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

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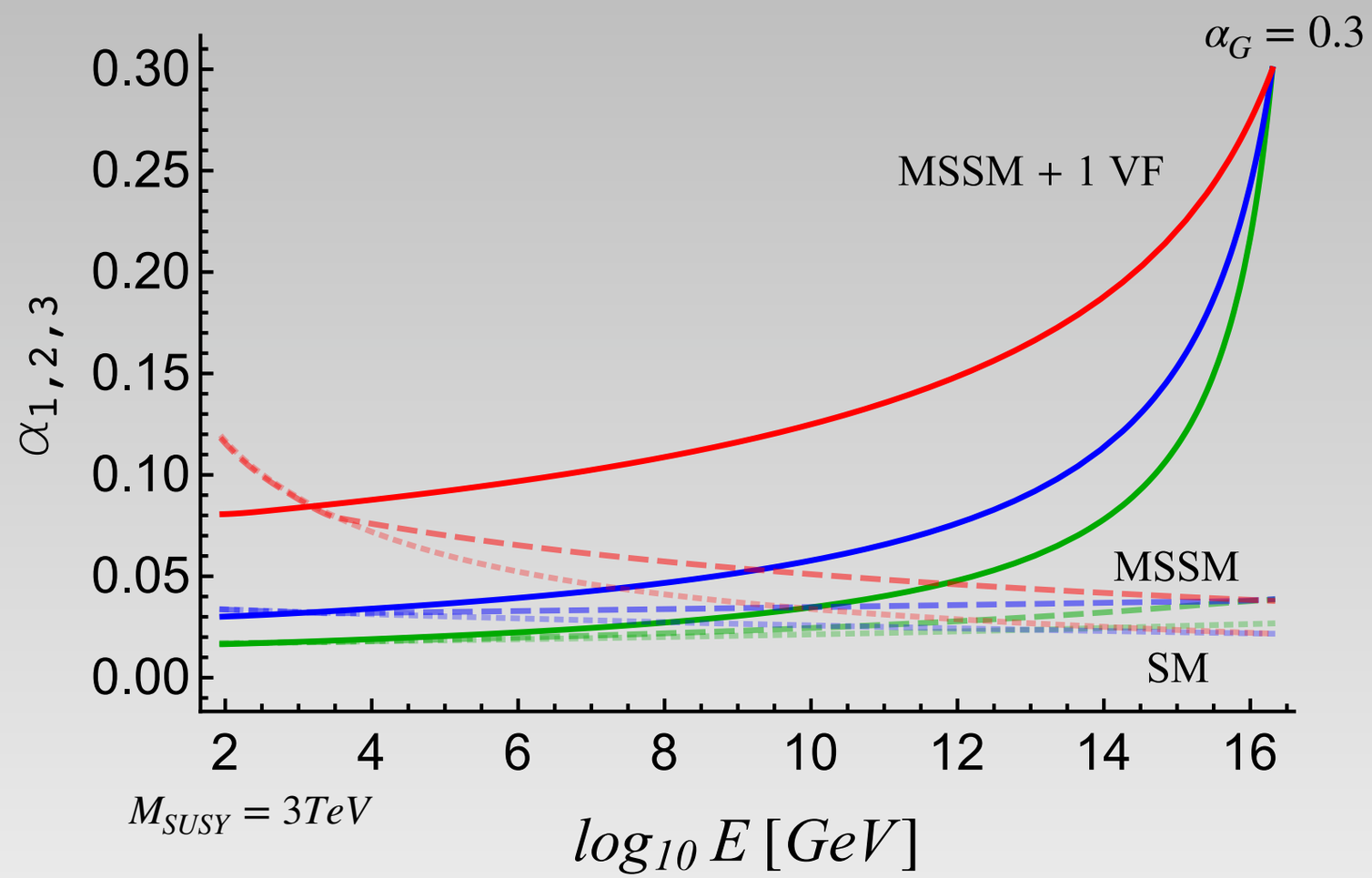
VL fermions and pheno

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

★ Extending models with VL fermions offers scenarios where parameters @ 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

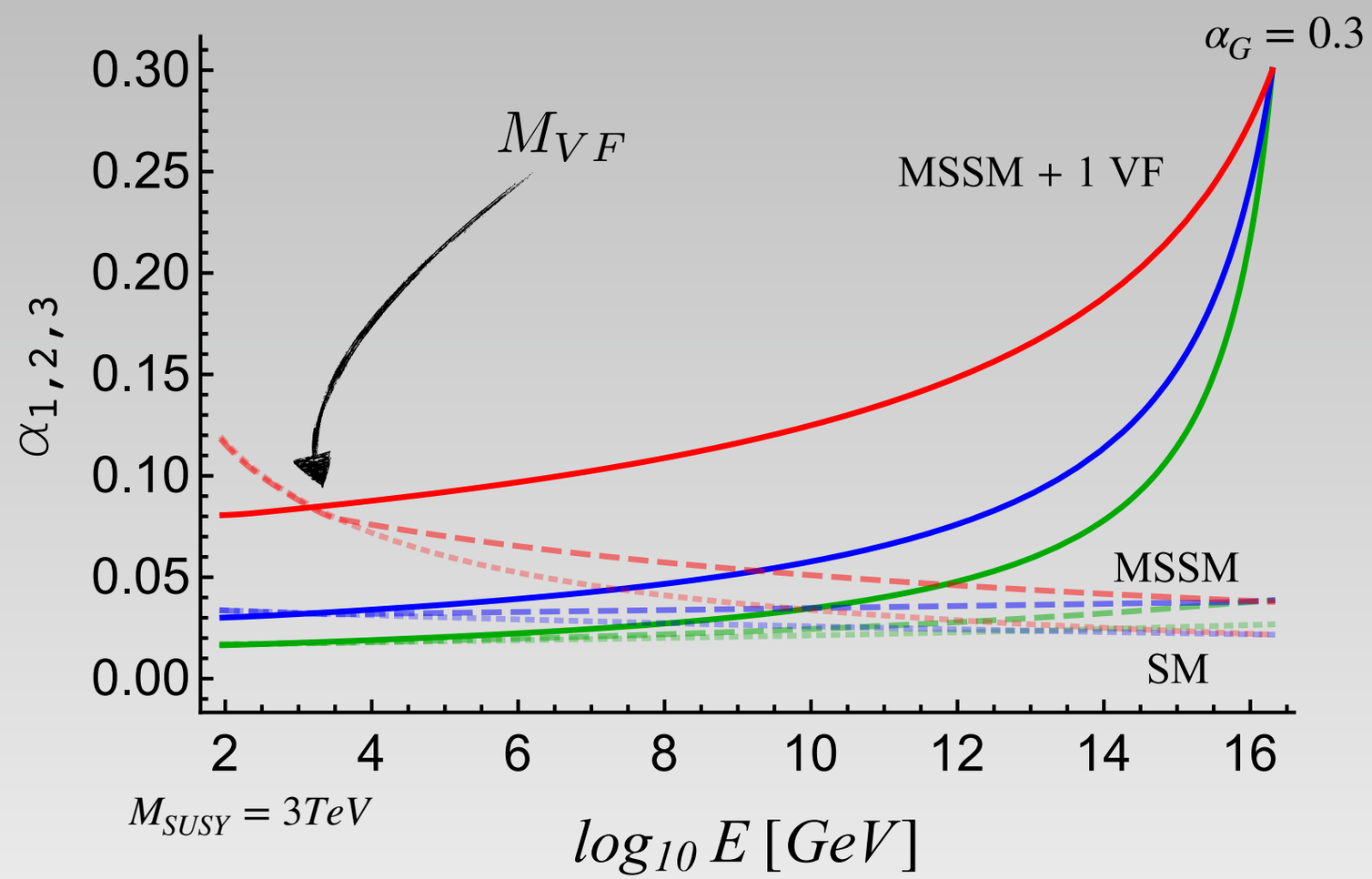
MSSM+1VF SUSY GUT



$$\text{1VF}\left\{\begin{matrix} Q, U, E, L, D \\ \bar{Q}, \bar{U}, \bar{E}, \bar{L}, \bar{D} \end{matrix}\right. \longrightarrow b_i > 0$$

R. Dermíšek & N.M: 1712.03527

MSSM+1VF SUSY GUT



$$\alpha_i^{-1}(M_Z) = \frac{b_i}{2\pi}\ln\frac{M_G}{M_Z} + \alpha^{-1}(M_G) \longrightarrow \sin^2\theta_W \equiv \frac{\alpha'}{\alpha_2+\alpha'} \simeq \frac{b_2}{b_2+b'} = 0.2205$$

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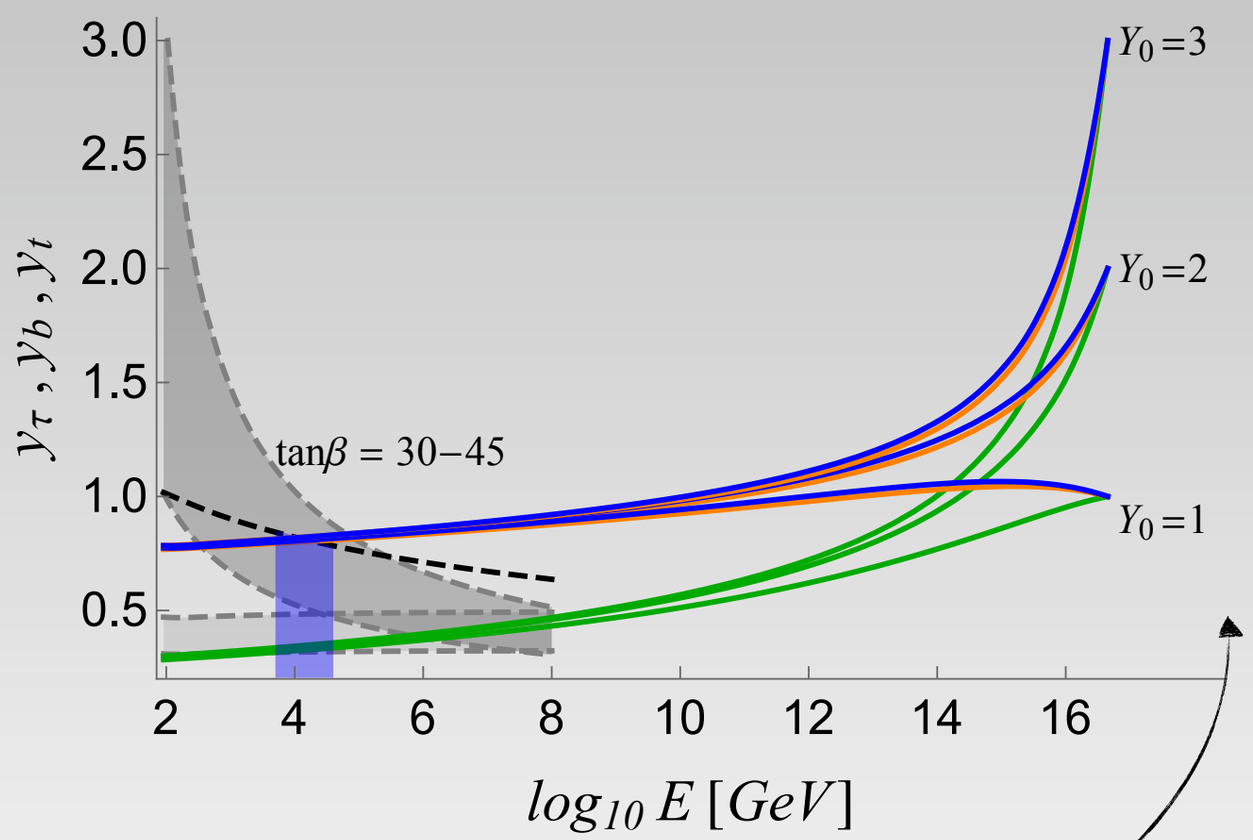
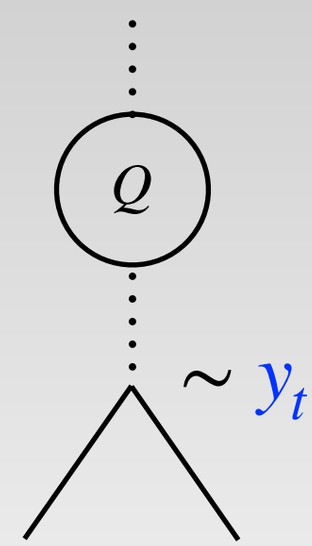
t-b-tau

$$Y_0 = y_t(M_G) = y_b(M_G) = y_\tau(M_G)$$

$$W \supset \bar{u} y_u q H_u - \bar{d} y_d q H_d - \bar{e} y_e L H_d$$
$$+ \bar{U} Y_U Q H_u - \bar{D} Y_D Q H_d - \bar{E} Y_E L H_d$$
$$+ \bar{Q} Y_{\bar{U}} D H_u - \bar{Q} Y_{\bar{D}} U H_d + E Y_{\bar{E}} \bar{L} H_u$$

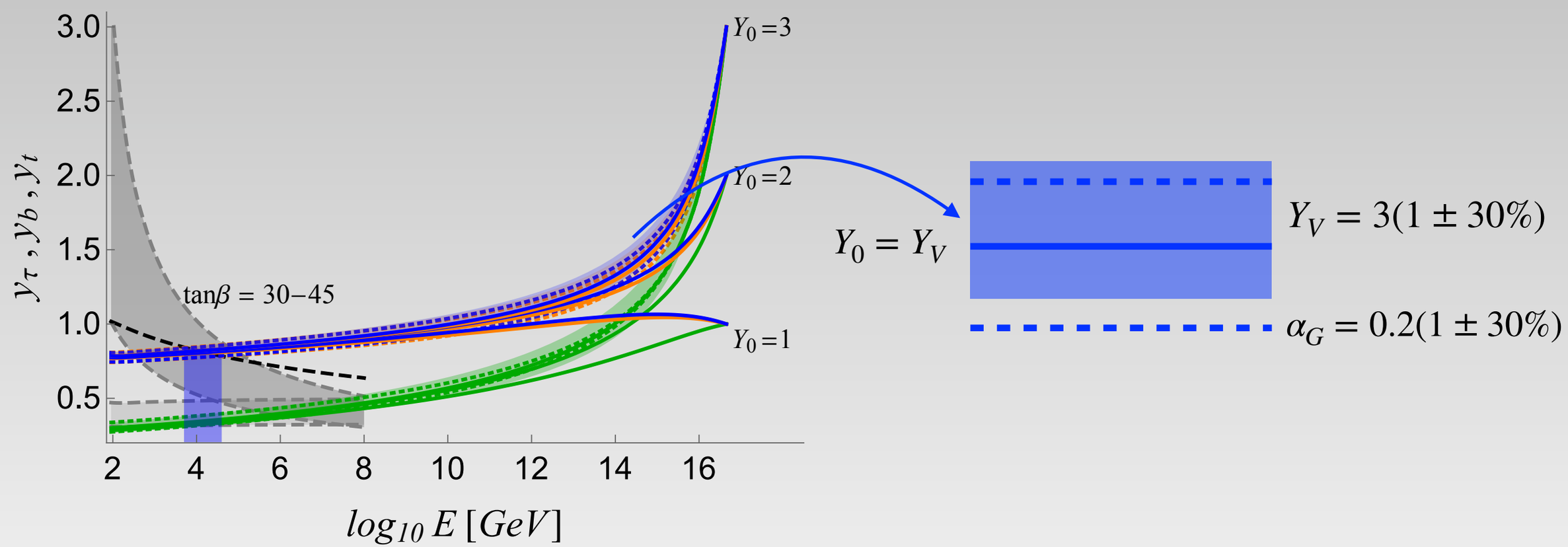




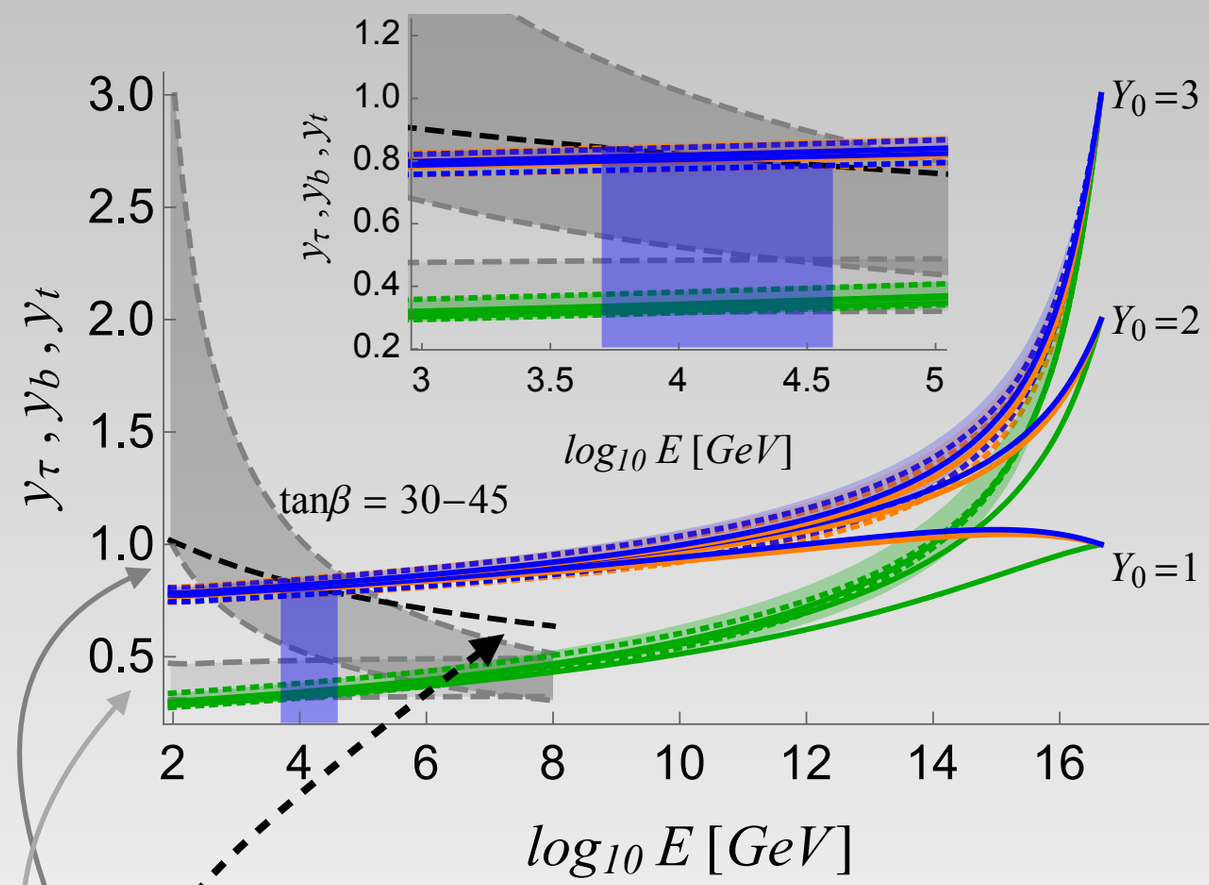
assuming universal VL Yukawa coupling Y_V, and setting $Y_V = Y_0$, $\alpha_G = 0.2$

t-b-tau

$$Y_0 = y_t(M_G) = y_b(M_G) = y_\tau(M_G)$$



t-b-tau



$$(y_t)_{SM} = y_t(1+\epsilon_t)\sin\beta$$
$$(y_b)_{SM} = y_b(1+\epsilon_b)\cos\beta$$
$$(y_\tau)_{SM} = y_\tau(1+\epsilon_\tau)\cos\beta$$

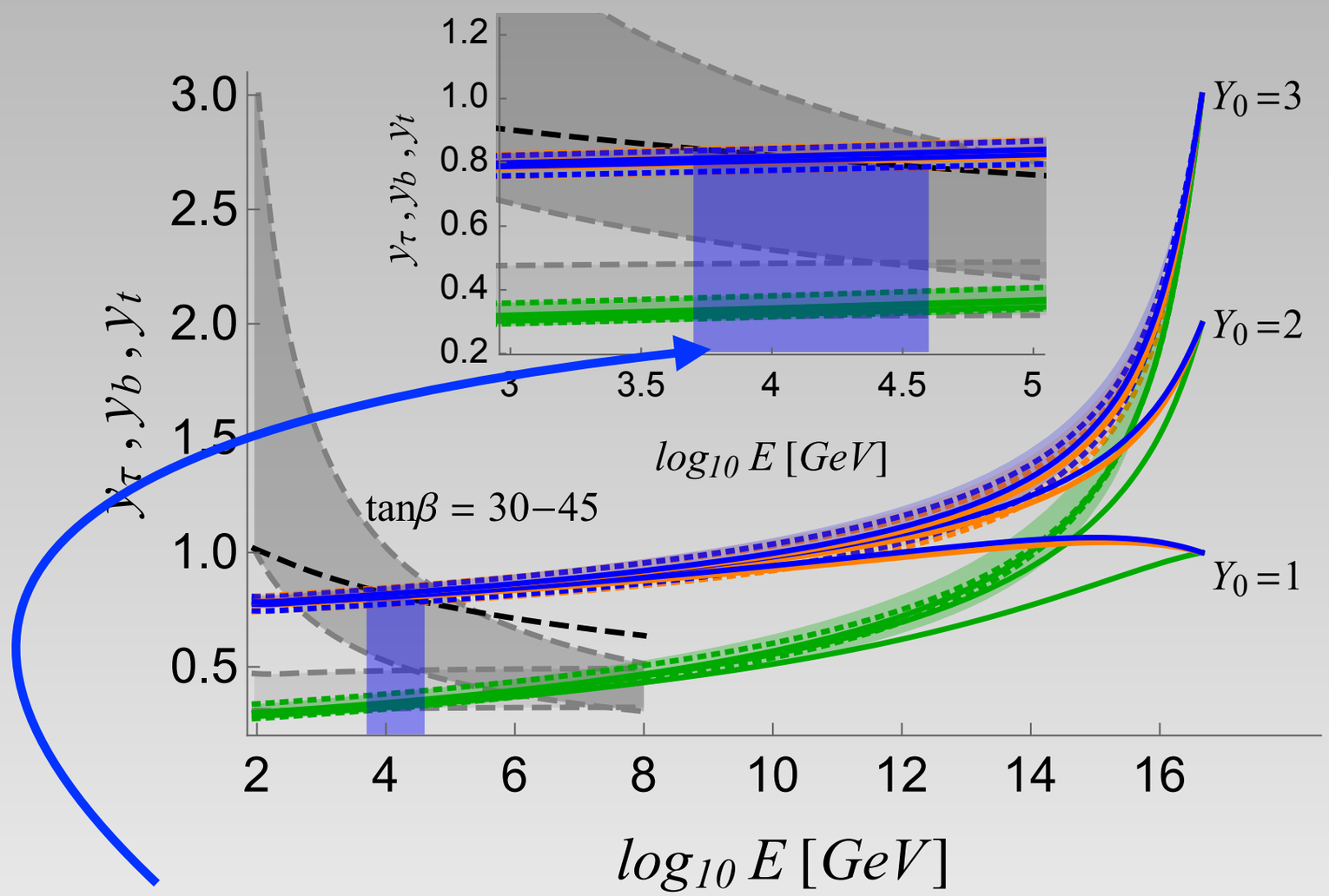
$$\epsilon_b \simeq \frac{2\alpha_3}{3\pi} M_{\tilde{g}}\mu \tan\beta I(m^2_{\tilde{b},1}, m^2_{\tilde{b},2}, M^2_{\tilde{g}}) + \frac{y_t^2}{16\pi^2} A_t \mu \tan\beta I(m^2_{\tilde{t},1}, m^2_{\tilde{t},2}, \mu^2)$$

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

$$\epsilon_b = -\frac{\sqrt{2}\alpha_3}{3\pi}\tan\beta$$

$$\epsilon_b \simeq -40\,\%$$

t-b-tau



Exact t-b-tau unification possible, for large $\tan\beta$ expect SUSY + VF ~ multi-TeV scale

✓gauge couplings
✓Higgs mass

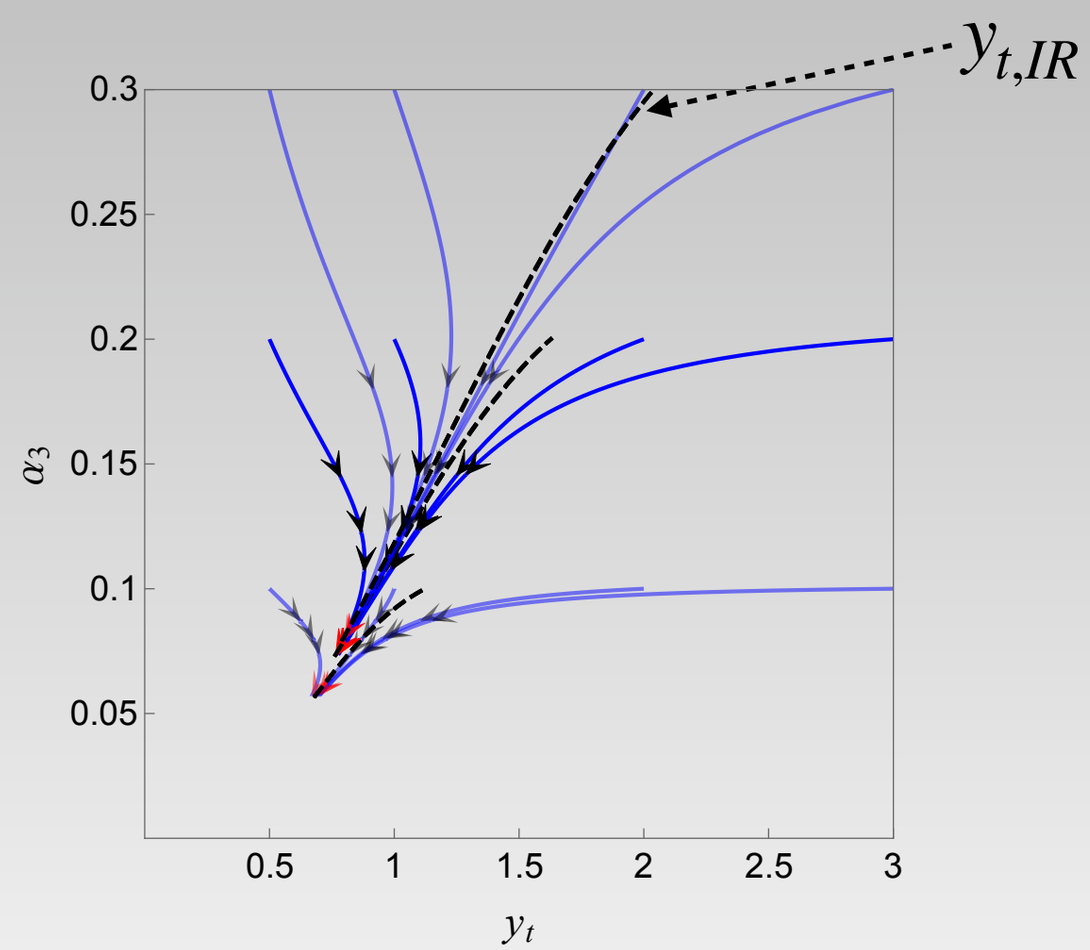
Can it be understood from particle content?

$$\frac{dy_t^2}{dt} \sim y_t^2(ay_t^2 - \frac{16}{3}g_3^2)$$

depends on # of extra quark Yukawas

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

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



Rapidly approaches fixed point given by ~ α_3
Similarly for bottom and tau

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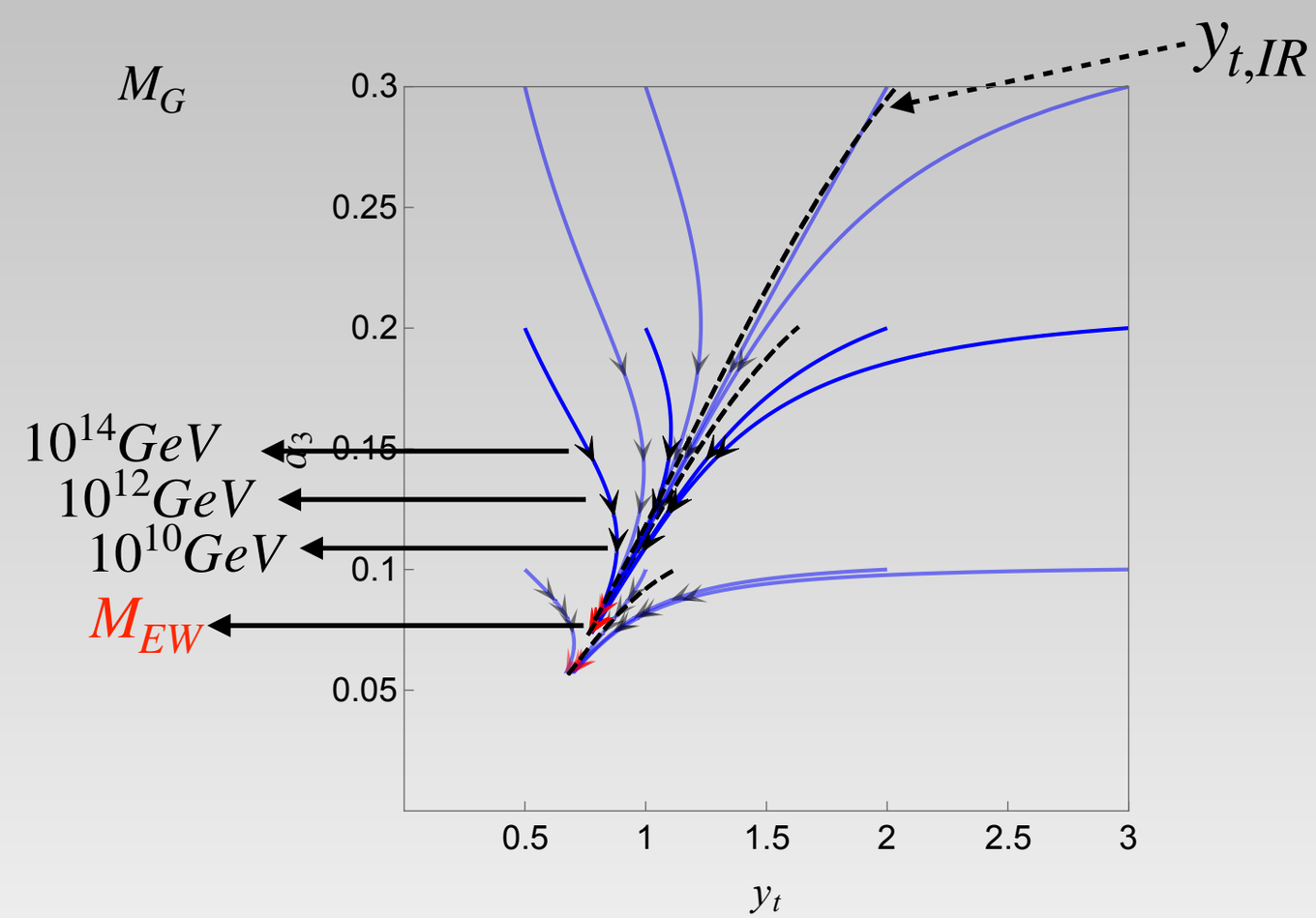

Rapidly approaches fixed point given by ~ α_3
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Determining t-b-tau masses

- M_G, M_{SUSY}, M_{VF}, $\tan\beta$
- α_G, ϵ, $Y_0 = y_t(M_G) = y_b(M_G) = y_\tau(M_G)$, Y_V

M_G

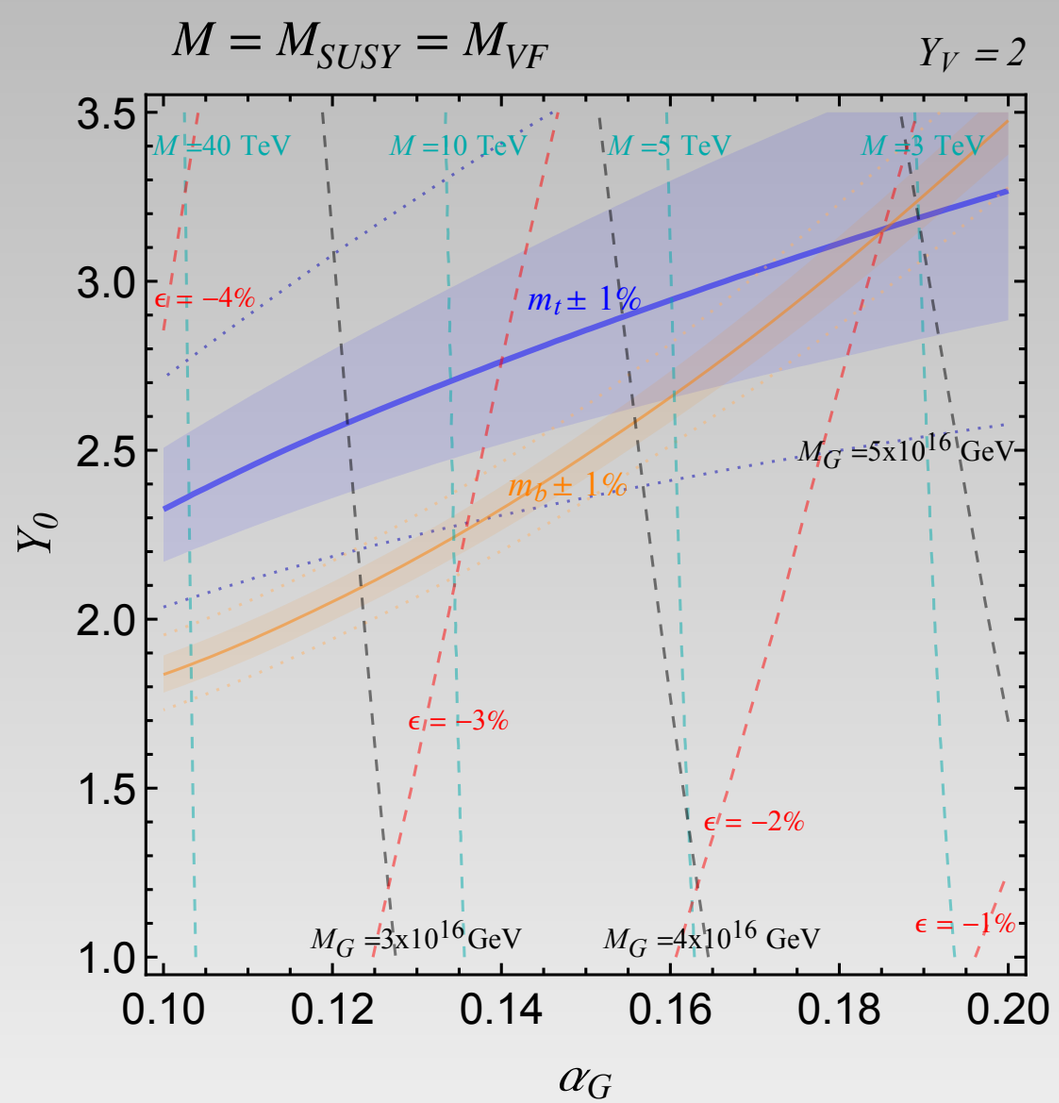
↓

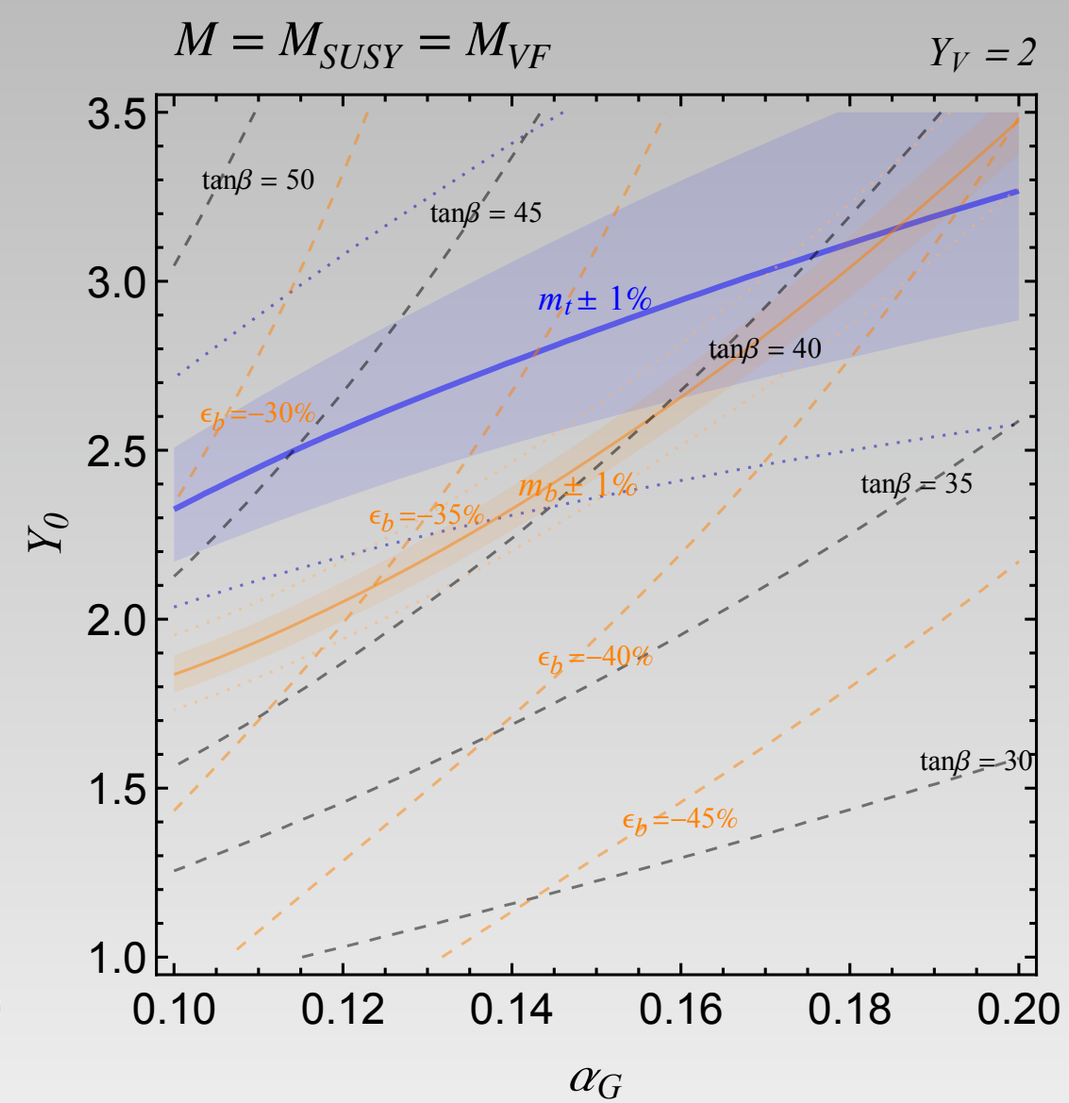
M_{SUSY}
- Compute nominal SUSY corrections
- match to SM

↓

M_Z
- fit gauge couplings and t-b-tau masses

Exact t-b-tau unification!

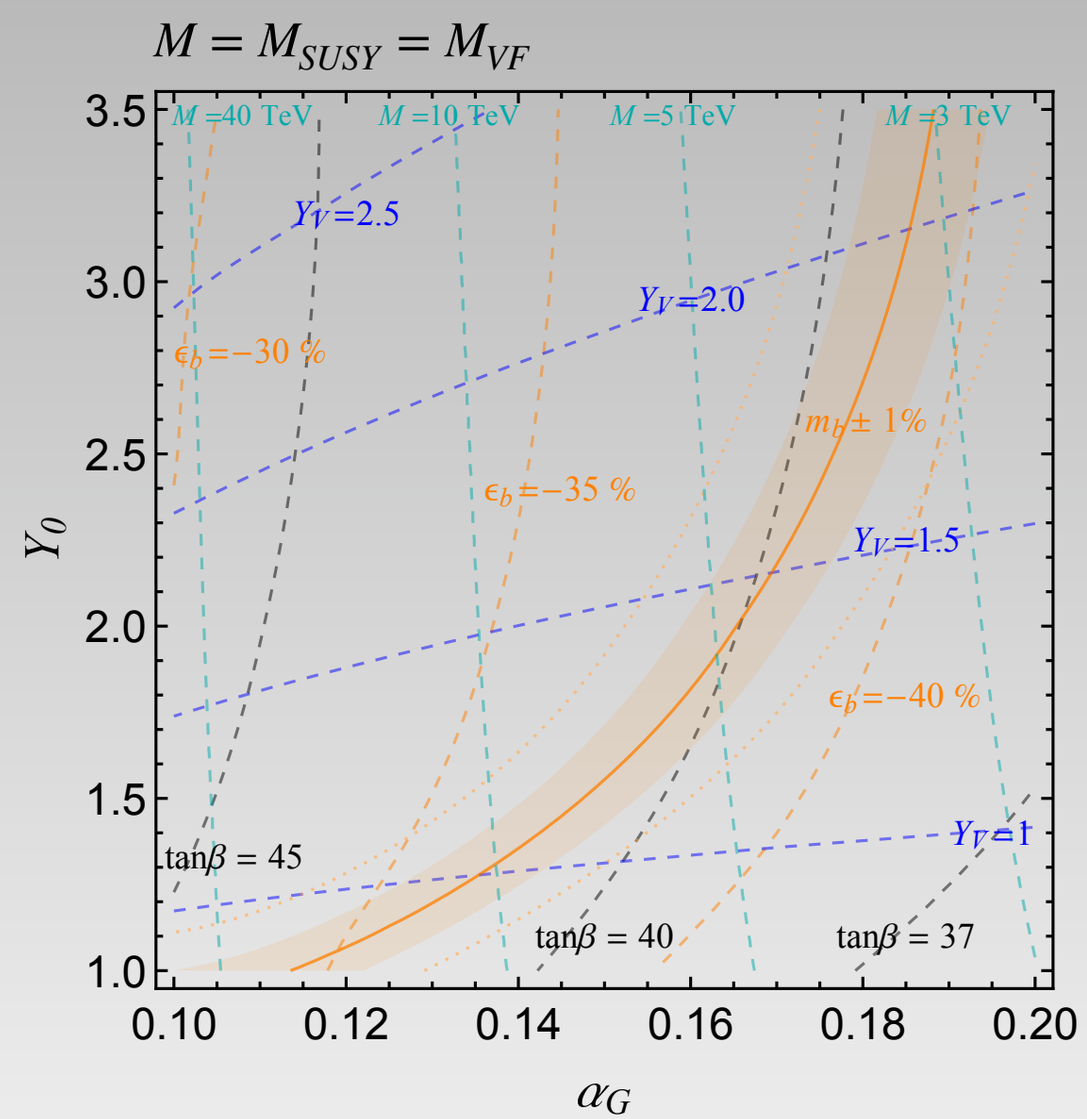




$$M_G, \epsilon, M \longrightarrow \alpha_1, \alpha_2, \alpha_3 \qquad \tan\beta \longrightarrow y_\tau$$

Fit precisely in the whole plane

Exact t-b-tau unification!

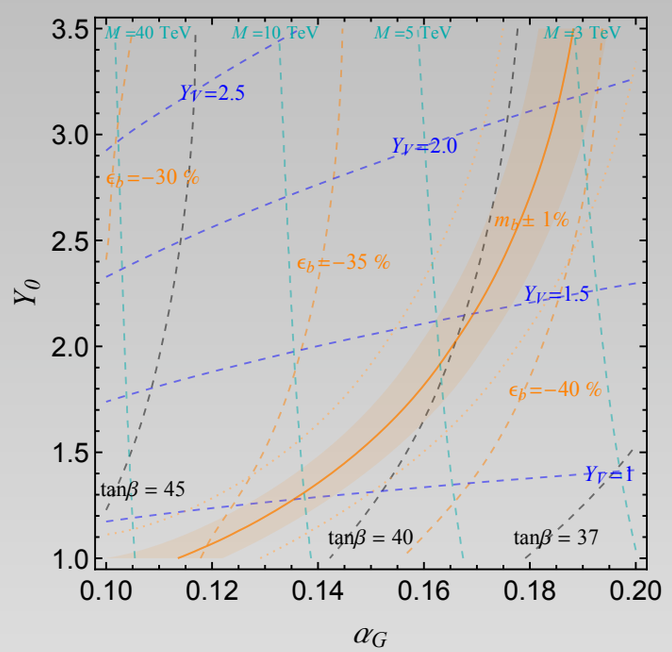


$$M_G, \epsilon, M \longrightarrow \alpha_1, \alpha_2, \alpha_3$$

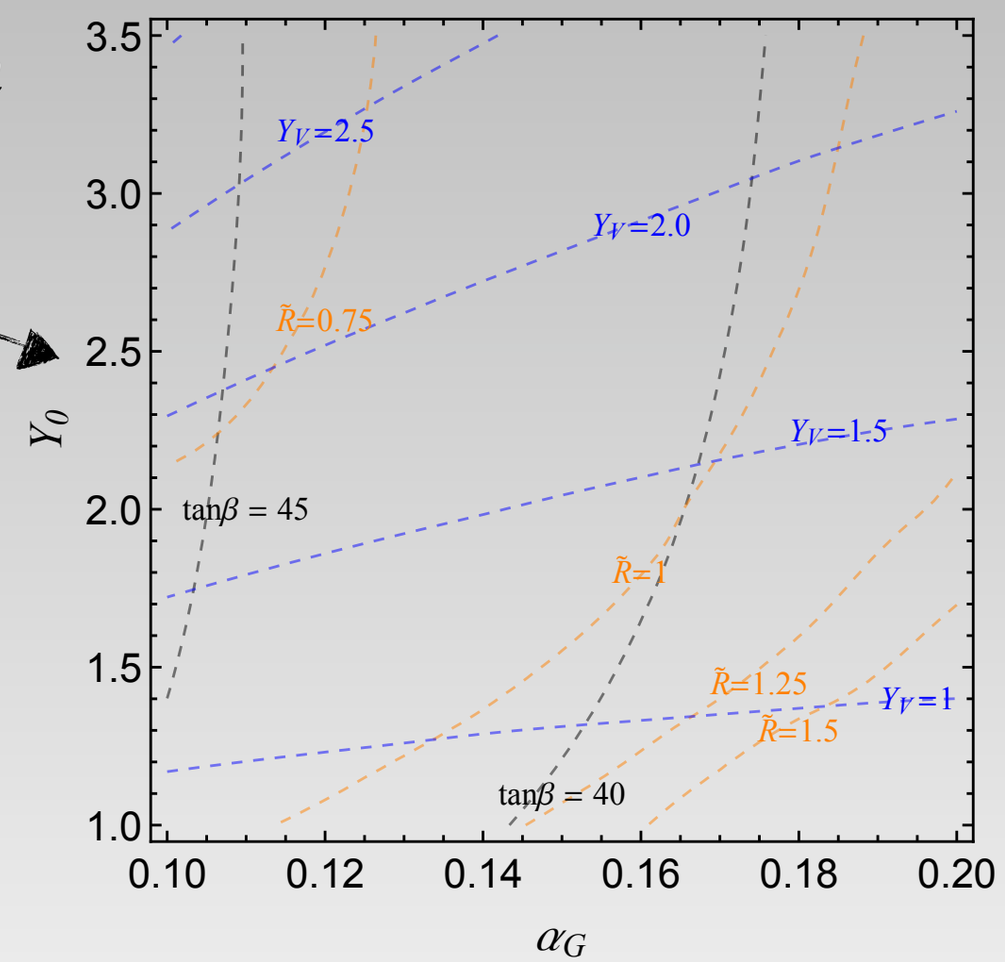
$$\tan\beta, Y_V \longrightarrow y_\tau, y_t$$

}Fit precisely in the whole plane

Splitting gaugino's



$$\tilde{R} = \tilde{M}/\tilde{m}$$



$$M_G, \epsilon, M \longrightarrow \alpha_1, \alpha_2, \alpha_3$$

$$\tan\beta, Y_V, \tilde{R} \longrightarrow y_\tau, y_t, y_b$$

}Fit precisely in the whole plane

Fin

- 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_{SUSY} & M_{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 —> multi-TeV...

Thanks!