Radiative EWSB in a Little Higgs Model

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Motivation

Little Hierarchy: v^2 << f^2 << Λ^2

(0.25 TeV)^2 (~1 TeV)^2 (~10 TeV)^2

Little Higgs (LH):

Collective Symmetry Breaking: If $g_1 = 0$ or $g_2 = 0$, H is a Goldstone Boson.

=> Quadratic divergences ~ Λ^2 vanish at one loop

Higgs Potential: $V = m^2 |H|^2 + \lambda |H|^4$

If potential is purely radiative, expect $m^2 \sim g^4 f^2$, $\lambda \sim g^4$

=> $v^2 \sim -m^2/\lambda^2 \sim f^2$

=> Too big!

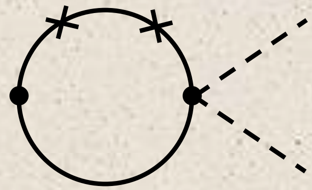
Typically, LH models introduce new operators to make λ larger.

Plaquettes, mass terms, quartic terms

Motivation (cont'd)

Fermions: Collective Symmetry Breaking also

Generic contribution to m^2 from heavy top partner T:



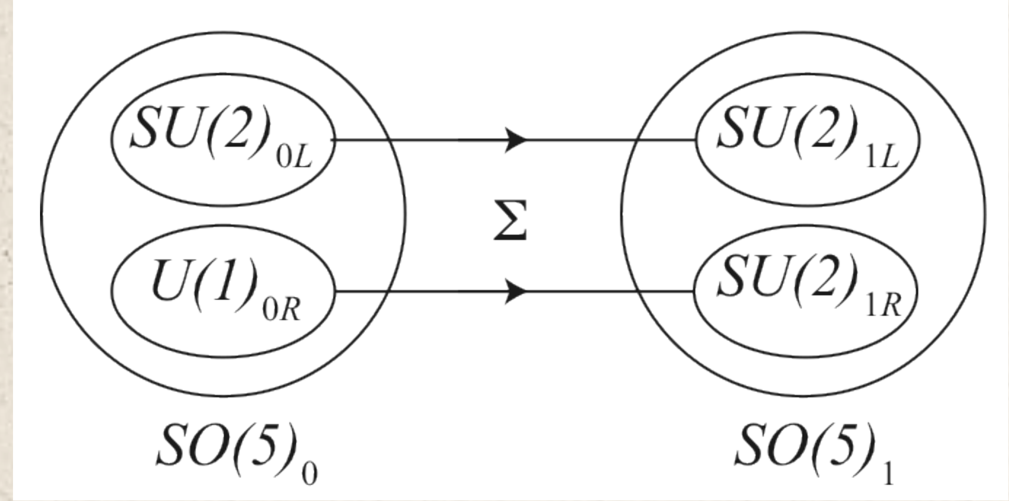
$$\delta m^2 = -\frac{3\lambda_t^2}{8\pi^2} M_T^2 \ln \frac{\Lambda^2}{M_T^2}$$

Good: Gives negative contribution to m^2.
Necessary for symmetry breaking.

Bad: Since $m_H^2 \sim -2m^2$, it gives contribution to Higgs mass of more than 1 TeV.
Still must have cancellation to get light Higgs.

=> Reconsider pure radiative EWSB

The Model



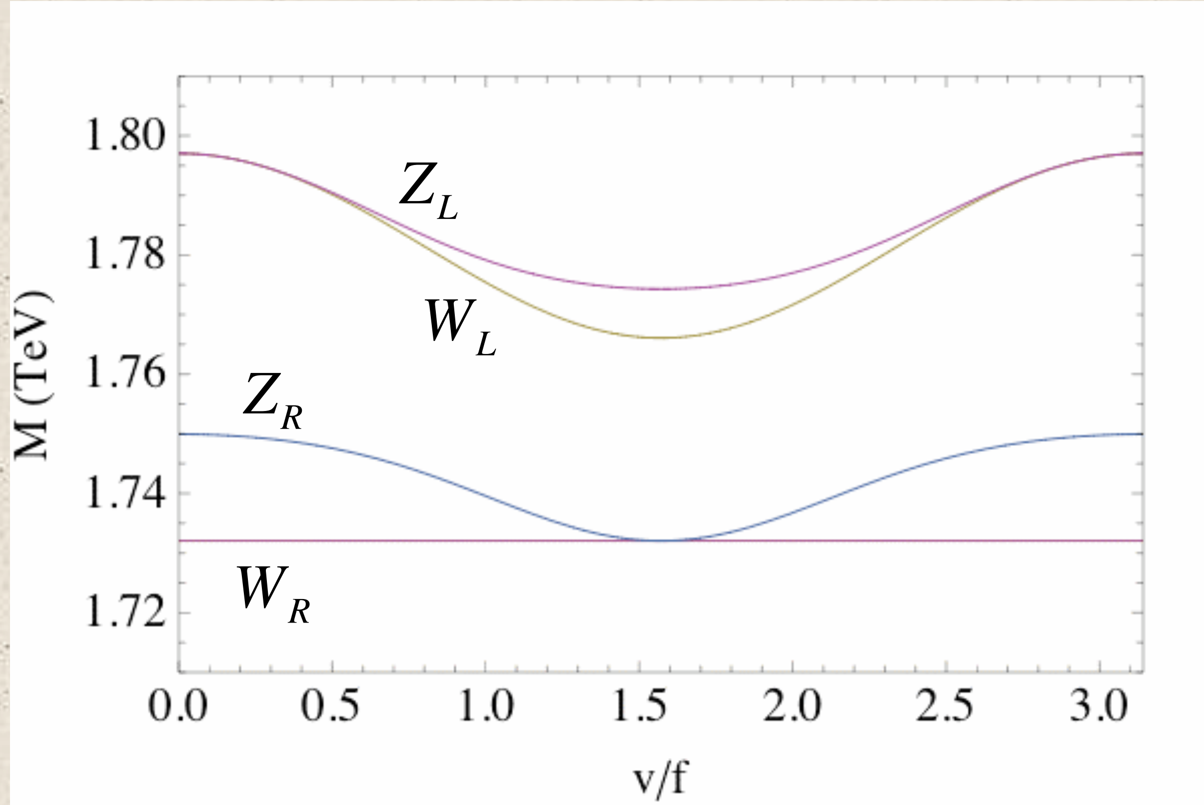
Global Symmetry: $SO(5)_0 \times SO(5)_1 \rightarrow SO(5)$

Gauge Symmetry: $[SU(2) \times U(1)]_0 \times [SU(2) \times SU(2)]_1$
$\rightarrow SU(2)_L \times U(1)_Y$

Collective Symmetry Breaking: If ($g_{0L} = g_{0R} = 0$) or ($g_{1L} = g_{1R} = 0$),
H is a Goldstone Boson. => Quadratic divergences vanish at one loop

Related Models: 5-dimensional Gauge-Higgs Model (Medina, Shah, Wagner)
Custodial Minimal Moose (Chang, Wacker)
Gauge Sector (Barbieri, Bellazzini, Rychkov, Varagnolo)

Heavy Gauge Bosons



$g_{1L}^2 = g_{1R}^2 = 6$

$f = 1$ TeV

$$M_{Z_L}^2 \approx \tfrac{1}{2}\left(g_{0L}^2 + g_{1L}^2\right) f^2 \qquad M_{Z_R}^2 \approx \tfrac{1}{2}\left(g_{0R}^2 + g_{1R}^2\right) f^2$$

$$M_{W_L}^2 \approx \tfrac{1}{2}\left(g_{0L}^2 + g_{1L}^2\right) f^2 \qquad M_{W_R}^2 \approx \tfrac{1}{2} g_{1R}^2 f^2$$

(Also SM *W* and *Z*)

Higgs boson is <u>only</u> light scalar. All other GB's from Σ are eaten.

Fermions

Q_L and t_R are in 5's of *SO(5)*:

$$\psi_L^A = \begin{pmatrix} Q \\ \chi \\ t' \end{pmatrix}_L^A \quad \psi_R^A = \begin{pmatrix} 0 \\ \chi \\ t' \end{pmatrix}_R^A \qquad \psi_L^B = \begin{pmatrix} Q' \\ \chi \\ 0 \end{pmatrix}_L^B \quad \psi_R^B = \begin{pmatrix} Q' \\ \chi \\ t \end{pmatrix}_R^B$$

- Dirac Fermions with missing SM partners
- Transform under $SU(2)_{0L} \times U(1)_{0R}$
- χ is *SU(2)* doublet with charge +5/3, +2/3 fermions
- b_R can be included in a 10 of *SO(5)*, with more heavy fermions

Fermion mass terms:

$SO(5)_1$-breaking spurion $\quad E = \begin{pmatrix} 0 \\ 0 \\ 0 \\ 0 \\ 1 \end{pmatrix}$

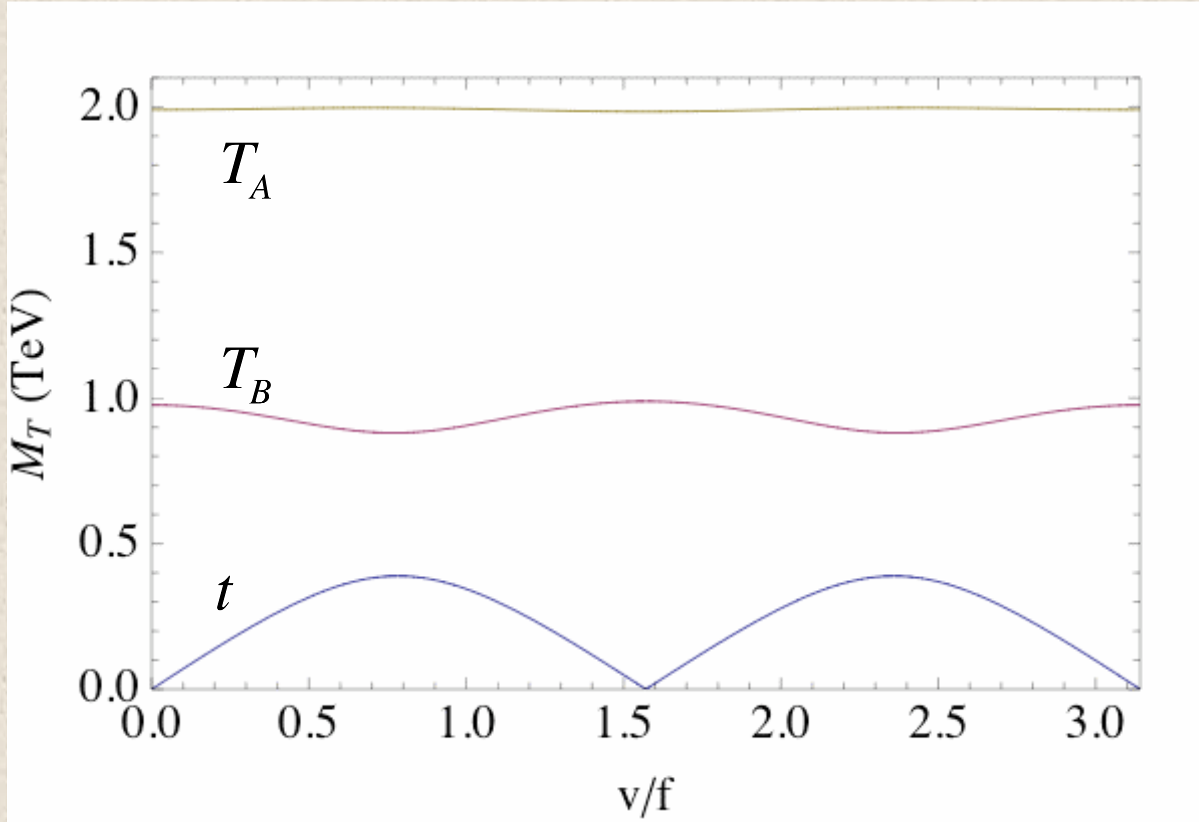
$$\mathcal{L}_{\text{mass}} = \underbrace{-\lambda_A f \overline{\psi}_L^A \psi_R^A - \lambda_B f \overline{\psi}_L^B \psi_R^B}_{\text{Breaks } SO(5)_0,\ \text{Preserves } SO(5)_1} - \underbrace{\lambda_1 f \overline{\psi}_L^A \Sigma E E^\dagger \Sigma^\dagger \psi_R^B}_{\text{Preserves } SO(5)_0,\ \text{Breaks } SO(5)_1} + \text{h.c.}$$

Breaks $SO(5)_0$
Preserves $SO(5)_1$

Preserves $SO(5)_0$
Breaks $SO(5)_1$

=> Collective Symmetry Breaking

Heavy Fermions



$$\lambda_A = \lambda_1 = \sqrt{2}\lambda_t$$

$$\lambda_B = 0.981\lambda_t$$

$$f = 1\,\text{TeV}$$

$$\frac{1}{\lambda_t^2} = \frac{1}{\lambda_1^2} + \frac{1}{\lambda_A^2}$$

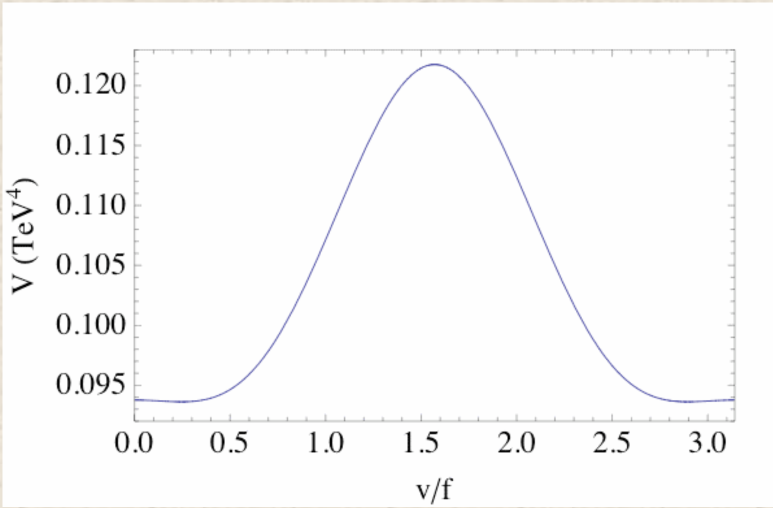
$$M_{T_A}^2 \approx \left(\lambda_A^2 + \lambda_1^2\right) f^2$$

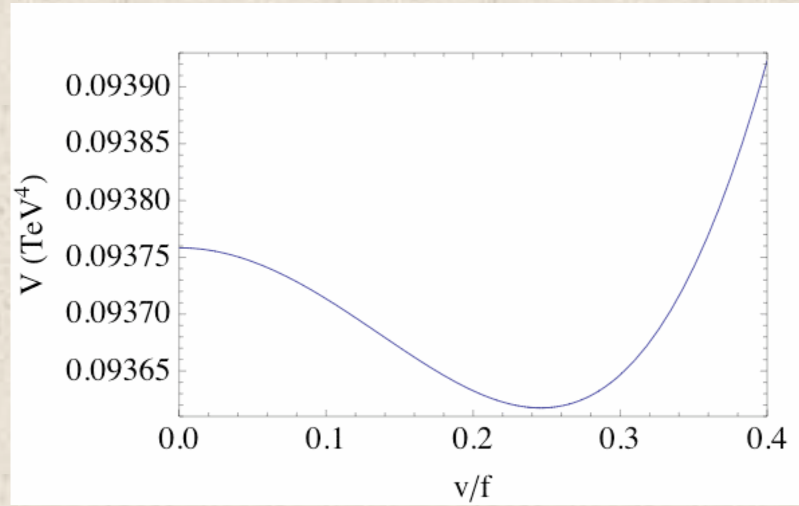
$$M_{T_B}^2 \approx \lambda_B^2 f^2$$

$$M_t^2 \approx \lambda_t^2 v^2 / 2$$

Three fermion masses depend on Higgs field

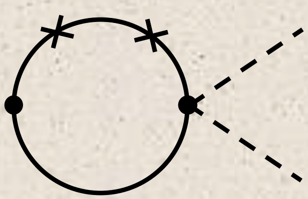
Effective Potential



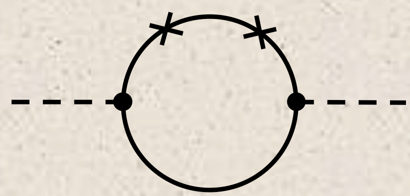


Possible to obtain EW scale v, because fermions give

$$\delta m^2 \approx \frac{3\lambda_1^2}{8\pi^2}\left(2\lambda_B^2 - \lambda_A^2\right)\ln\frac{\Lambda^2}{M_{T_A}^2}$$

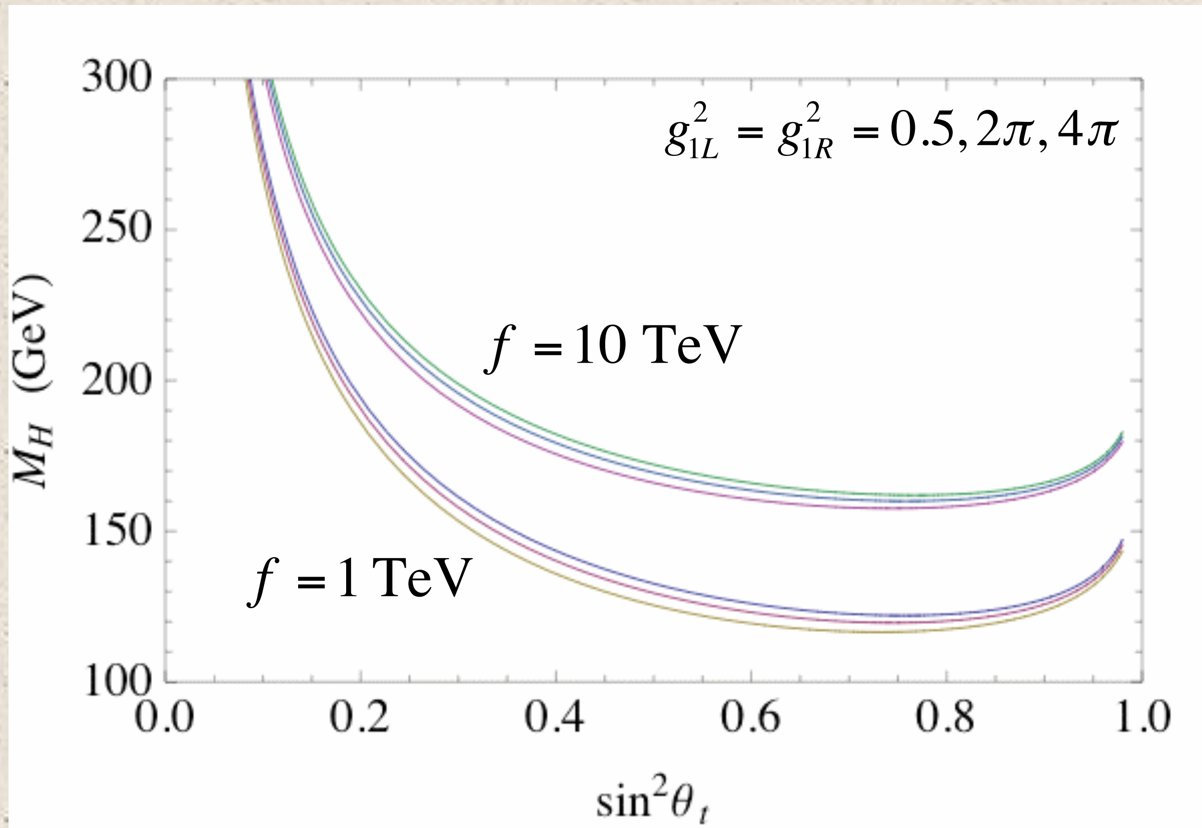


$\propto -2\lambda_1^2\lambda_A^2 f^2$



$\propto \frac{1}{2}\lambda_1^2\left(3\lambda_A^2 + 2\lambda_B^2\right)f^2$

Higgs Boson Mass



$$\sin\theta_t = \frac{\lambda_1}{\sqrt{\lambda_1^2 + \lambda_A^2}}$$

- Higgs boson is typically light.
- Mass insensitive to gauge couplings.

Sensitivity to UV Physics

Possible to have separate fermion cutoffs, Λ_A and Λ_B
Then:

$$\delta m^2 \approx \frac{3\lambda_1^2}{8\pi^2}\left(2\lambda_B^2 \ln\frac{\Lambda_B^2}{M_{T_A}^2} - \lambda_A^2 \ln\frac{\Lambda_A^2}{M_{T_A}^2}\right)$$

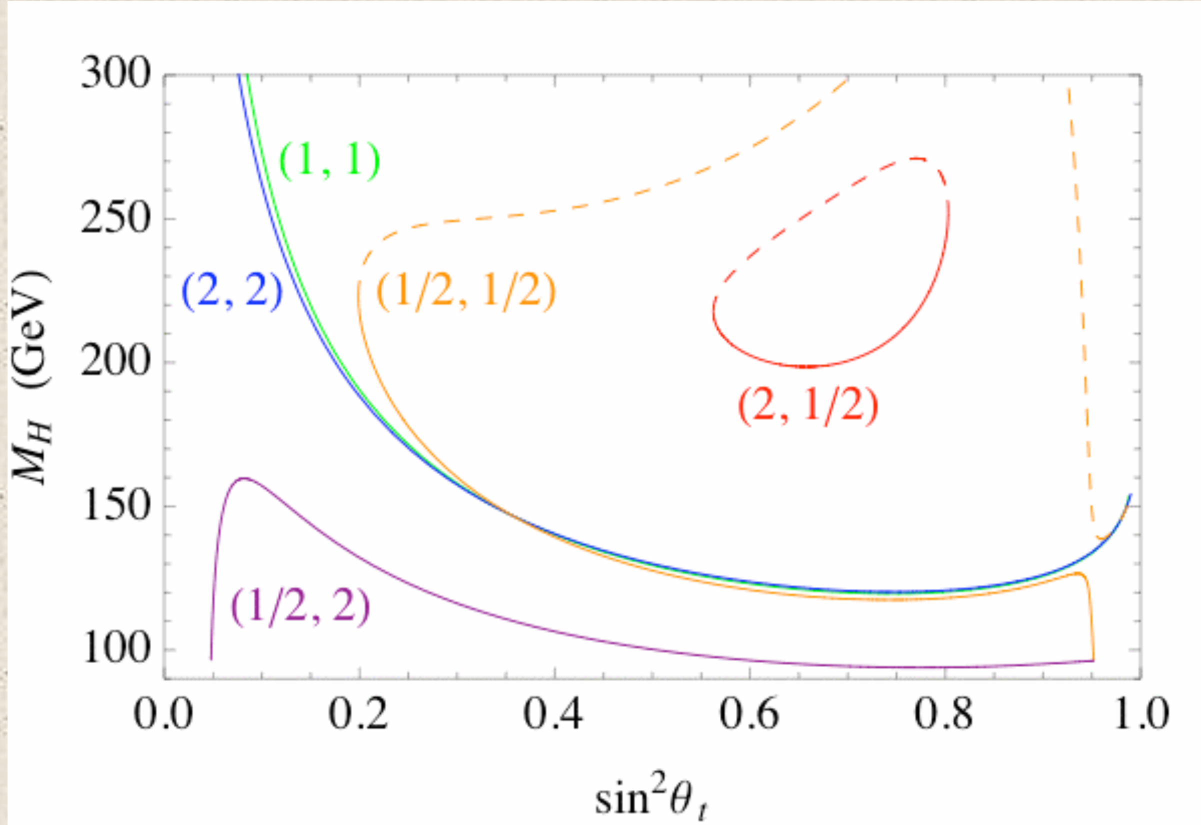
In fact, can make this precise:

- Make ψ^A and ψ^B complete Dirac multiplets (5s of *SO(5)*)
- Add new *SU(2)* doublet $Q_L''^A$ and singlet $t_R''^B$
- Add new mass term:

$$\Delta\mathcal{L}_{\text{mass}} = -\Lambda_A \overline{Q}_L''^A Q_R^A - \Lambda_B \bar{t}_L^B t_R''^B + \text{h.c.}$$

Gives above fermion contribution --- finite at one loop!

Sensitivity to UV Physics



$$g_{1L}^2 = g_{1R}^2 = 2\pi$$

$$f = 1\ \text{TeV}$$

$$\sin\theta_t = \frac{\lambda_1}{\sqrt{\lambda_1^2 + \lambda_A^2}}$$

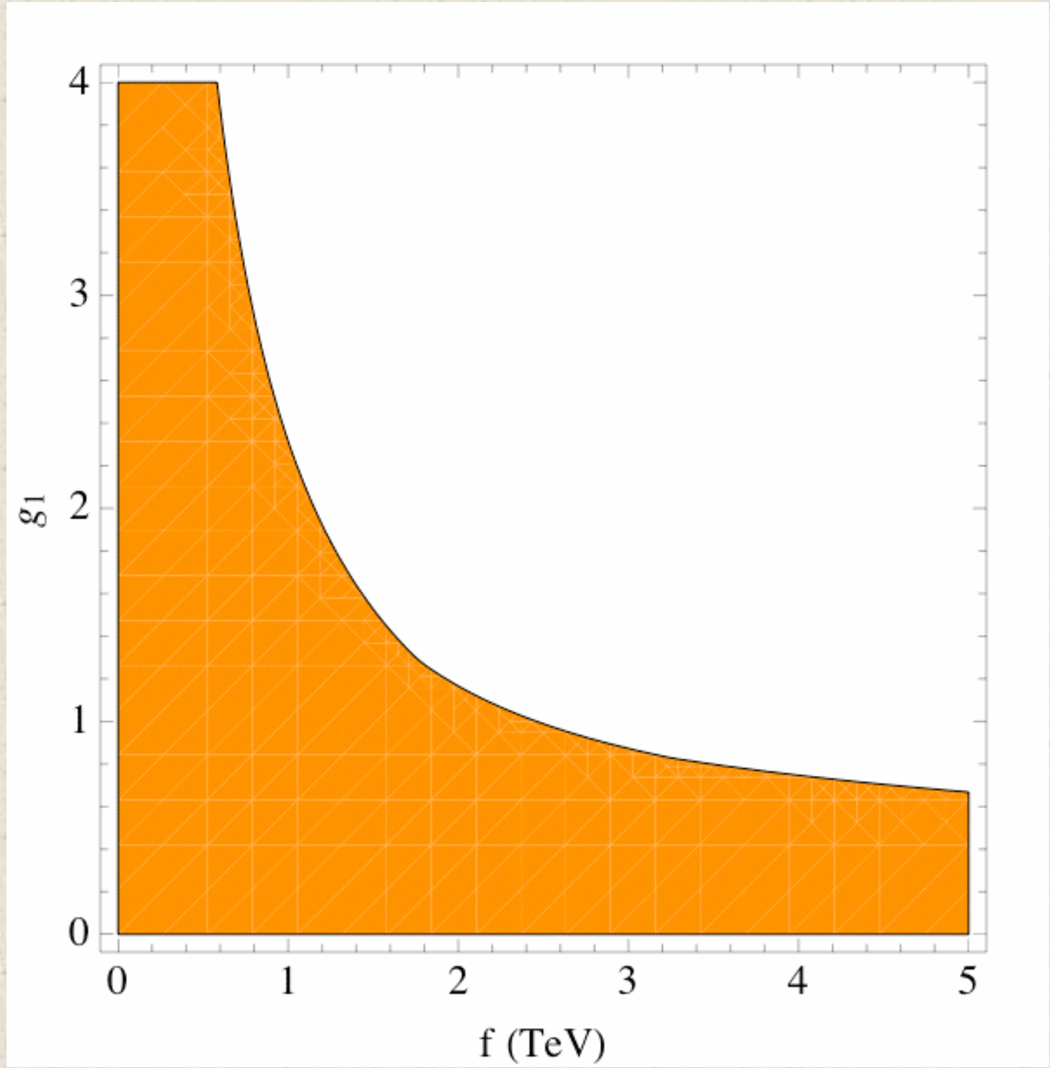
$$\left(\frac{\Lambda_A}{4\pi f}, \frac{\Lambda_B}{4\pi f}\right)$$

Why is Higgs mass solution typically light?

$$M_H^2 \approx 2\lambda v^2 \quad \text{with} \quad \lambda \approx \underbrace{\frac{3\lambda_t^4}{4\pi^2}\left\{\frac{1}{4}\ln\frac{M_{T_A}^2}{M_t^2}\right.}_{\text{Compare to SUSY}} + \left. F\left(\sin\theta_t, M_{T_A}^2/M_{T_B}^2\right)\right\}$$

Electroweak Constraints

$g_1 = g_{1L} = g_{1R}$



Bounds using universal electroweak parameters, $\hat{S}, \hat{T}, Y, W$

Heavy fermion contributions still to be done

Conclusions

- Presented a Little Higgs model with Higgs Potential fully radiatively-generated
- Cancellation in m^2 occurs between two heavy fermion contributions
- Higgs boson mass is generically light (< 200 GeV)
- Higgs is the only light scalar
- Electroweak constraints considered, but more phenomenology to be done