Study of $(W/Z)H$ production using $H \to WW^*$ decays with the ATLAS detector at LHC

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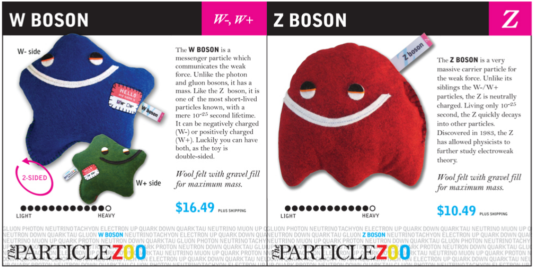


What we are studying!

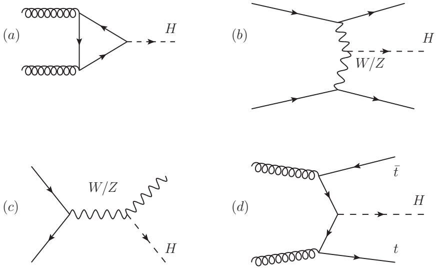
Introduction

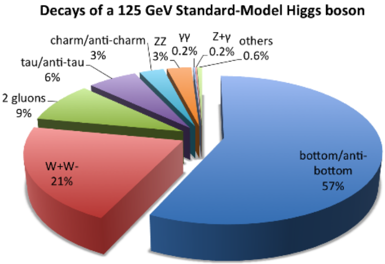
Physics Process: VH ($H \to WW^*$)

[arXiv:1307.1347]

ggF	VBF	*WH*	*ZH*	$t\bar{t}H$
19.27	1.578	0.7046	0.4153	0.1293

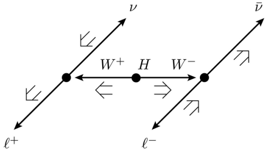
Higgs production @ 8 TeV
Cross Section [*pb*]

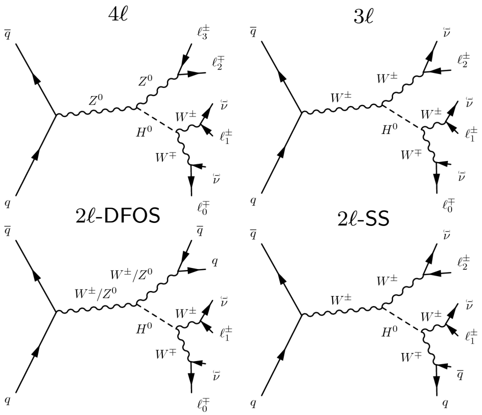




Results from [JHEP 08 (2015) 137]:
Study of $(W/Z)H$ production and Higgs boson couplings using $H \to WW^*$ decays with the ATLAS detector

In the $H \to WW^*$ decay the two leptons (ℓ_0, ℓ_1) tend to be close in angle ($\Delta R_{\ell_0 \ell_1}$)

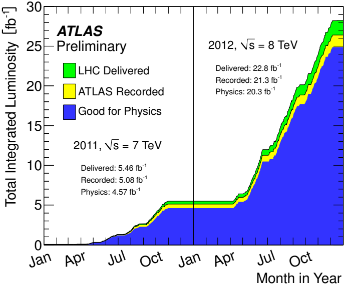




4ℓ	3ℓ	2ℓ-DFOS	2ℓ-SS
1/2 SFOS	3SF, 1/0 SFOS	1 DF	1/2 Jets
Main Signal Target			
ZH	*WH*	*WH*	*WH*

Data from ATLAS Run I
4.6 fb^{-1} @ 7 TeV
20.3 fb^{-1} @ 8 TeV

https://goo.gl/2GukAy

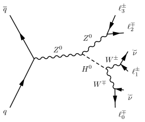


Pure Data Driven estimation is adopted whenever possible while control regions (CRs) are defined to compute Normalization Factors (NFs) on Monte Carlo (MC) background shapes in most cases

$\ell = \mu/e$
Same (Different) Flavour: SF (DF); Opposite (Same) Sign: OS (SS)

The analysis

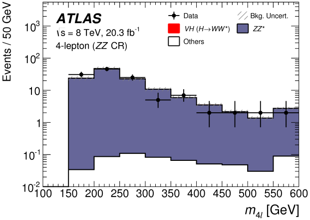
Signal topology and main backgrounds: 4ℓ, 2ℓ



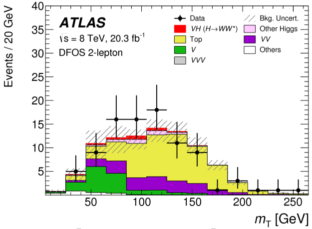
4ℓ
VVV, $WZ/W\gamma^*$,
top, ZZ^*

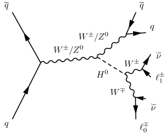
- p_T^ℓ, n_j, E_T^{miss}, p_T^{miss}, $m_{\ell\ell}$, $\underline{m_{4\ell}}$, $|\Sigma \mathbf{p}_T{}^{lep}|$, $\Delta\phi^{boost}_{\ell_0\ell_1}$

[JHEP 08 (2015) 137]



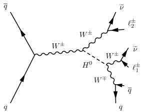
[JHEP 08 (2015) 137]





2ℓ-DFOS
VVV, $WZ/W\gamma^*$,
ZZ^*, WW, $Z\gamma$, Z/γ^*,
W+jets, multijets, top

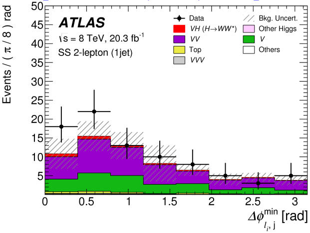
- p_T^ℓ, n_j, E_T^{miss}, $m_{\ell\ell}$, $m_{\tau\tau}$, $\Delta R_{\ell_0\ell_1}$, $\underline{m_T}$, Δy_{jj}, m_{jj}

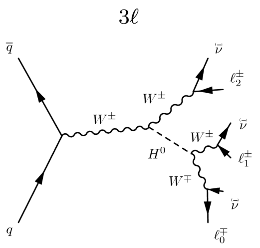


2ℓ-SS
VVV, ZZ^*, $Z\gamma$, WW,
$WZ/W\gamma^*$, $W\gamma$, Z/γ^*,
W+jets, multijets, top

- p_T^ℓ, n_j, E_T^{miss}, $\underline{\Delta\phi_{\ell_i j}}$, $m_{\ell\ell}$, $m_{\tau\tau}$, $\Delta R_{\ell_0\ell_1}$, m_T^{lead}, $m_{\ell_i j(j)}$

[JHEP 08 (2015) 137]





VVV, WW, ZZ^*, $WZ/W\gamma^*$, $Z\gamma$, Z/γ^*, top

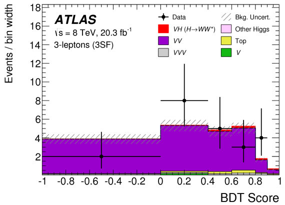
1. Cut-Based selection
   - p_T^{ℓ}, n_j, E_T^{miss}, p_T^{miss}, $m_{\ell\ell}$, $m_{3\ell}$, $|\Sigma \mathbf{p_T}^{lep}|$, $\Delta R_{\ell_0\ell_1}$
2. Shape Analysis:

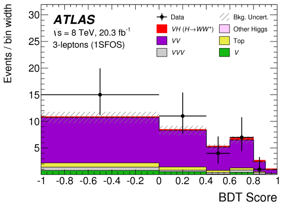
each bin is considered as a SR
⋆ BDT Score ⋆ $\Delta R_{\ell_0\ell_1}$
(3SF, 1SFOS) (0SFOS)

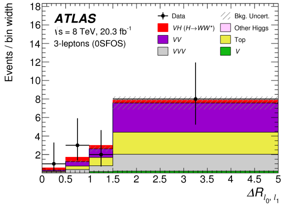
MVA in the 3SF, 1SFOS SRs

Training Sig. $WH \to WWW^{(*)} \to \ell\nu\ell\nu\ell\nu$
Training Bkg. $WZ/W\gamma^*$, ZZ^*

[JHEP 08 (2015) 137]







Results

Results I

Observed and predicted events at 8 TeV (7 TeV in backup) [JHEP 08 (2015) 137]

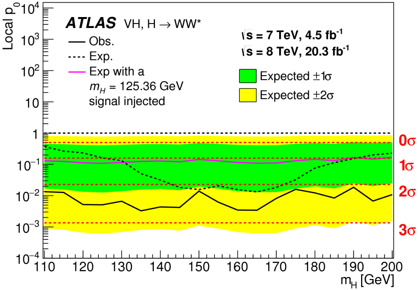
(a) 8 TeV data sample

Process	4ℓ		3ℓ			2ℓ		
Category	2SFOS	1SFOS	2SFOS	1SFOS	0SFOS	DFOS	SS2jet	SS1jet
Higgs boson								
VH ($H \to WW^*$)	0.203±0.030	0.228±0.034	0.73±0.10	1.61±0.18	1.43±0.16	2.15±0.30	1.04±0.18	2.04±0.30
VH ($H \to \tau\tau$)	0.0084±0.0032	0.012±0.004	0.057±0.011	0.152±0.023	0.248±0.035	—	0.036±0.008	0.27±0.04
ggF	—	—	0.076±0.015	0.085±0.018	—	2.4±0.5	—	—
VBF	—	—	—	—	—	0.180±0.025	—	—
ttH	—	—	—	—	—	—	—	—
Background								
V	—	—	0.22±0.16	1.9±0.6	0.37±0.15	14±4	8±4	15±5
VV	1.17±0.20	0.31±0.06	19±3	28±4	4.7±0.6	10.1±1.6	11.2±2.1	26±4
VVV	0.12±0.04	0.10±0.04	0.8±0.3	2.2±0.7	2.93±0.29	—	—	0.47±0.05
Top	0.014±0.011	—	0.91±0.26	2.4±0.6	3.7±0.9	24±4	0.75±0.19	1.3±0.5
Others	—	—	—	—	—	2.3±0.9	0.71±0.30	0.60±0.24
Total	1.30±0.23	0.41±0.09	22±4	34±6	11.7±1.8	50±5	21±5	44±6
Observed events	0	3	22	38	14	63	25	62

Maximisation of a binned likelihood function constructed as the product of Poisson probability terms P_s obtained from the number of expected signal (S_i) and background (B_i) events and from the observed (N_i) data in each i-th signal region considered:

$$L(\mu, \boldsymbol{\theta}) = \prod_{i}^{N_{SR}} P_s(N_i \mid \mu S_i(\boldsymbol{\theta}) + B_i(\boldsymbol{\theta})) \times A(\boldsymbol{\theta})$$

where μ is the *signal strength* parameter, $\boldsymbol{\theta}$ takes into account Normalisation Factors and the systematic uncertainties and $A(\boldsymbol{\theta})$ the Control Regions. μ and NFs are the free parameters of the fit procedure.

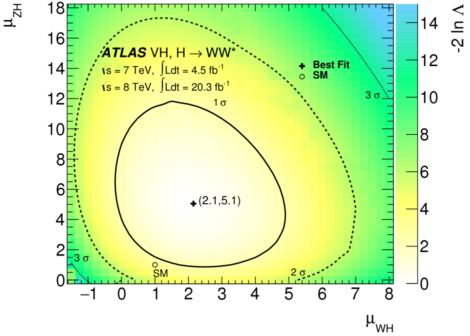


For $m_{\rm H} = 125.36\ \mathrm{GeV}$, the observed (expected) deviation from the background-only hypothesis corresponds to a significance of 2.5 (0.9)

[JHEP 08 (2015) 137]

Category	Signal significance Z_0: Exp. Z_0	Obs. Z_0	Obs. Z_0	Observed signal strength μ: μ	Tot. err. +	Tot. err. −	Syst. err. +	Syst. err. −	μ
4ℓ	0.41	1.9		**4.9**	4.6	3.1	1.1	0.40	
2SFOS	0.19	0		**−5.9**	6.8	4.1	0.33	0.72	
1SFOS	0.36	2.5		**9.6**	8.1	5.4	2.1	0.64	
3ℓ	0.79	0.66		**0.72**	1.3	1.1	0.40	0.29	
1SFOS and 3SF	0.41	0		**−2.9**	2.7	2.1	1.2	0.92	
0SFOS	0.68	1.2		**1.7**	1.9	1.4	0.51	0.29	
2ℓ	0.59	2.1		**3.7**	1.9	1.5	1.1	1.1	
DFOS	0.54	1.2		**2.2**	2.0	1.9	1.0	1.1	
SS2jet	0.17	1.4		**7.6**	6.0	5.4	3.2	3.2	
SS1jet	0.27	2.3		**8.4**	4.3	3.8	2.3	2.0	
			0 1 2 3						-10 -8 -6 -4 -2 0 2 4 6 8 10 12 14 16

Summary and Conclusions



The fit results for the μ values for the WH, ZH and VH production are:

$$\mu_{WH} = 2.1^{+1.5}_{-1.3}\,(\text{stat.})^{+1.2}_{-0.8}\,(\text{sys.}),$$

$$\mu_{ZH} = 5.1^{+3.8}_{-3.0}\,(\text{stat.})^{+1.9}_{-0.9}\,(\text{sys.}),$$

$$\mu_{VH} = 3.0^{+1.3}_{-1.1}\,(\text{stat.})^{+1.0}_{-0.7}\,(\text{sys.}).$$

[JHEP 08 (2015) 137]

- Analyses were optimised for 8 TeV data then extended to 7 TeV.
- Study of VH production and combined $H \to WW^*$ results in 8 TeV and 7 TeV data collected by ATLAS in Run I successfully concluded and published on JHEP.
- Excesses in $(W/Z)H$ should be re-examined with Run II data at 13 TeV.
- Results are essentially consistent with SM, main limitations due to statistics.
- It's time to work with new data at 13 TeV!

Many thanks for your attention

- $\mathbf{E}_{\mathrm{T}}^{\mathrm{miss}}$ is reconstrunced using energy deposits in calorimeter, $\mathbf{p}_{\mathrm{T}}^{\mathrm{miss}}$ using tracks
- $y = \frac{1}{2}\ln\left(\frac{E+p_{\mathrm{Z}}}{E-p_{\mathrm{Z}}}\right)$
- $\eta = -\ln\left[\tan\left(\frac{\theta}{2}\right)\right]$ or $\frac{1}{2}\ln\left(\frac{|\mathbf{p}|+p_{\mathrm{Z}}}{|\mathbf{p}|-p_{\mathrm{Z}}}\right)$
- $\Delta R = \sqrt{\Delta^2\eta + \Delta^2\phi}$
- (4ℓ) $\mathbf{p}_{\mathrm{T}}^{H} \sim -\mathbf{p}_{\mathrm{T}}^{Z}(-\mathbf{p}_{\mathrm{T}}^{\mathrm{jet}})$
- (2ℓ) $m_{\mathrm{T}} = \sqrt{(E_{\mathrm{T}}^{\ell\ell} + E_{\mathrm{T}}^{\mathrm{miss}})^2 - |\mathbf{p}_{\mathrm{T}}{}^{\ell\ell} + \mathbf{E}_{\mathrm{T}}^{\mathrm{miss}}|^2}$, where $E_{\mathrm{T}}^{\ell\ell} = \sqrt{|\mathbf{p}_{\mathrm{T}}{}^{\ell\ell}|^2 + m_{\ell\ell}^2}$
- (2ℓ) $m_{\tau\tau}$, ℓ_0 and ℓ_1 are considered as generated from a τ decay, m is reconstructed using collinear approximation and $E_{\mathrm{T}}^{\mathrm{miss}}$
- (2ℓ) $m_{\mathrm{T}}^{\mathrm{lead}} = \sqrt{2 \times p_{\mathrm{T,lead}} \times E_{\mathrm{T}}^{\mathrm{miss}} \times (1 - \cos(\phi_{\mathrm{lead}} - \phi_{E_{\mathrm{T}}^{\mathrm{miss}}}))}$

Backup Slides

Signal Regions definitions

[JHEP 08 (2015) 137]

Channel	4ℓ		3ℓ			2ℓ		
Category	2SFOS	1SFOS	3SF	1SFOS	0SFOS	DFOS	SS2jet	SS1jet
Trigger	single-lepton triggers		single-lepton triggers			single-lepton & dilepton triggers		
Num. of leptons	4	4	3	3	3	2	2	2
$p_{\mathrm{T,leptons}}$ [GeV]	$> 25, 20, 15$	$> 25, 20, 15$	> 15	> 15	> 15	$> 22, 15$	$> 22, 15$	$> 22, 15$
Total lepton charge	0	0	± 1	± 1	± 1	0	± 2	± 2
Num. of SFOS pairs	2	1	2	1	0	0	0	0
Num. of jets	≤ 1	≤ 1	≤ 1	≤ 1	≤ 1	≥ 2	2	1
$p_{\mathrm{T,jets}}$ [GeV]	> 25 (30)	> 25 (30)	> 25 (30)	> 25 (30)	> 25 (30)	> 25 (30)	> 25 (30)	> 25 (30)
Num. of b-tagged jets	0	0	0	0	0	0	0	0
$E_{\mathrm{T}}^{\mathrm{miss}}$ [GeV]	> 20	> 20	> 30	> 30	—	> 20	> 50	> 45
$p_{\mathrm{T}}^{\mathrm{miss}}$ [GeV]	> 15	> 15	> 20	> 20	—	—	—	—
$\lvert m_{\ell\ell} - m_Z \rvert$ [GeV]	< 10 ($m_{\ell_2\ell_3}$)	< 10 ($m_{\ell_2\ell_3}$)	> 25	> 25	—	—	> 15	> 15
Min. $m_{\ell\ell}$ [GeV]	> 10 ($m_{\ell_0\ell_1}$)	> 10 ($m_{\ell_0\ell_1}$)	> 12	> 12	> 6	> 10	> 12 ($ee, \mu\mu$)	> 12 ($ee, \mu\mu$)
							> 10 ($e\mu$)	> 10 ($e\mu$)
Max. $m_{\ell\ell}$ [GeV]	< 65 ($m_{\ell_0\ell_1}$)	< 65 ($m_{\ell_0\ell_1}$)	< 200	< 200	< 200	< 50	—	—
$m_{4\ell}$ [GeV]	> 140	—	—	—	—	—	—	—
$p_{\mathrm{T},4\ell}$ [GeV]	> 30	—	—	—	—	—	—	—
$m_{\tau\tau}$ [GeV]	—	—	—	—	—	$< (m_Z - 25)$	—	—
$\Delta R_{\ell_0\ell_1}$	—	—	< 2.0	< 2.0	—	—	—	—
$\Delta\phi_{\ell_0\ell_1}$ [rad]	< 2.5 ($\Delta\phi_{\ell_0\ell_1}^{\mathrm{boost}}$)	< 2.5 ($\Delta\phi_{\ell_0\ell_1}^{\mathrm{boost}}$)	—	—	—	< 1.8	—	—
m_{T} [GeV]	—	—	—	—	—	< 125	—	> 105 ($m_{\mathrm{T}}^{\mathrm{lead}}$)
Min. $m_{\ell_i j(j)}$ [GeV]	—	—	—	—	—	—	< 115	< 70
Min. $\phi_{\ell_i j}$ [rad]	—	—	—	—	—	—	< 1.5	< 1.5
Δy_{jj}	—	—	—	—	—	< 1.2	—	—
$\lvert m_{jj} - 85 \rvert$ [GeV]	—	—	—	—	—	< 15	—	—

Normalisation Factors

(a) 8 TeV data sample

Channel	4ℓ	3ℓ	2ℓ	
Category	2SFOS, 1SFOS	3SF, 1SFOS, 0SFOS	DFOS	SS2jet, SS1jet
Process				
$WZ/W\gamma^*$	—	$1.08^{+0.08}_{-0.06}$	—	0.94 ± 0.10
ZZ^*	$1.03^{+0.11}_{-0.10}$	$1.28^{+0.22}_{-0.20}$	—	—
OS WW	—	—	—	0.80 ± 0.33
$W\gamma$	—	—	—	1.06 ± 0.12
$Z\gamma$	—	$0.62^{+0.15}_{-0.14}$	—	—
Z/γ^*	—	$0.80^{+0.68}_{-0.53}$ (μ-misid) $0.33^{+0.12}_{-0.11}$ (e-misid)	$0.90^{+0.18}_{-0.16}$	0.86 ± 0.30
Top	—	$1.36^{+0.34}_{-0.30}$	$1.05^{+0.16}_{-0.14}$	1.04 ± 0.08

[JHEP 08 (2015) 137]

(b) 7 TeV data sample

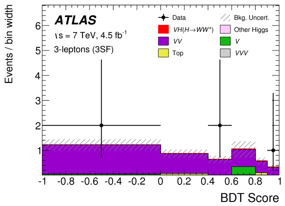
Process			
$WZ/W\gamma^*$	—	$1.02^{+0.12}_{-0.11}$	—
ZZ^*	$1.59^{+0.36}_{-0.31}$	$1.78^{+0.51}_{-0.42}$	—
OS WW	—	—	—
$W\gamma$	—	—	—
$Z\gamma$	—	$0.45^{+0.09}_{-0.09}$	—
Z/γ^*	—	$0.68^{+0.16}_{-0.15}$ (e-misid)	$1.11^{+0.38}_{-0.34}$
Top	—	$1.25^{+0.66}_{-0.52}$	$0.93^{+0.16}_{-0.14}$

[JHEP 08 (2015) 137]

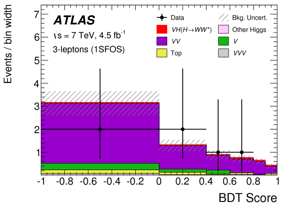
7 TeV data sample

Process	4ℓ		3ℓ			
Category	2SFOS	1SFOS	3SF	1SFOS	0SFOS	DFOS
Higgs boson						
$V(H \to WW^*)$	0.0226±0.0033	0.0208±0.0031	0.129±0.013	0.325±0.034	0.291±0.031	0.28±0.05
$V(H \to \tau\tau)$	0.0031±0.0012	0.0014±0.0008	0.0163±0.0035	0.041±0.006	0.067±0.010	0.0075±0.0032
ggF	—	—	0.0045±0.0015	0.0045±0.0019	0.0048±0.0027	0.32±0.09
VBF	—	—	—	—	—	0.021±0.004
$t\bar{t}$H	—	—	—	0.006±0.004	0.0041±0.0032	—
Background						
V	—	—	0.36±0.30	0.59±0.34	0.36±0.22	3.4±1.3
VV	0.37±0.14	0.031±0.013	4.1±0.6	5.7±1.0	1.3±0.2	0.89±0.27
VVV	0.014±0.005	0.0095±0.0033	0.082±0.028	0.21±0.07	0.338±0.031	—
Top	0.006±0.004	—	0.12±0.14	0.4±0.3	0.44±0.29	3.2±0.8
Others	—	—	—	—	—	—
Total	0.39±0.15	0.041±0.016	4.6±1.1	7.0±1.9	2.5±0.7	7.5±1.7
Observed events	1	0	5	6	2	7

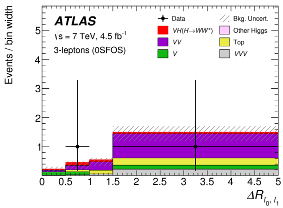
3ℓ 3SF



3ℓ 1SFOS



3ℓ 0SFOS



Commonly used BDT parameters

When a MVA technique is chosen, need to define the value of the parameters.
BDT is the most used, main parameters:

- NTrees: the number of trees in the forest;
- nEventsMin: the minimum number of events requested in a final node;
- MaxDepth: the maximum number of layers in one tree;
- Shrinkage: the learning rate of the BDTs;
- GradBaggingFrac: the bagging fraction, which is the fraction of events to be used at each iteration;
- nCuts: the number of steps during node cut optimization;
- AdaBoostBeta: the exponent of the boost weight[1] ($\alpha \rightarrow \alpha^{\beta}$);
- IgnoreNegWeightsInTraining: events with negative weights are ignored in the training (but are included for testing and performance evaluation);
- NNodesMax: limit the size of the tree (deprecated, use MaxDepth instead);
- MinNodeSize: minimum percentage of training events required in a leaf node.

[1] The boost weight is derived from the misclassification rate, err, of the previous tree: $\alpha = \frac{1 - err.}{err.}$.

Multivariate Analysis: details

BDT parameter	Used value
NTrees	1000
nEventsMin	1430
UseBaggedGrad	True
GradBaggingFraction	0.5
Shrinkage	0.1
MaxDepth	3

Training cuts

Cut 1: Selection of events with a SFOS lepton pair or 3SF leptons

Cut 2: 'jet-veto', at most one jet with $p_{\mathrm{T}} > 25$ GeV

Cut 3: 'top-veto', no *b*-tagged jets with $p_{\mathrm{T}} > 20$ GeV

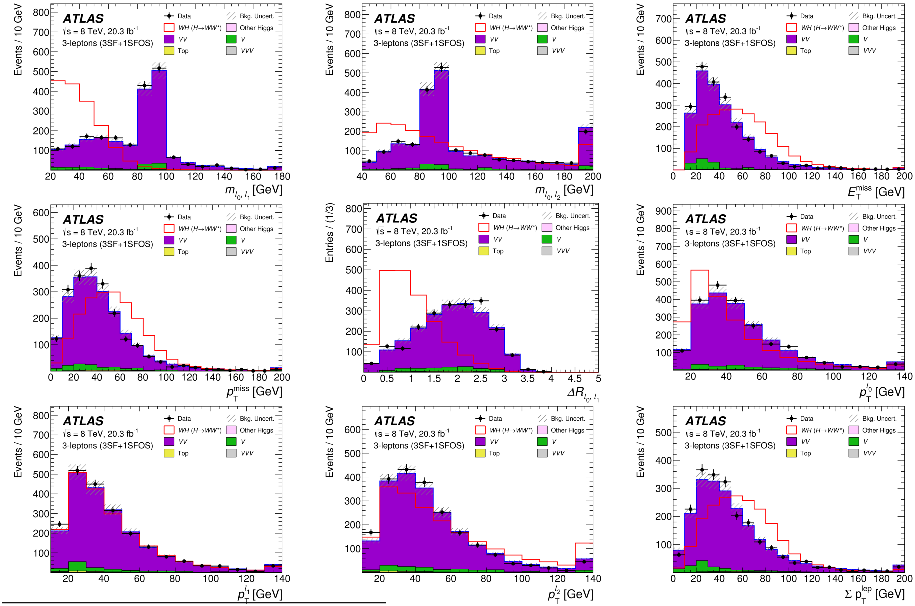
Cut 4: $E_{\mathrm{T}}^{\mathrm{miss}} > 15$ GeV

Training variables

- $p_{\mathrm{T}}^{\ell_0}$, $p_{\mathrm{T}}^{\ell_1}$, $p_{\mathrm{T}}^{\ell_2}$, $|\Sigma \mathbf{p}_{\mathrm{T}}{}^{\mathrm{lep}}|$;
- $m_{\ell_0\ell_1}$, $m_{\ell_0\ell_2}$, $\Delta R_{\ell_0\ell_1}$;
- $E_{\mathrm{T}}^{\mathrm{miss}}$, $p_{\mathrm{T}}^{\mathrm{miss}}$

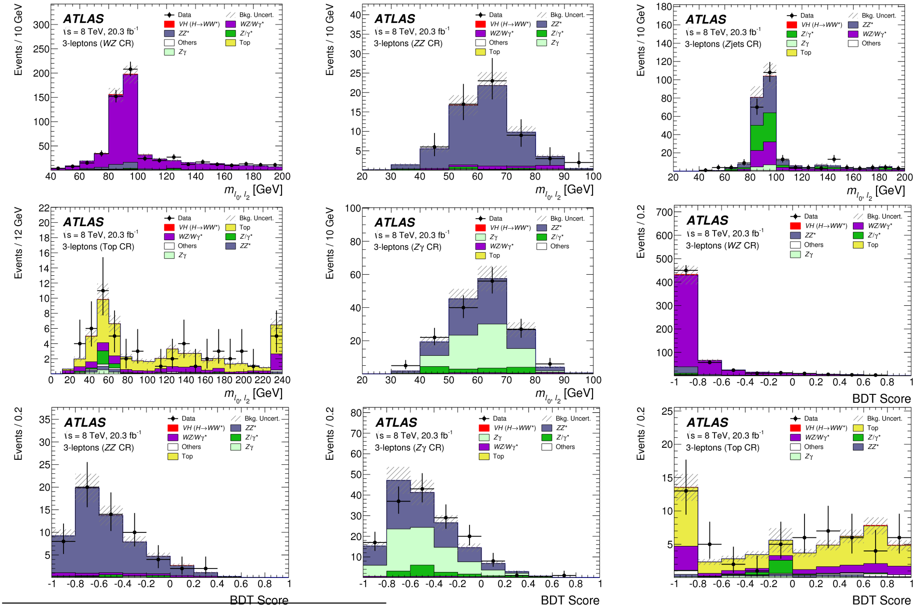
MC Sample	Events in the training
WH	45000
$WZ/W\gamma^*$ plus ZZ^*	180000

Number of signal and background MC events used in the training



WH × 500 [JHEP 08 (2015) 137]

Plots from 3ℓ Control Regions at 8 TeV



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VH uncertainties

(a) Uncertainties on the $VH(H \to WW^*)$ process (%)

Channel	4ℓ		3ℓ			2ℓ		
Category	2SFOS	1SFOS	3SF	1SFOS	0SFOS	DFOS	SS2jet	SS1jet
Theoretical uncertainties								
VH acceptance	9.2	9.3	9.9	9.9	9.9	10	10	9.9
Higgs boson branching fraction	4.2	4.2	4.2	4.2	4.2	4.2	4.2	4.2
QCD scale	3.1	3.0	1.2	1.0	1.0	1.3	1.0	1.0
PDF and α_S	1.0	1.1	2.1	2.2	2.2	1.9	2.3	2.2
VH NLO EW corrections	1.7	1.8	1.9	1.9	1.9	1.9	1.9	1.9
Experimental uncertainties								
Jet	2.0	3.1	2.5	2.5	2.9	3.2	8.9	5.8
E_T^{miss} soft term	0.2	0.3	–	–	–	0.3	0.6	0.2
Electron	2.6	2.8	1.6	2.2	2.2	1.5	2.1	1.7
Muon	2.6	2.4	2.2	1.8	1.7	0.8	1.8	1.9
Trigger efficiency	0.2	–	0.4	0.3	0.3	0.5	0.6	0.5
b-tagging efficiency	0.9	0.9	0.9	0.8	0.8	2.9	3.5	2.4
Pile-up	1.9	0.7	2.0	1.4	0.8	1.7	1.0	2.4
Luminosity	2.8	2.8	2.8	2.8	2.8	2.8	2.8	2.8

(b) Uncertainties on the total background (%)

Theoretical uncertainties								
QCD scale	0.2	0.1	1.0	0.9	–	3.7	13	2.3
PDF and α_S	0.2	2.4	0.3	0.3	1.6	1.4	0.5	0.6
VVV K-factor	2.8	8.1	1.1	1.9	0.5	–	–	0.3
MC modelling	5.3	4.3	7.0	6.6	–	4.1	0.8	1.4
Experimental uncertainties								
Jet	3.1	2.4	3.2	1.8	4.1	7.2	5.0	3.4
E_T^{miss} soft term	2.3	0.6	1.8	1.9	0.5	1.1	0.2	0.7
Electron	1.0	1.4	1.0	0.4	1.1	0.7	1.1	0.8
Muon	1.1	1.2	0.4	0.7	0.2	0.2	0.4	0.8
Trigger efficiency	–	0.2	0.2	–	–	0.1	–	–
b-tagging efficiency	0.6	0.8	0.6	0.8	2.6	0.7	1.4	0.3
Fake factor	–	–	–	–	–	2.8	10	10
Charge mis-assignment	–	–	–	–	1.4	–	0.7	0.8
Photon conversion rate	–	–	–	–	–	–	1.1	0.9
Pile-up	1.2	1.1	1.4	0.3	1.2	0.9	1.0	1.0
Luminosity	0.4	0.8	0.1	0.2	0.7	–	0.7	0.3
MC statistics	5.3	8.0	3.8	3.2	5.5	3.1	7.3	3.9
CR statistics	8.1	6.6	4.2	3.9	8.8	2.5	2.8	3.5

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Effect of VH uncertainties on μ_{VH}

Uncertainties on the signal strength μ_{VH} (%)		
Signal theoretical uncertainties	$\Delta\mu_{VH}/\mu_{VH}$	
	+	-
VH acceptance	11	7
Higgs boson branching fraction	7	4
QCD scale	1.6	0.7
PDF and α_S	3.2	1.5
VH NLO EW corrections	2.5	1.2
Background theoretical uncertainties		
QCD scale	10	9
PDF and α_S	2.3	2.0
VVV K-factor	3.0	3.0
MC modelling	7.5	6.9
Experimental uncertainties		
Jet	14	9
E_T^{miss} soft term	3.4	2.3
Electron	4.8	2.9
Muon	4.8	3.2
Trigger efficiency	1.7	0.9
b-tagging efficiency	4.7	3.2
Fake factor	14	12
Charge mis-assignment	1.1	1.0
Photon conversion rate	0.8	0.7
Pile-up	3.0	1.9
Luminosity	5.4	3.3
MC statistics	8	8
CR statistics	18	15
ggF SR statistics	5.5	4.4
VBF SR statistics	1.9	1.5
ggF+VBF CR statistics	10	9

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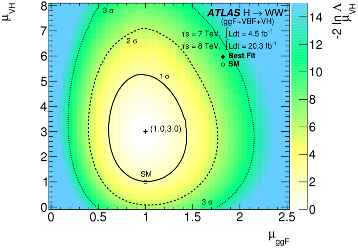
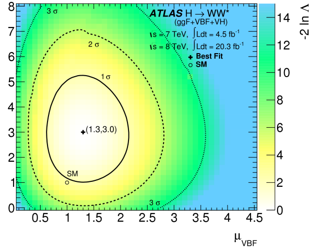
Combination VH+ggF+VBF production mode ($H \rightarrow WW^*$)

The best fit values are $\mu_{\mathrm{VH}} = 3.0^{+1.6}_{-1.3}$, and $k_F = 0.85^{+0.26}_{-0.20}$, $|k_V| = 1.06^{+0.10}_{-0.10}$





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