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HERWIG 6.5 Release Note

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Abstract

A new release of the Monte Carlo program HERWIG (version 6.5) is now available. The main new features are: support for the Les Houches interface to matrix element generators; additional SM and MSSM Higgs processes in lepton collisions; additional matrix elements for the spin correlation algorithm; a new version of the ISAWIG interface; interface to the MC@NLO program for heavy quark, Higgs and vector boson production in hadron collisions. This is planned to be the last major release of Fortran HERWIG. Future developments will be implemented in a new C++ event generator, HERWIG++.

Contents

1 Introduction

The last major public version (6.2) of HERWIG was reported in detail in [1]. The new features of version 6.3 and 6.4 are described in refs. [2] and [3], respectively. In this note we describe the main modifications and new features included in the latest public version, 6.5.

Please refer to [1] and to the present paper if using version 6.5 of the program. When running MSSM processes starting from version 6.1, please add reference to [4].

The program, together with other useful files and information, can be obtained from the following web site:

`http://hepwww.rl.ac.uk/theory/seymour/herwig/`

This will be mirrored at CERN:

`http://home.cern.ch/seymour/herwig/`

It is anticipated that version 6.5, with minor modifications in the series 6.5xx, will be the *last Fortran version* of HERWIG. Substantial physics improvements will be included in the new C++ event generator HERWIG++ [5].

2 Les Houches interface

We now include support for the interface between parton level generators and HERWIG using the Les Houches Accord as described in [6]. In general we have tried to code the interface in such a way that from the user point of view it behaves in the same way as that already included in PYTHIA [7].

The interface operates in the following way. If the `IPROC` code is set negative then HERWIG assumes that the user wants an external hard process using the Les Houches accord.

If this option is used the initialization will call the routine `UPINIT` to initialize the external hard process; this name is the same as that used by PYTHIA. This routine should set the values of the run parameters in the Les Houches run common block.

After the initialization during the event generation phase the routine `UPEVNT` (again this name is the same as that used by PYTHIA) is called. This routine should fill the event common block as described in [6].

Dummy copies of both these routines are supplied with HERWIG and should be deleted and replaced if you are using this option. Due to the internal structure of HERWIG two new parameters are needed to control the interface, in addition to those in the Les Houches common block. The logical input variable[1] `LHSOFT` [`.TRUE`] controls the generation of the soft underlying event; the default is to generate a soft underlying event and so `LHSOFT` must be set `.FALSE.` for lepton-lepton processes. The second variable `LHGLSF` [`.FALSE.`] controls the treatment of colour self-connected gluons, which may occur with some methods of colour decomposition. The default is to kill events with self-connected gluons whereas if `LHGLSF` = `.TRUE.` an information-only warning is issued instead.

We have not included full support for the interface. In particular

- It is assumed that all events have two particles of status `IDUP`=–1;
- We do not support the status codes –2 and –9;
- The treatment of the code `IDUP`=3 is the same as `IDUP`=2, i.e. all intermediate resonances have their masses preserved.

These restrictions are the same as those imposed by PYTHIA. If you have any problems with the interface or need the options we have not yet supported please let us know.

It should also be noted that while the interface has been tested with Standard Model processes, for example all the processes in ALPGEN [8], it is less well tested for SUSY processes.

3 New SM and MSSM Higgs processes

SM and MSSM Higgs production in association with fermion pairs in lepton-lepton collisions is now available. These processes were introduced in [9] and their phenomenological relevance was discussed in [10]. The relevant `IPROC` codes are given in table 1.

Two new subroutines, `HWHIGE` and `HWH2HE`, had to be included. Fermion masses are retained in the final state according to the HERWIG defaults. The same values appear in the Yukawa couplings. Notice that in the case of charged Higgs boson production the Cabibbo-Kobayashi-Maskawa mixing matrix has been assumed to be diagonal. Furthermore, due to the rather different phase space distribution of the final state products, all processes can only be produced separately, not collectively. Initial- and final-state radiation (both QED and QCD) and beamsstrahlung are included via the usual HERWIG algorithms. Finally notice that the use of the `IPROC` series 1000 and 1100 for $\ell^+\ell^-$ processes required some internal modification to HERWIG, which was originally designed to generate leptonic processes only for `IPROC` < 1000. Now we assume an $\ell^+\ell^-$ process whenever `IPROC` < 1300. These modifications have no implications for the traditional user, but may affect more knowledgeable ones who have edited previous versions of the main HERWIG code.

[1] Default values for input variables are shown in square brackets.

IPROC	Process
1000+ID	$\ell^+\ell^- \to t\,\bar{t}\,H^0_{\rm SM}$ (ID as in IPROC=300+ID)
1110+IQ	$\ell^+\ell^- \to q\,\bar{q}\,h^0$ (IQ as in IPROC=100+IQ)
1116+IL	$\ell^+\ell^- \to \ell^+\ell^- h^0$ (IL=1,2,3 for e,μ,τ)
1120+IQ	$\ell^+\ell^- \to q\,\bar{q}\,H^0$ (IQ as in IPROC=100+IQ)
1126+IL	$\ell^+\ell^- \to \ell^+\ell^- H^0$ (IL=1,2,3 for e,μ,τ)
1130+IQ	$\ell^+\ell^- \to q\,\bar{q}\,A^0$ (IQ as in IPROC=100+IQ)
1136+IL	$\ell^+\ell^- \to \ell^+\ell^- A^0$ (IL=1,2,3 for e,μ,τ)
1140	$\ell^+\ell^- \to d\,\bar{u}\,H^+ +$ c.c.
1141	$\ell^+\ell^- \to s\,\bar{c}\,H^+ +$ c.c.
1142	$\ell^+\ell^- \to b\,\bar{t}\,H^+ +$ c.c.
1143	$\ell^+\ell^- \to e\,\bar{\nu}_e H^+ +$ c.c.
1144	$\ell^+\ell^- \to \mu\,\bar{\nu}_\mu H^+ +$ c.c.
1145	$\ell^+\ell^- \to \tau\,\bar{\nu}_\tau H^+ +$ c.c.

Table 1: New SM and MSSM Higgs processes.

4 Spin correlations in R-parity violating decays

When we included spin correlations in HERWIG6.4 [11] we did not include either R-parity violating decays or decays producing gravitinos in the algorithm. This led to HERWIG stopping when such decays were included. This of course could be stopped by switching the spin correlations off, i.e. `SYSPIN=.FALSE.`. We have now included the relevant matrix elements for R-parity violating decays and hard processes and decays producing gravitinos. At the same time we have made changes so that at both the initialization and event generation stages many of the terminal warnings which were caused by the code not having the correct matrix elements are now information-only warnings. If you still get terminal error messages from any of the spin correlation routines please let us know.

5 Other interfaces

5.1 ISAWIG

To coincide with the release of HERWIG 6.5 we have produced a new version of the ISAWIG interface to ISAJET for the calculation of MSSM spectra and decay rates. Due to stability problems with the Oxford web-server we have moved the web-page to Cambridge. The new address is

`http://www.hep.phy.cam.ac.uk/~richardn/HERWIG/ISAWIG/`

At the moment the old page will redirect users here but we cannot be sure how long this will continue.

Since the original version of ISAWIG there have been a number of new versions of ISAJET, often with changes in the sizes of the common blocks from which we extract the information we need. This has necessitated periodical updating of the code to run with the most recent version of ISAJET, with the result that the code could no longer be run with older versions. However, the Snowmass points and slopes [12] are defined with ISAJET version 7.58 and so we can no longer continue in this way and still be able to generate these points. Therefore, starting with the new ISAWIG version 1.2, we are using C preprocessing so that users can define the version of ISAJET they are using at compile time. When compiling the main ISAWIG code and the modified SUGRUN and SSRUN programs the following compiler options should be specified:

- `-DISAJET758` to use ISAJET7.58,
- `-DISAJET763` to use ISAJET7.63.

The default at the moment is to compile code to run with ISAJET7.64. In the future this will change so that the most recent version of ISAJET becomes the default but we will continue to support the older versions.

5.2 HDECAY

There has also been a new release of the HDECAY package [13], version 3. In order to support this version, and the previous version 2.0, we are also using C preprocessing to control the version of HDECAY used. In order to achieve this the HDECAY interface code has been merged with the main ISAWIG program. The following options should be used when compiling ISAWIG if you are using HDECAY:

- `-DHDECAY2` if you are using version 2 of HDECAY
- `-DHDECAY3` if you are using version 3 of HDECAY.

As before the default is to compile a dummy routine. If you are using HDECAY you must link with a version of the HDECAY code which has the main HDECAY program removed.

5.3 MC@NLO

The program MC@NLO [14, 15, 16] generates events with

- exclusive rates and distributions accurate to next-to-leading order when expanded in α_s;
- multiple soft/collinear parton emission generated by HERWIG parton showering;
- hadronization according to the HERWIG cluster model.

The processes implemented in the current version (3.1) of MC@NLO are listed in Table 2. Here $H_{1,2}$ represent incoming hadrons, H^0 denotes the Standard Model Higgs boson and the value of `ID` controls its decay, as described in the HERWIG manual. The values of `IV`, `IL`, $\texttt{IL}_1$, and $\texttt{IL}_2$ control the identities of vector bosons and leptons: for details see the MC@NLO manual [16]. `IPROC`–10000 generates the same processes as `IPROC`, but eliminates the underlying event. A void entry indicates that the corresponding variable is unused. The 'Spin' column indicates whether spin correlations in vector boson or top decays are included ($\surd$), neglected ($\times$) or absent (void entry). Spin correlations in Higgs decays are included by HERWIG (e.g. in $H^0 \to W^+W^- \to l^+\nu l^-\bar{\nu}$).

Parton configurations must first be generated by the modified NLO program provided in the MC@NLO package. These are stored in a file which is then read into HERWIG via the Les Houches interface. For further details and updates see the MC@NLO web page:

`http://www.hep.phy.cam.ac.uk/theory/webber/MCatNLO/`

IPROC	IV	IL$_1$	IL$_2$	Spin	Process
–1350–IL				$\surd$	$H_1H_2 \to (Z/\gamma^* \to) l_{\rm IL}\bar{l}_{\rm IL} + X$
–1360–IL				$\surd$	$H_1H_2 \to (Z \to) l_{\rm IL}\bar{l}_{\rm IL} + X$
–1370–IL				$\surd$	$H_1H_2 \to (\gamma^* \to) l_{\rm IL}\bar{l}_{\rm IL} + X$
–1460–IL				$\surd$	$H_1H_2 \to (W^+ \to) l^+_{\rm IL}\nu_{\rm IL} + X$
–1470–IL				$\surd$	$H_1H_2 \to (W^- \to) l^-_{\rm IL}\bar{\nu}_{\rm IL} + X$
–1396				$\times$	$H_1H_2 \to \gamma^*(\to \sum_i f_i\bar{f}_i) + X$
–1397				$\times$	$H_1H_2 \to Z^0 + X$
–1497				$\times$	$H_1H_2 \to W^+ + X$
–1498				$\times$	$H_1H_2 \to W^- + X$
–1600–ID					$H_1H_2 \to H^0 + X$
–1705					$H_1H_2 \to b\bar{b} + X$
–1706				$\times$	$H_1H_2 \to t\bar{t} + X$
–2600–ID	1	7		$\times$	$H_1H_2 \to H^0W^+ + X$
–2600–ID	1	i		$\surd$	$H_1H_2 \to H^0(W^+ \to) l^+_i\nu_i + X$
–2600–ID	–1	7		$\times$	$H_1H_2 \to H^0W^- + X$
–2600–ID	–1	i		$\surd$	$H_1H_2 \to H^0(W^- \to) l^-_i\bar{\nu}_i + X$
–2700–ID	0	7		$\times$	$H_1H_2 \to H^0Z + X$
–2700–ID	0	i		$\surd$	$H_1H_2 \to H^0(Z \to) l_i\bar{l}_i + X$
–2850		7	7	$\times$	$H_1H_2 \to W^+W^- + X$
–2850		i	j	$\surd$	$H_1H_2 \to (W^+ \to) l^+_i\nu_i(W^- \to) l^-_j\bar{\nu}_j + X$
–2860		7	7	$\times$	$H_1H_2 \to Z^0Z^0 + X$
–2870		7	7	$\times$	$H_1H_2 \to W^+Z^0 + X$
–2880		7	7	$\times$	$H_1H_2 \to W^-Z^0 + X$

Table 2: Processes implemented in MC@NLO version 3.1.

6 Miscellaneous changes and corrections

- A new logical input variable, PRESPL [.TRUE.], has been introduced to control whether the longitudinal momentum (PRESPL = .TRUE.), or rapidity (PRESPL = .FALSE.), of the hard process centre-of-mass is preserved in hadron collisions after initial-state parton showering. At present the only function of this variable is to allow users to study the effects of momentum reshuffling, which is necessary after showering to compensate for jet masses. In future, it is anticipated that setting PRESPL=.FALSE. will simplify the treatment of other processes in MC@NLO.

- A bug has been fixed in the backward evolution in the logical structure structure of an IF statement controlling the branching. This was preventing the forced branching to valence partons and caused many of the HWSBRN=104 warnings. Users should find the number of such warnings is significantly reduced.

- When polarization effects in lepton collisions were added a bug was introduced in squark pair production which has now been fixed.

- A bug in the matrix element for $q\,\bar{q} \to g\,H^0_{\rm SM}$ (IPROC=2300 etc.) has been corrected.

- The effects of off-shell WW and ZZ decays of the SM Higgs boson are now included in the generated weights of $2 \to 3$ processes.

We list here the further changes made between the release of version 6.500 and the most recent version, 6.510 (October 31st 2005).
In **6.503**, only bug fixes and minor changes were made:

- Alignment of initial state radiation cones (affects HWBJCO)
- Some things needed by MC@NLO (affects HWBJCO)
- Bug fix in initial-state spin correlations (affects HWBSPA)
- Bug fix in finding gauge boson pairs (affects HWDBOS)
- Bug fix in heavy object decay correlations (affects HWDHO2)
- Les Houches underlying event (affects HWHGUP)
- Bug fix in Les Houches interface for $2 \to 1$ processes (affects HWHGUP)
- Bug fix: top lifetime (affects HWUDAT)
- Bug fix for tops with Les Houches (affects HWHGUP)
- Bug fix in spinor routines to avoid divide by zero (affects HWH2F1, HWH2F2, HWH2F3)
- Bug fix in error severity for negative energy underlying events (affects HWMULT)
- Bug fix for Les Houches Higgs decay (affects HWDHIG)

In **6.504**, a couple of the changes were slightly more significant:

- The use of the running quark mass for $q\bar{q} \to$ Higgs, this is to avoid the unphysically large contribution to cross section $u\bar{u} \to$ Higgs was giving using the constituent quark masses. (New routine HWURQM and affects HWHIGS). Note that this is not done for any other Higgs production or decay processes.
- Changes to allow the forcing of gauge boson decays in processes using the Les Houches interface (affects HWDBOS)
- A new flag ITOPRD to allow the use of PHOTOS to generate QED radiation in top quark pair production and decay. The default ITOPRD=0 is not to use PHOTOS whereas ITOPRD=1 will use PHOTOS. It should be noted that there may be a problem with double counting if the default HERWIG photon radiation in the parton shower is also switched on, however the new option will give radition for the leptons in the decay of the W which the HERWIG treatment does not. (New routines HWPHTP and HWPHTT and affects HWBCON, HWBTOP, HWDHO4, HWDTAU and HWUINC).

In **6.505**, one new feature was added and several minor improvements and bug fixes were made:

- New feature:
  - A major update of the Jimmy generator for multiple parton scattering has been made. Although this is still a separate package (available from the Jimmy web page) its incorporation into HERWIG is now much smoother - no HERWIG routines need to be modified or replaced. Moreover, it has been modified to run correctly in 'underlying event' mode, i.e. it can attach additional scatters to a high-pt scattering event or to events of other types, rather than always running in 'minimum bias' mode as before
- Improvements:
  - Value of MODMAX (size of MODBOS) increased to 50. Note that since MODBOS is the last member of its common block, this does not move the position of any other variables in the include file
  - Calculation of minimum invariant mass needed for a given hard process separated off from HWEGAM to a new routine HWEGAS
  - Several new features added to HWHSCT and new routine HWHSCU added to implement the underlying event mode of Jimmy
- Bug fixes:
  - Several modifications (in HWCFOR, HWCHAD and HWURES) to improve the calculation of the threshold for partonic decays of b baryons and B_c mesons
  - Hard scale variable EMSCA was not set correctly in gauge boson pair production (HWHGBS and HWHGBF)
  - In many places in the code, in several recently added processes, tests on IPROC were not performed correctly, leading to different behaviour in the same hard process, depending on whether the underlying event was switched on (IPROC < 10000) or off (IPROC > 10000)
  - Probability of backwards evolution to an 'anomalous' photon was not correctly calculated. New probability is somewhat larger at large x-gamma, but similar at small x-gamma (HWSFBR)
  - Protection against corruption of photon production cross sections due to infinitesimal parton distribution functions (HWHPHO and HWHPH2)
  - Corrected angular distributions in $gg \to tbH$ (HWHIGQ)
  - Corrected cross section in Higgs+jet production (HWHIGA)
  - Added protection against clusters of unknown flavour combinations (HWCHAD)

In **6.506**, one new feature was added and several minor improvements and bug fixes were made:

- New feature:

– Two new parameters, PDFX0 and PDFPOW, have been provided to control the probing of parton distribution functions at extremely small x values, potentially below where they are valid. For values of x below PDFX0, $xf(x, Q^2)$ is replaced by $PDFX0 f(PDFX0, Q^2)(x/PDFX0)^{PDFPOW}$. The default value of PDFX0 (D=0) means that the pdfs are unmodified and that the value of PDFPOW (D=0) is irrelevant. For 'valence-like' distributions at small x, set PDFX0=1d-5 for example, and PDFPOW=0. This feature is mainly needed in conjunction with Jimmy since, for PTJIM=2GeV at the LHC for example, x values down to 2×10^{-8} are probed, whereas most pdf sets are not considered reliable below x values of about 10^{-5}

- Improvements:
  - Spin correlations in the decay of the W/Z in W/Z+Higgs events are now included
  - In several gauge boson production processes, hard coded limits on the mass distribution have been replaced by GAMMAX [D=10] widths
  - Generation of Breit-Wigner distribution is changed from m to m^2
  - Infrared cutoffs on large x values implemented in Drell-Yan matrix element correction routine HWBDYP. Makes a negligible difference
  - Running electromagnetic coupling used in W+jet routine
  - Branching fraction replaced by running partial width divided by m times nominal total width in W production routine HWHWPR. This is only different in the rare events in which the chosen W mass is above the top threshold
  - More accurate calculation of hadron remnant mass used in HWSBRN
  - PDFSET is only called if the pdf set has changed since the last call, saving cpu time
- Bug fixes:
  - Kinematics were not calculated correctly in Drell-Yan matrix element correction routine HWBDYP. Has a tiny effect on W/Z kinematics, but more significant on the distributions of their decay products, giving too hard a lepton pt distribution at very high pt for example
  - In several Higgs and/or gauge boson production processes, including W+jet, W/Z+H and H+jet, Breit-Wigner was generated twice, leading to a too wide mass distribution by a factor of SQRT(2)
  - Mass distribution of W/Z in W/Z+H and W/Z+jet production were incorrect by a factor m^2/m_0^2, where m_0 is the nominal mass
  - Subprocess $bg \to Wt$ was previously included in W+jet routine in the massless quark approximation. This subprocess has been switched off
  - Off-shell hadron remnants sometimes led to momentum non-conservation in secondary scatters generated by Jimmy. Fixed by shuffling small amount of momentum between the two remnants in HWHREM

In **6.507**, only bug fixes were made:

- Bug fixes:
  - Space-time production position of hadrons from the underlying event was previously non-sensical. Now the cluster position is chosen according to a Gaussian distribution in its rest-frame and the hadron positions correctly take account of the position of the primary interaction point. Implemented in HWMEVT
  - Space-time production position of leptons and photons from gauge and Higgs boson decays was previously set to the origin. Now calculated correctly taking account of the position of the primary interaction point. Implemented in HWBJCO, HWCFOR, HWDBOS and HWDHIG
  - A bug has been found in the interface to Jimmy that led to errors (stable quarks in the final state and/or divide-by-zero crashes) when adding multiple scatters to Drell-Yan-type processes. Fixed in HWHSCT
  - MRST pdfs did not previously freeze at QSPAC in the ISPAC.GT.0 options, as they should. Fixed in HWSFUN
  - Printed version number was incorrect in several places in the LaTeX and html output formats. Fixed in HWUDPR and HWUEPR
  - A minor improvement to the formatting of the printed event record for minimum bias events, implemented in HWUEPR

In **6.510**, only bug fixes and improvements to the machine/compiler dependence were made:

- Bug fixes:
  - A bug has been found in the kinematic reconstruction of parton showers, that had particularly severe consequences for top quark decay. This step involves reshuffling a small amount of momentum between jets in order to restore overall momentum conservation. It is not Lorentz invariant, so the jet momenta must be boosted to and from the frame in which it is performed. In versions 6.504 to 6.507, these two boosts were performed via different intermediate frames, and therefore a (Thomas) rotation was induced. This lead to a significant shift in the direction of the b jet, even in events in which there was no radiation from it.
    Note that this fix has already been circulated to several experimental collaborations, who were asked to call the fixed version 6.508.
  - A bug in the logic of the azimuthal correlations between two back-to-back jets was present in versions 6.503 to 6.507, leading to a slight (a few parts per mille) asymmetry in the azimuthal distribution of produced hadrons in hadron collisions.
  - A minor bug was fixed in tau decays using TAUOLA, which had lead to Lorentz-noninvariance of some spin effects.
  - A variable, TMPRN, was used, but not declared, as an array in HWHSCT, leading to crashes or unpredictable results when using Jimmy on some machines.
  - Our particle numbering distinguishes Standard Model and BSM Higgs bosons, while the pdg use the same number for the SM and lightest CP even BSM Higgs. Our numbering is now only used internally and is converted to the pdg convention at the end of event processing.

- Changes made to reduce machine/compiler dependence:
  - Multiple-ENTRY routines have been replaced by independent routines.
  - Alternate return points have been removed. Note that in particular, this affects HWWARN, so users who use HWWARN should change their call accordingly:

    ```
    CALL HWWARN('HWANAL',ICODE,*999)
    ```

    should become

    ```
    CALL HWWARN('HWANAL',ICODE)
    IF (ICODE.LT.0.OR.(ICODE.GE.50.AND.ICODE.LT.200)) GOTO 999
    ```
  - An arithmetic IF statement has been removed.
  - All variables in DATA statements have also been SAVEd.
  - Line numbers have been removed from END statements.

  Several of these are necessary to compile under gcc4.0. Note that the first point necessitated moving the random number seeds from a SAVEd local variable to a COMMON block. We had some concerns that this may slow the program, but in fact on several compilers and machines we find that the new version is actually faster. Nevertheless, if you encounter significantly slower performance with the new version, please inform us, with details of the machine, compiler and compiler options.
  We are grateful to Mikhail Kirsanov and the GENSER group of the LCG project at CERN for their help with some of these changes.

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Since this is expected to be the last (Fortran) HERWIG release note, we would like to take this opportunity to thank again all those colleagues and users who have contributed to the development of the program, whether by providing code, suggesting improvements or reporting problems. Thanks also to those who worked so hard to establish the Les Houches accord, which should make it possible to expand the application of Fortran HERWIG to new processes without (much) further intervention by the authors. Meanwhile, many of us will be transferring our main efforts to HERWIG++, in preparation for the new era of object-oriented event generation.

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