Singlet scalar Dark Matter
Lagrangian, Rotations and Interactions for eigenstates 'EWSB' including Renormalization Group Equations including one-loop Self-Energies

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833,2011 (1002.0840) , **Comput.Phys.Commun.181:1077-1086,2010 (0909.2863)** , **arXiv: 0806.0538**
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1 Fields

1.1 Gauge Fields

Name	$SU(N)$	Coupling	Name
B	$U(1)$	g_1	hypercharge
W	SU(2)	g_2	left
g	SU(3)	g_3	color

1.2 Matter Superfields

Name	Spin	Generations	$(U(1) \otimes \mathrm{SU}(2) \otimes \mathrm{SU}(3))$
H	0	1	$(\frac{1}{2}, \mathbf{2}, \mathbf{1})$
S	0	1	$(0, \mathbf{1}, \mathbf{1})$
q	$\frac{1}{2}$	3	$(\frac{1}{6}, \mathbf{2}, \mathbf{3})$
l	$\frac{1}{2}$	3	$(-\frac{1}{2}, \mathbf{2}, \mathbf{1})$
d	$\frac{1}{2}$	3	$(\frac{1}{3}, \mathbf{1}, \overline{\mathbf{3}})$
u	$\frac{1}{2}$	3	$(-\frac{2}{3}, \mathbf{1}, \overline{\mathbf{3}})$
e	$\frac{1}{2}$	3	$(1, \mathbf{1}, \mathbf{1})$

2 Lagrangian

2.1 Input Lagrangian for Eigenstates GaugeES

$$L = 0 \tag{1}$$

2.2 Gauge fixing terms

2.2.1 Gauge fixing terms for eigenstates 'GaugeES'

$$L_{GF} = -\frac{1}{2}|\partial_\mu B|^2 \xi_B^{-1} - \frac{1}{2}|\partial_\mu g|^2 \xi_g^{-1} - \frac{1}{2}|\partial_\mu W|^2 \xi_W^{-1} \tag{2}$$

2.2.2 Gauge fixing terms for eigenstates 'EWSB'

$$\begin{aligned} L_{GF} = &-\frac{1}{2}|\partial_\mu g|^2 \xi_g^{-1} - \frac{1}{2}|\partial_\mu \gamma|^2 \xi_\gamma^{-1} - |-\frac{i}{2} g_2 H^+ v \xi_{W^+} + \partial_\mu W^+|^2 \xi_{W^+}^{-1} \\ &-\frac{1}{2}|-\frac{1}{2} A^0 v \xi_Z \Big(g_1 \sin\Theta_W + g_2 \cos\Theta_W \Big) + \partial_\mu Z|^2 \xi_Z^{-1} \end{aligned} \tag{3}$$

2.3 Fields integrated out

None

3 Renormalization Group Equations

3.1 Gauge Couplings

$$\beta_{g_1}^{(1)} = \frac{41}{10} g_1^3 \tag{4}$$

$$\beta_{g_1}^{(2)} = \frac{1}{50} g_1^3 \Big(135 g_2^2 + 199 g_1^2 - 25 \mathrm{Tr}\Big(Y_d Y_d^\dagger \Big) + 440 g_3^2 - 75 \mathrm{Tr}\Big(Y_e Y_e^\dagger \Big) - 85 \mathrm{Tr}\Big(Y_u Y_u^\dagger \Big) \Big) \tag{5}$$

$$\beta_{g_2}^{(1)} = -\frac{19}{6} g_2^3 \tag{6}$$

$$\beta_{g_2}^{(2)} = \frac{1}{30} g_2^3 \Big(-15 \mathrm{Tr}\Big(Y_e Y_e^\dagger \Big) + 175 g_2^2 + 27 g_1^2 + 360 g_3^2 - 45 \mathrm{Tr}\Big(Y_d Y_d^\dagger \Big) - 45 \mathrm{Tr}\Big(Y_u Y_u^\dagger \Big) \Big) \tag{7}$$

$$\beta_{g_3}^{(1)} = -7 g_3^3 \tag{8}$$

$$\beta_{g_3}^{(2)} = -\frac{1}{10} g_3^3 \Big(-11 g_1^2 + 20 \mathrm{Tr}\Big(Y_d Y_d^\dagger \Big) + 20 \mathrm{Tr}\Big(Y_u Y_u^\dagger \Big) + 260 g_3^2 - 45 g_2^2 \Big) \tag{9}$$

3.2 Quartic scalar couplings

$$\beta_{LamS}^{(1)} = 4 \Big(9 LamS^2 + LamSH^2 \Big) \tag{10}$$

$$\beta_{LamS}^{(2)} = -\frac{8}{5} \Big(-15 g_2^2 LamSH^2 + 15 LamSH^2 \mathrm{Tr}\Big(Y_d Y_d^\dagger \Big) + 15 LamSH^2 \mathrm{Tr}\Big(Y_u Y_u^\dagger \Big) + 20 LamSH^3 - 3 g_1^2 LamSH^2 + 50 LamSLamS$$

(11)

$$\beta_{LamSH}^{(1)} = \frac{1}{10} LamSH \Big(120 LamS + 20 \mathrm{Tr}\Big(Y_e Y_e^\dagger \Big) - 45 g_2^2 + 60 \lambda + 60 \mathrm{Tr}\Big(Y_d Y_d^\dagger \Big) + 60 \mathrm{Tr}\Big(Y_u Y_u^\dagger \Big) + 80 LamSH - 9 g_1^2 \Big) \tag{12}$$

$$\begin{aligned}
\beta_{LamSH}^{(2)} = {} & + \frac{1671}{400} g_1^4 LamSH + \frac{9}{8} g_1^2 g_2^2 LamSH - \frac{145}{16} g_2^4 LamSH + \frac{36}{5} g_1^2 \lambda LamSH + 36 g_2^2 \lambda LamSH - 15 \lambda^2 LamSH - 120 LamS^2 La \\
& - 144 LamSLamSH^2 - 42 LamSH^3 + \frac{1}{4} \Big(-144 \lambda + 160 g_3^2 + 45 g_2^2 + 5 g_1^2 - 96 LamSH \Big) LamSH \mathrm{Tr}\Big(Y_d Y_d^\dagger \Big) \\
& + \frac{1}{4} \Big(15 g_1^2 + 15 g_2^2 - 32 LamSH - 48 \lambda \Big) LamSH \mathrm{Tr}\Big(Y_e Y_e^\dagger \Big) + \frac{17}{4} g_1^2 LamSH \mathrm{Tr}\Big(Y_u Y_u^\dagger \Big) + \frac{45}{4} g_2^2 LamSH \mathrm{Tr}\Big(Y_u Y_u^\dagger \Big) \\
& + 40 g_3^2 LamSH \mathrm{Tr}\Big(Y_u Y_u^\dagger \Big) - 36 \lambda LamSH \mathrm{Tr}\Big(Y_u Y_u^\dagger \Big) - 24 LamSH^2 \mathrm{Tr}\Big(Y_u Y_u^\dagger \Big) - \frac{27}{2} LamSH \mathrm{Tr}\Big(Y_d Y_d^\dagger Y_d Y_d^\dagger \Big) \\
& - 21 LamSH \mathrm{Tr}\Big(Y_d Y_u^\dagger Y_u Y_d^\dagger \Big) - \frac{9}{2} LamSH \mathrm{Tr}\Big(Y_e Y_e^\dagger Y_e Y_e^\dagger \Big) - \frac{27}{2} LamSH \mathrm{Tr}\Big(Y_u Y_u^\dagger Y_u Y_u^\dagger \Big)
\end{aligned} \tag{13}$$

$$\begin{aligned}
\beta_{\lambda}^{(1)} = {} & + \frac{27}{100} g_1^4 + \frac{9}{10} g_1^2 g_2^2 + \frac{9}{4} g_2^4 - \frac{9}{5} g_1^2 \lambda - 9 g_2^2 \lambda + 12 \lambda^2 + 4 LamSH^2 + 12 \lambda \mathrm{Tr}\Big(Y_d Y_d^\dagger \Big) + 4 \lambda \mathrm{Tr}\Big(Y_e Y_e^\dagger \Big) \\
& + 12 \lambda \mathrm{Tr}\Big(Y_u Y_u^\dagger \Big) - 12 \mathrm{Tr}\Big(Y_d Y_d^\dagger Y_d Y_d^\dagger \Big) - 4 \mathrm{Tr}\Big(Y_e Y_e^\dagger Y_e Y_e^\dagger \Big) - 12 \mathrm{Tr}\Big(Y_u Y_u^\dagger Y_u Y_u^\dagger \Big)
\end{aligned} \tag{14}$$

$$\beta_{\lambda}^{(2)} = -\frac{3411}{1000}g_1^6 - \frac{1677}{200}g_1^4g_2^2 - \frac{289}{40}g_1^2g_2^4 + \frac{305}{8}g_2^6 + \frac{1887}{200}g_1^4\lambda + \frac{117}{20}g_1^2g_2^2\lambda - \frac{73}{8}g_2^4\lambda + \frac{54}{5}g_1^2\lambda^2 + 54g_2^2\lambda^2$$
$$- 78\lambda^3 - 20\lambda LamSH^2 - 32LamSH^3 + \frac{1}{10}\Big(225g_2^2\lambda - 45g_2^4 + 80\Big(10g_3^2 - 9\lambda\Big)\lambda + 9g_1^4 + g_1^2\Big(25\lambda + 54g_2^2\Big)\Big)\mathrm{Tr}\Big(Y_dY_d^\dagger\Big)$$
$$- \frac{3}{10}\Big(15g_1^4 + 5\Big(16\lambda^2 - 5g_2^2\lambda + g_2^4\Big) - g_1^2\Big(22g_2^2 + 25\lambda\Big)\Big)\mathrm{Tr}\Big(Y_eY_e^\dagger\Big) - \frac{171}{50}g_1^4\mathrm{Tr}\Big(Y_uY_u^\dagger\Big)$$
$$+ \frac{63}{5}g_1^2g_2^2\mathrm{Tr}\Big(Y_uY_u^\dagger\Big) - \frac{9}{2}g_2^4\mathrm{Tr}\Big(Y_uY_u^\dagger\Big) + \frac{17}{2}g_1^2\lambda\mathrm{Tr}\Big(Y_uY_u^\dagger\Big) + \frac{45}{2}g_2^2\lambda\mathrm{Tr}\Big(Y_uY_u^\dagger\Big)$$
$$+ 80g_3^2\lambda\mathrm{Tr}\Big(Y_uY_u^\dagger\Big) - 72\lambda^2\mathrm{Tr}\Big(Y_uY_u^\dagger\Big) + \frac{8}{5}g_1^2\mathrm{Tr}\Big(Y_dY_d^\dagger Y_dY_d^\dagger\Big) - 64g_3^2\mathrm{Tr}\Big(Y_dY_d^\dagger Y_dY_d^\dagger\Big)$$
$$- 3\lambda\mathrm{Tr}\Big(Y_dY_d^\dagger Y_dY_d^\dagger\Big) - 42\lambda\mathrm{Tr}\Big(Y_dY_u^\dagger Y_uY_d^\dagger\Big) - \frac{24}{5}g_1^2\mathrm{Tr}\Big(Y_eY_e^\dagger Y_eY_e^\dagger\Big) - \lambda\mathrm{Tr}\Big(Y_eY_e^\dagger Y_eY_e^\dagger\Big)$$
$$- \frac{16}{5}g_1^2\mathrm{Tr}\Big(Y_uY_u^\dagger Y_uY_u^\dagger\Big) - 64g_3^2\mathrm{Tr}\Big(Y_uY_u^\dagger Y_uY_u^\dagger\Big) - 3\lambda\mathrm{Tr}\Big(Y_uY_u^\dagger Y_uY_u^\dagger\Big) + 60\mathrm{Tr}\Big(Y_dY_d^\dagger Y_dY_d^\dagger Y_dY_d^\dagger\Big)$$
$$+ 12\mathrm{Tr}\Big(Y_dY_d^\dagger Y_dY_u^\dagger Y_uY_d^\dagger\Big) - 24\mathrm{Tr}\Big(Y_dY_u^\dagger Y_uY_d^\dagger Y_dY_d^\dagger\Big) - 12\mathrm{Tr}\Big(Y_dY_u^\dagger Y_uY_u^\dagger Y_uY_d^\dagger\Big)$$
$$+ 20\mathrm{Tr}\Big(Y_eY_e^\dagger Y_eY_e^\dagger Y_eY_e^\dagger\Big) + 60\mathrm{Tr}\Big(Y_uY_u^\dagger Y_uY_u^\dagger Y_uY_u^\dagger\Big) \tag{15}$$

3.3 Yukawa Couplings

$$\beta_{Y_u}^{(1)} = -\frac{3}{2}\Big(-Y_uY_u^\dagger Y_u + Y_uY_d^\dagger Y_d\Big)$$
$$+ Y_u\Big(3\mathrm{Tr}\Big(Y_dY_d^\dagger\Big) + 3\mathrm{Tr}\Big(Y_uY_u^\dagger\Big) - 8g_3^2 - \frac{17}{20}g_1^2 - \frac{9}{4}g_2^2 + \mathrm{Tr}\Big(Y_eY_e^\dagger\Big)\Big) \tag{16}$$
$$\beta_{Y_u}^{(2)} = +\frac{1}{80}\Big(20\Big(11Y_uY_d^\dagger Y_dY_d^\dagger Y_d - 4Y_uY_u^\dagger Y_uY_d^\dagger Y_d + 6Y_uY_u^\dagger Y_uY_u^\dagger Y_u - Y_uY_d^\dagger Y_dY_u^\dagger Y_u\Big)$$
$$+ Y_uY_u^\dagger Y_u\Big(1280g_3^2 - 180\mathrm{Tr}\Big(Y_eY_e^\dagger\Big) + 223g_1^2 - 480\lambda - 540\mathrm{Tr}\Big(Y_dY_d^\dagger\Big) - 540\mathrm{Tr}\Big(Y_uY_u^\dagger\Big) + 675g_2^2\Big)$$
$$+ Y_uY_d^\dagger Y_d\Big(100\mathrm{Tr}\Big(Y_eY_e^\dagger\Big) - 1280g_3^2 + 300\mathrm{Tr}\Big(Y_dY_d^\dagger\Big) + 300\mathrm{Tr}\Big(Y_uY_u^\dagger\Big) - 43g_1^2 + 45g_2^2\Big)\Big)$$
$$+ Y_u\Big(\frac{1187}{600}g_1^4 - \frac{9}{20}g_1^2g_2^2 - \frac{23}{4}g_2^4 + \frac{19}{15}g_1^2g_3^2 + 9g_2^2g_3^2 - 108g_3^4 + \frac{3}{2}\lambda^2 + LamSH^2$$
$$+ \frac{5}{8}\Big(32g_3^2 + 9g_2^2 + g_1^2\Big)\mathrm{Tr}\Big(Y_dY_d^\dagger\Big) + \frac{15}{8}\Big(g_1^2 + g_2^2\Big)\mathrm{Tr}\Big(Y_eY_e^\dagger\Big) + \frac{17}{8}g_1^2\mathrm{Tr}\Big(Y_uY_u^\dagger\Big) + \frac{45}{8}g_2^2\mathrm{Tr}\Big(Y_uY_u^\dagger\Big)$$
$$+ 20g_3^2\mathrm{Tr}\Big(Y_uY_u^\dagger\Big) - \frac{27}{4}\mathrm{Tr}\Big(Y_dY_d^\dagger Y_dY_d^\dagger\Big) + \frac{3}{2}\mathrm{Tr}\Big(Y_dY_u^\dagger Y_uY_d^\dagger\Big) - \frac{9}{4}\mathrm{Tr}\Big(Y_eY_e^\dagger Y_eY_e^\dagger\Big) - \frac{27}{4}\mathrm{Tr}\Big(Y_uY_u^\dagger Y_uY_u^\dagger\Big)\Big) \tag{17}$$
$$\beta_{Y_d}^{(1)} = \frac{1}{4}\Big(6\Big(-Y_dY_u^\dagger Y_u + Y_dY_d^\dagger Y_d\Big)$$
$$- Y_d\Big(-12\mathrm{Tr}\Big(Y_dY_d^\dagger\Big) - 12\mathrm{Tr}\Big(Y_uY_u^\dagger\Big) + 32g_3^2 - 4\mathrm{Tr}\Big(Y_eY_e^\dagger\Big) + 9g_2^2 + g_1^2\Big)\Big) \tag{18}$$
$$\beta_{Y_d}^{(2)} = +\frac{1}{80}\Big(20\Big(11Y_dY_u^\dagger Y_uY_u^\dagger Y_u - 4Y_dY_d^\dagger Y_dY_u^\dagger Y_u + 6Y_dY_d^\dagger Y_dY_d^\dagger Y_d - Y_dY_u^\dagger Y_uY_d^\dagger Y_d\Big)$$
$$+ Y_dY_d^\dagger Y_d\Big(1280g_3^2 - 180\mathrm{Tr}\Big(Y_eY_e^\dagger\Big) + 187g_1^2 - 480\lambda - 540\mathrm{Tr}\Big(Y_dY_d^\dagger\Big) - 540\mathrm{Tr}\Big(Y_uY_u^\dagger\Big) + 675g_2^2\Big)$$

$$
\begin{aligned}
&+ Y_d Y_u^\dagger Y_u \Big(100\mathrm{Tr}\Big(Y_e Y_e^\dagger\Big) - 1280 g_3^2 + 300\mathrm{Tr}\Big(Y_d Y_d^\dagger\Big) + 300\mathrm{Tr}\Big(Y_u Y_u^\dagger\Big) + 45 g_2^2 - 79 g_1^2\Big)\Big) \\
&+ Y_d\Big(- \frac{127}{600} g_1^4 - \frac{27}{20} g_1^2 g_2^2 - \frac{23}{4} g_2^4 + \frac{31}{15} g_1^2 g_3^2 + 9 g_2^2 g_3^2 - 108 g_3^4 + \frac{3}{2}\lambda^2 + LamSH^2 \\
&+ \frac{5}{8}\Big(32 g_3^2 + 9 g_2^2 + g_1^2\Big)\mathrm{Tr}\Big(Y_d Y_d^\dagger\Big) + \frac{15}{8}\Big(g_1^2 + g_2^2\Big)\mathrm{Tr}\Big(Y_e Y_e^\dagger\Big) + \frac{17}{8} g_1^2 \mathrm{Tr}\Big(Y_u Y_u^\dagger\Big) + \frac{45}{8} g_2^2 \mathrm{Tr}\Big(Y_u Y_u^\dagger\Big) \\
&+ 20 g_3^2 \mathrm{Tr}\Big(Y_u Y_u^\dagger\Big) - \frac{27}{4}\mathrm{Tr}\Big(Y_d Y_d^\dagger Y_d Y_d^\dagger\Big) + \frac{3}{2}\mathrm{Tr}\Big(Y_d Y_u^\dagger Y_u Y_d^\dagger\Big) - \frac{9}{4}\mathrm{Tr}\Big(Y_e Y_e^\dagger Y_e Y_e^\dagger\Big) - \frac{27}{4}\mathrm{Tr}\Big(Y_u Y_u^\dagger Y_u Y_u^\dagger\Big)\Big)
\end{aligned} \tag{19}
$$

$$
\beta_{Y_e}^{(1)} = \frac{3}{2} Y_e Y_e^\dagger Y_e + Y_e\Big(3\mathrm{Tr}\Big(Y_d Y_d^\dagger\Big) + 3\mathrm{Tr}\Big(Y_u Y_u^\dagger\Big) - \frac{9}{4} g_1^2 - \frac{9}{4} g_2^2 + \mathrm{Tr}\Big(Y_e Y_e^\dagger\Big)\Big) \tag{20}
$$

$$
\begin{aligned}
\beta_{Y_e}^{(2)} = &+ \frac{3}{80}\Big(40 Y_e Y_e^\dagger Y_e Y_e^\dagger Y_e \\
&+ Y_e Y_e^\dagger Y_e\Big(129 g_1^2 - 160\lambda - 180\mathrm{Tr}\Big(Y_d Y_d^\dagger\Big) - 180\mathrm{Tr}\Big(Y_u Y_u^\dagger\Big) + 225 g_2^2 - 60\mathrm{Tr}\Big(Y_e Y_e^\dagger\Big)\Big)\Big) \\
&+ \frac{1}{200} Y_e\Big(1371 g_1^4 + 270 g_1^2 g_2^2 - 1150 g_2^4 + 300\lambda^2 + 200 LamSH^2 + 125\Big(32 g_3^2 + 9 g_2^2 + g_1^2\Big)\mathrm{Tr}\Big(Y_d Y_d^\dagger\Big) \\
&+ 375\Big(g_1^2 + g_2^2\Big)\mathrm{Tr}\Big(Y_e Y_e^\dagger\Big) + 425 g_1^2 \mathrm{Tr}\Big(Y_u Y_u^\dagger\Big) + 1125 g_2^2 \mathrm{Tr}\Big(Y_u Y_u^\dagger\Big) + 4000 g_3^2 \mathrm{Tr}\Big(Y_u Y_u^\dagger\Big) \\
&- 1350\mathrm{Tr}\Big(Y_d Y_d^\dagger Y_d Y_d^\dagger\Big) + 300\mathrm{Tr}\Big(Y_d Y_u^\dagger Y_u Y_d^\dagger\Big) - 450\mathrm{Tr}\Big(Y_e Y_e^\dagger Y_e Y_e^\dagger\Big) - 1350\mathrm{Tr}\Big(Y_u Y_u^\dagger Y_u Y_u^\dagger\Big)\Big)
\end{aligned} \tag{21}
$$

3.4 Scalar Mass Terms

$$
\beta_{M_S^2}^{(1)} = 12 LamSM_S^2 + 8 LamSH\mu^2 \tag{22}
$$

$$
\begin{aligned}
\beta_{M_S^2}^{(2)} = &- \frac{8}{5}\Big(75 LamS^2 M_S^2 + 5 LamSH^2 M_S^2 - 6 g_1^2 LamSH\mu^2 - 30 g_2^2 LamSH\mu^2 + 20 LamSH^2\mu^2 + 30 LamSH\mu^2 \mathrm{Tr}\Big(Y_d Y_d^\dagger\Big) + 10 LamS \\
&+ 30 LamSH\mu^2 \mathrm{Tr}\Big(Y_u Y_u^\dagger\Big)\Big)
\end{aligned} \tag{23}
$$

$$
\beta_{\mu^2}^{(1)} = 2 LamSHM_S^2 + 2\mu^2 \mathrm{Tr}\Big(Y_e Y_e^\dagger\Big) + 6\lambda\mu^2 + 6\mu^2 \mathrm{Tr}\Big(Y_d Y_d^\dagger\Big) + 6\mu^2 \mathrm{Tr}\Big(Y_u Y_u^\dagger\Big) - \frac{9}{10} g_1^2 \mu^2 - \frac{9}{2} g_2^2 \mu^2 \tag{24}
$$

$$
\begin{aligned}
\beta_{\mu^2}^{(2)} = &- 8 LamSH^2 M_S^2 + \frac{1671}{400} g_1^4 \mu^2 + \frac{9}{8} g_1^2 g_2^2 \mu^2 - \frac{145}{16} g_2^4 \mu^2 + \frac{36}{5} g_1^2 \lambda\mu^2 + 36 g_2^2 \lambda\mu^2 - 15\lambda^2\mu^2 - 2 LamSH^2\mu^2 \\
&+ \frac{1}{4}\Big(- 144\lambda + 160 g_3^2 + 45 g_2^2 + 5 g_1^2\Big)\mu^2 \mathrm{Tr}\Big(Y_d Y_d^\dagger\Big) + \frac{3}{4}\Big(- 16\lambda + 5 g_1^2 + 5 g_2^2\Big)\mu^2 \mathrm{Tr}\Big(Y_e Y_e^\dagger\Big) \\
&+ \frac{17}{4} g_1^2 \mu^2 \mathrm{Tr}\Big(Y_u Y_u^\dagger\Big) + \frac{45}{4} g_2^2 \mu^2 \mathrm{Tr}\Big(Y_u Y_u^\dagger\Big) + 40 g_3^2 \mu^2 \mathrm{Tr}\Big(Y_u Y_u^\dagger\Big) - 36\lambda\mu^2 \mathrm{Tr}\Big(Y_u Y_u^\dagger\Big) \\
&- \frac{27}{2}\mu^2 \mathrm{Tr}\Big(Y_d Y_d^\dagger Y_d Y_d^\dagger\Big) - 21\mu^2 \mathrm{Tr}\Big(Y_d Y_u^\dagger Y_u Y_d^\dagger\Big) - \frac{9}{2}\mu^2 \mathrm{Tr}\Big(Y_e Y_e^\dagger Y_e Y_e^\dagger\Big) - \frac{27}{2}\mu^2 \mathrm{Tr}\Big(Y_u Y_u^\dagger Y_u Y_u^\dagger\Big)
\end{aligned} \tag{25}
$$

3.5 Vacuum expectation values

$$
\beta_v^{(1)} = \frac{1}{20} v\Big(15 g_2^2 \mathrm{Xi} - 20\mathrm{Tr}\Big(Y_e Y_e^\dagger\Big) + 3 g_1^2 \mathrm{Xi} + 45 g_2^2 - 60\mathrm{Tr}\Big(Y_d Y_d^\dagger\Big) - 60\mathrm{Tr}\Big(Y_u Y_u^\dagger\Big) + 9 g_1^2\Big) \tag{26}
$$

$$\beta_v^{(2)} = \frac{1}{800} v \Big(-1293 g_1^4 - 270 g_1^2 g_2^2 + 6775 g_2^4 - 1200 \lambda^2 - 800 LamSH^2 + 18 g_1^4 \mathrm{Xi} + 180 g_1^2 g_2^2 \mathrm{Xi} + 2250 g_2^4 \mathrm{Xi} + 18 g_1^4 \mathrm{Xi}^2$$
$$+ 180 g_1^2 g_2^2 \mathrm{Xi}^2 - 450 g_2^4 \mathrm{Xi}^2 - 20 \Big(45 g_2^2 \Big(2\mathrm{Xi} + 5 \Big) + 800 g_3^2 + g_1^2 \Big(18\mathrm{Xi} + 25 \Big) \Big) \mathrm{Tr} \Big(Y_d Y_d^\dagger \Big)$$
$$- 60 \Big(5 g_2^2 \Big(2\mathrm{Xi} + 5 \Big) + g_1^2 \Big(2\mathrm{Xi} + 25 \Big) \Big) \mathrm{Tr} \Big(Y_e Y_e^\dagger \Big) - 1700 g_1^2 \mathrm{Tr} \Big(Y_u Y_u^\dagger \Big) - 4500 g_2^2 \mathrm{Tr} \Big(Y_u Y_u^\dagger \Big)$$
$$- 16000 g_3^2 \mathrm{Tr} \Big(Y_u Y_u^\dagger \Big) - 360 g_1^2 \mathrm{XiTr} \Big(Y_u Y_u^\dagger \Big) - 1800 g_2^2 \mathrm{XiTr} \Big(Y_u Y_u^\dagger \Big) + 5400 \mathrm{Tr} \Big(Y_d Y_d^\dagger Y_d Y_d^\dagger \Big)$$
$$- 1200 \mathrm{Tr} \Big(Y_d Y_u^\dagger Y_u Y_d^\dagger \Big) + 1800 \mathrm{Tr} \Big(Y_e Y_e^\dagger Y_e Y_e^\dagger \Big) + 5400 \mathrm{Tr} \Big(Y_u Y_u^\dagger Y_u Y_u^\dagger \Big) \Big) \tag{27}$$

4 Field Rotations

4.1 Rotations in gauge sector for eigenstates 'EWSB'

$$\begin{pmatrix} B_\rho \\ W_{3\rho} \end{pmatrix} = Z^{\gamma Z} \begin{pmatrix} \gamma_\rho \\ Z_\rho \end{pmatrix} \tag{28}$$

$$\begin{pmatrix} W_{1\rho} \\ W_{2\rho} \end{pmatrix} = Z^W \begin{pmatrix} W_\rho^+ \\ W_\rho^+ \end{pmatrix} \tag{29}$$

$$\tag{30}$$

The mixing matrices are parametrized by

$$Z^{\gamma Z} = \begin{pmatrix} \cos\Theta_W & -\sin\Theta_W \\ \sin\Theta_W & \cos\Theta_W \end{pmatrix} \tag{31}$$

$$Z^W = \begin{pmatrix} \frac{1}{\sqrt{2}} & \frac{1}{\sqrt{2}} \\ i\frac{1}{\sqrt{2}} & -i\frac{1}{\sqrt{2}} \end{pmatrix} \tag{32}$$

$$\tag{33}$$

4.2 Rotations in Mass sector for eigenstates 'EWSB'

4.2.1 Mass Matrices for Scalars

- No Scalar Mixings

4.2.2 Mass Matrices for Fermions

- **Mass matrix for Down-Quarks**, Basis: $\left(d_{L,\alpha_1}\right), \left(d_{R,\beta_1}^*\right)$

$$m_d = \begin{pmatrix} \frac{1}{\sqrt{2}} v \delta_{\alpha_1 \beta_1} Y_d^T \end{pmatrix} \tag{34}$$

This matrix is diagonalized by U_L^d and U_R^d

$$U_L^{d,*} m_d U_R^{d,\dagger} = m_d^{dia} \tag{35}$$

with

$$d_{L,i\alpha} = \sum_{t_2} U_{L,ji}^{d,*} D_{L,j\alpha} \tag{36}$$

$$d_{R,i\alpha} = \sum_{t_2} U_{R,ij}^{d} D_{R,j\alpha}^{*} \tag{37}$$

- **Mass matrix for Up-Quarks**, Basis: $(u_{L,\alpha_1}), \left(u_{R,\beta_1}^*\right)$

$$m_u = \left(\begin{array}{c} -\frac{1}{\sqrt{2}} v \delta_{\alpha_1 \beta_1} Y_u^T \end{array} \right) \tag{38}$$

This matrix is diagonalized by U_L^u and U_R^u

$$U_L^{u,*} m_u U_R^{u,\dagger} = m_u^{dia} \tag{39}$$

with

$$u_{L,i\alpha} = \sum_{t_2} U_{L,ji}^{u,*} U_{L,j\alpha} \tag{40}$$

$$u_{R,i\alpha} = \sum_{t_2} U_{R,ij}^{u} U_{R,j\alpha}^{*} \tag{41}$$

- **Mass matrix for Leptons**, Basis: $(e_L), (e_R^*)$

$$m_e = \left(\begin{array}{c} \frac{1}{\sqrt{2}} v Y_e^T \end{array} \right) \tag{42}$$

This matrix is diagonalized by U_L^e and U_R^e

$$U_L^{e,*} m_e U_R^{e,\dagger} = m_e^{dia} \tag{43}$$

with

$$e_{L,i} = \sum_{t_2} U_{L,ji}^{e,*} E_{L,j} \tag{44}$$

$$e_{R,i} = \sum_{t_2} U_{R,ij}^{e} E_{R,j}^{*} \tag{45}$$

5 Vacuum Expectation Values

$$H^0 = \frac{1}{\sqrt{2}} h + \frac{1}{\sqrt{2}} v + i \frac{1}{\sqrt{2}} A^0 \tag{46}$$

6 Tadpole Equations

$$\frac{\partial V}{\partial h} = \frac{1}{2}\lambda v^3 + \mu^2 v \tag{47}$$

7 Particle content for eigenstates 'EWSB'

Name	Type	complex/real	Generations	Indices
H^+	Scalar	complex	1	
S	Scalar	real	1	
A^0	Scalar	real	1	
h	Scalar	real	1	
ν	Fermion	Dirac	3	generation, 3
d	Fermion	Dirac	3	generation, 3, color, 3
u	Fermion	Dirac	3	generation, 3, color, 3
e	Fermion	Dirac	3	generation, 3
g	Vector	real	1	color, 8, lorentz, 4
γ	Vector	real	1	lorentz, 4
Z	Vector	real	1	lorentz, 4
W^+	Vector	complex	1	lorentz, 4
η^G	Ghost	real	1	color, 8
η^γ	Ghost	real	1	
η^Z	Ghost	real	1	
η^+	Ghost	complex	1	
η^-	Ghost	complex	1	

8 One Loop Self-Energy and One Loop Tadpoles for eigenstates 'EWSB'

8.1 One Loop Self-Energy

- **Self-Energy for Down-Quarks** (d)

$$\Sigma^S_{i,j}(p^2) = +\sum_{a=1}^{3} B_0\Big(p^2, m^2_{d_a}, m^2_{A^0}\Big)\Gamma^{L*}_{\check{d}_j,d_a,A^0} m_{d_a} \Gamma^{R}_{\check{d}_i,d_a,A^0} + \sum_{b=1}^{3} B_0\Big(p^2, m^2_{d_b}, m^2_{h}\Big)\Gamma^{L*}_{\check{d}_j,h,d_b} m_{d_b} \Gamma^{R}_{\check{d}_i,h,d_b}$$

$$
\begin{aligned}
&- \frac{16}{3}\sum_{b=1}^{3}\Big(-\frac{1}{2}\mathrm{rMS}+B_0\Big(p^2,m_{d_b}^2,0\Big)\Big)\Gamma^{R*}_{\tilde{\tilde{d}}_j,g,d_b}m_{d_b}\Gamma^{L}_{\tilde{\tilde{d}}_i,g,d_b}-4\sum_{b=1}^{3}\Big(-\frac{1}{2}\mathrm{rMS}+B_0\Big(p^2,m_{d_b}^2,0\Big)\Big)\Gamma^{R*}_{\tilde{\tilde{d}}_j,\gamma,d_b}m_{d_b}\Gamma^{L}_{\tilde{\tilde{d}}_i,\gamma,d_b}\\
&-4\sum_{b=1}^{3}\Big(-\frac{1}{2}\mathrm{rMS}+B_0\Big(p^2,m_{d_b}^2,m_Z^2\Big)\Big)\Gamma^{R*}_{\tilde{\tilde{d}}_j,Z,d_b}m_{d_b}\Gamma^{L}_{\tilde{\tilde{d}}_i,Z,d_b}\\
&+\sum_{b=1}^{3}B_0\Big(p^2,m_{u_b}^2,m_{H^+}^2\Big)\Gamma^{L*}_{\tilde{\tilde{d}}_j,H^-,u_b}m_{u_b}\Gamma^{R}_{\tilde{\tilde{d}}_i,H^-,u_b}\\
&-4\sum_{b=1}^{3}\Big(-\frac{1}{2}\mathrm{rMS}+B_0\Big(p^2,m_{u_b}^2,m_{W^+}^2\Big)\Big)\Gamma^{R*}_{\tilde{\tilde{d}}_j,W^-,u_b}m_{u_b}\Gamma^{L}_{\tilde{\tilde{d}}_i,W^-,u_b} \qquad (48)\\
\Sigma^{R}_{i,j}(p^2)=&-\frac{1}{2}\sum_{a=1}^{3}B_1\Big(p^2,m_{d_a}^2,m_{A^0}^2\Big)\Gamma^{R*}_{\tilde{\tilde{d}}_j,d_a,A^0}\Gamma^{R}_{\tilde{\tilde{d}}_i,d_a,A^0}-\frac{1}{2}\sum_{b=1}^{3}B_1\Big(p^2,m_{d_b}^2,m_h^2\Big)\Gamma^{R*}_{\tilde{\tilde{d}}_j,h,d_b}\Gamma^{R}_{\tilde{\tilde{d}}_i,h,d_b}\\
&-\frac{4}{3}\sum_{b=1}^{3}B_1\Big(p^2,m_{d_b}^2,0\Big)\Gamma^{L*}_{\tilde{\tilde{d}}_j,g,d_b}\Gamma^{L}_{\tilde{\tilde{d}}_i,g,d_b}-\sum_{b=1}^{3}B_1\Big(p^2,m_{d_b}^2,0\Big)\Gamma^{L*}_{\tilde{\tilde{d}}_j,\gamma,d_b}\Gamma^{L}_{\tilde{\tilde{d}}_i,\gamma,d_b}\\
&-\sum_{b=1}^{3}B_1\Big(p^2,m_{d_b}^2,m_Z^2\Big)\Gamma^{L*}_{\tilde{\tilde{d}}_j,Z,d_b}\Gamma^{L}_{\tilde{\tilde{d}}_i,Z,d_b}-\frac{1}{2}\sum_{b=1}^{3}B_1\Big(p^2,m_{u_b}^2,m_{H^+}^2\Big)\Gamma^{R*}_{\tilde{\tilde{d}}_j,H^-,u_b}\Gamma^{R}_{\tilde{\tilde{d}}_i,H^-,u_b}\\
&-\sum_{b=1}^{3}B_1\Big(p^2,m_{u_b}^2,m_{W^+}^2\Big)\Gamma^{L*}_{\tilde{\tilde{d}}_j,W^-,u_b}\Gamma^{L}_{\tilde{\tilde{d}}_i,W^-,u_b} \qquad (49)\\
\Sigma^{L}_{i,j}(p^2)=&-\frac{1}{2}\sum_{a=1}^{3}B_1\Big(p^2,m_{d_a}^2,m_{A^0}^2\Big)\Gamma^{L*}_{\tilde{\tilde{d}}_j,d_a,A^0}\Gamma^{L}_{\tilde{\tilde{d}}_i,d_a,A^0}-\frac{1}{2}\sum_{b=1}^{3}B_1\Big(p^2,m_{d_b}^2,m_h^2\Big)\Gamma^{L*}_{\tilde{\tilde{d}}_j,h,d_b}\Gamma^{L}_{\tilde{\tilde{d}}_i,h,d_b}\\
&-\frac{4}{3}\sum_{b=1}^{3}B_1\Big(p^2,m_{d_b}^2,0\Big)\Gamma^{R*}_{\tilde{\tilde{d}}_j,g,d_b}\Gamma^{R}_{\tilde{\tilde{d}}_i,g,d_b}-\sum_{b=1}^{3}B_1\Big(p^2,m_{d_b}^2,0\Big)\Gamma^{R*}_{\tilde{\tilde{d}}_j,\gamma,d_b}\Gamma^{R}_{\tilde{\tilde{d}}_i,\gamma,d_b}\\
&-\sum_{b=1}^{3}B_1\Big(p^2,m_{d_b}^2,m_Z^2\Big)\Gamma^{R*}_{\tilde{\tilde{d}}_j,Z,d_b}\Gamma^{R}_{\tilde{\tilde{d}}_i,Z,d_b}-\frac{1}{2}\sum_{b=1}^{3}B_1\Big(p^2,m_{u_b}^2,m_{H^+}^2\Big)\Gamma^{L*}_{\tilde{\tilde{d}}_j,H^-,u_b}\Gamma^{L}_{\tilde{\tilde{d}}_i,H^-,u_b}\\
&-\sum_{b=1}^{3}B_1\Big(p^2,m_{u_b}^2,m_{W^+}^2\Big)\Gamma^{R*}_{\tilde{\tilde{d}}_j,W^-,u_b}\Gamma^{R}_{\tilde{\tilde{d}}_i,W^-,u_b} \qquad (50)
\end{aligned}
$$

- **Self-Energy for Up-Quarks** (u)

$$
\begin{aligned}
\Sigma^{S}_{i,j}(p^2)=&+\sum_{a=1}^{3}B_0\Big(p^2,m_{u_a}^2,m_{A^0}^2\Big)\Gamma^{L*}_{\tilde{\tilde{u}}_j,u_a,A^0}m_{u_a}\Gamma^{R}_{\tilde{\tilde{u}}_i,u_a,A^0}+\sum_{b=1}^{3}B_0\Big(p^2,m_{u_b}^2,m_h^2\Big)\Gamma^{L*}_{\tilde{\tilde{u}}_j,h,u_b}m_{u_b}\Gamma^{R}_{\tilde{\tilde{u}}_i,h,u_b}\\
&+\sum_{b=1}^{3}B_0\Big(p^2,m_{d_b}^2,m_{H^+}^2\Big)\Gamma^{L*}_{\tilde{\tilde{u}}_j,H^+,d_b}m_{d_b}\Gamma^{R}_{\tilde{\tilde{u}}_i,H^+,d_b}-\frac{16}{3}\sum_{b=1}^{3}\Big(-\frac{1}{2}\mathrm{rMS}+B_0\Big(p^2,m_{u_b}^2,0\Big)\Big)\Gamma^{R*}_{\tilde{\tilde{u}}_j,g,u_b}m_{u_b}\Gamma^{L}_{\tilde{\tilde{u}}_i,g,u_b}
\end{aligned}
$$

$$
\begin{aligned}
&- 4\sum_{b=1}^{3}\Big(-\frac{1}{2}\mathrm{rMS} + B_0\Big(p^2, m_{u_b}^2, 0\Big)\Big)\Gamma^{R*}_{\check{\tilde{u}}_j,\gamma,u_b} m_{u_b} \Gamma^{L}_{\check{\tilde{u}}_i,\gamma,u_b} \\
&- 4\sum_{b=1}^{3}\Big(-\frac{1}{2}\mathrm{rMS} + B_0\Big(p^2, m_{d_b}^2, m_{W^+}^2\Big)\Big)\Gamma^{R*}_{\check{\tilde{u}}_j,W^+,d_b} m_{d_b} \Gamma^{L}_{\check{\tilde{u}}_i,W^+,d_b} \\
&- 4\sum_{b=1}^{3}\Big(-\frac{1}{2}\mathrm{rMS} + B_0\Big(p^2, m_{u_b}^2, m_Z^2\Big)\Big)\Gamma^{R*}_{\check{\tilde{u}}_j,Z,u_b} m_{u_b} \Gamma^{L}_{\check{\tilde{u}}_i,Z,u_b} \qquad (51)
\end{aligned}
$$

$$
\begin{aligned}
\Sigma^{R}_{i,j}(p^2) = &-\frac{1}{2}\sum_{a=1}^{3} B_1\Big(p^2, m_{u_a}^2, m_{A^0}^2\Big)\Gamma^{R*}_{\check{\tilde{u}}_j,u_a,A^0}\Gamma^{R}_{\check{\tilde{u}}_i,u_a,A^0} - \frac{1}{2}\sum_{b=1}^{3} B_1\Big(p^2, m_{u_b}^2, m_h^2\Big)\Gamma^{R*}_{\check{\tilde{u}}_j,h,u_b}\Gamma^{R}_{\check{\tilde{u}}_i,h,u_b} \\
&- \frac{1}{2}\sum_{b=1}^{3} B_1\Big(p^2, m_{d_b}^2, m_{H^+}^2\Big)\Gamma^{R*}_{\check{\tilde{u}}_j,H^+,d_b}\Gamma^{R}_{\check{\tilde{u}}_i,H^+,d_b} - \frac{4}{3}\sum_{b=1}^{3} B_1\Big(p^2, m_{u_b}^2, 0\Big)\Gamma^{L*}_{\check{\tilde{u}}_j,g,u_b}\Gamma^{L}_{\check{\tilde{u}}_i,g,u_b} \\
&- \sum_{b=1}^{3} B_1\Big(p^2, m_{u_b}^2, 0\Big)\Gamma^{L*}_{\check{\tilde{u}}_j,\gamma,u_b}\Gamma^{L}_{\check{\tilde{u}}_i,\gamma,u_b} - \sum_{b=1}^{3} B_1\Big(p^2, m_{d_b}^2, m_{W^+}^2\Big)\Gamma^{L*}_{\check{\tilde{u}}_j,W^+,d_b}\Gamma^{L}_{\check{\tilde{u}}_i,W^+,d_b} \\
&- \sum_{b=1}^{3} B_1\Big(p^2, m_{u_b}^2, m_Z^2\Big)\Gamma^{L*}_{\check{\tilde{u}}_j,Z,u_b}\Gamma^{L}_{\check{\tilde{u}}_i,Z,u_b} \qquad (52)
\end{aligned}
$$

$$
\begin{aligned}
\Sigma^{L}_{i,j}(p^2) = &-\frac{1}{2}\sum_{a=1}^{3} B_1\Big(p^2, m_{u_a}^2, m_{A^0}^2\Big)\Gamma^{L*}_{\check{\tilde{u}}_j,u_a,A^0}\Gamma^{L}_{\check{\tilde{u}}_i,u_a,A^0} - \frac{1}{2}\sum_{b=1}^{3} B_1\Big(p^2, m_{u_b}^2, m_h^2\Big)\Gamma^{L*}_{\check{\tilde{u}}_j,h,u_b}\Gamma^{L}_{\check{\tilde{u}}_i,h,u_b} \\
&- \frac{1}{2}\sum_{b=1}^{3} B_1\Big(p^2, m_{d_b}^2, m_{H^+}^2\Big)\Gamma^{L*}_{\check{\tilde{u}}_j,H^+,d_b}\Gamma^{L}_{\check{\tilde{u}}_i,H^+,d_b} - \frac{4}{3}\sum_{b=1}^{3} B_1\Big(p^2, m_{u_b}^2, 0\Big)\Gamma^{R*}_{\check{\tilde{u}}_j,g,u_b}\Gamma^{R}_{\check{\tilde{u}}_i,g,u_b} \\
&- \sum_{b=1}^{3} B_1\Big(p^2, m_{u_b}^2, 0\Big)\Gamma^{R*}_{\check{\tilde{u}}_j,\gamma,u_b}\Gamma^{R}_{\check{\tilde{u}}_i,\gamma,u_b} - \sum_{b=1}^{3} B_1\Big(p^2, m_{d_b}^2, m_{W^+}^2\Big)\Gamma^{R*}_{\check{\tilde{u}}_j,W^+,d_b}\Gamma^{R}_{\check{\tilde{u}}_i,W^+,d_b} \\
&- \sum_{b=1}^{3} B_1\Big(p^2, m_{u_b}^2, m_Z^2\Big)\Gamma^{R*}_{\check{\tilde{u}}_j,Z,u_b}\Gamma^{R}_{\check{\tilde{u}}_i,Z,u_b} \qquad (53)
\end{aligned}
$$

- **Self-Energy for Leptons** (e)

$$
\begin{aligned}
\Sigma^{S}_{i,j}(p^2) = &+\sum_{a=1}^{3} B_0\Big(p^2, m_{e_a}^2, m_{A^0}^2\Big)\Gamma^{L*}_{\check{\tilde{e}}_j,e_a,A^0} m_{e_a} \Gamma^{R}_{\check{\tilde{e}}_i,e_a,A^0} + \sum_{b=1}^{3} B_0\Big(p^2, m_{e_b}^2, m_h^2\Big)\Gamma^{L*}_{\check{\tilde{e}}_j,h,e_b} m_{e_b} \Gamma^{R}_{\check{\tilde{e}}_i,h,e_b} \\
&- 4\sum_{b=1}^{3}\Big(-\frac{1}{2}\mathrm{rMS} + B_0\Big(p^2, m_{e_b}^2, 0\Big)\Big)\Gamma^{R*}_{\check{\tilde{e}}_j,\gamma,e_b} m_{e_b} \Gamma^{L}_{\check{\tilde{e}}_i,\gamma,e_b} - 4\sum_{b=1}^{3}\Big(-\frac{1}{2}\mathrm{rMS} + B_0\Big(p^2, m_{e_b}^2, m_Z^2\Big)\Big)\Gamma^{R*}_{\check{\tilde{e}}_j,Z,e_b} m_{e_b} \Gamma^{L}_{\check{\tilde{e}}_i,Z,e_b} \\
&+ \sum_{b=1}^{3} B_0\Big(p^2, m_{\nu_b}^2, m_{H^+}^2\Big)\Gamma^{L*}_{\check{\tilde{e}}_j,H^-,\nu_b} m_{\nu_b} \Gamma^{R}_{\check{\tilde{e}}_i,H^-,\nu_b}
\end{aligned}
$$

$$- 4\sum_{b=1}^{3}\Big(-\frac{1}{2}\mathrm{rMS} + B_0\Big(p^2, m^2_{\nu_b}, m^2_{W^+}\Big)\Big)\Gamma^{R*}_{\bar{\tilde{e}}_j,W^-,\nu_b} m_{\nu_b}\Gamma^{L}_{\bar{\tilde{e}}_i,W^-,\nu_b} \tag{54}$$

$$\begin{aligned}\Sigma^R_{i,j}(p^2) = &-\frac{1}{2}\sum_{a=1}^{3} B_1\Big(p^2, m^2_{e_a}, m^2_{A^0}\Big)\Gamma^{R*}_{\bar{\tilde{e}}_j,e_a,A^0}\Gamma^{R}_{\bar{\tilde{e}}_i,e_a,A^0} - \frac{1}{2}\sum_{b=1}^{3} B_1\Big(p^2, m^2_{e_b}, m^2_{h}\Big)\Gamma^{R*}_{\bar{\tilde{e}}_j,h,e_b}\Gamma^{R}_{\bar{\tilde{e}}_i,h,e_b}\\
&- \sum_{b=1}^{3} B_1\Big(p^2, m^2_{e_b}, 0\Big)\Gamma^{L*}_{\bar{\tilde{e}}_j,\gamma,e_b}\Gamma^{L}_{\bar{\tilde{e}}_i,\gamma,e_b} - \sum_{b=1}^{3} B_1\Big(p^2, m^2_{e_b}, m^2_{Z}\Big)\Gamma^{L*}_{\bar{\tilde{e}}_j,Z,e_b}\Gamma^{L}_{\bar{\tilde{e}}_i,Z,e_b}\\
&- \frac{1}{2}\sum_{b=1}^{3} B_1\Big(p^2, m^2_{\nu_b}, m^2_{H^+}\Big)\Gamma^{R*}_{\bar{\tilde{e}}_j,H^-,\nu_b}\Gamma^{R}_{\bar{\tilde{e}}_i,H^-,\nu_b} - \sum_{b=1}^{3} B_1\Big(p^2, m^2_{\nu_b}, m^2_{W^+}\Big)\Gamma^{L*}_{\bar{\tilde{e}}_j,W^-,\nu_b}\Gamma^{L}_{\bar{\tilde{e}}_i,W^-,\nu_b}\end{aligned} \tag{55}$$

$$\begin{aligned}\Sigma^L_{i,j}(p^2) = &-\frac{1}{2}\sum_{a=1}^{3} B_1\Big(p^2, m^2_{e_a}, m^2_{A^0}\Big)\Gamma^{L*}_{\bar{\tilde{e}}_j,e_a,A^0}\Gamma^{L}_{\bar{\tilde{e}}_i,e_a,A^0} - \frac{1}{2}\sum_{b=1}^{3} B_1\Big(p^2, m^2_{e_b}, m^2_{h}\Big)\Gamma^{L*}_{\bar{\tilde{e}}_j,h,e_b}\Gamma^{L}_{\bar{\tilde{e}}_i,h,e_b}\\
&- \sum_{b=1}^{3} B_1\Big(p^2, m^2_{e_b}, 0\Big)\Gamma^{R*}_{\bar{\tilde{e}}_j,\gamma,e_b}\Gamma^{R}_{\bar{\tilde{e}}_i,\gamma,e_b} - \sum_{b=1}^{3} B_1\Big(p^2, m^2_{e_b}, m^2_{Z}\Big)\Gamma^{R*}_{\bar{\tilde{e}}_j,Z,e_b}\Gamma^{R}_{\bar{\tilde{e}}_i,Z,e_b}\\
&- \frac{1}{2}\sum_{b=1}^{3} B_1\Big(p^2, m^2_{\nu_b}, m^2_{H^+}\Big)\Gamma^{L*}_{\bar{\tilde{e}}_j,H^-,\nu_b}\Gamma^{L}_{\bar{\tilde{e}}_i,H^-,\nu_b} - \sum_{b=1}^{3} B_1\Big(p^2, m^2_{\nu_b}, m^2_{W^+}\Big)\Gamma^{R*}_{\bar{\tilde{e}}_j,W^-,\nu_b}\Gamma^{R}_{\bar{\tilde{e}}_i,W^-,\nu_b}\end{aligned} \tag{56}$$

- **Self-Energy for Charged Higgs** (H^+)

$$\begin{aligned}\Pi(p^2) = &+4|\Gamma_{H^-,W^+,\gamma}|^2\Big(-\frac{1}{2}\mathrm{rMS} + B_0\Big(p^2, 0, m^2_{W^+}\Big)\Big) + |\Gamma_{H^-,H^+,h}|^2 B_0\Big(p^2, m^2_{H^+}, m^2_h\Big) + 4|\Gamma_{H^-,Z,W^+}|^2\Big(-\frac{1}{2}\mathrm{rMS} + B_0\Big(p^2, n\\
&- B_0\Big(p^2, m^2_{\eta^z}, m^2_{\eta^-}\Big)\Gamma_{H^+,\eta^-,\bar{\eta^z}}\Gamma_{H^-,\bar{\eta^-},\eta^z} - B_0\Big(p^2, m^2_{\eta^+}, m^2_{\eta^z}\Big)\Gamma_{H^+,\eta^z,\bar{\eta^+}}\Gamma_{H^-,\bar{\eta^z},\eta^+}\\
&- \frac{1}{2}A_0\Big(m^2_{A^0}\Big)\Gamma_{H^+,H^-,A^0,A^0} - \frac{1}{2}A_0\Big(m^2_h\Big)\Gamma_{H^+,H^-,h,h} - \frac{1}{2}A_0\Big(m^2_S\Big)\Gamma_{H^+,H^-,S,S}\\
&- A_0\Big(m^2_{H^+}\Big)\Gamma_{H^+,H^-,H^-,H^+} + |\Gamma_{H^-,W^+,A^0}|^2 F_0\Big(p^2, m^2_{A^0}, m^2_{W^+}\Big) + |\Gamma_{H^-,W^+,h}|^2 F_0\Big(p^2, m^2_h, m^2_{W^+}\Big)\\
&+ |\Gamma_{H^-,\gamma,H^+}|^2 F_0\Big(p^2, m^2_{H^+}, 0\Big) + |\Gamma_{H^-,Z,H^+}|^2 F_0\Big(p^2, m^2_{H^+}, m^2_Z\Big) + 4\Gamma_{H^+,H^-,W^-,W^+}\Big(-\frac{1}{2}\mathrm{rMS} m^2_{W^+} + A_0\Big(m^2_{W^+}\Big)\Big)\\
&+ 2\Gamma_{H^+,H^-,Z,Z}\Big(-\frac{1}{2}\mathrm{rMS} m^2_Z + A_0\Big(m^2_Z\Big)\Big) + 3\sum_{a=1}^{3}\sum_{b=1}^{3}\Big(|\Gamma^L_{H^-,\bar{d}_a,u_b}|^2 + |\Gamma^R_{H^-,\bar{d}_a,u_b}|^2\Big)G_0\Big(p^2, m^2_{d_a}, m^2_{u_b}\Big)\\
&+ \sum_{a=1}^{3}\sum_{b=1}^{3}\Big(|\Gamma^L_{H^-,\bar{e}_a,\nu_b}|^2 + |\Gamma^R_{H^-,\bar{e}_a,\nu_b}|^2\Big)G_0\Big(p^2, m^2_{e_a}, m^2_{\nu_b}\Big)\\
&- 6\sum_{a=1}^{3} m_{d_a}\sum_{b=1}^{3} B_0\Big(p^2, m^2_{d_a}, m^2_{u_b}\Big)m_{u_b}\Big(\Gamma^{L*}_{H^-,\bar{d}_a,u_b}\Gamma^{R}_{H^-,\bar{d}_a,u_b} + \Gamma^{R*}_{H^-,\bar{d}_a,u_b}\Gamma^{L}_{H^-,\bar{d}_a,u_b}\Big)\\
&- 2\sum_{a=1}^{3} m_{e_a}\sum_{b=1}^{3} B_0\Big(p^2, m^2_{e_a}, m^2_{\nu_b}\Big)m_{\nu_b}\Big(\Gamma^{L*}_{H^-,\bar{e}_a,\nu_b}\Gamma^{R}_{H^-,\bar{e}_a,\nu_b} + \Gamma^{R*}_{H^-,\bar{e}_a,\nu_b}\Gamma^{L}_{H^-,\bar{e}_a,\nu_b}\Big)\end{aligned} \tag{57}$$

- **Self-Energy for Singlet** (S)

$$\Pi(p^2) = +|\Gamma_{S,S,h}|^2 B_0\Big(p^2, m_S^2, m_h^2\Big) - \frac{1}{2}A_0\Big(m_{A^0}^2\Big)\Gamma_{S,S,A^0,A^0} - \frac{1}{2}A_0\Big(m_h^2\Big)\Gamma_{S,S,h,h} - \frac{1}{2}A_0\Big(m_S^2\Big)\Gamma_{S,S,S,S}$$
$$- A_0\Big(m_{H^+}^2\Big)\Gamma_{S,S,H^-,H^+} \tag{58}$$

- **Self-Energy for Pseudo-Scalar Higgs** (A^0)

$$\Pi(p^2) = +|\Gamma_{A^0,h,A^0}|^2 B_0\Big(p^2, m_h^2, m_{A^0}^2\Big) - B_0\Big(p^2, m_{\eta^+}^2, m_{\eta^+}^2\Big)\Gamma^2_{A^0,\bar{\eta^+},\eta^+} - B_0\Big(p^2, m_{\eta^-}^2, m_{\eta^-}^2\Big)\Gamma^2_{A^0,\eta^-,\eta^-} - \frac{1}{2}A_0\Big(m_{A^0}^2\Big)\Gamma_{A^0,A^0,A^0,}$$
$$- \frac{1}{2}A_0\Big(m_h^2\Big)\Gamma_{A^0,A^0,h,h} - \frac{1}{2}A_0\Big(m_S^2\Big)\Gamma_{A^0,A^0,S,S} - A_0\Big(m_{H^+}^2\Big)\Gamma_{A^0,A^0,H^-,H^+}$$
$$+ |\Gamma_{A^0,Z,h}|^2 F_0\Big(p^2, m_h^2, m_Z^2\Big) + 2|\Gamma_{A^0,W^-,H^+}|^2 F_0\Big(p^2, m_{H^+}^2, m_{W^+}^2\Big) + 4\Gamma_{A^0,A^0,W^-,W^+}\Big(-\frac{1}{2}\mathrm{rMS}m_{W^+}^2 + A_0\Big(m_{W^+}^2\Big)\Big)$$
$$+ 2\Gamma_{A^0,A^0,Z,Z}\Big(-\frac{1}{2}\mathrm{rMS}m_Z^2 + A_0\Big(m_Z^2\Big)\Big) + 3\sum_{a=1}^{3}\sum_{b=1}^{3}\Big(|\Gamma^L_{A^0,\bar{d}_a,d_b}|^2 + |\Gamma^R_{A^0,\bar{d}_a,d_b}|^2\Big)G_0\Big(p^2, m_{d_a}^2, m_{d_b}^2\Big)$$
$$+ \sum_{a=1}^{3}\sum_{b=1}^{3}\Big(|\Gamma^L_{A^0,\bar{e}_a,e_b}|^2 + |\Gamma^R_{A^0,\bar{e}_a,e_b}|^2\Big)G_0\Big(p^2, m_{e_a}^2, m_{e_b}^2\Big)$$
$$+ 3\sum_{a=1}^{3}\sum_{b=1}^{3}\Big(|\Gamma^L_{A^0,\bar{u}_a,u_b}|^2 + |\Gamma^R_{A^0,\bar{u}_a,u_b}|^2\Big)G_0\Big(p^2, m_{u_a}^2, m_{u_b}^2\Big)$$
$$- 6\sum_{a=1}^{3} m_{d_a}\sum_{b=1}^{3} B_0\Big(p^2, m_{d_a}^2, m_{d_b}^2\Big)m_{d_b}\Big(\Gamma^{L*}_{A^0,\bar{d}_a,d_b}\Gamma^R_{A^0,\bar{d}_a,d_b} + \Gamma^{R*}_{A^0,\bar{d}_a,d_b}\Gamma^L_{A^0,\bar{d}_a,d_b}\Big)$$
$$- 2\sum_{a=1}^{3} m_{e_a}\sum_{b=1}^{3} B_0\Big(p^2, m_{e_a}^2, m_{e_b}^2\Big)m_{e_b}\Big(\Gamma^{L*}_{A^0,\bar{e}_a,e_b}\Gamma^R_{A^0,\bar{e}_a,e_b} + \Gamma^{R*}_{A^0,\bar{e}_a,e_b}\Gamma^L_{A^0,\bar{e}_a,e_b}\Big)$$
$$- 6\sum_{a=1}^{3} m_{u_a}\sum_{b=1}^{3} B_0\Big(p^2, m_{u_a}^2, m_{u_b}^2\Big)m_{u_b}\Big(\Gamma^{L*}_{A^0,\bar{u}_a,u_b}\Gamma^R_{A^0,\bar{u}_a,u_b} + \Gamma^{R*}_{A^0,\bar{u}_a,u_b}\Gamma^L_{A^0,\bar{u}_a,u_b}\Big) \tag{59}$$

- **Self-Energy for Higgs** (h)

$$\Pi(p^2) = +\frac{1}{2}|\Gamma_{h,A^0,A^0}|^2 B_0\Big(p^2, m_{A^0}^2, m_{A^0}^2\Big) + \frac{1}{2}|\Gamma_{h,h,h}|^2 B_0\Big(p^2, m_h^2, m_h^2\Big) + |\Gamma_{h,H^-,H^+}|^2 B_0\Big(p^2, m_{H^+}^2, m_{H^+}^2\Big) + \frac{1}{2}|\Gamma_{h,S,S}|^2 B_0\Big(p^2,$$
$$+ 4|\Gamma_{h,W^-,W^+}|^2\Big(-\frac{1}{2}\mathrm{rMS} + B_0\Big(p^2, m_{W^+}^2, m_{W^+}^2\Big)\Big) + 2|\Gamma_{h,Z,Z}|^2\Big(-\frac{1}{2}\mathrm{rMS} + B_0\Big(p^2, m_Z^2, m_Z^2\Big)\Big) - B_0\Big(p^2, m_{\eta^+}^2, m_{\eta^+}^2\Big)\Gamma^2_{h,}$$
$$- B_0\Big(p^2, m_{\eta^-}^2, m_{\eta^-}^2\Big)\Gamma^2_{h,\bar{\eta^-},\eta^-} - B_0\Big(p^2, m_{\eta^Z}^2, m_{\eta^Z}^2\Big)\Gamma^2_{h,\bar{\eta^Z},\eta^Z} - \frac{1}{2}A_0\Big(m_{A^0}^2\Big)\Gamma_{h,h,A^0,A^0} - \frac{1}{2}A_0\Big(m_h^2\Big)\Gamma_{h,h,h,h}$$
$$- \frac{1}{2}A_0\Big(m_S^2\Big)\Gamma_{h,h,S,S} - A_0\Big(m_{H^+}^2\Big)\Gamma_{h,h,H^-,H^+} + |\Gamma_{h,Z,A^0}|^2 F_0\Big(p^2, m_{A^0}^2, m_Z^2\Big)$$
$$+ 2|\Gamma_{h,W^-,H^+}|^2 F_0\Big(p^2, m_{H^+}^2, m_{W^+}^2\Big) + 4\Gamma_{h,h,W^-,W^+}\Big(-\frac{1}{2}\mathrm{rMS}m_{W^+}^2 + A_0\Big(m_{W^+}^2\Big)\Big) + 2\Gamma_{h,h,Z,Z}\Big(-\frac{1}{2}\mathrm{rMS}m_Z^2 + A_0\Big(m_Z^2\Big)$$

$$
\begin{aligned}
&+ 3\sum_{a=1}^{3}\sum_{b=1}^{3}\Big(|\Gamma^{L}_{h,\bar{d}_a,d_b}|^2 + |\Gamma^{R}_{h,\bar{d}_a,d_b}|^2\Big)G_0\Big(p^2, m^2_{d_a}, m^2_{d_b}\Big)\\
&+ \sum_{a=1}^{3}\sum_{b=1}^{3}\Big(|\Gamma^{L}_{h,\bar{e}_a,e_b}|^2 + |\Gamma^{R}_{h,\bar{e}_a,e_b}|^2\Big)G_0\Big(p^2, m^2_{e_a}, m^2_{e_b}\Big)\\
&+ 3\sum_{a=1}^{3}\sum_{b=1}^{3}\Big(|\Gamma^{L}_{h,\bar{u}_a,u_b}|^2 + |\Gamma^{R}_{h,\bar{u}_a,u_b}|^2\Big)G_0\Big(p^2, m^2_{u_a}, m^2_{u_b}\Big)\\
&- 6\sum_{a=1}^{3} m_{d_a}\sum_{b=1}^{3}B_0\Big(p^2, m^2_{d_a}, m^2_{d_b}\Big)m_{d_b}\Big(\Gamma^{L*}_{h,\bar{d}_a,d_b}\Gamma^{R}_{h,\bar{d}_a,d_b} + \Gamma^{R*}_{h,\bar{d}_a,d_b}\Gamma^{L}_{h,\bar{d}_a,d_b}\Big)\\
&- 2\sum_{a=1}^{3} m_{e_a}\sum_{b=1}^{3}B_0\Big(p^2, m^2_{e_a}, m^2_{e_b}\Big)m_{e_b}\Big(\Gamma^{L*}_{h,\bar{e}_a,e_b}\Gamma^{R}_{h,\bar{e}_a,e_b} + \Gamma^{R*}_{h,\bar{e}_a,e_b}\Gamma^{L}_{h,\bar{e}_a,e_b}\Big)\\
&- 6\sum_{a=1}^{3} m_{u_a}\sum_{b=1}^{3}B_0\Big(p^2, m^2_{u_a}, m^2_{u_b}\Big)m_{u_b}\Big(\Gamma^{L*}_{h,\bar{u}_a,u_b}\Gamma^{R}_{h,\bar{u}_a,u_b} + \Gamma^{R*}_{h,\bar{u}_a,u_b}\Gamma^{L}_{h,\bar{u}_a,u_b}\Big) \qquad (60)
\end{aligned}
$$

- **Self-Energy for Z-Boson** (Z)

$$
\begin{aligned}
\Pi(p^2) = &+2|\Gamma_{Z,W^-,H^+}|^2 B_0\Big(p^2, m^2_{W^+}, m^2_{H^+}\Big) + |\Gamma_{Z,Z,h}|^2 B_0\Big(p^2, m^2_{Z}, m^2_{h}\Big) - 4|\Gamma_{Z,h,A^0}|^2 B_{00}\Big(p^2, m^2_{A^0}, m^2_{h}\Big)\\
&+ |\Gamma_{Z,\bar{\eta^+},\eta^+}|^2 B_{00}\Big(p^2, m^2_{\eta^+}, m^2_{\eta^+}\Big) + |\Gamma_{Z,\bar{\eta^-},\eta^-}|^2 B_{00}\Big(p^2, m^2_{\eta^-}, m^2_{\eta^-}\Big)\\
&- 4|\Gamma_{Z,H^-,H^+}|^2 B_{00}\Big(p^2, m^2_{H^+}, m^2_{H^+}\Big) + \frac{1}{2}A_0\Big(m^2_{A^0}\Big)\Gamma_{Z,Z,A^0,A^0} + \frac{1}{2}A_0\Big(m^2_{h}\Big)\Gamma_{Z,Z,h,h}\\
&+ A_0\Big(m^2_{H^+}\Big)\Gamma_{Z,Z,H^-,H^+}\\
&- |\Gamma_{Z,W^-,W^+}|^2\Big(10B_{00}\Big(p^2, m^2_{W^+}, m^2_{W^+}\Big) + 2A_0\Big(m^2_{W^+}\Big) - 2\mathrm{rMS}\Big(2m^2_{W^+} - \frac{1}{3}p^2\Big) + B_0\Big(p^2, m^2_{W^+}, m^2_{W^+}\Big)\Big(2m^2_{W^+} + 4p^2\Big)\Big)\\
&+ 3\sum_{a=1}^{3}\sum_{b=1}^{3}\Big[\Big(|\Gamma^{L}_{Z,\bar{d}_a,d_b}|^2 + |\Gamma^{R}_{Z,\bar{d}_a,d_b}|^2\Big)H_0\Big(p^2, m^2_{d_a}, m^2_{d_b}\Big)\\
&+ 4B_0\Big(p^2, m^2_{d_a}, m^2_{d_b}\Big)m_{d_a}m_{d_b}\Re\Big(\Gamma^{L*}_{Z,\bar{d}_a,d_b}\Gamma^{R}_{Z,\bar{d}_a,d_b}\Big)\Big]\\
&+ \sum_{a=1}^{3}\sum_{b=1}^{3}\Big[\Big(|\Gamma^{L}_{Z,\bar{e}_a,e_b}|^2 + |\Gamma^{R}_{Z,\bar{e}_a,e_b}|^2\Big)H_0\Big(p^2, m^2_{e_a}, m^2_{e_b}\Big)\\
&+ 4B_0\Big(p^2, m^2_{e_a}, m^2_{e_b}\Big)m_{e_a}m_{e_b}\Re\Big(\Gamma^{L*}_{Z,\bar{e}_a,e_b}\Gamma^{R}_{Z,\bar{e}_a,e_b}\Big)\Big]\\
&+ 3\sum_{a=1}^{3}\sum_{b=1}^{3}\Big[\Big(|\Gamma^{L}_{Z,\bar{u}_a,u_b}|^2 + |\Gamma^{R}_{Z,\bar{u}_a,u_b}|^2\Big)H_0\Big(p^2, m^2_{u_a}, m^2_{u_b}\Big)\\
&+ 4B_0\Big(p^2, m^2_{u_a}, m^2_{u_b}\Big)m_{u_a}m_{u_b}\Re\Big(\Gamma^{L*}_{Z,\bar{u}_a,u_b}\Gamma^{R}_{Z,\bar{u}_a,u_b}\Big)\Big]
\end{aligned}
$$

$$
\begin{aligned}
&+ \sum_{a=1}^{3}\sum_{b=1}^{3}\Big[\Big(|\Gamma^{L}_{Z,\bar{\nu}_a,\nu_b}|^2 + |\Gamma^{R}_{Z,\bar{\nu}_a,\nu_b}|^2\Big)H_0\Big(p^2, m^2_{\nu_a}, m^2_{\nu_b}\Big) \\
&+ 4B_0\Big(p^2, m^2_{\nu_a}, m^2_{\nu_b}\Big) m_{\nu_a} m_{\nu_b} \Re\Big(\Gamma^{L*}_{Z,\bar{\nu}_a,\nu_b}\Gamma^{R}_{Z,\bar{\nu}_a,\nu_b}\Big)\Big] + 2\mathrm{rMS}m^2_{W^+}\Gamma^{1}_{Z,Z,W^-,W^+} \\
&- A_0\Big(m^2_{W^+}\Big)\Big(4\Gamma^{1}_{Z,Z,W^-,W^+} + \Gamma^{2}_{Z,Z,W^-,W^+} + \Gamma^{3}_{Z,Z,W^-,W^+}\Big) \qquad (61)
\end{aligned}
$$

- **Self-Energy for W+ - Boson** (W^+)

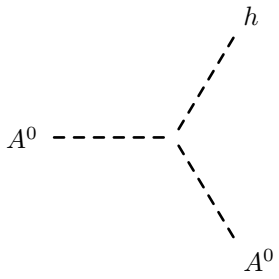
$$
\begin{aligned}
\Pi(p^2) = {} & 2\mathrm{rMS}m^2_{W^+}\Gamma^{1}_{W^+,W^-,W^-,W^+} + 3\sum_{a=1}^{3}\sum_{b=1}^{3}\Big[\Big(|\Gamma^{L}_{W^-,\bar{d}_a,u_b}|^2 + |\Gamma^{R}_{W^-,\bar{d}_a,u_b}|^2\Big)H_0\Big(p^2, m^2_{d_a}, m^2_{u_b}\Big) \\
&+ 4B_0\Big(p^2, m^2_{d_a}, m^2_{u_b}\Big) m_{d_a} m_{u_b} \Re\Big(\Gamma^{L*}_{W^-,\bar{d}_a,u_b}\Gamma^{R}_{W^-,\bar{d}_a,u_b}\Big)\Big] - 4|\Gamma_{W^-,H^+,A^0}|^2 B_{00}\Big(p^2, m^2_{A^0}, m^2_{H^+}\Big) - 4|\Gamma_{W^-,H^+,h}|^2 B_{00}\Big(p^2, m^2_{\\
&+ 4B_0\Big(p^2, m^2_{e_a}, m^2_{\nu_b}\Big) m_{e_a} m_{\nu_b} \Re\Big(\Gamma^{L*}_{W^-,\bar{e}_a,\nu_b}\Gamma^{R}_{W^-,\bar{e}_a,\nu_b}\Big)\Big] \qquad (62)
\end{aligned}
$$

8.2 Tadpoles

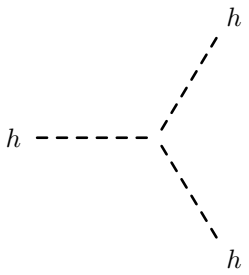
$$
\begin{aligned}
\delta t^{(1)}_h = {} & -\frac{1}{2}A_0\Big(m^2_{A^0}\Big)\Gamma_{h,A^0,A^0} - \frac{1}{2}A_0\Big(m^2_h\Big)\Gamma_{h,h,h} - \frac{1}{2}A_0\Big(m^2_S\Big)\Gamma_{h,S,S} + A_0\Big(m^2_{\eta^+}\Big)\Gamma_{h,\bar{\eta^+},\eta^+} \\
&+ A_0\Big(m^2_{\eta^-}\Big)\Gamma_{h,\bar{\eta^-},\eta^-} + A_0\Big(m^2_{\eta^Z}\Big)\Gamma_{h,\bar{\eta^Z},\eta^Z} - A_0\Big(m^2_{H^+}\Big)\Gamma_{h,H^-,H^+} \\
&+ 4\Gamma_{h,W^-,W^+}\Big(-\frac{1}{2}\mathrm{rMS}m^2_{W^+} + A_0\Big(m^2_{W^+}\Big)\Big) + 2\Gamma_{h,Z,Z}\Big(-\frac{1}{2}\mathrm{rMS}m^2_Z + A_0\Big(m^2_Z\Big)\Big) \\
&+ 6\sum_{a=1}^{3}A_0\Big(m^2_{d_a}\Big)m_{d_a}\Big(\Gamma^{L}_{h,\bar{d}_a,d_a} + \Gamma^{R}_{h,\bar{d}_a,d_a}\Big) \\
&+ 2\sum_{a=1}^{3}A_0\Big(m^2_{e_a}\Big)m_{e_a}\Big(\Gamma^{L}_{h,\bar{e}_a,e_a} + \Gamma^{R}_{h,\bar{e}_a,e_a}\Big) \\
&+ 6\sum_{a=1}^{3}A_0\Big(m^2_{u_a}\Big)m_{u_a}\Big(\Gamma^{L}_{h,\bar{u}_a,u_a} + \Gamma^{R}_{h,\bar{u}_a,u_a}\Big) \qquad (63)
\end{aligned}
$$

9 Interactions for eigenstates 'EWSB'

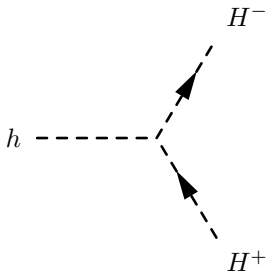
9.1 Three Scalar-Interaction



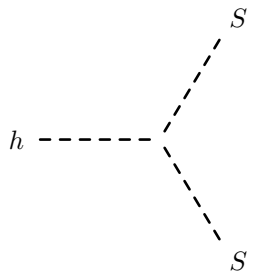
$$-i\lambda v \tag{64}$$



$$-3i\lambda v \tag{65}$$

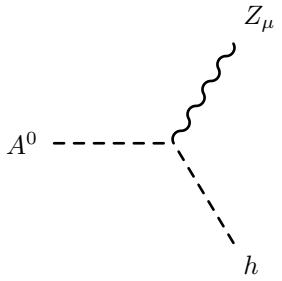


$$-i\lambda v \tag{66}$$

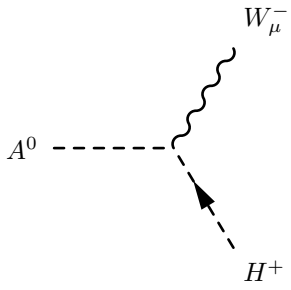


$$-2iLamSHv \tag{67}$$

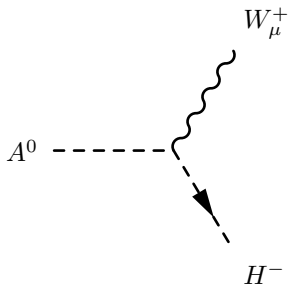
9.2 Two Scalar-One Vector Boson-Interaction



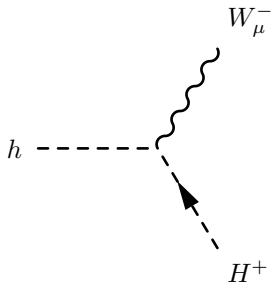
$$\frac{1}{2}\Big(-g_1 \sin\Theta_W - g_2 \cos\Theta_W\Big)\Big(-p_\mu^h + p_\mu^{A^0}\Big) \tag{68}$$



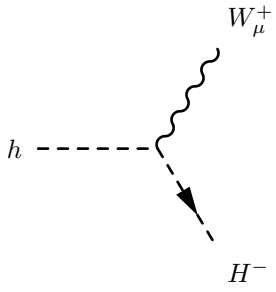
$$\frac{1}{2}g_2\Big(-p_\mu^{H^+} + p_\mu^{A^0}\Big) \tag{69}$$



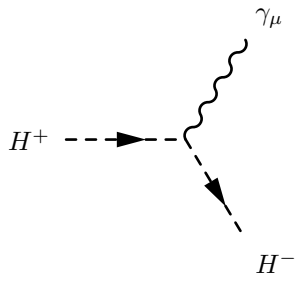
$$\frac{1}{2}g_2\Big(-p_\mu^{H^-}+p_\mu^{A^0}\Big) \tag{70}$$



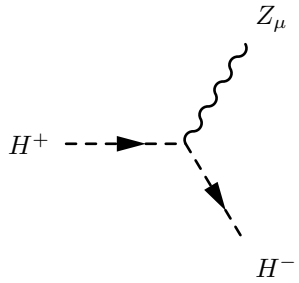
$$\frac{i}{2}g_2\Big(-p_\mu^{H^+}+p_\mu^{h}\Big) \tag{71}$$



$$-\frac{i}{2}g_2\Big(-p_\mu^{H^-}+p_\mu^{h}\Big) \tag{72}$$

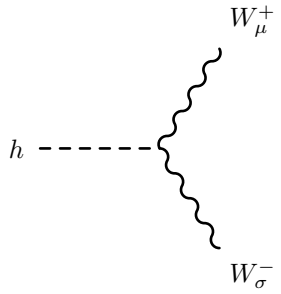


$$-\frac{i}{2}\Big(g_1\cos\Theta_W+g_2\sin\Theta_W\Big)\Big(-p_\mu^{H^-}+p_\mu^{H^+}\Big) \tag{73}$$

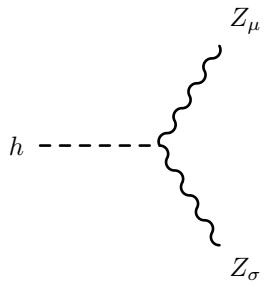


$$-\frac{i}{2}\Big(-g_1\sin\Theta_W+g_2\cos\Theta_W\Big)\Big(-p_\mu^{H^-}+p_\mu^{H^+}\Big) \tag{74}$$

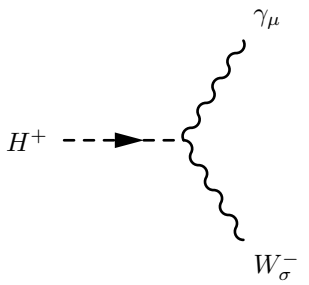
9.3 One Scalar-Two Vector Boson-Interaction



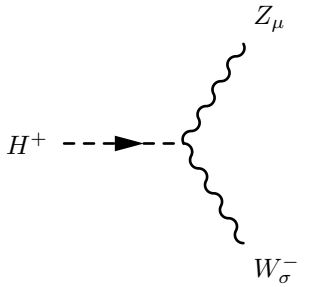
$$\frac{i}{2}g_2^2 v\Big(g_{\sigma\mu}\Big) \tag{75}$$



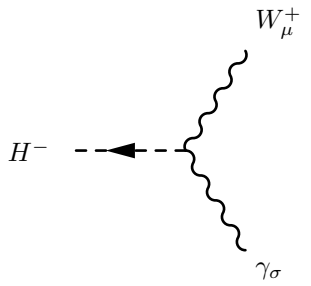
$$\frac{i}{2}v\Big(g_1\sin\Theta_W + g_2\cos\Theta_W\Big)^2\Big(g_{\sigma\mu}\Big) \tag{76}$$



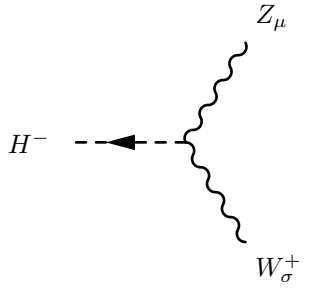
$$\frac{i}{2}g_1g_2v\cos\Theta_W\Big(g_{\sigma\mu}\Big) \tag{77}$$



$$-\frac{i}{2}g_1g_2v\sin\Theta_W\Big(g_{\sigma\mu}\Big) \tag{78}$$

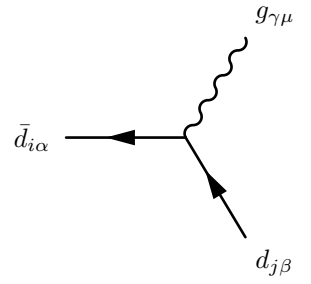


$$\frac{i}{2} g_1 g_2 v \cos\Theta_W \Big(g_{\sigma\mu} \Big) \tag{79}$$



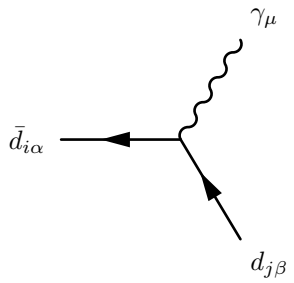
$$-\frac{i}{2} g_1 g_2 v \sin\Theta_W \Big(g_{\sigma\mu} \Big) \tag{80}$$

9.4 Two Fermion-One Vector Boson-Interaction



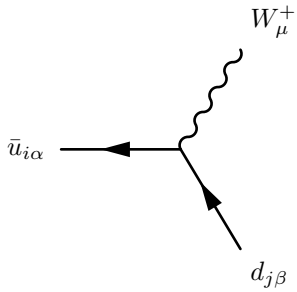
$$-\frac{i}{2} g_3 \delta_{ij} \lambda^\gamma_{\alpha,\beta} \Big(\gamma_\mu \cdot \frac{1-\gamma_5}{2} \Big) \tag{81}$$

$$+ \; -\frac{i}{2} g_3 \delta_{ij} \lambda^\gamma_{\alpha,\beta} \Big(\gamma_\mu \cdot \frac{1+\gamma_5}{2} \Big) \tag{82}$$

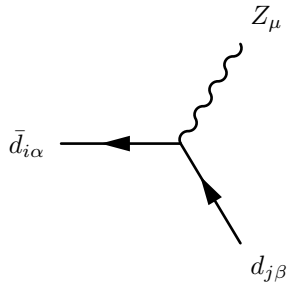


$$-\frac{i}{6}\delta_{\alpha\beta}\delta_{ij}\Big(-3g_2\sin\Theta_W+g_1\cos\Theta_W\Big)\Big(\gamma_\mu\cdot\frac{1-\gamma_5}{2}\Big) \tag{83}$$

$$+\ \frac{i}{3}g_1\cos\Theta_W\delta_{\alpha\beta}\delta_{ij}\Big(\gamma_\mu\cdot\frac{1+\gamma_5}{2}\Big) \tag{84}$$

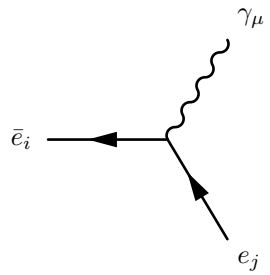


$$-i\frac{1}{\sqrt{2}}g_2\delta_{\alpha\beta}\sum_{a=1}^{3}U^{d,*}_{L,ja}U^{u}_{L,ia}\Big(\gamma_\mu\cdot\frac{1-\gamma_5}{2}\Big) \tag{85}$$



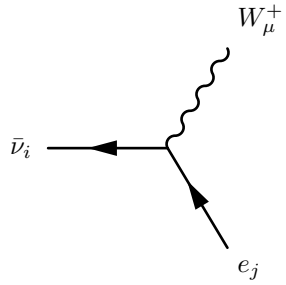
$$\frac{i}{6}\delta_{\alpha\beta}\delta_{ij}\Big(3g_2\cos\Theta_W+g_1\sin\Theta_W\Big)\Big(\gamma_\mu\cdot\frac{1-\gamma_5}{2}\Big) \tag{86}$$

$$+\ -\frac{i}{3}g_1\delta_{\alpha\beta}\delta_{ij}\sin\Theta_W\Big(\gamma_\mu\cdot\frac{1+\gamma_5}{2}\Big) \tag{87}$$

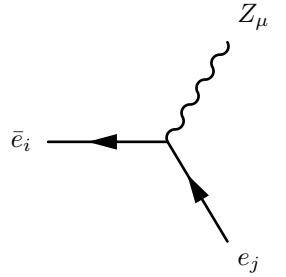


$$\frac{i}{2}\delta_{ij}\Big(g_1\cos\Theta_W + g_2\sin\Theta_W\Big)\Big(\gamma_\mu\cdot\frac{1-\gamma_5}{2}\Big) \tag{88}$$

$$+\ ig_1\cos\Theta_W\delta_{ij}\Big(\gamma_\mu\cdot\frac{1+\gamma_5}{2}\Big) \tag{89}$$

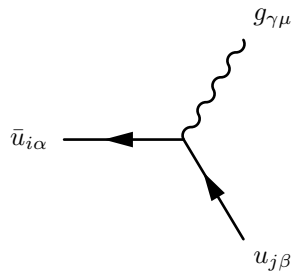


$$-\ i\frac{1}{\sqrt{2}}g_2U^{e,*}_{L,ji}\Theta_{i,3}\Big(\gamma_\mu\cdot\frac{1-\gamma_5}{2}\Big) \tag{90}$$



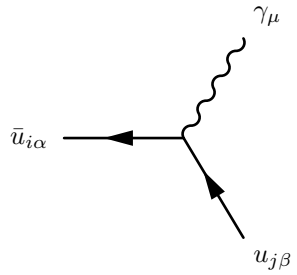
$$\frac{i}{2}\delta_{ij}\Big(-g_1\sin\Theta_W + g_2\cos\Theta_W\Big)\Big(\gamma_\mu\cdot\frac{1-\gamma_5}{2}\Big) \tag{91}$$

$$+\ -ig_1\delta_{ij}\sin\Theta_W\Big(\gamma_\mu\cdot\frac{1+\gamma_5}{2}\Big) \tag{92}$$



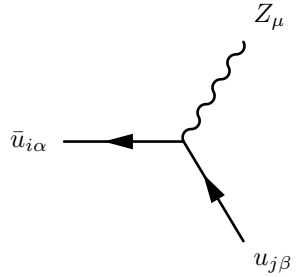
$$- \frac{i}{2} g_3 \delta_{ij} \lambda^{\gamma}_{\alpha,\beta} \Big(\gamma_\mu \cdot \frac{1-\gamma_5}{2} \Big) \tag{93}$$

$$+ \; - \frac{i}{2} g_3 \delta_{ij} \lambda^{\gamma}_{\alpha,\beta} \Big(\gamma_\mu \cdot \frac{1+\gamma_5}{2} \Big) \tag{94}$$



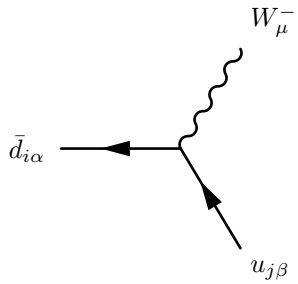
$$- \frac{i}{6} \delta_{\alpha\beta} \delta_{ij} \Big(3 g_2 \sin\Theta_W + g_1 \cos\Theta_W \Big) \Big(\gamma_\mu \cdot \frac{1-\gamma_5}{2} \Big) \tag{95}$$

$$+ \; - \frac{2i}{3} g_1 \cos\Theta_W \delta_{\alpha\beta} \delta_{ij} \Big(\gamma_\mu \cdot \frac{1+\gamma_5}{2} \Big) \tag{96}$$

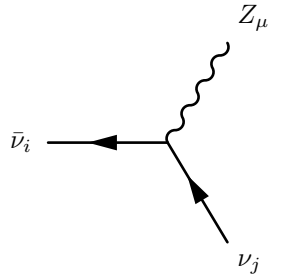


$$- \frac{i}{6} \delta_{\alpha\beta} \delta_{ij} \Big(3 g_2 \cos\Theta_W - g_1 \sin\Theta_W \Big) \Big(\gamma_\mu \cdot \frac{1-\gamma_5}{2} \Big) \tag{97}$$

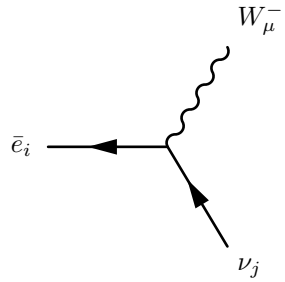
$$+ \; \frac{2i}{3} g_1 \delta_{\alpha\beta} \delta_{ij} \sin\Theta_W \Big(\gamma_\mu \cdot \frac{1+\gamma_5}{2} \Big) \tag{98}$$



$$-i\frac{1}{\sqrt{2}}g_2\delta_{\alpha\beta}\sum_{a=1}^{3}U_{L,ja}^{u,*}U_{L,ia}^{d}\Big(\gamma_\mu\cdot\frac{1-\gamma_5}{2}\Big) \tag{99}$$

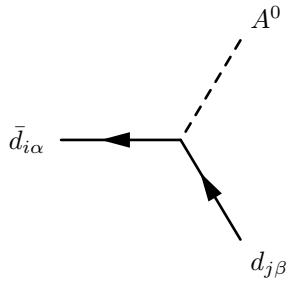


$$-\frac{i}{2}\delta_{ij}\Big(g_1\sin\Theta_W+g_2\cos\Theta_W\Big)\Big(\gamma_\mu\cdot\frac{1-\gamma_5}{2}\Big) \tag{100}$$



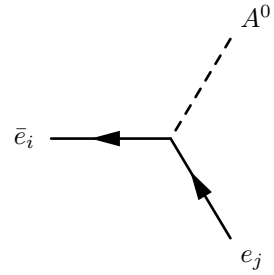
$$-i\frac{1}{\sqrt{2}}g_2\Theta_{j,3}U_{L,ij}^{e}\Big(\gamma_\mu\cdot\frac{1-\gamma_5}{2}\Big) \tag{101}$$

9.5 Two Fermion-One Scalar Boson-Interaction



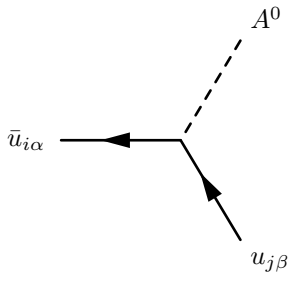
$$-\frac{1}{\sqrt{2}}\delta_{\alpha\beta}\sum_{b=1}^{3}U_{L,jb}^{d,*}\sum_{a=1}^{3}U_{R,ia}^{d,*}Y_{d,ab}\Big(\frac{1-\gamma_5}{2}\Big) \tag{102}$$

$$+\frac{1}{\sqrt{2}}\delta_{\alpha\beta}\sum_{b=1}^{3}\sum_{a=1}^{3}Y_{d,ab}^{*}U_{R,ja}^{d}U_{L,ib}^{d}\Big(\frac{1+\gamma_5}{2}\Big) \tag{103}$$



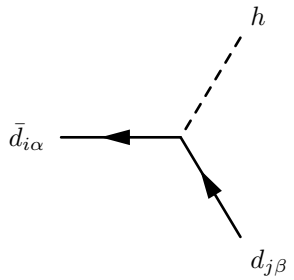
$$-\frac{1}{\sqrt{2}}\sum_{b=1}^{3}U_{L,jb}^{e,*}\sum_{a=1}^{3}U_{R,ia}^{e,*}Y_{e,ab}\Big(\frac{1-\gamma_5}{2}\Big) \tag{104}$$

$$+\frac{1}{\sqrt{2}}\sum_{b=1}^{3}\sum_{a=1}^{3}Y_{e,ab}^{*}U_{R,ja}^{e}U_{L,ib}^{e}\Big(\frac{1+\gamma_5}{2}\Big) \tag{105}$$



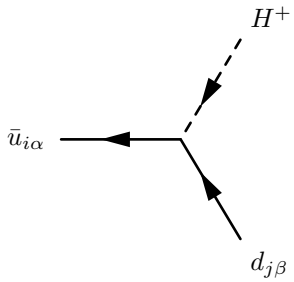
$$- \frac{1}{\sqrt{2}}\delta_{\alpha\beta}\sum_{b=1}^{3} U^{u,*}_{L,jb}\sum_{a=1}^{3} U^{u,*}_{R,ia} Y_{u,ab}\Big(\frac{1-\gamma_5}{2}\Big) \tag{106}$$

$$+ \frac{1}{\sqrt{2}}\delta_{\alpha\beta}\sum_{b=1}^{3}\sum_{a=1}^{3} Y^{*}_{u,ab} U^{u}_{R,ja} U^{u}_{L,ib}\Big(\frac{1+\gamma_5}{2}\Big) \tag{107}$$



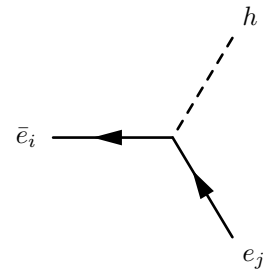
$$- i\frac{1}{\sqrt{2}}\delta_{\alpha\beta}\sum_{b=1}^{3} U^{d,*}_{L,jb}\sum_{a=1}^{3} U^{d,*}_{R,ia} Y_{d,ab}\Big(\frac{1-\gamma_5}{2}\Big) \tag{108}$$

$$+ -i\frac{1}{\sqrt{2}}\delta_{\alpha\beta}\sum_{b=1}^{3}\sum_{a=1}^{3} Y^{*}_{d,ab} U^{d}_{R,ja} U^{d}_{L,ib}\Big(\frac{1+\gamma_5}{2}\Big) \tag{109}$$



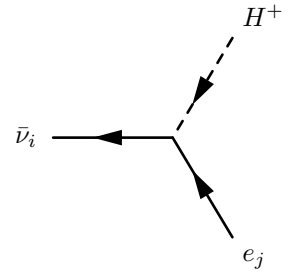
$$- i\delta_{\alpha\beta}\sum_{b=1}^{3} U^{d,*}_{L,jb}\sum_{a=1}^{3} U^{u,*}_{R,ia} Y_{u,ab}\Big(\frac{1-\gamma_5}{2}\Big) \tag{110}$$

$$+ -i\delta_{\alpha\beta}\sum_{b=1}^{3}\sum_{a=1}^{3} Y^{*}_{d,ab} U^{d}_{R,ja} U^{u}_{L,ib}\Big(\frac{1+\gamma_5}{2}\Big) \tag{111}$$



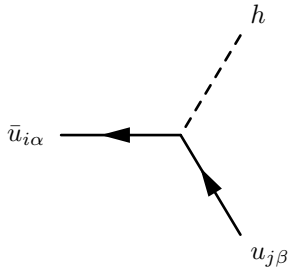
$$- i\frac{1}{\sqrt{2}}\sum_{b=1}^{3} U^{e,*}_{L,jb}\sum_{a=1}^{3} U^{e,*}_{R,ia} Y_{e,ab}\Big(\frac{1-\gamma_5}{2}\Big) \tag{112}$$

$$+\ -i\frac{1}{\sqrt{2}}\sum_{b=1}^{3}\sum_{a=1}^{3} Y^{*}_{e,ab} U^{e}_{R,ja} U^{e}_{L,ib}\Big(\frac{1+\gamma_5}{2}\Big) \tag{113}$$



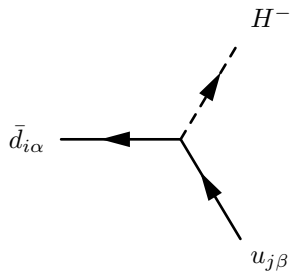
(114)

$$+\ -i\sum_{a=1}^{3} Y^{*}_{e,ai} U^{e}_{R,ja}\Big(\frac{1+\gamma_5}{2}\Big) \tag{115}$$



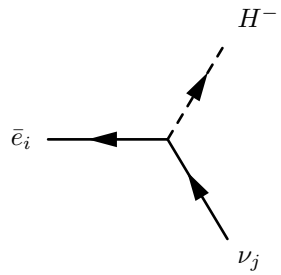
$$i\frac{1}{\sqrt{2}}\delta_{\alpha\beta}\sum_{b=1}^{3}U_{L,jb}^{u,*}\sum_{a=1}^{3}U_{R,ia}^{u,*}Y_{u,ab}\Big(\frac{1-\gamma_5}{2}\Big) \tag{116}$$

$$+\ i\frac{1}{\sqrt{2}}\delta_{\alpha\beta}\sum_{b=1}^{3}\sum_{a=1}^{3}Y_{u,ab}^{*}U_{R,ja}^{u}U_{L,ib}^{u}\Big(\frac{1+\gamma_5}{2}\Big) \tag{117}$$



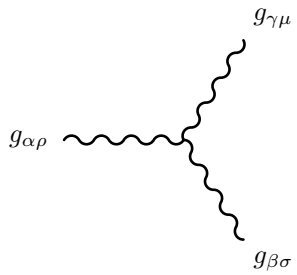
$$-\ i\delta_{\alpha\beta}\sum_{b=1}^{3}U_{L,jb}^{u,*}\sum_{a=1}^{3}U_{R,ia}^{d,*}Y_{d,ab}\Big(\frac{1-\gamma_5}{2}\Big) \tag{118}$$

$$+\ -i\delta_{\alpha\beta}\sum_{b=1}^{3}\sum_{a=1}^{3}Y_{u,ab}^{*}U_{R,ja}^{u}U_{L,ib}^{d}\Big(\frac{1+\gamma_5}{2}\Big) \tag{119}$$

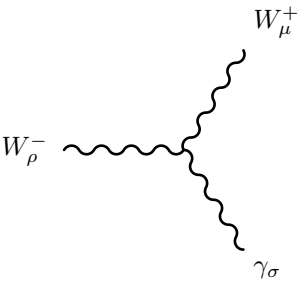


$$-\ i\sum_{a=1}^{3}U_{R,ia}^{e,*}Y_{e,aj}\Big(\frac{1-\gamma_5}{2}\Big) \tag{120}$$

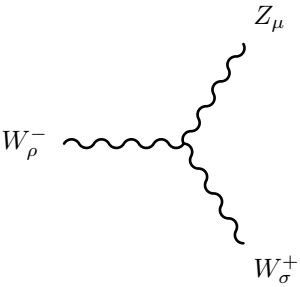
9.6 Three Vector Boson-Interaction



$$g_3 f_{\alpha,\beta,\gamma}\Big(g_{\rho\mu}\Big(-p_\sigma^{g_{\gamma\mu}}+p_\sigma^{g_{\alpha\rho}}\Big)+g_{\rho\sigma}\Big(-p_\mu^{g_{\alpha\rho}}+p_\mu^{g_{\beta\sigma}}\Big)+g_{\sigma\mu}\Big(-p_\rho^{g_{\beta\sigma}}+p_\rho^{g_{\gamma\mu}}\Big)\Big) \tag{121}$$

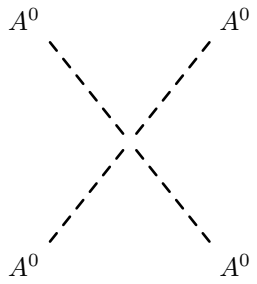


$$-ig_2\sin\Theta_W\Big(g_{\rho\mu}\Big(-p_\sigma^{W_\mu^+}+p_\sigma^{W_\rho^-}\Big)+g_{\rho\sigma}\Big(-p_\mu^{W_\rho^-}+p_\mu^{\gamma_\sigma}\Big)+g_{\sigma\mu}\Big(-p_\rho^{\gamma_\sigma}+p_\rho^{W_\mu^+}\Big)\Big) \tag{122}$$

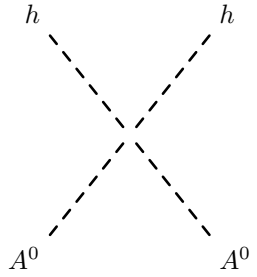


$$ig_2\cos\Theta_W\Big(g_{\rho\mu}\Big(-p_\sigma^{Z_\mu}+p_\sigma^{W_\rho^-}\Big)+g_{\rho\sigma}\Big(-p_\mu^{W_\rho^-}+p_\mu^{W_\sigma^+}\Big)+g_{\sigma\mu}\Big(-p_\rho^{W_\sigma^+}+p_\rho^{Z_\mu}\Big)\Big) \tag{123}$$

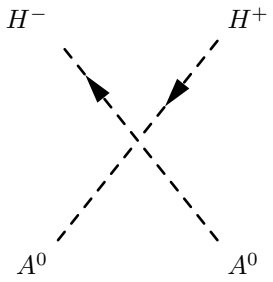
9.7 Four Scalar-Interaction



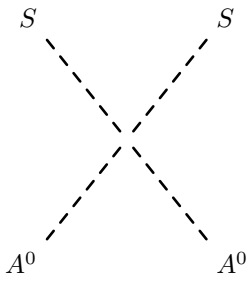
$$-3i\lambda \tag{124}$$



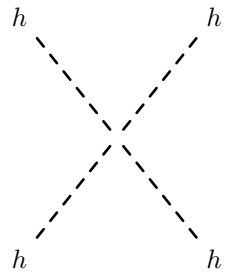
$$-i\lambda \tag{125}$$



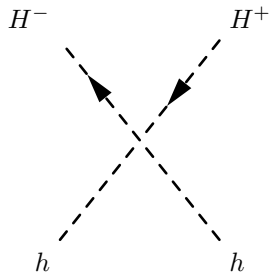
$$-i\lambda \tag{126}$$



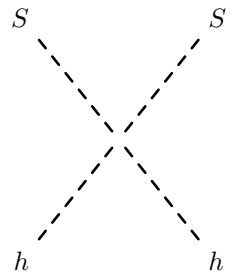
$$-2iLamSH \tag{127}$$



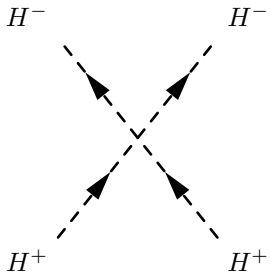
$$-3i\lambda \tag{128}$$



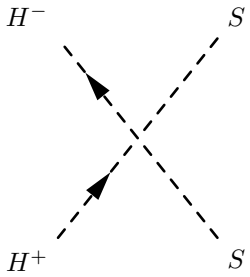
$$-i\lambda \tag{129}$$



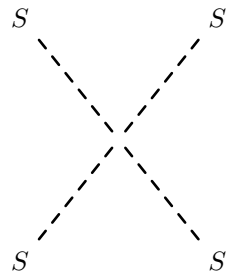
$$-2iLamSH \tag{130}$$



$$-2i\lambda \tag{131}$$

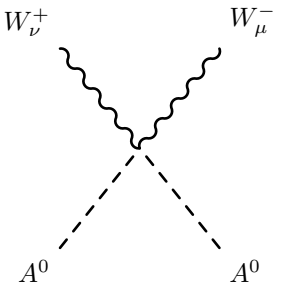


$$-2iLamSH \tag{132}$$

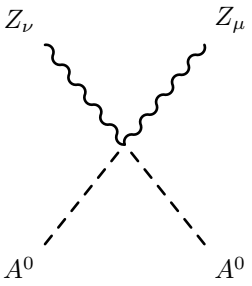


$$-12iLamS \tag{133}$$

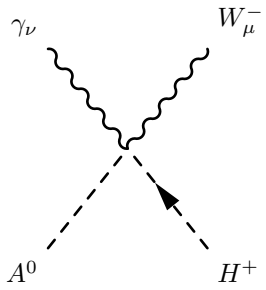
9.8 Two Scalar-Two Vector Boson-Interaction



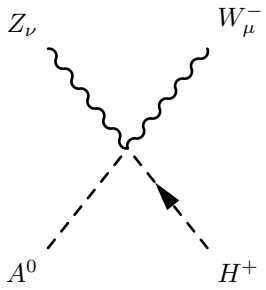
$$\frac{i}{2}g_2^2\Big(g_{\mu\nu}\Big) \tag{134}$$



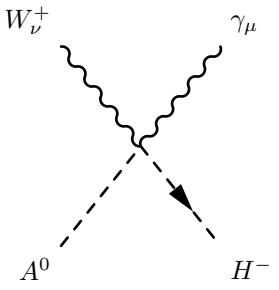
$$\frac{i}{2}\Big(g_1\sin\Theta_W + g_2\cos\Theta_W\Big)^2\Big(g_{\mu\nu}\Big) \tag{135}$$



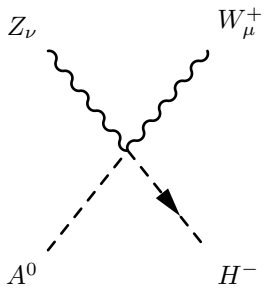
$$\frac{1}{2} g_1 g_2 \cos\Theta_W \Big(g_{\mu\nu} \Big) \tag{136}$$



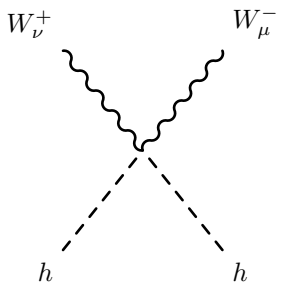
$$-\frac{1}{2} g_1 g_2 \sin\Theta_W \Big(g_{\mu\nu} \Big) \tag{137}$$



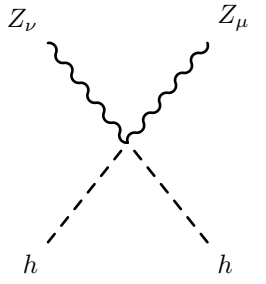
$$-\frac{1}{2} g_1 g_2 \cos\Theta_W \Big(g_{\mu\nu} \Big) \tag{138}$$



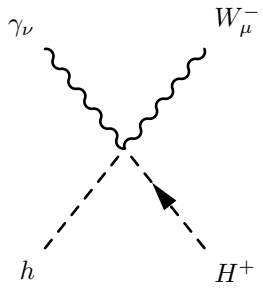
$$\frac{1}{2}g_1 g_2 \sin\Theta_W \Big(g_{\mu\nu}\Big) \tag{139}$$



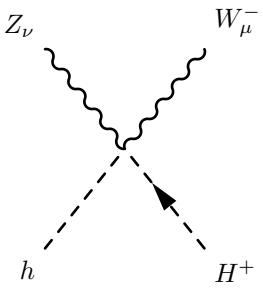
$$\frac{i}{2}g_2^2 \Big(g_{\mu\nu}\Big) \tag{140}$$



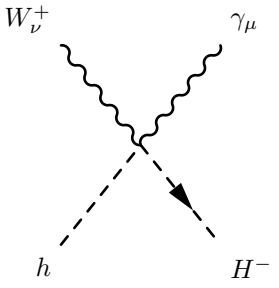
$$\frac{i}{2}\Big(g_1 \sin\Theta_W + g_2 \cos\Theta_W\Big)^2 \Big(g_{\mu\nu}\Big) \tag{141}$$



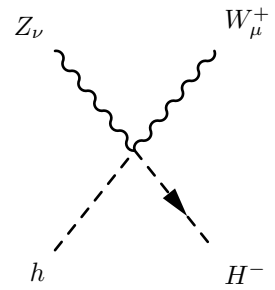
$$\frac{i}{2} g_1 g_2 \cos\Theta_W \Big(g_{\mu\nu} \Big) \tag{142}$$



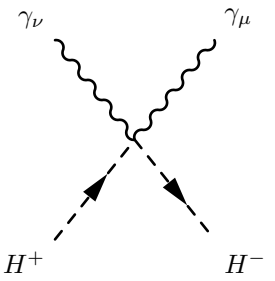
$$-\frac{i}{2} g_1 g_2 \sin\Theta_W \Big(g_{\mu\nu} \Big) \tag{143}$$



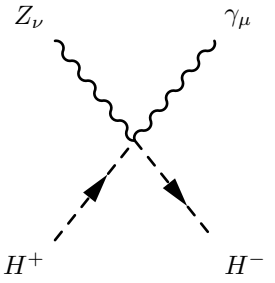
$$\frac{i}{2} g_1 g_2 \cos\Theta_W \Big(g_{\mu\nu} \Big) \tag{144}$$



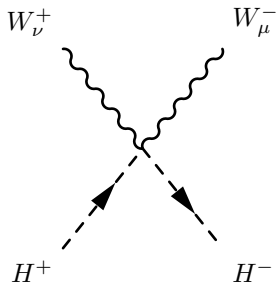
$$-\frac{i}{2}g_1 g_2 \sin\Theta_W\Big(g_{\mu\nu}\Big) \tag{145}$$



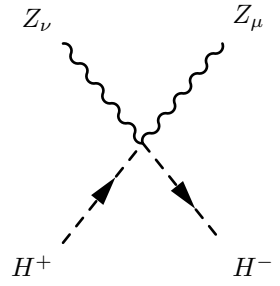
$$\frac{i}{2}\Big(g_1\cos\Theta_W + g_2\sin\Theta_W\Big)^2\Big(g_{\mu\nu}\Big) \tag{146}$$



$$-\frac{i}{4}\Big(-2g_1 g_2\cos 2\Theta_W + \Big(-g_2^2+g_1^2\Big)\sin 2\Theta_W\Big)\Big(g_{\mu\nu}\Big) \tag{147}$$

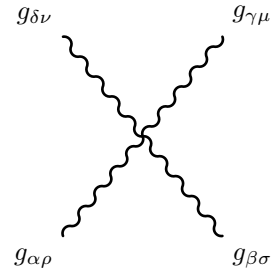


$$\frac{i}{2}g_2^2\Big(g_{\mu\nu}\Big) \tag{148}$$



$$\frac{i}{2}\Big(-g_1\sin\Theta_W+g_2\cos\Theta_W\Big)^2\Big(g_{\mu\nu}\Big) \tag{149}$$

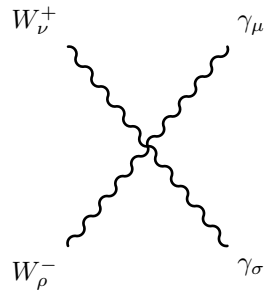
9.9 Four Vector Boson-Interaction



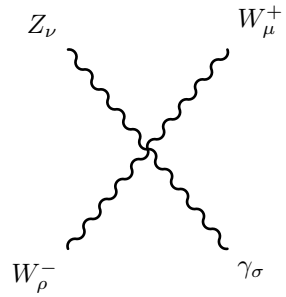
$$-ig_3^2\Big(\sum_{a=1}^{8}f_{\alpha,\delta,a}f_{\beta,\gamma,a}+\sum_{a=1}^{8}f_{\alpha,\gamma,a}f_{\beta,\delta,a}\Big)\Big(g_{\rho\sigma}g_{\mu\nu}\Big) \tag{150}$$

$$+\ ig_3^2\Big(-\sum_{a=1}^{8}f_{\alpha,\beta,a}f_{\gamma,\delta,a}+\sum_{a=1}^{8}f_{\alpha,\delta,a}f_{\beta,\gamma,a}\Big)\Big(g_{\rho\mu}g_{\sigma\nu}\Big) \tag{151}$$

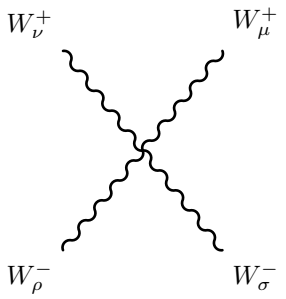
$$+\ ig_3^2\Big(\sum_{a=1}^{8} f_{\alpha,\gamma,a}f_{\beta,\delta,a} + \sum_{a=1}^{8} f_{\alpha,\beta,a}f_{\gamma,\delta,a}\Big)\Big(g_{\rho\nu}g_{\sigma\mu}\Big) \tag{152}$$



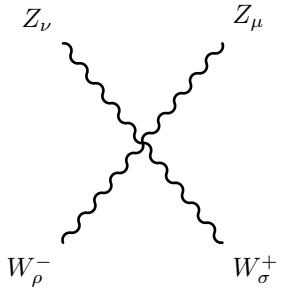
$$ig_2^2 \sin\Theta_W^2\Big(g_{\rho\sigma}g_{\mu\nu}\Big) \tag{153}$$
$$+\ ig_2^2 \sin\Theta_W^2\Big(g_{\rho\mu}g_{\sigma\nu}\Big) \tag{154}$$
$$+\ -2ig_2^2 \sin\Theta_W^2\Big(g_{\rho\nu}g_{\sigma\mu}\Big) \tag{155}$$



$$ig_2^2 \cos\Theta_W \sin\Theta_W\Big(g_{\rho\sigma}g_{\mu\nu}\Big) \tag{156}$$
$$+\ -ig_2^2 \sin 2\Theta_W\Big(g_{\rho\mu}g_{\sigma\nu}\Big) \tag{157}$$
$$+\ ig_2^2 \cos\Theta_W \sin\Theta_W\Big(g_{\rho\nu}g_{\sigma\mu}\Big) \tag{158}$$

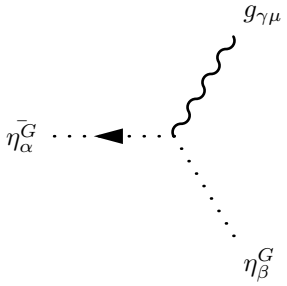


$$2ig_2^2\Big(g_{\rho\sigma}g_{\mu\nu}\Big) \tag{159}$$
$$+\ -ig_2^2\Big(g_{\rho\mu}g_{\sigma\nu}\Big) \tag{160}$$
$$+\ -ig_2^2\Big(g_{\rho\nu}g_{\sigma\mu}\Big) \tag{161}$$

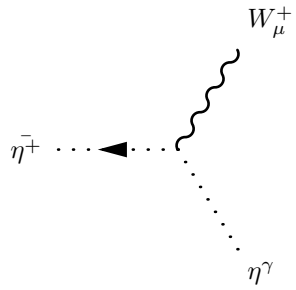


$$-\ 2ig_2^2\cos\Theta_W^2\Big(g_{\rho\sigma}g_{\mu\nu}\Big) \tag{162}$$
$$+\ ig_2^2\cos\Theta_W^2\Big(g_{\rho\mu}g_{\sigma\nu}\Big) \tag{163}$$
$$+\ ig_2^2\cos\Theta_W^2\Big(g_{\rho\nu}g_{\sigma\mu}\Big) \tag{164}$$

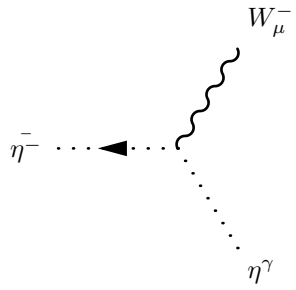
9.10 Two Ghosts-One Vector Boson-Interaction



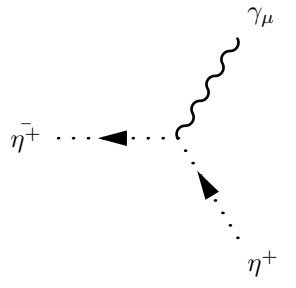
$$g_3 f_{\alpha,\beta,\gamma}\left(p_\mu^{\eta_\beta^G}\right) \tag{165}$$



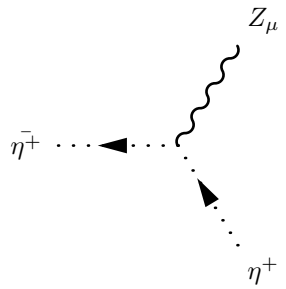
$$-ig_2 \sin\Theta_W\left(p_\mu^{\eta^\gamma}\right) \tag{166}$$



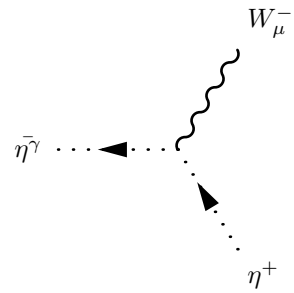
$$ig_2 \sin\Theta_W\left(p_\mu^{\eta^\gamma}\right) \tag{167}$$



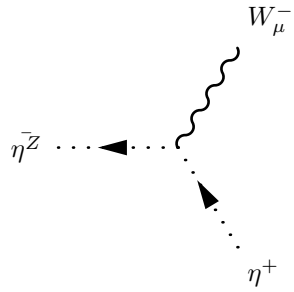
$$ig_2 \sin\Theta_W\left(p_\mu^{\eta^+}\right) \tag{168}$$



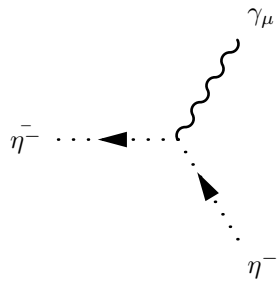
$$ig_2 \cos\Theta_W \left(p_\mu^{\eta^+}\right) \tag{169}$$



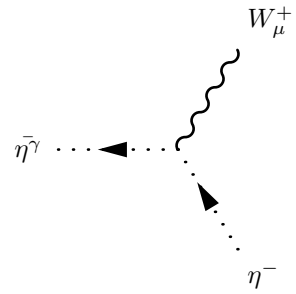
$$-ig_2 \sin\Theta_W \left(p_\mu^{\eta^+}\right) \tag{170}$$



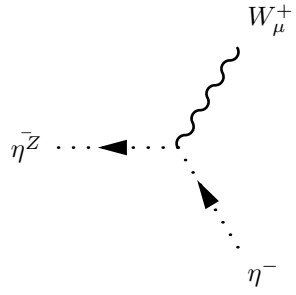
$$-ig_2 \cos\Theta_W \left(p_\mu^{\eta^+}\right) \tag{171}$$



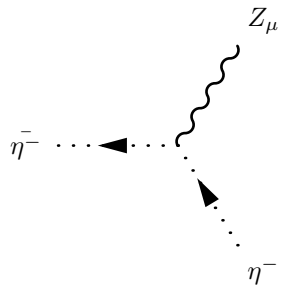
$$-ig_2 \sin\Theta_W \left(p_\mu^{\eta^-}\right) \tag{172}$$



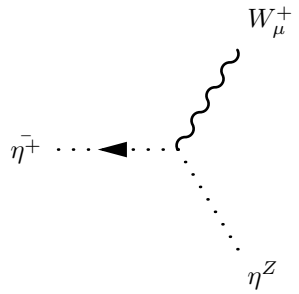
$$ig_2 \sin\Theta_W \left(p_\mu^{\eta^-}\right) \tag{173}$$



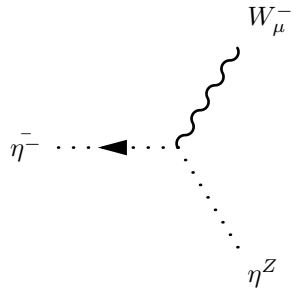
$$ig_2 \cos\Theta_W \left(p_\mu^{\eta^-}\right) \tag{174}$$



$$-ig_2 \cos\Theta_W \left(p_\mu^{\eta^-}\right) \tag{175}$$

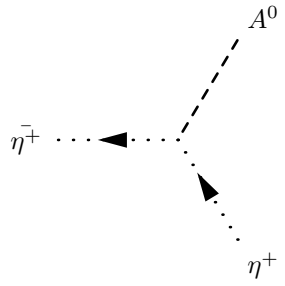


$$-ig_2 \cos\Theta_W \left(p_\mu^{\eta^Z}\right) \tag{176}$$

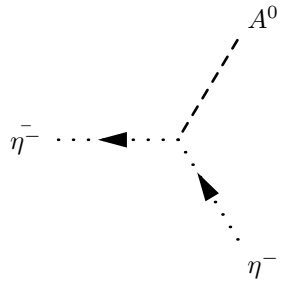


$$ig_2 \cos\Theta_W \left(p_\mu^{\eta^Z}\right) \tag{177}$$

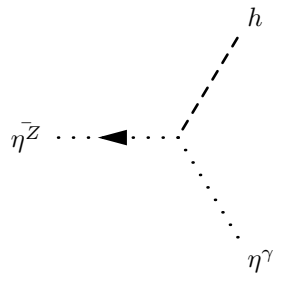
9.11 Two Ghosts-One Scalar-Interaction



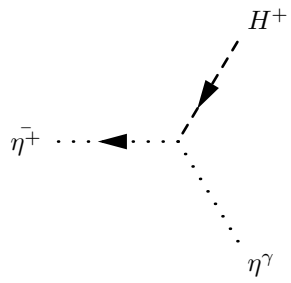
$$\frac{1}{4}g_2^2 v \xi_{W^+} \tag{178}$$



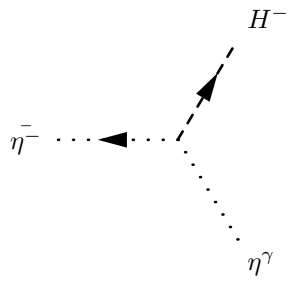
$$-\frac{1}{4}g_2^2 v \xi_{W^+} \tag{179}$$



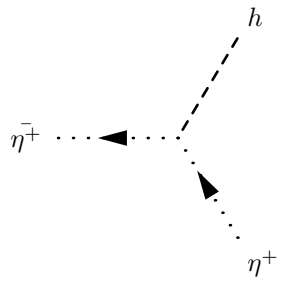
$$\frac{i}{8}v\xi_Z\Big(2g_1 g_2 \cos 2\Theta_W + \Big(-g_2^2 + g_1^2\Big)\sin 2\Theta_W\Big) \tag{180}$$



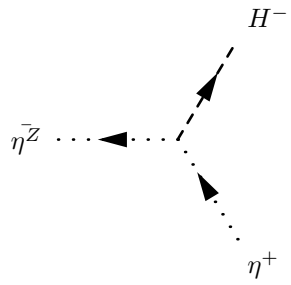
$$-\frac{i}{4}g_2 v \xi_{W^+}\Big(g_1\cos\Theta_W + g_2\sin\Theta_W\Big) \tag{181}$$



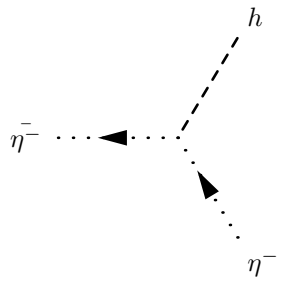
$$-\frac{i}{4}g_2 v \xi_{W^+}\Big(g_1\cos\Theta_W + g_2\sin\Theta_W\Big) \tag{182}$$



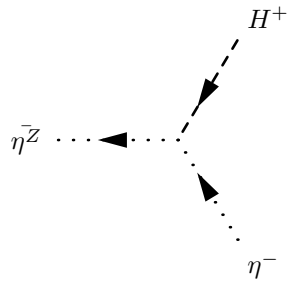
$$-\frac{i}{4}g_2^2 v \xi_{W^+} \tag{183}$$



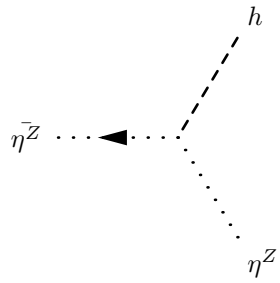
$$\frac{i}{4} g_2 v \xi_Z \Big(g_1 \sin\Theta_W + g_2 \cos\Theta_W \Big) \tag{184}$$



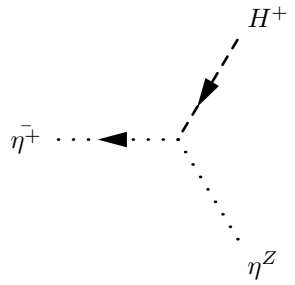
$$-\frac{i}{4} g_2^2 v \xi_{W^+} \tag{185}$$



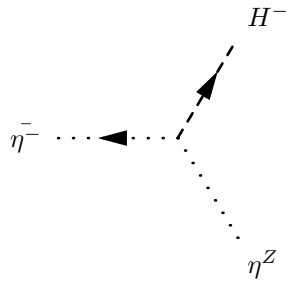
$$\frac{i}{4} g_2 v \xi_Z \Big(g_1 \sin\Theta_W + g_2 \cos\Theta_W \Big) \tag{186}$$



$$-\frac{i}{4}v\xi_Z\Big(g_1\sin\Theta_W+g_2\cos\Theta_W\Big)^2 \tag{187}$$



$$-\frac{i}{4}g_2v\xi_{W^+}\Big(-g_1\sin\Theta_W+g_2\cos\Theta_W\Big) \tag{188}$$



$$-\frac{i}{4}g_2v\xi_{W^+}\Big(-g_1\sin\Theta_W+g_2\cos\Theta_W\Big) \tag{189}$$

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10 Clebsch-Gordan Coefficients