Hardest radiation reweighting in POWHEG-W

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DY: precision

Several requests from the W mass WG. Name of the game: fit Z, predict W. Precision on the mass: 10 MeV. Can we achieve a 10 MeV precision on kinematic distributions?

One aspect: pdf uncertainty (discussed with Marteen Boonecamp):

- Tune MC parameters to fit p_T^Z with different PDF's
- Compute p_T^W with different PDF's and matching MC parameters
- Take envelope as error

Problems: in view of the high precision required, it would be desirable to do reweighting for PDF variation (and also for MC tunes ...)

POWHEG has a reweighting feature. Can we use it?

Not really for this. **POWHEG** formula:

$$d\sigma = \tilde{B}(\Phi_B)\exp\left[-\int_{p'_T > p_T} \frac{R(\Phi_B, \Phi'_{\rm rad})}{B(\Phi_B)} d\Phi'_{\rm rad}\right] \frac{R(\Phi_B, \Phi_{\rm rad})}{B(\Phi_B)} d\Phi_{\rm rad}$$

$$\tilde{B}(\Phi_B) = B(\Phi_B) + V(\Phi_B) + \int R(\Phi_B, \Phi_{\rm rad})\, d\Phi_{\rm rad}\,.$$

In essence: PDF reweighting applies to $\tilde{B}(\Phi_B)$, not to the rest
(for obvious reasons: PDF's enter non-linearly in the rest).
In other words: the rapidity distribution of the vector boson is reweighted;
The p_T distribution remains (almost) the same, up to normalization.

Can we remedy?

(Work in collaboration with A.Vicini)

Brief reminder of POWHEG formula (Webber,P.N.2012)

$$d\sigma = \tilde{B}(\Phi_B)\exp\left[-\int_{p_T'>p_T} \frac{R(\Phi_B,\Phi'_{\rm rad})}{B(\Phi_B)} d\Phi'_{\rm rad}\right]\frac{R(\Phi_B,\Phi_{\rm rad})}{B(\Phi_B)} d\Phi_{\rm rad}$$

$$\tilde{B}(\Phi_B) = B(\Phi_B) + V(\Phi_B) + \int R(\Phi_B,\Phi_{\rm rad})\, d\Phi_{\rm rad}\,.$$

- Φ_B: Born phase space for W: W rapidity and angles for decay
- $d\Phi_B\, d\Phi_{\rm rad}$: Real phase space, i.e. for $(W \to e\nu) + g \text{ or } q$
- B, R, V Born, Real and Virtual cross sections
- p_T is p_T of W

$$\int \exp\left[-\int_{p_T'>p_T} \frac{R(\Phi_B,\Phi'_{\rm rad})}{B(\Phi_B)} d\Phi'_{\rm rad}\right]\frac{R(\Phi_B,\Phi_{\rm rad})}{B(\Phi_B)} d\Phi_{\rm rad} = 1$$

Reweighting the hardest radiation

We have to rewight for the factor:

$$\frac{R(\Phi_B,\Phi_{\rm rad})}{B(\Phi_B)}\times\exp\left[-\int_{p_T'>p_T}\frac{R(\Phi_B,\Phi_{\rm rad}')}{B(\Phi_B)}{\rm d}\Phi_{\rm rad}'\right]{\rm d}\Phi_{\rm rad}.$$

The first factor is proportional to $\frac{\alpha_s f_1^R\times f_2^R}{f_1^B\times f_2^B}$; easily reweighted!

The second factor depends non-linearly upon the PDF's and α_s.

Reweighting factor

$$\exp\left[-\int_{p_T'>p_T}\left.\frac{R(\Phi_B,\Phi_{\rm rad}')}{B(\Phi_B)}\right|_{\rm old}^{\rm new}{\rm d}\Phi_{\rm rad}'\right]$$

where

$$\left.\frac{R(\Phi_B,\Phi_{\rm rad}')}{B(\Phi_B)}\right|_{\rm old}^{\rm new}=\frac{R^{\rm new}(\Phi_B,\Phi_{\rm rad}')}{B^{\rm new}(\Phi_B)}-\frac{R^{\rm old}(\Phi_B,\Phi_{\rm rad}')}{B^{\rm old}(\Phi_B)}$$

Several approximations were tried. The most convincing one was:

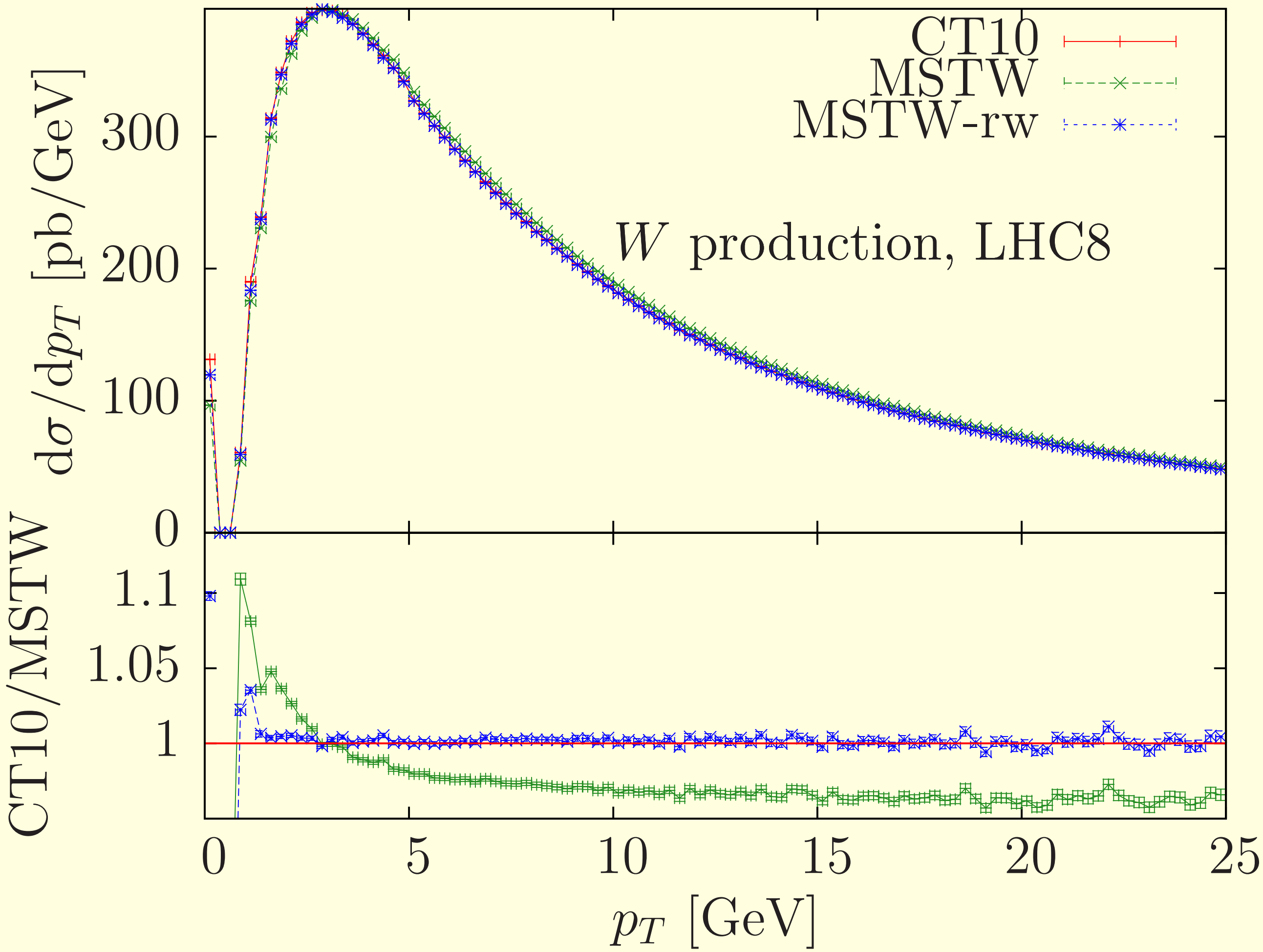
$$\frac{R^{\mathrm{ME}}(\Phi_B,\Phi'_{\mathrm{rad}})}{B^{\mathrm{ME}}(\Phi_B)}=\frac{4\,s\,\alpha_s}{k_T^2\,(1-x)\,f_q(x_1^B)\,f_{\bar{q}'}(x_2^B)}\left\{C_F\frac{1+x^2}{1-x}f_q(x_1)\,f_{\bar{q}'}(x_2)\right.$$

$$\left.+T_f(x^2+(1-x)^2)\times\left[f_q(x_1)\,f_g(x_2)\frac{k^0-k^l}{2k^0}+f_g(x_1)\,f_{\bar{q}'}(x_2)\frac{k^0+k^l}{2k^0}\right]\right\}$$

with:

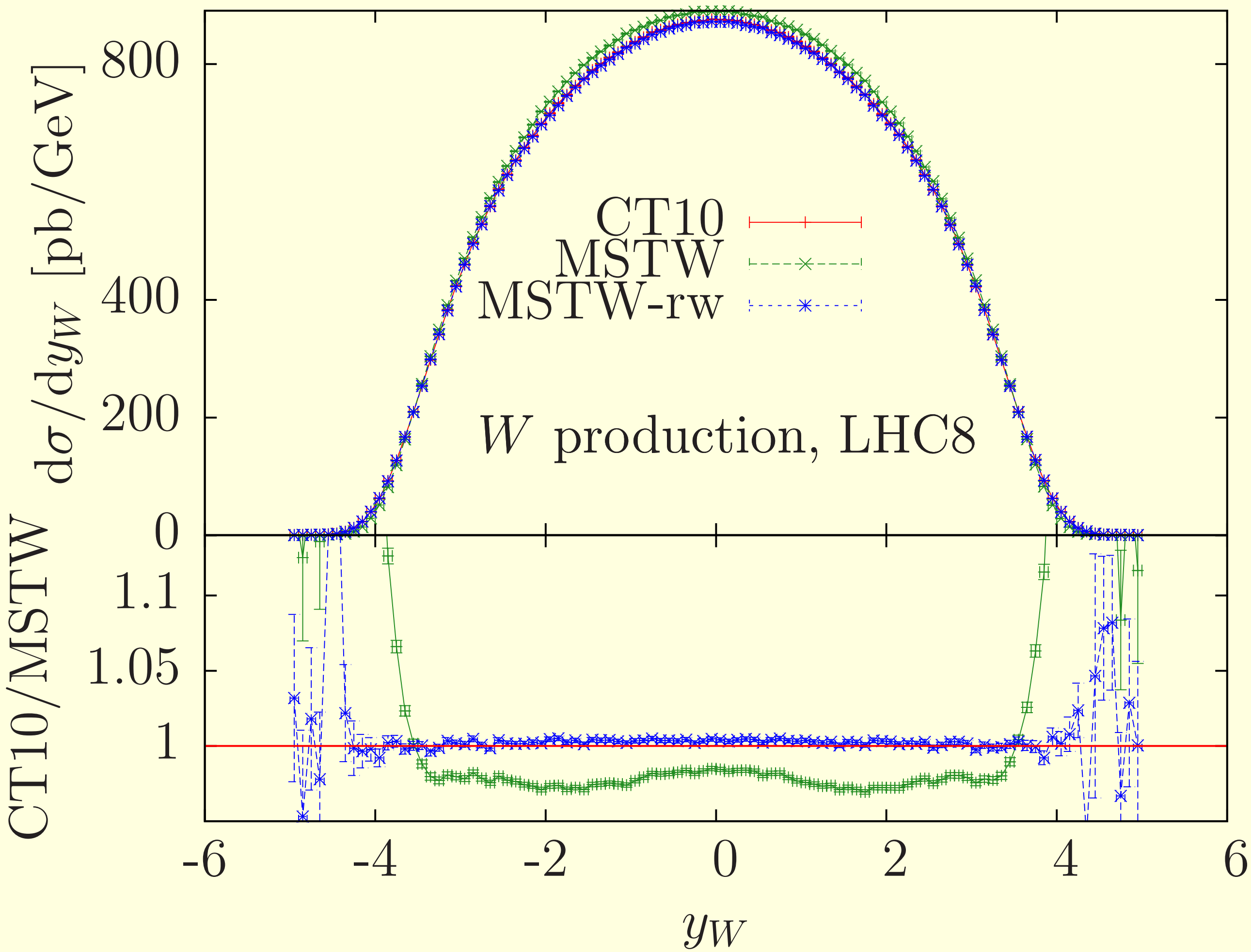
- $k=$ radiated parton momentum (in partonic CM)
- $x=p_W^2\,/\,s$
- x_1^B,x_2^B are the momentum fraction for the underlying Born kinematics
- x_1,x_2 are the momentum fraction for the Real kinematics

Method has similarities (and borrows code) from heavy quark mass effects in $H+\mathrm{jet}$ MiNLO (Hamilton,Zanderighi,P.N. 2015).



Reweighted result at LHE level (no shower).

Reweighted MRST result matches CT10 quite accurately up to $p_T = 1.2$ GeV. $2 \div 3\%$ differences below 1.2 and at 0 bin not well understood.



Rapidity distribution not spoiled by p_T reweighting procedure

(rapidity distribution already exactly reweighted by standard `POWHEG` procedure, p_T reweighting might have spoilt it)

Remarks and prospects

This reweighting procedure is a "tool"; how do we use it?

- Take a set of pdf's, get 1 sample of Les Houches events with weights; tune the shower for each member to fit the Z pt.
  We get one showered sample for each PDF member (no gain!)
- Reweight to a set of PDF's; find a way to vary parameters in the hardest radiation to fit the Z rapidity distribution. If the variation of parameters controlling the hardest radiation can be done by reweighting (which it should, with techniques similar to the one presented here), this would provide a single sample with different weights (more work from our side ...)
- Generate a set of pdf's with error, using all available data, plus the low transverse momentum distribution of the Z (suggested by Rojo). Then:
  - Generate an event sample with `POWHEG` + shower, with central set
  - Tune the shower to fit the Z p_T spectrum (just once)
  - Compute reweighting factor for each member of the set

  This again would provide a single sample with different weights.