$t\bar{t}H$ Associated Production

6^{th} LHC Higgs Cross Section Working Group

CERN, May, 24-25 2012

Theory conveners: L. Reina, M. Spira
Experimental conveners: C. Neu (CMS), C. Potter (ATLAS), A. Rizzi (CMS)

Joined this working group so far: S. Bevilacqua, S. Dittmaier, M. V. Garzelli, A. Juste, A. Kardos, S. Pozzorini, Z. Trócsányi, D. Wackeroth, M. Worek, ...

Preparing the inputs for the 8 TeV run

- NLO total and differential cross sections for $pp \to t\bar{t}H$ with uncertainties (scale, α_s, PDFs) calculated for $\sqrt{s} = 8$ TeV (update of YR1 and YR2).
- MC studies for $pp \to t\bar{t}H$ ready to be updated from YR2 where contributing Authors had
  - performed a comparison within a common set-up;
  - compared with ME+PS (as, e.g. in SHERPA);
  - included decay of $t\bar{t}H$ final state;
  - evaluated dependence of differential K-factors on realistic selection cuts.
- Discussion now focused on background processes: $pp \to t\bar{t} + jj$ and $pp \to t\bar{t} + b\bar{b}$.
  - held two meetings to update on experimental studies and theoretical tools;
  - systematic uncertainty from theory foreseen as main limitation;
  - NLO parton level available for both processes;
  - more than one group working on the interface of the NLO calculation of $pp \to t\bar{t} + b\bar{b}$ to PS Monte Carlos (results expected by end of summer);
  - $t\bar{t} + jj$ more complicated, will be considered next.

$pp \to t\bar{t}H$, theoretical uncertainty, NLO, @8 TeV

MSTW2008

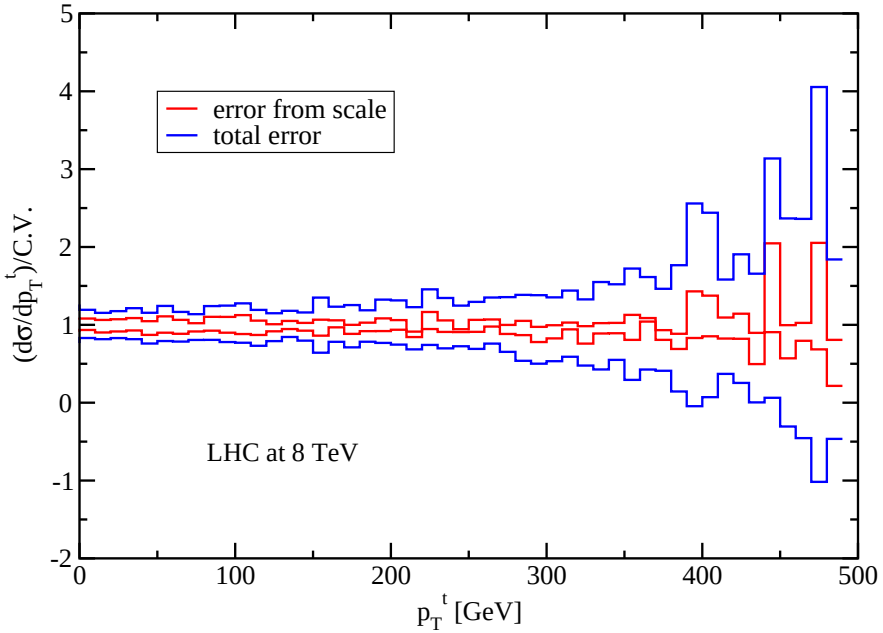
M_H [GeV]	σ_{NLO} [fb]	scale (%)	α_s (%)	PDF (%)
90	331.3	[-9.6,+4.6]	[-2.6,+2.1]	[-3.2,+2.7]
95	288.3	[-9.6,+4.4]	[-2.6,+2.1]	[-3.2,+2.7]
100	251.6	[-9.5,+4.3]	[-2.6,+2.1]	[-3.2,+2.7]
105	220.4	[-9.5,+4.2]	[-2.6,+2.2]	[-3.2,+2.7]
110	193.7	[-9.4,+4.1]	[-2.6,+2.2]	[-3.2,+2.7]
115	170.7	[-9.4,+4.0]	[-2.6,+2.2]	[-3.2,+2.7]
120	150.9	[-9.3,+3.9]	[-2.6,+2.1]	[-3.2,+2.7]
125	133.7	[-9.3,+3.8]	[-2.6,+2.1]	[-3.2,+2.7]
130	118.8	[-9.3,+3.7]	[-2.6,+2.2]	[-3.2,+2.8]
...	...	...	...	...

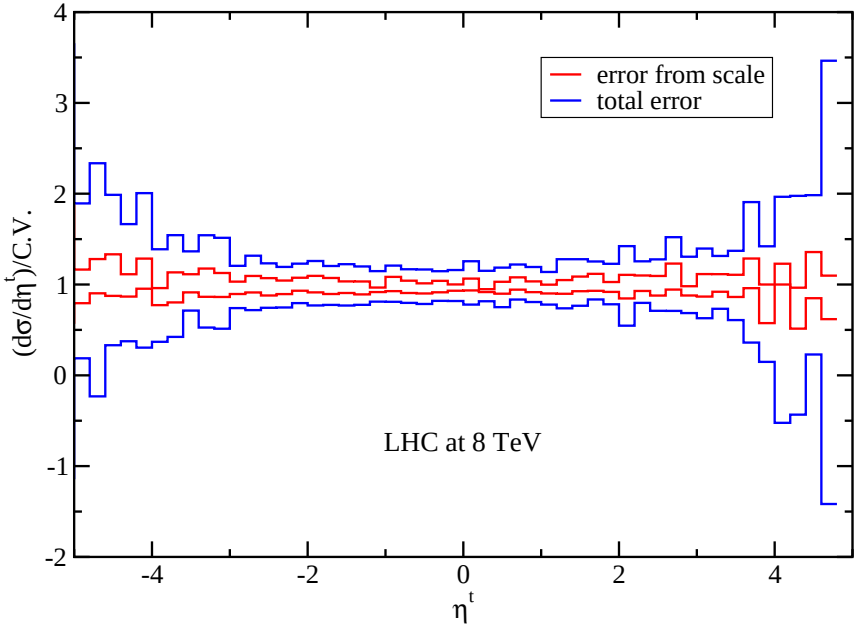
(M. Spira)

Similar set of results available for CTEQ6.6 and NNPDF 2.0: will be posted on ttH wikipage.

$pp \to t\bar{t}H$ NLO distributions, @8 TeV

CTEQ6.6





(L. Reina, D. Wackeroth)

MSTW2008 and NNPDF 2.0 will be available as well and combined..

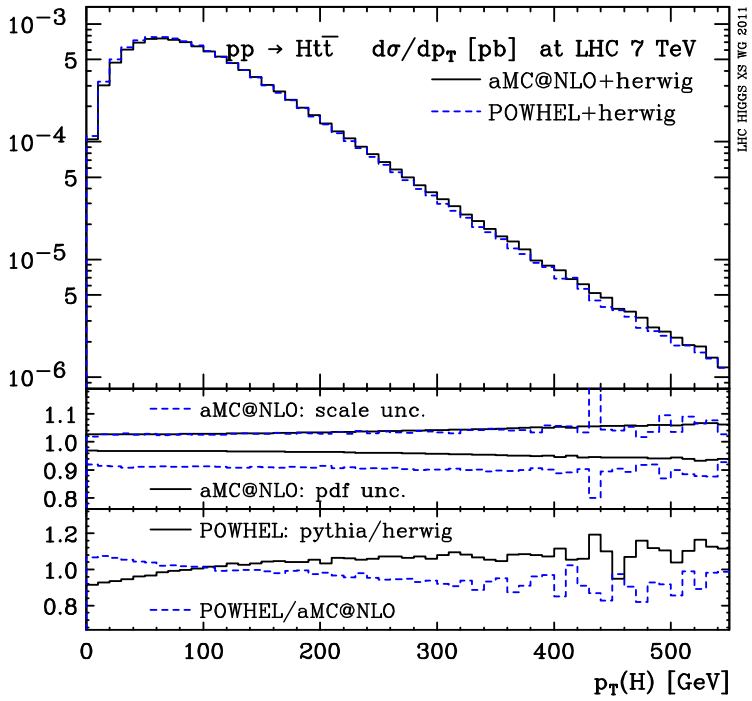
Full set of plots will be posted on ttH wikipage (with data files).

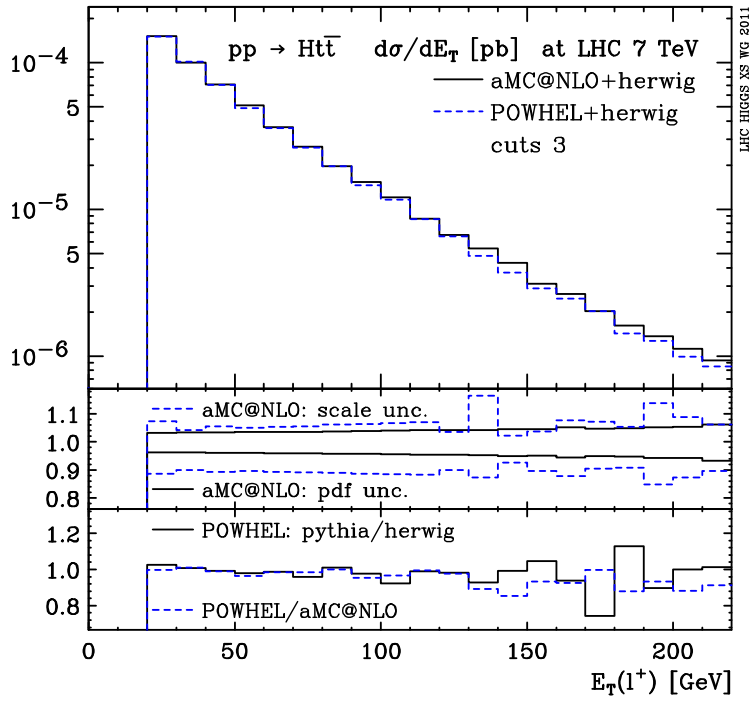
$t\bar{t}H$: matching NLO calculations with PS MC

YR2: Study of $t\bar{t}H$ (and $t\bar{t}A$) fully decayed and hadronized final state distributions, including scale+α_s+PDF uncertainty,@7 TeV using:

`aMC@NLO`: R. Fredrix, et al.

`PowHel`: M.V. Garzelli, A. Kardos, C.G. Papadopoulos, Z. Trócsányi





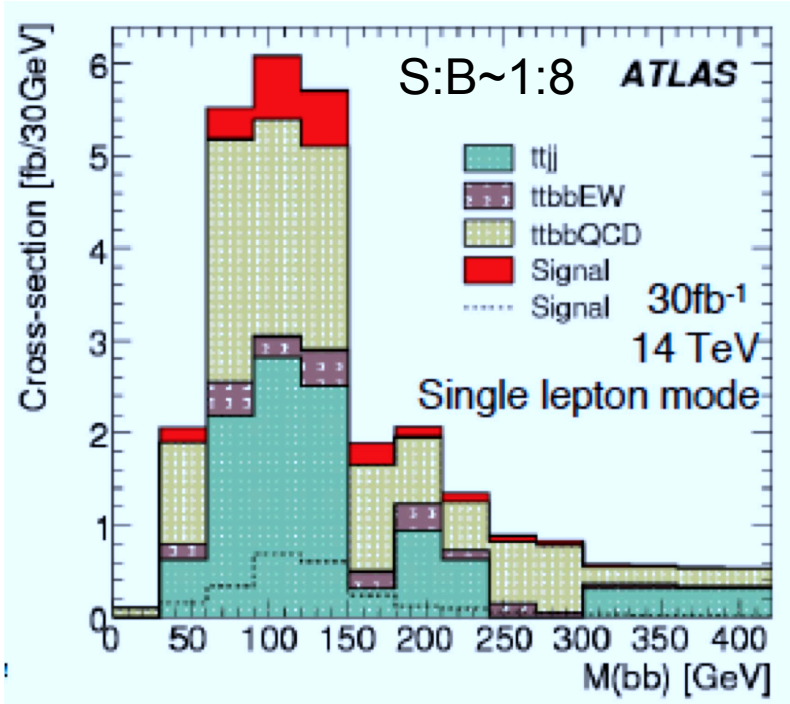
Theoretical uncertainty on signal under good control: results can easily be reproduced for 8 TeV.

Need to focus on Background processes

(see A. Juste's talk in $t\bar{t}H$ Meeting 1)

Small signal cross section on top of huge $t\bar{t}$ + jets background

Ex.: at $\sqrt{s} = 7$ TeV, for
$m_H = 120$ GeV,
$\sigma(t\bar{t}H) \times \mathrm{Br}(H \to b\bar{b}) \approx 65$ fb
$\sigma(t\bar{t}) \approx 160$ pb.



- currently focusing on lepton+jets channel: very sensitive to b-tagging systematic;
- signal reconstruction via constrained kinematic fit: large combinatorial background;
- large $t\bar{t}$ + jets background must be precisely estimated (normalization, shape): How to do it consistently?

Available tools

- $t\bar{t} + b\bar{b}$
  - ▷ fixed order NLO calculation
    (Bredenstein, Denner, Dittmaier, Pozzorini;
    Bevilacqua, Czakon, Papadopoulos, Pittau, Worek)
  - ▷ AcerMC: LO, QCD+EW contributions
  - ▷ `ALPGEN`: LO, QCD ME+PS (`PYTHIA` or `HERWIG`)
  - ▷ `SHERPA`: LO, QCD ME+PS
- $t\bar{t} + 2j$
  - ▷ fixed order NLO calculation
    (Bevilacqua, Czakon, Papadopoulos, Worek)
  - ▷ `ALPGEN`: LO, QCD ME+PS
  - ▷ `SHERPA`: LO, QCD ME+PS
  - ▷ `MC@NLO`: $t\bar{t}$, more jets by PS (`HERWIG`)
  - ▷ `POWHEG`: $t\bar{t} + j$, more jets by PS (`PYTHIA` or `HERWIG`)

Questions on $t\bar{t}$ + jets modeling

Q1: How to assess the systematic error when using tools such as `ALPGEN` to model the background?

Ex.: `ALPGEN` recipe to remove overlap between ME and PS:

- Generate $t\bar{t}$+light partons ME sample (with $Q\bar{Q}$ generated in PS)
- Generate $t\bar{t}Q\bar{Q}$ ($Q = b, c$) ME sample
- Use $t\bar{t}Q\bar{Q}$ ME sample if $\delta R(Q, \bar{Q}) > 0.4$ Otherwise use $Q\bar{Q}$ from PS (from $t\bar{t}$+light partons sample).

$\hookrightarrow$ How do we assess systematic uncertainties on the relative fraction of $t\bar{t}(Q\bar{Q})$ and $t\bar{t}Q\bar{Q}$ events? $\longrightarrow$ NLO MC needed

This would also allow to have a more comprehensive list of theoretical and experimental errors in each control region, since analyses heavily use kinematics.

Q2: Can one use existing NLO calculations to tune ALPGEN generation parameters to better describe shapes and/or constrain range of variation in parameters to explore?

Q3: How can we use existing NLO calculations to normalize ALPGEN at particular jet multiplicity bins? What are the related uncertainties?

Ex.: In order to have a more accurate background prediction it would be beneficial to normalize the ratio $t\bar{t} + b\bar{b}/t\bar{t} + jj$ to the NLO calculation. Does such ratio and related uncertainty exist at 7 and 8 TeV?

$\hookrightarrow$ NLO calculations can:

- point to a more educated scale choice, e.g. use a dynamical scale for $t\bar{t} + b\bar{b}$ ($\mu = m_t \sqrt{p_{T,b} p_{T,\bar{b}}}$) as opposed to a traditional fixed scale ($\mu = m_t + m_b$).
- study the effect of hard cuts, i.e. cuts that isolate some hard kinematic (not well reproduced in PS)

Outlook

- Signal: Complete compilation of results for $t\bar{t}H$ @8 TeV.
- Background:
  - ▷ Provide useful set of parton level results @7 and @8 TeV.
  - ▷ Implement interface of $t\bar{t} + b\bar{b}$ NLO calculation with PS MC using the POWHEG (Z. Trócsányi et al.) and/or MC@NLO methods (?).
  - ▷ Same for $t\bar{t} + jj$.