HXSWG - VH

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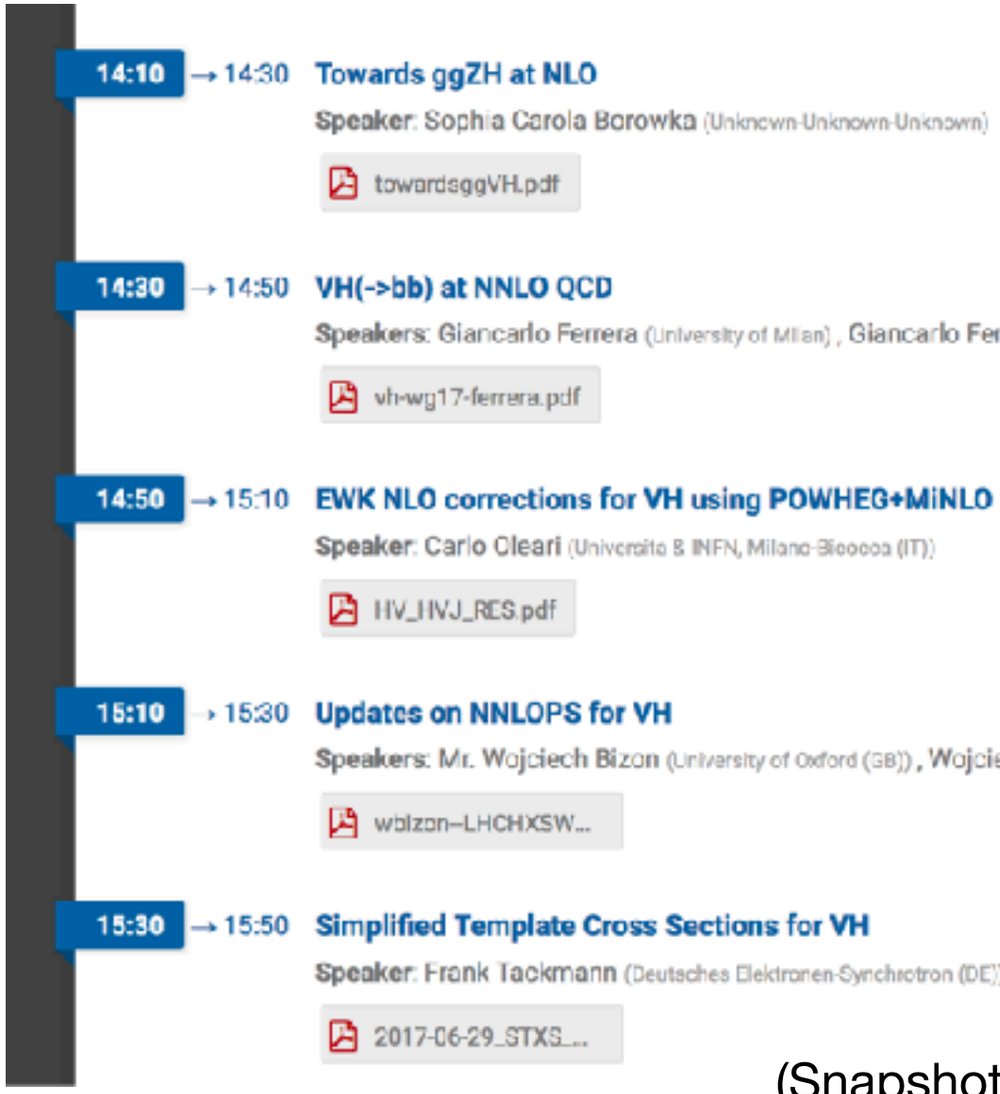
- Recent meetings

  - Overview of VH theory activities - 29/07/2017
    https://indico.cern.ch/event/648099/

  - ATLAS+CMS VH(bb) 13TeV results review / discussion - 17/10/2017
    https://indico.cern.ch/event/666958/



(Snapshot from 29/07 meeting)

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- Experimental points

1. interest from exp. collaboration in gauging the impact of theory advancements in VH experimental analyses - especially considering:

(shorter-term)

- VH NNLOPS prediction (and reduction of scale uncertainty) + NLO EW
- VH(bb)@NNLO production+decay
- assessment / better understanding of PS/UE/HAD uncertainties

(can we provide some guidelines?)

(longer-term)

- (loop-induced) ggZH @ NLO QCD
  (potential improvements considering LO 0+1jet merged samples?)

2. experimental analyses starting to consider STXS for the next round of results (esp. important for VH(bb) which should approach interesting sensitivity): provide support in the form of

- obtain theoretical uncertainties in the STXS framework according to the VH split, and unc. sources list (summary by Frank in WG2 workshop last week)
- SW tool to easily access uncertainty (along lines of ggF tool)
- in contact with WG2, not much discussion had yet past review of bin-split and uncertainties scheme

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- Experimental points - background studies

1. As emerged from the ATLAS+CMS results review - treatment of V+hf background (predictions and TH uncertainties) critical for experimental VH(bb) analyses. Provide some support with V+hf modeling studies **targeting VH(bb) phases space**:

   - alternative generator, possibly specific for V+hf production (e.g. Wbbj Powheg MiNLO)

   - guidelines for TH uncertainty estimate

Target: potential HXSWG-VH study providing guidelines for the choice&setup of MC generator for V+hf production for VH(bb) - considering exp. limitations (e.g. timescale for MC production, filtering options) to define a result that can support effectively the exp. collaboration choices for MC production.

Discussion of differences between ATLAS and CMS treatment of V+hf would also take place, to define the common ground for this study (e.g. split in V+bb, V+bc, etc., heavy flavor definition, ...).

HXSWG - VH

- Activities

  - next meeting: ~ January
    goals: clearly defining goals and details of studies to perform within HXSWG:VH
    start preparation of the material for the HXSWG workshop

  - **plans/options for documentation**

    - interest in possibility to prepare public notes from HXSWG sub-groups

      - especially useful for studies including ATLAS/CMS material not yet public (which should undergo internal approval)

      - especially useful if opening to background studies as well (with limited scope of the HXSWG - i.e. background to Higgs production)

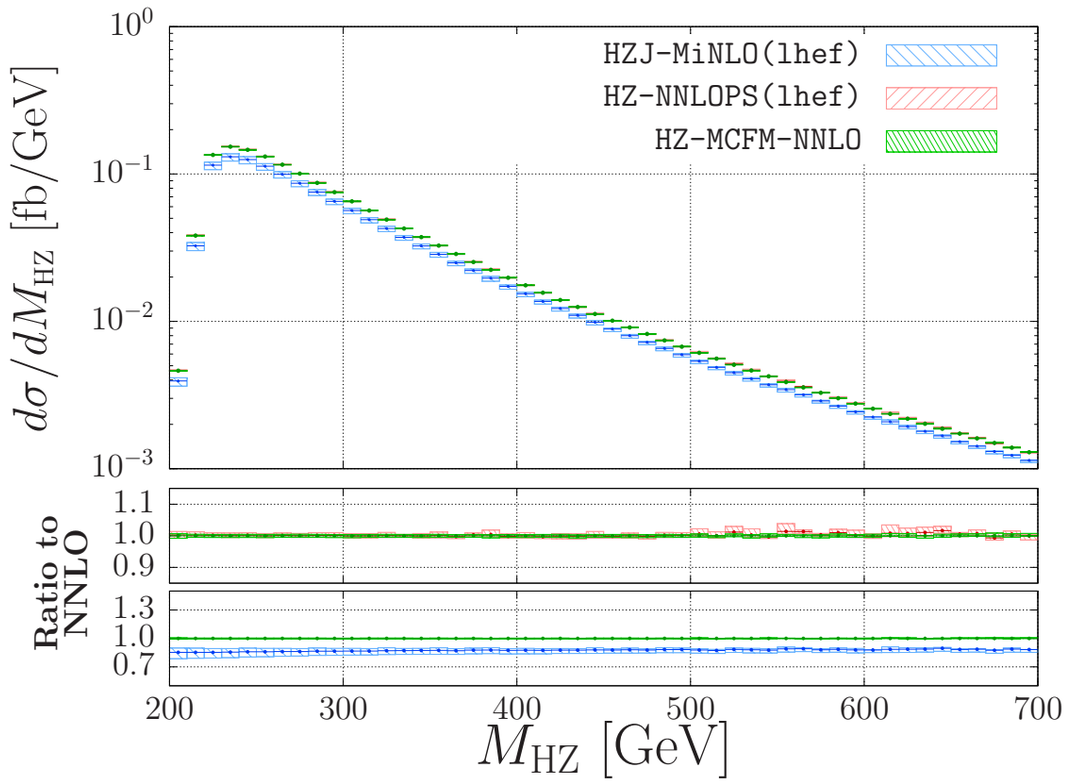
  - **HXSWG 14th workshop**:
    if possible, the usual 20min+20min of theory+experimental presentations seems to us like a good format - starting to discuss what material could suit the workshop

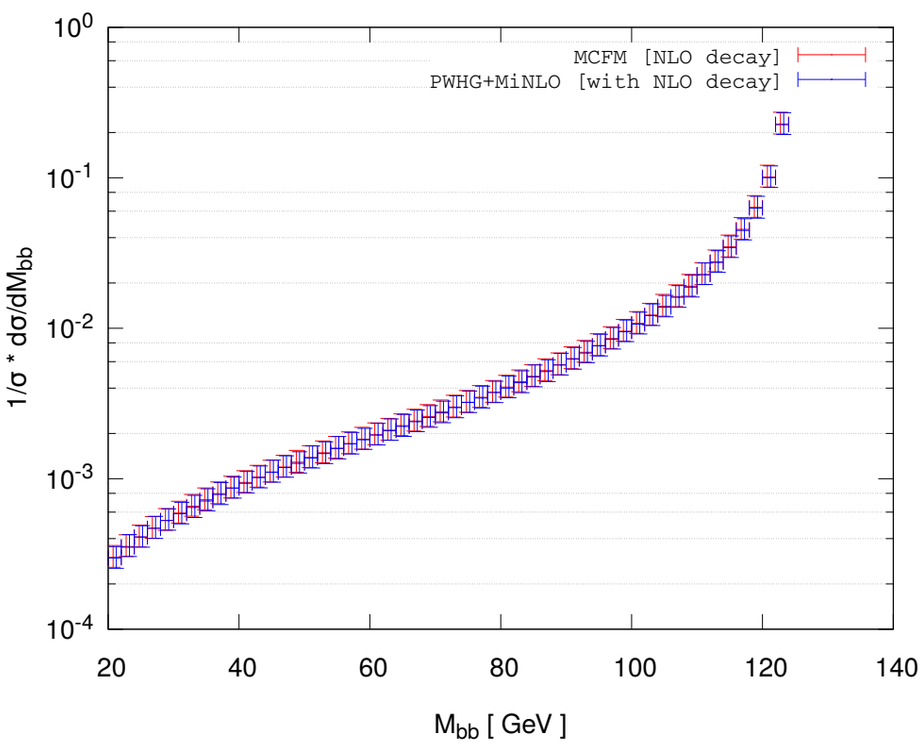
VH @ NNLOPS

[Astill,Bizon,Re,Zanderighi]

- starting point: NLO+PS-merged samples for VH and $VH+j$ with MiNLO [Luisoni,Nason,Oleari,Tramontano '13]
- NNLO+PS achieved by reweighting each event: to get new weight, one needs NNLO predictions differential in the Born phase space for VH (numerically challenging).
- for WH, we used the NNLO results from Ferrera,Grazzini,Tramontano. For ZH, we are using MCFM (Campbell,Ellis,Williams).
- for ZH, we have also included NLO correction to the $H \to b\bar{b}$ decay. They enter in the POWHEG $\bar{B}$ function, as well as when generating the hardest radiation.
  - we used the POWHEG-BOX-RES framework, as we have radiation from a resonance.
  - the $gg \to ZH$ loop-induced contribution is not included in the NNLO/MiNLO reweighting. A different event sample (generated at LO+PS) is used.

$\to$ PRELIMINARY RESULTS: we are finishing the paper, a public code will be released soon afterwards.





BACK-UP

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 $\sqrt{s}$=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.

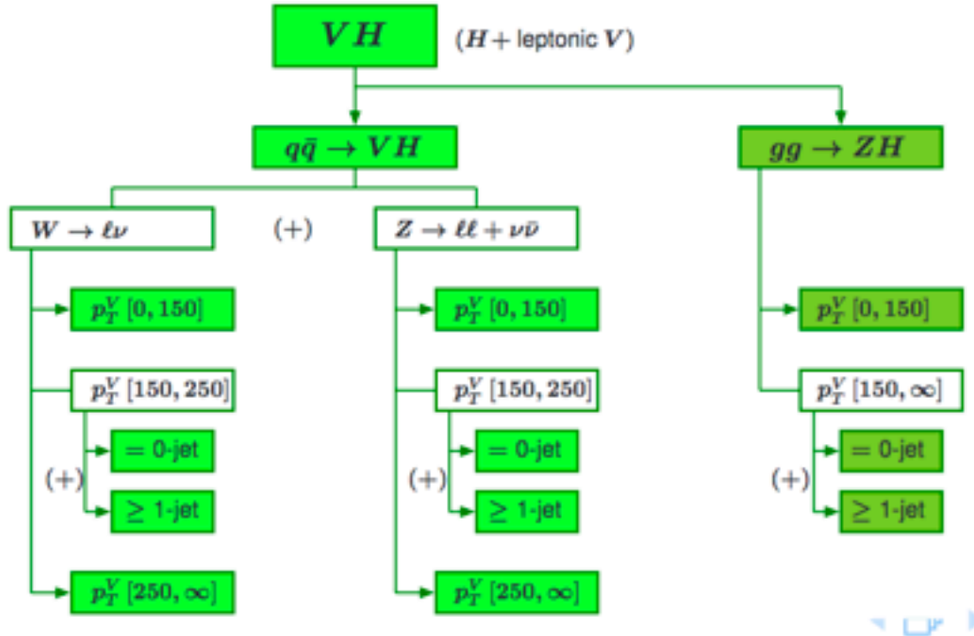
QCD uncertainties

- $\Delta_\mu, \Delta_{150}, \Delta_{250}$
  - 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



Parametrization of VH Uncertainties.

Bin	QCD uncertainties (Option 1)				EW uncertainties			
	Δ_μ	Δ_{150}	Δ_{250}	$\Delta_{0/1}$	Δ_{Sud}	Δ_W	Δ_Z	Δ_γ
W [0,150]	x_1	$-c$	0		y_1	$*$		$*$
W [150,250]	x_2	$+c$	$+d$	0	y_2	$*$		$*$
$=$0j [150,250]	$x_2 z$	$+cz$	$+dz$	$+1$	$\cdots$	$*$		$*$
$\geq$1j [150,250]	$x_2(1-z)$	$+c(1-z)$	$+d(1-z)$	-1	$\cdots$	$*$		$*$
W [250,∞]	x_3	0	$-d$		y_3	$*$		$*$
Z [0,150]	x_1	$-c$	0		y_1		$*$	
Z [150,250]	x_2	$+c$	$+d$	0	y_2		$*$	
$=$0j [150,250]	$x_2 z$	$+cz$	$+dz$	$+1$	$\cdots$		$*$	
$\geq$1j [150,250]	$x_2(1-z)$	$+c(1-z)$	$+d(1-z)$	-1	$\cdots$		$*$	
Z [250,∞]	x_3	0	$-d$		y_3		$*$	

$+$ Analogous uncorrelated sources for $gg \to ZH$

Simple prospects for single analysis

(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

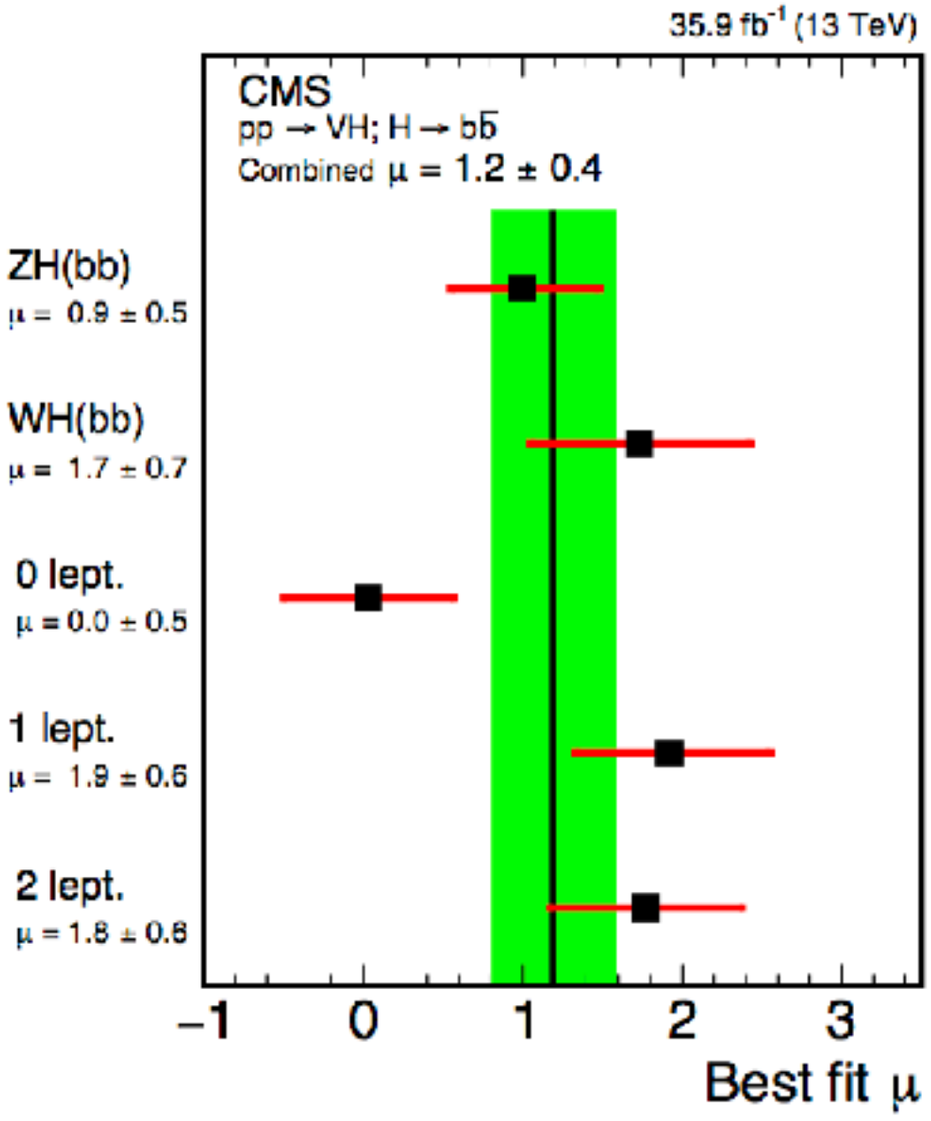
In addition: potential ATLAS+CMS combination ... which timescale?

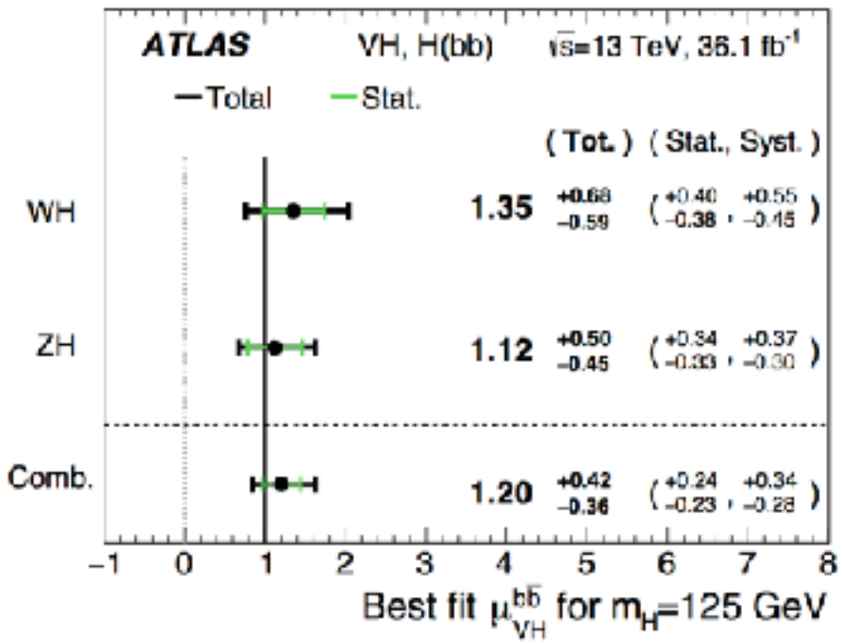
VH(bb) signal strength @ 13 TeV [L_{int} = 36/fb]

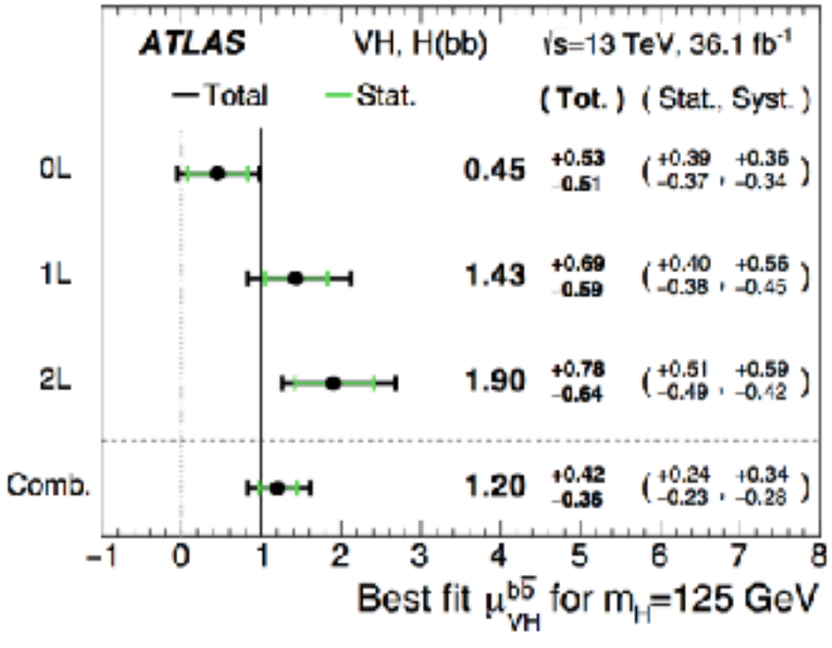
CMS

ATLAS

mu(VHbb) ***$1.19^{+0.21}_{-0.20}(stat)^{+0.34}_{-0.32}(syst)$*** ***$1.20^{+0.24}_{-0.23}(stat)^{+0.34}_{-0.28}(syst)$***







Systematic Uncertainties

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
	Simulated samples' modeling	shape	4.1	2.9
3	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

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

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

ATLAS

	Source of uncertainty		σ_μ
	Total		0.39
	Statistical		0.24
	Systematic		0.31
	Experimental uncertainties		
	Jets		0.03
	$E_{\mathrm{T}}^{\mathrm{miss}}$		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
3	Floating normalisations		0.07
	Z + jets		0.07
	W + jets		0.07
	$t\bar{t}$		0.07
	Single top quark		0.08
	Diboson		0.02
	Multijet		0.02
2	MC statistical		0.13

VH Signal Model

ME generator

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

Parton Shower = Pythia8

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

Cross-section - from HXSWG

	$ZH\to l^+l^-H$								$ZH\to\nu\nu H$							
m_H (GeV)	Cross Section (pb)	+QCD Scale %	-QCD Scale %	±(PDF+α_s) %	±PDF %	±α_s %	gg→ZH (pb)	σ_γ	Cross Section (pb)	+QCD Scale %	-QCD Scale %	±(PDF+α_s) %	±PDF %	±α_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 %	±(PDF+α_s) %	±PDF %	±α_s %	σ_γ	Cross Section (pb)	+QCD Scale %	-QCD Scale %	±(PDF+α_s) %	±PDF %	±α_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

PDF set: PDF4LHC15_nnlo_mc (QCD part) and NNPDF2.3QED (EW part).

VH signal systematic uncertainties

Uncertainties on the total XS from HXSWG numbers (previous slide)

Acceptance uncertainties (not coming from HXSWG prescriptions):

CMS

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

- **PDF uncertainties from** NNPDF replicas

  → 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
  [avoiding (0.5,2.0) and (2.0,0.5)
  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+Herwig comparison

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