Note on HiggsCharacterization

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This note presents the Lagrangians which are implemented via FeynRules for the Higgs characterization model.

I. UPDATE HISTORY

- 2013.01.16 v1.0 released.
- 2013.04.04 v1.1: Added the CP-odd Yukawa term in the X_0 lagrangian and modified the X_2 HD Lagrangian to be proportional to $1/\Lambda_3$.
- 2013.04.12 v2.0: Fixed a bug for the X_2 lowest dimensional intereactions with massive gauge bosons. Changed the parametrization for X_0.

II. LAGRANGIANS

A. Spin 0

The spin-0 X intereaction Lagrangians with fermions and vector-bosons are given by [1]

$$\mathcal{L}_0^f = \big[c_\alpha \kappa_{Hff} g_{Hff}\, \bar\psi_f \psi_f + s_\alpha \kappa_{Aff} g_{Aff}\, \bar\psi_f i\gamma_5 \psi_f\big] X_0, \tag{1}$$

and

$$\mathcal{L}_0^V = \Bigg[c_\alpha \kappa_{\rm SM} g_{HVV}\, V_\mu V^\mu \tag{2}$$

$$- \frac{1}{4}\big[c_\alpha \kappa_{H\gamma\gamma} g_{H\gamma\gamma}\, A_{\mu\nu}A^{\mu\nu} + s_\alpha \kappa_{A\gamma\gamma} g_{A\gamma\gamma}\, A_{\mu\nu}\widetilde{A}^{\mu\nu}\big] \tag{3}$$

$$- \frac{1}{4}\big[c_\alpha \kappa_{HZ\gamma} g_{HZ\gamma}\, Z_{\mu\nu}A^{\mu\nu} + s_\alpha \kappa_{AZ\gamma} g_{AZ\gamma}\, Z_{\mu\nu}\widetilde{A}^{\mu\nu}\big] \tag{4}$$

$$- \frac{1}{4}\big[c_\alpha \kappa_{Hgg} g_{Hgg}\, G^a_{\mu\nu}G^{a,\mu\nu} + s_\alpha \kappa_{Agg} g_{Agg}\, G^a_{\mu\nu}\widetilde{G}^{a,\mu\nu}\big] \tag{5}$$

$$- \frac{1}{4}\frac{1}{\Lambda}\big[c_\alpha \kappa_{HVV}\, V_{\mu\nu}V^{\mu\nu} + s_\alpha \kappa_{AVV}\, V_{\mu\nu}\widetilde{V}^{\mu\nu}\big]\Bigg] X_0, \tag{6}$$

where $V = Z, W^\pm$, the (reduced) field strength tensors are

$$V_{\mu\nu} = \partial_\mu V_\nu - \partial_\nu V_\mu, \tag{7}$$

$$A_{\mu\nu} = \partial_\mu A_\nu - \partial_\nu A_\mu, \tag{8}$$

$$G^a_{\mu\nu} = \partial_\mu G^a_\nu - \partial_\nu G^a_\mu + g_s f^{abc} G^b_\mu G^c_\nu, \tag{9}$$

parameter	default value	description
Λ [GeV]	10^3	cutoff scale
$c_\alpha (\equiv \cos\alpha)$	1	mixing between 0^+ and 0^-
κ_i	1 or 0	dimensionless coupling parameter

TABLE I: Model parameters.

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and the dual tensor is

$$\widetilde{V}_{\mu\nu} = \frac{1}{2}\epsilon_{\mu\nu\rho\sigma}V^{\rho\sigma}. \tag{10}$$

The model paprameters in the Lagrangians, which one can change, are listed in Table II.

The couplings are

$$g_{Hff} = g_{Aff} = m_f/v, \tag{11}$$
$$g_{HVV} = 2m_V^2/v, \tag{12}$$
$$g_{H\gamma\gamma} = \alpha_{\rm EM}/\pi v * (47/18), \tag{13}$$
$$g_{A\gamma\gamma} = \alpha_{\rm EM}/\pi v, \tag{14}$$
$$g_{HZ\gamma} = \alpha_{\rm EM}/\pi v, \tag{15}$$
$$g_{AZ\gamma} = \alpha_{\rm EM}/\pi v, \tag{16}$$
$$g_{Hgg} = -\alpha_s/3\pi v, \tag{17}$$
$$g_{Agg} = -\alpha_s/2\pi v. \tag{18}$$

B. Spin 1

The spin-1 X intereaction Lagrangian with fermions is

$$\mathcal{L}_1^f = -\sum_{f=u,d}\bar{\psi}_f\gamma_\mu(\kappa_{f_a}a_f - \kappa_{f_b}b_f\gamma_5)\psi_f X_1^\mu, \tag{19}$$

where u and d denote the up-type and down-type quarks, respectively. The a_f and b_f are the SM couplings, i.e.

$$a_u = \frac{g}{2c_W}\Big(\frac{1}{2} - \frac{4}{3}s_W^2\Big), \quad b_u = \frac{g}{2c_W}\frac{1}{2}, \tag{20}$$
$$a_d = \frac{g}{2c_W}\Big(-\frac{1}{2} + \frac{2}{3}s_W^2\Big), \quad b_d = -\frac{g}{2c_W}\frac{1}{2}. \tag{21}$$

The XWW intereaction at the lowest dimension is in general [2]

$$\mathcal{L}_1^W = + i\kappa_{V_1}g_{WWZ}(W_{\mu\nu}^+W^{-\mu} - W_{\mu\nu}^-W^{+\mu})X_1^\nu \tag{22}$$
$$+ i\kappa_{V_2}g_{WWZ}W_\mu^+W_\nu^-X_1^{\mu\nu} \tag{23}$$
$$- \kappa_{V_3}W_\mu^+W_\nu^-(\partial^\mu X_1^\nu + \partial^\nu X_1^\mu) \tag{24}$$
$$+ i\kappa_{V_4}W_\mu^+W_\nu^-\widetilde{X}_1^{\mu\nu} \tag{25}$$
$$- \kappa_{V_5}\epsilon_{\mu\nu\rho\sigma}[W^{+\mu}(\partial^\rho W^{-\nu}) - (\partial^\rho W^{+\mu})W^{-\nu}]X_1^\sigma, \tag{26}$$

where $g_{WWZ} = -e\cot\theta_W$. Similarly, the XZZ interaction is given by [3]

$$\mathcal{L}_1^Z = - \kappa_{V_3}X_1^\mu(\partial^\nu Z_\mu)Z_\nu \tag{27}$$
$$- \kappa_{V_5}\epsilon_{\mu\nu\rho\sigma}X_1^\mu Z^\nu(\partial^\rho Z^\sigma). \tag{28}$$

For $X_1 = 1^-$ in parity-conserving scenarios:

$$\kappa_{f_a,V_1,V_2,V_3} \neq 0. \tag{29}$$

For $X_1 = 1^+$ in parity-conserving scenarios:

$$\kappa_{f_b,V_4,V_5} \neq 0. \tag{30}$$

JHU scenario	HC parameter choice
0_m^+	$\kappa_{Hgg} = 1,\ \kappa_{\rm SM} = 1,\ c_\alpha = 1$
0_h^+	$\kappa_{Hgg} = 1,\ \kappa_{HVV} = 1,\ c_\alpha = 1$
0^-	$\kappa_{Agg} = 1,\ \kappa_{AVV} = 1,\ c_\alpha = 0$
1^+	$\kappa_{fu_a} = 1/a_u,\ \kappa_{fu_b} = -1/b_u,\ \kappa_{fd_a} = 1/a_d,\ \kappa_{fd_b} = -1/b_d,\ \kappa_{V_5} = 1$
1^-	$\kappa_{fu_a} = 1/a_u,\ \kappa_{fu_b} = -1/b_u,\ \kappa_{fd_a} = 1/a_d,\ \kappa_{fd_b} = -1/b_d,\ \kappa_{V_3} = 1$
2_m^+	$\kappa_g = 1,\ \kappa_V = 1$
2_h^+	$\kappa_{g_1} = 1,\ \kappa_{V_1} = 1$
2_h^-	$\kappa_{g_2} = 1,\ \kappa_{V_2} = 1$

TABLE II: Parameter set for the JHU comparison; see also TABLE I in the JHU paper [9].

C. Spin 2

The spin-2 X intereaction Lagrangian starts from the dimension-five terms [4–6]:

$$\mathcal{L}_2^f = -\sum_{f=q,\ell} \frac{\kappa_f}{\Lambda} T^f_{\mu\nu} X_2^{\mu\nu}, \tag{31}$$

and

$$\begin{aligned} \mathcal{L}_2^V = &- \frac{\kappa_V}{\Lambda} T^V_{\mu\nu} X_2^{\mu\nu} & (32)\\ &- \frac{\kappa_\gamma}{\Lambda} T^\gamma_{\mu\nu} X_2^{\mu\nu} & (33)\\ &- \frac{\kappa_g}{\Lambda} T^g_{\mu\nu} X_2^{\mu\nu}, & (34) \end{aligned}$$

where $V = Z, W^\pm$ and $T^i_{\mu\nu}$ is the energy-momentum tensor of the SM fields; see e.g. [7] for the explicit forms. The even higher dimensional terms [8, 9], dimension-seven, are also implemented as

$$\begin{aligned} \mathcal{L}_2^{V_{\rm HD}} = &- \frac{\kappa_{V_1}}{\Lambda^3}(\partial_\nu(\partial_\mu \frac{1}{4} V_{\rho\sigma} V^{\rho\sigma})) X_2^{\mu\nu} & (35)\\ &- \frac{\kappa_{V_2}}{\Lambda^3}(\partial_\nu(\partial_\mu \frac{1}{4} V_{\rho\sigma} \widetilde{V}^{\rho\sigma})) X_2^{\mu\nu} & (36)\\ &- \frac{\kappa_{\gamma_1}}{\Lambda^3}(\partial_\nu(\partial_\mu \frac{1}{4} A_{\rho\sigma} A^{\rho\sigma})) X_2^{\mu\nu} & (37)\\ &- \frac{\kappa_{\gamma_2}}{\Lambda^3}(\partial_\nu(\partial_\mu \frac{1}{4} A_{\rho\sigma} \widetilde{A}^{\rho\sigma})) X_2^{\mu\nu} & (38)\\ &- \frac{\kappa_{g_1}}{\Lambda^3}(\partial_\nu(\partial_\mu \frac{1}{4} G_{\rho\sigma} G^{\rho\sigma})) X_2^{\mu\nu} & (39)\\ &- \frac{\kappa_{g_2}}{\Lambda^3}(\partial_\nu(\partial_\mu \frac{1}{4} G_{\rho\sigma} \widetilde{G}^{\rho\sigma})) X_2^{\mu\nu}, & (40) \end{aligned}$$

where $V_{\mu\nu} = \partial_\mu V_\nu - \partial_\nu V_\mu$, etc, are the reduced field strength tensor.

For $X_2 = 2^+$ in the RS-like graviton scenario:

$$\kappa_f = \kappa_V = \kappa_\gamma = \kappa_g \neq 0. \tag{41}$$

For $X_2 = 2^+$ with the higer-diminsonal operator in parity-conserving scenarios:

$$\kappa_{V_1}, \kappa_{\gamma_1}, \kappa_{g_1} \neq 0. \tag{42}$$

For $X_2 = 2^-$ with the higer-diminsonal operator in parity-conserving scenarios:

$$\kappa_{V_2}, \kappa_{\gamma_2}, \kappa_{g_2} \neq 0. \tag{43}$$

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