ttH and tH modelling

"ATLAS ttH/tH lessons from Run-1 and strategy for Run-2".

Higgs (N)NLO MC and Tools workshop 18.12.14

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Overview

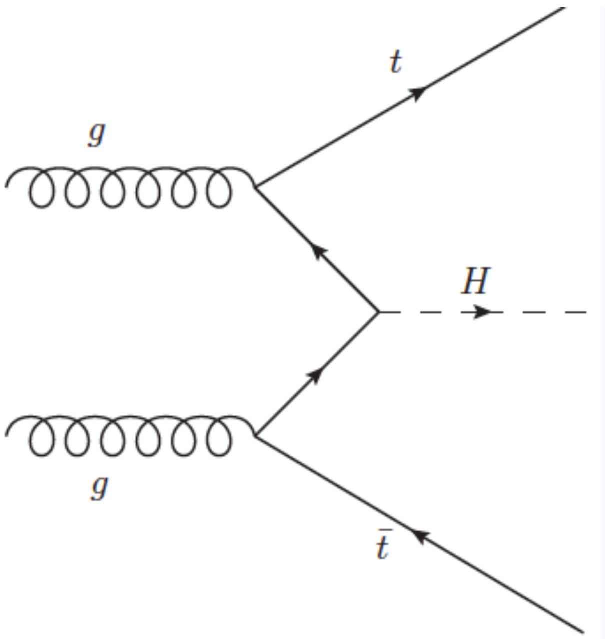
- ttH signal modelling
  - Run 1: PowHel (HelacNLO+Powheg box) + Pythia8
  - Other available generators:
    - MadGraph5_aMC@NLO
    - (Sherpa)

Cross-section at 8 TeV	
ttH	0.129 pb
tt+jets (ttbb)	252.9 pb (5 pb)
tH	0.022 pb

- tt+jets/HF background modelling
  - Run 1: Powheg + Pythia6 inclusive sample
    - uncertainties derived comparing to dedicated ttbb samples
  - Other available generators:
    - MadGraph5_aMC@NLO
    - Sherpa

- tH signal modelling
  - Run 1: t-channel (tHj and tHjb) ➔ MadGraph5 (4FS LO) + Pythia8
    tWH ➔ MadGraph5_aMC@NLO (5FS with DR) + Herwig++ (no MadSpin)

ttH signal



Run 1: Pythia8 LO at 7 TeV and PowHel+Pythia8 NLO at 8 TeV
Towards Run 2, other available generators are being studied.
Here, first studies with MadGraph5_aMC@NLO are presented.

ttH simulated samples

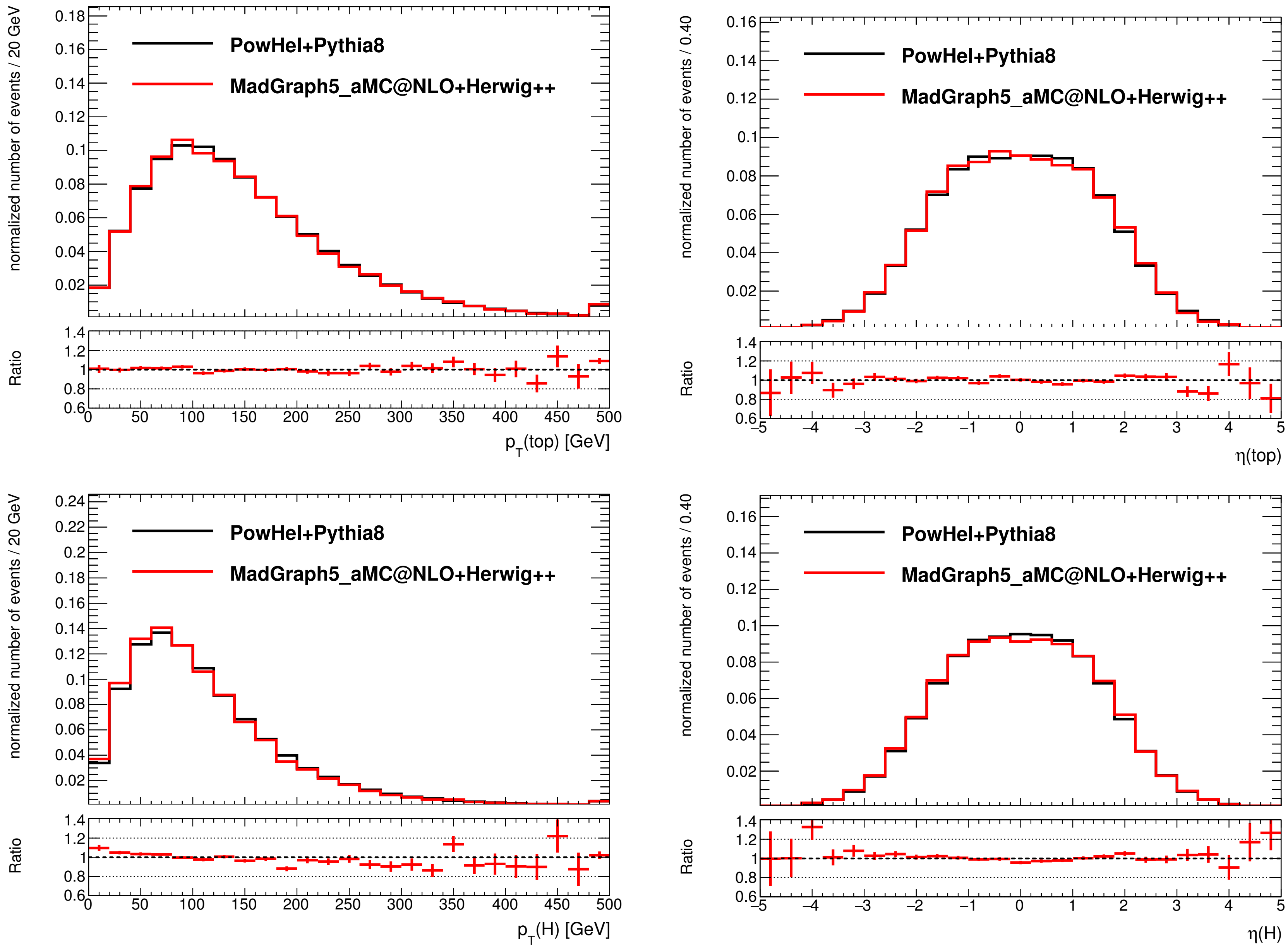
* **MadGraph5_aMC@NLO** (v2.2.1) **+ MadSpin**
  - scale: Q= $(m_{t,T}+m_{tbar,T}+m_{H,T})/2$ (dynamic)
  - PDF set: CT10 for ME
  - interfaced with Herwig++ (v2.7.1, UE-EE5 tune
  - interface with Pythia8 (with global recoil on) also possible (tuning effort ongoing)

* **PowHel** (HelacNLO+Powheg box)
  - h_{damp}=inf.
  - scale: Q= $(m_t+m_{tbar}+m_H)/2$=235 GeV (static)
  - PDF set: CT10nlo for ME
  - interfaced with Pythia8 (v8.175) AU2 tune (no main 31 used)

* **Sherpa**
  - coming soon…

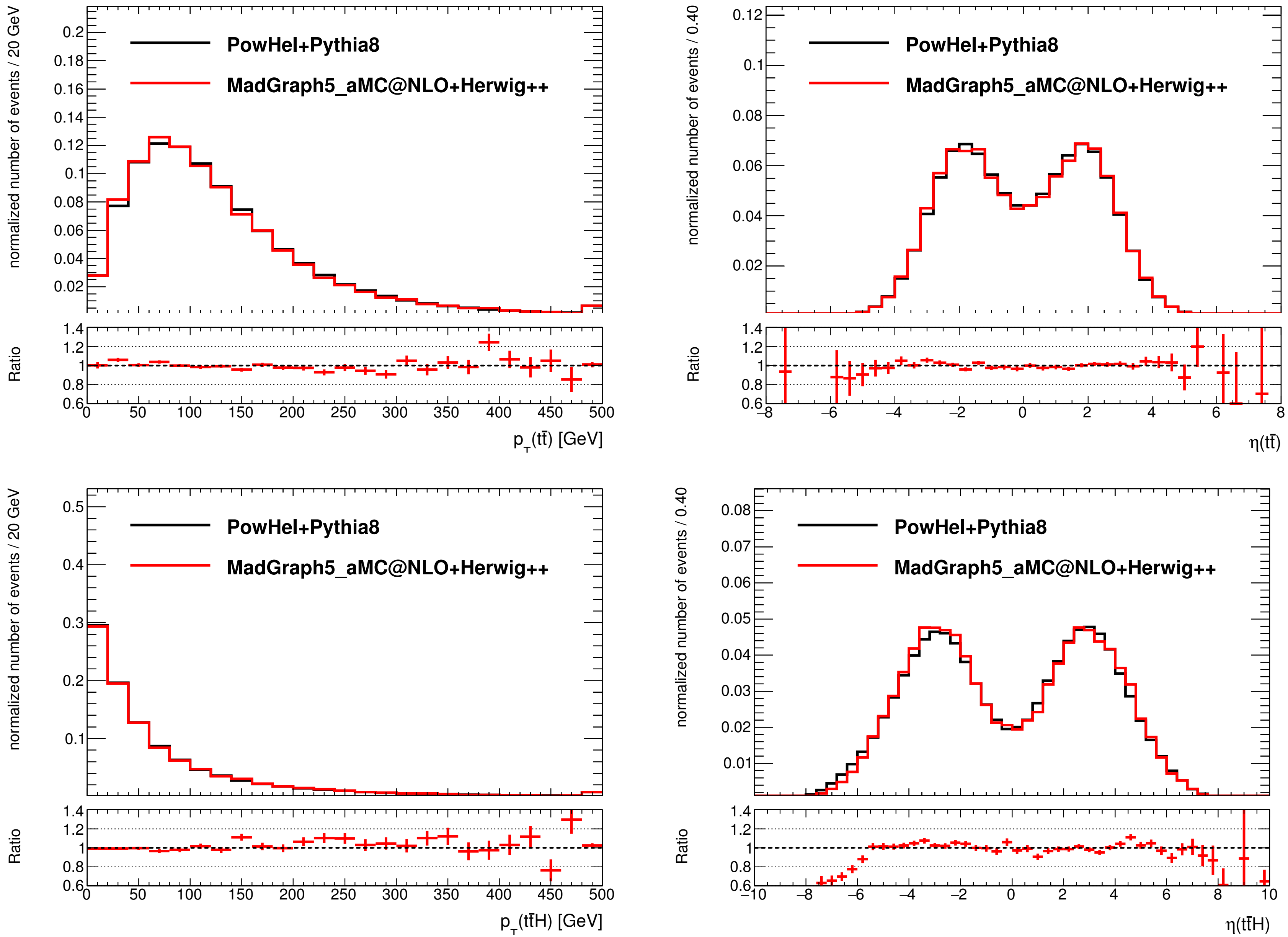
All samples at 8 TeV with m_{top}=172.5 GeV and m_H=125 GeV.

top quark & Higgs boson kinematics



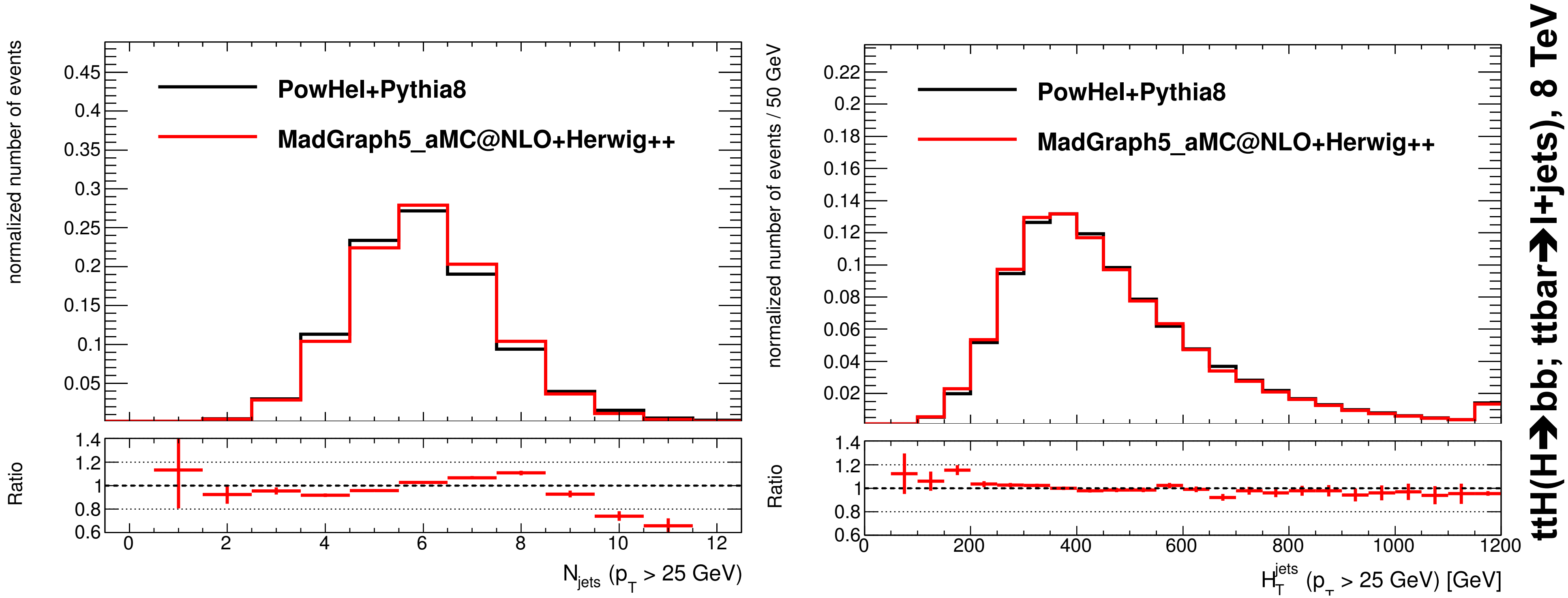
ttH(H→bb; ttbar→l+jets), 8 TeV

ttbar & ttH kinematics



ttH(H→bb; ttbar→l+jets), 8 TeV

N_{jets} and H_T



Jets are required to have p_T>25 GeV and |eta|<2.5.

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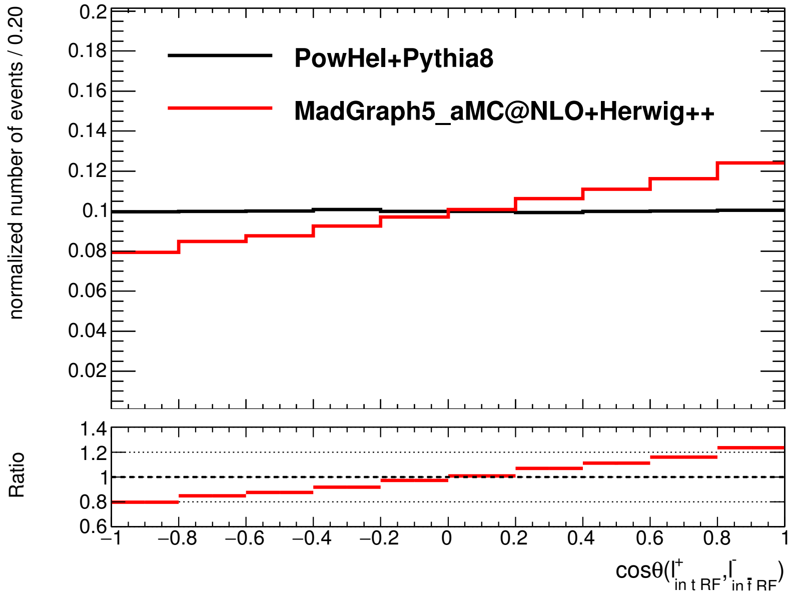
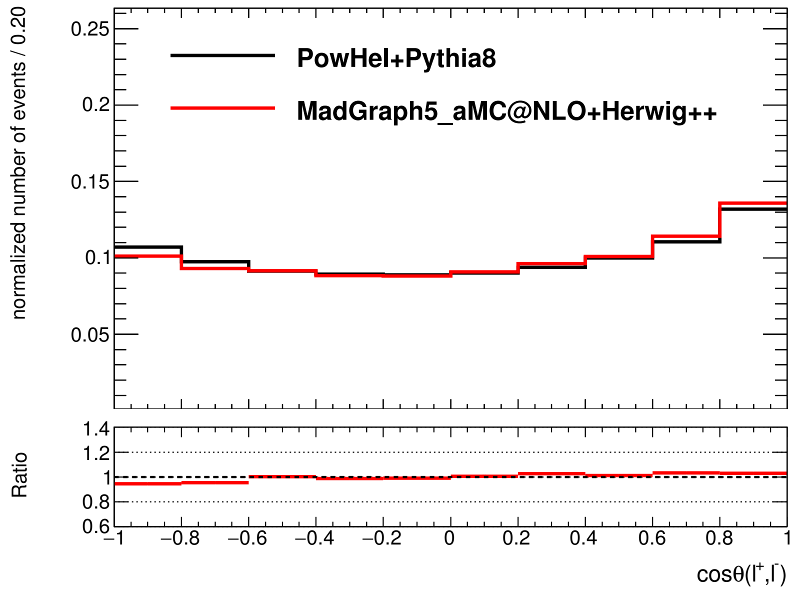
Observables sensitive to spin effects

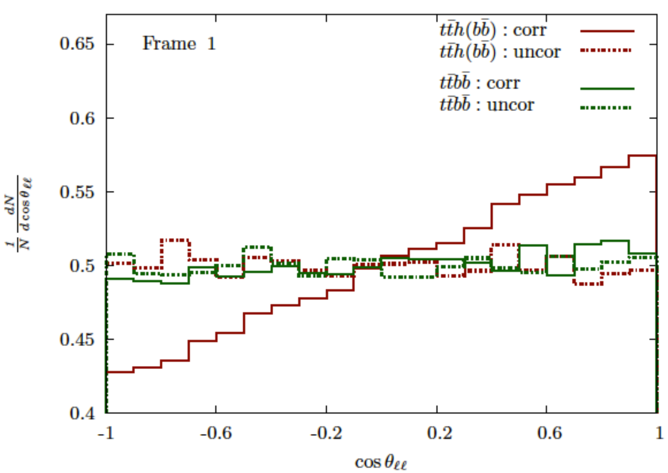
cosθ(l⁺,l⁻) l⁺ in top rest frame and l⁻ in tbar rest frame

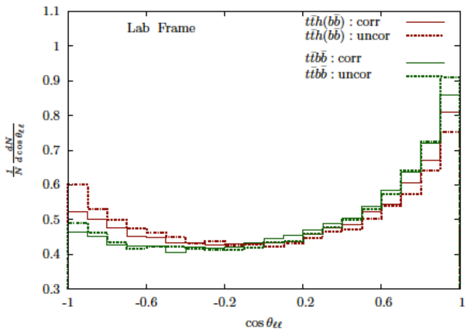


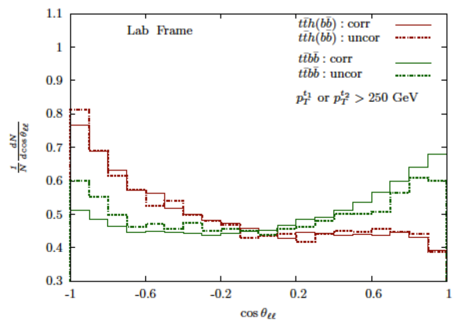
cosθ(l⁺,l⁻) l⁺ and l⁻ in the LAB frame



ttH(H→bb; ttbar→dilepton), 8 TeV







Observables sensitive to spin correlations: useful tool for enhancing sensitivity of S/B on ttH

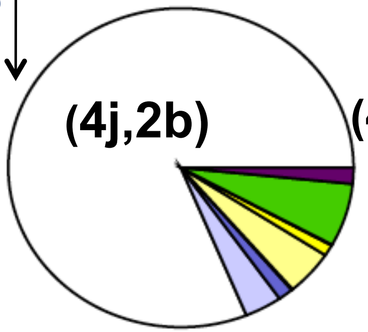
"Enhancing the ttH signal through top-spin polarization effects at the LHC" JHEP 07 (2014) 020

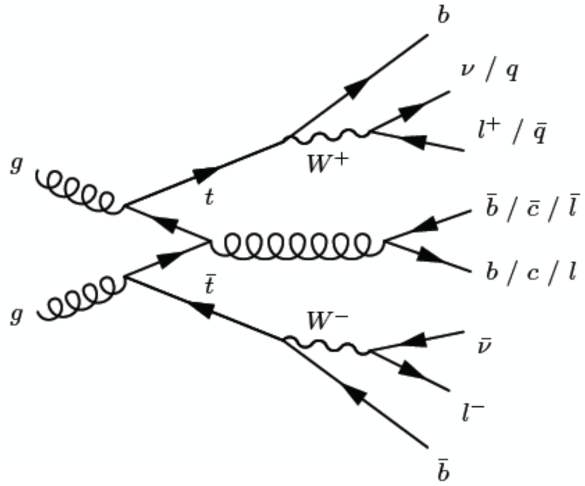
tt+jets (including tt+HF)

tt+jets (including tt+HF)

nbJets →
nJets ↓

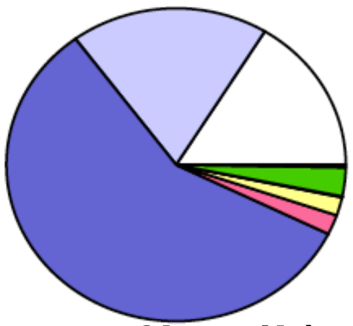
(4j,2b) **(4j,3b)** **(4j,4b)**





(5j,2b) **(5j,3b)** **(5j,4b)**

(>=6j,2b) **(>=6j,3b)**



(>=6j,>=4b)

Irreducible background to ttH(H→bb), with σ~5 pb (ttH signal σ~0.13 pb) at 8 TeV.

The modelling of tt+bb background, and the related uncertainties play a key role in this search. The implementation of the latest theoretical developments is therefore of critical importance.

ttH(H→bb), l+jets
Background composition

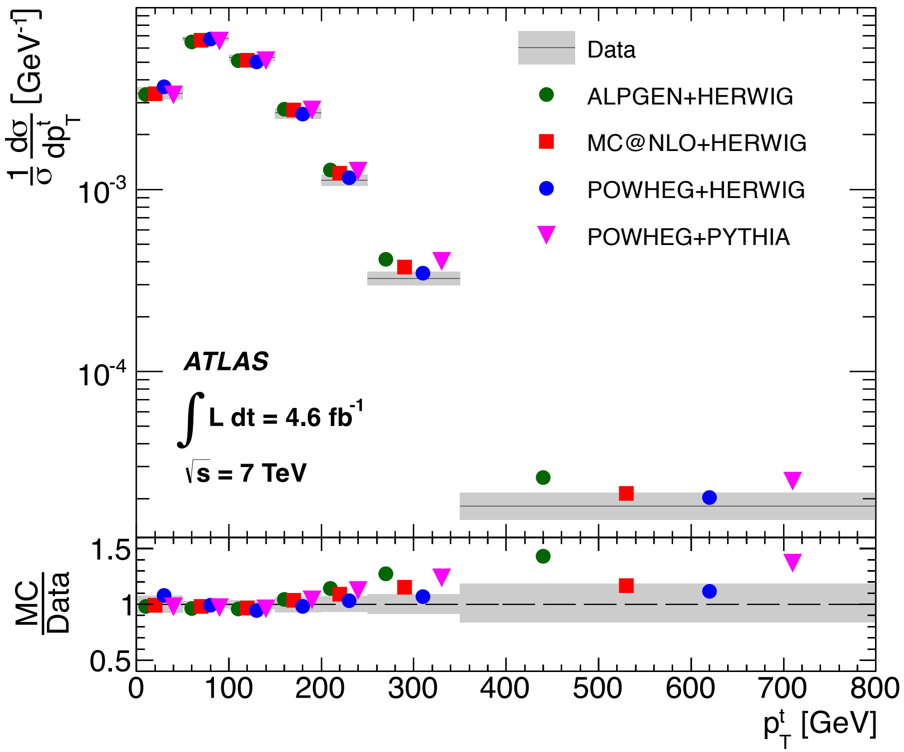
Run1 ttbar modelling

In Run1, an inclusive tt+jets sample simulated with Powheg+Pythia6(h_{damp}=inf) at NLO accuracy was used.

- Differential cross-section measurement at 7 TeV show that Powhel model, with the settings used, does not match the data.
In particular, ttbar and top p_T distributions showed that data softer than MC.
To correct for this, two reweightings were derived.

- It was observed that changing one of the settings (h_{damp}=m_{top}), the agreement with data improves.

- New generators available such as MadGraph5_aMC@NLO and Sherpa are also been studied (first studies in next slides).



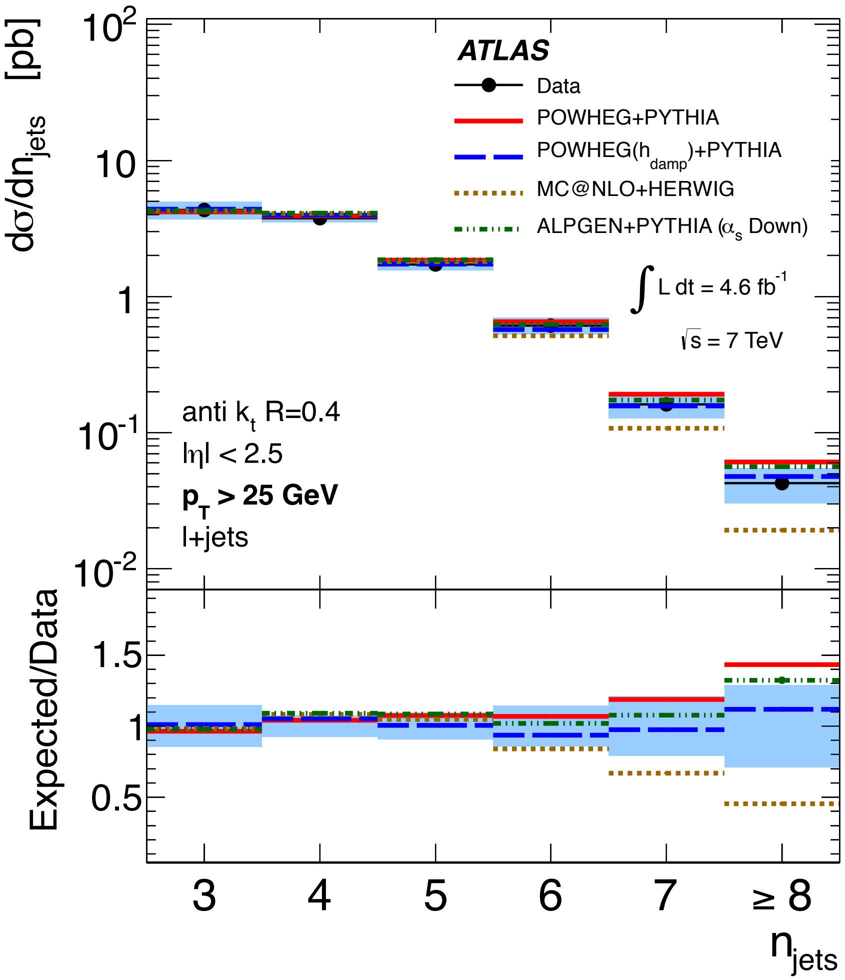
h_{damp}: parameter to regulate hardness of first radiation

First look at MadGraph5_aMC@NLO

* **MadGraph5_aMC@NLO** (v2.2.1) **+ MadSpin**
- scale: Q=sqrt[$m_{top}^2+(p_{top,T}^2+p_{antiop,T}^2)/2$]
- PDF set: CT10 for ME, CTEQ6L1 for PS
- interfaced with Herwig++ (v2.7.1) UE-EE5 tune

* **Powheg**
- $h_{damp}=m_{top}$
- scale: Q=sqrt[$m_{top}^2+p_{top,T}^2$]
- PDF set: CT10 for ME, CTEQ6L1 for PS
- interfaced with Pythia6 Perugia 2011c tune

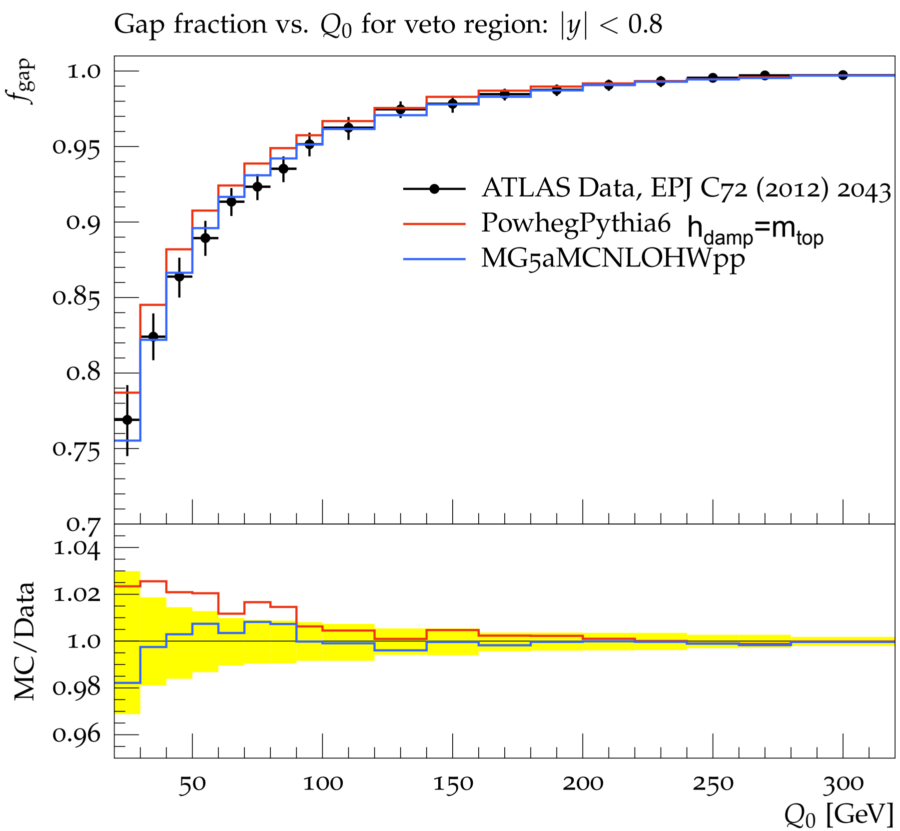
All samples at 7 TeV with m_{top}=172.5 GeV.

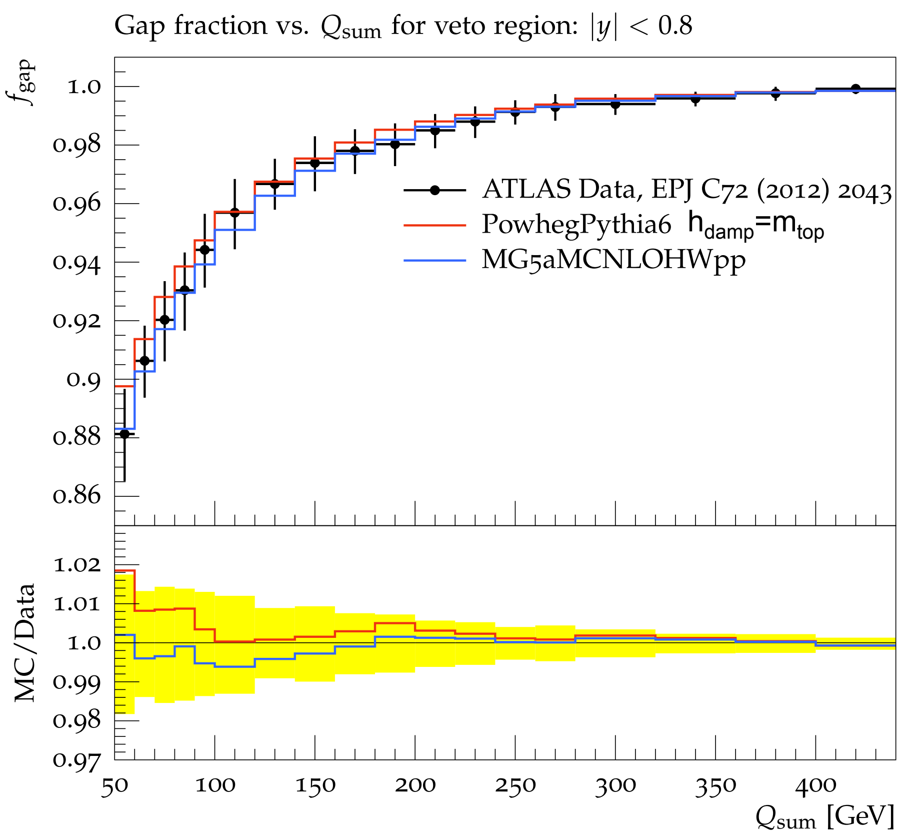


Rivet analysis routines:
gap fraction: **ATLAS_2012_I1094568**
jet shapes: **ATLAS_2013_I1243871**

First look at MadGraph5_aMC@NLO

Gap fraction vs. Q_0 (left) or Q_{sum} (right) for veto region |y|<0.8



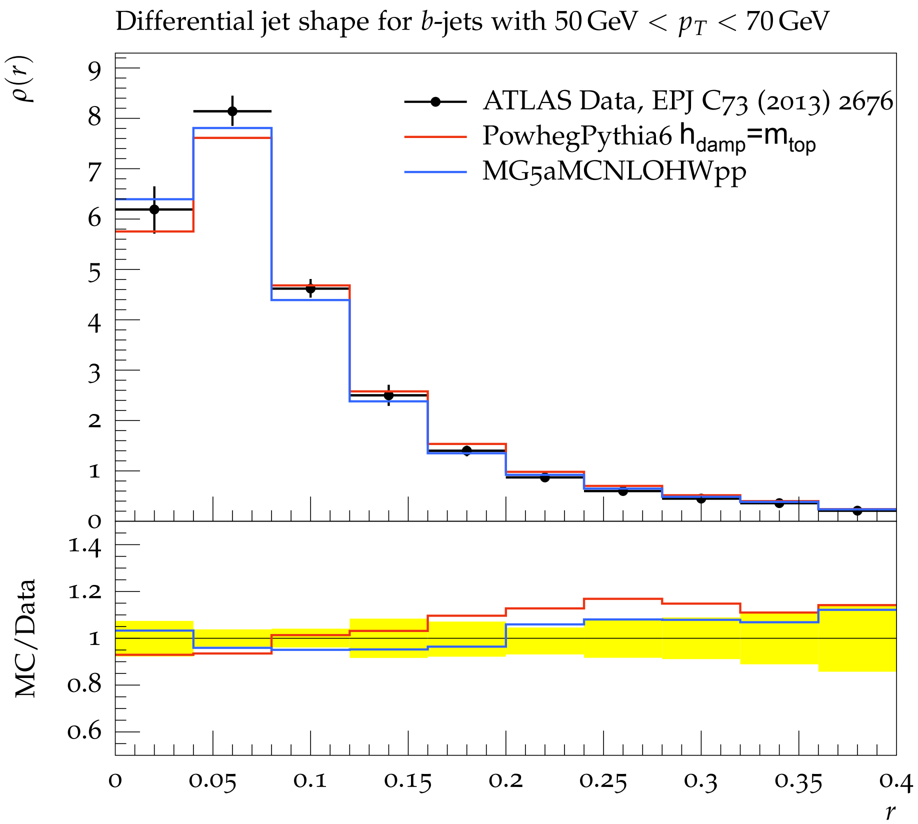


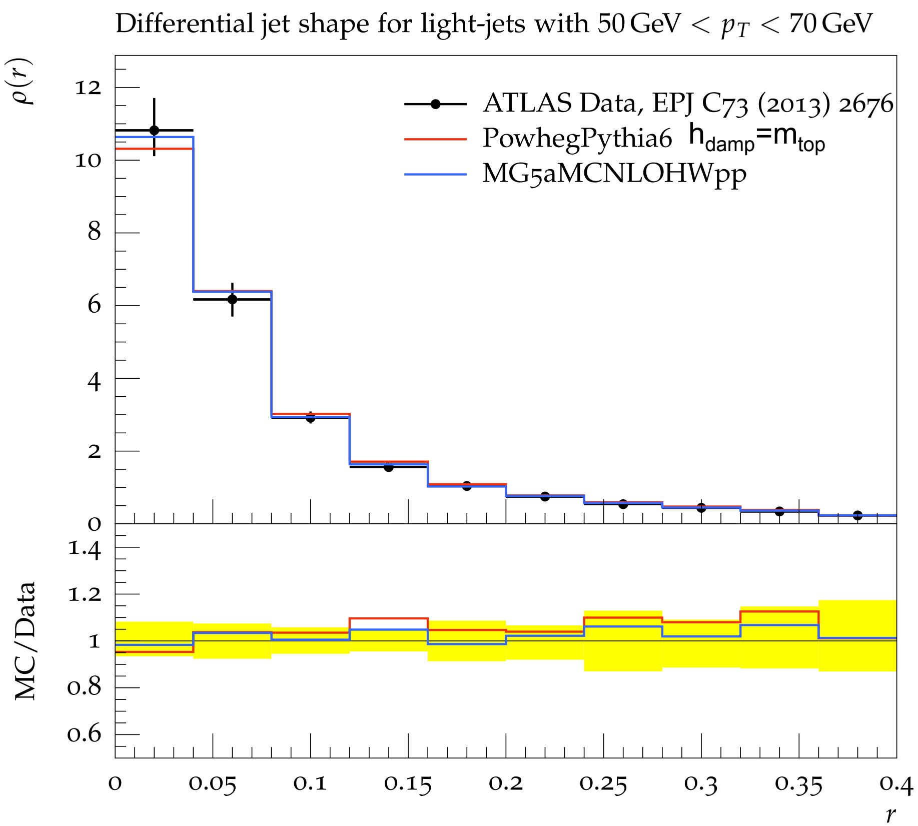
ttbar dilepton events, 7 TeV

- The gap fraction variables were observed to be sensitive to the modelling of the additional parton radiation in ttbar final states as well the renormalisation and factorisation scale choices.
- The gap fraction defined using Q_0 is mainly sensitive to the leading-p_T emission accompanying the ttbar system, while the one defined using Q_{sum} is mainly sensitive to all hard emissions.

First look at MadGraph5_aMC@NLO

Jet shapes





ttbar lepton+jets events, 7 TeV

First look at Sherpa samples

* **Sherpa v2.1.1+ OpenLoops:**
- NLO+PS
- MEPS@LO (up to 3 partons at LO)
- MEPS@NLO (0 and 1 parton at NLO + 2, 3 and 4 partons at LO)

- Q cut: 20 GeV
- scale (μ core): $Q=\mathrm{sqrt}[m_{top}^2+(p_{top,T}^2+p_{antiop,T}^2)/2]$
- PDF set: CT10nlo

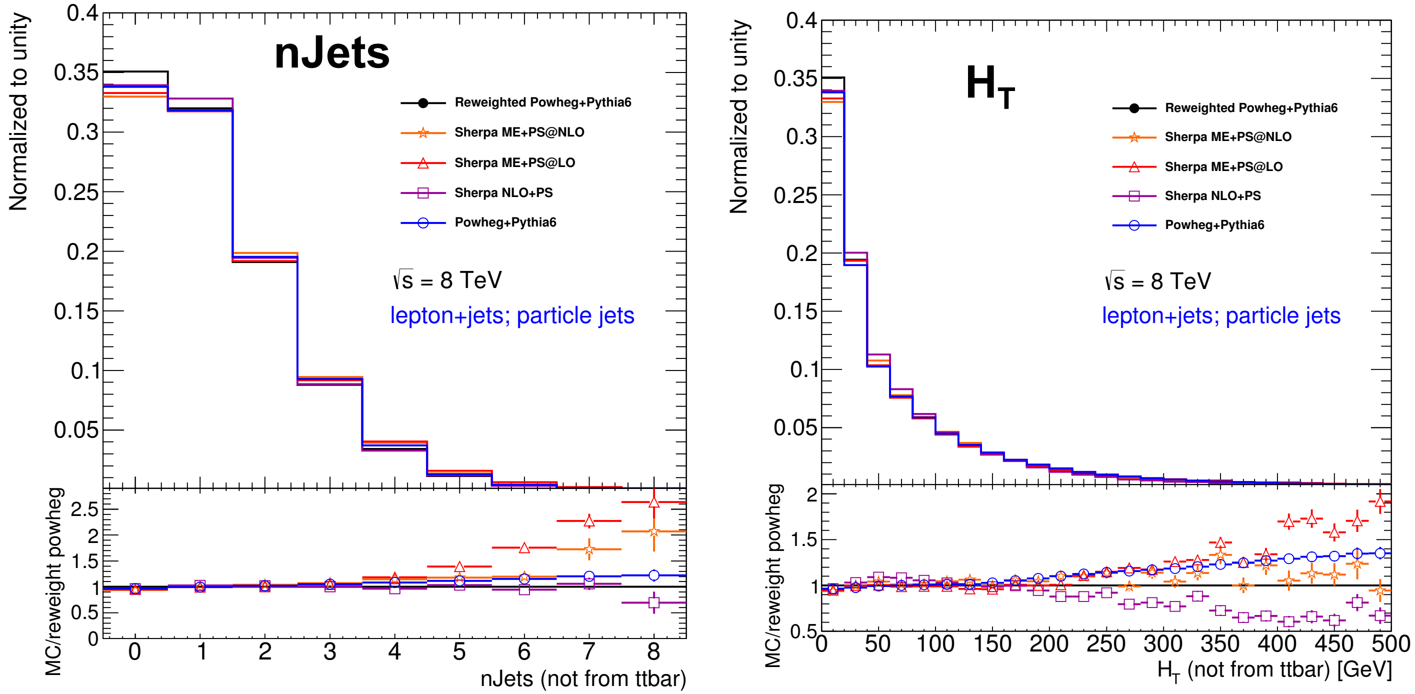
All samples at 8 TeV and m_{top}=172.5 GeV.

Sherpa samples are compared to Powheg+Pythia6 (both w/wo. top and ttbar RW), after selecting lepton+jets events. Studies performed at particle level:
- the top quarks are reconstructed using the correct combination of jets and leptons
- matching quarks and particle level jets (anti-k_t R=0.4): $0.5< p_T(\mathrm{jet})/p_T\,(\mathrm{quark}) <2$

First look at Sherpa samples

- Reweighted Powheg+Pythia6
- Sherpa ME+PS@NLO
- Sherpa ME+PS@LO
- Sherpa NLO+PS
- Powheg+Pythia6

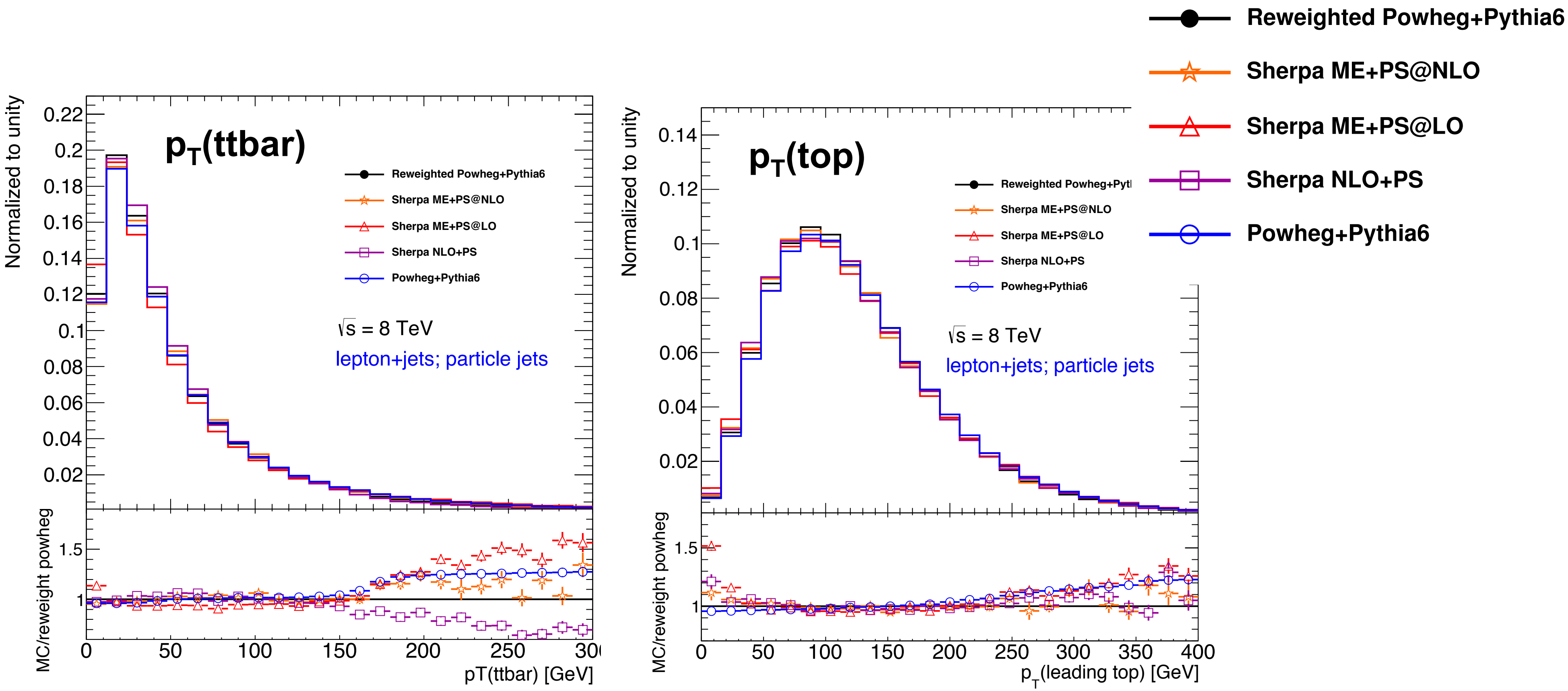
Excluding jets originating from top quarks decays



ttbar l+jets, 8 TeV

- Sherpa ME+PS@LO and Sherpa ME+PS@NLO samples predict more jets than Powheg+Pythia. The effect is more significant in the high multiplicity region. <u>Sherpa NLO+PS is compatible with Powheg+Pythia.</u>
- For H_T, Sherpa NLO+PS is softer than Powheg+Pythia while Sherpa ME+PS@LO is harder. <u>Sherpa ME+PS@NLO is compatible with Powheg+Pythia RW.</u>

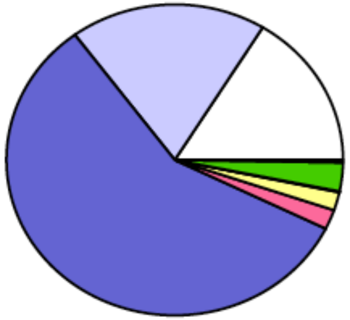
First look at Sherpa samples

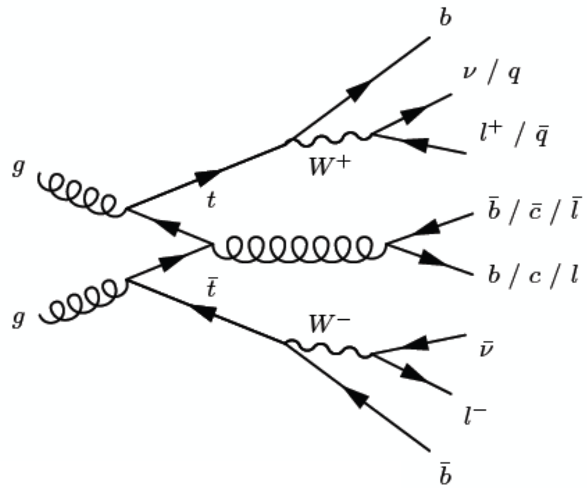


ttbar p_T ➔ Similar behaviour as in H_T dist.: Sherpa NLO+PS is softer than Powheg+Pythia while Sherpa ME+PS@LO is harder. Best agreement with Sherpa ME+PS@NLO.

top p_T ➔ Sherpa ME+PS@NLO prediction seems to be compatible with Powheg.

≥ 6 jets
≥ 4 b-tags





ttbar+HF (heavy flavour)

irreducible background to ttH(H→bb)

tt+bb is the main background to ttH(H→bb)

- pure QCD process with σ~5 pb (ttH signal σ~0.13 pb) at 8 TeV

similar final state as ttH(H→bb) ➔ irreducible background

- tt+HF: modelling much more difficult since no signal-free control region exists (rely on MC)
  - the modelling of ttbb/ttcc in Powheg+Pythia is purely at parton shower level

  → need to assign syst. unc.

  * normalization: 50% unc. separately for ttbb and ttcc (constrained down ~20% in the fit)
  * shape: compare with other MC predictions and recent NLO ttbb samples with Sherpa

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HF definition (at truth level)

- Truth jets: jets built from stable particles, excluding μ and ν (anti-k_t algorithm R=0.4)
- HF jet: jet containing a B/D hadron with p_T>5 GeV, not originated from another hadron decay

HF categories

- tt+HF event: event with >=1 HF jet (not coming from top decay) with p_T > 15 GeV, $|\eta|$ < 2.5
- Resolved HF (t+b): the additional HF jet contains exactly one heavy flavour hadron
- Merged HF (t+B): the additional HF jet contains more than one heavy flavour hadron

Samples with tt+HF events

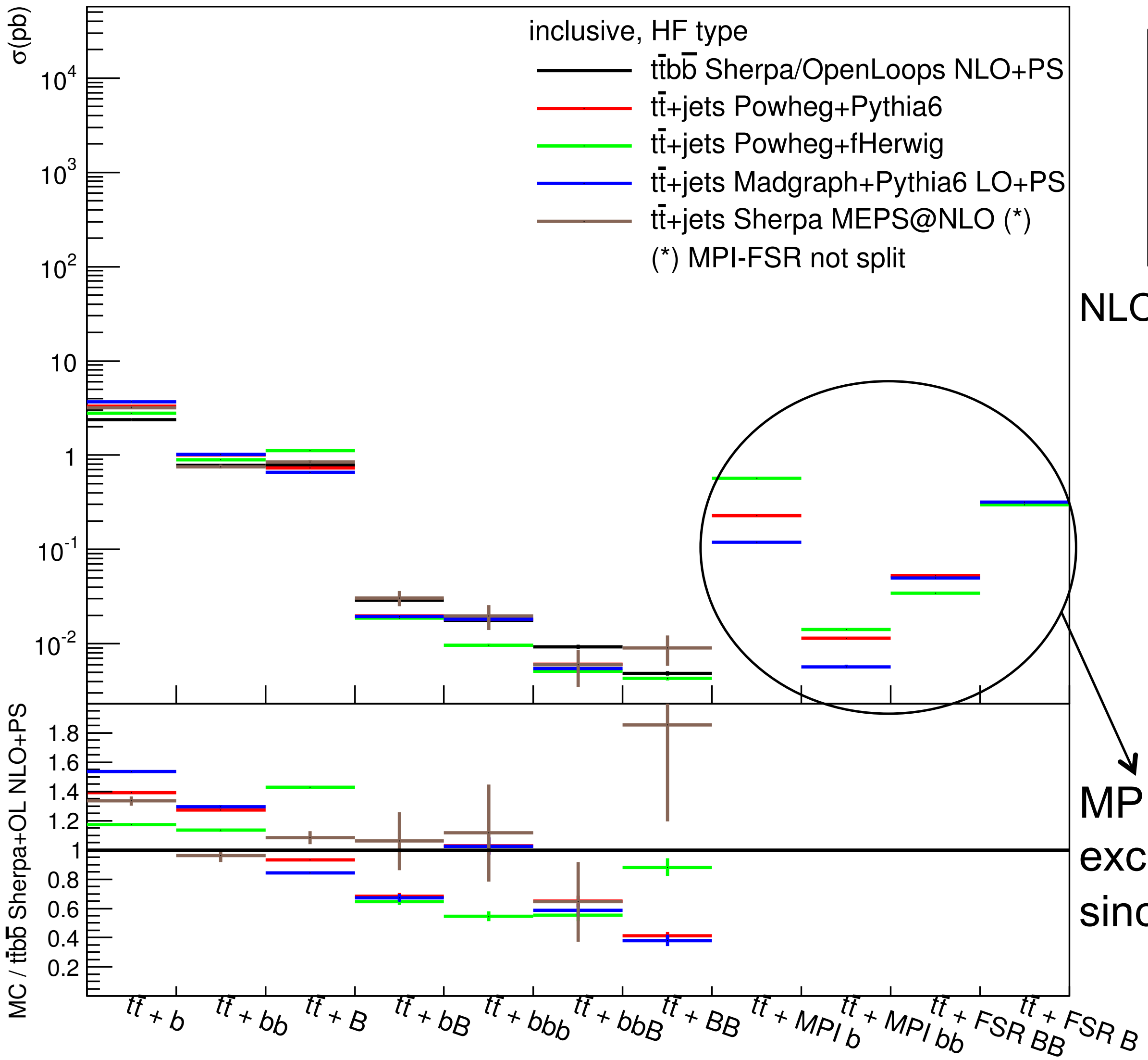
* **Sherpa v2.1.1 + OpenLoops: ttbb NLO+PS and tt+jets MEPS@NLO**
  - scale: geometric average of $p_T(t)$ and $p_T(b)$
  - PDF set: CT10nlo
  - m_{top}=173.2 GeV

Some contributions to the HF component are not included in the Sherpa sample
- MPI: ttbar+jets event with bb arising from MPI
- FSR: g→bb radiated from top decay products

* **Inclusive tt+jets sample with Powheg**
  - interfaced with Pythia6 Perugia 2011c tune or Herwig6

* **Inclusive tt+jets sample with MadGraph5**
  - scale: $Q=sqrt[m_{top}^2+(p_{top,T}^2+p_{antiop,T}^2)]$
  - PDF set: CT10
  - m_{top}=172.5 GeV
  - interfaced with Pythia6 (P2011c tune)

Absolute contribution of the various topologies



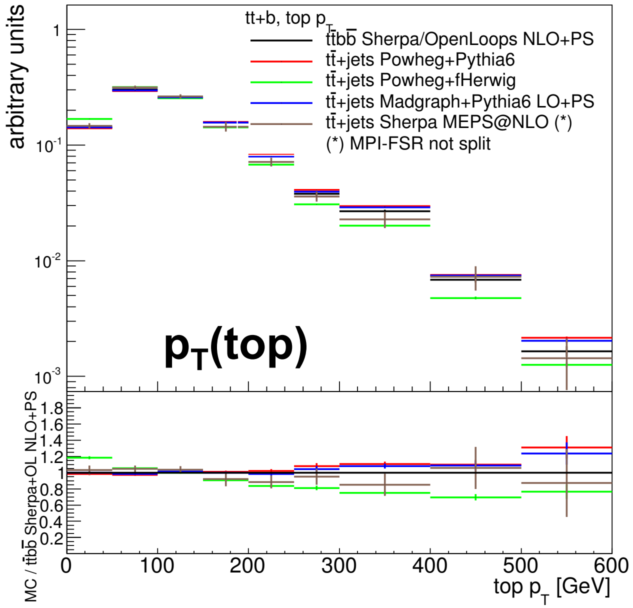
ttbb cross section:
- Sherpa+OpenLoops: 4.0 pb
- Powheg+Pythia: 4.9 pb
- Madgraph+Pythia: 5.5 pb

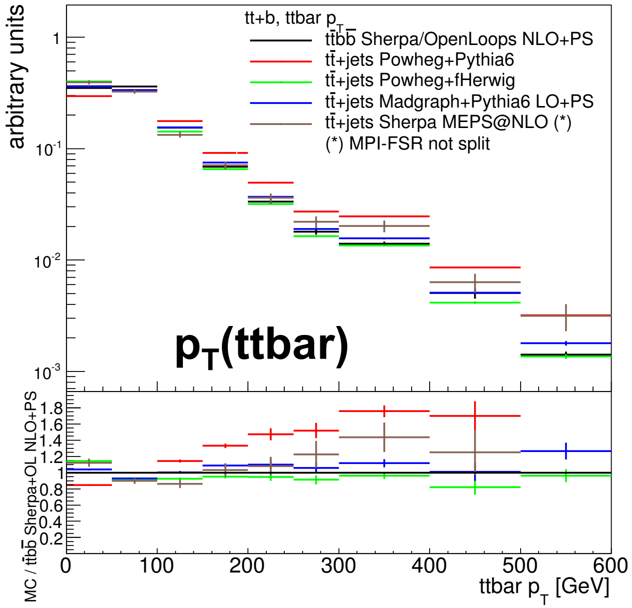
NLO cross section error ~ +33.3% -25.5%

MPI and FSR contributions are excluded in the Sherpa distributions since they are not simulated.

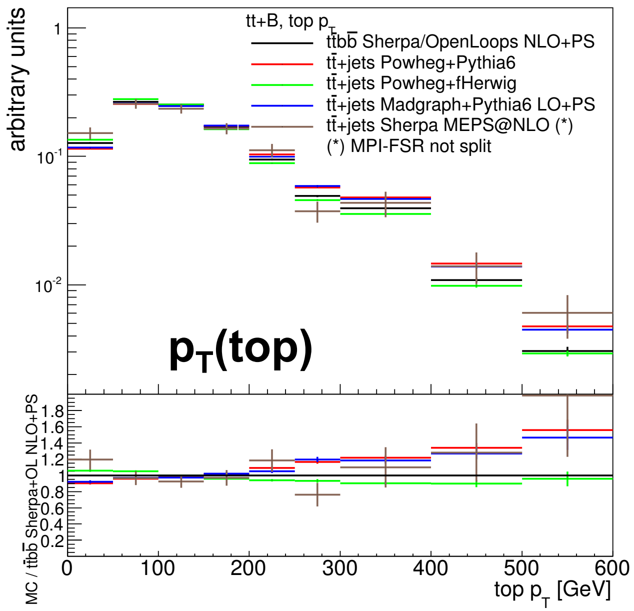
Kinematics in tt+b & tt+B topologies

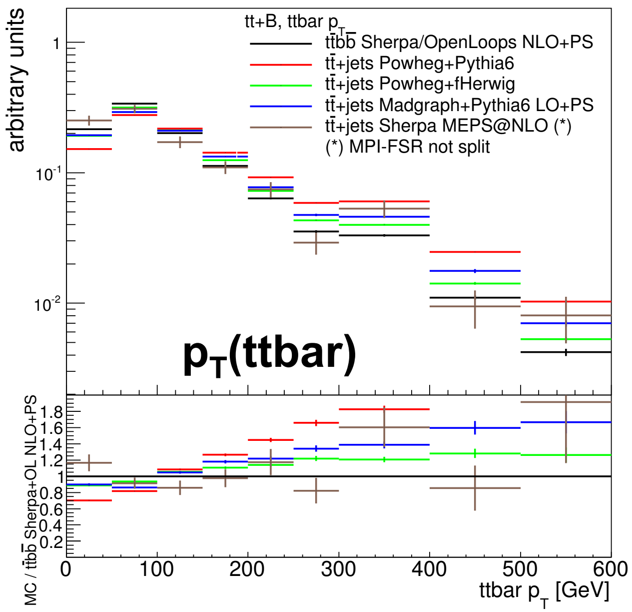
tt+b





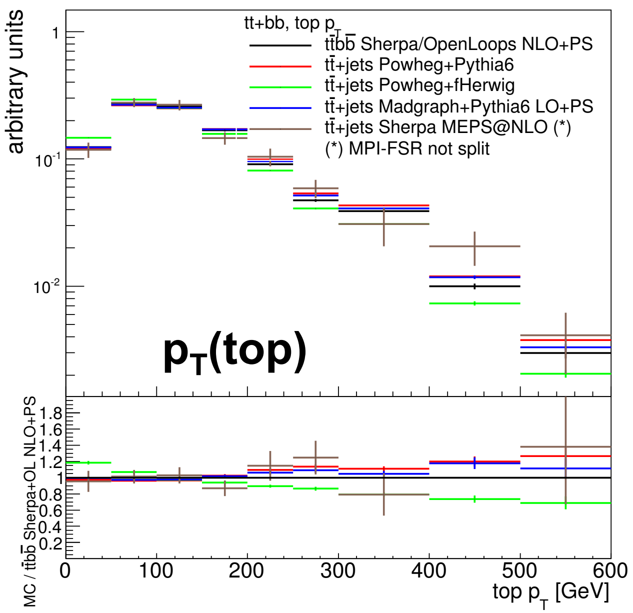
tt+B

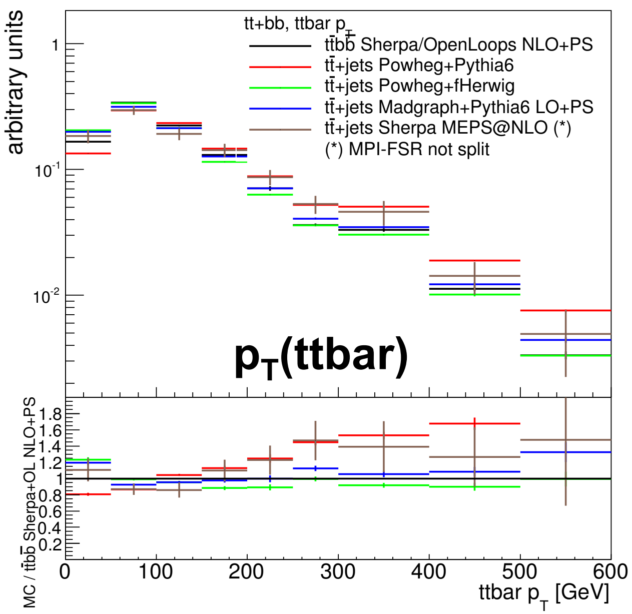


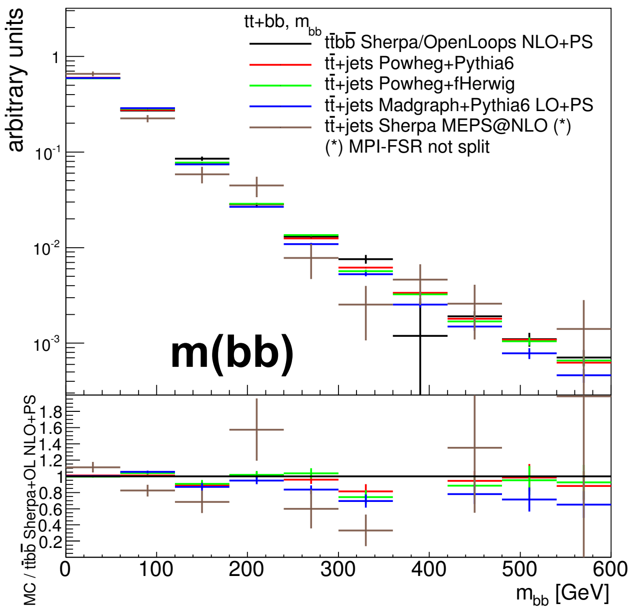


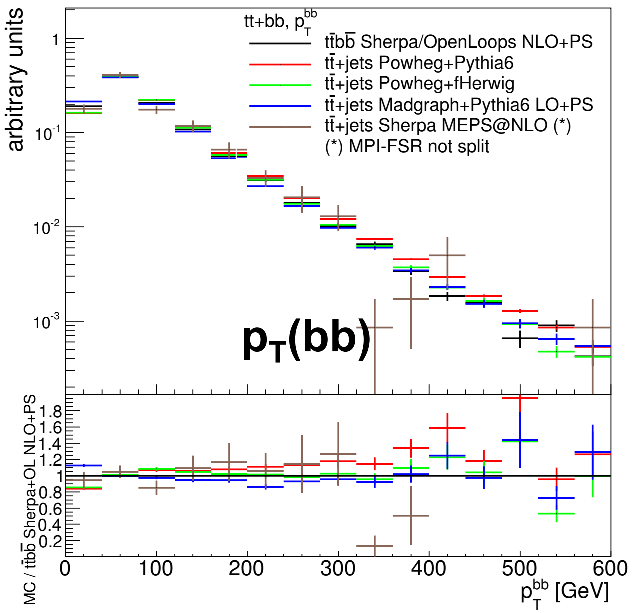
Kinematics in tt+bb topologies

tt+bb









tt+HF with MadGraph5_aMC@NLO

MadGraph5_aMC@NLO can be used for the simulation of ttbar+jets and ttbb dedicated sample:
- for ttbar+jets, FxFx merging can be used
  - vary the merging scale ~jet pt threshold
- for ttbar+HF, use the ttbb process (4F scheme)

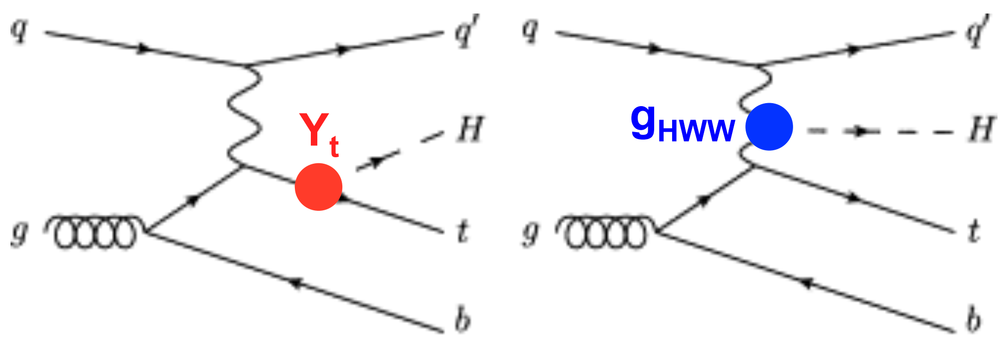
COMING SOON…

tH signal

tH process is not only sensitive to the magnitude of top Yukawa coupling, but also to the relative sign of Y_t with respect to g_{HWW}.

In the SM (c_V=c_F), the total rate of Wb→tH is highly reduced due to an almost perfect destructive interference between t-channel diagrams with Higgs bosons emitted from top quark and W boson lines.

Three processes contribute to tH production:
t-channel (tHqb), tWH process and s-channel (tH).
The s-ch. cross-section is very small compared.



tHj and tHjb

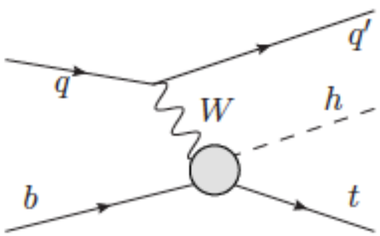
Official samples in Run1 (the simplest option): **MadGraph5 LO 4F** scheme (massive b-quark)

- scale: Q=75 GeV~$(m_t+m_H)/4$ (static)
- PDF set: CT10
- interfaced with Pythia8 (v8.176) AU2 tune
- Three sets of samples: c_F = +1, 0, -1 (always c_V = +1)

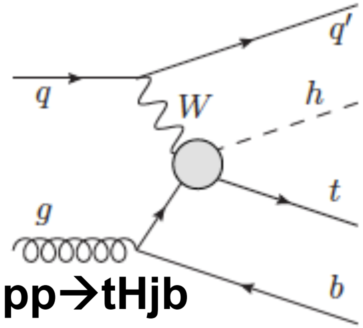
LO was used in the default configuration due to time constraints
→ several comparisons with diff. settings were performed:

- MadGraph5 LO 4FS: compared to MadGraph_aMC@NLO with 5FS and 4FS
  - NLO 5F scheme tHj(H→bb) predicts the 3b signature at NLO and the 4b signature at LO
  - NLO 4F scheme tHjb(H→bb) predicts the 3b and 4b signatures at NLO accuracy
- PDF choice: CT10 compared to CTEQ6L1 and MSTW2008 PDF sets
- Different parton shower and hadronisation model: Pythia8 vs. Herwig++ UEEE4 tune

All samples at 8 TeV, with m_H=125 GeV m_{top}=172.5 GeV and scale: Q=75 GeV.



pp→tHj

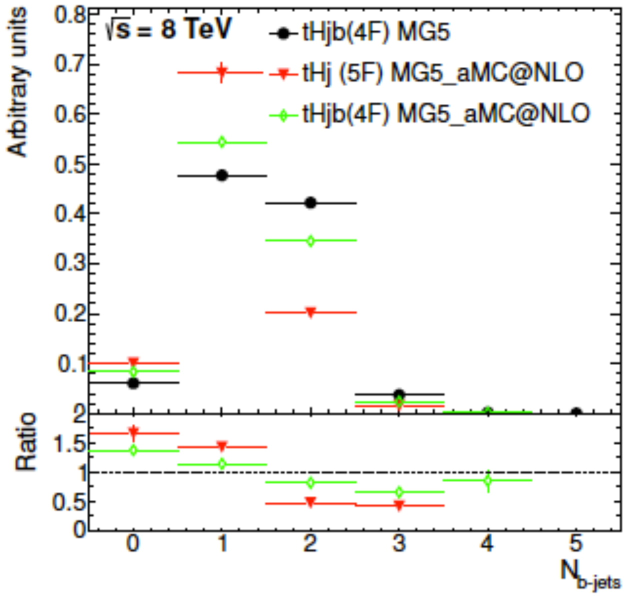


pp→tHjb

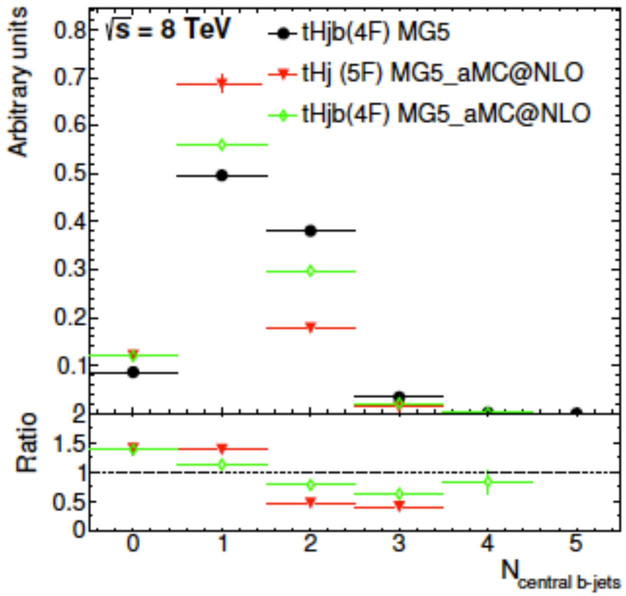
tHj and tHjb: 4FS vs. 5FS

lo.4f.75GeV.hpp
nlo.5f.hpp
nlo.4f.hpp

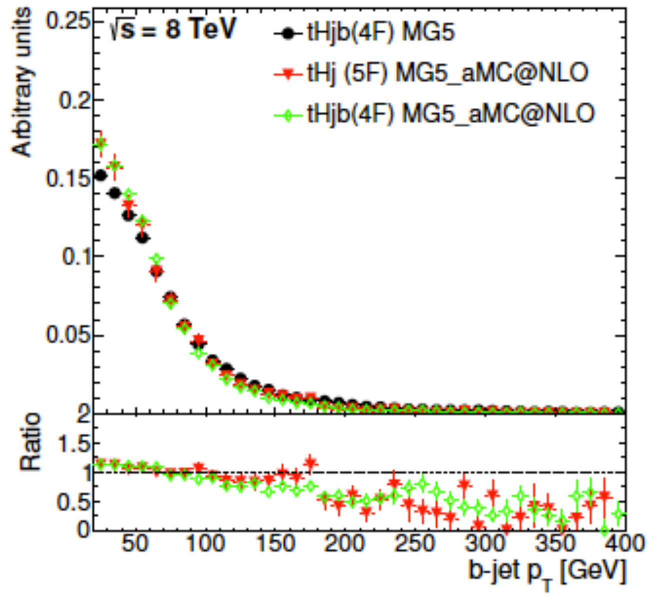
N(b-jets)
with p_T>25 GeV and $|\eta|$<4.5



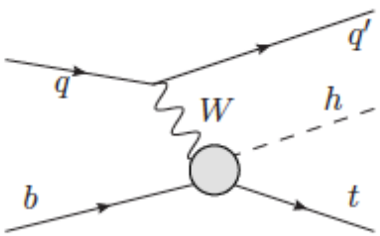
N(central b-jets)
with p_T>25 GeV and $|\eta|$<2.5



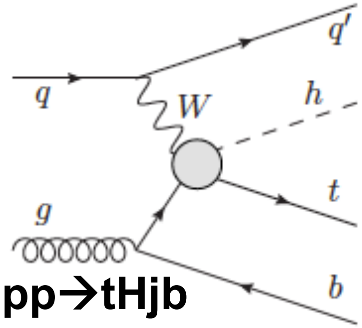
p_T(b)



As expected, the 4F scheme predicts more and harder b-jets than the 5FS since the second (spectator) b-quark appears at LO. In the NLO 4F calculation its kinematics is truly NLO.



pp→tHj



pp→tHjb

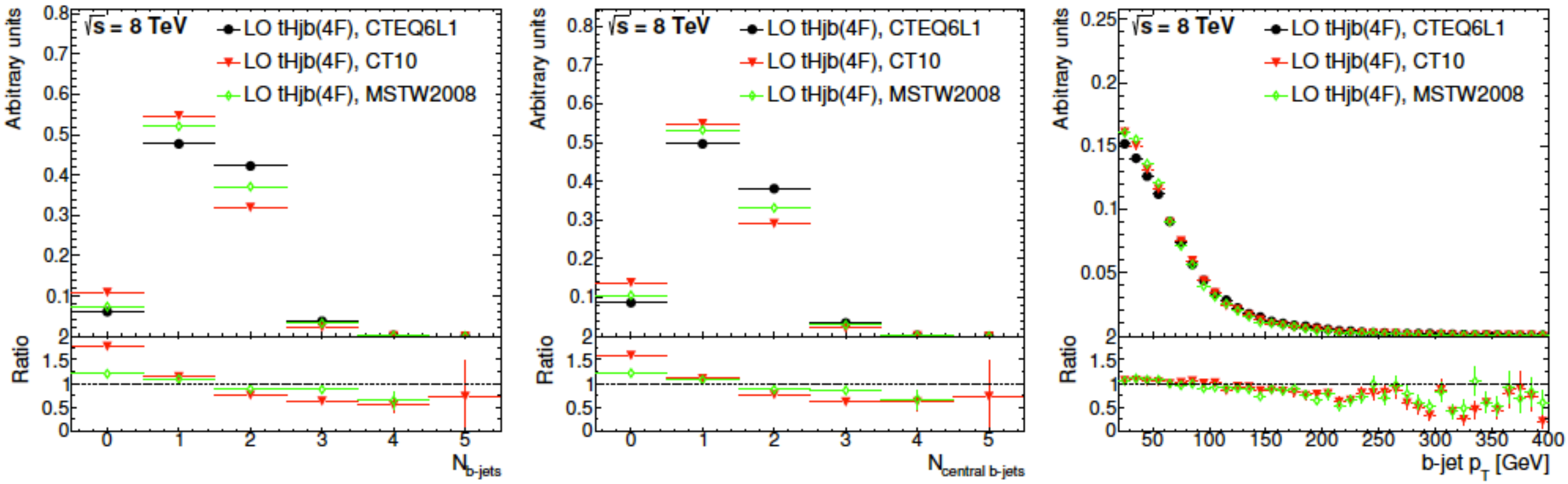
tHj and tHjb: PDF choice

- lo.4f.75GeV.hpp
- lo.4f.ct10.hpp
- lo.4f.mstw2008.hpp

N(b-jets) with p_T>25 GeV and |η|<4.5

N(central b-jets) with p_T>25 GeV and |η|<2.5

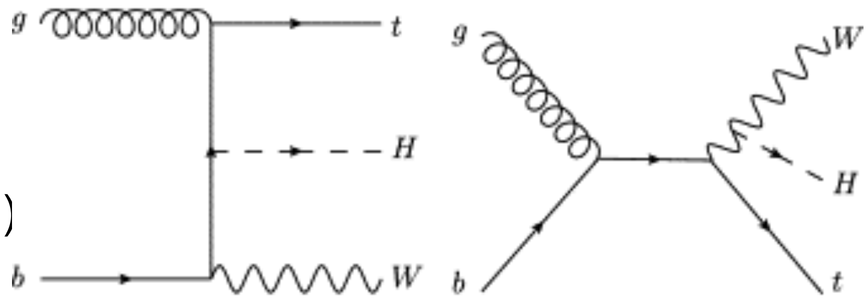
p_T(b)



Significant dependence on the PDF choice on the number of b-jets.
➔ Need to assign systematic uncertainties.

Official samples in Run1: **MadGraph5_aMC@NLO 5FS**, with diagram removal (DR)
- For tWH a diagram removal (DR) is necessary to remove ttH diagrams
- It was not possible generate tWH with aMC@NLO out-of-the box ➔ R.Frederix provided custom made code
- That code does not work with MadSpin ➔ no MadSpin used (check with LO tWH the effect)

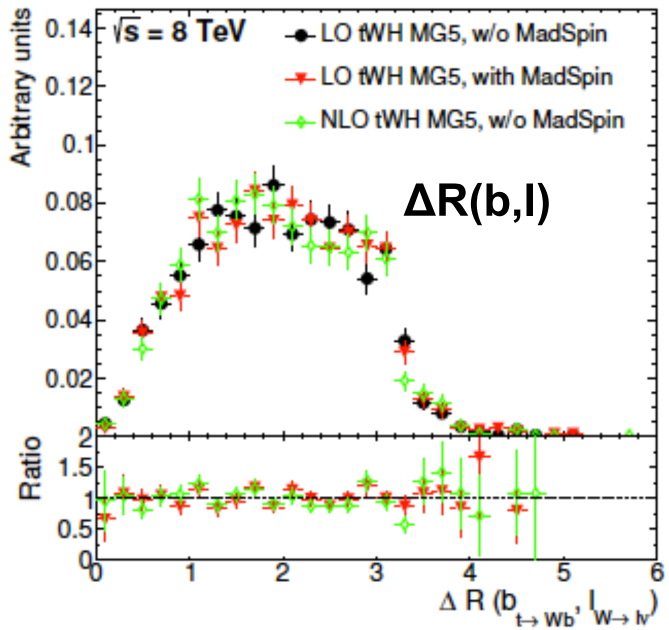
- scale: dynamic scale
- PDF set: CT10
- interfaced with Herwig++ UEEE4 tune
- Three sets of samples: c_F = +1, 0, -1 (c_V = +1)



→ several comparisons were done with diff. settings:

- No differences btw. LO samples w/wo. MadSpin at LO

All samples at 8 TeV, with m_H=125 GeV and m_{top}=172.5 GeV.

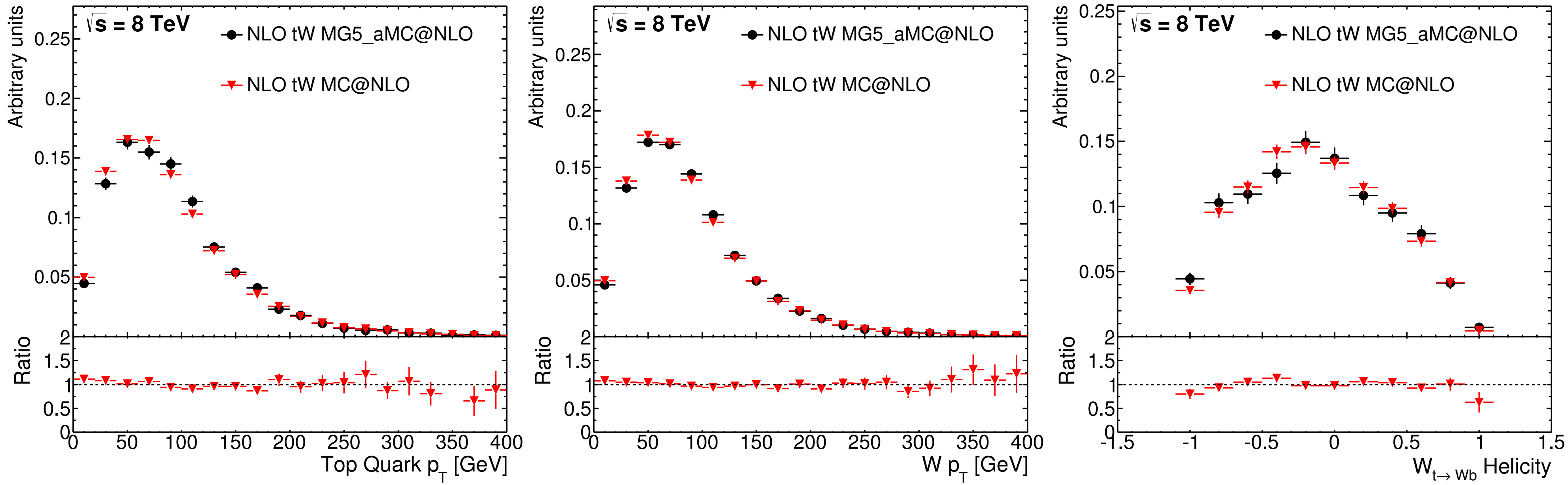


tW to validate tWH NLO sample

First time that tWH NLO samples were generated (no baseline to compare)
→ To validate the diagram removal used, **MadGraph5_aMC@NLO 5FS** tW sample was validated with respect to MC@NLO sample used for tW in ATLAS Run 1.

- scale: dynamic scale
- PDF set: CTEQ6L PDF in both samples

All samples at 8 TeV and m_{top}=172.5 GeV.



Nice agreement between the two MC generators.

Conclusions

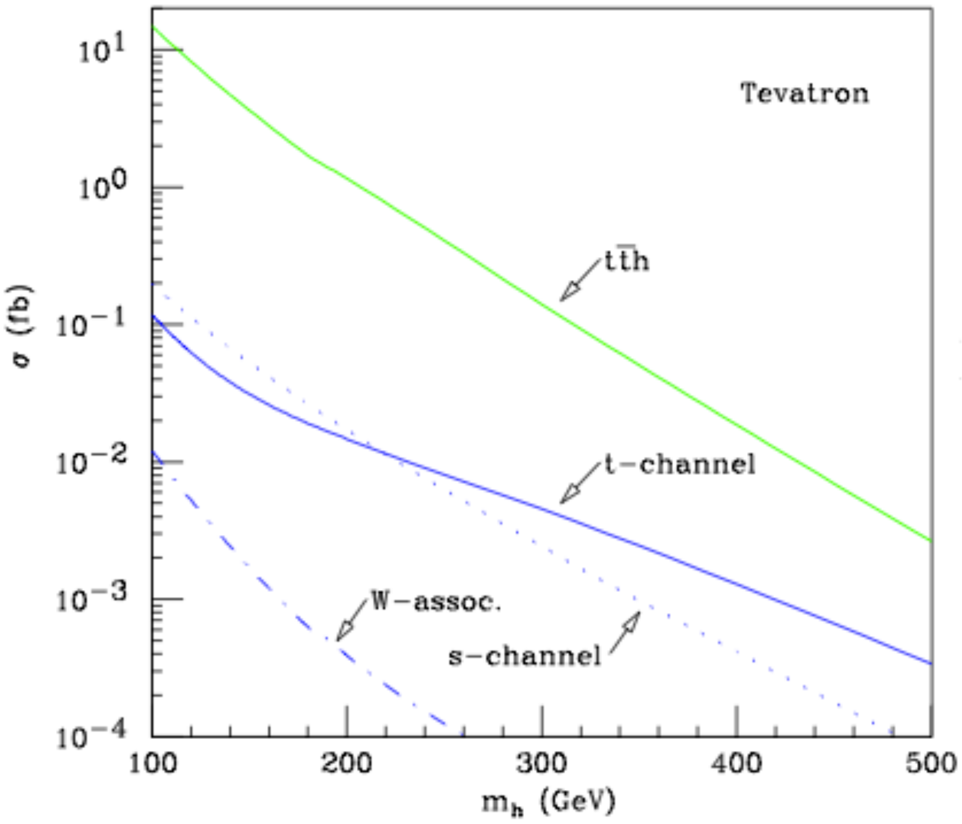
- ttH signal modelling
    - First look to MadGraph5_aMC@NLO+Herwig++ (studies ongoing with other parton shower models). Studies with Sherpa coming soon.

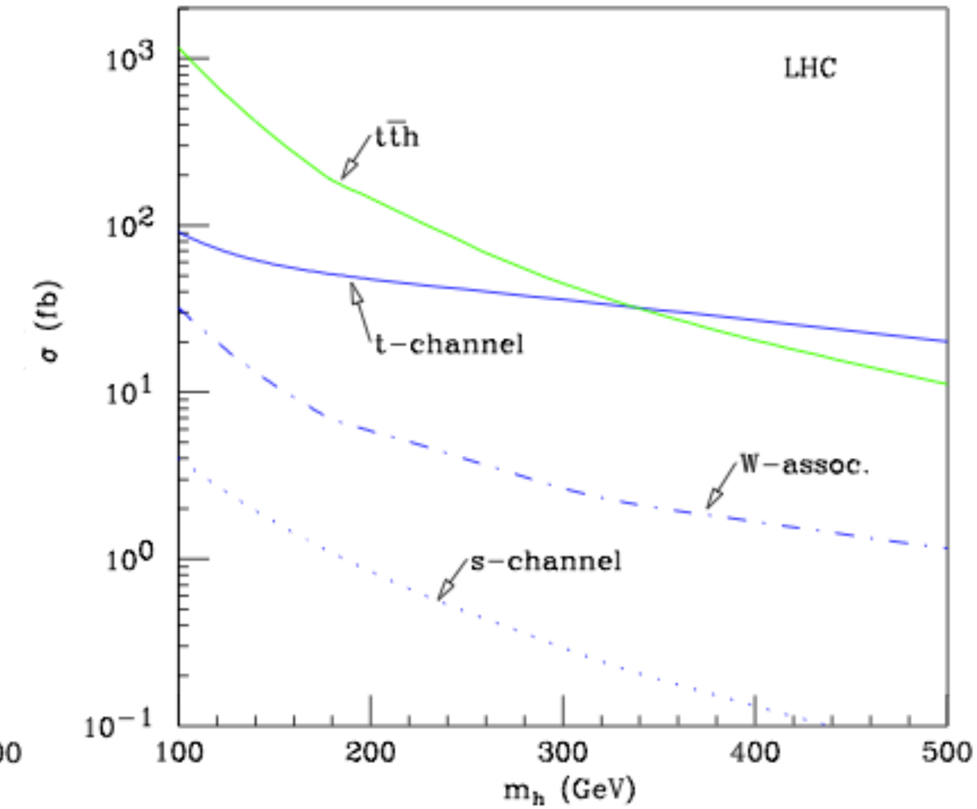
- tt+jets/HF background modelling
    - Different options on the market are being studied
        - How the merge tt+jets inclusive samples with dedicated ttbb samples?

- tH signal modelling
    - would like to simulate NLO samples with MadSpin
        - comparisons: 4FS vs. 5FS, PDF dependence, etc.

THANKS FOR YOUR ATTENTION

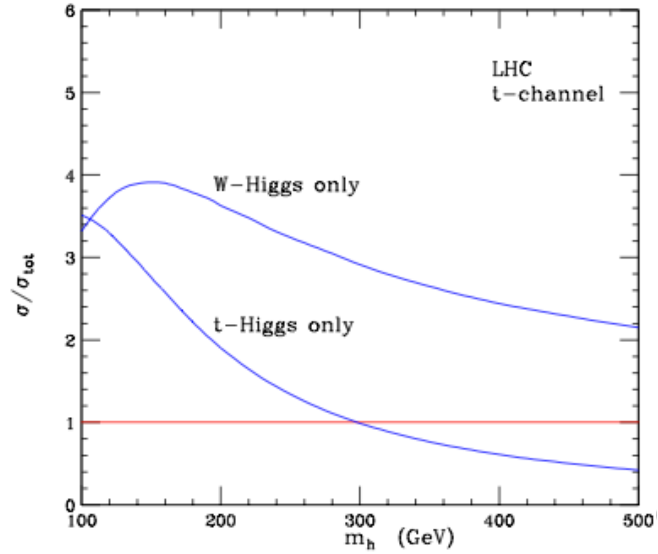
BACK-UP



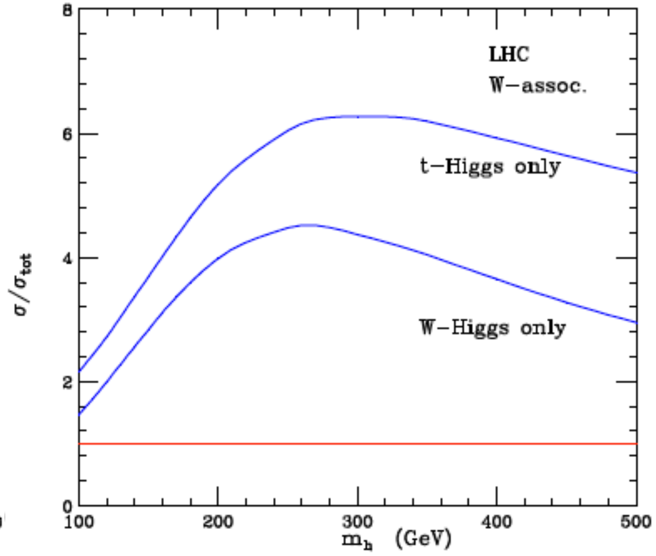


- $p\bar{p}$ @ $\sqrt{s} = 2$ TeV
- pp @ $\sqrt{s} = 14$ TeV

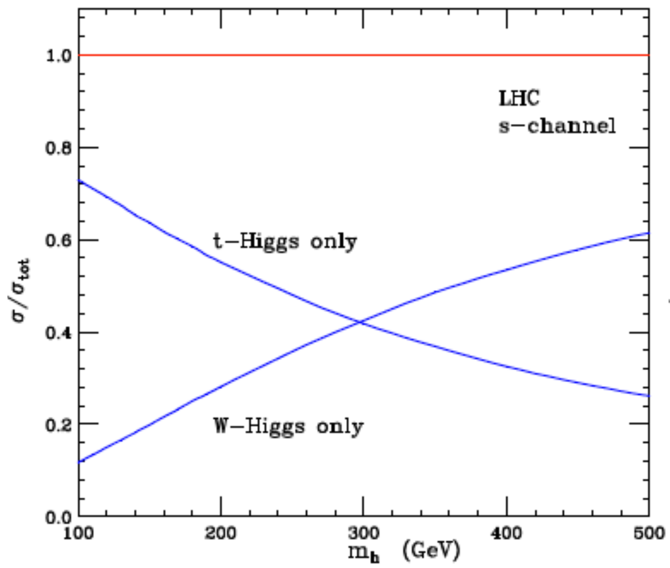
t-channel

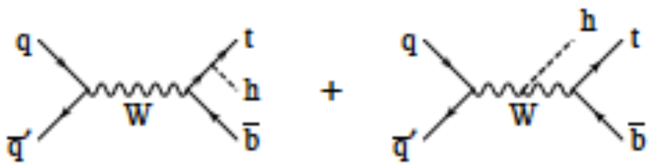


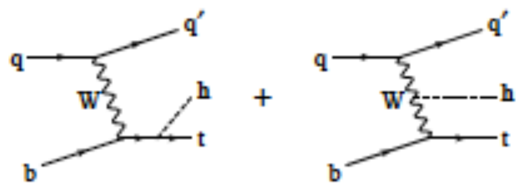
Wt associated production

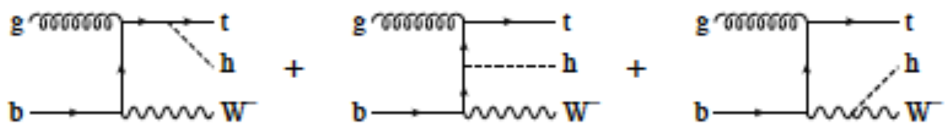


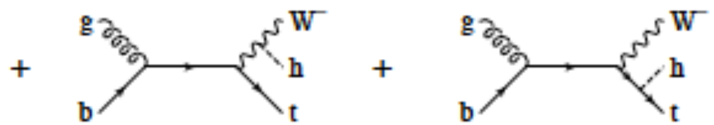
s-channel











Gap fraction observables

$f(Q_0)$ is defined as

$$f(Q_0) = \frac{n(Q_0)}{N}, \tag{5}$$

where N is the number of selected $t\bar{t}$ events and $n(Q_0)$ is the subset of these events that do not contain an additional high-p_T ($p_T > 25$ GeV) jet with transverse momentum, p_T, above a threshold, Q_0, in a rapidity interval ($|y| < 0.8$ and $|y| < 2.1$ are considered in this note).

$f(Q_{sum})$ is defined as

$$f(Q_{sum}) = \frac{n(Q_{sum})}{N}, \tag{6}$$

where $n(Q_{sum})$ is the number of $t\bar{t}$ events in which the scalar transverse momentum sum of the additional high-p_T jets in the rapidity interval is less than Q_{sum}.