A Study of Top mass observables with generators of increasing accuracy.

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A study with generators of increasing accuracy

(Ferrario-Ravasio,Ježo,Oleari,PN, arXiv:1801.03944)

- We focus upon the $pp \to l\bar{\nu}_l\bar{\ell}\nu_\ell b\bar{b}$ process. Can be studied with the `hvq`, `tt̄_dec`, and `bb̄4l` generators.
- We make the simplifying assumption that the W can be fully reconstructed.
- We consider the top mass determination from mass distribution of the system comprising the W and a (charge matched) b jet. (we also considered the b-jet energy spetrum, and the leptonic observables proposed by Frixione and Mitov.)
- We studied the effect of scale variation, PDF and α_s sensitivity, and the differences between the Pythia8 and Herwig7 shower interface, as a first rough estimate of non-perturbative errors.

General approach

Assuming we have an observable O sensitive to the top mass, we will have in general

$$O = O_{\rm c} + B(m_t - m_{t,\rm c}) + \mathcal{O}((m_t - m_{t,\rm c})^2)$$

where $m_{t,\rm c} = 172.5$ GeV is our central value for the top mass. $O_{\rm c}$ and B differ for different generator setup. Given an experimental result for O, the extracted mass value is

$$m_t = m_{t,\rm c} + (O_{\rm exp} - O_{\rm c})/B$$

By changing the generator setup $O_{\rm c}, B \to O'_{\rm c}, B'$:

$$m_t - m'_t = -\frac{O_{\rm c} - O'_{\rm c}}{B} - (O_{\rm exp} - O'_{\rm c})(B - B')/(BB') \approx -\frac{O_{\rm c} - O'_{\rm c}}{B}.$$

General approach

Thus:

- Compute the B coefficient using a single setup for the generator.
- Compute the O_{c} coefficient (i.e. the value of the observable for $m_t = m_{t,\mathrm{c}}$) for all different setup we want to explore.
- Extract the difference in the extracted m_t between different setups, according to the equation

$$\Delta m_t = -\frac{\Delta O_{\mathrm{c}}}{B}.$$

m_{W-bj}

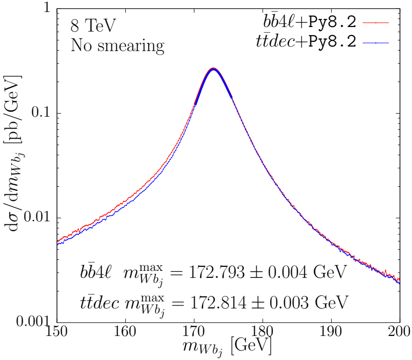
$W - bj$ is defined in the following way:

- Jets are defined using the anti-k_T algorithm with $R = 0.5$. The $b/\bar{b}$ jet is defined as the jet containing the hardest $b/\bar{b}$.
- $W^{\pm}$ is defined as the hardest $l^{\pm}$ paired with the hardest matching neutrino.
- The $W - bj$ system is obtained by matching a $W^{+/-}$ with a $b/\bar{b}$ jet (i.e. we assume we know the sign of the b).

A difference δm_{rec} in the reconstructed mass peak between two generators with the same m_t parameter will lead to a $\delta m_t = -\delta m_{rec}$ in the mass extracted by fitting a given data set (i.e. $B \approx 1$)

Impact of finite width

Both $\mathtt{b\bar{b}4l}$ and $\mathtt{t\bar{t}\_dec}$ include NLO radiation in decay.
$\mathtt{b\bar{b}4l}$ also includes finite width, non-resonant effects, interference of radiation in production and decay. Comparison of the two indicates that these effects, although not negligible, are not large.

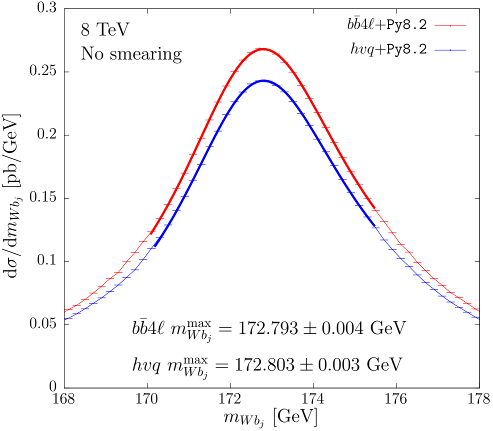


$M_{\rm rec}$ (GeV), $\mathtt{b\bar{b}4l}$-$\mathtt{t\bar{t}\_dec}$		
	bare	smeared
Py8	−0.03	−0.14
Hw7	−0.046	−0.052
Hw6	−0.012	−0.1

Focus upon $\mathtt{b\bar{b}4l}$-$\mathtt{hvq}$ comparison.

Pythia8, POWHEG-hvq - POWHEG-$b\bar{b}$4l comparison

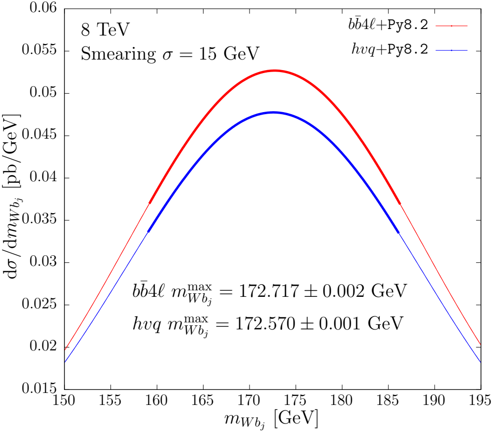
We compare the new $b\bar{b}$4l NLO+PS generator with the old hvq, using Pythia8 for the shower.



hvq−$b\bar{b}$4l: 10 MeV

Pythia8, POWHEG-hvq - POWHEG-$b\bar{b}4l$ comparison

Same, accounting for experimental errors by smearing the peak with a gaussian distribution with a width of 15 GeV.



$$f_{sm}(x) \propto \int \mathrm{d}y\, f(y) \times \exp\left[-\frac{(y-x)^2}{2\sigma^2}\right],$$

$\sigma = 15$ GeV,

Peak from a fit with a 4th degree polynomial.

$b\bar{b}4l$ – hvq: 147 MeV

Pythia8, hvq, $t\bar{t}$_dec,$b\bar{b}$4l comparison

	PS only		full	
	No smearing	15 GeV smearing	No smearing	15 GeV smearing
$b\bar{b}4\ell$	172.522 ± 0.002 GeV	171.403 ± 0.002 GeV	172.793 ± 0.004 GeV	172.717 ± 0.002 GeV
$t\bar{t}dec - b\bar{b}4\ell$	-18 ± 2 MeV	$+191 \pm 2$ MeV	$+21 \pm 6$ MeV	$+140 \pm 2$ MeV
$hvq - b\bar{b}4\ell$	-24 ± 2 MeV	-89 ± 2 MeV	$+10 \pm 6$ MeV	-147 ± 2 MeV

Table 3. Differences in the m_{Wb_j} peak position for m_t=172.5 GeV for $t\bar{t}dec$ and hvq with respect to $b\bar{b}4\ell$, showered with `Pythia8.2`, at the NLO+PS level and at the full hadron level.

	No smearing		15 GeV smearing	
	MEC	MEC − no MEC	MEC	MEC − no MEC
$b\bar{b}4\ell$	172.793 ± 0.004 GeV	-12 ± 6 MeV	172.717 ± 0.002 GeV	$+55 \pm 2$ MeV
$t\bar{t}dec$	172.814 ± 0.003 GeV	-4 ± 5 MeV	172.857 ± 0.001 GeV	-26 ± 2 MeV
hvq	172.803 ± 0.003 GeV	$+61 \pm 5$ MeV	172.570 ± 0.001 GeV	$+916 \pm 2$ MeV

Table 4. m_{Wb_j} peak position for m_t=172.5 GeV obtained with the three different generators, showered with `Pythia8.2`+MEC (default). We also show the differences between `Pythia8.2`+MEC and `Pythia8.2` without MEC.

Small differences in the smeared peak. Larger differences when smearing is included (i.e. modeling differences).

Pythia8, hvq, $t\bar{t}$_dec, $b\bar{b}$4l comparison

Jet radius dependence:

	$R = 0.4$		$R = 0.5$		$R = 0.6$	
	No smearing	15 GeV smearing	No smearing	15 GeV smearing	No smearing	15 GeV smearing
$b\bar{b}4\ell$ [GeV]	172.156 ± 0.004	171.018 ± 0.002	172.793 ± 0.004	172.717 ± 0.002	173.436 ± 0.005	174.378 ± 0.002
$t\bar{t}dec - b\bar{b}4\ell$	$+35 \pm 5$ MeV	$+195 \pm 2$ MeV	$+21 \pm 6$ MeV	$+140 \pm 2$ MeV	$+1 \pm 7$ MeV	$+97 \pm 2$ MeV
$hvq - b\bar{b}4\ell$	$+47 \pm 5$ MeV	-113 ± 2 MeV	$+10 \pm 6$ MeV	-147 ± 2 MeV	-7 ± 6 MeV	-174 ± 2 MeV

Table 7. m_{Wb_j} peak position obtained with the $b\bar{b}4\ell$ generator for three choices of the jet radius. The differences with the $t\bar{t}dec$ and the hvq generators are also shown.

Summary of theoretical uncertainties:

	No smearing				15 GeV smearing			
	% $-$ $b\bar{b}4\ell$	(μ_R, μ_F)	PDF	α_S	% $-$ $b\bar{b}4\ell$	(μ_R, μ_F)	PDF	α_S
$b\bar{b}4\ell$	+0 MeV	$^{+26}_{-17}$ MeV	-	± 8 MeV	+0 MeV	$^{+86}_{-53}$ MeV	-	± 64 MeV
$t\bar{t}dec$	+21 MeV	$^{+2}_{-10}$ MeV	-	± 8 MeV	+140 MeV	$^{+6}_{-6}$ MeV	-	± 54 MeV
hvq	+10 MeV	$^{+2}_{-6}$ MeV	± 3 MeV	± 2 MeV	-147 MeV	$^{+7}_{-7}$ MeV	± 5 MeV	± 9 MeV

Table 6. Theoretical uncertainties associated with the m_{Wb_j} peak position extraction for m_t=172.5 GeV for the three different generators, showered with `Pythia8.2`. The PDF uncertainty on the $b\bar{b}4\ell$ and $t\bar{t}dec$ generators is assumed to be equal to the hvq one, as explained in Sec. 6.1.2.

Summary of comparisons within Pythia8

We can summarize the comparison with Pythia8 by saying that we find a fairly consistent picture.

- The matrix element corrections (MEC) in Pythia work as well as the NLO corrections in decays, as expected.
- The smallness of scale variations in `tt̄_dec` and `hvq` with respect to the `bb̄4l` can be explained as being due to the way in which the two generators implement off-shell effects.
- Hadronization effects have a consistent impact on the three generators.
- The shift in mass associated to the use of the `bb̄4l` generator with respect to the other two is around 150 MeV, with opposite signs. Although not totally negligible, this shift is well below presently quoted errors.

POWHEG-$b\bar{b}4l$, Herwig7 - Pythia8 comparison

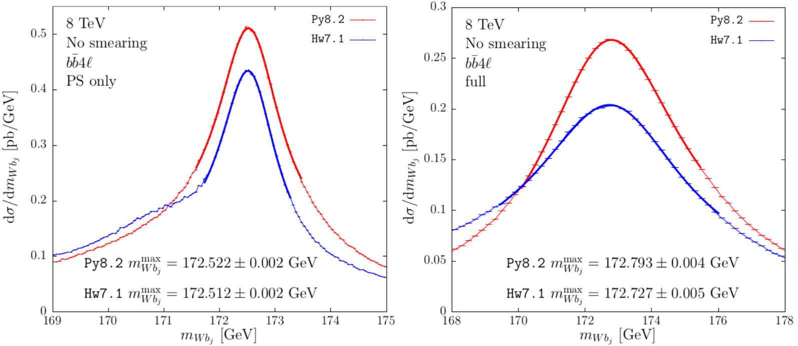
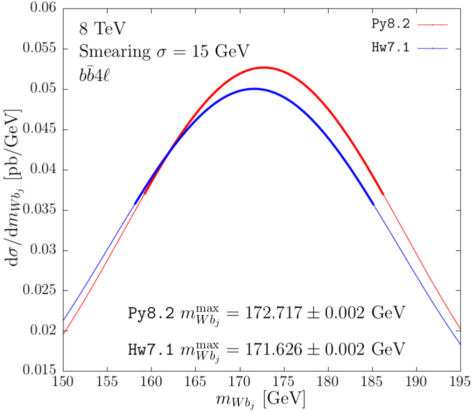


Figure 12. $d\sigma/dm_{Wb_j}$ distribution obtained by showering the $b\bar{b}4\ell$ results with `Pythia8.2` and `Herwig7.1`, at parton-shower level (left) and with hadronization and underlying events (right).

No large difference in the peak position (i.e. no indication here of large NP effects that displace the peak.). However, the marked difference in shape is bound to lead to problems when the experimental resolution is taken into account.

POWHEG-bb̄4l, Herwig7 - Pythia8 comparison



When the resolution is accounted for, we find a 1.1 GeV difference between Herwig7 and Pythia8.

POWHEG-$b\bar{b}4\ell$, Herwig7 - Pythia8 comparison

	No smearing		15 GeV smearing	
	`Hw7.1`	`Py8.2 − Hw7.1`	`Hw7.1`	`Py8.2 − Hw7.1`
$b\bar{b}4\ell$	172.727 ± 0.005 GeV	$+66 \pm 7$ MeV	171.626 ± 0.002 GeV	$+1091 \pm 2$ MeV
$t\bar{t}dec$	172.775 ± 0.004 GeV	$+39 \pm 5$ MeV	171.678 ± 0.001 GeV	$+1179 \pm 2$ MeV
hvq	173.038 ± 0.004 GeV	-235 ± 5 MeV	172.319 ± 0.001 GeV	$+251 \pm 2$ MeV

Table 8. m_{Wb_j} peak position for m_t=172.5 GeV obtained with the three different generators, showered with `Herwig7.1` (`Hw7.1`). The differences with `Pythia8.2` (`Py8.2`) are also shown.

	`Pythia8.2 − Herwig7.1`			
	PS only		full	
	No smearing	15 GeV smearing	No smearing	15 GeV smearing
$b\bar{b}4\ell$	$+10 \pm 2$ MeV	$+984 \pm 2$ MeV	$+66 \pm 7$ MeV	$+1091 \pm 2$ MeV
$t\bar{t}dec$	$+5 \pm 2$ MeV	$+1083 \pm 2$ MeV	$+39 \pm 5$ MeV	$+1179 \pm 2$ MeV
hvq	-0 ± 2 MeV	$+113 \pm 2$ MeV	-235 ± 5 MeV	$+251 \pm 2$ MeV

Table 9. Differences between `Pythia8.2` and `Herwig7.1` in the extracted m_{Wb_j} peak position for m_t=172.5 GeV obtained with the three different generators, at the NLO+PS level (PS only) and including also the underlying events, the multi-parton interactions and the hadronization (full).

POWHEG-$\mathtt{b\bar{b}4l}$

While in the Pythia8 case we found a fully consistent picture, we cannot say the same for Herwig7. Several results are hard to understand:

- While the new generators $\mathtt{b\bar{b}4l}$ and $\mathtt{t\bar{t}\_dec}$ behave consistently with Herwig7, they display a large difference with respect to `hvq`.
- This means that MEC in Herwig7 do not have the same (expected) effect as in Pythia8

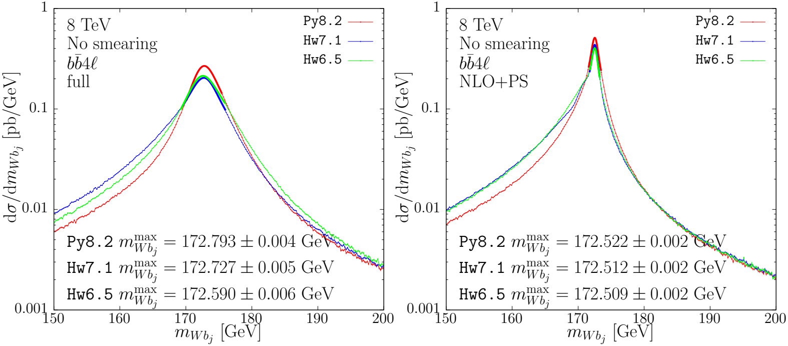
Can we dismiss Herwig7 on this ground? Consider that

- MEC in Pythia8 are also *technically* very similar to POWHEG.
- MEC in Herwig, being an angular ordered shower, are *technically* very different, since they are applied to the hardest emission found at each step of the shower.

So, the difference may well be beyond NLO effects, and thus may have to be considered as an uncertainty.

Including Herwig6

With the collaboration of Bryan Webber, we have also included Herwig6 in our study.



At the shower level, Hw7 and Hw6 are very similar. Glitch right before the peak absent in Hw6.
After hadronization and MPI, Hw6 becomes more symmetric with respect to Py8.

As a consequence of that:

M_{Wj} (GeV)						
	Py8		Hw6		Hw7	
	bare	smeared	bare	smeared	bare	smeared
$b\bar{b}4l$	172.793	172.717	172.59	172.384	172.727	171.626
$t\bar{t}$_dec	172.814	172.857	172.602	172.484	172.775	171.678
hvq	172.803	172.570	172.803	172.95	173.038	172.552

as a fortuitous consequence of compensation due to hadronization and MPI in Herwig6.
This findings also suggest that shower and hadronization uncertainties may be dominant in direct measurements.

Jet energy peak

Agashe,Franceschini,Kim,Schulze,2016

With Pythia8:

- $\mathtt{t\bar{t}\_dec}$ and $\mathtt{b\bar{b}4l}$ differ by less than 200 MeV
- `hvq` differs from the other two by more than 500 MeV
- `hvq` NO MEC differs from the others by more than 1.9 GeV.

Obviously more sensitive to radiation from the *b* quark.
Since $\delta m_t \approx \delta E_{\mathrm{bjet}}^{(\mathrm{max})}/0.45$, using `hvq` can cause a 1 GeV shift in mass (well below current uncertainties).

Jet energy peak

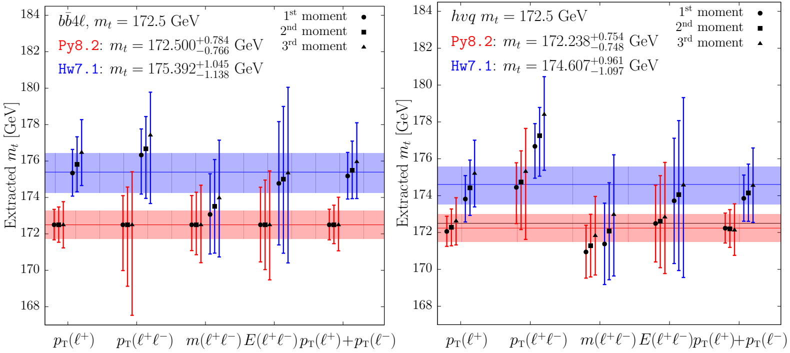
With Herwig7:

- $\texttt{t}\bar{\texttt{t}}\texttt{\_dec}$ and $\texttt{b}\bar{\texttt{b}}\texttt{4l}$ differ by 20 MeV
- `hvq` differs from the other two by more than 660 MeV
- $\texttt{b}\bar{\texttt{b}}\texttt{4l}$+Py8 and $\texttt{b}\bar{\texttt{b}}\texttt{4l}$+Hw7 differ by more than 2 GeV

Switching from Pythia8 to Herwig7 leads to large differences, that would impact the mass measurement by more than 4 GeV.

Lepton Observables

Frixione, Mitov, 2014



Looking only at Pythia8: only $p_T(\ell^+\ell^-)$ and $m(\ell^+\ell^-)$ differ, presumably because of their sensitivity to spin correlations.
Nearly 3 GeV difference between Pythia8 and Herwig7.

Prospect for MC studies

- Try Pythia6.
- Try Sherpa? (unfortunately, no POWHEG-BOX interface is given there ...)
- Include also fully hadronic decay in a `bb̄4l` style generator, and perform more realistic studies of direct measurements.

Caveat:

Our results cannot be directly translated into an error in standard measurement. This can only be done within the experimental collaborations. However, it strongly suggests to consider using other shower generators in the analysis to assess the errors.