Search for the H$\rightarrow b\bar{b}$ in the VH production channel using the ATLAS dector

Changqiao Li [1] [2]

[1] **U**niversity of **S**cience and **T**echnology of **C**hina

[2] **L**aboratoire de **P**hysique **N**ucléaire et de **H**autes **E**nergies - Paris

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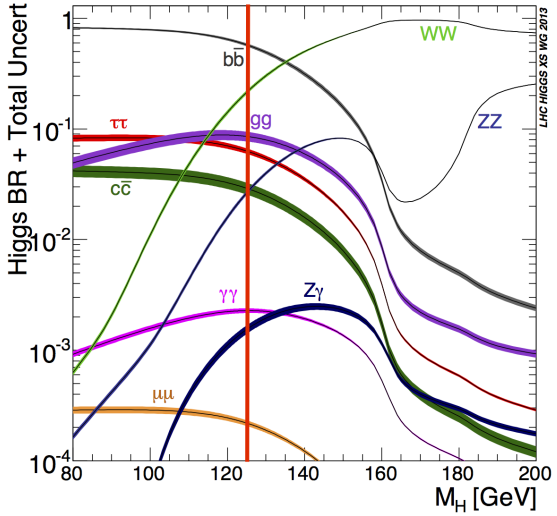
Introduction

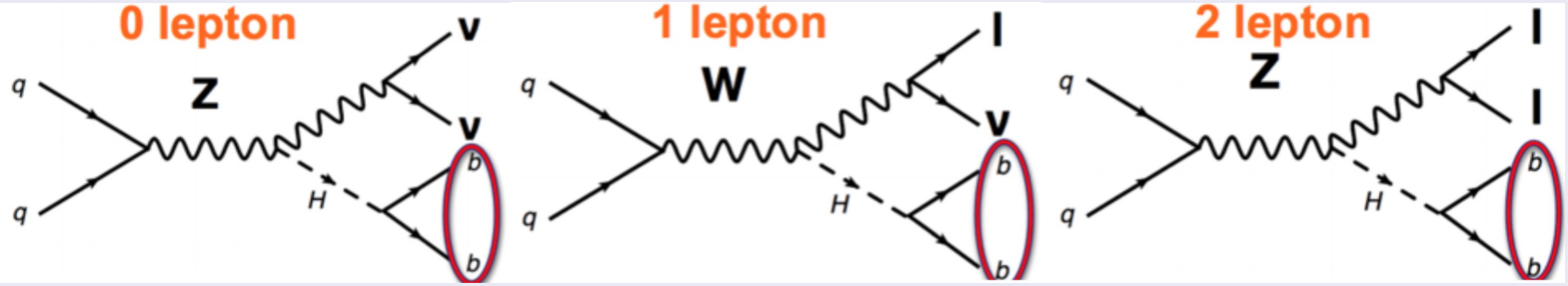
$H \to b\bar{b}$

- Direct measurement of Yukawa coupling to b
- Largest branch ratio (57%) @ 125GeV
- Constrain total width and measure absolute couplings
- In Run 1: $H \to b\bar{b}$: 2.6 σ (expected: 3.7 σ)



VH:provides the best sensitivity for H$\to b\bar{b}$ compared to the other modes

Trigger on e/μ from W/Z decay:(**3 channels**)



In Run1, ATLAS: 1.4 σ (Exp. 2.6 σ) and CMS: 2.1 σ (Exp. 2.1 σ)

New ATLAS Results for SM VH($\to b\bar{b}$) with 13.2 fb^{-1} of 13TeV pp collisions data

VH,H$\rightarrow b\bar{b}$ search

Object Selection

Electrons:	**Muons:**
p_T>25(7) GeV Loose/Tight ID Loose/Tight Isolation	p_T>25(7) GeV Loose/Tight ID Loose/Tight Isolation
Jets: Signal: $\lvert\eta\rvert$<2.5 Forward: 2.5<$\lvert\eta\rvert$<4.5	**Hadronic-τ** for Overlap Removal

0 lepton: E_T^{miss}> 150 GeV
1 lepton: e or μ, p_T>25GeV Tight isolation Missing ET p_T^V > 150 GeV
2 lepton: Isolated ee,$\mu\mu$ p_T^l>25 (7) GeV m_{ll} compatible with m_Z

Common Event Selection

Two signal jets,b tagged, p_T^{j1}>45GeV p_T^{j2}>20GeV

Categories

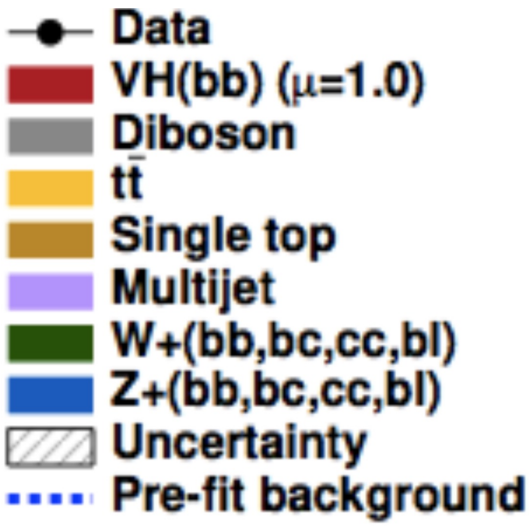
- 0/1 lepton: 2/3 jets
- 2 lepton: 2/3 jets $\times$ p_T^V<150 GeV/p_T^V>150 GeV

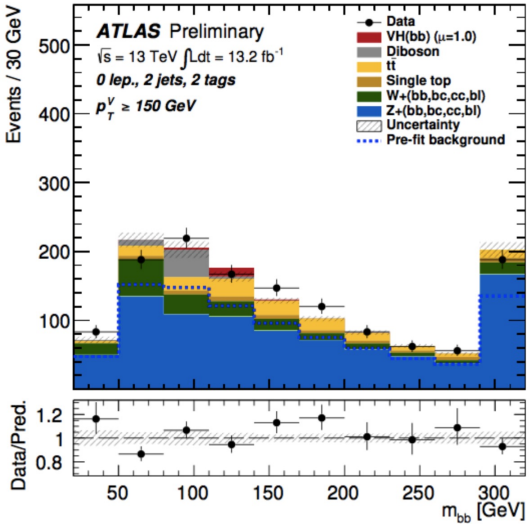
Main backgrounds

Dominant backgrounds dependent on channel

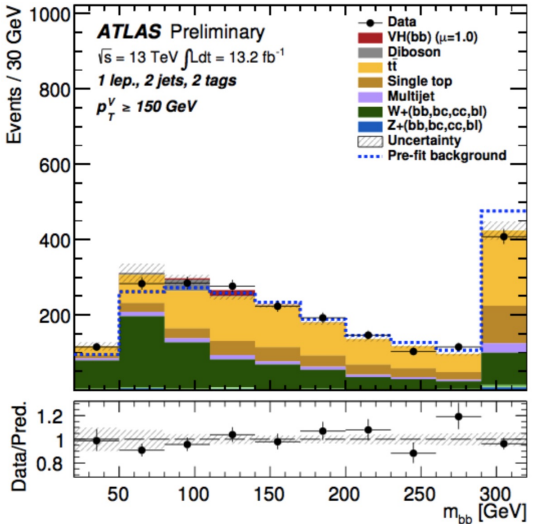
Z+bjets dominantes in 0,2 lepton channels
Top quark and W+jets in 1 lepton channel
Multi-jet:

- negligible in 0/2 lepton channels after anti-QCD cuts
- Data-driven in 1 lepton channel

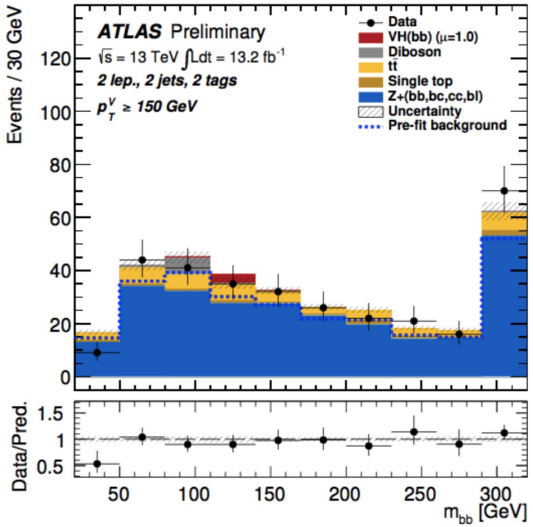




0 lepton



1 lepton



2 lepton

mBB resolution improvement

mbb mass resolution improvement is one of key items in this analysis

Muon-in-jet correction

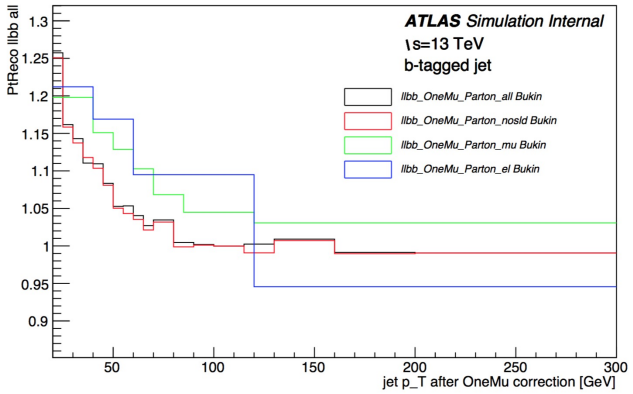
an observed non-isolated medium muon ($\Delta R(\mu, j)$<0.4) is added in jet 4-vector

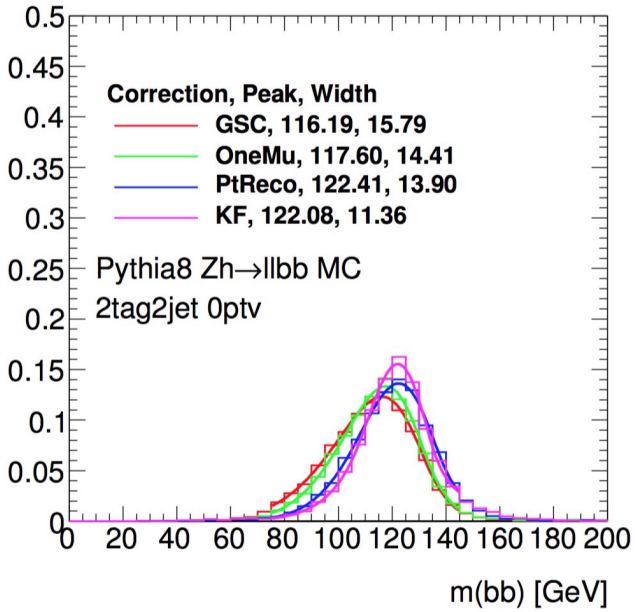
pT-reco correction

b-jet pT scale correction:
reconstructed level $\rightarrow$ *generated* level
based on MC response

Kinematic fitter correction (only 2 lepton 2jet)

mBB resolution improves by 20%





Multi Variate Analysis

- Multi variate analysis using BDT - following the Run1 setup
- Some new variables to suppress the ttbar background (1-lep) $|\Delta Y(V,H)|$ and m_{Top}
- 10-30% improvement with respect to mBB analysis
- BDT_{VH}: separate the VH(bb) from background
- BDT_{VZ}: separate the VZ(bb) from background

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

Fit Model

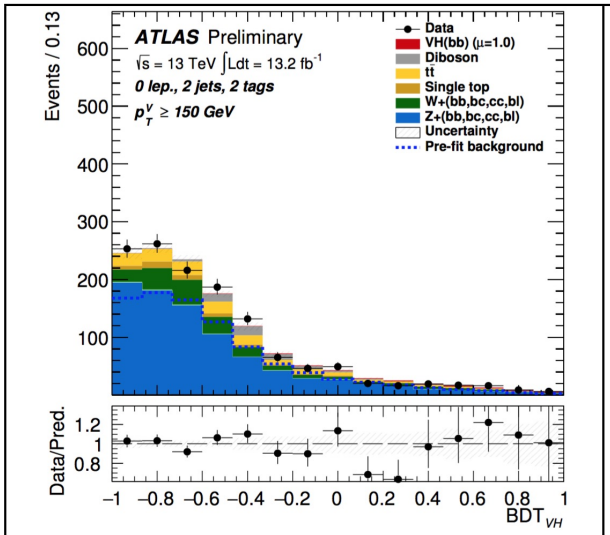
- Extract the signal strength(μ)[1] from the data
- Binned likelihood function $\mathcal{L}(\mu, \theta)$: product of Poisson-probability terms Data, signal and background involved. NPs(θ)[2] describing: **Floating background normalisations** and **systematic uncertainties** (**Modelling**: 1.normalisation 2.acceptance 3.shape and **Experimental**)
- Test statistic $q_\mu = -2ln\Lambda_\mu$ with $\Lambda_\mu = \mathcal{L}(\mu, \hat{\hat{\theta}}_\mu)/\mathcal{L}(\hat{\mu}, \hat{\theta})$
- 8 categories used in the global likelihood fit

Channel	Categories					
	2 b-tagged jets					
	p_T^V < 150 GeV			p_T^V > 150 GeV		
	2 jets	3 jets	≥ 3 jets	2 jets	3 jets	≥ 3 jets
0 lepton	-	-	-	BDT	BDT	-
1 lepton	-	-	-	BDT	BDT	-
2 lepton	BDT	-	BDT	BDT	-	BDT

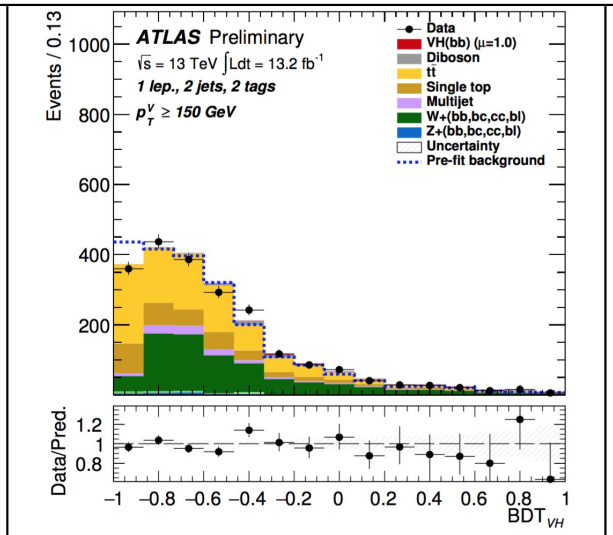
[1] scales the SM Higgs boson(m_H = 125 GeV) production cross section times branching ratio into $b\bar{b}$

[2] nuisance parameters

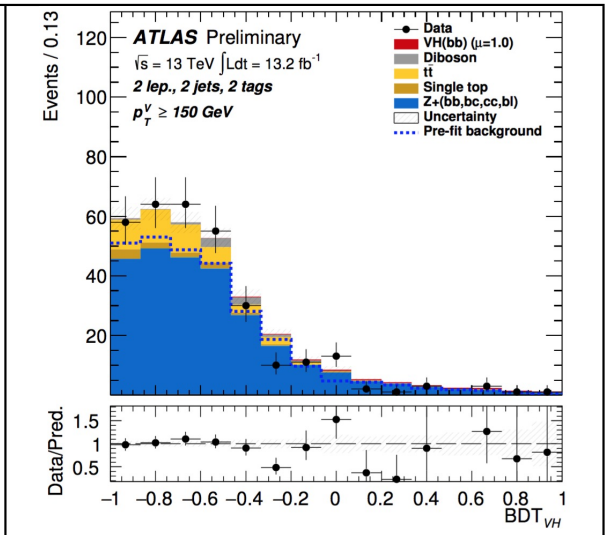
BDT_{VH} post-fit distribution (6/8)



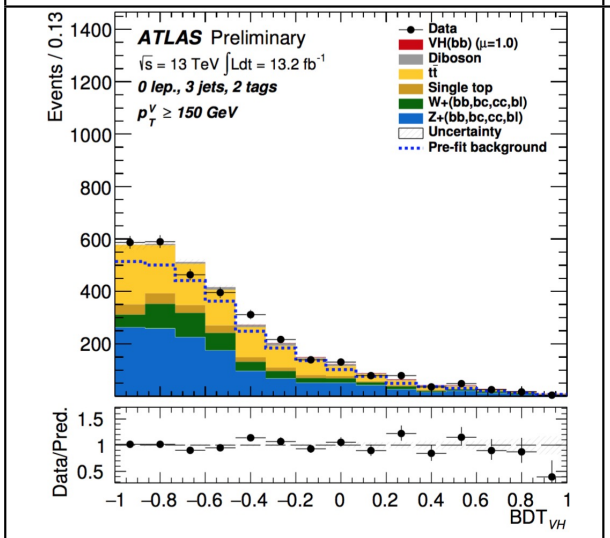
0lep 2jets



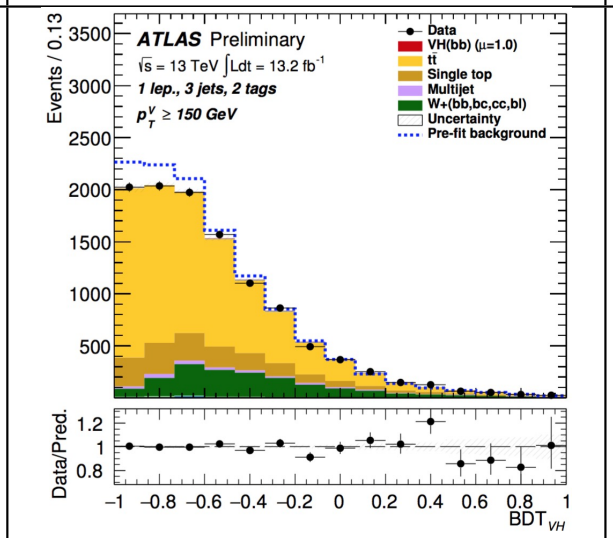
1lep 2jets



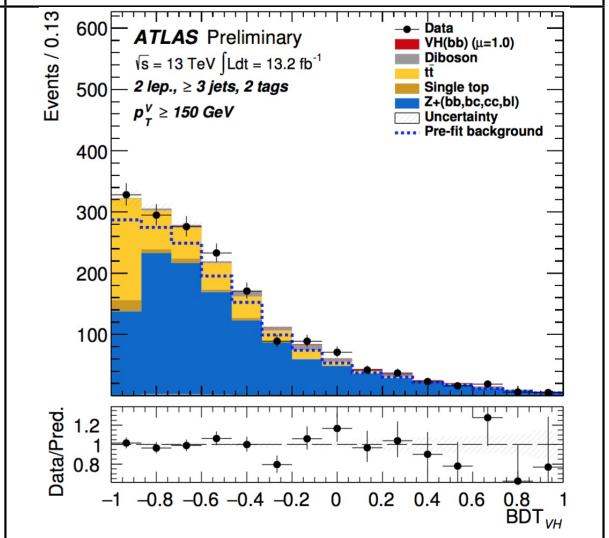
2lep 2jets



0lep 3jets



1lep 3jets



2lep 3jets

Fitting performed

Normalisation Factors (from the fitting)

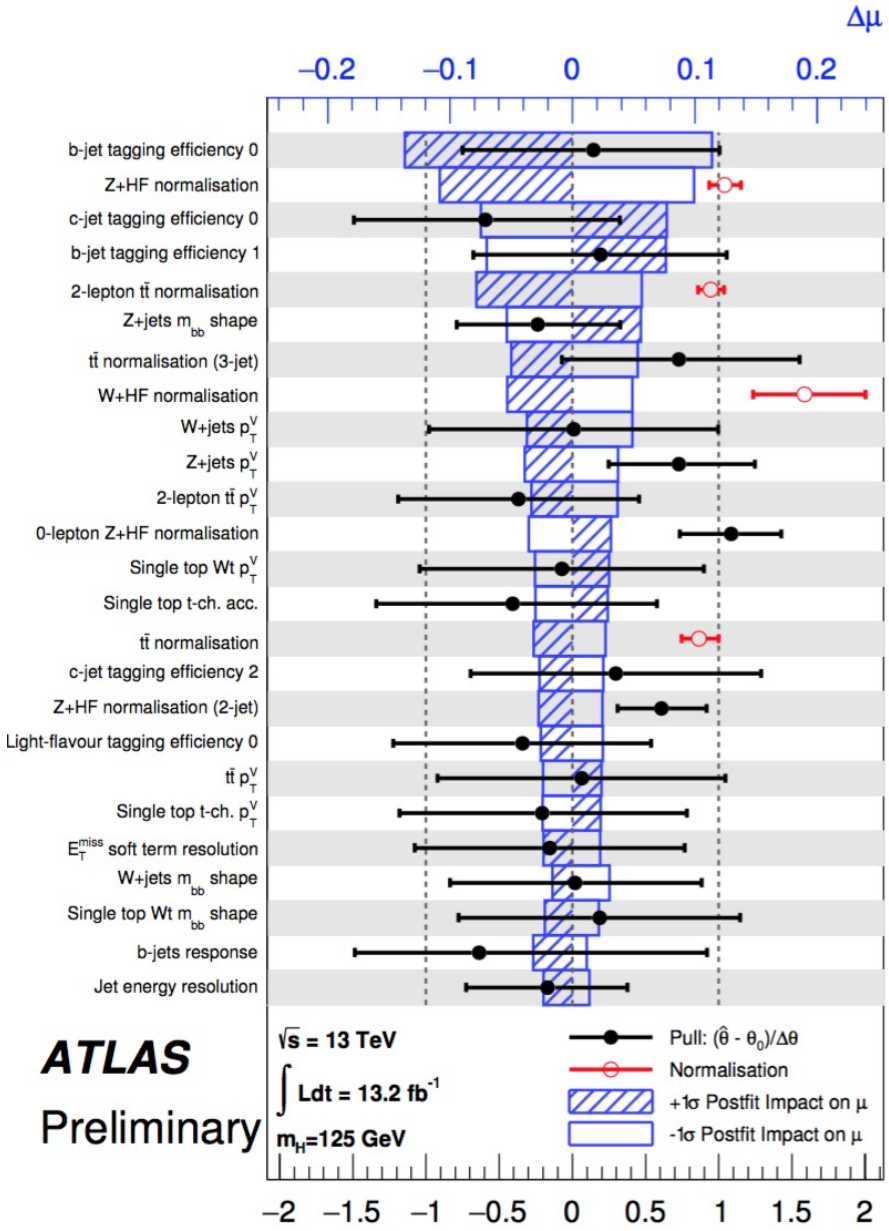
Sample	Scale factor
$t\bar{t}$ 0+1-lepton	0.86 ± 0.13
$t\bar{t}$ 2-lepton	0.94 ± 0.09
W + HF	1.59 ± 0.39
Z + HF	1.04 ± 0.11

5 largest impact systematic on μ

- two leading b-jet efficiency uncertainties
- leading c-jet efficiency uncertainty
- W+HF and Z+HF[a] normalisations

[a] V+HF: V+bb, V+bc, V+cc, V+bl

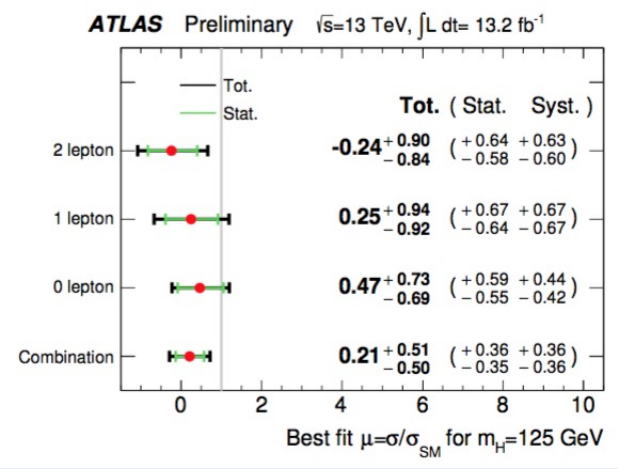
Rankings



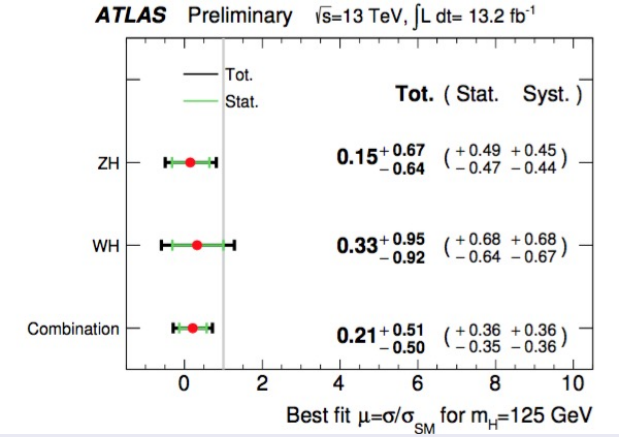
Results

Fitted value of μ_H

Individual μ value in **lep-ch** and combined



Individual μ value in **(W/Z)H** and combined



$\mu_{VH,H\to b\bar{b}} = 0.21^{+0.36}_{-0.35}(stat.) \pm 0.36(syst.)$ Exp.(Obs.) significance: 1.94(0.42)

Fitted value of μ_{VZ} (Diboson validation)

- using the BDT_{VZ} output with μ_{VZ}
- μ_H set to SM prediction with 50% normalisation uncertainty

$\mu_{VZ,Z\to b\bar{b}} = 0.91 \pm 0.17(stat.)^{+0.32}_{-0.27}(syst.)$ Exp.(Obs.) significance: 3.2(3.0)

Summary and conclusions

The search for the Higgs decays to b-quarks is essential to probe the nature of the Higgs boson

- Measure couplings to down-type quarks
- Constraint total width
- VH mode plays an important role (sensitive)

Presented very hot new ATLAS results on the search for $VH, H \to b\bar{b}$

- 13.2 fb^{-1} of 13 TeV pp collisions
- Expected (observed) significance: 1.92 (0.42)
- Signal strength: $\mu_{VH,H\to b\bar{b}} = 0.21^{+0.51}_{-0.50}$

Backup

Simulation samples

Process	Generator
qqZH	Pythia 8 (AZNLO)
ggZH	Powheg+Pythia 8 (AZNLO)
qqWH	Pythia 8 (AZNLO)
V+jets	Sherpa2.2
$t\bar{t}$	Powheg+Pythia 6
signle top	Powheg+Pythia 6
VV	Powheg+Pythia 8 (AZNLO)
multijet	data-driven (MC estim. in 0l)

- Normalised to the best available theoretical predictions.
- V+jets:
  Applying the # truth jet re-weighting provided by PMG.

Object Selection

Electrons

Type	pT	$\|\eta\|$	ID	d0sig	$\Delta z0 sin\theta$	Isolation
Loose	>7 GeV	<2.47	LooseLLHBLayer	<5	<0.5mm	LooseTrackOnly
Medium	>25 GeV	<2.47	LooseLLHBLayer	<5	<0.5mm	LooseTrackOnly
Tight	>25 GeV	<2.47	LHTight	<5	<0.5mm	FixedCutTight

Muons

Type	pT	$\|\eta\|$	ID	d0sig	$\Delta z0 sin\theta$	Isolation
Loose	>7 GeV	<2.7	Loose	<3	<0.5mm	LooseTrackOnly
Medium	>25 GeV	<2.5	Loose	<3	<0.5mm	LooseTrackOnly
Tight	>25 GeV	<2.5	Medium	<3	<0.5mm	FixedCutTight

Jets

Type	pT	$\|\eta\|$	JVT
Signal	>20 GeV	<2.5	>0.59 if pT<60 GeV
Forward	>30 GeV	2.5-4.5	Loose

Hadronic-τ

	pT	$\|\eta\|$	ID
for OR	>20 GeV	<2.5	Medium

Event Selection - Lepton Channels

0-leptons	1-leptons	2-leptons
MET Trigger No loose leptons MET > 150 GeV S_T > 120 GeV (2jets) S_T > 150 GeV (3jets) Cuts to suppress multi-jet: min| $\Delta\Phi$(MET,jet) | >20° | $\Delta\Phi$(MET,h) | >120° | $\Delta\Phi$(jet1,jet2) | <140° | $\Delta\Phi$(MET,trackMET) | <90°	(only e-channel) Single lepton trigger (only μ-channel) MET Trigger 1 tight lepton no additional loose lepton (only e-channel) MET > 30 GeV	Single lepton trigger 2 loose leptons, of which at least one medium lepton Same Flavour di-lepton (ee or $\mu\mu$) Opposite-sign for $\mu\mu$ Z mass window (71 < mll < 121 GeV)

S_T: scalar sum of the transverse momentum of the two or three signal jets[3]

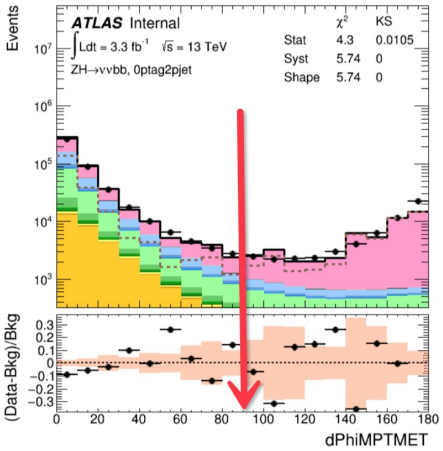
[3] or two leading signal + 1 forward for 3jets, if only 2 signal jets present

Multi-Jet Estimation 0-leptons

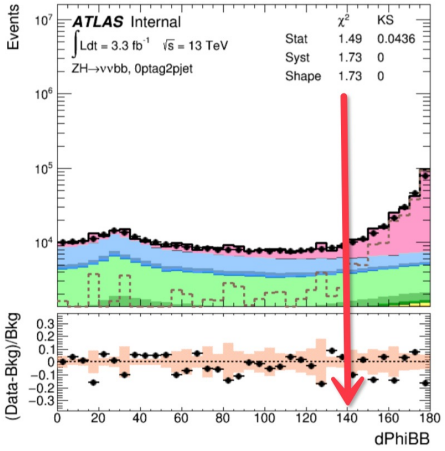
- Verify multi-jet contamination based on MC after anti-QCD cut.
- MC modelling looks reasonable

Multi-jet bkgs is

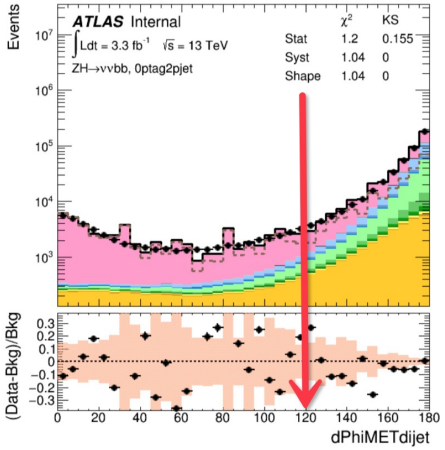
- < 1% total bkg in 2tag region
- multi-jet bkg i n 2tag is < 10% of VH signal in the H mass range



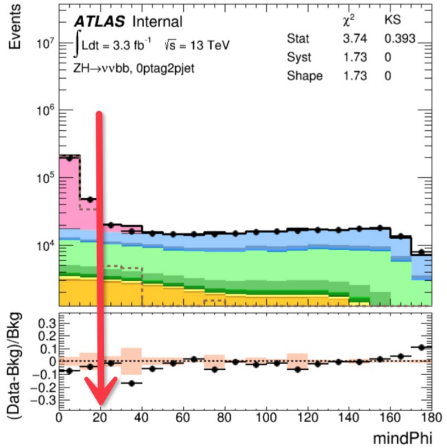
| ΔΦ(MET,trackMET) |



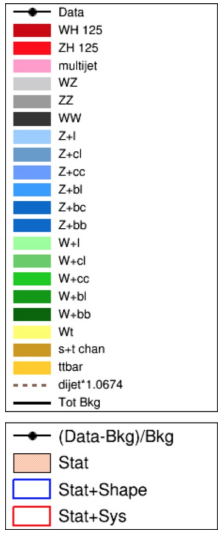
| ΔΦ(jet1,jet2) |



| ΔΦ(MET,h) |



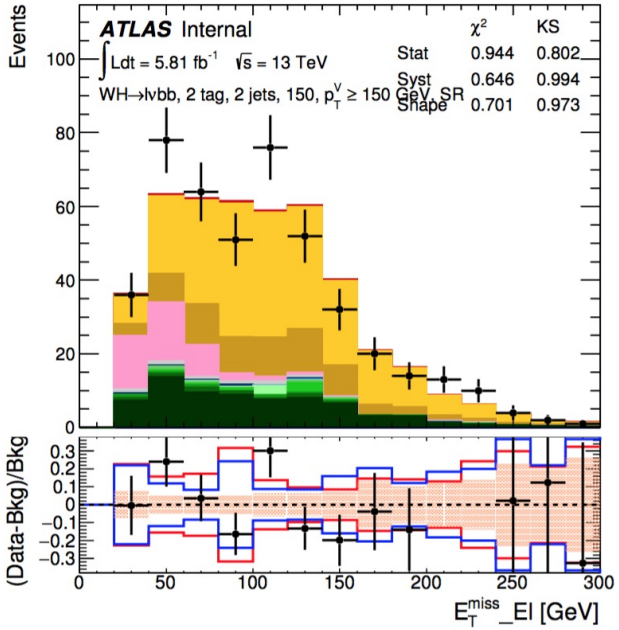
min| ΔΦ(MET,jet) |

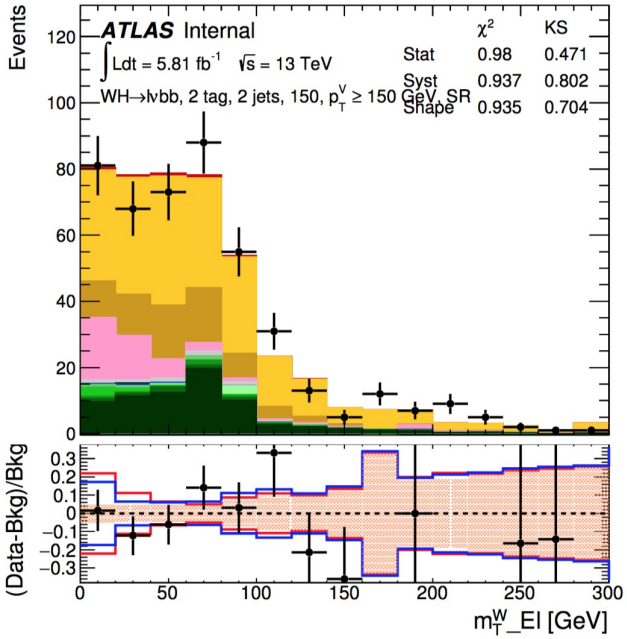


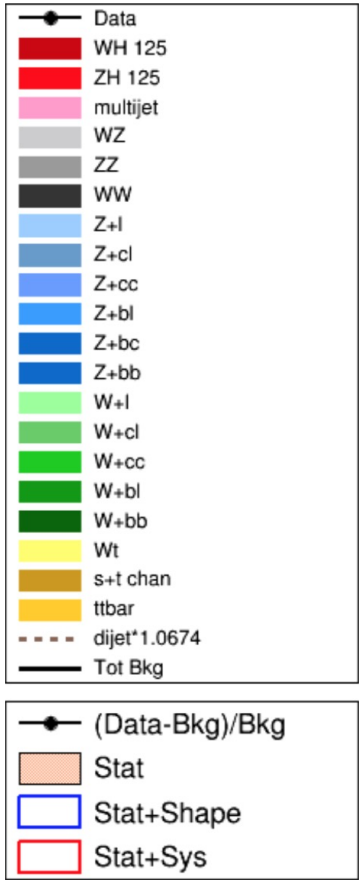
Multi-Jet Estimation 1-leptons

isolation	tight	loose-not-tight
1tag	CR1	CR2
2tag	SR	CR3

- Factor f = CR1/CR2
- SR = f $\times$ CR3
- dijet=data-EW(MC) $\rightarrow$ sensitive to the modelling of the EW
- data driven to constrain the EW (150<E_T^{miss}<250GeV)
- Binning in p_T,η and E_T^{miss} (electron sub-channel only)







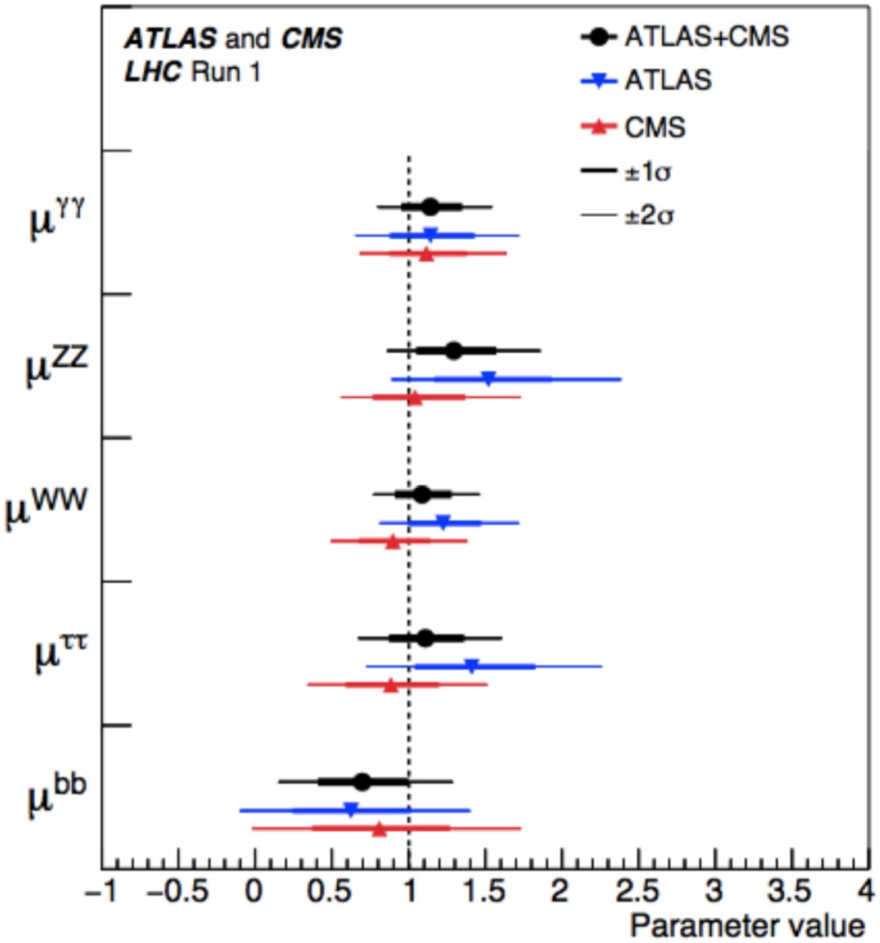
same as previous

Limits p0 and significance

Run2 Limits and Significance

Dataset	Limit		p_0		Significance	
	Exp.	Obs.	Exp.	Obs.	Exp.	Obs.
0-lepton	$1.4^{+0.6}_{-0.4}$	2.0	0.07	0.15	1.45	1.02
1-lepton	$2.0^{+0.8}_{-0.6}$	2.1	0.15	0.46	1.04	0.10
2-lepton	$1.8^{+0.7}_{-0.5}$	1.7	0.13	0.57	1.14	–0.17
Combined	$1.0^{+0.4}_{-0.3}$	1.2	0.03	0.34	1.94	0.42

ATLAS+CMS Run 1 signal strength



$$\mu_{b\bar{b}}^{ATLAS+CMS} = 0.70^{+0.29}_{-0.27}$$