t-b-tau Yukawa Unification in the MSSM with a Vector-like Family

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VL fermions and pheno

- Higgs mass in SUSY models
- $g-2$
- flavor anomalies
- top partners
- etc.

★ Extending models with VL fermions offers scenarios where parameters at $M_Z$ can be understood based on particle content
★ In MSSM + 1VF, exact t-b-tau Yukawa unification is possible, and SUSY + VF can be inferred
MSSM + 1VF SUSY GUT

$M_{\text{SUSY}} = 3\, \text{TeV}$

$log_{10} E [\text{GeV}]$

$\alpha_G = 0.3$

$\{Q, U, E, L, D\}$

$\{\bar{Q}, \bar{U}, \bar{E}, \bar{L}, \bar{D}\}$

$b_i > 0$

R. Dermíšek & N.M: 1712.03527
\[ \alpha_i^{-1}(M_Z) = \frac{b_i}{2\pi} \ln \frac{M_G}{M_Z} + \alpha^{-1}(M_G) \rightarrow \sin^2 \theta_W \equiv \frac{\alpha'}{\alpha_2 + \alpha'} \approx \frac{b_2}{b_2 + b'} = 0.2205 \]
\[ Y_0 = y_t(M_G) = y_b(M_G) = y_\tau(M_G) \]

\[ W \supset \bar{u} y_u q H_u - \bar{d} y_d q H_d - \bar{e} y_e L H_d \]

\[ + \bar{U} Y_U Q H_u - \bar{D} Y_D Q H_d - \bar{E} Y_E L H_d \]

\[ + \bar{Q} Y_\bar{U} D H_u - \bar{Q} Y_\bar{D} U H_d + E Y_{\bar{E}} \bar{L} H_u \]

assuming universal VL Yukawa coupling

\[ Y_V, \text{ and setting } Y_V = Y_0, \alpha_G = 0.2 \]
\[ Y_0 = y_t(M_G) = y_b(M_G) = y_\tau(M_G) \]
\( \tan \beta = 30 - 45 \)

\( Y_0 = 1 \)

\( Y_0 = 2 \)

\( Y_0 = 3 \)

\( Y_t, Y_b, Y_\tau \)

\( \log_{10} E [\text{GeV}] \)

\( (y_t)_{SM} = y_t (1 + \epsilon_t) \sin \beta \)

\( (y_b)_{SM} = y_b (1 + \epsilon_b) \cos \beta \)

\( (y_\tau)_{SM} = y_\tau (1 + \epsilon_\tau) \cos \beta \)

\( \epsilon_b \approx \frac{2\alpha_3}{3\pi} M_{\tilde{g}} \mu \tan \beta (m_{\tilde{b}_{1,2}}^2, M_{\tilde{g}}^2) + \frac{y_t^2}{16\pi^2} A_t \mu \tan \beta (m_{\tilde{t}_{1,2}}^2, \mu^2) \)

Assume
- universal SUSY
- zero A terms
- \( \mu = -\sqrt{2} m_{\tilde{q}} \)

\( \epsilon_b = \frac{\sqrt{2}\alpha_3}{3\pi} \tan \beta \)

\( \epsilon_b \approx -40\% \)
Exact t-b-tau unification possible, for large $\tan \beta$ expect SUSY + VF

- multi-TeV scale

✓ gauge couplings
✓ Higgs mass
Can it be understood from particle content?

\[
\frac{dy_t^2}{dt} \sim y_t^2 \left( ay_t^2 - \frac{16}{3} g_3^2 \right)
\]

depends on \# of extra quark Yukawas

\[
\frac{d}{dt} \left( \frac{y_{t,IR}^2}{g_3^2} \right) = 0
\]

\[
\Rightarrow \left( \frac{y_{t,IR}^2}{g_3^2} \right)^* = \frac{16 + 3b_3}{3a}
\]

Rapidly approaches fixed point given by \( \sim \alpha_3 \)

Similarly for bottom and tau
Can it be understood from particle content?

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Similarly for bottom and tau
Determining t-b-tau masses

- $M_G, M_{SUSY}, M_{V F}, \tan \beta$
- $\alpha_G, \epsilon, Y_0 = y_t(M_G) = y_b(M_G) = y_\tau(M_G), Y_V$

- $M_G \rightarrow$ Compute nominal SUSY corrections
- $M_{SUSY} \rightarrow$ match to SM
- $M_Z \rightarrow$ fit gauge couplings and t-b-tau masses
Exact t-b-tau unification!

Fit precisely in the whole plane
Exact t-b-tau unification!

\[ M = M_{\text{SUSY}} = M_{VF} \]

\[ M = \begin{cases} 3 \text{TeV} & \epsilon_b = -30\% \\ 5 \text{TeV} & \epsilon_b = -35\% \\ 10 \text{TeV} & \epsilon_b = -40\% \\ 40 \text{TeV} & \end{cases} \]

\[ \tan \beta = \begin{cases} 37 & Y_V = 1 \\ 40 & Y_V = 1.5 \\ 45 & Y_V = 2 \end{cases} \]

\( M_G, \epsilon, M \rightarrow \alpha_1, \alpha_2, \alpha_3 \)

\( \tan \beta, Y_V \rightarrow y_\tau, y_t \)

Fit precisely in the whole plane
Splitting gaugino’s

\[ \tilde{R} = \frac{\tilde{M}}{\tilde{m}} \]

- \( M_G, \epsilon, M \longrightarrow \alpha_1, \alpha_2, \alpha_3 \)
- \( \tan \beta, Y_V, \tilde{R} \longrightarrow y_\tau, y_t, y_b \)

\{Fit precisely in the whole plane\}
• In the MSSM + 1VF, the observed pattern of gauge couplings and fermion masses of the third generation can be understood from fixed points in the RGE, inferring the mass scale of $M_{\text{SUSY}}$ & $M_{\text{VF}}$
• Mass scales, 3 - 30 TeV, suggested in our study fall in the range that is good for Higgs mass in SUSY models
• Perhaps patterns seen in EW data suggest something about particle content $\rightarrow$ multi-TeV...

Thanks!