Robust predictions for gauge couplings and the top Yukawa in the MSSM with a vector-like family

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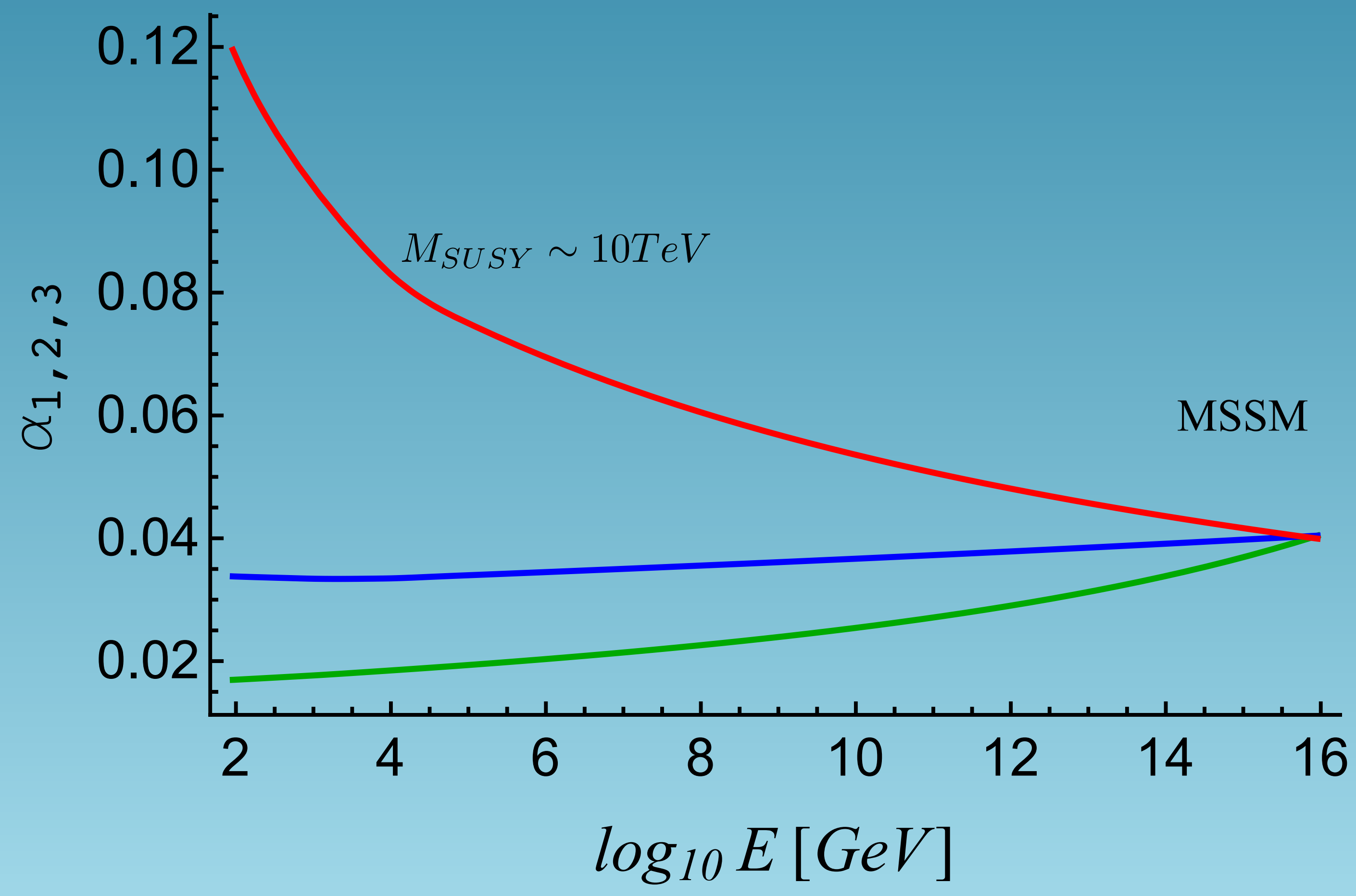
Gauge coupling unification in the MSSM

$$\underset{SU(5)}{\underline{\qquad}}\qquad \underset{SO(10)}{\underline{\qquad}}$$

$$Q, u, d, L, e \to \bar{5} \oplus 10 \subset 16$$



$$M_G \simeq 2 \times 10^{16} GeV$$

$$\Delta\alpha_G \sim -3\%$$

MSSM with vector-like fermions

MSSM+

$$W \supset M_Q Q\bar{Q} + M_U U\bar{U} + M_E E\bar{E} + M_L L\bar{L} + M_N N\bar{N} + M_D D\bar{D}$$

Part 1:

$$W \supset M_{VF} \bar{16} 16$$

- Consider universal masses at fixed scale or universal at GUT scale

Part 2:

$$W \supset Y_{T_1} H_u Q\bar{U} + Y_{T_2} H_u \bar{Q} D.$$

Part 1:

Gauge coupling unification in the MSSM

$$\frac{d\alpha_i}{dt} = \beta(\alpha_i) = \frac{\alpha_i^2}{2\pi} b_i$$

$$b_i = (33/5, 1, -3) + n_5(1,1,1) + 3n_{10}(1,1,1)$$

$$n_5 = 5 \oplus \bar{5} = (L \oplus \bar{L}) \oplus (D \oplus \bar{D})$$

$$n_{10} = 10 \oplus \bar{10} = (Q \oplus \bar{Q}) \oplus (U \oplus \bar{U}) \oplus (E \oplus \bar{E})$$

For 1VF: $b_i = (53/5, 5, 1)$

$n_5 = n_{10} = 1$

→ **Larger** α_G

One-loop estimates

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

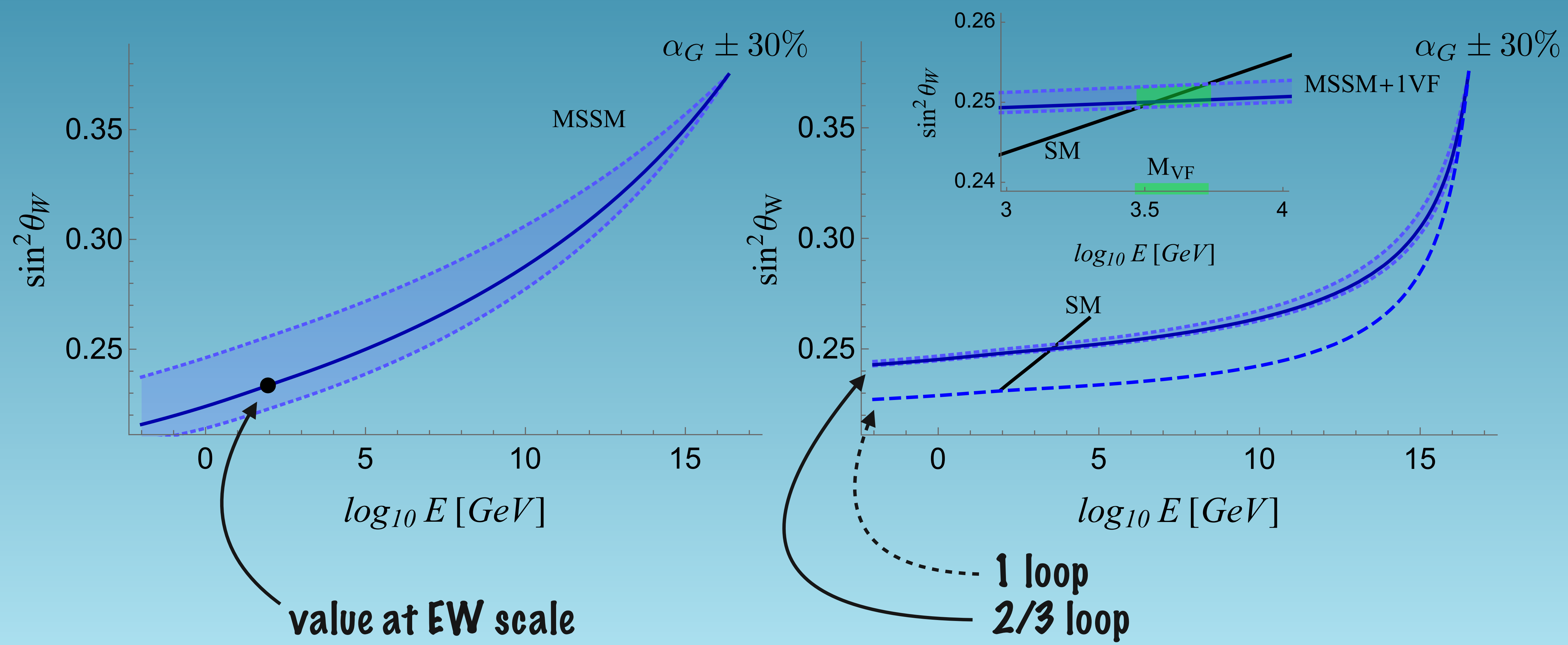
★ $$M_G = M_Z \exp\left(2\pi \frac{\alpha_1^{-1}(M_Z) - \alpha_2^{-1}(M_Z)}{b_1 - b_2}\right)$$

★ $$\frac{\alpha_i(M_Z)}{\alpha_j(M_Z)} \simeq \frac{b_j}{b_i}$$

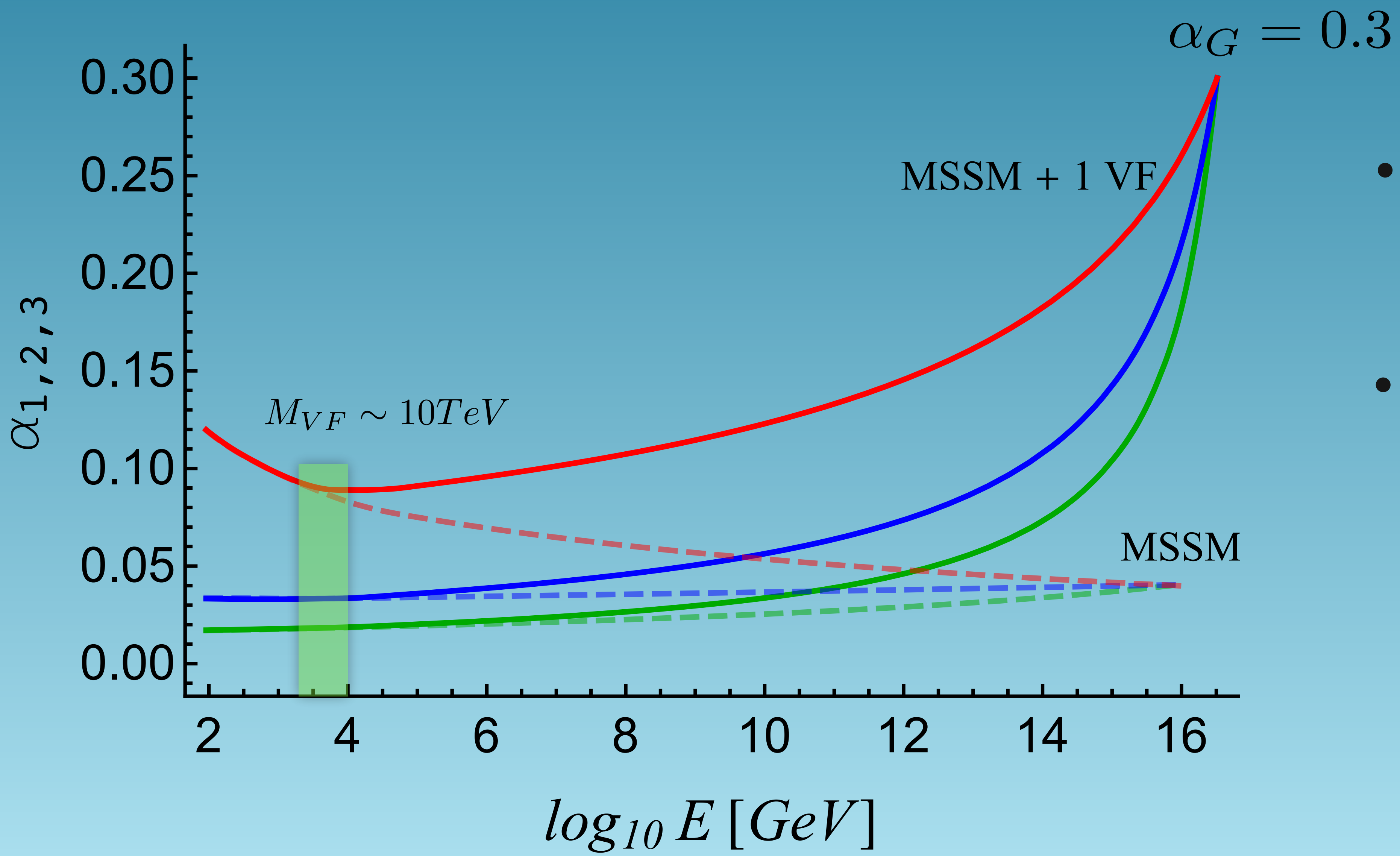
Predictions for weak scale parameters based on particle content

Weinberg angle

$$\sin^2\theta_W \equiv \frac{\alpha'}{\alpha_2 + \alpha'} \simeq \frac{b_2}{b_2 + b'} = 0.2205$$



Gauge Couplings

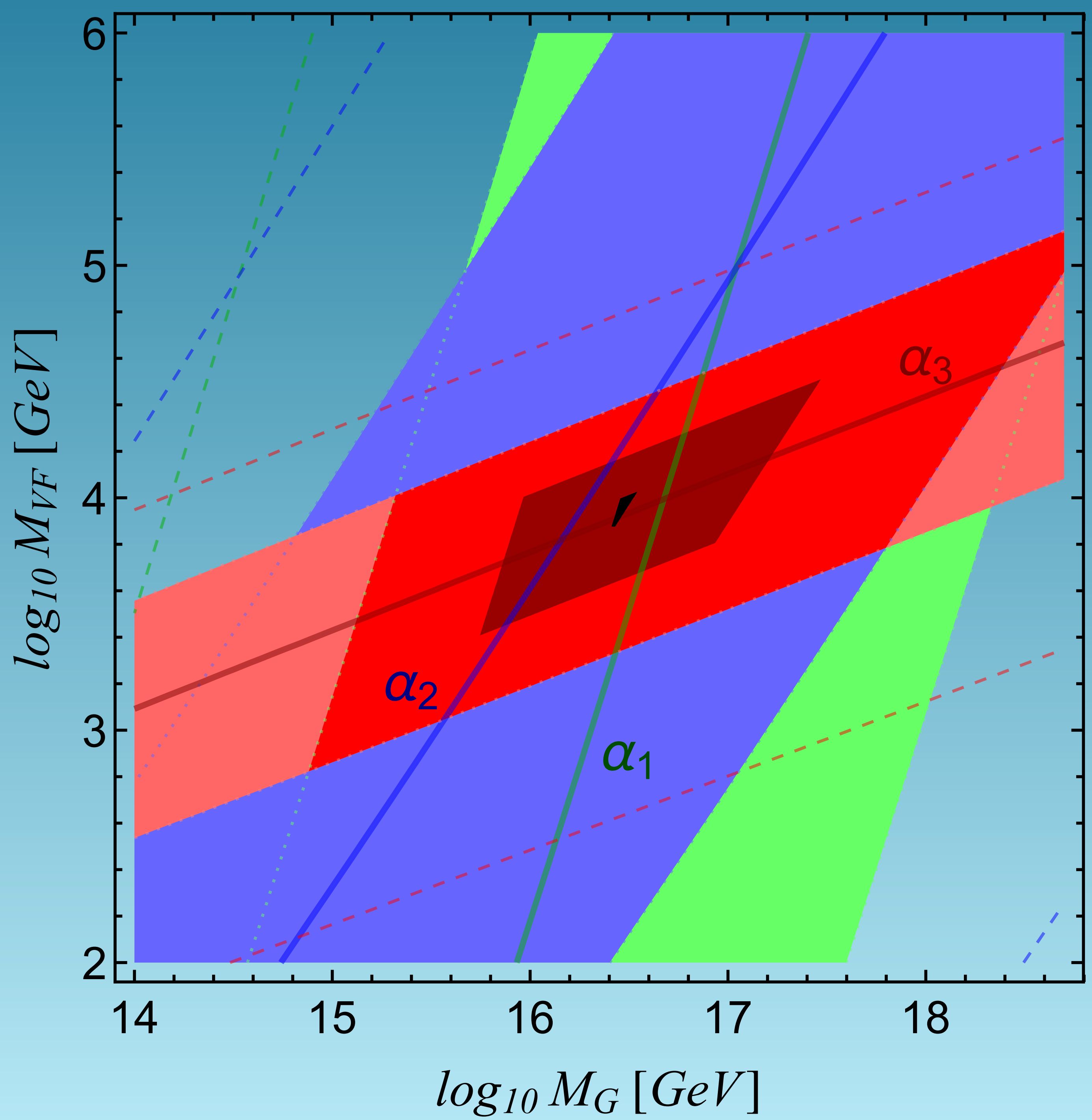


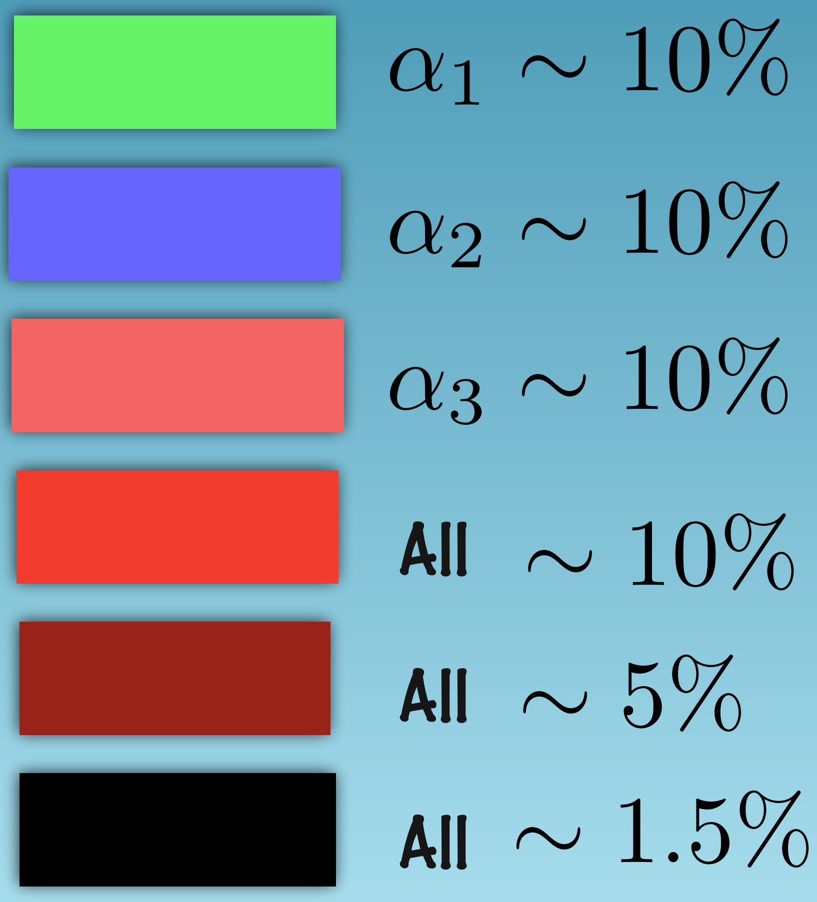
- $M_{SUSY}(M_G) = 10TeV$
  $(M_{1/2}, m_0)$
  - in the range for Higgs mass
- Consider vector-like matter at a universal weak scale value or universal at the GUT scale

Motivating a scale for M_{VF} (1)

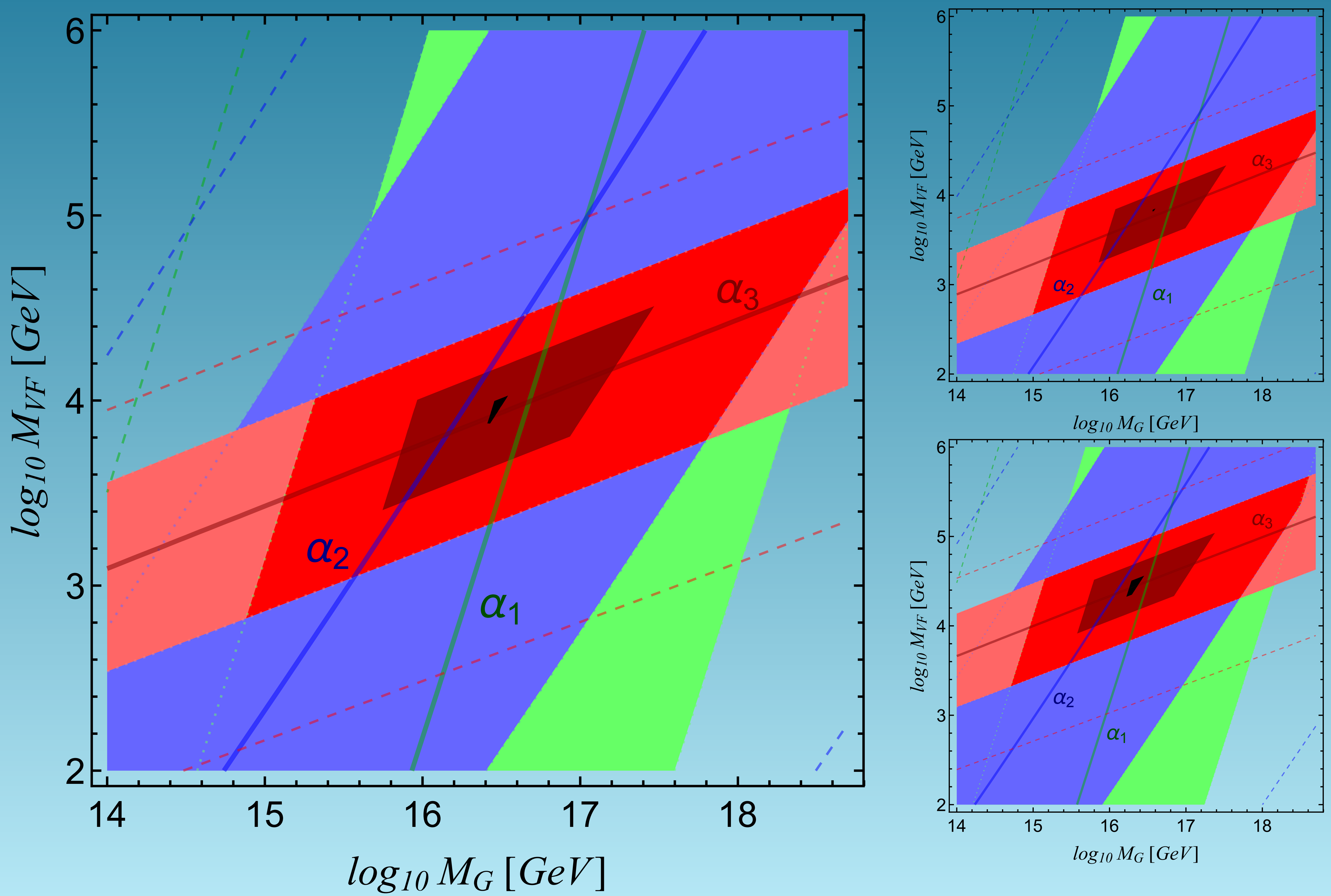
$\alpha_G = 0.3$

M_{VF} universal at low scale



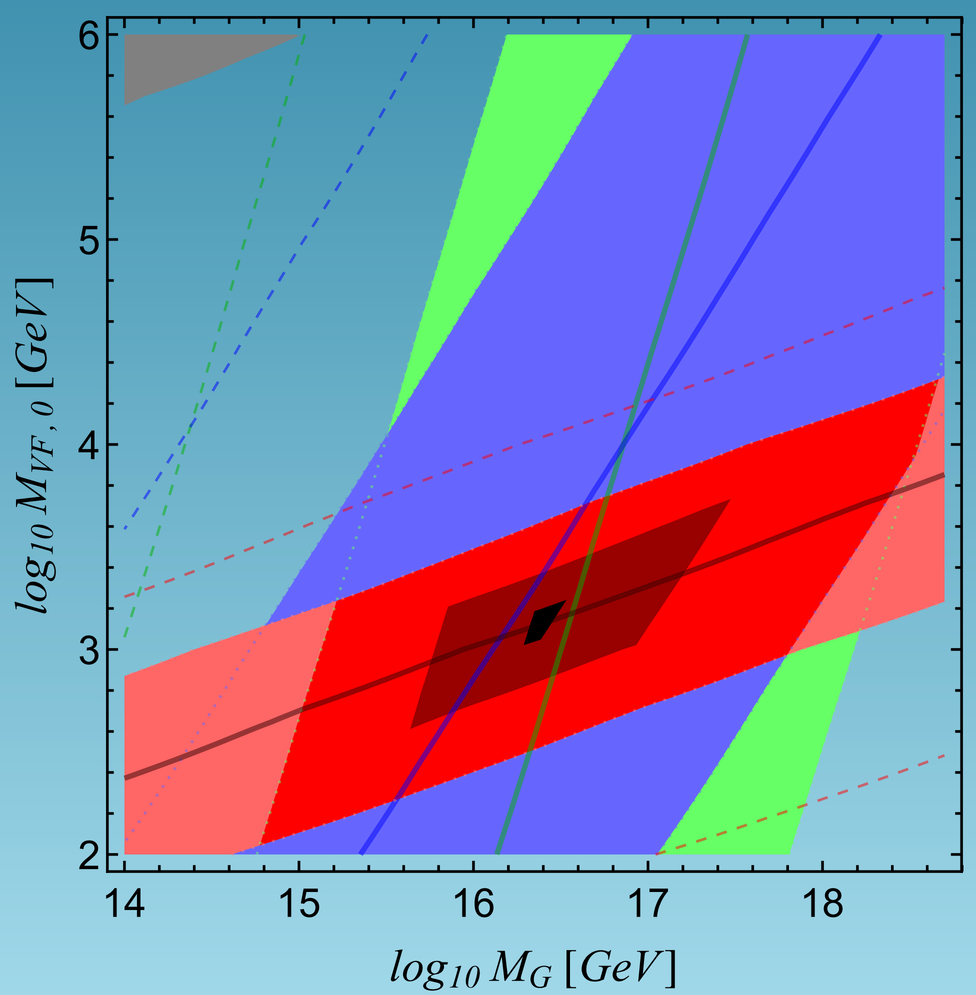


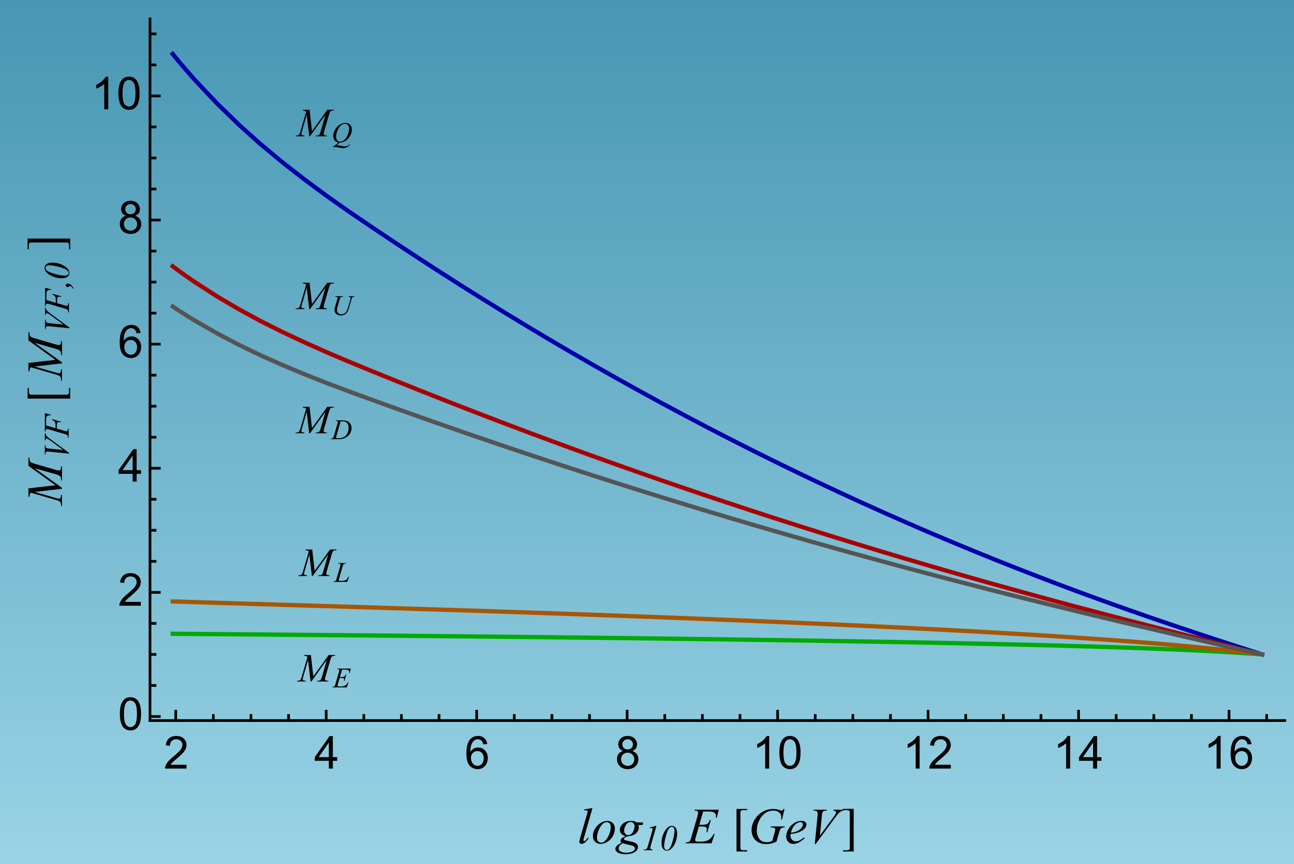
Motivating a scale for M$_{VF}$ (1)



$\alpha_G = 0.3 \pm 0.1$

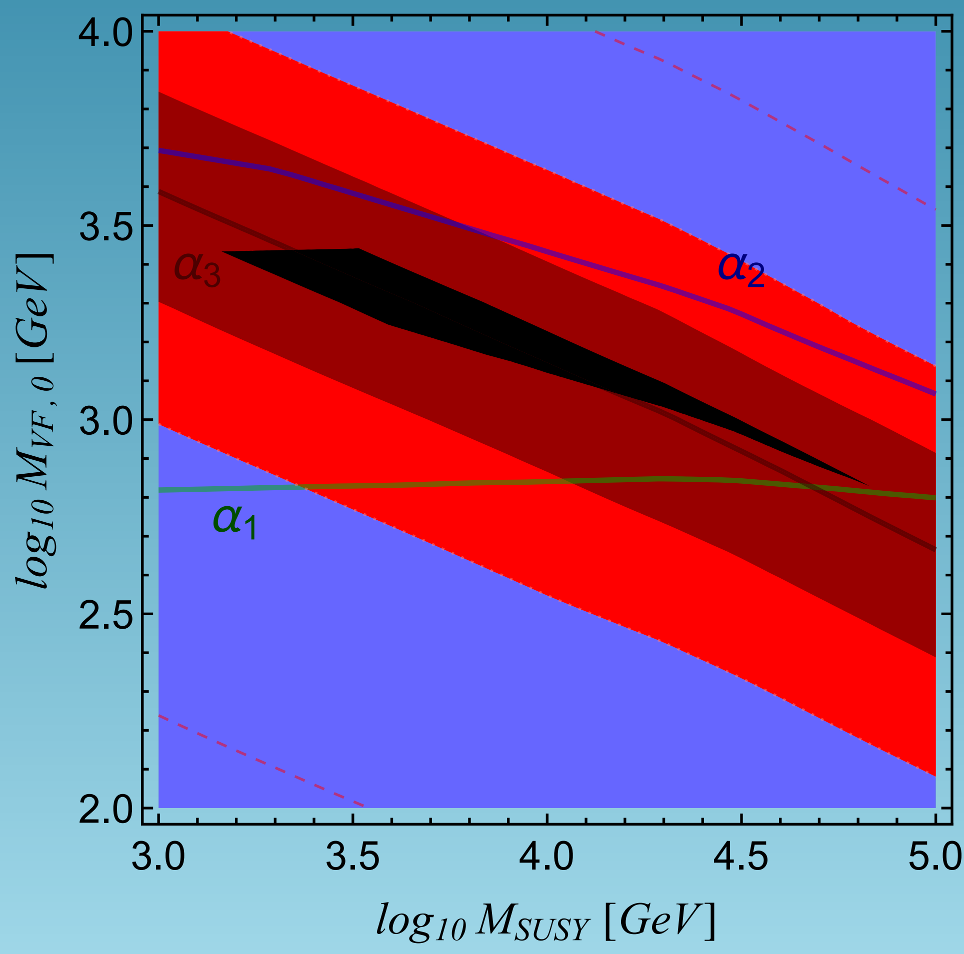
Mass scale for M_{VF} (2)

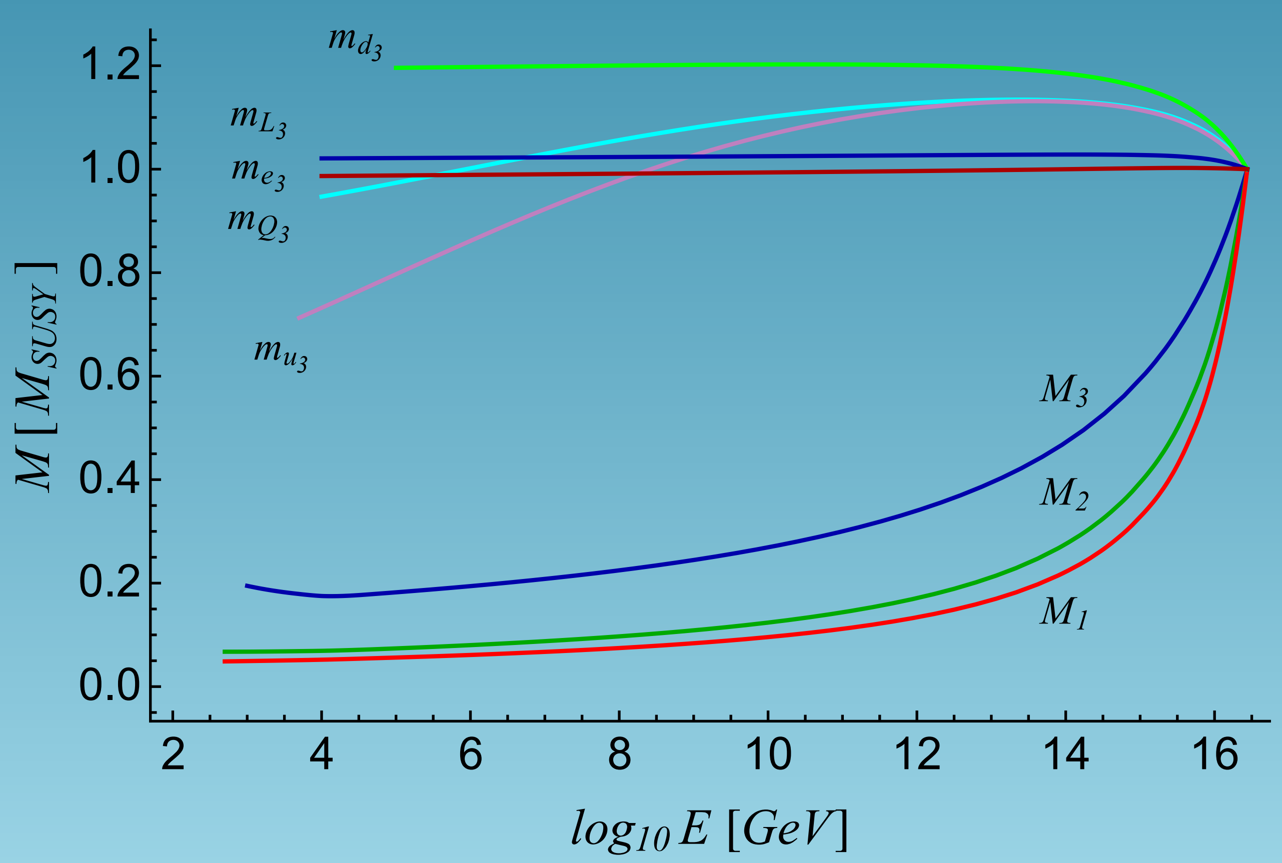




M_{VF} universal at GUT scale

Mass scale for M_{VF} (3)





- M_{VF} universal at GUT scale
- M_{SUSY} varied at GUT scale

- can get Wino LSP, lowering M2 -20/%

Recap for vector-like masses and gauge couplings

- IR predictions give indication of scale where vector-like matter decouples
- Possible to obtain predicted gauge couplings within 1.5% of experimental values with M_{VF} close to 10TeV

Can adjust GUT scale parameters over large ranges and still learn something about the scale of vector-like matter!

Part 2:

IR fixed points for the top Yukawa

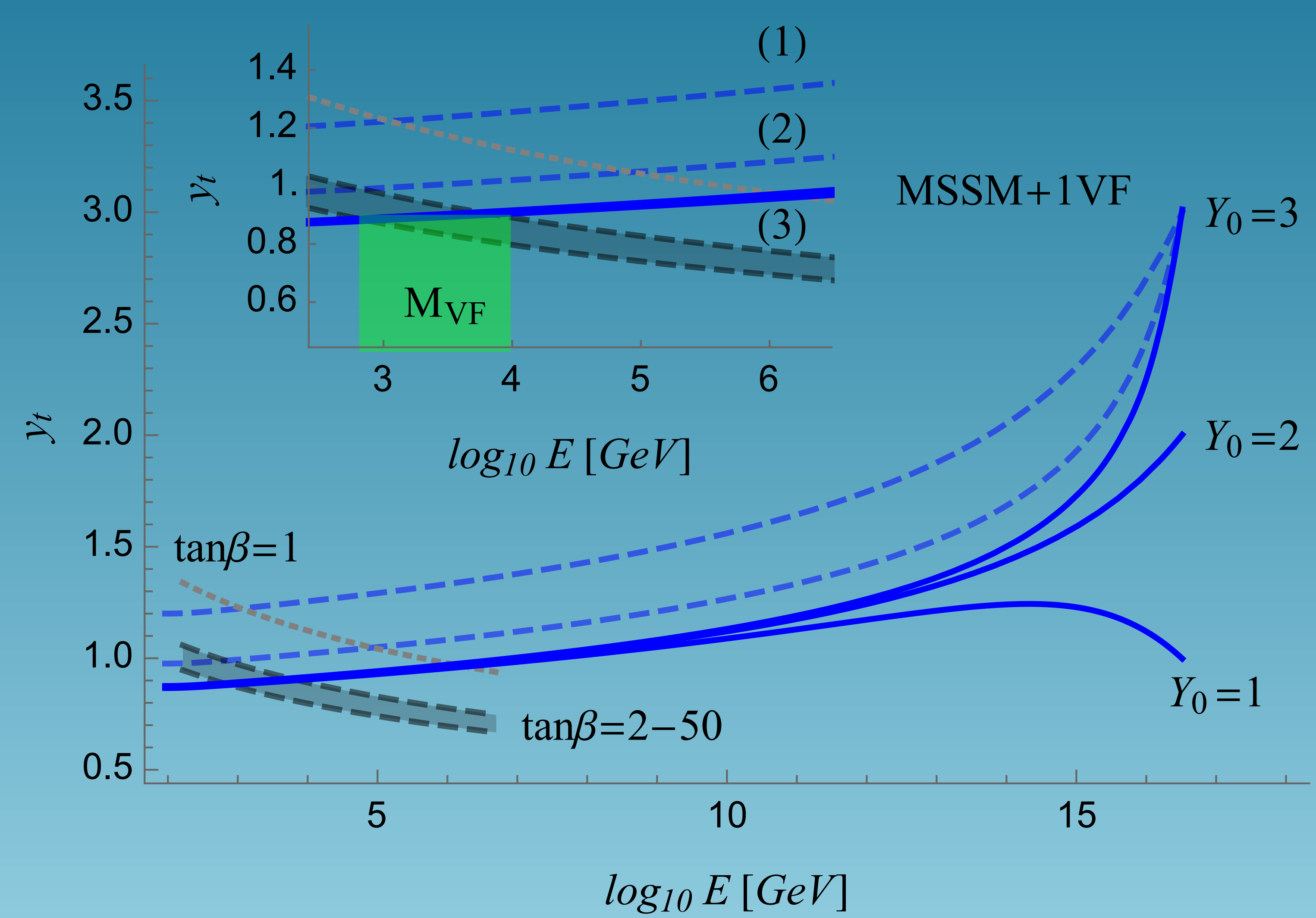
$$W \supset Y_{T_1} H_u Q \bar{U} + Y_{T_2} H_u \bar{Q} D.$$

$$\beta_{y_t}^{(1)} = y_t (6 y_t^2 + 3 Y_{T_1}^2 + 3 Y_{T_2}^2 - \frac{16}{3} g_3^2 - 3 g_2^2 - \frac{13}{15} g_1^2)$$

Fixed point: $y_{t,MSSM} \simeq 1.2$

+1VF: $y_t \simeq 0.87$

M_{VF} vs Y_t

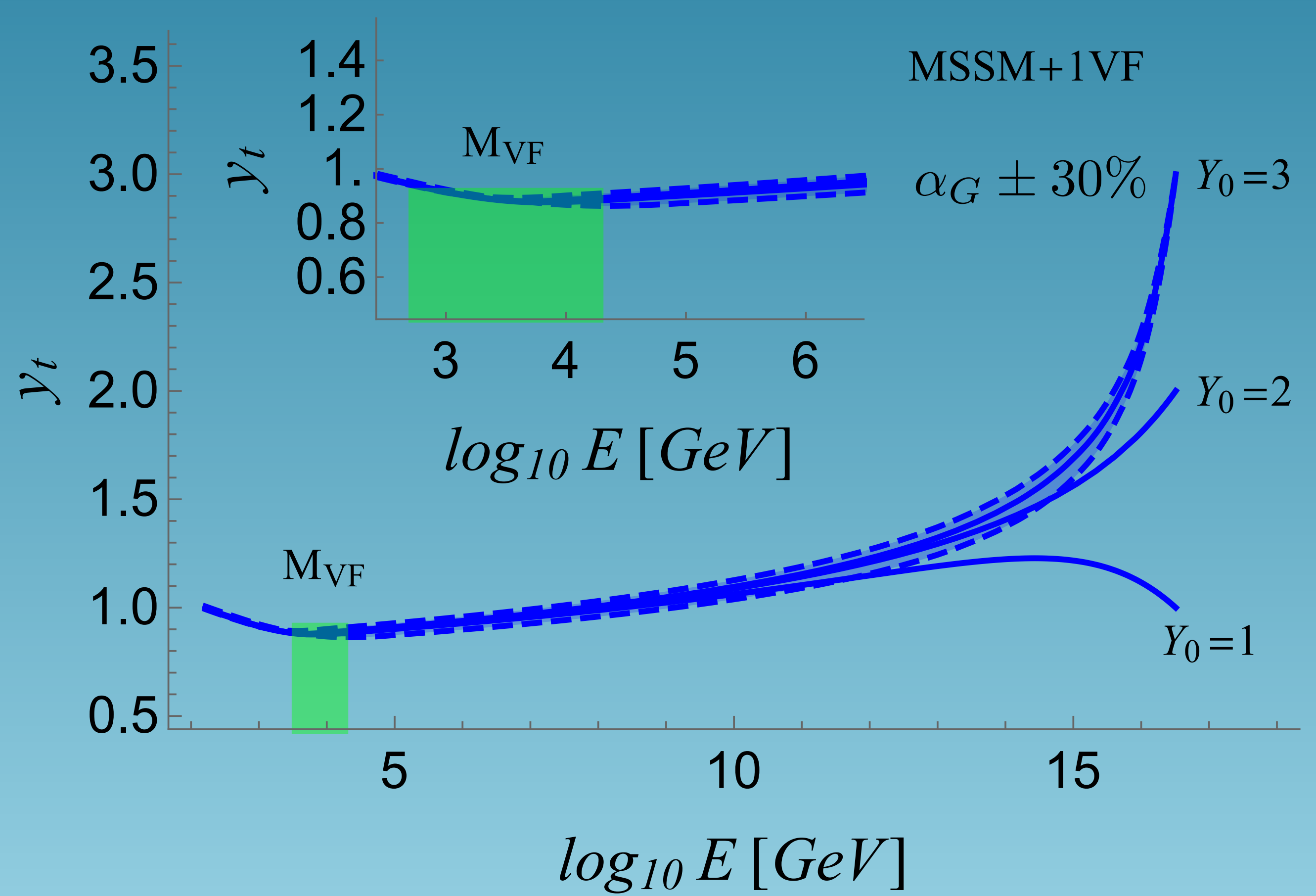


(1) top-yukawa
(2) top-yukawa + Y_{T1}
(3) top-yukawa + Y_{T1} + Y_{T2}

y_t in at low energies defined by $m_t = y_t v \sin\beta$

Indication of scale to decouple VF

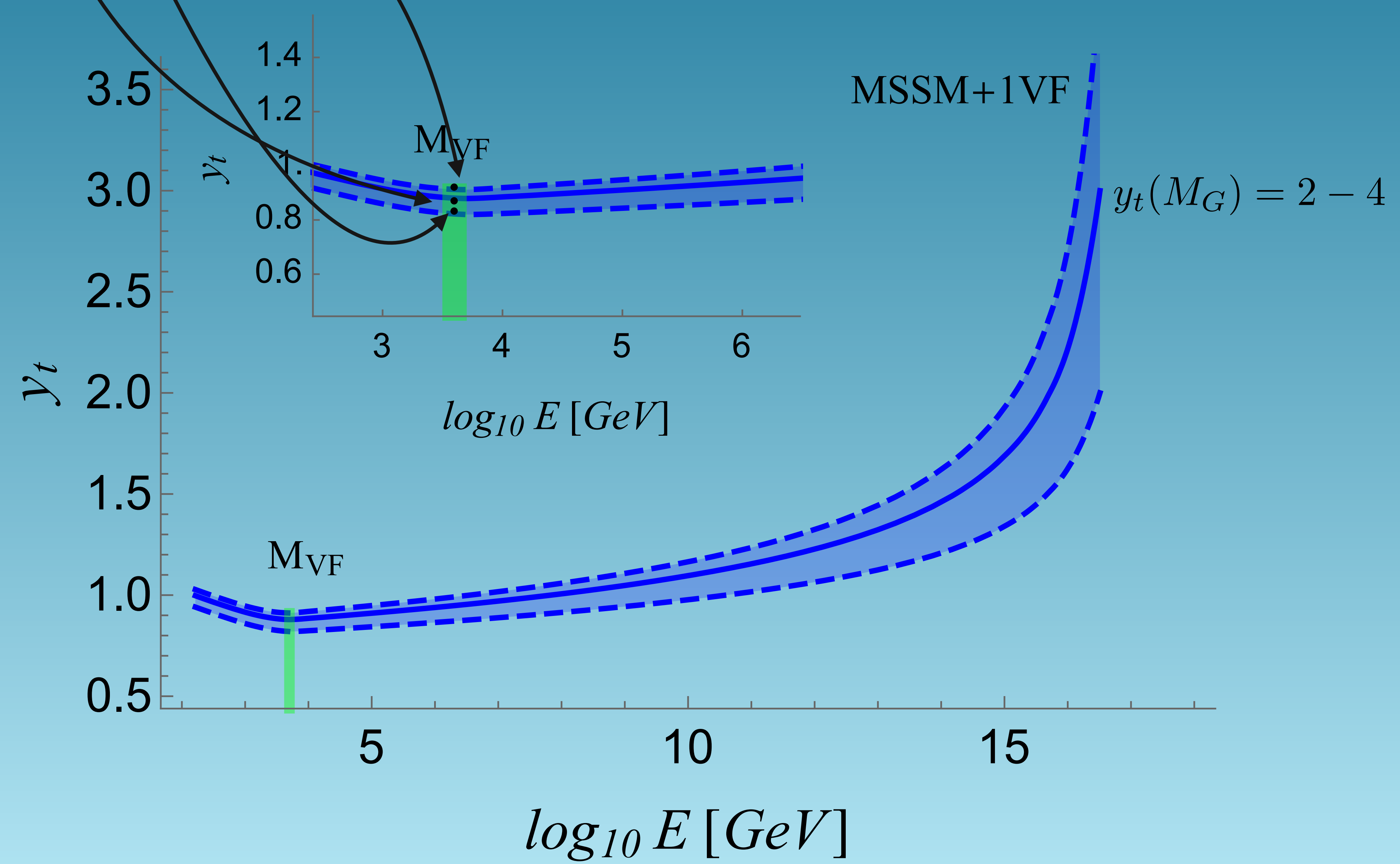
Sensitivity of M_t to α_G



Fixed point predictions for M_t for $\tan\beta = 2, 10$			
Y_0	M_{VF} (TeV)	M_t (GeV), $\tan\beta = 2$	M_t (GeV), $\tan\beta = 10$
1	$6.3^{-2.5}_{+17.9}$	$164.7^{-0.6}_{+0.8}$	$181.6^{-0.6}_{+1.1}$
2	$5.6^{-2.1}_{+15.7}$	$164.7^{-0.6}_{+0.8}$	$182.0^{-0.8}_{+1.4}$
3	$5.3^{-2.0}_{+14.3}$	$164.7^{-0.6}_{+0.8}$	$182.1^{-0.9}_{+1.4}$

Sensitivity of Mt to $y_t(M_G)$

$\tan\beta = 2, 3, 10$



Summary

- MSSM extended with a vector-like family gives IR predictions that can be understood based on particle content
    - Weinberg angle within 5%

- Scale for vector-like matter that gives best prediction for gauge couplings - 10TeV
    - extremely robust, not sensitive to GUT scale parameters

- IR fixed point for the top-yukawa gives another prediction that is insensitive to the GUT scale
    - Find again that the best scale for VF to decouple - 10TeV

MSSM+1VF → 10TeV