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MC@NLO: recent activity and future plans

TeV4LHC workshop, CERN, 29/4/2005

SF & Bryan Webber, JHEP 0206(2002)029 [hep-ph/0204244]
SF, Paolo Nason & Bryan Webber, JHEP 0308(2003)007 [hep-ph/0305252]

Many thanks to B. Quayle, V. Drollinger, and C. Oleari

MC@NLO 2.31 [hep-ph/0402116]

IPROC	Process
–1350–IL	$H_1H_2 \to (Z/\gamma^* \to) l_{\rm IL}\bar{l}_{\rm IL} + X$
–1360–IL	$H_1H_2 \to (Z \to) l_{\rm IL}\bar{l}_{\rm IL} + X$
–1370–IL	$H_1H_2 \to (\gamma^* \to) l_{\rm IL}\bar{l}_{\rm IL} + X$
–1460–IL	$H_1H_2 \to (W^+ \to) l^+_{\rm IL}\nu_{\rm IL} + X$
–1470–IL	$H_1H_2 \to (W^- \to) l^-_{\rm IL}\bar{\nu}_{\rm IL} + X$
–1396	$H_1H_2 \to \gamma^*(\to \sum_i f_i\bar{f}_i) + X$
–1397	$H_1H_2 \to Z^0 + X$
–1497	$H_1H_2 \to W^+ + X$
–1498	$H_1H_2 \to W^- + X$
–1600–ID	$H_1H_2 \to H^0 + X$
–1705	$H_1H_2 \to b\bar{b} + X$
–1706	$H_1H_2 \to t\bar{t} + X$
–2850	$H_1H_2 \to W^+W^- + X$
–2860	$H_1H_2 \to Z^0Z^0 + X$
–2870	$H_1H_2 \to W^+Z^0 + X$
–2880	$H_1H_2 \to W^-Z^0 + X$

- Works identically to HERWIG: the very same analysis routines can be used
- Reads shower initial conditions from an event file (as in ME corrections)
- Exploits Les Houches accord for process information and common blocks
- Features a self contained library of PDFs with old and new sets alike
- I understand that LHAPDF can be linked via LHAGLUE

What's going on

No major theoretical work: the MC@NLO formalism is as defined in the original paper (no need to change it – the implementation of final-state collinear singularities poses no problems, as sometimes incorrectly claimed)

We figured out a few tricks with impact on efficiency

- Alternative way of implementing spin correlations
- Cuts at the level of hard matrix elements

We made progress with the implementation of processes

- Format of hard event files will be different from v3.1 (should be irrelevant to the user, since these files are non-physical)
- WH and ZH with full spin correlations (with C. Oleari and V. del Duca)
- Spin correlations added to W^+W^- production
- Single top at advanced stage (with E. Laenen and P. Motylinski)

Spin correlations

First compute the amplitude for the process

$$a + b \longrightarrow (P \longrightarrow) d_1 + \cdots + d_n + X \qquad \text{Full ME}$$

Then that for

$$a + b \longrightarrow P + X \qquad \text{Undecayed ME}$$

Finally, go to the rest frame of P, and perform the decay

$$P \longrightarrow d_1 + \cdots + d_n \qquad \text{Decay}$$

> If the two computations give different predictions for any observable associated with any of the decay products d_i, then we have spin correlations. In general, this occurs when P has non zero spin

When one or more non-zero spin particles decay, we must therefore

- Use the full ME's
- Alternatively, compute the undecayed ME $\otimes$ decay chain for fixed polarizations of P

Spin correlations in MC@NLO

The computation of undecayed ME's for fixed polarizations is quite awkward. When two or more particles decay, a tensorial structure emerges

$\Longrightarrow$ Use full ME's. It's just another production process, which we know how to deal with

A couple of things to keep in mind

- ME must be integrated and unweighted
- The integration time increases and the unweighting efficiency decreases by increasing the number of final-state particles

One more things to keep in mind

- A young theorist will *never* get a job for doing this, in spite of (or perhaps because of) the many thanks he/she will receive from experimenters

And as far as I'm concerned

- I plead guilty: there are actually more exciting things to do...

The current situation

In spite of the previous complaints, all of the processes with spin correlations implemented so far in MC@NLO follow the "Full ME" strategy

- Single-V production ($V = W, Z, \gamma, Z/\gamma$)
- VH production ($V = W, Z$)

Remind that

- There are no spin correlations in Higgs production
  $H^0 \to W(\to l\nu)W(\to l\nu)$ is treated correctly!!

So the spin correlations left to be implemented are for

- $t\bar{t}$, V_1V_2 production

Final states are very complicated here, and it's unlikely we'd be able to achieve the usual unweighting efficiency ($\sim 30-50\%$) by implementing the "Full ME" strategy

■ This is a good motivation to try and find an alternative to the "Full ME" strategy

Hit-and-miss

Whatever the behaviours of the decay products, the momenta of the decaying particles will not change

$\Longrightarrow$ The full ME's must be bounded from above by the undecayed ME's, times a suitable constant. Find this bound and do hit-and-miss

Advantages

- Only the undecayed ME's will be integrated: no further loss of time
- Unweighting is a two-step procedure: first get the P's momenta, then the d's momenta with hit-and-miss. Decay ME's have no spikes, and thus the hit-and-miss only marginally degrades efficiency

So far, we only studied the decays of vector bosons (i.e. not of top)

$$\frac{d\sigma_{l_1\bar{l}_1\ldots l_n\bar{l}_n}}{d\Phi_{2n+k}} \leq \left(\prod_{i=1}^{n} \frac{2\,F_{V_i}^2\,(V_{V_i l_i} + A_{V_i l_i})^2}{\Gamma_i^2}\right) \frac{d\sigma_{V_1\ldots V_n}}{d\Phi_{n+k}}$$

$$-iF_V\gamma^\mu\left(V_{Vl} - A_{Vl}\gamma_5\right) \qquad \longleftarrow \qquad V l\bar{l} \text{ vertex}$$

This bound saturates!

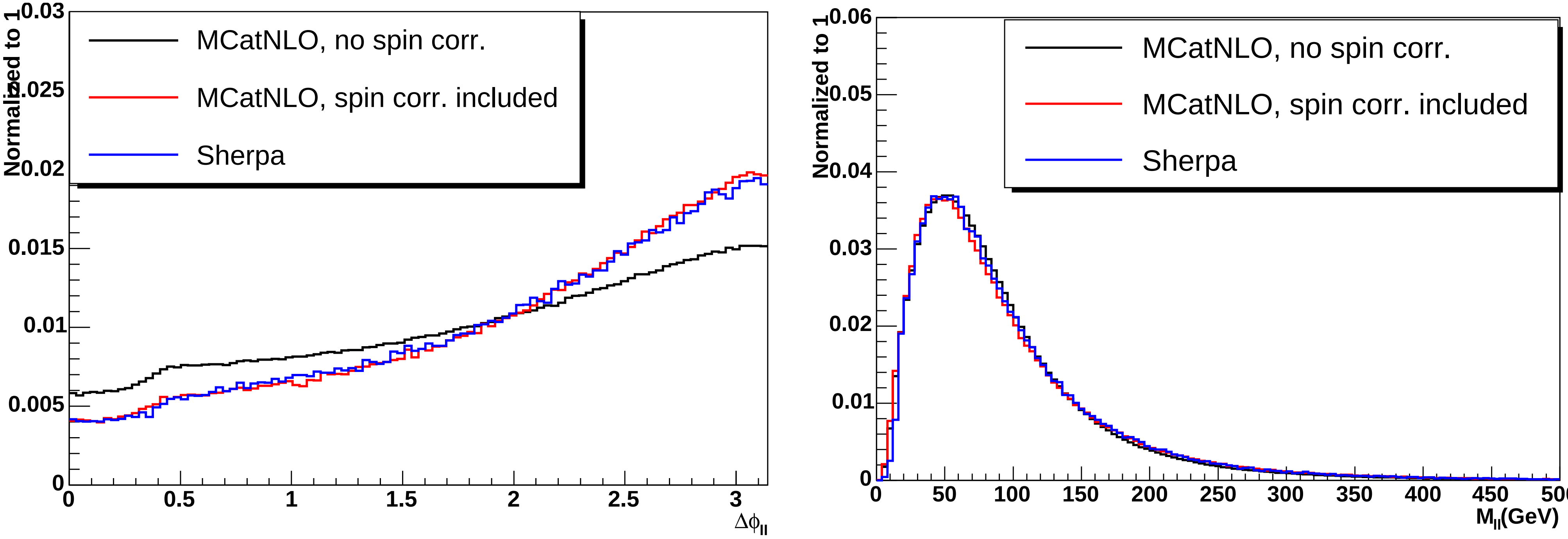
Implementation

The previous bound applies only to positive-definite quantities, which is not the case for NLO computations. It also applies to those spin-correlation effects that factorize the (fully decayed) Born

The bottom line: spin correlations can't be implemented to full NLO accuracy in MC@NLO *using hit-and-miss*. Non-factorizable effects are however expected to be small

- Regardless of the size of non-factorizable effects, MC@NLO with hit-and-miss is better than standard MC's for spin correlations
- Off-shell effects can also be taken into account (we still have only doubly-resonant diagrams)
- Implemented for W^+W^- production, and tested against MCFM: no difference seen
- The time spent in hit-and-miss unweighting is negligible wrt primary unweighting

Results for W^+W^-

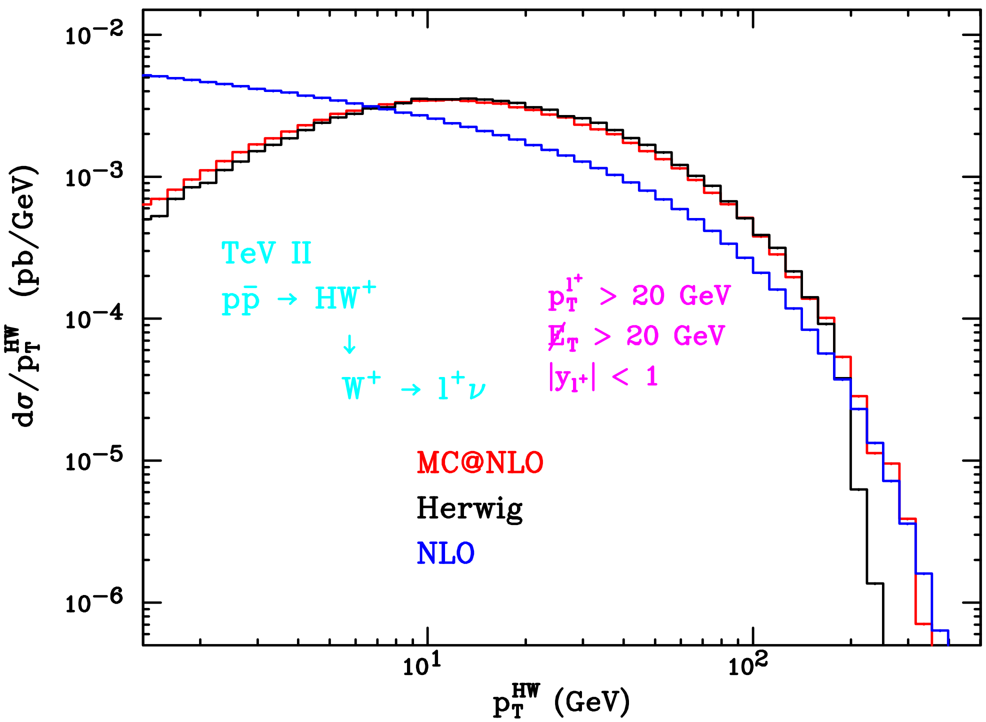


Plots: B. Quayle (preliminary)

- Virtual effects appear to be unimportant (apart from normalization)
- The effect of spin correlations is strictly dependent on the observable
- W^+W^- already used by ATLAS and CMS, official release with v3.1 (next month?)

Thanks to Bill Quayle and Volker Drollinger for testing a preliminary version

WH and ZH production



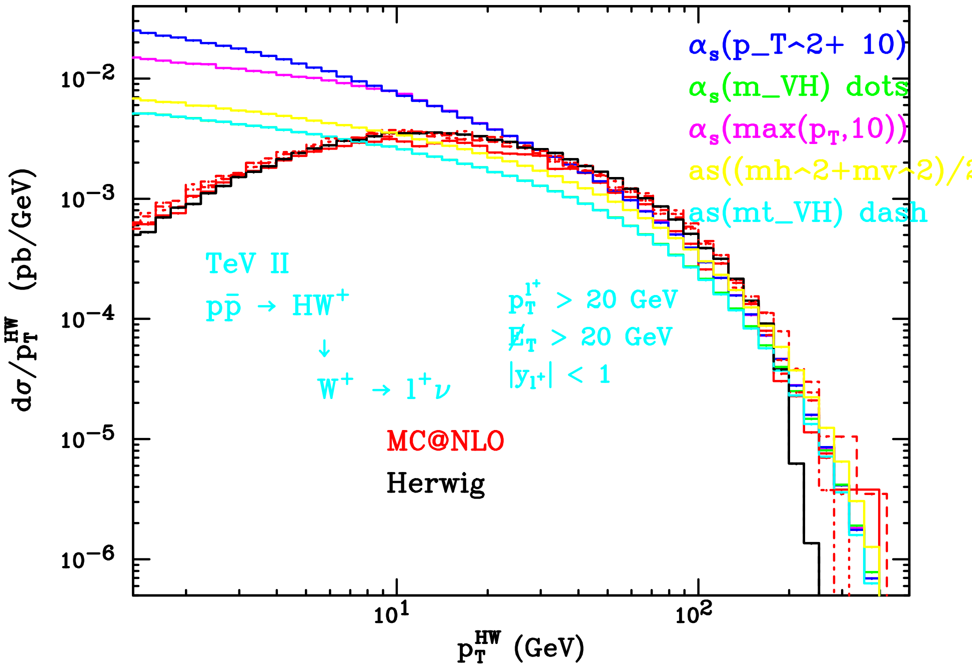
Plot: C. Oleari (preliminary)

- With C. Oleari, V. del Duca
- All matrix elements have been re-computed from scratch
- This is a warm-up exercise for VBF, which is a much more complicated case
- The construction of the pure NLO code took about 1.5 months, that of MC@NLO *two days*

♦ These processes will be released with v3.1

♦ The lenghty part of the game is the construction of a NLO code $\Longrightarrow$ When "one process per type" will be available in MC@NLO, implementation of new processes should be faster than now (we are not there yet)

MC@NLO versus NLO



Plot: C. Oleari (preliminary)

- The difference between MC@NLO and NLO is not small for moderate $p_T(WH)$
- This effect has been seen elsewhere in matched computations (also with standard analytic techniques)
- May be an artifact of the scale chosen?

♦ For this specific observable, $m_T(WH)$ is not an ideal choice at NLO

♦ When many different choices of scale are explored, huge variations in NLO, no changes in MC@NLO $\Longrightarrow$ A spectacular proof of the benefits of matched computations

Efficiency in Monte Carlo simulation

Suppose one is interested in jets with $p_T^{(jet)} > 1$ TeV at the LHC

- Straightforward solution: run jet production, and event by event reconstruct the jets and impose the $p_T^{(jet)} > 1$ TeV cut

The computer will spend most of its time doing nothing, since only about 1 event in 10^5 will pass the cut. There's nothing wrong, it is just terribly inefficient

- A better solution: run jet production by requiring $p_T > p_T^{(min)}$ at the level of primary partons (hard cut), and still impose $p_T^{(jet)} > 1$ TeV for each event

Clearly, this is not an exact solution, *which does not exist* owing to the complexity of the final states produced by MC's. Thus:

The parameter $p_T^{(min)}$ must be chosen as large as possible to maximize the efficiency, and yet avoiding any bias on the physics observables

- The problem in MC@NLO: the hard events have two different kinematics

Hard cuts in MC@NLO

MC@NLO without hard cuts

$$\mathcal{F}_{\text{MC@NLO}} = \sum_{ab} \int d\phi \, f_a \otimes f_b \otimes \Bigg[\mathcal{F}_{\text{MC}}^{(2\to3)} \left(\mathcal{M}_{ab}^{(r)} - \mathcal{M}_{ab}^{(\text{MC})} \right) + \mathcal{F}_{\text{MC}}^{(2\to2)} \left(\mathcal{M}_{ab}^{(b,v,c)} - \mathcal{M}_{ab}^{(c.t.)} + \mathcal{M}_{ab}^{(\text{MC})} \right) \Bigg]$$

MC@NLO with hard cuts

$$\mathcal{F}_{\text{MC@NLO}} = \sum_{ab} \int d\phi \, f_a \otimes f_b \otimes \Bigg[\mathcal{F}_{\text{MC}}^{(2\to3)} \left(\Theta(2\to3) \mathcal{M}_{ab}^{(r)} - \Theta(2\to2) \mathcal{M}_{ab}^{(\text{MC})} \right) + \mathcal{F}_{\text{MC}}^{(2\to2)} \Theta(2\to2) \left(\mathcal{M}_{ab}^{(b,v,c)} - \mathcal{M}_{ab}^{(c.t.)} + \mathcal{M}_{ab}^{(\text{MC})} \right) \Bigg]$$

- Local cancellation of singularities is preserved
- All the necessary formulae have been worked out analytically
- First implementation in $b\bar{b}$ production, but unlikely in v3.1

Single top production

I don't have physics results to show yet

- With E. Laenen and P. Motylinski
- We played around a bit with the subtraction formalism (Frixione, Kunszt, Signer) upon which MC@NLO is based, to have more flexibility in reducing negative weights (Θ functions have been replaced with smooth functions)
- We will start with s- and t-channels (i.e., no W production), without spin correlations
- NLO code completed on 26/4/05 (perhaps still minor differences wrt ZTOP). We only have to compute a jacobian to go to MC@NLO
- We will use this experience when implementing dijet production

Thanks to Joey Huston for supporting me at HCP2004, where this project was started

Event file

The general scheme of MC@NLO is as follows

- NLO code: integrates and unweights the matrix elements
- Event file: a list of hard events, i.e. the kinematics configurations emerging from hard subprocesses (typically, $2 \to 2$ and $2 \to 3$)
- MC code: Herwig, which reads the hard events and showers them

For each particle i in each hard event, the event files contains 4 `real*8` numbers

$$p_i^{(x)}, \quad p_i^{(y)}, \quad p_i^{(z)}, \quad E_i \qquad \text{up to v2.31}$$

These will now be replaced by

$$p_i^{(x)}, \quad p_i^{(y)}, \quad p_i^{(z)}, \quad m_i \qquad \text{from v3.1}$$

The event file contains unphysical events, that must be processes by Herwig to acquire a meaning. Make sure you don't use some old file with v3.1 (anyhow, the code has a protection against this)

Outlook

- Tutorial on MC@NLO at Les Houches (dates not fixed yet, but definitely before 11/5)
- $b\bar{b}$ with hard cuts, then other processes if OK
- Single-t production
- Spin correlations for ZZ, WZ, $t\bar{t}$ (presumably in this order)
- Dijets (start in Les Houches?)
- CKKW $\longrightarrow$ $W + n$ jets ?

`http://www.hep.phy.cam.ac.uk/theory/webber/MCatNLO`