

B-L extended Standard Model  
Lagrangian, Rotations and Interactions for eigenstates 'EWSB'  
including Renormalization Group Equations  
including one-loop Self-Energies

SARAH 4.6.0

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# 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
VBp	$U(1)$	$g_B$	BminusL

## 1.2 Matter Superfields

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

# 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'

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

### 2.2.2 Gauge fixing terms for eigenstates 'EWSB'

$$L_{GF} = -\frac{1}{2}|\partial_\mu g|^2 \xi_g^{-1} - \frac{1}{2}|\partial_\mu \gamma|^2 \xi_\gamma^{-1} - \frac{i}{2}g_2 H^- v \xi_{W^-} + \partial_\mu W^-|^2 \xi_{W^-}^{-1} \\ - \frac{1}{2} \frac{1}{2} \left( 2\partial_\mu Z + \xi_Z \left( - \left( 4g_B \text{sigmaB}x + g_{BY} \text{sigmaH}v \right) \sin \Theta'_W + \left( 4g_{YB} \text{sigmaB}x + g_1 \text{sigmaH}v \right) \cos \Theta'_W \sin \Theta_W + g_2 \text{sigmaH}v \right) \right)$$

$$-\frac{1}{2}\left|\frac{1}{2}\left(2\partial_\mu Z' - \xi_{Z'}\left(\left(4g_B\text{sigma}Bx + g_{BY}\text{sigma}Hv\right)\cos\Theta'_W + \left(4g_{YB}\text{sigma}Bx\sin\Theta_W + g_1\text{sigma}Hv\sin\Theta_W + g_2\text{sigma}Hv\cos\Theta_W\right)\right)\right)\right| \quad (3)$$

## 2.3 Fields integrated out

None

# 3 Renormalization Group Equations

## 3.1 Gauge Couplings

$$\beta_{g_1}^{(1)} = \frac{1}{10}\left(32\sqrt{10}g_1^2g_{YB} + 41g_1^3 + 4g_{BY}\left(45g_B + 4\sqrt{10}g_{BY}\right)g_{YB} + g_1\left(16\sqrt{10}g_{BY}g_B + 180g_{YB}^2 + 41g_{BY}^2\right)\right) \quad (4)$$

$$\begin{aligned} \beta_{g_1}^{(2)} = & \frac{1}{50}\left(199g_1^5 + 398g_1^3g_{BY}^2 + 199g_1g_{BY}^4 + 246\sqrt{10}g_1^3g_{BY}g_B + 246\sqrt{10}g_1g_{BY}^3g_B + 460g_1^3g_B^2\right. \\ & + 1380g_1g_{BY}^2g_B^2 + 280\sqrt{10}g_1g_{BY}g_B^3 + 328\sqrt{10}g_1^4g_{YB} + 410\sqrt{10}g_1^2g_{BY}^2g_{YB} \\ & + 82\sqrt{10}g_{BY}^4g_{YB} + 3220g_1^2g_{BY}g_Bg_{YB} + 1380g_{BY}^3g_Bg_{YB} + 560\sqrt{10}g_1^2g_B^2g_{YB} \\ & + 840\sqrt{10}g_{BY}^2g_B^2g_{YB} + 10000g_{BY}g_B^3g_{YB} + 2760g_1^3g_{YB}^2 + 1840g_1g_{BY}^2g_{YB}^2 \\ & + 1400\sqrt{10}g_1g_{BY}g_Bg_{YB}^2 + 10000g_1g_B^2g_{YB}^2 + 1120\sqrt{10}g_1^2g_{YB}^3 + 280\sqrt{10}g_{BY}^2g_{YB}^3 \\ & + 10000g_{BY}g_Bg_{YB}^3 + 10000g_1g_{YB}^4 + 135g_1^3g_2^2 + 135g_1g_{BY}^2g_2^2 + 90\sqrt{10}g_1g_{BY}g_Bg_2^2 \\ & + 180\sqrt{10}g_1^2g_{YB}g_2^2 + 90\sqrt{10}g_{BY}^2g_{YB}g_2^2 + 900g_{BY}g_Bg_{YB}g_2^2 + 900g_1g_{YB}^2g_2^2 + 440g_1^3g_3^2 \\ & + 440g_1g_{BY}^2g_3^2 + 80\sqrt{10}g_1g_{BY}g_Bg_3^2 + 160\sqrt{10}g_1^2g_{YB}g_3^2 + 80\sqrt{10}g_{BY}^2g_{YB}g_3^2 \\ & + 800g_{BY}g_Bg_{YB}g_3^2 + 800g_1g_{YB}^2g_3^2 \\ & - 5\left(-2\sqrt{10}g_1^2g_{YB} + 5g_1^3 + g_1\left(20g_{YB}^2 + 5g_{BY}^2 - \sqrt{10}g_{BY}g_B\right) + g_{BY}\left(20g_B - \sqrt{10}g_{BY}\right)g_{YB}\right)\text{Tr}\left(Y_dY_d^\dagger\right) \\ & - 15\left(5g_1^3 + 6\sqrt{10}g_1^2g_{YB} + g_1\left(20g_{YB}^2 + 3\sqrt{10}g_{BY}g_B + 5g_{BY}^2\right) + g_{BY}\left(20g_B + 3\sqrt{10}g_{BY}\right)g_{YB}\right)\text{Tr}\left(Y_eY_e^\dagger\right) \\ & - 85g_1^3\text{Tr}\left(Y_uY_u^\dagger\right) - 85g_1g_{BY}^2\text{Tr}\left(Y_uY_u^\dagger\right) - 25\sqrt{10}g_1g_{BY}g_B\text{Tr}\left(Y_uY_u^\dagger\right) \\ & - 50\sqrt{10}g_1^2g_{YB}\text{Tr}\left(Y_uY_u^\dagger\right) - 25\sqrt{10}g_{BY}^2g_{YB}\text{Tr}\left(Y_uY_u^\dagger\right) - 100g_{BY}g_Bg_{YB}\text{Tr}\left(Y_uY_u^\dagger\right) \\ & - 100g_1g_{YB}^2\text{Tr}\left(Y_uY_u^\dagger\right) - 15g_1^3\text{Tr}\left(Y_\nu Y_\nu^\dagger\right) - 15g_1g_{BY}^2\text{Tr}\left(Y_\nu Y_\nu^\dagger\right) \\ & - 15\sqrt{10}g_1g_{BY}g_B\text{Tr}\left(Y_\nu Y_\nu^\dagger\right) - 30\sqrt{10}g_1^2g_{YB}\text{Tr}\left(Y_\nu Y_\nu^\dagger\right) \\ & - 15\sqrt{10}g_{BY}^2g_{YB}\text{Tr}\left(Y_\nu Y_\nu^\dagger\right) - 300g_{BY}g_Bg_{YB}\text{Tr}\left(Y_\nu Y_\nu^\dagger\right) - 300g_1g_{YB}^2\text{Tr}\left(Y_\nu Y_\nu^\dagger\right) \\ & \left.- 300g_{BY}g_Bg_{YB}\text{Tr}\left(Y_xY_x^*\right) - 300g_1g_{YB}^2\text{Tr}\left(Y_xY_x^*\right)\right) \quad (5) \end{aligned}$$

$$\beta_{g_{BY}}^{(1)} = \frac{1}{10}\left(4g_1\left(45g_B + 4\sqrt{10}g_{BY}\right)g_{YB} + g_1^2\left(16\sqrt{10}g_B + 41g_{BY}\right) + g_{BY}\left(180g_B^2 + 32\sqrt{10}g_{BY}g_B + 41g_{BY}^2\right)\right) \quad (6)$$

$$\beta_{g_{BY}}^{(2)} = \frac{1}{50}\left(199g_1^4g_{BY} + 398g_1^2g_{BY}^3 + 199g_{BY}^5 + 82\sqrt{10}g_1^4g_B + 410\sqrt{10}g_1^2g_{BY}^2g_B\right)$$

$$\begin{aligned}
& + 328\sqrt{10}g_{BY}^4g_B + 1840g_1^2g_{BY}g_B^2 + 2760g_{BY}^3g_B^2 + 280\sqrt{10}g_1^2g_B^3 + 1120\sqrt{10}g_{BY}^2g_B^3 \\
& + 10000g_{BY}g_B^4 + 246\sqrt{10}g_1^3g_{BY}g_{YB} + 246\sqrt{10}g_1g_{BY}^3g_{YB} + 1380g_1^3g_Bg_{YB} + 3220g_1g_{BY}^2g_Bg_{YB} \\
& + 1400\sqrt{10}g_1g_{BY}g_B^2g_{YB} + 10000g_1g_B^3g_{YB} + 1380g_1^2g_{BY}g_{YB}^2 + 460g_{BY}^3g_{YB}^2 \\
& + 840\sqrt{10}g_1^2g_Bg_{YB}^2 + 560\sqrt{10}g_{BY}^2g_Bg_{YB}^2 + 10000g_{BY}g_B^2g_{YB}^2 + 280\sqrt{10}g_1g_{BY}g_{YB}^3 \\
& + 10000g_1g_Bg_{YB}^3 + 135g_1^2g_{BY}g_2^2 + 135g_{BY}^3g_2^2 + 90\sqrt{10}g_1^2g_Bg_2^2 + 180\sqrt{10}g_{BY}^2g_Bg_2^2 \\
& + 900g_{BY}g_B^2g_2^2 + 90\sqrt{10}g_1g_{BY}g_{YB}g_2^2 + 900g_1g_Bg_{YB}g_2^2 + 440g_1^2g_{BY}g_3^2 + 440g_{BY}^3g_3^2 \\
& + 80\sqrt{10}g_1^2g_Bg_3^2 + 160\sqrt{10}g_{BY}^2g_Bg_3^2 + 800g_{BY}g_B^2g_3^2 + 80\sqrt{10}g_1g_{BY}g_{YB}g_3^2 \\
& + 800g_1g_Bg_{YB}g_3^2 \\
& - 5\left(g_1\left(20g_Bg_{YB} - \sqrt{10}g_{BY}g_{YB}\right) + g_1^2\left(5g_{BY} - \sqrt{10}g_B\right) + g_{BY}\left(20g_B^2 - 2\sqrt{10}g_{BY}g_B + 5g_{BY}^2\right)\right)\text{Tr}\left(Y_dY_d^\dagger\right) \\
& - 15\left(g_1\left(20g_B + 3\sqrt{10}g_{BY}\right)g_{YB} + g_1^2\left(3\sqrt{10}g_B + 5g_{BY}\right) + g_{BY}\left(20g_B^2 + 5g_{BY}^2 + 6\sqrt{10}g_{BY}g_B\right)\right)\text{Tr}\left(Y_eY_e^\dagger\right) \\
& - 85g_1^2g_{BY}\text{Tr}\left(Y_uY_u^\dagger\right) - 85g_{BY}^3\text{Tr}\left(Y_uY_u^\dagger\right) - 25\sqrt{10}g_1^2g_B\text{Tr}\left(Y_uY_u^\dagger\right) \\
& - 50\sqrt{10}g_{BY}^2g_B\text{Tr}\left(Y_uY_u^\dagger\right) - 100g_{BY}g_B^2\text{Tr}\left(Y_uY_u^\dagger\right) - 25\sqrt{10}g_1g_{BY}g_{YB}\text{Tr}\left(Y_uY_u^\dagger\right) \\
& - 100g_1g_Bg_{YB}\text{Tr}\left(Y_uY_u^\dagger\right) - 15g_1^2g_{BY}\text{Tr}\left(Y_\nu Y_\nu^\dagger\right) - 15g_{BY}^3\text{Tr}\left(Y_\nu Y_\nu^\dagger\right) \\
& - 15\sqrt{10}g_1^2g_B\text{Tr}\left(Y_\nu Y_\nu^\dagger\right) - 30\sqrt{10}g_{BY}^2g_B\text{Tr}\left(Y_\nu Y_\nu^\dagger\right) - 300g_{BY}g_B^2\text{Tr}\left(Y_\nu Y_\nu^\dagger\right) \\
& - 15\sqrt{10}g_1g_{BY}g_{YB}\text{Tr}\left(Y_\nu Y_\nu^\dagger\right) - 300g_1g_Bg_{YB}\text{Tr}\left(Y_\nu Y_\nu^\dagger\right) - 300g_{BY}g_B^2\text{Tr}\left(Y_xY_x^*\right) \\
& - 300g_1g_Bg_{YB}\text{Tr}\left(Y_xY_x^*\right)
\end{aligned} \tag{7}$$

$$\beta_{g_2}^{(1)} = -\frac{19}{6}g_2^3 \tag{8}$$

$$\begin{aligned}
\beta_{g_2}^{(2)} = & \frac{1}{30}g_2^3\left(27g_1^2 + 27g_{BY}^2 + 36\sqrt{10}g_{BY}g_B + 180g_B^2 + 36\sqrt{10}g_1g_{YB} + 180g_{YB}^2 + 175g_2^2 + 360g_3^2\right) \\
& - 45\text{Tr}\left(Y_dY_d^\dagger\right) - 15\text{Tr}\left(Y_eY_e^\dagger\right) - 45\text{Tr}\left(Y_uY_u^\dagger\right) - 15\text{Tr}\left(Y_\nu Y_\nu^\dagger\right)
\end{aligned} \tag{9}$$

$$\beta_{g_3}^{(1)} = -7g_3^3 \tag{10}$$

$$\begin{aligned}
\beta_{g_3}^{(2)} = & \frac{1}{10}g_3^3\left(11g_1^2 + 11g_{BY}^2 + 4\sqrt{10}g_{BY}g_B + 20g_B^2 + 4\sqrt{10}g_1g_{YB} + 20g_{YB}^2 + 45g_2^2 - 260g_3^2 - 20\text{Tr}\left(Y_dY_d^\dagger\right)\right) \\
& - 20\text{Tr}\left(Y_uY_u^\dagger\right)
\end{aligned} \tag{11}$$

$$\beta_{g_B}^{(1)} = \frac{1}{10}\left(41g_{BY}^2g_B + 4g_B\left(45g_B^2 + g_{YB}\left(45g_{YB} + 4\sqrt{10}g_1\right)\right) + g_{BY}\left(32\sqrt{10}g_B^2 + g_{YB}\left(16\sqrt{10}g_{YB} + 41g_1\right)\right)\right) \tag{12}$$

$$\begin{aligned}
\beta_{g_B}^{(2)} = & \frac{1}{50}\left(199g_1^2g_{BY}^2g_B + 199g_{BY}^4g_B + 164\sqrt{10}g_1^2g_{BY}g_B^2 + 328\sqrt{10}g_{BY}^3g_B^2 + 460g_1^2g_B^3\right) \\
& + 2760g_{BY}^2g_B^3 + 1120\sqrt{10}g_{BY}g_B^4 + 10000g_B^5 + 199g_1^3g_{BY}g_{YB} + 199g_1g_{BY}^3g_{YB} + 82\sqrt{10}g_1^3g_Bg_{YB} \\
& + 410\sqrt{10}g_1g_{BY}g_Bg_{YB} + 3220g_1g_{BY}g_B^2g_{YB} + 840\sqrt{10}g_1g_B^3g_{YB} + 246\sqrt{10}g_1g_{BY}g_{YB}^2 \\
& + 82\sqrt{10}g_{BY}^3g_{YB}^2 + 1380g_1^2g_Bg_{YB}^2 + 1840g_{BY}^2g_Bg_{YB}^2 + 1400\sqrt{10}g_{BY}g_B^2g_{YB}^2 + 20000g_B^3g_{YB}^2
\end{aligned}$$

$$\begin{aligned}
& + 1380g_1g_{BY}g_{YB}^3 + 840\sqrt{10}g_1g_Bg_{YB}^3 + 280\sqrt{10}g_{BY}g_{YB}^4 + 10000g_Bg_{YB}^4 + 135g_{BY}^2g_Bg_2^2 \\
& + 180\sqrt{10}g_{BY}g_B^2g_2^2 + 900g_B^3g_2^2 + 135g_1g_{BY}g_{YB}g_2^2 + 90\sqrt{10}g_1g_Bg_{YB}g_2^2 \\
& + 90\sqrt{10}g_{BY}g_{YB}^2g_2^2 + 900g_Bg_{YB}^2g_2^2 + 440g_{BY}^2g_Bg_3^2 + 160\sqrt{10}g_{BY}g_B^2g_3^2 + 800g_B^3g_3^2 \\
& + 440g_1g_{BY}g_{YB}g_3^2 + 80\sqrt{10}g_1g_Bg_{YB}g_3^2 + 80\sqrt{10}g_{BY}g_{YB}^2g_3^2 + 800g_Bg_{YB}^2g_3^2 \\
& - 5\left(5g_{BY}^2g_B - 2\sqrt{10}g_{BY}g_B^2 + 20g_B^3 + 5g_1g_{BY}g_{YB} - \sqrt{10}g_1g_Bg_{YB} - \sqrt{10}g_{BY}g_{YB}^2\right. \\
& \left.+ 20g_Bg_{YB}^2\right)\text{Tr}\left(Y_dY_d^\dagger\right) \\
& - 15\left(5g_{BY}^2g_B + 6\sqrt{10}g_{BY}g_B^2 + 20g_B^3 + 5g_1g_{BY}g_{YB} + 3\sqrt{10}g_1g_Bg_{YB} + 3\sqrt{10}g_{BY}g_{YB}^2\right. \\
& \left.+ 20g_Bg_{YB}^2\right)\text{Tr}\left(Y_eY_e^\dagger\right) \\
& - 85g_{BY}^2g_B\text{Tr}\left(Y_uY_u^\dagger\right) - 50\sqrt{10}g_{BY}g_B^2\text{Tr}\left(Y_uY_u^\dagger\right) - 100g_B^3\text{Tr}\left(Y_uY_u^\dagger\right) \\
& - 85g_1g_{BY}g_{YB}\text{Tr}\left(Y_uY_u^\dagger\right) - 25\sqrt{10}g_1g_Bg_{YB}\text{Tr}\left(Y_uY_u^\dagger\right) - 25\sqrt{10}g_{BY}g_{YB}^2\text{Tr}\left(Y_uY_u^\dagger\right) \\
& - 100g_Bg_{YB}^2\text{Tr}\left(Y_uY_u^\dagger\right) - 15g_{BY}^2g_B\text{Tr}\left(Y_\nu Y_\nu^\dagger\right) - 30\sqrt{10}g_{BY}g_B^2\text{Tr}\left(Y_\nu Y_\nu^\dagger\right) \\
& - 300g_B^3\text{Tr}\left(Y_\nu Y_\nu^\dagger\right) - 15g_1g_{BY}g_{YB}\text{Tr}\left(Y_\nu Y_\nu^\dagger\right) - 15\sqrt{10}g_1g_Bg_{YB}\text{Tr}\left(Y_\nu Y_\nu^\dagger\right) \\
& - 15\sqrt{10}g_{BY}g_{YB}^2\text{Tr}\left(Y_\nu Y_\nu^\dagger\right) - 300g_Bg_{YB}^2\text{Tr}\left(Y_\nu Y_\nu^\dagger\right) - 300g_B^3\text{Tr}\left(Y_xY_x^*\right) \\
& - 300g_Bg_{YB}^2\text{Tr}\left(Y_xY_x^*\right)
\end{aligned} \tag{13}$$

$$\beta_{g_{YB}}^{(1)} = \frac{1}{10}\left(41g_1^2g_{YB} + 4g_{YB}\left(45\left(g_B^2 + g_{YB}^2\right) + 4\sqrt{10}g_{BY}g_B\right) + g_1\left(16\sqrt{10}\left(2g_{YB}^2 + g_B^2\right) + 41g_{BY}g_B\right)\right) \tag{14}$$

$$\begin{aligned}
\beta_{g_{YB}}^{(2)} = & \frac{1}{50}\left(199g_1^3g_{BY}g_B + 199g_1g_{BY}^3g_B + 82\sqrt{10}g_1^3g_B^2 + 246\sqrt{10}g_1g_{BY}^2g_B^2 + 1380g_1g_{BY}g_B^3\right. \\
& + 280\sqrt{10}g_1g_B^4 + 199g_1^4g_{YB} + 199g_1^2g_{BY}^2g_{YB} + 410\sqrt{10}g_1^2g_{BY}g_Bg_{YB} \\
& + 82\sqrt{10}g_{BY}^3g_Bg_{YB} + 1840g_1^2g_B^2g_{YB} + 1380g_{BY}^2g_B^2g_{YB} + 840\sqrt{10}g_{BY}g_B^3g_{YB} + 10000g_B^4g_{YB} \\
& + 328\sqrt{10}g_1^3g_{YB}^2 + 164\sqrt{10}g_1g_{BY}^2g_{YB}^2 + 3220g_1g_{BY}g_Bg_{YB}^2 + 1400\sqrt{10}g_1g_B^2g_{YB}^2 \\
& + 2760g_1^2g_{YB}^3 + 460g_{BY}^2g_{YB}^3 + 840\sqrt{10}g_{BY}g_Bg_{YB}^3 + 20000g_B^2g_{YB}^3 + 1120\sqrt{10}g_1g_{YB}^4 + 10000g_{YB}^5 \\
& + 135g_1g_{BY}g_Bg_2^2 + 90\sqrt{10}g_1g_B^2g_2^2 + 135g_1^2g_{YB}g_2^2 + 90\sqrt{10}g_{BY}g_Bg_{YB}g_2^2 \\
& + 900g_B^2g_{YB}g_2^2 + 180\sqrt{10}g_1g_{YB}^2g_2^2 + 900g_{YB}^3g_2^2 + 440g_1g_{BY}g_Bg_3^2 + 80\sqrt{10}g_1g_B^2g_3^2 \\
& + 440g_1^2g_{YB}g_3^2 + 80\sqrt{10}g_{BY}g_Bg_{YB}g_3^2 + 800g_B^2g_{YB}g_3^2 + 160\sqrt{10}g_1g_{YB}^2g_3^2 + 800g_{YB}^3g_3^2 \\
& - 5\left(20g_{YB}\left(g_B^2 + g_{YB}^2\right) + 5g_1^2g_{YB} + g_1\left(5g_{BY}g_B - \sqrt{10}\left(2g_{YB}^2 + g_B^2\right)\right) - \sqrt{10}g_{BY}g_Bg_{YB}\right)\text{Tr}\left(Y_dY_d^\dagger\right) \\
& - 15\left(5g_1^2g_{YB} + g_1\left(3\sqrt{10}\left(2g_{YB}^2 + g_B^2\right) + 5g_{BY}g_B\right) + g_{YB}\left(20\left(g_B^2 + g_{YB}^2\right) + 3\sqrt{10}g_{BY}g_B\right)\right)\text{Tr}\left(Y_eY_e^\dagger\right) \\
& - 85g_1g_{BY}g_B\text{Tr}\left(Y_uY_u^\dagger\right) - 25\sqrt{10}g_1g_B^2\text{Tr}\left(Y_uY_u^\dagger\right) - 85g_1^2g_{YB}\text{Tr}\left(Y_uY_u^\dagger\right) \\
& - 25\sqrt{10}g_{BY}g_Bg_{YB}\text{Tr}\left(Y_uY_u^\dagger\right) - 100g_B^2g_{YB}\text{Tr}\left(Y_uY_u^\dagger\right) - 50\sqrt{10}g_1g_{YB}^2\text{Tr}\left(Y_uY_u^\dagger\right)
\end{aligned}$$

$$\begin{aligned}
& -100g_{YB}^3\text{Tr}\left(Y_uY_u^\dagger\right) - 15g_1g_{BY}g_B\text{Tr}\left(Y_\nu Y_\nu^\dagger\right) - 15\sqrt{10}g_1g_B^2\text{Tr}\left(Y_\nu Y_\nu^\dagger\right) \\
& - 15g_1^2g_{YB}\text{Tr}\left(Y_\nu Y_\nu^\dagger\right) - 15\sqrt{10}g_{BY}g_Bg_{YB}\text{Tr}\left(Y_\nu Y_\nu^\dagger\right) - 300g_B^2g_{YB}\text{Tr}\left(Y_\nu Y_\nu^\dagger\right) \\
& - 30\sqrt{10}g_1g_{YB}^2\text{Tr}\left(Y_\nu Y_\nu^\dagger\right) - 300g_{YB}^3\text{Tr}\left(Y_\nu Y_\nu^\dagger\right) - 300g_B^2g_{YB}\text{Tr}\left(Y_xY_x^*\right) - 300g_{YB}^3\text{Tr}\left(Y_xY_x^*\right)
\end{aligned} \tag{15}$$

### 3.2 Quartic scalar couplings

$$\beta_{\lambda_2}^{(1)} = -2\left(108g_B^4 + 108g_{YB}^4 + 10\lambda_2^2 + 216g_B^2g_{YB}^2 + 36g_B^2\lambda_2 + 36g_{YB}^2\lambda_2 - 4\lambda_2\text{Tr}\left(Y_xY_x^*\right) - 8\text{Tr}\left(Y_xY_x^*Y_xY_x^*\right) + \lambda_3^2\right) \tag{16}$$

$$\begin{aligned}
\beta_{\lambda_2}^{(2)} = & \frac{2}{5}\left(6012g_{BY}^2g_B^4 + 4608\sqrt{10}g_{BY}g_B^5 + 60480g_B^6 + 6012g_1^2g_B^2g_{YB}^2 + 6012g_{BY}^2g_B^2g_{YB}^2 \right. \\
& + 4608\sqrt{10}g_{BY}g_B^3g_{YB}^2 + 125280g_B^4g_{YB}^2 + 4608\sqrt{10}g_1g_B^2g_{YB}^3 + 6012g_1^2g_{YB}^4 + 125280g_B^2g_{YB}^4 \\
& + 4608\sqrt{10}g_1g_{YB}^5 + 60480g_{YB}^6 + 633g_{BY}^2g_B^2\lambda_2 + 480\sqrt{10}g_{BY}g_B^3\lambda_2 + 11880g_B^4\lambda_2 \\
& + 633g_1^2g_{YB}^2\lambda_2 + 17640g_B^2g_{YB}^2\lambda_2 + 480\sqrt{10}g_1g_{YB}^3\lambda_2 + 11880g_{YB}^4\lambda_2 - 1680g_B^2\lambda_2^2 \\
& - 1680g_{YB}^2\lambda_2^2 - 600\lambda_2^3 + 90g_{BY}^2g_B^2\lambda_3 + 180g_1g_{BY}g_Bg_{YB}\lambda_3 + 90g_1^2g_{YB}^2\lambda_3 - 6g_1^2\lambda_3^2 \\
& - 6g_{BY}^2\lambda_3^2 - 30g_2^2\lambda_3^2 - 50\lambda_2\lambda_3^2 - 20\lambda_3^3 + 30\lambda_3^2\text{Tr}\left(Y_dY_d^\dagger\right) + 10\lambda_3^2\text{Tr}\left(Y_eY_e^\dagger\right) \\
& + 30\lambda_3^2\text{Tr}\left(Y_uY_u^\dagger\right) + 10\lambda_3^2\text{Tr}\left(Y_\nu Y_\nu^\dagger\right) - 1440g_B^4\text{Tr}\left(Y_xY_x^*\right) - 2880g_B^2g_{YB}^2\text{Tr}\left(Y_xY_x^*\right) \\
& - 1440g_{YB}^4\text{Tr}\left(Y_xY_x^*\right) + 150g_B^2\lambda_2\text{Tr}\left(Y_xY_x^*\right) + 150g_{YB}^2\lambda_2\text{Tr}\left(Y_xY_x^*\right) + 200\lambda_2^2\text{Tr}\left(Y_xY_x^*\right) \\
& - 60\lambda_2\text{Tr}\left(Y_\nu Y_\nu^*Y_xY_x^\dagger\right) - 240g_B^2\text{Tr}\left(Y_xY_x^*Y_xY_x^*\right) - 240g_{YB}^2\text{Tr}\left(Y_xY_x^*Y_xY_x^*\right) + 40\lambda_2\text{Tr}\left(Y_xY_x^*Y_xY_x^*\right) \\
& \left. - 160\text{Tr}\left(Y_\nu Y_\nu^*Y_xY_x^*Y_xY_\nu^\dagger\right) - 640\text{Tr}\left(Y_xY_x^*Y_xY_x^*Y_xY_x^*\right)\right)
\end{aligned} \tag{17}$$

$$\begin{aligned}
\beta_{\lambda_3}^{(1)} = & -\frac{54}{5}g_{BY}^2g_B^2 - \frac{108}{5}g_1g_{BY}g_Bg_{YB} - \frac{54}{5}g_1^2g_{YB}^2 - \frac{9}{10}g_1^2\lambda_3 - \frac{9}{10}g_{BY}^2\lambda_3 - 36g_B^2\lambda_3 - 36g_{YB}^2\lambda_3 - \frac{9}{2}g_2^2\lambda_3 \\
& - 12\lambda_1\lambda_3 - 8\lambda_2\lambda_3 - 4\lambda_3^2 + 6\lambda_3\text{Tr}\left(Y_dY_d^\dagger\right) + 2\lambda_3\text{Tr}\left(Y_eY_e^\dagger\right) + 6\lambda_3\text{Tr}\left(Y_uY_u^\dagger\right) + 2\lambda_3\text{Tr}\left(Y_\nu Y_\nu^\dagger\right) \\
& + 4\lambda_3\text{Tr}\left(Y_xY_x^*\right) + 16\text{Tr}\left(Y_\nu Y_\nu^*Y_xY_\nu^\dagger\right)
\end{aligned} \tag{18}$$

$$\begin{aligned}
\beta_{\lambda_3}^{(2)} = & +\frac{81}{10}g_1^2g_{BY}^2g_B^2 + \frac{6417}{50}g_{BY}^4g_B^2 + \frac{2304}{5}\sqrt{\frac{2}{5}}g_{BY}^3g_B^3 + \frac{4428}{5}g_{BY}^2g_B^4 + \frac{3411}{25}g_1^3g_{BY}g_Bg_{YB} + \frac{3411}{25}g_1g_{BY}^3g_Bg_{YB} \\
& + \frac{2304}{5}\sqrt{\frac{2}{5}}g_1g_{BY}^2g_B^2g_{YB} + \frac{6048}{5}g_1g_{BY}g_B^3g_{YB} + \frac{6417}{50}g_1^4g_{YB}^2 + \frac{81}{10}g_1^2g_{BY}^2g_{YB}^2 + \frac{2304}{5}\sqrt{\frac{2}{5}}g_1^2g_{BY}g_Bg_{YB}^2 \\
& + 324g_1^2g_B^2g_{YB}^2 + 324g_{BY}^2g_B^2g_{YB}^2 + \frac{2304}{5}\sqrt{\frac{2}{5}}g_1^3g_{YB}^3 + \frac{6048}{5}g_1g_{BY}g_Bg_{YB}^3 + \frac{4428}{5}g_1^2g_{YB}^4 + \frac{81}{2}g_{BY}^2g_B^2g_2^2 \\
& + 81g_1g_{BY}g_Bg_{YB}g_2^2 + \frac{81}{2}g_1^2g_{YB}^2g_2^2 + 108g_{BY}^2g_B^2\lambda_1 + 216g_1g_{BY}g_Bg_{YB}\lambda_1 + 108g_1^2g_{YB}^2\lambda_1 \\
& + 72g_{BY}^2g_B^2\lambda_2 + 144g_1g_{BY}g_Bg_{YB}\lambda_2 + 72g_1^2g_{YB}^2\lambda_2 + \frac{1671}{400}g_1^4\lambda_3 + \frac{81}{40}g_1^2g_{BY}^2\lambda_3 + \frac{1671}{400}g_{BY}^4\lambda_3
\end{aligned}$$



$$\begin{aligned}
& + 12\sqrt{\frac{2}{5}}g_{BY}^3g_B\lambda_3 + \frac{1491}{10}g_{BY}^2g_B^2\lambda_3 + 96\sqrt{10}g_{BY}g_B^3\lambda_3 + 1512g_B^4\lambda_3 + 12\sqrt{\frac{2}{5}}g_1^3g_{YB}\lambda_3 \\
& + \frac{72}{5}g_1g_{BY}g_Bg_{YB}\lambda_3 + \frac{1491}{10}g_1^2g_{YB}^2\lambda_3 + 1800g_B^2g_{YB}^2\lambda_3 + 96\sqrt{10}g_1g_{YB}^3\lambda_3 + 1512g_{YB}^4\lambda_3 \\
& + \frac{9}{8}g_1^2g_2^2\lambda_3 + \frac{9}{8}g_{BY}^2g_2^2\lambda_3 - \frac{145}{16}g_2^4\lambda_3 - \frac{72}{5}g_1^2\lambda_1\lambda_3 - \frac{72}{5}g_{BY}^2\lambda_1\lambda_3 - 72g_2^2\lambda_1\lambda_3 - 60\lambda_1^2\lambda_3 \\
& - 384g_B^2\lambda_2\lambda_3 - 384g_{YB}^2\lambda_2\lambda_3 - 40\lambda_2^2\lambda_3 - \frac{3}{5}g_1^2\lambda_3^2 - \frac{3}{5}g_{BY}^2\lambda_3^2 - 24g_B^2\lambda_3^2 - 24g_{YB}^2\lambda_3^2 \\
& - 3g_2^2\lambda_3^2 - 72\lambda_1\lambda_3^2 - 48\lambda_2\lambda_3^2 - 11\lambda_3^3 \\
& + \left(144g_B^4 - 18g_1^2g_{YB}^2 - 72\sqrt{\frac{2}{5}}g_1g_{YB}^3 + 144g_{YB}^4 + \frac{5}{4}g_1^2\lambda_3 - \sqrt{\frac{5}{2}}g_1g_{YB}\lambda_3 + 5g_{YB}^2\lambda_3 + \frac{45}{4}g_2^2\lambda_3\right. \\
& + 40g_3^2\lambda_3 + 72\lambda_1\lambda_3 + 12\lambda_3^2 + g_{BY}^2\left(-18g_B^2 + \frac{5}{4}\lambda_3\right) + g_B^2\left(288g_{YB}^2 + 5\lambda_3 - 72\sqrt{\frac{2}{5}}g_1g_{YB}\right) \\
& - \frac{1}{10}g_{BY}g_B\left(144\sqrt{10}g_B^2 + 360g_1g_{YB} + \sqrt{10}\left(144g_{YB}^2 + 5\lambda_3\right)\right)\left.\right)\text{Tr}\left(Y_dY_d^\dagger\right) \\
& + \frac{1}{20}\left(8640g_B^4 + 1800g_1^2g_{YB}^2 + 2592\sqrt{10}g_1g_{YB}^3 + 8640g_{YB}^4 + 75g_1^2\lambda_3 + 90\sqrt{10}g_1g_{YB}\lambda_3 + 300g_{YB}^2\lambda_3\right. \\
& + 75g_2^2\lambda_3 + 480\lambda_1\lambda_3 + 80\lambda_3^2 + 75g_{BY}^2\left(24g_B^2 + \lambda_3\right) + 12g_B^2\left(1440g_{YB}^2 + 216\sqrt{10}g_1g_{YB} + 25\lambda_3\right) \\
& + 18g_{BY}g_B\left(144\sqrt{10}g_B^2 + 200g_1g_{YB} + \sqrt{10}\left(144g_{YB}^2 + 5\lambda_3\right)\right)\left.\right)\text{Tr}\left(Y_eY_e^\dagger\right) \\
& + \frac{342}{5}g_{BY}^2g_B^2\text{Tr}\left(Y_uY_u^\dagger\right) + 72\sqrt{10}g_{BY}g_B^3\text{Tr}\left(Y_uY_u^\dagger\right) + 144g_B^4\text{Tr}\left(Y_uY_u^\dagger\right) \\
& + \frac{684}{5}g_1g_{BY}g_Bg_{YB}\text{Tr}\left(Y_uY_u^\dagger\right) + 72\sqrt{10}g_1g_B^2g_{YB}\text{Tr}\left(Y_uY_u^\dagger\right) + \frac{342}{5}g_1^2g_{YB}^2\text{Tr}\left(Y_uY_u^\dagger\right) \\
& + 72\sqrt{10}g_{BY}g_Bg_{YB}^2\text{Tr}\left(Y_uY_u^\dagger\right) + 288g_B^2g_{YB}^2\text{Tr}\left(Y_uY_u^\dagger\right) + 72\sqrt{10}g_1g_{YB}^3\text{Tr}\left(Y_uY_u^\dagger\right) \\
& + 144g_{YB}^4\text{Tr}\left(Y_uY_u^\dagger\right) + \frac{17}{4}g_1^2\lambda_3\text{Tr}\left(Y_uY_u^\dagger\right) + \frac{17}{4}g_{BY}^2\lambda_3\text{Tr}\left(Y_uY_u^\dagger\right) + 5\sqrt{\frac{5}{2}}g_{BY}g_B\lambda_3\text{Tr}\left(Y_uY_u^\dagger\right) \\
& + 5g_B^2\lambda_3\text{Tr}\left(Y_uY_u^\dagger\right) + 5\sqrt{\frac{5}{2}}g_1g_{YB}\lambda_3\text{Tr}\left(Y_uY_u^\dagger\right) + 5g_{YB}^2\lambda_3\text{Tr}\left(Y_uY_u^\dagger\right) + \frac{45}{4}g_2^2\lambda_3\text{Tr}\left(Y_uY_u^\dagger\right) \\
& + 40g_3^2\lambda_3\text{Tr}\left(Y_uY_u^\dagger\right) + 72\lambda_1\lambda_3\text{Tr}\left(Y_uY_u^\dagger\right) + 12\lambda_3^2\text{Tr}\left(Y_uY_u^\dagger\right) + \frac{18}{5}g_{BY}^2g_B^2\text{Tr}\left(Y_\nu Y_\nu^\dagger\right) \\
& + 216\sqrt{\frac{2}{5}}g_{BY}g_B^3\text{Tr}\left(Y_\nu Y_\nu^\dagger\right) + 432g_B^4\text{Tr}\left(Y_\nu Y_\nu^\dagger\right) + \frac{36}{5}g_1g_{BY}g_Bg_{YB}\text{Tr}\left(Y_\nu Y_\nu^\dagger\right) \\
& + 216\sqrt{\frac{2}{5}}g_1g_B^2g_{YB}\text{Tr}\left(Y_\nu Y_\nu^\dagger\right) + \frac{18}{5}g_1^2g_{YB}^2\text{Tr}\left(Y_\nu Y_\nu^\dagger\right) + 216\sqrt{\frac{2}{5}}g_{BY}g_Bg_{YB}^2\text{Tr}\left(Y_\nu Y_\nu^\dagger\right) \\
& + 864g_B^2g_{YB}^2\text{Tr}\left(Y_\nu Y_\nu^\dagger\right) + 216\sqrt{\frac{2}{5}}g_1g_{YB}^3\text{Tr}\left(Y_\nu Y_\nu^\dagger\right) + 432g_{YB}^4\text{Tr}\left(Y_\nu Y_\nu^\dagger\right) + \frac{3}{4}g_1^2\lambda_3\text{Tr}\left(Y_\nu Y_\nu^\dagger\right) \\
& + \frac{3}{4}g_{BY}^2\lambda_3\text{Tr}\left(Y_\nu Y_\nu^\dagger\right) + 3\sqrt{\frac{5}{2}}g_{BY}g_B\lambda_3\text{Tr}\left(Y_\nu Y_\nu^\dagger\right) + 15g_B^2\lambda_3\text{Tr}\left(Y_\nu Y_\nu^\dagger\right) \\
& + 3\sqrt{\frac{5}{2}}g_1g_{YB}\lambda_3\text{Tr}\left(Y_\nu Y_\nu^\dagger\right) + 15g_{YB}^2\lambda_3\text{Tr}\left(Y_\nu Y_\nu^\dagger\right) + \frac{15}{4}g_2^2\lambda_3\text{Tr}\left(Y_\nu Y_\nu^\dagger\right) + 24\lambda_1\lambda_3\text{Tr}\left(Y_\nu Y_\nu^\dagger\right)
\end{aligned}$$

$$\begin{aligned}
& + 4\lambda_3^2 \text{Tr}(Y_\nu Y_\nu^\dagger) - \frac{72}{5} g_{BY}^2 g_B^2 \text{Tr}(Y_x Y_x^*) - \frac{144}{5} g_1 g_{BY} g_B g_{YB} \text{Tr}(Y_x Y_x^*) - \frac{72}{5} g_1^2 g_{YB}^2 \text{Tr}(Y_x Y_x^*) \\
& + 30 g_B^2 \lambda_3 \text{Tr}(Y_x Y_x^*) + 30 g_{YB}^2 \lambda_3 \text{Tr}(Y_x Y_x^*) + 32 \lambda_2 \lambda_3 \text{Tr}(Y_x Y_x^*) + 8 \lambda_3^2 \text{Tr}(Y_x Y_x^*) \\
& - \frac{27}{2} \lambda_3 \text{Tr}(Y_d Y_d^\dagger Y_d Y_d^\dagger) - 21 \lambda_3 \text{Tr}(Y_d Y_u^\dagger Y_u Y_d^\dagger) - \frac{9}{2} \lambda_3 \text{Tr}(Y_e Y_e^\dagger Y_e Y_e^\dagger) - \frac{27}{2} \lambda_3 \text{Tr}(Y_u Y_u^\dagger Y_u Y_u^\dagger) \\
& - \frac{9}{2} \lambda_3 \text{Tr}(Y_\nu Y_\nu^\dagger Y_\nu Y_\nu^\dagger) - 7 \lambda_3 \text{Tr}(Y_\nu Y_\nu^\dagger Y_e^T Y_e^*) + 24 \sqrt{\frac{2}{5}} g_{BY} g_B \text{Tr}(Y_\nu Y_x^* Y_x Y_\nu^\dagger) \\
& + 24 \sqrt{\frac{2}{5}} g_1 g_{YB} \text{Tr}(Y_\nu Y_x^* Y_x Y_\nu^\dagger) + 14 \lambda_3 \text{Tr}(Y_\nu Y_x^* Y_x Y_\nu^\dagger) - 24 \lambda_3 \text{Tr}(Y_x Y_x^* Y_x Y_x^*) \\
& - 36 \text{Tr}(Y_\nu Y_\nu^\dagger Y_\nu Y_x^* Y_x Y_\nu^\dagger) - 20 \text{Tr}(Y_\nu Y_x^* Y_x Y_\nu^\dagger Y_\nu Y_\nu^\dagger) + 8 \text{Tr}(Y_\nu Y_x^* Y_x Y_\nu^\dagger Y_e^T Y_e^*) \\
& - 160 \text{Tr}(Y_\nu Y_x^* Y_x Y_x^* Y_x Y_\nu^\dagger) - 32 \text{Tr}(Y_\nu Y_x^* Y_\nu^T Y_\nu^* Y_x Y_\nu^\dagger)
\end{aligned} \tag{19}$$

$$\begin{aligned}
\beta_{\lambda_1}^{(1)} = & -\frac{27}{200} g_1^4 - \frac{27}{100} g_1^2 g_{BY}^2 - \frac{27}{200} g_{BY}^4 - \frac{9}{20} g_1^2 g_2^2 - \frac{9}{20} g_{BY}^2 g_2^2 - \frac{9}{8} g_2^4 - \frac{9}{5} g_1^2 \lambda_1 - \frac{9}{5} g_{BY}^2 \lambda_1 - 9 g_2^2 \lambda_1 \\
& - 24 \lambda_1^2 - \lambda_3^2 + 12 \lambda_1 \text{Tr}(Y_d Y_d^\dagger) + 4 \lambda_1 \text{Tr}(Y_e Y_e^\dagger) + 12 \lambda_1 \text{Tr}(Y_u Y_u^\dagger) + 4 \lambda_1 \text{Tr}(Y_\nu Y_\nu^\dagger) \\
& + 6 \text{Tr}(Y_d Y_d^\dagger Y_d Y_d^\dagger) + 2 \text{Tr}(Y_e Y_e^\dagger Y_e Y_e^\dagger) + 6 \text{Tr}(Y_u Y_u^\dagger Y_u Y_u^\dagger) + 2 \text{Tr}(Y_\nu Y_\nu^\dagger Y_\nu Y_\nu^\dagger)
\end{aligned} \tag{20}$$

$$\begin{aligned}
\beta_{\lambda_1}^{(2)} = & + \frac{3411}{2000} g_1^6 + \frac{4221}{2000} g_1^4 g_{BY}^2 + \frac{4221}{2000} g_1^2 g_{BY}^4 + \frac{3411}{2000} g_{BY}^6 + \frac{144}{25} \sqrt{\frac{2}{5}} g_1^2 g_{BY}^3 g_B + \frac{144}{25} \sqrt{\frac{2}{5}} g_{BY}^5 g_B + \frac{351}{50} g_1^2 g_{BY}^2 g_B^2 + \frac{351}{50} g_{BY}^4 g_B^2 \\
& + \frac{144}{25} \sqrt{\frac{2}{5}} g_1^5 g_{YB} + \frac{144}{25} \sqrt{\frac{2}{5}} g_1^3 g_{BY}^2 g_{YB} + \frac{351}{50} g_1^4 g_{YB}^2 + \frac{351}{50} g_1^2 g_{BY}^2 g_{YB}^2 + \frac{1677}{400} g_1^4 g_2^2 + \frac{27}{8} g_1^2 g_{BY}^2 g_2^2 \\
& + \frac{1677}{400} g_{BY}^4 g_2^2 + \frac{48}{5} \sqrt{\frac{2}{5}} g_{BY}^3 g_B g_2^2 + \frac{117}{10} g_{BY}^2 g_B^2 g_2^2 + \frac{48}{5} \sqrt{\frac{2}{5}} g_1^3 g_{YB} g_2^2 + \frac{117}{10} g_1^2 g_{YB}^2 g_2^2 + \frac{289}{80} g_1^4 g_2^4 \\
& + \frac{289}{80} g_{BY}^2 g_2^4 - \frac{305}{16} g_2^6 + \frac{1887}{200} g_1^4 \lambda_1 + \frac{621}{100} g_1^2 g_{BY}^2 \lambda_1 + \frac{1887}{200} g_{BY}^4 \lambda_1 + 24 \sqrt{\frac{2}{5}} g_{BY}^3 g_B \lambda_1 + \frac{153}{5} g_{BY}^2 g_B^2 \lambda_1 \\
& + 24 \sqrt{\frac{2}{5}} g_1^3 g_{YB} \lambda_1 + \frac{153}{5} g_1^2 g_{YB}^2 \lambda_1 + \frac{117}{20} g_1^2 g_2^2 \lambda_1 + \frac{117}{20} g_{BY}^2 g_2^2 \lambda_1 - \frac{73}{8} g_2^4 \lambda_1 - \frac{108}{5} g_1^2 \lambda_1^2 - \frac{108}{5} g_{BY}^2 \lambda_1^2 \\
& - 108 g_2^2 \lambda_1^2 - 312 \lambda_1^3 + 18 g_{BY}^2 g_B^2 \lambda_3 + 36 g_1 g_{BY} g_B g_{YB} \lambda_3 + 18 g_1^2 g_{YB}^2 \lambda_3 - 48 g_B^2 \lambda_3^2 \\
& - 48 g_{YB}^2 \lambda_3^2 - 10 \lambda_1 \lambda_3^2 - 4 \lambda_3^3 \\
& - \frac{1}{100} (45 g_1^4 + 45 g_{BY}^4 + 36 \sqrt{10} g_{BY}^3 g_B + 36 \sqrt{10} g_1^3 g_{YB} \\
& + g_1^2 (-250 \lambda_1 + 270 g_2^2 - 360 g_{YB}^2 + 36 \sqrt{10} g_{BY} g_B + 90 g_{BY}^2) - 20 \sqrt{10} g_{BY} g_B (-5 \lambda_1 + 9 g_2^2) \\
& - 10 g_{BY}^2 (25 \lambda_1 - 27 g_2^2 + 36 g_B^2) + 4 g_1 g_{YB} (-180 g_{BY} g_B + 5 \sqrt{10} (5 \lambda_1 - 9 g_2^2) + 9 \sqrt{10} g_{BY}^2) \\
& - 25 (8 \lambda_1 (40 g_3^2 + 5 g_B^2 + 5 g_{YB}^2 + 72 \lambda_1) + 90 g_2^2 \lambda_1 + 9 g_2^4) \text{Tr}(Y_d Y_d^\dagger) \\
& + \frac{3}{100} (75 g_1^4 + 75 g_{BY}^4 + 108 \sqrt{10} g_{BY}^3 g_B + 108 \sqrt{10} g_1^3 g_{YB} \\
& + 12 g_1 g_{YB} (-5 \sqrt{10} (-5 \lambda_1 + g_2^2) + 60 g_{BY} g_B + 9 \sqrt{10} g_{BY}^2) - 60 \sqrt{10} g_{BY} g_B (-5 \lambda_1 + g_2^2)
\end{aligned}$$

$$\begin{aligned}
& + 10g_{BY}^2 \left( -11g_2^2 + 25\lambda_1 + 36g_B^2 \right) + 2g_1^2 \left( 125\lambda_1 + 180g_{YB}^2 + 54\sqrt{10}g_{BY}g_B - 55g_2^2 + 75g_{BY}^2 \right) \\
& + 25 \left( 10g_2^2\lambda_1 + 8\lambda_1 \left( 5g_B^2 + 5g_{YB}^2 + 8\lambda_1 \right) + g_2^4 \right) \text{Tr} \left( Y_e Y_e^\dagger \right) \\
& + \frac{171}{100} g_1^4 \text{Tr} \left( Y_u Y_u^\dagger \right) + \frac{171}{50} g_1^2 g_{BY}^2 \text{Tr} \left( Y_u Y_u^\dagger \right) + \frac{171}{100} g_{BY}^4 \text{Tr} \left( Y_u Y_u^\dagger \right) + 9\sqrt{\frac{2}{5}} g_1^2 g_{BY} g_B \text{Tr} \left( Y_u Y_u^\dagger \right) \\
& + 9\sqrt{\frac{2}{5}} g_{BY}^3 g_B \text{Tr} \left( Y_u Y_u^\dagger \right) + \frac{18}{5} g_{BY}^2 g_B^2 \text{Tr} \left( Y_u Y_u^\dagger \right) + 9\sqrt{\frac{2}{5}} g_1^3 g_{YB} \text{Tr} \left( Y_u Y_u^\dagger \right) \\
& + 9\sqrt{\frac{2}{5}} g_1 g_{BY}^2 g_{YB} \text{Tr} \left( Y_u Y_u^\dagger \right) + \frac{36}{5} g_1 g_{BY} g_B g_{YB} \text{Tr} \left( Y_u Y_u^\dagger \right) + \frac{18}{5} g_1^2 g_{YB}^2 \text{Tr} \left( Y_u Y_u^\dagger \right) \\
& - \frac{63}{10} g_1^2 g_2^2 \text{Tr} \left( Y_u Y_u^\dagger \right) - \frac{63}{10} g_{BY}^2 g_2^2 \text{Tr} \left( Y_u Y_u^\dagger \right) - 9\sqrt{\frac{2}{5}} g_{BY} g_B g_2^2 \text{Tr} \left( Y_u Y_u^\dagger \right) \\
& - 9\sqrt{\frac{2}{5}} g_1 g_{YB} g_2^2 \text{Tr} \left( Y_u Y_u^\dagger \right) + \frac{9}{4} g_2^4 \text{Tr} \left( Y_u Y_u^\dagger \right) + \frac{17}{2} g_1^2 \lambda_1 \text{Tr} \left( Y_u Y_u^\dagger \right) + \frac{17}{2} g_{BY}^2 \lambda_1 \text{Tr} \left( Y_u Y_u^\dagger \right) \\
& + 5\sqrt{10} g_{BY} g_B \lambda_1 \text{Tr} \left( Y_u Y_u^\dagger \right) + 10g_B^2 \lambda_1 \text{Tr} \left( Y_u Y_u^\dagger \right) + 5\sqrt{10} g_1 g_{YB} \lambda_1 \text{Tr} \left( Y_u Y_u^\dagger \right) \\
& + 10g_{YB}^2 \lambda_1 \text{Tr} \left( Y_u Y_u^\dagger \right) + \frac{45}{2} g_2^2 \lambda_1 \text{Tr} \left( Y_u Y_u^\dagger \right) + 80g_3^2 \lambda_1 \text{Tr} \left( Y_u Y_u^\dagger \right) + 144\lambda_1^2 \text{Tr} \left( Y_u Y_u^\dagger \right) \\
& + \frac{9}{100} g_1^4 \text{Tr} \left( Y_\nu Y_\nu^\dagger \right) + \frac{9}{50} g_1^2 g_{BY}^2 \text{Tr} \left( Y_\nu Y_\nu^\dagger \right) + \frac{9}{100} g_{BY}^4 \text{Tr} \left( Y_\nu Y_\nu^\dagger \right) + \frac{27}{5} \sqrt{\frac{2}{5}} g_1^2 g_{BY} g_B \text{Tr} \left( Y_\nu Y_\nu^\dagger \right) \\
& + \frac{27}{5} \sqrt{\frac{2}{5}} g_{BY}^3 g_B \text{Tr} \left( Y_\nu Y_\nu^\dagger \right) + \frac{54}{5} g_{BY}^2 g_B^2 \text{Tr} \left( Y_\nu Y_\nu^\dagger \right) + \frac{27}{5} \sqrt{\frac{2}{5}} g_1^3 g_{YB} \text{Tr} \left( Y_\nu Y_\nu^\dagger \right) \\
& + \frac{27}{5} \sqrt{\frac{2}{5}} g_1 g_{BY}^2 g_{YB} \text{Tr} \left( Y_\nu Y_\nu^\dagger \right) + \frac{108}{5} g_1 g_{BY} g_B g_{YB} \text{Tr} \left( Y_\nu Y_\nu^\dagger \right) + \frac{54}{5} g_1^2 g_{YB}^2 \text{Tr} \left( Y_\nu Y_\nu^\dagger \right) \\
& + \frac{3}{10} g_1^2 g_2^2 \text{Tr} \left( Y_\nu Y_\nu^\dagger \right) + \frac{3}{10} g_{BY}^2 g_2^2 \text{Tr} \left( Y_\nu Y_\nu^\dagger \right) + 9\sqrt{\frac{2}{5}} g_{BY} g_B g_2^2 \text{Tr} \left( Y_\nu Y_\nu^\dagger \right) \\
& + 9\sqrt{\frac{2}{5}} g_1 g_{YB} g_2^2 \text{Tr} \left( Y_\nu Y_\nu^\dagger \right) + \frac{3}{4} g_2^4 \text{Tr} \left( Y_\nu Y_\nu^\dagger \right) + \frac{3}{2} g_1^2 \lambda_1 \text{Tr} \left( Y_\nu Y_\nu^\dagger \right) + \frac{3}{2} g_{BY}^2 \lambda_1 \text{Tr} \left( Y_\nu Y_\nu^\dagger \right) \\
& + 3\sqrt{10} g_{BY} g_B \lambda_1 \text{Tr} \left( Y_\nu Y_\nu^\dagger \right) + 30g_B^2 \lambda_1 \text{Tr} \left( Y_\nu Y_\nu^\dagger \right) + 3\sqrt{10} g_1 g_{YB} \lambda_1 \text{Tr} \left( Y_\nu Y_\nu^\dagger \right) \\
& + 30g_{YB}^2 \lambda_1 \text{Tr} \left( Y_\nu Y_\nu^\dagger \right) + \frac{15}{2} g_2^2 \lambda_1 \text{Tr} \left( Y_\nu Y_\nu^\dagger \right) + 48\lambda_1^2 \text{Tr} \left( Y_\nu Y_\nu^\dagger \right) + 4\lambda_3^2 \text{Tr} \left( Y_x Y_x^* \right) \\
& - \frac{4}{5} g_1^2 \text{Tr} \left( Y_d Y_d^\dagger Y_d Y_d^\dagger \right) - \frac{4}{5} g_{BY}^2 \text{Tr} \left( Y_d Y_d^\dagger Y_d Y_d^\dagger \right) - 2\sqrt{\frac{2}{5}} g_{BY} g_B \text{Tr} \left( Y_d Y_d^\dagger Y_d Y_d^\dagger \right) + 4g_B^2 \text{Tr} \left( Y_d Y_d^\dagger Y_d Y_d^\dagger \right) \\
& - 2\sqrt{\frac{2}{5}} g_1 g_{YB} \text{Tr} \left( Y_d Y_d^\dagger Y_d Y_d^\dagger \right) + 4g_{YB}^2 \text{Tr} \left( Y_d Y_d^\dagger Y_d Y_d^\dagger \right) + 32g_3^2 \text{Tr} \left( Y_d Y_d^\dagger Y_d Y_d^\dagger \right) - 3\lambda_1 \text{Tr} \left( Y_d Y_d^\dagger Y_d Y_d^\dagger \right) \\
& - 42\lambda_1 \text{Tr} \left( Y_d Y_u^\dagger Y_u Y_d^\dagger \right) + \frac{12}{5} g_1^2 \text{Tr} \left( Y_e Y_e^\dagger Y_e Y_e^\dagger \right) + \frac{12}{5} g_{BY}^2 \text{Tr} \left( Y_e Y_e^\dagger Y_e Y_e^\dagger \right) \\
& + 18\sqrt{\frac{2}{5}} g_{BY} g_B \text{Tr} \left( Y_e Y_e^\dagger Y_e Y_e^\dagger \right) + 12g_B^2 \text{Tr} \left( Y_e Y_e^\dagger Y_e Y_e^\dagger \right) + 18\sqrt{\frac{2}{5}} g_1 g_{YB} \text{Tr} \left( Y_e Y_e^\dagger Y_e Y_e^\dagger \right) + 12g_{YB}^2 \text{Tr} \left( Y_e Y_e^\dagger Y_e Y_e^\dagger \right) \\
& - \lambda_1 \text{Tr} \left( Y_e Y_e^\dagger Y_e Y_e^\dagger \right) + \frac{8}{5} g_1^2 \text{Tr} \left( Y_u Y_u^\dagger Y_u Y_u^\dagger \right) + \frac{8}{5} g_{BY}^2 \text{Tr} \left( Y_u Y_u^\dagger Y_u Y_u^\dagger \right)
\end{aligned}$$

$$\begin{aligned}
& + 2\sqrt{10}g_{BY}g_B\text{Tr}\left(Y_uY_u^\dagger Y_uY_u^\dagger\right) + 4g_B^2\text{Tr}\left(Y_uY_u^\dagger Y_uY_u^\dagger\right) + 2\sqrt{10}g_1g_{YB}\text{Tr}\left(Y_uY_u^\dagger Y_uY_u^\dagger\right) \\
& + 4g_{YB}^2\text{Tr}\left(Y_uY_u^\dagger Y_uY_u^\dagger\right) + 32g_3^2\text{Tr}\left(Y_uY_u^\dagger Y_uY_u^\dagger\right) - 3\lambda_1\text{Tr}\left(Y_uY_u^\dagger Y_uY_u^\dagger\right) + 6\sqrt{\frac{2}{5}}g_{BY}g_B\text{Tr}\left(Y_\nu Y_\nu^\dagger Y_\nu Y_\nu^\dagger\right) \\
& + 12g_B^2\text{Tr}\left(Y_\nu Y_\nu^\dagger Y_\nu Y_\nu^\dagger\right) + 6\sqrt{\frac{2}{5}}g_1g_{YB}\text{Tr}\left(Y_\nu Y_\nu^\dagger Y_\nu Y_\nu^\dagger\right) + 12g_{YB}^2\text{Tr}\left(Y_\nu Y_\nu^\dagger Y_\nu Y_\nu^\dagger\right) - \lambda_1\text{Tr}\left(Y_\nu Y_\nu^\dagger Y_\nu Y_\nu^\dagger\right) \\
& - 14\lambda_1\text{Tr}\left(Y_\nu Y_\nu^\dagger Y_e^T Y_e^*\right) - 12\lambda_1\text{Tr}\left(Y_\nu Y_x^* Y_x Y_\nu^\dagger\right) - 30\text{Tr}\left(Y_d Y_d^\dagger Y_d Y_d^\dagger Y_d Y_d^\dagger\right) \\
& - 6\text{Tr}\left(Y_d Y_d^\dagger Y_d Y_u^\dagger Y_u Y_d^\dagger\right) + 12\text{Tr}\left(Y_d Y_u^\dagger Y_u Y_d^\dagger Y_d Y_d^\dagger\right) + 6\text{Tr}\left(Y_d Y_u^\dagger Y_u Y_u^\dagger Y_u Y_d^\dagger\right) \\
& - 10\text{Tr}\left(Y_e Y_e^\dagger Y_e Y_e^\dagger Y_e Y_e^\dagger\right) - 30\text{Tr}\left(Y_u Y_u^\dagger Y_u Y_u^\dagger Y_u Y_u^\dagger\right) - 10\text{Tr}\left(Y_\nu Y_\nu^\dagger Y_\nu Y_\nu^\dagger Y_\nu Y_\nu^\dagger\right) - 4\text{Tr}\left(Y_\nu Y_\nu^\dagger Y_\nu Y_x^* Y_x Y_\nu^\dagger\right) \\
& + 2\text{Tr}\left(Y_\nu Y_\nu^\dagger Y_e^T Y_e^* Y_\nu Y_\nu^\dagger\right) + 2\text{Tr}\left(Y_\nu Y_\nu^\dagger Y_e^T Y_e^* Y_e^T Y_e^*\right) - 4\text{Tr}\left(Y_\nu Y_x^* Y_x Y_\nu^\dagger Y_\nu Y_\nu^\dagger\right) \\
& - 8\text{Tr}\left(Y_\nu Y_x^* Y_\nu^T Y_\nu^* Y_x Y_\nu^\dagger\right)
\end{aligned} \tag{21}$$

### 3.3 Yukawa Couplings

$$\begin{aligned}
\beta_{Y_x}^{(1)} &= 4Y_x Y_x^* Y_x + Y_x \left( 2\text{Tr}\left(Y_x Y_x^*\right) - 9\left(g_B^2 + g_{YB}^2\right) \right) + Y_x Y_\nu^\dagger Y_\nu + Y_\nu^T Y_\nu^* Y_x \\
\beta_{Y_x}^{(2)} &= \frac{1}{40} \left( 10560g_B^2 Y_x Y_x^* Y_x + 10560g_{YB}^2 Y_x Y_x^* Y_x + 1280\lambda_2 Y_x Y_x^* Y_x + 51g_1^2 Y_\nu^T Y_\nu^* Y_x \right. \\
& + 51g_{BY}^2 Y_\nu^T Y_\nu^* Y_x - 78\sqrt{10}g_{BY}g_B Y_\nu^T Y_\nu^* Y_x - 960g_B^2 Y_\nu^T Y_\nu^* Y_x \\
& - 78\sqrt{10}g_1g_{YB} Y_\nu^T Y_\nu^* Y_x - 960g_{YB}^2 Y_\nu^T Y_\nu^* Y_x + 255g_2^2 Y_\nu^T Y_\nu^* Y_x \\
& + 160\lambda_3 Y_\nu^T Y_\nu^* Y_x - 10Y_x Y_\nu^\dagger Y_\nu Y_\nu^\dagger Y_\nu - 40Y_x Y_\nu^\dagger Y_\nu Y_x^* Y_x - 10Y_x Y_\nu^\dagger Y_e^T Y_e^* Y_\nu \\
& + 1120Y_x Y_x^* Y_x Y_x^* Y_x - 40Y_x Y_x^* Y_\nu^T Y_\nu^* Y_x - 10Y_\nu^T Y_e^\dagger Y_e Y_\nu^* Y_x + 160Y_\nu^T Y_\nu^* Y_x Y_\nu^\dagger Y_\nu \\
& - 10Y_\nu^T Y_\nu^* Y_\nu^T Y_\nu^* Y_x - 180Y_\nu^T Y_\nu^* Y_x \text{Tr}\left(Y_d Y_d^\dagger\right) - 60Y_\nu^T Y_\nu^* Y_x \text{Tr}\left(Y_e Y_e^\dagger\right) \\
& - 180Y_\nu^T Y_\nu^* Y_x \text{Tr}\left(Y_u Y_u^\dagger\right) \\
& + Y_x Y_\nu^\dagger Y_\nu \left( 51g_1^2 + 51g_{BY}^2 - 78\sqrt{10}g_{BY}g_B - 960g_B^2 - 78\sqrt{10}g_1g_{YB} - 960g_{YB}^2 + 255g_2^2 + 160\lambda_3 \right. \\
& - 180\text{Tr}\left(Y_d Y_d^\dagger\right) - 60\text{Tr}\left(Y_e Y_e^\dagger\right) - 180\text{Tr}\left(Y_u Y_u^\dagger\right) - 60\text{Tr}\left(Y_\nu Y_\nu^\dagger\right) \\
& - 60Y_\nu^T Y_\nu^* Y_x \text{Tr}\left(Y_\nu Y_\nu^\dagger\right) - 480Y_x Y_x^* Y_x \text{Tr}\left(Y_x Y_x^*\right) \\
& - 2Y_x \left( 105g_{BY}^2 g_B^2 + 96\sqrt{10}g_{BY}g_B^3 + 5715g_B^4 + 210g_1g_{BY}g_Bg_{YB} + 96\sqrt{10}g_1g_B^2g_{YB} + 105g_1^2g_{YB}^2 \right. \\
& + 96\sqrt{10}g_{BY}g_Bg_{YB}^2 + 11430g_B^2g_{YB}^2 + 96\sqrt{10}g_1g_{YB}^3 + 5715g_{YB}^4 - 80\lambda_2^2 - 20\lambda_3^2 \\
& \left. \left. - 300\left(g_B^2 + g_{YB}^2\right)\text{Tr}\left(Y_x Y_x^*\right) + 120\text{Tr}\left(Y_\nu Y_x^* Y_x Y_\nu^\dagger\right) + 240\text{Tr}\left(Y_x Y_x^* Y_x Y_x^*\right) \right) \right) \\
\beta_{Y_d}^{(1)} &= +\frac{3}{2} \left( -Y_d Y_u^\dagger Y_u + Y_d Y_d^\dagger Y_d \right)
\end{aligned} \tag{23}$$

$$\begin{aligned}
& + Y_d \left( -\frac{1}{4}g_1^2 - \frac{1}{4}g_{BY}^2 + \frac{1}{\sqrt{10}}g_{BY}g_B - g_B^2 + \frac{1}{\sqrt{10}}g_1g_{YB} - g_{YB}^2 - \frac{9}{4}g_2^2 - 8g_3^2 + 3\text{Tr}(Y_d Y_d^\dagger) \right. \\
& \left. + \text{Tr}(Y_e Y_e^\dagger) + 3\text{Tr}(Y_u Y_u^\dagger) + \text{Tr}(Y_\nu Y_\nu^\dagger) \right)
\end{aligned} \tag{24}$$

$$\begin{aligned}
\beta_{Y_d}^{(2)} = & + \frac{1}{80} \left( 20 \left( 11Y_d Y_u^\dagger Y_u Y_u^\dagger Y_u - 4Y_d Y_d^\dagger Y_d Y_u^\dagger Y_u + 6Y_d Y_d^\dagger Y_d Y_d^\dagger Y_d - Y_d Y_u^\dagger Y_u Y_d^\dagger Y_d \right) \right. \\
& + Y_d Y_d^\dagger Y_d \left( 187g_1^2 + 187g_{BY}^2 + 14\sqrt{10}g_{BY}g_B + 160g_B^2 + 14\sqrt{10}g_1g_{YB} + 160g_{YB}^2 + 675g_2^2 + 1280g_3^2 + 960\lambda_1 \right. \\
& - 540\text{Tr}(Y_d Y_d^\dagger) - 180\text{Tr}(Y_e Y_e^\dagger) - 540\text{Tr}(Y_u Y_u^\dagger) - 180\text{Tr}(Y_\nu Y_\nu^\dagger) \Big) \\
& - Y_d Y_u^\dagger Y_u \left( 79g_1^2 + 79g_{BY}^2 + 50\sqrt{10}g_{BY}g_B + 160g_B^2 + 50\sqrt{10}g_1g_{YB} + 160g_{YB}^2 - 45g_2^2 + 1280g_3^2 \right. \\
& - 300\text{Tr}(Y_d Y_d^\dagger) - 100\text{Tr}(Y_e Y_e^\dagger) - 300\text{Tr}(Y_u Y_u^\dagger) - 100\text{Tr}(Y_\nu Y_\nu^\dagger) \Big) \\
& - \frac{1}{600} Y_d \left( 127g_1^4 + 254g_1^2g_{BY}^2 + 127g_{BY}^4 + 254\sqrt{10}g_1^2g_{BY}g_B + 254\sqrt{10}g_{BY}^3g_B + 645g_1^2g_B^2 \right. \\
& - 735g_{BY}^2g_B^2 - 590\sqrt{10}g_{BY}g_B^3 - 10150g_B^4 + 254\sqrt{10}g_1^3g_{YB} + 254\sqrt{10}g_1g_{BY}^2g_{YB} \\
& - 2760g_1g_{BY}g_Bg_{YB} - 590\sqrt{10}g_1g_B^2g_{YB} - 735g_1^2g_{YB}^2 + 645g_{BY}^2g_{YB}^2 - 590\sqrt{10}g_{BY}g_Bg_{YB}^2 \\
& - 20300g_B^2g_{YB}^2 - 590\sqrt{10}g_1g_{YB}^3 - 10150g_{YB}^4 + 810g_1^2g_2^2 + 810g_{BY}^2g_2^2 + 135\sqrt{10}g_{BY}g_Bg_2^2 \\
& - 675g_B^2g_2^2 + 135\sqrt{10}g_1g_{YB}g_2^2 - 675g_{YB}^2g_2^2 + 3450g_2^4 - 1240g_1^2g_3^2 - 1240g_{BY}^2g_3^2 \\
& - 80\sqrt{10}g_{BY}g_Bg_3^2 + 800g_B^2g_3^2 - 80\sqrt{10}g_1g_{YB}g_3^2 + 800g_{YB}^2g_3^2 - 5400g_2^2g_3^2 \\
& + 64800g_3^4 - 3600\lambda_1^2 - 300\lambda_3^2 \\
& - 75 \left( -2\sqrt{10}g_1g_{YB} - 2\sqrt{10}g_{BY}g_B + 5(32g_3^2 + 4g_B^2 + 4g_{YB}^2 + 9g_2^2) + 5g_1^2 + 5g_{BY}^2 \right) \text{Tr}(Y_d Y_d^\dagger) \\
& - 225 \left( 5(4g_B^2 + 4g_{YB}^2 + g_2^2) + 5g_1^2 + 5g_{BY}^2 + 6\sqrt{10}g_1g_{YB} + 6\sqrt{10}g_{BY}g_B \right) \text{Tr}(Y_e Y_e^\dagger) \\
& - 1275g_1^2\text{Tr}(Y_u Y_u^\dagger) - 1275g_{BY}^2\text{Tr}(Y_u Y_u^\dagger) - 750\sqrt{10}g_{BY}g_B\text{Tr}(Y_u Y_u^\dagger) \\
& - 1500g_B^2\text{Tr}(Y_u Y_u^\dagger) - 750\sqrt{10}g_1g_{YB}\text{Tr}(Y_u Y_u^\dagger) - 1500g_{YB}^2\text{Tr}(Y_u Y_u^\dagger) \\
& - 3375g_2^2\text{Tr}(Y_u Y_u^\dagger) - 12000g_3^2\text{Tr}(Y_u Y_u^\dagger) - 225g_1^2\text{Tr}(Y_\nu Y_\nu^\dagger) - 225g_{BY}^2\text{Tr}(Y_\nu Y_\nu^\dagger) \\
& - 450\sqrt{10}g_{BY}g_B\text{Tr}(Y_\nu Y_\nu^\dagger) - 4500g_B^2\text{Tr}(Y_\nu Y_\nu^\dagger) - 450\sqrt{10}g_1g_{YB}\text{Tr}(Y_\nu Y_\nu^\dagger) \\
& - 4500g_{YB}^2\text{Tr}(Y_\nu Y_\nu^\dagger) - 1125g_2^2\text{Tr}(Y_\nu Y_\nu^\dagger) + 4050\text{Tr}(Y_d Y_d^\dagger Y_d Y_d^\dagger) - 900\text{Tr}(Y_d Y_u^\dagger Y_u Y_d^\dagger) \\
& + 1350\text{Tr}(Y_e Y_e^\dagger Y_e Y_e^\dagger) + 4050\text{Tr}(Y_u Y_u^\dagger Y_u Y_u^\dagger) + 1350\text{Tr}(Y_\nu Y_\nu^\dagger Y_\nu Y_\nu^\dagger) - 300\text{Tr}(Y_\nu Y_\nu^\dagger Y_e^T Y_e^*) \\
& \left. + 1800\text{Tr}(Y_\nu Y_x^* Y_x Y_\nu^\dagger) \right)
\end{aligned} \tag{25}$$

$$\begin{aligned}
\beta_{Y_e}^{(1)} = & + \frac{3}{2} \left( -Y_e Y_\nu^* Y_\nu^T + Y_e Y_e^\dagger Y_e \right) \\
& + Y_e \left( -\frac{9}{4}g_1^2 - \frac{9}{4}g_{BY}^2 - 27\frac{1}{\sqrt{10}}g_{BY}g_B - 9g_B^2 - 27\frac{1}{\sqrt{10}}g_1g_{YB} - 9g_{YB}^2 - \frac{9}{4}g_2^2 + 3\text{Tr}(Y_d Y_d^\dagger) \right. \\
& \left. + \text{Tr}(Y_e Y_e^\dagger) + 3\text{Tr}(Y_u Y_u^\dagger) + \text{Tr}(Y_\nu Y_\nu^\dagger) \right)
\end{aligned} \tag{26}$$

$$\begin{aligned}
\beta_{Y_e}^{(2)} = & \frac{1}{400} \left( 5 \left( 20 \left( 6Y_e Y_e^\dagger Y_e Y_e^\dagger Y_e - 4Y_e Y_e^\dagger Y_e Y_\nu^* Y_\nu^T + 14Y_e Y_\nu^* Y_x Y_x^* Y_\nu^T - Y_e Y_\nu^* Y_\nu^T Y_e^\dagger Y_e \right. \right. \right. \\
& + 11Y_e Y_\nu^* Y_\nu^T Y_\nu^* Y_\nu^T \Big) \\
& + 3Y_e Y_e^\dagger Y_e \left( 129g_1^2 + 129g_{BY}^2 + 114\sqrt{10}g_{BY}g_B + 480g_B^2 + 114\sqrt{10}g_1g_{YB} + 480g_{YB}^2 + 225g_2^2 + 320\lambda_1 \right. \\
& - 180\text{Tr}\left(Y_d Y_d^\dagger\right) - 60\text{Tr}\left(Y_e Y_e^\dagger\right) - 180\text{Tr}\left(Y_u Y_u^\dagger\right) - 60\text{Tr}\left(Y_\nu Y_\nu^\dagger\right) \Big) \\
& + Y_e Y_\nu^* Y_\nu^T \left( -135g_1^2 - 135g_{BY}^2 - 234\sqrt{10}g_{BY}g_B - 1440g_B^2 - 234\sqrt{10}g_1g_{YB} - 1440g_{YB}^2 + 45g_2^2 \right. \\
& + 300\text{Tr}\left(Y_d Y_d^\dagger\right) + 100\text{Tr}\left(Y_e Y_e^\dagger\right) + 300\text{Tr}\left(Y_u Y_u^\dagger\right) + 100\text{Tr}\left(Y_\nu Y_\nu^\dagger\right) \Big) \\
& + 2Y_e \left( 1371g_1^4 + 2742g_1^2g_{BY}^2 + 1371g_{BY}^4 + 2874\sqrt{10}g_1^2g_{BY}g_B + 2874\sqrt{10}g_{BY}^3g_B + 7065g_1^2g_B^2 \right. \\
& + 26085g_{BY}^2g_B^2 + 13170\sqrt{10}g_{BY}g_B^3 + 29250g_B^4 + 2874\sqrt{10}g_1^3g_{YB} + 2874\sqrt{10}g_1g_{BY}^2g_{YB} \\
& + 38040g_1g_{BY}g_Bg_{YB} + 13170\sqrt{10}g_1g_B^2g_{YB} + 26085g_1^2g_{YB}^2 + 7065g_{BY}^2g_{YB}^2 + 13170\sqrt{10}g_{BY}g_Bg_{YB}^2 \\
& + 58500g_B^2g_{YB}^2 + 13170\sqrt{10}g_1g_{YB}^3 + 29250g_{YB}^4 + 270g_1^2g_2^2 + 270g_{BY}^2g_2^2 + 675\sqrt{10}g_{BY}g_Bg_2^2 \\
& + 2025g_B^2g_2^2 + 675\sqrt{10}g_1g_{YB}g_2^2 + 2025g_{YB}^2g_2^2 - 1150g_2^4 + 1200\lambda_1^2 + 100\lambda_3^2 \\
& + 25 \left( -2\sqrt{10}g_1g_{YB} - 2\sqrt{10}g_{BY}g_B + 5 \left( 32g_3^2 + 4g_B^2 + 4g_{YB}^2 + 9g_2^2 \right) + 5g_1^2 + 5g_{BY}^2 \right) \text{Tr}\left(Y_d Y_d^\dagger\right) \\
& + 75 \left( 5 \left( 4g_B^2 + 4g_{YB}^2 + g_2^2 \right) + 5g_1^2 + 5g_{BY}^2 + 6\sqrt{10}g_1g_{YB} + 6\sqrt{10}g_{BY}g_B \right) \text{Tr}\left(Y_e Y_e^\dagger\right) \\
& + 425g_1^2\text{Tr}\left(Y_u Y_u^\dagger\right) + 425g_{BY}^2\text{Tr}\left(Y_u Y_u^\dagger\right) + 250\sqrt{10}g_{BY}g_B\text{Tr}\left(Y_u Y_u^\dagger\right) + 500g_B^2\text{Tr}\left(Y_u Y_u^\dagger\right) \\
& + 250\sqrt{10}g_1g_{YB}\text{Tr}\left(Y_u Y_u^\dagger\right) + 500g_{YB}^2\text{Tr}\left(Y_u Y_u^\dagger\right) + 1125g_2^2\text{Tr}\left(Y_u Y_u^\dagger\right) + 4000g_3^2\text{Tr}\left(Y_u Y_u^\dagger\right) \\
& + 75g_1^2\text{Tr}\left(Y_\nu Y_\nu^\dagger\right) + 75g_{BY}^2\text{Tr}\left(Y_\nu Y_\nu^\dagger\right) + 150\sqrt{10}g_{BY}g_B\text{Tr}\left(Y_\nu Y_\nu^\dagger\right) + 1500g_B^2\text{Tr}\left(Y_\nu Y_\nu^\dagger\right) \\
& + 150\sqrt{10}g_1g_{YB}\text{Tr}\left(Y_\nu Y_\nu^\dagger\right) + 1500g_{YB}^2\text{Tr}\left(Y_\nu Y_\nu^\dagger\right) + 375g_2^2\text{Tr}\left(Y_\nu Y_\nu^\dagger\right) - 1350\text{Tr}\left(Y_d Y_d^\dagger Y_d Y_d^\dagger\right) \\
& + 300\text{Tr}\left(Y_d Y_u^\dagger Y_u Y_d^\dagger\right) - 450\text{Tr}\left(Y_e Y_e^\dagger Y_e Y_e^\dagger\right) - 1350\text{Tr}\left(Y_u Y_u^\dagger Y_u Y_u^\dagger\right) - 450\text{Tr}\left(Y_\nu Y_\nu^\dagger Y_\nu Y_\nu^\dagger\right) \\
& + 100\text{Tr}\left(Y_\nu Y_\nu^\dagger Y_e^T Y_e^*\right) - 600\text{Tr}\left(Y_\nu Y_x^* Y_x Y_\nu^\dagger\right) \Big) \Big) \tag{27}
\end{aligned}$$

$$\begin{aligned}
\beta_{Y_\nu}^{(1)} = & + \frac{1}{2} \left( -3Y_e^T Y_e^* Y_\nu + 3Y_\nu Y_\nu^\dagger Y_\nu + 4Y_\nu Y_x^* Y_x \right) \\
& + Y_\nu \left( -\frac{9}{20}g_1^2 - \frac{9}{20}g_{BY}^2 - 9\frac{1}{\sqrt{10}}g_{BY}g_B - 9g_B^2 - 9\frac{1}{\sqrt{10}}g_1g_{YB} - 9g_{YB}^2 - \frac{9}{4}g_2^2 + 3\text{Tr}\left(Y_d Y_d^\dagger\right) + \text{Tr}\left(Y_e Y_e^\dagger\right) \right. \\
& + 3\text{Tr}\left(Y_u Y_u^\dagger\right) + \text{Tr}\left(Y_\nu Y_\nu^\dagger\right) \Big) \tag{28}
\end{aligned}$$

$$\begin{aligned}
\beta_{Y_\nu}^{(2)} = & \frac{1}{400} \left( 5 \left( -243g_1^2 Y_e^T Y_e^* Y_\nu - 243g_{BY}^2 Y_e^T Y_e^* Y_\nu - 342\sqrt{10}g_{BY}g_B Y_e^T Y_e^* Y_\nu \right. \right. \\
& - 1440g_B^2 Y_e^T Y_e^* Y_\nu - 342\sqrt{10}g_1g_{YB} Y_e^T Y_e^* Y_\nu - 1440g_{YB}^2 Y_e^T Y_e^* Y_\nu \\
& + 45g_2^2 Y_e^T Y_e^* Y_\nu + 120Y_\nu Y_\nu^\dagger Y_\nu Y_\nu^\dagger Y_\nu - 20Y_\nu Y_\nu^\dagger Y_e^T Y_e^* Y_\nu - 40Y_\nu Y_x^* Y_x Y_\nu^\dagger Y_\nu \\
& - 160Y_\nu Y_x^* Y_x Y_x^* Y_\nu + 560Y_\nu Y_x^* Y_\nu^T Y_\nu^* Y_x - 80Y_e^T Y_e^* Y_\nu Y_\nu^\dagger Y_\nu + 220Y_e^T Y_e^* Y_e^T Y_e^* Y_\nu \Big)
\end{aligned}$$

$$\begin{aligned}
& + 300Y_e^T Y_e^* Y_\nu \text{Tr}(Y_d Y_d^\dagger) + 100Y_e^T Y_e^* Y_\nu \text{Tr}(Y_e Y_e^\dagger) + 300Y_e^T Y_e^* Y_\nu \text{Tr}(Y_u Y_u^\dagger) \\
& + 3Y_\nu Y_\nu^\dagger Y_\nu \left( 93g_1^2 + 93g_{BY}^2 + 78\sqrt{10}g_{BY}g_B + 480g_B^2 + 78\sqrt{10}g_1g_{YB} + 480g_{YB}^2 + 225g_2^2 + 320\lambda_1 \right. \\
& - 180\text{Tr}(Y_d Y_d^\dagger) - 60\text{Tr}(Y_e Y_e^\dagger) - 180\text{Tr}(Y_u Y_u^\dagger) - 60\text{Tr}(Y_\nu Y_\nu^\dagger) \Big) \\
& + 100Y_e^T Y_e^* Y_\nu \text{Tr}(Y_\nu Y_\nu^\dagger) \\
& - 32Y_\nu Y_x^* Y_x \left( -150g_B^2 - 150g_{YB}^2 + 15\text{Tr}(Y_x Y_x^*) - 20\lambda_3 + 9\sqrt{10}g_1g_{YB} + 9\sqrt{10}g_{BY}g_B \right) \\
& + 2Y_\nu \left( 105g_1^4 + 210g_1^2g_{BY}^2 + 105g_{BY}^4 + 756\sqrt{10}g_1^2g_{BY}g_B + 756\sqrt{10}g_{BY}^3g_B + 2805g_1^2g_B^2 \right. \\
& + 11985g_{BY}^2g_B^2 + 7590\sqrt{10}g_{BY}g_B^3 + 29250g_B^4 + 756\sqrt{10}g_1^3g_{YB} + 756\sqrt{10}g_1g_{BY}^2g_{YB} \\
& + 18360g_1g_{BY}g_Bg_{YB} + 7590\sqrt{10}g_1g_B^2g_{YB} + 11985g_1^2g_{YB}^2 + 2805g_{BY}^2g_{YB}^2 + 7590\sqrt{10}g_{BY}g_Bg_{YB}^2 \\
& + 58500g_B^2g_{YB}^2 + 7590\sqrt{10}g_1g_{YB}^3 + 29250g_{YB}^4 - 270g_1^2g_2^2 - 270g_{BY}^2g_2^2 + 135\sqrt{10}g_{BY}g_Bg_2^2 \\
& + 2025g_B^2g_2^2 + 135\sqrt{10}g_1g_{YB}g_2^2 + 2025g_{YB}^2g_2^2 - 1150g_2^4 + 1200\lambda_1^2 + 100\lambda_3^2 \Big) \\
& + 25 \left( -2\sqrt{10}g_1g_{YB} - 2\sqrt{10}g_{BY}g_B + 5(32g_3^2 + 4g_B^2 + 4g_{YB}^2 + 9g_2^2) + 5g_1^2 + 5g_{BY}^2 \right) \text{Tr}(Y_d Y_d^\dagger) \\
& + 75 \left( 5(4g_B^2 + 4g_{YB}^2 + g_2^2) + 5g_1^2 + 5g_{BY}^2 + 6\sqrt{10}g_1g_{YB} + 6\sqrt{10}g_{BY}g_B \right) \text{Tr}(Y_e Y_e^\dagger) \\
& + 425g_1^2 \text{Tr}(Y_u Y_u^\dagger) + 425g_{BY}^2 \text{Tr}(Y_u Y_u^\dagger) + 250\sqrt{10}g_{BY}g_B \text{Tr}(Y_u Y_u^\dagger) + 500g_B^2 \text{Tr}(Y_u Y_u^\dagger) \\
& + 250\sqrt{10}g_1g_{YB} \text{Tr}(Y_u Y_u^\dagger) + 500g_{YB}^2 \text{Tr}(Y_u Y_u^\dagger) + 1125g_2^2 \text{Tr}(Y_u Y_u^\dagger) + 4000g_3^2 \text{Tr}(Y_u Y_u^\dagger) \\
& + 75g_1^2 \text{Tr}(Y_\nu Y_\nu^\dagger) + 75g_{BY}^2 \text{Tr}(Y_\nu Y_\nu^\dagger) + 150\sqrt{10}g_{BY}g_B \text{Tr}(Y_\nu Y_\nu^\dagger) + 1500g_B^2 \text{Tr}(Y_\nu Y_\nu^\dagger) \\
& + 150\sqrt{10}g_1g_{YB} \text{Tr}(Y_\nu Y_\nu^\dagger) + 1500g_{YB}^2 \text{Tr}(Y_\nu Y_\nu^\dagger) + 375g_2^2 \text{Tr}(Y_\nu Y_\nu^\dagger) - 1350\text{Tr}(Y_d Y_d^\dagger Y_d Y_d^\dagger) \\
& + 300\text{Tr}(Y_d Y_u^\dagger Y_u Y_d^\dagger) - 450\text{Tr}(Y_e Y_e^\dagger Y_e Y_e^\dagger) - 1350\text{Tr}(Y_u Y_u^\dagger Y_u Y_u^\dagger) - 450\text{Tr}(Y_\nu Y_\nu^\dagger Y_\nu Y_\nu^\dagger) \\
& + 100\text{Tr}(Y_\nu Y_\nu^\dagger Y_e^T Y_e^*) - 600\text{Tr}(Y_\nu Y_x^* Y_x Y_\nu^\dagger) \Big) \tag{29}
\end{aligned}$$

$$\begin{aligned}
\beta_{Y_u}^{(1)} &= -\frac{3}{2} \left( -Y_u Y_u^\dagger Y_u + Y_u Y_d^\dagger Y_d \right) \\
&+ Y_u \left( -\frac{17}{20}g_1^2 - \frac{17}{20}g_{BY}^2 - \sqrt{\frac{5}{2}}g_{BY}g_B - g_B^2 - \sqrt{\frac{5}{2}}g_1g_{YB} - g_{YB}^2 - \frac{9}{4}g_2^2 - 8g_3^2 + 3\text{Tr}(Y_d Y_d^\dagger) + \text{Tr}(Y_e Y_e^\dagger) \right. \\
&+ 3\text{Tr}(Y_u Y_u^\dagger) + \text{Tr}(Y_\nu Y_\nu^\dagger) \Big) \tag{30}
\end{aligned}$$

$$\begin{aligned}
\beta_{Y_u}^{(2)} &= +\frac{1}{80} \left( 20(11Y_u Y_d^\dagger Y_d Y_d^\dagger Y_d - 4Y_u Y_u^\dagger Y_u Y_d^\dagger Y_d + 6Y_u Y_u^\dagger Y_u Y_u^\dagger Y_u - Y_u Y_d^\dagger Y_d Y_u^\dagger Y_u) \right. \\
&+ Y_u Y_u^\dagger Y_u \left( 223g_1^2 + 223g_{BY}^2 + 50\sqrt{10}g_{BY}g_B + 160g_B^2 + 50\sqrt{10}g_1g_{YB} + 160g_{YB}^2 + 675g_2^2 + 1280g_3^2 + 960\lambda_1 \right. \\
&- 540\text{Tr}(Y_d Y_d^\dagger) - 180\text{Tr}(Y_e Y_e^\dagger) - 540\text{Tr}(Y_u Y_u^\dagger) - 180\text{Tr}(Y_\nu Y_\nu^\dagger) \Big) \\
&- Y_u Y_d^\dagger Y_d \left( 43g_1^2 + 43g_{BY}^2 + 14\sqrt{10}g_{BY}g_B + 160g_B^2 + 14\sqrt{10}g_1g_{YB} + 160g_{YB}^2 - 45g_2^2 + 1280g_3^2 \right.
\end{aligned}$$

$$\begin{aligned}
& -300\text{Tr}\left(Y_d Y_d^\dagger\right) - 100\text{Tr}\left(Y_e Y_e^\dagger\right) - 300\text{Tr}\left(Y_u Y_u^\dagger\right) - 100\text{Tr}\left(Y_\nu Y_\nu^\dagger\right) \\
& + \frac{1}{600} Y_u \left( 1187g_1^4 + 2374g_1^2 g_{BY}^2 + 1187g_{BY}^4 + 2008\sqrt{10}g_1^2 g_{BY} g_B + 2008\sqrt{10}g_{BY}^3 g_B + 4095g_1^2 g_B^2 \right. \\
& + 16275g_{BY}^2 g_B^2 + 6650\sqrt{10}g_{BY} g_B^3 + 10150g_B^4 + 2008\sqrt{10}g_1^3 g_{YB} + 2008\sqrt{10}g_1 g_{BY}^2 g_{YB} \\
& + 24360g_1 g_{BY} g_B g_{YB} + 6650\sqrt{10}g_1 g_B^2 g_{YB} + 16275g_1^2 g_{YB}^2 + 4095g_{BY}^2 g_{YB}^2 + 6650\sqrt{10}g_{BY} g_B g_{YB}^2 \\
& + 20300g_B^2 g_{YB}^2 + 6650\sqrt{10}g_1 g_{YB}^3 + 10150g_{YB}^4 - 270g_1^2 g_2^2 - 270g_{BY}^2 g_2^2 + 405\sqrt{10}g_{BY} g_B g_2^2 \\
& + 675g_B^2 g_2^2 + 405\sqrt{10}g_1 g_{YB} g_2^2 + 675g_{YB}^2 g_2^2 - 3450g_2^4 + 760g_1^2 g_3^2 + 760g_{BY}^2 g_3^2 \\
& - 400\sqrt{10}g_{BY} g_B g_3^2 - 800g_B^2 g_3^2 - 400\sqrt{10}g_1 g_{YB} g_3^2 - 800g_{YB}^2 g_3^2 + 5400g_2^2 g_3^2 \\
& - 64800g_3^4 + 3600\lambda_1^2 + 300\lambda_3^2 \\
& + 75 \left( -2\sqrt{10}g_1 g_{YB} - 2\sqrt{10}g_{BY} g_B + 5 \left( 32g_3^2 + 4g_B^2 + 4g_{YB}^2 + 9g_2^2 \right) + 5g_1^2 + 5g_{BY}^2 \right) \text{Tr}\left(Y_d Y_d^\dagger\right) \\
& + 225 \left( 5 \left( 4g_B^2 + 4g_{YB}^2 + g_2^2 \right) + 5g_1^2 + 5g_{BY}^2 + 6\sqrt{10}g_1 g_{YB} + 6\sqrt{10}g_{BY} g_B \right) \text{Tr}\left(Y_e Y_e^\dagger\right) \\
& + 1275g_1^2 \text{Tr}\left(Y_u Y_u^\dagger\right) + 1275g_{BY}^2 \text{Tr}\left(Y_u Y_u^\dagger\right) + 750\sqrt{10}g_{BY} g_B \text{Tr}\left(Y_u Y_u^\dagger\right) + 1500g_B^2 \text{Tr}\left(Y_u Y_u^\dagger\right) \\
& + 750\sqrt{10}g_1 g_{YB} \text{Tr}\left(Y_u Y_u^\dagger\right) + 1500g_{YB}^2 \text{Tr}\left(Y_u Y_u^\dagger\right) + 3375g_2^2 \text{Tr}\left(Y_u Y_u^\dagger\right) + 12000g_3^2 \text{Tr}\left(Y_u Y_u^\dagger\right) \\
& + 225g_1^2 \text{Tr}\left(Y_\nu Y_\nu^\dagger\right) + 225g_{BY}^2 \text{Tr}\left(Y_\nu Y_\nu^\dagger\right) + 450\sqrt{10}g_{BY} g_B \text{Tr}\left(Y_\nu Y_\nu^\dagger\right) + 4500g_B^2 \text{Tr}\left(Y_\nu Y_\nu^\dagger\right) \\
& + 450\sqrt{10}g_1 g_{YB} \text{Tr}\left(Y_\nu Y_\nu^\dagger\right) + 4500g_{YB}^2 \text{Tr}\left(Y_\nu Y_\nu^\dagger\right) + 1125g_2^2 \text{Tr}\left(Y_\nu Y_\nu^\dagger\right) - 4050 \text{Tr}\left(Y_d Y_d^\dagger Y_d Y_d^\dagger\right) \\
& + 900 \text{Tr}\left(Y_d Y_u^\dagger Y_u Y_d^\dagger\right) - 1350 \text{Tr}\left(Y_e Y_e^\dagger Y_e Y_e^\dagger\right) - 4050 \text{Tr}\left(Y_u Y_u^\dagger Y_u Y_u^\dagger\right) - 1350 \text{Tr}\left(Y_\nu Y_\nu^\dagger Y_\nu Y_\nu^\dagger\right) \\
& + 300 \text{Tr}\left(Y_\nu Y_\nu^\dagger Y_e^T Y_e^*\right) - 1800 \text{Tr}\left(Y_\nu Y_x^* Y_x Y_\nu^\dagger\right) \Big) \tag{31}
\end{aligned}$$

### 3.4 Scalar Mass Terms

$$\beta_{\mu'}^{(1)} = -4 \left( (2\lambda_2 + 9g_B^2 + 9g_{YB}^2) \mu' + \lambda_3 \mu_2 - \mu' \text{Tr}\left(Y_x Y_x^*\right) \right) \tag{32}$$

$$\begin{aligned}
\beta_{\mu'}^{(2)} = & +36g_{BY}^2 g_B^2 \mu_2 + 72g_1 g_{BY} g_B g_{YB} \mu_2 + 36g_1^2 g_{YB}^2 \mu_2 - \frac{24}{5} g_1^2 \lambda_3 \mu_2 - \frac{24}{5} g_{BY}^2 \lambda_3 \mu_2 - 24g_2^2 \lambda_3 \mu_2 \\
& - 8\lambda_3^2 \mu_2 + \frac{633}{5} g_{BY}^2 g_B^2 \mu' + 96\sqrt{10}g_{BY} g_B^3 \mu' + 1512g_B^4 \mu' + \frac{633}{5} g_1^2 g_{YB}^2 \mu' + 1800g_B^2 g_{YB}^2 \mu' \\
& + 96\sqrt{10}g_1 g_{YB}^3 \mu' + 1512g_{YB}^4 \mu' - 384g_B^2 \lambda_2 \mu' - 384g_{YB}^2 \lambda_2 \mu' - 40\lambda_2^2 \mu' - 2\lambda_3^2 \mu' \\
& + 24\lambda_3 \mu_2 \text{Tr}\left(Y_d Y_d^\dagger\right) + 8\lambda_3 \mu_2 \text{Tr}\left(Y_e Y_e^\dagger\right) + 24\lambda_3 \mu_2 \text{Tr}\left(Y_u Y_u^\dagger\right) + 8\lambda_3 \mu_2 \text{Tr}\left(Y_\nu Y_\nu^\dagger\right) \\
& + 30g_B^2 \mu' \text{Tr}\left(Y_x Y_x^*\right) + 30g_{YB}^2 \mu' \text{Tr}\left(Y_x Y_x^*\right) + 32\lambda_2 \mu' \text{Tr}\left(Y_x Y_x^*\right) - 12\mu' \text{Tr}\left(Y_\nu Y_x^* Y_x Y_\nu^\dagger\right) \\
& - 24\mu' \text{Tr}\left(Y_x Y_x^* Y_x Y_x^*\right) \tag{33}
\end{aligned}$$

$$\beta_{\mu_2}^{(1)} = -\frac{9}{10} g_1^2 \mu_2 - \frac{9}{10} g_{BY}^2 \mu_2 - \frac{9}{2} g_2^2 \mu_2 - 12\lambda_1 \mu_2 - 2\lambda_3 \mu' + 6\mu_2 \text{Tr}\left(Y_d Y_d^\dagger\right) + 2\mu_2 \text{Tr}\left(Y_e Y_e^\dagger\right)$$



$$\begin{aligned}
& + 6\mu_2 \text{Tr}(Y_u Y_u^\dagger) + 2\mu_2 \text{Tr}(Y_\nu Y_\nu^\dagger) \\
\beta_{\mu_2}^{(2)} = & + \frac{1671}{400} g_1^4 \mu_2 + \frac{81}{40} g_1^2 g_{BY}^2 \mu_2 + \frac{1671}{400} g_{BY}^4 \mu_2 + 12\sqrt{\frac{2}{5}} g_{BY}^3 g_B \mu_2 + \frac{153}{10} g_{BY}^2 g_B^2 \mu_2 + 12\sqrt{\frac{2}{5}} g_1^3 g_{YB} \mu_2 \\
& + \frac{153}{10} g_1^2 g_{YB}^2 \mu_2 + \frac{9}{8} g_1^2 g_2^2 \mu_2 + \frac{9}{8} g_{BY}^2 g_2^2 \mu_2 - \frac{145}{16} g_2^4 \mu_2 - \frac{72}{5} g_1^2 \lambda_1 \mu_2 - \frac{72}{5} g_{BY}^2 \lambda_1 \mu_2 \\
& - 72 g_2^2 \lambda_1 \mu_2 - 60 \lambda_1^2 \mu_2 - \lambda_3^2 \mu_2 + 18 g_{BY}^2 g_B^2 \mu' + 36 g_1 g_{BY} g_B g_{YB} \mu' + 18 g_1^2 g_{YB}^2 \mu' - 96 g_B^2 \lambda_3 \mu' \\
& - 96 g_{YB}^2 \lambda_3 \mu' - 4 \lambda_3^2 \mu' \\
& + \frac{1}{4} (160 g_3^2 + 20 g_B^2 + 20 g_{YB}^2 + 288 \lambda_1 - 2\sqrt{10} g_1 g_{YB} - 2\sqrt{10} g_{BY} g_B + 45 g_2^2 + 5 g_1^2 + 5 g_{BY}^2) \mu_2 \text{Tr}(Y_d Y_d^\dagger) \\
& + \frac{3}{4} (20 g_B^2 + 20 g_{YB}^2 + 32 \lambda_1 + 5 g_1^2 + 5 g_2^2 + 5 g_{BY}^2 + 6\sqrt{10} g_1 g_{YB} + 6\sqrt{10} g_{BY} g_B) \mu_2 \text{Tr}(Y_e Y_e^\dagger) \\
& + \frac{17}{4} g_1^2 \mu_2 \text{Tr}(Y_u Y_u^\dagger) + \frac{17}{4} g_{BY}^2 \mu_2 \text{Tr}(Y_u Y_u^\dagger) + 5\sqrt{\frac{5}{2}} g_{BY} g_B \mu_2 \text{Tr}(Y_u Y_u^\dagger) + 5 g_B^2 \mu_2 \text{Tr}(Y_u Y_u^\dagger) \\
& + 5\sqrt{\frac{5}{2}} g_1 g_{YB} \mu_2 \text{Tr}(Y_u Y_u^\dagger) + 5 g_{YB}^2 \mu_2 \text{Tr}(Y_u Y_u^\dagger) + \frac{45}{4} g_2^2 \mu_2 \text{Tr}(Y_u Y_u^\dagger) + 40 g_3^2 \mu_2 \text{Tr}(Y_u Y_u^\dagger) \\
& + 72 \lambda_1 \mu_2 \text{Tr}(Y_u Y_u^\dagger) + \frac{3}{4} g_1^2 \mu_2 \text{Tr}(Y_\nu Y_\nu^\dagger) + \frac{3}{4} g_{BY}^2 \mu_2 \text{Tr}(Y_\nu Y_\nu^\dagger) + 3\sqrt{\frac{5}{2}} g_{BY} g_B \mu_2 \text{Tr}(Y_\nu Y_\nu^\dagger) \\
& + 15 g_B^2 \mu_2 \text{Tr}(Y_\nu Y_\nu^\dagger) + 3\sqrt{\frac{5}{2}} g_1 g_{YB} \mu_2 \text{Tr}(Y_\nu Y_\nu^\dagger) + 15 g_{YB}^2 \mu_2 \text{Tr}(Y_\nu Y_\nu^\dagger) + \frac{15}{4} g_2^2 \mu_2 \text{Tr}(Y_\nu Y_\nu^\dagger) \\
& + 24 \lambda_1 \mu_2 \text{Tr}(Y_\nu Y_\nu^\dagger) + 8 \lambda_3 \mu' \text{Tr}(Y_x Y_x^*) - \frac{27}{2} \mu_2 \text{Tr}(Y_d Y_d^\dagger Y_d Y_d^\dagger) - 21 \mu_2 \text{Tr}(Y_d Y_u^\dagger Y_u Y_d^\dagger) \\
& - \frac{9}{2} \mu_2 \text{Tr}(Y_e Y_e^\dagger Y_e Y_e^\dagger) - \frac{27}{2} \mu_2 \text{Tr}(Y_u Y_u^\dagger Y_u Y_u^\dagger) - \frac{9}{2} \mu_2 \text{Tr}(Y_\nu Y_\nu^\dagger Y_\nu Y_\nu^\dagger) - 7 \mu_2 \text{Tr}(Y_\nu Y_\nu^\dagger Y_e^T Y_e^*) \\
& - 6 \mu_2 \text{Tr}(Y_\nu Y_x^* Y_x Y_\nu^\dagger)
\end{aligned} \tag{34}$$

$$\begin{aligned}
& - 6 \mu_2 \text{Tr}(Y_\nu Y_x^* Y_x Y_\nu^\dagger)
\end{aligned} \tag{35}$$

### 3.5 Vacuum expectation values

$$\begin{aligned}
\beta_v^{(1)} = & \frac{1}{20} v (9 g_1^2 + 9 g_{BY}^2 + 45 g_2^2 + 3 g_1^2 \text{Xi} + 3 g_{BY}^2 \text{Xi} + 15 g_2^2 \text{Xi} - 60 \text{Tr}(Y_d Y_d^\dagger) - 20 \text{Tr}(Y_e Y_e^\dagger) - 60 \text{Tr}(Y_u Y_u^\dagger) \\
& - 20 \text{Tr}(Y_\nu Y_\nu^\dagger)) \\
\beta_v^{(2)} = & \frac{1}{800} v (-1293 g_1^4 - 54 g_1^2 g_{BY}^2 - 1293 g_{BY}^4 - 960 \sqrt{10} g_{BY}^3 g_B - 6120 g_{BY}^2 g_B^2 - 960 \sqrt{10} g_1^3 g_{YB} \\
& - 6120 g_1^2 g_{YB}^2 - 270 g_1^2 g_2^2 - 270 g_{BY}^2 g_2^2 + 6775 g_2^4 - 4800 \lambda_1^2 - 400 \lambda_3^2 + 18 g_1^4 \text{Xi} + 36 g_1^2 g_{BY}^2 \text{Xi} \\
& + 18 g_{BY}^4 \text{Xi} + 180 g_1^2 g_2^2 \text{Xi} + 180 g_{BY}^2 g_2^2 \text{Xi} + 2250 g_2^4 \text{Xi} + 18 g_1^4 \text{Xi}^2 + 36 g_1^2 g_{BY}^2 \text{Xi}^2 + 18 g_{BY}^4 \text{Xi}^2 + 180 g_1^2 g_2^2 \text{Xi}^2 \\
& + 180 g_{BY}^2 g_2^2 \text{Xi}^2 - 450 g_2^4 \text{Xi}^2 \\
& - 20 (-10 \sqrt{10} g_{BY} g_B - 10 \sqrt{10} g_1 g_{YB} + g_1^2 (18 \text{Xi} + 25) + g_{BY}^2 (18 \text{Xi} + 25)) \\
& + 5 (160 g_3^2 + 18 g_2^2 \text{Xi} + 20 g_B^2 + 20 g_{YB}^2 + 45 g_2^2) \text{Tr}(Y_d Y_d^\dagger)
\end{aligned} \tag{36}$$

$$\begin{aligned}
& -60\left(30\sqrt{10}g_1g_{YB} + 30\sqrt{10}g_{BY}g_B + 5\left(20g_B^2 + 20g_{YB}^2 + g_2^2(2\text{Xi} + 5)\right) + g_1^2(2\text{Xi} + 25) + g_{BY}^2(2\text{Xi} + 25)\right)\text{Tr}\left(Y_e Y_e^\dagger\right) \\
& -1700g_1^2\text{Tr}\left(Y_u Y_u^\dagger\right) - 1700g_{BY}^2\text{Tr}\left(Y_u Y_u^\dagger\right) - 1000\sqrt{10}g_{BY}g_B\text{Tr}\left(Y_u Y_u^\dagger\right) \\
& -2000g_B^2\text{Tr}\left(Y_u Y_u^\dagger\right) - 1000\sqrt{10}g_1g_{YB}\text{Tr}\left(Y_u Y_u^\dagger\right) - 2000g_{YB}^2\text{Tr}\left(Y_u Y_u^\dagger\right) \\
& -4500g_2^2\text{Tr}\left(Y_u Y_u^\dagger\right) - 16000g_3^2\text{Tr}\left(Y_u Y_u^\dagger\right) - 360g_1^2\text{Xi}\text{Tr}\left(Y_u Y_u^\dagger\right) - 360g_{BY}^2\text{Xi}\text{Tr}\left(Y_u Y_u^\dagger\right) \\
& -1800g_2^2\text{Xi}\text{Tr}\left(Y_u Y_u^\dagger\right) - 300g_1^2\text{Tr}\left(Y_\nu Y_\nu^\dagger\right) - 300g_{BY}^2\text{Tr}\left(Y_\nu Y_\nu^\dagger\right) - 600\sqrt{10}g_{BY}g_B\text{Tr}\left(Y_\nu Y_\nu^\dagger\right) \\
& -6000g_B^2\text{Tr}\left(Y_\nu Y_\nu^\dagger\right) - 600\sqrt{10}g_1g_{YB}\text{Tr}\left(Y_\nu Y_\nu^\dagger\right) - 6000g_{YB}^2\text{Tr}\left(Y_\nu Y_\nu^\dagger\right) \\
& -1500g_2^2\text{Tr}\left(Y_\nu Y_\nu^\dagger\right) - 120g_1^2\text{Xi}\text{Tr}\left(Y_\nu Y_\nu^\dagger\right) - 120g_{BY}^2\text{Xi}\text{Tr}\left(Y_\nu Y_\nu^\dagger\right) - 600g_2^2\text{Xi}\text{Tr}\left(Y_\nu Y_\nu^\dagger\right) \\
& +5400\text{Tr}\left(Y_d Y_d^\dagger Y_d Y_d^\dagger\right) - 1200\text{Tr}\left(Y_d Y_u^\dagger Y_u Y_d^\dagger\right) + 1800\text{Tr}\left(Y_e Y_e^\dagger Y_e Y_e^\dagger\right) + 5400\text{Tr}\left(Y_u Y_u^\dagger Y_u Y_u^\dagger\right) \\
& +1800\text{Tr}\left(Y_\nu Y_\nu^\dagger Y_\nu Y_\nu^\dagger\right) - 400\text{Tr}\left(Y_\nu Y_\nu^\dagger Y_e^T Y_e^*\right) + 2400\text{Tr}\left(Y_\nu Y_x^* Y_x Y_\nu^\dagger\right)
\end{aligned} \tag{37}$$

$$\beta_x^{(1)} = -2x\text{Tr}\left(Y_x Y_x^*\right) \tag{38}$$

$$\beta_x^{(2)} = -x\left(-12\text{Tr}\left(Y_x Y_x^* Y_x Y_x^*\right) + 15\left(g_B^2 + g_{YB}^2\right)\text{Tr}\left(Y_x Y_x^*\right) + 4\lambda_2^2 - 6\text{Tr}\left(Y_\nu Y_x^* Y_x Y_\nu^\dagger\right) + \lambda_3^2\right) \tag{39}$$

## 4 Field Rotations

### 4.1 Rotations in gauge sector for eigenstates 'EWSB'

$$\begin{pmatrix} B_\rho \\ W_{3\rho} \\ \text{VBp}(\{\text{lt1}\}) \end{pmatrix} = Z^{\gamma ZZ'} \begin{pmatrix} \gamma_\rho \\ Z_\rho \\ Z'_\rho \end{pmatrix} \tag{40}$$

$$\begin{pmatrix} W_{1\rho} \\ W_{2\rho} \end{pmatrix} = Z^W \begin{pmatrix} W_\rho^- \\ W_\rho^- \end{pmatrix} \tag{41}$$

$$\tag{42}$$

The mixing matrices are parametrized by

$$Z^{\gamma ZZ'} = \begin{pmatrix} \cos \Theta_W & -\cos \Theta'_W \sin \Theta_W & \sin \Theta_W \sin \Theta'_W \\ \sin \Theta_W & \cos \Theta_W \cos \Theta'_W & -\cos \Theta_W \sin \Theta'_W \\ 0 & \sin \Theta'_W & \cos \Theta'_W \end{pmatrix} \tag{43}$$

$$Z^W = \begin{pmatrix} \frac{1}{\sqrt{2}} & \frac{1}{\sqrt{2}} \\ -i\frac{1}{\sqrt{2}} & i\frac{1}{\sqrt{2}} \end{pmatrix} \tag{44}$$

(45)

## 4.2 Rotations in Mass sector for eigenstates 'EWSB'

### 4.2.1 Mass Matrices for Scalars

- **Mass matrix for Higgs**, Basis:  $(\text{phiH}, \text{phiB}), (\text{phiH}, \text{phiB})$

$$m_h^2 = \begin{pmatrix} -3\lambda_1 v^2 - \frac{1}{2}\lambda_3 x^2 + \mu_2 & -\lambda_3 vx \\ -\lambda_3 vx & -3\lambda_2 x^2 - \frac{1}{2}\lambda_3 v^2 + \mu' \end{pmatrix} \quad (46)$$

This matrix is diagonalized by  $Z^H$ :

$$Z^H m_h^2 Z^{H,\dagger} = m_{2,h}^{dia} \quad (47)$$

with

$$\text{phiH} = \sum_j Z_{j1}^H h_j, \quad \text{phiB} = \sum_j Z_{j2}^H h_j \quad (48)$$

- **Mass matrix for Pseudo-Scalar Higgs**, Basis:  $(\text{sigmaH}, \text{sigmaB}), (\text{sigmaH}, \text{sigmaB})$

$$m_{A_h}^2 = \begin{pmatrix} -\frac{1}{2}\lambda_3 x^2 - \lambda_1 v^2 + \mu_2 & 0 \\ 0 & -\frac{1}{2}\lambda_3 v^2 - \lambda_2 x^2 + \mu' \end{pmatrix} + \xi_Z m^2(Z) + \xi_{Z'} m^2(Z') \quad (49)$$

Gauge fixing contributions:

$$m^2(\xi_Z) = \begin{pmatrix} m_{\text{sigmaHsigmaH}} & m_{\text{sigmaBsigmaH}} \\ m_{\text{sigmaHsigmaB}} & m_{\text{sigmaBsigmaB}} \end{pmatrix} \quad (50)$$

$$m_{\text{sigmaHsigmaH}} = \frac{1}{4}v^2 \left( \cos \Theta'_W (g_1 \sin \Theta_W + g_2 \cos \Theta_W) - g_{BY} \sin \Theta'_W \right)^2 \quad (51)$$

$$m_{\text{sigmaHsigmaB}} = vx \left( \cos \Theta'_W (g_1 \sin \Theta_W + g_2 \cos \Theta_W) - g_{BY} \sin \Theta'_W \right) \left( -g_B \sin \Theta'_W + g_{YB} \cos \Theta'_W \sin \Theta_W \right) \quad (52)$$

$$m_{\text{sigmaBsigmaB}} = 4x^2 \left( -g_B \sin \Theta'_W + g_{YB} \cos \Theta'_W \sin \Theta_W \right)^2 \quad (53)$$

$$m^2(\xi_{Z'}) = \begin{pmatrix} m_{\text{sigmaHsigmaH}} & m_{\text{sigmaBsigmaH}} \\ m_{\text{sigmaHsigmaB}} & m_{\text{sigmaBsigmaB}} \end{pmatrix} \quad (54)$$

$$m_{\text{sigmaHsigmaH}} = \frac{1}{4}v^2 \left( (g_1 \sin \Theta_W + g_2 \cos \Theta_W) \sin \Theta'_W + g_{BY} \cos \Theta'_W \right)^2 \quad (55)$$

$$m_{\text{sigmaHsigmaB}} = vx \left( g_B \cos \Theta'_W + g_{YB} \sin \Theta_W \sin \Theta'_W \right) \left( (g_1 \sin \Theta_W + g_2 \cos \Theta_W) \sin \Theta'_W + g_{BY} \cos \Theta'_W \right) \quad (56)$$

$$m_{\text{sigmaBsigmaB}} = 4x^2 \left( g_B \cos \Theta'_W + g_{YB} \sin \Theta_W \sin \Theta'_W \right)^2 \quad (57)$$

This matrix is diagonalized by  $Z^A$ :

$$Z^A m_{A_h}^2 Z^{A,\dagger} = m_{2,A_h}^{dia} \quad (58)$$

with

$$\text{sigmaH} = \sum_j Z_{j1}^A A_{h,j}, \quad \text{sigmaB} = \sum_j Z_{j2}^A A_{h,j} \quad (59)$$

#### 4.2.2 Mass Matrices for Fermions

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

$$m_d = \left( \frac{1}{\sqrt{2}} v \delta_{\alpha_1 \beta_1} Y_d^T \right) \quad (60)$$

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

$$U_L^{d,*} m_d U_R^{d,\dagger} = m_d^{dia} \quad (61)$$

with

$$d_{L,i\alpha} = \sum_{t_2} U_{L,ji}^{d,*} D_{L,j\alpha} \quad (62)$$

$$d_{R,i\alpha} = \sum_{t_2} U_{R,ij}^d D_{R,j\alpha}^* \quad (63)$$

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

$$m_u = \left( \frac{1}{\sqrt{2}} v \delta_{\alpha_1 \beta_1} Y_u^T \right) \quad (64)$$

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

$$U_L^{u,*} m_u U_R^{u,\dagger} = m_u^{dia} \quad (65)$$

with

$$u_{L,i\alpha} = \sum_{t_2} U_{L,ji}^{u,*} U_{L,j\alpha} \quad (66)$$

$$u_{R,i\alpha} = \sum_{t_2} U_{R,ij}^u U_{R,j\alpha}^* \quad (67)$$

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

$$m_e = \left( \frac{1}{\sqrt{2}} v Y_e^T \right) \quad (68)$$

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

$$U_L^{e,*} m_e U_R^{e,\dagger} = m_e^{dia} \quad (69)$$

with

$$e_{L,i} = \sum_{t_2} U_{L,ji}^{e,*} E_{L,j} \quad (70)$$

$$e_{R,i} = \sum_{t_2} U_{R,ij}^e E_{R,j}^* \quad (71)$$

- **Mass matrix for Neutrinos**, Basis:  $\left( \nu_L, \text{conj}(\nu_R) \right), \left( \nu_L, \text{conj}(\nu_R) \right)$

$$m_\nu = \begin{pmatrix} 0 & \frac{1}{\sqrt{2}} v Y_\nu \\ \frac{1}{\sqrt{2}} v Y_\nu^T & \sqrt{2} x Y_x \end{pmatrix} \quad (72)$$

This matrix is diagonalized by  $U^V$ :

$$U^{V,*} m_\nu U^{V,\dagger} = m_\nu^{dia} \quad (73)$$

with

$$\nu_{L,i} = \sum_j U_{ji}^{V,*} \text{VL}(\{\text{gt2}\}), \quad \nu_R(\{\text{gt1}\}) = \sum_j U_{ji}^V \text{conj}(\text{VL}(\{\text{gt2}\})) \quad (74)$$

## 5 Vacuum Expectation Values

$$H^0 = \frac{1}{\sqrt{2}} \text{phiH} + \frac{1}{\sqrt{2}} v + i \frac{1}{\sqrt{2}} \text{sigmaH} \quad (75)$$

$$\text{BiD} = \frac{1}{\sqrt{2}} \text{phiB} + \frac{1}{\sqrt{2}} x + i \frac{1}{\sqrt{2}} \text{sigmaB} \quad (76)$$

## 6 Tadpole Equations

$$\frac{\partial V}{\partial \text{phiH}} = -\lambda_1 v^3 + v \left( -\frac{1}{2} \lambda_3 x^2 + \mu_2 \right) \quad (77)$$

$$\frac{\partial V}{\partial \text{phiB}} = \left( -\frac{1}{2} \lambda_3 v^2 + \mu' \right) x - \lambda_2 x^3 \quad (78)$$

## 7 Particle content for eigenstates 'EWSB'

Name	Type	complex/real	Generations	Indices
$H^-$	Scalar	complex	1	
$h$	Scalar	real	2	generation, 2
$A_h$	Scalar	real	2	generation, 2

$d$	Fermion	Dirac	3	generation, 3, color, 3
$u$	Fermion	Dirac	3	generation, 3, color, 3
$e$	Fermion	Dirac	3	generation, 3
$\nu$	Fermion	Majorana	6	generation, 6
$g$	Vector	real	1	color, 8, lorentz, 4
$\gamma$	Vector	real	1	lorentz, 4
$Z$	Vector	real	1	lorentz, 4
$Z'$	Vector	real	1	lorentz, 4
$W^-$	Vector	complex	1	lorentz, 4
$\eta^G$	Ghost	real	1	color, 8
$\eta^\gamma$	Ghost	real	1	
$\eta^Z$	Ghost	real	1	
$\eta^{Z'}$	Ghost	real	1	
$\eta^-$	Ghost	complex	1	
$\eta^+$	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, 0, 0)\right)\Gamma_{\tilde{h}_j, \gamma, \gamma}^* \Gamma_{\tilde{h}_i, \gamma, \gamma} + 4\left(-\frac{1}{2}\text{rMS} + B_0(p^2, 0, m_Z^2)\right)\Gamma_{\tilde{h}_j, Z, \gamma}^* \Gamma_{\tilde{h}_i, Z, \gamma} + 2\left(-\frac{1}{2}\text{rMS} + B_0(p^2, m_Z^2, m_{Z'}^2)\right)\Gamma_{\tilde{h}_j, Z', \gamma}^* \Gamma_{\tilde{h}_i, Z', \gamma} \\
& + 4\left(-\frac{1}{2}\text{rMS} + B_0(p^2, 0, m_{Z'}^2)\right)\Gamma_{\tilde{h}_j, Z', \gamma}^* \Gamma_{\tilde{h}_i, Z', \gamma} + 4\left(-\frac{1}{2}\text{rMS} + B_0(p^2, m_Z^2, m_{Z'}^2)\right)\Gamma_{\tilde{h}_j, Z', Z}^* \Gamma_{\tilde{h}_i, Z', Z} + 2\left(-\frac{1}{2}\text{rMS} + B_0(p^2, m_{H^-}^2, m_{H^-}^2)\right)\Gamma_{\tilde{h}_j, H^-, * , H^-}^* \Gamma_{\tilde{h}_i, H^-, * , H^-} \\
& + B_0(p^2, m_{H^-}^2, m_{H^-}^2)\Gamma_{\tilde{h}_j, H^-, * , H^-}^* \Gamma_{\tilde{h}_i, H^-, * , H^-} + 4\left(-\frac{1}{2}\text{rMS} + B_0(p^2, m_{W^-}^2, m_{W^-}^2)\right)\Gamma_{\tilde{h}_j, W^+, W^-}^* \Gamma_{\tilde{h}_i, W^+, 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^+} \\
& - B_0(p^2, m_{\eta^Z}^2, m_{\eta^Z}^2)\Gamma_{\tilde{h}_i, \eta^{\bar{Z}}, \eta^Z} \Gamma_{\tilde{h}_j, \eta^{\bar{Z}}, \eta^Z} - 2B_0(p^2, m_{\eta^Z}^2, m_{\eta^{Z'}}^2)\Gamma_{\tilde{h}_i, \eta^{\bar{Z}'}, \eta^Z} \Gamma_{\tilde{h}_j, \eta^{\bar{Z}'}, \eta^Z} \\
& - B_0(p^2, m_{\eta^{Z'}}^2, m_{\eta^{Z'}}^2)\Gamma_{\tilde{h}_i, \eta^{\bar{Z}'}, \eta^{Z'}} \Gamma_{\tilde{h}_j, \eta^{\bar{Z}'}, \eta^{Z'}} - A_0(m_{H^-}^2)\Gamma_{\tilde{h}_i, \tilde{h}_j, H^-, * , H^-} \\
& + 2\Gamma_{\tilde{h}_j, W^+, H^-}^* \Gamma_{\tilde{h}_i, W^+, H^-} - F_0(p^2, m_{H^-}^2, m_{W^-}^2) + 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) + 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_{h,a}}^2) \Gamma_{\tilde{h}_i, \tilde{h}_j, A_{h,a}, A_{h,a}}
\end{aligned}$$

$$\begin{aligned}
& -\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_{h,a}}^2, m_{A_{h,b}}^2) \Gamma_{\check{h}_j, A_{h,a}, A_{h,b}}^* \Gamma_{\check{h}_i, A_{h,a}, 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) \\
& - 6 \sum_{a=1}^3 m_{u_a} \sum_{b=1}^3 B_0(p^2, m_{u_a}^2, m_{u_b}^2) m_{u_b} \left( \Gamma_{\check{h}_j, \bar{u}_a, u_b}^{L*} \Gamma_{\check{h}_i, \bar{u}_a, u_b}^R + \Gamma_{\check{h}_j, \bar{u}_a, u_b}^{R*} \Gamma_{\check{h}_i, \bar{u}_a, u_b}^L \right) \\
& + 3 \sum_{a=1}^3 \sum_{b=1}^3 G_0(p^2, m_{u_a}^2, m_{u_b}^2) \left( \Gamma_{\check{h}_j, \bar{u}_a, u_b}^{L*} \Gamma_{\check{h}_i, \bar{u}_a, u_b}^L + \Gamma_{\check{h}_j, \bar{u}_a, u_b}^{R*} \Gamma_{\check{h}_i, \bar{u}_a, u_b}^R \right) \\
& - \sum_{a=1}^6 m_{\nu_a} \sum_{b=1}^6 B_0(p^2, m_{\nu_a}^2, m_{\nu_b}^2) m_{\nu_b} \left( \Gamma_{\check{h}_j, \nu_a, \nu_b}^{L*} \Gamma_{\check{h}_i, \nu_a, \nu_b}^R + \Gamma_{\check{h}_j, \nu_a, \nu_b}^{R*} \Gamma_{\check{h}_i, \nu_a, \nu_b}^L \right) \\
& + \frac{1}{2} \sum_{a=1}^6 \sum_{b=1}^6 G_0(p^2, m_{\nu_a}^2, m_{\nu_b}^2) \left( \Gamma_{\check{h}_j, \nu_a, \nu_b}^{L*} \Gamma_{\check{h}_i, \nu_a, \nu_b}^L + \Gamma_{\check{h}_j, \nu_a, \nu_b}^{R*} \Gamma_{\check{h}_i, \nu_a, \nu_b}^R \right) \\
& + \sum_{b=1}^2 \Gamma_{\check{h}_j, \gamma, A_{h,b}}^* \Gamma_{\check{h}_i, \gamma, A_{h,b}} F_0(p^2, m_{A_{h,b}}^2, 0) + \sum_{b=1}^2 \Gamma_{\check{h}_j, Z, A_{h,b}}^* \Gamma_{\check{h}_i, Z, A_{h,b}} F_0(p^2, m_{A_{h,b}}^2, m_Z^2) \\
& + \sum_{b=1}^2 \Gamma_{\check{h}_j, Z', A_{h,b}}^* \Gamma_{\check{h}_i, Z', A_{h,b}} F_0(p^2, m_{A_{h,b}}^2, m_{Z'}^2) \tag{79}
\end{aligned}$$

• **Self-Energy for Pseudo-Scalar Higgs ( $A_h$ )**

$$\begin{aligned}
\Pi_{i,j}(p^2) = & -B_0(p^2, m_{\eta^-}^2, m_{\eta^-}^2) \Gamma_{\check{A}_{h,i}, \eta^-, \eta^-} \Gamma_{\check{A}_{h,j}, \eta^-, \eta^-} - B_0(p^2, m_{\eta^+}^2, m_{\eta^+}^2) \Gamma_{\check{A}_{h,i}, \eta^+, \eta^+} \Gamma_{\check{A}_{h,j}, \eta^+, \eta^+} \\
& - A_0(m_{H^-}^2) \Gamma_{\check{A}_{h,i}, \check{A}_{h,j}, H^-, * , H^-} + 2\Gamma_{\check{A}_{h,j}, W^+, H^-}^* \Gamma_{\check{A}_{h,i}, W^+, H^-} F_0(p^2, m_{H^-}^2, m_{W^-}^2) \\
& + 4\Gamma_{\check{A}_{h,i}, \check{A}_{h,j}, W^+, W^-} \left( -\frac{1}{2} \text{rMS} m_{W^-}^2 + A_0(m_{W^-}^2) \right) + 2\Gamma_{\check{A}_{h,i}, \check{A}_{h,j}, Z, Z} \left( -\frac{1}{2} \text{rMS} m_Z^2 + A_0(m_Z^2) \right) \\
& + 2\Gamma_{\check{A}_{h,i}, \check{A}_{h,j}, Z', Z'} \left( -\frac{1}{2} \text{rMS} m_{Z'}^2 + A_0(m_{Z'}^2) \right) - \frac{1}{2} \sum_{a=1}^2 A_0(m_{A_{h,a}}^2) \Gamma_{\check{A}_{h,i}, \check{A}_{h,j}, A_{h,a}, A_{h,a}}
\end{aligned}$$

$$\begin{aligned}
& -\frac{1}{2} \sum_{a=1}^2 A_0(m_{h_a}^2) \Gamma_{\check{A}_{h,i}, \check{A}_{h,j}, h_a, h_a} + \sum_{a=1}^2 \sum_{b=1}^2 B_0(p^2, m_{h_a}^2, m_{A_{h,b}}^2) \Gamma_{\check{A}_{h,j}, h_a, A_{h,b}}^* \Gamma_{\check{A}_{h,i}, h_a, A_{h,b}} \\
& -6 \sum_{a=1}^3 m_{d_a} \sum_{b=1}^3 B_0(p^2, m_{d_a}^2, m_{d_b}^2) m_{d_b} \left( \Gamma_{\check{A}_{h,j}, \check{d}_a, d_b}^{L*} \Gamma_{\check{A}_{h,i}, \check{d}_a, d_b}^R + \Gamma_{\check{A}_{h,j}, \check{d}_a, d_b}^{R*} \Gamma_{\check{A}_{h,i}, \check{d}_a, d_b}^L \right) \\
& +3 \sum_{a=1}^3 \sum_{b=1}^3 G_0(p^2, m_{d_a}^2, m_{d_b}^2) \left( \Gamma_{\check{A}_{h,j}, \check{d}_a, d_b}^{L*} \Gamma_{\check{A}_{h,i}, \check{d}_a, d_b}^L + \Gamma_{\check{A}_{h,j}, \check{d}_a, d_b}^{R*} \Gamma_{\check{A}_{h,i}, \check{d}_a, d_b}^R \right) \\
& -2 \sum_{a=1}^3 m_{e_a} \sum_{b=1}^3 B_0(p^2, m_{e_a}^2, m_{e_b}^2) m_{e_b} \left( \Gamma_{\check{A}_{h,j}, \check{e}_a, e_b}^{L*} \Gamma_{\check{A}_{h,i}, \check{e}_a, e_b}^R + \Gamma_{\check{A}_{h,j}, \check{e}_a, e_b}^{R*} \Gamma_{\check{A}_{h,i}, \check{e}_a, e_b}^L \right) \\
& + \sum_{a=1}^3 \sum_{b=1}^3 G_0(p^2, m_{e_a}^2, m_{e_b}^2) \left( \Gamma_{\check{A}_{h,j}, \check{e}_a, e_b}^{L*} \Gamma_{\check{A}_{h,i}, \check{e}_a, e_b}^L + \Gamma_{\check{A}_{h,j}, \check{e}_a, e_b}^{R*} \Gamma_{\check{A}_{h,i}, \check{e}_a, e_b}^R \right) \\
& -6 \sum_{a=1}^3 m_{u_a} \sum_{b=1}^3 B_0(p^2, m_{u_a}^2, m_{u_b}^2) m_{u_b} \left( \Gamma_{\check{A}_{h,j}, \check{u}_a, u_b}^{L*} \Gamma_{\check{A}_{h,i}, \check{u}_a, u_b}^R + \Gamma_{\check{A}_{h,j}, \check{u}_a, u_b}^{R*} \Gamma_{\check{A}_{h,i}, \check{u}_a, u_b}^L \right) \\
& +3 \sum_{a=1}^3 \sum_{b=1}^3 G_0(p^2, m_{u_a}^2, m_{u_b}^2) \left( \Gamma_{\check{A}_{h,j}, \check{u}_a, u_b}^{L*} \Gamma_{\check{A}_{h,i}, \check{u}_a, u_b}^L + \Gamma_{\check{A}_{h,j}, \check{u}_a, u_b}^{R*} \Gamma_{\check{A}_{h,i}, \check{u}_a, u_b}^R \right) \\
& - \sum_{a=1}^6 m_{\nu_a} \sum_{b=1}^6 B_0(p^2, m_{\nu_a}^2, m_{\nu_b}^2) m_{\nu_b} \left( \Gamma_{\check{A}_{h,j}, \check{\nu}_a, \nu_b}^{L*} \Gamma_{\check{A}_{h,i}, \check{\nu}_a, \nu_b}^R + \Gamma_{\check{A}_{h,j}, \check{\nu}_a, \nu_b}^{R*} \Gamma_{\check{A}_{h,i}, \check{\nu}_a, \nu_b}^L \right) \\
& + \frac{1}{2} \sum_{a=1}^6 \sum_{b=1}^6 G_0(p^2, m_{\nu_a}^2, m_{\nu_b}^2) \left( \Gamma_{\check{A}_{h,j}, \check{\nu}_a, \nu_b}^{L*} \Gamma_{\check{A}_{h,i}, \check{\nu}_a, \nu_b}^L + \Gamma_{\check{A}_{h,j}, \check{\nu}_a, \nu_b}^{R*} \Gamma_{\check{A}_{h,i}, \check{\nu}_a, \nu_b}^R \right) \\
& + \sum_{b=1}^2 \Gamma_{\check{A}_{h,j}, \gamma, h_b}^* \Gamma_{\check{A}_{h,i}, \gamma, h_b} F_0(p^2, m_{h_b}^2, 0) + \sum_{b=1}^2 \Gamma_{\check{A}_{h,j}, Z, h_b}^* \Gamma_{\check{A}_{h,i}, Z, h_b} F_0(p^2, m_{h_b}^2, m_Z^2) \\
& + \sum_{b=1}^2 \Gamma_{\check{A}_{h,j}, Z', h_b}^* \Gamma_{\check{A}_{h,i}, Z', h_b} F_0(p^2, m_{h_b}^2, m_{Z'}^2) \tag{80}
\end{aligned}$$

• Self-Energy for Down-Quarks (d)

$$\begin{aligned}
\Sigma_{i,j}^S(p^2) &= + \sum_{a=1}^2 \sum_{b=1}^3 B_0(p^2, m_{d_b}^2, m_{h_a}^2) \Gamma_{\check{d}_j, h_a, d_b}^{L*} m_{d_b} \Gamma_{\check{d}_i, h_a, d_b}^R \\
&+ \sum_{a=1}^3 m_{d_a} \sum_{b=1}^2 B_0(p^2, m_{d_a}^2, m_{A_{h,b}}^2) \Gamma_{\check{d}_j, d_a, A_{h,b}}^{L*} \Gamma_{\check{d}_i, d_a, A_{h,b}}^R \\
&+ \sum_{b=1}^3 B_0(p^2, m_{u_b}^2, m_{H^-}^2) \Gamma_{\check{d}_j, H^-, u_b}^{L*} m_{u_b} \Gamma_{\check{d}_i, H^-, u_b}^R - \frac{16}{3} \sum_{b=1}^3 \left( -\frac{1}{2} \text{rMS} + B_0(p^2, m_{d_b}^2, 0) \right) \Gamma_{\check{d}_j, g, d_b}^{R*} m_{d_b} \Gamma_{\check{d}_i, g, d_b}^L
\end{aligned}$$



$$\begin{aligned}
& -4 \sum_{b=1}^3 \left( -\frac{1}{2} \text{rMS} + B_0(p^2, m_{d_b}^2, 0) \right) \Gamma_{\tilde{d}_j, \gamma, d_b}^{R*} m_{d_b} \Gamma_{\tilde{d}_i, \gamma, d_b}^L \\
& -4 \sum_{b=1}^3 \left( -\frac{1}{2} \text{rMS} + B_0(p^2, m_{u_b}^2, m_{W^-}^2) \right) \Gamma_{\tilde{d}_j, W^-, u_b}^{R*} m_{u_b} \Gamma_{\tilde{d}_i, W^-, u_b}^L \\
& -4 \sum_{b=1}^3 \left( -\frac{1}{2} \text{rMS} + B_0(p^2, m_{d_b}^2, m_Z^2) \right) \Gamma_{\tilde{d}_j, Z, d_b}^{R*} m_{d_b} \Gamma_{\tilde{d}_i, Z, d_b}^L \\
& -4 \sum_{b=1}^3 \left( -\frac{1}{2} \text{rMS} + B_0(p^2, m_{d_b}^2, m_{Z'}^2) \right) \Gamma_{\tilde{d}_j, Z', d_b}^{R*} m_{d_b} \Gamma_{\tilde{d}_i, Z', d_b}^L
\end{aligned} \tag{81}$$

$$\begin{aligned}
\Sigma_{i,j}^R(p^2) &= -\frac{1}{2} \sum_{a=1}^2 \sum_{b=1}^3 B_1(p^2, m_{d_b}^2, m_{h_a}^2) \Gamma_{\tilde{d}_j, h_a, d_b}^{R*} \Gamma_{\tilde{d}_i, h_a, d_b}^R \\
& -\frac{1}{2} \sum_{a=1}^3 \sum_{b=1}^2 B_1(p^2, m_{d_a}^2, m_{A_{h,b}}^2) \Gamma_{\tilde{d}_j, d_a, A_{h,b}}^{R*} \Gamma_{\tilde{d}_i, d_a, A_{h,b}}^R \\
& -\frac{1}{2} \sum_{b=1}^3 B_1(p^2, m_{u_b}^2, m_{H^-}^2) \Gamma_{\tilde{d}_j, H^-, u_b}^{R*} \Gamma_{\tilde{d}_i, H^-, u_b}^R - \frac{4}{3} \sum_{b=1}^3 B_1(p^2, m_{d_b}^2, 0) \Gamma_{\tilde{d}_j, g, d_b}^{L*} \Gamma_{\tilde{d}_i, g, d_b}^L \\
& -\sum_{b=1}^3 B_1(p^2, m_{d_b}^2, 0) \Gamma_{\tilde{d}_j, \gamma, d_b}^{L*} \Gamma_{\tilde{d}_i, \gamma, d_b}^L - \sum_{b=1}^3 B_1(p^2, m_{u_b}^2, m_{W^-}^2) \Gamma_{\tilde{d}_j, W^-, u_b}^{L*} \Gamma_{\tilde{d}_i, W^-, u_b}^L \\
& -\sum_{b=1}^3 B_1(p^2, m_{d_b}^2, m_Z^2) \Gamma_{\tilde{d}_j, Z, d_b}^{L*} \Gamma_{\tilde{d}_i, Z, d_b}^L - \sum_{b=1}^3 B_1(p^2, m_{d_b}^2, m_{Z'}^2) \Gamma_{\tilde{d}_j, Z', d_b}^{L*} \Gamma_{\tilde{d}_i, Z', d_b}^L
\end{aligned} \tag{82}$$

$$\begin{aligned}
\Sigma_{i,j}^L(p^2) &= -\frac{1}{2} \sum_{a=1}^2 \sum_{b=1}^3 B_1(p^2, m_{d_b}^2, m_{h_a}^2) \Gamma_{\tilde{d}_j, h_a, d_b}^{L*} \Gamma_{\tilde{d}_i, h_a, d_b}^L \\
& -\frac{1}{2} \sum_{a=1}^3 \sum_{b=1}^2 B_1(p^2, m_{d_a}^2, m_{A_{h,b}}^2) \Gamma_{\tilde{d}_j, d_a, A_{h,b}}^{L*} \Gamma_{\tilde{d}_i, d_a, A_{h,b}}^L \\
& -\frac{1}{2} \sum_{b=1}^3 B_1(p^2, m_{u_b}^2, m_{H^-}^2) \Gamma_{\tilde{d}_j, H^-, u_b}^{L*} \Gamma_{\tilde{d}_i, H^-, u_b}^L - \frac{4}{3} \sum_{b=1}^3 B_1(p^2, m_{d_b}^2, 0) \Gamma_{\tilde{d}_j, g, d_b}^{R*} \Gamma_{\tilde{d}_i, g, d_b}^R \\
& -\sum_{b=1}^3 B_1(p^2, m_{d_b}^2, 0) \Gamma_{\tilde{d}_j, \gamma, d_b}^{R*} \Gamma_{\tilde{d}_i, \gamma, d_b}^R - \sum_{b=1}^3 B_1(p^2, m_{u_b}^2, m_{W^-}^2) \Gamma_{\tilde{d}_j, W^-, u_b}^{R*} \Gamma_{\tilde{d}_i, W^-, u_b}^R \\
& -\sum_{b=1}^3 B_1(p^2, m_{d_b}^2, m_Z^2) \Gamma_{\tilde{d}_j, Z, d_b}^{R*} \Gamma_{\tilde{d}_i, Z, d_b}^R - \sum_{b=1}^3 B_1(p^2, m_{d_b}^2, m_{Z'}^2) \Gamma_{\tilde{d}_j, Z', d_b}^{R*} \Gamma_{\tilde{d}_i, Z', d_b}^R
\end{aligned} \tag{83}$$

• Self-Energy for Up-Quarks ( $u$ )

$$\begin{aligned}
\Sigma_{i,j}^S(p^2) = & + \sum_{a=1}^2 \sum_{b=1}^3 B_0(p^2, m_{u_b}^2, m_{h_a}^2) \Gamma_{\tilde{u}_j, h_a, u_b}^{L*} m_{u_b} \Gamma_{\tilde{u}_i, h_a, u_b}^R \\
& + \sum_{a=1}^3 m_{u_a} \sum_{b=1}^2 B_0(p^2, m_{u_a}^2, m_{A_{h,b}}^2) \Gamma_{\tilde{u}_j, u_a, A_{h,b}}^{L*} \Gamma_{\tilde{u}_i, u_a, A_{h,b}}^R \\
& - \frac{16}{3} \sum_{b=1}^3 \left( -\frac{1}{2} \text{rMS} + B_0(p^2, m_{u_b}^2, 0) \right) \Gamma_{\tilde{u}_j, g, u_b}^{R*} m_{u_b} \Gamma_{\tilde{u}_i, g, u_b}^L - 4 \sum_{b=1}^3 \left( -\frac{1}{2} \text{rMS} + B_0(p^2, m_{u_b}^2, 0) \right) \Gamma_{\tilde{u}_j, \gamma, u_b}^{R*} m_{u_b} \Gamma_{\tilde{u}_i, \gamma, u_b}^L \\
& - 4 \sum_{b=1}^3 \left( -\frac{1}{2} \text{rMS} + B_0(p^2, m_{u_b}^2, m_Z^2) \right) \Gamma_{\tilde{u}_j, Z, u_b}^{R*} m_{u_b} \Gamma_{\tilde{u}_i, Z, u_b}^L \\
& - 4 \sum_{b=1}^3 \left( -\frac{1}{2} \text{rMS} + B_0(p^2, m_{u_b}^2, m_{Z'}^2) \right) \Gamma_{\tilde{u}_j, Z', u_b}^{R*} m_{u_b} \Gamma_{\tilde{u}_i, Z', u_b}^L \\
& + \sum_{b=1}^3 B_0(p^2, m_{d_b}^2, m_{H^-}^2) \Gamma_{\tilde{u}_j, H^-, *, d_b}^{L*} m_{d_b} \Gamma_{\tilde{u}_i, H^-, *, d_b}^R \\
& - 4 \sum_{b=1}^3 \left( -\frac{1}{2} \text{rMS} + B_0(p^2, m_{d_b}^2, m_{W^-}^2) \right) \Gamma_{\tilde{u}_j, W^+, d_b}^{R*} m_{d_b} \Gamma_{\tilde{u}_i, W^+, d_b}^L \tag{84}
\end{aligned}$$

$$\begin{aligned}
\Sigma_{i,j}^R(p^2) = & -\frac{1}{2} \sum_{a=1}^2 \sum_{b=1}^3 B_1(p^2, m_{u_b}^2, m_{h_a}^2) \Gamma_{\tilde{u}_j, h_a, u_b}^{R*} \Gamma_{\tilde{u}_i, h_a, u_b}^R \\
& - \frac{1}{2} \sum_{a=1}^3 \sum_{b=1}^2 B_1(p^2, m_{u_a}^2, m_{A_{h,b}}^2) \Gamma_{\tilde{u}_j, u_a, A_{h,b}}^{R*} \Gamma_{\tilde{u}_i, u_a, A_{h,b}}^R - \frac{4}{3} \sum_{b=1}^3 B_1(p^2, m_{u_b}^2, 0) \Gamma_{\tilde{u}_j, g, u_b}^{L*} \Gamma_{\tilde{u}_i, g, u_b}^L \\
& - \sum_{b=1}^3 B_1(p^2, m_{u_b}^2, 0) \Gamma_{\tilde{u}_j, \gamma, u_b}^{L*} \Gamma_{\tilde{u}_i, \gamma, u_b}^L - \sum_{b=1}^3 B_1(p^2, m_{u_b}^2, m_Z^2) \Gamma_{\tilde{u}_j, Z, u_b}^{L*} \Gamma_{\tilde{u}_i, Z, u_b}^L \\
& - \sum_{b=1}^3 B_1(p^2, m_{u_b}^2, m_{Z'}^2) \Gamma_{\tilde{u}_j, Z', u_b}^{L*} \Gamma_{\tilde{u}_i, Z', u_b}^L - \frac{1}{2} \sum_{b=1}^3 B_1(p^2, m_{d_b}^2, m_{H^-}^2) \Gamma_{\tilde{u}_j, H^-, *, d_b}^{R*} \Gamma_{\tilde{u}_i, H^-, *, d_b}^R \\
& - \sum_{b=1}^3 B_1(p^2, m_{d_b}^2, m_{W^-}^2) \Gamma_{\tilde{u}_j, W^+, d_b}^{L*} \Gamma_{\tilde{u}_i, W^+, d_b}^L \tag{85}
\end{aligned}$$

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

$$\begin{aligned}
& - \sum_{b=1}^3 B_1(p^2, m_{u_b}^2, m_{Z'}^2) \Gamma_{\tilde{u}_j, Z', u_b}^{R*} \Gamma_{\tilde{u}_i, Z', u_b}^R - \frac{1}{2} \sum_{b=1}^3 B_1(p^2, m_{d_b}^2, m_{H^-}^2) \Gamma_{\tilde{u}_j, H^-, * , d_b}^{L*} \Gamma_{\tilde{u}_i, H^-, * , d_b}^L \\
& - \sum_{b=1}^3 B_1(p^2, m_{d_b}^2, m_{W^-}^2) \Gamma_{\tilde{u}_j, W^+, d_b}^{R*} \Gamma_{\tilde{u}_i, W^+, d_b}^R
\end{aligned} \tag{86}$$

• **Self-Energy for Leptons (e)**

$$\begin{aligned}
\Sigma_{i,j}^S(p^2) = & + \sum_{a=1}^2 \sum_{b=1}^3 B_0(p^2, m_{e_b}^2, m_{h_a}^2) \Gamma_{\tilde{e}_j, h_a, e_b}^{L*} m_{e_b} \Gamma_{\tilde{e}_i, h_a, e_b}^R \\
& + \sum_{a=1}^3 m_{e_a} \sum_{b=1}^2 B_0(p^2, m_{e_a}^2, m_{A_{h,b}}^2) \Gamma_{\tilde{e}_j, e_a, A_{h,b}}^{L*} \Gamma_{\tilde{e}_i, e_a, A_{h,b}}^R \\
& - 4 \sum_{b=1}^3 \left( -\frac{1}{2} \text{rMS} + B_0(p^2, m_{e_b}^2, 0) \right) \Gamma_{\tilde{e}_j, \gamma, e_b}^{R*} m_{e_b} \Gamma_{\tilde{e}_i, \gamma, e_b}^L - 4 \sum_{b=1}^3 \left( -\frac{1}{2} \text{rMS} + B_0(p^2, m_{e_b}^2, m_Z^2) \right) \Gamma_{\tilde{e}_j, Z, e_b}^{R*} m_{e_b} \Gamma_{\tilde{e}_i, Z, e_b}^L \\
& - 4 \sum_{b=1}^3 \left( -\frac{1}{2} \text{rMS} + B_0(p^2, m_{e_b}^2, m_{Z'}^2) \right) \Gamma_{\tilde{e}_j, Z', e_b}^{R*} m_{e_b} \Gamma_{\tilde{e}_i, Z', e_b}^L \\
& + \sum_{b=1}^6 B_0(p^2, m_{\nu_b}^2, m_{H^-}^2) \Gamma_{\tilde{e}_j, H^-, \nu_b}^{L*} m_{\nu_b} \Gamma_{\tilde{e}_i, H^-, \nu_b}^R \\
& - 4 \sum_{b=1}^6 \left( -\frac{1}{2} \text{rMS} + B_0(p^2, m_{\nu_b}^2, m_{W^-}^2) \right) \Gamma_{\tilde{e}_j, W^-, \nu_b}^{R*} m_{\nu_b} \Gamma_{\tilde{e}_i, W^-, \nu_b}^L
\end{aligned} \tag{87}$$

$$\begin{aligned}
\Sigma_{i,j}^R(p^2) = & -\frac{1}{2} \sum_{a=1}^2 \sum_{b=1}^3 B_1(p^2, m_{e_b}^2, m_{h_a}^2) \Gamma_{\tilde{e}_j, h_a, e_b}^{R*} \Gamma_{\tilde{e}_i, h_a, e_b}^R \\
& - \frac{1}{2} \sum_{a=1}^3 \sum_{b=1}^2 B_1(p^2, m_{e_a}^2, m_{A_{h,b}}^2) \Gamma_{\tilde{e}_j, e_a, A_{h,b}}^{R*} \Gamma_{\tilde{e}_i, e_a, A_{h,b}}^R - \sum_{b=1}^3 B_1(p^2, m_{e_b}^2, 0) \Gamma_{\tilde{e}_j, \gamma, e_b}^{L*} \Gamma_{\tilde{e}_i, \gamma, e_b}^L \\
& - \sum_{b=1}^3 B_1(p^2, m_{e_b}^2, m_Z^2) \Gamma_{\tilde{e}_j, Z, e_b}^{L*} \Gamma_{\tilde{e}_i, Z, e_b}^L - \sum_{b=1}^3 B_1(p^2, m_{e_b}^2, m_{Z'}^2) \Gamma_{\tilde{e}_j, Z', e_b}^{L*} \Gamma_{\tilde{e}_i, Z', e_b}^L \\
& - \frac{1}{2} \sum_{b=1}^6 B_1(p^2, m_{\nu_b}^2, m_{H^-}^2) \Gamma_{\tilde{e}_j, H^-, \nu_b}^{R*} \Gamma_{\tilde{e}_i, H^-, \nu_b}^R - \sum_{b=1}^6 B_1(p^2, m_{\nu_b}^2, m_{W^-}^2) \Gamma_{\tilde{e}_j, W^-, \nu_b}^{L*} \Gamma_{\tilde{e}_i, W^-, \nu_b}^L
\end{aligned} \tag{88}$$

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

$$\begin{aligned}
& - \sum_{b=1}^3 B_1(p^2, m_{e_b}^2, m_Z^2) \Gamma_{\tilde{e}_j, Z, e_b}^{R*} \Gamma_{\tilde{e}_i, Z, e_b}^R - \sum_{b=1}^3 B_1(p^2, m_{e_b}^2, m_{Z'}^2) \Gamma_{\tilde{e}_j, Z', e_b}^{R*} \Gamma_{\tilde{e}_i, Z', e_b}^R \\
& - \frac{1}{2} \sum_{b=1}^6 B_1(p^2, m_{\nu_b}^2, m_{H^-}^2) \Gamma_{\tilde{e}_j, H^-, \nu_b}^{L*} \Gamma_{\tilde{e}_i, H^-, \nu_b}^L - \sum_{b=1}^6 B_1(p^2, m_{\nu_b}^2, m_{W^-}^2) \Gamma_{\tilde{e}_j, W^-, \nu_b}^{R*} \Gamma_{\tilde{e}_i, W^-, \nu_b}^R
\end{aligned} \tag{89}$$

• **Self-Energy for Neutrinos ( $\nu$ )**

$$\begin{aligned}
\Sigma_{i,j}^S(p^2) = & + \sum_{a=1}^2 \sum_{b=1}^6 B_0(p^2, m_{\nu_b}^2, m_{h_a}^2) \Gamma_{\tilde{\nu}_j, h_a, \nu_b}^{L*} m_{\nu_b} \Gamma_{\tilde{\nu}_i, h_a, \nu_b}^R \\
& + \sum_{a=1}^6 m_{\nu_a} \sum_{b=1}^2 B_0(p^2, m_{\nu_a}^2, m_{A_{h,b}}^2) \Gamma_{\tilde{\nu}_j, \nu_a, A_{h,b}}^{L*} \Gamma_{\tilde{\nu}_i, \nu_a, A_{h,b}}^R \\
& + 2 \sum_{b=1}^3 B_0(p^2, m_{e_b}^2, m_{H^-}^2) \Gamma_{\tilde{\nu}_j, H^-, *, e_b}^{L*} m_{e_b} \Gamma_{\tilde{\nu}_i, H^-, *, e_b}^R \\
& - 8 \sum_{b=1}^3 \left( -\frac{1}{2} \text{rMS} + B_0(p^2, m_{e_b}^2, m_{W^-}^2) \right) \Gamma_{\tilde{\nu}_j, W^+, e_b}^{R*} m_{e_b} \Gamma_{\tilde{\nu}_i, W^+, e_b}^L - 4 \sum_{b=1}^6 \left( -\frac{1}{2} \text{rMS} + B_0(p^2, m_{\nu_b}^2, 0) \right) \Gamma_{\tilde{\nu}_j, \gamma, \nu_b}^{R*} m_{\nu_b} \Gamma_{\tilde{\nu}_i, \gamma, \nu_b}^L \\
& - 4 \sum_{b=1}^6 \left( -\frac{1}{2} \text{rMS} + B_0(p^2, m_{\nu_b}^2, m_Z^2) \right) \Gamma_{\tilde{\nu}_j, Z, \nu_b}^{R*} m_{\nu_b} \Gamma_{\tilde{\nu}_i, Z, \nu_b}^L - 4 \sum_{b=1}^6 \left( -\frac{1}{2} \text{rMS} + B_0(p^2, m_{\nu_b}^2, m_{Z'}^2) \right) \Gamma_{\tilde{\nu}_j, Z', \nu_b}^{R*} m_{\nu_b} \Gamma_{\tilde{\nu}_i, Z', \nu_b}^L
\end{aligned} \tag{90}$$

$$\begin{aligned}
\Sigma_{i,j}^R(p^2) = & -\frac{1}{2} \sum_{a=1}^2 \sum_{b=1}^6 B_1(p^2, m_{\nu_b}^2, m_{h_a}^2) \Gamma_{\tilde{\nu}_j, h_a, \nu_b}^{R*} \Gamma_{\tilde{\nu}_i, h_a, \nu_b}^R \\
& - \frac{1}{2} \sum_{a=1}^6 \sum_{b=1}^2 B_1(p^2, m_{\nu_a}^2, m_{A_{h,b}}^2) \Gamma_{\tilde{\nu}_j, \nu_a, A_{h,b}}^{R*} \Gamma_{\tilde{\nu}_i, \nu_a, A_{h,b}}^R - \sum_{b=1}^3 B_1(p^2, m_{e_b}^2, m_{H^-}^2) \Gamma_{\tilde{\nu}_j, H^-, *, e_b}^{R*} \Gamma_{\tilde{\nu}_i, H^-, *, e_b}^R \\
& - 2 \sum_{b=1}^3 B_1(p^2, m_{e_b}^2, m_{W^-}^2) \Gamma_{\tilde{\nu}_j, W^+, e_b}^{L*} \Gamma_{\tilde{\nu}_i, W^+, e_b}^L - \sum_{b=1}^6 B_1(p^2, m_{\nu_b}^2, 0) \Gamma_{\tilde{\nu}_j, \gamma, \nu_b}^{L*} \Gamma_{\tilde{\nu}_i, \gamma, \nu_b}^L \\
& - \sum_{b=1}^6 B_1(p^2, m_{\nu_b}^2, m_Z^2) \Gamma_{\tilde{\nu}_j, Z, \nu_b}^{L*} \Gamma_{\tilde{\nu}_i, Z, \nu_b}^L - \sum_{b=1}^6 B_1(p^2, m_{\nu_b}^2, m_{Z'}^2) \Gamma_{\tilde{\nu}_j, Z', \nu_b}^{L*} \Gamma_{\tilde{\nu}_i, Z', \nu_b}^L
\end{aligned} \tag{91}$$

$$\begin{aligned}
\Sigma_{i,j}^L(p^2) = & -\frac{1}{2} \sum_{a=1}^2 \sum_{b=1}^6 B_1(p^2, m_{\nu_b}^2, m_{h_a}^2) \Gamma_{\tilde{\nu}_j, h_a, \nu_b}^{L*} \Gamma_{\tilde{\nu}_i, h_a, \nu_b}^L \\
& - \frac{1}{2} \sum_{a=1}^6 \sum_{b=1}^2 B_1(p^2, m_{\nu_a}^2, m_{A_{h,b}}^2) \Gamma_{\tilde{\nu}_j, \nu_a, A_{h,b}}^{L*} \Gamma_{\tilde{\nu}_i, \nu_a, A_{h,b}}^L - \sum_{b=1}^3 B_1(p^2, m_{e_b}^2, m_{H^-}^2) \Gamma_{\tilde{\nu}_j, H^-, *, e_b}^{L*} \Gamma_{\tilde{\nu}_i, H^-, *, e_b}^L \\
& - 2 \sum_{b=1}^3 B_1(p^2, m_{e_b}^2, m_{W^-}^2) \Gamma_{\tilde{\nu}_j, W^+, e_b}^{R*} \Gamma_{\tilde{\nu}_i, W^+, e_b}^R - \sum_{b=1}^6 B_1(p^2, m_{\nu_b}^2, 0) \Gamma_{\tilde{\nu}_j, \gamma, \nu_b}^{R*} \Gamma_{\tilde{\nu}_i, \gamma, \nu_b}^R
\end{aligned}$$

$$- \sum_{b=1}^6 B_1(p^2, m_{\nu_b}^2, m_Z^2) \Gamma_{\tilde{\nu}_j, Z, \nu_b}^{R*} \Gamma_{\tilde{\nu}_i, Z, \nu_b}^R - \sum_{b=1}^6 B_1(p^2, m_{\nu_b}^2, m_{Z'}^2) \Gamma_{\tilde{\nu}_j, Z', \nu_b}^{R*} \Gamma_{\tilde{\nu}_i, Z', \nu_b}^R \quad (92)$$

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

$$\begin{aligned} \Pi(p^2) = & 4|\Gamma_{H^-, *, W^-, \gamma}|^2 \left( -\frac{1}{2} \text{rMS} + B_0(p^2, 0, m_{W^-}^2) \right) + 4|\Gamma_{H^-, *, Z, W^-}|^2 \left( -\frac{1}{2} \text{rMS} + B_0(p^2, m_{W^-}^2, m_Z^2) \right) + 4|\Gamma_{H^-, *, Z', W^-}|^2 \\ & - B_0(p^2, m_{\eta^+}^2, m_{\eta^+}^2) \Gamma_{H^-, \eta^+, \eta^+} \Gamma_{H^-, *, \eta^+, \eta^+} - B_0(p^2, m_{\eta^+}^2, m_{\eta^+}^2) \Gamma_{H^-, \eta^+, \eta^+} \Gamma_{H^-, *, \eta^+, \eta^+} \\ & - B_0(p^2, m_{\eta^-}^2, m_{\eta^-}^2) \Gamma_{H^-, \eta^-, \eta^-} \Gamma_{H^-, *, \eta^-, \eta^-} - B_0(p^2, m_{\eta^-}^2, m_{\eta^-}^2) \Gamma_{H^-, \eta^-, \eta^-} \Gamma_{H^-, *, \eta^-, \eta^-} \\ & - A_0(m_{H^-}^2) \Gamma_{H^-, H^-, *, H^-, *} + |\Gamma_{H^-, *, \gamma, H^-}|^2 F_0(p^2, m_{H^-}^2, 0) + |\Gamma_{H^-, *, Z, H^-}|^2 F_0(p^2, m_{H^-}^2, m_Z^2) \\ & + |\Gamma_{H^-, *, Z', H^-}|^2 F_0(p^2, m_{H^-}^2, m_{Z'}^2) + 4\Gamma_{H^-, H^-, *, W^+, W^-} \left( -\frac{1}{2} \text{rMS} m_{W^-}^2 + A_0(m_{W^-}^2) \right) \\ & + 2\Gamma_{H^-, H^-, *, Z, Z} \left( -\frac{1}{2} \text{rMS} m_Z^2 + A_0(m_Z^2) \right) + 2\Gamma_{H^-, H^-, *, 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_{h,a}}^2) \Gamma_{H^-, H^-, *, A_{h,a}, A_{h,a}} - \frac{1}{2} \sum_{a=1}^2 A_0(m_{h_a}^2) \Gamma_{H^-, H^-, *, h_a, h_a} \\ & + 3 \sum_{a=1}^3 \sum_{b=1}^3 \left( |\Gamma_{H^-, *, \bar{u}_a, d_b}^L|^2 + |\Gamma_{H^-, *, \bar{u}_a, d_b}^R|^2 \right) G_0(p^2, m_{u_a}^2, m_{d_b}^2) \\ & - 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_{H^-, *, \bar{u}_a, d_b}^{L*} \Gamma_{H^-, *, \bar{u}_a, d_b}^R + \Gamma_{H^-, *, \bar{u}_a, d_b}^{R*} \Gamma_{H^-, *, \bar{u}_a, d_b}^L \right) \\ & + \sum_{a=1}^6 \sum_{b=1}^3 \left( |\Gamma_{H^-, *, \nu_a, e_b}^L|^2 + |\Gamma_{H^-, *, \nu_a, e_b}^R|^2 \right) G_0(p^2, m_{\nu_a}^2, m_{e_b}^2) \\ & - 2 \sum_{a=1}^6 m_{\nu_a} \sum_{b=1}^3 B_0(p^2, m_{\nu_a}^2, m_{e_b}^2) m_{e_b} \left( \Gamma_{H^-, *, \nu_a, e_b}^{L*} \Gamma_{H^-, *, \nu_a, e_b}^R + \Gamma_{H^-, *, \nu_a, e_b}^{R*} \Gamma_{H^-, *, \nu_a, e_b}^L \right) \\ & + \sum_{b=1}^2 |\Gamma_{H^-, *, H^-, h_b}|^2 B_0(p^2, m_{H^-}^2, m_{h_b}^2) + \sum_{b=1}^2 |\Gamma_{H^-, *, W^-, A_{h,b}}|^2 F_0(p^2, m_{A_{h,b}}^2, m_{W^-}^2) \\ & + \sum_{b=1}^2 |\Gamma_{H^-, *, W^-, h_b}|^2 F_0(p^2, m_{h_b}^2, m_{W^-}^2) \quad (93) \end{aligned}$$

• **Self-Energy for Z-Boson ( $Z$ )**

$$\begin{aligned} \Pi(p^2) = & 2|\Gamma_{Z, W^+, H^-}|^2 B_0(p^2, m_{W^-}^2, m_{H^-}^2) + |\Gamma_{Z, \eta^-, \eta^-}|^2 B_{00}(p^2, m_{\eta^-}^2, m_{\eta^-}^2) + |\Gamma_{Z, \eta^+, \eta^+}|^2 B_{00}(p^2, m_{\eta^+}^2, m_{\eta^+}^2) \\ & - 4|\Gamma_{Z, H^-, *, H^-}|^2 B_{00}(p^2, m_{H^-}^2, m_{H^-}^2) + A_0(m_{H^-}^2) \Gamma_{Z, Z, H^-, *, H^-} \end{aligned}$$

$$\begin{aligned}
& -|\Gamma_{Z,W^+,W^-}|^2 \left( 10B_{00}(p^2, m_{W^-}^2, m_{W^-}^2) + 2A_0(m_{W^-}^2) - 2\text{rMS}(2m_{W^-}^2 - \frac{1}{3}p^2) + B_0(p^2, m_{W^-}^2, m_{W^-}^2) (2m_{W^-}^2 + 4p^2) \right) \\
& + \frac{1}{2} \sum_{a=1}^2 A_0(m_{A_{h,a}}^2) \Gamma_{Z,Z,A_{h,a},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_{h,b}}|^2 B_{00}(p^2, m_{A_{h,b}}^2, m_{h_a}^2) \\
& + 3 \sum_{a=1}^3 \sum_{b=1}^3 \left[ \left( |\Gamma_{Z,\bar{d}_a,d_b}^L|^2 + |\Gamma_{Z,\bar{d}_a,d_b}^R|^2 \right) H_0(p^2, m_{d_a}^2, m_{d_b}^2) \right. \\
& \left. + 4B_0(p^2, m_{d_a}^2, m_{d_b}^2) m_{d_a} m_{d_b} \Re \left( \Gamma_{Z,\bar{d}_a,d_b}^{L*} \Gamma_{Z,\bar{d}_a,d_b}^R \right) \right] \\
& + \sum_{a=1}^3 \sum_{b=1}^3 \left[ \left( |\Gamma_{Z,\bar{e}_a,e_b}^L|^2 + |\Gamma_{Z,\bar{e}_a,e_b}^R|^2 \right) H_0(p^2, m_{e_a}^2, m_{e_b}^2) \right. \\
& \left. + 4B_0(p^2, m_{e_a}^2, m_{e_b}^2) m_{e_a} m_{e_b} \Re \left( \Gamma_{Z,\bar{e}_a,e_b}^{L*} \Gamma_{Z,\bar{e}_a,e_b}^R \right) \right] \\
& + 3 \sum_{a=1}^3 \sum_{b=1}^3 \left[ \left( |\Gamma_{Z,\bar{u}_a,u_b}^L|^2 + |\Gamma_{Z,\bar{u}_a,u_b}^R|^2 \right) H_0(p^2, m_{u_a}^2, m_{u_b}^2) \right. \\
& \left. + 4B_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] \\
& + \frac{1}{2} \sum_{a=1}^6 \sum_{b=1}^6 \left[ \left( |\Gamma_{Z,\nu_a,\nu_b}^L|^2 + |\Gamma_{Z,\nu_a,\nu_b}^R|^2 \right) H_0(p^2, m_{\nu_a}^2, m_{\nu_b}^2) \right. \\
& \left. + 4B_0(p^2, m_{\nu_a}^2, m_{\nu_b}^2) m_{\nu_a} m_{\nu_b} \Re \left( \Gamma_{Z,\nu_a,\nu_b}^{L*} \Gamma_{Z,\nu_a,\nu_b}^R \right) \right] \\
& + \sum_{b=1}^2 |\Gamma_{Z,\gamma,h_b}|^2 B_0(p^2, 0, 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) + \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) \tag{94}
\end{aligned}$$

• **Self-Energy for Z'-Boson ( $Z'$ )**

$$\begin{aligned}
\Pi(p^2) = & 2|\Gamma_{Z',W^+,H^-}|^2 B_0(p^2, m_{W^-}^2, m_{H^-}^2) + |\Gamma_{Z',\eta^-, \eta^-}|^2 B_{00}(p^2, m_{\eta^-}^2, m_{\eta^-}^2) + |\Gamma_{Z',\eta^+, \eta^+}|^2 B_{00}(p^2, m_{\eta^+}^2, m_{\eta^+}^2) \\
& - 4|\Gamma_{Z',H^-,*,H^-}|^2 B_{00}(p^2, m_{H^-}^2, m_{H^-}^2) + A_0(m_{H^-}^2) \Gamma_{Z',Z',H^-,*,H^-} \\
& - |\Gamma_{Z',W^+,W^-}|^2 \left( 10B_{00}(p^2, m_{W^-}^2, m_{W^-}^2) + 2A_0(m_{W^-}^2) - 2\text{rMS}(2m_{W^-}^2 - \frac{1}{3}p^2) + B_0(p^2, m_{W^-}^2, m_{W^-}^2) (2m_{W^-}^2 + 4p^2) \right) \\
& + \frac{1}{2} \sum_{a=1}^2 A_0(m_{A_{h,a}}^2) \Gamma_{Z',Z',A_{h,a},A_{h,a}} + \frac{1}{2} \sum_{a=1}^2 A_0(m_{h_a}^2) \Gamma_{Z',Z',h_a,h_a} \\
& - 4 \sum_{a=1}^2 \sum_{b=1}^2 |\Gamma_{Z',h_a,A_{h,b}}|^2 B_{00}(p^2, m_{A_{h,b}}^2, m_{h_a}^2)
\end{aligned}$$

$$\begin{aligned}
& + 3 \sum_{a=1}^3 \sum_{b=1}^3 \left[ \left( |\Gamma_{Z', \bar{d}_a, d_b}^L|^2 + |\Gamma_{Z', \bar{d}_a, d_b}^R|^2 \right) H_0(p^2, m_{d_a}^2, m_{d_b}^2) \right. \\
& + 4B_0(p^2, m_{d_a}^2, m_{d_b}^2) m_{d_a} m_{d_b} \Re \left( \Gamma_{Z', \bar{d}_a, d_b}^{L*} \Gamma_{Z', \bar{d}_a, d_b}^R \right) \Big] \\
& + \sum_{a=1}^3 \sum_{b=1}^3 \left[ \left( |\Gamma_{Z', \bar{e}_a, e_b}^L|^2 + |\Gamma_{Z', \bar{e}_a, e_b}^R|^2 \right) H_0(p^2, m_{e_a}^2, m_{e_b}^2) \right. \\
& + 4B_0(p^2, m_{e_a}^2, m_{e_b}^2) m_{e_a} m_{e_b} \Re \left( \Gamma_{Z', \bar{e}_a, e_b}^{L*} \Gamma_{Z', \bar{e}_a, e_b}^R \right) \Big] \\
& + 3 \sum_{a=1}^3 \sum_{b=1}^3 \left[ \left( |\Gamma_{Z', \bar{u}_a, u_b}^L|^2 + |\Gamma_{Z', \bar{u}_a, u_b}^R|^2 \right) H_0(p^2, m_{u_a}^2, m_{u_b}^2) \right. \\
& + 4B_0(p^2, m_{u_a}^2, m_{u_b}^2) m_{u_a} m_{u_b} \Re \left( \Gamma_{Z', \bar{u}_a, u_b}^{L*} \Gamma_{Z', \bar{u}_a, u_b}^R \right) \Big] \\
& + \frac{1}{2} \sum_{a=1}^6 \sum_{b=1}^6 \left[ \left( |\Gamma_{Z', \nu_a, \nu_b}^L|^2 + |\Gamma_{Z', \nu_a, \nu_b}^R|^2 \right) H_0(p^2, m_{\nu_a}^2, m_{\nu_b}^2) \right. \\
& + 4B_0(p^2, m_{\nu_a}^2, m_{\nu_b}^2) m_{\nu_a} m_{\nu_b} \Re \left( \Gamma_{Z', \nu_a, \nu_b}^{L*} \Gamma_{Z', \nu_a, \nu_b}^R \right) \Big] \\
& + \sum_{b=1}^2 |\Gamma_{Z', \gamma, h_b}|^2 B_0(p^2, 0, m_{h_b}^2) + \sum_{b=1}^2 |\Gamma_{Z', Z, h_b}|^2 B_0(p^2, m_Z^2, m_{h_b}^2) + \sum_{b=1}^2 |\Gamma_{Z', Z', h_b}|^2 B_0(p^2, m_{Z'}^2, m_{h_b}^2) \\
& + 2\text{rMS} m_{W^-}^2 \Gamma_{Z', Z', W^+, W^-}^1 - A_0(m_{W^-}^2) \left( 4\Gamma_{Z', Z', W^+, W^-}^1 + \Gamma_{Z', Z', W^+, W^-}^2 + \Gamma_{Z', Z', W^+, W^-}^3 \right) \tag{95}
\end{aligned}$$

• **Self-Energy for W-Boson ( $W^-$ )**

$$\begin{aligned}
\Pi(p^2) &= 2\text{rMS} m_{W^-}^2 \Gamma_{W^-, W^+, W^+, W^-}^1 + 3 \sum_{a=1}^3 \sum_{b=1}^3 \left[ \left( |\Gamma_{W^+, \bar{u}_a, d_b}^L|^2 + |\Gamma_{W^+, \bar{u}_a, d_b}^R|^2 \right) H_0(p^2, m_{u_a}^2, m_{d_b}^2) \right. \\
& + 4B_0(p^2, m_{u_a}^2, m_{d_b}^2) m_{d_b} m_{u_a} \Re \left( \Gamma_{W^+, \bar{u}_a, d_b}^{L*} \Gamma_{W^+, \bar{u}_a, d_b}^R \right) \Big] - 4 \sum_{b=1}^2 |\Gamma_{W^+, H^-, A_{h,b}}|^2 B_{00}(p^2, m_{A_{h,b}}^2, m_{H^-}^2) - 4 \sum_{b=1}^2 |\Gamma_{W^+, H^-, h_b}|^2 B_{00}(p^2, m_{h_b}^2, m_{H^-}^2) \\
& + 4B_0(p^2, m_{\nu_a}^2, m_{e_b}^2) m_{e_b} m_{\nu_a} \Re \left( \Gamma_{W^+, \nu_a, e_b}^{L*} \Gamma_{W^+, \nu_a, e_b}^R \right) \Big] + \sum_{b=1}^2 |\Gamma_{W^+, W^-, h_b}|^2 B_0(p^2, m_{W^-}^2, m_{h_b}^2) \tag{96}
\end{aligned}$$

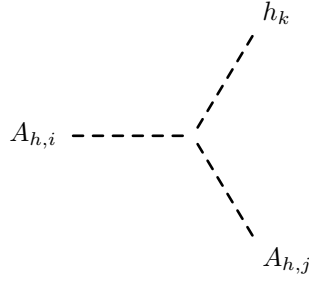
## 8.2 Tadpoles

$$\begin{aligned}
\delta t_h^{(1)} &= + A_0(m_{\eta^-}^2) \Gamma_{\check{h}_i, \eta^-, \eta^-} + A_0(m_{\eta^+}^2) \Gamma_{\check{h}_i, \eta^+, \eta^+} + A_0(m_{\eta^Z}^2) \Gamma_{\check{h}_i, \eta^Z, \eta^Z} \\
& + A_0(m_{\eta^{Z'}}^2) \Gamma_{\check{h}_i, \eta^{Z'}, \eta^{Z'}} - A_0(m_{H^-}^2) \Gamma_{\check{h}_i, H^-, *, H^-} + 4\Gamma_{\check{h}_i, W^+, W^-} \left( -\frac{1}{2} \text{rMS} m_{W^-}^2 + A_0(m_{W^-}^2) \right) \\
& + 2\Gamma_{\check{h}_i, Z, Z} \left( -\frac{1}{2} \text{rMS} m_Z^2 + A_0(m_Z^2) \right) + 2\Gamma_{\check{h}_i, Z', Z'} \left( -\frac{1}{2} \text{rMS} m_{Z'}^2 + A_0(m_{Z'}^2) \right) - \frac{1}{2} \sum_{a=1}^2 A_0(m_{A_{h,a}}^2) \Gamma_{\check{h}_i, A_{h,a}, A_{h,a}}
\end{aligned}$$

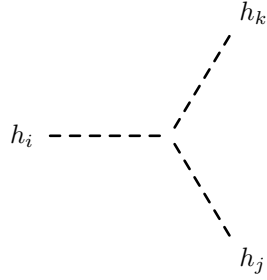
$$\begin{aligned}
& -\frac{1}{2} \sum_{a=1}^2 A_0(m_{h_a}^2) \Gamma_{\tilde{h}_i, h_a, h_a} + 6 \sum_{a=1}^3 A_0(m_{d_a}^2) m_{d_a} \left( \Gamma_{\tilde{h}_i, \bar{d}_a, d_a}^L + \Gamma_{\tilde{h}_i, \bar{d}_a, d_a}^R \right) \\
& + 2 \sum_{a=1}^3 A_0(m_{e_a}^2) m_{e_a} \left( \Gamma_{\tilde{h}_i, \bar{e}_a, e_a}^L + \Gamma_{\tilde{h}_i, \bar{e}_a, e_a}^R \right) \\
& + 6 \sum_{a=1}^3 A_0(m_{u_a}^2) m_{u_a} \left( \Gamma_{\tilde{h}_i, \bar{u}_a, u_a}^L + \Gamma_{\tilde{h}_i, \bar{u}_a, u_a}^R \right) + \sum_{a=1}^6 A_0(m_{\nu_a}^2) m_{\nu_a} \left( \Gamma_{\tilde{h}_i, \nu_a, \nu_a}^L + \Gamma_{\tilde{h}_i, \nu_a, \nu_a}^R \right)
\end{aligned} \tag{97}$$

## 9 Interactions for eigenstates 'EWSB'

### 9.1 Three Scalar-Interaction

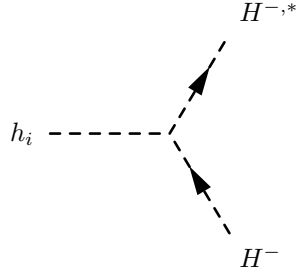


$$i \left( Z_{i1}^A Z_{j1}^A \left( 2\lambda_1 v Z_{k1}^H + \lambda_3 x Z_{k2}^H \right) + Z_{i2}^A Z_{j2}^A \left( 2\lambda_2 x Z_{k2}^H + \lambda_3 v Z_{k1}^H \right) \right) \tag{98}$$



$$\begin{aligned}
& i \left( Z_{i2}^H \left( \lambda_3 Z_{j1}^H \left( v Z_{k2}^H + x Z_{k1}^H \right) + Z_{j2}^H \left( 6\lambda_2 x Z_{k2}^H + \lambda_3 v Z_{k1}^H \right) \right) \right. \\
& \left. + Z_{i1}^H \left( \lambda_3 Z_{j2}^H \left( v Z_{k2}^H + x Z_{k1}^H \right) + Z_{j1}^H \left( 6\lambda_1 v Z_{k1}^H + \lambda_3 x Z_{k2}^H \right) \right) \right)
\end{aligned} \tag{99}$$

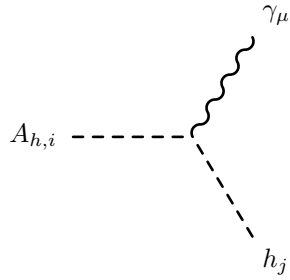




$$i \left( 2\lambda_1 v Z_{i1}^H + \lambda_3 x Z_{i2}^H \right) \quad (100)$$

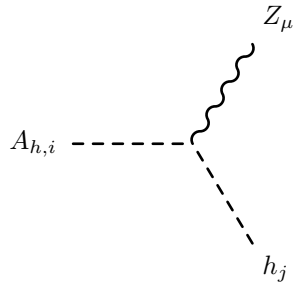

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## 9.2 Two Scalar-One Vector Boson-Interaction



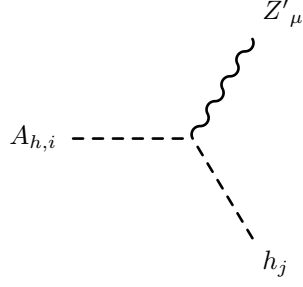
$$\frac{1}{2} \left( -4g_{YB} \cos \Theta_W Z_{i2}^A Z_{j2}^H - \left( g_1 \cos \Theta_W - g_2 \sin \Theta_W \right) Z_{i1}^A Z_{j1}^H \right) \left( -p_\mu^{h_j} + p_\mu^{A_{h,i}} \right) \quad (101)$$


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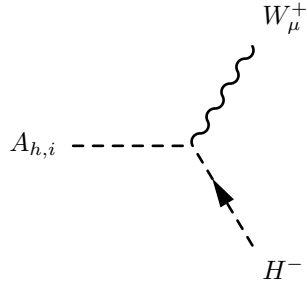
$$\begin{aligned} & \frac{1}{2} \left( \left( g_1 \cos \Theta'_W \sin \Theta_W + g_2 \cos \Theta_W \cos \Theta'_W - g_{BY} \sin \Theta'_W \right) Z_{i1}^A Z_{j1}^H \right. \\ & \left. + 4 \left( -g_B \sin \Theta'_W + g_{YB} \cos \Theta'_W \sin \Theta_W \right) Z_{i2}^A Z_{j2}^H \right) \left( -p_\mu^{h_j} + p_\mu^{A_{h,i}} \right) \end{aligned} \quad (102)$$


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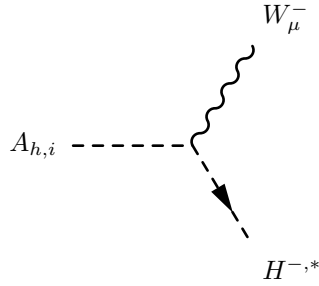
$$\frac{1}{2} \left( - \left( (g_1 \sin \Theta_W + g_2 \cos \Theta_W) \sin \Theta'_W + g_{BY} \cos \Theta'_W \right) Z_{i1}^A Z_{j1}^H \right. \\ \left. - 4 \left( g_B \cos \Theta'_W + g_{YB} \sin \Theta_W \sin \Theta'_W \right) Z_{i2}^A Z_{j2}^H \right) \left( -p_\mu^{h_j} + p_\mu^{A_{h,i}} \right) \quad (103)$$


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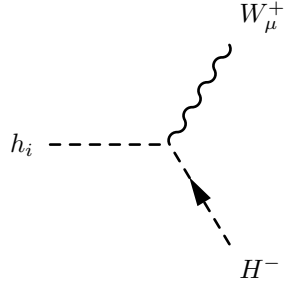
$$\frac{1}{2} g_2 Z_{i1}^A \left( -p_\mu^{H^-} + p_\mu^{A_{h,i}} \right) \quad (104)$$


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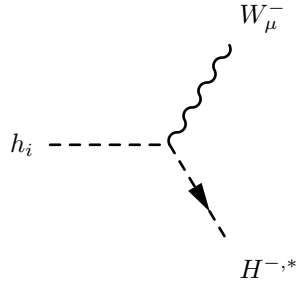
$$\frac{1}{2} g_2 Z_{i1}^A \left( -p_\mu^{H^{-,*}} + p_\mu^{A_{h,i}} \right) \quad (105)$$


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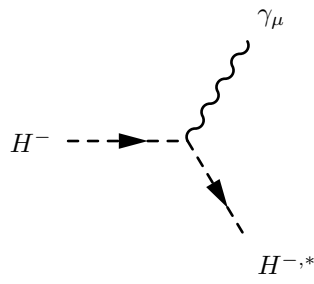
$$\frac{i}{2} g_2 Z_{i1}^H \left( -p_\mu^{H^-} + p_\mu^{h_i} \right) \quad (106)$$


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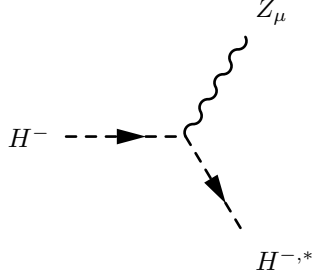
$$-\frac{i}{2} g_2 Z_{i1}^H \left( -p_\mu^{H^{-,*}} + p_\mu^{h_i} \right) \quad (107)$$


---



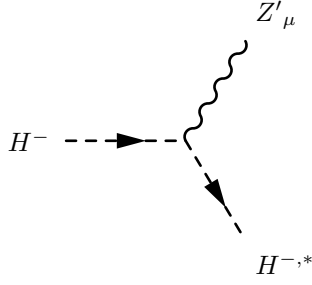
$$\frac{i}{2} \left( g_1 \cos \Theta_W + g_2 \sin \Theta_W \right) \left( -p_\mu^{H^{-,*}} + p_\mu^{H^-} \right) \quad (108)$$


---



$$\frac{i}{2} \left( -g_1 \cos \Theta'_W \sin \Theta_W + g_2 \cos \Theta_W \cos \Theta'_W + g_{BY} \sin \Theta'_W \right) \left( -p_\mu^{H^{-,*}} + p_\mu^{H^-} \right) \quad (109)$$

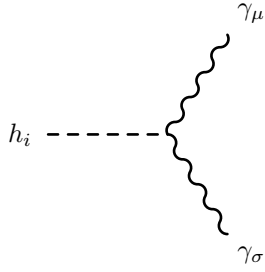

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$$\frac{i}{2} \left( \left( g_1 \sin \Theta_W - g_2 \cos \Theta_W \right) \sin \Theta'_W + g_{BY} \cos \Theta'_W \right) \left( -p_\mu^{H^{-,*}} + p_\mu^{H^-} \right) \quad (110)$$

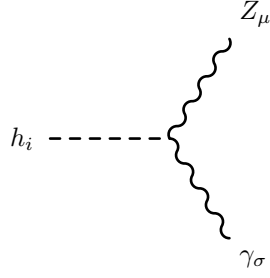

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### 9.3 One Scalar-Two Vector Boson-Interaction



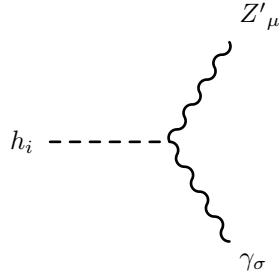
$$\frac{i}{2} \left( 16g_{YB}^2 x \cos \Theta_W^2 Z_{i2}^H + v \left( g_1 \cos \Theta_W - g_2 \sin \Theta_W \right)^2 Z_{i1}^H \right) \left( g_{\sigma\mu} \right) \quad (111)$$


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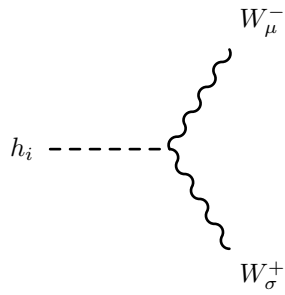
$$\begin{aligned}
& -\frac{i}{2} \left( v \left( g_1 \cos \Theta_W - g_2 \sin \Theta_W \right) \left( g_1 \cos \Theta'_W \sin \Theta_W + g_2 \cos \Theta_W \cos \Theta'_W - g_{BY} \sin \Theta'_W \right) Z_{i1}^H \right. \\
& \left. + 8g_{YB} x \left( -2g_B \cos \Theta_W \sin \Theta'_W + g_{YB} \cos \Theta'_W \sin 2\Theta_W \right) Z_{i2}^H \right) (g_{\sigma\mu})
\end{aligned} \tag{112}$$


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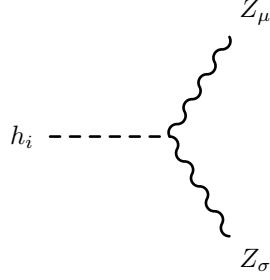
$$\begin{aligned}
& \frac{i}{2} \left( v \left( g_1 \cos \Theta_W - g_2 \sin \Theta_W \right) \left( \left( g_1 \sin \Theta_W + g_2 \cos \Theta_W \right) \sin \Theta'_W + g_{BY} \cos \Theta'_W \right) Z_{i1}^H \right. \\
& \left. + 8g_{YB} x \left( 2g_B \cos \Theta_W \cos \Theta'_W + g_{YB} \sin 2\Theta_W \sin \Theta'_W \right) Z_{i2}^H \right) (g_{\sigma\mu})
\end{aligned} \tag{113}$$


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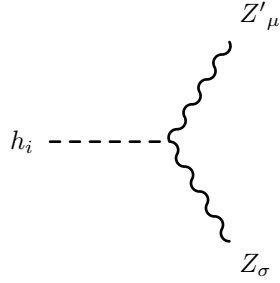
$$\frac{i}{2} g_2^2 v Z_{i1}^H (g_{\sigma\mu}) \tag{114}$$


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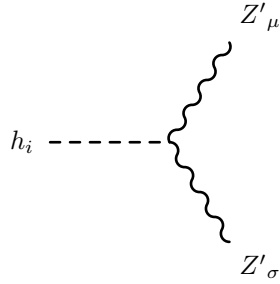
$$\begin{aligned}
& \frac{i}{2} \left( v \left( g_1 \cos \Theta'_W \sin \Theta_W + g_2 \cos \Theta_W \cos \Theta'_W - g_{BY} \sin \Theta'_W \right)^2 Z_{i1}^H \right. \\
& \left. + 16x \left( -g_B \sin \Theta'_W + g_{YB} \cos \Theta'_W \sin \Theta_W \right)^2 Z_{i2}^H \right) (g_{\sigma\mu})
\end{aligned} \tag{115}$$


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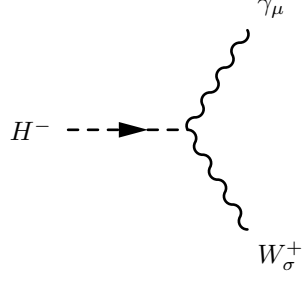
$$\begin{aligned}
& -\frac{i}{2} \left( v \left( g_1 g_{BY} \cos \Theta'^2_W \sin \Theta_W + g_2^2 \cos \Theta_W^2 \cos \Theta'_W \sin \Theta'_W \right. \right. \\
& \left. \left. + \cos \Theta'_W \left( g_1^2 \sin \Theta_W^2 - g_{BY}^2 \right) \sin \Theta'_W - g_1 g_{BY} \sin \Theta_W \sin \Theta'^2_W \right. \right. \\
& \left. \left. + g_2 \cos \Theta_W \left( g_1 \sin \Theta_W \sin 2\Theta'_W + g_{BY} \cos \Theta'^2_W - g_{BY} \sin \Theta'^2_W \right) \right) Z_{i1}^H \right. \\
& \left. + 8x \left( 2g_B g_{YB} \cos \Theta'^2_W \sin \Theta_W - 2g_B g_{YB} \sin \Theta_W \sin \Theta'^2_W - g_B^2 \sin 2\Theta'_W \right. \right. \\
& \left. \left. + g_{YB}^2 \sin \Theta_W^2 \sin 2\Theta'_W \right) Z_{i2}^H \right) (g_{\sigma\mu})
\end{aligned} \tag{116}$$


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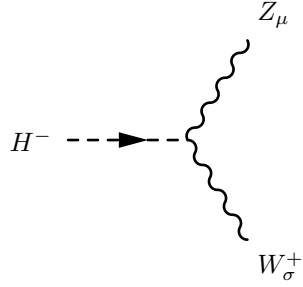
$$\begin{aligned}
& \frac{i}{2} \left( v \left( \left( g_1 \sin \Theta_W + g_2 \cos \Theta_W \right) \sin \Theta'_W + g_{BY} \cos \Theta'_W \right)^2 Z_{i1}^H \right. \\
& \left. + 16x \left( g_B \cos \Theta'_W + g_{YB} \sin \Theta_W \sin \Theta'_W \right)^2 Z_{i2}^H \right) (g_{\sigma\mu})
\end{aligned} \tag{117}$$


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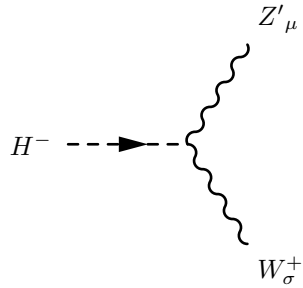
$$-\frac{i}{2} g_1 g_2 v \cos \Theta_W (g_{\sigma\mu}) \tag{118}$$


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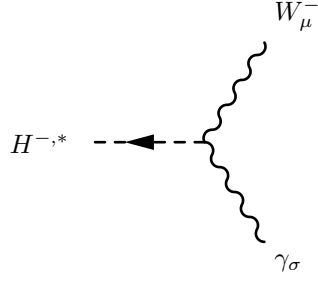
$$\frac{i}{2} g_2 v \left( g_1 \cos \Theta'_W \sin \Theta_W - g_{BY} \sin \Theta'_W \right) (g_{\sigma\mu}) \tag{119}$$


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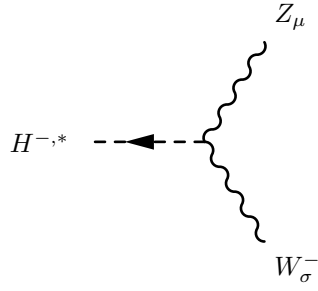
$$-\frac{i}{2}g_2v\left(g_1\sin\Theta_W\sin\Theta'_W+g_{BY}\cos\Theta'_W\right)\left(g_{\sigma\mu}\right) \quad (120)$$


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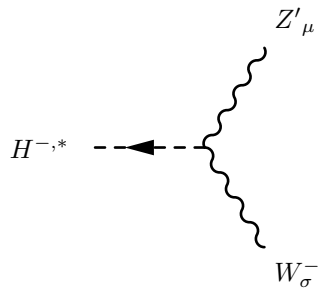
$$-\frac{i}{2}g_1g_2v\cos\Theta_W\left(g_{\sigma\mu}\right) \quad (121)$$


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$$\frac{i}{2}g_2v\left(g_1\cos\Theta'_W\sin\Theta_W-g_{BY}\sin\Theta'_W\right)\left(g_{\sigma\mu}\right) \quad (122)$$


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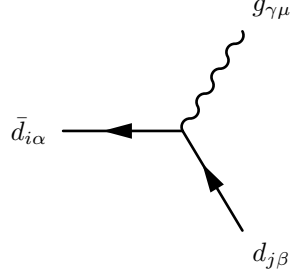


$$-\frac{i}{2}g_2v\left(g_1\sin\Theta_W\sin\Theta'_W+g_{BY}\cos\Theta'_W\right)\left(g_{\sigma\mu}\right) \quad (123)$$


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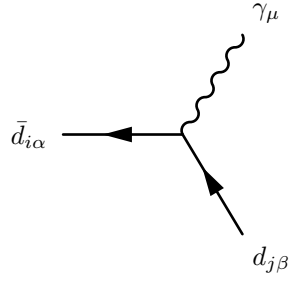
## 9.4 Two Fermion-One Vector Boson-Interaction



$$-\frac{i}{2}g_3\delta_{ij}\lambda_{\alpha,\beta}^\gamma\left(\gamma_\mu\cdot\frac{1-\gamma_5}{2}\right) \quad (124)$$

$$+\frac{i}{2}g_3\delta_{ij}\lambda_{\alpha,\beta}^\gamma\left(\gamma_\mu\cdot\frac{1+\gamma_5}{2}\right) \quad (125)$$

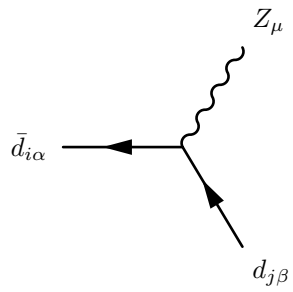

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$$-\frac{i}{6}\delta_{\alpha\beta}\delta_{ij}\left(\left(2g_{YB}+g_1\right)\cos\Theta_W-3g_2\sin\Theta_W\right)\left(\gamma_\mu\cdot\frac{1-\gamma_5}{2}\right) \quad (126)$$

$$+\frac{i}{3}\left(-g_{YB}+g_1\right)\cos\Theta_W\delta_{\alpha\beta}\delta_{ij}\left(\gamma_\mu\cdot\frac{1+\gamma_5}{2}\right) \quad (127)$$

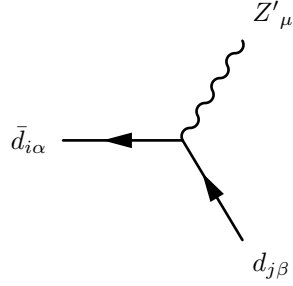

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$$\frac{i}{6}\delta_{\alpha\beta}\delta_{ij}\left(-\left(2g_B+g_{BY}\right)\sin\Theta'_W+\left(2g_{YB}+g_1\right)\cos\Theta'_W\sin\Theta_W+3g_2\cos\Theta_W\cos\Theta'_W\right)\left(\gamma_\mu\cdot\frac{1-\gamma_5}{2}\right) \quad (128)$$

$$+\frac{i}{3}\delta_{\alpha\beta}\delta_{ij}\left(\left(-g_{BY}+g_B\right)\sin\Theta'_W+\left(-g_{YB}+g_1\right)\cos\Theta'_W\sin\Theta_W\right)\left(\gamma_\mu\cdot\frac{1+\gamma_5}{2}\right) \quad (129)$$

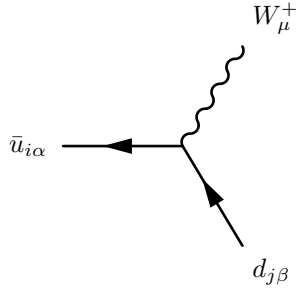

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$$-\frac{i}{6}\delta_{\alpha\beta}\delta_{ij}\left(\left(2g_B+g_{BY}\right)\cos\Theta'_W+\left(\left(2g_{YB}+g_1\right)\sin\Theta_W+3g_2\cos\Theta_W\right)\sin\Theta'_W\right)\left(\gamma_\mu\cdot\frac{1-\gamma_5}{2}\right) \quad (130)$$

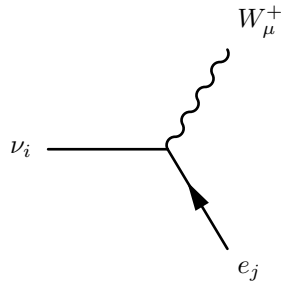
$$+\frac{i}{3}\delta_{\alpha\beta}\delta_{ij}\left(\left(-g_B+g_{BY}\right)\cos\Theta'_W+\left(-g_{YB}+g_1\right)\sin\Theta_W\sin\Theta'_W\right)\left(\gamma_\mu\cdot\frac{1+\gamma_5}{2}\right) \quad (131)$$


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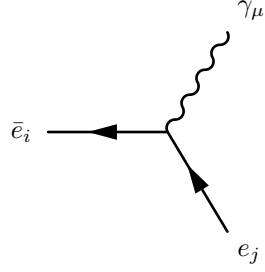
$$-i\frac{1}{\sqrt{2}}g_2\delta_{\alpha\beta}\sum_{a=1}^3U_{L,ja}^{d,*}U_{L,ia}^u\left(\gamma_\mu\cdot\frac{1-\gamma_5}{2}\right) \quad (132)$$


---



$$-i \frac{1}{\sqrt{2}} g_2 \sum_{a=1}^3 U_{L,ja}^{e,*} U_{ia}^V \left( \gamma_\mu \cdot \frac{1 - \gamma_5}{2} \right) \quad (133)$$

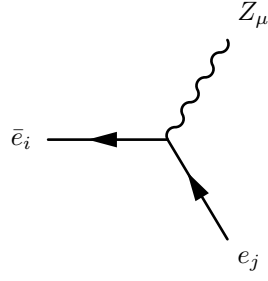

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$$\frac{i}{2} \delta_{ij} \left( (2g_{YB} + g_1) \cos \Theta_W + g_2 \sin \Theta_W \right) \left( \gamma_\mu \cdot \frac{1 - \gamma_5}{2} \right) \quad (134)$$

$$+ i (g_1 + g_{YB}) \cos \Theta_W \delta_{ij} \left( \gamma_\mu \cdot \frac{1 + \gamma_5}{2} \right) \quad (135)$$

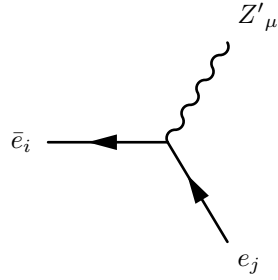

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$$\frac{i}{2} \delta_{ij} \left( (2g_B + g_{BY}) \sin \Theta'_W - (2g_{YB} + g_1) \cos \Theta'_W \sin \Theta_W + g_2 \cos \Theta_W \cos \Theta'_W \right) \left( \gamma_\mu \cdot \frac{1 - \gamma_5}{2} \right) \quad (136)$$

$$+ -i \delta_{ij} \left( (g_1 + g_{YB}) \cos \Theta'_W \sin \Theta_W - (g_{BY} + g_B) \sin \Theta'_W \right) \left( \gamma_\mu \cdot \frac{1 + \gamma_5}{2} \right) \quad (137)$$

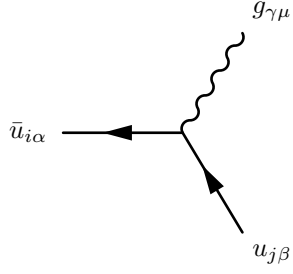

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$$\frac{i}{2}\delta_{ij}\left(\left(2g_B + g_{BY}\right)\cos\Theta'_W + \left(\left(2g_{YB} + g_1\right)\sin\Theta_W - g_2\cos\Theta_W\right)\sin\Theta'_W\right)\left(\gamma_\mu \cdot \frac{1-\gamma_5}{2}\right) \quad (138)$$

$$+ i\delta_{ij}\left(\left(g_1 + g_{YB}\right)\sin\Theta_W\sin\Theta'_W + \left(g_{BY} + g_B\right)\cos\Theta'_W\right)\left(\gamma_\mu \cdot \frac{1+\gamma_5}{2}\right) \quad (139)$$

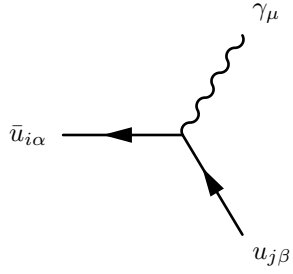

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$$- \frac{i}{2}g_3\delta_{ij}\lambda_{\alpha,\beta}^\gamma\left(\gamma_\mu \cdot \frac{1-\gamma_5}{2}\right) \quad (140)$$

$$+ -\frac{i}{2}g_3\delta_{ij}\lambda_{\alpha,\beta}^\gamma\left(\gamma_\mu \cdot \frac{1+\gamma_5}{2}\right) \quad (141)$$

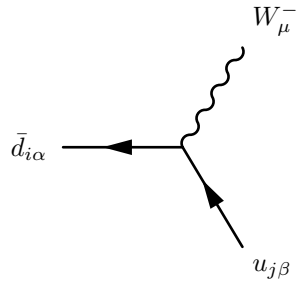

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$$- \frac{i}{6}\delta_{\alpha\beta}\delta_{ij}\left(\left(2g_{YB} + g_1\right)\cos\Theta_W + 3g_2\sin\Theta_W\right)\left(\gamma_\mu \cdot \frac{1-\gamma_5}{2}\right) \quad (142)$$

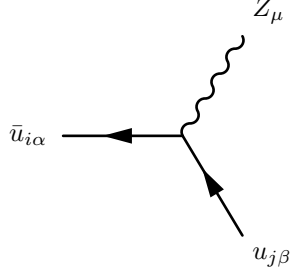
$$+ -\frac{i}{3}\left(2g_1 + g_{YB}\right)\cos\Theta_W\delta_{\alpha\beta}\delta_{ij}\left(\gamma_\mu \cdot \frac{1+\gamma_5}{2}\right) \quad (143)$$


---



$$-i \frac{1}{\sqrt{2}} g_2 \delta_{\alpha\beta} \sum_{a=1}^3 U_{L,ja}^{u,*} U_{L,ia}^d \left( \gamma_\mu \cdot \frac{1-\gamma_5}{2} \right) \quad (144)$$

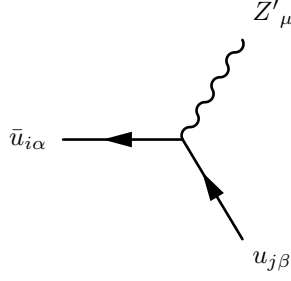

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$$- \frac{i}{6} \delta_{\alpha\beta} \delta_{ij} \left( (2g_B + g_{BY}) \sin \Theta'_W - (2g_{YB} + g_1) \cos \Theta'_W \sin \Theta_W + 3g_2 \cos \Theta_W \cos \Theta'_W \right) \left( \gamma_\mu \cdot \frac{1-\gamma_5}{2} \right) \quad (145)$$

$$+ \frac{i}{3} \delta_{\alpha\beta} \delta_{ij} \left( (2g_1 + g_{YB}) \cos \Theta'_W \sin \Theta_W - (2g_{BY} + g_B) \sin \Theta'_W \right) \left( \gamma_\mu \cdot \frac{1+\gamma_5}{2} \right) \quad (146)$$

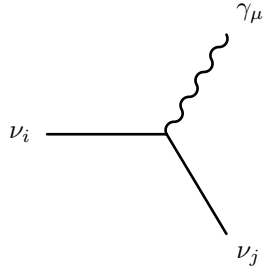

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$$- \frac{i}{6} \delta_{\alpha\beta} \delta_{ij} \left( (2g_B + g_{BY}) \cos \Theta'_W + \left( (2g_{YB} + g_1) \sin \Theta_W - 3g_2 \cos \Theta_W \right) \sin \Theta'_W \right) \left( \gamma_\mu \cdot \frac{1-\gamma_5}{2} \right) \quad (147)$$

$$+ - \frac{i}{3} \delta_{\alpha\beta} \delta_{ij} \left( (2g_1 + g_{YB}) \sin \Theta_W \sin \Theta'_W + (2g_{BY} + g_B) \cos \Theta'_W \right) \left( \gamma_\mu \cdot \frac{1+\gamma_5}{2} \right) \quad (148)$$

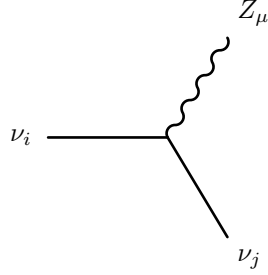

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$$\frac{i}{2} \left( -2g_{YB} \cos \Theta_W \sum_{a=1}^3 U_{j3+a}^{V,*} U_{i3+a}^V + \left( (2g_{YB} + g_1) \cos \Theta_W - g_2 \sin \Theta_W \right) \sum_{a=1}^3 U_{ja}^{V,*} U_{ia}^V \right) \left( \gamma_\mu \cdot \frac{1-\gamma_5}{2} \right) \quad (149)$$

$$+ \frac{i}{2} \left( -2g_{YB} \cos \Theta_W \sum_{a=1}^3 U_{i3+a}^{V,*} U_{j3+a}^V + \left( (2g_{YB} + g_1) \cos \Theta_W - g_2 \sin \Theta_W \right) \sum_{a=1}^3 U_{ia}^{V,*} U_{ja}^V \right) \left( \gamma_\mu \cdot \frac{1+\gamma_5}{2} \right) \quad (150)$$

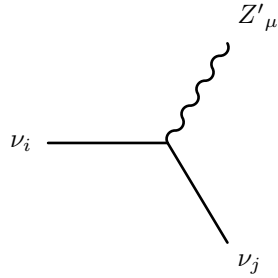

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$$- \frac{i}{2} \left( \left( - (2g_B + g_{BY}) \sin \Theta'_W + (2g_{YB} + g_1) \cos \Theta'_W \sin \Theta_W + g_2 \cos \Theta_W \cos \Theta'_W \right) \sum_{a=1}^3 U_{ja}^{V,*} U_{ia}^V \right. \\ \left. + 2 \left( g_B \sin \Theta'_W - g_{YB} \cos \Theta'_W \sin \Theta_W \right) \sum_{a=1}^3 U_{j3+a}^{V,*} U_{i3+a}^V \right) \left( \gamma_\mu \cdot \frac{1-\gamma_5}{2} \right) \quad (151)$$

$$+ \frac{i}{2} \left( \left( - (2g_B + g_{BY}) \sin \Theta'_W + (2g_{YB} + g_1) \cos \Theta'_W \sin \Theta_W + g_2 \cos \Theta_W \cos \Theta'_W \right) \sum_{a=1}^3 U_{ia}^{V,*} U_{ja}^V \right. \\ \left. + 2 \left( g_B \sin \Theta'_W - g_{YB} \cos \Theta'_W \sin \Theta_W \right) \sum_{a=1}^3 U_{i3+a}^{V,*} U_{j3+a}^V \right) \left( \gamma_\mu \cdot \frac{1+\gamma_5}{2} \right) \quad (152)$$

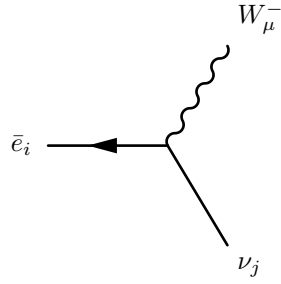

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$$\frac{i}{2} \left( \left( (2g_B + g_{BY}) \cos \Theta'_W + \left( (2g_{YB} + g_1) \sin \Theta_W + g_2 \cos \Theta_W \right) \sin \Theta'_W \right) \sum_{a=1}^3 U_{ja}^{V,*} U_{ia}^V \right.$$

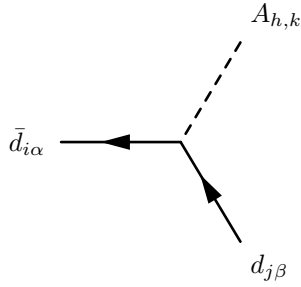
$$- 2 \left( g_B \cos \Theta'_W + g_{YB} \sin \Theta_W \sin \Theta'_W \right) \sum_{a=1}^3 U_{j3+a}^{V,*} U_{i3+a}^V \left( \gamma_\mu \cdot \frac{1 - \gamma_5}{2} \right) \quad (153)$$

$$+ -\frac{i}{2} \left( \left( (2g_B + g_{BY}) \cos \Theta'_W + \left( (2g_{YB} + g_1) \sin \Theta_W + g_2 \cos \Theta_W \right) \sin \Theta'_W \right) \sum_{a=1}^3 U_{ia}^{V,*} U_{ja}^V \right. \\ \left. - 2 \left( g_B \cos \Theta'_W + g_{YB} \sin \Theta_W \sin \Theta'_W \right) \sum_{a=1}^3 U_{i3+a}^{V,*} U_{j3+a}^V \right) \left( \gamma_\mu \cdot \frac{1 + \gamma_5}{2} \right) \quad (154)$$



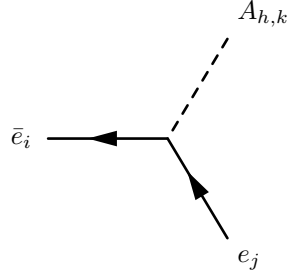
$$- i \frac{1}{\sqrt{2}} g_2 \sum_{a=1}^3 U_{ja}^{V,*} U_{L,ia}^e \left( \gamma_\mu \cdot \frac{1 - \gamma_5}{2} \right) \quad (155)$$

## 9.5 Two Fermion-One Scalar Boson-Interaction



$$\frac{1}{\sqrt{2}} \delta_{\alpha\beta} \sum_{b=1}^3 U_{L,jb}^{d,*} \sum_{a=1}^3 U_{R,ia}^{d,*} Y_{d,ab} Z_{k1}^A \left( \frac{1 - \gamma_5}{2} \right) \quad (156)$$

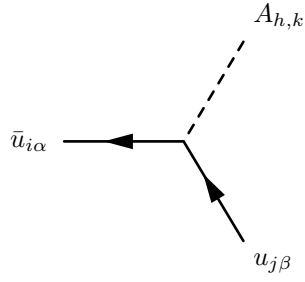
$$+ -\frac{1}{\sqrt{2}} \delta_{\alpha\beta} \sum_{b=1}^3 \sum_{a=1}^3 Y_{d,ab}^* U_{R,ja}^d U_{L,ib}^d Z_{k1}^A \left( \frac{1 + \gamma_5}{2} \right) \quad (157)$$



$$\frac{1}{\sqrt{2}} \sum_{b=1}^3 U_{L,jb}^{e,*} \sum_{a=1}^3 U_{R,ia}^{e,*} Y_{e,ab} Z_{k1}^A \left( \frac{1-\gamma_5}{2} \right) \quad (158)$$

$$+ -\frac{1}{\sqrt{2}} \sum_{b=1}^3 \sum_{a=1}^3 Y_{e,ab}^* U_{R,ja}^e U_{L,ib}^e Z_{k1}^A \left( \frac{1+\gamma_5}{2} \right) \quad (159)$$

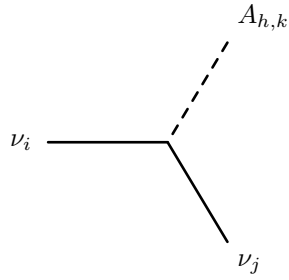

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$$- \frac{1}{\sqrt{2}} \delta_{\alpha\beta} \sum_{b=1}^3 U_{L,jb}^{u,*} \sum_{a=1}^3 U_{R,ia}^{u,*} Y_{u,ab} Z_{k1}^A \left( \frac{1-\gamma_5}{2} \right) \quad (160)$$

$$+ \frac{1}{\sqrt{2}} \delta_{\alpha\beta} \sum_{b=1}^3 \sum_{a=1}^3 Y_{u,ab}^* U_{R,ja}^u U_{L,ib}^u Z_{k1}^A \left( \frac{1+\gamma_5}{2} \right) \quad (161)$$

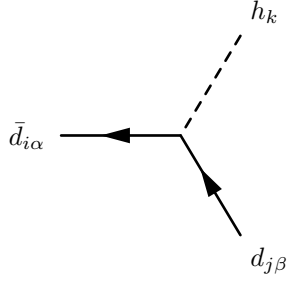

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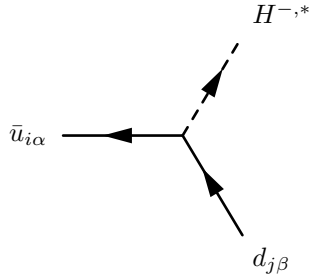
$$\begin{aligned}
& \frac{1}{\sqrt{2}} \left( - \sum_{b=1}^3 U_{j3+b}^{V,*} \sum_{a=1}^3 U_{ia}^{V,*} Y_{\nu,ab} Z_{k1}^A - \sum_{b=1}^3 U_{i3+b}^{V,*} \sum_{a=1}^3 U_{ja}^{V,*} Y_{\nu,ab} Z_{k1}^A \right. \\
& \left. + \left( \sum_{b=1}^3 U_{j3+b}^{V,*} \sum_{a=1}^3 U_{i3+a}^{V,*} Y_{x,ab} + \sum_{b=1}^3 U_{i3+b}^{V,*} \sum_{a=1}^3 U_{j3+a}^{V,*} Y_{x,ab} \right) Z_{k2}^A \right) \left( \frac{1-\gamma_5}{2} \right)
\end{aligned} \tag{162}$$

$$\begin{aligned}
& + \frac{1}{\sqrt{2}} \left( \sum_{b=1}^3 \sum_{a=1}^3 Y_{\nu,ab}^* U_{ja}^V U_{i3+b}^V Z_{k1}^A + \sum_{b=1}^3 \sum_{a=1}^3 Y_{\nu,ab}^* U_{ia}^V U_{j3+b}^V Z_{k1}^A \right. \\
& \left. - \left( \sum_{b=1}^3 \sum_{a=1}^3 Y_{x,ab}^* U_{j3+a}^V U_{i3+b}^V + \sum_{b=1}^3 \sum_{a=1}^3 Y_{x,ab}^* U_{i3+a}^V U_{j3+b}^V \right) Z_{k2}^A \right) \left( \frac{1+\gamma_5}{2} \right)
\end{aligned} \tag{163}$$



$$- i \frac{1}{\sqrt{2}} \delta_{\alpha\beta} \sum_{b=1}^3 U_{L,jb}^{d,*} \sum_{a=1}^3 U_{R,ia}^{d,*} Y_{d,ab} Z_{k1}^H \left( \frac{1-\gamma_5}{2} \right) \tag{164}$$

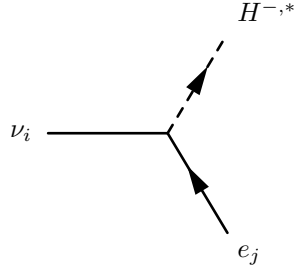
$$+ -i \frac{1}{\sqrt{2}} \delta_{\alpha\beta} \sum_{b=1}^3 \sum_{a=1}^3 Y_{d,ab}^* U_{R,ja}^d U_{L,ib}^d Z_{k1}^H \left( \frac{1+\gamma_5}{2} \right) \tag{165}$$



$$- i \delta_{\alpha\beta} \sum_{b=1}^3 U_{L,jb}^{d,*} \sum_{a=1}^3 U_{R,ia}^{u,*} Y_{u,ab} \left( \frac{1-\gamma_5}{2} \right) \tag{166}$$

$$+ i\delta_{\alpha\beta} \sum_{b=1}^3 \sum_{a=1}^3 Y_{d,ab}^* U_{R,ja}^d U_{L,ib}^u \left( \frac{1+\gamma_5}{2} \right) \quad (167)$$

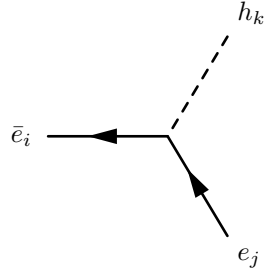

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$$- i \sum_{b=1}^3 U_{i3+b}^{V,*} \sum_{a=1}^3 U_{L,ja}^{e,*} Y_{\nu,ab} \left( \frac{1-\gamma_5}{2} \right) \quad (168)$$

$$+ i \sum_{b=1}^3 \sum_{a=1}^3 Y_{e,ab}^* U_{R,ja}^e U_{ib}^V \left( \frac{1+\gamma_5}{2} \right) \quad (169)$$

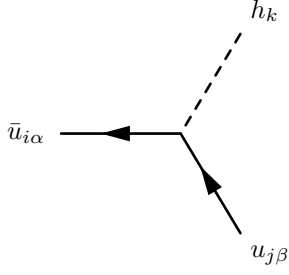

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$$- i \frac{1}{\sqrt{2}} \sum_{b=1}^3 U_{L,jb}^{e,*} \sum_{a=1}^3 U_{R,ia}^{e,*} Y_{e,ab} Z_{k1}^H \left( \frac{1-\gamma_5}{2} \right) \quad (170)$$

$$+ -i \frac{1}{\sqrt{2}} \sum_{b=1}^3 \sum_{a=1}^3 Y_{e,ab}^* U_{R,ja}^e U_{L,ib}^e Z_{k1}^H \left( \frac{1+\gamma_5}{2} \right) \quad (171)$$

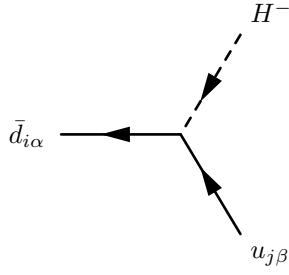

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$$-i \frac{1}{\sqrt{2}} \delta_{\alpha\beta} \sum_{b=1}^3 U_{L,jb}^{u,*} \sum_{a=1}^3 U_{R,ia}^{u,*} Y_{u,ab} Z_{k1}^H \left( \frac{1-\gamma_5}{2} \right) \quad (172)$$

$$+ -i \frac{1}{\sqrt{2}} \delta_{\alpha\beta} \sum_{b=1}^3 \sum_{a=1}^3 Y_{u,ab}^* U_{R,ja}^u U_{L,ib}^u Z_{k1}^H \left( \frac{1+\gamma_5}{2} \right) \quad (173)$$

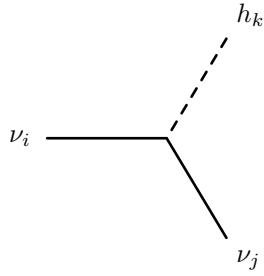

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$$i \delta_{\alpha\beta} \sum_{b=1}^3 U_{L,jb}^{u,*} \sum_{a=1}^3 U_{R,ia}^{d,*} Y_{d,ab} \left( \frac{1-\gamma_5}{2} \right) \quad (174)$$

$$+ -i \delta_{\alpha\beta} \sum_{b=1}^3 \sum_{a=1}^3 Y_{u,ab}^* U_{R,ja}^u U_{L,ib}^d \left( \frac{1+\gamma_5}{2} \right) \quad (175)$$

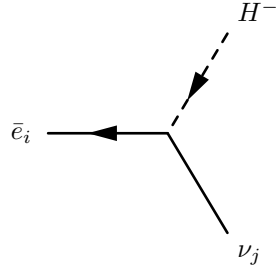

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$$\begin{aligned}
& -i \frac{1}{\sqrt{2}} \left( \sum_{b=1}^3 U_{j3+b}^{V,*} \sum_{a=1}^3 U_{ia}^{V,*} Y_{\nu,ab} Z_{k1}^H + \sum_{b=1}^3 U_{i3+b}^{V,*} \sum_{a=1}^3 U_{ja}^{V,*} Y_{\nu,ab} Z_{k1}^H \right. \\
& \left. + \left( \sum_{b=1}^3 U_{j3+b}^{V,*} \sum_{a=1}^3 U_{i3+a}^{V,*} Y_{x,ab} + \sum_{b=1}^3 U_{i3+b}^{V,*} \sum_{a=1}^3 U_{j3+a}^{V,*} Y_{x,ab} \right) Z_{k2}^H \right) \left( \frac{1-\gamma_5}{2} \right) \quad (176)
\end{aligned}$$

$$\begin{aligned}
& + -i \frac{1}{\sqrt{2}} \left( \sum_{b=1}^3 \sum_{a=1}^3 Y_{\nu,ab}^* U_{ja}^V U_{i3+b}^V Z_{k1}^H + \sum_{b=1}^3 \sum_{a=1}^3 Y_{\nu,ab}^* U_{ia}^V U_{j3+b}^V Z_{k1}^H \right. \\
& \left. + \left( \sum_{b=1}^3 \sum_{a=1}^3 Y_{x,ab}^* U_{j3+a}^V U_{i3+b}^V + \sum_{b=1}^3 \sum_{a=1}^3 Y_{x,ab}^* U_{i3+a}^V U_{j3+b}^V \right) Z_{k2}^H \right) \left( \frac{1+\gamma_5}{2} \right) \quad (177)
\end{aligned}$$


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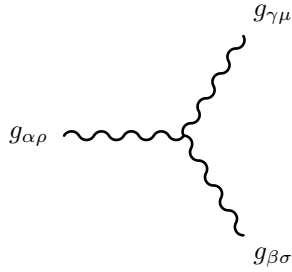


$$i \sum_{b=1}^3 U_{jb}^{V,*} \sum_{a=1}^3 U_{R,ia}^{e,*} Y_{e,ab} \left( \frac{1-\gamma_5}{2} \right) \quad (178)$$

$$+ -i \sum_{b=1}^3 \sum_{a=1}^3 Y_{\nu,ab}^* U_{L,ia}^e U_{j3+b}^V \left( \frac{1+\gamma_5}{2} \right) \quad (179)$$

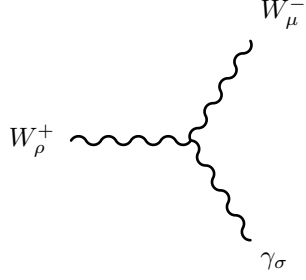

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## 9.6 Three Vector Boson-Interaction



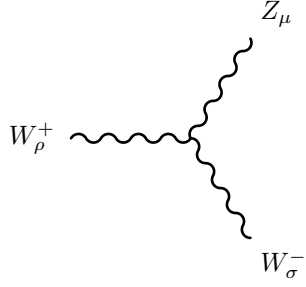
$$g_3 f_{\alpha,\beta,\gamma} \left( g_{\rho\mu} \left( -p_\sigma^{g\gamma\mu} + p_\sigma^{g\alpha\rho} \right) + g_{\rho\sigma} \left( -p_\mu^{g\alpha\rho} + p_\mu^{g\beta\sigma} \right) + g_{\sigma\mu} \left( -p_\rho^{g\beta\sigma} + p_\rho^{g\gamma\mu} \right) \right) \quad (180)$$


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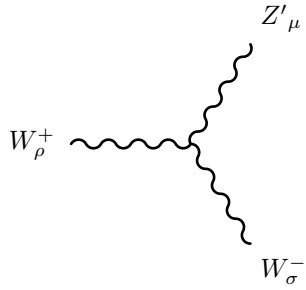
$$ig_2 \sin \Theta_W \left( g_{\rho\mu} \left( -p_{\sigma}^{W^-} + p_{\sigma}^{W^+} \right) + g_{\rho\sigma} \left( -p_{\mu}^{W^+} + p_{\mu}^{\gamma_\sigma} \right) + g_{\sigma\mu} \left( -p_{\rho}^{\gamma_\sigma} + p_{\rho}^{W^-} \right) \right) \quad (181)$$


---



$$-ig_2 \cos \Theta_W \cos \Theta'_W \left( g_{\rho\mu} \left( -p_{\sigma}^{Z^\mu} + p_{\sigma}^{W^+} \right) + g_{\rho\sigma} \left( -p_{\mu}^{W^+} + p_{\mu}^{W_\sigma^-} \right) + g_{\sigma\mu} \left( -p_{\rho}^{W_\sigma^-} + p_{\rho}^{Z^\mu} \right) \right) \quad (182)$$

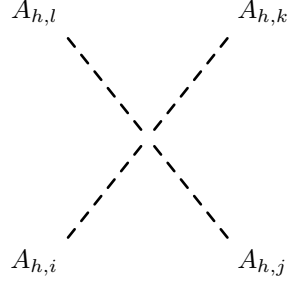

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$$ig_2 \cos \Theta_W \sin \Theta'_W \left( g_{\rho\mu} \left( -p_{\sigma}^{Z'^\mu} + p_{\sigma}^{W^+} \right) + g_{\rho\sigma} \left( -p_{\mu}^{W^+} + p_{\mu}^{W_\sigma^-} \right) + g_{\sigma\mu} \left( -p_{\rho}^{W_\sigma^-} + p_{\rho}^{Z'^\mu} \right) \right) \quad (183)$$

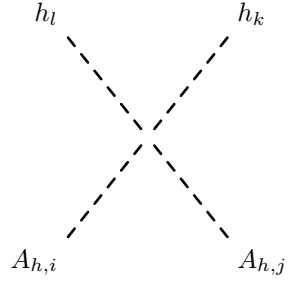

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## 9.7 Four Scalar-Interaction



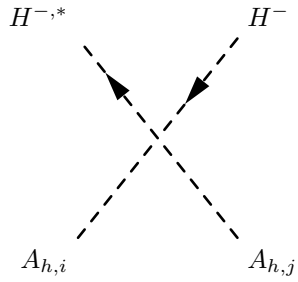
$$\begin{aligned}
& i \left( Z_{i2}^A \left( \lambda_3 Z_{j1}^A \left( Z_{k1}^A Z_{l2}^A + Z_{k2}^A Z_{l1}^A \right) + Z_{j2}^A \left( 6\lambda_2 Z_{k2}^A Z_{l2}^A + \lambda_3 Z_{k1}^A Z_{l1}^A \right) \right) \right. \\
& \left. + Z_{i1}^A \left( \lambda_3 Z_{j2}^A \left( Z_{k1}^A Z_{l2}^A + Z_{k2}^A Z_{l1}^A \right) + Z_{j1}^A \left( 6\lambda_1 Z_{k1}^A Z_{l1}^A + \lambda_3 Z_{k2}^A Z_{l2}^A \right) \right) \right)
\end{aligned} \tag{184}$$


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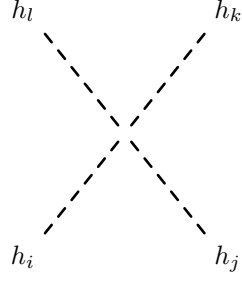
$$i \left( Z_{i1}^A Z_{j1}^A \left( 2\lambda_1 Z_{k1}^H Z_{l1}^H + \lambda_3 Z_{k2}^H Z_{l2}^H \right) + Z_{i2}^A Z_{j2}^A \left( 2\lambda_2 Z_{k2}^H Z_{l2}^H + \lambda_3 Z_{k1}^H Z_{l1}^H \right) \right) \tag{185}$$


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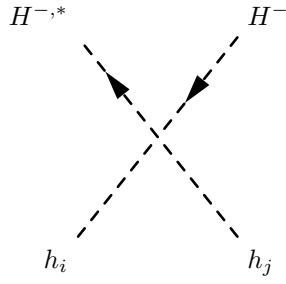
$$i \left( 2\lambda_1 Z_{i1}^A Z_{j1}^A + \lambda_3 Z_{i2}^A Z_{j2}^A \right) \tag{186}$$


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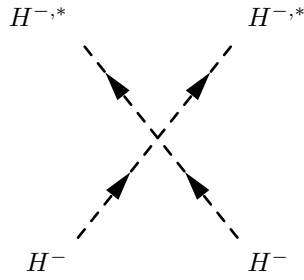
$$\begin{aligned}
& i \left( Z_{i2}^H \left( \lambda_3 Z_{j1}^H \left( Z_{k1}^H Z_{l2}^H + Z_{k2}^H Z_{l1}^H \right) + Z_{j2}^H \left( 6\lambda_2 Z_{k2}^H Z_{l2}^H + \lambda_3 Z_{k1}^H Z_{l1}^H \right) \right) \right. \\
& \left. + Z_{i1}^H \left( \lambda_3 Z_{j2}^H \left( Z_{k1}^H Z_{l2}^H + Z_{k2}^H Z_{l1}^H \right) + Z_{j1}^H \left( 6\lambda_1 Z_{k1}^H Z_{l1}^H + \lambda_3 Z_{k2}^H Z_{l2}^H \right) \right) \right)
\end{aligned} \tag{187}$$


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$$i \left( 2\lambda_1 Z_{i1}^H Z_{j1}^H + \lambda_3 Z_{i2}^H Z_{j2}^H \right) \tag{188}$$

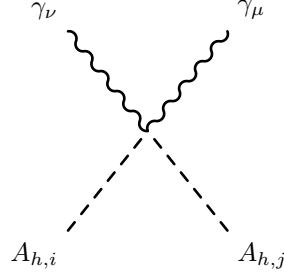

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$$4i\lambda_1 \tag{189}$$

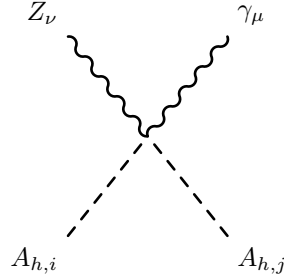

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## 9.8 Two Scalar-Two Vector Boson-Interaction



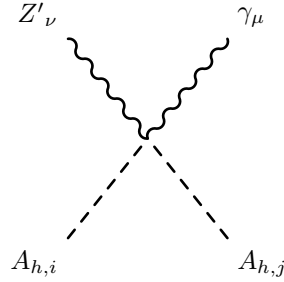
$$\frac{i}{2} \left( 16g_{YB}^2 \cos^2 \Theta_W Z_{i2}^A Z_{j2}^A + \left( g_1 \cos \Theta_W - g_2 \sin \Theta_W \right)^2 Z_{i1}^A Z_{j1}^A \right) (g_{\mu\nu}) \quad (190)$$


---



$$\begin{aligned} & -\frac{i}{2} \left( \left( g_1 \cos \Theta_W - g_2 \sin \Theta_W \right) \left( g_1 \cos \Theta'_W \sin \Theta_W + g_2 \cos \Theta_W \cos \Theta'_W - g_{BY} \sin \Theta'_W \right) Z_{i1}^A Z_{j1}^A \right. \\ & \left. + 8g_{YB} \left( -2g_B \cos \Theta_W \sin \Theta'_W + g_{YB} \cos \Theta'_W \sin 2\Theta_W \right) Z_{i2}^A Z_{j2}^A \right) (g_{\mu\nu}) \end{aligned} \quad (191)$$

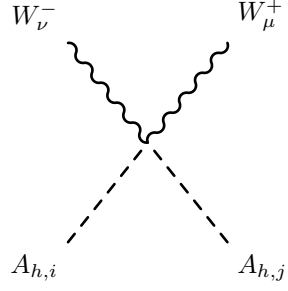

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$$\begin{aligned} & \frac{i}{2} \left( \left( g_1 \cos \Theta_W - g_2 \sin \Theta_W \right) \left( \left( g_1 \sin \Theta_W + g_2 \cos \Theta_W \right) \sin \Theta'_W + g_{BY} \cos \Theta'_W \right) Z_{i1}^A Z_{j1}^A \right. \\ & \left. + 8g_{YB} \left( 2g_B \cos \Theta_W \cos \Theta'_W + g_{YB} \sin 2\Theta_W \sin \Theta'_W \right) Z_{i2}^A Z_{j2}^A \right) (g_{\mu\nu}) \end{aligned} \quad (192)$$

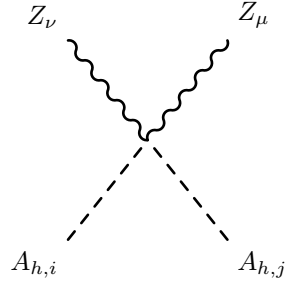

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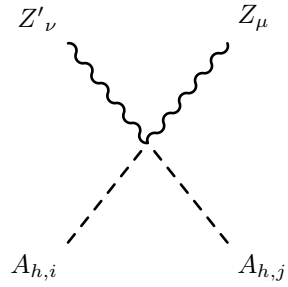
$$\frac{i}{2} g_2^2 Z_{i1}^A Z_{j1}^A (g_{\mu\nu}) \quad (193)$$


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$$\begin{aligned} & \frac{i}{2} \left( \left( g_1 \cos \Theta'_W \sin \Theta_W + g_2 \cos \Theta_W \cos \Theta'_W - g_{BY} \sin \Theta'_W \right)^2 Z_{i1}^A Z_{j1}^A \right. \\ & \left. + 16 \left( -g_B \sin \Theta'_W + g_{YB} \cos \Theta'_W \sin \Theta_W \right)^2 Z_{i2}^A Z_{j2}^A \right) (g_{\mu\nu}) \end{aligned} \quad (194)$$

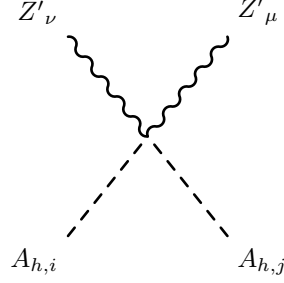

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$$\begin{aligned} & - \frac{i}{2} \left( \left( g_1 g_{BY} \cos \Theta'^2_W \sin \Theta_W + g_2^2 \cos \Theta_W^2 \cos \Theta'_W \sin \Theta'_W \right. \right. \\ & \left. \left. + \cos \Theta'_W \left( g_1^2 \sin \Theta_W^2 - g_{BY}^2 \right) \sin \Theta'_W - g_1 g_{BY} \sin \Theta_W \sin \Theta'^2_W \right) \right) \end{aligned}$$

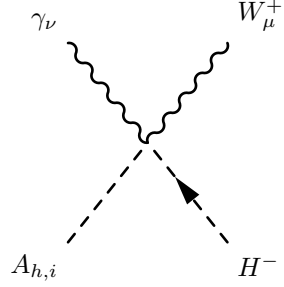
$$\begin{aligned}
& + g_2 \cos \Theta_W \left( g_1 \sin \Theta_W \sin 2\Theta'_W + g_{BY} \cos \Theta'^2_W - g_{BY} \sin \Theta'^2_W \right) Z_{i1}^A Z_{j1}^A \\
& + 8 \left( 2g_B g_{YB} \cos \Theta'^2_W \sin \Theta_W - 2g_B g_{YB} \sin \Theta_W \sin \Theta'^2_W - g_B^2 \sin 2\Theta'_W \right. \\
& \left. + g_{YB}^2 \sin \Theta_W^2 \sin 2\Theta'_W \right) Z_{i2}^A Z_{j2}^A \left( g_{\mu\nu} \right)
\end{aligned} \tag{195}$$


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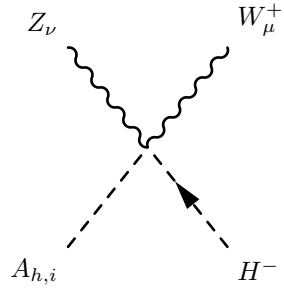
$$\begin{aligned}
& \frac{i}{2} \left( \left( \left( g_1 \sin \Theta_W + g_2 \cos \Theta_W \right) \sin \Theta'_W + g_{BY} \cos \Theta'_W \right)^2 Z_{i1}^A Z_{j1}^A \right. \\
& \left. + 16 \left( g_B \cos \Theta'_W + g_{YB} \sin \Theta_W \sin \Theta'_W \right)^2 Z_{i2}^A Z_{j2}^A \right) \left( g_{\mu\nu} \right)
\end{aligned} \tag{196}$$


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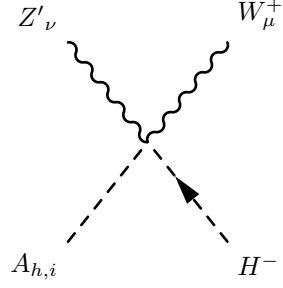
$$- \frac{1}{2} g_1 g_2 \cos \Theta_W Z_{i1}^A \left( g_{\mu\nu} \right) \tag{197}$$


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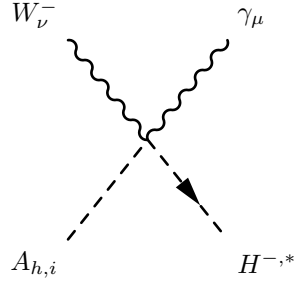
$$\frac{1}{2}g_2\left(g_1\cos\Theta'_W\sin\Theta_W-g_{BY}\sin\Theta'_W\right)Z_{i1}^A\left(g_{\mu\nu}\right) \quad (198)$$


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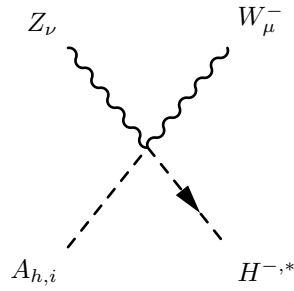
$$-\frac{1}{2}g_2\left(g_1\sin\Theta_W\sin\Theta'_W+g_{BY}\cos\Theta'_W\right)Z_{i1}^A\left(g_{\mu\nu}\right) \quad (199)$$


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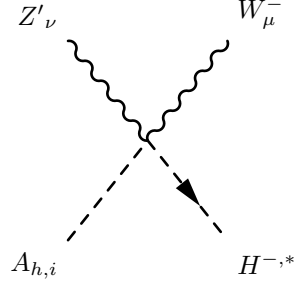
$$\frac{1}{2}g_1g_2\cos\Theta_W Z_{i1}^A\left(g_{\mu\nu}\right) \quad (200)$$


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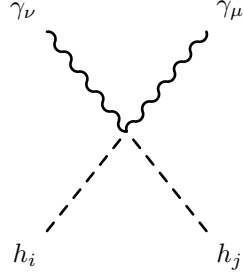
$$\frac{1}{2}g_2\left(-g_1\cos\Theta'_W\sin\Theta_W+g_{BY}\sin\Theta'_W\right)Z_{i1}^A\left(g_{\mu\nu}\right) \quad (201)$$


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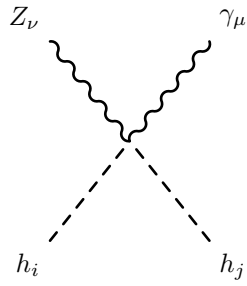
$$\frac{1}{2}g_2\left(g_1\sin\Theta_W\sin\Theta'_W+g_{BY}\cos\Theta'_W\right)Z_{i1}^A\left(g_{\mu\nu}\right) \quad (202)$$


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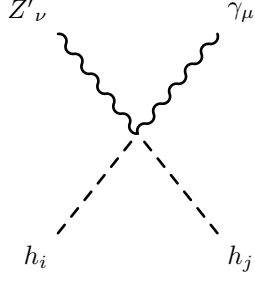
$$\frac{i}{2}\left(16g_{YB}^2\cos\Theta_W^2Z_{i2}^HZ_{j2}^H+\left(g_1\cos\Theta_W-g_2\sin\Theta_W\right)^2Z_{i1}^HZ_{j1}^H\right)\left(g_{\mu\nu}\right) \quad (203)$$


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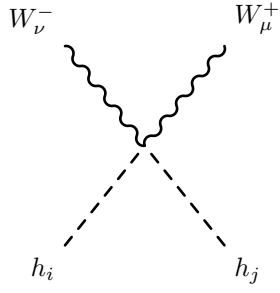
$$\begin{aligned} & -\frac{i}{2}\left(\left(g_1\cos\Theta_W-g_2\sin\Theta_W\right)\left(g_1\cos\Theta'_W\sin\Theta_W+g_2\cos\Theta_W\cos\Theta'_W-g_{BY}\sin\Theta'_W\right)Z_{i1}^HZ_{j1}^H\right. \\ & \left.+8g_{YB}\left(-2g_B\cos\Theta_W\sin\Theta'_W+g_{YB}\cos\Theta'_W\sin2\Theta_W\right)Z_{i2}^HZ_{j2}^H\right)\left(g_{\mu\nu}\right) \end{aligned} \quad (204)$$


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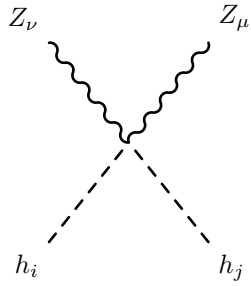
$$\begin{aligned} & \frac{i}{2} \left( (g_1 \cos \Theta_W - g_2 \sin \Theta_W) \left( (g_1 \sin \Theta_W + g_2 \cos \Theta_W) \sin \Theta'_W + g_{BY} \cos \Theta'_W \right) Z_{i1}^H Z_{j1}^H \right. \\ & \left. + 8g_{YB} \left( 2g_B \cos \Theta_W \cos \Theta'_W + g_{YB} \sin 2\Theta_W \sin \Theta'_W \right) Z_{i2}^H Z_{j2}^H \right) (g_{\mu\nu}) \end{aligned} \quad (205)$$


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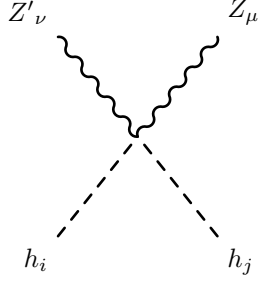
$$\frac{i}{2} g_2^2 Z_{i1}^H Z_{j1}^H (g_{\mu\nu}) \quad (206)$$


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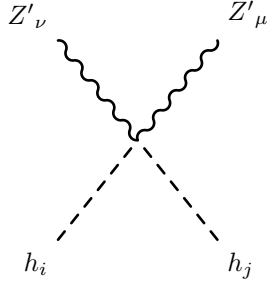
$$\begin{aligned} & \frac{i}{2} \left( (g_1 \cos \Theta'_W \sin \Theta_W + g_2 \cos \Theta_W \cos \Theta'_W - g_{BY} \sin \Theta'_W)^2 Z_{i1}^H Z_{j1}^H \right. \\ & \left. + 16 \left( -g_B \sin \Theta'_W + g_{YB} \cos \Theta'_W \sin \Theta_W \right)^2 Z_{i2}^H Z_{j2}^H \right) (g_{\mu\nu}) \end{aligned} \quad (207)$$


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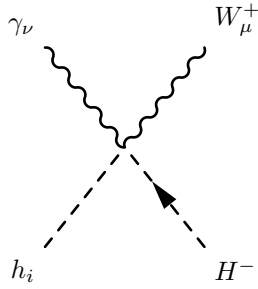
$$\begin{aligned}
& -\frac{i}{2} \left( \left( g_1 g_{BY} \cos \Theta_W'^2 \sin \Theta_W + g_2^2 \cos \Theta_W^2 \cos \Theta_W' \sin \Theta_W' \right. \right. \\
& + \cos \Theta_W' \left( g_1^2 \sin \Theta_W^2 - g_{BY}^2 \right) \sin \Theta_W' - g_1 g_{BY} \sin \Theta_W \sin \Theta_W'^2 \\
& + g_2 \cos \Theta_W \left( g_1 \sin \Theta_W \sin 2\Theta_W' + g_{BY} \cos \Theta_W'^2 - g_{BY} \sin \Theta_W'^2 \right) \left. \right) Z_{i1}^H Z_{j1}^H \\
& + 8 \left( 2g_B g_{YB} \cos \Theta_W'^2 \sin \Theta_W - 2g_B g_{YB} \sin \Theta_W \sin \Theta_W'^2 - g_B^2 \sin 2\Theta_W' \right. \\
& \left. + g_{YB}^2 \sin \Theta_W^2 \sin 2\Theta_W' \right) Z_{i2}^H Z_{j2}^H \left( g_{\mu\nu} \right)
\end{aligned} \tag{208}$$


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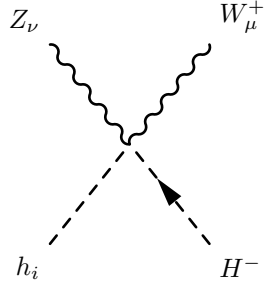
$$\begin{aligned}
& \frac{i}{2} \left( \left( \left( g_1 \sin \Theta_W + g_2 \cos \Theta_W \right) \sin \Theta_W' + g_{BY} \cos \Theta_W' \right)^2 Z_{i1}^H Z_{j1}^H \right. \\
& \left. + 16 \left( g_B \cos \Theta_W' + g_{YB} \sin \Theta_W \sin \Theta_W' \right)^2 Z_{i2}^H Z_{j2}^H \right) \left( g_{\mu\nu} \right)
\end{aligned} \tag{209}$$


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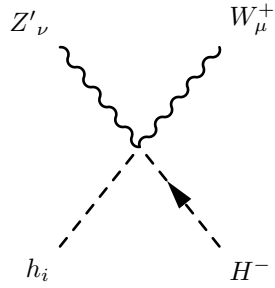
$$-\frac{i}{2}g_1g_2\cos\Theta_W Z_{i1}^H(g_{\mu\nu}) \quad (210)$$


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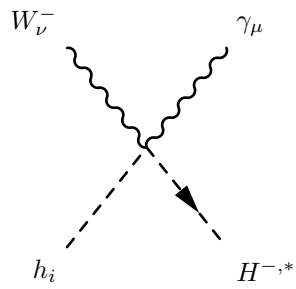
$$\frac{i}{2}g_2\left(g_1\cos\Theta'_W\sin\Theta_W - g_{BY}\sin\Theta'_W\right)Z_{i1}^H(g_{\mu\nu}) \quad (211)$$


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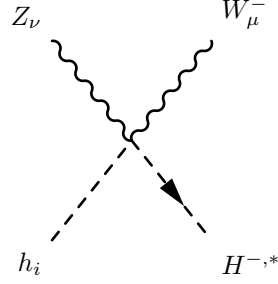
$$-\frac{i}{2}g_2\left(g_1\sin\Theta_W\sin\Theta'_W + g_{BY}\cos\Theta'_W\right)Z_{i1}^H(g_{\mu\nu}) \quad (212)$$


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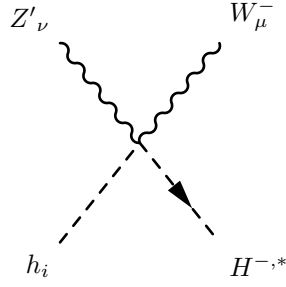
$$-\frac{i}{2}g_1g_2\cos\Theta_W Z_{i1}^H(g_{\mu\nu}) \quad (213)$$


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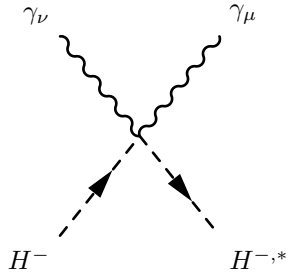
$$\frac{i}{2}g_2\left(g_1\cos\Theta'_W\sin\Theta_W-g_{BY}\sin\Theta'_W\right)Z_{i1}^H\left(g_{\mu\nu}\right) \quad (214)$$


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$$-\frac{i}{2}g_2\left(g_1\sin\Theta_W\sin\Theta'_W+g_{BY}\cos\Theta'_W\right)Z_{i1}^H\left(g_{\mu\nu}\right) \quad (215)$$

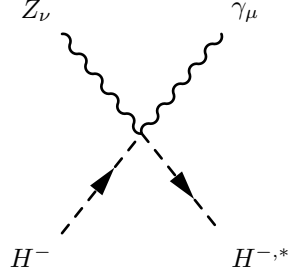

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$$\frac{i}{2}\left(g_1\cos\Theta_W+g_2\sin\Theta_W\right)^2\left(g_{\mu\nu}\right) \quad (216)$$


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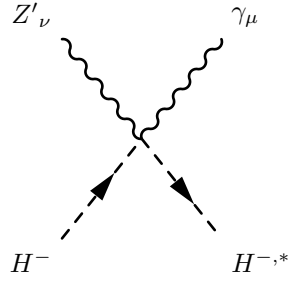




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$$\frac{i}{2} \left( g_1 \cos \Theta_W + g_2 \sin \Theta_W \right) \left( -g_1 \cos \Theta'_W \sin \Theta_W + g_2 \cos \Theta_W \cos \Theta'_W + g_{BY} \sin \Theta'_W \right) (g_{\mu\nu}) \quad (217)$$

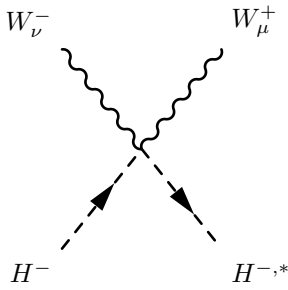

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$$\frac{i}{2} \left( g_1 \cos \Theta_W + g_2 \sin \Theta_W \right) \left( \left( g_1 \sin \Theta_W - g_2 \cos \Theta_W \right) \sin \Theta'_W + g_{BY} \cos \Theta'_W \right) (g_{\mu\nu}) \quad (218)$$

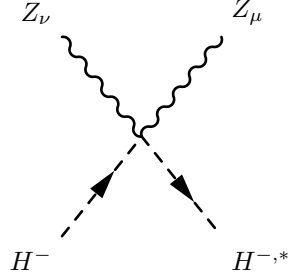

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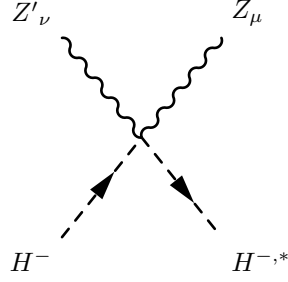

$$\frac{i}{2} g_2^2 (g_{\mu\nu}) \quad (219)$$


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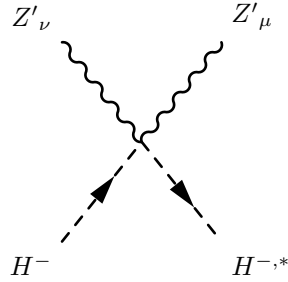
$$\frac{i}{2} \left( -g_1 \cos \Theta'_W \sin \Theta_W + g_2 \cos \Theta_W \cos \Theta'_W + g_{BY} \sin \Theta'_W \right)^2 (g_{\mu\nu}) \quad (220)$$


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$$\begin{aligned} & \frac{i}{2} \left( -g_1 g_{BY} \cos \Theta'^2_W \sin \Theta_W - g_2^2 \cos \Theta_W^2 \cos \Theta'_W \sin \Theta'_W \right. \\ & + \cos \Theta'_W \left( -g_1^2 \sin \Theta_W^2 + g_{BY}^2 \right) \sin \Theta'_W + g_1 g_{BY} \sin \Theta_W \sin \Theta'^2_W \\ & \left. + g_2 \cos \Theta_W \left( g_1 \sin \Theta_W \sin 2\Theta'_W + g_{BY} \cos \Theta'^2_W - g_{BY} \sin \Theta'^2_W \right) \right) (g_{\mu\nu}) \end{aligned} \quad (221)$$

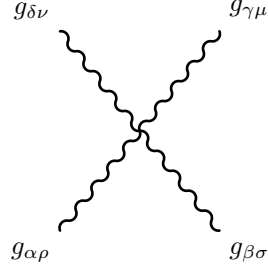

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$$\frac{i}{2} \left( \left( g_1 \sin \Theta_W - g_2 \cos \Theta_W \right) \sin \Theta'_W + g_{BY} \cos \Theta'_W \right)^2 (g_{\mu\nu}) \quad (222)$$


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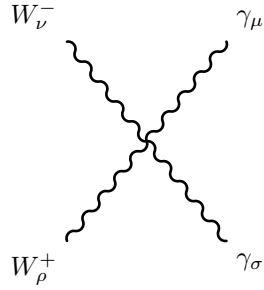
## 9.9 Four Vector Boson-Interaction



$$-ig_3^2 \left( \sum_{a=1}^8 f_{\alpha,\delta,a} f_{\beta,\gamma,a} + \sum_{a=1}^8 f_{\alpha,\gamma,a} f_{\beta,\delta,a} \right) (g_{\rho\sigma} g_{\mu\nu}) \quad (223)$$

$$+ ig_3^2 \left( - \sum_{a=1}^8 f_{\alpha,\beta,a} f_{\gamma,\delta,a} + \sum_{a=1}^8 f_{\alpha,\delta,a} f_{\beta,\gamma,a} \right) (g_{\rho\mu} g_{\sigma\nu}) \quad (224)$$

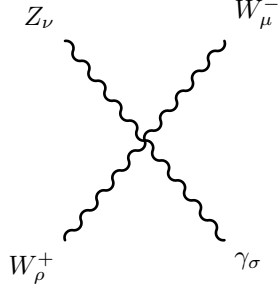
$$+ ig_3^2 \left( \sum_{a=1}^8 f_{\alpha,\gamma,a} f_{\beta,\delta,a} + \sum_{a=1}^8 f_{\alpha,\beta,a} f_{\gamma,\delta,a} \right) (g_{\rho\nu} g_{\sigma\mu}) \quad (225)$$



$$ig_2^2 \sin \Theta_W^2 (g_{\rho\sigma} g_{\mu\nu}) \quad (226)$$

$$+ ig_2^2 \sin \Theta_W^2 (g_{\rho\mu} g_{\sigma\nu}) \quad (227)$$

$$+ -2ig_2^2 \sin \Theta_W^2 (g_{\rho\nu} g_{\sigma\mu}) \quad (228)$$

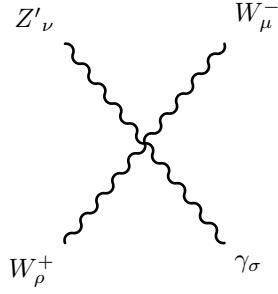


$$ig_2^2 \cos \Theta_W \cos \Theta'_W \sin \Theta_W (g_{\rho\sigma} g_{\mu\nu}) \quad (229)$$

$$+ -ig_2^2 \cos \Theta'_W \sin 2\Theta_W (g_{\rho\mu} g_{\sigma\nu}) \quad (230)$$

$$+ ig_2^2 \cos \Theta_W \cos \Theta'_W \sin \Theta_W (g_{\rho\nu} g_{\sigma\mu}) \quad (231)$$


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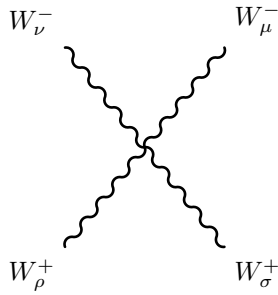


$$- ig_2^2 \cos \Theta_W \sin \Theta_W \sin \Theta'_W (g_{\rho\sigma} g_{\mu\nu}) \quad (232)$$

$$+ ig_2^2 \sin 2\Theta_W \sin \Theta'_W (g_{\rho\mu} g_{\sigma\nu}) \quad (233)$$

$$+ -ig_2^2 \cos \Theta_W \sin \Theta_W \sin \Theta'_W (g_{\rho\nu} g_{\sigma\mu}) \quad (234)$$

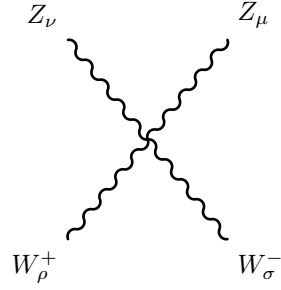

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$$2ig_2^2(g_{\rho\sigma}g_{\mu\nu}) \quad (235)$$

$$+ -ig_2^2(g_{\rho\mu}g_{\sigma\nu}) \quad (236)$$

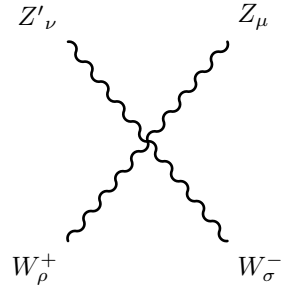
$$+ -ig_2^2(g_{\rho\nu}g_{\sigma\mu}) \quad (237)$$



$$- 2ig_2^2 \cos \Theta_W^2 \cos \Theta_W'^2 (g_{\rho\sigma}g_{\mu\nu}) \quad (238)$$

$$+ ig_2^2 \cos \Theta_W^2 \cos \Theta_W'^2 (g_{\rho\mu}g_{\sigma\nu}) \quad (239)$$

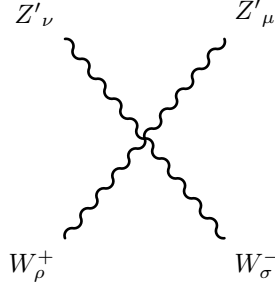
$$+ ig_2^2 \cos \Theta_W^2 \cos \Theta_W'^2 (g_{\rho\nu}g_{\sigma\mu}) \quad (240)$$



$$ig_2^2 \cos \Theta_W^2 \sin 2\Theta'_W (g_{\rho\sigma}g_{\mu\nu}) \quad (241)$$

$$+ -ig_2^2 \cos \Theta_W^2 \cos \Theta'_W \sin \Theta'_W (g_{\rho\mu}g_{\sigma\nu}) \quad (242)$$

$$+ -ig_2^2 \cos \Theta_W^2 \cos \Theta'_W \sin \Theta'_W (g_{\rho\nu}g_{\sigma\mu}) \quad (243)$$

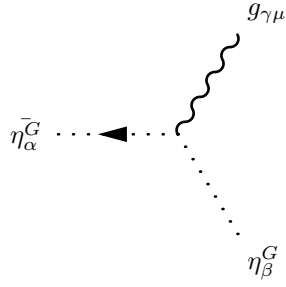


$$- 2ig_2^2 \cos \Theta_W^2 \sin \Theta_W'^2 \left( g_{\rho\sigma} g_{\mu\nu} \right) \quad (244)$$

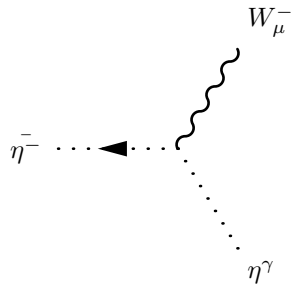
$$+ ig_2^2 \cos \Theta_W^2 \sin \Theta_W'^2 \left( g_{\rho\mu} g_{\sigma\nu} \right) \quad (245)$$

$$+ ig_2^2 \cos \Theta_W^2 \sin \Theta_W'^2 \left( g_{\rho\nu} g_{\sigma\mu} \right) \quad (246)$$

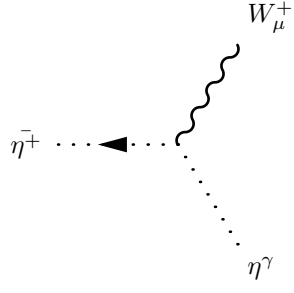
## 9.10 Two Ghosts-One Vector Boson-Interaction



$$g_3 f_{\alpha,\beta,\gamma} \left( p_\mu^{\eta_\beta^G} \right) \quad (247)$$

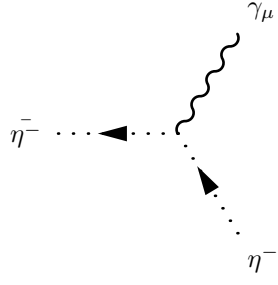


$$ig_2 \sin \Theta_W \left( p_\mu^{\eta^\gamma} \right) \quad (248)$$



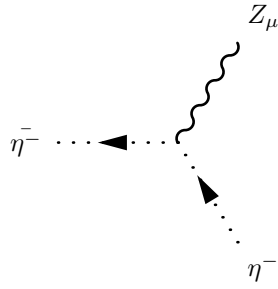
$$-ig_2 \sin \Theta_W \left( p_\mu^{\eta^\gamma} \right) \quad (249)$$


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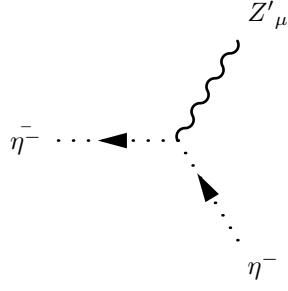
$$-ig_2 \sin \Theta_W \left( p_\mu^{\eta^-} \right) \quad (250)$$


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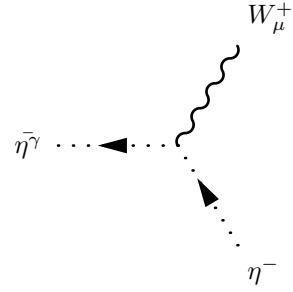
$$-ig_2 \cos \Theta_W \cos \Theta'_W \left( p_\mu^{\eta^-} \right) \quad (251)$$


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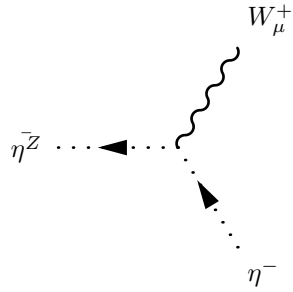
$$ig_2 \cos \Theta_W \sin \Theta'_W (p_\mu^{\eta^-}) \quad (252)$$


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$$ig_2 \sin \Theta_W (p_\mu^{\eta^-}) \quad (253)$$

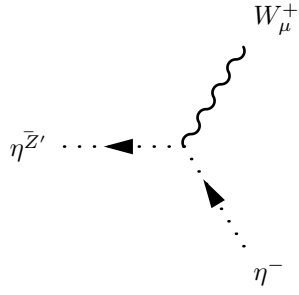

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$$ig_2 \cos \Theta_W \cos \Theta'_W (p_\mu^{\eta^-}) \quad (254)$$

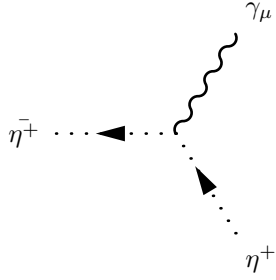

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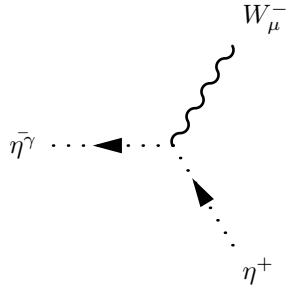
$$-ig_2 \cos \Theta_W \sin \Theta'_W (p_\mu^{\eta^-}) \quad (255)$$


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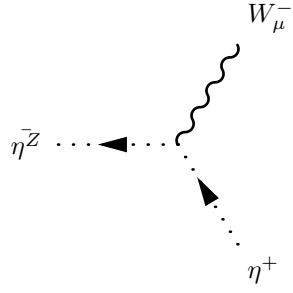
$$ig_2 \sin \Theta_W (p_\mu^{\eta^+}) \quad (256)$$


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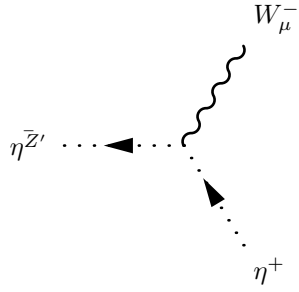
$$-ig_2 \sin \Theta_W (p_\mu^{\eta^+}) \quad (257)$$


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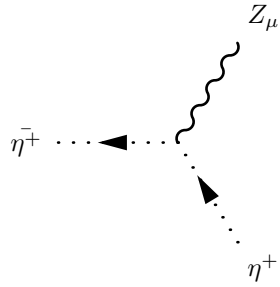
$$-ig_2 \cos \Theta_W \cos \Theta'_W (p_\mu^{\eta^+}) \quad (258)$$


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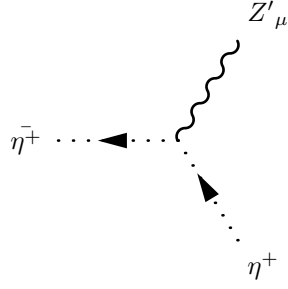
$$ig_2 \cos \Theta_W \sin \Theta'_W (p_\mu^{\eta^+}) \quad (259)$$


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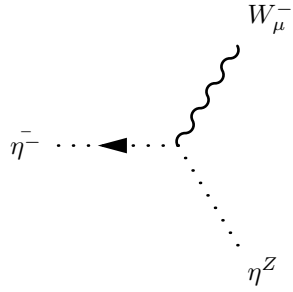
$$ig_2 \cos \Theta_W \cos \Theta'_W (p_\mu^{\eta^+}) \quad (260)$$


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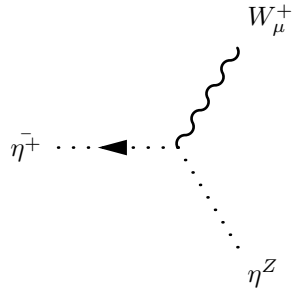
$$-ig_2 \cos \Theta_W \sin \Theta'_W \left( p_\mu^{\eta^+} \right) \quad (261)$$


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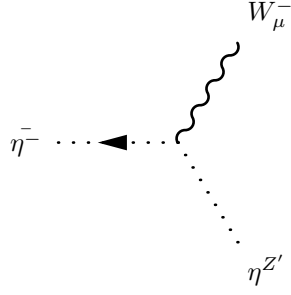
$$ig_2 \cos \Theta_W \cos \Theta'_W \left( p_\mu^{\eta^Z} \right) \quad (262)$$


---



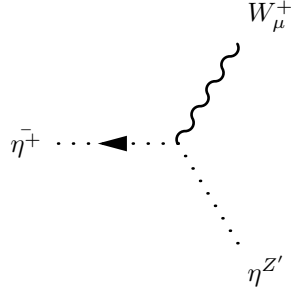
$$-ig_2 \cos \Theta_W \cos \Theta'_W \left( p_\mu^{\eta^Z} \right) \quad (263)$$


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$$-ig_2 \cos \Theta_W \sin \Theta'_W \left( p_\mu^{\eta^{Z'}} \right) \quad (264)$$

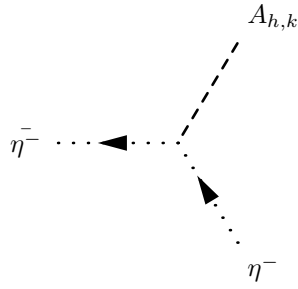

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$$ig_2 \cos \Theta_W \sin \Theta'_W \left( p_\mu^{\eta^{Z'}} \right) \quad (265)$$

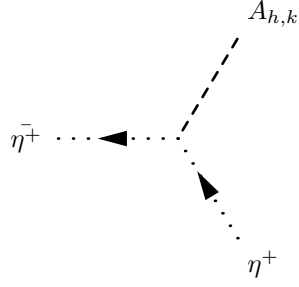

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### 9.11 Two Ghosts-One Scalar-Interaction



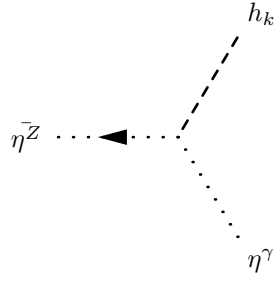
$$\frac{1}{4} g_2^2 v \xi_{W^-} Z_{k1}^A \quad (266)$$


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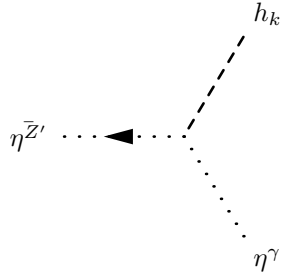
$$-\frac{1}{4}g_2^2 v \xi_{W^-} Z_{k1}^A \quad (267)$$


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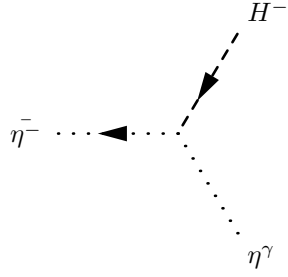
$$\begin{aligned} & \frac{i}{4} \xi_Z \left( v \left( g_1 \cos \Theta_W - g_2 \sin \Theta_W \right) \left( g_1 \cos \Theta'_W \sin \Theta_W + g_2 \cos \Theta_W \cos \Theta'_W - g_{BY} \sin \Theta'_W \right) Z_{k1}^H \right. \\ & \left. + 8g_{YB} x \left( -2g_B \cos \Theta_W \sin \Theta'_W + g_{YB} \cos \Theta'_W \sin 2\Theta_W \right) Z_{k2}^H \right) \end{aligned} \quad (268)$$


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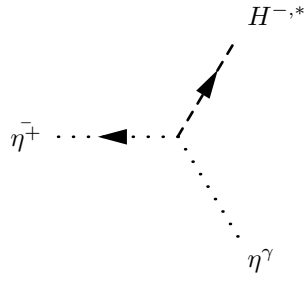
$$\begin{aligned} & -\frac{i}{4} \xi_{Z'} \left( v \left( g_1 \cos \Theta_W - g_2 \sin \Theta_W \right) \left( \left( g_1 \sin \Theta_W + g_2 \cos \Theta_W \right) \sin \Theta'_W + g_{BY} \cos \Theta'_W \right) Z_{k1}^H \right. \\ & \left. + 8g_{YB} x \left( 2g_B \cos \Theta_W \cos \Theta'_W + g_{YB} \sin 2\Theta_W \sin \Theta'_W \right) Z_{k2}^H \right) \end{aligned} \quad (269)$$


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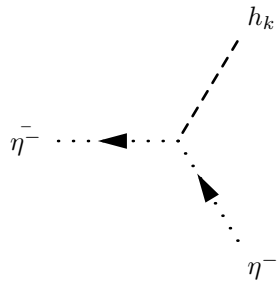
$$\frac{i}{4}g_2v\xi_{W^-}\left(g_1\cos\Theta_W+g_2\sin\Theta_W\right) \quad (270)$$


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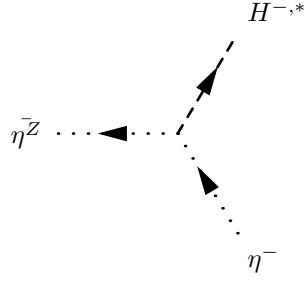
$$\frac{i}{4}g_2v\xi_{W^-}\left(g_1\cos\Theta_W+g_2\sin\Theta_W\right) \quad (271)$$


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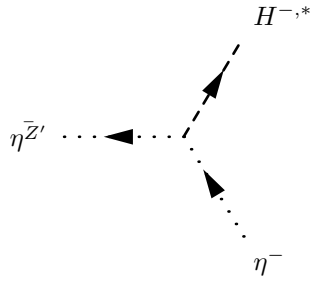
$$-\frac{i}{4}g_2^2v\xi_{W^-}Z_{k1}^H \quad (272)$$


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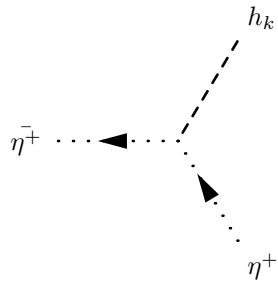
$$-\frac{i}{4}g_2v\xi_Z\left(g_1\cos\Theta'_W\sin\Theta_W+g_2\cos\Theta_W\cos\Theta'_W-g_{BY}\sin\Theta'_W\right) \quad (273)$$


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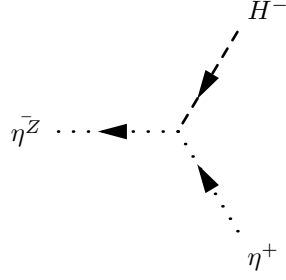
$$\frac{i}{4}g_2v\xi_{Z'}\left(\left(g_1\sin\Theta_W+g_2\cos\Theta_W\right)\sin\Theta'_W+g_{BY}\cos\Theta'_W\right) \quad (274)$$


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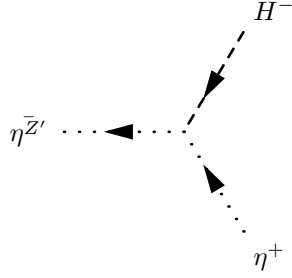
$$-\frac{i}{4}g_2^2v\xi_{W^-}Z_{k1}^H \quad (275)$$


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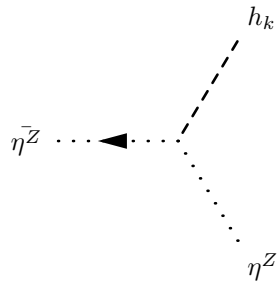
$$-\frac{i}{4}g_2v\xi_Z\left(g_1\cos\Theta'_W\sin\Theta_W+g_2\cos\Theta_W\cos\Theta'_W-g_{BY}\sin\Theta'_W\right) \quad (276)$$


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$$\frac{i}{4}g_2v\xi_{Z'}\left(\left(g_1\sin\Theta_W+g_2\cos\Theta_W\right)\sin\Theta'_W+g_{BY}\cos\Theta'_W\right) \quad (277)$$

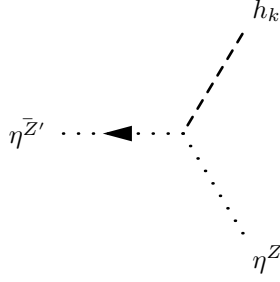

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$$\begin{aligned} &-\frac{i}{4}\xi_Z\left(v\left(g_1\cos\Theta'_W\sin\Theta_W+g_2\cos\Theta_W\cos\Theta'_W-g_{BY}\sin\Theta'_W\right)^2Z_{k1}^H\right. \\ &\left.+16x\left(-g_B\sin\Theta'_W+g_{YB}\cos\Theta'_W\sin\Theta_W\right)^2Z_{k2}^H\right) \end{aligned} \quad (278)$$

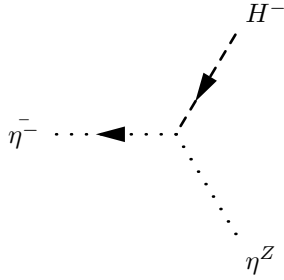

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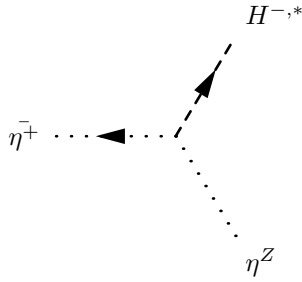
$$\begin{aligned}
& \frac{i}{4} \xi_{Z'} \left( v \left( g_1 g_{BY} \cos \Theta'_W \sin \Theta_W + g_2^2 \cos \Theta_W^2 \cos \Theta'_W \sin \Theta'_W \right. \right. \\
& + \cos \Theta'_W \left( g_1^2 \sin \Theta_W^2 - g_{BY}^2 \right) \sin \Theta'_W - g_1 g_{BY} \sin \Theta_W \sin \Theta_W'^2 \\
& + g_2 \cos \Theta_W \left( g_1 \sin \Theta_W \sin 2\Theta'_W + g_{BY} \cos \Theta_W'^2 - g_{BY} \sin \Theta_W'^2 \right) \Big) Z_{k1}^H \\
& + 8x \left( 2g_B g_{YB} \cos \Theta_W'^2 \sin \Theta_W - 2g_B g_{YB} \sin \Theta_W \sin \Theta_W'^2 - g_B^2 \sin 2\Theta'_W \right. \\
& \left. + g_{YB}^2 \sin \Theta_W^2 \sin 2\Theta'_W \right) Z_{k2}^H \Big) \quad (279)
\end{aligned}$$


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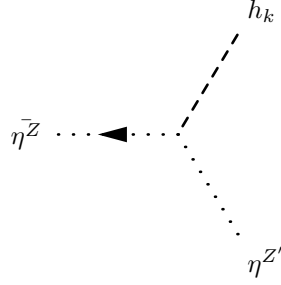
$$\frac{i}{4} g_2 v \xi_{W^-} \left( -g_1 \cos \Theta'_W \sin \Theta_W + g_2 \cos \Theta_W \cos \Theta'_W + g_{BY} \sin \Theta'_W \right) \quad (280)$$


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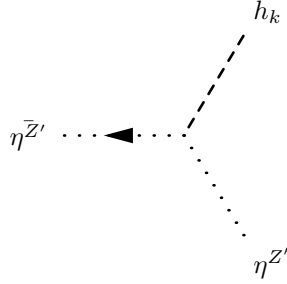
$$\frac{i}{4}g_2v\xi_W-\left(-g_1\cos\Theta'_W\sin\Theta_W+g_2\cos\Theta_W\cos\Theta'_W+g_{BY}\sin\Theta'_W\right) \quad (281)$$


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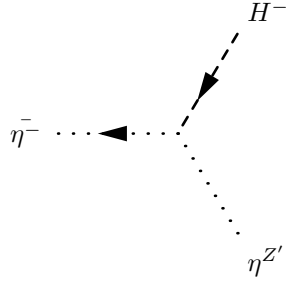
$$\begin{aligned} & \frac{i}{4}\xi_Z\left(v\left(g_1g_{BY}\cos\Theta'^2_W\sin\Theta_W+g_2^2\cos\Theta_W^2\cos\Theta'_W\sin\Theta'_W\right.\right. \\ & +\cos\Theta'_W\left(g_1^2\sin\Theta_W^2-g_{BY}^2\right)\sin\Theta'_W-g_1g_{BY}\sin\Theta_W\sin\Theta'^2_W \\ & +g_2\cos\Theta_W\left(g_1\sin\Theta_W\sin2\Theta'_W+g_{BY}\cos\Theta'^2_W-g_{BY}\sin\Theta'^2_W\right)\Big)Z_{k1}^H \\ & +8x\left(2g_Bg_{YB}\cos\Theta'^2_W\sin\Theta_W-2g_Bg_{YB}\sin\Theta_W\sin\Theta'^2_W-g_B^2\sin2\Theta'_W\right. \\ & \left.+g_{YB}^2\sin\Theta_W^2\sin2\Theta'_W\right)Z_{k2}^H\Big) \quad (282) \end{aligned}$$


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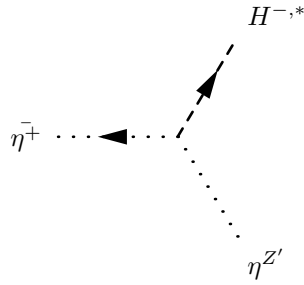
$$\begin{aligned} & -\frac{i}{4}\xi_{Z'}\left(v\left(\left(g_1\sin\Theta_W+g_2\cos\Theta_W\right)\sin\Theta'_W+g_{BY}\cos\Theta'_W\right)^2Z_{k1}^H\right. \\ & \left.+16x\left(g_B\cos\Theta'_W+g_{YB}\sin\Theta_W\sin\Theta'_W\right)^2Z_{k2}^H\right) \quad (283) \end{aligned}$$


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$$\frac{i}{4}g_2v\xi_{W^-}\left(\left(g_1\sin\Theta_W-g_2\cos\Theta_W\right)\sin\Theta'_W+g_{BY}\cos\Theta'_W\right) \quad (284)$$


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$$\frac{i}{4}g_2v\xi_{W^-}\left(\left(g_1\sin\Theta_W-g_2\cos\Theta_W\right)\sin\Theta'_W+g_{BY}\cos\Theta'_W\right) \quad (285)$$


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## 10 Clebsch-Gordan Coefficients