IR fixed point pattern of couplings in the MSSM+1VF

with N. McGinnis, arXiv:1812.05240

and other papers with N. McGinnis, E. Lunghi and S. Shin

Radovan Dermisek

Indiana University, Bloomington

SUSY 2019, Corpus Christi, May 22, 2019

Standard model

Out of 17 dimensionless parameters:

$$\alpha_1,\ \alpha_2,\ \alpha_3,\ y_t,\ y_b,\ y_\tau,\ \lambda_h$$

only 7 couplings are sizable

all others = 0 (in the first approximation)

In the MSSM+1VF

the values of all large couplings:

$$\alpha_1,\ \alpha_2,\ \alpha_3,\ y_t,\ y_b,\ y_\tau,\ \lambda_h$$

can be understood from the IR fixed point structure of renormalization group equations

MSSM with a complete vectorlike family

We add to the MSSM:

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

or $16 + \overline{16}$ **in SO(10) language**

We consider:

- **unrelated** gauge couplings at the GUT scale (fundamental scale)
- **unrelated** Yukawa couplings at the GUT scale:
- universal Yukawa c. of vectorlike fields at the GUT scale: Y_V
- common scale for superpartners: M_{SUSY} (and zero A-terms)
- common scale for vectorlike matter: M_V

    in this talk we identify the two scales: $M_{SUSY} = M_V \equiv M$

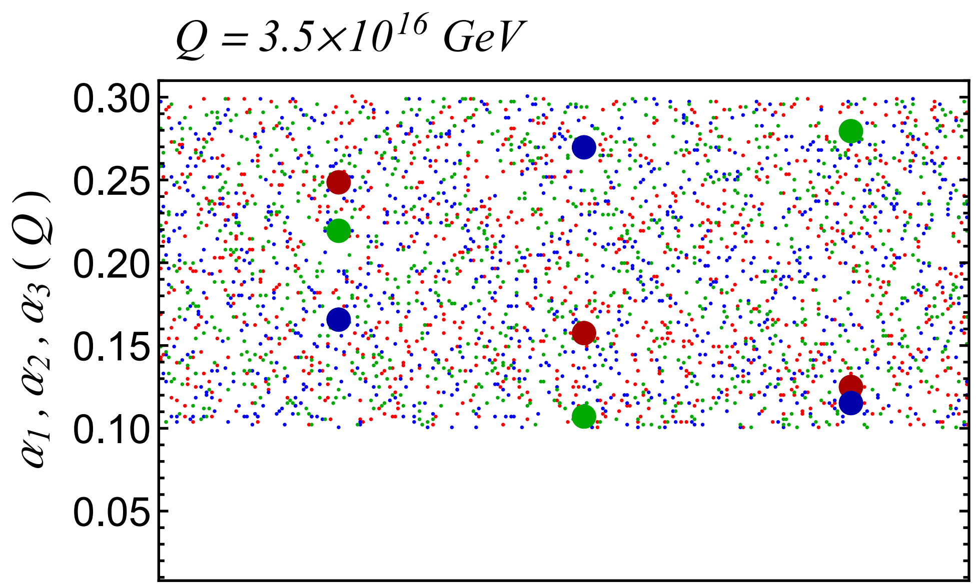
Big picture

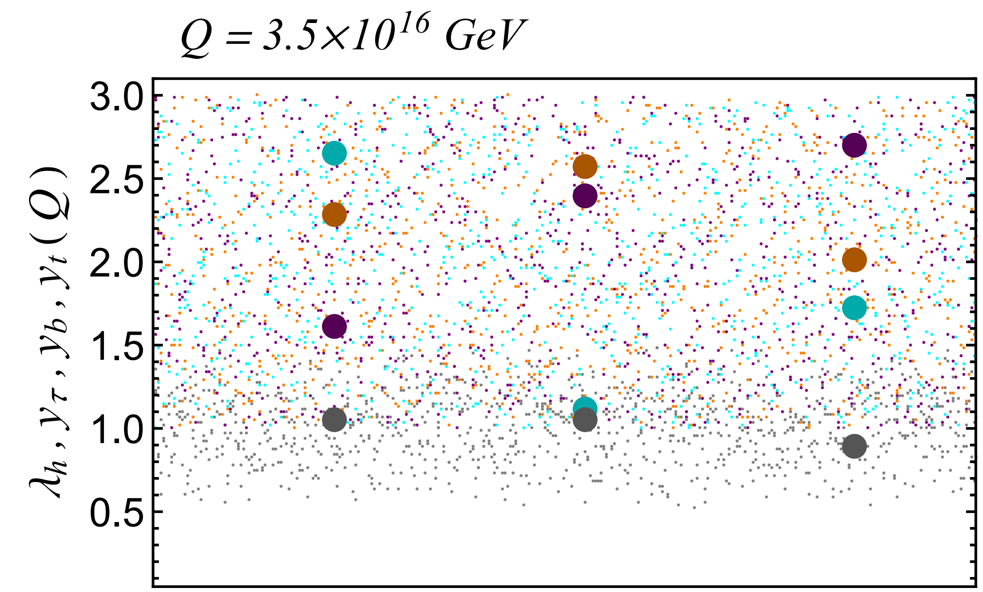
GUT scale

$\sim 3 \times 10^{16}$ GeV

MSSM+1VF

few TeV





Random unrelated boundary conditions:

$\alpha_1(M_G), \alpha_2(M_G), \alpha_3(M_G) \in [0.1, 0.3]$ $\quad$ $y_t(M_G), y_b(M_G), y_\tau(M_G), Y_V(M_G) \in [1,3]$

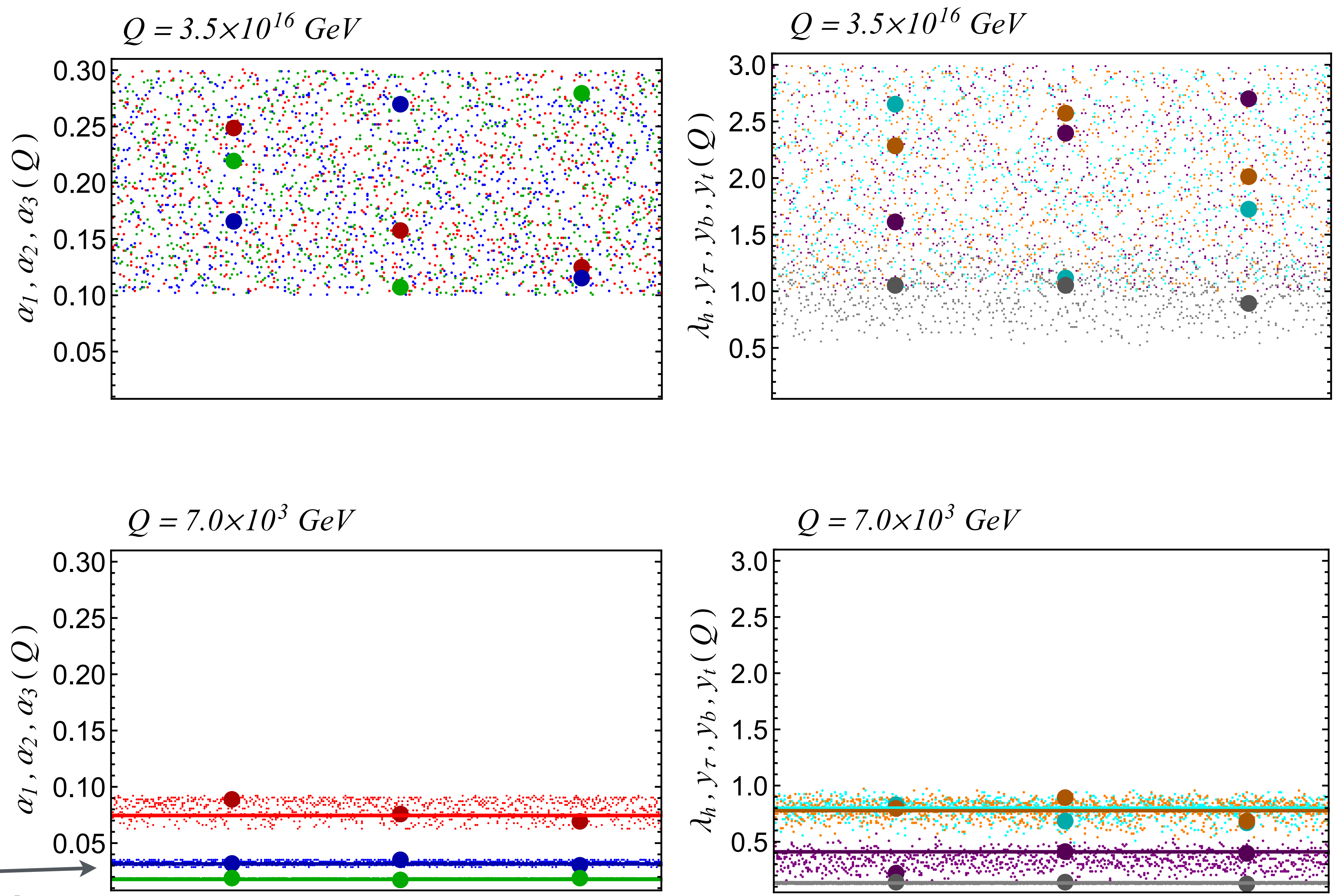
(larger values of couplings do not affect results significantly)

Higgs quartic given by gauge couplings at any scale:

$$\lambda_h(Q) \equiv \frac{g_2^2(Q) + (3/5)g_1^2(Q)}{4} \cos^2 2\beta$$

the plots assume: $\tan\beta = 40$

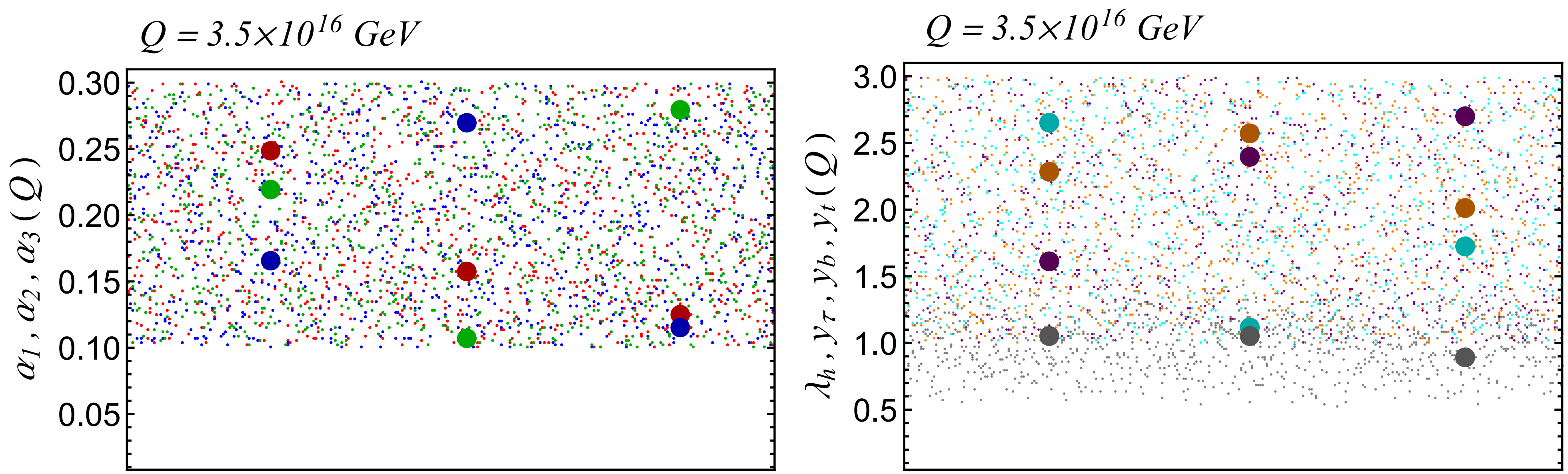
Big picture



solid line are SM measured values evolved to a given scale, they include SUSY threshold corrections assuming $\tan\beta = 40$

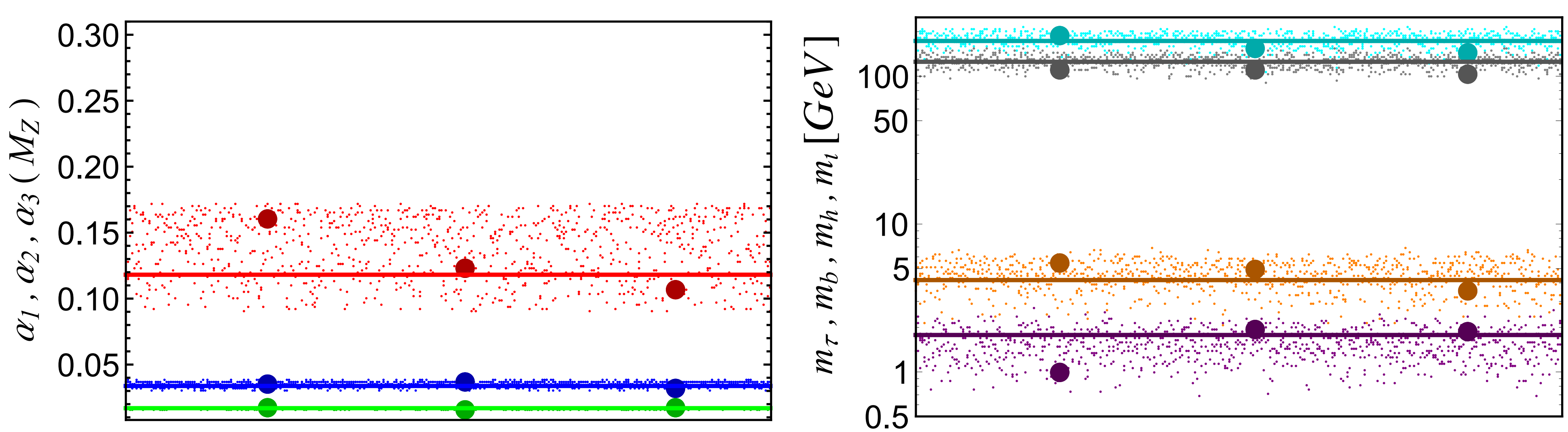
Distinctive pattern of couplings emerges

Big picture



GUT: Random boundary conditions

EW: familiar pattern of couplings and masses



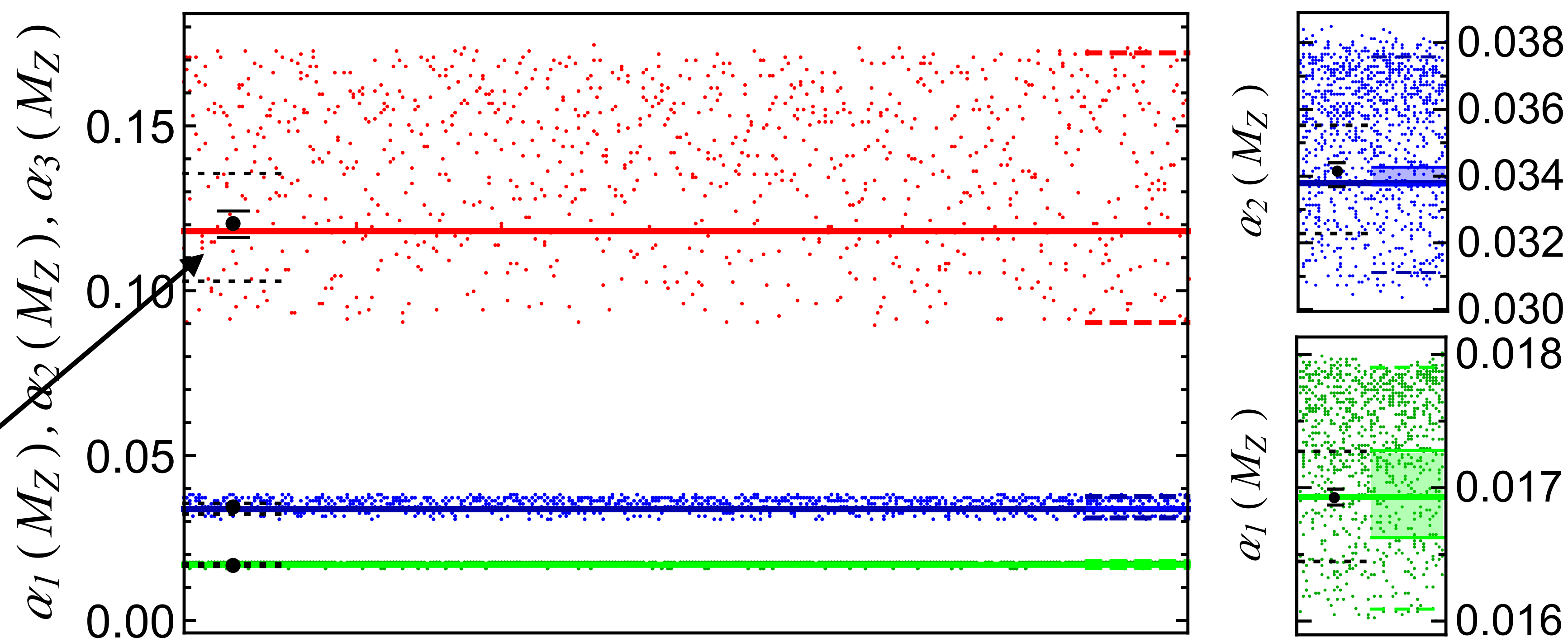
Predicted pattern of gauge couplings

In the MSSM+1VF:

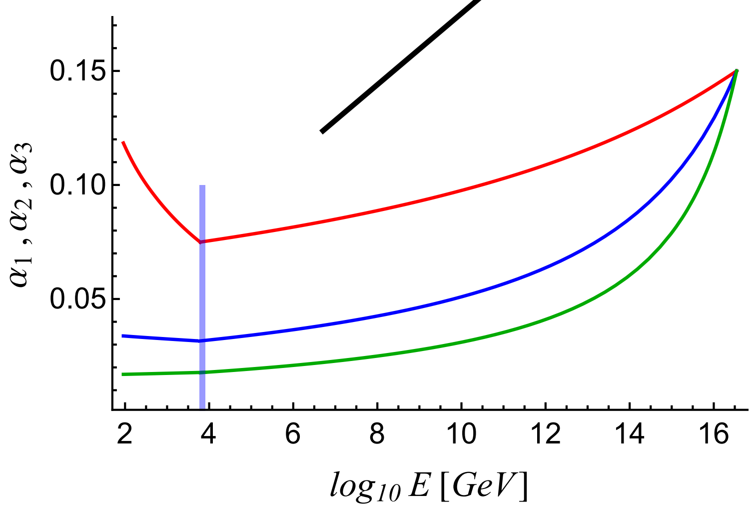
$\alpha_1(M_G), \alpha_2(M_G), \alpha_3(M_G) \in [0.1, 0.3]$

$M_G = 3.5 \times 10^{16}$ GeV, $M = 7$ TeV and $\tan\beta = 40$

– – – universal b.c. ▬ M optimized for α_3



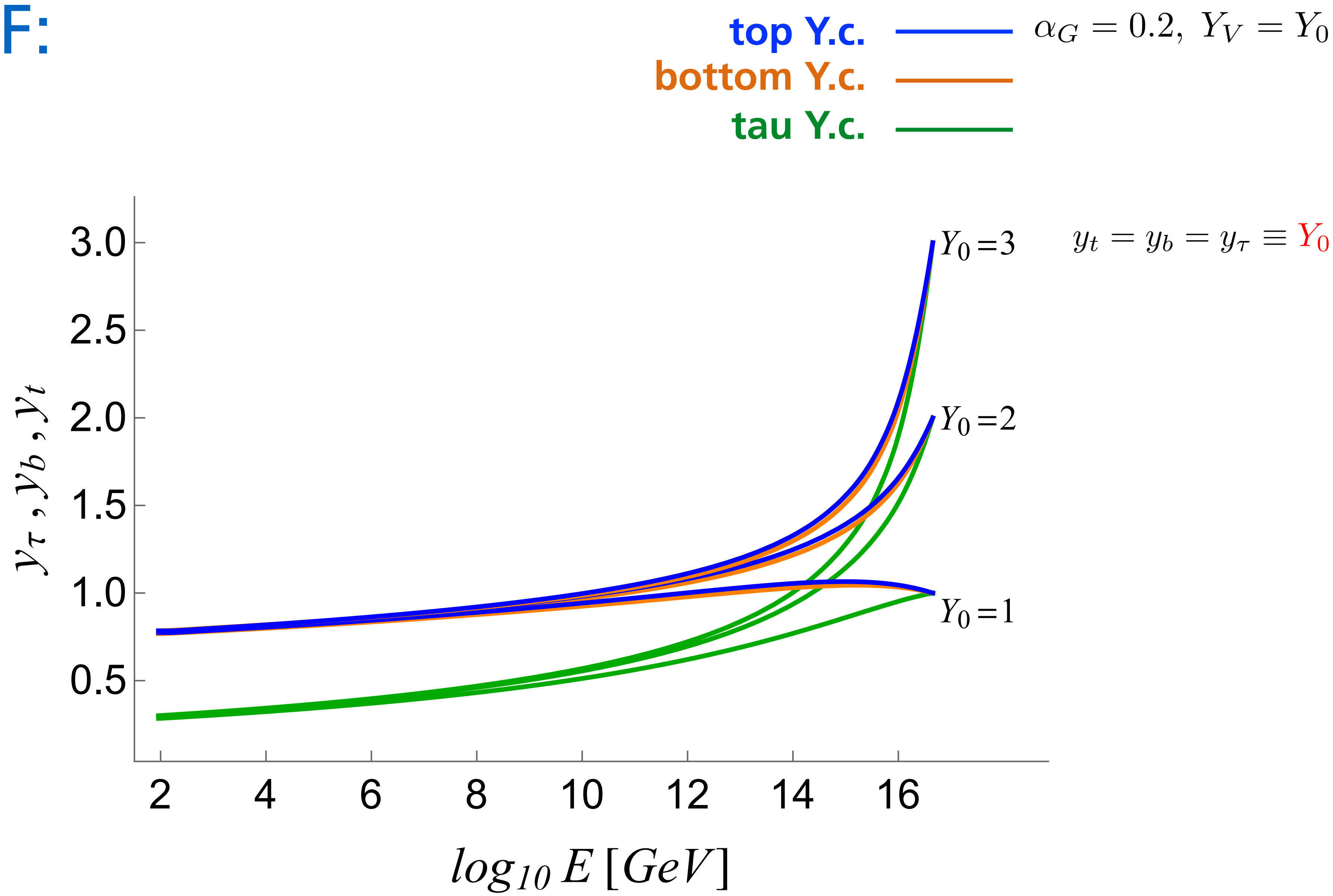
20% variations of M ——
and all couplings - - - -



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

Evolution of top, bottom and tau Y.c.

In the MSSM+1VF:



common IR fixed points remain good approximations for a large range of boundary conditions

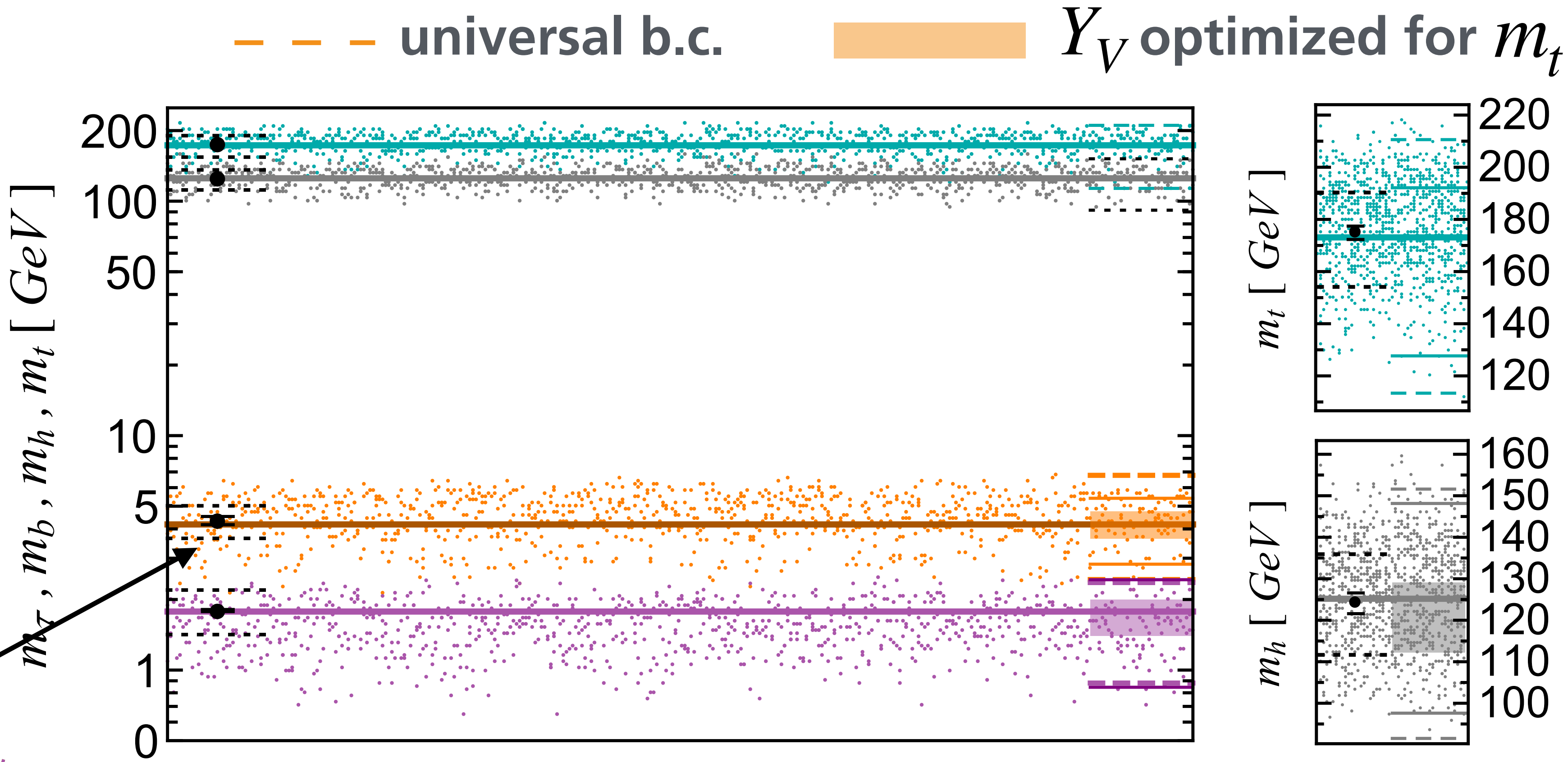
very effective IR fixed point behavior

Predicted pattern of fermion masses

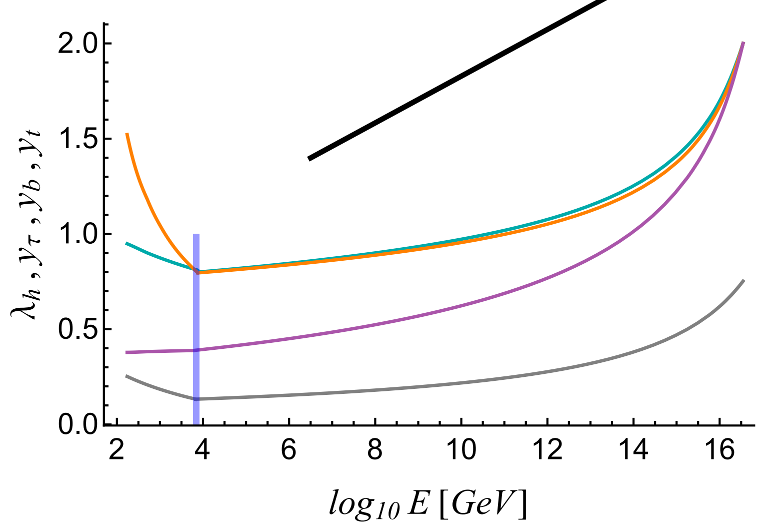
In the MSSM+1VF:

$\alpha_1(M_G), \alpha_2(M_G), \alpha_3(M_G) \in [0.1, 0.3]$ $y_t(M_G), y_b(M_G), y_\tau(M_G), Y_V(M_G) \in [1,3]$

$M_G = 3.5 \times 10^{16}$ GeV, $M = 7$ TeV and $\tan\beta = 40$



20% variations of M ——
and all couplings - - - -

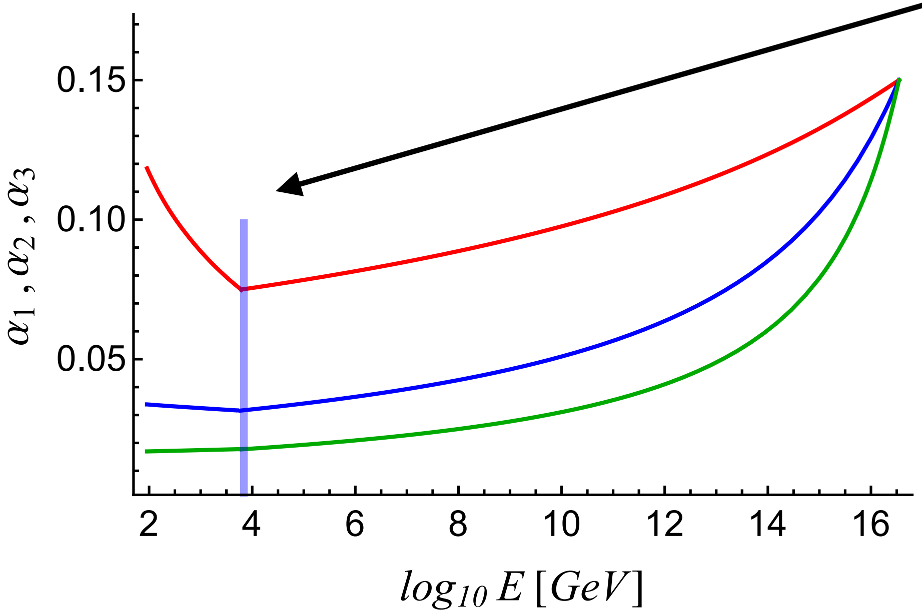


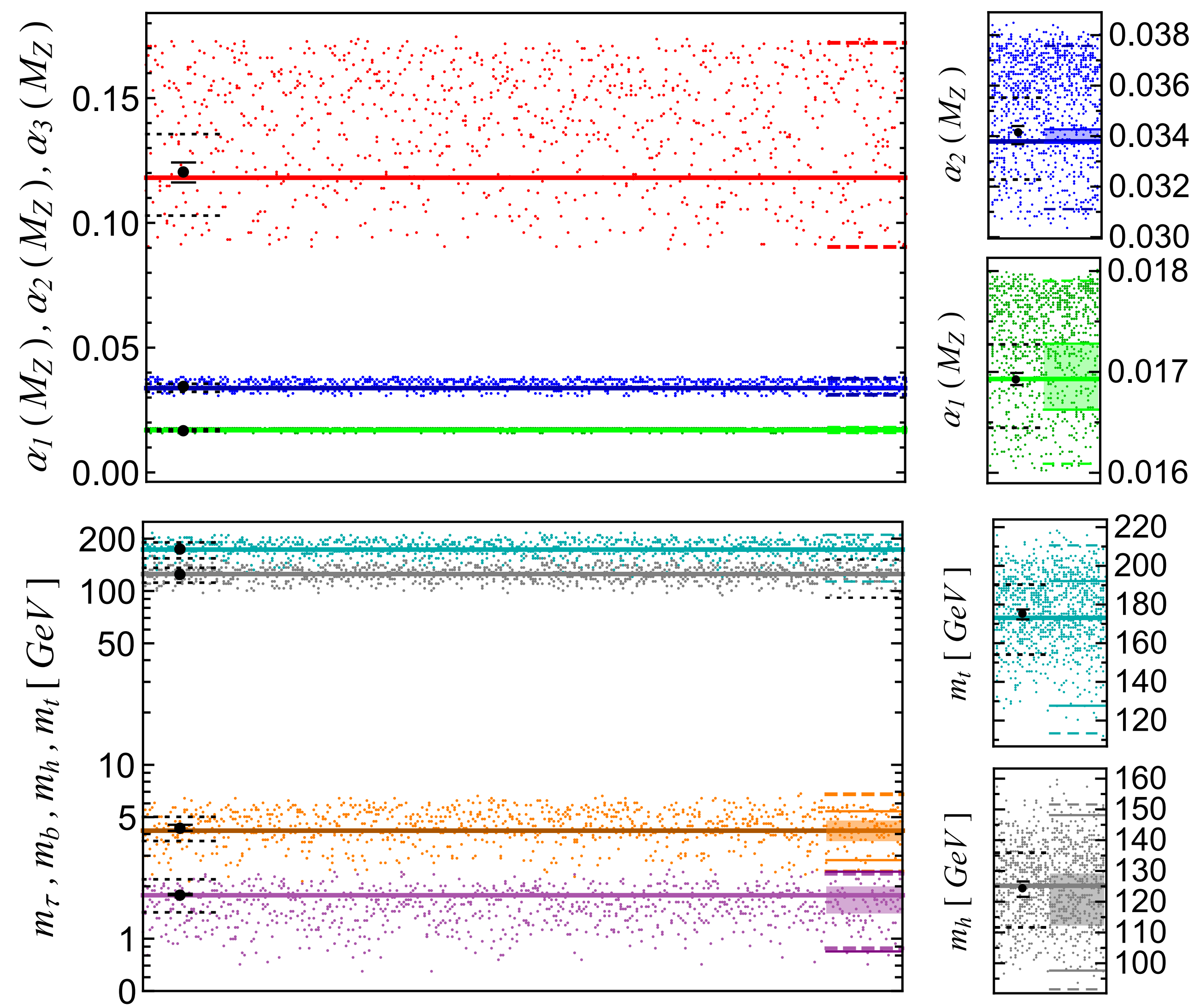
SUSY corrections at M assume all superpartners at the same scale, zero A-terms and $\mu = -\sqrt{2} M_{SUSY}$

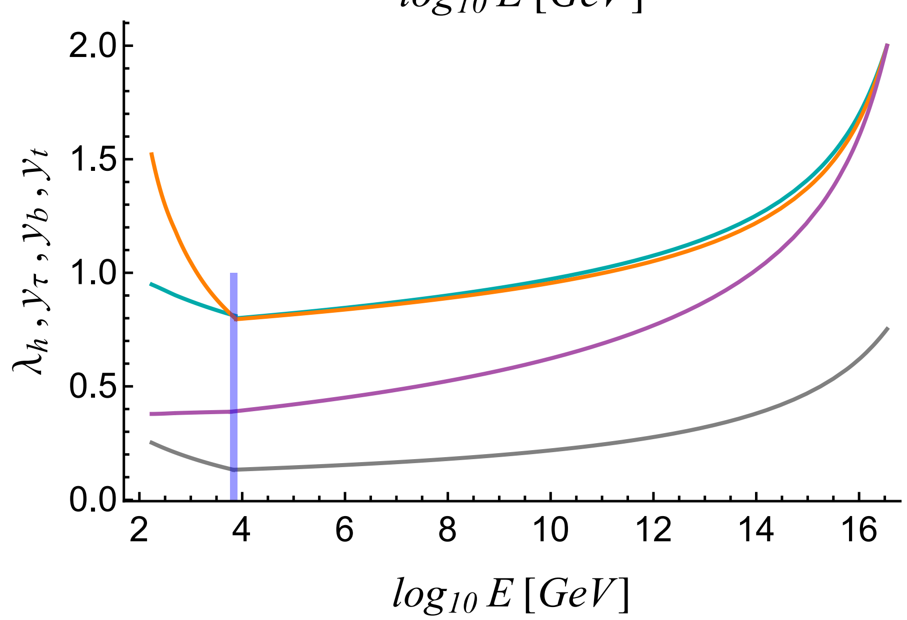
for top-bottom-tau Yukawa c. unification, see the talk of N. McGinnis

In the MSSM+1VF

For large range of b.c. there is a narrow range of M within which all the couplings in the MSSM+1VF meet the corresponding parameters in the SM:







Optimizing parameters related to scales

For random unrelated (or unified) parameters:

$$\alpha_1(M_G), \alpha_2(M_G), \alpha_3(M_G) \in [0.1, 0.3]$$

$$y_t(M_G), y_b(M_G), y_\tau(M_G), Y_V(M_G) \in [1, 3]$$

three parameters,

$$M_G,\ M,\ \tan\beta,$$

can be optimized so that none of the seven observables is more than 25% (or 15%) from the measured values.

Further optimizing Y_V to obtain the required overall scale of Yukawa couplings, all 7 observables are within 11% (or 7.5%) from their measured values.

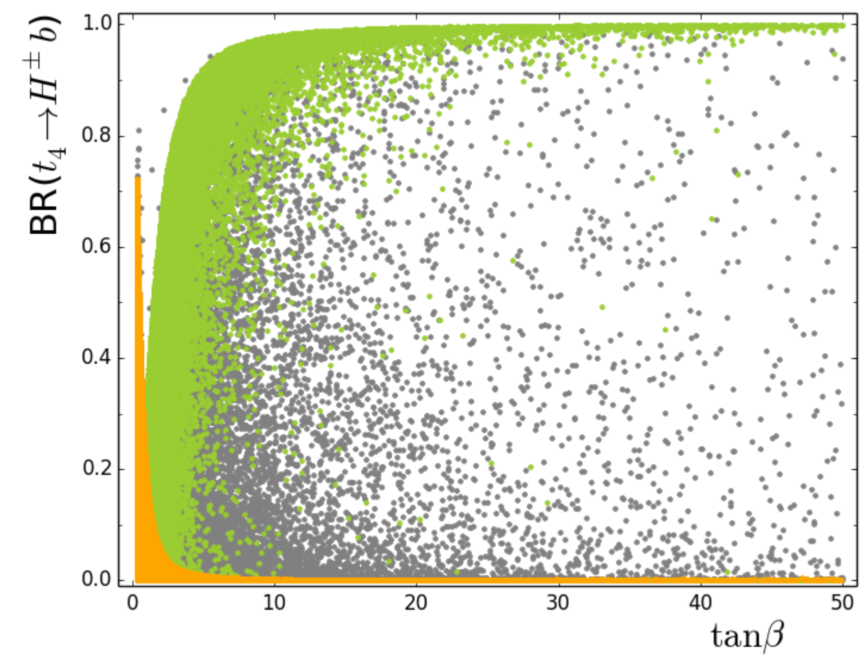
Combined signatures of
heavy Higgses and vectorlike fermions

Heavy Higgses in vectorlike quark decays

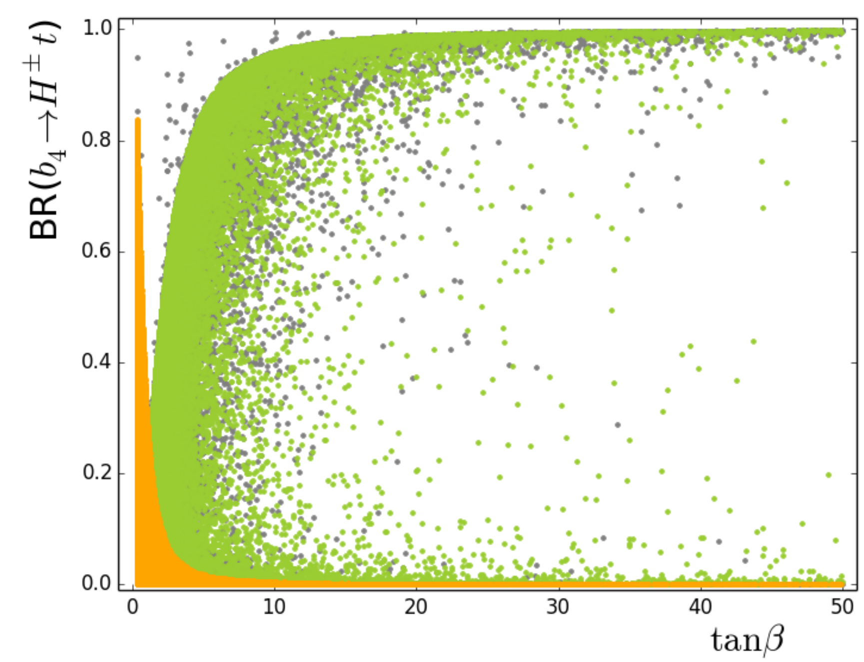
R.D., E. Lunghi and S. Shin, arXiv:1901.03701

Large (QCD) production rates:

$$gg \to t_4\, t_4$$
$$t_4 \to Ht\,, H^{\pm}b$$



$$gg \to b_4\, b_4$$
$$b_4 \to Hb\,, H^{\pm}t$$



even tiny couplings that mix VQ with SM quarks make them decay, and decays through heavy Higgses easily dominate especially at large tan β

close to 100% BRs to heavy Higgses, final states: 6t, 4t2b, 2t4b, 6b

Conclusions

In the **MSSM+1VF** with vectorlike matter and superpartners at a multi-TeV scale:

$$\alpha_1, \ \alpha_2, \ \alpha_3, \ y_t, \ y_b, \ y_\tau, \ \lambda_h$$

can be understood from the IR fixed point structure of the RGEs

- **just one example, similar scenarios might have other interesting features and consequences**
- **1st and 2nd generations? —> different models for fermion masses**
- **motivation for more complex UV embeddings besides simple SU(5) or SO(10), e.g. Pati-Salam, flipped SU(5), …**
- **part of the spectrum might be with the reach of LHC and combined signatures of heavy Higgses and VQ and VL are very promising**