Report on WH/ZH Studies in ATLAS and CMS

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LHC Higgs Cross Section Working Group

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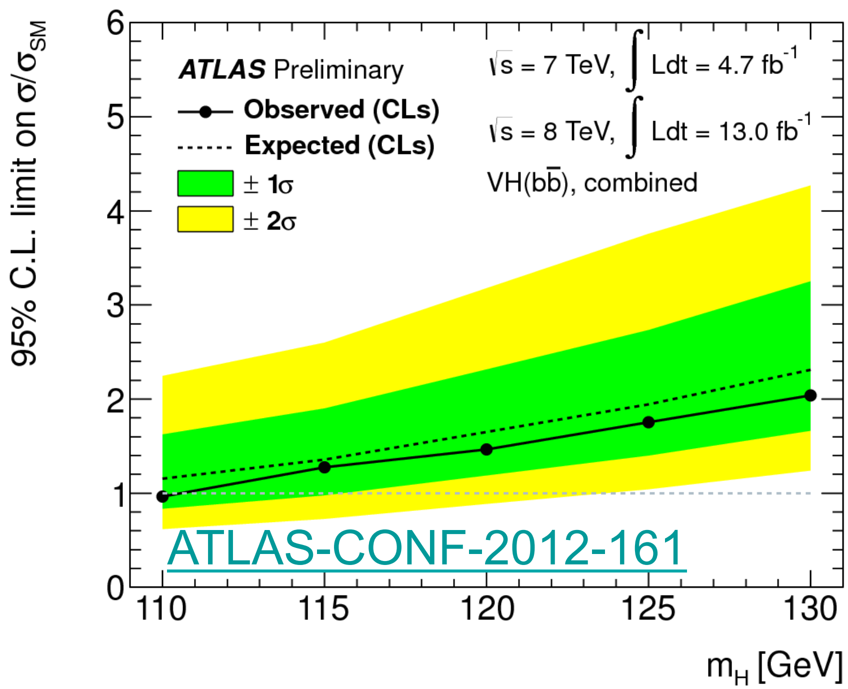
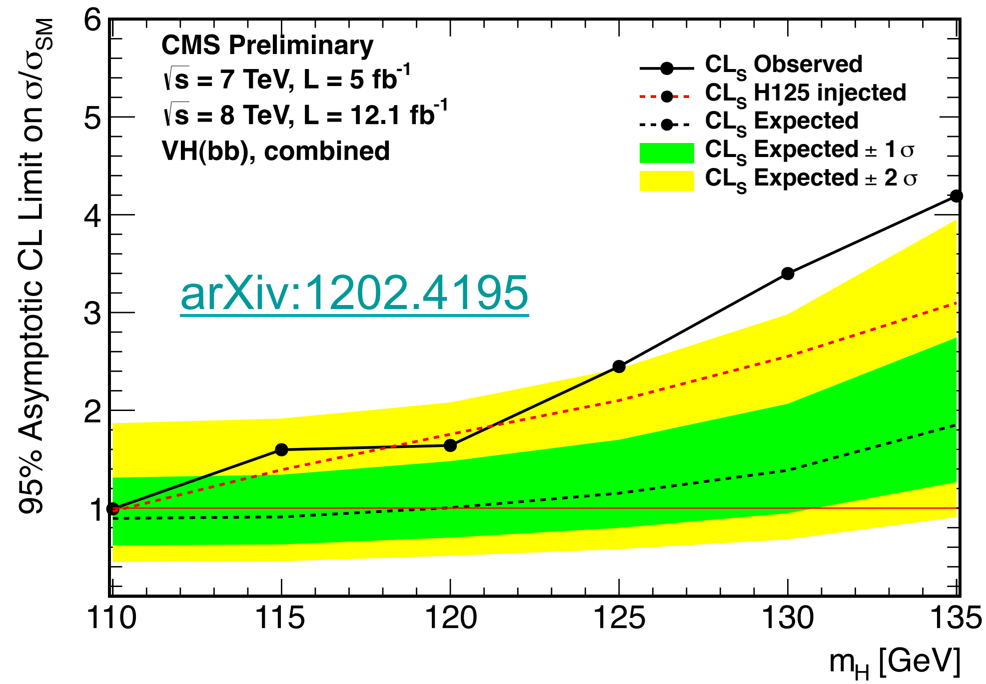
Quick Overview of WH/ZH Results

- Both experiments updated with 12-13 fb^{-1} 8 TeV data
- Approaching SM sensitivity at 125 GeV





- CMS observes excess of 2.2σ relative to background-only
  - Best-fit signal strength $1.3^{+0.7}_{-0.6}$

Signal Uncertainty on Final VH Results

From ATLAS-CONF-2012-161

Table 5: A summary of the size of the components of the systematic uncertainty on the signal with $m_H = 125$ GeV for the three channels of the $\sqrt{s} = 8$ TeV analysis. The dominant signal is shown for the 1 lepton and 2 lepton channels, while for the 0 lepton channel both ZH and WH signals are listed. The uncertainties are shown as a percentage, grouped together into broad categories and are calculated by summing in quadrature within each p_T^V bin and then averaging over all p_T^V bins in a channel.

Uncertainty [%]	0 lepton		1 lepton	2 leptons
	ZH	WH	WH	ZH
b-tagging	8.9	9.0	8.8	8.6
Jet/Pile-up/E_T^{miss}	19	25	6.7	4.2
Lepton	0.0	0.0	2.1	1.8
$H \rightarrow bb$ BR	3.3	3.3	3.3	3.3
VH p_T-dependence	5.3	8.1	7.6	5.0
VH theory PDF	3.5	3.5	3.5	3.5
VH theory scale	1.6	0.4	0.4	1.6
Statistical	4.9	18	4.1	2.6
Luminosity	3.6	3.6	3.6	3.6
Total	24	34	16	13

Use of WH/ZH Cross Sections

- Analyses split into bins of $p_T(V)$ to maximize sensitivity
  - Each bin of pT(V) is treated as a separate channel, with a separate cross section (correlated between bins)
- Take YR2 NNLO QCD + NLO EW cross section as the baseline inclusive cross section, then try to create differential cross section after corrections
  - Differential corrections can be calculated for one Higgs mass, assuming that the dependence is weak
- This procedure gives differential cross sections with small uncertainties, but
  - What is the effect of corrections on other distributions?
  - How do parton-level theory uncertainties compare to non-perturbative effects relevant for acceptance * efficiency?

Study of WH/ZH Acceptance Effects

- Compare particle-level acceptance with best matched PDFs, ATLAS UE & shower tunes
- LO Pythia8 (400K events)
- LO Pythia6 (400K events)
- NLO PowHeg/Herwig++ (400K events)

- Reconstruct truth-level quantities, including truth-jets
- Following comparison plots require 1 b-jet (no jet veto)
- Signal efficiency comparisons use “HCP” selection w/ 2 b-jets and jet veto required

Study of WH/ZH Acceptance Effects

"HCP" Selection

Ratios of number of generated and selected WH $\rightarrow \mu\nu b\bar{b}$ events, and ratios of selection efficiencies

Pythia6/PowHeg-H++	generated	selected	selection efficiency
$0 < p_T(W) < 50$ GeV	$(98.89 \pm 0.36)\%$	$(108.90 \pm 1.18)\%$	$(110.12 \pm 1.12)\%$
$50 < p_T(W) < 100$ GeV	$(100.19 \pm 0.36)\%$	$(107.20 \pm 1.15)\%$	$(107.00 \pm 1.08)\%$
$100 < p_T(W) < 150$ GeV	$(100.52 \pm 0.58)\%$	$(108.25 \pm 1.68)\%$	$(107.69 \pm 1.55)\%$
$150 < p_T(W) < 200$ GeV	$(100.52 \pm 0.95)\%$	$(101.53 \pm 2.26)\%$	$(101.00 \pm 2.04)\%$
$p_T(W) > 200$ GeV	$(105.91 \pm 1.18)\%$	$(110.07 \pm 2.54)\%$	$(103.93 \pm 2.10)\%$
Pythia8/PowHeg-H++	**generated**	**selected**	**selection efficiency**
$0 < p_T(W) < 50$ GeV	$(99.88 \pm 0.37)\%$	$(102.58 \pm 1.12)\%$	$(102.70 \pm 1.06)\%$
$50 < p_T(W) < 100$ GeV	$(99.50 \pm 0.36)\%$	$(100.00 \pm 1.09)\%$	$(100.50 \pm 1.03)\%$
$100 < p_T(W) < 150$ GeV	$(100.04 \pm 0.57)\%$	$(100.88 \pm 1.59)\%$	$(100.84 \pm 1.48)\%$
$150 < p_T(W) < 200$ GeV	$(101.33 \pm 0.96)\%$	$(96.62 \pm 2.18)\%$	$(95.36 \pm 1.95)\%$
$p_T(W) > 200$ GeV	$(103.89 \pm 1.16)\%$	$(92.58 \pm 2.23)\%$	$(89.11 \pm 1.90)\%$

$\Rightarrow$ Significant differences!

Up to 10% differences between Pythia and PowHeg.
Are these differences really due to the NLO effects, or some other generator differences?

Study of WH/ZH Acceptance Effects

Ratios of number of generated and selected ZH $\rightarrow \nu\nu b\bar{b}$ events, and ratios of selection efficiencies

Pythia6/PowHeg-H++	generated	selected	selection efficiency
$90 < \not{E}_T < 120$ GeV	$(99.26 \pm 0.60)\%$	$(103.47 \pm 1.58)\%$	$(104.24 \pm 1.47)\%$
$120 < \not{E}_T < 160$ GeV	$(100.46 \pm 0.74)\%$	$(105.32 \pm 1.65)\%$	$(104.84 \pm 1.45)\%$
$160 < \not{E}_T < 200$ GeV	$(100.34 \pm 1.10)\%$	$(107.25 \pm 2.36)\%$	$(106.89 \pm 2.04)\%$
$\not{E}_T > 200$ GeV	$(102.87 \pm 1.13)\%$	$(109.61 \pm 2.20)\%$	$(106.56 \pm 1.79)\%$
Pythia8/PowHeg-H++	**generated**	**selected**	**selection efficiency**
$90 < \not{E}_T < 120$ GeV	$(99.77 \pm 0.60)\%$	$(95.74 \pm 1.49)\%$	$(95.97 \pm 1.38)\%$
$120 < \not{E}_T < 160$ GeV	$(102.63 \pm 0.75)\%$	$(100.80 \pm 1.60)\%$	$(98.21 \pm 1.38)\%$
$160 < \not{E}_T < 200$ GeV	$(101.00 \pm 1.11)\%$	$(98.37 \pm 2.21)\%$	$(97.39 \pm 1.91)\%$
$\not{E}_T > 200$ GeV	$(101.16 \pm 1.12)\%$	$(93.26 \pm 1.95)\%$	$(92.19 \pm 1.64)\%$

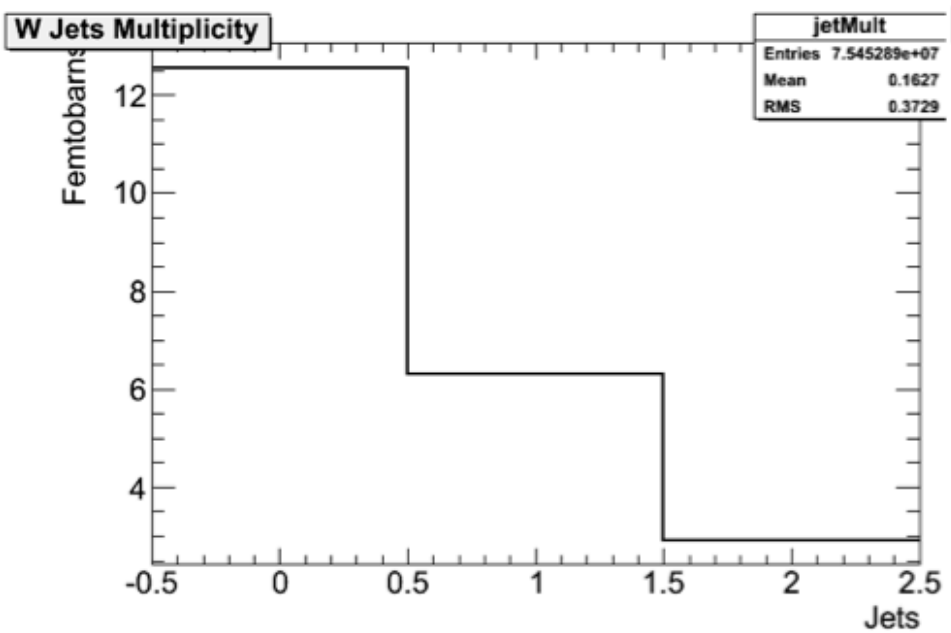
$\Rightarrow$ Significant differences!

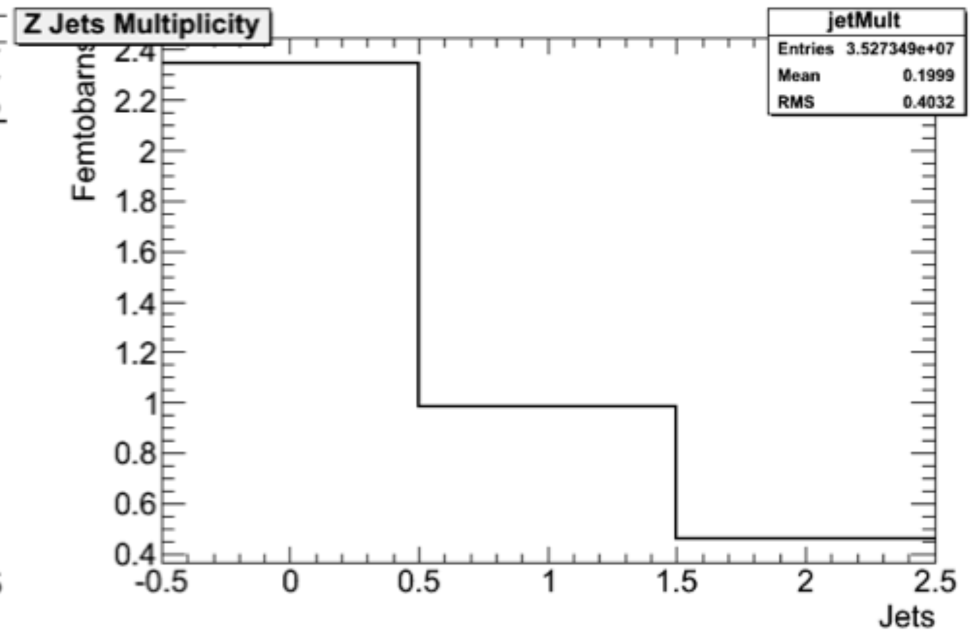
Parton-Level Studies of NNLO Corrections

- Trying to pin down the NNLO QCD corrections to the VH cross section, especially in differential distributions like p_T (V), jet multiplicity, and ΔR(jets)
- Working with weighted events from Ferrera et al. at NNLO, but without NLO corrections to Higgs decay
  - Use these samples, with scale variations, to estimate uncertainties on jet veto efficiency, as already done by CMS
  - Would be interesting to compare NNLO and NLO distributions
- Apply basic selection requirements, including b-tagging, but no jet veto

Distributions for Jet Veto Efficiency

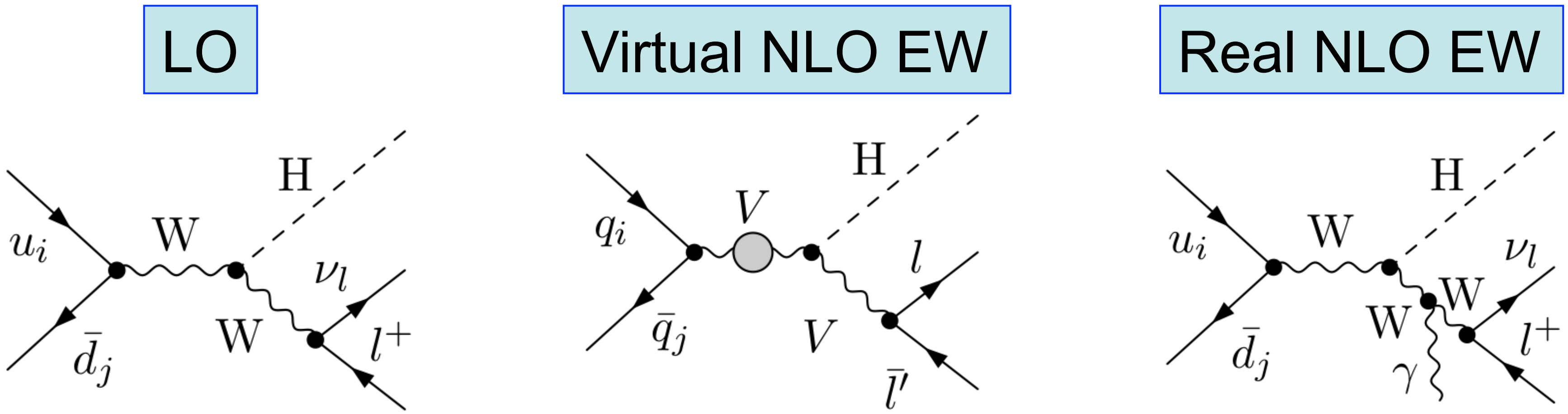
- Number of additional jets (beyond the 2 b-jets required)



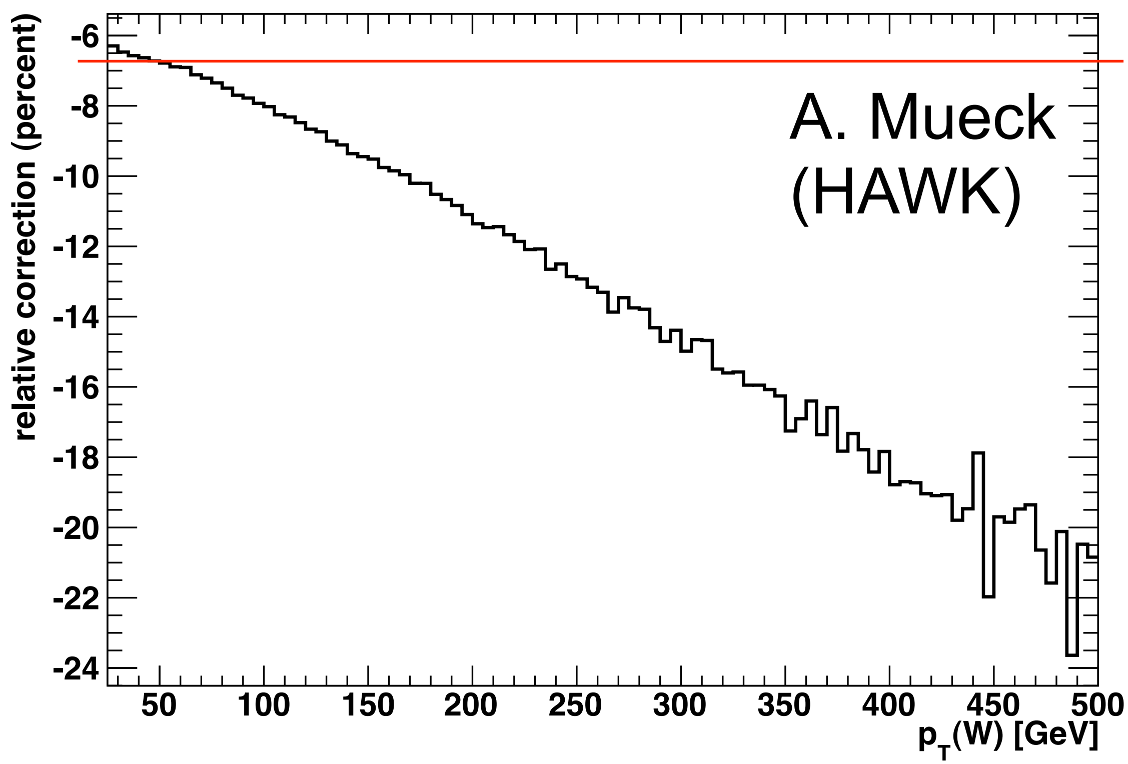


- Looking into Rivet as way of investigating the non-perturbative effects between these calculations and the parton-shower results on previous slides

NLO Electroweak Corrections



- HAWK Monte Carlo program (Denner, Dittmaier, Kallweit, Mueck) calculates NLO QCD+EW for all VH processes [arXiv: 1112.5142]



NLO EWK pT-Dependent Corrections

- Results from HCP analysis similar to 7 TeV results, but integrated for new analysis pT(V) bins.
- Full correction δ_{EW} taken as uncertainty(!); to discuss
  - Correction applied in ATLAS, to be applied in CMS

8 TeV $WH \rightarrow \ell\nu b\bar{b}$	[0-50]	[50-100]	[100-150]	[150-200]	[200-∞]
Δ_{EW}	-6.8%	-7.5%	-9.2%	-11.1%	-14.8%
δ_{EW}	-0.5%	-1.3	-3.2%	-5.2%	-9.1%
8 TeV $ZH \rightarrow \ell\ell b\bar{b}$	[0-50]	[50-100]	[100-150]	[150-200]	[200-∞]
Δ_{EW}	-5.8%	-7.4%	-8.1%	-8.8%	-12.2%
δ_{EW}	-1.0%	-2.6%	-3.4%	-4.1%	-7.7%
8 TeV ZH -> ννbb		[90,120]	[120,160]	[160,200]	[200-∞]
Δ_{EW}		-8.6%	-9.9%	-11.4%	-14.7%
δ_{EW}		-2.4%	-3.8%	-5.4%	-9.1%

Other Issues & Wishes from Experiments

- Standardize corrections for m_H=125 or 126 GeV
- Standardize treatment of EWK corrections and uncertainties, as applied to differential cross sections
- Willing to look at NNLO corrections with scale variations for jet veto efficiency; NLO decays helpful here
- Interesting in understanding differences in acceptance*efficiency (large "uncertainty")
  - Is this effect of NLO vs. LO?
  - Some difference in the non-perturbative calculations?
  - Looking into Rivet studies to help disentangle these effects

Backup

"HCP" Selection in Acceptance Comparison

- Reconstruct truth-jets, using standard jets (`antiKt4`)
  * No electron / tau jets
  * Jet selection: $p_T > 20$ GeV, $|\eta| < 2.5$
  * Match jets to nearest "initial-state" b-hadron
    $\Delta R(\text{jet b-hadron}) < 0.3$
  * At least one b-jet
- $p_T(\mu) > 25$ GeV, $|\eta_\mu| < 2.5$, $\not{E}_T > 25$ GeV, $m_T > 40$ GeV
- Normalize all distributions to the same cross-section
- Following plots are all for the WH $\rightarrow \mu\nu b\bar{b}$ samples