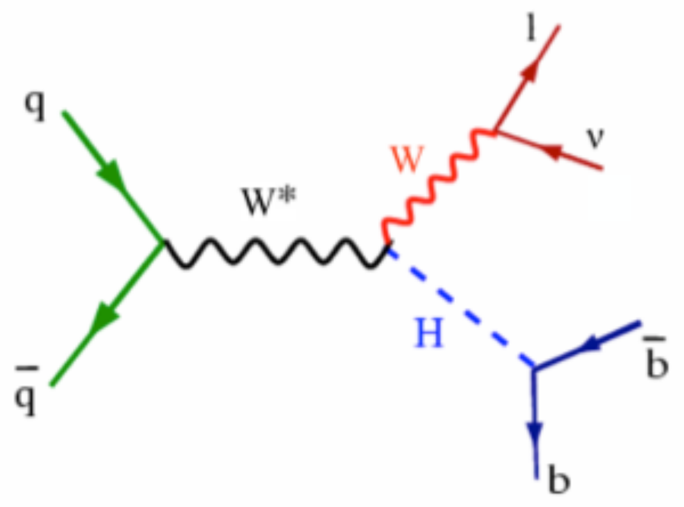
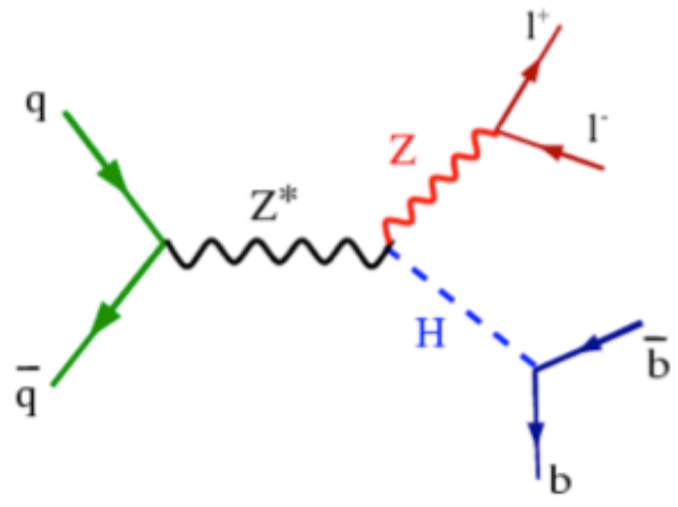
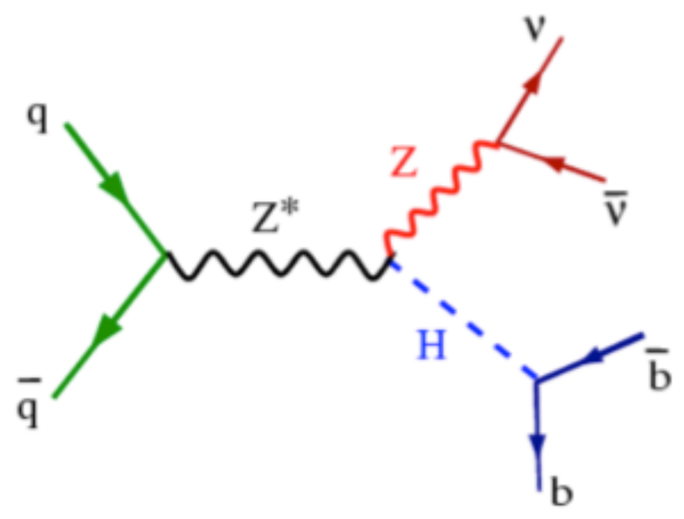
VH - HXSWG
VH(bb) CMS & ATLAS

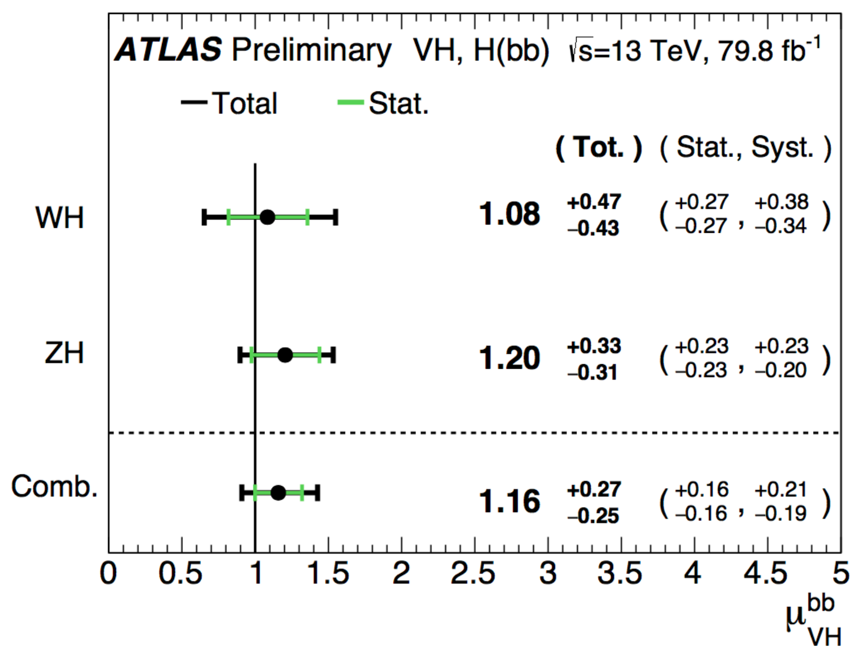


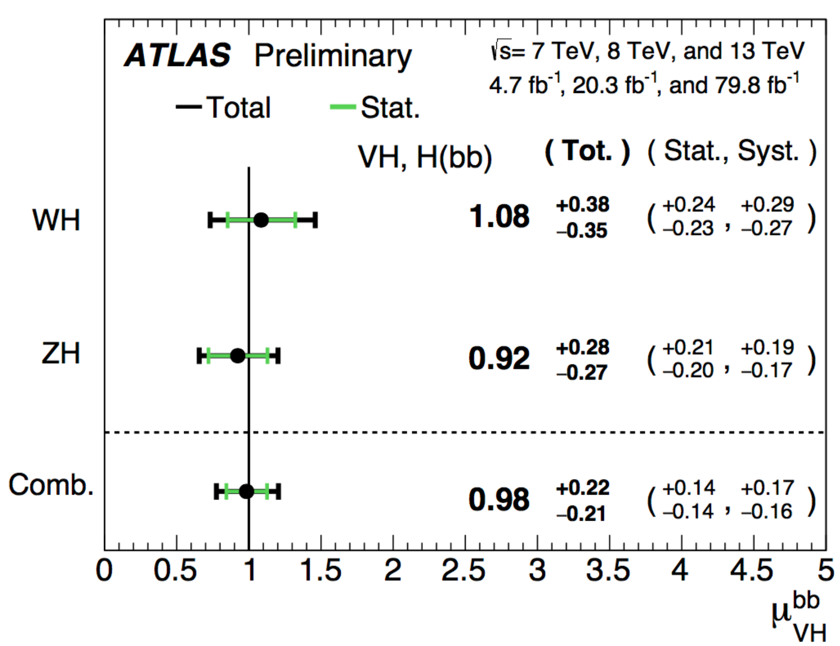


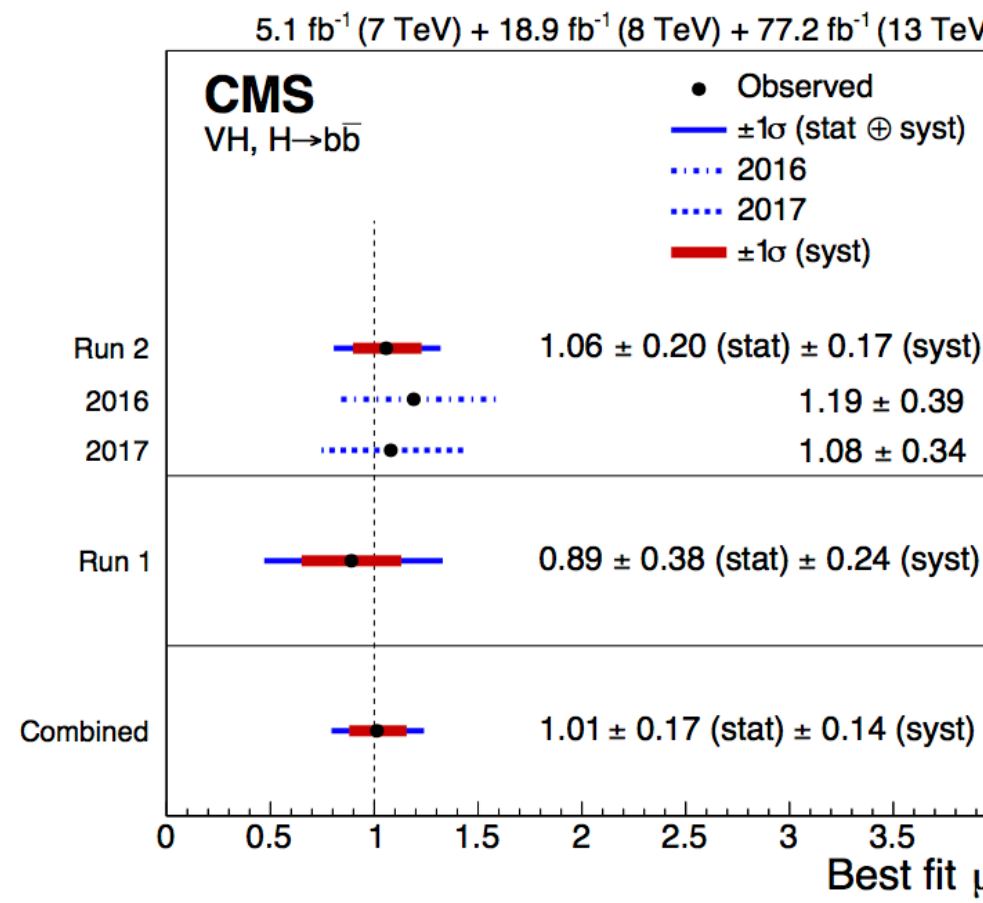


Signal strength parameter	Signal strength	p_0		Significance	
		Exp.	Obs.	Exp.	Obs.
0-lepton	$1.04^{+0.34}_{-0.32}$	$9.5 \cdot 10^{-4}$	$5.1 \cdot 10^{-4}$	3.1	3.3
1-lepton	$1.09^{+0.46}_{-0.42}$	$8.7 \cdot 10^{-3}$	$4.9 \cdot 10^{-3}$	2.4	2.6
2-lepton	$1.38^{+0.46}_{-0.42}$	$4.0 \cdot 10^{-3}$	$3.3 \cdot 10^{-4}$	2.6	3.4
$VH, H \rightarrow b\bar{b}$ combination	$1.16^{+0.27}_{-0.25}$	$7.3 \cdot 10^{-6}$	$5.3 \cdot 10^{-7}$	4.3	4.9

	Significance (σ)		
Data set	Expected	Observed	Signal strength
2017			
0-lepton	1.9	1.3	0.73 ± 0.65
1-lepton	1.8	2.6	1.32 ± 0.55
2-lepton	1.9	1.9	1.05 ± 0.59
Combined	3.1	3.3	1.08 ± 0.34
Run 2	4.2	4.4	1.06 ± 0.26
Run 1 + Run 2	4.9	4.8	1.01 ± 0.22







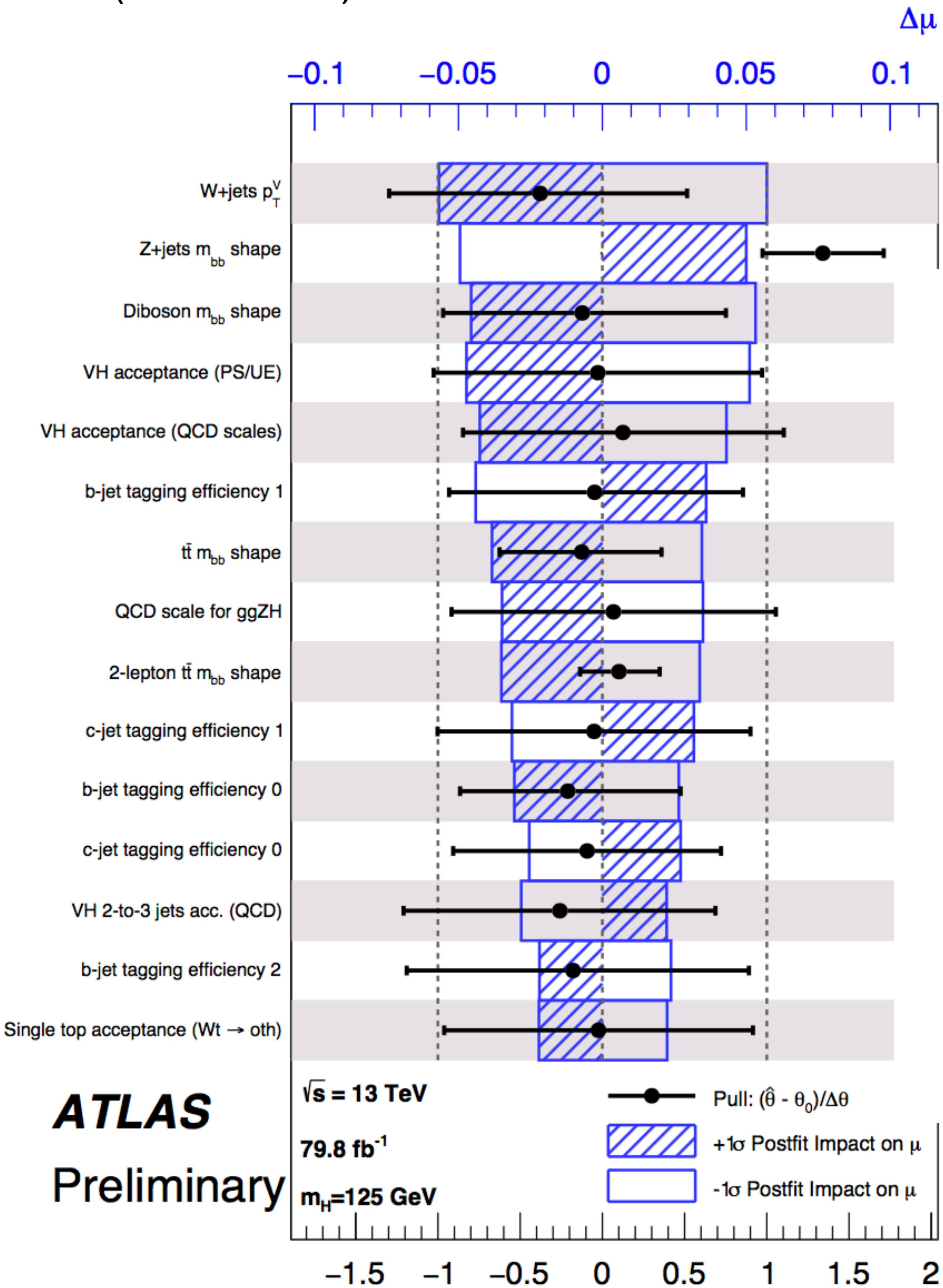
(13TeV data)

Source of uncertainty		σ_μ
Total		0.259
Statistical		0.161
Systematic		0.203
Experimental uncertainties		
Jets		0.035
E_T^{miss}		0.014
Leptons		0.009
b-tagging	b-jets	0.061
	c-jets	0.042
	light jets	0.009
	extrapolation	0.008
Pile-up		0.007
Luminosity		0.023
Theoretical and modelling uncertainties		
Signal		0.094
Floating normalisations		0.035
Z + jets		0.055
W + jets		0.060
$t\bar{t}$		0.050
Single top quark		0.028
Diboson		0.054
Multijet		0.005
MC statistical		0.070

(2017 data)

Uncertainty source	$\Delta\mu$	
Statistical	+0.26	−0.26
Normalization of backgrounds	+0.12	−0.12
Experimental	+0.16	−0.15
b-tagging efficiency and misid	+0.09	−0.08
V+jets modeling	+0.08	−0.07
Jet energy scale and resolution	+0.05	−0.05
Lepton identification	+0.02	−0.01
Luminosity	+0.03	−0.03
Other experimental uncertainties	+0.06	−0.05
MC sample size	+0.12	−0.12
Theory	+0.11	−0.09
Background modeling	+0.08	−0.08
Signal modeling	+0.07	−0.04
Total	+0.35	−0.33

(13TeV data)



(2017 data)

Uncertainty source	$\Delta\mu$	
Statistical	+0.26	−0.26
Normalization of backgrounds	+0.12	−0.12
Experimental	+0.16	−0.15
b-tagging efficiency and misid	+0.09	−0.08
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Jet energy scale and resolution	+0.05	−0.05
Lepton identification	+0.02	−0.01
Luminosity	+0.03	−0.03
Other experimental uncertainties	+0.06	−0.05
MC sample size	+0.12	−0.12
Theory	+0.11	−0.09
Background modeling	+0.08	−0.08
Signal modeling	+0.07	−0.04
Total	+0.35	−0.33

Process	Normalisation factor
$t\bar{t}$ 0- and 1-lepton	0.98 ± 0.08
$t\bar{t}$ 2-lepton 2-jet	1.06 ± 0.09
$t\bar{t}$ 2-lepton 3-jet	0.95 ± 0.06
W + HF 2-jet	1.19 ± 0.12
W + HF 3-jet	1.05 ± 0.12
Z + HF 2-jet	1.37 ± 0.11
Z + HF 3-jet	1.09 ± 0.09

(13TeV data)

2016

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

2017

Process	$Z(\nu\nu)H$	$W(\ell\nu)H$	$Z(\ell\ell)H$ low-p_T	$Z(\ell\ell)H$ high-p_T
W + udscg	1.04 ± 0.07	1.04 ± 0.07	–	–
W + b	2.09 ± 0.16	2.09 ± 0.16	–	–
W + $b\bar{b}$	1.74 ± 0.21	1.74 ± 0.21	–	–
Z + udscg	0.95 ± 0.09	–	0.89 ± 0.06	0.81 ± 0.05
Z + b	1.02 ± 0.17	–	0.94 ± 0.12	1.17 ± 0.10
Z + $b\bar{b}$	1.20 ± 0.11	–	0.81 ± 0.07	0.88 ± 0.08
$t\bar{t}$	0.99 ± 0.07	0.93 ± 0.07	0.89 ± 0.07	0.91 ± 0.07

Note: change in PDF, UE tune, generator versions, b-tagging algorithm, fit binning and 1-lepton pT(V) increase from 100 to 150 GeV between 2016 and 2017: no direct comparison of SF possible

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 %	$\pm(PDF+\alpha_s)$ %	±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)

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

VH Signal Model

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:** AZNLO eigentune variations Powheg+Pythia8 / Powheg+Herwig comparison

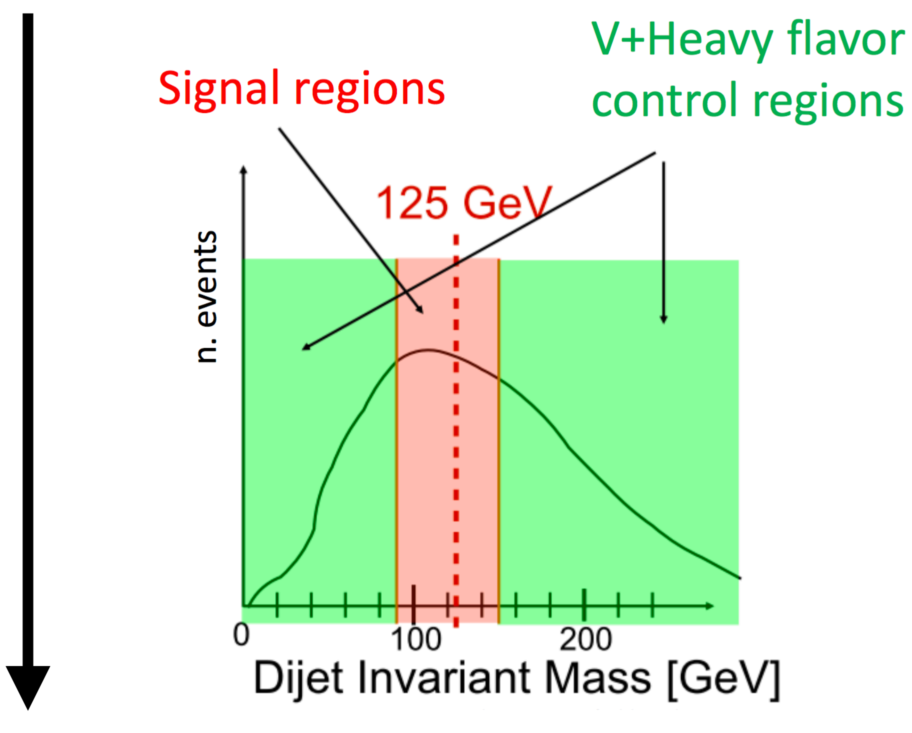
→ uncertainties on the signal acceptance **and** on the shape of pTV and m(bb)

V+jets background modeling strategies

CMS (Madgraph V+0,1,2,3,4j@LO)

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

  (DCSV2 or DNN fit in CR)

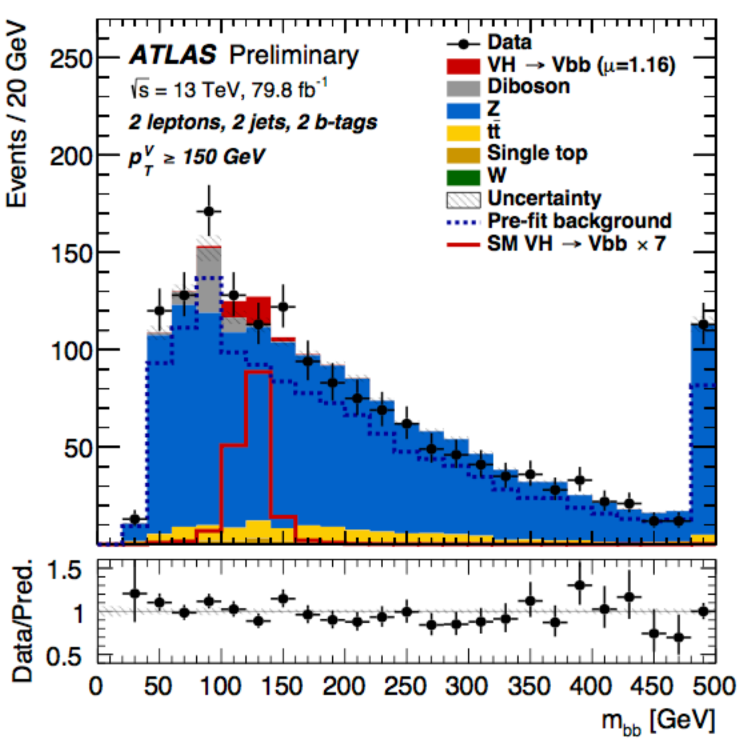


ATLAS (Sherpa V+0,1,2j@NLO + 3,4j@LO)

- **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)

ATLAS



Background reweighting corrections for V+jets:

- $f(p_T^V)$ inclusive 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)

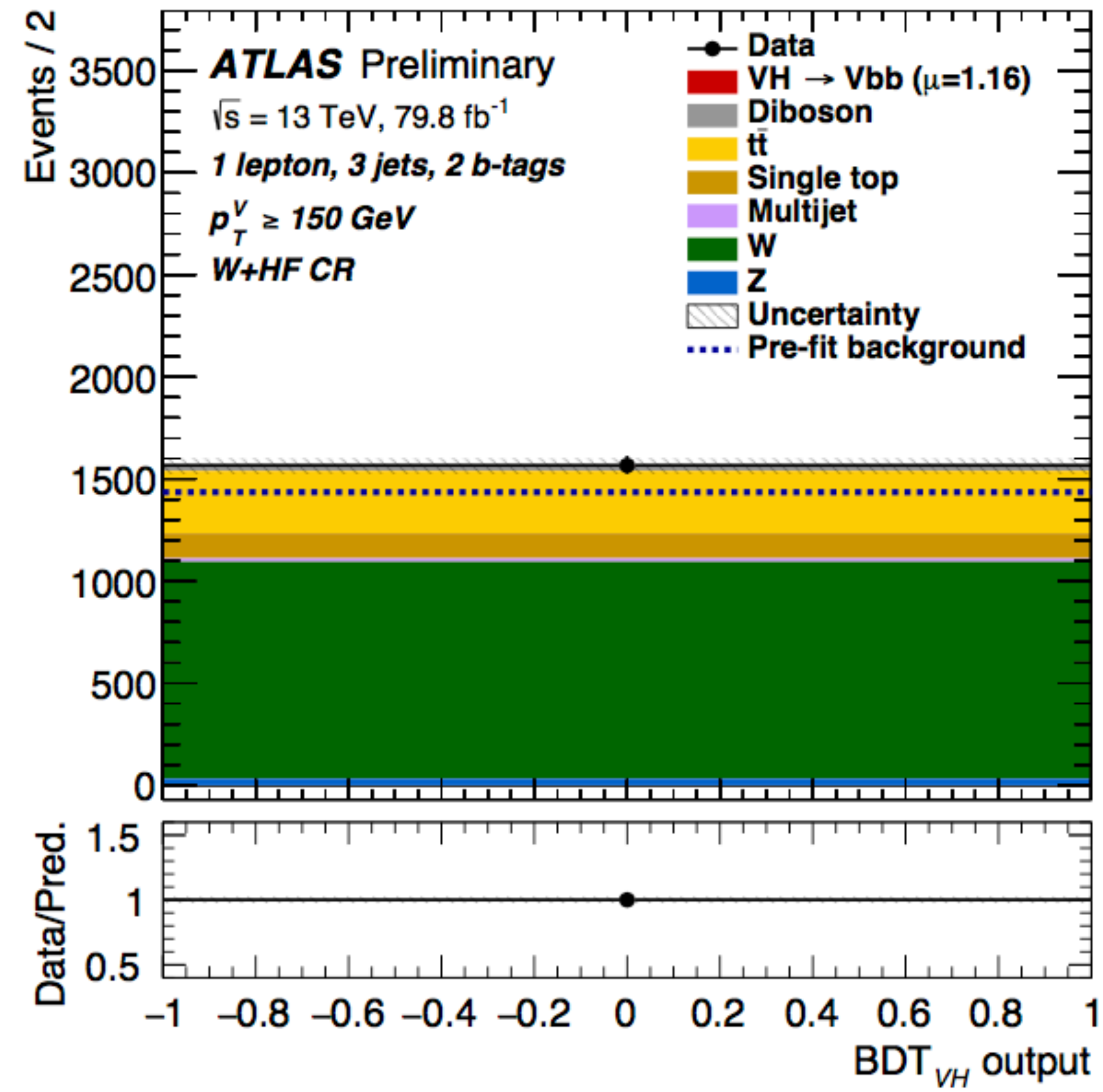
W+heavy flavors - dominated by 1-lepton channel

ATLAS

- **standard 1-lepton selection +**
  m(bb) < 75GeV
  m(top) > 225GeV

- extrapolation uncertainties from CR to SR obtained from

  - Sherpa 2.2.1 muR, muF, ckkw, qsf scale variations
  - Sherpa 2.2.1 comparison with Madgraph_aMC@NLO 2.2.2 (merging up to four extra parton CKKW-L @ LO, Qcut = 30GeV)



	W + jets
$W + ll$ normalisation	32%
$W + cl$ normalisation	37%
W + HF 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

Z+heavy flavors - dominated by (0)2-lepton channel

ATLAS

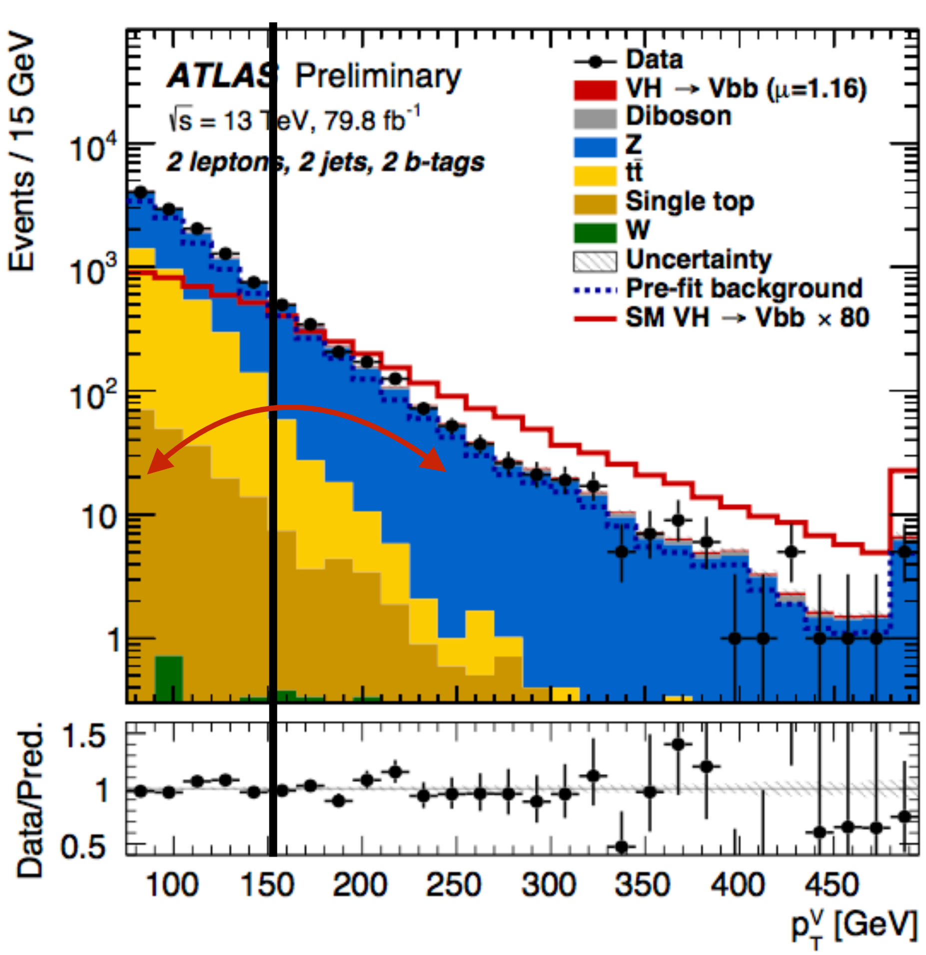
- **no dedicated control region for Z+hf**
- no m(bb) window selection applied in the nominal analysis selection

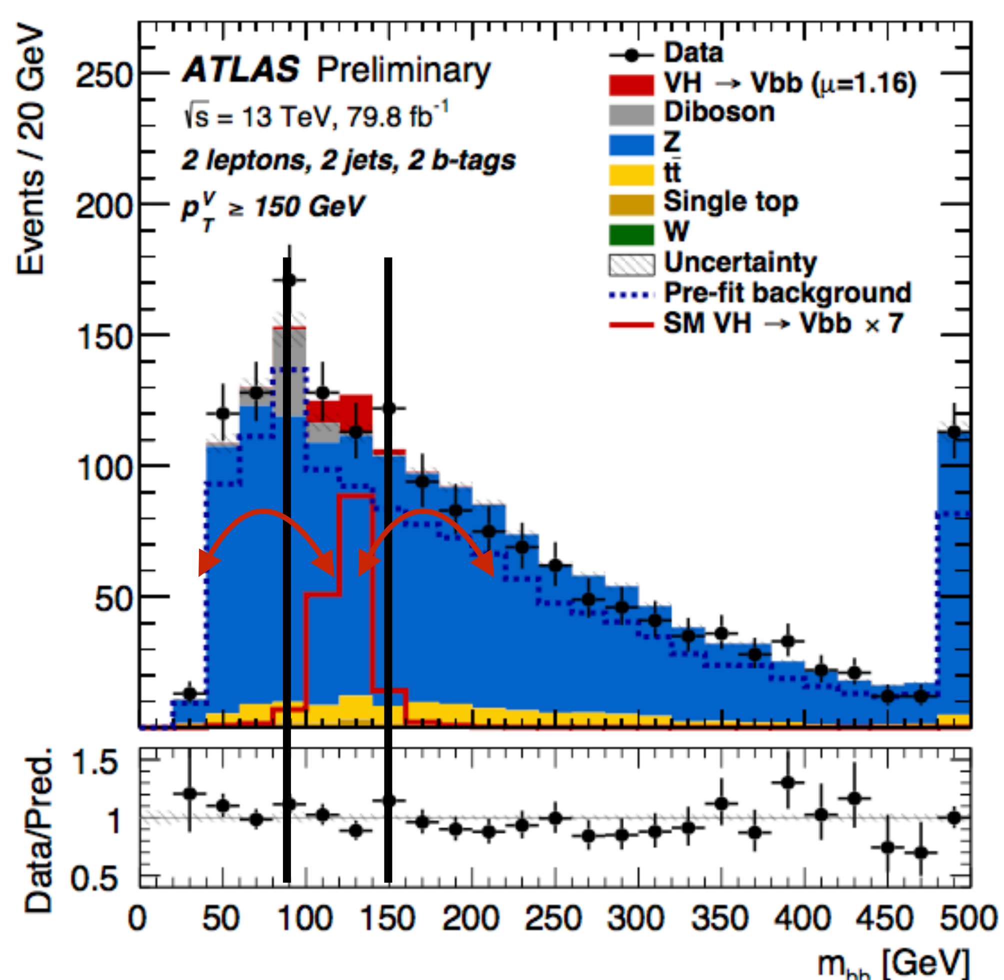
	Z + jets
$Z + ll$ normalisation	18%
$Z + cl$ normalisation	23%
Z + HF normalisation	Floating (2-jet, 3-jet)
$Z + bc$-to-$Z + bb$ ratio	30 – 40%
$Z + cc$-to-$Z + bb$ ratio	13 – 15%
$Z + bl$-to-$Z + bb$ ratio	20 – 25%
0-to-2 lepton ratio	7%
m_{bb}, p_T^V	S

- **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 mH)

(+ MET-significance cut
to suppress ttbar contamination)

control over (high/low-VpT) or (sidebands/central m(bb)) normalization





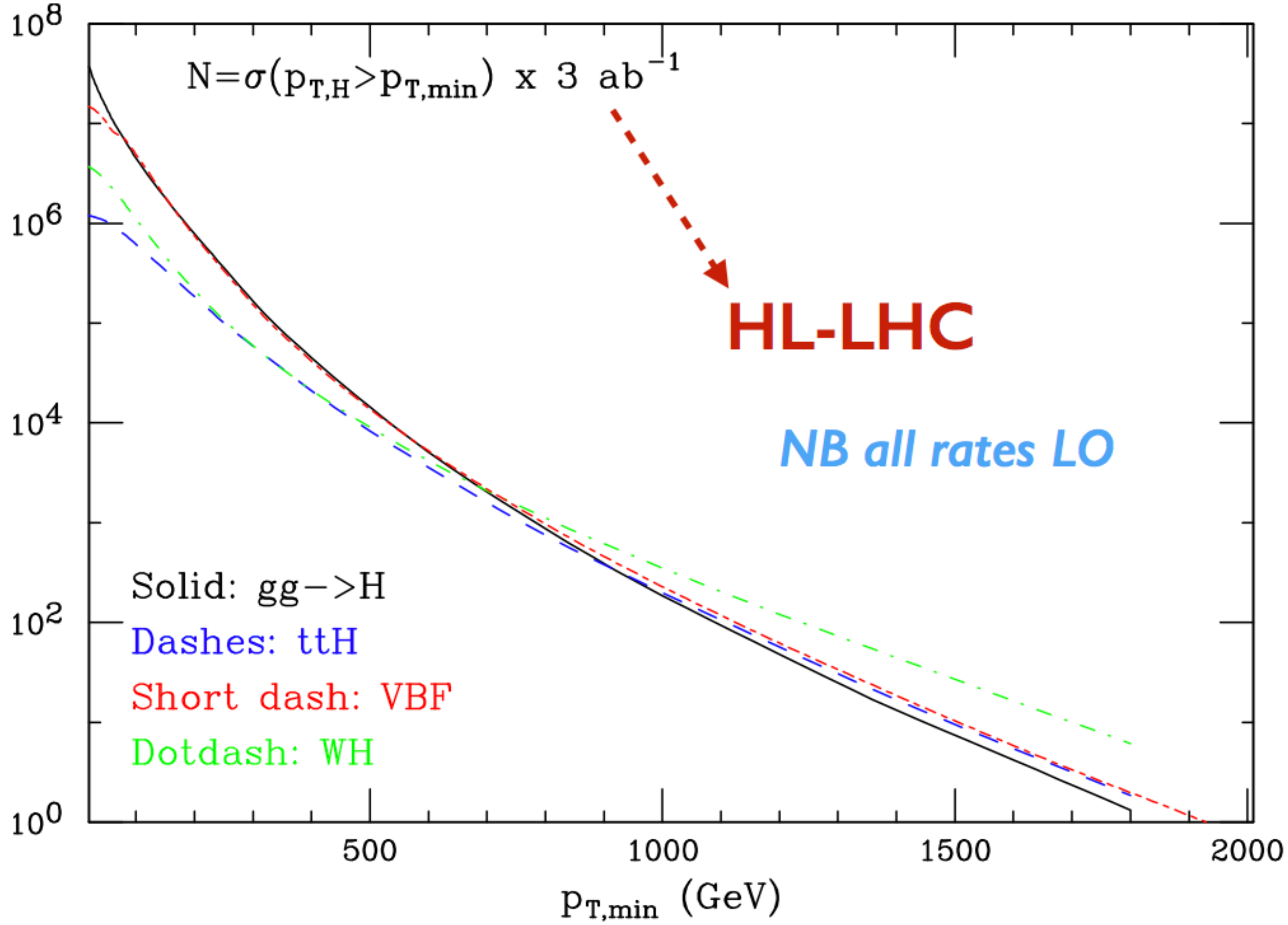
Additional Material

VH @ high-pT

H(bb) boosted results by CMS sparked interest on high-pT Higgs searches/measurements

$p_T^{\rm cut}$	$\Sigma_{\rm ggF}(p_T^{\rm cut}) \times {\rm BR}$ [fb]	$\Sigma_{\rm VBF}(p_T^{\rm cut}) \times {\rm BR}$ [fb]	$\Sigma_{\rm ggF+VBF}(p_T^{\rm cut}) \times {\rm BR}$ [fb]
450 GeV	$11.1^{+4\%}_{-8.9\%}$	$4.71^{+1\%}_{-1\%}$	$15.3^{+2.8\%}_{-6.3\%}$

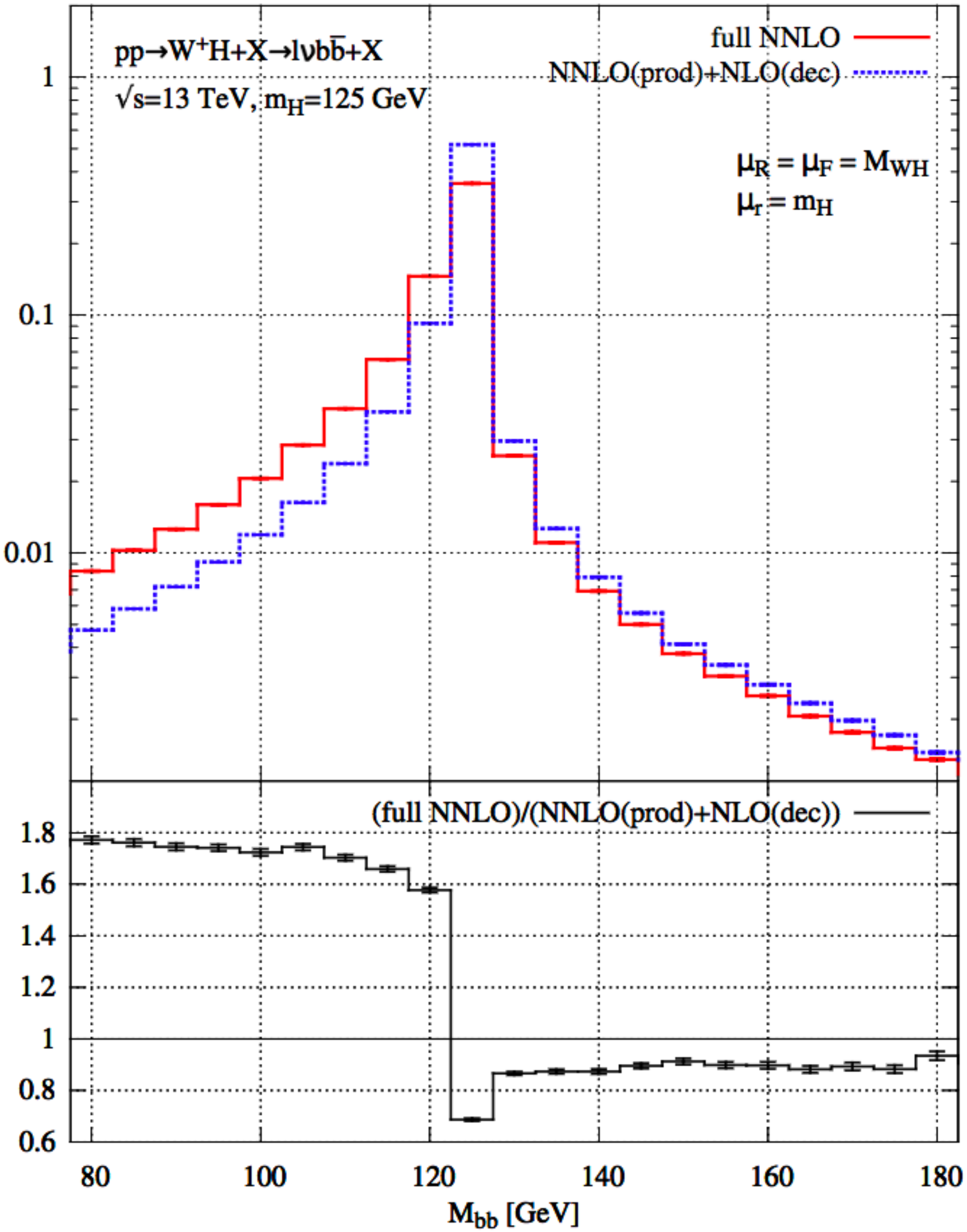
What is the impact of VH?



Important to keep high-pT modeling under control: EW@NLO, ggZH contribution

QCD → H(bb) @ NNLO decay

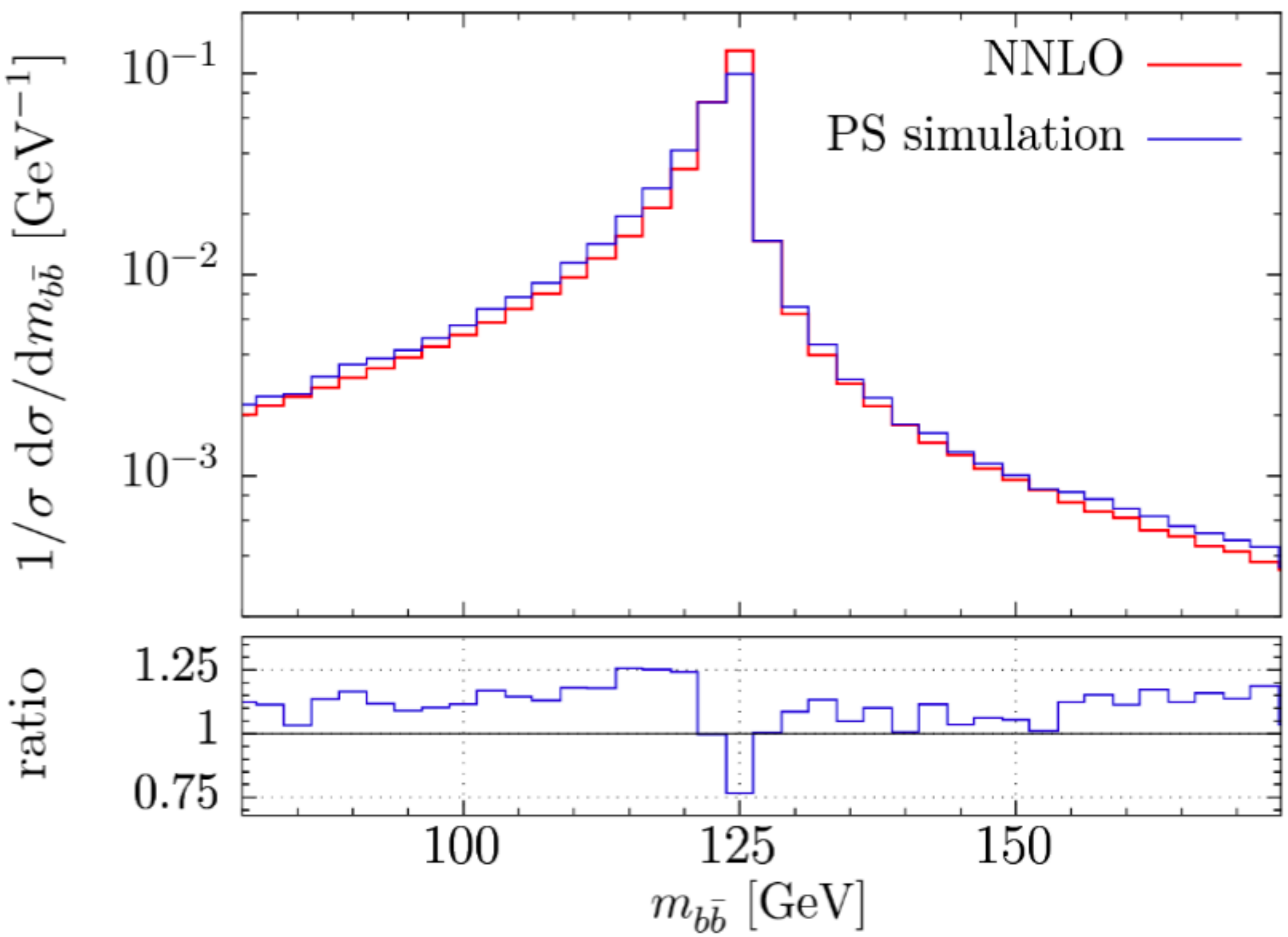
G.F.,Somogyi,Tramontano arXiv:1705.0304

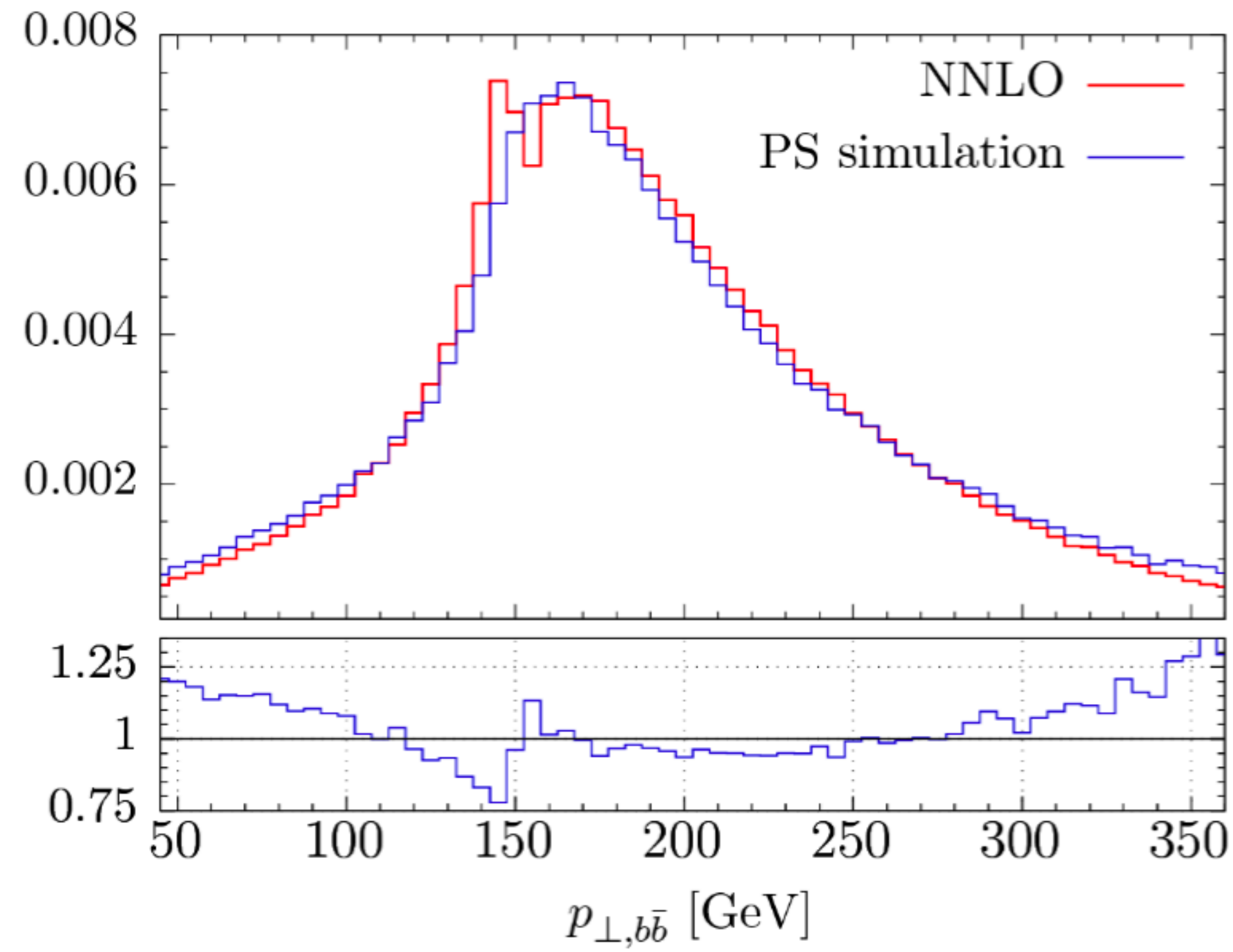


- small impact on total XS (~7%)
- impact is strongly phase space dependent
- up to 80% for m(bb)<120GeV (NNLO extra FSR)

New investigation of interference effects between ME and decay, and **comparison to parton-showered MC prediction**

QCD → H(bb) @ NNLO decay



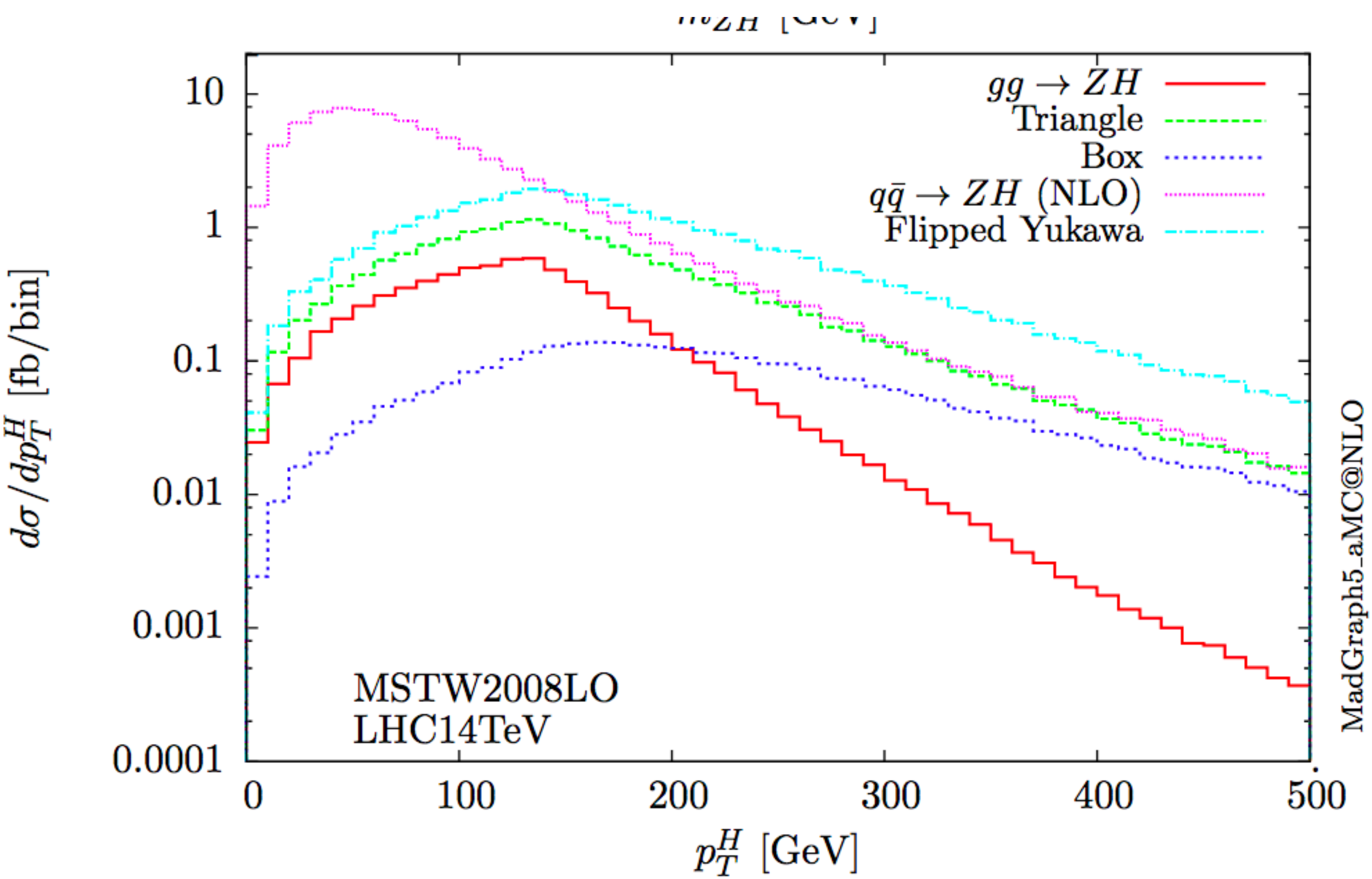


New investigation of interference effects between ME and decay, and **comparison to parton-showered MC prediction** (PowhegMiNLO+Pythia8 as we are using)

PS provides a good description of the NNLO shape, with more events in the more events in the m(bb) and pT(bb) tails

(Ongoing work to re-compute with massive b-quarks)

gg→ZH (loop-induced) MC modeling



EW → NLO corrections

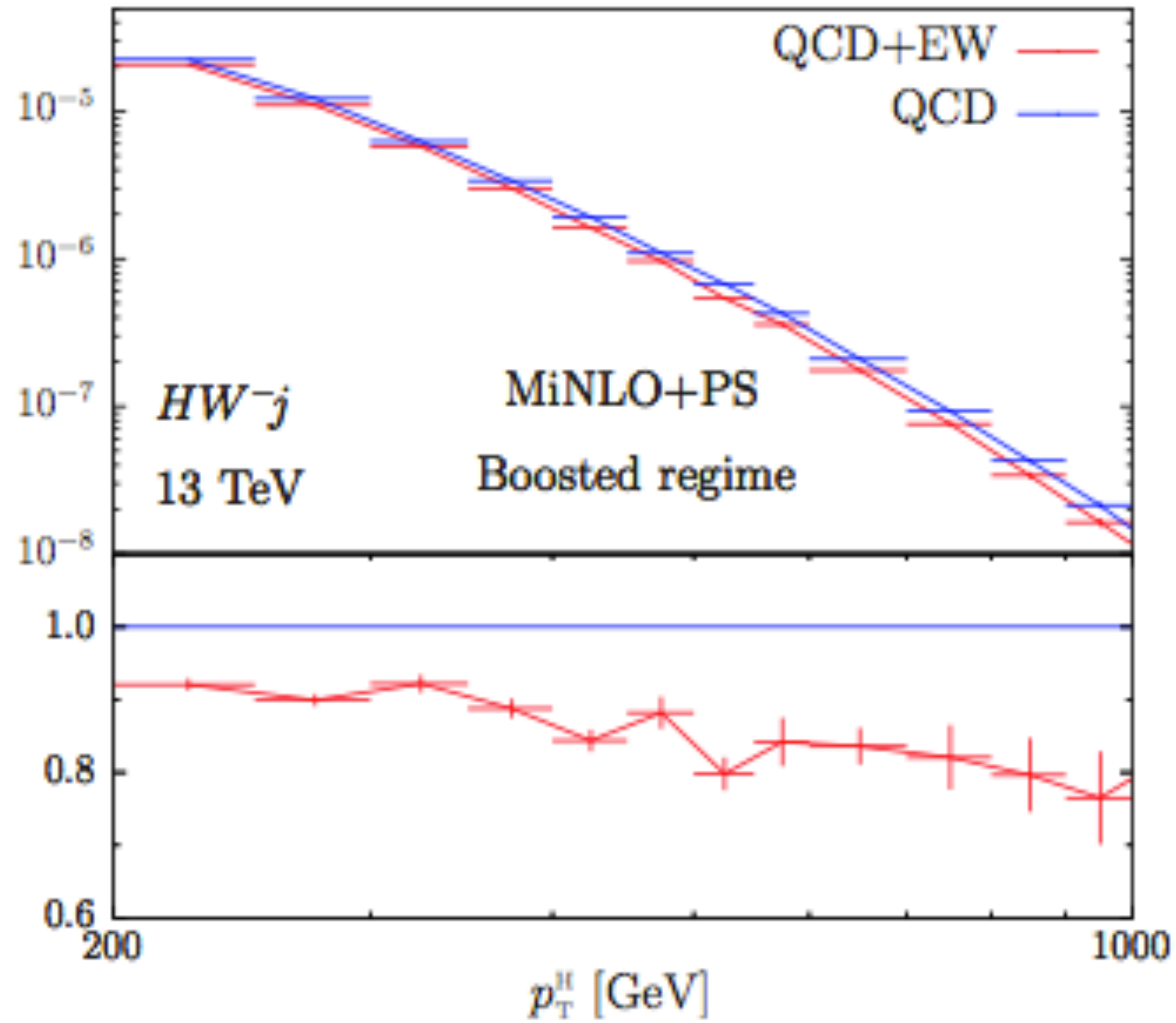
Last updates at WG1:VH

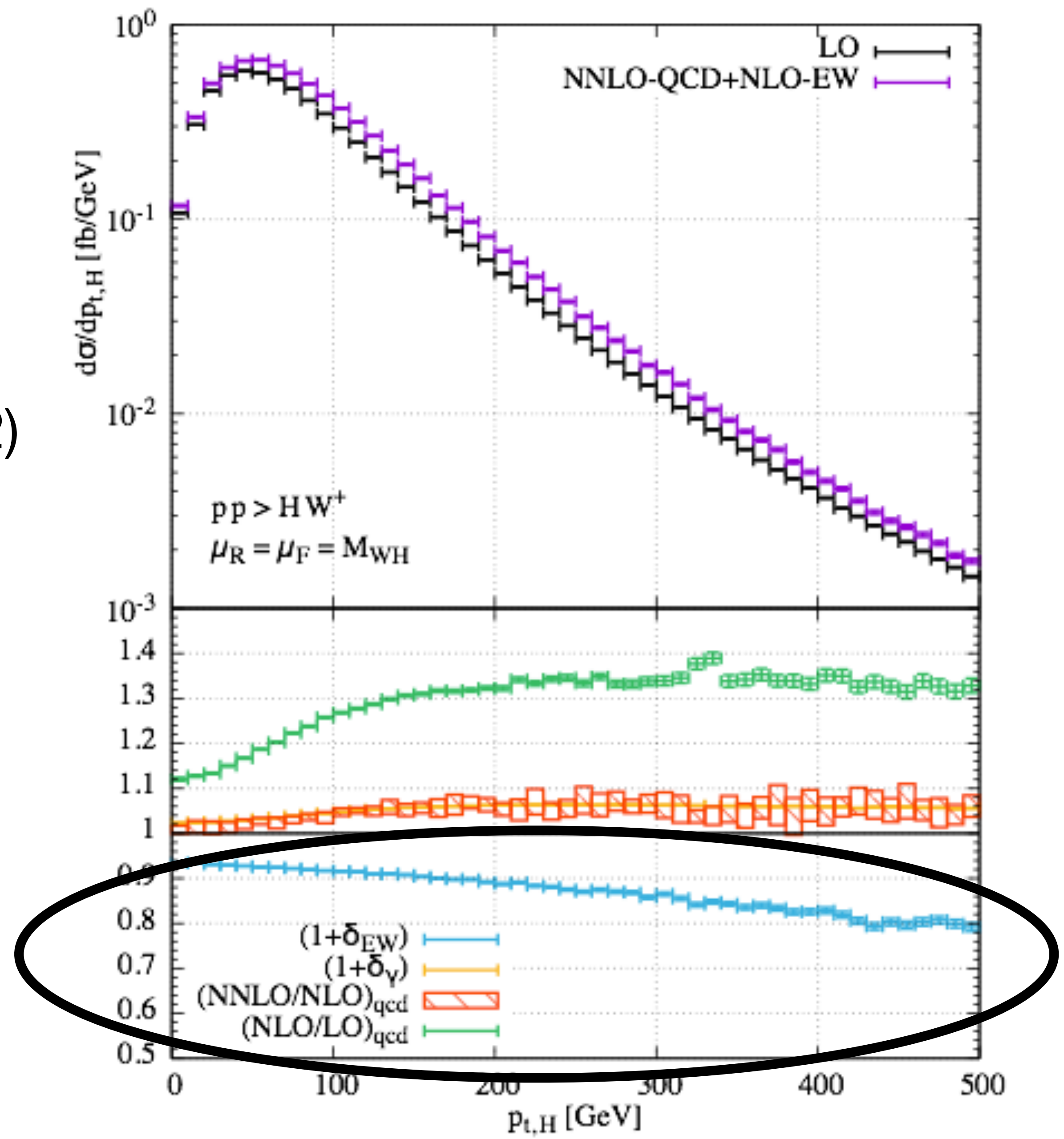
EW Corrections from YR4:

- NLO EW differential reweighting (applied as f(p_T^V)) from HAWK

Only available for V(leptons)H processes

Now available directly from POWHEGBOX-RES code, for HV and HVJ processes (arXiv:1706.03522)





MiNLO achieves NLO accuracy for quantities inclusive (wrt the additional jet) e.g. pT(WH)

HVJ can be NLO accurate (for inclusive quantites) in QCD **and** EW