Automated NLO computations matched to Parton Showers

Paolo Torrielli

EPFL

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Motivations

Why NLO matching with parton showers

- NLO and parton shower Monte Carlos (MC's) are complementary approaches, the former good for hard emissions, the latter for soft / collinear ones
- Retain the virtues of the two while discarding the weaknesses: give a prediction which is MC in the soft / collinear region and NLO for hard radiation
- Attain NLO precision
- Avoid double counting
- Achieve a smooth transition between the two regimes

Matched computations are some of the most accurate / realistic predictions currently available

Why automation

- Save large amount of time, and dedicate manpower to phenomenology
- Reduce drastically the probability of bugs and avoid writing / debugging / validating one code for each physical process
- Develop a unique framework that can be applied in principle to any model and multiplicity (up to CPU time)

automation + PSMC + NLO = aMC@NLO

MC@NLO and its automation

MC@NLO in one slide

$$\frac{d\sigma_{\text{MC@NLO}}}{dO} = \left[d\Phi_B\left(B + V + \int d\Phi_{(+1)} MC\right)\right] I_{\text{MC}}^{(n)}(O) + \left[d\Phi_B d\Phi_{(+1)}\left(R - MC\right)\right] I_{\text{MC}}^{(n+1)}(O)$$

[Frixione, Webber, hep-ph/0204244]

- B, V, R = Born, virtual, and real amplitudes squared, relevant for any NLO computation
- MC = Monte Carlo couterterm $\propto \left|\frac{\partial(t^{\text{MC}}, z^{\text{MC}}, \phi)}{\partial\Phi_{(+1)}}\right| \frac{\alpha_S}{t^{\text{MC}}} P(z^{\text{MC}}) B$
  - It is the cross section for the first emission in the parton shower
  - It acts as a local counterterm for the real and virtual amplitudes
  - Its process-dependence is trivial
  - It depends on the Monte Carlo one is interfacing the NLO computation to

aMC@NLO step 1: automation of the NLO

- MadGraph: automatic computation of tree-level amplitudes.
- MadFKS: automatic calculation of the real contribution and of the subtraction of infrared singularities according to the FKS method

  [Frederix, Frixione, Maltoni, Stelzer, 0908.4272]

  [Frixione, Kunszt, Signer, hep-ph/9512328]
- MadLoop: automatic calculation of the finite part of the virtual contribution, based on the OPP reduction method as implemented in CutTools, exploiting MadGraph tree-level computations

  [Hirschi, Frederix, Frixione, Garzelli, Maltoni, Pittau, 1103.0621]

  [Ossola, Papadopoulos, Pittau, hep-ph/0609007]

  [Ossola, Papadopoulos, Pittau, 0711.3596]

MadGraph + MadFKS + MadLoop = MadGraph@NLO

aMC@NLO step 2: automation of the MC counterterm

$$MC \propto \left| \frac{\partial(t^{\mathrm{MC}}, z^{\mathrm{MC}}, \phi)}{\partial \Phi_{(+1)}} \right| \frac{\alpha_{\mathrm{S}}}{t^{\mathrm{MC}}} P(z^{\mathrm{MC}}) B$$

Kinematics and color

- Assignment of the splitting type (ISR from leg 1 or 2, FSR from massive or massless leg)
- Assignment if color flow and color partner of the splitting parton (MC scales and variables may depend on it)

Achieved in a way completely independent of the process and of the particle multiplicity

Variable definition

- Evolution variables t^{MC}, z^{MC} are MC specific

Status

Status of the matching 1: aMC@NLO/HERWIG

HERWIG6: complete

- Validated for all kinds of emission types against MC@NLO4.0
  Full agreement: not trivial since the structure of the codes is completely different
- Moved to new more complex phenomenology:
  - $pp \to t\bar{t}H \ / \ t\bar{t}A + X$
  - $pp \to b\bar{b}(W^{\pm *})/b\bar{b}(Z^{*}) \to b\bar{b}ll + X$
  - $p\bar{p} \to jj(W^{+}) \to jj\bar{l}\nu + X$
  - $pp \to 2(\gamma^{*}/Z^{*}) \to e^{+}e^{-}\mu^{+}\mu^{-} + X$

[Frederix, Frixione, Hirschi, Maltoni, Pittau, Torrielli, 1104.5613, 1106.6019, 1110.4783, 1110.5502]

HERWIG++: almost complete

- All formulae implemented. Validated against MC@NLO4.0 for ISR processes. Full agreement
- Currently under validation against MC@NLO4.0 and aMC@NLO/HERWIG6 for more complicated processes

Status of the matching 2: aMC@NLO/PYTHIA

PYHTIA6 (virtuality-ordered): complete

- Validated against the few available MC@NLO/PYTHIA ISR processes. Full agreement
- Produced new results: first time aMC@NLO/PYTHIA with FSR
- The implementation is at the same level as aMC@NLO/HERWIG6, so to date, what can be produced with aMC@NLO/HERWIG6 can be as well produced with aMC@NLO/PYTHIA6. There is just less experience

PYTHIA8: incomplete

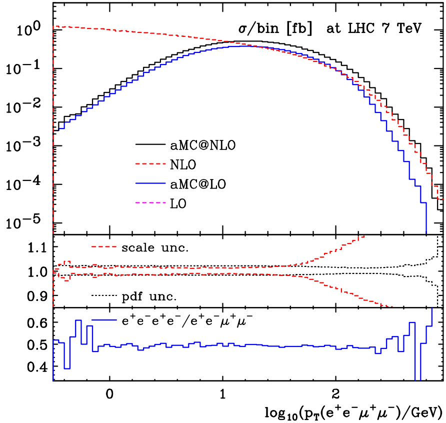
- All formulae implemented, but no available MC@NLO benchmark for comparison. Need for extensive testing and validation

Recent developments in the program

- Validation of processes with divergent Born
  - Predictions in the 'signal' region independent of the generation-level cuts
  - First time for MC@NLO with massless final state partons
- Automatic evaluation of scale and PDF uncertainties
  - Short-distance cross section (at the LO-, NLO-, and MC@NLO-level) can be written as a linear combination of scale- and PDF-dependent terms times coefficients independent of both
  - The evaluation of these coefficients is the time-consuming part of the computation
  - Save these coefficients once in the event file, and evaluate scale and PDF dependence by reweighting the existing events
  - This allows to generate events only once, and to obtain theoretical uncertainties at no extra time and CPU cost

An example

Process: $pp \to (Z/\gamma^*)(Z/\gamma^*) \to l^+ l^- l^{(\prime)+} l^{(\prime)-}$, 1110.5502



- aMC@NLO = MC in shape at small p_T, = NLO at high p_T
- Smaller scale dependence at low p_T than at high p_T: shower brings the NLO-like scale dependence at intermediate p_T
- Statistical fluctuations are correlated since the event sample is unique: smooth uncertainty band

Plans

Plans for the near future

Code developments

- Adapt the code for MadGraph5 and, after that, make it public
- This will entail relevant improvements in terms of
  - Capabilities (many current limitations will be trivially removed)
  - Speed
  - User-friendliness

Matching

- Extensively test the new matching implementations, especially HERWIG++ and PYTHIA8

Thank you

http://amcatnlo.cern.ch