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Special Article - Tools for Experiment and Theory

W^+W^-, WZ and ZZ production in the POWHEG-BOX-V2

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Abstract We present an implementation of the vector boson pair production processes ZZ, W^+W^- and WZ within the POWHEG-BOX-V2. This implementation, derived from the POWHEG BOX version, has several improvements over the old one, among which the inclusion of all decay modes of the vector bosons, the possibility to generate different decay modes in the same run, speed optimization and phase space improvements in the handling of interference and singly resonant contributions.

Contents

1 Introduction

In Ref. [1] an implementation of vector boson pair production at NLO in QCD, that can be interfaced to a shower generator according to the POWHEG method, was presented. Only decays into leptons and neutrinos were considered. Singly resonant contributions and interference effects were included, and in fact all diagrams relevant to the production of four leptons were accounted for, with the exception of interference effects between W^+W^- and ZZ production when the decay products are the same. These last effects were shown to be fully negligible at Born level.

In the present work, we present a new implementation of these processes that has the following improvements over the old one:

- all possible decay modes are allowed;
- different decay modes can be produced in a single run;
- there is a considerable speed improvement;
- there is an improvement in the treatment of the phase space and interference terms.

Although hadronic final states are all allowed, no NLO corrections to the vector boson decays are included. W and Z decays are in fact properly handled by the shower Monte Carlo programs, like PYTHIA [2,3] and HERWIG [4,5], that can be interfaced to the POWHEG BOX, their resonance decay machinery being tuned to closely reproduce collider data.

The new implementation exploits the fact that in the POWHEG-BOX-V2 version one can specify if final state particles arise from a resonance decay. The algorithm for finding the radiation region in real graphs, checks if a parton arises from a resonance rather than from the production vertex, and handles the radiation accordingly. In the present implementation, where no radiative corrections to decaying resonances are considered, the only singular regions that are produced by POWHEG are thus relative to the production vertex.

2 Matrix elements

We have used the same MCFM matrix elements [6] as in the old implementation, extending them to deal with hadronic decays. A considerable increase in performance was achieved by storing intermediate results in the matrix element calculation. Strong corrections in hadronic decays, of the form $1+\alpha_s(M_V)/\pi$, are also included.

A non diagonal Cabibbo matrix is used by default (an arbitrary CKM matrix can be entered in input by the user). This is done in the following way. The only process in which flavour changing interactions can arise in production is WZ (in fact, in W^+W^- production flavour changing interactions are suppressed by the GIM mechanism). In the WZ case we

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thus generate explicitly from the beginning all CKM allowed flavour changing processes. In W decays, one generates the matrix elements for the decay into $\bar{u}d'$, $\bar{c}s'$ (and the corresponding ones for the W^+), where d' and s' are the electroweak flavour eigenstates. Once the event is generated, the d' or s' are transformed randomly into a d or s mass eigenstate, with a probability corresponding to the square of the appropriate CKM entry.

3 Phase space

The treatment of the phase space, especially when handling processes with interference, has been changed with respect to the original version.

When interference is present, we compute both the amplitudes $\mathcal{A}$ and $\mathcal{A}_{\text{exch}}$, where $\mathcal{A}_{\text{exch}}$ is the amplitude with the final state identical particles exchanged. In the previous version we computed the cross section using the squared amplitude

$$|\mathcal{A}|^2 + |\mathcal{A}_{\text{exch}}|^2 + 2\text{Re}(\mathcal{A}\mathcal{A}^*_{\text{exch}})\,. \tag{3.1}$$

This had the disadvantage that the regions for the importance sampling of the resonances were mixed up, and had to be handled with care [1]. In the present version, we instead do the following. We rewrite Eq. (3.1) as

$$\left(|\mathcal{A}|^2 + |\mathcal{A}_{\text{exch}}|^2\right) \times \left\{1 + \frac{2\text{Re}(\mathcal{A}\mathcal{A}^*_{\text{exch}})}{|\mathcal{A}|^2 + |\mathcal{A}_{\text{exch}}|^2}\right\}. \tag{3.2}$$

Noticing that both factors are symmetric for the exchange of the momenta of the identical particles, and that $|\mathcal{A}|^2$ and $|\mathcal{A}_{\text{exch}}|^2$ go into each other by this exchange, we can as well use the expression

$$2|\mathcal{A}|^2 \times \left\{1 + \frac{2\text{Re}(\mathcal{A}\mathcal{A}^*_{\text{exch}})}{|\mathcal{A}|^2 + |\mathcal{A}_{\text{exch}}|^2}\right\}, \tag{3.3}$$

that yields the same result upon integration. We then assign the resonances according to the structure of the $|\mathcal{A}|^2$ term. The ambiguity in the assignment is only present now in the small interference term, and no particular importance sampling tricks are needed to handle it.

Notice that what would seem to be the most obvious choice

$$2|\mathcal{A}|^2 + 2\text{Re}(\mathcal{A}\mathcal{A}^*_{\text{exch}}), \tag{3.4}$$

is in fact problematic, since it does not yield a positive definite cross section.

A further improvement was given by generating the partonic s variable in the underlying Born configuration with Lorenzian importance sampling over the possible single-resonant contribution. This leads to a better description of the single-resonant region.

4 Generation of the subprocesses

In this version of the VV production codes it is possible to generate the matrix elements for all possible decays of the vector bosons. This leads to a large proliferation of amplitudes. For example, there are 880 Born parton level configurations that arise in WZ production. Generating all processes at once slows down the program considerably. Furthermore, even if the total result is computed with a satisfactory accuracy, it is not easy to check that all decay processes have been accurately probed. This is particularly critical when computing the upper bounds for radiation, since they are computed individually for each underlying Born configuration. Because of this reason a new feature was introduced in `POWHEG-BOX-V2`, such that the upper bound for radiation of equivalent amplitudes (i.e. amplitudes that are equal up to constant couplings) are combined. This feature is activated by default for the processes at hand, but can also be activated for other processes by including the line `evenmaxrat 1` in the `powheg.input` file. Still it is often convenient to restrict the generated decay modes to the ones one is really interested into. All generators offer a number of pre-defined options to select specific decay modes (e.g. leptonic, semi-leptonic, hadronic, etc.). It is however difficult to anticipate all interesting possibilities. For this reason, the code has been written in such a way that the selection of decay modes can also be carried out by the user by editing the subroutine `alloweddec` in the `init_processes.f` file. Further explanations on how to do this are given in the respective manual.

5 Availability

The new code has been made available in the `POWHEG BOX` svn repository, and instructions for downloading the V2 version of `POWHEG` and the corresponding user processes are given at the URL http://powhegbox.mib.infn.it.

If you use this code, please quote the present note, and Ref. [1]. Furthermore we remind that the matrix elements were obtained from Ref. [6], and the `POWHEG BOX` framework has been developed in the sequel of publications [7–9].

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