Accurate (Shower) MC's for Higgs Physics

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Scope

With Accurate MC we consider all improvements over standard Shower MC's that include higher order QCD effects to some extent.
Thus:

- NLO+SMC generators: These improve over standard SMC's with matrix element corrections by adding NLO accuracy for inclusive quantities. Available generators:
  `MC@NLO+Herwig`, `POWHEG(+PYTHIA,Herwig,Herwig++)`
- ME+SMC generators: These add exact tree level matrix element accuracy to associated multi-jet production. Several available generators:
  `ALPGEN(+Pythia,Herwig)`,`MADGRAPH(+Pythia,Herwig)`,`SHERPA`, etc.

ME+SMC

CKKW (Catani, Krauss, Kuhn and Webber)

SMC's describe multiparton emissions in the collinear (i.e. small angle) or soft (i.e. small energy) approximation. Their description of high energy, widely separated jets is incorrect (by a factor of order 1).

ME+SMC's improve over SMC, by describing large angle, high energy jets with the correct tree-level matrix elements.

First proporsal: CKKW (Catani, Krauss, Kuhn and Webber)
used in SHERPA
Variants:
MLM matching (ALPGEN, MADGRAPH),
Pseudo showers (Mrenna and Richardson, 2003),
CKKW-L (Lonnblad, 2002), etc.

NLO+SMC

MC@NLO, POWHEG

- 1 extra jet has tree-level matrix element accuracy (same as ME)
- Inclusive distributions in the basic process have NLO accuracy
- more jets are accurate only in the collinear or soft limit (they are provided by the shower program).

Example: $gg \to H + X$

	NLO+SMC	ME+SMC	SMC
$\frac{d\sigma}{dy_H}$	exact α_s^3	exact α_s^2	exact α_s^2
$\frac{d\sigma}{dp_T^{j1} dy^{j1}}$	exact α_s^3	exact α_s^3	only order of magnitude α_s^3
$\frac{d\sigma}{dp_T^{j2} dy^{j2}}$	only order of magnitude α_s^4	exact α_s^4	only order of magnitude α_s^4
etc.			

Inclusive quantities like $\frac{d\sigma}{dy_H}$ are predicted at order α_s^3 by NLO+SMC
(only leading order α_s^2 accuracy for ME+SMC and SMC)
Distribution of the first jet has α_s^3 accuracy in both NLO+SMC and ME+SMC
($\mathcal{O}(1)$ uncertainty in SMC for this quantity)
Distribution of second jet has α_s^4 accuracy in both ME+SMC
($\mathcal{O}(1)$ uncertainty in SMC and NLO+SMC for this quantity)

So:

- SMC alone never to be preferred
- NLO+SMC to be preferred if we are interested in inclusive distribution (for example, rapidity distribution of Higgs with a low energy jet veto)
- ME+SMC to be preferred when distributions in more than one relatively hard jets are considered (as in studies of Higgs +2 jets to discriminate CP properties).

This discussion is relative to NLO+SMC for Higgs production.
If NLO+SMC becomes available for Higgs+1jet, it becomes better than ME+SMC for distributions of up to two jets.

Merging NLO+SMC and ME+SMC is possible
(a pioneering study in Hamilton, Nason, 2010, applied to W and $t\bar{t}$ prod.)

Merging NLO+SMC with NLO+SMC for more jets is also possible
(pioneering study in Alioli, Oleari, Nason Re, Z and $Z+1\mathrm{jet}$, in preparation

Status

Latest review and comparison of available tools:

arXiv:1003.1643 [hep-ph]: THE TOOLS AND MONTE CARLO WORKING GROUP
Summary Report from the Les Houches 2009 Workshop on TeV Colliders

Gluon Fusion	Available in MC@NLO and POWHEG
VH	Available in MC@NLO and POWHEG
VBF Higgs	Available in POWHEG
ttH and bbH	Not yet available (should be not hard to do)
bsm Higgs	Some results (t+charged H) in MC@NLO and POWHEG

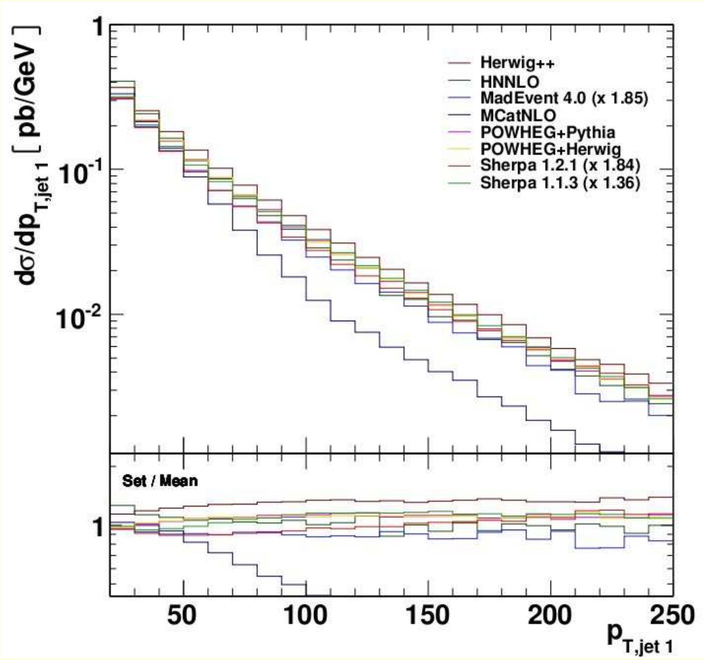
All these processes can be obtained in an SMC+ME context, within ALPGEN(+Pythia,Herwig),MADGRAPH(+Pythia,Herwig),SHERPA, etc.

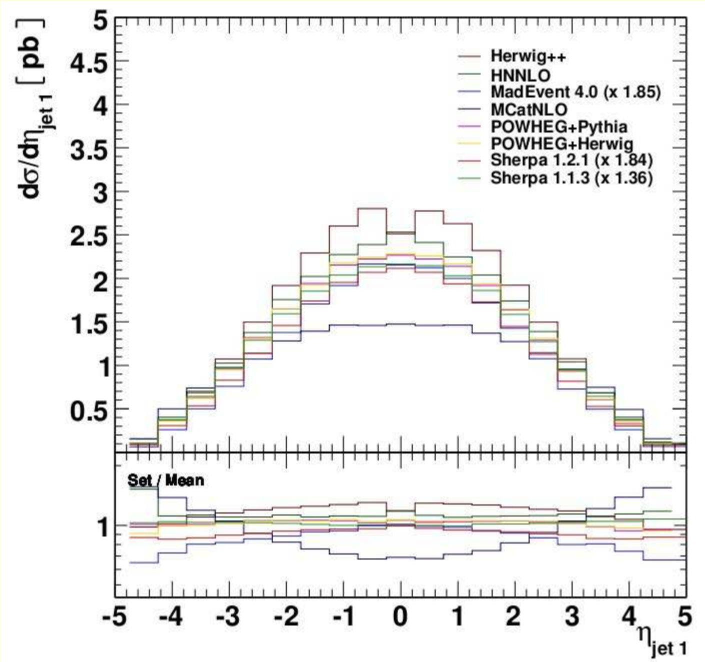
Highlights

SMC+NLO generators are fairly mature, and have been subject to several comparative studies among each other, with respect SMC+ME generators, and with respect to generic SMC programs.

Aim of the subgroup is to collect relevant studies and references.

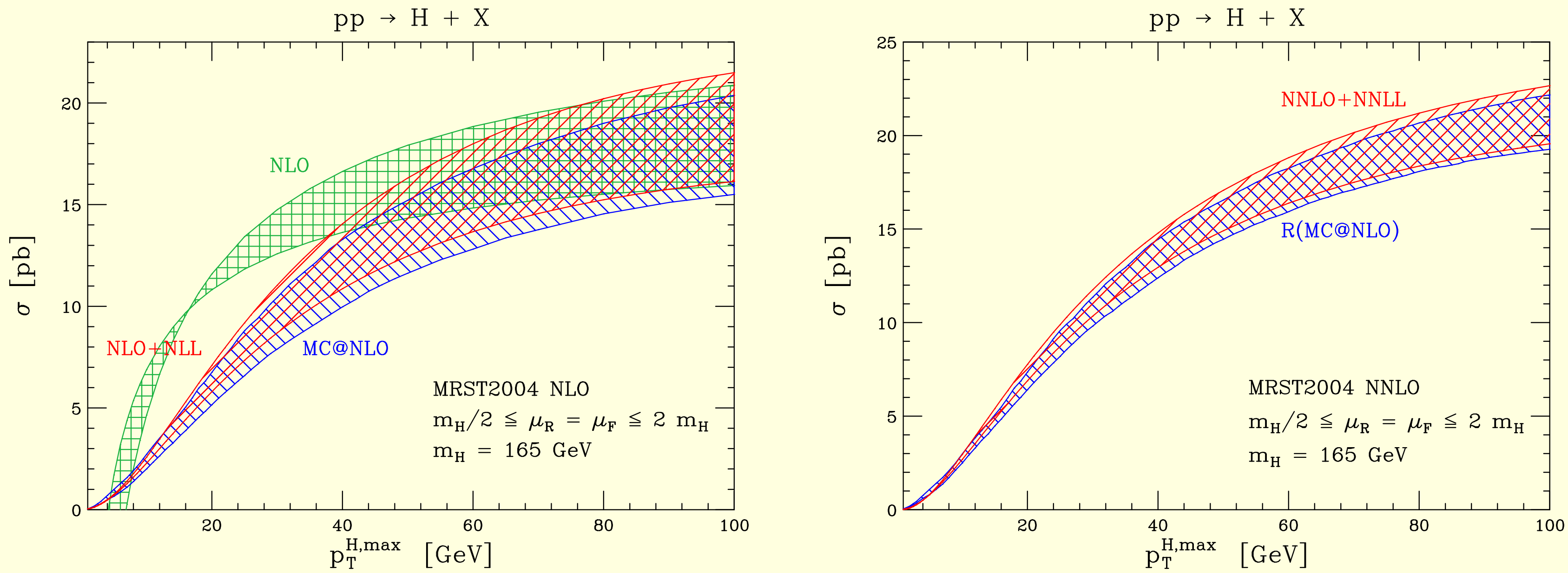
As an example, from the Les Houches workshop:





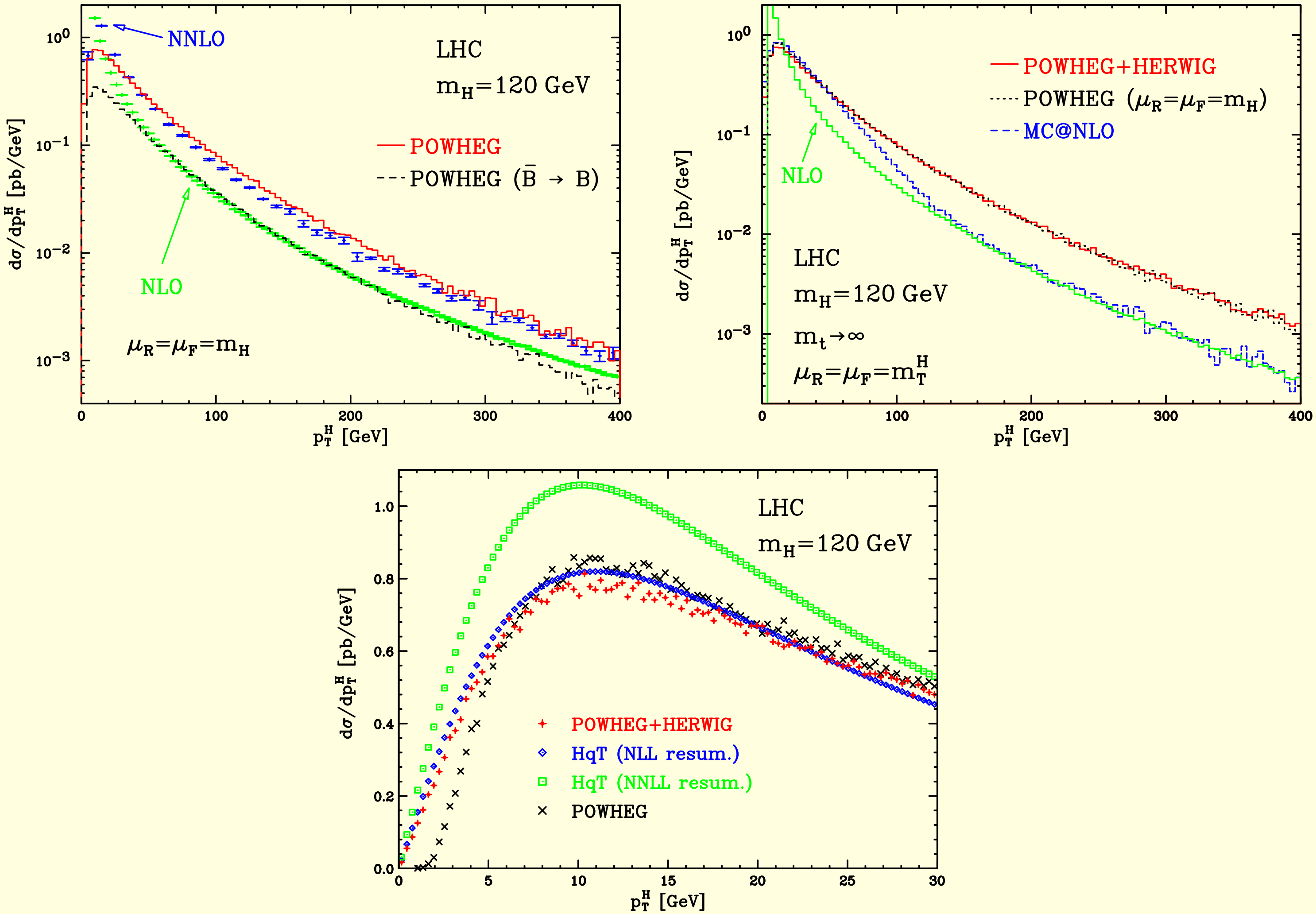
Comparison of `MC@NLO`, `POWHEG`, `MadEvent`, `Sherpa`

Another example (Anastasiou, Dissertori, Stöckli, Webber, 2008)

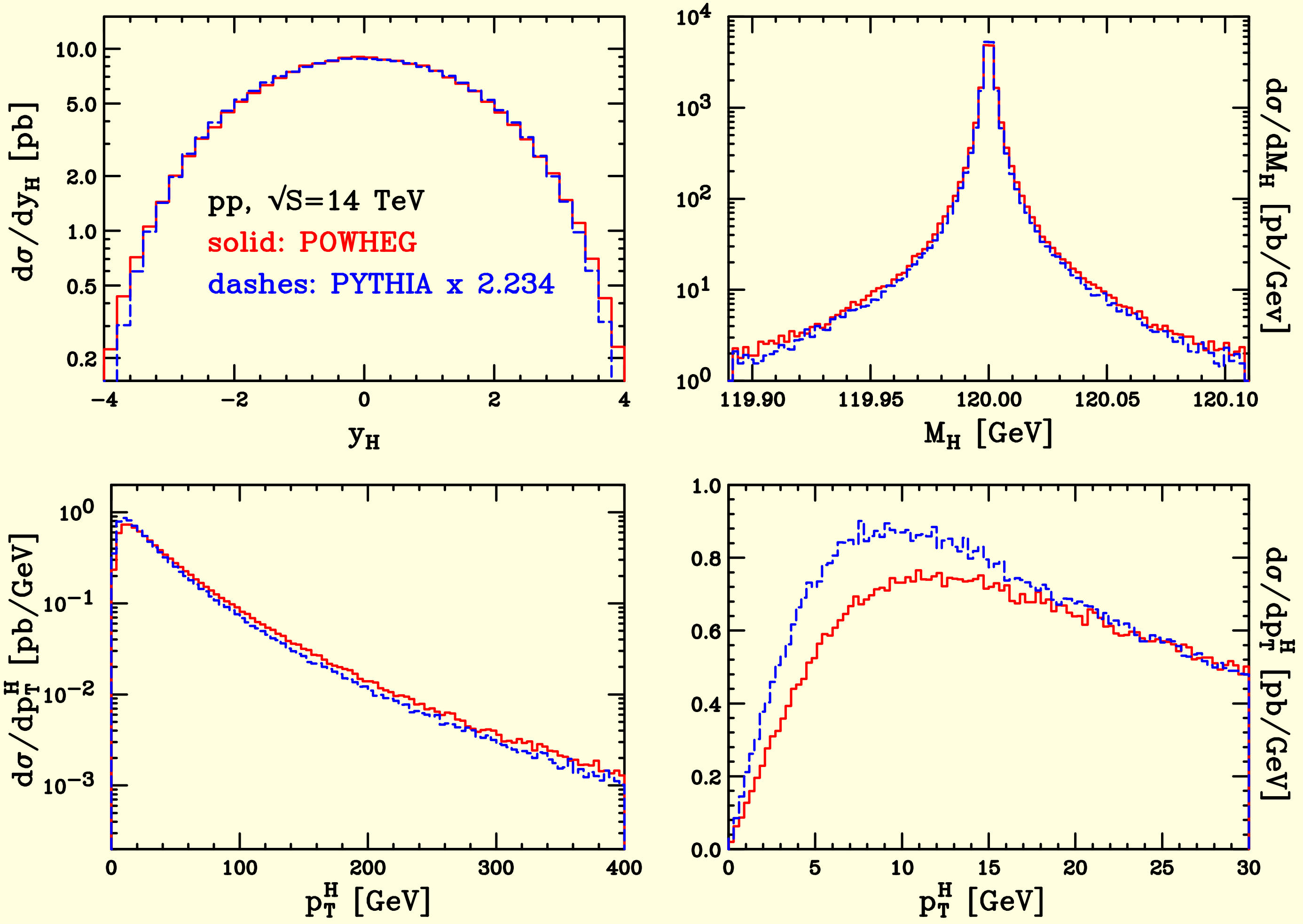


In the framework of $H \rightarrow WW$, a jet veto is used to reject $t\bar{t}$ background. In this reference the cross section as a function of a p_T cut on the Higgs p_T is computed at fixed order NLO, NNLO, at NNLO+NNLL resummation, and with full simulation in `MC@NLO` and `HERWIG`.

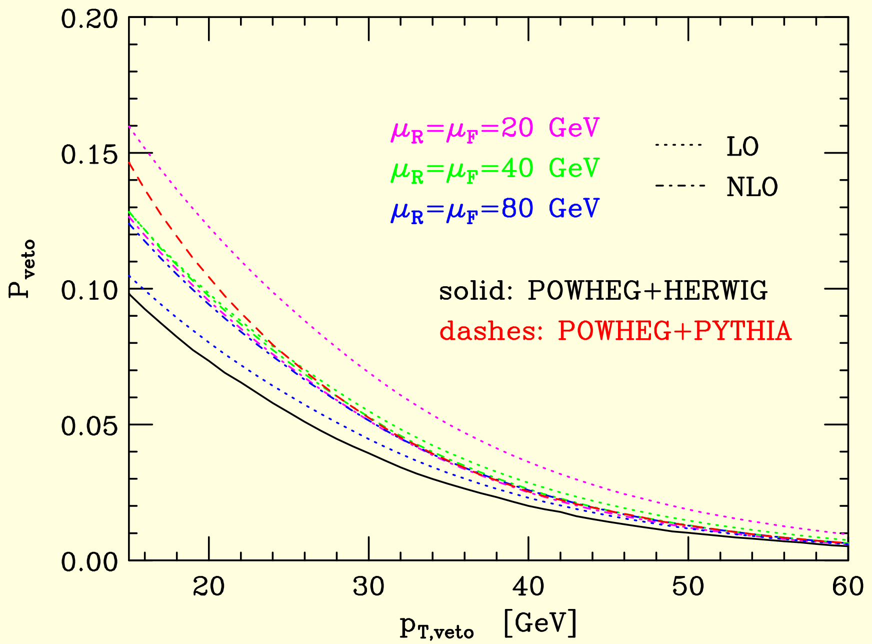
Comparisons between POWHEG, MC@NLO, NLO, NNLO, NNLL (gluon fusion) (Alioli, Oleari, Re, Nason, 2009)



POWHEG and PYTHIA comparison (gluon fusion);



(Oleari, Nason, 2009) Probability to find a veto jet in a VBF sample:



compared to VBF H +1jet LO,NLO (Figy, Hankele and Zeppenfeld, 2008)

The subsequent shower makes more difference than NLO scale variation.

So:

- several SMC+NLO tools already available, more to come soon
- Comparisons with NLO, NNLO, analytic resummation (NLL, NNLL) have been carried out where available
- Several comparisons of SMC+NLO different implementations have been carried out
- Comparisons with SMC+ME results are available
- Comparisons with standard SMC's are there
- Progress in automation is likely to accelerate the addition of more SMC+ME implementations of NLO processes.

Theorist's goals in the subgroup:

- Provide reviews of generators
- Provide guidelines for estimating uncertainties
- Review differences and discrepancies among generatos, and provide guidelines to experimentalists on how to interpret these differences.

From discussions within the subgroup, it has emerged that the use of SMC+NLO tools by experimentalists is only marginal at the moment.
It is useful to understand the causes of this, and to better clarify what are the needs of the experimental community, in order for these newer and better tools to be used routinely.

Our recommendation (and target) for this group is to have all experiments use NLO+SMC as a default for Higgs signals (and possibly also for backgrounds when available)

THIS IS POSSIBLE ALREADY NOW FOR MOST HIGGS CHANNELS
(the only missing one, tth, is likely to be implemented soon).