FeynRules Implementation of Abelian_Higgs_Model

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Abstract

We describe the implementation of the Abelian_Higgs_Model model using the FeynRules package.

Contents

List of Tables

1 Introduction

We describe the implementation of the Abelian_Higgs_Model model using the FeynRules [2] package. More information about this model can be found in [1].

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2 Gauge Symmetries

The gauge group of this model is

$$U1Y \times U1X \times SU2L \times SU3C. \tag{1}$$

Details of these gauge groups can be found in Table 1.

Group	Abelian	Gauge Boson	Coupling Constant	Charge	Structure Constant	Symmetric Tensor	Reps
U1Y	T	B	g1	Y			
U1X	T	X	ee	QX			
SU2L	F	Wi	gw		Eps		$FSU2L_{MR}$IndForm[SU2W],MR$IndForm[SU2W]$
SU3C	F	G	gs		f	dSUN	$T_{i,i}$
							$FSU3C_{a,a}$

Table 1: Details of gauge groups.

The definitions of the indices can be found in Table 2.

Index	Symbol	Range
Generation	f	1-3
Colour	i	1-3
Gluon	a	1-8
SU2W	SU2W	1-3

Table 2: Definition of the indices.

3 Fields

In this section, we describe the field content of our model implementation.

3.1 Vector Fields

In this subsection, we describe the vector fields of our model. The details of the physical vectors can be found in Table 3.

Class	SC	I	FI	QN	Mem	M	W	PDG
A	T				A	0	0	22
Z	T				Z	MZ= 91.188	WZ= 2.4414	23
Zp	T				Zp	MZp= 500	WZp= 0.0008252	1023
W	F			$Q = 1$	W	MW= 80.419	WW= 2.0476	24
G	T	a			G	0	0	21

Table 3: Details of physical vector fields. The headers are as follows: SC = self conjugate, I = indices, FI = flavor index, QN = quantum numbers, Mem = members, M = mass, W = width, and PDG = particle data group number.

The details of the unphysical vectors can be found in Table 4.

Class	SC	I	FI	QN	Mem	Definitions
Bp	T				Bp	$\mathrm{Bp}_\mu :\rightarrow c_w A_\mu - s_w c_\alpha Z_\mu + s_w s_\alpha \mathrm{Zp}_\mu$
Xp	T				Xp	$\mathrm{Xp}_\mu :\rightarrow s_\alpha Z_\mu + c_\alpha \mathrm{Zp}_\mu$
Wi	T	SU2W	SU2W		Wi	$\mathrm{Wi}_{\mu,1} \rightarrow \frac{W_\mu + {W_\mu}^\dagger}{\sqrt{2}}$
						$\mathrm{Wi}_{\mu,2} \rightarrow -\frac{i(-W_\mu + {W_\mu}^\dagger)}{\sqrt{2}}$
						$\mathrm{Wi}_{\mu,3} \rightarrow s_w A_\mu + c_\alpha c_w Z_\mu - c_w s_\alpha \mathrm{Zp}_\mu$
B	T				B	$B_\mu \rightarrow \mathrm{Bp}_\mu + \eta \mathrm{Xp}_\mu$
X	T				X	$X_\mu \rightarrow \eta\chi \mathrm{Xp}_\mu$

Table 4: Details of unphysical vector fields. The headers are as follows: SC = self conjugate, I = indices, FI = flavor index, QN = quantum numbers, and Mem = members.

3.2 Fermion Fields

In this subsection, we describe the fermion fields of our model. The details of the physical fermions can be found in Table 5.

3.3 Scalar Fields

In this subsection, we describe the scalar fields of our model. The details of the physical scalars can be found in Table 6. The details of the unphysical scalars can be found in Table 7.

3.4 Ghost Fields

In this subsection, we describe the ghost fields of our model. The details of the physical ghosts can be found in Table 8.

Class	SC	I	FI	QN	Mem	M	W	PDG
vl	F	f	f	$LeptonNumber = 1$				
					ve			12
					vm			14
					vt			16
l	F	f	f	$Q = -1$		Ml		
				$LeptonNumber = 1$	e	ME= 0		11
					m	MM= 0		13
					tt	MTA= 1.777		15
uq	F	f, i	f	$Q = 2/3$		Mu		
					u	MU= 0	0	2
					c	MC= 1.42	0	4
					t	MT= 174.3	WT= 1.50834	6
dq	F	f, i	f	$Q = -1/3$		Md		
					d	MD= 0		1
					s	MS= 0		3
					b	MB= 4.7		5

Table 5: Details of physical fermion fields. The headers are as follows: SC = self conjugate, I = indices, FI = flavor index, QN = quantum numbers, Mem = members, M = mass, W = width, and PDG = particle data group number.

Class	SC	I	FI	QN	Mem	M	W	PDG
h1	T				h1	MH1= Internal	WH1= 0.00282299	25
h2	T				h2	MH2= Internal	WH2= 5.23795	35

Table 6: Details of physical scalar fields. The headers are as follows: SC = self conjugate, I = indices, FI = flavor index, QN = quantum numbers, Mem = members, M = mass, W = width, and PDG = particle data group number.

Class	SC	I	FI	QN	Mem	Definitions
H	T				H	$H \to c_h \mathrm{h1} + \mathrm{h2} s_h$
phih	F				phih	$\mathrm{phih} \to c_h \mathrm{h2} - \mathrm{h1} s_h + \frac{\xi}{\sqrt{2}}$

Table 7: Details of unphysical scalar fields. The headers are as follows: SC = self conjugate, I = indices, FI = flavor index, QN = quantum numbers, and Mem = members.

Class	SC	I	FI	QN	Mem	M	W	PDG
ghG	F	a		$GhostNumber = 1$	ghG	0	0	

Table 8: Details of physical ghost fields. The headers are as follows: SC = self conjugate, I = indices, FI = flavor index, QN = quantum numbers, Mem = members, M = mass, W = width, and PDG = particle data group number.

4 Lagrangian

In this section, we describe the Lagrangian of our model implementation.

4.1 L_1

$$-\frac{1}{4}\left(-\partial_\nu\left[B_\mu\right]+\partial_\mu\left[B_\nu\right]\right)^2+\frac{1}{2}\chi\left(-\partial_\nu\left[B_\mu\right]+\partial_\mu\left[B_\nu\right]\right)\left(-\partial_\nu\left[X_\mu\right]+\partial_\mu\left[X_\nu\right]\right)-\frac{1}{4}\left(-\partial_\nu\left[X_\mu\right]+\partial_\mu\left[X_\nu\right]\right)^2-$$
$$\frac{1}{4}\left(-\partial_\nu\left[G_{\mu,\mathrm{a1}}\right]+\partial_\mu\left[G_{\nu,\mathrm{a1}}\right]+g_s f_{\mathrm{a1,a2,a3}}G_{\mu,\mathrm{a2}}G_{\nu,\mathrm{a3}}\right)\left(-\partial_\nu\left[G_{\mu,\mathrm{a1}}\right]+\partial_\mu\left[G_{\nu,\mathrm{a1}}\right]+g_s f_{\mathrm{a1,a4,a5}}G_{\mu,\mathrm{a4}}G_{\nu,\mathrm{a5}}\right)-$$
$$\frac{1}{4}\left(-\partial_\nu\left[\mathrm{Wi}_{\mu,\mathrm{i1}}\right]+\partial_\mu\left[\mathrm{Wi}_{\nu,\mathrm{i1}}\right]+g_w\epsilon_{\mathrm{i1,i2,i3}}\mathrm{Wi}_{\mu,\mathrm{i2}}\mathrm{Wi}_{\nu,\mathrm{i3}}\right)\left(-\partial_\nu\left[\mathrm{Wi}_{\mu,\mathrm{i1}}\right]+\partial_\mu\left[\mathrm{Wi}_{\nu,\mathrm{i1}}\right]+g_w\epsilon_{\mathrm{i1,i4,i5}}\mathrm{Wi}_{\mu,\mathrm{i4}}\mathrm{Wi}_{\nu,\mathrm{i5}}\right)$$

4.2 L_2

$$-\frac{1}{2}\mathrm{phihphih}^\dagger(H+v)^2\kappa-\frac{1}{4}(H+v)^4\lambda+\mathrm{phihphih}^\dagger{\mu_H}^2+\frac{1}{2}(H+v)^2{\mu_{\mathrm{SM}}}^2-\mathrm{phih}^2\left(\mathrm{phih}^\dagger\right)^2\rho+\frac{e^2(H+v)^2(\mathrm{Wi}_{\mu,1}-i\mathrm{Wi}_{\mu,2})(\mathrm{Wi}_{\mu,1}+i\mathrm{Wi}_{\mu,2})}{8{s_w}^2}+$$
$$\left(\frac{e(H+v)B_\mu}{2\sqrt{2}c_w}-\frac{i\partial_\mu[H]}{\sqrt{2}}-\frac{e(H+v)\mathrm{Wi}_{\mu,3}}{2\sqrt{2}s_w}\right)\left(\frac{e(H+v)B_\mu}{2\sqrt{2}c_w}+\frac{i\partial_\mu[H]}{\sqrt{2}}-\frac{e(H+v)\mathrm{Wi}_{\mu,3}}{2\sqrt{2}s_w}\right)+\left(\partial_\mu[\mathrm{phih}]-ig_X\mathrm{phih}X_\mu\right)\left(\partial_\mu\left[\mathrm{phih}^\dagger\right]+ig_X\mathrm{phih}^\dagger X_\mu\right)$$

4.3 L_3

$$-\frac{(H+v)\bar{\mathrm{dq}}_{\mathrm{s\$1234,n\$1234,i\$1234}}.\mathrm{dq}_{\mathrm{r\$1234,n\$1234,i\$1234}}P_{+\mathrm{s\$1234,r\$1234}}\mathrm{yd}_{\mathrm{n\$1234}}}{\sqrt{2}}-\frac{(H+v)\bar{\mathrm{dq}}_{\mathrm{r\$1236,n\$1235,i\$1235}}.\mathrm{dq}_{\mathrm{r\$1237,n\$1235,i\$1235}}P_{-\mathrm{r\$1236,r\$1237}}\mathrm{yd}_{\mathrm{n\$1235}}}{\sqrt{2}}-$$
$$\frac{(H+v)\,\bar{l}_{\mathrm{s\$1234,n\$1234}}.l_{\mathrm{r\$1234,n\$1234}}P_{+\mathrm{s\$1234,r\$1234}}\mathrm{yl}_{\mathrm{n\$1234}}}{\sqrt{2}}-\frac{(H+v)\,\bar{l}_{\mathrm{r\$1238,n\$1235}}.l_{\mathrm{r\$1239,n\$1235}}P_{-\mathrm{r\$1238,r\$1239}}\mathrm{yl}_{\mathrm{n\$1235}}}{\sqrt{2}}-$$
$$\frac{(H+v)\bar{\mathrm{uq}}_{\mathrm{s\$1234,n\$1234,i\$1234}}.\mathrm{uq}_{\mathrm{r\$1234,n\$1234,i\$1234}}P_{+\mathrm{s\$1234,r\$1234}}\mathrm{yu}_{\mathrm{n\$1234}}}{\sqrt{2}}-\frac{(H+v)\bar{\mathrm{uq}}_{\mathrm{r\$1240,n\$1235,i\$1235}}.\mathrm{uq}_{\mathrm{r\$1241,n\$1235,i\$1235}}P_{-\mathrm{r\$1240,r\$1241}}\mathrm{yu}_{\mathrm{n\$1235}}}{\sqrt{2}}$$

4.4 L_4

$$i\bar{\mathrm{dq}}.\gamma^\mu.\partial_\mu[\mathrm{dq}]+i\,\bar{l}.\gamma^\mu.\partial_\mu[l]+i\bar{\mathrm{uq}}.\gamma^\mu.\partial_\mu[\mathrm{uq}]+i\bar{\mathrm{vl}}.\gamma^\mu.\partial_\mu[\mathrm{vl}]+\frac{eB_\mu\bar{\mathrm{dq}}.\gamma^\mu.P_-.\mathrm{dq}}{6c_w}-\frac{eB_\mu\bar{\mathrm{dq}}.\gamma^\mu.P_+.\mathrm{dq}}{3c_w}-\frac{eB_\mu\,\bar{l}.\gamma^\mu.P_-.l}{2c_w}-\frac{eB_\mu\,\bar{l}.\gamma^\mu.P_+.l}{c_w}+$$
$$\frac{eB_\mu\bar{\mathrm{uq}}.\gamma^\mu.P_-.\mathrm{uq}}{6c_w}+\frac{2eB_\mu\bar{\mathrm{uq}}.\gamma^\mu.P_+.\mathrm{uq}}{3c_w}-\frac{eB_\mu\bar{\mathrm{vl}}.\gamma^\mu.P_-.\mathrm{vl}}{2c_w}+g_s\left(\bar{\mathrm{dq}}.T^a.\gamma^\mu.\mathrm{dq}+\bar{\mathrm{uq}}.T^a.\gamma^\mu.\mathrm{uq}\right)G_{\mu,a}+$$
$$\frac{e\Big(\sqrt{2}\bar{\mathrm{vl}}.\gamma^\mu.P_-.lW_\mu+\sqrt{2}\bar{\mathrm{uq}}.\mathrm{CKM}.\gamma^\mu.P_-.\mathrm{dq}W_\mu+\sqrt{2}\,\bar{l}.\gamma^\mu.P_-.\mathrm{vl}{W_\mu}^\dagger+\sqrt{2}\bar{\mathrm{dq}}.\mathrm{CKM}^\dagger.\gamma^\mu.P_-.\mathrm{uq}{W_\mu}^\dagger-\bar{\mathrm{dq}}.\gamma^\mu.P_-.\mathrm{dq}\mathrm{Wi}_{\mu,3}-\bar{l}.\gamma^\mu.P_-.l\mathrm{Wi}_{\mu,3}+\bar{\mathrm{uq}}.\gamma^\mu.P_-.\mathrm{uq}\mathrm{Wi}_{\mu,3}+\bar{\mathrm{vl}}.}{2s_w}$$

5 Parameters

In this section, we describe the parameters of our model implementation.

5.1 External Parameters

In this subsection, we describe the external parameters of our model. The details of the external parameters can be found in

P	C	I	V	D	PN	BN	OB	IO	Description
αEWM1	F		127.9		aEWM1	SMINPUTS		QED, -2	Inverse of the electroweak coupling constant
Gf	F		0.0000116639			SMINPUTS		QED, 2	Fermi constant
αS	F		0.118		aS	SMINPUTS		QCD, 2	Strong coupling constant at the Z pole.
ymc	F		0.			YUKAWA	4		Charm Yukawa mass
ymb	F		4.7			YUKAWA	5		Bottom Yukawa mass
ymt	F		174.3			YUKAWA	6		Top Yukawa mass
ymtau	F		1.777			YUKAWA	15		Tau Yukawa mass
λ	F		0.42568		l	HIGGS		QED, 2	SM Higgs self-coupling
θ_c	F		0.488			CKMBLOCK	1		Cabibbo angle
αXM1	F		127.9		aXM1	HIDDEN		QED, -2	Inverse of the U(1)X coupling constant
η	F		0.01		η	HIDDEN			U(1)X - U(1)Y mixing parameter
ρ	F		0.010142		ρ	HIDDEN		QED, 2	Abelian Higgs self-coupling
κ	F		0.0977392		kap	HIDDEN		QED, 2	Coupling between the abelian and the SM Higgs

Table 9: Details of external parameters. The headers are as follows: P = parameter, C = complex, I = indices, V = value, D = definition, PN = parameter name, BN = block name, OB = order block, and IO = interaction order.

Table 9.

5.2 Internal Parameters

In this subsection, we describe the internal parameters of our model. The details of the internal parameters can be found

P	C	I	V	NV	D	PN	IO	Description
c_w	F		Eq. 2	0.881903				Cos of the Weinberg angle
s_w	F		Eq. 3	0.47143				Sin of the Weinberg angle
αEW	F		Eq. 4	0.00781861		aEW	QED, 2	Electroweak coupling constant
e	F		Eq. 5	0.313451			QED, 1	Electric coupling constant
g_w	F		Eq. 6	0.664894			QED, 1	Weak coupling constant
g_1	F		Eq. 7	0.355426			QED, 1	U(1)Y coupling constant
g_s	F		Eq. 8	1.21772		G	QCD, 1	Strong coupling constant
αX	F		Eq. 9	0.00781861		aX	QED, 2	U(1)X coupling contant
g_X	F		Eq. 10	0.313451			QED, 1	U(1)X coupling constant
MZ0	F			91.188				Z mass before mixing
MX	F			500.				X mass before mixing
ΔZ	F		Eq. 13	30.0652		DZ		Ratio of scales
v	F		Eq. 14	246.218			QED, -1	SM Higgs VEV
ξ	F		Eq. 15	1595.15		ξ	QED, -1	Abelian Higgs VEV
MH1	F		Eq. 16	115.				Mass of H1
MH2	F		Eq. 17	300.				Mass of H2
${\mu_{\rm SM}}^2$	F		Eq. 18	124656.		muSM2		Quadratic SM potential term
${\mu_H}^2$	F		Eq. 19	544532.		muH2		Quadratic abelian potential term
θ_α	F		Eq. 20	0.000162197		alp		Mixing in the weak sector
c_α	F		Eq. 21	1.				Cosine of alp
s_α	F		Eq. 22	0.000162197				Sine of alp
χ	F		Eq. 23	0.009999		χ		kinetic mixing parameter
θ_h	F		Eq. 24	-0.785398		th		Mixing in the Higgs sector
c_h	F		Eq. 25	0.707107				Cosine of th
s_h	F		Eq. 26	-0.707107				Sine of th
yl	F	f	Eq. 27	$\mathrm{yl}_1 \to 0.$	$\mathrm{yl}_1 \to 0$	$\mathrm{yl}_1 \to$ ye	QED, 1	Lepton Yukawa coupling
				$\mathrm{yl}_2 \to 0.$	$\mathrm{yl}_2 \to 0$	$\mathrm{yl}_2 \to$ ym		
				$\mathrm{yl}_3 \to 0.0102066$		$\mathrm{yl}_3 \to$ ytau		

Table 10: Details of internal parameters. The headers are as follows: P = parameter, C = complex, I = Indices, V = value, NV = numerical value, D = definition, PN = parameter name, and IO = interaction order.

in Tables 10, 11. The values and definitions of the internal parameters will be written below.

$$c_w = \frac{\mathrm{MW}}{\mathrm{MZ}} \tag{2}$$

$$s_w = \sqrt{1 - {c_w}^2} \tag{3}$$

$$\alpha\mathrm{EW} = \frac{1}{\alpha\mathrm{EWM1}} \tag{4}$$

$$e = 2\sqrt{\pi}\sqrt{\alpha\mathrm{EW}} \tag{5}$$

$$g_w = \frac{e}{s_w} \tag{6}$$

P	C	I	V	NV	D	PN	IO	Description
yu	F	f	Eq. 28	$\mathrm{yu}_1 \to 0.$	$\mathrm{yu}_1 \to 0$	$\mathrm{yu}_1 \to \mathrm{yu}$	QED, 1	U-quark Yukawa coupling
				$\mathrm{yu}_2 \to 0.$		$\mathrm{yu}_2 \to \mathrm{yc}$		
				$\mathrm{yu}_3 \to 1.00113$		$\mathrm{yu}_3 \to \mathrm{yt}$		
yd	F	f	Eq. 29	$\mathrm{yd}_1 \to 0.$	$\mathrm{yd}_1 \to 0$	$\mathrm{yd}_1 \to \mathrm{yd}$	QED, 1	D-quark Yukawa coupling
				$\mathrm{yd}_2 \to 0.$	$\mathrm{yd}_2 \to 0$	$\mathrm{yd}_2 \to \mathrm{ys}$		
				$\mathrm{yd}_3 \to 0.0269956$		$\mathrm{yd}_3 \to \mathrm{yb}$		
CKM	F	f, f	Eq. 30	$\mathrm{CKM}_{1,1} \to 0.883272$	$\mathrm{CKM}_{3,3} \to 1$			CKM-Matrix
				$\mathrm{CKM}_{1,2} \to 0.46886$	$\mathrm{CKM}_{i,3} :\to 0/;i \neq 3$			
				$\mathrm{CKM}_{1,3} \to 0.$	$\mathrm{CKM}_{3,i} :\to 0/;i \neq 3$			
				$\mathrm{CKM}_{2,1} \to -0.46886$				
				$\mathrm{CKM}_{2,2} \to 0.883272$				
				$\mathrm{CKM}_{2,3} \to 0.$				
				$\mathrm{CKM}_{3,1} \to 0.$				
				$\mathrm{CKM}_{3,2} \to 0.$				
				$\mathrm{CKM}_{3,3} \to 1.$				

Table 11: Details of internal parameters. The headers are as follows: P = parameter, C = complex, I = Indices, V = value, NV = numerical value, D = definition, PN = parameter name, and IO = interaction order.

$$g_1 = \frac{e}{c_w} \tag{7}$$

$$g_s = 2\sqrt{\pi}\sqrt{\alpha\mathrm{S}} \tag{8}$$

$$\alpha\mathrm{X} = \frac{1}{\alpha\mathrm{XM1}} \tag{9}$$

$$g_X = 2\sqrt{\pi}\sqrt{\alpha\mathrm{X}} \tag{10}$$

$$\mathrm{MZ0} = \mathrm{MZ} \tag{11}$$

$$\mathrm{MX} = \mathrm{MZp} \tag{12}$$

$$\Delta\mathrm{Z} = \frac{\mathrm{MX}^2}{\mathrm{MZ0}^2} \tag{13}$$

$$v = \frac{1}{2^{1/4}\sqrt{\mathrm{Gf}}} \tag{14}$$

$$\xi = \frac{\mathrm{MX}}{g_X} \tag{15}$$

$$\mathrm{MH1} = \sqrt{v^2\lambda + \xi^2\rho - \sqrt{v^2\kappa^2\xi^2 + \left(v^2\lambda - \xi^2\rho\right)^2}} \tag{16}$$

$$\mathrm{MH2} = \sqrt{v^2\lambda + \xi^2\rho + \sqrt{v^2\kappa^2\xi^2 + \left(v^2\lambda - \xi^2\rho\right)^2}} \tag{17}$$

$$\mu_{\mathrm{SM}}{}^2 = \frac{1}{2}\left(\kappa\xi^2 + v^2\rho\right) \tag{18}$$

$$\mu_H{}^2 = \frac{1}{2}\left(v^2\kappa + \lambda\xi^2\right) \tag{19}$$

$$\theta_\alpha = -\frac{1}{2}\text{ArcTan}\left[\frac{2s_w\eta}{1-\Delta\text{Z}-s_w{}^2\eta^2}\right] \tag{20}$$

$$c_\alpha = \text{Cos}\left[\theta_\alpha\right] \tag{21}$$

$$s_\alpha = \text{Sin}\left[\theta_\alpha\right] \tag{22}$$

$$\chi = \frac{-1+\sqrt{1+4\eta^2}}{2\eta} \tag{23}$$

$$\theta_h = \frac{1}{2}\text{ArcTan}\left[\frac{v\kappa\xi}{-v^2\lambda+\xi^2\rho}\right] \tag{24}$$

$$c_h = \text{Cos}\left[\theta_h\right] \tag{25}$$

$$s_h = \text{Sin}\left[\theta_h\right] \tag{26}$$

$$\begin{aligned} \text{yl}_1 &= 0 \\ \text{yl}_2 &= 0 \\ \text{yl}_3 &= \frac{\sqrt{2}\text{ymtau}}{v} \end{aligned} \tag{27}$$

$$\begin{aligned} \text{yu}_1 &= 0 \\ \text{yu}_2 &= \frac{\sqrt{2}\text{ymc}}{v} \\ \text{yu}_3 &= \frac{\sqrt{2}\text{ymt}}{v} \end{aligned} \tag{28}$$

$$\begin{aligned} \text{yd}_1 &= 0 \\ \text{yd}_2 &= 0 \\ \text{yd}_3 &= \frac{\sqrt{2}\text{ymb}}{v} \end{aligned} \tag{29}$$

$$\begin{aligned} \text{CKM}_{1,2} &= \text{Sin}\left[\theta_c\right] \\ \text{CKM}_{1,1} &= \text{Cos}\left[\theta_c\right] \\ \text{CKM}_{2,1} &= -\text{Sin}\left[\theta_c\right] \\ \text{CKM}_{2,2} &= \text{Cos}\left[\theta_c\right] \end{aligned} \tag{30}$$

6 Vertices

In this section, we describe the vertices of our model implementation.

6.1 V_1

$$\begin{pmatrix} \text{h1} & 1 \\ \text{h1} & 2 \\ \text{h2} & 3 \\ \text{h2} & 4 \end{pmatrix} \quad -2ic_h{}^4\kappa + 8ic_h{}^2s_h{}^2\kappa - 2is_h{}^4\kappa - 6ic_h{}^2s_h{}^2\lambda - 24ic_h{}^2s_h{}^2\rho$$

$$\begin{pmatrix} \text{h1} & 1 \\ \text{h1} & 2 \\ \text{h1} & 3 \\ \text{h2} & 4 \end{pmatrix} \quad 6ic_h{}^3s_h\kappa - 6ic_hs_h{}^3\kappa - 6ic_h{}^3s_h\lambda + 24ic_hs_h{}^3\rho$$

$$\begin{pmatrix} \text{h1} & 1 \\ \text{h2} & 2 \\ \text{h2} & 3 \\ \text{h2} & 4 \end{pmatrix} \quad -6ic_h{}^3s_h\kappa + 6ic_hs_h{}^3\kappa - 6ic_hs_h{}^3\lambda + 24ic_h{}^3s_h\rho$$

$$\begin{pmatrix} \text{h1} & 1 \\ \text{h1} & 2 \\ \text{h1} & 3 \\ \text{h1} & 4 \end{pmatrix} \quad -12ic_h{}^2s_h{}^2\kappa - 6ic_h{}^4\lambda - 24is_h{}^4\rho$$

$$\begin{pmatrix} \text{h2} & 1 \\ \text{h2} & 2 \\ \text{h2} & 3 \\ \text{h2} & 4 \end{pmatrix} \quad -12ic_h{}^2s_h{}^2\kappa - 6is_h{}^4\lambda - 24ic_h{}^4\rho$$

$$\begin{pmatrix} \text{h1} & 1 \\ \text{h2} & 2 \\ \text{h2} & 3 \end{pmatrix} \quad -2ic_h{}^3v\kappa + 4ic_hs_h{}^2v\kappa - 6ic_hs_h{}^2v\lambda - 2i\sqrt{2}c_h{}^2s_h\kappa\xi + i\sqrt{2}s_h{}^3\kappa\xi + 12i\sqrt{2}c_h{}^2s_h\xi\rho$$

$$\begin{pmatrix} \text{h1} & 1 \\ \text{h1} & 2 \\ \text{h2} & 3 \end{pmatrix} \quad 4ic_h{}^2s_hv\kappa - 2is_h{}^3v\kappa - 6ic_h{}^2s_hv\lambda - i\sqrt{2}c_h{}^3\kappa\xi + 2i\sqrt{2}c_hs_h{}^2\kappa\xi - 12i\sqrt{2}c_hs_h{}^2\xi\rho$$

$$\begin{pmatrix} \text{h2} & 1 \\ \text{h2} & 2 \\ \text{h2} & 3 \end{pmatrix} \quad -6ic_h{}^2s_hv\kappa - 6is_h{}^3v\lambda - 3i\sqrt{2}c_hs_h{}^2\kappa\xi - 12i\sqrt{2}c_h{}^3\xi\rho$$

$$\begin{pmatrix} \text{h1} & 1 \\ \text{h1} & 2 \\ \text{h1} & 3 \end{pmatrix} \quad -6ic_hs_h{}^2v\kappa - 6ic_h{}^3v\lambda + 3i\sqrt{2}c_h{}^2s_h\kappa\xi + 12i\sqrt{2}s_h{}^3\xi\rho$$

$$\begin{pmatrix} G & 1 \\ \text{ghG}^\dagger & 2 \\ \text{ghG} & 3 \end{pmatrix} \quad g_sf_{\text{a}_1,\text{a}_2,\text{a}_3}\text{p}_1{}^{\mu_1} + g_sf_{\text{a}_1,\text{a}_2,\text{a}_3}\text{p}_3{}^{\mu_1}$$

$$\begin{pmatrix} G & 1 \\ G & 2 \\ G & 3 \end{pmatrix} \quad g_sf_{\text{a}_1,\text{a}_2,\text{a}_3}\text{p}_1{}^{\mu_3}\eta_{\mu_1,\mu_2} - g_sf_{\text{a}_1,\text{a}_2,\text{a}_3}\text{p}_2{}^{\mu_3}\eta_{\mu_1,\mu_2} - g_sf_{\text{a}_1,\text{a}_2,\text{a}_3}\text{p}_1{}^{\mu_2}\eta_{\mu_1,\mu_3} + g_sf_{\text{a}_1,\text{a}_2,\text{a}_3}\text{p}_3{}^{\mu_2}\eta_{\mu_1,\mu_3} + g_sf_{\text{a}_1,\text{a}_2,\text{a}_3}\text{p}_2{}^{\mu_1}\eta_{\mu_2,\mu_3} - g_sf_{\text{a}_1,\text{a}_2,\text{a}_3}\text{p}_3{}^{\mu_1}\eta_{\mu_2,\mu_3}$$

$$\begin{pmatrix} G & 1 \\ G & 2 \\ G & 3 \\ G & 4 \end{pmatrix} \quad ig_s{}^2f_{\text{a}_1,\text{a}_3,\text{a}1}f_{\text{a}_2,\text{a}_4,\text{a}1}\eta_{\mu_1,\mu_4}\eta_{\mu_2,\mu_3} + ig_s{}^2f_{\text{a}_1,\text{a}_2,\text{a}1}f_{\text{a}_3,\text{a}_4,\text{a}1}\eta_{\mu_1,\mu_4}\eta_{\mu_2,\mu_3} + ig_s{}^2f_{\text{a}_1,\text{a}_4,\text{a}1}f_{\text{a}_2,\text{a}_3,\text{a}1}\eta_{\mu_1,\mu_3}\eta_{\mu_2,\mu_4} - ig_s{}^2f_{\text{a}_1,\text{a}_2,\text{a}1}f_{\text{a}_3,\text{a}_4,\text{a}1}\eta_{\mu_1,\mu_3}\eta_{\mu_2,\mu_4} - ig_s{}^2f_{\text{a}_1,\text{a}_4,\text{a}1}f_{\text{a}_2,\text{a}_3,\text{a}1}\eta_{\mu_1,\mu_2}\eta_{\mu_3,\mu_4} - ig_s{}^2f_{\text{a}_1,\text{a}_3,\text{a}1}f_{\text{a}_2,\text{a}_4,\text{a}1}\eta_{\mu_1,\mu_2}\eta_{\mu_3,\mu_4}$$

$$\begin{pmatrix} \mathrm{dq} & 1 \\ \bar{\mathrm{dq}} & 2 \\ G & 3 \end{pmatrix} \quad ig_s\gamma_{\mathrm{s}_2,\mathrm{s}_1}{}^{\mu_3}\delta_{\mathrm{f}_1,\mathrm{f}_2}T_{\mathrm{i}_2,\mathrm{i}_1}{}^{\mathrm{a}_3}$$

$$\begin{pmatrix} G & 1 \\ \mathrm{uq} & 2 \\ \bar{\mathrm{uq}} & 3 \end{pmatrix} \quad ig_s\gamma_{\mathrm{s}_3,\mathrm{s}_2}{}^{\mu_1}\delta_{\mathrm{f}_2,\mathrm{f}_3}T_{\mathrm{i}_3,\mathrm{i}_2}{}^{\mathrm{a}_1}$$

$$\begin{pmatrix} A & 1 \\ W & 2 \\ W^\dagger & 3 \end{pmatrix} \quad -ig_w s_w \mathrm{p}_1{}^{\mu_3}\eta_{\mu_1,\mu_2} + ig_w s_w \mathrm{p}_2{}^{\mu_3}\eta_{\mu_1,\mu_2} + ig_w s_w \mathrm{p}_1{}^{\mu_2}\eta_{\mu_1,\mu_3} - ig_w s_w \mathrm{p}_3{}^{\mu_2}\eta_{\mu_1,\mu_3} - ig_w s_w \mathrm{p}_2{}^{\mu_1}\eta_{\mu_2,\mu_3} + ig_w s_w \mathrm{p}_3{}^{\mu_1}\eta_{\mu_2,\mu_3}$$

$$\begin{pmatrix} \mathrm{h1} & 1 \\ \mathrm{h1} & 2 \\ W & 3 \\ W^\dagger & 4 \end{pmatrix} \quad \frac{ic_h{}^2 e^2 \eta_{\mu_3,\mu_4}}{2{s_w}^2}$$

$$\begin{pmatrix} \mathrm{h1} & 1 \\ \mathrm{h2} & 2 \\ W & 3 \\ W^\dagger & 4 \end{pmatrix} \quad \frac{ic_h e^2 s_h \eta_{\mu_3,\mu_4}}{2{s_w}^2}$$

$$\begin{pmatrix} \mathrm{h2} & 1 \\ \mathrm{h2} & 2 \\ W & 3 \\ W^\dagger & 4 \end{pmatrix} \quad \frac{ie^2 {s_h}^2 \eta_{\mu_3,\mu_4}}{2{s_w}^2}$$

$$\begin{pmatrix} \mathrm{h1} & 1 \\ W & 2 \\ W^\dagger & 3 \end{pmatrix} \quad \frac{ic_h e^2 v \eta_{\mu_2,\mu_3}}{2{s_w}^2}$$

$$\begin{pmatrix} \mathrm{h2} & 1 \\ W & 2 \\ W^\dagger & 3 \end{pmatrix} \quad \frac{ie^2 s_h v \eta_{\mu_2,\mu_3}}{2{s_w}^2}$$

$$\begin{pmatrix} A & 1 \\ A & 2 \\ W & 3 \\ W^\dagger & 4 \end{pmatrix} \quad ig_w{}^2 s_w{}^2 \eta_{\mu_1,\mu_4}\eta_{\mu_2,\mu_3} + ig_w{}^2 s_w{}^2 \eta_{\mu_1,\mu_3}\eta_{\mu_2,\mu_4} - 2ig_w{}^2 s_w{}^2 \eta_{\mu_1,\mu_2}\eta_{\mu_3,\mu_4}$$

$$\begin{pmatrix} W & 1 \\ W^\dagger & 2 \\ Z & 3 \end{pmatrix} \quad -ic_\alpha c_w g_w \mathrm{p}_1{}^{\mu_3}\eta_{\mu_1,\mu_2} + ic_\alpha c_w g_w \mathrm{p}_2{}^{\mu_3}\eta_{\mu_1,\mu_2} + ic_\alpha c_w g_w \mathrm{p}_1{}^{\mu_2}\eta_{\mu_1,\mu_3} - ic_\alpha c_w g_w \mathrm{p}_3{}^{\mu_2}\eta_{\mu_1,\mu_3} - ic_\alpha c_w g_w \mathrm{p}_2{}^{\mu_1}\eta_{\mu_2,\mu_3} + ic_\alpha c_w g_w \mathrm{p}_3{}^{\mu_1}\eta_{\mu_2,\mu_3}$$

$$\begin{pmatrix} W & 1 \\ W^\dagger & 2 \\ \mathrm{Zp} & 3 \end{pmatrix} \quad ic_w g_w s_\alpha \mathrm{p}_1{}^{\mu_3}\eta_{\mu_1,\mu_2} - ic_w g_w s_\alpha \mathrm{p}_2{}^{\mu_3}\eta_{\mu_1,\mu_2} - ic_w g_w s_\alpha \mathrm{p}_1{}^{\mu_2}\eta_{\mu_1,\mu_3} + ic_w g_w s_\alpha \mathrm{p}_3{}^{\mu_2}\eta_{\mu_1,\mu_3} + ic_w g_w s_\alpha \mathrm{p}_2{}^{\mu_1}\eta_{\mu_2,\mu_3} - ic_w g_w s_\alpha \mathrm{p}_3{}^{\mu_1}\eta_{\mu_2,\mu_3}$$

$$\begin{pmatrix} W & 1 \\ W & 2 \\ W^\dagger & 3 \\ W^\dagger & 4 \end{pmatrix} \quad -ig_w{}^2 \eta_{\mu_1,\mu_4}\eta_{\mu_2,\mu_3} - ig_w{}^2 \eta_{\mu_1,\mu_3}\eta_{\mu_2,\mu_4} + 2ig_w{}^2 \eta_{\mu_1,\mu_2}\eta_{\mu_3,\mu_4}$$

$$\begin{pmatrix} \mathrm{dq} & 1 \\ \bar{\mathrm{dq}} & 2 \\ \mathrm{h1} & 3 \end{pmatrix} \quad -\frac{ic_h \delta_{\mathrm{i}_1,\mathrm{i}_2}\delta_{\mathrm{f}_1,\mathrm{f}_2}\delta_{\mathrm{s}_2,\mathrm{s}_1}\mathrm{yd}_{\mathrm{f}_1}}{\sqrt{2}}$$

$$\begin{pmatrix} \mathrm{dq} & 1 \\ \bar{\mathrm{dq}} & 2 \\ \mathrm{h2} & 3 \end{pmatrix} \quad -\frac{is_h \delta_{\mathrm{i}_1,\mathrm{i}_2} \delta_{\mathrm{f}_1,\mathrm{f}_2} \delta_{\mathrm{s}_2,\mathrm{s}_1} \mathrm{yd}_{\mathrm{f}_1}}{\sqrt{2}}$$

$$\begin{pmatrix} \mathrm{h1} & 1 \\ l & 2 \\ \bar{l} & 3 \end{pmatrix} \quad -\frac{ic_h \delta_{\mathrm{f}_2,\mathrm{f}_3} \delta_{\mathrm{s}_3,\mathrm{s}_2} \mathrm{yl}_{\mathrm{f}_2}}{\sqrt{2}}$$

$$\begin{pmatrix} \mathrm{h2} & 1 \\ l & 2 \\ \bar{l} & 3 \end{pmatrix} \quad -\frac{is_h \delta_{\mathrm{f}_2,\mathrm{f}_3} \delta_{\mathrm{s}_3,\mathrm{s}_2} \mathrm{yl}_{\mathrm{f}_2}}{\sqrt{2}}$$

$$\begin{pmatrix} \mathrm{h1} & 1 \\ \mathrm{uq} & 2 \\ \bar{\mathrm{uq}} & 3 \end{pmatrix} \quad -\frac{ic_h \delta_{\mathrm{i}_2,\mathrm{i}_3} \delta_{\mathrm{f}_2,\mathrm{f}_3} \delta_{\mathrm{s}_3,\mathrm{s}_2} \mathrm{yu}_{\mathrm{f}_2}}{\sqrt{2}}$$

$$\begin{pmatrix} \mathrm{h2} & 1 \\ \mathrm{uq} & 2 \\ \bar{\mathrm{uq}} & 3 \end{pmatrix} \quad -\frac{is_h \delta_{\mathrm{i}_2,\mathrm{i}_3} \delta_{\mathrm{f}_2,\mathrm{f}_3} \delta_{\mathrm{s}_3,\mathrm{s}_2} \mathrm{yu}_{\mathrm{f}_2}}{\sqrt{2}}$$

$$\begin{pmatrix} A & 1 \\ W & 2 \\ W^\dagger & 3 \\ Z & 4 \end{pmatrix} \quad -2ic_\alpha c_w {g_w}^2 s_w \eta_{\mu_1,\mu_4} \eta_{\mu_2,\mu_3} + ic_\alpha c_w {g_w}^2 s_w \eta_{\mu_1,\mu_3} \eta_{\mu_2,\mu_4} + ic_\alpha c_w {g_w}^2 s_w \eta_{\mu_1,\mu_2} \eta_{\mu_3,\mu_4}$$

$$\begin{pmatrix} \mathrm{h1} & 1 \\ \mathrm{h1} & 2 \\ Z & 3 \\ Z & 4 \end{pmatrix} \quad ic_\alpha{}^2 c_h{}^2 e^2 \eta_{\mu_3,\mu_4} + \frac{ic_\alpha{}^2 c_h{}^2 c_w{}^2 e^2 \eta_{\mu_3,\mu_4}}{2{s_w}^2} + \frac{ic_\alpha{}^2 c_h{}^2 e^2 {s_w}^2 \eta_{\mu_3,\mu_4}}{2{c_w}^2} - \frac{ic_\alpha c_h{}^2 e^2 s_\alpha \eta\eta_{\mu_3,\mu_4}}{s_w} - \frac{ic_\alpha c_h{}^2 e^2 s_\alpha s_w \eta\eta_{\mu_3,\mu_4}}{{c_w}^2} + \frac{ic_h{}^2 e^2 s_\alpha{}^2 \eta^2 \eta_{\mu_3,\mu_4}}{2{c_w}^2} + 4ig_X{}^2 s_\alpha{}^2 s_h{}^2 \eta^2 \chi^2 \eta_{\mu_3,\mu_4}$$

$$\begin{pmatrix} \mathrm{h1} & 1 \\ \mathrm{h2} & 2 \\ Z & 3 \\ Z & 4 \end{pmatrix} \quad ic_\alpha{}^2 c_h e^2 s_h \eta_{\mu_3,\mu_4} + \frac{ic_\alpha{}^2 c_h c_w{}^2 e^2 s_h \eta_{\mu_3,\mu_4}}{2{s_w}^2} + \frac{ic_\alpha{}^2 c_h e^2 s_h {s_w}^2 \eta_{\mu_3,\mu_4}}{2{c_w}^2} - \frac{ic_\alpha c_h e^2 s_\alpha s_h \eta\eta_{\mu_3,\mu_4}}{s_w} - \frac{ic_\alpha c_h e^2 s_\alpha s_h s_w \eta\eta_{\mu_3,\mu_4}}{{c_w}^2} + \frac{ic_h e^2 s_\alpha{}^2 s_h \eta^2 \eta_{\mu_3,\mu_4}}{2{c_w}^2} - 4ic_h g_X{}^2 s_\alpha{}^2 s_h \eta^2 \chi^2 \eta_{\mu_3,\mu_4}$$

$$\begin{pmatrix} \mathrm{h2} & 1 \\ \mathrm{h2} & 2 \\ Z & 3 \\ Z & 4 \end{pmatrix} \quad ic_\alpha{}^2 e^2 s_h{}^2 \eta_{\mu_3,\mu_4} + \frac{ic_\alpha{}^2 c_w{}^2 e^2 s_h{}^2 \eta_{\mu_3,\mu_4}}{2{s_w}^2} + \frac{ic_\alpha{}^2 e^2 s_h{}^2 {s_w}^2 \eta_{\mu_3,\mu_4}}{2{c_w}^2} - \frac{ic_\alpha e^2 s_\alpha s_h{}^2 \eta\eta_{\mu_3,\mu_4}}{s_w} - \frac{ic_\alpha e^2 s_\alpha s_h{}^2 s_w \eta\eta_{\mu_3,\mu_4}}{{c_w}^2} + \frac{ie^2 s_\alpha{}^2 s_h{}^2 \eta^2 \eta_{\mu_3,\mu_4}}{2{c_w}^2} + 4ic_h{}^2 g_X{}^2 s_\alpha{}^2 \eta^2 \chi^2 \eta_{\mu_3,\mu_4}$$

$$\begin{pmatrix} \mathrm{h1} & 1 \\ Z & 2 \\ Z & 3 \end{pmatrix} \quad ic_\alpha{}^2 c_h e^2 v \eta_{\mu_2,\mu_3} + \frac{ic_\alpha{}^2 c_h c_w{}^2 e^2 v \eta_{\mu_2,\mu_3}}{2{s_w}^2} + \frac{ic_\alpha{}^2 c_h e^2 {s_w}^2 v \eta_{\mu_2,\mu_3}}{2{c_w}^2} - \frac{ic_\alpha c_h e^2 s_\alpha v \eta\eta_{\mu_2,\mu_3}}{s_w} - \frac{ic_\alpha c_h e^2 s_\alpha s_w v \eta\eta_{\mu_2,\mu_3}}{{c_w}^2} + \frac{ic_h e^2 s_\alpha{}^2 v \eta^2 \eta_{\mu_2,\mu_3}}{2{c_w}^2} - 2i\sqrt{2} g_X{}^2 s_\alpha{}^2 s_h \eta^2 \xi \chi^2 \eta_{\mu_2,\mu_3}$$

$$\begin{pmatrix} \mathrm{h2} & 1 \\ Z & 2 \\ Z & 3 \end{pmatrix} \quad ic_\alpha{}^2 e^2 s_h v \eta_{\mu_2,\mu_3} + \frac{ic_\alpha{}^2 c_w{}^2 e^2 s_h v \eta_{\mu_2,\mu_3}}{2{s_w}^2} + \frac{ic_\alpha{}^2 e^2 s_h {s_w}^2 v \eta_{\mu_2,\mu_3}}{2{c_w}^2} - \frac{ic_\alpha e^2 s_\alpha s_h v \eta\eta_{\mu_2,\mu_3}}{s_w} - \frac{ic_\alpha e^2 s_\alpha s_h s_w v \eta\eta_{\mu_2,\mu_3}}{{c_w}^2} + \frac{ie^2 s_\alpha{}^2 s_h v \eta^2 \eta_{\mu_2,\mu_3}}{2{c_w}^2} + 2i\sqrt{2} c_h g_X{}^2 s_\alpha{}^2 \eta^2 \xi \chi^2 \eta_{\mu_2,\mu_3}$$

$$\begin{pmatrix} W & 1 \\ W^\dagger & 2 \\ Z & 3 \\ Z & 4 \end{pmatrix} \quad ic_\alpha{}^2 c_w{}^2 {g_w}^2 \eta_{\mu_1,\mu_4} \eta_{\mu_2,\mu_3} + ic_\alpha{}^2 c_w{}^2 {g_w}^2 \eta_{\mu_1,\mu_3} \eta_{\mu_2,\mu_4} - 2ic_\alpha{}^2 c_w{}^2 {g_w}^2 \eta_{\mu_1,\mu_2} \eta_{\mu_3,\mu_4}$$

$$\begin{pmatrix} A & 1 \\ W & 2 \\ W^\dagger & 3 \\ \mathrm{Zp} & 4 \end{pmatrix} \quad 2ic_w {g_w}^2 s_\alpha s_w \eta_{\mu_1,\mu_4} \eta_{\mu_2,\mu_3} - ic_w {g_w}^2 s_\alpha s_w \eta_{\mu_1,\mu_3} \eta_{\mu_2,\mu_4} - ic_w {g_w}^2 s_\alpha s_w \eta_{\mu_1,\mu_2} \eta_{\mu_3,\mu_4}$$

$$\begin{pmatrix} \mathrm{h1} & 1 \\ \mathrm{h1} & 2 \\ Z & 3 \\ \mathrm{Zp} & 4 \end{pmatrix} \quad -ic_\alpha {c_h}^2 e^2 s_\alpha \eta_{\mu_3,\mu_4} - \frac{ic_\alpha {c_h}^2 {c_w}^2 e^2 s_\alpha \eta_{\mu_3,\mu_4}}{2{s_w}^2} - \frac{ic_\alpha {c_h}^2 e^2 s_\alpha {s_w}^2 \eta_{\mu_3,\mu_4}}{2{c_w}^2} - \frac{ic_\alpha {c_h}^2 e^2 \eta\eta_{\mu_3,\mu_4}}{2s_w} + \frac{ic_h {}^2 e^2 {s_\alpha}^2 \eta\eta_{\mu_3,\mu_4}}{2s_w} - \frac{ic_\alpha {c_h}^2 e^2 s_w \eta\eta_{\mu_3,\mu_4}}{2{c_w}^2} + \frac{ic_h {}^2 e^2 {s_\alpha}^2 s_w \eta\eta_{\mu_3,\mu_4}}{2{c_w}^2} + \frac{ic_\alpha {c_h}^2 e^2 s_\alpha \eta^2 \eta_{\mu_3,\mu_4}}{2{c_w}^2} + 4ic_\alpha {g_X}^2 s_\alpha {s_h}^2 \eta^2 \chi^2 \eta_{\mu_3,\mu_4}$$

$$\begin{pmatrix} \mathrm{h1} & 1 \\ \mathrm{h2} & 2 \\ Z & 3 \\ \mathrm{Zp} & 4 \end{pmatrix} \quad -ic_\alpha c_h e^2 s_\alpha s_h \eta_{\mu_3,\mu_4} - \frac{ic_\alpha c_h {c_w}^2 e^2 s_\alpha s_h \eta_{\mu_3,\mu_4}}{2{s_w}^2} - \frac{ic_\alpha c_h e^2 s_\alpha s_h {s_w}^2 \eta_{\mu_3,\mu_4}}{2{c_w}^2} - \frac{ic_\alpha {}^2 c_h e^2 s_h \eta\eta_{\mu_3,\mu_4}}{2s_w} + \frac{ic_h e^2 {s_\alpha}^2 s_h \eta\eta_{\mu_3,\mu_4}}{2s_w} - \frac{ic_\alpha {}^2 c_h e^2 s_h s_w \eta\eta_{\mu_3,\mu_4}}{2{c_w}^2} + \frac{ic_h e^2 {s_\alpha}^2 s_h s_w \eta\eta_{\mu_3,\mu_4}}{2{c_w}^2} + \frac{ic_\alpha c_h e^2 s_\alpha s_h \eta^2 \eta_{\mu_3,\mu_4}}{2{c_w}^2} - 4ic_\alpha c_h {g_X}^2 s_\alpha s_h \eta^2 \chi^2 \eta_{\mu_3,\mu_4}$$

$$\begin{pmatrix} \mathrm{h2} & 1 \\ \mathrm{h2} & 2 \\ Z & 3 \\ \mathrm{Zp} & 4 \end{pmatrix} \quad -ic_\alpha e^2 s_\alpha {s_h}^2 \eta_{\mu_3,\mu_4} - \frac{ic_\alpha {c_w}^2 e^2 s_\alpha {s_h}^2 \eta_{\mu_3,\mu_4}}{2{s_w}^2} - \frac{ic_\alpha e^2 s_\alpha {s_h}^2 {s_w}^2 \eta_{\mu_3,\mu_4}}{2{c_w}^2} - \frac{ic_\alpha {}^2 e^2 {s_h}^2 \eta\eta_{\mu_3,\mu_4}}{2s_w} + \frac{ie^2 {s_\alpha}^2 {s_h}^2 \eta\eta_{\mu_3,\mu_4}}{2s_w} - \frac{ic_\alpha {}^2 e^2 {s_h}^2 s_w \eta\eta_{\mu_3,\mu_4}}{2{c_w}^2} + \frac{ie^2 {s_\alpha}^2 {s_h}^2 s_w \eta\eta_{\mu_3,\mu_4}}{2{c_w}^2} + \frac{ic_\alpha e^2 s_\alpha {s_h}^2 \eta^2 \eta_{\mu_3,\mu_4}}{2{c_w}^2} + 4ic_\alpha {c_h}^2 {g_X}^2 s_\alpha \eta^2 \chi^2 \eta_{\mu_3,\mu_4}$$

$$\begin{pmatrix} \mathrm{h1} & 1 \\ Z & 2 \\ \mathrm{Zp} & 3 \end{pmatrix} \quad -ic_\alpha c_h e^2 s_\alpha v \eta_{\mu_2,\mu_3} - \frac{ic_\alpha c_h {c_w}^2 e^2 s_\alpha v \eta_{\mu_2,\mu_3}}{2{s_w}^2} - \frac{ic_\alpha c_h e^2 s_\alpha {s_w}^2 v \eta_{\mu_2,\mu_3}}{2{c_w}^2} - \frac{ic_\alpha {}^2 c_h e^2 v \eta\eta_{\mu_2,\mu_3}}{2s_w} + \frac{ic_h e^2 {s_\alpha}^2 v \eta\eta_{\mu_2,\mu_3}}{2s_w} - \frac{ic_\alpha {}^2 c_h e^2 s_w v \eta\eta_{\mu_2,\mu_3}}{2{c_w}^2} + \frac{ic_h e^2 {s_\alpha}^2 s_w v \eta\eta_{\mu_2,\mu_3}}{2{c_w}^2} + \frac{ic_\alpha c_h e^2 s_\alpha v \eta^2 \eta_{\mu_2,\mu_3}}{2{c_w}^2} - 2i\sqrt{2} c_\alpha {g_X}^2 s_\alpha s_h \eta^2 \xi \chi^2 \eta_{\mu_2,\mu_3}$$

$$\begin{pmatrix} \mathrm{h2} & 1 \\ Z & 2 \\ \mathrm{Zp} & 3 \end{pmatrix} \quad -ic_\alpha e^2 s_\alpha s_h v \eta_{\mu_2,\mu_3} - \frac{ic_\alpha {c_w}^2 e^2 s_\alpha s_h v \eta_{\mu_2,\mu_3}}{2{s_w}^2} - \frac{ic_\alpha e^2 s_\alpha s_h {s_w}^2 v \eta_{\mu_2,\mu_3}}{2{c_w}^2} - \frac{ic_\alpha {}^2 e^2 s_h v \eta\eta_{\mu_2,\mu_3}}{2s_w} + \frac{ie^2 {s_\alpha}^2 s_h v \eta\eta_{\mu_2,\mu_3}}{2s_w} - \frac{ic_\alpha {}^2 e^2 s_h s_w v \eta\eta_{\mu_2,\mu_3}}{2{c_w}^2} + \frac{ie^2 {s_\alpha}^2 s_h s_w v \eta\eta_{\mu_2,\mu_3}}{2{c_w}^2} + \frac{ic_\alpha e^2 s_\alpha s_h v \eta^2 \eta_{\mu_2,\mu_3}}{2{c_w}^2} + 2i\sqrt{2} c_\alpha c_h {g_X}^2 s_\alpha \eta^2 \xi \chi^2 \eta_{\mu_2,\mu_3}$$

$$\begin{pmatrix} W & 1 \\ W^\dagger & 2 \\ Z & 3 \\ \mathrm{Zp} & 4 \end{pmatrix} \quad -ic_\alpha {c_w}^2 {g_w}^2 s_\alpha \eta_{\mu_1,\mu_4} \eta_{\mu_2,\mu_3} - ic_\alpha {c_w}^2 {g_w}^2 s_\alpha \eta_{\mu_1,\mu_3} \eta_{\mu_2,\mu_4} + 2ic_\alpha {c_w}^2 {g_w}^2 s_\alpha \eta_{\mu_1,\mu_2} \eta_{\mu_3,\mu_4}$$

$$\begin{pmatrix} \mathrm{h1} & 1 \\ \mathrm{h1} & 2 \\ \mathrm{Zp} & 3 \\ \mathrm{Zp} & 4 \end{pmatrix} \quad ic_h {}^2 e^2 {s_\alpha}^2 \eta_{\mu_3,\mu_4} + \frac{ic_h {}^2 {c_w}^2 e^2 {s_\alpha}^2 \eta_{\mu_3,\mu_4}}{2{s_w}^2} + \frac{ic_h {}^2 e^2 {s_\alpha}^2 {s_w}^2 \eta_{\mu_3,\mu_4}}{2{c_w}^2} + \frac{ic_\alpha {c_h}^2 e^2 s_\alpha \eta\eta_{\mu_3,\mu_4}}{s_w} + \frac{ic_\alpha {c_h}^2 e^2 s_\alpha s_w \eta\eta_{\mu_3,\mu_4}}{{c_w}^2} + \frac{ic_\alpha {}^2 {c_h}^2 e^2 \eta^2 \eta_{\mu_3,\mu_4}}{2{c_w}^2} + 4ic_\alpha {}^2 {g_X}^2 {s_h}^2 \eta^2 \chi^2 \eta_{\mu_3,\mu_4}$$

$$\begin{pmatrix} \mathrm{h1} & 1 \\ \mathrm{h2} & 2 \\ \mathrm{Zp} & 3 \\ \mathrm{Zp} & 4 \end{pmatrix} \quad ic_h e^2 {s_\alpha}^2 s_h \eta_{\mu_3,\mu_4} + \frac{ic_h {c_w}^2 e^2 {s_\alpha}^2 s_h \eta_{\mu_3,\mu_4}}{2{s_w}^2} + \frac{ic_h e^2 {s_\alpha}^2 s_h {s_w}^2 \eta_{\mu_3,\mu_4}}{2{c_w}^2} + \frac{ic_\alpha c_h e^2 s_\alpha s_h \eta\eta_{\mu_3,\mu_4}}{s_w} + \frac{ic_\alpha c_h e^2 s_\alpha s_h s_w \eta\eta_{\mu_3,\mu_4}}{{c_w}^2} + \frac{ic_\alpha {}^2 c_h e^2 s_h \eta^2 \eta_{\mu_3,\mu_4}}{2{c_w}^2} - 4ic_\alpha {}^2 c_h {g_X}^2 s_h \eta^2 \chi^2 \eta_{\mu_3,\mu_4}$$

$$\begin{pmatrix} \mathrm{h2} & 1 \\ \mathrm{h2} & 2 \\ \mathrm{Zp} & 3 \\ \mathrm{Zp} & 4 \end{pmatrix} \quad ie^2 {s_\alpha}^2 {s_h}^2 \eta_{\mu_3,\mu_4} + \frac{ic_w {}^2 e^2 {s_\alpha}^2 {s_h}^2 \eta_{\mu_3,\mu_4}}{2{s_w}^2} + \frac{ie^2 {s_\alpha}^2 {s_h}^2 {s_w}^2 \eta_{\mu_3,\mu_4}}{2{c_w}^2} + \frac{ic_\alpha e^2 s_\alpha {s_h}^2 \eta\eta_{\mu_3,\mu_4}}{s_w} + \frac{ic_\alpha e^2 s_\alpha {s_h}^2 s_w \eta\eta_{\mu_3,\mu_4}}{{c_w}^2} + \frac{ic_\alpha {}^2 e^2 {s_h}^2 \eta^2 \eta_{\mu_3,\mu_4}}{2{c_w}^2} + 4ic_\alpha {}^2 {c_h}^2 {g_X}^2 \eta^2 \chi^2 \eta_{\mu_3,\mu_4}$$

$$\begin{pmatrix} \mathrm{h1} & 1 \\ \mathrm{Zp} & 2 \\ \mathrm{Zp} & 3 \end{pmatrix} \quad ic_h e^2 {s_\alpha}^2 v \eta_{\mu_2,\mu_3} + \frac{ic_h {c_w}^2 e^2 {s_\alpha}^2 v \eta_{\mu_2,\mu_3}}{2{s_w}^2} + \frac{ic_h e^2 {s_\alpha}^2 {s_w}^2 v \eta_{\mu_2,\mu_3}}{2{c_w}^2} + \frac{ic_\alpha c_h e^2 s_\alpha v \eta\eta_{\mu_2,\mu_3}}{s_w} + \frac{ic_\alpha c_h e^2 s_\alpha s_w v \eta\eta_{\mu_2,\mu_3}}{{c_w}^2} + \frac{ic_\alpha {}^2 c_h e^2 v \eta^2 \eta_{\mu_2,\mu_3}}{2{c_w}^2} - 2i\sqrt{2} c_\alpha {}^2 {g_X}^2 s_h \eta^2 \xi \chi^2 \eta_{\mu_2,\mu_3}$$

$$\begin{pmatrix} \mathrm{h2} & 1 \\ \mathrm{Zp} & 2 \\ \mathrm{Zp} & 3 \end{pmatrix} \quad ie^2 {s_\alpha}^2 s_h v \eta_{\mu_2,\mu_3} + \frac{ic_w {}^2 e^2 {s_\alpha}^2 s_h v \eta_{\mu_2,\mu_3}}{2{s_w}^2} + \frac{ie^2 {s_\alpha}^2 s_h {s_w}^2 v \eta_{\mu_2,\mu_3}}{2{c_w}^2} + \frac{ic_\alpha e^2 s_\alpha s_h v \eta\eta_{\mu_2,\mu_3}}{s_w} + \frac{ic_\alpha e^2 s_\alpha s_h s_w v \eta\eta_{\mu_2,\mu_3}}{{c_w}^2} + \frac{ic_\alpha {}^2 e^2 s_h v \eta^2 \eta_{\mu_2,\mu_3}}{2{c_w}^2} + 2i\sqrt{2} c_\alpha {}^2 c_h {g_X}^2 \eta^2 \xi \chi^2 \eta_{\mu_2,\mu_3}$$

$$\begin{pmatrix} W & 1 \\ W^\dagger & 2 \\ \mathrm{Zp} & 3 \\ \mathrm{Zp} & 4 \end{pmatrix} \quad ic_w {}^2 {g_w}^2 {s_\alpha}^2 \eta_{\mu_1,\mu_4} \eta_{\mu_2,\mu_3} + ic_w {}^2 {g_w}^2 {s_\alpha}^2 \eta_{\mu_1,\mu_3} \eta_{\mu_2,\mu_4} - 2ic_w {}^2 {g_w}^2 {s_\alpha}^2 \eta_{\mu_1,\mu_2} \eta_{\mu_3,\mu_4}$$

$$\begin{pmatrix} A & 1 \\ \mathrm{dq} & 2 \\ \bar{\mathrm{dq}} & 3 \end{pmatrix} \quad -\tfrac{1}{3} ie \gamma_{\mathrm{s_3,s_2}}{}^{\mu_1} \delta_{\mathrm{i_2,i_3}} \delta_{\mathrm{f_2,f_3}}$$

$$\begin{pmatrix} A & 1 \\ l & 2 \\ \bar{l} & 3 \end{pmatrix} \quad -ie\gamma_{\mathrm{s}_3,\mathrm{s}_2}{}^{\mu_1}\delta_{\mathrm{f}_2,\mathrm{f}_3}$$

$$\begin{pmatrix} A & 1 \\ \mathrm{uq} & 2 \\ \bar{\mathrm{uq}} & 3 \end{pmatrix} \quad \frac{2}{3}ie\gamma_{\mathrm{s}_3,\mathrm{s}_2}{}^{\mu_1}\delta_{\mathrm{i}_2,\mathrm{i}_3}\delta_{\mathrm{f}_2,\mathrm{f}_3}$$

$$\begin{pmatrix} l & 1 \\ \bar{\mathrm{vl}} & 2 \\ W & 3 \end{pmatrix} \quad \frac{ie\delta_{\mathrm{f}_1,\mathrm{f}_2}\gamma^{\mu_3}.P_{-\mathrm{s}_2,\mathrm{s}_1}}{\sqrt{2}s_w}$$

$$\begin{pmatrix} \mathrm{dq} & 1 \\ \bar{\mathrm{uq}} & 2 \\ W & 3 \end{pmatrix} \quad \frac{ie\mathrm{CKM}_{\mathrm{f}_2,\mathrm{f}_1}\delta_{\mathrm{i}_1,\mathrm{i}_2}\gamma^{\mu_3}.P_{-\mathrm{s}_2,\mathrm{s}_1}}{\sqrt{2}s_w}$$

$$\begin{pmatrix} \bar{l} & 1 \\ \mathrm{vl} & 2 \\ W^\dagger & 3 \end{pmatrix} \quad \frac{ie\delta_{\mathrm{f}_1,\mathrm{f}_2}\gamma^{\mu_3}.P_{-\mathrm{s}_1,\mathrm{s}_2}}{\sqrt{2}s_w}$$

$$\begin{pmatrix} \bar{\mathrm{dq}} & 1 \\ \mathrm{uq} & 2 \\ W^\dagger & 3 \end{pmatrix} \quad \frac{ie\mathrm{CKM}_{\mathrm{f}_2,\mathrm{f}_1}{}^*\delta_{\mathrm{i}_1,\mathrm{i}_2}\gamma^{\mu_3}.P_{-\mathrm{s}_1,\mathrm{s}_2}}{\sqrt{2}s_w}$$

$$\begin{pmatrix} \mathrm{dq} & 1 \\ \bar{\mathrm{dq}} & 2 \\ Z & 3 \end{pmatrix} \quad -\frac{ic_\alpha c_w e\delta_{\mathrm{i}_1,\mathrm{i}_2}\delta_{\mathrm{f}_1,\mathrm{f}_2}\gamma^{\mu_3}.P_{-\mathrm{s}_2,\mathrm{s}_1}}{2s_w} - \frac{ic_\alpha e s_w\delta_{\mathrm{i}_1,\mathrm{i}_2}\delta_{\mathrm{f}_1,\mathrm{f}_2}\gamma^{\mu_3}.P_{-\mathrm{s}_2,\mathrm{s}_1}}{6c_w} + \frac{ie s_\alpha\eta\delta_{\mathrm{i}_1,\mathrm{i}_2}\delta_{\mathrm{f}_1,\mathrm{f}_2}\gamma^{\mu_3}.P_{-\mathrm{s}_2,\mathrm{s}_1}}{6c_w} + \frac{ic_\alpha e s_w\delta_{\mathrm{i}_1,\mathrm{i}_2}\delta_{\mathrm{f}_1,\mathrm{f}_2}\gamma^{\mu_3}.P_{+\mathrm{s}_2,\mathrm{s}_1}}{3c_w} - \frac{ie s_\alpha\eta\delta_{\mathrm{i}_1,\mathrm{i}_2}\delta_{\mathrm{f}_1,\mathrm{f}_2}\gamma^{\mu_3}.P_{+\mathrm{s}_2,\mathrm{s}_1}}{3c_w}$$

$$\begin{pmatrix} l & 1 \\ \bar{l} & 2 \\ Z & 3 \end{pmatrix} \quad -\frac{ic_\alpha c_w e\delta_{\mathrm{f}_1,\mathrm{f}_2}\gamma^{\mu_3}.P_{-\mathrm{s}_2,\mathrm{s}_1}}{2s_w} + \frac{ic_\alpha e s_w\delta_{\mathrm{f}_1,\mathrm{f}_2}\gamma^{\mu_3}.P_{-\mathrm{s}_2,\mathrm{s}_1}}{2c_w} - \frac{ie s_\alpha\eta\delta_{\mathrm{f}_1,\mathrm{f}_2}\gamma^{\mu_3}.P_{-\mathrm{s}_2,\mathrm{s}_1}}{2c_w} + \frac{ic_\alpha e s_w\delta_{\mathrm{f}_1,\mathrm{f}_2}\gamma^{\mu_3}.P_{+\mathrm{s}_2,\mathrm{s}_1}}{c_w} - \frac{ie s_\alpha\eta\delta_{\mathrm{f}_1,\mathrm{f}_2}\gamma^{\mu_3}.P_{+\mathrm{s}_2,\mathrm{s}_1}}{c_w}$$

$$\begin{pmatrix} \mathrm{uq} & 1 \\ \bar{\mathrm{uq}} & 2 \\ Z & 3 \end{pmatrix} \quad \frac{ic_\alpha c_w e\delta_{\mathrm{i}_1,\mathrm{i}_2}\delta_{\mathrm{f}_1,\mathrm{f}_2}\gamma^{\mu_3}.P_{-\mathrm{s}_2,\mathrm{s}_1}}{2s_w} - \frac{ic_\alpha e s_w\delta_{\mathrm{i}_1,\mathrm{i}_2}\delta_{\mathrm{f}_1,\mathrm{f}_2}\gamma^{\mu_3}.P_{-\mathrm{s}_2,\mathrm{s}_1}}{6c_w} + \frac{ie s_\alpha\eta\delta_{\mathrm{i}_1,\mathrm{i}_2}\delta_{\mathrm{f}_1,\mathrm{f}_2}\gamma^{\mu_3}.P_{-\mathrm{s}_2,\mathrm{s}_1}}{6c_w} - \frac{2ic_\alpha e s_w\delta_{\mathrm{i}_1,\mathrm{i}_2}\delta_{\mathrm{f}_1,\mathrm{f}_2}\gamma^{\mu_3}.P_{+\mathrm{s}_2,\mathrm{s}_1}}{3c_w} + \frac{2ie s_\alpha\eta\delta_{\mathrm{i}_1,\mathrm{i}_2}\delta_{\mathrm{f}_1,\mathrm{f}_2}\gamma^{\mu_3}.P_{+\mathrm{s}_2,\mathrm{s}_1}}{3c_w}$$

$$\begin{pmatrix} \mathrm{vl} & 1 \\ \bar{\mathrm{vl}} & 2 \\ Z & 3 \end{pmatrix} \quad \frac{ic_\alpha c_w e\delta_{\mathrm{f}_1,\mathrm{f}_2}\gamma^{\mu_3}.P_{-\mathrm{s}_2,\mathrm{s}_1}}{2s_w} + \frac{ic_\alpha e s_w\delta_{\mathrm{f}_1,\mathrm{f}_2}\gamma^{\mu_3}.P_{-\mathrm{s}_2,\mathrm{s}_1}}{2c_w} - \frac{ie s_\alpha\eta\delta_{\mathrm{f}_1,\mathrm{f}_2}\gamma^{\mu_3}.P_{-\mathrm{s}_2,\mathrm{s}_1}}{2c_w}$$

$$\begin{pmatrix} \mathrm{dq} & 1 \\ \bar{\mathrm{dq}} & 2 \\ \mathrm{Zp} & 3 \end{pmatrix} \quad \frac{ic_w e s_\alpha\delta_{\mathrm{i}_1,\mathrm{i}_2}\delta_{\mathrm{f}_1,\mathrm{f}_2}\gamma^{\mu_3}.P_{-\mathrm{s}_2,\mathrm{s}_1}}{2s_w} + \frac{ie s_\alpha s_w\delta_{\mathrm{i}_1,\mathrm{i}_2}\delta_{\mathrm{f}_1,\mathrm{f}_2}\gamma^{\mu_3}.P_{-\mathrm{s}_2,\mathrm{s}_1}}{6c_w} + \frac{ic_\alpha e\eta\delta_{\mathrm{i}_1,\mathrm{i}_2}\delta_{\mathrm{f}_1,\mathrm{f}_2}\gamma^{\mu_3}.P_{-\mathrm{s}_2,\mathrm{s}_1}}{6c_w} - \frac{ie s_\alpha s_w\delta_{\mathrm{i}_1,\mathrm{i}_2}\delta_{\mathrm{f}_1,\mathrm{f}_2}\gamma^{\mu_3}.P_{+\mathrm{s}_2,\mathrm{s}_1}}{3c_w} - \frac{ic_\alpha e\eta\delta_{\mathrm{i}_1,\mathrm{i}_2}\delta_{\mathrm{f}_1,\mathrm{f}_2}\gamma^{\mu_3}.P_{+\mathrm{s}_2,\mathrm{s}_1}}{3c_w}$$

$$\begin{pmatrix} l & 1 \\ \bar{l} & 2 \\ \mathrm{Zp} & 3 \end{pmatrix} \quad \frac{ic_w e s_\alpha\delta_{\mathrm{f}_1,\mathrm{f}_2}\gamma^{\mu_3}.P_{-\mathrm{s}_2,\mathrm{s}_1}}{2s_w} - \frac{ie s_\alpha s_w\delta_{\mathrm{f}_1,\mathrm{f}_2}\gamma^{\mu_3}.P_{-\mathrm{s}_2,\mathrm{s}_1}}{2c_w} - \frac{ic_\alpha e\eta\delta_{\mathrm{f}_1,\mathrm{f}_2}\gamma^{\mu_3}.P_{-\mathrm{s}_2,\mathrm{s}_1}}{2c_w} - \frac{ie s_\alpha s_w\delta_{\mathrm{f}_1,\mathrm{f}_2}\gamma^{\mu_3}.P_{+\mathrm{s}_2,\mathrm{s}_1}}{c_w} - \frac{ic_\alpha e\eta\delta_{\mathrm{f}_1,\mathrm{f}_2}\gamma^{\mu_3}.P_{+\mathrm{s}_2,\mathrm{s}_1}}{c_w}$$

$$\begin{pmatrix} \mathrm{uq} & 1 \\ \bar{\mathrm{uq}} & 2 \\ \mathrm{Zp} & 3 \end{pmatrix} \quad -\frac{ic_w e s_\alpha\delta_{\mathrm{i}_1,\mathrm{i}_2}\delta_{\mathrm{f}_1,\mathrm{f}_2}\gamma^{\mu_3}.P_{-\mathrm{s}_2,\mathrm{s}_1}}{2s_w} + \frac{ie s_\alpha s_w\delta_{\mathrm{i}_1,\mathrm{i}_2}\delta_{\mathrm{f}_1,\mathrm{f}_2}\gamma^{\mu_3}.P_{-\mathrm{s}_2,\mathrm{s}_1}}{6c_w} + \frac{ic_\alpha e\eta\delta_{\mathrm{i}_1,\mathrm{i}_2}\delta_{\mathrm{f}_1,\mathrm{f}_2}\gamma^{\mu_3}.P_{-\mathrm{s}_2,\mathrm{s}_1}}{6c_w} + \frac{2ie s_\alpha s_w\delta_{\mathrm{i}_1,\mathrm{i}_2}\delta_{\mathrm{f}_1,\mathrm{f}_2}\gamma^{\mu_3}.P_{+\mathrm{s}_2,\mathrm{s}_1}}{3c_w} + \frac{2ic_\alpha e\eta\delta_{\mathrm{i}_1,\mathrm{i}_2}\delta_{\mathrm{f}_1,\mathrm{f}_2}\gamma^{\mu_3}.P_{+\mathrm{s}_2,\mathrm{s}_1}}{3c_w}$$

$$\begin{pmatrix} \mathrm{vl} & 1 \\ \bar{\mathrm{vl}} & 2 \\ \mathrm{Zp} & 3 \end{pmatrix} \quad -\frac{ic_w e s_\alpha\delta_{\mathrm{f}_1,\mathrm{f}_2}\gamma^{\mu_3}.P_{-\mathrm{s}_2,\mathrm{s}_1}}{2s_w} - \frac{ie s_\alpha s_w\delta_{\mathrm{f}_1,\mathrm{f}_2}\gamma^{\mu_3}.P_{-\mathrm{s}_2,\mathrm{s}_1}}{2c_w} - \frac{ic_\alpha e\eta\delta_{\mathrm{f}_1,\mathrm{f}_2}\gamma^{\mu_3}.P_{-\mathrm{s}_2,\mathrm{s}_1}}{2c_w}$$

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