Higgs Boson Searches in the $H \rightarrow bb$ channels in ATLAS

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Royal Holloway
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New Worlds in Particle and Astroparticle Physics

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The story so far… we found a Higgs-like boson! ☺

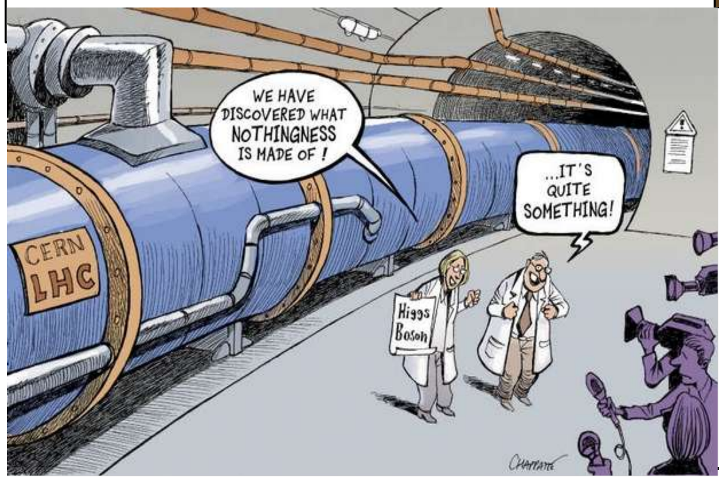
EUROPEAN ORGANISATION FOR NUCLEAR RESEARCH (CERN)

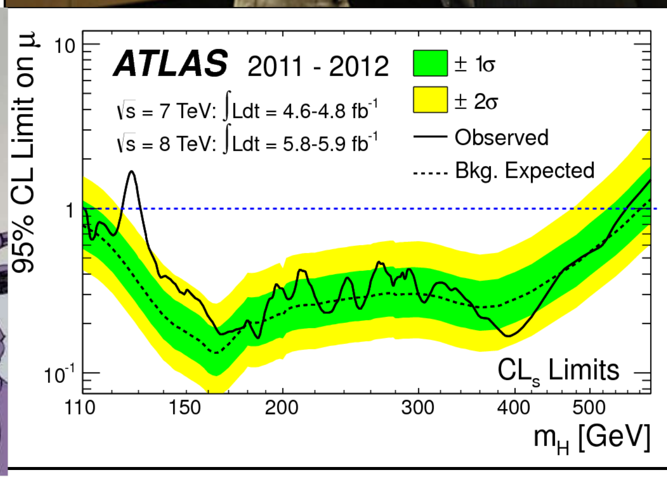
ATLAS

CERN-PH-EP-2012-218

Accepted by: Physics Letters B

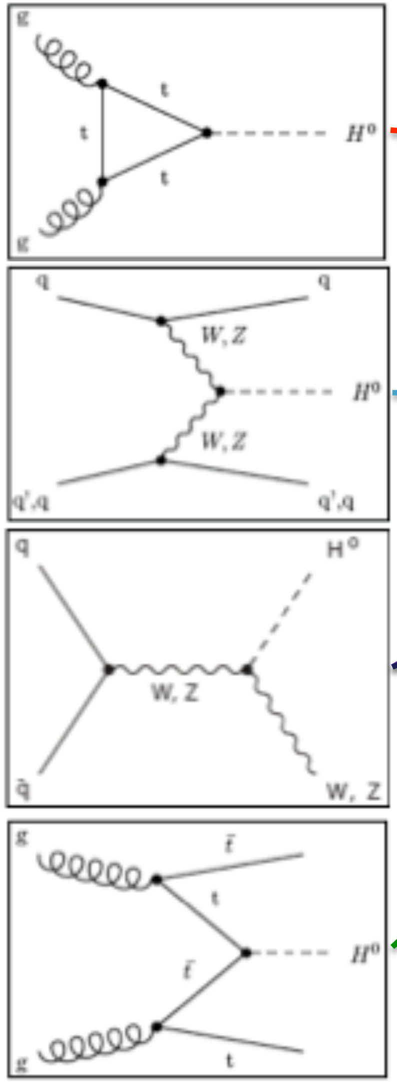
Observation of a New Particle in the Search for the Standard Model Higgs Boson with the ATLAS Detector at the LHC

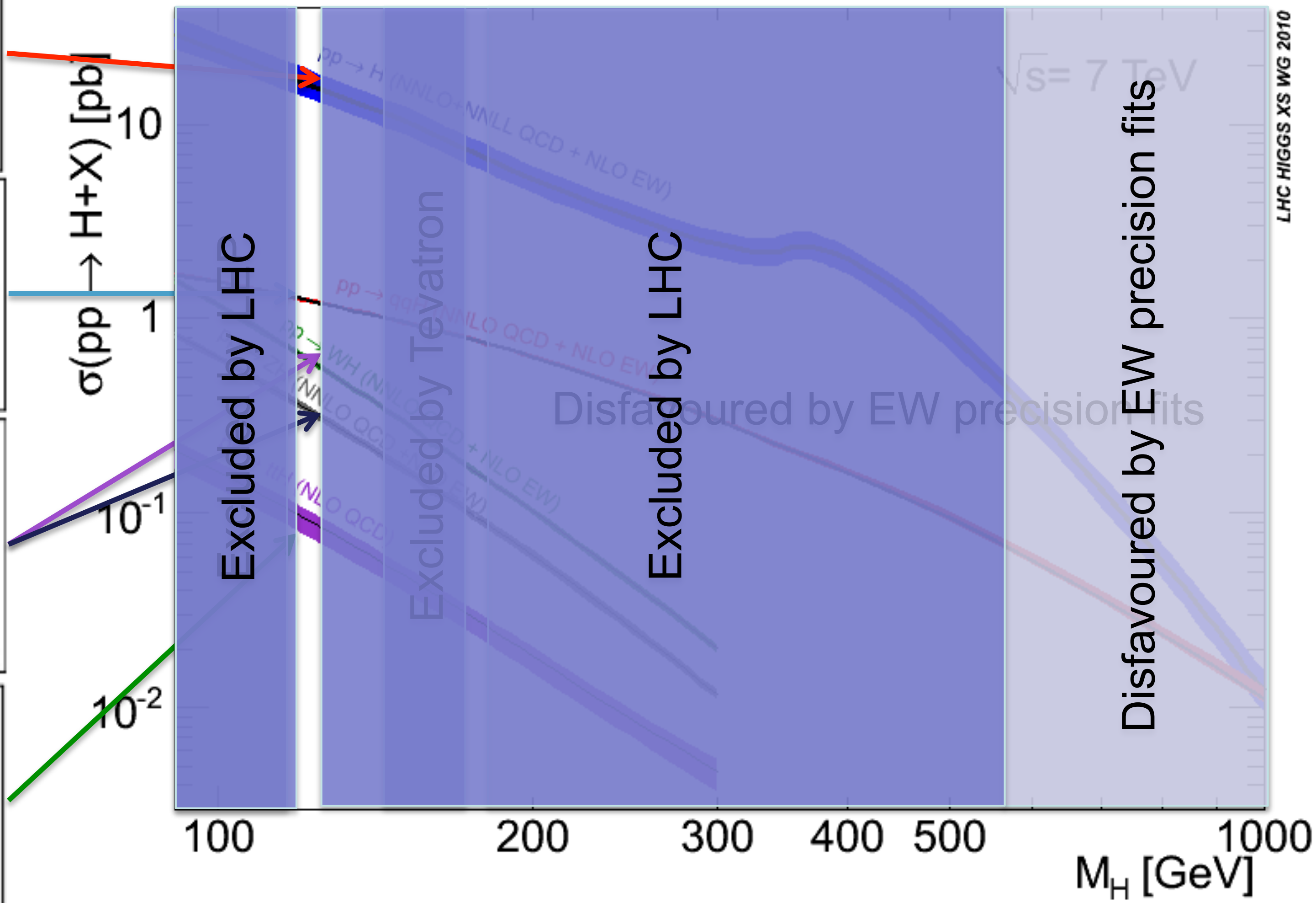




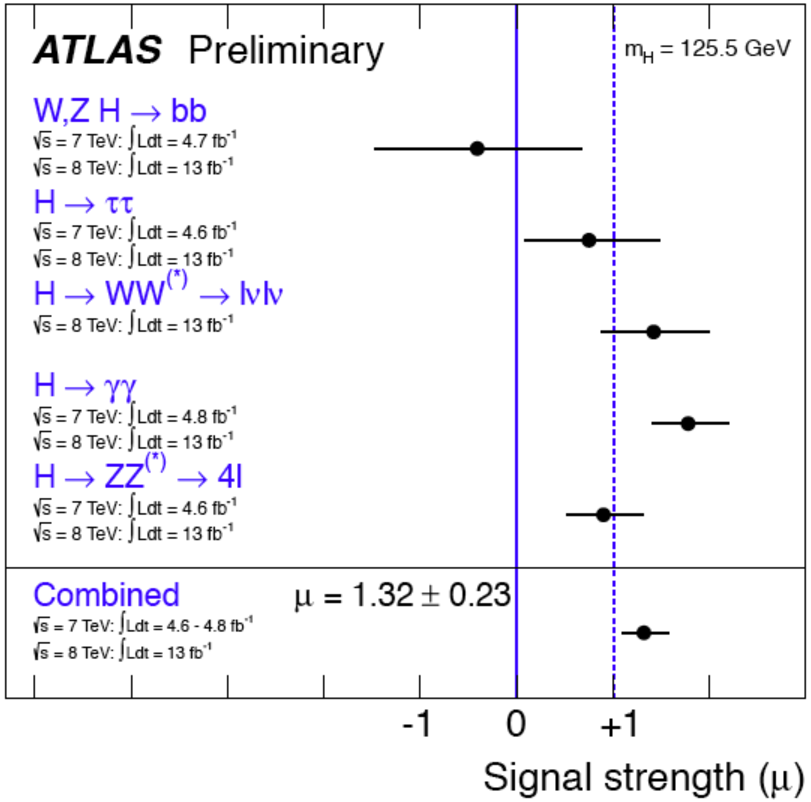
6 months ago: ICHEP 2012

CERN-2011-002; arXiv:1101.0593





- 5σ – discovery! Announced on 4th of July independently by ATLAS and CMS!!
  - Now up to ≈7σ … **no doubts left!!**
- Clear excess only in bosonic decay channels: esp. H→ZZ, H→γγ, but also H→WW
- Hints of H→ττ from LHC; 3σ evidence from Tevatron for H→bb and hints from CMS
- Data analysed:
  4.8 fb^{-1} @7TeV & 13 fb^{-1} @8TeV
  Another ≈10 fb^{-1} waiting to be analysed! ☺



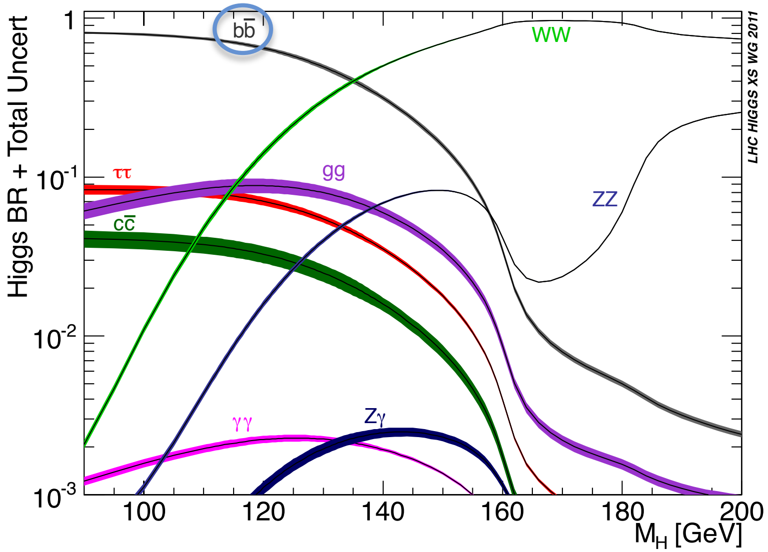
The 6 billion Swiss Franc question (Plus M&O…):

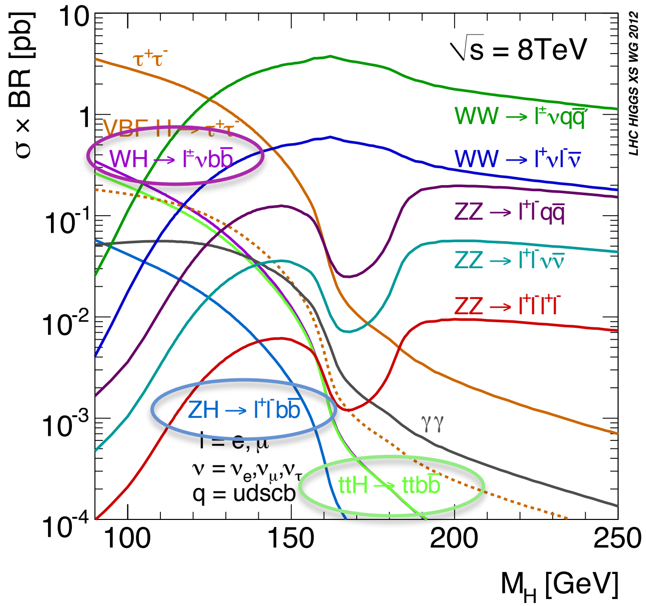
Is this THE Standard Model Higgs?...
Or something **even more interesting**?

SM Higgs search is a great way to search for new physics!

See e.g. talks by Andre David and Patricia Conde-Muiño yesterday

Why H→bb ?





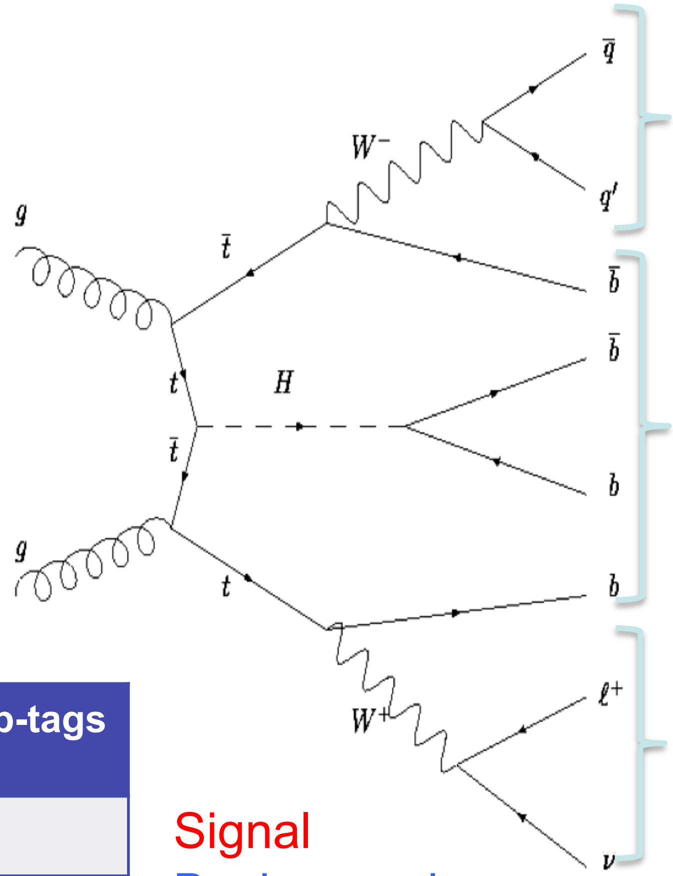
- H → bb is essential to answer this new big question!
  - Direct sensitivity to Higgs couplings to fermions
  - Largest SM Higgs BR (58% at ≈125GeV) – help constrain total width
  - Measure top Yukawa coupling directly – largest in SM
  - Challenging backgrounds: use associated production with W, Z, tt
- This talk: VH results from 7 and 8 TeV and ttH for 7TeV

ttH analysis of 7 TeV data

ttH, H→bb Analysis

- Challenging analysis!
  - High combinatorial background
  - Small signal cross section
- Data: 4.7fb^{-1} at $\sqrt{s}$ = 7 TeV (2011)
  - ATLAS-CONF-2012-135: https://cdsweb.cern.ch/record/1478423
- 9 categories based on jet & b-tag multiplicity
  - Signal enriched: (5 jets, ≥6 jets) x (3,≥4 b-tag)
  - Other categories are background enriched to constrain those backgrounds
- Final discriminants
  - m_{bb} for ≥6 jets and (≥3 b-tag) categories
    - Do kinematic fit to reconstruct tt+H→bb
  - H_T^{had} ($\sum p_{T,jet}$) for other categories

- Backgrounds constrained in limits fit by profiling nuisance parameters
- To check fit control regions are used



2 light jets (mostly)

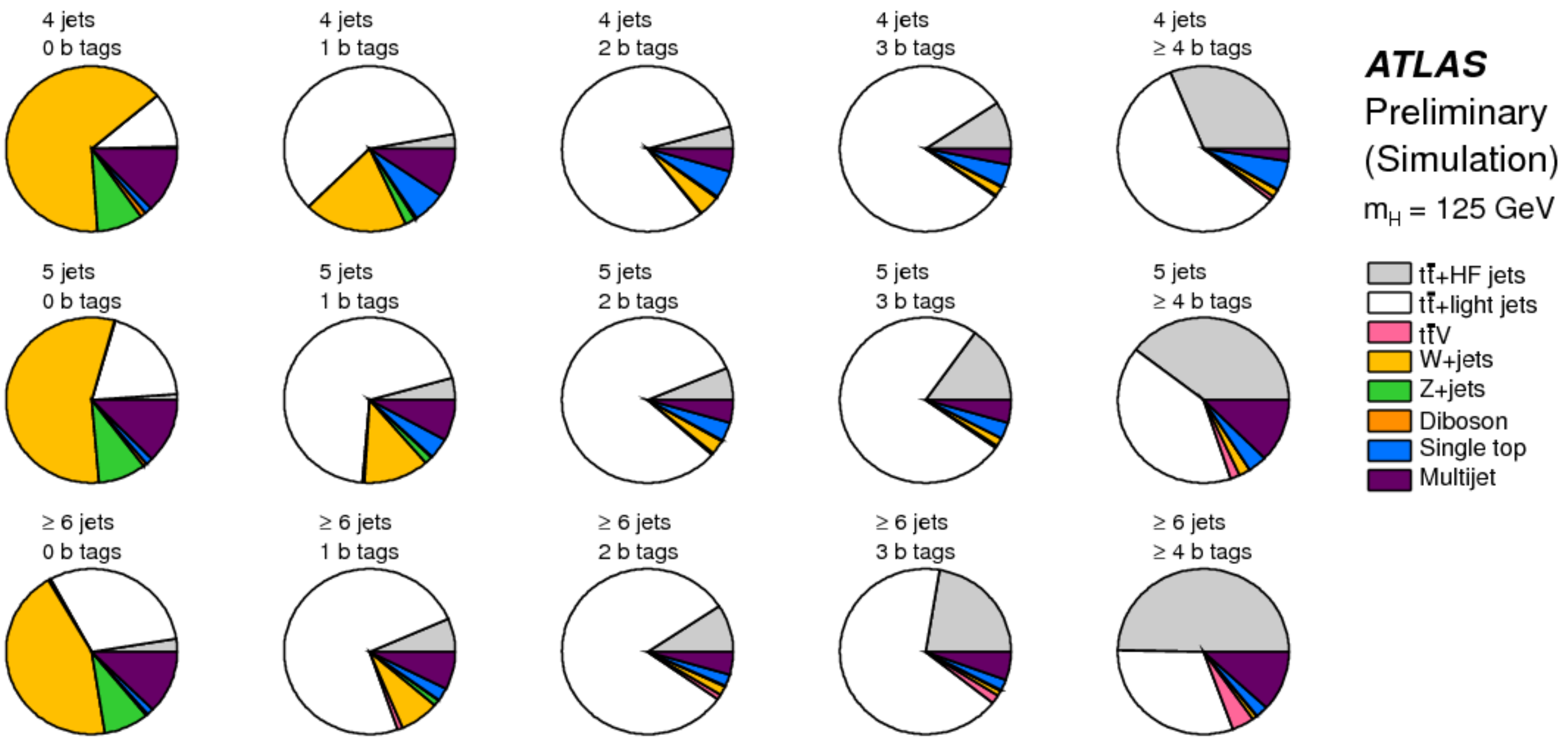
Up to 4 b-tags

e or μ, E_T^{miss}, M_T^W

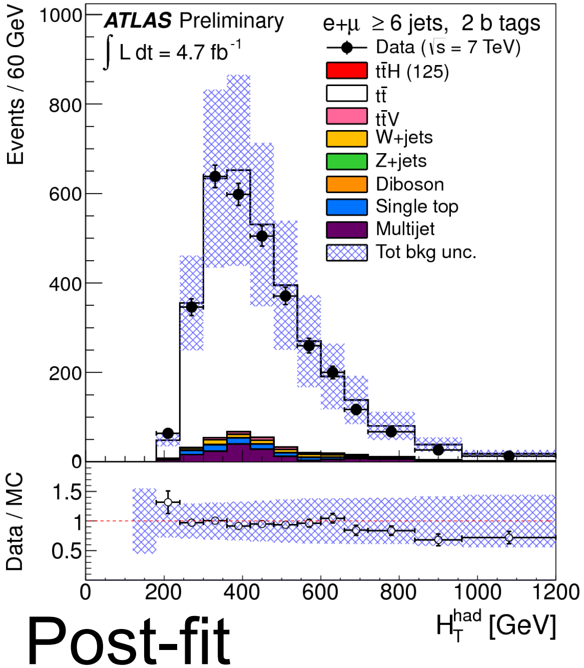
	0 b-tags	1 b-tag	2 b-tags	3 b-tags	≥4 b-tags
4 jets	H_T^{had}	H_T^{had}	H_T^{had}		
5 jets	H_T^{had}	H_T^{had}	H_T^{had}	H_T^{had}	H_T^{had}
≥6 jets	H_T^{had}	H_T^{had}	H_T^{had}	m_{bb}	m_{bb}

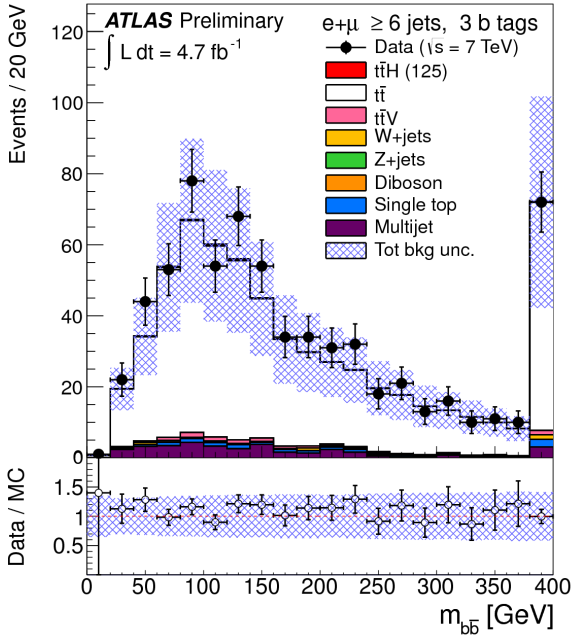
Signal
Background
Control regions

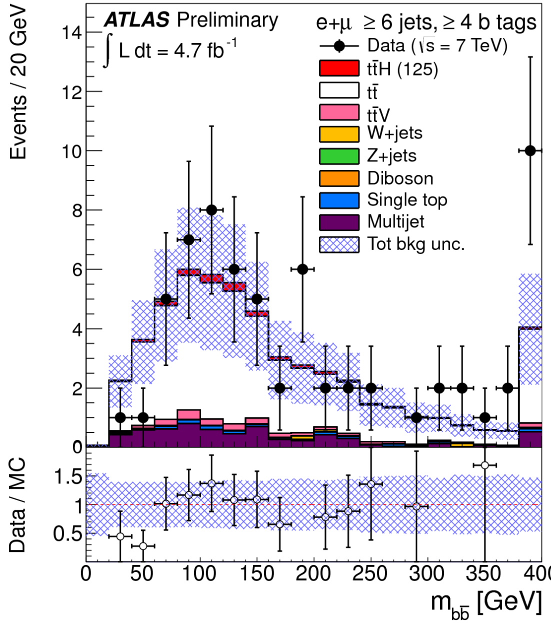
ttH, H→bb Analysis



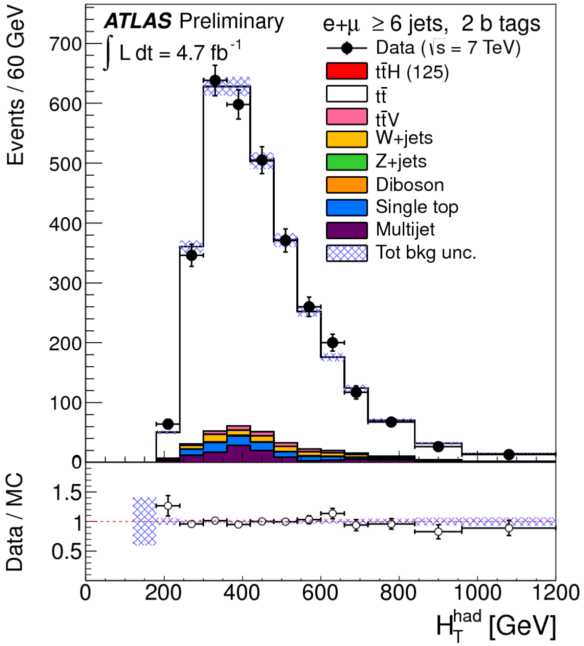
Pre-fit

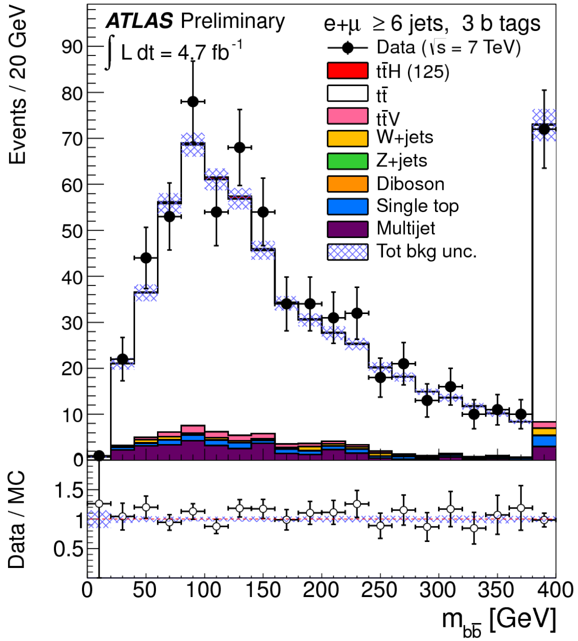


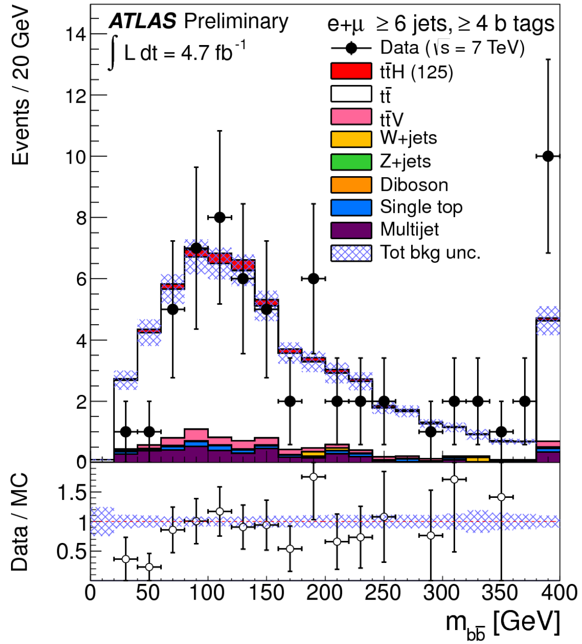




Post-fit







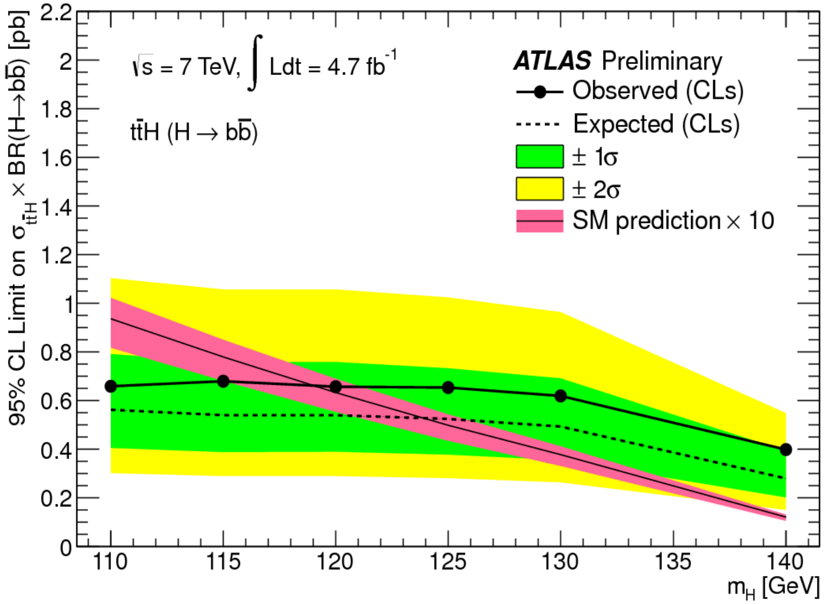
ttH Systematic Uncertainties

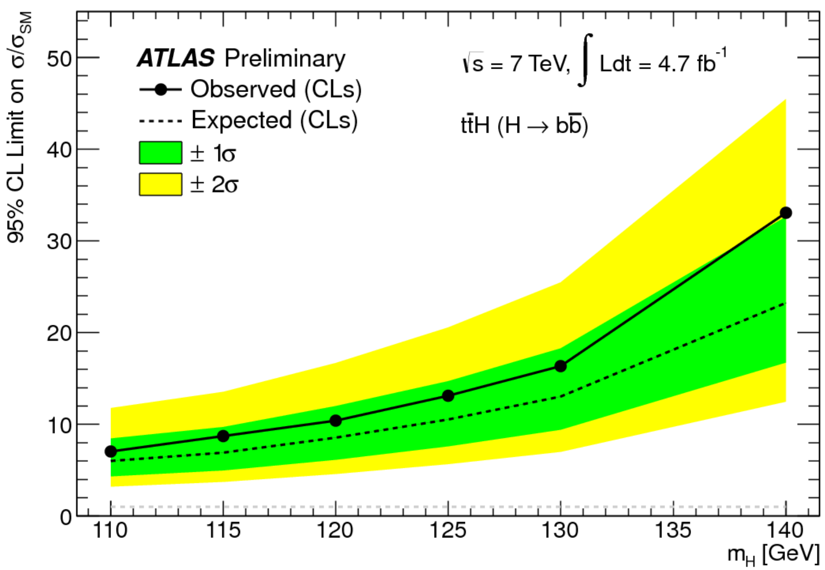
- **tt+heavy-flavour** fractions: vary by 50% - theory studies suggest cross section uncertainty is 50-75% ; should be weighted down by the fraction of this background. Fit puts it at 30%.

- **tt modeling** (Alpgen):
  - **Qfac**: (±2.3%) The factorization scale for the hard scatter is varied by a factor of two up and down relative to the original scale, $Q^2 = \Sigma_{partons} m^2 + p^2_T$
  - **kTfac**: (±9.2%) The renormalisation scale associated with the evaluation of α_s at each local vertex in the matrix element calculation is varied by a factor of two up and down relative to the original scale, k_T , between two partons.
  - Functional form of the factorization scale (**iqopt2**): (± 13%) Default choice (=1) for dynamic factorization scale, $Q^2 = \Sigma_{partons} m^2 + p^2_T$, changed to $Q^2 = x_1 x_2 s$. This has an order of magnitude larger effect than Qfac.

- **tt cross section**: +9.9 -10.7% using NNLO Hathor.
- **Jet Energy scale**: 16 eigenvectors recommended by the jet/ ETmiss group are varied.
- **b, c and light tagging**: 9 (btag),5(ctag) eigenvectors recommended by b-tagging group are varied for heavy flavours and the one value for light flavours.
- **QCD Multijets**: Mostly in the electron channel. Correlated 50% uncertainty plus uncorrelated statistical estimate in each channel (66% in 6 jet 4 b-tag)
- **ttH parton shower modelling**: 1-5% effect at mH = 120 GeV

ttH, H->bb Analysis





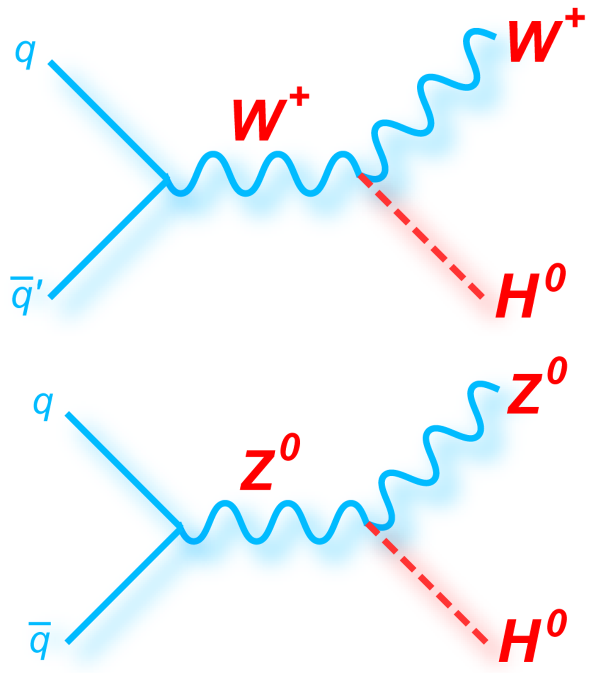
- Poor theory constraints on ttbb/ttjj ratio – ongoing interaction with theory community (important!)
- Large impact of systematic uncertainties
- …but we can do it! ☺

m_H (GeV)	Obs. limit	Exp. limit	Stat.-only
110	7.0	6.0	3.5
115	8.7	6.9	4.0
120	10.4	8.5	4.9
125	13.1	10.5	6.1
130	16.4	13.0	7.8
140	33.0	23.2	14.2

WH/ZH analysis of 7 and 8 TeV data

Search Strategy

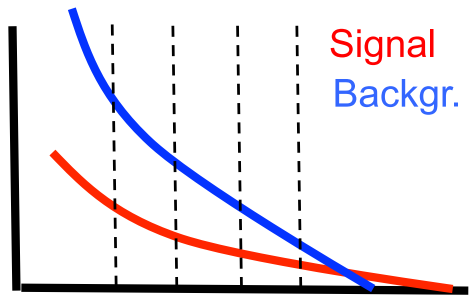
- Search for Higgs decaying to pair of b-quarks
  - Associated production to reduce backgrounds
- The analysis is divided into three channels
  - Two (llbb), one (lνbb) or zero (ννbb) leptons, (l=e,μ)
- Cuts common to all channels:
  - Two or three jets: 1st jet p_T > 45 & other jets > 20 GeV
  - Two b-tags: 70% efficiency per tag
    - c-jet rejection factor ≈5
    - Light-jet rejection factor ≈150



Two lepton	One lepton	Zero lepton
ZH → llbb • No additional leptons • E_T^{miss} < 60 GeV • 83 < m_Z < 99 GeV • Single & di-lepton trigger	WH → lνbb • No additional leptons • E_T^{miss} > 25 GeV • 40 < M_T^W < 120 GeV • Single lepton trigger	ZH → ννbb • No leptons • E_T^{miss} > 120 GeV • E_T^{miss} trigger

Analysis Overview

- Previous publication: 4.7 fb^{-1} $\sqrt{s}$=7 TeV
  http://arxiv.org/abs/1207.0210



- This analysis: 4.7fb^{-1} $\sqrt{s}$ = 7 TeV & 13fb^{-1} $\sqrt{s}$ = 8 TeV
  - S/B is not large, but increases as p_T^{bb} increases
  - Therefore analysis broken into different p_T bins (use $\mathbf{p_T^V}$ of W or Z)
  - Not yet enough ∫Ldt to use jet substructure techniques – future!

- Various substantial improvements wrt previous analysis
  - The analysis is divided into 16 categories using p_T^V
    - 0-lepton: E_T^{miss} [120-160] [160-200] [>200] GeV x (2 jets or 3 jets)
    - 1 & 2 lepton: $p_T^{W/Z}$ [0-50],[50,100],[100-150],[150-200] [>200] GeV
  - Cuts are optimised for each category (~30% increase in sensitivity)
  - Muon energy (p_T>4 GeV) added for b-jets (~10% resolution improve/)
  - Additional ttbar based b-tagging calibration (~50% reduction in b-tagging systematic uncertainty)

Details of event selection

- Basic event selection:

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 $p_T^1 > 45$ GeV $p_T^2 > 20$ GeV $+ \leq 1$ extra jets	2 b-tags $p_T^1 > 45$ GeV $p_T^2 > 20$ GeV + 0 extra jets	2 b-tags $p_T^1 > 45$ 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

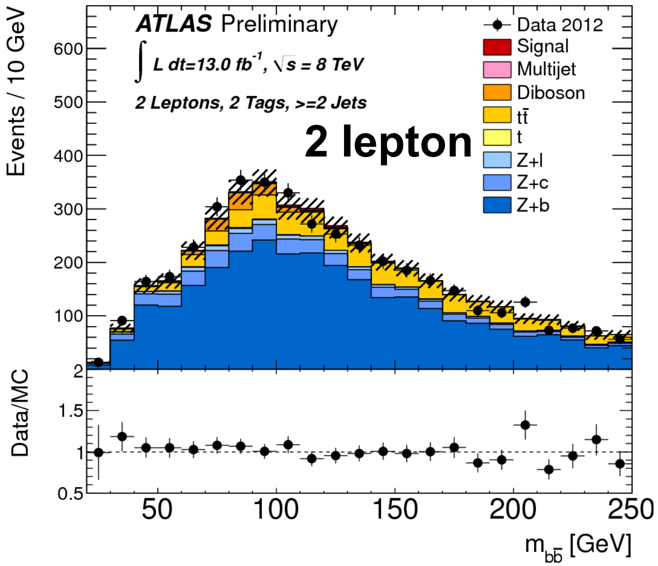
- Tuned kinematic cuts to optimise sensitivity in each category:

0-lepton channel					
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

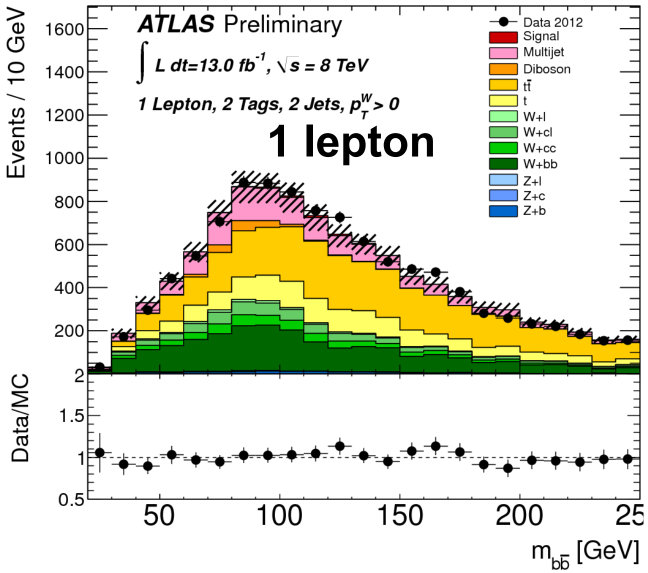
Backgrounds and MC

- Signal: WH/ZH Pythia6/8
- Diboson WW/WZ/ZZ Herwig
- Multijet: Data driven
- ttbar: MC@NLO
- Single Top Acer/MC@NLO
- W+b Powheg
- W+c/light-jets Alpgen
- Z+ b/c/light-jets Alpgen/Sherpa

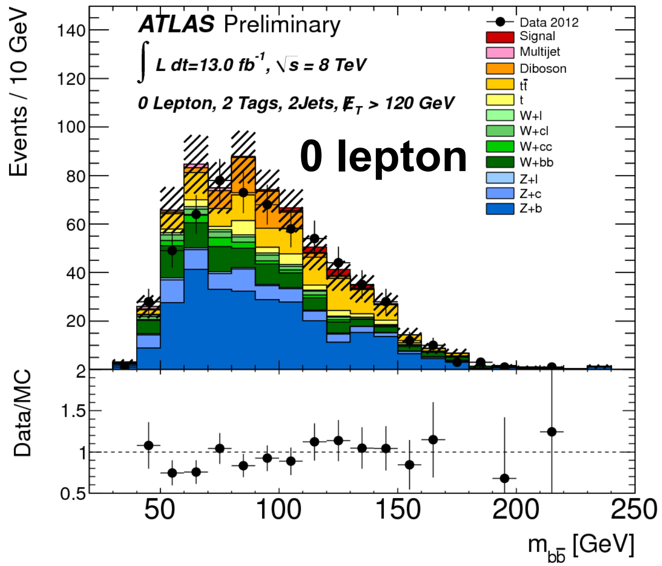
- Background shapes from simulation and normalised using flavour & data fit
- Multi-jet bkg determined by data-driven techniques
- WZ(Z→bb) & ZZ(Z→bb) resonant bkg normalisation and shape from simulation



Z+jets



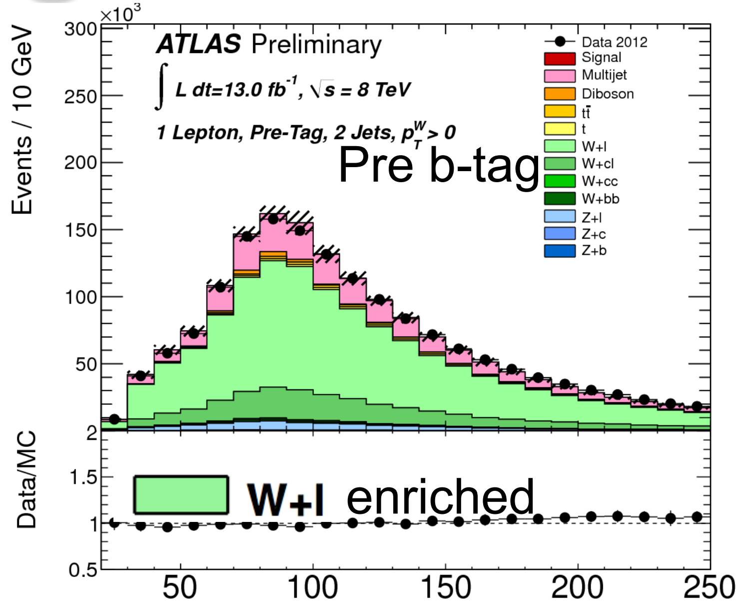
Top/W+jets

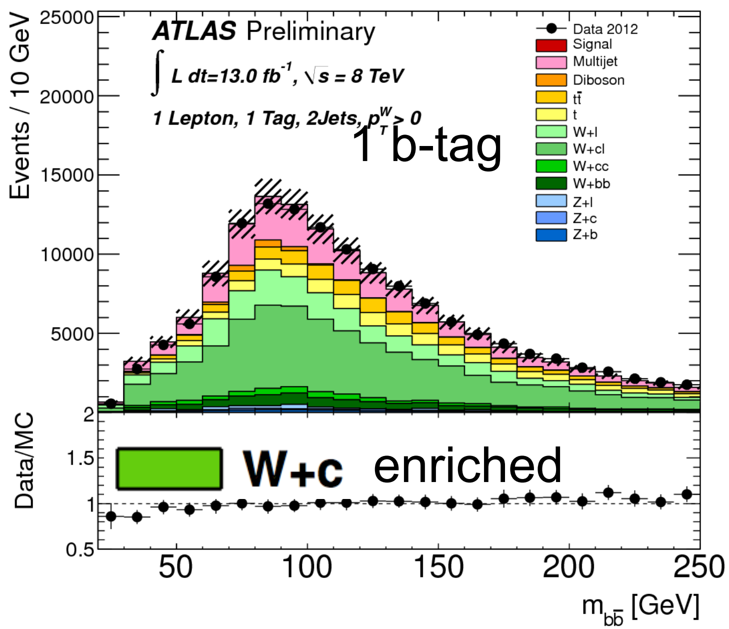


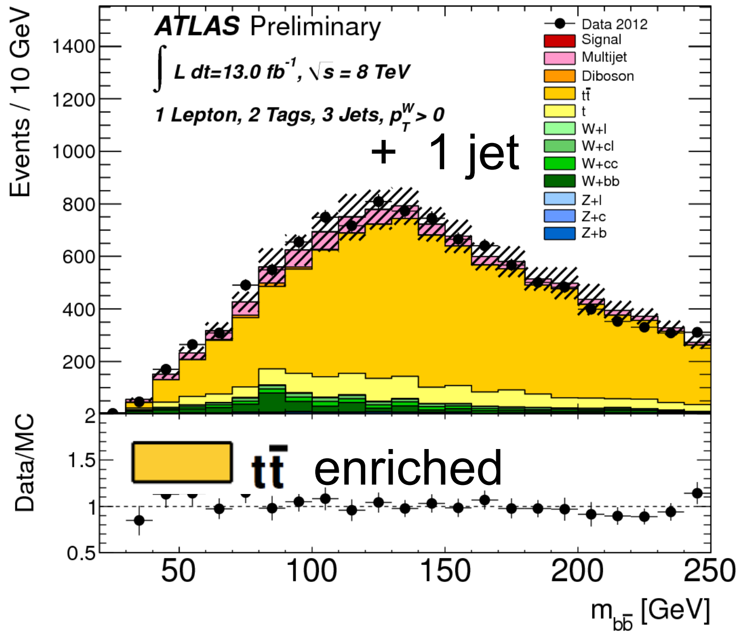
Z+jets/W+jets/Top

Control regions:

- Pre b-tag: rich in V+light jets
- 1 b-tag: V+light, V+c, V+b etc
- Top:
  - ➢ 1-lepton: ≥3-jet region;
  - ➢ 2-lepton: m(ll) sidebands of m_Z







Maximum likelihood Fits

- First perform the flavour ML fit
  - Determined V+light and V+c scale factors
  - Z+c factor changes due to MC treatment

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

- Improved understanding of bkg V pT
  - Using the high statistics at 8 TeV we discovered that the V pT spectrum falls more rapidly in data than expected from MC ☺
  - W + jets and Z + jets: 5-10 % correction required
  - Top background: 15 % correction required

- Using corrections & scale factors get good MC/data agreement
- Binned profile likelihood fit to 16 signal regions & top control regions
  - W+b, Z+b and top bkg are floated
  - Rescaling factors from the fit ➠

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

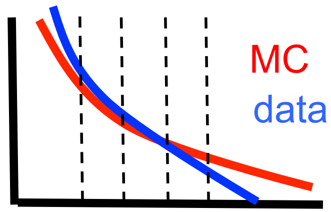
- $L(\mu,\theta)$ fit to signal strength μ (= σ/σ_{SM})
  - Nuisance parameters θ for systematics

Analysis

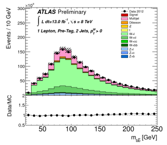
Event selection:

0 lepton | 1 lepton | 2 lepton

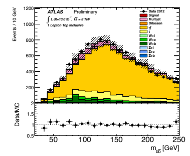
Data-driven corrections:
p_T^V correction of W+jets, Z +jets and top



Pre-tag

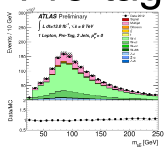


top CR (3/4j)

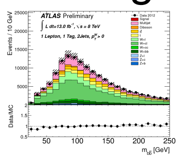


Flavour fit (V+c, V+light):
Use different b/c/light content to get correction to flavour fractions

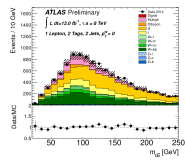
Pre-tag



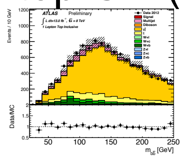
1 b-tag



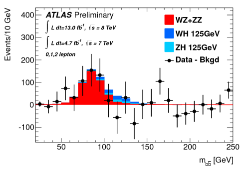
2 b-tag



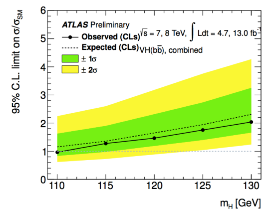
top CR (3/4j)



Fix Higgs to SM and fit to get diboson significance:



Fix diboson to SM and do fit to extract final background normalizations and limits:



Systematic Uncertainties

- **Experimental uncertainties**

  b-tagging and **jet energy** dominate

  - Jets: components (7 JES, 1 p_T^{Reco}, resol.)
  - E_T^{miss} – scale and resolution of soft components. Data/MC for E_T^{miss} trigger
  - bTagging – light, c & 6 p_T bins for b-jet efficiency
  - Lepton – energy, resolution, efficiency
  - Multijet / diboson / Luminosity / MC stats

- **Theoretical uncertainties**
  - BR(H→bb) @ mH=125 GeV (3.3%)
  - W/Z+jet m_{bb} (20%) and V pT (5-10%)
  - Single top/top normalisation (15%)
  - W+c/W+jets (30%), Z+c/Z+jets (30%)
  - Diboson (11%)

Uncertainties given are after full cuts (pre-fit)

Systematic [%]	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_T^{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

Background systematics

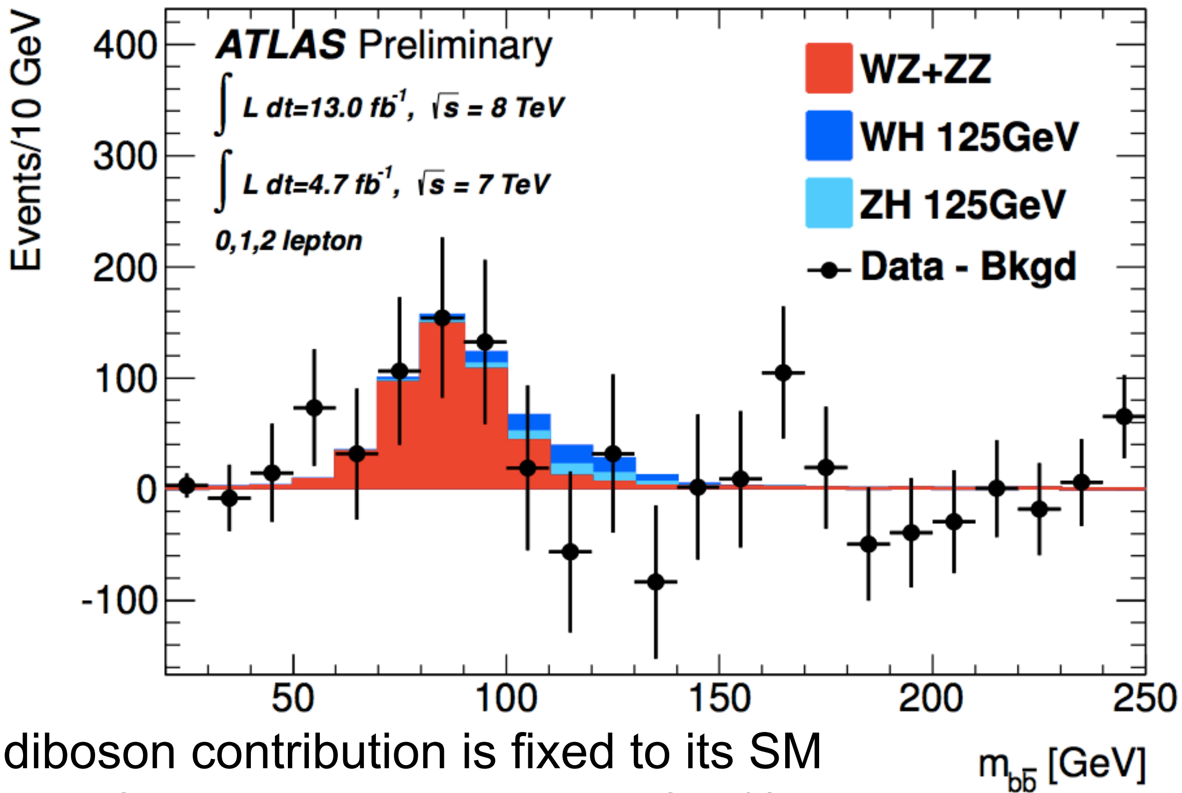
Systematic [%]	0 lepton		1 lepton	2 leptons
	ZH	*WH*	*WH*	*ZH*
b-tagging	8.9	9.0	8.8	8.6
c-tagging	0.1	0.1	0.0	0.1
light tagging	0.0	0.0	0.1	0.3
Jet/Pile-up/E_T^{miss}	19	25	6.7	4.2
Lepton	0.0	0.0	2.1	1.8
$H \to bb$ BR	3.3	3.3	3.3	3.3
VH p_T-dependence	5.3	8.1	7.6	5.0
VH theory PDF	3.5	3.5	3.5	3.5
VH theory scale	1.6	0.4	0.4	1.6
Luminosity	3.6	3.6	3.6	3.6

Signal systematics

Diboson production

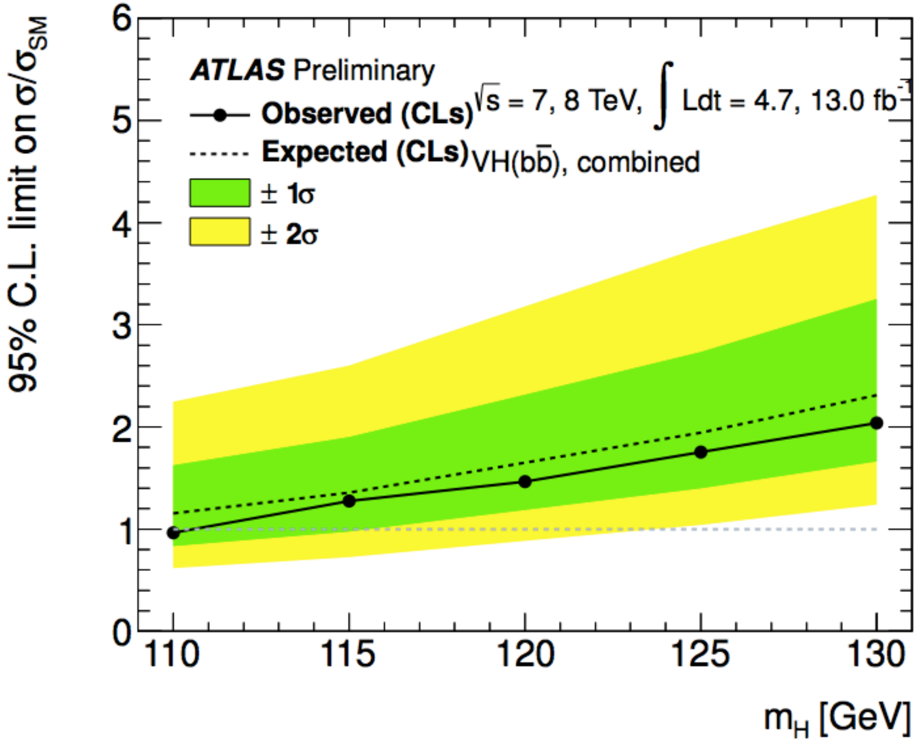
- WZ & ZZ production with $Z \rightarrow bb$
  - ➢ Similar signature, but 5 times larger cross-section
- Perform a separate fit for this to validate the analysis procedure
  - ➢ Profile likelihood fit performed (with systematics)
  - ➢ All bkgs (except diboson) subtracted
- Clear excess is observed in data at the expected mass

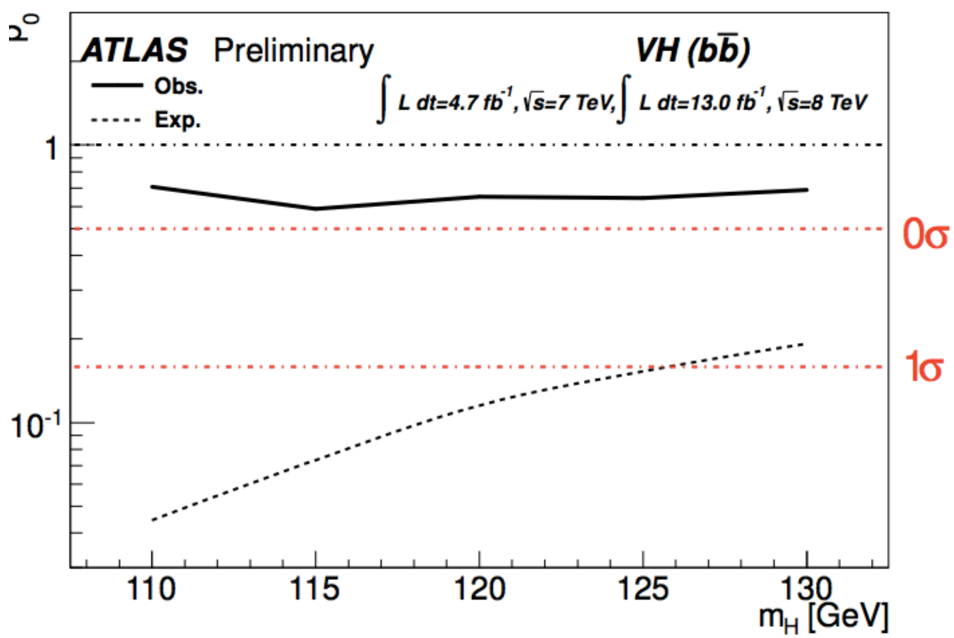
- 0,1 and 2- lepton channels combined
- 2011 & 2012 data combined
- Full systematics are applied
- Results
  - ➢ $\sigma/\sigma_{SM} = \mu_D = 1.05 \pm 0.32$
  - ➢ Significance = 4.0 σ
- In agreement with Standard Model



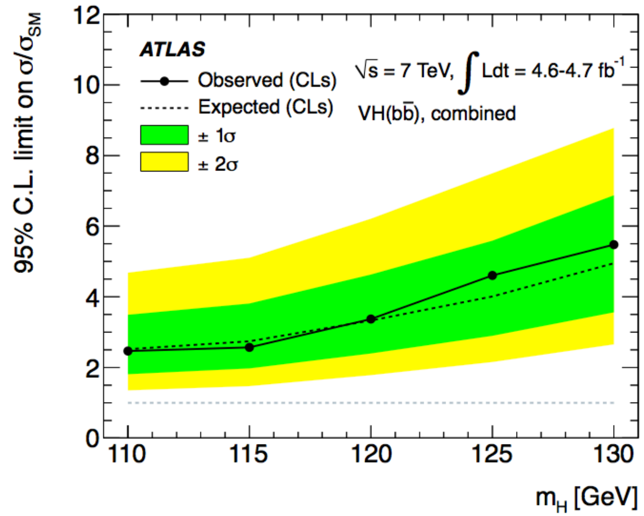
- For the Higgs analysis the diboson contribution is fixed to its SM expectation in the likelihood profile, with an uncertainty of 11%

Combined (2011 & 2012) result





Previous publication



- Observed (expected) limit at m_H =125 GeV
  - 1.8 (1.9) x SM prediction
- Observed (expected) p_0 value 0.64 (0.15)
- $\sigma/\sigma_{SM} = \mu = -0.4 \pm 0.7(\text{stat.}) \pm 0.8(\text{syst.})$
- Exclusion at m_H ~ 110 GeV

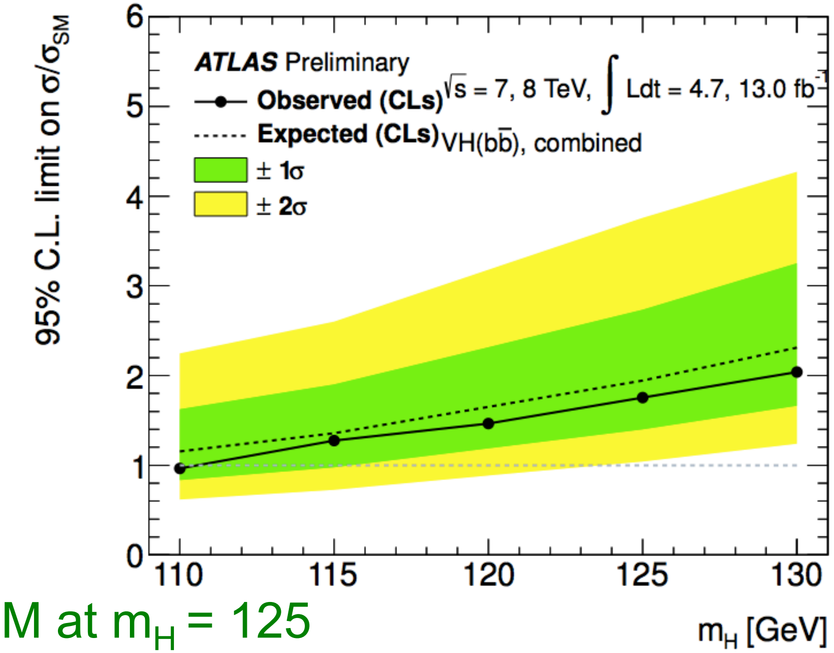
More than doubled the analysis sensitivity ➠

Conclusions

- First combined 2011 & 2012 VH analysis in H->bb channel
  - Using 4.7fb^{-1} (2011) and 13fb^{-1} (2012) data
  - Significant improvements to all aspects of the analysis
- Observed (exp.) limits are 1.8 (1.9) x SM at m_H = 125
- Clear di-boson signal measured

  $\mu_{Diboson}$ = 1.05 ± 0.32

  Significance = 3.9σ



- ttH analysis of 7TeV data
  - First iteration of a difficult analysis
  - Severely affected by systematics
    - But will benefit much from more stats
  - Observed (exp.) limits are 13.1 (10.5) x SM at m_H = 125

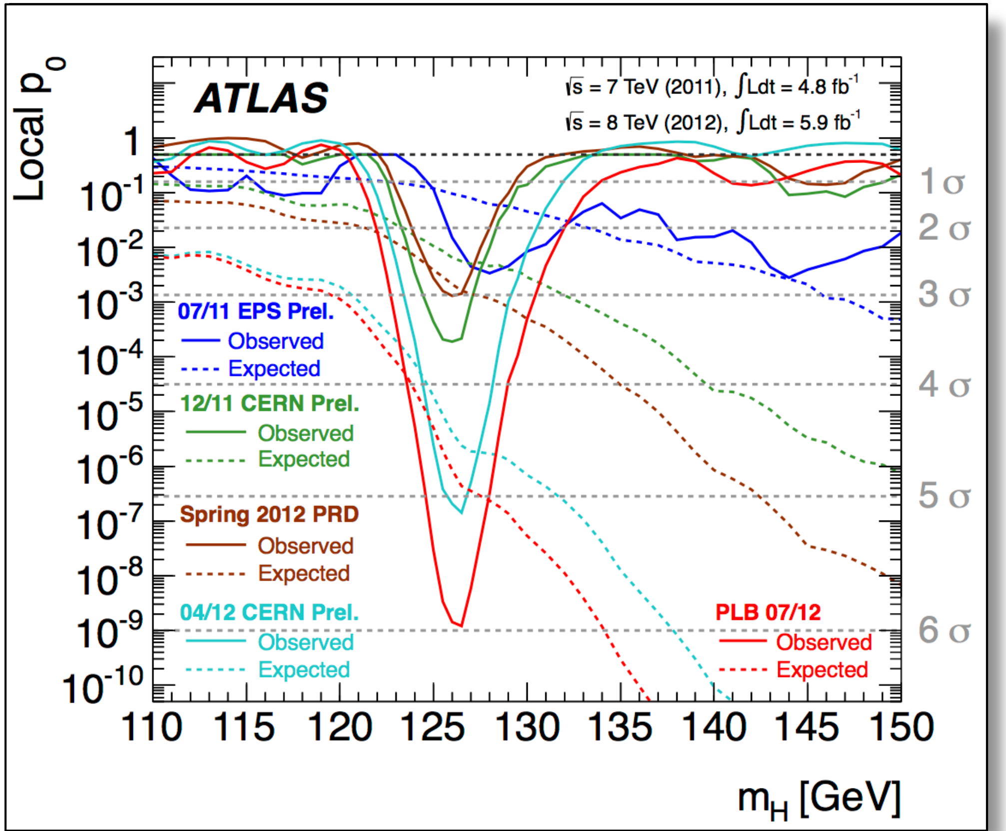
- **No observation and no surprises… YET!**

  (But watch this space! Unless it's the end of the world…)

Bonus slides


POR QUE VOCÊ PAROU DE ESCULPIR EM 2012?
É QUE EU FIQUEI SEM ESPAÇO NA PEDRA...
ENFIM, REVELADO O MISTÉRIO DO CALENDÁRIO MAIA

- 5σ announced on 4th of July independently by ATLAS and CMS!!
- Data analysed:
  4.8 fb^{-1} @7TeV & 5.6 fb^{-1} @8TeV
- Clear excess only in bosonic decay channels:
  - H→ZZ, H→γγ, H→WW
- Hints of H→ττ from LHC and evidence from Tevatron for H→bb and hints from CMS



- Need to keep looking!
  - SM Higgs search is a great way to search new physics!

Search channel	Dataset	m_{max} [GeV]	Z_l [σ]	$E(Z_l)$ [σ]
$H \to ZZ^{(*)} \to 4\ell$	7 TeV	125.0	2.5	1.6
	8 TeV	125.5	2.6	2.1
	7 & 8 TeV	125.0	3.6	2.7
$H \to \gamma\gamma$	7 TeV	126.0	3.4	1.6
	8 TeV	127.0	3.2	1.9
	7 & 8 TeV	126.5	4.5	2.5
$H \to WW^{(*)} \to \ell\nu\ell\nu$	7 TeV	135.0	1.1	3.4
	8 TeV	120.0	3.3	1.0
	7 & 8 TeV	125.0	2.8	2.3
Combined	7 TeV	126.5	3.6	3.2
	8 TeV	126.5	4.9	3.8
	7 & 8 TeV	126.5	6.0	4.9

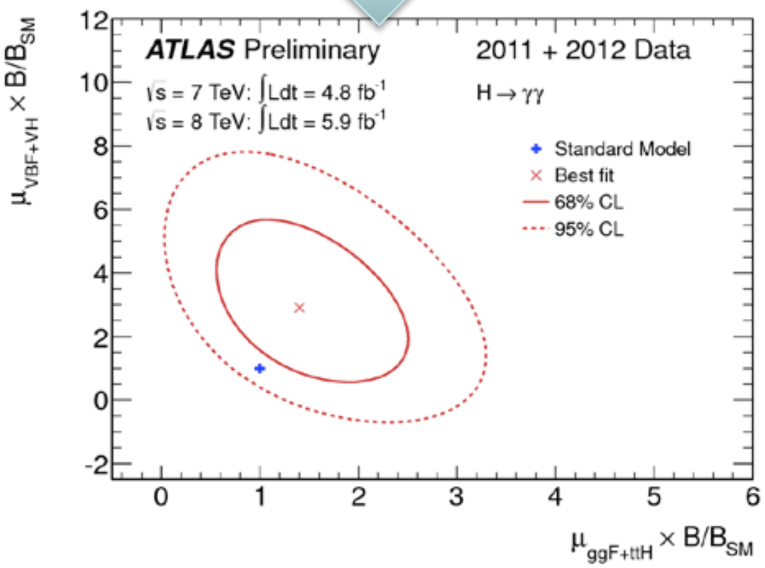
- The 6 billion Swiss Franc question (+ M&O):

Is it THE Standard Model Higgs?...
Or something even more interesting?

- What do we know about the new particle?
  - Mass ≈ 126 GeV
  - Electric charge = 0 (neutral final state)
- Unknown/incomplete knowledge:
  - Spin (*J*) = 0, 1, 2, ... ? *J*=1 disfavored (Landau-Yang theorem and observation in $H\rightarrow\gamma\gamma$)
  - Charge-conjugation, parity (CP)
  - Couplings?

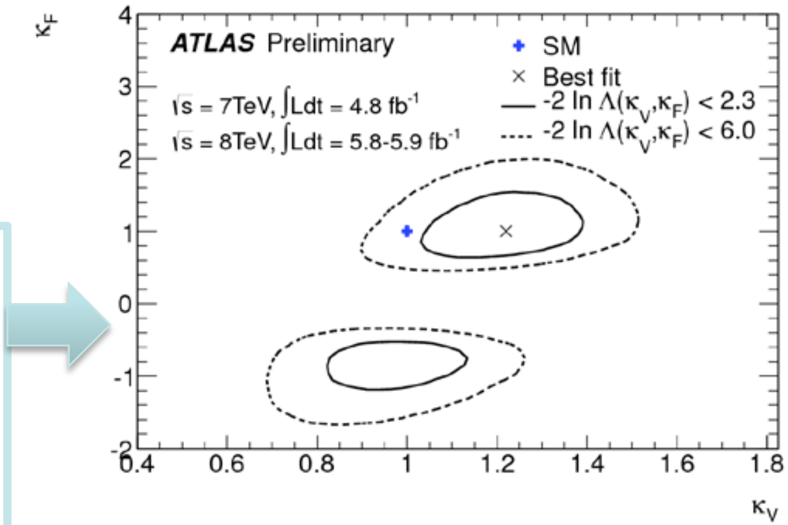
- September analysis used same data as July 2012 observation paper
  - ATLAS-CONF-2012-127: https://cdsweb.cern.ch/record/1476765?ln=en
- Fit data to estimate factors *κ* multiplying coupling in each SM production and decay mode

Signal strength for the γγ final state (gluon fusion vs VBF +VH)



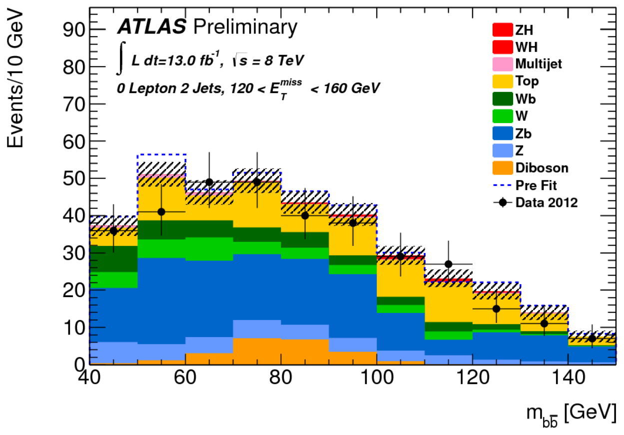
κ_V versus κ_F – assume a single κ_F factor for all fermions t, b, τ and a single factor κ_V for vector

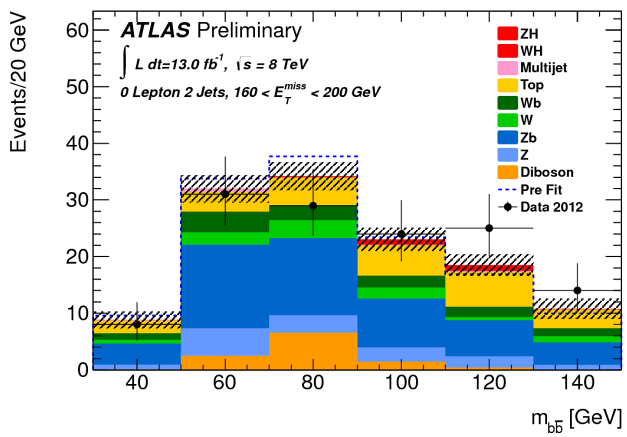
Sign comes from interference between t and W loops in $H\rightarrow\gamma\gamma$

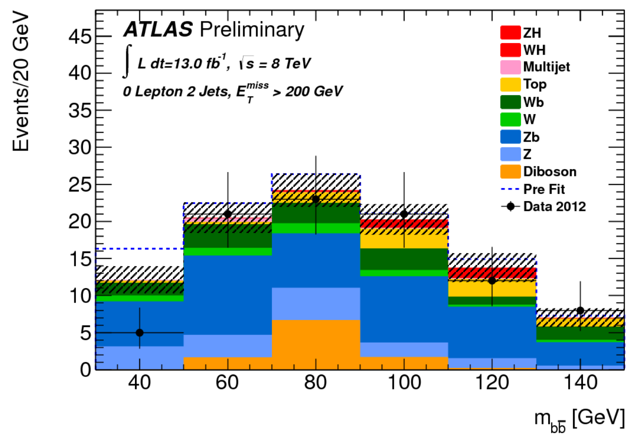


M_{bb} distribution (0-lepton, 8TeV)

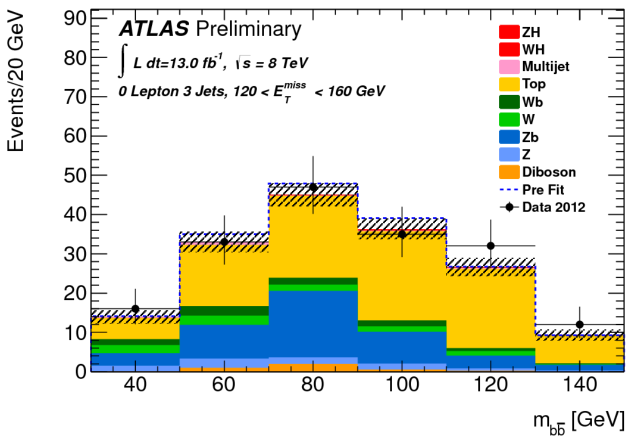
2-jet categories

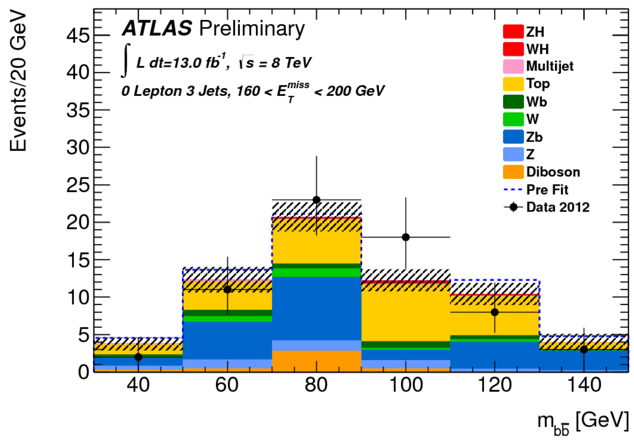


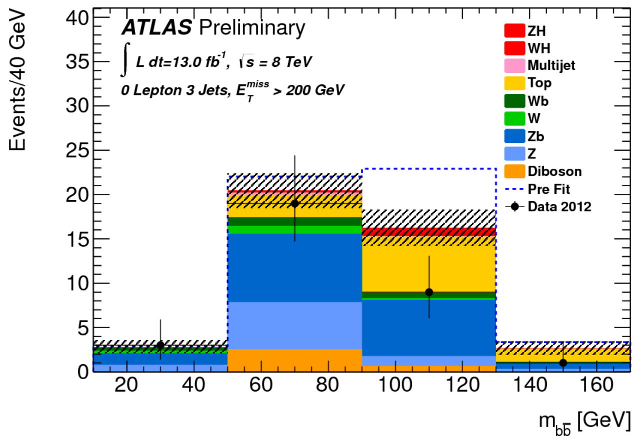




3-jet categories

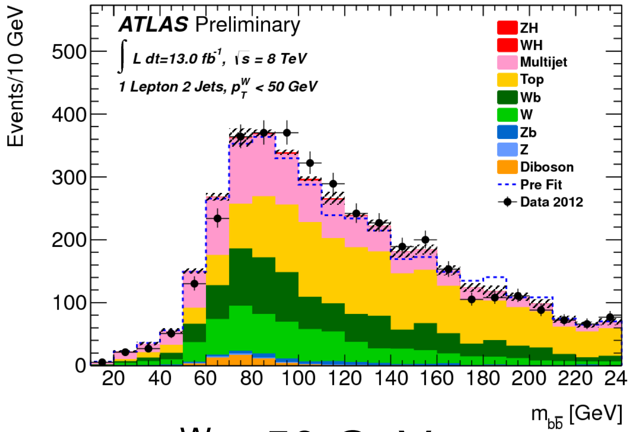




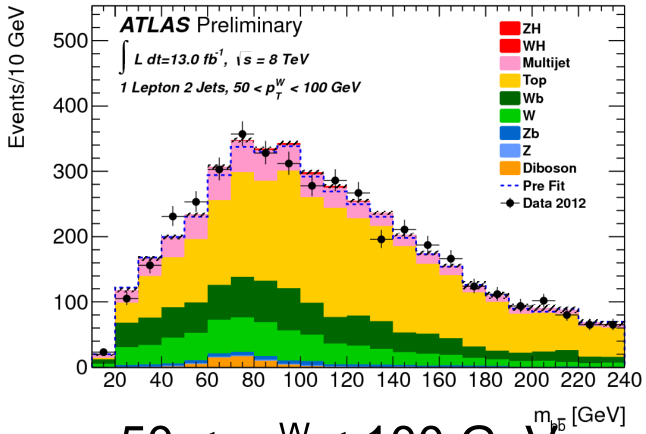


$120 < E_T^{miss} < 160$ GeV | $160 < E_T^{miss} < 200$ GeV | $160 < E_T^{miss} < 200$ GeV

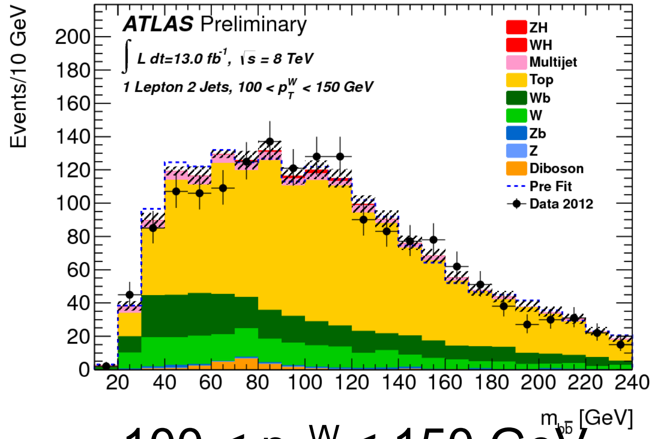
M_{bb} distribution (1-lepton, 8TeV)



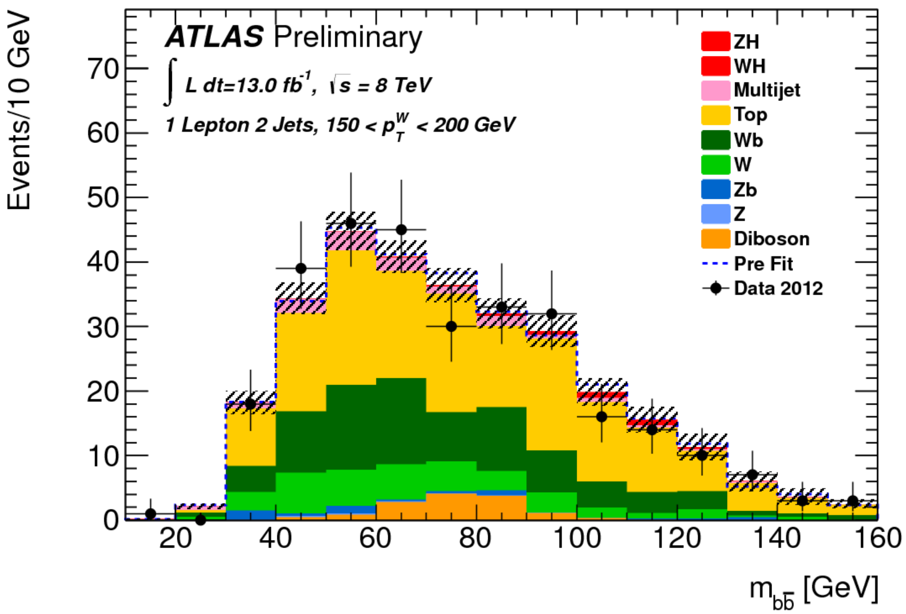
$p_T^W < 50$ GeV



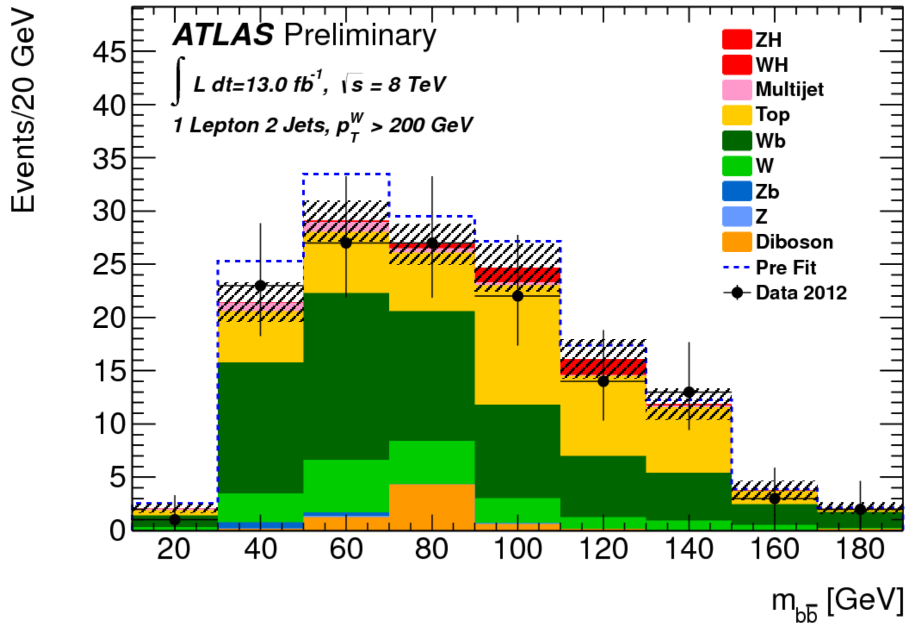
$50 < p_T^W < 100$ GeV



$100 < p_T^W < 150$ GeV

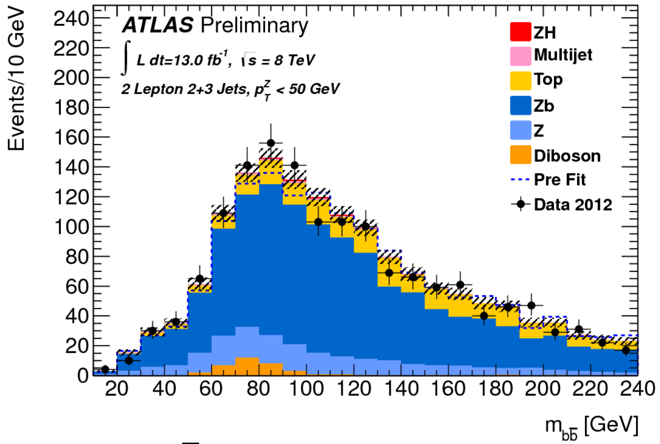


$150 < p_T^W < 200$ GeV

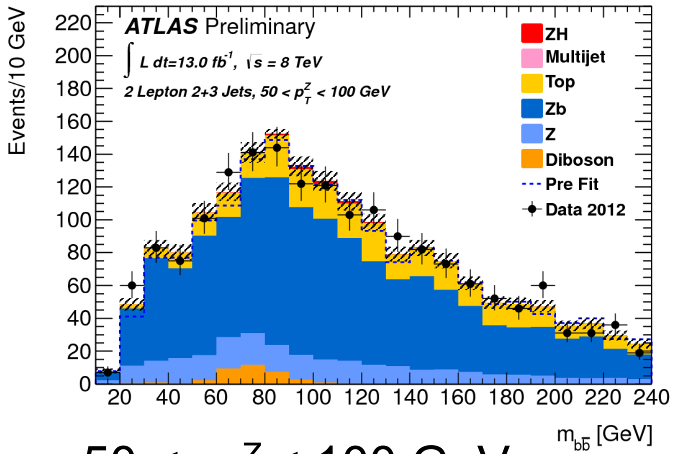


$p_T^W > 200$ GeV

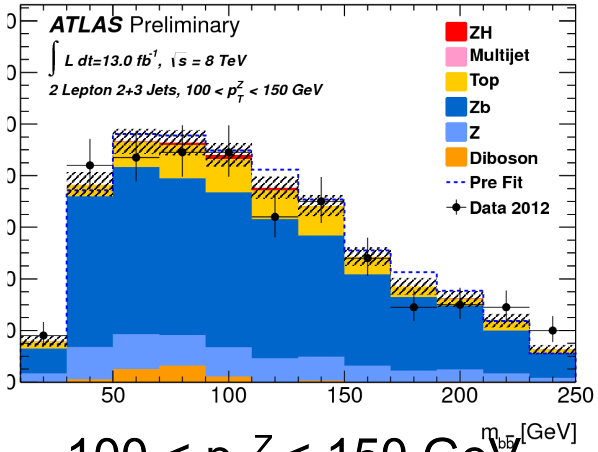
M_{bb} distribution (2-lepton, 8TeV)



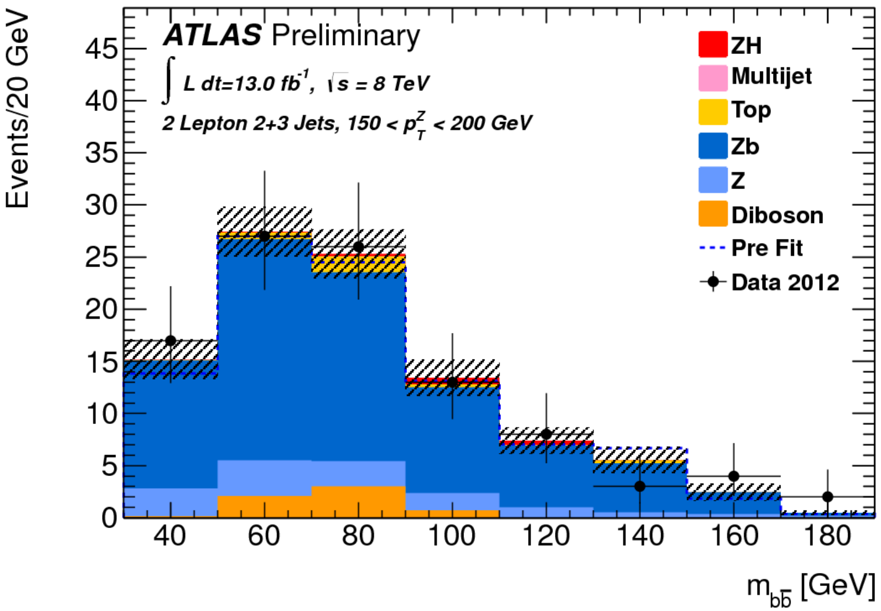
$p_T^Z < 50$ GeV



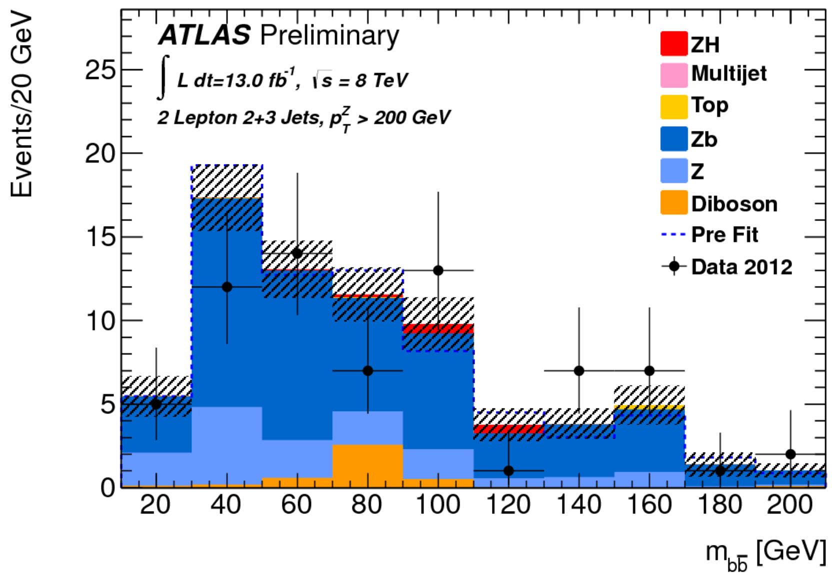
$50 < p_T^Z < 100$ GeV



$100 < p_T^Z < 150$ GeV



$150 < p_T^Z < 200$ GeV



$p_T^Z > 200$ GeV

Results: Exp. S+B & Obs. events

8TeV analysis:

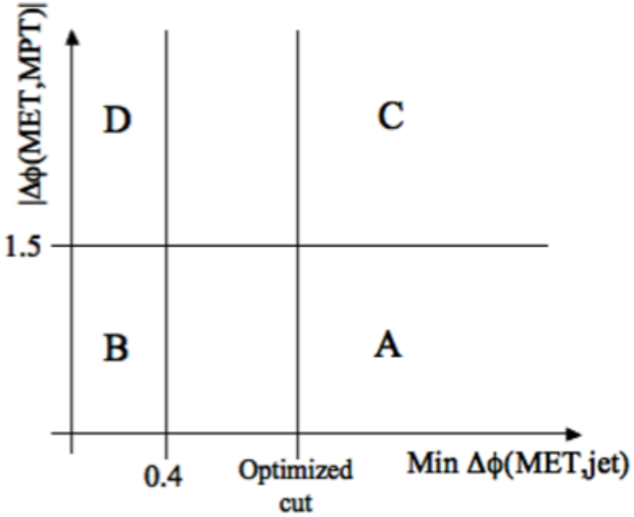
Bin	0-lepton, 2 jet E_T^{miss} [GeV]			0-lepton, 3 jet E_T^{miss} [GeV]			1-lepton p_T^W [GeV]					2-lepton p_T^Z [GeV]				
	120-160	160-200	>200	120-160	160-200	>200	0-50	50-100	100-150	150-200	> 200	0-50	50-100	100-150	150-200	>200
ZH	2.9	2.1	2.6	0.8	0.8	1.1	0.3	0.4	0.1	0.0	0.0	4.7	6.8	4.0	1.5	1.4
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 ± 29	127 ± 11	98 ± 12	164 ± 13	63 ± 8	42 ± 5	3810 ± 150	4310 ± 86	1730 ± 90	297 ± 27	138 ± 14	1500 ± 90	1770 ± 110	665 ± 47	97 ± 12	72 ± 12
Data	342	131	90	175	65	32	3821	4301	1697	297	132	1485	1773	657	100	69

QCD/multi-jet modelling

- 0 lepton
  - Use ABCD method
  - Regions defined by relative directions of MET/jets/pTmiss
  - Found to be small (~1%)
- 1 lepton
  - MET template by reverse isolation cuts
  - Normalised by fitting each WpT bin
  - Electroweak contamination removed from template
- 2 lepton
  - Template: reverse isolation/quality selection
  - Found to be small (<1%)

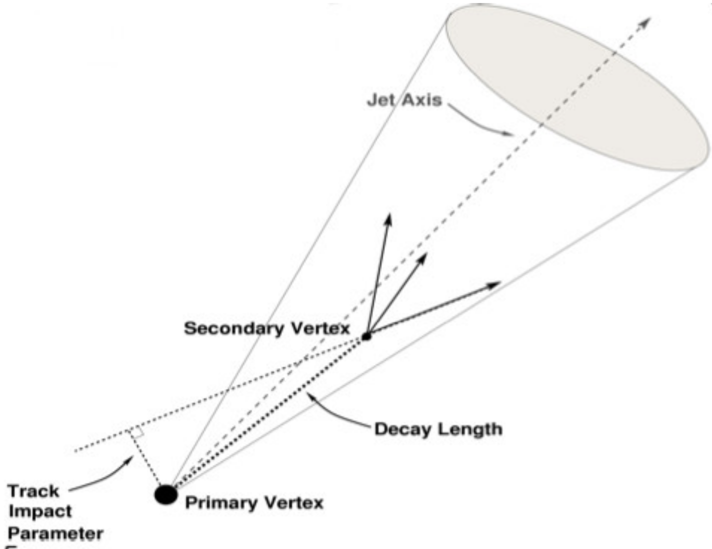
ABCD method

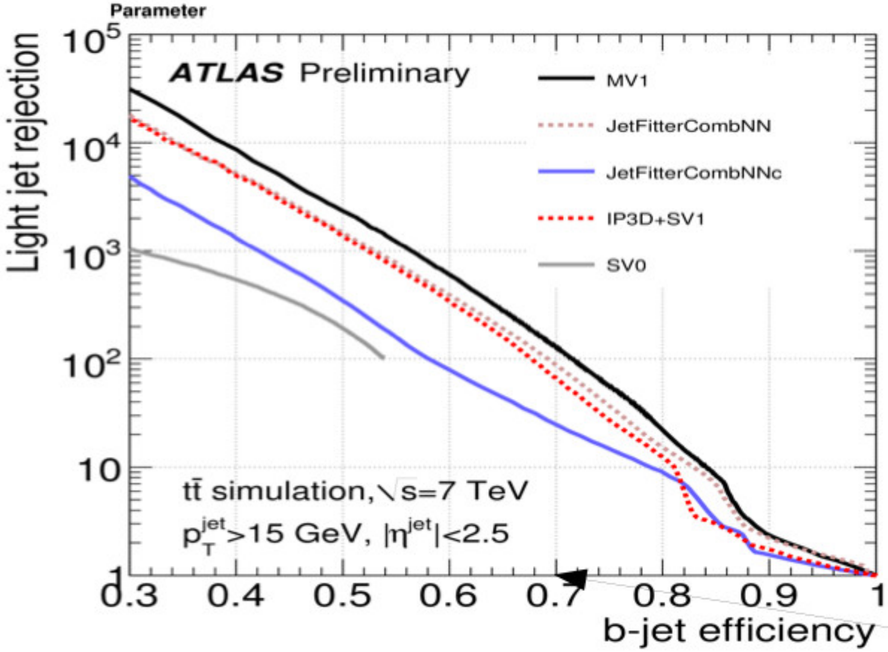
Use lack of correlation
 Δϕ (Etmiss,pTmiss) vs
 Δϕ (Etmiss,jets)
for multi-jet background estimation in signal region



$$N_{QCD}(A) = \frac{N(B)}{N(D)} \times N(C)$$

B-tagging

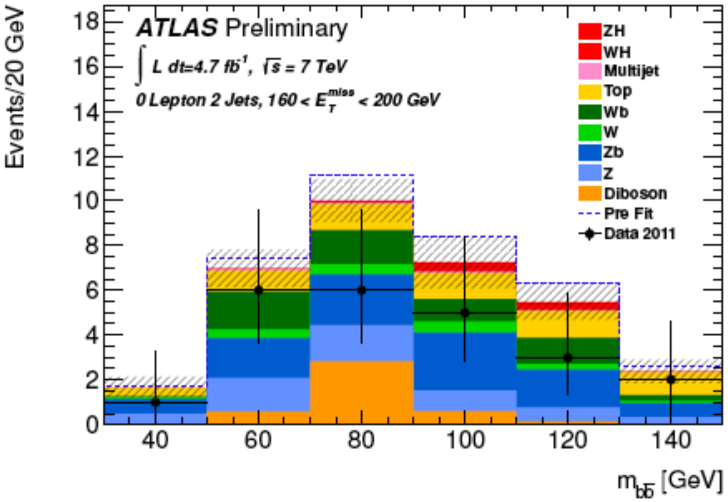




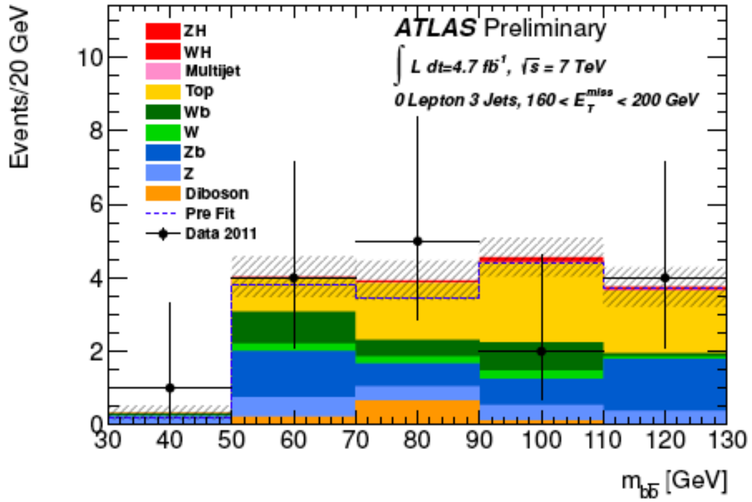
- Algorithms to identify heavy flavour content in reconstructed jets
- Impact parameter of tracks in jet
  - **IP3D** uses track weights based on longitudinal and transverse IP significance
- Displaced secondary vertex
  - **SV1** reconstructs inclusive displaced vertex
  - **JetFitter** reconstructs multiple vertices along implied b-hadron line of flight
    - Cascade decay topologies
- Advanced NN based algorithms
  - **JetFitterCombNN**: IP3D+JetFitter
  - **MV1**: IP3D+JetFitterCombNN+SV1

MC calibration results illustrated with MV1 @ 70% b-jet efficiency

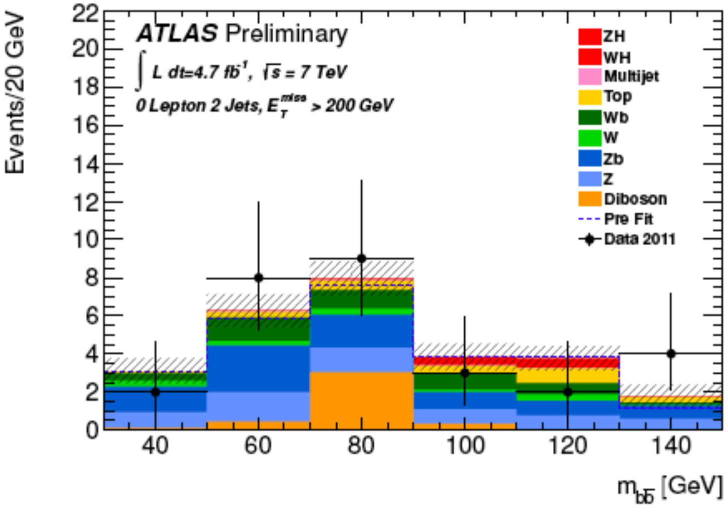
Mbb distributions (0-lep, 7TeV)



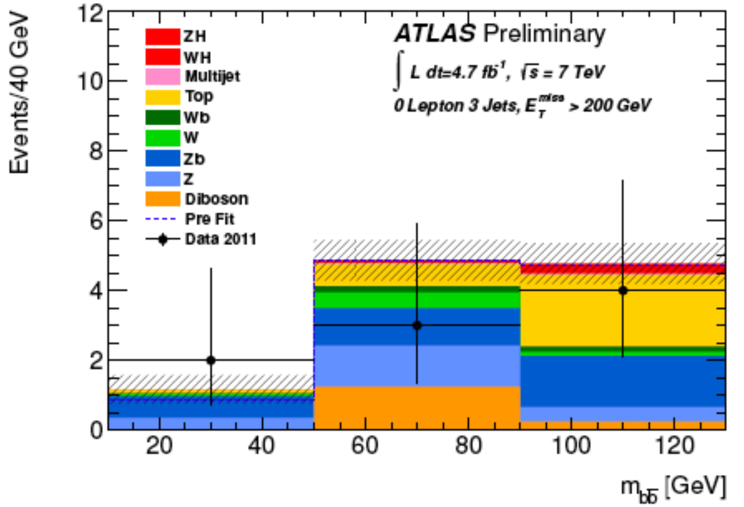
(c) $160 < E_{\mathrm{T}}^{\mathrm{miss}} < 200$ GeV, 2 jets



(d) $160 < E_{\mathrm{T}}^{\mathrm{miss}} < 200$ GeV, 3 jets



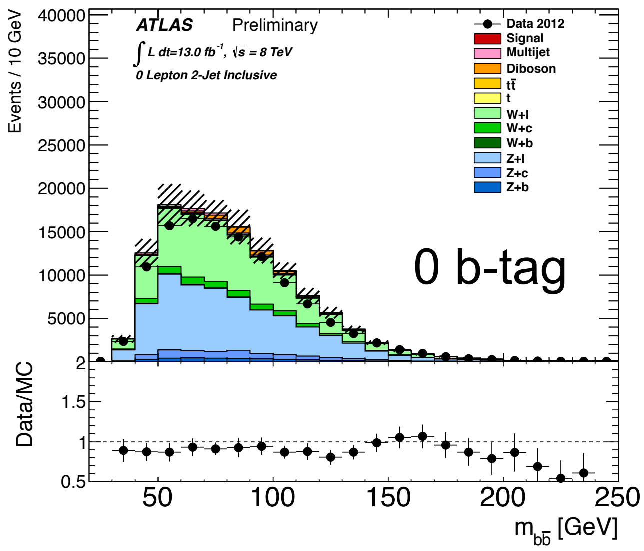
(e) $E_{\mathrm{T}}^{\mathrm{miss}} > 200$ GeV, 2 jets



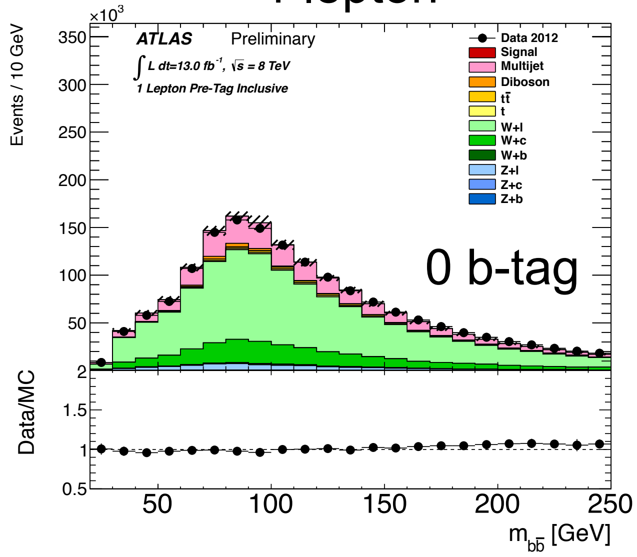
(f) $E_{\mathrm{T}}^{\mathrm{miss}} > 200$ GeV, 3 jets

V+light & V+c flavour fit

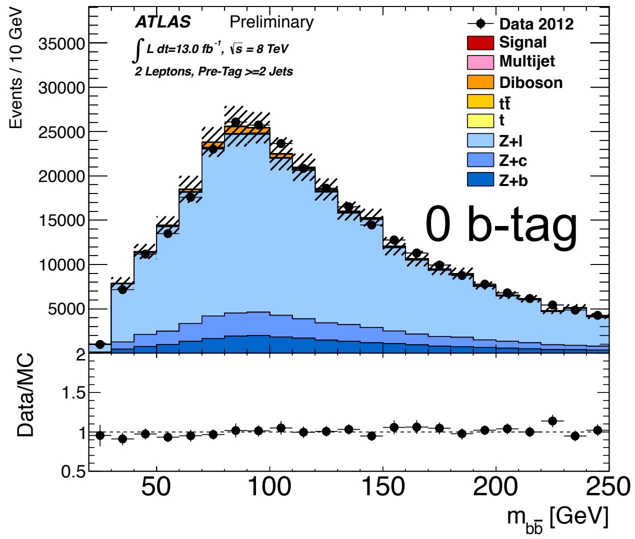
0 lepton

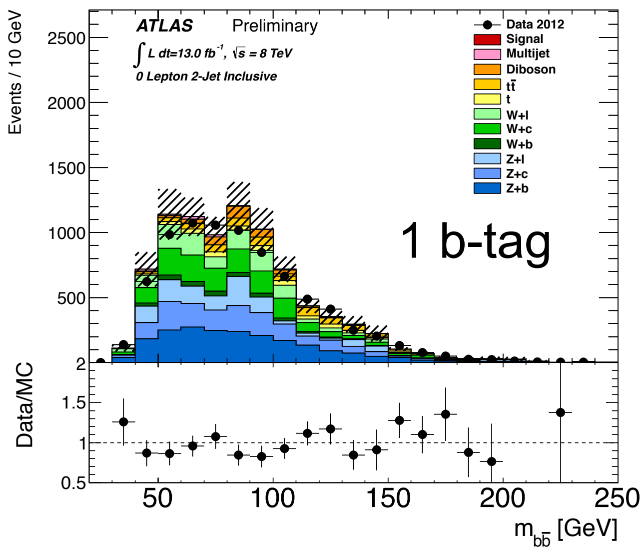


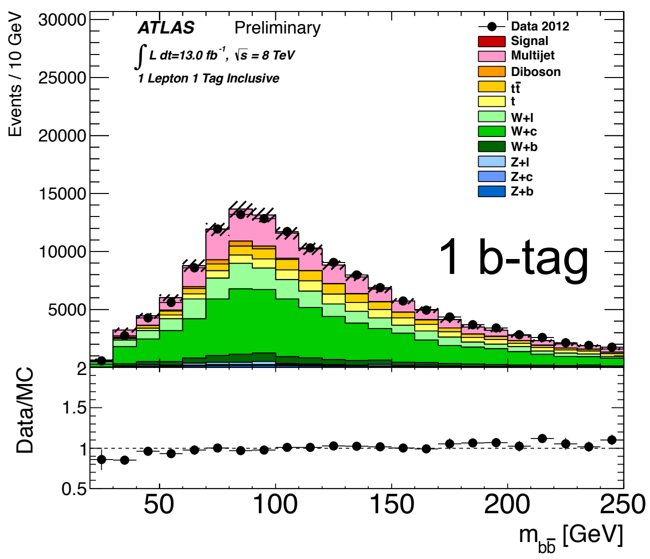
1 lepton

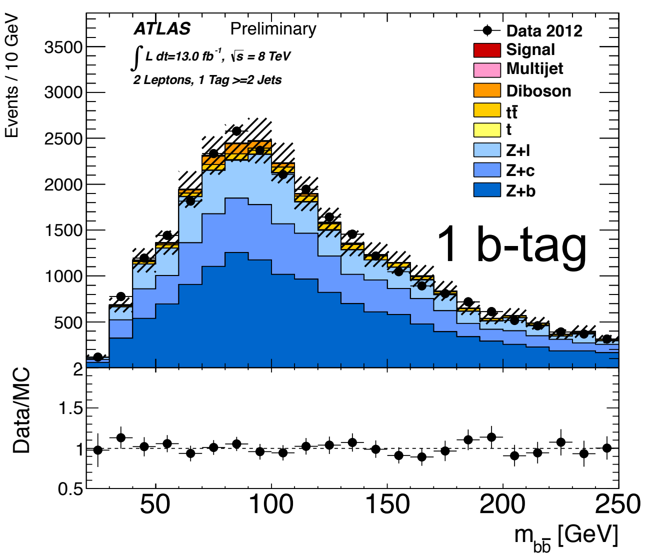


2 lepton

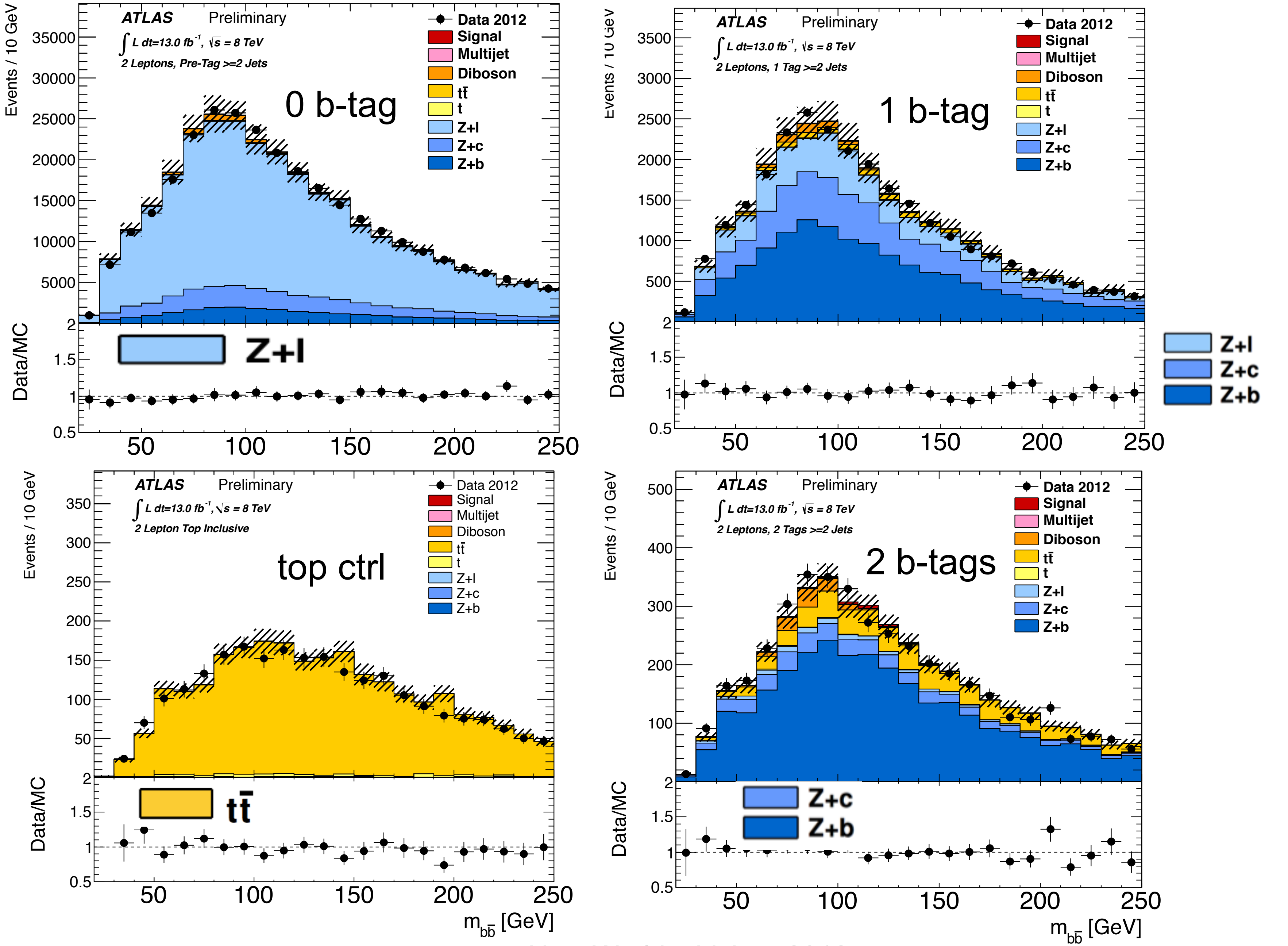




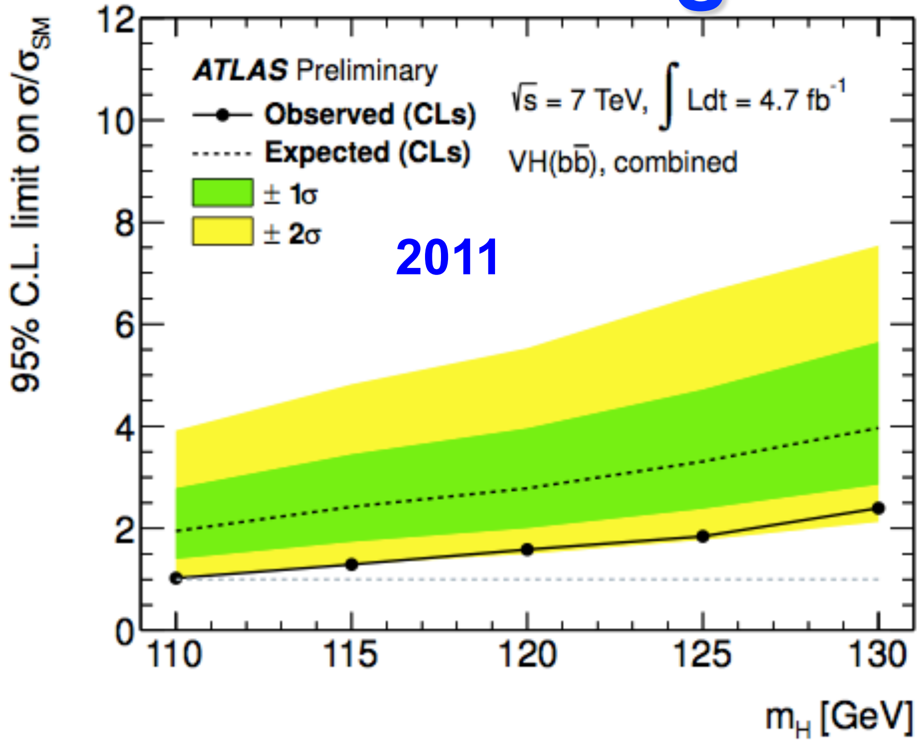


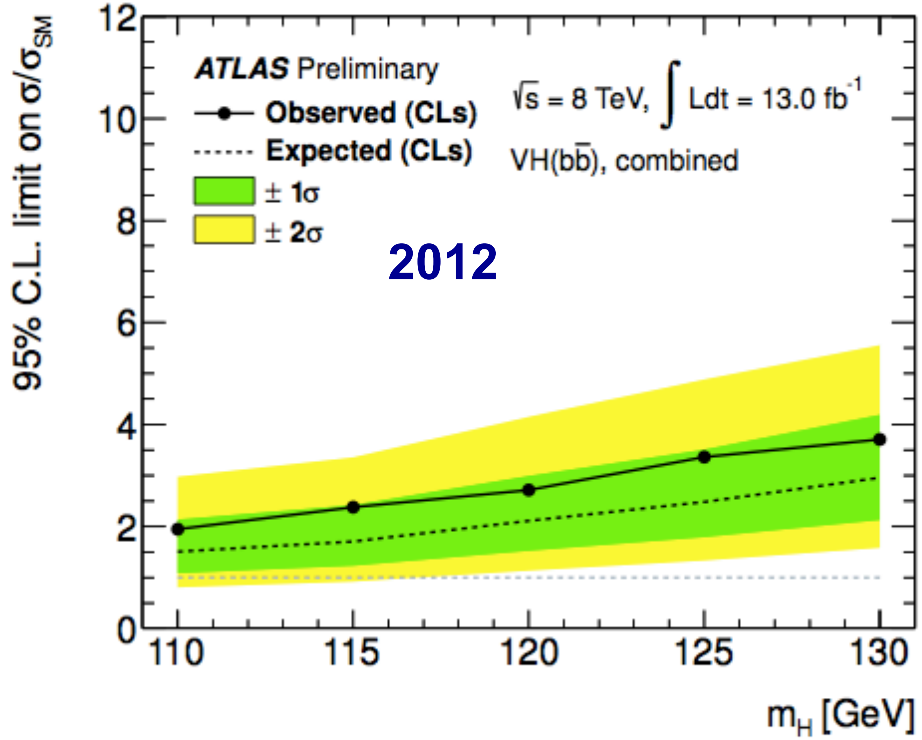


Flavour fit results (2-lepton)



CL_S limit results





- Observed & expected CL_S limit on normalised signal strength as function of Higgs Boson mass (0,1,2 lepton combined)
- Observed (expected) values at m_H =125 GeV
  - Limits 1.8 (3.3) & 3.4 (2.5) times the Standard Model
  - p_0 values: 0.97 (0.26) & 0.17 (0.20)
  - σ/σ_{SM}: $\mu = -2.7 \pm 1.1$(stat.) $\pm$ 1.1(syst.) & $\mu = 1.0 \pm 0.9$(stat.) $\pm$ 1.1(syst.)

Samples & Yields for ≥ 6 jets ≥ 4 b's

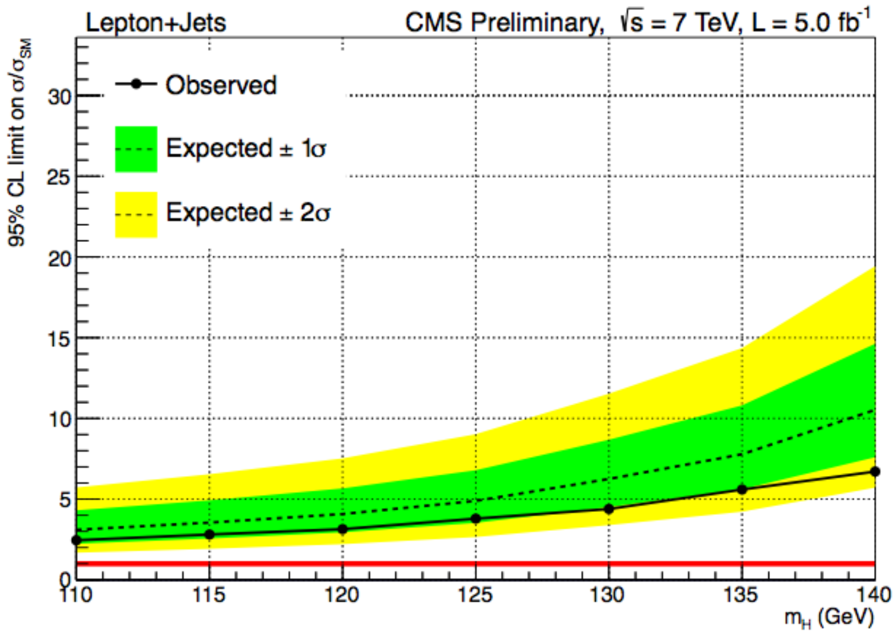
Signal: 2.3 events

- PYTHIA 6.425, m_t = 172.5 GeV. Charged lepton filter: $p_T > 5$, $|\eta| < 5$

Backgrounds:

- **Dominant** are **tt+jets** (16.4 events) and **ttbb** (26.5 events):
  - ALPGEN 2.13+HERWIG 6.520 HFOR overlap removal.
  - tt+jets: Npartons = 0−5, σ=73.08pb, K=1.755;
  - ttbb : σ = 0.856 pb, K=1.687 (biggest sys.)
- Multijets (data-driven): 6.22 events (5.67 e channel; 0.55 μ channel)
- ttV: 2.2 events
  - Madgraph 4 + PYTHIA 6.425 σ_{ttW}= 0.12pb, σ_{ttZ} = 0.096pb
- Single Top: 1.28 events
  - s-channel (1.5 pb) and Wt (15.74 pb): MC@NLO 4.01 with HERWIG 6.520 and Jimmy 4.31.
  - t-channel (20.92 pb, K=0.866): AcerMC 3.8 with PYTHIA 6.425
- W+jets: 0.54 events
  - ALPGEN 2.13+HERWIG 6.520: Wbb, Wcc, Wc, Z → ll, W → lν; HFOR overlap removal
  - Uses data to normalize and change mix of heavy flavours
- Minor backgrounds: 0.2 events
  - Dibosons and Z + jets;
  - Dibosons: HERWIG 6.520 and JIMMY 4.31; charged lepton filter p_T > 10GeV, $|\eta| < 2.8$.

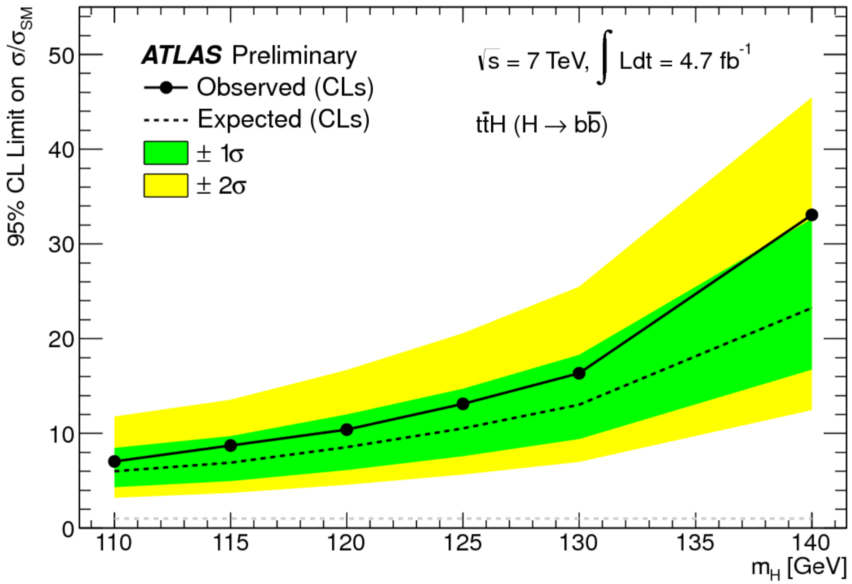
CMS



m_H (GeV/c^2)	Obs limit	Median Exp limit
110	2.5	3.1
115	2.8	3.6
120	3.1	4.1
125	3.8	4.9
130	4.4	6.3
135	5.6	7.8
140	6.7	10.5

Lepton+jets mode

ATLAS



m_H (GeV)	observed	median	stat only
110	7.0	6.0	3.5
115	8.7	6.9	4.0
120	10.4	8.5	4.9
125	13.1	10.5	6.1
130	16.4	13.0	7.8
140	33.0	23.2	14.2

Very big difference!...

ttH Systematic Uncertainties

- **tt+heavy-flavour** fractions: vary by 50% - theory studies suggest cross section uncertainty is 50-75% ; should be weighted down by the fraction of this background. Fit puts it at 30%.

- **tt modeling** (Alpgen):
  - **Qfac**: (±2.3%) The factorization scale for the hard scatter is varied by a factor of two up and down relative to the original scale, $Q^2 = \Sigma_{partons} m^2 + p^2_T$
  - **kTfac**: (±9.2%) The renormalisation scale associated with the evaluation of α_s at each local vertex in the matrix element calculation is varied by a factor of two up and down relative to the original scale, k_T , between two partons.
  - Functional form of the factorization scale (**iqopt2**): (± 13%) Default choice (=1) for dynamic factorization scale, $Q^2 = \Sigma_{partons} m^2 + p^2_T$, changed to $Q^2 = x_1 x_2 s$. This has an order of magnitude larger effect than Qfac.

- **tt cross section**: +9.9 -10.7% using NNLO Hathor.
- **Jet Energy scale**: 16 eigenvectors recommended by the jet/ ETmiss group are varied.
- **b, c and light tagging**: 9 (btag),5(ctag) eigenvectors recommended by b-tagging group are varied for heavy flavours and the one value for light flavours.
- **QCD Multijets**: Mostly in the electron channel. Correlated 50% uncertainty plus uncorrelated statistical estimate in each channel (66% in 6 jet 4 b-tag)
- **ttH parton shower modelling**: 1-5% effect at mH = 120 GeV

ATLAS/CMS differences

Systematics:
- No QCD systematics (no QCD background?!)
- No ttH modeling
- No W+jets/HF systematic
- No JVF systematic (pileup suppression)
- Different treatment of Jet Energy Scale (ATLAS 16 NP), b-tag sys. (ATLAS 9 NP) and c-tag sys (ATLAS 5 NP): CMS one Nuis. Par.
- b and c tagging correlated
- One tt systematic uncertainty (ATLAS 3 NP)
- ttbar+HF 20% instead of 50% uncertainty

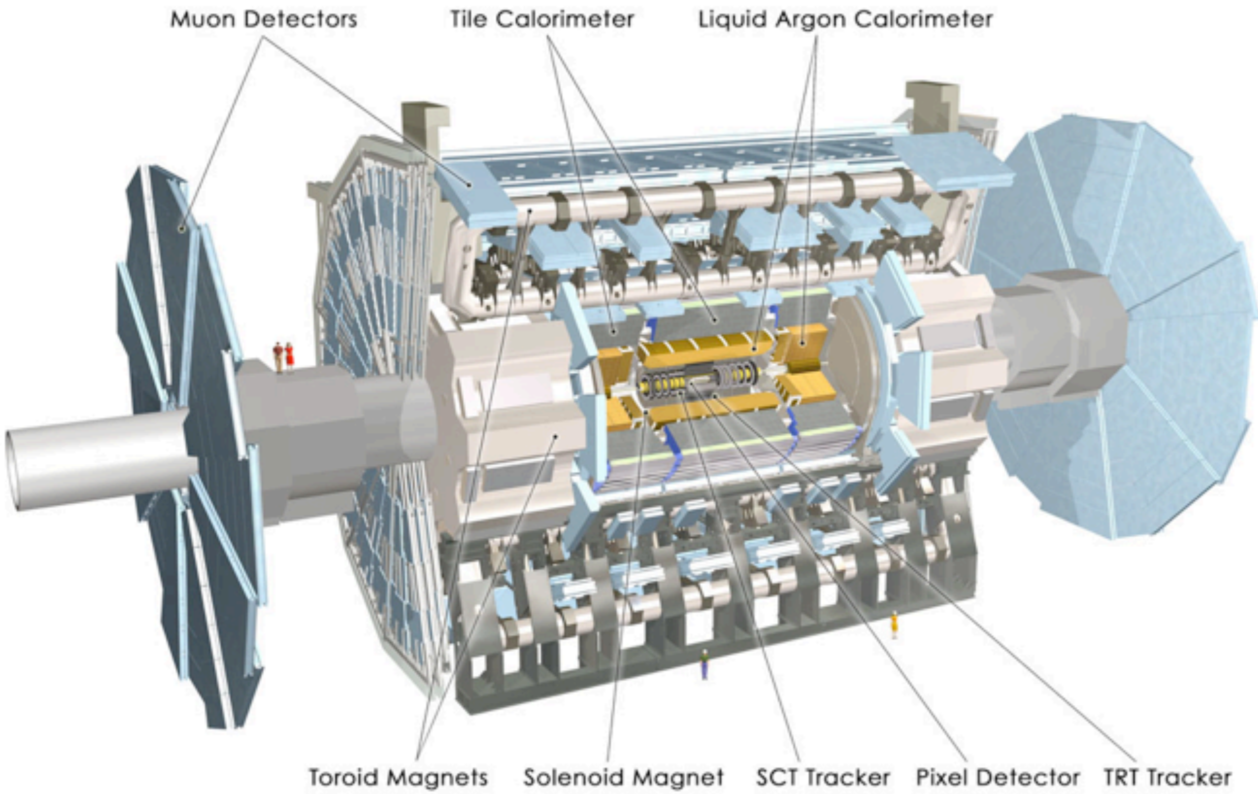
Cuts:
- Electrons and muon:
  - ATLAS p_T>20/25GeV
  - CMS p_T > 30 GeV
- Jets:
  - ATLAS pT>25GeV
  - CMS 3 leading jets pt > 40 GeV (otherwise 30 GeV)
- More signal and higher cuts. Not clear what signal sources are used

Summary:
- ATLAS using CMS systematics: 35% better
- 20% improvement from more signal
- Remaining improvement from use of Multivariate analysis (22%)

In numbers:
- σ/σ_{SM} = 10.5 -> 7.8 from systematics
- Take 22% improvement from MVA: -> 6.1
- Take 20% additional signal: σ/σ_{SM} -> 5.1 (expect)
- CMS: 4.9 (expected)

Channel	Signal		Background		$S/\sqrt{(B)}$		Ratio: $S/\sqrt{(B)}$
	ATLAS	CMS	ATLAS	CMS	ATLAS	CMS	CMS/ATLAS
6jet, 2tag	4.45	6.3	3567.38	2255.8	0.0745	0.133	1.78
4jet, 3tag	1.23	3.5	1294.14	1041.6	0.0341	0.108	3.17
5jet, 3tag	2.8	4.7	887.25	666.7	0.0940	0.182	1.94
6jet, 3tag	4.61	4.4	622.88	404.9	0.1847	0.219	1.18
4jet, 4tag	0.16	0.5	19.94	20	0.0358	0.112	3.12
5jet, 4tag	0.83	1.2	38.33	31.8	0.1341	0.213	1.59
6jet, 4tag	2.28	1.7	53.12	39.3	0.3128	0.271	0.86
Total	16.4	22.3			0.4084	0.492	1.20

The ATLAS detector



Calorimeters

- Pb/LAr accordion structure for **EM**
- provides e/γ energy measurement with $\sigma/E \sim 10\%/\sqrt{E(GeV)} \oplus 0.7\%$

- Iron scintillator tiles for **hadronic**
- provides jet and E_t^{miss} measurement with $\sigma/E \sim 50\%/\sqrt{E\ (GeV)} \oplus 3\%$

- Forward calorimeter: FCAL covers up to $|\eta|<4.9$

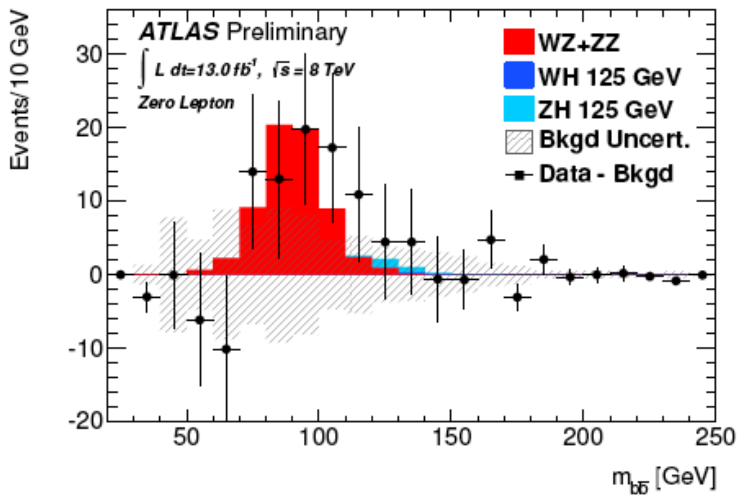
Inner detector

- for $\eta=0$, track has typically 3 Pixel, 8 SCT and 30 TRT hits
- magnetic field (~2 T) produced by solenoid
- coverage: $|\eta|<2.5$ (2.0 for TRT)
- resolution: $\sigma(p_t)/p_t = 0.05\% \oplus 1\%$

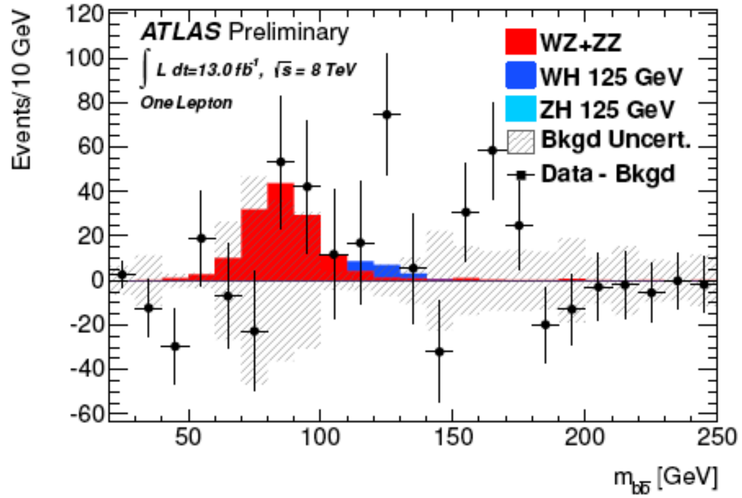
Muon spectrometer

- coverage: $|\eta|<2.7$
- magnetic field (~0.5 T) produced by toroids
- $\sigma(p_t)/p_t \approx 10\%$ for $p_t = 1TeV$

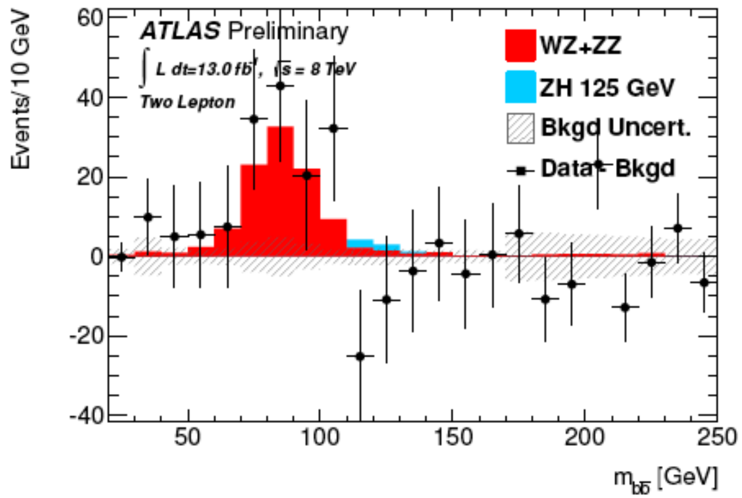
DIBOSON

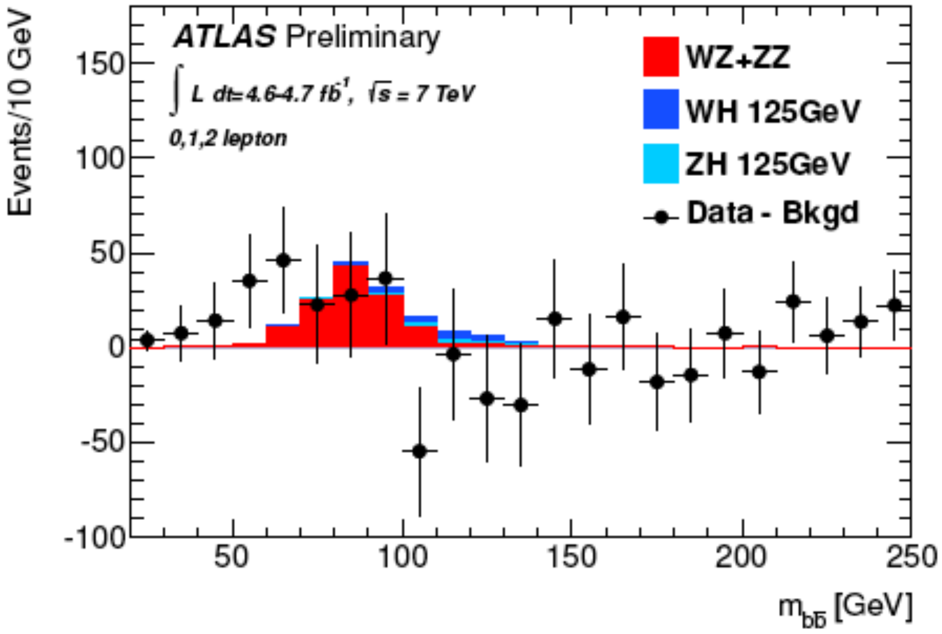


(a) Zero Lepton

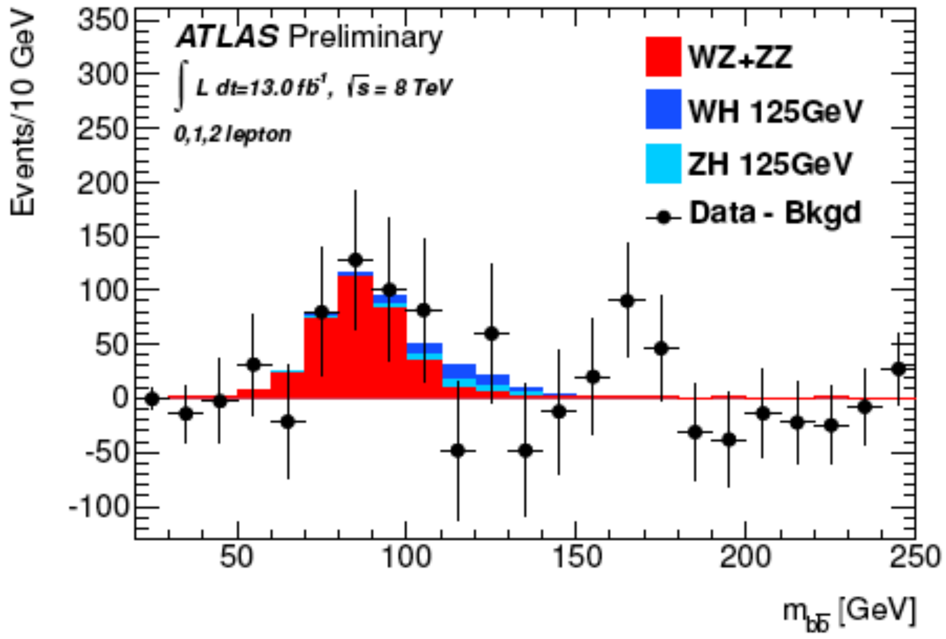


(b) One Lepton





(a) $\sqrt{s} = 7$ TeV



(b) $\sqrt{s} = 8$ TeV