Insensitive Unification of Gauge Couplings, Muon g-2 and Higgs decays

Radovan Dermisek

Indiana University, Bloomington

R.D., arXiv:1204.6533 [hep-ph], arXiv:1212.3035 [hep-ph]

R.D. and A. Raval, arXiv:1305.3522 [hep-ph]

Snowmass on the Pacific, KITP, May 30, 2013

Motivation

- Natural EWSB ship has sailed...

Motivation and Outline

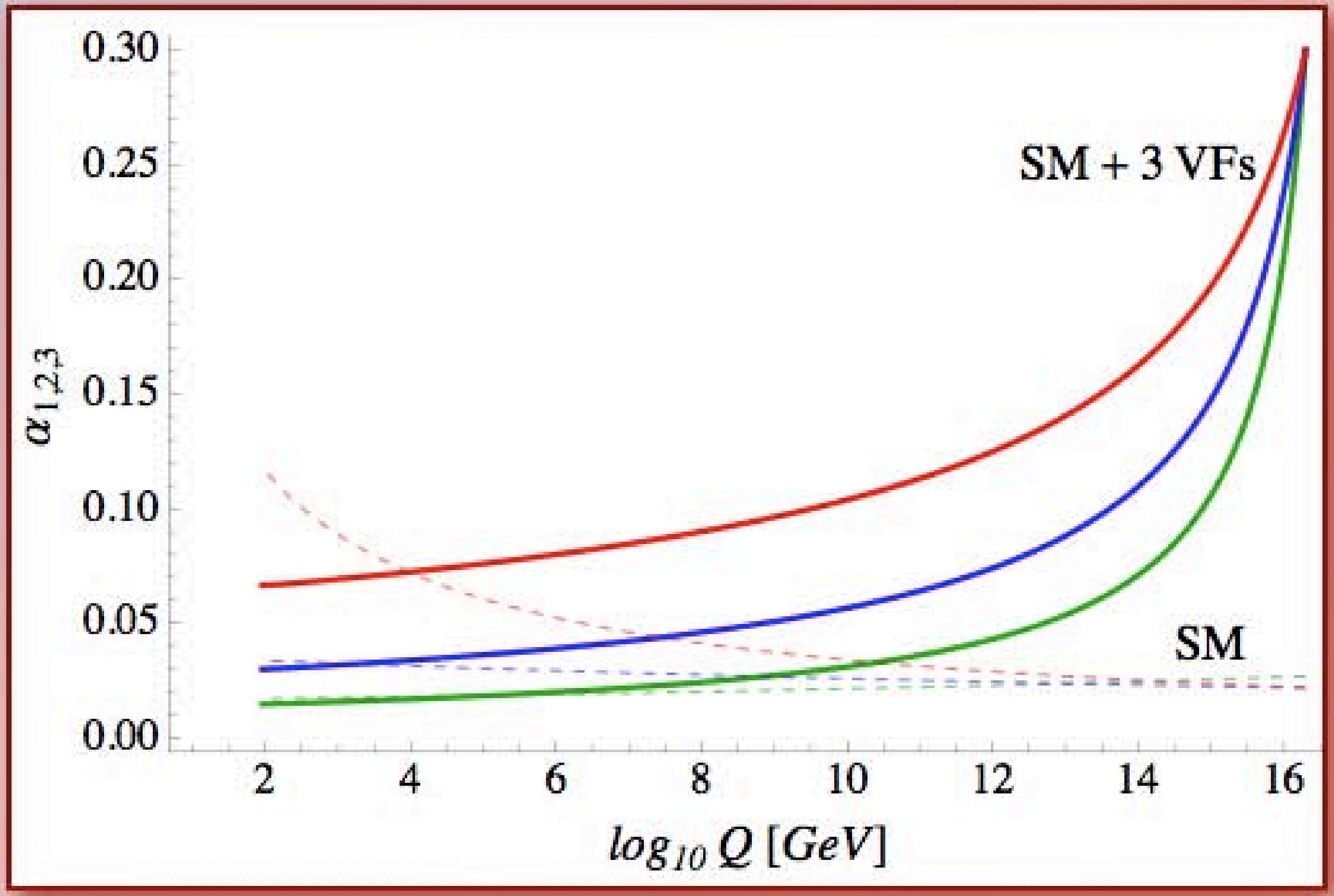
- **Natural EWSB ship has sailed...**
- **Just the standard model? (possible but not satisfactory)**

Ignoring the hierarchy problem, what simple extensions of the SM provide more satisfactory picture?

SM + 3 complete vector-like families (at 1 TeV - 100 TeV):

- **gauge coupling unification**
  couplings at the EW scale are highly insensitive to fundamental parameters
- **resurrects simple non-supersymmetric GUTs**
  easily avoids limits on proton lifetime,
  GUT scale can be identified with string/Planck scale
- **the electroweak minimum is stable**
  Higgs quartic coupling positive all the way to the GUT scale

Gauge couplings in the SM + 3VFs



$$b_i = (121/10,\ 29/6,\ +1)$$

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

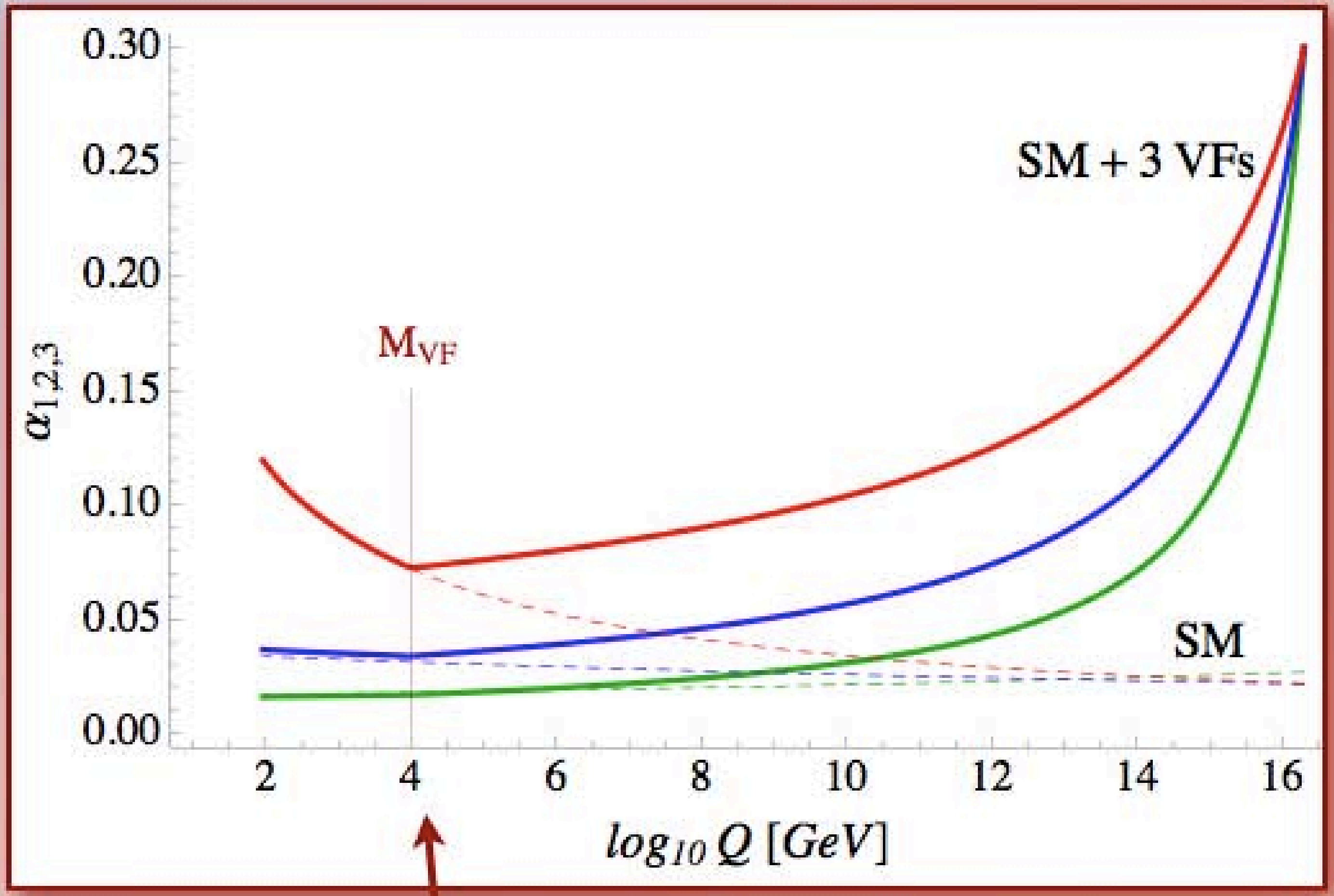
gauge couplings understood from:

- **IR fixed point predictions (two parameter free predictions)**

$$\sin^2\theta_W \equiv \frac{\alpha'}{\alpha_2 + \alpha'} = \frac{b_2}{b_2 + b'} = 0.193$$

$$\alpha_3\big|_{\alpha_{EM}^{exp}} \simeq 0.072$$

Gauge couplings in the SM + 3VFs



$$b_i = (121/10,\ 29/6,\ +1)$$

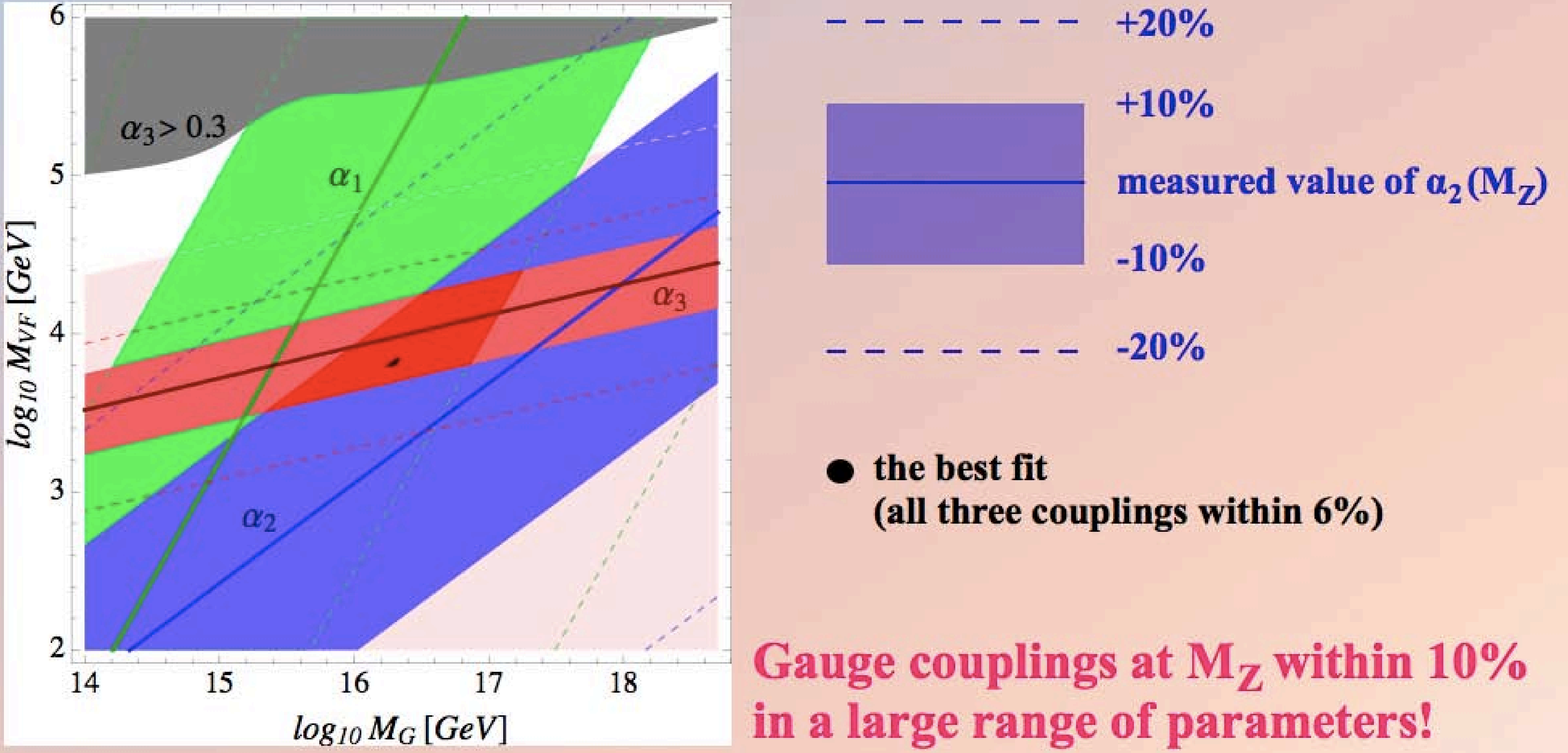
$$\alpha_i^{-1}(M_Z) = \frac{b_i}{2\pi} \ln \frac{M_G}{M_Z} + \alpha_i^{-1}(M_G)$$

gauge couplings understood from:

- **IR fixed point predictions (two parameter free predictions)**
- **threshold effects from masses of VFs**

Ranges of M_G , and M_{VF}

$\alpha_G = 0.3$ (for larger values results almost identical)



Gauge couplings at M_Z within 10% in a large range of parameters!

Realistic example

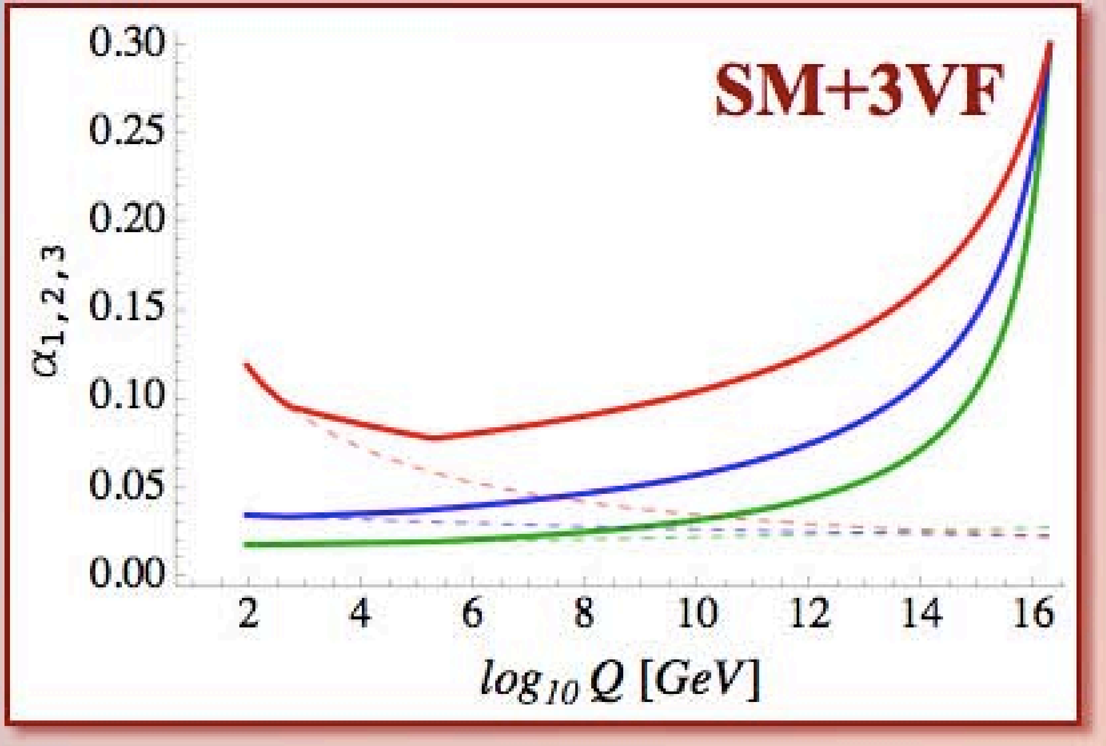
$\alpha_3(M_Z)_{exp} = 0.1184$
$\alpha_2(M_Z)_{exp} = 0.03380$
$\alpha_1(M_Z)_{exp} = 0.01695$
$\alpha_{EM}(M_Z) = 1/127.916$
$\sin^2\theta_W = 0.2313$

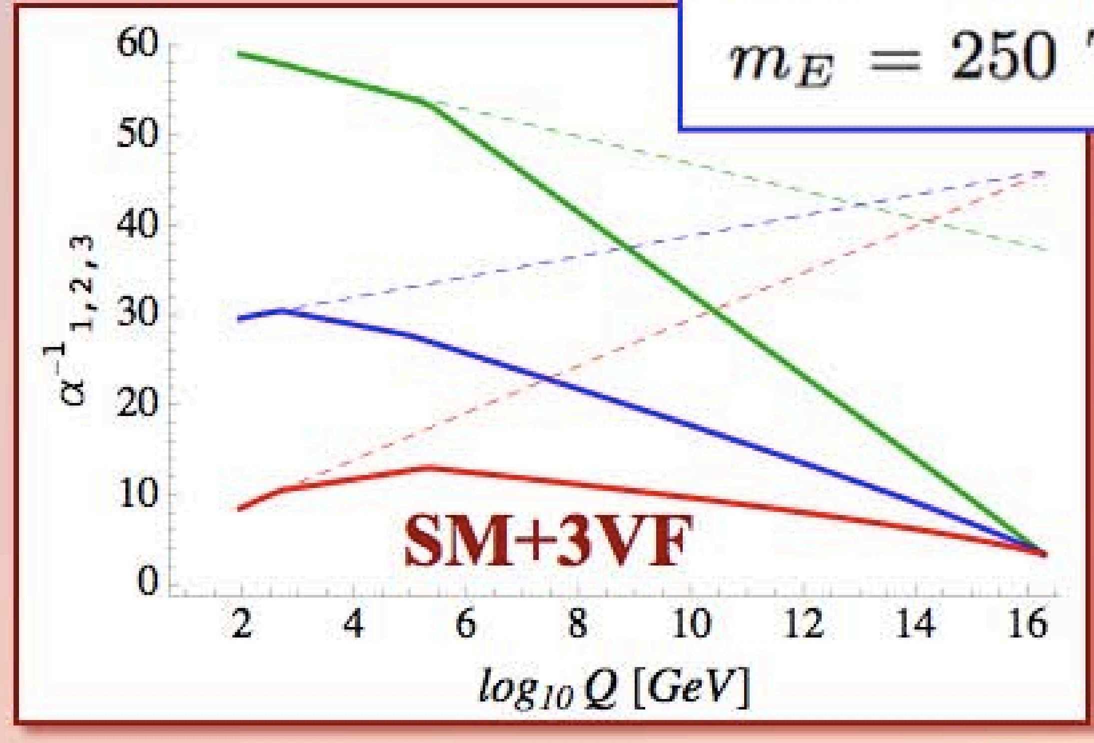
Gauge couplings reproduced (within fractions of exp. uncertainties) for :

$$m_Q = 500 \text{ GeV}$$
$$m_L = 95 \text{ TeV}$$
$$m_U = 220 \text{ TeV}$$
$$m_D = 180 \text{ TeV}$$
$$m_E = 250 \text{ TeV}$$

4 sig. figures

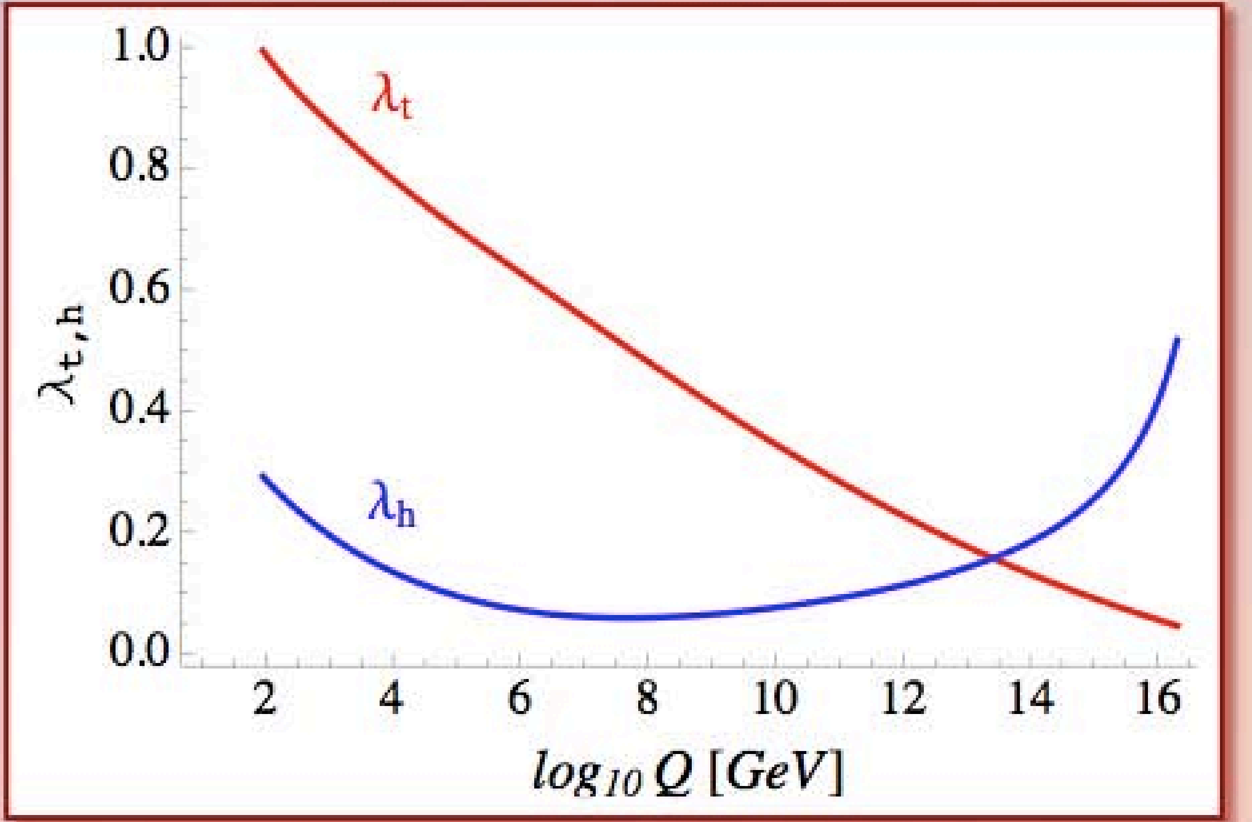
2 sig. figures





Many possible solutions!

Top Yukawa and Higgs quartic couplings



$m_H = 125$ GeV

(different textures for fermion masses compared to usual GUTs)

- **Electroweak minimum is stable!**

What else are extra VFs good for?

- **muon g-2**

K. Kannike, M. Raidal, D.M. Straub and A. Strumia, 1111.2551 [hep-ph]
R.D. and A. Raval, 1305.3522 [hep-ph]

$$\Delta a_\mu = a_\mu^{exp} - a_\mu^{SM} = 2.7 \pm 0.80 \times 10^{-9}$$

- **anomalies in Z-pole observables $\mathbf{A^b_{FB}}$ and $\mathbf{A_e}$**

D. Choudhury, T.M.P. Tait and C.E.M. Wagner, hep-ph/0109097
R.D., S.G. Kim and A. Raval, 1105.0773 [hep-ph], 1201.0315 [hep-ph]
B. Batell, S. Gori and L.T. Wang 1209.6382 [hep-ph]

- **$h \rightarrow \gamma\gamma$, ...**

A. Joglekar, P. Schwaller and C.E.M. Wagner, 1207.4235 [hep-ph]
N. Arkani-Hamed, K. Blum, R.T. D'Agnolo and J. Fan, 1207.4482 [hep-ph]
L.G. Almeida, E. Bertuzzo, P.A.N. Machado and R.Z. Funchal, 1207.5254 [hep-ph]
J. Kearney, A. Pierce and N. Weiner, 1207.7062 [hep-ph]

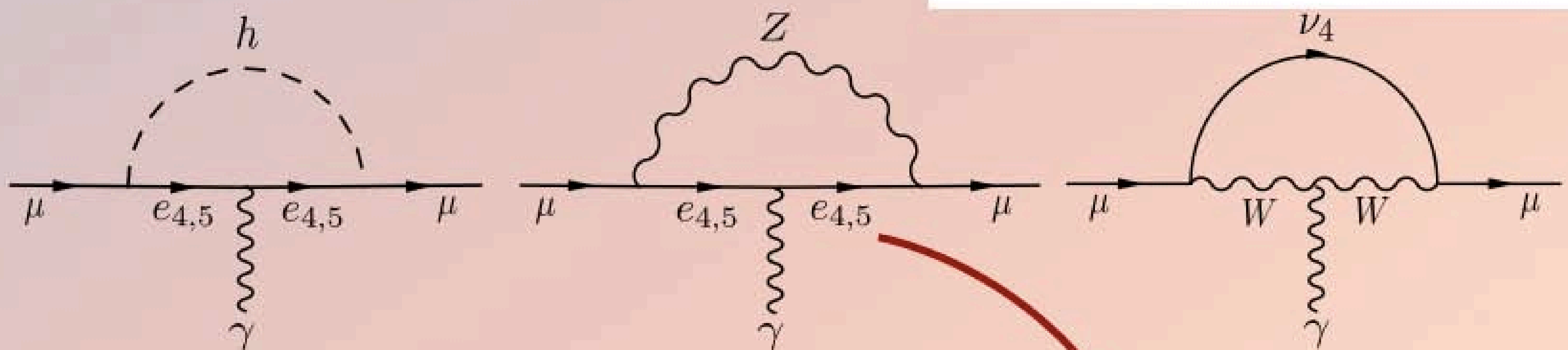
Muon g-2

K. Kannike, M. Raidal, D.M. Straub and A. Strumia, 1111.2551 [hep-ph]

R.D. and A. Raval, 1305.3522 [hep-ph]

$$\mathcal{L} \supset -\bar{l}_{Li} y_{ij} e_{Rj} H - \bar{l}_{Li} \lambda_i^E E_R H - \bar{L}_L \lambda_j^L e_{Rj} H - \lambda \bar{L}_L E_R H - \bar{\lambda} H^\dagger \bar{E}_L L_R$$
$$- M_L \bar{L}_L L_R - M_E \bar{E}_L E_R + h.c.,$$

$$(\bar{e}_{Li}, \bar{L}_L^-, \bar{E}_L) \begin{pmatrix} y_{ij} v & 0 & \lambda_i^E v \\ \lambda_j^L v & M_L & \lambda v \\ 0 & \bar{\lambda} v & M_E \end{pmatrix} \begin{pmatrix} e_{Rj} \\ L_R^- \\ E_R \end{pmatrix}$$



$$\delta a_\mu^Z = -\frac{g^2 m_\mu}{8\pi^2 M_W^2} \left\{ (g_L^2 + g_R^2) m_\mu F_Z(x) + g_L g_R m_f G_Z(x) \right\}$$

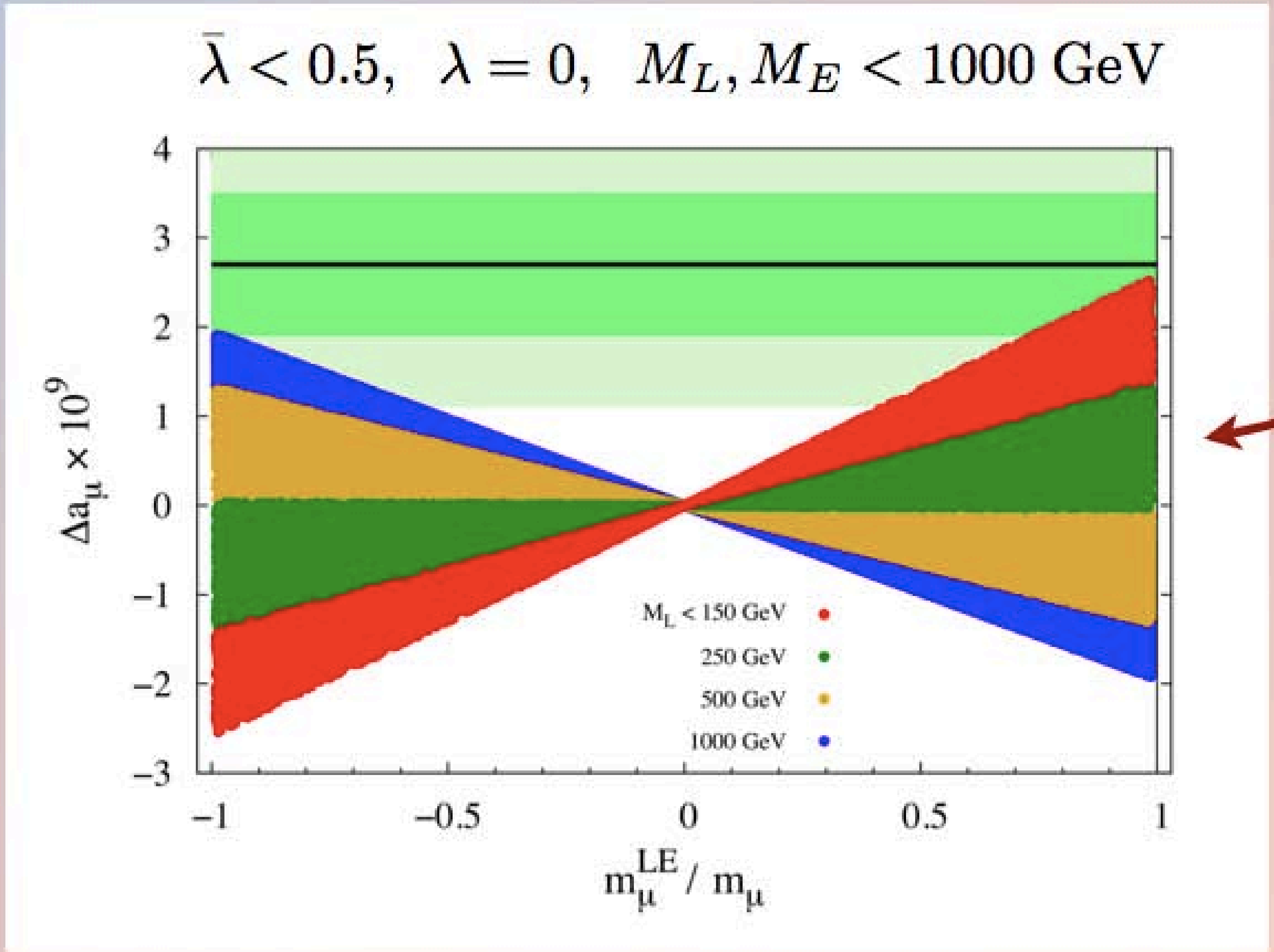
$$x = (m_f / M_Z)^2$$

integrating out vectorlike leptons:

$$\mathcal{L}_{eff} \supset -\bar{\mu}_L \left(y_\mu + \frac{\lambda^L \bar{\lambda} \lambda^E}{M_L M_E} H H^\dagger \right) \mu_R H + h.c. \longrightarrow -\left(m_\mu^H + m_\mu^{LE}\right) \bar{\mu}_L \mu_R + h.c.$$

$$\Delta a_\mu \simeq c \frac{m_\mu m_\mu^{LE}}{(4\pi v)^2} \simeq 0.85\, c \frac{m_\mu^{LE}}{m_\mu} \Delta a_\mu^{exp}$$

Random scan:



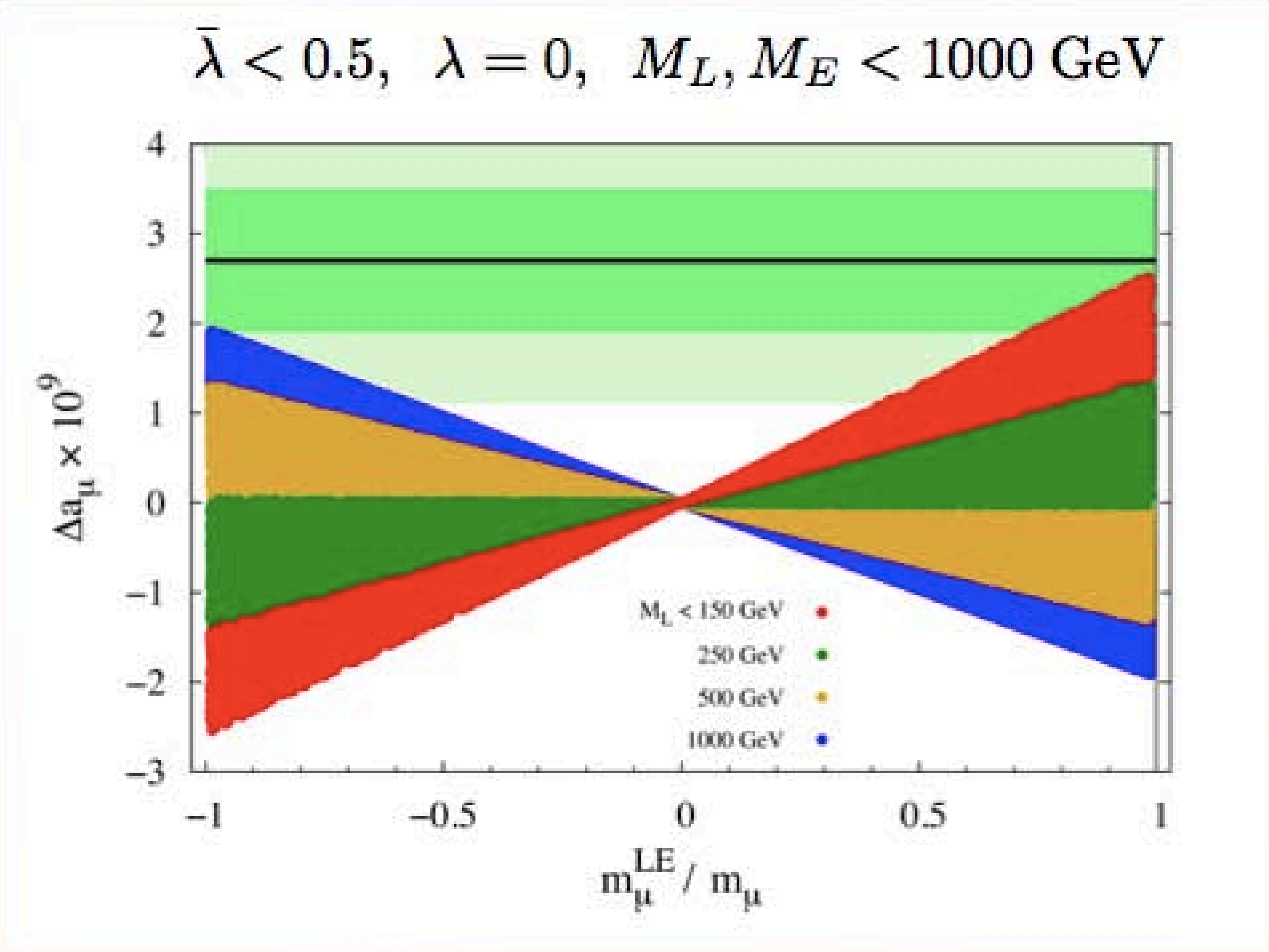
$$c = f(M_L)$$

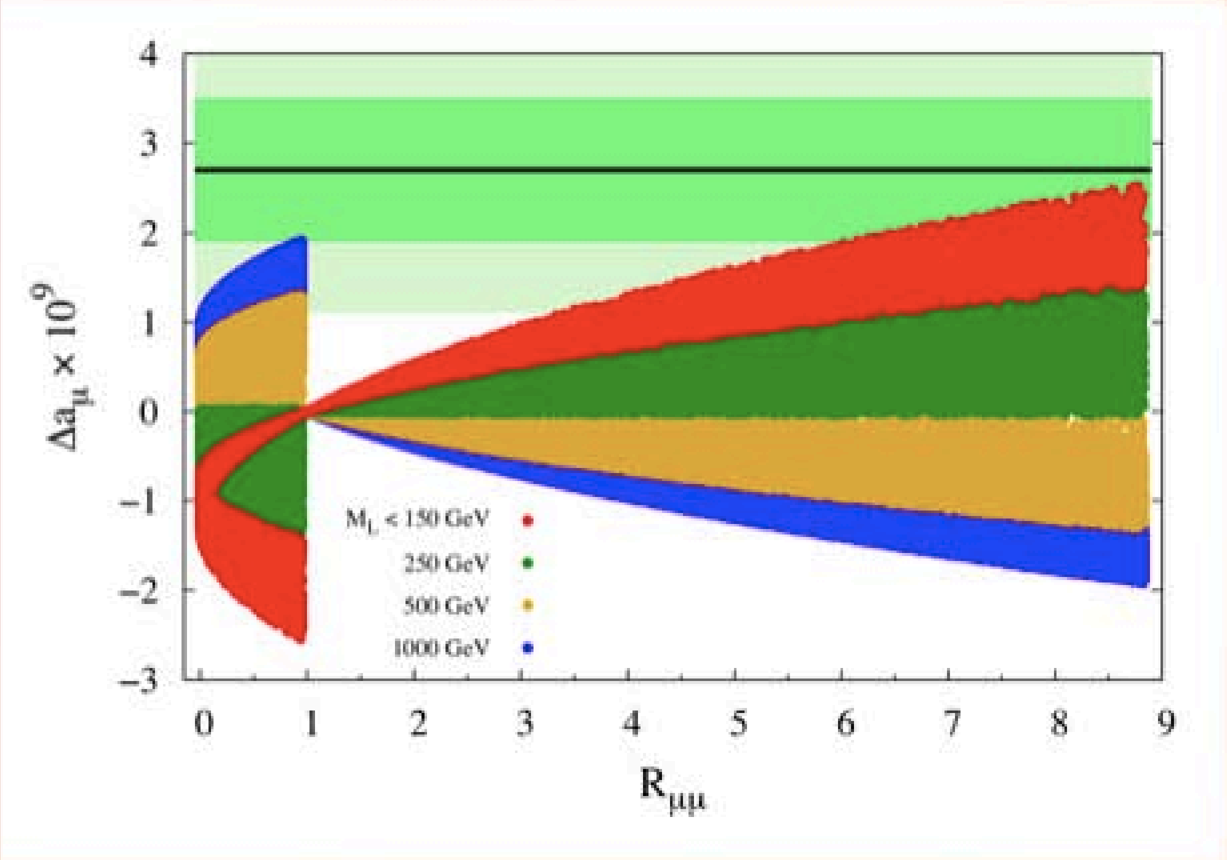
Constraints from precision EW data:

$$\frac{\lambda_E v}{M_E} < 0.03, \qquad \frac{\lambda_L v}{M_L} < 0.04$$

h → $\mu\mu$

$$\mathcal{L}_{eff} \supset -\bar{\mu}_L \left(y_\mu + \frac{\lambda^L \bar{\lambda} \lambda^E}{M_L M_E} H H^\dagger \right) \mu_R H + h.c. \longrightarrow - \left(m_\mu^H + m_\mu^{LE} \right) \bar{\mu}_L \mu_R + h.c.$$

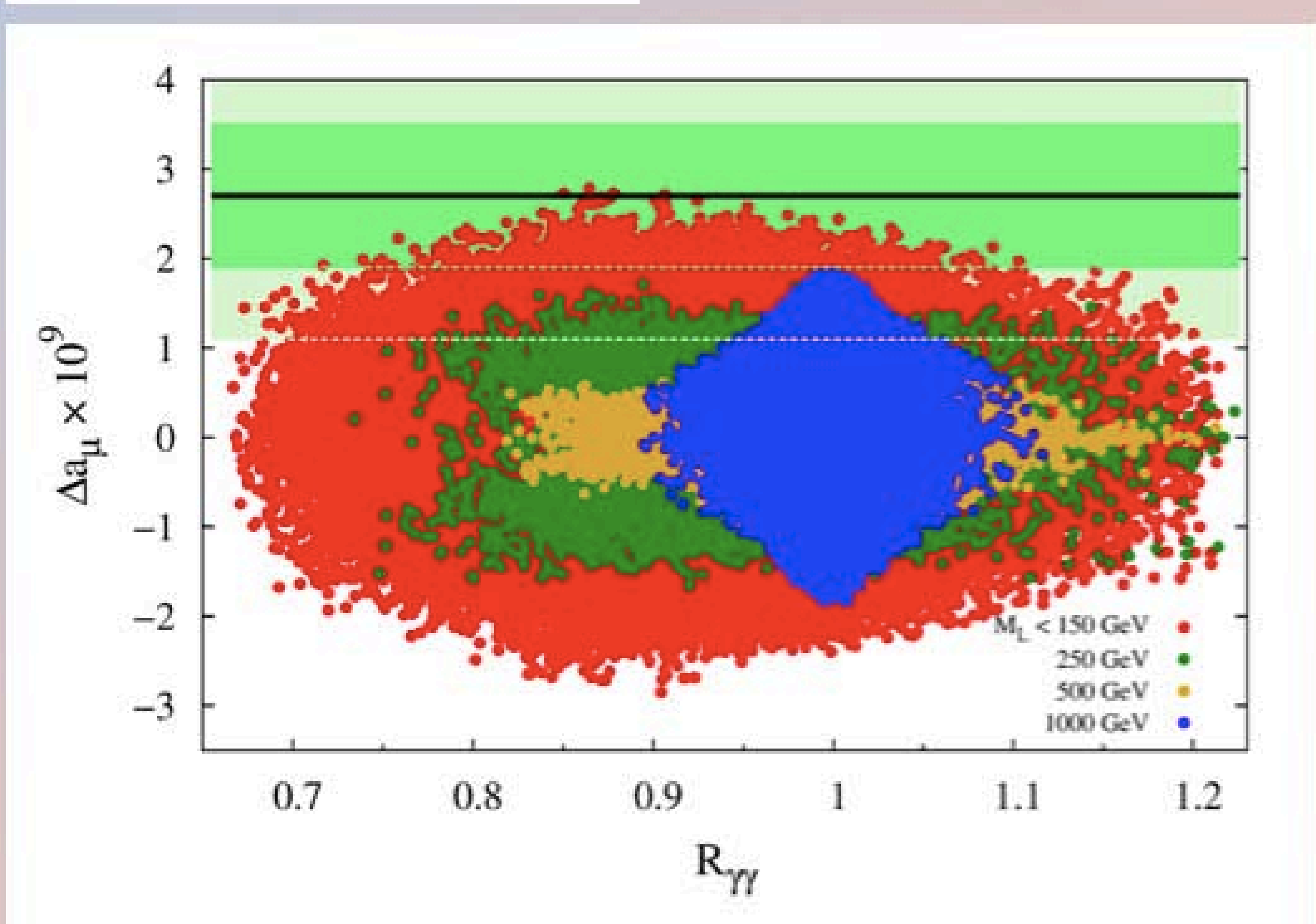


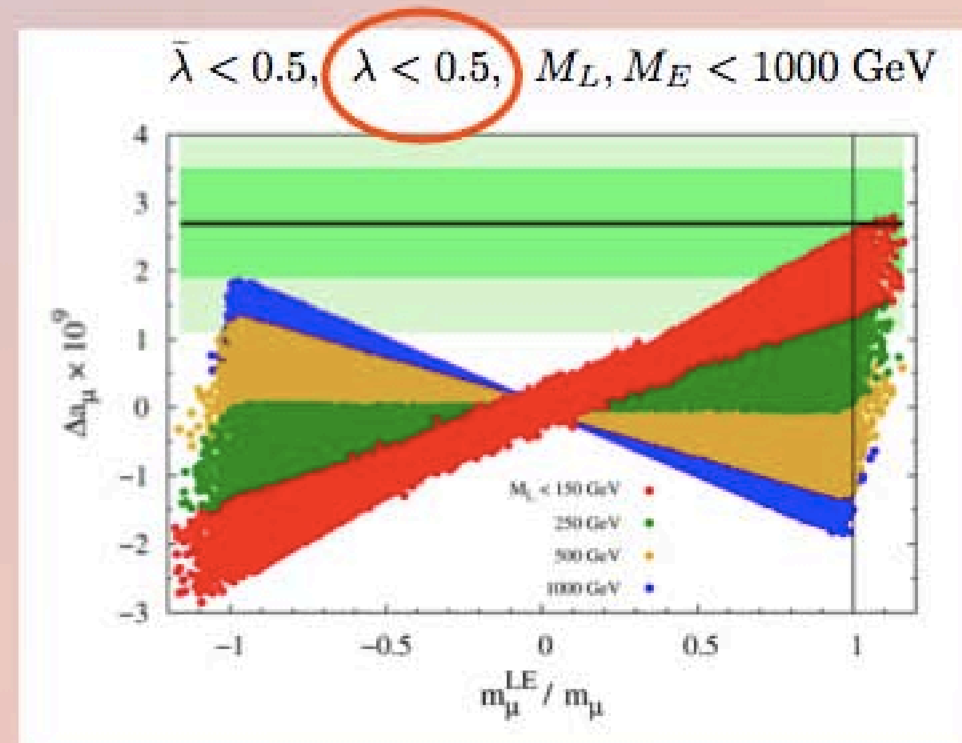


$$R_{\mu\mu} = \frac{\Gamma(h \to \mu^+ \mu^-)}{\Gamma(h \to \mu^+ \mu^-)_{SM}}$$

h → γγ

$$R_{\gamma\gamma} = \frac{\Gamma(h \to \gamma\gamma)}{\Gamma(h \to \gamma\gamma)_{SM}}$$



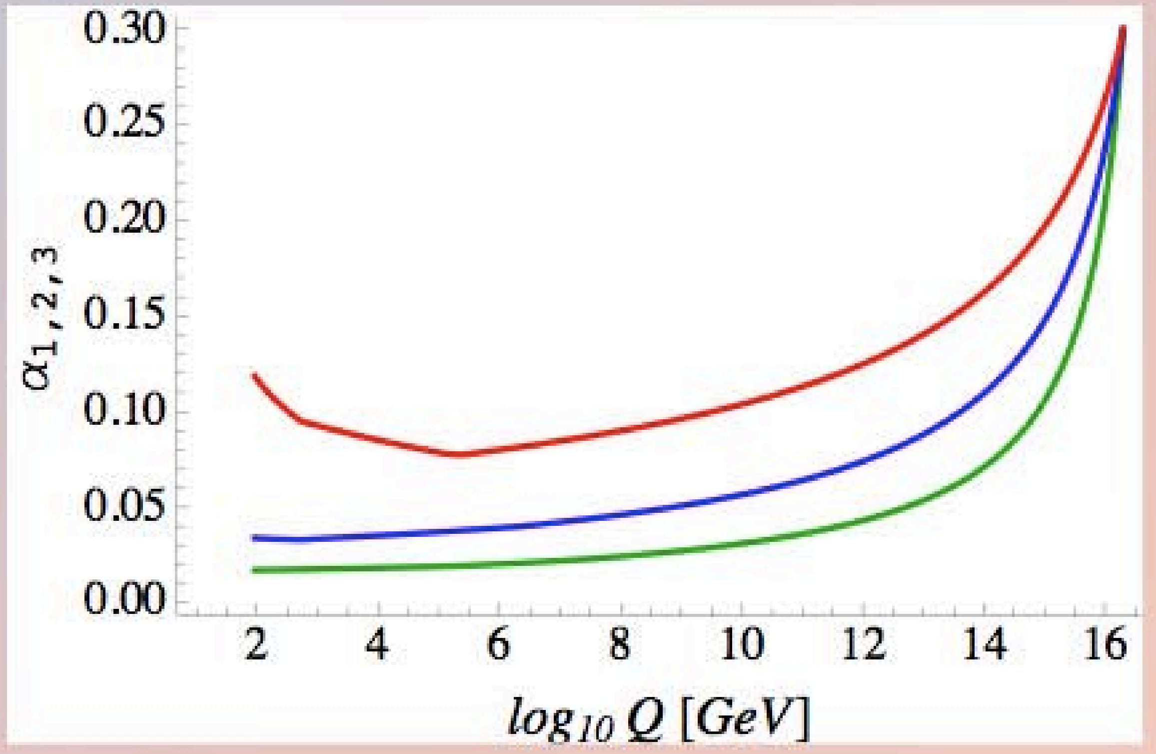


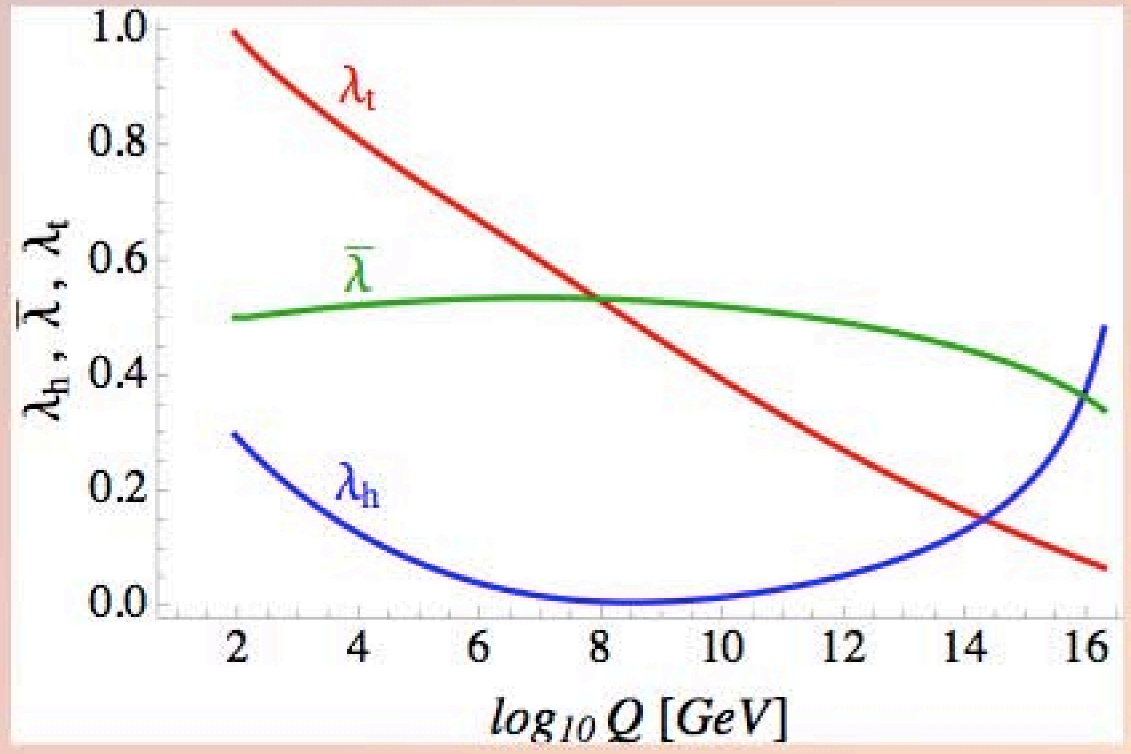
$$(\bar{e}_{Li}, \bar{L}_L^-, \bar{E}_L) \begin{pmatrix} y_{ij} v & 0 & \lambda_i^E v \\ \lambda_j^L v & M_L & \lambda v \\ 0 & \bar{\lambda} v & M_E \end{pmatrix} \begin{pmatrix} e_{Rj} \\ L_R^- \\ E_R \end{pmatrix}$$

$$\text{amplitude} \propto -\frac{\bar{\lambda}\lambda v^2}{M_L M_E - \bar{\lambda}\lambda v^2}$$

UV completion with 3VFs

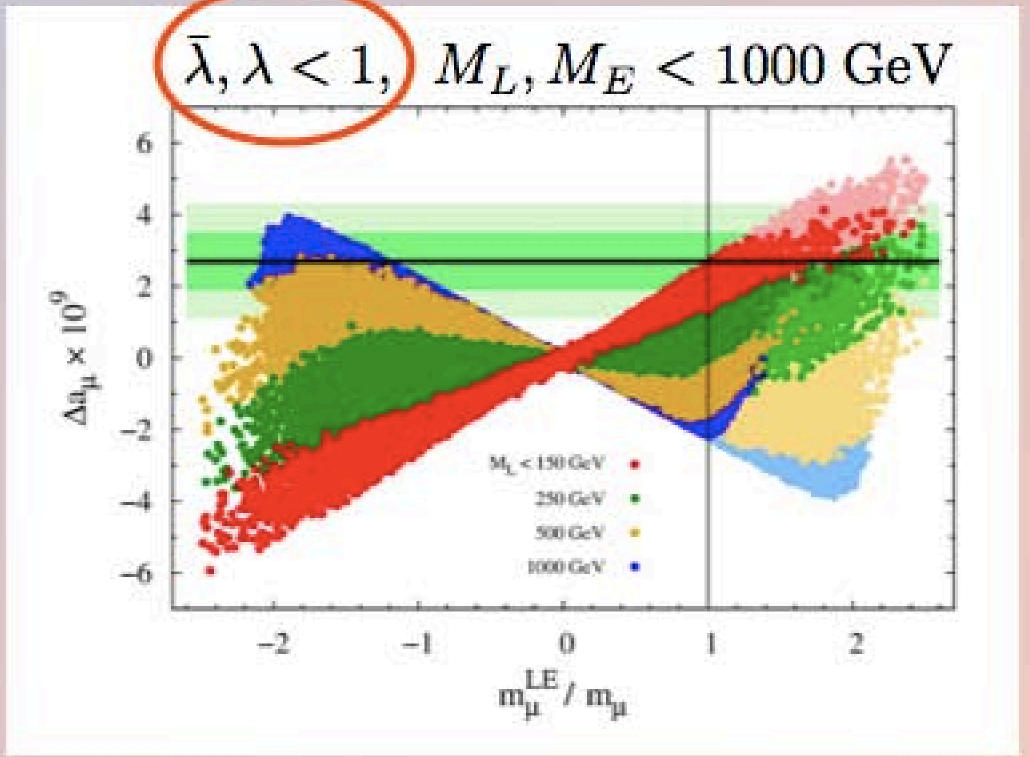
All the features of insensitive unification, including the stability of the EW minimum of the Higgs potential, with Yukawa couplings of the size needed for the explanation of the muon g-2 anomaly:

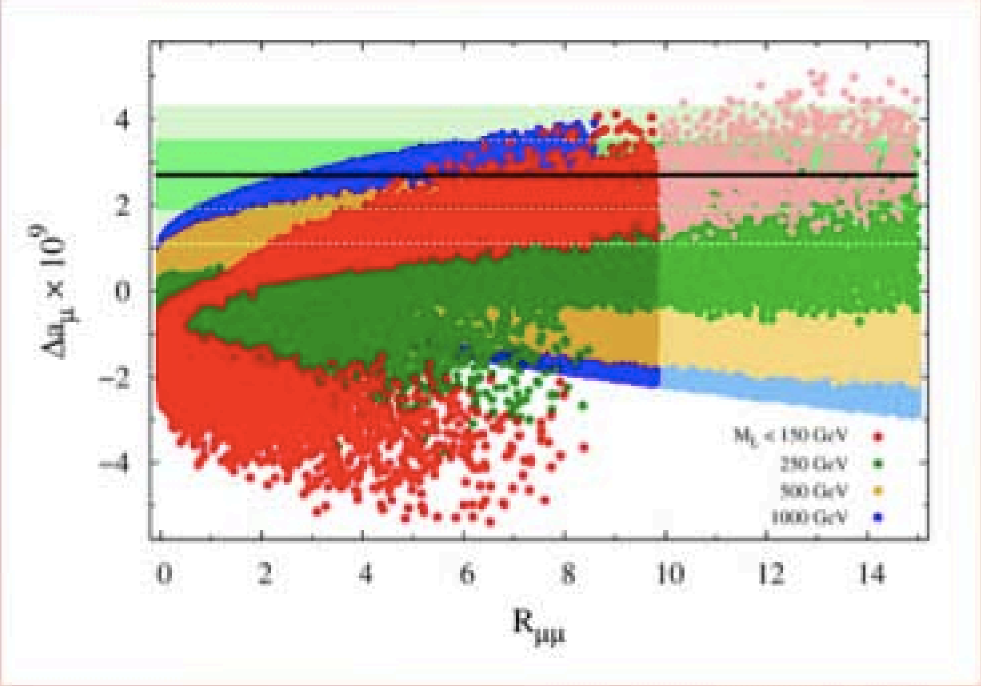


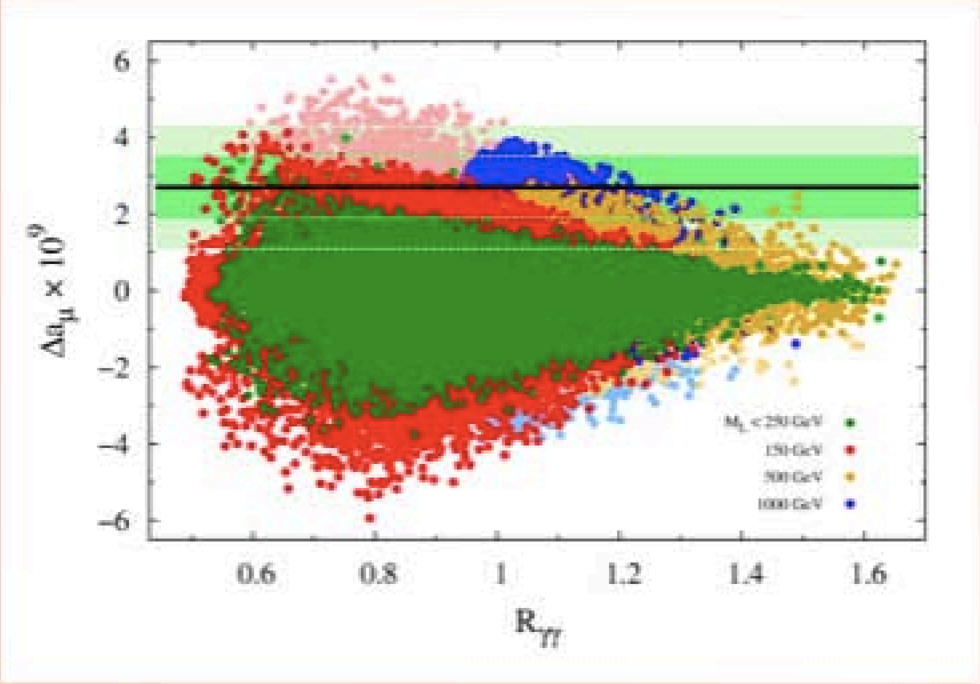


$$M_{L_1} = M_{E_1} = 150 \text{ GeV}$$

Allowing larger Yukawa couplings







Conclusions

- **3 (or more) pairs of vectorlike families allow for insensitive unification of gauge couplings**

  predictive

- **resurrects simple non-supersymmetric GUTs (proton decay)**

  the GUT scale is adjustable and could be identified with the string or Planck scale

- **the electroweak minimum is stable all the way to the GUT scale**

- **some of the extra fermions might be within the reach of the LHC**

  and modify phenomenology of the SM: small flavor violation from mixing through Yukawa couplings, contributions in loops, ...