IR fixed point predictions for third generation masses in the MSSM with a vectorlike family

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SUSY 2019

VL fermions in model building

- Among simplest possibilities for extra matter in BSM physics
  - automatic anomaly cancellation
  - vectorlike GUT multiplets maintain gauge coupling unification (@ 1-loop)

$$b_i = b_{i,MSSM} + n_5 + 3n_{10}$$

$$\ln(M_G/M_Z) = 2\pi \frac{\alpha_3(M_Z) - \alpha_2(M_Z)}{b_3 - b_2}$$

- In SUSY models, known to alleviate the hierarchy btw the Higgs mass and the SUSY scale
  - new Yukawa couplings to Higgs doublets give additional contributions to m_h

- In SO(10), Yukawa couplings of $16/\overline{16}$ unify at the GUT scale

$$W \supset Y_0 16_3 10_H 16_3 + Y_V 16 10_H 16 + \bar{Y}_V \bar{16} 10_H \bar{16} + M_{VF} 16 \bar{16}$$

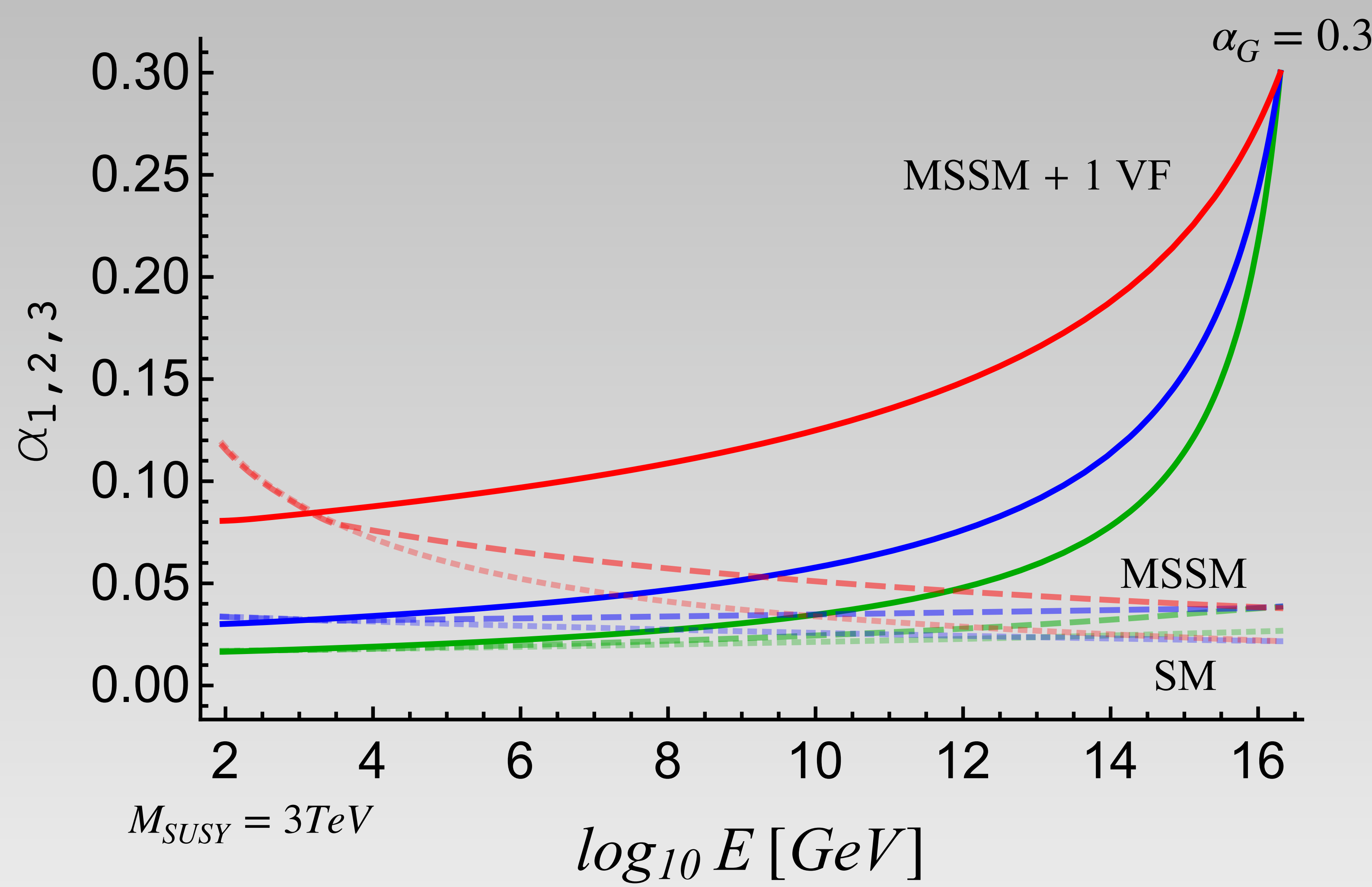
VL fermions and pheno

- Higgs mass in SUSY models
- g -2
- flavor anomalies
- top partners
- Dark Matter
- 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 scale can be inferred from fixed points of RG flow**

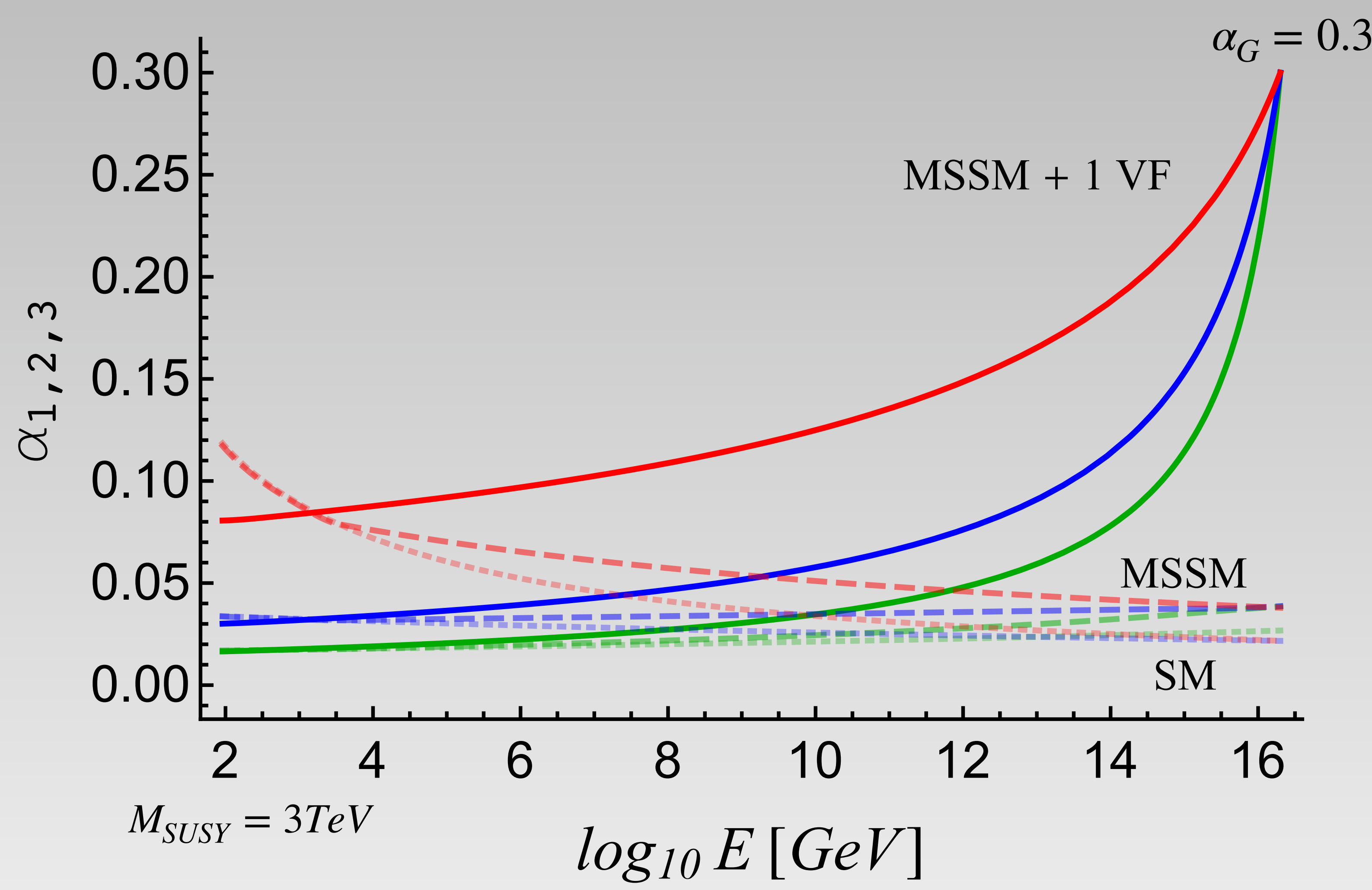
MSSM+1VF SUSY GUT



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

R. Dermíšek & N.M: 1712.03527

MSSM+1VF SUSY GUT



$$\alpha_i^{-1}(M_Z) = \frac{b_i}{2\pi} \ln \frac{M_G}{M_Z} + \alpha^{-1}(M_G)$$

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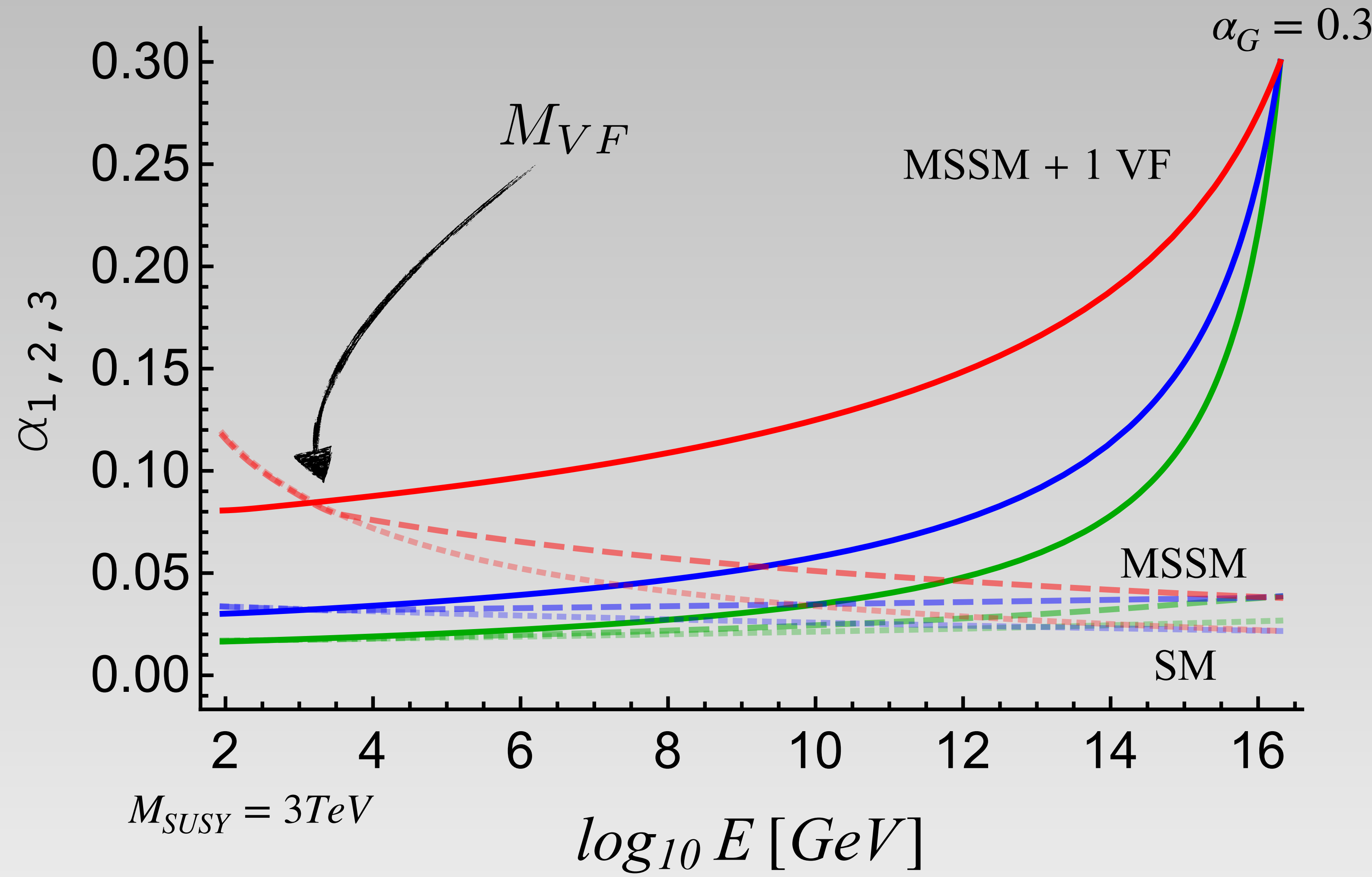

$$\alpha_i^{-1}(M_Z) = \frac{b_i}{2\pi} \ln \frac{M_G}{M_Z} + \alpha^{-1}(M_G) \longrightarrow \sin^2\theta_W \equiv \frac{\alpha'}{\alpha_2 + \alpha'} \simeq \frac{b_2}{b_2 + b'} = 0.2205$$

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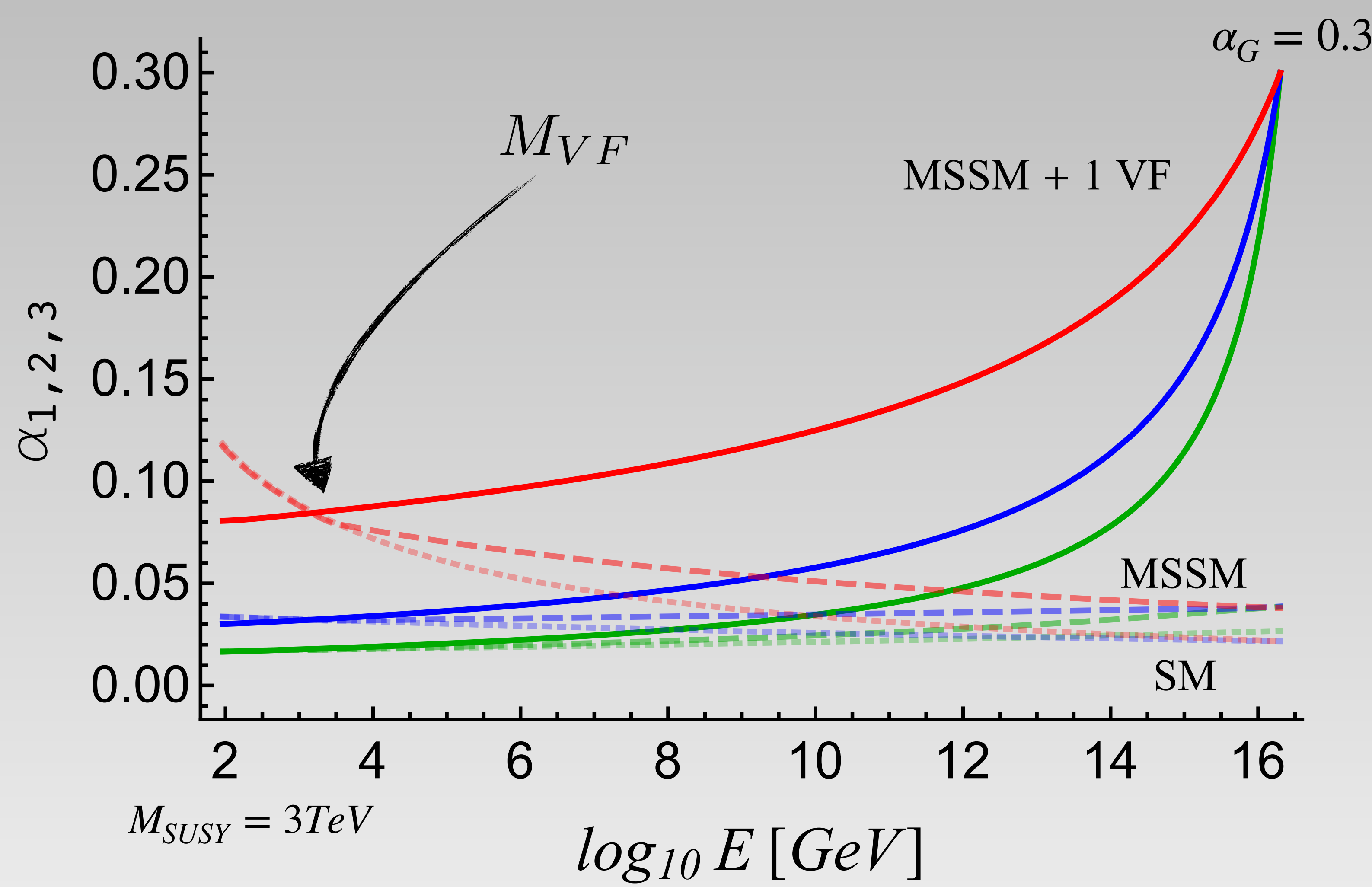
MSSM+1VF SUSY GUT



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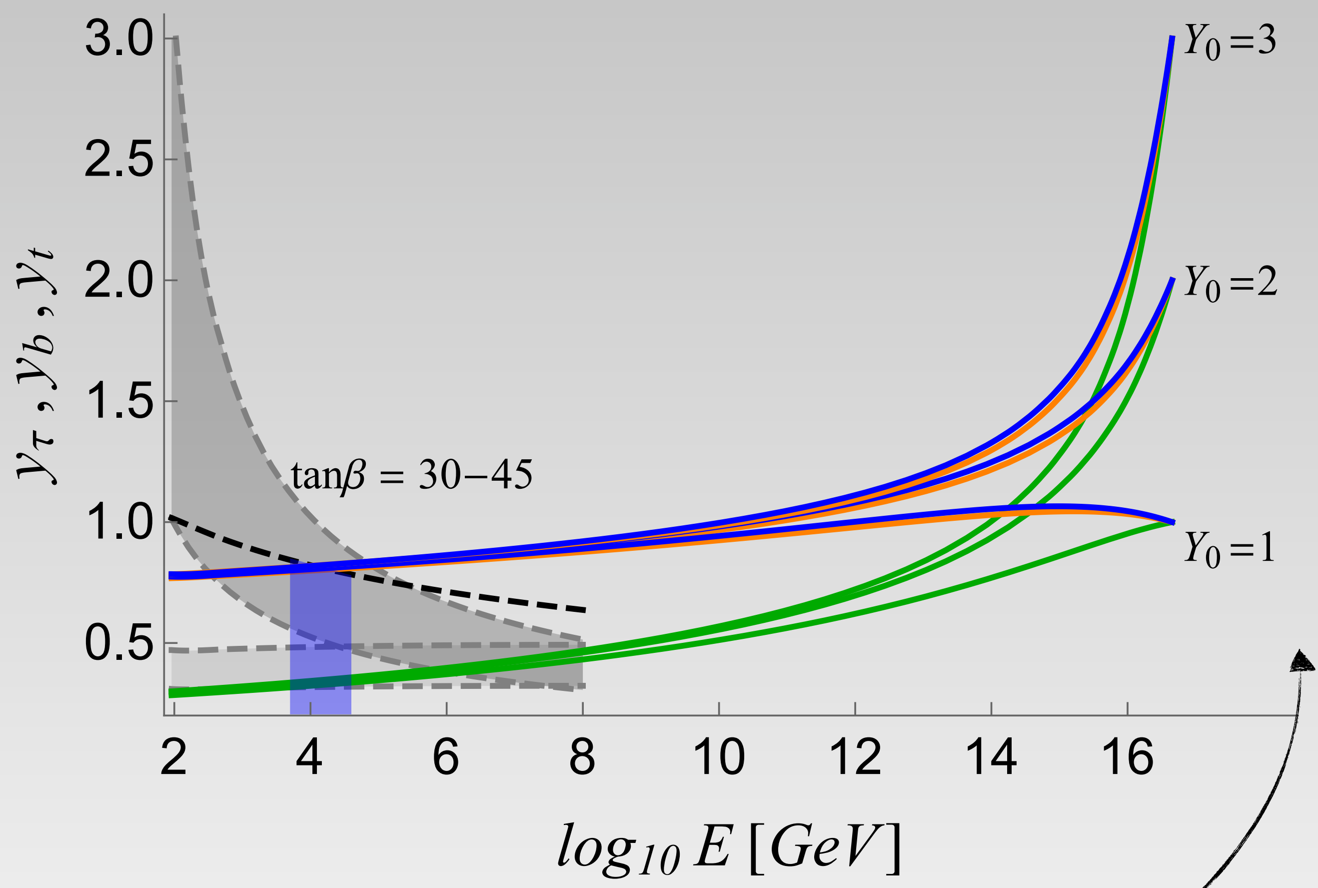
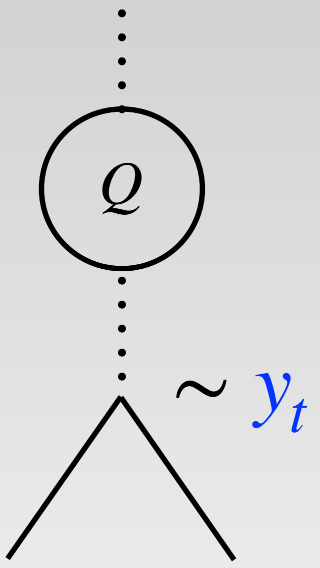
t-b-tau

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



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

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



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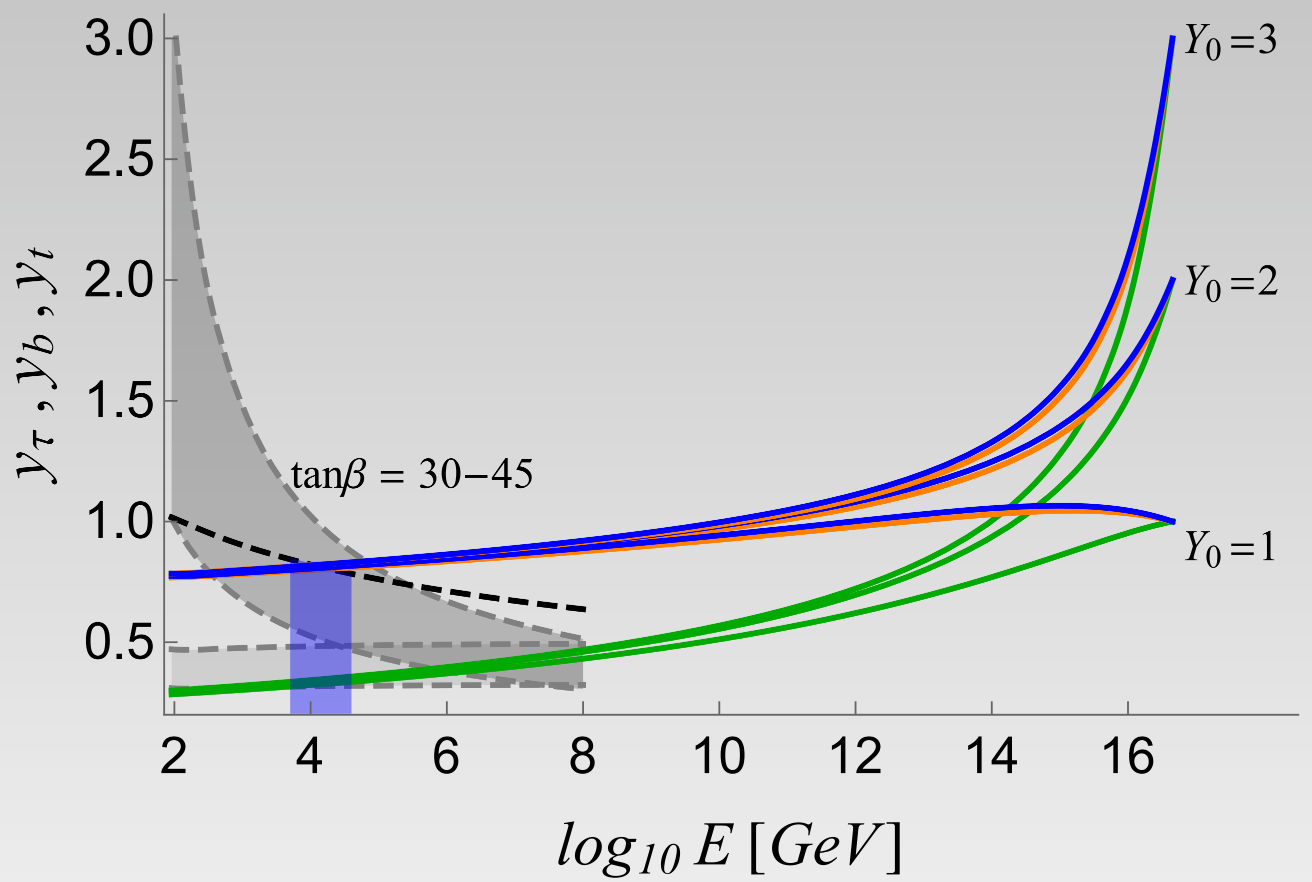

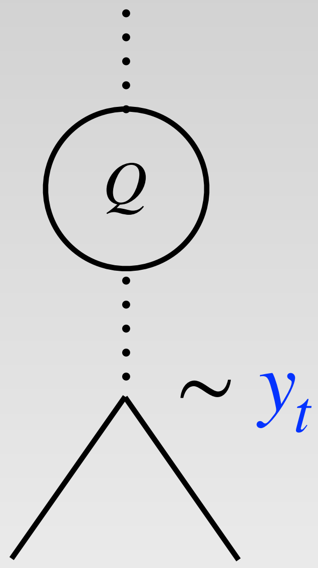

$$\frac{dy_t}{dt} = \frac{y_t}{16\pi^2}\left(3y_t^* y_t + y_b^* y_b + T_{H_u} - \frac{16}{3}g_3^2 - 3g_2^2 - \frac{13}{15}g_1^2\right)$$

$$T_{H_u} = 3y_t^* y_t + 3Y_U^* Y_U + 3\bar{Y}_D^* \bar{Y}_D + \bar{Y}_E^* Y_E$$

t-b-tau

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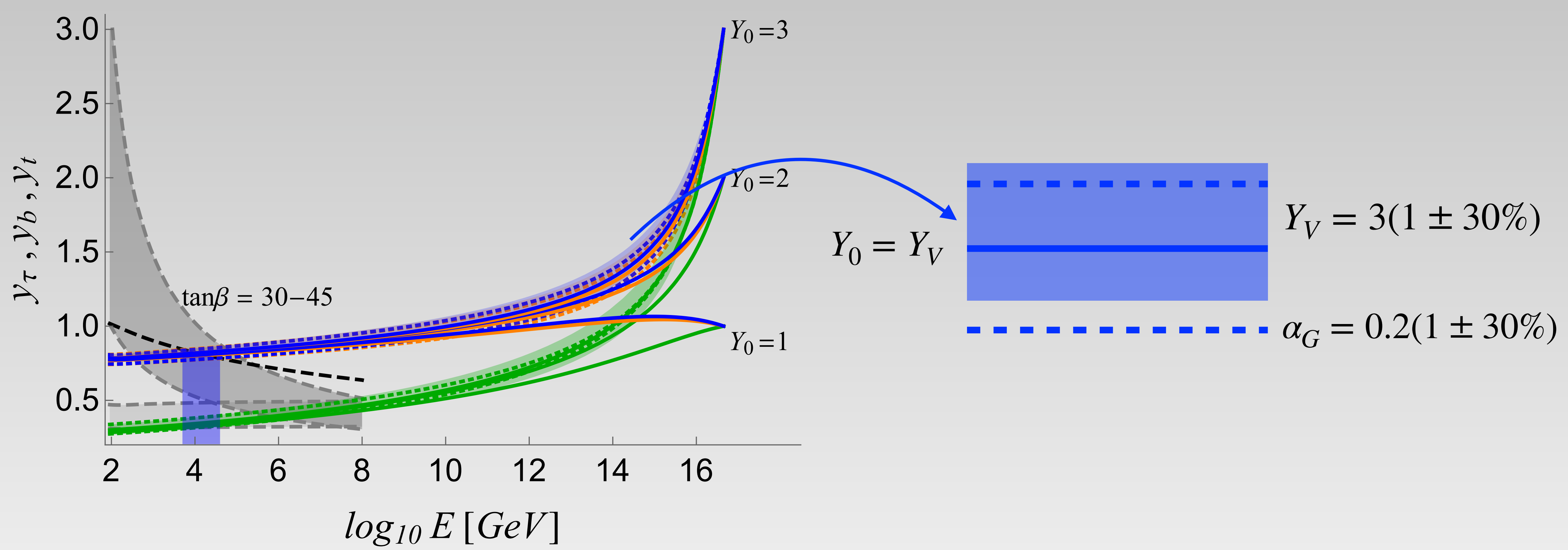
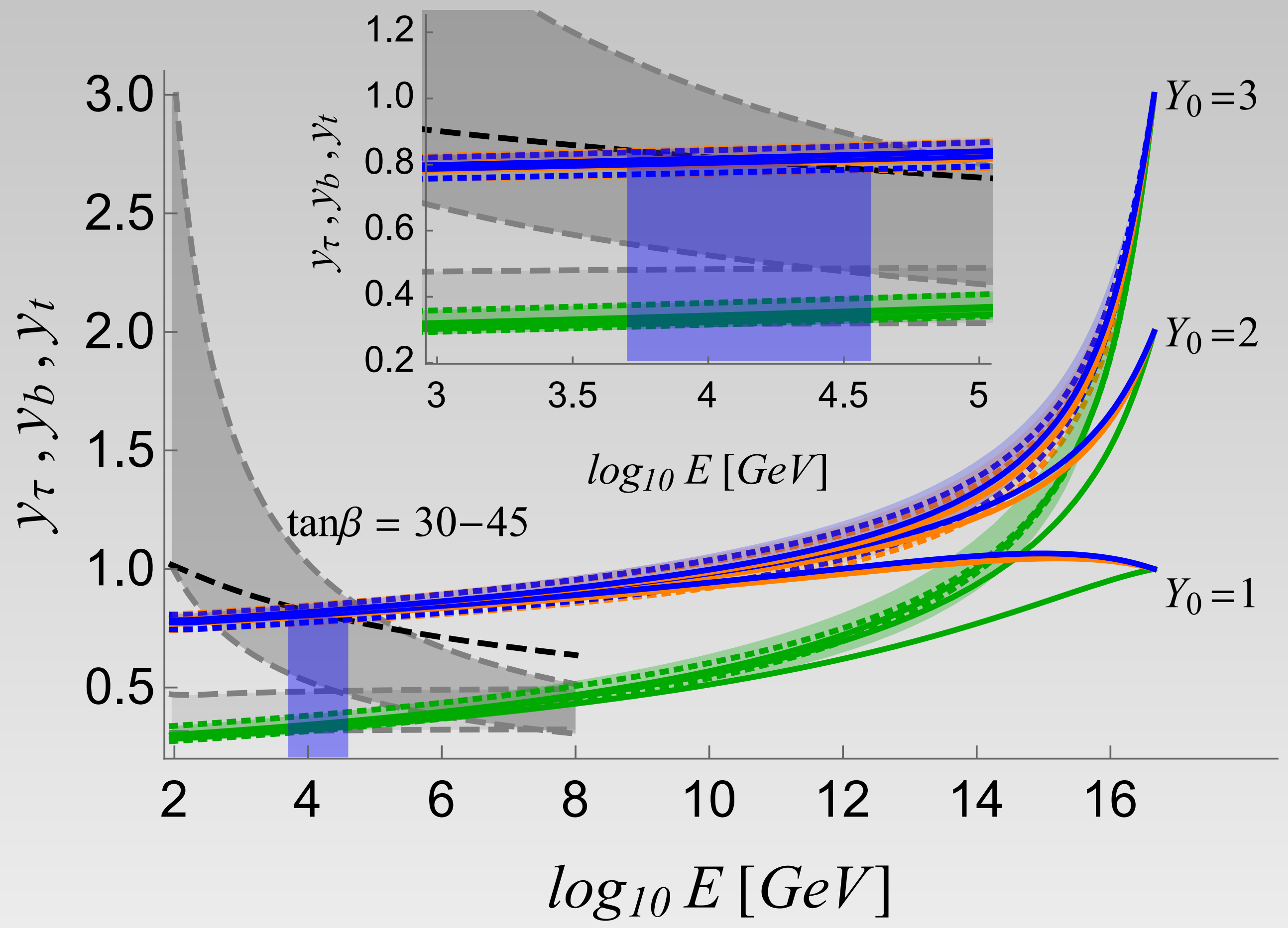


t-b-tau



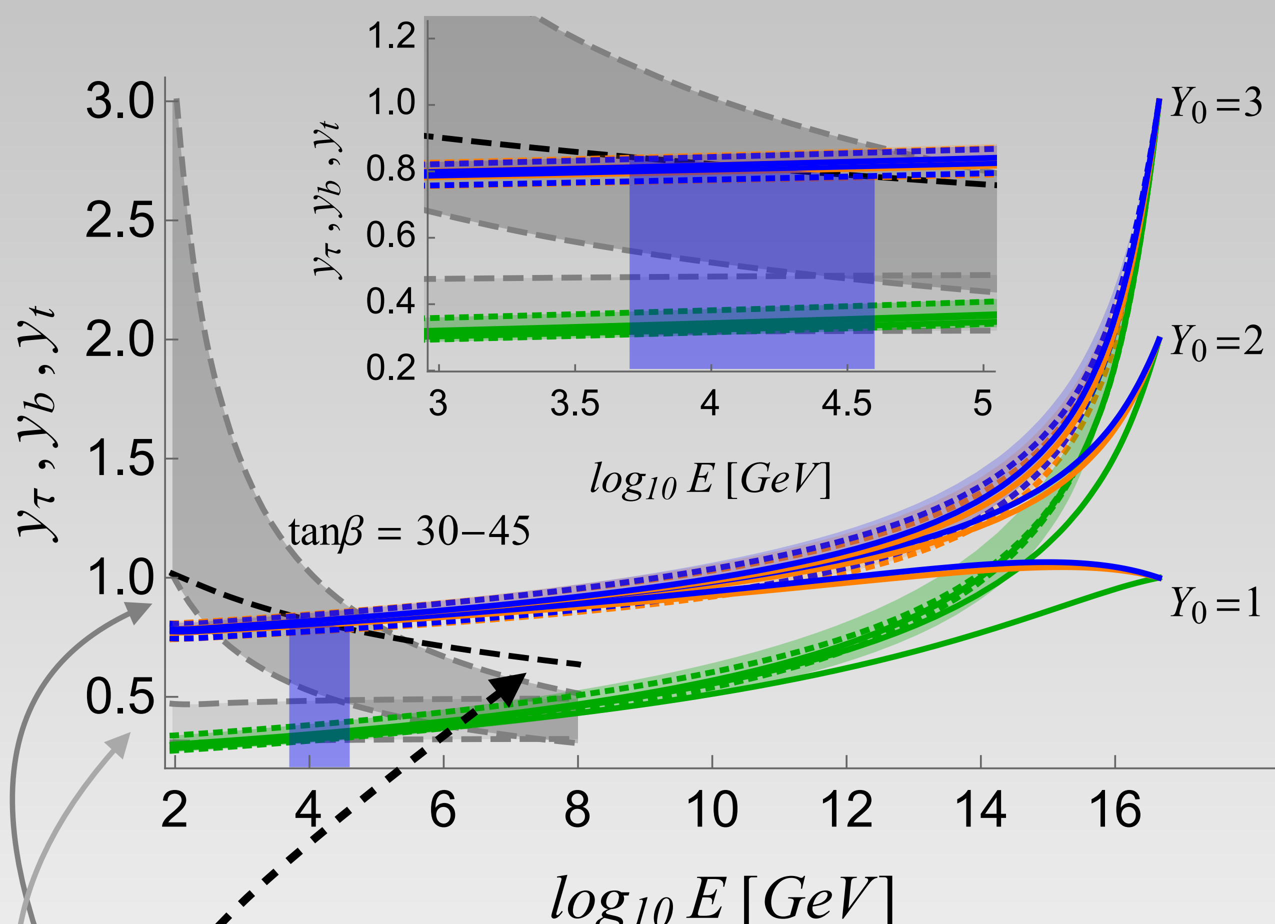
$$\epsilon_b \simeq \frac{2\alpha_3}{3\pi} M_{\tilde{g}} \mu \tan\beta I(m^2_{\tilde{b},1}, m^2_{\tilde{b},2}, M^2_{\tilde{g}}) + \frac{y_t^2}{16\pi^2} A_t \mu \tan\beta I(m^2_{\tilde{t},1}, m^2_{\tilde{t},2}, \mu^2)$$

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

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

$$\boxed{\epsilon_b \simeq -40\,\%}$$

t-b-tau



$$y_t = (y_t)_{SM}/\left(1+\epsilon_t(M)\right)\sin\beta$$

$$y_b = (y_b)_{SM}/\left(1+\epsilon_b(M)\right)\cos\beta$$

$$y_\tau = (y_\tau)_{SM}/\left(1+\epsilon_\tau(M)\right)\cos\beta$$

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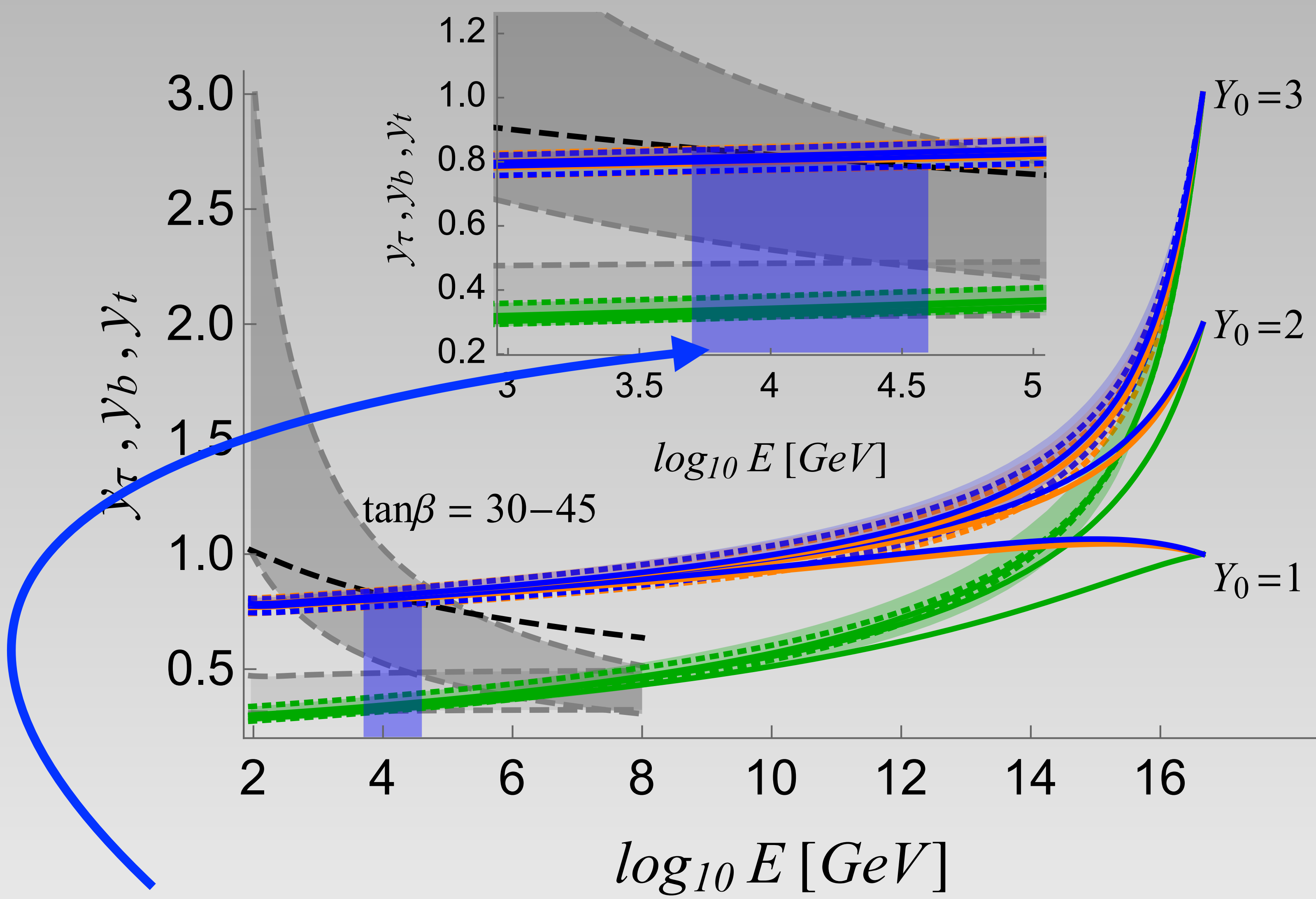


Exact t-b-tau unification possible, for large $\tan\beta$ expect SUSY + VF~ multi-TeV scale

✓gauge couplings

✓Higgs mass

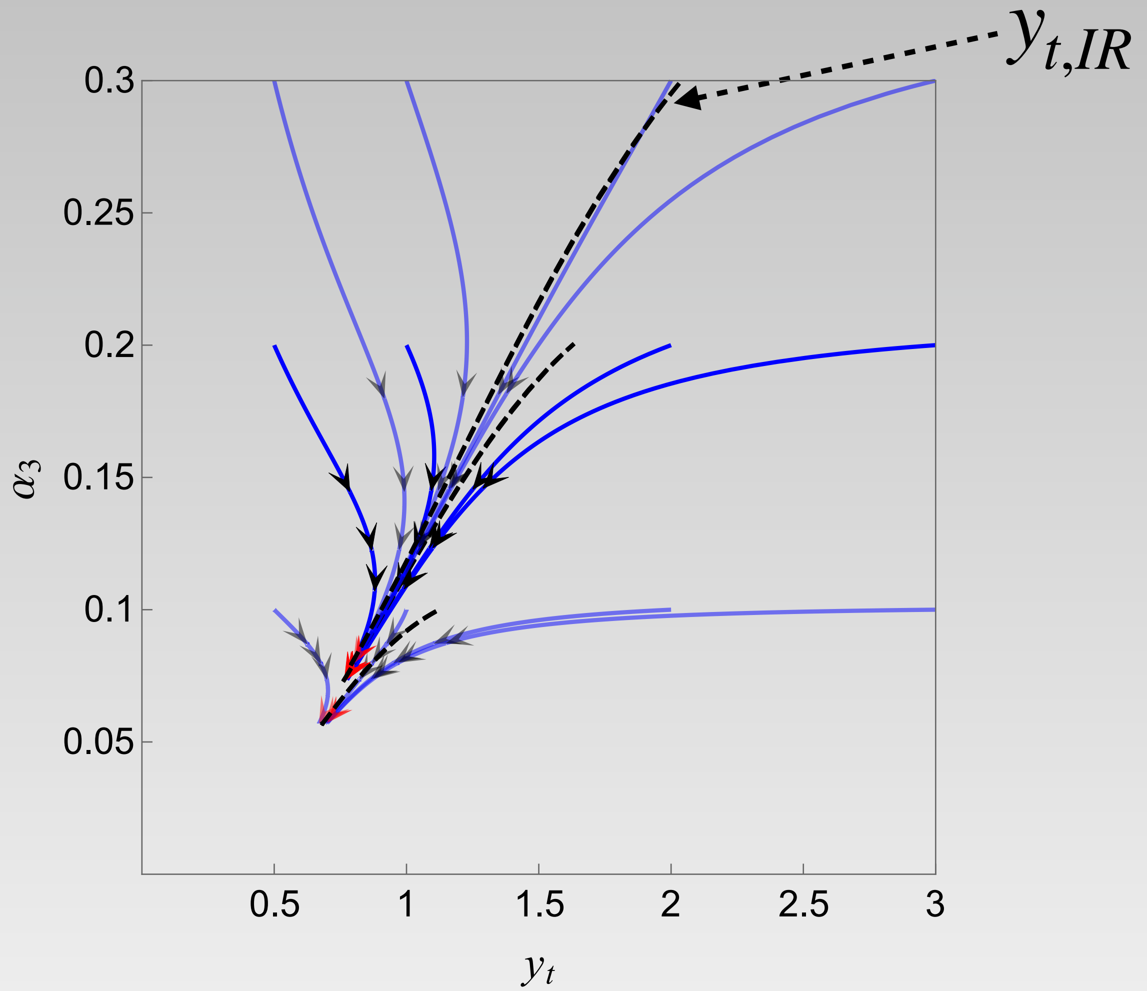
Can it be understood from particle content?

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

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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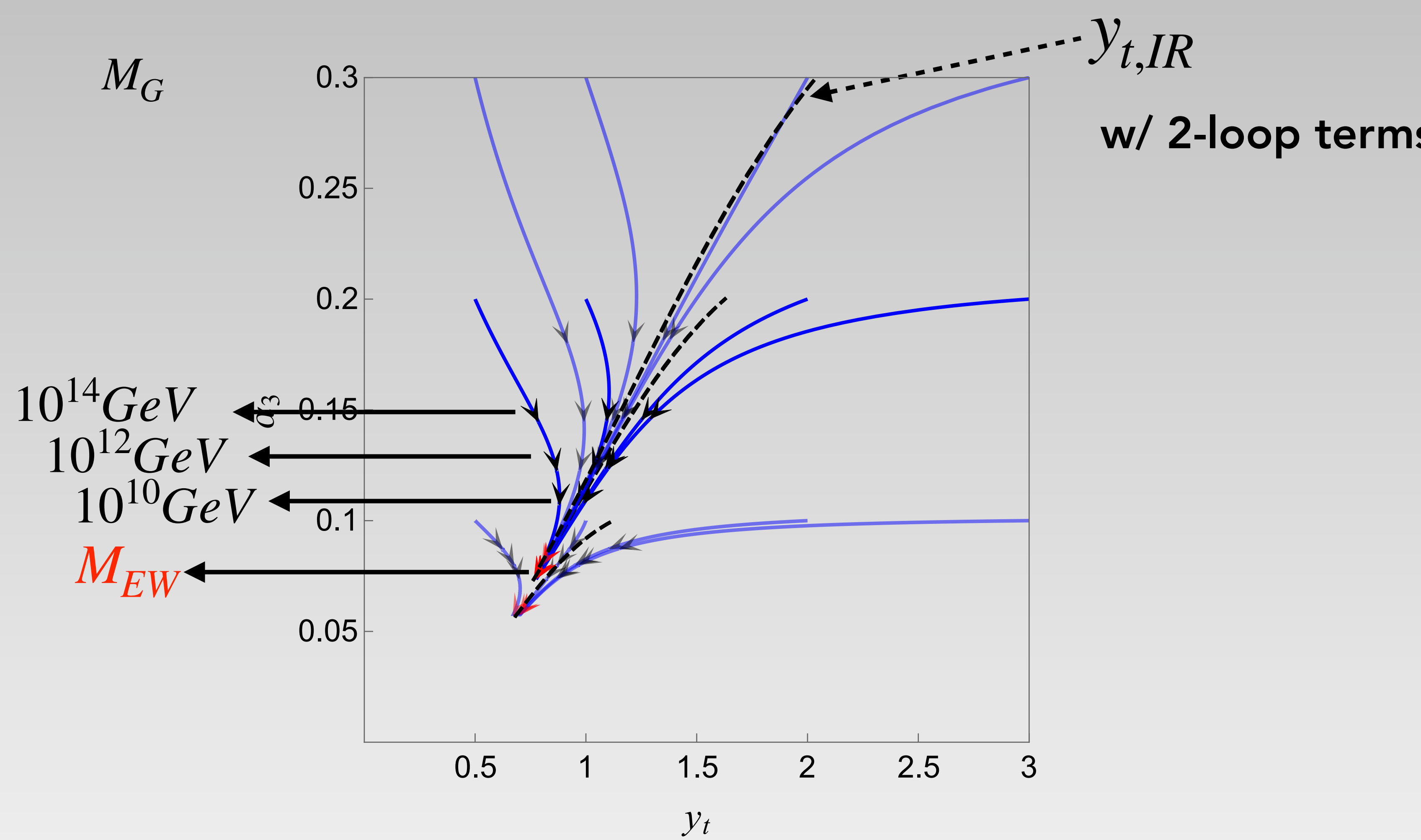

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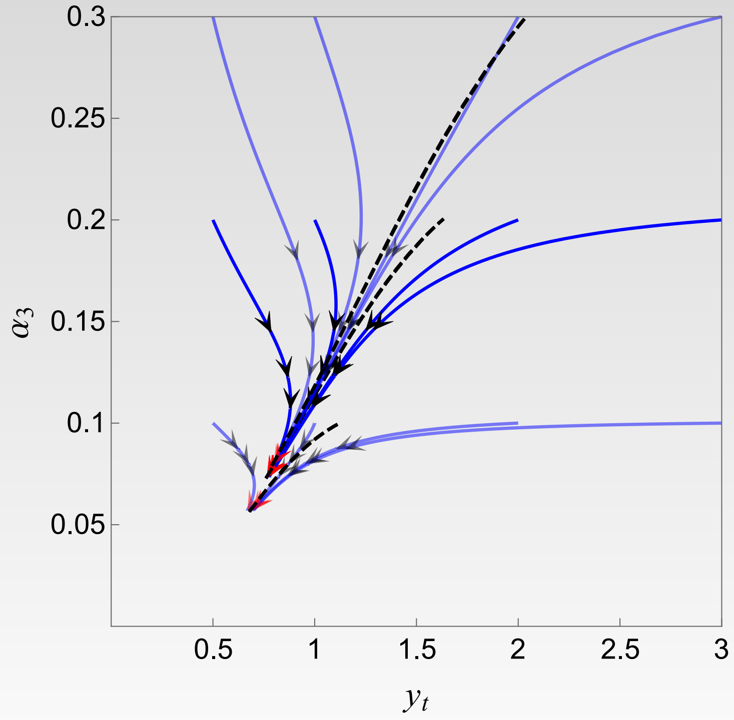
Definition of IR fixed point

- Definition of Pendleton-Ross ('81): $\left(\frac{y_{t,IR}^2}{g_3^2}\right)^* = \frac{16+3b_3}{3a}$
- Not a good numerical approximation due to slow approach (Hill '81)

$$\frac{dy_t^2/\alpha}{dt} = 0$$

$$\alpha = \alpha_3 + \frac{9}{16}\alpha_2 + \frac{13}{80}\alpha_1$$

$$\boxed{\frac{a}{4\pi} y_{t,IR}^2 = \frac{16}{3}\alpha + \frac{2\pi}{\alpha}\frac{d\alpha}{dt}}$$



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

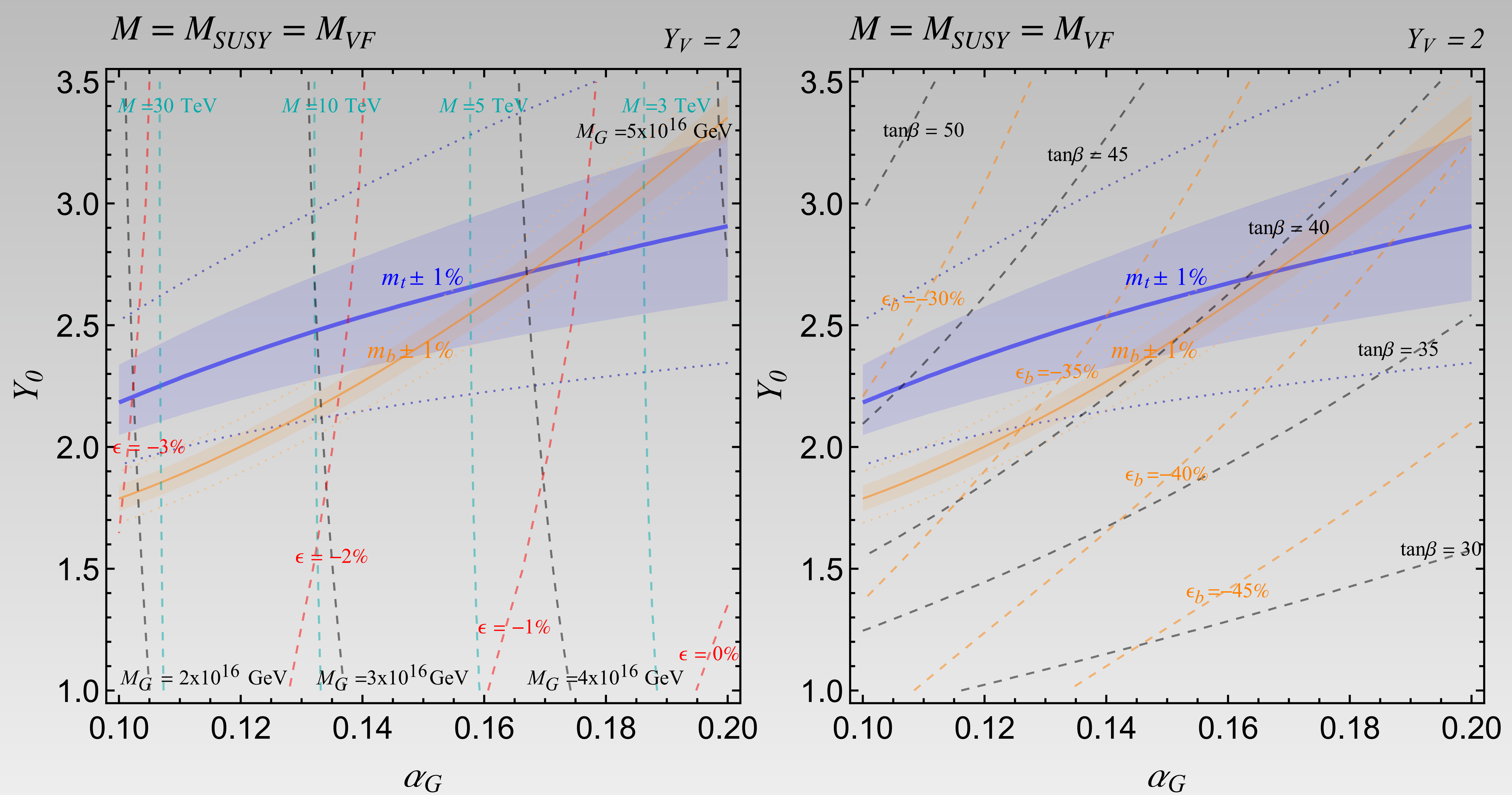
↓

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

↓

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

Exact t-b-tau unification!



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

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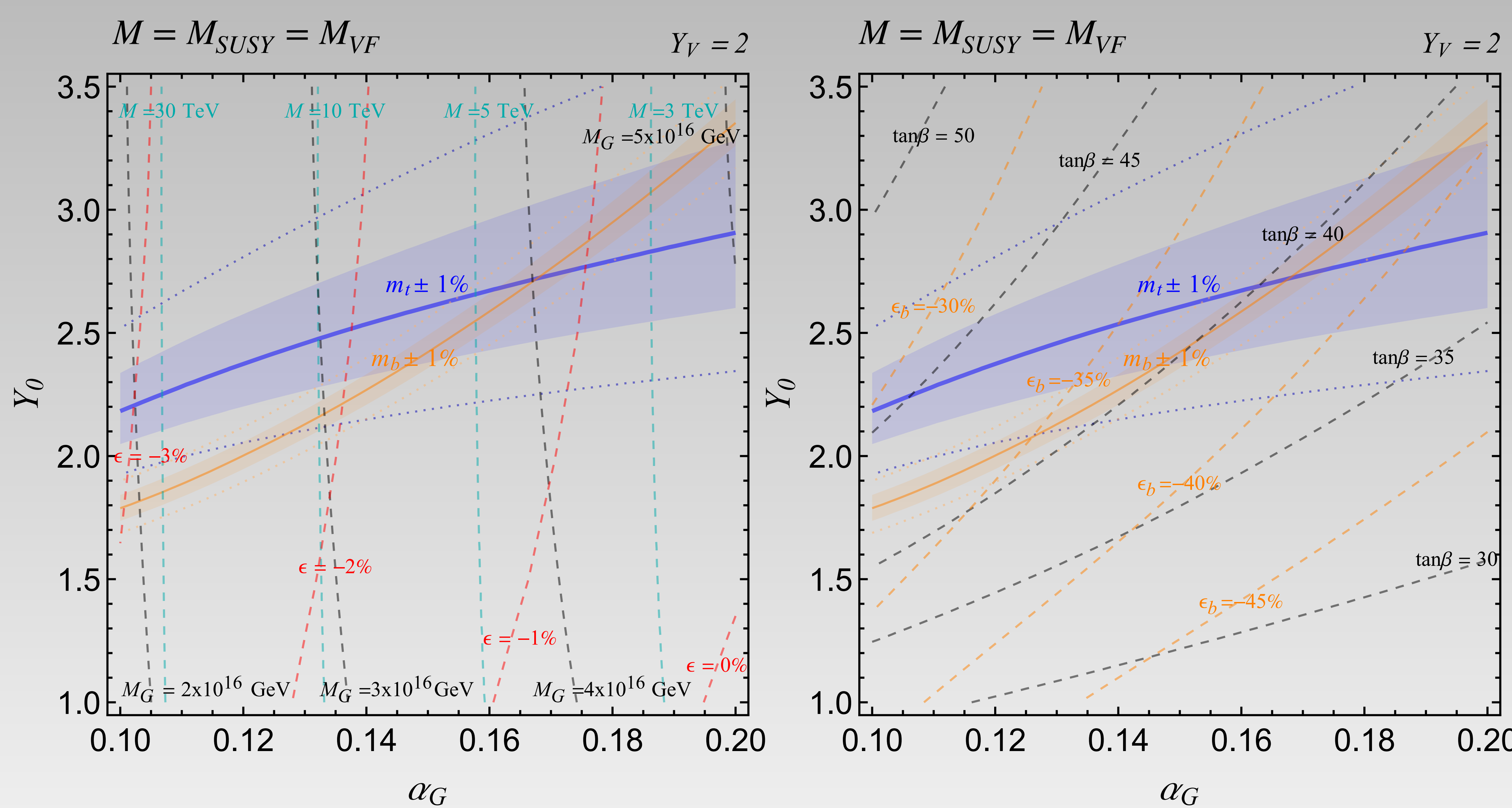

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Fit precisely in the whole plane

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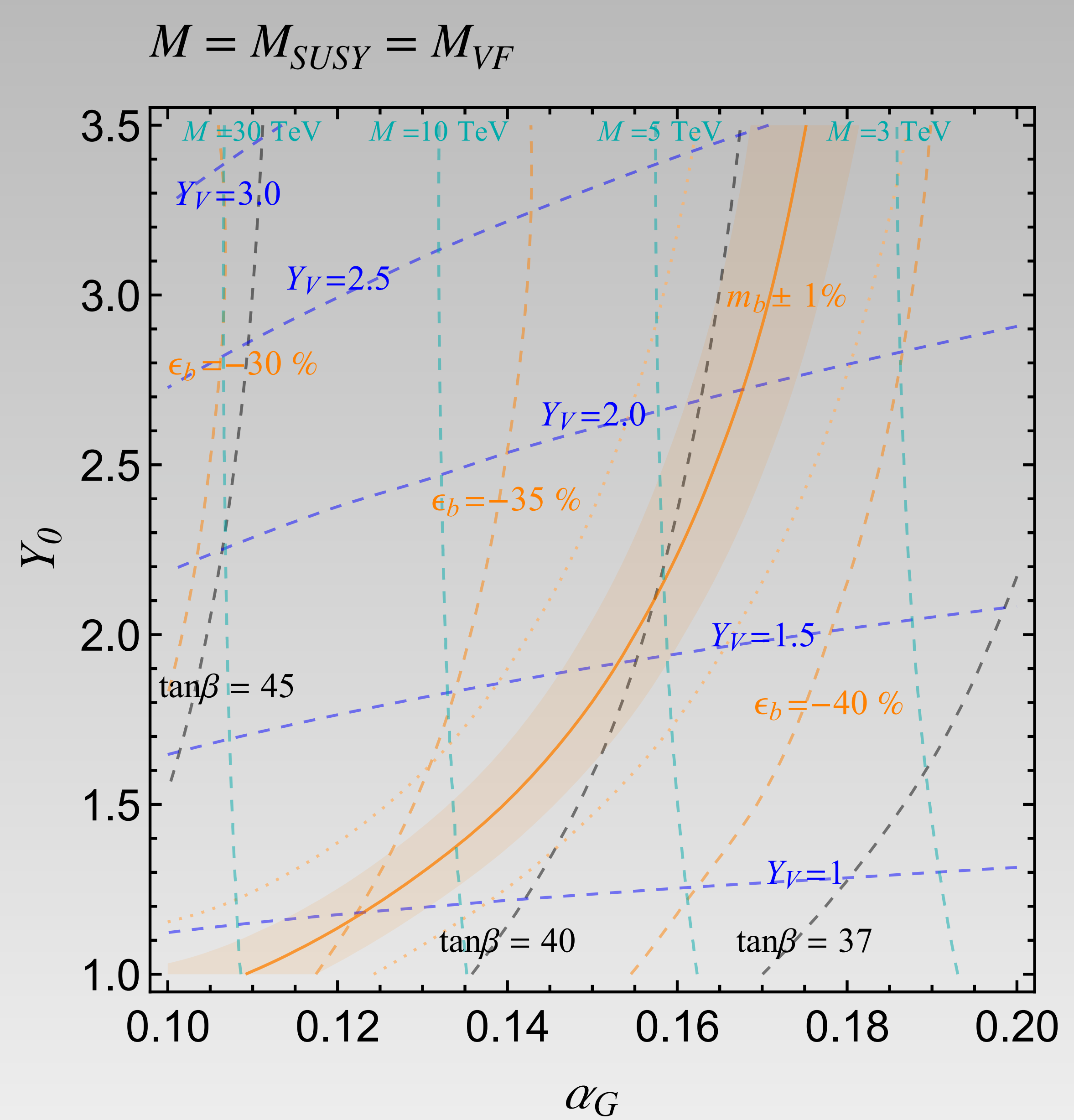
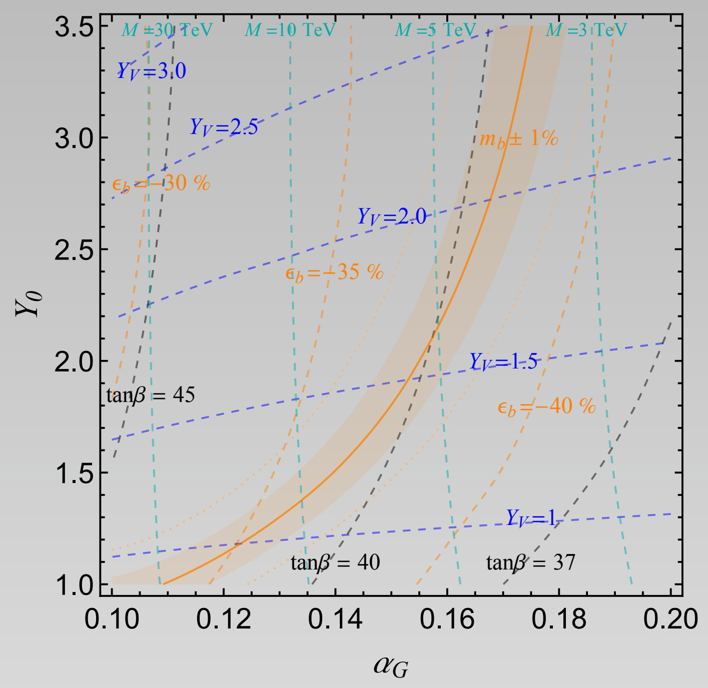


$M_G, \epsilon, M \longrightarrow \alpha_1, \alpha_2, \alpha_3$

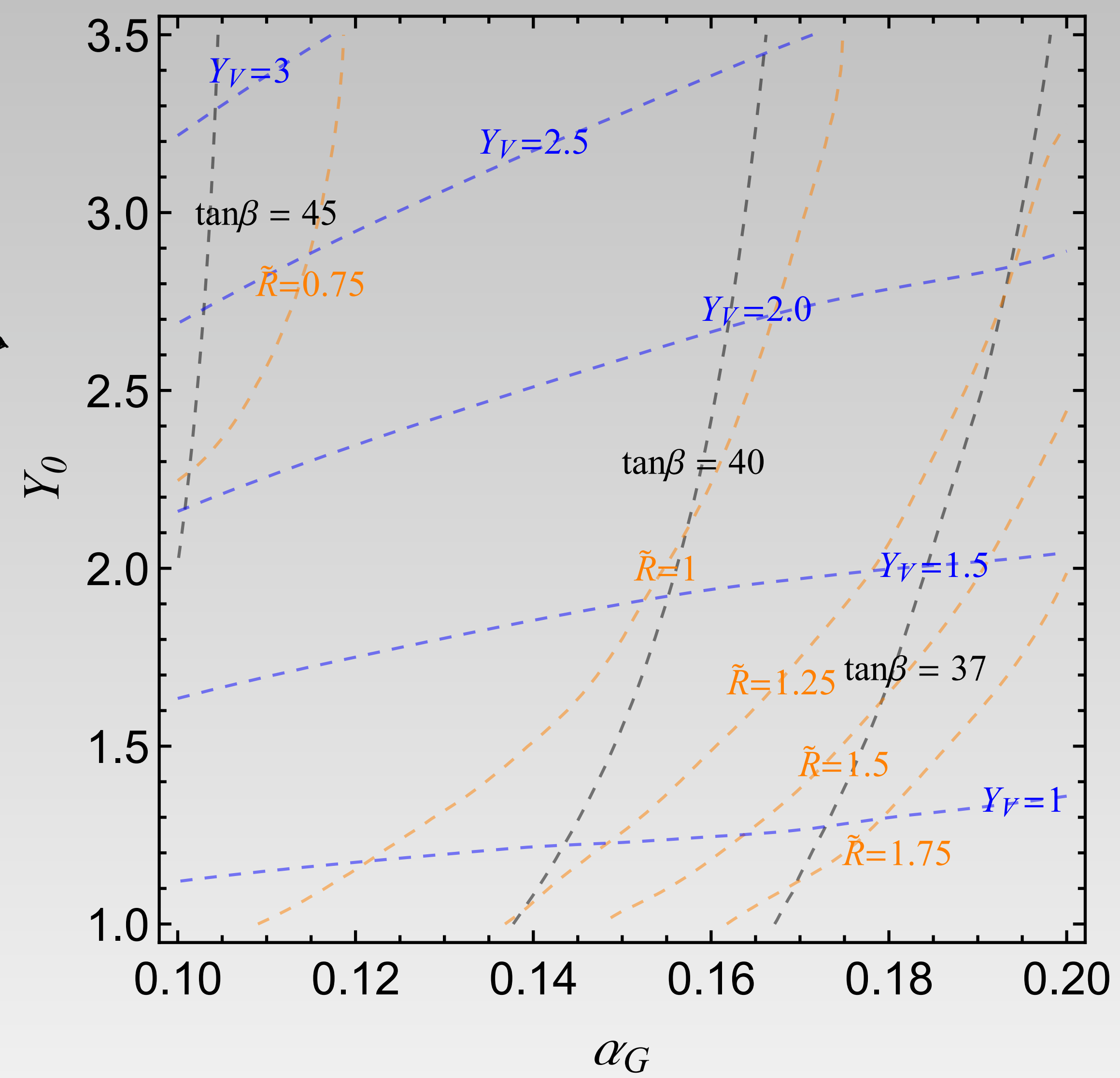
$\tan\beta, Y_V \longrightarrow y_\tau, y_t$

} **Fit precisely in the whole plane**

Splitting gaugino's



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

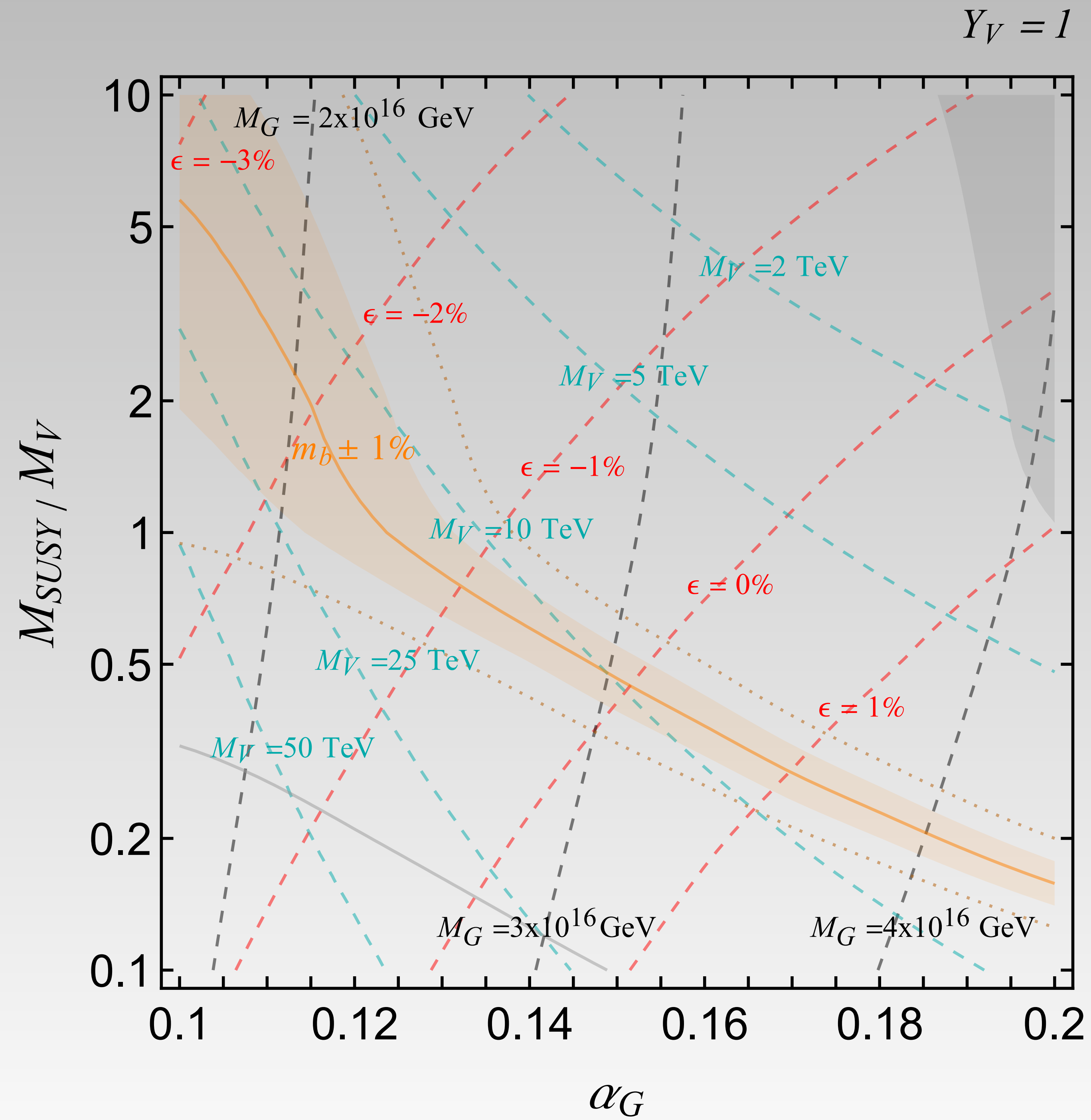


$$M_G, \epsilon, M \longrightarrow \alpha_1, \alpha_2, \alpha_3$$

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

} **Fit precisely in the whole plane**

Splitting SUSY and VF



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!