Prepared for submission to JHEP

NNLOPS simulation of Higgs boson production

Keith Hamilton[a] **Paolo Nason**[b] **Emanuele Re**[c] **Giulia Zanderighi**[c]

[a]*Department of Physics and Astronomy, University College London,*
London, WC1E 6BT, UK

[b]*INFN, Sezione di Milano Bicocca,*
Piazza della Scienza 3, 20126 Milan, Italy

[c]*Rudolf Peierls Centre for Theoretical Physics, University of Oxford*
1 Keble Road, UK

E-mail: keith.hamilton@ucl.ac.uk, paolo.nason@mib.infn.it, e.re1@physics.ox.ac.uk, g.zanderighi1@physics.ox.ac.uk

Abstract: We describe the usage of the generator, developed in ref. [1], for gluon fusion Higgs production interfaced to a shower Monte Carlo that achieves next-to-next to leading order accuracy in QCD.

Contents

1 Introduction

Here we give the instructions to use the code developed in ref. [1] for the construction of a Monte Carlo showered sample for gluon fusion Higgs production that is accurate at the next-to-next to leading order (NNLO) in QCD. The method makes use of the `hnnlo` code of refs. [2, 3] and of the `POWHEG` `HJ` generator [4] improved with the `MiNLO` procedure according to refs. [5, 6].

The `MiNLO` improved `HJ` generator (`HJ-MiNLO` from now on) as it is set out in [6], is crucial for our NNLOPS implementation. In fact, it reaches NLO accuracy not only for $H + 1$jet observables, but also for inclusive ones. Furthermore, it does this in a seamless way, without introducing unphysical cuts in order to separate the 0 and 1-jet final states. This feature allows to reach NNLO accuracy by a simple reweighting procedure, making use of a one parameter distribution computed with the `hnnlo` code.

These instructions explain how to use the relevant code[1] in conjunction with the `hnnlo` and `HJ` programs to generate `NNLOPS` accurate samples.

[1]The code can be found in the `HNNLOPS` subdirectory of the `HJ` process in the `User-Processes-V2` directory. Instructions for downloading the code can be found in `http://powhegbox.mib.infn.it`.

2 Input: NNLO rapidity spectrum

The fundamental NNLO ingredient required to obtain NNLO accurate event samples is, for gluon fusion Higgs production, the Higgs boson's rapidity spectrum.[2] We here give instructions on how to obtain such distributions, suitable for combination with the `HJ-MiNLO` events via the `HJ/NNLOPS` reweighting code.

1. Make sure that the `LHAPDF` package is installed:
   https://lhapdf.hepforge.org
   The current version of this code has only been tested with up to version 5.8.9. In particular, for the installation of `hnnlo`, the command `lhapdf-config --libdir` should return the location of the installed `Lhapdf` libraries.

2. Download `hnnlo` from the following `url`:
   http://theory.fi.infn.it/grazzini/codes/hnnlo-v1.3.tgz

3. Unpack the tarball in a convenient location
   ```
   work$ cp  /Downloads/hnnlo-v1.3.tgz ./
   work$ tar -xzvf hnnlo-v1.3.tgz
   work$ ls hnnlo-v1.3
   ```
   Under the parent directory `hnnlo-v1.3` one should find subdirectories `bin`, `doc`, `obj`, `src`, and a `makefile`.

4. Enter the `hnnlo` parent directory
   ```
   work$ cd hnnlo-v1.3
   ```

5. Replace the `hnnlo` default `makefile` with the one from the `HJ/NNLOPS` directory
   ```
   work$ cp /path/to/HJ/NNLOPS/HNNLO-makefile ./makefile
   ```

6. Copy the `hnnlo` patches directory into the parent directory
   ```
   work$ cp -r /path/to/HJ/NNLOPS/HNNLO-patches ./
   ```

7. Build the code
   ```
   work$ make
   ```
   A message `--> HNNLO compiled with LHAPDF routines <--` indicates success.

8. Copy over the template input file and, if parallel runs are required, the related script to set up multiple runs
   ```
   work$ cd bin
   work$ cp /path/to/HJ/NNLOPS/HNNLO.input ./
   work$ cp /path/to/HJ/NNLOPS/HNNLO-mur-muf-scan.sh ./
   ```

[2]In general, for `NNLOPS` simulations one requires an NNLO accurate distribution for some Born kinematics. In this case the Born kinematics is fully specified in terms of the rapidity of the boson.

9. Either edit the input file or the script for parallel runs as desired. The former is nothing but a standard hnnlo input file and may be run simply by typing

```
work$ ./hnnlo < HNNLO.input >> my.log
```

yielding a hnnlo.top histogram file.

Alternatively one can run the HNNLO-mur-muf-scan.sh script in the same directory. The script generates hnnlo input files and shell scripts for the generation of runs for a number of different rescaling factors for μ_{R} and μ_{F}, and, moreover, a number of sequentially ordered seeds (specified by the njobs variable) for each μ_{R}, μ_{F} value. Runs different only by the value of the random seed may be combined to increase the statistical precision. Statistically equivalent histogram files may be combined with the mergedata program:

```
work$ cp /path/to/HJ/NNLOPS/mergedata.f ./
work$ gfortran -o mergedata -c mergedata.f ; chmod +x mergedata
work$ ./mergedata 1 file_1.top ...  file_N.top
work$ mv fort.12 hnnlo.top
```

Lastly, we draw attention to the fact that the default HNNLO.input file supplied sets $\mu_{\mathrm{R}} = \mu_{\mathrm{F}} = \frac{1}{2} m_H$ as the central scale choices about which the scale variations are carried out by the factors mentioned earlier.

In order to produce the hnnlo output for ref. [1], for each scale choice, we used 120M integration points for the grid preparation, and about 150-200 runs with 240M points each for the integration stage.

10. Finally, for the purposes of setting the HJ-MiNLO input parameters consistently with those used for hnnlo, make a note of the Higgs boson width calculated by hnnlo in its initialisation phase. This will appear at the beginning of the hnnlo on-screen output, as follows

```
CCCCCCCCCCCCCCC SM Higgs parameters CCCCCCCCCCCCCCCC
C                                                  C
C Mh = 125.50 GeV                                  C
C Gamma(H)= 0.004221 GeV                           C
C                                                  C
```

We emphasise that hnnlo and HJ-MiNLO must be run with the same values of the Higgs mass and decay width, and with the same PDFs (and α_s).

3 Input: HJ-MiNLO events

With the NNLO input in hand the other fundamental ingredient needed for the NNLO reweighting procedure are the HJ-MiNLO Les Houches event files. Strictly speaking, the HJ-MiNLO code does not require any modification for this purpose. Moreover the running of the program proceeds in the usual way. The important (albeit obvious) point is to maintain consistency of the physical parameters in `hnnlo` and `HJ-MiNLO`. To this end we describe, below, all relevant details involved in this.

1. The denominator in the reweighting factor is computed from the generated Les Houches sample. Thus, for the reweighting to make sense, there should be enough events in the Les Houches file. As a guideline, we suggest to use no less than 500K events.

2. A large number of physical parameters used by the `HJ-MiNLO` code, such as the Fermi constant, are assigned by the subroutine `init_couplings` defined in file `HJ/init_couplings.f`. As in the case of the `hnnlo mdata.f` file, some of the parameters in this file may be irrelevant for gluon fusion Higgs production. Nevertheless, in `HJ/NNLOPS/init_couplings.f` we provide a version of this routine edited for maximum consistency with the physical parameters in the `mdata.f` file we supply for `hnnlo`. We therefore recommend using these inputs in place of the `POWHEG BOX` defaults. This can be done, for instance, by overwriting the latter and (re-)compiling the `HJ-MiNLO` code:

```
work$ cd /path/to/HJ/
work$ cp NNLOPS/init_couplings.f ./
work$ make
```

3. The main physical parameters to ensure consistency with respect to the `hnnlo` runs are set in the `powheg.input` file under `HJ/testrun-lhc/`, or, if running parallel `HJ-MiNLO` jobs, in `powheg.input-save` under `HJ/testparallel-lhc/`. In particular, the Higgs boson mass should be set according to the value input to `hnnlo`, and the Higgs boson width should be set to the on-screen value computed by `hnnlo`. For a Higgs mass of 125.5 GeV for example we set in `powheg.input` or `powheg.input-save`:

```
hmass 125.5
hwidth 0.004221D0
bwcutoff 1000
```

   where `bwcutoff 1000` determines that the code generate off-shell Higgs masses, m_{H}^{*}, in the range $m_{\mathrm{H}} - 1000\,\Gamma_{\mathrm{H}} < m_{\mathrm{H}}^{*} < m_{\mathrm{H}} + 1000\,\Gamma_{\mathrm{H}}$. In addition we require that the Higgs particle is left undecayed at the Les Houches event level

```
hdecaymode -1
```

   A further useful (although not mandatory) technical input, involves suppressing the generation of low transverse momentum events in order to better populate high p_{T} tails. This can be achieved by setting e.g.

```
bornsuppfact 10
```

   Further explanation of the `bornsuppfact` parameter and other workings of the `HJ-MiNLO` program can be found in `/path/to/HJ/Docs/manual-BOX-HJ.pdf`. Also, for detailed instructions on setting up the `HJ-MiNLO` program to perform numerous runs in parallel see section 4.1 in `/path/to/W2jet/Docs/manual-BOX-WZ2jet.pdf`

Lastly, we add that although it is not strictly necessary to generate the `HJ-MiNLO` events using a NNLO PDF, in the limited studies that we have carried out to date with the `NNLOPS` code, we have found good agreement with higher order resummation programs using the MSTW 2008 NNLO set [7]. This can be selected by setting `LHAPDF` indices `lhans1 21200` and `lhans2 21200` in `powheg.input` or `powheg.input-save`.

Again, we emphasise that ultimately the responsibility for ensuring the consistent running of `hnnlo` and `HJ-MiNLO`, to obtain inputs for reweighting procedure, rests with the user.

4 Reweighting

The NLO-to-NNLO weight factor assigned to the `HJ-MiNLO` events is

$$\mathcal{W}(y,\, p_{\mathrm{T}}) = h(p_{\mathrm{T}})\, \frac{\int d\sigma^{\mathrm{NNLO}}\;\; \delta\left(y - y\left(\Phi\right)\right) - \int d\sigma_{B}^{\mathrm{MINLO}}\, \delta\left(y - y\left(\Phi\right)\right)}{\int d\sigma_{A}^{\mathrm{MINLO}}\, \delta\left(y - y\left(\Phi\right)\right)} + \left(1 - h\left(p_{\mathrm{T}}\right)\right)\,, \tag{4.1}$$

where y is the Higgs boson rapidity and p_{T} is the transverse momentum of the leading jet in the LHE events, and

$$d\sigma_A = d\sigma\, h\left(p_{\mathrm{T}}\right)\,, \tag{4.2}$$

$$d\sigma_B = d\sigma\, \left(1 - h\left(p_{\mathrm{T}}\right)\right)\,, \tag{4.3}$$

with h a monotonic profile function

$$h(p_{\mathrm{T}}) = \frac{(\beta\, m_{\mathrm{H}})^2}{(\beta\, m_{\mathrm{H}})^2 + p_{\mathrm{T}}^2}, \tag{4.4}$$

and β a constant parameter. On convoluting $\mathcal{W}(y,\, p_{\mathrm{T}})$ with the `HJ-MiNLO` differential cross section and integrating over p_{T} one finds, exactly,

$$\left(\frac{d\sigma}{dy}\right)^{\mathrm{NNLOPS}} = \left(\frac{d\sigma}{dy}\right)^{\mathrm{NNLO}}\,. \tag{4.5}$$

For a proof of why such a reweighting procedure leads to NNLO accuracy in general, and not simply the inclusive rapidity spectrum, we refer the reader to Sect. 2.1 of ref. [1].

The role of the profile function h and, in particular, the β parameter within it, is, roughly speaking, to determine how to spread out the NLO-to-NNLO corrections along the p_{T} axis. For $\beta = \infty$ the corrections are spread uniformly in p_{T} (see e.g. fig. 3 of ref. [1]), while for $\beta = \frac{1}{2}$ they are concentrated in the region $p_{\mathrm{T}} < \beta\, m_{\mathrm{H}}$. In the latter respect the β parameter plays a similar role to the resummation scale in dedicated resummation calculations, and as such we favour that β be set consistently with the preferred values in those. Thus we recommend $\beta = \frac{1}{2}$ in carrying out the reweighting. Indeed for $\beta = \frac{1}{2}$ we find good agreement with dedicated NNLL+NNLO calculations of the Higgs boson transverse momentum and the 0-jet veto efficiency wherein the resummation scale was set to $\frac{1}{2}m_{\mathrm{H}}$ (see figs. 5 and 7 of ref. [1]).

We should emphasise that, while our NNLOPS simulation is formally NNLO accurate for inclusive quantities, the accuracy of its resummation of all-orders large logarithms is not at the NNLL+NNLO level. We recommend that the predictions of such calculations be used to 'tune' the NNLOPS simulation (in particular the β parameter) to approximate the yet higher order, large logarithmic terms which are not properly accounted for. Setting $\beta = \frac{1}{2}$ appears to do a very good job in this respect, thus it is our default, recommended value.

4.1 A simple run

The code to be used in order to produce an NNLO-reweighted event file can be found in the NNLOPS/Reweighter/ directory. This program takes as input the hnnlo output files (i.e. the files with the .top suffix) and the HJ-MiNLO LHE file, and produces as output a new LHE file, where after each event new weights are added, corresponding to the NNLO reweighted events. The new weights appear, before the <\event> line, in lines of the form

```
#new weight,renfact,facfact,pdf1,pdf2 <weight> <KR> <KF> <npdf1> <npdf2> \
       <pdftag>  <HNNLO-identifier>
```

where <weight> is the weight of the event, <KR> and <KF> are the renormalization and factorization scale factors, <npdf1> and <npdf2> are the pdf set number for the negative and positive rapidity incoming hadrons, <pdftag> is either mlm if the internal PDF package of the POWHEG BOX is used, or lha if LHAPDF is used instead. Finally <HNNLO-identifier> is an identifier of no more than six characters, provided by the user when the run is performed.

The run is carried out in the following way. In the NNLOPS/Reweighter/ directory one enters

```
$ make minnlo
$ ./minnlo <HJMiNLO-eventfile> <HNNLO-identifier1> <HNNLO-outputfile1> \
          [<HNNLO-identifier2> <HNNLO-outputfile2> ... ]}}\vspace{3mm}
```

where <HJMiNLO-eventfile[1...]> is a LH file (suffix .lhe) containing events produced with HJ-MiNLO, obtained as described in sec. 3, whereas <HNNLO-outputfile[1 ...]> are the final histogram file (suffix .top) produced from the hnnlo run(s), as described in sec 2. It is good practice to use for the HNNLO-identifier a name related to the particular hnnlo settings being used when generating the corresponding <HNNLO-outputfile[1 ...]> file (i.e. scales, parton distributions, etc.), as it will be more clear in sec. 4.2. At the end of the program execution, a new LH file will be present in the run directory, named as the HJMiNLO-eventfile event file, but with a suffix .nnlo. This LH file is the final output of the minnlo NLO-to-NNLO reweighter program, and can now be read and showered by Pythia or Herwig, as it is usually done with LH event files generated by POWHEG BOX.

The program takes few minutes to reweight a LH file produced by HJ-MiNLO containing 500000 events. The output printed on the terminal at run time is self explanatory.

4.2 Estimating uncertainties

The conservative Ansatz we recommend in estimating errors (the one employed in ref. [1]) is that the $\mu_{\rm R}$ and $\mu_{\rm F}$ scales in the NNLO and NLO inputs should be varied in a fully independent way. In doing so we regard the uncertainties in the normalizations of distributions, e.g. the transverse momentum spectrum of the Higgs boson, as being independent of the respective uncertainties in the shapes — at least in the low $p_{\rm T}$ region covered by the profile function, $h(p_{\rm T})$. The former are determined by the `hnnlo` program, while the latter are due to `HJ-MiNLO`. Outside of the low $p_{\rm T}$ region, in the part corresponding to the $1-h(p_{\rm T})$ term in eq. (4.1), the uncertainty is given by the standard `HJ-MiNLO` computation (which there corresponds to that of conventional NLO with $\mu_{\rm R}=\mu_{\rm F}=p_{\rm T}$ for the central scale choice).

In order to compute an uncertainty band, one first needs to have obtained multiple outputs from `hnnlo` and `HJ-MiNLO` varying $\mu_{\rm R}$ and $\mu_{\rm F}$. For the sake of simplicity, we will now describe a case where $\mu_{\rm R}$ and $\mu_{\rm F}$ are kept equal both when running `hnnlo` and `HJ-MiNLO`. We call this situation a "3x3 pts" scale variation study: for each event we will obtain 9 NNLO weights, associated to each of the 9 possible combinations among 3 results from `hnnlo` and 3 from `HJ-MiNLO`. This procedure is general enough to be straightforwardly adapted to the more general case of a "7x7 pts" scale variation, or variation thereof.

In the "3x3 pts" case, the needed inputs are 3 histogram files from `hnnlo`, which we will call `HNNLO-outputfile-QQ.top`, `HNNLO-outputfile-HH.top` and `HNNLO-outputfile-11.top`, for values of $\mu_{\rm R}=\mu_{\rm F}=\{m_{\rm H}/4, m_{\rm H}/2, m_{\rm H}\}$ respectively. Similarly, the user needs to have obtained a LH file from `HJ-MiNLO` where 3 weights are associated to each event. This file has to be obtained with the `POWHEG BOX` reweighting machinery: the 3 lines in between the last line of each event record and the `</event>` tag should have the format

```
#new weight,renfact,facfact,pdf1,pdf2 <weight> <KR> \
    <KF> <npdf1> <npdf2> <pdftag>
```

The NLO-to-NNLO reweighter program should now be invoked as follows:

```
$ ./minnlo HJMiNLO-events.lhe HH HNNLO-outputfile-HH.top \
        QQ HNNLO-outputfile-QQ.top 11  HNNLO-outputfile-11.top
```

and in this case it is reasonable to use `HH, QQ, 11` as "identifier" strings for the 3 `hnnlo` histogram files. At the end of the run, 9 lines will be present after each event record, each one containing the NNLO weight associated to the `HJ-MiNLO` result labelled by the values of the pair (`<KR>`, `<KF>`) and the `hnnlo` result identified by the `HNNLO-identifier` appended at the end of each line.

5 Example analysis

The analysis used for the study in ref. [1] can be found in `pwhg_analysis-pheno_2.f`. Either this analysis, or the `pwhg_analysis-release.f` should be used to produce the NNLO-reweighted LH file (the former is extension of the latter to include physical distributions of interest). More interestingly, it can also be used to analyse events after the showering stage.

In this case, in the Makefile under the HJ directory, in the section where the analysis files are defined, the following line should be used:

```
PWHGANAL=pwhg_bookhist-multi.o pwhg_analysis-pheno_2.o fastjetfortran.o
      genclust_kt.o miscclust.o ptyrap.o r.o swapjet.o jet_finder.o
      auxiliary.o get_hdamp.o
```

As usual, FastJet should be linked too.

In order to perform showering and analysis of the NNLOPS LHE files, one needs to be able to use the information in the #new weight lines. This information can easily be converted to the standard Les Houches format specified in http://phystev.in2p3.fr/wiki/2013:groups:tools_lheextension. At the moment we do not provide script executable in order to perform this conversion. These can be provided upon request.

6 Suggested citations

If you use this code please cite the inclusive Higgs boson production NNLOPS paper [1] and the HJ-MiNLO paper which precedes and lays much of the foundations for it [6]. The NNLOPS simulation fundamentally relies on the NNLO Higgs boson production calculation of refs. [2, 3], and so these works should also be cited.

A Code description

In this section we briefly record the various additions and modifications to existing hnnlo and POWHEG BOX code used to produce NNLOPS events.

A.1 hnnlo

- makefile (HNNLO-makefile)
  - The hnnlo makefile is modified by prepending $(HNNLOHOME)/HNNLO-patches to the $DIRS variable, introducing a variable $PATCHES equal to the concatenation of the following object files in this list, plus the removal of those elements from the other Makefile variables (avoiding duplication). In this way the modified hnnlo files below are compiled and linked from HNNLO-patches instead of the default versions in the default locations.
- mbook.f
  - The mtop subroutine, which outputs the hnnlo histograms to a text file, has undergone a minor modification so as to have the same format as the HJ-MiNLO histogram output, to ease comparisons and for use in the reweighting program.
- mdata.f
  - This file contains the values of numerous physical constants in hnnlo e.g. the Fermi's constant G_F. The great majority of these constants should be irrelevant

in the context of gluon fusion Higgs boson production. Moreover, any inconsistencies between these and the corresponding values used in the HJ-MiNLO program should result in negligible differences. The main parameters to seek consistency between HJ-MiNLO and hnnlo codes are the Fermi's constant G_F and the top mass. Nevertheless, we have edited all parameters in this file to maximize agreement with the corresponding HJ-MiNLO settings.

- plotter.f
  - This file contains an example analysis for hnnlo by default. We have modified this analysis substantially to produce histograms of the Higgs boson's rapidity distribution inclusively and also in the presence of a number of different profile functions. All but the first of these histograms, the inclusive Higgs boson rapidity, are not used in our default, recommended, reweighting procedure. The inclusive rapidity spectrum is the first histogram appearing in the output .top file and is titled simply 'yh'. The histogram range has been set to $-5 < y < 5$ and the bin width is 0.1. These values may be altered by the user as desired, by editing the relevant bookplot subroutine call. However, in this case one must take care to modify the relevant POWHEG BOX analysis file used by the reweighting code, under the HJ/NNLOPS directory, in the same way (either pwhg_analysis-release.f or pwhg_analysis-pheno_2.f).
- setup.f
  - This file was modified to set hnnlo to fill histograms with the relevant Higgs decay branching fractions divided out: removebr=.true.. Thus the integral of the Higgs boson rapidity spectrum histogram output is the total cross section. This is required for consistency with the HJ-MiNLO program and its analysis, in order to carry out the NNLO reweighting.
- writeinfo.f
  - Originally the writeinfo subroutine in this file copied the contents of the input file used in running the program, plus the cross section, as a series of comments to the top of the histogram output file. In order to have a simple uniform format for HJ-MiNLO and hnnlo we removed these comments (the bulk of which was simply a copy of the input file used to run the program).

A.2 HJ-MiNLO

- init_couplings.f
  - This file contains the values of numerous physical constants in HJ-MiNLO.
- powheg.input/powheg.input-save

- Here the Higgs boson mass and width should be set consistently with the values used by `hnnlo` in the `HJ-MiNLO` input file (`hmass` and `hwidth` parameters). Also, the mass window on the off-shell mass range for the Higgs boson (the Breit-Wigner generation cut-off) should be set to a large value (in ref. [1] we have set `bwcutoff 1000`). Lastly, again for consistency with the running of `hnnlo` we require that the Higgs boson be left undecayed at the Les Houches event level, this is achieved by setting `hdecaymode -1` in the relevant `HJ-MiNLO` input file.

A.3 NNLO reweighting

- `Makefile`
  - The default value for the `ANALYSIS` variable should be `release`. Other options are described below, but they are intended mainly for debugging purposes or developers. `FastJet` must be linked properly too, and as usual it is recommended to let the `Makefile` call the `fastjet-config` command.
- `minnlo.f`
  - This file contains the main program to perform the NLO-to-NNLO reweighting. Some parameters useful for debugging purposes can be found here, as described in the commented section at the beginning of the file. However, the user is recommended not to change them.
- `opencount.f`, `auxiliary.f`, `lhef_readwrite.f`, `get_hdamp.f`, `genclust_kt.f`, `swapjet.f`, `miscclust.f`, `ptyrap.f`, `r.f`
  - These files contain several functions and routines needed by `minnlo.f` and/or by the analysis subroutine used to process the `HJ-MiNLO` LH file and compute $d\sigma_{A/B}^{\rm MINLO}\,\delta\left(y-y\left(\Phi\right)\right)$.

    (`jetlabel.f`, `jetcuts.f`, `mxpart.f` and `npart.f` contain common blocks used in the source files.)
- `pwhg_analysis-release.f`, `jet_finder-release.f`
  - These files contain the minimal analysis needed to extract $d\sigma_{A/B}^{\rm MINLO}\,\delta\left(y-y\left(\Phi\right)\right)$ from the LH input file. They are compiled if `ANALYSIS=release` is set, which is the default option.
- `pwhg_analysis-pheno_2.f`, `jet_finder.f`
  - These files are compiled when `ANALYSIS=pheno_2`. Although they extend the '`release`' analysis, allowing to plot more distributions, the LH file obtained by running the `minnlo` reweighter is identical to that obtained with the previously-described files. The '`pheno_2`' analysis was used to produce the plots in ref. [1].
- `pwhg_analysis-pheno.f`, `pwhg_analysis-HNNLO.f`
  - These files are kept for backward-compatibility reasons.

References

[1] K. Hamilton, P. Nason, E. Re, and G. Zanderighi, *NNLOPS simulation of Higgs boson production*, *JHEP* **1310** (2013) 222, [arXiv:1309.0017].

[2] S. Catani and M. Grazzini, *An NNLO subtraction formalism in hadron collisions and its application to Higgs boson production at the LHC*, *Phys.Rev.Lett.* **98** (2007) 222002, [hep-ph/0703012].

[3] M. Grazzini, *NNLO predictions for the Higgs boson signal in the $H \to W^+W^- \to \bar{l}\nu\ l\bar{\nu}$ and $H \to ZZ \to 4l$ decay channels*, *JHEP* **0802** (2008) 043, [arXiv:0801.3232].

[4] J. M. Campbell, R. K. Ellis, R. Frederix, P. Nason, C. Oleari, et al., *NLO Higgs Boson Production Plus One and Two Jets Using the POWHEG BOX, MadGraph4 and MCFM*, *JHEP* **1207** (2012) 092, [arXiv:1202.5475].

[5] K. Hamilton, P. Nason, and G. Zanderighi, *MINLO: Multi-Scale Improved NLO*, *JHEP* **1210** (2012) 155, [arXiv:1206.3572].

[6] K. Hamilton, P. Nason, C. Oleari, and G. Zanderighi, *Merging H/W/Z + 0 and 1 jet at NLO with no merging scale: a path to parton shower + NNLO matching*, *JHEP* **1305** (2013) 082, [arXiv:1212.4504].

[7] A. Martin, W. Stirling, R. Thorne, and G. Watt, *Parton distributions for the LHC*, *Eur.Phys.J.* **C63** (2009) 189–285, [arXiv:0901.0002].