

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

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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 | $(\frac{1}{3}, \mathbf{1}, \bar{\mathbf{3}})$ |
| u | $\frac{1}{2}$ | 3 | $(-\frac{2}{3}, \mathbf{1}, \bar{\mathbf{3}})$ |
| e | $\frac{1}{2}$ | 3 | $(1, \mathbf{1}, \mathbf{1})$ |

2 Lagrangian

2.1 Input Lagrangian for Eigenstates GaugeES

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

2.2 Gauge fixing terms

2.2.1 Gauge fixing terms for eigenstates 'GaugeES'

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

2.2.2 Gauge fixing terms for eigenstates 'EWSB'

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

2.3 Fields integrated out

None

3 Renormalization Group Equations

3.1 Gauge Couplings

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

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

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

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

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

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

3.2 Quartic scalar couplings

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

$$\begin{aligned} \beta_{\lambda_5}^{(2)} = & +\frac{1413}{200} g_1^4 \lambda_5 + \frac{57}{20} g_1^2 g_2^2 \lambda_5 - \frac{231}{8} g_2^4 \lambda_5 - \frac{12}{5} g_1^2 \lambda_1 \lambda_5 - 28 \lambda_1^2 \lambda_5 - \frac{12}{5} g_1^2 \lambda_2 \lambda_5 - 28 \lambda_2^2 \lambda_5 \\ & + \frac{48}{5} g_1^2 \lambda_3 \lambda_5 + 36 g_2^2 \lambda_3 \lambda_5 - 80 \lambda_1 \lambda_3 \lambda_5 - 80 \lambda_2 \lambda_3 \lambda_5 - 28 \lambda_3^2 \lambda_5 + \frac{72}{5} g_1^2 \lambda_4 \lambda_5 + 72 g_2^2 \lambda_4 \lambda_5 \\ & - 88 \lambda_1 \lambda_4 \lambda_5 - 88 \lambda_2 \lambda_4 \lambda_5 - 76 \lambda_3 \lambda_4 \lambda_5 - 32 \lambda_4^2 \lambda_5 + 6 \lambda_5^3 \\ & + \frac{1}{4} \left(16 \left(10 g_3^2 - 6 \lambda_1 - 6 \lambda_3 - 9 \lambda_4 \right) + 45 g_2^2 + 5 g_1^2 \right) \lambda_5 \text{Tr}(Y_d Y_d^\dagger) \\ & + \frac{1}{4} \left(15 g_1^2 + 15 g_2^2 - 16 \left(2 \lambda_1 + 2 \lambda_3 + 3 \lambda_4 \right) \right) \lambda_5 \text{Tr}(Y_e Y_e^\dagger) + \frac{17}{4} g_1^2 \lambda_5 \text{Tr}(Y_u Y_u^\dagger) + \frac{45}{4} g_2^2 \lambda_5 \text{Tr}(Y_u Y_u^\dagger) \\ & + 40 g_3^2 \lambda_5 \text{Tr}(Y_u Y_u^\dagger) - 24 \lambda_2 \lambda_5 \text{Tr}(Y_u Y_u^\dagger) - 24 \lambda_3 \lambda_5 \text{Tr}(Y_u Y_u^\dagger) - 36 \lambda_4 \lambda_5 \text{Tr}(Y_u Y_u^\dagger) \\ & - \frac{3}{2} \lambda_5 \text{Tr}(Y_d Y_d^\dagger Y_d Y_d^\dagger) - 33 \lambda_5 \text{Tr}(Y_d Y_u^\dagger Y_u Y_d^\dagger) - \frac{1}{2} \lambda_5 \text{Tr}(Y_e Y_e^\dagger Y_e Y_e^\dagger) - \frac{3}{2} \lambda_5 \text{Tr}(Y_u Y_u^\dagger Y_u Y_u^\dagger) \end{aligned} \quad (11)$$

$$\begin{aligned} \beta_{\lambda_1}^{(1)} = & +\frac{27}{200} g_1^4 + \frac{9}{20} g_1^2 g_2^2 + \frac{9}{8} g_2^4 - \frac{9}{5} g_1^2 \lambda_1 - 9 g_2^2 \lambda_1 + 24 \lambda_1^2 + 2 \lambda_3^2 + 2 \lambda_3 \lambda_4 + \lambda_4^2 + \lambda_5^2 + 12 \lambda_1 \text{Tr}(Y_d Y_d^\dagger) \\ & + 4 \lambda_1 \text{Tr}(Y_e Y_e^\dagger) - 6 \text{Tr}(Y_d Y_d^\dagger Y_d Y_d^\dagger) - 2 \text{Tr}(Y_e Y_e^\dagger Y_e Y_e^\dagger) \end{aligned} \quad (12)$$

$$\begin{aligned}
\beta_{\lambda_1}^{(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_1 + \frac{117}{20}g_1^2g_2^2\lambda_1 - \frac{51}{8}g_2^4\lambda_1 + \frac{108}{5}g_1^2\lambda_1^2 \\
& + 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 \\
& + \frac{1}{20}\left(-5\left(64\lambda_1\left(-5g_2^2+9\lambda_1\right)-90g_2^2\lambda_1+9g_2^4\right)+9g_1^4+g_1^2\left(50\lambda_1+54g_2^2\right)\right)\text{Tr}\left(Y_dY_d^\dagger\right) \\
& - \frac{3}{20}\left(15g_1^4-2g_1^2\left(11g_2^2+25\lambda_1\right)+5\left(-10g_2^2\lambda_1+64\lambda_1^2+g_2^4\right)\right)\text{Tr}\left(Y_eY_e^\dagger\right)-12\lambda_3^2\text{Tr}\left(Y_uY_u^\dagger\right) \\
& - 12\lambda_3\lambda_4\text{Tr}\left(Y_uY_u^\dagger\right)-6\lambda_4^2\text{Tr}\left(Y_uY_u^\dagger\right)-6\lambda_5^2\text{Tr}\left(Y_uY_u^\dagger\right)+\frac{4}{5}g_1^2\text{Tr}\left(Y_dY_d^\dagger Y_dY_d^\dagger\right) \\
& - 32g_3^2\text{Tr}\left(Y_dY_d^\dagger Y_dY_d^\dagger\right)-3\lambda_1\text{Tr}\left(Y_dY_d^\dagger Y_dY_d^\dagger\right)-9\lambda_1\text{Tr}\left(Y_dY_u^\dagger Y_uY_d^\dagger\right)-\frac{12}{5}g_1^2\text{Tr}\left(Y_eY_e^\dagger Y_eY_e^\dagger\right) \\
& - \lambda_1\text{Tr}\left(Y_eY_e^\dagger Y_eY_e^\dagger\right)+30\text{Tr}\left(Y_dY_d^\dagger Y_dY_d^\dagger Y_dY_d^\dagger\right)+6\text{Tr}\left(Y_dY_u^\dagger Y_uY_d^\dagger Y_dY_d^\dagger\right)+10\text{Tr}\left(Y_eY_e^\dagger Y_eY_e^\dagger Y_eY_e^\dagger\right) \tag{13}
\end{aligned}$$

$$\begin{aligned}
\beta_{\lambda_4}^{(1)} = & +\frac{9}{5}g_1^2g_2^2 - \frac{9}{5}g_1^2\lambda_4 - 9g_2^2\lambda_4 + 4\lambda_1\lambda_4 + 4\lambda_2\lambda_4 + 8\lambda_3\lambda_4 + 4\lambda_4^2 + 8\lambda_5^2 + 6\lambda_4\text{Tr}\left(Y_dY_d^\dagger\right) \\
& + 2\lambda_4\text{Tr}\left(Y_eY_e^\dagger\right) + 6\lambda_4\text{Tr}\left(Y_uY_u^\dagger\right) + 12\text{Tr}\left(Y_dY_u^\dagger Y_uY_d^\dagger\right) \tag{14}
\end{aligned}$$

$$\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_1\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_dY_d^\dagger\right) \\
& + \left(-4\left(2\lambda_1\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_eY_e^\dagger\right) \\
& + \frac{63}{5}g_1^2g_2^2\text{Tr}\left(Y_uY_u^\dagger\right)+\frac{17}{4}g_1^2\lambda_4\text{Tr}\left(Y_uY_u^\dagger\right)+\frac{45}{4}g_2^2\lambda_4\text{Tr}\left(Y_uY_u^\dagger\right)+40g_3^2\lambda_4\text{Tr}\left(Y_uY_u^\dagger\right) \\
& - 24\lambda_2\lambda_4\text{Tr}\left(Y_uY_u^\dagger\right)-24\lambda_3\lambda_4\text{Tr}\left(Y_uY_u^\dagger\right)-12\lambda_4^2\text{Tr}\left(Y_uY_u^\dagger\right)-24\lambda_5^2\text{Tr}\left(Y_uY_u^\dagger\right) \\
& - \frac{27}{2}\lambda_4\text{Tr}\left(Y_dY_d^\dagger Y_dY_d^\dagger\right)+\frac{4}{5}g_1^2\text{Tr}\left(Y_dY_u^\dagger Y_uY_d^\dagger\right)+64g_3^2\text{Tr}\left(Y_dY_u^\dagger Y_uY_d^\dagger\right) \\
& - 24\lambda_3\text{Tr}\left(Y_dY_u^\dagger Y_uY_d^\dagger\right)-33\lambda_4\text{Tr}\left(Y_dY_u^\dagger Y_uY_d^\dagger\right)-\frac{9}{2}\lambda_4\text{Tr}\left(Y_eY_e^\dagger Y_eY_e^\dagger\right)-\frac{27}{2}\lambda_4\text{Tr}\left(Y_uY_u^\dagger Y_uY_u^\dagger\right) \\
& - 12\text{Tr}\left(Y_dY_d^\dagger Y_dY_u^\dagger Y_uY_d^\dagger\right)-12\text{Tr}\left(Y_dY_u^\dagger Y_uY_d^\dagger Y_dY_d^\dagger\right)-24\text{Tr}\left(Y_dY_u^\dagger Y_uY_u^\dagger Y_uY_d^\dagger\right) \tag{15}
\end{aligned}$$

$$\beta_{\lambda_3}^{(1)} = +\frac{27}{100}g_1^4 - \frac{9}{10}g_1^2g_2^2 + \frac{9}{4}g_2^4 - \frac{9}{5}g_1^2\lambda_3 - 9g_2^2\lambda_3 + 12\lambda_1\lambda_3 + 12\lambda_2\lambda_3 + 4\lambda_3^2 + 4\lambda_1\lambda_4 + 4\lambda_2\lambda_4 + 2\lambda_4^2$$

$$+ 2\lambda_5^2 + 6\lambda_3 \text{Tr}(Y_d Y_d^\dagger) + 2\lambda_3 \text{Tr}(Y_e Y_e^\dagger) + 6\lambda_3 \text{Tr}(Y_u Y_u^\dagger) - 12 \text{Tr}(Y_d Y_u^\dagger Y_u Y_d^\dagger) \quad (16)$$

$$\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 \\ & + 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_1 \left(3\lambda_3 + \lambda_4 \right) + \lambda_4^2 + \lambda_5^2 \right) \right) + 9g_4^2 \right) + 9g_1^4 + g_1^2 \left(25\lambda_3 - 54g_2^2 \right) \right) \text{Tr}(Y_d Y_d^\dagger) \\ & - \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_1 \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}(Y_e Y_e^\dagger) \\ & - \frac{171}{100}g_1^4 \text{Tr}(Y_u Y_u^\dagger) - \frac{63}{10}g_1^2g_2^2 \text{Tr}(Y_u Y_u^\dagger) - \frac{9}{4}g_2^4 \text{Tr}(Y_u Y_u^\dagger) + \frac{17}{4}g_1^2\lambda_3 \text{Tr}(Y_u Y_u^\dagger) \\ & + \frac{45}{4}g_2^2\lambda_3 \text{Tr}(Y_u Y_u^\dagger) + 40g_3^2\lambda_3 \text{Tr}(Y_u Y_u^\dagger) - 72\lambda_2\lambda_3 \text{Tr}(Y_u Y_u^\dagger) - 12\lambda_3^2 \text{Tr}(Y_u Y_u^\dagger) \\ & - 24\lambda_2\lambda_4 \text{Tr}(Y_u Y_u^\dagger) - 6\lambda_4^2 \text{Tr}(Y_u Y_u^\dagger) - 6\lambda_5^2 \text{Tr}(Y_u Y_u^\dagger) - \frac{27}{2}\lambda_3 \text{Tr}(Y_d Y_d^\dagger Y_d Y_d^\dagger) \\ & - \frac{4}{5}g_1^2 \text{Tr}(Y_d Y_u^\dagger Y_u Y_d^\dagger) - 64g_3^2 \text{Tr}(Y_d Y_u^\dagger Y_u Y_d^\dagger) + 15\lambda_3 \text{Tr}(Y_d Y_u^\dagger Y_u Y_d^\dagger) \\ & - \frac{9}{2}\lambda_3 \text{Tr}(Y_e Y_e^\dagger Y_e Y_e^\dagger) - \frac{27}{2}\lambda_3 \text{Tr}(Y_u Y_u^\dagger Y_u Y_u^\dagger) + 18 \text{Tr}(Y_d Y_d^\dagger Y_d Y_u^\dagger Y_u Y_d^\dagger) + 18 \text{Tr}(Y_d Y_u^\dagger Y_u Y_d^\dagger Y_d Y_d^\dagger) \\ & + 36 \text{Tr}(Y_d Y_u^\dagger Y_u Y_u^\dagger Y_u Y_d^\dagger) \end{aligned} \quad (17)$$

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

$$\begin{aligned} \beta_{\lambda_2}^{(2)} = & -\frac{3537}{2000}g_1^6 - \frac{1719}{400}g_1^4g_2^2 - \frac{303}{80}g_1^2g_2^4 + \frac{291}{16}g_2^6 + \frac{1953}{200}g_1^4\lambda_2 + \frac{117}{20}g_1^2g_2^2\lambda_2 - \frac{51}{8}g_2^4\lambda_2 + \frac{108}{5}g_1^2\lambda_2^2 \\ & + 108g_2^2\lambda_2^2 - 312\lambda_2^3 + \frac{9}{10}g_1^4\lambda_3 + \frac{15}{2}g_2^4\lambda_3 + \frac{12}{5}g_1^2\lambda_3^2 + 12g_2^2\lambda_3^2 - 20\lambda_2\lambda_3^2 - 8\lambda_3^3 + \frac{9}{20}g_1^4\lambda_4 \\ & + \frac{3}{2}g_1^2g_2^2\lambda_4 + \frac{15}{4}g_2^4\lambda_4 + \frac{12}{5}g_1^2\lambda_3\lambda_4 + 12g_2^2\lambda_3\lambda_4 - 20\lambda_2\lambda_3\lambda_4 - 12\lambda_3^2\lambda_4 + \frac{6}{5}g_1^2\lambda_4^2 \\ & + 3g_2^2\lambda_4^2 - 12\lambda_2\lambda_4^2 - 16\lambda_3\lambda_4^2 - 6\lambda_4^3 - \frac{3}{5}g_1^2\lambda_5^2 - 14\lambda_2\lambda_5^2 - 20\lambda_3\lambda_5^2 - 22\lambda_4\lambda_5^2 \\ & - 6 \left(2\lambda_3^2 + 2\lambda_3\lambda_4 + \lambda_4^2 + \lambda_5^2 \right) \text{Tr}(Y_d Y_d^\dagger) - 2 \left(2\lambda_3^2 + 2\lambda_3\lambda_4 + \lambda_4^2 + \lambda_5^2 \right) \text{Tr}(Y_e Y_e^\dagger) - \frac{171}{100}g_1^4 \text{Tr}(Y_u Y_u^\dagger) \end{aligned}$$

$$\begin{aligned}
& + \frac{63}{10} g_1^2 g_2^2 \text{Tr}(Y_u Y_u^\dagger) - \frac{9}{4} g_2^4 \text{Tr}(Y_u Y_u^\dagger) + \frac{17}{2} g_1^2 \lambda_2 \text{Tr}(Y_u Y_u^\dagger) + \frac{45}{2} g_2^2 \lambda_2 \text{Tr}(Y_u Y_u^\dagger) \\
& + 80 g_3^2 \lambda_2 \text{Tr}(Y_u Y_u^\dagger) - 144 \lambda_2^2 \text{Tr}(Y_u Y_u^\dagger) - 9 \lambda_2 \text{Tr}(Y_d Y_u^\dagger Y_u Y_d^\dagger) - \frac{8}{5} g_1^2 \text{Tr}(Y_u Y_u^\dagger Y_u Y_u^\dagger) \\
& - 32 g_3^2 \text{Tr}(Y_u Y_u^\dagger Y_u Y_u^\dagger) - 3 \lambda_2 \text{Tr}(Y_u Y_u^\dagger Y_u Y_u^\dagger) + 6 \text{Tr}(Y_d Y_u^\dagger Y_u Y_u^\dagger Y_u Y_d^\dagger) + 30 \text{Tr}(Y_u Y_u^\dagger Y_u Y_u^\dagger Y_u Y_u^\dagger)
\end{aligned} \tag{19}$$

3.3 Yukawa Couplings

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

$$\begin{aligned}
\beta_{Y_u}^{(2)} = & + Y_u Y_d^\dagger Y_d \left(-2 \lambda_3 + 2 \lambda_4 + \frac{16}{3} g_3^2 + \frac{33}{16} g_2^2 - \frac{3}{4} \text{Tr}(Y_e Y_e^\dagger) - \frac{41}{240} g_1^2 - \frac{9}{4} \text{Tr}(Y_d Y_d^\dagger) \right) \\
& + \frac{1}{80} \left(-20 \left(-6 Y_u Y_u^\dagger Y_u Y_u^\dagger Y_u + Y_u Y_d^\dagger Y_d Y_d^\dagger Y_d + Y_u Y_d^\dagger Y_d Y_u^\dagger Y_u \right) \right. \\
& + Y_u Y_u^\dagger Y_u \left(1280 g_3^2 + 223 g_1^2 - 540 \text{Tr}(Y_u Y_u^\dagger) + 675 g_2^2 - 960 \lambda_2 \right) \Big) \\
& + Y_u \left(\frac{1267}{600} g_1^4 - \frac{9}{20} g_1^2 g_2^2 - \frac{21}{4} g_2^4 + \frac{19}{15} g_1^2 g_3^2 + 9 g_2^2 g_3^2 - 108 g_3^4 + 6 \lambda_2^2 + \lambda_3^2 + \lambda_3 \lambda_4 + \lambda_4^2 + \frac{3}{2} \lambda_5^2 \right. \\
& + \frac{1}{8} \left(160 g_3^2 + 17 g_1^2 + 45 g_2^2 \right) \text{Tr}(Y_u Y_u^\dagger) - \frac{9}{4} \text{Tr}(Y_d Y_u^\dagger Y_u Y_d^\dagger) - \frac{27}{4} \text{Tr}(Y_u Y_u^\dagger Y_u Y_u^\dagger) \Big)
\end{aligned} \tag{21}$$

$$\beta_{Y_d}^{(1)} = \frac{1}{4} \left(2 \left(3 Y_d Y_d^\dagger Y_d + Y_d Y_u^\dagger Y_u \right) - Y_d \left(-12 \text{Tr}(Y_d Y_d^\dagger) + 32 g_3^2 - 4 \text{Tr}(Y_e Y_e^\dagger) + 9 g_2^2 + g_1^2 \right) \right) \tag{22}$$

$$\begin{aligned}
\beta_{Y_d}^{(2)} = & + \frac{1}{240} \left(60 \left(6 Y_d Y_d^\dagger Y_d Y_d^\dagger Y_d - Y_d Y_u^\dagger Y_u Y_d^\dagger Y_d - Y_d Y_u^\dagger Y_u Y_u^\dagger Y_u \right) \right. \\
& + 3 Y_d Y_d^\dagger Y_d \left(1280 g_3^2 - 180 \text{Tr}(Y_e Y_e^\dagger) + 187 g_1^2 - 540 \text{Tr}(Y_d Y_d^\dagger) + 675 g_2^2 - 960 \lambda_1 \right) \\
& + Y_d Y_u^\dagger Y_u \left(5 \left(256 g_3^2 - 96 \lambda_3 + 96 \lambda_4 + 99 g_2^2 \right) - 53 g_1^2 - 540 \text{Tr}(Y_u Y_u^\dagger) \right) \Big) \\
& + Y_d \left(-\frac{113}{600} g_1^4 - \frac{27}{20} g_1^2 g_2^2 - \frac{21}{4} g_2^4 + \frac{31}{15} g_1^2 g_3^2 + 9 g_2^2 g_3^2 - 108 g_3^4 + 6 \lambda_1^2 + \lambda_3^2 + \lambda_3 \lambda_4 + \lambda_4^2 + \frac{3}{2} \lambda_5^2 \right. \\
& + \frac{5}{8} \left(32 g_3^2 + 9 g_2^2 + g_1^2 \right) \text{Tr}(Y_d Y_d^\dagger) + \frac{15}{8} \left(g_1^2 + g_2^2 \right) \text{Tr}(Y_e Y_e^\dagger) - \frac{27}{4} \text{Tr}(Y_d Y_d^\dagger Y_d Y_d^\dagger) \\
& - \frac{9}{4} \text{Tr}(Y_d Y_u^\dagger Y_u Y_d^\dagger) - \frac{9}{4} \text{Tr}(Y_e Y_e^\dagger Y_e Y_e^\dagger) \Big)
\end{aligned} \tag{23}$$

$$\beta_{Y_e}^{(1)} = \frac{1}{4} \left(6 Y_e Y_e^\dagger Y_e + Y_e \left(12 \text{Tr}(Y_d Y_d^\dagger) + 4 \text{Tr}(Y_e Y_e^\dagger) - 9 \left(g_1^2 + g_2^2 \right) \right) \right) \tag{24}$$

$$\begin{aligned}
\beta_{Y_e}^{(2)} = & + \frac{3}{80} \left(40 Y_e Y_e^\dagger Y_e Y_e^\dagger Y_e + Y_e Y_e^\dagger Y_e \left(129 g_1^2 - 180 \text{Tr}(Y_d Y_d^\dagger) + 225 g_2^2 - 320 \lambda_1 - 60 \text{Tr}(Y_e Y_e^\dagger) \right) \right) \\
& + Y_e \left(\frac{1449}{200} g_1^4 + \frac{27}{20} g_1^2 g_2^2 - \frac{21}{4} g_2^4 + 6 \lambda_1^2 + \lambda_3^2 + \lambda_3 \lambda_4 + \lambda_4^2 + \frac{3}{2} \lambda_5^2 + \frac{5}{8} \left(32 g_3^2 + 9 g_2^2 + g_1^2 \right) \text{Tr}(Y_d Y_d^\dagger) \right. \\
& + \frac{15}{8} \left(g_1^2 + g_2^2 \right) \text{Tr}(Y_e Y_e^\dagger) - \frac{27}{4} \text{Tr}(Y_d Y_d^\dagger Y_d Y_d^\dagger) - \frac{9}{4} \text{Tr}(Y_d Y_u^\dagger Y_u Y_d^\dagger) - \frac{9}{4} \text{Tr}(Y_e Y_e^\dagger Y_e Y_e^\dagger) \Big)
\end{aligned} \tag{25}$$

3.4 Scalar Mass Terms

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

$$\begin{aligned} \beta_{m_{12}}^{(2)} = & + \frac{1377}{400} g_1^4 m_{12} + \frac{9}{8} g_1^2 g_2^2 m_{12} - \frac{243}{16} g_2^4 m_{12} + 6\lambda_1^2 m_{12} + 6\lambda_2^2 m_{12} + \frac{12}{5} g_1^2 \lambda_3 m_{12} + 12g_2^2 \lambda_3 m_{12} - 12\lambda_1 \lambda_3 m_{12} \\ & - 12\lambda_2 \lambda_3 m_{12} + \frac{24}{5} g_1^2 \lambda_4 m_{12} + 24g_2^2 \lambda_4 m_{12} - 12\lambda_1 \lambda_4 m_{12} - 12\lambda_2 \lambda_4 m_{12} - 6\lambda_3 \lambda_4 m_{12} + \frac{36}{5} g_1^2 \lambda_5 m_{12} \\ & + 36g_2^2 \lambda_5 m_{12} - 12\lambda_1 \lambda_5 m_{12} - 12\lambda_2 \lambda_5 m_{12} - 12\lambda_3 \lambda_5 m_{12} - 12\lambda_4 \lambda_5 m_{12} + 3\lambda_5^2 m_{12} \\ & + \frac{1}{8} \left(16 \left(10g_3^2 - 3(2\lambda_4 + 3\lambda_5 + \lambda_3) \right) + 45g_2^2 + 5g_1^2 \right) m_{12} \text{Tr}(Y_d Y_d^\dagger) \\ & + \frac{1}{8} \left(15g_1^2 + 15g_2^2 - 16(2\lambda_4 + 3\lambda_5 + \lambda_3) \right) m_{12} \text{Tr}(Y_e Y_e^\dagger) + \frac{17}{8} g_1^2 m_{12} \text{Tr}(Y_u Y_u^\dagger) + \frac{45}{8} g_2^2 m_{12} \text{Tr}(Y_u Y_u^\dagger) \\ & + 20g_3^2 m_{12} \text{Tr}(Y_u Y_u^\dagger) - 6\lambda_3 m_{12} \text{Tr}(Y_u Y_u^\dagger) - 12\lambda_4 m_{12} \text{Tr}(Y_u Y_u^\dagger) - 18\lambda_5 m_{12} \text{Tr}(Y_u Y_u^\dagger) \\ & - \frac{27}{4} m_{12} \text{Tr}(Y_d Y_d^\dagger Y_d Y_d^\dagger) - \frac{33}{2} m_{12} \text{Tr}(Y_d Y_u^\dagger Y_u Y_d^\dagger) - \frac{9}{4} m_{12} \text{Tr}(Y_e Y_e^\dagger Y_e Y_e^\dagger) - \frac{27}{4} m_{12} \text{Tr}(Y_u Y_u^\dagger Y_u Y_u^\dagger) \end{aligned} \quad (27)$$

$$\beta_{m_1^2}^{(1)} = 12\lambda_1 m_1^2 + 2\lambda_4 m_1^2 + 2m_1^2 \text{Tr}(Y_e Y_e^\dagger) + 4\lambda_3 m_1^2 + 6m_1^2 \text{Tr}(Y_d Y_d^\dagger) - \frac{9}{10} g_1^2 m_1^2 - \frac{9}{2} g_2^2 m_1^2 \quad (28)$$

$$\begin{aligned} \beta_{m_1^2}^{(2)} = & + \frac{1737}{400} g_1^4 m_1^2 + \frac{9}{8} g_1^2 g_2^2 m_1^2 - \frac{123}{16} g_2^4 m_1^2 + \frac{72}{5} g_1^2 \lambda_1 m_1^2 + 72g_2^2 \lambda_1 m_1^2 - 60\lambda_1^2 m_1^2 - 2\lambda_3^2 m_1^2 \\ & - 2\lambda_3 \lambda_4 m_1^2 - 2\lambda_4^2 m_1^2 - 3\lambda_5^2 m_1^2 + \frac{9}{10} g_1^4 m_2^2 + \frac{15}{2} g_2^4 m_2^2 + \frac{24}{5} g_1^2 \lambda_3 m_2^2 + 24g_2^2 \lambda_3 m_2^2 \\ & - 8\lambda_3^2 m_2^2 + \frac{12}{5} g_1^2 \lambda_4 m_2^2 + 12g_2^2 \lambda_4 m_2^2 - 8\lambda_3 \lambda_4 m_2^2 - 8\lambda_4^2 m_2^2 - 12\lambda_5^2 m_2^2 \\ & + \frac{1}{4} \left(160g_3^2 - 288\lambda_1 + 45g_2^2 + 5g_1^2 \right) m_1^2 \text{Tr}(Y_d Y_d^\dagger) + \frac{3}{4} \left(-32\lambda_1 + 5g_1^2 + 5g_2^2 \right) m_1^2 \text{Tr}(Y_e Y_e^\dagger) \\ & - 24\lambda_3 m_2^2 \text{Tr}(Y_u Y_u^\dagger) - 12\lambda_4 m_2^2 \text{Tr}(Y_u Y_u^\dagger) - \frac{27}{2} m_1^2 \text{Tr}(Y_d Y_d^\dagger Y_d Y_d^\dagger) - \frac{9}{2} m_1^2 \text{Tr}(Y_d Y_u^\dagger Y_u Y_d^\dagger) \\ & - \frac{9}{2} m_1^2 \text{Tr}(Y_e Y_e^\dagger Y_e Y_e^\dagger) \end{aligned} \quad (29)$$

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

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

3.5 Vacuum expectation values

$$\beta_{v_1}^{(1)} = \frac{1}{20}v_1 \left(-20\text{Tr}(Y_e Y_e^\dagger) + 3(5g_2^2 + g_1^2)(3 + \text{Xi}) - 60\text{Tr}(Y_d Y_d^\dagger) \right) \quad (32)$$

$$\begin{aligned} \beta_{v_1}^{(2)} = & \frac{1}{800}v_1 \left(-1359g_1^4 - 270g_1^2g_2^2 + 6225g_2^4 - 4800\lambda_1^2 - 800\lambda_3^2 - 800\lambda_3\lambda_4 - 800\lambda_4^2 - 1200\lambda_5^2 + 18g_1^4\text{Xi} \right. \\ & + 180g_1^2g_2^2\text{Xi} + 2250g_2^4\text{Xi} + 18g_1^4\text{Xi}^2 + 180g_1^2g_2^2\text{Xi}^2 - 450g_2^4\text{Xi}^2 \\ & - 20(45g_2^2(2\text{Xi} + 5) + 800g_3^2 + g_1^2(18\text{Xi} + 25))\text{Tr}(Y_d Y_d^\dagger) - 60(5g_2^2(2\text{Xi} + 5) + g_1^2(2\text{Xi} + 25))\text{Tr}(Y_e Y_e^\dagger) \\ & \left. + 5400\text{Tr}(Y_d Y_d^\dagger Y_d Y_d^\dagger) + 1800\text{Tr}(Y_d Y_u^\dagger Y_u Y_d^\dagger) + 1800\text{Tr}(Y_e Y_e^\dagger Y_e Y_e^\dagger) \right) \end{aligned} \quad (33)$$

$$\beta_{v_2}^{(1)} = \frac{3}{20}v_2 \left(-20\text{Tr}(Y_u Y_u^\dagger) + (5g_2^2 + g_1^2)(3 + \text{Xi}) \right) \quad (34)$$

$$\begin{aligned} \beta_{v_2}^{(2)} = & \frac{1}{800}v_2 \left(-1359g_1^4 - 270g_1^2g_2^2 + 6225g_2^4 - 4800\lambda_2^2 - 800\lambda_3^2 - 800\lambda_3\lambda_4 - 800\lambda_4^2 - 1200\lambda_5^2 + 18g_1^4\text{Xi} \right. \\ & + 180g_1^2g_2^2\text{Xi} + 2250g_2^4\text{Xi} + 18g_1^4\text{Xi}^2 + 180g_1^2g_2^2\text{Xi}^2 - 450g_2^4\text{Xi}^2 \\ & \left. - 20(45g_2^2(2\text{Xi} + 5) + 800g_3^2 + g_1^2(18\text{Xi} + 85))\text{Tr}(Y_u Y_u^\dagger) + 1800\text{Tr}(Y_d Y_u^\dagger Y_u Y_d^\dagger) + 5400\text{Tr}(Y_u Y_u^\dagger Y_u Y_u^\dagger) \right) \end{aligned} \quad (35)$$

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: $(H_1^{+,*}, H_2^{+,*}), (H_1^+, H_2^+)$

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

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: $(d_{L, \alpha_1}), (d_{R, \beta_1}^*)$

$$m_d = \left(\frac{1}{\sqrt{2}} v_1 \delta_{\alpha_1 \beta_1} Y_d^T \right) \quad (53)$$

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: $(e_L), (e_R^*)$

$$m_e = \left(\frac{1}{\sqrt{2}} v_1 Y_e^T \right) \quad (61)$$

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_{h_b}^2)\Gamma_{\check{h}_j, h_a, h_b}^* \Gamma_{\check{h}_i, h_a, h_b} + \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}$$

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

• **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_{\tilde{A}_i^0, \eta^-, \eta^-} \Gamma_{\tilde{A}_j^0, \eta^-, \eta^-} - B_0(p^2, m_{\eta^+}^2, m_{\eta^+}^2) \Gamma_{\tilde{A}_i^0, \eta^+, \eta^+} \Gamma_{\tilde{A}_j^0, \eta^+, \eta^+} \\
& + 4\Gamma_{\tilde{A}_i^0, \tilde{A}_j^0, W^+, W^-} \left(-\frac{1}{2} \text{rMS} m_{W^-}^2 + A_0(m_{W^-}^2) \right) + 2\Gamma_{\tilde{A}_i^0, \tilde{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_{\tilde{A}_i^0, \tilde{A}_j^0, A_a^0, A_a^0} - \sum_{a=1}^2 A_0(m_{H_a^-}^2) \Gamma_{\tilde{A}_i^0, \tilde{A}_j^0, H_a^+, H_a^-} \\
& - \frac{1}{2} \sum_{a=1}^2 A_0(m_{h_a}^2) \Gamma_{\tilde{A}_i^0, \tilde{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_{\tilde{A}_j^0, A_a^0, A_b^0}^* \Gamma_{\tilde{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_{\tilde{A}_j^0, H_a^+, H_b^-}^* \Gamma_{\tilde{A}_i^0, 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_{\tilde{A}_j^0, h_a, A_b^0}^* \Gamma_{\tilde{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_{\tilde{A}_j^0, h_a, h_b}^* \Gamma_{\tilde{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_{\tilde{A}_j^0, \bar{d}_a, d_b}^{L*} \Gamma_{\tilde{A}_i^0, \bar{d}_a, d_b}^R + \Gamma_{\tilde{A}_j^0, \bar{d}_a, d_b}^{R*} \Gamma_{\tilde{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_{\tilde{A}_j^0, \bar{d}_a, d_b}^{L*} \Gamma_{\tilde{A}_i^0, \bar{d}_a, d_b}^L + \Gamma_{\tilde{A}_j^0, \bar{d}_a, d_b}^{R*} \Gamma_{\tilde{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_{\tilde{A}_j^0, \bar{e}_a, e_b}^{L*} \Gamma_{\tilde{A}_i^0, \bar{e}_a, e_b}^R + \Gamma_{\tilde{A}_j^0, \bar{e}_a, e_b}^{R*} \Gamma_{\tilde{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_{\tilde{A}_j^0, \bar{e}_a, e_b}^{L*} \Gamma_{\tilde{A}_i^0, \bar{e}_a, e_b}^L + \Gamma_{\tilde{A}_j^0, \bar{e}_a, e_b}^{R*} \Gamma_{\tilde{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_{\tilde{A}_j^0, \bar{u}_a, u_b}^{L*} \Gamma_{\tilde{A}_i^0, \bar{u}_a, u_b}^R + \Gamma_{\tilde{A}_j^0, \bar{u}_a, u_b}^{R*} \Gamma_{\tilde{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)

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

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

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

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

• 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) (2 m_{W^-}^2 + 4 p^2) \right) \\ & + \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. \\ & \quad \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. \\ & \quad \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. \\ & \quad \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. \\ & \quad \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) \end{aligned} \quad (81)$$

• **Self-Energy for W-Boson** (W^-)

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

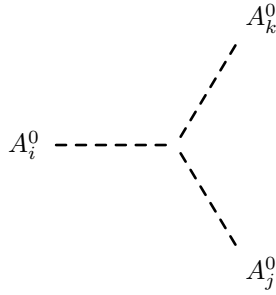
$$\begin{aligned}
& + 4B_0\left(p^2, m_{u_a}^2, m_{d_b}^2\right) m_{d_b} m_{u_a} \Re\left(\Gamma_{W^+, \bar{u}_a, d_b}^{L*} \Gamma_{W^+, \bar{u}_a, d_b}^R\right) \Big] - 4 \sum_{a=1}^2 \sum_{b=1}^2 |\Gamma_{W^+, H_a^-, A_b^0}|^2 B_{00}\left(p^2, m_{A_b^0}^2, m_{H_a^-}^2\right) - 4 \sum_{a=1}^2 \sum_{b=1}^2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

8.2 Tadpoles

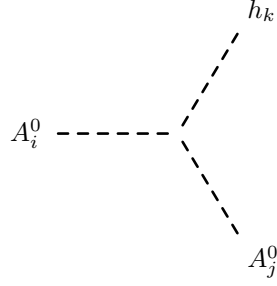
$$\begin{aligned}
\delta t_h^{(1)} = & + A_0\left(m_{\eta^-}^2\right) \Gamma_{\tilde{h}_i, \eta^-, \eta^-} + A_0\left(m_{\eta^+}^2\right) \Gamma_{\tilde{h}_i, \eta^+, \eta^+} + A_0\left(m_{\eta^Z}^2\right) \Gamma_{\tilde{h}_i, \eta^Z, \eta^Z} \\
& + 4\Gamma_{\tilde{h}_i, W^+, W^-} \left(-\frac{1}{2}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

9 Interactions for eigenstates 'EWSB'

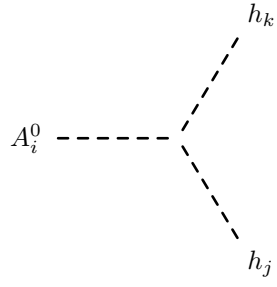
9.1 Three Scalar-Interaction



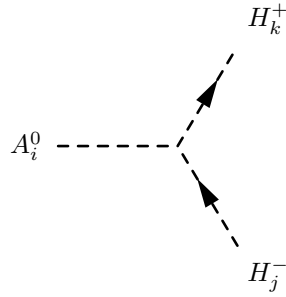
$$\begin{aligned}
& \frac{1}{2} \left(-\lambda_5^* + \lambda_5 \right) \left(Z_{i2}^A \left(-v_1 Z_{j2}^A Z_{k1}^A + Z_{j1}^A \left(-v_1 Z_{k2}^A + v_2 Z_{k1}^A \right) \right) \right. \\
& \left. + Z_{i1}^A \left(v_2 Z_{j1}^A Z_{k2}^A + Z_{j2}^A \left(-v_1 Z_{k2}^A + v_2 Z_{k1}^A \right) \right) \right)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



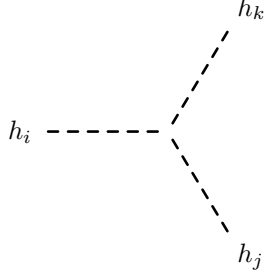
$$\begin{aligned}
& -\frac{i}{2} \left(Z_{i2}^A \left((\lambda_5 + \lambda_5^*) Z_{j1}^A (v_1 Z_{k2}^H + v_2 Z_{k1}^H) + Z_{j2}^A (4\lambda_2 v_2 Z_{k2}^H + v_1 (2\lambda_3 + 2\lambda_4 - \lambda_5 - \lambda_5^*) Z_{k1}^H) \right) \right. \\
& \left. + Z_{i1}^A \left((\lambda_5 + \lambda_5^*) Z_{j2}^A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



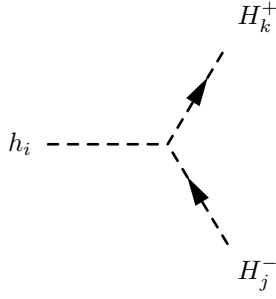
$$-\frac{1}{2} \left(-\lambda_5^* + \lambda_5 \right) \left(-Z_{i1}^A \left(v_2 Z_{j1}^H Z_{k2}^H + Z_{j2}^H (v_1 Z_{k2}^H + v_2 Z_{k1}^H) \right) + Z_{i2}^A \left(v_1 Z_{j2}^H Z_{k1}^H + Z_{j1}^H (v_1 Z_{k2}^H + v_2 Z_{k1}^H) \right) \right) \quad (86)$$



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

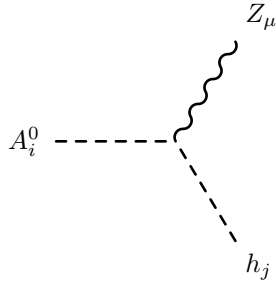


$$\begin{aligned}
& -\frac{i}{2} \left(Z_{i2}^H \left((2\lambda_3 + 2\lambda_4 + \lambda_5 + \lambda_5^*) Z_{j1}^H (v_1 Z_{k2}^H + v_2 Z_{k1}^H) + Z_{j2}^H (12\lambda_2 v_2 Z_{k2}^H + v_1 (2\lambda_3 + 2\lambda_4 + \lambda_5 + \lambda_5^*) Z_{k1}^H) \right) \right. \\
& \left. + Z_{i1}^H \left((2\lambda_3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

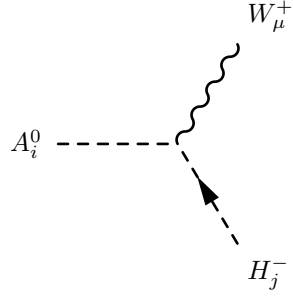


$$\begin{aligned}
& -\frac{i}{2} \left(Z_{i2}^H \left(Z_{j1}^+ (2\lambda_3 v_2 Z_{k1}^+ + v_1 (\lambda_4 + \lambda_5^*) Z_{k2}^+) + Z_{j2}^+ (4\lambda_2 v_2 Z_{k2}^+ + (\lambda_4 + \lambda_5) v_1 Z_{k1}^+) \right) \right. \\
& \left. + Z_{i1}^H \left(Z_{j1}^+ (4\lambda_1 v_1 Z_{k1}^+ + v_2 (\lambda_4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

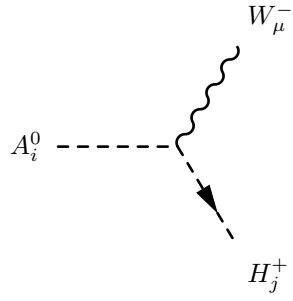
9.2 Two Scalar-One Vector Boson-Interaction



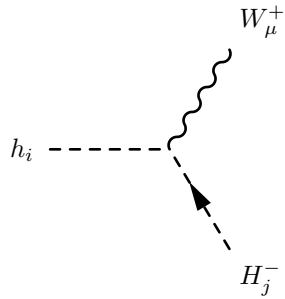
$$-\frac{1}{2}\left(g_1 \sin \Theta_W + g_2 \cos \Theta_W\right)\left(Z_{i1}^A Z_{j1}^H + Z_{i2}^A Z_{j2}^H\right)\left(-p_\mu^{h_j} + p_\mu^{A_i^0}\right) \quad (90)$$



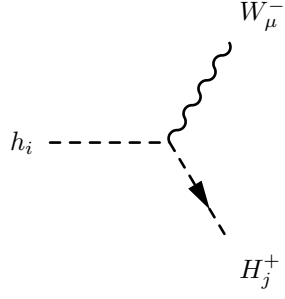
$$\frac{1}{2}g_2\left(Z_{i1}^A Z_{j1}^+ + Z_{i2}^A Z_{j2}^+\right)\left(-p_\mu^{H_j^-} + p_\mu^{A_i^0}\right) \quad (91)$$



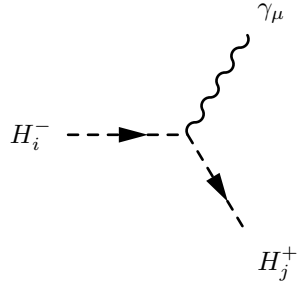
$$\frac{1}{2}g_2\left(Z_{i1}^A Z_{j1}^+ + Z_{i2}^A Z_{j2}^+\right)\left(-p_\mu^{H_j^+} + p_\mu^{A_i^0}\right) \quad (92)$$



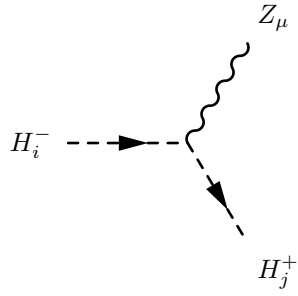
$$-\frac{i}{2}g_2\left(Z_{i1}^H Z_{j1}^+ + Z_{i2}^H Z_{j2}^+\right)\left(-p_\mu^{H_j^-} + p_\mu^{h_i}\right) \quad (93)$$



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

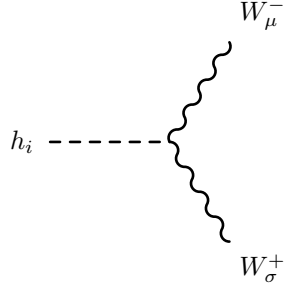


$$\frac{i}{2} \left(g_1 \cos \Theta_W + g_2 \sin \Theta_W \right) \left(Z_{i1}^+ Z_{j1}^+ + Z_{i2}^+ Z_{j2}^+ \right) \left(-p_\mu^{H_j^+} + p_\mu^{H_i^-} \right) \quad (95)$$

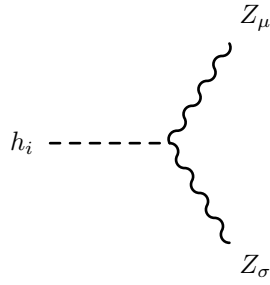


$$\frac{i}{2} \left(-g_1 \sin \Theta_W + g_2 \cos \Theta_W \right) \left(Z_{i1}^+ Z_{j1}^+ + Z_{i2}^+ Z_{j2}^+ \right) \left(-p_\mu^{H_j^+} + p_\mu^{H_i^-} \right) \quad (96)$$

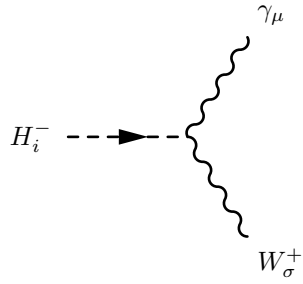
9.3 One Scalar-Two Vector Boson-Interaction



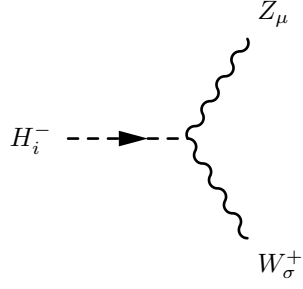
$$\frac{i}{2} g_2^2 \left(v_1 Z_{i1}^H + v_2 Z_{i2}^H \right) \left(g_{\sigma\mu} \right) \quad (97)$$



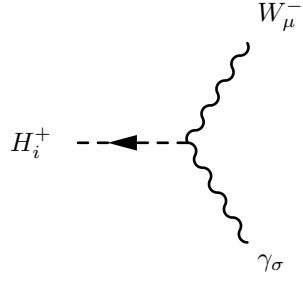
$$\frac{i}{2} \left(g_1 \sin \Theta_W + g_2 \cos \Theta_W \right)^2 \left(v_1 Z_{i1}^H + v_2 Z_{i2}^H \right) \left(g_{\sigma\mu} \right) \quad (98)$$



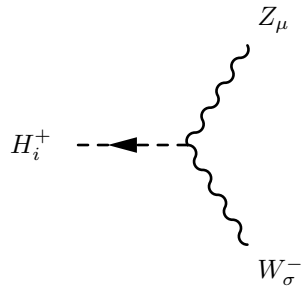
$$\frac{i}{2} g_1 g_2 \cos \Theta_W \left(v_1 Z_{i1}^+ + v_2 Z_{i2}^+ \right) \left(g_{\sigma\mu} \right) \quad (99)$$



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

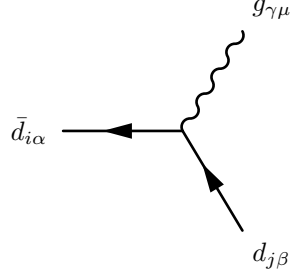


$$\frac{i}{2}g_1g_2\cos\Theta_W\left(v_1Z_{i1}^++v_2Z_{i2}^+\right)\left(g_{\sigma\mu}\right) \quad (101)$$



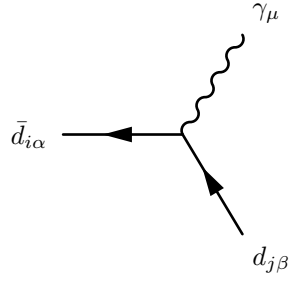
$$-\frac{i}{2}g_1g_2\sin\Theta_W\left(v_1Z_{i1}^++v_2Z_{i2}^+\right)\left(g_{\sigma\mu}\right) \quad (102)$$

9.4 Two Fermion-One Vector Boson-Interaction



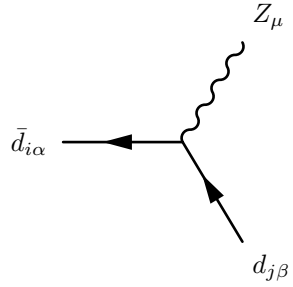
$$-\frac{i}{2}g_3\delta_{ij}\lambda_{\alpha,\beta}^\gamma\left(\gamma_\mu\cdot\frac{1-\gamma_5}{2}\right) \quad (103)$$

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



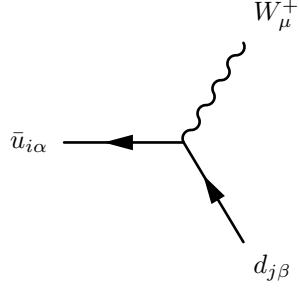
$$-\frac{i}{6}\delta_{\alpha\beta}\delta_{ij}\left(-3g_2\sin\Theta_W+g_1\cos\Theta_W\right)\left(\gamma_\mu\cdot\frac{1-\gamma_5}{2}\right) \quad (105)$$

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

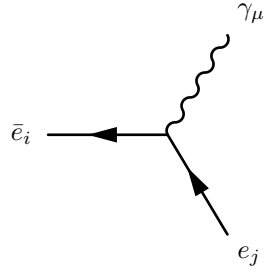


$$\frac{i}{6}\delta_{\alpha\beta}\delta_{ij}\left(3g_2\cos\Theta_W+g_1\sin\Theta_W\right)\left(\gamma_\mu\cdot\frac{1-\gamma_5}{2}\right) \quad (107)$$

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

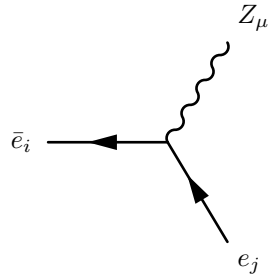


$$-i\frac{1}{\sqrt{2}}g_2\delta_{\alpha\beta}\sum_{a=1}^3U_{L,ja}^{d,*}U_{L,ia}^u\left(\gamma_\mu\cdot\frac{1-\gamma_5}{2}\right) \quad (109)$$



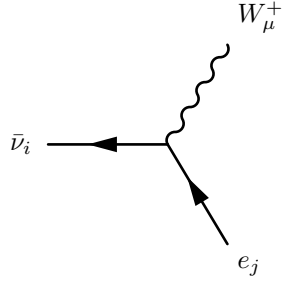
$$\frac{i}{2}\delta_{ij}\left(g_1\cos\Theta_W+g_2\sin\Theta_W\right)\left(\gamma_\mu\cdot\frac{1-\gamma_5}{2}\right) \quad (110)$$

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

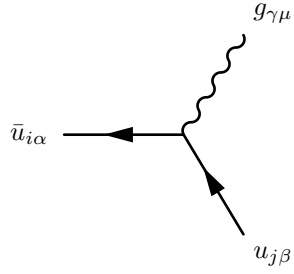


$$\frac{i}{2}\delta_{ij}\left(-g_1\sin\Theta_W+g_2\cos\Theta_W\right)\left(\gamma_\mu\cdot\frac{1-\gamma_5}{2}\right) \quad (112)$$

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

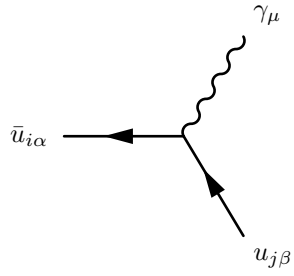


$$-i\frac{1}{\sqrt{2}}g_2U_{L,ji}^{e,*}\Theta_{i,3}\left(\gamma_\mu\cdot\frac{1-\gamma_5}{2}\right) \quad (114)$$



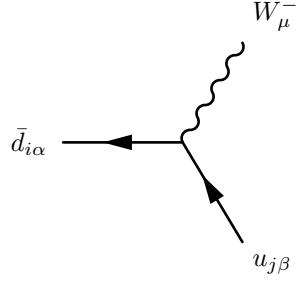
$$-\frac{i}{2}g_3\delta_{ij}\lambda_{\alpha,\beta}^\gamma\left(\gamma_\mu\cdot\frac{1-\gamma_5}{2}\right) \quad (115)$$

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

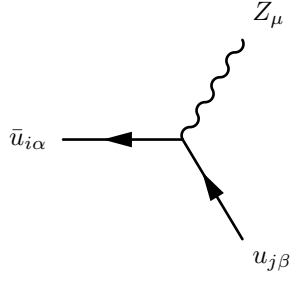


$$- \frac{i}{6} \delta_{\alpha\beta} \delta_{ij} \left(3g_2 \sin \Theta_W + g_1 \cos \Theta_W \right) \left(\gamma_\mu \cdot \frac{1 - \gamma_5}{2} \right) \quad (117)$$

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

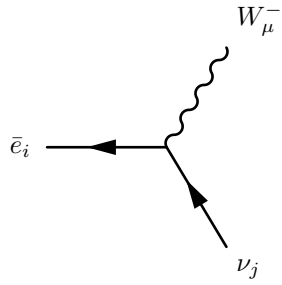


$$- i \frac{1}{\sqrt{2}} g_2 \delta_{\alpha\beta} \sum_{a=1}^3 U_{L,ja}^{u,*} U_{L,ia}^d \left(\gamma_\mu \cdot \frac{1 - \gamma_5}{2} \right) \quad (119)$$

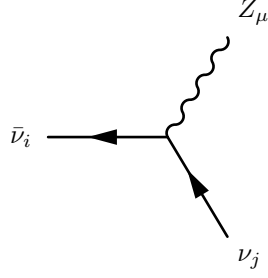


$$- \frac{i}{6} \delta_{\alpha\beta} \delta_{ij} \left(3g_2 \cos \Theta_W - g_1 \sin \Theta_W \right) \left(\gamma_\mu \cdot \frac{1 - \gamma_5}{2} \right) \quad (120)$$

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

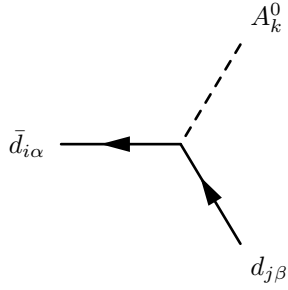


$$-i \frac{1}{\sqrt{2}} g_2 \Theta_{j,3} U_{L,ij}^e \left(\gamma_\mu \cdot \frac{1-\gamma_5}{2} \right) \quad (122)$$



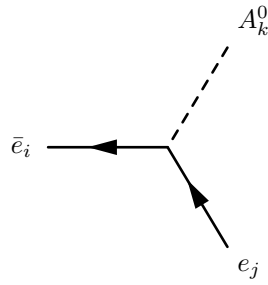
$$- \frac{i}{2} \delta_{ij} \left(g_1 \sin \Theta_W + g_2 \cos \Theta_W \right) \left(\gamma_\mu \cdot \frac{1-\gamma_5}{2} \right) \quad (123)$$

9.5 Two Fermion-One Scalar Boson-Interaction



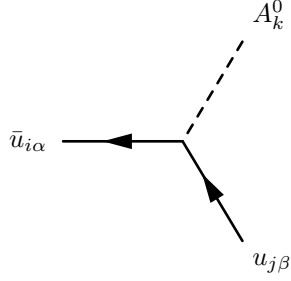
$$- \frac{1}{\sqrt{2}} \delta_{\alpha\beta} \sum_{b=1}^3 U_{L,jb}^{d,*} \sum_{a=1}^3 U_{R,ia}^{d,*} Y_{d,ab} Z_{k1}^A \left(\frac{1-\gamma_5}{2} \right) \quad (124)$$

$$+ \frac{1}{\sqrt{2}} \delta_{\alpha\beta} \sum_{b=1}^3 \sum_{a=1}^3 Y_{d,ab}^* U_{R,ja}^d U_{L,ib}^d Z_{k1}^A \left(\frac{1+\gamma_5}{2} \right) \quad (125)$$



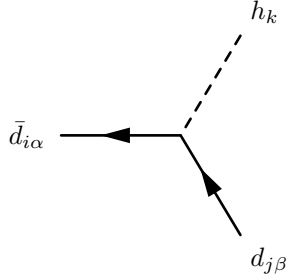
$$- \frac{1}{\sqrt{2}} \sum_{b=1}^3 U_{L,jb}^{e,*} \sum_{a=1}^3 U_{R,ia}^{e,*} Y_{e,ab} Z_{k1}^A \left(\frac{1-\gamma_5}{2} \right) \quad (126)$$

$$+ \frac{1}{\sqrt{2}} \sum_{b=1}^3 \sum_{a=1}^3 Y_{e,ab}^* U_{R,ja}^e U_{L,ib}^e Z_{k1}^A \left(\frac{1+\gamma_5}{2} \right) \quad (127)$$



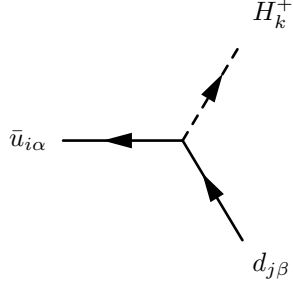
$$- \frac{1}{\sqrt{2}} \delta_{\alpha\beta} \sum_{b=1}^3 U_{L,jb}^{u,*} \sum_{a=1}^3 U_{R,ia}^{u,*} Y_{u,ab} Z_{k2}^A \left(\frac{1-\gamma_5}{2} \right) \quad (128)$$

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



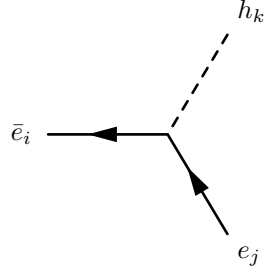
$$- i \frac{1}{\sqrt{2}} \delta_{\alpha\beta} \sum_{b=1}^3 U_{L,jb}^{d,*} \sum_{a=1}^3 U_{R,ia}^{d,*} Y_{d,ab} Z_{k1}^H \left(\frac{1-\gamma_5}{2} \right) \quad (130)$$

$$+ -i \frac{1}{\sqrt{2}} \delta_{\alpha\beta} \sum_{b=1}^3 \sum_{a=1}^3 Y_{d,ab}^* U_{R,ja}^d U_{L,ib}^d Z_{k1}^H \left(\frac{1+\gamma_5}{2} \right) \quad (131)$$



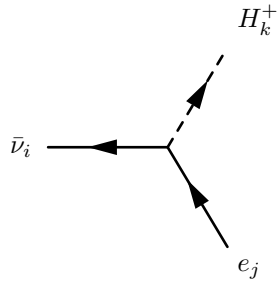
$$-i\delta_{\alpha\beta} \sum_{b=1}^3 U_{L,jb}^{d,*} \sum_{a=1}^3 U_{R,ia}^{u,*} Y_{u,ab} Z_{k2}^+ \left(\frac{1-\gamma_5}{2} \right) \quad (132)$$

$$+ -i\delta_{\alpha\beta} \sum_{b=1}^3 \sum_{a=1}^3 Y_{d,ab}^* U_{R,ja}^d U_{L,ib}^u Z_{k1}^+ \left(\frac{1+\gamma_5}{2} \right) \quad (133)$$



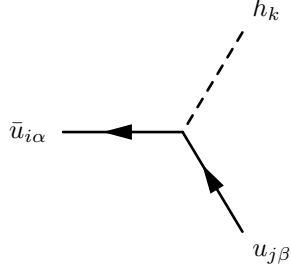
$$-i \frac{1}{\sqrt{2}} \sum_{b=1}^3 U_{L,jb}^{e,*} \sum_{a=1}^3 U_{R,ia}^{e,*} Y_{e,ab} Z_{k1}^H \left(\frac{1-\gamma_5}{2} \right) \quad (134)$$

$$+ -i \frac{1}{\sqrt{2}} \sum_{b=1}^3 \sum_{a=1}^3 Y_{e,ab}^* U_{R,ja}^e U_{L,ib}^e Z_{k1}^H \left(\frac{1+\gamma_5}{2} \right) \quad (135)$$



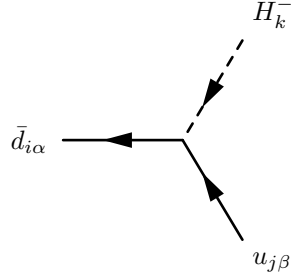
(136)

$$+ -i \sum_{a=1}^3 Y_{e,ai}^* U_{R,ja}^e Z_{k1}^+ \left(\frac{1+\gamma_5}{2} \right) \quad (137)$$



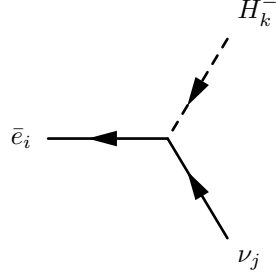
$$i \frac{1}{\sqrt{2}} \delta_{\alpha\beta} \sum_{b=1}^3 U_{L,jb}^{u,*} \sum_{a=1}^3 U_{R,ia}^u Y_{u,ab} Z_{k2}^H \left(\frac{1-\gamma_5}{2} \right) \quad (138)$$

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



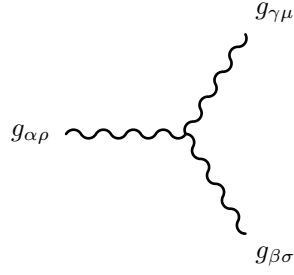
$$- i \delta_{\alpha\beta} \sum_{b=1}^3 U_{L,jb}^{u,*} \sum_{a=1}^3 U_{R,ia}^d Y_{d,ab} Z_{k1}^+ \left(\frac{1-\gamma_5}{2} \right) \quad (140)$$

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

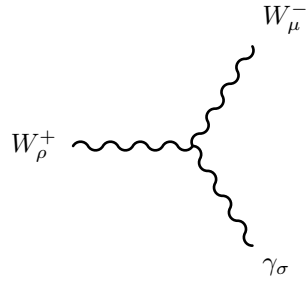


$$-i \sum_{a=1}^3 U_{R,ia}^{e,*} Y_{e,aj} Z_{k1}^+ \left(\frac{1 - \gamma_5}{2} \right) \quad (142)$$

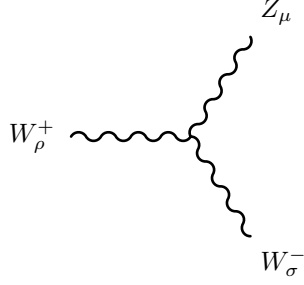
9.6 Three Vector Boson-Interaction



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

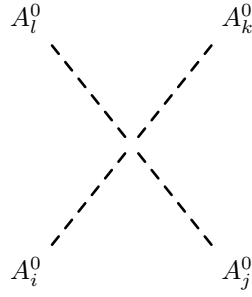


$$ig_2 \sin \Theta_W \left(g_{\rho\mu} \left(-p_\sigma^{W^-} + p_\sigma^{W^+} \right) + g_{\rho\sigma} \left(-p_\mu^{W^+} + p_\mu^{\gamma\sigma} \right) + g_{\sigma\mu} \left(-p_\rho^{\gamma\sigma} + p_\rho^{W^-} \right) \right) \quad (144)$$

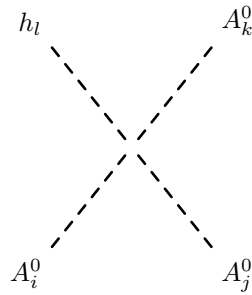


$$-ig_2 \cos \Theta_W \left(g_{\rho\mu} \left(-p_\sigma^{Z_\mu} + p_\sigma^{W_\rho^+} \right) + g_{\rho\sigma} \left(-p_\mu^{W_\rho^+} + p_\mu^{W_\sigma^-} \right) + g_{\sigma\mu} \left(-p_\rho^{W_\sigma^-} + p_\rho^{Z_\mu} \right) \right) \quad (145)$$

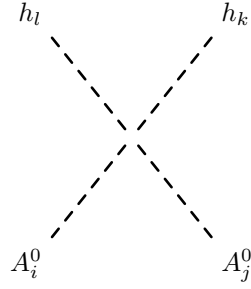
9.7 Four Scalar-Interaction



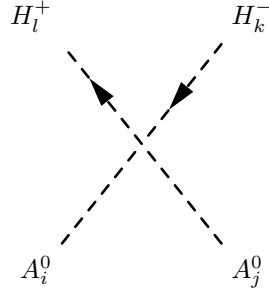
$$\begin{aligned} & -\frac{i}{2} \left(Z_{i2}^A \left((2\lambda_3 + 2\lambda_4 + \lambda_5 + \lambda_5^*) Z_{j1}^A (Z_{k1}^A Z_{l2}^A + Z_{k2}^A Z_{l1}^A) \right. \right. \\ & + Z_{j2}^A (12\lambda_2 Z_{k2}^A Z_{l2}^A + (2\lambda_3 + 2\lambda_4 + \lambda_5 + \lambda_5^*) Z_{k1}^A Z_{l1}^A) \Big) \\ &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



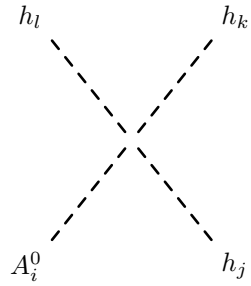
$$\begin{aligned}
& -\frac{1}{2}\left(-\lambda_5^* + \lambda_5\right)\left(Z_{i2}^A\left(Z_{j1}^A\left(-Z_{k1}^AZ_{l2}^H + Z_{k2}^AZ_{l1}^H\right) + Z_{j2}^AZ_{k1}^AZ_{l1}^H\right)\right. \\
& \left.+ Z_{i1}^A\left(-Z_{j1}^AZ_{k2}^AZ_{l2}^H + Z_{j2}^A\left(-Z_{k1}^AZ_{l2}^H + Z_{k2}^AZ_{l1}^H\right)\right)\right)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



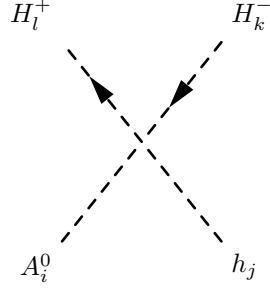
$$\begin{aligned}
& -\frac{i}{2}\left(Z_{i2}^A\left((\lambda_5 + \lambda_5^*)Z_{j1}^A\left(Z_{k1}^HZ_{l2}^H + Z_{k2}^HZ_{l1}^H\right) + Z_{j2}^A\left((2\lambda_3 + 2\lambda_4 - \lambda_5 - \lambda_5^*)Z_{k1}^HZ_{l1}^H + 4\lambda_2Z_{k2}^HZ_{l2}^H\right)\right)\right. \\
& \left.+ Z_{i1}^A\left((\lambda_5 + \lambda_5^*)Z_{j2}^A\left(Z_{k1}^HZ_{l2}^H + Z_{k2}^HZ_{l1}^H\right) + Z_{j1}^A\left((2\lambda_3 + 2\lambda_4 - \lambda_5 - \lambda_5^*)Z_{k2}^HZ_{l2}^H + 4\lambda_1Z_{k1}^HZ_{l1}^H\right)\right)\right)
\end{aligned} \tag{148}$$



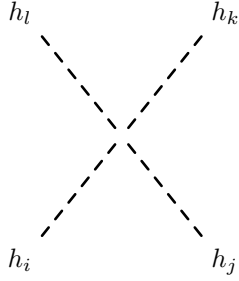
$$\begin{aligned}
& -\frac{i}{2}\left(Z_{i2}^A\left(2Z_{j2}^A\left(2\lambda_2Z_{k2}^+Z_{l2}^+ + \lambda_3Z_{k1}^+Z_{l1}^+\right) + Z_{j1}^A\left((\lambda_4 + \lambda_5^*)Z_{k1}^+Z_{l2}^+ + (\lambda_4 + \lambda_5)Z_{k2}^+Z_{l1}^+\right)\right)\right. \\
& \left.+ Z_{i1}^A\left(2Z_{j1}^A\left(2\lambda_1Z_{k1}^+Z_{l1}^+ + \lambda_3Z_{k2}^+Z_{l2}^+\right) + Z_{j2}^A\left((\lambda_4 + \lambda_5^*)Z_{k1}^+Z_{l2}^+ + (\lambda_4 + \lambda_5)Z_{k2}^+Z_{l1}^+\right)\right)\right)
\end{aligned} \tag{149}$$



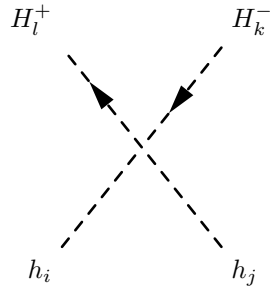
$$\begin{aligned}
& -\frac{1}{2}\left(-\lambda_5^* + \lambda_5\right)\left(Z_{i2}^A\left(Z_{j1}^H\left(Z_{k1}^H Z_{l2}^H + Z_{k2}^H Z_{l1}^H\right) + Z_{j2}^H Z_{k1}^H Z_{l1}^H\right)\right. \\
& \left. - Z_{i1}^A\left(Z_{j1}^H Z_{k2}^H Z_{l2}^H + Z_{j2}^H\left(Z_{k1}^H Z_{l2}^H + Z_{k2}^H Z_{l1}^H\right)\right)\right)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



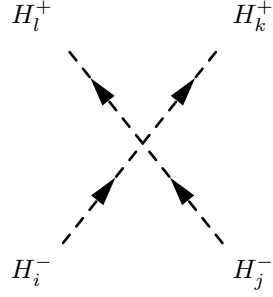
$$\frac{1}{2}\left(-Z_{i1}^A Z_{j2}^H + Z_{i2}^A Z_{j1}^H\right)\left(\left(-\lambda_4 + \lambda_5^*\right)Z_{k1}^+ Z_{l2}^+ + \left(-\lambda_5 + \lambda_4\right)Z_{k2}^+ Z_{l1}^+\right) \tag{151}$$



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

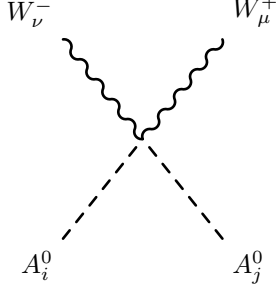


$$\begin{aligned}
& -\frac{i}{2} \left(Z_{i2}^H \left(2Z_{j2}^H \left(2\lambda_2 Z_{k2}^+ Z_{l2}^+ + \lambda_3 Z_{k1}^+ Z_{l1}^+ \right) + Z_{j1}^H \left(\left(\lambda_4 + \lambda_5^* \right) Z_{k1}^+ Z_{l2}^+ + \left(\lambda_4 + \lambda_5 \right) Z_{k2}^+ Z_{l1}^+ \right) \right) \right. \\
& \left.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

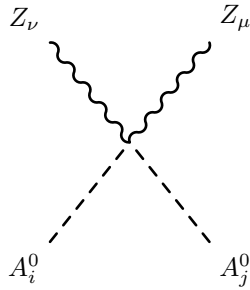


$$\begin{aligned}
& -i \left(Z_{i2}^+ \left(2Z_{j2}^+ \left(2\lambda_2 Z_{k2}^+ Z_{l2}^+ + \lambda_5 Z_{k1}^+ Z_{l1}^+ \right) + \left(\lambda_3 + \lambda_4 \right) Z_{j1}^+ \left(Z_{k1}^+ Z_{l2}^+ + Z_{k2}^+ Z_{l1}^+ \right) \right) \right. \\
& \left. + Z_{i1}^+ \left(2Z_{j1}^+ \left(2\lambda_1 Z_{k1}^+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

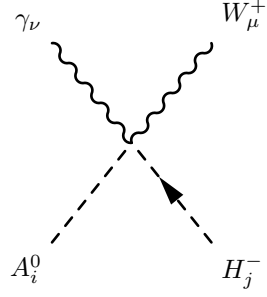
9.8 Two Scalar-Two Vector Boson-Interaction



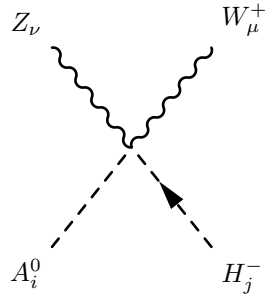
$$\frac{i}{2} g_2^2 \left(Z_{i1}^A Z_{j1}^A + Z_{i2}^A Z_{j2}^A \right) \left(g_{\mu\nu} \right) \tag{155}$$



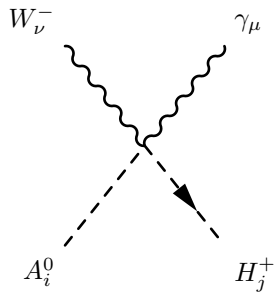
$$\frac{i}{2} \left(g_1 \sin \Theta_W + g_2 \cos \Theta_W \right)^2 \left(Z_{i1}^A Z_{j1}^A + Z_{i2}^A Z_{j2}^A \right) \left(g_{\mu\nu} \right) \quad (156)$$



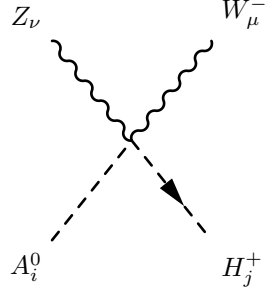
$$- \frac{1}{2} g_1 g_2 \cos \Theta_W \left(Z_{i1}^A Z_{j1}^+ + Z_{i2}^A Z_{j2}^+ \right) \left(g_{\mu\nu} \right) \quad (157)$$



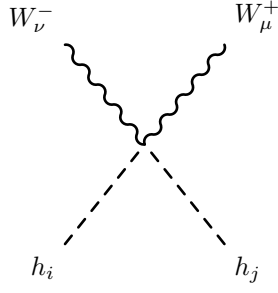
$$\frac{1}{2} g_1 g_2 \sin \Theta_W \left(Z_{i1}^A Z_{j1}^+ + Z_{i2}^A Z_{j2}^+ \right) \left(g_{\mu\nu} \right) \quad (158)$$



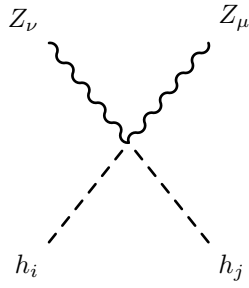
$$\frac{1}{2} g_1 g_2 \cos \Theta_W \left(Z_{i1}^A Z_{j1}^+ + Z_{i2}^A Z_{j2}^+ \right) \left(g_{\mu\nu} \right) \quad (159)$$



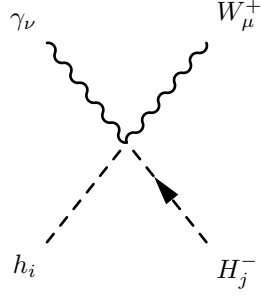
$$-\frac{1}{2}g_1g_2\sin\Theta_W\left(Z_{i1}^AZ_{j1}^++Z_{i2}^AZ_{j2}^+\right)\left(g_{\mu\nu}\right) \quad (160)$$



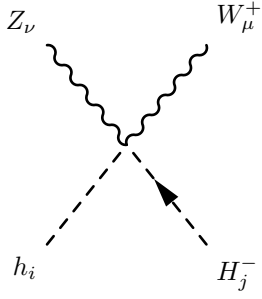
$$\frac{i}{2}g_2^2\left(Z_{i1}^HZ_{j1}^H+Z_{i2}^HZ_{j2}^H\right)\left(g_{\mu\nu}\right) \quad (161)$$



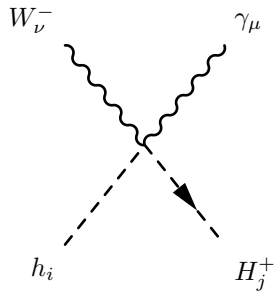
$$\frac{i}{2}\left(g_1\sin\Theta_W+g_2\cos\Theta_W\right)^2\left(Z_{i1}^HZ_{j1}^H+Z_{i2}^HZ_{j2}^H\right)\left(g_{\mu\nu}\right) \quad (162)$$



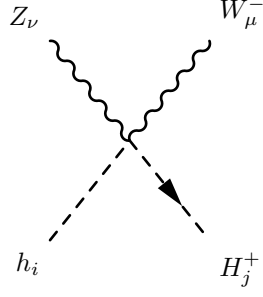
$$\frac{i}{2} g_1 g_2 \cos \Theta_W \left(Z_{i1}^H Z_{j1}^+ + Z_{i2}^H Z_{j2}^+ \right) (g_{\mu\nu}) \quad (163)$$



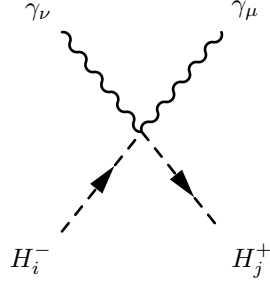
$$- \frac{i}{2} g_1 g_2 \sin \Theta_W \left(Z_{i1}^H Z_{j1}^+ + Z_{i2}^H Z_{j2}^+ \right) (g_{\mu\nu}) \quad (164)$$



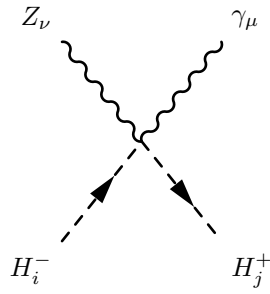
$$\frac{i}{2} g_1 g_2 \cos \Theta_W \left(Z_{i1}^H Z_{j1}^+ + Z_{i2}^H Z_{j2}^+ \right) (g_{\mu\nu}) \quad (165)$$



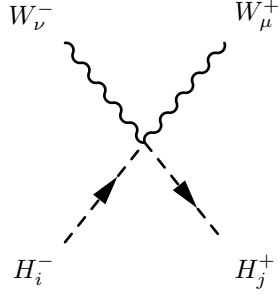
$$-\frac{i}{2}g_1g_2\sin\Theta_W\left(Z_{i1}^HZ_{j1}^++Z_{i2}^HZ_{j2}^+\right)\left(g_{\mu\nu}\right) \quad (166)$$



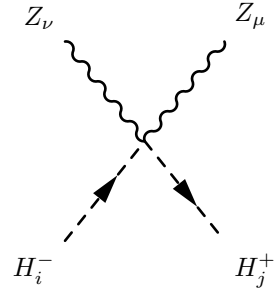
$$\frac{i}{2}\left(g_1\cos\Theta_W+g_2\sin\Theta_W\right)^2\left(Z_{i1}^+Z_{j1}^++Z_{i2}^+Z_{j2}^+\right)\left(g_{\mu\nu}\right) \quad (167)$$



$$-\frac{i}{4}\left(-2g_1g_2\cos2\Theta_W+\left(-g_2^2+g_1^2\right)\sin2\Theta_W\right)\left(Z_{i1}^+Z_{j1}^++Z_{i2}^+Z_{j2}^+\right)\left(g_{\mu\nu}\right) \quad (168)$$

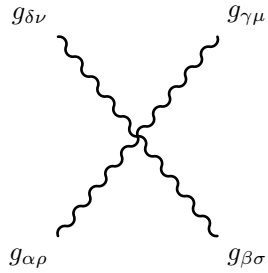


$$\frac{i}{2}g_2^2\left(Z_{i1}^+Z_{j1}^+ + Z_{i2}^+Z_{j2}^+\right)\left(g_{\mu\nu}\right) \quad (169)$$



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

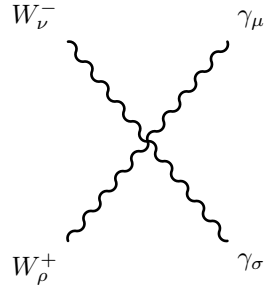
9.9 Four Vector Boson-Interaction



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

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

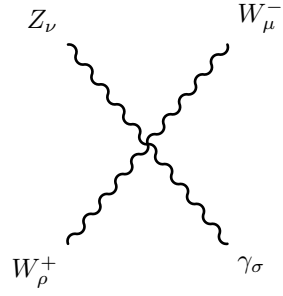
$$+ ig_3^2 \left(\sum_{a=1}^8 f_{\alpha,\gamma,a} f_{\beta,\delta,a} + \sum_{a=1}^8 f_{\alpha,\beta,a} f_{\gamma,\delta,a} \right) (g_{\rho\nu} g_{\sigma\mu}) \quad (173)$$



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

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

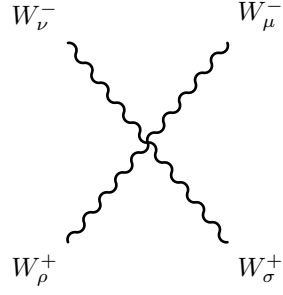
$$+ -2ig_2^2 \sin \Theta_W^2 (g_{\rho\nu} g_{\sigma\mu}) \quad (176)$$



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

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

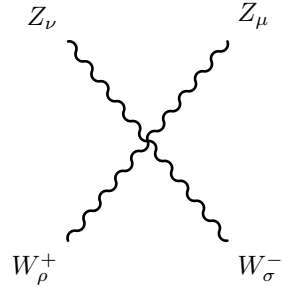
$$+ ig_2^2 \cos \Theta_W \sin \Theta_W (g_{\rho\nu} g_{\sigma\mu}) \quad (179)$$



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

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

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

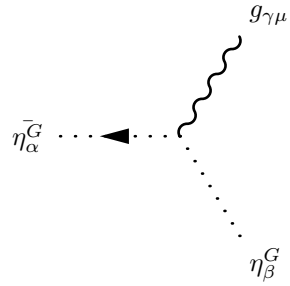


$$- 2ig_2^2 \cos \Theta_W^2(g_{\rho\sigma}g_{\mu\nu}) \quad (183)$$

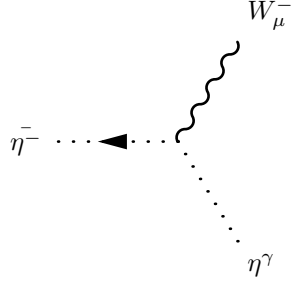
$$+ ig_2^2 \cos \Theta_W^2(g_{\rho\mu}g_{\sigma\nu}) \quad (184)$$

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

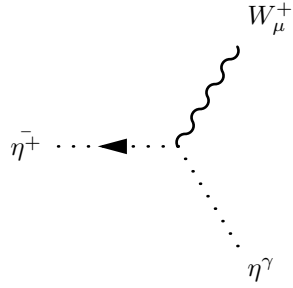
9.10 Two Ghosts-One Vector Boson-Interaction



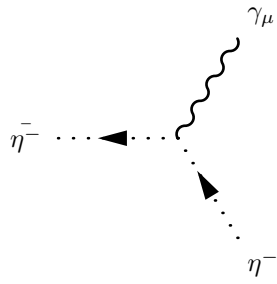
$$g_3 f_{\alpha,\beta,\gamma} \left(p_\mu^{\eta_\beta^G} \right) \quad (186)$$



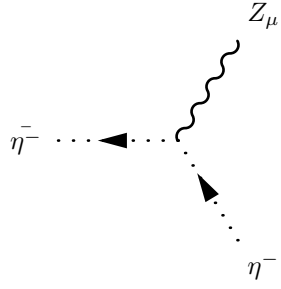
$$i g_2 \sin \Theta_W \left(p_\mu^{\eta^\gamma} \right) \quad (187)$$



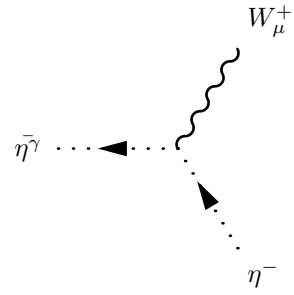
$$- i g_2 \sin \Theta_W \left(p_\mu^{\eta^\gamma} \right) \quad (188)$$



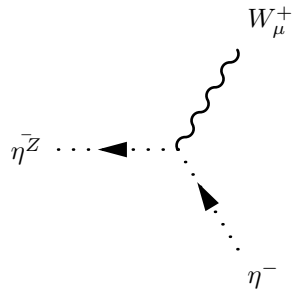
$$- i g_2 \sin \Theta_W \left(p_\mu^{\eta^-} \right) \quad (189)$$



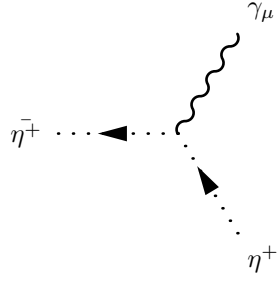
$$-ig_2 \cos \Theta_W (p_\mu^{\eta^-}) \quad (190)$$



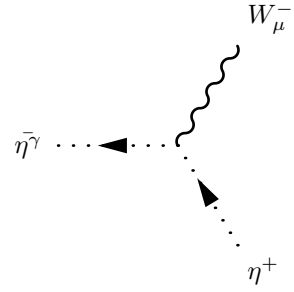
$$ig_2 \sin \Theta_W (p_\mu^{\eta^-}) \quad (191)$$



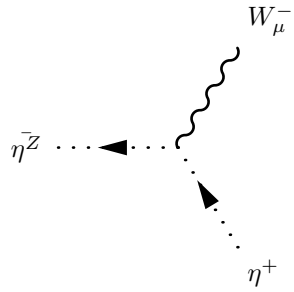
$$ig_2 \cos \Theta_W (p_\mu^{\eta^-}) \quad (192)$$



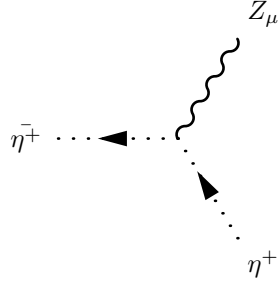
$$ig_2 \sin \Theta_W (p_\mu^{\eta^+}) \quad (193)$$



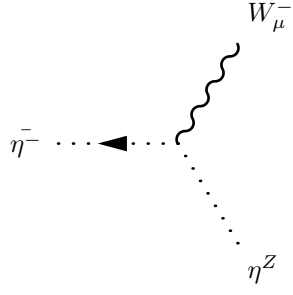
$$-ig_2 \sin \Theta_W (p_\mu^{\eta^+}) \quad (194)$$



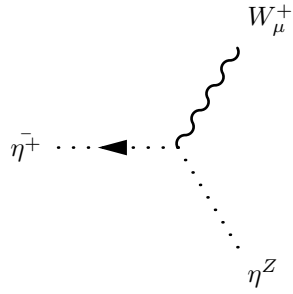
$$-ig_2 \cos \Theta_W (p_\mu^{\eta^+}) \quad (195)$$



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

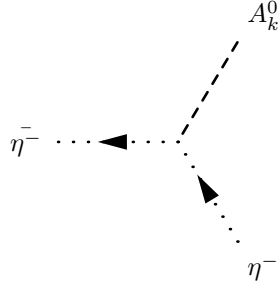


$$ig_2 \cos \Theta_W (p_\mu^{\eta^Z}) \quad (197)$$

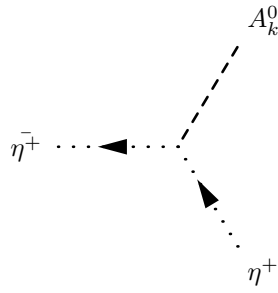


$$-ig_2 \cos \Theta_W (p_\mu^{\eta^Z}) \quad (198)$$

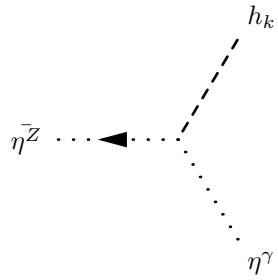
9.11 Two Ghosts-One Scalar-Interaction



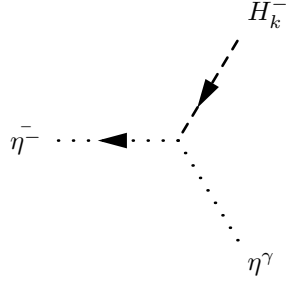
$$-\frac{1}{4}g_2^2\xi_{W-}\left(v_1Z_{k1}^A+v_2Z_{k2}^A\right) \quad (199)$$



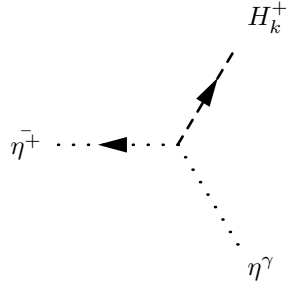
$$\frac{1}{4}g_2^2\xi_{W-}\left(v_1Z_{k1}^A+v_2Z_{k2}^A\right) \quad (200)$$



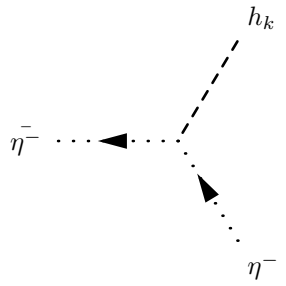
$$\frac{i}{8}\xi_Z\left(2g_1g_2\cos 2\Theta_W+\left(-g_2^2+g_1^2\right)\sin 2\Theta_W\right)\left(v_1Z_{k1}^H+v_2Z_{k2}^H\right) \quad (201)$$



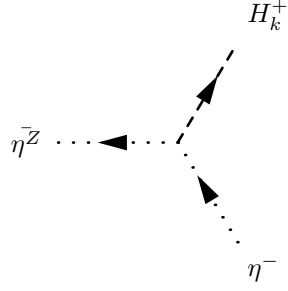
$$-\frac{i}{4}g_2\xi_{W-}\left(g_1\cos\Theta_W+g_2\sin\Theta_W\right)\left(v_1Z_{k1}^++v_2Z_{k2}^+\right) \quad (202)$$



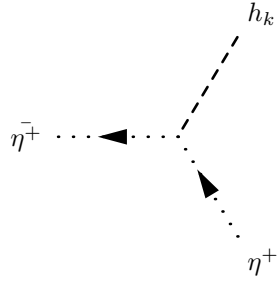
$$-\frac{i}{4}g_2\xi_{W-}\left(g_1\cos\Theta_W+g_2\sin\Theta_W\right)\left(v_1Z_{k1}^++v_2Z_{k2}^+\right) \quad (203)$$



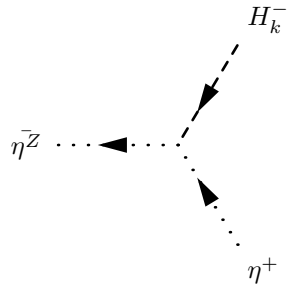
$$-\frac{i}{4}g_2^2\xi_{W-}\left(v_1Z_{k1}^H+v_2Z_{k2}^H\right) \quad (204)$$



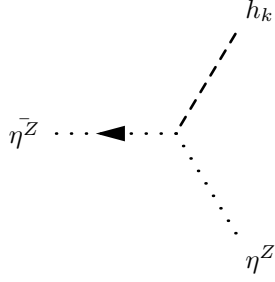
$$\frac{i}{4}g_2\xi_Z\left(g_1\sin\Theta_W+g_2\cos\Theta_W\right)\left(v_1Z_{k1}^++v_2Z_{k2}^+\right) \quad (205)$$



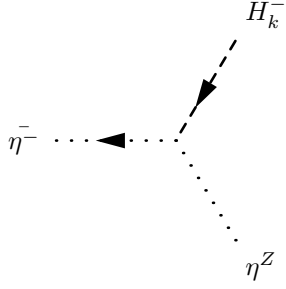
$$-\frac{i}{4}g_2^2\xi_{W-}\left(v_1Z_{k1}^H+v_2Z_{k2}^H\right) \quad (206)$$



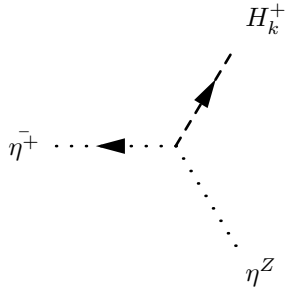
$$\frac{i}{4}g_2\xi_Z\left(g_1\sin\Theta_W+g_2\cos\Theta_W\right)\left(v_1Z_{k1}^++v_2Z_{k2}^+\right) \quad (207)$$



$$-\frac{i}{4}\xi_Z\left(g_1\sin\Theta_W+g_2\cos\Theta_W\right)^2\left(v_1Z_{k1}^H+v_2Z_{k2}^H\right) \quad (208)$$



$$-\frac{i}{4}g_2\xi_{W-}\left(-g_1\sin\Theta_W+g_2\cos\Theta_W\right)\left(v_1Z_{k1}^++v_2Z_{k2}^+\right) \quad (209)$$



$$-\frac{i}{4}g_2\xi_{W-}\left(-g_1\sin\Theta_W+g_2\cos\Theta_W\right)\left(v_1Z_{k1}^++v_2Z_{k2}^+\right) \quad (210)$$

10 Clebsch-Gordan Coefficients