RECENT PROGRESS IN NLO MONTE CARLOS

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I discuss selected topics relevant to the progress recently made in the inclusion of the complete NLO QCD corrections into Parton Shower Monte Carlo frameworks

1. Introduction

As is well known, Parton Shower Monte Carlos (PSMC's) are the main analysis tools of high-energy experiments, thanks to their flexibility and realistic descriptions of complicated final states, based on perturbative parton-level dynamics, and on simple modelisations of the non-perturbative regime. The perturbative description of the production process begins with the computation of a leading order (LO) cross section for the hard scattering of interest. Next, one considers all of the strongly-interacting initial- and final-state QCD partons, and let them emit a pair of partons, using for such emission (or *branching*) the collinear approximation. The procedure is then iterated, till a (pre-defined) low scale is reached; at this point several partons are present in the final state, which are given in input to a hadronization model which converts them into observable hadrons.

In spite of the relative simplicity of the structure outlined above, PSMC's do remarkably well in describing (with a proper parameter tuning) a huge variety of observables in collider physics. Nevertheless, it is clear that the collinear approximation will not work well if the emphasis is on multi-jet observables, and the LO-based picture is largely insufficient to give a reliable description of collision processes if precision is an issue. Clearly, both problems can be solved by considering perturbative orders higher than leading in the computation of the matrix elements relevant to the hard scattering. Two different strategies for including these matrix

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elements into an MC framework have emerged in the past few years. *a)* Matrix Elements Corrections (MEC): this implies considering all of the *real emission* corrections to the LO processes. *b)* NLOwPS: this implies considering both real and virtual corrections to the LO processes, but at the NLO only. MEC are suited when many-jet final states are relevant to the analysis considered (for example, SUSY searches). NLOwPS on the other hand should be the default choice for studies of SM physics, and for final states where the number of jets is not too large; the latter limitation is not intrinsic to the strategy, but is simply due to the fact that NLO QCD results for many-leg processes are very difficult to obtain. In the following, I shall concentrate on the only NLOwPS formalism, namely MC@NLO [1,2], that has so far resulted into a public code for hadronic collisions.

2. MC@NLO, progress and future plans

The generating functional of MC@NLO can symbolically be written in the following form:

$$\begin{aligned}\mathcal{F}_{\rm MC@NLO} = \sum_{ab} \int dx_1\, dx_2\, d\phi_{n+1}\, f_a(x_1) f_b(x_2) \times \\ \Big[\mathcal{F}_{\rm MC}^{(2\to n+1)} \left(\mathcal{M}_{ab}^{(r)} - \mathcal{M}_{ab}^{(\rm MC)}\right) + \\ \mathcal{F}_{\rm MC}^{(2\to n)} \left(\mathcal{M}_{ab}^{(b,v,c)} - \mathcal{M}_{ab}^{(c.t.)} + \mathcal{M}_{ab}^{(\rm MC)}\right)\Big]. \qquad (1)\end{aligned}$$

Here, it is assumed that the LO process has a $2 \to n$ kinematics. The $2 \to n+1$ real matrix elements are denoted by $\mathcal{M}_{ab}^{(r)}$; the Born, soft-virtual, counterterms and initial-state collinear reminders are denoted by $\mathcal{M}_{ab}^{(b,v,c)}$ and $\mathcal{M}_{ab}^{(c.t.)}$ (possibly times a phase-space volume normalization factor). Finally, the quantities $\mathcal{M}_{ab}^{(\rm MC)}$ are called MC subtraction terms. Their role is that of avoiding the double counting that would arise by naively attaching showers to the pure-NLO cross section. It is worth noting that *two* MC subtraction terms, with different kinematics, appear in eq. (1). This is because a double counting arises from a final-state branching, but also from the probability that such branching does not occur; the spurious terms of NLO that would appear in the case of double counting are removed by the first and second MC subtraction term in eq. (1) respectively. The MC subtraction terms have two important features. First, they cancel locally the phase-space divergences that appear in NLO matrix elements. This implies that the weights associated with the two showers in the integrand of eq. (1) are finite in the whole phase space. In turn, this means that unweighted events can be produced, which is not the case for a pure NLO computation (unweighted events in NLO computations require an *ad hoc* cutoff procedure, and are therefore always biased). Secondly, the MC subtraction terms are dependent on the hard scattering only in a factorized form; all the information on that is included in an LO cross section. The part of the MC subtraction terms that describes the branching process is universal, and therefore needs to be computed only once and for all. In the case of HERWIG, this was done in refs. [1,2] and ref. [3] for initial- and final-state emissions respectively.

The generation of events in MC@NLO is based on the computation of the following integrals

$$J_{\mathbb{H}} = \sum_{ab} \int dx_1\, dx_2\, d\phi_{n+1}\, f_a(x_1) f_b(x_2) \left| \mathcal{M}_{ab}^{(r)} - \mathcal{M}_{ab}^{(\mathrm{MC})} \right| \tag{2}$$

$$J_{\mathbb{S}} = \sum_{ab} \int dx_1\, dx_2\, d\phi_{n+1}\, f_a(x_1) f_b(x_2) \left| \mathcal{M}_{ab}^{(b,v,c)} - \mathcal{M}_{ab}^{(c.t.)} + \mathcal{M}_{ab}^{(\mathrm{MC})} \right| \tag{3}$$

relevant to $2 \to n+1$ ($\mathbb{H}$) and $2 \to n$ ($\mathbb{S}$) kinematics configurations respectively. The numbers of $\mathbb{H}$ and $\mathbb{S}$ events are determined by the relative weights of the integrals in eqs. (2) and (3). An alternative event generation, which I denote as βMC@NLO, starts by computing the integral

$$J_{\mathbb{H}+\mathbb{S}} = \sum_{ab} \int dx_1\, dx_2\, d\phi_{n+1}\, f_a(x_1) f_b(x_2) \left| \mathcal{M}_{ab}^{(r)} + \mathcal{M}_{ab}^{(b,v,c)} - \mathcal{M}_{ab}^{(c.t.)} \right| \tag{4}$$

(which would coincide with the total NLO rate by removing the absolute value). Each phase-space point (x_1, x_2, ϕ_{n+1}) at this stage may give an $\mathbb{H}$ or an $\mathbb{S}$ event; only one is chosen, on a statistical basis by comparing the relative weights of the *integrand* of eqs. (2) and (3). An example of the comparison of the results obtained with MC@NLO and βMC@NLO is shown in fig. 1, where the p_T of the charged lepton emerging from W decay in single-W production at the LHC is presented. As one can see, there is a perfect agreement between the two methods, and this is the case for all the observables in single-W production, as well as for dijet production in e^+e^- collisions, the other process for which βMC@NLO has been tested. This is interesting, since one can prove that event generation based on eq. (4) introduces double counting! The explanation of the good agreement between MC@NLO and βMC@NLO is the following: the phase-space regions where βMC@NLO is affected by double counting coincide with those where the MC subtraction terms are numerically important.

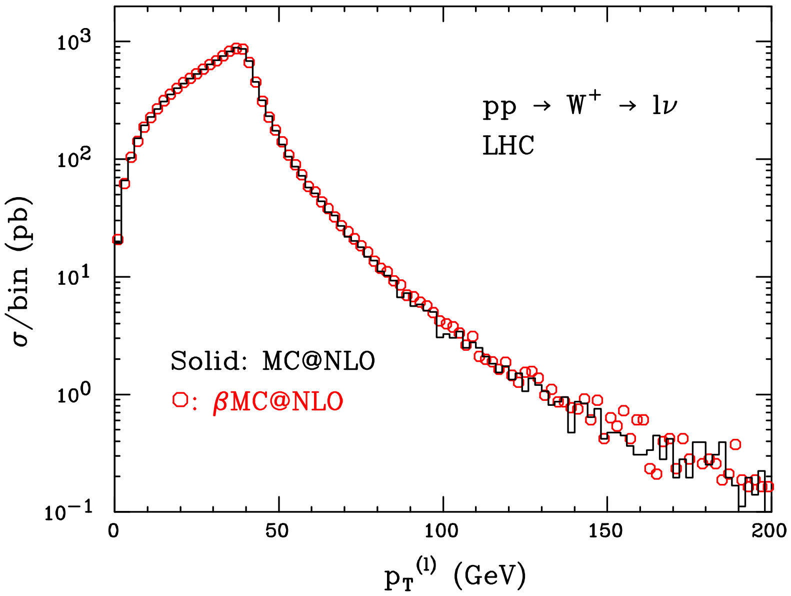

Figure 1. W production in MC@NLO and βMC@NLO.

There, double counting is effectively not an issue, since NLO results are not reliable, and the kinematics is dominated by the MC.
Conclusions: present activities include efforts for extending the number of processes and features in MC@NLO, and the general formulation of NLO computations for matching with showers based on the formalism of ref. [4]. More systematic attempts with βMC@NLO will also be considered.

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References

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