FeynRules Implementation of 2HDM

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Abstract

We describe the implementation of the 2HDM model using the FeynRules package.

Contents

List of Tables

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1 Introduction

We describe the implementation of the 2HDM model using the FeynRules [1] package.

2 Gauge Symmetries

The gauge group of this model is

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

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

Group	Abelian	Gauge Boson	Coupling Constant	Charge	Structure Constant	Symmetric Tensor	Reps	Defs
U1Y	T	B	g1	Y				
SU2L	F	Wi	gw		Eps		$FSU2L_{k,k}$	FSU2L[a$_, b$_, c$_] → -I Eps[a$, b$,
SU3C	F	G	gs		f	dSUN	$T_{i,i}$ $FSU3C_{a,a}$	FSU3C[a$_, b$_, c$_] → -I f[a$, b$, c

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	k	1-3
Higgs	j	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
W	F			$Q = 1$	W	MW= Internal	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
Wi	T	k	k		Wi	$\mathrm{Wi}_{\mu,1} \to \frac{W_\mu + {W_\mu}^\dagger}{\sqrt{2}}$ $\mathrm{Wi}_{\mu,2} \to -\frac{i\left(-W_\mu + {W_\mu}^\dagger\right)}{\sqrt{2}}$ $\mathrm{Wi}_{\mu,3} \to s_w A_\mu + c_w Z_\mu$
B	T				B	$B_\mu \to c_w A_\mu - s_w Z_\mu$

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= 0.106		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= 0.1		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
Hc	F			$Q = 1$	Hc	mhc= 120	whc= 1	37
H	T	j	j			MH	WH	
					h1	mh1= 120	Wh1= 1	25
					h2	mh2= 130	Wh2= 1	35
					h3	mh3= 140	Wh3= 1	36

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
Phi]1P	F			$Q = 1$	Phi]1P	ϕ1P $\rightarrow 0$
Phi]10	F				Phi]10	ϕ10 $\rightarrow \frac{v+\text{Nh}_1}{\sqrt{2}}$
Phi]2P	F			$Q = 1$	Phi]2P	ϕ2P $\rightarrow$ Hc
Phi]20	F				Phi]20	ϕ20 $\rightarrow \frac{\text{Nh}_2+i\text{Nh}_3}{\sqrt{2}}$
Nh	T	j	j			
					Nh1	$\text{Nh}_i :\rightarrow \text{Module}\left[\{j\}, T_{Hi,j} H_j\right]$
					Nh2	
					Nh3	

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		

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

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

4.2 L_2

$$-\mathrm{mu2P2s2}-\mathrm{mu1}\left(\phi10\phi10^\dagger+\phi1\mathrm{P}\phi1\mathrm{P}^\dagger\right)-\lambda_1\left(\phi10\phi10^\dagger+\phi1\mathrm{P}\phi1\mathrm{P}^\dagger\right)^2+\mathrm{mu3}\left(\phi10^\dagger\phi20+\phi1\mathrm{P}^\dagger\phi2\mathrm{P}\right)+$$
$$\mathrm{mu3}^2\left(\phi10\phi20^\dagger+\phi1\mathrm{P}\phi2\mathrm{P}^\dagger\right)-\lambda_4\left(\phi10^\dagger\phi20+\phi1\mathrm{P}^\dagger\phi2\mathrm{P}\right)\left(\phi10\phi20^\dagger+\phi1\mathrm{P}\phi2\mathrm{P}^\dagger\right)-$$
$$\lambda_3\left(\phi10\phi10^\dagger+\phi1\mathrm{P}\phi1\mathrm{P}^\dagger\right)\left(\phi20\phi20^\dagger+\phi2\mathrm{P}\phi2\mathrm{P}^\dagger\right)-\lambda_2\left(\phi20\phi20^\dagger+\phi2\mathrm{P}\phi2\mathrm{P}^\dagger\right)^2-$$
$$\lambda_5\left(\left(\phi10^\dagger\phi20+\phi1\mathrm{P}^\dagger\phi2\mathrm{P}\right)^2+\left(\phi10\phi20^\dagger+\phi1\mathrm{P}\phi2\mathrm{P}^\dagger\right)^2\right)-$$
$$\left(\phi10\phi10^\dagger+\phi1\mathrm{P}\phi1\mathrm{P}^\dagger\right)\left(\lambda_6\left(\phi10^\dagger\phi20+\phi1\mathrm{P}^\dagger\phi2\mathrm{P}\right)+\left(\phi10\phi20^\dagger+\phi1\mathrm{P}\phi2\mathrm{P}^\dagger\right)\lambda_6{}^*\right)-$$
$$\left(\phi20\phi20^\dagger+\phi2\mathrm{P}\phi2\mathrm{P}^\dagger\right)\left(\lambda_7\left(\phi10^\dagger\phi20+\phi1\mathrm{P}^\dagger\phi2\mathrm{P}\right)+\left(\phi10\phi20^\dagger+\phi1\mathrm{P}\phi2\mathrm{P}^\dagger\right)\lambda_7{}^*\right)+$$
$$\left(\frac{e\phi10B_\mu}{2c_w}+i\partial_\mu[\phi10]+\frac{e(\phi1\mathrm{P}(\mathrm{Wi}_{\mu,1}+i\mathrm{Wi}_{\mu,2})-\phi10\mathrm{Wi}_{\mu,3})}{2s_w}\right)\left(\frac{e\phi10^\dagger B_\mu}{2c_w}-i\partial_\mu\left[\phi10^\dagger\right]+\frac{e\left(\phi1\mathrm{P}^\dagger(\mathrm{Wi}_{\mu,1}-i\mathrm{Wi}_{\mu,2})-\phi10^\dagger\mathrm{Wi}_{\mu,3}\right)}{2s_w}\right)+$$
$$\left(\frac{e\phi1\mathrm{P}B_\mu}{2c_w}+i\partial_\mu[\phi1\mathrm{P}]+\frac{e(\phi10(\mathrm{Wi}_{\mu,1}-i\mathrm{Wi}_{\mu,2})+\phi1\mathrm{P}\mathrm{Wi}_{\mu,3})}{2s_w}\right)\left(\frac{e\phi1\mathrm{P}^\dagger B_\mu}{2c_w}-i\partial_\mu\left[\phi1\mathrm{P}^\dagger\right]+\frac{e\left(\phi10^\dagger(\mathrm{Wi}_{\mu,1}+i\mathrm{Wi}_{\mu,2})+\phi1\mathrm{P}^\dagger\mathrm{Wi}_{\mu,3}\right)}{2s_w}\right)+$$
$$\left(\frac{e\phi20B_\mu}{2c_w}+i\partial_\mu[\phi20]+\frac{e(\phi2\mathrm{P}(\mathrm{Wi}_{\mu,1}+i\mathrm{Wi}_{\mu,2})-\phi20\mathrm{Wi}_{\mu,3})}{2s_w}\right)\left(\frac{e\phi20^\dagger B_\mu}{2c_w}-i\partial_\mu\left[\phi20^\dagger\right]+\frac{e\left(\phi2\mathrm{P}^\dagger(\mathrm{Wi}_{\mu,1}-i\mathrm{Wi}_{\mu,2})-\phi20^\dagger\mathrm{Wi}_{\mu,3}\right)}{2s_w}\right)+$$
$$\left(\frac{e\phi2\mathrm{P}B_\mu}{2c_w}+i\partial_\mu[\phi2\mathrm{P}]+\frac{e(\phi20(\mathrm{Wi}_{\mu,1}-i\mathrm{Wi}_{\mu,2})+\phi2\mathrm{P}\mathrm{Wi}_{\mu,3})}{2s_w}\right)\left(\frac{e\phi2\mathrm{P}^\dagger B_\mu}{2c_w}-i\partial_\mu\left[\phi2\mathrm{P}^\dagger\right]+\frac{e\left(\phi20^\dagger(\mathrm{Wi}_{\mu,1}+i\mathrm{Wi}_{\mu,2})+\phi2\mathrm{P}^\dagger\mathrm{Wi}_{\mu,3}\right)}{2s_w}\right)$$

4.3 L_3

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

4.4 L_4

$$-\frac{\sqrt{2}\left(\phi10^\dagger\overline{\mathrm{dq}}.\mathrm{DD}^\dagger.P_-.\mathrm{dq}+\phi20^\dagger\overline{\mathrm{dq}}.\mathrm{GD}^\dagger.P_-.\mathrm{dq}+\phi2\mathrm{P}^\dagger\overline{\mathrm{dq}}.\mathrm{GD}^\dagger.P_-.\mathrm{uq}\right)}{v}-\frac{\sqrt{2}\left(\phi10^\dagger\bar{l}.\mathrm{DL}^\dagger.P_-.l+\phi20^\dagger\bar{l}.\mathrm{GL}^\dagger.P_-.l+\phi2\mathrm{P}^\dagger\bar{l}.\mathrm{GL}^\dagger.P_-.\mathrm{vl}\right)}{v}-$$
$$\frac{\sqrt{2}\left(\phi10\overline{\mathrm{dq}}.\mathrm{DD}.P_+.\mathrm{dq}+\phi20\overline{\mathrm{dq}}.\mathrm{GD}.P_+.\mathrm{dq}+\phi2\mathrm{P}\overline{\mathrm{uq}}.\mathrm{GD}.P_+.\mathrm{dq}\right)}{v}-\frac{\sqrt{2}\left(-\phi2\mathrm{P}^\dagger\overline{\mathrm{dq}}.\mathrm{GU}.P_+.\mathrm{uq}+\phi10^\dagger\overline{\mathrm{uq}}.\mathrm{DU}.P_+.\mathrm{uq}+\phi20^\dagger\overline{\mathrm{uq}}.\mathrm{GU}.P_+.\mathrm{uq}\right)}{v}-$$
$$\frac{\sqrt{2}\left(\phi10\overline{\mathrm{uq}}.\mathrm{DU}^\dagger.P_-.\mathrm{uq}-\phi2\mathrm{P}\overline{\mathrm{uq}}.\mathrm{GU}^\dagger.P_-.\mathrm{dq}+\phi20\overline{\mathrm{uq}}.\mathrm{GU}^\dagger.P_-.\mathrm{uq}\right)}{v}-\frac{\sqrt{2}\left(\phi10\bar{l}.\mathrm{DL}.P_+.l+\phi20\bar{l}.\mathrm{GL}.P_+.l+\phi2\mathrm{P}\overline{\mathrm{vl}}.\mathrm{GL}.P_+.l\right)}{v}$$

4.5 L_5

$$-g_s\mathrm{ghG}_a{}^\dagger.\left(\frac{\partial_\mu[\partial_\mu[\mathrm{ghG}_a]]}{g_s}+f_{a,\mathrm{a2\$1086,a3\$1086}}\left(\partial_\mu\left[\mathrm{ghG}_{\mathrm{a3\$1086}}\right]G_{\mu,\mathrm{a2\$1086}}+\partial_\mu\left[G_{\mu,\mathrm{a2\$1086}}\right]\mathrm{ghG}_{\mathrm{a3\$1086}}\right)\right)$$

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

P	C	I	V	D	PN	BN	OB	IO	Description
αEWM1	F		127.934		aEWM1	SMINPUTS		QED, -2	Inverse of the electroweak coupling constant
Gf	F		0.0000116637			SMINPUTS		QED, 2	Fermi constant
αS	F		0.1172		aS	SMINPUTS		QCD, 2	Strong coupling constant at the Z pole.
yuku	F	f	$\mathrm{yuku}_1 \to 0.$ $\mathrm{yuku}_2 \to 0.6$ $\mathrm{yuku}_3 \to 175.$			YUKAWAU		QED, 1	Up Yukawa mass
yukd	F	f	$\mathrm{yukd}_1 \to 0.$ $\mathrm{yukd}_2 \to 0.$ $\mathrm{yukd}_3 \to 3.$			YUKAWAD		QED, 1	Down Yukawa mass
yukl	F	f	$\mathrm{yukl}_1 \to 0.$ $\mathrm{yukl}_2 \to 0.$ $\mathrm{yukl}_3 \to 1.777$			YUKAWAL		QED, 1	Lepton Yukawa mass
CKMR	F	f, f	$\mathrm{CKMR}_{1,1} \to 1.$ $\mathrm{CKMR}_{1,2} \to 1$ $\mathrm{CKMR}_{1,3} \to 1$ $\mathrm{CKMR}_{2,1} \to 1$ $\mathrm{CKMR}_{2,2} \to 1$ $\mathrm{CKMR}_{2,3} \to 1$ $\mathrm{CKMR}_{3,1} \to 1$ $\mathrm{CKMR}_{3,2} \to 1$ $\mathrm{CKMR}_{3,3} \to 1$			CKMR			Real Part of the CKM-Matrix
CKMI	F	f, f	$\mathrm{CKMI}_{1,1} \to 1.$ $\mathrm{CKMI}_{1,2} \to 1$ $\mathrm{CKMI}_{1,3} \to 1$ $\mathrm{CKMI}_{2,1} \to 1$ $\mathrm{CKMI}_{2,2} \to 1$ $\mathrm{CKMI}_{2,3} \to 1$ $\mathrm{CKMI}_{3,1} \to 1$ $\mathrm{CKMI}_{3,2} \to 1$ $\mathrm{CKMI}_{3,3} \to 1$			CKMI			Imaginary Part of the CKM-Matrix
λ_1	F		1.		l1	Higgs		QED, 2	
λ_2	F		1.		l2	Higgs		QED, 2	
λ_3	F		1.		l3	Higgs		QED, 2	
λ_4	F		0.5		l4	Higgs		QED, 2	

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.

in Tables 9, 10, 11.

P	C	I	V	D	PN	BN	OB	IO	Description
λ_5	F		0.4		l5	Higgs		QED, 2	
λ_{R6}	F		0.3		lR6	Higgs		QED, 2	
λ_{I6}	F		0.		lI6	Higgs		QED, 2	
λ_{R7}	F		0.2		lR7	Higgs		QED, 2	
λ_{I7}	F		0.		lI7	Higgs		QED, 2	
GUR	F	f, f	$\Gamma_{UR1,1} \to 0.$ $\Gamma_{UR1,2} \to 0.$ $\Gamma_{UR1,3} \to 0.$ $\Gamma_{UR2,1} \to 0.$ $\Gamma_{UR2,2} \to 0.$ $\Gamma_{UR2,3} \to 0.$ $\Gamma_{UR3,1} \to 0.$ $\Gamma_{UR3,2} \to 0.$ $\Gamma_{UR3,3} \to 0.$			YukawaGUR			
GUI	F	f, f	$\Gamma_{UI1,1} \to 0.$ $\Gamma_{UI1,2} \to 0.$ $\Gamma_{UI1,3} \to 0.$ $\Gamma_{UI2,1} \to 0.$ $\Gamma_{UI2,2} \to 0.$ $\Gamma_{UI2,3} \to 0.$ $\Gamma_{UI3,1} \to 0.$ $\Gamma_{UI3,2} \to 0.$ $\Gamma_{UI3,3} \to 0.$			YukawaGUI			
GDR	F	f, f	$\Gamma_{DR1,1} \to 0.$ $\Gamma_{DR1,2} \to 0.$ $\Gamma_{DR1,3} \to 0.$ $\Gamma_{DR2,1} \to 0.$ $\Gamma_{DR2,2} \to 0.$ $\Gamma_{DR2,3} \to 0.$ $\Gamma_{DR3,1} \to 0.$ $\Gamma_{DR3,2} \to 0.$ $\Gamma_{DR3,3} \to 0.$			YukawaGDR			
GDI	F	f, f	$\Gamma_{DI1,1} \to 0.$ $\Gamma_{DI1,2} \to 0.$ $\Gamma_{DI1,3} \to 0.$ $\Gamma_{DI2,1} \to 0.$ $\Gamma_{DI2,2} \to 0.$ $\Gamma_{DI2,3} \to 0.$ $\Gamma_{DI3,1} \to 0.$ $\Gamma_{DI3,2} \to 0.$ $\Gamma_{DI3,3} \to 0.$			YukawaGDI			

Table 10: 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.

P	C	I	V	D	PN	BN	OB	IO	Description
GLR	F	f, f	$\Gamma_{\text{LR}1,1} \to 0.$			YukawaGLR			
			$\Gamma_{\text{LR}1,2} \to 0.$						
			$\Gamma_{\text{LR}1,3} \to 0.$						
			$\Gamma_{\text{LR}2,1} \to 0.$						
			$\Gamma_{\text{LR}2,2} \to 0.$						
			$\Gamma_{\text{LR}2,3} \to 0.$						
			$\Gamma_{\text{LR}3,1} \to 0.$						
			$\Gamma_{\text{LR}3,2} \to 0.$						
			$\Gamma_{\text{LR}3,3} \to 0.$						
GLI	F	f, f	$\Gamma_{\text{LI}1,1} \to 0.$			YukawaGLI			
			$\Gamma_{\text{LI}1,2} \to 0.$						
			$\Gamma_{\text{LI}1,3} \to 0.$						
			$\Gamma_{\text{LI}2,1} \to 0.$						
			$\Gamma_{\text{LI}2,2} \to 0.$						
			$\Gamma_{\text{LI}2,3} \to 0.$						
			$\Gamma_{\text{LI}3,1} \to 0.$						
			$\Gamma_{\text{LI}3,2} \to 0.$						
			$\Gamma_{\text{LI}3,3} \to 0.$						
TH	F	j, j	$T_{H1,1} \to 1.$			HiggsMix			
			$T_{H1,2} \to 0.$						
			$T_{H1,3} \to 0.$						
			$T_{H2,1} \to 0.$						
			$T_{H2,2} \to 1$						
			$T_{H2,3} \to 0.$						
			$T_{H3,1} \to 0.$						
			$T_{H3,2} \to 0.$						
			$T_{H3,3} \to 1$						

Table 11: 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.

5.2 Internal Parameters

In this subsection, we describe the internal parameters of our model. The details of the internal parameters can be found in Tables 12, 13, 14. The values and definitions of the internal parameters will be written below.

P	C	I	V	NV	D	PN	IO	Description
αEW	F		Eq. 2	0.00781653		aEW	QED, 2	Electroweak coupling contant
MW	F		Eq. 3	79.829				W mass
sw2	F		Eq. 4	0.23361				Squared Sin of the Weinberg angle
e	F		Eq. 5	0.313409			QED, 1	Electric coupling constant
c_w	F		Eq. 6	0.875437				Cos of the Weinberg angle
s_w	F		Eq. 7	0.483332				Sin of the Weinberg angle
g_w	F		Eq. 8	0.648435			QED, 1	Weak coupling constant
g_1	F		Eq. 9	0.358003			QED, 1	U(1)Y coupling constant
g_s	F		Eq. 10	1.21358		G	QCD, 1	Strong coupling constant
v	F		Eq. 11	246.221			QED, -1	Higgs VEV
CKM	T	f, f	Eq. 12	$\mathrm{CKM}_{1,1} \to 0.974589 + 0.I$				CKM-Matrix
				$\mathrm{CKM}_{1,2} \to 0.224 + 0.I$				
				$\mathrm{CKM}_{1,3} \to 0.$				
				$\mathrm{CKM}_{2,1} \to -0.224 + 0.I$				
				$\mathrm{CKM}_{2,2} \to 0.974589 + 0.I$				
				$\mathrm{CKM}_{2,3} \to 0.$				
				$\mathrm{CKM}_{3,1} \to 0.$				
				$\mathrm{CKM}_{3,2} \to 0.$				
				$\mathrm{CKM}_{3,3} \to 1.$				
λ_6	T		Eq. 13	$0.3 + 0.I$		l6	QED, 2	
λ_7	T		Eq. 14	$0.2 + 0.I$		l7	QED, 2	
DU	T	f, f	Eq. 15	$\Delta_{U\,1,1} \to 0.$				
				$\Delta_{U\,1,2} \to 0.$				
				$\Delta_{U\,1,3} \to 0.$				
				$\Delta_{U\,2,1} \to 0.$				
				$\Delta_{U\,2,2} \to 0.6$				
				$\Delta_{U\,2,3} \to 0.$				
				$\Delta_{U\,3,1} \to 0.$				
				$\Delta_{U\,3,2} \to 0.$				
				$\Delta_{U\,3,3} \to 175.$				

Table 12: 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.

$$\alpha\mathrm{EW} = \frac{1}{\alpha\mathrm{EWM1}} \tag{2}$$

$$\mathrm{MW} = \sqrt{\frac{\mathrm{MZ}^2}{2} + \sqrt{\frac{\mathrm{MZ}^4}{4} - \frac{\mathrm{MZ}^2 \pi \alpha\mathrm{EW}}{\sqrt{2}\mathrm{Gf}}}} \tag{3}$$

$$\mathrm{sw2} = 1 - \frac{\mathrm{MW}^2}{\mathrm{MZ}^2} \tag{4}$$

P	C	I	V	NV	D	PN	IO	Description
GU	T	f, f	Eq. 16	$\Gamma_{U1,1} \to 0. + 0.I$				
				$\Gamma_{U1,2} \to 0. + 0.I$				
				$\Gamma_{U1,3} \to 0. + 0.I$				
				$\Gamma_{U2,1} \to 0. + 0.I$				
				$\Gamma_{U2,2} \to 2. + 0.I$				
				$\Gamma_{U2,3} \to 0. + 0.I$				
				$\Gamma_{U3,1} \to 0. + 0.I$				
				$\Gamma_{U3,2} \to 1. + 0.I$				
				$\Gamma_{U3,3} \to 100. + 0.I$				
DD	T	f, f	Eq. 17	$\Delta_{D1,1} \to 0.$				
				$\Delta_{D1,2} \to 0.$				
				$\Delta_{D1,3} \to 0.$				
				$\Delta_{D2,1} \to 0.$				
				$\Delta_{D2,2} \to 0.$				
				$\Delta_{D2,3} \to 0.$				
				$\Delta_{D3,1} \to 0.$				
				$\Delta_{D3,2} \to 0.$				
				$\Delta_{D3,3} \to 3.$				
GD	T	f, f	Eq. 18	$\Gamma_{D1,1} \to 0. + 0.I$				
				$\Gamma_{D1,2} \to 0. + 0.I$				
				$\Gamma_{D1,3} \to 0. + 0.I$				
				$\Gamma_{D2,1} \to 0. + 0.I$				
				$\Gamma_{D2,2} \to 0.4 + 0.I$				
				$\Gamma_{D2,3} \to 0. + 0.I$				
				$\Gamma_{D3,1} \to 0. + 0.I$				
				$\Gamma_{D3,2} \to 0.2 + 0.I$				
				$\Gamma_{D3,3} \to 5. + 0.I$				
DL	T	f, f	Eq. 19	$\Delta_{L1,1} \to 0.$				
				$\Delta_{L1,2} \to 0.$				
				$\Delta_{L1,3} \to 0.$				
				$\Delta_{L2,1} \to 0.$				
				$\Delta_{L2,2} \to 0.$				
				$\Delta_{L2,3} \to 0.$				

Table 13: 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.

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

$$c_w = \sqrt{1 - \mathrm{sw2}} \tag{6}$$

$$s_w = \sqrt{\mathrm{sw2}} \tag{7}$$

$$g_w = \frac{e}{s_w} \tag{8}$$

$$g_1 = \frac{e}{c_w} \tag{9}$$

P	C	I	V	NV	D	PN	IO	Description
GL	T	f, f	Eq. 20	$\Delta_{L3,1} \to 0.$ $\Delta_{L3,2} \to 0.$ $\Delta_{L3,3} \to 1.777$ $\Gamma_{L1,1} \to 0. + 0.I$ $\Gamma_{L1,2} \to 0. + 0.I$ $\Gamma_{L1,3} \to 0. + 0.I$ $\Gamma_{L2,1} \to 0. + 0.I$ $\Gamma_{L2,2} \to 0.1 + 0.I$ $\Gamma_{L2,3} \to 0. + 0.I$ $\Gamma_{L3,1} \to 0. + 0.I$ $\Gamma_{L3,2} \to 0.5 + 0.I$ $\Gamma_{L3,3} \to 3. + 0.I$				
mu1	F		Eq. 21	-60624.6				Phi1 mass term
mu2	F		Eq. 22	59687.7				Phi2 mass term
mu3	F		Eq. 23	$-9093.69 + 0.I$				Phi1 Phi2 mass term

Table 14: 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.

$$g_s = 2\sqrt{\pi}\sqrt{\alpha\text{S}} \tag{10}$$

$$v = \frac{2\text{MW}s_w}{e} \tag{11}$$

$$\text{CKM}_{i,j} \quad = \quad i\text{CKMI}_{i,j} + \text{CKMR}_{i,j} \tag{12}$$

$$\lambda_6 = i\lambda_{\text{I6}} + \lambda_{\text{R6}} \tag{13}$$

$$\lambda_7 = i\lambda_{\text{I7}} + \lambda_{\text{R7}} \tag{14}$$

$$\Delta_{U\,i,j} \quad = \quad 0 \tag{15}$$

$$\Gamma_{U\,i,j} \quad = \quad i\Gamma_{\text{UI}\,i,j} + \Gamma_{\text{UR}\,i,j} \tag{16}$$

$$\Delta_{D\,i,j} \quad = \quad 0 \tag{17}$$

$$\Gamma_{D\,i,j} \quad = \quad i\Gamma_{\text{DI}\,i,j} + \Gamma_{\text{DR}\,i,j} \tag{18}$$

$$\Delta_{L\,i,j} \quad = \quad 0 \tag{19}$$

$$\Gamma_{L\,i,j} \quad = \quad i\Gamma_{\text{LI}\,i,j} + \Gamma_{\text{LR}\,i,j} \tag{20}$$

$$\text{mu1} = -v^2\lambda_1 \tag{21}$$

$$\text{mu2} = \text{mhc}^2 - \frac{v^2\lambda_3}{2} \tag{22}$$

$$\text{mu3} = -\frac{1}{2}v^2\lambda_6 \tag{23}$$

References

[1] N. D. Christensen and C. Duhr, arXiv:0806.4194 [hep-ph].