

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

## 1.2 Matter Superfields

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

# 2 Lagrangian

## 2.1 Input Lagrangian for Eigenstates GaugeES

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

## 2.2 Gauge fixing terms

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

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

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

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

## 2.3 Fields integrated out

None

### 3 Renormalization Group Equations

#### 3.1 Gauge Couplings

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

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

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

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

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

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

#### 3.2 Quartic scalar couplings

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

$$\begin{aligned} \beta_\lambda^{(2)} = & -\frac{3411}{1000} g_1^6 - \frac{1677}{200} g_1^4 g_2^2 - \frac{289}{40} g_1^2 g_2^4 + \frac{305}{8} g_2^6 + \frac{1887}{200} g_1^4 \lambda + \frac{117}{20} g_1^2 g_2^2 \lambda - \frac{73}{8} g_2^4 \lambda + \frac{54}{5} g_1^2 \lambda^2 + 54 g_2^2 \lambda^2 \\ & - 78 \lambda^3 + \frac{1}{10} \left( 225 g_2^2 \lambda - 45 g_2^4 + 80 (10 g_3^2 - 9 \lambda) \lambda + 9 g_1^4 + g_1^2 (25 \lambda + 54 g_2^2) \right) \text{Tr}(Y_d Y_d^\dagger) \\ & - \frac{3}{10} \left( 15 g_1^4 + 5 (16 \lambda^2 - 5 g_2^2 \lambda + g_2^4) - g_1^2 (22 g_2^2 + 25 \lambda) \right) \text{Tr}(Y_e Y_e^\dagger) - \frac{171}{50} g_1^4 \text{Tr}(Y_u Y_u^\dagger) \\ & + \frac{63}{5} g_1^2 g_2^2 \text{Tr}(Y_u Y_u^\dagger) - \frac{9}{2} g_2^4 \text{Tr}(Y_u Y_u^\dagger) + \frac{17}{2} g_1^2 \lambda \text{Tr}(Y_u Y_u^\dagger) + \frac{45}{2} g_2^2 \lambda \text{Tr}(Y_u Y_u^\dagger) \\ & + 80 g_3^2 \lambda \text{Tr}(Y_u Y_u^\dagger) - 72 \lambda^2 \text{Tr}(Y_u Y_u^\dagger) + \frac{8}{5} g_1^2 \text{Tr}(Y_d Y_d^\dagger Y_d Y_d^\dagger) - 64 g_3^2 \text{Tr}(Y_d Y_d^\dagger Y_d Y_d^\dagger) \\ & - 3 \lambda \text{Tr}(Y_d Y_d^\dagger Y_d Y_d^\dagger) - 42 \lambda \text{Tr}(Y_d Y_u^\dagger Y_u Y_d^\dagger) - \frac{24}{5} g_1^2 \text{Tr}(Y_e Y_e^\dagger Y_e Y_e^\dagger) - \lambda \text{Tr}(Y_e Y_e^\dagger Y_e Y_e^\dagger) \\ & - \frac{16}{5} g_1^2 \text{Tr}(Y_u Y_u^\dagger Y_u Y_u^\dagger) - 64 g_3^2 \text{Tr}(Y_u Y_u^\dagger Y_u Y_u^\dagger) - 3 \lambda \text{Tr}(Y_u Y_u^\dagger Y_u Y_u^\dagger) + 60 \text{Tr}(Y_d Y_d^\dagger Y_d Y_d^\dagger Y_d Y_d^\dagger) \\ & + 12 \text{Tr}(Y_d Y_d^\dagger Y_d Y_u^\dagger Y_u Y_d^\dagger) - 24 \text{Tr}(Y_d Y_u^\dagger Y_u Y_d^\dagger Y_d Y_d^\dagger) - 12 \text{Tr}(Y_d Y_u^\dagger Y_u Y_u^\dagger Y_u Y_d^\dagger) \\ & + 20 \text{Tr}(Y_e Y_e^\dagger Y_e Y_e^\dagger Y_e Y_e^\dagger) + 60 \text{Tr}(Y_u Y_u^\dagger Y_u Y_u^\dagger Y_u Y_u^\dagger) \end{aligned} \quad (11)$$

### 3.3 Yukawa Couplings

$$\begin{aligned}\beta_{Y_u}^{(1)} = & -\frac{3}{2} \left( -Y_u Y_u^\dagger Y_u + Y_u Y_d^\dagger Y_d \right) \\ & + Y_u \left( 3\text{Tr}(Y_d Y_d^\dagger) + 3\text{Tr}(Y_u Y_u^\dagger) - 8g_3^2 - \frac{17}{20}g_1^2 - \frac{9}{4}g_2^2 + \text{Tr}(Y_e Y_e^\dagger) \right)\end{aligned}\quad (12)$$

$$\begin{aligned}\beta_{Y_u}^{(2)} = & +\frac{1}{80} \left( 20 \left( 11Y_u Y_d^\dagger Y_d Y_d^\dagger Y_d - 4Y_u Y_u^\dagger Y_u Y_d^\dagger Y_d + 6Y_u Y_u^\dagger Y_u Y_u^\dagger Y_u - Y_u Y_d^\dagger Y_d Y_u^\dagger Y_u \right) \right. \\ & + Y_u Y_u^\dagger Y_u \left( 1280g_3^2 - 180\text{Tr}(Y_e Y_e^\dagger) + 223g_1^2 - 480\lambda - 540\text{Tr}(Y_d Y_d^\dagger) - 540\text{Tr}(Y_u Y_u^\dagger) + 675g_2^2 \right) \\ & + Y_u Y_d^\dagger Y_d \left( 100\text{Tr}(Y_e Y_e^\dagger) - 1280g_3^2 + 300\text{Tr}(Y_d Y_d^\dagger) + 300\text{Tr}(Y_u Y_u^\dagger) - 43g_1^2 + 45g_2^2 \right) \\ & + \frac{1}{600} Y_u \left( 1187g_1^4 - 270g_1^2 g_2^2 - 3450g_2^4 + 760g_1^2 g_3^2 + 5400g_2^2 g_3^2 - 64800g_3^4 + 900\lambda^2 \right. \\ & + 375 \left( 32g_3^2 + 9g_2^2 + g_1^2 \right) \text{Tr}(Y_d Y_d^\dagger) + 1125 \left( g_1^2 + g_2^2 \right) \text{Tr}(Y_e Y_e^\dagger) + 1275g_1^2 \text{Tr}(Y_u Y_u^\dagger) \\ & + 3375g_2^2 \text{Tr}(Y_u Y_u^\dagger) + 12000g_3^2 \text{Tr}(Y_u Y_u^\dagger) - 4050\text{Tr}(Y_d Y_d^\dagger Y_d Y_d^\dagger) + 900\text{Tr}(Y_d Y_u^\dagger Y_u Y_d^\dagger) \\ & \left. - 1350\text{Tr}(Y_e Y_e^\dagger Y_e Y_e^\dagger) - 4050\text{Tr}(Y_u Y_u^\dagger Y_u Y_u^\dagger) \right)\end{aligned}\quad (13)$$

$$\begin{aligned}\beta_{Y_d}^{(1)} = & \frac{1}{4} \left( 6 \left( -Y_d Y_u^\dagger Y_u + Y_d Y_d^\dagger Y_d \right) \right. \\ & \left. - Y_d \left( -12\text{Tr}(Y_d Y_d^\dagger) - 12\text{Tr}(Y_u Y_u^\dagger) + 32g_3^2 - 4\text{Tr}(Y_e Y_e^\dagger) + 9g_2^2 + g_1^2 \right) \right)\end{aligned}\quad (14)$$

$$\begin{aligned}\beta_{Y_d}^{(2)} = & +\frac{1}{80} \left( 20 \left( 11Y_d Y_u^\dagger Y_u Y_u^\dagger Y_u - 4Y_d Y_d^\dagger Y_d Y_u^\dagger Y_u + 6Y_d Y_d^\dagger Y_d Y_d^\dagger Y_d - Y_d Y_u^\dagger Y_u Y_d^\dagger Y_d \right) \right. \\ & + Y_d Y_d^\dagger Y_d \left( 1280g_3^2 - 180\text{Tr}(Y_e Y_e^\dagger) + 187g_1^2 - 480\lambda - 540\text{Tr}(Y_d Y_d^\dagger) - 540\text{Tr}(Y_u Y_u^\dagger) + 675g_2^2 \right) \\ & + Y_d Y_u^\dagger Y_u \left( 100\text{Tr}(Y_e Y_e^\dagger) - 1280g_3^2 + 300\text{Tr}(Y_d Y_d^\dagger) + 300\text{Tr}(Y_u Y_u^\dagger) + 45g_2^2 - 79g_1^2 \right) \\ & + Y_d \left( -\frac{127}{600}g_1^4 - \frac{27}{20}g_1^2 g_2^2 - \frac{23}{4}g_2^4 + \frac{31}{15}g_1^2 g_3^2 + 9g_2^2 g_3^2 - 108g_3^4 + \frac{3}{2}\lambda^2 \right. \\ & + \frac{5}{8} \left( 32g_3^2 + 9g_2^2 + g_1^2 \right) \text{Tr}(Y_d Y_d^\dagger) + \frac{15}{8} \left( g_1^2 + g_2^2 \right) \text{Tr}(Y_e Y_e^\dagger) + \frac{17}{8}g_1^2 \text{Tr}(Y_u Y_u^\dagger) + \frac{45}{8}g_2^2 \text{Tr}(Y_u Y_u^\dagger) \\ & \left. + 20g_3^2 \text{Tr}(Y_u Y_u^\dagger) - \frac{27}{4}\text{Tr}(Y_d Y_d^\dagger Y_d Y_d^\dagger) + \frac{3}{2}\text{Tr}(Y_d Y_u^\dagger Y_u Y_d^\dagger) - \frac{9}{4}\text{Tr}(Y_e Y_e^\dagger Y_e Y_e^\dagger) - \frac{27}{4}\text{Tr}(Y_u Y_u^\dagger Y_u Y_u^\dagger) \right)\end{aligned}\quad (15)$$

$$\beta_{Y_e}^{(1)} = \frac{3}{2} Y_e Y_e^\dagger Y_e + Y_e \left( 3\text{Tr}(Y_d Y_d^\dagger) + 3\text{Tr}(Y_u Y_u^\dagger) - \frac{9}{4}g_1^2 - \frac{9}{4}g_2^2 + \text{Tr}(Y_e Y_e^\dagger) \right)\quad (16)$$

$$\begin{aligned}\beta_{Y_e}^{(2)} = & \frac{1}{400} \left( 15 \left( 40Y_e Y_e^\dagger Y_e Y_e^\dagger Y_e \right. \right. \\ & + Y_e Y_e^\dagger Y_e \left( 129g_1^2 - 160\lambda - 180\text{Tr}(Y_d Y_d^\dagger) - 180\text{Tr}(Y_u Y_u^\dagger) + 225g_2^2 - 60\text{Tr}(Y_e Y_e^\dagger) \right) \\ & + Y_e \left( 2742g_1^4 + 540g_1^2 g_2^2 - 2300g_2^4 + 600\lambda^2 + 250 \left( 32g_3^2 + 9g_2^2 + g_1^2 \right) \text{Tr}(Y_d Y_d^\dagger) \right. \\ & + 750 \left( g_1^2 + g_2^2 \right) \text{Tr}(Y_e Y_e^\dagger) + 850g_1^2 \text{Tr}(Y_u Y_u^\dagger) + 2250g_2^2 \text{Tr}(Y_u Y_u^\dagger) + 8000g_3^2 \text{Tr}(Y_u Y_u^\dagger) \\ & \left. \left. - 2700\text{Tr}(Y_d Y_d^\dagger Y_d Y_d^\dagger) + 600\text{Tr}(Y_d Y_u^\dagger Y_u Y_d^\dagger) - 900\text{Tr}(Y_e Y_e^\dagger Y_e Y_e^\dagger) - 2700\text{Tr}(Y_u Y_u^\dagger Y_u Y_u^\dagger) \right) \right)\end{aligned}\quad (17)$$

### 3.4 Scalar Mass Terms

$$\beta_\mu^{(1)} = 2\mu\text{Tr}(Y_e Y_e^\dagger) + 6\mu\lambda + 6\mu\text{Tr}(Y_d Y_d^\dagger) + 6\mu\text{Tr}(Y_u Y_u^\dagger) - \frac{9}{10}g_1^2\mu - \frac{9}{2}g_2^2\mu \quad (18)$$

$$\begin{aligned} \beta_\mu^{(2)} = & \frac{1}{400}\mu\left(1671g_1^4 + 450g_1^2g_2^2 - 3625g_2^4 + 2880g_1^2\lambda + 14400g_2^2\lambda - 6000\lambda^2\right. \\ & + 100\left(-144\lambda + 160g_3^2 + 45g_2^2 + 5g_1^2\right)\text{Tr}(Y_d Y_d^\dagger) + 300\left(-16\lambda + 5g_1^2 + 5g_2^2\right)\text{Tr}(Y_e Y_e^\dagger) \\ & + 1700g_1^2\text{Tr}(Y_u Y_u^\dagger) + 4500g_2^2\text{Tr}(Y_u Y_u^\dagger) + 16000g_3^2\text{Tr}(Y_u Y_u^\dagger) - 14400\lambda\text{Tr}(Y_u Y_u^\dagger) \\ & \left. - 5400\text{Tr}(Y_d Y_d^\dagger Y_d Y_d^\dagger) - 8400\text{Tr}(Y_d Y_u^\dagger Y_u Y_d^\dagger) - 1800\text{Tr}(Y_e Y_e^\dagger Y_e Y_e^\dagger) - 5400\text{Tr}(Y_u Y_u^\dagger Y_u Y_u^\dagger)\right) \end{aligned} \quad (19)$$

### 3.5 Vacuum expectation values

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

$$\begin{aligned} \beta_v^{(2)} = & \frac{1}{800}v\left(-1293g_1^4 - 270g_1^2g_2^2 + 6775g_2^4 + 18g_1^4\text{Xi} + 180g_1^2g_2^2\text{Xi} + 2250g_2^4\text{Xi} + 18g_1^4\text{Xi}^2 + 180g_1^2g_2^2\text{Xi}^2\right. \\ & - 450g_2^4\text{Xi}^2 - 1200\lambda^2 - 20\left(45g_2^2(2\text{Xi} + 5) + 800g_3^2 + g_1^2(18\text{Xi} + 25)\right)\text{Tr}(Y_d Y_d^\dagger) \\ & - 60\left(5g_2^2(2\text{Xi} + 5) + g_1^2(2\text{Xi} + 25)\right)\text{Tr}(Y_e Y_e^\dagger) - 1700g_1^2\text{Tr}(Y_u Y_u^\dagger) - 4500g_2^2\text{Tr}(Y_u Y_u^\dagger) \\ & - 16000g_3^2\text{Tr}(Y_u Y_u^\dagger) - 360g_1^2\text{Xi}\text{Tr}(Y_u Y_u^\dagger) - 1800g_2^2\text{Xi}\text{Tr}(Y_u Y_u^\dagger) + 5400\text{Tr}(Y_d Y_d^\dagger Y_d Y_d^\dagger) \\ & \left. - 1200\text{Tr}(Y_d Y_u^\dagger Y_u Y_d^\dagger) + 1800\text{Tr}(Y_e Y_e^\dagger Y_e Y_e^\dagger) + 5400\text{Tr}(Y_u Y_u^\dagger Y_u Y_u^\dagger)\right) \end{aligned} \quad (21)$$

## 4 Field Rotations

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

$$\begin{pmatrix} B_\rho \\ W_{3\rho} \end{pmatrix} = Z^{\gamma Z} \begin{pmatrix} \gamma_\rho \\ Z_\rho \end{pmatrix} \quad (22)$$

$$\begin{pmatrix} W_{1\rho} \\ W_{2\rho} \end{pmatrix} = Z^W \begin{pmatrix} W_\rho^+ \\ W_\rho^- \end{pmatrix} \quad (23)$$

$$(24)$$

The mixing matrices are parametrized by

$$Z^{\gamma Z} = \begin{pmatrix} \cos \Theta_W & -\sin \Theta_W \\ \sin \Theta_W & \cos \Theta_W \end{pmatrix} \quad (25)$$

$$Z^W = \begin{pmatrix} \frac{1}{\sqrt{2}} & \frac{1}{\sqrt{2}} \\ i\frac{1}{\sqrt{2}} & -i\frac{1}{\sqrt{2}} \end{pmatrix} \quad (26)$$

$$(27)$$

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

### 4.2.1 Mass Matrices for Scalars

- No Scalar Mixings

### 4.2.2 Mass Matrices for Fermions

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

$$m_d = \left( \frac{1}{\sqrt{2}} v \delta_{\alpha_1 \beta_1} Y_d^T \right) \quad (28)$$

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

$$U_L^{d,*} m_d U_R^{d,\dagger} = m_d^{dia} \quad (29)$$

with

$$d_{L,i\alpha} = \sum_{t_2} U_{L,ji}^{d,*} D_{L,j\alpha} \quad (30)$$

$$d_{R,i\alpha} = \sum_{t_2} U_{R,ij}^d D_{R,j\alpha}^* \quad (31)$$

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

$$m_u = \left( -\frac{1}{\sqrt{2}} v \delta_{\alpha_1 \beta_1} Y_u^T \right) \quad (32)$$

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

$$U_L^{u,*} m_u U_R^{u,\dagger} = m_u^{dia} \quad (33)$$

with

$$u_{L,i\alpha} = \sum_{t_2} U_{L,ji}^{u,*} U_{L,j\alpha} \quad (34)$$

$$u_{R,i\alpha} = \sum_{t_2} U_{R,ij}^u U_{R,j\alpha}^* \quad (35)$$



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

$$m_e = \left( \frac{1}{\sqrt{2}} v Y_e^T \right) \quad (36)$$

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

$$U_L^{e,*} m_e U_R^{e,\dagger} = m_e^{dia} \quad (37)$$

with

$$e_{L,i} = \sum_{t_2} U_{L,ji}^{e,*} E_{L,j} \quad (38)$$

$$e_{R,i} = \sum_{t_2} U_{R,ij}^e E_{R,j}^* \quad (39)$$

## 5 Vacuum Expectation Values

$$H^0 = \frac{1}{\sqrt{2}} h + \frac{1}{\sqrt{2}} v + i \frac{1}{\sqrt{2}} A^0 \quad (40)$$

## 6 Tadpole Equations

$$\frac{\partial V}{\partial h} = \frac{1}{2} v^3 \lambda - \mu v \quad (41)$$

## 7 Particle content for eigenstates 'EWSB'

Name	Type	complex/real	Generations	Indices
$H^+$	Scalar	complex	1	
$A^0$	Scalar	real	1	
$h$	Scalar	real	1	
$\nu$	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 Down-Quarks ( $d$ )

$$\begin{aligned}
\Sigma_{i,j}^S(p^2) = & + \sum_{a=1}^3 B_0(p^2, m_{d_a}^2, m_{A^0}^2) \Gamma_{\check{d}_j, d_a, A^0}^{L*} m_{d_a} \Gamma_{\check{d}_i, d_a, A^0}^R + \sum_{b=1}^3 B_0(p^2, m_{d_b}^2, m_h^2) \Gamma_{\check{d}_j, h, d_b}^{L*} m_{d_b} \Gamma_{\check{d}_i, h, d_b}^R \\
& - \frac{16}{3} \sum_{b=1}^3 \left( -\frac{1}{2} \text{rMS} + B_0(p^2, m_{d_b}^2, 0) \right) \Gamma_{\check{d}_j, g, d_b}^{R*} m_{d_b} \Gamma_{\check{d}_i, g, d_b}^L - 4 \sum_{b=1}^3 \left( -\frac{1}{2} \text{rMS} + B_0(p^2, m_{d_b}^2, 0) \right) \Gamma_{\check{d}_j, \gamma, d_b}^{R*} m_{d_b} \Gamma_{\check{d}_i, \gamma, d_b}^L \\
& - 4 \sum_{b=1}^3 \left( -\frac{1}{2} \text{rMS} + B_0(p^2, m_{d_b}^2, m_Z^2) \right) \Gamma_{\check{d}_j, Z, d_b}^{R*} m_{d_b} \Gamma_{\check{d}_i, Z, d_b}^L \\
& + \sum_{b=1}^3 B_0(p^2, m_{u_b}^2, m_{H^+}^2) \Gamma_{\check{d}_j, H^-, u_b}^{L*} m_{u_b} \Gamma_{\check{d}_i, H^-, u_b}^R \\
& - 4 \sum_{b=1}^3 \left( -\frac{1}{2} \text{rMS} + B_0(p^2, m_{u_b}^2, m_{W^+}^2) \right) \Gamma_{\check{d}_j, W^-, u_b}^{R*} m_{u_b} \Gamma_{\check{d}_i, W^-, u_b}^L
\end{aligned} \tag{42}$$

$$\begin{aligned}
\Sigma_{i,j}^R(p^2) = & -\frac{1}{2} \sum_{a=1}^3 B_1(p^2, m_{d_a}^2, m_{A^0}^2) \Gamma_{\check{d}_j, d_a, A^0}^{R*} \Gamma_{\check{d}_i, d_a, A^0}^R - \frac{1}{2} \sum_{b=1}^3 B_1(p^2, m_{d_b}^2, m_h^2) \Gamma_{\check{d}_j, h, d_b}^{R*} \Gamma_{\check{d}_i, h, d_b}^R \\
& - \frac{4}{3} \sum_{b=1}^3 B_1(p^2, m_{d_b}^2, 0) \Gamma_{\check{d}_j, g, d_b}^{L*} \Gamma_{\check{d}_i, g, d_b}^L - \sum_{b=1}^3 B_1(p^2, m_{d_b}^2, 0) \Gamma_{\check{d}_j, \gamma, d_b}^{L*} \Gamma_{\check{d}_i, \gamma, d_b}^L \\
& - \sum_{b=1}^3 B_1(p^2, m_{d_b}^2, m_Z^2) \Gamma_{\check{d}_j, Z, d_b}^{L*} \Gamma_{\check{d}_i, Z, d_b}^L - \frac{1}{2} \sum_{b=1}^3 B_1(p^2, m_{u_b}^2, m_{H^+}^2) \Gamma_{\check{d}_j, H^-, u_b}^{R*} \Gamma_{\check{d}_i, H^-, u_b}^R \\
& - \sum_{b=1}^3 B_1(p^2, m_{u_b}^2, m_{W^+}^2) \Gamma_{\check{d}_j, W^-, u_b}^{L*} \Gamma_{\check{d}_i, W^-, u_b}^L
\end{aligned} \tag{43}$$

$$\Sigma_{i,j}^L(p^2) = -\frac{1}{2} \sum_{a=1}^3 B_1(p^2, m_{d_a}^2, m_{A^0}^2) \Gamma_{\check{d}_j, d_a, A^0}^{L*} \Gamma_{\check{d}_i, d_a, A^0}^L - \frac{1}{2} \sum_{b=1}^3 B_1(p^2, m_{d_b}^2, m_h^2) \Gamma_{\check{d}_j, h, d_b}^{L*} \Gamma_{\check{d}_i, h, d_b}^L$$

$$\begin{aligned}
& -\frac{4}{3} \sum_{b=1}^3 B_1(p^2, m_{d_b}^2, 0) \Gamma_{\tilde{d}_j, g, d_b}^{R*} \Gamma_{\tilde{d}_i, g, d_b}^R - \sum_{b=1}^3 B_1(p^2, m_{d_b}^2, 0) \Gamma_{\tilde{d}_j, \gamma, d_b}^{R*} \Gamma_{\tilde{d}_i, \gamma, d_b}^R \\
& - \sum_{b=1}^3 B_1(p^2, m_{d_b}^2, m_Z^2) \Gamma_{\tilde{d}_j, Z, d_b}^{R*} \Gamma_{\tilde{d}_i, Z, d_b}^R - \frac{1}{2} \sum_{b=1}^3 B_1(p^2, m_{u_b}^2, m_{H^+}^2) \Gamma_{\tilde{d}_j, H^-, u_b}^{L*} \Gamma_{\tilde{d}_i, H^-, u_b}^L \\
& - \sum_{b=1}^3 B_1(p^2, m_{u_b}^2, m_{W^+}^2) \Gamma_{\tilde{d}_j, W^-, u_b}^{R*} \Gamma_{\tilde{d}_i, W^-, u_b}^R
\end{aligned} \tag{44}$$

• Self-Energy for Up-Quarks ( $u$ )

$$\begin{aligned}
\Sigma_{i,j}^S(p^2) = & + \sum_{a=1}^3 B_0(p^2, m_{u_a}^2, m_{A^0}^2) \Gamma_{\tilde{u}_j, u_a, A^0}^{L*} m_{u_a} \Gamma_{\tilde{u}_i, u_a, A^0}^R + \sum_{b=1}^3 B_0(p^2, m_{u_b}^2, m_h^2) \Gamma_{\tilde{u}_j, h, u_b}^{L*} m_{u_b} \Gamma_{\tilde{u}_i, h, u_b}^R \\
& + \sum_{b=1}^3 B_0(p^2, m_{d_b}^2, m_{H^+}^2) \Gamma_{\tilde{u}_j, H^+, d_b}^{L*} m_{d_b} \Gamma_{\tilde{u}_i, H^+, d_b}^R - \frac{16}{3} \sum_{b=1}^3 \left( -\frac{1}{2} \text{rMS} + B_0(p^2, m_{u_b}^2, 0) \right) \Gamma_{\tilde{u}_j, g, u_b}^{R*} m_{u_b} \Gamma_{\tilde{u}_i, g, u_b}^L \\
& - 4 \sum_{b=1}^3 \left( -\frac{1}{2} \text{rMS} + B_0(p^2, m_{u_b}^2, 0) \right) \Gamma_{\tilde{u}_j, \gamma, u_b}^{R*} m_{u_b} \Gamma_{\tilde{u}_i, \gamma, u_b}^L \\
& - 4 \sum_{b=1}^3 \left( -\frac{1}{2} \text{rMS} + B_0(p^2, m_{d_b}^2, m_{W^+}^2) \right) \Gamma_{\tilde{u}_j, W^+, d_b}^{R*} m_{d_b} \Gamma_{\tilde{u}_i, W^+, d_b}^L \\
& - 4 \sum_{b=1}^3 \left( -\frac{1}{2} \text{rMS} + B_0(p^2, m_{u_b}^2, m_Z^2) \right) \Gamma_{\tilde{u}_j, Z, u_b}^{R*} m_{u_b} \Gamma_{\tilde{u}_i, Z, u_b}^L
\end{aligned} \tag{45}$$

$$\begin{aligned}
\Sigma_{i,j}^R(p^2) = & -\frac{1}{2} \sum_{a=1}^3 B_1(p^2, m_{u_a}^2, m_{A^0}^2) \Gamma_{\tilde{u}_j, u_a, A^0}^{R*} \Gamma_{\tilde{u}_i, u_a, A^0}^R - \frac{1}{2} \sum_{b=1}^3 B_1(p^2, m_{u_b}^2, m_h^2) \Gamma_{\tilde{u}_j, h, u_b}^{R*} \Gamma_{\tilde{u}_i, h, u_b}^R \\
& - \frac{1}{2} \sum_{b=1}^3 B_1(p^2, m_{d_b}^2, m_{H^+}^2) \Gamma_{\tilde{u}_j, H^+, d_b}^{R*} \Gamma_{\tilde{u}_i, H^+, d_b}^R - \frac{4}{3} \sum_{b=1}^3 B_1(p^2, m_{u_b}^2, 0) \Gamma_{\tilde{u}_j, g, u_b}^{L*} \Gamma_{\tilde{u}_i, g, u_b}^L \\
& - \sum_{b=1}^3 B_1(p^2, m_{u_b}^2, 0) \Gamma_{\tilde{u}_j, \gamma, u_b}^{L*} \Gamma_{\tilde{u}_i, \gamma, u_b}^L - \sum_{b=1}^3 B_1(p^2, m_{d_b}^2, m_{W^+}^2) \Gamma_{\tilde{u}_j, W^+, d_b}^{L*} \Gamma_{\tilde{u}_i, W^+, d_b}^L \\
& - \sum_{b=1}^3 B_1(p^2, m_{u_b}^2, m_Z^2) \Gamma_{\tilde{u}_j, Z, u_b}^{L*} \Gamma_{\tilde{u}_i, Z, u_b}^L
\end{aligned} \tag{46}$$

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

$$\begin{aligned}
& - \sum_{b=1}^3 B_1(p^2, m_{u_b}^2, 0) \Gamma_{\tilde{u}_j, \gamma, u_b}^{R*} \Gamma_{\tilde{u}_i, \gamma, u_b}^R - \sum_{b=1}^3 B_1(p^2, m_{d_b}^2, m_{W^+}^2) \Gamma_{\tilde{u}_j, W^+, d_b}^{R*} \Gamma_{\tilde{u}_i, W^+, d_b}^R \\
& - \sum_{b=1}^3 B_1(p^2, m_{u_b}^2, m_Z^2) \Gamma_{\tilde{u}_j, Z, u_b}^{R*} \Gamma_{\tilde{u}_i, Z, u_b}^R
\end{aligned} \tag{47}$$

• **Self-Energy for Leptons ( $e$ )**

$$\begin{aligned}
\Sigma_{i,j}^S(p^2) = & + \sum_{a=1}^3 B_0(p^2, m_{e_a}^2, m_{A^0}^2) \Gamma_{\tilde{e}_j, e_a, A^0}^{L*} m_{e_a} \Gamma_{\tilde{e}_i, e_a, A^0}^R + \sum_{b=1}^3 B_0(p^2, m_{e_b}^2, m_h^2) \Gamma_{\tilde{e}_j, h, e_b}^{L*} m_{e_b} \Gamma_{\tilde{e}_i, h, e_b}^R \\
& - 4 \sum_{b=1}^3 \left( -\frac{1}{2} \text{rMS} + B_0(p^2, m_{e_b}^2, 0) \right) \Gamma_{\tilde{e}_j, \gamma, e_b}^{R*} m_{e_b} \Gamma_{\tilde{e}_i, \gamma, e_b}^L - 4 \sum_{b=1}^3 \left( -\frac{1}{2} \text{rMS} + B_0(p^2, m_{e_b}^2, m_Z^2) \right) \Gamma_{\tilde{e}_j, Z, e_b}^{R*} m_{e_b} \Gamma_{\tilde{e}_i, Z, e_b}^L \\
& + \sum_{b=1}^3 B_0(p^2, m_{\nu_b}^2, m_{H^+}^2) \Gamma_{\tilde{e}_j, H^-, \nu_b}^{L*} m_{\nu_b} \Gamma_{\tilde{e}_i, H^-, \nu_b}^R \\
& - 4 \sum_{b=1}^3 \left( -\frac{1}{2} \text{rMS} + B_0(p^2, m_{\nu_b}^2, m_{W^+}^2) \right) \Gamma_{\tilde{e}_j, W^-, \nu_b}^{R*} m_{\nu_b} \Gamma_{\tilde{e}_i, W^-, \nu_b}^L
\end{aligned} \tag{48}$$

$$\begin{aligned}
\Sigma_{i,j}^R(p^2) = & -\frac{1}{2} \sum_{a=1}^3 B_1(p^2, m_{e_a}^2, m_{A^0}^2) \Gamma_{\tilde{e}_j, e_a, A^0}^{R*} \Gamma_{\tilde{e}_i, e_a, A^0}^R - \frac{1}{2} \sum_{b=1}^3 B_1(p^2, m_{e_b}^2, m_h^2) \Gamma_{\tilde{e}_j, h, e_b}^{R*} \Gamma_{\tilde{e}_i, h, e_b}^R \\
& - \sum_{b=1}^3 B_1(p^2, m_{e_b}^2, 0) \Gamma_{\tilde{e}_j, \gamma, e_b}^{L*} \Gamma_{\tilde{e}_i, \gamma, e_b}^L - \sum_{b=1}^3 B_1(p^2, m_{e_b}^2, m_Z^2) \Gamma_{\tilde{e}_j, Z, e_b}^{L*} \Gamma_{\tilde{e}_i, Z, e_b}^L \\
& - \frac{1}{2} \sum_{b=1}^3 B_1(p^2, m_{\nu_b}^2, m_{H^+}^2) \Gamma_{\tilde{e}_j, H^-, \nu_b}^{R*} \Gamma_{\tilde{e}_i, H^-, \nu_b}^R - \sum_{b=1}^3 B_1(p^2, m_{\nu_b}^2, m_{W^+}^2) \Gamma_{\tilde{e}_j, W^-, \nu_b}^{L*} \Gamma_{\tilde{e}_i, W^-, \nu_b}^L
\end{aligned} \tag{49}$$

$$\begin{aligned}
\Sigma_{i,j}^L(p^2) = & -\frac{1}{2} \sum_{a=1}^3 B_1(p^2, m_{e_a}^2, m_{A^0}^2) \Gamma_{\tilde{e}_j, e_a, A^0}^{L*} \Gamma_{\tilde{e}_i, e_a, A^0}^L - \frac{1}{2} \sum_{b=1}^3 B_1(p^2, m_{e_b}^2, m_h^2) \Gamma_{\tilde{e}_j, h, e_b}^{L*} \Gamma_{\tilde{e}_i, h, e_b}^L \\
& - \sum_{b=1}^3 B_1(p^2, m_{e_b}^2, 0) \Gamma_{\tilde{e}_j, \gamma, e_b}^{R*} \Gamma_{\tilde{e}_i, \gamma, e_b}^R - \sum_{b=1}^3 B_1(p^2, m_{e_b}^2, m_Z^2) \Gamma_{\tilde{e}_j, Z, e_b}^{R*} \Gamma_{\tilde{e}_i, Z, e_b}^R \\
& - \frac{1}{2} \sum_{b=1}^3 B_1(p^2, m_{\nu_b}^2, m_{H^+}^2) \Gamma_{\tilde{e}_j, H^-, \nu_b}^{L*} \Gamma_{\tilde{e}_i, H^-, \nu_b}^L - \sum_{b=1}^3 B_1(p^2, m_{\nu_b}^2, m_{W^+}^2) \Gamma_{\tilde{e}_j, W^-, \nu_b}^{R*} \Gamma_{\tilde{e}_i, W^-, \nu_b}^R
\end{aligned} \tag{50}$$

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

$$\begin{aligned}
\Pi(p^2) = & +4|\Gamma_{H^-, W^+, \gamma}|^2 \left( -\frac{1}{2} \text{rMS} + B_0(p^2, 0, m_{W^+}^2) \right) + |\Gamma_{H^-, H^+, h}|^2 B_0(p^2, m_{H^+}^2, m_h^2) + 4|\Gamma_{H^-, Z, W^+}|^2 \left( -\frac{1}{2} \text{rMS} + B_0(p^2, m_{H^+}^2, m_Z^2) \right) \\
& - B_0(p^2, m_{\eta^Z}^2, m_{\eta^-}^2) \Gamma_{H^+, \eta^-, \eta^Z} \Gamma_{H^-, \eta^-, \eta^Z} - B_0(p^2, m_{\eta^+}^2, m_{\eta^Z}^2) \Gamma_{H^+, \eta^Z, \eta^+} \Gamma_{H^-, \eta^Z, \eta^+}
\end{aligned}$$

$$\begin{aligned}
& -\frac{1}{2}A_0(m_{A^0}^2)\Gamma_{H^+,H^-,A^0,A^0} - \frac{1}{2}A_0(m_h^2)\Gamma_{H^+,H^-,h,h} - A_0(m_{H^+}^2)\Gamma_{H^+,H^-,H^-,H^+} \\
& + |\Gamma_{H^-,W^+,A^0}|^2 F_0(p^2, m_{A^0}^2, m_{W^+}^2) + |\Gamma_{H^-,W^+,h}|^2 F_0(p^2, m_h^2, m_{W^+}^2) + |\Gamma_{H^-, \gamma, H^+}|^2 F_0(p^2, m_{H^+}^2, 0) \\
& + |\Gamma_{H^-,Z,H^+}|^2 F_0(p^2, m_{H^+}^2, m_Z^2) + 4\Gamma_{H^+,H^-,W^-,W^+} \left( -\frac{1}{2}\text{rMS}m_{W^+}^2 + A_0(m_{W^+}^2) \right) \\
& + 2\Gamma_{H^+,H^-,Z,Z} \left( -\frac{1}{2}\text{rMS}m_Z^2 + A_0(m_Z^2) \right) + 3 \sum_{a=1}^3 \sum_{b=1}^3 \left( |\Gamma_{H^-, \bar{d}_a, u_b}^L|^2 + |\Gamma_{H^-, \bar{d}_a, u_b}^R|^2 \right) G_0(p^2, m_{d_a}^2, m_{u_b}^2) \\
& + \sum_{a=1}^3 \sum_{b=1}^3 \left( |\Gamma_{H^-, \bar{e}_a, \nu_b}^L|^2 + |\Gamma_{H^-, \bar{e}_a, \nu_b}^R|^2 \right) G_0(p^2, m_{e_a}^2, m_{\nu_b}^2) \\
& - 6 \sum_{a=1}^3 m_{d_a} \sum_{b=1}^3 B_0(p^2, m_{d_a}^2, m_{u_b}^2) m_{u_b} \left( \Gamma_{H^-, \bar{d}_a, u_b}^{L*} \Gamma_{H^-, \bar{d}_a, u_b}^R + \Gamma_{H^-, \bar{d}_a, u_b}^{R*} \Gamma_{H^-, \bar{d}_a, u_b}^L \right) \\
& - 2 \sum_{a=1}^3 m_{e_a} \sum_{b=1}^3 B_0(p^2, m_{e_a}^2, m_{\nu_b}^2) m_{\nu_b} \left( \Gamma_{H^-, \bar{e}_a, \nu_b}^{L*} \Gamma_{H^-, \bar{e}_a, \nu_b}^R + \Gamma_{H^-, \bar{e}_a, \nu_b}^{R*} \Gamma_{H^-, \bar{e}_a, \nu_b}^L \right) \tag{51}
\end{aligned}$$

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

$$\begin{aligned}
\Pi(p^2) = & +|\Gamma_{A^0,h,A^0}|^2 B_0(p^2, m_h^2, m_{A^0}^2) - B_0(p^2, m_{\eta^+}^2, m_{\eta^+}^2) \Gamma_{A^0, \eta^+, \eta^+}^2 - B_0(p^2, m_{\eta^-}^2, m_{\eta^-}^2) \Gamma_{A^0, \eta^-, \eta^-}^2 - \frac{1}{2}A_0(m_{A^0}^2) \Gamma_{A^0, A^0, A^0}, \\
& -\frac{1}{2}A_0(m_h^2) \Gamma_{A^0, A^0, h, h} - A_0(m_{H^+}^2) \Gamma_{A^0, A^0, H^-, H^+} + |\Gamma_{A^0, Z, h}|^2 F_0(p^2, m_h^2, m_Z^2) \\
& + 2|\Gamma_{A^0, W^-, H^+}|^2 F_0(p^2, m_{H^+}^2, m_{W^+}^2) + 4\Gamma_{A^0, A^0, W^-, W^+} \left( -\frac{1}{2}\text{rMS}m_{W^+}^2 + A_0(m_{W^+}^2) \right) + 2\Gamma_{A^0, A^0, Z, Z} \left( -\frac{1}{2}\text{rMS}m_Z^2 + A_0(m_Z^2) \right) \\
& + 3 \sum_{a=1}^3 \sum_{b=1}^3 \left( |\Gamma_{A^0, \bar{d}_a, d_b}^L|^2 + |\Gamma_{A^0, \bar{d}_a, d_b}^R|^2 \right) G_0(p^2, m_{d_a}^2, m_{d_b}^2) \\
& + \sum_{a=1}^3 \sum_{b=1}^3 \left( |\Gamma_{A^0, \bar{e}_a, e_b}^L|^2 + |\Gamma_{A^0, \bar{e}_a, e_b}^R|^2 \right) G_0(p^2, m_{e_a}^2, m_{e_b}^2) \\
& + 3 \sum_{a=1}^3 \sum_{b=1}^3 \left( |\Gamma_{A^0, \bar{u}_a, u_b}^L|^2 + |\Gamma_{A^0, \bar{u}_a, u_b}^R|^2 \right) G_0(p^2, m_{u_a}^2, m_{u_b}^2) \\
& - 6 \sum_{a=1}^3 m_{d_a} \sum_{b=1}^3 B_0(p^2, m_{d_a}^2, m_{d_b}^2) m_{d_b} \left( \Gamma_{A^0, \bar{d}_a, d_b}^{L*} \Gamma_{A^0, \bar{d}_a, d_b}^R + \Gamma_{A^0, \bar{d}_a, d_b}^{R*} \Gamma_{A^0, \bar{d}_a, d_b}^L \right) \\
& - 2 \sum_{a=1}^3 m_{e_a} \sum_{b=1}^3 B_0(p^2, m_{e_a}^2, m_{e_b}^2) m_{e_b} \left( \Gamma_{A^0, \bar{e}_a, e_b}^{L*} \Gamma_{A^0, \bar{e}_a, e_b}^R + \Gamma_{A^0, \bar{e}_a, e_b}^{R*} \Gamma_{A^0, \bar{e}_a, e_b}^L \right) \\
& - 6 \sum_{a=1}^3 m_{u_a} \sum_{b=1}^3 B_0(p^2, m_{u_a}^2, m_{u_b}^2) m_{u_b} \left( \Gamma_{A^0, \bar{u}_a, u_b}^{L*} \Gamma_{A^0, \bar{u}_a, u_b}^R + \Gamma_{A^0, \bar{u}_a, u_b}^{R*} \Gamma_{A^0, \bar{u}_a, u_b}^L \right) \tag{52}
\end{aligned}$$

• **Self-Energy for Higgs ( $h$ )**

$$\begin{aligned}
\Pi(p^2) = & +\frac{1}{2}|\Gamma_{h,A^0,A^0}|^2 B_0(p^2, m_{A^0}^2, m_{A^0}^2) + \frac{1}{2}|\Gamma_{h,h,h}|^2 B_0(p^2, m_h^2, m_h^2) + |\Gamma_{h,H^-,H^+}|^2 B_0(p^2, m_{H^+}^2, m_{H^+}^2) \\
& + 4|\Gamma_{h,W^-,W^+}|^2 \left( -\frac{1}{2}\text{rMS} + B_0(p^2, m_{W^+}^2, m_{W^+}^2) \right) + 2|\Gamma_{h,Z,Z}|^2 \left( -\frac{1}{2}\text{rMS} + B_0(p^2, m_Z^2, m_Z^2) \right) - B_0(p^2, m_{\eta^+}^2, m_{\eta^+}^2) \Gamma_{h,h}^2 \\
& - B_0(p^2, m_{\eta^-}^2, m_{\eta^-}^2) \Gamma_{h,\eta^-, \eta^-}^2 - B_0(p^2, m_{\eta^Z}^2, m_{\eta^Z}^2) \Gamma_{h,\eta^Z, \eta^Z}^2 - \frac{1}{2}A_0(m_{A^0}^2) \Gamma_{h,h,A^0,A^0} - \frac{1}{2}A_0(m_h^2) \Gamma_{h,h,h,h} \\
& - A_0(m_{H^+}^2) \Gamma_{h,h,H^-,H^+} + |\Gamma_{h,Z,A^0}|^2 F_0(p^2, m_{A^0}^2, m_Z^2) + 2|\Gamma_{h,W^-,H^+}|^2 F_0(p^2, m_{H^+}^2, m_{W^+}^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) \\
& + 3 \sum_{a=1}^3 \sum_{b=1}^3 \left( |\Gamma_{h,\bar{d}_a,d_b}^L|^2 + |\Gamma_{h,\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_{h,\bar{e}_a,e_b}^L|^2 + |\Gamma_{h,\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_{h,\bar{u}_a,u_b}^L|^2 + |\Gamma_{h,\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_{h,\bar{d}_a,d_b}^{L*} \Gamma_{h,\bar{d}_a,d_b}^R + \Gamma_{h,\bar{d}_a,d_b}^{R*} \Gamma_{h,\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_{h,\bar{e}_a,e_b}^{L*} \Gamma_{h,\bar{e}_a,e_b}^R + \Gamma_{h,\bar{e}_a,e_b}^{R*} \Gamma_{h,\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_{h,\bar{u}_a,u_b}^{L*} \Gamma_{h,\bar{u}_a,u_b}^R + \Gamma_{h,\bar{u}_a,u_b}^{R*} \Gamma_{h,\bar{u}_a,u_b}^L \right) \tag{53}
\end{aligned}$$

• **Self-Energy for Z-Boson** ( $Z$ )

$$\begin{aligned}
\Pi(p^2) = & +2|\Gamma_{Z,W^-,H^+}|^2 B_0(p^2, m_{W^+}^2, m_{H^+}^2) + |\Gamma_{Z,Z,h}|^2 B_0(p^2, m_Z^2, m_h^2) - 4|\Gamma_{Z,h,A^0}|^2 B_{00}(p^2, m_{A^0}^2, m_h^2) \\
& + |\Gamma_{Z,\eta^+, \eta^+}|^2 B_{00}(p^2, m_{\eta^+}^2, m_{\eta^+}^2) + |\Gamma_{Z,\eta^-, \eta^-}|^2 B_{00}(p^2, m_{\eta^-}^2, m_{\eta^-}^2) \\
& - 4|\Gamma_{Z,H^-,H^+}|^2 B_{00}(p^2, m_{H^+}^2, m_{H^+}^2) + \frac{1}{2}A_0(m_{A^0}^2) \Gamma_{Z,Z,A^0,A^0} + \frac{1}{2}A_0(m_h^2) \Gamma_{Z,Z,h,h} \\
& + A_0(m_{H^+}^2) \Gamma_{Z,Z,H^-,H^+} \\
& - |\Gamma_{Z,W^-,W^+}|^2 \left( 10B_{00}(p^2, m_{W^+}^2, m_{W^+}^2) + 2A_0(m_{W^+}^2) - 2\text{rMS}(2m_{W^+}^2 - \frac{1}{3}p^2) + B_0(p^2, m_{W^+}^2, m_{W^+}^2) (2m_{W^+}^2 + 4p^2) \right) \\
& + 3 \sum_{a=1}^3 \sum_{b=1}^3 \left[ \left( |\Gamma_{Z,\bar{d}_a,d_b}^L|^2 + |\Gamma_{Z,\bar{d}_a,d_b}^R|^2 \right) H_0(p^2, m_{d_a}^2, m_{d_b}^2) \right. \\
& \left. + 4B_0(p^2, m_{d_a}^2, m_{d_b}^2) m_{d_a} m_{d_b} \Re \left( \Gamma_{Z,\bar{d}_a,d_b}^{L*} \Gamma_{Z,\bar{d}_a,d_b}^R \right) \right]
\end{aligned}$$

$$\begin{aligned}
& + \sum_{a=1}^3 \sum_{b=1}^3 \left[ \left( |\Gamma_{Z,\bar{e}_a,e_b}^L|^2 + |\Gamma_{Z,\bar{e}_a,e_b}^R|^2 \right) H_0(p^2, m_{e_a}^2, m_{e_b}^2) \right. \\
& + 4B_0(p^2, m_{e_a}^2, m_{e_b}^2) m_{e_a} m_{e_b} \Re \left( \Gamma_{Z,\bar{e}_a,e_b}^{L*} \Gamma_{Z,\bar{e}_a,e_b}^R \right) \Big] \\
& + 3 \sum_{a=1}^3 \sum_{b=1}^3 \left[ \left( |\Gamma_{Z,\bar{u}_a,u_b}^L|^2 + |\Gamma_{Z,\bar{u}_a,u_b}^R|^2 \right) H_0(p^2, m_{u_a}^2, m_{u_b}^2) \right. \\
& + 4B_0(p^2, m_{u_a}^2, m_{u_b}^2) m_{u_a} m_{u_b} \Re \left( \Gamma_{Z,\bar{u}_a,u_b}^{L*} \Gamma_{Z,\bar{u}_a,u_b}^R \right) \Big] \\
& + \sum_{a=1}^3 \sum_{b=1}^3 \left[ \left( |\Gamma_{Z,\bar{\nu}_a,\nu_b}^L|^2 + |\Gamma_{Z,\bar{\nu}_a,\nu_b}^R|^2 \right) H_0(p^2, m_{\nu_a}^2, m_{\nu_b}^2) \right. \\
& + 4B_0(p^2, m_{\nu_a}^2, m_{\nu_b}^2) m_{\nu_a} m_{\nu_b} \Re \left( \Gamma_{Z,\bar{\nu}_a,\nu_b}^{L*} \Gamma_{Z,\bar{\nu}_a,\nu_b}^R \right) \Big] + 2\text{rMS} m_{W^+}^2 \Gamma_{Z,Z,W^-,W^+}^1 \\
& - A_0(m_{W^+}^2) \left( 4\Gamma_{Z,Z,W^-,W^+}^1 + \Gamma_{Z,Z,W^-,W^+}^2 + \Gamma_{Z,Z,W^-,W^+}^3 \right)
\end{aligned} \tag{54}$$

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

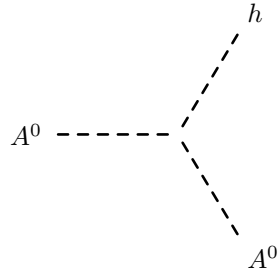
$$\begin{aligned}
\Pi(p^2) &= 2\text{rMS} m_{W^+}^2 \Gamma_{W^+,W^-,W^-,W^+}^1 + 3 \sum_{a=1}^3 \sum_{b=1}^3 \left[ \left( |\Gamma_{W^-, \bar{d}_a, u_b}^L|^2 + |\Gamma_{W^-, \bar{d}_a, u_b}^R|^2 \right) H_0(p^2, m_{d_a}^2, m_{u_b}^2) \right. \\
& + 4B_0(p^2, m_{d_a}^2, m_{u_b}^2) m_{d_a} m_{u_b} \Re \left( \Gamma_{W^-, \bar{d}_a, u_b}^{L*} \Gamma_{W^-, \bar{d}_a, u_b}^R \right) \Big] - 4|\Gamma_{W^-, H^+, A^0}|^2 B_{00}(p^2, m_{A^0}^2, m_{H^+}^2) - 4|\Gamma_{W^-, H^+, h}|^2 B_{00}(p^2, m_h^2, m_{H^+}^2) \\
& + 4B_0(p^2, m_{e_a}^2, m_{\nu_b}^2) m_{e_a} m_{\nu_b} \Re \left( \Gamma_{W^-, \bar{e}_a, \nu_b}^{L*} \Gamma_{W^-, \bar{e}_a, \nu_b}^R \right) \Big]
\end{aligned} \tag{55}$$

## 8.2 Tadpoles

$$\begin{aligned}
\delta t_h^{(1)} &= -\frac{1}{2} A_0(m_{A^0}^2) \Gamma_{h,A^0,A^0} - \frac{1}{2} A_0(m_h^2) \Gamma_{h,h,h} + A_0(m_{\eta^+}^2) \Gamma_{h,\eta^+, \eta^+} + A_0(m_{\eta^-}^2) \Gamma_{h,\eta^-, \eta^-} \\
& + A_0(m_{\eta^Z}^2) \Gamma_{h,\eta^Z, \eta^Z} - A_0(m_{H^+}^2) \Gamma_{h,H^-, H^+} + 4\Gamma_{h,W^-, W^+} \left( -\frac{1}{2} \text{rMS} m_{W^+}^2 + A_0(m_{W^+}^2) \right) \\
& + 2\Gamma_{h,Z,Z} \left( -\frac{1}{2} \text{rMS} m_Z^2 + A_0(m_Z^2) \right) + 6 \sum_{a=1}^3 A_0(m_{d_a}^2) m_{d_a} \left( \Gamma_{h,\bar{d}_a, d_a}^L + \Gamma_{h,\bar{d}_a, d_a}^R \right) \\
& + 2 \sum_{a=1}^3 A_0(m_{e_a}^2) m_{e_a} \left( \Gamma_{h,\bar{e}_a, e_a}^L + \Gamma_{h,\bar{e}_a, e_a}^R \right) \\
& + 6 \sum_{a=1}^3 A_0(m_{u_a}^2) m_{u_a} \left( \Gamma_{h,\bar{u}_a, u_a}^L + \Gamma_{h,\bar{u}_a, u_a}^R \right)
\end{aligned} \tag{56}$$

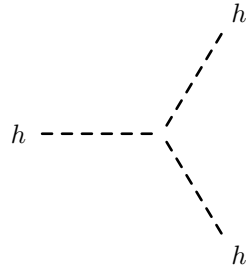
## 9 Interactions for eigenstates 'EWSB'

### 9.1 Three Scalar-Interaction



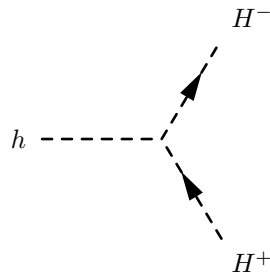
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$$-iv\lambda \quad (57)$$



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$$-3iv\lambda \quad (58)$$

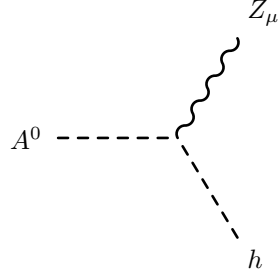


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$$-iv\lambda \quad (59)$$

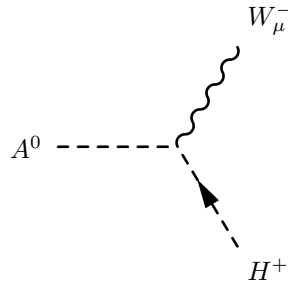


## 9.2 Two Scalar-One Vector Boson-Interaction



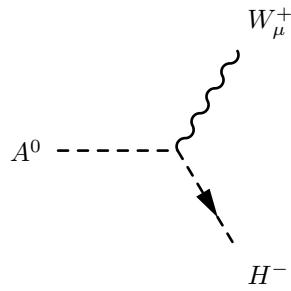
$$\frac{1}{2} \left( -g_1 \sin \Theta_W - g_2 \cos \Theta_W \right) \left( -p_\mu^h + p_\mu^{A^0} \right) \quad (60)$$


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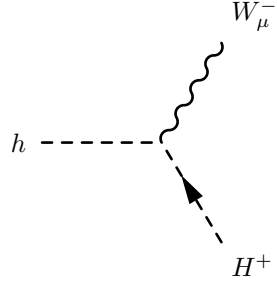
$$\frac{1}{2} g_2 \left( -p_\mu^{H^+} + p_\mu^{A^0} \right) \quad (61)$$


---



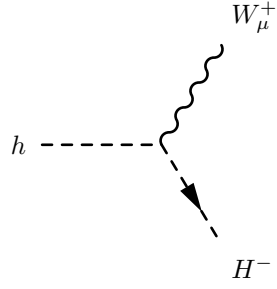
$$\frac{1}{2} g_2 \left( -p_\mu^{H^-} + p_\mu^{A^0} \right) \quad (62)$$


---



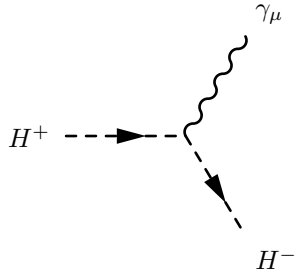
$$\frac{i}{2}g_2\left(-p_\mu^{H^+}+p_\mu^h\right) \quad (63)$$


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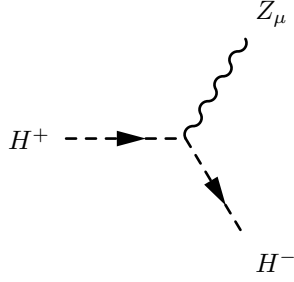
$$-\frac{i}{2}g_2\left(-p_\mu^{H^-}+p_\mu^h\right) \quad (64)$$


---



$$-\frac{i}{2}\left(g_1\cos\Theta_W+g_2\sin\Theta_W\right)\left(-p_\mu^{H^-}+p_\mu^{H^+}\right) \quad (65)$$

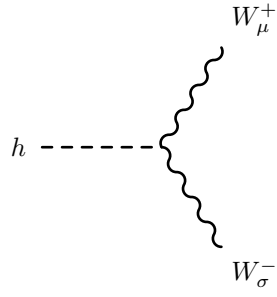

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$$-\frac{i}{2}\left(-g_1\sin\Theta_W+g_2\cos\Theta_W\right)\left(-p_\mu^{H^-}+p_\mu^{H^+}\right) \quad (66)$$

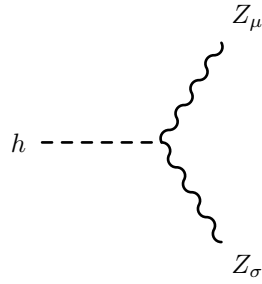

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### 9.3 One Scalar-Two Vector Boson-Interaction



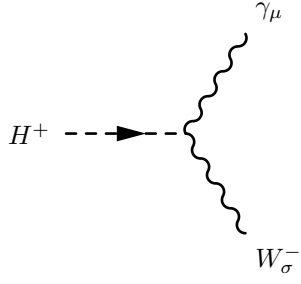
$$\frac{i}{2}g_2^2v\left(g_{\sigma\mu}\right) \quad (67)$$


---



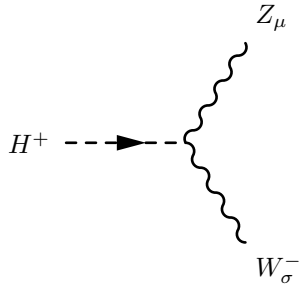
$$\frac{i}{2}v\left(g_1\sin\Theta_W+g_2\cos\Theta_W\right)^2\left(g_{\sigma\mu}\right) \quad (68)$$


---



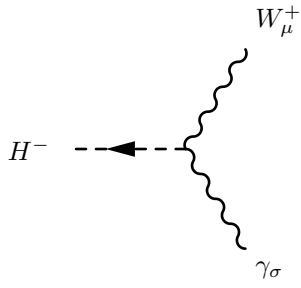
$$\frac{i}{2}g_1g_2v\cos\Theta_W\left(g_{\sigma\mu}\right) \quad (69)$$


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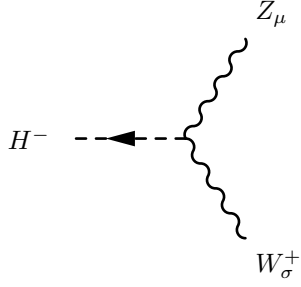
$$-\frac{i}{2}g_1g_2v\sin\Theta_W\left(g_{\sigma\mu}\right) \quad (70)$$


---



$$\frac{i}{2}g_1g_2v\cos\Theta_W\left(g_{\sigma\mu}\right) \quad (71)$$

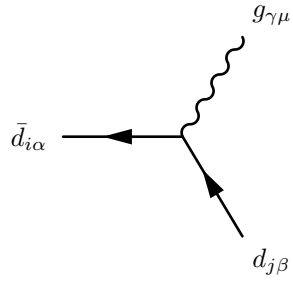

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$$-\frac{i}{2}g_1g_2v\sin\Theta_W\left(g_{\sigma\mu}\right) \quad (72)$$


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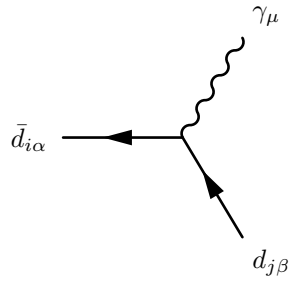
#### 9.4 Two Fermion-One Vector Boson-Interaction



$$-\frac{i}{2}g_3\delta_{ij}\lambda_{\alpha,\beta}^\gamma\left(\gamma_\mu\cdot\frac{1-\gamma_5}{2}\right) \quad (73)$$

$$+\frac{i}{2}g_3\delta_{ij}\lambda_{\alpha,\beta}^\gamma\left(\gamma_\mu\cdot\frac{1+\gamma_5}{2}\right) \quad (74)$$

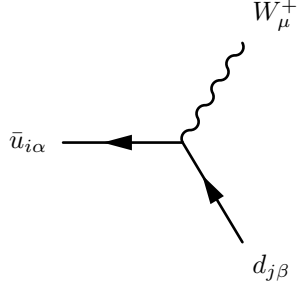

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$$-\frac{i}{6}\delta_{\alpha\beta}\delta_{ij}\left(-3g_2\sin\Theta_W+g_1\cos\Theta_W\right)\left(\gamma_\mu\cdot\frac{1-\gamma_5}{2}\right) \quad (75)$$

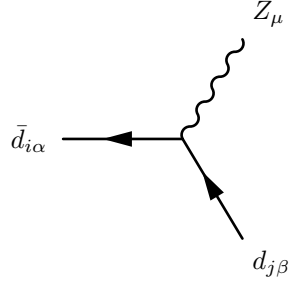
$$+\frac{i}{3}g_1\cos\Theta_W\delta_{\alpha\beta}\delta_{ij}\left(\gamma_\mu\cdot\frac{1+\gamma_5}{2}\right) \quad (76)$$


---



$$-i \frac{1}{\sqrt{2}} g_2 \delta_{\alpha\beta} \sum_{a=1}^3 U_{L,ja}^{d,*} U_{L,ia}^u \left( \gamma_\mu \cdot \frac{1 - \gamma_5}{2} \right) \quad (77)$$

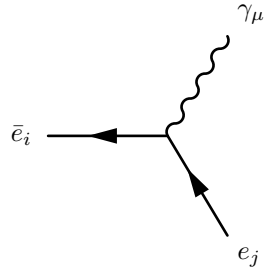

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$$\frac{i}{6} \delta_{\alpha\beta} \delta_{ij} \left( 3g_2 \cos \Theta_W + g_1 \sin \Theta_W \right) \left( \gamma_\mu \cdot \frac{1 - \gamma_5}{2} \right) \quad (78)$$

$$+ -\frac{i}{3} g_1 \delta_{\alpha\beta} \delta_{ij} \sin \Theta_W \left( \gamma_\mu \cdot \frac{1 + \gamma_5}{2} \right) \quad (79)$$

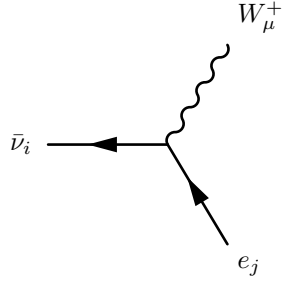

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$$\frac{i}{2} \delta_{ij} \left( g_1 \cos \Theta_W + g_2 \sin \Theta_W \right) \left( \gamma_\mu \cdot \frac{1 - \gamma_5}{2} \right) \quad (80)$$

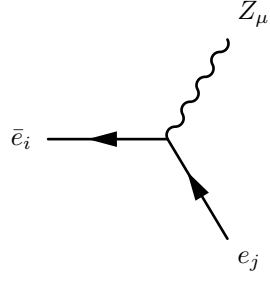
$$+ i g_1 \cos \Theta_W \delta_{ij} \left( \gamma_\mu \cdot \frac{1 + \gamma_5}{2} \right) \quad (81)$$


---



$$-i \frac{1}{\sqrt{2}} g_2 U_{L,ji}^{e,*} \Theta_{i,3} \left( \gamma_\mu \cdot \frac{1 - \gamma_5}{2} \right) \quad (82)$$

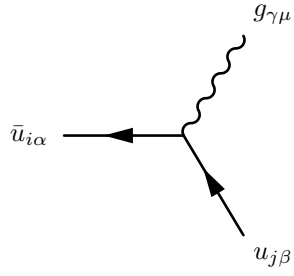

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$$\frac{i}{2} \delta_{ij} \left( -g_1 \sin \Theta_W + g_2 \cos \Theta_W \right) \left( \gamma_\mu \cdot \frac{1 - \gamma_5}{2} \right) \quad (83)$$

$$+ -i g_1 \delta_{ij} \sin \Theta_W \left( \gamma_\mu \cdot \frac{1 + \gamma_5}{2} \right) \quad (84)$$

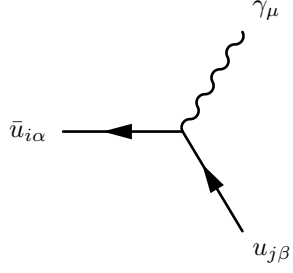

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$$- \frac{i}{2} g_3 \delta_{ij} \lambda_{\alpha,\beta}^\gamma \left( \gamma_\mu \cdot \frac{1 - \gamma_5}{2} \right) \quad (85)$$

$$+ - \frac{i}{2} g_3 \delta_{ij} \lambda_{\alpha,\beta}^\gamma \left( \gamma_\mu \cdot \frac{1 + \gamma_5}{2} \right) \quad (86)$$

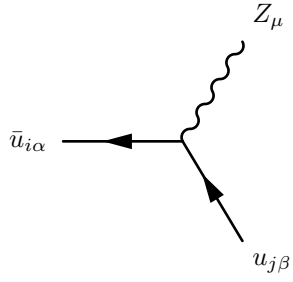

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$$-\frac{i}{6}\delta_{\alpha\beta}\delta_{ij}\left(3g_2\sin\Theta_W+g_1\cos\Theta_W\right)\left(\gamma_\mu\cdot\frac{1-\gamma_5}{2}\right) \quad (87)$$

$$+\frac{2i}{3}g_1\cos\Theta_W\delta_{\alpha\beta}\delta_{ij}\left(\gamma_\mu\cdot\frac{1+\gamma_5}{2}\right) \quad (88)$$

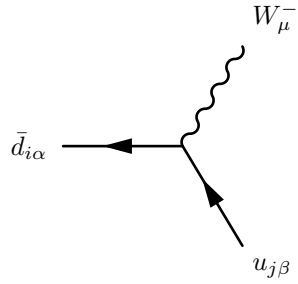

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$$-\frac{i}{6}\delta_{\alpha\beta}\delta_{ij}\left(3g_2\cos\Theta_W-g_1\sin\Theta_W\right)\left(\gamma_\mu\cdot\frac{1-\gamma_5}{2}\right) \quad (89)$$

$$+\frac{2i}{3}g_1\delta_{\alpha\beta}\delta_{ij}\sin\Theta_W\left(\gamma_\mu\cdot\frac{1+\gamma_5}{2}\right) \quad (90)$$

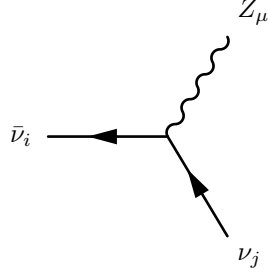

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$$-i\frac{1}{\sqrt{2}}g_2\delta_{\alpha\beta}\sum_{a=1}^3U_{L,ja}^{u,*}U_{L,ia}^d\left(\gamma_\mu\cdot\frac{1-\gamma_5}{2}\right) \quad (91)$$

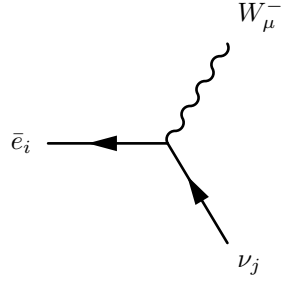

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$$-\frac{i}{2}\delta_{ij}\left(g_1\sin\Theta_W+g_2\cos\Theta_W\right)\left(\gamma_\mu\cdot\frac{1-\gamma_5}{2}\right) \quad (92)$$

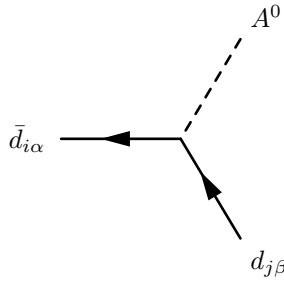

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$$-i\frac{1}{\sqrt{2}}g_2\Theta_{j,3}U_{L,ij}^e\left(\gamma_\mu\cdot\frac{1-\gamma_5}{2}\right) \quad (93)$$


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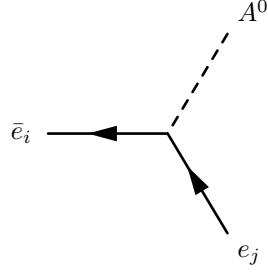
## 9.5 Two Fermion-One Scalar Boson-Interaction



$$-\frac{1}{\sqrt{2}}\delta_{\alpha\beta}\sum_{b=1}^3U_{L,jb}^{d,*}\sum_{a=1}^3U_{R,ia}^dY_{d,ab}\left(\frac{1-\gamma_5}{2}\right) \quad (94)$$

$$+\frac{1}{\sqrt{2}}\delta_{\alpha\beta}\sum_{b=1}^3\sum_{a=1}^3Y_{d,ab}^*U_{R,ja}^dU_{L,ib}^d\left(\frac{1+\gamma_5}{2}\right) \quad (95)$$

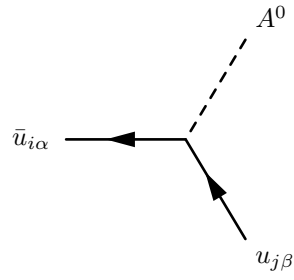

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$$- \frac{1}{\sqrt{2}} \sum_{b=1}^3 U_{L,jb}^{e,*} \sum_{a=1}^3 U_{R,ia}^{e,*} Y_{e,ab} \left( \frac{1 - \gamma_5}{2} \right) \quad (96)$$

$$+ \frac{1}{\sqrt{2}} \sum_{b=1}^3 \sum_{a=1}^3 Y_{e,ab}^* U_{R,ja}^e U_{L,ib}^e \left( \frac{1 + \gamma_5}{2} \right) \quad (97)$$

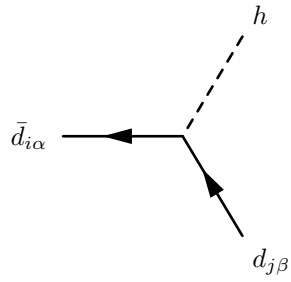

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$$- \frac{1}{\sqrt{2}} \delta_{\alpha\beta} \sum_{b=1}^3 U_{L,jb}^{u,*} \sum_{a=1}^3 U_{R,ia}^{u,*} Y_{u,ab} \left( \frac{1 - \gamma_5}{2} \right) \quad (98)$$

$$+ \frac{1}{\sqrt{2}} \delta_{\alpha\beta} \sum_{b=1}^3 \sum_{a=1}^3 Y_{u,ab}^* U_{R,ja}^u U_{L,ib}^u \left( \frac{1 + \gamma_5}{2} \right) \quad (99)$$

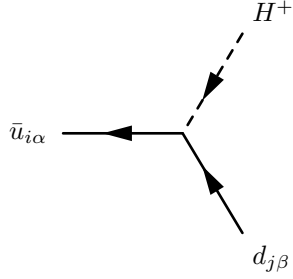

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$$-i \frac{1}{\sqrt{2}} \delta_{\alpha\beta} \sum_{b=1}^3 U_{L,jb}^{d,*} \sum_{a=1}^3 U_{R,ia}^{d,*} Y_{d,ab} \left( \frac{1-\gamma_5}{2} \right) \quad (100)$$

$$+ -i \frac{1}{\sqrt{2}} \delta_{\alpha\beta} \sum_{b=1}^3 \sum_{a=1}^3 Y_{d,ab}^* U_{R,ja}^d U_{L,ib}^d \left( \frac{1+\gamma_5}{2} \right) \quad (101)$$

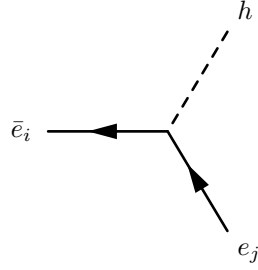

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$$-i \delta_{\alpha\beta} \sum_{b=1}^3 U_{L,jb}^{d,*} \sum_{a=1}^3 U_{R,ia}^{u,*} Y_{u,ab} \left( \frac{1-\gamma_5}{2} \right) \quad (102)$$

$$+ -i \delta_{\alpha\beta} \sum_{b=1}^3 \sum_{a=1}^3 Y_{d,ab}^* U_{R,ja}^d U_{L,ib}^u \left( \frac{1+\gamma_5}{2} \right) \quad (103)$$

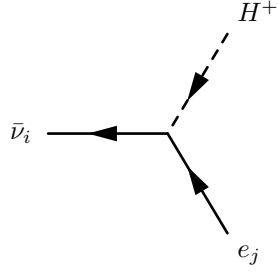

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$$-i \frac{1}{\sqrt{2}} \sum_{b=1}^3 U_{L,jb}^{e,*} \sum_{a=1}^3 U_{R,ia}^{e,*} Y_{e,ab} \left( \frac{1-\gamma_5}{2} \right) \quad (104)$$

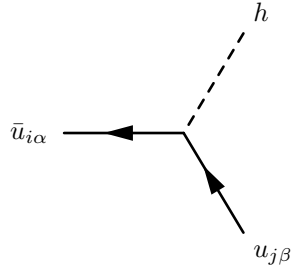
$$+ -i \frac{1}{\sqrt{2}} \sum_{b=1}^3 \sum_{a=1}^3 Y_{e,ab}^* U_{R,ja}^e U_{L,ib}^e \left( \frac{1+\gamma_5}{2} \right) \quad (105)$$


---



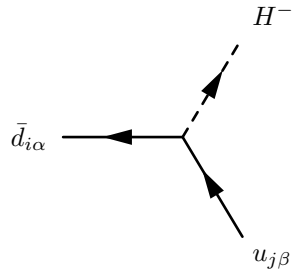
(106)

$$+ -i \sum_{a=1}^3 Y_{e,ai}^* U_{R,ja}^e \left( \frac{1+\gamma_5}{2} \right) \quad (107)$$



$$i \frac{1}{\sqrt{2}} \delta_{\alpha\beta} \sum_{b=1}^3 U_{L,jb}^{u,*} \sum_{a=1}^3 U_{R,ia}^{u,*} Y_{u,ab} \left( \frac{1-\gamma_5}{2} \right) \quad (108)$$

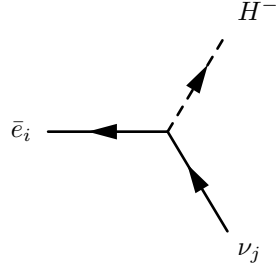
$$+ i \frac{1}{\sqrt{2}} \delta_{\alpha\beta} \sum_{b=1}^3 \sum_{a=1}^3 Y_{u,ab}^* U_{R,ja}^u U_{L,ib}^u \left( \frac{1+\gamma_5}{2} \right) \quad (109)$$



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

$$+ -i\delta_{\alpha\beta} \sum_{b=1}^3 \sum_{a=1}^3 Y_{u,ab}^* U_{R,ja}^u U_{L,ib}^d \left( \frac{1+\gamma_5}{2} \right) \quad (111)$$

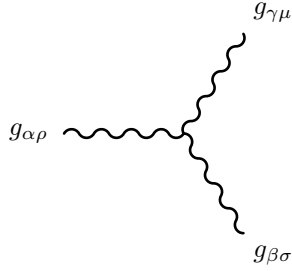

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$$-i \sum_{a=1}^3 U_{R,ia}^{e,*} Y_{e,aj} \left( \frac{1-\gamma_5}{2} \right) \quad (112)$$

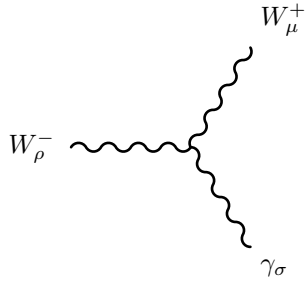

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## 9.6 Three Vector Boson-Interaction



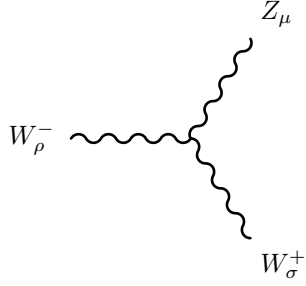
$$g_3 f_{\alpha,\beta,\gamma} \left( g_{\rho\mu} \left( -p_\sigma^{g\gamma\mu} + p_\sigma^{g\alpha\rho} \right) + g_{\rho\sigma} \left( -p_\mu^{g\alpha\rho} + p_\mu^{g\beta\sigma} \right) + g_{\sigma\mu} \left( -p_\rho^{g\beta\sigma} + p_\rho^{g\gamma\mu} \right) \right) \quad (113)$$


---



$$-ig_2 \sin \Theta_W \left( g_{\rho\mu} \left( -p_\sigma^{W_\mu^+} + p_\sigma^{W_\rho^-} \right) + g_{\rho\sigma} \left( -p_\mu^{W_\rho^-} + p_\mu^{\gamma_\sigma} \right) + g_{\sigma\mu} \left( -p_\rho^{\gamma_\sigma} + p_\rho^{W_\mu^+} \right) \right) \quad (114)$$

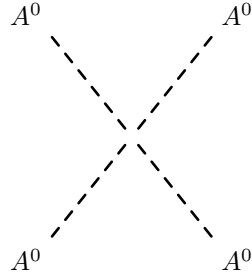

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$$ig_2 \cos \Theta_W \left( g_{\rho\mu} \left( -p_\sigma^{Z_\mu} + p_\sigma^{W_\rho^-} \right) + g_{\rho\sigma} \left( -p_\mu^{W_\rho^-} + p_\mu^{W_\sigma^+} \right) + g_{\sigma\mu} \left( -p_\rho^{W_\sigma^+} + p_\rho^{Z_\mu} \right) \right) \quad (115)$$

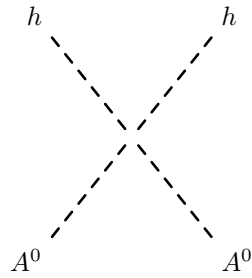

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## 9.7 Four Scalar-Interaction



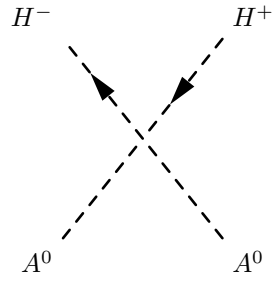
$$-3i\lambda \quad (116)$$


---



$$-i\lambda \quad (117)$$

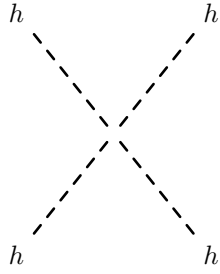

---



$$-i\lambda$$

(118)

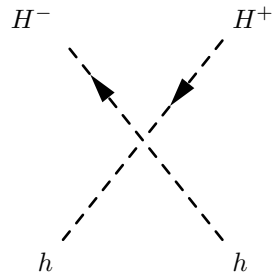
---



$$-3i\lambda$$

(119)

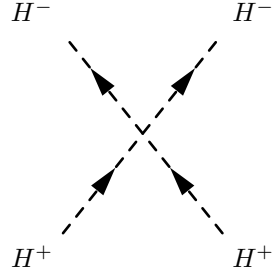
---



$$-i\lambda$$

(120)

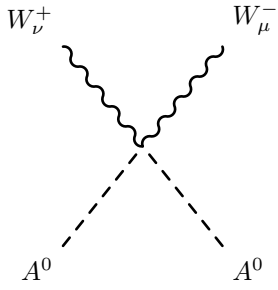
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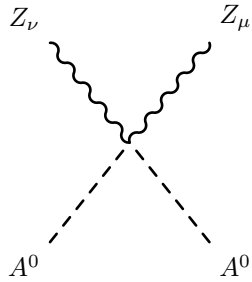

$$-2i\lambda \tag{121}$$

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



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$$\frac{i}{2}g_2^2(g_{\mu\nu}) \tag{122}$$

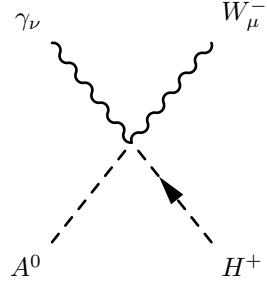


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$$\frac{i}{2}\left(g_1 \sin \Theta_W + g_2 \cos \Theta_W\right)^2(g_{\mu\nu}) \tag{123}$$

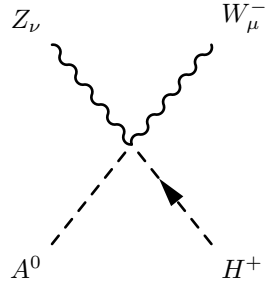

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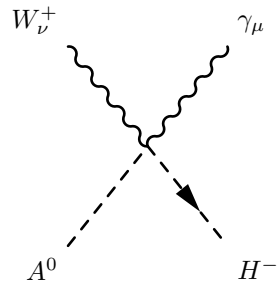
$$\frac{1}{2}g_1g_2\cos\Theta_W\left(g_{\mu\nu}\right) \quad (124)$$


---



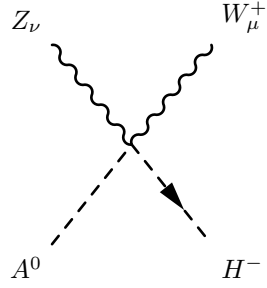
$$-\frac{1}{2}g_1g_2\sin\Theta_W\left(g_{\mu\nu}\right) \quad (125)$$


---



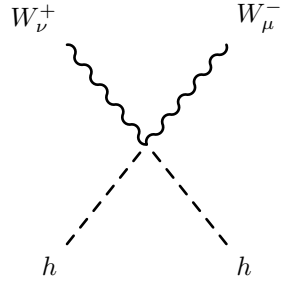
$$-\frac{1}{2}g_1g_2\cos\Theta_W\left(g_{\mu\nu}\right) \quad (126)$$


---



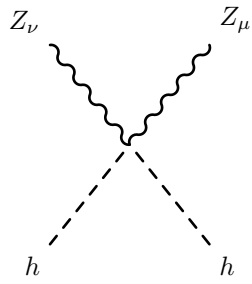
$$\frac{1}{2}g_1g_2\sin\Theta_W\left(g_{\mu\nu}\right) \quad (127)$$


---



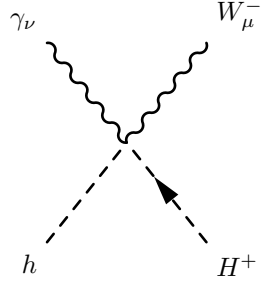
$$\frac{i}{2}g_2^2\left(g_{\mu\nu}\right) \quad (128)$$


---



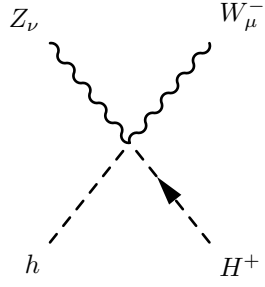
$$\frac{i}{2}\left(g_1\sin\Theta_W+g_2\cos\Theta_W\right)^2\left(g_{\mu\nu}\right) \quad (129)$$


---



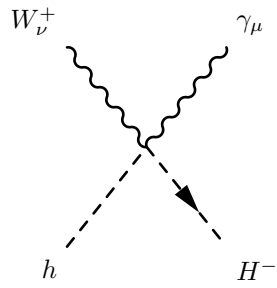
$$\frac{i}{2} g_1 g_2 \cos \Theta_W (g_{\mu\nu}) \quad (130)$$


---



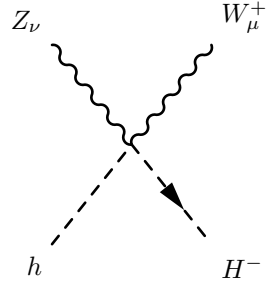
$$-\frac{i}{2} g_1 g_2 \sin \Theta_W (g_{\mu\nu}) \quad (131)$$


---



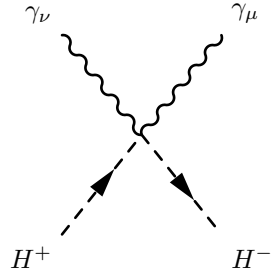
$$\frac{i}{2} g_1 g_2 \cos \Theta_W (g_{\mu\nu}) \quad (132)$$


---



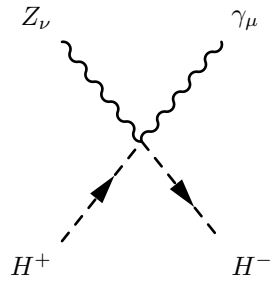
$$-\frac{i}{2}g_1g_2\sin\Theta_W\left(g_{\mu\nu}\right) \quad (133)$$


---



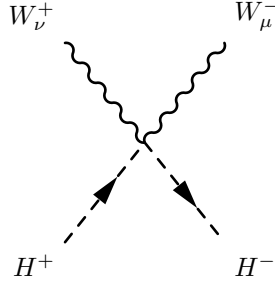
$$\frac{i}{2}\left(g_1\cos\Theta_W+g_2\sin\Theta_W\right)^2\left(g_{\mu\nu}\right) \quad (134)$$


---



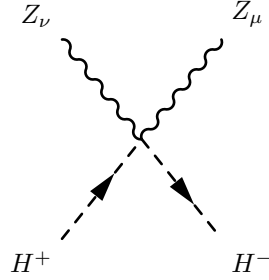
$$-\frac{i}{4}\left(-2g_1g_2\cos2\Theta_W+\left(-g_2^2+g_1^2\right)\sin2\Theta_W\right)\left(g_{\mu\nu}\right) \quad (135)$$


---



$$\frac{i}{2}g_2^2(g_{\mu\nu}) \quad (136)$$

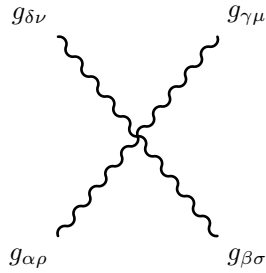

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$$\frac{i}{2}\left(-g_1\sin\Theta_W + g_2\cos\Theta_W\right)^2(g_{\mu\nu}) \quad (137)$$


---

## 9.9 Four Vector Boson-Interaction

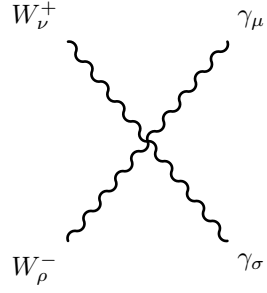


$$-ig_3^2\left(\sum_{a=1}^8 f_{\alpha,\delta,a}f_{\beta,\gamma,a} + \sum_{a=1}^8 f_{\alpha,\gamma,a}f_{\beta,\delta,a}\right)(g_{\rho\sigma}g_{\mu\nu}) \quad (138)$$

$$+ ig_3^2\left(-\sum_{a=1}^8 f_{\alpha,\beta,a}f_{\gamma,\delta,a} + \sum_{a=1}^8 f_{\alpha,\delta,a}f_{\beta,\gamma,a}\right)(g_{\rho\mu}g_{\sigma\nu}) \quad (139)$$

$$+ ig_3^2 \left( \sum_{a=1}^8 f_{\alpha,\gamma,a} f_{\beta,\delta,a} + \sum_{a=1}^8 f_{\alpha,\beta,a} f_{\gamma,\delta,a} \right) (g_{\rho\nu} g_{\sigma\mu}) \quad (140)$$


---

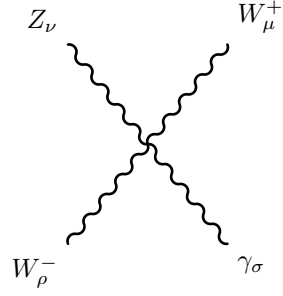


$$ig_2^2 \sin \Theta_W^2 (g_{\rho\sigma} g_{\mu\nu}) \quad (141)$$

$$+ ig_2^2 \sin \Theta_W^2 (g_{\rho\mu} g_{\sigma\nu}) \quad (142)$$

$$+ -2ig_2^2 \sin \Theta_W^2 (g_{\rho\nu} g_{\sigma\mu}) \quad (143)$$


---

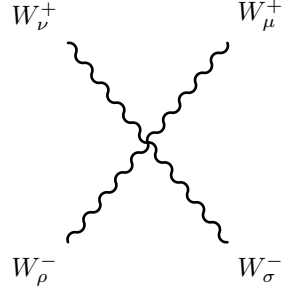


$$ig_2^2 \cos \Theta_W \sin \Theta_W (g_{\rho\sigma} g_{\mu\nu}) \quad (144)$$

$$+ -ig_2^2 \sin 2\Theta_W (g_{\rho\mu} g_{\sigma\nu}) \quad (145)$$

$$+ ig_2^2 \cos \Theta_W \sin \Theta_W (g_{\rho\nu} g_{\sigma\mu}) \quad (146)$$


---

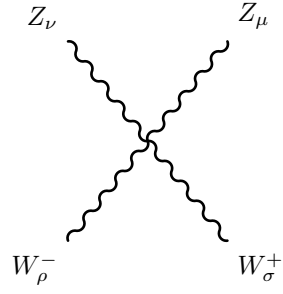


$$2ig_2^2(g_{\rho\sigma}g_{\mu\nu}) \quad (147)$$

$$+ -ig_2^2(g_{\rho\mu}g_{\sigma\nu}) \quad (148)$$

$$+ -ig_2^2(g_{\rho\nu}g_{\sigma\mu}) \quad (149)$$


---



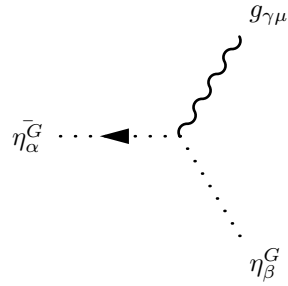
$$- 2ig_2^2 \cos \Theta_W^2(g_{\rho\sigma}g_{\mu\nu}) \quad (150)$$

$$+ ig_2^2 \cos \Theta_W^2(g_{\rho\mu}g_{\sigma\nu}) \quad (151)$$

$$+ ig_2^2 \cos \Theta_W^2(g_{\rho\nu}g_{\sigma\mu}) \quad (152)$$

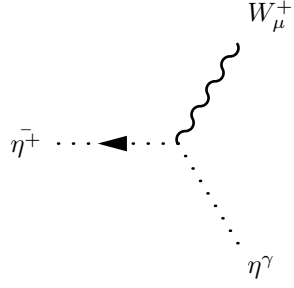

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## 9.10 Two Ghosts-One Vector Boson-Interaction



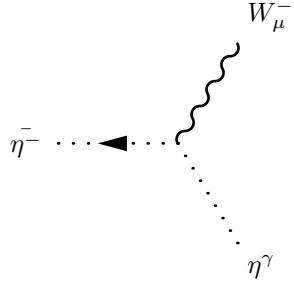
$$g_3 f_{\alpha,\beta,\gamma} \left( p_{\mu}^{\eta_{\beta}^G} \right) \quad (153)$$


---



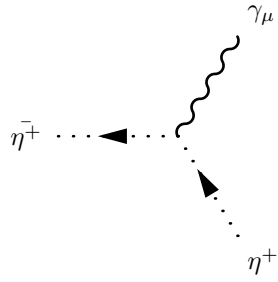
$$-ig_2 \sin \Theta_W \left( p_{\mu}^{\eta^{\gamma}} \right) \quad (154)$$


---



$$ig_2 \sin \Theta_W \left( p_{\mu}^{\eta^{\gamma}} \right) \quad (155)$$

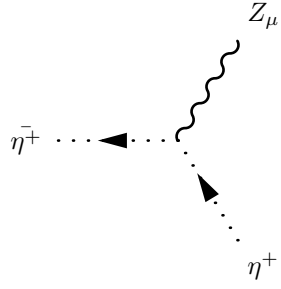

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$$ig_2 \sin \Theta_W \left( p_{\mu}^{\eta^{+}} \right) \quad (156)$$

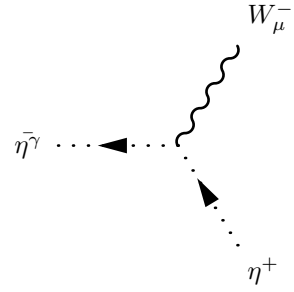

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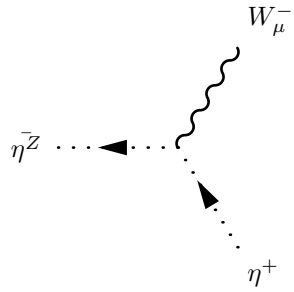
$$ig_2 \cos \Theta_W (p_\mu^{\eta^+}) \quad (157)$$


---



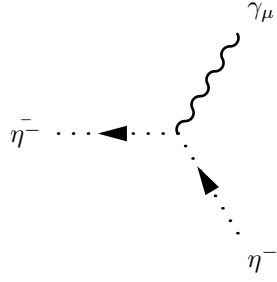
$$-ig_2 \sin \Theta_W (p_\mu^{\eta^+}) \quad (158)$$


---



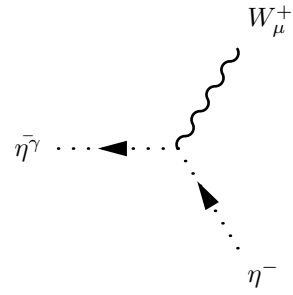
$$-ig_2 \cos \Theta_W (p_\mu^{\eta^+}) \quad (159)$$


---



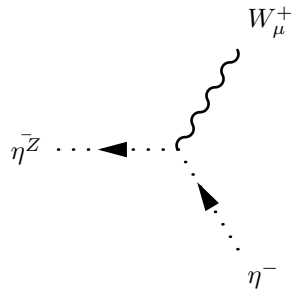
$$-ig_2 \sin \Theta_W (p_\mu^{\eta^-}) \quad (160)$$


---



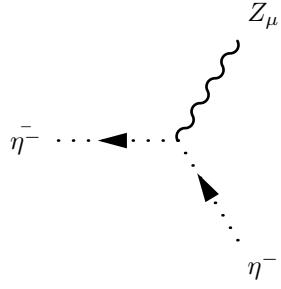
$$ig_2 \sin \Theta_W (p_\mu^{\eta^-}) \quad (161)$$


---



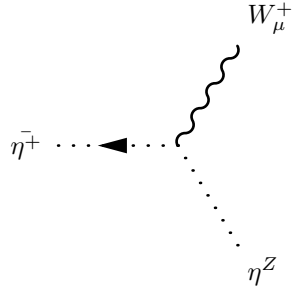
$$ig_2 \cos \Theta_W (p_\mu^{\eta^-}) \quad (162)$$


---



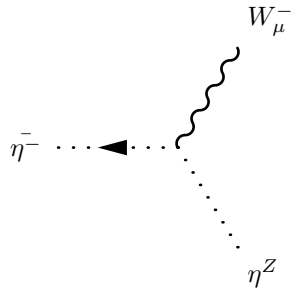
$$-ig_2 \cos \Theta_W \left( p_\mu^{\eta^-} \right) \quad (163)$$


---



$$-ig_2 \cos \Theta_W \left( p_\mu^{\eta^Z} \right) \quad (164)$$

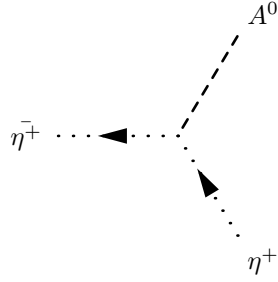

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$$ig_2 \cos \Theta_W \left( p_\mu^{\eta^Z} \right) \quad (165)$$

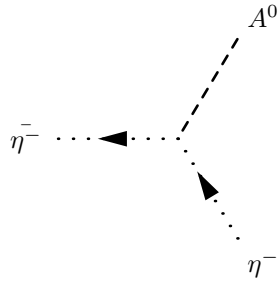

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### 9.11 Two Ghosts-One Scalar-Interaction



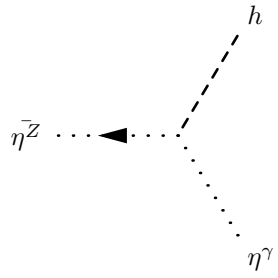
$$\frac{1}{4}g_2^2 v \xi_{W^+} \quad (166)$$


---



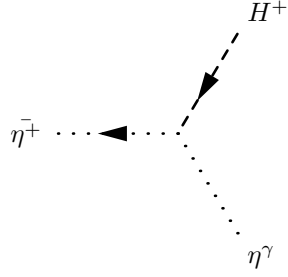
$$-\frac{1}{4}g_2^2 v \xi_{W^+} \quad (167)$$


---



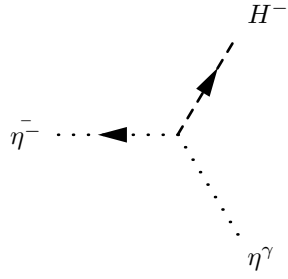
$$\frac{i}{8}v \xi_Z \left( 2g_1 g_2 \cos 2\Theta_W + \left( -g_2^2 + g_1^2 \right) \sin 2\Theta_W \right) \quad (168)$$


---



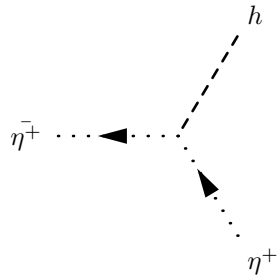
$$-\frac{i}{4}g_2v\xi_{W^+}\left(g_1\cos\Theta_W+g_2\sin\Theta_W\right) \quad (169)$$


---



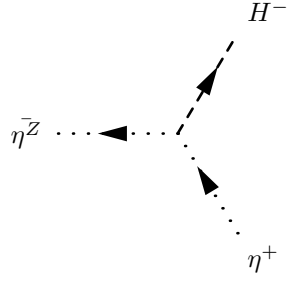
$$-\frac{i}{4}g_2v\xi_{W^+}\left(g_1\cos\Theta_W+g_2\sin\Theta_W\right) \quad (170)$$


---



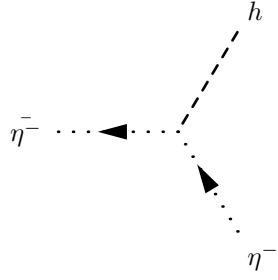
$$-\frac{i}{4}g_2^2v\xi_{W^+} \quad (171)$$


---



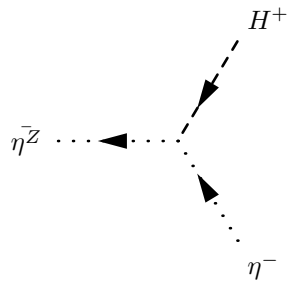
$$\frac{i}{4}g_2v\xi_Z\left(g_1\sin\Theta_W+g_2\cos\Theta_W\right) \quad (172)$$


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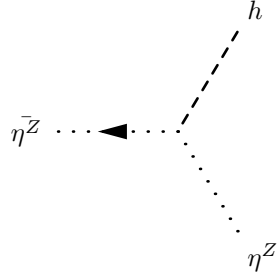
$$-\frac{i}{4}g_2^2v\xi_{W^+} \quad (173)$$


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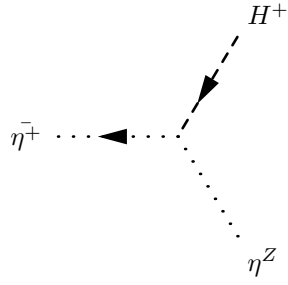
$$\frac{i}{4}g_2v\xi_Z\left(g_1\sin\Theta_W+g_2\cos\Theta_W\right) \quad (174)$$


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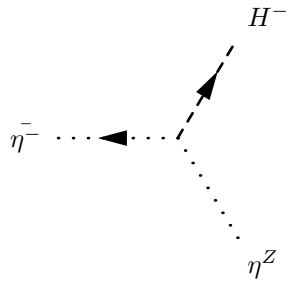
$$-\frac{i}{4}v\xi_Z\left(g_1\sin\Theta_W+g_2\cos\Theta_W\right)^2 \quad (175)$$


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$$-\frac{i}{4}g_2v\xi_{W^+}\left(-g_1\sin\Theta_W+g_2\cos\Theta_W\right) \quad (176)$$


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$$-\frac{i}{4}g_2v\xi_{W^+}\left(-g_1\sin\Theta_W+g_2\cos\Theta_W\right) \quad (177)$$


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## 10 Clebsch-Gordan Coefficients