Searches for Higgs Bosons in the VH(bb) Channel at ATLAS

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Birmingham PP Seminar
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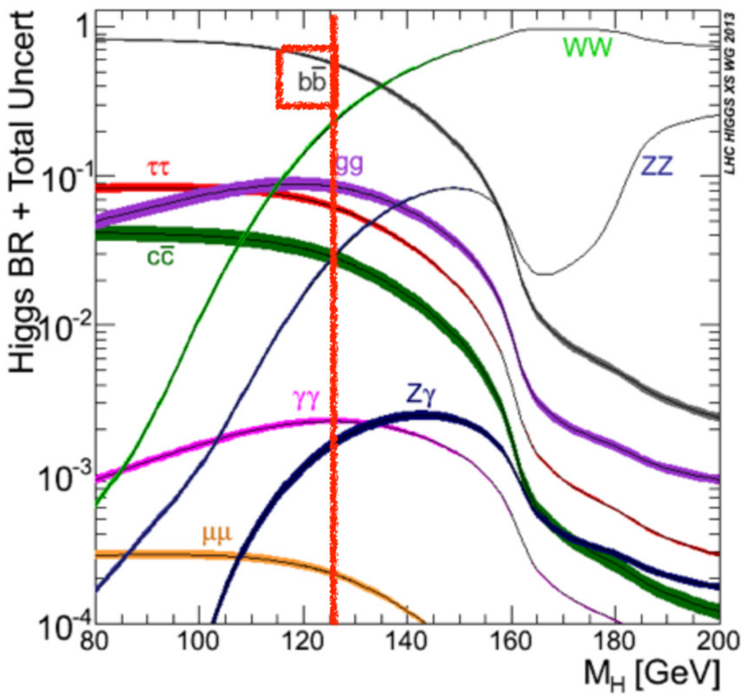
- Recent final results on the search in the VH(bb) channel at ATLAS in LHC Run 1
- Prospects for search in LHC Run 2
- Using the same final state to probe physics Beyond the Standard Model (BSM)

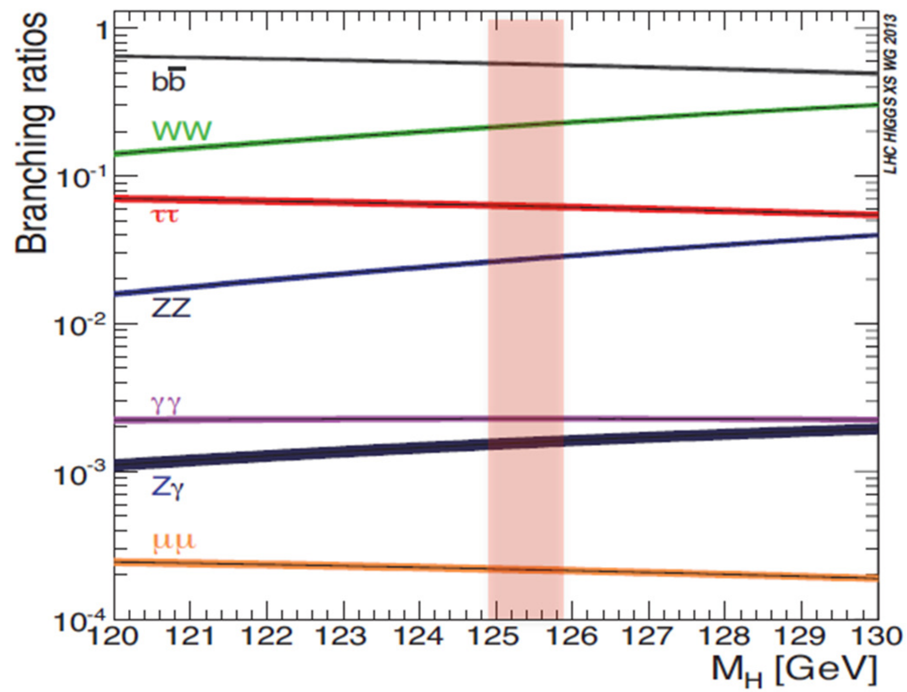
Why H->bb

- Since discovery on 4th July 2012 of a new particle with $J^P=0^+$ decaying via H->$\gamma\gamma$, H->ZZ,H->WW and with mass m_H=125 GeV
- No strong deviations from the BEH properties and the Higgs boson which is responsible for electroweak symmetry breaking

- Some evidence for direct decay of H to fermionic modes (as well as indirect couplings to quarks) important to see evidence of coupling to down type quarks
- H->bb predicted largest SM branching ratio at m_H=125 GeV Also good to measure H->bb rate as many BSM theories involve enhanced couplings to b

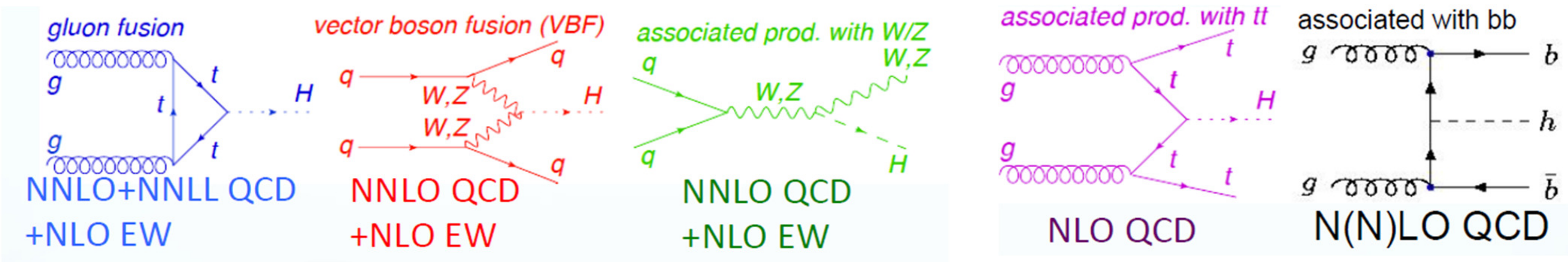
Standard Model H->bb Branching Ratio

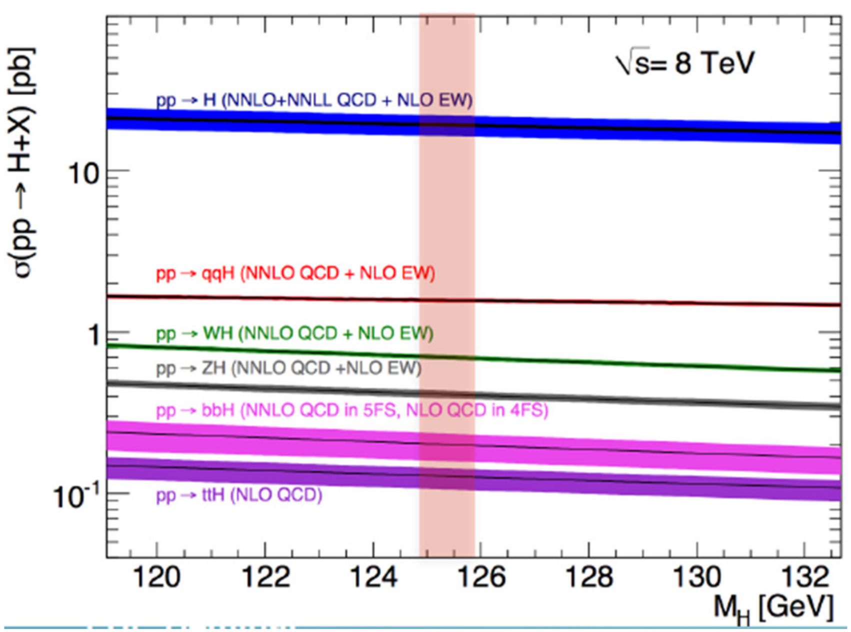




SM Branching ratio at 125.4 GeV						
bb	WW	ττ	ZZ	γγ	Zγ	μμ
57%	22%	6.3%	2.7%	0.23%	0.15%	0.02%

Production Modes





Inclusive H->bb, multijet cross section g->bb is overwhelming(10^7 larger)!

<u>VH process</u> V=W,Z

- Cross section : 0.70pb(WH),0.41pb(ZH)
- Associated W/Z helps triggering events, background suppression (lepton, MET)
  ➔ Main process for H→bb analysis

SM Higgs Latest Status

From LHC seminar 07/10/2014

- Updated coupling measurements of "big 5" channels using full Run1 data

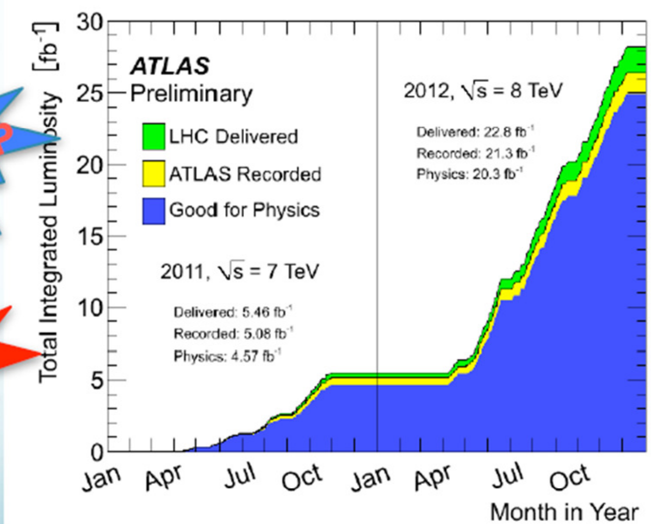
Channels	Reference and submission date	Recent Update
H→ZZ→4l	http://arxiv.org/abs/1408.5191 (Aug 22nd)	Coupling
H→γγ	http://arxiv.org/abs/1408.7084 (Aug 29th)	Coupling
VH→bb	http://arxiv.org/abs/1409.6212 (Sep 22nd)	Coupling, Search
H→WW→lνlν	ATLAS-CONF-2014-060	Coupling
H→ττ	ATLAS-CONF-2014-061	Coupling

Updated after ICHEP

Released today!!

7 TeV ~4.5fb^{-1}, 8 TeV ~20fb^{-1}

Good quality data collected by ATLAS

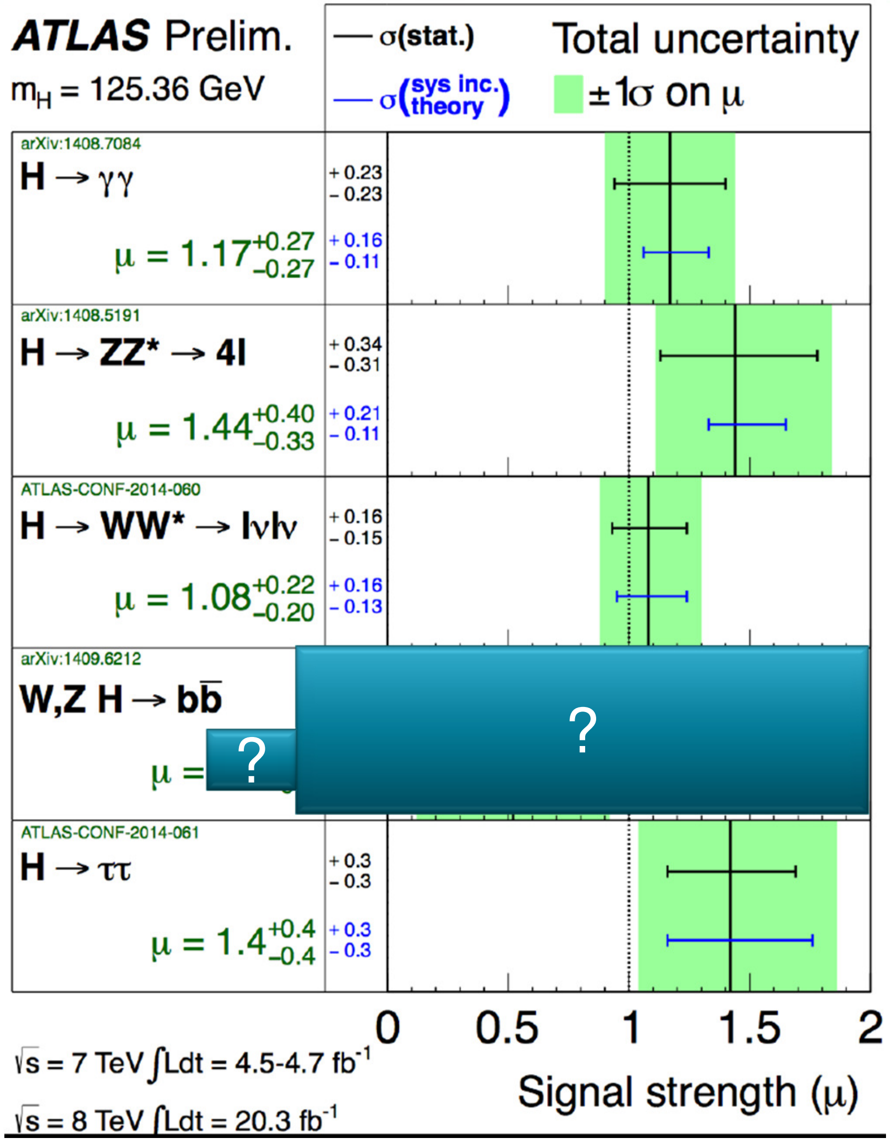


https://twiki.cern.ch/twiki/bin/view/AtlasPublic/HiggsPublicResults

LHC Seminar 2014/10/07

The final Run 1 Higgs picture from ATLAS nearly complete…

Latest ATLAS Higgs Results



5.2σ, 10% gain in recent improvements, consistent with SM in all production modes ggF, VBF, VH,…

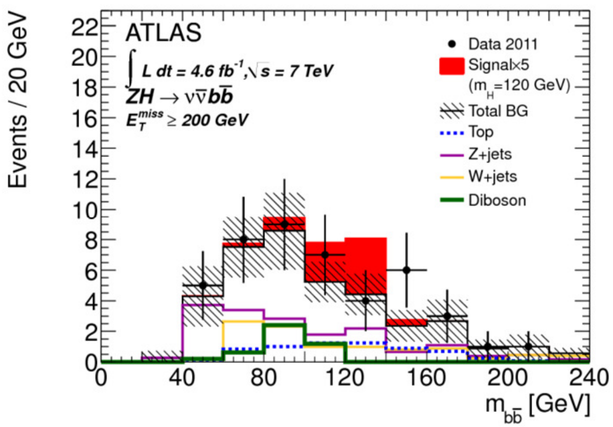
8.1σ, 20% gain in recent improvements. Richard Mudd's seminar 12th November

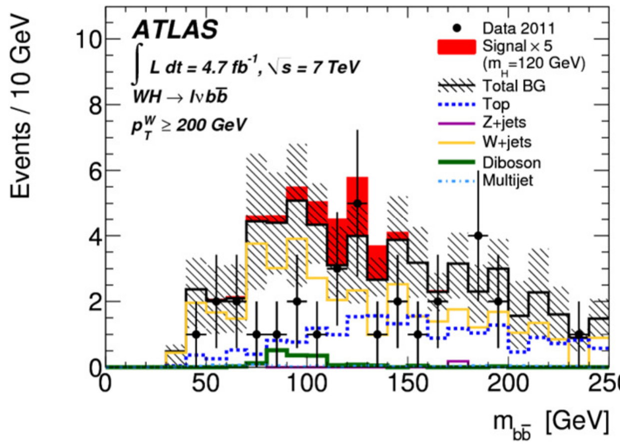
6.1σ, 30% gain in recent improvements, VBF@3.2σ

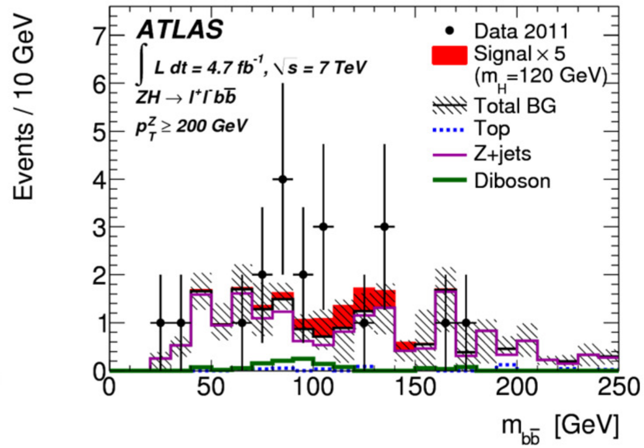
4.5σ evidence of Higgs boson coupling to taus!

The Road to H->bb Results

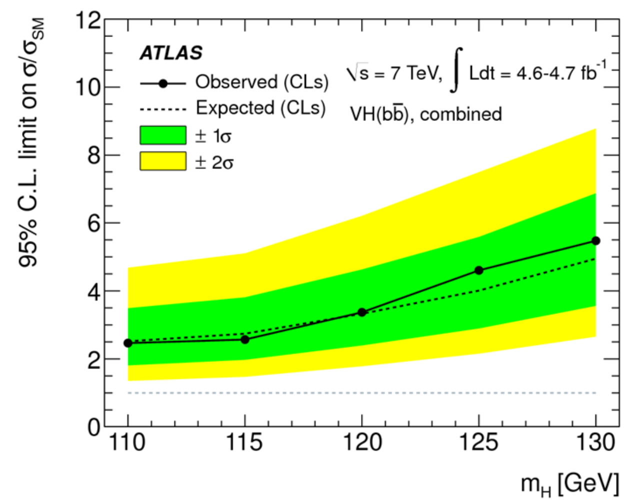
- First ATLAS publication on search for VH (V=W,Z) and H->bb on 2011 7 TeV data submitted in the June 2012







- 95% exclusion on Higgs mass around 2-5 times the standard model
- Slower turn around of analysis due to large and complicated background composition, calibration of detector e.g. b-tagging
- Analysis teams (myself and Benedict Allbrooke @Bham) plus 1-2@Liverpool
- Things were smaller scale back then…



“HSG5” Meeting, Dubna, Russia, 2011

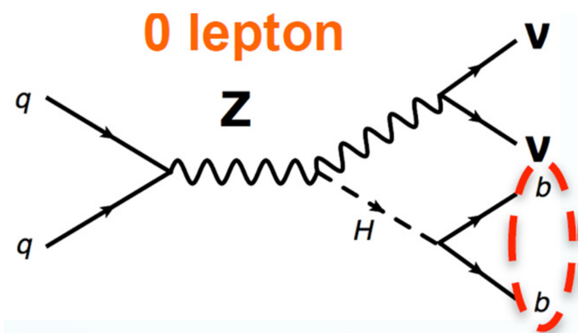
ATLAS HSG5 Workshop, 17-19 May 2011, Dubna

“HSG5” Meeting, Marseille, France, 2013

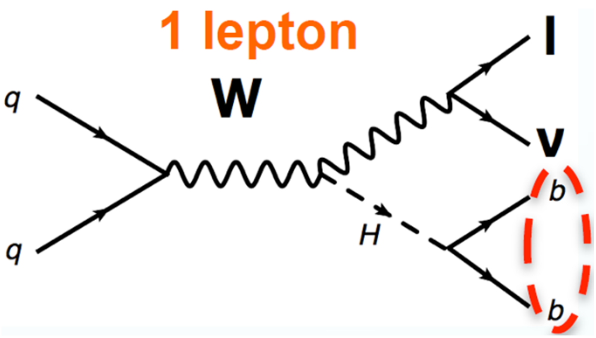
Discussing final analysis improvements and optimisations mainly on 2012 8TeV dataset, including extensions to multi-variate analyses,…

H->bb: How?

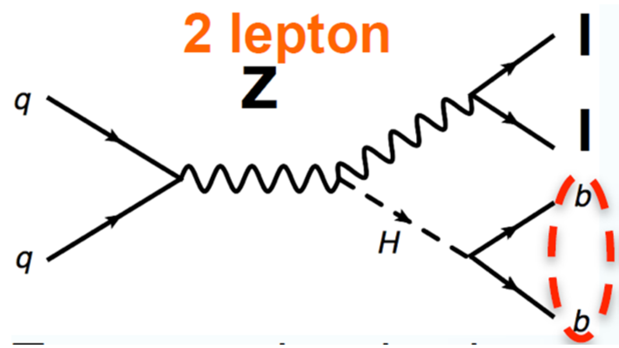
Analysis is divided into different V decays, each with different backgrounds



Low $\Delta\Phi(E_T^{miss}, p_T^{miss})$, High p_T^{miss} to reject multi-jets



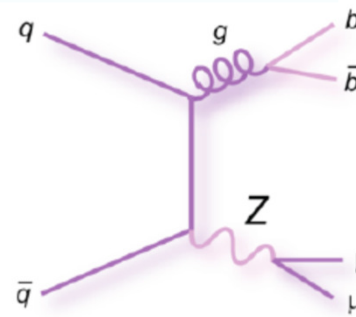
Tight lepton identification to reject multi-jet events

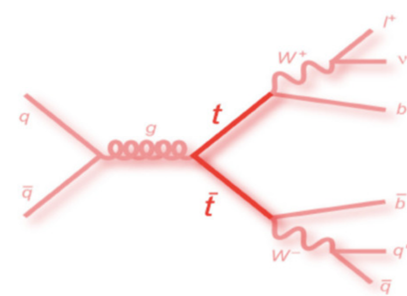


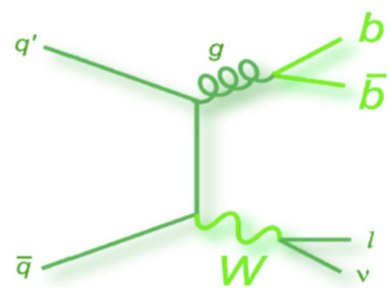
Two opposite-sign leptons, Z mass requirement

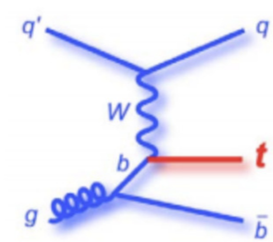
Dominant backgrounds:

- W/Z+heavy(light) flavour jets
- Top (ttbar and single top)
- QCD Multijet
- Diboson VZ, with Z->bb and V=W,Z. Z resonance can be used as "standard candle"





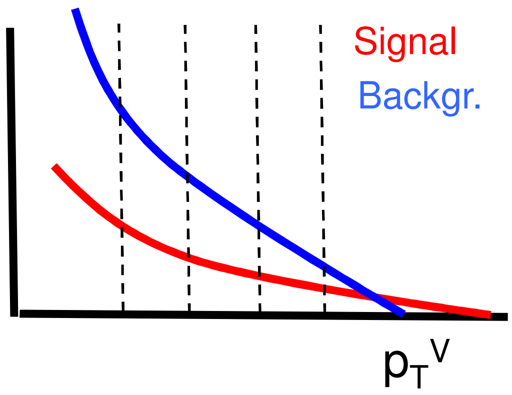




H->bb: Analysis Strategy

Analysis strategy:

- Best sensitivity use multivariate techniques (MVA)
- "Dijet mass" ("cut-based") analysis using m_{bb} as discriminant serves as a cross check
- In both cases exploit signal bkg differences vs p_T^V, jet multiplicity, b-tagging
- Improve m_{bb} resolution to increase sensitivity, improve separation from VZ
- Control backgrounds across 0,1,2 channels

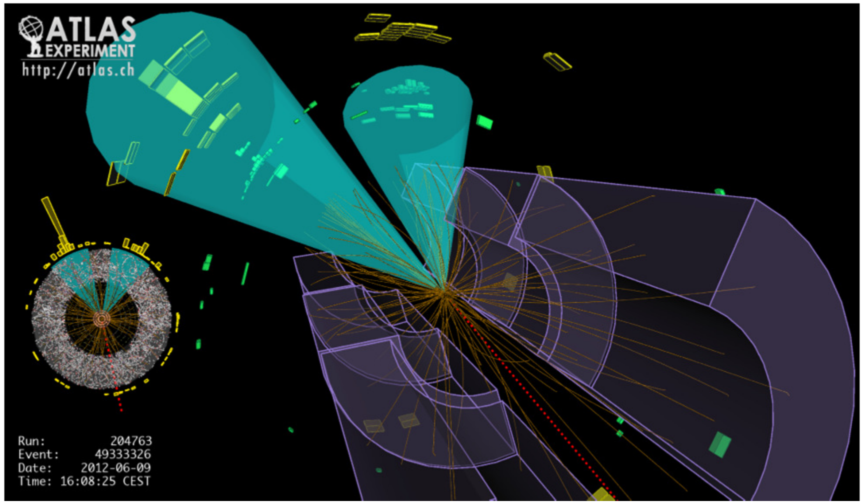


Background modelling and control regions (CR):

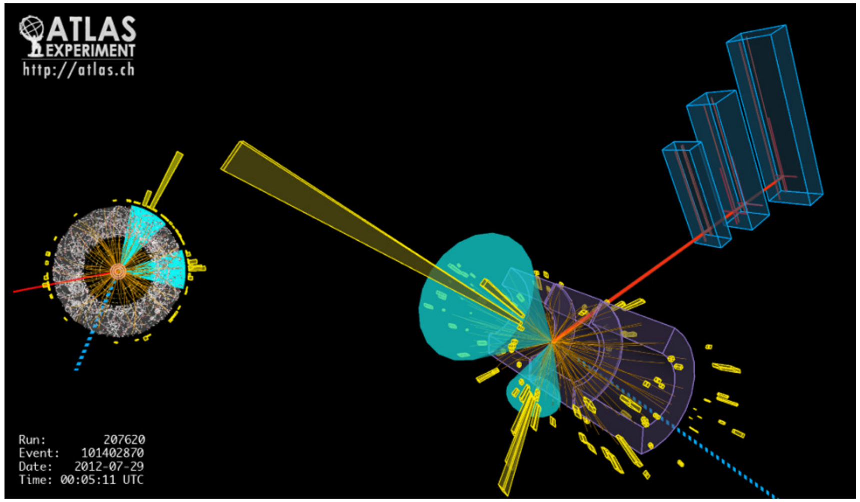
- Z+heavy(light) flavour jets, define control regions/shape uncertainties from data
- W+heavy, light/charm from CR, Wbb shape from MC
- Top (ttbar and single top), control regions at higher jet multiplicity, shape uncertainty from MC
- Multijet, derived shapes/normalisations from the data. Keep it small!

ATLAS Detector

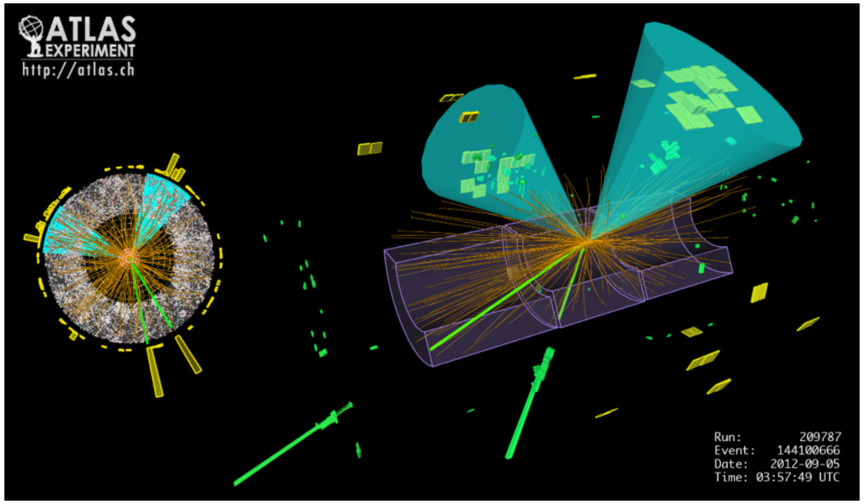
0 Lepton: Level 1 Calorimeter trigger, calorimeter up to $|\eta|<4.9$



1 Lepton: Single lepton triggers and reconstruction $p_T>25$ GeV, $|\eta|<2.5$,



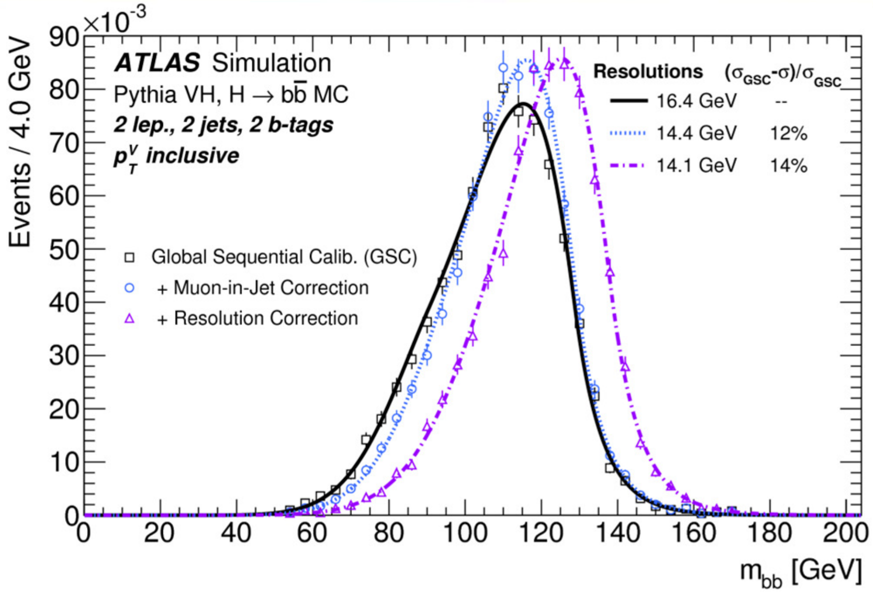
2 Lepton: 2nd leptons from $p_T>7$ GeV

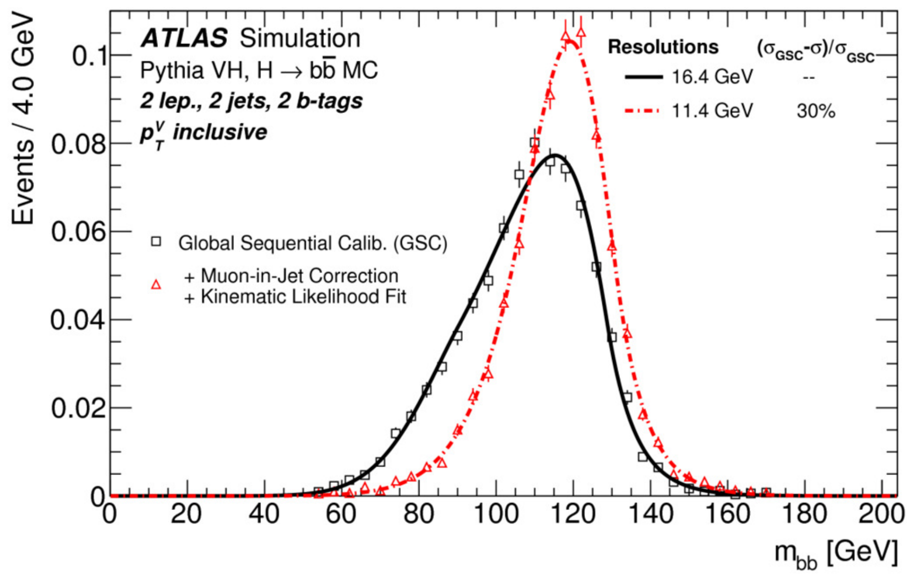


0,1,2 Lepton: Silicon Tracking

- -b-tagging up to $|\eta|<2.5$, with high rejection of light (1400) and charm (26) for 50% efficiency
- -Reduce pile-up by matching tracks in jet to primary vertex

m_{bb} Reconstruction

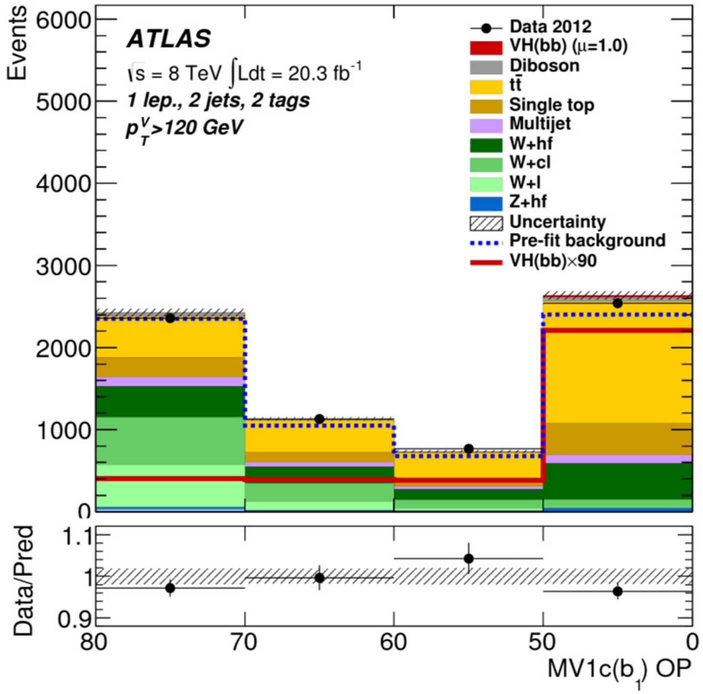


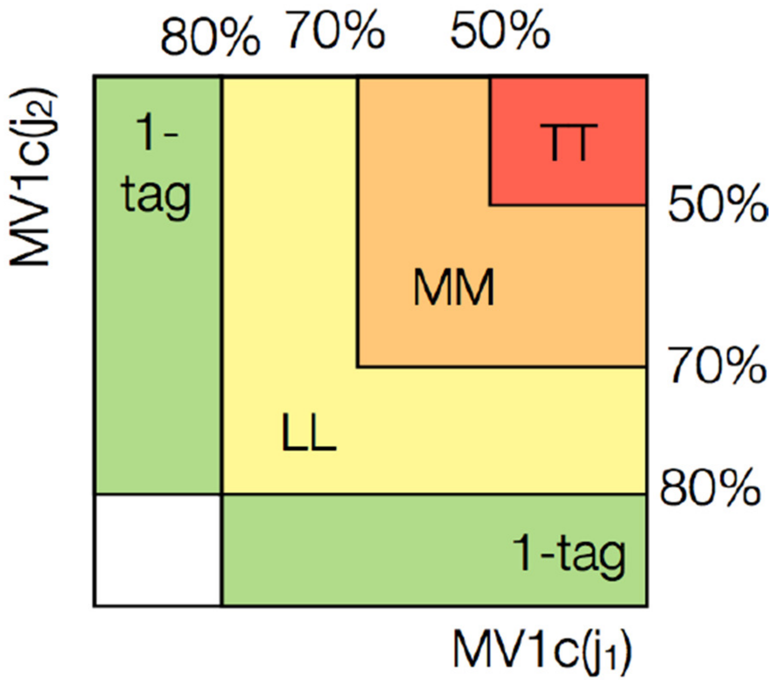


- Start from jets from topological calorimeter clusters
- Apply a series of jet level corrections (Global Sequential Calibration)
- Add any close by muons from semi-leptonic decays to the jet
- Apply a "resolution correction" as a function of pT of the jet to get to "true" pT
- In 2 lepton events have additional constraint that no real MET in event. Apply kinematic fitting to further improve resolution

"Selected Jets" used in optimisation. p_T>20 GeV and $|\eta|$<2.5

b-tagging categories





- Use the “MV1c” tagger. Multivariate tagger with inputs based on track parameter significance and secondary decay reconstruction. Gives improved charm rejection. Select jets starting from 80% efficiency working point
- Working points from 80%,70%, 50% called “Loose”, “medium”, “Tight”
- Define TT,MM,LL categories to improve sensitivity
- TT and MM more signal, LL used to constrain backgrounds

Event Selection

NU – not used | "Cut-based" – optimised cuts! | "MVA" – looser cuts

V+jets

multijet

multijet

Top

Variable	Dijet-mass analysis					Multivariate analysis	
Common selection							
p_T^V [GeV]	0–90	$90^{(*)}$–120	120–160	160–200	> 200	0–120	> 120
$\Delta R(\text{jet}_1, \text{jet}_2)$	0.7–3.4	0.7–3.0	0.7–2.3	0.7–1.8	< 1.4	> 0.7 (p_T^V<200 GeV)	
0-lepton selection (MET Trigger, MET>100 GeV)							
p_T^{miss} [GeV]	NU trigger	> 30	> 30			NU	> 30
$\Delta\phi(\boldsymbol{E}_T^{miss}, \boldsymbol{p}_T^{miss})$		$< \pi/2$	$< \pi/2$				$< \pi/2$
$\min[\Delta\phi(\boldsymbol{E}_T^{miss}, \text{jet})]$		–	> 1.5				> 1.5
$\Delta\phi(\boldsymbol{E}_T^{miss}, \text{dijet})$		> 2.2	> 2.8				> 2.8
$\sum_{i=1}^{N_{jet}=2(3)} p_T^{\text{jet}_i}$ [GeV]		> 120 (NU)	> 120 (150)				> 120 (150)
1-lepton selection (Single Lepton trigger, plus MET trigger(μ))							
m_T^W [GeV]	< 120					–	
H_T [GeV]	> 180		–			> 180	–
E_T^{miss} [GeV]	–		> 20		> 50	–	> 20
2-lepton selection (Single/dilepton trigger)							
$m_{\ell\ell}$ [GeV]	83-99					71-121	
E_T^{miss} [GeV]	< 60					–	

2 b-jets highest p_T jets and 1 jet p_T>45 GeV. Reduce top, no jets p_T>30 GeV and 2.5<|η|<4.5

MC Production

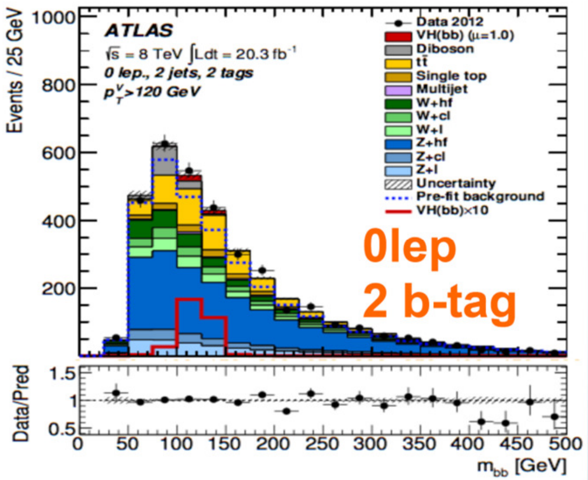
LO and NLO MC Generators

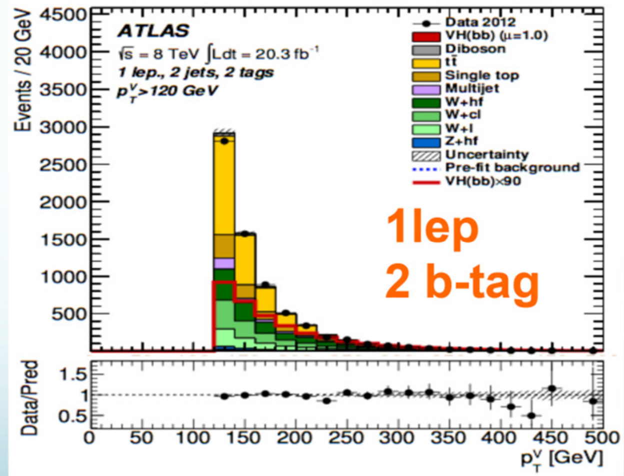
Process	Generator
Signal$^{(\star)}$	
$q\bar{q} \to ZH \to \nu\nu bb/\ell\ell bb$	PYTHIA8
$gg \to ZH \to \nu\nu bb/\ell\ell bb$	POWHEG+PYTHIA8
$q\bar{q} \to WH \to \ell\nu bb$	PYTHIA8
Vector boson + jets	
$W \to \ell\nu$	SHERPA 1.4.1
$Z/\gamma* \to \ell\ell$	SHERPA 1.4.1
$Z \to \nu\nu$	SHERPA 1.4.1
Top-quark	
$t\bar{t}$	POWHEG+PYTHIA
t-channel	ACERMC+PYTHIA
s-channel	POWHEG+PYTHIA
Wt	POWHEG+PYTHIA
Diboson$^{(\star)}$	POWHEG+PYTHIA8
WW	POWHEG+PYTHIA8
WZ	POWHEG+PYTHIA8
ZZ	POWHEG+PYTHIA8

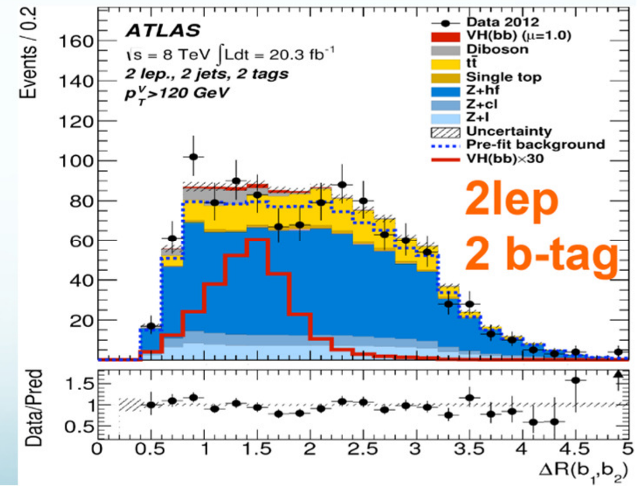
Plus many more programs used to evaluate modelling systematic uncertainties

- Monte Carlo statistics vital (many times data luminosity required)
- Use ATLFAST-II simulation (fast parameterisation of calorimeter response, else GEANT4). ~0.5×10^9 evts
- High signal statistics required for MVA training. Multiple mass points for exclusion limits.
- For V+jets use heavy flavour filters, p_T^V slicing, jet multiplicity enhanced weighting
- Difficult to get enough V+light jets due to large cross section. Apply mis-tagging probability as a weight as function of p_T, η with ΔR correction
- Common group level "mini-ntuples" obtained from MC or derived datasets on the Grid. All preselected samples with systematics ~1.5 TB

Multivariate Analysis



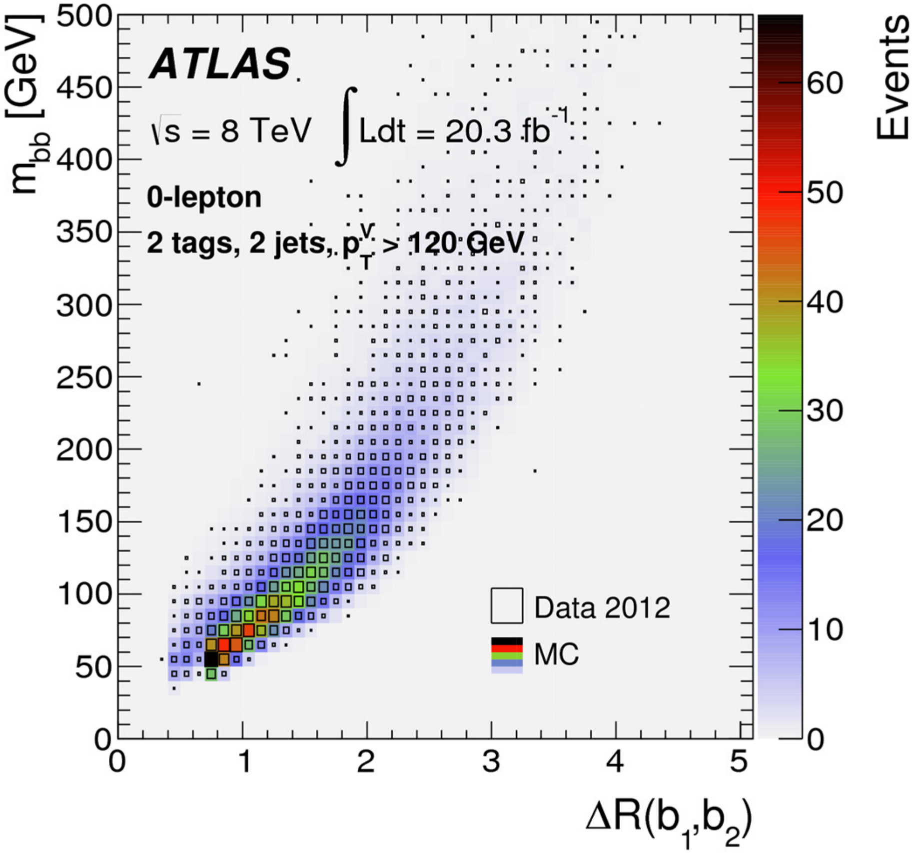


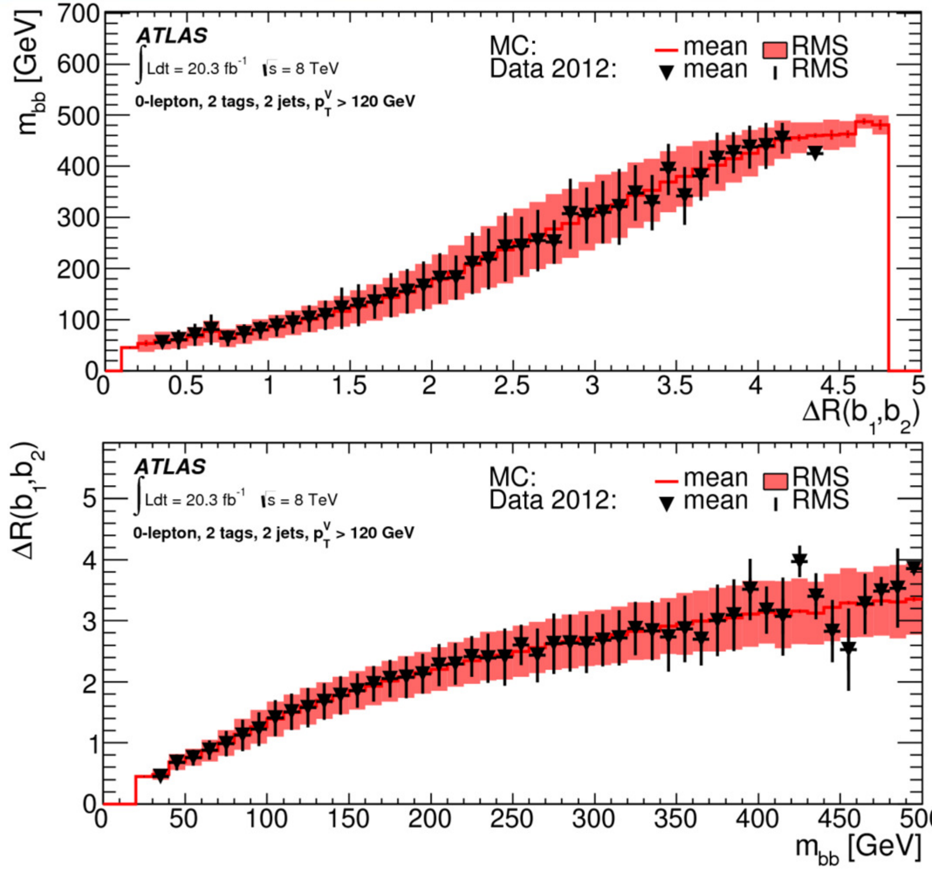


- Use a boosted decision tree (BDT)
- As well as m_{bb} train using up to 16 discriminating variables, including p_T^V and $\Delta R(b,b)$. Make sure variables are well described by MC models.
- Train signal against weighted sum of backgrounds, similar results as using “cascade”
- Train in 2/3 jet categories and at high and low p_T^V
- Train for different m_H for exclusion plot

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		×	
$m_{\ell\ell}$			×
$MV1c(b_1)$	×	×	×
$MV1c(b_2)$	×	×	×
	Only in 3-jet events		
$p_T^{jet_3}$	×	×	×
m_{bbj}	×	×	×

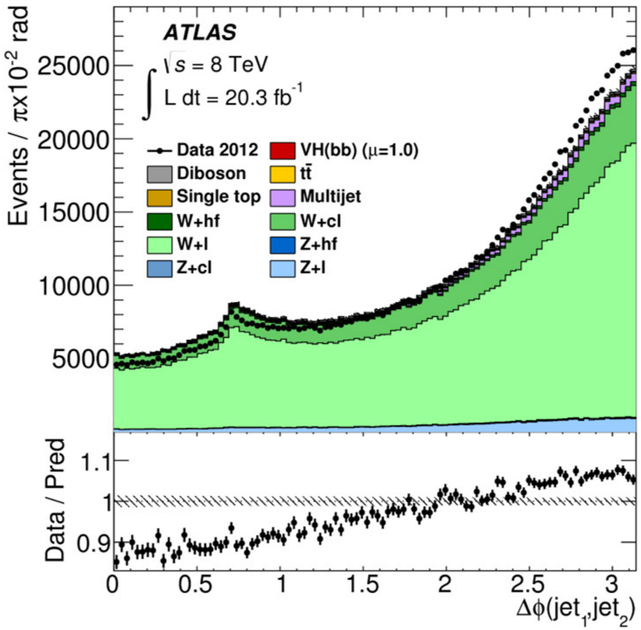
BDT Training

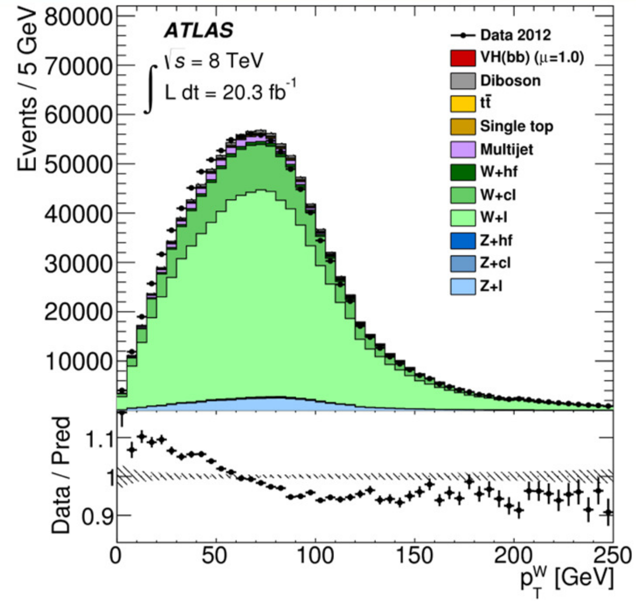


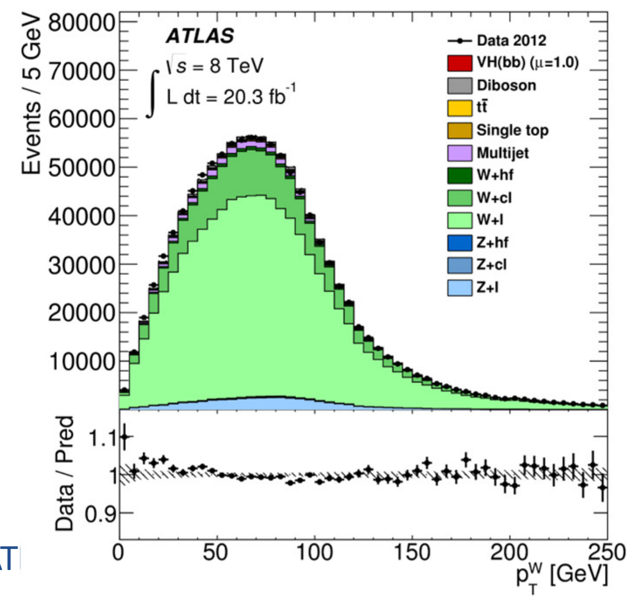


- Use TMVA. Tune parameters of training across phase space, finer 1-D scans, study effect of adding each new variable
- Need high signal stats, also maximise MC statistics. Split sample into 2. Train and evaluate each half against each other
- Check correlations of all variables from 2D histograms!

Background Modelling

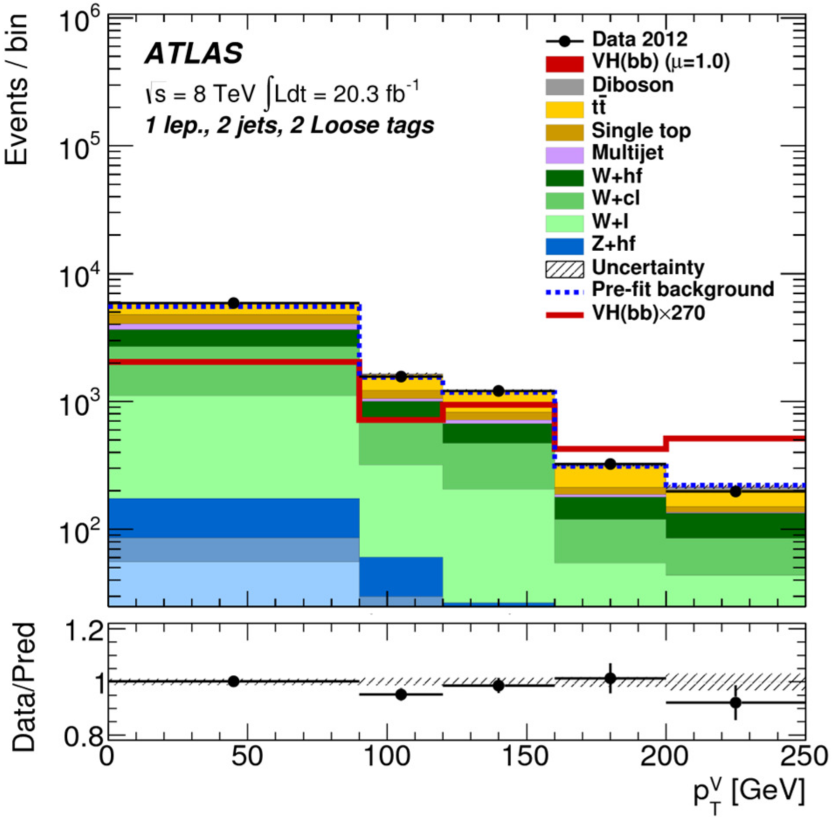


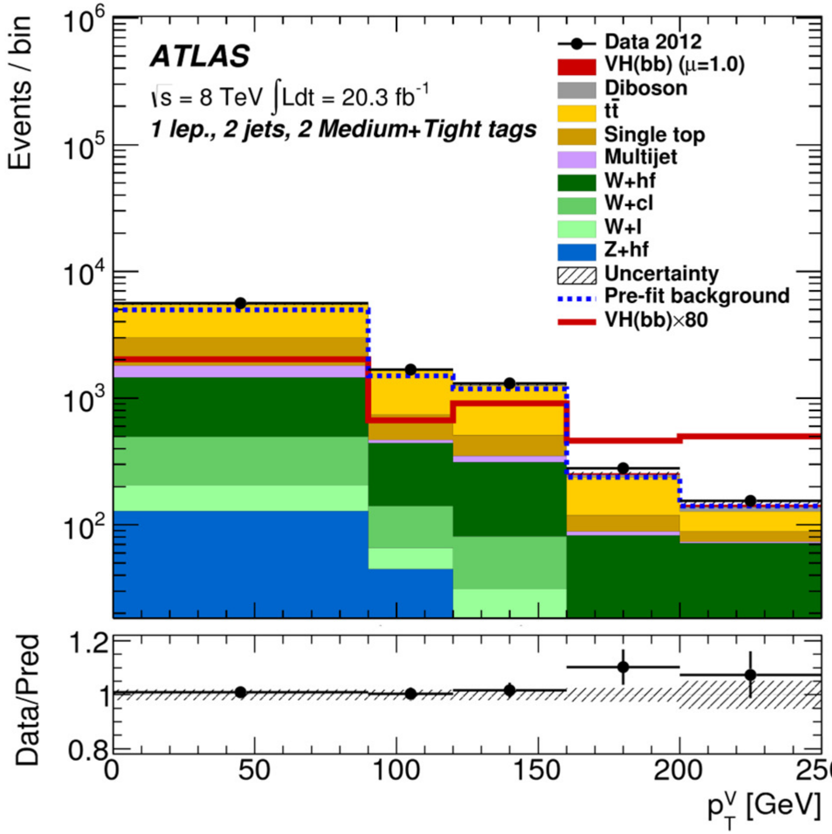




- MC doesn't always describe data!
- E.g. mismodelling in 1 Lepton, 0 tag $\Delta\phi(jet_1,jet_2)$
- Reweighting improves p_T^W modelling
- Similar story in 2 lepton (2 tag CR)
- Systematic errors (nuisance parameters) applied for the different backgrounds

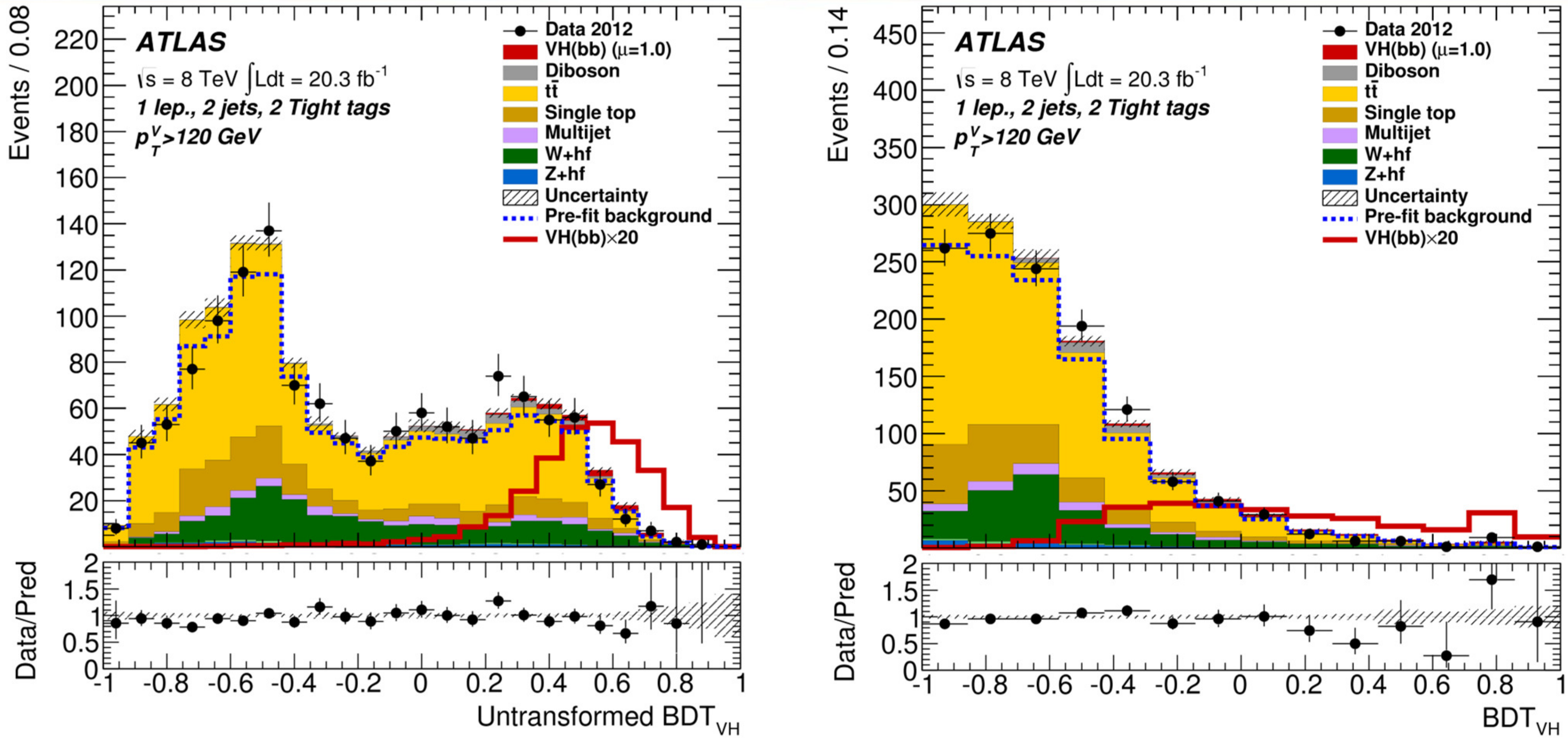
Background Modelling





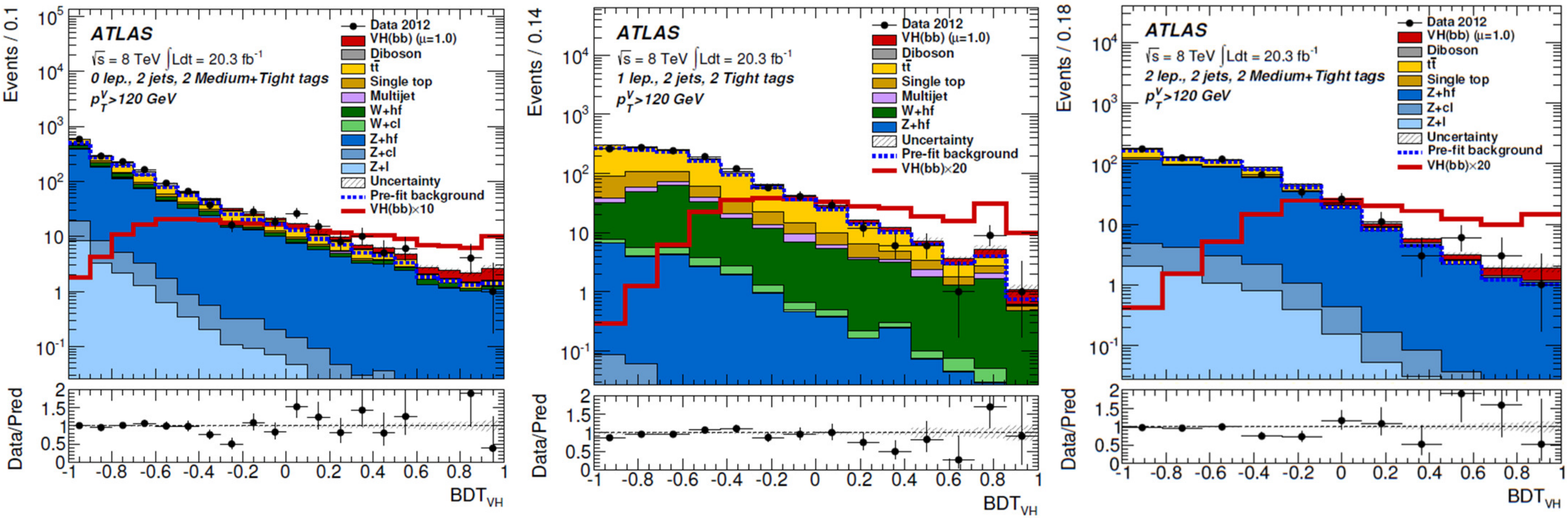
- Can check that the corrections to the backgrounds worked
- p_T^W distribution in 1 lepton loose tags and medium+tight tag regions

Binning Transformations



- Want finer binning in signal region. Coarser in background region.
- Rebinning algorithm applied (based on Nsig and Nbkg), plus further requirement <10% statistical error on total background
- Parameters of algorithm tuned to maximise signal sensitivity
- Also applied to m_{bb} in dijet-mass analysis

Final Discriminants



- BDT Output distribution (2 btag) and MV1c (1 tag)
- 2 b-tag: (0,1,2 leptons) x (p_T^V bin)x (2,3 jets) x (LL, MM+TT)
- 1-tag region helps to constrain backgrounds e.g. Vcl
- BDT Output distribution (2 btag) and MV1c (1 tag):251 and 38 regions

"Global Fits"

- Binned maximum likelihood fits
- Impact of systematic uncertainties described by nuisance parameters (NPs)
- Each NP constrained by penalty term in likelihood, associated with its error
- The statistical uncertainty of MC taken into account using bin-by-bin NPs
- Some statistical variations need to be smoothed
- To save processing time, errors with negligible impact are "pruned"
- 170 NPs (approx. half experimental)
- Plus add in previously analysed 7 TeV data
- Dijet mass analysis serves as a cross check

- Some backgrounds constrained by data
- Described by scale-factors e.g. 8 TeV MVA
- Different scale factors for top background in 3 channels due to different final state objects

Process	Scale factor
$t\bar{t}$ 0-lepton	1.36 ± 0.14
$t\bar{t}$ 1-lepton	1.12 ± 0.09
$t\bar{t}$ 2-lepton	0.99 ± 0.04
Wbb	0.83 ± 0.15
Wcl	1.14 ± 0.10
Zbb	1.09 ± 0.05
Zcl	0.88 ± 0.12

Systematics

Experimental Sources

- Jet energy scale, resolution, flavour response
- b-tagging efficiency (10 parameters), charm and light jet rejection
- MET trigger and reconstruction
- Lepton trigger and identification
- Luminosity (3%)

Effect on signal strength μ

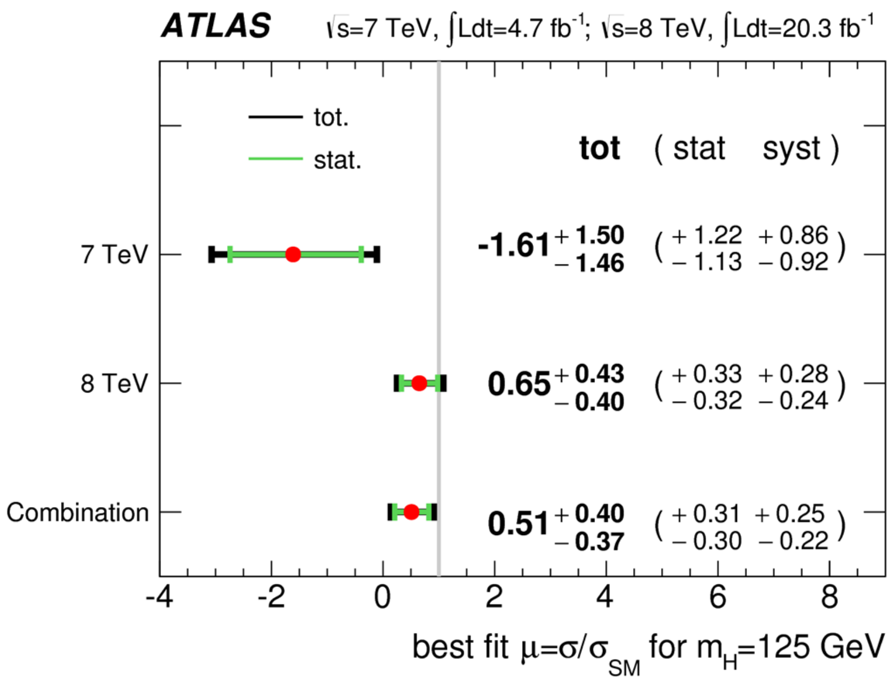
Source of uncertainty		σ_μ
Total		0.41
Statistical		0.32
Systematic		0.26
Experimental uncertainties		
Jets		0.08
E_T^{miss}		0.03
Leptons		0.01
b-tagging$^{(*)}$	b-jets	0.07
	c-jets	0.04
	light jets	0.04
Luminosity		0.03

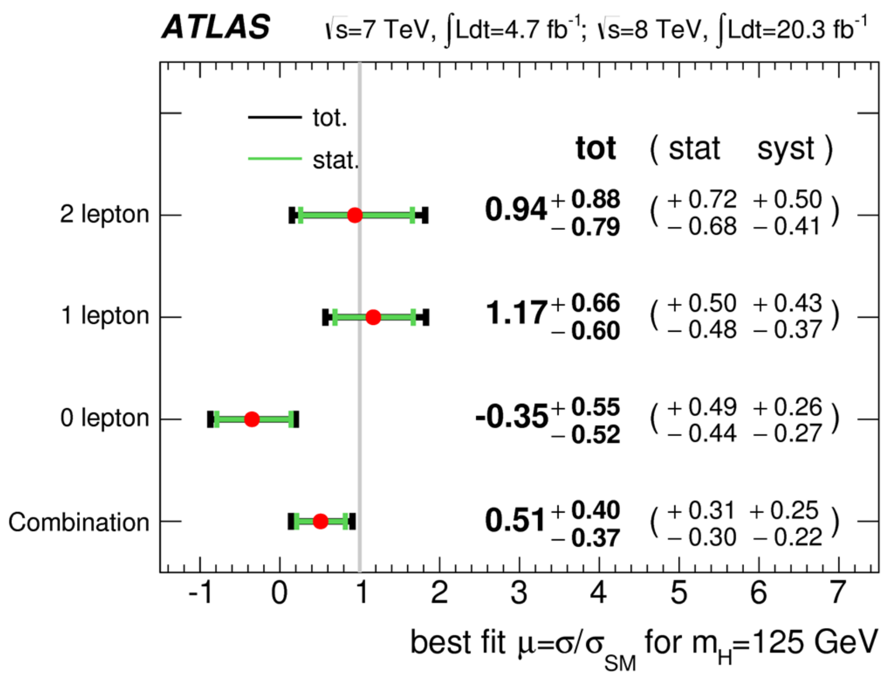
Theoretical and modelling uncertainties		
Signal		0.07
Floating normalisations	W+jets	0.06
	Z-jets	0.03
	$t\bar{t}$	0.04
Background modelling	W+jets	0.11
	Z-jets	0.08
	$t\bar{t}$	0.05
Single-top		0.04
Diboson		0.02
Multijet		0.06

Modelling

Signal	
Cross section (scale)	1% ($q\bar{q}$), 50% (gg)
Cross section (PDF)	2.4% ($q\bar{q}$), 17% (gg)
Branching ratio	3.3 %
Acceptance (scale)	1.5%–3.3%
3-jet acceptance (scale)	3.3%–4.2%
p_T^V shape (scale)	S
Acceptance (PDF)	2%–5%
p_T^V shape (NLO EW correction)	S
Acceptance (parton shower)	8%–13%
Z+jets	
Zl normalisation, 3/2-jet ratio	5%
Zcl 3/2-jet ratio	26%
Z+hf 3/2-jet ratio	20%
Z+hf/Zbb ratio	12%
$\Delta\phi(\text{jet}_1, \text{jet}_2)$, p_T^V, m_{bb}	S
W+jets	
Wl normalisation, 3/2-jet ratio	10%
Wcl, W+hf 3/2-jet ratio	10%
Wbl/Wbb ratio	35%
Wbc/Wbb, Wcc/Wbb ratio	12%
$\Delta\phi(\text{jet}_1, \text{jet}_2)$, p_T^V, m_{bb}	S
$t\bar{t}$	
3/2-jet ratio	20%
High/low-p_T^V ratio	7.5%
Top-quark p_T, m_{bb}, E_T^{miss}	S
Single top	
Cross section	4% (s-,t-channel), 7% (Wt)
Acceptance (generator)	3%–52%
m_{bb}, $p_T^{b_2}$	S
Diboson	
Cross section and acceptance (scale)	3%–29%
Cross section and acceptance (PDF)	2%–4%
m_{bb}	S
Multijet	
0-, 2-lepton channels normalisation	100%
1-lepton channel normalisation	2%–60%
Template variations, reweighting	S

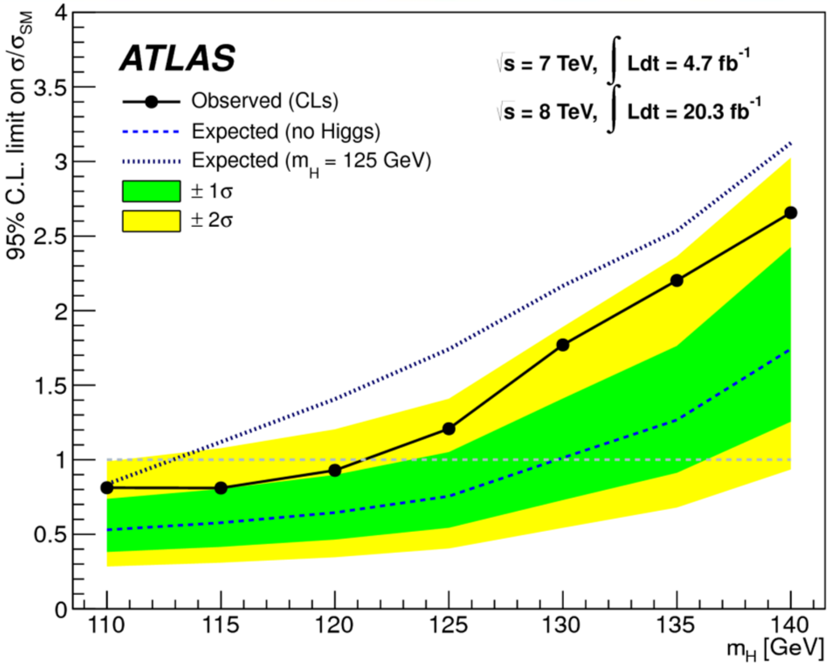
Results

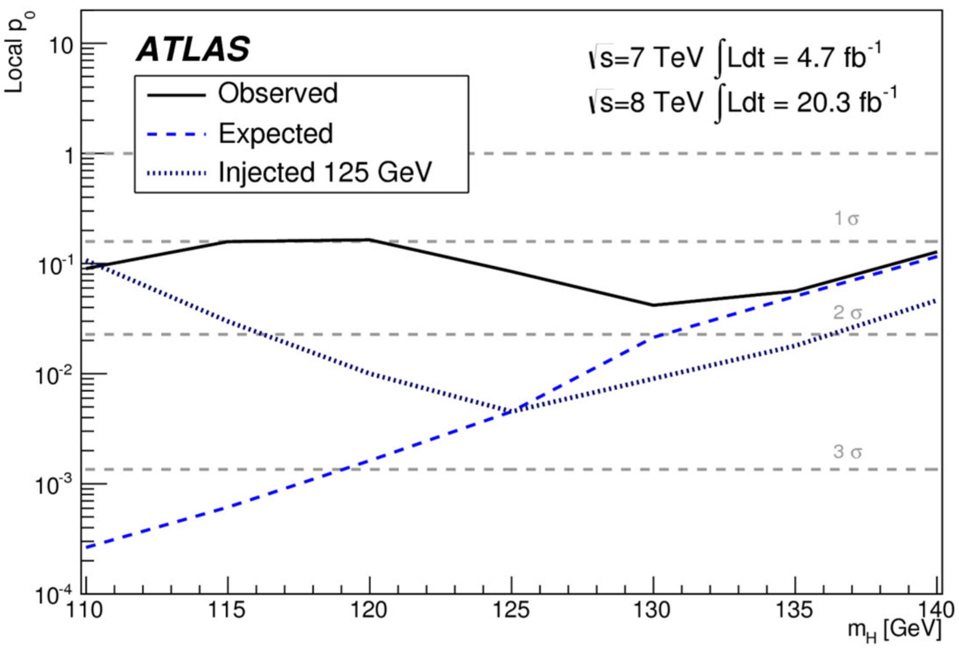




- Fitted **signal strength** parameters shown per year and per channel

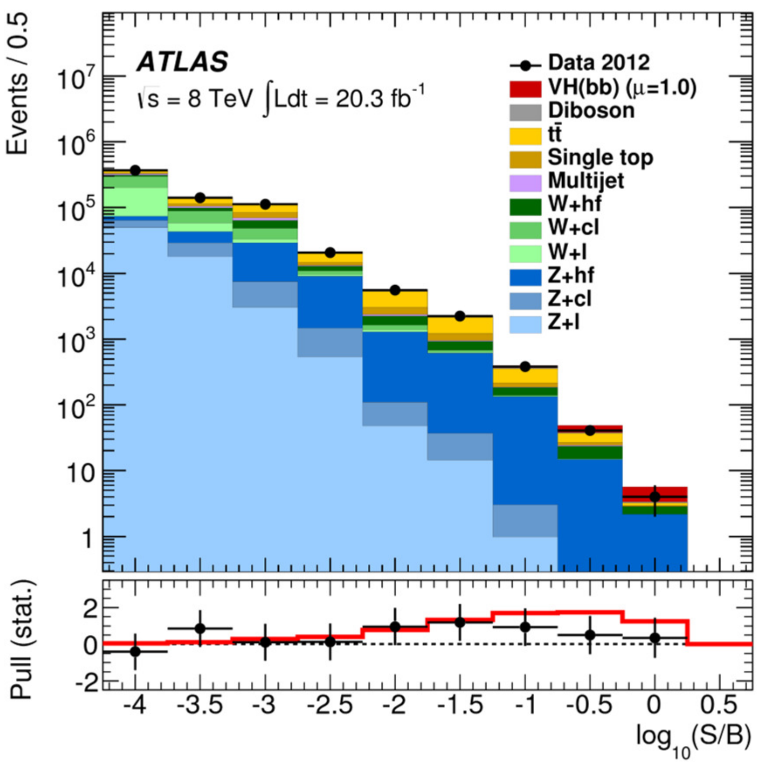
Exclusion Limits, p_0

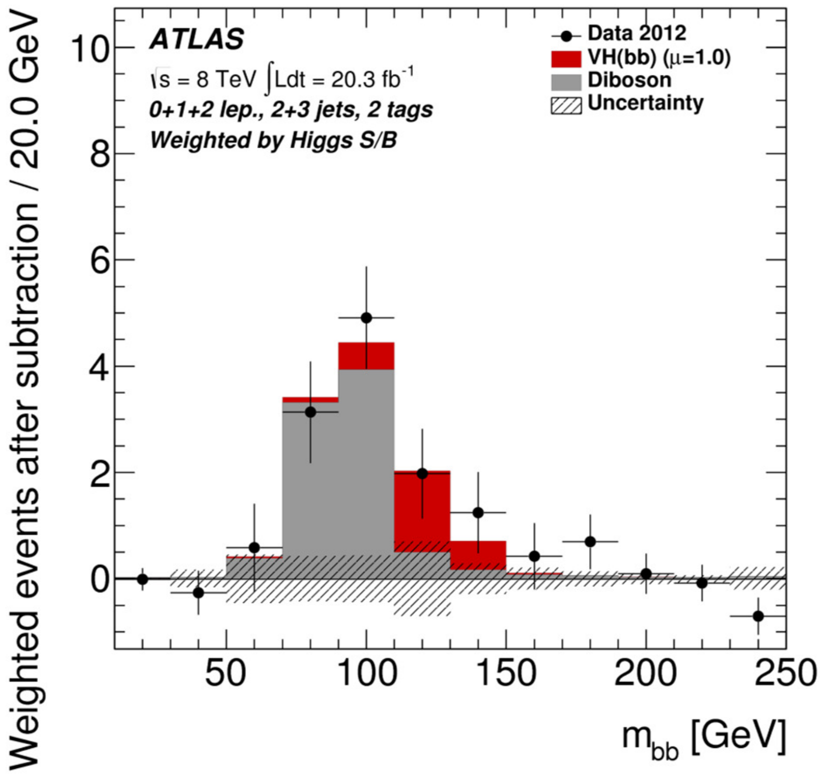




- Exclusion 1.2 times SM at m_H=125 GeV, expect 0.8 in absence of signal
- Probability p_0 to be described by background only is 8% at m_H=125 GeV with 0.5% expected
- Observed significance of 1.4σ for 2.6σ expected

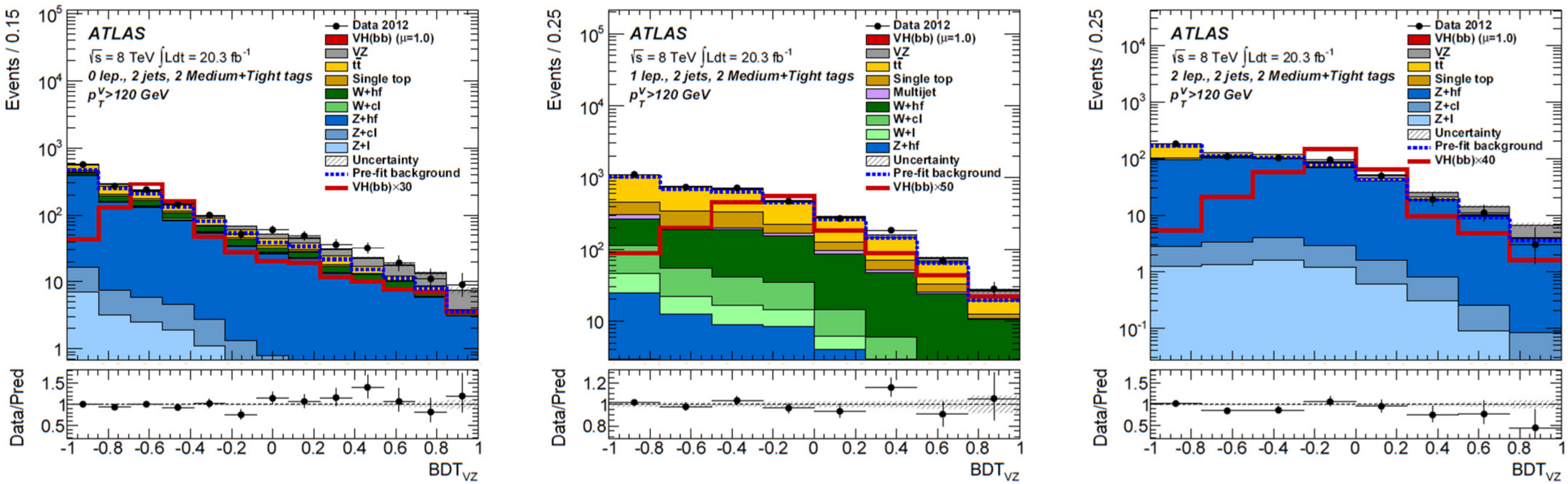
What can we "see" in 8TeV data?





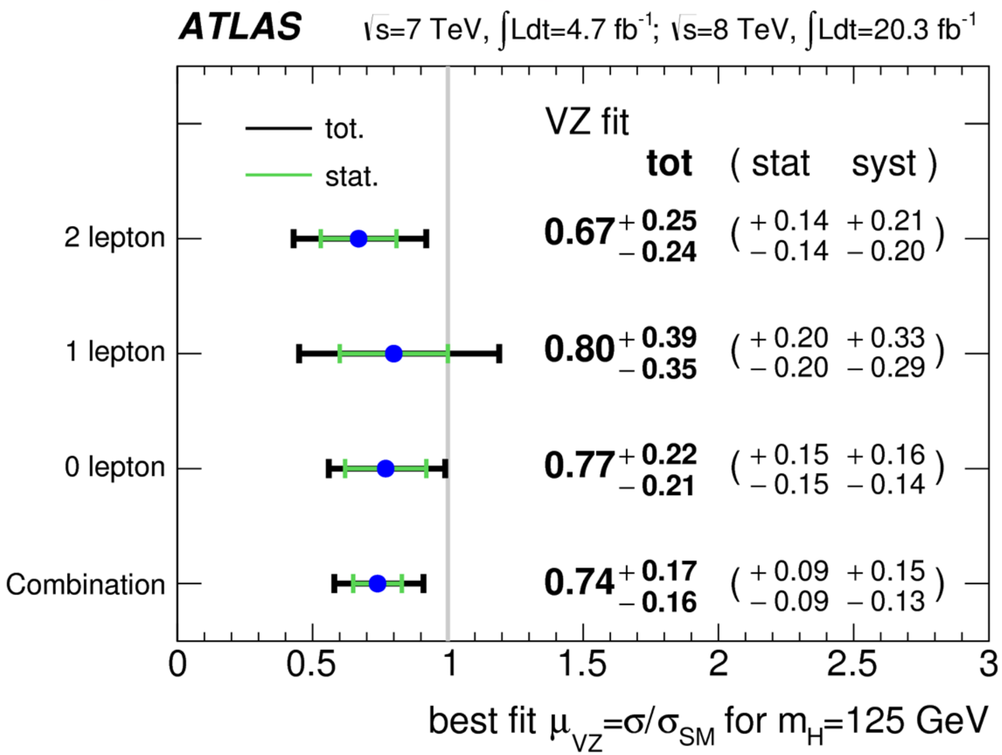
- Bin signal and background distributions in bins of expected S/fitted B. Data shown with statistical errors only.
- Similarly look at background subtracted (except VZ) m_{bb} distribution from dijet analysis weighted by S/B. Clear VZ peak at Z mass. Higgs signal shown for μ=1

Diboson VZ Cross Check



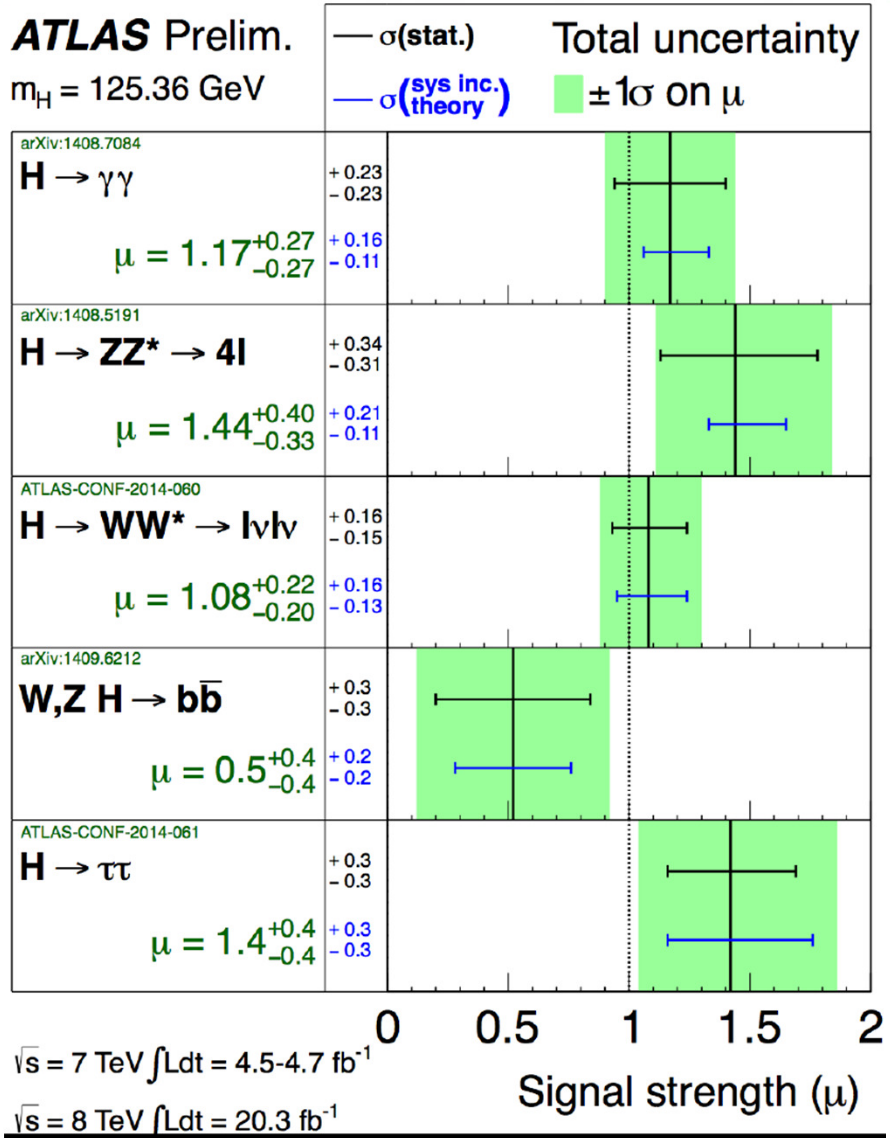
- Instead of training VH signal against background, train diboson as signal against other backgrounds (including VH)
- Perform a fit with μ_{VZ} and μ_{VH} left free…

VZ Results



- Signal strength of VZ fit. The value of μ_{VH} obtained in the VZ fit consistent with VH fit. The correlation between VH and VZ is low (3%) due to different m_{bb} and p_T^V distributions
- Observed (expected) significance for VZ 4.9(6.3)σ

Latest ATLAS Higgs Results (with H->bb!)



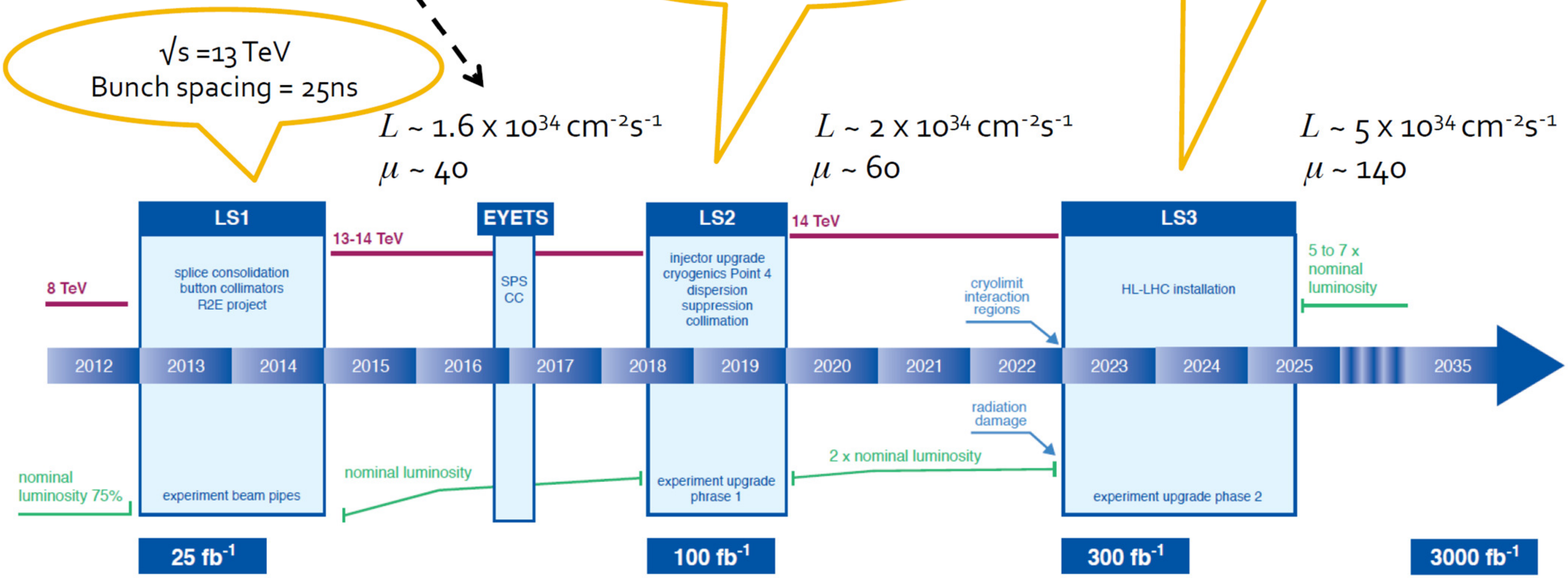
1.4σ(2.6σ), 50% gain with recent improvements

CMS μ=1.0+/-0.5 and 2.1σ

The final word from LHC on VH until Run 2

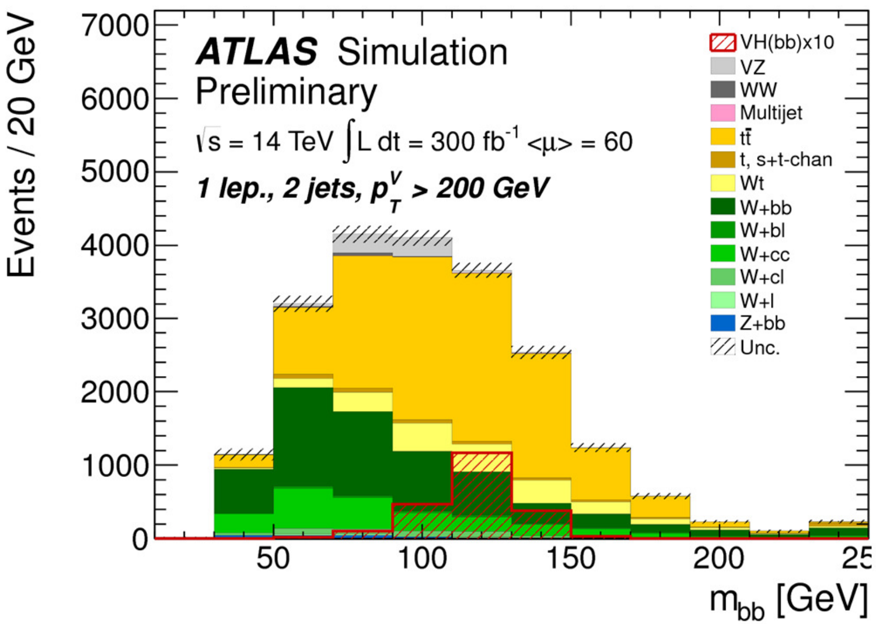
Run 2 and Toward HL-LHC

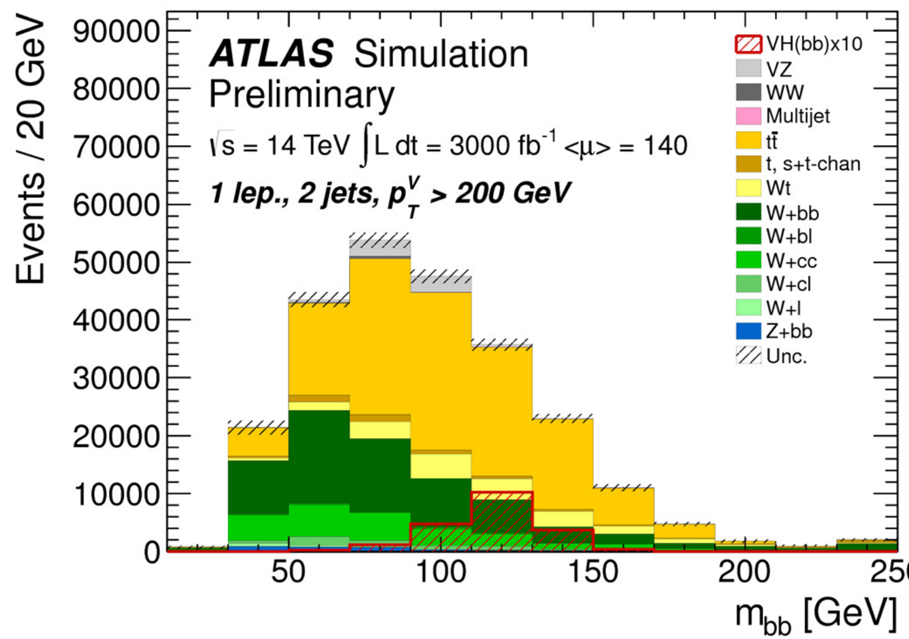
- So far
  - $\sqrt{s}$ = 7-8 TeV
  - Bunch spacing = 50 ns
  - Luminosity: L ~ 6 x 10^{33} $cm^{-2}s^{-1}$
  - Pileup μ ~ 20



Prospects for VH in Run 2

ATL-PHYS-PUB-2014-011





- Consider 2 upgrade scenarios 300fb^{-1} with pile-up <μ>=60 and 3000fb^{-1} with pile-up <μ>=140
- Particle level study uses parameterisations of resolution on upgraded detector including b-tagging upgrades
- Analysis uses one and two lepton analysis only, It will still be possible to use zero lepton channel with the use of topological calorimeter trigger.

Run 2 Prospects VH Results

300 fb^{-1}

		One-lepton	Two-lepton	One+Two-lepton
Stat-only	Significance	2.7	3.0	4.1
	$\hat{\mu}_{\mathrm{Stats}}$ error	+0.37 −0.37	+0.33 −0.33	+0.25 −0.25
Theory-only	$\hat{\mu}_{\mathrm{Theory}}$ error	+0.08 −0.05	+0.08 −0.05	+0.09 −0.06
Scenario I	Significance	1.2	2.4	2.6
	$\hat{\mu}_{\mathrm{w/Theory}}$ error	+0.86 −0.85	+0.44 −0.43	+0.39 −0.38
10% JES	$\hat{\mu}_{\mathrm{wo/Theory}}$ error	+0.85 −0.85	+0.43 −0.43	+0.38 −0.38
	Significance	1.4	-	2.8
Scenario II	$\hat{\mu}_{\mathrm{w/Theory}}$ error	+0.71 −0.70	-	+0.38 −0.37
5% JES	$\hat{\mu}_{\mathrm{wo/Theory}}$ error	+0.70 −0.70	-	+0.37 −0.36

3000 fb^{-1}

One-lepton	Two-lepton	One+Two-lepton
7.7	7.5	10.7
+0.13 −0.13	+0.14 −0.13	+0.09 −0.09
+0.09 −0.07	+0.07 −0.08	+0.07 −0.07
1.8	5.6	5.9
+0.56 −0.54	+0.20 −0.19	+0.19 −0.19
+0.54 −0.54	+0.18 −0.18	+0.18 −0.17
3.2	-	6.4
+0.33 −0.32	-	+0.18 −0.17
+0.32 −0.32	-	+0.16 −0.16

- Combined analysis reaches $S/\sqrt{B}$ of 2.6(5.9) for 300 (3000)fb^{-1}
- Analysis restricted to cut-based only, no extra b-tagging categories, no improved jet energy resolution, no extensions to boosted “fat-jets”
- Validation of analysis in comparison with 8 TeV analysis: combined expected significance of 1.14 to be compared with 2.5
- Estimate improvements of a more “performant” analysis: combined significance of 3.9σ(8.8σ) for 300 (3000)fb^{-1}
- So discovery in H->bb perhaps not so far away, combine with Run 1 data/CMS etc.

And now for something (slightly) different

Question: Is the Higgs observed at the LHC the standard model Higgs or the h from an extended sector?

- In the Standard Model (SM) only 1 complex Higgs doublet is responsible for electroweak symmetry breaking: there is one neutral CP even Higgs boson h
- Two Higgs Doublet Models (2HDM) simple extension beyond the SM Higgs sector to include two complex Higgs Doublets . Leads to five physical states H^+, H^- , A(CP-odd), H, h (CP-even)
- *Entering a new realm of exploration: the couplings and decays rates of the observed Higgs boson to probe physics beyond the standard model*

2HDM

- Higgs sector of 2HDM models described by 6 parameters: 4 Higgs masses, tan β(ratio of vacuum expectation values vev) and α mixing between the two neutral CP even states h,H
- Type I: One doublet couples to V("fermiophobic"), one to fermions
- Type II: "MSSM like" model, one doublet couples to up-type quarks, one to d-type quarks and leptons
- Type III: "Lepton-specific" model, Higgs bosons have same couplings to quarks as type I and to leptons as in type II
- Type IV: "Flipped" model, Higgs bosons have same couplings to quarks as in type II and to leptons as in type I
- *In MSSM/2HDM type II models the couplings to b quarks and τ leptons are enhanced at high tan β*

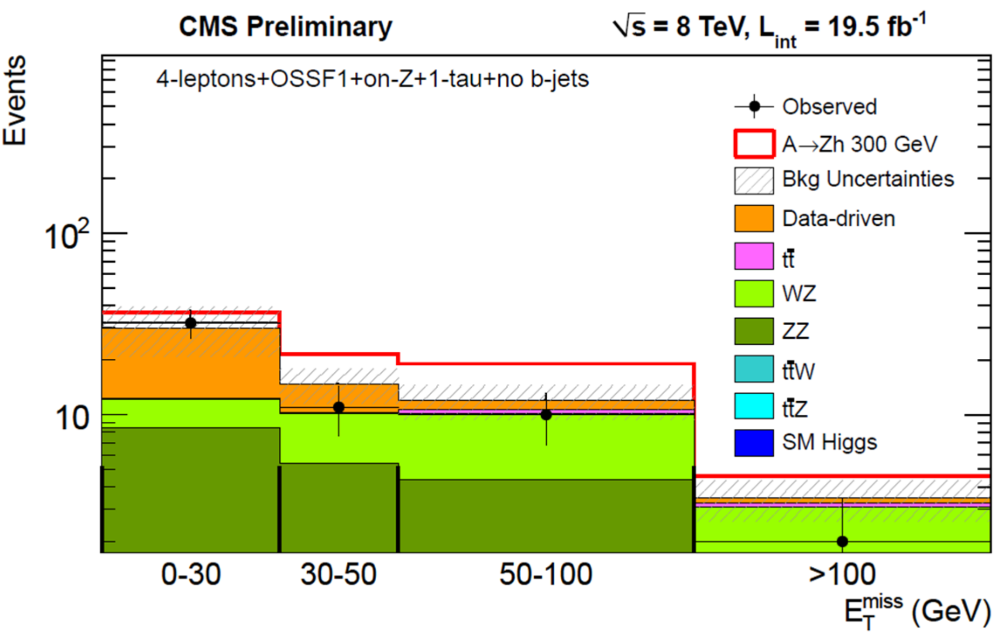
Direct A->Zh Searches from CMS

- For m_A in range $2m_h<m_A<2m_t$, then A->Zh dominates

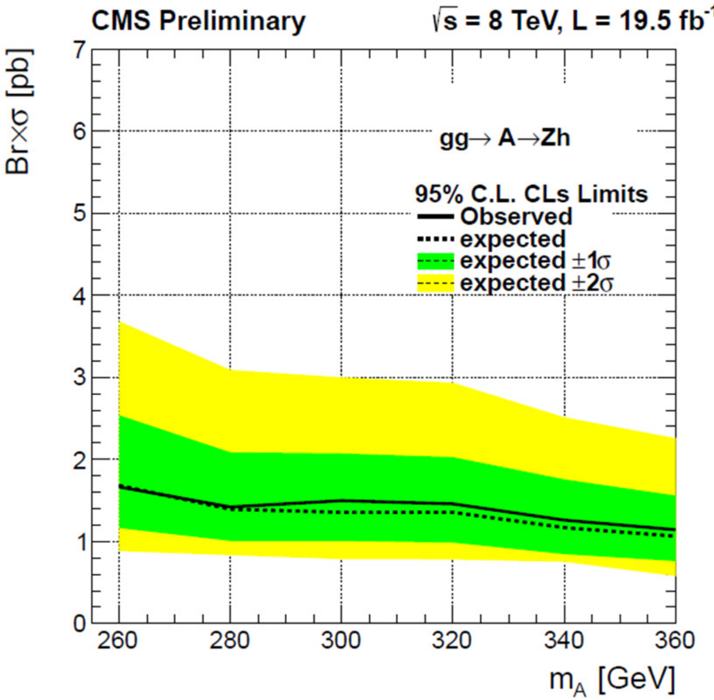
CMS-PAS-HIG-13-025

- Assume SM decays of h. Look at leptonic and diphoton decays

	$h \to WW^*$	$h \to ZZ^*$	$h \to \tau\tau$	$h \to \gamma\gamma$
$Z \to ll$	✓	✓	✓	✓
$Z \to qq$	X	✓	X	X
$Z \to \nu\nu$	X	✓	X	X

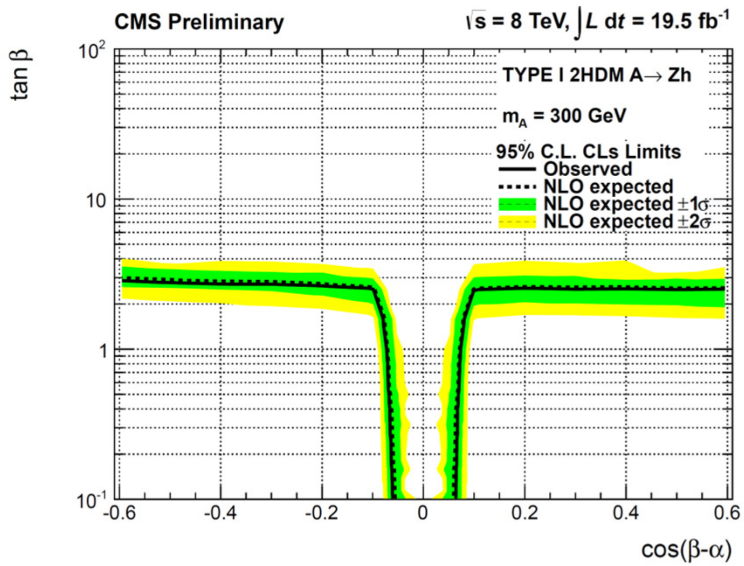


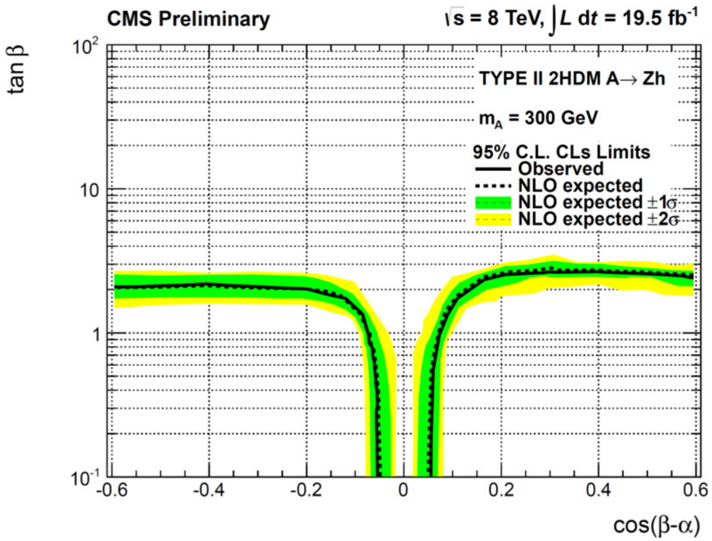
- Limits on Br*sigma. 95% CL of 2pb



2HDM Limits

- Limits on 2HDM Type I and Type II in the tan β, cos(β–α) plane





Region below curves excluded. cos(β–α)=0 is SM alignment

- Indirect search from ATLAS CONF-2014-010 where re-interpret SM Higgs coupling measurements in 2HDM models (less stringent around tan β=1)
- A->Zh (h->bb) channels can improve sensitivity. Same final state as 0/2 lepton VH analyses. Z->ll better resolution in reconstructed m_A than Z->νν. Maybe results next time…

Summary

- Presented final run 1 results on VH(H->bb) searches at ATLAS
- Expected(observed) significance $2.6(1.4)\sigma$
- Analysis validated using diboson measurement
- H->bb is a run 2 “measurement”. First estimates at expected sensitivity from parameterisations of upgraded simulation. Every little bit of improvement in analysis helps – plus combination with run 1 data/CMS
- Higgs coupling to b-quarks sensitive area for BSM physics. E.g. 2HDM searches for A->Zh using same final state as 0/2 lepton VH analysis will improve constraints on model phase space
- Lots of hard work and many exciting results to come in run 2…

ATLAS Higgs group is ready!

ATLAS Higgs Workshop, Rome, April 2014

Back up

Signal Acceptance

$m_H = 125$ GeV at $\sqrt{s} = 8$TeV				
Process	Cross section × BR [fb]	Acceptance [%]		
		0-lepton	1-lepton	2-lepton
$q\bar{q} \to (Z \to \ell\ell)(H \to b\bar{b})$	14.9	–	1.3 (1.1)	13.4 (10.9)
$gg \to (Z \to \ell\ell)(H \to b\bar{b})$	1.3	–	0.9 (0.7)	10.5 (8.1)
$q\bar{q} \to (W \to \ell\nu)(H \to b\bar{b})$	131.7	0.3 (0.3)	4.2 (3.7)	–
$q\bar{q} \to (Z \to \nu\nu)(H \to b\bar{b})$	44.2	4.0 (3.8)	–	–
$gg \to (Z \to \nu\nu)(H \to b\bar{b})$	3.8	5.5 (5.0)	–	–

MVA(Dijet Mass)

2HDM Models

- Couplings of the light Higgs boson h to vector bosons, up-type, down-type quarks and charged leptons for 4 types of 2HDMs can be expressed as ratios expressed as functions of α (mixing angle) and tan β (ratio of vevs)

Coupling scale factor	Type I	Type II	Type III	Type IV
κ_V	$\sin(\beta-\alpha)$	$\sin(\beta-\alpha)$	$\sin(\beta-\alpha)$	$\sin(\beta-\alpha)$
κ_u	$\cos(\alpha)/\sin(\beta)$	$\cos(\alpha)/\sin(\beta)$	$\cos(\alpha)/\sin(\beta)$	$\cos(\alpha)/\sin(\beta)$
κ_d	$\cos(\alpha)/\sin(\beta)$	$-\sin(\alpha)/\cos(\beta)$	$\cos(\alpha)/\sin(\beta)$	$-\sin(\alpha)/\cos(\beta)$
κ_l	$\cos(\alpha)/\sin(\beta)$	$-\sin(\alpha)/\cos(\beta)$	$-\sin(\alpha)/\cos(\beta)$	$\cos(\alpha)/\sin(\beta)$