# IR fixed point pattern of standard model couplings

with N. McGinnis, arXiv:1812.05240

Radovan Dermisek

Indiana University, Bloomington

Planck 2019, Granada, Spain, June 3, 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: $M_{SUSY} = M_V \equiv M$

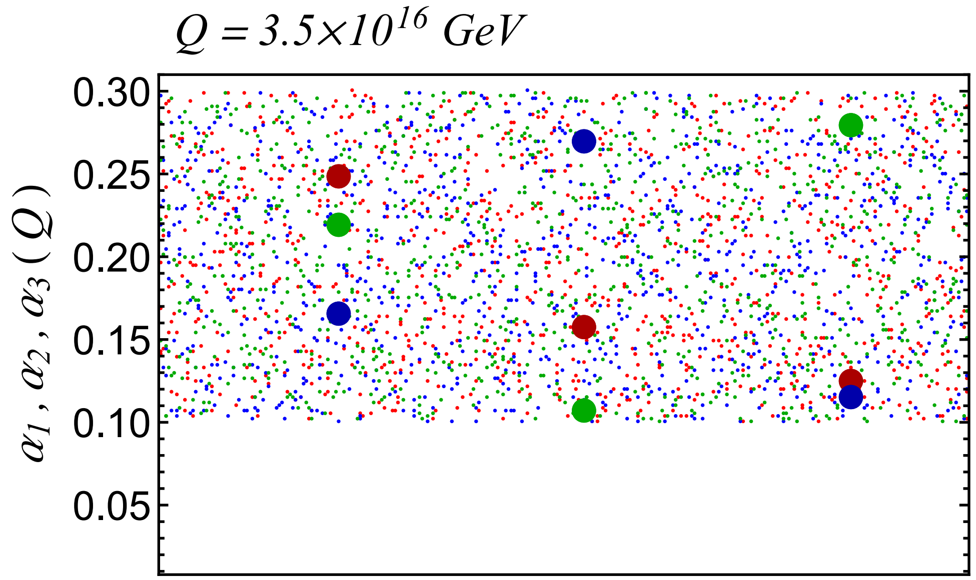
# Big picture

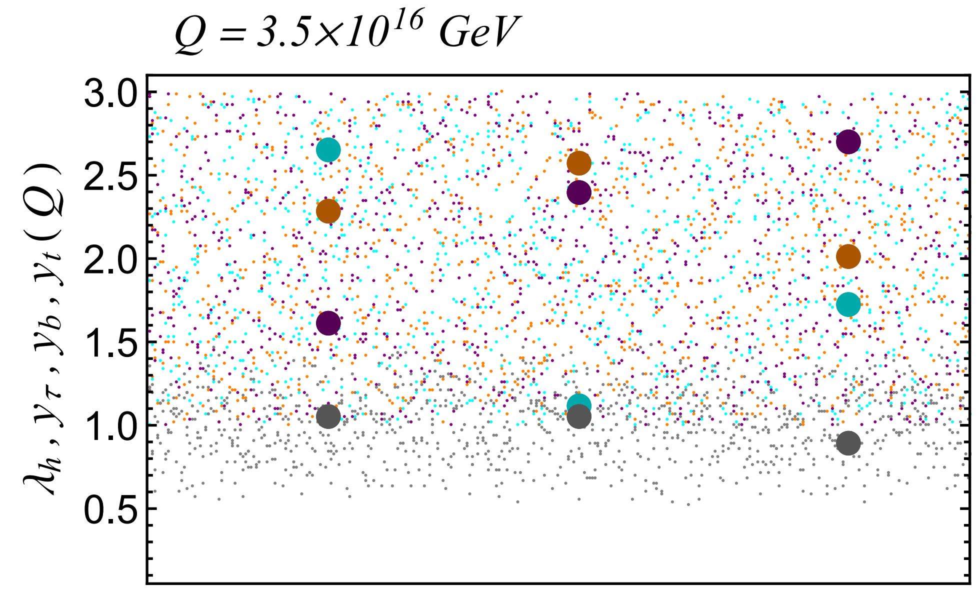
GUT scale

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

**MSSM+1VF**

**few** TeV




**Random unrelated boundary conditions:**

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

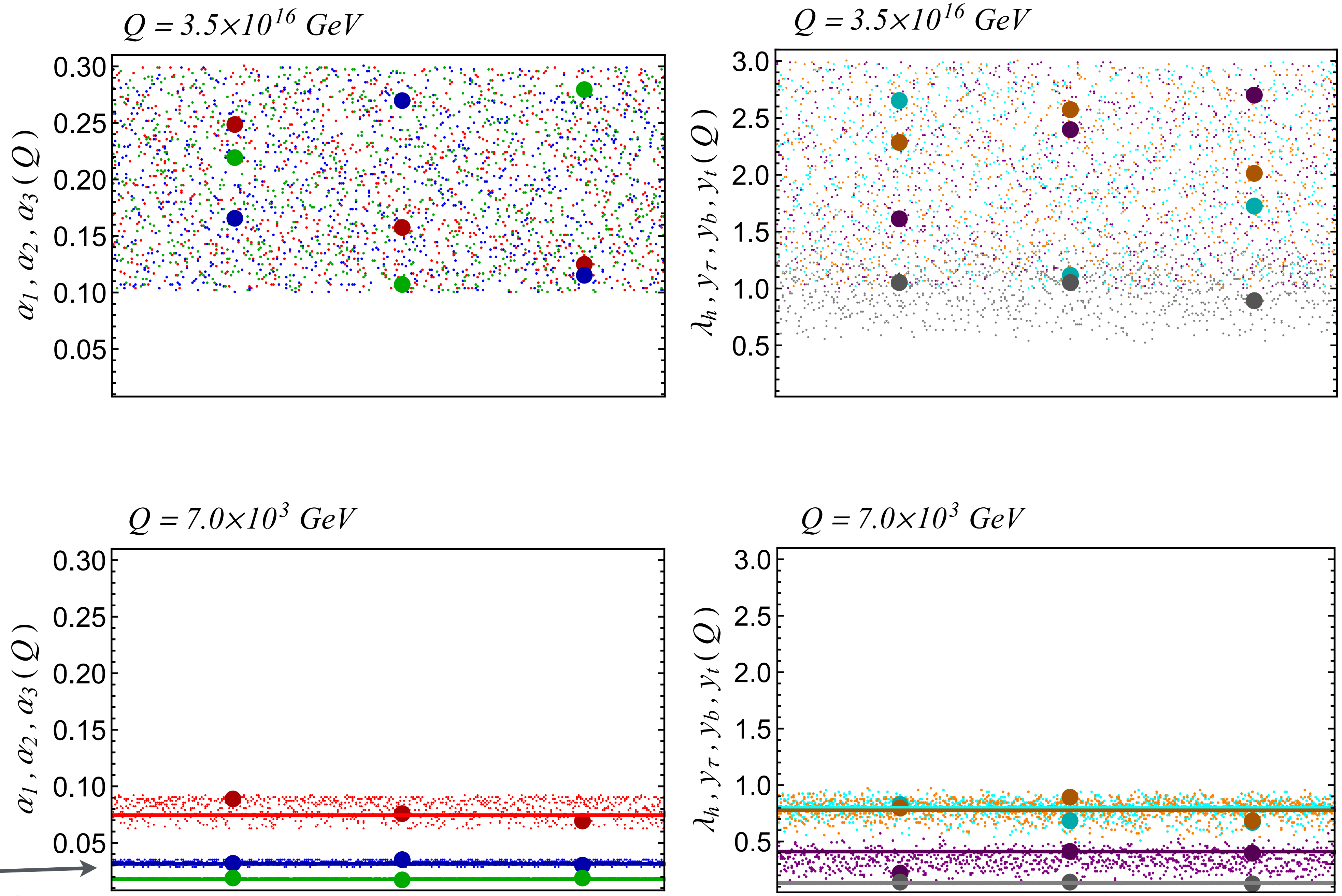
(larger values of couplings do not affect results significantly)

**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:** $\tan\beta = 40$

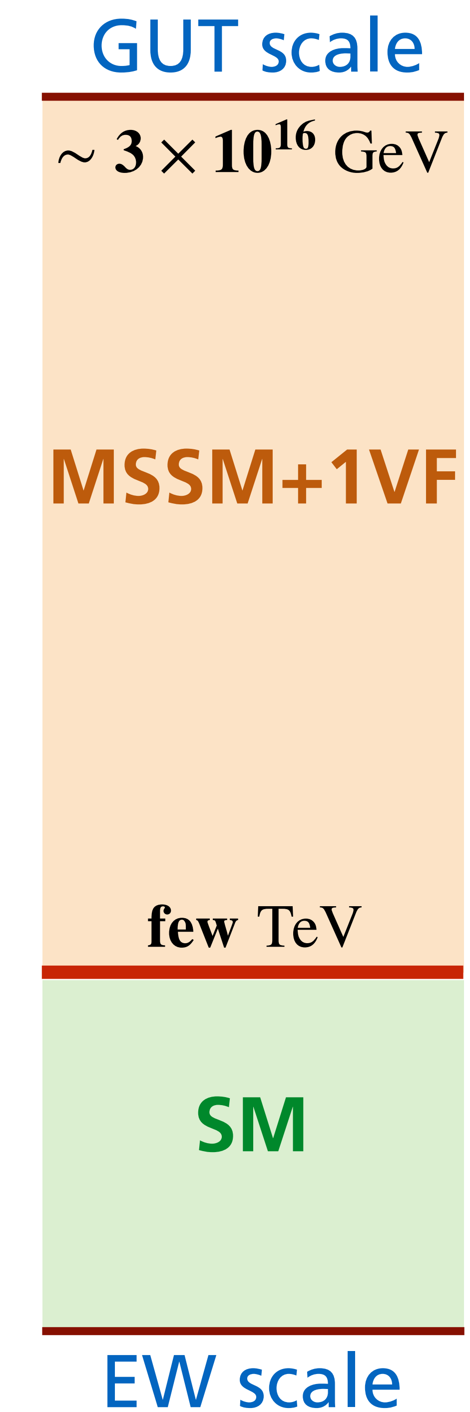
# Big picture

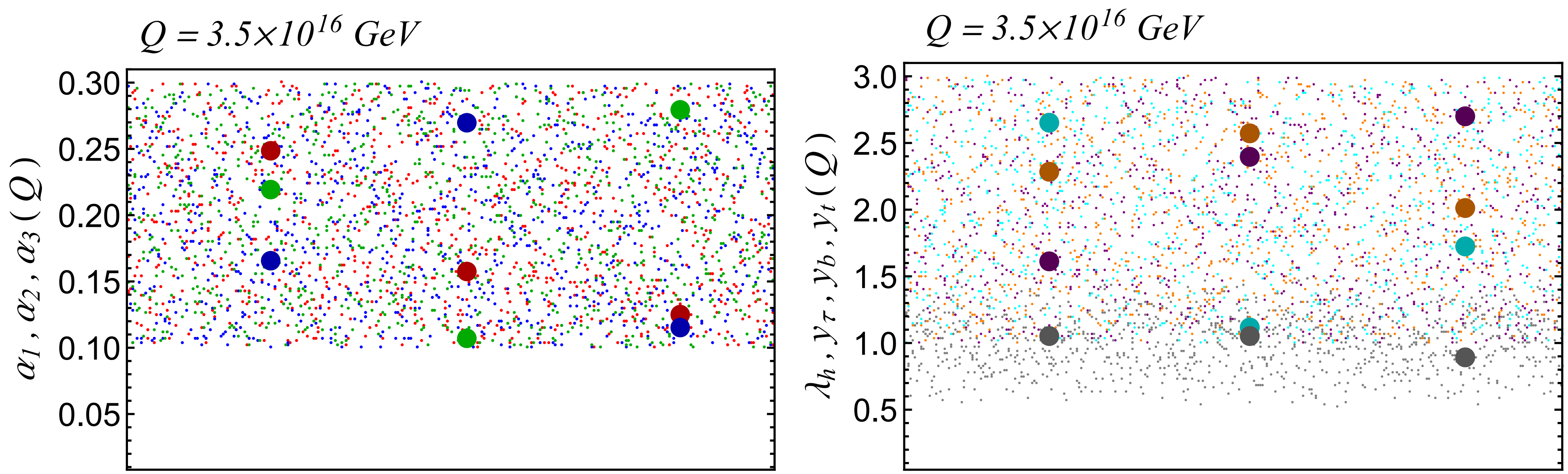




solid line are SM measured values evolved to a given scale; they include SUSY threshold corrections assuming $\tan\beta = 40$

**Distinctive pattern of couplings emerges**

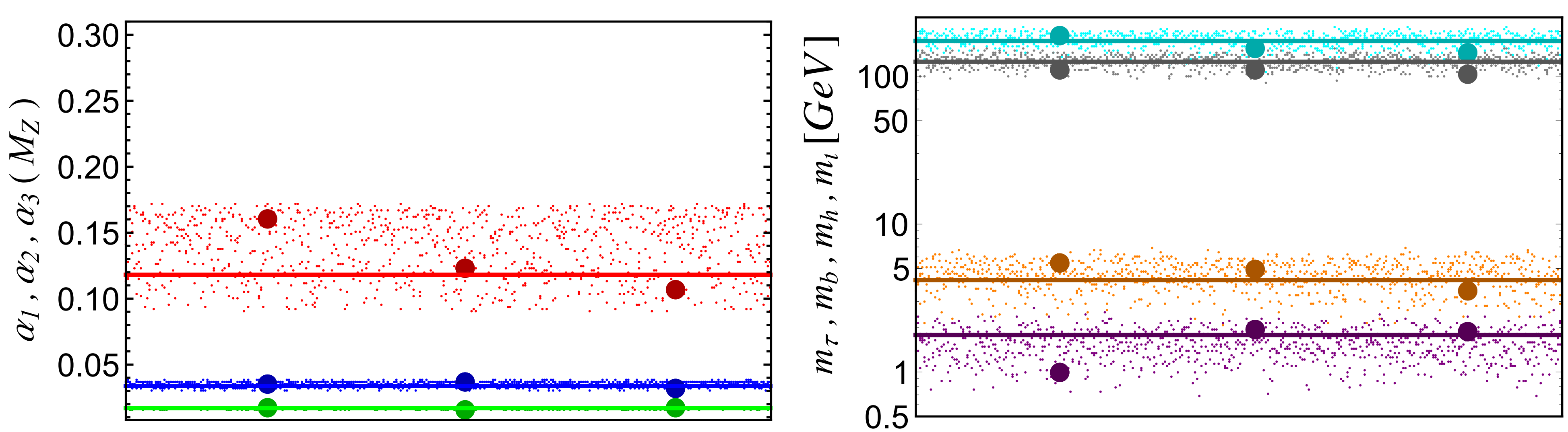
# Big picture




**GUT: Random boundary conditions**

**EW: familiar pattern of couplings and masses**



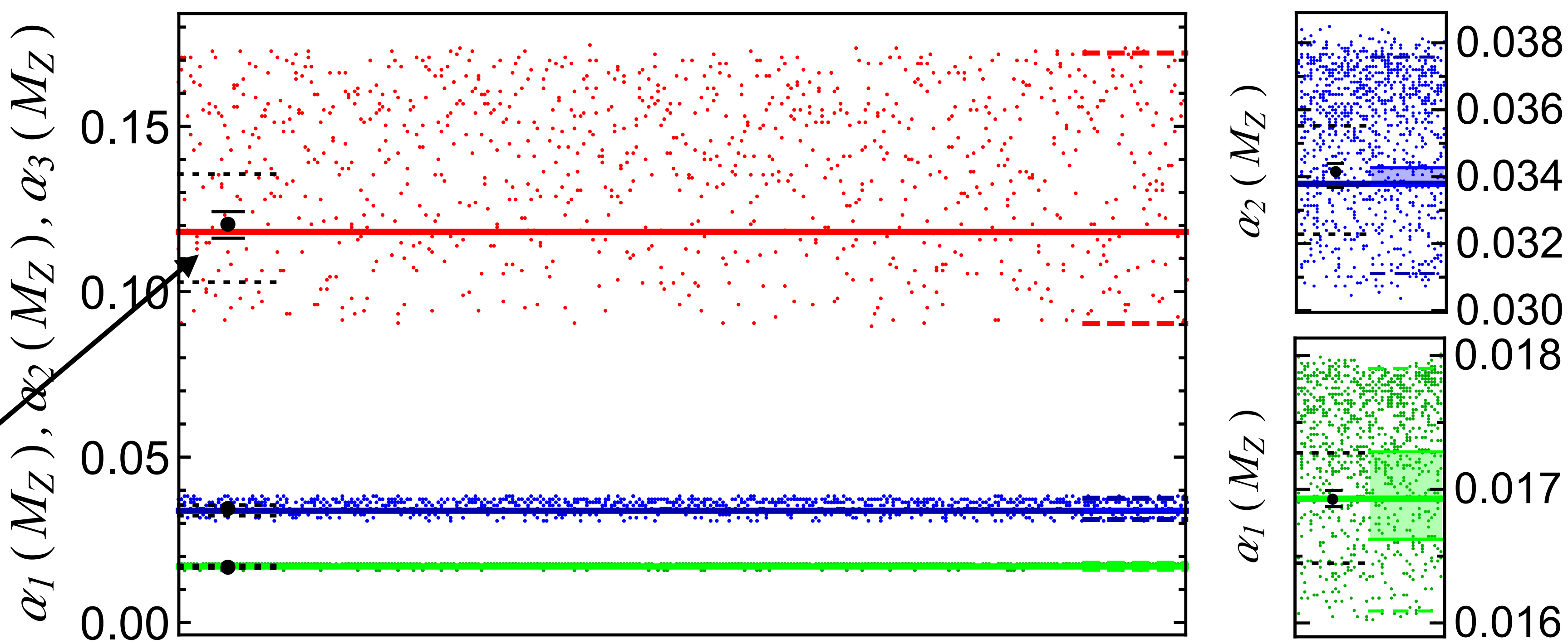
# Predicted pattern of gauge couplings

## In the MSSM+1VF:

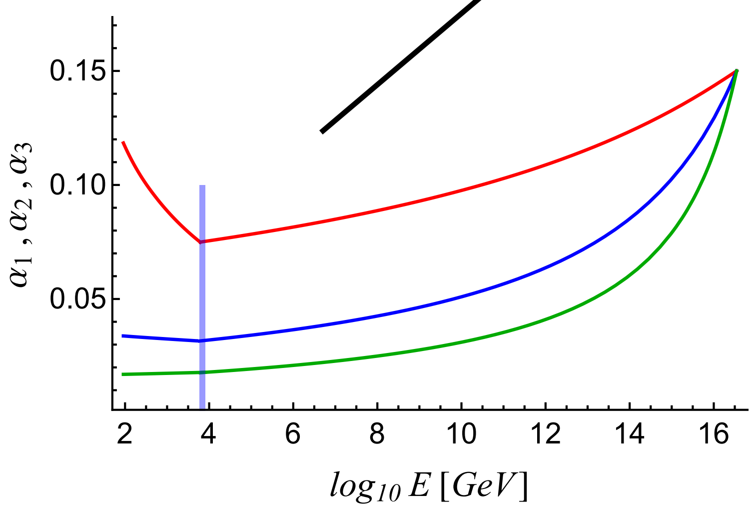
$\alpha_1(M_G), \alpha_2(M_G), \alpha_3(M_G) \in [0.1, 0.3]$

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

- - - universal b.c. M optimized for $\alpha_3$



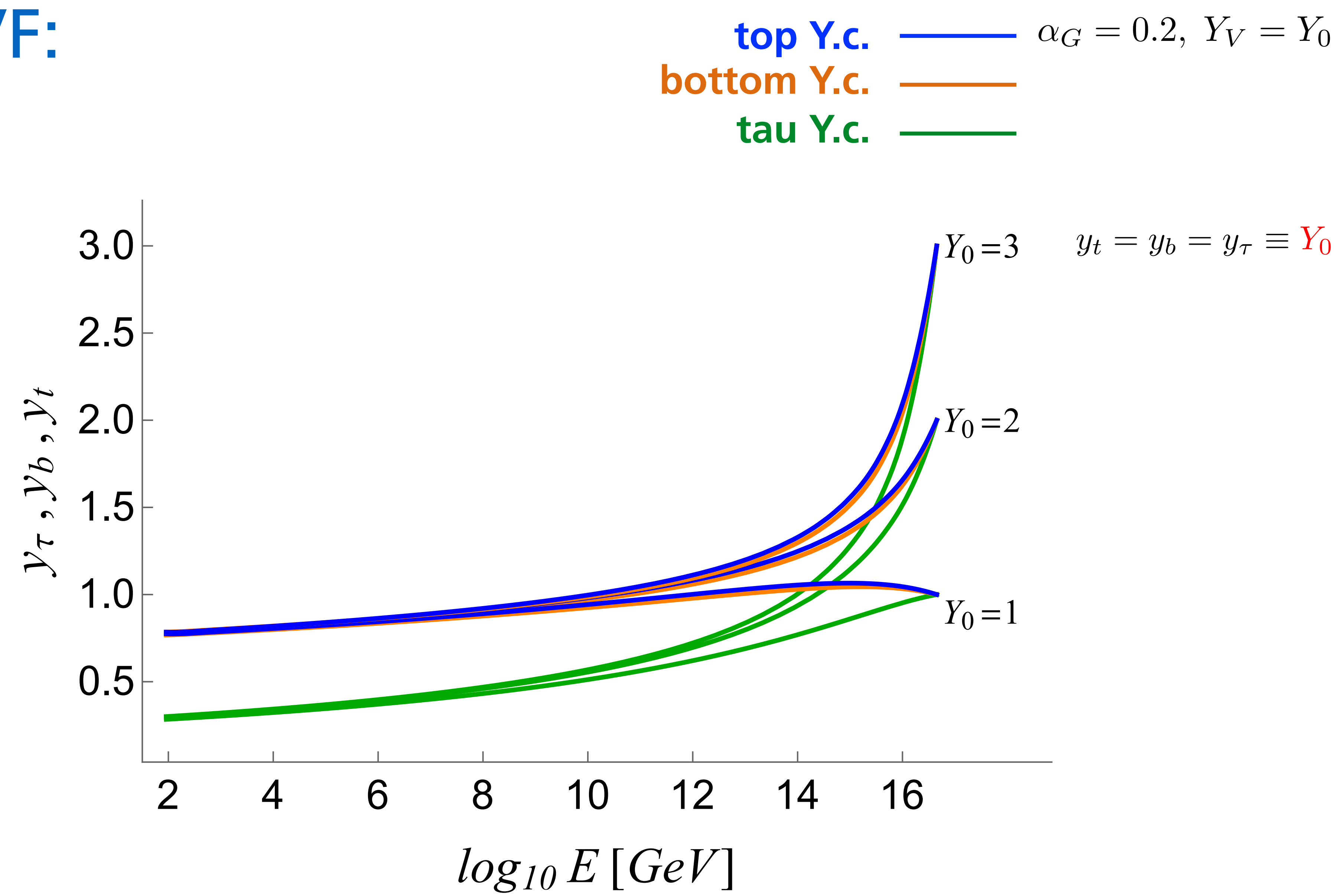

20% variations of M ——
and all couplings - - - -




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

# 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**

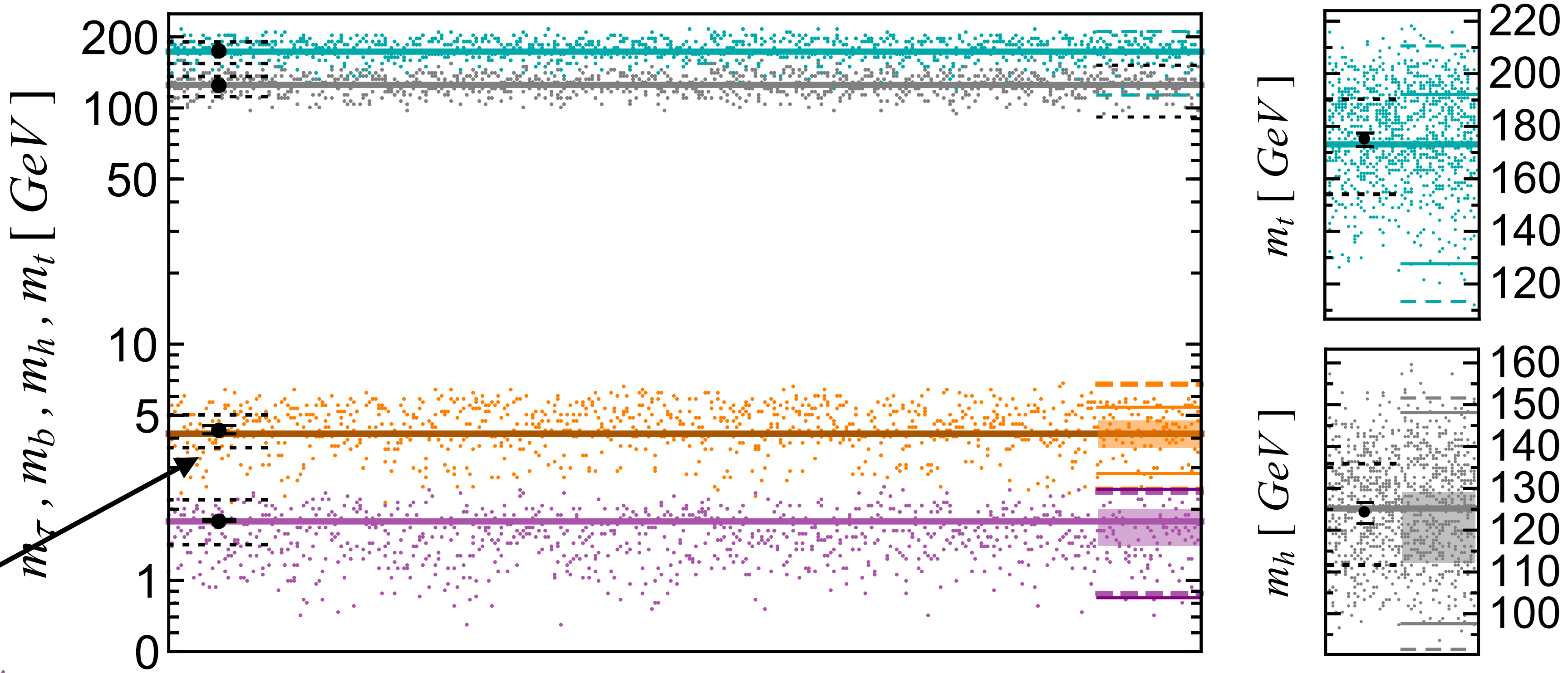
# Predicted pattern of fermion masses

## In the MSSM+1VF:

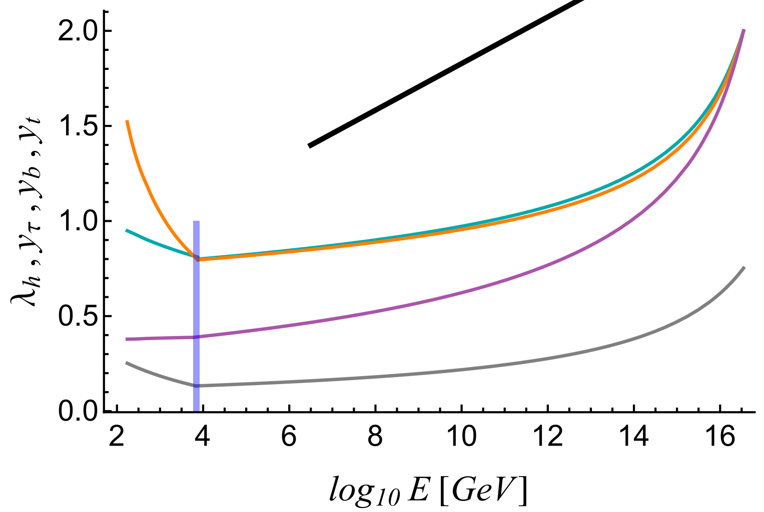
$\alpha_1(M_G), \alpha_2(M_G), \alpha_3(M_G) \in [0.1, 0.3]$ $y_t(M_G), y_b(M_G), y_\tau(M_G), Y_V(M_G) \in [1,3]$

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

universal b.c. $Y_V$ optimized for $m_t$



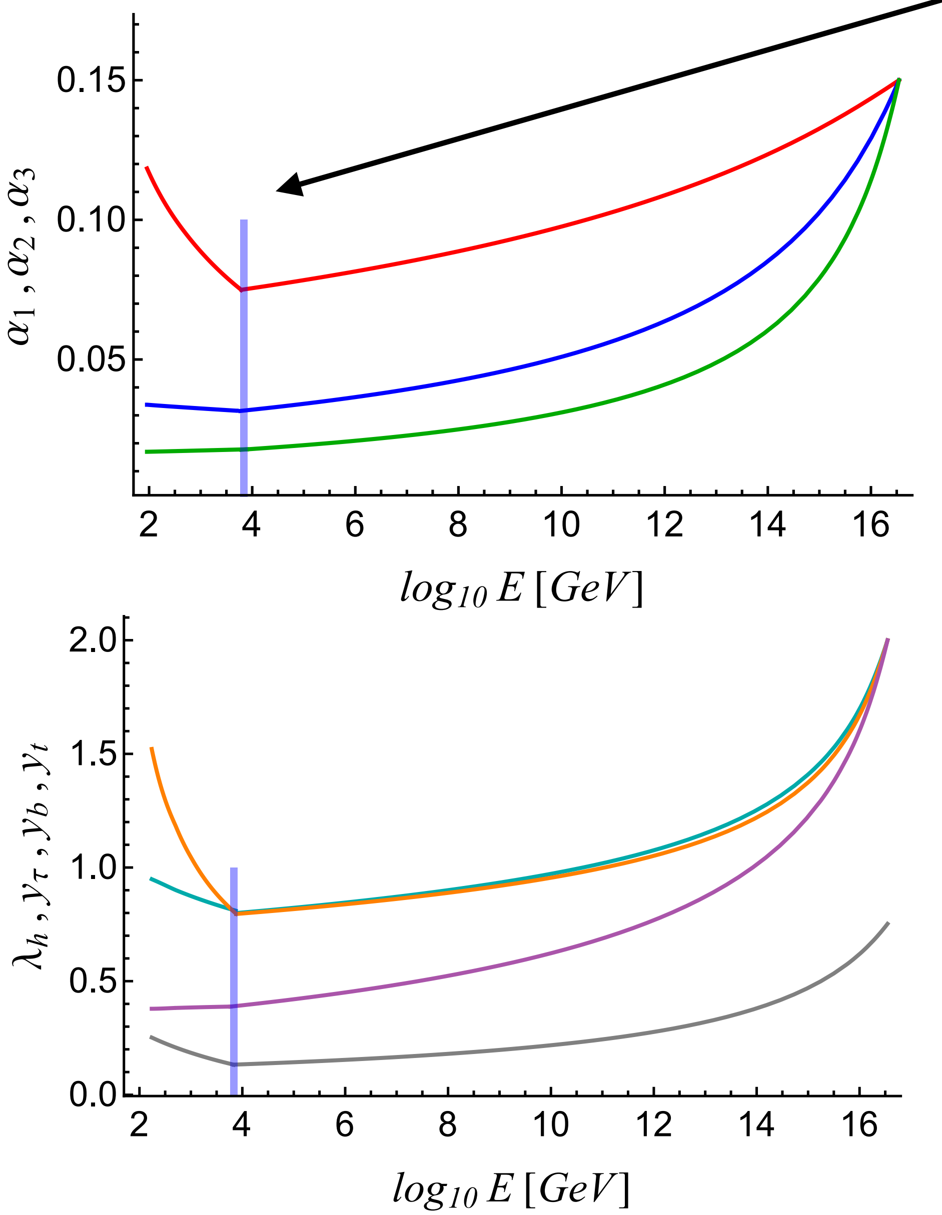

20% variations of M ——
and all couplings - - - -



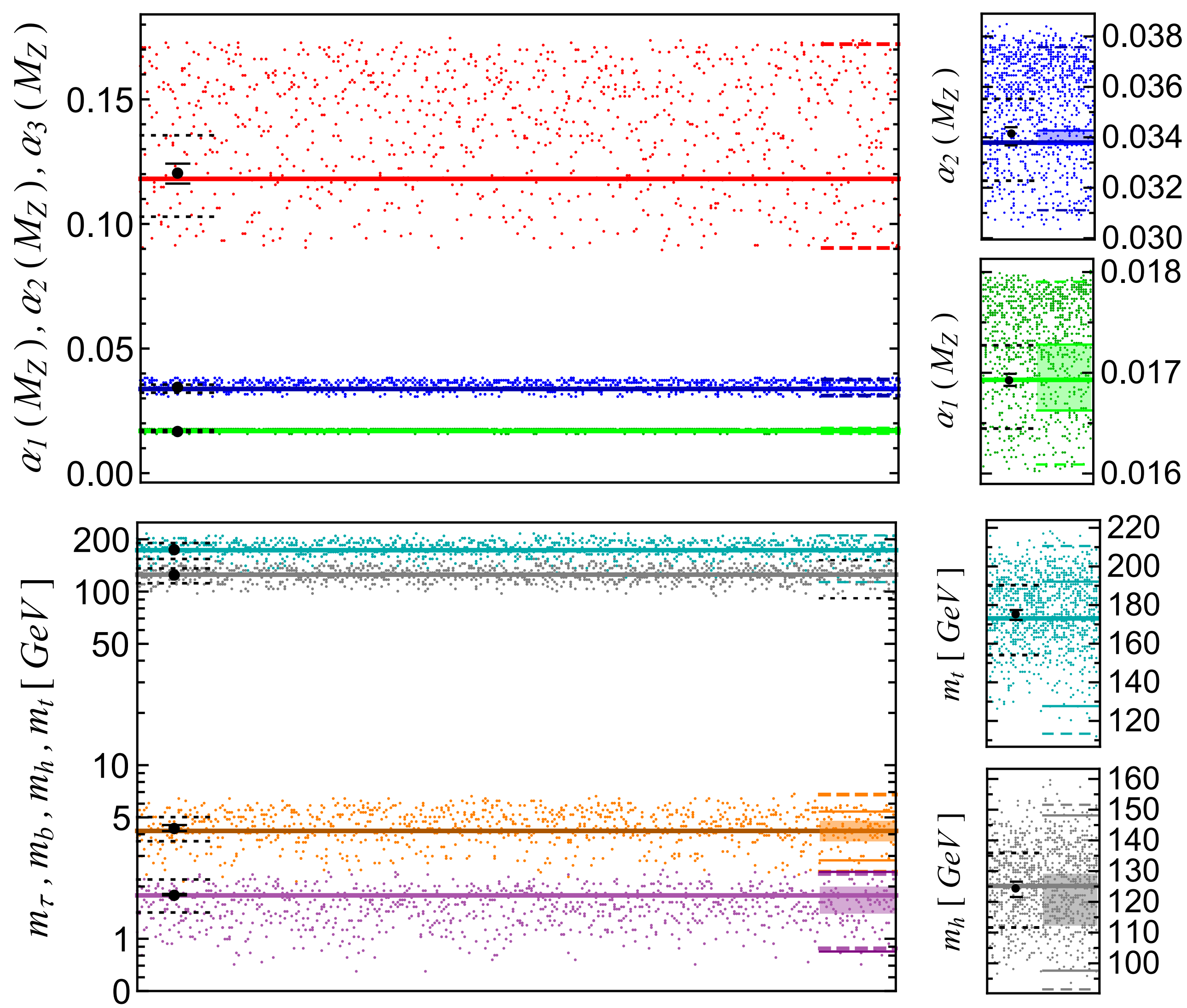

**SUSY corrections at M assume all superpartners at the same scale, zero A-terms and** $\mu = -\sqrt{2} M_{SUSY}$

# 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:**




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



# 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 size of Yukawa couplings, all 7 observables are within 11% (or 7.5%) from their measured values.**

# The Electroweak scale

In the MSSM, the EW scale is related to soft SUSY breaking masses and the μ-term, e.g:

$$M_Z^2 \simeq -1.9\mu^2 + 5.9M_3^2 - 1.2m_{H_u}^2 + 1.5m_{\tilde{t}}^2 - 0.8A_t M_3 + 0.2A_t^2 + \ldots$$

boundary conditions at the GUT scale and $\tan\beta = 10$

**Prediction of SUSY:**

$$M_Z^2 \leq M_{SUSY}^2$$

**includes the EW scale arbitrarily below the SUSY scale.**

**However, any hierarchy is viewed as unnatural or fine-tuned.**

**based on intuition that contributions of two parameters precisely cancel only if parameters are carefully chosen/tuned**

**usually demonstrated by small probability in scans, sensitivity measures…**

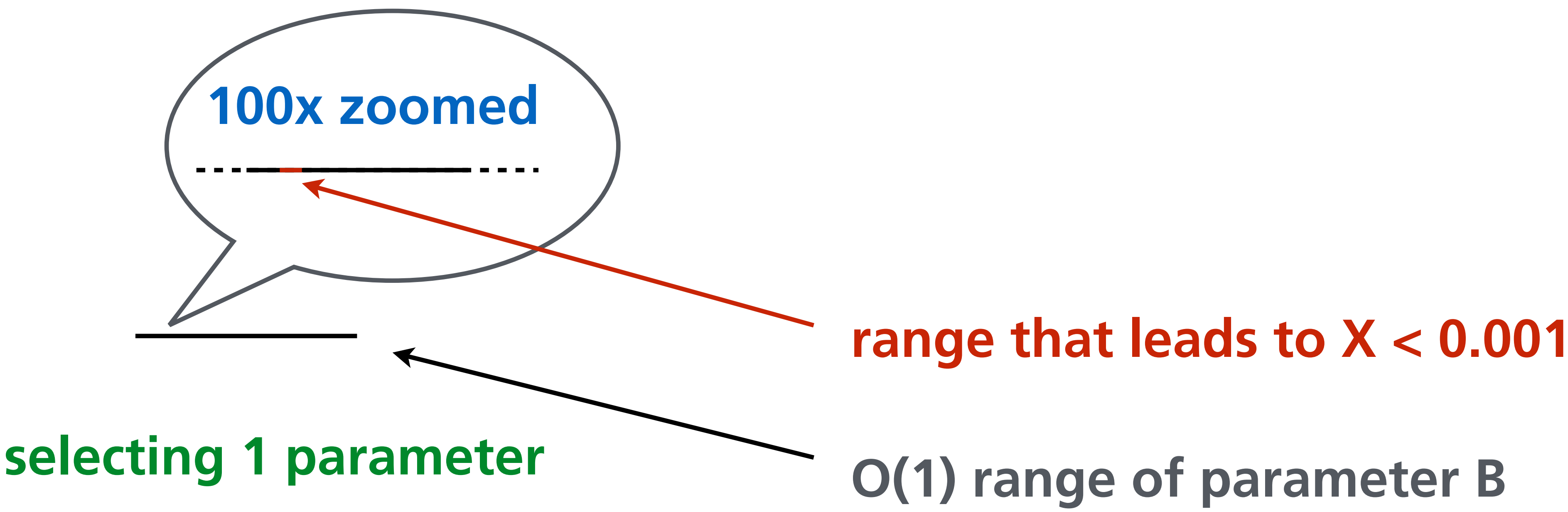
# Model parameter selection

In a model with two parameters: $A$, $B \sim 1$ contributing to $X$,

$$X = A - B$$

in order to get $X < 0.001$, for any $A$, the $B$ has to carefully selected:

e.g.: $A = 0.963$
$B = 0.962$



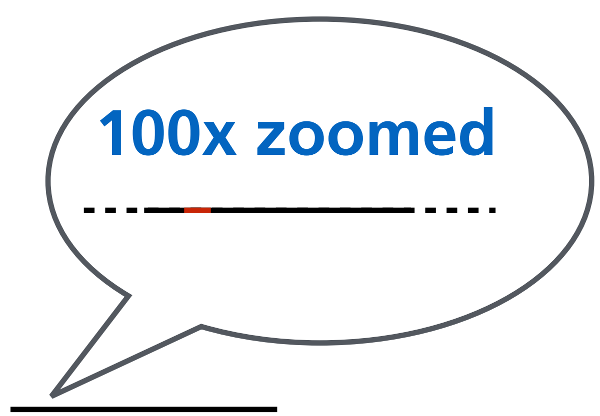

**The range that leads to the desired outcome is not visible!**

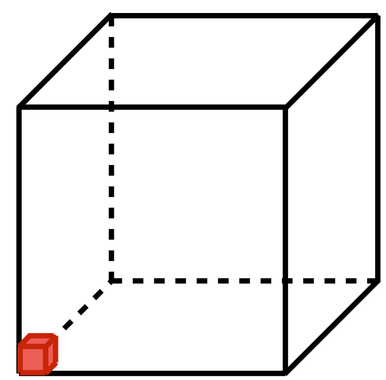
# Model parameter selection

In a model with more O(1) parameters contributing to X,

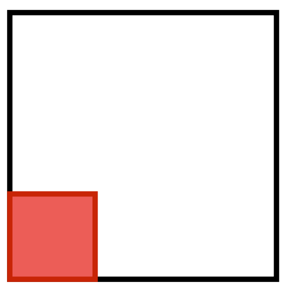
$$X = A - B + C - D + \ldots$$

in order to get $X < 0.001$, no parameter has to be carefully selected:



2d view, the same for
any two parameters



...

selecting 1 parameter

3 parameters

6 parameters

about 1/3 of the range of each
parameter leads to $X < 0.001$

effective range that leads to
$X < 0.001$ is clearly visible

Making just ~3 random choices for each parameter
will necessarily produce an outcome with $X<0.001$!

# Small EW scale is completely ordinary

In SUSY models there are many parameters significantly contributing to the electroweak scale, e.g:

$$M_Z^2 \simeq -1.9\mu^2 + 5.9M_3^2 - 1.2m_{H_u}^2 + 1.5m_{\tilde{t}}^2 - 0.8A_tM_3 + 0.2A_t^2 + \dots$$

boundary conditions at the GUT scale and $\tan\beta = 10$
(these are additional implicit parameters)

and quite a few even in constrained versions.

$$\sqrt[N]{\frac{M_{SUSY}^2}{M_Z^2}} \simeq n$$

**Just a few (n) random choices of a handful (N) of SUSY parameters will produce an outcome with the EW scale 1 - 2 orders of magnitude smaller.**

**No parameter has to be carefully chosen!**

**What is "special/extreme/unexpected/tuned" based on our intuition, is completely ordinary in more complex models.**

**for more discussion, see:**

RD, arXiv:1611.03188 ; RD and N. McGinnis, arXiv:1705.01910

# 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**
- **additional motivation for more complex UV embeddings besides simple SU(5) or SO(10), e.g. Pati-Salam, flipped SU(5), …**