Manual for W and Z Production via Vector Boson Fusion in the POWHEG BOX

This document describes the settings and input parameters that are specific to the implementation of W and Z production via vector boson fusion at the LHC within the POWHEG BOX framework. The parameters that are common to all POWHEG BOX implementations are given in the `manual-BOX.pdf` document in the `POWHEG-BOX/Docs` directory. Since there are singular configurations in the Born contributions, due care has to be exercised to avoid these regions when generating the Born phase space. Two available options are described in the Input parameters section. On this account, the code is not expected to give reliable results when used with very inclusive cuts. If you use our program, please cite Refs. [1–3].

Running the program

Go to the directory `$ cd POWHEG-BOX/VBF_W-Z` and create a directory where you want to run the code:

```
$ mkdir testrun
```

The directory must contain the `powheg.input` and `vbfnlo.input` file. To compile the code with `gfortran`, type

```
$ make
```

The code needs `fastjet` and `lhapdf`, so make sure that `fastjet-config` and `lhapdf-config` are in the path.

After compiling, enter the testrun directory:

```
$ cd testrun
```

The program can be run sequentially by deactivating the variable `manyseeds` in `powheg.input`. Execute the program with

```
$../pwhg_main
```

The program can also be run in parallel by setting `manyseeds` to `1` in `powheg.input` and in several steps as for instance described in the manual for VBF Z production [4].

Input parameters

To have more flexible choices for the input parameters of the calculation, a new input file (`vbfnlo.input`) was added in addition to the standard `powheg.input` file. The use of this new file and some special parameters for `powheg.input` will be explained in the following.

`powheg.input`

- `mll_gencut` : cut on the invariant dilepton mass for Zjj production, set to 15 GeV if lower than 15 GeV. This cut is needed to avoid singularities when a virtual photon decays into two massless leptons.

- `bornsuppfact`:

  0 No Born suppression factor. You should use generation cuts via `ptj_gencut` when using this option.

  1 Use a Born suppression factor $F(\Phi_n)$ with

  $$F(\Phi_n) = \left(\frac{p_{T,j1}^2}{p_{T,j1}^2 + \Lambda_{pTj}^2}\right)^n \left(\frac{p_{T,j2}^2}{p_{T,j2}^2 + \Lambda_{pTj}^2}\right)^n .$$

  Λ_{pTj} is set to the value given in `ptsuppfact` and $F(\Phi_n)$ vanishes whenever a singular region in the Born phase space Φ_n is reached. The underlying Born kinematics are then generated in the POWHEG-BOX according to a modified $\overline{B}$ function,

  $$\overline{B}_{\text{supp}} = \overline{B}(\Phi_n)F(\Phi_n).$$

- `ptj_gencut`: Generation cut on the jets' p_T in the phase space generator. Should be used when `bornsuppfact` is set to 0.

- `Phasespace`:

  1 Default value, use the standard phase space (with `bornsuppfact` or `ptj_gencut`).

  2 Use unweighted events as phase space generator. To use this option, unweighted events with very inclusive cuts have to be generated with VBFNLO in a seperate run. Each event which survives the unweighting procedure has to be reweighted by the factor $J_i = \sigma_{LO}/(|\mathcal{M}_B(\Phi_i)|^2\,\text{pdf}(\Phi_i))$, the Born cross section over the respective numerical value of the squared Born matrix element including pdfs. This factor J_i is exactly the Jacobian factor of the Born phase space. Place the file with the reweighted events called `event.total.lhe` in the running directory.

- `bornxsec`: Born cross section in nb of the unweighted events used for `Phasespace` 2. Not needed otherwise.

- `fakevirt` : If the program is run in several steps, the generation of the grid can be performed with `fakevirt 1`, where the virtual amplitude is set to a factor proportional to the Born amplitude.

`vbfnlo.input`

The input parameters which can be changed by the user are explained in the VBFNLO Manual [5] in detail. Here we give a list of the supported parameters with a short description.

- `PROC_ID`:

  120 $pp \to Z\,jj \to \ell^+\ell^-\,jj$

  130 $pp \to W^+\,jj \to \ell^+\nu_\ell\,jj$

  140 $pp \to W^-\,jj \to \ell^-\bar{\nu}_\ell\,jj$

- `HMASS`: Standard Model Higgs boson mass in GeV. Default value is 126 GeV.

- `HWIDTH`: It is possible to set the Higgs boson width with this input parameter. Default is -999 GeV, which means that the internally calculated value of the width is used.

- `EWSCHEME`: Sets the scheme for the calculation of electroweak parameters. A summary of the four available options is given in Table 1. Note that if `EWSCHEME = 4` is chosen, all variables in Table 1 are taken as inputs. As the parameters are not independent, this can lead to problems if the input values are not consistent. In this scheme, all photon couplings are set according to the input variable `INVALFA` and all other couplings are set according to `FERMI_CONST`. Default value is 3.

- `ANOM_CPL`: If set to `1`, anomalous gauge boson couplings are used if available for the selected process. Anomalous coupling parameters are set via the file `anomV.dat` which has to be located in the running directory. For details on the possible choices and parameterisations of the anomalous couplings see the VBFNLO Manual [5]. This is not a tested feature and should always be compared to the NLO result of VBFNLO. Default value is `0`.

- `TOPMASS`: Top-quark mass in GeV. Default value is 172.4 GeV.

- `TAU_MASS`: Tau mass in GeV used in the calculation of the Higgs boson width and branching ratios. Default value is 1.77684 GeV.

- `BOTTOMMASS`: Bottom-quark pole mass in GeV, used in the calculation of the Higgs boson width and branching ratios. Default value is 4.855 GeV, which corresponds to $m_b^{\overline{MS}}(m_b) =$ 4.204 GeV.

- `CHARMMASS`: Charm-quark pole mass in GeV used in the calculation of the Higgs boson width and branching ratios. Default value is 1.65 GeV, corresponding to $m_c^{\overline{MS}}(m_c) =$ 1.273 GeV.

- `FERMI_CONST`: Fermi constant, used as input for the calculation of electroweak parameters in `EWSCHEME` = 1-4. Default value is 1.16637×10^{-5} GeV^{-2}.

- `INVALFA:` One over the fine structure constant, used as input for `EWSCHEME` = 1 and 4. Within the other schemes this parameter is calculated. The default value depends on the choice of `EWSCHEME`, as given in Table 1.

To compare the code with [4], the flag `consistency` in the `qqbqq.f` and `qqZWjqqi.f` file in the `vbfnlo-files` directory has to be set to `.true.`. Than, all amplitudes with $Q^2 < 4$ GeV are provided with a large damping factor, not only the ones with photons in the t-channel. After that, the code has to be recompiled.

EWSCHEME	Parameter	Default Value	Input/Calculated
1	FERMI_CONST	1.16637×10^{-5} GeV^{-2}	Input
	INVALFA	128.944341122	Input
	SIN2W	0.230990	Calculated
	WMASS	79.9654 GeV	Calculated
	ZMASS	91.1876 GeV	Input
2	FERMI_CONST	1.16637×10^{-5} GeV^{-2}	Input
	INVALFA	132.340643024	Calculated
	SIN2W	0.222646	Input
	WMASS	80.3980 GeV	Calculated
	ZMASS	91.1876 GeV	Input
3	FERMI_CONST	1.16637×10^{-5} GeV^{-2}	Input
	INVALFA	132.340705199	Calculated
	SIN2W	0.222646	Calculated
	WMASS	80.3980 GeV	Input
	ZMASS	91.1876 GeV	Input
4	FERMI_CONST	1.16637×10^{-5} GeV^{-2}	Input
	INVALFA	137.035999679	Input
	SIN2W	0.222646	Input
	WMASS	80.3980 GeV	Input
	ZMASS	91.1876 GeV	Input

Table 1: *Electroweak input parameter schemes.*

References

[1] F. Schissler, and D. Zeppenfeld, *Parton Shower Effects on W and Z Production via Vector Boson Fusion at NLO QCD*, arXiv:1302.2884.

[2] C. Oleari and D. Zeppenfeld, *QCD corrections to electroweak nu(l) j j and l+ l- j j production*, Phys. Rev. D **69**, 093004 (2004) [hep-ph/0310156].

[3] S. Alioli, P. Nason, C. Oleari, and E. Re, *A general framework for implementing NLO calculations in shower Monte Carlo programs: the POWHEG BOX*, JHEP **1006** (2010) 043 [arXiv:1002.2581 [hep-ph]].

[4] B. Jäger, S. Schneider, G. Zanderighi, *Next-to-leading order QCD corrections to electroweak Zjj production in the POWHEG BOX*, arXiv:1207.2626 [hep-ph].

[5] K. Arnold, M. Bähr, G. Bozzi, F. Campanario, C. Englert, T. Figy, N. Greiner and C. Hackstein *et al.*, Comput. Phys. Commun. **180**, 1661 (2009) [arXiv:0811.4559 [hep-ph]];
K. Arnold, J. Bellm, G. Bozzi, F. Campanario, C. Englert, B. Feigl, J. Frank and T. Figy *et al.*, [arXiv:1207.4975 [hep-ph]];
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