Stefano Frixione

Update on MC@NLO

MCWS, Frascati, 24/10/2006

SF & B. Webber, JHEP 0206(2002)029 [hep-ph/0204244]
SF, P. Nason & B. Webber, JHEP 0308(2003)007 [hep-ph/0305252]
SF, E. Laenen, P. Motylinski & B. Webber, JHEP 0603(2006)092 [hep-ph/0512250]

MC@NLO 3.2 [hep-ph/0601192]

IPROC	IV	IL$_1$	IL$_2$	Spin	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				×	$H_1H_2 \to t\bar{t} + X$
–2000–IC				×	$H_1H_2 \to t/\bar{t} + X$
–2001–IC				×	$H_1H_2 \to \bar{t} + X$
–2004–IC				×	$H_1H_2 \to t + X$
–2600–ID	1	7		×	$H_1H_2 \to H^0W^+ + X$
–2600–ID	1	i		✓	$H_1H_2 \to H^0(W^+ \to) l^+_i\nu_i + X$
–2600–ID	-1	7		×	$H_1H_2 \to H^0W^- + X$
–2600–ID	-1	i		✓	$H_1H_2 \to H^0(W^- \to) l^-_i\bar{\nu}_i + X$
–2700–ID	0	7		×	$H_1H_2 \to H^0Z + X$
–2700–ID	0	i		✓	$H_1H_2 \to H^0(Z \to) l_i\bar{l}_i + X$
–2850		7	7	×	$H_1H_2 \to W^+W^- + X$
–2850		i	j	✓	$H_1H_2 \to (W^+ \to) l^+_i\nu_i(W^- \to) l^-_j\bar{\nu}_j + X$
–2860		7	7	×	$H_1H_2 \to Z^0Z^0 + X$
–2870		7	7	×	$H_1H_2 \to W^+Z^0 + X$
–2880		7	7	×	$H_1H_2 \to W^-Z^0 + X$

Recent activities:

- Spin correlations in $t\bar{t}$ and single-top production
- Wt channel for single-top production
- Improvements to Higgs production
- Interface to HERWIG++ (ISR only)
- Dijet production

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

Spin correlations: definitions

In the production process

$$a + b \longrightarrow P(\longrightarrow d_1 + \cdots + d_n) + X$$

there are

- *Decay* s.c.: if there is a non-trivial dependence on $(d_i \cdot d_j)$
- *Production* s.c.: if there is a non-trivial dependence on $(d_i \cdot a)$, $(d_i \cdot b)$, $(d_i \cdot X)$

MC@NLO always implements decay s.c. through HERWIG

Production s.c. are available in v3.2 for dilepton, H, WH, ZH, W^+W^- processes

Production s.c. are now also included in $t\bar{t}$ and single-top processes

Production spin correlations

The standard way: compute the matrix elements for

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

This full-ME strategy is implemented in MC@NLO for:

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

For large-multiplicity final states this may not be convenient, since

- ME must be integrated and unweighted
- The integration time increases and the unweighting efficiency decreases (for MC@NLO, typically ε=10–40%) by increasing the number of final-state particles

For W^+W^-, $t\bar{t}$ and t production we have implemented an alternative strategy: hit-and-miss

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

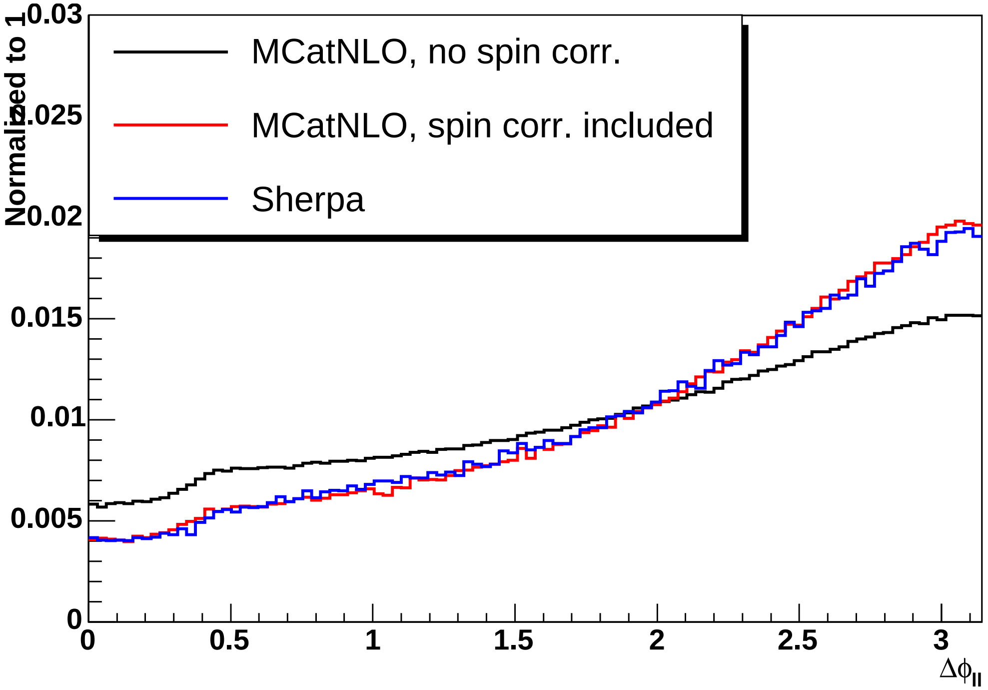
Vector bosons (tested and running)

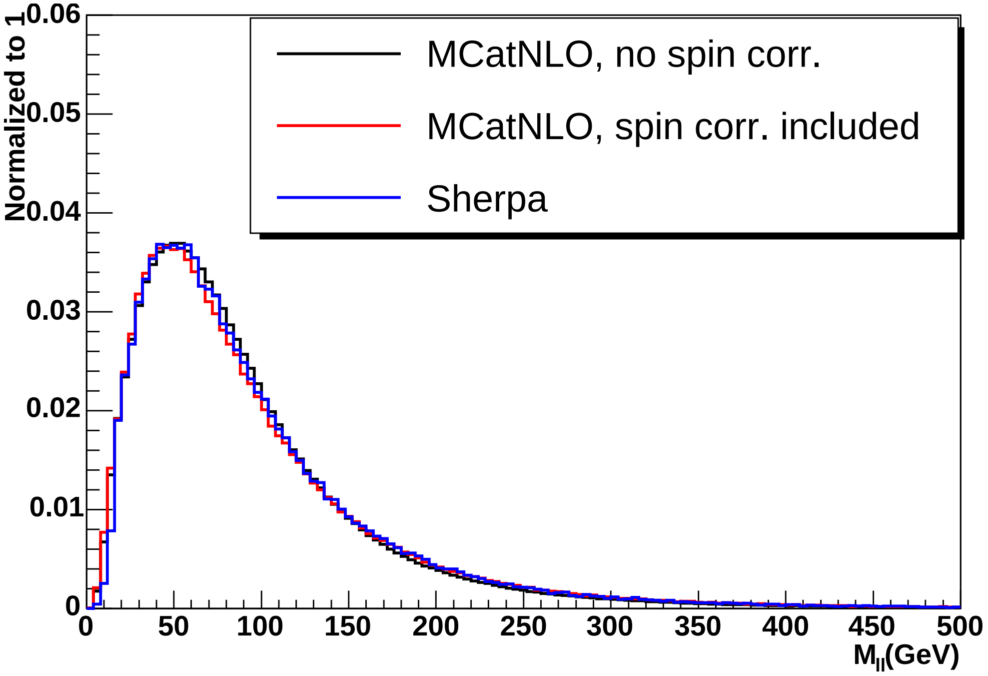
$$\frac{d\sigma_{l_1\bar{l}_1\ldots l_n\bar{l}_n}}{d\Phi_{2n+k}} \leq \left(\prod_{i=1}^{n} \frac{2\,F_{V_i}^2\,(V_{V_i l_i}+A_{V_i l_i})^2}{\Gamma_{V_i}^2}\right) \frac{d\sigma_{V_1\ldots V_n}}{d\Phi_{n+k}}$$

Top (tests done – not yet released)

$$\frac{d\sigma_{b_1 l_1 \nu_1 \ldots b_n l_n \nu_n}}{d\Phi_{3n+k}} \leq \left(\prod_{i=1}^{n} \frac{4 g_W^4 \left|V_{tb}\right|^2 (k_{t_i}\cdot k_{l_i})(k_{b_i}\cdot k_{\nu_i})}{\Big((q_i^2-m_W^2)^2+(m_W\Gamma_W)^2\Big) m_t^2\Gamma_t^2}\right) \frac{d\sigma_{t_1\ldots t_n}}{d\Phi_{n+k}}$$

Results for W^+W^-



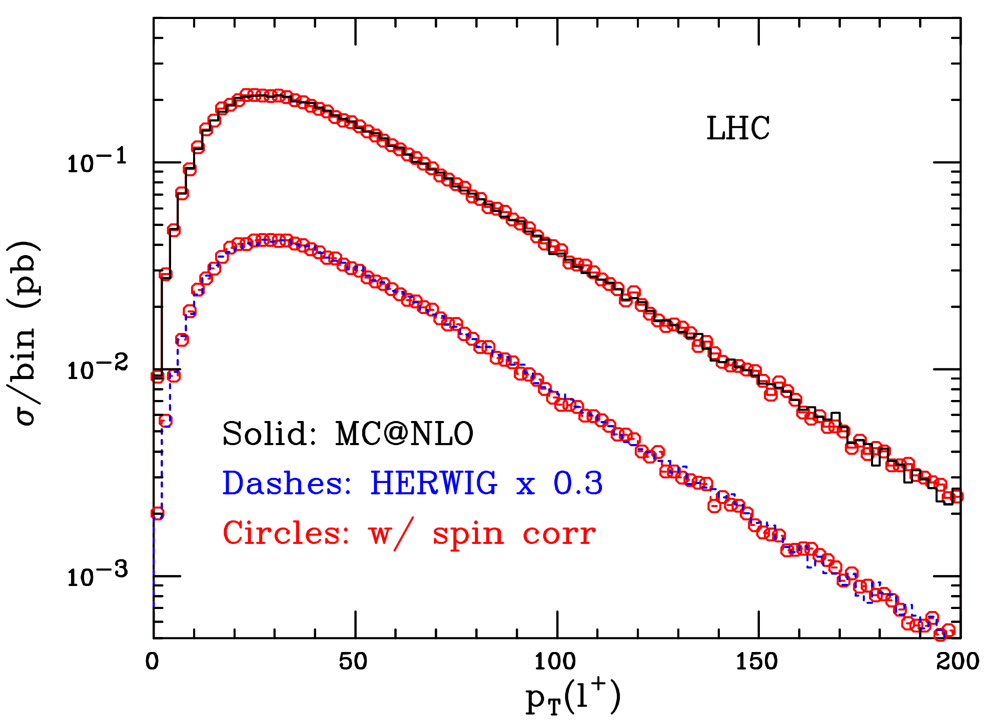


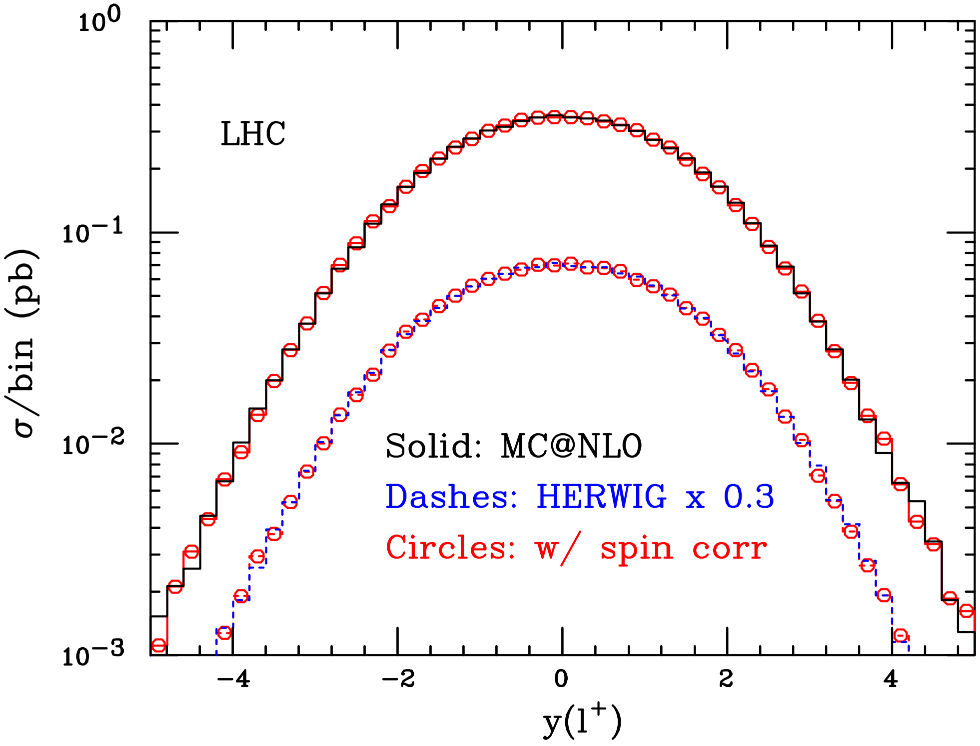
Plots: B. Quayle

- Virtual effects appear to be unimportant
- The effect of spin correlations is strictly dependent on the observable
- Released with v3.1

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

Spin correlations in $t\bar{t}$ I

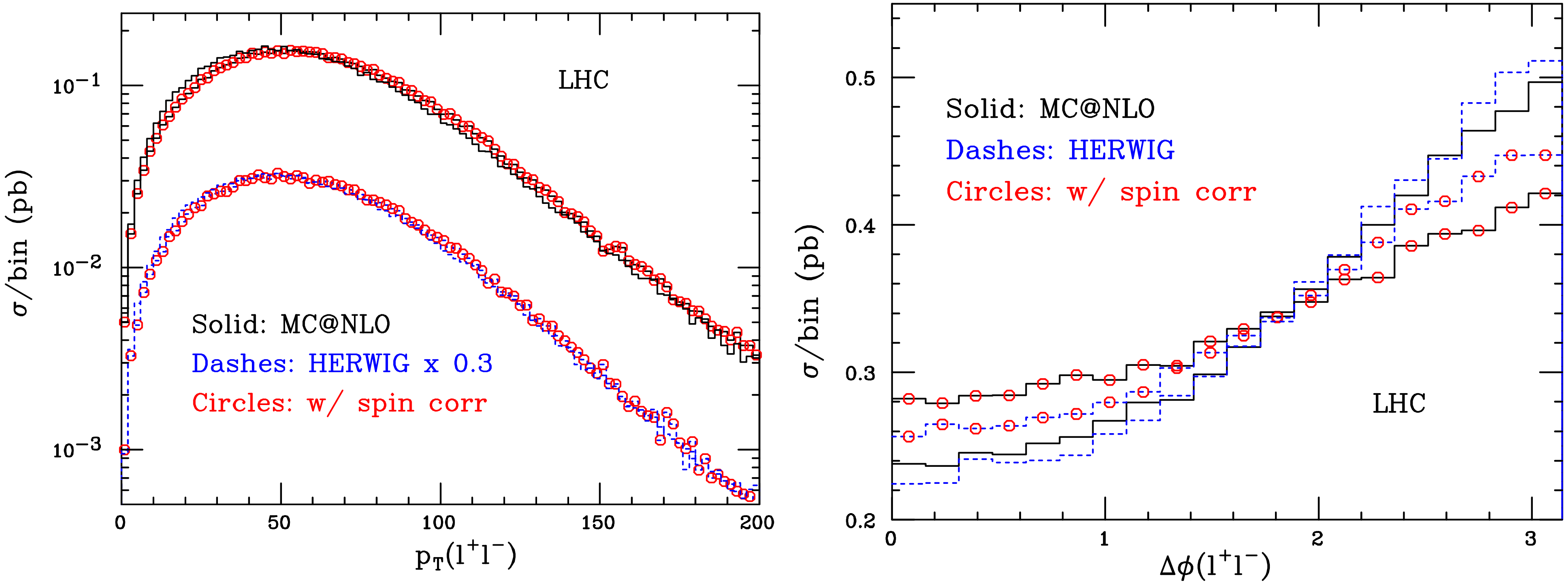




- All single-inclusive distributions have this pattern
- Almost all correlations display a similar behaviour

“Large” is here confortably small. Will this stay true after acceptance cuts?

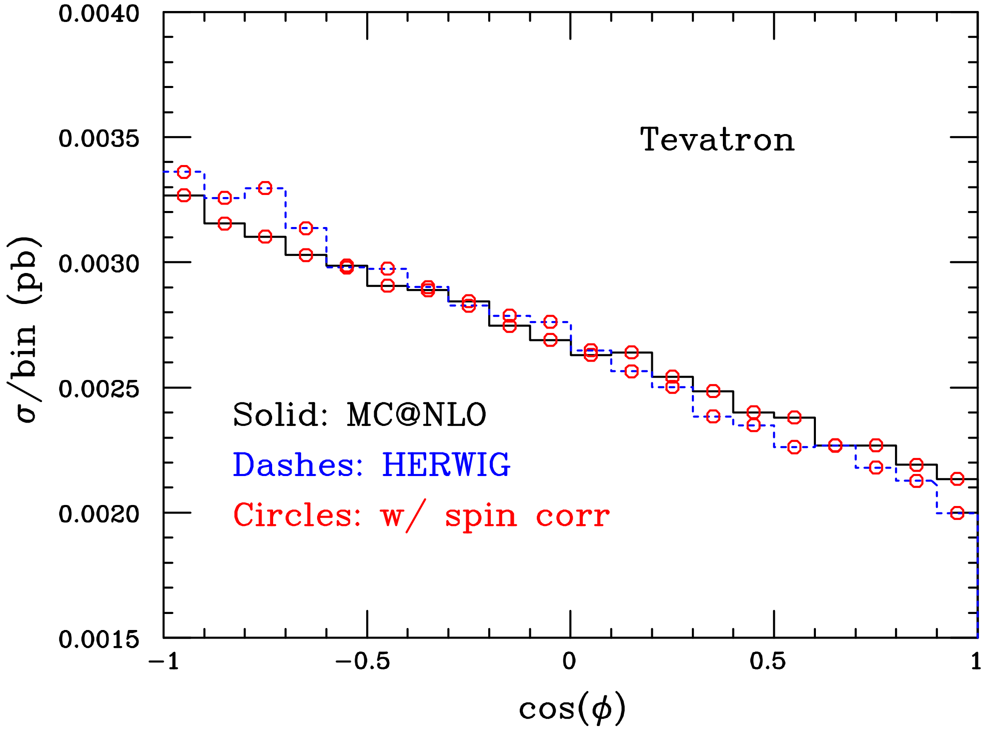
Spin correlations in $t\bar{t}$ II

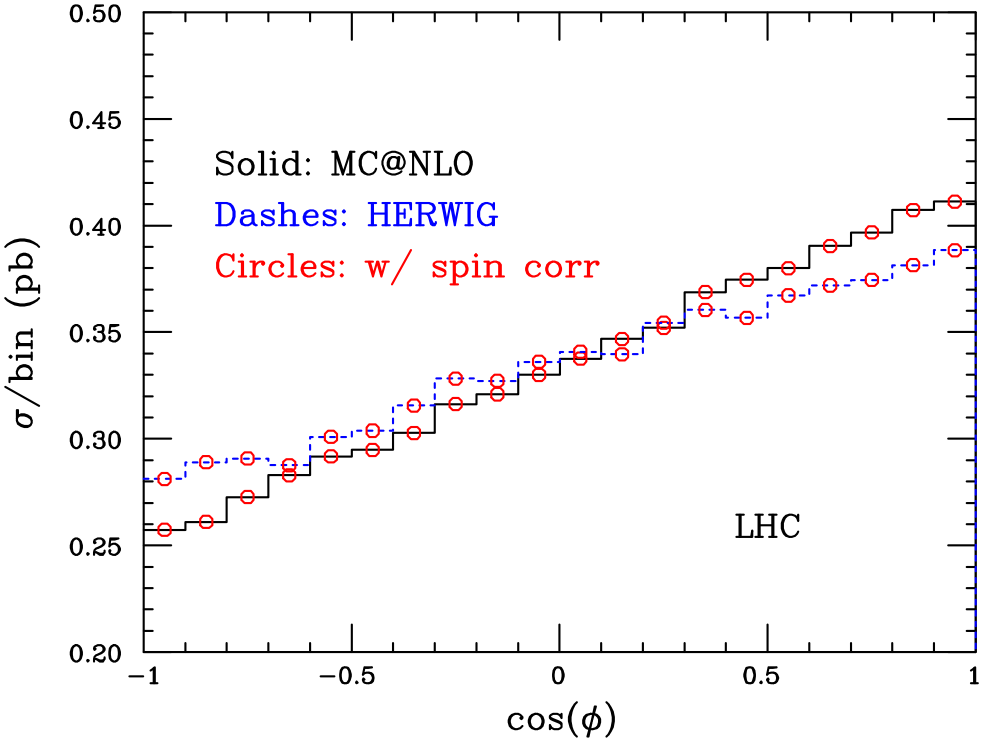


- These are the only cases in which I've found non-negligible effects
- Spin correlations are not the whole story: for $\Delta\phi$, NLO effects are clearly visible

Observables can be designed to specifically target spin correlations ⟶

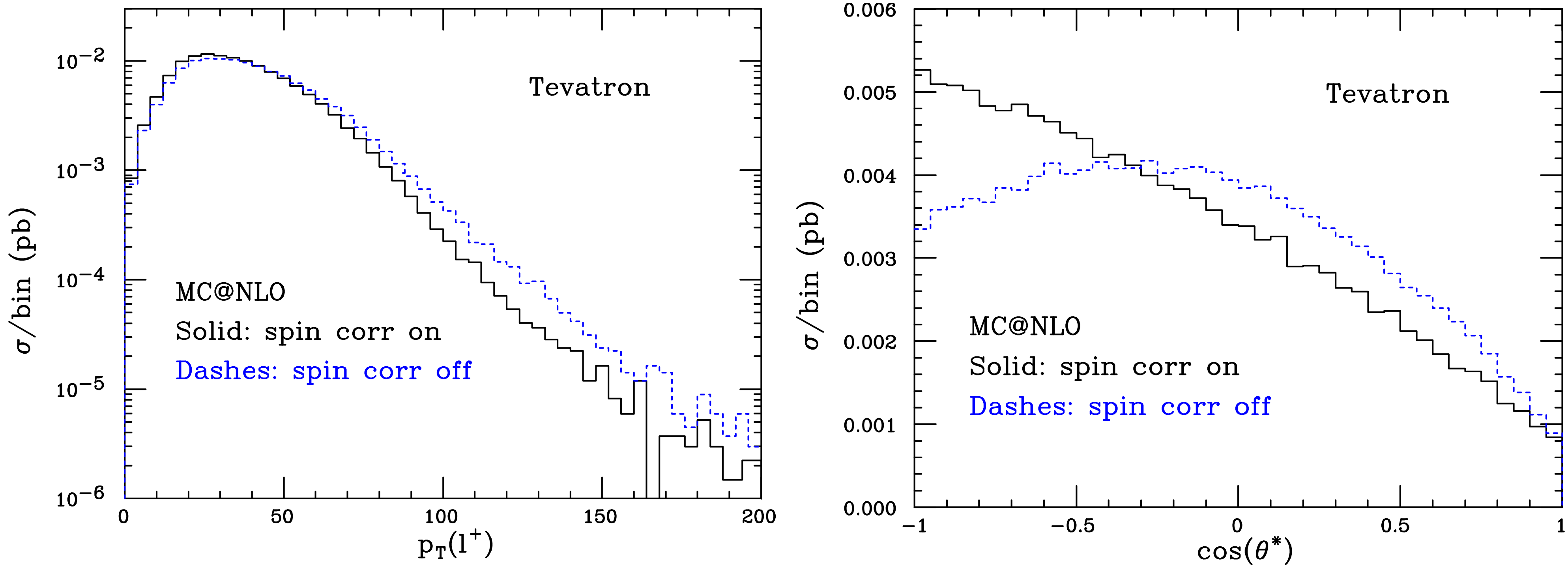
Spin correlations in $t\bar{t}$ III





- NLO corrections again visible and in agreement with parton-level fixed-order results
- These kinds of observables are difficult to define in practice: need to know the rest frames of the $t\bar{t}$ system, of the t and of the $\bar{t}$

Spin correlations in single top



- For single-top, “large” is large indeed: the production proceeds through W exchange which effectively polarizes the top
- The effects are visible in single-inclusive observables (at variance with $t\bar{t}$)

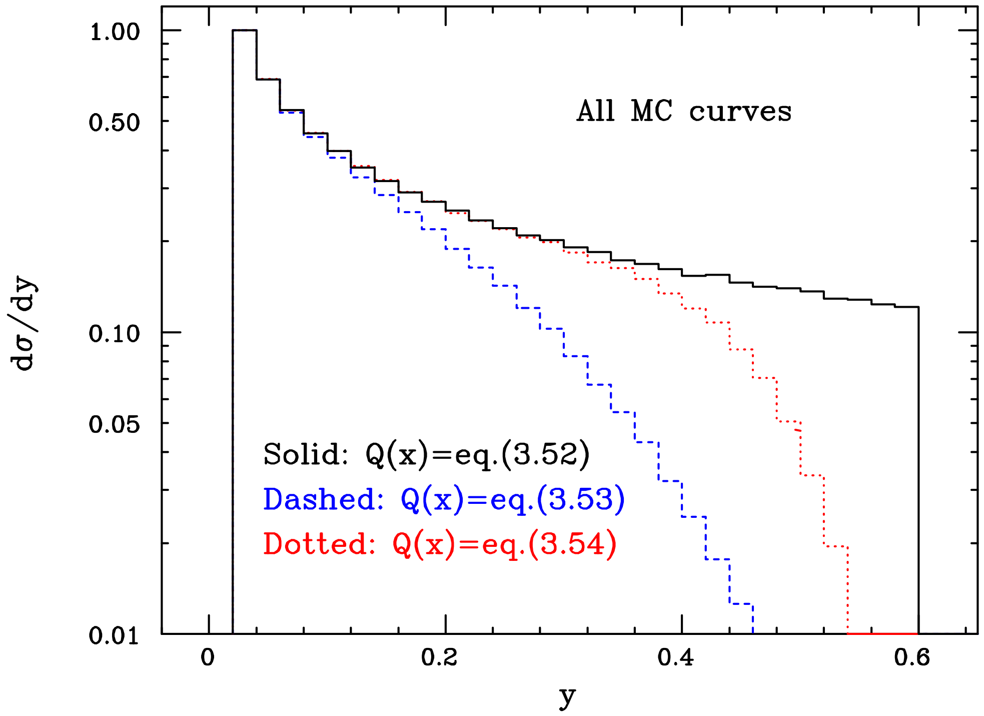
MC@NLO: reminder

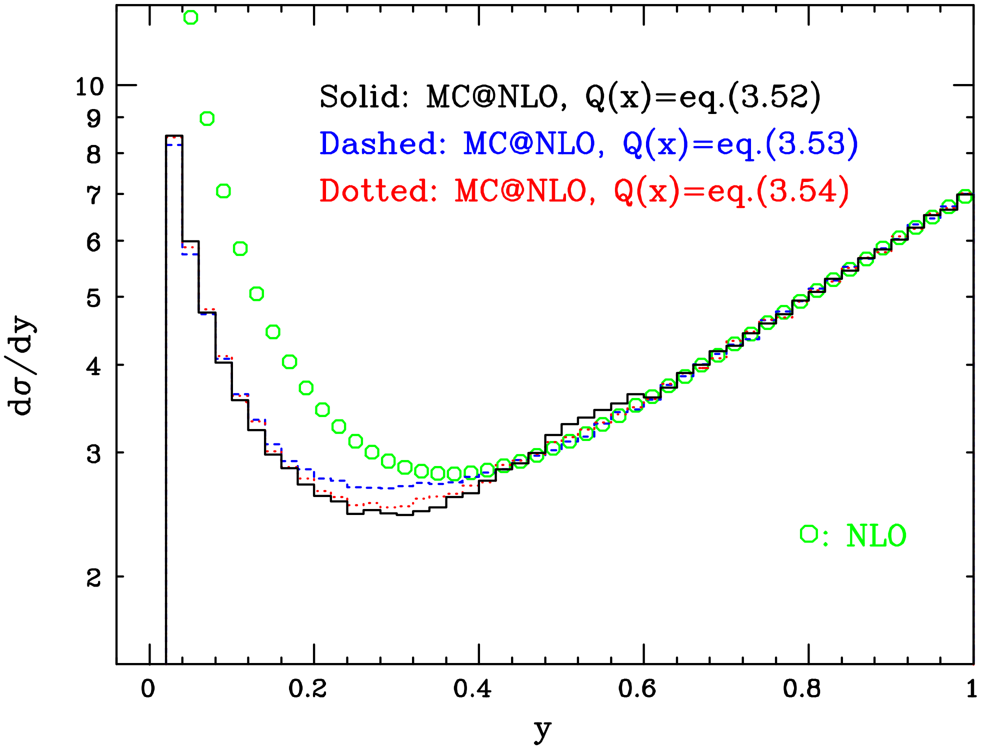
- MC@NLO generating functional (simplified notation)

$$\begin{aligned}\mathcal{F}_{\text{MC@NLO}} &= \int_0^1 dx \Bigg[\mathcal{F}_{\text{MC}}(S,x)\frac{\alpha_S[R(x) - BQ(x)]}{x} \\ &+ \mathcal{F}_{\text{MC}}(S,0)\left(B + \alpha_S V + \frac{\alpha_S B[Q(x)-1]}{x}\right)\Bigg]\end{aligned}$$

- The form of $Q(x)$ is dictated by the parton shower MC@NLO is interfaced to. For HERWIG, it is a Θ function $\longrightarrow$ dead zone
- We may, however, replace the Θ function in HERWIG with a smoother function, in order to reduce border effects. This can be done easily *without* modifying the code
- This also allows one to study matching ambiguity
- Never done in practice so far, border effects being invisible

Results (for a toy model)



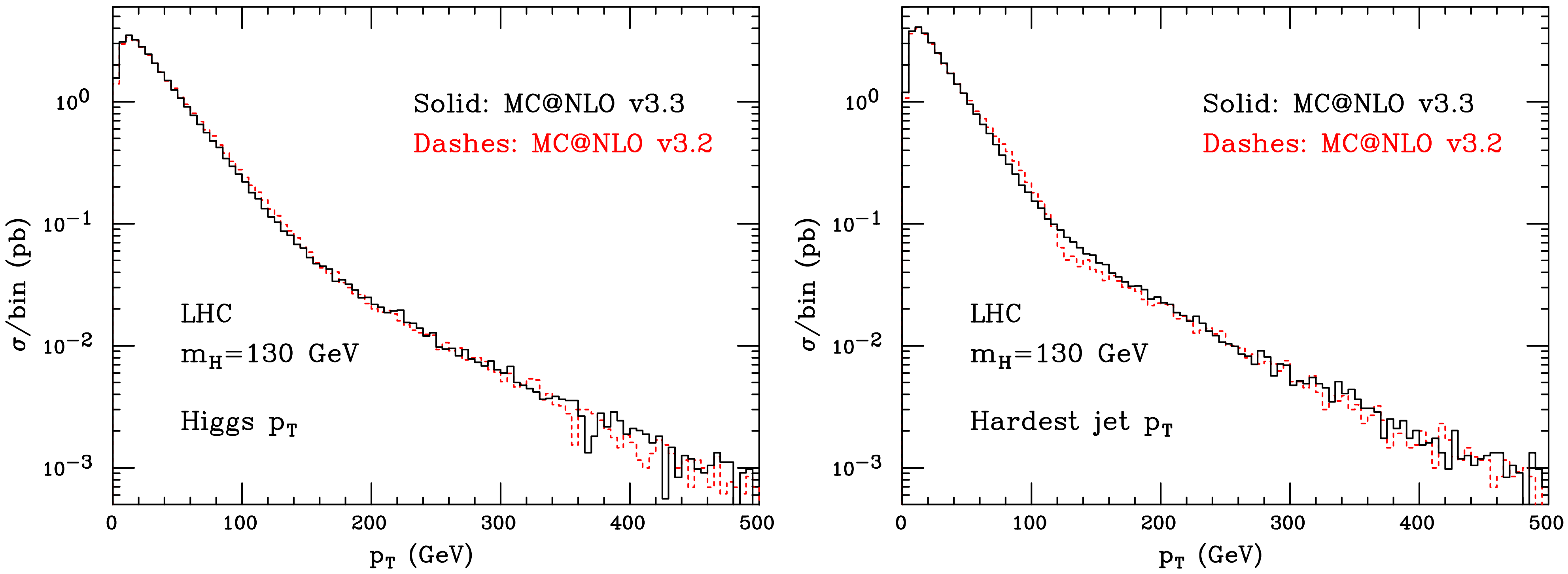


1. $Q(x) = \Theta(x_{dead} - x)$;
2. $Q(x) = \Theta(x_{dead} - x) G(x/x_{dead})$, with $\alpha = 1, \beta = 1, c = 1$;
3. $Q(x) = \Theta(x_{dead} - x) G(x/x_{dead})$, with $\alpha = 2, \beta = 1, c = 8$.

$$G(x) = \frac{c^2(1-x)^{2\beta}}{x^{2\alpha} + c^2(1-x)^{2\beta}}$$

- Very smooth transition across the dead zone border (good control beyond NLO)

Border effects in Higgs production



- Pointed out by the Wisconsin group (ATLAS)
- Affects hardest-jet p_T
- New version stops HERWIG shower at $\alpha m_H \leq p_T \leq m_H/\sqrt{2}$, with p_T generated according to a probability function $\mathcal{P}(\alpha m_H) = 1$, $\mathcal{P}(m_H/\sqrt{2}) = 0$
- This also allowed us to change the scale of α_S in the MC counterterms $\Longrightarrow$ negative weights went down to 5% (were 8%)

On MC@NLO code

Time for the inclusion of a new process is spent:

- 80% for the pure-NLO computation
- 15% for MC counterterms and LHI-related code
- 5% debugging

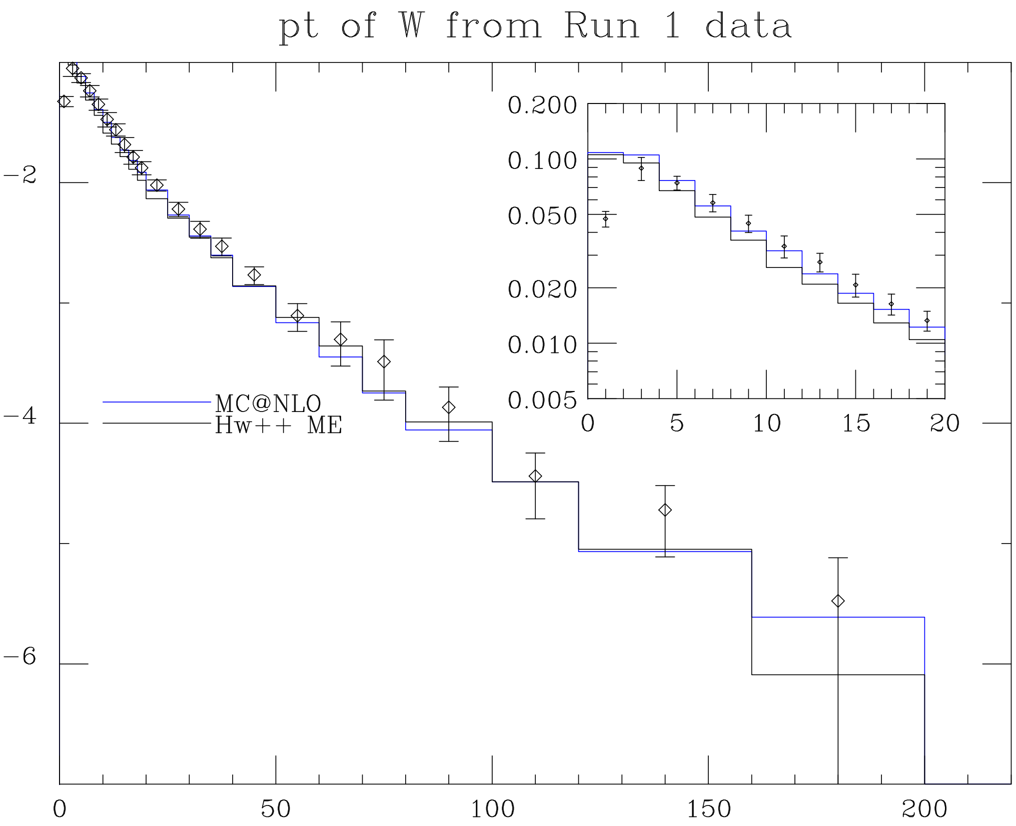
The structure of the MC counterterms is modular

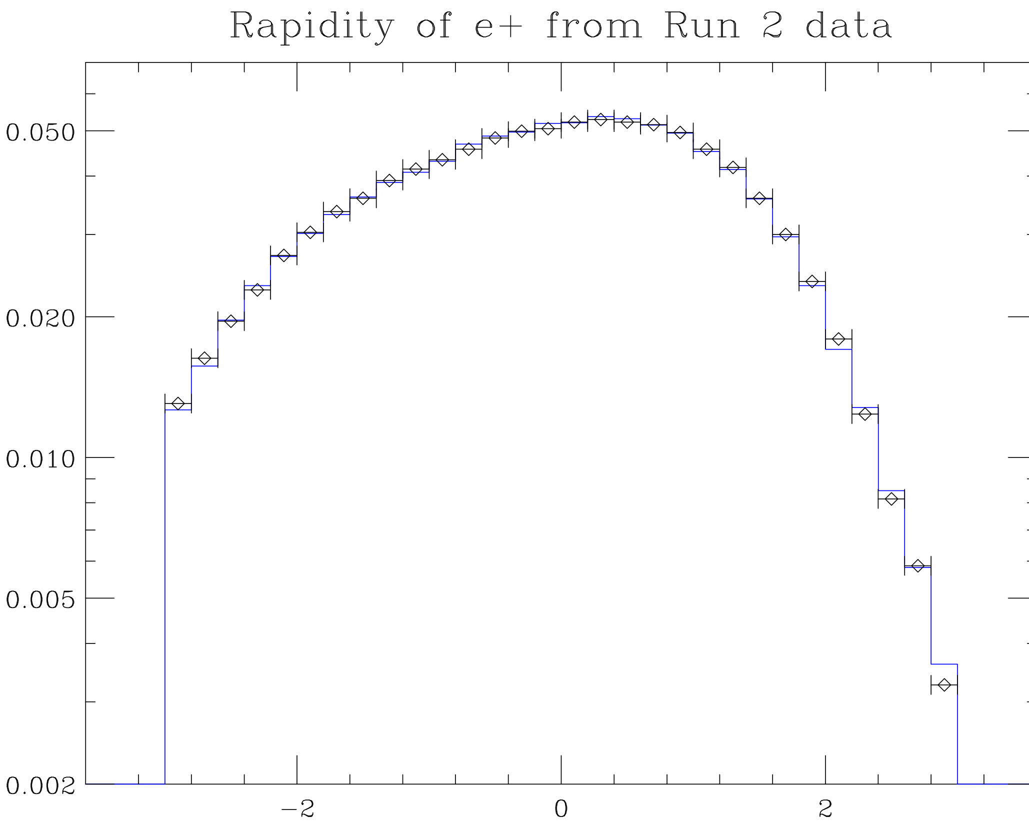
$$\mathcal{M}^{(\mathrm{MC})} = \mathcal{K}^{(\mathrm{MC})}\mathcal{M}^{(b)}$$

Kernels $\mathcal{K}^{(\mathrm{MC})}$ now fully worked out for HERWIG

- Work in progress (Seyi Latunde-Dada) on the computation of $\mathcal{K}^{(\mathrm{MC})}$ for HERWIG++. ISR now done

W production with MC@NLO/HERWIG++


pt of W from Run 1 data


Rapidity of e+ from Run 2 data

- We know that old-style ME corrections distort the p_T spectrum
- We see that by adding the full NLO MEs one improves the agreement to data
- This is without specific tuning. Also, it is not yet known how to include a k_T-kick into HERWIG++ (affects lowest-p_T bins)

Conclusions

- The addition of spin correlations (to be officially released with the next version) adds interesting features in top physics – we are beginning to study phenomenology implications
- We have seen in the case of Higgs production that by limiting MC radiation one has beneficial effects. Presumably will have an impact on jet shapes in $t\bar{t}$ production (to be tested soon)
- This is a very well known technique in matched computations based on analytical resummations
- HERWIG++ has started producing results. More will follow