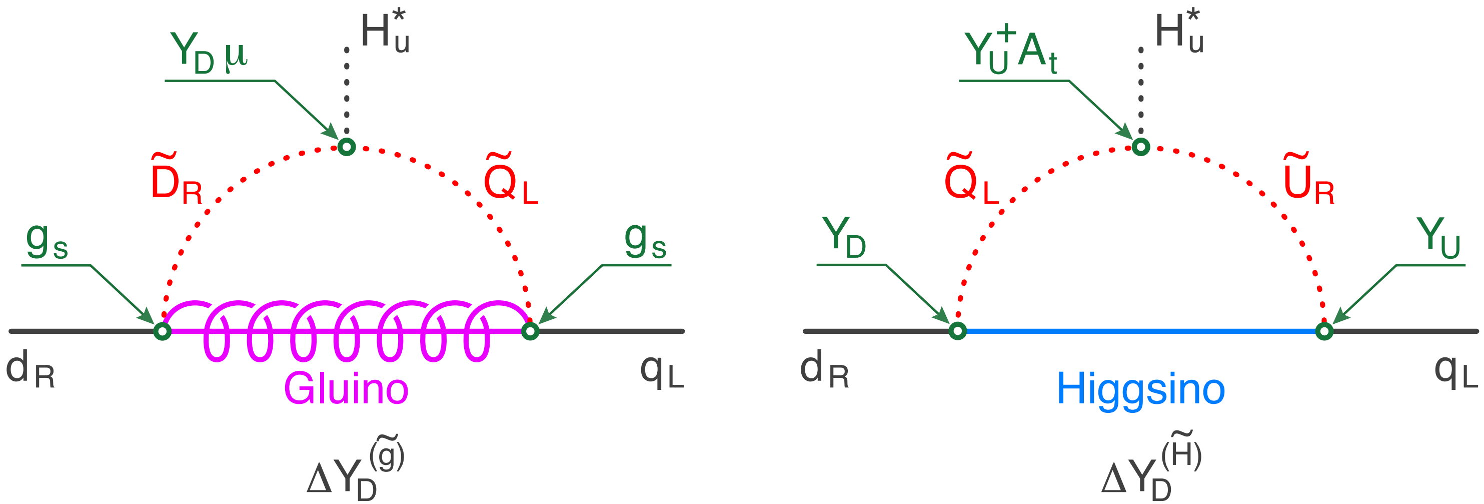
Scalar mass is determined to realize $m_h = 125.09$ GeV



- $R_{b\tau}$ is typically ~ 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]

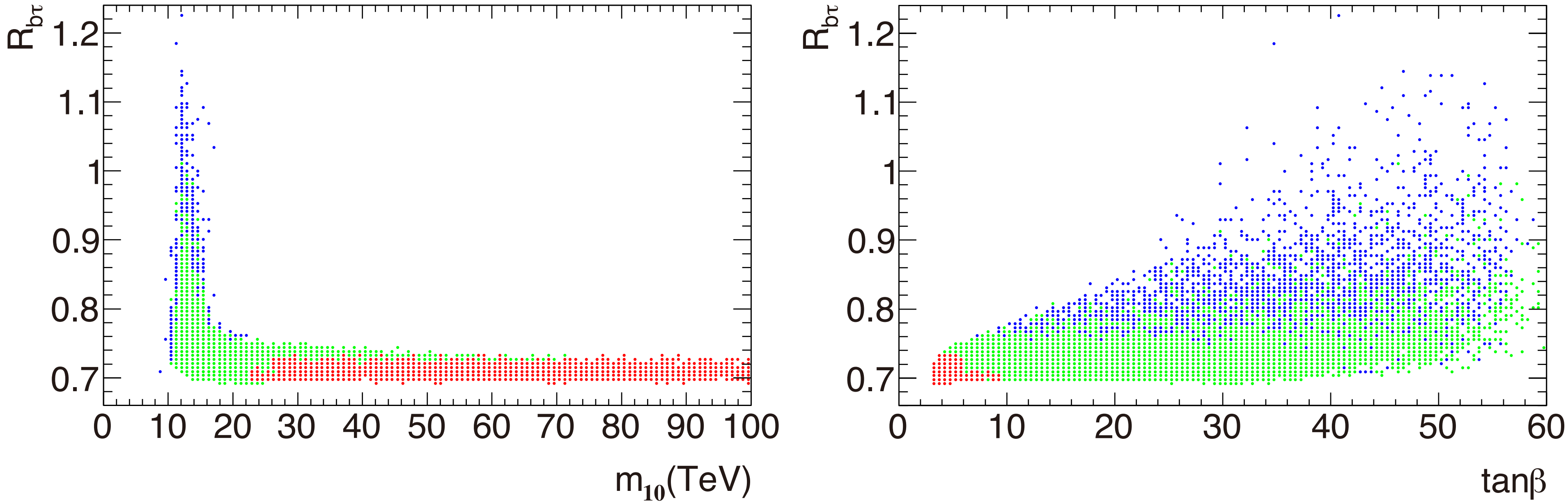


$$\frac{\Delta m_b}{m_b} \simeq \left[\frac{2\alpha_s}{3\pi} M_3 \mu \, I(m_{\tilde{b}_1}^2, m_{\tilde{b}_2}^2, M_3^2) + \frac{y_t^2}{16\pi^2} \mu A_t \, I(m_{\tilde{t}_1}^2, m_{\tilde{t}_2}^2, \mu^2)\right] \tan\beta$$

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

$\Leftrightarrow$ $|\Delta m_b|$ is suppressed when the sfermions masses are very high (because $\tan\beta$ is not large for $m_h \simeq 125$ GeV)

$R_{b\tau}$, as a result of parameter scan



- Red: $(m^2_{\mathbf{10}}/m^2_{3/2}) > 0.1$
- Green: $0.1 < (m^2_{\mathbf{10}}/m^2_{3/2}) < 1$
- Blue: $(m^2_{\mathbf{10}}/m^2_{3/2}) < 0.01$

4. Summary

Today, I discussed:

- b-τ unification in SUSY model with heavy sfermions

  $\Rightarrow$ Pure gravity mediation (in which gaugino masses obey anomaly-mediation relation)

- Detailed RG analysis has been performed

We found:

- $R_{b\tau} \simeq 0.7$, if the threshold correction is negligible

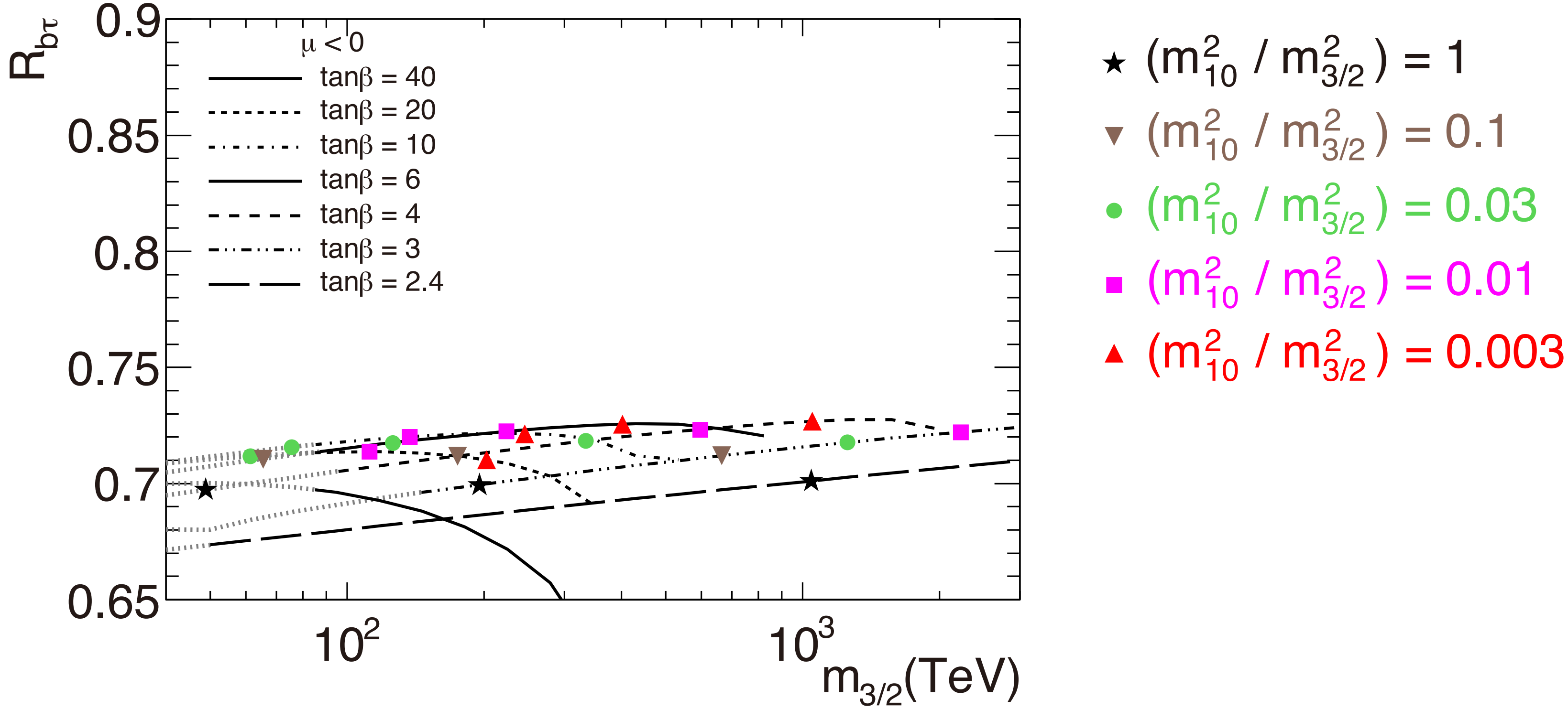
- In pure gravity mediation model, a large threshold correction at the GUT scale is suggested

  For e.g., $W \sim \frac{c}{M_{\mathrm{GUT}}} \Sigma(\mathbf{24})\, H(\bar{\mathbf{5}})\, T(\mathbf{10})\, \bar{F}(\bar{\mathbf{5}})$

- If $M_i \sim m_{\tilde{q}}$, $R_{b\tau} \simeq 1$ is possible with large $\tan\beta$

Back Up

$R_{b\tau}$, assuming universal sfermion masses: $\mu < 0$

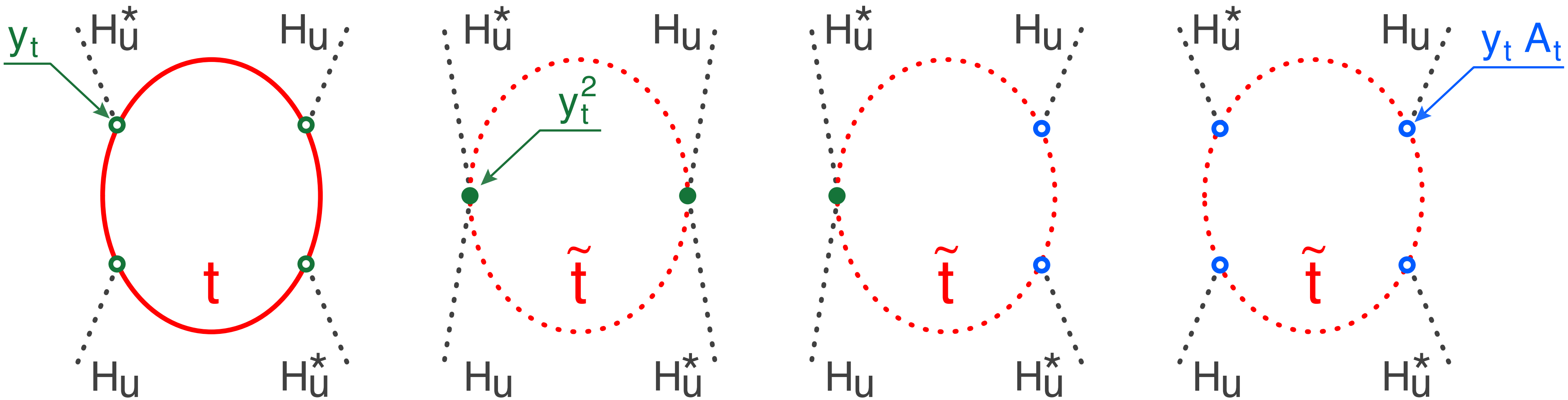


Higgs properties are sensitive to A_t parameter

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

Radiative correction to the lightest Higgs mass

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



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