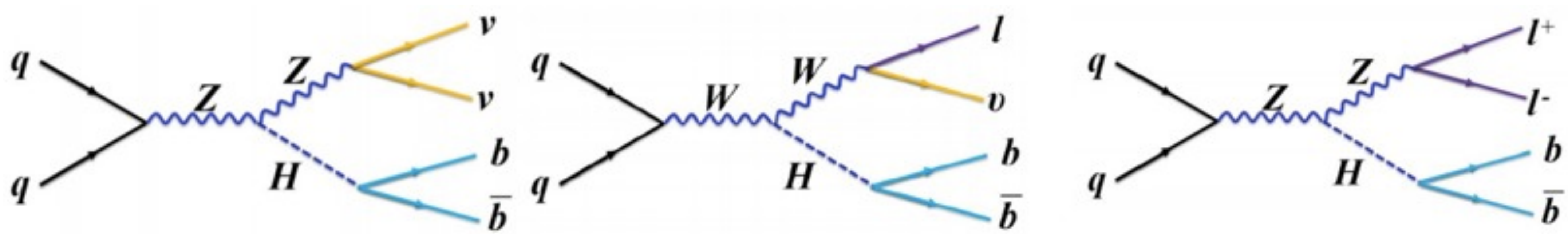
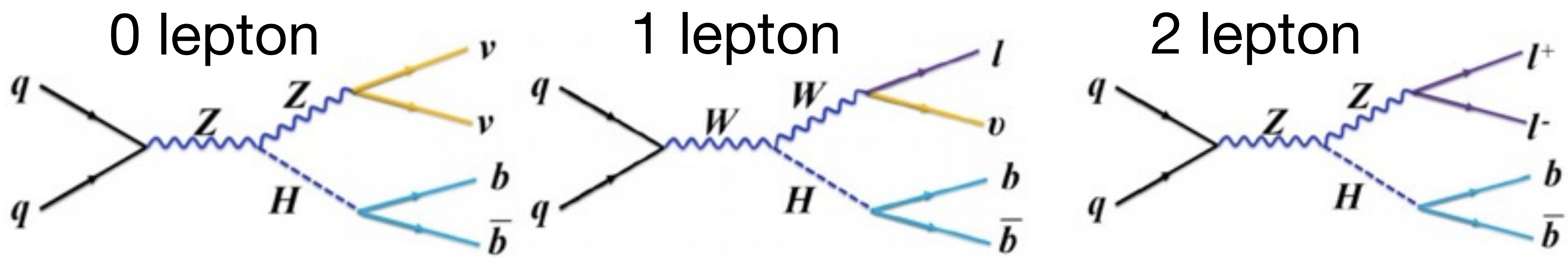
Search for the bb decay of the Standard Model Higgs boson in ATLAS



Higgs Hunting, 26th July 2013

Jason Sang Hun Lee, Osaka University
On behalf of the ATLAS Collaboration

Introduction

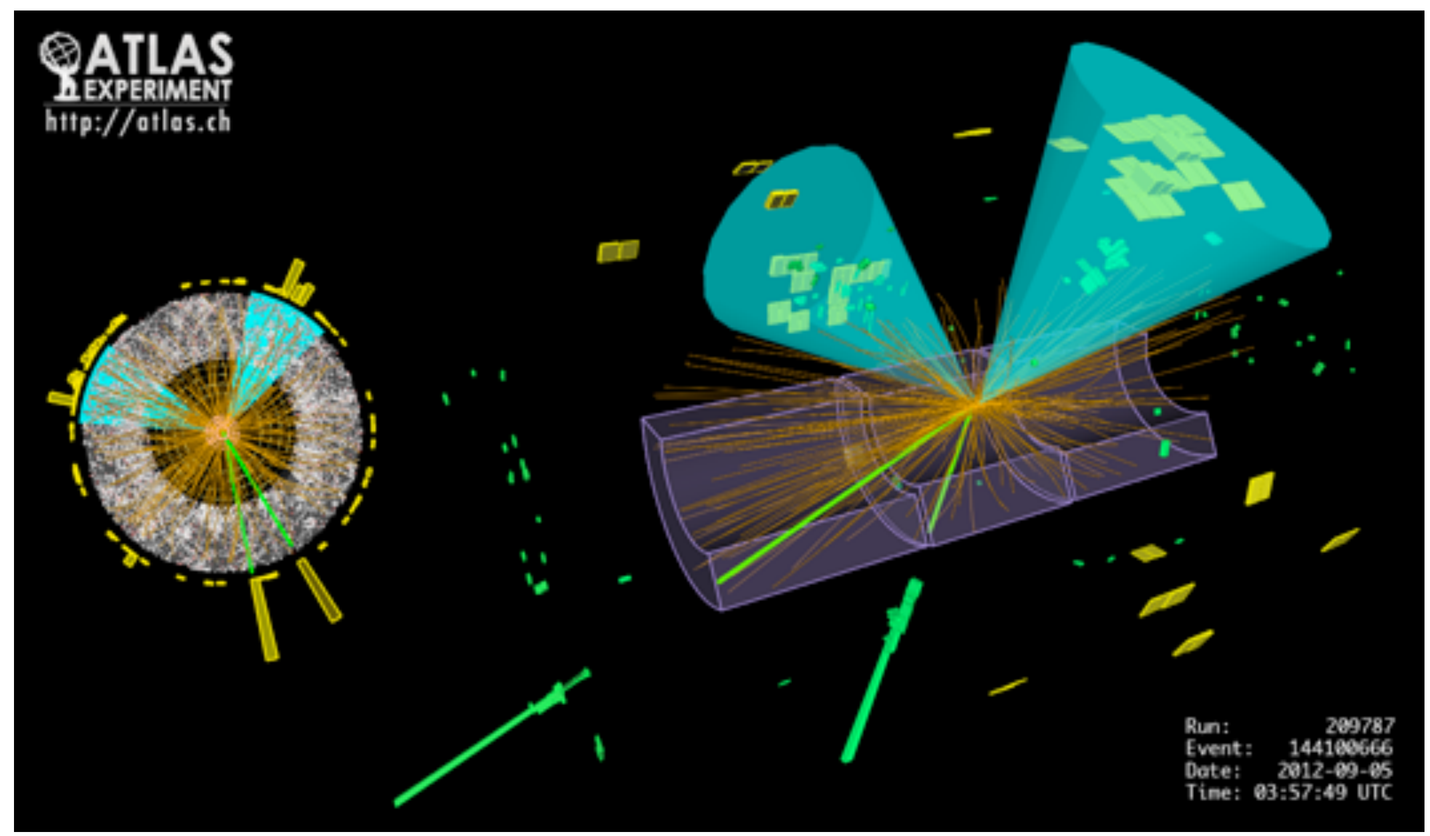


Full 2011 (4.7 fb^{-1} @ 7 TeV) and 2012 (20.3 fb^{-1} @ 8TeV)

ATLAS-CONF-2013-079

talk outline:

- ➡ Event Selection
- ➡ Background Modeling
- ➡ Diboson fit results
- ➡ Higgs fit results
- ➡ ttH, H to bb summary



See Inês Ochoa talk for more on details about the VH analysis

Analysis strategy

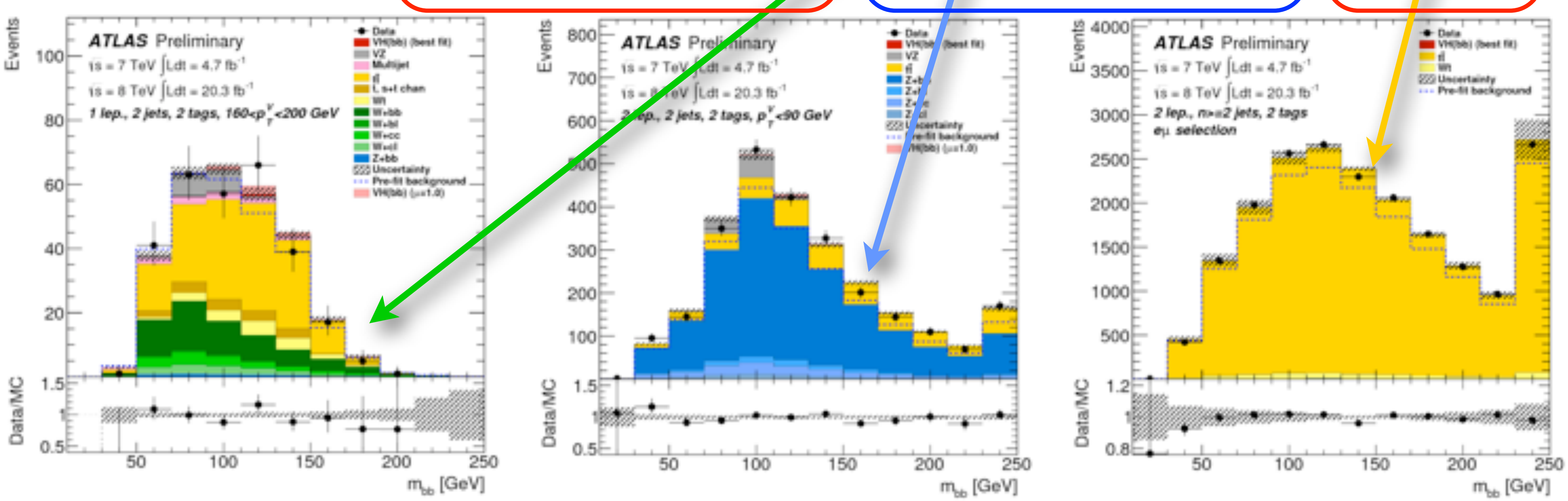
Events categorised by V p_T to boost sensitivity

Additional categories used to determine backgrounds

- ➡ number of leptons (0, 1, 2)
- ➡ number of jets (2, 3)
- ➡ number of b-tagged jets (1, 2)
- ➡ p_T^V bins (at 0, 90,120,160, 200 GeV intervals)

The main backgrounds are determined in the following regions

	2 jet 1 btag	3 jet 1 btag	2 jet 2 btag	3 jet 2 btag	top e-μ CR
0 lepton × 3 p_T^V bins	admixture	admixture	admixture	admixture	-
1 lepton × 5 p_T^V bins	W+c	W+c / Top	W+b / Top	Top	-
2 lepton × 5 p_T^V bins	Z+c / Z+b	Z+c / Z+b	Z+b	Z+b	Top
	Control	Control	Signal	Signal	Control



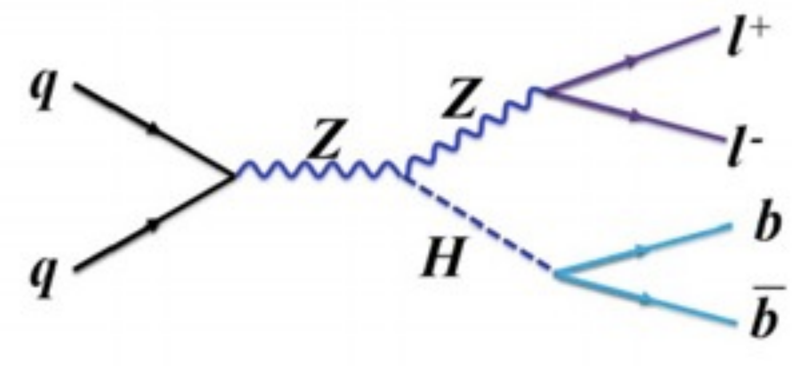
Event Selections - 2 lepton

Trigger - single and di-lepton

Leptons - 1 medium and 1 loose leptons

Missing Transverse Momentum < 60 GeV

Mass cut on Z boson - $83 < m_{ll} < 99$ reduce tt



boson p_T^V is vector sum of the two leptons

Analysis Selections of Jets

- ➡ $p_T > 20$ GeV & $|\eta| < 2.5$
- ➡ at least 2 jets
- ➡ leading jet $p_T > 45$ GeV
- ➡ 2 b-tagged jets (70% efficiency each jet, event efficiency is ~50%)

3 types of lepton identification increasing in purity

- ➡ Loose
  - $p_T > 10$ GeV
  - electrons $|\eta| < 2.47$ & muons $|\eta| < 2.7$
  - impact parameter
  - basic quality requirements
  - track isolation
- ➡ Medium
  - $p_T > 25$ GeV
  - electrons - additional track quality and the shower shape
  - muons - $|\eta| < 2.5$
- ➡ Tight
  - tighter track isolation
  - calorimeter isolation
  - electrons - more stringent quality requirements

Event Selections - 1 lepton

Trigger - single lepton or Missing E_T (20% increase for muons)

Leptons - 1 tight and no loose leptons

Missing Transverse Momentum > 25 GeV

Transverse Mass < 120 GeV select W

Transverse Mass > 40 GeV reduce multijet

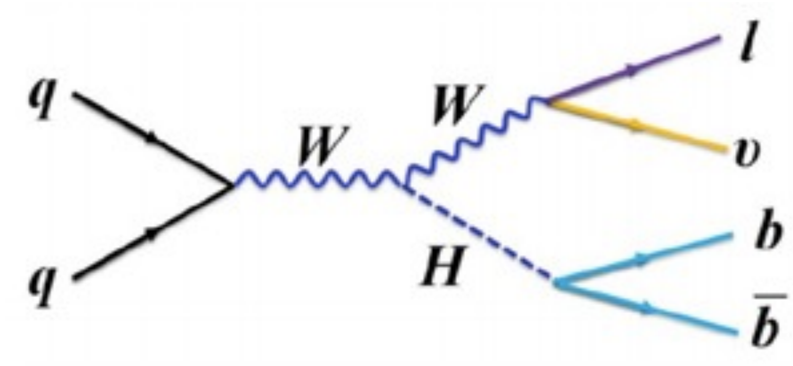
Veto jets - p_T > 30 GeV & |η| > 2.5 reduce tt

boson p_T^V is magnitude of the vector sum of the lepton and Missing E_T

Analysis Selections of Jets

- p_T > 20 GeV & |η| < 2.5
- at least 2 jets
- leading jet pT > 45 GeV
- 2 b-tagged jets (70% efficiency each jet, event efficiency is ~50%)

$$m_T^W = \sqrt{2 p_T^\ell E_T^{\rm miss} (1 - \cos(\phi^\ell - \phi^{\rm miss}))}$$



3 types of lepton identification increasing in purity

- Loose
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  - track isolation
- Medium
  - p_T > 25 GeV
  - electrons - additional track quality and the shower shape
  - muons - |η| < 2.5
- Tight
  - tighter track isolation
  - calorimeter isolation
  - electrons - more stringent quality requirements

Event Selections - 0 lepton

Trigger - Missing E_T

Leptons - no loose leptons

Missing Transverse Momentum > 120 GeV

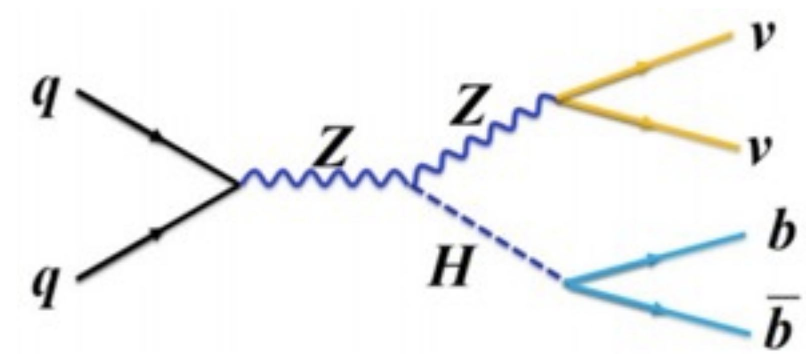
Track-based Missing Transverse Momentum p_T^{miss} > 30 GeV

$$\Delta\phi(E_T^{miss}, p_T^{miss}) < \pi/2$$
$$\min[\Delta\phi(E_T^{miss}, \mathrm{jet})] > 1.5$$
$$\Delta\phi(E_T^{miss}, b\bar{b}) > 2.8$$

reduce multijet to < 1%

Veto jets - p_T > 30 GeV & $|\eta|$ > 2.5 reduce tt

boson p_T^V is Missing E_T



Analysis Selections of Jets

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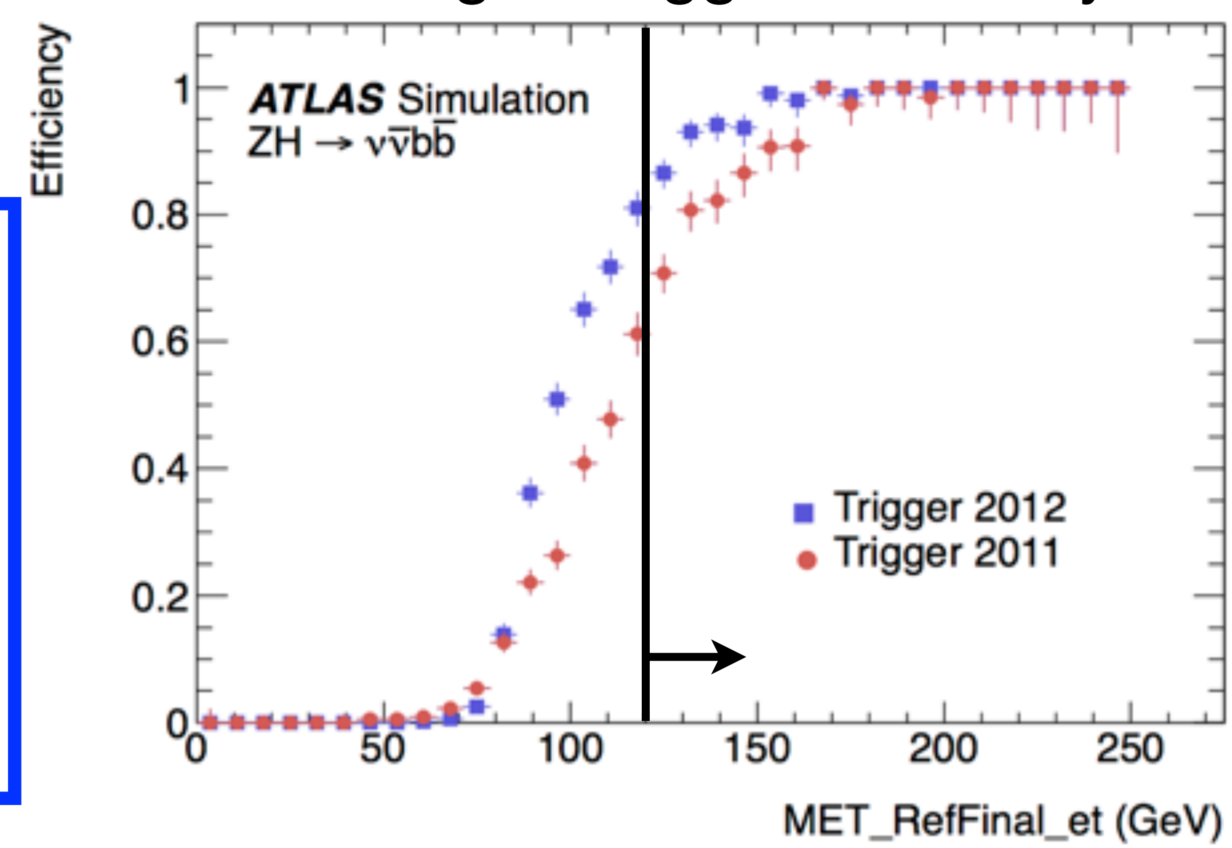
- ➡ 2 b-tagged jets (70% efficiency each jet, event efficiency is ~50%)

Missing E_T trigger efficiency

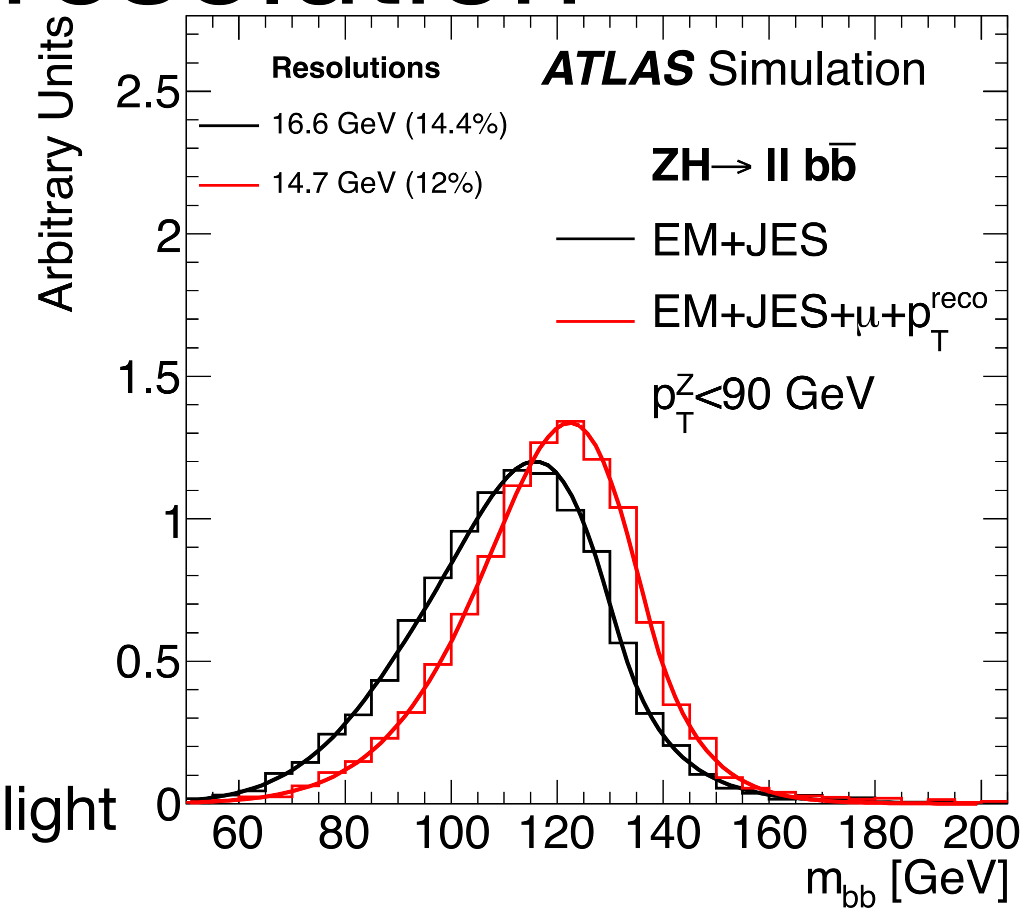


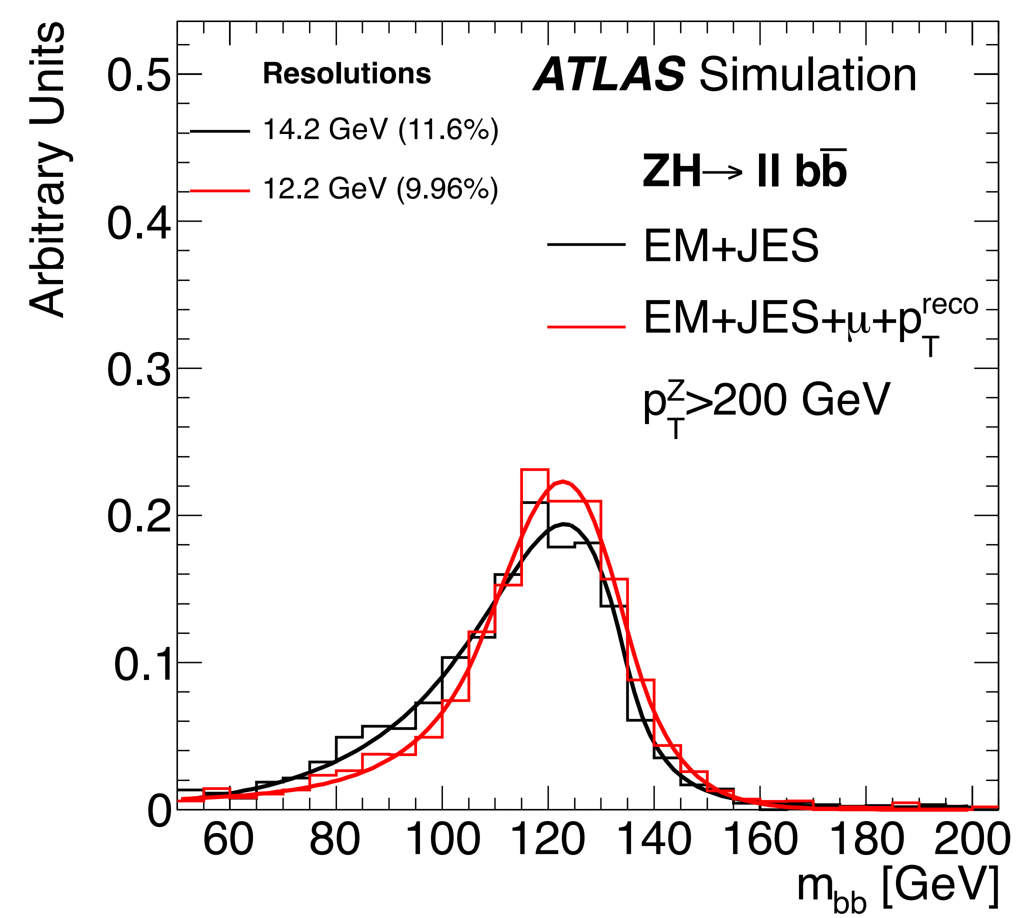
fully efficient for E_T^{miss} > 160 GeV

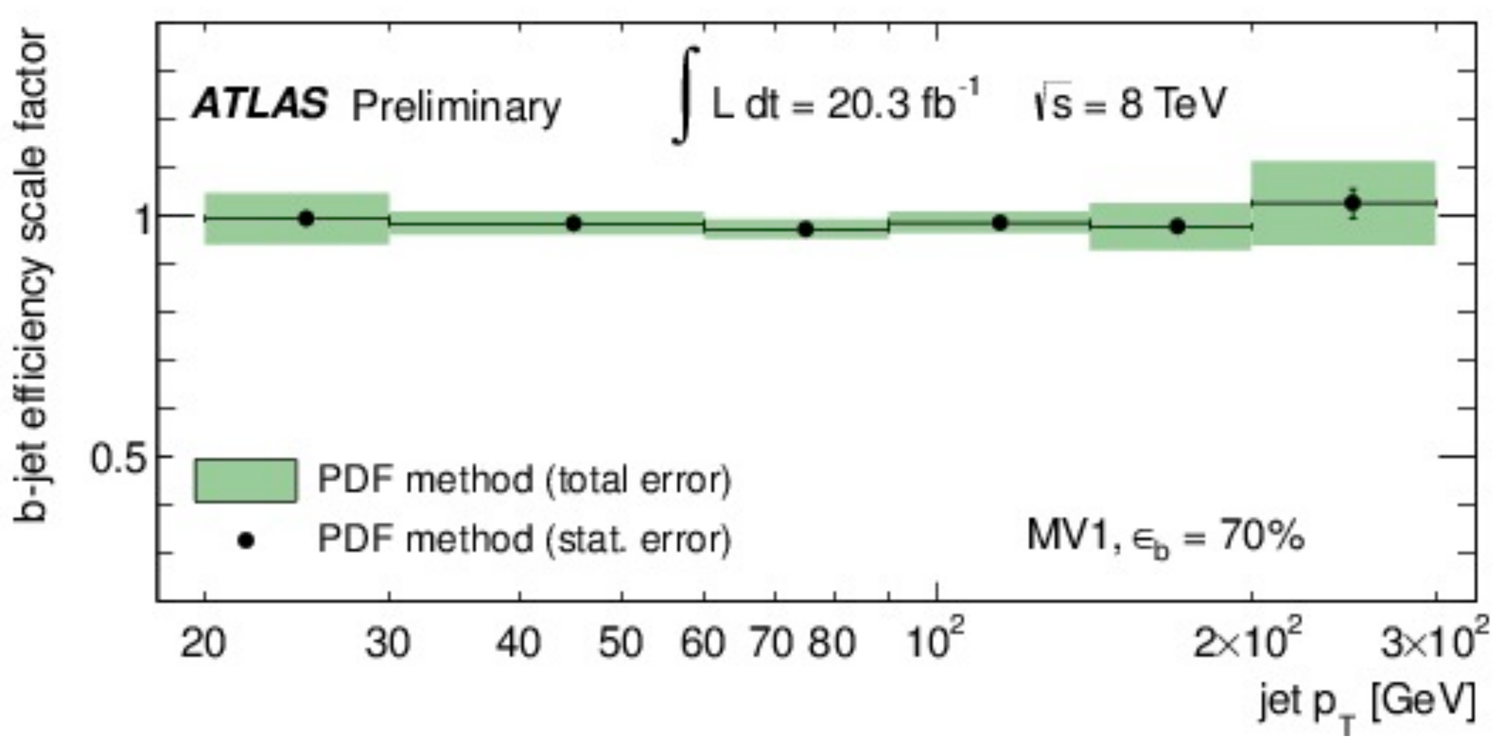
B-tagging and m_{bb} mass resolution

Jet Reconstruction

- ➡ **Anti-k_t** R=0.4
- ➡ Pile-up correction jet-area based
- ➡ Calibrated using p_T and η dependent factors
- ➡ Corrections applied for muons in jet
- ➡ B-tagging is neural network-based
  - inputs: 3 different b-tagging methods
  - efficiency: 70% for b, ~20% for c, ~0.6% for light
  - ~2% precision achieved in the calibration analysis (intermediate p_T region)







Further Optimisations

$\Delta R(b,b)$ optimisations

- ➡ max cuts reduces background
- ➡ min cuts reduces V+jets background

1 lepton channel

- ➡ Missing E_T cut increase at highest bin
- ➡ Min Transverse Mass cut removed in higher bins

	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	

After object ID and kinematic selection, the main discriminator is m_{bb}

tt Background

Normalisation determined by fit to data

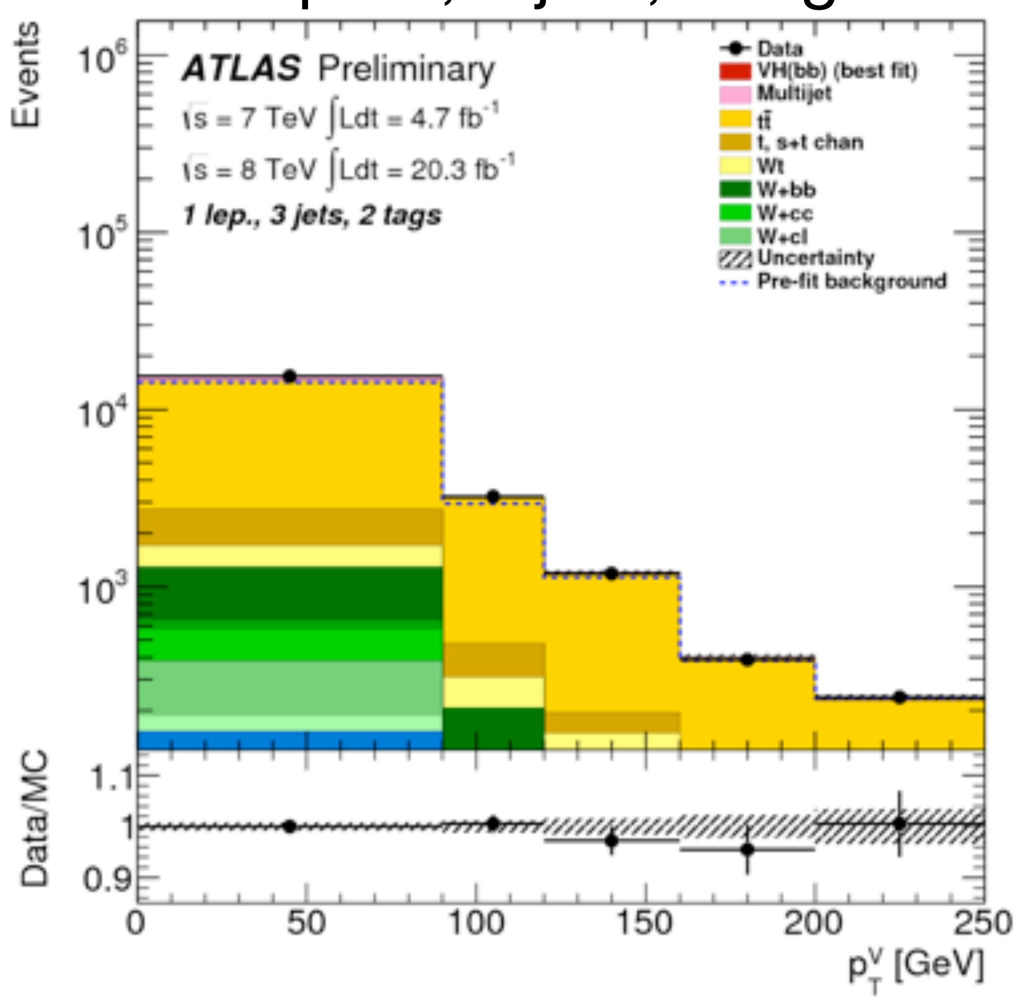
Mismodeling p_T

- PowHeg predicts too hard a p_T distribution
- correction applied at generator level

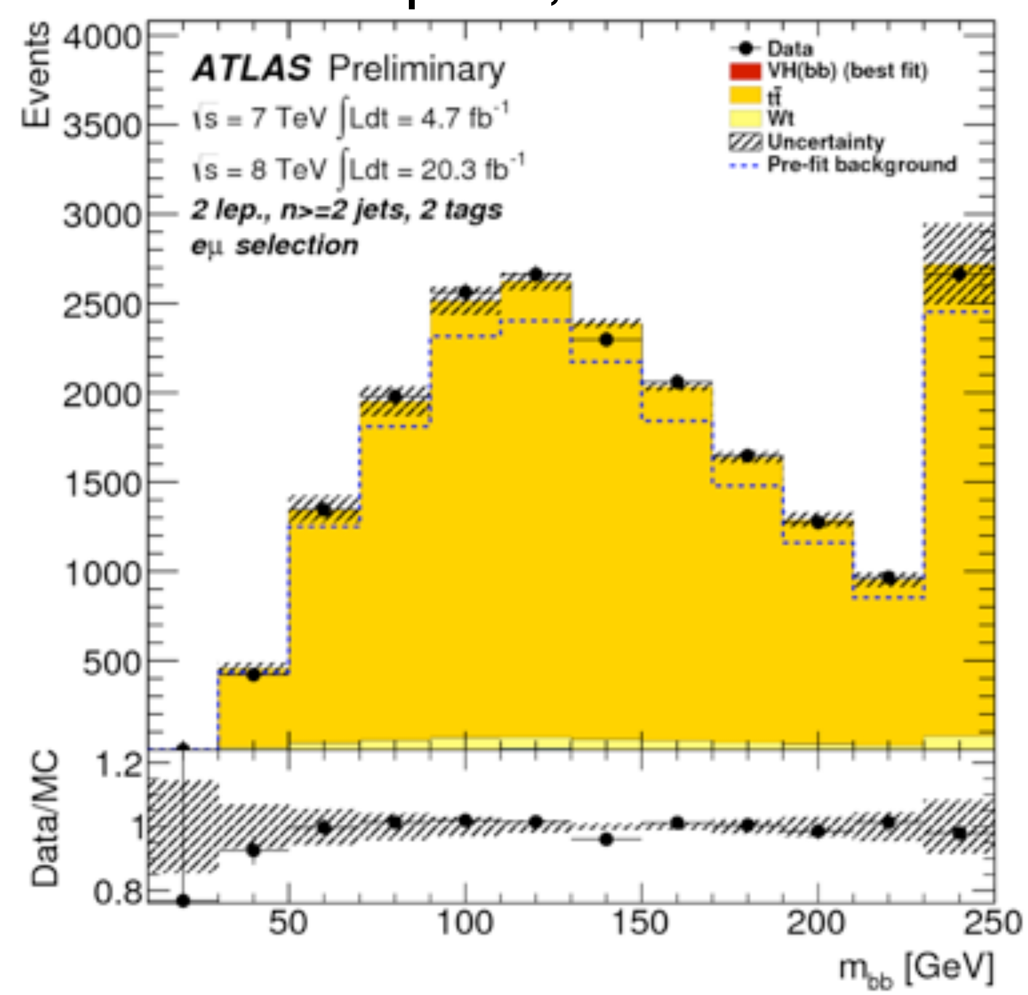
Systematic uncertainties

- 3-to-2 jet ratio: 5%
- m_{bb} shape: 5%
- top p_T correction
- c jet efficiency at high p_T^V

1 lepton, 3 jets, 2 tags



2 lepton, tt control



V+jets Background

Normalisation determined by fit to data

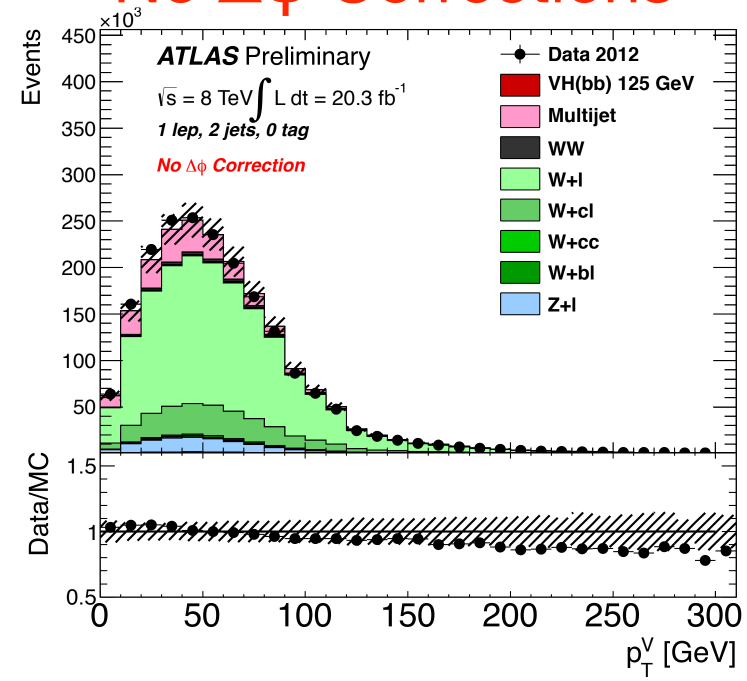
Mismodeling of $\Delta\phi$(j,j):

- 0 b-tag control
- subtract from data all other background (except Z+jets)
- divide by MC Z+jets
- linear parametrisation
- p_T^V distributions are affected
- treated as uncorrelated
  - W+jets and Z+jets
  - no. of b jets
  - no. of jet

Systematics uncertainties:

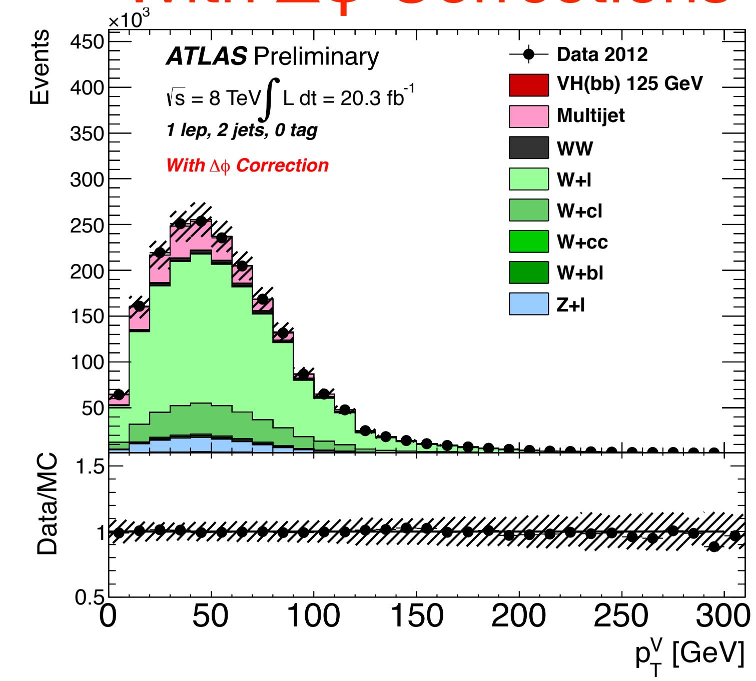
- flavour composition
- 3-to-2 jet ratio
- m_{bb} shape
- p_T^V

No Δφ Corrections

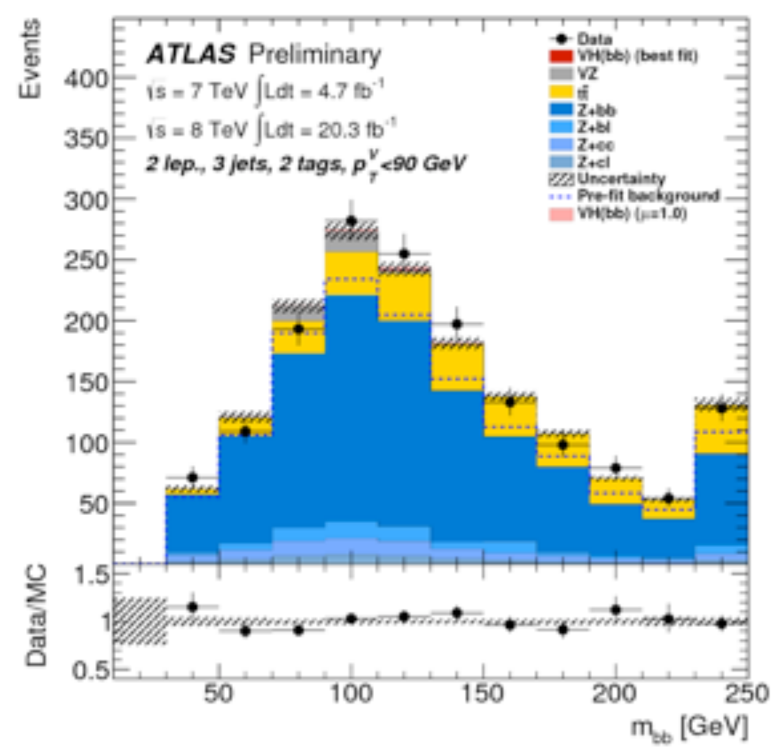


1 lepton, 2 jets, 0 tags

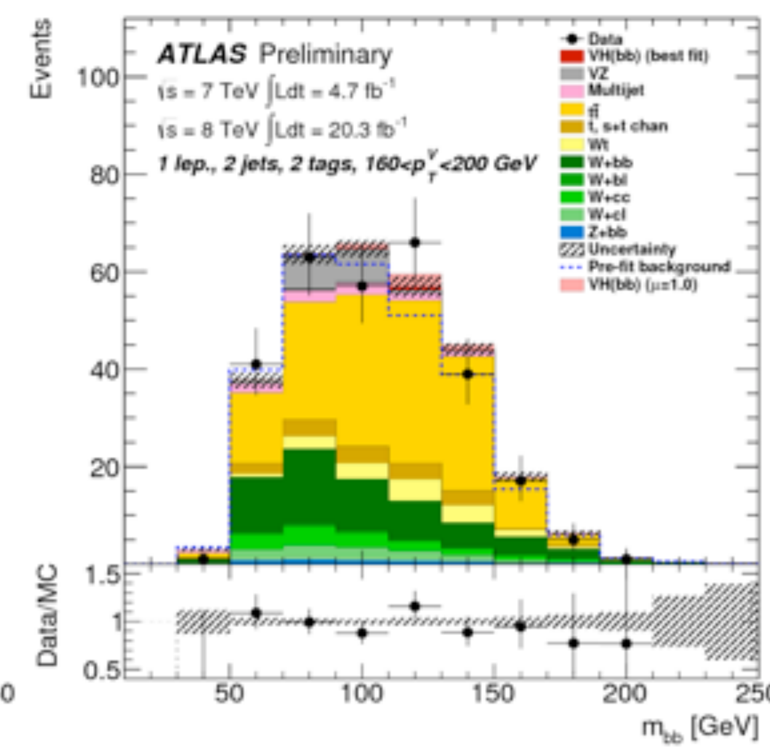
With Δφ Corrections



1 lepton, 2 jets, 0 tags



2 lepton, 3 jets, 2 tags



1 lepton, 2 jets, 2 tags

Systematics

Experimental systematic uncertainties

- ➡ lepton reconstruction and PID
- ➡ **Jet Energy Scale**
- ➡ **B-tagging**
- ➡ **Missing E_T**
- ➡ **Multijet background:**
  - **normalisation uncertainties 100% for the 0- and 2-lepton channels**
  - **1 lepton freely floating in global fit, independently of no. of jets and tags**
  - **p_T^V**
- ➡ Luminosity: 2.8% for 2012, 1.8% for the 2011
- ➡ Pile-up

	m_{bb}	$\Delta\phi$	p_T^V	3/2 jet ratio
tt	MC	-	data	MC
W+jets	MC	data	data	MC
Z+jets	data	data	-	MC
single top	MC	-	MC	MC
Diboson	MC	-	MC	MC

Simulated background systematic uncertainties

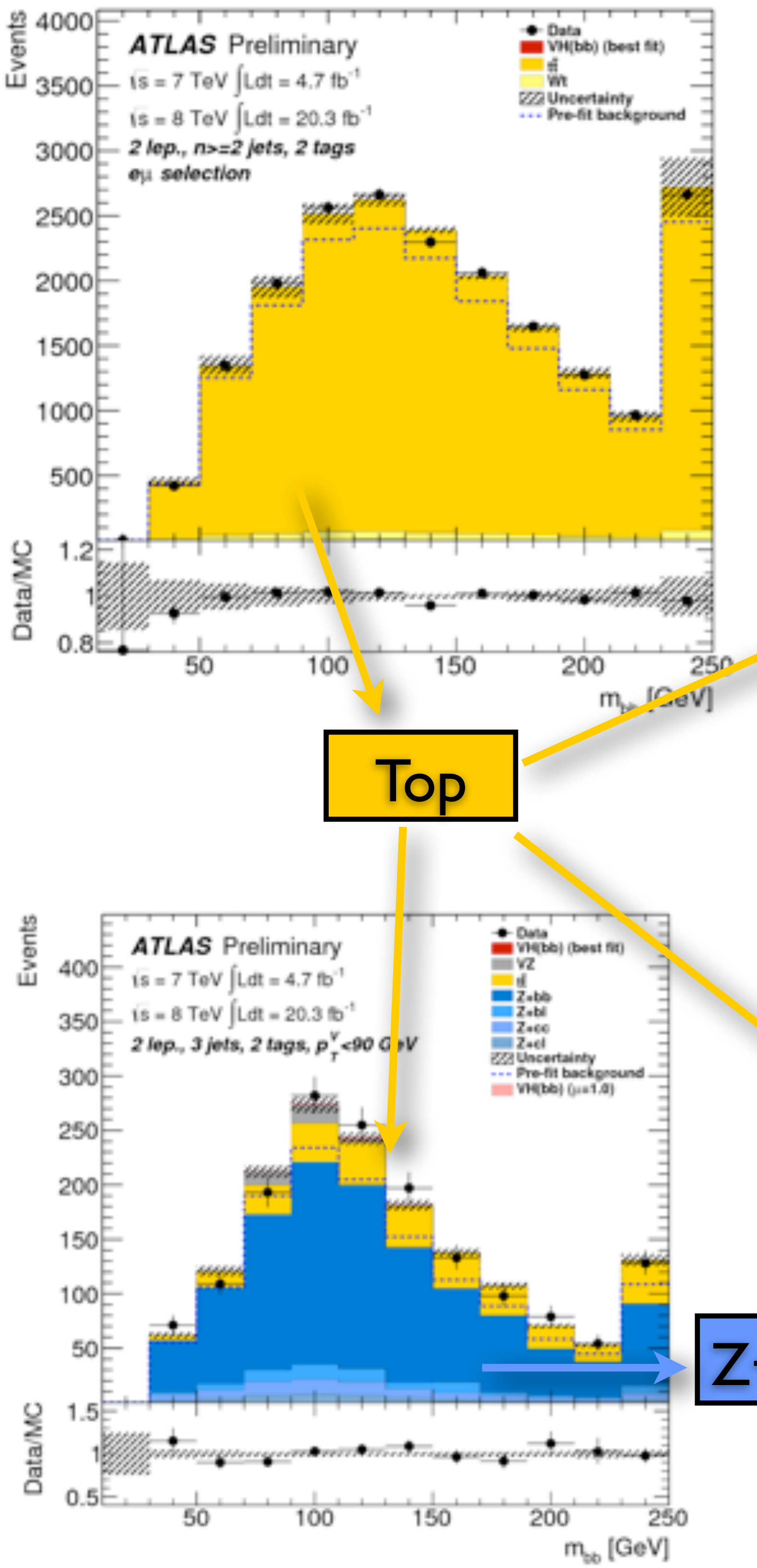
- ➡ single top
  - σ: 4-7%
  - 3-to-2 jet ratio: 5-15%
  - p_T^V shape: 5%
  - m_{bb} shape: 5-10%
- ➡ diboson
  - σ: 5-7%
  - 3-jet to 2-jet ratios
  - p_T^V : 5-60%

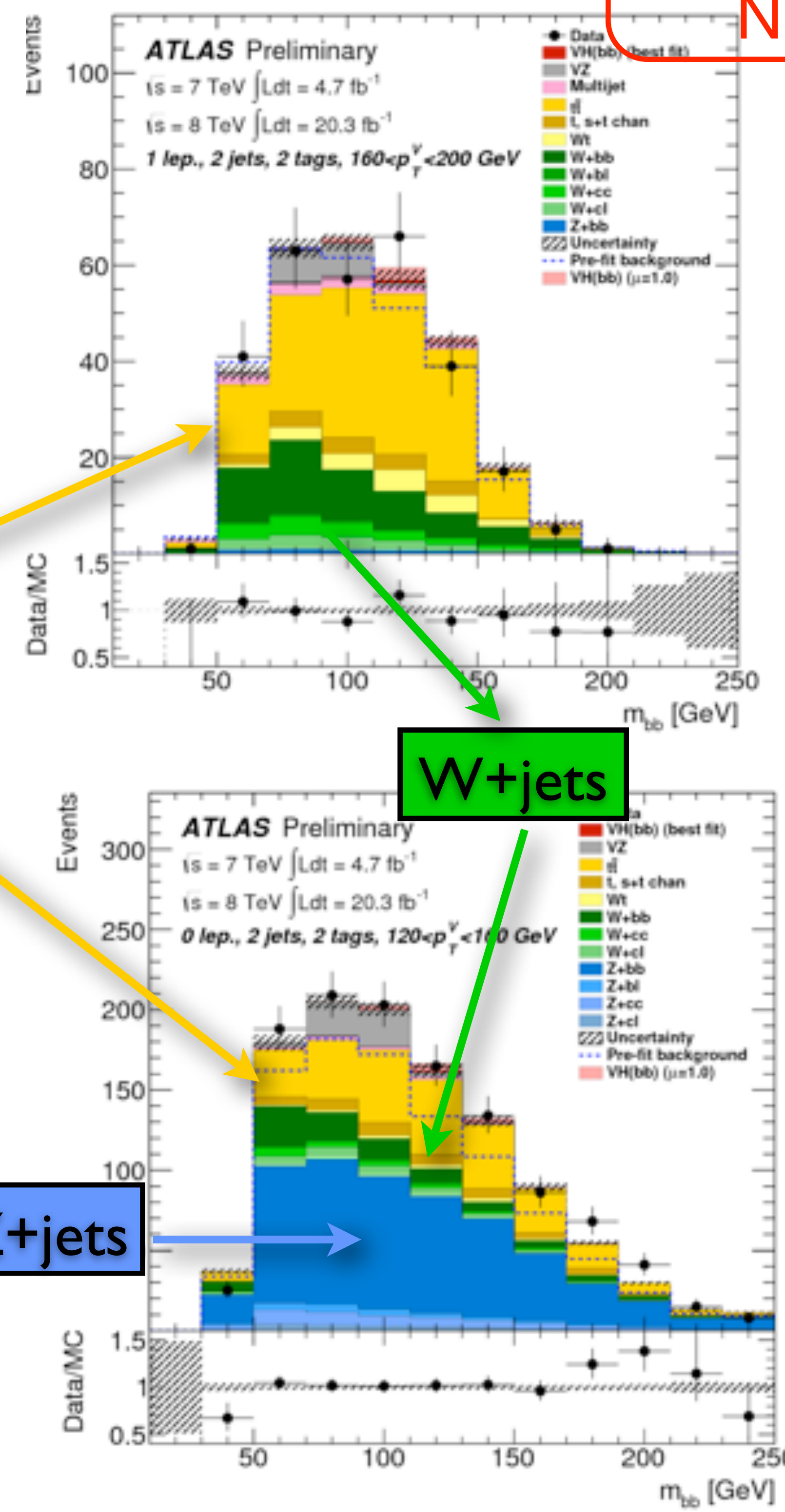
Signal systematic uncertainties

- ➡ cross sections: 5-7%, calculated at NNLO in QCD, applying electroweak corrections at NLO
- ➡ NLO EW corrections: ~2%, differential cross sections applied as function of p_T^V on the LO WH and ZH signals (pythia8)
- ➡ Higgs boson BR to bb: 3.3% for m_H = 125 GeV
- ➡ **Signal Acceptance: 10% comparing pythia8, pythia6 and herwig**

Global Fit

	2 jet 1 tag	3 jet 1 tag	2 jet 2 tag	3 jet 2 tag	top e-μ CR
0 lepton × 3 p_T^V bins	admixture	admixture	admixture	admixture	-
1 lepton × 5 p_T^V bins	W+c	W+c, Top	W+b, Top	Top	-
2 lepton × 5 p_T^V bins	Z+c	Z+c	Z+b	Z+b	Top
	Norm.		Shape		Norm.



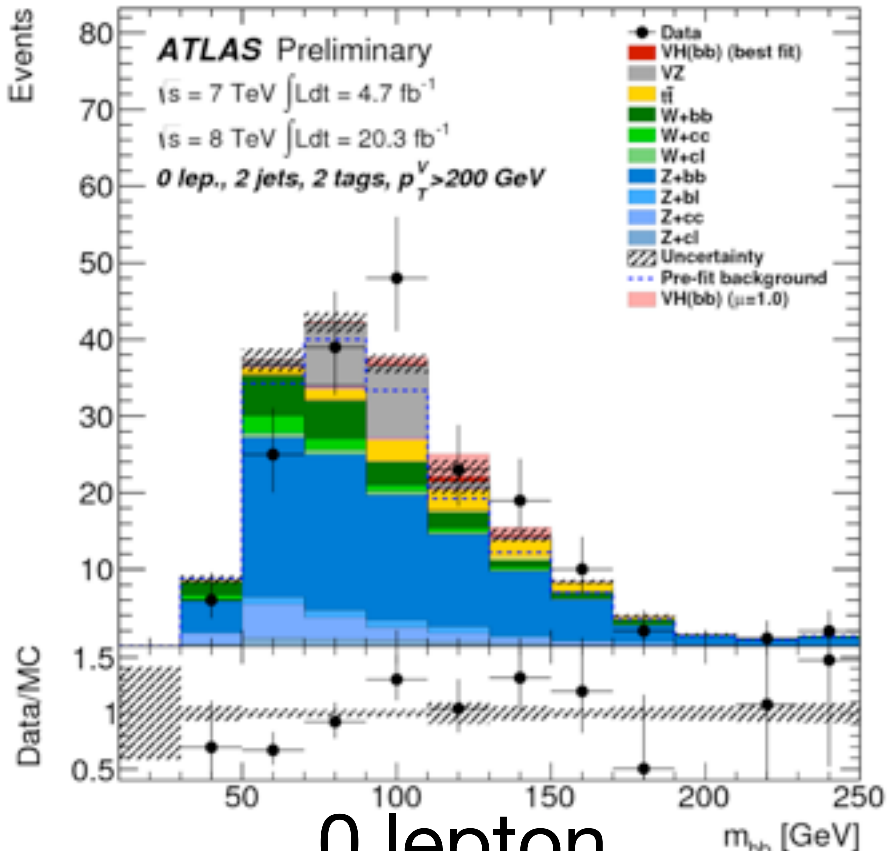


The fit also adjusts the shapes of the dijet mass distributions within the constraints from the systematic uncertainties:

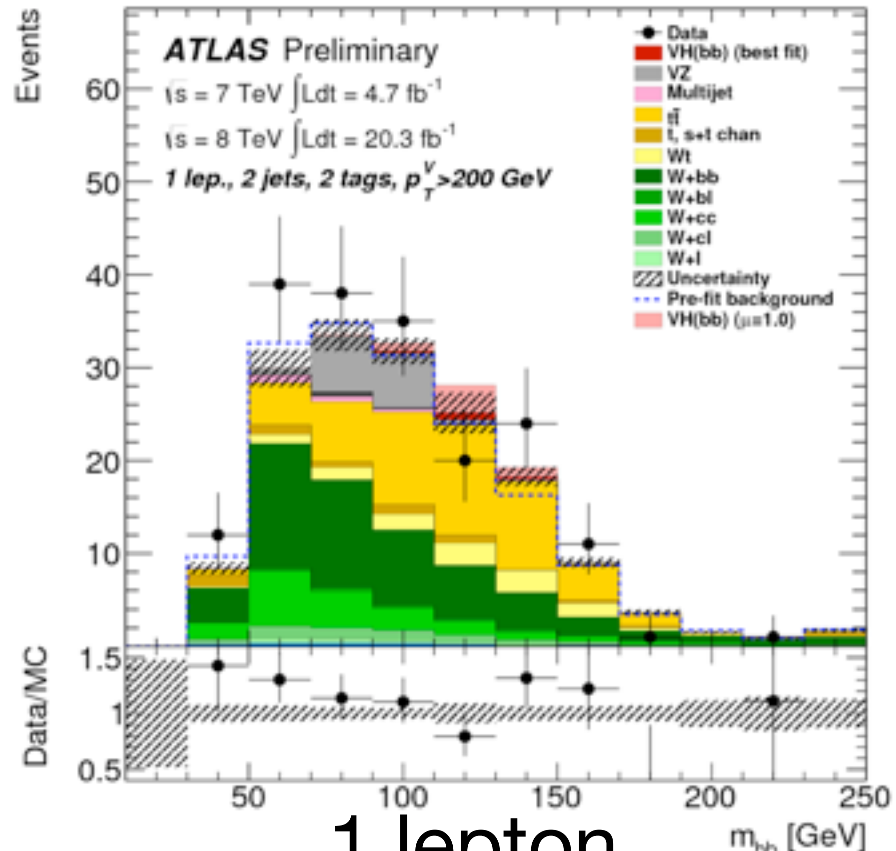
- ➡ Multijet: determined in data before final fit
- ➡ Diboson, single top, V+light: Normalisation constrained by theoretical uncertainties
- ➡ tt, Vb, Vcl: Normalisation completely determined by fit to data

Post-fit m_{bb} distributions

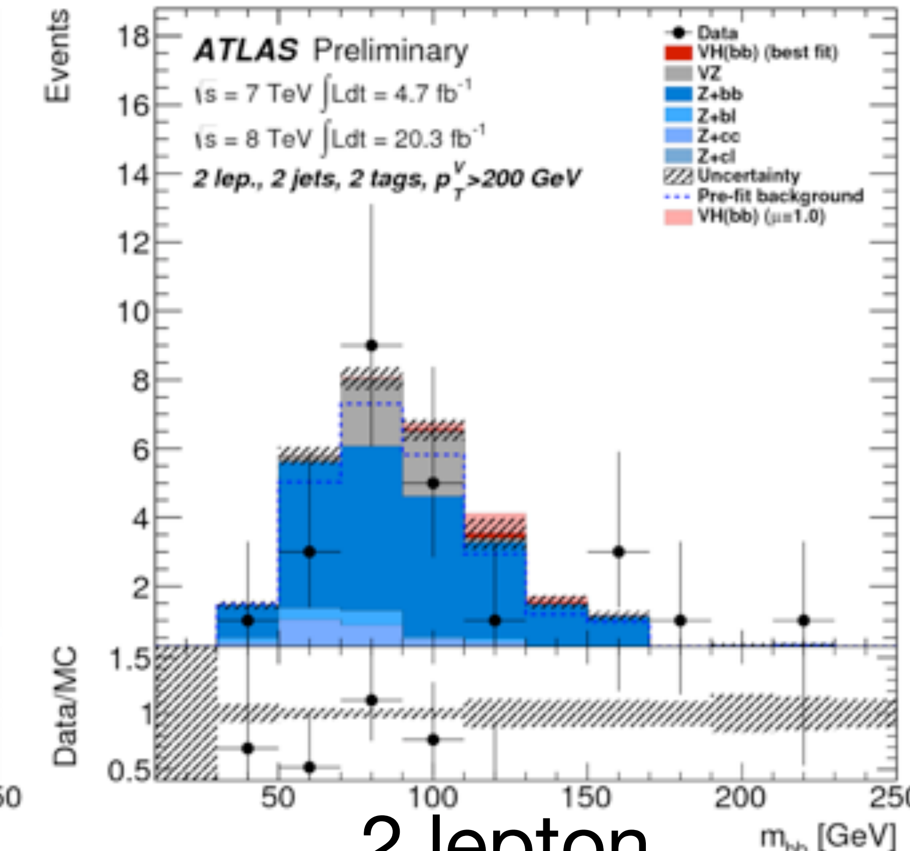
2 jets 2 tags, highest p_T^V bin (> 200 GeV)



0 lepton



1 lepton



2 lepton

Good agreement between data and signal+background expectation

After global fit, uncertainties on the background and signal yields are 3% and 12% (Before fit, 10-13% and 13-14%)

Dominant systematic uncertainties include:

- ➡ tt modeling (m_{bb} shape, 2-3-jet ratio, p_T^V)
- ➡ tagging efficiency for c jets
- ➡ multijet normalisation 1 lepton
- ➡ signal acceptance

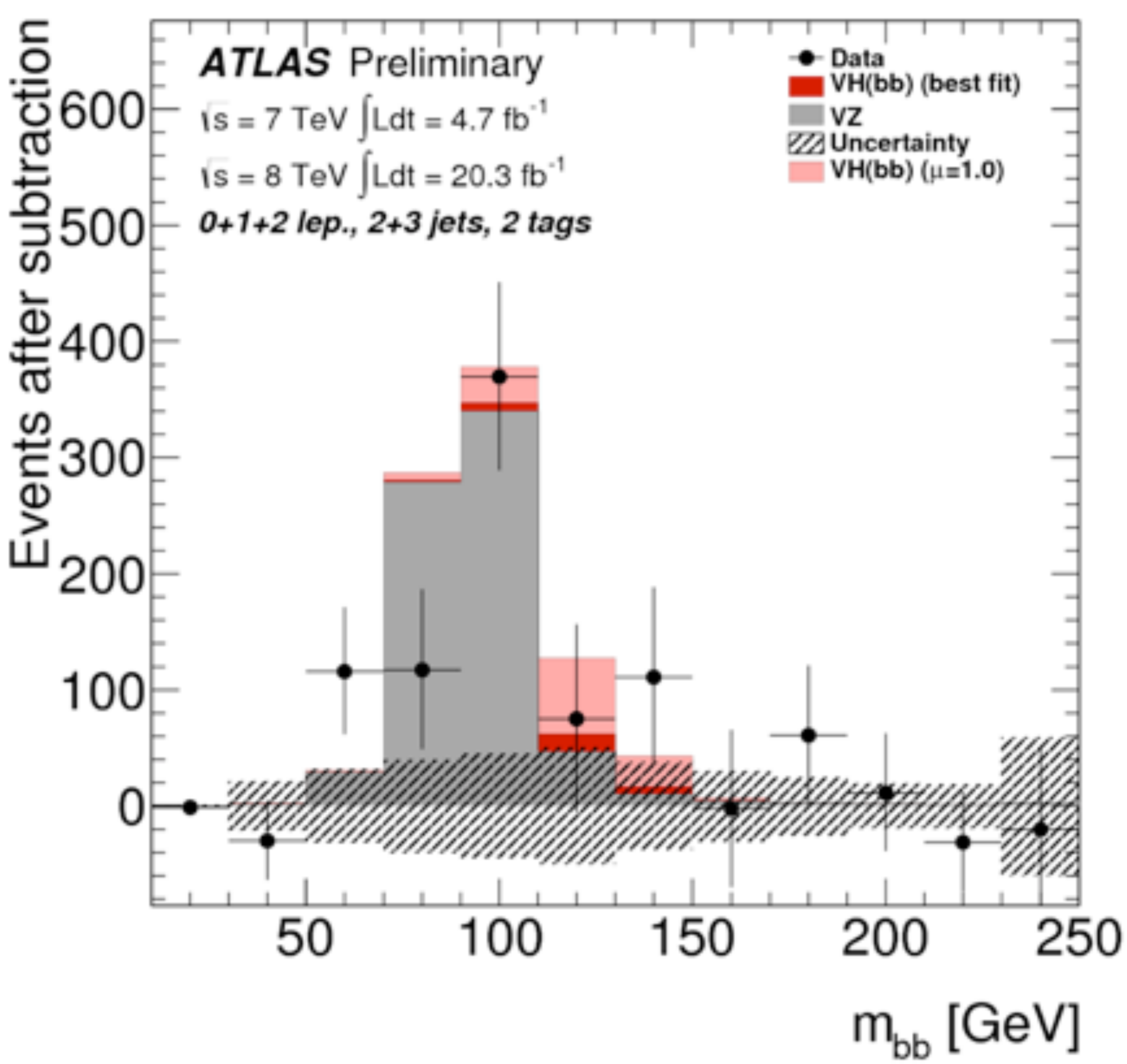
rest of p_T^V bins in backups

Fitting Cross Check - Diboson

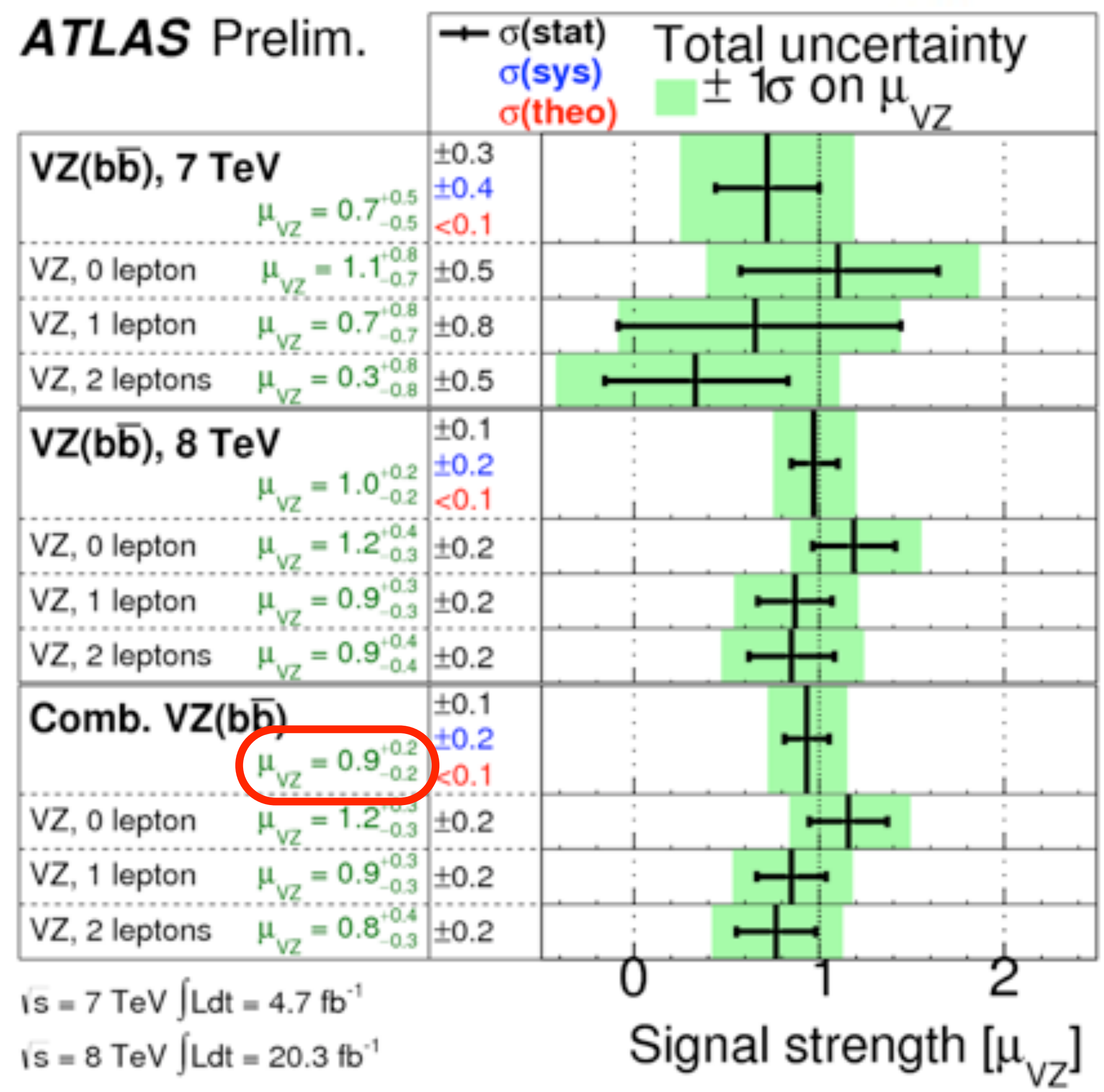
Diboson decay, VZ, Z→bb

- very similar decay signature
- softer p_T spectrum & lower m_{bb}
- cross section ~5 times larger

Fit to diboson peak, fixing Higgs peak to SM expectation



signal strength parameter: $\mu = \frac{\sigma_{\mathrm{meas}}}{\sigma_{\mathrm{SM}}}$

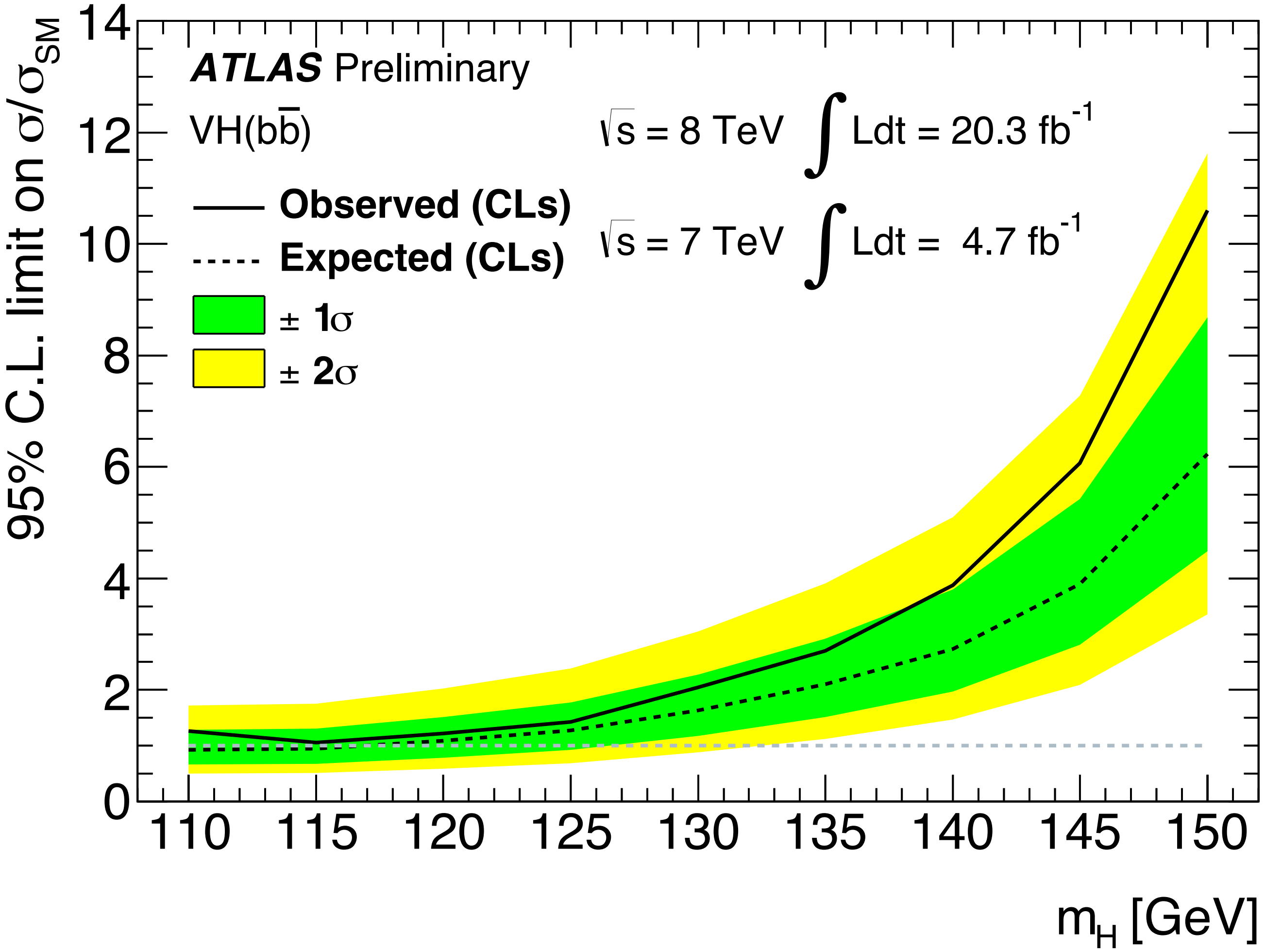


Fit summary for each channel and both years

μ_{VZ} = 0.9 ± 0.2 agrees with SM expectation of 1, corresponds to 4.8σ observed significance (5.1σ expected)

20% uncertainties with run 1 dataset

Limits

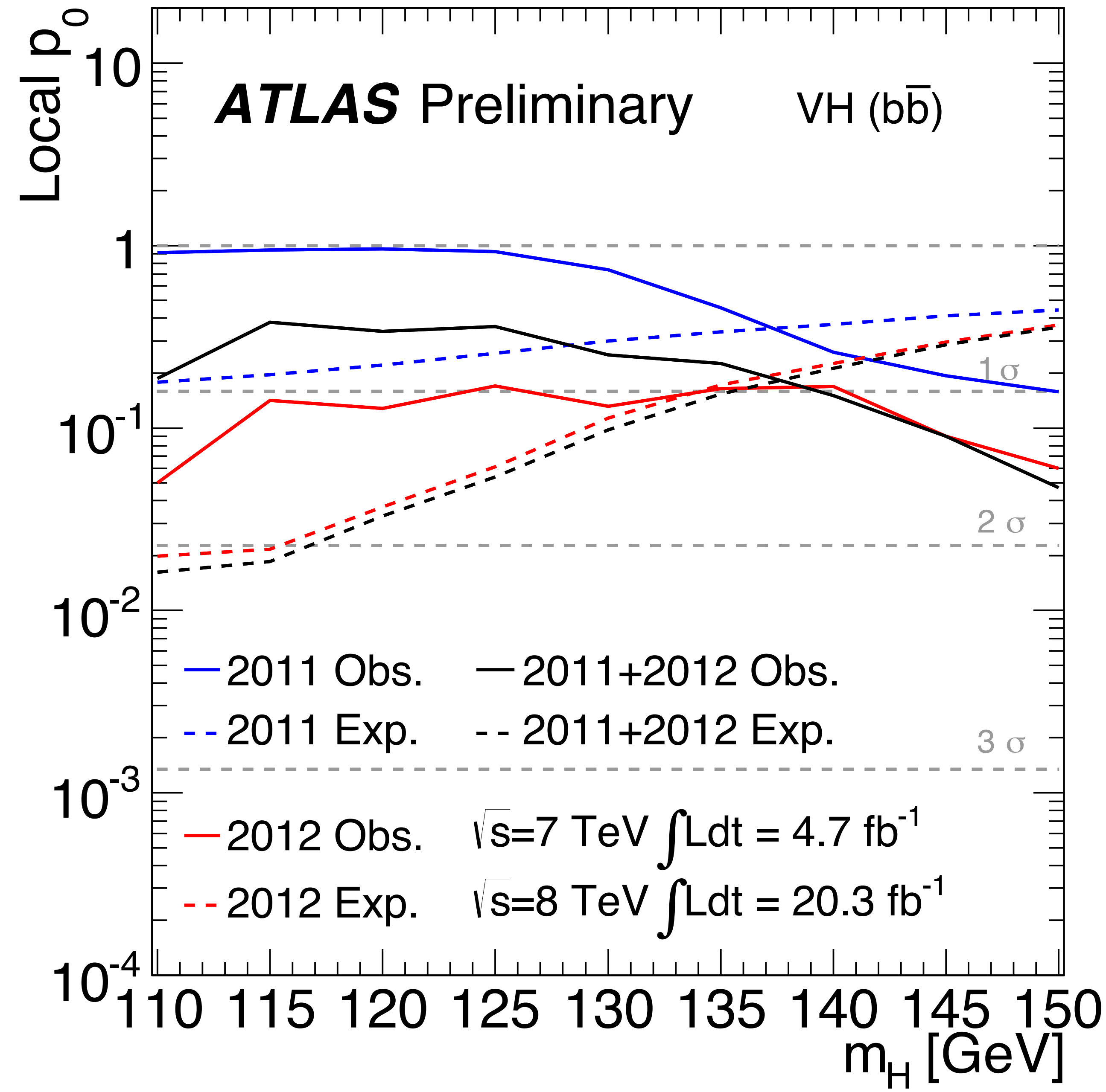


Cross section upper limits, normalised to the SM Higgs boson production cross section

Observed (expected) limits for m_H = 125 GeV:

- 7 TeV: 2.0 (3.3) x SM
- 8 TeV: 1.9 (1.3) x SM
- Combined: 1.4 (1.3) x SM

No significant excess is observed



Observed local p0 as a function of the Higgs boson mass (the black shows the combined results):

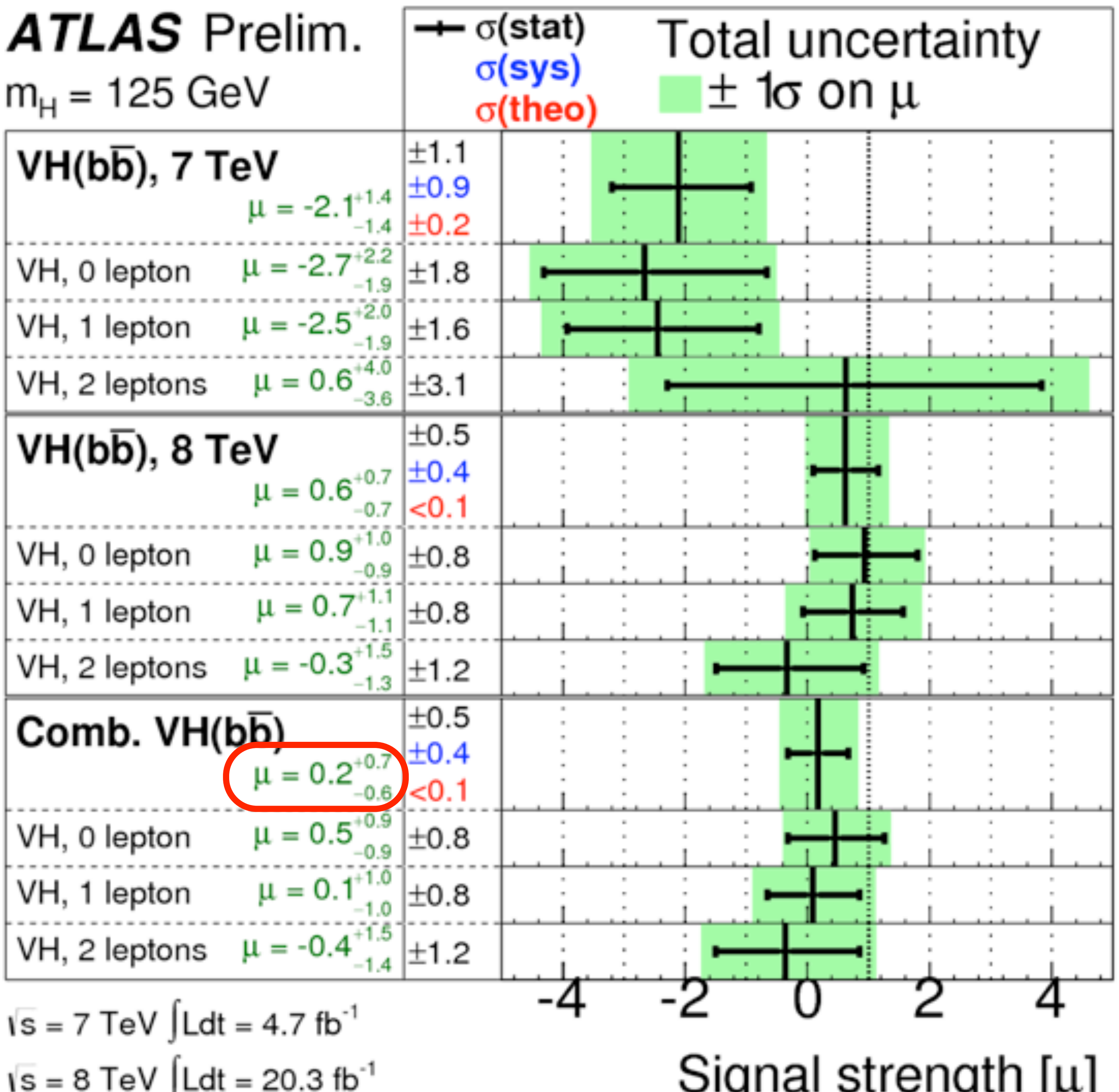
- 0.36 (0.36σ) in the absence of signal
- 0.05 (1.64σ) in the presence of signal

Probability to obtain a result at most as signal-like as observed if a SM Higgs boson with m_H = 125 GeV is present: 0.11

This expected limit represents a 35% improvement in the analysis sensitivity

Fit to Higgs Cross Section

Fit summary for each channel and both years



signal strength parameter: $\mu = \frac{\sigma_{\mathrm{meas}}}{\sigma_{\mathrm{SM}}}$

The fitted value of the signal strength parameter is:

$\mu = 0.2 \pm 0.5(\mathrm{stat.}) \pm 0.4(\mathrm{syst.})$

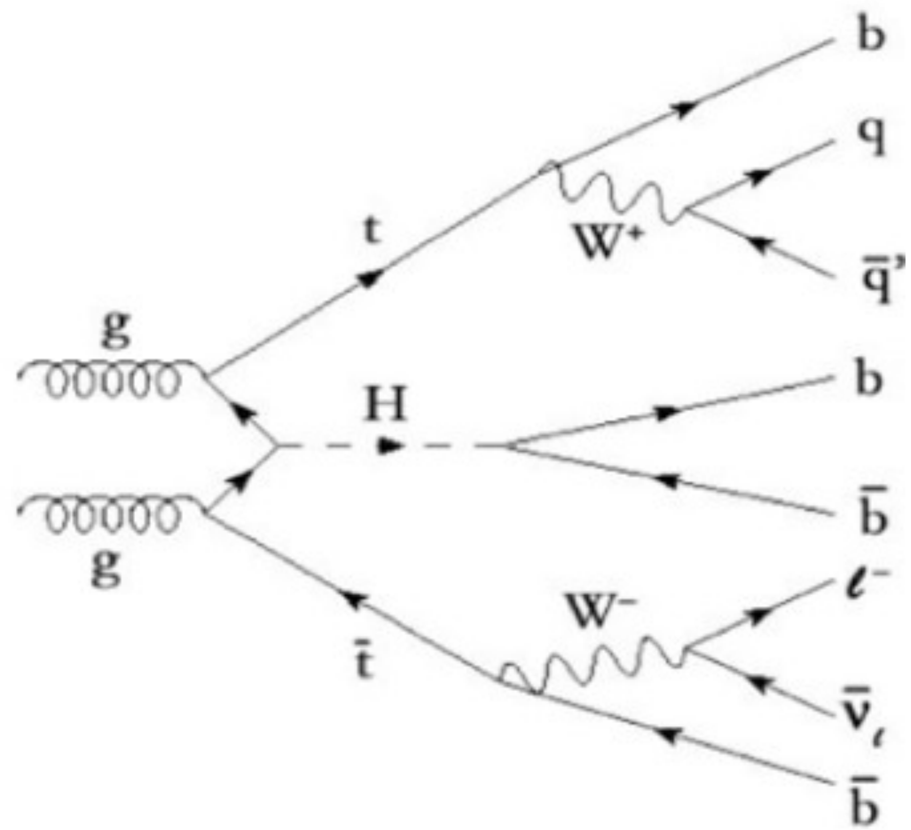
ttH

2011 (4.7 fb^{-1} @ 7 TeV)

ATLAS-CONF-2012-135

tt semileptonic decay: ttH→Wb Wb bb→lvb jjb bb

Direct measurement of the H→tt coupling



Selections

- ➡ single lepton trigger
- ➡ High jet multiplicity: 4 b-jets + 2 jets
  - p_T > 25 GeV
  - $|\eta|$ < 2.5
  - b-tagging - 70% efficiency
- ➡ 1 isolated high p_T lepton
  - electron p_T > 25 GeV
  - muon p_T > 20 GeV
- ➡ high missing E_T
  - e channel: missing E_T > 30 GeV, m_T > 30 GeV
  - μ channel: missing E_T > 20 GeV, missing E_T + m_T > 60 GeV

ttH fit distributions

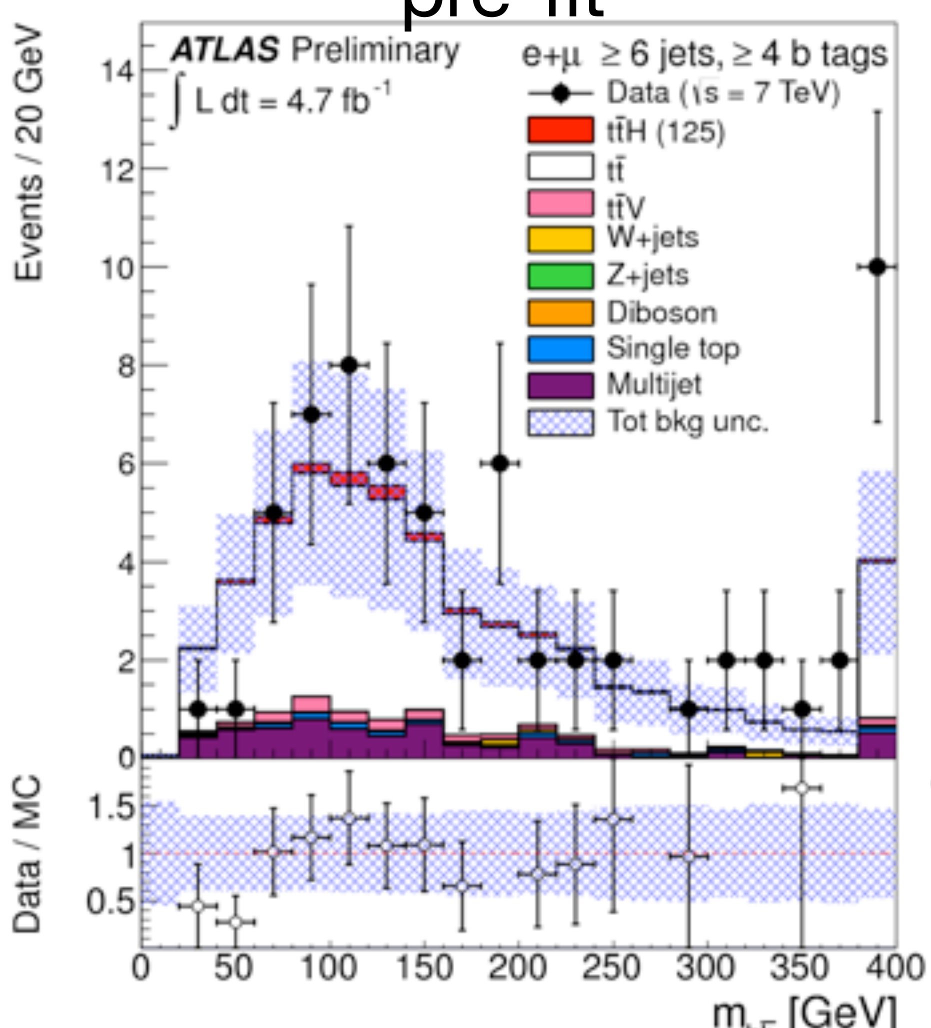
- ➡ Signal categories:
  - 5 or ≥ 6 jets; 3 or ≥ 4 b-jets
- ➡ Background categories:
  - 4 jets; 0 or 1 or ≥ 2 b-jets
  - 5 or 6 jets; 2 b-tags

After selections; fit to data constraining systematics

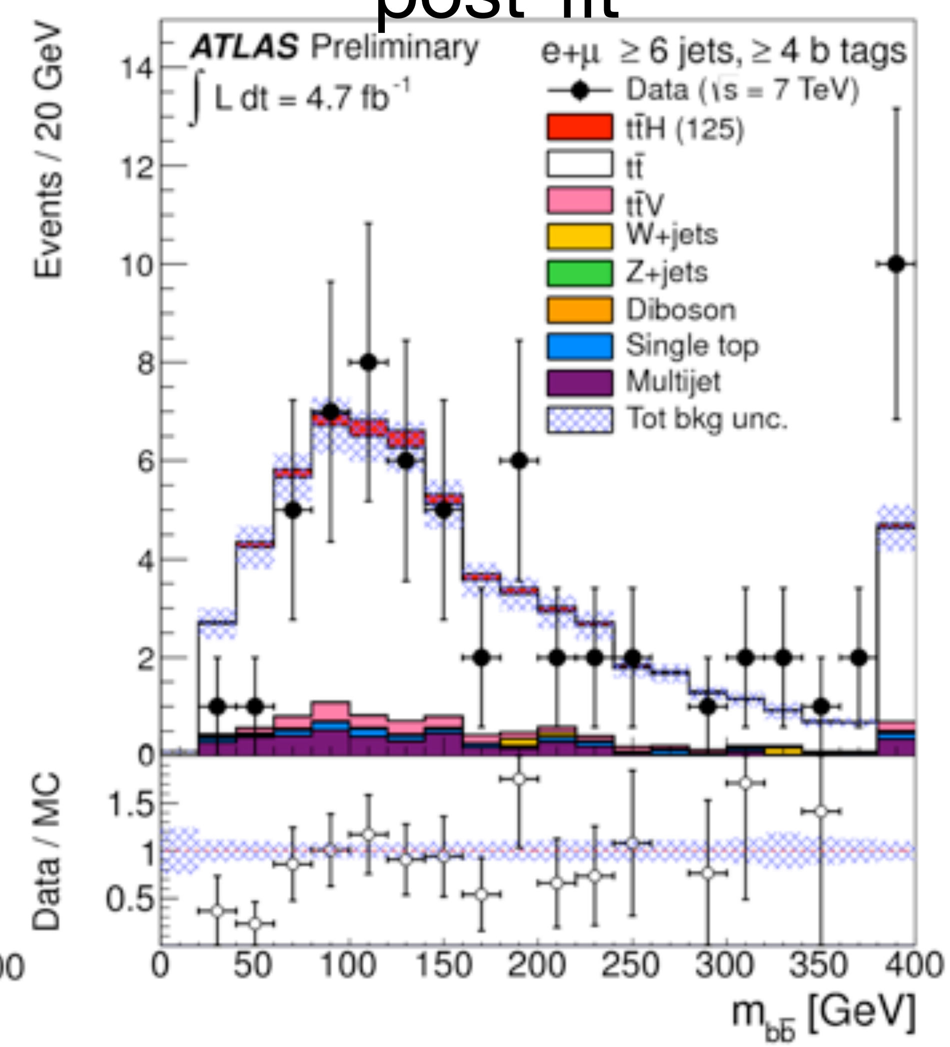
Main background: tt

Main systematics: b/c tagging, tt modeling

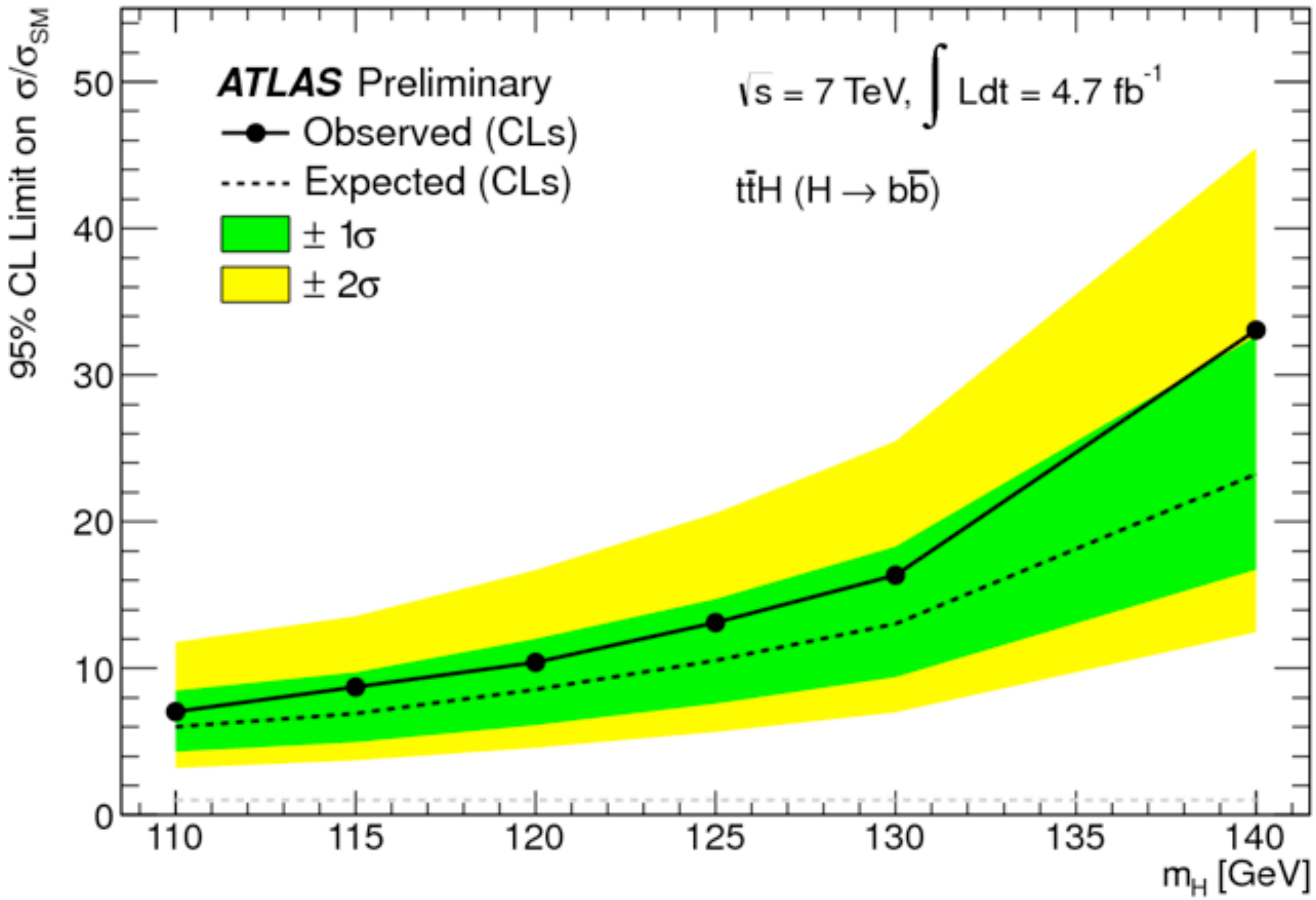
pre-fit



post-fit



ttH results



Cross section upper limits, normalised to the SM Higgs boson production cross section

Observed (expected) limits for m_H = 125 GeV:

- 13.1 (10.5) x SM

No significant excess is observed

Conclusions

➡ Results on the search for VH, H to bb on full 2011 and 2012 data

➡ Results on the search for ttH, H to bb on 2011 data

➡ 35% gain in significance on top of the luminosity:

- $\Delta R(b,b)$ optimisation
- background modeling
- experimental systematics

➡ Fit to diboson peak consistent with SM expectation.

➡ No significant excess is observed.

➡ Observed (expected) limit for m_H = 125 GeV is 1.4 (1.3) xSM @ 95% CL

➡ The corresponding limit expected in the absence of signal is 1.3.

➡ The ratio of the measured Higgs-boson production strength to the SM expectation is found to be **μ = 0.2 ± 0.5(stat.) ± 0.4(syst.)**

➡ ttH, Observed (expected) limit for m_H = 125 GeV is 13.1 (10.5) xSM @ 95% CL

Backups

Signal Acceptance

m_H = 125 at 7 TeV				
$(W/Z)(H \to b\bar{b})$	Cross-section × BR [fb]	Acceptance [%]		
		0-lepton	1-lepton	2-lepton
$Z \to \ell\ell$	12.3	0.0	0.7	8.2
$W \to \ell\nu$	107.1	0.2	3.5	-
$Z \to \nu\nu$	36.4	2.2	-	-
m_H = 125 at 8 TeV				
$(W/Z)(H \to b\bar{b})$	Cross-section × BR [fb]	Acceptance [%]		
		0-lepton	1-lepton	2-lepton
$Z \to \ell\ell$	15.3	0.0	0.9	8.4
$W \to \ell\nu$	130.2	0.2	3.3	-
$Z \to \nu\nu$	45.5	2.5	-	-

Model of the Fit

Likelihood of Poisson probabilities:

$$L(\mu, \theta) = \prod_{j=1}^{N} \frac{(\mu s_j + b_j)^{n_j}}{n_j!} e^{-(\mu s_j + b_j)} \prod_{k=1}^{M} \frac{u_k^{m_k}}{m_k!} e^{-u_k}$$

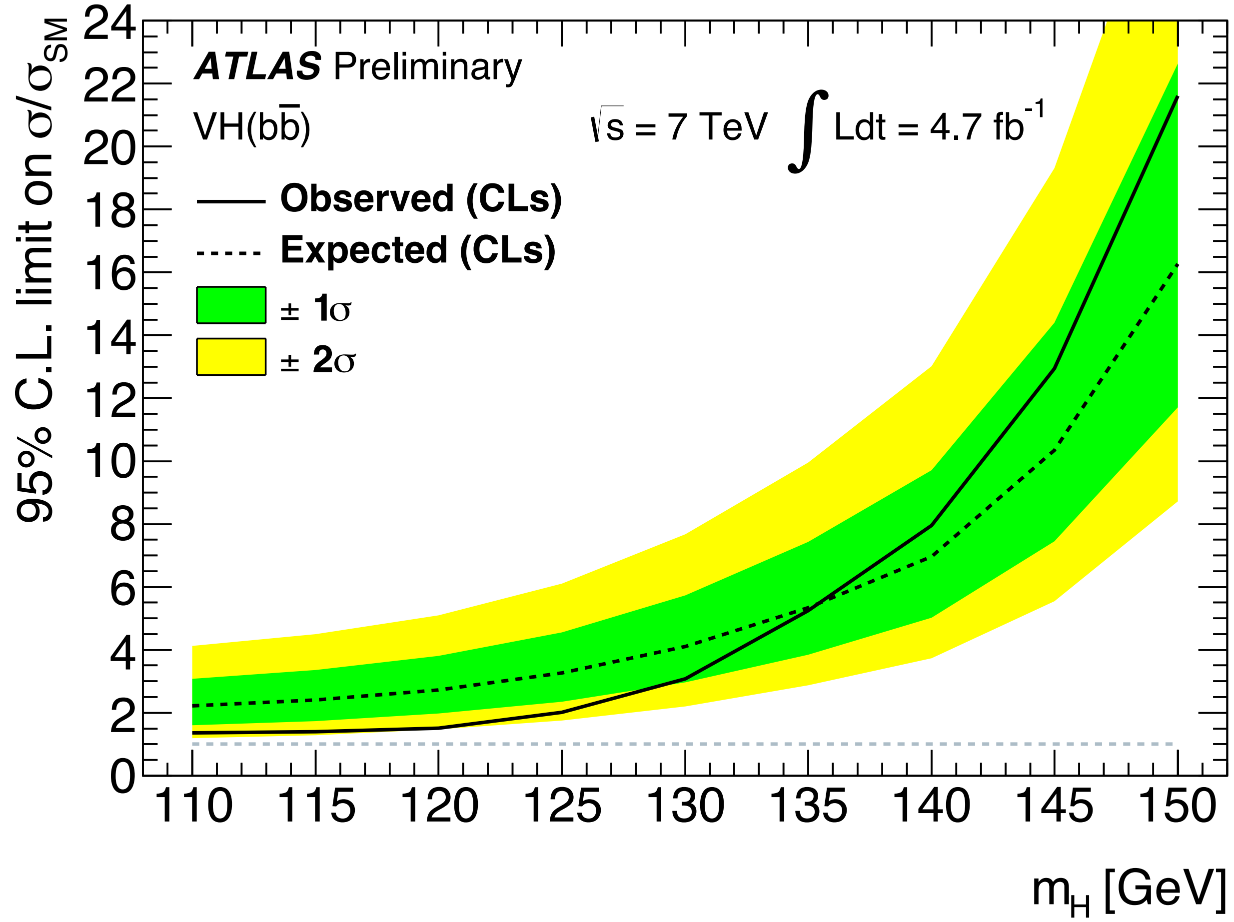
signal and background parameterisations:

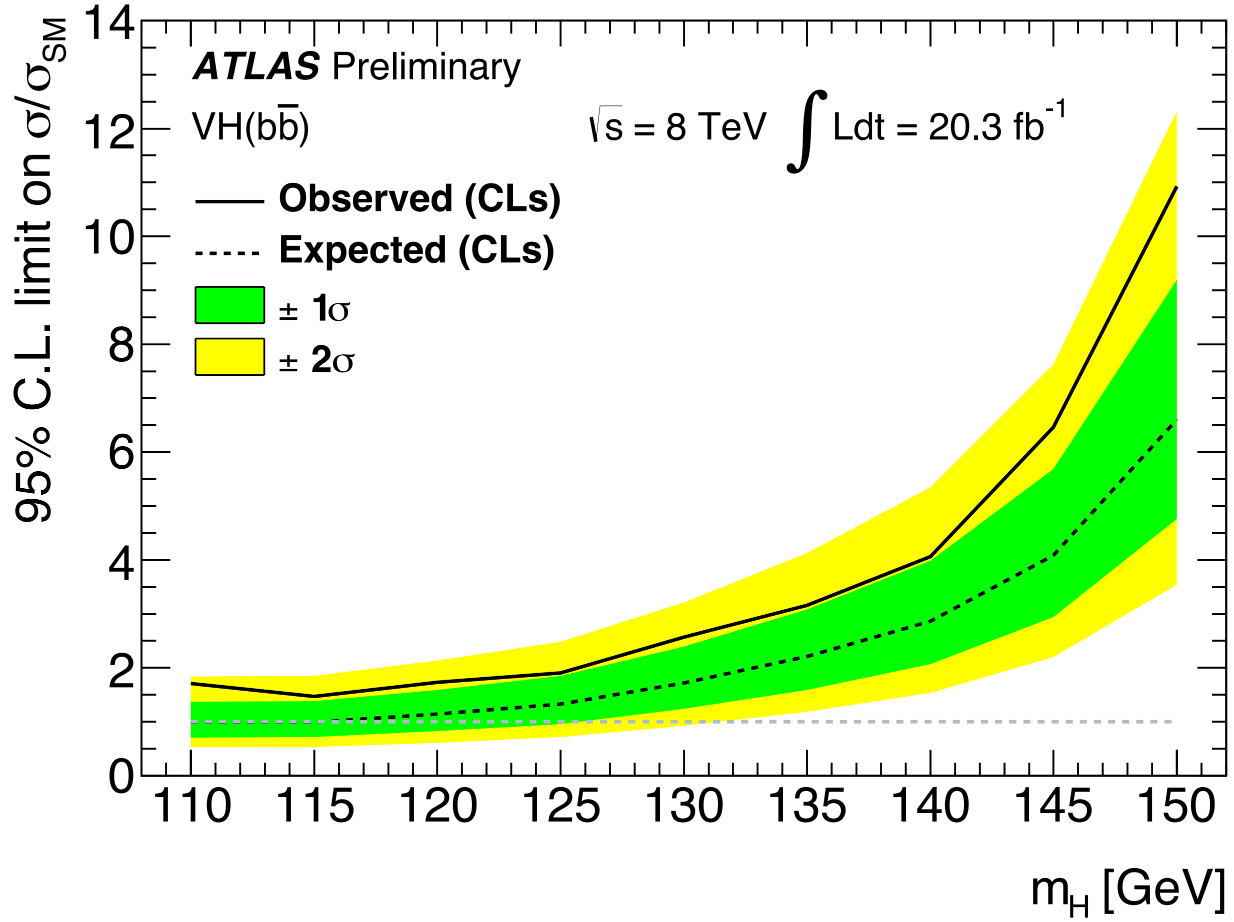
$$s_i = s_{tot} \int_{\mathrm{bin}\ i} f_s(x; \theta_s) dx \qquad b_i = b_{tot} \int_{\mathrm{bin}\ i} f_b(x; \theta_b) dx$$

test hypothesised values of μ with a test statistics:

$$\Lambda(\mu) = \frac{L(\mu, \hat{\hat{\theta}}(\mu))}{L(\hat{\mu}, \hat{\theta})}$$

7 and 8 TeV Limits





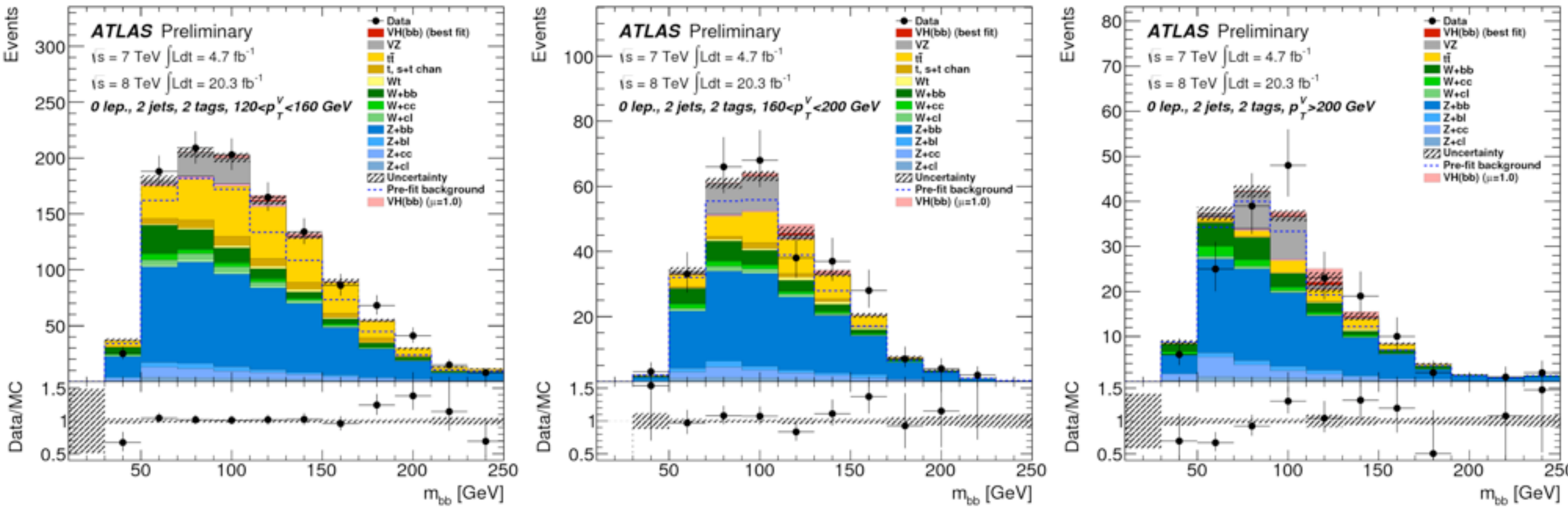
2 jet, 2 tag fitted numbers of signal and background events and the observed numbers of events

2-jet, 2-tag sample													
	0-lepton			1-lepton					2-lepton				
Process	E_T^{miss} [GeV]			p_T^W [GeV]					p_T^Z [GeV]				
	120-160	160-200	>200	0-90	90-120	120-160	160-200	> 200	0-90	90-120	120-160	160-200	>200
$Z \rightarrow \nu\nu$	1.6	0.9	1.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
$Z \rightarrow \ell\ell$	0.0	0.0	0.0	0.2	0.0	0.0	0.0	0.0	2.1	0.5	0.4	0.2	0.2
$W \rightarrow \ell\nu$	0.4	0.2	0.0	7.6	1.7	0.0	1.0	1.1	0.0	0.0	0.0	0.0	0.0
VH total	2.0	1.1	1.1	7.8	1.8	1.2	1.1	1.1	2.1	0.5	0.4	0.2	0.2
VH expected	11	5.8	6.1	42	9.5	6.6	5.6	6.1	11	2.7	2.2	1.1	1.1
Top	159	33	8	2763	729	359	113	40	166	32	8.0	0.5	0.0
W+c, light	22	5.5	2.8	623	67	28	13	8.9	0.0	0.0	0.0	0.0	0.0
W+b	30	10	6.1	909	106	49	25	19	0.0	0.0	0.0	0.0	0.0
Z+c, light	24	8.1	5.2	22	2.2	0.6	0.3	0.1	93	13	6.0	1.8	1.2
Z+b	226	71	39	97	13	3.9	1.8	0.5	938	146	64	14	8.3
WW	0.5	0.1	0.1	11	1.0	0.7	0.3	0.2	0.0	0.0	0.0	0.0	0.0
VZ	26	11	10.3	145	20	12	7.6	6.5	60	8.6	4.5	2.2	2.0
Multijet	4.8	1.1	0.7	1306	45.6	8.7	4.8	0.4	0.0	0.0	0.0	0.0	0.0
Total Bkg.	491 ± 10	141 ± 3	72 ± 2	5869 ± 64	981 ± 16	460 ± 9	165 ± 4	74 ± 3	1255 ± 24	199 ± 4	82 ± 2	18 ± 1	11 ± 0
Data	502	143	90	5916	990	458	162	79	1282	204	70	22	6
S/B	0.004	0.008	0.02	0.001	0.002	0.003	0.006	0.01	0.002	0.003	0.005	0.01	0.02

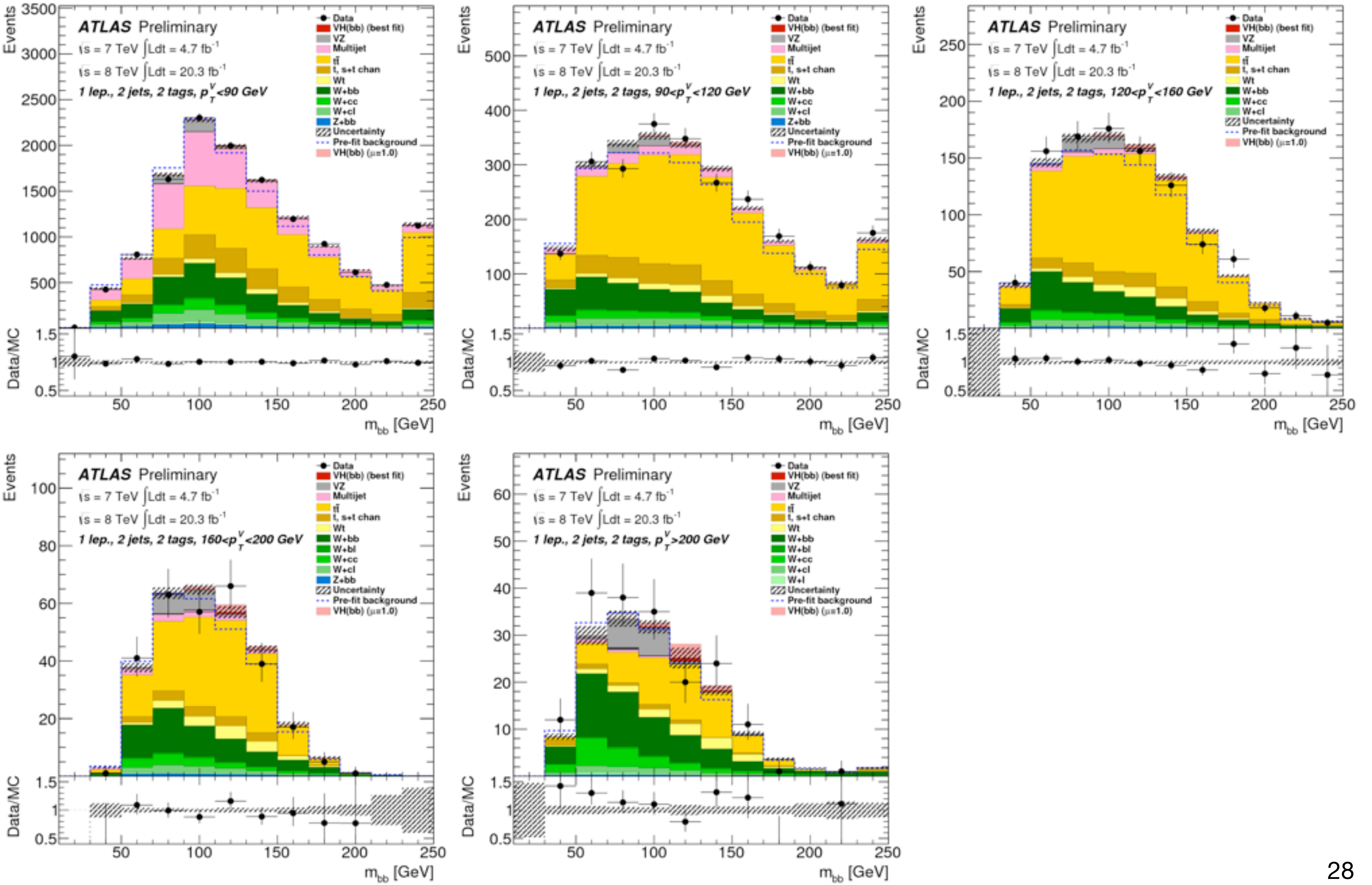
3 jet, 2 tag fitted numbers of signal and background events and the observed numbers of events

3-jet, 2-tag sample														
	0-lepton			1-lepton					2-lepton					
Process	E_T^{miss} [GeV]			p_T^W [GeV]					p_T^Z [GeV]					
	120-160	160-200	>200	0-90	90-120	120-160	160-200	> 200	0-90	90-120	120-160	160-200	>200
$Z \to \nu\nu$	0.4	0.2	0.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
$Z \to \ell\ell$	0.0	0.0	0.0	0.1	0.0	0.0	0.0	0.0	0.9	0.3	0.2	0.1	0.1
$W \to \ell\nu$	0.1	0.1	0.0	2.1	0.6	0.0	0.5	0.6	0.0	0.0	0.0	0.0	0.0
VH total	0.5	0.3	0.4	2.2	0.6	0.5	0.5	0.6	0.9	0.3	0.2	0.1	0.1
VH expected	2.7	1.6	1.9	12	3.2	2.6	2.8	3.4	4.9	1.4	1.1	0.6	0.7
Top	169	44	13	4444	1171	592	238	121	114	22	5.5	0.3	0.0
W+c, light	7.2	2.2	1.3	191	24	12.2	7.3	6.0	0.0	0.0	0.0	0.0	0.0
W+b	12	4.7	3.3	318	36	22	14.2	12	0.0	0.0	0.0	0.0	0.0
Z+c, light	6.3	2.8	2.5	8.9	0.9	0.5	0.2	0.1	54	9.8	4.7	1.5	1.3
Z+b	59	26	17	56	6.9	2.5	1.4	0.7	509	91	45	12	7.6
WW	0.2	0.1	0.1	4.0	0.5	0.3	0.1	0.1	0.0	0.0	0.0	0.0	0.0
VZ	3.7	1.8	2.3	31	4.7	3.1	2.5	3.7	20.1	3.1	1.6	0.8	1.1
Multijet	3.1	0.6	0.3	425	17	5.5	3.0	0.8	0.0	0.0	0.0	0.0	0.0
Total Bkg.	260 ± 6	82 ± 2	40 ± 1	5476 ± 57	1260 ± 17	637 ± 11	266 ± 7	143 ± 5	696 ± 16	125 ± 3	57 ± 2	15 ± 1	10 ± 1
Data	287	59	40	5523	1233	639	249	154	734	119	56	13	9
S/B	0.002	0.004	0.009	0.0004	0.0005	0.008	0.002	0.004	0.001	0.002	0.004	0.008	0.01

0 lepton, 2 jet 2 tag



1 lepton, 2 jet 2 tag



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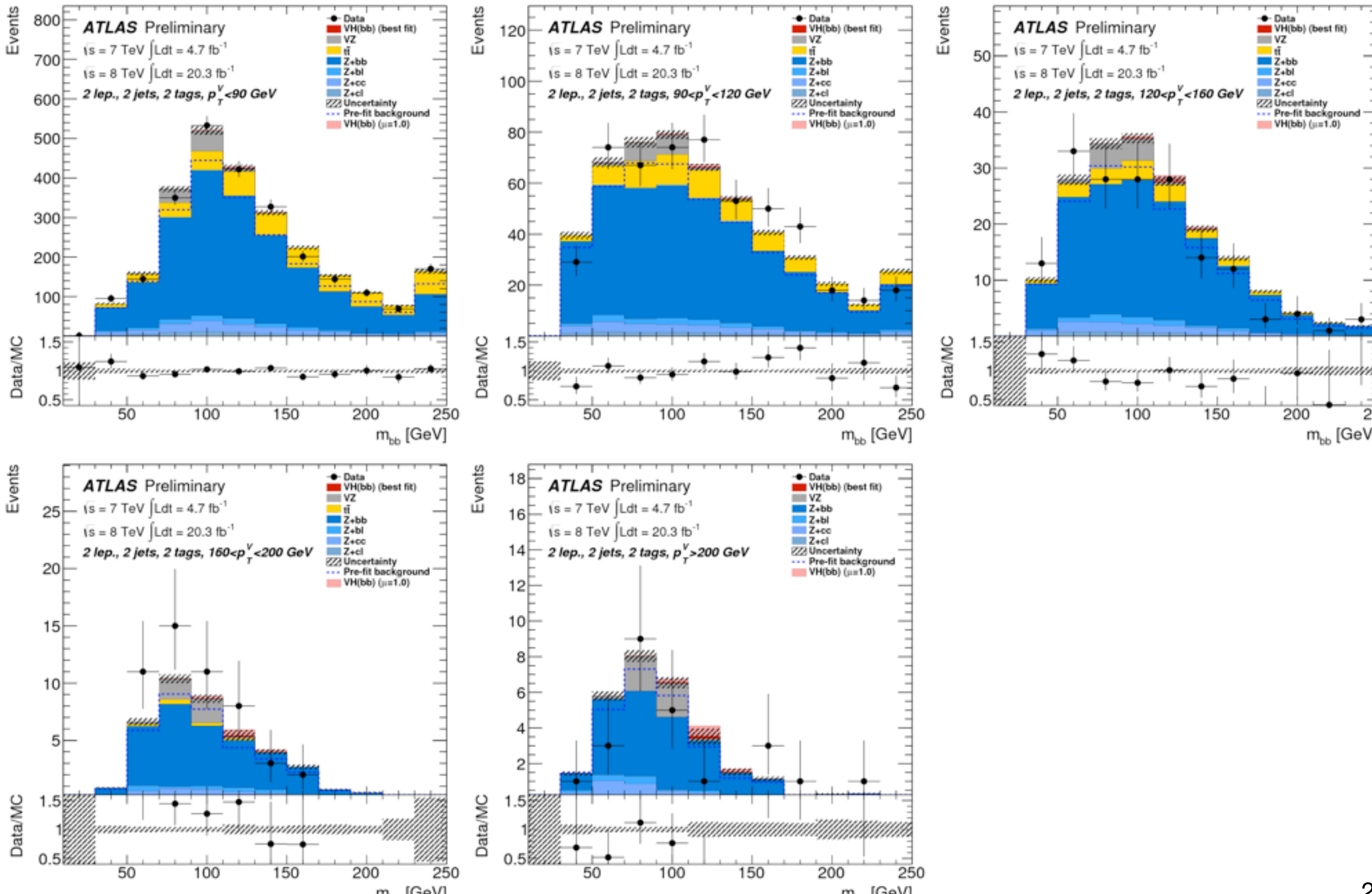
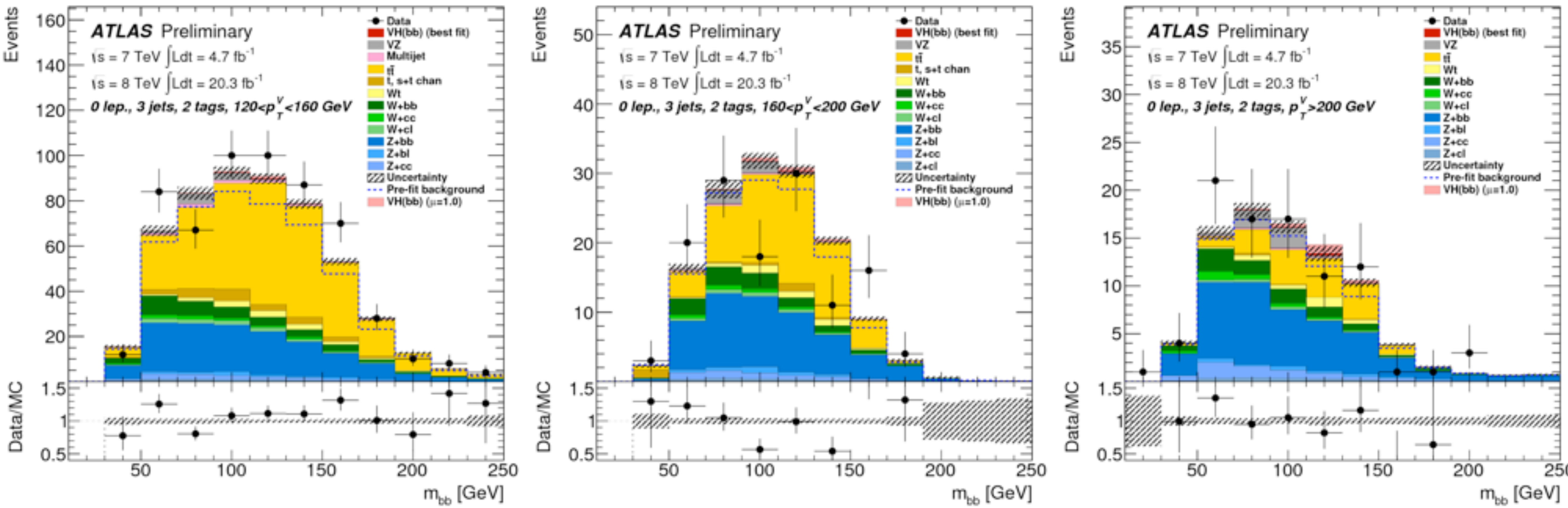
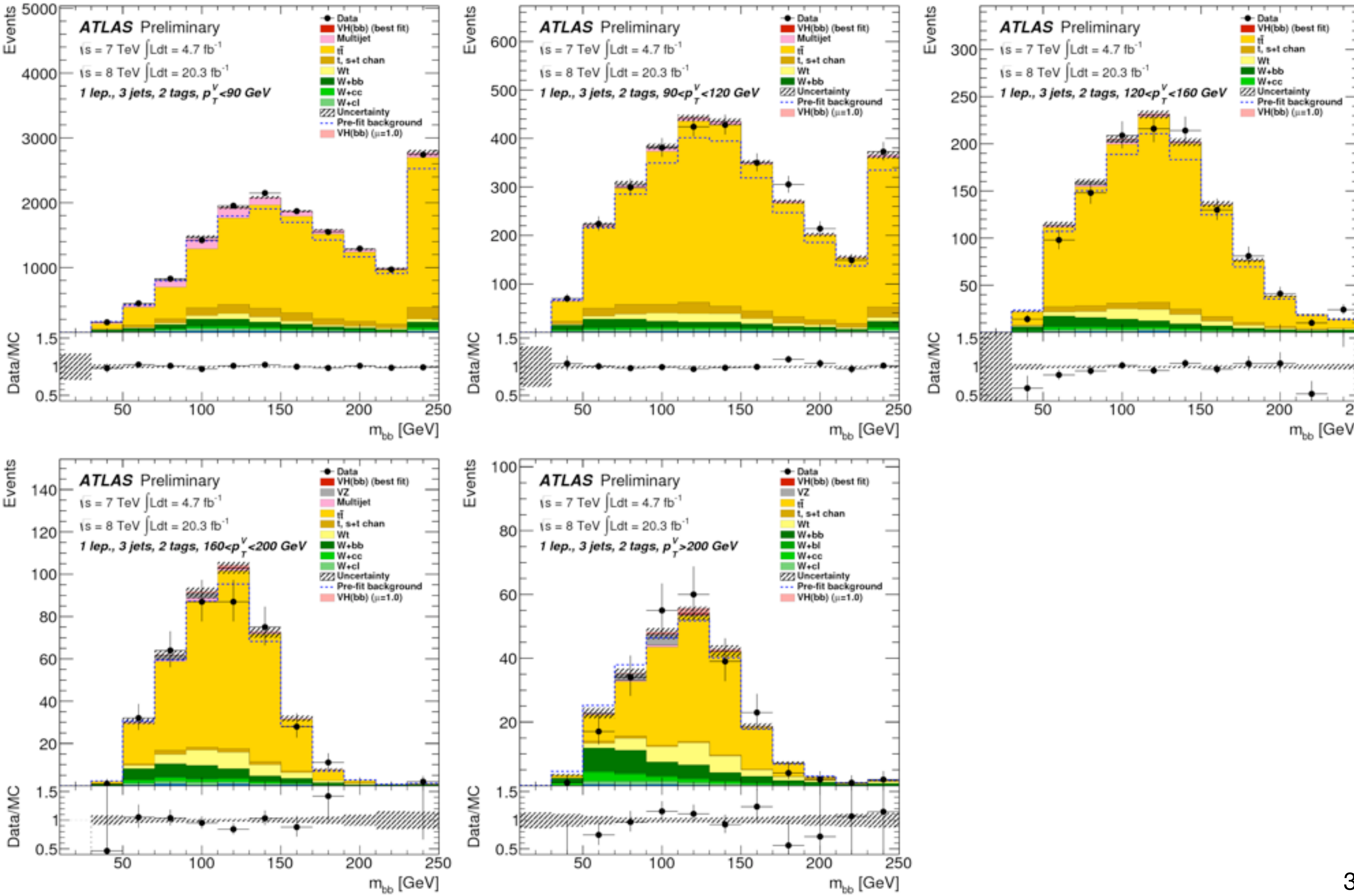


0 lepton, 3 jet 2 tag



1 lepton, 3 jet 2 tag



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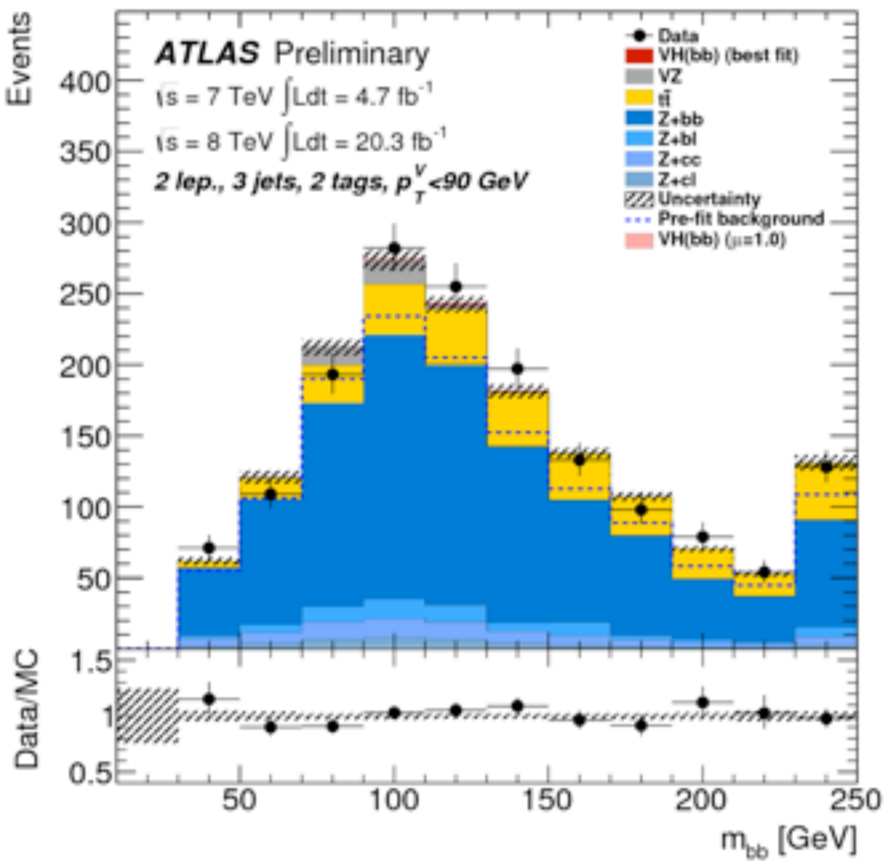
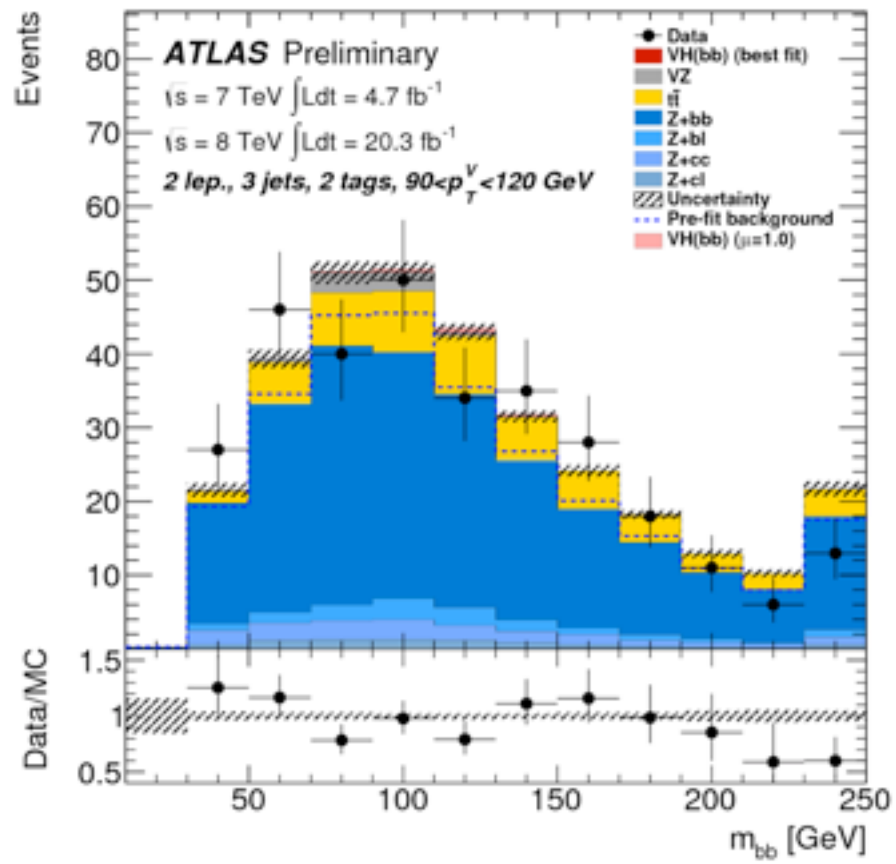
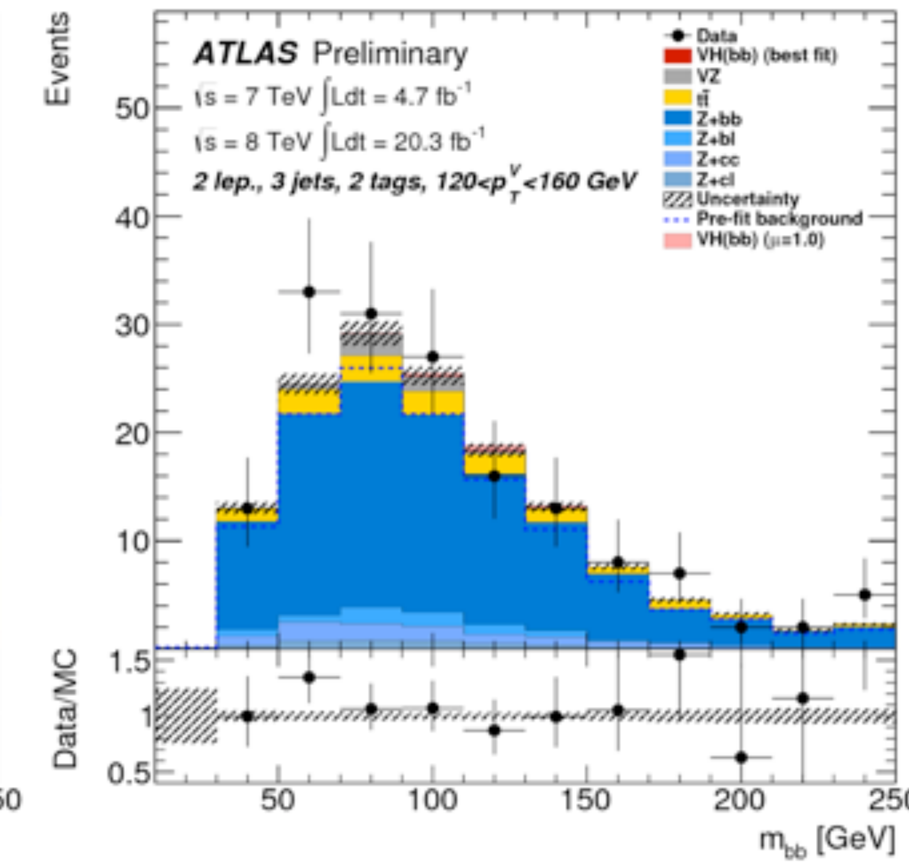
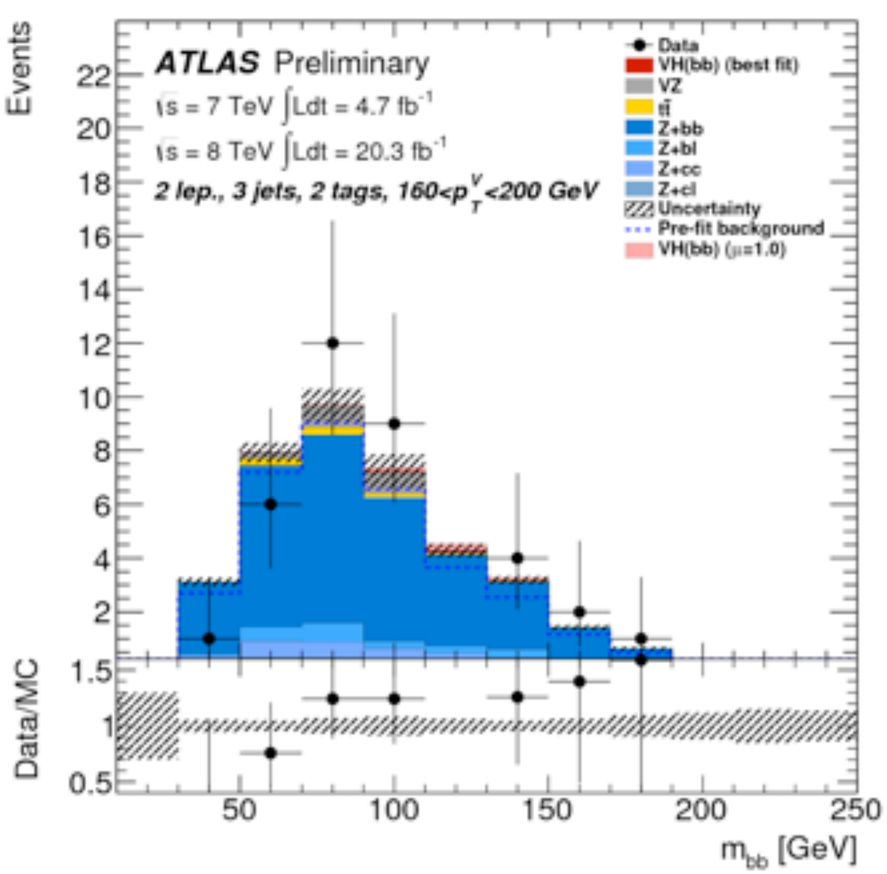
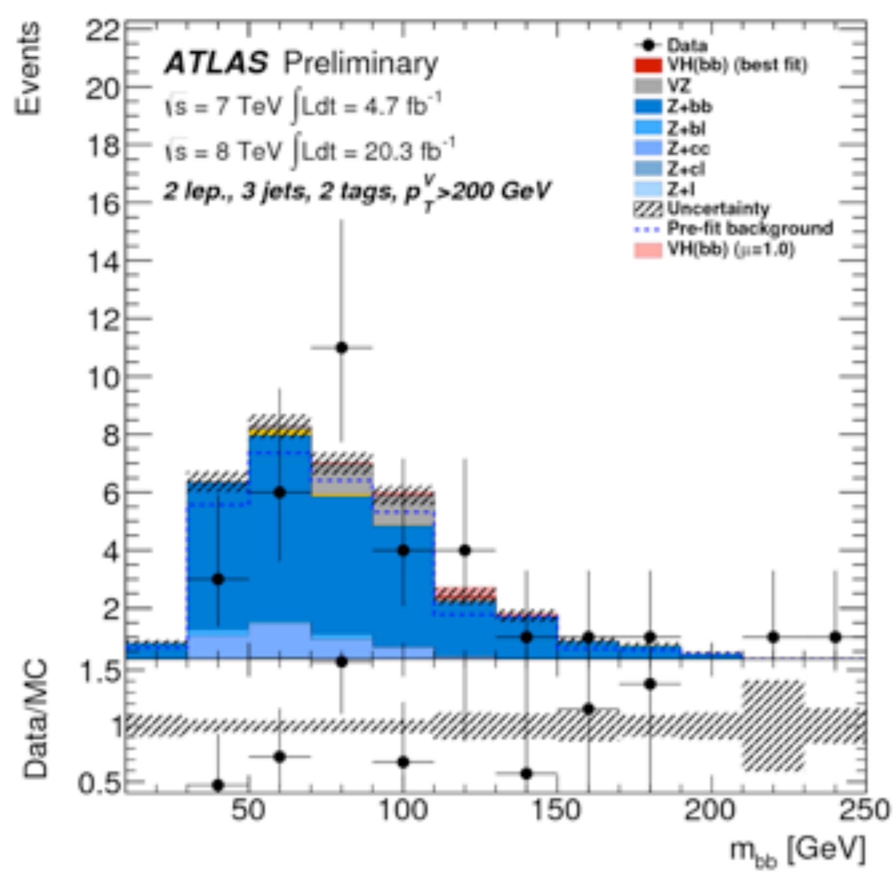


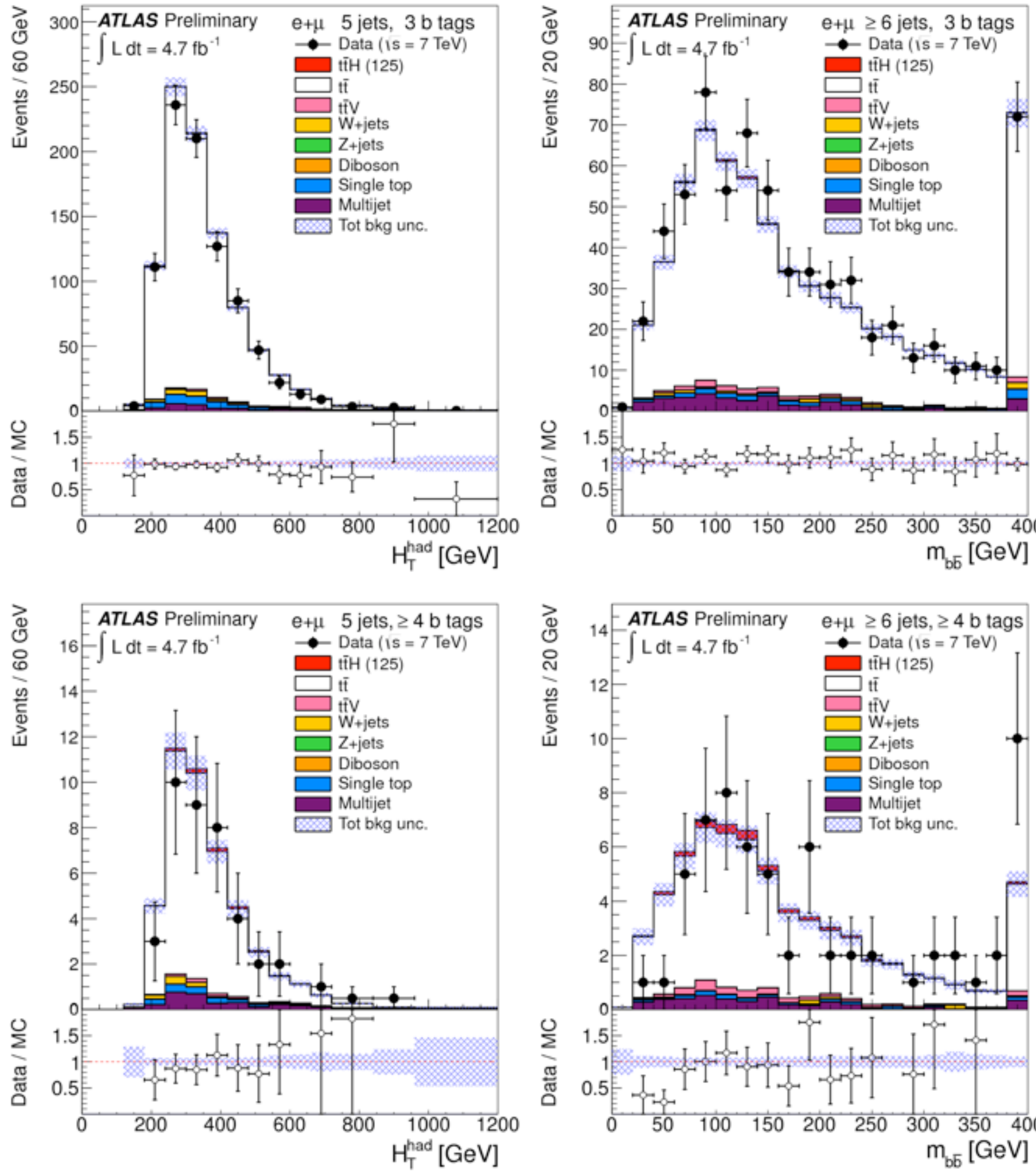








ttH Signal



ATLAS Preliminary
∫ L dt = 4.7 fb⁻¹
e+μ 5 jets, 3 b tags
e+μ ≥ 6 jets, 3 b tags
e+μ 5 jets, ≥ 4 b tags
e+μ ≥ 6 jets, ≥ 4 b tags
Data (√s = 7 TeV)
tt̄H (125)
tt̄
tt̄V
W+jets
Z+jets
Diboson
Single top
Multijet
Tot bkg unc.
Events / 60 GeV
Events / 20 GeV
Data / MC
H_T^had [GeV]
m_bb̄ [GeV]

ttH Backgrounds