correspondence between models & EFT

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motivation

what is the corresponding effective field theory for a certain model

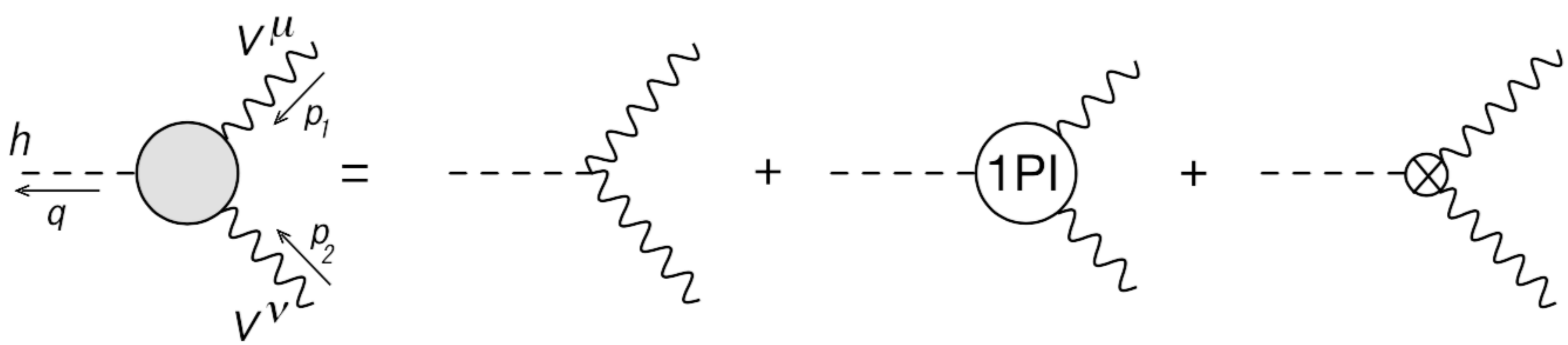
how do the EFT operators depend on the mass of new particles

how would the EFT break down

what would be the strategy if EFT is invalid

a first step

look at effective hZZ coupling in models: SM, HSM, 2HDM



renormalized hZZ vertex can be decomposed into 3 form factors

$$\hat{\Gamma}^{\mu\nu}_{hVV}(p_1^2, p_2^2, q^2) = g^{\mu\nu}\hat{\Gamma}^1_{hVV} + \frac{p_1^\mu p_2^\nu}{m_V^2}\hat{\Gamma}^2_{hVV} + i\epsilon^{\mu\nu\rho\sigma}\frac{p_{1\rho}p_{2\sigma}}{m_V^2}\hat{\Gamma}^3_{hVV}$$

the three Γs, which are usually functions of (p_i^2,q^2), can be calculated numerically by H-Coup (arXiv:1710.04603)

a first step

if we start from EFT Lagrangian for hZZ coupling

$$\delta\mathcal{L} = (1+a)\frac{m_Z^2}{v} h Z_\mu Z^\mu + b\frac{h}{2v} Z_{\mu\nu} Z^{\mu\nu} + \tilde{b}\frac{h}{2v} Z_{\mu\nu}\tilde{Z}^{\mu\nu}$$

$$Z_{\mu\nu} = \partial_\mu Z_\nu - \partial_\nu Z_\mu$$

$$\tilde{Z}_{\mu\nu} = \frac{1}{2}\epsilon_{\mu\nu\rho\sigma} Z^{\rho\sigma}$$

let's focus on CP-even terms for now

vertex from a-term: $g^{\mu\nu}\frac{2m_Z^2}{v}(1+a)$

vertex from b-term: $(g^{\mu\nu} p_1 \cdot p_2 - p_1^\mu p_2^\nu)\frac{2b}{v}$

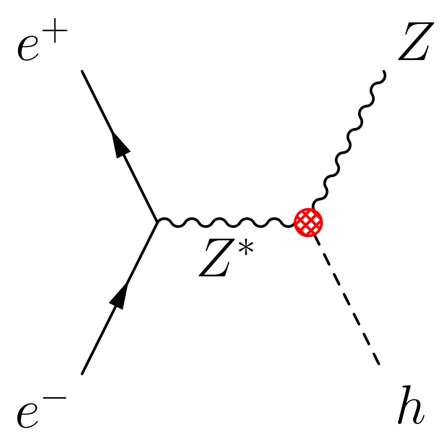
a first step

by comparing the vertices in two approaches:

$$\hat{\Gamma}^1_{hZZ} = \frac{2m_Z^2}{v}(1+a) + p_1 \cdot p_2 \frac{2b}{v}$$

$$\hat{\Gamma}^2_{hZZ} = -\frac{2m_Z^2}{v} b$$

in case of



$$p_1 = (\sqrt{s}, \mathbf{0})$$

$$p_2 = (E_Z, \mathbf{p}_Z)$$

$$a = \frac{v}{2m_Z^2}\hat{\Gamma}^1 + \frac{\sqrt{s}E_Z v}{2m_Z^4}\hat{\Gamma}^2 - 1$$

$$b = -\frac{v}{2m_Z^2}\hat{\Gamma}^2$$

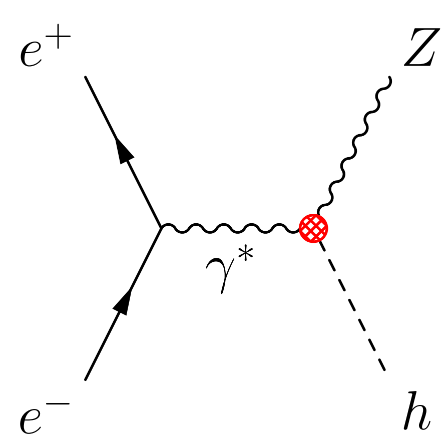
(first EFT correspondence…)

questions to theorists

1. is there any problem in this naive correspondence?

2. how to deal with the imaginary part of Γ^i (in H-Coup)?

3. if we add s-channel photon diagram, can we obtain the similar decomposed hγZ vertices in H-Coup? (there seems now only partial width for h->γZ)



numerical results by H-COUP

$$\hat{\Gamma}^{\mu\nu}_{hVV}(p_1^2, p_2^2, q^2) = g^{\mu\nu}\hat{\Gamma}^1_{hVV} + \frac{p_1^\mu p_2^\nu}{m_V^2}\hat{\Gamma}^2_{hVV} + i\epsilon^{\mu\nu\rho\sigma}\frac{p_{1\rho}p_{2\sigma}}{m_V^2}\hat{\Gamma}^3_{hVV}$$

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Re[rGam_hZZ(1)]:    6.63606456E+01    Im[rGam_hZZ(1)]:   -1.55052694E+00
Re[rGam_hZZ(2)]:   -1.13818683E-01    Im[rGam_hZZ(2)]:   -9.24725320E-01
Re[rGam_hZZ(3)]:    4.43306800E-03    Im[rGam_hZZ(3)]:   -2.48999837E-06
Re[rGam_hWW(1)]:    5.31463661E+01    Im[rGam_hWW(1)]:   -1.41296896E+00
Re[rGam_hWW(2)]:   -9.76599594E-02    Im[rGam_hWW(2)]:   -9.09232189E-01
Re[rGam_hWW(3)]:    1.45357025E-03    Im[rGam_hWW(3)]:   -4.38354919E-02
Re[rGam_htt(S)]:   -7.26874884E-01    Im[rGam_htt(S)]:   -1.08793467E-03
Re[rGam_hbb(S)]:   -1.88039217E-02    Im[rGam_hbb(S)]:    7.78472272E-05
Re[rGam_hcc(S)]:   -5.13690642E-03    Im[rGam_hcc(S)]:   -3.68162893E-05
Re[rGam_hll(S)]:   -6.98376220E-03    Im[rGam_hll(S)]:   -1.90054055E-04
   Re[rGam_hhh]:   -1.84513810E+02       Im[rGam_hhh]:    1.67554069E+00
 Gam(h->gamgam):    9.07406501E-06
   Gam(h->Zgam):    6.30760961E-06
     Gam(h->gg):    1.90735956E-04
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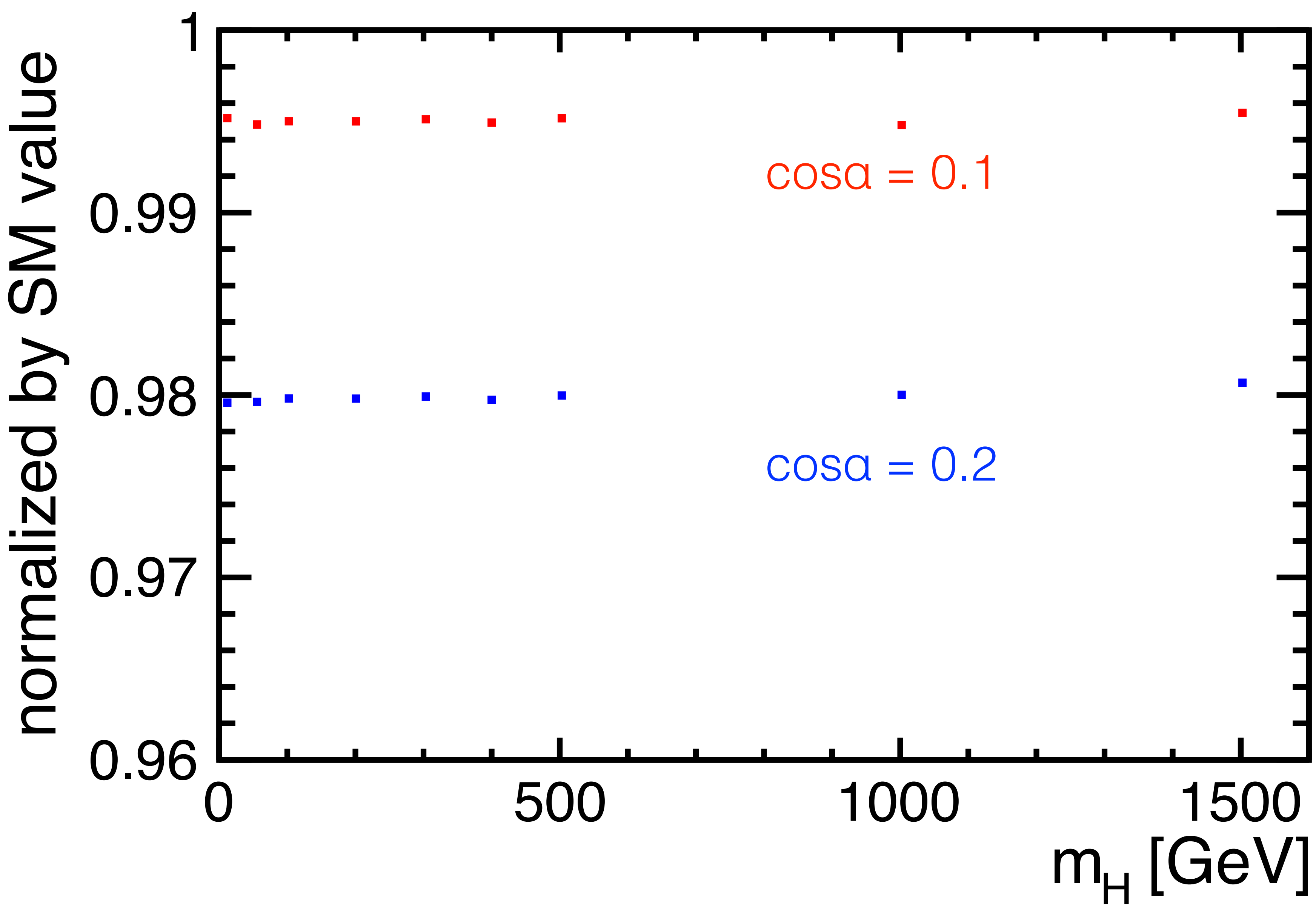
arXiv:1710.04603

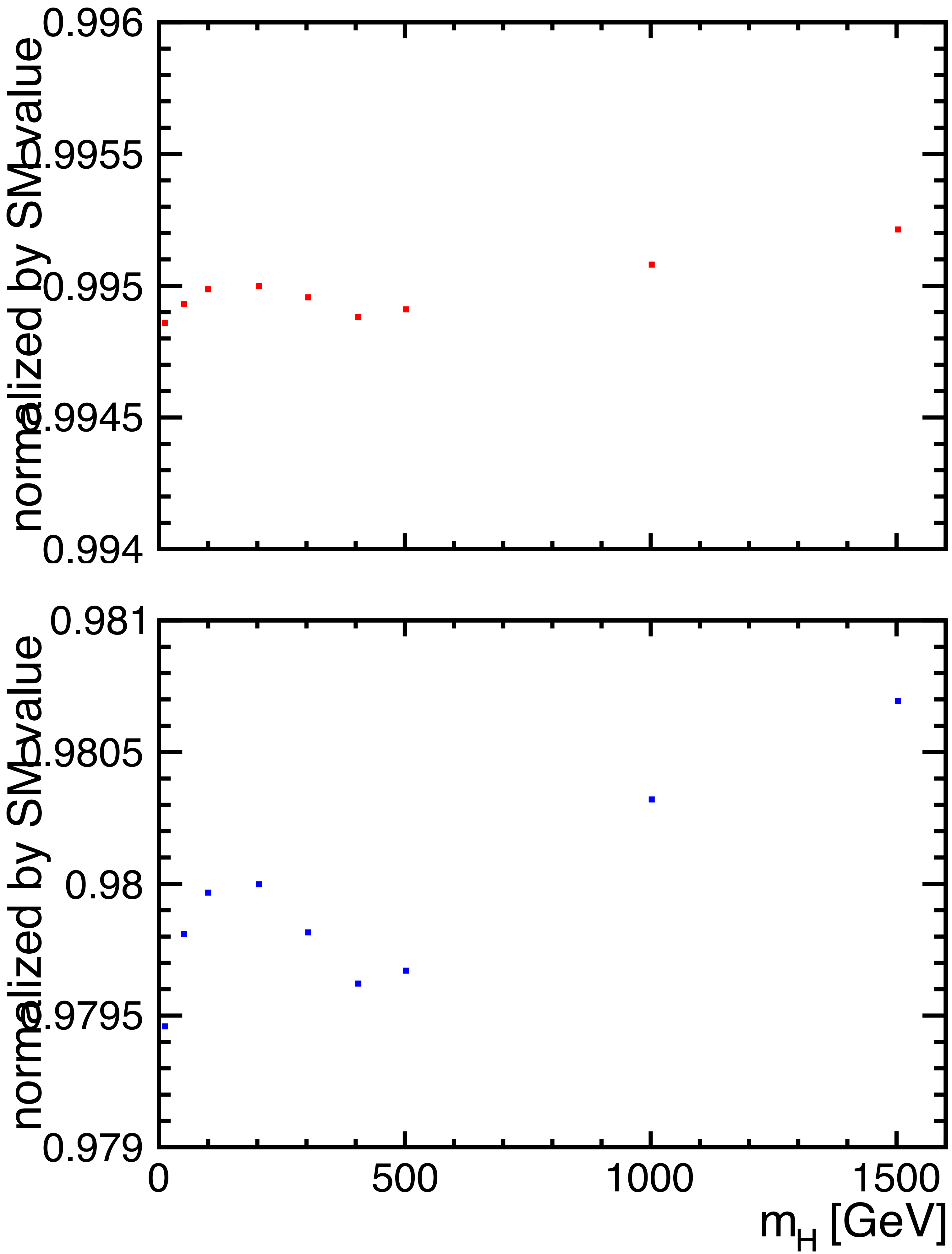
FIG. 3: Example of the output file (out_hsm.txt).

some preliminary results: HSM

$$\frac{\hat{\Gamma}^1}{\hat{\Gamma}^1_{\rm SM}}$$ (real part)



α: mixing angle



0.996
0.9955
0.995
0.9945
0.994
normalized by SM-value
0.981
0.9805
0.98
0.9795
0.979
normalized by SM-value
0
500
1000
1500
m_H [GeV]

some preliminary findings & next

1. there seems existing simple correspondence between models and EFT, in the case of e+e- -> Zh in terms of hZZ couplings

2. in HSM, at least for certain model parameters, EFT for hZZ is valid even when the mass scale of the additional Higgs boson is very light

3. going to study four-point function (e.g. eeZh contact interaction), and its dependence on mass scale

4. byproduct: in addition to Γ^1, which was usually used to test the deviation, at the ILC we expect good sensitivity to Γ^2 or Γ^3 as well

backup

model: HSM

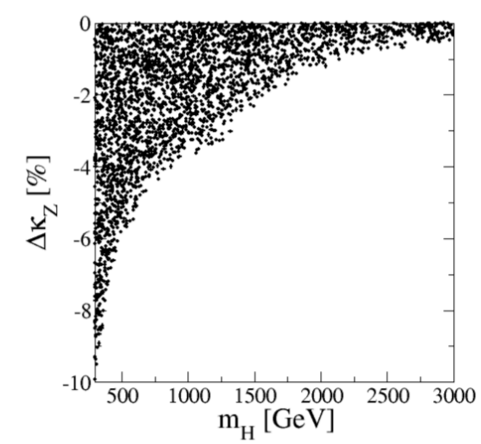
arXiv:1710.04603

$$V(\Phi, S) = m_\Phi^2|\Phi|^2 + \lambda|\Phi|^4 + \mu_{\Phi S}|\Phi|^2 S + \lambda_{\Phi S}|\Phi|^2 S^2 + t_S S + m_S^2 S^2 + \mu_S S^3 + \lambda_S S^4,$$

$$\begin{pmatrix} s \\ \phi \end{pmatrix} = R(\alpha) \begin{pmatrix} H \\ h \end{pmatrix} \quad \text{with} \quad R(\theta) = \begin{pmatrix} c_\theta & -s_\theta \\ s_\theta & c_\theta \end{pmatrix}.$$

Their squared masses and the mixing angle α are expressed as

$$m_H^2 = M_{11}^2 c_\alpha^2 + M_{22}^2 s_\alpha^2 + M_{12}^2 s_{2\alpha},$$
$$m_h^2 = M_{11}^2 s_\alpha^2 + M_{22}^2 c_\alpha^2 - M_{12}^2 s_{2\alpha},$$
$$\tan 2\alpha = \frac{2M_{12}^2}{M_{11}^2 - M_{22}^2},$$



where the mass matrix elements M_{ij}^2 are given by

$$M_{11}^2 = 2m_S^2 + v^2\lambda_{\Phi S}, \quad M_{22}^2 = 2\lambda v^2, \quad M_{12}^2 = v\mu_{\Phi S}.$$

As a result, there are the following 5 input free parameters in the HSM:

$$m_H, \quad \alpha, \quad \lambda_S, \quad \lambda_{\Phi S}, \quad \mu_S.$$