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POWHEG BOX 1.0

# The POWHEG BOX user manual: Higgs production via vector boson fusion in the SM-EFT

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Abstract: This note documents the use of the package POWHEG BOX for Higgs production via Vector Boson Fusion, in the presence of SM-EFT operators.

## Contents



## 1. Introduction

The POWHEG BOX program is a framework for implementing NLO calculations in Shower Monte Carlo programs according to the POWHEG method. An explanation of the method and a discussion of how the code is organized can be found in refs. [1, 2, 3]. The code is distributed according to the "MCNET GUIDELINES for Event Generator Authors and Users" and can be found at the web page

http://powhegbox.mib.infn.it.

This program is an implementation of the Higgs production via Vector Boson Fusion (VBF) cross sections induced by SM-EFT operators. A detailed description of the implementation can be found in ref. [4]. Please cite the paper when you use the program. The implementation included in the POWHEG-BOX/VBF_H_smeft subdirectory package is based on the original work of Ref. [5], to which refer for more details.

In order to run the POWHEG BOX program, we recommend the reader to start from the POWHEG BOX user manual, which contains all the information and settings that are common between all subprocesses. In this note we focus on the settings and parameters specific to the VBF implementation.

## 2. Generation of events

Due to the large number of coefficients of dimension-six operators, before building the executables, the user should increase the value of the parameter maxnum in the file POWHEG-BOX-V2/include/pwhg_pwin.h. maxnum = 500 is sufficient to run the program. Build the executables

```
$ cd POWHEG-BOX-V2/VBF_H_smeft
$ make pwhg_main
$ make main-PYTHIA8-lhef
```

| | Operator | | | Operator | |
|---|---|---|---|---|---|
| $C_{\varphi W,\,\varphi B,\,\varphi WB}$, | CC_ww, CC_bb, CC_wb | | $C_{\varphi\tilde{W},\varphi\tilde{B},\varphi\tilde{W}B}$ | CC_wwt, CC_bbt, CC_wbt | |
| $\Gamma^u_W$ | ReGUw_$ii$ | ImGUw_$ii$ | $\Gamma^d_W$ | ReGDw_$jj$ | ImGDw_$jj$ |
| $\Gamma^u_\gamma$ | ReGUe_$ii$ | ImGUe_$ii$ | $\Gamma^d_\gamma$ | ReGDe_$jj$ | ImGDe_$jj$ |
| $c_{Q\varphi,\,U}$ | QphiU_$ii$ | | $c_{Q\varphi,\,D}$ | QphiD_$jj$ | |
| $c_{U\varphi}$ | Uphi_$ii$ | | $c_{D\varphi}$ | Dphi_$jj$ | |
| $\xi$ | ReXi_ $ij$ | ImXi_$ij$ | | | |

**Table 1:** Notation for the coefficients of the dimension-six operators that can be set in POWHEG. The index $i$ runs on $u$-type quark flavors $i \in \{$u,c,t$\}$, while $j$ on $d$-type quark flavors $j \in \{$d,s,b$\}$.

Then do (for example)

```
$ cd testrun-lhc-smeft
$ ../pwhg_main
```

At the end of the run, the file pwgevents.lhe will contain 100000 events for VBF in the Les Houches format. In order to shower them with PYTHIA do

```
$ cd testrun-lhc-smeft
$ ../main-PYTHIA8-lhef
```

## 3. Process specific input parameters

The process inherits all the parameters of the Standard Model $HZ$ production POWHEG process, described in Ref. [5].

By default, all dimension-six corrections are switched off in the POWHEG input card. To investigate the effect of one or more dimension-six operator, the user needs to set the flag dim6 to 1 and specify the values of one or more coefficents of dimension-six operators in the input file. The definition of the SM-EFT operators are given in Ref. [4], and their coefficients are defined to be dimensionless, and scaling as $(v/\Lambda)^2$, where $\Lambda$ is the scale of new physics.

Differently from neutral-current DY and $HZ$ production, in VBF we do not allow for flavor-changing $Z$ boson couplings. As discussed in more detail in Ref. [4], the user is allowed to set flavor-diagonal couplings to the $Z$ boson and to the photon in the quark mass basis. As a consequence, the couplings to $W$ bosons include factors of the CKM matrix, which are automatically included in init_couplings.f. The notation for the coefficients of SM-EFT operators in this scenario is given in Table 1, and example for the powheg.input card can be found in the folder testrun-lhc-smeft.

As an alternative to considering generic flavor structures, the code also provides the option to assume the Minimal Flavor Violation (MFV) framework. In this scenario, the allowed forms of the couplings are constrained by flavor symmetries, which significantly decreases the number of free parameters. The implications for the flavor structures of the couplings are discussed in Appendix B of Ref. [4]. To choose this scenario, the user should set the flag mfv to 1, and select some of the couplings in Table 2. An example for the powheg.input card in this scenario is given in the folder testrun-lhc-mfv. The

| Operator | $a_i$ | $b_i$ | Operator | $a_i$ | $b_i$ |
|---|---|---|---|---|---|
| $c_{Q\varphi,U}$ | A_QphiU | - | $c_{Q\varphi,D}$ | A_QphiD | B_QphiD |
| $c_{U\varphi}$ | A_Uphi | - | $c_{D\varphi}$ | A_Dphi | - |

**Table 2:** Notation for the coefficients of the different flavor structures in the MFV framework, discussed in Appendix B of Ref. [4], which can be set in POWHEG. The couplings $C_{\varphi W,\,\varphi B,\,\varphi WB}$ and $C_{\varphi\tilde{W},\varphi\tilde{B},\varphi\tilde{W}B}$ are not affected by the MFV assumption, and the notation is as in Table 1. Dipole and right-handed current couplings are set to zero.

couplings of the Higgs-gauge operators $C_{\varphi W,\,\varphi B,\,\varphi WB}$ and $C_{\varphi\tilde{W},\varphi\tilde{B},\varphi\tilde{W}B}$ are not affected by the assumption of MFV, and their notation is as in Table 1.

In addition to the couplings of dimension-six operators, the user can input the elements of the CKM matrix by setting CKM_V$ij$, with $i \in \{$u,c,t$\}$ and $j \in \{$d,s,b$\}$, in the input file. By default the CKM matrix is assumed to be real, and terms of $\mathcal{O}(\lambda^2)$, where $\lambda \sim |V_{us}|$, and higher are neglected.

The dipole operators in Table 1 run in QCD, and therefore the user should specify the scale at which the coefficents are evaluated. The new physics scale $\Lambda$, at which the coefficients are defined, can be specified by setting the flag LambdaNP to the desired value. The coefficients are then run from $\Lambda$ to $\mu_R$, the renormalization scale of the process. By default, LambdaNP $= 1$ TeV. For the coefficients that do not have QCD evolution, the flag LambdaNP is irrelevant.

Some of the operators in Table 1, such as $\Gamma_\gamma^{u,d}$ or $C_{\varphi B}$, induce contributions to VBF mediated by the exchange of a photon. These contributions can generate collinear divergences, which are cut-off by the $p_T$ and rapidity cuts in the experimentally relevant region, but can make the generation of events extremely inefficient. In order to avoid these singular regions, if the coefficients of operators involving photons are turned on, the generation of events should be performed setting the bornsuppfact flag to an appropriate value in the powheg.input file.

## References


[1] P. Nason, "A new method for combining NLO QCD with shower Monte Carlo algorithms," JHEP **0411** (2004) 040 [arXiv:hep-ph/0409146].

[2] S. Frixione, P. Nason and C. Oleari, "Matching NLO QCD computations with Parton Shower simulations: the POWHEG method," JHEP **0711** (2007) 070 [arXiv:0709.2092 [hep-ph]].

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[4] S. Alioli, W. Dekens, M. Girard and E. Mereghetti, JHEP **1808**, 205 (2018) doi:10.1007/JHEP08(2018)205 [arXiv:1804.07407 [hep-ph]].

[5] P. Nason and C. Oleari, JHEP **1002**, 037 (2010) doi:10.1007/JHEP02(2010)037 [arXiv:0911.5299 [hep-ph]].