

$t\bar{t}H$ signal: theory status

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$t\bar{t}H$ production at LHC

- * traditionally considered one of the relevant Higgs production mechanisms, at least for light Higgses ($m_h < 130\text{GeV}$)

- * Smaller cross-section with respect to the other “relevant” production mechanisms, but its relative importance increases with energy

$\sigma_{t\bar{t}H} \sim 0.13\text{ pb}$ vs $\sigma_{ggF} \sim 19\text{ pb}$ at 8 TeV

- * Higgs radiated out of top quarks: direct access to info on $Y_{t\bar{t}H}$, the largest among the Higgs Yukawa couplings.

- * Complementary info (more model dependent) on this coupling from ggF.

- * Further info on this coupling (and CP violating phase) from single top + Higgs boson production.

- * Investigating deviations from the SM could provide signature of new physics: $\Delta Y_{t\bar{t}H}$ from very few percent to tens of % depending on NP models.

- * to be compared with $\sim 10\%$ expected sensitivity on $\Delta Y_{t\bar{t}H}$ for LHC at 14 TeV, 3 ab^{-1} integrated luminosity.

$t\bar{t}H$ production cross-section: computations pre-HXSWG

- * LO results from several tools
(PYTHIA, MCFM, general purpose LO event generators)
- * NLO QCD corrections computed already long ago by tensor-reduction approaches
 - W. Beenakker et al. [arXiv:hep-ph/0107081], [arXiv:hep-ph/0211352]
 - L. Reina et al. [arXiv:hep-ph/0107101]
 - S. Dawson et al. [arXiv:hep-ph/0211438], [arXiv:hep-ph/0305087]
- * Further cross-checked by NLO event generators
(MadLoop/MadFKS, Helac-NLO, Gosam+SHERPA, OpenLoops+SHERPA)

$t\bar{t}H$ production cross-section: advances in the framework of the HXSWG

* YR1:

- inclusive σ_{NLO} at 7 and 14 TeV for different values of m_H
- estimate of the theoretical uncertainties related to $\mu_R = \mu_F$ scale, α_S and PDF (CTEQ6.6, MSTW2008, NNPDFv2.0) variations.

* YR2:

- differential NLO distributions at 7 TeV
- estimate of their theoretical uncertainties
- NLO + Parton Shower matching: comparison of differential distributions from PowHel and aMC@NLO
- some considerations on the background ($t\bar{t}b\bar{b}$)

* YR3:

- inclusive σ_{NLO} at 8 TeV for different m_H
- estimate of their theoretical uncertainties
- effects of the inclusion of spin correlations in $t\bar{t}H$ production and decay
- NLO QCD study of the $t\bar{t}b\bar{b}$ background at 8 TeV by OpenLoops + SHERPA
- first comparisons between $t\bar{t}H$ signal and $t\bar{t}b\bar{b}$ background at NLO QCD + PS accuracy, at 14 TeV, by PowHel + PYTHIA

Considerations from these studies

- * σ_{LO} and K -factor depend heavily on the PDF set chosen
 - ⇒ better agreement in **normalization** is reached at NLO, although variations of PDFs within a same set do not always cover the central value from a different set → use of PDF envelope prescription for computing the uncertainties.
 - * **Shape** of distributions at NLO in general differ mildly from those at LO in case of inclusive cuts (within 10%), although specific kinematics regimes experience larger changes (e.g. those relevant for boosted Higgs searches).
 - * Furthermore, **differences increase for more exclusive cuts**.
 - * Effects of including **spin correlations** in production and decay can be even larger than the NLO vs LO ones on some selected distributions.
- ⇒ even **in experimental analyses** it is **important to use NLO or NLO predictions matched with Parton Shower** (instead of LO ones), **complemented by tools for describing spin correlations in top production and decay**.

What is available for use by the experiments ?

- * NLO QCD + PS predictions of $t\bar{t}H$ by aMC@NLO [arXiv:1104.5613]
 - can be obtained by running the aMC@NLO code
- * NLO QCD + PS predictions by PowHel [arXiv:1108.0387]
 - Les Houches events available on the web or upon request
<http://grid.kfki.hu/twiki/bin/view/DbTheory/TthProd>
 - ready to be showered by SMCs
- * NLO QCD + PS implementation of $t\bar{t}H$ in POWHEG-BOX
(on the basis of virtual routines by L. Reina et al.)
 - cross-checked with PowHel [arXiv:1405.1067]
 - publicly available soon
- * NLO QCD + PS implementation of $t\bar{t}H$ in SHERPA
(on the basis of virtual routines by L. Reina et al.)
 - still preliminary and under test [arXiv:1405.1067]

What about spin correlations ?

Tools to take care of spin correlations effects in both production and decay, acting directly on $t\bar{t}H$ LHE events (generated with on-shell top quarks), adding LO decays in the NWA and reinstating a-posteriori off-shell effects on the tops:

- internal implementation in POWHEG-BOX (applied in $Wb\bar{b}$, $t\bar{t}$, $t\bar{t}j$)
- MadSpin [arXiv:1212.3460]
- Decayer [arXiv:1405.5859]

Implementations independent one from each other, although all of them are based on the work of Frixione et al. [arXiv:hep-ph/0702198].

N.B. SHERPA has also its own internal implementation.

Recent work on spin correlations

In the chiral limit polarization properties of $t\bar{t}$ in $t\bar{t}H$ differ from those of $t\bar{t}$.

Idea: exploit the different effect of spin correlations on $t\bar{t}H$ signal and its backgrounds, in order to maximize the signal/background ratio, looking at specific polarization observables.

S. Biswas et al. [arXiv:1403.1790]

LO analysis, to be repeated at NLO/NLO+PS level.

Still to be done / ongoing

- * update of signal NLO QCD cross-sections and their uncertainties in specific kinematic regimes, by considering dynamical scale (in view of the studies at $\sqrt{s} = 13$ and 14 TeV)
- * study of $W^+ W^- b\bar{b}H$ including NLO QCD corrections (off-shell tops): interesting, although probably non too urgent.
- * merging $t\bar{t}H$ and $t\bar{t}Hj$
- * including NLO EW corrections (probably more important than including NNLO QCD corrections)
- * computing $t\bar{t}Vj$ including NLO QCD corrections matched to PS, with t -quarks decayed preserving spin correlations: request by the experimentalists, feasible.
- * **ongoing**: study of the backgrounds and their uncertainties

Final aim: study of signal/background with the best accuracy within reach, in presence of experimental cuts.

Main backgrounds: most recent works

* $t\bar{t}b\bar{b}$

- NLO QCD + PS matching by PowHel (in the 5-flavour scheme) [arXiv:1303.6291]
- NLO QCD + PS matching by OpenLoops + SHERPA (in the 4-flavour scheme) [arXiv:1309.5912]

* $t\bar{t}j\bar{j}$

- NLO QCD + PS matching by OpenLoops + SHERPA and merging with lower jet multiplicities [arXiv:1402.6293]

* $t\bar{t}W^+W^-$

- NLO QCD + PS matching by aMC@NLO [arXiv:1405.0301]

* $t\bar{t}\gamma$, $t\bar{t}\gamma\gamma$

- NLO QCD + PS matching by aMC@NLO (with Frixione isolation)
- NLO QCD + PS matching by PowHel (with Frixione or cone isolation) [arXiv:1406.2324]

.....more on the backgrounds in the next talk by Stefano Pozzorini