Fine-tuning in composite Higgs

Gautam Bhattacharyya

Saha Institute of Nuclear Physics

Collaborators: Avik Banerjee (SINP), Tirtha Sankar Ray (IIT-Kgp)

Higgs @ 125 GeV too light?

The Higgs mass has the following dependence on the resonance mass and the fine-tuning parameter

$$m_h^2 \sim \frac{m_t^2 m_Q^2}{f^2} \sim y_t^2 \frac{m_Q^2}{\Delta}$$

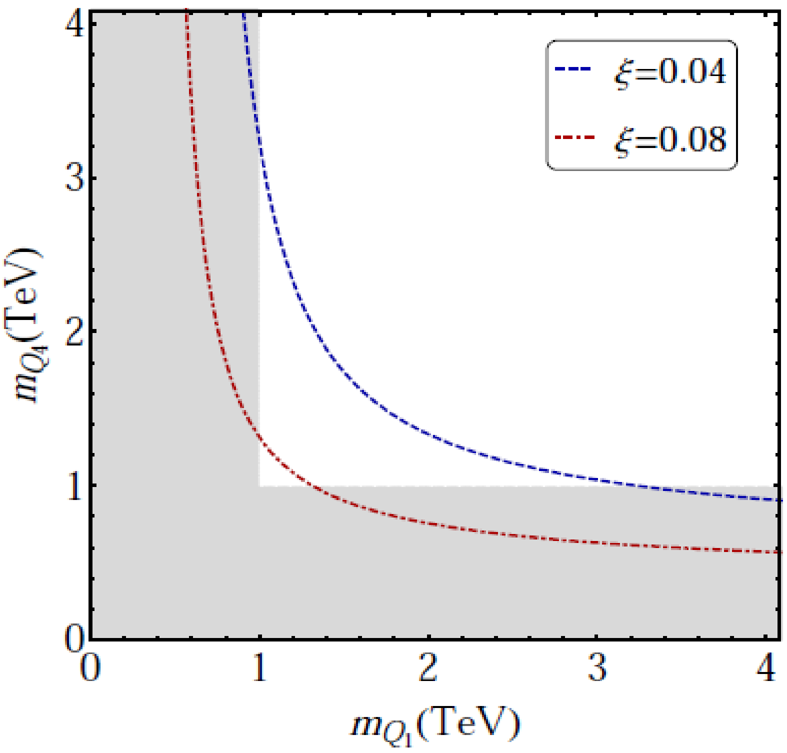
$$\Delta \equiv \xi^{-1} \equiv f^2/v_{ew}^2$$

- Light Higgs means either
- **resonance mass is light** (challenged by LHC) OR
- **fine-tuning is large**

F.T. in Minimal model SO(5)/SO(4)

- Fermions in 5-plet of SO(5) $\mathcal{L} = \bar{t}_L \not{p} \left[\Pi_0^{t_L} + \frac{\tilde{\Pi}_1^{t_L}}{2} s_h^2 \right] t_L + \bar{t}_R \not{p} \left[\Pi_0^{t_R} + \tilde{\Pi}_1^{t_R} c_h^2 \right] t_R + \bar{t}_L \left[\frac{M^t}{\sqrt{2}} s_h c_h \right] t_R + h.c.$

- Coleman-Weinberg potential $V_{top}(h) = -\alpha_t s_h^2 + \beta_t s_h^4 + \mathcal{O}(s_h^6)$



$$\alpha_t = \beta_t = 2N_c \int \frac{d^4 q_E}{(2\pi)^4} \left[\frac{1}{8} \left(\frac{\tilde{\Pi}_1^{t_L}}{\Pi_0^{t_L}} \right)^2 + \frac{1}{2} \left(\frac{\tilde{\Pi}_1^{t_R}}{\Pi_0^{t_R}} \right)^2 + \frac{|M^t|^2}{2q_E^2 \Pi_0^{t_L} \Pi_0^{t_R}} \right]$$
$$= \frac{N_c}{8\pi^2} \frac{m_t^2 m_{Q_1}^2 m_{Q_4}^2}{m_{Q_1}^2 - m_{Q_4}^2} \log\left(\frac{m_{Q_1}^2}{m_{Q_4}^2} \right) \frac{1}{\xi(1-\xi)} \,.$$

WSR: $\lim_{q_E^2 \to 0} q_E^n \tilde{\Pi}_1^{t_L, t_R} = 0 \,, \; (n = 0, 2)$

- LHC constraints are tight. Heavier resonances can be accommodated at the expense of larger fine-tuning.

Next-to-minimal model SO(6)/SO(5)

- 15 – 10 = 5 NGBs = (2,2) + (1,1) of SO(4) (= SU(2) X SU(2))
- In unitary gauge $\Sigma(x) = \left(0,\ 0,\ 0,\ h,\ \eta,\ \sqrt{1-h^2-\eta^2}\right)^T$
- Potential of singlet protected by U(1) symmetry in 5-6 plane
- Fermions embedded in 6 of SO(6) $\mathbf{6}_0 = (\mathbf{2},\mathbf{2})_0 \oplus (\mathbf{1},\mathbf{1})_2 \oplus (\mathbf{1},\mathbf{1})_{-2}$

$$SO(6) \supset SO(4) \times SO(2) \simeq SU(2)_L \times SU(2)_R \times U(1)_\eta$$

$$Q_L = \frac{1}{\sqrt{2}}(-ib_L,\ -b_L,\ -it_L,\ t_L,\ 0,\ 0)^T,$$
$$T_R = (0,\ 0,\ 0,\ 0,\ e^{i\delta}c_\theta t_R,\ s_\theta t_R)^T.$$

- C-W potential

$$V_{\text{eff}}(h,\eta) = -\frac{\mu_1^2}{2}h^2 + \frac{\lambda_1}{4}h^4 - \frac{\mu_2^2}{2}\eta^2 + \frac{\lambda_2}{4}\eta^4 - \frac{\lambda_m}{2}h^2\eta^2$$

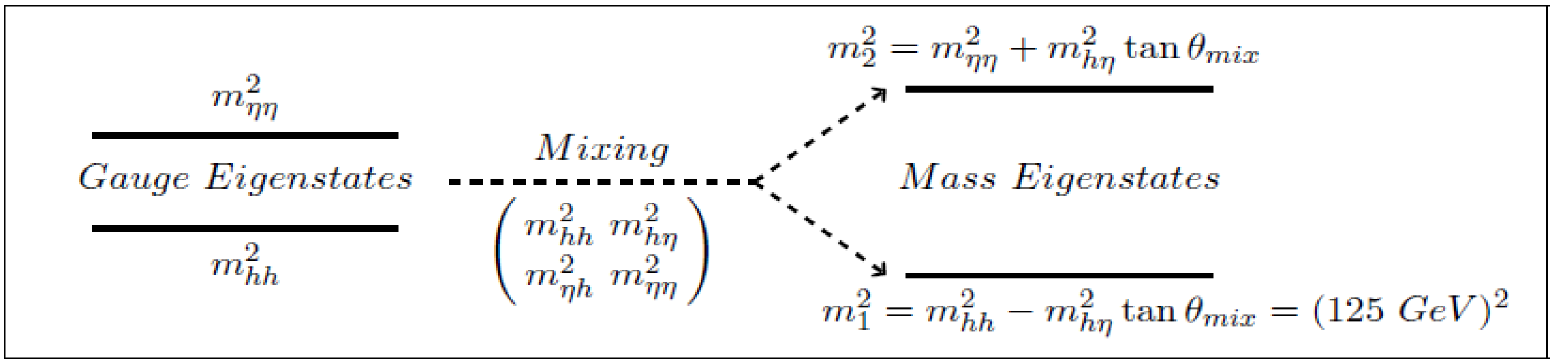
VEVs:

$$\xi = \langle h\rangle^2 = \frac{\lambda_2\mu_1^2 + \lambda_m\mu_2^2}{\lambda_1\lambda_2 - \lambda_m^2}$$

$$\chi = \langle \eta\rangle^2 = \frac{\lambda_1\mu_2^2 + \lambda_m\mu_1^2}{\lambda_1\lambda_2 - \lambda_m^2}$$

F.T. in next-to-minimal model

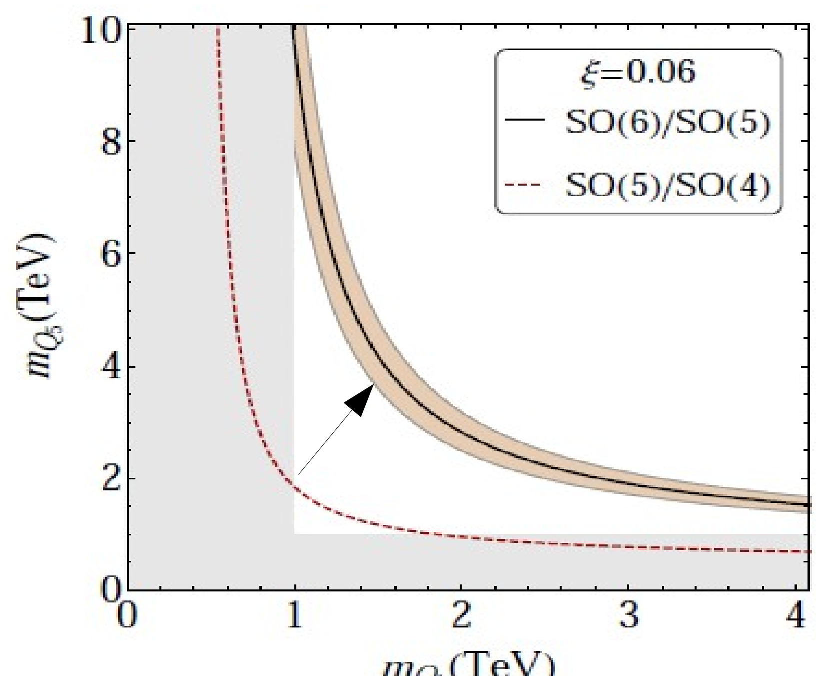
- Level repulsion



- Improvement in F.T.

Larger top partner masses for same F.T.

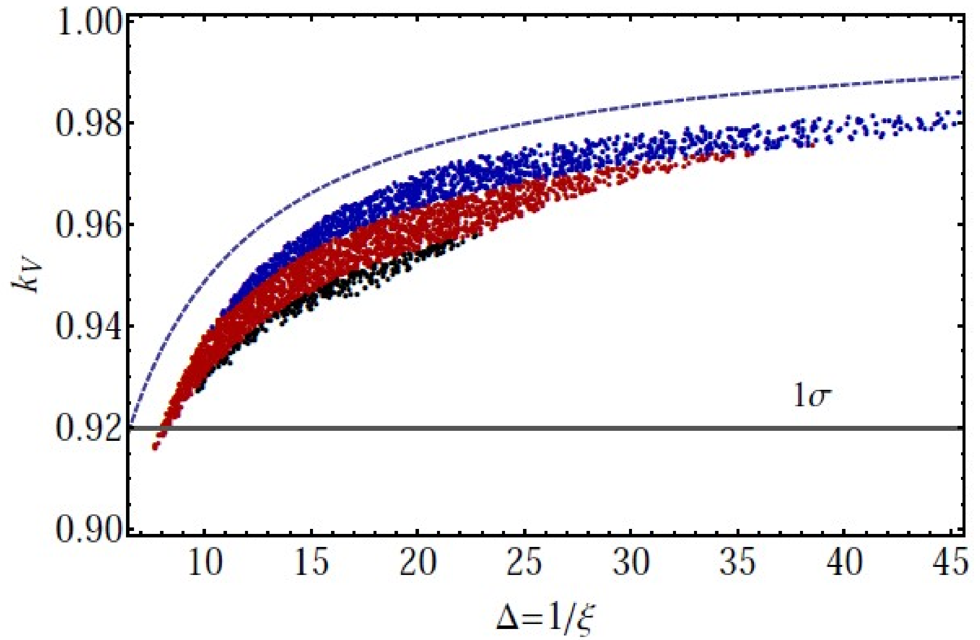
Compositeness scale f = 1 TeV



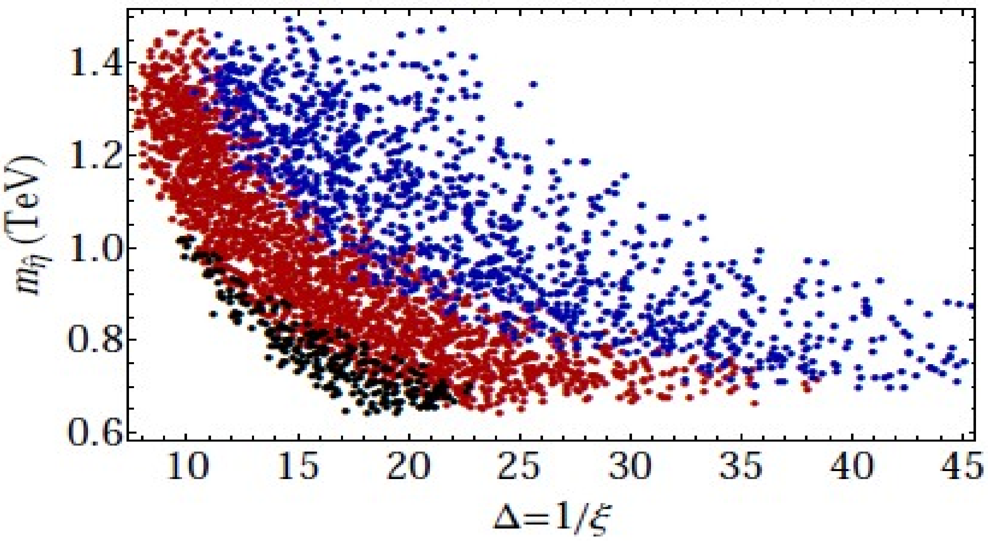
Higgs coupling, singlet mass

- **Modification in hVV**

$$k_V = \frac{g_{\hat{h}VV}}{g^{SM}_{\hat{h}VV}} = \cos\theta_{mix}\sqrt{1-\xi}$$



- **Singlet scalar mass**



Conclusions

- Fine-tuning is improved in SO(6)/SO(5) compared to the minimal model SO(5)/SO(4) by level repulsion
- The price to pay is that the singlet is not a DM
- Further modification in hVV coupling (LHC)
- Top-right compositeness – crucial expt test