# The Higgs Inverse Problem

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One of the primary goals of future colliders is to make precise measurements of Standard Model processes, with the hope of discovering new physics. The SM effective field theory (SMEFT) framework is useful for parameterizing new physics effects in terms of coefficients of higher dimension operators containing only SM fields, $\mathcal{L} = \mathcal{L}_{SM} + \sum_i \frac{C_i}{\Lambda^2}\mathcal{O}_i^6 + \ldots$ The SMEFT provides a consistent, gauge-invariant theoretical interpretation of the data and connects Higgs data with electroweak precision observables (EWPO) at the $Z$ and $W$ poles, diboson data, and top quark measurements.

In this note, we discuss how measurements of SMEFT coefficients at the LHC can give information on underlying high scale physics scenarios[1]. Weakly interacting models make predictions for the SMEFT coefficients at the high scale, $C_i(\Lambda)$, and typically only a small subset of the possible dimension-6 operators are generated [2, 3] and the models predict particular relationships between the different coefficients. Renormalization group evolution can be used to evolve the coefficients to the weak scale and this evolution typically generates further non-zero SMEFT coefficients. At the weak scale, limits can be obtained from global fits and we explore the differences that result from fitting with the particular patterns from a specific model, as opposed to general values of the coefficients.

We consider 2 simple example models: A singlet model that generates the operators $\mathcal{O}_H$ and $\mathcal{O}_{H\Box}$ at tree level in the Warsaw basis[4] and a model with a vector-like doublet of heavy quarks, $(TB)$, that couple only to the third generation quarks. When the heavy fermions are degenerate, $M_T \sim M_B$, the $(TB)$ model generates tree level SMEFT operators in the pattern,

$$C_{Hb} = -C_{Ht} = \frac{1}{2}C_{Htb} = \frac{C_{th}}{Y_t} = \frac{C_{bH}}{Y_b}\,, \tag{1}$$

where $Y_f = \sqrt{2}m_f/v$. At one-loop, $\mathcal{O}_{HG}$ is also generated, with $\frac{v^2}{\Lambda^2}C_{HG} \sim \frac{\alpha_s}{8\pi}(s_R^b)^2(.32)$ for $M_T = 1\,TeV$. The mixing between the heavy quarks and the Standard Model $(t, b)$ is controlled by a mixing angle $s_R^b$.

A global fit to $C_H$ and $C_{H\Box}$, assuming all other operators vanish (as in the singlet model) is shown on the LHS of Fig. 1. $\mathcal{O}_{H\Box}$ leads to a universal suppression of the Higgs couplings by a factor of $\cos\theta$ and these shifts are constrained by LHC data. In addition, a non-zero $\mathcal{O}_{H\Box}$ at the matching scale generates the operators $\mathcal{O}_{HD}$, $\mathcal{O}_{Hq}^{(1)}$, and $\mathcal{O}_{Hq}^{(3)}$ at the weak scale, yielding shifts to the EWPOs proportional to $\log(\Lambda/M_Z)$. The magenta curve shows allowed values in the $Z_2$ symmetric model for a heavy scalar mass of 1 $TeV$, while the cyan and yellow curves show allowed values in the singlet model without the $Z_2$ symmetry. It is obvious that most of the parameter space in the figure cannot be generated by the model.

We consider the global fit in the context of the $(TB)$ model in the center curve in Fig. 1. The coefficients at the matching scale are taken in the pattern generated by the model (Eq. 1) and then evolved to the weak scale using the renormalization group evolution. We see that, even including all of these correlations, the EWPO constraint sets a superior bound to the Higgs plus diboson data. The parameters generated by the model for $M_T = M_B = 1\ TeV$ are shown in the magenta line. Allowing for a nonzero mass splitting of $M_T - M_B = 10\ GeV$ shifts the theoretically generated region to the yellow line, which is excluded by the fit.

An interesting feature of our work is the importance of the renormalization group evolution of the coefficients on the interpretation of the fits. If a model predicts coefficients at the matching scale that generates operators through renormalization group evolution that are constrained by EWPOs or diboson data, then these coefficients are strongly constrained. This suggests that redoing the study with complete one-loop matching would be of interest.

On the RHS of Fig. 1, we summarize our SMEFT results in terms of the physical parameters of some example models and show the maximum allowed mixing angle from the global fits in each model as a function of the mass of the heavy particles. We note that these are the limits in the SMEFT where the heavy particles have been integrated out of the UV complete model. The fits are sensitive to the ratios $C_i/\Lambda^2$, modulo the logarithmic dependence from the renormalization group running.

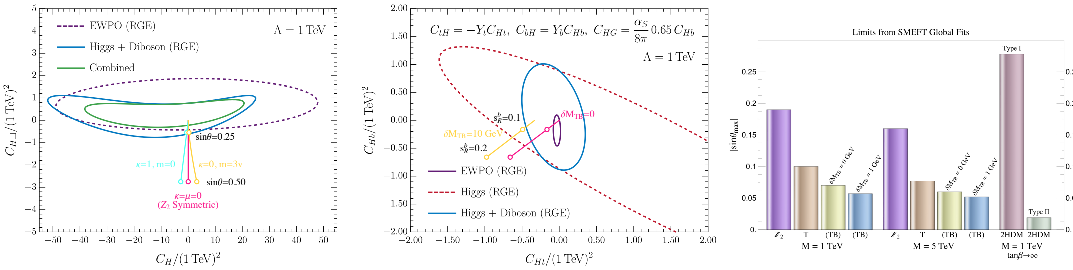


FIG. 1: LHS: 95% C.L. limits on the Wilson coefficients $C_{H\Box}$ and $C_H$ generated at the matching scale. The magenta, cyan, and yellow curves show combinations generated by the singlet model assuming a $Z_2$ symmetry, and with $\kappa = 1, m = 0$, and $\kappa = 0, m = 3v$, respectively. The open circles indicate the point along the curve with $\sin\theta = 0.25, 0.50$. Middle: 95% confidence level limits on $C_{Ht}$ and $C_{Hb}$ when the other coefficients are set to the correlated values of the $(T\,B)$ VLQ model with $M_T = M_B$ at the matching scale and including RG evolution of the coefficients to $M_Z$. The magenta and yellow lines correspond to predictions for the coefficients with $\delta M_{TB} = 0$ and $\delta M_{TB} = 10$ GeV. The coefficients on the axes are evaluated at $\Lambda = 1\,\text{TeV}$. RHS: Summary of limits on singlet model, $T$ VLQ model, and $(TB)$ VLQ model from a global fit to SMEFT coefficients.

Our study is just the beginning of an understanding of the discrimination between UV theories from SMEFT fits and future work will examine the capabilities of various proposed colliders to discriminate between test models using global SMEFT fits. It also is of considerable interest to expand our study by examining the fits for more complicated models and to understand the numerical implications of keeping only the linear SMEFT terms.


[1] S. Dawson, S. Homiller, and S. D. Lane, "Putting SMEFT Fits to Work," arXiv:2007.01296 [hep-ph].

[2] J. de Blas, J. Criado, M. Perez-Victoria, and J. Santiago, "Effective description of general extensions of the Standard Model: the complete tree-level dictionary," *JHEP* **03** (2018) 109, arXiv:1711.10391 [hep-ph].

[3] B. Henning, X. Lu, and H. Murayama, "How to use the Standard Model effective field theory," *JHEP* **01** (2016) 023, arXiv:1412.1837 [hep-ph].

[4] A. Dedes, W. Materkowska, M. Paraskevas, J. Rosiek, and K. Suxho, "Feynman Rules for the Standard Model Effective Field Theory in $R_\xi$-gauges," arXiv:1704.03888 [hep-ph].