Higgs Mass from Compositeness at a Multi-TeV Scale

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based on current work with Hsin-Chia Cheng and Bogdan A. Dobrescu

Introduction

- Hierarchy problem.
- One solution: no light fundamental scalar!
- Composite Higgs that no longer exists above the compositeness scale.
- No new physics at LHC yet. Are we at a crossroads?
- Small hierarchy may still exist.
- New strong dynamics at the compositeness scale.
- Usually predicts a heavy Higgs due to large quartic couplings, unless the Higgs mass is protected by some symmetry.

The Nambu-Jona-Lasinio Model

- Consider some theory at scale Λ with an effective four-fermion vertex

$$\mathcal{L}_\Lambda = \overline{\psi}_L i\partial\!\!\!/ \psi_L + \overline{\psi}_R i\partial\!\!\!/ \psi_R + \frac{g^2}{\Lambda^2}(\overline{\psi}_L \psi_R)(\overline{\psi}_L \psi_R) \ . \tag{1}$$

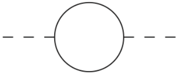
- The four-fermion vertex may come from some spontaneously broken gauge theory by integrating out the heavy gauge bosons.
- Eq. (1) can be rewritten in the following form with an auxilliary field H

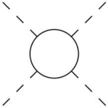
$$\mathcal{L}_\Lambda = \overline{\psi}_L i\partial\!\!\!/ \psi_L + \overline{\psi}_R i\partial\!\!\!/ \psi_R + (g\overline{\psi}_L \psi_R H + \text{h.c.}) - \Lambda^2 H^\dagger H \ . \tag{2}$$

(I will follow the appendix of arXiv:hep-ph/0203079 (C. T. Hill & E .H. Simmons).)

The Nambu-Jona-Lasinio Model

- Evolving down to scale μ with the fermion bubble approximation





- which generates kinetic and quartic terms of the H field and also gives a correction to the mass term

$$\begin{aligned}\mathcal{L}_\mu &= \overline{\psi}_L i\not\partial\psi_L + \overline{\psi}_R i\not\partial\psi_R + (g\overline{\psi}_L\psi_R H + \text{h.c.}) \\ &\quad + Z_H|\partial_\nu H|^2 - m_H^2 H^\dagger H - \frac{\lambda_0}{2}(H^\dagger H)^2 \end{aligned} \tag{3}$$

- where

$$Z_H = \frac{g^2 N_c}{(4\pi)^2}\log(\Lambda^2/\mu^2),\ \ m_H^2 = \Lambda^2 - \frac{2g^2N_c}{(4\pi)^2}(\Lambda^2-\mu^2),\ \ \lambda_0 = \frac{2g^2N_c}{(4\pi)^2}\log(\Lambda^2/\mu^2). \tag{4}$$

The Nambu-Jona-Lasinio Model

- When $\mu \to \Lambda$, $Z_H \to 0$, which mean H is no longer a physical degree of freedom.
- If we normalize the kinetic term of H, then the couplings blow up at Λ.

$$\begin{aligned} \mathcal{L}_\mu &= \overline{\psi}_L i\partial\!\!\!/ \psi_L + \overline{\psi}_R i\partial\!\!\!/ \psi_R + (\xi \overline{\psi}_L \psi_R H + \text{h.c.}) \\ &\quad + |\partial_\nu H|^2 - \tilde{m}_H^2 H^\dagger H - \frac{\lambda}{2}(H^\dagger H)^2 \end{aligned} \tag{5}$$

$$\begin{aligned} \xi^2 &= g^2/Z_H = \frac{16\pi^2}{N_c \log(\Lambda^2/\mu^2)} \,, \qquad \tilde{m}_H^2 = m_H^2/Z_H \,, \\ \lambda &= \lambda_0/Z_H^2 = \frac{32\pi^2}{N_c \log(\Lambda^2/\mu^2)} = 2\xi^2 \,. \end{aligned} \tag{6}$$

- One can think of H as a composite particle of the fermions, while Λ is the compositeness scale, at which the couplings are strong.

The Nambu-Jona-Lasinio Model

$$m_H^2 = \Lambda^2 - \frac{2g^2 N_c}{(4\pi)^2}(\Lambda^2 - \mu^2). \tag{7}$$

- $m_H^2 < 0$ if g is large enough. (Spontaneous symmetry breaking!)
- If the theory is spontaneously broken, $\lambda = 2\xi^2$ implies

$$m_h = 2m_f \ . \tag{8}$$

- The results are subject to change when effects of other interactions are included.

Top Condensation

- The Higgs field is a low energy condensate $\langle \bar{t}t \rangle$ triggered by some new fundamental interaction at a higher scale Λ.
- Instead of the fermion bubble approximation, the full one-loop RG equations are used. [Phys. Rev. D 41, 16471660 (1990), (Bardeen, Hill, Lindner)]
- To get the right Electroweak VEV, top quark is too heavy unless the compositeness scale is extremely large. (Need the top Yukawa coupling to be very large at Λ and be ≈ 1 at weak scale.)
  - $\Lambda = 10^5$ GeV $\Rightarrow m_{top} \approx 360$ GeV.
  - $\Lambda = 10^{19}$ GeV $\Rightarrow m_{top} \approx 220$ GeV.
- $m_h \gtrsim m_{top}$.
- It doesn't work!

Top Condensation Seesaw

- option 1: Give up.
- option 2: Modify the theory until it works!
- Minimal modification: add a new vector-like top partner.
- A number of papers at the end of last century
  - arXiv:hep-ph/9712319 (Dobrescu, Hill)
  - arXiv:hep-ph/9809470 (Chivukula, Dobrescu, Georgi, Hill)
  - arXiv:hep-ph/9908391 (Dobrescu)
- With the top seesaw mechanism, one can have a large ($\gg 1$) Yukawa coupling while keeping the correct top mass (173 GeV).
- We found that by imposing an approximate $U(3)_L$ symmetry, the Higgs mass has a rather restricted range and we can easily obtain a 126 GeV Higgs.

Introducing a new vector-like quark

- We introduce a new $SU(2)_W$-singlet vector-like quark, χ of electric charge $+2/3$.
- $\psi_L^3 = \begin{pmatrix} t_L \\ b_L \end{pmatrix}$, χ_L, t_R, χ_R form bound states due to some strong interactions at scale Λ, which approximately preserves $U(3)_L \times U(2)_R$ flavor symmetry.
- We label the composite scalars collectively as Φ, which is a 3×2 matrix

$$\Phi = \begin{pmatrix} \Phi_t & \Phi_\chi \end{pmatrix} , \tag{9}$$

$$\Phi_t \sim \bar{t}_R \begin{pmatrix} \psi_L^3 \\ \chi_L \end{pmatrix} \qquad , \qquad \Phi_\chi \sim \overline{\chi}_R \begin{pmatrix} \psi_L^3 \\ \chi_L \end{pmatrix} . \tag{10}$$

- Yukawa couplings of the fermions and composite scalars:

$$\mathcal{L}_{\text{Yukawa}} = -\xi \begin{pmatrix} \overline{\psi}_L^3 & \overline{\chi}_L \end{pmatrix} \Phi \begin{pmatrix} t_R \\ \chi_R \end{pmatrix} + \text{H.c.} \tag{11}$$

- The ligher mass eigenstate is the physical top, which can be “light” because of the seesaw mechanism.

Effective potential of the scalar sector

- The Yukawa couplings give rise to the following potential for Φ:

$$V_\Phi = \frac{\lambda_1}{2}\,\mathrm{Tr}\left[(\Phi^\dagger\Phi)^2\right] + \frac{\lambda_2}{2}\left(\mathrm{Tr}[\Phi^\dagger\Phi]\right)^2 + M_\Phi^2\Phi^\dagger\Phi \quad . \tag{12}$$

- We introduce additional explicit $U(2)_R$ breaking effects in the mass term which distinguish t_R and χ_R.

$$V_{\not{U(2)}} = \delta M_{tt}^2\,\Phi_t^\dagger\Phi_t + \delta M_{\chi\chi}^2\,\Phi_\chi^\dagger\Phi_\chi + (M_{\chi t}^2\Phi_\chi^\dagger\Phi_t + \mathrm{H.c.}) \tag{13}$$

- SM gauge invariant mass terms at scale Λ

$$\mathcal{L}_{\rm mass} = -\mu_{\chi t}\bar{\chi}_L t_R - \mu_{\chi\chi}\bar{\chi}_L\chi_R + \mathrm{H.c.} \tag{14}$$

map to tadpole terms for the $SU(2)_W$-singlet scalars below Λ

$$V_{\rm tadpole} = -(0,0,C_{\chi t})\Phi_t - (0,0,C_{\chi\chi})\Phi_\chi + \mathrm{H.c.} \tag{15}$$

$$C_{\chi t} \approx \frac{\mu_{\chi t}}{\xi}\Lambda^2 \quad , \quad C_{\chi\chi} \approx \frac{\mu_{\chi\chi}}{\xi}\Lambda^2 \,. \tag{16}$$

- $U(3)_L \times U(2)_R$ is broken down to $U(2)_L \times U(1)_R$ (with approximate $U(3)_L$).

Two doublets + two singlets

- Rewrite the scalar potential

$$
\begin{aligned}
V_{\text{scalar}} \quad = \quad & \frac{\lambda_1+\lambda_2}{2}\left[(\Phi_t^\dagger\Phi_t)^2+(\Phi_\chi^\dagger\Phi_\chi)^2\right]+\lambda_1|\Phi_t^\dagger\Phi_\chi|^2+\lambda_2(\Phi_t^\dagger\Phi_t)(\Phi_\chi^\dagger\Phi_\chi) \\
& +M_{tt}^2\Phi_t^\dagger\Phi_t+M_{\chi\chi}^2\Phi_\chi^\dagger\Phi_\chi+(M_{\chi t}^2\Phi_\chi^\dagger\Phi_t+\text{H.c.}) \\
& -(0,0,2C_{\chi t})\text{Re}\,\Phi_t-(0,0,2C_{\chi\chi})\text{Re}\,\Phi_\chi \quad . \qquad (17)
\end{aligned}
$$

- Write Φ_t and Φ_χ

$$
\Phi_t=\begin{pmatrix}H_t\\ \phi_t\end{pmatrix} \qquad , \qquad \Phi_\chi=\begin{pmatrix}H_\chi\\ \phi_\chi\end{pmatrix} . \qquad (18)
$$

- For certain values of parameters, all 4 scalars will have vacuum expectation values. (We will have $M_{tt}^2>0$, $M_{\chi\chi}^2<0$.)

$$
\langle H_t\rangle=\begin{pmatrix}\frac{v_t}{\sqrt{2}}\\ 0\end{pmatrix}, \quad \langle H_\chi\rangle=\begin{pmatrix}\frac{v_\chi}{\sqrt{2}}\\ 0\end{pmatrix}, \quad \langle\phi_t\rangle=\frac{u_t}{\sqrt{2}}\,, \quad \langle\phi_\chi\rangle=\frac{u_\chi}{\sqrt{2}}\,. \qquad (19)
$$

Chiral symmetry breaking scale

- We need to have the correct electroweak VEV, $v = 246$ GeV.

$$v_t^2 + v_\chi^2 = v^2 \qquad , \qquad u_t^2 + u_\chi^2 = u^2 \; . \tag{20}$$

- Chiral symmetry breaking scale

$$f = \sqrt{u^2 + v^2} \; . \tag{21}$$

- We expect $\Lambda \sim 4\pi f$ for f to be natural.
- T parameter constraint requires $v \ll f$, which requires tuning!
- The $U(3)_L$ symmetry does not contain a custodial $SU(2)$ symmetry.
- No new physics at LHC so far, some tuning in the electroweak scale is probably inevitable.

Choosing a particular basis

- Perform an $U(2)_R$ transformation to go to a basis where $v_t = 0$ and $v_\chi = v$. (no more $\tan\beta$!)
- Also define angle γ so that

$$u_t = u \sin\gamma \qquad , \qquad u_\chi = u \cos\gamma \tag{22}$$

- Short-hand notation $s_\gamma = \sin\gamma$.
- In the limit $s_\gamma \to 0$, the tadpole terms will vanish and the Higgs field becomes massless.

Top Seesaw

- Neglecting the mixing of the charm and up quarks with t and χ, the mass terms of the heavy charge-2/3 fermions quarks are given by

$$-\frac{\xi}{\sqrt{2}}\,(\bar{t}_L, \overline{\chi}_L)\begin{pmatrix} 0 & v \\ u s_\gamma & u c_\gamma \end{pmatrix}\begin{pmatrix} t_R \\ \chi_R \end{pmatrix} + \mathrm{H.c.} \tag{23}$$

- The mass of the top quark is suppressed by s_γ so that ξ can be much larger than one.

$$m_t \approx \frac{\xi\, v\, s_\gamma}{\sqrt{2}} \qquad \Rightarrow \qquad s_\gamma \approx \frac{y_t}{\xi}\,. \tag{24}$$

- We can obtain the correct top mass while keeping the compositeness scale relatively small.
- The heaver eigenstate is the “top partner” and has mass

$$m_{t'} \approx \frac{\xi\, f}{\sqrt{2}}\,. \tag{25}$$

Light Higgs

- two doublets + two singlets

$$\Phi_t = \begin{pmatrix} H_t \\ \phi_t \end{pmatrix} \quad , \quad \Phi_\chi = \begin{pmatrix} H_\chi \\ \phi_\chi \end{pmatrix} . \tag{26}$$

- Three NGBs that will become the longitudinal modes of W and Z.
- 4 CP-even neutral scalars, 3 CP-old neutral scalars and 1 charged scalar.
- The lightest mass eigenstate of the 4 CP-even neutral scalars is a PNGB of the approximate $U(3)_L$ symmetry. It is the 126 GeV "Higgs".
- Keeping the leading order terms in v^2/f^2 and s_γ,

$$M_h^2 \approx \frac{\lambda_1}{2\xi^2} \left(1 + \frac{\lambda_1 m_{t'}^2}{\xi^2 M_{H\pm}^2} \right)^{-1} y_t^2 \, v^2 \, . \tag{27}$$

- With $0.4 \lesssim \frac{\lambda_1}{2\xi^2} \lesssim 1$, we have $M_h \lesssim 185$ GeV.

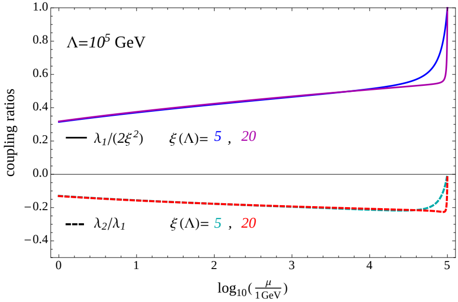
Using RGE to estimate $\lambda_1/(2\xi^2)$ and λ_2/λ_1

- The Yukawa coupling ξ and the quartic couplings λ_1, λ_2 are related.

$$V_{\text{quartic}} = \frac{\lambda_1}{2}\,\mathrm{Tr}\left[(\Phi^\dagger\Phi)^2\right] + \frac{\lambda_2}{2}\left(\mathrm{Tr}[\Phi^\dagger\Phi]\right)^2 \quad . \qquad (28)$$

- In the fermion loop approximation, $\lambda_1 = 2\xi^2$, $\lambda_2 = 0$.
- In one loop RG running, the ratios of couplings $\lambda_1/(2\xi^2)$ and λ_2/λ_1 are quickly driven to some approximate fixed points.
- The Evolutions of $\lambda_1/(2\xi^2)$ and λ_2/λ_1 are quite insensitive to the value of ξ.

Using RGE to estimate $\lambda_1/(2\xi^2)$ and λ_2/λ_1



- Boundary conditions: $\lambda_1/(2\xi^2) = 1, \;\; \lambda_2/\lambda_1 = 0$ at Λ.
- Choosing different boundary conditions for $\xi, \;\; \xi(\Lambda) = 5, \; 20$.
- One loop RG running predicts that

$$\frac{\lambda_1}{2\xi^2} \approx 0.4 \quad , \quad \frac{\lambda_2}{\lambda_1} \approx -0.2 \; . \tag{29}$$

Using RGE to estimate $\lambda_1/(2\xi^2)$ and λ_2/λ_1

- Do we trust the results from 1-loop RGEs? No.
- Coupling is strong, higher loop contributions may be large.
- To avoid excessive tuning, the chiral symmetry breaking scale is not far below the compositeness scale.
- If we assume a smooth evolution, the ratios of couplings are expected to lie in between their initial values and the infrared fixed point values:

$$0.4 \lesssim \frac{\lambda_1}{2\xi^2} \lesssim 1 \quad , \quad -0.2 \lesssim \frac{\lambda_2}{\lambda_1} \lesssim 0 \,. \tag{30}$$

$U(3)_L$ breaking from electroweak interactions

- So far we assume that the only explicit $U(3)_L$ breaking comes from the tadpole terms.
- Other explicit $U(3)_L$ breaking effects can feed into the mass and quartic terms through loops.
- We can parameterize the $U(3)_L$ breaking terms as

$$\begin{aligned}\Delta V_{\text{breaking}} \quad = \quad & \frac{\kappa_1}{2}[(H_t^\dagger H_t)^2 + (H_\chi^\dagger H_\chi)^2 + 2(H_t^\dagger H_\chi)(H_\chi^\dagger H_t)] + \frac{\kappa_2}{2}(H_t^\dagger H_t + H_\chi^\dagger H_\chi)^2 \\ & + \kappa_1'[H_t^\dagger H_t \phi_t^\dagger \phi_t + H_\chi^\dagger H_\chi \phi_\chi^\dagger \phi_\chi + (H_t^\dagger H_\chi \phi_\chi^\dagger \phi_t + \text{H.c.})] \\ & + \kappa_2'(H_t^\dagger H_t + H_\chi^\dagger H_\chi)(\phi_t^\dagger \phi_t + \phi_\chi^\dagger \phi_\chi) \\ & + \Delta M_{tt}^2 H_t^\dagger H_t + \Delta M_{\chi\chi}^2 H_\chi^\dagger H_\chi + (\Delta M_{\chi t}^2 H_\chi^\dagger H_t + \text{H.c.}) \quad . \end{aligned} \tag{31}$$

- In leading order of s_γ and v^2/f^2,

$$\Delta M_h^2 \approx \left(\kappa_1 + \kappa_2 - \frac{5}{2}(\kappa_1' + \kappa_2') - \frac{\Delta M_{\chi\chi}^2}{f^2} \right) v^2 \, . \tag{32}$$

- This can screw up the prediction of Higgs mass!

$U(3)_L$ breaking from electroweak interactions

- In our model, the additional $U(3)_L$ breaking effects come from the $SU(2)_W \times U(1)_Y$ gauge interactions.
- We assume this contribution is cut off by M_ρ, presumably the mass of some vector state in the theory.
- Contributions to mass terms and quartic couplings ($\mu \sim m_{t'} \approx \xi f/\sqrt{2}$)

$$\Delta M^2_{\chi\chi} = \Delta M^2_{tt} = \frac{9g_2^2 + 3g_1^2}{64\pi^2} M_\rho^2 \,, \qquad \Delta M^2_{\chi t} = 0 \,, \tag{33}$$

$$\frac{\kappa_{1(2)}}{\lambda_{1(2)}} \approx 2\, \frac{\kappa'_{1(2)}}{\lambda_{1(2)}} \approx \frac{3(3g_2^2 + g_1^2)}{16\pi^2} \ln\left(\frac{M_\rho}{\mu}\right) \,. \tag{34}$$

- The contributions to mass terms and quartic couplings both reduce the Higgs mass.
- With not too large M_ρ ($\lesssim 5f$), we can still get the correct Higgs mass.

Numerical study!

- We want to verify the Higgs mass prediction with a numerical study.
- Our model contains the following parameters:

$$\xi, \quad \lambda_1, \quad \lambda_2, \quad M_{tt}^2, \quad M_{\chi\chi}^2, \quad M_{\chi t}^2, \quad C_{\chi t}, \quad C_{\chi\chi}, \quad M_\rho. \tag{35}$$

- Choose the $v_t = 0$ basis and write in terms of $M_{H^\pm}$ and the VEVs,

$$\xi, \quad \lambda_1, \quad \lambda_2, \quad M_{H^\pm}, \quad v, \quad f, \quad s_\gamma, \quad M_\rho. \tag{36}$$

- $v = 246$ GeV, use top mass to solve for s_γ,

$$\xi, \quad \lambda_1/(2\xi^2), \quad \lambda_2/\lambda_1, \quad f, \quad M_{H^\pm}/f, \quad M_\rho/f. \tag{37}$$

- To calculate the Higgs mass, we match the theory with SM at scale $m_{t'} \approx \frac{\xi f}{\sqrt{2}}$, compute λ_h and evolve it down to the weak scale.

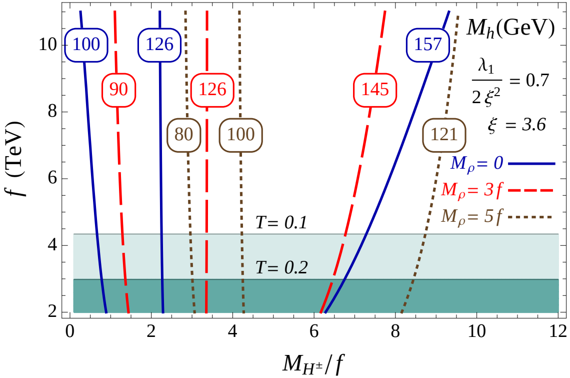
Parameter space

- What are the expected ranges of the 6 parameters?

$$\xi, \quad \lambda_1/2\xi^2, \quad \lambda_2/\lambda_1, \quad f, \quad M_{H^\pm}/f, \quad M_\rho/f. \tag{38}$$

- T parameter constraint requires $f \gg v$. We consider f up to 10 TeV to avoid excessive fine tuning.
- The states in the theory should have masses below the cutoff scale $M_{H^\pm}, M_\rho \lesssim 4\pi f$.
- Using 1-loop RGE, we expect $0.4 \lesssim \lambda_1/(2\xi^2) \lesssim 1$ and $-0.2 \lesssim \lambda_2/\lambda_1 \lesssim 0$.
- ξ is expected to be roughly between 2.5 and 5. Use $\xi = 2\pi/\sqrt{3} \approx 3.6$ as the standard reference value.

We can have a 126 GeV Higgs!



- Plot Higgs mass as a function of the dimensionful parameters. ($\lambda_2 = 0$)
- $M_h = 126$ GeV can be obtained with reasonable parameters of our model.

T parameter

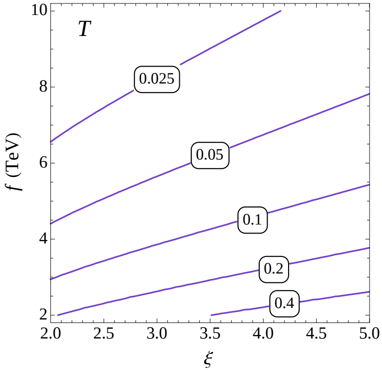
- The heavy fermion t' can give a large contribution to the T parameter, which is related to the fact that $U(3)_L$ does not contain a custodial $SU(2)$ symmetry.

$$T = \frac{3}{16\pi^2 \alpha v^2}\left[s_L^4 m_{t'}^2 + 2s_L^2(1-s_L^2)\frac{m_{t'}^2 m_t^2}{m_{t'}^2 - m_t^2}\ln\left(\frac{m_{t'}^2}{m_t^2}\right) - s_L^2(2-s_L^2)m_t^2\right], \quad (39)$$

- can be rewritten in terms of ξ and f as

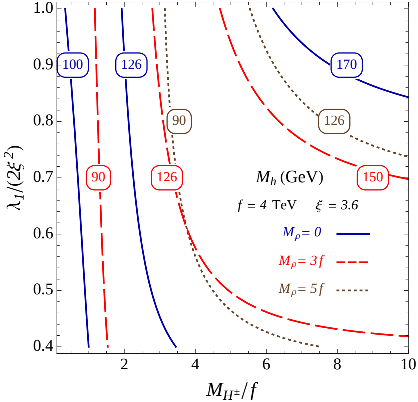
$$T \approx \frac{3}{16\pi^2 \alpha f^2}\left[\frac{v^2\xi^2}{2} + 4m_t^2 \ln\left(\frac{\xi f}{\sqrt{2}m_t}\right) - 2m_t^2\right]. \quad (40)$$

T parameter



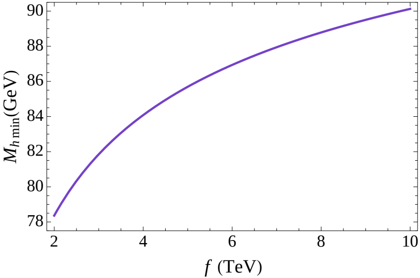
- 68% bound → $T \lesssim 0.1$ corresponds to $f \gtrsim 4.3$ TeV (for $\xi = 3.6$).
- 95% bound → $T \lesssim 0.15$ corresponds to $f \gtrsim 3.5$ TeV (for $\xi = 3.6$).

Upper bound on Higgs mass



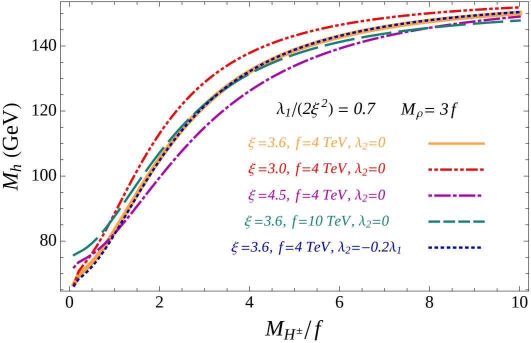
- The Higgs mass in the leading order is sensitive to $\lambda_1/(2\xi^2)$, $M_{H\pm}/f$ and M_ρ/f.
- Fix $f = 4$ TeV, $\xi = 3.6$, $\lambda_2 = 0$. The dependence on these parameters is mild.
- A larger Higgs mass occurs for larger $M_{H\pm}/f$, $\lambda_1/(2\xi^2)$ and smaller M_ρ/f.
- $M_h \lesssim 175$ GeV .

Lower bound on Higgs mass



- M_h min as a funtion of f for $\xi = 3.6$, allowed by the condition $\lambda_h > 0$ at scale $m_{t'} \approx \xi f/\sqrt{2}$.
- Higgs mass is restricted by $80 \lesssim M_h \lesssim 175$ GeV .

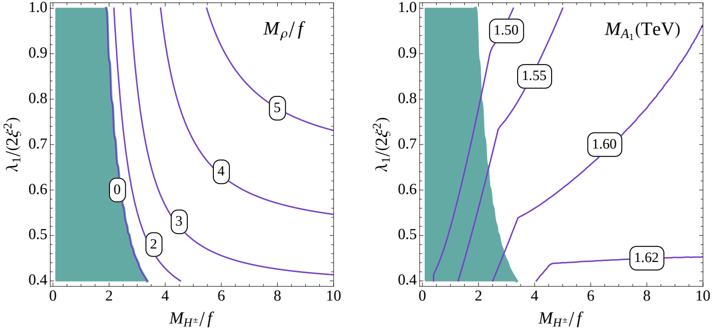
The dependence on ξ, f, λ_2 are mild



- The dependence of Higgs mass on ξ, f, λ_2 is mild.

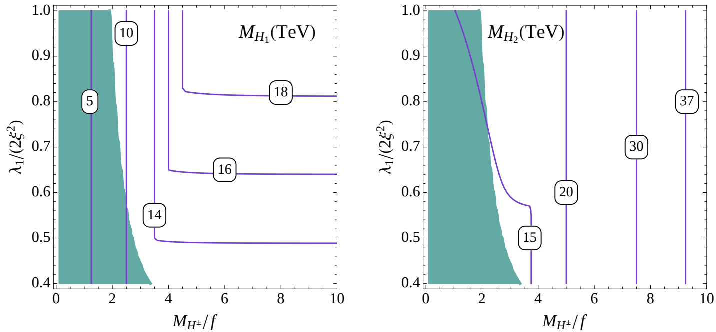
Heavy state spectrum

- Use Higgs mass (126 GeV) to fix M_ρ, plot the required M_ρ that gives the correct Higgs mass.



- $f = 4$ TeV, $\xi = 3.6$, $\lambda_2 = 0$ $(m_{t'} = 10.2$ TeV).
- The lightest CP-odd neutral scalar is also a PNGB.

Heavy state spectrum



- $f = 4$ TeV, $\xi = 3.6$, $\lambda_2 = 0$.
- Too heavy for LHC!

Phenomenology?

- New states (apart from the 126 GeV Higgs) are too heavy to be probed at the LHC.
- But they can be probed at a $\mathcal{O}(100)$ TeV hadron collider!
- Higgs couplings are very close to SM values, approximately given by SM values times a factor of $\cos(v/f) \approx 1 - v^2/(2f^2)$.
- 0.2% deviation for $f = 4$ TeV, probably even beyond the reach of a future e^+e^- collider.
- A precise determination of the T parameter would help probe or constrain this model.

Conclusion

- The Top Seesaw Model is a modification of Top Condensation by introducing a new vector like top partner.
- It addresses the origin of both electroweak symmetry breaking and top Yukawa coupling.
- The Higgs mass is related to the top mass and has a rather restricted range, $80 \lesssim M_h \lesssim 175$ GeV , and one can easily obtain a 126 GeV Higgs.
- Constraint from T-parameter requires the chiral symmetry breaking scale to be much higher than the electroweak scale, which requires tuning.
- What if LHC doesn't find anything?
- Modifications that embeds custodial symmetry can bring down the chiral symmetry breaking scale and predict interesting phenomenology at the LHC.

sidenote: I also worked on Stop searches using kinematic variables.