Search for associated production $VH(b\bar{b})$ at ATLAS: analysis strategy

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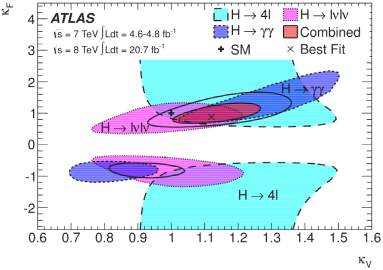
The University of Iowa

Why still searching for the Higgs ?

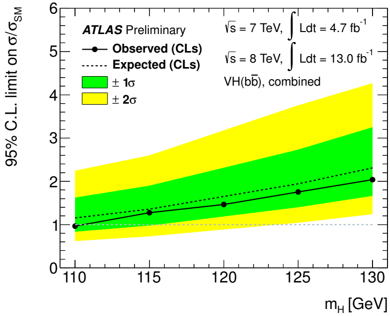
Observation of a Higgs boson in July 2012 at a mass ∼ 125 GeV

- Evidence found in bosonic channels only
- Measurement of Higgs properties started, still using bosonic channels
- Coupling to fermions known only indirectly
- Direct evidence for coupling to quarks and leptons very important measurement



Main search channels:

- $H \to \tau\tau$,
- $H \to b\bar{b}$,
- associated production $t\bar{t}H$



Current results on $H \to b\bar{b}$

- Tevatron: $\hat{\mu} = 1.6 \pm 0.7$ (FERMILAB-PUB-13-081-E)
- CMS: excess of 2.1σ, $\hat{\mu} = 1.0 \pm 0.5$ (CMS-PAS-HIG-13-012)
- ATLAS: observed limit 1.8 SM prediction (ATLAS-CONF-2012-161)

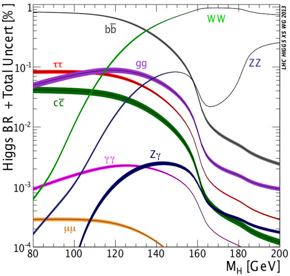
$H \to b\bar{b}$ in associated production

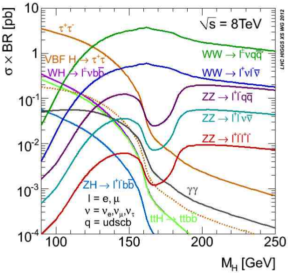
Looking at BR

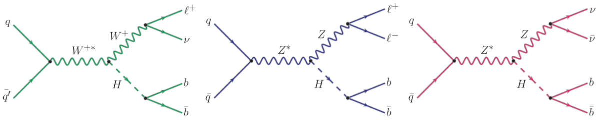
- $H \to b\bar{b}$ largest BR at 125 GeV (∼ 60%)

Taking production modes into account

- *gg* fusion and VBF very difficult channels: large multijet backgrounds
- ⇒ Next is associated production with vector boson (*W* or *Z*)
- *V* boson: easy to trigger, good background rejection
- Total $\sigma \times$ BR same ballpark as bosonic channels







Backgrounds

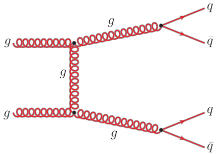
Numerous backgrounds to consider, that will shape the analysis selections

Fake objects

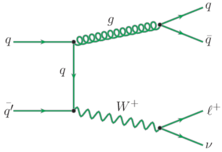
- Fake leptons or MET: multijet
- Mistagged jets: Z+jets, W+jets, with c or light jets

Same objects in the acceptance

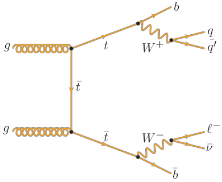
- Additional objects out of acceptance: $t\bar{t}$, $Wb\bar{b}$ in $Z(\nu\nu)H$ search. . .
- Similar final state: $Zb\bar{b}$, $Wb\bar{b}$, single top, diboson



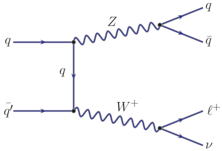
Multijet



W+jets



$t\bar{t}$



WZ

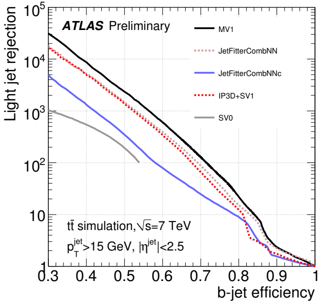
Critical points of the analysis

Multijet reduction

- Tight leptons in 1 lepton channel
- MET reconstruction in 0 lepton channel

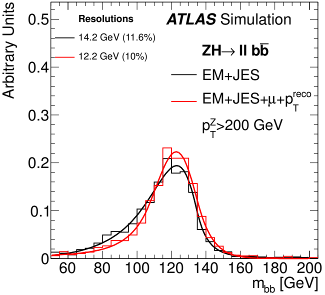
b-tagging

- Advanced MVA-based tagger (impact parameters, secondary vertices): 70 % efficiency, rejections of 5 (*c*-jets) and 150 (light jets)
- Precise calibration in $t\bar{t}$ dilepton events



$m_{b\bar{b}}$

- Most discriminant variable
- Resolution improved with *b*-jet energy corrections



Important kinematic variables

- Analysis divided in bins of p_T of vector boson (harder spectra for Higgs): 0-90, 90-120, 120-160, 160-200, >200 GeV
- Angular cuts tuned in each bin

Preselections

Dataset

Use full 7 TeV ($5\,\text{fb}^{-1}$) and 8 TeV ($20\,\text{fb}^{-1}$) *pp* statistics from the 2011 and 2012 runs.

Triggers

- single lepton triggers for 1 and 2 leptons
- dilepton triggers for 2 lepton channel
- E_T^{miss} triggers for 0 lepton and 1 lepton (muon)

Selections

Lepton tightness: different quality cuts and isolation

Object	0-lepton	1-lepton	2-lepton
Leptons	0 loose leptons	1 tight lepton + 0 loose leptons	1 medium lepton + 1 loose lepton
Jets	2 *b*-tags $p_T^{jet_1} > 45$ GeV $p_T^{jet_2} > 20$ GeV $+ \leq 1$ extra jets		
Missing E_T	$E_T^{miss} > 120$ GeV $p_T^{miss} > 30$ GeV $\Delta\phi(\mathbf{E}_T^{miss}, \mathbf{p}_T^{miss}) < \pi/2$ $\min[\Delta\phi(\mathbf{E}_T^{miss}, \text{jet})] > 1.5$ $\Delta\phi(\mathbf{E}_T^{miss}, b\bar{b}) > 2.8$	$E_T^{miss} > 25$ Gev	$E_T^{miss} < 60$ GeV
Vector Boson	-	$m_T^W < 120$ GeV	$83 < m_{\ell\ell} < 99$ GeV

Additional selections

Further use of kinematics

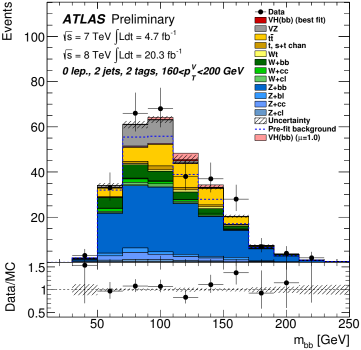
	p_T^V [GeV]	0-90	90-120	120-160	160-200	>200
All Channels	$\Delta R(b,\bar{b})$	0.7-3.4	0.7-3.0	0.7-2.3	0.7-1.8	<1.4
1-lepton	E_T^{miss} [GeV]	>25				>50
	m_T^W [GeV]	40-120			<120	

Selection acceptance

- 0-lepton: 2.2 %
- 1-lepton: 3.5 %
- 2-lepton: 8.2 %

S/B in mass window 90-150 GeV

- 0.1 % to 2 %, depending on p_T^V bin.

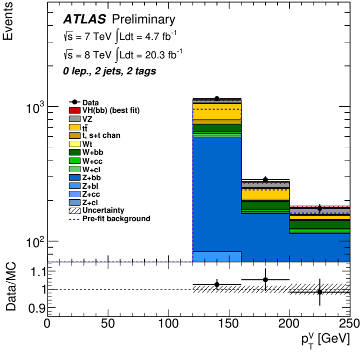


0 lepton, 2 jets, 2 tags, $160 < p_T^V < 200$ GeV

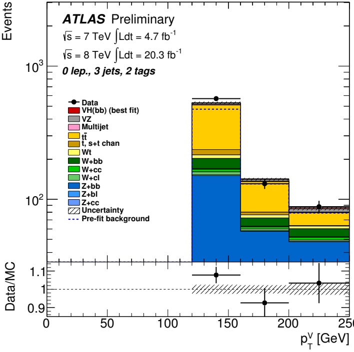
Higgs
Diboson
$t\bar{t}$
W+jets
Z+jets

0 lepton

- $Zb\bar{b}$ main background
- $t\bar{t}$ and $Wb\bar{b}$ also important



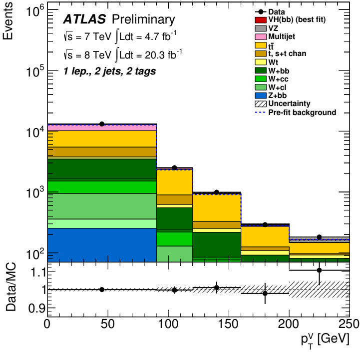
2 jets



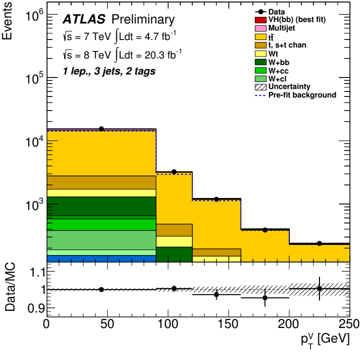
3 jets

1 lepton

- $t\bar{t}$ main background
- Single top and $Wb\bar{b}$ also sizeable
- Multijet important at low p_T^V.



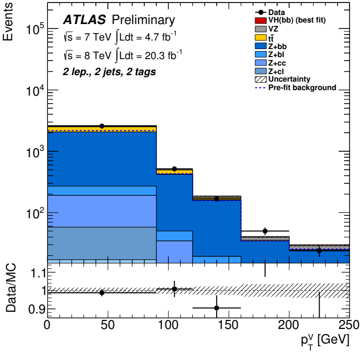
2 jets



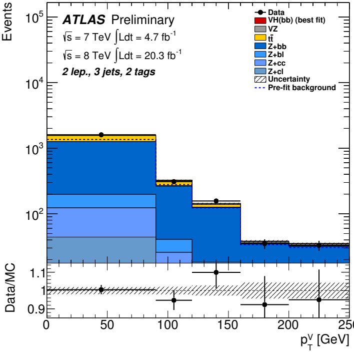
3 jets

2 leptons

- $Zb\bar{b}$ main background
- Some contribution from $t\bar{t}$



2 jets



3 jets

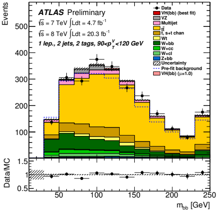
Categorization

Complex analysis, divided into numerous categories

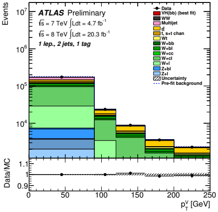
- Signal Regions (SR): $m_{b\bar{b}}$ used as discriminant variable
- Control Regions (CR): only total yields used

Channel	Nb p_T^V bins	2jets, 1tag	3jets, 1tag	2jets, 2tags	3jets, 2tags	e-μ CR
0-lepton	3	CR	CR	SR	SR	–
1-lepton	5	CR	CR	SR	SR	–
2-lepton	5	CR	CR	SR	SR	CR

- e-μ CR: 1 electron, 1 muon, $m_{\ell\ell} > 40$ GeV



SR: 1lep, 2tag 2jet, $90 < p_T^V < 120$ GeV



CR: 1lep, 1tag 2jet

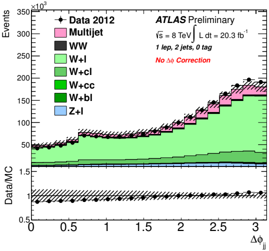
- One fit containing all categories. Wait for next talk for details !
- Needs careful evaluation of modelling systematics

Background Modelling: V+jets

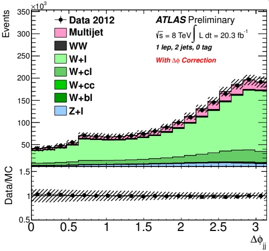
V+jets

- Mismodelling of $\Delta\phi(jj)$ found in 0-tag regions
- ⇒ Correction derived and applied
- Consistent with NLO studies
- Improves agreement in all distributions, incl. p_{T}^{V}.
- Normalizations of W+hf, Wcl, Z+hf, Zcl floated in the fit

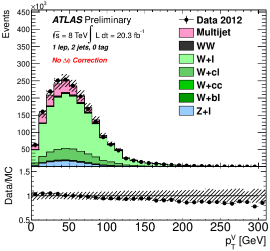
  hf $= bb + bc + cc$



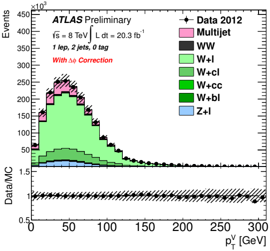
W+jets $\Delta\phi$ before correction



W+jets $\Delta\phi$ after correction



W+jets p_{T}^{V} before $\Delta\phi$ correction



W+jets p_{T}^{V} after $\Delta\phi$ correction

Background Modelling

Multijets

- 0 lepton
  - Control regions from inversion of some $E_{\mathrm{T}}^{\mathrm{miss}}$ cuts
  - Normalization and shapes from the CR
- 1 lepton
  - Shape from CR with inverted lepton isolations
  - Normalizations from the fit
- 2 lepton
  - Estimated in sidebands of $m_{\ell\ell}$
  - Found negligible

$t\bar{t}$

- Correction of top p_{T} at generator level
- Normalization floated in the fit

Diboson, single top

- Normalizations and shapes from MC

Estimating Modelling systematics

Signal

- Renormalization and factorization scales, PDF (3.5 %)
- p_T^V dependence of NLO EW corrections (up to 2.6 %)
- Acceptance (comparison LO generators): 10 %
- Total uncertainty $\sim$ 14 %

Backgrounds

- Numerous categories of the analysis
  $\Rightarrow$ need to get $m_{b\bar{b}}$, p_T^V, 3-to-2 jet ratios and flavour compositions right. More on this in the next talk !
- Systematics on p_T^V through $\Delta\phi$ for V+jets
- MC-based systematics: comparisons of generators LO or NLO, UE/PS tunes, renormalization scales

	$m_{b\bar{b}}$	$\Delta\phi$	p_T^V	3-to-2-jet ratio	flav. compo.
$t\bar{t}$	MC	–	data	MC	–
Z+jets	data	data	–	MC	MC
W+jets	MC	data	data	MC	MC
Single top	MC	–	MC	MC	–
Diboson	MC	–	MC	MC	–

Complex final state and categorization

Lepton systematics

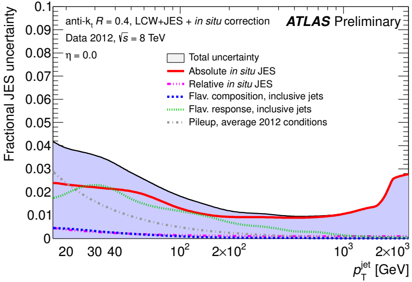
- Lepton reconstruction/identification efficiencies
- Lepton energy scales

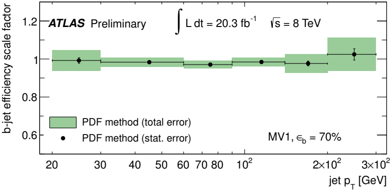
Jet systematics

- Jet Energy Scale systematics: shift $m_{b\bar{b}}$ but also 3-to-2 jets ratios and p_T^V bins (E_T^{miss})
- Jet Energy Resolution: affect $m_{b\bar{b}}$ shapes

b-tagging systematics

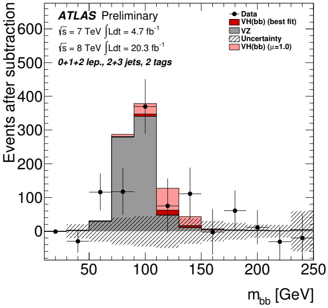
- Affect flavour compositions in 1tag and 2tag regions
- Precise calibration in $t\bar{t}$ events
- Larger uncertainty for fake rates (*c* and light)
- Additional systematics for V+jets





Results

Only general overview here. Detailed results in next talk.

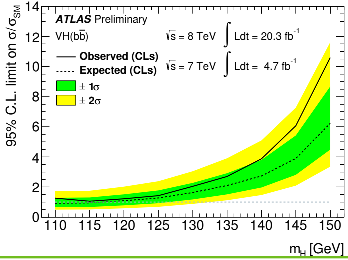


Fit using profile likelihood

- All systematics treated as nuisance parameters in the fit
- Background normalizations: floated or treated as additional nuisance parameters
- Postfit MC - data agreement obtained in the 26 SR and 31 CR

Observation of diboson peak

- Extensive validation of modelling and fit: $WZ+ZZ$ as signal
- Diboson peak observed with 4.8σ, $\sigma/\sigma_{SM} = 0.9 \pm 0.2$



Higgs search

- Very small excess $\mu_H = 0.2 \pm 0.5(\text{stat}) \pm 0.4(\text{syst})$
- Observed limit $1.4\sigma_{SM}$, 1.3 expected in absence of signal

Conclusions

- First ATLAS results on search for $VH(b\bar{b})$ with full 2011+2012 dataset (ATLAS-CONF-2013-079)
- Search in 3 channels $Z(\nu\nu)H$, $Z(\ell^+\ell^-)H$, $W(\ell\nu)H$
- Further splitting into p_T^V categories, 2 jet and 3 jet categories
- Price is complex fit model, detailed in next talk

⇒ Optimizations and reduced syst. uncertainties give 35 % improvement wrt previous analysis, not counting lumi. increase

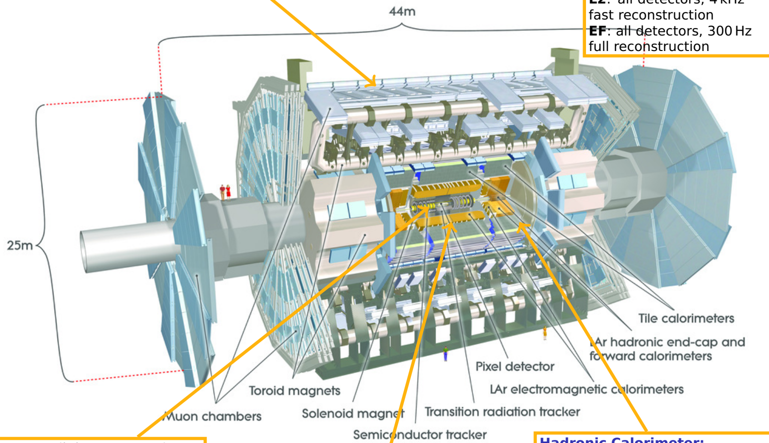
- This is not the final ATLAS result on this channel ! Stay tuned for further improvements.

Additional material

The ATLAS detector

Muon Spectrometer: ($|\eta| < 2.7$)
Air toroid with drift chambers,
Provides μ trigger and momentum measurement,
Resolution $< 10\%$ up to $p \sim 1$ TeV.

Trigger System:
3 levels
L1: calo and muons, 75 kHz
dedicated electronics
L2: all detectors, 4 kHz
fast reconstruction
EF: all detectors, 300 Hz
full reconstruction

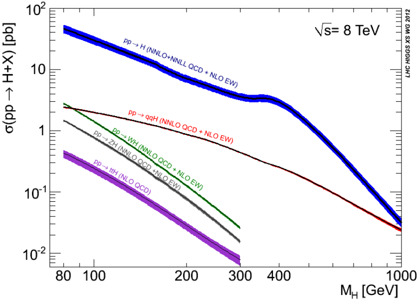


Inner Detector: ($|\eta| < 2.5$, B=2T)
Si Pixels, SCT, TRT
Precision tracking,
Vertex reconstruction,
e/π separation
$\sigma/p_T \sim 3.8 10^{-4} p_T \oplus 0.015$

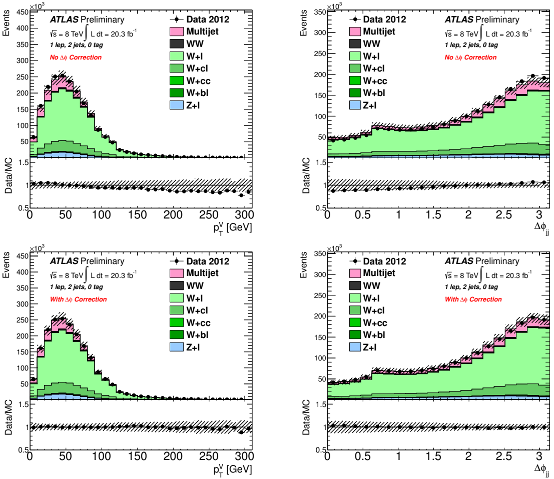
EM Calorimeter: ($|\eta| < 3.2$)
Pb-LAr, accordion structure
Provides trigger on e/γ,
Identification and measurement
$\sigma/E \sim 10\%/\sqrt{E} \oplus 0.7\%$

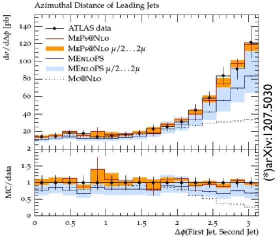
Hadronic Calorimeter:
Scint/Fe tiles in barrel ($|\eta| < 1.7$)
W/Cu-LAr in endcaps ($|\eta| < 4.9$)
Provides jet trigger and energy measurement,
$\sigma/E \sim 50\%/\sqrt{E} \oplus 3\%$
Hermetic coverage for MET

Higgs production



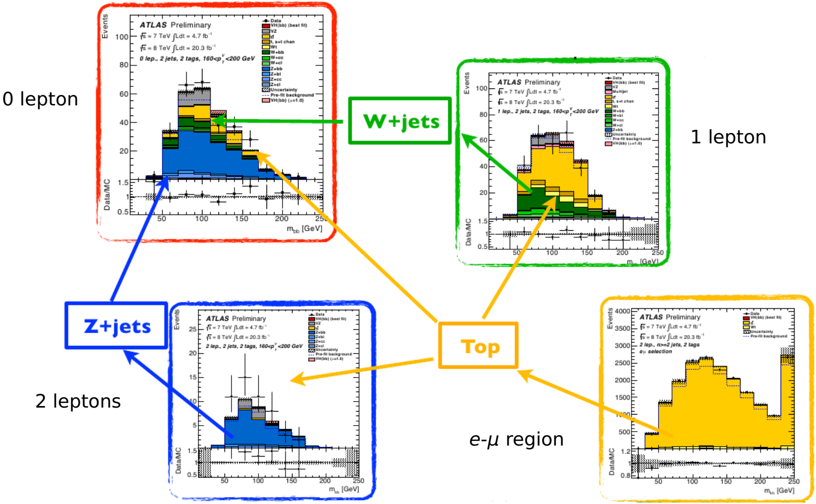
$\Delta\phi$ correction





Introducing the fit model

All categories enter a global fit



- Lots of information on backgrounds and *b*-tagging in CR
- Needs careful evaluation of modelling systematics

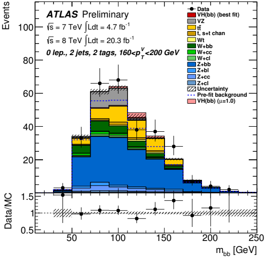
Fit results

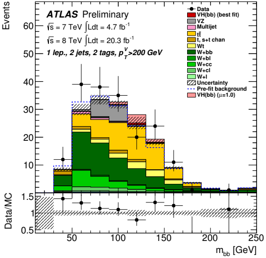
Profile likelihood

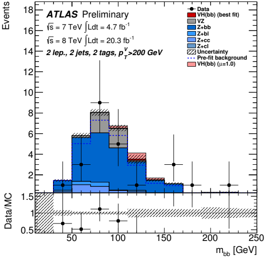
- All systematics treated as nuisance parameters in the fit
- Background normalizations: floated or treated as additional nuisance parameters
- Postfit MC - data agreement obtained in the 26 SR and 31 CR, both normalizations and shapes

Process	Scale factor
$t\bar{t}$	1.13±0.05
Wb	0.89±0.15
Wcl	1.05±0.14
Zb	1.30±0.07
Zcl	0.89±0.48

Example: highest sensitivity bins





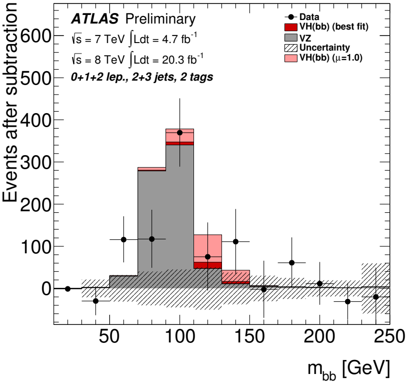


Uncertainties still dominated by statistics

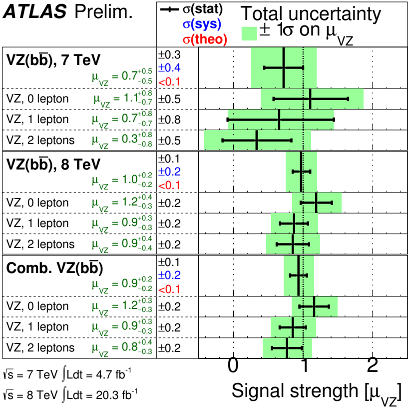
Observation of diboson peak

An important check

- $WZ+ZZ$ as signal
- Higgs at 125 GeV treated as background
- Very good check of validity of modelling and fit
- Measure $\mu_{VZ} = \sigma/\sigma_{SM} = 0.9 \pm 0.1(\text{stat}) \pm 0.2(\text{syst})$
- Significance 4.8σ (5.1σ expected)
- Compatibility between years:
  - $\mu_{VZ} = 0.7 \pm 0.5$ in 2011
  - $\mu_{VZ} = 1.0 \pm 0.2$ in 2012



Diboson results



Higgs results

7 TeV

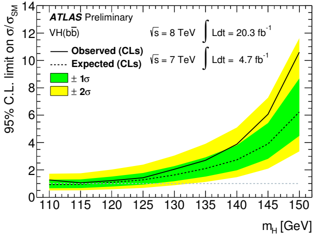
- 2σ deficit in 7 TeV data
- Observed in previous analysis

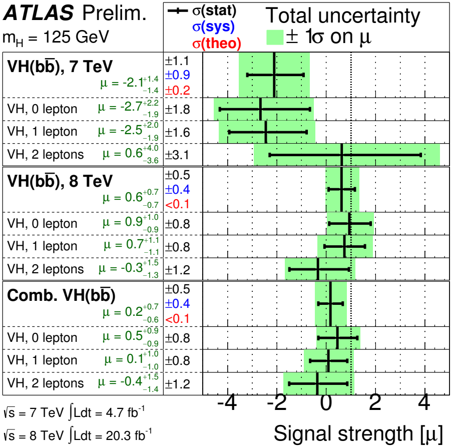
8 TeV

- $\sim 1\sigma$ excess in 8 TeV data

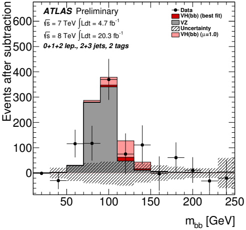
Combination

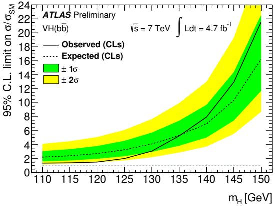
- Result is a very small excess
- $\mu_H = 0.2 \pm 0.5(\text{stat}) \pm 0.4(\text{syst})$
- Compatible with both $\mu = 0$ and $\mu = 1$
- Observed limit $1.4\sigma_{SM}$, 1.3 expected in absence of signal

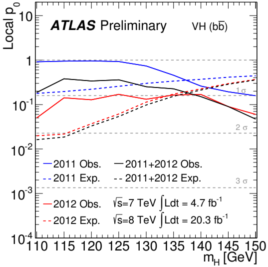


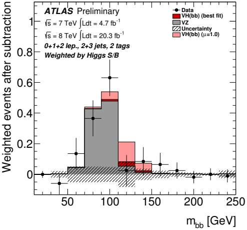


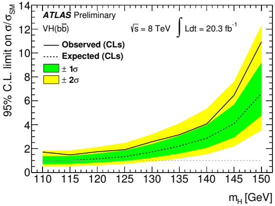
More Higgs results











Higgs combination