Search for the Higgs boson in the VH(bb) channel with the ATLAS detector

Faig Ahmadov

Institute of Physics, ANAS
Joint Institute for Nuclear Research

25.04.2018

Overview

- *Introduction*
- *SM Higgs boson*
- *Analysis methods*
- *The 2015-2016 data analysis results*
- *Expected results from full Run-II*
- *Conclusion*

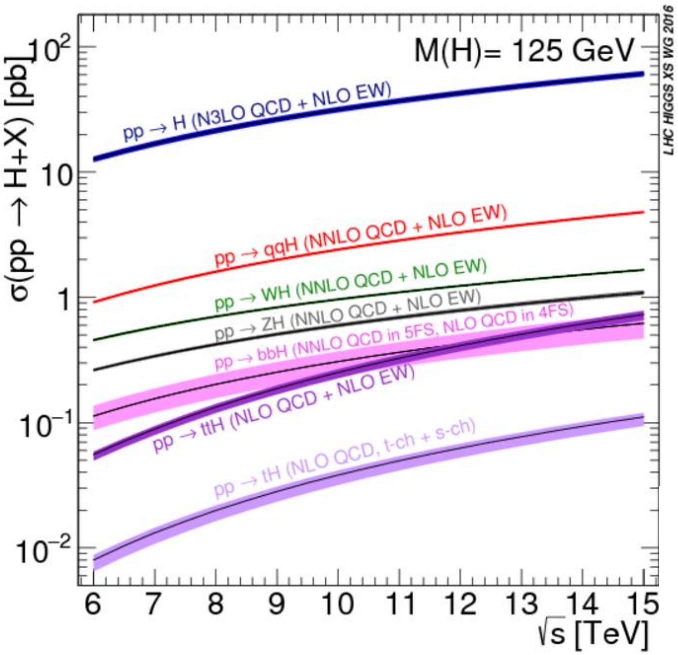
Introduction

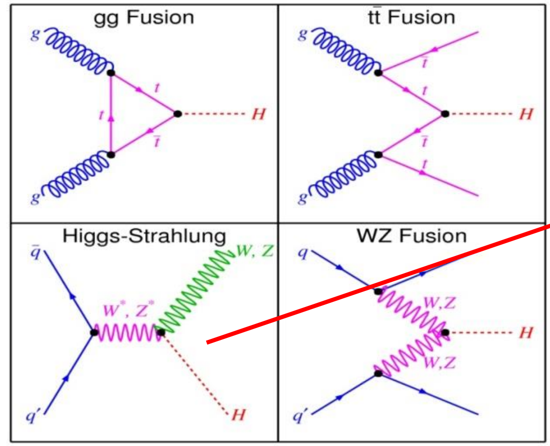
- *Understanding the mechanism that breaks electroweak symmetry and generates the mass of all known elementary particles is one of the most fundamental problems in particle physics.*
- *The most popular theory to introduce mass into the SM is the Higgs mechanism.*
- *Higgs boson to give the W, Z bosons, and fermions their masses.*
- *The search for the SM Higgs boson was a central component of the physics program not only at the LHC, also at previous colliders as LEP and Tevatron.*
- *In July 2012, the ATLAS and CMS experiments reported the observation of a new particle with a mass of about 125 GeV and with properties consistent with those expected from the SM Higgs boson.*

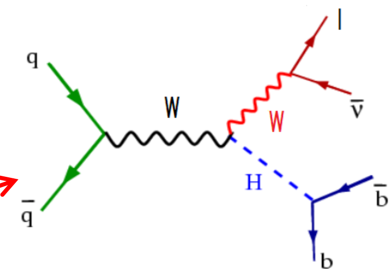
Higgs boson

- *Determining the nature of this boson - whether it is indeed the SM Higgs boson - is one of the most important questions in particle physics.*
- *An SM Higgs boson with a mass of about 125 GeV would be accessible in both bosonic and fermionic decay channels at the LHC.*
- *The ATLAS & CMS measurements have been performed in the bosonic decay modes of the new particle ($H \to \gamma\gamma$, $H \to ZZ$, & $H \to WW$);*
- *Since then, more precise measurements have strengthened the hypothesis that the new particle is indeed a Higgs boson.*
- *Observing the decay into fermions is vital in testing whether the new boson is compatible with a SM Higgs boson.*
- *In particular, the decay to b-quarks plays an important role since this is the dominant decay mode at this mass ($BR(H \to bb) \approx 58\%$).*
- *Therefore an observation in this channel is crucial in order to provide a direct constraint on the largest decay mode.*

Production & decay channels



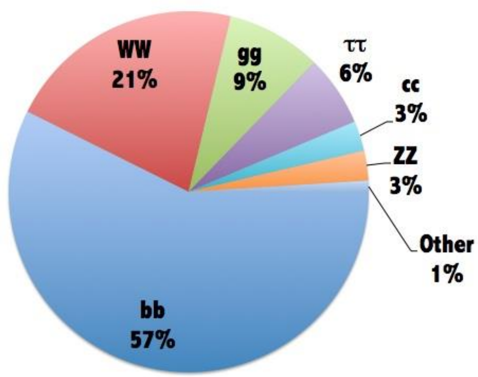




V (H→bb); V=W or Z

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

Higgs decays at m_H=125GeV



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

Higgs boson production cross section as a function of the CoM energy.

XS(pp->H->bb) ~ 30pb
XS(Bkg->bb)~10^6pb

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

*XS(Bkg) ~ **10^3 pb***

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

Analysis methods

Two methods are used for data analysis:

- ***Cut-flow*** *- which based on some kinematic variables and the best cuts for them (for cross check);*
- ***Multivariate*** *-* ***a****nalyze (****MVA****) data with more than one variable and take into account relation between them (For main result).*

In this analysis used two MVA techniques:

B*oosted* ***D****ecision* ***T****ree (****BDT****) and* ***N****eural* ***N****etwork (****NN****).*

Input variables

Variable	0-lepton	1-lepton	2-lepton
p_T^V		$\times$	$\times$
E_T^{miss}	$\times$	$\times$	$\times$
$p_T^{b_1}$	$\times$	$\times$	$\times$
$p_T^{b_2}$	$\times$	$\times$	$\times$
m_{bb}	$\times$	$\times$	$\times$
$\Delta R(b_1, b_2)$	$\times$	$\times$	$\times$
$\|\Delta\eta(b_1, b_2)\|$	$\times$		$\times$
$\Delta\phi(V, bb)$	$\times$	$\times$	$\times$
$\|\Delta\eta(V, bb)\|$			$\times$
H_T	$\times$		
$\min[\Delta\phi(\ell, b)]$		$\times$	
m_T^W		$\times$	
m_{ll}			$\times$
m_{Top}		$\times$	
$\|\Delta Y(V, H)\|$		$\times$	
	Only in 3-jet events		
$p_T^{jet_3}$	$\times$	$\times$	$\times$
m_{bbj}	$\times$	$\times$	$\times$

$V(H\rightarrow bb)$ event selection

Trigger: MET trigger, single electron and muon triggers

Selection cuts: at least 2 "signal" jets ($|\eta|<2.5$ and $p_T > 20$ GeV)

exactly two b-tags (MV2c10 @70%); $p_T(j_1) > 45$ GeV;

pTV or MET regions: reg.1. 150-200GeV & reg.2. >200GeV

ZH→vvbb: *0 Lepton*

- *0 loose leptons*
- *max. 3 signal jets*
- *Anti-QCD cuts (topological cuts)*
- *$E_T^{miss} > 150$ GeV*

WH→lvbb: *1 Lepton*

- *exactly 1 signal lepton*
- *max. 3 signal jets*
- *$E_T^{miss} > 30$ GeV (for electron channel)*
- *$p_T^W > 150$ GeV*

ZH→llbb: *2 Leptons*

- *exactly 2 loose leptons (of which at least 1 is signal lepton)*
- *$71 < m_{ll} < 121$ GeV*
- *$p_T^Z > 75$ GeV*

Cut-flow analysis

Event preselection
Object selection:
- Electron selection
- Muon selection
- Jet selection (b-jet selection)
- Neutrino selection (Missing transverse energy)

Final event selection

Additional event selection cuts for cut-based analysis:

ZH→ννbb: *0 Lepton*	***WH→lνbb:*** *1 Lepton*	***ZH→llbb:*** *2 Leptons*
$dR(b_1,b_2)<1.8$ (reg. 1)	$dR(b_1,b_2)<1.8$ (reg. 1)	$dR(b_1,b_2)<1.8$ (reg. 1)
$dR(b_1,b_2)<1.2$ (reg. 2)	$dR(b_1,b_2)<1.2$ (reg. 2)	$dR(b_1,b_2)<1.2$ (reg. 2)
	$m_T W < 120$ GeV	$81 < m_{ll} < 101$

Object selection

Event preselection: GRL, Vertex, min. 3 tracks, pile-up reweighting, triggers, Cleaning cuts: MET cleaning, Jet cleaning, LAr error, Tile error, Incomplete events;

Electrons:
Loose: $|\eta|<2.47$, $E_T > 7$GeV , $|d0|<0.1$mm (for 7TeV data), pT cone(0.2) <0.04, OR
Signal: Loose + $E_T > 25$GeV, E_T cone (0.3) <0.04.

Muons:
Loose: $|\eta|<2.7$, $E_T > 10$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: pT > 20GeV & $|\eta|<2.5$ or pT > 30GeV & $2.5<|\eta|<4.5$, OR with mu and el.
Signal: Veto + pT > 20GeV & $|\eta|<2.5$

b-jets: The MV1 b-tagging algorithm is used to identify jets originating from b-quark fragmentation), MV1 with 70% eff. , (80% for 8 TeV data).

Event selection cuts

Variable	Cut-flow analysis				
Common selection					
p_T^W[Gev]	0-90	90-120	120-160	160-200	>200
$\Delta R(b_1,b_2)$	0.7-3.4	0.7-3.0	0.7-2.3	0.7-1.8	<1.4
Event selection					
M_T^W [GeV]	<120				
H_T [GeV]	>180		-		
E_T^{miss} [GeV]	-		>20		>50

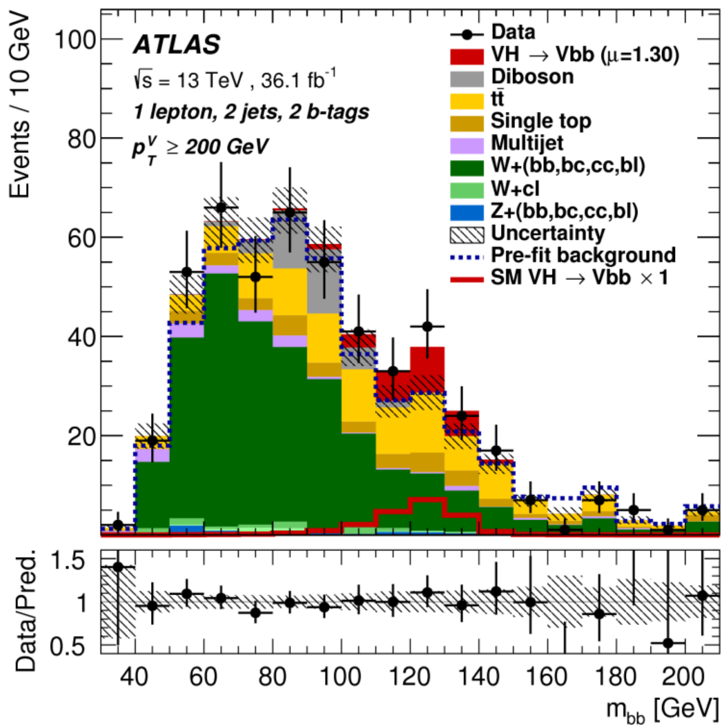
$$H_T = p_T^l + E_T^{miss} + p_T^b + p_T^{\bar{b}}$$

Yields (2 jets)

sampleName	entries	integral	error	error/integ.
qqWlvH125	158823	52.0287	0.145262	0.00279196
qqZvvH125	2	0.000540332	0.000382636	0.708151
qqZllH125	7059	0.797726	0.0106718	0.0133778
ZZ	291	3.34421	0.409395	0.122419
WZ	1684	72.8807	3.55603	0.0487926
WW	24	7.29472	2.88302	0.39522
multijet	201	42.4723	17.5272	0.412673
Zl	4	0.303305	0.377876	1.24586
Zcl	18	1.11229	0.906433	0.814927
Zcc	19	2.40191	1.14183	0.475384
Zbl	152	4.58319	1.38337	0.301835
Zbc	135	2.67225	0.559203	0.209263
Zbb	3017	53.7849	2.03166	0.0377737
Wl	39	7.33822	6.3967	0.871696
Wcl	170	83.6492	11.673	0.139547
Wcc	145	54.0292	9.66264	0.178841
Wbl	794	59.3359	3.65196	0.0615472
Wbc	1621	116.668	4.96555	0.0425615
Wbb	13377	748.986	10.5132	0.0140365
stopWt	1405	345.969	9.45009	0.0273149
stopt	1734	399.554	14.3798	0.0359897
stops	2678	146.56	2.95796	0.0201827
ttbar	12401	3116.44	29.2527	0.00938658
bkg:	39909	5269.38		
data	5906	5906		

Cut-flow output

The m_{bb} distributions in the 1-lepton channels for 2-b-tag events, in the 2-jet categories for $p_T V > 200$ GeV. The background contributions after the global likelihood fit are shown as filled histograms. The Higgs boson signal (m_H=125 GeV) is shown as a filled histogram on top of the fitted backgrounds

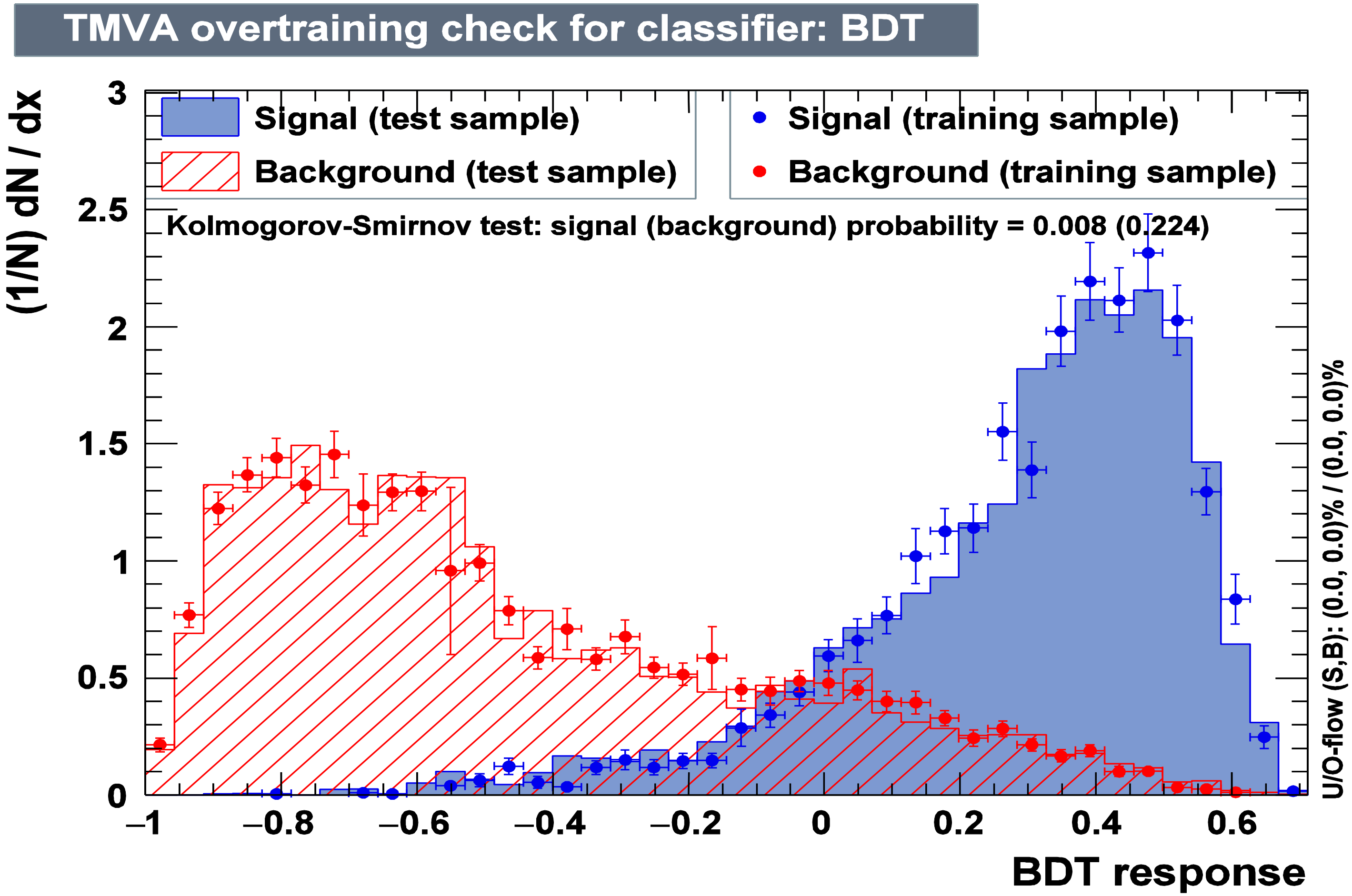


Agreement between data and estimated background is observed within the uncertainties

Multivariate Analysis

- The input variables are chosen in order to maximise the separation of the signal and background events.
- MVA is used to improve cut-flow analysis results.
- The selection criteria are looser in the MVA than in the cut-flow analysis in order to maximize the information available to the final discriminant.
- BDT & NN technique as an effective multivariate method, is used to properly account for correlations between variables.

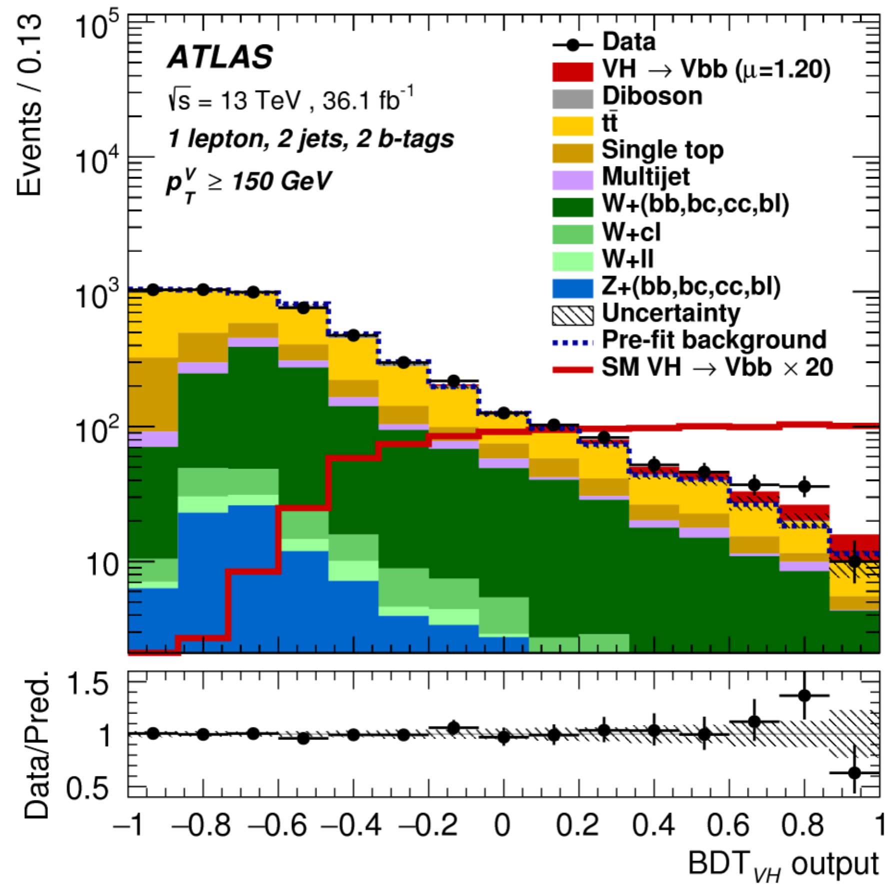
BDT response



Good separation of signal and background events in the BDT

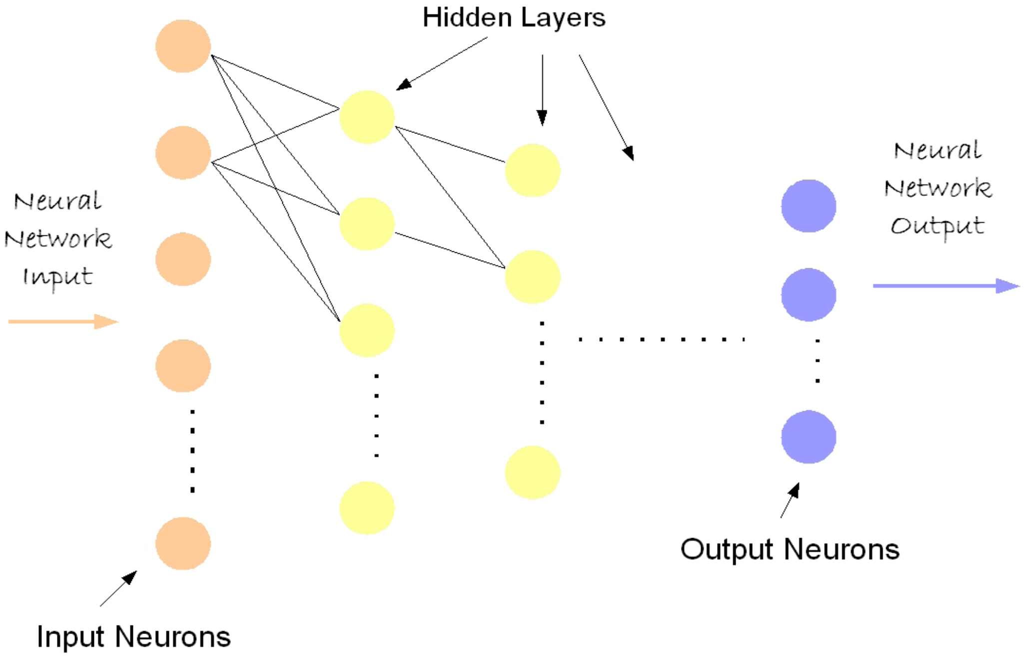
BDT output

The BDTVH output post-fit distributions in the 1-lepton channel for 2-b-tag events, in the 2-jet categories in the high $p_T V$ region. The background contributions after the global likelihood fit are shown as filled histograms. The Higgs boson signal (m_H = 125 GeV) is shown as a filled histogram on top of the fitted backgrounds normalised to the signal yield extracted from data (μ=1.20).



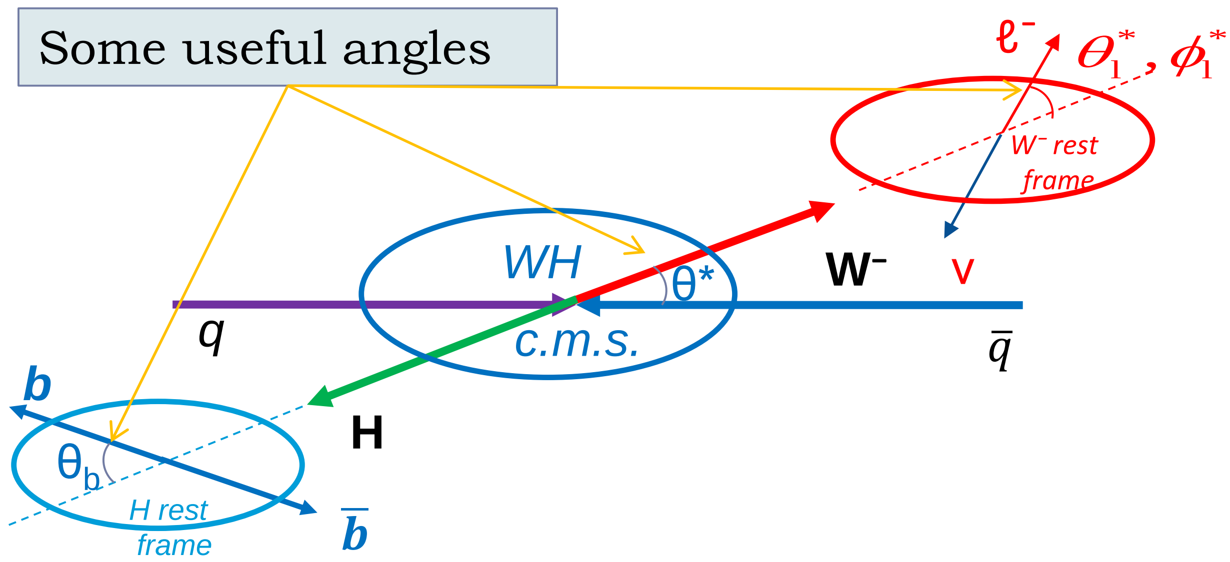
Neural Network (NN)

- Skimmed dataset files with the only variables we need (incl. proper corrections)
- Flat ntuples with new variables which we need as NN inputs
- NN training and testing
- NN output values change in the interval [-1,1] or [0,1]



additional input variables: $\cos\theta_W$, $\cos\theta_l$, $\cos\theta_b$

Some new variables in NN

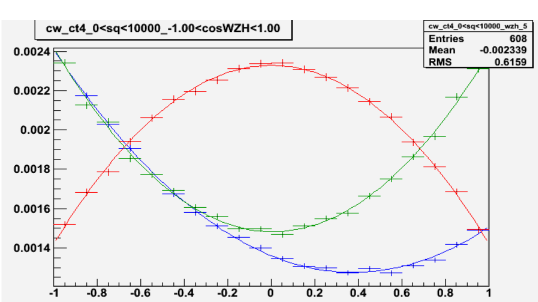


WZ($b\bar{b}$)

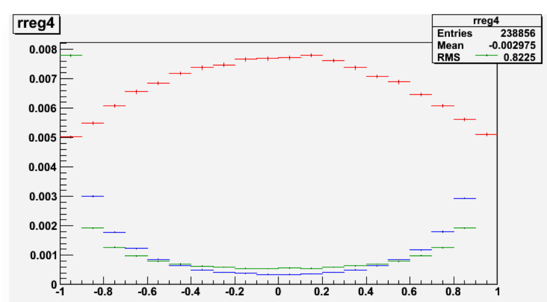
WH($b\bar{b}$)

W$b\bar{b}$

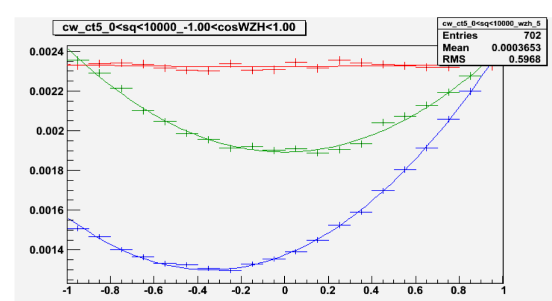
$\cos\vartheta_e^*$



$\cos\vartheta_w$



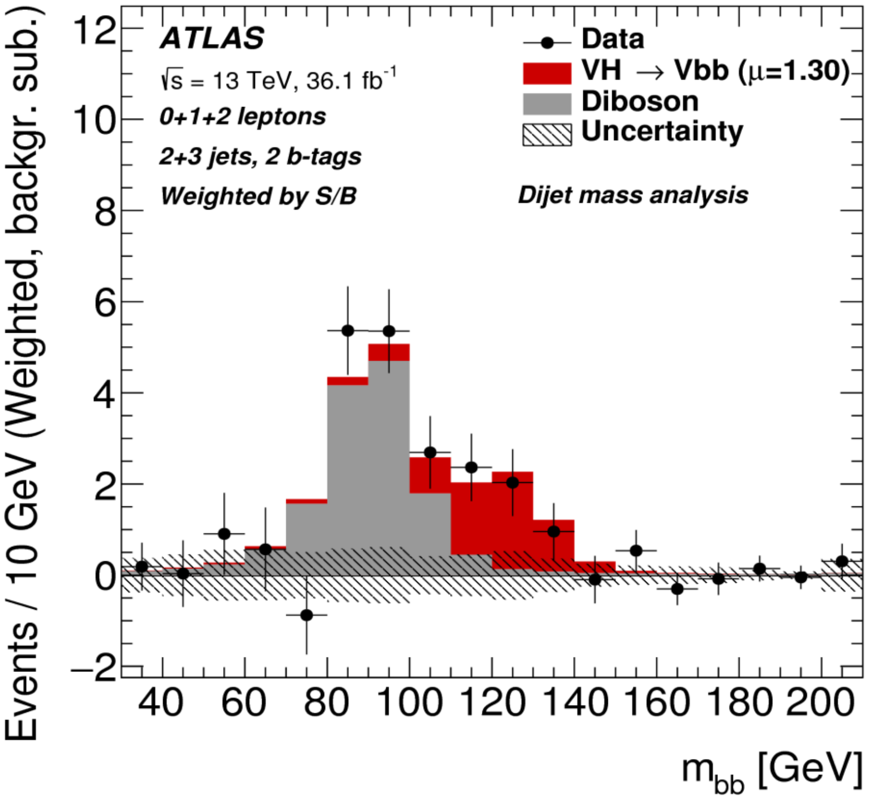
$\cos\vartheta_b^*$



Cut-Flow result

The cut-flow method of the analysis was applied to the experimental data at 13 TeV for crosscheck and revealed excess of the observed (expected) events over the expected background from the Standard Model is 3.5σ (2.8σ) and for the μ found

$$1.30^{+0.28}_{-0.27}(\text{stat.})^{+0.37}_{-0.29}(\text{syst.})$$



MVA result

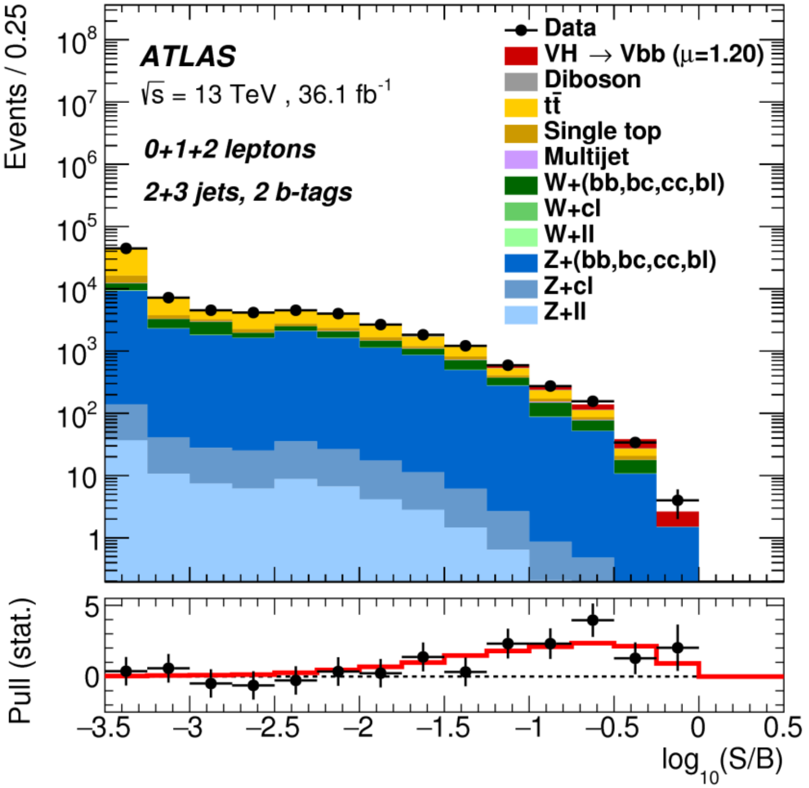
The multi-dimensional MVA method of the analysis was applied to the experimental data at 13 TeV and revealed excess of the observed events over the expected background from the Standard Model.

Event yields as a function of log(S/B) for data, background and a Higgs boson signal with m_H=125GeV.

For the Higgs boson mass of 125 GeV, the observation corresponds to an excess with a significance of 3.5σ, to be compared to an expectation of 3.0σ.

For all channels combined the fitted value of the signal strength parameter is

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



Expected results from full Run-II datasets

Two times more data in full 13TeV datasets $L=80fb^{-1}$;

Reasonable agreement between data and MC in full 13TeV data;

Signal efficiency can be improved by adding the new variables;

Expected some other improvements;

Processing of data collected in 2017 ($43.8fb^{-1}$) continues;

We are aiming for 5σ significance in later summer 2018.

Conclusions

The data of the ATLAS experiment collected in 2015-2016, corresponding to an integrated luminosity of **36.1fb^{-1}**, are analyzed in order to search for the decay of the Higgs boson into a bb quarks pair when produced in association with a vector boson.

Two methods were used for data analysis, BDT multivariate techniques for obtaining the main results and “cut-base” method for the validation of the results.

For the Higgs boson with a mass of 125GeV, an excess of events over the expected background from other Standard Model processes is found with an observed significance of **3.5 standard deviations**, compared to an expectation of **3.0 standard deviations**.

This excess indicates the existence of the decay of the Higgs boson into bb quarks and for its production in association with a vector boson.

Thank You!