Precision Higgs Couplings in Neutral Naturalness Models: an Effective Field Theory Approach

Based on :

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[Arxiv:2007.15021]

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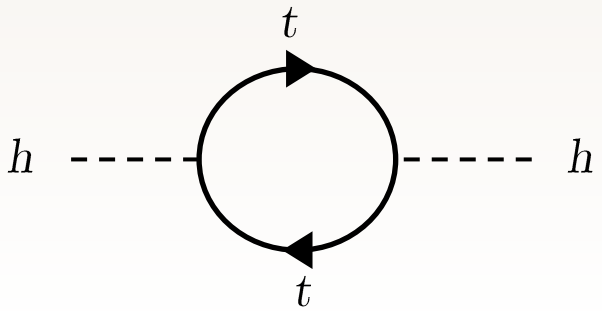
The need for a UV sector

Although the SM has been very successful so far experimentally speaking…

→ **Cosmology** suggests the existence of physics BSM

→ The **Hierarchy problem** remains the biggest weakness of the SM…



$\delta m_h^2 \propto y^2 \Lambda^2$

Solutions to the Hierarchy Problem

Supersymmetry,
Composite Higgs models

→ Coloured top partners @ TeV undiscovered...
Little Hierarchy Pbm

Alternative : Neutral Naturalness Models

→ Partners do not need be coloured under the SM SU(3)

→ Mirror QCD' sector

→ SM higgs = pNGB from the breaking of global sym.

→ Loop corrections cancelled by some discrete symmetry

Experimental Probes

- Modification of the SM Higgs couplings
- Heavy Higgs (radial mode) and mirror fermions
- Invisible Higgs decay

Future Higgs Factories

→ Production of about 10^6 Higgs boson

→ Test SM couplings up to the $\mathcal{O}(0.1)\%$ level

Our Goal

Searches of the heavy Higgs in NN naturalness models consider it as a dynamical d.o.f.

[Z. Chacko *et. al.*, Phys. Rev. D97 (2018)][A. Ahmed, JHEP 02 (2018) 048].

What if the UV scale is out of reach for future colliders?

Derive an EFT for the SM Higgs boson at $E_{EW} \ll f$

Perform a global fit to the Higgs coupling precision measurements at current and future colliders

Our Set Up

$$\mathcal{L}_S = (D_\mu \mathcal{H})^\dagger (D^\mu \mathcal{H}) - V_{sym}(\mathcal{H}) - V_{break}(\mathcal{H}),$$

Cosets	p	n
Twin Higgs	4	4
SO6/SO5	2	4
SO5/SO4	1	4

$$V_{sym} = -\mu^2 |\mathcal{H}|^2 + \lambda |\mathcal{H}|^4 ,$$
$$V_{break} = +\mathcal{H}^\dagger \mathbf{m}^2 \mathcal{H} + \left| \mathcal{H}^\dagger \boldsymbol{\delta} \mathcal{H} \right|^2 .$$

$$H \equiv \begin{pmatrix} \Pi_2 + i\Pi_1, \\ \Pi_4 - i\Pi_3 \end{pmatrix}$$

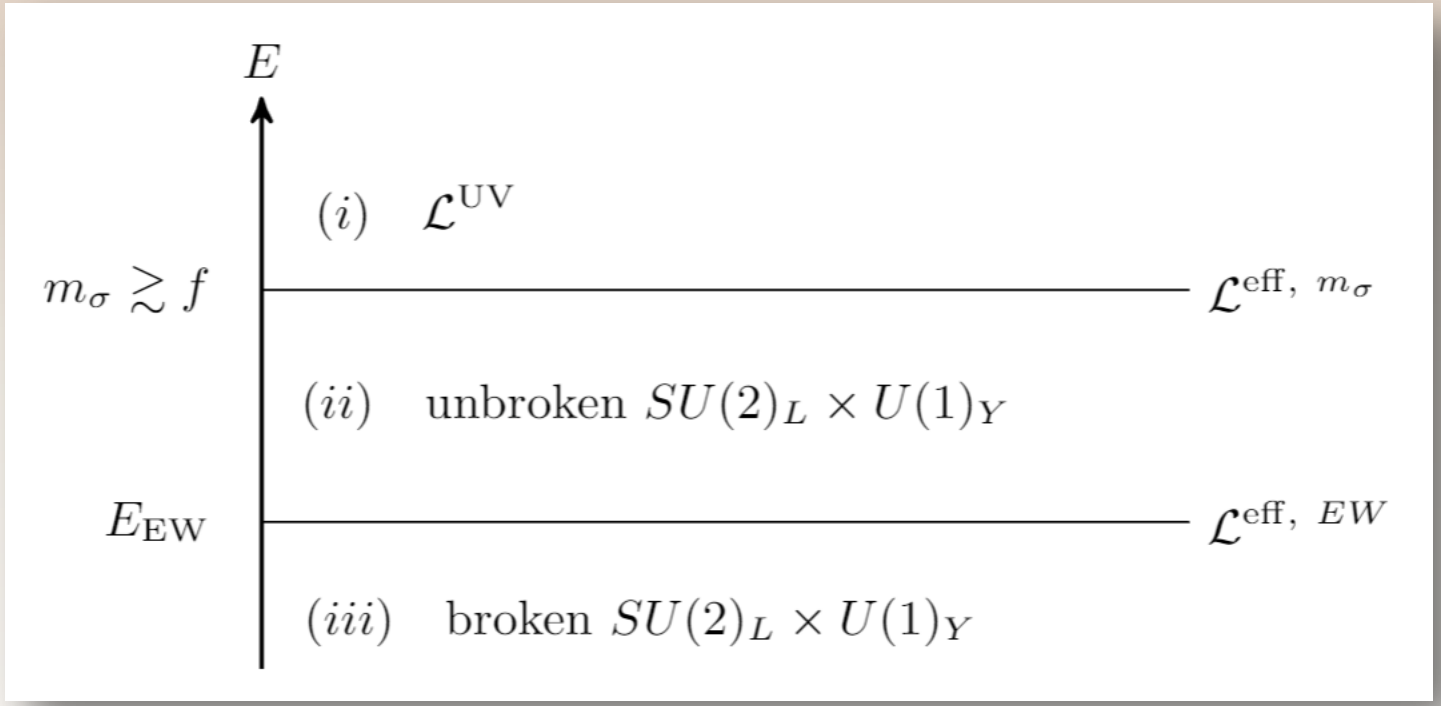
$$\mathcal{H} = \left(f + \frac{\sigma}{\sqrt{2}} \right) e^{i \frac{\sqrt{2}\Pi_a T^{\hat{a}}}{f}} \Phi$$

$$\mathbf{m}^2 = \begin{pmatrix} m^2 1_{n\times n} & 0 \\ 0 & -m^2 1_{p\times p} \end{pmatrix}, \quad \boldsymbol{\delta} = \begin{pmatrix} \sqrt{\delta} 1_{n\times n} & 0 \\ 0 & -i\sqrt{\delta} 1_{p\times p} \end{pmatrix}$$

$$\Phi = (0, \ldots, 0, 1)^T$$

$$\mathcal{L}_F \supset \left(f + \frac{\sigma}{\sqrt{2}} \right) \left[\lambda_t \bar{\Psi}_L \mathcal{U} \Psi_R + \tilde{\lambda}_t \bar{\tilde{\Psi}}_L \mathcal{U} \tilde{\Psi}_R \right] + h.c.$$

Methodology



Methodology

E

$$\mathcal{L}_S = (D_\mu \mathcal{H})^\dagger (D^\mu \mathcal{H}) - V_{sym}(\mathcal{H}) - V_{break}(\mathcal{H}),$$

$$V_{sym} + V_{break} = \left(f + \frac{\sigma}{\sqrt{2}}\right)^2 \left(-\mu^2 - m^2 \cos\frac{2|H|}{f}\right) + \left(f + \frac{\sigma}{\sqrt{2}}\right)^4 \left(\lambda + \delta - \frac{\delta}{2}\sin^2\frac{2|H|}{f}\right)$$

$$\mathcal{L}_F^{\mathrm{UV}} \supset \left(f + \frac{\sigma}{\sqrt{2}}\right)\left[\lambda_t \frac{\bar{Q}_L H^c t_R}{|H|}\sin\left(\frac{|H|}{f}\right) + \tilde{\lambda}_t \bar{\tilde{t}}_L \tilde{t}_R \cos\left(\frac{|H|}{f}\right) + h.c.\right]$$

m_σ

Integrate Out the Radial Mode

Methodology

E

m_σ

Integrate Out the Radial Mode

$$\mathcal{L}_S^{\text{eff},\, m_\sigma} = |D_\mu^A H|^2 - V^{\text{eff},m_\sigma}$$
$$= |D_\mu^A H|^2 + \mu_H^2 |H|^2 - \lambda_H |H|^4 + \frac{c_H}{2f^2}\mathcal{O}_H + \frac{c_6}{f^2}\mathcal{O}_6$$

$$\mathcal{O}_H \equiv (\partial_\mu |H|^2)^2\,, \qquad \mathcal{O}_6 \equiv |H|^6$$

$$\mu_H^2 = 2\delta f^2 - 2m^2\,, \quad \lambda_H = 2\delta + \frac{4m^4}{f^2 m_\sigma^2} - \frac{8\delta m^2}{m_\sigma^2}$$

$$c_H = \frac{1}{2} + \frac{4m^2}{m_\sigma^2} - \frac{8\delta f^2}{m_\sigma^2}\,, \quad c_6 = \frac{16m^2}{45f^2} - \frac{16\delta}{45}$$

$$\mathcal{L}_F^{\text{eff},\, m_\sigma} \supset \left[\lambda_t \bar{Q}_L H^c t_R + \tilde{\lambda}_t \bar{\tilde{t}}_L \tilde{t}_R f \left(1 - \frac{|H|^2}{2f^2} + \frac{|H|^2}{f^2}\left(\frac{4\delta f^2}{m_\sigma^2} - \frac{2m^2}{m_\sigma^2}\right)\right) + h.c.\right]$$

RGE

E_{EW}

Methodology

E

m_σ

$$\lambda_t(m_\sigma) = \tilde{\lambda}_t(m_\sigma), \quad g_S(m_\sigma) = \tilde{g}_S(m_\sigma) \quad \text{and} \quad g_2(m_\sigma) = \tilde{g}_2(m_\sigma)$$

$$\frac{dV_F(H_c,t)}{dt} = \frac{3}{16\pi^2}\left[M_t^4(H_c,t) + M_{\tilde{t}}^4(H_c,t)\right],$$

$$V_{gauge}(H_c,t) = -\frac{3}{64\pi^2}\left[2M_W^4(H_c) + M_Z^4(H_c) + 3M_{\tilde{W}}^4(H_c)\right]t\,.$$

$$V_S(H_c,t) = -\frac{1}{64\pi^2}\left[M_H(H_c)\right]^4 t = -\frac{1}{64\pi^2}\left[-\frac{1}{2}\mu_H^2 + \frac{3}{2}\lambda_H h_c^2 - \frac{15c_6}{8f^2}h_c^4\right]^2 t\,.$$

$$V^{\text{full}}(H_c,t) = V^{\text{eff},m_\sigma}(H_c) + V^{\text{RGE}}(H_c,t)\,,$$

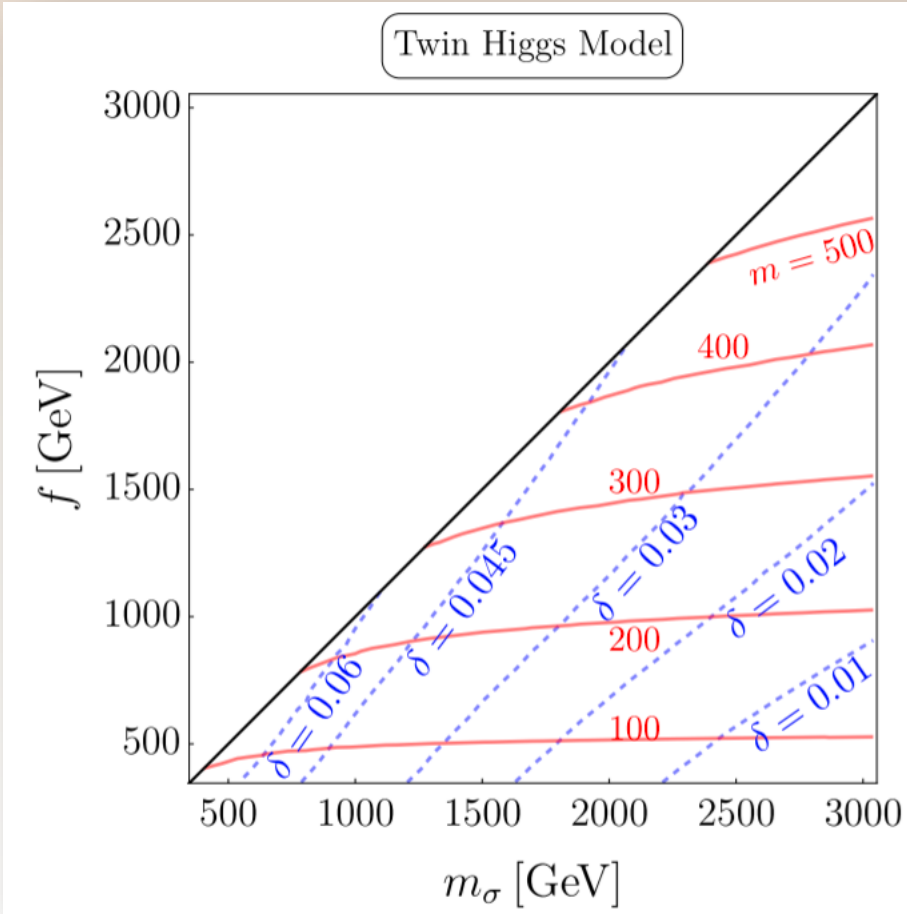
$$V^{\text{RGE}}(H_c,t) = V_S(H_c,t) + V_{gauge}(H_c,t) + V_F(H_c,t)\,,$$

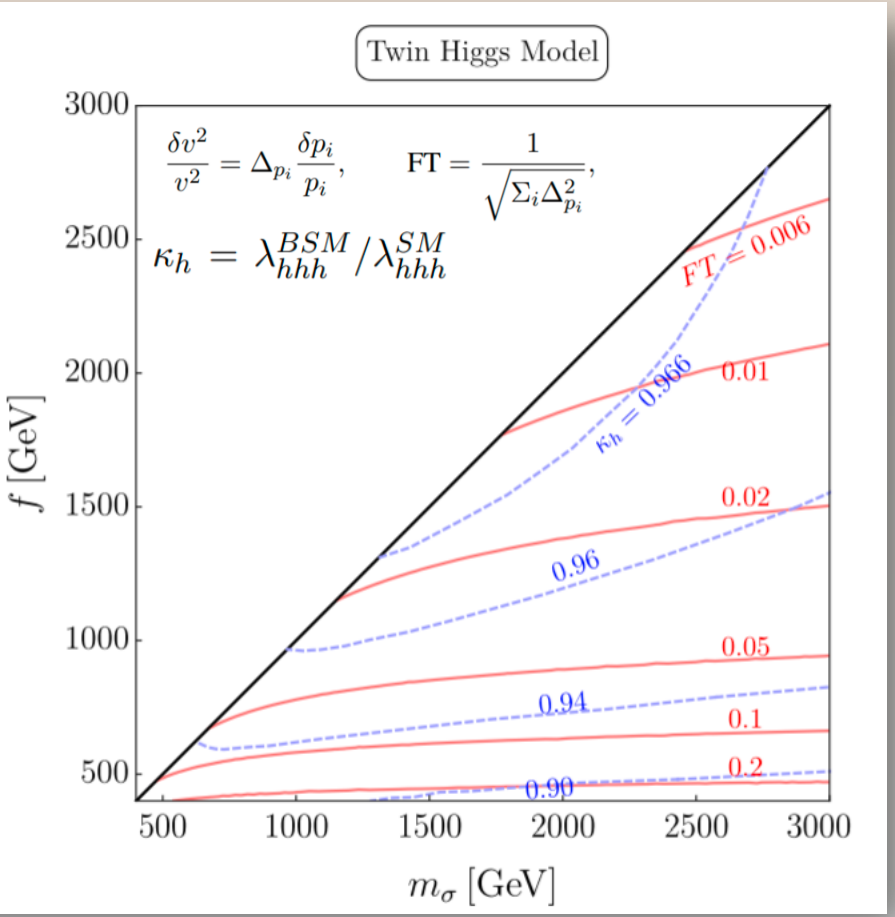
RGE

E_{EW}

Methodology

$$(f, m_\sigma, \delta, m) \xrightarrow{m_h = 125\ \text{GeV},\ v = 246\ \text{GeV}} (f, m_\sigma)$$

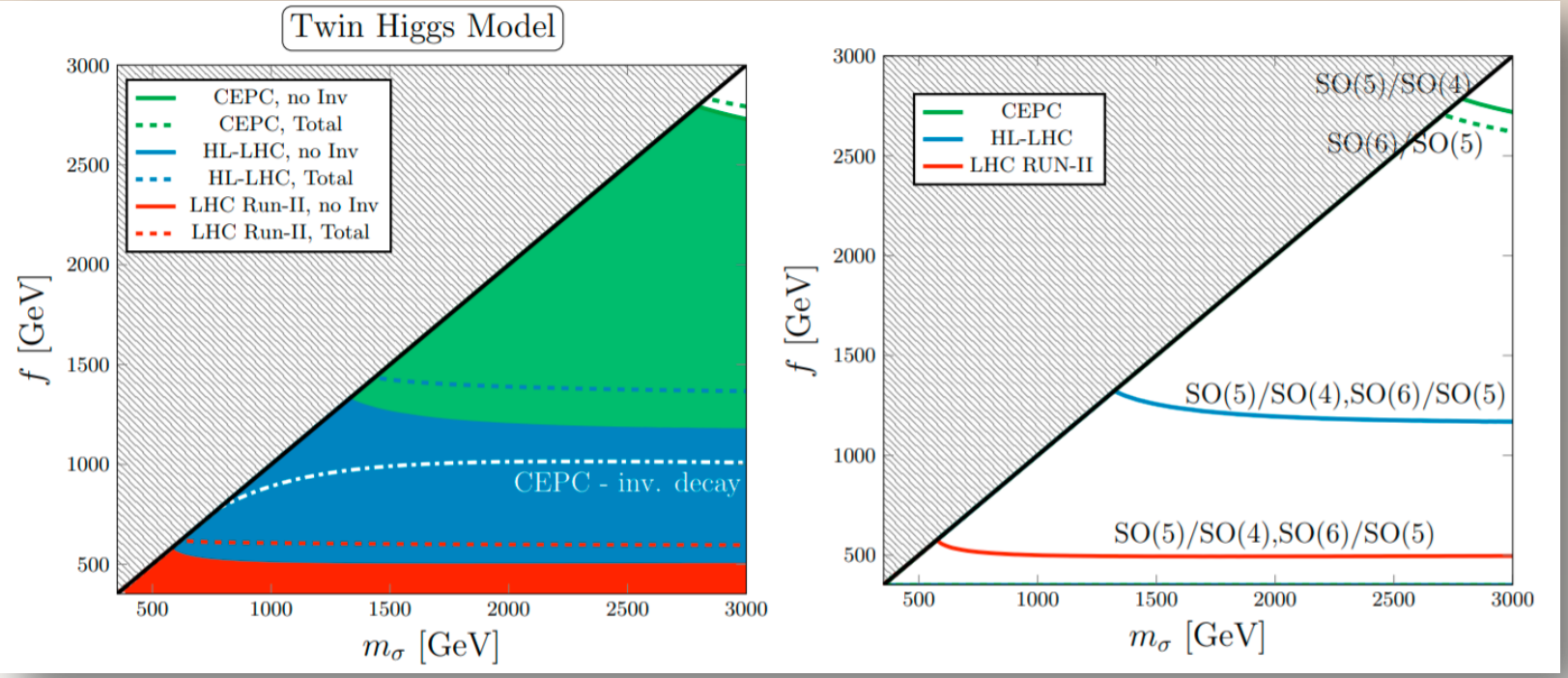




Global Fit Results

$$\Delta\chi^2 = \chi^2 - \chi^2_{\text{min}} \leqslant 5.99$$

$$\chi^2 = \Sigma_i \frac{(\mu_i^{\text{BSM}} - \mu_i^{\text{obs}})^2}{\sigma_{\mu_i}^2} + \frac{(\Sigma_i \text{Br}_i^{\text{Inv,BSM}} - \text{Br}^{\text{Inv,obs}})^2}{(\sigma_{\text{BR}^{\text{Inv}}})^2}$$



$\text{BR}_{\text{Inv}} < 30\%$ for the current LHC Run-II, 4.6% at HL-LHC and 0.3% at CEPC

Summary

- New prospections in order to constraint Neutral Naturalness scenarioswith coset structure SO(N)/SO(N-1) using Higgs factories
- CEPC limits compete with HL-LHC
- Taking into account the Higgs invisible branching ratio improves the constraints in the Twin Higgs case
- The method could be applied to other UV sectors of physics in order to constrain High Energy models with precision measurements

Backup

pNGB Higgs + Discrete Symm

Global Symmetry	Discrete Symmetry
(Composite)Twin Higgs (SO8/SO7) hep-ph0506256, arXiv: 0811.0394	Mirror Z_2 hep-ph0506256, arXiv: 0811.0394,1810.07704
Brother Higgs (SO6/SO5) arXiv:1709.05399, 1709.08636	Left-Right Z_2 arXiv: 1904.05359
Minimal Neutral Natraulness (SO5/SO4) arXiv: 1810.01882	Collective symmetry breaking hep-ph0612048, arXiv: 1402.2987,1410.8413

[Table from Hao-Lin Li]

coset	D_μ^A	D_μ^B
twin Higgs SU(4)/SU(3)	$\partial_\mu 1_{2\times 2} - ig\frac{\sigma^\alpha}{2}W_\mu^\alpha - i\frac{g'}{2}B_\mu$	$\partial_\mu 1_{2\times 2} - i\tilde{g}\frac{\sigma^\alpha}{2}\tilde{W}_\mu^\alpha - i\frac{\tilde{g}'}{2}\tilde{B}_\mu$
twin Higgs SO(8)/SO(7)	$\partial_\mu 1_{4\times 4} - igt_L^\alpha W_\mu^\alpha - ig't_R^3 B_\mu$	$\partial_\mu 1_{4\times 4} - i\tilde{g}t_L^\alpha \tilde{W}_\mu^\alpha - i\tilde{g}'t_R^3 \tilde{B}_\mu$
SO(5)/SO(4)	$\partial_\mu 1_{4\times 4} - igt_L^\alpha W_\mu^\alpha - ig't_R^3 B_\mu$	$\partial_\mu 1_{1\times 1}$
SO(6)/SO(5)	$\partial_\mu 1_{4\times 4} - igt_L^\alpha W_\mu^\alpha - ig't_R^3 B_\mu$	$\partial_\mu 1_{2\times 2} - i\tilde{g}_1\frac{\sigma^2}{\sqrt{2}}\tilde{B}'_\mu$

Table 5. Covariant derivative in different models.