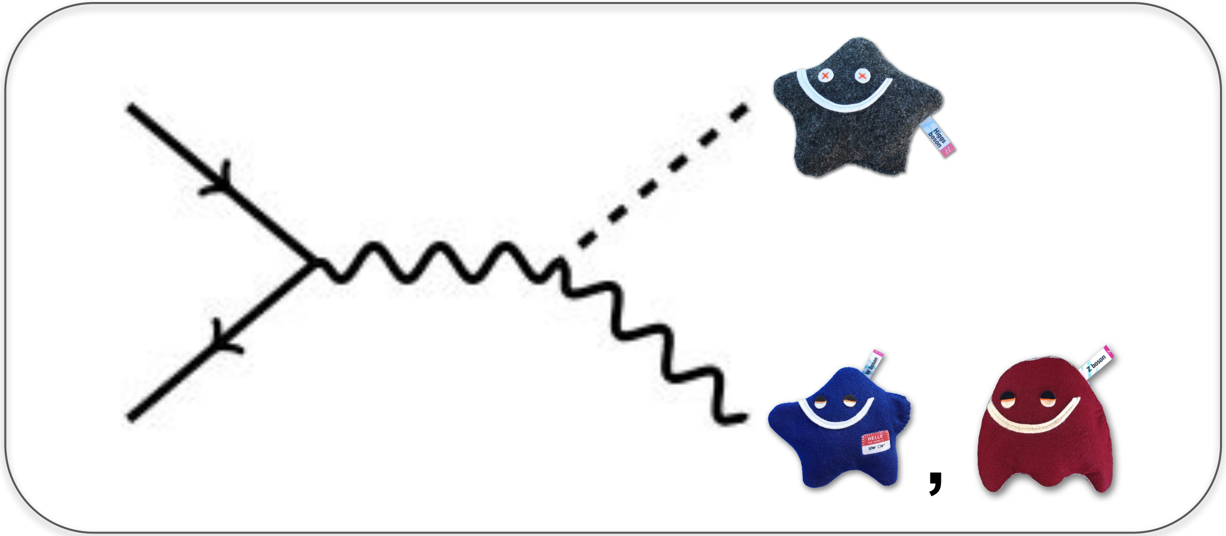


WG1 VH experimental report

LHCHXSWG general assembly

March 26th 2018

Carlo Pandini, Chris Palmer, Luca Perrozzi, Emanuele Re, Francesco Tramontano

Outline

- Brief discussion of the ATLAS and CMS results
  - VH(bb) signal strength @ 13 TeV
  - Systematic Uncertainties
  - Simple prospects for single analysis

- VH signal systematic uncertainties

- V+jets background modeling strategies
  - W+heavy flavors - dominated by 1-lepton channel
  - Z+heavy flavors - dominated by (0)2-lepton channel

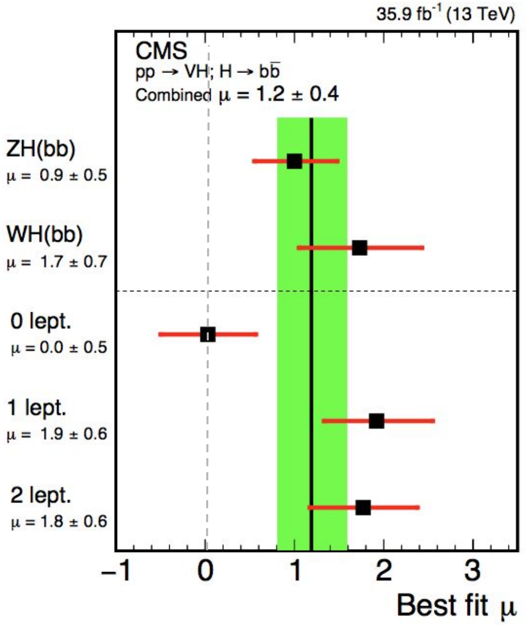
- Towards simplified Template XS

VH(bb) signal strength @ 13 TeV

Latest results with 2016 dataset in a nutshell

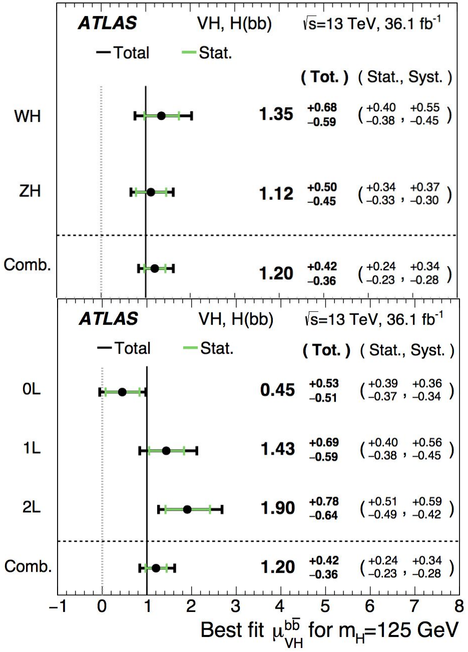
CMS

$\mu = 1.19^{+0.21}_{-0.20}(stat)^{+0.34}_{-0.32}(syst)$



ATLAS

$\mu = 1.20^{+0.24}_{-0.23}(stat)^{+0.34}_{-0.28}(syst)$



[Just published in PLB]

[Published in JHEP]

Systematic Uncertainties

Latest results with 2016 dataset in a nutshell

CMS

	Source	Type	Individual contribution to the μ uncertainty (%)	Effect of removal to the μ uncertainty (%)
1	Scale factors ($t\bar{t}$, V+jets)	norm.	9.4	3.5
2	Size of simulated samples	shape	8.1	3.1
3	Simulated samples' modeling	shape	4.1	2.9
	b tagging efficiency	shape	7.9	1.8
	Jet energy scale	shape	4.2	1.8
5	Signal cross sections	norm.	5.3	1.1
	Cross section uncertainties (single-top, VV)	norm.	4.7	1.1
4	Jet energy resolution	shape	5.6	0.9
	b tagging mistag rate	shape	4.6	0.9
	Integrated luminosity	norm.	2.2	0.9
	Unclustered energy	shape	1.3	0.2
	Lepton efficiency and trigger	norm.	1.9	0.1

ATLAS

	Source of uncertainty		σ_μ
	Total		0.39
	Statistical		0.24
	Systematic		0.31
	Experimental uncertainties		
	Jets		0.03
	E_T^{miss}		0.03
	Leptons		0.01
4	b-tagging	b-jets	0.09
		c-jets	0.04
		light jets	0.04
		extrapolation	0.01
	Pile-up		0.01
	Luminosity		0.04
	Theoretical and modelling uncertainties		
1	Signal		0.17
	Floating normalisations		0.07
3	Z + jets		0.07
3	W + jets		0.07
3	$t\bar{t}$		0.07
3	Single top quark		0.08
	Diboson		0.02
	Multijet		0.02
2	MC statistical		0.13

CMS $1.19^{+0.21}_{-0.20}(stat)^{+0.34}_{-0.32}(syst)$

ATLAS $1.20^{+0.24}_{-0.23}(stat)^{+0.34}_{-0.28}(syst)$

VH Signal Model

ME generator

- qq/qg→ZH = Powheg-Box v2 + GoSam + MiNLO
- gg→ZH = Powheg-Box v2 (LO)

Parton Shower and Higgs decay = Pythia8

Electroweak NLO differential correction $f(p_T^V)$ = HAWK

	$ZH \to l^+l^-H$								$ZH \to \nu\nu H$							
m_H (GeV)	Cross Section (pb)	+QCD Scale %	-QCD Scale %	$\pm(PDF+\alpha_s)$ %	±PDF %	$\pm\alpha_s$ %	gg→ZH (pb)	σ_γ	Cross Section (pb)	+QCD Scale %	-QCD Scale %	$\pm(PDF+\alpha_s)$ %	±PDF %	$\pm\alpha_s$ %	gg→ZH (pb)	σ_γ
125.00	2.982E-02	+3.8	-3.1	±1.6	±1.3	±0.9	4.14E-03	1.10E-04	1.776E-01	+3.8	-3.1	±1.6	±1.3	±0.9	2.457E-02	0.00E+00

	$W^+H \to l^+\nu H$							$W^-H \to l^-\nu H$						
m_H (GeV)	Cross Section (pb)	+QCD Scale %	-QCD Scale %	$\pm(PDF+\alpha_s)$ %	±PDF %	$\pm\alpha_s$ %	σ_γ	Cross Section (pb)	+QCD Scale %	-QCD Scale %	$\pm(PDF+\alpha_s)$ %	±PDF %	$\pm\alpha_s$ %	σ_γ
125.00	9.426E-02	+0.5	-0.7	±1.8	±1.6	±0.9	3.09E-03	5.983E-02	+0.4	-0.7	±2.0	±1.8	±0.8	2.00E-03

qq/qg→ZH
NNLO QCD(VH@NNLO) + NLO EW(HAWK) including photon-induced contribution

gg→ZH
NLO+NLL QCD(VH@NNLO rescaled with inclusive scale factor)

VH signal systematic uncertainties

Uncertainties on the total XS from HXSWG numbers
Acceptance uncertainties (not coming from HXSWG prescriptions):

CMS

- **QCD factorization / renormalization** scale variations by 0.5 and 2.0 independently

- **PDF uncertainties from** NNPDF3.0 replicas taking 68% CL interval

- **UE/PS/MPI uncertainties from:** Eigentune variations negliglble

→ uncertainties on the total rate of the signal, **and** on the shape of the BDT discriminating function

ATLAS

- **QCD factorization / renormalization** scale variations by 0.5 and 2.0 independently applied according to Stewart-Tackmann method for exclusive jet-bins

- **PDF uncertainties from:** PDF4LHC15_30 PDFs set at 68% CL interval

- **UE/PS/MPI uncertainties from:** A14 eigentune variations from mg5_aMC+Pythia8 alternative sample Powheg+Pythia8 / Powheg+Herwig7 comparison

→ uncertainties on the signal acceptance **and** on the shape of pTV and m(bb)

V+jets background modeling strategies

CMS

- **V+(light-flavor) modeling**
  CRs defined by inverting b-tagging requirements (anti-2-btag)

- **V+(heavy-flavor) modeling**
  CRs defined by inverting M(jj)-window

  (b-tag $CMVA_{min}$ shape fitted from CRs)

Process	0-lepton	1-lepton	2-lepton low-$p_T(V)$	2-lepton high-$p_T(V)$
W0b	1.14 ± 0.07	1.14 ± 0.07	—	—
W1b	1.66 ± 0.12	1.66 ± 0.12	—	—
W2b	1.49 ± 0.12	1.49 ± 0.12	—	—
Z0b	1.03 ± 0.07	—	1.01 ± 0.06	1.02 ± 0.06
Z1b	1.28 ± 0.17	—	0.98 ± 0.06	1.02 ± 0.11
Z2b	1.61 ± 0.10	—	1.09 ± 0.07	1.28 ± 0.09
tt	0.78 ± 0.05	0.91 ± 0.03	1.00 ± 0.03	1.04 ± 0.05

ATLAS

- **V+(heavy-flavor) modeling**
  W: dedicated CR (large m-top, low m-bb) - yield only, no shape
  Z: no *dedicated* CR - full m-bb spectrum included in the SRs

V+hf = V+(bb, bc, bl, cc)

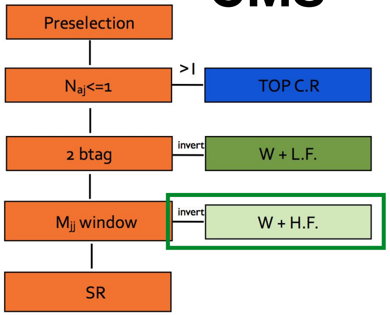
Process	Normalisation factor
$t\bar{t}$ 0- and 1-lepton	0.90 ± 0.08
$t\bar{t}$ 2-lepton 2-jet	0.97 ± 0.09
$t\bar{t}$ 2-lepton 3-jet	1.04 ± 0.06
W + HF 2-jet	1.22 ± 0.14
W + HF 3-jet	1.27 ± 0.14
Z + HF 2-jet	1.30 ± 0.10
Z + HF 3-jet	1.22 ± 0.09

Background **reweighting corrections** **for V+jets:**

- $f(p_T^V)$ differential correction (up to 10% at 400GeV) accounting for EW corrections
- $f(p_T^V)$ dedicated 1-lepton correction on W+light, W+b(b), ttbar, single-t
- deltaEta(jj) correction from LO/NLO comparison (depending on #b-labeled jets)

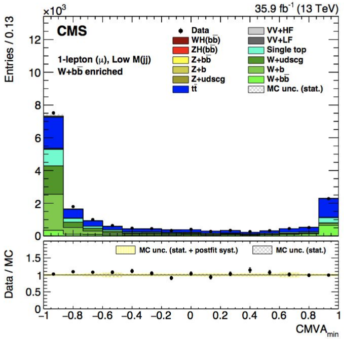
W+heavy flavors (1-lepton channel)

CMS



- Define dedicated control region (CR)
- Scale factors applied from CR to Signal Regions (SR)
- Systematic uncertainties fully correlated between CR and SR

Variable	W+HF
$p_T(j_1)$	>25
$p_T(j_2)$	>25
$p_T(jj)$	>100
$p_T(V)$	>100
$CMVA_{max}$	$>CMVA_T$
N_{aj}	=0
$N_{a\ell}$	=0
$\sigma(p_T^{miss})$	>2.0
$\Delta\phi(\vec{p}_T^{miss}, \ell)$	<2
$M(jj)$	<90, [150,250]

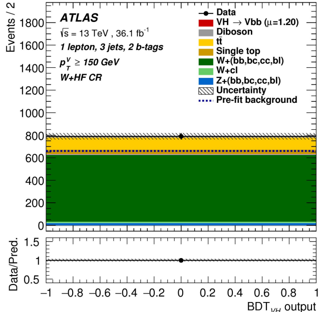


ATLAS

- **standard 1-lepton selection + m(bb) < 75GeV m(top) > 225GeV**
- Scale factor fitted directly in the SR
- extrapolation uncertainties from CR to SR obtained from theory
  - Sherpa 2.2.1 muR, muF, ckkw, qsf scale variations
  - Sherpa 2.2.1 comparison with Madgraph_aMC@NLO 2.2.2

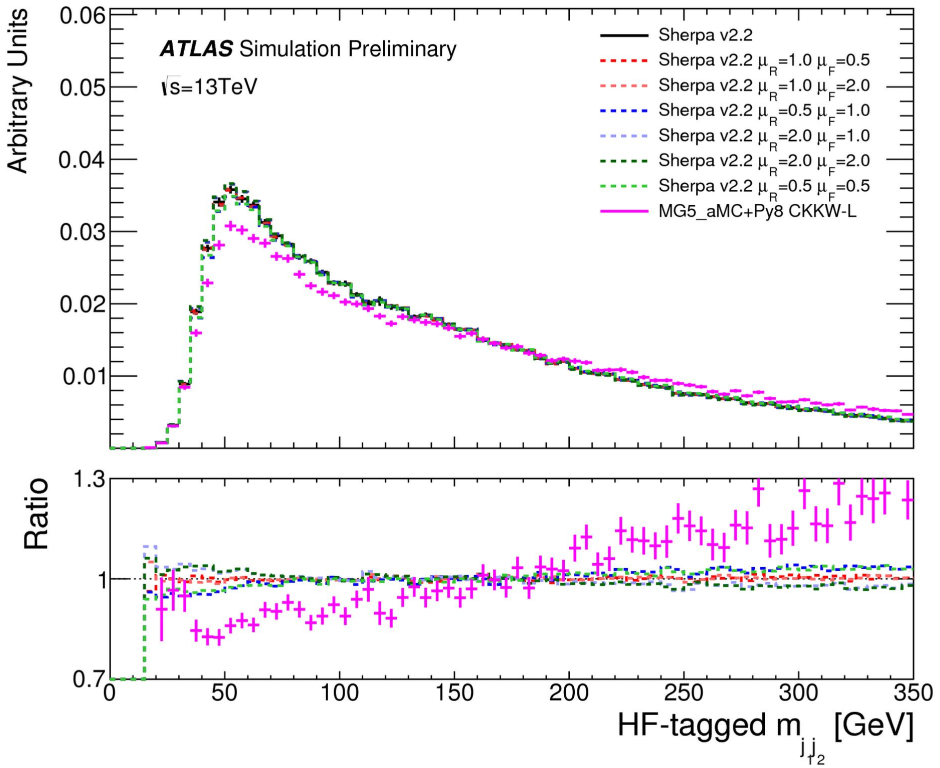
- Pre-fit theory modeling uncertainties

	W + jets
$W + ll$ normalisation	32%
$W + cl$ normalisation	37%
$W + bb$ normalisation	Floating (2-jet, 3-jet)
$W + bl$-to-$W + bb$ ratio	26% (0-lepton) and 23% (1-lepton)
$W + bc$-to-$W + bb$ ratio	15% (0-lepton) and 30% (1-lepton)
$W + cc$-to-$W + bb$ ratio	10% (0-lepton) and 30% (1-lepton)
0-to-1 lepton ratio	5%
W + HF CR to SR ratio	10% (1-lepton)
m_{bb}, p_T^V	S



V+jets background modeling

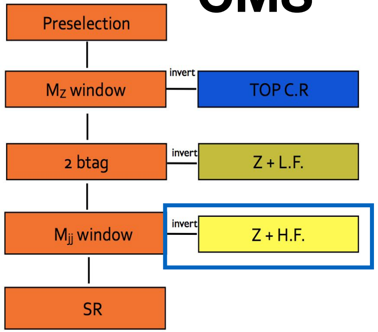
ATLAS PUB note on V+jets modeling and MC simulation



- **selection close to nominal VH(bb) analysis regions**
- no W+hf CR/SR separation

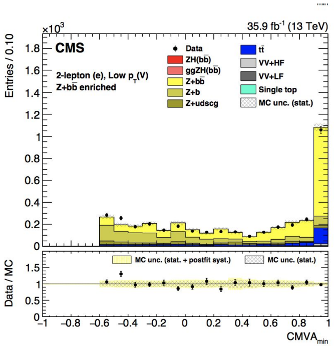
Z+heavy flavors (0-/2-lepton channel)

CMS



- Define dedicated control region (CR)
- Scale factors applied from CR to Signal Regions (SR)
- Systematic uncertainties fully correlated between CR and SR

Variable	Z+HF
$p_T(jj)$	—
$p_T(V)$	[50, 150], >150
$CMVA_{max}$	$>CMVA_T$
$CMVA_{min}$	$>CMVA_L$
N_{aj}	—
$N_{a\ell}$	—
p_T^{miss}	<60
$\Delta\phi(V,jj)$	>2.5
$M(\ell\ell)$	[85, 97]
$M(jj)$	$\notin$ [90, 150]



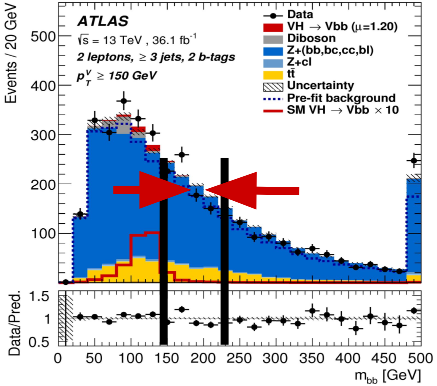
ATLAS

- **no dedicated control region for Z+hf**
- no m(bb) window selection applied in the nominal analysis selection

- **m(bb) and pTV** shape systematic derived from data/MC in Z+hf enriched-region
  (2-lepton) x (1-btag)
  (2-lepton) x (2-btag) x (remove events with m(jj) around m

- Pre-fit theory modeling uncertainties

	Z + jets
$Z + ll$ normalisation	18%
$Z + cl$ normalisation	23%
$Z + bb$ normalisation	Floating (2-jet, 3-jet)
$Z + bc$-to-$Z + bb$ ratio	30 – 40%
$Z + cc$-to-$Z + bb$ ratio	13 – 15%
$Z + bl$-to-$Z + bb$ ratio	20 – 25%
0-to-2 lepton ratio	7%
m_{bb}, p_T^V	S



Layman's scaling

- Simple back-of-the-envelope luminosity scaling / no improvements or correlations

L_{int}	**stat.** error on $\mu = \sigma/\sigma_{SM}$ (from ATLAS numbers)	**syst.** error on $\mu = \sigma/\sigma_{SM}$ (from ATLAS numbers)	**expected significance** (from ATLAS numbers)
36/fb	0.24	0.31	**3.0**
80/fb	0.16	?	**4.5**
100/fb	0.14	?	**5.0**
150/fb	0.12	?	**6.1**

In addition: ATLAS+CMS combination ... which timescale?

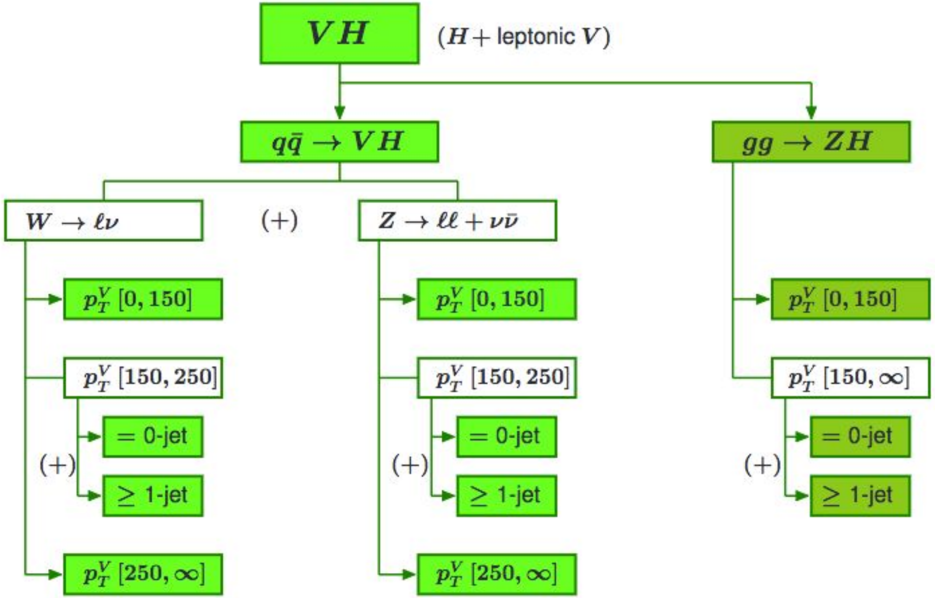
Towards simplified Template Cross sections

Stage-0 split already *possible* with current analyses
(WH, ZH signal strength provided, no split in qqZH and ggZH)

Stage-1 is the "minimal hoped for" split for Run-2 analyses: analysed dataset (~36/fb) too small to extract a full stage-1 split → promising with next update including additional luminosity

Current analyses can provide an interesting case for the implementation of STXS framework at stage-1

- *Encourage exp. analyses to implement STXS stage-1 split (ready **for** the next analysis iteration - start to test with current analyses)*
- *From HXSWG VH:*
  provide theory uncertainty for stage-1 split (per-bin uncertainties with correlation scheme)



Towards simplified Template Cross sections

Two aspects to theory uncertainties

- Residual theoretical uncertainties related to “unfolding” experimental event categories to STXS bins
- Uncertainties in interpretation of STXS bins, i.e. in SM (or beyond) cross section predictions for each bin
  - Also enter as “residual” uncertainties in measurement whenever bins with different sensitivities are merged

Implementation of uncertainties (in measurement or interpretation)

- Requires uncertainties per bin and their correlations
  - Particularly important when binning cut itself introduces a source of uncertainty that affects each bin but cancels in their sum
  - Implementation in terms of $\pm 100\%$ correlated or uncorrelated nuisance parameters

$\rightarrow$ Need to identify and distinguish different sources of uncertainties and evaluate also their correlations between kinematic bins

  - Use generic parametrization of uncertainties in kinematic bins as discussed in `YR4` Section 1.4.2a

First implementation of stage 0

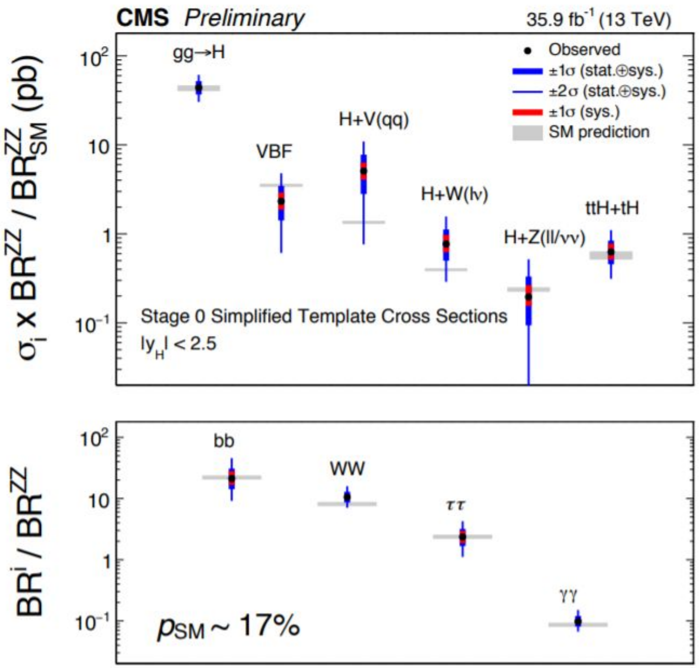
Simplified Template XS

CMS

First STXS* measurement using combination of 5 decay channels

Extract production modes cross-sections in fiducial regions, profile ratios of branching ratios

Decouple (inclusive) theory uncertainties from experimental ones



*from YR4: arXiv:1610.07922

LHCHXS WG1 VH sub-group: projects

- **VH XS prediction and uncertainties in STXS framework**
  - deliverables: Software tool providing central value and uncertainties + recommendations
  - timescale: ~mid-summer
  - status: in progress

- **HL/HE-LHC 27TeV VH cross-section**
  - deliverables: VH cross-section and uncertainties calculation at 27TeV
    - Assume results similar to what quoted for 13TeV, i.e. XS central values and uncertainties
    - Please let us know in case something more/different would be needed - as this could affect the timescale
  - timescale: few months / summer
  - status: not started yet

- **V+hf modeling for VH(bb)**
  - deliverables: [public note] MC comparison across several V+hf MC tools targeting VH(bb) phase space, guidelines for theory uncertainties on V+hf predictions
  - timescale: autumn 2018
  - status: in progress [https://indico.cern.ch/event/698454/]

- **ggZH merged predictions**
  - deliverables: [potentially public note] Comparison between showered ggZH 0+1jet merged LO MC prediction, and ggZH LO prediction
  - timescale: ~mid-summer 2018
  - status: not yet started

(more) BACK-UP

Outline of July's talk

Swift start of activities in the VH WG1 subgroup

first topics considered to design a roadmap for the future (short / medium / long term):

- precise modeling of VH processes @NNLO[QCD] and @NLO[EW]
- treatment of loop-induced gg→ZH
- latest experimental VH results
  - → state of VH predictions / tools used by experimental collaborations
  - → main theory limitations & "whishlist", possible improvements
- Simplified Template Cross Section STXS approach
- open point: treatment of main SM backgrounds for VH measurements

This talk: experimental take on VH matters, in light of recent results and towards the full Run-2 analyses

Francesco's talk: overview from the theory side - several contributions from the first VH subgroup meeting

Topics of interest

- **Combination of NNLO QCD and NLO EW corrections in parton showers**
  - Short-term proposal: use POWHEG_MiNLO and reweight using YR4 EW correction factors either in the cross-section or differentially in VpT.
  - Longer-term: investigate/encourage authors to collaborate on joint implementation in POWHEG, as has already been done for (simpler) W/Z production.
- **How can predictions for gg—>VH contribution be improved?**
  - try to improve approximation (tension between effectiveness of HEFT and boosted region where gg contribution is large);
  - can we exploit similarities with (very similar) gg—>HH process of G. Heinrich et al;
  - is there any mileage in a direct appeal to the Goldstone equivalence theorem (perhaps applies well enough in boosted region)?
- **Benchmark existing calculations of gg —> VH**
  - Should benchmark existing calculations of gg —> VH, which may contain different treatments and approximations, both with and without matching/merging.
- **Discuss backgrounds**
  - Desire within experiments for more guidance/sharing of experience with background generation and benchmarking in boosted region.
  - General agreement that, while not the focus of this subgroup, we should help to facilitate such discussions.
- **VH theoretical uncertainties under simplified template cross-section approach (STXS)**
  - How should the calculation of uncertainties for VH be handled under simplified template cross-section approach (STXS), c.f. YR4.
  - In particular, correlated uncertainties between jet bins — either using Stewart/Tackmann or other similar approaches.
  - How to apply/extend ggF experience to VH?

Lepton channel significances

CMS

Channels	Significance expected	Significance observed
0-lepton	1.5	0.0
1-lepton	1.5	3.2
2-lepton	1.8	3.1
Combined	2.8	3.3

ATLAS

Dataset	p_0		Significance	
	Exp.	Obs.	Exp.	Obs.
0-lepton	4.2%	30%	1.7	0.5
1-lepton	3.5%	1.1%	1.8	2.3
2-lepton	3.1%	0.019%	1.9	3.6
Combined	0.12%	0.019%	3.0	3.5

Fit Result: Background Normalizations

- Simultaneous max-likelihood fit over 7 signal regions (BDT score) and 63 control regions (minimum jet b-tag discriminant).
  - Background normalizations allowed to float for V+jets, tt.
  - V+jets normalization fitted separately for 0/1/2 b-jets.

	Missing E_T > 170 GeV	$p_T(W)$ > 100 GeV	100 GeV < $p_T(Z)$ > 150 GeV	$p_T(Z)$ > 150 GeV
Process	0-lepton	1-lepton	2-lepton low-p_T(V)	2-lepton high-p_T(V)
W0b	1.14 ± 0.07	1.14 ± 0.07	—	—
W1b	1.66 ± 0.12	1.66 ± 0.12	—	—
W2b	1.49 ± 0.12	1.49 ± 0.12	—	—
Z0b	1.03 ± 0.07	—	1.01 ± 0.06	1.02 ± 0.06
Z1b	1.28 ± 0.17	—	0.98 ± 0.06	1.02 ± 0.11
Z2b	1.61 ± 0.10	—	1.09 ± 0.07	1.28 ± 0.09
$t\bar{t}$	0.78 ± 0.05	0.91 ± 0.03	1.00 ± 0.03	1.04 ± 0.05

Signal Modelling

- qqVH signal MC produced with POWHEG+MiNLO and then rescaled to NNLO QCD.
- NLO EWK corrections applied differentially in $p_T(V)$.
  - More details here and in YR4.

Sample	Generator
VH	Powheg with pythia8 parton-showering
ggZH	Powheg with pythia8 parton-showering

Background Modelling

- **Statistical power of MC** for primary backgrounds ($t\bar{t}$, V+jets) **critical for this analysis.**
- **V+jets modelled with MG5_aMC at LO** due to relatively high available statistics.
  - EWK NLO corrections differential in $p_T(V)$.
  - V+jets $\Delta\eta(jj)$ distribution re-weighted to match NLO prediction.
- Separate linear $p_T(W)$ corrections applied in 1-lepton channel to $t\bar{t}$, W +udscg, and combination of W+b(b) and single top.
  - Derived from simultaneous fit to data in 1-lepton control regions.

Sample	Generator
$t\bar{t}$	Inclusive powheg-pythia8
V+jets	HT-binned MG5_aMC at LO + b-enriched samples
VV	MG5_aMC at NLO
Single top s/t-channel	ST_t/s-channel_4f_leptonDecays_13TeV-amcatnlo-pythia8
tW	ST_tW_(anti)top_5f_inclusiveDecays_13TeV-powheg-pythia8
QCD	HT-binned MG5_aMC at LO

Systematics (experimental)

experimental

Source	Type	Individual contribution to the μ uncertainty (%)	Effect of removal to the μ uncertainty (%)
Scale factors (tt, V+jets)	norm.	9.4	3.5
Size of simulated samples	shape	8.1	3.1
Simulated samples' modeling	shape	4.1	2.9
b tagging efficiency	shape	7.9	1.8
Jet energy scale	shape	4.2	1.8
Signal cross sections	norm.	5.3	1.1
Cross section uncertainties (single-top, VV)	norm.	4.7	1.1
Jet energy resolution	shape	5.6	0.9
b tagging mistag rate	shape	4.6	0.9
Integrated luminosity	norm.	2.2	0.9
Unclustered energy	shape	1.3	0.2
Lepton efficiency and trigger	norm.	1.9	0.1

- **Experimental uncertainties:**
  - **Background scale factors:**
    - **Uncertainty on $t\bar{t}$, V+jets norms.** constrained by control regions in simultaneous fit but **limited by:**
      - **Acceptance differences** between control region and signal region selections.
      - **Uncertainty on background** process **cross sections**.
      - **Statistics in data**.
  - **B-tagging efficiency:**
    - Split into independent uncertainty sources and further de-correlated based on b-jet kinematics (p_T, η).
  - **Jet energy scale:**
    - Split into 27 independent uncertainty sources.

Systematics (MC and Theory)

MC&theory

Source	Type	Individual contribution to the μ uncertainty (%)	Effect of removal to the μ uncertainty (%)
Scale factors ($t\bar{t}$, V+jets)	norm.	9.4	3.5
Size of simulated samples	shape	8.1	3.1
Simulated samples' modeling	shape	4.1	2.9
b tagging efficiency	shape	7.9	1.8
Jet energy scale	shape	4.2	1.8
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Jet energy resolution	shape	5.6	0.9
b tagging mistag rate	shape	4.6	0.9
Integrated luminosity	norm.	2.2	0.9
Unclustered energy	shape	1.3	0.2
Lepton efficiency and trigger	norm.	1.9	0.1

- **MC and Theory Systematics:**
  - **Size of simulated samples:**
    - **Limited** available MC statistics **in crucial high-p_T(V) phase space.**
      - **Particularly an issue for V+jets MC**, also affected (less) by available $t\bar{t}$ MC stats in 1-lepton channel.
  - **Simulated samples modelling:**
    - **Modelling of p_T(W)** for $t\bar{t}$ and V+jets **with leading-order** samples.
  - Factorization and normalization scales varied up/down by factor 0.5/2.0. Individual yield uncertainties per process from PDF.
  - Signal cross sections:
    - NNLO QCD correction uncertainty 1% (4%) for WH/ZH production processes.
  - 15% uncertainty for single top and diboson cross sections.
  - Uncertainty on parton shower modelling/tune not included.
    - Effect of variations in tune found to be negligible. Parton shower modelling to some extent covered by μ_F/μ_R variations.

Thanks to the LHC Higgs XS WG

Simulated samples

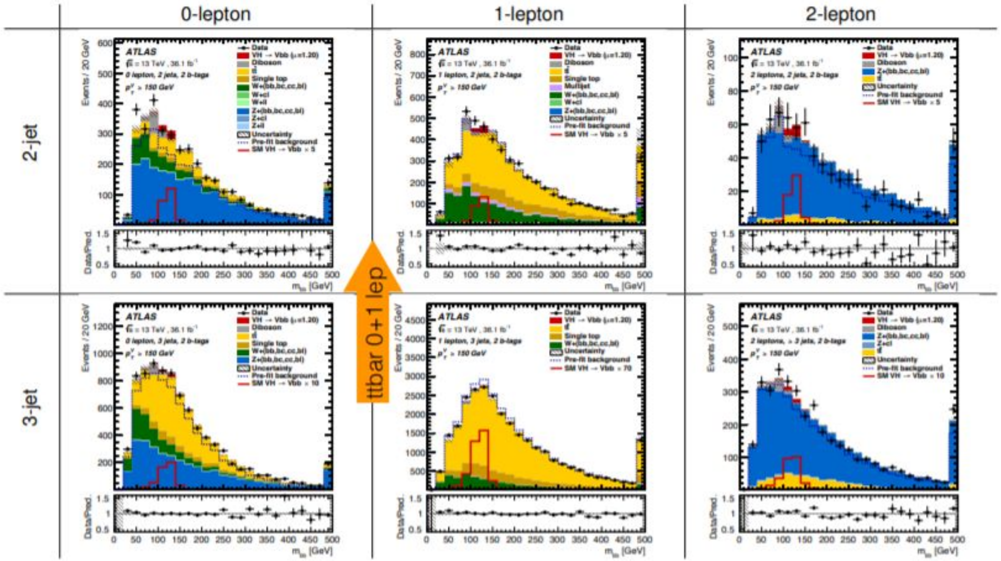
- Simulated samples summarised in table below

Process	ME generator	ME PDF	PS and Hadronisation	UE model tune	Cross-section order
Signal					
$qq \to WH \to \ell\nu b\bar{b}$	Powheg-Box v2 [37] + GoSam [40] + MiNLO [41, 42]	NNPDF3.0NLO$^{(\star)}$ [38]	Pythia8.212 [31]	AZNLO [39]	NNLO(QCD)+ NLO(EW) [43–49]
$qq \to ZH \to \nu\nu b\bar{b}/\ell\ell b\bar{b}$	Powheg-Box v2 + GoSam + MiNLO	NNPDF3.0NLO$^{(\star)}$	Pythia8.212	AZNLO	NNLO(QCD)$^{(\dagger)}$+ NLO(EW)
$gg \to ZH \to \nu\nu b\bar{b}/\ell\ell b\bar{b}$	Powheg-Box v2	NNPDF3.0NLO$^{(\star)}$	Pythia8.212	AZNLO	NLO+ NLL [50–54]
Top quark					
$t\bar{t}$	Powheg-Box v2 [55]	NNPDF3.0NLO	Pythia8.212	A14 [56]	NNLO+NNLL [57]
s-channel	Powheg-Box v1 [58]	CT10 [59]	Pythia6.428 [60]	P2012 [61]	NLO [62]
t-channel	Powheg-Box v1 [58]	CT10f4	Pythia6.428	P2012	NLO [63]
Wt	Powheg-Box v1 [64]	CT10	Pythia6.428	P2012	NLO [65]
Vector boson + jets					
$W \to \ell\nu$	Sherpa 2.2.1 [34, 66, 67]	NNPDF3.0NNLO	Sherpa 2.2.1 [68, 69]	Default	NNLO [70]
$Z/\gamma^* \to \ell\ell$	Sherpa 2.2.1	NNPDF3.0NNLO	Sherpa 2.2.1	Default	NNLO
$Z \to \nu\nu$	Sherpa 2.2.1	NNPDF3.0NNLO	Sherpa 2.2.1	Default	NNLO
Diboson					
WW	Sherpa 2.1.1	CT10	Sherpa 2.1.1	Default	NLO
WZ	Sherpa 2.2.1	NNPDF3.0NNLO	Sherpa 2.2.1	Default	NLO
ZZ	Sherpa 2.2.1	NNPDF3.0NNLO	Sherpa 2.2.1	Default	NLO

- Signal events generated using the first PDF in the NNPDF3.0NLO set and reweighted to the PDF4LHC15NLO set using Powheg-Boxv2
- Sherpa 2.2.1 V+jets is NLO@0,1,2-partons; LO@3,4-partons. CKKW matching with matching scale of 20 GeV, 5FS for the matrix element calculations
- $V+bb$, $V+bc$, $V+bl$, $V+cc$ grouped as $V+\mathrm{HF}$ as dominant $V+$jets contribution
  - Truth flavour labels of b-tagged jets (ΔR matching of reconstructed jets to truth hadrons)
- Multijet background negligible in 0- and 2-lepton channels
  - Determined from data-driven studies
- Estimated in 1-lepton channel using hybrid of template method and fake factor method (anti-isolated to isolated bias correction)
  - Multijet contamination $\sim 5\%$ in 2-jet, $\sim 0.5\%$ in 3-jet

Fit model: Floating normalisations

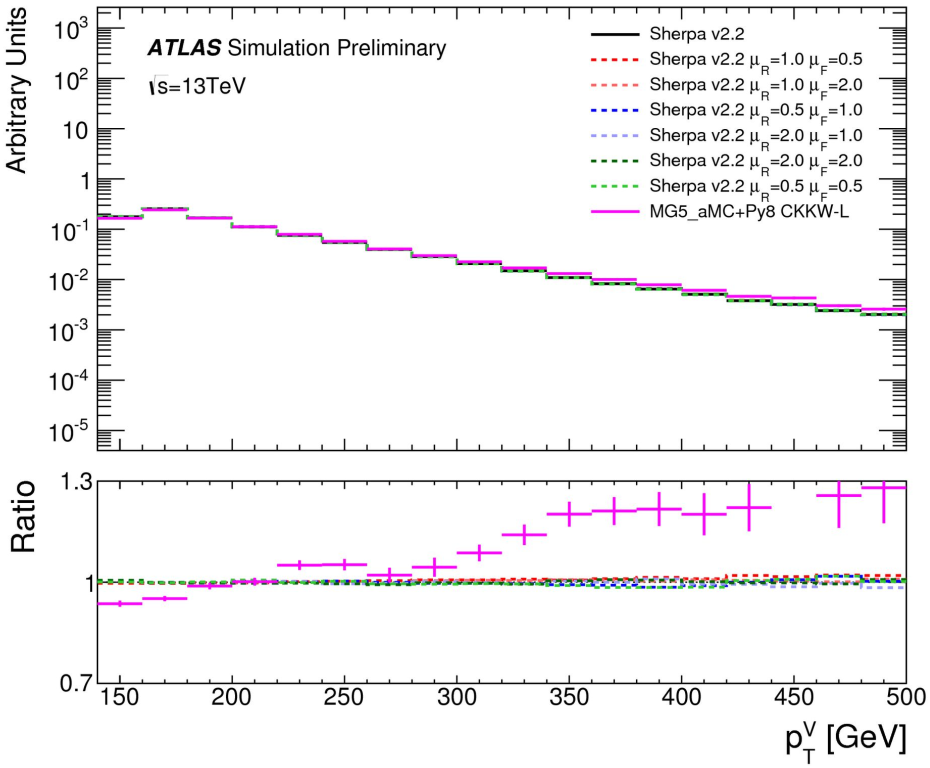
- Overview of fit model concept
- 5 floating background normalisations for:
  - $t\bar{t}$ (0+1 lepton, 2-lepton 2-jet, 2-lepton 3+-jet)
  - $W+\mathrm{HF}$, $Z+\mathrm{HF}$ (2-jet, 3-jet)
- $t\bar{t}$ contribution is very different in 0- and 1-lepton to 2-lepton case:
  - In 0- and 1-lepton, have missed an object (jet or lepton) $\rightarrow$ one common floating normalisation
  - In 2-lepton, dileptonic $t\bar{t}$ contributes directly $\rightarrow$ top $e\mu$ CR can constrain normalisation in 2-/3+-jet
- Normalisation driven by a region, with appropriate extrapolation uncertainties



V+jets background modeling

https://atlas.web.cern.ch/Atlas/GROUPS/PHYSICS/PUBNOTES/ATL-PHYS-PUB-2017-006/

ATLAS PUB not on V+jets modeling and MC simulation



- **selection close to nominal VH(bb) analysis regions**

- no cut on #jets<=3
- no W+hf CR/SR separation

gg→ZH Cross Section

- ZH production has two distinct sources of gg→ZH:
    1. a genuine NNLO contribution to what called “Drell-Yan-like”, where ZH is accompanied by two-parton radiation, gg→HZ+qqbar.
    2. top- and bottom-loop induced contribution without any additional partons in the final state.
- What is usually meant by gg→HZ below is 2) above.
- The statement that “all but gg→HZ” is the same as “qq- and qg-initiated” is correct only through NLO QCD.
- For separate cross sections and associated QCD scale uncertainties in qq/qg→ZH(+gg→HZ+qqbar) and gg→ZH for NLO/LO MC normalization, use
    - σ(all but gg→ZH) = σ(pp→ZH)@(NNLO QCD + NLO EW, NLO+NLL QCD gg→ZH) - σ(gg→ZH)@(NLO+NLL QCD),
    - Separate QCD scale uncertainties are σ(all but gg→ZH) or on σ(gg→ZH) are calculated with VH@NNLO program.
- For M_H=125.0 GeV and at √s=13 TeV,

Process	Cross Section (pb)	+QCD Scale %	-QCD Scale %	±(PDF+α_s) %	±PDF %	±α_s %
pp→ZH	0.8839	+3.8%	-3.1%	±1.6%	±1.3%	±0.9%
qq/qg→ZH, gg→HZ+qqbar (all but gg→ZH)	0.7612	+0.5%	-0.6%	±1.9%	±1.7%	±0.9%
gg→ZH	0.1227	+25.1%	-18.9%	±2.4%	±1.8%	±1.6%

Parametrization of VH Uncertainties: Sources.

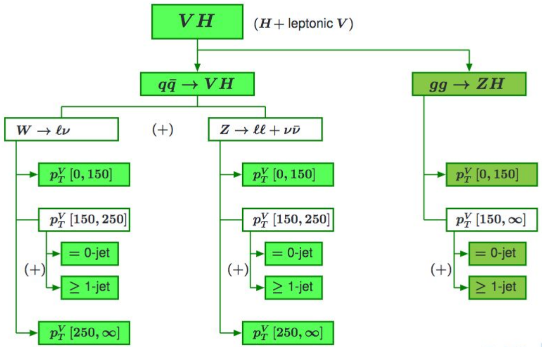
QCD uncertainties

- $\Delta_\mu, \Delta_{150}, \Delta_{250}$
  - Option 1: overall yield uncertainty plus two p_T^V binning (shape) uncertainties
  - Option 2: one uncorrelated uncertainty for each p_T^V bin
- $\Delta_{0/1}$: jet bin migration uncertainty
- Same nuisance parameter for W and Z (i.e. 100% correlated)

EW uncertainties

- Δ_{Sud}: EW Sudakov effects (correlated between W and Z)
- $\Delta_W, \Delta_Z, \Delta_\gamma$
  - Separate uncertainties for non-Sudakov contributions

- Separate sources (uncorrelated uncertainties) for $q\bar{q} \to VH$ and $gg \to ZH$
  - Study which sources for $gg \to ZH$ should be correlated with $gg \to H$
- Some of this also impact "VBF" bins through its hadronic VH contribution



	QCD uncertainties				EW uncertainties		
$q\bar{q}' \to W$	$\Delta^{\mathrm{y}}_{\mathrm{WH}}$	$\Delta^{\mathrm{WH}}_{150}$	$\Delta^{\mathrm{WH}}_{250}$	$\Delta^{\mathrm{WH}}_{0/1}$	$\Delta^{\mathrm{WH}}_{\mathrm{Sud}}$	$\Delta^{\mathrm{WH}}_{\mathrm{hard}}$	
p_T^V [0,150]	x_1	-1	$-y$		x_1	$\cdots$	
p_T^V [150,250]	x_2	$+1-y$	$-(1-y)$	0	x_2	$\cdots$	
$=$ 0-jet	$x_2 z$	$+(1-y)z$	$-(1-y)z$	$+1$	$\cdots$	$\cdots$	
$\geq$ 1-jet	$x_2(1-z)$	$+(1-y)(1-z)$	$-(1-y)(1-z)$	-1	$\cdots$	$\cdots$	
p_T^V [250,∞]	x_3	y	$+1$		x_3	$\cdots$	
$q\bar{q} \to Z$	$\Delta^{\mathrm{y}}_{\mathrm{ZH}}$	$\Delta^{\mathrm{ZH}}_{150}$	$\Delta^{\mathrm{ZH}}_{250}$	$\Delta^{\mathrm{ZH}}_{0/1}$	$\Delta^{\mathrm{ZH}}_{\mathrm{Sud}}$		$\Delta^{\mathrm{ZH}}_{\mathrm{hard}}$
p_T^V [0,150]	x_1	-1	$-y$		x_1		$\cdots$
p_T^V [150,250]	x_2	$+1-y$	$-(1-y)$	0	x_2		$\cdots$
$=$ 0-jet	$x_2 z$	$+(1-y)z$	$-(1-y)z$	$+1$	$\cdots$		$\cdots$
$\geq$ 1-jet	$x_2(1-z)$	$+(1-y)(1-z)$	$-(1-y)(1-z)$	-1	$\cdots$		$\cdots$
p_T^V [250,∞]	x_3	y	$+1$		x_3		$\cdots$