

Two Higgs Doublet Model
Lagrangian, Rotations and Interactions for eigenstates 'EWSB'
including Renormalization Group Equations
including one-loop Self-Energies

SARAH 4.6.0

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References: [arXiv: 1309.7223](#) , [Comput.Phys.Commun.184:1792-1809,2011 \(1207.0906\)](#) , [Comput.Phys.Commun.182:833,2011 \(1002.0840\)](#) , [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	$(U(1) \otimes SU(2) \otimes SU(3))$
H1	0	1	$(\frac{1}{2}, \mathbf{2}, \mathbf{1})$
H2	0	1	$(\frac{1}{2}, \mathbf{2}, \mathbf{1})$
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	$(\frac{1}{3}, \mathbf{1}, \mathbf{\bar{3}})$
u	$\frac{1}{2}$	3	$(-\frac{2}{3}, \mathbf{1}, \mathbf{\bar{3}})$
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'

$$L_{GF} = -\frac{1}{2}|\partial_\mu g|^2 \xi_g^{-1} - \frac{1}{2}|\partial_\mu \gamma|^2 \xi_\gamma^{-1} - \frac{i}{2}g_2(v_1 H_1^{+,*} + v_2 H_2^{+,*})\xi_{W^-} + \partial_\mu W^-|^2 \xi_{W^-}^{-1} - \frac{1}{2}\frac{1}{2}\left(2\partial_\mu Z - (\sigma_1 v_1 + \sigma_2 v_2)\xi_Z\left(g_1 \sin \Theta_W + g_2 \cos \Theta_W\right)\right)^2 \xi_Z^{-1} \tag{3}$$

2.3 Fields integrated out

None

3 Renormalization Group Equations

3.1 Gauge Couplings

$$\beta_{g_1}^{(1)} = \frac{21}{5} g_1^3 \quad (4)$$

$$\beta_{g_1}^{(2)} = \frac{1}{50} g_1^3 \left(180g_2^2 + 208g_1^2 - 25\text{Tr}(Y_d Y_d^\dagger) + 440g_3^2 - 75\text{Tr}(Y_e Y_e^\dagger) - 85\text{Tr}(Y_u Y_u^\dagger) \right) \quad (5)$$

$$\beta_{g_2}^{(1)} = -3g_2^3 \quad (6)$$

$$\beta_{g_2}^{(2)} = \frac{1}{10} g_2^3 \left(120g_3^2 + 12g_1^2 - 15\text{Tr}(Y_d Y_d^\dagger) - 15\text{Tr}(Y_u Y_u^\dagger) - 5\text{Tr}(Y_e Y_e^\dagger) + 80g_2^2 \right) \quad (7)$$

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

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

3.2 Quartic scalar couplings

$$\begin{aligned} \beta_{\lambda_5}^{(1)} = & -\frac{9}{5} g_1^2 \lambda_5 - 9g_2^2 \lambda_5 + 4\lambda_1 \lambda_5 + 4\lambda_2 \lambda_5 + 8\lambda_3 \lambda_5 + 12\lambda_4 \lambda_5 + 6\lambda_5 \text{Tr}(Y_d Y_d^\dagger) + 2\lambda_5 \text{Tr}(Y_e Y_e^\dagger) \\ & + 6\lambda_5 \text{Tr}(Y_u Y_u^\dagger) \end{aligned} \quad (10)$$

$$\begin{aligned} \beta_{\lambda_5}^{(2)} = & +\frac{1413}{200} g_1^4 \lambda_5 + \frac{57}{20} g_1^2 g_2^2 \lambda_5 - \frac{231}{8} g_2^4 \lambda_5 - \frac{12}{5} g_1^2 \lambda_1 \lambda_5 - 28\lambda_1^2 \lambda_5 - \frac{12}{5} g_1^2 \lambda_2 \lambda_5 - 28\lambda_2^2 \lambda_5 \\ & + \frac{48}{5} g_1^2 \lambda_3 \lambda_5 + 36g_2^2 \lambda_3 \lambda_5 - 80\lambda_1 \lambda_3 \lambda_5 - 80\lambda_2 \lambda_3 \lambda_5 - 28\lambda_3^2 \lambda_5 + \frac{72}{5} g_1^2 \lambda_4 \lambda_5 + 72g_2^2 \lambda_4 \lambda_5 \\ & - 88\lambda_1 \lambda_4 \lambda_5 - 88\lambda_2 \lambda_4 \lambda_5 - 76\lambda_3 \lambda_4 \lambda_5 - 32\lambda_4^2 \lambda_5 + 6\lambda_5^3 \\ & + \frac{1}{4} \left(16(10g_3^2 - 6\lambda_2 - 6\lambda_3 - 9\lambda_4) + 45g_2^2 + 5g_1^2 \right) \lambda_5 \text{Tr}(Y_d Y_d^\dagger) \\ & + \frac{1}{4} \left(15g_1^2 + 15g_2^2 - 16(2\lambda_2 + 2\lambda_3 + 3\lambda_4) \right) \lambda_5 \text{Tr}(Y_e Y_e^\dagger) + \frac{17}{4} g_1^2 \lambda_5 \text{Tr}(Y_u Y_u^\dagger) + \frac{45}{4} g_2^2 \lambda_5 \text{Tr}(Y_u Y_u^\dagger) \\ & + 40g_3^2 \lambda_5 \text{Tr}(Y_u Y_u^\dagger) - 24\lambda_2 \lambda_5 \text{Tr}(Y_u Y_u^\dagger) - 24\lambda_3 \lambda_5 \text{Tr}(Y_u Y_u^\dagger) - 36\lambda_4 \lambda_5 \text{Tr}(Y_u Y_u^\dagger) \\ & - \frac{3}{2} \lambda_5 \text{Tr}(Y_d Y_d^\dagger Y_d Y_d^\dagger) + 3\lambda_5 \text{Tr}(Y_d Y_u^\dagger Y_u Y_d^\dagger) - \frac{1}{2} \lambda_5 \text{Tr}(Y_e Y_e^\dagger Y_e Y_e^\dagger) - \frac{3}{2} \lambda_5 \text{Tr}(Y_u Y_u^\dagger Y_u Y_u^\dagger) \end{aligned} \quad (11)$$

$$\beta_{\lambda_1}^{(1)} = 24\lambda_1^2 + 2\lambda_3^2 + 2\lambda_3 \lambda_4 - 9g_2^2 \lambda_1 + \frac{27}{200} g_1^4 + \frac{9}{20} g_1^2 \left(-4\lambda_1 + g_2^2 \right) + \frac{9}{8} g_2^4 + \lambda_4^2 + \lambda_5^2 \quad (12)$$

$$\beta_{\lambda_1}^{(2)} = -\frac{3537}{2000} g_1^6 - \frac{1719}{400} g_1^4 g_2^2 - \frac{303}{80} g_1^2 g_2^4 + \frac{291}{16} g_2^6 + \frac{1953}{200} g_1^4 \lambda_1 + \frac{117}{20} g_1^2 g_2^2 \lambda_1 - \frac{51}{8} g_2^4 \lambda_1 + \frac{108}{5} g_1^2 \lambda_1^2$$

$$\begin{aligned}
& + 108g_2^2\lambda_1^2 - 312\lambda_1^3 + \frac{9}{10}g_1^4\lambda_3 + \frac{15}{2}g_2^4\lambda_3 + \frac{12}{5}g_1^2\lambda_3^2 + 12g_2^2\lambda_3^2 - 20\lambda_1\lambda_3^2 - 8\lambda_3^3 + \frac{9}{20}g_1^4\lambda_4 \\
& + \frac{3}{2}g_1^2g_2^2\lambda_4 + \frac{15}{4}g_2^4\lambda_4 + \frac{12}{5}g_1^2\lambda_3\lambda_4 + 12g_2^2\lambda_3\lambda_4 - 20\lambda_1\lambda_3\lambda_4 - 12\lambda_3^2\lambda_4 + \frac{6}{5}g_1^2\lambda_4^2 \\
& + 3g_2^2\lambda_4^2 - 12\lambda_1\lambda_4^2 - 16\lambda_3\lambda_4^2 - 6\lambda_4^3 - \frac{3}{5}g_1^2\lambda_5^2 - 14\lambda_1\lambda_5^2 - 20\lambda_3\lambda_5^2 - 22\lambda_4\lambda_5^2 \\
& - 6\left(2\lambda_3^2 + 2\lambda_3\lambda_4 + \lambda_4^2 + \lambda_5^2\right)\text{Tr}\left(Y_d Y_d^\dagger\right) - 2\left(2\lambda_3^2 + 2\lambda_3\lambda_4 + \lambda_4^2 + \lambda_5^2\right)\text{Tr}\left(Y_e Y_e^\dagger\right) \\
& - 12\lambda_3^2\text{Tr}\left(Y_u Y_u^\dagger\right) - 12\lambda_3\lambda_4\text{Tr}\left(Y_u Y_u^\dagger\right) - 6\lambda_4^2\text{Tr}\left(Y_u Y_u^\dagger\right) - 6\lambda_5^2\text{Tr}\left(Y_u Y_u^\dagger\right)
\end{aligned} \tag{13}$$

$$\begin{aligned}
\beta_{\lambda_4}^{(1)} & = +\frac{9}{5}g_1^2g_2^2 - \frac{9}{5}g_1^2\lambda_4 - 9g_2^2\lambda_4 + 4\lambda_1\lambda_4 + 4\lambda_2\lambda_4 + 8\lambda_3\lambda_4 + 4\lambda_4^2 + 8\lambda_5^2 + 6\lambda_4\text{Tr}\left(Y_d Y_d^\dagger\right) \\
& + 2\lambda_4\text{Tr}\left(Y_e Y_e^\dagger\right) + 6\lambda_4\text{Tr}\left(Y_u Y_u^\dagger\right)
\end{aligned} \tag{14}$$

$$\begin{aligned}
\beta_{\lambda_4}^{(2)} & = -\frac{657}{50}g_1^4g_2^2 - \frac{42}{5}g_1^2g_2^4 + 6g_1^2g_2^2\lambda_1 + 6g_1^2g_2^2\lambda_2 + \frac{6}{5}g_1^2g_2^2\lambda_3 + \frac{1413}{200}g_1^4\lambda_4 + \frac{153}{20}g_1^2g_2^2\lambda_4 \\
& - \frac{231}{8}g_2^4\lambda_4 + \frac{24}{5}g_1^2\lambda_1\lambda_4 - 28\lambda_1^2\lambda_4 + \frac{24}{5}g_1^2\lambda_2\lambda_4 - 28\lambda_2^2\lambda_4 + \frac{12}{5}g_1^2\lambda_3\lambda_4 + 36g_2^2\lambda_3\lambda_4 \\
& - 80\lambda_1\lambda_3\lambda_4 - 80\lambda_2\lambda_3\lambda_4 - 28\lambda_3^2\lambda_4 + \frac{24}{5}g_1^2\lambda_4^2 + 18g_2^2\lambda_4^2 - 40\lambda_1\lambda_4^2 - 40\lambda_2\lambda_4^2 - 28\lambda_3\lambda_4^2 \\
& + \frac{48}{5}g_1^2\lambda_5^2 + 54g_2^2\lambda_5^2 - 48\lambda_1\lambda_5^2 - 48\lambda_2\lambda_5^2 - 48\lambda_3\lambda_5^2 - 26\lambda_4\lambda_5^2 \\
& + \left(4\left(10g_3^2\lambda_4 - 3\left(2\lambda_2\lambda_4 + 2\lambda_3\lambda_4 + 2\lambda_5^2 + \lambda_4^2\right)\right) + \frac{45}{4}g_2^2\lambda_4 + g_1^2\left(\frac{27}{5}g_2^2 + \frac{5}{4}\lambda_4\right)\right)\text{Tr}\left(Y_d Y_d^\dagger\right) \\
& + \left(-4\left(2\lambda_2\lambda_4 + 2\lambda_3\lambda_4 + 2\lambda_5^2 + \lambda_4^2\right) + \frac{15}{4}g_2^2\lambda_4 + \frac{3}{20}g_1^2\left(25\lambda_4 + 44g_2^2\right)\right)\text{Tr}\left(Y_e Y_e^\dagger\right) \\
& + \frac{63}{5}g_1^2g_2^2\text{Tr}\left(Y_u Y_u^\dagger\right) + \frac{17}{4}g_1^2\lambda_4\text{Tr}\left(Y_u Y_u^\dagger\right) + \frac{45}{4}g_2^2\lambda_4\text{Tr}\left(Y_u Y_u^\dagger\right) + 40g_3^2\lambda_4\text{Tr}\left(Y_u Y_u^\dagger\right) \\
& - 24\lambda_2\lambda_4\text{Tr}\left(Y_u Y_u^\dagger\right) - 24\lambda_3\lambda_4\text{Tr}\left(Y_u Y_u^\dagger\right) - 12\lambda_4^2\text{Tr}\left(Y_u Y_u^\dagger\right) - 24\lambda_5^2\text{Tr}\left(Y_u Y_u^\dagger\right) \\
& - \frac{27}{2}\lambda_4\text{Tr}\left(Y_d Y_d^\dagger Y_d Y_d^\dagger\right) + 27\lambda_4\text{Tr}\left(Y_d Y_u^\dagger Y_u Y_d^\dagger\right) - \frac{9}{2}\lambda_4\text{Tr}\left(Y_e Y_e^\dagger Y_e Y_e^\dagger\right) - \frac{27}{2}\lambda_4\text{Tr}\left(Y_u Y_u^\dagger Y_u Y_u^\dagger\right)
\end{aligned} \tag{15}$$

$$\begin{aligned}
\beta_{\lambda_3}^{(1)} & = +\frac{27}{100}g_1^4 - \frac{9}{10}g_1^2g_2^2 + \frac{9}{4}g_2^4 - \frac{9}{5}g_1^2\lambda_3 - 9g_2^2\lambda_3 + 12\lambda_1\lambda_3 + 12\lambda_2\lambda_3 + 4\lambda_3^2 + 4\lambda_1\lambda_4 + 4\lambda_2\lambda_4 + 2\lambda_4^2 \\
& + 2\lambda_5^2 + 6\lambda_3\text{Tr}\left(Y_d Y_d^\dagger\right) + 2\lambda_3\text{Tr}\left(Y_e Y_e^\dagger\right) + 6\lambda_3\text{Tr}\left(Y_u Y_u^\dagger\right)
\end{aligned} \tag{16}$$

$$\begin{aligned}
\beta_{\lambda_3}^{(2)} & = -\frac{3537}{1000}g_1^6 + \frac{909}{200}g_1^4g_2^2 + \frac{33}{40}g_1^2g_2^4 + \frac{291}{8}g_2^6 + \frac{27}{10}g_1^4\lambda_1 - 3g_1^2g_2^2\lambda_1 + \frac{45}{2}g_2^4\lambda_1 + \frac{27}{10}g_1^4\lambda_2 \\
& - 3g_1^2g_2^2\lambda_2 + \frac{45}{2}g_2^4\lambda_2 + \frac{1773}{200}g_1^4\lambda_3 + \frac{33}{20}g_1^2g_2^2\lambda_3 - \frac{111}{8}g_2^4\lambda_3 + \frac{72}{5}g_1^2\lambda_1\lambda_3 + 72g_2^2\lambda_1\lambda_3 \\
& - 60\lambda_1^2\lambda_3 + \frac{72}{5}g_1^2\lambda_2\lambda_3 + 72g_2^2\lambda_2\lambda_3 - 60\lambda_2^2\lambda_3 + \frac{6}{5}g_1^2\lambda_3^2 + 6g_2^2\lambda_3^2 - 72\lambda_1\lambda_3^2 - 72\lambda_2\lambda_3^2 \\
& - 12\lambda_3^3 + \frac{9}{10}g_1^4\lambda_4 - \frac{9}{5}g_1^2g_2^2\lambda_4 + \frac{15}{2}g_2^4\lambda_4 + \frac{24}{5}g_1^2\lambda_1\lambda_4 + 36g_2^2\lambda_1\lambda_4 - 16\lambda_1^2\lambda_4 + \frac{24}{5}g_1^2\lambda_2\lambda_4 \\
& + 36g_2^2\lambda_2\lambda_4 - 16\lambda_2^2\lambda_4 - 12g_2^2\lambda_3\lambda_4 - 32\lambda_1\lambda_3\lambda_4 - 32\lambda_2\lambda_3\lambda_4 - 4\lambda_3^2\lambda_4 - \frac{6}{5}g_1^2\lambda_4^2
\end{aligned}$$

$$\begin{aligned}
& + 6g_2^2\lambda_4^2 - 28\lambda_1\lambda_4^2 - 28\lambda_2\lambda_4^2 - 16\lambda_3\lambda_4^2 - 12\lambda_4^3 + \frac{12}{5}g_1^2\lambda_5^2 - 36\lambda_1\lambda_5^2 - 36\lambda_2\lambda_5^2 \\
& - 18\lambda_3\lambda_5^2 - 44\lambda_4\lambda_5^2 \\
& + \frac{1}{20}\left(-5\left(-45g_2^2\lambda_3 + 8\left(-20g_3^2\lambda_3 + 3\left(2\lambda_3^2 + 4\lambda_2\left(3\lambda_3 + \lambda_4\right) + \lambda_4^2 + \lambda_5^2\right)\right) + 9g_2^4\right) + 9g_1^4 + g_1^2\left(25\lambda_3 - 54g_2^2\right)\right)\text{Tr}\left(Y_d Y_d^\dagger\right) \\
& - \frac{1}{20}\left(45g_1^4 + 5\left(-15g_2^2\lambda_3 + 3g_2^4 + 8\left(2\lambda_3^2 + 4\lambda_2\left(3\lambda_3 + \lambda_4\right) + \lambda_4^2 + \lambda_5^2\right)\right) + g_1^2\left(66g_2^2 - 75\lambda_3\right)\right)\text{Tr}\left(Y_e Y_e^\dagger\right) \\
& - \frac{171}{100}g_1^4\text{Tr}\left(Y_u Y_u^\dagger\right) - \frac{63}{10}g_1^2g_2^2\text{Tr}\left(Y_u Y_u^\dagger\right) - \frac{9}{4}g_2^4\text{Tr}\left(Y_u Y_u^\dagger\right) + \frac{17}{4}g_1^2\lambda_3\text{Tr}\left(Y_u Y_u^\dagger\right) \\
& + \frac{45}{4}g_2^2\lambda_3\text{Tr}\left(Y_u Y_u^\dagger\right) + 40g_3^2\lambda_3\text{Tr}\left(Y_u Y_u^\dagger\right) - 72\lambda_2\lambda_3\text{Tr}\left(Y_u Y_u^\dagger\right) - 12\lambda_3^2\text{Tr}\left(Y_u Y_u^\dagger\right) \\
& - 24\lambda_2\lambda_4\text{Tr}\left(Y_u Y_u^\dagger\right) - 6\lambda_4^2\text{Tr}\left(Y_u Y_u^\dagger\right) - 6\lambda_5^2\text{Tr}\left(Y_u Y_u^\dagger\right) - \frac{27}{2}\lambda_3\text{Tr}\left(Y_d Y_d^\dagger Y_d Y_d^\dagger\right) \\
& - 21\lambda_3\text{Tr}\left(Y_d Y_u^\dagger Y_u Y_d^\dagger\right) - 24\lambda_4\text{Tr}\left(Y_d Y_u^\dagger Y_u Y_d^\dagger\right) - \frac{9}{2}\lambda_3\text{Tr}\left(Y_e Y_e^\dagger Y_e Y_e^\dagger\right) - \frac{27}{2}\lambda_3\text{Tr}\left(Y_u Y_u^\dagger Y_u Y_u^\dagger\right) \tag{17}
\end{aligned}$$

$$\begin{aligned}
\beta_{\lambda_2}^{(1)} & = + \frac{27}{200}g_1^4 + \frac{9}{20}g_1^2g_2^2 + \frac{9}{8}g_2^4 - \frac{9}{5}g_1^2\lambda_2 - 9g_2^2\lambda_2 + 24\lambda_2^2 + 2\lambda_3^2 + 2\lambda_3\lambda_4 + \lambda_4^2 + \lambda_5^2 + 12\lambda_2\text{Tr}\left(Y_d Y_d^\dagger\right) \\
& + 4\lambda_2\text{Tr}\left(Y_e Y_e^\dagger\right) + 12\lambda_2\text{Tr}\left(Y_u Y_u^\dagger\right) - 6\text{Tr}\left(Y_d Y_d^\dagger Y_d Y_d^\dagger\right) - 2\text{Tr}\left(Y_e Y_e^\dagger Y_e Y_e^\dagger\right) - 6\text{Tr}\left(Y_u Y_u^\dagger Y_u Y_u^\dagger\right) \tag{18}
\end{aligned}$$

$$\begin{aligned}
\beta_{\lambda_2}^{(2)} & = - \frac{3537}{2000}g_1^6 - \frac{1719}{400}g_1^4g_2^2 - \frac{303}{80}g_1^2g_2^4 + \frac{291}{16}g_2^6 + \frac{1953}{200}g_1^4\lambda_2 + \frac{117}{20}g_1^2g_2^2\lambda_2 - \frac{51}{8}g_2^4\lambda_2 + \frac{108}{5}g_1^2\lambda_2^2 \\
& + 108g_2^2\lambda_2^2 - 312\lambda_3^2 + \frac{9}{10}g_1^4\lambda_3 + \frac{15}{2}g_2^4\lambda_3 + \frac{12}{5}g_1^2\lambda_3^2 + 12g_2^2\lambda_3^2 - 20\lambda_2\lambda_3^2 - 8\lambda_3^3 + \frac{9}{20}g_1^4\lambda_4 \\
& + \frac{3}{2}g_1^2g_2^2\lambda_4 + \frac{15}{4}g_2^4\lambda_4 + \frac{12}{5}g_1^2\lambda_3\lambda_4 + 12g_2^2\lambda_3\lambda_4 - 20\lambda_2\lambda_3\lambda_4 - 12\lambda_3^2\lambda_4 + \frac{6}{5}g_1^2\lambda_4^2 \\
& + 3g_2^2\lambda_4^2 - 12\lambda_2\lambda_4^2 - 16\lambda_3\lambda_4^2 - 6\lambda_4^3 - \frac{3}{5}g_1^2\lambda_5^2 - 14\lambda_2\lambda_5^2 - 20\lambda_3\lambda_5^2 - 22\lambda_4\lambda_5^2 \\
& + \frac{1}{20}\left(-5\left(64\lambda_2\left(-5g_3^2 + 9\lambda_2\right) - 90g_2^2\lambda_2 + 9g_2^4\right) + 9g_1^4 + g_1^2\left(50\lambda_2 + 54g_2^2\right)\right)\text{Tr}\left(Y_d Y_d^\dagger\right) \\
& - \frac{3}{20}\left(15g_1^4 - 2g_1^2\left(11g_2^2 + 25\lambda_2\right) + 5\left(-10g_2^2\lambda_2 + 64\lambda_2^2 + g_2^4\right)\right)\text{Tr}\left(Y_e Y_e^\dagger\right) - \frac{171}{100}g_1^4\text{Tr}\left(Y_u Y_u^\dagger\right) \\
& + \frac{63}{10}g_1^2g_2^2\text{Tr}\left(Y_u Y_u^\dagger\right) - \frac{9}{4}g_2^4\text{Tr}\left(Y_u Y_u^\dagger\right) + \frac{17}{2}g_1^2\lambda_2\text{Tr}\left(Y_u Y_u^\dagger\right) + \frac{45}{2}g_2^2\lambda_2\text{Tr}\left(Y_u Y_u^\dagger\right) \\
& + 80g_3^2\lambda_2\text{Tr}\left(Y_u Y_u^\dagger\right) - 144\lambda_2^2\text{Tr}\left(Y_u Y_u^\dagger\right) + \frac{4}{5}g_1^2\text{Tr}\left(Y_d Y_d^\dagger Y_d Y_d^\dagger\right) - 32g_3^2\text{Tr}\left(Y_d Y_d^\dagger Y_d Y_d^\dagger\right) \\
& - 3\lambda_2\text{Tr}\left(Y_d Y_u^\dagger Y_u Y_d^\dagger\right) - 42\lambda_2\text{Tr}\left(Y_d Y_u^\dagger Y_u Y_d^\dagger\right) - \frac{12}{5}g_1^2\text{Tr}\left(Y_e Y_e^\dagger Y_e Y_e^\dagger\right) - \lambda_2\text{Tr}\left(Y_e Y_e^\dagger Y_e Y_e^\dagger\right) \\
& - \frac{8}{5}g_1^2\text{Tr}\left(Y_u Y_u^\dagger Y_u Y_u^\dagger\right) - 32g_3^2\text{Tr}\left(Y_u Y_u^\dagger Y_u Y_u^\dagger\right) - 3\lambda_2\text{Tr}\left(Y_u Y_u^\dagger Y_u Y_u^\dagger\right) + 30\text{Tr}\left(Y_d Y_d^\dagger Y_d Y_d^\dagger Y_d Y_d^\dagger\right) \\
& + 6\text{Tr}\left(Y_d Y_d^\dagger Y_d Y_u^\dagger Y_u Y_d^\dagger\right) - 12\text{Tr}\left(Y_d Y_u^\dagger Y_u Y_d^\dagger Y_d Y_d^\dagger\right) - 6\text{Tr}\left(Y_d Y_u^\dagger Y_u Y_u^\dagger Y_u Y_d^\dagger\right) \\
& + 10\text{Tr}\left(Y_e Y_e^\dagger Y_e Y_e^\dagger Y_e Y_e^\dagger\right) + 30\text{Tr}\left(Y_u Y_u^\dagger Y_u Y_u^\dagger Y_u Y_u^\dagger\right) \tag{19}
\end{aligned}$$

3.3 Yukawa Couplings

$$\begin{aligned} \beta_{Y_u}^{(1)} = & -\frac{3}{2} \left(-Y_u Y_u^\dagger Y_u + Y_u Y_d^\dagger Y_d \right) \\ & + Y_u \left(3\text{Tr}(Y_d Y_d^\dagger) + 3\text{Tr}(Y_u Y_u^\dagger) - 8g_3^2 - \frac{17}{20}g_1^2 - \frac{9}{4}g_2^2 + \text{Tr}(Y_e Y_e^\dagger) \right) \end{aligned} \quad (20)$$

$$\begin{aligned} \beta_{Y_u}^{(2)} = & +\frac{1}{80} \left(20 \left(11Y_u Y_d^\dagger Y_d Y_d^\dagger Y_d - 4Y_u Y_u^\dagger Y_u Y_d^\dagger Y_d + 6Y_u Y_u^\dagger Y_u Y_u^\dagger Y_u - Y_u Y_d^\dagger Y_d Y_u^\dagger Y_u \right) \right. \\ & + Y_u Y_u^\dagger Y_u \left(1280g_3^2 - 180\text{Tr}(Y_e Y_e^\dagger) + 223g_1^2 - 540\text{Tr}(Y_d Y_d^\dagger) - 540\text{Tr}(Y_u Y_u^\dagger) + 675g_2^2 - 960\lambda_2 \right) \\ & + Y_u Y_d^\dagger Y_d \left(100\text{Tr}(Y_e Y_e^\dagger) - 1280g_3^2 + 300\text{Tr}(Y_d Y_d^\dagger) + 300\text{Tr}(Y_u Y_u^\dagger) - 43g_1^2 + 45g_2^2 \right) \\ & + Y_u \left(\frac{1267}{600}g_1^4 - \frac{9}{20}g_1^2 g_2^2 - \frac{21}{4}g_2^4 + \frac{19}{15}g_1^2 g_3^2 + 9g_2^2 g_3^2 - 108g_3^4 + 6\lambda_2^2 + \lambda_3^2 + \lambda_3 \lambda_4 + \lambda_4^2 + \frac{3}{2}\lambda_5^2 \right. \\ & + \frac{5}{8} \left(32g_3^2 + 9g_2^2 + g_1^2 \right) \text{Tr}(Y_d Y_d^\dagger) + \frac{15}{8} \left(g_1^2 + g_2^2 \right) \text{Tr}(Y_e Y_e^\dagger) + \frac{17}{8}g_1^2 \text{Tr}(Y_u Y_u^\dagger) + \frac{45}{8}g_2^2 \text{Tr}(Y_u Y_u^\dagger) \\ & \left. + 20g_3^2 \text{Tr}(Y_u Y_u^\dagger) - \frac{27}{4} \text{Tr}(Y_d Y_d^\dagger Y_d Y_d^\dagger) + \frac{3}{2} \text{Tr}(Y_d Y_u^\dagger Y_u Y_d^\dagger) - \frac{9}{4} \text{Tr}(Y_e Y_e^\dagger Y_e Y_e^\dagger) - \frac{27}{4} \text{Tr}(Y_u Y_u^\dagger Y_u Y_u^\dagger) \right) \end{aligned} \quad (21)$$

$$\begin{aligned} \beta_{Y_d}^{(1)} = & \frac{1}{4} \left(6 \left(-Y_d Y_u^\dagger Y_u + Y_d Y_d^\dagger Y_d \right) \right. \\ & \left. - Y_d \left(-12\text{Tr}(Y_d Y_d^\dagger) - 12\text{Tr}(Y_u Y_u^\dagger) + 32g_3^2 - 4\text{Tr}(Y_e Y_e^\dagger) + 9g_2^2 + g_1^2 \right) \right) \end{aligned} \quad (22)$$

$$\begin{aligned} \beta_{Y_d}^{(2)} = & +\frac{1}{80} \left(20 \left(11Y_d Y_u^\dagger Y_u Y_u^\dagger Y_u - 4Y_d Y_d^\dagger Y_d Y_u^\dagger Y_u + 6Y_d Y_d^\dagger Y_d Y_d^\dagger Y_d - Y_d Y_u^\dagger Y_u Y_d^\dagger Y_d \right) \right. \\ & + Y_d Y_d^\dagger Y_d \left(1280g_3^2 - 180\text{Tr}(Y_e Y_e^\dagger) + 187g_1^2 - 540\text{Tr}(Y_d Y_d^\dagger) - 540\text{Tr}(Y_u Y_u^\dagger) + 675g_2^2 - 960\lambda_2 \right) \\ & + Y_d Y_u^\dagger Y_u \left(100\text{Tr}(Y_e Y_e^\dagger) - 1280g_3^2 + 300\text{Tr}(Y_d Y_d^\dagger) + 300\text{Tr}(Y_u Y_u^\dagger) + 45g_2^2 - 79g_1^2 \right) \\ & + Y_d \left(-\frac{113}{600}g_1^4 - \frac{27}{20}g_1^2 g_2^2 - \frac{21}{4}g_2^4 + \frac{31}{15}g_1^2 g_3^2 + 9g_2^2 g_3^2 - 108g_3^4 + 6\lambda_2^2 + \lambda_3^2 + \lambda_3 \lambda_4 + \lambda_4^2 + \frac{3}{2}\lambda_5^2 \right. \\ & + \frac{5}{8} \left(32g_3^2 + 9g_2^2 + g_1^2 \right) \text{Tr}(Y_d Y_d^\dagger) + \frac{15}{8} \left(g_1^2 + g_2^2 \right) \text{Tr}(Y_e Y_e^\dagger) + \frac{17}{8}g_1^2 \text{Tr}(Y_u Y_u^\dagger) + \frac{45}{8}g_2^2 \text{Tr}(Y_u Y_u^\dagger) \\ & \left. + 20g_3^2 \text{Tr}(Y_u Y_u^\dagger) - \frac{27}{4} \text{Tr}(Y_d Y_d^\dagger Y_d Y_d^\dagger) + \frac{3}{2} \text{Tr}(Y_d Y_u^\dagger Y_u Y_d^\dagger) - \frac{9}{4} \text{Tr}(Y_e Y_e^\dagger Y_e Y_e^\dagger) - \frac{27}{4} \text{Tr}(Y_u Y_u^\dagger Y_u Y_u^\dagger) \right) \end{aligned} \quad (23)$$

$$\beta_{Y_e}^{(1)} = \frac{3}{2} Y_e Y_e^\dagger Y_e + Y_e \left(3\text{Tr}(Y_d Y_d^\dagger) + 3\text{Tr}(Y_u Y_u^\dagger) - \frac{9}{4}g_1^2 - \frac{9}{4}g_2^2 + \text{Tr}(Y_e Y_e^\dagger) \right) \quad (24)$$

$$\begin{aligned} \beta_{Y_e}^{(2)} = & +\frac{3}{80} \left(40Y_e Y_e^\dagger Y_e Y_e^\dagger Y_e \right. \\ & + Y_e Y_e^\dagger Y_e \left(129g_1^2 - 180\text{Tr}(Y_d Y_d^\dagger) - 180\text{Tr}(Y_u Y_u^\dagger) + 225g_2^2 - 320\lambda_2 - 60\text{Tr}(Y_e Y_e^\dagger) \right) \\ & + Y_e \left(\frac{1449}{200}g_1^4 + \frac{27}{20}g_1^2 g_2^2 - \frac{21}{4}g_2^4 + 6\lambda_2^2 + \lambda_3^2 + \lambda_3 \lambda_4 + \lambda_4^2 + \frac{3}{2}\lambda_5^2 + \frac{5}{8} \left(32g_3^2 + 9g_2^2 + g_1^2 \right) \text{Tr}(Y_d Y_d^\dagger) \right. \\ & + \frac{15}{8} \left(g_1^2 + g_2^2 \right) \text{Tr}(Y_e Y_e^\dagger) + \frac{17}{8}g_1^2 \text{Tr}(Y_u Y_u^\dagger) + \frac{45}{8}g_2^2 \text{Tr}(Y_u Y_u^\dagger) + 20g_3^2 \text{Tr}(Y_u Y_u^\dagger) \\ & \left. - \frac{27}{4} \text{Tr}(Y_d Y_d^\dagger Y_d Y_d^\dagger) + \frac{3}{2} \text{Tr}(Y_d Y_u^\dagger Y_u Y_d^\dagger) - \frac{9}{4} \text{Tr}(Y_e Y_e^\dagger Y_e Y_e^\dagger) - \frac{27}{4} \text{Tr}(Y_u Y_u^\dagger Y_u Y_u^\dagger) \right) \end{aligned} \quad (25)$$

3.4 Scalar Mass Terms

$$\beta_{m_{12}}^{(1)} = 2\lambda_3 m_{12} + 4\lambda_4 m_{12} + 6\lambda_5 m_{12} + 6m_{12} \text{Tr}(Y_u Y_u^\dagger) - \frac{9}{10} g_1^2 m_{12} - \frac{9}{2} g_2^2 m_{12} \quad (26)$$

$$\begin{aligned} \beta_{m_{12}}^{(2)} = & + \frac{1377}{400} g_1^4 m_{12} + \frac{9}{8} g_1^2 g_2^2 m_{12} - \frac{243}{16} g_2^4 m_{12} + 6\lambda_1^2 m_{12} + 6\lambda_2^2 m_{12} + \frac{12}{5} g_1^2 \lambda_3 m_{12} + 12g_2^2 \lambda_3 m_{12} - 12\lambda_1 \lambda_3 m_{12} \\ & - 12\lambda_2 \lambda_3 m_{12} + \frac{24}{5} g_1^2 \lambda_4 m_{12} + 24g_2^2 \lambda_4 m_{12} - 12\lambda_1 \lambda_4 m_{12} - 12\lambda_2 \lambda_4 m_{12} - 6\lambda_3 \lambda_4 m_{12} + \frac{36}{5} g_1^2 \lambda_5 m_{12} \\ & + 36g_2^2 \lambda_5 m_{12} - 12\lambda_1 \lambda_5 m_{12} - 12\lambda_2 \lambda_5 m_{12} - 12\lambda_3 \lambda_5 m_{12} - 12\lambda_4 \lambda_5 m_{12} + 3\lambda_5^2 m_{12} \\ & + \frac{1}{8} (16(10g_3^2 - 3(2\lambda_4 + 3\lambda_5 + \lambda_3)) + 45g_2^2 + 5g_1^2) m_{12} \text{Tr}(Y_d Y_d^\dagger) \\ & + \frac{1}{8} (15g_1^2 + 15g_2^2 - 16(2\lambda_4 + 3\lambda_5 + \lambda_3)) m_{12} \text{Tr}(Y_e Y_e^\dagger) + \frac{17}{8} g_1^2 m_{12} \text{Tr}(Y_u Y_u^\dagger) + \frac{45}{8} g_2^2 m_{12} \text{Tr}(Y_u Y_u^\dagger) \\ & + 20g_3^2 m_{12} \text{Tr}(Y_u Y_u^\dagger) - 6\lambda_3 m_{12} \text{Tr}(Y_u Y_u^\dagger) - 12\lambda_4 m_{12} \text{Tr}(Y_u Y_u^\dagger) - 18\lambda_5 m_{12} \text{Tr}(Y_u Y_u^\dagger) \\ & - \frac{27}{4} m_{12} \text{Tr}(Y_d Y_d^\dagger Y_d Y_d^\dagger) + \frac{3}{2} m_{12} \text{Tr}(Y_d Y_u^\dagger Y_u Y_d^\dagger) - \frac{9}{4} m_{12} \text{Tr}(Y_e Y_e^\dagger Y_e Y_e^\dagger) - \frac{27}{4} m_{12} \text{Tr}(Y_u Y_u^\dagger Y_u Y_u^\dagger) \end{aligned} \quad (27)$$

$$\beta_{m_1^2}^{(1)} = 12\lambda_1 m_1^2 + 2\lambda_4 m_2^2 + 4\lambda_3 m_2^2 - \frac{9}{10} g_1^2 m_1^2 - \frac{9}{2} g_2^2 m_1^2 \quad (28)$$

$$\begin{aligned} \beta_{m_1^2}^{(2)} = & + \frac{1737}{400} g_1^4 m_1^2 + \frac{9}{8} g_1^2 g_2^2 m_1^2 - \frac{123}{16} g_2^4 m_1^2 + \frac{72}{5} g_1^2 \lambda_1 m_1^2 + 72g_2^2 \lambda_1 m_1^2 - 60\lambda_1^2 m_1^2 - 2\lambda_3^2 m_1^2 \\ & - 2\lambda_3 \lambda_4 m_1^2 - 2\lambda_4^2 m_1^2 - 3\lambda_5^2 m_1^2 + \frac{9}{10} g_1^4 m_2^2 + \frac{15}{2} g_2^4 m_2^2 + \frac{24}{5} g_1^2 \lambda_3 m_2^2 + 24g_2^2 \lambda_3 m_2^2 \\ & - 8\lambda_3^2 m_2^2 + \frac{12}{5} g_1^2 \lambda_4 m_2^2 + 12g_2^2 \lambda_4 m_2^2 - 8\lambda_3 \lambda_4 m_2^2 - 8\lambda_4^2 m_2^2 - 12\lambda_5^2 m_2^2 \\ & - 12(2\lambda_3 + \lambda_4) m_2^2 \text{Tr}(Y_d Y_d^\dagger) - 4(2\lambda_3 + \lambda_4) m_2^2 \text{Tr}(Y_e Y_e^\dagger) - 24\lambda_3 m_2^2 \text{Tr}(Y_u Y_u^\dagger) \\ & - 12\lambda_4 m_2^2 \text{Tr}(Y_u Y_u^\dagger) \end{aligned} \quad (29)$$

$$\begin{aligned} \beta_{m_2^2}^{(1)} = & + 4\lambda_3 m_1^2 + 2\lambda_4 m_1^2 - \frac{9}{10} g_1^2 m_2^2 - \frac{9}{2} g_2^2 m_2^2 + 12\lambda_2 m_2^2 + 6m_2^2 \text{Tr}(Y_d Y_d^\dagger) + 2m_2^2 \text{Tr}(Y_e Y_e^\dagger) \\ & + 6m_2^2 \text{Tr}(Y_u Y_u^\dagger) \end{aligned} \quad (30)$$

$$\begin{aligned} \beta_{m_2^2}^{(2)} = & + \frac{9}{10} g_1^4 m_1^2 + \frac{15}{2} g_2^4 m_1^2 + \frac{24}{5} g_1^2 \lambda_3 m_1^2 + 24g_2^2 \lambda_3 m_1^2 - 8\lambda_3^2 m_1^2 + \frac{12}{5} g_1^2 \lambda_4 m_1^2 + 12g_2^2 \lambda_4 m_1^2 \\ & - 8\lambda_3 \lambda_4 m_1^2 - 8\lambda_4^2 m_1^2 - 12\lambda_5^2 m_1^2 + \frac{1737}{400} g_1^4 m_2^2 + \frac{9}{8} g_1^2 g_2^2 m_2^2 - \frac{123}{16} g_2^4 m_2^2 + \frac{72}{5} g_1^2 \lambda_2 m_2^2 \\ & + 72g_2^2 \lambda_2 m_2^2 - 60\lambda_2^2 m_2^2 - 2\lambda_3^2 m_2^2 - 2\lambda_3 \lambda_4 m_2^2 - 2\lambda_4^2 m_2^2 - 3\lambda_5^2 m_2^2 \\ & + \frac{1}{4} (160g_3^2 - 288\lambda_2 + 45g_2^2 + 5g_1^2) m_2^2 \text{Tr}(Y_d Y_d^\dagger) + \frac{3}{4} (-32\lambda_2 + 5g_1^2 + 5g_2^2) m_2^2 \text{Tr}(Y_e Y_e^\dagger) \\ & + \frac{17}{4} g_1^2 m_2^2 \text{Tr}(Y_u Y_u^\dagger) + \frac{45}{4} g_2^2 m_2^2 \text{Tr}(Y_u Y_u^\dagger) + 40g_3^2 m_2^2 \text{Tr}(Y_u Y_u^\dagger) - 72\lambda_2 m_2^2 \text{Tr}(Y_u Y_u^\dagger) \\ & - \frac{27}{2} m_2^2 \text{Tr}(Y_d Y_d^\dagger Y_d Y_d^\dagger) - 21m_2^2 \text{Tr}(Y_d Y_u^\dagger Y_u Y_d^\dagger) - \frac{9}{2} m_2^2 \text{Tr}(Y_e Y_e^\dagger Y_e Y_e^\dagger) - \frac{27}{2} m_2^2 \text{Tr}(Y_u Y_u^\dagger Y_u Y_u^\dagger) \end{aligned} \quad (31)$$

3.5 Vacuum expectation values

$$\beta_{v_1}^{(1)} = \frac{3}{20} (5g_2^2 + g_1^2) v_1 (3 + \text{Xi}) \quad (32)$$

$$\beta_{v_1}^{(2)} = \frac{1}{800} v_1 \left(-25 \left(16 \left(12\lambda_1^2 + 2\lambda_3^2 + 2\lambda_3\lambda_4 + 2\lambda_4^2 + 3\lambda_5^2 \right) + 3g_2^4 \left(-30\text{Xi} + 6\text{Xi}^2 - 83 \right) \right) + 90g_1^2g_2^2 \left(2\text{Xi} + 2\text{Xi}^2 - 3 \right) + 9g_1^4 \left(2\text{Xi} + 2\text{Xi}^2 \right) \right) \quad (33)$$

$$\beta_{v_2}^{(1)} = \frac{1}{20} v_2 \left(15g_2^2\text{Xi} - 20\text{Tr} \left(Y_e Y_e^\dagger \right) + 3g_1^2\text{Xi} + 45g_2^2 - 60\text{Tr} \left(Y_d Y_d^\dagger \right) - 60\text{Tr} \left(Y_u Y_u^\dagger \right) + 9g_1^2 \right) \quad (34)$$

$$\begin{aligned} \beta_{v_2}^{(2)} = & \frac{1}{800} v_2 \left(-1359g_1^4 - 270g_1^2g_2^2 + 6225g_2^4 - 4800\lambda_2^2 - 800\lambda_3^2 - 800\lambda_3\lambda_4 - 800\lambda_4^2 - 1200\lambda_5^2 + 18g_1^4\text{Xi} \right. \\ & + 180g_1^2g_2^2\text{Xi} + 2250g_2^4\text{Xi} + 18g_1^4\text{Xi}^2 + 180g_1^2g_2^2\text{Xi}^2 - 450g_2^4\text{Xi}^2 \\ & - 20 \left(45g_2^2 \left(2\text{Xi} + 5 \right) + 800g_3^2 + g_1^2 \left(18\text{Xi} + 25 \right) \right) \text{Tr} \left(Y_d Y_d^\dagger \right) - 60 \left(5g_2^2 \left(2\text{Xi} + 5 \right) + g_1^2 \left(2\text{Xi} + 25 \right) \right) \text{Tr} \left(Y_e Y_e^\dagger \right) \\ & - 1700g_1^2 \text{Tr} \left(Y_u Y_u^\dagger \right) - 4500g_2^2 \text{Tr} \left(Y_u Y_u^\dagger \right) - 16000g_3^2 \text{Tr} \left(Y_u Y_u^\dagger \right) - 360g_1^2\text{Xi} \text{Tr} \left(Y_u Y_u^\dagger \right) \\ & - 1800g_2^2\text{Xi} \text{Tr} \left(Y_u Y_u^\dagger \right) + 5400 \text{Tr} \left(Y_d Y_d^\dagger Y_d Y_d^\dagger \right) - 1200 \text{Tr} \left(Y_d Y_d^\dagger Y_u Y_u^\dagger \right) + 1800 \text{Tr} \left(Y_e Y_e^\dagger Y_e Y_e^\dagger \right) \\ & \left. + 5400 \text{Tr} \left(Y_u Y_u^\dagger Y_u Y_u^\dagger \right) \right) \quad (35) \end{aligned}$$

4 Field Rotations

4.1 Rotations in gauge sector for eigenstates 'EWSB'

$$\begin{pmatrix} B_\rho \\ W_{3\rho} \end{pmatrix} = Z^{\gamma Z} \begin{pmatrix} \gamma_\rho \\ Z_\rho \end{pmatrix} \quad (36)$$

$$\begin{pmatrix} W_{1\rho} \\ W_{2\rho} \end{pmatrix} = Z^W \begin{pmatrix} W_\rho^- \\ W_\rho^- \end{pmatrix} \quad (37)$$

$$(38)$$

The mixing matrices are parametrized by

$$Z^{\gamma Z} = \begin{pmatrix} \cos \Theta_W & -\sin \Theta_W \\ \sin \Theta_W & \cos \Theta_W \end{pmatrix} \quad (39)$$

$$Z^W = \begin{pmatrix} \frac{1}{\sqrt{2}} & \frac{1}{\sqrt{2}} \\ -i\frac{1}{\sqrt{2}} & i\frac{1}{\sqrt{2}} \end{pmatrix} \quad (40)$$

$$(41)$$

4.2 Rotations in Mass sector for eigenstates 'EWSB'

4.2.1 Mass Matrices for Scalars

- **Mass matrix for Higgs**, Basis: $(\phi_1, \phi_2), (\phi_1, \phi_2)$

$$m_h^2 = \begin{pmatrix} \frac{1}{2}(6\lambda_1 v_1^2 + v_2^2(\lambda_3 + \lambda_4 + \Re(\lambda_5))) + m_1^2 & \frac{1}{2}v_1 v_2(2(\lambda_3 + \lambda_4) + 2\Re(\lambda_5)) + \Re(m_{12}) \\ \frac{1}{2}v_1 v_2(2(\lambda_3 + \lambda_4) + 2\Re(\lambda_5)) + \Re(m_{12}) & \frac{1}{2}(6\lambda_2 v_2^2 + v_1^2(\lambda_3 + \lambda_4 + \Re(\lambda_5))) + m_2^2 \end{pmatrix} \quad (42)$$

This matrix is diagonalized by Z^H :

$$Z^H m_h^2 Z^{H,\dagger} = m_{2,h}^{dia} \quad (43)$$

with

$$\phi_1 = \sum_j Z_{j1}^H h_j, \quad \phi_2 = \sum_j Z_{j2}^H h_j \quad (44)$$

- **Mass matrix for Pseudo-Scalar Higgs**, Basis: $(\sigma_1, \sigma_2), (\sigma_1, \sigma_2)$

$$m_{A^0}^2 = \begin{pmatrix} \frac{1}{2}(2\lambda_1 v_1^2 + v_2^2(-\Re(\lambda_5) + \lambda_3 + \lambda_4)) + m_1^2 & v_1 v_2 \Re(\lambda_5) + \Re(m_{12}) \\ v_1 v_2 \Re(\lambda_5) + \Re(m_{12}) & \frac{1}{2}(2\lambda_2 v_2^2 + v_1^2(-\Re(\lambda_5) + \lambda_3 + \lambda_4)) + m_2^2 \end{pmatrix} + \xi_Z m^2(Z) \quad (45)$$

Gauge fixing contributions:

$$m^2(\xi_Z) = \begin{pmatrix} \frac{1}{4}v_1^2(g_1 \sin \Theta_W + g_2 \cos \Theta_W)^2 & \frac{1}{4}v_1 v_2(g_1 \sin \Theta_W + g_2 \cos \Theta_W)^2 \\ \frac{1}{4}v_1 v_2(g_1 \sin \Theta_W + g_2 \cos \Theta_W)^2 & \frac{1}{4}v_2^2(g_1 \sin \Theta_W + g_2 \cos \Theta_W)^2 \end{pmatrix} \quad (46)$$

This matrix is diagonalized by Z^A :

$$Z^A m_{A^0}^2 Z^{A,\dagger} = m_{2,A^0}^{dia} \quad (47)$$

with

$$\sigma_1 = \sum_j Z_{j1}^A A_j^0, \quad \sigma_2 = \sum_j Z_{j2}^A A_j^0 \quad (48)$$

- **Mass matrix for Charged Higgs**, Basis: $(H_1^{+,*}, H_2^{+,*}), (H_1^+, H_2^+)$

$$m_{H^\pm}^2 = \begin{pmatrix} \frac{1}{2}\lambda_3 v_2^2 + \lambda_1 v_1^2 + m_1^2 & \frac{1}{2}(\lambda_4 + \lambda_5)v_1 v_2 + m_{12}^* \\ \frac{1}{2}v_1 v_2(\lambda_4 + \lambda_5^*) + m_{12} & \frac{1}{2}\lambda_3 v_1^2 + \lambda_2 v_2^2 + m_2^2 \end{pmatrix} + \xi_{W^-} m^2(W^-) \quad (49)$$

Gauge fixing contributions:

$$m^2(\xi_{W^-}) = \begin{pmatrix} \frac{1}{4}g_2^2 v_1^2 & \frac{1}{4}g_2^2 v_1 v_2 \\ \frac{1}{4}g_2^2 v_1 v_2 & \frac{1}{4}g_2^2 v_2^2 \end{pmatrix} \quad (50)$$

This matrix is diagonalized by Z^+ :

$$Z^+ m_{H^-}^2 Z^{+\dagger} = m_{2,H^-}^{dia} \quad (51)$$

with

$$H_1^+ = \sum_j Z_{j1}^+ H_j^+, \quad H_2^+ = \sum_j Z_{j2}^+ H_j^+ \quad (52)$$

4.2.2 Mass Matrices for Fermions

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

$$m_d = \left(\frac{1}{\sqrt{2}} v_2 \delta_{\alpha_1 \beta_1} Y_d^T \right) \quad (53)$$

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

$$U_L^{d,*} m_d U_R^{d,\dagger} = m_d^{dia} \quad (54)$$

with

$$d_{L,i\alpha} = \sum_{t_2} U_{L,ji}^{d,*} D_{L,j\alpha} \quad (55)$$

$$d_{R,i\alpha} = \sum_{t_2} U_{R,ij}^d D_{R,j\alpha}^* \quad (56)$$

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

$$m_u = \left(-\frac{1}{\sqrt{2}} v_2 \delta_{\alpha_1 \beta_1} Y_u^T \right) \quad (57)$$

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

$$U_L^{u,*} m_u U_R^{u,\dagger} = m_u^{dia} \quad (58)$$

with

$$u_{L,i\alpha} = \sum_{t_2} U_{L,ji}^{u,*} U_{L,j\alpha} \quad (59)$$

$$u_{R,i\alpha} = \sum_{t_2} U_{R,ij}^u U_{R,j\alpha}^* \quad (60)$$

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

$$m_e = \left(\frac{1}{\sqrt{2}} v_2 Y_e^T \right) \quad (61)$$

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

$$U_L^{e,*} m_e U_R^{e,\dagger} = m_e^{dia} \quad (62)$$

with

$$e_{L,i} = \sum_{t_2} U_{L,ji}^{e,*} E_{L,j} \quad (63)$$

$$e_{R,i} = \sum_{t_2} U_{R,ij}^e E_{R,j}^* \quad (64)$$

5 Vacuum Expectation Values

$$H_1^0 = \frac{1}{\sqrt{2}}\phi_1 + \frac{1}{\sqrt{2}}v_1 + i\frac{1}{\sqrt{2}}\sigma_1 \quad (65)$$

$$H_2^0 = \frac{1}{\sqrt{2}}\phi_2 + \frac{1}{\sqrt{2}}v_2 + i\frac{1}{\sqrt{2}}\sigma_2 \quad (66)$$

6 Tadpole Equations

$$\frac{\partial V}{\partial \phi_1} = \frac{1}{4} \left(2v_2 (m_{12} + m_{12}^*) + v_1 \left(4(\lambda_1 v_1^2 + m_1^2) + v_2^2 (2(\lambda_3 + \lambda_4) + \lambda_5 + \lambda_5^*) \right) \right) \quad (67)$$

$$\frac{\partial V}{\partial \phi_2} = \frac{1}{4} \left(2v_1 (m_{12} + m_{12}^*) + 4\lambda_2 v_2^3 + v_2 \left(4m_2^2 + v_1^2 (2(\lambda_3 + \lambda_4) + \lambda_5 + \lambda_5^*) \right) \right) \quad (68)$$

7 Particle content for eigenstates 'EWSB'

Name	Type	complex/real	Generations	Indices
h	Scalar	real	2	generation, 2
A^0	Scalar	real	2	generation, 2
H^-	Scalar	complex	2	generation, 2
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 Higgs (h)

$$\begin{aligned}
\Pi_{i,j}(p^2) = & +2\left(-\frac{1}{2}\text{rMS} + B_0(p^2, m_Z^2, m_Z^2)\right)\Gamma_{\check{h}_j, Z, Z}^* \Gamma_{\check{h}_i, Z, Z} + 4\left(-\frac{1}{2}\text{rMS} + B_0(p^2, m_{W^-}^2, m_{W^-}^2)\right)\Gamma_{\check{h}_j, W^+, W^-}^* \Gamma_{\check{h}_i, W^+, W^-} \\
& - B_0(p^2, m_{\eta^-}^2, m_{\eta^-}^2)\Gamma_{\check{h}_i, \eta^-, \eta^-} \Gamma_{\check{h}_j, \eta^-, \eta^-} - B_0(p^2, m_{\eta^+}^2, m_{\eta^+}^2)\Gamma_{\check{h}_i, \eta^+, \eta^+} \Gamma_{\check{h}_j, \eta^+, \eta^+} \\
& - B_0(p^2, m_{\eta^Z}^2, m_{\eta^Z}^2)\Gamma_{\check{h}_i, \eta^Z, \eta^Z} \Gamma_{\check{h}_j, \eta^Z, \eta^Z} + 4\Gamma_{\check{h}_i, \check{h}_j, W^+, W^-} \left(-\frac{1}{2}\text{rMS}m_{W^-}^2 + A_0(m_{W^-}^2)\right) \\
& + 2\Gamma_{\check{h}_i, \check{h}_j, Z, Z} \left(-\frac{1}{2}\text{rMS}m_Z^2 + A_0(m_Z^2)\right) - \frac{1}{2}\sum_{a=1}^2 A_0(m_{A_a^0}^2)\Gamma_{\check{h}_i, \check{h}_j, A_a^0, A_a^0} \\
& - \sum_{a=1}^2 A_0(m_{H_a^-}^2)\Gamma_{\check{h}_i, \check{h}_j, H_a^+, H_a^-} - \frac{1}{2}\sum_{a=1}^2 A_0(m_{h_a}^2)\Gamma_{\check{h}_i, \check{h}_j, h_a, h_a} \\
& + \frac{1}{2}\sum_{a=1}^2 \sum_{b=1}^2 B_0(p^2, m_{A_a^0}^2, m_{A_b^0}^2)\Gamma_{\check{h}_j, A_a^0, A_b^0}^* \Gamma_{\check{h}_i, A_a^0, A_b^0} \\
& + \sum_{a=1}^2 \sum_{b=1}^2 B_0(p^2, m_{H_a^-}^2, m_{H_b^-}^2)\Gamma_{\check{h}_j, H_a^+, H_b^-}^* \Gamma_{\check{h}_i, H_a^+, H_b^-} \\
& + \sum_{a=1}^2 \sum_{b=1}^2 B_0(p^2, m_{h_a}^2, m_{A_b^0}^2)\Gamma_{\check{h}_j, h_a, A_b^0}^* \Gamma_{\check{h}_i, h_a, A_b^0} + \frac{1}{2}\sum_{a=1}^2 \sum_{b=1}^2 B_0(p^2, m_{h_a}^2, m_{h_b}^2)\Gamma_{\check{h}_j, h_a, h_b}^* \Gamma_{\check{h}_i, h_a, h_b} \\
& - 6\sum_{a=1}^3 m_{d_a} \sum_{b=1}^3 B_0(p^2, m_{d_a}^2, m_{d_b}^2)m_{d_b} \left(\Gamma_{\check{h}_j, \bar{d}_a, d_b}^{L*} \Gamma_{\check{h}_i, \bar{d}_a, d_b}^R + \Gamma_{\check{h}_j, \bar{d}_a, d_b}^{R*} \Gamma_{\check{h}_i, \bar{d}_a, d_b}^L\right) \\
& + 3\sum_{a=1}^3 \sum_{b=1}^3 G_0(p^2, m_{d_a}^2, m_{d_b}^2) \left(\Gamma_{\check{h}_j, \bar{d}_a, d_b}^{L*} \Gamma_{\check{h}_i, \bar{d}_a, d_b}^L + \Gamma_{\check{h}_j, \bar{d}_a, d_b}^{R*} \Gamma_{\check{h}_i, \bar{d}_a, d_b}^R\right) \\
& - 2\sum_{a=1}^3 m_{e_a} \sum_{b=1}^3 B_0(p^2, m_{e_a}^2, m_{e_b}^2)m_{e_b} \left(\Gamma_{\check{h}_j, \bar{e}_a, e_b}^{L*} \Gamma_{\check{h}_i, \bar{e}_a, e_b}^R + \Gamma_{\check{h}_j, \bar{e}_a, e_b}^{R*} \Gamma_{\check{h}_i, \bar{e}_a, e_b}^L\right) \\
& + \sum_{a=1}^3 \sum_{b=1}^3 G_0(p^2, m_{e_a}^2, m_{e_b}^2) \left(\Gamma_{\check{h}_j, \bar{e}_a, e_b}^{L*} \Gamma_{\check{h}_i, \bar{e}_a, e_b}^L + \Gamma_{\check{h}_j, \bar{e}_a, e_b}^{R*} \Gamma_{\check{h}_i, \bar{e}_a, e_b}^R\right)
\end{aligned}$$

$$\begin{aligned}
& -6 \sum_{a=1}^3 m_{u_a} \sum_{b=1}^3 B_0(p^2, m_{u_a}^2, m_{u_b}^2) m_{u_b} \left(\Gamma_{\check{h}_j, \bar{u}_a, u_b}^{L*} \Gamma_{\check{h}_i, \bar{u}_a, u_b}^R + \Gamma_{\check{h}_j, \bar{u}_a, u_b}^{R*} \Gamma_{\check{h}_i, \bar{u}_a, u_b}^L \right) \\
& + 3 \sum_{a=1}^3 \sum_{b=1}^3 G_0(p^2, m_{u_a}^2, m_{u_b}^2) \left(\Gamma_{\check{h}_j, \bar{u}_a, u_b}^{L*} \Gamma_{\check{h}_i, \bar{u}_a, u_b}^L + \Gamma_{\check{h}_j, \bar{u}_a, u_b}^{R*} \Gamma_{\check{h}_i, \bar{u}_a, u_b}^R \right) \\
& + \sum_{b=1}^2 \Gamma_{\check{h}_j, Z, A_b^0}^* \Gamma_{\check{h}_i, Z, A_b^0} F_0(p^2, m_{A_b^0}^2, m_Z^2) + 2 \sum_{b=1}^2 \Gamma_{\check{h}_j, W^+, H_b^-}^* \Gamma_{\check{h}_i, W^+, H_b^-} F_0(p^2, m_{H_b^-}^2, m_{W^-}^2)
\end{aligned} \tag{69}$$

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

$$\begin{aligned}
\Pi_{i,j}(p^2) = & -B_0(p^2, m_{\eta^-}^2, m_{\eta^-}^2) \Gamma_{\check{A}_i^0, \eta^-, \eta^-} \Gamma_{\check{A}_j^0, \eta^-, \eta^-} - B_0(p^2, m_{\eta^+}^2, m_{\eta^+}^2) \Gamma_{\check{A}_i^0, \eta^+, \eta^+} \Gamma_{\check{A}_j^0, \eta^+, \eta^+} \\
& + 4\Gamma_{\check{A}_i^0, \check{A}_j^0, W^+, W^-} \left(-\frac{1}{2} \text{rMS} m_{W^-}^2 + A_0(m_{W^-}^2) \right) + 2\Gamma_{\check{A}_i^0, \check{A}_j^0, Z, Z} \left(-\frac{1}{2} \text{rMS} m_Z^2 + A_0(m_Z^2) \right) \\
& - \frac{1}{2} \sum_{a=1}^2 A_0(m_{A_a^0}^2) \Gamma_{\check{A}_i^0, \check{A}_j^0, A_a^0, A_a^0} - \sum_{a=1}^2 A_0(m_{H_a^-}^2) \Gamma_{\check{A}_i^0, \check{A}_j^0, H_a^+, H_a^-} \\
& - \frac{1}{2} \sum_{a=1}^2 A_0(m_{h_a}^2) \Gamma_{\check{A}_i^0, \check{A}_j^0, h_a, h_a} + \frac{1}{2} \sum_{a=1}^2 \sum_{b=1}^2 B_0(p^2, m_{A_a^0}^2, m_{A_b^0}^2) \Gamma_{\check{A}_j^0, A_a^0, A_b^0}^* \Gamma_{\check{A}_i^0, A_a^0, A_b^0} \\
& + \sum_{a=1}^2 \sum_{b=1}^2 B_0(p^2, m_{H_a^-}^2, m_{H_b^-}^2) \Gamma_{\check{A}_j^0, H_a^+, H_b^-}^* \Gamma_{\check{A}_i^0, H_a^+, H_b^-} \\
& + \sum_{a=1}^2 \sum_{b=1}^2 B_0(p^2, m_{h_a}^2, m_{h_b}^2) \Gamma_{\check{A}_j^0, h_a, A_b^0}^* \Gamma_{\check{A}_i^0, h_a, A_b^0} \\
& + \frac{1}{2} \sum_{a=1}^2 \sum_{b=1}^2 B_0(p^2, m_{h_a}^2, m_{h_b}^2) \Gamma_{\check{A}_j^0, h_a, h_b}^* \Gamma_{\check{A}_i^0, h_a, h_b} \\
& - 6 \sum_{a=1}^3 m_{d_a} \sum_{b=1}^3 B_0(p^2, m_{d_a}^2, m_{d_b}^2) m_{d_b} \left(\Gamma_{\check{A}_j^0, \bar{d}_a, d_b}^{L*} \Gamma_{\check{A}_i^0, \bar{d}_a, d_b}^R + \Gamma_{\check{A}_j^0, \bar{d}_a, d_b}^{R*} \Gamma_{\check{A}_i^0, \bar{d}_a, d_b}^L \right) \\
& + 3 \sum_{a=1}^3 \sum_{b=1}^3 G_0(p^2, m_{d_a}^2, m_{d_b}^2) \left(\Gamma_{\check{A}_j^0, \bar{d}_a, d_b}^{L*} \Gamma_{\check{A}_i^0, \bar{d}_a, d_b}^L + \Gamma_{\check{A}_j^0, \bar{d}_a, d_b}^{R*} \Gamma_{\check{A}_i^0, \bar{d}_a, d_b}^R \right) \\
& - 2 \sum_{a=1}^3 m_{e_a} \sum_{b=1}^3 B_0(p^2, m_{e_a}^2, m_{e_b}^2) m_{e_b} \left(\Gamma_{\check{A}_j^0, \bar{e}_a, e_b}^{L*} \Gamma_{\check{A}_i^0, \bar{e}_a, e_b}^R + \Gamma_{\check{A}_j^0, \bar{e}_a, e_b}^{R*} \Gamma_{\check{A}_i^0, \bar{e}_a, e_b}^L \right) \\
& + \sum_{a=1}^3 \sum_{b=1}^3 G_0(p^2, m_{e_a}^2, m_{e_b}^2) \left(\Gamma_{\check{A}_j^0, \bar{e}_a, e_b}^{L*} \Gamma_{\check{A}_i^0, \bar{e}_a, e_b}^L + \Gamma_{\check{A}_j^0, \bar{e}_a, e_b}^{R*} \Gamma_{\check{A}_i^0, \bar{e}_a, e_b}^R \right) \\
& - 6 \sum_{a=1}^3 m_{u_a} \sum_{b=1}^3 B_0(p^2, m_{u_a}^2, m_{u_b}^2) m_{u_b} \left(\Gamma_{\check{A}_j^0, \bar{u}_a, u_b}^{L*} \Gamma_{\check{A}_i^0, \bar{u}_a, u_b}^R + \Gamma_{\check{A}_j^0, \bar{u}_a, u_b}^{R*} \Gamma_{\check{A}_i^0, \bar{u}_a, u_b}^L \right)
\end{aligned}$$

$$\begin{aligned}
& + 3 \sum_{a=1}^3 \sum_{b=1}^3 G_0(p^2, m_{u_a}^2, m_{u_b}^2) \left(\Gamma_{\tilde{A}_j^0, \tilde{u}_a, u_b}^{L*} \Gamma_{\tilde{A}_i^0, \tilde{u}_a, u_b}^L + \Gamma_{\tilde{A}_j^0, \tilde{u}_a, u_b}^{R*} \Gamma_{\tilde{A}_i^0, \tilde{u}_a, u_b}^R \right) \\
& + \sum_{b=1}^2 \Gamma_{\tilde{A}_j^0, Z, h_b}^* \Gamma_{\tilde{A}_i^0, Z, h_b} F_0(p^2, m_{h_b}^2, m_Z^2) + 2 \sum_{b=1}^2 \Gamma_{\tilde{A}_j^0, W^+, H_b^-}^* \Gamma_{\tilde{A}_i^0, W^+, H_b^-} F_0(p^2, m_{H_b^-}^2, m_{W^-}^2) \quad (70)
\end{aligned}$$

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

$$\begin{aligned}
\Pi_{i,j}(p^2) = & +4 \left(-\frac{1}{2} \text{rMS} + B_0(p^2, 0, m_{W^-}^2) \right) \Gamma_{\tilde{H}_j^+, W^-, \gamma}^* \Gamma_{\tilde{H}_i^+, W^-, \gamma} + 4 \left(-\frac{1}{2} \text{rMS} + B_0(p^2, m_{W^-}^2, m_Z^2) \right) \Gamma_{\tilde{H}_j^+, Z, W^-}^* \Gamma_{\tilde{H}_i^+, Z, W^-} \\
& - B_0(p^2, m_{\eta^+}^2, m_{\eta^+}^2) \Gamma_{\tilde{H}_i^+, \eta^+, \eta^+} \Gamma_{\tilde{H}_j^-, \eta^+, \eta^+} - B_0(p^2, m_{\eta^-}^2, m_{\eta^-}^2) \Gamma_{\tilde{H}_i^+, \eta^+, \eta^-} \Gamma_{\tilde{H}_j^-, \eta^+, \eta^-} \\
& + 4 \Gamma_{\tilde{H}_i^-, \tilde{H}_j^+, W^+, W^-} \left(-\frac{1}{2} \text{rMS} m_{W^-}^2 + A_0(m_{W^-}^2) \right) + 2 \Gamma_{\tilde{H}_i^-, \tilde{H}_j^+, Z, Z} \left(-\frac{1}{2} \text{rMS} m_Z^2 + A_0(m_Z^2) \right) \\
& - \frac{1}{2} \sum_{a=1}^2 A_0(m_{A_a^0}^2) \Gamma_{\tilde{H}_i^-, \tilde{H}_j^+, A_a^0, A_a^0} - \sum_{a=1}^2 A_0(m_{H_a^-}^2) \Gamma_{\tilde{H}_i^-, \tilde{H}_j^+, H_a^+, H_a^-} \\
& - \frac{1}{2} \sum_{a=1}^2 A_0(m_{h_a}^2) \Gamma_{\tilde{H}_i^-, \tilde{H}_j^+, h_a, h_a} + \sum_{a=1}^2 \sum_{b=1}^2 B_0(p^2, m_{H_a^-}^2, m_{A_b^0}^2) \Gamma_{\tilde{H}_j^+, H_a^-, A_b^0}^* \Gamma_{\tilde{H}_i^+, H_a^-, A_b^0} \\
& + \sum_{a=1}^2 \sum_{b=1}^2 B_0(p^2, m_{H_a^-}^2, m_{h_b}^2) \Gamma_{\tilde{H}_j^+, H_a^-, h_b}^* \Gamma_{\tilde{H}_i^+, H_a^-, h_b} \\
& - 6 \sum_{a=1}^3 m_{u_a} \sum_{b=1}^3 B_0(p^2, m_{u_a}^2, m_{d_b}^2) m_{d_b} \left(\Gamma_{\tilde{H}_j^+, \tilde{u}_a, d_b}^{L*} \Gamma_{\tilde{H}_i^+, \tilde{u}_a, d_b}^R + \Gamma_{\tilde{H}_j^+, \tilde{u}_a, d_b}^{R*} \Gamma_{\tilde{H}_i^+, \tilde{u}_a, d_b}^L \right) \\
& + 3 \sum_{a=1}^3 \sum_{b=1}^3 G_0(p^2, m_{u_a}^2, m_{d_b}^2) \left(\Gamma_{\tilde{H}_j^+, \tilde{u}_a, d_b}^{L*} \Gamma_{\tilde{H}_i^+, \tilde{u}_a, d_b}^L + \Gamma_{\tilde{H}_j^+, \tilde{u}_a, d_b}^{R*} \Gamma_{\tilde{H}_i^+, \tilde{u}_a, d_b}^R \right) \\
& - 2 \sum_{a=1}^3 m_{\nu_a} \sum_{b=1}^3 B_0(p^2, m_{\nu_a}^2, m_{e_b}^2) m_{e_b} \left(\Gamma_{\tilde{H}_j^+, \tilde{\nu}_a, e_b}^{L*} \Gamma_{\tilde{H}_i^+, \tilde{\nu}_a, e_b}^R + \Gamma_{\tilde{H}_j^+, \tilde{\nu}_a, e_b}^{R*} \Gamma_{\tilde{H}_i^+, \tilde{\nu}_a, e_b}^L \right) \\
& + \sum_{a=1}^3 \sum_{b=1}^3 G_0(p^2, m_{\nu_a}^2, m_{e_b}^2) \left(\Gamma_{\tilde{H}_j^+, \tilde{\nu}_a, e_b}^{L*} \Gamma_{\tilde{H}_i^+, \tilde{\nu}_a, e_b}^L + \Gamma_{\tilde{H}_j^+, \tilde{\nu}_a, e_b}^{R*} \Gamma_{\tilde{H}_i^+, \tilde{\nu}_a, e_b}^R \right) \\
& + \sum_{b=1}^2 \Gamma_{\tilde{H}_j^+, W^-, A_b^0}^* \Gamma_{\tilde{H}_i^+, W^-, A_b^0} F_0(p^2, m_{A_b^0}^2, m_{W^-}^2) + \sum_{b=1}^2 \Gamma_{\tilde{H}_j^+, W^-, h_b}^* \Gamma_{\tilde{H}_i^+, W^-, h_b} F_0(p^2, m_{h_b}^2, m_{W^-}^2) \\
& + \sum_{b=1}^2 \Gamma_{\tilde{H}_j^+, \gamma, H_b^-}^* \Gamma_{\tilde{H}_i^+, \gamma, H_b^-} F_0(p^2, m_{H_b^-}^2, 0) + \sum_{b=1}^2 \Gamma_{\tilde{H}_j^+, Z, H_b^-}^* \Gamma_{\tilde{H}_i^+, Z, H_b^-} F_0(p^2, m_{H_b^-}^2, m_Z^2) \quad (71)
\end{aligned}$$

• **Self-Energy for Down-Quarks (d)**

$$\Sigma_{i,j}^S(p^2) = + \sum_{a=1}^2 \sum_{b=1}^3 B_0(p^2, m_{d_b}^2, m_{h_a}^2) \Gamma_{\tilde{d}_j, h_a, d_b}^{L*} m_{d_b} \Gamma_{\tilde{d}_i, h_a, d_b}^R$$

$$\begin{aligned}
& + \sum_{a=1}^2 \sum_{b=1}^3 B_0(p^2, m_{u_b}^2, m_{H_a^-}^2) \Gamma_{\tilde{d}_j, H_a^-, u_b}^{L*} m_{u_b} \Gamma_{\tilde{d}_i, H_a^-, u_b}^R \\
& + \sum_{a=1}^3 m_{d_a} \sum_{b=1}^2 B_0(p^2, m_{d_a}^2, m_{A_b^0}^2) \Gamma_{\tilde{d}_j, d_a, A_b^0}^{L*} \Gamma_{\tilde{d}_i, d_a, A_b^0}^R \\
& - \frac{16}{3} \sum_{b=1}^3 \left(-\frac{1}{2} \text{rMS} + B_0(p^2, m_{d_b}^2, 0) \right) \Gamma_{\tilde{d}_j, g, d_b}^{R*} m_{d_b} \Gamma_{\tilde{d}_i, g, d_b}^L - 4 \sum_{b=1}^3 \left(-\frac{1}{2} \text{rMS} + B_0(p^2, m_{d_b}^2, 0) \right) \Gamma_{\tilde{d}_j, \gamma, d_b}^{R*} m_{d_b} \Gamma_{\tilde{d}_i, \gamma, d_b}^L \\
& - 4 \sum_{b=1}^3 \left(-\frac{1}{2} \text{rMS} + B_0(p^2, m_{u_b}^2, m_{W^-}^2) \right) \Gamma_{\tilde{d}_j, W^-, u_b}^{R*} m_{u_b} \Gamma_{\tilde{d}_i, W^-, u_b}^L \\
& - 4 \sum_{b=1}^3 \left(-\frac{1}{2} \text{rMS} + B_0(p^2, m_{d_b}^2, m_Z^2) \right) \Gamma_{\tilde{d}_j, Z, d_b}^{R*} m_{d_b} \Gamma_{\tilde{d}_i, Z, d_b}^L \tag{72}
\end{aligned}$$

$$\begin{aligned}
\Sigma_{i,j}^R(p^2) &= -\frac{1}{2} \sum_{a=1}^2 \sum_{b=1}^3 B_1(p^2, m_{d_b}^2, m_{h_a}^2) \Gamma_{\tilde{d}_j, h_a, d_b}^{R*} \Gamma_{\tilde{d}_i, h_a, d_b}^R \\
& - \frac{1}{2} \sum_{a=1}^2 \sum_{b=1}^3 B_1(p^2, m_{u_b}^2, m_{H_a^-}^2) \Gamma_{\tilde{d}_j, H_a^-, u_b}^{R*} \Gamma_{\tilde{d}_i, H_a^-, u_b}^R \\
& - \frac{1}{2} \sum_{a=1}^3 \sum_{b=1}^2 B_1(p^2, m_{d_a}^2, m_{A_b^0}^2) \Gamma_{\tilde{d}_j, d_a, A_b^0}^{R*} \Gamma_{\tilde{d}_i, d_a, A_b^0}^R - \frac{4}{3} \sum_{b=1}^3 B_1(p^2, m_{d_b}^2, 0) \Gamma_{\tilde{d}_j, g, d_b}^{L*} \Gamma_{\tilde{d}_i, g, d_b}^L \\
& - \sum_{b=1}^3 B_1(p^2, m_{d_b}^2, 0) \Gamma_{\tilde{d}_j, \gamma, d_b}^{L*} \Gamma_{\tilde{d}_i, \gamma, d_b}^L - \sum_{b=1}^3 B_1(p^2, m_{u_b}^2, m_{W^-}^2) \Gamma_{\tilde{d}_j, W^-, u_b}^{L*} \Gamma_{\tilde{d}_i, W^-, u_b}^L \\
& - \sum_{b=1}^3 B_1(p^2, m_{d_b}^2, m_Z^2) \Gamma_{\tilde{d}_j, Z, d_b}^{L*} \Gamma_{\tilde{d}_i, Z, d_b}^L \tag{73}
\end{aligned}$$

$$\begin{aligned}
\Sigma_{i,j}^L(p^2) &= -\frac{1}{2} \sum_{a=1}^2 \sum_{b=1}^3 B_1(p^2, m_{d_b}^2, m_{h_a}^2) \Gamma_{\tilde{d}_j, h_a, d_b}^{L*} \Gamma_{\tilde{d}_i, h_a, d_b}^L \\
& - \frac{1}{2} \sum_{a=1}^2 \sum_{b=1}^3 B_1(p^2, m_{u_b}^2, m_{H_a^-}^2) \Gamma_{\tilde{d}_j, H_a^-, u_b}^{L*} \Gamma_{\tilde{d}_i, H_a^-, u_b}^L \\
& - \frac{1}{2} \sum_{a=1}^3 \sum_{b=1}^2 B_1(p^2, m_{d_a}^2, m_{A_b^0}^2) \Gamma_{\tilde{d}_j, d_a, A_b^0}^{L*} \Gamma_{\tilde{d}_i, d_a, A_b^0}^L - \frac{4}{3} \sum_{b=1}^3 B_1(p^2, m_{d_b}^2, 0) \Gamma_{\tilde{d}_j, g, d_b}^{R*} \Gamma_{\tilde{d}_i, g, d_b}^R \\
& - \sum_{b=1}^3 B_1(p^2, m_{d_b}^2, 0) \Gamma_{\tilde{d}_j, \gamma, d_b}^{R*} \Gamma_{\tilde{d}_i, \gamma, d_b}^R - \sum_{b=1}^3 B_1(p^2, m_{u_b}^2, m_{W^-}^2) \Gamma_{\tilde{d}_j, W^-, u_b}^{R*} \Gamma_{\tilde{d}_i, W^-, u_b}^R \\
& - \sum_{b=1}^3 B_1(p^2, m_{d_b}^2, m_Z^2) \Gamma_{\tilde{d}_j, Z, d_b}^{R*} \Gamma_{\tilde{d}_i, Z, d_b}^R \tag{74}
\end{aligned}$$

• Self-Energy for Up-Quarks (u)

$$\begin{aligned}
\Sigma_{i,j}^S(p^2) = & + \sum_{a=1}^2 \sum_{b=1}^3 B_0(p^2, m_{d_b}^2, m_{H_a^-}^2) \Gamma_{\tilde{u}_j, H_a^+, d_b}^{L*} m_{d_b} \Gamma_{\tilde{u}_i, H_a^+, d_b}^R \\
& + \sum_{a=1}^2 \sum_{b=1}^3 B_0(p^2, m_{u_b}^2, m_{h_a}^2) \Gamma_{\tilde{u}_j, h_a, u_b}^{L*} m_{u_b} \Gamma_{\tilde{u}_i, h_a, u_b}^R \\
& + \sum_{a=1}^3 m_{u_a} \sum_{b=1}^2 B_0(p^2, m_{u_a}^2, m_{A_b^0}^2) \Gamma_{\tilde{u}_j, u_a, A_b^0}^{L*} \Gamma_{\tilde{u}_i, u_a, A_b^0}^R \\
& - \frac{16}{3} \sum_{b=1}^3 \left(-\frac{1}{2} \text{rMS} + B_0(p^2, m_{u_b}^2, 0) \right) \Gamma_{\tilde{u}_j, g, u_b}^{R*} m_{u_b} \Gamma_{\tilde{u}_i, g, u_b}^L - 4 \sum_{b=1}^3 \left(-\frac{1}{2} \text{rMS} + B_0(p^2, m_{u_b}^2, 0) \right) \Gamma_{\tilde{u}_j, \gamma, u_b}^{R*} m_{u_b} \Gamma_{\tilde{u}_i, \gamma, u_b}^L \\
& - 4 \sum_{b=1}^3 \left(-\frac{1}{2} \text{rMS} + B_0(p^2, m_{u_b}^2, m_Z^2) \right) \Gamma_{\tilde{u}_j, Z, u_b}^{R*} m_{u_b} \Gamma_{\tilde{u}_i, Z, u_b}^L \\
& - 4 \sum_{b=1}^3 \left(-\frac{1}{2} \text{rMS} + B_0(p^2, m_{d_b}^2, m_{W^-}^2) \right) \Gamma_{\tilde{u}_j, W^+, d_b}^{R*} m_{d_b} \Gamma_{\tilde{u}_i, W^+, d_b}^L \tag{75}
\end{aligned}$$

$$\begin{aligned}
\Sigma_{i,j}^R(p^2) = & -\frac{1}{2} \sum_{a=1}^2 \sum_{b=1}^3 B_1(p^2, m_{d_b}^2, m_{H_a^-}^2) \Gamma_{\tilde{u}_j, H_a^+, d_b}^{R*} \Gamma_{\tilde{u}_i, H_a^+, d_b}^R \\
& - \frac{1}{2} \sum_{a=1}^2 \sum_{b=1}^3 B_1(p^2, m_{u_b}^2, m_{h_a}^2) \Gamma_{\tilde{u}_j, h_a, u_b}^{R*} \Gamma_{\tilde{u}_i, h_a, u_b}^R \\
& - \frac{1}{2} \sum_{a=1}^3 \sum_{b=1}^2 B_1(p^2, m_{u_a}^2, m_{A_b^0}^2) \Gamma_{\tilde{u}_j, u_a, A_b^0}^{R*} \Gamma_{\tilde{u}_i, u_a, A_b^0}^R - \frac{4}{3} \sum_{b=1}^3 B_1(p^2, m_{u_b}^2, 0) \Gamma_{\tilde{u}_j, g, u_b}^{L*} \Gamma_{\tilde{u}_i, g, u_b}^L \\
& - \sum_{b=1}^3 B_1(p^2, m_{u_b}^2, 0) \Gamma_{\tilde{u}_j, \gamma, u_b}^{L*} \Gamma_{\tilde{u}_i, \gamma, u_b}^L - \sum_{b=1}^3 B_1(p^2, m_{u_b}^2, m_Z^2) \Gamma_{\tilde{u}_j, Z, u_b}^{L*} \Gamma_{\tilde{u}_i, Z, u_b}^L \\
& - \sum_{b=1}^3 B_1(p^2, m_{d_b}^2, m_{W^-}^2) \Gamma_{\tilde{u}_j, W^+, d_b}^{L*} \Gamma_{\tilde{u}_i, W^+, d_b}^L \tag{76}
\end{aligned}$$

$$\begin{aligned}
\Sigma_{i,j}^L(p^2) = & -\frac{1}{2} \sum_{a=1}^2 \sum_{b=1}^3 B_1(p^2, m_{d_b}^2, m_{H_a^-}^2) \Gamma_{\tilde{u}_j, H_a^+, d_b}^{L*} \Gamma_{\tilde{u}_i, H_a^+, d_b}^L \\
& - \frac{1}{2} \sum_{a=1}^2 \sum_{b=1}^3 B_1(p^2, m_{u_b}^2, m_{h_a}^2) \Gamma_{\tilde{u}_j, h_a, u_b}^{L*} \Gamma_{\tilde{u}_i, h_a, u_b}^L \\
& - \frac{1}{2} \sum_{a=1}^3 \sum_{b=1}^2 B_1(p^2, m_{u_a}^2, m_{A_b^0}^2) \Gamma_{\tilde{u}_j, u_a, A_b^0}^{L*} \Gamma_{\tilde{u}_i, u_a, A_b^0}^L - \frac{4}{3} \sum_{b=1}^3 B_1(p^2, m_{u_b}^2, 0) \Gamma_{\tilde{u}_j, g, u_b}^{R*} \Gamma_{\tilde{u}_i, g, u_b}^R \\
& - \sum_{b=1}^3 B_1(p^2, m_{u_b}^2, 0) \Gamma_{\tilde{u}_j, \gamma, u_b}^{R*} \Gamma_{\tilde{u}_i, \gamma, u_b}^R - \sum_{b=1}^3 B_1(p^2, m_{u_b}^2, m_Z^2) \Gamma_{\tilde{u}_j, Z, u_b}^{R*} \Gamma_{\tilde{u}_i, Z, u_b}^R
\end{aligned}$$

$$- \sum_{b=1}^3 B_1(p^2, m_{d_b}^2, m_{W^-}^2) \Gamma_{\tilde{u}_j, W^+, d_b}^{R*} \Gamma_{\tilde{u}_i, W^+, d_b}^R \quad (77)$$

• Self-Energy for Leptons (e)

$$\begin{aligned} \Sigma_{i,j}^S(p^2) = & + \sum_{a=1}^2 \sum_{b=1}^3 B_0(p^2, m_{e_b}^2, m_{h_a}^2) \Gamma_{\tilde{e}_j, h_a, e_b}^{L*} m_{e_b} \Gamma_{\tilde{e}_i, h_a, e_b}^R \\ & + \sum_{a=1}^2 \sum_{b=1}^3 B_0(p^2, m_{\nu_b}^2, m_{H_a^-}^2) \Gamma_{\tilde{e}_j, H_a^-, \nu_b}^{L*} m_{\nu_b} \Gamma_{\tilde{e}_i, H_a^-, \nu_b}^R \\ & + \sum_{a=1}^3 m_{e_a} \sum_{b=1}^2 B_0(p^2, m_{e_a}^2, m_{A_b^0}^2) \Gamma_{\tilde{e}_j, e_a, A_b^0}^{L*} \Gamma_{\tilde{e}_i, e_a, A_b^0}^R \\ & - 4 \sum_{b=1}^3 \left(-\frac{1}{2} \text{rMS} + B_0(p^2, m_{e_b}^2, 0) \right) \Gamma_{\tilde{e}_j, \gamma, e_b}^{R*} m_{e_b} \Gamma_{\tilde{e}_i, \gamma, e_b}^L \\ & - 4 \sum_{b=1}^3 \left(-\frac{1}{2} \text{rMS} + B_0(p^2, m_{\nu_b}^2, m_{W^-}^2) \right) \Gamma_{\tilde{e}_j, W^-, \nu_b}^{R*} m_{\nu_b} \Gamma_{\tilde{e}_i, W^-, \nu_b}^L \\ & - 4 \sum_{b=1}^3 \left(-\frac{1}{2} \text{rMS} + B_0(p^2, m_{e_b}^2, m_Z^2) \right) \Gamma_{\tilde{e}_j, Z, e_b}^{R*} m_{e_b} \Gamma_{\tilde{e}_i, Z, e_b}^L \end{aligned} \quad (78)$$

$$\begin{aligned} \Sigma_{i,j}^R(p^2) = & -\frac{1}{2} \sum_{a=1}^2 \sum_{b=1}^3 B_1(p^2, m_{e_b}^2, m_{h_a}^2) \Gamma_{\tilde{e}_j, h_a, e_b}^{R*} \Gamma_{\tilde{e}_i, h_a, e_b}^R \\ & - \frac{1}{2} \sum_{a=1}^2 \sum_{b=1}^3 B_1(p^2, m_{\nu_b}^2, m_{H_a^-}^2) \Gamma_{\tilde{e}_j, H_a^-, \nu_b}^{R*} \Gamma_{\tilde{e}_i, H_a^-, \nu_b}^R \\ & - \frac{1}{2} \sum_{a=1}^3 \sum_{b=1}^2 B_1(p^2, m_{e_a}^2, m_{A_b^0}^2) \Gamma_{\tilde{e}_j, e_a, A_b^0}^{R*} \Gamma_{\tilde{e}_i, e_a, A_b^0}^R - \sum_{b=1}^3 B_1(p^2, m_{e_b}^2, 0) \Gamma_{\tilde{e}_j, \gamma, e_b}^{L*} \Gamma_{\tilde{e}_i, \gamma, e_b}^L \\ & - \sum_{b=1}^3 B_1(p^2, m_{\nu_b}^2, m_{W^-}^2) \Gamma_{\tilde{e}_j, W^-, \nu_b}^{L*} \Gamma_{\tilde{e}_i, W^-, \nu_b}^L - \sum_{b=1}^3 B_1(p^2, m_{e_b}^2, m_Z^2) \Gamma_{\tilde{e}_j, Z, e_b}^{L*} \Gamma_{\tilde{e}_i, Z, e_b}^L \end{aligned} \quad (79)$$

$$\begin{aligned} \Sigma_{i,j}^L(p^2) = & -\frac{1}{2} \sum_{a=1}^2 \sum_{b=1}^3 B_1(p^2, m_{e_b}^2, m_{h_a}^2) \Gamma_{\tilde{e}_j, h_a, e_b}^{L*} \Gamma_{\tilde{e}_i, h_a, e_b}^L \\ & - \frac{1}{2} \sum_{a=1}^2 \sum_{b=1}^3 B_1(p^2, m_{\nu_b}^2, m_{H_a^-}^2) \Gamma_{\tilde{e}_j, H_a^-, \nu_b}^{L*} \Gamma_{\tilde{e}_i, H_a^-, \nu_b}^L \\ & - \frac{1}{2} \sum_{a=1}^3 \sum_{b=1}^2 B_1(p^2, m_{e_a}^2, m_{A_b^0}^2) \Gamma_{\tilde{e}_j, e_a, A_b^0}^{L*} \Gamma_{\tilde{e}_i, e_a, A_b^0}^L - \sum_{b=1}^3 B_1(p^2, m_{e_b}^2, 0) \Gamma_{\tilde{e}_j, \gamma, e_b}^{R*} \Gamma_{\tilde{e}_i, \gamma, e_b}^R \end{aligned}$$

$$- \sum_{b=1}^3 B_1(p^2, m_{\nu_b}^2, m_{W^-}^2) \Gamma_{\tilde{e}_j, W^-, \nu_b}^{R*} \Gamma_{\tilde{e}_i, W^-, \nu_b}^R - \sum_{b=1}^3 B_1(p^2, m_{e_b}^2, m_Z^2) \Gamma_{\tilde{e}_j, Z, e_b}^{R*} \Gamma_{\tilde{e}_i, Z, e_b}^R \quad (80)$$

• **Self-Energy for Z-Boson (Z)**

$$\begin{aligned}
\Pi(p^2) = & + |\Gamma_{Z, \eta^-, \eta^-}|^2 B_{00}(p^2, m_{\eta^-}^2, m_{\eta^-}^2) + |\Gamma_{Z, \eta^+, \eta^+}|^2 B_{00}(p^2, m_{\eta^+}^2, m_{\eta^+}^2) \\
& - |\Gamma_{Z, W^+, W^-}|^2 \left(10 B_{00}(p^2, m_{W^-}^2, m_{W^-}^2) + 2 A_0(m_{W^-}^2) - 2 \text{rMS} \left(2 m_{W^-}^2 - \frac{1}{3} p^2 \right) + B_0(p^2, m_{W^-}^2, m_{W^-}^2) \right) (2 m_{W^-}^2 + 4 p^2) \\
& + \frac{1}{2} \sum_{a=1}^2 A_0(m_{A_a^0}^2) \Gamma_{Z, Z, A_a^0, A_a^0} + \sum_{a=1}^2 A_0(m_{H_a^-}^2) \Gamma_{Z, Z, H_a^+, H_a^-} + \frac{1}{2} \sum_{a=1}^2 A_0(m_{h_a}^2) \Gamma_{Z, Z, h_a, h_a} \\
& - 4 \sum_{a=1}^2 \sum_{b=1}^2 |\Gamma_{Z, h_a, A_b^0}|^2 B_{00}(p^2, m_{A_b^0}^2, m_{h_a}^2) - 4 \sum_{a=1}^2 \sum_{b=1}^2 |\Gamma_{Z, H_a^+, H_b^-}|^2 B_{00}(p^2, m_{H_a^-}^2, m_{H_b^-}^2) \\
& + 3 \sum_{a=1}^3 \sum_{b=1}^3 \left[\left(|\Gamma_{Z, \bar{d}_a, d_b}^L|^2 + |\Gamma_{Z, \bar{d}_a, d_b}^R|^2 \right) H_0(p^2, m_{d_a}^2, m_{d_b}^2) \right. \\
& \left. + 4 B_0(p^2, m_{d_a}^2, m_{d_b}^2) m_{d_a} m_{d_b} \Re \left(\Gamma_{Z, \bar{d}_a, d_b}^{L*} \Gamma_{Z, \bar{d}_a, d_b}^R \right) \right] \\
& + \sum_{a=1}^3 \sum_{b=1}^3 \left[\left(|\Gamma_{Z, \bar{e}_a, e_b}^L|^2 + |\Gamma_{Z, \bar{e}_a, e_b}^R|^2 \right) H_0(p^2, m_{e_a}^2, m_{e_b}^2) \right. \\
& \left. + 4 B_0(p^2, m_{e_a}^2, m_{e_b}^2) m_{e_a} m_{e_b} \Re \left(\Gamma_{Z, \bar{e}_a, e_b}^{L*} \Gamma_{Z, \bar{e}_a, e_b}^R \right) \right] \\
& + 3 \sum_{a=1}^3 \sum_{b=1}^3 \left[\left(|\Gamma_{Z, \bar{u}_a, u_b}^L|^2 + |\Gamma_{Z, \bar{u}_a, u_b}^R|^2 \right) H_0(p^2, m_{u_a}^2, m_{u_b}^2) \right. \\
& \left. + 4 B_0(p^2, m_{u_a}^2, m_{u_b}^2) m_{u_a} m_{u_b} \Re \left(\Gamma_{Z, \bar{u}_a, u_b}^{L*} \Gamma_{Z, \bar{u}_a, u_b}^R \right) \right] \\
& + \sum_{a=1}^3 \sum_{b=1}^3 \left[\left(|\Gamma_{Z, \bar{\nu}_a, \nu_b}^L|^2 + |\Gamma_{Z, \bar{\nu}_a, \nu_b}^R|^2 \right) H_0(p^2, m_{\nu_a}^2, m_{\nu_b}^2) \right. \\
& \left. + 4 B_0(p^2, m_{\nu_a}^2, m_{\nu_b}^2) m_{\nu_a} m_{\nu_b} \Re \left(\Gamma_{Z, \bar{\nu}_a, \nu_b}^{L*} \Gamma_{Z, \bar{\nu}_a, \nu_b}^R \right) \right] \\
& + 2 \sum_{b=1}^2 |\Gamma_{Z, W^+, H_b^-}|^2 B_0(p^2, m_{W^-}^2, m_{H_b^-}^2) + \sum_{b=1}^2 |\Gamma_{Z, Z, h_b}|^2 B_0(p^2, m_Z^2, m_{h_b}^2) + 2 \text{rMS} m_{W^-}^2 - \Gamma_{Z, Z, W^+, W^-}^1 \\
& - A_0(m_{W^-}^2) \left(4 \Gamma_{Z, Z, W^+, W^-}^1 + \Gamma_{Z, Z, W^+, W^-}^2 + \Gamma_{Z, Z, W^+, W^-}^3 \right) \quad (81)
\end{aligned}$$

• **Self-Energy for W-Boson (W^-)**

$$\Pi(p^2) = 2 \text{rMS} m_{W^-}^2 - \Gamma_{W^-, W^+, W^+, W^-}^1 + 3 \sum_{a=1}^3 \sum_{b=1}^3 \left[\left(|\Gamma_{W^+, \bar{u}_a, d_b}^L|^2 + |\Gamma_{W^+, \bar{u}_a, d_b}^R|^2 \right) H_0(p^2, m_{u_a}^2, m_{d_b}^2) \right]$$

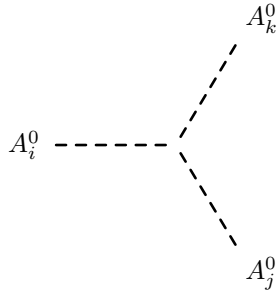
$$\begin{aligned}
& + 4B_0\left(p^2, m_{u_a}^2, m_{d_b}^2\right) m_{d_b} m_{u_a} \Re\left(\Gamma_{W^+, \bar{u}_a, d_b}^{L*} \Gamma_{W^+, \bar{u}_a, d_b}^R\right) - 4 \sum_{a=1}^2 \sum_{b=1}^2 |\Gamma_{W^+, H_a^-, A_b^0}|^2 B_{00}\left(p^2, m_{A_b^0}^2, m_{H_a^-}^2\right) - 4 \sum_{a=1}^2 \sum_{b=1}^2 |\Gamma_{W^+, H} \\
& + 4B_0\left(p^2, m_{\nu_a}^2, m_{e_b}^2\right) m_{e_b} m_{\nu_a} \Re\left(\Gamma_{W^+, \bar{\nu}_a, e_b}^{L*} \Gamma_{W^+, \bar{\nu}_a, e_b}^R\right) + \sum_{b=1}^2 |\Gamma_{W^+, \gamma, H_b^-}|^2 B_0\left(p^2, 0, m_{H_b^-}^2\right) + \sum_{b=1}^2 |\Gamma_{W^+, W^-, h_b}|^2 B_0\left(p^2, m_{W}^2
\end{aligned} \tag{82}$$

8.2 Tadpoles

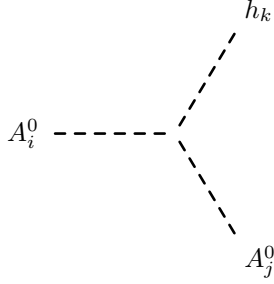
$$\begin{aligned}
\delta t_h^{(1)} = & + A_0\left(m_{\eta^-}^2\right) \Gamma_{\tilde{h}_i, \eta^-, \eta^-} + A_0\left(m_{\eta^+}^2\right) \Gamma_{\tilde{h}_i, \eta^+, \eta^+} + A_0\left(m_{\eta^Z}^2\right) \Gamma_{\tilde{h}_i, \eta^Z, \eta^Z} \\
& + 4\Gamma_{\tilde{h}_i, W^+, W^-} \left(-\frac{1}{2} \text{rMS} m_{W^-}^2 + A_0\left(m_{W^-}^2\right)\right) + 2\Gamma_{\tilde{h}_i, Z, Z} \left(-\frac{1}{2} \text{rMS} m_Z^2 + A_0\left(m_Z^2\right)\right) - \frac{1}{2} \sum_{a=1}^2 A_0\left(m_{A_a^0}^2\right) \Gamma_{\tilde{h}_i, A_a^0, A_a^0} \\
& - \sum_{a=1}^2 A_0\left(m_{H_a^-}^2\right) \Gamma_{\tilde{h}_i, H_a^+, H_a^-} - \frac{1}{2} \sum_{a=1}^2 A_0\left(m_{h_a}^2\right) \Gamma_{\tilde{h}_i, h_a, h_a} \\
& + 6 \sum_{a=1}^3 A_0\left(m_{d_a}^2\right) m_{d_a} \left(\Gamma_{\tilde{h}_i, \bar{d}_a, d_a}^L + \Gamma_{\tilde{h}_i, \bar{d}_a, d_a}^R\right) \\
& + 2 \sum_{a=1}^3 A_0\left(m_{e_a}^2\right) m_{e_a} \left(\Gamma_{\tilde{h}_i, \bar{e}_a, e_a}^L + \Gamma_{\tilde{h}_i, \bar{e}_a, e_a}^R\right) \\
& + 6 \sum_{a=1}^3 A_0\left(m_{u_a}^2\right) m_{u_a} \left(\Gamma_{\tilde{h}_i, \bar{u}_a, u_a}^L + \Gamma_{\tilde{h}_i, \bar{u}_a, u_a}^R\right)
\end{aligned} \tag{83}$$

9 Interactions for eigenstates 'EWSB'

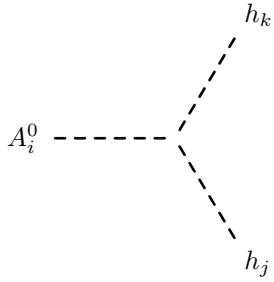
9.1 Three Scalar-Interaction



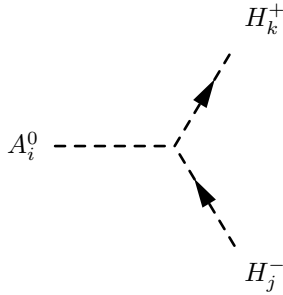
$$\begin{aligned}
& \frac{1}{2} \left(-\lambda_5^* + \lambda_5 \right) \left(Z_{i2}^A \left(-v_1 Z_{j2}^A Z_{k1}^A + Z_{j1}^A \left(-v_1 Z_{k2}^A + v_2 Z_{k1}^A \right) \right) \right. \\
& \left. + Z_{i1}^A \left(v_2 Z_{j1}^A Z_{k2}^A + Z_{j2}^A \left(-v_1 Z_{k2}^A + v_2 Z_{k1}^A \right) \right) \right)
\end{aligned} \tag{84}$$



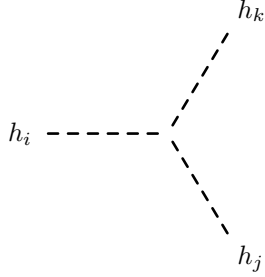
$$\begin{aligned}
& -\frac{i}{2} \left(Z_{i2}^A \left((\lambda_5 + \lambda_5^*) Z_{j1}^A (v_1 Z_{k2}^H + v_2 Z_{k1}^H) + Z_{j2}^A (4\lambda_2 v_2 Z_{k2}^H + v_1 (2\lambda_3 + 2\lambda_4 - \lambda_5 - \lambda_5^*) Z_{k1}^H) \right) \right. \\
& \left. + Z_{i1}^A \left((\lambda_5 + \lambda_5^*) Z_{j2}^A (v_1 Z_{k2}^H + v_2 Z_{k1}^H) + Z_{j1}^A (4\lambda_1 v_1 Z_{k1}^H + v_2 (2\lambda_3 + 2\lambda_4 - \lambda_5 - \lambda_5^*) Z_{k2}^H) \right) \right) \quad (85)
\end{aligned}$$



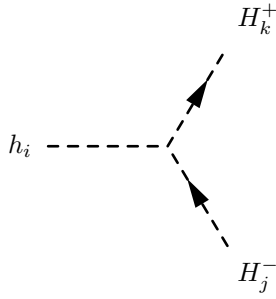
$$-\frac{1}{2} \left(-\lambda_5^* + \lambda_5 \right) \left(-Z_{i1}^A \left(v_2 Z_{j1}^H Z_{k2}^H + Z_{j2}^H \left(v_1 Z_{k2}^H + v_2 Z_{k1}^H \right) \right) + Z_{i2}^A \left(v_1 Z_{j2}^H Z_{k1}^H + Z_{j1}^H \left(v_1 Z_{k2}^H + v_2 Z_{k1}^H \right) \right) \right) \quad (86)$$



$$-\frac{1}{2} \left(-v_1 Z_{i2}^A + v_2 Z_{i1}^A \right) \left(\left(-\lambda_4 + \lambda_5^* \right) Z_{j1}^+ Z_{k2}^+ + \left(-\lambda_5 + \lambda_4 \right) Z_{j2}^+ Z_{k1}^+ \right) \quad (87)$$

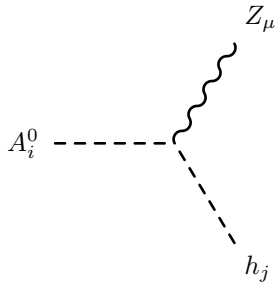


$$\begin{aligned}
& -\frac{i}{2} \left(Z_{i2}^H \left((2\lambda_3 + 2\lambda_4 + \lambda_5 + \lambda_5^*) Z_{j1}^H (v_1 Z_{k2}^H + v_2 Z_{k1}^H) + Z_{j2}^H (12\lambda_2 v_2 Z_{k2}^H + v_1 (2\lambda_3 + 2\lambda_4 + \lambda_5 + \lambda_5^*) Z_{k1}^H) \right) \right. \\
& \left. + Z_{i1}^H \left((2\lambda_3 + 2\lambda_4 + \lambda_5 + \lambda_5^*) Z_{j2}^H (v_1 Z_{k2}^H + v_2 Z_{k1}^H) + Z_{j1}^H (12\lambda_1 v_1 Z_{k1}^H + v_2 (2\lambda_3 + 2\lambda_4 + \lambda_5 + \lambda_5^*) Z_{k2}^H) \right) \right) \quad (88)
\end{aligned}$$

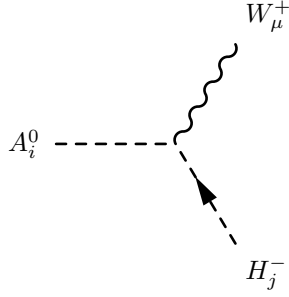


$$\begin{aligned}
& -\frac{i}{2} \left(Z_{i2}^H \left(Z_{j1}^+ (2\lambda_3 v_2 Z_{k1}^+ + v_1 (\lambda_4 + \lambda_5^*) Z_{k2}^+) + Z_{j2}^+ (4\lambda_2 v_2 Z_{k2}^+ + (\lambda_4 + \lambda_5) v_1 Z_{k1}^+) \right) \right. \\
& \left. + Z_{i1}^H \left(Z_{j1}^+ (4\lambda_1 v_1 Z_{k1}^+ + v_2 (\lambda_4 + \lambda_5^*) Z_{k2}^+) + Z_{j2}^+ (2\lambda_3 v_1 Z_{k2}^+ + (\lambda_4 + \lambda_5) v_2 Z_{k1}^+) \right) \right) \quad (89)
\end{aligned}$$

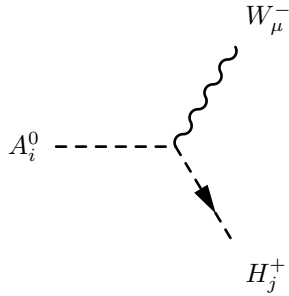
9.2 Two Scalar-One Vector Boson-Interaction



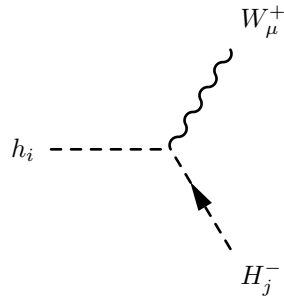
$$-\frac{1}{2}(g_1 \sin \Theta_W + g_2 \cos \Theta_W)(Z_{i1}^A Z_{j1}^H + Z_{i2}^A Z_{j2}^H)(-p_\mu^{h_j} + p_\mu^{A_i^0}) \quad (90)$$



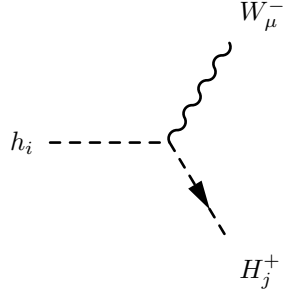
$$\frac{1}{2}g_2(Z_{i1}^A Z_{j1}^+ + Z_{i2}^A Z_{j2}^+)(-p_\mu^{H_j^-} + p_\mu^{A_i^0}) \quad (91)$$



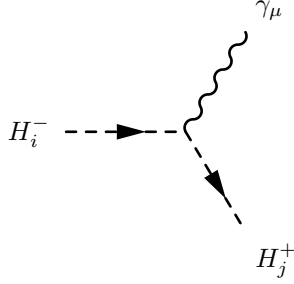
$$\frac{1}{2}g_2(Z_{i1}^A Z_{j1}^+ + Z_{i2}^A Z_{j2}^+)(-p_\mu^{H_j^+} + p_\mu^{A_i^0}) \quad (92)$$



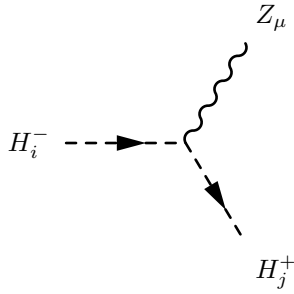
$$-\frac{i}{2}g_2(Z_{i1}^H Z_{j1}^+ + Z_{i2}^H Z_{j2}^+)(-p_\mu^{H_j^-} + p_\mu^{h_i}) \quad (93)$$



$$\frac{i}{2} g_2 \left(Z_{i1}^H Z_{j1}^+ + Z_{i2}^H Z_{j2}^+ \right) \left(-p_\mu^{H_j^+} + p_\mu^{h_i} \right) \quad (94)$$

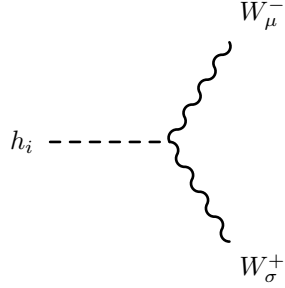


$$\frac{i}{2} \left(g_1 \cos \Theta_W + g_2 \sin \Theta_W \right) \left(Z_{i1}^+ Z_{j1}^+ + Z_{i2}^+ Z_{j2}^+ \right) \left(-p_\mu^{H_j^+} + p_\mu^{H_i^-} \right) \quad (95)$$

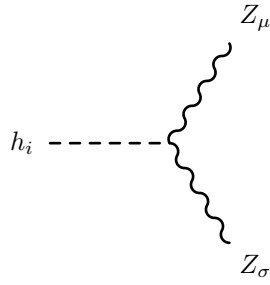


$$\frac{i}{2} \left(-g_1 \sin \Theta_W + g_2 \cos \Theta_W \right) \left(Z_{i1}^+ Z_{j1}^+ + Z_{i2}^+ Z_{j2}^+ \right) \left(-p_\mu^{H_j^+} + p_\mu^{H_i^-} \right) \quad (96)$$

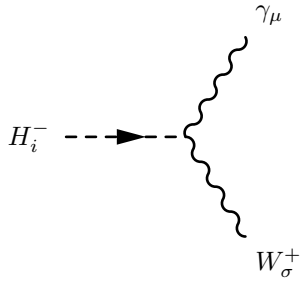
9.3 One Scalar-Two Vector Boson-Interaction



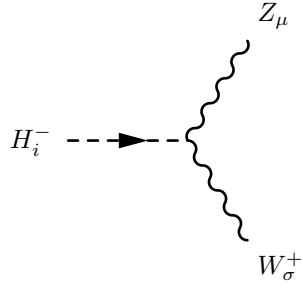
$$\frac{i}{2}g_2^2(v_1Z_{i1}^H + v_2Z_{i2}^H)(g_{\sigma\mu}) \quad (97)$$



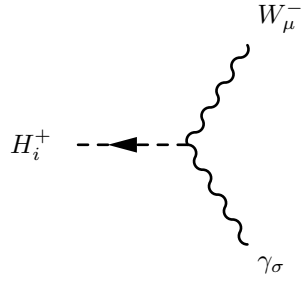
$$\frac{i}{2}(g_1 \sin \Theta_W + g_2 \cos \Theta_W)^2 (v_1Z_{i1}^H + v_2Z_{i2}^H)(g_{\sigma\mu}) \quad (98)$$



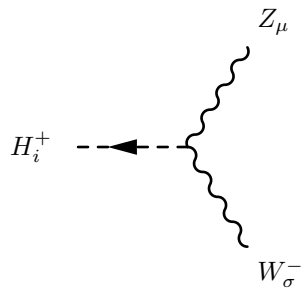
$$\frac{i}{2}g_1g_2 \cos \Theta_W (v_1Z_{i1}^+ + v_2Z_{i2}^+)(g_{\sigma\mu}) \quad (99)$$



$$-\frac{i}{2}g_1g_2\sin\Theta_W\left(v_1Z_{i1}^+ + v_2Z_{i2}^+\right)\left(g_{\sigma\mu}\right) \quad (100)$$

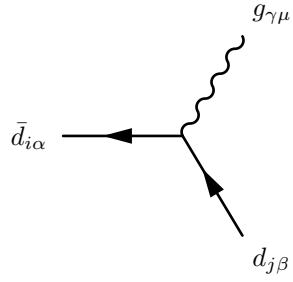


$$\frac{i}{2}g_1g_2\cos\Theta_W\left(v_1Z_{i1}^+ + v_2Z_{i2}^+\right)\left(g_{\sigma\mu}\right) \quad (101)$$



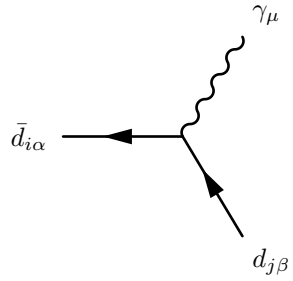
$$-\frac{i}{2}g_1g_2\sin\Theta_W\left(v_1Z_{i1}^+ + v_2Z_{i2}^+\right)\left(g_{\sigma\mu}\right) \quad (102)$$

9.4 Two Fermion-One Vector Boson-Interaction



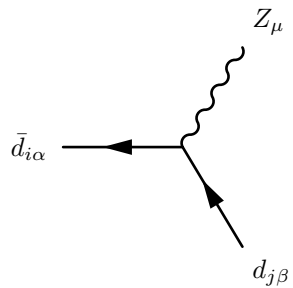
$$-\frac{i}{2}g_3\delta_{ij}\lambda_{\alpha,\beta}^\gamma\left(\gamma_\mu\cdot\frac{1-\gamma_5}{2}\right) \quad (103)$$

$$+\frac{i}{2}g_3\delta_{ij}\lambda_{\alpha,\beta}^\gamma\left(\gamma_\mu\cdot\frac{1+\gamma_5}{2}\right) \quad (104)$$



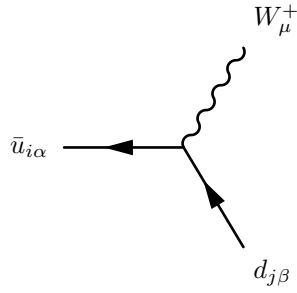
$$-\frac{i}{6}\delta_{\alpha\beta}\delta_{ij}\left(-3g_2\sin\Theta_W+g_1\cos\Theta_W\right)\left(\gamma_\mu\cdot\frac{1-\gamma_5}{2}\right) \quad (105)$$

$$+\frac{i}{3}g_1\cos\Theta_W\delta_{\alpha\beta}\delta_{ij}\left(\gamma_\mu\cdot\frac{1+\gamma_5}{2}\right) \quad (106)$$

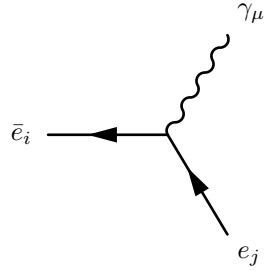


$$\frac{i}{6}\delta_{\alpha\beta}\delta_{ij}\left(3g_2\cos\Theta_W+g_1\sin\Theta_W\right)\left(\gamma_\mu\cdot\frac{1-\gamma_5}{2}\right) \quad (107)$$

$$+ \frac{i}{3}g_1\delta_{\alpha\beta}\delta_{ij}\sin\Theta_W\left(\gamma_\mu\cdot\frac{1+\gamma_5}{2}\right) \quad (108)$$

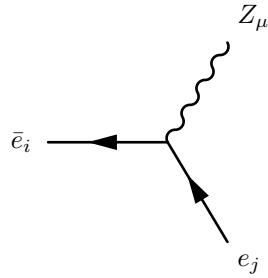


$$-i\frac{1}{\sqrt{2}}g_2\delta_{\alpha\beta}\sum_{a=1}^3U_{L,ja}^{d,*}U_{L,ia}^u\left(\gamma_\mu\cdot\frac{1-\gamma_5}{2}\right) \quad (109)$$



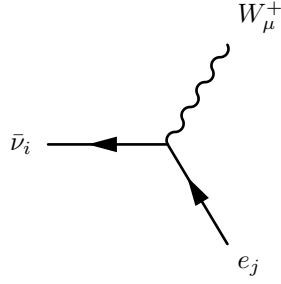
$$\frac{i}{2}\delta_{ij}\left(g_1\cos\Theta_W+g_2\sin\Theta_W\right)\left(\gamma_\mu\cdot\frac{1-\gamma_5}{2}\right) \quad (110)$$

$$+ ig_1\cos\Theta_W\delta_{ij}\left(\gamma_\mu\cdot\frac{1+\gamma_5}{2}\right) \quad (111)$$

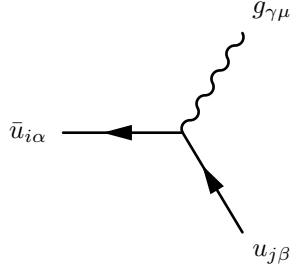


$$\frac{i}{2}\delta_{ij}\left(-g_1\sin\Theta_W+g_2\cos\Theta_W\right)\left(\gamma_\mu\cdot\frac{1-\gamma_5}{2}\right) \quad (112)$$

$$+ -ig_1\delta_{ij}\sin\Theta_W\left(\gamma_\mu\cdot\frac{1+\gamma_5}{2}\right) \quad (113)$$

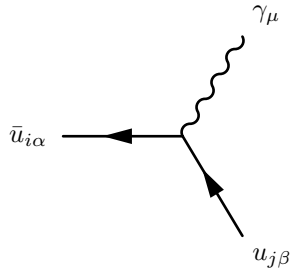


$$-i\frac{1}{\sqrt{2}}g_2U_{L,ji}^{e,*}\Theta_{i,3}\left(\gamma_\mu\cdot\frac{1-\gamma_5}{2}\right) \quad (114)$$



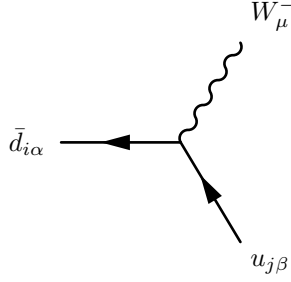
$$-\frac{i}{2}g_3\delta_{ij}\lambda_{\alpha,\beta}^\gamma\left(\gamma_\mu\cdot\frac{1-\gamma_5}{2}\right) \quad (115)$$

$$+\frac{i}{2}g_3\delta_{ij}\lambda_{\alpha,\beta}^\gamma\left(\gamma_\mu\cdot\frac{1+\gamma_5}{2}\right) \quad (116)$$

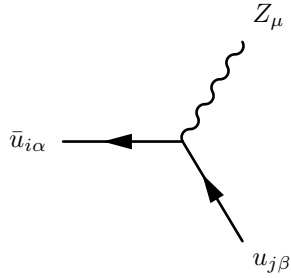


$$-\frac{i}{6}\delta_{\alpha\beta}\delta_{ij}\left(3g_2\sin\Theta_W+g_1\cos\Theta_W\right)\left(\gamma_\mu\cdot\frac{1-\gamma_5}{2}\right) \quad (117)$$

$$+\frac{2i}{3}g_1\cos\Theta_W\delta_{\alpha\beta}\delta_{ij}\left(\gamma_\mu\cdot\frac{1+\gamma_5}{2}\right) \quad (118)$$

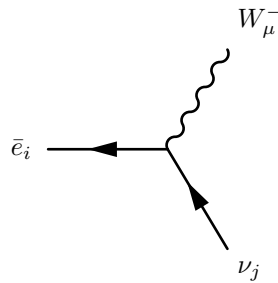


$$-i\frac{1}{\sqrt{2}}g_2\delta_{\alpha\beta}\sum_{a=1}^3U_{L,ja}^{u,*}U_{L,ia}^d\left(\gamma_\mu\cdot\frac{1-\gamma_5}{2}\right) \quad (119)$$

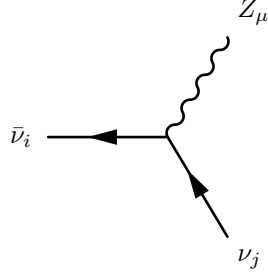


$$-\frac{i}{6}\delta_{\alpha\beta}\delta_{ij}\left(3g_2\cos\Theta_W-g_1\sin\Theta_W\right)\left(\gamma_\mu\cdot\frac{1-\gamma_5}{2}\right) \quad (120)$$

$$+\frac{2i}{3}g_1\delta_{\alpha\beta}\delta_{ij}\sin\Theta_W\left(\gamma_\mu\cdot\frac{1+\gamma_5}{2}\right) \quad (121)$$

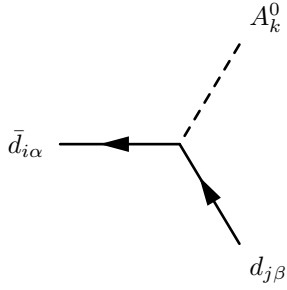


$$-i \frac{1}{\sqrt{2}} g_2 \Theta_{j,3} U_{L,ij}^e \left(\gamma_\mu \cdot \frac{1-\gamma_5}{2} \right) \quad (122)$$



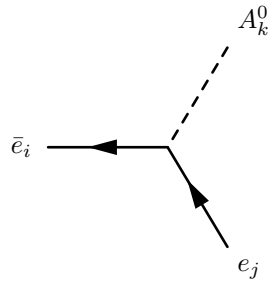
$$- \frac{i}{2} \delta_{ij} \left(g_1 \sin \Theta_W + g_2 \cos \Theta_W \right) \left(\gamma_\mu \cdot \frac{1-\gamma_5}{2} \right) \quad (123)$$

9.5 Two Fermion-One Scalar Boson-Interaction



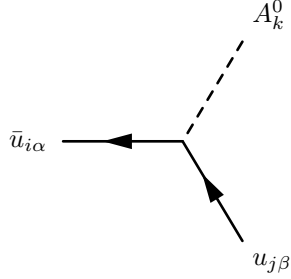
$$- \frac{1}{\sqrt{2}} \delta_{\alpha\beta} \sum_{b=1}^3 U_{L,jb}^{d,*} \sum_{a=1}^3 U_{R,ia}^{d,*} Y_{d,ab} Z_{k2}^A \left(\frac{1-\gamma_5}{2} \right) \quad (124)$$

$$+ \frac{1}{\sqrt{2}} \delta_{\alpha\beta} \sum_{b=1}^3 \sum_{a=1}^3 Y_{d,ab}^* U_{R,ja}^d U_{L,ib}^d Z_{k2}^A \left(\frac{1+\gamma_5}{2} \right) \quad (125)$$



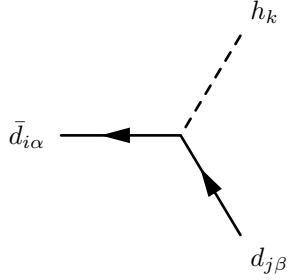
$$- \frac{1}{\sqrt{2}} \sum_{b=1}^3 U_{L,jb}^{e,*} \sum_{a=1}^3 U_{R,ia}^e Y_{e,ab} Z_{k2}^A \left(\frac{1-\gamma_5}{2} \right) \quad (126)$$

$$+ \frac{1}{\sqrt{2}} \sum_{b=1}^3 \sum_{a=1}^3 Y_{e,ab}^* U_{R,ja}^e U_{L,ib}^e Z_{k2}^A \left(\frac{1+\gamma_5}{2} \right) \quad (127)$$



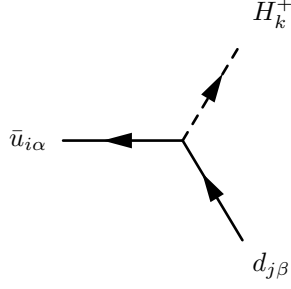
$$- \frac{1}{\sqrt{2}} \delta_{\alpha\beta} \sum_{b=1}^3 U_{L,jb}^{u,*} \sum_{a=1}^3 U_{R,ia}^u Y_{u,ab} Z_{k2}^A \left(\frac{1-\gamma_5}{2} \right) \quad (128)$$

$$+ \frac{1}{\sqrt{2}} \delta_{\alpha\beta} \sum_{b=1}^3 \sum_{a=1}^3 Y_{u,ab}^* U_{R,ja}^u U_{L,ib}^u Z_{k2}^A \left(\frac{1+\gamma_5}{2} \right) \quad (129)$$



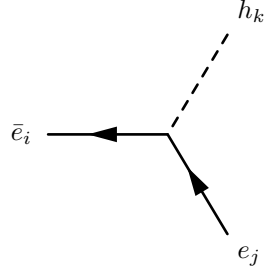
$$- i \frac{1}{\sqrt{2}} \delta_{\alpha\beta} \sum_{b=1}^3 U_{L,jb}^{d,*} \sum_{a=1}^3 U_{R,ia}^d Y_{d,ab} Z_{k2}^H \left(\frac{1-\gamma_5}{2} \right) \quad (130)$$

$$+ -i \frac{1}{\sqrt{2}} \delta_{\alpha\beta} \sum_{b=1}^3 \sum_{a=1}^3 Y_{d,ab}^* U_{R,ja}^d U_{L,ib}^d Z_{k2}^H \left(\frac{1+\gamma_5}{2} \right) \quad (131)$$



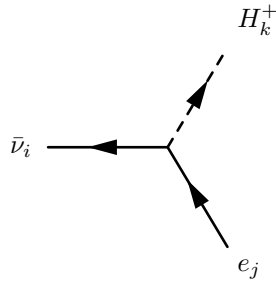
$$-i\delta_{\alpha\beta} \sum_{b=1}^3 U_{L,jb}^{d,*} \sum_{a=1}^3 U_{R,ia}^{u,*} Y_{u,ab} Z_{k2}^+ \left(\frac{1-\gamma_5}{2} \right) \quad (132)$$

$$+ -i\delta_{\alpha\beta} \sum_{b=1}^3 \sum_{a=1}^3 Y_{d,ab}^* U_{R,ja}^d U_{L,ib}^u Z_{k2}^+ \left(\frac{1+\gamma_5}{2} \right) \quad (133)$$



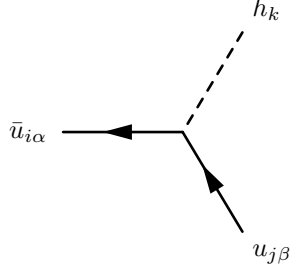
$$-i \frac{1}{\sqrt{2}} \sum_{b=1}^3 U_{L,jb}^{e,*} \sum_{a=1}^3 U_{R,ia}^{e,*} Y_{e,ab} Z_{k2}^H \left(\frac{1-\gamma_5}{2} \right) \quad (134)$$

$$+ -i \frac{1}{\sqrt{2}} \sum_{b=1}^3 \sum_{a=1}^3 Y_{e,ab}^* U_{R,ja}^e U_{L,ib}^e Z_{k2}^H \left(\frac{1+\gamma_5}{2} \right) \quad (135)$$



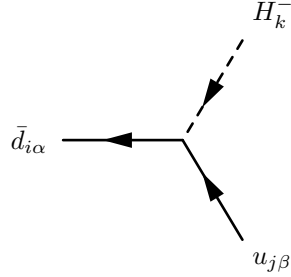
(136)

$$+ -i \sum_{a=1}^3 Y_{e,ai}^* U_{R,ja}^e Z_{k2}^+ \left(\frac{1+\gamma_5}{2} \right) \quad (137)$$



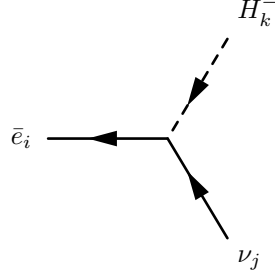
$$i \frac{1}{\sqrt{2}} \delta_{\alpha\beta} \sum_{b=1}^3 U_{L,jb}^{u,*} \sum_{a=1}^3 U_{R,ia}^{u,*} Y_{u,ab} Z_{k2}^H \left(\frac{1-\gamma_5}{2} \right) \quad (138)$$

$$+ i \frac{1}{\sqrt{2}} \delta_{\alpha\beta} \sum_{b=1}^3 \sum_{a=1}^3 Y_{u,ab}^* U_{R,ja}^u U_{L,ib}^u Z_{k2}^H \left(\frac{1+\gamma_5}{2} \right) \quad (139)$$



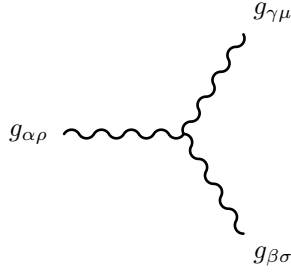
$$- i \delta_{\alpha\beta} \sum_{b=1}^3 U_{L,jb}^{u,*} \sum_{a=1}^3 U_{R,ia}^{d,*} Y_{d,ab} Z_{k2}^+ \left(\frac{1-\gamma_5}{2} \right) \quad (140)$$

$$+ -i \delta_{\alpha\beta} \sum_{b=1}^3 \sum_{a=1}^3 Y_{u,ab}^* U_{R,ja}^u U_{L,ib}^d Z_{k2}^+ \left(\frac{1+\gamma_5}{2} \right) \quad (141)$$

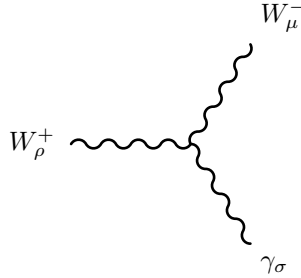


$$-i \sum_{a=1}^3 U_{R,ia}^{e,*} Y_{e,aj} Z_{k2}^+ \left(\frac{1-\gamma_5}{2} \right) \quad (142)$$

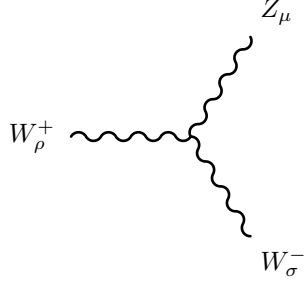
9.6 Three Vector Boson-Interaction



$$g_3 f_{\alpha,\beta,\gamma} \left(g_{\rho\mu} \left(-p_\sigma^{g\gamma\mu} + p_\sigma^{g\alpha\rho} \right) + g_{\rho\sigma} \left(-p_\mu^{g\alpha\rho} + p_\mu^{g\beta\sigma} \right) + g_{\sigma\mu} \left(-p_\rho^{g\beta\sigma} + p_\rho^{g\gamma\mu} \right) \right) \quad (143)$$

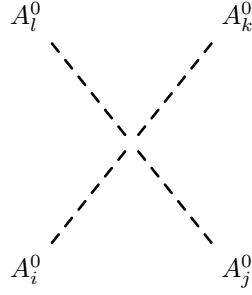


$$ig_2 \sin \Theta_W \left(g_{\rho\mu} \left(-p_\sigma^{W^-} + p_\sigma^{W^+} \right) + g_{\rho\sigma} \left(-p_\mu^{W^+} + p_\mu^{\gamma\sigma} \right) + g_{\sigma\mu} \left(-p_\rho^{\gamma\sigma} + p_\rho^{W^-} \right) \right) \quad (144)$$

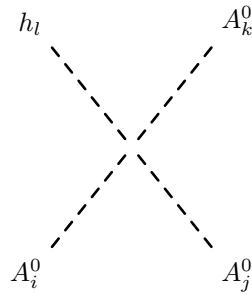


$$-ig_2 \cos \Theta_W \left(g_{\rho\mu} \left(-p_\sigma^{Z_\mu} + p_\sigma^{W_\rho^+} \right) + g_{\rho\sigma} \left(-p_\mu^{W_\rho^+} + p_\mu^{W_\sigma^-} \right) + g_{\sigma\mu} \left(-p_\rho^{W_\sigma^-} + p_\rho^{Z_\mu} \right) \right) \quad (145)$$

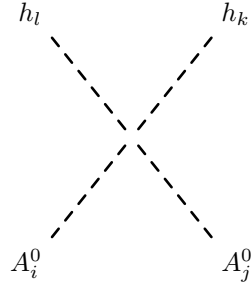
9.7 Four Scalar-Interaction



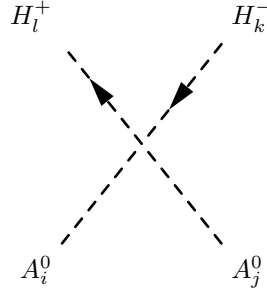
$$\begin{aligned} & -\frac{i}{2} \left(Z_{i2}^A \left((2\lambda_3 + 2\lambda_4 + \lambda_5 + \lambda_5^*) Z_{j1}^A \left(Z_{k1}^A Z_{l2}^A + Z_{k2}^A Z_{l1}^A \right) \right. \right. \\ & + Z_{j2}^A \left(12\lambda_2 Z_{k2}^A Z_{l2}^A + (2\lambda_3 + 2\lambda_4 + \lambda_5 + \lambda_5^*) Z_{k1}^A Z_{l1}^A \right) \\ & + Z_{i1}^A \left((2\lambda_3 + 2\lambda_4 + \lambda_5 + \lambda_5^*) Z_{j2}^A \left(Z_{k1}^A Z_{l2}^A + Z_{k2}^A Z_{l1}^A \right) \right. \\ & \left. \left. + Z_{j1}^A \left(12\lambda_1 Z_{k1}^A Z_{l1}^A + (2\lambda_3 + 2\lambda_4 + \lambda_5 + \lambda_5^*) Z_{k2}^A Z_{l2}^A \right) \right) \right) \end{aligned} \quad (146)$$



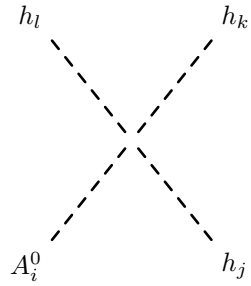
$$\begin{aligned}
& -\frac{1}{2} \left(-\lambda_5^* + \lambda_5 \right) \left(Z_{i2}^A \left(Z_{j1}^A \left(-Z_{k1}^A Z_{l2}^H + Z_{k2}^A Z_{l1}^H \right) + Z_{j2}^A Z_{k1}^A Z_{l1}^H \right) \right. \\
& \left. + Z_{i1}^A \left(-Z_{j1}^A Z_{k2}^A Z_{l2}^H + Z_{j2}^A \left(-Z_{k1}^A Z_{l2}^H + Z_{k2}^A Z_{l1}^H \right) \right) \right) \quad (147)
\end{aligned}$$



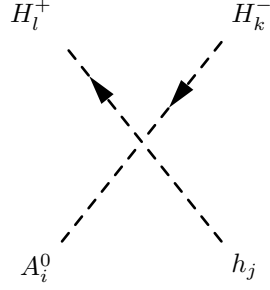
$$\begin{aligned}
& -\frac{i}{2} \left(Z_{i2}^A \left((\lambda_5 + \lambda_5^*) Z_{j1}^A \left(Z_{k1}^H Z_{l2}^H + Z_{k2}^H Z_{l1}^H \right) + Z_{j2}^A \left((2\lambda_3 + 2\lambda_4 - \lambda_5 - \lambda_5^*) Z_{k1}^H Z_{l1}^H + 4\lambda_2 Z_{k2}^H Z_{l2}^H \right) \right) \right. \\
& \left. + Z_{i1}^A \left((\lambda_5 + \lambda_5^*) Z_{j2}^A \left(Z_{k1}^H Z_{l2}^H + Z_{k2}^H Z_{l1}^H \right) + Z_{j1}^A \left((2\lambda_3 + 2\lambda_4 - \lambda_5 - \lambda_5^*) Z_{k2}^H Z_{l2}^H + 4\lambda_1 Z_{k1}^H Z_{l1}^H \right) \right) \right) \quad (148)
\end{aligned}$$



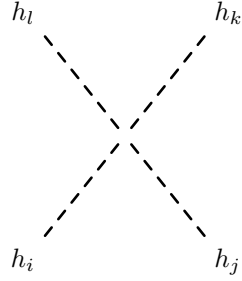
$$\begin{aligned}
& -\frac{i}{2} \left(Z_{i2}^A \left(2Z_{j2}^A \left(2\lambda_2 Z_{k2}^+ Z_{l2}^+ + \lambda_3 Z_{k1}^+ Z_{l1}^+ \right) + Z_{j1}^A \left((\lambda_4 + \lambda_5^*) Z_{k1}^+ Z_{l2}^+ + (\lambda_4 + \lambda_5) Z_{k2}^+ Z_{l1}^+ \right) \right) \right. \\
& \left. + Z_{i1}^A \left(2Z_{j1}^A \left(2\lambda_1 Z_{k1}^+ Z_{l1}^+ + \lambda_3 Z_{k2}^+ Z_{l2}^+ \right) + Z_{j2}^A \left((\lambda_4 + \lambda_5^*) Z_{k1}^+ Z_{l2}^+ + (\lambda_4 + \lambda_5) Z_{k2}^+ Z_{l1}^+ \right) \right) \right) \quad (149)
\end{aligned}$$



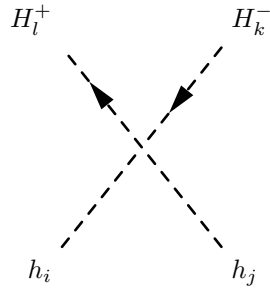
$$\begin{aligned}
& -\frac{1}{2} \left(-\lambda_5^* + \lambda_5 \right) \left(Z_{i2}^A \left(Z_{j1}^H \left(Z_{k1}^H Z_{l2}^H + Z_{k2}^H Z_{l1}^H \right) + Z_{j2}^H Z_{k1}^H Z_{l1}^H \right) \right. \\
& \left. - Z_{i1}^A \left(Z_{j1}^H Z_{k2}^H Z_{l2}^H + Z_{j2}^H \left(Z_{k1}^H Z_{l2}^H + Z_{k2}^H Z_{l1}^H \right) \right) \right)
\end{aligned} \tag{150}$$



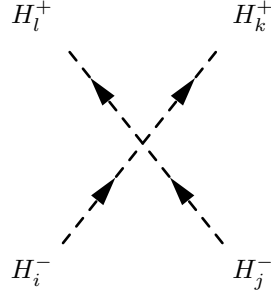
$$\frac{1}{2} \left(-Z_{i1}^A Z_{j2}^H + Z_{i2}^A Z_{j1}^H \right) \left(\left(-\lambda_4 + \lambda_5^* \right) Z_{k1}^+ Z_{l2}^+ + \left(-\lambda_5 + \lambda_4 \right) Z_{k2}^+ Z_{l1}^+ \right) \tag{151}$$



$$\begin{aligned}
& -\frac{i}{2} \left(Z_{i2}^H \left(\left(2\lambda_3 + 2\lambda_4 + \lambda_5 + \lambda_5^* \right) Z_{j1}^H \left(Z_{k1}^H Z_{l2}^H + Z_{k2}^H Z_{l1}^H \right) \right. \right. \\
& + Z_{j2}^H \left(12\lambda_2 Z_{k2}^H Z_{l2}^H + \left(2\lambda_3 + 2\lambda_4 + \lambda_5 + \lambda_5^* \right) Z_{k1}^H Z_{l1}^H \right) \left. \right) \\
& + Z_{i1}^H \left(\left(2\lambda_3 + 2\lambda_4 + \lambda_5 + \lambda_5^* \right) Z_{j2}^H \left(Z_{k1}^H Z_{l2}^H + Z_{k2}^H Z_{l1}^H \right) \right. \\
& \left. \left. + Z_{j1}^H \left(12\lambda_1 Z_{k1}^H Z_{l1}^H + \left(2\lambda_3 + 2\lambda_4 + \lambda_5 + \lambda_5^* \right) Z_{k2}^H Z_{l2}^H \right) \right) \right)
\end{aligned} \tag{152}$$

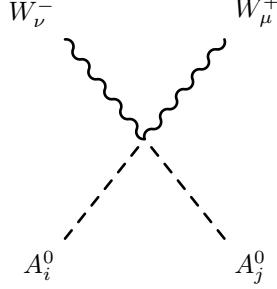


$$\begin{aligned}
& -\frac{i}{2} \left(Z_{i2}^H \left(2Z_{j2}^H \left(2\lambda_2 Z_{k2}^+ Z_{l2}^+ + \lambda_3 Z_{k1}^+ Z_{l1}^+ \right) + Z_{j1}^H \left((\lambda_4 + \lambda_5^*) Z_{k1}^+ Z_{l2}^+ + (\lambda_4 + \lambda_5) Z_{k2}^+ Z_{l1}^+ \right) \right) \right. \\
& \left. + Z_{i1}^H \left(2Z_{j1}^H \left(2\lambda_1 Z_{k1}^+ Z_{l1}^+ + \lambda_3 Z_{k2}^+ Z_{l2}^+ \right) + Z_{j2}^H \left((\lambda_4 + \lambda_5^*) Z_{k1}^+ Z_{l2}^+ + (\lambda_4 + \lambda_5) Z_{k2}^+ Z_{l1}^+ \right) \right) \right) \quad (153)
\end{aligned}$$

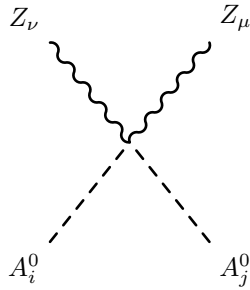


$$\begin{aligned}
& -i \left(Z_{i2}^+ \left(2Z_{j2}^+ \left(2\lambda_2 Z_{k2}^+ Z_{l2}^+ + \lambda_5 Z_{k1}^+ Z_{l1}^+ \right) + (\lambda_3 + \lambda_4) Z_{j1}^+ \left(Z_{k1}^+ Z_{l2}^+ + Z_{k2}^+ Z_{l1}^+ \right) \right) \right. \\
& \left. + Z_{i1}^+ \left(2Z_{j1}^+ \left(2\lambda_1 Z_{k1}^+ Z_{l1}^+ + \lambda_5^* Z_{k2}^+ Z_{l2}^+ \right) + (\lambda_3 + \lambda_4) Z_{j2}^+ \left(Z_{k1}^+ Z_{l2}^+ + Z_{k2}^+ Z_{l1}^+ \right) \right) \right) \quad (154)
\end{aligned}$$

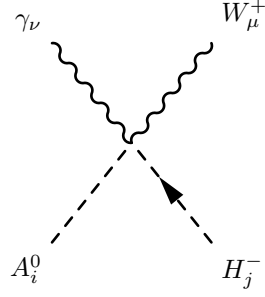
9.8 Two Scalar-Two Vector Boson-Interaction



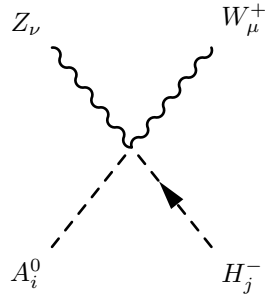
$$\frac{i}{2} g_2^2 \left(Z_{i1}^A Z_{j1}^A + Z_{i2}^A Z_{j2}^A \right) (g_{\mu\nu}) \quad (155)$$



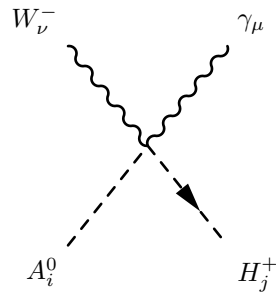
$$\frac{i}{2} (g_1 \sin \Theta_W + g_2 \cos \Theta_W)^2 (Z_{i1}^A Z_{j1}^A + Z_{i2}^A Z_{j2}^A) (g_{\mu\nu}) \quad (156)$$



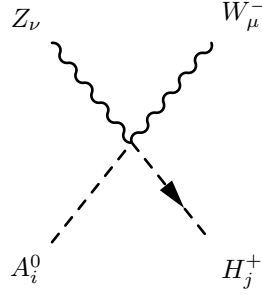
$$- \frac{1}{2} g_1 g_2 \cos \Theta_W (Z_{i1}^A Z_{j1}^+ + Z_{i2}^A Z_{j2}^+) (g_{\mu\nu}) \quad (157)$$



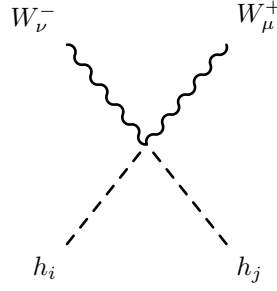
$$\frac{1}{2} g_1 g_2 \sin \Theta_W (Z_{i1}^A Z_{j1}^+ + Z_{i2}^A Z_{j2}^+) (g_{\mu\nu}) \quad (158)$$



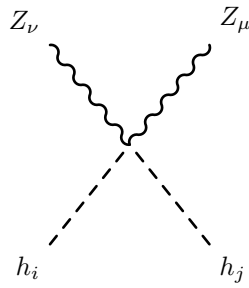
$$\frac{1}{2} g_1 g_2 \cos \Theta_W (Z_{i1}^A Z_{j1}^+ + Z_{i2}^A Z_{j2}^+) (g_{\mu\nu}) \quad (159)$$



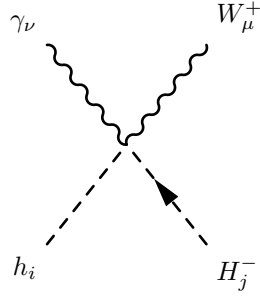
$$-\frac{1}{2}g_1g_2\sin\Theta_W\left(Z_{i1}^AZ_{j1}^++Z_{i2}^AZ_{j2}^+\right)\left(g_{\mu\nu}\right) \quad (160)$$



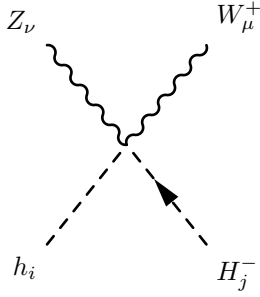
$$\frac{i}{2}g_2^2\left(Z_{i1}^HZ_{j1}^H+Z_{i2}^HZ_{j2}^H\right)\left(g_{\mu\nu}\right) \quad (161)$$



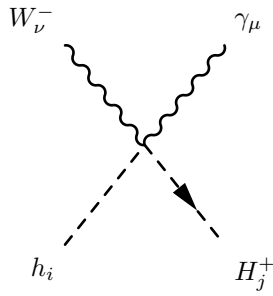
$$\frac{i}{2}\left(g_1\sin\Theta_W+g_2\cos\Theta_W\right)^2\left(Z_{i1}^HZ_{j1}^H+Z_{i2}^HZ_{j2}^H\right)\left(g_{\mu\nu}\right) \quad (162)$$



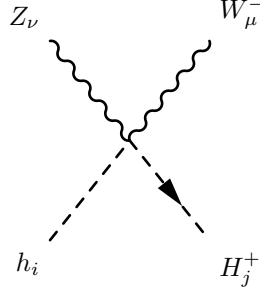
$$\frac{i}{2} g_1 g_2 \cos \Theta_W \left(Z_{i1}^H Z_{j1}^+ + Z_{i2}^H Z_{j2}^+ \right) (g_{\mu\nu}) \quad (163)$$



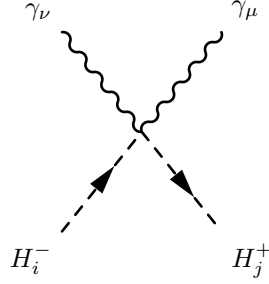
$$- \frac{i}{2} g_1 g_2 \sin \Theta_W \left(Z_{i1}^H Z_{j1}^+ + Z_{i2}^H Z_{j2}^+ \right) (g_{\mu\nu}) \quad (164)$$



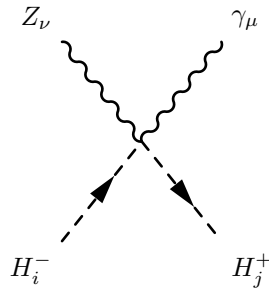
$$\frac{i}{2} g_1 g_2 \cos \Theta_W \left(Z_{i1}^H Z_{j1}^+ + Z_{i2}^H Z_{j2}^+ \right) (g_{\mu\nu}) \quad (165)$$



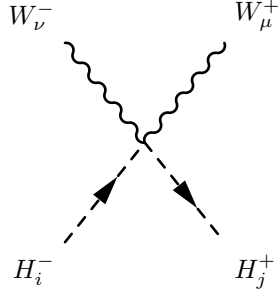
$$-\frac{i}{2}g_1g_2\sin\Theta_W\left(Z_{i1}^H Z_{j1}^+ + Z_{i2}^H Z_{j2}^+\right)\left(g_{\mu\nu}\right) \quad (166)$$



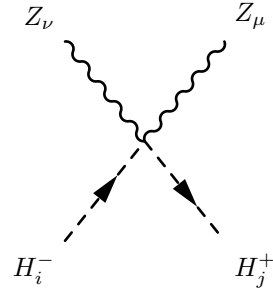
$$\frac{i}{2}\left(g_1\cos\Theta_W + g_2\sin\Theta_W\right)^2\left(Z_{i1}^+ Z_{j1}^+ + Z_{i2}^+ Z_{j2}^+\right)\left(g_{\mu\nu}\right) \quad (167)$$



$$-\frac{i}{4}\left(-2g_1g_2\cos 2\Theta_W + \left(-g_2^2 + g_1^2\right)\sin 2\Theta_W\right)\left(Z_{i1}^+ Z_{j1}^+ + Z_{i2}^+ Z_{j2}^+\right)\left(g_{\mu\nu}\right) \quad (168)$$

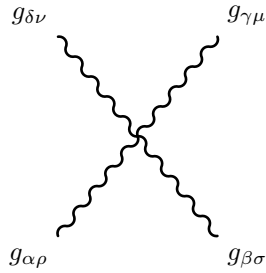


$$\frac{i}{2}g_2^2\left(Z_{i1}^+Z_{j1}^+ + Z_{i2}^+Z_{j2}^+\right)\left(g_{\mu\nu}\right) \quad (169)$$



$$\frac{i}{2}\left(-g_1\sin\Theta_W + g_2\cos\Theta_W\right)^2\left(Z_{i1}^+Z_{j1}^+ + Z_{i2}^+Z_{j2}^+\right)\left(g_{\mu\nu}\right) \quad (170)$$

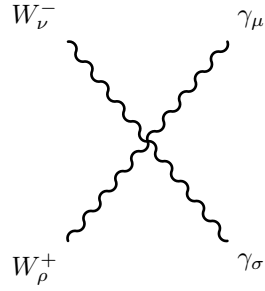
9.9 Four Vector Boson-Interaction



$$-ig_3^2\left(\sum_{a=1}^8 f_{\alpha,\delta,a}f_{\beta,\gamma,a} + \sum_{a=1}^8 f_{\alpha,\gamma,a}f_{\beta,\delta,a}\right)\left(g_{\rho\sigma}g_{\mu\nu}\right) \quad (171)$$

$$+ig_3^2\left(-\sum_{a=1}^8 f_{\alpha,\beta,a}f_{\gamma,\delta,a} + \sum_{a=1}^8 f_{\alpha,\delta,a}f_{\beta,\gamma,a}\right)\left(g_{\rho\mu}g_{\sigma\nu}\right) \quad (172)$$

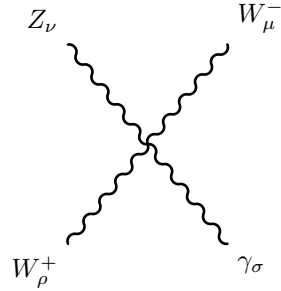
$$+ ig_3^2 \left(\sum_{a=1}^8 f_{\alpha,\gamma,a} f_{\beta,\delta,a} + \sum_{a=1}^8 f_{\alpha,\beta,a} f_{\gamma,\delta,a} \right) (g_{\rho\nu} g_{\sigma\mu}) \quad (173)$$



$$ig_2^2 \sin^2 \Theta_W (g_{\rho\sigma} g_{\mu\nu}) \quad (174)$$

$$+ ig_2^2 \sin^2 \Theta_W (g_{\rho\mu} g_{\sigma\nu}) \quad (175)$$

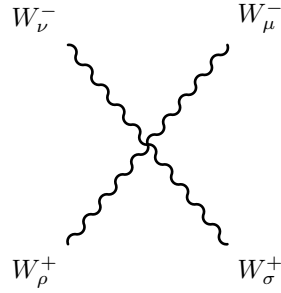
$$+ -2ig_2^2 \sin^2 \Theta_W (g_{\rho\nu} g_{\sigma\mu}) \quad (176)$$



$$ig_2^2 \cos \Theta_W \sin \Theta_W (g_{\rho\sigma} g_{\mu\nu}) \quad (177)$$

$$+ -ig_2^2 \sin 2\Theta_W (g_{\rho\mu} g_{\sigma\nu}) \quad (178)$$

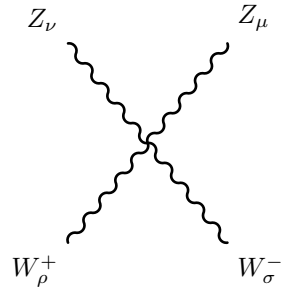
$$+ ig_2^2 \cos \Theta_W \sin \Theta_W (g_{\rho\nu} g_{\sigma\mu}) \quad (179)$$



$$2ig_2^2(g_{\rho\sigma}g_{\mu\nu}) \tag{180}$$

$$+ -ig_2^2(g_{\rho\mu}g_{\sigma\nu}) \tag{181}$$

$$+ -ig_2^2(g_{\rho\nu}g_{\sigma\mu}) \tag{182}$$

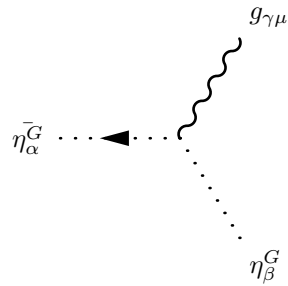


$$- 2ig_2^2 \cos^2 \Theta_W^2 (g_{\rho\sigma}g_{\mu\nu}) \tag{183}$$

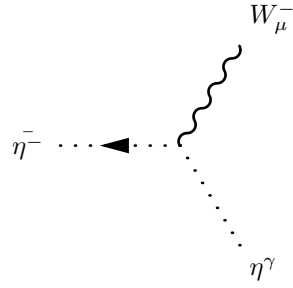
$$+ ig_2^2 \cos^2 \Theta_W^2 (g_{\rho\mu}g_{\sigma\nu}) \tag{184}$$

$$+ ig_2^2 \cos^2 \Theta_W^2 (g_{\rho\nu}g_{\sigma\mu}) \tag{185}$$

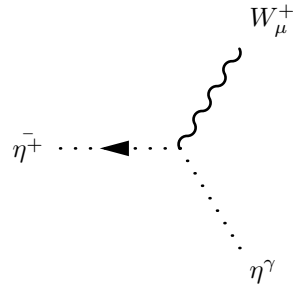
9.10 Two Ghosts-One Vector Boson-Interaction



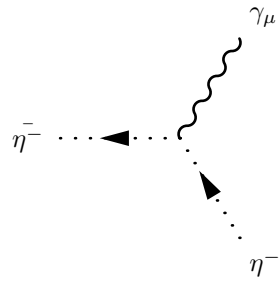
$$g_3 f_{\alpha,\beta,\gamma} \left(p_\mu^{\eta_\beta^G} \right) \quad (186)$$



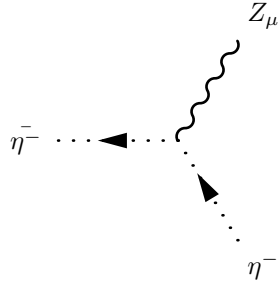
$$i g_2 \sin \Theta_W \left(p_\mu^{\eta^\gamma} \right) \quad (187)$$



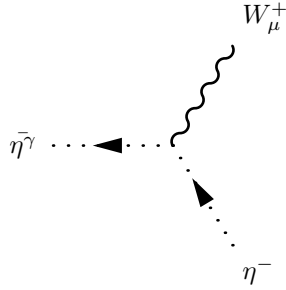
$$- i g_2 \sin \Theta_W \left(p_\mu^{\eta^\gamma} \right) \quad (188)$$



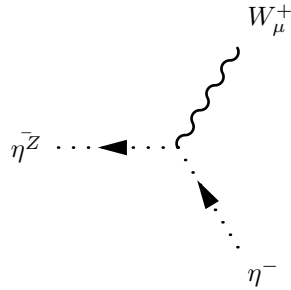
$$- i g_2 \sin \Theta_W \left(p_\mu^{\eta^-} \right) \quad (189)$$



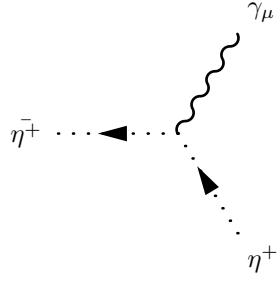
$$-ig_2 \cos \Theta_W (p_\mu^{\eta^-}) \quad (190)$$



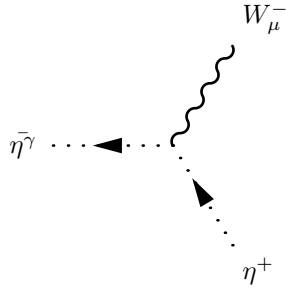
$$ig_2 \sin \Theta_W (p_\mu^{\eta^-}) \quad (191)$$



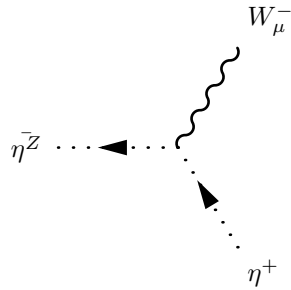
$$ig_2 \cos \Theta_W (p_\mu^{\eta^-}) \quad (192)$$



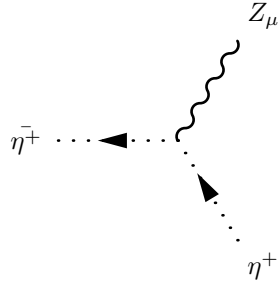
$$ig_2 \sin \Theta_W (p_\mu^{\eta^+}) \quad (193)$$



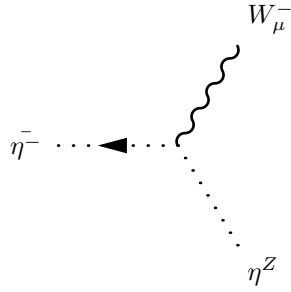
$$-ig_2 \sin \Theta_W (p_\mu^{\eta^+}) \quad (194)$$



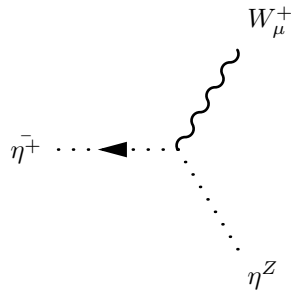
$$-ig_2 \cos \Theta_W (p_\mu^{\eta^+}) \quad (195)$$



$$ig_2 \cos \Theta_W (p_\mu^{\eta^+}) \quad (196)$$

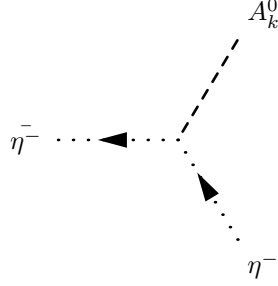


$$ig_2 \cos \Theta_W (p_\mu^{\eta^Z}) \quad (197)$$

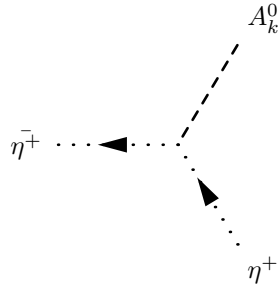


$$-ig_2 \cos \Theta_W (p_\mu^{\eta^Z}) \quad (198)$$

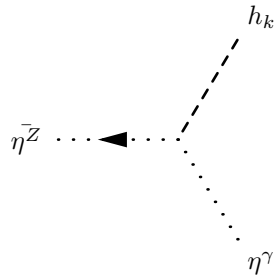
9.11 Two Ghosts-One Scalar-Interaction



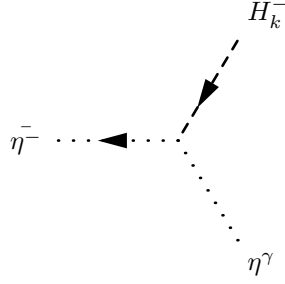
$$-\frac{1}{4}g_2^2\xi_{W^-}\left(v_1Z_{k1}^A+v_2Z_{k2}^A\right) \quad (199)$$



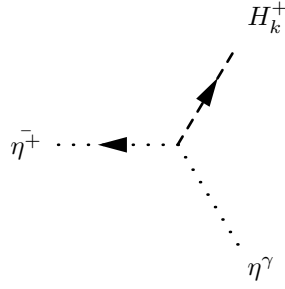
$$\frac{1}{4}g_2^2\xi_{W^-}\left(v_1Z_{k1}^A+v_2Z_{k2}^A\right) \quad (200)$$



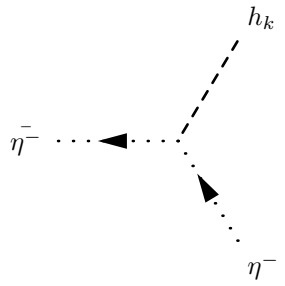
$$\frac{i}{8}\xi_Z\left(2g_1g_2\cos 2\Theta_W+\left(-g_2^2+g_1^2\right)\sin 2\Theta_W\right)\left(v_1Z_{k1}^H+v_2Z_{k2}^H\right) \quad (201)$$



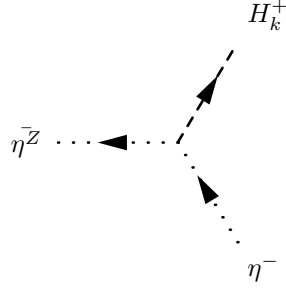
$$-\frac{i}{4}g_2\xi_{W^-}\left(g_1\cos\Theta_W+g_2\sin\Theta_W\right)\left(v_1Z_{k1}^++v_2Z_{k2}^+\right) \quad (202)$$



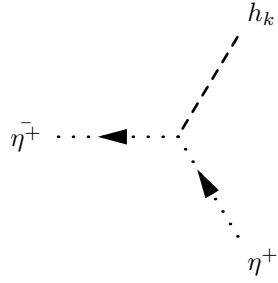
$$-\frac{i}{4}g_2\xi_{W^-}\left(g_1\cos\Theta_W+g_2\sin\Theta_W\right)\left(v_1Z_{k1}^++v_2Z_{k2}^+\right) \quad (203)$$



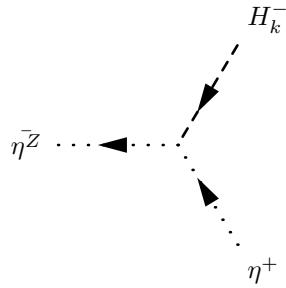
$$-\frac{i}{4}g_2^2\xi_{W^-}\left(v_1Z_{k1}^H+v_2Z_{k2}^H\right) \quad (204)$$



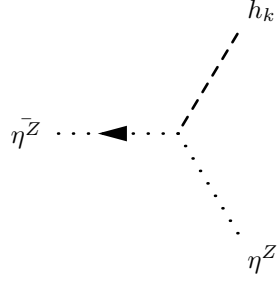
$$\frac{i}{4}g_2\xi_Z(g_1\sin\Theta_W + g_2\cos\Theta_W)(v_1Z_{k1}^+ + v_2Z_{k2}^+) \quad (205)$$



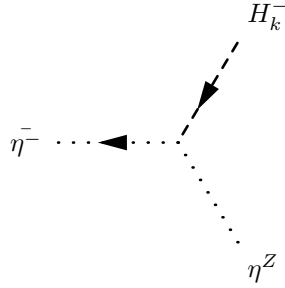
$$-\frac{i}{4}g_2^2\xi_{W^-}(v_1Z_{k1}^H + v_2Z_{k2}^H) \quad (206)$$



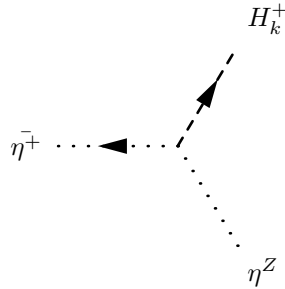
$$\frac{i}{4}g_2\xi_Z(g_1\sin\Theta_W + g_2\cos\Theta_W)(v_1Z_{k1}^+ + v_2Z_{k2}^+) \quad (207)$$



$$-\frac{i}{4}\xi_Z(g_1 \sin \Theta_W + g_2 \cos \Theta_W)^2(v_1 Z_{k1}^H + v_2 Z_{k2}^H) \quad (208)$$



$$-\frac{i}{4}g_2\xi_{W^-}(-g_1 \sin \Theta_W + g_2 \cos \Theta_W)(v_1 Z_{k1}^+ + v_2 Z_{k2}^+) \quad (209)$$



$$-\frac{i}{4}g_2\xi_{W^-}(-g_1 \sin \Theta_W + g_2 \cos \Theta_W)(v_1 Z_{k1}^+ + v_2 Z_{k2}^+) \quad (210)$$

10 Clebsch-Gordan Coefficients