Next Generation Multi-particle event generators for the MSSM

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We present a next generation of multi-particle Monte Carlo (MC) Event generators for LHC and ILC for the MSSM, namely the three program packages Madgraph/MadEvent, WHiZard/O'Mega and Sherpa/Amegic++. The interesting but difficult phenomenology of supersymmetric models at the upcoming colliders demands a corresponding complexity and maturity from simulation tools. This includes multi-particle final states, reducible and irreducible backgrounds, spin correlations, real emission of photons and gluons, etc., which are incorporated in the programs presented here. The framework of a model with such a huge particle content and as complicated as the MSSM makes strenuous tests and comparison of codes inevitable. Various tests show agreement among the three different programs; the tables of cross sections produced in these tests may serve as a future reference for other codes. Furthermore, first MSSM physics analyses performed with these programs are presented here.

1. MOTIVATION: SUSY PHENOMENOLOGY

At the end of 2007, first physics data are expected to be delivered by the Large Hadron Collider (LHC). This experiment may probe the mechanism of electroweak (EW) symmetry breaking and possibly find signals of new physics. There are many theoretical arguments for physics beyond the Standard Model (SM). The most prominent among them is low-energy supersymmetry in the form of the minimal supersymmetric SM, the MSSM. If deviations from the SM are seen at the LHC, it is important to distinguish which SM extension is realized in nature. The spectrum of new particles would have to be determined by measurements (cascade decays), the spin of new particles assesed, and the couplings measured: supersymmetry (SUSY) would be verified by revealing the SUSY relations among these quantum numbers.

Furthermore, SUSY parameters would have to be determined as precisely as possible for two reasons: simpler SUSY processes appear as backgrounds for more complicated ones, and renormalization-group evolution would allow us to get a handle on the GUT parameters and SUSY breaking mechanism. The second task is part of the Supersymmetry Parameter Analysis (SPA) project [1].

To match the expected experimental accuracy, which is mostly at the per-cent level at the LHC and at the per-mille level at the ILC, simulation tools will have to cope with the complexity of multi-particle final states. The factorization of SUSY processes into $2 \to 2$ on-shell production processes and subsequent decay of the SUSY particles is in most cases not sufficient, since off-shell effects can be important. Hence, off-shell intermediate states and full gauge-invariant (sub)sets of Feynman diagrams for final states with six, eight and more particles have to be included. Furthermore, SM and MSSM backgrounds must be taken into account, and since in general a separation of signal and background is not guaranteed, interferences have to be accounted for. To identify intermediate particles in a cascade, spin information is important. It can e.g. be accessed by the spin density matrix formalism.

The more traditional MC event generators like Pythia, Herwig and SUSYGEN were designed for a different purpose, and hence do not fulfill one or more of the abovementioned requirements. In the next section, we present three programs which are especially designed to fulfill these requirements.

2. NEXT GENERATION EVENT GENERATORS FOR THE MSSM

2.1. Description of the tools

In this section, we present the three multi-purpose multi-particle event generators for the MSSM at LHC and ILC, Madgraph/MadEvent [2, 3], WHiZard/O'Mega [4, 5] and Sherpa/Amegic++ [6, 7]. More details about the programs and their comparison can be found in [8, 9]. We briefly describe the structure of the three codes. For matrix element generation, where all codes use the helicity-amplitude formalism, Sherpa first generates the topologies and then decorates them with the particles and vertices. So the full set of Feynman diagrams is present as a chain of subroutine calls. Madgraph is very similar. In both programs duplicate calls are eliminated, such that identical subamplitudes are calculated only once. O'Mega avoids all redundancies in the matrix elements by the use of directed acyclical graphs [5].

The next crucial step is phase space parameterization, since the set of well-suited integration variables is different for each phase space channel. The best solution is a multi-channel adaptive integration using MC sampling. In Sherpa, the dominant channels are selected according to the Feynman graph structure, and the channel weights are adapted iteratively. WHiZard is quite similar. In both programs the channel mappings are adapted iteratively as well. MadEvent, a front-end for Madgraph, first integrates the single squared diagrams separately and accounts for the interferences by correction factors afterwards. In the final step, all programs can unweight the events, after a mapping that transforms the integrand as closely to a constant as possible.

The "dressing" of the partonic processes is done by structure functions for the incoming partons. This makes efficient matrix elements necessary, since integrations over two additional variables, x_1 and x_2, are needed. For the ILC, beamstrahlung and beam energy spread have to be taken into account to simulate a realistic collider environment. Moreover, for polarized beams the full spin information should be kept which is done by spin density matrices in WHiZard. Initial state radiation (ISR) must be included, since it is essential for the height and shape of distributions. The parton shower of the colored particles in the final state, hadronization and the simulation of underlying events, is performed by an interface to Pythia in MadEvent and in WHiZard, while Sherpa provides its own code for strong interaction effects by a systematic merging of matrix elements with inital and final state parton showers using the CKKW algorithm [14].

2.2. Tests and Consistency checks of the codes

Madgraph/MadEvent, WHiZard/O'Mega and Sherpa all read in the spectrum and the mixing angles from a spectrum generator via the SUSY Les Houches Accord (SLHA). For the conventions the three programs use, cf. [8]. The MSSM is an extremely complicated model, containing several thousands of vertices. Tests are mandatory which guarantee their correct implementation. One stringent test is unitarity of scattering processes, namely that partial-wave amplitudes for $2 \to 2$ processes cannot arbitarily grow with the energy. In many cases gauge cancellations make the amplitudes constant (up to logarithmic corrections). This has been checked for almost all possible $2 \to 2$ and $2 \to 3$ processes. One can also use Ward and Slavnov-Taylor identities to check the gauge invariance of matrix elements, and even supersymmetric Ward- and Slavnov-Tayler identities have been tested [12]. Furthermore, an extensive comparison has been undertaken of all relevant $2 \to 2$ processes necessary to test all MSSM Feynman rules. All these tests were passed by the three programs, establishing agreement between all the codes. The results of these tests, as well as references for first physics results obtained with these programs (cf. also [13]), may be found in [8].

3. Conclusions

Madgraph/MadEvent, WHiZard/O'Mega and Sherpa form a new generation of multi-particle Monte Carlo event generators for LHC and the ILC. In the present versions, all three programs provide a full description of the SM and the MSSM suitable for realistic physics simulations within the collider environment, and are extensible towards further alternative models beyond the SM. While the packages are completely independent in their implementations of Feynman rules, matrix element generation and phase space sampling, we found complete agreement in a comprehensive comparison of numerical results. The three codes are very well tested and available publicly [2–7]. First full MSSM physics analyses have been performed with the three programs, including backgrounds, hadronic environments and corrections from real emission. A major open point is the incorporation of virtual radiative corrections into the programs with the ultimate goal of a Monte Carlo for general processes at next-to-leading order.

Acknowledgments

T. O., J. R. and W. K. are supported in part by the German Helmholtz-Gemeinschaft, Grant No. VH–NG–005. T. O. is supported in part by Bundesministerium für Bildung und Forschung Germany, Grant No. 05HT1WWA/2. D.R. was supported in part by the U.S. Department of Energy under grant Nos. DOE-FG02-91ER40685, DOE-FG02-96ER40956 and DOE-FG02-95ER40893.

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