The neutrino option

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The issue: dynamics of the Higgs potential

The Higgs potential gives a successful parameterization of the electroweak symmetry breaking

$$V_c(H^\dagger H) = -\frac{m^2}{2}\,(H^\dagger\, H) + \lambda\,(H^\dagger\, H)^2$$

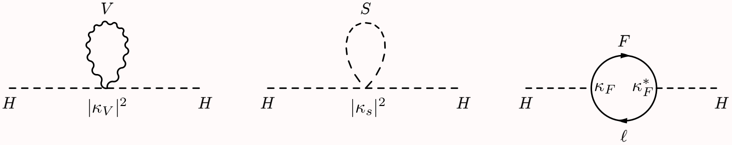
but it lacks **a dynamical origin**! $\longleftrightarrow$ several theoretical **problems**:

hierarchy, stability, triviality, phase transition? ...

The hierarchy problem in an EFT perspective

Brivio,Trott 1706.08945

Heavy new physics can give loop corrections to $(H^\dagger H)$



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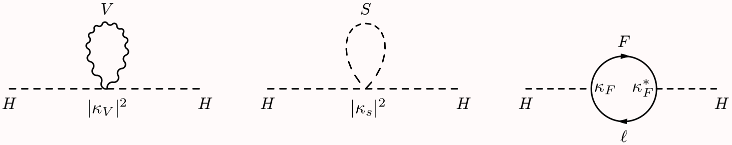

$\downarrow$ integrating it out

threshold matching contributions at $E \ll m_i$

[loops in DR+$\overline{MS}$ in the lim $v/m_i \to 0$]

$$\Delta V(H^\dagger H) \simeq H^\dagger H \left(\frac{3|\kappa_v|^2 \; m_v^2 \; N_v}{16\,\pi^2} + \frac{|\kappa_s|^2 \; m_s^2 \; N_s}{16\,\pi^2} - \frac{|\kappa_F|^2 \; m_F^2 \; N_F}{16\,\pi^2} \right) + \ldots$$

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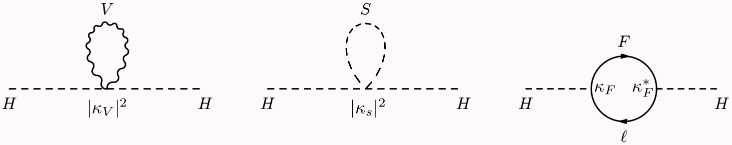

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these corrections are always proportional to the scale integrated out

$\rightarrow$ one of the main complications when UV completing the potential

Traditional solutions

Common approaches:

(a) SUSY way: extra symmetry to **force cancellations** among thresholds

(b) Composite way: shift symmetry to protect $H^\dagger H$

$\downarrow$

potential **generated radiatively**. Gives: $m^2 \sim \frac{g_{SM}^2}{4\pi^2}\Lambda^2 \quad \lambda \sim \frac{g_{SM}^2}{8\pi^2}\frac{\Lambda^2}{f^2}$

Bellazzini,Csáki,Serra 1401.2457

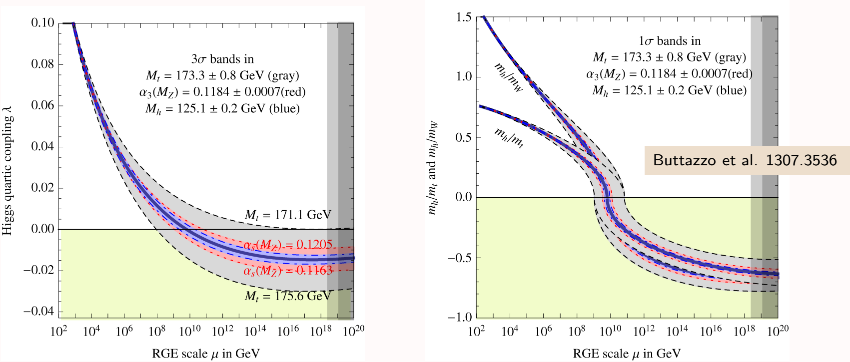
Main problem. to be natural, both require new physics close to the TeV.

If no new physics is found in this region $\rightarrow$ additional fine tuning required!

Trying to change perspective

Having measured the Higgs mass opens new possibilities!

An important one: controlling the running of the potential to very high energies.



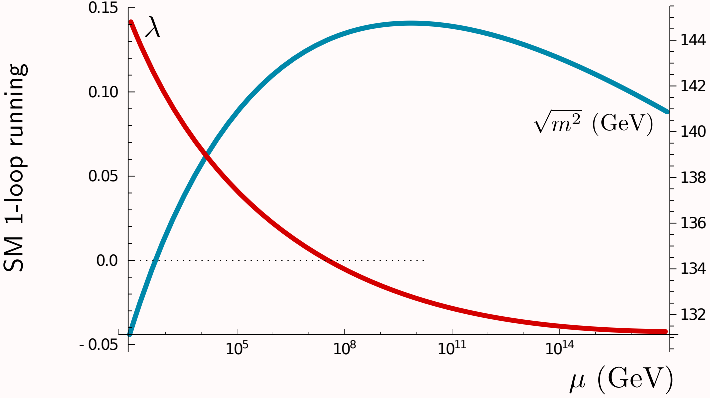
We can move the stabilization problem from the TeV to a much higher scale

- evade the problem of missing discoveries
- λ runs to 0 $\rightarrow$ maybe easier theoretically?

The key idea

have some very heavy UV set the initial conditions at a high scale

interesting region: where $\lambda \sim 0$: $\mu \sim 10 - 100$ PeV



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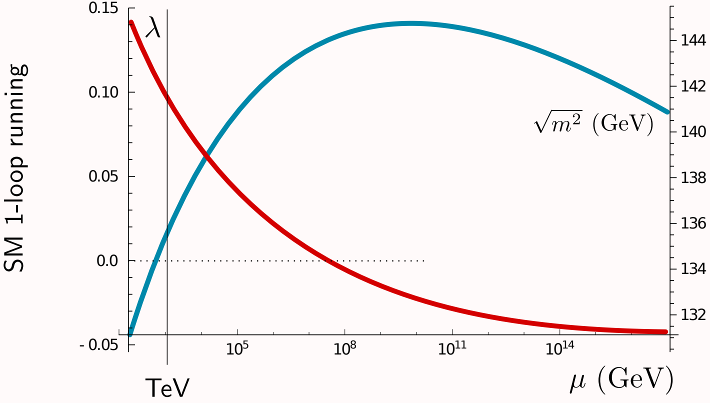

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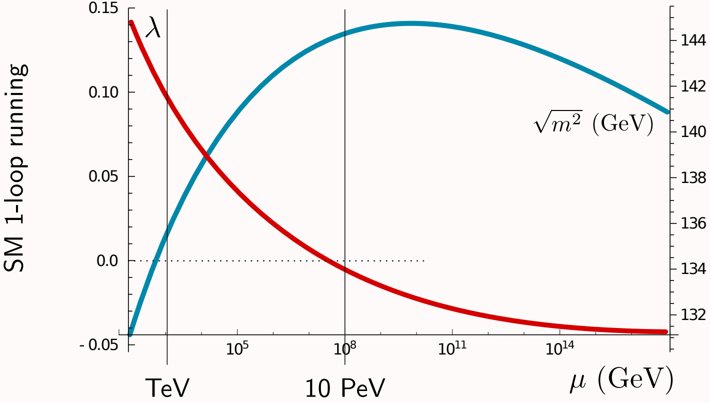

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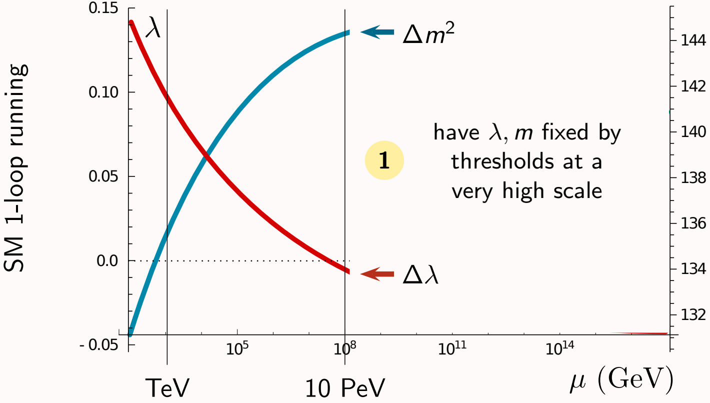

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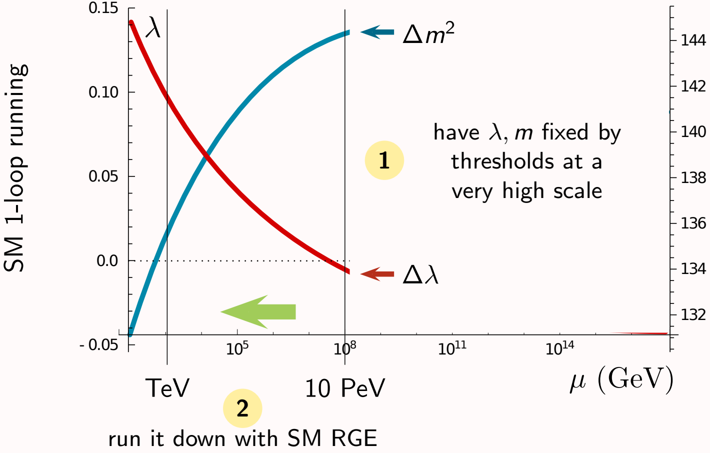


A compelling case: type I seesaw

minimal extension of the SM: adds 3 heavy Majorana neutrinos $N \equiv N^c$

$$\mathcal{L}_N = \frac{1}{2}\overline{N}(i\partial\!\!\!/ - M)N - \frac{1}{2}\left[\overline{N}\omega^* \tilde{H}^T \ell_L^c + \overline{N}\omega \tilde{H}^\dagger \ell_L + \text{h.c.}\right]$$

integrating out the N gives the Weinberg operator: $\frac{1}{2}(\bar{\ell}_L^c \omega^T \tilde{H}^*) M^{-1} (\tilde{H}^\dagger \omega \ell_L)$

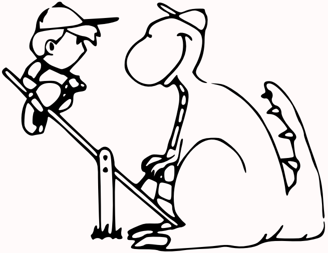
$\rightarrow$ light neutrino masses $\boxed{m_\nu = \frac{v^2}{2}\omega^T M^{-1}\omega}$

Minkowski 1977
Gell-Mann,Ramond,Slansky 1979
Mohapatra,Senjanovic 1980
Yanagida 1980

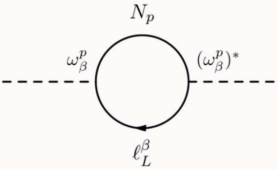
2 free quantities:

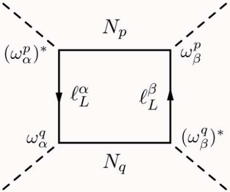
$M = \mathrm{diag}(M_1, M_2, M_3)$

ω a 3×3 matrix in flavor space



❶ Thresholds from the seesaw





$$\Delta\, m^2 = M_p^2 \frac{|\omega_p|^2}{8\,\pi^2} \qquad\qquad \Delta\,\lambda = -5\frac{(\omega_q\cdot\omega^{p,\star})(\omega_p\cdot\omega^{q,\star})}{64\,\pi^2}.$$

Vissani hep-ph/9709409
Casas et al hep-ph/9904295

We need to assume these are the dominant contributions to λ, m^2 at $\mu \simeq M$

- nearly-vanishing potential at $\mu \gtrsim M$:
  approximate scale invariance + explicit breaking only from Majorana mass
- threshold contributions **from other NP** are subdominant wrt these
- **SM contributions** to the Coleman-Weinberg potential are also smaller.
  OK for $M|\omega| \gg v, \Lambda_{QCD}$.

❷ Running down

Coupled differential system

- **1-loop SM RGE** for $\{\lambda,\ m^2,\ Y_t,\ g_1,\ g_2,\ g_3\}$
- 1-loop **boundary conditions** ($\sim$ degenerate N_p)

$$\lambda(M) = \boxed{-9\frac{5}{64\pi^2}|\omega|^4} \qquad m^2(M) = \boxed{\frac{3|\omega|^2}{8\pi^2}M^2}$$

$$Y_t(m_t) = 0.9460 \qquad g_1(m_t) = 0.3668$$

$$g_2(m_t) = 0.6390 \qquad g_3(m_t) = 1.1671$$

solve for $\left|\begin{array}{l} \lambda(m_t) = 0.127 \\ m^2(m_t) = (132.2\,\mathrm{GeV})^2 \end{array}\right.$ $\rightarrow$ "best-fit" values for $M, |\omega|$

Test: this fixes the m_ν scale. Can we get realistic values?

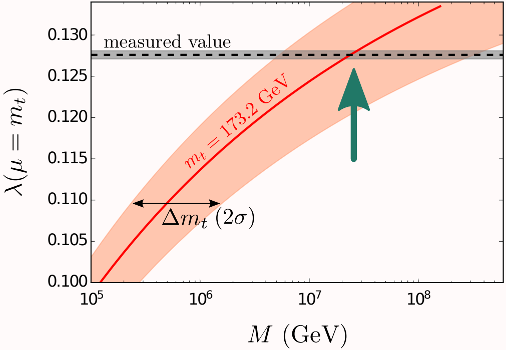
Results

$\lambda(m_t)$ is not sensitive to $|\omega|$ but depends significantly on M

$\downarrow$

best fit $M \simeq 10^{7.4}$ GeV $\simeq$ 25 PeV

! large uncertainty due to m_t



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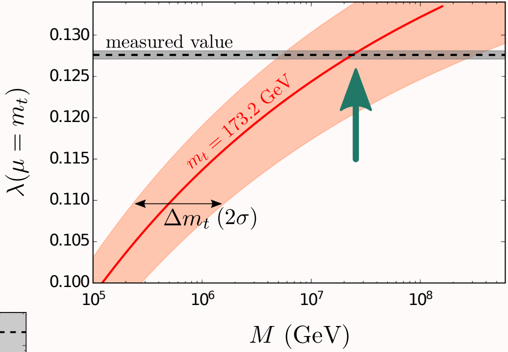

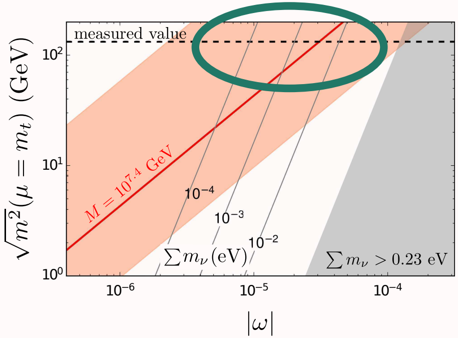

with fixed M, $m^2(m_t)$ determines uniquely $|\omega| \simeq 10^{-4.5}$

$\downarrow$

$$\sum |m_\nu| = \frac{3|\omega|^2}{2} \frac{v^2}{M} \simeq 3 \cdot 10^{-3} \text{ eV}$$

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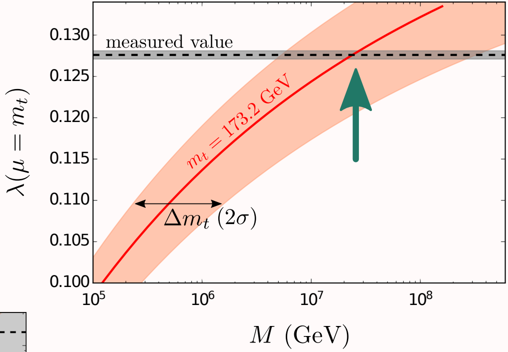

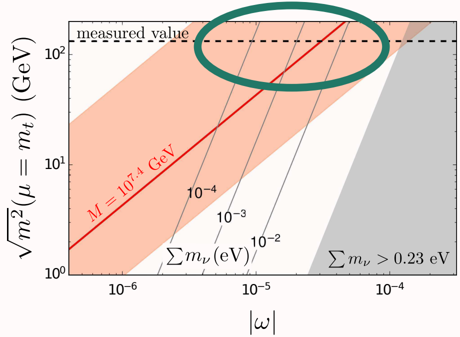

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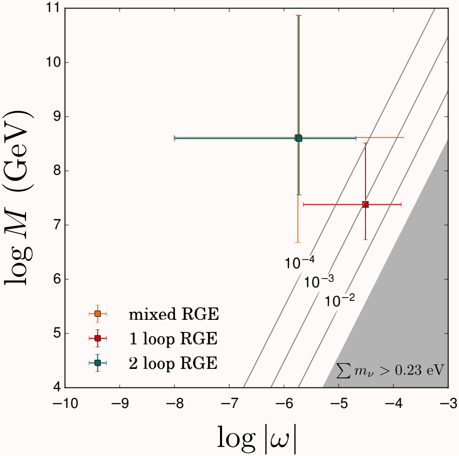
The neutrino option: troubles

- High **numerical sensitivity** to top mass + RGE order
- No leptogenesis in this scenario (needs $|\omega| \gtrsim 10^{-4}$)
  Davoudiasl,Lewis 1404.6260
- No BSM signatures predicted (besides ν masses) up to the PeV
- Does NOT solve the hierarchy problem



New challenge:

construct a UV leading to

Majorana masses + quasi-conformal potential at the PeV scale

The neutrino option: good points

- it's minimal
- λ, m^2, m_ν can <u>all</u> be generated with the correct values
- neutrino mass splittings and mixing can be accommodated!
  (adjusted with additional parameters)
- ties the **breaking of scale invariance** with that of the **lepton number**
  $\rightarrow$ SM terms are accidentally protected!
- no BSM signatures predicted (besides ν masses) up to the PeV
- the key idea of generating the potential at high scale is general!
  Can be applied to other UVs