Summary of MC4BSM Discussions

MC4BSM participants, compiled by J. Hubisz and P. Skands

Abstract
The general problem of obtaining fully exclusive descriptions of collider final states for an arbitrary Beyond-the-Standard-Model (BSM) physics scenario can in principle be addressed using presently existing tools. However, the necessary steps are not always transparent to non-experts, and similar physics implementations often involve duplication of effort. The workshop on Monte Carlo Tools for Beyond-the-Standard-Model Physics (MC4BSM, Fermilab, March 20-21, 2006) featured two sessions devoted to discussion of these issues; one centered on fixed-order Matrix Element Generators (MEG's) and the other on Parton Shower and Hadronisation Monte Carlos (PSMC's). We here summarize those two discussions.

1. Matrix Element Generator Discussion

Currently, the different available matrix element generators which allow for entering new particles and interactions (i.e. COMPHEP [1]/CALCHEP [2], MADGRAPH [3], WHIZARD [4], SHERPA [5],GRACE [6]) all use a different format for defining the particle content of a model, and the associated interactions which contribute to matrix elements. In this meeting, we discussed the feasibility and utility of having all matrix element generators (MEG's) use a common standard for entering in particles, interactions, and relevant free parameters.

The conclusion/consensus was that this would be both feasible and exceedingly useful, and should be implemented as soon as possible in order to facilitate rapid integration of new models of beyond the standard model (BSM) physics into matrix element generators. The remaining part of the meeting covered what the best format for entering new physics would be, and addressed the issue of who would be responsible for bringing the different existing codes in line with the standardization.

The main reason for the popularity of the COMPHEP/CALCHEP programs among BSM theorists is the simplicity of the model files which define the particle content and Lagrangian associated with the model under investigation. It was agreed in the discussions that these model files would be a good starting point for universal standard. With slight modification, the COMPHEP/CALCHEP standards can be used to define nearly all BSM physics proposed thus far. The other benefit to using this structure is that many theorists are already familiar with it, and little additional learning will be necessary to implement new models.

The information necessary for a new physics model can be contained in 4 tables. First is a table of the particles. This table contains information about the transformation properties of the particles in the model (e.g. spin, whether a fermion is Majorana or not, $SU(3)$ representation). In addition, it contains the masses and widths of the new particles. Another table defines the independent free parameters associated with the model. Next, useful functions of the free parameters that are needed in expressing the Lagrangian can be given. Finally, the Lagrangian, and relevant Lorentz contractions are specified. The fact that some MEG's have capabilities that others do not (for example, the ability to deal with spin 2 particles) is not an issue, as the MEG could be programmed to ignore new particles and interactions which it does not know how to deal with (and provide an associated error message).

The question then arises as to who is best suited to implement this structure into the different MEG's that exist. There are two options:

- **MEG Authors** - We can ask for the authors of the different sets of code to make modifications such that the MEG's accept input from the universal model file standard.
- **"End" users** - People who are familiar with the standards of entering new particles/interactions for each of the existing codes, should be convinced to write code which translates from the universal standard to the program of their expertise.

Ideally, the MEG authors, acknowledging the importance of and demand for a common standard, would do some work towards modifying their code to use the universal format. This would have the benefit that the resulting code is 'blessed' by the original authors, and thereby more trustworthy. In the absence of this the next best thing would be for expert users of the different codes to write scripts which translate between the universal standard and the MEG with which they are familiar. Ideally, these scripts would be made public so that they can be used by other members of the community.

2. Parton Shower Monte Carlo Discussion

Loosely speaking, for the previous discussion, the relevant question was how to obtain automated predictions in fixed-order pertubation theory for an arbitrary physics model. I.e. how to consistently go from a given particle content and Lagrangian (or pre-calculated matrix elements) to parton–level generated events, with a minimum of (duplication of) effort.

For sufficiently inclusive observables, the parton level predictions from MEG's receive only small corrections from lower-scale physics, and hence no further action is in principle needed. However, a realistic phenomenological analysis of a new physics signal will more often than not also be impacted by more exclusive physics, directly or indirectly.

Most directly, sensitivity to lower scales appear from the necessity of imposing exclusive, rather than inclusive, cuts. Typical examples include the requirement of n and only n jets of a given hardness and/or in a given rapidity region, and imposing isolation criteria on leptons and photons. Other effects which are hard to quantify at the fixed–order level are the difference between single partons and hadron jets, detector resolution effects, etc.

The question of how to "pass" parton–level final states from a MEG to a Parton Showering and Hadronisation Monte Carlo, such as HERWIG [7] or PYTHIA [8], has been addressed before, by the so-called Les Houches Accord for Event Generators [9]. For any final state containing only Standard Model particles (i.e. without any exotic particles) this Accord is in principle sufficient, and many codes already implement it, both on the MEG and on the PSMC side.

Among the issues raised on this point were treatment of parton showers off intermediate resonances, in particular in cases where the latter have already decayed when the event is passed to the PSMC. This was already foreseen in [9], and a possibility exists to pass both the explicit final states together with information on any decayed intermediate states, with indices telling which final states come from which resonances. If provided with this information, it is possible for the PSMC not only to add showers off intermediate coloured resonances, but also to enforce conservation of the invariant mass of any resonant systems present in the event. Providing the event generator with this information is thus not only useful, but should be considered mandatory any time intermediate resonances are present in the generated process.

A second issue on usage of the LHA was spin correllations and how/if spin information is passed and processed. The answer here is that the LHA includes a possibility to pass polarization information, but none of the presently existing event generators will actually use it, their parton showers being derived for unpolarized partons. While they will not use it, however, they will also not destroy it, hence after the parton shower the information will still be present and can still be accessed by the user. Keep in mind, though, that the polarization information thus obtained pertains to the relevant parton *before* processing by the PSMC.

Finally, one is frequently interested in a cascade decay chain, with successive resonances decaying to each other. In such cases, the final state multiplicity may easily reach 6-10 partons or even higher before all exotic states have disappeared. At present, such high final-state multiplicities are quite expensive to calculate with matrix element generators, often too expensive for practical consideration. In addition, some states might be long-lived or stable. The question that we devoted the most time to was therefore how best to deal with generic exotic states. We considered 2 conceptual ways of doing this, as follows:

Solution 1: the MEG does it: The most generic solution is probably to let the MEG handle the decays of exotic resonances, since they are anyway capable of calculating the relevant matrix elements and hence give the correct phase space population, etc. The bottleneck with this, at the moment, is that current general-purpose MEG's do not factorize phase space for such decays, causing the result of a sequence of resonance decays to be treated as a full n-body final state, instead of as a product of much smaller phase spaces. In principle, the current treatment is more correct, since off-shell and interference effects are correctly accounted for, but as already mentioned it is also enormously slow for high final-state multiplicities. Including a possibility for using successive narrow width approximations in multi-body final states would greatly enhance the performance of MEG's and would be an extremely welcome future development.

Solution 2: the PSMC does it: Given a few facts about a new resonance, such as its colour and electric charges, its mass, some identifying label, and a list of decay modes, it is possible for a PSMC to do something at least moderately satisfactory with it, a crude version of what was advocated above, factorizing a large decay cascade into successive simple $1 \to$ a few processes. However, for this to be practical, several shortcuts are made. Firstly, the PSMC does not know the full matrix elements, so in the absence of other information, it will simply use a flat phase space for each decay. To improve substantially on this would most likely require passing so much information that it would be equivalent to the MEG procedure above, in which case the MEG might as well do the whole thing. Note, however, that a flat phase space is not as bad as it sounds, even in cases where it is known that the correct phase space population is not flat. A post facto reweighting of the events can always be applied, if the correct matrix element is known, since the full event history is normally available after generation. The only thing that is needed, then, is a way to specify the essential facts about a new state. Part of this can be considered already solved, by using particle decay tables in the SUSY Les Houches Accord (SLHA) format, see [10], which again is already implemented in a number of codes. What the SLHA does not allow for is the specification of the quantum numbers of entirely new particles, since it was designed with SUSY in mind, whose states were already known to the relevant PSMC's. The SLHA is presently undergoing revisions to extend it in a number of ways [11], and so we propose as part of this effort to include a new "block" in the SLHA definitions, called `QNUMBERS` or `PARTICLE` (whichever is nicer), to contain a PDG number assignment for the particle, its colour and electric charge, and possibly an indication whether it is identical with its antiparticle or not, and its spin. Its mass would be given in the existing SLHA block `MASS`, and its decay width and partial fractions in the existing SLHA `DECAY` format. Combined, this would allow a generic PSMC to recognize these states, and decay and shower them and their decay products consistently, within the given approximations. A proof-of-concept along these lines has already been carried out for the NMSSM, interfacing CALCHEP, NMHDECAY, and PYTHIA [12].

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