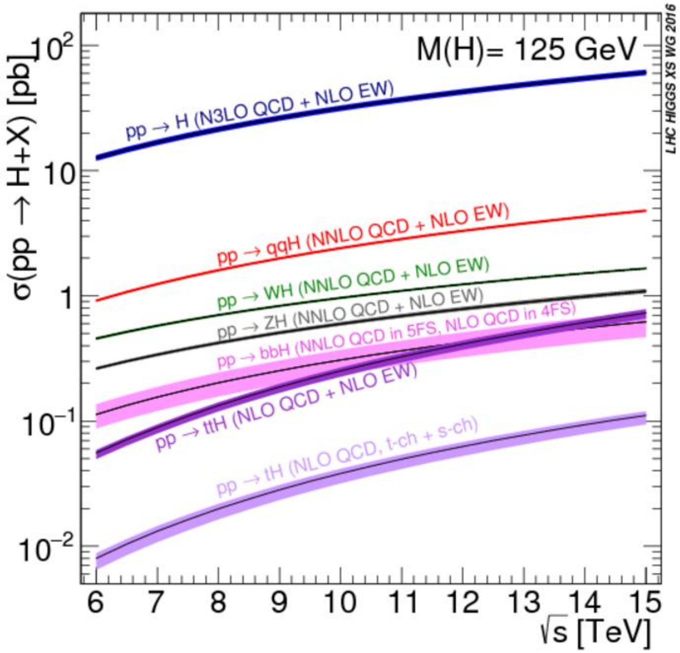
A study of the VH associated production process

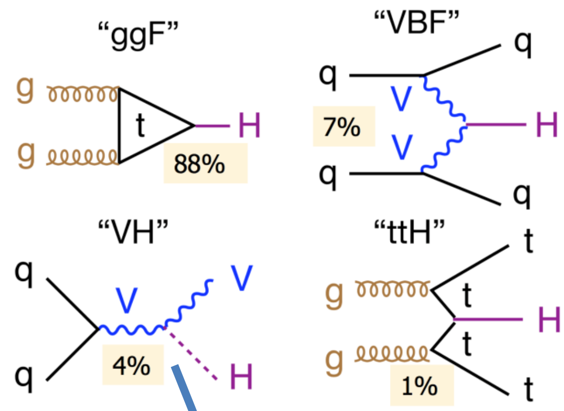
Faig Ahmadov & VHbb WG

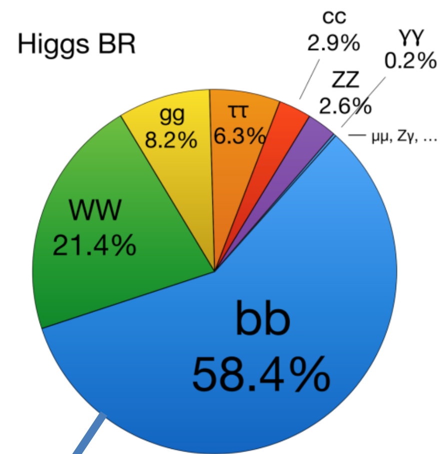
JINR Prize Competition for young scientists and specialists
JINR, Dubna

6 December 2019

H production & decay channels





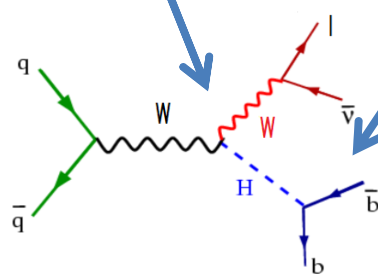


V (H→bb); *V=W or Z*

$\sqrt{s}$*=13TeV,* m_H*=125 GeV*

XS(pp->H->bb) ~ 30pb

XS(Bkg->bb) ~ 10^6*pb*



BR (H→bb) ~ 58%
BR (W→lv) ~ 33%
BR (Z→ll+vv) ~ 30%
XS (WH+ZH) ~ 2.3 pb

The leptonic decays of the vector boson, W or Z can be used for triggering and background reduction purposes.

XS(VH-llbb) ~ ***0.4 pb***

XS(Bkg) ~ ***10³ pb***

VH (H→bb) analysis

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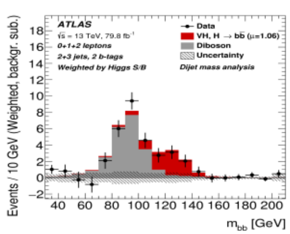
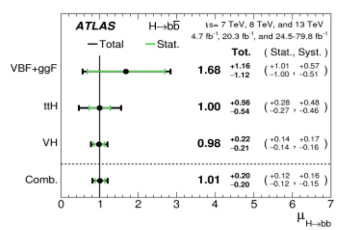
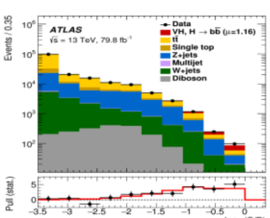
1. Combination of Run 2 (*13 TeV*) with Run 1 (*7TeV* & *8TeV). **Obs. sig. 4.9σ and exp. sig. 5.1σ***
2. Combination of VH(*$H\to b\bar{b}$*) with the *$t\bar{t}H$(H→bb)* & *VBF+ggH (H→bb).* **Obs. sig. 5.4σ and exp. sig. 5.5σ**
3. Combination Run 2 *VH(H→bb)* result with V*H(H→γγ)* & V*H(H→ZZ*→4l*). **Obs. sig. 5.3σ and exp. sig. 4.8σ**







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- Measurement of *VH,* $H\to b\bar{b}$ production (2015-2017 data);

Last public results (measurement)

"Measurement of VH, H->bb̄ production as a function of the vector-boson transverse momentum in 13TeV pp collisions with the ATLAS detector"

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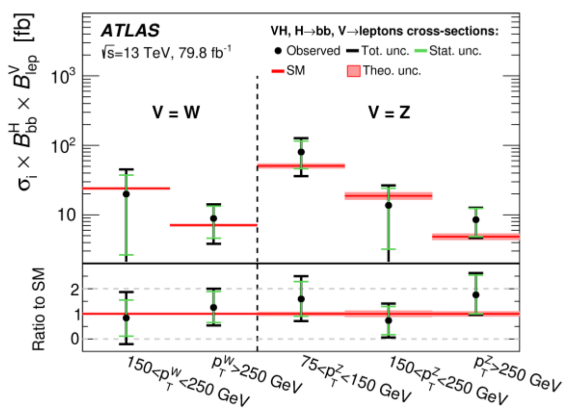


Measured VH, V→leptons reduced stage-1 simplified template cross-sections times the H→bb̄ branching ratio.

Best-fit values and uncertainties for the VH, V→leptons reduced stage-1 STXS times the H→ bb̄ branching ratio, in the 5-POI and 3-POI schemes. All leptonic decays of the V bosons (including those to τ-leptons, ℓ=e,μ,τ) are considered.

Measurement region ($\|y_H\| < 2.5$, $H \to b\bar{b}$)	SM prediction [fb]	Result [fb]	Stat. unc. [fb]	Syst. unc. [fb] Th. sig.	Th. bkg.	Exp.
5-POI scheme						
$W \to \ell\nu$; $150 < p_T^V < 250$ GeV	24.0 ± 1.1	20 ± 25	± 17	± 2	± 13	± 9
$W \to \ell\nu$; $p_T^V > 250$ GeV	7.1 ± 0.3	8.8 ± 5.2	± 4.4	± 0.5	± 2.5	± 0.9
$Z \to \ell\ell, \nu\nu$; $75 < p_T^V < 150$ GeV	50.6 ± 4.1	81 ± 45	± 35	± 10	± 21	± 19
$Z \to \ell\ell, \nu\nu$; $150 < p_T^V < 250$ GeV	18.8 ± 2.4	14 ± 13	± 11	± 1	± 6	± 3
$Z \to \ell\ell, \nu\nu$; $p_T^V > 250$ GeV	4.9 ± 0.5	8.5 ± 4.0	± 3.7	± 0.8	± 1.2	± 0.6
3-POI scheme						
$W \to \ell\nu$; $p_T^V > 150$ GeV	31.1 ± 1.4	35 ± 14	± 9	± 2	± 9	± 4
$Z \to \ell\ell, \nu\nu$; $75 < p_T^V < 150$ GeV	50.6 ± 4.1	81 ± 45	± 35	± 10	± 21	± 19
$Z \to \ell\ell, \nu\nu$; $p_T^V > 150$ GeV	23.7 ± 3.0	28.4 ± 8.1	± 6.4	± 2.4	± 3.6	± 2.3

The measurements are in agreement with the Standard Model predictions, even in high pVT (> 250 GeV) regions that are most sensitive to enhancements from potential anomalous interactions between the Higgs boson and the electroweak gauge bosons.

Data and simulated samples

- Data: √s=*13TeV*, ***79.8±1.6 fb⁻¹*** (2015 – 2017).
- The **generators** used for the simulation of the signal and background processes:

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

Data: √s=*13TeV*, ~***140 fb⁻¹*** (2015 – 2018).

Additional filtered MC samples: *V+jets, ttbar* (100GeV - 200GeV, >200GeV)

Object selection

Event preselection: GRL, Vertex, min. 3 tracks, pile-up reweighting, triggers,
Cleaning : MET cleaning, Jet cleaning, …;

Electrons:

Loose: $|\eta|<2.47$, $E_T > 7$GeV , $|d_0|<0.1$mm (for 7TeV data), p_T cone(0.2) <0.04, OR
Signal: Loose + $E_T > 27$GeV, E_T cone (0.3) <0.04.

Muons:

Loose: $|\eta|<2.7$, $E_T > 7$GeV, $|d_0|<0.1$mm & $|z_0|<10$mm , OR (jets electrons)
Signal: Loose + $|\eta|<2.5$, $E_T > 25$GeV , E_T cone (0.3) <0.04.

Jets:

Veto: $p_T > 20$GeV & $|\eta|<2.5$ or $p_T > 30$GeV & $2.5<|\eta|<4.5$, OR with mu and el.
Signal: Veto + $p_T > 20$GeV & $|\eta|<2.5$

b-jets: The MV1 b-tagging algorithm is used to identify jets originating from b-quark fragmentation), MV1 with 70% eff.

MET: The missing transverse momentum E_T^{miss} is reconstructed as the negative vector sum of the momenta of leptons, hadronically decaying τ-leptons and jets, and of a 'soft term' built from additional tracks matched to the primary vertex.

Object selection updates

✓Updated recommendation for jets & leptons.

✓ **Isolation working points**: LooseTrackOnly → FixedCutLoose.

✓EMTopo or PFlow jets (already used by CMS):

- Higher jet multiplicity with PFlow in all 0/1/2L.
- JVT efficiency difference (JVT>0.59(EM), >0.2 (PF); eff=92 % (EM), 97%(PF))
- PFlow has larger contamination of pile-up jets
- Resolution of PF is slightly better than EM in 0- & 2-lepton channel

✓**MET significance** as an anti-QCD cut

- MET sig > 1.5, $d\phi(b,b) < 140^\circ \rightarrow d\phi(b,b) < 126^\circ$ ($S/\sqrt{B}$ increase 3.1%)

✓**b-jet energy correction**: Regression is getting better than muon-in-jet + PtReco → maybe it will become default in future;

✓B-tagging: Official b-tagging algorithms in ATLAS: MV2c10 (or DL1).

✓MV2 -> DL1 -> DL1r (DL1+RNNIP) -> DL1rmu (DL1+RNNIP+SMT) improvement in light rejection ~50% & c-rejection by more than 20%.

✓Usage of Particle Flow jets consolidated at training level, being actively investigated at calibration stage.

✓No new recommendations for EMTopo jets will be available (no new taggers, no calibrations with full Run 2 data).

EM/PF comparison for 1L

WH

# j	mc16	EM	PF	Variation (%)
2tag2jet	*a*	54.9344	52.6968	-4.1
	d	60.2752	55.8564	-7.3
	e	71.3411	66.5553	-6.7
	ade	186.5507	175.1085	-6.1
2tag3jet	*a*	49.9553	50.9416	2
	d	58.668	60.2477	2.7
	e	70.326	72.231	2.7
	ade	178.9493	183.4203	2.5

ttbar

# j	mc16	EM	PF	Variation (%)
2tag2jet	*a*	3410.63	3013.24	-11.7
	d	3847.86	3195.82	-16.9
	e	4621.82	3930.27	-15
	ade	11880.31	10139.33	-14.7
2tag3jet	*a*	25845	23279.4	-9.9
	d	28582.4	24618.3	-13.9
	e	34794.3	29833.4	-14.3
	ade	89221.7	77731.1	-12.9

Data 15-18

# j	data	EM	PF	Variation (%)
2tag2jet	*2015*	525	527	0.4
	2017	6429	5771	-10.2
	2018	7369	6501	-11.8
	sum	14323	12799	-10.6
2tag3jet	*2015*	3043	2896	-4.8
	2017	34574	30955	-10.5
	2018	40389	35658	-11.7
	sum	78006	69509	-10.9

Event selection

Selection	0-lepton	1-lepton e sub-channel	1-lepton μ sub-channel	2-lepton
Trigger	E_T^{miss}	Single lepton	E_T^{miss}	Single lepton
Leptons	0 *loose* leptons with $p_T > 7$ GeV	1 *tight* electron $p_T > 27$ GeV	1 *tight* muon $p_T > 25$ GeV	2 *loose* leptons with $p_T > 7$ GeV ≥ 1 lepton with $p_T > 27$ GeV
E_T^{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)	–		–
$\min[\Delta\phi(\vec{E}_T^{miss}, \text{jets})]$	$> 20°$ (2 jets), $> 30°$ (3 jets)	–		–
$\Delta\phi(\vec{E}_T^{miss}, \vec{bb})$	$> 120°$	–		–
$\Delta\phi(\vec{b_1}, \vec{b_2})$	$< 140°$	–		–
$\Delta\phi(\vec{E}_T^{miss}, \vec{p}_T^{miss})$	$< 90°$	–		–
p_T^V regions	> 150 GeV			75 GeV $< p_T^V <$ 150 GeV, > 150 GeV
Signal regions	–	$m_{bb} \geq 75$ GeV or $m_{top} \leq 225$ GeV		Same-flavour leptons Opposite-sign charges ($\mu\mu$ sub-channel)
Control regions	–	$m_{bb} < 75$ GeV and $m_{top} > 225$ GeV		Different-flavour leptons Opposite-sign charges

Updates:

✓1-lepton: include 75GeV<pTV<150GeV

✓0/1/2-lepton: Split pTV>150GeV

↓

150GeV<pTV<250GeV and pTV>250GeV

✓CR -> CR low & CR high (dRbb)

✓Harmonize dijet mass and mva analyses

Selection	Channel: 0-lepton	1-lepton	2-lepton
m_T^W	-	< 120 GeV	-
$E_T^{miss}/\sqrt{S_T}$	-	-	$< 3.5\sqrt{\text{GeV}}$

p_T^V regions			
p_T^V	75 – 150 GeV (2-lepton only)	150 – 200 GeV	> 200 GeV
$\Delta R(\vec{b}_1, \vec{b}_2)$	<3.0	<1.8	<1.2

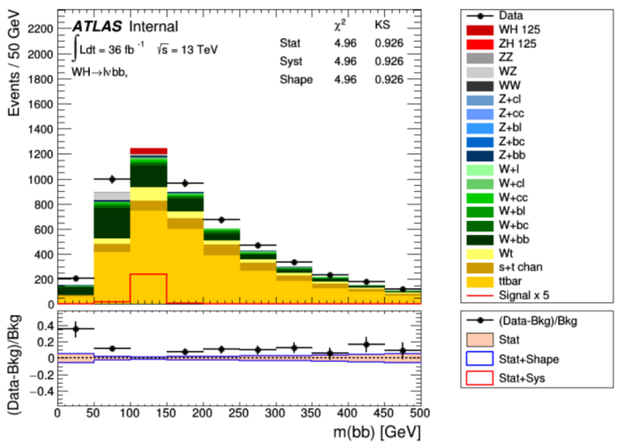
Additional cuts for Cut-flow analysis

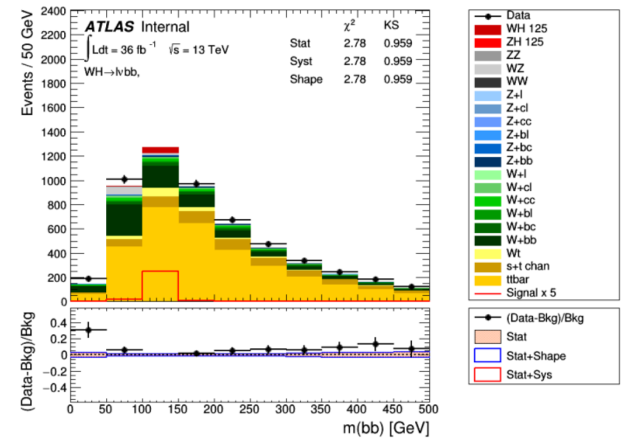
CxAOD r32-07 validation

31-10 (ICHEP)

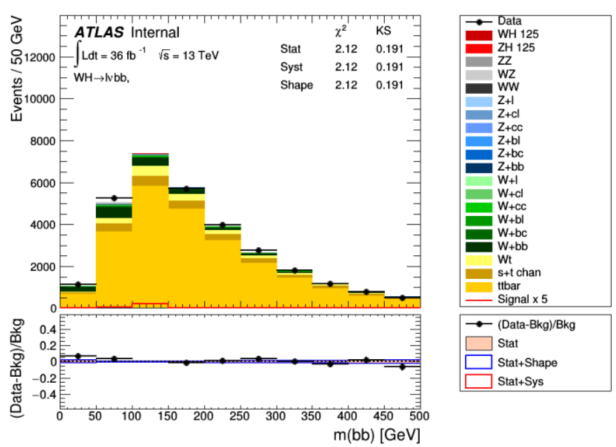
32-207

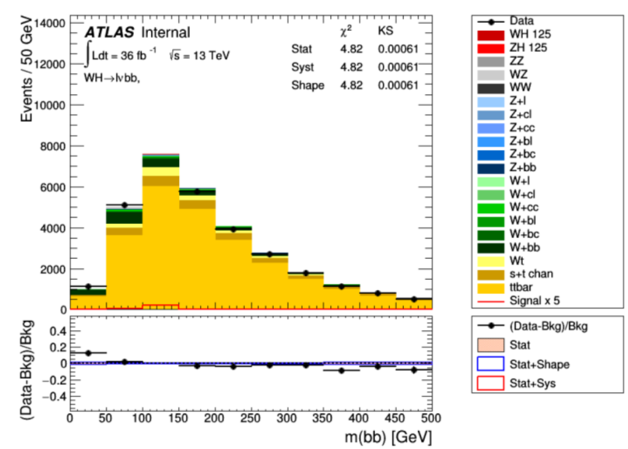
2tag2jet





2tag3jet





Main changes between 32-07 – 32-15

[2019-04-01] **Tag r32-15**
[2019-03-29] MR CxAODMaker: Updated Calibration release for Muon efficiency scale factor
[2019-03-29] MR CxAODBootstrap_VHbb: Bump to **AB.21.2.68**
[2019-03-25] MR CxAODMaker: update electron ptcone, cluster eta and jet NumTrkPt1000PV
[2019-03-25] MR CxAODReader_VHbb: Updating the Tight Isolation Cuts
[2019-03-25] MR CxAODMaker: fix EL_EFF_Iso_TOTAL_1NPCOR_PLUS_UNCOR
[2019-03-20] MR CxAODTools: add cluster eta and ptcone for electron; refactor CxAODProperties.cxx with the automatic script to be consistent with .h
[2019-03-20] MR CxAODMaker: Master ckato xbb3: Removing leading 2 track jet b-tag requirement from hbb muon-in-jet correction, applying VR10 dR cut, muons eta up to 2.7
[2019-03-20] MR CxAODTools: Add QG Variables for QG Calibration
[2019-03-18] MR CxAODReader_VHbb: Further restructure histogram filling + fix duplicated filling
[2019-03-11] MR CxAODOperations_VHbb: update to latest 2018 data ilumicalc file. Change GRL directory although it is...
[2019-03-11] MR CxAODOperations_VHbb: use averageMu for PRW in mc16e as recommended
[2019-03-09] MR CxAODBootstrap_VHbb: Bump to **AB.21.2.66**
[2019-03-06] MR CxAODMaker: Master ckato xbb to hbb migration
[2019-03-01] MR CxAODTools: Missing L1Topo triggers in 2018
[2019-03-01] MR CxAODReader_VHbb: VR track jet overlap removal for 2L reader
[2019-02-28] MR CxAODReader_VHbb: Add FSR selection.
[2019-02-27] MR CxAODReader_VHbb: 1L VR Jet Overlap Removal Implementation
[2019-02-26] MR CxAODMaker: Update JetSemileptonic.cxx to get now the PtReco from 32-07 ade instead of 31-10 ad
[2019-02-26] MR CxAODMaker: adding LooseTrackOnly trigger SFs for Electrons
[2019-02-26] MR CxAODTools: add trigToolLooseLHIsoLooseTrackOnly for electrons
[2019-02-25] MR CxAODBootstrap_VHbb: Update /afs .root files location from 181026 to 190225 for new PtReco (32-10 ad -> 32-07 ade)
[2019-02-25] MR CxAODReader_VHbb: Implementation OR in 0lep reader
[2019-02-25] MR CxAODBootstrap_VHbb: Update **AnalysisBase to 21.2.64**
[2019-02-25] MR CxAODMaker: Not applying met rebuilding for truth met
[2019-02-22] MR CxAODMaker: Update Muon CP recommendation
[2019-02-19] MR CxAODOperations_VHbb: Update submitReader.sh to turn of ggVV in period e that are missing now
[2019-02-19] MR CxAODReader_VHbb: switched from trackjethybrid to trackjetcone
[2019-02-19] MR CxAODOperations_VHbb: Update submitReader.sh to use in 0L e ZnunuC_PTV and ZnunuL_PTV
[2019-02-19] MR CxAODReader_VHbb: Add b-tag weight to MVATree_VHbb
[2019-02-19] MR CxAODTools: add 2018 MET trigger SFs
[2019-02-18] MR CxAODReader: if doICHEP then FR else VR for v31 OneMu and PtReco
[2019-02-17] MR CxAODReader: Update AnalysisReader.cxx to allow in period e use PTV slices at full weight
[2019-02-17] MR CxAODOperations_VHbb: Update submitReader.sh to run Znunu only in 0L, and differently for a,d,e
[2019-02-16] MR CxAODOperations_VHbb: Update submitReader.sh to not run Znunu for 2L
[2019-02-16] MR CxAODOperations_VHbb: Update submitReader.sh to use also Znunu_B slices also in period e of 1L and 2L
[2019-02-15] MR CxAODReader_VHbb: update the dilepton event veto for tag32 stopWt samples in 2L reader
[2019-02-14] MR CxAODOperations: Update XSections_13TeV.txt for Znunu PTV slices for B, C, L filtering; and rename stopWt_dilep to stopWt to allow for merging for stat extensions
[2019-02-14] MR CxAODOperations: Add alternative ttbar Sherpa samples
[2019-02-12] MR CxAODReader_VHbb: Add a new variable in tagTrackjet_selection function
[2019-02-06] MR CxAODReader_VHbb: Add ptv 250 GeV splitting.
[2019-02-05] MR CxAODOperations_VHbb: Update submitReader.sh to fix bug for data and Znunu samples, change 1L e to use MET trigger again
[2019-02-04] MR CxAODMaker: Moved Jvt to default list of stored variables for jets
[2019-01-29] MR CxAODOperations_VHbb: Update submitReder.sh for 0L e to use the Z+jets pTV slices instead of max(HT,PTV)
[2019-01-28] MR CxAODMaker: Adding possibility to use RNN taus & fixing Tau SF bug
[2019-01-24] MR CxAODOperations_VHbb: turn on the ttbar pTW filter extension for 1L
[2019-01-19] MR CxAODBootstrap_VHbb: Bump AnalysisBase version to **AB 21.2.60**
[2019-01-15] MR CxAODTools: adding tau plus lep triggers for 2017
[2019-01-12] MR CxAODBootstrap_VHbb: Master abuzatu bump to **AnalysisBase 21.2.59** and create compile.sh with has to be run by hand to compile after build is removed
[2019-01-11] MR CxAODMaker: bug fix for newStyle truth regarding checkSherpaVZqqZbb func
[2019-01-10] MR CxAODTools_VHbb: Temporary Muon Isolation update
[2019-01-10] MR CxAODMaker: Changed Isolation WP adding order in MuonHandler
[2019-01-09] MR CxAODMaker: Add back IsoLooseTrackOnly in ElectronHandler
[2019-01-09] MR CxAODTools: Add back IsoLooseTrackOnly SFs for Electrons
[2019-01-04] **Tag r32-07**

Expected signal eff.loss 25/27GeV→30GeV

Expected signal efficiency loss, when the offline electron/muon threshold raised to 30 GeV

Cannel and regions			WH yield		
Channel	Njet reg.	pTV reg.	Default, pTL>27GeV (>25GeV for muon in ptV>150GeV reg.)	pTL>30GeV	Eff. loss (%)
Electron	2tag2jet	75GeV<pTV<150GeV	128.8±0.6	125.3±0.6	2.7
		pTV>150GeV	91.2±0.2	90.4±0.2	0.9
	2tag3jets	75GeV<pTV<150GeV	105.1±0.5	102. 5±0.5	2.5
		pTV>150GeV	87.3±0.2	86.5±0.2	0.9
Muon	2tag2jets	75GeV<pTV<150GeV	149.8±0.6	145.3±0.6	3
		pTV>150GeV	107.8±0.2	105.4±0.2	2.3
	2tag3jets	75GeV<pTV<150GeV	119.0±0.6	115.2±0.6	3.2
		pTV>150GeV	101.3±0.2	98.9±0.2	2.3
Electron + Muon	2tag2jets	75GeV<pTV<150GeV	278.6±0.9	270.6±0.9	2.9
		pTV>150GeV	199.0±0.3	195. 8±0.3	1.6
	2tag3jets	75GeV<pTV<150GeV	224.1±0.8	217.7±0.8	2.9
		pTV>150GeV	188.6±0.3	185.4±0.3	1.7

Systematic uncertainties

Signal	
Cross-section (scale)	0.7% (qq), 27% (gg)
Cross-section (PDF)	1.9% ($qq \to WH$), 1.6% ($qq \to ZH$), 5% (gg)
$H \to b\bar{b}$ branching fraction	1.7%
Acceptance from scale variations	2.5 – 8.8%
Acceptance from PS/UE variations for 2 or more jets	2.9 – 6.2% (depending on lepton channel)
Acceptance from PS/UE variations for 3 jets	1.8 – 11%
Acceptance from PDF+α_S variations	0.5 – 1.3%
m_{bb}, p_T^V, from scale variations	S
m_{bb}, p_T^V, from PS/UE variations	S
m_{bb}, p_T^V, from PDF+α_S variations	S
p_T^V from NLO EW correction	S

ZZ	
Normalisation	20%
0-to-2 lepton ratio	6%
Acceptance from scale variations	10 – 18%
Acceptance from PS/UE variations for 2 or more jets	6%
Acceptance from PS/UE variations for 3 jets	7% (0-lepton), 3% (2-lepton)
m_{bb}, p_T^V, from scale variations	S (correlated with WZ uncertainties)
m_{bb}, p_T^V, from PS/UE variations	S (correlated with WZ uncertainties)
m_{bb}, from matrix-element variations	S (correlated with WZ uncertainties)
WZ	
Normalisation	26%
0-to-1 lepton ratio	11%
Acceptance from scale variations	13 – 21%
Acceptance from PS/UE variations for 2 or more jets	4%
Acceptance from PS/UE variations for 3 jets	11%
m_{bb}, p_T^V, from scale variations	S (correlated with ZZ uncertainties)
m_{bb}, p_T^V, from PS/UE variations	S (correlated with ZZ uncertainties)
m_{bb}, from matrix-element variations	S (correlated with ZZ uncertainties)
WW	
Normalisation	25%

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
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
$t\bar{t}$ (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
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))
Multi-jet (1-lepton)	
Normalisation	60 – 100% (2-jet), 90 – 140% (3-jet)
BDT template	S

Modeling updates

✓Complete migration from RIVET → VHbbTruthFramework
(RIVET: Standalone C++. Independent of ATLAS software. mbb at reco formed by two b-tagged jets). TRUTH3 format now used in CxAODFramework, with complete Reco-to-Truth matching;

✓Harmonisation of truth information between CxAODFramework ↔ VHbbTruthFramework.

✓Utilising **filtered samples** from around ATLAS to decrease MC stat. uncertainty in VH:
- ttbar SUSY MET filtered samples
- ttbar pWT filtered samples

✓Investigation of **ttbar data-driven estimation** (2L).

✓Mtop was not covered by pTV and mBB Systematics.
✓mBB and pTV systematics → **BDT-based systematics**.
✓BDT-reweighting approach:
-Alternative method of producing Monte Carlo based shape systematics.
-BDT to parameterize the differences in phase space between the nominal (Sherpa) and alternative (MadGraph) MC.
✓Signal uncertainties - possible improvement on MC:
Cross section gg→ZH, pp→VH improve Powheg(MiNLO), Electroweak corrections.

Statistical analysis

- ***Multivariate analysis (MVA)*** - for main results
- ***Cut-flow analysis*** – for cross-check
- ***Diboson analysis*** – for cross-check

Multivariate analysis

Variable	0-lepton	1-lepton	2-lepton
p_T^V	$\equiv E_T^{miss}$	$\times$	$\times$
E_T^{miss}	$\times$	$\times$	
$p_T^{b_1}$	$\times$	$\times$	$\times$
$p_T^{b_2}$	$\times$	$\times$	$\times$
m_{bb}	$\times$	$\times$	$\times$
$\Delta R(\vec{b_1}, \vec{b_2})$	$\times$	$\times$	$\times$
$\lvert\Delta\eta(\vec{b_1}, \vec{b_2})\rvert$	$\times$		
$\Delta\phi(\vec{V}, \vec{bb})$	$\times$	$\times$	$\times$
$\lvert\Delta\eta(\vec{V}, \vec{bb})\rvert$			$\times$
m_{eff}	$\times$		
$\min[\Delta\phi(\vec{\ell}, \vec{b})]$		$\times$	
m_T^W		$\times$	
$m_{\ell\ell}$			$\times$
$E_T^{miss}/\sqrt{S_T}$			$\times$
m_{top}		$\times$	
$\lvert\Delta Y(\vec{V}, \vec{bb})\rvert$		$\times$	
Only in 3-jet events			
$p_T^{jet_3}$	$\times$	$\times$	$\times$
m_{bbj}	$\times$	$\times$	$\times$

Process	$\sigma \times \mathcal{B}$ [fb]	Acceptance [%]		
		0-lepton	1-lepton	2-lepton
$qq \to ZH \to \ell\ell b\bar{b}$	29.9	<0.1	0.1	6.0
$gg \to ZH \to \ell\ell b\bar{b}$	4.8	<0.1	0.2	13.5
$qq \to WH \to \ell\nu b\bar{b}$	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	–	–

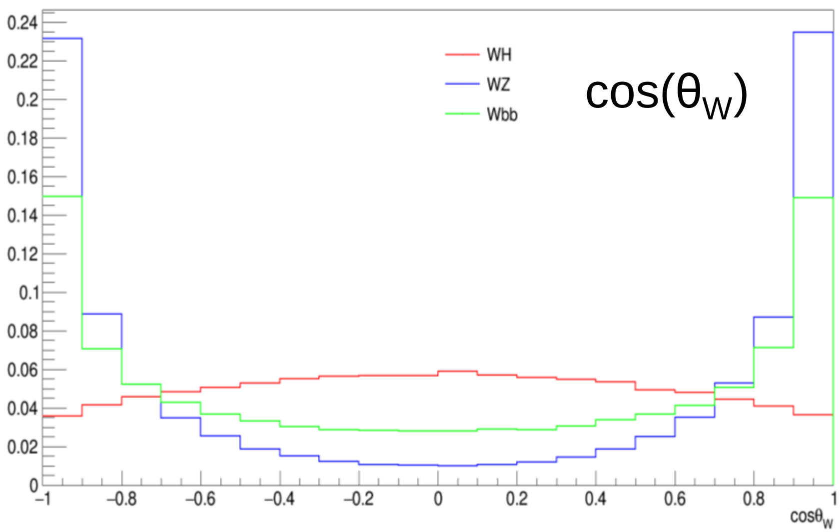
Process	Normalisation factor
$t\bar{t}$ 0- and 1-lepton	0.98 ± 0.08
$t\bar{t}$ 2-lepton 2-jet	1.06 ± 0.09
$t\bar{t}$ 2-lepton 3-jet	0.95 ± 0.06
$W+$ HF 2-jet	1.19 ± 0.12
$W+$ HF 3-jet	1.05 ± 0.12
$Z+$ HF 2-jet	1.37 ± 0.11
$Z+$ HF 3-jet	1.09 ± 0.09

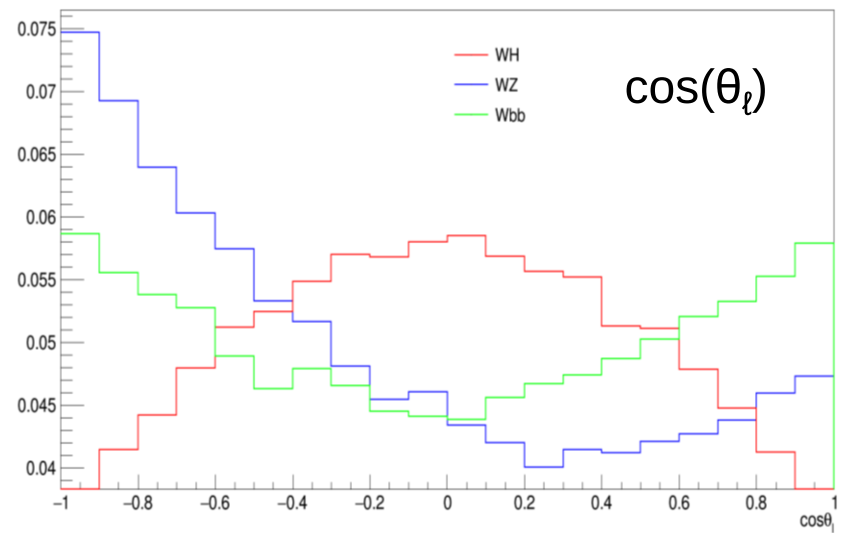
Pseudo-continuous b-tagging (j1 & j2)

Addition of Z polarization variables in 2 lepton +7% on 2-lep fit significance

Angular variables

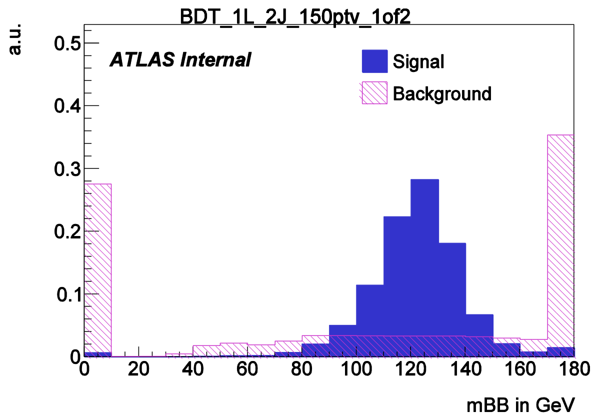
Generator level distributions

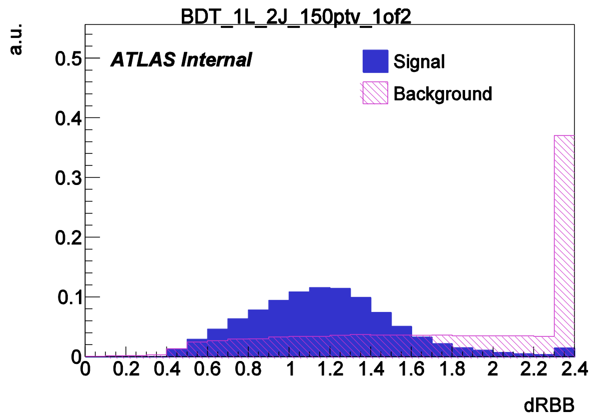


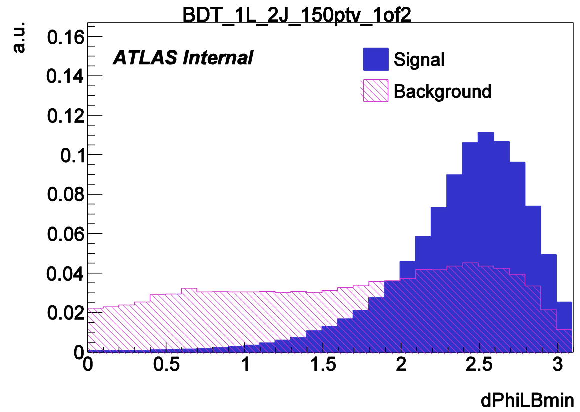


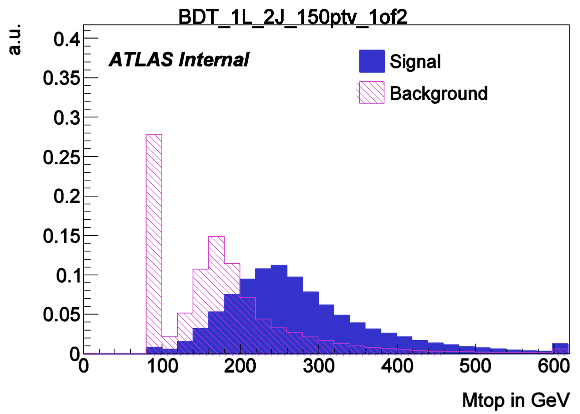
Check the new variables in MVA

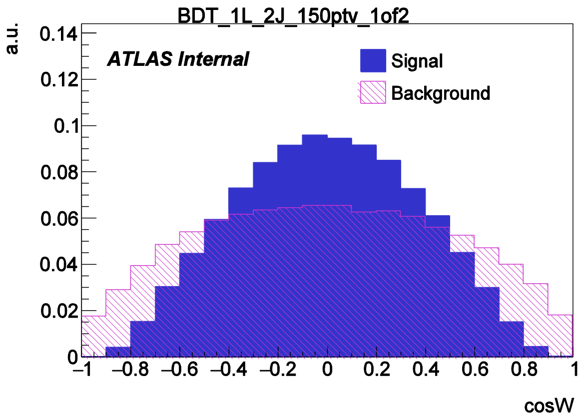
BDT input variables

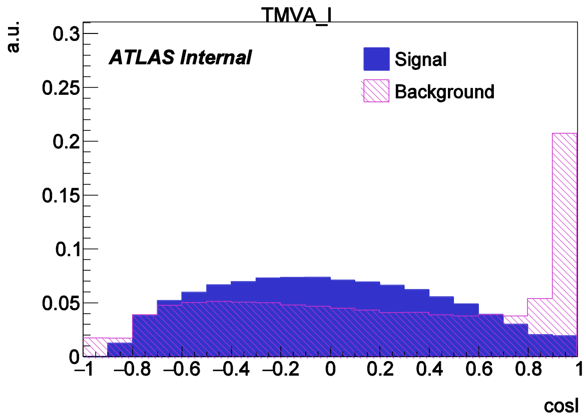




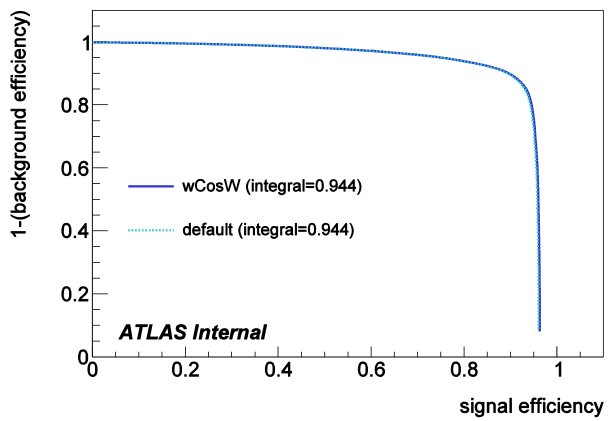




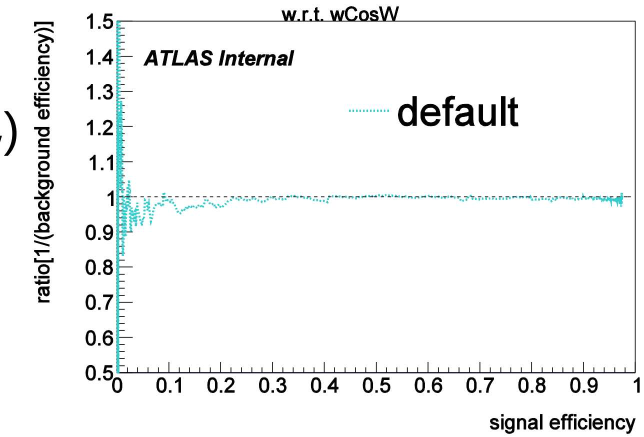


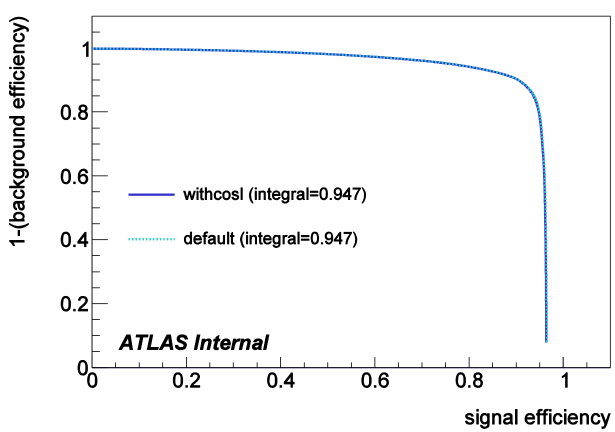


BDT output, ROC comparison

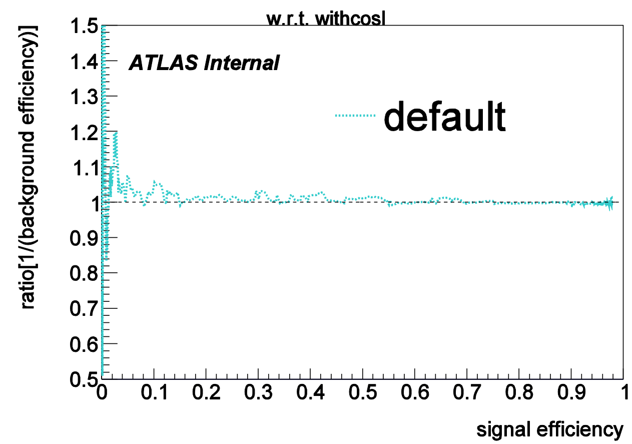


11 var.+cos(θ_W)





11 var.+cos(θ_ℓ)



S/sqrt(S+B)=**28.1564** default,
S/sqrt(S+B)=**28.1636** default + cos(θ_ℓ), and S/sqrt(S+B)=**28.1622** default + cos(θ_W)

Other activities

CxAOD production and validations (*xAOD→DxAOD→CxAOD).*

- CxAODFramework validation
  - CxAOD Maker, CxAOD Maker_VHbb
  - CxAOD Reader, CxAOD Reader_VHbb
- DxAOD validation
  - r31-10 and r32-02
- CxAOD validation
  - CxAOD_r31-10 (ICHEP)
  - CxAOD_r32-02
  - CxAOD_r32-06
  - CxAOD_r32-07
  - CxAOD_r32-15
- EMTopo and Particle Flow jet comparison
- Signal efficiency checks (different cuts)
- Angular variables for 1lepton MVA.

Conclusion

✓Over the past few months, many improvements have been included in the analysis;

✓Medium p_T^V bin in 1-lepton: 75 < p_T^V < 150 GeV, Split at 250 GeV;

✓Pseudo-continuous b-tagging and BDTr;

✓Data driven top in 2lep; Redefinition of SRs and CRs (all channels);

✓ Including polarization variables as BDT input (2L-channel);

✓ MVA re-training: decision was taken on the best setup;

✓ Optimisation and validation will continue;

Plan before the end of the year:

✓To complete the analysis of full Run 2 data (140 fb^{-1}),

✓ Improve *VH*, $H \rightarrow b\bar{b}$ measurement (cross-section, μ …),

✓ Observation separately VH($b\bar{b}$) and ZH($b\bar{b}$) (expected >5σ for ZH alone).

✓ A full Run2 paper by Moriond 2020 (JHEP).

Thank You!