Associated Higgs Production VH(bb)+ttH, all channels

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on behalf of the ATLAS and CMS Collaborations

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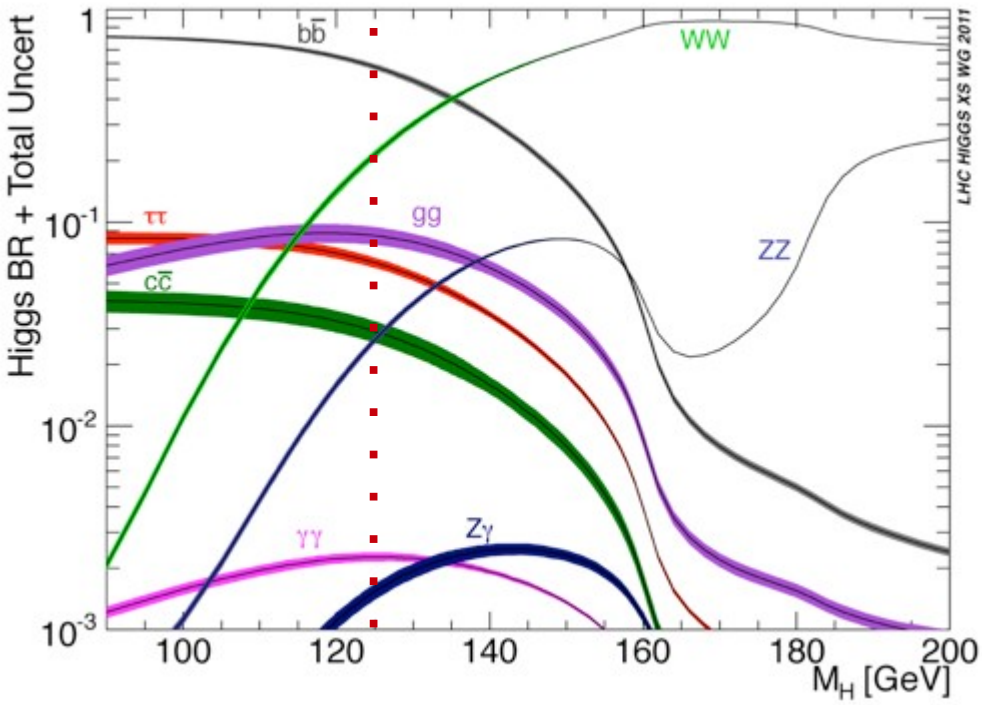
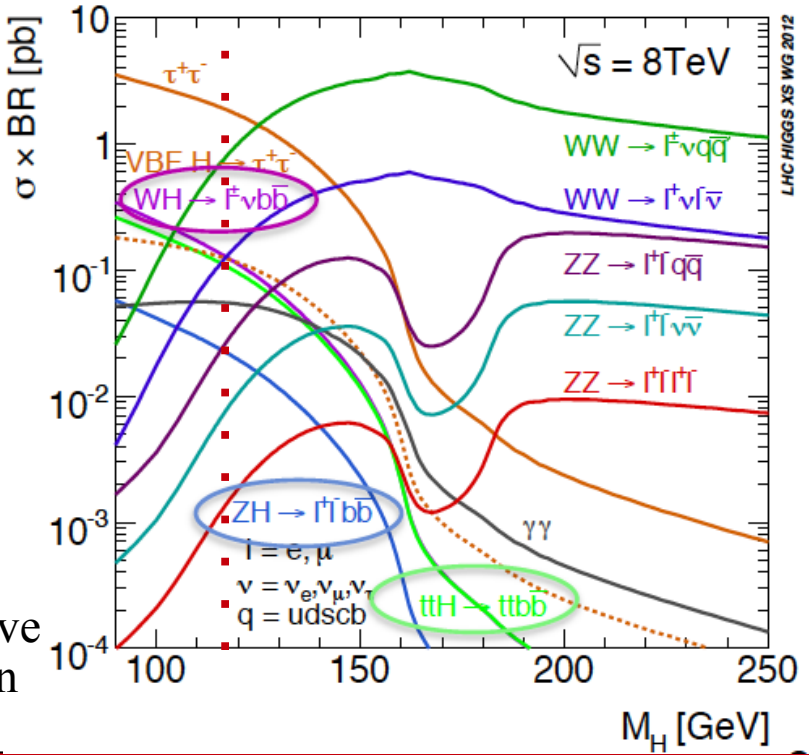
Why H→bb and associated production?



- Is the new particle the Standard Model Higgs?
  - Direct test of Yukawa coupling predictions
  - Largest decay BR (58%) at 125 GeV

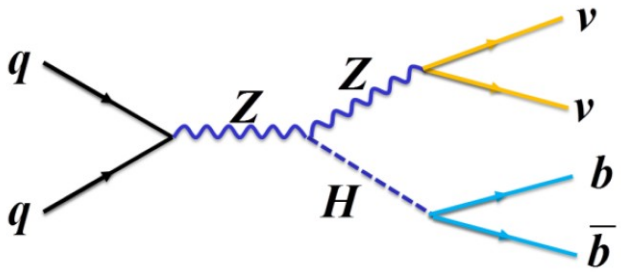


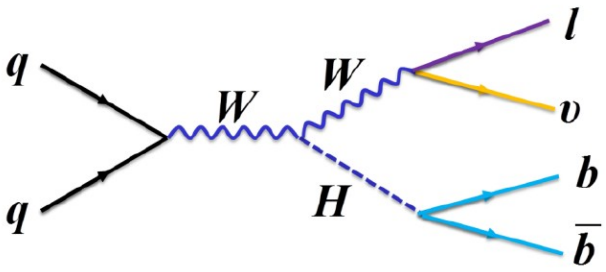
- Large QCD backgrounds
  - High p_T b-jet production ~10^6 x larger
  - Use W or Z or tt pair in associated production to reduce backgrounds
    - productio smaller for VH (1.09 pb, inclusive W) and ttH (0.13 pb) with respect to gluon fusion (19.52 pb)

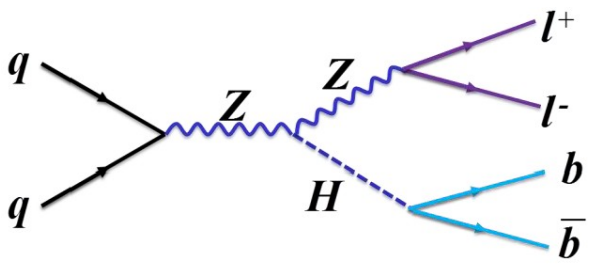
- $ZH \rightarrow \nu\nu bb$
  - 0-leptons
- $WH \rightarrow l\nu bb$
  - 1-lepton*
- $ZH \rightarrow llbb$
  - 2-leptons*

* lepton = electron or muon

VH, H→bb







	7 TeV	8 TeV	Reference
ATLAS	4.7 fb^{-1}	13.0 fb^{-1}	ATLAS-CONF-2012-161
CMS	5.0 fb^{-1}	12.1 fb^{-1}	CMS-PAS-HIG-12-044

!Still not the full 8 TeV dataset! (~21 fb^{-1})

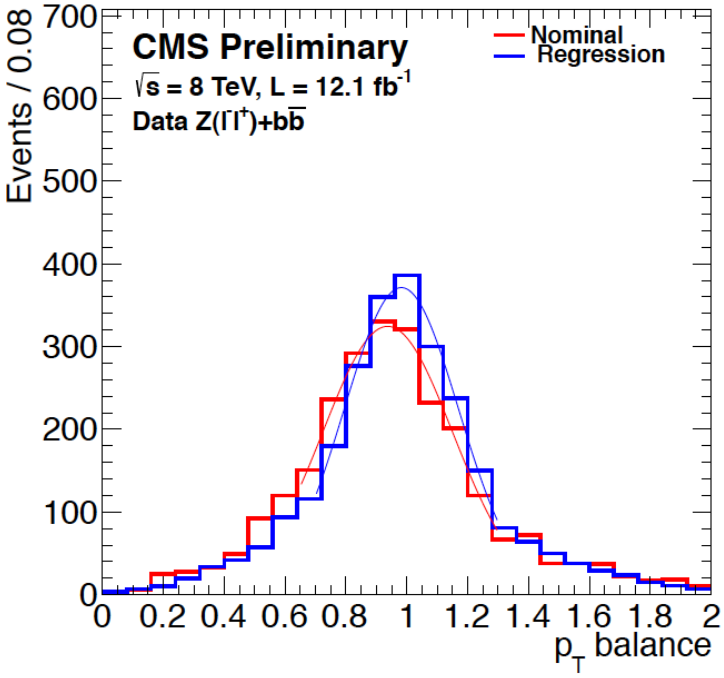
B-Jet tagging and Mbb response

Use track impact parameters, secondary and subsequent vertices

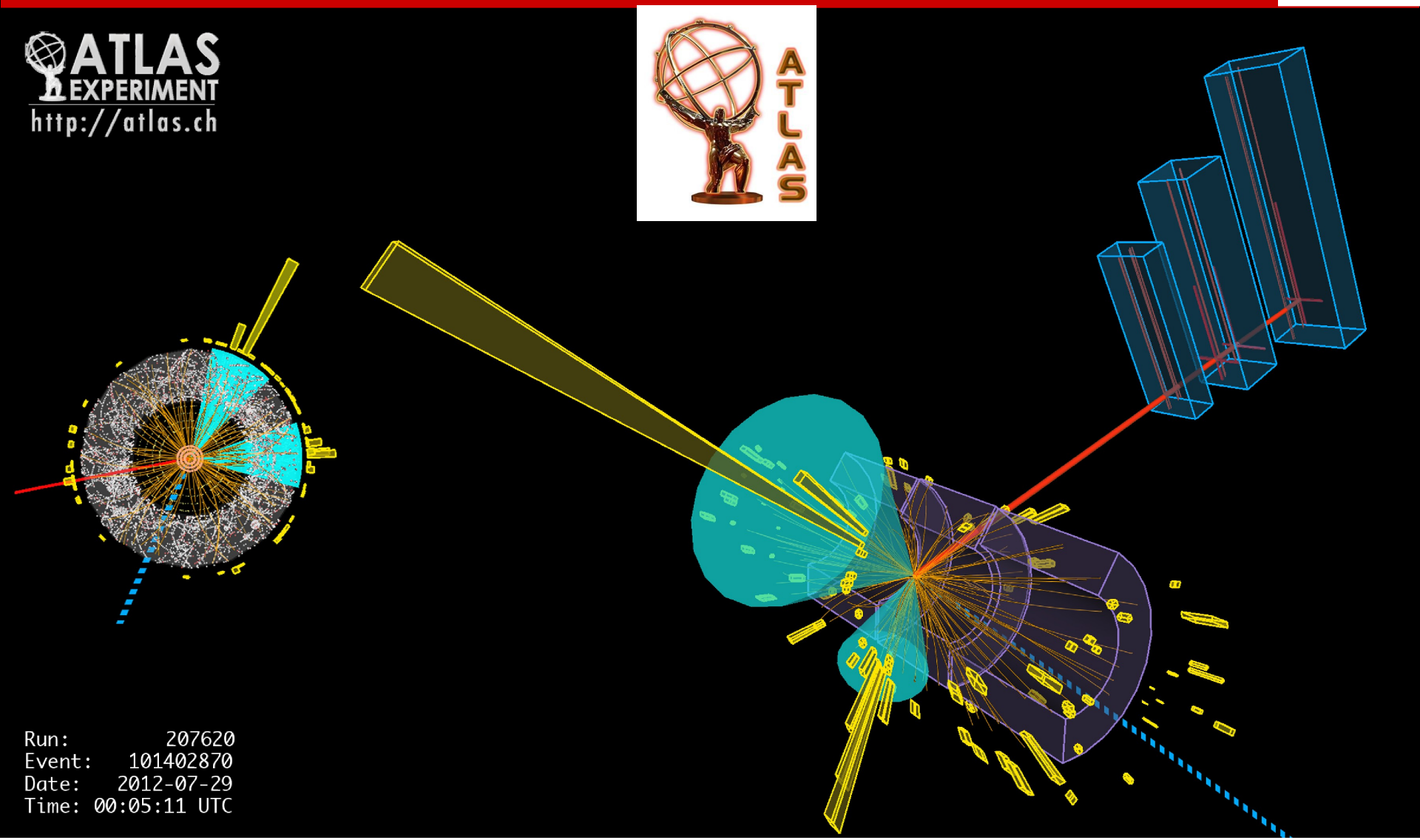
ATLAS-CONF-2012-043
ATLAS-CONF-2012-161
CMS PAS HIG-12-044

	Technique	Efficiency at example operating point		
		b-quarks	c-quarks	light-quarks+gluons
ATLAS	Multivariate	70%	20%	0.7%
CMS	Likelihood	72%	23%	3%

- Jets from b-quarks
  - Scale different than light jets
  - With leptons/neutrinos, more massive
- ATLAS (Anti-kT jets R=0.4)
  - Corrections for muon-in-jet, p_T-dependent bias
- CMS (Particle flow R=0.5)
  - BDT energy regression algorithm exploiting b-tag and jet variables
    - ~ 15% improvement in mass resolution (~10%), validated with Z(ll) + bb



ATLAS VH analysis



ATLAS WH(bb) candidate event

VH event selection

Trigger: MET single-lepton single+di-lepton

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

Datasets: 4.7 fb^{-1} for $\sqrt{s}$ = 7 TeV
13.0 fb^{-1} for $\sqrt{s}$ = 8 TeV

16 Signal regions

	0-lepton channel 2 and 3jets				
E_T^{miss} (GeV)	120-160	160-200	>200		
$\Delta R(b,\bar{b})$	0.7-1.9	0.7-1.7	<1.5		
	1-lepton channel				
p_T^W (GeV)	0-50	50-100	100-150	150-200	>200
$\Delta R(b,\bar{b})$	>0.7			0.7-1.6	<1.4
E_T^{miss} (GeV)	> 25				> 50
m_T^W (GeV)	> 40			-	
	2-lepton channel				
p_T^Z(GeV)	0-50	50-100	100-150	150-200	>200
$\Delta R(b,\bar{b})$	>0.7			0.7-1.8	<1.6

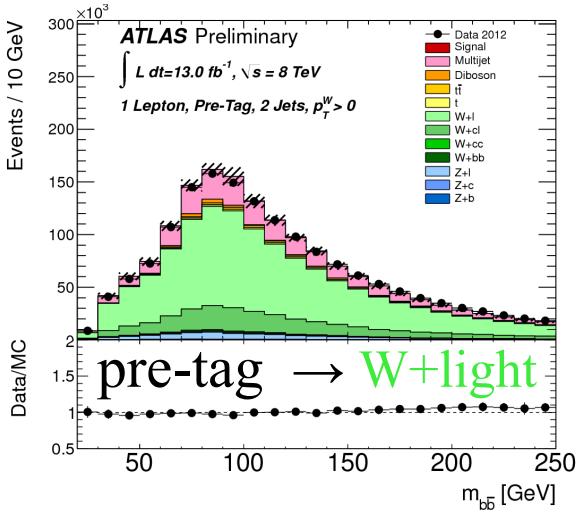
- S/B increases with vector boson p_T
- Events separated in p_T(V) bins to optimize the cuts
- Not yet enough $\sqrt{s}$ and $\int Ldt$ to use jet substructure techniques

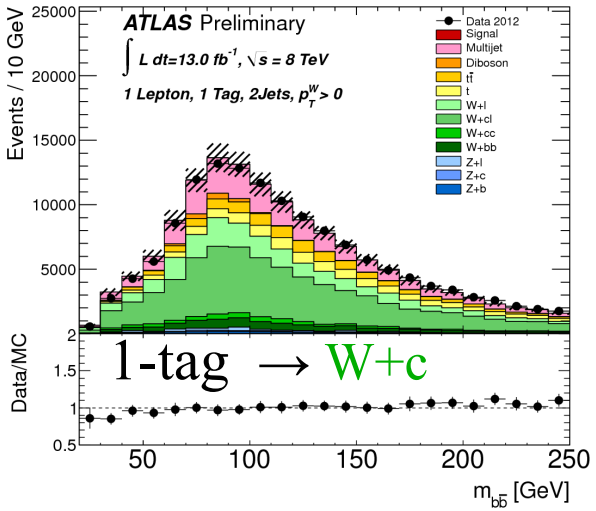
VH(bb) backgrounds

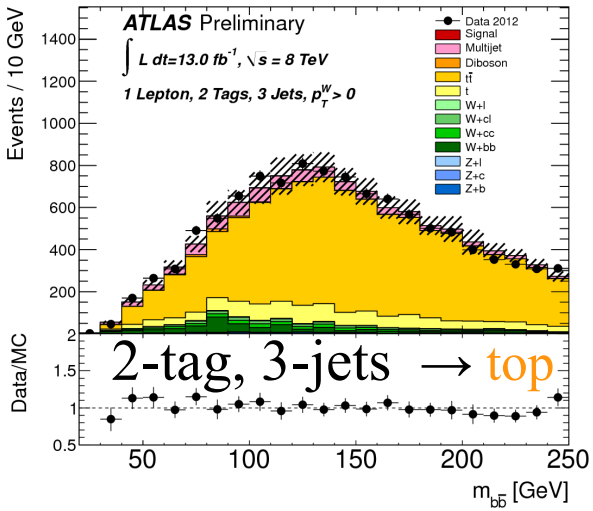
Signal	WH/ZH Pythia8
Multijet	Data driven
Diboson	WW/WW/ZZ Herwig
ttbar	MC@NLO
Single Top	Acer/MC@NLO
W+c/light-jets	Alpgen
W+b	Powheg
Z+b/c/light-jets	Alpgen/Sherpa

- QCD Multi-jet
  - Data-driven methods
- diboson WZ/ZZ (Z→bb)
  - Shape, normalization from MC
- All other backgrounds
  - Shapes from MC, normalization from fits to signal and control regions

1-lepton control regions

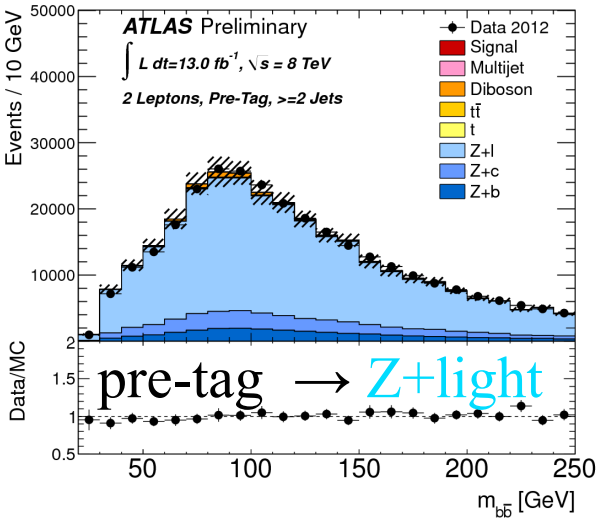




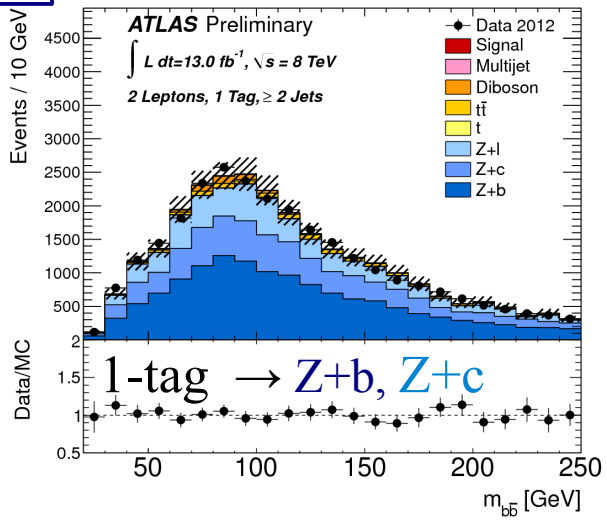


Additional control regions

2-lepton control regions

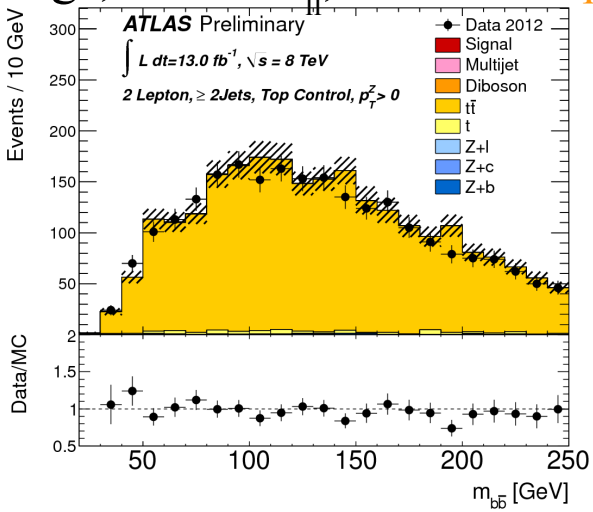


pre-tag → Z+light

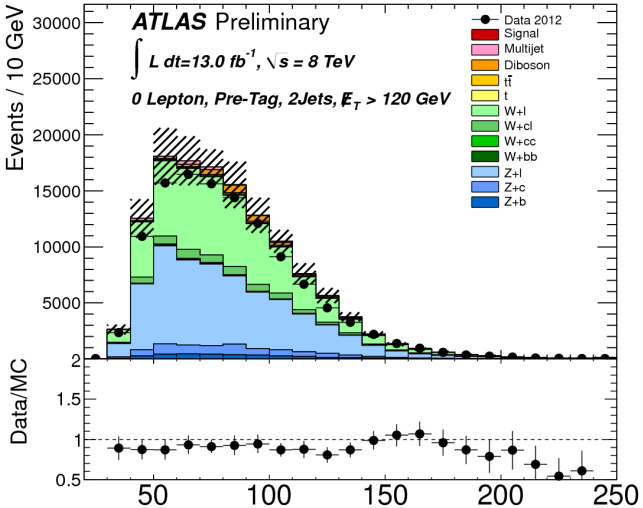


1-tag → Z+b, Z+c

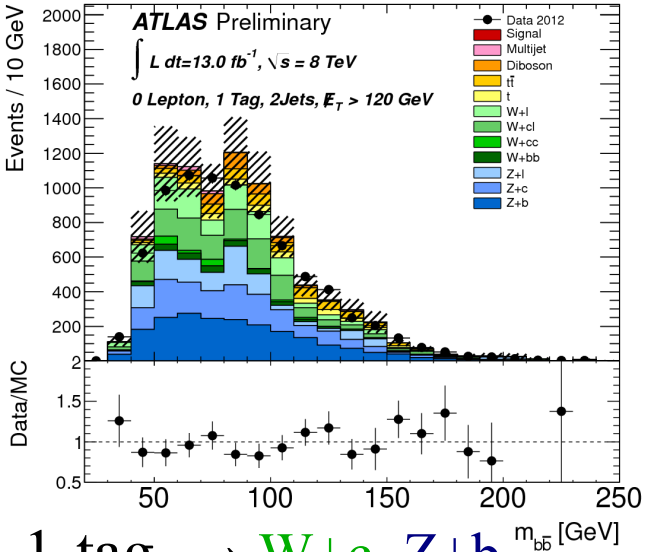
2-tags, invert m_{ll}, MET → top



0-lepton control regions cross-check



pre-tag → Z+light, W+light



1-tag → W+c, Z+b

Flavour and signal fits

- Flavour maximum likelihood fit
  - 1 and 2-leptons, 0/1/2 tag+top control regions
  - One floating scale factor for each background
  - Determine V+c, V+light scale factors
    - V+b, top also floated
  - Improved understanding of background
    - $p_T(V)$ distribution falls off more rapidly in data than MC, so MC is reweighted to data
    - V+jets: correction of 5-10% from pre-tag, checked on 1-tag
    - top: correction of 15% from 1-lepton 3 jets/4 jets CR

different MC for Z+c 7/8 TeV

	$\sqrt{s}$ = 7 TeV	$\sqrt{s}$ = 8 TeV
$Z + c$	1.99 ± 0.51	0.71 ± 0.23
Z+ light	0.91 ± 0.12	0.98 ± 0.11
$W + c$	1.04 ± 0.23	1.04 ± 0.24
W+ light	1.03 ± 0.08	1.01 ± 0.14

- Binned profile likelihood fit
  - 16 signal regions + top control regions
  - Systematic uncertainties as nuisance parameters
  - W+b, Z+b, top floated in fit
    - account for syst. and signal contamination

	$\sqrt{s}$ = 7 TeV	$\sqrt{s}$ = 8 TeV
Top	1.10 ± 0.14	1.29 ± 0.16
$Z + b$	1.22 ± 0.20	1.11 ± 0.15
$W + b$	1.19 ± 0.23	0.79 ± 0.20

Systematic uncertainties

Signal

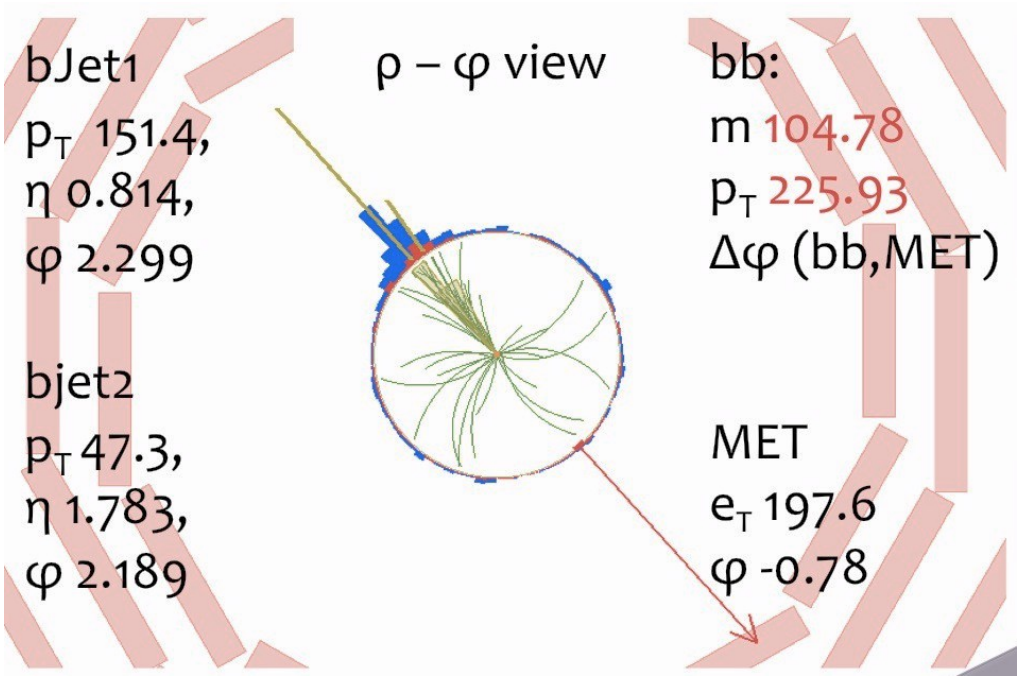
Uncertainty [%]	0 lepton		1 lepton	2 leptons
	ZH	WH	WH	ZH
b-tagging	8.9	9.0	8.8	8.6
Jet/Pile-up/$E_{\mathrm{T}}^{\mathrm{miss}}$	19	25	6.7	4.2
Lepton	0.0	0.0	2.1	1.8
$H \to bb$ BR	3.3	3.3	3.3	3.3
VH p_T-dependence	5.3	8.1	7.6	5.0
VH theory PDF	3.5	3.5	3.5	3.5
VH theory scale	1.6	0.4	0.4	1.6
Statistical	4.9	18	4.1	2.6
Luminosity	3.6	3.6	3.6	3.6
Total	24	34	16	13

Background

Uncertainty [%]	0 lepton	1 lepton	2 leptons
b-tagging	6.5	6.0	6.9
c-tagging	7.3	6.4	3.6
light tagging	2.1	2.2	2.8
Jet/Pile-up/$E_{\mathrm{T}}^{\mathrm{miss}}$	20	7.0	5.4
Lepton	0.0	2.1	1.8
Top modelling	2.7	4.1	0.5
W modelling	1.8	5.4	0.0
Z modelling	2.8	0.1	4.7
Diboson	0.8	0.3	0.5
Multijet	0.6	2.6	0.0
Luminosity	3.6	3.6	3.6
Statistical	8.3	3.6	6.6
Total	25	15	14

Largest experimental uncertainties:
b-tagging, jet energy scale and resolution

CMS VH analysis



VH event selection, analysis

- 8 signal regions
  - 0, 1, 2 lepton categories
  - Low and high $p_T(V)$ bins
  - Standard and loose b-tagging (in 0,1 lepton, high p_T)

Variable	W($\ell\nu$)H	Z($\ell\ell$)H	Z($\nu\nu$)H
$m_{\ell\ell}$	–	[75 – 105]	–
$p_T(j_1)$	> 30	> 20	> 60
$p_T(j_2)$	> 30	> 20	> 30
$p_T(jj)$	> 120	–	> 130
$m(jj)$	< 250	[80 – 150] (< 250)	< 250
$p_T(V)$	[120 – 170] (> 170)	[50 – 100] (> 100)	–
CSV_{max}	> 0.40	> 0.50 (> 0.244)	> 0.679
CSV_{min}	> 0.40	> 0.244	> 0.244
CSV_{min}^{loose}	– (< 0.40)	–	– (< 0.244)
N_{al}	= 0	–	= 0
E_T^{miss}	> 45 (elec)	–	[130 – 170] (> 170)
$\Delta\phi(E_T^{miss}, jet)$	–	–	> 0.5
$\Delta\phi(E_T^{miss}, E_T^{miss(trks)})$	–	–	< 0.5
$\Delta\phi(V, H)$	–	–	> 2.0

BDT input variables

p_{Tj}	transverse momentum of each Higgs daughter
m(jj)	dijet invariant mass
p_T(jj)	dijet transverse momentum
p_T(V)	vector boson transverse momentum (or E_T^{miss})
CSV_{max}	b-tag disc. value for Higgs daughter with largest value
CSV_{min}	b-tag disc. value for Higgs daughter with second largest value
Δφ(V, H)	azimuthal angle between V (or E_T^{miss}) and dijet
|Δη(jj)|	difference in η between Higgs daughters
ΔR(jj)	difference in η-φ between Higgs daughters
N_{aj}	number of additional jets
Δφ(E_T^{miss}, jet)	azimuthal angle between E_T^{miss} and closest jet (only for Z(νν)H)
$\Delta\theta_{pull}$	color pull angle

- Multivariate analysis
  - Boosted Decision Tree (BDT) method
  - Most discriminating variables: mass, p_T, b-tag, jet veto

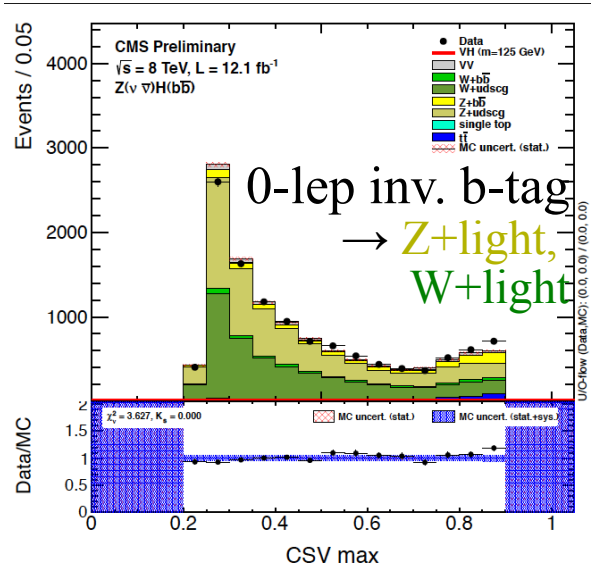
Background control regions

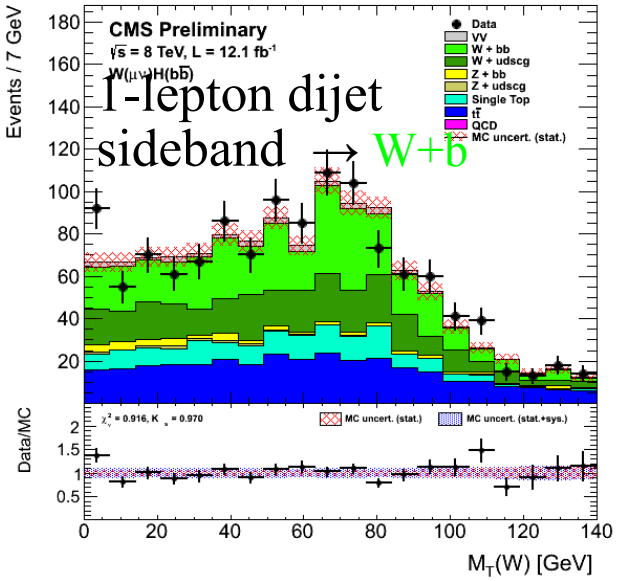
- Single-top and dibosons from MC
- QCD multijet considered negligible
- Other backgrounds shape from MC and normalization from fit to variables in control regions (CR)

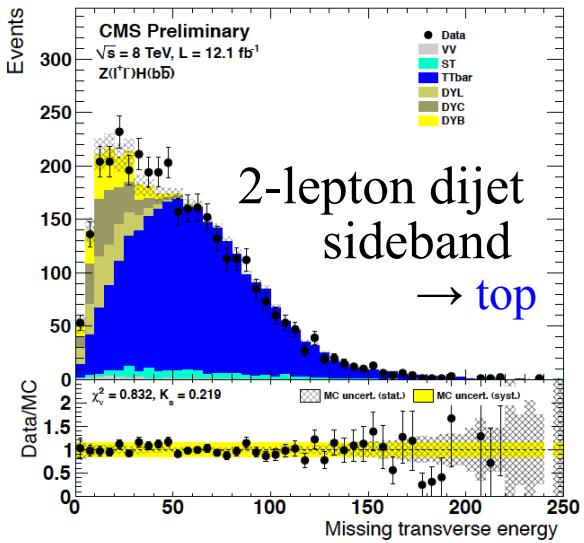
5+5 regions in 0-lepton low + high p_T channels

Variable	Z+LF	Z+HF	$t\bar{t}$	W+LF	W+HF
$p_T(j_1)$	> 60	> 60	> 60	> 60	> 60
$p_T(j_2)$	> 30	> 30	> 30	> 30	> 30
$p_T(jj)$	> 130	> 130	> 130	> 130	> 130
$p_T(V)$	–	–	–	–	–
CSV_{max}	$[0.244 - 0.898]$	> 0.679	> 0.898	$[0.244 - 0.898]$	> 0.679
CSV_{min}	–	> 0.244	–	–	> 0.244
N_{aj}	–	–	≥ 1	$= 0$	$= 0$
N_{al}	$= 0$	$= 0$	$= 1$	$= 1$	$= 1$
E_T^{miss}	$[130 - 170](> 170)$	$[130 - 170](> 170)$	$[130 - 170](> 170)$	$[130 - 170](> 170)$	$[130 - 170](> 170)$
$\Delta\phi(E_T^{miss}, jet)$	> 0.5	> 0.5	> 0.5	> 0.5	> 0.5
$\Delta\phi(E_T^{miss}, E_T^{miss(trks)})$	< 0.5	< 0.5	–	–	–
$m(jj)$	< 250	veto $[100 - 140]$	veto $[100 - 140]$	< 250	veto $[100 - 140]$

Also: 3+3 regions in 1-lepton low + high p_T channels; 2 regions in 2-lepton channels



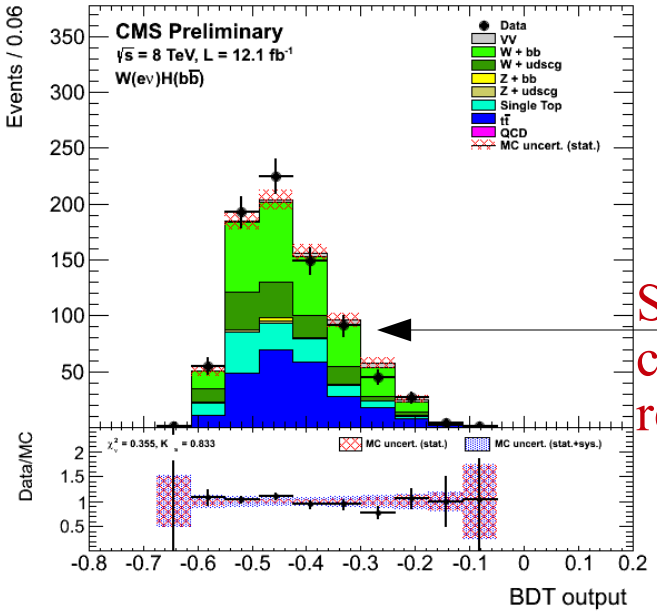




Uncertainties

Background scale factors from fit: W/Z+b, W/Z+light, tt

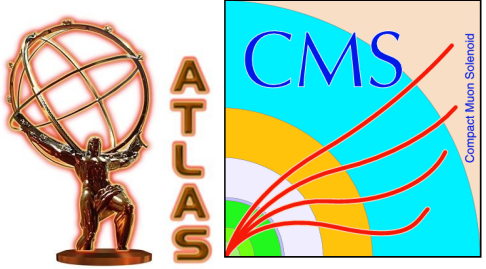
Process	W($\ell\nu$)H	W($\ell\nu$)H	Z($\ell\ell$)H	Z($\ell\ell$)H	Z($\nu\nu$)H	Z($\nu\nu$)H
Low p_T	7 TeV	8 TeV	7 TeV	8 TeV	7 TeV	8 TeV
W + udscg	$0.88 \pm 0.01 \pm 0.03$	$1.01 \pm 0.02 \pm 0.01$	–	–	$0.89 \pm 0.01 \pm 0.03$	$0.96 \pm 0.06 \pm 0.03$
W$b\bar{b}$	$1.91 \pm 0.14 \pm 0.31$	$2.07 \pm 0.15 \pm 0.10$	–	–	$1.36 \pm 0.10 \pm 0.15$	$1.30 \pm 0.17 \pm 0.10$
Z + udscg	–	–	$1.11 \pm 0.03 \pm 0.11$	$1.10 \pm 0.02 \pm 0.06$	$0.87 \pm 0.01 \pm 0.03$	$1.15 \pm 0.07 \pm 0.03$
Z$b\bar{b}$	–	–	$0.98 \pm 0.05 \pm 0.12$	$1.08 \pm 0.04 \pm 0.08$	$0.96 \pm 0.02 \pm 0.03$	$1.12 \pm 0.10 \pm 0.04$
$t\bar{t}$	$0.93 \pm 0.02 \pm 0.05$	$1.07 \pm 0.01 \pm 0.01$	$1.03 \pm 0.04 \pm 0.11$	$1.01 \pm 0.02 \pm 0.06$	$0.97 \pm 0.02 \pm 0.04$	$1.05 \pm 0.07 \pm 0.03$
High p_T	7 TeV	8 TeV	7 TeV	8 TeV	7 TeV	8 TeV
W + udscg	$0.79 \pm 0.01 \pm 0.02$	$0.94 \pm 0.02 \pm 0.01$	–	–	$0.78 \pm 0.02 \pm 0.03$	$0.95 \pm 0.05 \pm 0.02$
W$b\bar{b}$	$1.49 \pm 0.14 \pm 0.19$	$1.72 \pm 0.16 \pm 0.08$	–	–	$1.48 \pm 0.15 \pm 0.20$	$1.27 \pm 0.18 \pm 0.10$
Z + udscg	–	–	$1.11 \pm 0.03 \pm 0.11$	$1.10 \pm 0.02 \pm 0.06$	$0.97 \pm 0.02 \pm 0.04$	$1.04 \pm 0.07 \pm 0.02$
Z$b\bar{b}$	–	–	$0.98 \pm 0.05 \pm 0.12$	$1.08 \pm 0.04 \pm 0.08$	$1.08 \pm 0.09 \pm 0.06$	$1.15 \pm 0.10 \pm 0.04$
$t\bar{t}$	$0.84 \pm 0.02 \pm 0.03$	$0.99 \pm 0.01 \pm 0.01$	$1.03 \pm 0.04 \pm 0.11$	$1.01 \pm 0.02 \pm 0.06$	$0.97 \pm 0.02 \pm 0.04$	$1.03 \pm 0.07 \pm 0.03$



Scale factors from fit checked with control region BDT distributions

Uncertainties on signal/Bkg yields

Source	Range
Luminosity	2.2-4.4%
Lepton efficiency and trigger (per lepton)	3%
Z($\nu\nu$)H triggers	3%
Jet energy scale	2–3%
Jet energy resolution	3–6%
Missing transverse energy	3%
b-tagging	3–15%
Signal cross section (scale and PDF)	4%
Signal cross section (p_T boost, EWK/QCD)	5–10% / 10%
Signal Monte Carlo statistics	1-5%
Backgrounds (data estimate)	≈ 10%
Single-top (simulation estimate)	15–30%
Dibosons (simulation estimate)	30%

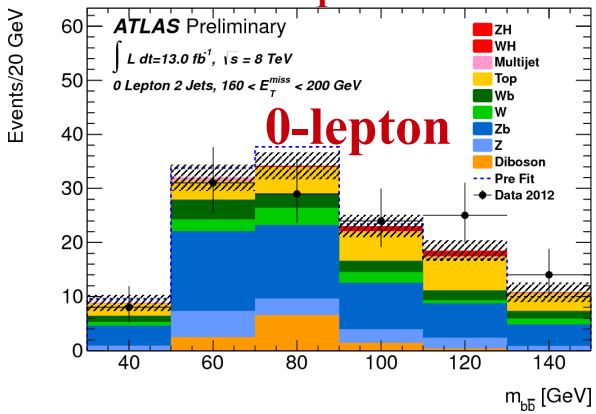


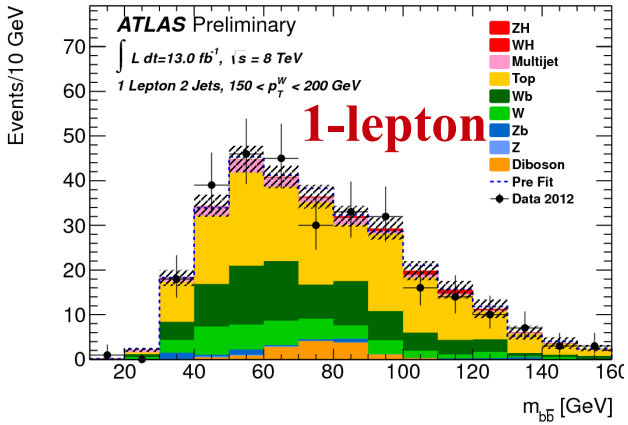
Results

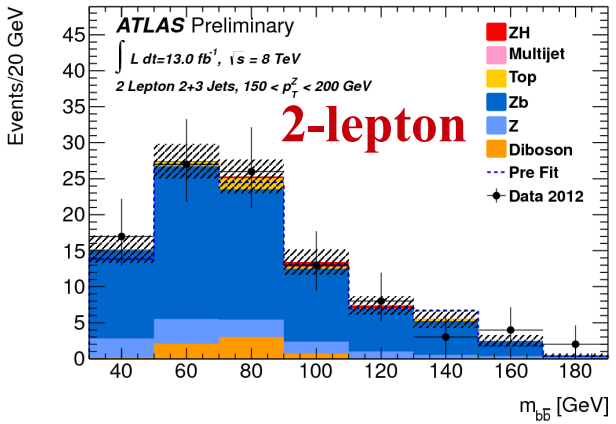
VH ATLAS Mbb

150,160 < $p_T(V)$ < 200 GeV

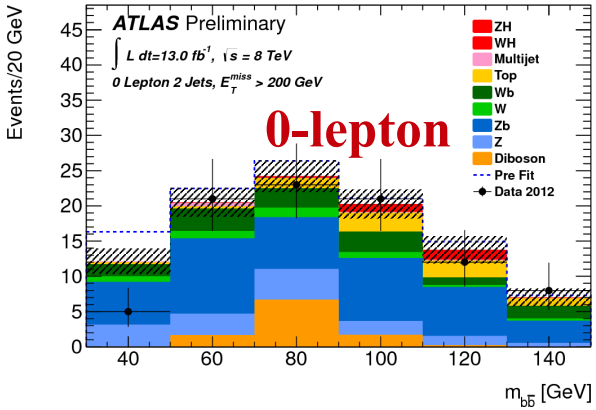
Showing only the two highest p_T bins

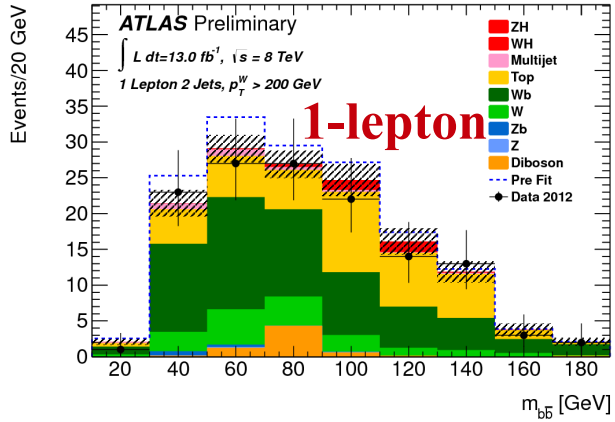


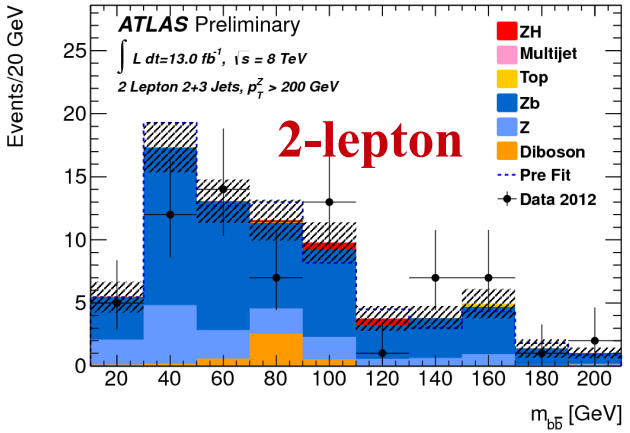




$p_T(V)$ > 200 GeV





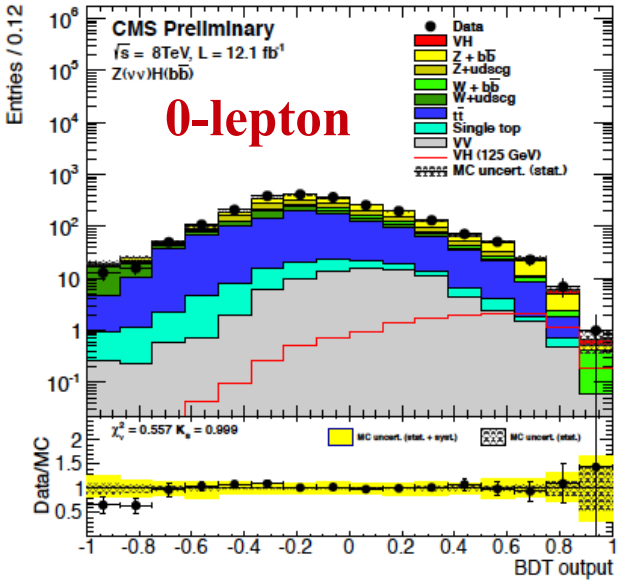


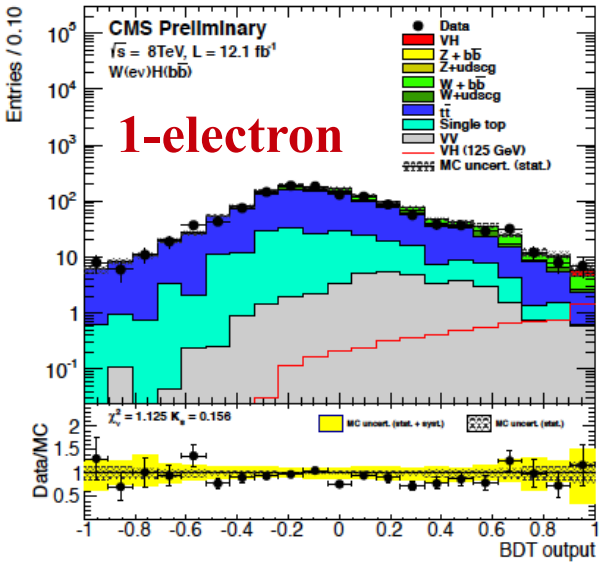
No significant excess is found.

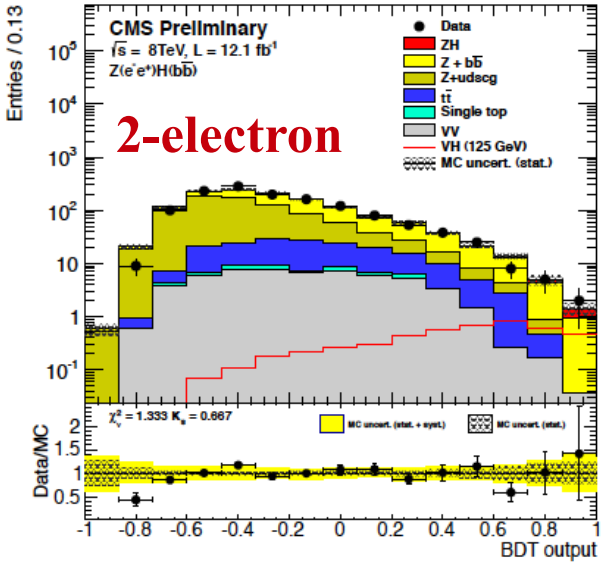
CMS VH BDT

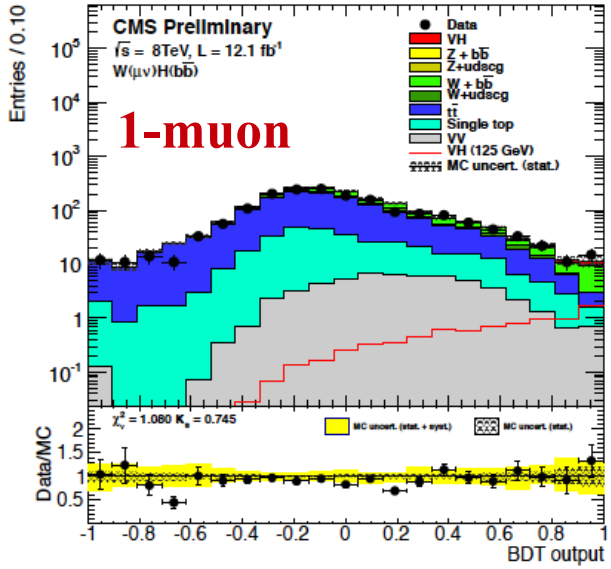
Showing only the highest p_T bin, with standard b-tagging

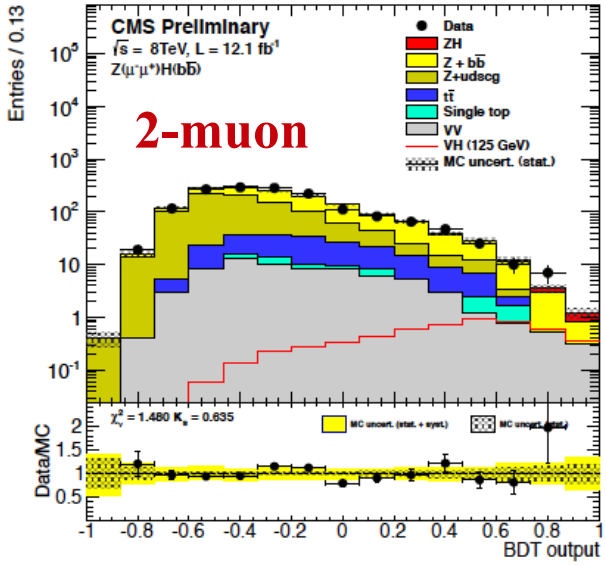
$p_T(V) > 170$ GeV









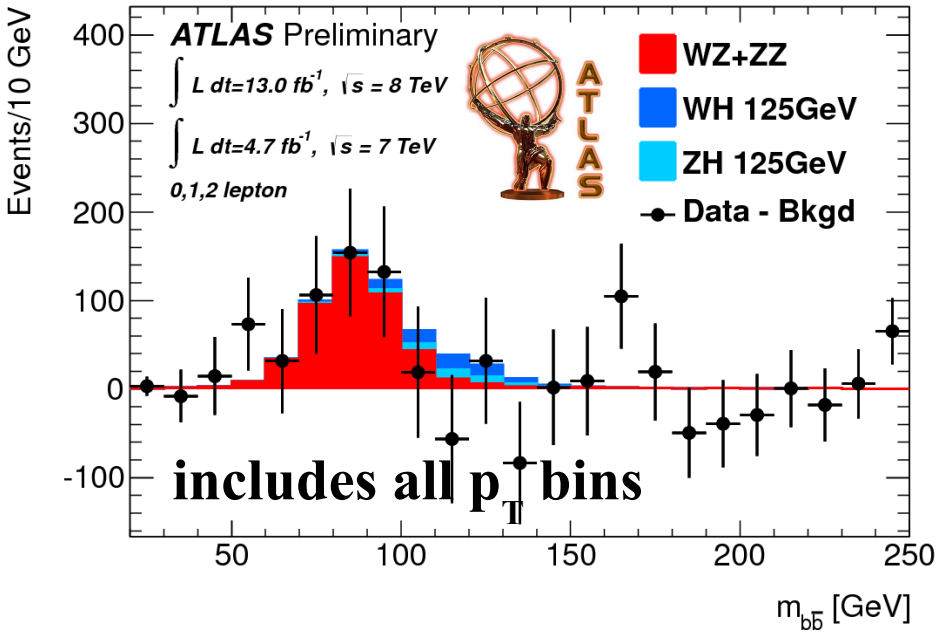


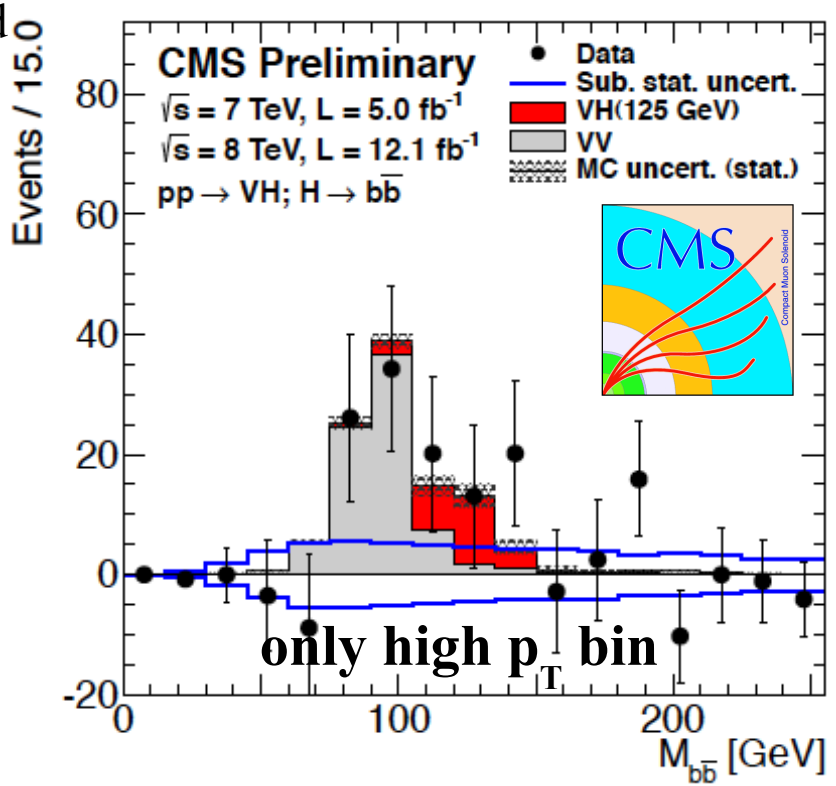
Small excess in all channels.

WZ/ZZ cross-check

- WZ, ZZ production, with Z→bb
  - Similar signature, cross-section 5x higher
  - Separate fit to validate the WH analysis
    - Individually for 0, 1, 2 lepton channels
    - All backgrounds except VH are subtracted

CMS: excess compatible with SM Higgs

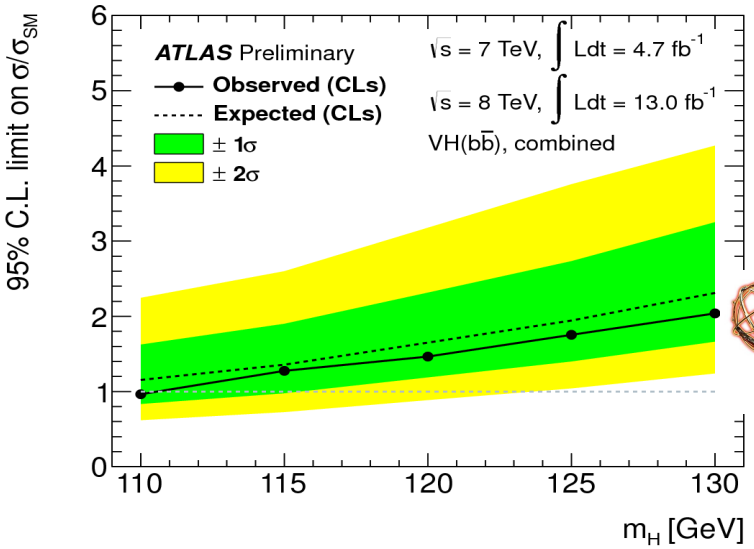


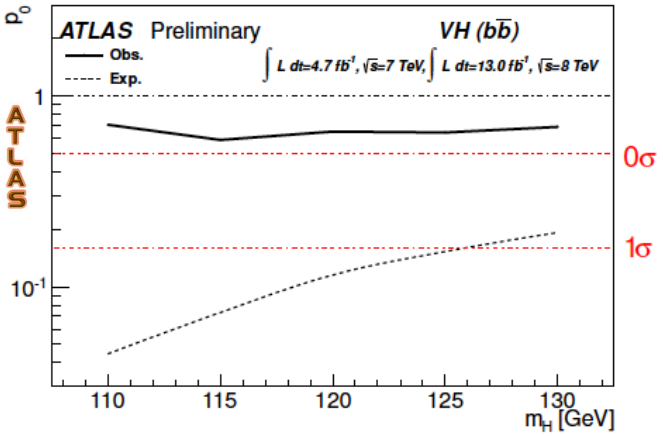


ATLAS:

$\sigma/\sigma_{SM} = \mu_D = 1.09 \pm 0.20\ (stat) \pm 0.22\ (syst)$. The significance is 4.0σ

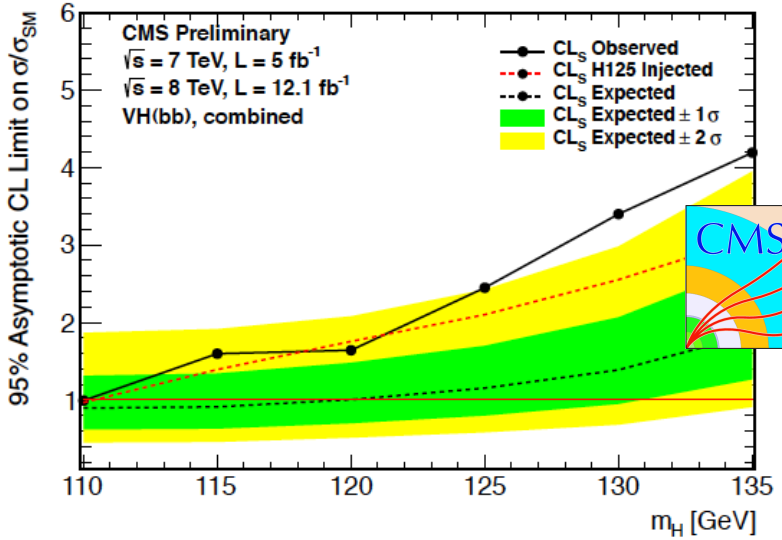
Results

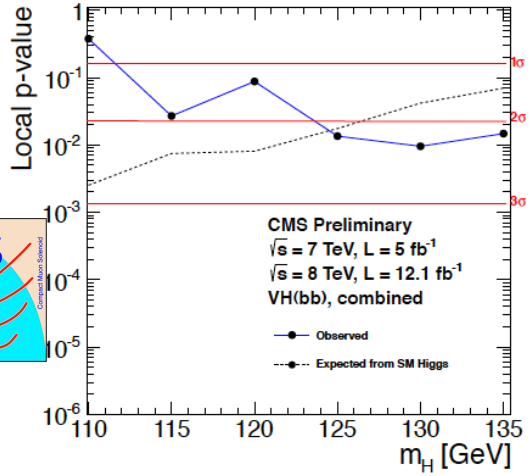


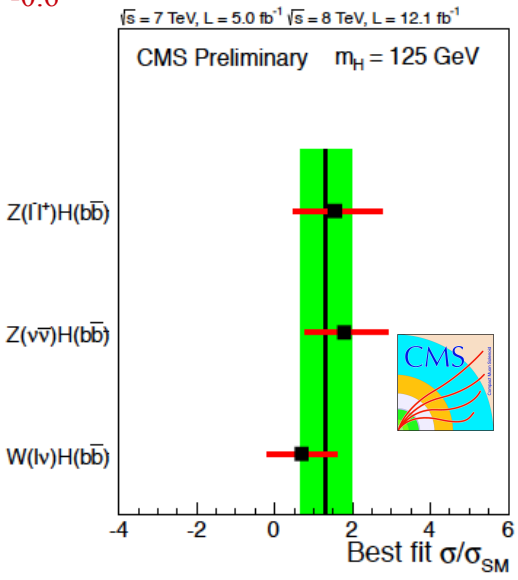


Obs. (exp.) limit @125 GeV: 1.8 (1.9) x σ(SM) $\mu = -0.4 \pm 0.7$ (stat.)± 0.8 (syst.)

Obs. (exp.) limit @125 GeV: 2.5 (1.2) x σ(SM) $\mu = 1.3^{+0.7}_{-0.6}$ 2.2σ (2.1σ) excess







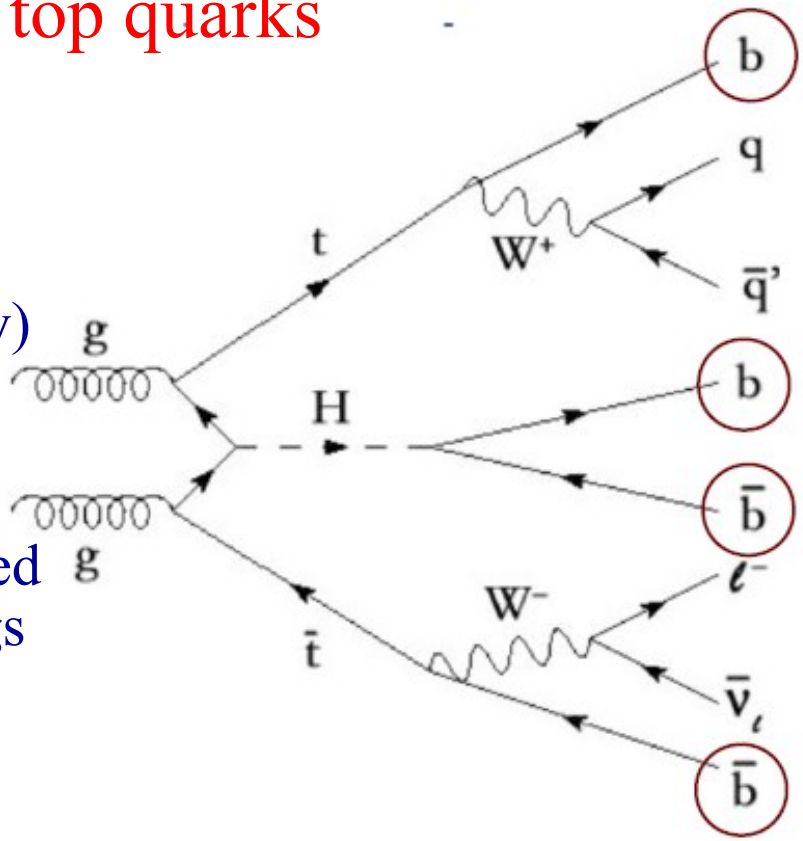
ttH, H→bb

	7 TeV	8 TeV	Reference
ATLAS	4.7 fb^{-1}		ATLAS-CONF-2012-135
CMS	5.0 fb^{-1}	5.1 fb^{-1}	CERN-PH-EP-2013-027

!Still not the full 8 TeV dataset! (~21 fb^{-1})

ttH Overview

- Associated production with two top quarks
  - Up to 4 b-tagged jets
  - Lepton (e or μ) + jets channel
    - 1 lepton + MET + up to 2 additional jets
  - Di-lepton (e or μ) channel (CMS only)
    - 2 leptons + MET + 0 additional jets
- Search strategy
  - Signal and background regions defined according to number of jets and b-tags
  - Backgrounds: tt+jets, combinatorial
  - ATLAS: decay into bb only
  - CMS: allow other decays
    - but contribution from H→bb in the most sensitive categories is 95%



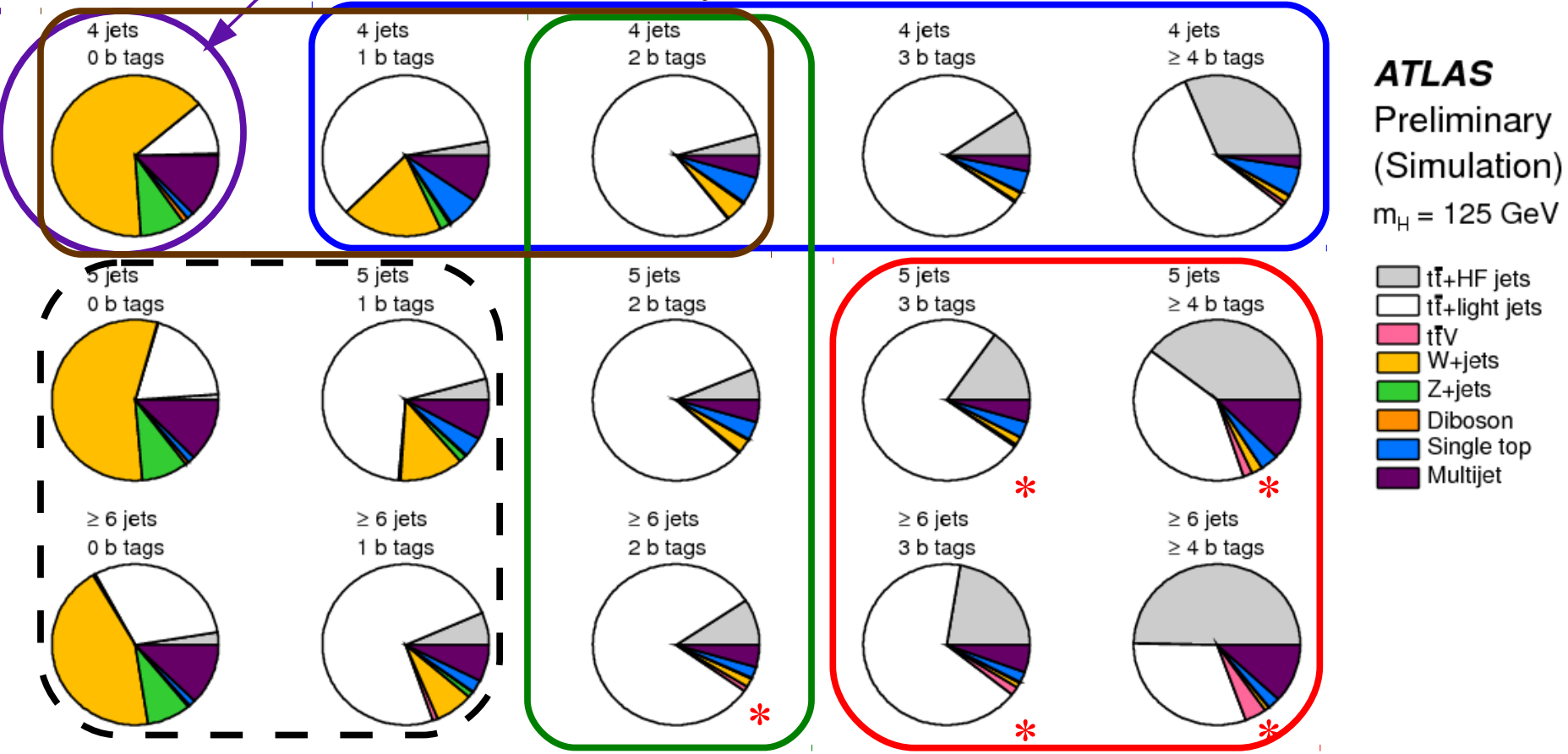
Directly probe strongest Yukawa coupling

ttH Backgrounds

constrain W+jets and multijets normalization

constrain b-tag efficiency

constrain tt normalization



cross-check regions

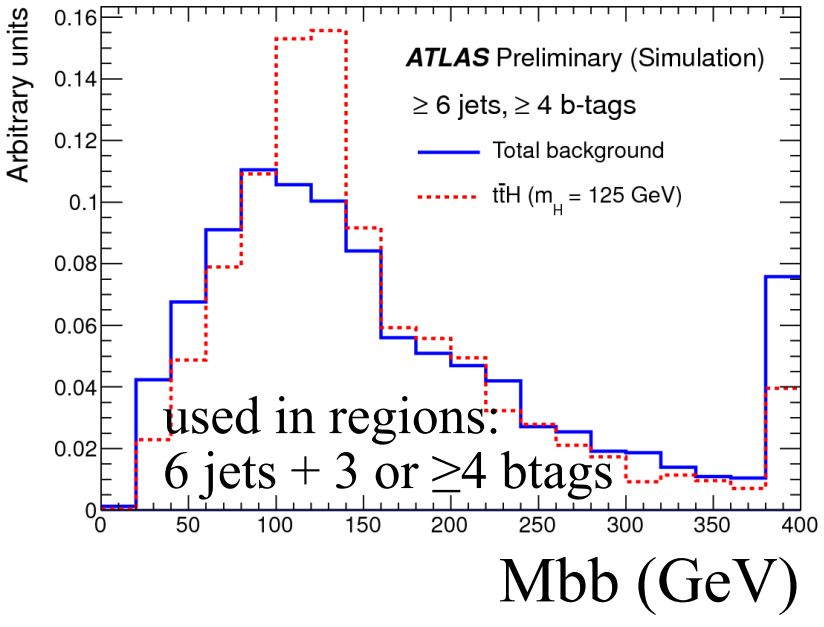
constrain tt modeling (HThad shape...)

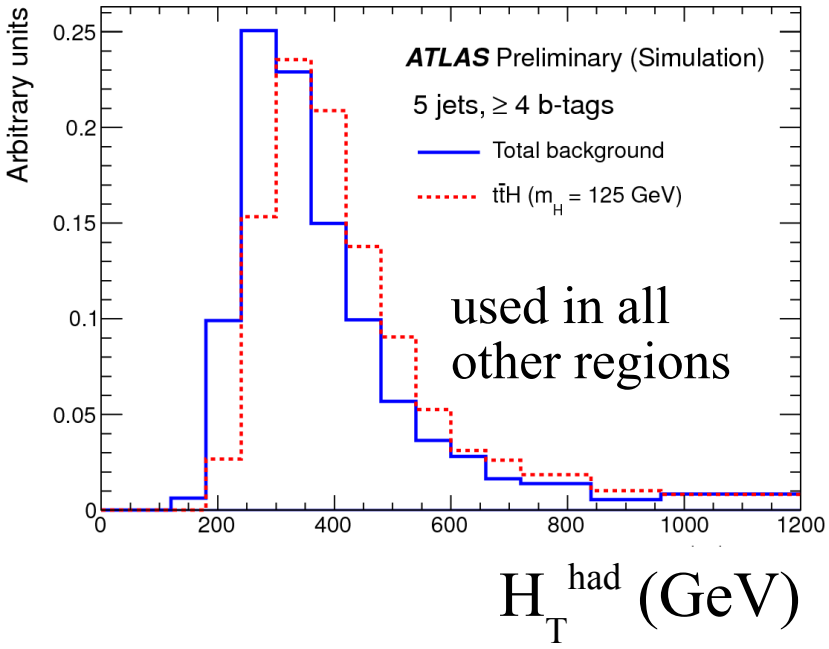
constrain tt+ heavy flavor

* S/√B> 5%

ttH analysis

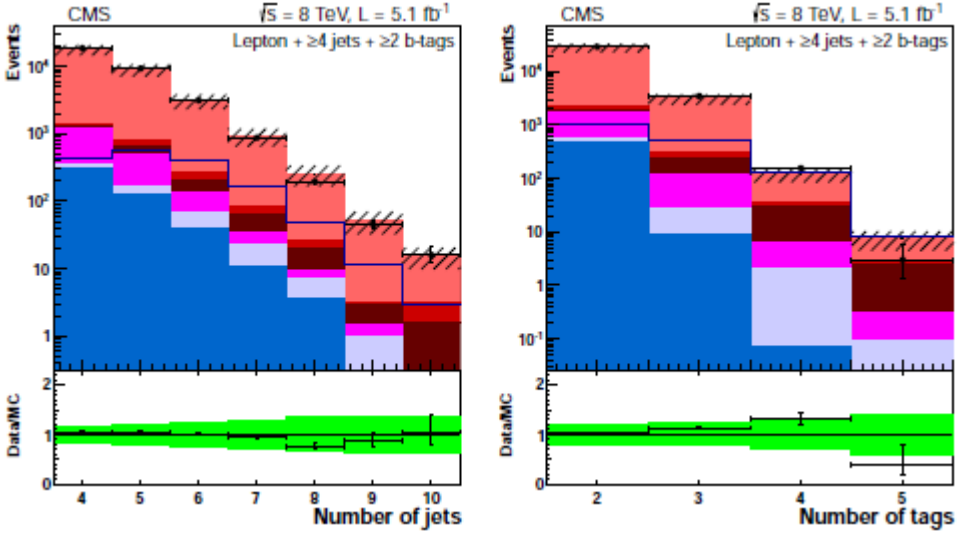
- Kinematic maximum likelihood fit
  - Find the most likely assignment of jets to build the 2 top masses
  - Remaining b-jets assigned to Higgs (26% prob. to assign correct b-jet pair, with 4 b-tags)

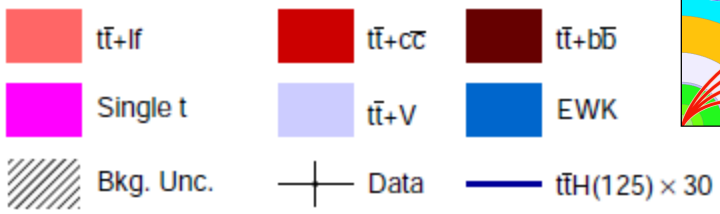




- Simultaneous fit to signal and background regions
  - Discriminating variables: Mbb and H_T^{had} (scalar sum of jets' pT)

ttH analysis

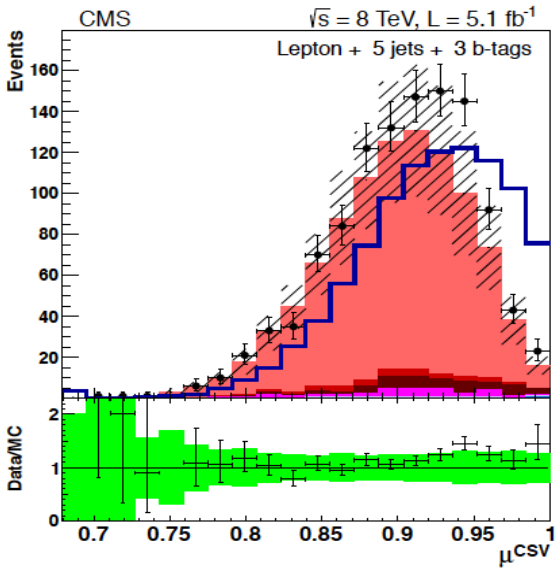


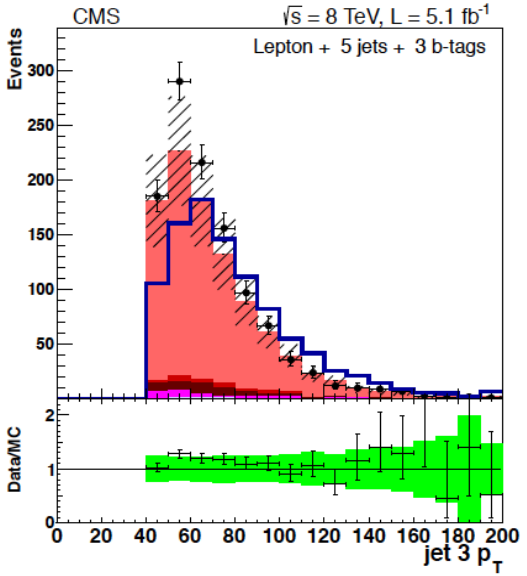


	Lepton+Jets							Dilepton	
Jets	≥6	4	5	≥6	4	5	≥6	2	≥3
Tags	2	3	3	3	4	≥4	≥4	2	≥3

9 signal regions

- Artificial Neural Network (ANN)
  - From 9 variables
    - CSV (b-tag), kinematics, etc...
  - Output is discriminant variable





Systematics

Systematic uncertainty	Status	Components
Luminosity	N	1
Lepton ID+reco+trigger	N	1
Jet vertex fraction efficiency	N	1
Jet energy scale	SN	16
Jet energy resolution	N	1
b-tagging efficiency	SN	9
c-tagging efficiency	SN	5
Light jet-tagging efficiency	SN	1
$t\bar{t}$ cross section	N	1
$t\bar{t}V$ cross section	N	1
Single top cross section	N	1
Dibosons cross section	N	1
V+jets normalisation	N	3
Multijet normalisation	N	7
W+heavy-flavour fractions	SN	4
$t\bar{t}$ modelling	SN	3
$t\bar{t}$+heavy-flavour fractions	SN	1
$t\bar{t}H$ modelling	N	1

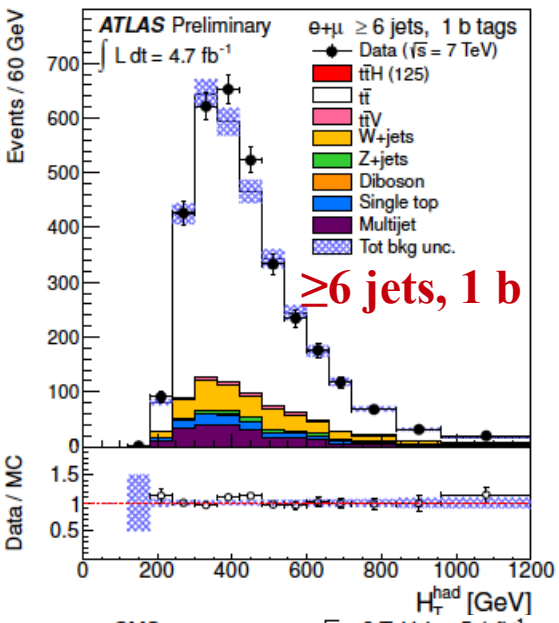
- ATLAS
  - Main source: tt + heavy flavor (50% unc.)
  - Breakdown in components for btag (9), ctag (5), jet energy scale (16), background normalization and modeling
    - avoid over-constraining nuisance parameters

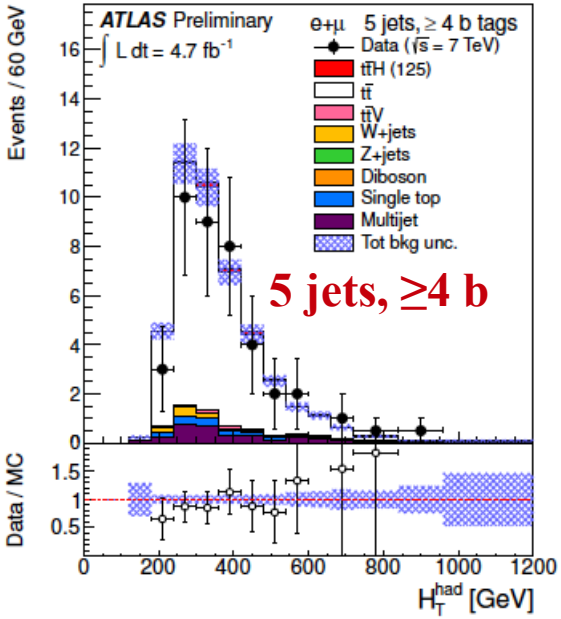
- CMS
  - no QCD uncertainty
    - tighter jet selection

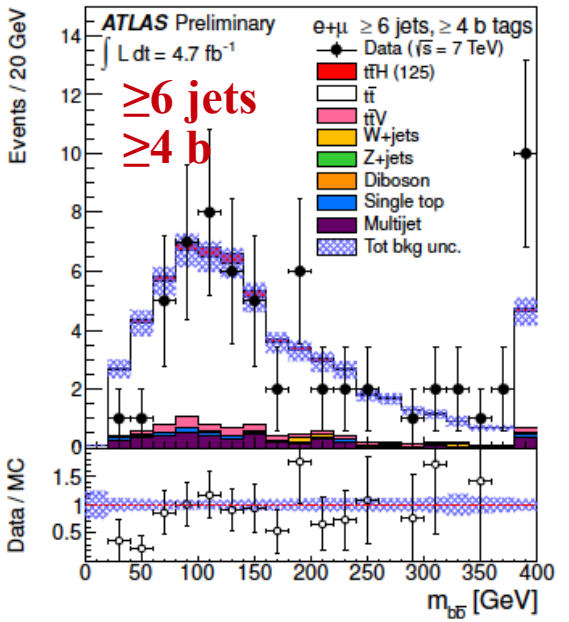
Source	Rate Uncertainty	Shape
Luminosity (7 TeV)	2.2%	No
Luminosity (8 TeV)	4.4%	No
Lepton ID/Trig	4%	No
Pileup	1%	No
Additional Pileup Corr.	–	Yes
Jet Energy Resolution	1.5%	No
Jet Energy Scale	0–60%	Yes
b-Tag SF (b/c)	0–33.6%	Yes
b-Tag SF (mistag)	0–23.5%	Yes
MC Statistics	–	Yes
PDF (gg)	9%	No
PDF ($q\bar{q}$)	4.2–7%	No
PDF (qg)	4.6%	No
QCD Scale ($t\bar{t}H$)	15%	No
QCD Scale ($t\bar{t}$)	2–12%	No
QCD Scale (V)	1.2–1.3%	No
QCD Scale (VV)	3.5%	No
Madgraph Scale ($t\bar{t}$)	0–20%	Yes
Madgraph Scale (V)	20–60%	No
$t\bar{t} + b\bar{b}$	50%	No

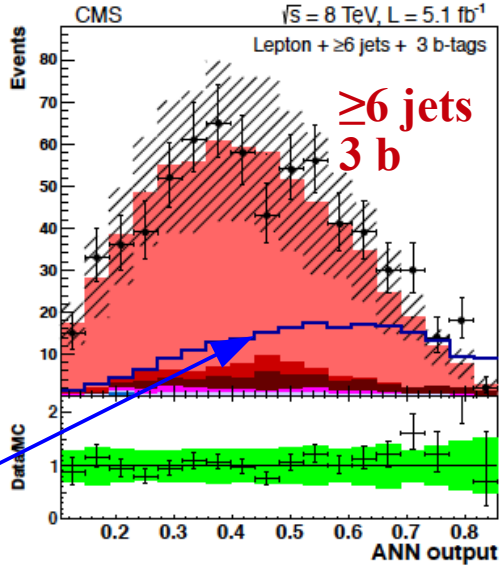
ttH Results

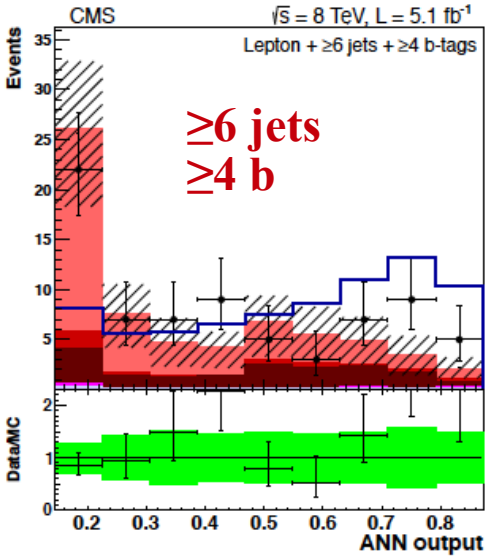
ttH results

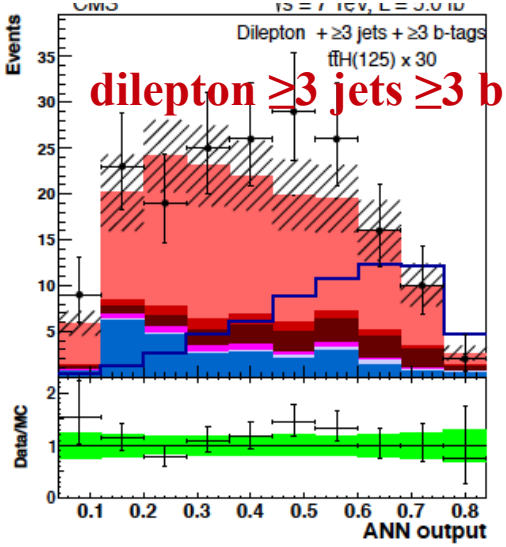






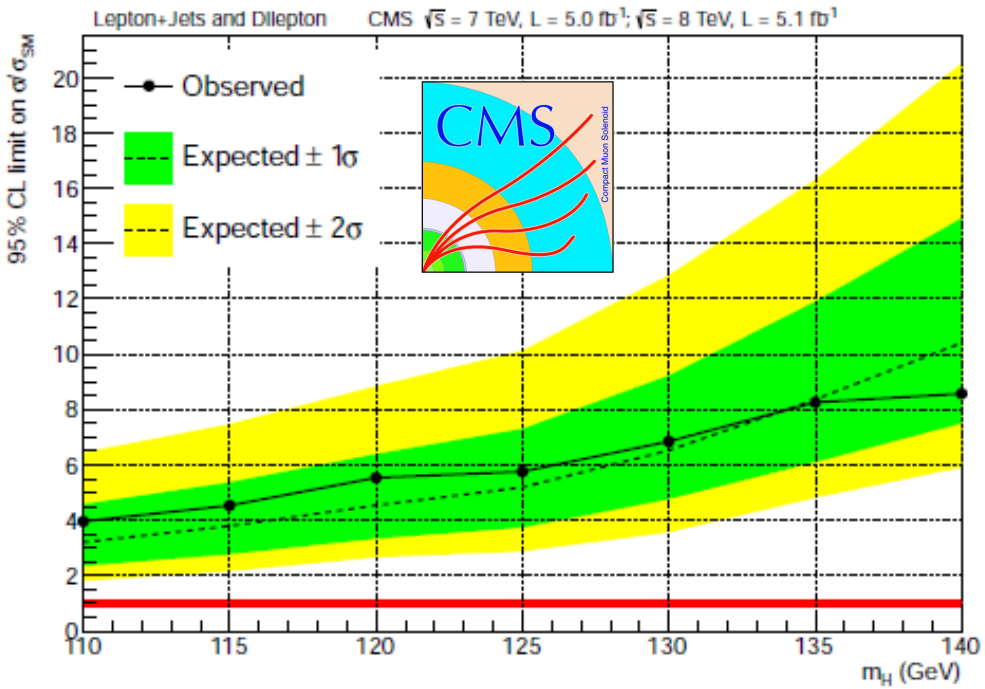






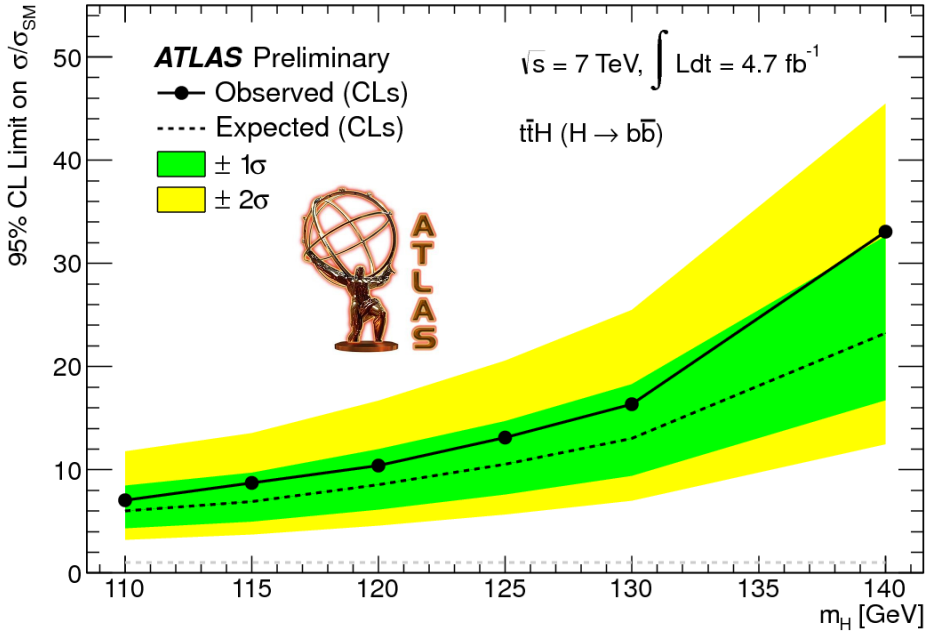
signal x30

ttH limits



Limit on ttH production
Observed (expected) limit on $\sigma(ttH)$ is 5.8 (5.2) x σ_{SM}.

Limit on ttH production x Hbb decay
Observed (expected) limit on $\sigma(ttH)\times BR(H \rightarrow bb)$ is 13.1 (10.5) x σ_{SM}.



Conclusions

- ATLAS & CMS searches for Hbb
  - Diboson WZ/ZZ: observed peak with 4σ significance
  - VH: sensitivity @125 GeV close to SM. CMS sees 2.2σ excess
  - ttH: sensitivity @125 GeV 5x SM, setting limits.
- Results with increased significance expected soon
  - None of the Hbb analysis has used the full 2012 dataset yet
  - ATLAS & CMS working on analysis improvements

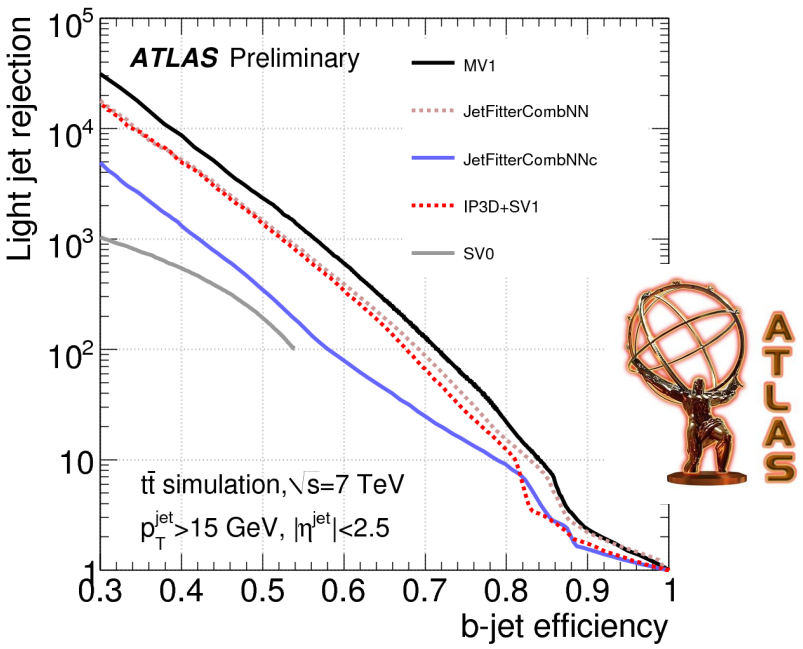
Acknowledgments

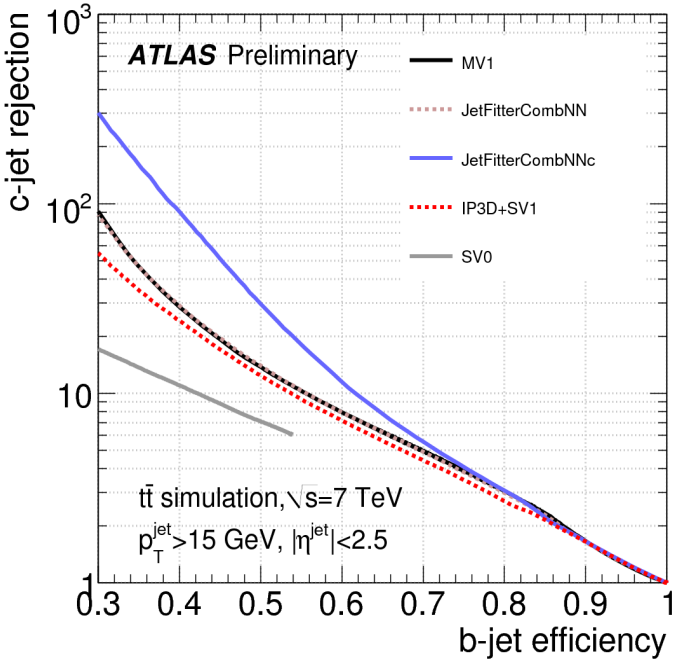
Acknowledgments: Portuguese participation in ATLAS funded by FCT project CERN/FP/123595/2011

Extra slides

B-jet tagging

ATLAS-CONF-2012-043
ATLAS-CONF-2012-161
CMS PAS HIG-12-044

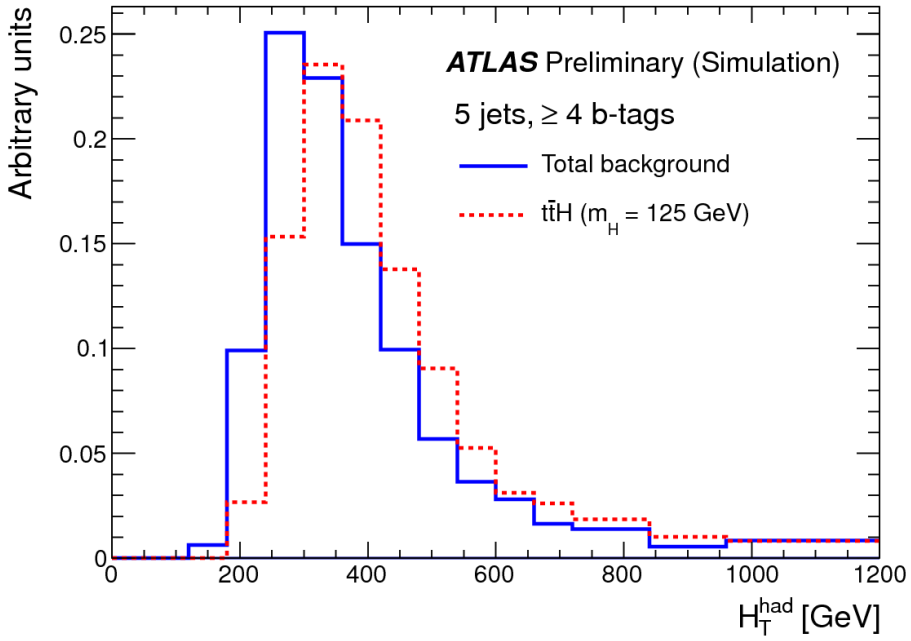




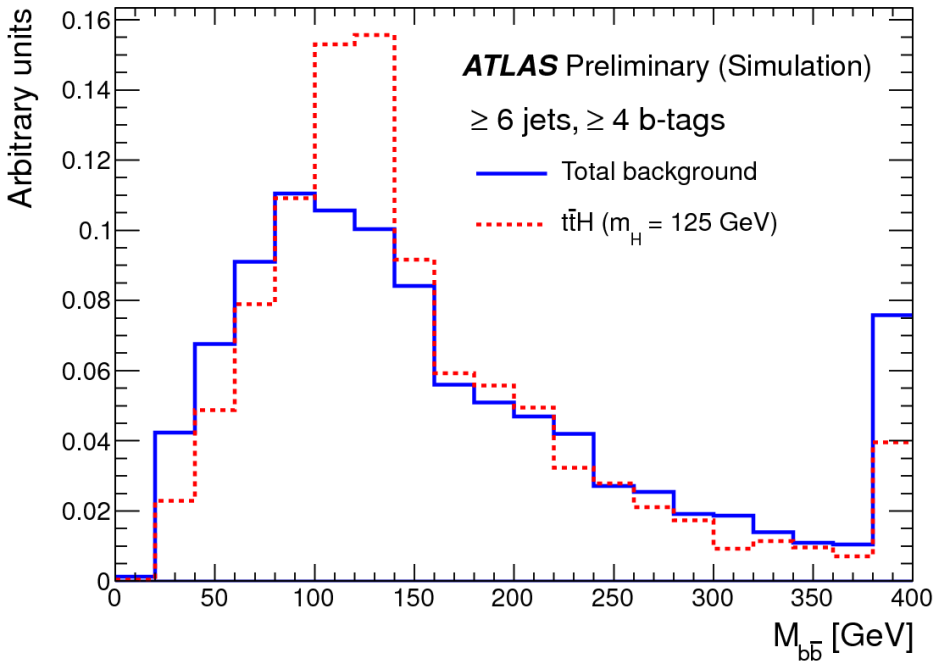
ATLAS VH event yields

	0-lepton, 2 jet			0-lepton, 3 jet			1-lepton					2-lepton				
Bin	$E_{\mathrm{T}}^{\mathrm{miss}}$ [GeV]						p_{T}^{W} [GeV]					p_{T}^{Z} [GeV]				
	120-160	160-200	>200	120-160	160-200	>200	0-50	50-100	100-150	150-200	> 200	0-50	50-100	100-150	150-200	>200
ZH	2.9	2.1	2.6	0.8	0.8	1.1	0.3	0.4	0.1	0.0	0.0	4.7	6.8	4.0	1.5	1.4
WH	0.8	0.4	0.4	0.2	0.2	0.2	10.6	12.9	7.5	3.6	3.6	0.0	0.0	0.0	0.0	0.0
Top	89	25	8	92	25	10	1440	2276	1120	147	43	230	310	84	3	0
$W + c$,light	30	10	5	9	3	2	580	585	209	36	17	0	0	0	0	0
$W + b$	35	13	13	8	3	2	770	778	288	77	64	0	0	0	0	0
$Z + c$,light	35	14	14	8	5	8	17	17	4	1	0	201	230	91	12	15
$Z + b$	144	51	43	41	22	16	50	63	13	5	1	1010	1180	469	75	51
Diboson	23	11	10	4	4	3	53	59	23	13	7	37	39	16	6	4
Multijet	3	1	1	1	1	0	890	522	68	14	3	12	3	0	0	0
Total Bkg.	361	127	98	164	63	42	3810	4310	1730	297	138	1500	1770	665	97	72
	± 29	± 11	± 12	± 13	± 8	± 5	± 150	± 86	± 90	± 27	± 14	± 90	± 110	± 47	± 12	± 12
Data	342	131	90	175	65	32	3821	4301	1697	297	132	1485	1773	657	100	69

ttH signal variables



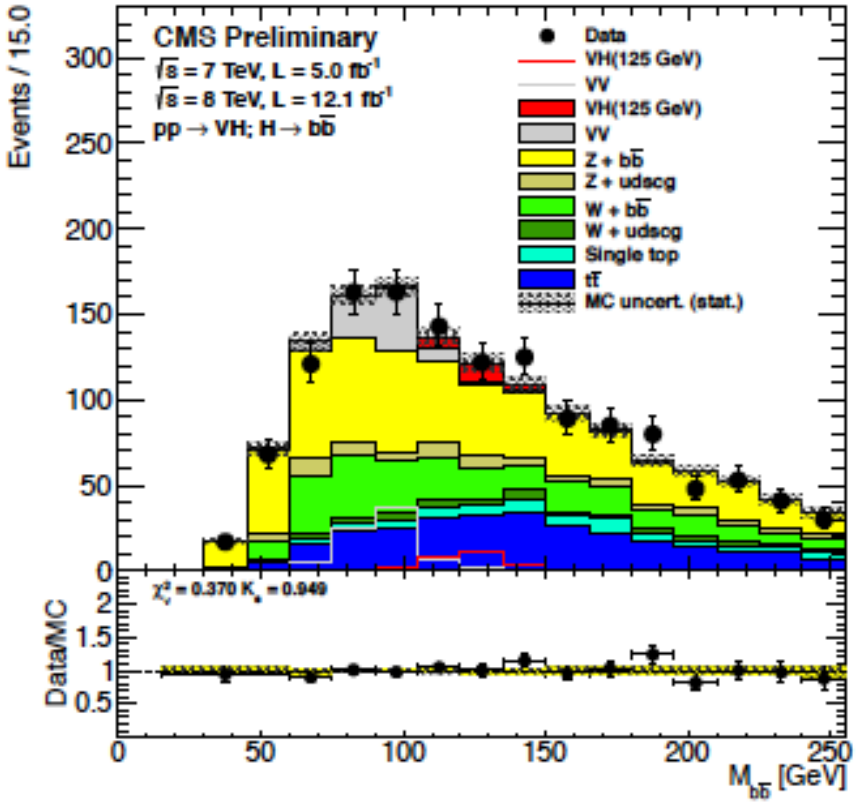
scalar sum of jets pT

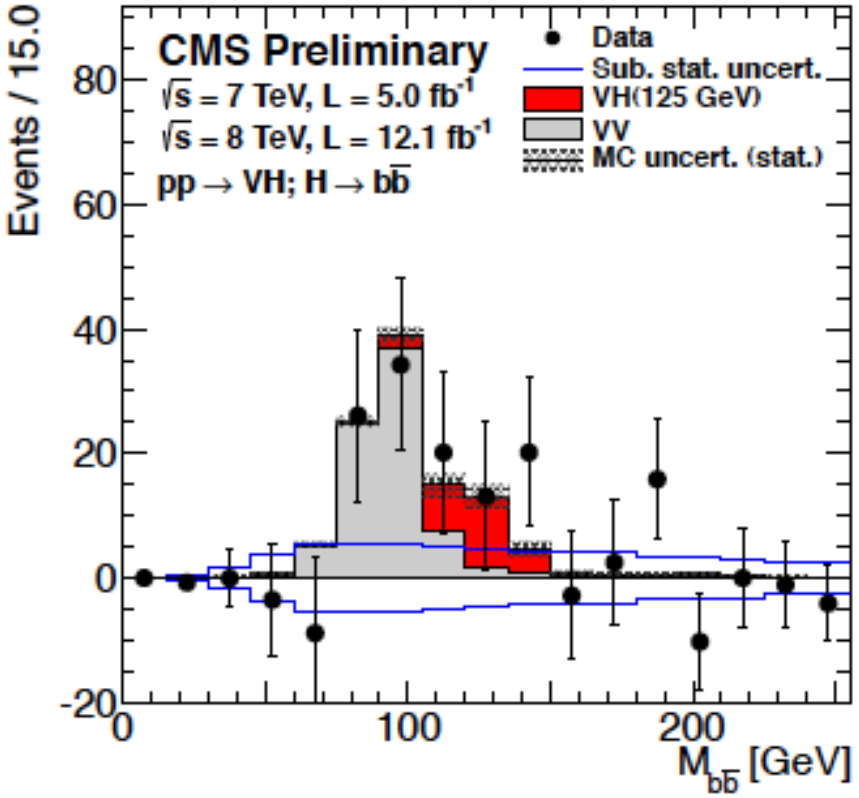


QCD data-driven details

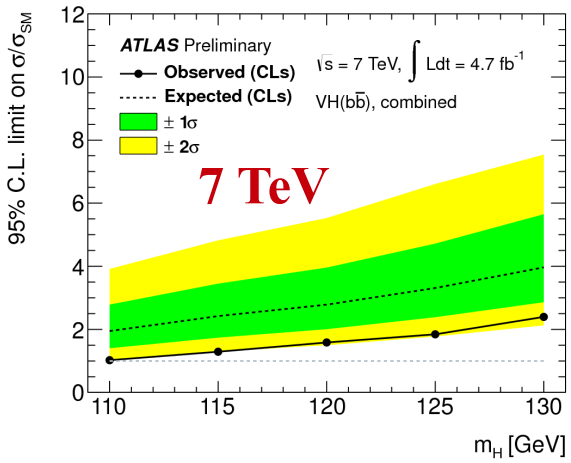
- Di-Boson:
  Shape and normalisation from MC
- QCD Multi-jet: Data driven methods
  - 0 lepton: ABCD method using
    $Min[\Delta\Phi(E_T^{miss}, jets)]$ and $\Delta\Phi(E_T^{miss}, p_T^{miss})$
  - 1 lepton: inversion of lepton isolation and template fits to missing E_T
  - 2 lepton: loosen lepton ID, inversion of lepton isolation: fit to m_{ll}
- Other backgrounds:
  Shape from MC,
  normalisation from fits in control regions

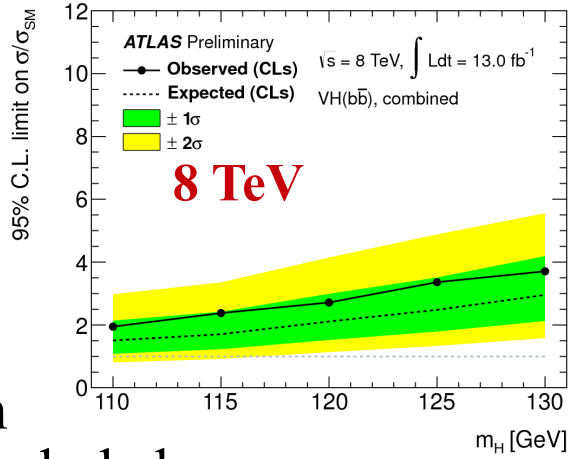
CMS Mbb cross-check

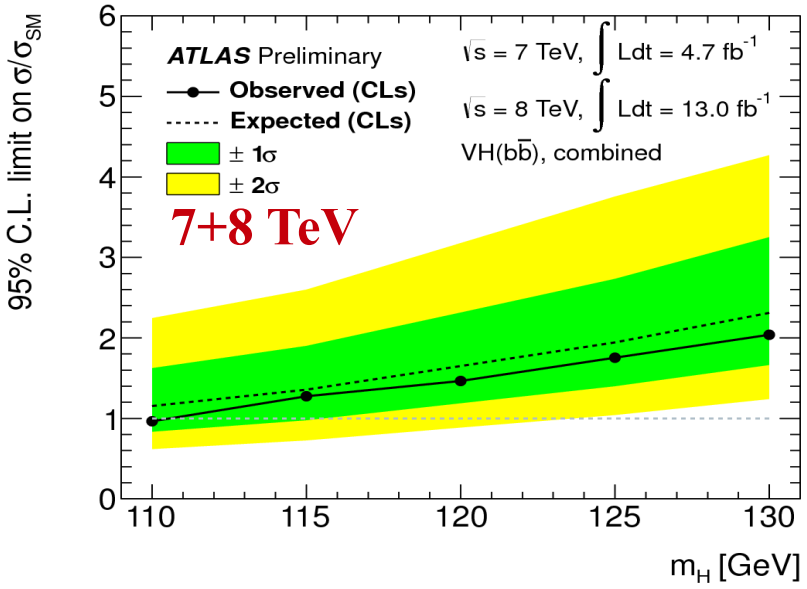




VH ATLAS Limits



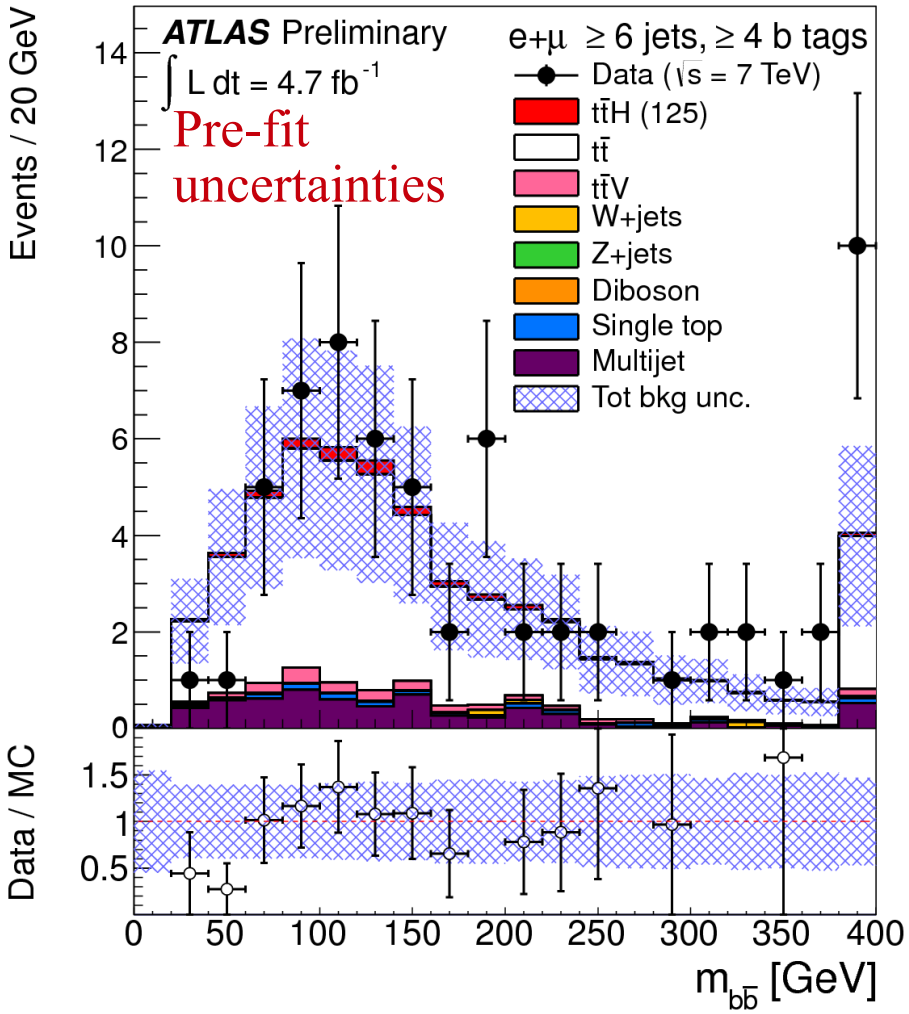


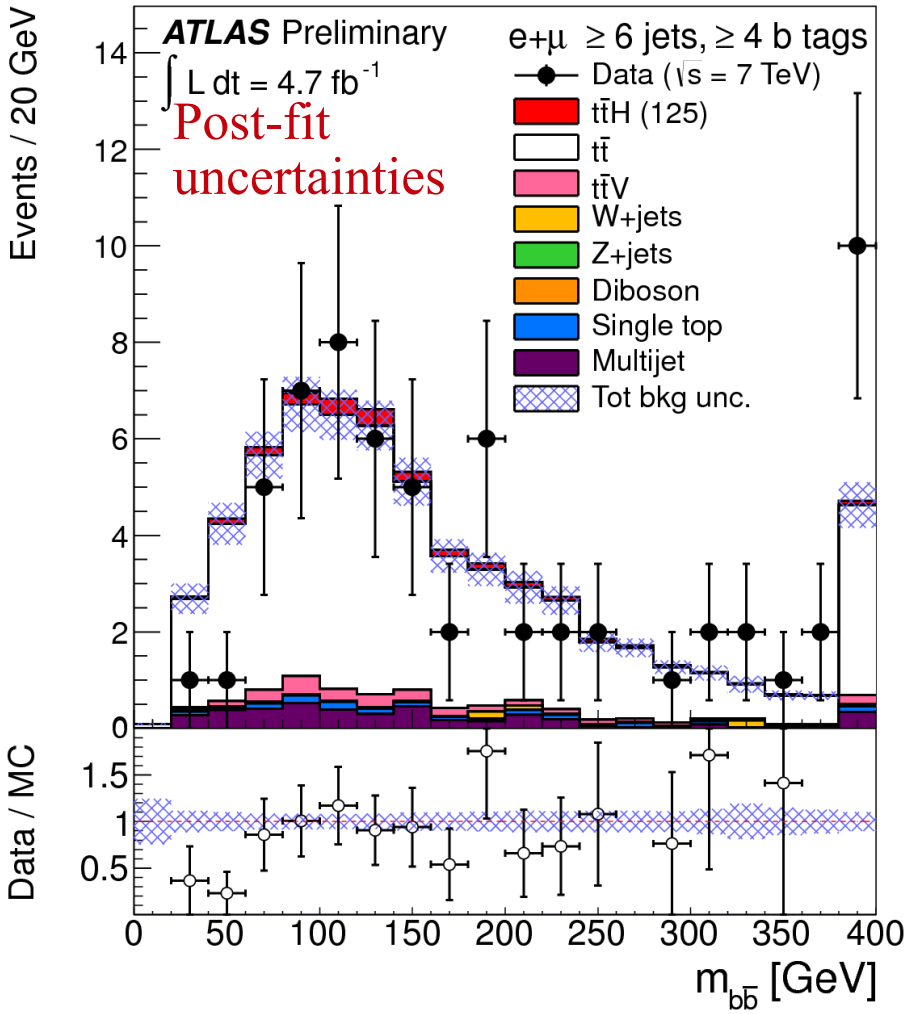


SM Higgs boson with 110 GeV excluded.

m_H = 125 GeV	7 TeV	8 TeV	7 TeV + 8 TeV
Expected CL_s limit	3.3	2.5	1.9
Obs. CL_s limit	1.8	3.4	1.8
μ (σ/σ_{SM})	-2.7 ± 1.1 ± 1.1	1.0 ± 0.9 ± 1.1	-0.4 ± 0.7 (stat.) ± 0.8 (syst.)

ttH comparison pre/post fit





No significant excess found.