Theory uncertainties in WH/ZH → bb analyses in ATLAS

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VH theory cross section
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Present theory uncertainties in the ATLAS VH → bb analyses

Bin	$ZH \to \ell^+\ell^- b\bar{b}$ p_T^Z [GeV] 0-50	50-100	100-200	>200	$WH \to \ell\nu b\bar{b}$ p_T^W [GeV] 0-50	50-100	100-200	>200	$ZH \to \nu\bar{\nu}b\bar{b}$ E_T^{miss} [GeV] 120-160	160-200	>200
Components of the Background Systematic Uncertainties											
b-tag Eff	1.4%	1.0%	0.3%	4.8%	0.9%	1.3%	0.9%	7.2%	4.5%	4.8%	5.3%
Bkg Norm	3.6%	3.4%	3.6%	3.8%	2.7%	1.8%	1.8%	4.5%	3.2%	3.2%	2.9%
JES/MET	2.1%	1.2%	2.7%	5.1%	1.5%	1.4%	2.1%	9.5%	8.0%	9.2%	11.8%
Leptons	0.2%	0.3%	1.1%	3.4%	0.1%	0.2%	0.2%	1.7%	0.0%	0.0%	0.0%
Luminosity	0.2%	0.1%	0.2%	0.4%	0.1%	0.1%	0.1%	0.2%	0.2%	0.5%	0.7%
Pileup	0.9%	1.6%	0.5%	1.3%	0.1%	0.2%	0.8%	0.5%	1.9%	3.2%	2.8%
Theory	5.2%	1.3%	4.7%	14.9%	2.3%	0.4%	1.6%	14.8%	3.9%	4.4%	7.8%
Total Bkg	6.9%	4.3%	6.6%	17.3%	3.9%	2.7%	3.4%	19.6%	10.7%	12.2%	15.6%
Components of the Signal Systematic Uncertainties											
b-tag Eff	6.4%	6.4%	7.0%	13.7%	6.4%	6.4%	7.0%	12.1%	7.1%	8.2%	9.2%
JES/MET	4.9%	3.2%	3.5%	5.5%	6.6%	5.5%	4.8%	4.4%	7.9%	6.0%	6.9%
Leptons	0.9%	1.2%	1.7%	2.6%	3.0%	3.0%	3.0%	3.2%	0.0%	0.0%	0.0%
Luminosity	3.9%	3.9%	3.9%	3.9%	3.9%	3.9%	3.9%	3.9%	3.9%	3.9%	3.9%
Pileup	0.5%	1.1%	1.8%	2.2%	1.2%	0.3%	0.3%	1.6%	0.2%	0.2%	0.0%
Theory	4.6%	3.6%	3.3%	5.3%	4.4%	4.7%	5.0%	8.0%	3.3%	3.3%	5.6%
Total Signal	10.1%	9.1%	9.6%	16.5%	11.4%	10.8%	11.0%	16.0%	11.8%	11.4%	13.4%

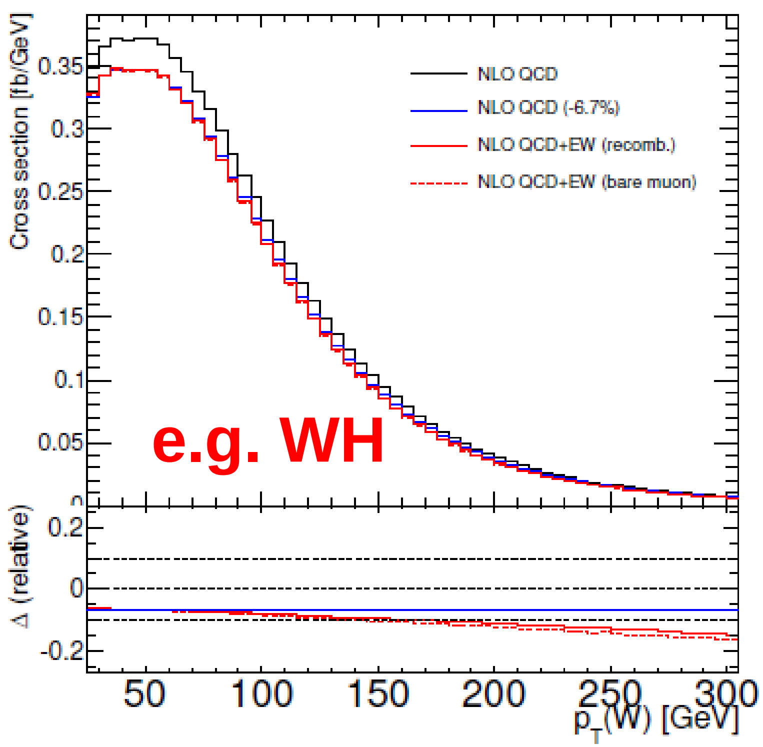
- VH/ZH theory signal uncertainty:
  - 30-50% of total uncertainty
- Background theory uncertainty (mainly Vbb):
  - Leading uncertainty, in particular in the high pT bins with the best sensitivity.

Signal: cross section estimate + uncertainties

- The overall cross section is normalized to the NNLO QCD + NLO EW inclusive computation (YR I).
- But the ATLAS analysis relies on binning in pT(W/Z) to increase the analysis sensitivity. Differential corrections are important!
- For NLO QCD we can use an parton shower code @ NLO (can use Powheg or (a)MC@NLO for the default sample, normalized to the NNLO QCD+NLO EW computation)
  - CMS is using Powheg already
  - ATLAS found some problem with b-jet tagging in the Powheg sample, used Pythia as backup solution, but aims at using Powheg or (a)MC@NLO next time
- For NLO EW, we can apply differential corrections as well.

NLO EW differential corrections

- Obtained by **Alexander Mueck** from the HAWK team (~YR II) and expressed as a function of pT(W) for WH and pT(Z) for ZH.
- Correction derived with respect to inclusive correction and applied to reweight events as a function of pT(W) or pT(Z).



$WH \to \ell\nu bb$	$[0,50]$	$[50,100]$	$[100-200]$	$[200-\infty]$
Δ_{EW}	-6.8%	-7.5%	-9.8%	-14.7%
δ_{EW}	-0.1%	-0.8%	-3.3%	-8.6%
$ZH \to \ell\ell bb$	$[0,50]$	$[50,100]$	$[100-200]$	$[200-\infty]$
Δ_{EW}	-5.7%	-6.6%	-6.7%	-9.2%
δ_{EW}	-0.7%	-1.6%	-1.7%	-4.3%
$ZH \to \nu\nu bb$	$[0,50]$	$[50,100]$	$[100-200]$	$[200-\infty]$
Δ_{EW}	-3.9%	-4.3%	-4.2%	-6.4%
δ_{EW}	$+1.3\%$	$+0.8\%$	$+1.0\%$	-1.4%
$ZH \to \nu\nu b\bar{b}$	–	$[120-160]$	$160-200$	$[200-\infty]$
Δ_{EW}	–	-4.0%	-4.1%	-6.4%
δ_{EW}	–	$+1.1\%$	$+1.1\%$	-1.4%
$WH \to \ell\nu bb$	–	$[120-160]$	$160-200$	$[200-\infty]$
Δ_{EW}	–	-9.1%	-10.3%	-13.3%
δ_{EW}	–	-2.5%	-3.9%	-7.0%

- Applied in ATLAS. Significantly reduces signal cross section at high pT!

Signal uncertainties considered (I)

- Overall PDF, scale and BR uncertainties from YR1

	WH	ZH ($Z \to \ell\ell$)	ZH ($Z \to \nu\nu$)
Scale uncertainty	0.6%	1.4%	1.4%
PDF uncertainty	3.7%	3.5%	3.5%
BR uncertainty	2%	2%	2%
Overall inclusive	4.3%	4.3%	4.3%

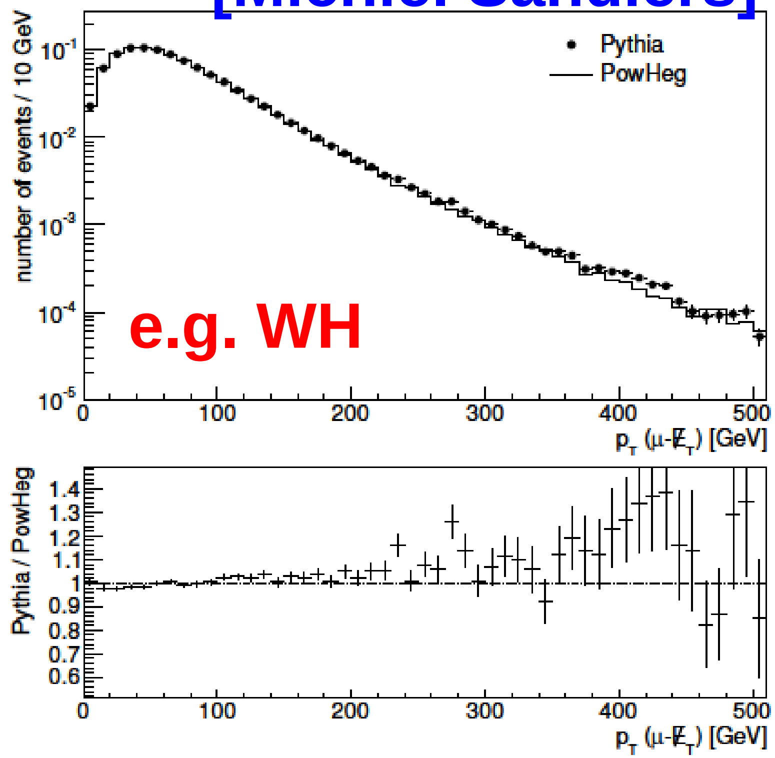
- Additional uncertainty considered on differential acceptance:
  - Uncertainty on NLO EW corrections (subtraction scheme + approximation in how the correction is applied)
  - Residual uncertainties from comparison of different parton shower Monte Carlo generators
    - Jet veto uncertainty
    - NLO vs LO acceptance uncertainty
    - Parton shower and hadronization model uncertainty

Signal uncertainties considered (II)

- Presently we only finally consider the difference between Pythia and Powheg+Herwig.

[Michiel Sandiers]

	$p_T(\mathrm{V})$	WH	ZH $(Z \to \ell\ell)$
NLO QCD	$[0, 50]$	-4.5%	-4.9%
	$[50, 100]$	-4.9%	-2.3%
	$[100, 200]$	-4.7%	-0.7%
	$[200, \infty]$	-5.9%	-4.5%



- This is added to the uncertainty due to the NLO EW correction:

	$p_T(\mathrm{V})$	WH	ZH $(Z \to \ell\ell)$
Uncertainty	$[0, 50]$	4.5%	4.9%
	$[50, 100]$	5.0%	2.8%
	$[100, 200]$	5.7%	1.8%
	$[200, \infty]$	10.4%	6.2%

- These „acceptance“ or „differential“ uncertainties dominate over the inclusive parton level uncertainties.

- We need more effort to disentangle the differences we see, in order to finally reduce the systematic uncertainty.

Prospects (contributions welcome!)

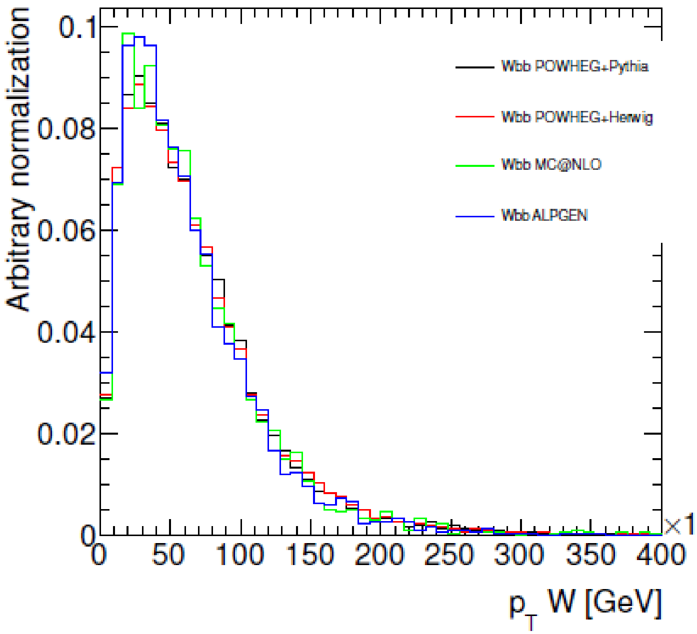
- More systematically derive parton level corrections:
  - NLO to NNLO QCD (Giancarlo and Andrea already started)
    - Is NNLO differential available also for ZH?
  - NLO EW (start from Alexander's results)
  - compute jet veto uncertainty using new methods (e.g. from Frank Tackman or Gavin Salam et al.)
- Disentangle various effect in parton shower based generators
  - Compare NLO shower based generator with original NLO parton level computation, to understand differences and/or effect of hadronization / UE / MPI corrections
  - Understand what decay model for the Higgs boson is implemented in the various generators and compare to the NNLO differential $H \rightarrow bb$ decay computation (can production and decay be factorized? How good is the narrow width approximation?)
  - Isolate effect of different parton shower models (Pythia vs Herwig) and hadronization models, understand role of b-fragmentation function/b-hadron decay model
- Collaboration is crucial on many of these issues with jet theory group!

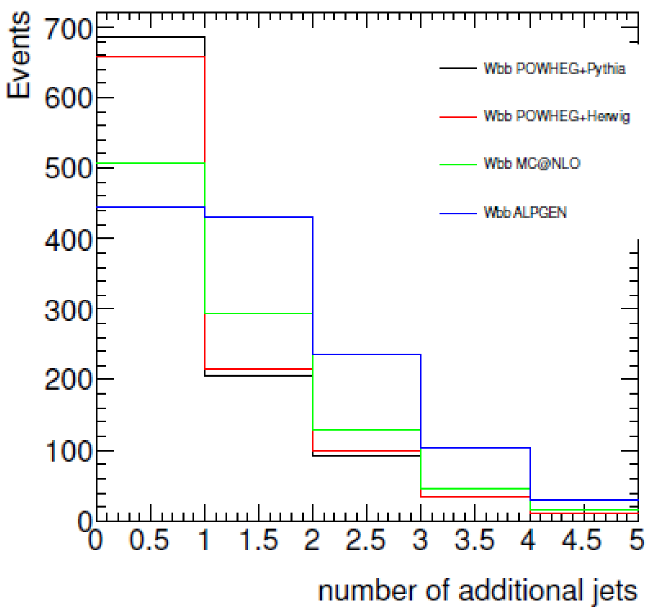
W/Z+bb backgrounds

- These backgrounds are not particularly well modelled theoretically
- For the ZH analysis the main background is Z+bb, for WH the main non-top background is W+bb.
- While Z+bb can be controlled well in the mass sidebands, W+bb is not easy to extract cleanly due to the other background.
- In the ATLAS present analysis, it is crucial to model correctly:
  - m(bb) distribution
  - pT(W) or pT(Z) distribution
- As the uncertainties on the Vbb modelling is one of the main uncertainties affecting the H $\rightarrow$ bb analyses, it is crucial to improve the modelling of these backgrounds.
- Presently (in ATLAS) for example the systematics on the Wbb modelling relies on a hadron level comparison, where all analyses cuts are applied and the m(bb) and pT(W) distribution are compared among different models.

W+bb background comparison

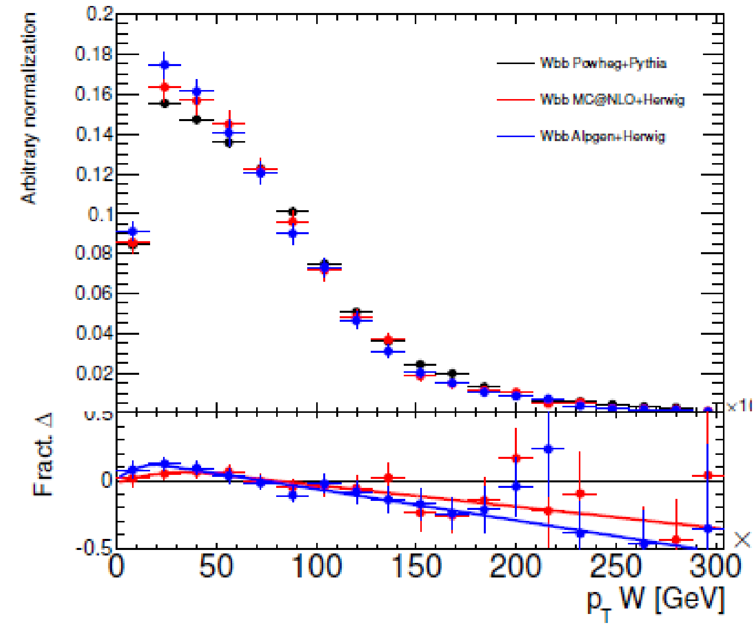
- The following (realistic) MC generators are presently used:
  - Alpgen
  - aMC@NLO
  - Powheg (+Pythia or Herwig)
- The choice of renormalization scale has been made identical in Powheg and aMC@NLO.
- Most of the distributions are in fair agreement, but some important exceptions as the number of additional jets to the two b-jets.
- Basically the number of jets cannot be trusted !

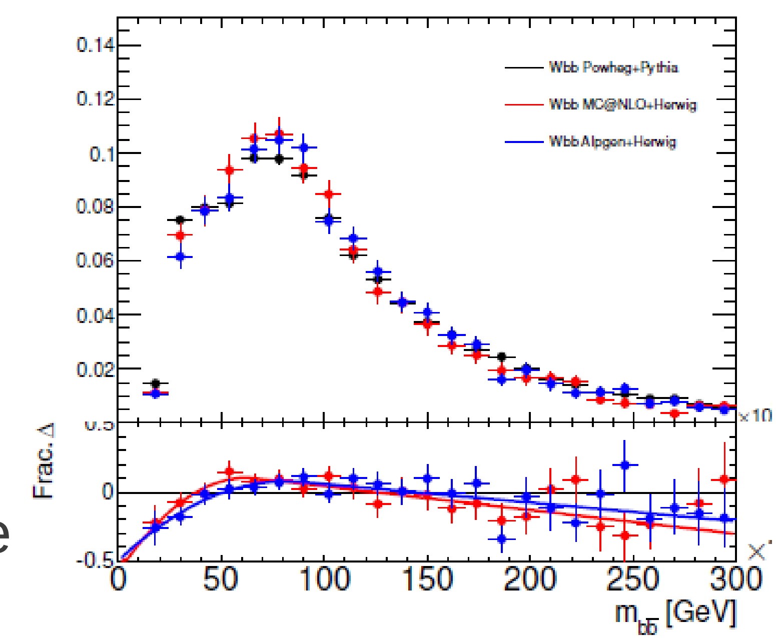




W+bb background comparison (II)

- The overall normalization is derived from data (m(bb) sidebands).
- From the difference between generators, a systematic uncertainty on m(bb) and pT(W) is derived (presently dominated by statistical uncertainties).
- Difference in number of jets presently overcome by normalizing W+bb+0 jets and W+bb+1 jets separately in data.
- Presently one of the leading uncertainties of the analysis.
- Additional 2012 statistics will not improve analysis if we don't solve this!





W+bb background: possible plan

- Try to solve possible inconsistencies and pin down the uncertainties:
  - generate a sample with Sherpa , which uses 5FNS and is able to deal with massive b-jets in the splitting
  - Compare Powheg and MC@NLO predictions with the pure NLO prediction (MCFM) on possibly infrared safe quantities (eventually compare LO first)
  - Understand the effect of the Alpgen matching uncertainty on the Alpgen prediction
  - Compute PDF and scale variation uncertainties on top of the aMC@NLO and Powheg predictions (interesting new developments for aMC@NLO, arXiv:1110.4738)
- Improve the prediction
  - The availability the Wbb+1 jet @ NLO would be a fantastic way to have a more reliable prediction for Wbb+1 jet ($qg \rightarrow Wbbj$ is leading) (already available within aMC@NLO?)
- There is quite some room to contribute!

Other items

- Cross sections being re-evaluated at 8 TeV
- Request to separate W+ and W- cross sections for WH
- Desirable to implement $H \rightarrow WW$ and $H \rightarrow ZZ$ decays as well, to provide predictions for other decay modes beyond $H \rightarrow bb$

Interested people can contact the working group conveeners. This effort is crucial to get closer to the SM H->bb signal sensitivity this year!