O'Mega & WHIZARD: Monte Carlo Event Generator Generation For Future Colliders

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Abstract. I describe the optimizing matrix element generator *O'Mega* [1,2] and Wolfgang Kilian's event generator generator *WHIZARD* [3]. These tools cooperate in the automated production of efficient unweighted event generators for linear collider physics.

I INTRODUCTION

Current and planned experiments in high energy physics can probe processes with many tagged—potentially polarized—particles in the final state, in particular at a linear collider. The combinatorial explosion of the number of Feynman diagrams contributing to scattering amplitudes for many external particles calls for the development of more compact representations that translate well to efficient and reliable numerical code. In gauge theories, strong numerical cancellations in a redundant representation built from necessarily gauge dependent Feynman diagrams lead to a loss of numerical precision, stressing further the need for eliminating redundancies.

At the same time, the final state phase space becomes more and more intricate and efficient Monte Carlo sampling turns into a highly non-trivial problem. The rapidly growing number of nonfactorizable singularities poses a challenge to adaptive sampling algorithms (see [4]).

Due to the large number of processes that have to be studied in order to unleash the potential of current and planned experiments, including a linear collider, the construction of optimized representations of scattering amplitudes must be possible algorithmically on a computer and should not require human ingenuity for each new application. For the same reason, improved phase space sampling algorithms should be adaptive and robust, allowing the construction of unweighted event generators with a minimum of human intervention.

II O'MEGA

O'Mega [1,2] is a generator for tree-level scattering amplitudes that satisfies the requirements set forth in the introduction. O'Mega constructs the scattering amplitude from *One Particle Off-shell Wave functions* (1POWs)

$$W^{q_1,\ldots,q_m}_{p_1,\ldots,p_n}(x) = \langle \phi(q_1),\ldots,\phi(q_m); out|\Phi(x)|\phi(p_1),\ldots,\phi(p_n); in\rangle\ . \tag{1}$$

The 1POWs are sums of Feynman diagrams. Therefore, expressing the scattering amplitude in terms of the 1POWs achieves a factorization of the sum of all Feynman diagrams. Indeed, this representation removes all redundancies and dramatically reduces the growth in calculational effort from a factorial of the number of particles to an exponential. O'Mega can emulate both numerical approaches in [5] and produces code that is empirically at least twice as fast. In addition, the symbolic nature of O'Mega provides greater flexibility in the translation to numerical code: treatment of unstable particles, verification of Ward identities, etc.

O'Mega is independent of the target language and can support code in any programming language for which a simple output module has been written. The code generated by the Fortran90/95 backend is the most efficient code available for polarized scattering amplitudes for many particles. To support a physics model, O'Mega requires as input only the Feynman rules and the relations among coupling constants. Currently, the standard model is well tested (the numerical results agree with MADGRAPH [6]) and the MSSM is in preparation.

III WHIZARD

WHIZARD [3] solves the other problem set forth in the introduction: the efficient sampling of multi particle phase space. In addition, it provides a driver routine for the automated construction of efficient unweighted event generators. The unweighted events are written either in ASCII or STDHEP [7] format. Leading order initial state radiation, beamstrahlung (via CIRCE [8]) and beam polarization are supported.

For a given process, WHIZARD automatically identifies the kinematical variables in which singularities can appear. In a second step, WHIZARD constructs a set of phase space parameterizations in which all singular variables appear explicitely. In general, it is impossible to find a single parameterization that includes all singular variables [4], but it is always possible to cover them by a finite set of parameterizations. Finally, WHIZARD sets up the adaptive multi channel sampling library *VAMP* [4] for this set of parameterizations, calls an external matrix element generator and creates an unweighted Monte Carlo event generator. So far, this approach has been shown to work well for processes with up to eight particles in the final state.

Among matrix element generators, O'Mega is the preferred choice for polarized scattering of many weakly interacting particles. It generates the most efficient

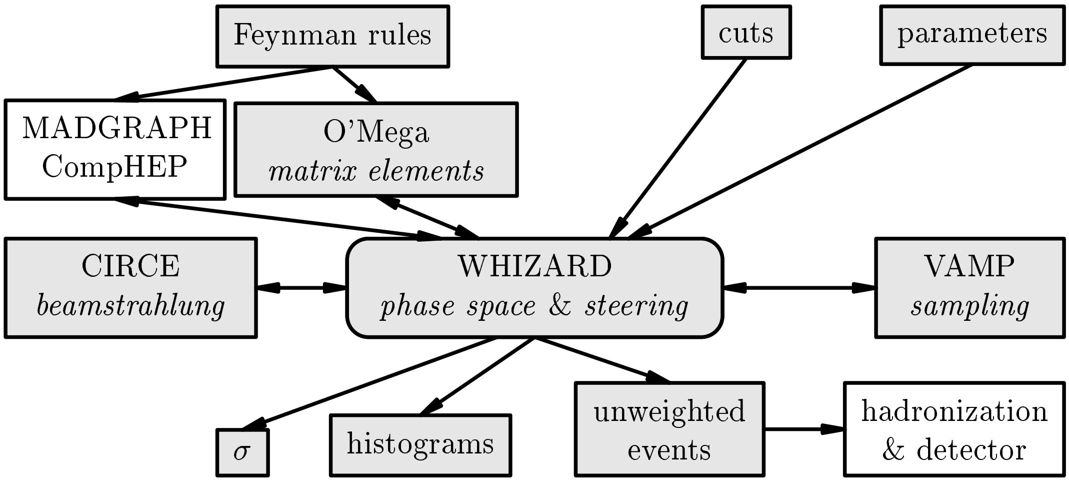

FIGURE 1. The event generator generator WHIZARD provides phase space parametrizations and utilizes external components for matrix element generation and adaptive multi channel Monte Carlo sampling.

code in this case and offers the greatest flexibility for handling unstable vector bosons and for including some deviations from the standard model. But WHIZARD does not depend on O'Mega and can use other matrix element generators as well. Indeed, MADGRAPH [6] is used for standard model amplitudes with interfering color structures, while CompHEP [9] can be more efficient for the scattering of few and unpolarized particles.

IV APPLICATIONS

The first complete experimental study of vector boson scattering in six fermion production for linear collider physics has been the first serious application and is discussed elsewhere [10].

The *Higgsstrahlung* process $e^-e^+ \to \nu_e\bar\nu_e b\bar b$ provides a simple example for a completely automated calculation (cf. Figure 2). There are 21 diagrams in four groves: 5×Higgsstrahlung, 10×WW-fusion, 4×ZZ production, 2×Z-bremsstrahlung. These diagrams contribute singularities in many time-like and space-like channels.

After adapting the grids with 20000 events with fixed relative weights of the channels, an error in the total cross section of $2.2\% = 3.76/\sqrt{N}$ is obtained with a projected efficiency of 2% for unweighted event generation. After ten steps of adapting the relative weights, each using 20000 events, the relative error in the total cross section for 20000 events is reduced to $0.48\% = 0.68/\sqrt{N}$ and efficiency for unweighted event generation is increased to 19.3%. This process consumes 24 min for adaptation and 5 min for generating 10000 *unweighted* events on a Pentium 450 MHz. Since the adaption typically consumes more than the subsequent

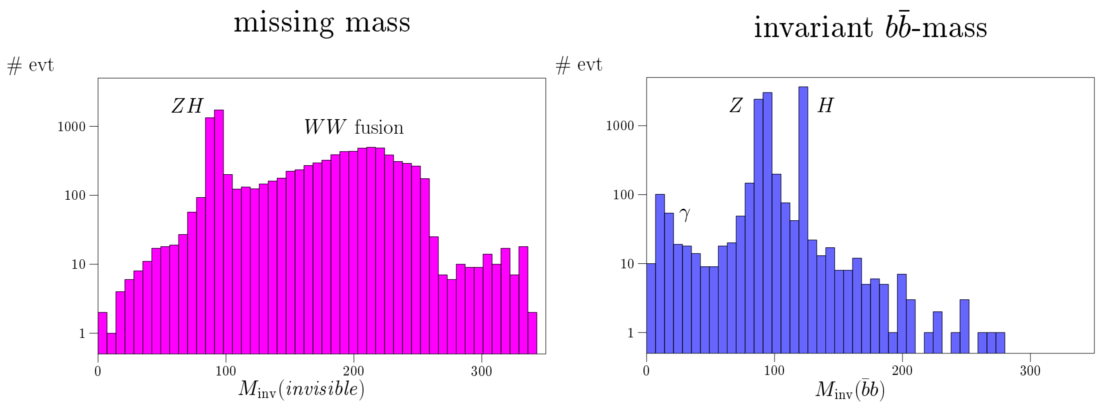

FIGURE 2. Distributions of 10000 *unweighted* $e^-e^+ \to \nu_e\bar{\nu}_e b\bar{b}$ events at $\sqrt{s} = 350$ GeV for $m_H = 120$ GeV, corresponding to $16.68\,\mathrm{fb}^{-1}$.

event generation, the adapted grids and weights can be saved and reloaded for generating sets of event samples with similar parameters and cuts.

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