Functional matching of a heavy scalar singlet onto the type-I seesaw and the Higgs potential

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Motivation

- There have been no definite signs of new physics at the LHC or with presision experiments
- Conventional beyond the Standard Model (BSM) theories are under pressure.
- Thus, alternative ideas are worth investigating.
- One alternative idea is **generating the Standard Model Higgs potential using radiative corrections in the type-I seesaw model**.
- This has been called the neutrino option and was originally realized at a ultra high energy scale (~PeV) [1].
- Although the neutrino option starts with the usual seesaw Lagrangian, the tree-level Higgs potential is required to vanish in the UV limit.
- To meet that requirement **we propose starting from a classically scale invariant model that introduces a new real scalar singlet for neutrino masses**

Our Classically Scale Invariant Model

- We start with a classically scale-invariant model that introduces a new real scalar singlet plus the type-I seesaw.
- The **new scalar can serve multiple roles**, as a dark matter portal, or being related to some global B-L symmetry, etc.

$$\mathcal{L}_{\rm UV} \subset \mathcal{L}_{\rm SM} + \mathcal{L}_{\rm SH} + \mathcal{L}_N + \cdots ,$$

Scale Invariance

$$\mathcal{L}_{\rm SH} = \frac{1}{2}\partial_\mu S \partial^\mu S + (D_\mu H)^\dagger (D^\mu H) - \lambda_H (H^\dagger H)^2 - \frac{1}{4}\lambda_S S^4 - \frac{1}{2}\lambda_{\rm HS} S^2 (H^\dagger H)$$

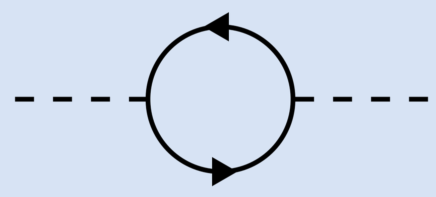
Real Scalar Singlet

- After the scalar acquires a vacuum expectation value (vev) a mass scale is set for the Higgs and right-handed neutrinos

$$\mathcal{L}_N = \frac{i}{2}\overline{N_R}\, \partial\!\!\!/ N_R - \left(\overline{L} y_\nu \tilde{H} \frac{1+\gamma_5}{2} N_R + \frac{1}{2} N_R^T C y_M S N_R + {\rm h.c.}\right) .$$

Type-I Seesaw → **Neutrino masses, Electroweak hierarchy, SMEFT, etc ...**

How the usual neutrino option generates the Higgs potential

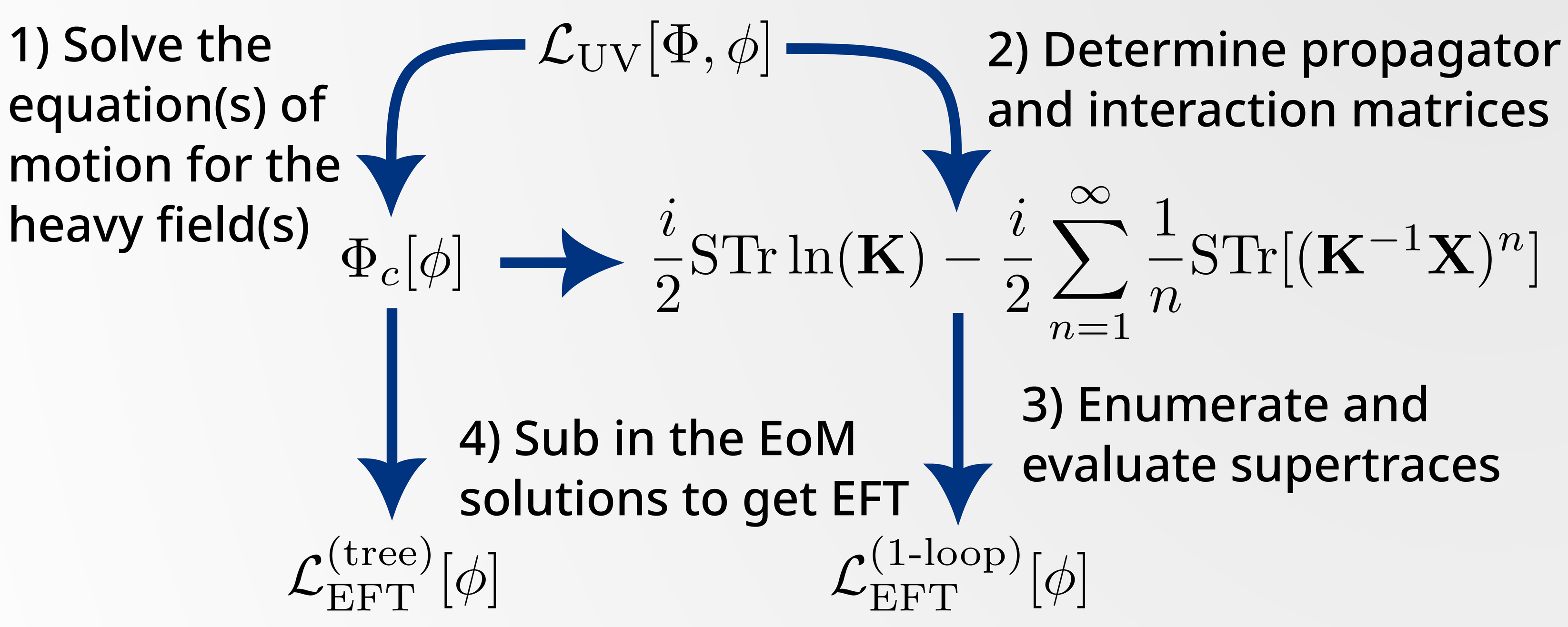


- After S acquires a vacuum expectation value (vev) we integrate out the real scalar and the right-handed neutrinos.

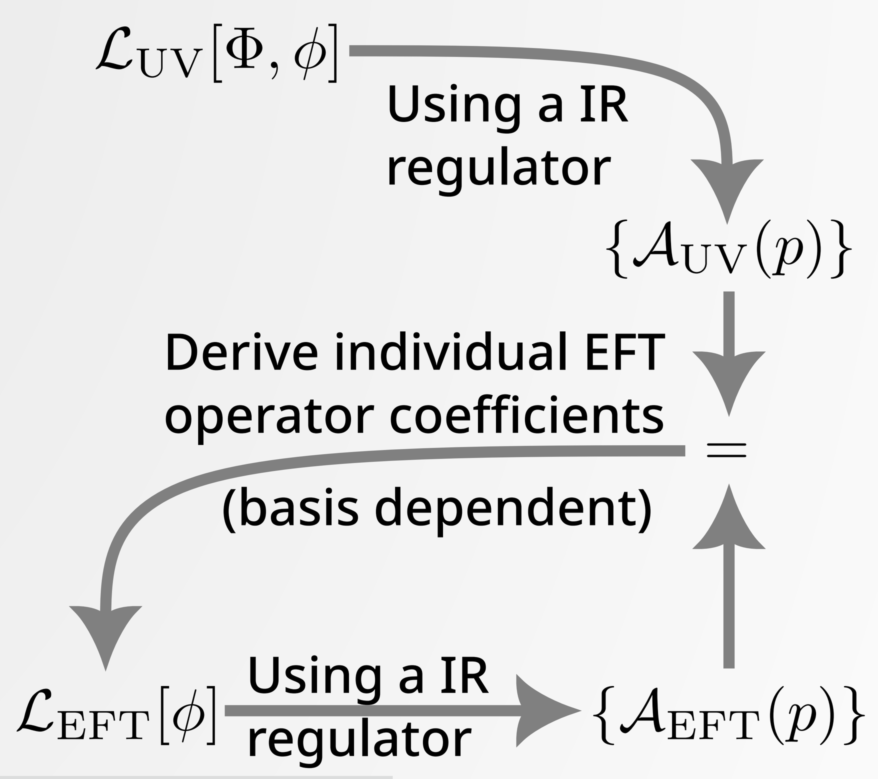
Functional Matching

- Because we are interested in mulitiple EFT operators, it is simplier to use functional matching to calculate the one-loop and tree effects

New Functional Matching method using 1PI actions [2]



Usual amplitude matching using Feynman diagrams



Example Supertrace Calculation and Conclusions

- We evalute the supertraces we use the Mathematica package SuperTracer [3]. For example the simplest supertrace is,

Higgs Mass generated by the scalar

$$-\frac{i}{2}{\rm STr}\left[\frac{1}{K_S}X^{[2]}_{SS}\right] = \int d^dx \frac{1}{16\pi^2}\left[\frac{1}{4}m_S^2\lambda_{HS}\left(1+\log\frac{\mu^2}{m_S^2}\right)(H^\dagger H + H^T H^*) + m_S^3\left(1+\log\frac{\mu^2}{m_S^2}\right) + \frac{3}{2}m_S^2\lambda_S\left(1+\log\frac{\mu^2}{m_S^2}\right)s^2 + 3v_S m_S^4\lambda_S\left(1+\log\frac{\mu^2}{m_S^2}\right)s\right]$$

Corrections to the Higgs quartic coupling after using the EoM solution for *s*

$$-\frac{i}{2}{\rm STr}\left[\frac{1}{K_N}X^{[1]}_{NL}\frac{1}{K_L}X^{[1]}_{LN}\right]$$

Supertrace responsible for generating the Higgs Mass by the heavy neutrino

- Combing that with the neutrino supertrace generates the Higgs potential.
- Taking the MS-bar scheme at the matching scale where s acquires a vev, $\mu_1 \sim \mu_2 = v_S e^{-3/4}$

$$(16\pi^2)(\delta m_H^2)_{\rm s} \equiv \frac{1}{2}\lambda_{HS}m_S^2\left(1+\log\frac{\mu_1^2}{m_S^2}\right) + \cdots$$

$$(16\pi^2)(\delta m_H^2)_{\rm n} \equiv -2(y_\nu^\dagger y_\nu)M_n^2\left(1+\log\frac{\mu_2^2}{M_n^2}\right)$$

Same result as the neutrino option

- **Conclusion: we can use functional matching as an effective method to integrate out heavy particles.**
- **This allows us to effectively study how the Higgs potential is generated between the scalar and the neutrinos in detail**
- In the future, we plan to use the supertraces to constrain our model by matching to the dimension 6 operators of SMEFT

References:
[1] I. Brivio and M. Trott, Phys. Rev. Lett. 119, 141801 (2017).
[2] T. Cohen, X. Lu, and Z. Zhang; J. High Energ. Phys. 2021, 228 (2021).
[3] J. Fuentes-Martín, M. König, J. Pagès, A. E. Thomsen, and F. Wilsch; J. High Energ. Phys. 2021, 281 (2021).

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