1 Description

This model is an extension of the Standard Model (SM) that describes in a general way the flavour changing neutral interactions of the top quark with other particles of the SM. The implementation in FeynRules was done in the context of an effective field theory using dimension-six gauge invariant operators. This provides a direct connection between experimental observables and the new anomalous couplings. Because this model just describes interactions of the top quark with other SM particles, there are no additional fields. The summary of the parameters of this model are described in the next section.

2 Model Implementation

Our lagrangian was derived in the context of an effective field theory using dimension-six gauge invariant operators $\mathcal{O}_x$. In general this lagrangian can be written as

$$\mathcal{L}^{eff.} = \sum_x \frac{C_x}{\Lambda^2}\mathcal{O}_x \tag{1}$$

where C_x is a complex number and $\mathcal{O}_x$ is a dimension-six gauge invariant operator. In [1, 2] we can find the list of the most relevant and non-redundant operators O_x that are responsible for top anomalous interactions, in particular for flavour changing neutral interactions. Using the results from those papers we arrive at the lagrangian of equation 2 wich is added to the SM lagrangian.

$$\begin{aligned}\mathcal{L}_{FCNC} = &\sum_{q=u,c} \frac{g_s}{2m_t}\bar{q}\lambda^a\sigma^{\mu\nu}(\zeta^L_{qt}P^L + \zeta^R_{qt}P^R)tG^a_{\mu\nu} - \frac{1}{\sqrt{2}}\bar{q}(\eta^L_{qt}P^L + \eta^R_{qt}P^R)tH- \\ &-\frac{g_W}{2c_W}\bar{q}\gamma^\mu(X^L_{qt}P_L + X^R_{qt}P_R)tZ_\mu + \frac{g_W}{4c_W m_Z}\bar{q}\sigma^{\mu\nu}(K^L_{qt}P_L + K^R_{qt}P_R)tZ_{\mu\nu}+ \\ &+\frac{e}{2m_t}\bar{q}\sigma^{\mu\nu}(\lambda^L_{qt}P_L + \lambda^R_{qt}P_R)tA_{\mu\nu} + H.c.\end{aligned} \tag{2}$$

where $G^a_{\mu\nu} = \partial_\mu G^a_\nu - \partial_\nu G^a_\mu$, $Z_{\mu\nu} = \partial_\mu Z_\nu - \partial_\nu Z_\mu$ and $A_{\mu\nu} = \partial_\mu A_\nu - \partial_\nu A_\mu$. This lagrangian is implemented in the file `topFCNC.fr` wich is then loaded in Mathematica with the notebook `topFCNC.nb` .

The paremeters that appear in $\mathcal{L}_{topFCNC}$ are complex numbers in general and their real and imaginary parts can be set manually by the user. They can be divided in the following blocks :

- the ζ block : set the strenght of the coupling between the top, a gluon and a up or charm quark, as well the chirality of this coupling. The default values of the real and imaginary parts are 0.
- the η block : set the strenght of the coupling between the top, the Higgs boson and a up or charm quark, as well the chirality of this coupling. The default values of the real and imaginary parts are 0.
- the X block : set the strenght of the vector coupling between the top, the Z boson and a up or charm quark, as well the chirality of this coupling. The default values of the real and imaginary parts are 0.
- the K block : set the strenght of the tensorial coupling between the top, the Z boson and a up or charm quark, as well the chirality of this coupling. The default values of the real and imaginary parts are 0.
- the λ block : set the strenght of the coupling between the top, the photon and a up or charm quark, as well the chirality of this coupling. The default values of the real and imaginary parts are 0.

This model can be used in Madgraph5 by typing in the command line

```
import model topFCNC_UFO
```

3 Model Parameters

We present here the default values of the parameters used in `topFCNC.fr`. For the Standard Model we use the default paraments of MadGraph5 which are given in table 1. The default values of the anomalous couplings are presented in table 2. The values can be changed by editing the file param_card.dat when MadGraph is running.

4 Validation

To validate the UFO model we performed hermicity, mass spectrum tests as well cross-section tests. It was confirmed that the lagrangian is indeed hermitean. Since this lagrangian is just an extension of the SM lagrangian we obtained the same mass mass spectrum of the SM. In cross-section tests we verified that the cross-section is proportional to the modulos squared of the value of the anomalous couplings (exactly one non-zero coupling) and that it does not depend on the chirality of the coupling (with the same

Parameter	Symbol	MG Symbol	Value
SMINPUTS BLOCK			
Inverse of the electromagnetic coupling	$\alpha_{EW}^{-1}(M_Z)$	aEWM1	127.9
Fermi constant	G_F	Gf	$1.166 \times 10^{-5}\ GeV^{-2}$
Strong coupling	$\alpha_s(M_Z)$	aS	0.118
MASS BLOCK			
u quark pole (Yukawa) mass	$m_u^{(Yuk.)}$	MU (ymup)	5.04×10^{-3} GeV
d quark pole (Yukawa) mass	$m_d^{(Yuk.)}$	MD (ymdo)	2.55×10^{-3} GeV
c quark pole (Yukawa) mass	$m_c^{(Yuk.)}$	MC (ymc)	1.27 GeV
s quark pole (Yukawa) mass	$m_s^{(Yuk.)}$	MS (yms)	1.01×10^{-1} GeV
t quark pole (Yukawa) mass	$m_t^{(Yuk.)}$	MT (ymb)	172 GeV
b quark pole (Yukawa) mass	$m_b^{(Yuk.)}$	MB (ymb)	4.7 GeV
Z pole mass	m_Z	MZ	91.19 GeV
Higgs mass	m_h	MH	125 GeV
electron pole (Yukawa) mass	$m_e^{(Yuk.)}$	Me (yme)	5.11×10^{-4} GeV
muon pole (Yukawa) mass	$m_\mu^{(Yuk.)}$	MMU (ymmm)	1.0566×10^{-1} GeV
τ pole (Yukawa) mass	$m_\tau^{(Yuk.)}$	MTA (ymtau)	1.777 GeV
DECAY BLOCK			
t quark width		WT	1.508 GeV
Z boson width		WZ	2.495 GeV
W boson width		WW	2.085 GeV
Higgs boson width		WH	4.07×10^{-3}
CKM BLOCK			
Cabibbo angle	$\sin\theta_C$	cabi	2.277×10^{-1}

Table 1: SM default parameters in param_card.dat. Neutrino masses and Yukawa couplings are set to zero and by this reason are omited in the table. In the CKM matrix it is assumed that there is only mixing betweent the first and second quark families

Parameter	Symbol	MG Symbol	Default Value
Real part of X^L_{ut}	ReX^L_{ut}	ReXLut	0
Imaginary part of X^L_{ut}	ImX^L_{ut}	ImXLut	0
Real part of X^R_{ut}	ReX^R_{ut}	ReXRut	0
Imaginary part of X^R_{ut}	ImX^R_{ut}	ImXRut	0
Real part of X^L_{ct}	ReX^L_{ct}	ReXLct	0
Imaginary part of X^L_{ct}	ImX^L_{ct}	ImXLct	0
Real part of X^R_{ct}	ReX^R_{ct}	ReXRct	0
Imaginary part of X^R_{ct}	ImX^R_{ct}	ImXRct	0
Real part of K^L_{ut}	ReK^L_{ut}	ReKLut	0
Imaginary part of K^L_{ut}	ImK^L_{ut}	ImKLut	0
Real part of K^R_{ut}	ReK^R_{ut}	ReKRut	0
Imaginary part of K^R_{ut}	ImK^R_{ut}	ImKRut	0
Real part of K^L_{ct}	ReK^L_{ct}	ReKLct	0
Imaginary part of K^L_{ct}	ImK^L_{ct}	ImKLct	0
Real part of K^R_{ct}	ReK^R_{ct}	ReKRct	0
Imaginary part of K^R_{ct}	ImK^R_{ct}	ImKRct	0
Real part of ζ^L_{ut}	Reζ^L_{ut}	ReZetaLut	0
Imaginary part of ζ^L_{ut}	Imζ^L_{ut}	ImZetaLut	0
Real part of ζ^R_{ut}	Reζ^R_{ut}	ReZetaRut	0
Imaginary part of ζ^R_{ut}	Imζ^R_{ut}	ImZetaRut	0
Real part of ζ^L_{ct}	Reζ^L_{ct}	ReZetaLct	0
Imaginary part of ζ^L_{ct}	Imζ^L_{ct}	ImZetaLct	0
Real part of ζ^R_{ct}	Reζ^R_{ct}	ReZetaRct	0
Imaginary part of ζ^R_{ct}	Imζ^R_{ct}	ImZetaRct	0
Real part of η^L_{ut}	Reη^L_{ut}	ReEtaLut	0
Imaginary part of η^L_{ut}	Imη^L_{ut}	ImEtaLut	0
Real part of η^R_{ut}	Reη^R_{ut}	ReEtaRut	0
Imaginary part of η^R_{ut}	Imη^R_{ut}	ImEtaRut	0
Real part of η^L_{ct}	Reη^L_{ct}	ReEtaLct	0
Imaginary part of η^L_{ct}	Imη^L_{ct}	ImEtaLct	0
Real part of η^R_{ct}	Reη^R_{ct}	ReEtaRct	0
Imaginary part of η^R_{ct}	Imη^R_{ct}	ImEtaRct	0
Real part of λ^L_{ut}	Reλ^L_{ut}	ReLambdaLut	0
Imaginary part of λ^L_{ut}	Imλ^L_{ut}	ImLambdaLut	0
Real part of λ^R_{ut}	Reλ^R_{ut}	ReLambdaRut	0
Imaginary part of λ^R_{ut}	Imλ^R_{ut}	ImLambdaRut	0
Real part of λ^L_{ct}	Reλ^L_{ct}	ReLambdaLct	0
Imaginary part of λ^L_{ct}	Imλ^L_{ct}	ImLambdaLct	0
Real part of λ^R_{ct}	Reλ^R_{ct}	ReLambdaRct	0
Imaginary part of λ^R_{ct}	Imλ^R_{ct}	ImLambdaRct	0

Table 2: Adjustable paramenters of $\mathcal{L}_{topFCNC}$ in param_card.dat . Remember that in general the parameters are complex, hence you need to specify both their real and imaginary parts.

numerical value the left-handed coupling had the same cross-section as the right-handed coupling). The samples used for the cross-section tests were generated with MadGraph.

References

[1] J.A. Aguilar Saavedra, A minimal set of top anomalous couplings, arXiv:0811.3842v2 [hep-ph], 2008

[2] J.A. Aguilar Saavedra, A minimal set of top-Higgs anomalous couplings, arXiv:0904.2387v2 [hep-ph], 2009