

Herwig++ 2.3 Release Note

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Abstract

A new release of the Monte Carlo program Herwig++ (version 2.3) is now available. This version includes a number of improvements including: the extension of the program to lepton-hadron collisions; the inclusion of several processes accurate at next-to-leading order in the POSitive Weight Hardest Emission Generator (POWHEG) scheme; the inclusion of three-body decays and finite-width effects in Beyond the Standard Model (BSM) physics processes; a new procedure for reconstructing the kinematics of the parton shower based on the colour structure of the hard scattering process; a new model for baryon decays including excited baryon multiplets; the addition of a soft component to the multiple scattering model of the underlying event; new matrix elements for Deep Inelastic Scattering (DIS) and e^+e^- processes.

Contents

1	Introduction	1
1.1	Availability	1
2	Lepton-Hadron Collisions and Kinematic Reconstruction	2
3	Powheg	2
4	BSM Physics	3
5	New Matrix Elements	3
6	Baryon Decays	3

7	Underlying Event	3
7.1	Double parton scattering	4
7.2	Soft component	4
8	Contrib	4
9	Other Changes	6
10	Summary	8

1 Introduction

The last major public version (2.2) of **Herwig++**, is described in great detail in [1, 2]. This release note therefore only lists the changes which have been made since the last release (2.2). The manual has been updated to reflect these changes and this release note is only intended to highlight these new features and the other minor changes made since the last version.

Please refer to [1] and the present paper if using version 2.3 of the program.

The main new features of this version are the extension of the program to lepton-hadron collisions, the inclusion of several processes accurate at next-to-leading order (NLO) in the POWHEG scheme, the extension of our simulation of BSM physics processes to include finite-width effects and three-body decays, a new procedure for reconstructing the kinematics of the parton shower based on the colour structure of the hard scattering process, a new model for baryon decays including excited baryon multiplets, the addition of a soft component to the multiple scattering model of the underlying event, the inclusion of the matrix elements for charged and neutral current processes in DIS and Higgs boson production via gauge boson fusion processes in lepton-lepton collisions.

Some code which we use to test and develop **Herwig++** but we do not expect to be required by the vast majority of users has been moved from the core parts of the program and included in the new **Contrib** directory together with some code we had not previously released. It is intended that in future this directory will both provide a repository of examples and allow us to distribute external modules. In addition a number of other changes have been made and a number of bugs have been fixed.

1.1 Availability

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

<http://hepforge.cedar.ac.uk/herwig/>

In order to improve our response to user queries, all problems and requests for user support should be reported via the bug tracker on our wiki. Requests for an account to submit tickets and modify the wiki should be sent to herwig@projects.hepforge.org.

Herwig++ is released under the GNU General Public License (GPL) version 2 and the MCnet guidelines for the distribution and usage of event generator software in an academic setting, which are distributed together with the source, and can also be obtained from

<http://www.montecarlonet.org/index.php?p=Publications/Guidelines>

2 Lepton-Hadron Collisions and Kinematic Reconstruction

Rather than the simple procedure used in previous versions of the program which preserved the centre-of-mass energy and rapidity of the final-state system in initial-state parton showers and the momentum of the system for final-state showers we now use a procedure that preserves the properties of colour-singlet systems where possible as originally intended in Ref. [3]. For example in Higgs production via vector boson fusion we would now preserve the momenta of the two virtual gauge bosons. The new procedure [[ReconstructionOption=Colour](#)] is now the default, however for many processes, for example Drell-Yan, it is identical to the previous procedure. The procedure used is described in more detail in [4].

As a consequence of this extension the kinematic reconstruction of DIS events is now possible for the first time, an example of using `Herwig++` for DIS is provided with the release.

3 Powheg

A number of processes are now included at next-to-leading order in the POWHEG scheme of Refs. [5, 6] which allows the generation of events with NLO accuracy while only generating positive weight events. Our implementation includes both the generation of the kinematics of the hard process scattering process with NLO accuracy, the generation of the hardest emission and the full treatment of soft wide angle radiation, more details can be found in Refs. [4, 7]. The Born-level process is generated with NLO accuracy by the

- [MEqq2gZ2ffPowheg](#) class for the production and decay of the γ^*/Z^0 boson in the Drell-Yan process;
- [MEqq2W2ffPowheg](#) class for the production and decay of the $W^\pm$ boson in the Drell-Yan process;
- [MEPP2HiggsPowheg](#) class for the production of the Higgs boson via the gluon-gluon fusion process;
- [MEPP2WHPowheg](#) class for the production of the Higgs boson in association with the $W^\pm$ boson;
- [MEPP2ZHPowheg](#) class for the production of the Higgs boson in association with the Z^0 boson.

The parton shower in these processes is then generated using the [PowhegEvolver](#) which inherits from the standard `Herwig++` [Evolver](#) and implements both the generation of the truncated shower and the hardest emission in the event using the:

- [DrellYanHardGenerator](#) class for processes with an intermediate vector boson;
- [GGtoHHardGenerator](#) class for Higgs boson production via gluon-gluon fusion.

Examples of using these new processes can be found in the `LHC-Powheg.in` and `TVT-Powheg.in` example files supplied with the release for the LHC and Tevatron.

4 BSM Physics

The previous version of **Herwig++** included the automatic generation of both $2 \rightarrow 2$ scattering processes and $1 \rightarrow 2$ decays in BSM physics models. This has now been extended [8] to include the automatic generation of three-body decays. In addition whereas previously all the BSM particles were produced on-shell we have extended the mechanism used to generate off-shell hadron decays to BSM processes [8]. These new features are described in more detail in Refs. [4, 8].

In addition we have made a number of changes to **ThePEG** which introduces a new layer of abstraction in the hierarchy of the vertex classes. This makes it much easier to add new vertices which do not have the standard perturbative Lorentz structure. The mechanisms for handling BSM models can now handle any Lorentz structure for the vertices.

5 New Matrix Elements

A number of new matrix elements are included in this release:

- the **MENeutralCurrentDIS** and **MEChargedCurrentDIS** classes for the simulation of neutral and charged current processes in lepton-hadron collisions;
- the **MEee2HiggsVBF** class for the simulation of $e^+e^- \rightarrow h^0 e^+e^-$ and $e^+e^- \rightarrow h^0 \nu_e \bar{\nu}_e$ via gauge boson fusion;
- the **MEMinBias** class for soft non-perturbative scatterings in hadron-hadron collisions which is solely intended for use in the improved underlying event model.

6 Baryon Decays

We now include a new model for baryon decays including updated particle properties and decays, matrix elements for many important decays including spin correlations and include several excited baryon multiplets for the first time. This is intended to have the same sophistication for the modelling of the baryons as we had already for the mesons.

By default we have included a number of additional baryon multiplets which are produced in the hadronization phase and slightly improve the agreement with LEP data. In association with this we have retuned the default parameters to improve the description of LEP and B-factory data. A full description can be found in [4].

7 Underlying Event

The underlying event simulation of **Herwig++** now includes two new features. The first one may be summarized by the term *double parton scattering*, which refers to events where two independent hard scatterings can be observed. The second new feature is the inclusion of non-perturbative partonic scatterings into the existing underlying event model [9]. Thereby we replace the existing transverse momentum cut-off, $p_t^{\min}$, by a matching scale and describe the entire transverse momentum spectrum. This enables **Herwig++** to describe minimum bias data for the first time.

7.1 Double parton scattering

This feature allows the user to specify a given number of hard scatterings that are simulated in each event in addition to the regular underlying event. Double/multiple-parton scattering signatures like several high- p_t jets or b -quark pairs or several W -pairs can be simulated using this functionality. Every production process can be accompanied by a set of kinematical cuts, which are freely selectable and completely independent of the corresponding cuts of other processes that are simultaneously simulated. We describe the configuration needed to enable this simulation in [4].

7.2 Soft component

We have implemented the inclusion of additional partonic scatters *below* the transverse momentum cut-off along the lines of Ref. [11]. Additional improvements include:

- Automatic determination of the additional parameters in the *soft* sector for any centre-of-mass energy.
- The possibility of different partonic overlap distributions for semi-hard and soft scatters. The soft overlap distribution is automatically fixed by the requirement to match existing data on the elastic t -slope. For energies beyond 2 TeV we use the parametrization of Ref. [12] as we do for the total cross section. This option resolves eventual inconsistencies between measurements of the elastic t -slope and the effective cross section in double parton scattering events as anticipated in Ref. [13].

The simulation has been tuned to data on the underlying event from CDF [10]. For this comparison we could now make use of all available data, i.e. the jet *and* minimum bias sample. Figure 1 displays the χ^2 values of describing this data as colour code in our two-dimensional parameter space. A detailed comparison to data is shown in Fig. 2.

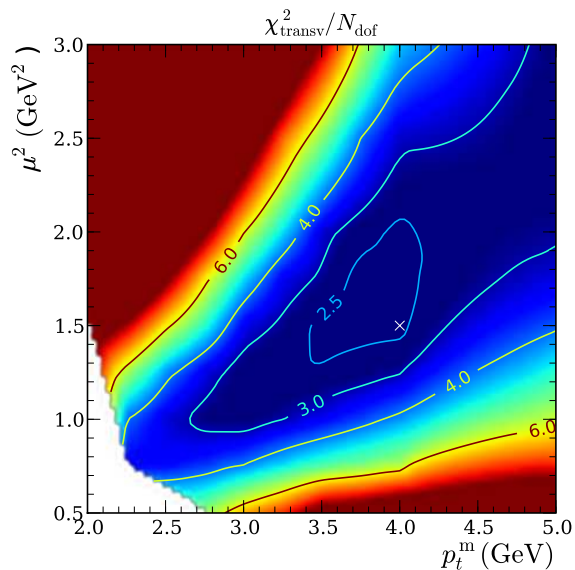


Figure 1: Contour plots for the χ^2 per degree of freedom of describing the transverse region from [10]. The cross indicates the location of our preferred tune and the white area consists of parameter choices where the elastic t -slope and the total cross section cannot be reproduced simultaneously.

8 Contrib

Starting with this release we have included a number of external modules which use **Herwig++** in the **Contrib** directory supplied with the release. These will hopefully be of use to some users but are not expected to be needed by most users and are not supported at the same level as the main **Herwig++** code. In the current release these are mainly modules we used to test and

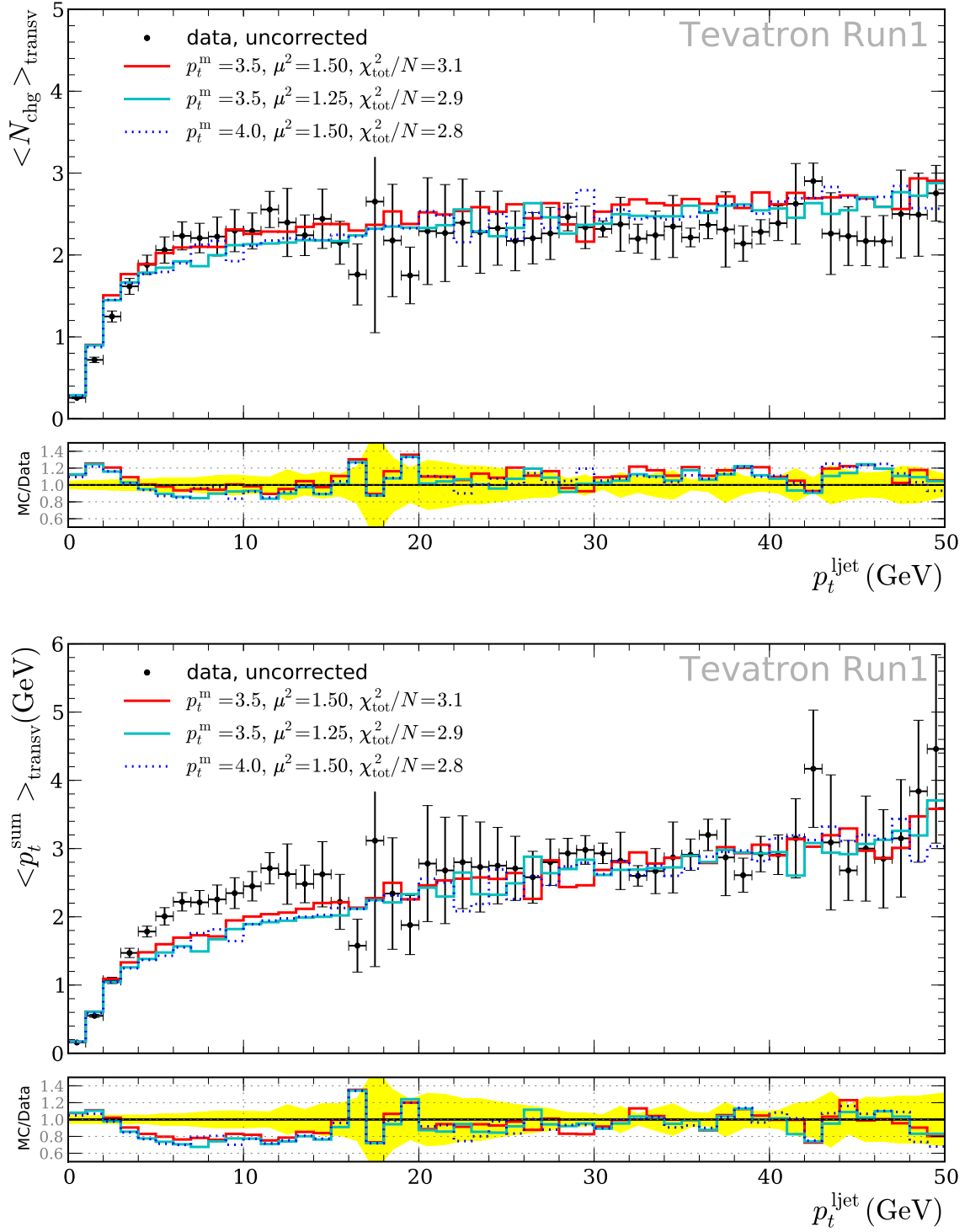


Figure 2: Multiplicity and transverse momentum sum in the transverse region. CDF data are shown as black circles. The histograms show **Herwig++** with the improved model for semi-hard and soft additional scatters using the MRST 2001 LO [14] PDFs for three different parameter sets. The lower plot shows the ratio Monte Carlo to data and the data error band. The legend on the upper plot shows the total χ^2 for all observables.

develop **Herwig++** and were either previously not released or have been removed from the main release. A full description of the available modules can be found in [4].

9 Other Changes

A number of other more minor changes have been made. The following changes have been made to improve the physics simulation:

- The **IncomingPhotonEvolver** has been added to allow the simulation of partonic processes with incoming photons in hadron collisions.
- A new **KTRapidityCut** class has been added to allow cuts on the p_T and rapidity, rather than just the p_T and pseudorapidity used in the **SimpleKTCut** class. This is now used by default for cuts on massive particles such as the $W^\pm$, Z^0 and Higgs bosons and the top quark.
- Several changes to the decayers of B mesons have been made both to resolve problems with the modelling of partonic decays and improve agreement with $\Upsilon(4s)$ data.
- Changes have been made to allow the value of either **SCALUP** for Les Houches events or the scale of the hard process for internally generated hard processes to be used rather than the transverse mass of the final-state particles as the maximum transverse momentum for radiation in the parton shower.
- The defaults for the intrinsic transverse momentum in hadron collisions have been reduced to 1.9 GeV, 2.1 GeV and 2.2 GeV for the Tevatron and LHC at 10 TeV and 14 TeV, respectively.
- The **Pdfinfo** object is now created in the **HepMC** interface. However in order to support all versions of **HepMC** containing this feature the PDF set is not specified as not all versions contain this information.
- The option of only decaying particles with lifetimes below a user specified value has been added.
- New options for the cut-off in the shower have been added and some obsolete parameters removed.
- The option of switching off certain decay modes in BSM models has been added.
- A **Matcher** has been added for the Higgs boson to allow cuts to be placed on it.
- The diffractive particles, which were not used, have been deleted from our default input files.

A number of technical changes have been made:

- Some **AnalysisHandler** classes comparing to LEP data have been renamed, *e.g.* **MultiplicityCount** becomes **LEPMultiplicityCount** to avoid confusion with those supplied in **Contrib** for observables at the $\Upsilon(4s)$ resonance.
- We have reorganised the code to remove the majority of the **.icc** files by moving the inlined functions to the headers in an effort to improve compile time.

- We have restructured the decay libraries to reduce the amount of memory allocation and de-allocation which improves run-time performance.
- The switch to turn off `LoopTools` has been removed because `LoopTools` is now used by several core modules. As `LoopTools` does not work on 64-bit platforms with g77 this build option is not supported.
- We have removed support for the obsolete version of `HepMC` supplied with `CLHEP` and improved the support for different units options with `HepMC`.
- The `EvtGen` interface has been removed until it is more stable.
- Support for `ROOT` which was not used has been removed.
- The CKKW infrastructure present in previous releases has been removed from the release.
- The default optimisation has been increased from `-O2` to `-O3`.
- The handling of the `FORTRAN` compiler has been improved, mainly due to improvements in the `autotools`.
- The `FixedAllocator` use to allocate memory for `Particle` objects in `ThePEG` has been removed as it had no performance benefits.

The following bugs have been fixed:

- Problems with the mother/daughter relations in the hard process and diagram selection in $W^\pm$ and Z^0 production in association with a hard jet.
- A minor bug in the general matrix element code for fermion-vector to fermion-scalar where the outgoing fermion is coloured and the scalar neutral has been fixed.
- A bug involving the selection of diagrams in some associated squark gaugino processes has been fixed.
- A bug has been fixed which lead to $h^0 \rightarrow \mu^+\mu^-$ being generated rather than $h^0 \rightarrow \tau^+\tau^-$.
- The normalisation in the `Histogram` class for non unit-weight events has been fixed.
- The protection against negative PDF values, which can occur when using NLO PDF sets, has been improved.
- The lifetime for BSM particles is now automatically calculated at the same time as the width.
- We now treat hadrons containing a top quark in the same way as hadrons containing BSM particles in order to support this possibility.
- Several ambiguous uses of unsigned int have been corrected.
- Several variables which may have been used undefined have been initialised.
- Several memory leaks at initialisation have been fixed.
- The configuration of `Herwig++` now aborts if no `FORTRAN` compiler is found as this is required to compile `LoopTools`.
- Several minor floating point errors that did not affect results have been corrected.

10 Summary

Herwig++ 2.3 is the fourth version of the Herwig++ program with a complete simulation of hadron-hadron physics and contains a number of important improvements with respect to the previous version. The program has been extensively tested against a large number of observables from LEP, Tevatron and B factories. All the features needed for realistic studies for hadron-hadron collisions are now present and we look forward to feedback and input from users, especially from the Tevatron and LHC experiments.

Our next major milestone is the release of version 3.0 which will be at least as complete as HERWIG in all aspects of LHC and linear collider simulation. Following the release of Herwig++ 3.0 we expect that support for the FORTRAN program will cease.

Acknowledgements

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