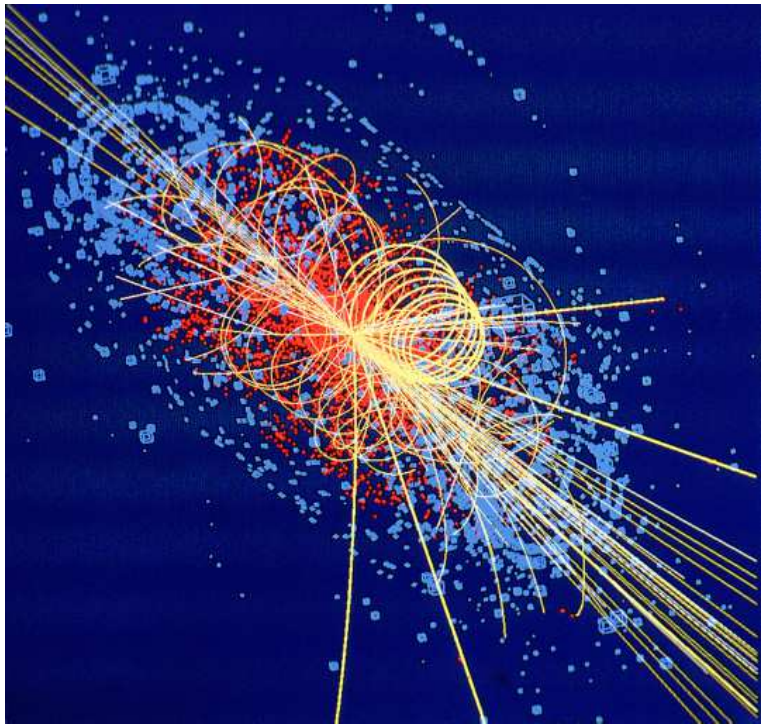
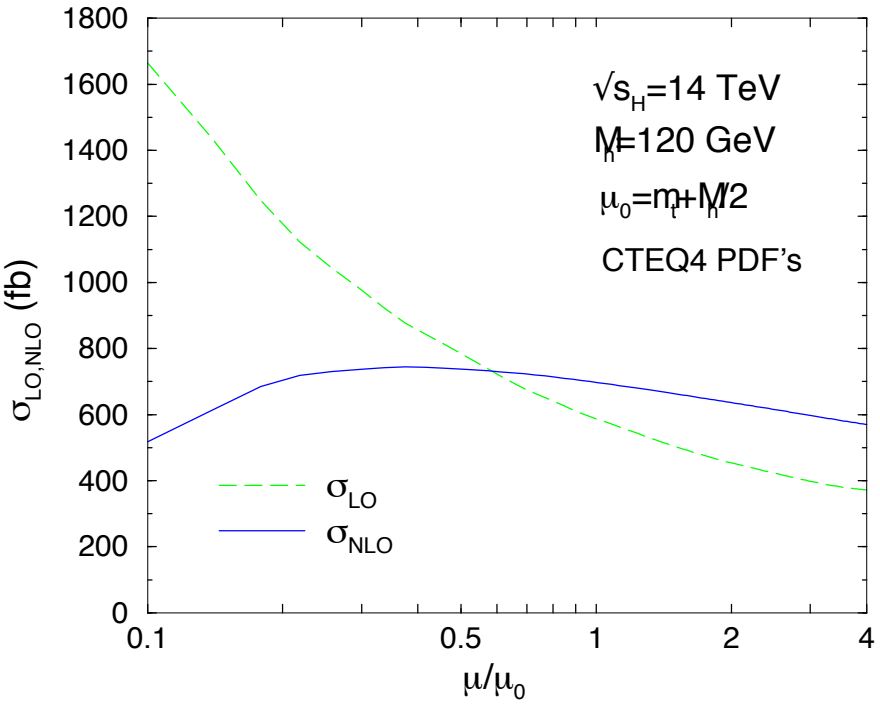
Higgs production in association with top quarks



Barbara Jäger

meeting of the LHC HXS WG 1 / ttH subgroup – October 2014

$pp \to t\bar{t}H$: NLO-QCD corrections



- two independent calculations:

  Beenakker et al. (2001)

  Dawson et al. (2001-2002)

- first NLO-QCD calculation for a massive $2 \to 3$ process

  technique: Feynman diagram approach

  (tricky: numerically stable reduction of tensor integrals)

- size of corrections dependent on scale choice (about 20 to 40%)
- theoretical uncertainty at NLO dramatically reduced to $\sim$15%

$pp \to t\bar{t}H$: NLO-QCD matched with parton shower

several implementations available
(make use of MC@NLO or POWHEG formalism)

- aMC@NLO: *Frederix et al. (2011)*

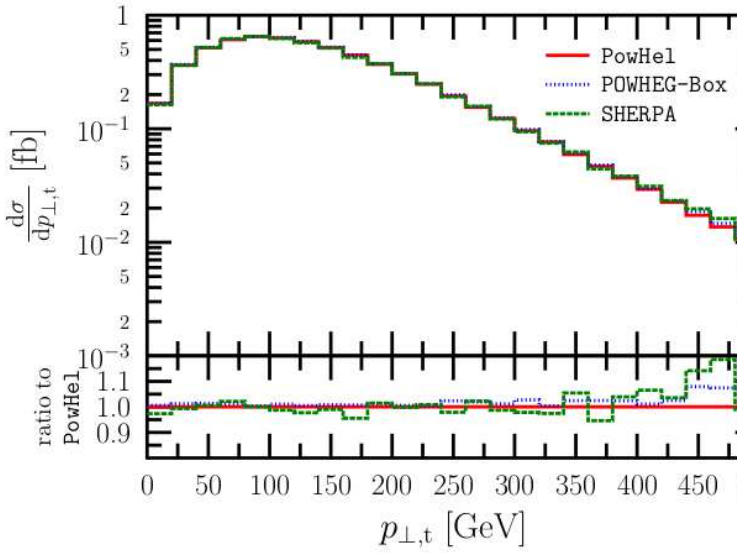
- PowHel: *Garzelli, Kardos, Papadopoulos, Trocsanyi (2011)*
  matrix elements from HELAC-OneLoop
  matching with private version of the POWHEG-BOX

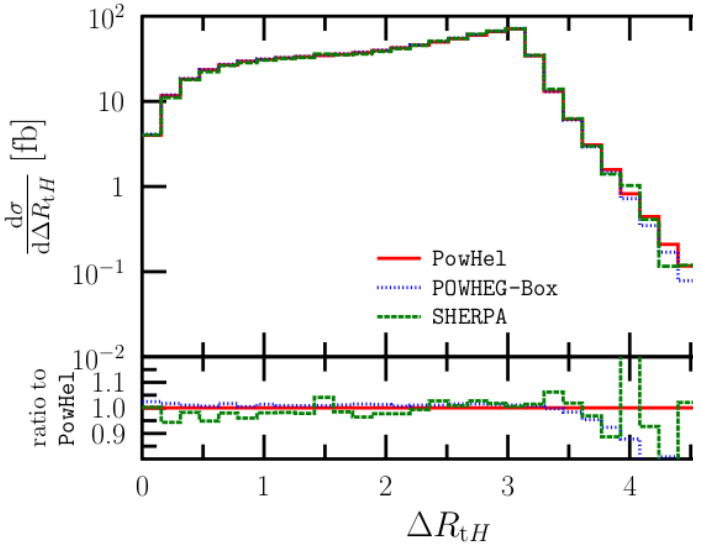
- POWHEG-BOX: *Hartanto, B. J., Reina, Wackeroth (2014)*
  implementation in public version of the POWHEG-BOX
  cross-checked with PowHel; code to be relased soon

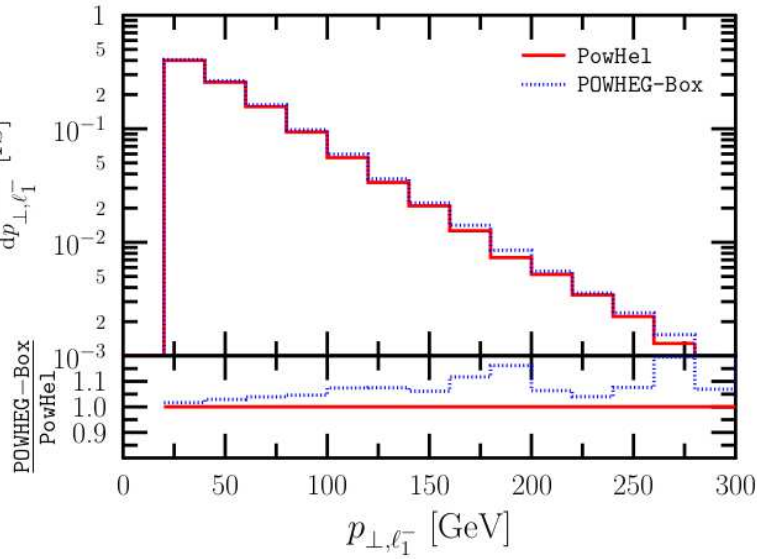
- Sherpa: *Hartanto, Reina, Hoeche*
  in testing phase; to be released soon

$pp \to t\bar{t}H$: NLO-QCD matched with parton shower

Standard Model Working Group: Les Houches Proceedings (2014)







systematic comparison: full agreement at NLO and NLO+PS

between implementations in `PowHel`, `POWHEG-BOX`, `Sherpa`

$pp \to t\bar{t}H$: higher jet multiplicities

NLO-QCD corrections to $pp \to t\bar{t}H+$ jet completed by *Deurzen et al. (2013)* with the help of `GoSam`:

* NLO corrections can be sizable
* scale uncertainty reduced

$\to$ better control on extra jet activity in $pp \to t\bar{t}H$

important pre-requisite for merged samples

at NLO+PS level with different jet multiplicities

$pp \to t\bar{t}H$: NLO-EW corrections

generally: expect NLO-EW corrections to be smaller than NLO-QCD corrections ($\alpha \sim 0.1\alpha_s$),
but they can become significant in high-energy domain because of large Sudakov logarithms

recent calculation of technically challenging weak and EW corrections by

(a) Frixione, Hirschi, Pagani, Shao, Zaro (2014)

(b) Zhang, Ma, Zhang, Chen, Guo (2014) :

- predictions for LHC at $\sqrt{s} = 8, 13, 100$ and $14, 33, 100$ TeV
- in (b) top decays considered in narrow-width approximation
- NLO-EW corrections to incl. x-sec $\lesssim -1\%$
- tails of p_T distributions receive corrections up to -10%

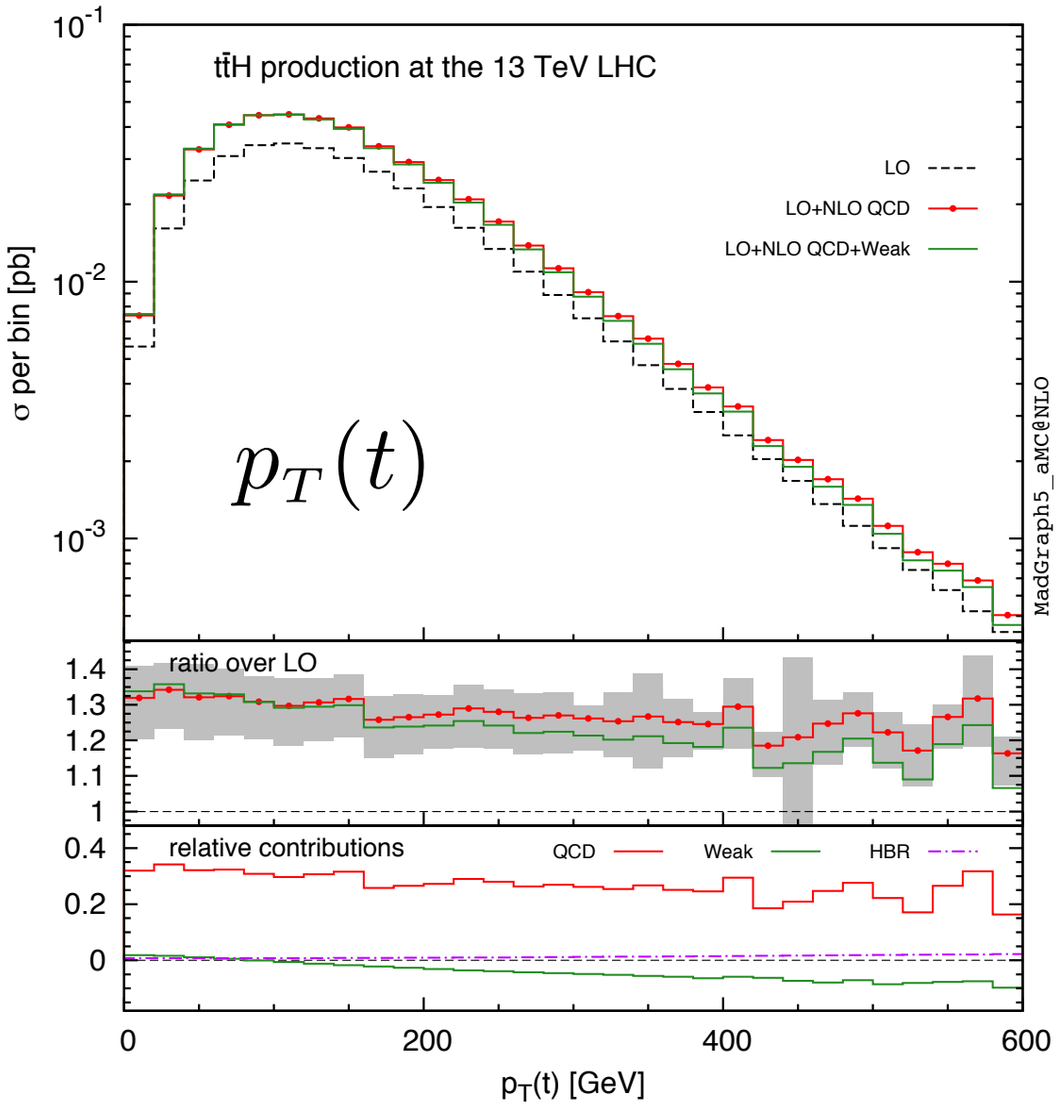
NLO Weak corrections to $t\bar{t}H$ production

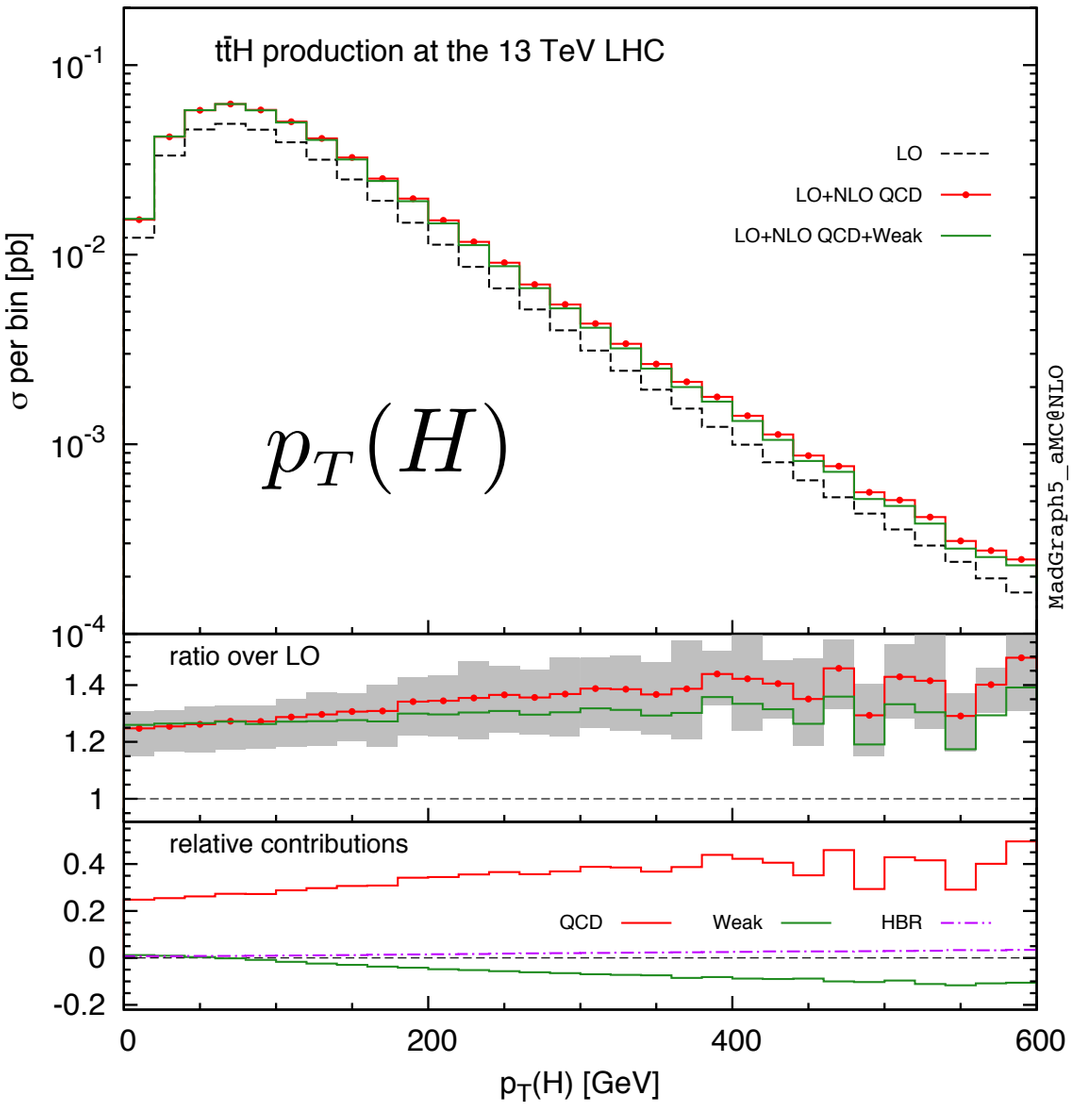
Relative corrections

(Boosted regime in brackets)

$p_T(t) \geq 200$ GeV, $p_T(\bar{t}) \geq 200$ GeV, $p_T(H) \geq 200$ GeV

$\delta_{\rm NLO}(\%)$	8 TeV	13 TeV	100 TeV
QCD	$+25.6^{+6.2}_{-11.8}$ $(+19.6^{+3.7}_{-11.0})$	$+29.3^{+7.4}_{-11.6}$ $(+23.9^{+5.4}_{-11.2})$	$+40.4^{+9.9}_{-11.6}$ $(+39.1^{+9.7}_{-10.4})$
weak	-1.2 (-8.3)	-1.8 (-8.2)	-3.0 (-7.8)
HBR	$+0.9$ $(+1.7)$	$+0.9$ $(+1.9)$	$+0.9$ $(+1.7)$





QED effects soon available

Frixione, Hirschi, Pagani, Shao, Zaro, JHEP09(2014)065 (arXiv:1407.0823)

$pp \to t\bar{t}H$ signal: achievements of the HXSWG

YR1:

- NLO-QCD: σ(incl.) at 7 and 14 TeV for different values of M_H
- estimate of theor. uncertainties due to variation of scales, α_s, PDFs

YR2:

- differential distributions at NLO-QCD for $\sqrt{s} = 7$ TeV
- estimate of theoretical uncertainties at NLO-QCD
- matching of NLO+PS: comparison between `PowHel` and `aMC@NLO`

YR3:

- NLO-QCD: σ(incl.) at 8 TeV for different values of M_H
- estimate of theoretical uncertainties at NLO-QCD
- effects of top spin correlations in production and decay

$pp \to t\bar{t}H$ signal: findings of the HXSWG

- LO results strongly depend on PDF set and scale choice
- better agreement at NLO, but still sizeable PDF uncertainties
  $\to$ recommend envelope prescription for uncertainty estimates
- mild changes ($\lesssim 10\%$) in shapes of distributions for inclusive cuts,
  more pronounced for exclusive cuts and in boosted regime
- effects of top spin correlations in production and decay
  can be pronounced for selected distributions

☞ recommendation: whenever possible, use NLO+PS tool,
ideally including spin correlations in top production and decay

beyond on-shell & spin-averaged $t\bar{t}H$ production

experimental signature of $pp \to t\bar{t}H$: not tops, but their decay products (e.g. from $t \to Wb \to \ell\nu b$ decay chains)

but: full NLO-QCD calculation of $pp \to \ell^+\nu b\ell^-\bar{\nu}\bar{b}H$ out of reach

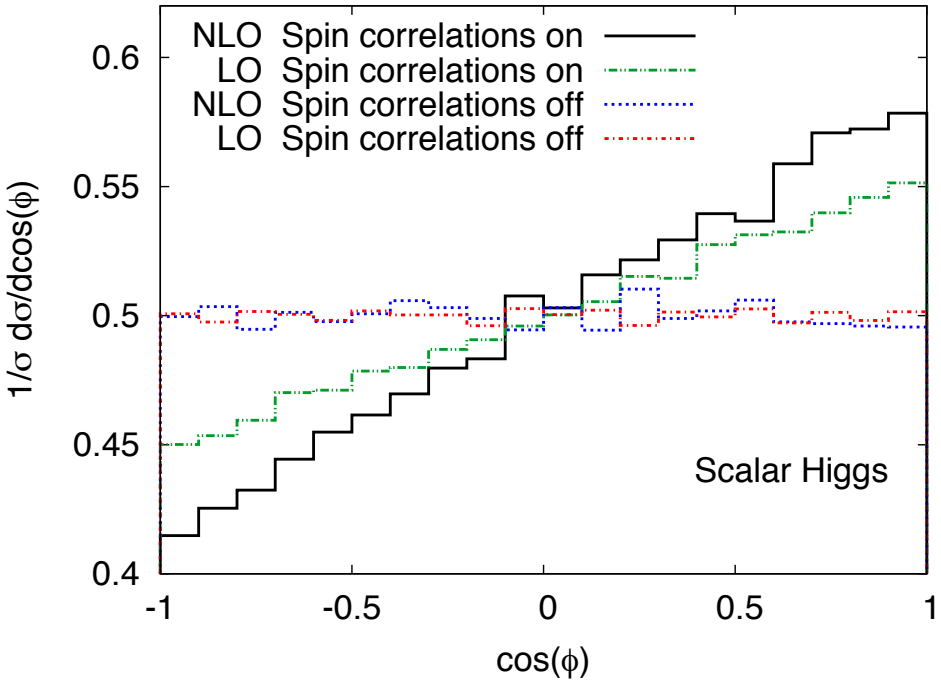
☞ use prescription of *Frixione, Laenen, Motylinski, Webber (2007)*:

1) generate LHE events for $t\bar{t}H$ on-shell at NLO-QCD,
2) add decays of tops at LO in narrow-width approximation,
3) re-instate off-shell effects of the tops

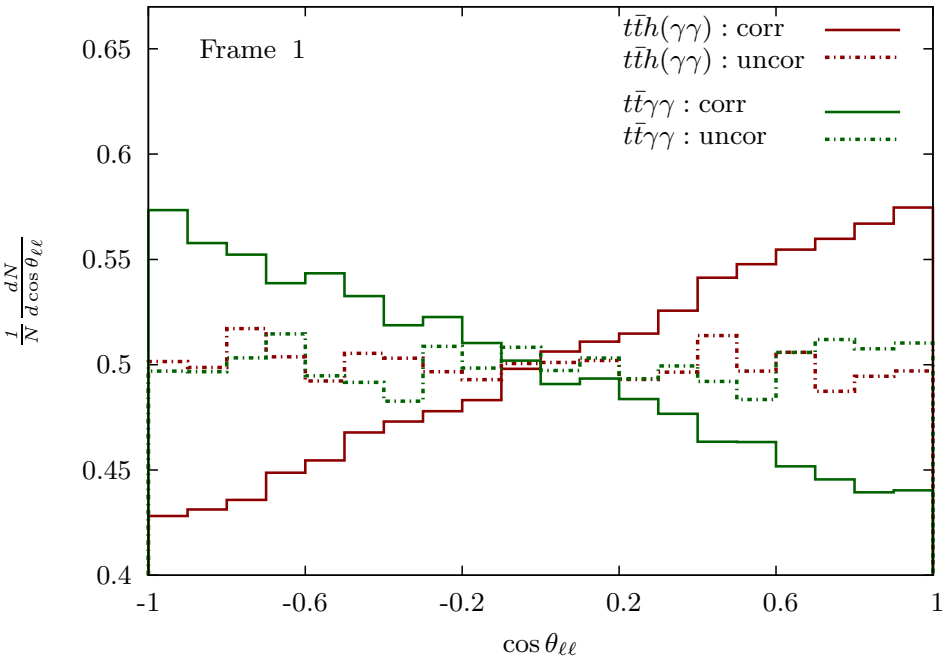
options for this prescription in `MadGraph5_aMC@NLO (MadSpin)`, `PowHel (Decayer)`, and `POWHEG-BOX`

spin correlations

Artoisenet et al. (2012)



Biswas et al. (2014)



spin correlations of top quarks persist at NLO and help in discrimination of signal and background

off-shell effects

recall: full NLO-QCD calculation for $pp \to \ell^+\nu b \ell^- \bar{\nu} \bar{b} H$
out of reach

$\to$ how can we estimate impact of missing off-shell effects?

c.f. related process of $pp \to t\bar{t}$:

systematic comparison of NLO-QCD calculation for
$pp \to t\bar{t}$, amended by decays $t \to W^+ b$ and $\bar{t} \to W^- \bar{b}$
with full $pp \to W^+ W^- b\bar{b}$ process

Garzelli, Kardos, Trocsanyi (2014)

☞ off-shell effects can be sizable for
distributions/correlations of decay products (e.g. $M_{b\ell}$)

more studies needed . . .

- full NLO-QCD calculation for $pp \to \ell^+\nu b \ell^- \bar{\nu} \bar{b} H$

  first step: on-shell calculation for $pp \to t\bar{t}H$

  with NLO-QCD corrections to decay

- matching and merging at NLO-QCD for $pp \to t\bar{t}H + \text{jets}$

- interplay of QCD and EW corrections:

  explore kinematic regimes where effects are different from inclusive scenario (boosted setup etc.)

- interference of the $t\bar{t}H$ signal with various backgrounds

expect these effects to be more important than NNLO-QCD corrections (which are out of reach at the moment)