

Standard Model with color octet  
Lagrangian, Rotations and Interactions for eigenstates 'EWSB'  
including Renormalization Group Equations  
including one-loop Self-Energies

SARAH 4.6.0

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# Contents

<b>1</b>	<b>Fields</b>	<b>3</b>
1.1	Gauge Fields . . . . .	3
1.2	Matter Superfields . . . . .	3
<b>2</b>	<b>Lagrangian</b>	<b>3</b>
2.1	Input Lagrangian for Eigenstates GaugeES . . . . .	3
2.2	Gauge fixing terms . . . . .	4
2.2.1	Gauge fixing terms for eigenstates 'GaugeES' . . . . .	4
2.2.2	Gauge fixing terms for eigenstates 'EWSB' . . . . .	4
2.3	Fields integrated out . . . . .	4
<b>3</b>	<b>Renormalization Group Equations</b>	<b>4</b>
3.1	Gauge Couplings . . . . .	4
3.2	Quartic scalar couplings . . . . .	4
3.3	Yukawa Couplings . . . . .	6
3.4	Trilinear Scalar couplings . . . . .	7
3.5	Scalar Mass Terms . . . . .	8
3.6	Vacuum expectation values . . . . .	8
<b>4</b>	<b>Field Rotations</b>	<b>9</b>
4.1	Rotations in gauge sector for eigenstates 'EWSB' . . . . .	9
4.2	Rotations in Mass sector for eigenstates 'EWSB' . . . . .	9
4.2.1	Mass Matrices for Scalars . . . . .	9
4.2.2	Mass Matrices for Fermions . . . . .	10
<b>5</b>	<b>Vacuum Expectation Values</b>	<b>11</b>
<b>6</b>	<b>Tadpole Equations</b>	<b>11</b>
<b>7</b>	<b>Particle content for eigenstates 'EWSB'</b>	<b>11</b>
<b>8</b>	<b>One Loop Self-Energy and One Loop Tadpoles for eigenstates 'EWSB'</b>	<b>12</b>
8.1	One Loop Self-Energy . . . . .	12
8.2	Tadpoles . . . . .	18
<b>9</b>	<b>Interactions for eigenstates 'EWSB'</b>	<b>18</b>
9.1	Three Scalar-Interaction . . . . .	18
9.2	Two Scalar-One Vector Boson-Interaction . . . . .	19
9.3	One Scalar-Two Vector Boson-Interaction . . . . .	22
9.4	Two Fermion-One Vector Boson-Interaction . . . . .	24
9.5	Two Fermion-One Scalar Boson-Interaction . . . . .	28
9.6	Three Vector Boson-Interaction . . . . .	32
9.7	Four Scalar-Interaction . . . . .	33
9.8	Two Scalar-Two Vector Boson-Interaction . . . . .	36
9.9	Four Vector Boson-Interaction . . . . .	42

9.10 Two Ghosts-One Vector Boson-Interaction . . . . .	44
9.11 Two Ghosts-One Scalar-Interaction . . . . .	48
<b>10 Clebsch-Gordan Coefficients</b>	<b>52</b>

# 1 Fields

## 1.1 Gauge Fields

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

## 1.2 Matter Superfields

Name	Spin	Generations	$(U(1) \otimes SU(2) \otimes SU(3))$
$H$	0	1	$(\frac{1}{2}, \mathbf{2}, \mathbf{1})$
$s$	0	1	$(0, \mathbf{1}, \mathbf{1})$
oc	0	1	$(0, \mathbf{1}, \mathbf{8})$
$q$	$\frac{1}{2}$	3	$(\frac{1}{6}, \mathbf{2}, \mathbf{3})$
$l$	$\frac{1}{2}$	3	$(-\frac{1}{2}, \mathbf{2}, \mathbf{1})$
$d$	$\frac{1}{2}$	3	$(\frac{1}{3}, \mathbf{1}, \mathbf{\bar{3}})$
$u$	$\frac{1}{2}$	3	$(-\frac{2}{3}, \mathbf{1}, \mathbf{\bar{3}})$
$e$	$\frac{1}{2}$	3	$(1, \mathbf{1}, \mathbf{1})$

# 2 Lagrangian

## 2.1 Input Lagrangian for Eigenstates GaugeES

$$\begin{aligned}
L = & -\frac{1}{2}\mu_S \text{Sing}^2 + eS \text{Sing}^3 + \frac{1}{4}\lambda_S \text{Sing}^4 - \mu|H^0|^2 + eH \text{Sing}|H^0|^2 + \frac{1}{2}\lambda_{HS} \text{Sing}^2|H^0|^2 - \mu|H^+|^2 + eH \text{Sing}|H^+|^2 \\
& + \frac{1}{2}\lambda_{HS} \text{Sing}^2|H^+|^2 + \frac{1}{2}H^{0,2}\lambda H^{0,*2} + H^+\lambda|H^0|^2 H^- + \frac{1}{2}H^{+,2}\lambda H^{-,2} - H^0 \text{conj}\left(\text{dL}\left(\{\text{gt3}, \text{ct3}\}\right)\right)Y_{d,jk}^* \delta_{\beta\gamma} \text{dR}\left(\{\text{gt2}, \text{ct2}\}\right) \\
& - H^+ \text{conj}\left(\text{uL}\left(\{\text{gt3}, \text{ct3}\}\right)\right)Y_{d,jk}^* \delta_{\beta\gamma} \text{dR}\left(\{\text{gt2}, \text{ct2}\}\right) - H^0 \text{conj}\left(\text{eL}\left(\{\text{gt3}\}\right)\right)Y_{e,jk}^* \text{eR}\left(\{\text{gt2}\}\right) - H^+ \text{conj}\left(\text{vL}\left(\{\text{gt3}\}\right)\right)Y_{e,jk}^* \text{eR}\left(\{\text{gt2}\}\right) \\
& + \lambda_{HC}|H^0|^2 O_\gamma^* \delta_{\gamma\delta} O_\delta + \lambda_{HC}|H^+|^2 O_\gamma^* \delta_{\gamma\delta} O_\delta - H^- \text{conj}\left(\text{dL}\left(\{\text{gt3}, \text{ct3}\}\right)\right)Y_{u,jk}^* \delta_{\beta\gamma} \text{uR}\left(\{\text{gt2}, \text{ct2}\}\right) + H^{0,*} \text{conj}\left(\text{uL}\left(\{\text{gt3}, \text{ct3}\}\right)\right)Y_{u,jk}^* \delta_{\beta\gamma} \text{uR}\left(\{\text{gt2}, \text{ct2}\}\right) \\
& - H^{0,*} \text{conj}\left(\text{dR}\left(\{\text{gt2}, \text{ct2}\}\right)\right)\delta_{\beta\gamma} \text{dL}\left(\{\text{gt3}, \text{ct3}\}\right)Y_{d,jk} - H^- \text{conj}\left(\text{dR}\left(\{\text{gt2}, \text{ct2}\}\right)\right)\delta_{\beta\gamma} \text{uL}\left(\{\text{gt3}, \text{ct3}\}\right)Y_{d,jk} - H^{0,*} \text{conj}\left(\text{eR}\left(\{\text{gt2}\}\right)\right)Y_{e,jk}^* \delta_{\beta\gamma} \text{eL}\left(\{\text{gt3}\}\right) \\
& - H^+ \text{conj}\left(\text{uR}\left(\{\text{gt2}, \text{ct2}\}\right)\right)\delta_{\beta\gamma} \text{dL}\left(\{\text{gt3}, \text{ct3}\}\right)Y_{u,jk} + H^0 \text{conj}\left(\text{uR}\left(\{\text{gt2}, \text{ct2}\}\right)\right)\delta_{\beta\gamma} \text{uL}\left(\{\text{gt3}, \text{ct3}\}\right)Y_{u,jk} \quad (1)
\end{aligned}$$

## 2.2 Gauge fixing terms

### 2.2.1 Gauge fixing terms for eigenstates 'GaugeES'

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

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

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

## 2.3 Fields integrated out

None

# 3 Renormalization Group Equations

## 3.1 Gauge Couplings

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

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

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

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

$$\beta_{g_3}^{(1)} = -6g_3^3 \quad (8)$$

$$\beta_{g_3}^{(2)} = \frac{1}{10}g_3^3 \left( 11g_1^2 + 160g_3^2 - 20\text{Tr}(Y_d Y_d^\dagger) - 20\text{Tr}(Y_u Y_u^\dagger) + 45g_2^2 \right) \quad (9)$$

## 3.2 Quartic scalar couplings

$$\beta_{\lambda_S}^{(1)} = -2 \left( 4\lambda_{C_s}^2 + 9\lambda_S^2 + \lambda_{HS}^2 \right) \quad (10)$$

$$\begin{aligned} \beta_{\lambda_S}^{(2)} = & -\frac{4}{5} \left( 240g_3^2\lambda_{C_s}^2 + 40\lambda_{C_s}^3 + 3g_1^2\lambda_{HS}^2 + 15g_2^2\lambda_{HS}^2 + 10\lambda_{HS}^3 + 100\lambda_{C_s}^2\lambda_S + 25\lambda_{HS}^2\lambda_S + 255\lambda_S^3 \right. \\ & \left. - 15\lambda_{HS}^2\text{Tr}(Y_d Y_d^\dagger) - 5\lambda_{HS}^2\text{Tr}(Y_e Y_e^\dagger) - 15\lambda_{HS}^2\text{Tr}(Y_u Y_u^\dagger) \right) \end{aligned} \quad (11)$$

$$\beta_{\lambda_{HS}}^{(1)} = -16\lambda_{C_s}\lambda_{HS} - \frac{9}{10}g_1^2\lambda_{HS} - \frac{9}{2}g_2^2\lambda_{HS} - 6\lambda\lambda_{HS} - 4\lambda_{HS}^2 - 6\lambda_{HS}\lambda_S + 6\lambda_{HS}\text{Tr}(Y_d Y_d^\dagger) + 2\lambda_{HS}\text{Tr}(Y_e Y_e^\dagger)$$

$$+ 6\lambda_{HS}\text{Tr}\left(Y_u Y_u^\dagger\right) \quad (12)$$

$$\begin{aligned} \beta_{\lambda_{HS}}^{(2)} = & -384g_3^2\lambda_{Cs}\lambda_{HC} - 32\lambda_{Cs}^2\lambda_{HC} - 32\lambda_{Cs}\lambda_{HC}^2 + \frac{1671}{400}g_1^4\lambda_{HS} + \frac{9}{8}g_1^2g_2^2\lambda_{HS} - \frac{145}{16}g_2^4\lambda_{HS} - \frac{36}{5}g_1^2\lambda\lambda_{HS} \\ & - 36g_2^2\lambda\lambda_{HS} - 15\lambda^2\lambda_{HS} - 8\lambda_{Cs}^2\lambda_{HS} - 64\lambda_{Cs}\lambda_{HC}\lambda_{HS} - 8\lambda_{HC}^2\lambda_{HS} - \frac{3}{5}g_1^2\lambda_{HS}^2 - 3g_2^2\lambda_{HS}^2 - 36\lambda\lambda_{HS}^2 \\ & - \frac{21}{2}\lambda_{HS}^3 - 36\lambda_{HS}^2\lambda_S - 30\lambda_{HS}\lambda_S^2 + \frac{1}{4}\lambda_{HS}\left(144\lambda + 160g_3^2 + 45g_2^2 + 48\lambda_{HS} + 5g_1^2\right)\text{Tr}\left(Y_d Y_d^\dagger\right) \\ & + \frac{1}{4}\lambda_{HS}\left(15g_1^2 + 15g_2^2 + 16\lambda_{HS} + 48\lambda\right)\text{Tr}\left(Y_e Y_e^\dagger\right) + \frac{17}{4}g_1^2\lambda_{HS}\text{Tr}\left(Y_u Y_u^\dagger\right) + \frac{45}{4}g_2^2\lambda_{HS}\text{Tr}\left(Y_u Y_u^\dagger\right) \\ & + 40g_3^2\lambda_{HS}\text{Tr}\left(Y_u Y_u^\dagger\right) + 36\lambda\lambda_{HS}\text{Tr}\left(Y_u Y_u^\dagger\right) + 12\lambda_{HS}^2\text{Tr}\left(Y_u Y_u^\dagger\right) - \frac{27}{2}\lambda_{HS}\text{Tr}\left(Y_d Y_d^\dagger Y_d Y_d^\dagger\right) \\ & - 21\lambda_{HS}\text{Tr}\left(Y_d Y_u^\dagger Y_u Y_d^\dagger\right) - \frac{9}{2}\lambda_{HS}\text{Tr}\left(Y_e Y_e^\dagger Y_e Y_e^\dagger\right) - \frac{27}{2}\lambda_{HS}\text{Tr}\left(Y_u Y_u^\dagger Y_u Y_u^\dagger\right) \end{aligned} \quad (13)$$

$$\begin{aligned} \beta_\lambda^{(1)} = & -\frac{27}{100}g_1^4 - \frac{9}{10}g_1^2g_2^2 - \frac{9}{4}g_2^4 - \frac{9}{5}g_1^2\lambda - 9g_2^2\lambda - 12\lambda^2 - 16\lambda_{HC}^2 - \lambda_{HS}^2 + 12\lambda\text{Tr}\left(Y_d Y_d^\dagger\right) \\ & + 4\lambda\text{Tr}\left(Y_e Y_e^\dagger\right) + 12\lambda\text{Tr}\left(Y_u Y_u^\dagger\right) + 12\text{Tr}\left(Y_d Y_d^\dagger Y_d Y_d^\dagger\right) + 4\text{Tr}\left(Y_e Y_e^\dagger Y_e Y_e^\dagger\right) + 12\text{Tr}\left(Y_u Y_u^\dagger Y_u Y_u^\dagger\right) \end{aligned} \quad (14)$$

$$\begin{aligned} \beta_\lambda^{(2)} = & +\frac{3411}{1000}g_1^6 + \frac{1677}{200}g_1^4g_2^2 + \frac{289}{40}g_1^2g_2^4 - \frac{305}{8}g_2^6 + \frac{1887}{200}g_1^4\lambda + \frac{117}{20}g_1^2g_2^2\lambda - \frac{73}{8}g_2^4\lambda - \frac{54}{5}g_1^2\lambda^2 - 54g_2^2\lambda^2 \\ & - 78\lambda^3 - 384g_3^2\lambda_{HC}^2 - 80\lambda\lambda_{HC}^2 - 64\lambda_{HC}^3 - 5\lambda\lambda_{HS}^2 - 4\lambda_{HS}^3 \\ & - \frac{1}{10}\left(-5\left(16\lambda\left(10g_3^2 + 9\lambda\right) + 45g_2^2\lambda + 9g_2^4\right) + 9g_1^4 + g_1^2\left(-25\lambda + 54g_2^2\right)\right)\text{Tr}\left(Y_d Y_d^\dagger\right) \\ & + \frac{3}{10}\left(15g_1^4 + 5\left(16\lambda^2 + 5g_2^2\lambda + g_2^4\right) + g_1^2\left(-22g_2^2 + 25\lambda\right)\right)\text{Tr}\left(Y_e Y_e^\dagger\right) + \frac{171}{50}g_1^4\text{Tr}\left(Y_u Y_u^\dagger\right) \\ & - \frac{63}{5}g_1^2g_2^2\text{Tr}\left(Y_u Y_u^\dagger\right) + \frac{9}{2}g_2^4\text{Tr}\left(Y_u Y_u^\dagger\right) + \frac{17}{2}g_1^2\lambda\text{Tr}\left(Y_u Y_u^\dagger\right) + \frac{45}{2}g_2^2\lambda\text{Tr}\left(Y_u Y_u^\dagger\right) \\ & + 80g_3^2\lambda\text{Tr}\left(Y_u Y_u^\dagger\right) + 72\lambda^2\text{Tr}\left(Y_u Y_u^\dagger\right) - \frac{8}{5}g_1^2\text{Tr}\left(Y_d Y_d^\dagger Y_d Y_d^\dagger\right) + 64g_3^2\text{Tr}\left(Y_d Y_d^\dagger Y_d Y_d^\dagger\right) \\ & - 3\lambda\text{Tr}\left(Y_d Y_d^\dagger Y_d Y_d^\dagger\right) - 42\lambda\text{Tr}\left(Y_d Y_u^\dagger Y_u Y_d^\dagger\right) + \frac{24}{5}g_1^2\text{Tr}\left(Y_e Y_e^\dagger Y_e Y_e^\dagger\right) - \lambda\text{Tr}\left(Y_e Y_e^\dagger Y_e Y_e^\dagger\right) \\ & + \frac{16}{5}g_1^2\text{Tr}\left(Y_u Y_u^\dagger Y_u Y_u^\dagger\right) + 64g_3^2\text{Tr}\left(Y_u Y_u^\dagger Y_u Y_u^\dagger\right) - 3\lambda\text{Tr}\left(Y_u Y_u^\dagger Y_u Y_u^\dagger\right) - 60\text{Tr}\left(Y_d Y_d^\dagger Y_d Y_d^\dagger Y_d Y_d^\dagger\right) \\ & - 12\text{Tr}\left(Y_d Y_d^\dagger Y_d Y_u^\dagger Y_u Y_d^\dagger\right) + 24\text{Tr}\left(Y_d Y_u^\dagger Y_u Y_d^\dagger Y_d Y_d^\dagger\right) + 12\text{Tr}\left(Y_d Y_u^\dagger Y_u Y_u^\dagger Y_u Y_d^\dagger\right) \\ & - 20\text{Tr}\left(Y_e Y_e^\dagger Y_e Y_e^\dagger Y_e Y_e^\dagger\right) - 60\text{Tr}\left(Y_u Y_u^\dagger Y_u Y_u^\dagger Y_u Y_u^\dagger\right) \end{aligned} \quad (15)$$

$$\begin{aligned} \beta_{\lambda_{HC}}^{(1)} = & -\frac{9}{10}g_1^2\lambda_{HC} - \frac{9}{2}g_2^2\lambda_{HC} - 18g_3^2\lambda_{HC} - 6\lambda\lambda_{HC} - 4\lambda_{HC}^2 - \lambda_{Cs}\lambda_{HS} + 6\lambda_{HC}\text{Tr}\left(Y_d Y_d^\dagger\right) + 2\lambda_{HC}\text{Tr}\left(Y_e Y_e^\dagger\right) \\ & + 6\lambda_{HC}\text{Tr}\left(Y_u Y_u^\dagger\right) \end{aligned} \quad (16)$$

$$\begin{aligned} \beta_{\lambda_{HC}}^{(2)} = & +\frac{1671}{400}g_1^4\lambda_{HC} + \frac{9}{8}g_1^2g_2^2\lambda_{HC} - \frac{145}{16}g_2^4\lambda_{HC} + \frac{207}{2}g_3^4\lambda_{HC} - \frac{36}{5}g_1^2\lambda\lambda_{HC} - 36g_2^2\lambda\lambda_{HC} - 15\lambda^2\lambda_{HC} - \frac{1}{2}\lambda_{Cs}^2\lambda_{HC} \\ & - \frac{3}{5}g_1^2\lambda_{HC}^2 - 3g_2^2\lambda_{HC}^2 - 12g_3^2\lambda_{HC}^2 - 36\lambda\lambda_{HC}^2 - 18\lambda_{HC}^3 - 2\lambda_{Cs}^2\lambda_{HS} - 4\lambda_{Cs}\lambda_{HC}\lambda_{HS} - 2\lambda_{Cs}\lambda_{HS}^2 \end{aligned}$$

$$\begin{aligned}
& -\frac{1}{2}\lambda_{HC}\lambda_{HS}^2 + \left(40g_3^2\lambda_{HC} + 72g_3^4 + \frac{1}{4}\lambda_{HC}\left(45g_2^2 + 48(3\lambda + \lambda_{HC}) + 5g_1^2\right)\right)\text{Tr}(Y_d Y_d^\dagger) \\
& + \frac{1}{4}\lambda_{HC}\left(15g_1^2 + 15g_2^2 + 16(3\lambda + \lambda_{HC})\right)\text{Tr}(Y_e Y_e^\dagger) + 72g_3^4\text{Tr}(Y_u Y_u^\dagger) + \frac{17}{4}g_1^2\lambda_{HC}\text{Tr}(Y_u Y_u^\dagger) \\
& + \frac{45}{4}g_2^2\lambda_{HC}\text{Tr}(Y_u Y_u^\dagger) + 40g_3^2\lambda_{HC}\text{Tr}(Y_u Y_u^\dagger) + 36\lambda\lambda_{HC}\text{Tr}(Y_u Y_u^\dagger) + 12\lambda_{HC}^2\text{Tr}(Y_u Y_u^\dagger) \\
& - \frac{27}{2}\lambda_{HC}\text{Tr}(Y_d Y_d^\dagger Y_d Y_d^\dagger) - 21\lambda_{HC}\text{Tr}(Y_d Y_u^\dagger Y_u Y_d^\dagger) - \frac{9}{2}\lambda_{HC}\text{Tr}(Y_e Y_e^\dagger Y_e Y_e^\dagger) - \frac{27}{2}\lambda_{HC}\text{Tr}(Y_u Y_u^\dagger Y_u Y_u^\dagger) \quad (17)
\end{aligned}$$

$$\beta_{\lambda_{Cs}}^{(1)} = -2\left(2\lambda_{Cs}^2 + 2\lambda_{HC}\lambda_{HS} + 3\lambda_{Cs}\lambda_S + 9g_3^2\lambda_{Cs}\right) \quad (18)$$

$$\begin{aligned}
\beta_{\lambda_{Cs}}^{(2)} = & +\frac{207}{2}g_3^4\lambda_{Cs} - 12g_3^2\lambda_{Cs}^2 - \frac{33}{2}\lambda_{Cs}^3 - 2\lambda_{Cs}\lambda_{HC}^2 - \frac{24}{5}g_1^2\lambda_{HC}\lambda_{HS} - 24g_2^2\lambda_{HC}\lambda_{HS} - 16\lambda_{Cs}\lambda_{HC}\lambda_{HS} - 8\lambda_{HC}^2\lambda_{HS} \\
& - 2\lambda_{Cs}\lambda_{HS}^2 - 8\lambda_{HC}\lambda_{HS}^2 - 36\lambda_{Cs}^2\lambda_S - 30\lambda_{Cs}\lambda_S^2 + 24\lambda_{HC}\lambda_{HS}\text{Tr}(Y_d Y_d^\dagger) + 8\lambda_{HC}\lambda_{HS}\text{Tr}(Y_e Y_e^\dagger) \\
& + 24\lambda_{HC}\lambda_{HS}\text{Tr}(Y_u Y_u^\dagger) \quad (19)
\end{aligned}$$

### 3.3 Yukawa Couplings

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

$$\begin{aligned}
\beta_{Y_u}^{(2)} = & +\frac{1}{80}\left(20\left(11Y_u Y_d^\dagger Y_d Y_d^\dagger Y_d - 4Y_u Y_u^\dagger Y_u Y_d^\dagger Y_d + 6Y_u Y_u^\dagger Y_u Y_u^\dagger Y_u - Y_u Y_d^\dagger Y_d Y_u^\dagger Y_u\right)\right. \\
& + Y_u Y_u^\dagger Y_u\left(1280g_3^2 - 180\text{Tr}(Y_e Y_e^\dagger) + 223g_1^2 + 480\lambda - 540\text{Tr}(Y_d Y_d^\dagger) - 540\text{Tr}(Y_u Y_u^\dagger) + 675g_2^2\right) \\
& + Y_u Y_d^\dagger Y_d\left(100\text{Tr}(Y_e Y_e^\dagger) - 1280g_3^2 + 300\text{Tr}(Y_d Y_d^\dagger) + 300\text{Tr}(Y_u Y_u^\dagger) - 43g_1^2 + 45g_2^2\right) \\
& + \frac{1}{600}Y_u\left(1187g_1^4 - 270g_1^2g_2^2 - 3450g_2^4 + 760g_1^2g_3^2 + 5400g_2^2g_3^2 - 56000g_3^4 + 900\lambda^2 + 2400\lambda_{HC}^2 + 150\lambda_{HS}^2\right. \\
& + 375\left(32g_3^2 + 9g_2^2 + g_1^2\right)\text{Tr}(Y_d Y_d^\dagger) + 1125\left(g_1^2 + g_2^2\right)\text{Tr}(Y_e Y_e^\dagger) + 1275g_1^2\text{Tr}(Y_u Y_u^\dagger) \\
& + 3375g_2^2\text{Tr}(Y_u Y_u^\dagger) + 12000g_3^2\text{Tr}(Y_u Y_u^\dagger) - 4050\text{Tr}(Y_d Y_d^\dagger Y_d Y_d^\dagger) + 900\text{Tr}(Y_d Y_u^\dagger Y_u Y_d^\dagger) \\
& \left. - 1350\text{Tr}(Y_e Y_e^\dagger Y_e Y_e^\dagger) - 4050\text{Tr}(Y_u Y_u^\dagger Y_u Y_u^\dagger)\right) \quad (21)
\end{aligned}$$

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

$$\begin{aligned}
\beta_{Y_d}^{(2)} = & +\frac{1}{80}\left(20\left(11Y_d Y_u^\dagger Y_u Y_u^\dagger Y_u - 4Y_d Y_d^\dagger Y_d Y_u^\dagger Y_u + 6Y_d Y_d^\dagger Y_d Y_d^\dagger Y_d - Y_d Y_u^\dagger Y_u Y_d^\dagger Y_d\right)\right. \\
& + Y_d Y_d^\dagger Y_d\left(1280g_3^2 - 180\text{Tr}(Y_e Y_e^\dagger) + 187g_1^2 + 480\lambda - 540\text{Tr}(Y_d Y_d^\dagger) - 540\text{Tr}(Y_u Y_u^\dagger) + 675g_2^2\right) \\
& + Y_d Y_u^\dagger Y_u\left(100\text{Tr}(Y_e Y_e^\dagger) - 1280g_3^2 + 300\text{Tr}(Y_d Y_d^\dagger) + 300\text{Tr}(Y_u Y_u^\dagger) + 45g_2^2 - 79g_1^2\right) \\
& \left. - 1350\text{Tr}(Y_e Y_e^\dagger Y_e Y_e^\dagger) - 4050\text{Tr}(Y_u Y_u^\dagger Y_u Y_u^\dagger)\right)
\end{aligned}$$

$$\begin{aligned}
& + Y_d \left( -\frac{127}{600} g_1^4 - \frac{27}{20} g_1^2 g_2^2 - \frac{23}{4} g_2^4 + \frac{31}{15} g_1^2 g_3^2 + 9 g_2^2 g_3^2 - \frac{280}{3} g_3^4 + \frac{3}{2} \lambda^2 + 4 \lambda_{HC}^2 + \frac{1}{4} \lambda_{HS}^2 \right. \\
& + \frac{5}{8} (32 g_3^2 + 9 g_2^2 + g_1^2) \text{Tr}(Y_d Y_d^\dagger) + \frac{15}{8} (g_1^2 + g_2^2) \text{Tr}(Y_e Y_e^\dagger) + \frac{17}{8} g_1^2 \text{Tr}(Y_u Y_u^\dagger) + \frac{45}{8} g_2^2 \text{Tr}(Y_u Y_u^\dagger) \\
& \left. + 20 g_3^2 \text{Tr}(Y_u Y_u^\dagger) - \frac{27}{4} \text{Tr}(Y_d Y_d^\dagger Y_d Y_d^\dagger) + \frac{3}{2} \text{Tr}(Y_d Y_u^\dagger Y_u Y_d^\dagger) - \frac{9}{4} \text{Tr}(Y_e Y_e^\dagger Y_e Y_e^\dagger) - \frac{27}{4} \text{Tr}(Y_u Y_u^\dagger Y_u Y_u^\dagger) \right) \quad (23)
\end{aligned}$$

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

$$\begin{aligned}
\beta_{Y_e}^{(2)} = & + \frac{3}{80} \left( 40 Y_e Y_e^\dagger Y_e Y_e^\dagger Y_e \right. \\
& + Y_e Y_e^\dagger Y_e \left( 129 g_1^2 + 160 \lambda - 180 \text{Tr}(Y_d Y_d^\dagger) - 180 \text{Tr}(Y_u Y_u^\dagger) + 225 g_2^2 - 60 \text{Tr}(Y_e Y_e^\dagger) \right) \\
& + \frac{1}{200} Y_e \left( 1371 g_1^4 + 270 g_1^2 g_2^2 - 1150 g_2^4 + 300 \lambda^2 + 800 \lambda_{HC}^2 + 50 \lambda_{HS}^2 + 125 (32 g_3^2 + 9 g_2^2 + g_1^2) \text{Tr}(Y_d Y_d^\dagger) \right. \\
& + 375 (g_1^2 + g_2^2) \text{Tr}(Y_e Y_e^\dagger) + 425 g_1^2 \text{Tr}(Y_u Y_u^\dagger) + 1125 g_2^2 \text{Tr}(Y_u Y_u^\dagger) + 4000 g_3^2 \text{Tr}(Y_u Y_u^\dagger) \\
& \left. \left. - 1350 \text{Tr}(Y_d Y_d^\dagger Y_d Y_d^\dagger) + 300 \text{Tr}(Y_d Y_u^\dagger Y_u Y_d^\dagger) - 450 \text{Tr}(Y_e Y_e^\dagger Y_e Y_e^\dagger) - 1350 \text{Tr}(Y_u Y_u^\dagger Y_u Y_u^\dagger) \right) \right) \quad (25)
\end{aligned}$$

### 3.4 Trilinear Scalar couplings

$$\beta_{eS}^{(1)} = -2 \left( 4eC\lambda_{Cs} + 9eS\lambda_S + eH\lambda_{HS} \right) \quad (26)$$

$$\begin{aligned}
\beta_{eS}^{(2)} = & -192eCg_3^2\lambda_{Cs} - 32eC\lambda_{Cs}^2 - 36eS\lambda_{Cs}^2 - \frac{12}{5}eHg_1^2\lambda_{HS} - 12eHg_2^2\lambda_{HS} - 8eH\lambda_{HS}^2 - 9eS\lambda_{HS}^2 - 48eC\lambda_{Cs}\lambda_S \\
& - 12eH\lambda_{HS}\lambda_S - 207eS\lambda_S^2 + 12eH\lambda_{HS}\text{Tr}(Y_d Y_d^\dagger) + 4eH\lambda_{HS}\text{Tr}(Y_e Y_e^\dagger) + 12eH\lambda_{HS}\text{Tr}(Y_u Y_u^\dagger) \quad (27)
\end{aligned}$$

$$\begin{aligned}
\beta_{eH}^{(1)} = & -\frac{9}{10}eHg_1^2 - \frac{9}{2}eHg_2^2 - 6eH\lambda - 16eC\lambda_{HC} - 4eH\lambda_{HS} - 6eS\lambda_{HS} + 6eH\text{Tr}(Y_d Y_d^\dagger) + 2eH\text{Tr}(Y_e Y_e^\dagger) \\
& + 6eH\text{Tr}(Y_u Y_u^\dagger) \quad (28)
\end{aligned}$$

$$\begin{aligned}
\beta_{eH}^{(2)} = & + \frac{1671}{400}eHg_1^4 + \frac{9}{8}eHg_1^2g_2^2 - \frac{145}{16}eHg_2^4 - \frac{36}{5}eHg_1^2\lambda - 36eHg_2^2\lambda - 15eH\lambda^2 + 4eH\lambda_{Cs}^2 - 384eCg_3^2\lambda_{HC} \\
& - 32eC\lambda_{Cs}\lambda_{HC} - 32eH\lambda_{Cs}\lambda_{HC} - 32eC\lambda_{HC}^2 - 8eH\lambda_{HC}^2 - \frac{3}{5}eHg_1^2\lambda_{HS} - 3eHg_2^2\lambda_{HS} - 36eH\lambda\lambda_{HS} - 16eC\lambda_{Cs}\lambda_{HS} \\
& - 32eC\lambda_{HC}\lambda_{HS} - \frac{23}{2}eH\lambda_{HS}^2 - 24eS\lambda_{HS}^2 - 12eH\lambda_{HS}\lambda_S - 36eS\lambda_{HS}\lambda_S + 3eH\lambda_S^2 \\
& + \frac{1}{4}eH \left( 144\lambda + 160g_3^2 + 45g_2^2 + 48\lambda_{HS} + 5g_1^2 \right) \text{Tr}(Y_d Y_d^\dagger) + \frac{1}{4}eH \left( 15g_1^2 + 15g_2^2 + 16\lambda_{HS} + 48\lambda \right) \text{Tr}(Y_e Y_e^\dagger) \\
& + \frac{17}{4}eHg_1^2\text{Tr}(Y_u Y_u^\dagger) + \frac{45}{4}eHg_2^2\text{Tr}(Y_u Y_u^\dagger) + 40eHg_3^2\text{Tr}(Y_u Y_u^\dagger) + 36eH\lambda\text{Tr}(Y_u Y_u^\dagger) \\
& + 12eH\lambda_{HS}\text{Tr}(Y_u Y_u^\dagger) - \frac{27}{2}eH\text{Tr}(Y_d Y_d^\dagger Y_d Y_d^\dagger) - 21eH\text{Tr}(Y_d Y_u^\dagger Y_u Y_d^\dagger) - \frac{9}{2}eH\text{Tr}(Y_e Y_e^\dagger Y_e Y_e^\dagger) \\
& - \frac{27}{2}eH\text{Tr}(Y_u Y_u^\dagger Y_u Y_u^\dagger) \quad (29)
\end{aligned}$$



$$\beta_{eC}^{(1)} = -2 \left( 2eC\lambda_{Cs} + 2eH\lambda_{HC} + 3eS\lambda_{Cs} + 9eCg_3^2 \right) \quad (30)$$

$$\begin{aligned} \beta_{eC}^{(2)} = & + \frac{207}{2}eCg_3^4 - 12eCg_3^2\lambda_{Cs} - \frac{41}{2}eC\lambda_{Cs}^2 - 24eS\lambda_{Cs}^2 - \frac{24}{5}eHg_1^2\lambda_{HC} - 24eHg_2^2\lambda_{HC} - 8eH\lambda_{Cs}\lambda_{HC} - 2eC\lambda_{HC}^2 \\ & - 8eH\lambda_{HC}^2 - 4eH\lambda_{Cs}\lambda_{HS} - 8eC\lambda_{HC}\lambda_{HS} - 8eH\lambda_{HC}\lambda_{HS} + eC\lambda_{HS}^2 - 12eC\lambda_{Cs}\lambda_S - 36eS\lambda_{Cs}\lambda_S + 3eC\lambda_S^2 \\ & + 24eH\lambda_{HC}\text{Tr}(Y_d Y_d^\dagger) + 8eH\lambda_{HC}\text{Tr}(Y_e Y_e^\dagger) + 24eH\lambda_{HC}\text{Tr}(Y_u Y_u^\dagger) \end{aligned} \quad (31)$$

### 3.5 Scalar Mass Terms

$$\beta_{\mu S}^{(1)} = 16eC^2 + 36eS^2 + 4eH^2 - 4\lambda_{HS}\mu - 6\lambda_S\mu_S \quad (32)$$

$$\begin{aligned} \beta_{\mu S}^{(2)} = & + \frac{24}{5}eH^2g_1^2 + 24eH^2g_2^2 + 384eC^2g_3^2 + 80eC^2\lambda_{Cs} + 192eCeS\lambda_{Cs} + 20eH^2\lambda_{HS} + 48eHeS\lambda_{HS} + 48eC^2\lambda_S + 12eH^2\lambda_S \\ & + 540eS^2\lambda_S - 8\lambda_{Cs}^2\mu_S - 2\lambda_{HS}^2\mu_S - 30\lambda_S^2\mu_S - \frac{24}{5}g_1^2\lambda_{HS}\mu - 24g_2^2\lambda_{HS}\mu - 8\lambda_{HS}^2\mu \\ & - 24 \left( -\lambda_{HS}\mu + eH^2 \right) \text{Tr}(Y_d Y_d^\dagger) - 8 \left( -\lambda_{HS}\mu + eH^2 \right) \text{Tr}(Y_e Y_e^\dagger) - 24eH^2\text{Tr}(Y_u Y_u^\dagger) + 24\lambda_{HS}\mu\text{Tr}(Y_u Y_u^\dagger) \end{aligned} \quad (33)$$

$$\beta_{\mu}^{(1)} = 2eH^2 + 2\mu\text{Tr}(Y_e Y_e^\dagger) - 6\lambda\mu + 6\mu\text{Tr}(Y_d Y_d^\dagger) + 6\mu\text{Tr}(Y_u Y_u^\dagger) - \frac{9}{10}g_1^2\mu - \frac{9}{2}g_2^2\mu - \lambda_{HS}\mu_S \quad (34)$$

$$\begin{aligned} \beta_{\mu}^{(2)} = & + \frac{3}{10}eH^2g_1^2 + \frac{3}{2}eH^2g_2^2 + 18eH^2\lambda + 16eC^2\lambda_{HC} + 32eCeH\lambda_{HC} + 8eC^2\lambda_{HS} + 6eH^2\lambda_{HS} + 12eHeS\lambda_{HS} + 18eS^2\lambda_{HS} \\ & - 2\lambda_{HS}^2\mu_S + \frac{1671}{400}g_1^4\mu + \frac{9}{8}g_1^2g_2^2\mu - \frac{145}{16}g_2^4\mu - \frac{36}{5}g_1^2\lambda\mu - 36g_2^2\lambda\mu - 15\lambda^2\mu - 8\lambda_{HC}^2\mu \\ & - \frac{1}{2}\lambda_{HS}^2\mu + \left( -6eH^2 + \frac{1}{4}(144\lambda + 160g_3^2 + 45g_2^2 + 5g_1^2)\mu \right) \text{Tr}(Y_d Y_d^\dagger) \\ & + \frac{1}{4} \left( 3(16\lambda + 5g_1^2 + 5g_2^2)\mu - 8eH^2 \right) \text{Tr}(Y_e Y_e^\dagger) - 6eH^2\text{Tr}(Y_u Y_u^\dagger) + \frac{17}{4}g_1^2\mu\text{Tr}(Y_u Y_u^\dagger) \\ & + \frac{45}{4}g_2^2\mu\text{Tr}(Y_u Y_u^\dagger) + 40g_3^2\mu\text{Tr}(Y_u Y_u^\dagger) + 36\lambda\mu\text{Tr}(Y_u Y_u^\dagger) - \frac{27}{2}\mu\text{Tr}(Y_d Y_d^\dagger Y_d Y_d^\dagger) \\ & - 21\mu\text{Tr}(Y_d Y_u^\dagger Y_u Y_d^\dagger) - \frac{9}{2}\mu\text{Tr}(Y_e Y_e^\dagger Y_e Y_e^\dagger) - \frac{27}{2}\mu\text{Tr}(Y_u Y_u^\dagger Y_u Y_u^\dagger) \end{aligned} \quad (35)$$

### 3.6 Vacuum expectation values

$$\beta_v^{(1)} = \frac{1}{20}v \left( 15g_2^2\text{Xi} - 20\text{Tr}(Y_e Y_e^\dagger) + 3g_1^2\text{Xi} + 45g_2^2 - 60\text{Tr}(Y_d Y_d^\dagger) - 60\text{Tr}(Y_u Y_u^\dagger) + 9g_1^2 \right) \quad (36)$$

$$\begin{aligned} \beta_v^{(2)} = & \frac{1}{800}v \left( -1293g_1^4 - 270g_1^2g_2^2 + 6775g_2^4 - 1200\lambda^2 - 3200\lambda_{HC}^2 - 200\lambda_{HS}^2 + 18g_1^4\text{Xi} + 180g_1^2g_2^2\text{Xi} + 2250g_2^4\text{Xi} \right. \\ & + 18g_1^4\text{Xi}^2 + 180g_1^2g_2^2\text{Xi}^2 - 450g_2^4\text{Xi}^2 - 20 \left( 45g_2^2(2\text{Xi} + 5) + 800g_3^2 + g_1^2(18\text{Xi} + 25) \right) \text{Tr}(Y_d Y_d^\dagger) \\ & \left. - 60 \left( 5g_2^2(2\text{Xi} + 5) + g_1^2(2\text{Xi} + 25) \right) \text{Tr}(Y_e Y_e^\dagger) - 1700g_1^2\text{Tr}(Y_u Y_u^\dagger) - 4500g_2^2\text{Tr}(Y_u Y_u^\dagger) \right) \end{aligned}$$

$$\begin{aligned}
& -16000g_3^2\text{Tr}\left(Y_u Y_u^\dagger\right) - 360g_1^2\text{XiTr}\left(Y_u Y_u^\dagger\right) - 1800g_2^2\text{XiTr}\left(Y_u Y_u^\dagger\right) + 5400\text{Tr}\left(Y_d Y_d^\dagger Y_d Y_d^\dagger\right) \\
& - 1200\text{Tr}\left(Y_d Y_u^\dagger Y_u Y_d^\dagger\right) + 1800\text{Tr}\left(Y_e Y_e^\dagger Y_e Y_e^\dagger\right) + 5400\text{Tr}\left(Y_u Y_u^\dagger Y_u Y_u^\dagger\right)
\end{aligned} \tag{37}$$

$$\beta_{v_S}^{(1)} = 0 \tag{38}$$

$$\beta_{v_S}^{(2)} = -\left(3\lambda_S^2 + 4\lambda_{C_S}^2 + \lambda_{H_S}^2\right)v_S \tag{39}$$

## 4 Field Rotations

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

$$\begin{pmatrix} B_\rho \\ W_{3\rho} \end{pmatrix} = Z^{\gamma Z} \begin{pmatrix} \gamma_\rho \\ Z_\rho \end{pmatrix} \tag{40}$$

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

$$\tag{42}$$

The mixing matrices are parametrized by

$$Z^{\gamma Z} = \begin{pmatrix} \cos \Theta_W & -\sin \Theta_W \\ \sin \Theta_W & \cos \Theta_W \end{pmatrix} \tag{43}$$

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

$$\tag{45}$$

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

#### 4.2.1 Mass Matrices for Scalars

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

$$m_h^2 = \begin{pmatrix} \frac{1}{2}\left(-3\lambda v^2 - v_S(2eH + \lambda_{HS}v_S)\right) + \mu & -v(\lambda_{HS}v_S + eH) \\ -v(\lambda_{HS}v_S + eH) & -3v_S(2eS + \lambda_S v_S) - \frac{1}{2}\lambda_{HS}v^2 + \mu_S \end{pmatrix} \tag{46}$$

This matrix is diagonalized by  $Z^H$ :

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

with

$$\text{phiH} = \sum_j Z_{j1}^H h_j, \quad \text{phiS} = \sum_j Z_{j2}^H h_j \tag{48}$$

#### 4.2.2 Mass Matrices for Fermions

- **Mass matrix for Down-Quarks**, Basis:  $\left( \text{dL}\left(\{\text{cm1}\}\right), \left(\text{conj}\left(\text{dR}\left(\{\text{cn1}\}\right)\right)\right) \right)$

$$m_d = \left( \frac{1}{\sqrt{2}} v \delta_{\alpha_1 \beta_1} Y_d^T \right) \quad (49)$$

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

$$U_L^{d,*} m_d U_R^{d,\dagger} = m_d^{dia} \quad (50)$$

with

$$\text{dL}\left(\{\text{gt1}, \text{ct1}\}\right) = \sum_{t_2} U_{L,ji}^{d,*} \text{FDL}\left(\{\text{gt2}, \text{ct1}\}\right) \quad (51)$$

$$\text{dR}\left(\{\text{gt1}, \text{ct1}\}\right) = \sum_{t_2} U_{R,ij}^d \text{conj}\left(\text{FDR}\left(\{\text{gt2}, \text{ct1}\}\right)\right) \quad (52)$$

- **Mass matrix for Up-Quarks**, Basis:  $\left( \text{uL}\left(\{\text{cm1}\}\right), \left(\text{conj}\left(\text{uR}\left(\{\text{cn1}\}\right)\right)\right) \right)$

$$m_u = \left( -\frac{1}{\sqrt{2}} v \delta_{\alpha_1 \beta_1} Y_u^T \right) \quad (53)$$

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

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

with

$$\text{uL}\left(\{\text{gt1}, \text{ct1}\}\right) = \sum_{t_2} U_{L,ji}^{u,*} \text{FUL}\left(\{\text{gt2}, \text{ct1}\}\right) \quad (55)$$

$$\text{uR}\left(\{\text{gt1}, \text{ct1}\}\right) = \sum_{t_2} U_{R,ij}^u \text{conj}\left(\text{FUR}\left(\{\text{gt2}, \text{ct1}\}\right)\right) \quad (56)$$

- **Mass matrix for Leptons**, Basis:  $\left( \text{eL}, \left(\text{conj}\left(\text{eR}\right)\right) \right)$

$$m_e = \left( \frac{1}{\sqrt{2}} v Y_e^T \right) \quad (57)$$

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

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

with

$$\text{eL}\left(\{\text{gt1}\}\right) = \sum_{t_2} U_{L,ji}^{e,*} \text{FEL}\left(\{\text{gt2}\}\right) \quad (59)$$

$$\text{eR}\left(\{\text{gt1}\}\right) = \sum_{t_2} U_{R,ij}^e \text{conj}\left(\text{FER}\left(\{\text{gt2}\}\right)\right) \quad (60)$$

## 5 Vacuum Expectation Values

$$H^0 = \frac{1}{\sqrt{2}}\text{phiH} + \frac{1}{\sqrt{2}}v + i\frac{1}{\sqrt{2}}A^0 \quad (61)$$

$$\text{Sing} = \text{phiS} + v_S \quad (62)$$

## 6 Tadpole Equations

$$\frac{\partial V}{\partial \text{phiH}} = -\frac{1}{2}v \left( -2\mu + \lambda v^2 + v_S \left( 2eH + \lambda_{HS}v_S \right) \right) \quad (63)$$

$$\frac{\partial V}{\partial \text{phiS}} = \frac{1}{2} \left( -eHv^2 - v_S \left( 2\lambda_S v_S^2 - 2\mu_S + 6eSv_S + \lambda_{HS}v^2 \right) \right) \quad (64)$$

## 7 Particle content for eigenstates 'EWSB'

Name	Type	complex/real	Generations	Indices
$H^+$	Scalar	complex	1	
$O$	Scalar	complex	1	color, 8
$A^0$	Scalar	real	1	
$h$	Scalar	real	2	generation, 2
$\nu$	Fermion	Dirac	3	generation, 3
$d$	Fermion	Dirac	3	generation, 3, color, 3
$u$	Fermion	Dirac	3	generation, 3, color, 3
$e$	Fermion	Dirac	3	generation, 3
$g$	Vector	real	1	color, 8, lorentz, 4
$\gamma$	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	
$\eta^+$	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) = & +\frac{1}{2}B_0(p^2, m_{A^0}^2, m_{A^0}^2)\Gamma_{\tilde{h}_j, A^0, A^0}^*\Gamma_{\tilde{h}_i, A^0, A^0} + 2\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} + B_0(p^2, m_{H^+}^2, m_{H^+}^2)\Gamma_{\tilde{h}_j, H^+, H^+}^*\Gamma_{\tilde{h}_i, H^+, H^+} \\
& + 3B_0(p^2, m_O^2, m_O^2)\Gamma_{\tilde{h}_j, O^*, O}^*\Gamma_{\tilde{h}_i, O^*, O} + 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^Z, \eta^Z}\Gamma_{\tilde{h}_j, \eta^Z, \eta^Z} - \frac{1}{2}A_0(m_{A^0}^2)\Gamma_{\tilde{h}_i, \tilde{h}_j, A^0, A^0} - A_0(m_{H^+}^2)\Gamma_{\tilde{h}_i, \tilde{h}_j, H^-, H^+} \\
& - 8A_0(m_O^2)\Gamma_{\tilde{h}_i, \tilde{h}_j, O^*, O} + \Gamma_{\tilde{h}_j, Z, A^0}^*\Gamma_{\tilde{h}_i, Z, A^0}F_0(p^2, m_{A^0}^2, m_Z^2) + 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) - \frac{1}{2}\sum_{a=1}^2A_0(m_{h_a}^2)\Gamma_{\tilde{h}_i, \tilde{h}_j, h_a, h_a} \\
& + \frac{1}{2}\sum_{a=1}^2\sum_{b=1}^2B_0(p^2, m_{h_a}^2, m_{h_b}^2)\Gamma_{\tilde{h}_j, h_a, h_b}^*\Gamma_{\tilde{h}_i, h_a, h_b} \\
& - 6\sum_{a=1}^3m_{d_a}\sum_{b=1}^3B_0(p^2, m_{d_a}^2, m_{d_b}^2)m_{d_b}\left(\Gamma_{\tilde{h}_j, \bar{d}_a, d_b}^{L*}\Gamma_{\tilde{h}_i, \bar{d}_a, d_b}^R + \Gamma_{\tilde{h}_j, \bar{d}_a, d_b}^{R*}\Gamma_{\tilde{h}_i, \bar{d}_a, d_b}^L\right) \\
& + 3\sum_{a=1}^3\sum_{b=1}^3G_0(p^2, m_{d_a}^2, m_{d_b}^2)\left(\Gamma_{\tilde{h}_j, \bar{d}_a, d_b}^{L*}\Gamma_{\tilde{h}_i, \bar{d}_a, d_b}^L + \Gamma_{\tilde{h}_j, \bar{d}_a, d_b}^{R*}\Gamma_{\tilde{h}_i, \bar{d}_a, d_b}^R\right) \\
& - 2\sum_{a=1}^3m_{e_a}\sum_{b=1}^3B_0(p^2, m_{e_a}^2, m_{e_b}^2)m_{e_b}\left(\Gamma_{\tilde{h}_j, \bar{e}_a, e_b}^{L*}\Gamma_{\tilde{h}_i, \bar{e}_a, e_b}^R + \Gamma_{\tilde{h}_j, \bar{e}_a, e_b}^{R*}\Gamma_{\tilde{h}_i, \bar{e}_a, e_b}^L\right) \\
& + \sum_{a=1}^3\sum_{b=1}^3G_0(p^2, m_{e_a}^2, m_{e_b}^2)\left(\Gamma_{\tilde{h}_j, \bar{e}_a, e_b}^{L*}\Gamma_{\tilde{h}_i, \bar{e}_a, e_b}^L + \Gamma_{\tilde{h}_j, \bar{e}_a, e_b}^{R*}\Gamma_{\tilde{h}_i, \bar{e}_a, e_b}^R\right) \\
& - 6\sum_{a=1}^3m_{u_a}\sum_{b=1}^3B_0(p^2, m_{u_a}^2, m_{u_b}^2)m_{u_b}\left(\Gamma_{\tilde{h}_j, \bar{u}_a, u_b}^{L*}\Gamma_{\tilde{h}_i, \bar{u}_a, u_b}^R + \Gamma_{\tilde{h}_j, \bar{u}_a, u_b}^{R*}\Gamma_{\tilde{h}_i, \bar{u}_a, u_b}^L\right) \\
& + 3\sum_{a=1}^3\sum_{b=1}^3G_0(p^2, m_{u_a}^2, m_{u_b}^2)\left(\Gamma_{\tilde{h}_j, \bar{u}_a, u_b}^{L*}\Gamma_{\tilde{h}_i, \bar{u}_a, u_b}^L + \Gamma_{\tilde{h}_j, \bar{u}_a, u_b}^{R*}\Gamma_{\tilde{h}_i, \bar{u}_a, u_b}^R\right)
\end{aligned} \tag{65}$$

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

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

$$\begin{aligned}
& + \sum_{a=1}^3 B_0(p^2, m_{d_a}^2, m_{A^0}^2) \Gamma_{\tilde{d}_j, d_a, A^0}^{L*} m_{d_a} \Gamma_{\tilde{d}_i, d_a, A^0}^R - \frac{16}{3} \sum_{b=1}^3 \left( -\frac{1}{2} \text{rMS} + B_0(p^2, m_{d_b}^2, 0) \right) \Gamma_{\tilde{d}_j, g, d_b}^{R*} m_{d_b} \Gamma_{\tilde{d}_i, g, d_b}^L \\
& - 4 \sum_{b=1}^3 \left( -\frac{1}{2} \text{rMS} + B_0(p^2, m_{d_b}^2, 0) \right) \Gamma_{\tilde{d}_j, \gamma, d_b}^{R*} m_{d_b} \Gamma_{\tilde{d}_i, \gamma, d_b}^L - 4 \sum_{b=1}^3 \left( -\frac{1}{2} \text{rMS} + B_0(p^2, m_{d_b}^2, m_Z^2) \right) \Gamma_{\tilde{d}_j, Z, d_b}^{R*} m_{d_b} \Gamma_{\tilde{d}_i, Z, d_b}^L \\
& + \sum_{b=1}^3 B_0(p^2, m_{u_b}^2, m_{H^+}^2) \Gamma_{\tilde{d}_j, H^-, u_b}^{L*} m_{u_b} \Gamma_{\tilde{d}_i, H^-, u_b}^R \\
& - 4 \sum_{b=1}^3 \left( -\frac{1}{2} \text{rMS} + B_0(p^2, m_{u_b}^2, m_{W^+}^2) \right) \Gamma_{\tilde{d}_j, W^-, u_b}^{R*} m_{u_b} \Gamma_{\tilde{d}_i, W^-, u_b}^L \tag{66}
\end{aligned}$$

$$\begin{aligned}
\Sigma_{i,j}^R(p^2) &= -\frac{1}{2} \sum_{a=1}^2 \sum_{b=1}^3 B_1(p^2, m_{d_b}^2, m_{h_a}^2) \Gamma_{\tilde{d}_j, h_a, d_b}^{R*} \Gamma_{\tilde{d}_i, h_a, d_b}^R - \frac{1}{2} \sum_{a=1}^3 B_1(p^2, m_{d_a}^2, m_{A^0}^2) \Gamma_{\tilde{d}_j, d_a, A^0}^{R*} \Gamma_{\tilde{d}_i, d_a, A^0}^R \\
& - \frac{4}{3} \sum_{b=1}^3 B_1(p^2, m_{d_b}^2, 0) \Gamma_{\tilde{d}_j, g, d_b}^{L*} \Gamma_{\tilde{d}_i, g, d_b}^L - \sum_{b=1}^3 B_1(p^2, m_{d_b}^2, 0) \Gamma_{\tilde{d}_j, \gamma, d_b}^{L*} \Gamma_{\tilde{d}_i, \gamma, d_b}^L \\
& - \sum_{b=1}^3 B_1(p^2, m_{d_b}^2, m_Z^2) \Gamma_{\tilde{d}_j, Z, d_b}^{L*} \Gamma_{\tilde{d}_i, Z, d_b}^L - \frac{1}{2} \sum_{b=1}^3 B_1(p^2, m_{u_b}^2, m_{H^+}^2) \Gamma_{\tilde{d}_j, H^-, u_b}^{R*} \Gamma_{\tilde{d}_i, H^-, u_b}^R \\
& - \sum_{b=1}^3 B_1(p^2, m_{u_b}^2, m_{W^+}^2) \Gamma_{\tilde{d}_j, W^-, u_b}^{L*} \Gamma_{\tilde{d}_i, W^-, u_b}^L \tag{67}
\end{aligned}$$

$$\begin{aligned}
\Sigma_{i,j}^L(p^2) &= -\frac{1}{2} \sum_{a=1}^2 \sum_{b=1}^3 B_1(p^2, m_{d_b}^2, m_{h_a}^2) \Gamma_{\tilde{d}_j, h_a, d_b}^{L*} \Gamma_{\tilde{d}_i, h_a, d_b}^L - \frac{1}{2} \sum_{a=1}^3 B_1(p^2, m_{d_a}^2, m_{A^0}^2) \Gamma_{\tilde{d}_j, d_a, A^0}^{L*} \Gamma_{\tilde{d}_i, d_a, A^0}^L \\
& - \frac{4}{3} \sum_{b=1}^3 B_1(p^2, m_{d_b}^2, 0) \Gamma_{\tilde{d}_j, g, d_b}^{R*} \Gamma_{\tilde{d}_i, g, d_b}^R - \sum_{b=1}^3 B_1(p^2, m_{d_b}^2, 0) \Gamma_{\tilde{d}_j, \gamma, d_b}^{R*} \Gamma_{\tilde{d}_i, \gamma, d_b}^R \\
& - \sum_{b=1}^3 B_1(p^2, m_{d_b}^2, m_Z^2) \Gamma_{\tilde{d}_j, Z, d_b}^{R*} \Gamma_{\tilde{d}_i, Z, d_b}^R - \frac{1}{2} \sum_{b=1}^3 B_1(p^2, m_{u_b}^2, m_{H^+}^2) \Gamma_{\tilde{d}_j, H^-, u_b}^{L*} \Gamma_{\tilde{d}_i, H^-, u_b}^L \\
& - \sum_{b=1}^3 B_1(p^2, m_{u_b}^2, m_{W^+}^2) \Gamma_{\tilde{d}_j, W^-, u_b}^{R*} \Gamma_{\tilde{d}_i, W^-, u_b}^R \tag{68}
\end{aligned}$$

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

$$\begin{aligned}
\Sigma_{i,j}^S(p^2) &= + \sum_{a=1}^2 \sum_{b=1}^3 B_0(p^2, m_{u_b}^2, m_{h_a}^2) \Gamma_{\tilde{u}_j, h_a, u_b}^{L*} m_{u_b} \Gamma_{\tilde{u}_i, h_a, u_b}^R \\
& + \sum_{a=1}^3 B_0(p^2, m_{u_a}^2, m_{A^0}^2) \Gamma_{\tilde{u}_j, u_a, A^0}^{L*} m_{u_a} \Gamma_{\tilde{u}_i, u_a, A^0}^R + \sum_{b=1}^3 B_0(p^2, m_{d_b}^2, m_{H^+}^2) \Gamma_{\tilde{u}_j, H^+, d_b}^{L*} m_{d_b} \Gamma_{\tilde{u}_i, H^+, d_b}^R
\end{aligned}$$

$$\begin{aligned}
& -\frac{16}{3} \sum_{b=1}^3 \left( -\frac{1}{2} \text{rMS} + B_0(p^2, m_{u_b}^2, 0) \right) \Gamma_{\tilde{u}_j, g, u_b}^{R*} m_{u_b} \Gamma_{\tilde{u}_i, g, u_b}^L - 4 \sum_{b=1}^3 \left( -\frac{1}{2} \text{rMS} + B_0(p^2, m_{u_b}^2, 0) \right) \Gamma_{\tilde{u}_j, \gamma, u_b}^{R*} m_{u_b} \Gamma_{\tilde{u}_i, \gamma, u_b}^L \\
& - 4 \sum_{b=1}^3 \left( -\frac{1}{2} \text{rMS} + B_0(p^2, m_{d_b}^2, m_{W^+}^2) \right) \Gamma_{\tilde{u}_j, W^+, d_b}^{R*} m_{d_b} \Gamma_{\tilde{u}_i, W^+, d_b}^L \\
& - 4 \sum_{b=1}^3 \left( -\frac{1}{2} \text{rMS} + B_0(p^2, m_{u_b}^2, m_Z^2) \right) \Gamma_{\tilde{u}_j, Z, u_b}^{R*} m_{u_b} \Gamma_{\tilde{u}_i, Z, u_b}^L \tag{69}
\end{aligned}$$

$$\begin{aligned}
\Sigma_{i,j}^R(p^2) &= -\frac{1}{2} \sum_{a=1}^2 \sum_{b=1}^3 B_1(p^2, m_{u_b}^2, m_{h_a}^2) \Gamma_{\tilde{u}_j, h_a, u_b}^{R*} \Gamma_{\tilde{u}_i, h_a, u_b}^R - \frac{1}{2} \sum_{a=1}^3 B_1(p^2, m_{u_a}^2, m_{A^0}^2) \Gamma_{\tilde{u}_j, u_a, A^0}^{R*} \Gamma_{\tilde{u}_i, u_a, A^0}^R \\
& - \frac{1}{2} \sum_{b=1}^3 B_1(p^2, m_{d_b}^2, m_{H^+}^2) \Gamma_{\tilde{u}_j, H^+, d_b}^{R*} \Gamma_{\tilde{u}_i, H^+, d_b}^R - \frac{4}{3} \sum_{b=1}^3 B_1(p^2, m_{u_b}^2, 0) \Gamma_{\tilde{u}_j, g, u_b}^{L*} \Gamma_{\tilde{u}_i, g, u_b}^L \\
& - \sum_{b=1}^3 B_1(p^2, m_{u_b}^2, 0) \Gamma_{\tilde{u}_j, \gamma, u_b}^{L*} \Gamma_{\tilde{u}_i, \gamma, u_b}^L - \sum_{b=1}^3 B_1(p^2, m_{d_b}^2, m_{W^+}^2) \Gamma_{\tilde{u}_j, W^+, d_b}^{L*} \Gamma_{\tilde{u}_i, W^+, d_b}^L \\
& - \sum_{b=1}^3 B_1(p^2, m_{u_b}^2, m_Z^2) \Gamma_{\tilde{u}_j, Z, u_b}^{L*} \Gamma_{\tilde{u}_i, Z, u_b}^L \tag{70}
\end{aligned}$$

$$\begin{aligned}
\Sigma_{i,j}^L(p^2) &= -\frac{1}{2} \sum_{a=1}^2 \sum_{b=1}^3 B_1(p^2, m_{u_b}^2, m_{h_a}^2) \Gamma_{\tilde{u}_j, h_a, u_b}^{L*} \Gamma_{\tilde{u}_i, h_a, u_b}^L - \frac{1}{2} \sum_{a=1}^3 B_1(p^2, m_{u_a}^2, m_{A^0}^2) \Gamma_{\tilde{u}_j, u_a, A^0}^{L*} \Gamma_{\tilde{u}_i, u_a, A^0}^L \\
& - \frac{1}{2} \sum_{b=1}^3 B_1(p^2, m_{d_b}^2, m_{H^+}^2) \Gamma_{\tilde{u}_j, H^+, d_b}^{L*} \Gamma_{\tilde{u}_i, H^+, d_b}^L - \frac{4}{3} \sum_{b=1}^3 B_1(p^2, m_{u_b}^2, 0) \Gamma_{\tilde{u}_j, g, u_b}^{R*} \Gamma_{\tilde{u}_i, g, u_b}^R \\
& - \sum_{b=1}^3 B_1(p^2, m_{u_b}^2, 0) \Gamma_{\tilde{u}_j, \gamma, u_b}^{R*} \Gamma_{\tilde{u}_i, \gamma, u_b}^R - \sum_{b=1}^3 B_1(p^2, m_{d_b}^2, m_{W^+}^2) \Gamma_{\tilde{u}_j, W^+, d_b}^{R*} \Gamma_{\tilde{u}_i, W^+, d_b}^R \\
& - \sum_{b=1}^3 B_1(p^2, m_{u_b}^2, m_Z^2) \Gamma_{\tilde{u}_j, Z, u_b}^{R*} \Gamma_{\tilde{u}_i, Z, u_b}^R \tag{71}
\end{aligned}$$

• **Self-Energy for Leptons ( $e$ )**

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

$$\begin{aligned}
& + \sum_{b=1}^3 B_0(p^2, m_{\nu_b}^2, m_{H^+}^2) \Gamma_{\tilde{e}_j, H^-, \nu_b}^{L*} m_{\nu_b} \Gamma_{\tilde{e}_i, H^-, \nu_b}^R \\
& - 4 \sum_{b=1}^3 \left( -\frac{1}{2} \text{rMS} + B_0(p^2, m_{\nu_b}^2, m_{W^+}^2) \right) \Gamma_{\tilde{e}_j, W^-, \nu_b}^{R*} m_{\nu_b} \Gamma_{\tilde{e}_i, W^-, \nu_b}^L
\end{aligned} \tag{72}$$

$$\begin{aligned}
\Sigma_{i,j}^R(p^2) = & -\frac{1}{2} \sum_{a=1}^2 \sum_{b=1}^3 B_1(p^2, m_{e_b}^2, m_{h_a}^2) \Gamma_{\tilde{e}_j, h_a, e_b}^{R*} \Gamma_{\tilde{e}_i, h_a, e_b}^R - \frac{1}{2} \sum_{a=1}^3 B_1(p^2, m_{e_a}^2, m_{A^0}^2) \Gamma_{\tilde{e}_j, e_a, A^0}^{R*} \Gamma_{\tilde{e}_i, e_a, A^0}^R \\
& - \sum_{b=1}^3 B_1(p^2, m_{e_b}^2, 0) \Gamma_{\tilde{e}_j, \gamma, e_b}^{L*} \Gamma_{\tilde{e}_i, \gamma, e_b}^L - \sum_{b=1}^3 B_1(p^2, m_{e_b}^2, m_Z^2) \Gamma_{\tilde{e}_j, Z, e_b}^{L*} \Gamma_{\tilde{e}_i, Z, e_b}^L \\
& - \frac{1}{2} \sum_{b=1}^3 B_1(p^2, m_{\nu_b}^2, m_{H^+}^2) \Gamma_{\tilde{e}_j, H^-, \nu_b}^{R*} \Gamma_{\tilde{e}_i, H^-, \nu_b}^R - \sum_{b=1}^3 B_1(p^2, m_{\nu_b}^2, m_{W^+}^2) \Gamma_{\tilde{e}_j, W^-, \nu_b}^{L*} \Gamma_{\tilde{e}_i, W^-, \nu_b}^L
\end{aligned} \tag{73}$$

$$\begin{aligned}
\Sigma_{i,j}^L(p^2) = & -\frac{1}{2} \sum_{a=1}^2 \sum_{b=1}^3 B_1(p^2, m_{e_b}^2, m_{h_a}^2) \Gamma_{\tilde{e}_j, h_a, e_b}^{L*} \Gamma_{\tilde{e}_i, h_a, e_b}^L - \frac{1}{2} \sum_{a=1}^3 B_1(p^2, m_{e_a}^2, m_{A^0}^2) \Gamma_{\tilde{e}_j, e_a, A^0}^{L*} \Gamma_{\tilde{e}_i, e_a, A^0}^L \\
& - \sum_{b=1}^3 B_1(p^2, m_{e_b}^2, 0) \Gamma_{\tilde{e}_j, \gamma, e_b}^{R*} \Gamma_{\tilde{e}_i, \gamma, e_b}^R - \sum_{b=1}^3 B_1(p^2, m_{e_b}^2, m_Z^2) \Gamma_{\tilde{e}_j, Z, e_b}^{R*} \Gamma_{\tilde{e}_i, Z, e_b}^R \\
& - \frac{1}{2} \sum_{b=1}^3 B_1(p^2, m_{\nu_b}^2, m_{H^+}^2) \Gamma_{\tilde{e}_j, H^-, \nu_b}^{L*} \Gamma_{\tilde{e}_i, H^-, \nu_b}^L - \sum_{b=1}^3 B_1(p^2, m_{\nu_b}^2, m_{W^+}^2) \Gamma_{\tilde{e}_j, W^-, \nu_b}^{R*} \Gamma_{\tilde{e}_i, W^-, \nu_b}^R
\end{aligned} \tag{74}$$

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

$$\begin{aligned}
\Pi(p^2) = & +4|\Gamma_{H^-, W^+, \gamma}|^2 \left( -\frac{1}{2} \text{rMS} + B_0(p^2, 0, m_{W^+}^2) \right) + 4|\Gamma_{H^-, Z, W^+}|^2 \left( -\frac{1}{2} \text{rMS} + B_0(p^2, m_{W^+}^2, m_Z^2) \right) \\
& - B_0(p^2, m_{\eta^+}^2, m_{\eta^-}^2) \Gamma_{H^+, \eta^-, \eta^+} \Gamma_{H^-, \eta^-, \eta^+} - B_0(p^2, m_{\eta^+}^2, m_{\eta^+}^2) \Gamma_{H^+, \eta^+, \eta^+} \Gamma_{H^-, \eta^+, \eta^+} \\
& - \frac{1}{2} A_0(m_{A^0}^2) \Gamma_{H^+, H^-, A^0, A^0} - A_0(m_{H^+}^2) \Gamma_{H^+, H^-, H^-, H^+} - 8A_0(m_O^2) \Gamma_{H^+, H^-, O^*, O} \\
& + |\Gamma_{H^-, W^+, A^0}|^2 F_0(p^2, m_{A^0}^2, m_{W^+}^2) + |\Gamma_{H^-, \gamma, H^+}|^2 F_0(p^2, m_{H^+}^2, 0) + |\Gamma_{H^-, Z, H^+}|^2 F_0(p^2, m_{H^+}^2, m_Z^2) \\
& + 4\Gamma_{H^+, H^-, W^-, W^+} \left( -\frac{1}{2} \text{rMS} m_{W^+}^2 + A_0(m_{W^+}^2) \right) + 2\Gamma_{H^+, H^-, Z, Z} \left( -\frac{1}{2} \text{rMS} m_Z^2 + A_0(m_Z^2) \right) \\
& - \frac{1}{2} \sum_{a=1}^2 A_0(m_{h_a}^2) \Gamma_{H^+, H^-, h_a, h_a} + 3 \sum_{a=1}^3 \sum_{b=1}^3 \left( |\Gamma_{H^-, \bar{d}_a, u_b}^L|^2 + |\Gamma_{H^-, \bar{d}_a, u_b}^R|^2 \right) G_0(p^2, m_{d_a}^2, m_{u_b}^2) \\
& + \sum_{a=1}^3 \sum_{b=1}^3 \left( |\Gamma_{H^-, \bar{e}_a, \nu_b}^L|^2 + |\Gamma_{H^-, \bar{e}_a, \nu_b}^R|^2 \right) G_0(p^2, m_{e_a}^2, m_{\nu_b}^2) \\
& - 6 \sum_{a=1}^3 m_{d_a} \sum_{b=1}^3 B_0(p^2, m_{d_a}^2, m_{u_b}^2) m_{u_b} \left( \Gamma_{H^-, \bar{d}_a, u_b}^{L*} \Gamma_{H^-, \bar{d}_a, u_b}^R + \Gamma_{H^-, \bar{d}_a, u_b}^{R*} \Gamma_{H^-, \bar{d}_a, u_b}^L \right)
\end{aligned}$$



$$\begin{aligned}
& -2 \sum_{a=1}^3 m_{e_a} \sum_{b=1}^3 B_0(p^2, m_{e_a}^2, m_{\nu_b}^2) m_{\nu_b} \left( \Gamma_{H^-, \bar{e}_a, \nu_b}^{L*} \Gamma_{H^-, \bar{e}_a, \nu_b}^R + \Gamma_{H^-, \bar{e}_a, \nu_b}^{R*} \Gamma_{H^-, \bar{e}_a, \nu_b}^L \right) \\
& + \sum_{b=1}^2 |\Gamma_{H^-, H^+, h_b}|^2 B_0(p^2, m_{H^+}^2, m_{h_b}^2) + \sum_{b=1}^2 |\Gamma_{H^-, W^+, h_b}|^2 F_0(p^2, m_{h_b}^2, m_{W^+}^2)
\end{aligned} \tag{75}$$

• **Self-Energy for Color Octet** ( $O$ )

$$\begin{aligned}
\Pi(p^2) = & -\frac{1}{2} A_0(m_{A^0}^2) \Gamma_{O, O^*, A^0, A^0} - A_0(m_{H^+}^2) \Gamma_{O, O^*, H^-, H^+} + 3 |\Gamma_{O^*, g, O}|^2 F_0(p^2, m_O^2, 0) \\
& - \frac{1}{2} \sum_{a=1}^2 A_0(m_{h_a}^2) \Gamma_{O, O^*, h_a, h_a} + \sum_{b=1}^2 |\Gamma_{O^*, O, h_b}|^2 B_0(p^2, m_O^2, m_{h_b}^2)
\end{aligned} \tag{76}$$

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

$$\begin{aligned}
\Pi(p^2) = & -B_0(p^2, m_{\eta^+}^2, m_{\eta^+}^2) \Gamma_{A^0, \eta^+, \eta^+}^2 - B_0(p^2, m_{\eta^-}^2, m_{\eta^-}^2) \Gamma_{A^0, \eta^-, \eta^-}^2 - \frac{1}{2} A_0(m_{A^0}^2) \Gamma_{A^0, A^0, A^0, A^0} \\
& - A_0(m_{H^+}^2) \Gamma_{A^0, A^0, H^-, H^+} - 8 A_0(m_O^2) \Gamma_{A^0, A^0, O^*, O} + 2 |\Gamma_{A^0, W^-, H^+}|^2 F_0(p^2, m_{H^+}^2, m_{W^+}^2) \\
& + 4 \Gamma_{A^0, A^0, W^-, W^+} \left( -\frac{1}{2} \text{rMS} m_{W^+}^2 + A_0(m_{W^+}^2) \right) + 2 \Gamma_{A^0, A^0, Z, Z} \left( -\frac{1}{2} \text{rMS} m_Z^2 + A_0(m_Z^2) \right) + \sum_{a=1}^2 |\Gamma_{A^0, h_a, A^0}|^2 B_0(p^2, m_{h_a}^2, m_{A^0}^2) \\
& - \frac{1}{2} \sum_{a=1}^2 A_0(m_{h_a}^2) \Gamma_{A^0, A^0, h_a, h_a} + 3 \sum_{a=1}^3 \sum_{b=1}^3 \left( |\Gamma_{A^0, \bar{d}_a, d_b}^L|^2 + |\Gamma_{A^0, \bar{d}_a, d_b}^R|^2 \right) G_0(p^2, m_{d_a}^2, m_{d_b}^2) \\
& + \sum_{a=1}^3 \sum_{b=1}^3 \left( |\Gamma_{A^0, \bar{e}_a, e_b}^L|^2 + |\Gamma_{A^0, \bar{e}_a, e_b}^R|^2 \right) G_0(p^2, m_{e_a}^2, m_{e_b}^2) \\
& + 3 \sum_{a=1}^3 \sum_{b=1}^3 \left( |\Gamma_{A^0, \bar{u}_a, u_b}^L|^2 + |\Gamma_{A^0, \bar{u}_a, u_b}^R|^2 \right) G_0(p^2, m_{u_a}^2, m_{u_b}^2) \\
& - 6 \sum_{a=1}^3 m_{d_a} \sum_{b=1}^3 B_0(p^2, m_{d_a}^2, m_{d_b}^2) m_{d_b} \left( \Gamma_{A^0, \bar{d}_a, d_b}^{L*} \Gamma_{A^0, \bar{d}_a, d_b}^R + \Gamma_{A^0, \bar{d}_a, d_b}^{R*} \Gamma_{A^0, \bar{d}_a, d_b}^L \right) \\
& - 2 \sum_{a=1}^3 m_{e_a} \sum_{b=1}^3 B_0(p^2, m_{e_a}^2, m_{e_b}^2) m_{e_b} \left( \Gamma_{A^0, \bar{e}_a, e_b}^{L*} \Gamma_{A^0, \bar{e}_a, e_b}^R + \Gamma_{A^0, \bar{e}_a, e_b}^{R*} \Gamma_{A^0, \bar{e}_a, e_b}^L \right) \\
& - 6 \sum_{a=1}^3 m_{u_a} \sum_{b=1}^3 B_0(p^2, m_{u_a}^2, m_{u_b}^2) m_{u_b} \left( \Gamma_{A^0, \bar{u}_a, u_b}^{L*} \Gamma_{A^0, \bar{u}_a, u_b}^R + \Gamma_{A^0, \bar{u}_a, u_b}^{R*} \Gamma_{A^0, \bar{u}_a, u_b}^L \right) \\
& + \sum_{b=1}^2 |\Gamma_{A^0, Z, h_b}|^2 F_0(p^2, m_{h_b}^2, m_Z^2)
\end{aligned} \tag{77}$$

• **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) + \frac{1}{2}A_0(m_{A^0}^2)\Gamma_{Z,Z,A^0,A^0} + 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) \\
& - 4\sum_{a=1}^2 |\Gamma_{Z,h_a,A^0}|^2 B_{00}(p^2, m_{A^0}^2, m_{h_a}^2) + \frac{1}{2}\sum_{a=1}^2 A_0(m_{h_a}^2)\Gamma_{Z,Z,h_a,h_a} \\
& + 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(\Gamma_{Z,\bar{d}_a,d_b}^{L*} \Gamma_{Z,\bar{d}_a,d_b}^R) \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(\Gamma_{Z,\bar{e}_a,e_b}^{L*} \Gamma_{Z,\bar{e}_a,e_b}^R) \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(\Gamma_{Z,\bar{u}_a,u_b}^{L*} \Gamma_{Z,\bar{u}_a,u_b}^R) \right] \\
& + \sum_{a=1}^3 \sum_{b=1}^3 \left[ \left( |\Gamma_{Z,\bar{\nu}_a,\nu_b}^L|^2 + |\Gamma_{Z,\bar{\nu}_a,\nu_b}^R|^2 \right) H_0(p^2, m_{\nu_a}^2, m_{\nu_b}^2) \right. \\
& \left. + 4B_0(p^2, m_{\nu_a}^2, m_{\nu_b}^2) m_{\nu_a} m_{\nu_b} \Re(\Gamma_{Z,\bar{\nu}_a,\nu_b}^{L*} \Gamma_{Z,\bar{\nu}_a,\nu_b}^R) \right] \\
& + \sum_{b=1}^2 |\Gamma_{Z,Z,h_b}|^2 B_0(p^2, m_Z^2, m_{h_b}^2) + 2\text{rMS}m_{W^+}^2 \Gamma_{Z,Z,W^-,W^+}^1 - A_0(m_{W^+}^2) \left( 4\Gamma_{Z,Z,W^-,W^+}^1 + \Gamma_{Z,Z,W^-,W^+}^2 + \Gamma_{Z,Z,W^-,W^+}^3 \right)
\end{aligned} \tag{78}$$

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

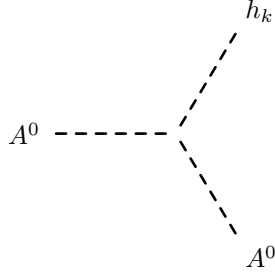
$$\begin{aligned}
\Pi(p^2) = & 2\text{rMS}m_{W^+}^2 \Gamma_{W^+,W^-,W^-,W^+}^1 + 3\sum_{a=1}^3 \sum_{b=1}^3 \left[ \left( |\Gamma_{W^-, \bar{d}_a, u_b}^L|^2 + |\Gamma_{W^-, \bar{d}_a, u_b}^R|^2 \right) H_0(p^2, m_{d_a}^2, m_{u_b}^2) \right. \\
& \left. + 4B_0(p^2, m_{d_a}^2, m_{u_b}^2) m_{d_a} m_{u_b} \Re(\Gamma_{W^-, \bar{d}_a, u_b}^{L*} \Gamma_{W^-, \bar{d}_a, u_b}^R) \right] - 4|\Gamma_{W^-, H^+, A^0}|^2 B_{00}(p^2, m_{A^0}^2, m_{H^+}^2) - 4\sum_{b=1}^2 |\Gamma_{W^-, H^+, h_b}|^2 B_{00}(p^2, m_{H^+}^2, m_{h_b}^2) \\
& + 4B_0(p^2, m_{e_a}^2, m_{\nu_b}^2) m_{e_a} m_{\nu_b} \Re(\Gamma_{W^-, \bar{e}_a, \nu_b}^{L*} \Gamma_{W^-, \bar{e}_a, \nu_b}^R) + \sum_{b=1}^2 |\Gamma_{W^-, W^+, h_b}|^2 B_0(p^2, m_{W^+}^2, m_{h_b}^2)
\end{aligned} \tag{79}$$

## 8.2 Tadpoles

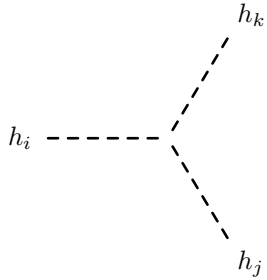
$$\begin{aligned}
\delta t_h^{(1)} = & -\frac{1}{2}A_0(m_{A^0}^2)\Gamma_{\check{h}_i,A^0,A^0} + A_0(m_{\eta^+}^2)\Gamma_{\check{h}_i,\eta^+,\eta^+} + A_0(m_{\eta^-}^2)\Gamma_{\check{h}_i,\eta^-,\eta^-} + A_0(m_{\eta^Z}^2)\Gamma_{\check{h}_i,\eta^Z,\eta^Z} \\
& - A_0(m_{H^+}^2)\Gamma_{\check{h}_i,H^-,H^+} - 3A_0(m_O^2)\Gamma_{\check{h}_i,O^*,O} + 4\Gamma_{\check{h}_i,W^-,W^+} \left( -\frac{1}{2}\text{rMS}m_{W^+}^2 + A_0(m_{W^+}^2) \right) \\
& + 2\Gamma_{\check{h}_i,Z,Z} \left( -\frac{1}{2}\text{rMS}m_Z^2 + A_0(m_Z^2) \right) - \frac{1}{2}\sum_{a=1}^2 A_0(m_{h_a}^2)\Gamma_{\check{h}_i,h_a,h_a} \\
& + 6\sum_{a=1}^3 A_0(m_{d_a}^2)m_{d_a} \left( \Gamma_{\check{h}_i,\bar{d}_a,d_a}^L + \Gamma_{\check{h}_i,\bar{d}_a,d_a}^R \right) \\
& + 2\sum_{a=1}^3 A_0(m_{e_a}^2)m_{e_a} \left( \Gamma_{\check{h}_i,\bar{e}_a,e_a}^L + \Gamma_{\check{h}_i,\bar{e}_a,e_a}^R \right) \\
& + 6\sum_{a=1}^3 A_0(m_{u_a}^2)m_{u_a} \left( \Gamma_{\check{h}_i,\bar{u}_a,u_a}^L + \Gamma_{\check{h}_i,\bar{u}_a,u_a}^R \right)
\end{aligned} \tag{80}$$

## 9 Interactions for eigenstates 'EWSB'

### 9.1 Three Scalar-Interaction

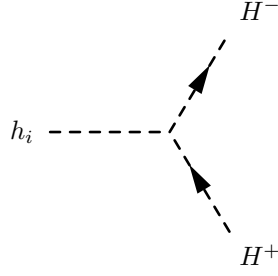


$$i \left( \left( \lambda_{HS} v_S + eH \right) Z_{k2}^H + \lambda v Z_{k1}^H \right) \tag{81}$$



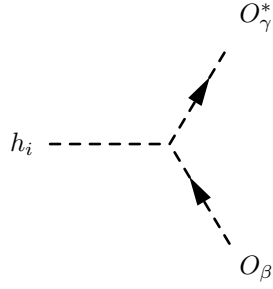
$$\begin{aligned}
& i \left( Z_{i1}^H \left( Z_{j1}^H \left( 3\lambda v Z_{k1}^H + \left( \lambda_{HS} v_S + eH \right) Z_{k2}^H \right) + Z_{j2}^H \left( \left( \lambda_{HS} v_S + eH \right) Z_{k1}^H + \lambda_{HS} v Z_{k2}^H \right) \right) \right. \\
& \left. + Z_{i2}^H \left( Z_{j1}^H \left( \left( \lambda_{HS} v_S + eH \right) Z_{k1}^H + \lambda_{HS} v Z_{k2}^H \right) + Z_{j2}^H \left( 6 \left( \lambda_S v_S + eS \right) Z_{k2}^H + \lambda_{HS} v Z_{k1}^H \right) \right) \right)
\end{aligned} \tag{82}$$


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$$i \left( \left( \lambda_{HS} v_S + eH \right) Z_{i2}^H + \lambda v Z_{i1}^H \right) \tag{83}$$

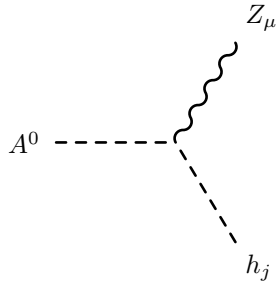

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$$i\delta_{\beta\gamma} \left( \left( \lambda_{Cs} v_S + eC \right) Z_{i2}^H + \lambda_{HC} v Z_{i1}^H \right) \tag{84}$$

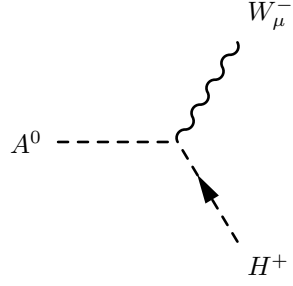

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## 9.2 Two Scalar-One Vector Boson-Interaction



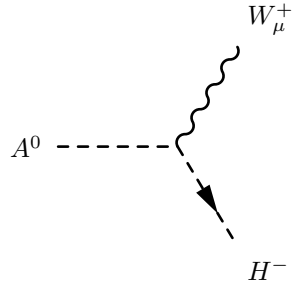
$$-\frac{1}{2}\left(g_1 \sin \Theta_W + g_2 \cos \Theta_W\right) Z_{j1}^H\left(-p_\mu^{h_j} + p_\mu^{A^0}\right) \quad (85)$$


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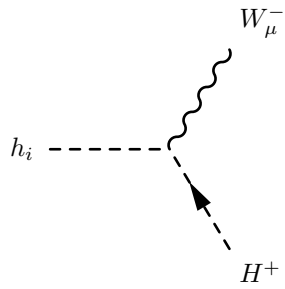
$$\frac{1}{2} g_2\left(-p_\mu^{H^+} + p_\mu^{A^0}\right) \quad (86)$$


---



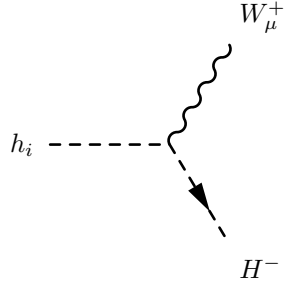
$$\frac{1}{2} g_2\left(-p_\mu^{H^-} + p_\mu^{A^0}\right) \quad (87)$$


---



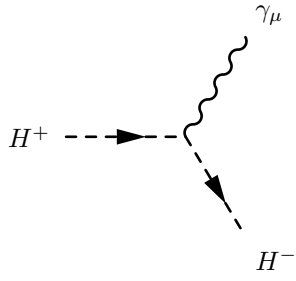
$$\frac{i}{2} g_2 Z_{i1}^H\left(-p_\mu^{H^+} + p_\mu^{h_i}\right) \quad (88)$$


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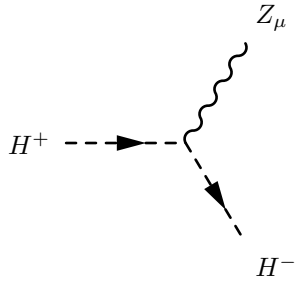
$$-\frac{i}{2}g_2Z_{i1}^H\left(-p_\mu^{H^-}+p_\mu^{h_i}\right) \quad (89)$$


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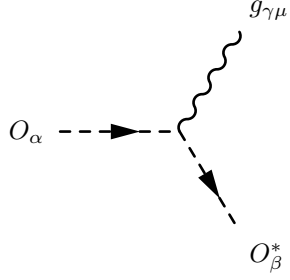
$$-\frac{i}{2}\left(g_1\cos\Theta_W+g_2\sin\Theta_W\right)\left(-p_\mu^{H^-}+p_\mu^{H^+}\right) \quad (90)$$


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$$-\frac{i}{2}\left(-g_1\sin\Theta_W+g_2\cos\Theta_W\right)\left(-p_\mu^{H^-}+p_\mu^{H^+}\right) \quad (91)$$

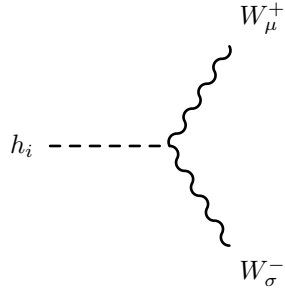

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$$g_3 f_{\alpha,\beta,\gamma} \left( -p_\mu^{O_\beta^*} + p_\mu^{O_\alpha} \right) \quad (92)$$

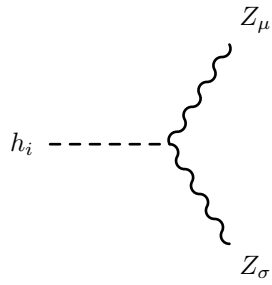

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### 9.3 One Scalar-Two Vector Boson-Interaction



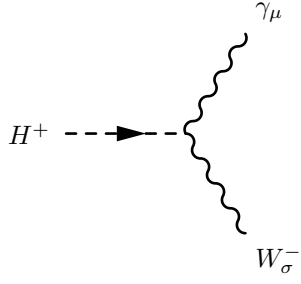
$$\frac{i}{2} g_2^2 v Z_{i1}^H \left( g_{\sigma\mu} \right) \quad (93)$$


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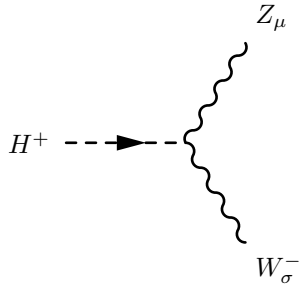
$$\frac{i}{2} v \left( g_1 \sin \Theta_W + g_2 \cos \Theta_W \right)^2 Z_{i1}^H \left( g_{\sigma\mu} \right) \quad (94)$$


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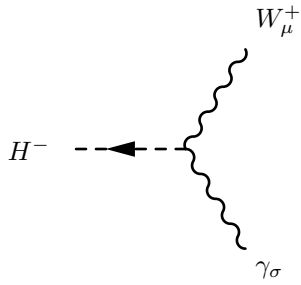
$$\frac{i}{2}g_1g_2v\cos\Theta_W\left(g_{\sigma\mu}\right) \quad (95)$$


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$$-\frac{i}{2}g_1g_2v\sin\Theta_W\left(g_{\sigma\mu}\right) \quad (96)$$

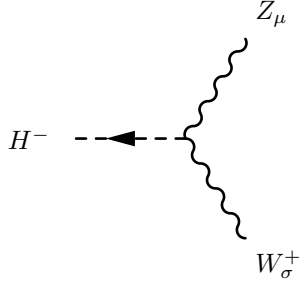

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$$\frac{i}{2}g_1g_2v\cos\Theta_W\left(g_{\sigma\mu}\right) \quad (97)$$


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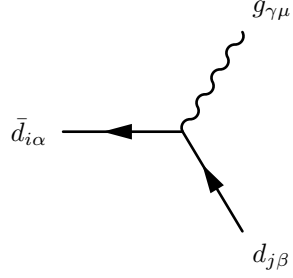




$$-\frac{i}{2}g_1g_2v\sin\Theta_W\left(g_{\sigma\mu}\right) \quad (98)$$


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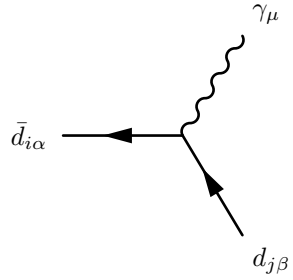
#### 9.4 Two Fermion-One Vector Boson-Interaction



$$-\frac{i}{2}g_3\delta_{ij}\lambda_{\alpha,\beta}^\gamma\left(\gamma_\mu\cdot\frac{1-\gamma_5}{2}\right) \quad (99)$$

$$+\frac{i}{2}g_3\delta_{ij}\lambda_{\alpha,\beta}^\gamma\left(\gamma_\mu\cdot\frac{1+\gamma_5}{2}\right) \quad (100)$$

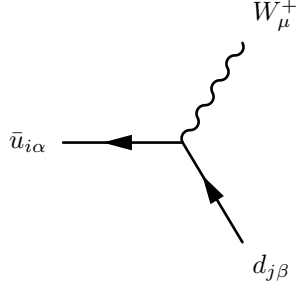

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$$-\frac{i}{6}\delta_{\alpha\beta}\delta_{ij}\left(-3g_2\sin\Theta_W+g_1\cos\Theta_W\right)\left(\gamma_\mu\cdot\frac{1-\gamma_5}{2}\right) \quad (101)$$

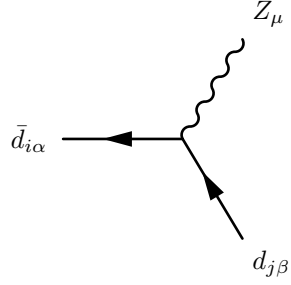
$$+\frac{i}{3}g_1\cos\Theta_W\delta_{\alpha\beta}\delta_{ij}\left(\gamma_\mu\cdot\frac{1+\gamma_5}{2}\right) \quad (102)$$


---



$$-i \frac{1}{\sqrt{2}} g_2 \delta_{\alpha\beta} \sum_{a=1}^3 U_{L,ja}^{d,*} U_{L,ia}^u \left( \gamma_\mu \cdot \frac{1 - \gamma_5}{2} \right) \quad (103)$$

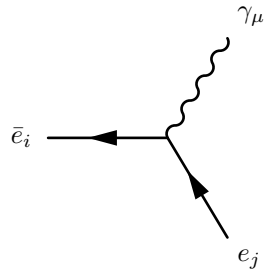

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$$\frac{i}{6} \delta_{\alpha\beta} \delta_{ij} \left( 3g_2 \cos \Theta_W + g_1 \sin \Theta_W \right) \left( \gamma_\mu \cdot \frac{1 - \gamma_5}{2} \right) \quad (104)$$

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

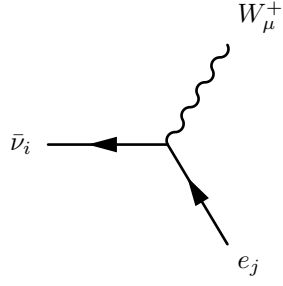

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$$\frac{i}{2} \delta_{ij} \left( g_1 \cos \Theta_W + g_2 \sin \Theta_W \right) \left( \gamma_\mu \cdot \frac{1 - \gamma_5}{2} \right) \quad (106)$$

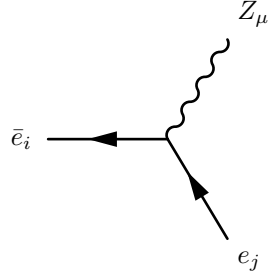
$$+ i g_1 \cos \Theta_W \delta_{ij} \left( \gamma_\mu \cdot \frac{1 + \gamma_5}{2} \right) \quad (107)$$


---



$$-i \frac{1}{\sqrt{2}} g_2 U_{L,ji}^{e,*} \Theta_{i,3} \left( \gamma_\mu \cdot \frac{1 - \gamma_5}{2} \right) \quad (108)$$

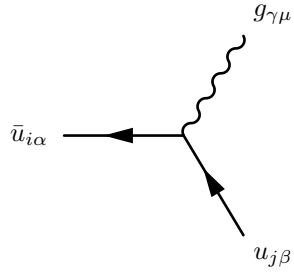

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$$\frac{i}{2} \delta_{ij} \left( -g_1 \sin \Theta_W + g_2 \cos \Theta_W \right) \left( \gamma_\mu \cdot \frac{1 - \gamma_5}{2} \right) \quad (109)$$

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

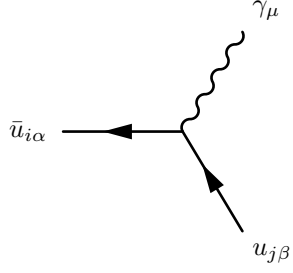

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$$- \frac{i}{2} g_3 \delta_{ij} \lambda_{\alpha,\beta}^\gamma \left( \gamma_\mu \cdot \frac{1 - \gamma_5}{2} \right) \quad (111)$$

$$+ - \frac{i}{2} g_3 \delta_{ij} \lambda_{\alpha,\beta}^\gamma \left( \gamma_\mu \cdot \frac{1 + \gamma_5}{2} \right) \quad (112)$$

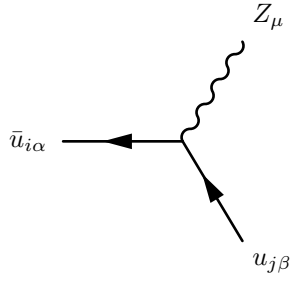

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$$-\frac{i}{6}\delta_{\alpha\beta}\delta_{ij}\left(3g_2\sin\Theta_W+g_1\cos\Theta_W\right)\left(\gamma_\mu\cdot\frac{1-\gamma_5}{2}\right) \quad (113)$$

$$+\frac{2i}{3}g_1\cos\Theta_W\delta_{\alpha\beta}\delta_{ij}\left(\gamma_\mu\cdot\frac{1+\gamma_5}{2}\right) \quad (114)$$

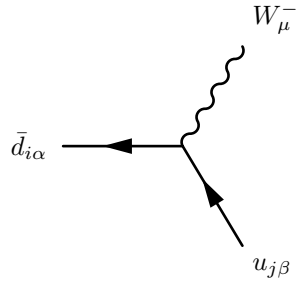

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$$-\frac{i}{6}\delta_{\alpha\beta}\delta_{ij}\left(3g_2\cos\Theta_W-g_1\sin\Theta_W\right)\left(\gamma_\mu\cdot\frac{1-\gamma_5}{2}\right) \quad (115)$$

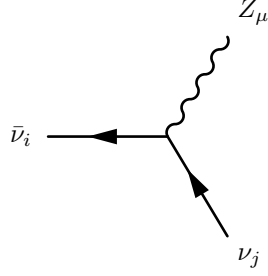
$$+\frac{2i}{3}g_1\delta_{\alpha\beta}\delta_{ij}\sin\Theta_W\left(\gamma_\mu\cdot\frac{1+\gamma_5}{2}\right) \quad (116)$$


---



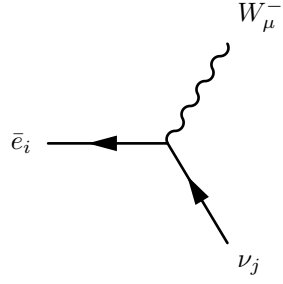
$$-i\frac{1}{\sqrt{2}}g_2\delta_{\alpha\beta}\sum_{a=1}^3U_{L,ja}^{u,*}U_{L,ia}^d\left(\gamma_\mu\cdot\frac{1-\gamma_5}{2}\right) \quad (117)$$


---



$$-\frac{i}{2}\delta_{ij}\left(g_1\sin\Theta_W+g_2\cos\Theta_W\right)\left(\gamma_\mu\cdot\frac{1-\gamma_5}{2}\right) \quad (118)$$

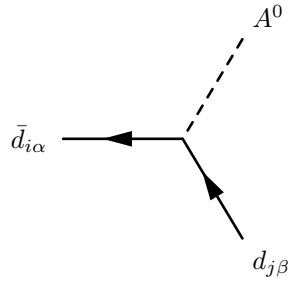

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$$-i\frac{1}{\sqrt{2}}g_2\Theta_{j,3}U_{L,ij}^e\left(\gamma_\mu\cdot\frac{1-\gamma_5}{2}\right) \quad (119)$$


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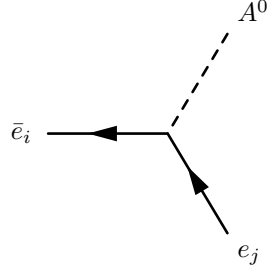
## 9.5 Two Fermion-One Scalar Boson-Interaction



$$-\frac{1}{\sqrt{2}}\delta_{\alpha\beta}\sum_{b=1}^3U_{L,jb}^{d,*}\sum_{a=1}^3U_{R,ia}^dY_{d,ab}\left(\frac{1-\gamma_5}{2}\right) \quad (120)$$

$$+\frac{1}{\sqrt{2}}\delta_{\alpha\beta}\sum_{b=1}^3\sum_{a=1}^3Y_{d,ab}^*U_{R,ja}^dU_{L,ib}^d\left(\frac{1+\gamma_5}{2}\right) \quad (121)$$

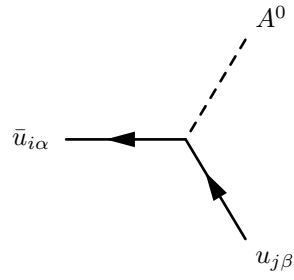

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$$- \frac{1}{\sqrt{2}} \sum_{b=1}^3 U_{L,jb}^{e,*} \sum_{a=1}^3 U_{R,ia}^{e,*} Y_{e,ab} \left( \frac{1 - \gamma_5}{2} \right) \quad (122)$$

$$+ \frac{1}{\sqrt{2}} \sum_{b=1}^3 \sum_{a=1}^3 Y_{e,ab}^* U_{R,ja}^e U_{L,ib}^e \left( \frac{1 + \gamma_5}{2} \right) \quad (123)$$

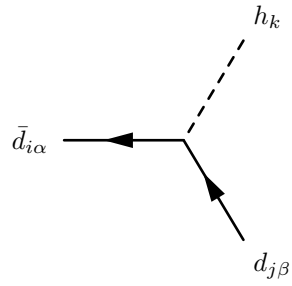

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$$- \frac{1}{\sqrt{2}} \delta_{\alpha\beta} \sum_{b=1}^3 U_{L,jb}^{u,*} \sum_{a=1}^3 U_{R,ia}^{u,*} Y_{u,ab} \left( \frac{1 - \gamma_5}{2} \right) \quad (124)$$

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

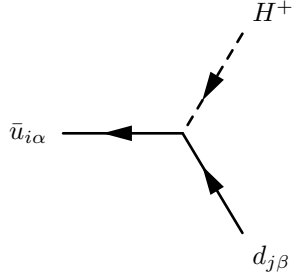

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$$-i \frac{1}{\sqrt{2}} \delta_{\alpha\beta} \sum_{b=1}^3 U_{L,jb}^{d,*} \sum_{a=1}^3 U_{R,ia}^{d,*} Y_{d,ab} Z_{k1}^H \left( \frac{1-\gamma_5}{2} \right) \quad (126)$$

$$+ -i \frac{1}{\sqrt{2}} \delta_{\alpha\beta} \sum_{b=1}^3 \sum_{a=1}^3 Y_{d,ab}^* U_{R,ja}^d U_{L,ib}^d Z_{k1}^H \left( \frac{1+\gamma_5}{2} \right) \quad (127)$$

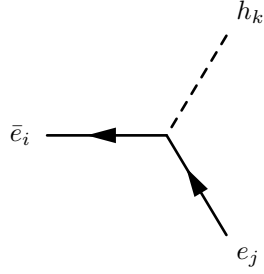

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$$-i \delta_{\alpha\beta} \sum_{b=1}^3 U_{L,jb}^{d,*} \sum_{a=1}^3 U_{R,ia}^{u,*} Y_{u,ab} \left( \frac{1-\gamma_5}{2} \right) \quad (128)$$

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

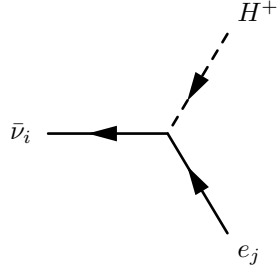

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$$-i \frac{1}{\sqrt{2}} \sum_{b=1}^3 U_{L,jb}^{e,*} \sum_{a=1}^3 U_{R,ia}^{e,*} Y_{e,ab} Z_{k1}^H \left( \frac{1-\gamma_5}{2} \right) \quad (130)$$

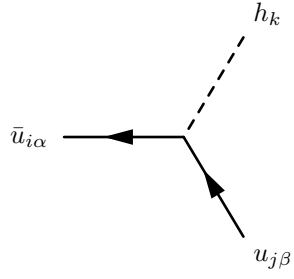
$$+ -i \frac{1}{\sqrt{2}} \sum_{b=1}^3 \sum_{a=1}^3 Y_{e,ab}^* U_{R,ja}^e U_{L,ib}^e Z_{k1}^H \left( \frac{1+\gamma_5}{2} \right) \quad (131)$$


---



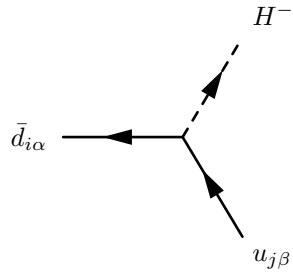
(132)

$$+ -i \sum_{a=1}^3 Y_{e,ai}^* U_{R,ja}^e \left( \frac{1+\gamma_5}{2} \right) \quad (133)$$



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

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

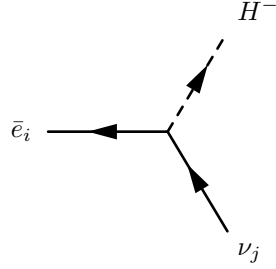




$$-i\delta_{\alpha\beta} \sum_{b=1}^3 U_{L,jb}^{u,*} \sum_{a=1}^3 U_{R,ia}^{d,*} Y_{d,ab} \left( \frac{1-\gamma_5}{2} \right) \quad (136)$$

$$+ -i\delta_{\alpha\beta} \sum_{b=1}^3 \sum_{a=1}^3 Y_{u,ab}^* U_{R,ja}^u U_{L,ib}^d \left( \frac{1+\gamma_5}{2} \right) \quad (137)$$

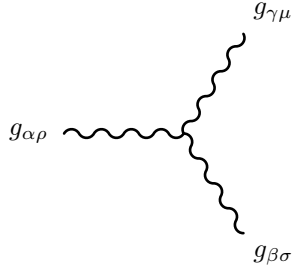

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$$-i \sum_{a=1}^3 U_{R,ia}^{e,*} Y_{e,aj} \left( \frac{1-\gamma_5}{2} \right) \quad (138)$$

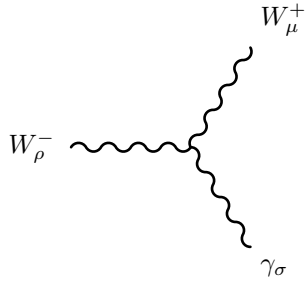

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## 9.6 Three Vector Boson-Interaction



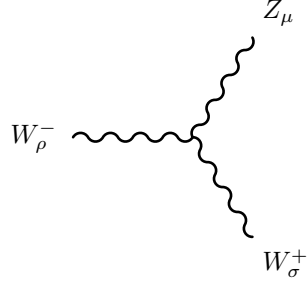
$$g_3 f_{\alpha,\beta,\gamma} \left( g_{\rho\mu} \left( -p_\sigma^{g\gamma\mu} + p_\sigma^{g\alpha\rho} \right) + g_{\rho\sigma} \left( -p_\mu^{g\alpha\rho} + p_\mu^{g\beta\sigma} \right) + g_{\sigma\mu} \left( -p_\rho^{g\beta\sigma} + p_\rho^{g\gamma\mu} \right) \right) \quad (139)$$


---



$$-ig_2 \sin \Theta_W \left( g_{\rho\mu} \left( -p_\sigma^{W_\mu^+} + p_\sigma^{W_\rho^-} \right) + g_{\rho\sigma} \left( -p_\mu^{W_\rho^-} + p_\mu^{\gamma_\sigma} \right) + g_{\sigma\mu} \left( -p_\rho^{\gamma_\sigma} + p_\rho^{W_\mu^+} \right) \right) \quad (140)$$

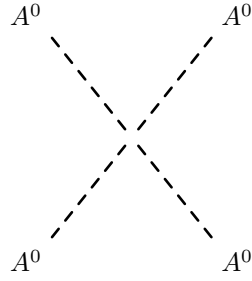

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$$ig_2 \cos \Theta_W \left( g_{\rho\mu} \left( -p_\sigma^{Z_\mu} + p_\sigma^{W_\rho^-} \right) + g_{\rho\sigma} \left( -p_\mu^{W_\rho^-} + p_\mu^{W_\sigma^+} \right) + g_{\sigma\mu} \left( -p_\rho^{W_\sigma^+} + p_\rho^{Z_\mu} \right) \right) \quad (141)$$

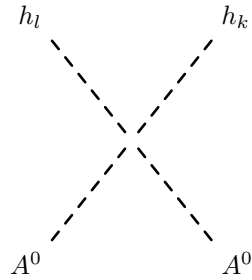

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## 9.7 Four Scalar-Interaction



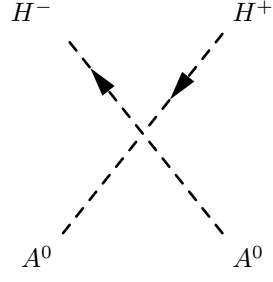
$$3i\lambda \quad (142)$$


---



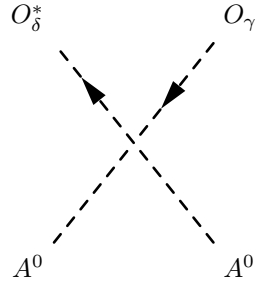
$$i \left( \lambda_{HS} Z_{k2}^H Z_{l2}^H + \lambda Z_{k1}^H Z_{l1}^H \right) \quad (143)$$


---



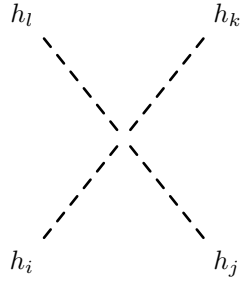
$$i\lambda \quad (144)$$


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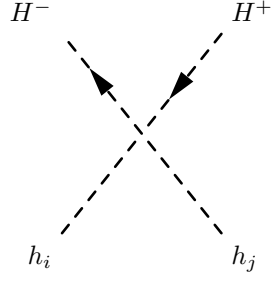
$$i\lambda_{HC}\delta_{\gamma\delta} \quad (145)$$


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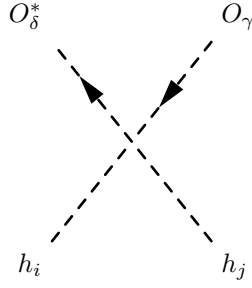
$$\begin{aligned} & i \left( Z_{i1}^H \left( \lambda_{HS} Z_{j2}^H \left( Z_{k1}^H Z_{l2}^H + Z_{k2}^H Z_{l1}^H \right) + Z_{j1}^H \left( 3\lambda Z_{k1}^H Z_{l1}^H + \lambda_{HS} Z_{k2}^H Z_{l2}^H \right) \right) \right. \\ & \left. + Z_{i2}^H \left( \lambda_{HS} Z_{j1}^H \left( Z_{k1}^H Z_{l2}^H + Z_{k2}^H Z_{l1}^H \right) + Z_{j2}^H \left( 6\lambda_S Z_{k2}^H Z_{l2}^H + \lambda_{HS} Z_{k1}^H Z_{l1}^H \right) \right) \right) \end{aligned} \quad (146)$$


---



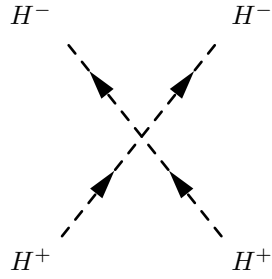
$$i\left(\lambda_{HS}Z_{i2}^HZ_{j2}^H+\lambda Z_{i1}^HZ_{j1}^H\right) \quad (147)$$


---



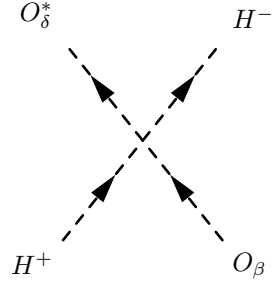
$$i\delta_{\gamma\delta}\left(\lambda_{Cs}Z_{i2}^HZ_{j2}^H+\lambda_{HC}Z_{i1}^HZ_{j1}^H\right) \quad (148)$$


---



$$2i\lambda \quad (149)$$

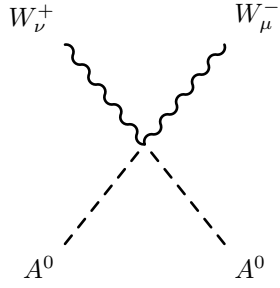

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$$i\lambda_{HC}\delta_{\beta\delta} \quad (150)$$

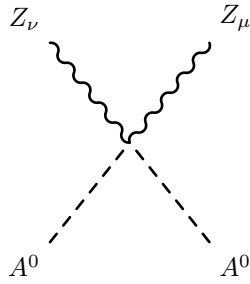

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### 9.8 Two Scalar-Two Vector Boson-Interaction



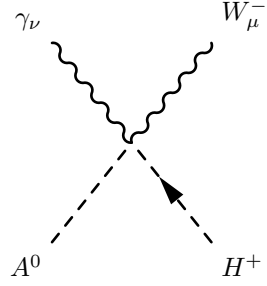
$$\frac{i}{2}g_2^2(g_{\mu\nu}) \quad (151)$$


---



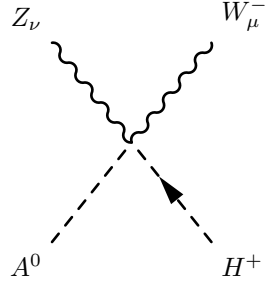
$$\frac{i}{2}\left(g_1\sin\Theta_W + g_2\cos\Theta_W\right)^2(g_{\mu\nu}) \quad (152)$$


---



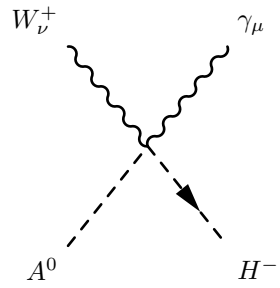
$$\frac{1}{2}g_1g_2\cos\Theta_W\left(g_{\mu\nu}\right) \quad (153)$$


---



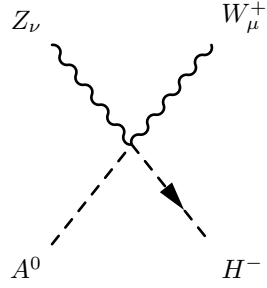
$$-\frac{1}{2}g_1g_2\sin\Theta_W\left(g_{\mu\nu}\right) \quad (154)$$


---



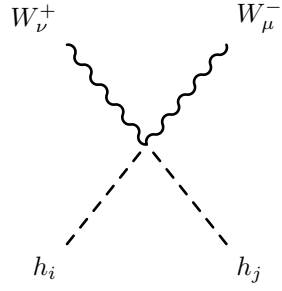
$$-\frac{1}{2}g_1g_2\cos\Theta_W\left(g_{\mu\nu}\right) \quad (155)$$


---



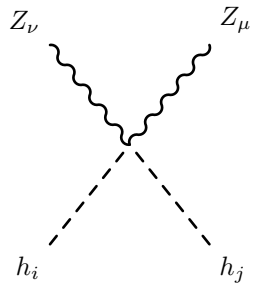
$$\frac{1}{2}g_1g_2\sin\Theta_W\left(g_{\mu\nu}\right) \quad (156)$$


---



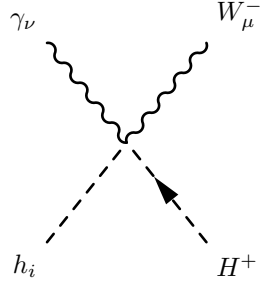
$$\frac{i}{2}g_2^2Z_{i1}^HZ_{j1}^H\left(g_{\mu\nu}\right) \quad (157)$$


---



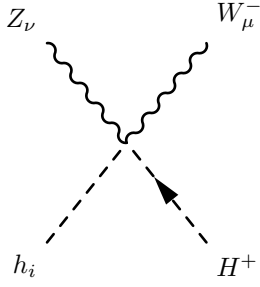
$$\frac{i}{2}\left(g_1\sin\Theta_W+g_2\cos\Theta_W\right)^2Z_{i1}^HZ_{j1}^H\left(g_{\mu\nu}\right) \quad (158)$$


---



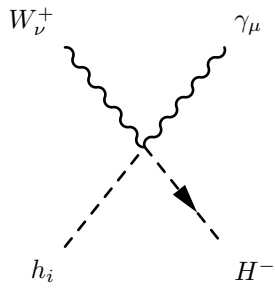
$$\frac{i}{2}g_1g_2\cos\Theta_W Z_{i1}^H(g_{\mu\nu}) \quad (159)$$


---



$$-\frac{i}{2}g_1g_2\sin\Theta_W Z_{i1}^H(g_{\mu\nu}) \quad (160)$$

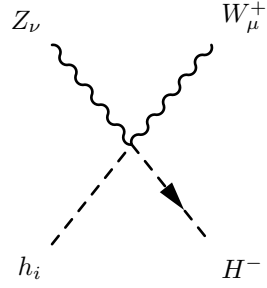

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$$\frac{i}{2}g_1g_2\cos\Theta_W Z_{i1}^H(g_{\mu\nu}) \quad (161)$$

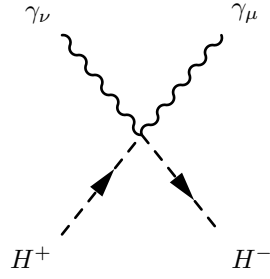

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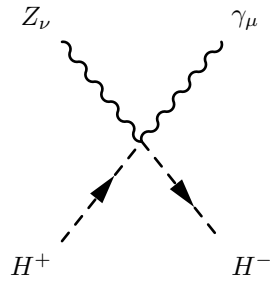
$$-\frac{i}{2}g_1g_2\sin\Theta_W Z_{i1}^H(g_{\mu\nu}) \quad (162)$$


---



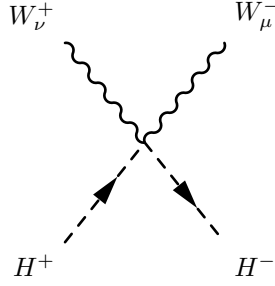
$$\frac{i}{2}\left(g_1\cos\Theta_W+g_2\sin\Theta_W\right)^2\left(g_{\mu\nu}\right) \quad (163)$$


---



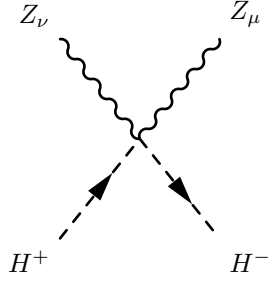
$$-\frac{i}{4}\left(-2g_1g_2\cos2\Theta_W+\left(-g_2^2+g_1^2\right)\sin2\Theta_W\right)\left(g_{\mu\nu}\right) \quad (164)$$


---



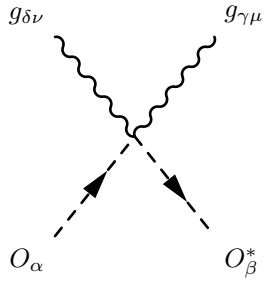
$$\frac{i}{2}g_2^2(g_{\mu\nu}) \quad (165)$$


---



$$\frac{i}{2}\left(-g_1\sin\Theta_W + g_2\cos\Theta_W\right)^2(g_{\mu\nu}) \quad (166)$$

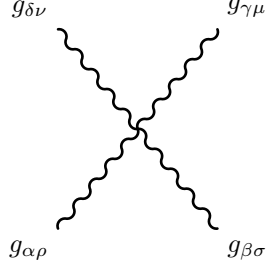

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$$ig_3^2\left(\sum_{a=1}^8 f_{\alpha,\delta,a}f_{\beta,\gamma,a} + \sum_{a=1}^8 f_{\alpha,\gamma,a}f_{\beta,\delta,a}\right)(g_{\mu\nu}) \quad (167)$$


---

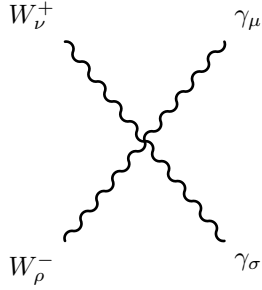
## 9.9 Four Vector Boson-Interaction



$$-ig_3^2 \left( \sum_{a=1}^8 f_{\alpha,\delta,a} f_{\beta,\gamma,a} + \sum_{a=1}^8 f_{\alpha,\gamma,a} f_{\beta,\delta,a} \right) (g_{\rho\sigma} g_{\mu\nu}) \quad (168)$$

$$+ ig_3^2 \left( - \sum_{a=1}^8 f_{\alpha,\beta,a} f_{\gamma,\delta,a} + \sum_{a=1}^8 f_{\alpha,\delta,a} f_{\beta,\gamma,a} \right) (g_{\rho\mu} g_{\sigma\nu}) \quad (169)$$

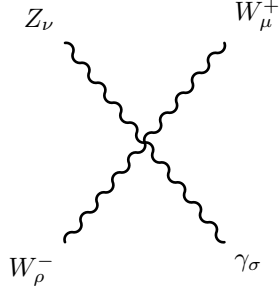
$$+ ig_3^2 \left( \sum_{a=1}^8 f_{\alpha,\gamma,a} f_{\beta,\delta,a} + \sum_{a=1}^8 f_{\alpha,\beta,a} f_{\gamma,\delta,a} \right) (g_{\rho\nu} g_{\sigma\mu}) \quad (170)$$



$$ig_2^2 \sin \Theta_W^2 (g_{\rho\sigma} g_{\mu\nu}) \quad (171)$$

$$+ ig_2^2 \sin \Theta_W^2 (g_{\rho\mu} g_{\sigma\nu}) \quad (172)$$

$$+ -2ig_2^2 \sin \Theta_W^2 (g_{\rho\nu} g_{\sigma\mu}) \quad (173)$$

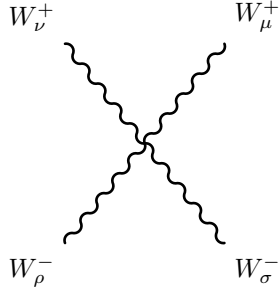


$$ig_2^2 \cos \Theta_W \sin \Theta_W (g_{\rho\sigma} g_{\mu\nu}) \quad (174)$$

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

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


---

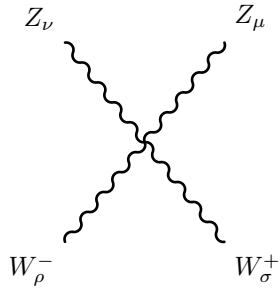


$$2ig_2^2 (g_{\rho\sigma} g_{\mu\nu}) \quad (177)$$

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

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


---

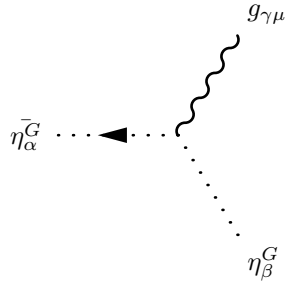


$$- 2ig_2^2 \cos \Theta_W^2 (g_{\rho\sigma} g_{\mu\nu}) \quad (180)$$

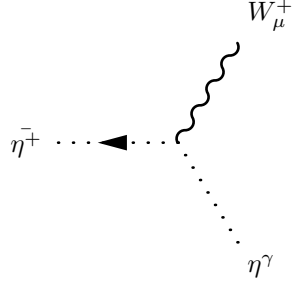
$$+ ig_2^2 \cos \Theta_W^2 (g_{\rho\mu} g_{\sigma\nu}) \quad (181)$$

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

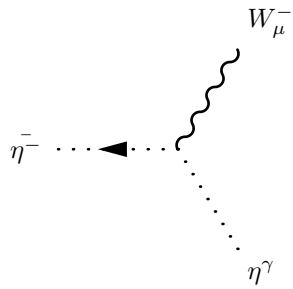
### 9.10 Two Ghosts-One Vector Boson-Interaction



$$g_3 f_{\alpha,\beta,\gamma} (p_\mu^{\eta_\beta^G}) \quad (183)$$

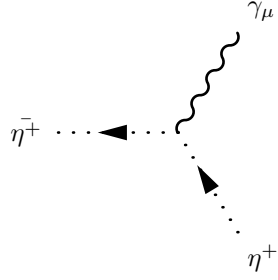


$$- ig_2 \sin \Theta_W (p_\mu^{\eta^\gamma}) \quad (184)$$



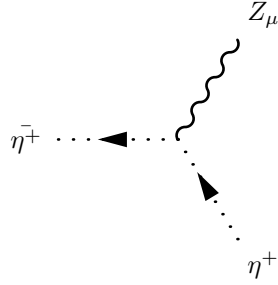
$$ig_2 \sin \Theta_W \left( p_\mu^{\eta^\gamma} \right) \quad (185)$$


---



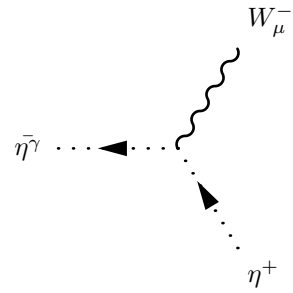
$$ig_2 \sin \Theta_W \left( p_\mu^{\eta^+} \right) \quad (186)$$


---



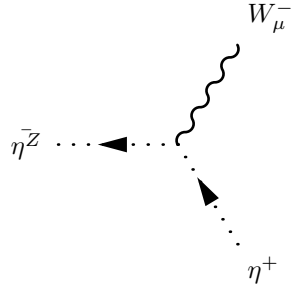
$$ig_2 \cos \Theta_W \left( p_\mu^{\eta^+} \right) \quad (187)$$


---



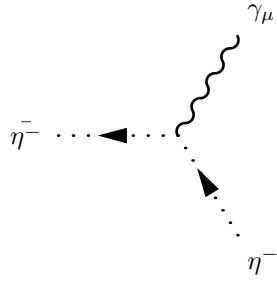
$$-ig_2 \sin \Theta_W \left( p_\mu^{\eta^+} \right) \quad (188)$$


---



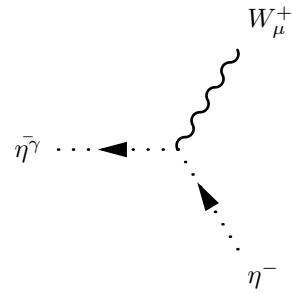
$$-ig_2 \cos \Theta_W (p_\mu^{\eta^+}) \quad (189)$$


---



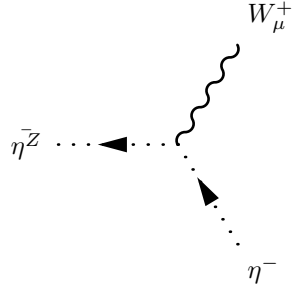
$$-ig_2 \sin \Theta_W (p_\mu^{\eta^-}) \quad (190)$$


---



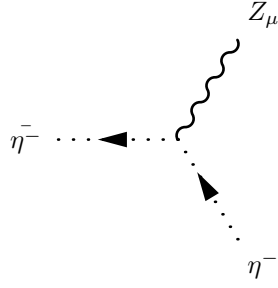
$$ig_2 \sin \Theta_W (p_\mu^{\eta^-}) \quad (191)$$


---



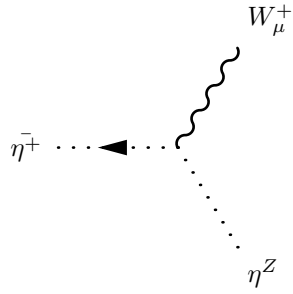
$$ig_2 \cos \Theta_W (p_\mu^{\eta^-}) \quad (192)$$


---



$$-ig_2 \cos \Theta_W (p_\mu^{\eta^-}) \quad (193)$$

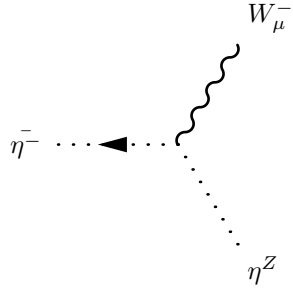

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$$-ig_2 \cos \Theta_W (p_\mu^{\eta^Z}) \quad (194)$$


---

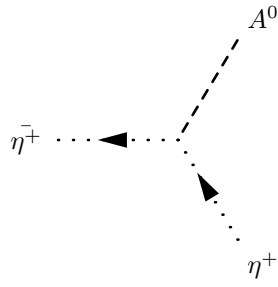




$$ig_2 \cos \Theta_W \left( p_\mu^{\eta^Z} \right) \quad (195)$$

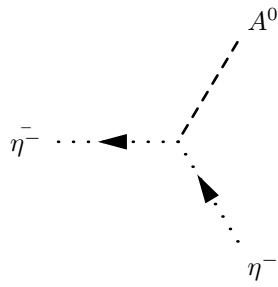

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### 9.11 Two Ghosts-One Scalar-Interaction



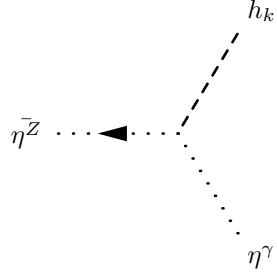
$$\frac{1}{4} g_2^2 v \xi_{W^+} \quad (196)$$


---



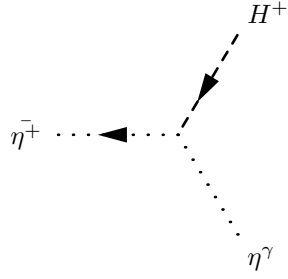
$$-\frac{1}{4} g_2^2 v \xi_{W^+} \quad (197)$$


---



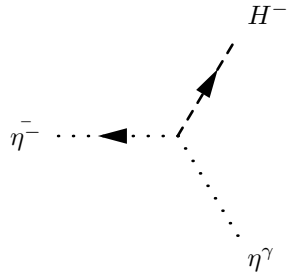
$$\frac{i}{8} v \xi_Z \left( 2g_1 g_2 \cos 2\Theta_W + \left( -g_2^2 + g_1^2 \right) \sin 2\Theta_W \right) Z_{k1}^H \quad (198)$$


---



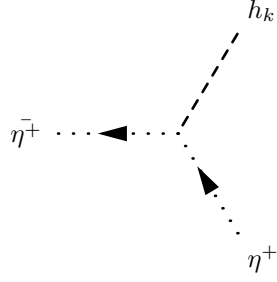
$$-\frac{i}{4} g_2 v \xi_{W^+} \left( g_1 \cos \Theta_W + g_2 \sin \Theta_W \right) \quad (199)$$


---



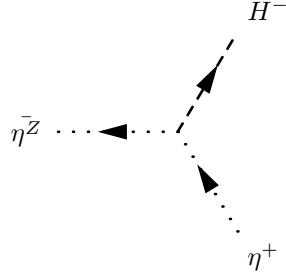
$$-\frac{i}{4} g_2 v \xi_{W^+} \left( g_1 \cos \Theta_W + g_2 \sin \Theta_W \right) \quad (200)$$


---



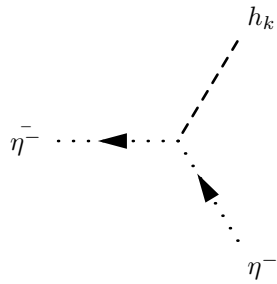
$$-\frac{i}{4}g_2^2v\xi_{W^+}Z_{k1}^H \quad (201)$$


---



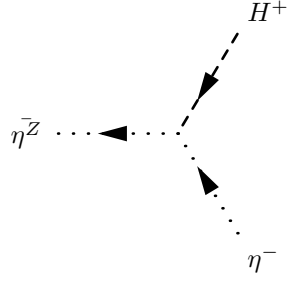
$$\frac{i}{4}g_2v\xi_Z\left(g_1\sin\Theta_W+g_2\cos\Theta_W\right) \quad (202)$$


---



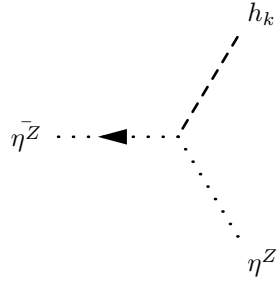
$$-\frac{i}{4}g_2^2v\xi_{W^+}Z_{k1}^H \quad (203)$$


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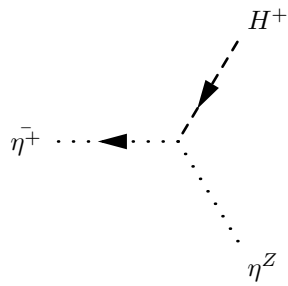
$$\frac{i}{4}g_2v\xi_Z\left(g_1\sin\Theta_W+g_2\cos\Theta_W\right) \quad (204)$$


---



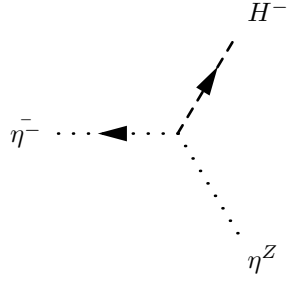
$$-\frac{i}{4}v\xi_Z\left(g_1\sin\Theta_W+g_2\cos\Theta_W\right)^2Z_{k1}^H \quad (205)$$


---



$$-\frac{i}{4}g_2v\xi_{W+}\left(-g_1\sin\Theta_W+g_2\cos\Theta_W\right) \quad (206)$$


---



$$-\frac{i}{4}g_2v\xi_{W^+}\left(-g_1\sin\Theta_W+g_2\cos\Theta_W\right) \tag{207}$$

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## 10 Clebsch-Gordan Coefficients