Higgs in ATLAS

A Look at $H \to b\bar{b}$

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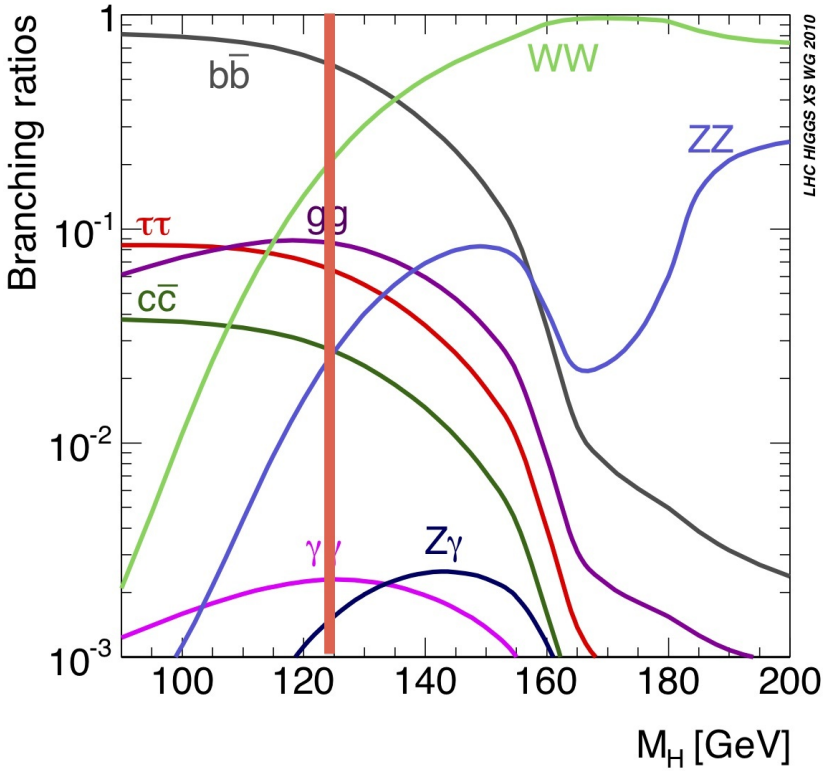
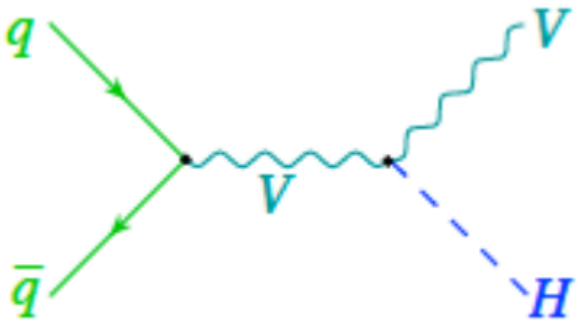
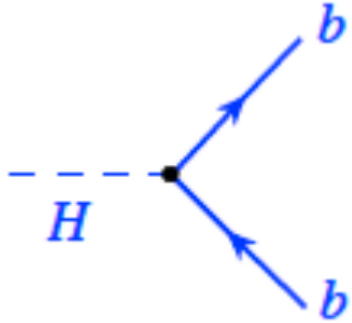
Introduction

- With the boson discovery using $H \to \gamma\gamma$ and $H \to ZZ^*$, $H \to b\bar{b}$ very important to test if SM Higgs, constrains coupling to fermions.
- Gluon-gluon-fusion nearly unattainable, thus associated production used, to allow for clean leptonic decay.
- $t\bar{t}H$ also possible, with some results shown at the end of this talk.







$H \to b\bar{b}$ - Analysis Strategy

- Analysis divided into three channels: 0 ($\nu\nu bb$), 1 ($l\nu bb$) and 2 ($llbb$) leptons ($l = e, \mu$).

0-lepton

Missing transverse energy $(E_T^{miss}) > 120$ GeV

1-lepton

$40 < m_T^W < 120$ GeV

$\left(m_T^W \equiv \sqrt{2p_T^l E_T^{\text{miss}}(1 - \cos\Delta\phi)}\right)$

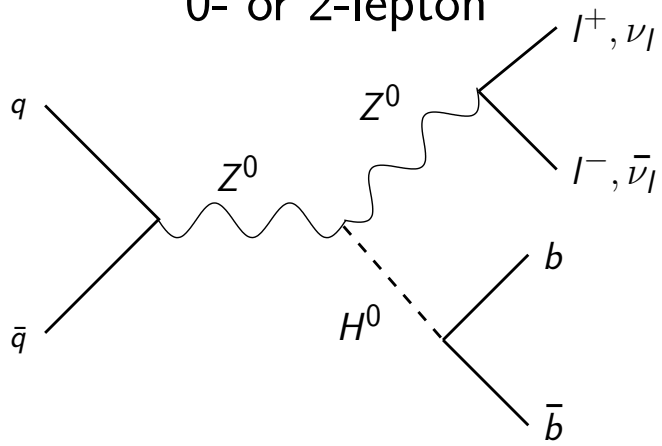
and $E_T^{miss} > 25$ GeV

2-lepton

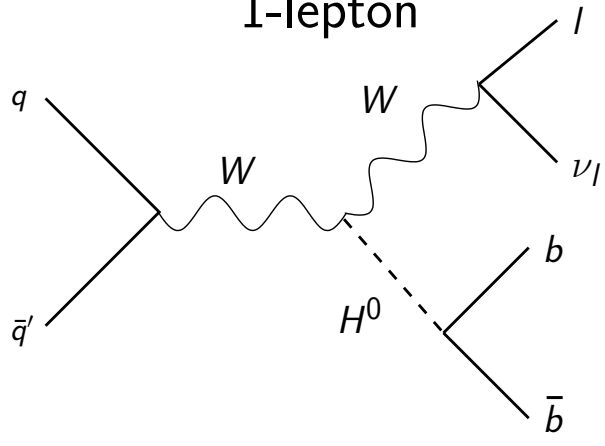
$83 < m_{ll} < 99$ GeV,

$E_T^{miss} < 60$ GeV

0- or 2-lepton



1-lepton



(see ATLAS-CONF-2012-061 for more)

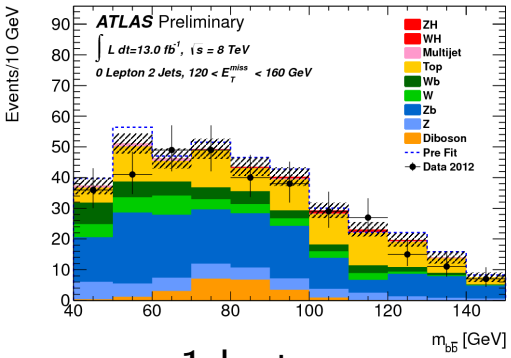
$H \to b\bar{b}$ - Analysis Strategy

- **0-lepton** subdivided into regions of E_T^{miss}, **1-lepton** in p_T^W (using E_T^{miss} and l) and **2-lepton** in p_T^Z (using ll).
  - Great benefit in dividing in regions of "vector boson boost", since $S/\sqrt{B}$ improves in higher boost regions.
- Mass resolution of bb pair improved by adding energy from muons within the b-jets.
- Additional cuts on ΔR_{bb}, p_T^{miss} (track based missing p_T), and $\Delta\phi[E_T^{miss}, p_T^{miss}/\text{jet}/b\bar{b}]$ depending on topological region. Cuts are meant to enhance signal while rejecting more background in each region.
- **Analysis run on 4.7 fb^{-1} of 7 TeV (2011) and 13 fb^{-1} of 8 TeV (2012) data.**

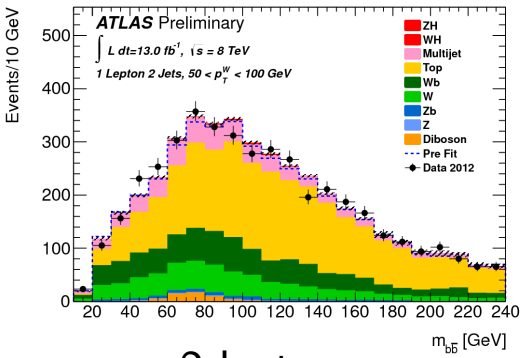
Backgrounds

- Background's quite large in this channel, needs to be very well understood for Higgs search.
- Many backgrounds to consider:
  - Z+jets (dominant for 0, 2 lepton)
  - t and $t\bar{t}$ (significant for 0, 1 lepton)
  - W+jets (significant for 0, 1 lepton)
  - Diboson (WW, WZ and ZZ)
  - Multijet
- Multijet background derived from data-driven techniques (not presented).
- In general, background shapes taken from simulation, and normalized using data.

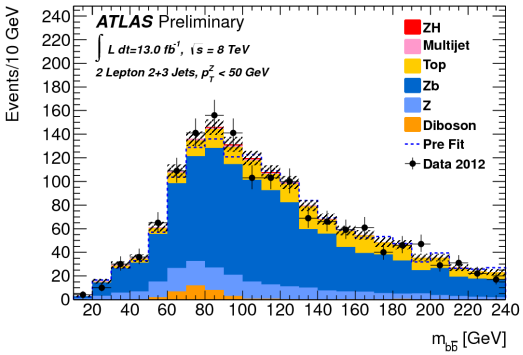
0-lepton



1-lepton



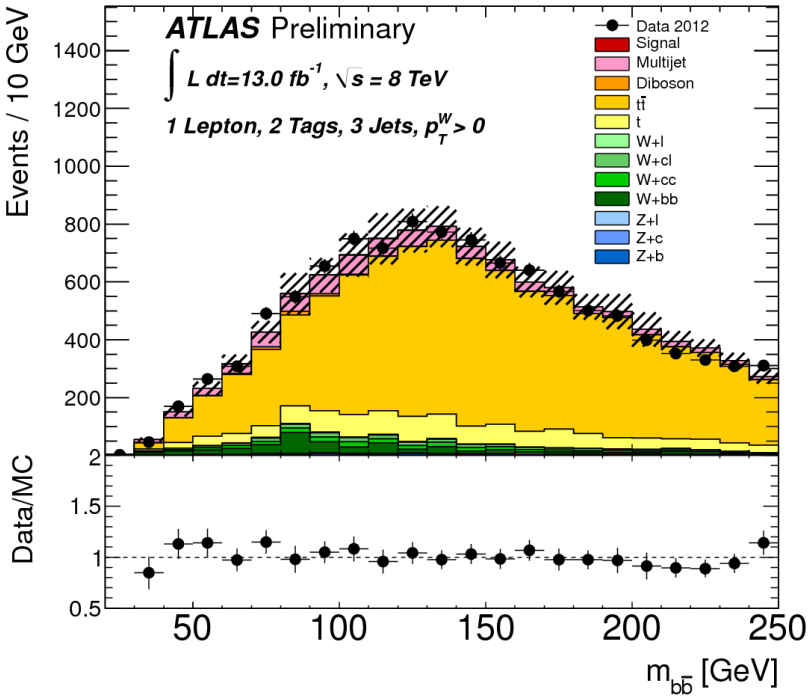
2-lepton



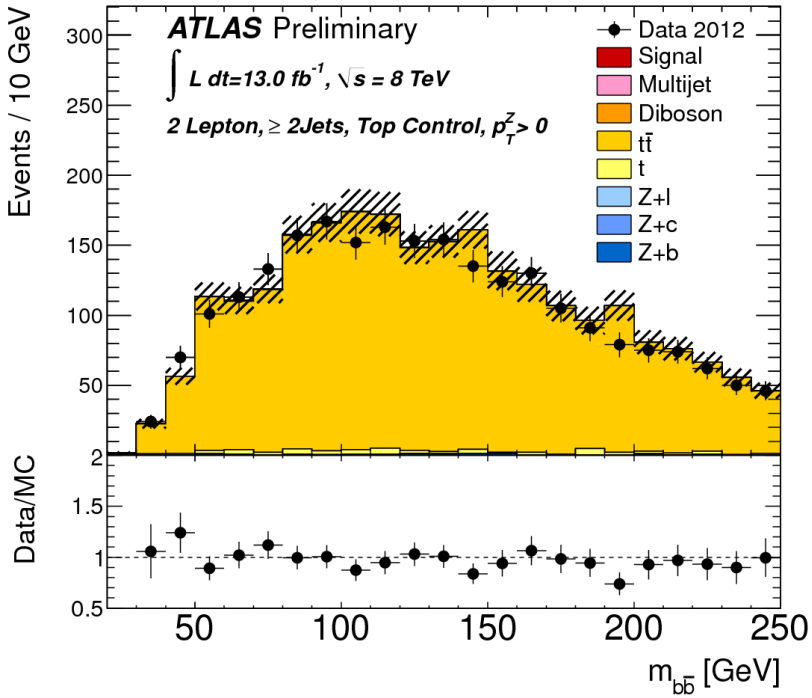
Background - Top Control Samples

- Top normalization taken by looking at 1-lepton region with an additional jet, and at 2-lepton region with inverted m_{ll} and E_t^{miss} cuts.

1-lepton



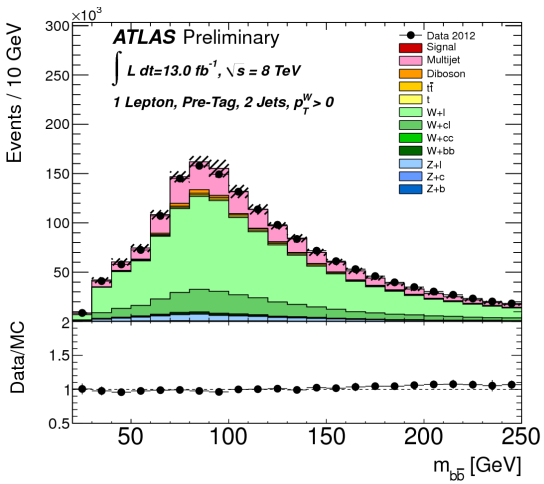
2-lepton



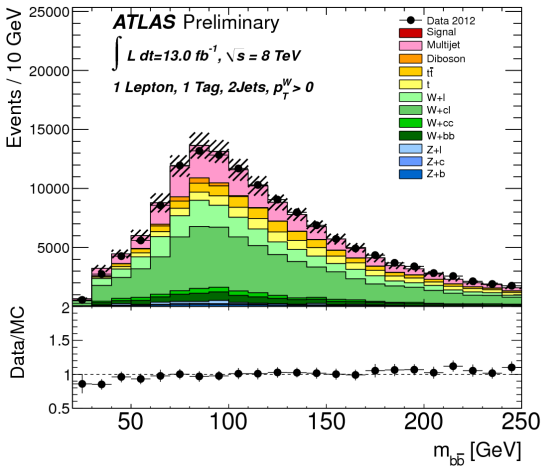
Background - V+jets Control Samples

- V+jets control regions divided by number of b-tagged jets: 0, 1, or 2.
- Normalizations determined by a maximum likelihood fit to all control and signal regions, in 1- and 2-lepton channels.
- Z+light, $Z + c$, $Z + b$, W+light, $W + c$, $W + b$, and top are all allowed to float in the fit.

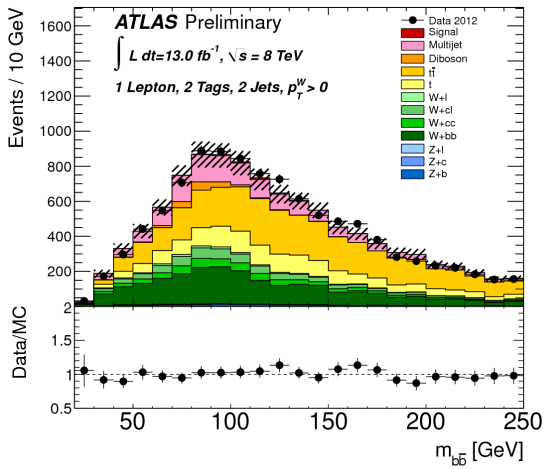
1-lepton, 0+ b's



1-lepton, 1 b



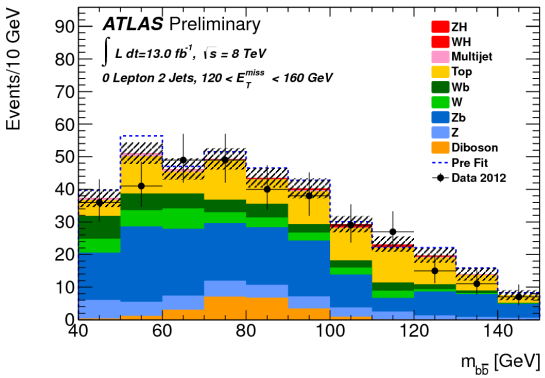
1-lepton, 2 b's

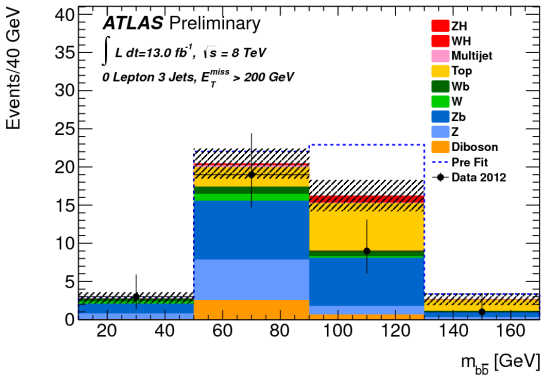


m_{bb} distributions (a selection)

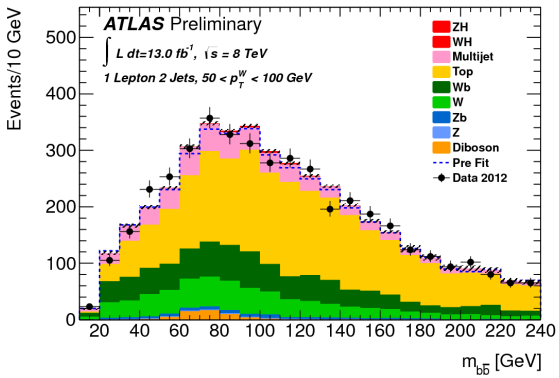
- Result is 16 plots of m_{bb} (6 in 0-lepton, 5 in 1-lepton, 5 in 2-lepton) in the signal region post-fit (pre-fit in dashed line).
- Used in exclusion limit calculation.

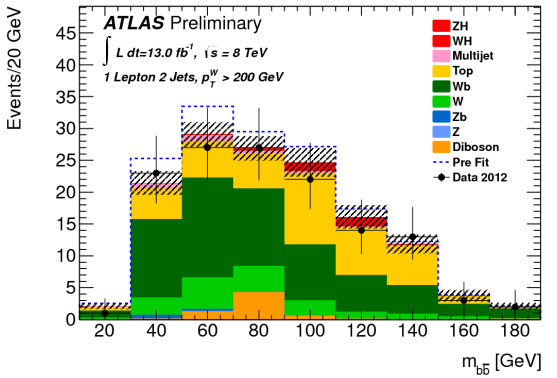
0-lepton



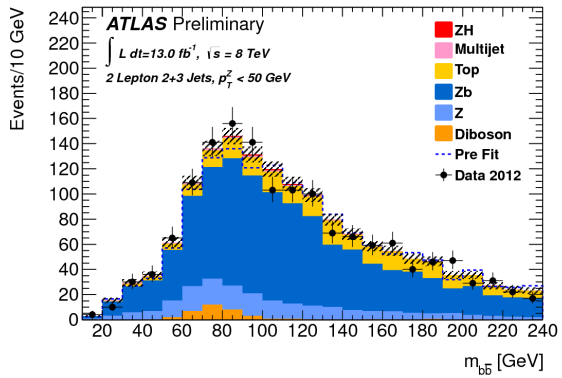


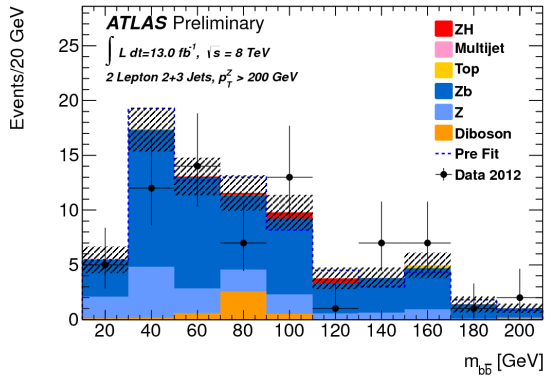
1-lepton





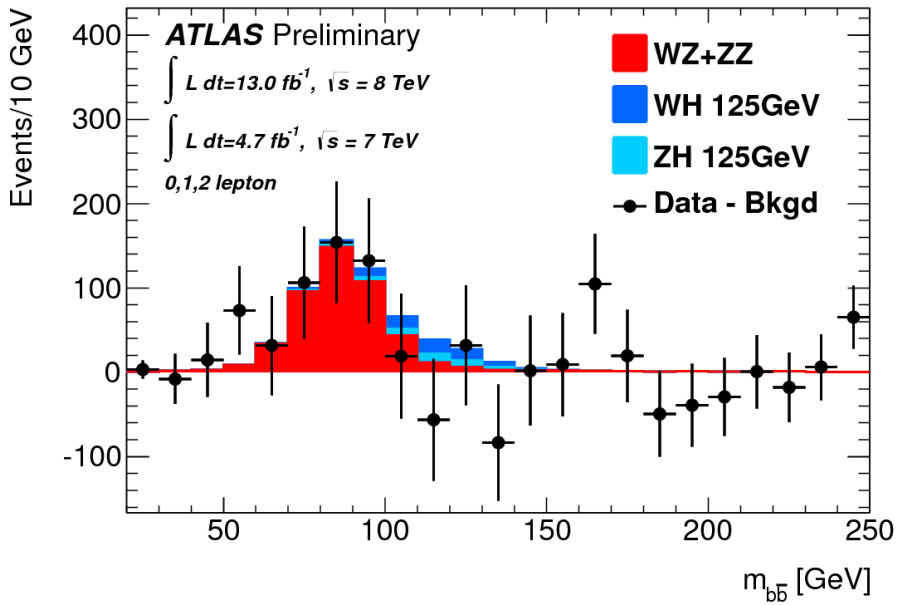
2-lepton





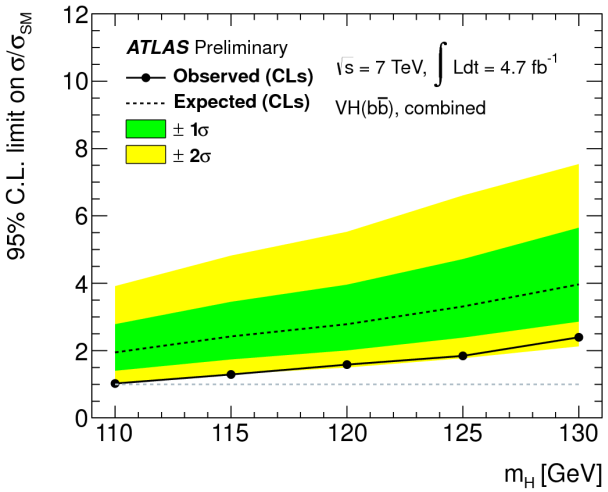
Analysis Validation

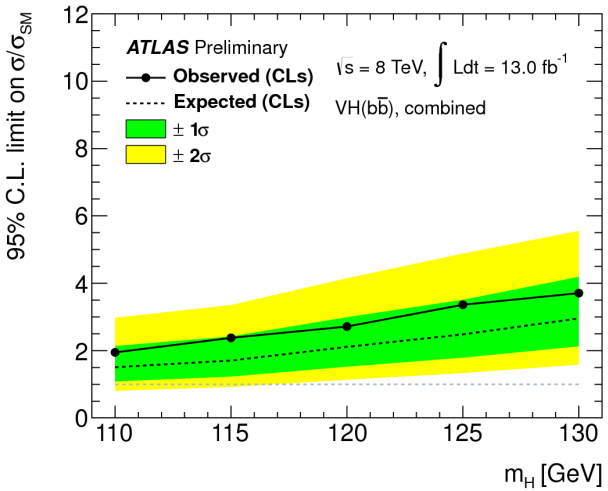
- Diboson production (WZ and ZZ) with $Z \to b\bar{b}$ has similar signature, but with 5X the cross section of SM Higgs.
- Thus, to validate the analysis, separate fit performed to search for diboson processes.
- Results in clear excess at expected mass range, with a $\sigma/\sigma_{SM} = \hat{\mu} = 1.09 \pm 0.20(\text{stat}) \pm 0.22(\text{syst})$.
- Corresponds to 4σ significance; agrees with $\hat{\mu}_{SM} = 1$.

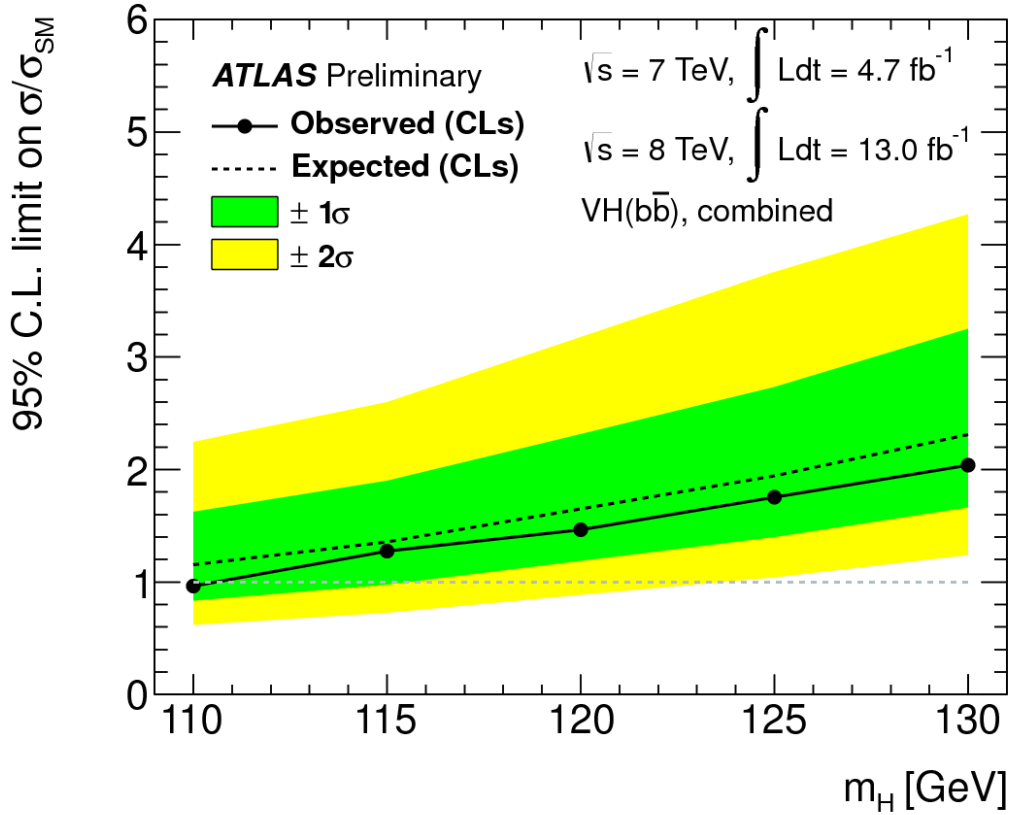


Limit Calculation

- The 95% CL_S limit is calculated as a function of Higgs mass.
- All channels are combined.



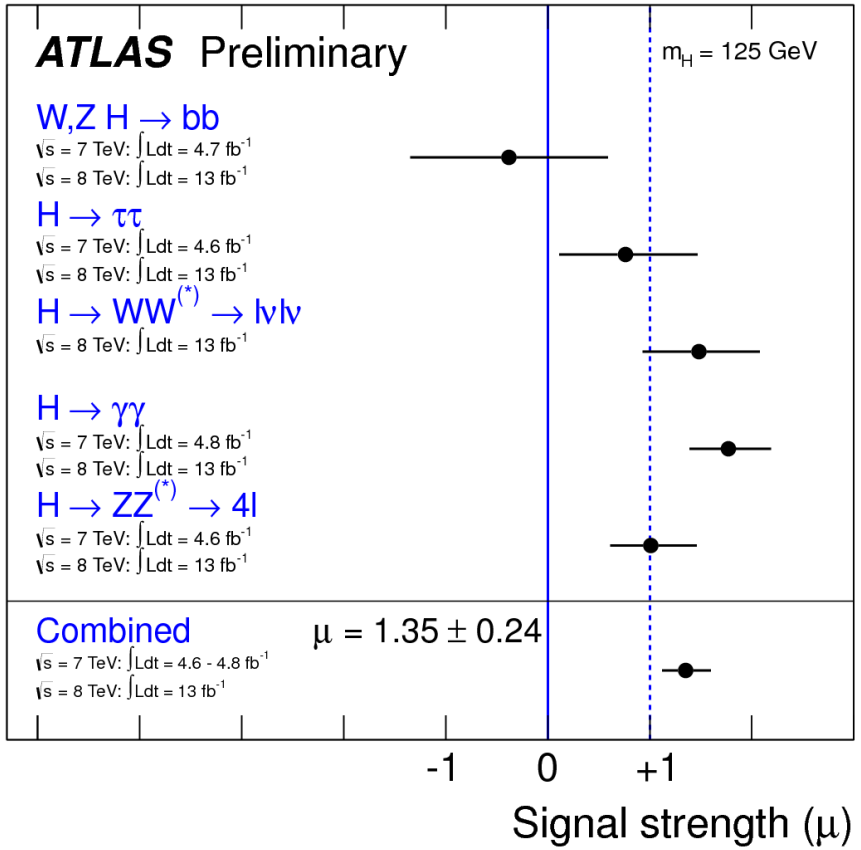




Higgs Signal Strength

- For a $m_H = 125$ GeV, we have an observed (expected) limit of 1.8 (1.9) $\times \sigma_{SM}$.
- This amounts to a $\mu = -0.4 \pm 0.7(\text{stat}) \pm 0.8(\text{syst})$.
- No excess is observed.

(see ATLAS-CONF-2012-170 for more)



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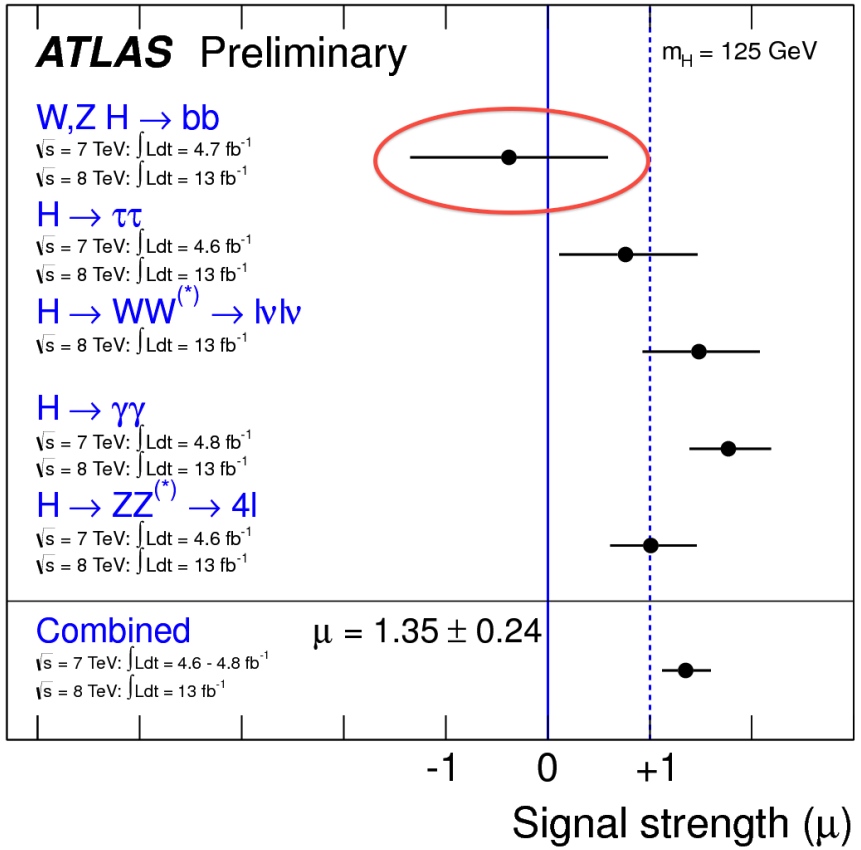
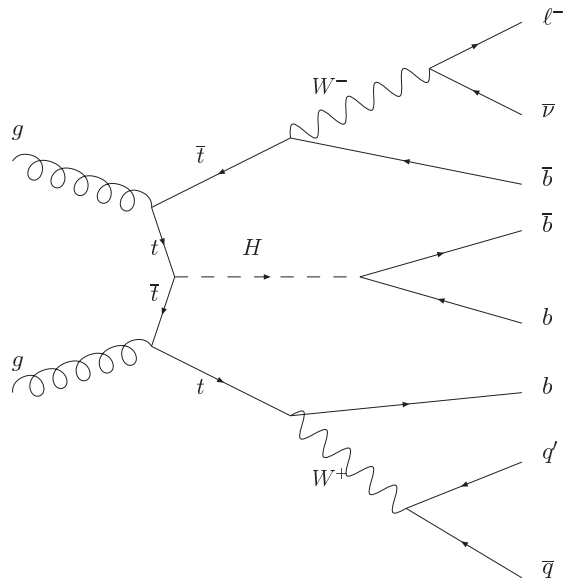
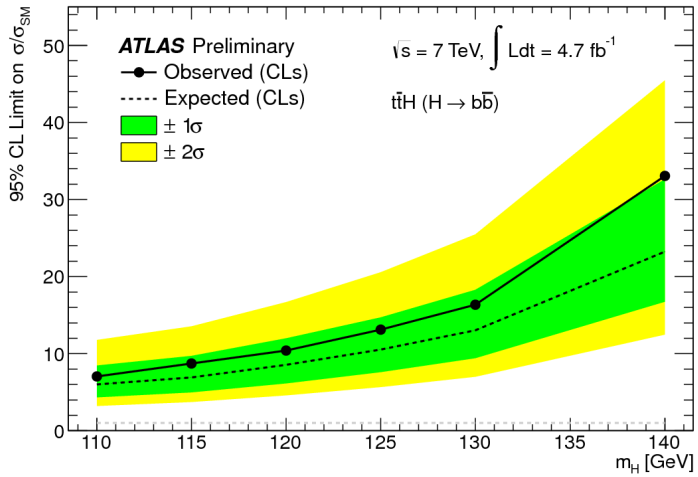


$t\bar{t}H$, $H \to b\bar{b}$

- Very challenging channel.
- Use 4.7 fb^{-1} of $\sqrt{s} = 7$ TeV (2011) data.
- 9 topologies used, based on jet, and b-jet multiplicities.
  - Signal enriched in ≥ 5 jets, ≥ 3 b's.
  - Others used for background determination.
- Results in observed (expected) 95% exclusion limits ranging from 7 (6) to 33 (23) over $110 \leq m_H \leq 140$ GeV.

(see ATLAS-CONF-2012-135 for more)





Conclusions

- Higgs search was performed using the VH, $H \to b\bar{b}$ channel.
- Observed (expected) combined 95% CL_S exclusion limit for $m_H = 125$ GeV measured to be 1.8 (1.9), improvement on previous result of 4.6 (4.0).
- $m_H = 110$ GeV excluded at the 95% CL.
- Diboson signal strength in agreement with SM.
- $t\bar{t}H$ also considered, with 7 TeV analysis yielding observed (expected) limits of 13.1 (10.5) for $m_H = 125$ GeV.
- Updated results on full 2011/2012 dataset coming early 2013!

Thanks for listening!

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Appendix - $H \to b\bar{b}$ - Analysis Strategy

- Analysis divided into three channels: 0 ($\nu\nu bb$), 1 ($l\nu bb$) and 2 ($llbb$) leptons ($l = e, \mu$).
- Each channel has optimized cuts to increase sensitivity, with some cuts common to all channels:
  - 2 jets $p_{T,j1} > 45$ GeV, $p_{T,j2,j3} > 20$ GeV,
  - 2 b-tags, with 70% efficiency per tag (mistag rate of $\sim$1%).
- 0 lepton channel most sensitive to ZH, 1 lepton to WH, and 2 lepton to ZH.

0 leptons	**1 lepton**	**2 leptons**
$ZH \to \nu\nu bb$	$WH \to l\nu bb$	$ZH \to llbb$
No leptons	No additional leptons	No additional leptons
$E_t^{miss} > 120$ GeV	$E_t^{miss} > 25$ GeV	$E_t^{miss} < 60$ GeV
E_t^{miss} trigger	$40 < m_T^W < 120$ GeV	$83 < m_Z < 99$ GeV
≤ 1 extra jet	Single lepton trigger	Single and dilepton trigger
	0 extra jets	

Appendix - Systematics

- Experimental uncertainties dominated by:
  - b-tagging and Jet Energy Scale calibration
  - Top, W, and Z modelling
  - Luminosity, lepton, multijet, and diboson.
  - MC Statistics
- Theoretical uncertainties dominated by:
  - Signal branching ratio and cross section uncertainty
  - Single top, $t\bar{t}$ normalization

Signal Systematics

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 Systematics

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