New developments in the Whizard event generator

Jürgen Reuter[1,*], *Pia* Bredt[2,**], *Marius* Höfer[3,***], *Wolfgang* Kilian[2,****], *Nils* Kreher[2,†], *Maximilian* Löschner[1,‡], *Krzysztof* Mękała[1,4,§], *Thorsten* Ohl[5,¶], *Tobias* Striegl[2,‖], and *Aleksander Filip* Żarnecki[4,**]

[1]Deutsches Elektronen-Synchrotron DESY, Notkestr 85, 22607 Hamburg, Germany

[2]Department of Physics, University of Siegen, Walter-Flex-Straße 3, 57068 Siegen, Germany

[3]Karlsruhe Institute of Technology, Institute for Theoretical Physics, Wolfgang-Gaede-Str. 1, 76131 Karlsruhe, Germany

[4]Faculty of Physics, University of Warsaw, Pasteura 5, Warszawa, 02-093, Poland

[5]University of Würzburg, Institut für Theoretische Physik und Astrophysik, Emil-Hilb-Weg 22, 97074 Würzburg, Germany

Abstract. We give a status report on new developments within the Whizard event generator. Important new features comprise NLO electroweak automation (incl. extension to BSM processes like SMEFT), loop-induced processes and new developments in the UFO interface. We highlight work in progress and further plans, such as the implementation of electroweak PDFs, photon radiation, the exclusive top threshold and features for exotic new physics searches.

1 Introduction

Whizard is a multi-purpose Monte Carlo event generator which was released in its first version 25 years ago, with the main focus on simulating physics at lepton colliders, especially linear colliders. It has been greatly modernized due to the needs of LHC physics [1] towards version 2 in 2010, and then underwent another drastic development for the next-to-leading order (NLO) automation for version 3 in 2021 [2–9]. Whizard comes with its own tree-level matrix element generator, O'Mega [10–12]. Whizard supports fully general beam polarization in terms of spin density matrices, factorized processes in narrow-width approximation with full spin correlations, comes with an analytic parton shower [13], and directly interfaces to shower and hadronization of Pythia6 [14] or Pythia8 [15] (other shower and hadronization programs are possible through LHE files). Whizard uses an adaptive multi-channel Monte

*e-mail: juergen.reuter@desy.de
**e-mail: pia.bredt@uni-siegen.de
***e-mail: marius.hoefer@kit.edu
****e-mail: kilian@physik.uni-siegen.de
†e-mail: nils.kreher@uni-siegen.de
‡e-mail: maximilian.loeschner@desy.de
§e-mail: krzysztof.mekala@desy.de
¶e-mail: ohl@physik.uni-wuerzburg.de
‖e-mail: tobias.strieglr@uni-siegen.de
**e-mail: zarnecki@fuw.edu.pl

Carlo integration (VAMP) [16] with phase-space parameterizations optimized for either resonant or multi-peripheral multi-particle processes which also has an MPI-parallelized incarnation [17].

Strong emphases in Whizard is laid upon the simulation of lepton-collider beam spectra via the dedicated subpackage CIRCE2 [18]. This uses a 2-dimensional binned histogram fit to the beam spectrum with a special smoothening and a dedicated treatment of the high-energy peak to avoid artifical beam energy spreads.

Whizard supports a special exclusive treatment of the top threshold, matching the NRQCD next-to-leading logarithmic (NLL) corrections with the relativistic NLO QCD corrections [19, 20].

For BSM models, Whizard supports the most recent UFO2 standard [21], while still keeping partial backwards compatibility via its Feynrules interface [22]. Some recent applications of the UFO2 interface are shown here [23–27].

In the next section, we are summarizing new features and ongoing developments roughly since the last LCWS in May 2023 at SLAC.

2 New developments and current progress

As there are several proposed collider options for electron-positron colliders, Whizard has provided several CIRCE2 spectra for using their beam spectra in simulations. Since quite some time, ILC and CLIC spectra have become available while CEPC was provided around the time of the CEPC CDR. Recently, beam spectra for the Cool Copper Collider (C^3) have been simulated; these simulations have been shown that a special handling for depleted regions within the spectra is needed in order to avoid the appearance of unphysical artifacts. Simulations for the FCC-ee spectra are coming soon, however, the beam delivery system of FCC-ee is still being updated after the feasibility study midterm report. Also, due to the work of the SLAC group around Timothy Barklow on XFEL-based lasers, photon-collider options have been revived, which can also be simulated with CIRCE2. A special Gaussian-like spectrum will become available in the future as well. End of 2023, support for muon collider spectra have been added to CIRCE2, but as of now no particle muon collider spectrum is available.

For QCD quantum numbers, Whizard uses the color flow basis for their representation and evaluation [28]. Recently, the matrix element generator O'Mega has been geeneralized for arbitrary tensors in color space (epsilon tensors, sextets, decuplets, higher exotic representation, which are potentially important for colorful dark-sector models) [29]. The support of these exotic color structures in the Whizard interface is work in progress, to be released in v3.2.

One active line of development is the completion of NLO EW corrections at lepton colliders with massless fermions, while those for massive fermions are already completed [8]. The current implementation of NLL QED PDFs has been completed in 2023 [30], while in the past months the numerical stability has been greatly improved close to the integrable singularity $z \to 1$. Complete NLO EW results will be ready within the next few months, which will then allow to also properly match (soft- and collinear) photon radiation to all orders, where first hard-coded attempts have been made in [31, 32] without solving the problem of double-couting. For the very high-energy regime, electroweak factorization might become relevant, e.g. for muon colliders in the multi-TeV regime or FCC-hh. This approach is similar to the equivalent vector-boson approximation (EVA or EWA) which, however, is a purely kinematic approximation, where the corresponding factorized piece is not necessarily a splitting function obeying a DGLAP equation. Those objects that fulfill a DGLAP equation are rather called EW PDFs. While the traditional implementation of the EWA in Whizard has been recently rederived and revalidated, the basic infrastructure for EW PDFs has been implemented as well. This will allow to read in EW PDFs from LHAPDF-like grids, to be interpolated and DGLAP-evolved to according scales. Here, we do expect first reliable numerical results mid-2025.

Another current line of development is to port Whizard to GPUs; already at LCWS last year it was reported that there is an automated way to port O'Mega matrix elements as CUDA code to be evaluated on the GPU. Meanwhile, the VAMP Monte-Carlo integrator routines have been ported to the GPU as well with a medium number of sanity checks and a as of yet small number of benchmarking runs. These look quite promising but are not yet conclusive as for simple phase-space configurations the efficiency is dominated by the matrix elements. Work in progress is to also offload cut expressions and clustering statements to the GPU, and first non-trivial are to be expected early next year.

3 Summary, open developments and outlook

This is a status report on the availability of new features in the Whizard event generator based upon the version 3.1.5 from late summer 2024. Besides a large number of bug fixes on the UFO interface, on the NLO interfaces to the one-loop providers, the event format interfaces to HepMC and for intermediate diagram restrictions in matrix elemenets, there was support for Pythia versions 8.310 and newer. Among the new features is the extension of the resonance-aware FKS NLO subtraction both for hadron-collider processes as well as to NLO EW corrections. Also the GoSam interface has been overhauled to support NLO processes at LHC. The current development is preparing interfacing the upcoming new major release 3 of GoSam and full support for NLO QCD corrections for UFO-based BSM models. Finally, the special simulation for photon-induced processes to low-p_T hadrons at low energies, parameterized with cross sections measured at fixed-target experiments like Crystal Ball that had been used for the ILC TDR simulations with Whizard 1.95 has now been ported to Whizard 3.1.5. The current main lines of development include the finalization of (squared) matrix elements exclusive in coupling orders in conjunction with a refactoring of quantum number handling in Whizard, the GPU parallelization of the full Whizard integration (and ultimately also event generation) and also fully general color structures. The NLO development focuses on NLL QED PDFs for complete NLO EW cross sections at lepton colliders with massless fermions, in the further future a soft (YFS) exponentiation of photons, and the support for effective W approximation or NLO EW PDFs. Also, a native EDM4HEP interface is being developed. A next update is expected for the FCC Physics Workshop in January 2025.

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