Matching Higgs pseudo observables to effective couplings

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1 Higgs pseudo-observables (HiggsPO)

When working at the leading order, the pseudo-observables defined in [1, 2] are in one-to-one correspondence with the following effective interactions:

$$
\begin{aligned}
\mathcal{L}^{\text{eff}}_{\text{HPO}} = & \, \kappa_{ZZ} \frac{m_Z^2}{v} Z_\mu Z^\mu h + \kappa_{WW} \frac{2m_W^2}{v} W^+_\mu W^{-\,\mu} h + \\
& - \epsilon_{\gamma\gamma} \frac{h}{2v} A_{\mu\nu} A^{\mu\nu} - \epsilon_{Z\gamma} \frac{h}{v} Z_{\mu\nu} A^{\mu\nu} - \epsilon_{ZZ} \frac{h}{2v} Z_{\mu\nu} Z^{\mu\nu} - \epsilon_{WW} \frac{h}{v} W^+_{\mu\nu} W^{-\,\mu\nu} + \\
& - \epsilon^{\text{CP}}_{\gamma\gamma} \frac{h}{2v} A_{\mu\nu} \widetilde{A}^{\mu\nu} - \epsilon^{\text{CP}}_{Z\gamma} \frac{h}{v} Z_{\mu\nu} \widetilde{A}^{\mu\nu} - \epsilon^{\text{CP}}_{ZZ} \frac{h}{2v} Z_{\mu\nu} \widetilde{Z}^{\mu\nu} - \epsilon^{\text{CP}}_{WW} \frac{h}{v} W^+_{\mu\nu} \widetilde{W}^{-\,\mu\nu} + \\
& + \sum_f \sum_i \epsilon_{Zf_i} \frac{2h}{v} Z_\mu \bar{f}^i \gamma^\mu f^i + \\
& + \sum_{i,j} \left[\epsilon_{We^{ij}} \frac{2h}{v} W^+_\mu \bar{\nu}_{e^i L} \gamma^\mu e^j_L + \epsilon_{Wu^i_L d^j_L} \frac{2h}{v} W^+_\mu \bar{u}^i_L \gamma^\mu d^j_L + \epsilon_{Wu^i_R d^j_R} \frac{2h}{v} W^+_\mu \bar{u}^i_R \gamma^\mu d^j_R + \text{h.c.} \right] ,
\end{aligned}
\tag{1}
$$

where $f = e_L, e_R, \nu_L, u_L, u_R, d_L, d_R$ and $i, j = 1 \ldots 3$ are flavour indices. Moreover $V_{\mu\nu} = \partial_\mu V_\nu - \partial_\nu V_\mu$ and $\widetilde{V}^{\mu\nu} = \frac{1}{2}\epsilon^{\mu\nu\rho\sigma} V_{\rho\sigma}$.

The PO in the last row are complex while all the others are real (in the limit where we neglect re-scattering effects due to light-quark loops). If the Higgs is a parity-even state and CP is conserved, then all couplings are real and all the ϵ^{CP}_X vanish.

The PO describing the on-shell vertices of SM vector bosons to two fermions correspond to the leading-order Lagrangian

$$
\begin{aligned}
\mathcal{L}^{\text{eff}}_{Vff} = & \sum_f \sum_i g_Z^{f_i} \, Z_\mu \bar{f}^i \gamma^\mu f^i + \\
& + \sum_{i,j} \left[(g_W^{e_L})_{ij} \, W^+_\mu \bar{\nu}_{e^i L} \gamma^\mu e^j_L + (g_W^{q_L})_{ij} \, W^+_\mu \bar{u}^i_L \gamma^\mu d^j_L + (g_W^{q_R})_{ij} \, W^+_\mu \bar{u}^i_R \gamma^\mu d^j_R + \text{h.c.} \right] .
\end{aligned}
\tag{2}
$$

For some of the PO in eq. (1) it is useful to introduce the ratio with respect to the SM contribution, in particular:

$$
\begin{aligned}
\kappa_{\gamma\gamma} &\equiv \frac{\text{Re}(\epsilon_{\gamma\gamma})}{\text{Re}(\epsilon^{\text{SM}}_{\gamma\gamma})}, \qquad \delta_{\gamma\gamma} \equiv \frac{\text{Re}(\epsilon^{\text{CP}}_{\gamma\gamma})}{\text{Re}(\epsilon^{\text{SM}}_{\gamma\gamma})} , \\
\kappa_{Z\gamma} &\equiv \frac{\text{Re}(\epsilon_{Z\gamma})}{\text{Re}(\epsilon^{\text{SM}}_{Z\gamma})}, \qquad \delta_{Z\gamma} \equiv \frac{\text{Re}(\epsilon^{\text{CP}}_{Z\gamma})}{\text{Re}(\epsilon^{\text{SM}}_{Z\gamma})} ,
\end{aligned}
\tag{3}
$$

where $\epsilon^{\text{SM}}_{\gamma\gamma} = 3.8 \times 10^{-3}$ and $\epsilon^{\text{SM}}_{Z\gamma} = 6.9 \times 10^{-3}$.

2 HiggsPO — BSM Characterization Lagrangian dictionary: Tree-level matching

2.1 Expressions of the PO in terms of BSMC couplings

Computing the PO, at the tree level, in terms of the BSMC Lagrangian [3, 4] we get:

$$
\begin{aligned}
\kappa_{ZZ} &= 1 + \delta c_z + g^2 c_{z\Box} \ , \\
\kappa_{WW} &= 1 + \delta c_w + g^2 c_{w\Box} \ , \\
\epsilon_{ZZ} &= -\frac{g^2+g'^2}{2} c_{zz} \ , \qquad \epsilon^{CP}_{ZZ} = -\frac{g^2+g'^2}{2} \widetilde{c}_{zz} \ , \\
\epsilon_{Z\gamma} &= -\frac{e\sqrt{g^2+g'^2}}{2} c_{z\gamma} \ , \qquad \epsilon^{CP}_{Z\gamma} = -\frac{e\sqrt{g^2+g'^2}}{2} \widetilde{c}_{z\gamma} \ , \\
\epsilon_{\gamma\gamma} &= -\frac{e^2}{2} c_{\gamma\gamma} \ , \qquad \epsilon^{CP}_{\gamma\gamma} = -\frac{e^2}{2} \widetilde{c}_{\gamma\gamma} \ , \\
\epsilon_{WW} &= -\frac{g^2}{2} c_{ww} \ , \qquad \epsilon^{CP}_{WW} = -\frac{g^2}{2} \widetilde{c}_{ww} \ , \\
\epsilon_{Zf} &= \frac{g^3}{2c_W}\left(T^3_f - Q_f s^2_W\right) c_{z\Box} + \frac{gg'e}{2} Q_f c_{\gamma\Box} + \sqrt{g^2+g'^2}\,\delta g^{hZf}_{L,R} \ , \\
\epsilon_{We^{ij}} &= \frac{g^3}{2\sqrt{2}}(\mathbf{1} + \delta g^{W\ell}_L)_{ij} c_{w\Box} + \frac{g}{\sqrt{2}}(\delta g^{hW\ell}_L)_{ij} \ , \\
\epsilon_{Wu^i_L d^j_L} &= \frac{g^3}{2\sqrt{2}}(\mathbf{V}_{\rm CKM} + \delta g^{Wq}_L)_{ij} c_{w\Box} + \frac{g}{\sqrt{2}}(\delta g^{hWq}_L)_{ij} \ , \\
\epsilon_{Wu^i_R d^j_R} &= \frac{g^3}{2\sqrt{2}}(\delta g^{Wq}_R)_{ij} c_{w\Box} + \frac{g}{\sqrt{2}}(\delta g^{hWq}_R)_{ij} \ .
\end{aligned}
\tag{4}
$$

At the same time, we get the following contributions to the PO describing the on-shell vertices of SM vector bosons:

$$
\begin{aligned}
g^{f_{L,R}}_Z &= \sqrt{g^2+g'^2}\left(T^3_f - Q_f s^2_W + \delta g^{Zf}_{L,R}\right) \ , \\
(g^{e_L}_W)_{ij} &= \frac{g}{\sqrt{2}}(\mathbf{1} + \delta g^{W\ell}_L)_{ij} \ , \\
(g^{q_L}_W)_{ij} &= \frac{g}{\sqrt{2}}(\mathbf{V}_{\rm CKM} + \delta g^{Wq}_L)_{ij} \ , \\
(g^{q_R}_W)_{ij} &= \frac{g}{\sqrt{2}}(\delta g^{Wq}_R)_{ij} \ .
\end{aligned}
\tag{5}
$$

2.2 Expressions of the BSMC in terms of the PO

Due to the unphysical redundancies in the BSMC Lagrangian, there are multiple ways to express BSMC effective couplings in terms of the Higgs PO. We present below one such translation:

$$
\begin{aligned}
c_{z\Box} &= c_{w\Box} = c_{\gamma\Box} = 0 \ , \\
\delta c_z &= \kappa_{ZZ} - 1 \ , \\
\delta c_w &= \kappa_{WW} - 1 \ , \\
c_{zz} &= \frac{-2}{g^2+g'^2}\epsilon_{ZZ} \ , \quad \widetilde{c}_{zz} = \frac{-2}{g^2+g'^2}\epsilon_{ZZ}^{CP} \ , \\
c_{z\gamma} &= \frac{-2}{e\sqrt{g^2+g'^2}}\epsilon_{Z\gamma} \ , \quad \widetilde{c}_{z\gamma} = \frac{-2}{e\sqrt{g^2+g'^2}}\epsilon_{Z\gamma}^{CP} \ , \\
c_{\gamma\gamma} &= \frac{-2}{e^2}\epsilon_{\gamma\gamma} \ , \quad \widetilde{c}_{\gamma\gamma} = \frac{-2}{e^2}\epsilon_{\gamma\gamma}^{CP} \ , \\
c_{ww} &= \frac{-2}{g^2}\epsilon_{WW} \ , \quad \widetilde{c}_{ww} = \frac{-2}{g^2}\epsilon_{WW}^{CP} \ , \\
\delta g_{L,R}^{hZf} &= \frac{1}{\sqrt{g^2+g'^2}}\epsilon_{Zf} \ , \quad (\delta g_L^{hW\ell})_{ij} = \frac{\sqrt{2}}{g}\epsilon_{We^{ij}} \ , \\
(\delta g_L^{hWq})_{ij} &= \frac{\sqrt{2}}{g}\epsilon_{Wu_L^i d_L^j} \ , \quad (\delta g_R^{hWq})_{ij} = \frac{\sqrt{2}}{g}\epsilon_{Wu_R^i d_R^j} \ ,
\end{aligned}
\tag{6}
$$

and in addition,

$$
\begin{aligned}
(\delta g_L^{W\ell})_{ij} &= \frac{\sqrt{2}}{g}(g_W^{e_L})_{ij} - \delta_{ij} \ , \quad (\delta g_L^{Wq})_{ij} = \frac{\sqrt{2}}{g}(g_W^{q_L})_{ij} - V_{ij}^{\rm CKM} \ , \\
(\delta g_R^{Wq})_{ij} &= \frac{\sqrt{2}}{g}(g_W^{q_R})_{ij} \ , \quad \delta g_{L,R}^{Zf} = \frac{1}{\sqrt{g^2+g'^2}} g_Z^{f_{L,R}} - (T^3_{f_{L,R}} - Q_f s_W^2) \ .
\end{aligned}
\tag{7}
$$

Note that the four terms in Eq. (7) vanishes in the limit where we fix the PO describing the on-shell vertices of SM vector bosons to their SM values.

References

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