Accurate (Shower) MC's for Higgs Pysics

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Shower tools

- PS: Standard Parton Shower programs. Dress with radiation basic partonic processes; accurate only in the collinear limit.
- ME+PS: Matrix Elements+Parton Shower merging: can dress basic processes with tree-level accurate radiation, up to a fairly large multiplicity
- NLO+PS: Add NLO accuracy to a basic process, by including
  - tree-level accurate hardest radiation
  - virtual corrections to the basic process
- MENLOPS: Merge NLO+PS and ME+PS, to achieve
  - tree-level accurate hardest radiation up to a given multiplicity
  - virtual corrections to the basic process

PS

PYTHIA 6, PYTHIA 8, HERWIG, HERWIG++, SHERPA

All these programs are capable of dressing a basic process with collinear QCD radiation.

Note: for the simplest processes ($2 \to 1$,W, Z and ggH, $1 \to 2$, $t \to bW$,...)
can include Matrix Element Corrections:
the hardest radiation is made accurate at the tree level.

ME+PS

In essence:

Use exact LO Matrix Elements to compute radiation up to a given (high) multiplicity, with some jet resolution parameter $Q_{\rm cut}$.
Use a PS to generate further radiation below $Q_{\rm cut}$.

Dominant virtual corrections are included in ME result by reweighting with running couplings and Sudakov form factors, according to several merging schemes, like CKKW and MLM matching.

CKKW: `Sherpa`, `Herwig++`

MLM: `AlpGen`, `HELAC`, `MadGraph/MadEvent`, PS from `PYTHIA` and `HERWIG`

NLO+PS

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).

MENLOPS

Merging NLO+SMC and ME+SMC is possible

Hamilton, Nason, 2010, applied to W and $t\bar{t}$ prod.
Höche, Krauss, Schönherr, Siegert, 2010, W, Z, H, vector boson pairs.

Example: $gg \to H + X$

	NLO+PS	ME+PS	PS	PS with MEC	MENLOPS
$\frac{d\sigma}{dy_H}$	exact α_s^3	exact α_s^2	exact α_s^2	exact α_s^2	exact α_s^3
$\frac{d\sigma}{dp_T^{j1} dy^{j1}}$	exact α_s^3	exact α_s^3	coll.lim. α_s^3	exact α_s^3	exact α_s^3
$\frac{d\sigma}{dp_T^{j2} dy^{j2}}$	coll.lim. α_s^4	exact α_s^4	coll.lim. α_s^4	coll.lim. α_s^4	exact α_s^4
etc.					

$\frac{d\sigma}{dy_H}$ predicted at order α_s^3 by NLO+PS and MENLOPS
(only leading order α_s^2 accuracy for ME+PS and PS)

Distribution of the first jet has α_s^3 accuracy in both NLO+PS and ME+PS
PS with MEC, MENLOPS, $\mathcal{O}(1)$ uncertainty in PS.

Distribution of second jet has α_s^4 accuracy in both ME+PS and MENLOPS
($\mathcal{O}(1)$ uncertainty in PS and NLO+PS for this quantity)

Production channels: $gg \to H$

Implemented with all methods:

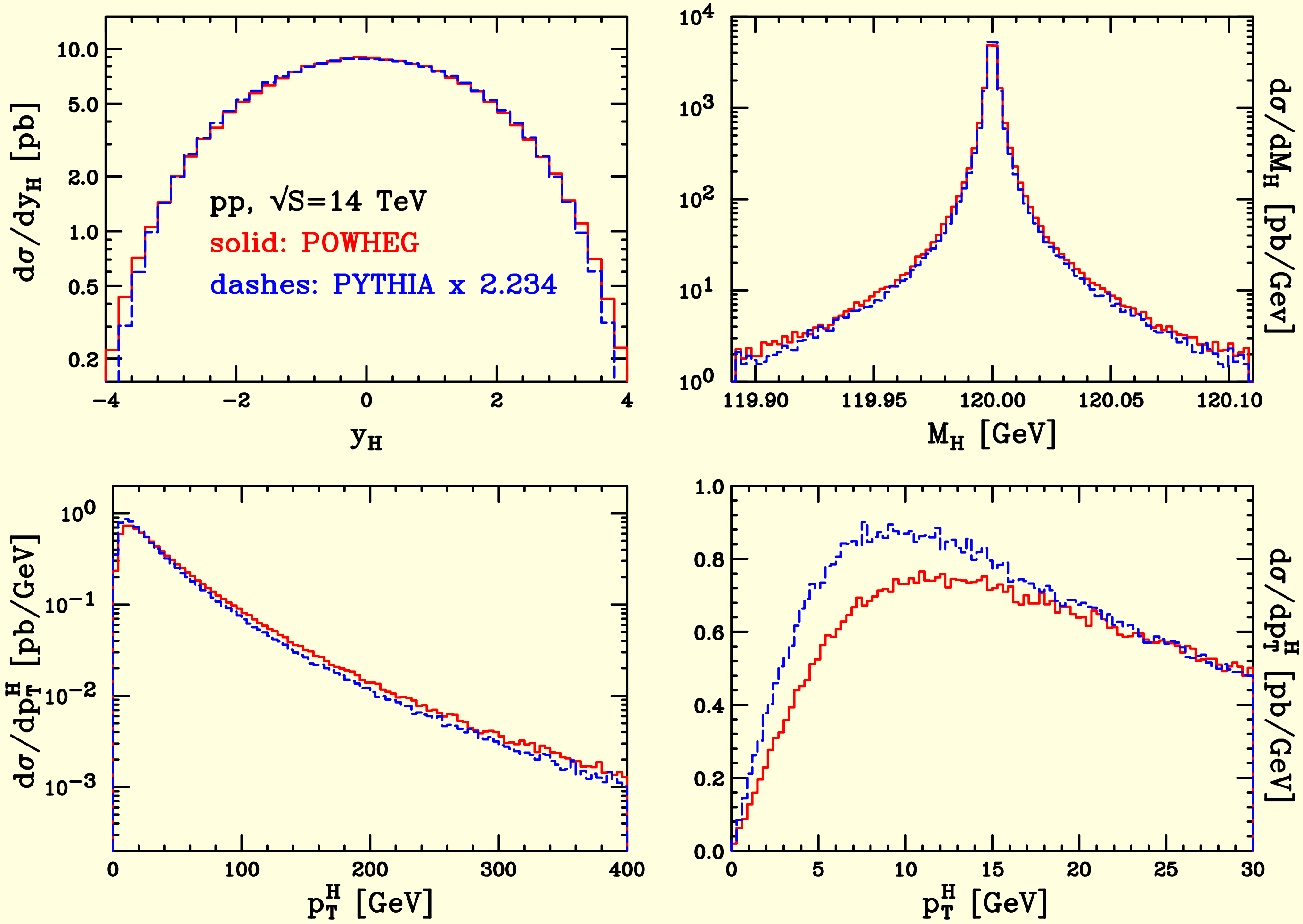
PS, LO with full m_t dependence, MEC

ME+PS, large m_t limit, several generators: AlpGen, MadGraph, SHERPA

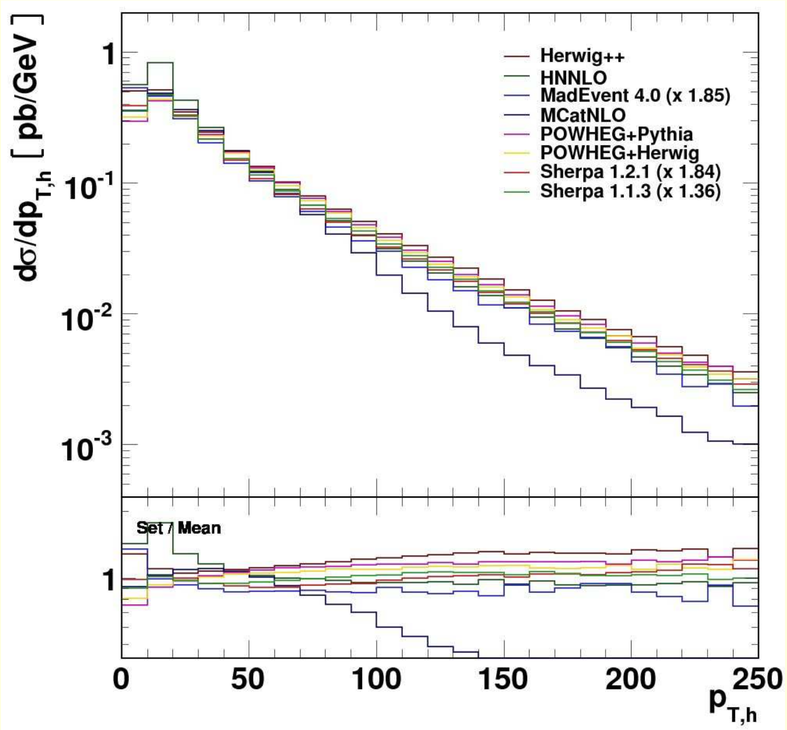
NLO+PS: MC@NLO, POWHEG: POWHEG BOX, HERWIG++, SHERPA;
LO with full m_t dependence, NLO correction with large m_t limit.
(NLO with exact m_t dependence available, not implemented yet)

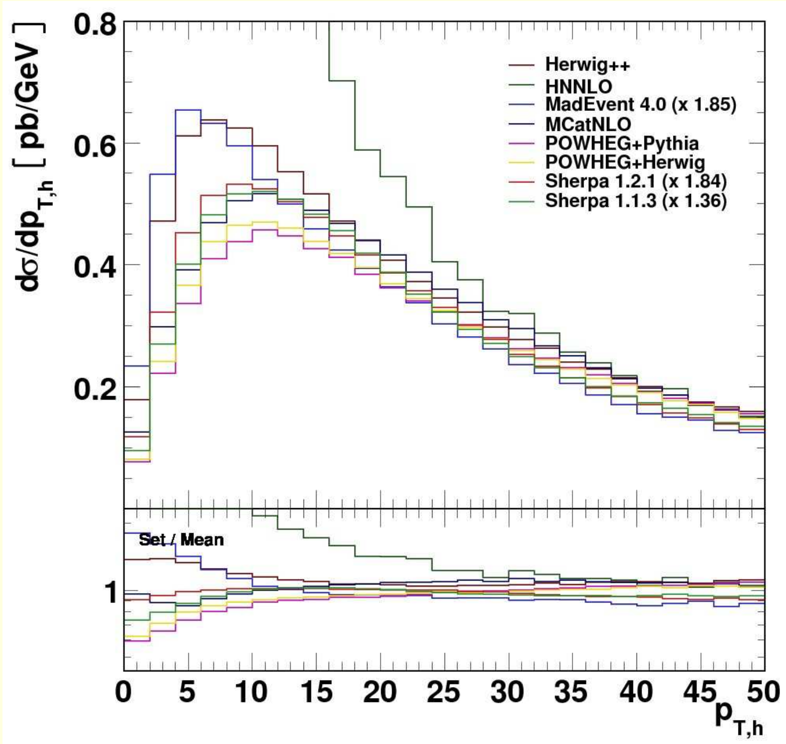
MENLOPS: possible, studied in SHERPA.

Comparison of MC generators among themselves and with analytic result carried out in the literature and well understood.
Can be used as starting point for further studies.



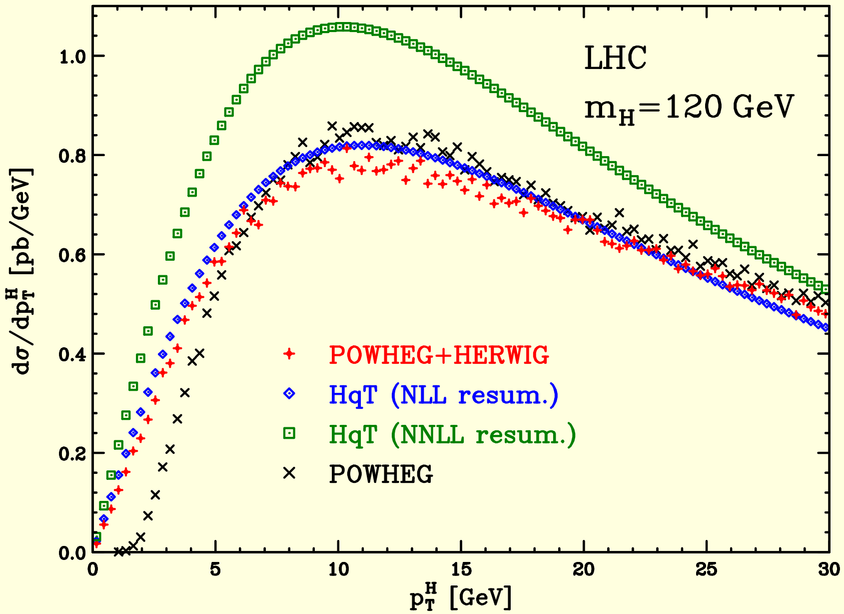
MEC in PYTHIA very similar to POWHEG generation of radiation.
Only remaining difference: y_H dependent K-factor.

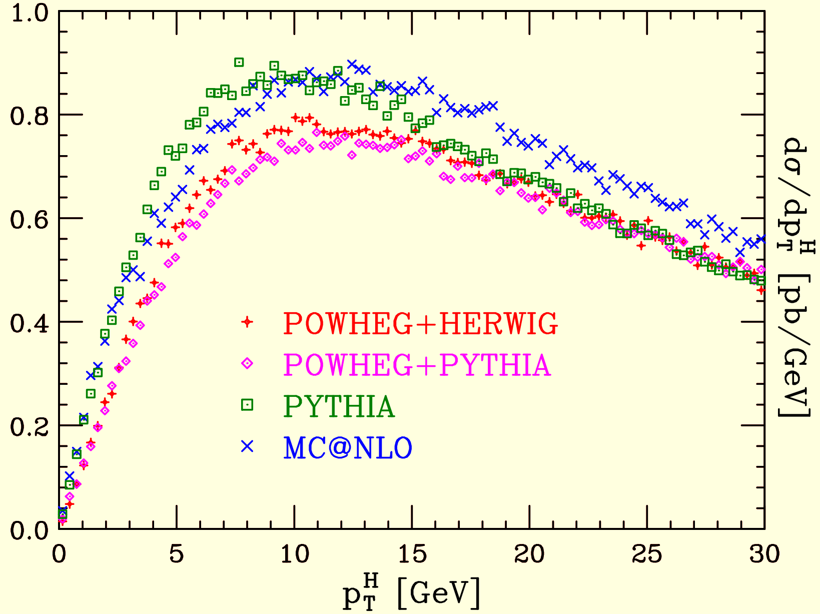




Difference of MC@NLO w.r.t all others at large p_T
All other methods have NLO K factor present on the whole p_T range,
In MC@NLO K factor only present in $\mathcal{S}$ events (moderate p_T)

Sudakov shape slightly different in MadGraph and SHERPA
(but: missing hadronization for both of them, study should be redone)



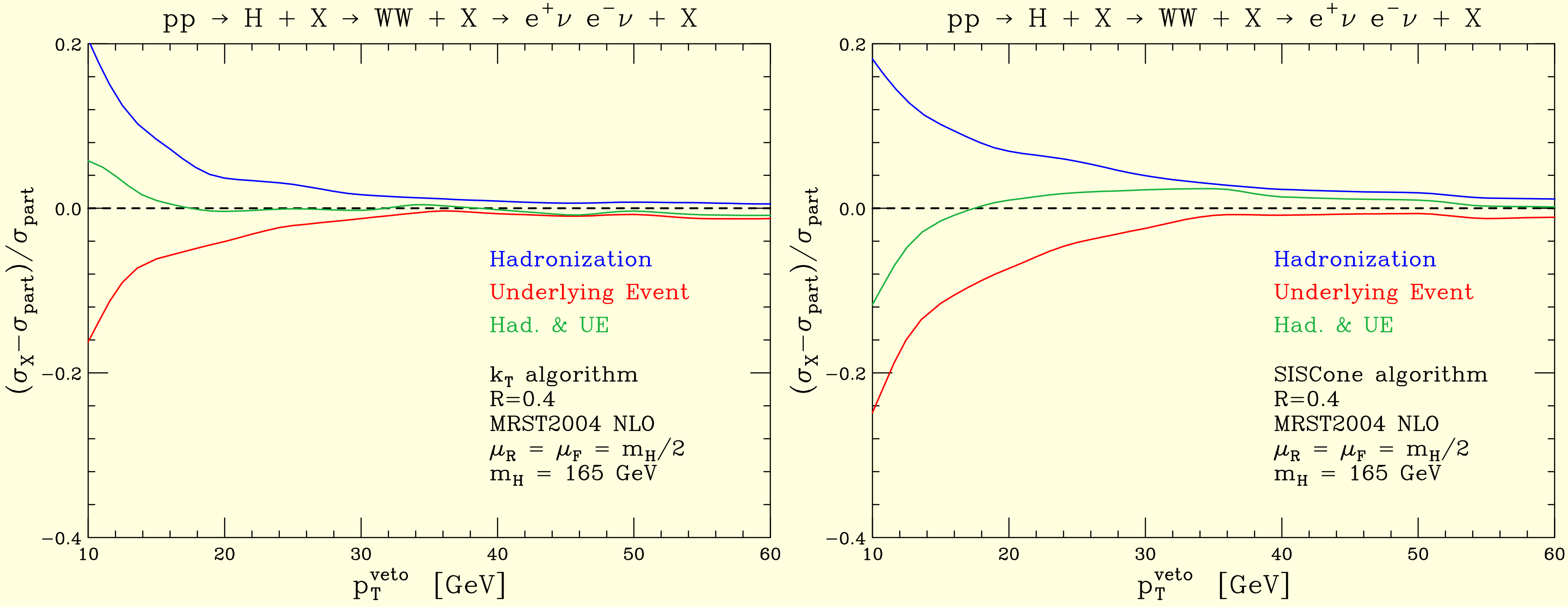


Sudakov shape compared with analytic NLL and NNLL calculations.
Good agreement with shapes for `MC@NLO` and `POWHEG` (Relevant to jet veto).

Further studies: hardest jet rapidity, dip in MC@NLO, not present in other methods (its origin is well understood).

Full acceptance study comparing MC@NLO, NNLO, NNLL, carried out for the $\gamma\gamma$ channel (Stockli,Holzner,Dissertori, 2005) and for the W^+W^- channel (Anastasiou,Dissertori,Stockli,Webber, 2008). Good agreement found between MC@NLO and NNLO.

Effect of hadronization and underlying event also studied. Should be repeated with other UE and hadronization models.



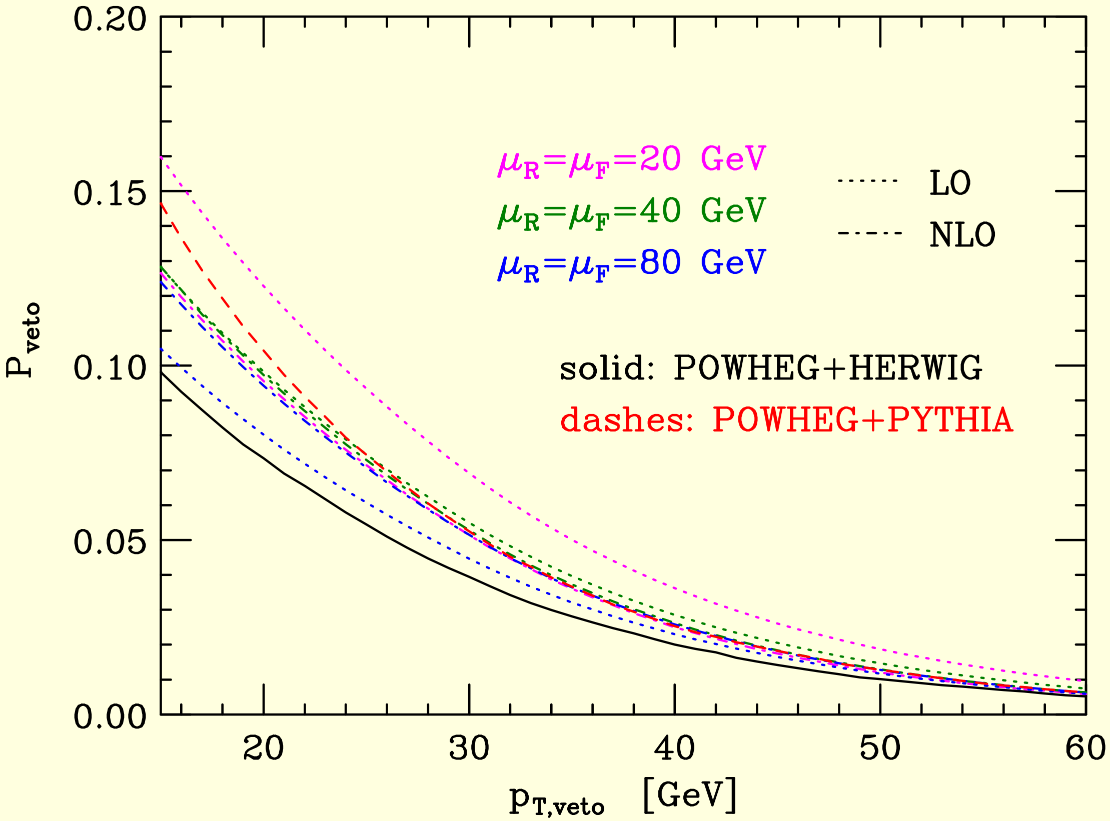
Production channels: VBF

PS: available
ME+PS: available in several generators;
NLO+PS: available in `POWHEG BOX`, in preparation in `HERWIG++`.

NLO corrections quite small in VBF, with suppressed extra QCD radiation.
PS results should be validated by comparison with ME+PS and NLO+PS.
First studies using ME+PS in Del Duca et al., 2006, substantial agreement between parton level prediction and ME+PS for key observables.

The `POWHEG BOX` implementation of VBF has been extensively compared to partonic NLO calculations, and to the NLO calculation of VBF plus 1 jet production

(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.

Production channels: VH

PS, ME+PS are capable to simulate this process.
NLO+PS: `MC@NLO`, `POWHEG:HERWIG++`.
Detailed comparison in Hamilton,Richardson,Tully 2009.

Because of the relevance of the boosted H production mode, with $H \to b\bar{b}$, NLO corrections to the decay process are particularly relevant.

Notice: `PYTHIA` includes MEC correction in its $H \to b\bar{b}$ decay.
Since H has spin zero, this is equivalent, up to a constant K factor, to an NLO+PS implementation of the decay.

(one argument in favour of separating the hardest event generation from the PS stage)

Production channels: ttH

ME+PS: available in several generators.

NLO+PS: not yet available as of now.

Also in this case, $H \to b\bar{b}$ including extra hard radiation may be necessary.

BSM

ME+PS: ME generators like `MadGraph` and `SHERPA` implement easily new physics models. MSSM or NMSSM scenario are available in these frameworks.

However: no systematic comparisons with standard PS or even with NLO calculations exist.

NLO+PS: Processes that are obtained from SM processes by coupling rescaling, like VBF and VH for neutral higgs production. Once ttH will be available, also bbH will be.

However: gluon fusion, where a b-quark loop could give a sizeable contribution is not available.

Besides promoting a full `POWHEG/MC@NLO` implementation of Higgs production including finite top mass effects, other approximate approaches may be attempted, like rescaling the large m_t cross section using the LO result. Comparison of the NLO+PS results with parton level NLO calculation may help to validate this method.

Charged Higgs production in association with a top quark is available in MC@NLO (and will soon be available in POWHEG), but not via $t\bar{t}$ production for the case of a light $H^{\pm}$.

More specifically: $t\bar{t}$ production is available at NLO both in MC@NLO and in POWHEG. The decay mode $t \to H^{+}b$ can be generated from the parton shower. However, spin correlations and NLO corrections to the decay are not included.

Backgrounds

$\gamma\gamma$ signal: NLO calculations should be enough

WW: $t\bar{t}$, NLO+PS (MC@NLO and POWHEG BOX)
WW, NLO+PS (MC@NLO, POWHEG: HERWIG++,SHERPA)

VH: $V + \text{jets}$, ME+PS, NLO+PS: $V + 1\text{jet}$ in POWHEG BOX
VV, NLO+PS (MC@NLO, POWHEG: HERWIG++,SHERPA)
Wt, NLO+PS (MC@NLO, POWHEG BOX)
$Vb\bar{b}$, (work in progress)

ZZ: ZZ, NLO+PS (MC@NLO, POWHEG: HERWIG++,SHERPA) ($ZZ^\star$?)
$Zb\bar{b}$ (work in progress)

$t\bar{t}H \to t\,\bar{t}b\bar{b}$: $t\bar{t}b\bar{b}$, $t\bar{t} + \text{Jets}$

Notice: $gg \to W^+W^-$ and $gg \to ZZ$ not included in NLO generators.
Give a sizeable contribution.
However, parton level events for these processes can be generated independently (they are finite!) and can be fed through a PS (talk by N.Kauer at Workshop II (gg2ZZ)).

Points for discussion

Signal MC priorities?
Background studies?
Wish lists?

Guideline: focus upon what is easily done, and what is extremely useful.

Signal MC:

$H \to b\bar{b}$ at NLO	Easy and very important. Is PS+MEC enough?
Finite m_t in $gg \to H$	Do this easy thing, and you've got yourself a paper!
$pp \to (t \to H^+ b)\,\bar{t}$	Include $t \to H^+ b$ in `POWHEG BOX` and `MC@NLO`; NLO correction in decay? Interesting open issue
$pp \to t\bar{t}H$	All ingredients are there; you get $b\,\bar{b}H$ for free.
$pp \to bH$	Easy for learning

Background MC:

$ZZ^\star$	Almost there (no γZ interference); very important, should be completed.
Vbb	Work in progress; (Oleari and Reina)

$t\bar{t}b\bar{b}$, $t\bar{t} + \mathrm{jets}$, $V + \mathrm{jets}$: more difficult.

Purpose of the NLO MC group

How do we organize our following work? We will continue to

Collect available programs and existing validation studies;
  These can be a starting point for further validation studies
Spot weaknesses in present implementation;
  Promote new work, in the areas where weaknesses are found.

Several "signal" working group have manifested the intention to perform validation study on shower tools.
Should we organize "virtual" meetings with them?