VH (H->bb) at ATLAS

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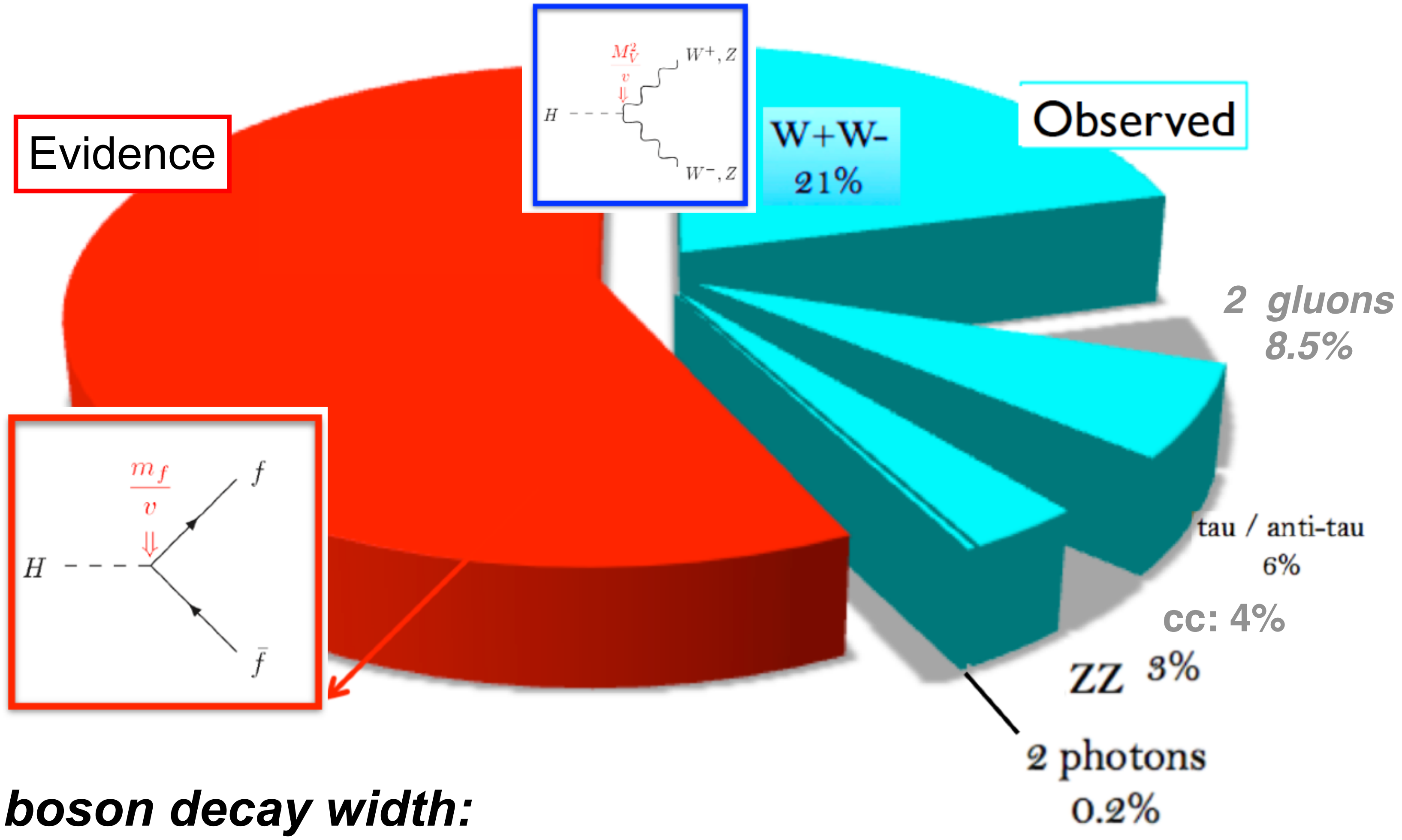
Hbb decay

- Higgs boson physics represents the new and fresh playground at Run2 of the LHC to understand the consistency of the SM and explore new physics effects

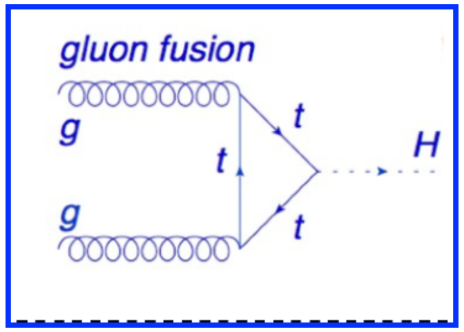
- ***Largest Higgs boson decay mode for m_H=125 GeV: 58%:***
  - direct probe of Higgs boson-to-quark interactions (together with ttH)
  - most accessible decay to quarks

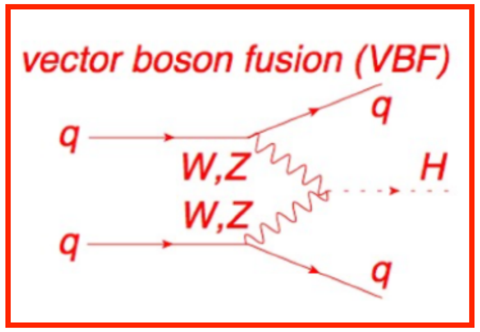
- *Higgs boson width in SM*: ***4 MeV***

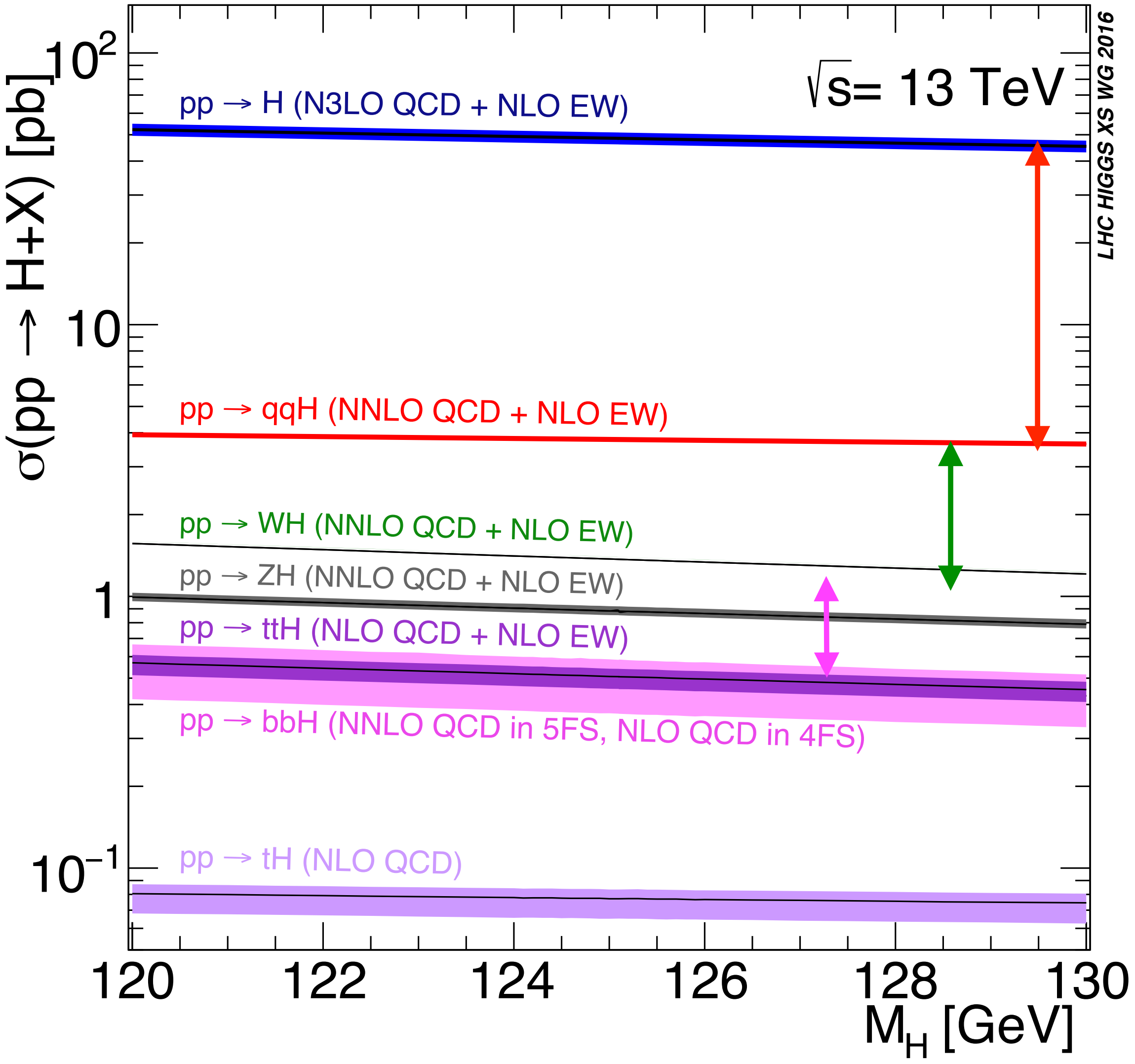


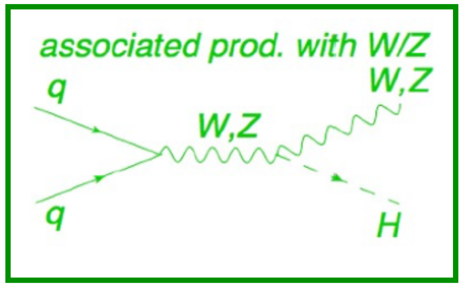
- ***Largest contribution to Higgs boson decay width:***
  - key ingredient in absolute decay rate analysis
  - deviation from SM behaviour could easily accommodate room for new physics (invisible decays)
  - preferential H→bb coupling in some beyond the Standard Model (BSM) scenarios

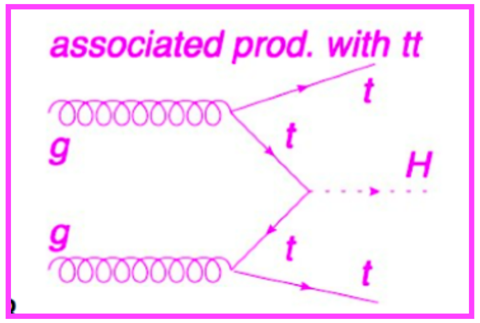
Hbb: how?







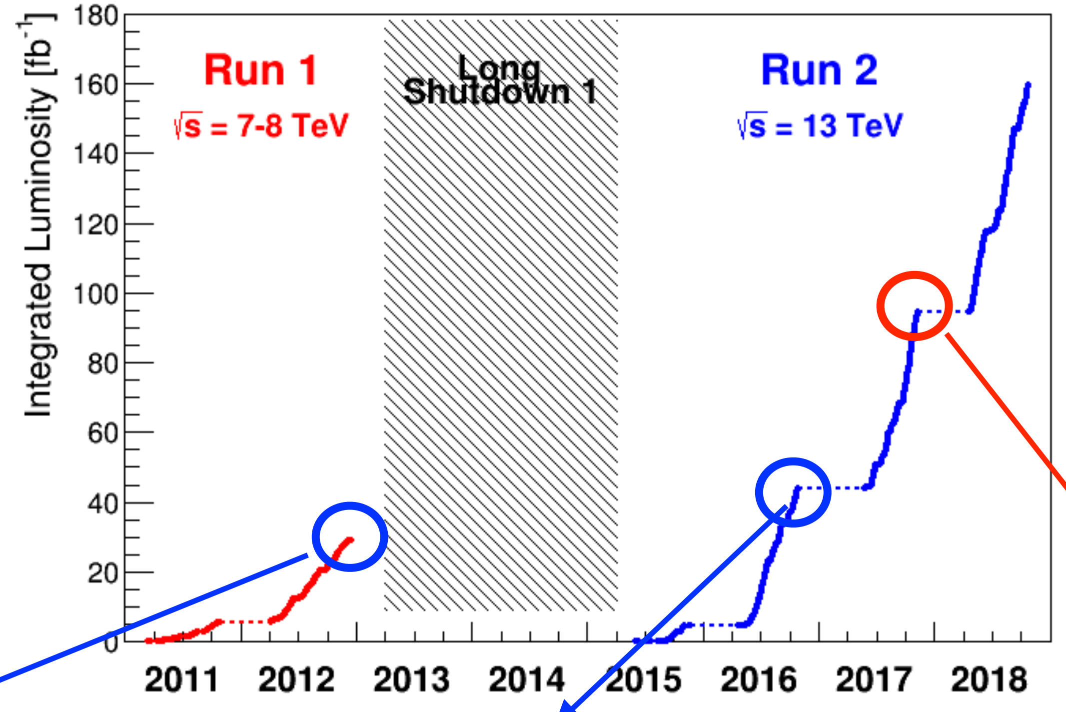


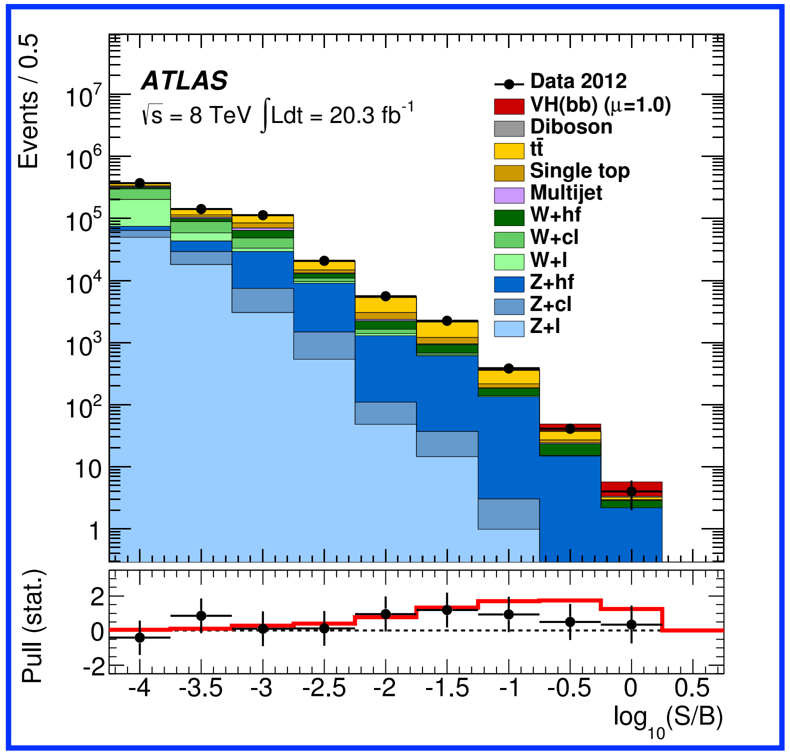


- ***gluon fusion***:
  - overwhelming multi-jet background
  - only limited to very high p_T
- ***Vector Boson Fusion***: 1/10 of total cross section
  - forward jets topology helps reduce the background
  - fully hadronic final state still maintains many experimental difficulties (trigger)
- ***VH production***: 1/20 of total cross section
  - can use leptonic decays of V for triggering/background reduction
  - *GOLDEN H->bb channel at hadronic machines*
- ***ttH***: 1/100 of total cross section
  - can rely on leptonic decays of top quarks for triggering/background reduction
  - complicated combinatorics: difficult to extract a mass peak already for the signal

ATLAS VHbb: history

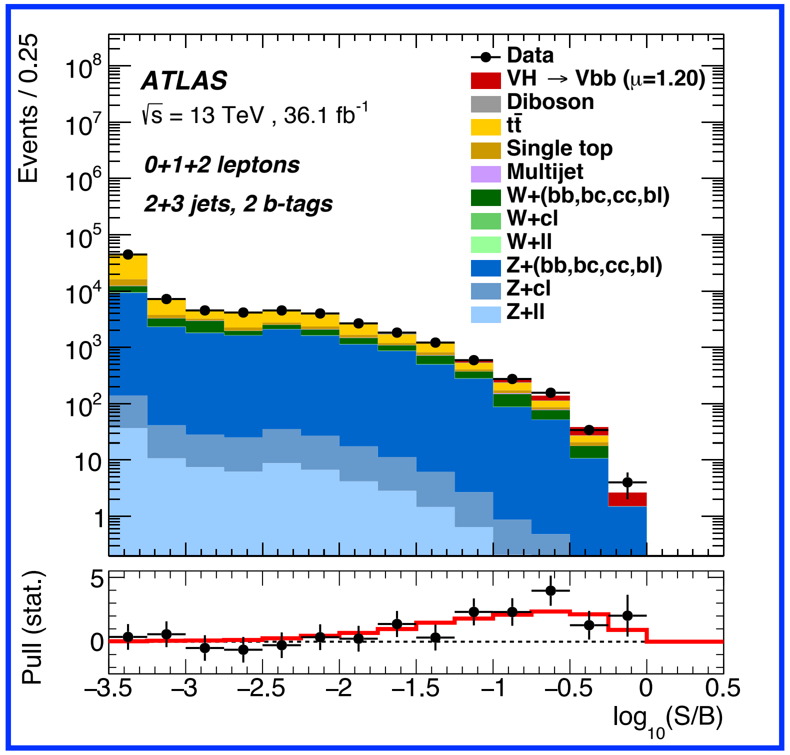
Source: https://twiki.cern.ch/twiki/bin/viewauth/LhcMachine/LhcCoordinationMain





8TeV , 20.3 fb⁻¹

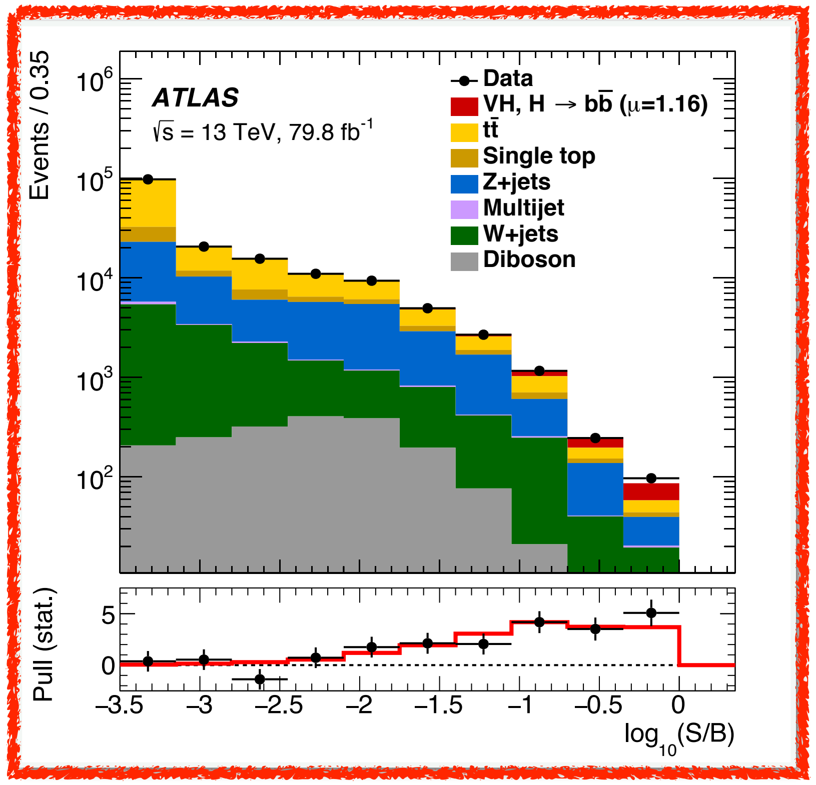
JHEP01 (2015) 069



13TeV , 36.1 fb⁻¹

JHEP12 (2017) 024

Evidence for VHbb



13TeV , 79.8 fb⁻¹

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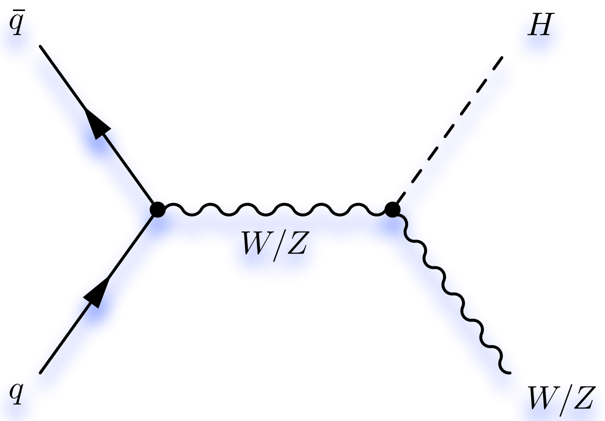
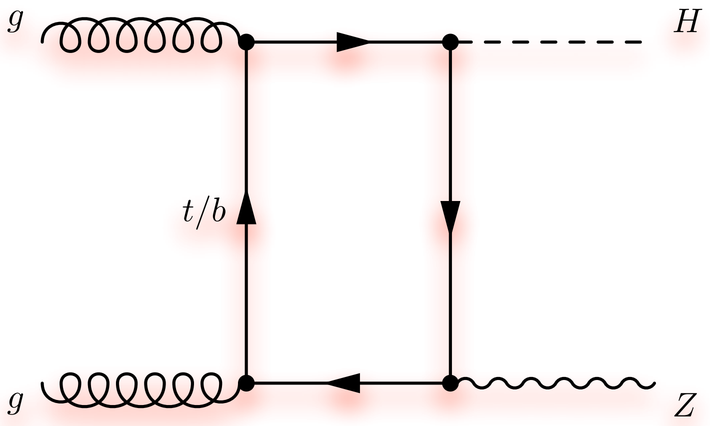
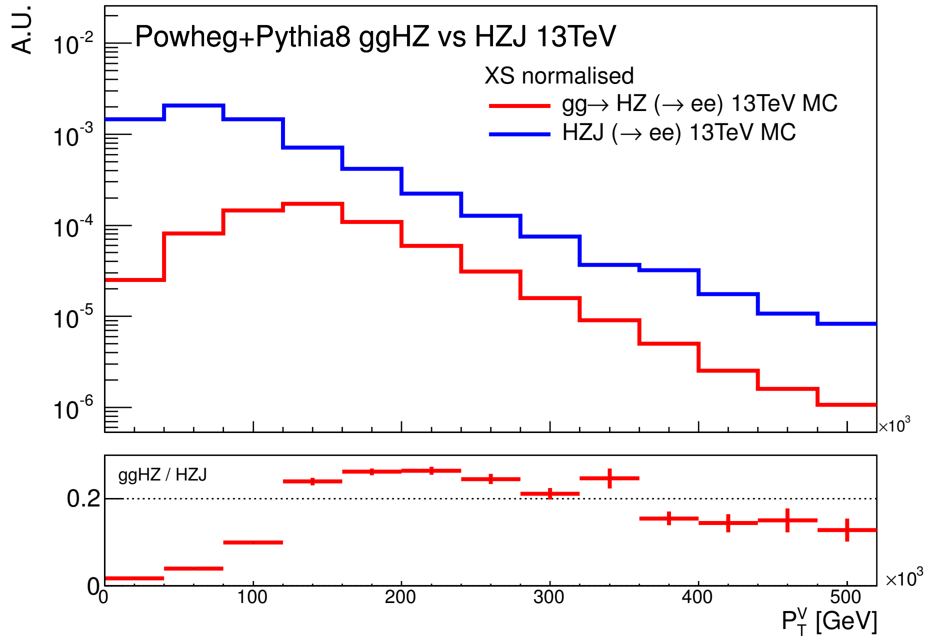
VH production







- A **“golden channel” for H->bb**:
  - production xSection predicted quite precisely from the theory point of view: NNLO QCD + NLO EWK
  - can exploit leptonic decay leptonic decays of vector boson for an easy triggering / background reduction
  - ***mostly fully reconstructed/low multiplicity final state***

- (WH+ZH)*Br(H->bb) ~ 1.3 pb —> **~100k Higgs events in 80 fb^{-1}**:
  - need to add V->ll’ BR + reconstruction + tight event selection to make the signal more visible

- ATLAS MC:
  - qq->VH : Powheg (MiNLO) + Pythia8 [NLO EWK applied parametrically as a function of V p_T]
  - gg->ZH : Powheg + Pythia8 : LO+PS

VHbb: channels

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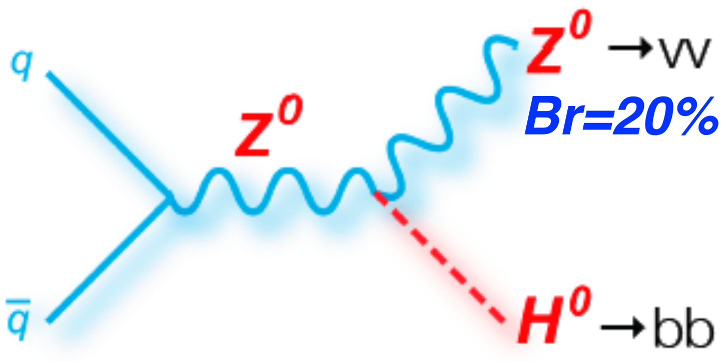
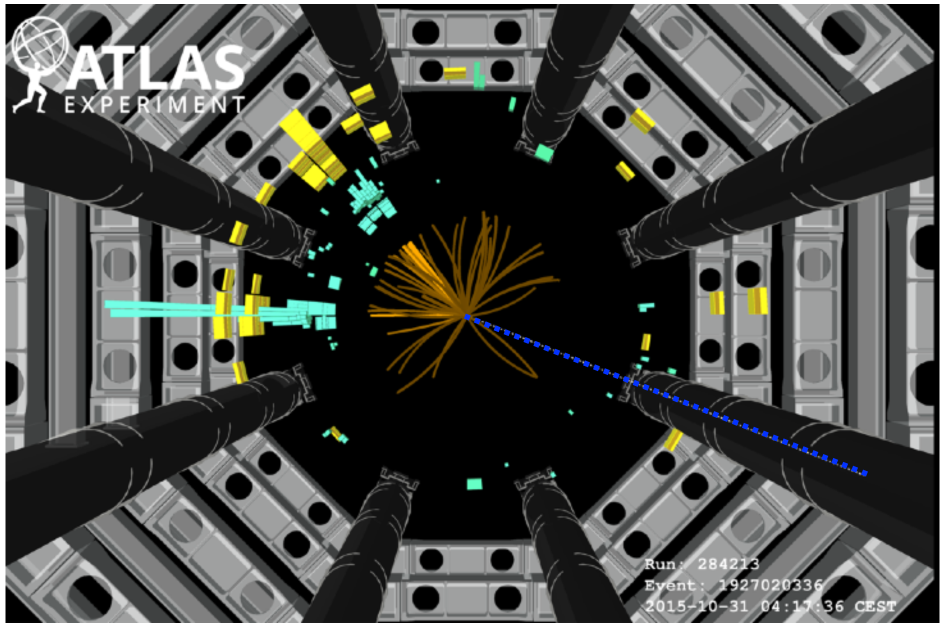
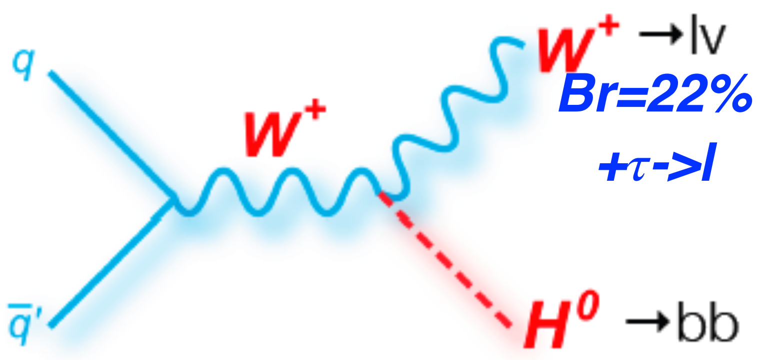
- **3 main channels**: very different way to reconstruct the vector boson candidate



0-lepton:

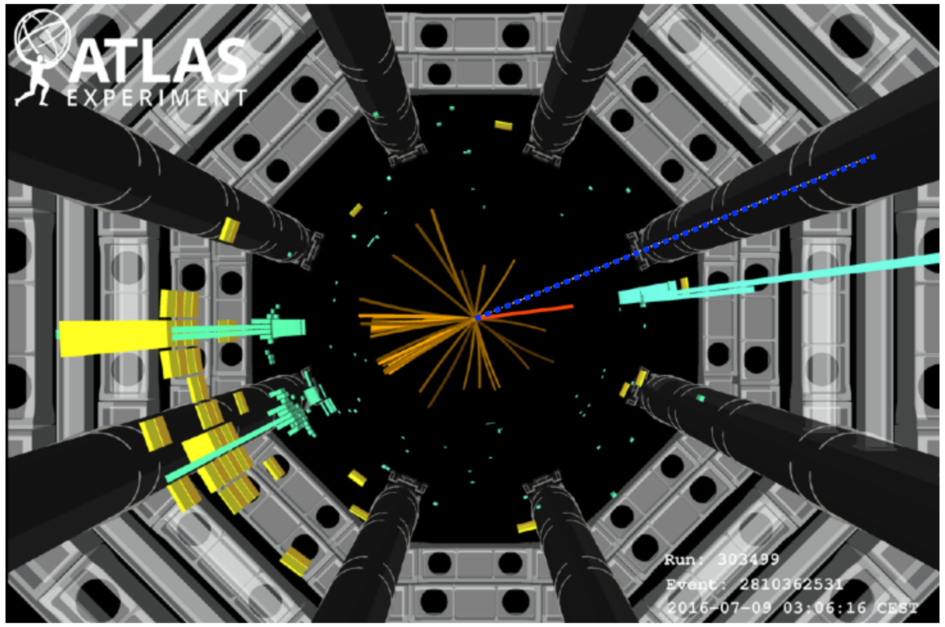
- mainly Z->νν but also W->τ
- V p_T = MET

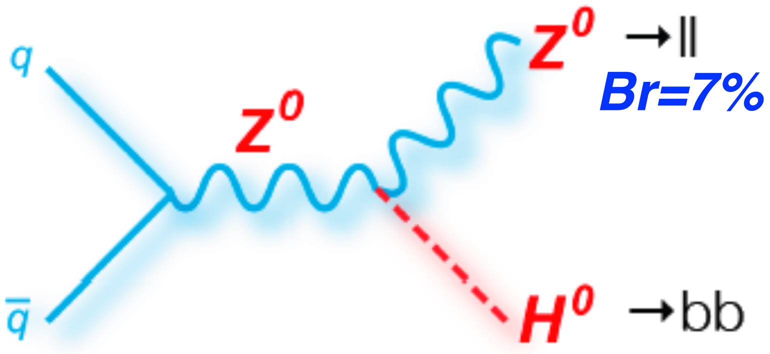




1-lepton (l=e,μ):

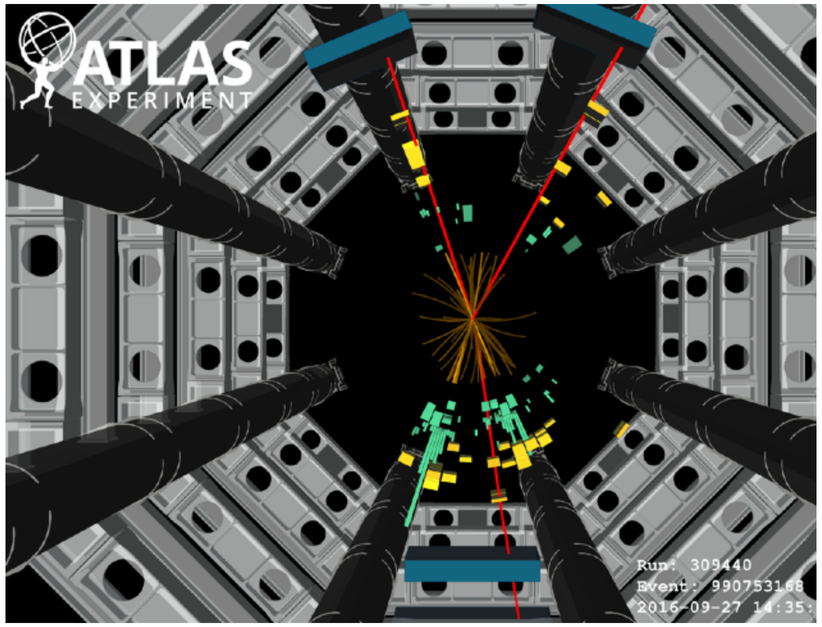
- mainly W->lν
- V p_T = p_T(l,MET)





2-lepton (l=e,μ):

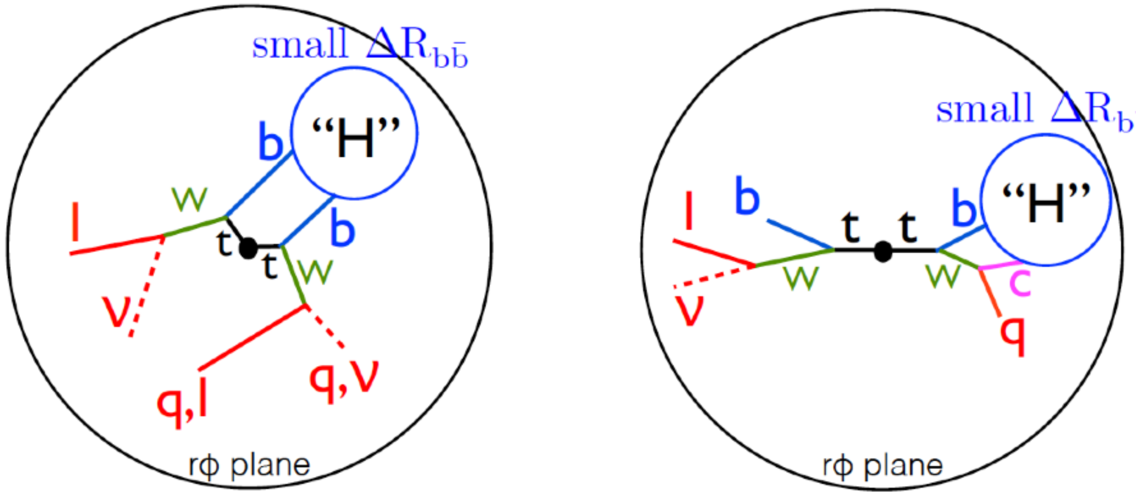
- same flavour, mainly Z->ll
- V p_T = p_T ll



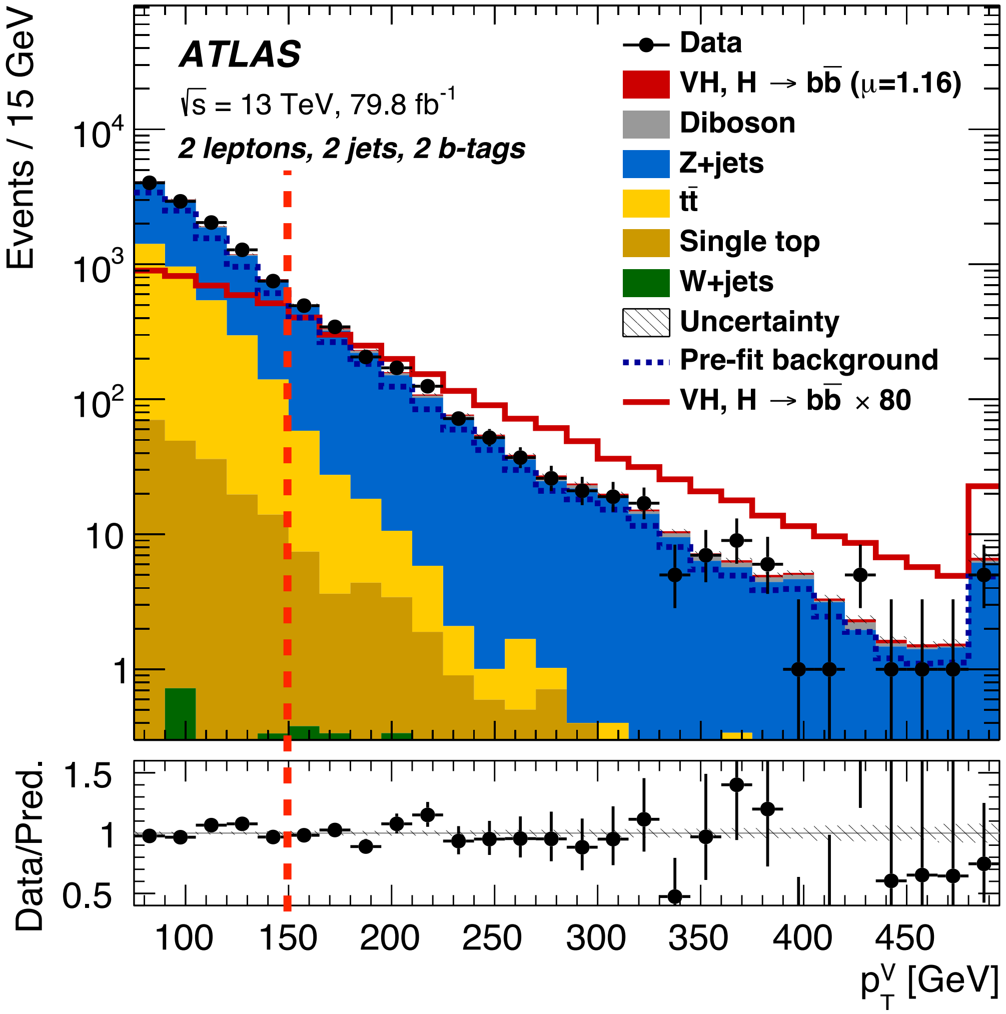
VHbb: selection

- Common aspects among channels:
  - triggering on vector boson object: MET trigger (0L, 1L-μ) , single lepton trigger (1L-e, 2L)
  - ***exactly 2 central (|η|<2.5) b-tagged jets (70% b-jet efficiency)***
  - categorising events as a function of additional jets

- Hight V p_T selection strongly suppresses certain background topologies:



low p_T(V/H) high p_T(V/H)



- Chosen cut values:
  - ***0-Lepton:*** **V p_T > 150 GeV** [imposed by MET trigger]
  - ***1-Lepton:*** **V p_T > 150 GeV** [considerably reduced multi-jet background]
  - ***2-Lepton:*** **V p_T > 75 GeV** [split signal region at 150 GeV]

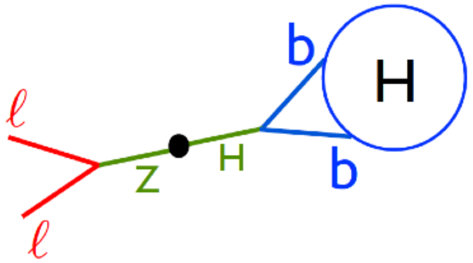
- Overall acceptance for signal: 1-7%

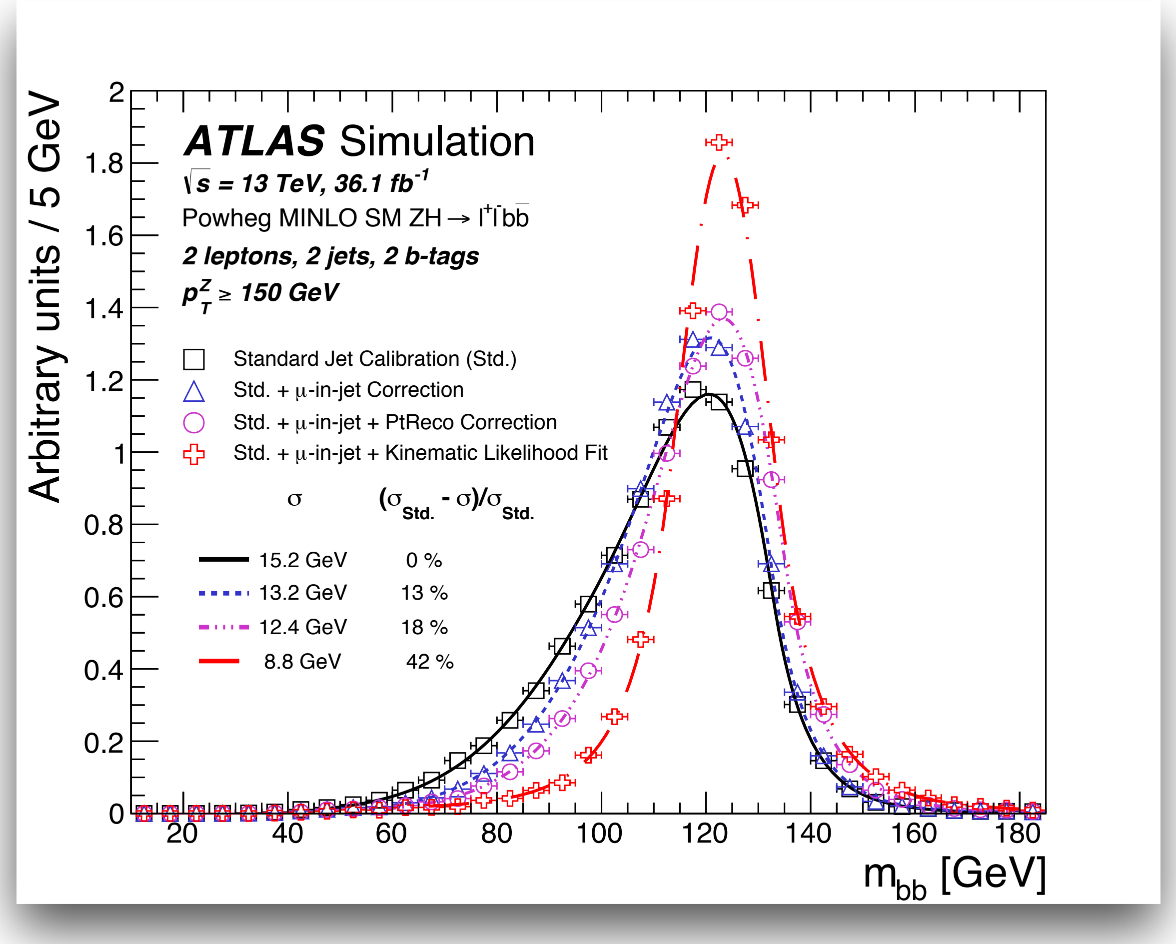
VHbb and b-tagging

- ***Exactly 2 central (|η|<2.5) b-tagged jets (70% b-jet efficiency)***:
  - using MV2c10 tagger (c rej : ~10, light rej : ~0.5%)
  - excellent tagging performance reduces combinatorics to a minimum
  - very high light jet rejection: vast majority of the background contains 2 true b-jets
  - good c-jet rejection needed to suppress ttbar (more later)

see talk from C. Pollard

- Improving ***m_{bb} resolution*** on top of default Anti-kt R=0.4 calorimeter jet reconstruction performance:
  - **adding soft muon** (when found inside the jet cone) to jet 4-momentum: **+13%**
  - additional scaling of jet momentum (**p_T correction**) to compensate from missing neutrino: **+5%**
  - ***kinematic likelihood fit*** to constrain jet response: only if topology allows



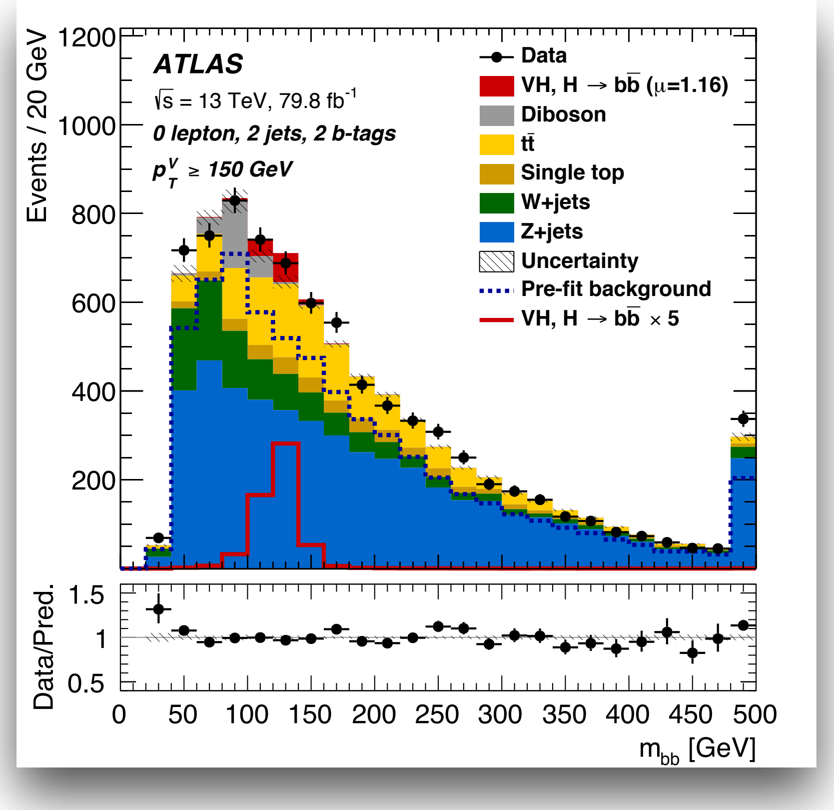


for comparison with rejection see E. Schopf's thesis

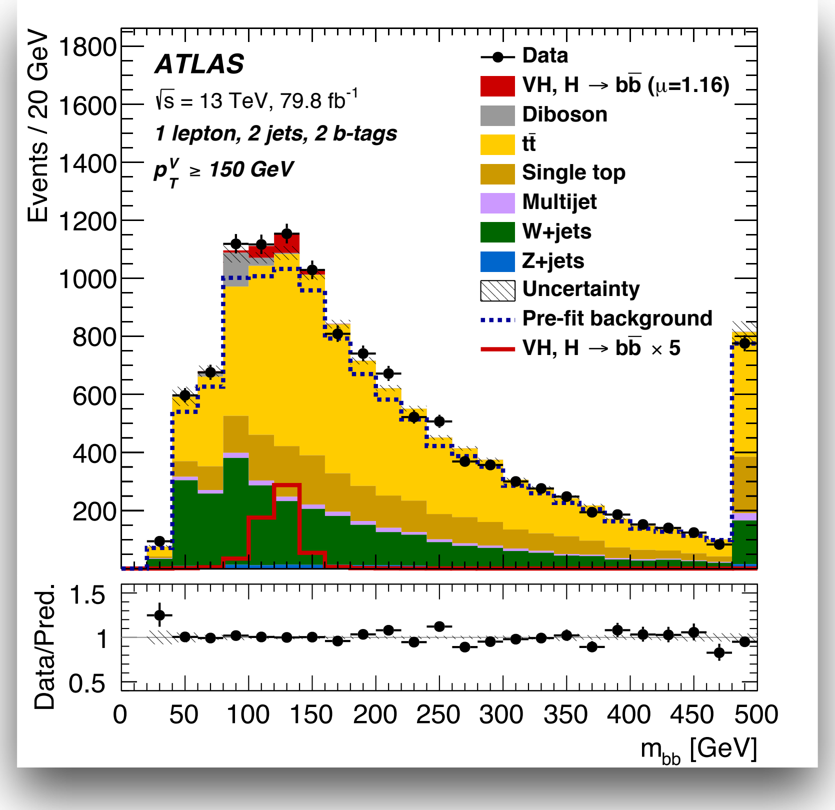
VHbb: backgrounds

- Different **background composition** in each channel

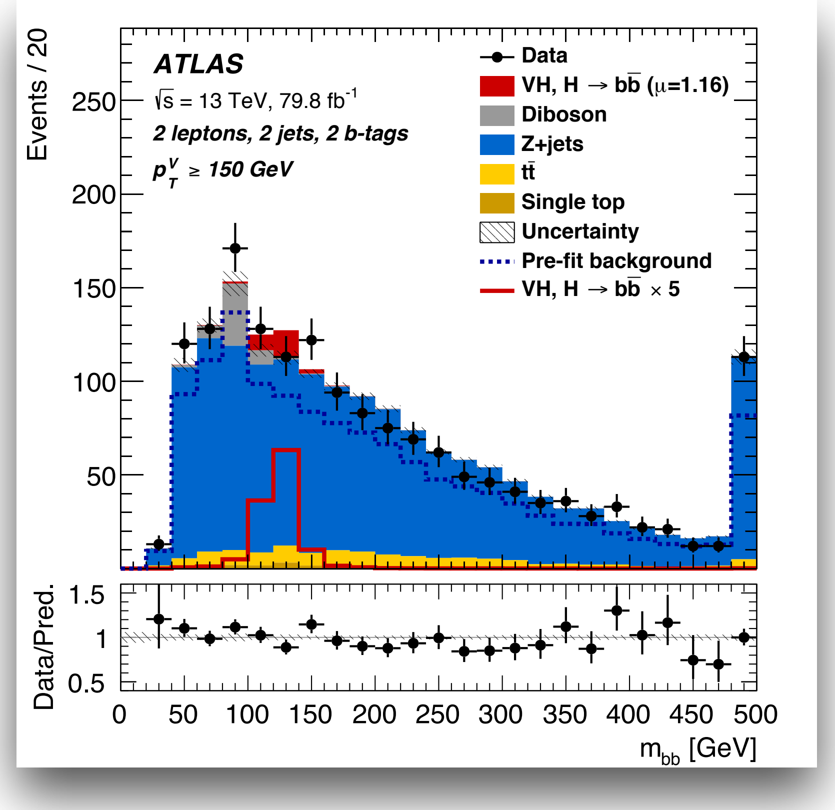
0-lepton



1-lepton



2-lepton



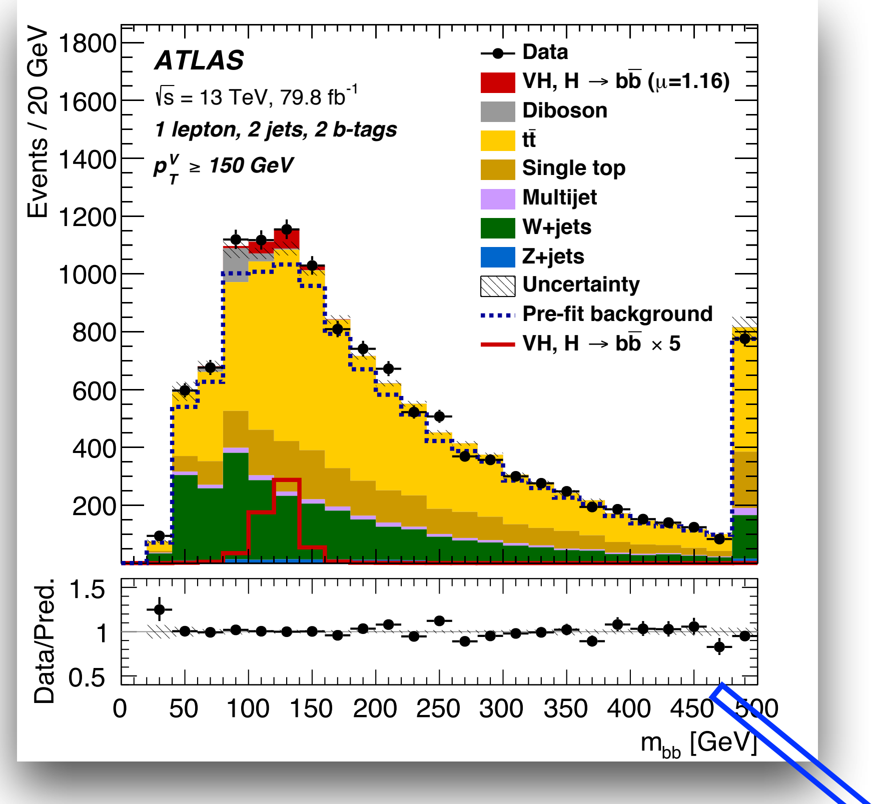
- ***V+jet*** [Sherpa 2.2.1 (0,1j,2j @ NLO + 3j,4j @LO)]: dominated by Z+bb, W+bb
  - ***Z+hf***: 0L and 2L , ***W+hf***: 0L and 1L

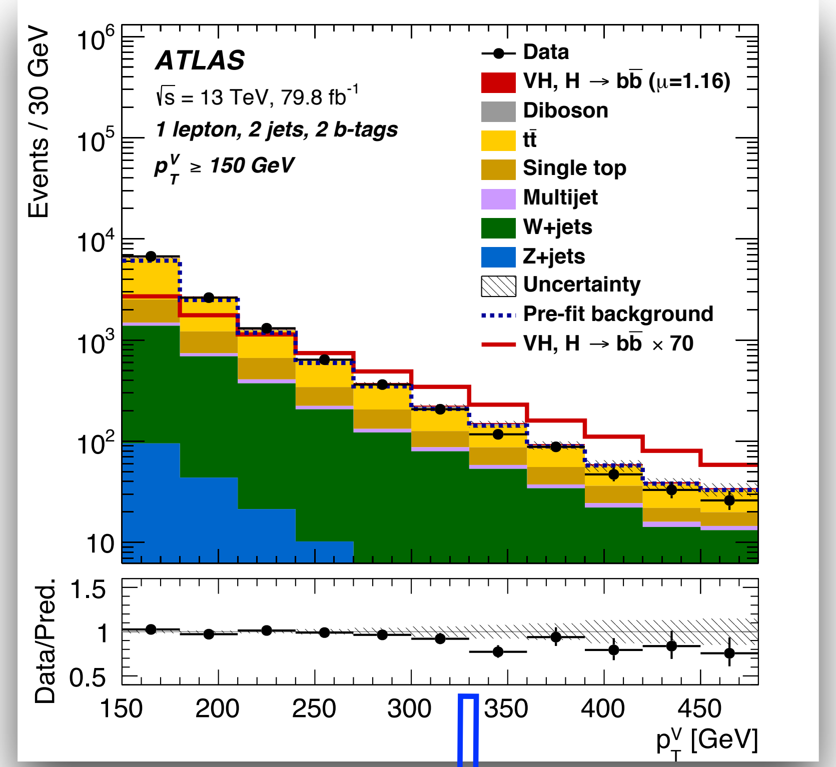
- ***ttbar*** [Powheg+Pythia8]: present in every channel
  - very different topology of selected events between 0L/1L and 2L channels

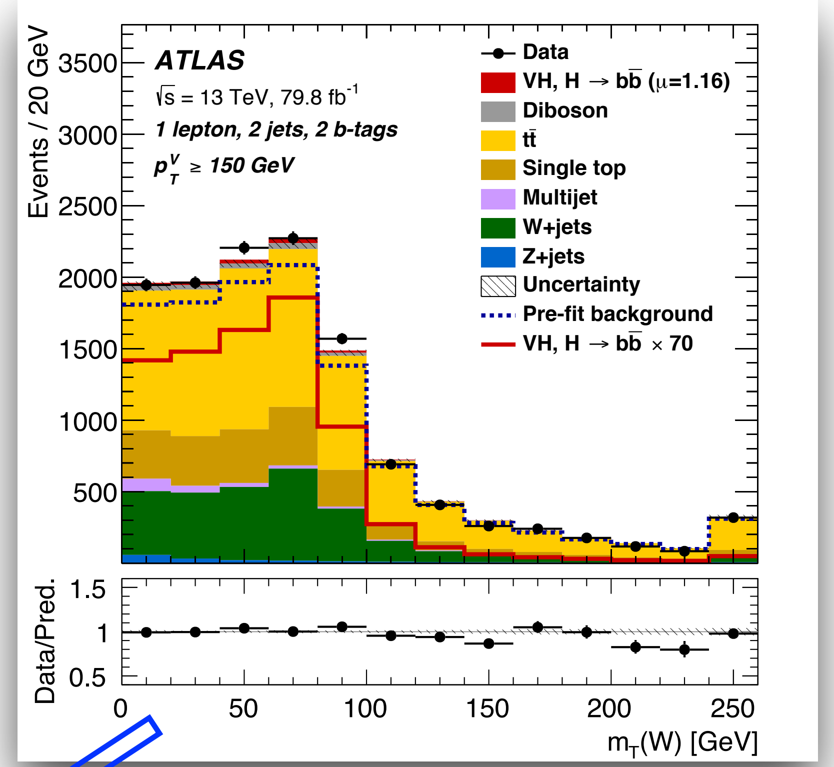
- Resonant ***VZ, Z->bb*** [Sherpa 2.2.1] background: used to validate the analysis procedure

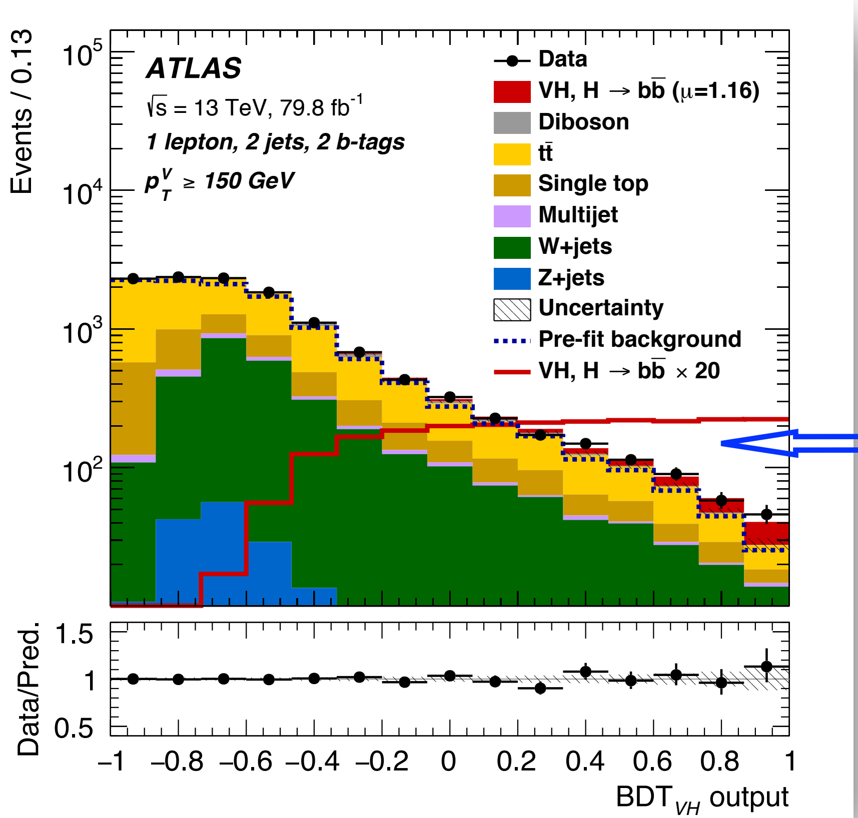
- ***Single top*** [Powheg+Pythia8] and ***QCD multi-jet background***: subdominant contributions only in 1L

Multivariate discriminant









Variable	0-lepton	1-lepton	2-lepton
p_T^V	$\equiv E_T^{\mathrm{miss}}$	×	×
E_T^{miss}	×	×	
$p_T^{b_1}$	×	×	×
$p_T^{b_2}$	×	×	×
m_{bb}	×	×	×
$\Delta R(\vec{b}_1, \vec{b}_2)$	×	×	×
$\lvert\Delta\eta(\vec{b}_1, \vec{b}_2)\rvert$	×		
$\Delta\phi(\vec{V}, \vec{bb})$	×	×	×
$\lvert\Delta\eta(\vec{V}, \vec{bb})\rvert$			×
m_{eff}	×		
$\min[\Delta\phi(\vec{\ell}, \vec{b})]$		×	
m_T^W		×	
$m_{\ell\ell}$			×
$E_T^{\mathrm{miss}}/\sqrt{S_T}$			×
m_{top}		×	
$\lvert\Delta Y(\vec{V}, \vec{bb})\rvert$		×	
	Only in 3-jet events		
$p_T^{\mathrm{jet}_3}$	×	×	×
m_{bbj}	×	×	×

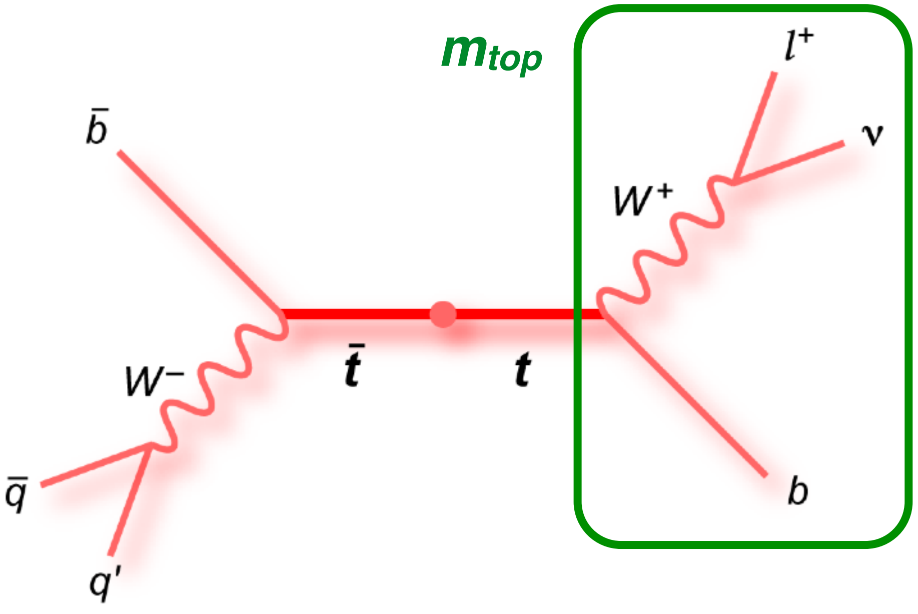
- using TMVA boosted decision tree [AdaBoost, nTree~200, maxDepth 4-6]
- discriminant trained in each analysis region
- rebinning algorithm to improve sensitivity (and reduce number of bins)

VHbb: regions overview

- **8 SRs, 6 CRs**

Channel	SR/CR	Categories			
		75 GeV $< p_T^V <$ 150 GeV		$p_T^V >$ 150 GeV	
		2 jets	3 jets	2 jets	3 jets
0-lepton	SR	-	-	BDT	BDT
1-lepton	SR	-	-	BDT	BDT
2-lepton	SR	BDT	BDT	BDT	BDT
1-lepton	W + HF CR	-	-	Yield	Yield
2-lepton	$e\mu$ CR	m_{bb}	m_{bb}	Yield	m_{bb}

- ***WCR*** in 1-lepton: disentangle W+jets and ttbar in 1-lepton
  - m_{bb} <75 GeV : reduce signal contamination
  - m_{top} >225 : reduce ttbar contamination
  - 77% purity: need extrapolation to SR

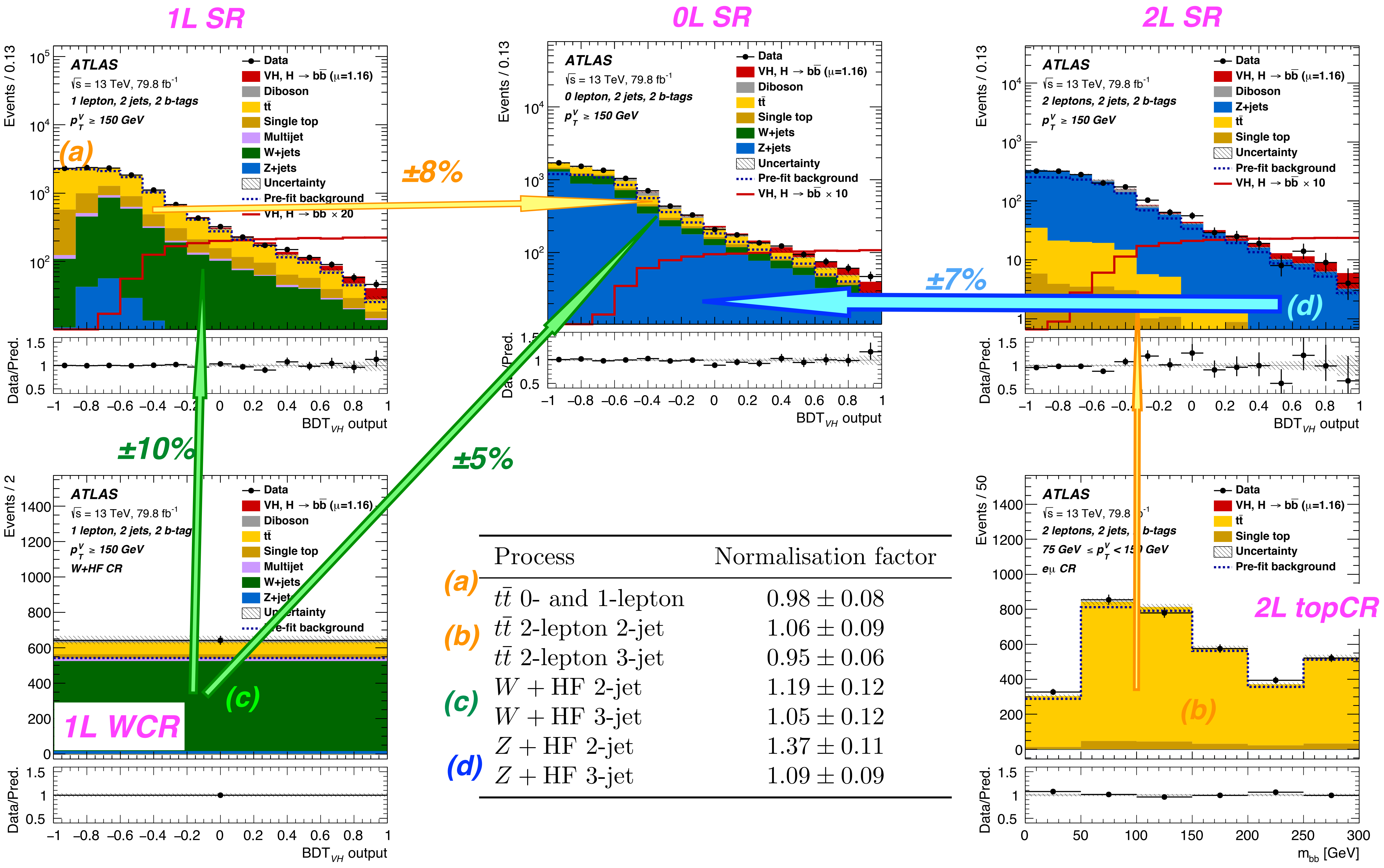


- **top CRs** in 2-lepton: exactly the same selection but e+μ final state
  - 99% pure in ttbar, no signal contamination
  - practically no theoretical extrapolation between CR and SR

- Normalisations extracted directly from BDT in SR: ***top*** in 1L, ***Z+HF*** in 2L
- Other backgrounds have MC-based normalisation

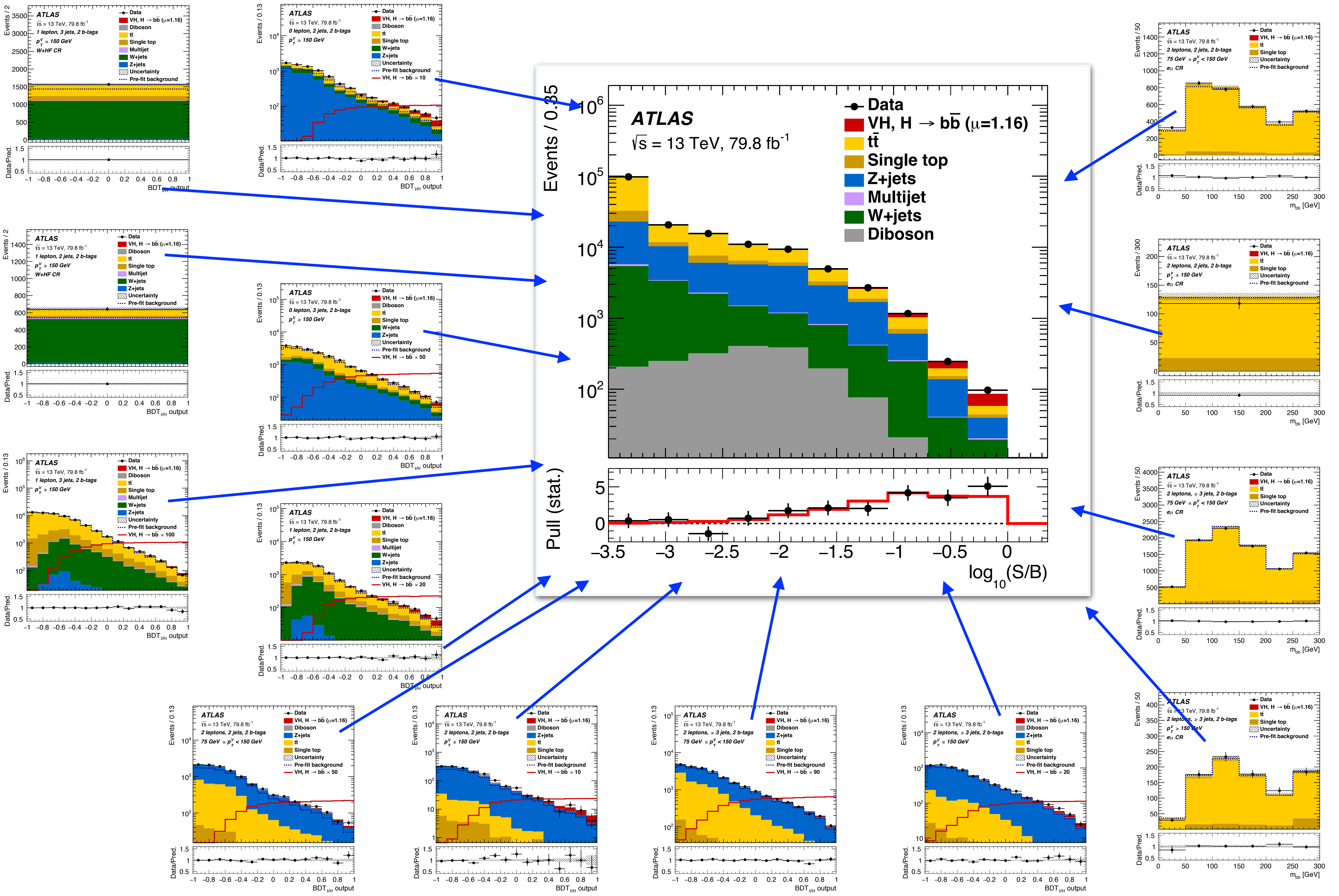
VH-bb: fit model

- Warning: slightly simplified version, only 1 jet multiplicity bin shown

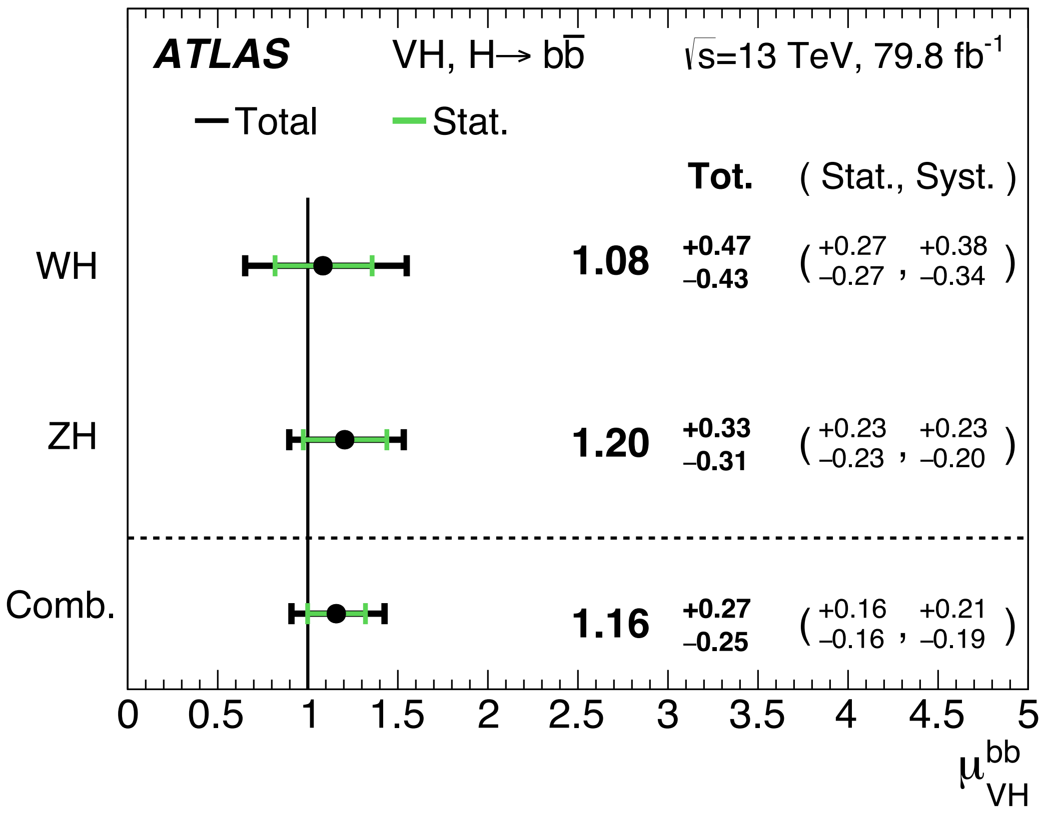


	Process	Normalisation factor
(a)	$t\bar{t}$ 0- and 1-lepton	0.98 ± 0.08
(b)	$t\bar{t}$ 2-lepton 2-jet	1.06 ± 0.09
	$t\bar{t}$ 2-lepton 3-jet	0.95 ± 0.06
(c)	$W+\mathrm{HF}$ 2-jet	1.19 ± 0.12
	$W+\mathrm{HF}$ 3-jet	1.05 ± 0.12
(d)	$Z+\mathrm{HF}$ 2-jet	1.37 ± 0.11
	$Z+\mathrm{HF}$ 3-jet	1.09 ± 0.09

Putting it all together



VHbb: results



Signal strength	Signal strength	Significance	
		Exp.	Obs.
0-lepton	$1.04^{+0.34}_{-0.32}$	3.1	3.3
1-lepton	$1.09^{+0.46}_{-0.42}$	2.4	2.6
2-lepton	$1.38^{+0.46}_{-0.42}$	2.6	3.4
VH, $H \to b\bar{b}$ combination	$1.16^{+0.27}_{-0.25}$	4.3	4.9

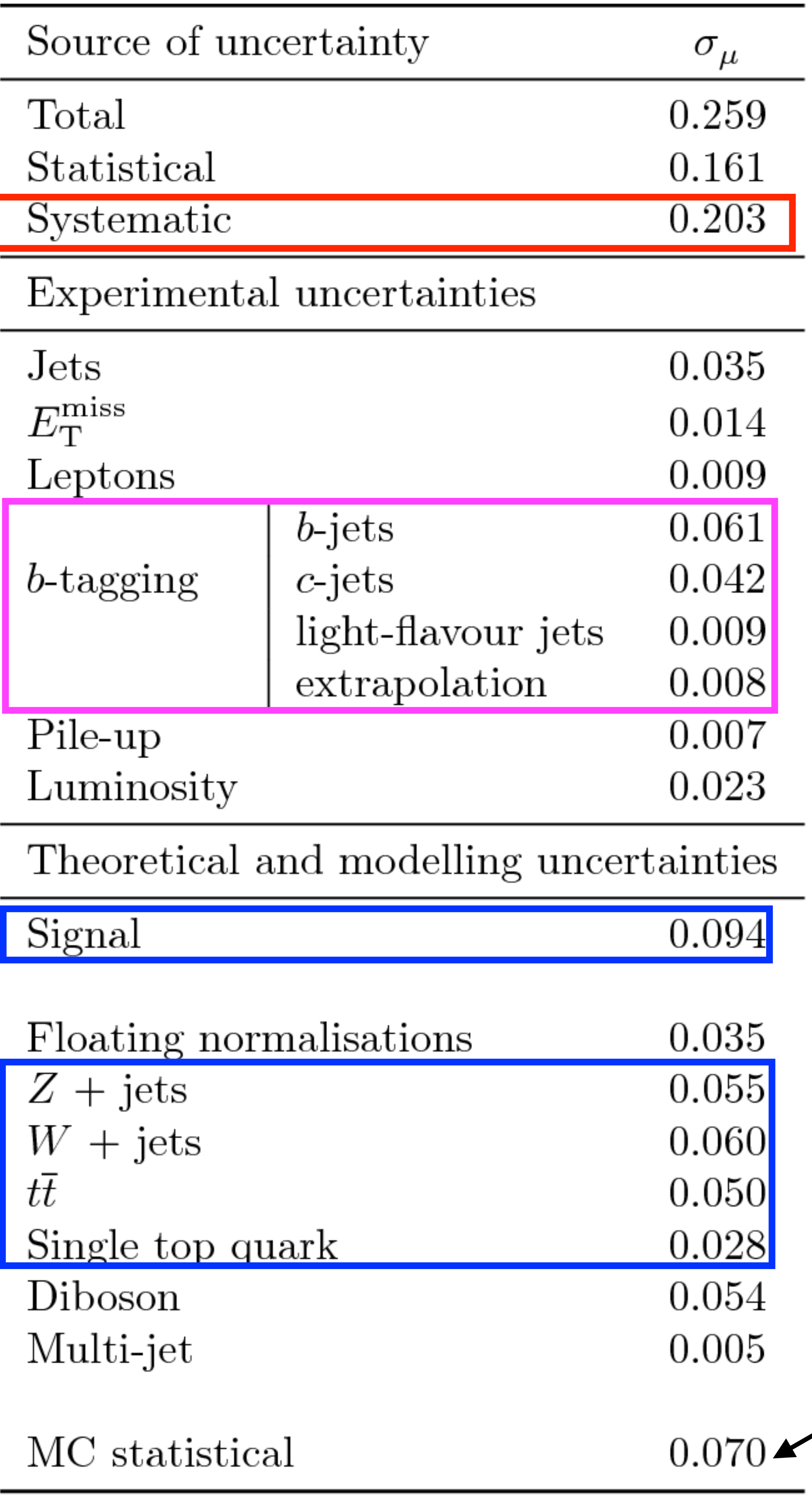
$$\mu^{bb}_{VH} = 1.16^{+0.27}_{-0.25}$$

Run2 signal significance:

4.9 s.d. obs. , 4.3 s.d. exp.

- signal compatibility across channels: 80%
- WH-ZH correlation: ~1%

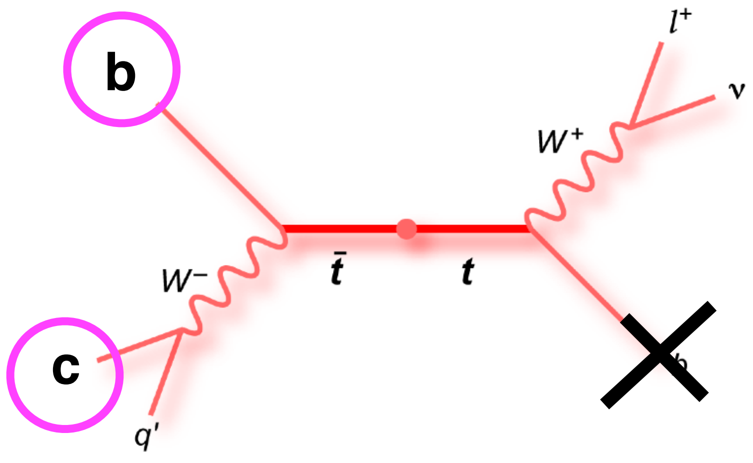
VHbb: results (2)



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-flavour 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
Multi-jet		0.005
MC statistical		0.070

- ***Analysis systematically dominated*** : syst. component represent ~80% of total error [does not mean that it will not shrink with luminosity]

- ***Detector systematics effects*** dominated by flavour tagging [sensitivity to c-jet mis-tag from ttbar events]



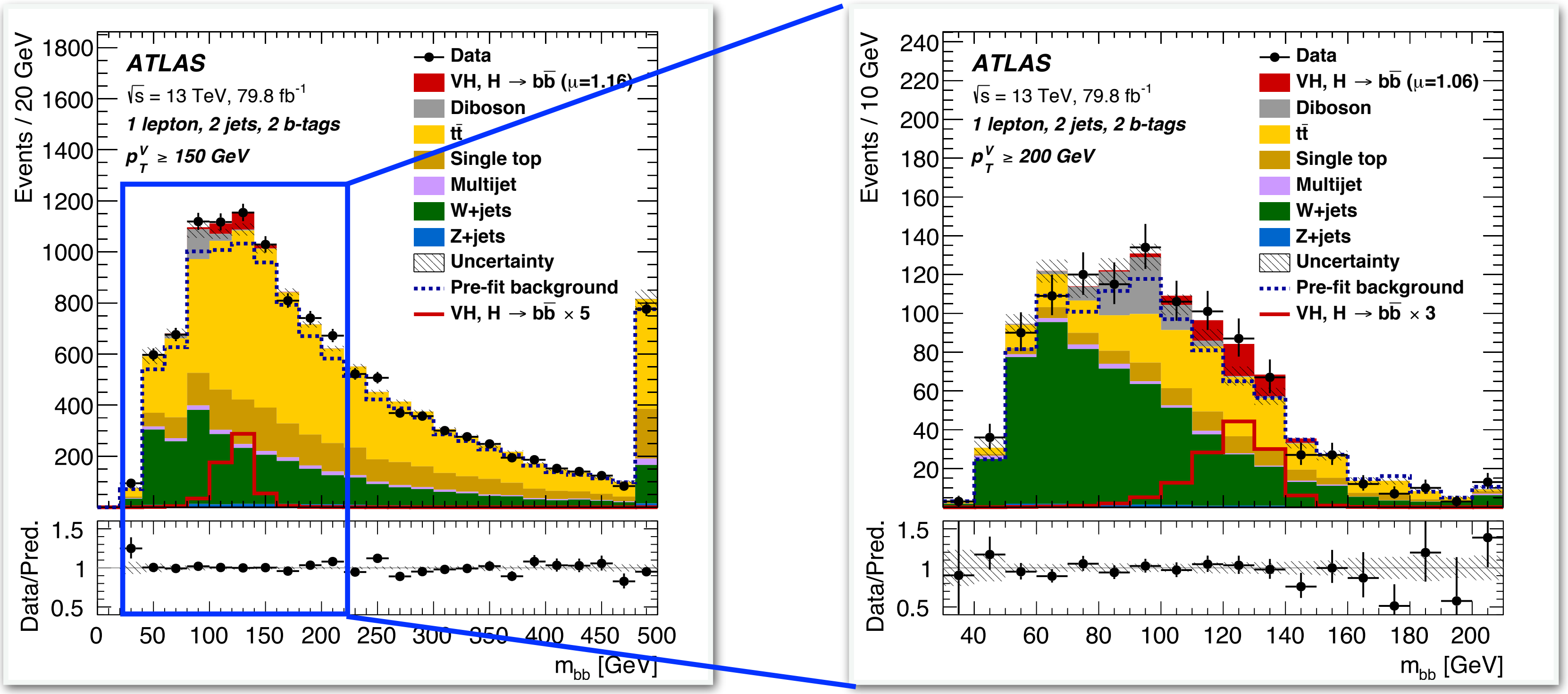
- ***Signal modelling systematics***: dominated by Parton Shower acceptance effects
  - do not impact the significance of the measured signal

- Similar contribution from ***modelling uncertainty*** of various processes:
  - ***W+jets***: W p_T shape uncertainty
  - ***Z+jets***: m_{bb} shape uncertainty
  - ***diboson***: m_{bb} lineshape

- ***MC statistics:*** heavily relying on generator filters at different level to provide enough statistics (huge CPU investment)

A more intuitive analysis

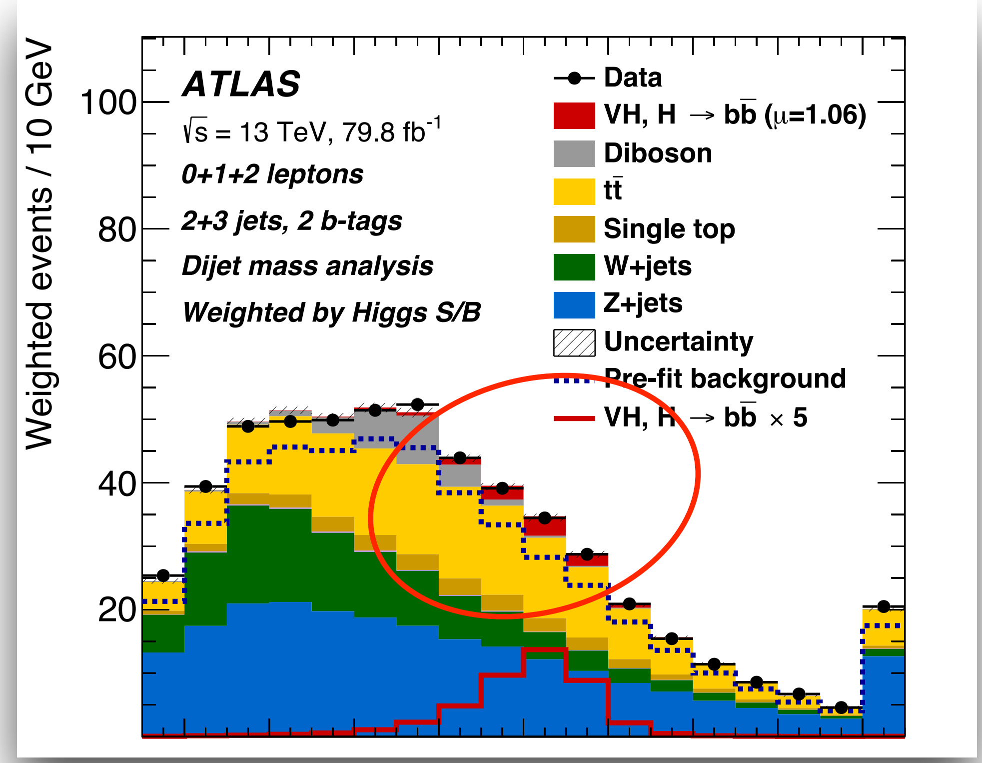
- fitting m_{bb} instead of MVA discriminant:
  - *additional splitting in Vpt: 200 GeV*
  - *additional upper cut on dRbb: 1.2 - 3.0*
  - *additional selection on 1L/2L to reduce ttbar background*

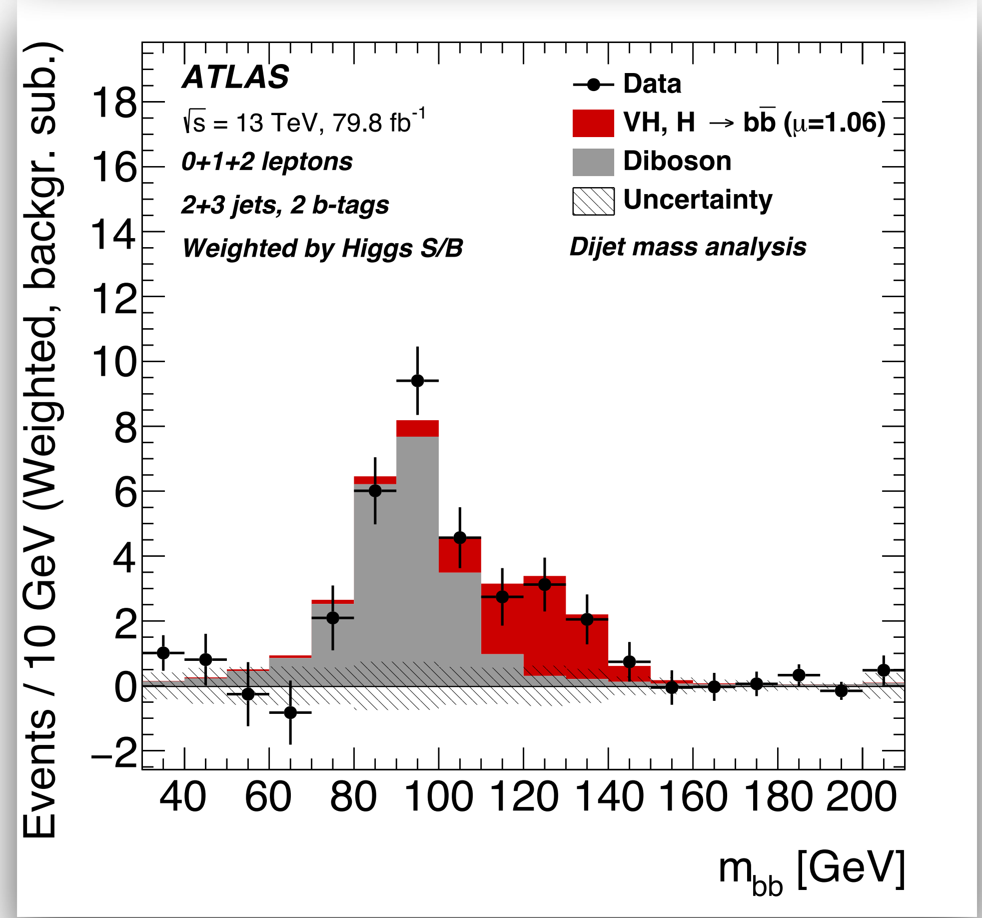


$$\mu^{bb}_{\mathrm{VH}} = 1.06^{+0.36}_{-0.33}$$

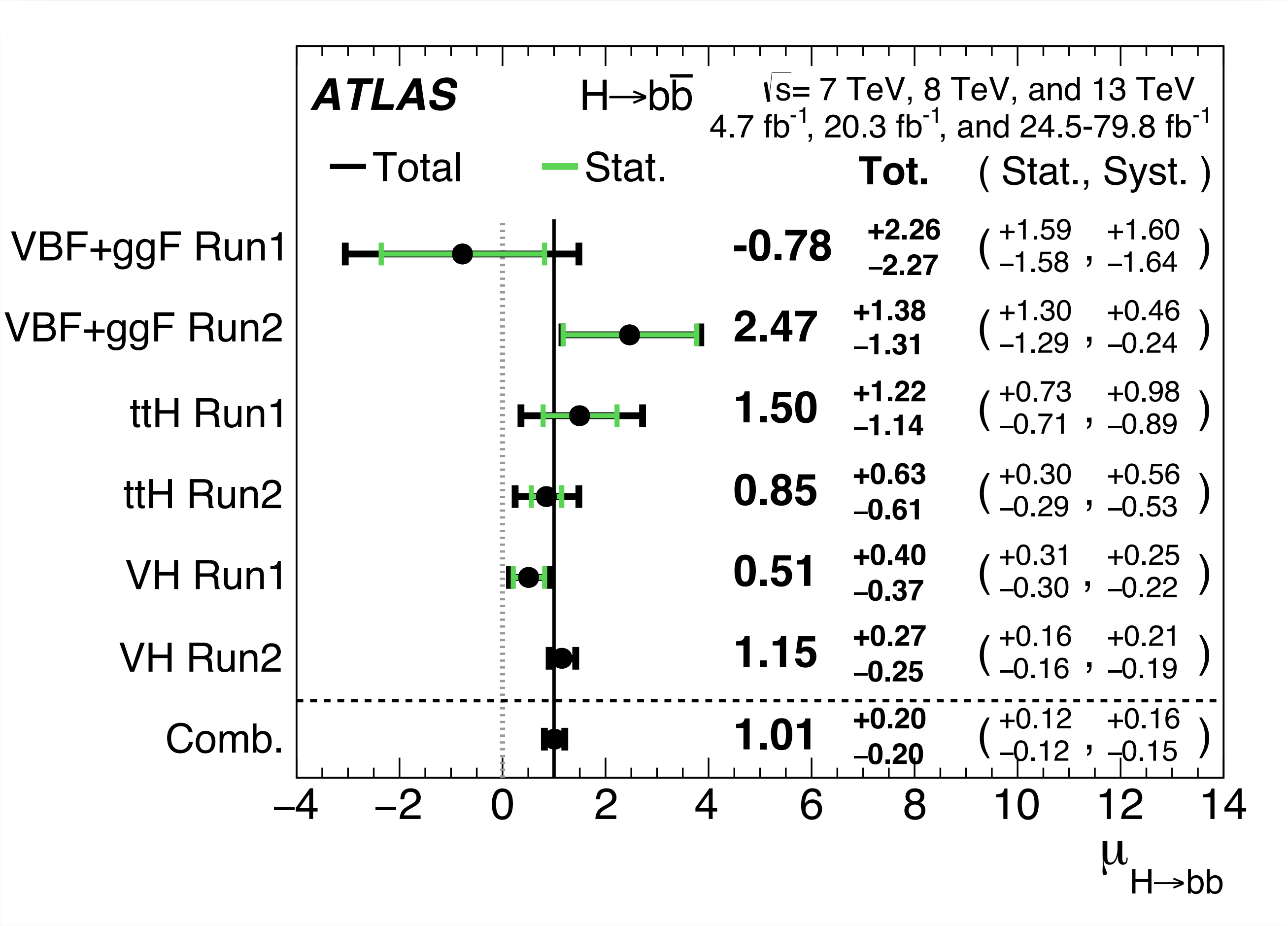
Run2 signal significance:

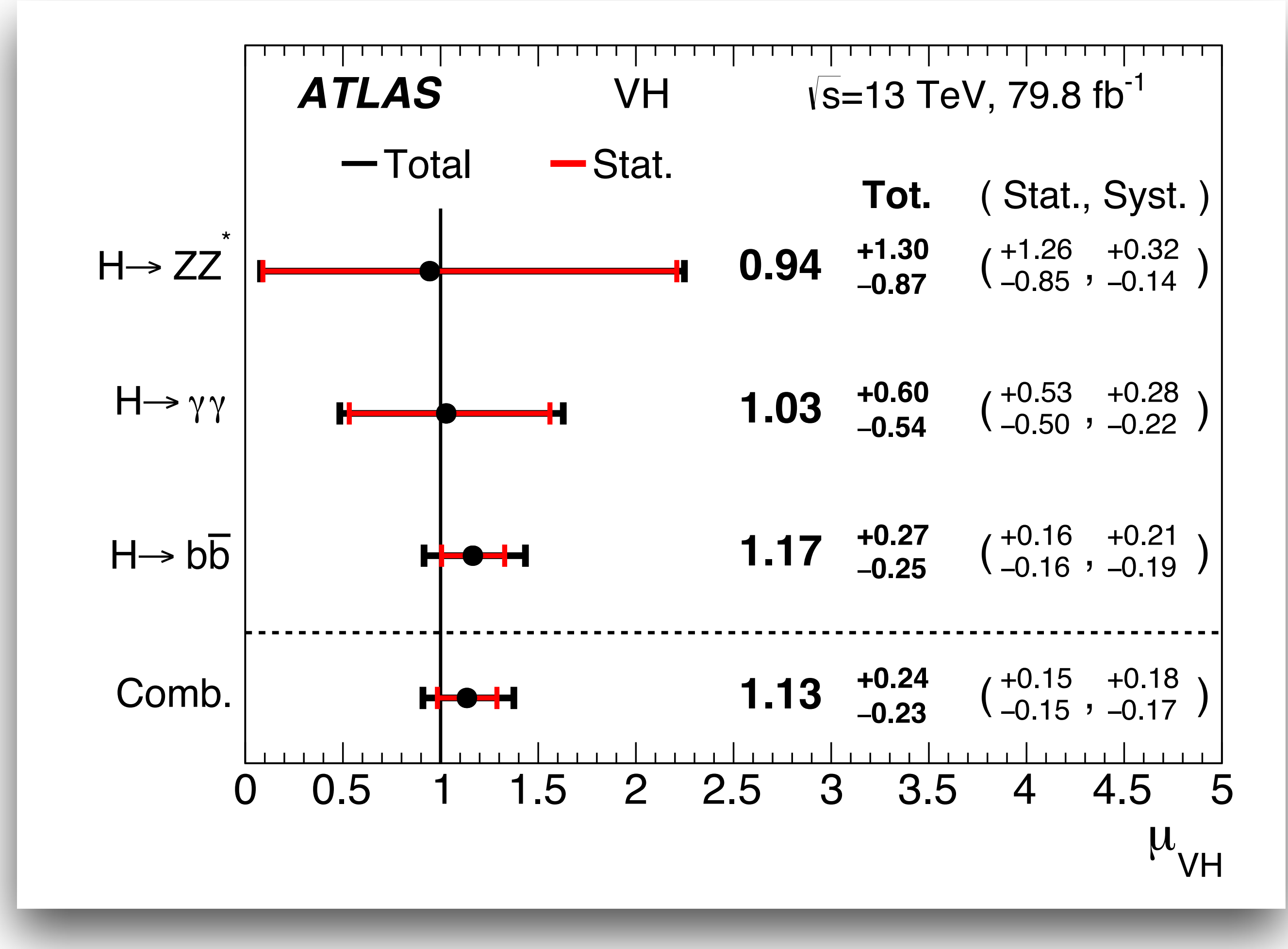
***3.6 s.d. obs.** , 3.5 s.d. exp.*





Important Run2 milestones





Run1+Run2 significance:

***5.4 s.d. obs. ,** 5.5 s.d. exp.*

!!! OBSERVATION of H->bb !!!

Run2 significance:

***5.3 s.d. obs. ,** 4.8 s.d. exp.*

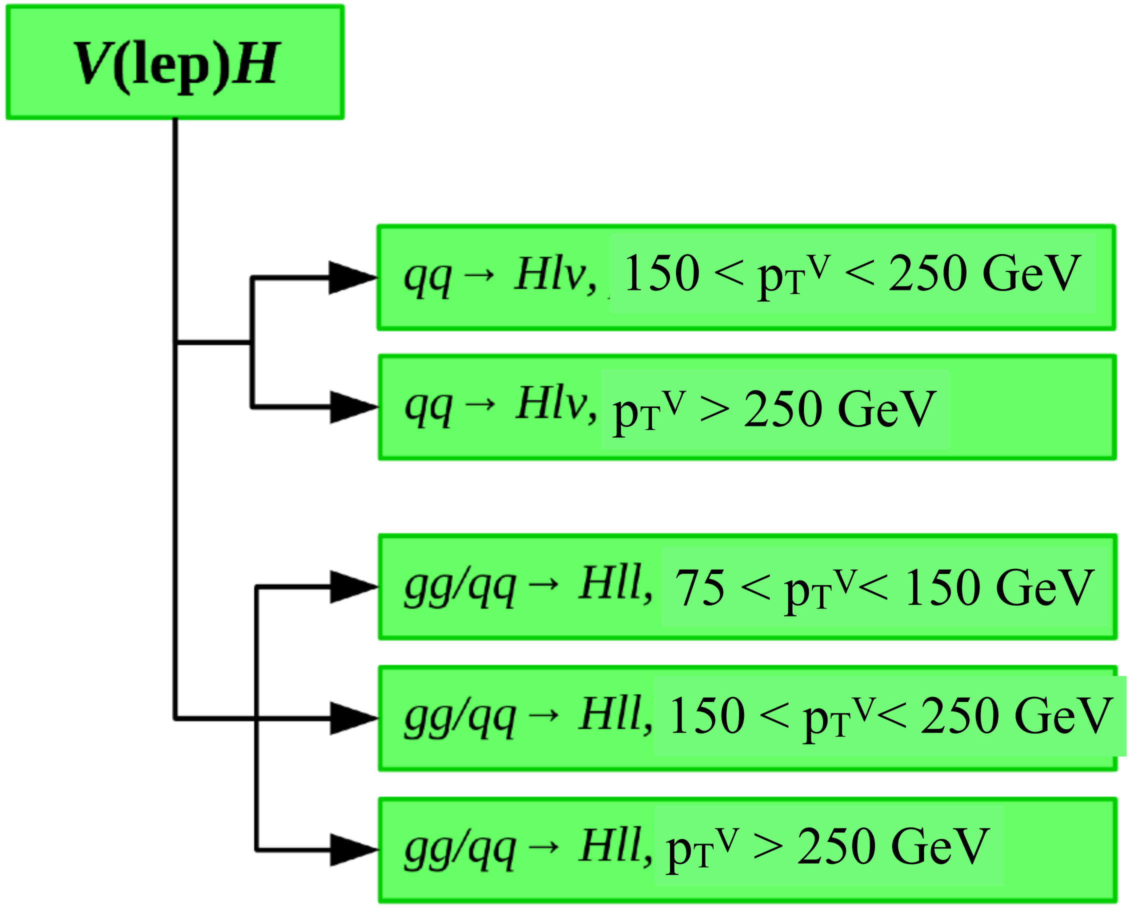
!!! OBSERVATION of VH production !!!

- VH (H->bb) plays a LEADING role in the measurement of the Hbb Br as well as VH production mode

more differential information

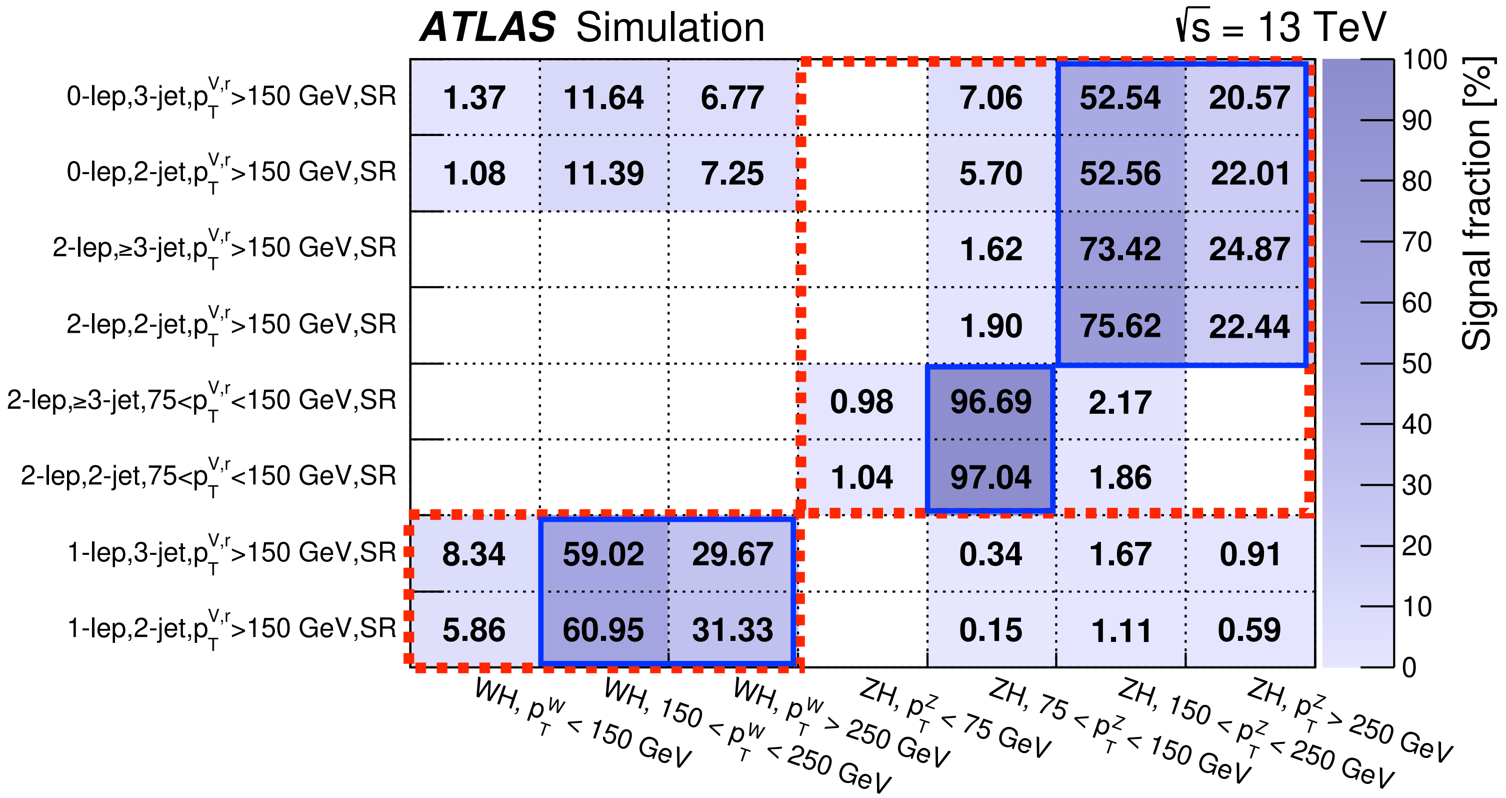
arXiv:1903.04618 (submitted to JHEP)

- From inclusive signal strength to Simplified Template cross section (STXS)
- Re-interpreting observation result, measuring cross section in bins of *V p_T separately* for *WH and ZH production*:
  - *experimentally:* better resolution on V p_T than on Higgs p_T
  - *reduces amount of extrapolation to inclusive result*
  - *following analysis categorisation:* split at 250 exploits BDT shape



V(lep)H

- $qq \to Hl\nu$, $150 < p_T^V < 250$ GeV
- $qq \to Hl\nu$, $p_T^V > 250$ GeV
- $gg/qq \to Hll$, $75 < p_T^V < 150$ GeV
- $gg/qq \to Hll$, $150 < p_T^V < 250$ GeV
- $gg/qq \to Hll$, $p_T^V > 250$ GeV



ATLAS Simulation $\sqrt{s}$ = 13 TeV

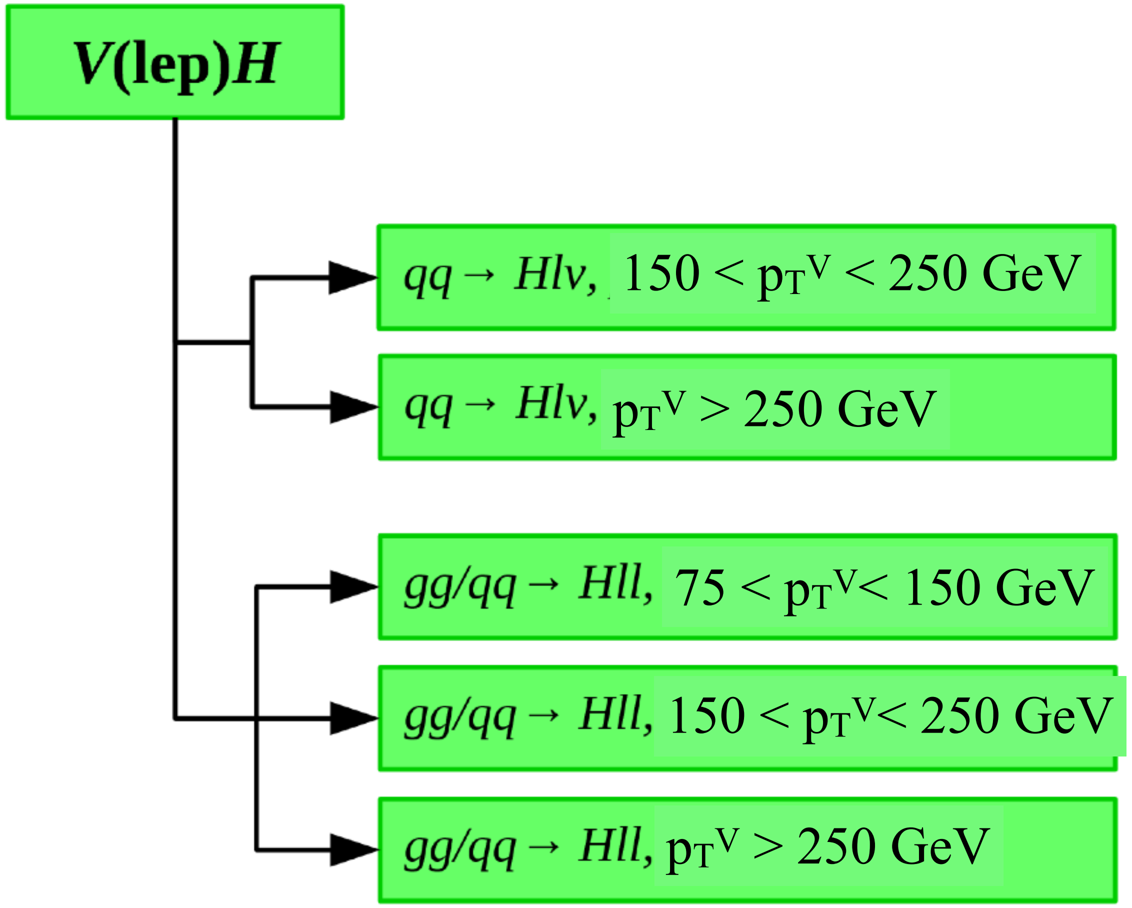
	WH, $p_T^W < 150$ GeV	WH, $150 < p_T^W < 250$ GeV	WH, $p_T^W > 250$ GeV	ZH, $p_T^Z < 75$ GeV	ZH, $75 < p_T^Z < 150$ GeV	ZH, $150 < p_T^Z < 250$ GeV	ZH, $p_T^Z > 250$ GeV
0-lep,3-jet,$p_T^{V,r}$>150 GeV,SR	1.37	11.64	6.77		7.06	52.54	20.57
0-lep,2-jet,$p_T^{V,r}$>150 GeV,SR	1.08	11.39	7.25		5.70	52.56	22.01
2-lep,≥3-jet,$p_T^{V,r}$>150 GeV,SR					1.62	73.42	24.87
2-lep,2-jet,$p_T^{V,r}$>150 GeV,SR					1.90	75.62	22.44
2-lep,≥3-jet,75<$p_T^{V,r}$<150 GeV,SR				0.98	96.69	2.17	
2-lep,2-jet,75<$p_T^{V,r}$<150 GeV,SR				1.04	97.04	1.86	
1-lep,3-jet,$p_T^{V,r}$>150 GeV,SR	8.34	59.02	29.67		0.34	1.67	0.91
1-lep,2-jet,$p_T^{V,r}$>150 GeV,SR	5.86	60.95	31.33		0.15	1.11	0.59

more differential information

arXiv:1903.04618 (submitted to JHEP)

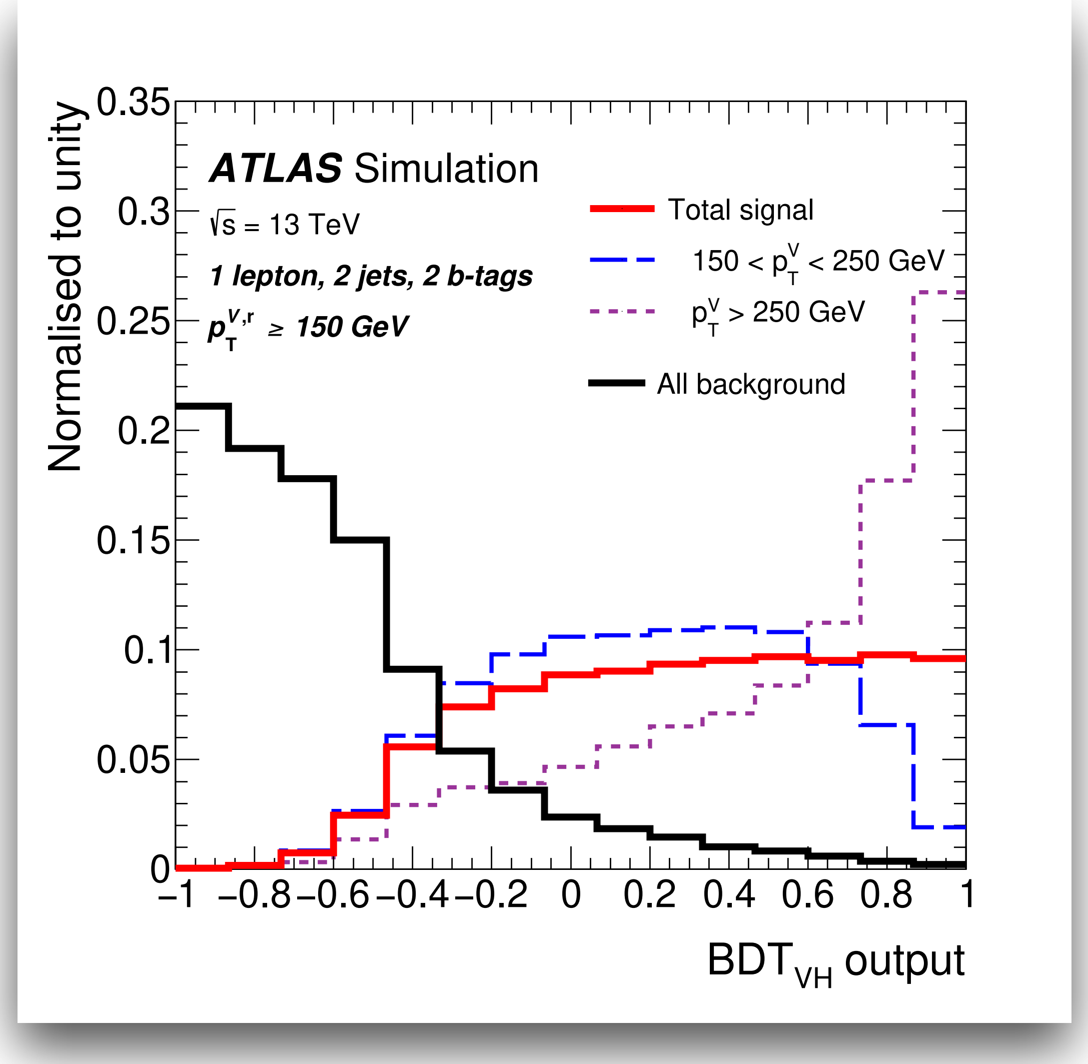
- From inclusive signal strength to Simplified Template cross section (STXS)

- Re-interpreting observation result, measuring cross section in bins of *V p_T separately* for *WH and ZH production*:
  - *experimentally:* better resolution on V p_T than on Higgs p_T
  - *reduces amount of extrapolation to inclusive result*
  - *following analysis categorisation:* split at 250 exploits BDT shape

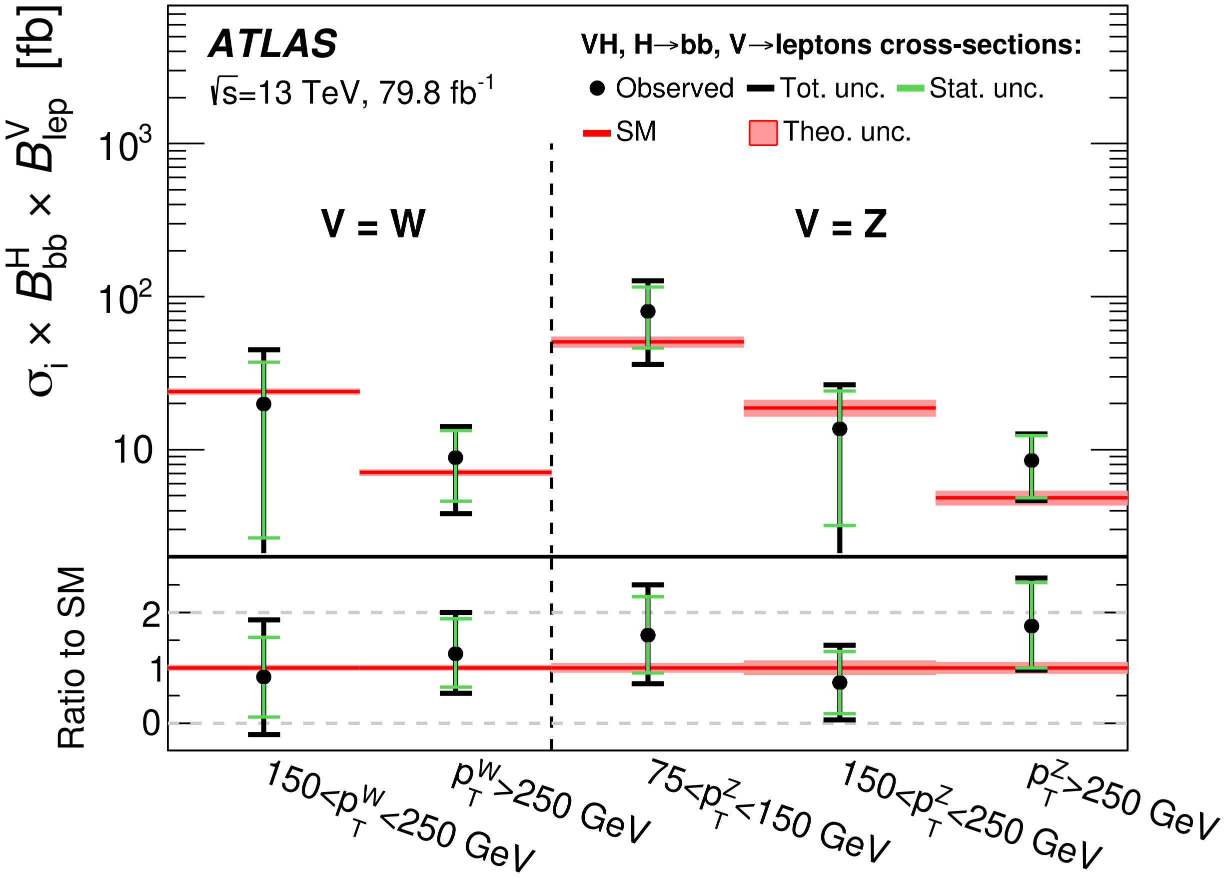


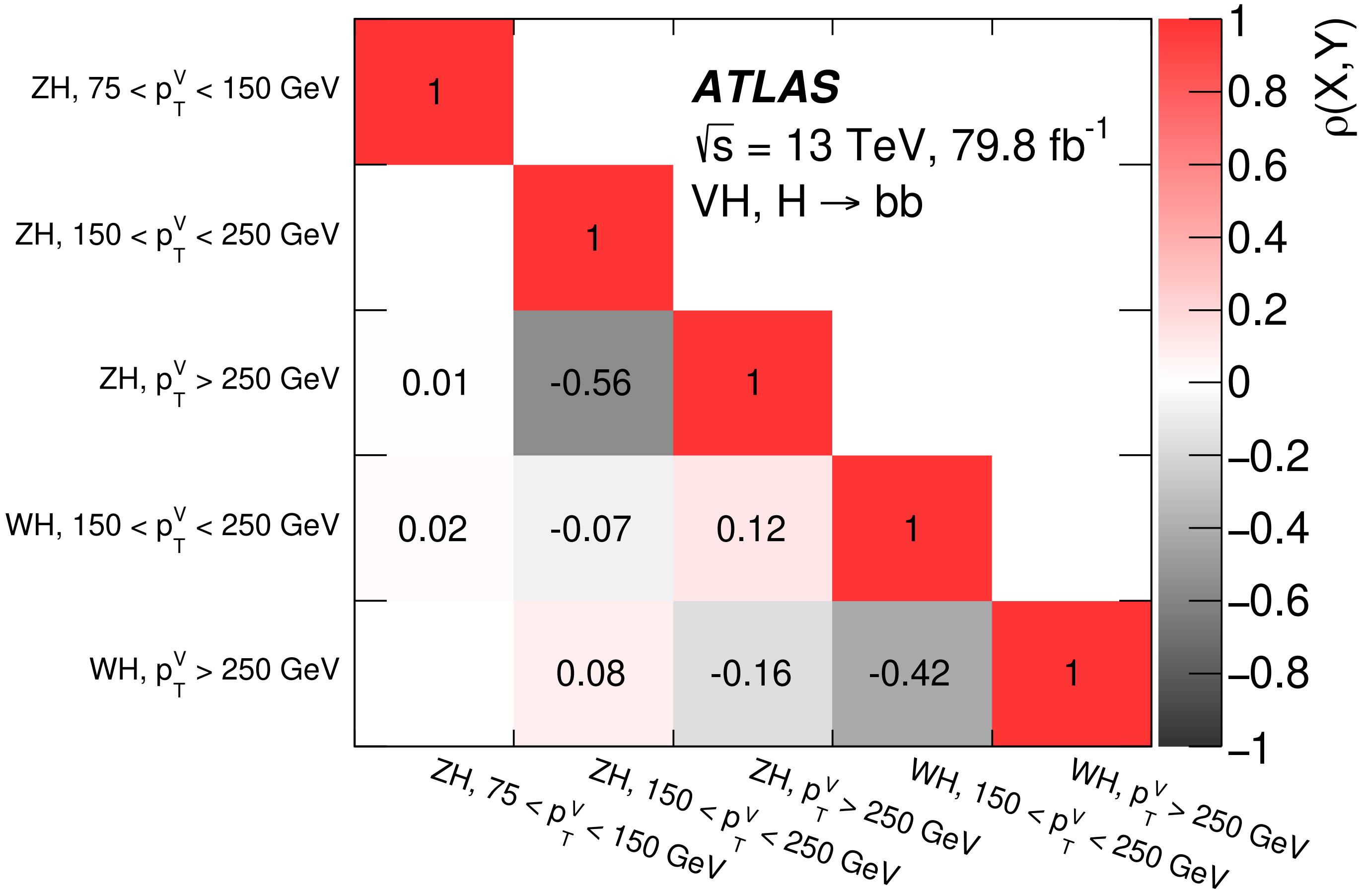
$V(lep)H$

- $qq \rightarrow Hl\nu$, $150 < p_T^V < 250$ GeV
- $qq \rightarrow Hl\nu$, $p_T^V > 250$ GeV
- $gg/qq \rightarrow Hll$, $75 < p_T^V < 150$ GeV
- $gg/qq \rightarrow Hll$, $150 < p_T^V < 250$ GeV
- $gg/qq \rightarrow Hll$, $p_T^V > 250$ GeV



more differential information: result





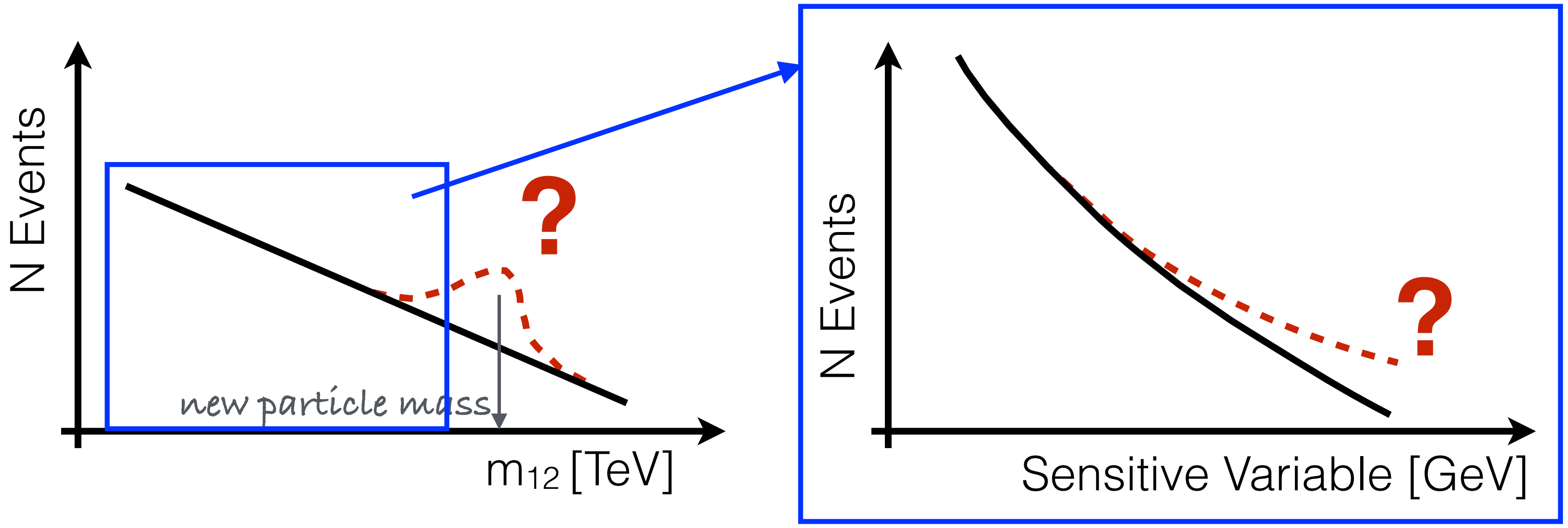
	ZH, $75 < p_T^V < 150$ GeV	ZH, $150 < p_T^V < 250$ GeV	ZH, $p_T^V > 250$ GeV	WH, $150 < p_T^V < 250$ GeV	WH, $p_T^V > 250$ GeV
ZH, $75 < p_T^V < 150$ GeV	1				
ZH, $150 < p_T^V < 250$ GeV		1			
ZH, $p_T^V > 250$ GeV	0.01	-0.56	1		
WH, $150 < p_T^V < 250$ GeV	0.02	-0.07	0.12	1	
WH, $p_T^V > 250$ GeV		0.08	-0.16	-0.42	1

- First STXS in VH (H->bb):
  - *all bins have obs./exp. significance between 1 and 2 sigma*
  - *still dominated by statistical uncertainty*
  - *correlation between neighbouring V pt bins due to lack of proper data splitting*

- High pT bins particularly suited to study effects from new physics

beyond coupling modifiers

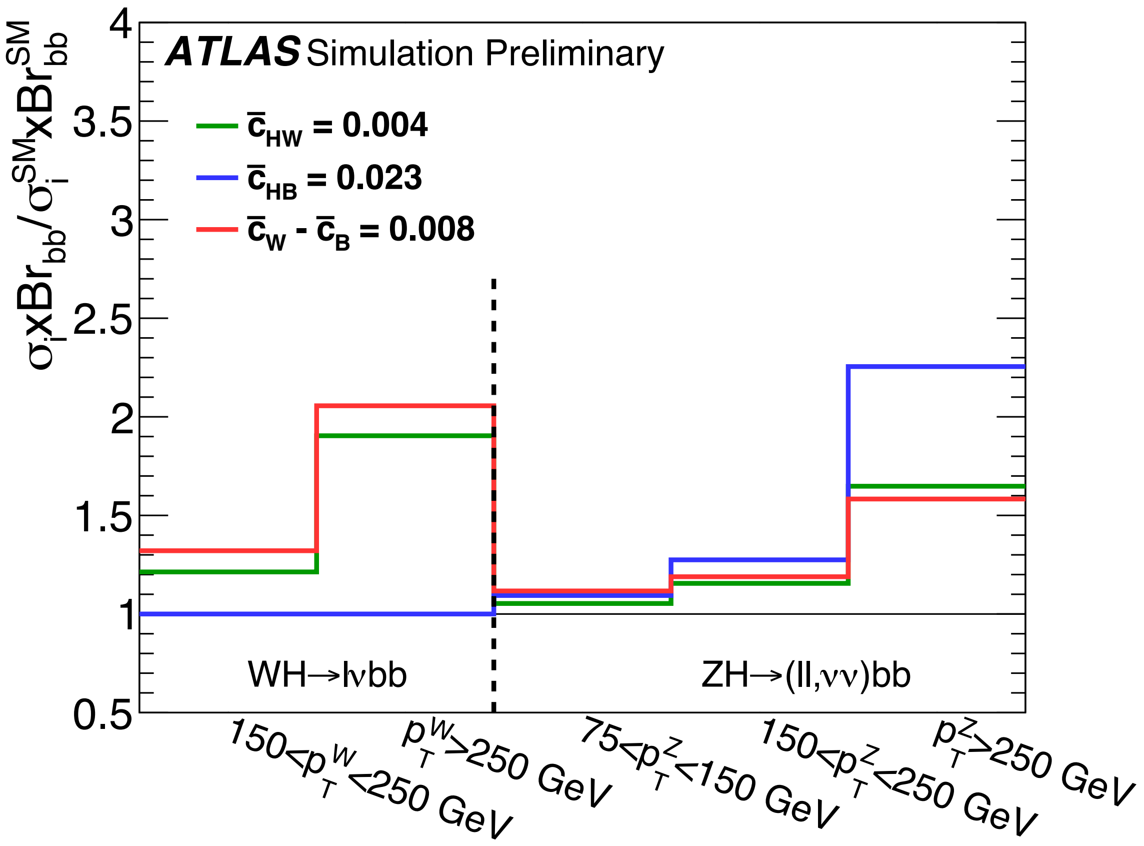
ATL-PHYS-PUB-2017-018



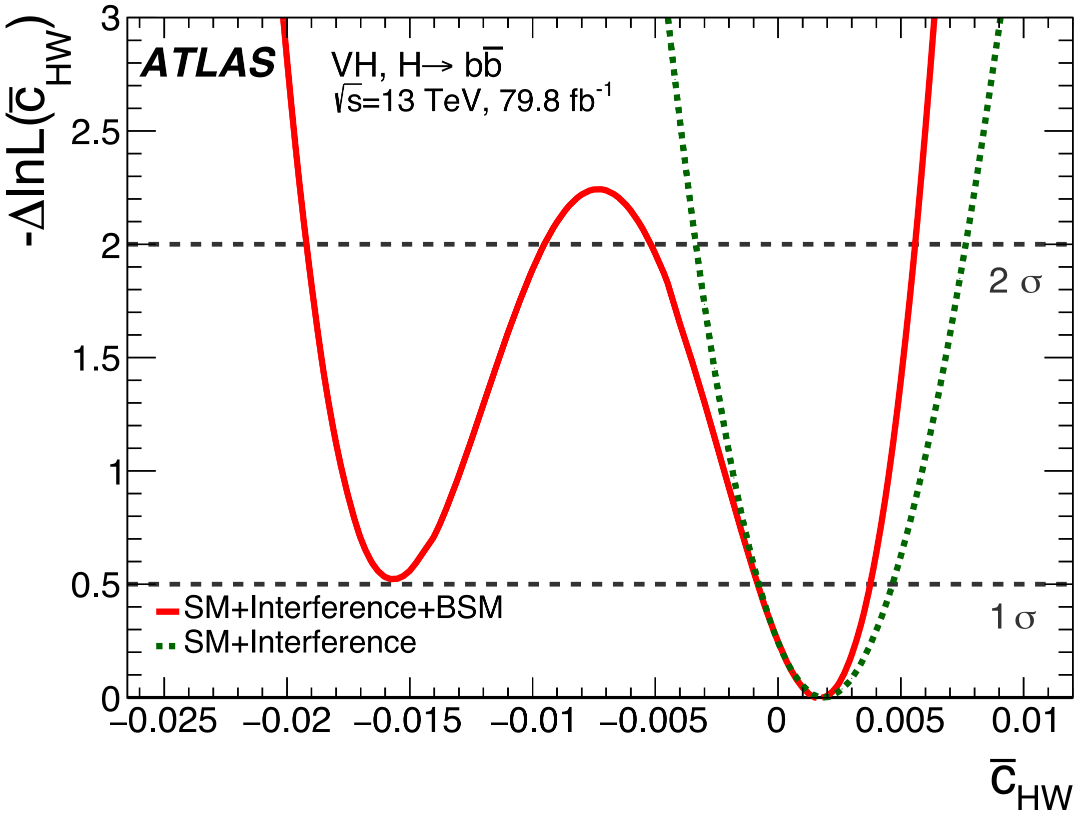
- EFT approach: consider modification to SM through dim 6 operators

$$\mathcal{L} = \mathcal{L}_{\mathrm{SM}} + \sum_i c_i^{(6)} O_i^{(6)} / \Lambda^2$$

- Effect of operators usually increases with V pT

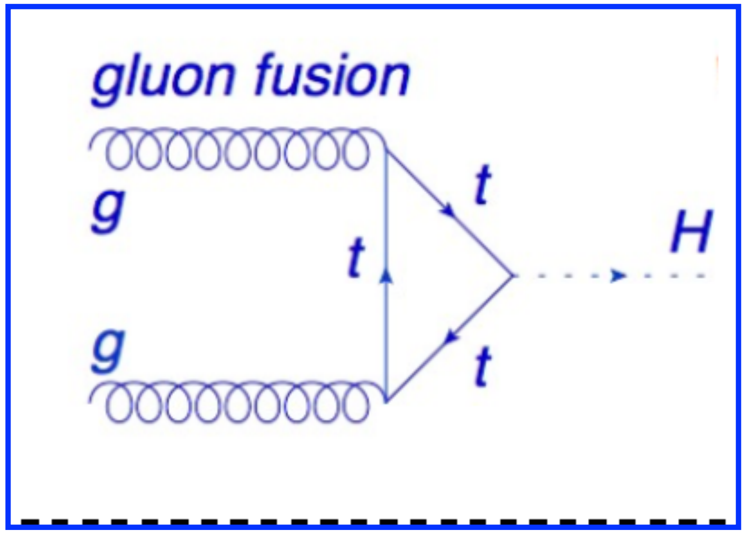


- Fitting one coefficient at the time

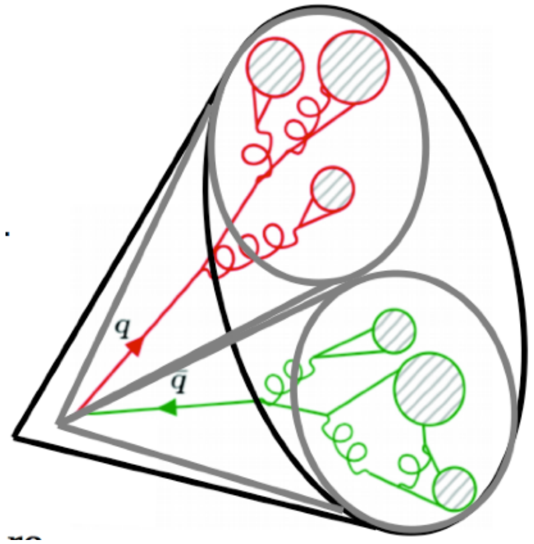


H->bb: boosted

ATLAS-CONF-2018-052



- very high p_T regime is the only solution to counteract overwhelming QCD multi jet background

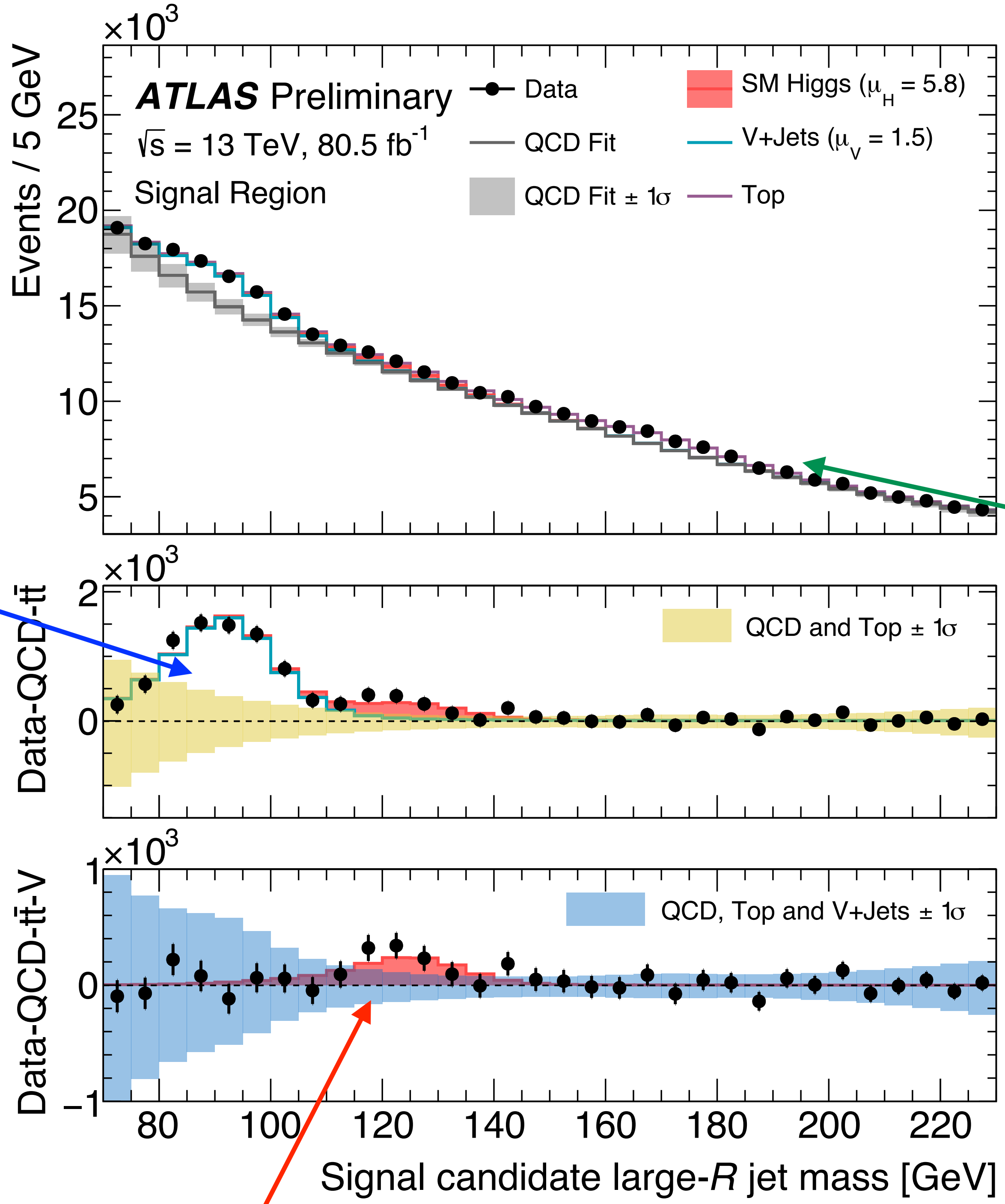


- LargeR jet selection:
  - leading Akt R=1.0 trimmed jets (f=0.05) with p_T>450 GeV, $|\eta|$<2.0
  - $2m/p_T<1$
  - at least 2 ghost-matched VR track jets (p_T>10 GeV): an implicit substructure requirement
  - leading 2 VR jets satisfying 77% b-tag WP

- Continuum QCD background estimation:
  - (from MC studies) tagging requirements do not bias jet mass distribution for m_J>70 GeV
  - use signal free 0-tag region to determine analytical fit functions [+ bias studies etc]

H->bb: boosted

ATLAS-CONF-2018-052



ttbar normalised in 1L control region. NF=0.84

$\mu_V = 1.5 \pm 0.22\ (\text{stat.})\ ^{+0.29}_{-0.25}\ (\text{syst.})\ \pm 0.18\ (\text{th.})$

observed significance: ~5 s.d.

$\mu_H = 5.8 \pm 3.1\ (\text{stat.})\ \pm\ 1.9\ (\text{syst.})\ \pm 1.7\ (\text{th.})$

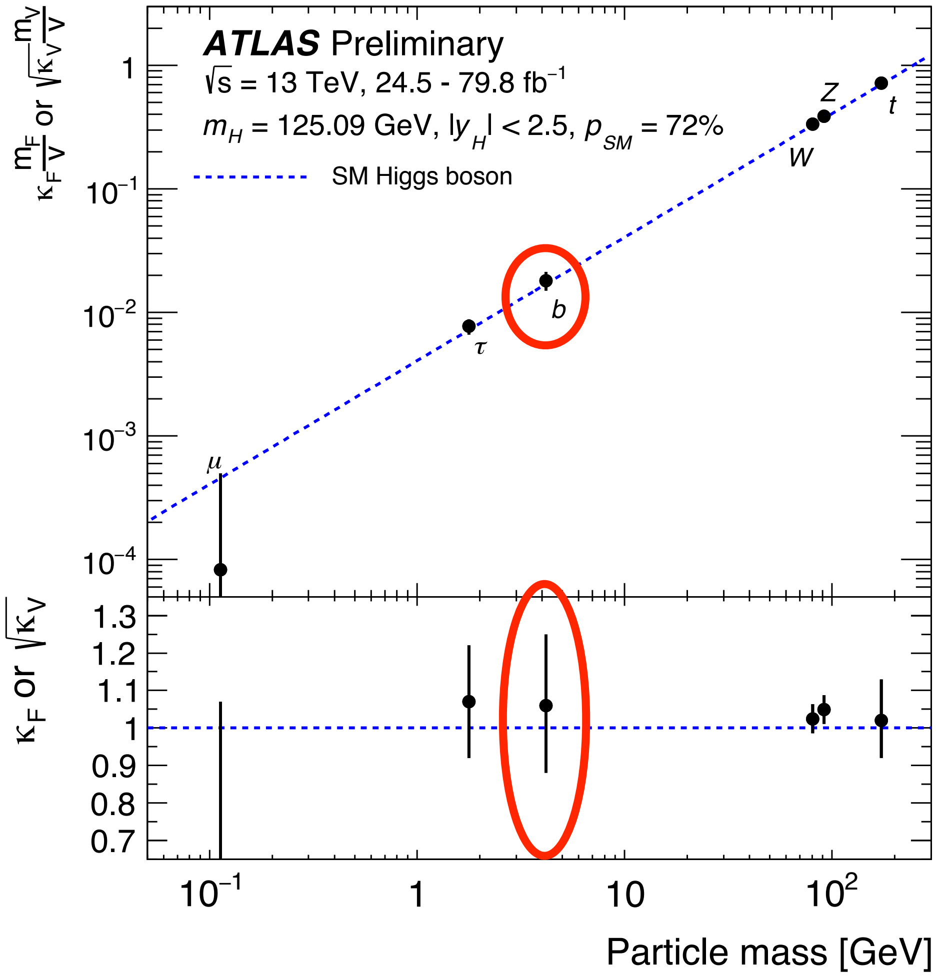
observed significance: ~1.6 s.d.

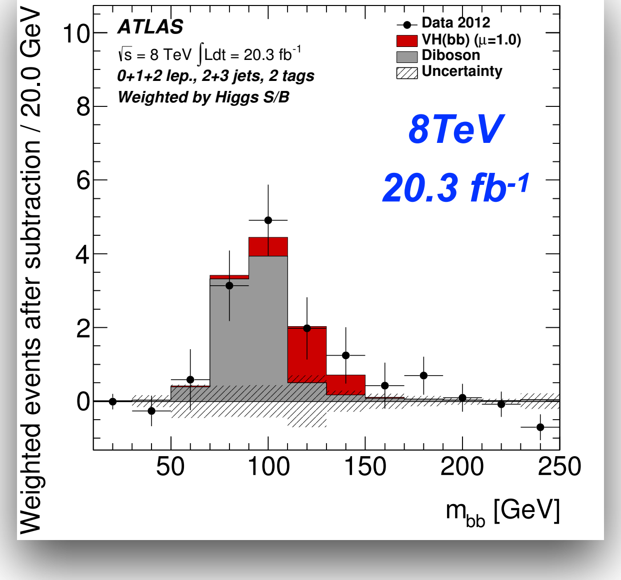
Summary and Conclusions

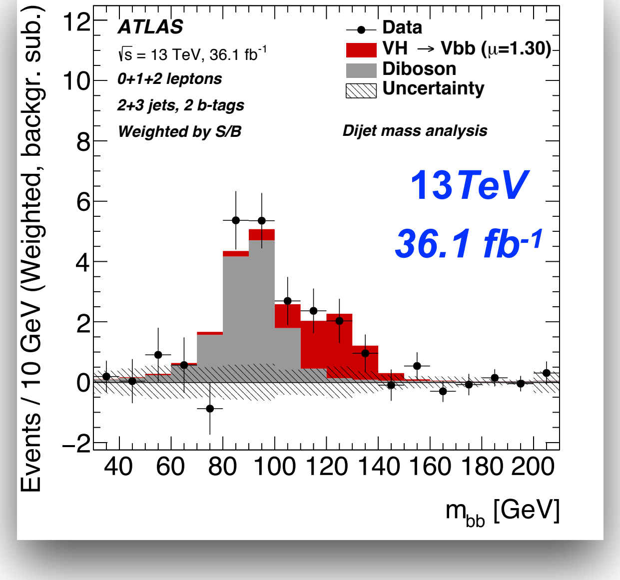
ATLAS-CONF-2019-005

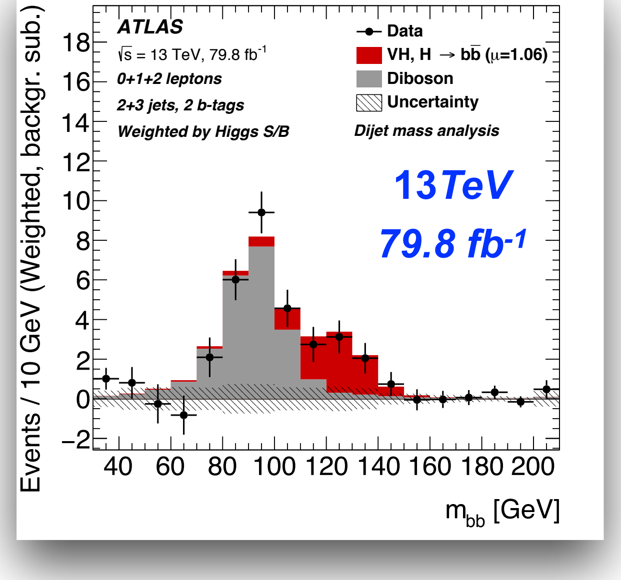
- The update of the VH (H->bb) analysis with partial Run2 dataset was the key ingredient to meet to important milestones for the ATLAS experiment*:*
  - *observation of H->bb decay*
  - *observation of VH production*

- A robust and conservative analysis will serve as a starting point for future improvements:
  - *80% more data already on tape*
  - *shifting attention to differential information*
  - *improvements in MC modelling and ML techniques*
  - *pushing into high p_T (boosted) regime to increase sensitivity to new physics*







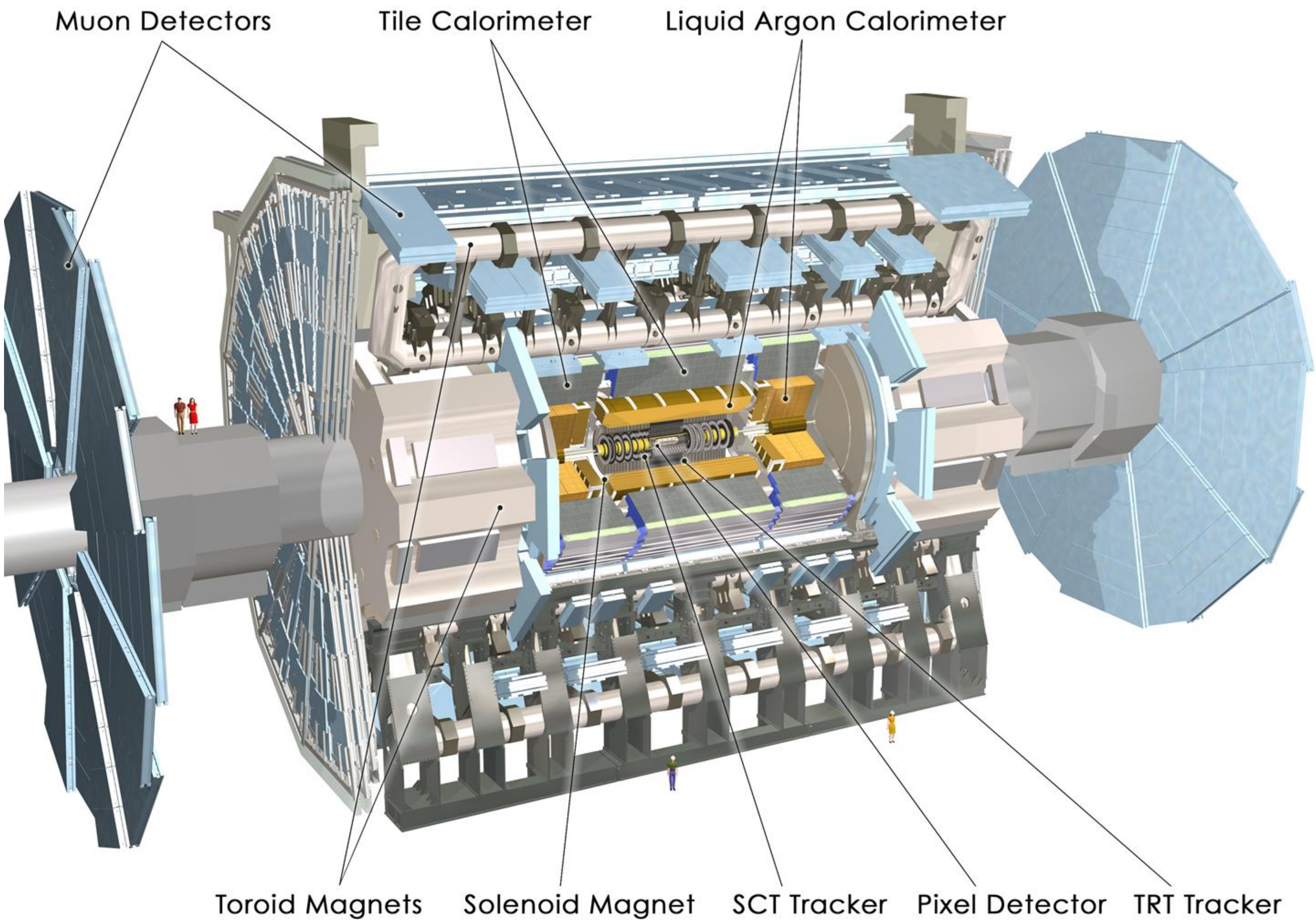


13TeV
140 fb^{-1}

Stay tuned for upcoming results !!!!

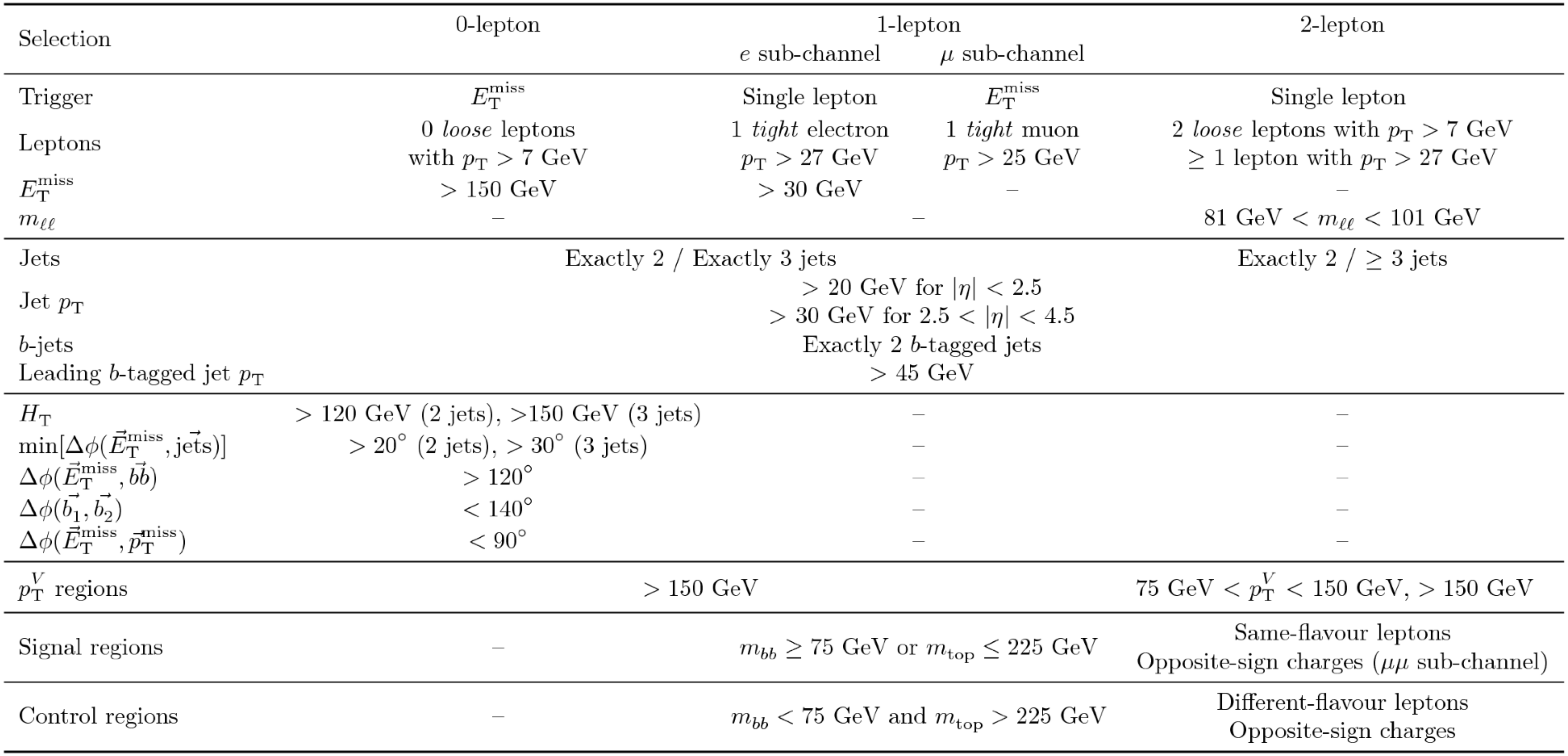
BackUp

“would you like to know more?”



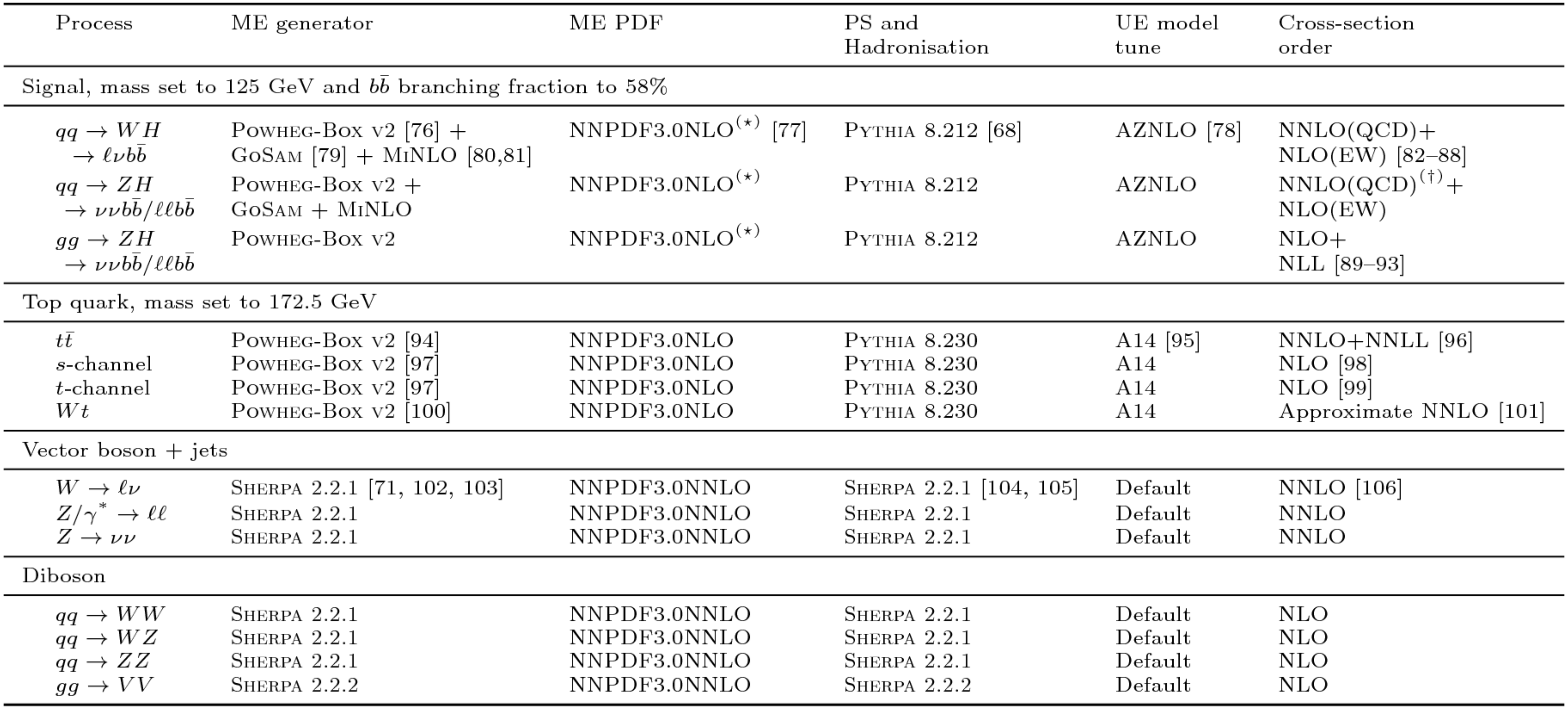
https://twiki.cern.ch/twiki/bin/view/AtlasPublic/HiggsPublicResults

VH H->bb: selection



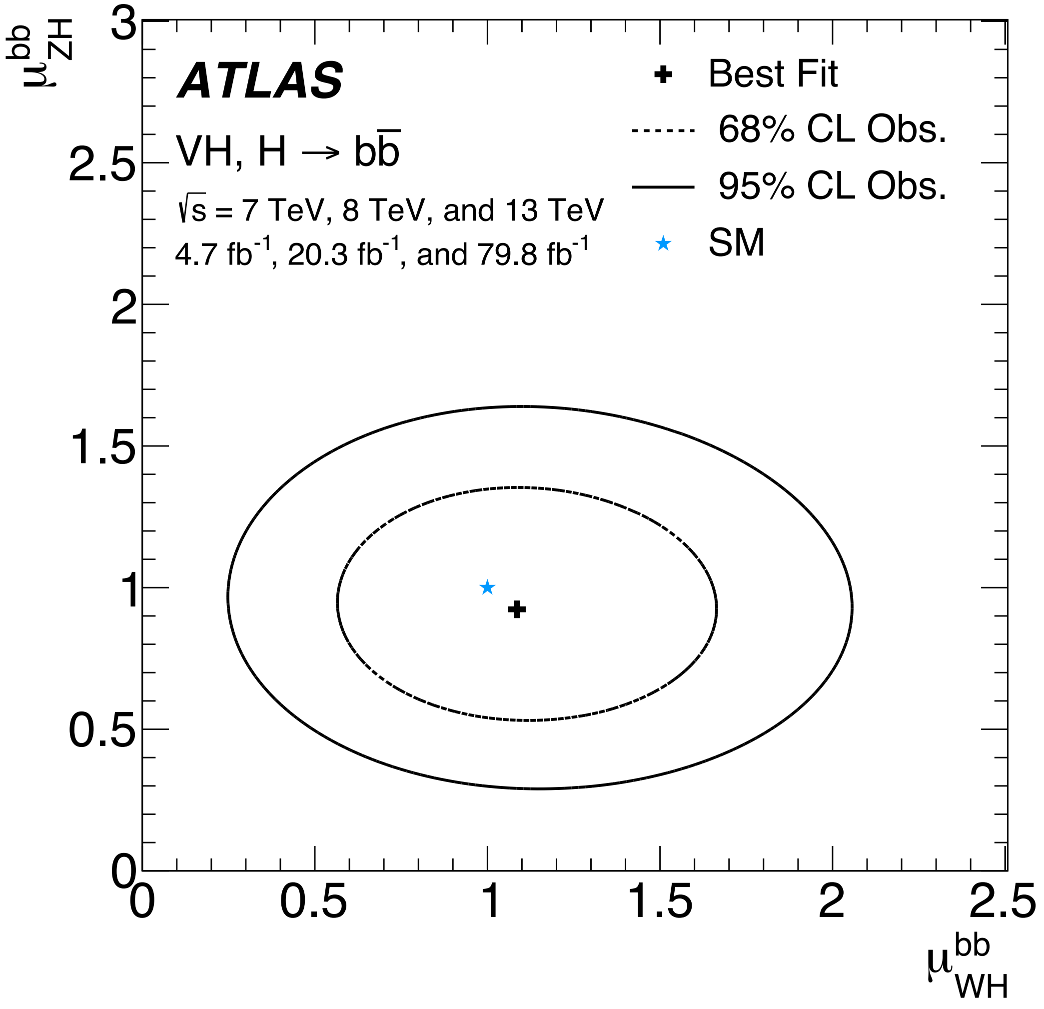
Selection	0-lepton	1-lepton		2-lepton
		e sub-channel	μ sub-channel	
Trigger	$E_{\mathrm{T}}^{\mathrm{miss}}$	Single lepton	$E_{\mathrm{T}}^{\mathrm{miss}}$	Single lepton
Leptons	0 *loose* leptons with $p_{\mathrm{T}} > 7$ GeV	1 *tight* electron $p_{\mathrm{T}} > 27$ GeV	1 *tight* muon $p_{\mathrm{T}} > 25$ GeV	2 *loose* leptons with $p_{\mathrm{T}} > 7$ GeV ≥ 1 lepton with $p_{\mathrm{T}} > 27$ GeV
$E_{\mathrm{T}}^{\mathrm{miss}}$	> 150 GeV	> 30 GeV	–	–
$m_{\ell\ell}$	–	–		81 GeV $< m_{\ell\ell} <$ 101 GeV
Jets	Exactly 2 / Exactly 3 jets			Exactly 2 / ≥ 3 jets
Jet p_{T}	> 20 GeV for $\lvert\eta\rvert < 2.5$ > 30 GeV for $2.5 < \lvert\eta\rvert < 4.5$			
b-jets	Exactly 2 b-tagged jets			
Leading b-tagged jet p_{T}	> 45 GeV			
H_{T}	> 120 GeV (2 jets), >150 GeV (3 jets)	–		–
$\min[\Delta\phi(\vec{E}_{\mathrm{T}}^{\mathrm{miss}}, \vec{\mathrm{jets}})]$	$> 20^{\circ}$ (2 jets), $> 30^{\circ}$ (3 jets)	–		–
$\Delta\phi(\vec{E}_{\mathrm{T}}^{\mathrm{miss}}, \vec{bb})$	$> 120^{\circ}$	–		–
$\Delta\phi(\vec{b}_1, \vec{b}_2)$	$< 140^{\circ}$	–		–
$\Delta\phi(\vec{E}_{\mathrm{T}}^{\mathrm{miss}}, \vec{p}_{\mathrm{T}}^{\mathrm{miss}})$	$< 90^{\circ}$	–		–
p_{T}^{V} regions	> 150 GeV			75 GeV $< p_{\mathrm{T}}^{V} <$ 150 GeV, > 150 GeV
Signal regions	–	$m_{bb} \geq 75$ GeV or $m_{\mathrm{top}} \leq 225$ GeV		Same-flavour leptons Opposite-sign charges ($\mu\mu$ sub-channel)
Control regions	–	$m_{bb} < 75$ GeV and $m_{\mathrm{top}} > 225$ GeV		Different-flavour leptons Opposite-sign charges

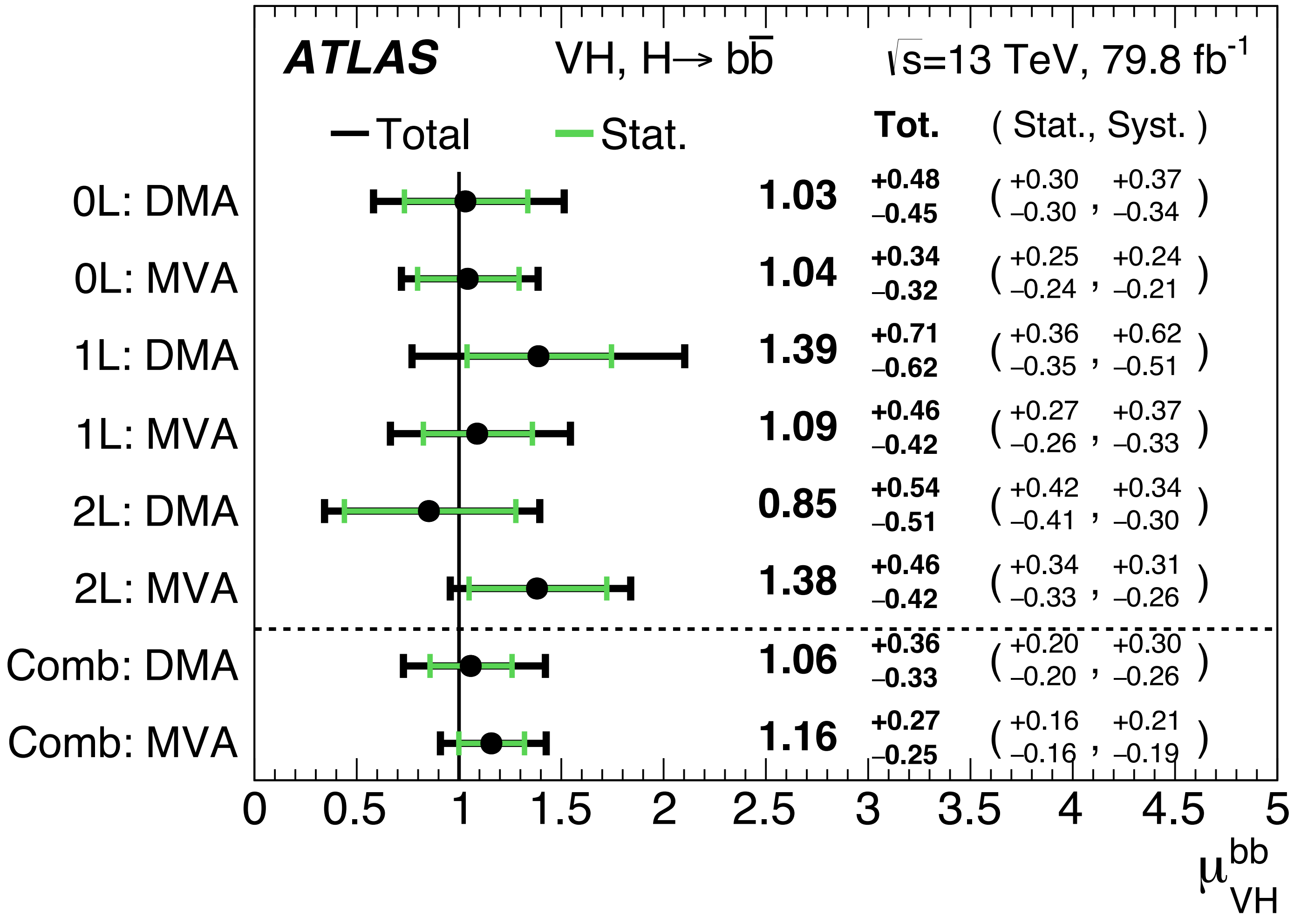
VH H->bb: MC



Process	ME generator	ME PDF	PS and Hadronisation	UE model tune	Cross-section order
Signal, mass set to 125 GeV and $b\bar{b}$ branching fraction to 58%					
$qq \to WH \to \ell\nu b\bar{b}$	Powheg-Box v2 [76] + GoSam [79] + MiNLO [80,81]	NNPDF3.0NLO$^{(\star)}$ [77]	Pythia 8.212 [68]	AZNLO [78]	NNLO(QCD)+ NLO(EW) [82–88]
$qq \to ZH \to \nu\nu b\bar{b}/\ell\ell b\bar{b}$	Powheg-Box v2 + GoSam + MiNLO	NNPDF3.0NLO$^{(\star)}$	Pythia 8.212	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$^{(\star)}$	Pythia 8.212	AZNLO	NLO+ NLL [89–93]
Top quark, mass set to 172.5 GeV					
$t\bar{t}$	Powheg-Box v2 [94]	NNPDF3.0NLO	Pythia 8.230	A14 [95]	NNLO+NNLL [96]
s-channel	Powheg-Box v2 [97]	NNPDF3.0NLO	Pythia 8.230	A14	NLO [98]
t-channel	Powheg-Box v2 [97]	NNPDF3.0NLO	Pythia 8.230	A14	NLO [99]
Wt	Powheg-Box v2 [100]	NNPDF3.0NLO	Pythia 8.230	A14	Approximate NNLO [101]
Vector boson + jets					
$W \to \ell\nu$	Sherpa 2.2.1 [71, 102, 103]	NNPDF3.0NNLO	Sherpa 2.2.1 [104, 105]	Default	NNLO [106]
$Z/\gamma^* \to \ell\ell$	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					
$qq \to WW$	Sherpa 2.2.1	NNPDF3.0NNLO	Sherpa 2.2.1	Default	NLO
$qq \to WZ$	Sherpa 2.2.1	NNPDF3.0NNLO	Sherpa 2.2.1	Default	NLO
$qq \to ZZ$	Sherpa 2.2.1	NNPDF3.0NNLO	Sherpa 2.2.1	Default	NLO
$gg \to VV$	Sherpa 2.2.2	NNPDF3.0NNLO	Sherpa 2.2.2	Default	NLO

H->bb: VH


ATLAS
VH, H → bb̄
√s = 7 TeV, 8 TeV, and 13 TeV
4.7 fb^{-1}, 20.3 fb^{-1}, and 79.8 fb^{-1}
Best Fit
68% CL Obs.
95% CL Obs.
SM
μ^{bb}_{ZH}
μ^{bb}_{WH}
0
0.5
1
1.5
2
2.5
3


ATLAS
VH, H→ bb̄
√s=13 TeV, 79.8 fb^{-1}
Total
Stat.
Tot.
(Stat., Syst.)
0L: DMA
1.03 $^{+0.48}_{-0.45}$ ($^{+0.30}_{-0.30}$, $^{+0.37}_{-0.34}$)
0L: MVA
1.04 $^{+0.34}_{-0.32}$ ($^{+0.25}_{-0.24}$, $^{+0.24}_{-0.21}$)
1L: DMA
1.39 $^{+0.71}_{-0.62}$ ($^{+0.36}_{-0.35}$, $^{+0.62}_{-0.51}$)
1L: MVA
1.09 $^{+0.46}_{-0.42}$ ($^{+0.27}_{-0.26}$, $^{+0.37}_{-0.33}$)
2L: DMA
0.85 $^{+0.54}_{-0.51}$ ($^{+0.42}_{-0.41}$, $^{+0.34}_{-0.30}$)
2L: MVA
1.38 $^{+0.46}_{-0.42}$ ($^{+0.34}_{-0.33}$, $^{+0.31}_{-0.26}$)
Comb: DMA
1.06 $^{+0.36}_{-0.33}$ ($^{+0.20}_{-0.20}$, $^{+0.30}_{-0.26}$)
Comb: MVA
1.16 $^{+0.27}_{-0.25}$ ($^{+0.16}_{-0.16}$, $^{+0.21}_{-0.19}$)
0
0.5
1
1.5
2
2.5
3
3.5
4
4.5
5
μ^{bb}_{VH}

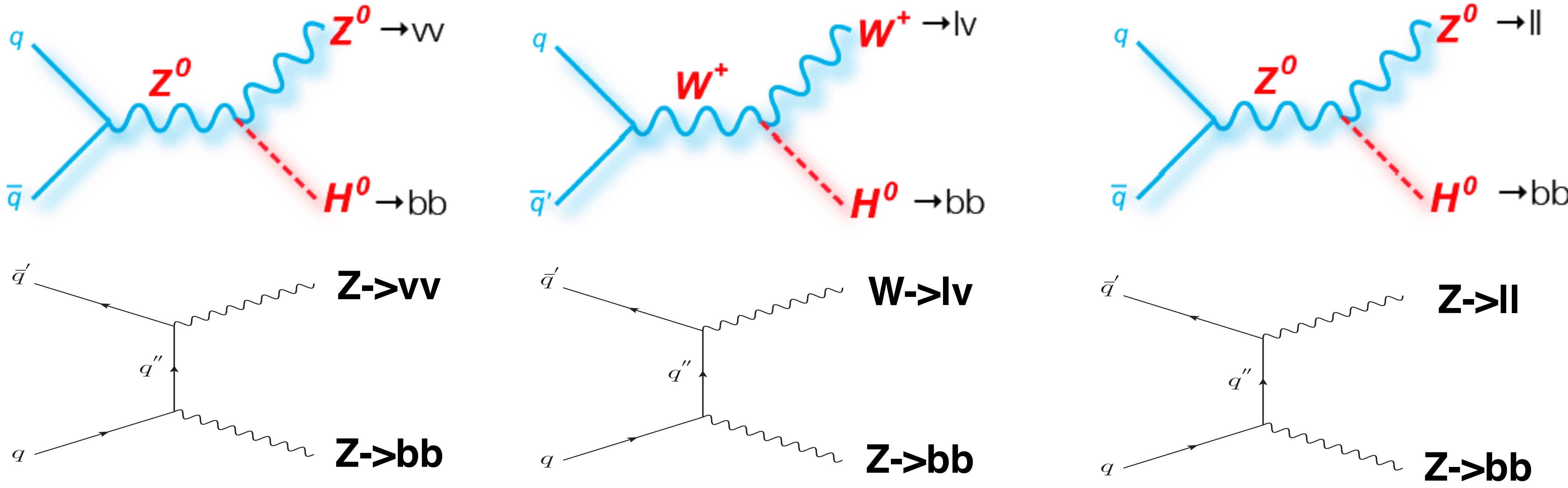
Intermezzo:'a cross check analysis'

- Validating the MVA analysis: **V+Z->bb** is irreducible background with a peak in m_{bb}

Larger x-sec for VZ

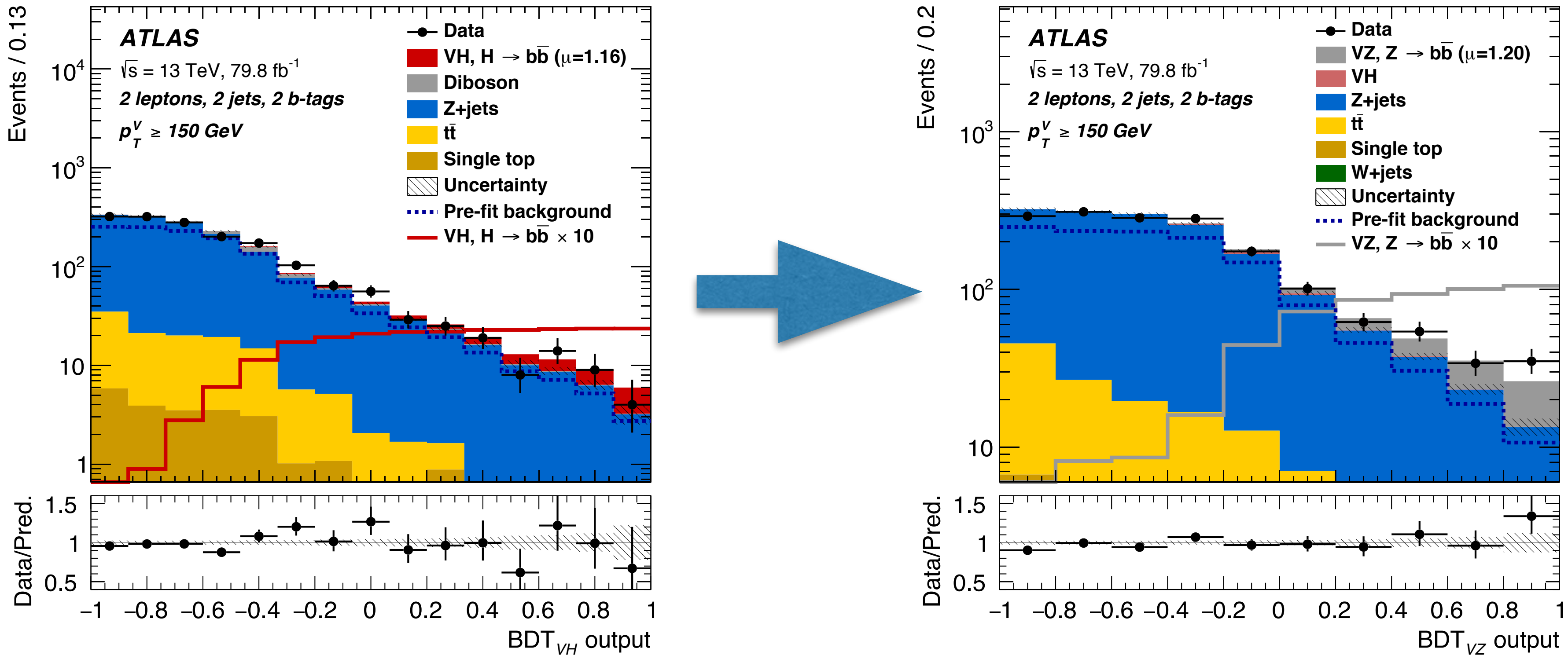
$Br(H_{bb})/Br(Z_{bb})$~4

High V p_T selection favours VH



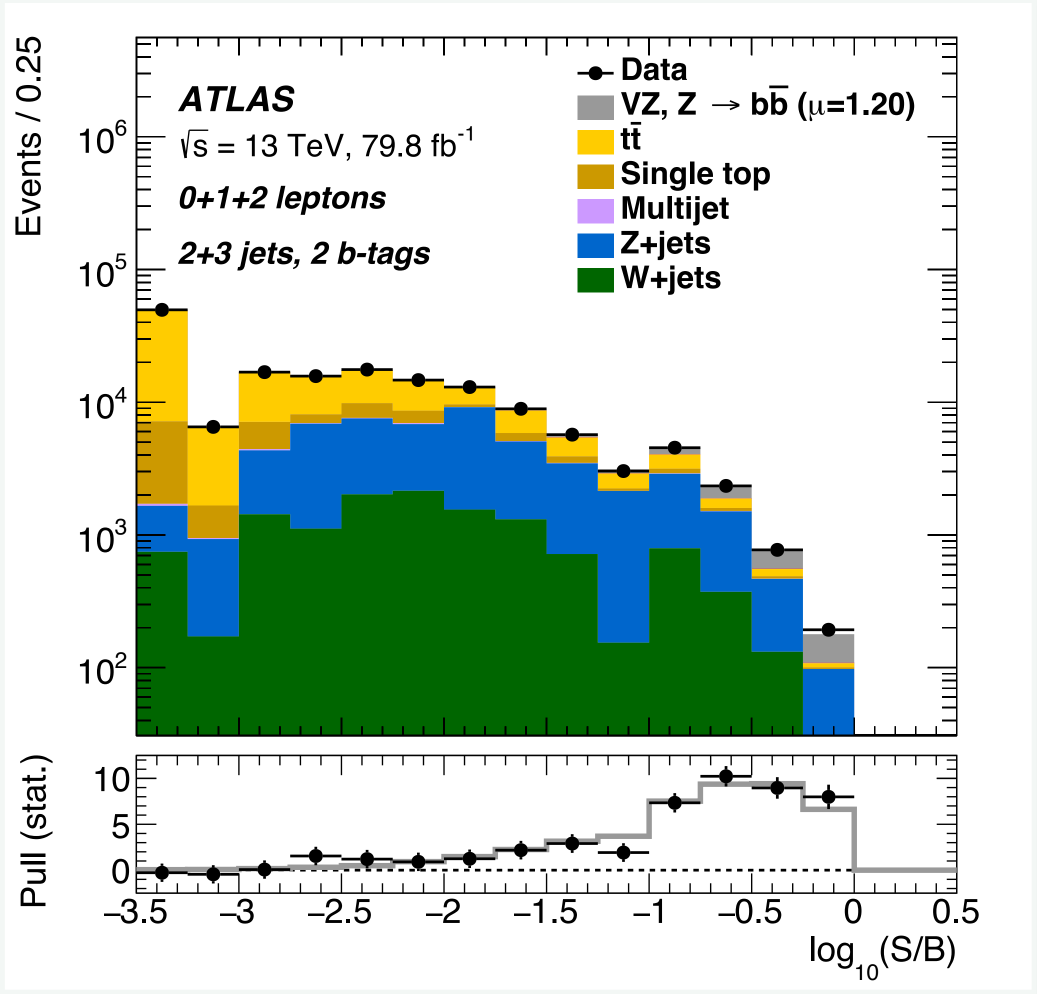
- yields ratio in SR: *ZZ/ZH~2* *WZ/WH~1* *ZZ/ZH~2-3*

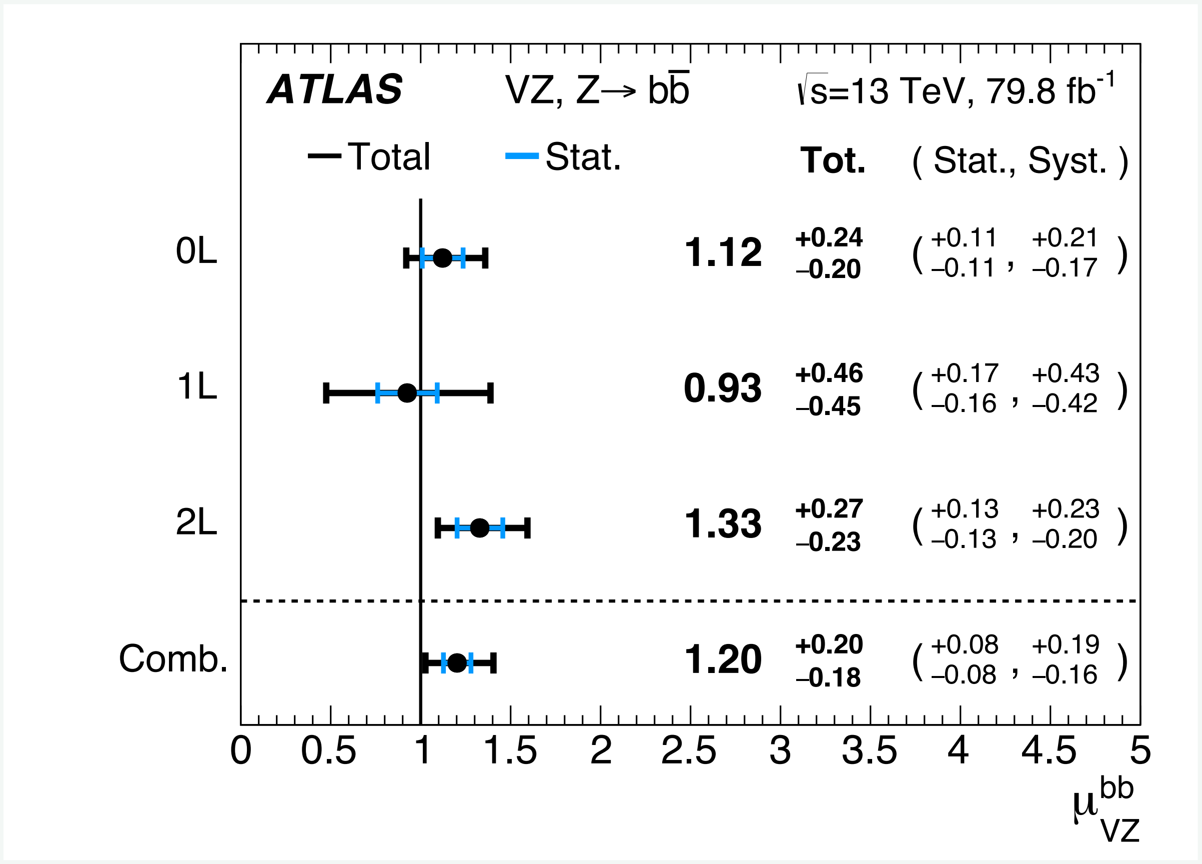
- Same region definition
- Same event selection
- Same analysis model
- BDT is retrained (with the SAME variables) for diboson VS background separation



Intermezzo: 'a cross check analysis'

- All bins in the analysis arranged according to S/B





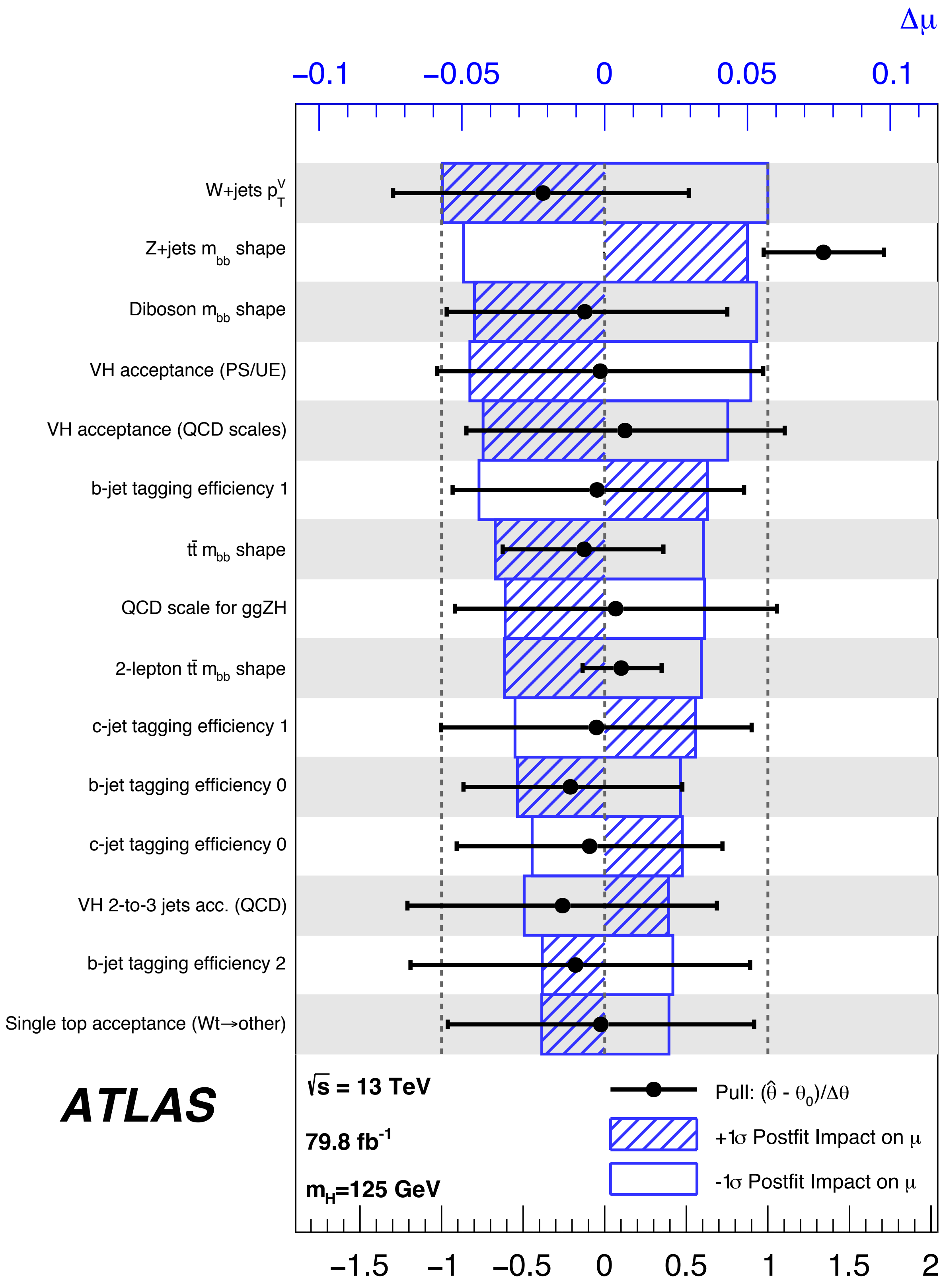
- *Observed significance: >7 σ*

$$\boxed{\mu_{VZ}^{bb} = 1.20^{+0.20}_{-0.18} = 1.20 \pm 0.08(\text{stat.})^{+0.19}_{-0.16}(\text{syst.})}$$

observation of diboson production in VZ->ll'bb final state

- Signal strength compatible with SM prediction:
  - nominal MC is Sherpa 2.2 (NLO prediction)
  - systematic uncertainties dominated by signal acceptance term (Sherpa VS Powheg)

VH H->bb: ranking



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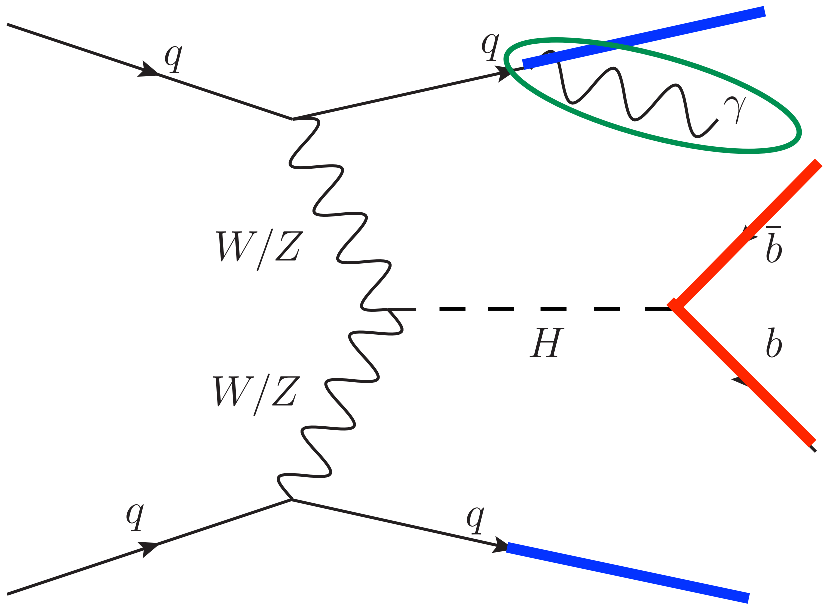
H->bb: VBF

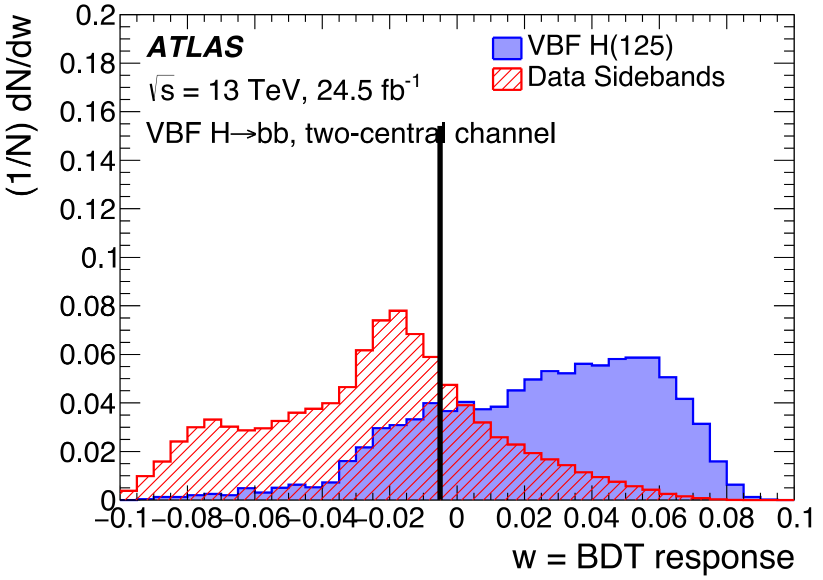


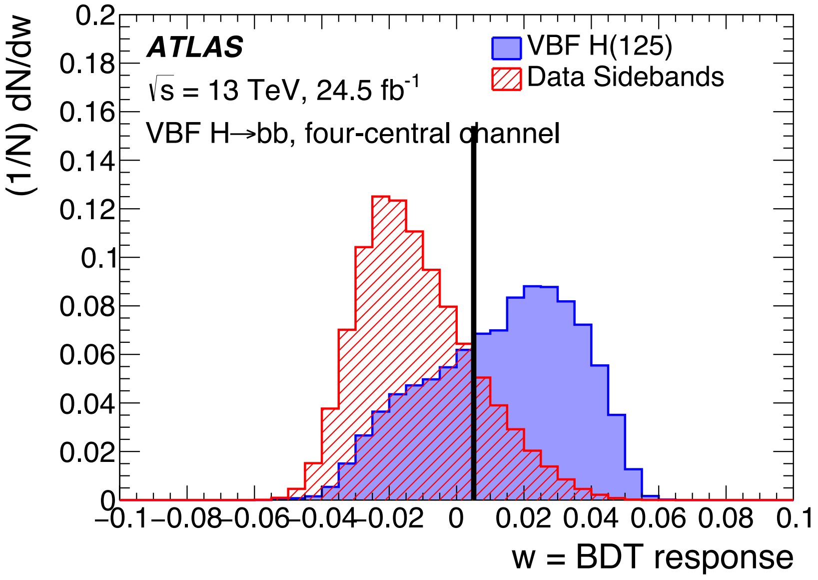
2 b-jets + 2jets (+photon):

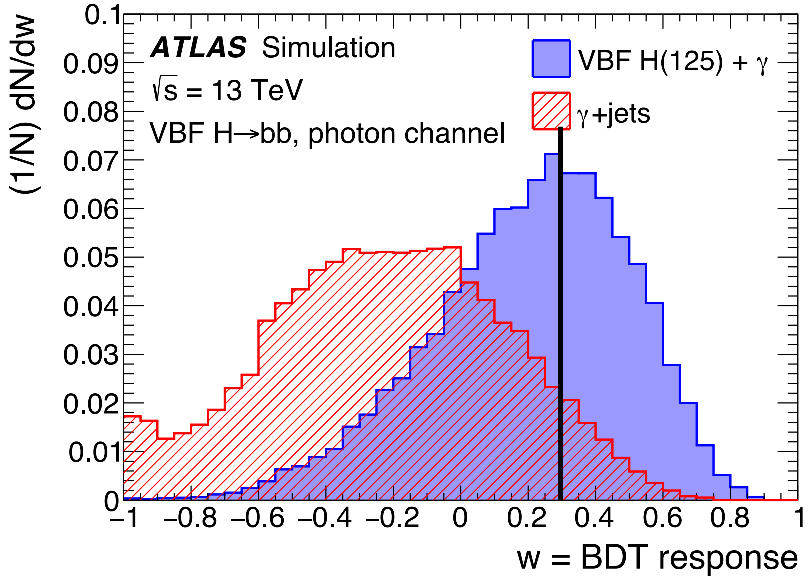
- *the photon reduces bkgd and ease triggering*

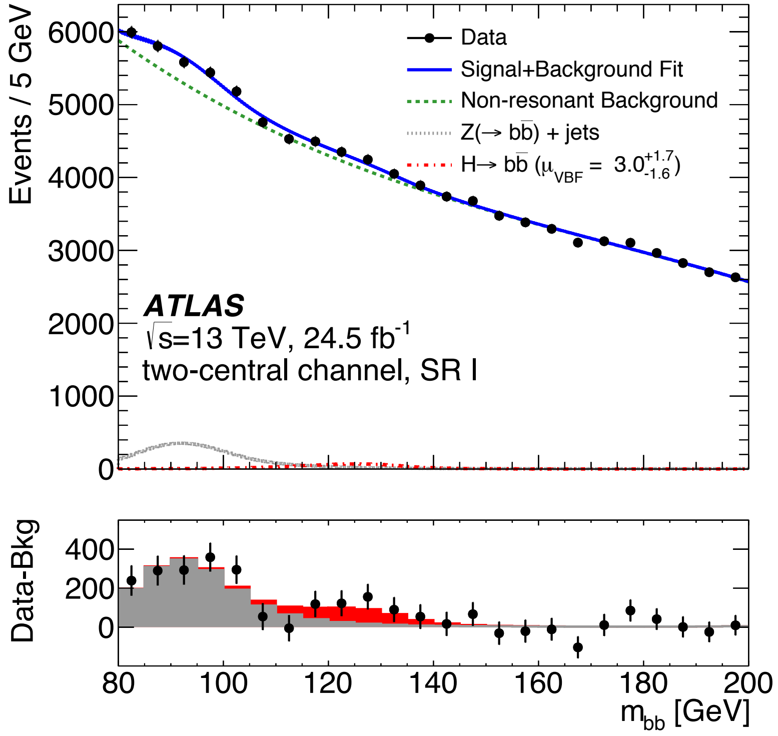
~1.2 s.d. obs

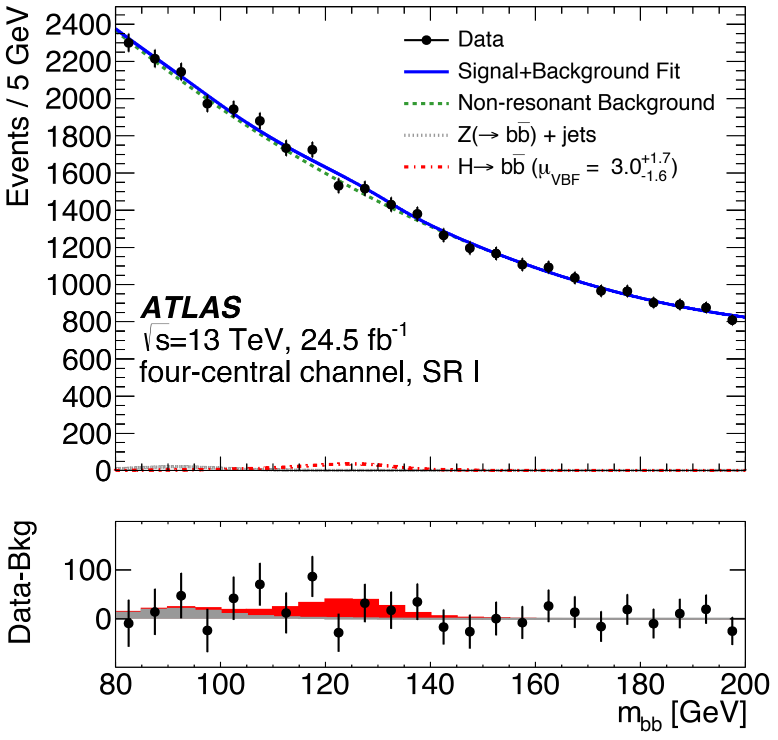
~0.6 s.d. exp

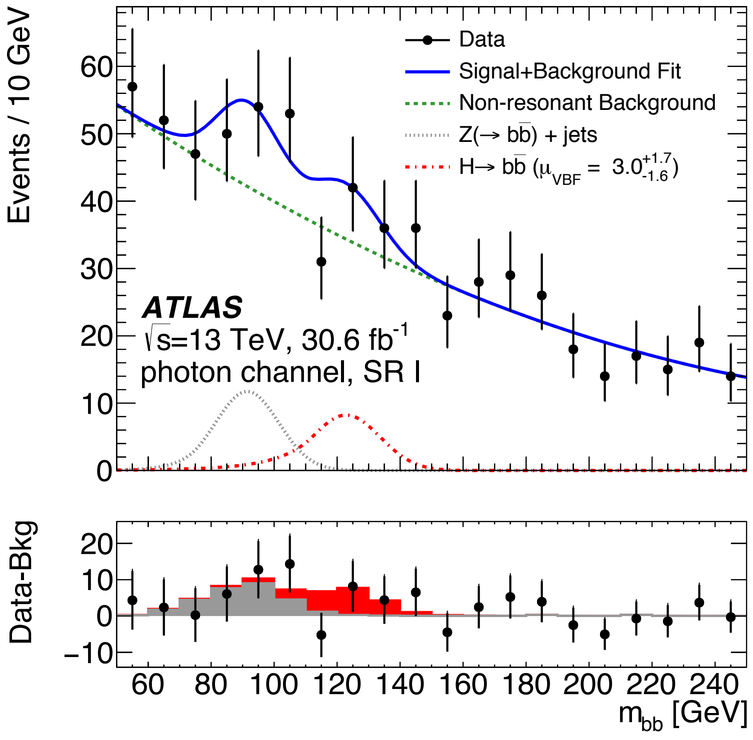




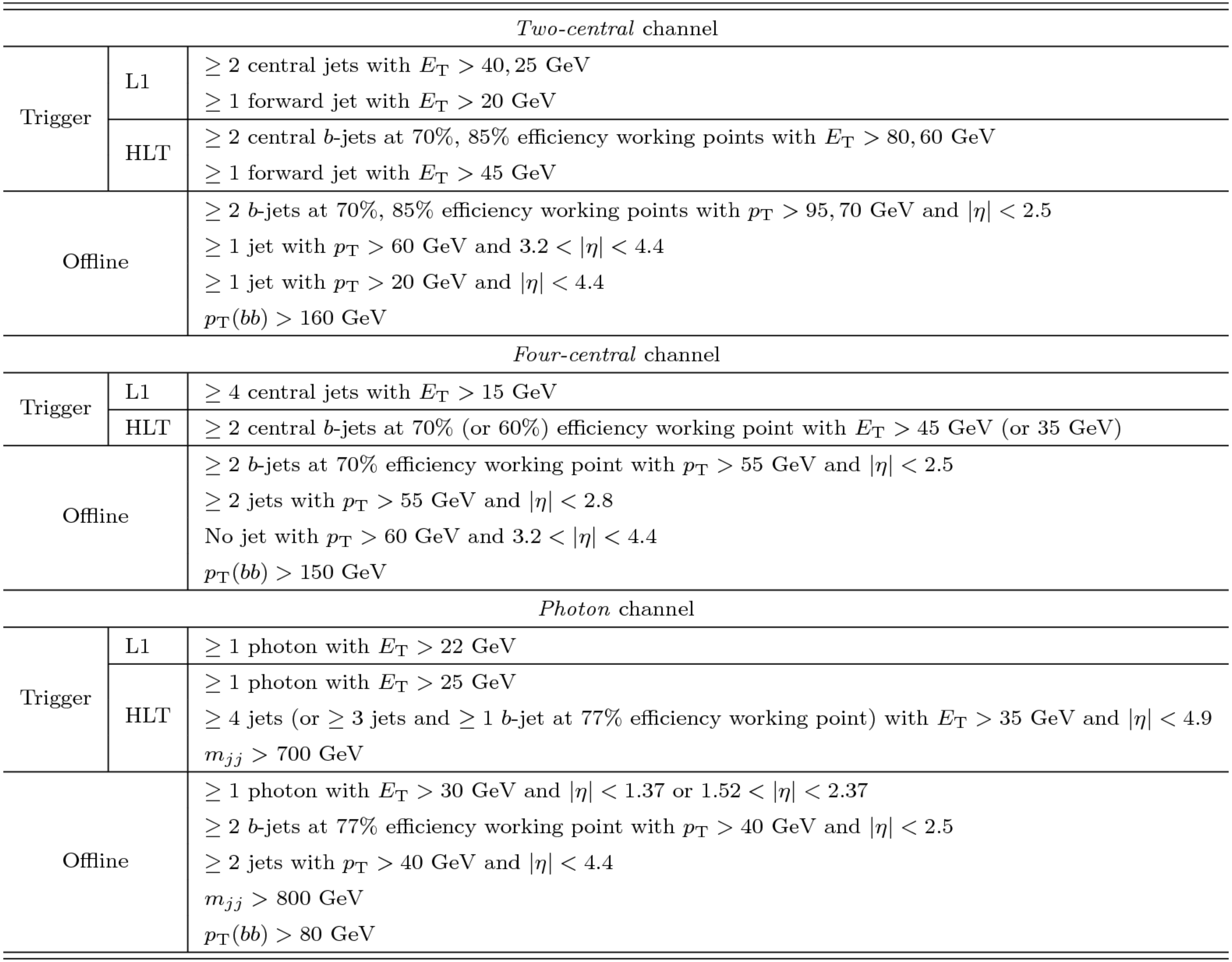






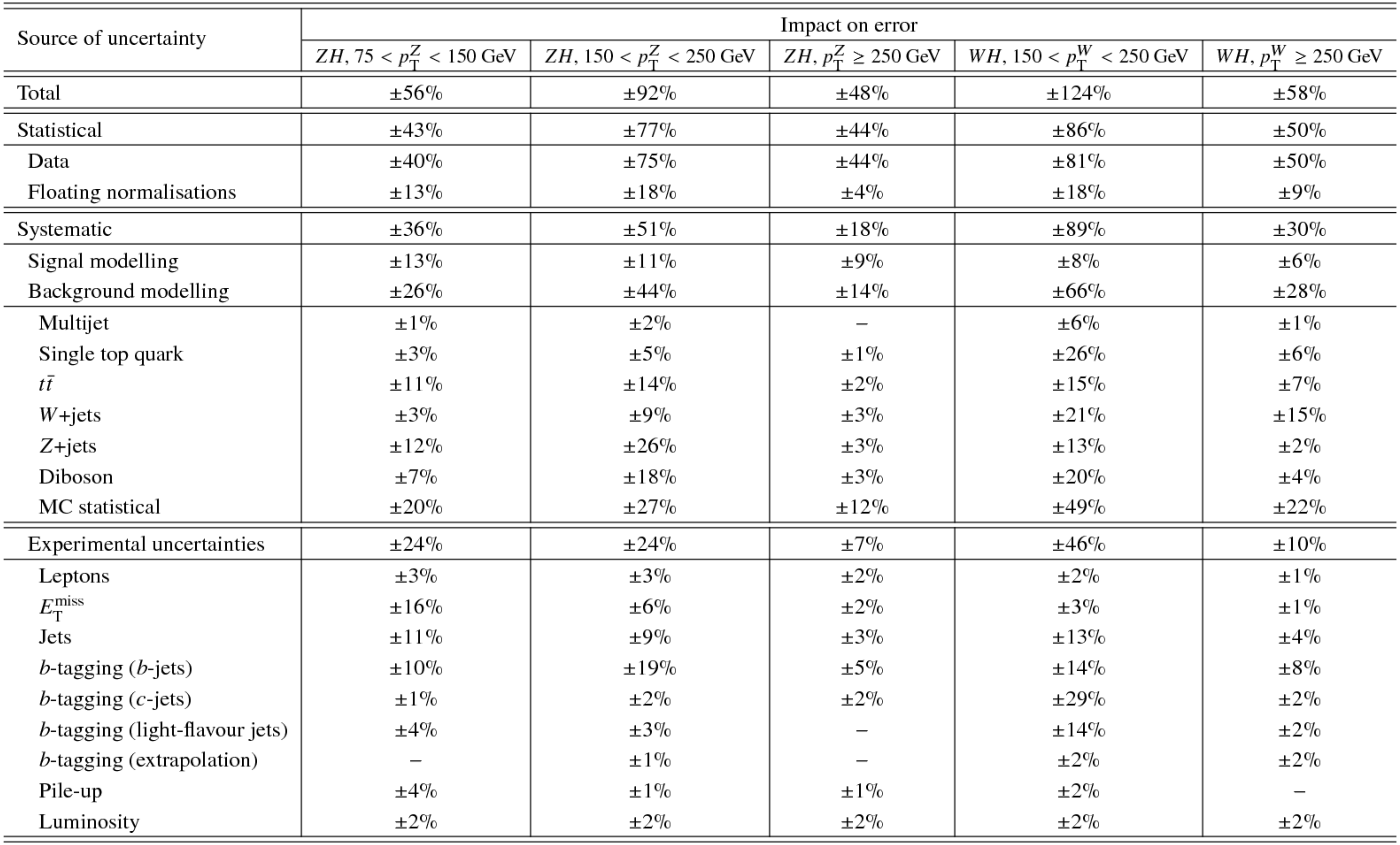


H->bb: VBF triggers



		Two-central channel
Trigger	L1	≥ 2 central jets with $E_{\mathrm{T}} > 40, 25$ GeV ≥ 1 forward jet with $E_{\mathrm{T}} > 20$ GeV
	HLT	≥ 2 central b-jets at 70%, 85% efficiency working points with $E_{\mathrm{T}} > 80, 60$ GeV ≥ 1 forward jet with $E_{\mathrm{T}} > 45$ GeV
Offline		≥ 2 b-jets at 70%, 85% efficiency working points with $p_{\mathrm{T}} > 95, 70$ GeV and $\lvert\eta\rvert < 2.5$ ≥ 1 jet with $p_{\mathrm{T}} > 60$ GeV and $3.2 < \lvert\eta\rvert < 4.4$ ≥ 1 jet with $p_{\mathrm{T}} > 20$ GeV and $\lvert\eta\rvert < 4.4$ $p_{\mathrm{T}}(bb) > 160$ GeV
		Four-central channel
Trigger	L1	≥ 4 central jets with $E_{\mathrm{T}} > 15$ GeV
	HLT	≥ 2 central b-jets at 70% (or 60%) efficiency working point with $E_{\mathrm{T}} > 45$ GeV (or 35 GeV)
Offline		≥ 2 b-jets at 70% efficiency working point with $p_{\mathrm{T}} > 55$ GeV and $\lvert\eta\rvert < 2.5$ ≥ 2 jets with $p_{\mathrm{T}} > 55$ GeV and $\lvert\eta\rvert < 2.8$ No jet with $p_{\mathrm{T}} > 60$ GeV and $3.2 < \lvert\eta\rvert < 4.4$ $p_{\mathrm{T}}(bb) > 150$ GeV
		Photon channel
Trigger	L1	≥ 1 photon with $E_{\mathrm{T}} > 22$ GeV
	HLT	≥ 1 photon with $E_{\mathrm{T}} > 25$ GeV ≥ 4 jets (or ≥ 3 jets and ≥ 1 b-jet at 77% efficiency working point) with $E_{\mathrm{T}} > 35$ GeV and $\lvert\eta\rvert < 4.9$ $m_{jj} > 700$ GeV
Offline		≥ 1 photon with $E_{\mathrm{T}} > 30$ GeV and $\lvert\eta\rvert < 1.37$ or $1.52 < \lvert\eta\rvert < 2.37$ ≥ 2 b-jets at 77% efficiency working point with $p_{\mathrm{T}} > 40$ GeV and $\lvert\eta\rvert < 2.5$ ≥ 2 jets with $p_{\mathrm{T}} > 40$ GeV and $\lvert\eta\rvert < 4.4$ $m_{jj} > 800$ GeV $p_{\mathrm{T}}(bb) > 80$ GeV

VHbb STXS unc



Source of uncertainty	Impact on error				
	ZH, $75 < p_T^Z < 150$ GeV	ZH, $150 < p_T^Z < 250$ GeV	ZH, $p_T^Z \geq 250$ GeV	WH, $150 < p_T^W < 250$ GeV	WH, $p_T^W \geq 250$ GeV
Total	±56%	±92%	±48%	±124%	±58%
Statistical	±43%	±77%	±44%	±86%	±50%
Data	±40%	±75%	±44%	±81%	±50%
Floating normalisations	±13%	±18%	±4%	±18%	±9%
Systematic	±36%	±51%	±18%	±89%	±30%
Signal modelling	±13%	±11%	±9%	±8%	±6%
Background modelling	±26%	±44%	±14%	±66%	±28%
Multijet	±1%	±2%	–	±6%	±1%
Single top quark	±3%	±5%	±1%	±26%	±6%
$t\bar{t}$	±11%	±14%	±2%	±15%	±7%
W+jets	±3%	±9%	±3%	±21%	±15%
Z+jets	±12%	±26%	±3%	±13%	±2%
Diboson	±7%	±18%	±3%	±20%	±4%
MC statistical	±20%	±27%	±12%	±49%	±22%
Experimental uncertainties	±24%	±24%	±7%	±46%	±10%
Leptons	±3%	±3%	±2%	±2%	±1%
E_T^{miss}	±16%	±6%	±2%	±3%	±1%
Jets	±11%	±9%	±3%	±13%	±4%
b-tagging (b-jets)	±10%	±19%	±5%	±14%	±8%
b-tagging (c-jets)	±1%	±2%	±2%	±29%	±2%
b-tagging (light-flavour jets)	±4%	±3%	–	±14%	±2%
b-tagging (extrapolation)	–	±1%	–	±2%	±2%
Pile-up	±4%	±1%	±1%	±2%	–
Luminosity	±2%	±2%	±2%	±2%	±2%

The push for high p_T: theory

"***Sensitivity*** might not require extreme ***Precision***"

M. Mangano's talk

size of deviation

$$\delta O_Q \sim \left(\frac{Q}{\Lambda}\right)^2$$

scale of your analysis

NP scale

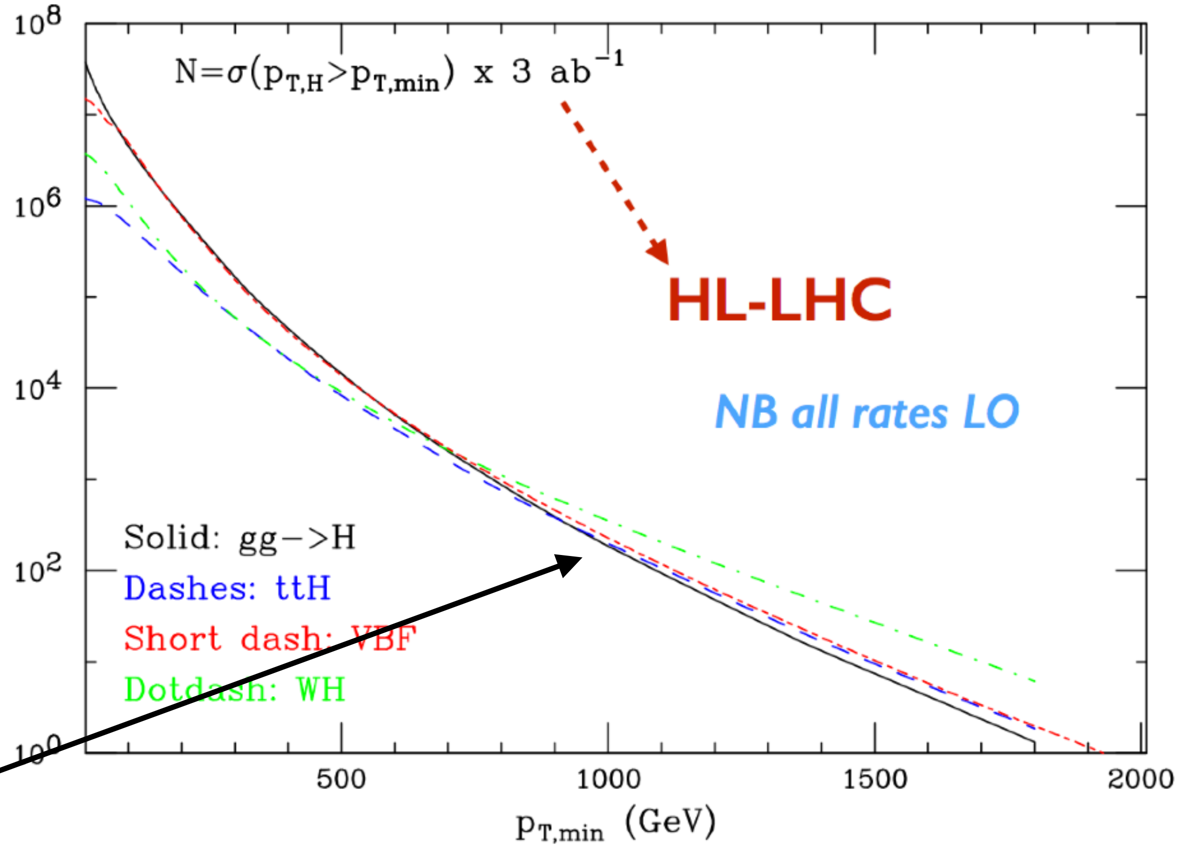
- Probing higher scale in the analysis makes you mode ***sensitive*** to NP therefore you can afford to be less **precise**

- One example:
  - *3% uncertainty for p_T>150GeV : probes scales up to 890 GeV*
  - *10% uncertainty for p_T>600GeV : probes scales up to 1800 TeV*
  - *an analysis 3 times less precise has twice the sensitivity*

- High pT VH analysis could become competitive with inclusive H->WW measurement

- ***As Higgs p_T increases, VH becomes more and more competitive with ggF as dominate Higgs production mode***

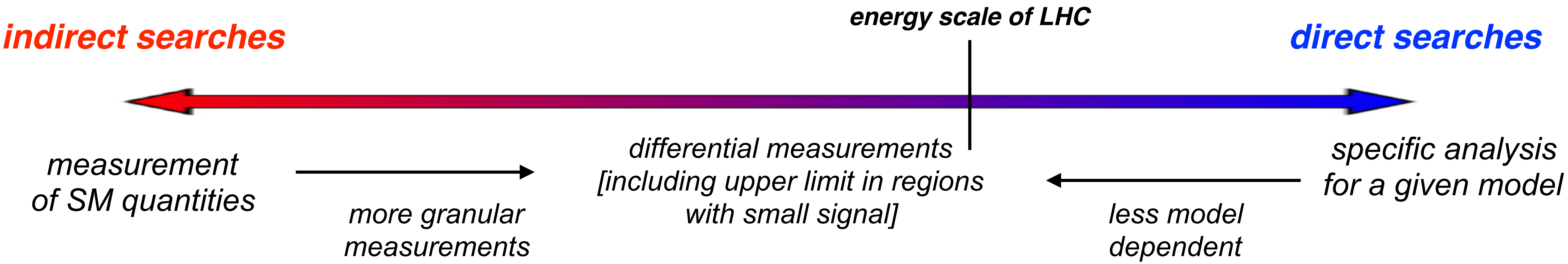
Higgs production at large p_T



H_{bb} as a tool for BSM searches

- ***Direct searches**:*
  - *new physics signature include SM Higgs boson or SM Higgs-boson-like particles in final states:*
  - *consider simplified models as a prototype for a large variety of models: heavy vector triplets, vector-like quarks, Higgs+invisible, SUSY EWK decay chains, di-Higgs resonances*
- ***Indirect searches**:*
  - *modified interaction of Higgs boson can be revealed through deviations of production/decays with respect to SM*
  - *often interpreted in the context of effective field theory (EFT)*

$$\boxed{\mathcal{L} = \mathcal{L}_{\mathrm{SM}} + \sum_i c_i^{(6)} \mathcal{O}_i^{(6)}/\Lambda^2}$$



indirect searches

energy scale of LHC

direct searches

measurement of SM quantities

more granular measurements

differential measurements [including upper limit in regions with small signal]

less model dependent

specific analysis for a given model

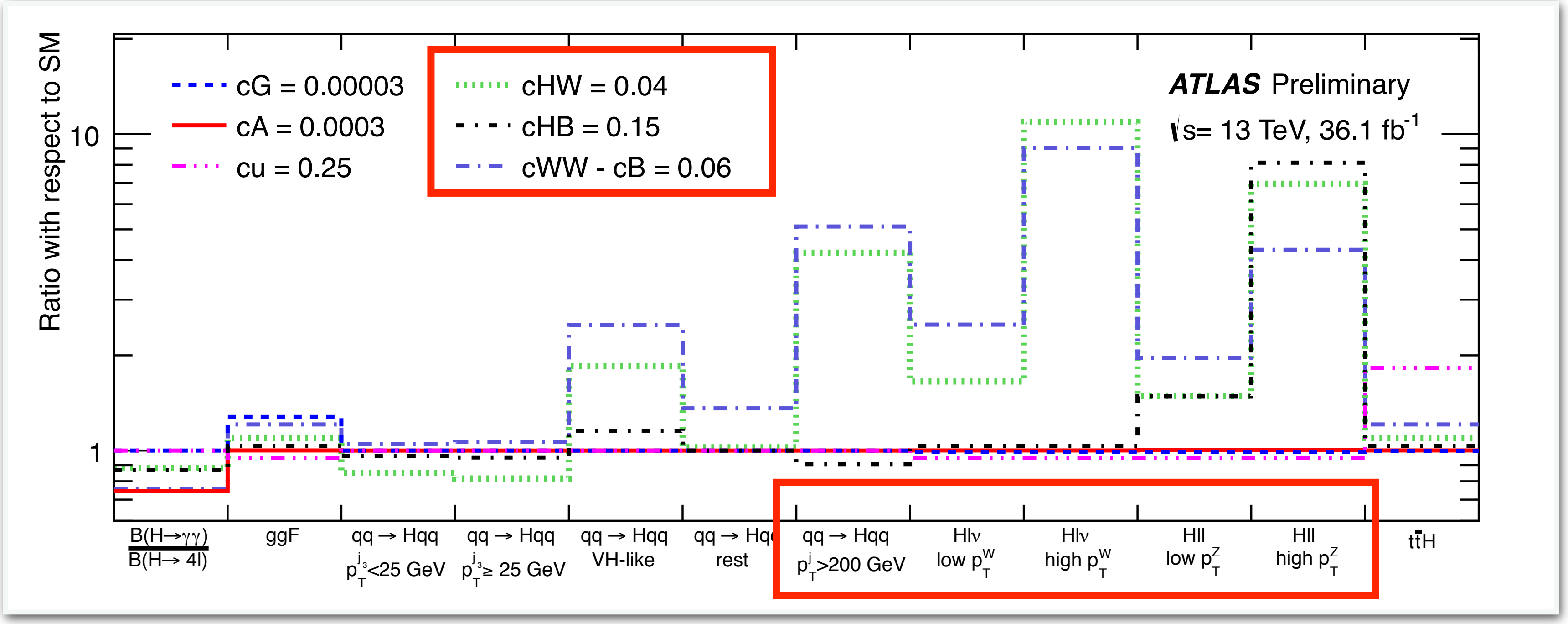
Going more differential: EFT

- VH production very sensitive to anomalous Higgs-Vector boson interactions

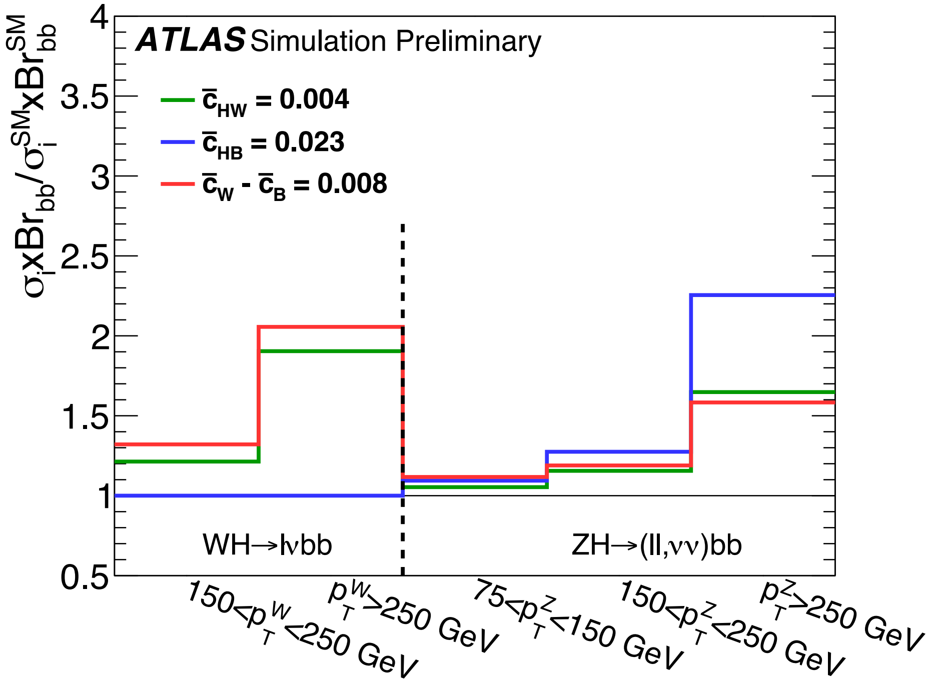
- ***"Sensitivity" VS "Precision" balance***:
    - *effects are small on quantities we can measure very precisely*
    - *effects are much larger in tails where the precision of the measurements in less high*

7 / 59 dim 6 operators

Operator	Expression	HEL coefficient	Vertices
O_g	$\lvert H\rvert^2 G^A_{\mu\nu} G^{A\mu\nu}$	$\mathtt{cG} = \frac{m_W^2}{g_s^2}\bar{c}_g$	Hgg
O_γ	$\lvert H\rvert^2 B_{\mu\nu} B^{\mu\nu}$	$\mathtt{cA} = \frac{m_W^2}{g'^2}\bar{c}_\gamma$	$H\gamma\gamma, HZZ$
O_u	$y_u \lvert H\rvert^2 \bar{u}_l H u_R + \text{h.c.}$	$\mathtt{cu} = v^2 \bar{c}_u$	$Ht\bar{t}$
O_{HW}	$i\,(D^\mu H)^\dagger\,\sigma^a\,(D^\nu H)\,W^a_{\mu\nu}$	$\mathtt{cHW} = \frac{m_W^2}{g}\bar{c}_{HW}$	HWW, HZZ
O_{HB}	$i\,(D^\mu H)^\dagger\,(D^\nu H)\,B_{\mu\nu}$	$\mathtt{cHB} = \frac{m_W^2}{g'}\bar{c}_{HB}$	HZZ
O_W	$i\,(H^\dagger \sigma^a D^\mu H)\,D^\nu W^a_{\mu\nu}$	$\mathtt{cWW} = \frac{m_W^2}{g}\bar{c}_W$	HWW, HZZ
O_B	$i\,(H^\dagger D^\mu H)\,\partial^\nu B_{\mu\nu}$	$\mathtt{cB} = \frac{m_W^2}{g'}\bar{c}_B$	HZZ



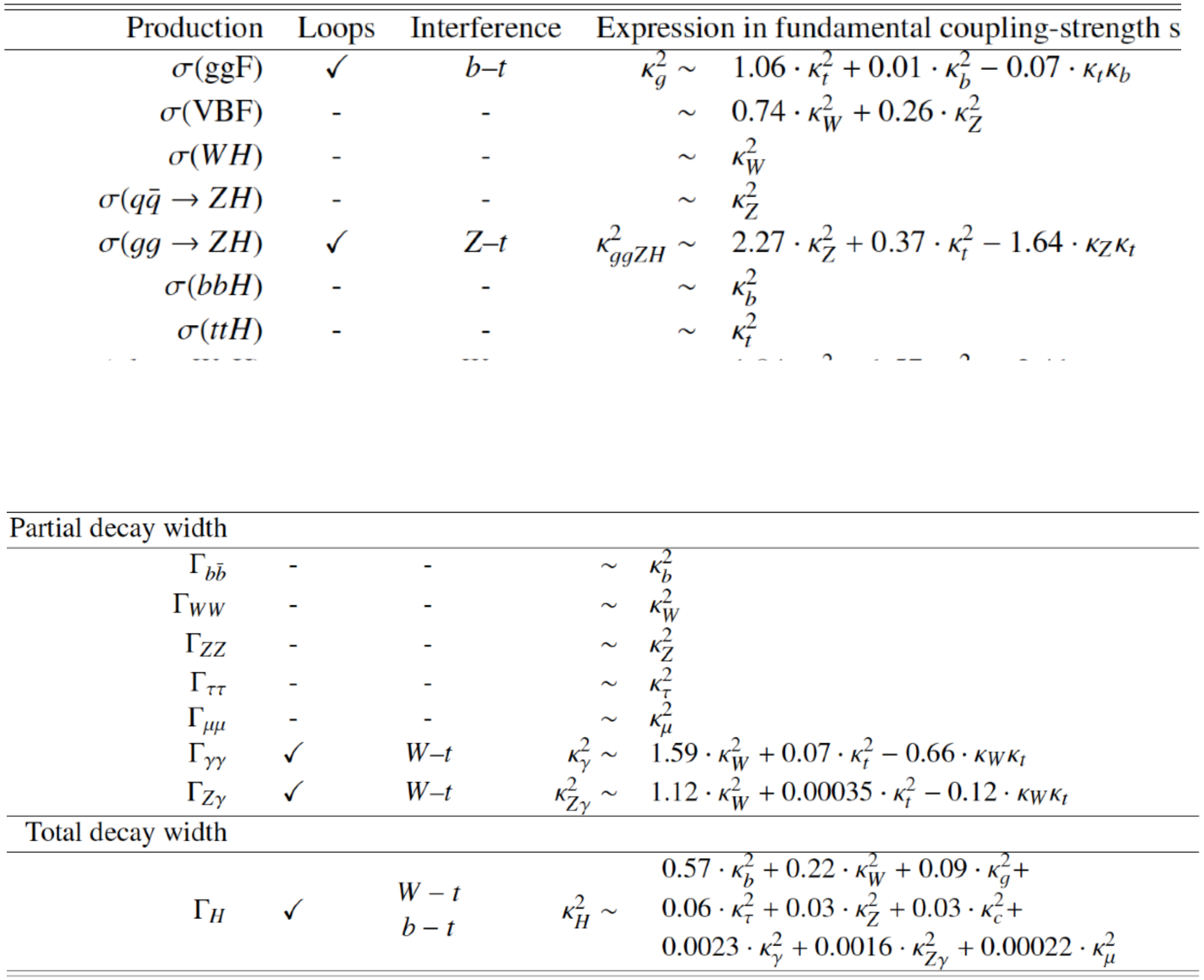
$p_T{}^W > 150$ $p_T{}^Z > 150$



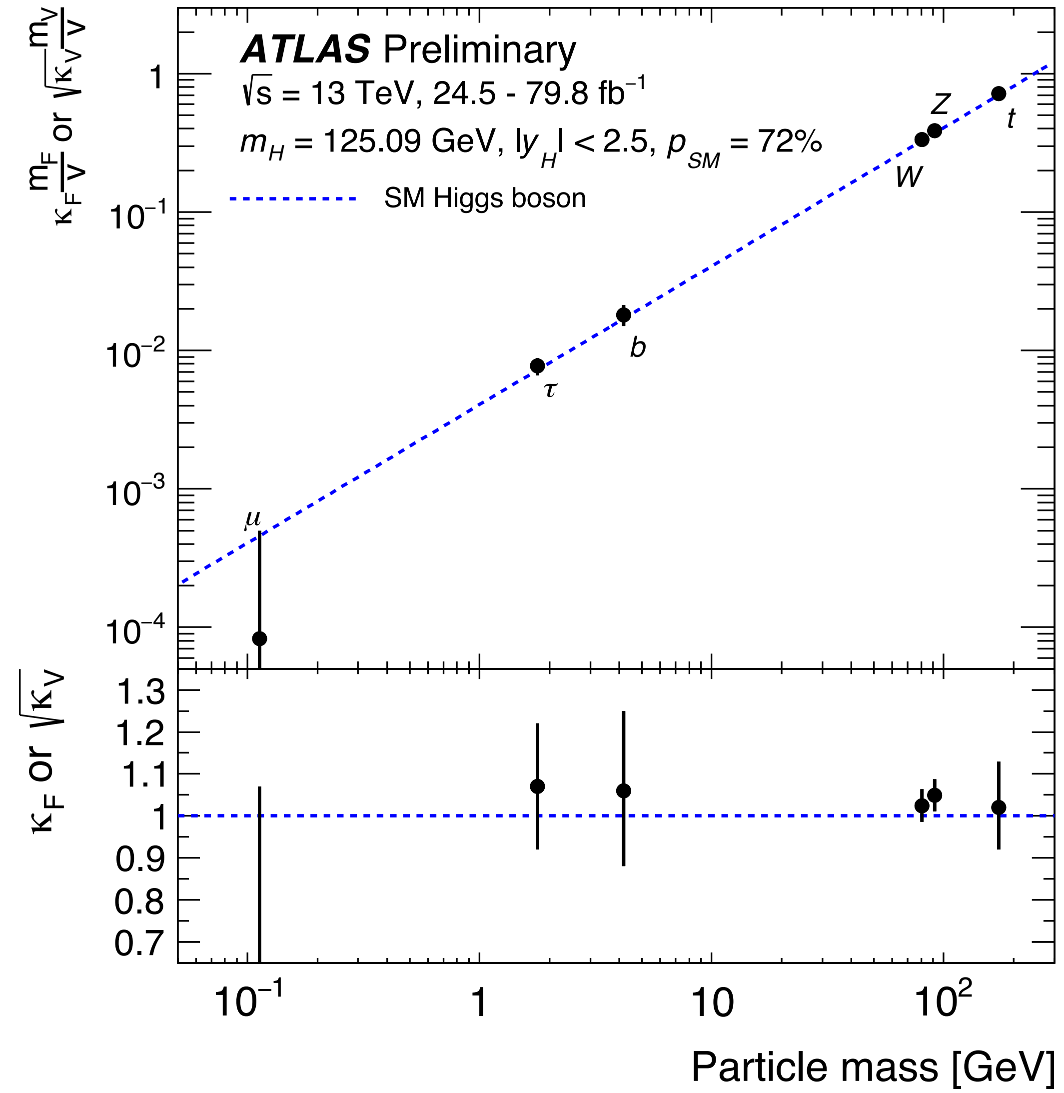
putting it all together (*)

ATLAS-CONF-2018-031

- Good complementarity and consistence among the various analyses
- ***Leading production and decay mode established at more than 5 sigma***: no major deviation from SM.



Production	Loops	Interference	Expression in fundamental coupling-strength s
$\sigma(ggF)$	✓	b–t	$\kappa_g^2 \sim 1.06 \cdot \kappa_t^2 + 0.01 \cdot \kappa_b^2 - 0.07 \cdot \kappa_t \kappa_b$
$\sigma(VBF)$	-	-	$\sim 0.74 \cdot \kappa_W^2 + 0.26 \cdot \kappa_Z^2$
$\sigma(WH)$	-	-	$\sim \kappa_W^2$
$\sigma(q\bar{q} \to ZH)$	-	-	$\sim \kappa_Z^2$
$\sigma(gg \to ZH)$	✓	Z–t	$\kappa_{ggZH}^2 \sim 2.27 \cdot \kappa_Z^2 + 0.37 \cdot \kappa_t^2 - 1.64 \cdot \kappa_Z \kappa_t$
$\sigma(bbH)$	-	-	$\sim \kappa_b^2$
$\sigma(ttH)$	-	-	$\sim \kappa_t^2$
Partial decay width			
$\Gamma_{b\bar{b}}$	-	-	$\sim \kappa_b^2$
Γ_{WW}	-	-	$\sim \kappa_W^2$
Γ_{ZZ}	-	-	$\sim \kappa_Z^2$
$\Gamma_{\tau\tau}$	-	-	$\sim \kappa_\tau^2$
$\Gamma_{\mu\mu}$	-	-	$\sim \kappa_\mu^2$
$\Gamma_{\gamma\gamma}$	✓	W–t	$\kappa_\gamma^2 \sim 1.59 \cdot \kappa_W^2 + 0.07 \cdot \kappa_t^2 - 0.66 \cdot \kappa_W \kappa_t$
$\Gamma_{Z\gamma}$	✓	W–t	$\kappa_{Z\gamma}^2 \sim 1.12 \cdot \kappa_W^2 + 0.00035 \cdot \kappa_t^2 - 0.12 \cdot \kappa_W \kappa_t$
Total decay width			
Γ_H	✓	$W-t$ $b-t$	$\kappa_H^2 \sim 0.57 \cdot \kappa_b^2 + 0.22 \cdot \kappa_W^2 + 0.09 \cdot \kappa_g^2 +$ $0.06 \cdot \kappa_\tau^2 + 0.03 \cdot \kappa_Z^2 + 0.03 \cdot \kappa_c^2 +$ $0.0023 \cdot \kappa_\gamma^2 + 0.0016 \cdot \kappa_{Z\gamma}^2 + 0.00022 \cdot \kappa_\mu^2$



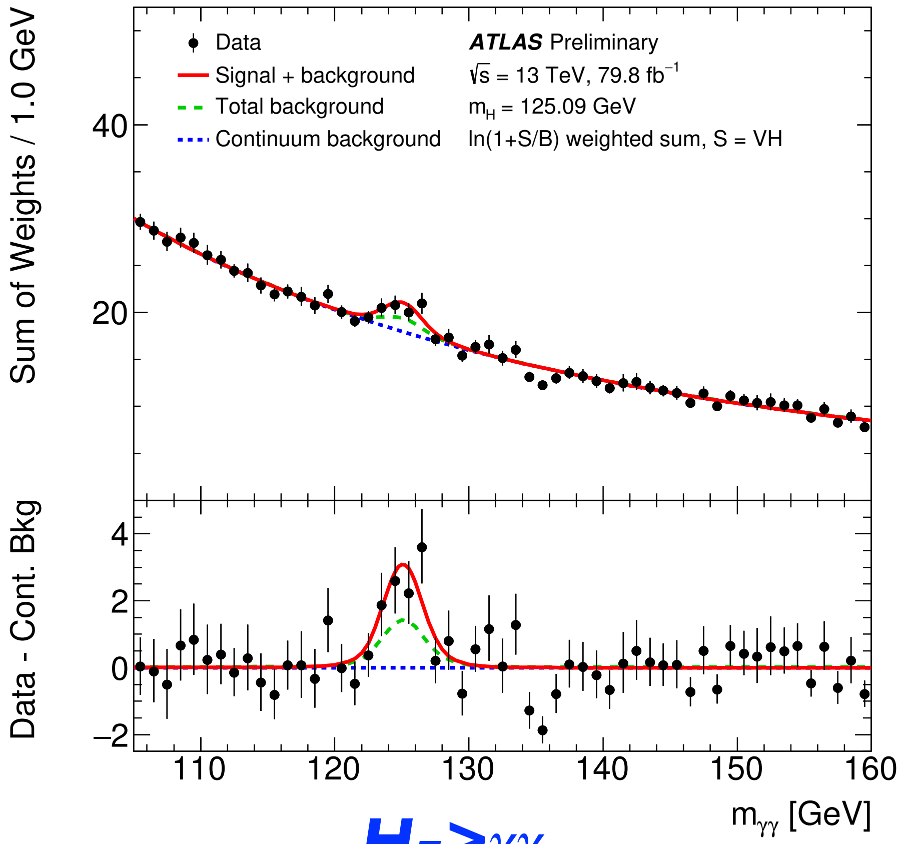
- reaching very high precision in determination of coupling to SM particles

(*) not including the latest Hbb results

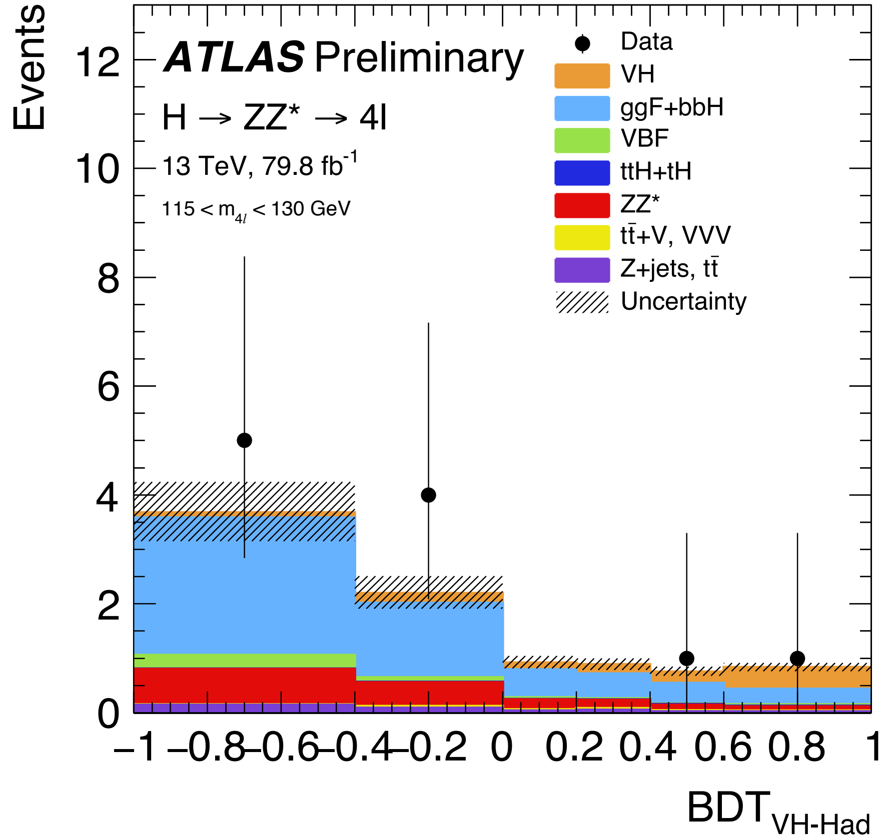
ATLAS-CONF-2018-018

VH: ! bb

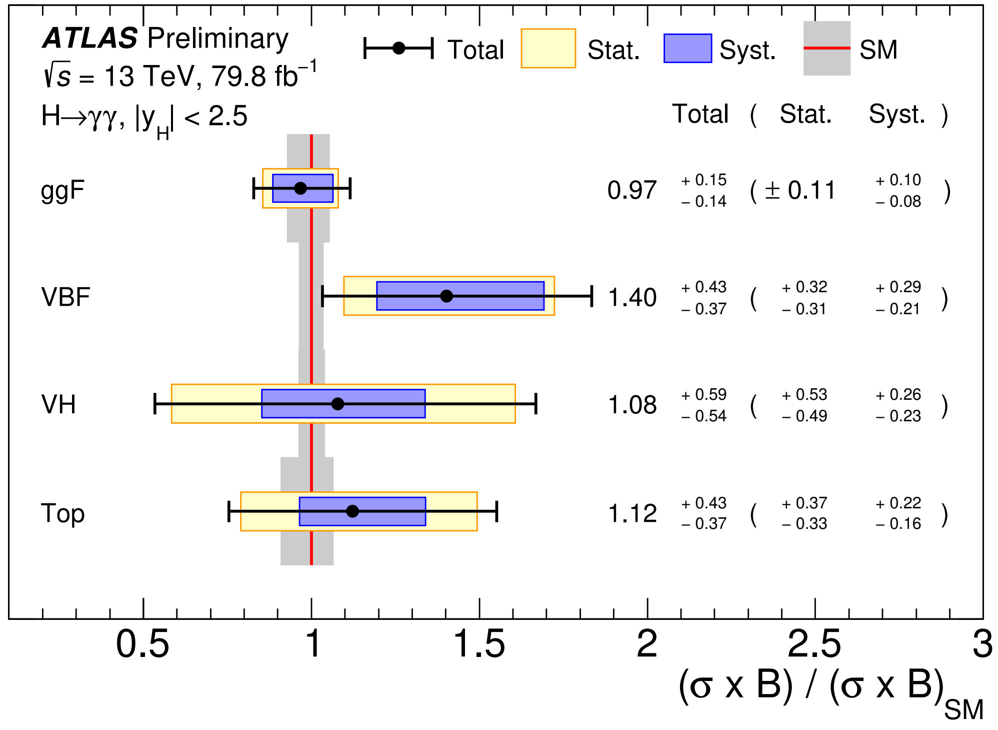
ATLAS-CONF-2018-028

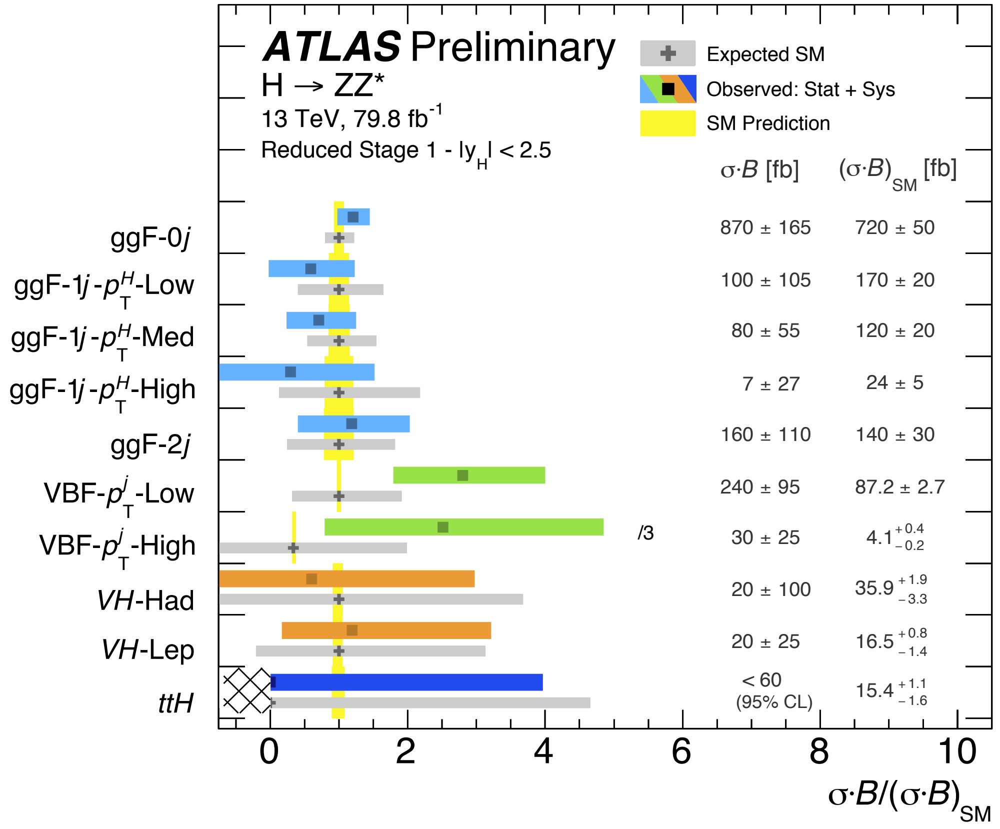


H->$\gamma\gamma$



H->ZZ*->4l





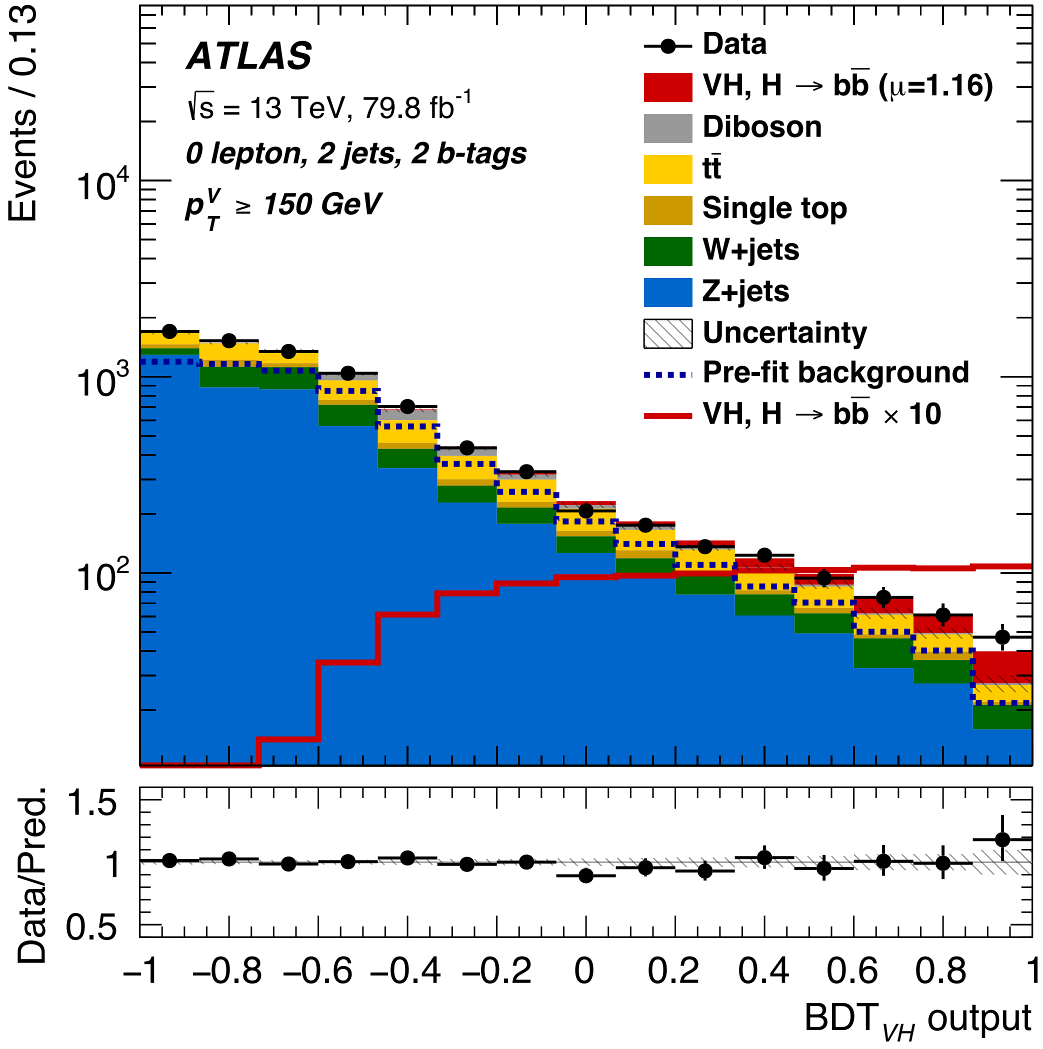
MVA rebinning

- merging bins from the left until Z>1

$$Z = z_s n_s / N_s + z_b n_b / N_b .$$

- adopting $z_b = z_s = 10$

- highest BDT bins roughly contains 10% of signal each



W+jets modelling uncertainties

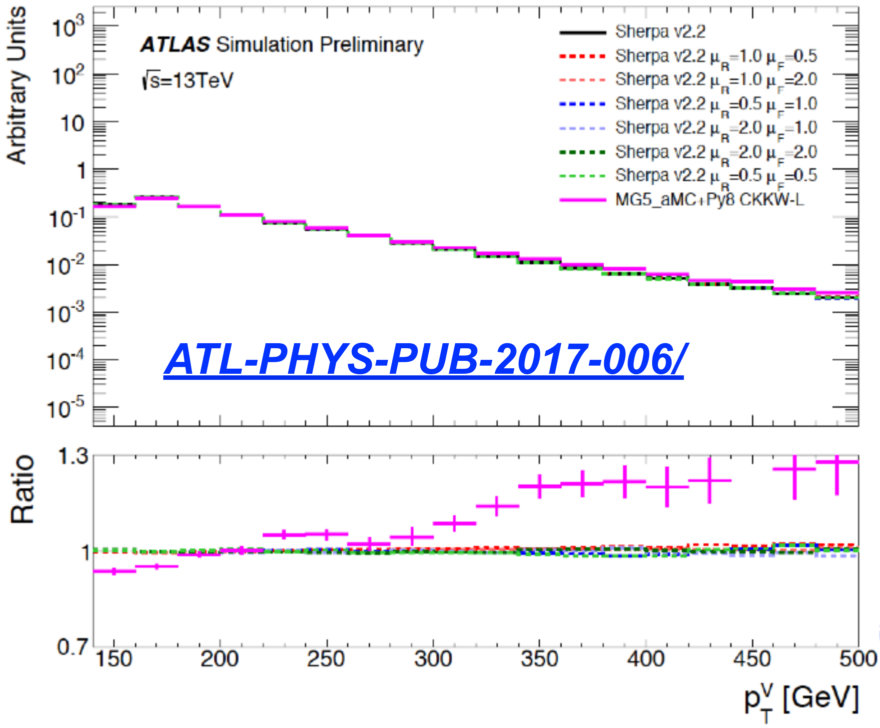
- Nominal sample: ***Sherpa 2.2.1 5F MEPS@NLO*** (0,1,2 parton @NLO, 3,4 @LO)
- Uncertainties variations:
  - fact/ren scale and PDF variations in Sherpa 2.2.1 sample —> subleading effect on shape
  - ckkw and matching scale variation in Sherpa 2.1 sample —> small effect but statistically limited
  - comparison with MadGraph+Pythia8 5F MEPS@LO (up to 4 partons)

	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)

- *analysis dominated by W+bb contribution* (uncertainties on flavour composition are subdominant)
- *floating normalisation of W+HF separately in 2 and 3jets*

W + HF 2-jet	1.19 ± 0.12
W + HF 3-jet	1.05 ± 0.12

- Shape uncertainties are dominated by comparison between Sherpa and MadGraph. Leading contribution to analysis sensitivity comes from differences in W p_T spectrum between Sherpa and MadGraph (large impact on signal-like tail of the BDT)



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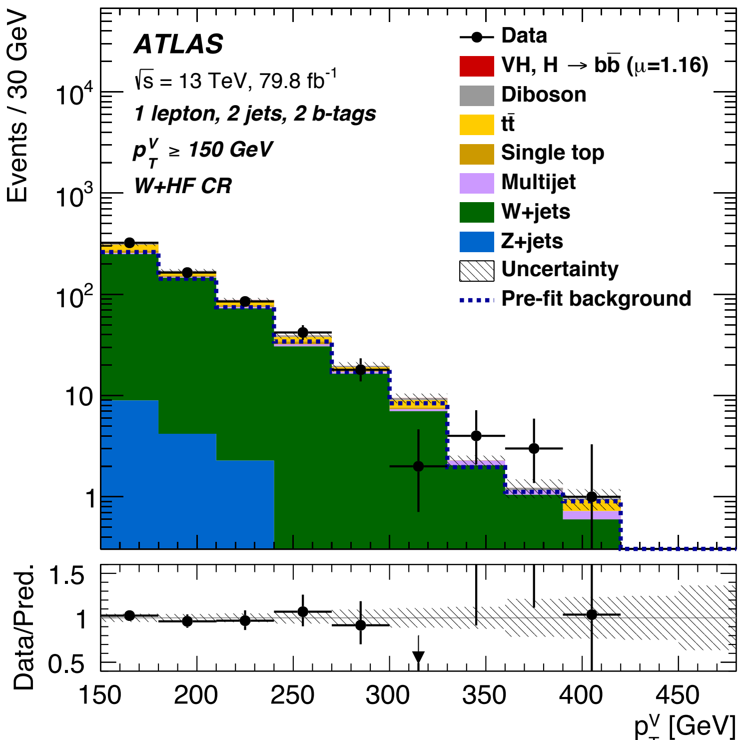
- with more data, the difference could be reduced in the dedicated WCR (not used in current iteration of the analysis)
- … but is such a difference expected??



Z+jets modelling uncertainties

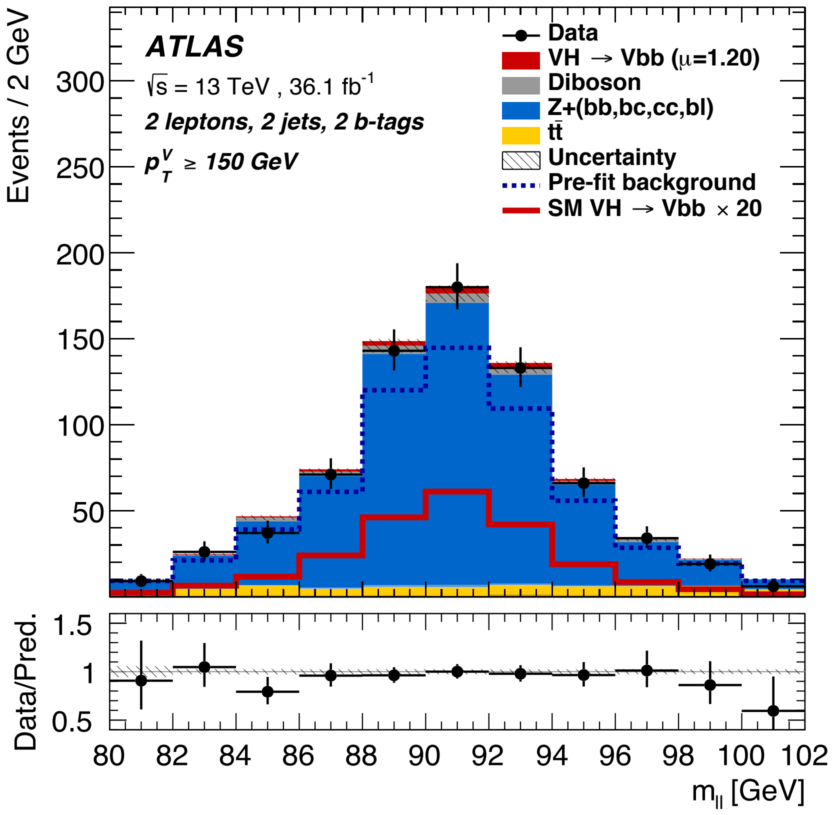
- Exactly same prescriptions as for W+jets in terms of available MC and variations

	$Z + \text{jets}$
$Z + ll$ 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

- *analysis dominated by Z+bb contribution* (uncertainties on flavour composition are subdominant)
- *floating normalisation of W+HF separately in 2 and 3jets*: Sherpa NLO 5F MC consistently underestimates the data as for the W+HF case

$Z + \mathrm{HF}$ 2-jet	1.37 ± 0.11
$Z + \mathrm{HF}$ 3-jet	1.09 ± 0.09

- 2-lepton SR quite pure in Z+HF thanks to the mll window around the Z peak
- (contrary to W+HF) Z+HF Shape uncertainties extracted in subset of SR:
  - m_{bb} [100-150] veto to remove signal contribution
  - $E_T^{miss}/\mathrm{sqrt}(H_T)<3.5$ to further minimise ttbar contamination
  - data-MC difference taken as the variation for the shape uncertainties: reduced effect w.r.t. MC-MC comparison
- normalisation mainly driven by 2-lepton channel:
  - extrapolation uncertainties to 0-lepton channel computed from MC inputs only using the in the V p_T>150GeV bin



ttbar modelling uncertainties

- 2 different phase space for ttbar in the analysis:
  - ***0+1 lepton***: 4-jet veto selects mainly events with missing ttbar decay products (very different from final state of usual ttbar measurements)
  - ***2 lepton***: more natural ttbar decay topology: 2lep + 2b-jets (+ jets)

every uncertainty is considered decorrelated between 0+1 lepton and 2-lepton regions

- Nominal sample: ***Powheg (V2)+Pythia8*** (hdamp=1.5*mtop)

- Alternative samples:
  - Parton Shower: Powheg+Herwig7, MatrixElement: aMC@NLO+Pythia8
  - radiation settings (hdamp, μ_R, μ_F, shower tune)

$t\bar{t}$ (all are uncorrelated between the 0+1 and 2-lepton channels)	
$t\bar{t}$ normalisation	Floating (0+1 lepton, 2-lepton 2-jet, 2-lepton 3-jet)
0-to-1 lepton ratio	8%
2-to-3-jet ratio	9% (0+1 lepton only)
W + HF CR to SR ratio	25%
m_{bb}, p_T^V	S

- *Normalisation factors consistent with unity*

$t\bar{t}$ 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

- Extrapolation and shape uncertainties effects *dominated by the differences between Powheg and aMC@NLO*:
  - 2-lepton channel manages to reduce the impact of the uncertainties thanks to the dedicated control region
  - in 0-1 lepton channel: main SR has the largest top contribution

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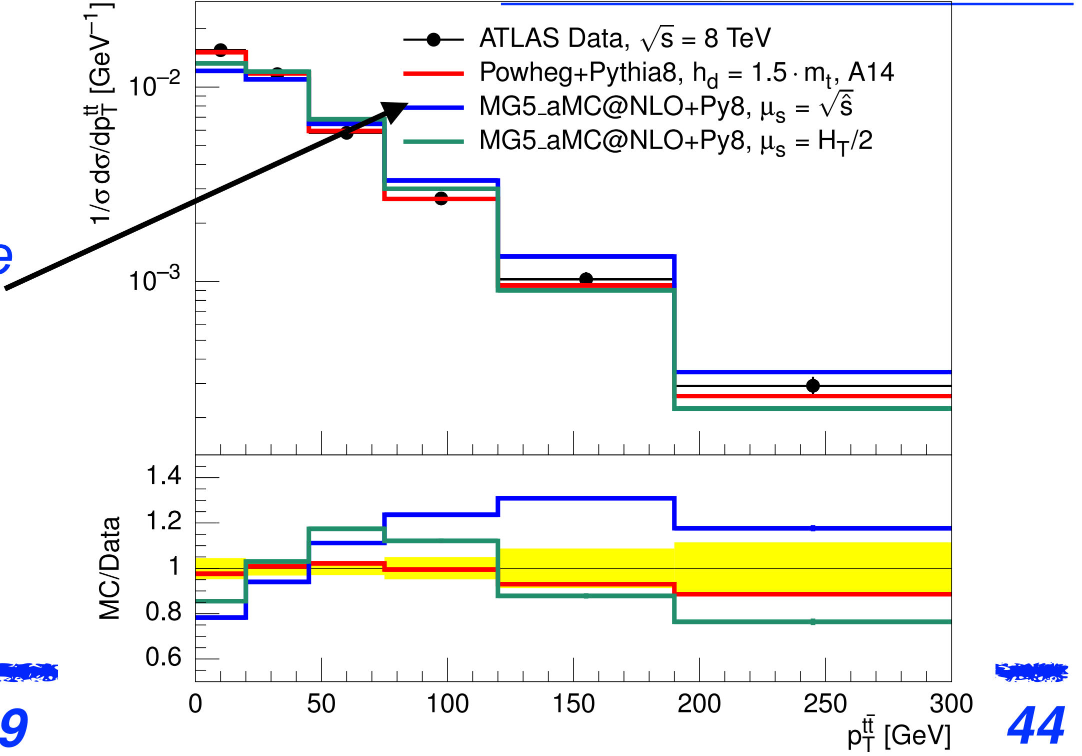
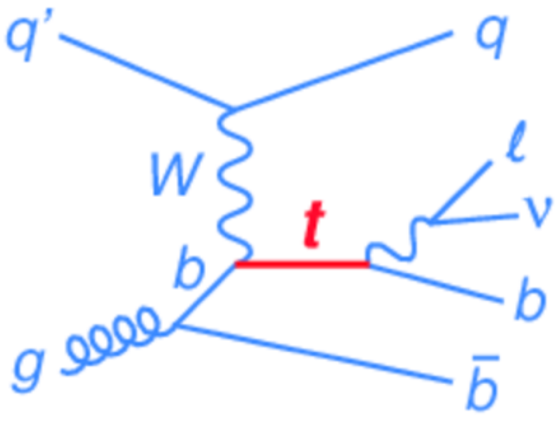
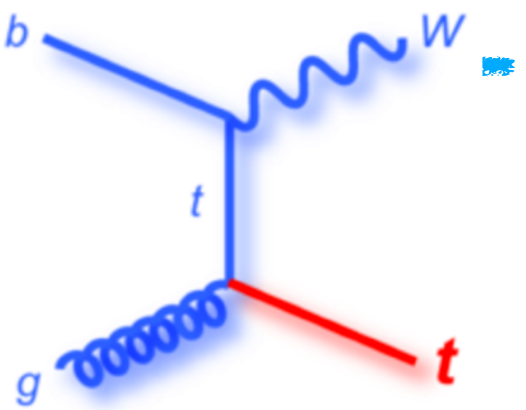


single top modelling





- Solely relevant in the 1-lepton channel:
  - 50/50 contribution between t-channel and Wt
  - Wt more important since it has more signal-like features

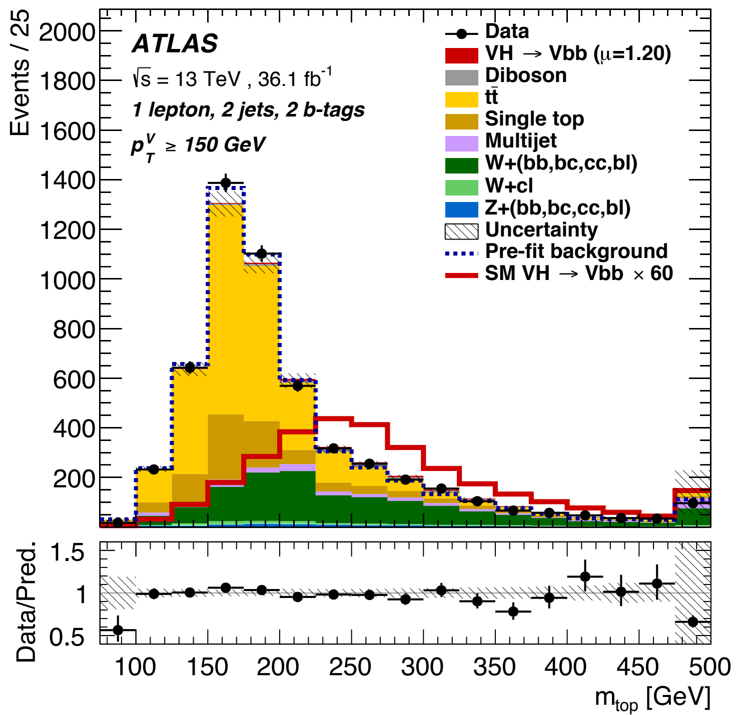
- Nominal sample: ***Pohweg+Pythia8*** (diagram removal procedure for Wt)

- Alternative samples:
  - Powheg+Herwig++
  - radiation settings: (hdamp+PS tune)
  - aMC@NLO+Herwig++
  - diagram subtraction procedure for Wt

	Single top-quark
Cross-section	4.6% (s-channel), 4.4% (t-channel), 6.2% (Wt)
Acceptance 2-jet	17% (t-channel), 55% ($Wt(bb)$), 24% (Wt(other))
Acceptance 3-jet	20% (t-channel), 51% ($Wt(bb)$), 21% (Wt(other))
m_{bb}, p_{T}^{V}	S (t-channel, $Wt(bb)$, Wt(other))

- Wt uncertainties split according to flavour composition of selected jets:
  - bb component has larger uncertainties (involves b not from top) but less signal like
  - bc component originates from the top decay (smaller unc). but more signal like

- Wt uncertainties completely driven by comparison of DR-DS schema:
  - strong shape difference in many kinematic quantities (mbb, V pT)
  - further sensitive variable: m_{top} (proxy from) used both in MVA and region definition



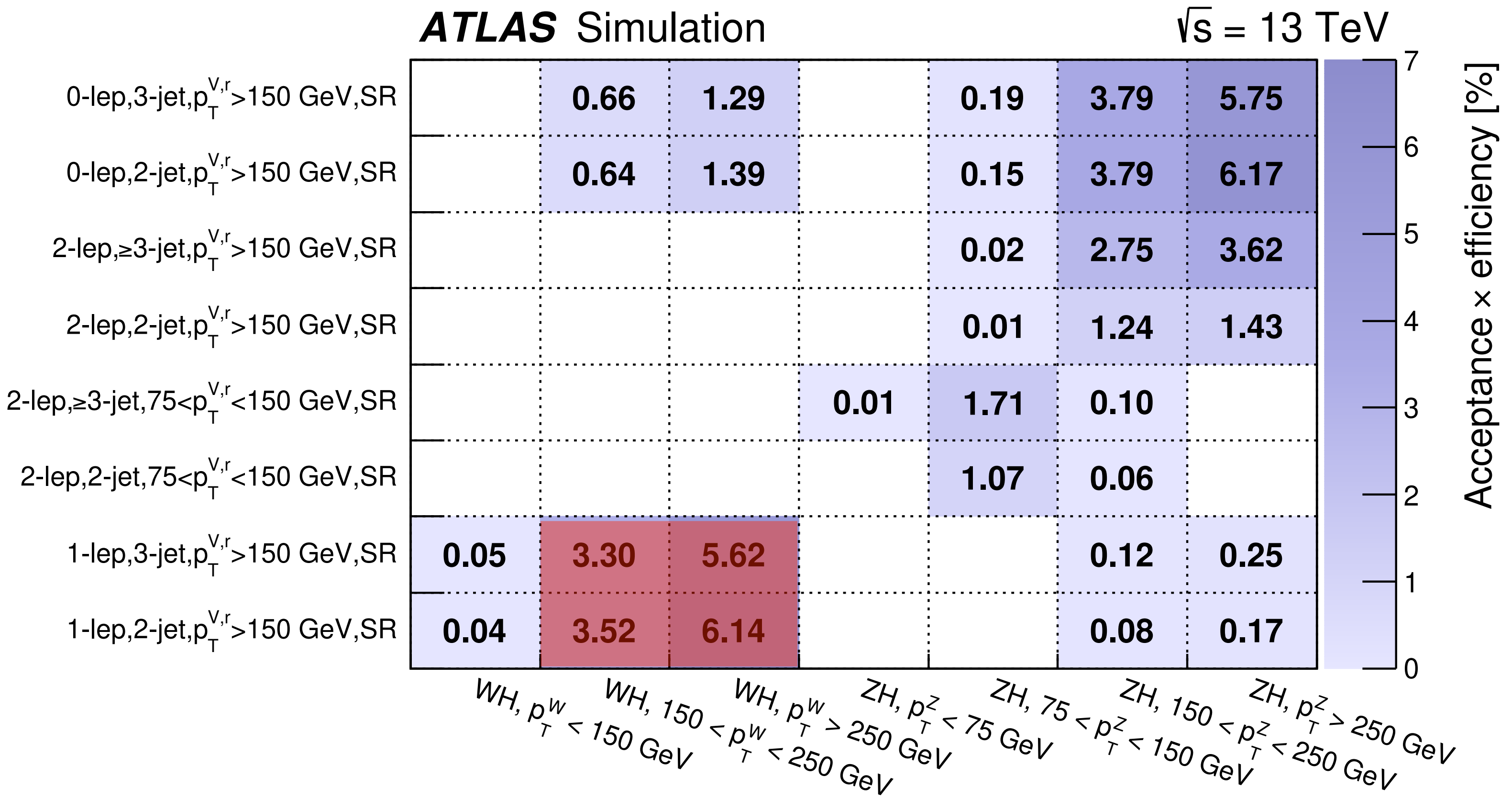
signal modelling

STXS acceptance

- inclusive analysis

$m_H = 125$ GeV at $\sqrt{s} = 13$ TeV				
Process	Cross-section × B [fb]	Acceptance [%]		
		0-lepton	1-lepton	2-lepton
$qq \to ZH \to \ell\ell b\bar{b}$	29.9	< 0.1	< 0.1	7.0
$gg \to ZH \to \ell\ell b\bar{b}$	4.8	< 0.1	< 0.1	15.7
$qq \to WH \to \ell\nu b\bar{b}$	269.0	0.2	1.0	–
$qq \to ZH \to \nu\nu b\bar{b}$	89.1	1.9	–	–
$gg \to ZH \to \nu\nu b\bar{b}$	14.3	3.5	–	–

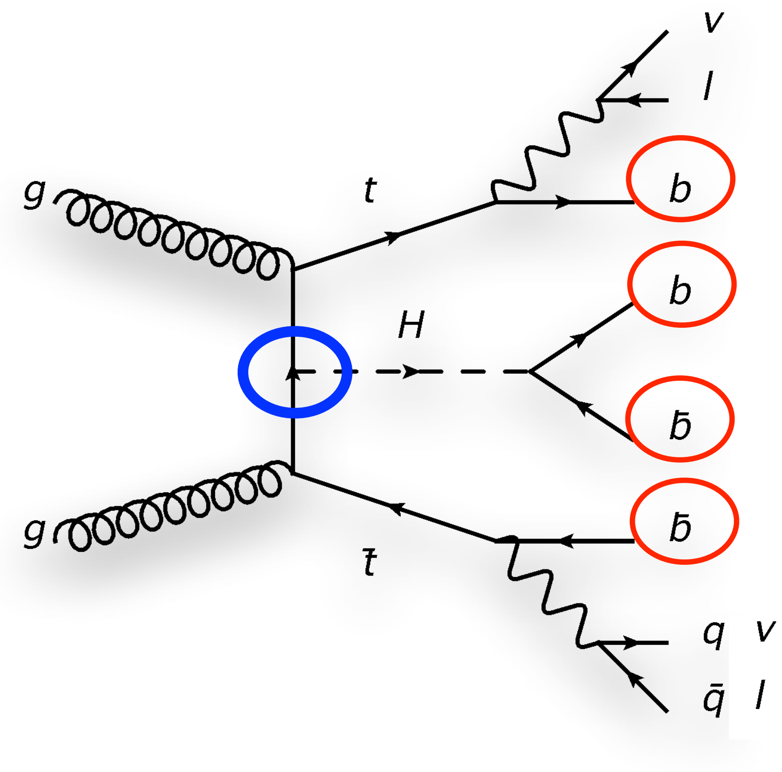
- STXS analysis: acceptance x efficiency increase from 1% to 18% [though redefinition of measured target]



	WH, $p_T^W < 150$ GeV	WH, $150 < p_T^W < 250$ GeV	WH, $p_T^W > 250$ GeV	ZH, $p_T^Z < 75$ GeV	ZH, $75 < p_T^Z < 150$ GeV	ZH, $150 < p_T^Z < 250$ GeV	ZH, $p_T^Z > 250$ GeV
0-lep,3-jet,$p_T^{V,r}$>150 GeV,SR		0.66	1.29		0.19	3.79	5.75
0-lep,2-jet,$p_T^{V,r}$>150 GeV,SR		0.64	1.39		0.15	3.79	6.17
2-lep,≥3-jet,$p_T^{V,r}$>150 GeV,SR					0.02	2.75	3.62
2-lep,2-jet,$p_T^{V,r}$>150 GeV,SR					0.01	1.24	1.43
2-lep,≥3-jet,75<$p_T^{V,r}$<150 GeV,SR				0.01	1.71	0.10	
2-lep,2-jet,75<$p_T^{V,r}$<150 GeV,SR					1.07	0.06	
1-lep,3-jet,$p_T^{V,r}$>150 GeV,SR	0.05	3.30	5.62			0.12	0.25
1-lep,2-jet,$p_T^{V,r}$>150 GeV,SR	0.04	3.52	6.14			0.08	0.17

- in STXS ZH is ll+vv

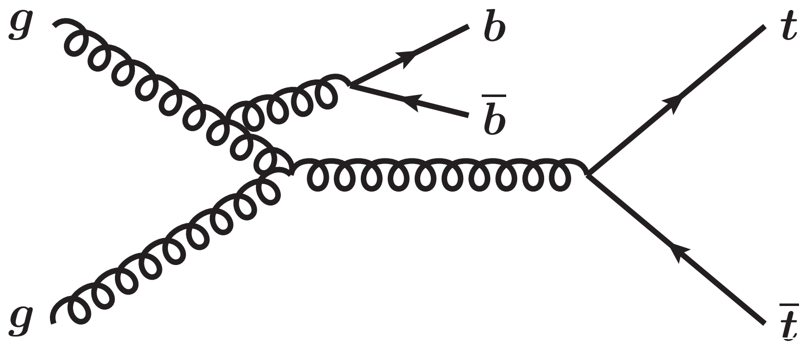
$\bar{t}tH$ ($H \rightarrow b\bar{b}$)



- Preferred gateway to ***top Yukawa coupling*** measurement

- ‘Crowded’ final state with multiple possibilities given by ttbar decay products:
  - *consider events with only one (1L) or two (2L) leptons in the final state*
  - *categorising events according to the number of reconstructed jets*
  - ***heavily relying on flavour tagging information***

- Large and difficult to control irreducible tt+bb background



Run2: $t\bar{t}H$ ($H\rightarrow b\bar{b}$)

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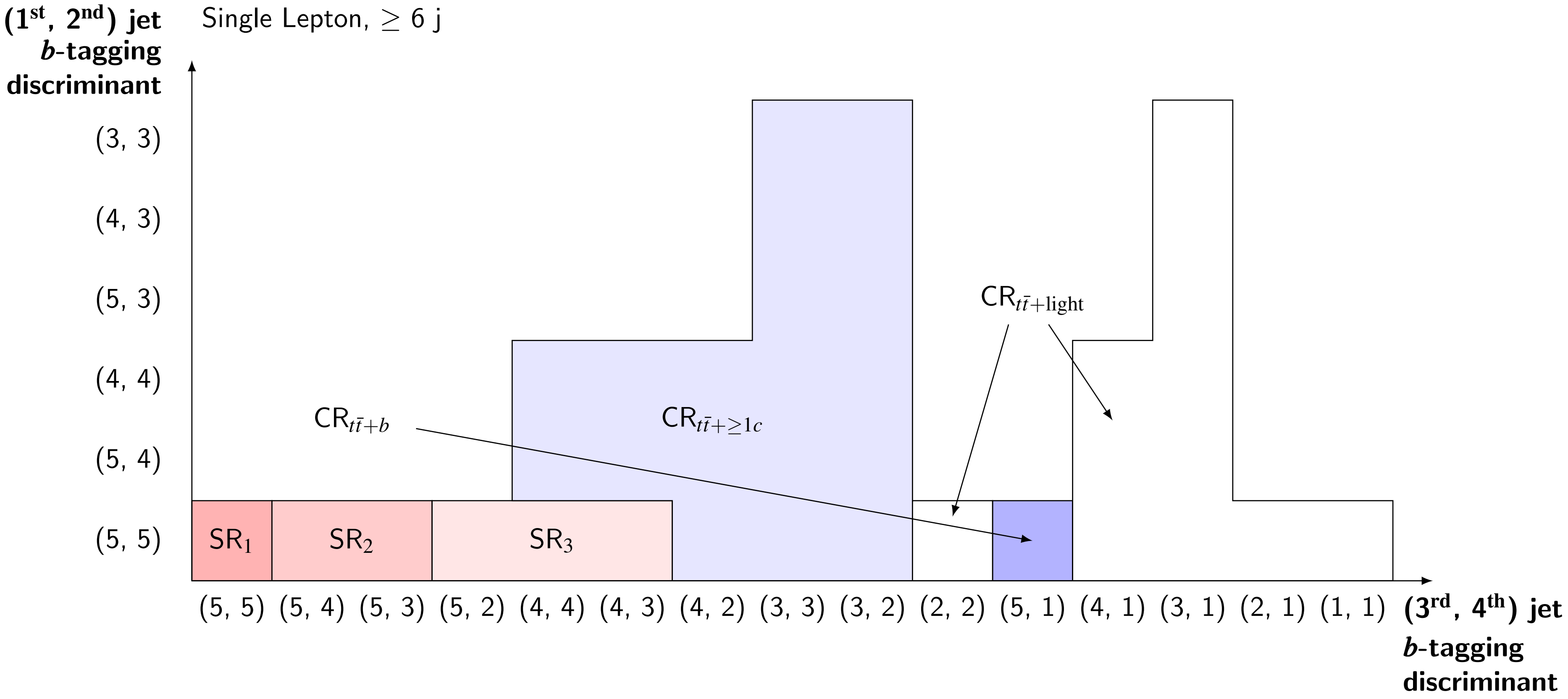
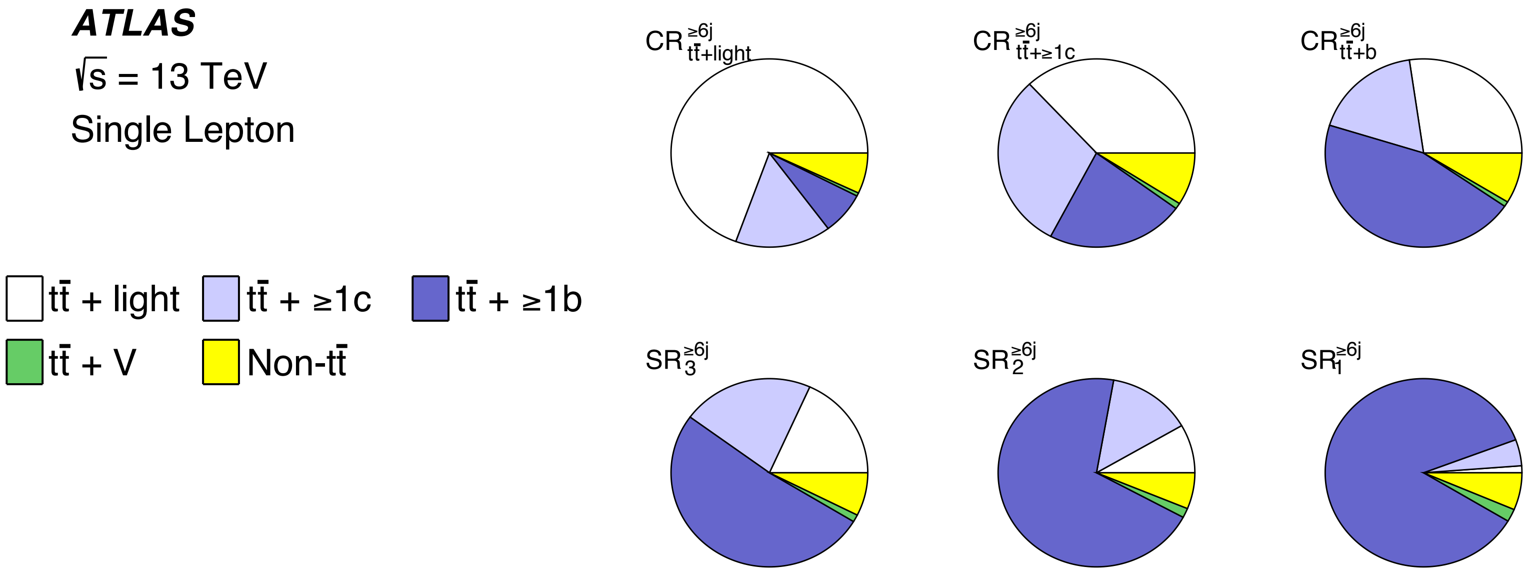
- (for a given jet multiplicity) **Categorise events according to the b-tagging score of the jets:**
  - *increase signal acceptance, exploit different S/B [and S/sqrt(B)] in each region*

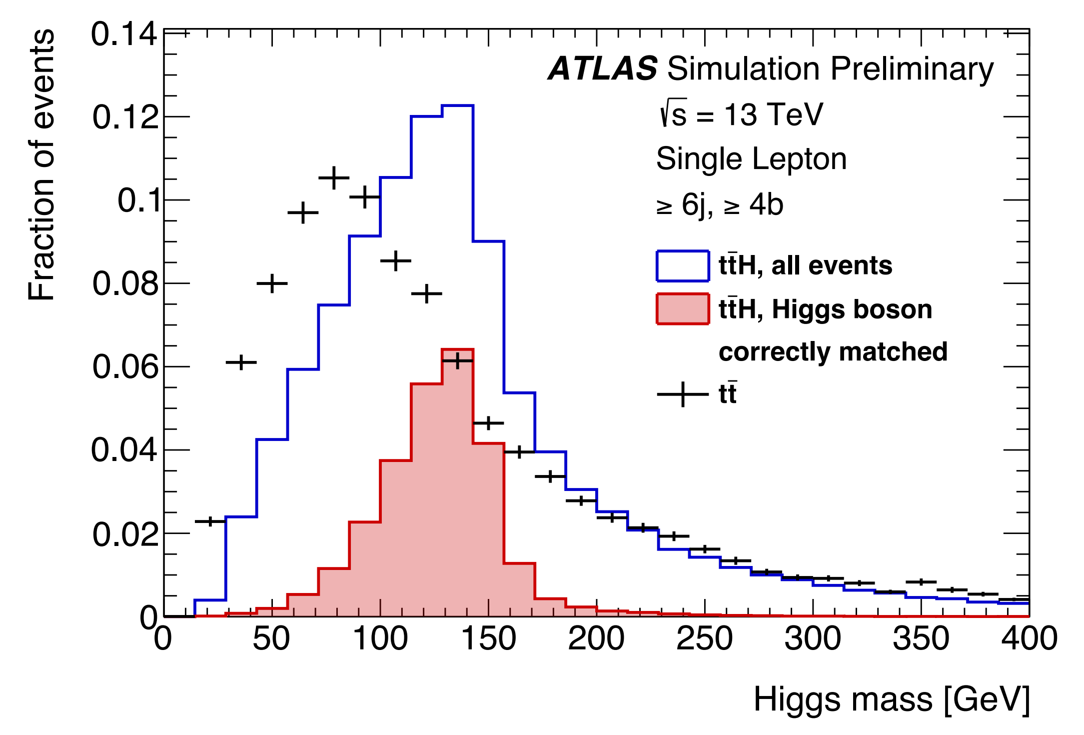


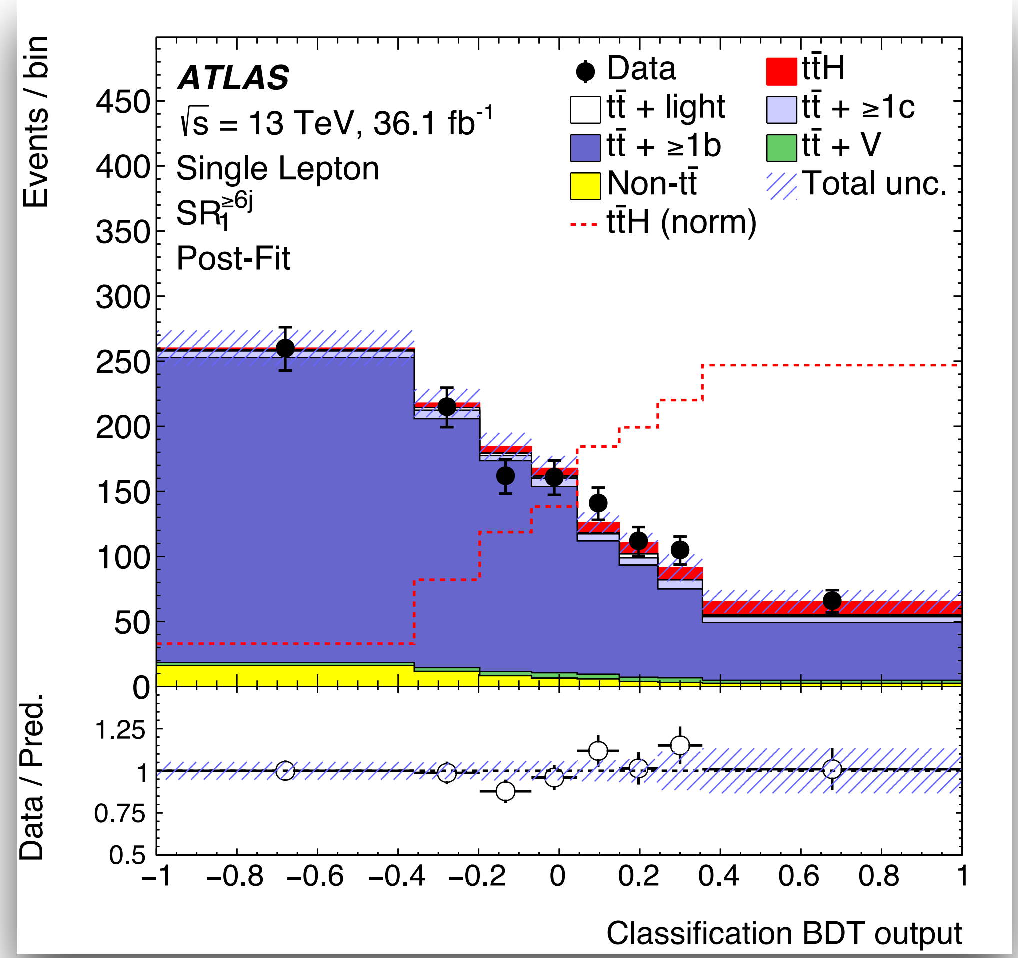
- *Very different background composition in each regions*
  - *used to constrain the normalisation*



$t\bar{t}H$ ($H\to b\bar{b}$): discriminant

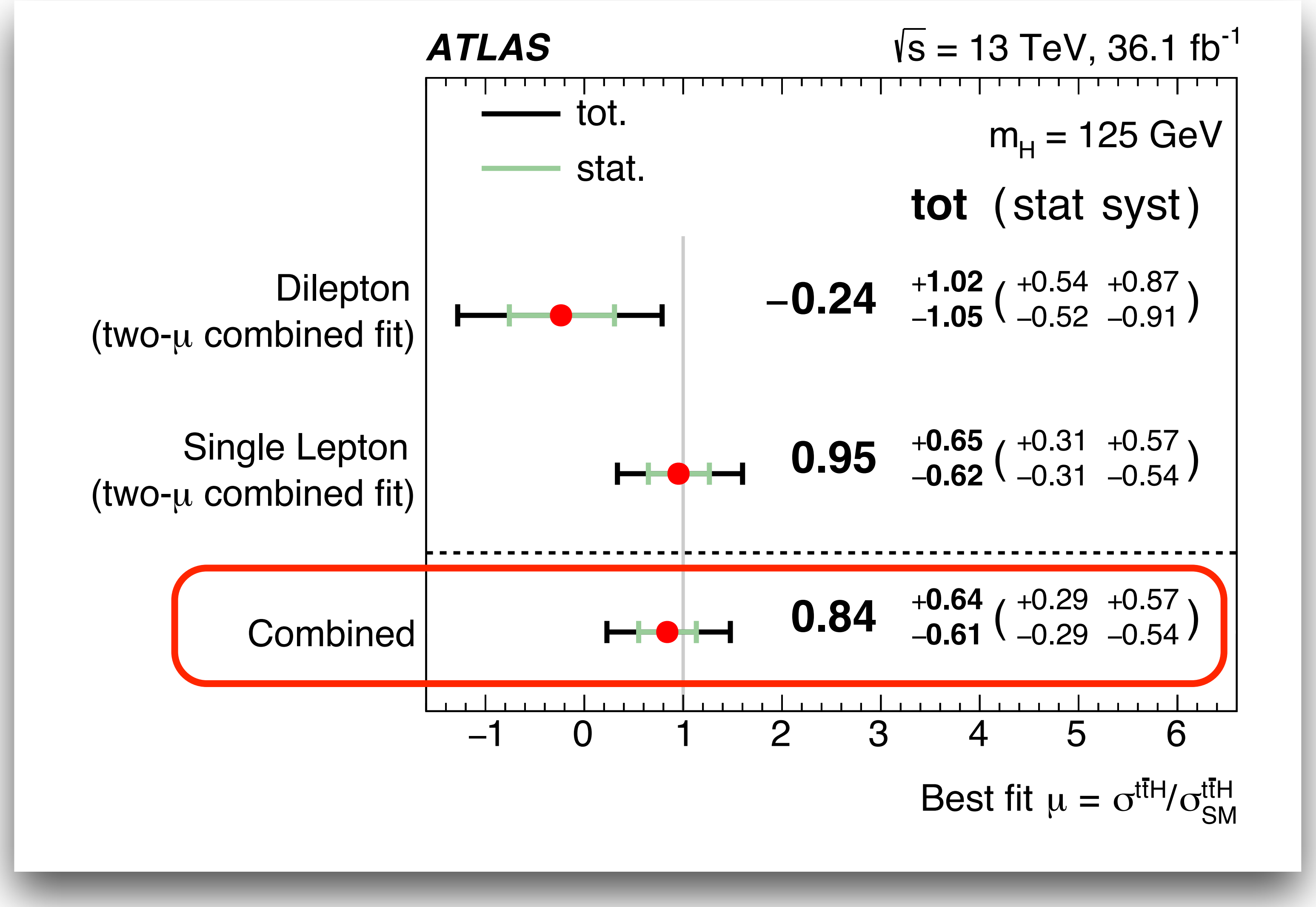
- 4b in the final state complicates combinatorics:
  - *only 30% of Higgs boson correctly reconstructed inside the signal —> can't directly rely on the mass peak*
  - *will improve at high p_T topologies*





- Final discriminant in signal regions: BDT
  - *jet kinematic variables*
  - *global event variables*
  - *jet b-tagging scores*
  - *event reconstruction through additional BDT: assigning reconstructed jets to partons in ttbar/ ttH decay*
  - *Likelihood/MEM discriminant (signal VS ttbb)*

$t\bar{t}H$ (H->$b\bar{b}$): results



***1.4* (1.6) observed (expected) significance**
w.r.t. no Higgs hypothesis

- At 95% CL, for m_H=125 GeV:

observed σ*BR/(σ*BR)$_{SM}$ < 4.0

expected σ*BR/(σ*BR)$_{SM}$ < 1.9

- Analysis dominated by systematic uncertainties: MC modelling of tt+$b\bar{b}$ background, **mis-tag of c and light jets**