Search for H->bb and Measurement of the Production Cross Section of a W+b-jets with the ATLAS Detector

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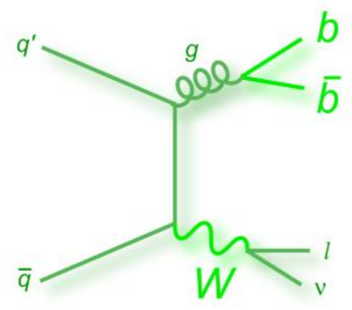
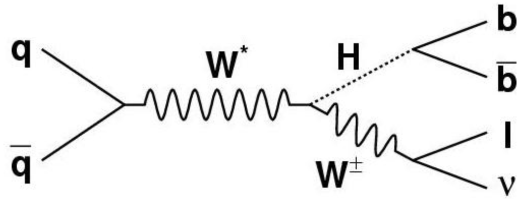
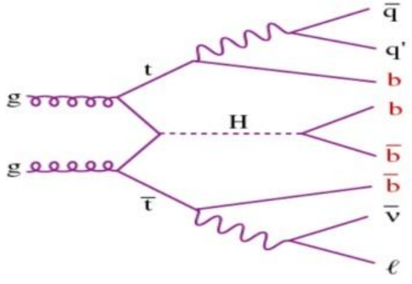
Outline

- W+ heavy flavor jet production
  - W+b cross section measurements
    - Theoretical consideration and motivation
    - Measurement strategy
    - ATLAS results



- Higgs boson decaying to b-quark pair
  - VH channel
    - H->bb importance
    - ATLAS analysis
    - Limits extracted with ATLAS
  - ttH channel
    - ttH importance
    - Quick overview of the current ATLAS results





Wb Measurements

arXiv:1302.2929

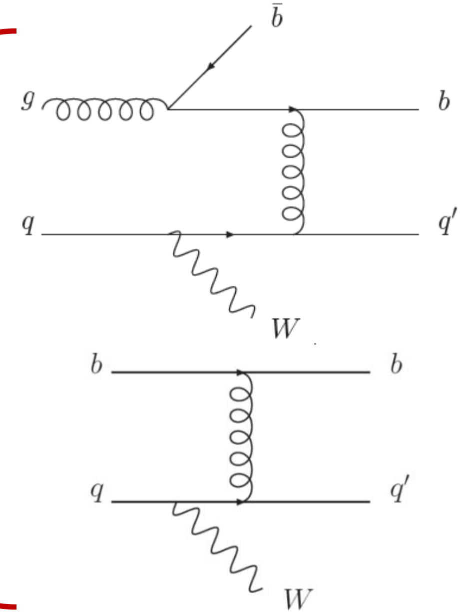
W+b-jets: the Theory Side

- Many improvements from the theoretical side
- Some phenomenological considerations
  - Choice of QCD scale not obvious (W,Z or associated jets or sum of both): need higher order calculations
  - Testing recent NLO computations and state-of-the-art generators (NLO+PS)
  - Testing hard radiations: ME-PS matching (e.g. MLM, CKKW)
  - Testing theoretical effects in MC: b/c-quarks mass effects, b-quark in the initial state (4FNS vs 5FNS)

Previous measurement with some tension between data and predictions

	Measured [pb]	Theory [pb]
CDF	**2.74 ± 0.5**	**1.22 ± 0.14**
D0	**1.05 ± 0.12**	**1.34^{+41}_{-34}**
ATLAS (2010 data)	**10.2 ± 3.2**	**4.8 ± 1.3**

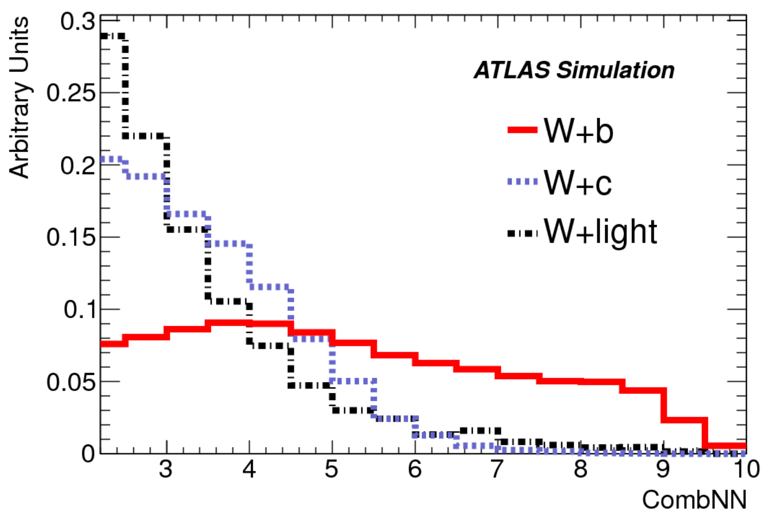
Initial b-quark from PS Vs initial b-quark from PDF



W+b-jets: Measurement Strategy

- Selection:
  - One isolated high-pT lepton: pT>25 GeV, |eta|<2.5
  - W boson selection: E_T^{miss}>25GeV, mT(W)>60 GeV
  - One or two jets: pT>25 GeV, |eta|<2.1
  - Exactly one b-tagging jets
    - CombNN tagger: 50% b-tagging efficiency, 10% (1‰) for c-jets (light jets)
  - Veto additional b-tagged jets to remove ttbar
    - The measurement is unfolded to events with one or two truth b-jets

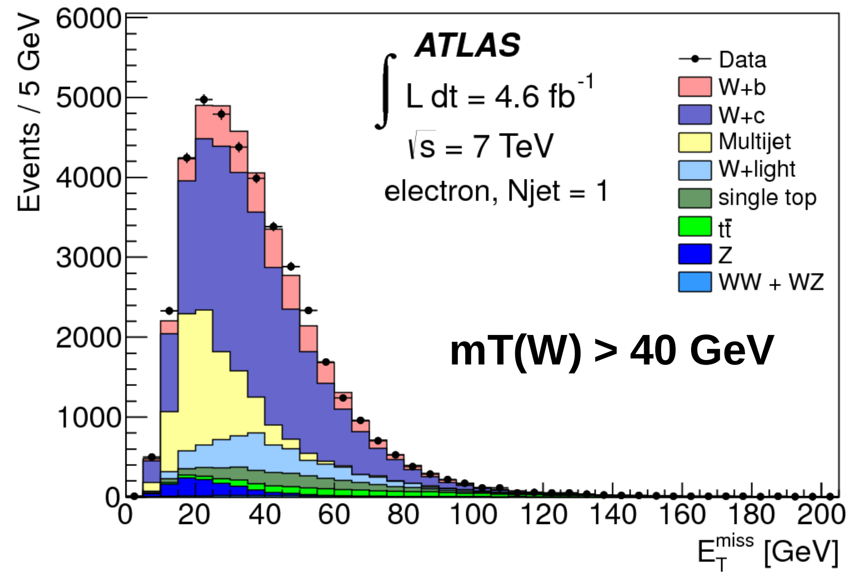
- b-tagging (combNN tagger)
  - Combined secondary vertex and impact parameter (using NN) taggers
- Analysis strategy
  - Template fit of the combNN distributions for W + b, c and light jets
  - Backgrounds also included in the fit with additional constraints from control regions

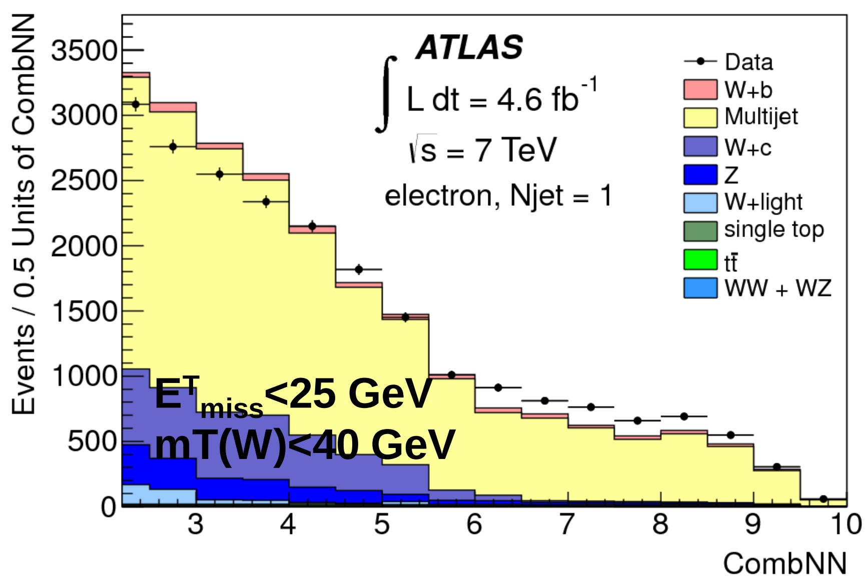


W+b-jets: Multijet Backgrounds

- Normalization
  - Template fit to E^T_{miss}
    - relaxed mT(W) cuts
  - Multijet template from data
    - Inverted isolation and some identification cuts for the lepton
  - Non-multijet template from MC
  - 50% uncertainty on the fitted yields

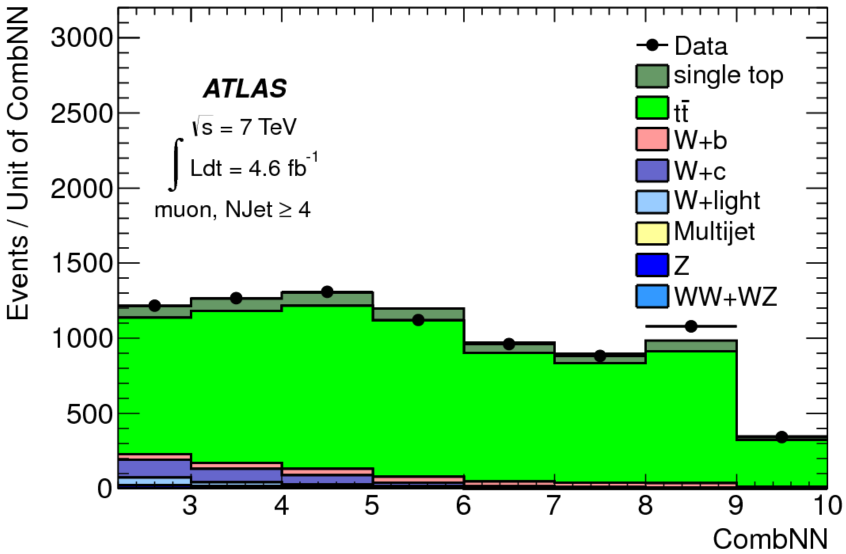
- CombNN shape
  - Control region with inverted E^T_{miss} and mT(W) cuts
  - Mismodeling assigned as systematic uncertainties (1-10%)

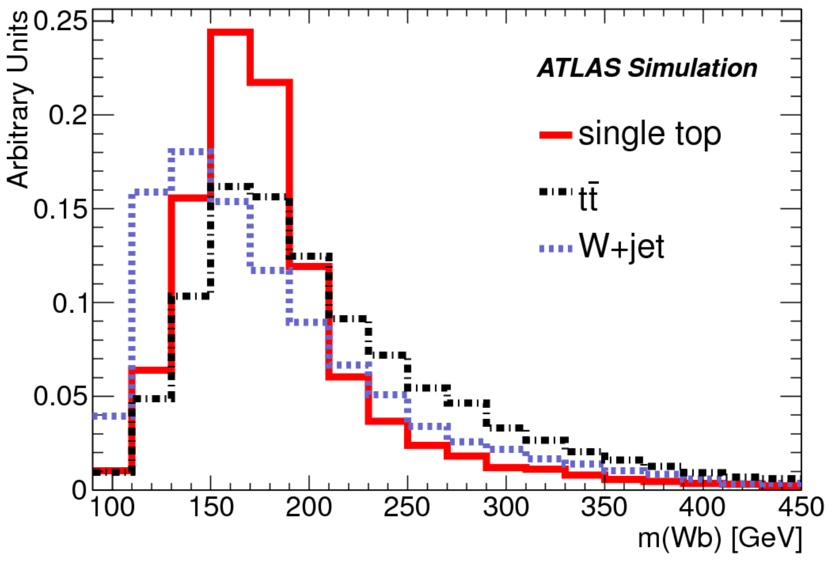




W+b-jets: Other Backgrounds

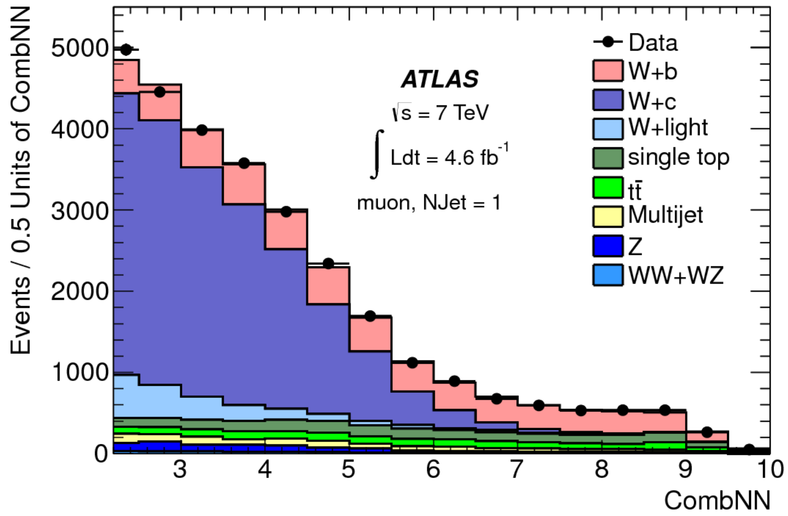
- ttbar control sample
  - Normalized with events with high-jet multiplicity
  - Extrapolate to signal region using MC
  - 10% uncertainty on the ttbar normalization
  - Same region used to control the b-jet combNN shape
- Single top
  - Fit m(Wb) distribution in the 2-jets bin (20% uncertainty)
  - MC is used in the 1-jet bin (50% uncertainty)
- Other backgrounds from MC
  - Z+jets and di-boson
  - 10% uncertainty

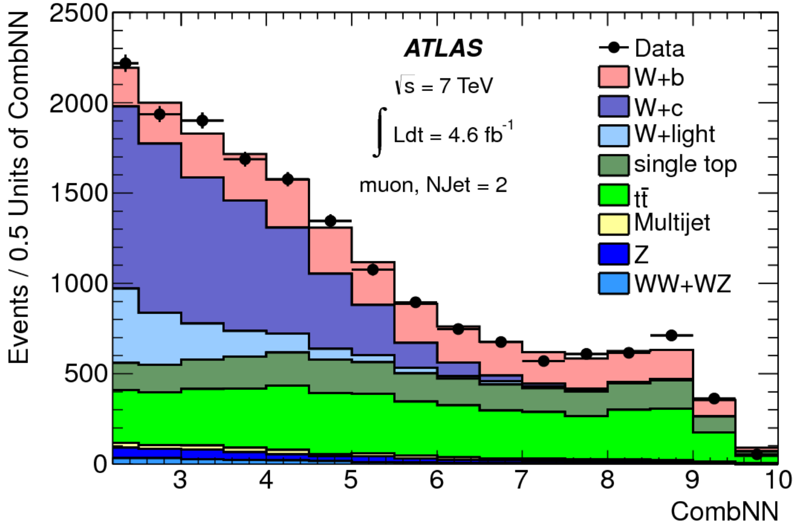




W+b-jets: Fitting the Wb Contribution

- Fit W+b, W+c and W+light contributions to the combNN distribution
  - Background included in the fit as nuisance parameters with Gaussian constraints
- Very large contribution from the W+c background
  - But good separation at high combNN values
- Large contribution from top backgrounds in the 2-jets bin
- Fit also performed in 4 pT-b-jet bins for the differential measurement





W+b-jets: Unfolding Detector Effects

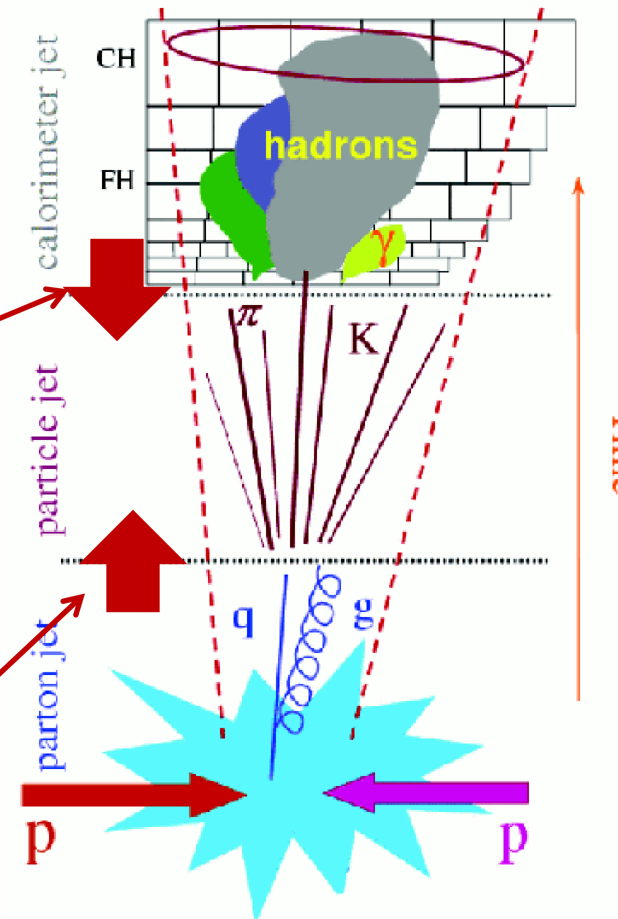
Cross section defined at particle level and in a fiducial range corresponding to the ATLAS detector and trigger acceptance

$$\frac{d\sigma}{d\xi} = \frac{1}{\Delta\xi} \frac{N_{yields}}{\int L dt} U(\xi)$$

Fit results

Correction factor

- Correction factor from detector level to particle level
  - Correct for trigger, reconstruction, and identification efficiencies (measured in data)
  - Differential measurements (resolution effects):
    - Iterative Bayesian unfolding



- Fixed order calculations corrected from parton to particle level (using MC)

W+b-jets: Main uncertainties

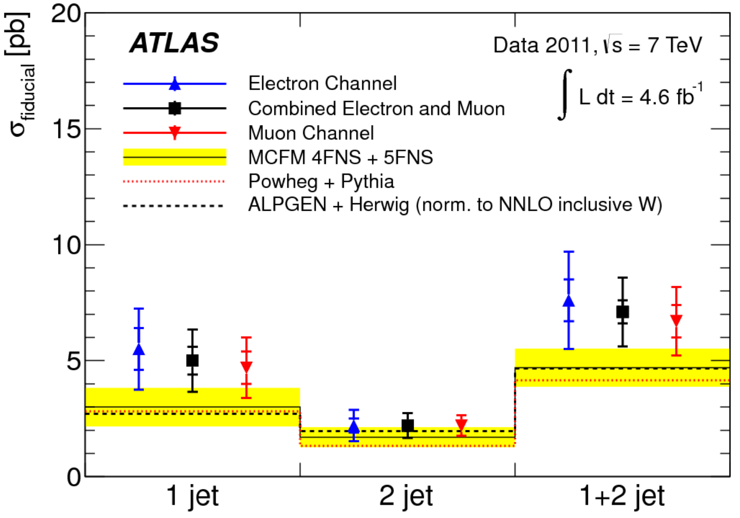
- Dominated by systematic uncertainties
- Main systematics
  - Jet and MET energy scale and resolution
  - b-tagging efficiencies
  - b-tagging template shapes
  - MC modeling

- Main uncertainties for correcting fixed order calculation (MCFM) to particle level
  - Non-perturbative (PS, hadronization and UE): 2-4%
  - MPI: 7-10%
  - 23% scale uncertainty

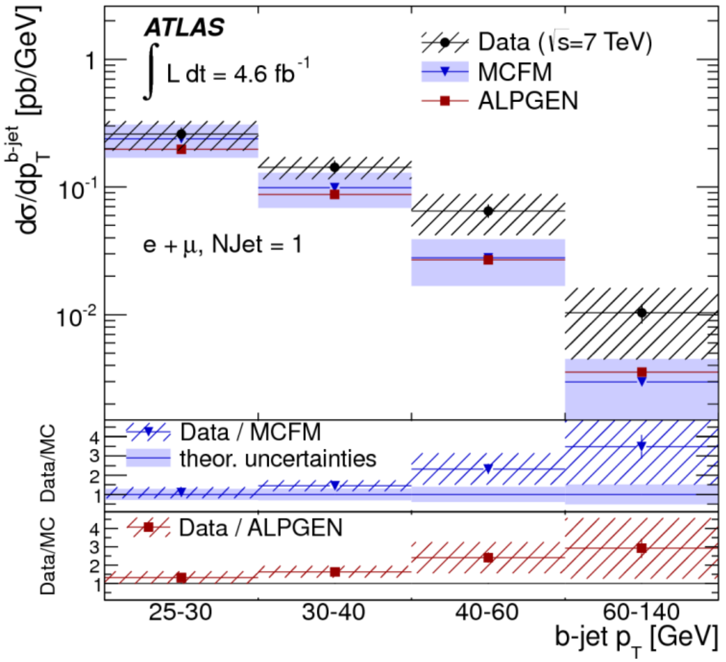
Fiducial cross-section [pb]			
	1 jet	2 jet	1+2 jet
σ_{fid}	5.0	2.2	7.1
Statistical uncertainty	0.5	0.2	0.5
Systematic uncertainty	1.2	0.5	1.4
Breakdown of systematic uncertainty [%]			
Jet energy scale	15	15	15
Jet energy resolution	14	4	8
b-jet efficiency	6	4	5
c-jet efficiency	1	1	0
light-jet efficiency	1	3	2
ISR/FSR	4	8	3
MC modelling	8	4	6
Lepton resolution	1	1	0
Trigger efficiency	1	2	2
Lepton efficiency	1	2	1
$E_{\text{T}}^{\text{miss}}$ scale	3	6	2
$E_{\text{T}}^{\text{miss}}$ pile-up	2	2	2
b-jet template	3	5	4
c-jet template	4	2	3
light-jet template	0	0	0
Multijet template	2	2	2
Total syst. uncertainty	24	23	20

W+b-jets: Results

- Cross section measured in the 1-jet and 2-jets bins with at least one b-jet
  - Good agreement with NLO predictions and Alpgen MC (normalized to NNLO inclusive W production)



- Differential measurement shows a trend with excess in data going to higher b-jet pT
  - Still in agreement within uncertainties



- Interesting measurement for the future
  - Differential as function of pT(W)
  - DeltaR(b,b) or m(bb)

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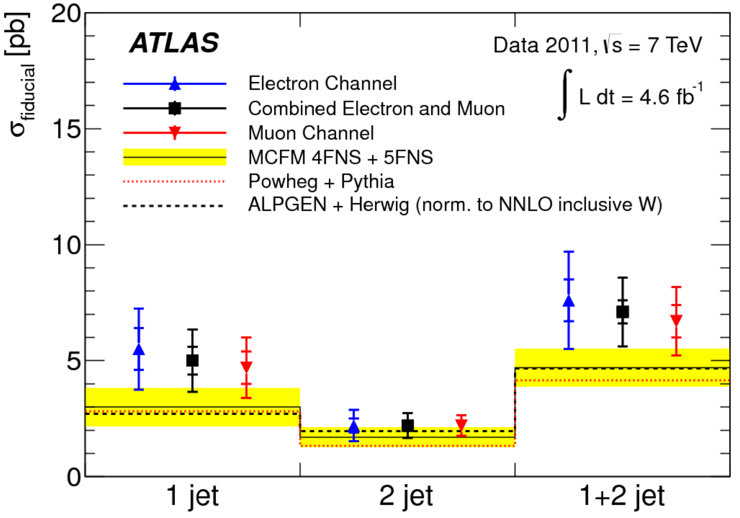
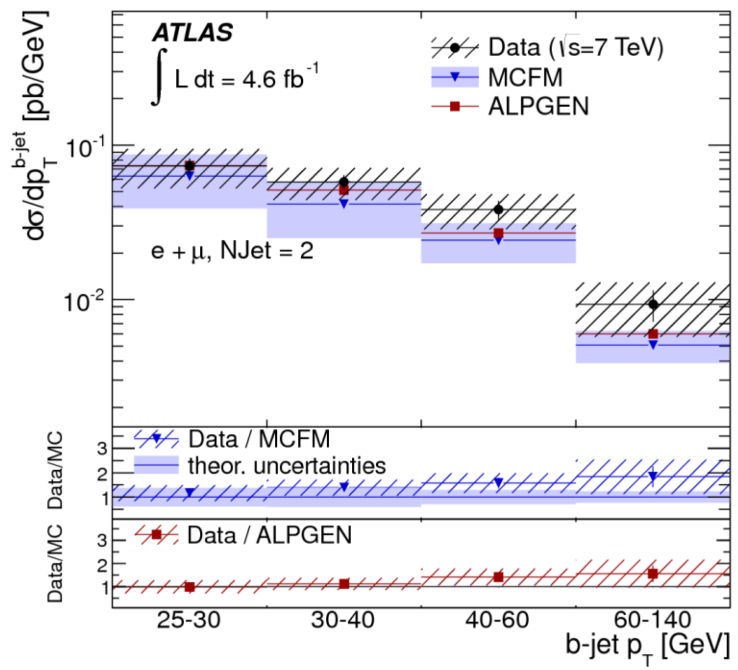
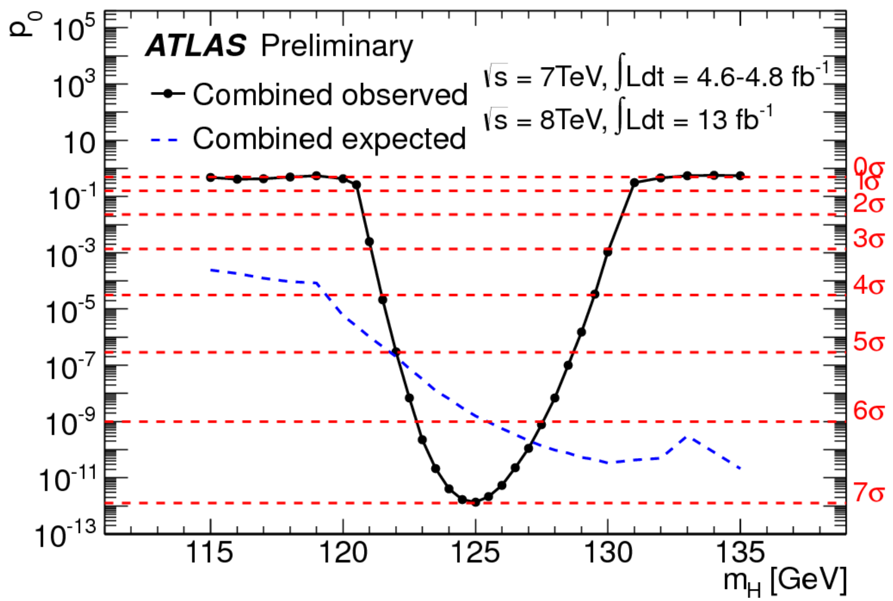




Now Lets Switch to the H->bb

Observation of a Higgs-like Boson

ATLAS-CONF-2012-170



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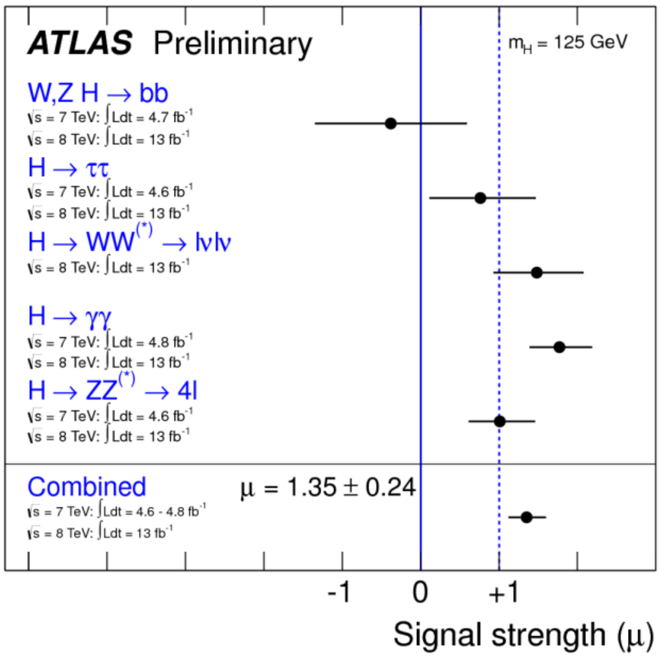
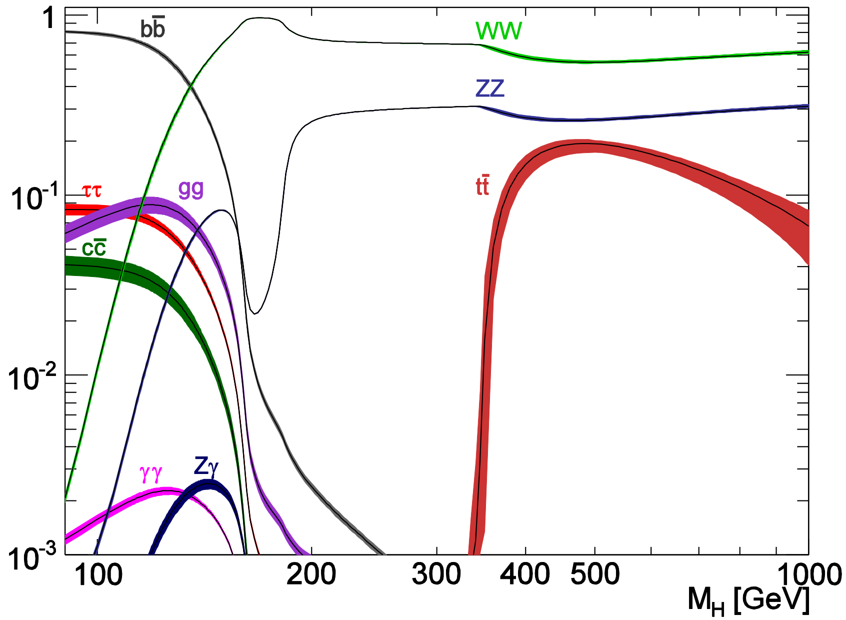
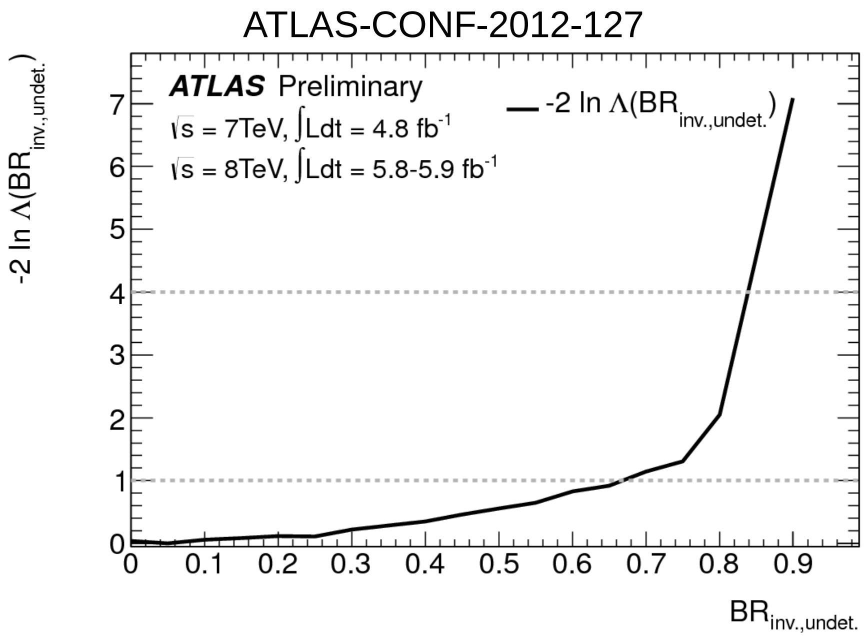


- In July 2012 ATLAS and CMS announced the discovery of a new boson compatible with the SM Higgs boson
  - New boson observed decaying into photons and Z (4 leptons) and W (leptons + MET) bosons
- Decay into fermions not yet observed at the LHC
  - Tevatron experiment reported an excess (~3 sigma) in H->bb in the same mass range

VH(H->bb) analysis

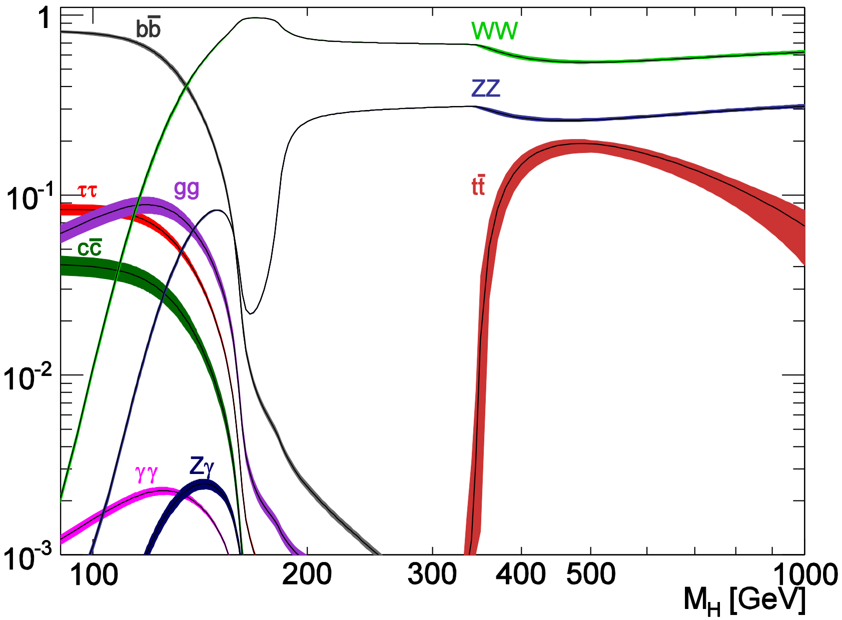
H->bb Importance

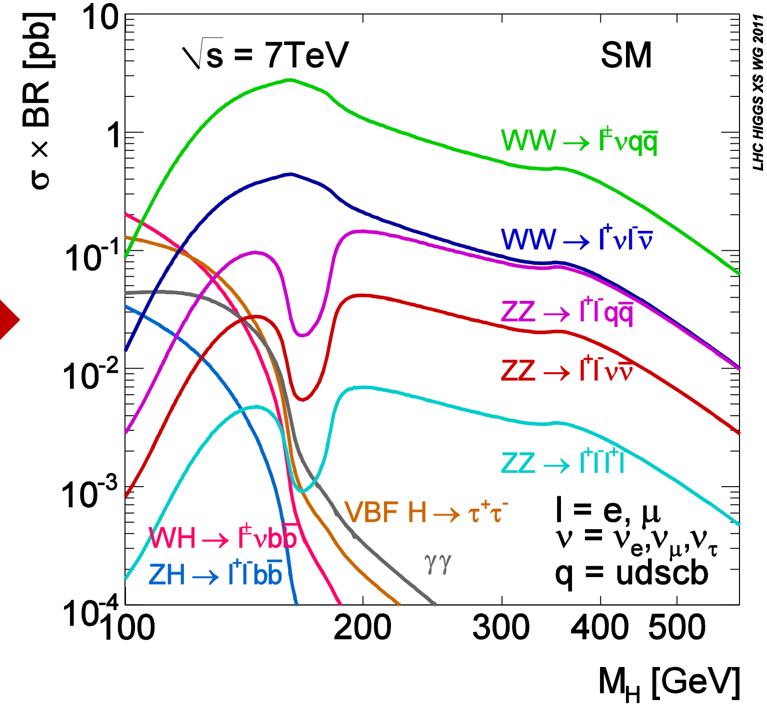




- Obviously the observation H->bb and H->ττ is mandatory to establish the presence of the SM Higgs boson
- Constraint on the total decay width and on eventual decay to invisible particles is particularly sensitive to the uncertainties on the H->bb channel
  - Total width not accessible at the LHC
  - H->bb presents the largest partial width

VH->bb: Overview





- gg->H->bb can't be extracted from QCD background
- Need associated production e.g. with a W/Z boson
  - Provide leptons or large E^{T}_{miss} to separate QCD background
  - Advantage of the large branching ratio diluted by the lower associated production cross section
  - VH->bb channel also present large backgrounds which makes them hard compared to H->bosons channels

VH(H->bb): Strategy

- Using a cut based analysis
  - Split to 0,1 or 2-lepton final state
  - Split into 5 pT(V) bins (3 for 0-lepton)
  - Optimize cuts independently in each of the bins

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			-	

- 0-lepton selection
  - E_T^{miss} > 120 GeV
  - MET cleaning cuts

- 2-lepton selection
  - 2 high-pT isolated leptons
  - E_T^{miss} <60 GeV
  - Z boson mass window

- 1-lepton selection (WH)
  - Exactly one isolated high-pT lepton
  - High E_T^{miss} and mT(W) cuts
  - mT(W)<120 GeV to reduce top

- Jet selection
  - Exactly 2 jets: pT1>45 GeV, pT2>20 GeV
  - Exactly 2-btags

Likelihood fit using the m(bb) invariant mass to extract the signal yields: expressed as a function of the SM cross section

VH(H->bb): Background Estimation

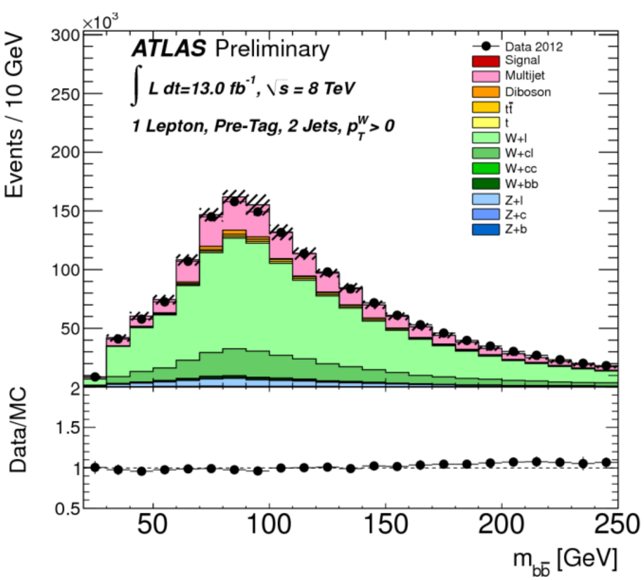
- Main backgrounds:
  - 0-lepton: top, Z+jets, W+jets
  - 1-lepton: top, W+jets
  - 2-lepton: Z+jets
- Multijet background
  - Negligible in 0-lepton
  - ~Negligible in 2-leptons [m(l,l) sideband]
  - 1-lepton channel
    - template fit to the E_T^{miss} distribution
    - multijet template from data by inverting lepton isolation cuts (same as for Wb analysis)
- top, W+jets and Z+jets backgrounds (details next slide)
  - Estimated from a simultaneous fit in several control regions
  - The same control regions are used to estimate corrections/systematics to the pT(V) and m(bb) distributions
- Diboson from MC

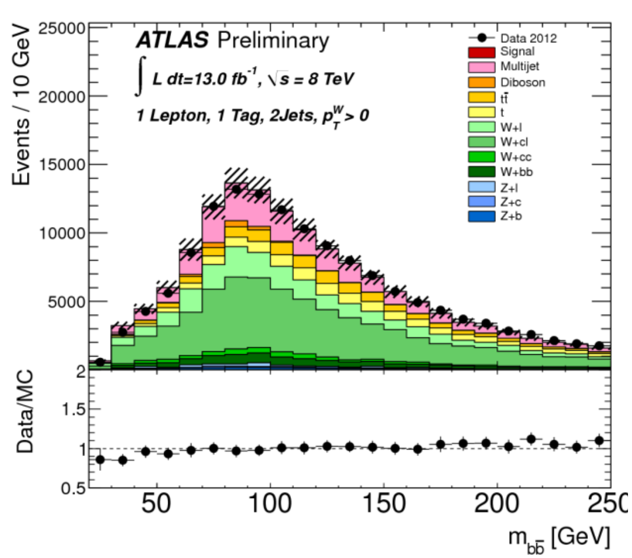
VH(H->bb): Flavor Fit

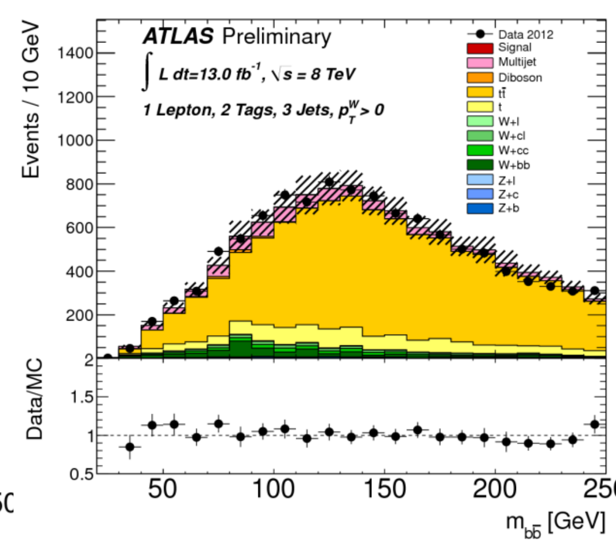
- V+jets control regions
  - Split in 0-tag, 1-tag and 2-tag regions to separate the flavors

- Top control regions
  - 3,4-jets for 1-lepton
  - invert m(l,l) cut for 2-leptons

- Extract scale factors for V+c and V+light backgrounds
  - Uncertainties used as nuisance parameter in the final fit
- top and V+b-jets: dominating backgrounds
  - Free in the final fit (which contains the top background CR)







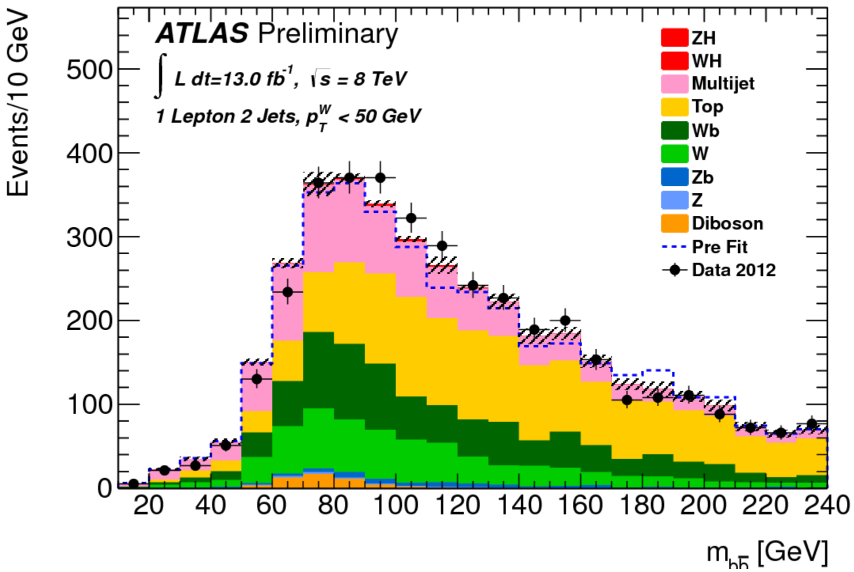
VH(H->bb): Yields (concentrate on WH)

- Top background dominating in all pT(V) bins
  - Mainly ttbar
- Wb is also an important background
  - Irreducible, not match to do about it
- QCD mainly at low pT(W)

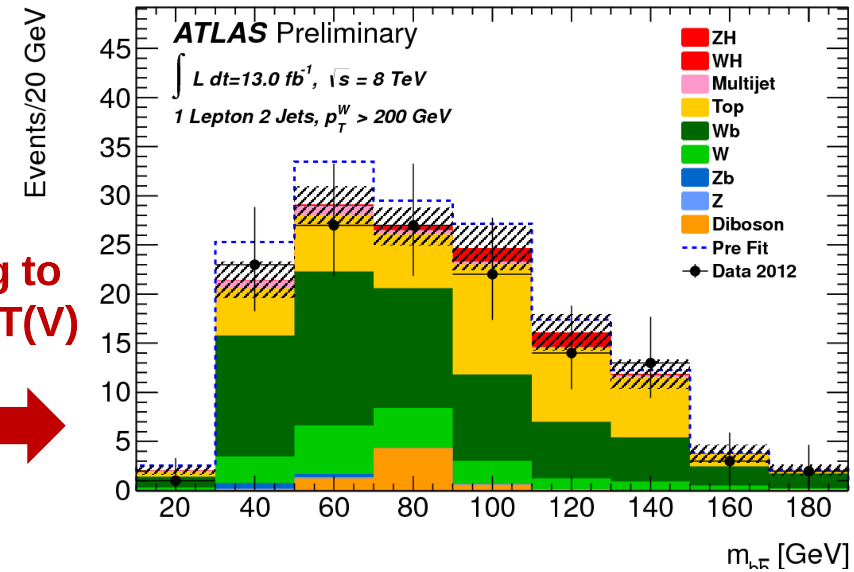
Bin	p_T^W [GeV]				
	0-50	50-100	100-150	150-200	> 200
ZH	0.3	0.4	0.1	0.0	0.0
WH	10.6	12.9	7.5	3.6	3.6
Top	1440	2276	1120	147	43
$W + c$,light	580	585	209	36	17
$W + b$	770	778	288	77	64
$Z + c$,light	17	17	4	1	0
$Z + b$	50	63	13	5	1
Diboson	53	59	23	13	7
Multijet	890	522	68	14	3

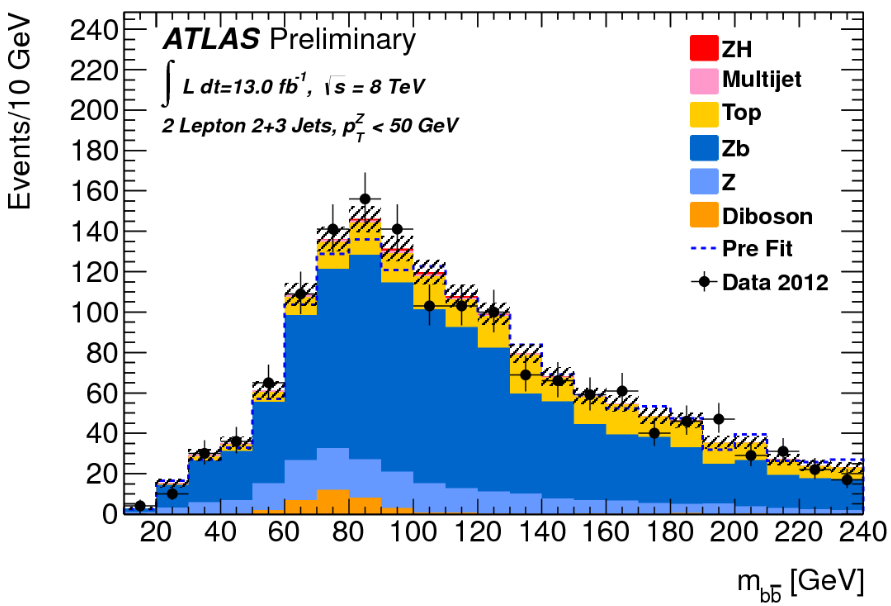
S/B going from 0.3% in the first pT(W) bin to 2.6% in the last bin

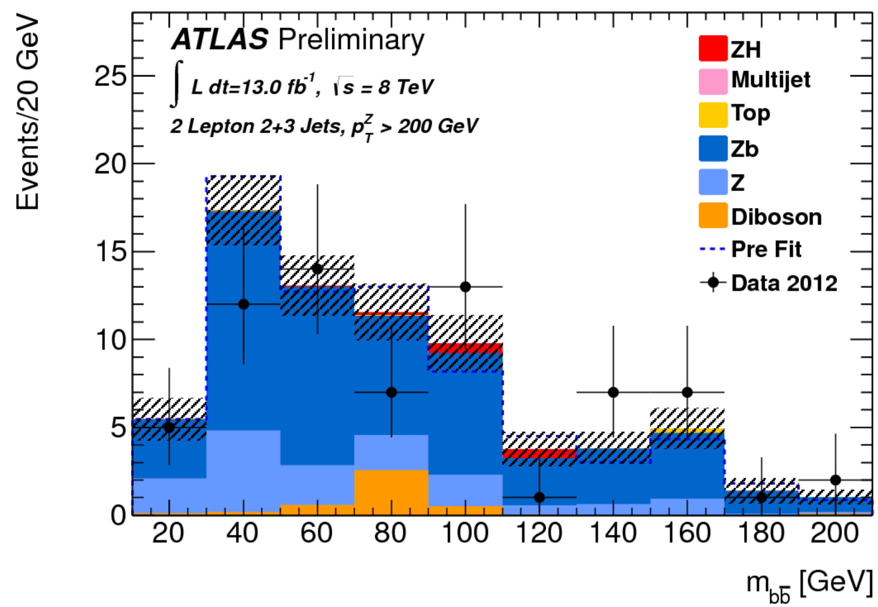
WH(H->bb): Invariant Mass Plots



Going to high pT(V)







VH(H->bb): Systematic Uncertainties

- Most important background systematics
  - Jet/ E_T^{miss} energy scale and resolution
  - b-tagging
  - MC stat

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_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
Total	25	15	14

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_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
Statistical	4.9	18	4.1	2.6
Luminosity	3.6	3.6	3.6	3.6
Total	24	34	16	13

- Most important signal systematics
  - Jet/ E_T^{miss} energy scale and resolution
  - b-tagging
  - EW NLO corrections

WH(H->bb): Final Fit

- Final fit to the m(bb) distribution including:
  - 13 signal regions for 0,1 and 2-lepton in pT(V) bins
  - includes also top control regions
  - 2011 and 2012 data sets
  - ~140 nuisance parameters (+ statistics terms)

Poison term **Penalty terms**

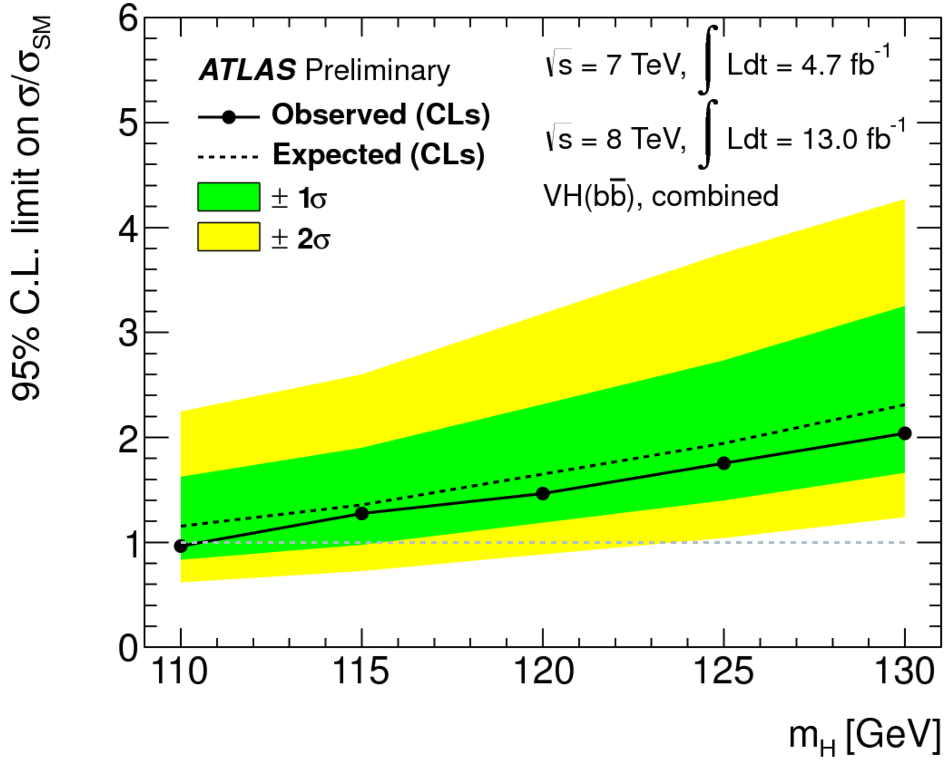
$$L(\mu,\theta) = \boxed{\prod_{i=1}^{N} P(n_i \mid \mu s(\theta) + b(\theta))} . \boxed{G(\theta \mid \tilde{\theta}, \sigma_\theta)}$$

- Limit computed using the CLs method
  - Log likelihood ratio as test statistics

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

WH(H->bb): Limits

- Current ATLAS results
  - full 7 TeV data and 13 fb^{-1} of 8 TeV data
  - Observed: 1.8 @125 GeV
  - Expected: 1.9 @125 GeV
  - Small deficit in data
- Current CMS results
  - ~ same Lumi
  - Observed: 2.6 @125 GeV
  - Expected: 1.2 @125 GeV
  - Excess in data with 2.2 sigma



- Atlas collected 21 fb^{-1} at 8 TeV
- Increase of luminosity not enough to reach a limit of 1 at 125 GeV
- Need 60% improvement
  - Cut optimizations, Multivariate analysis, m(bb) resolution, b-tagging ….

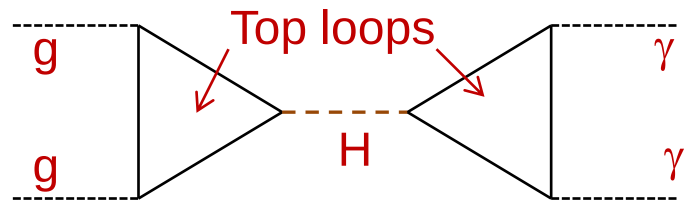
Few Words About ttH

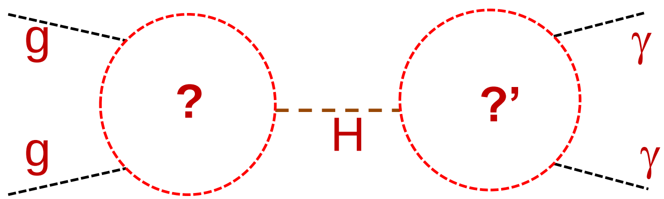
ATLAS-CONF-2012-135

ttH Importance

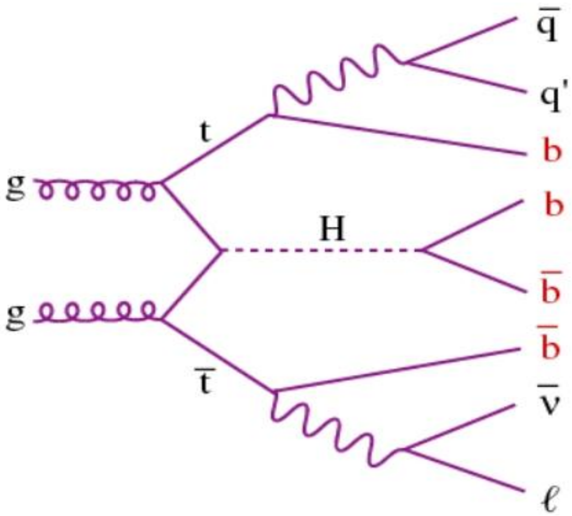
- Higgs boson couples preferentially to top quarks
  - Top quark is the main contribution to coupling via loops

- gg->H->γγ is the channel with the highest sensitivity at the LHC
  - Involves (mainly) two top loops
  - What if additional new particles contribute to the loops?
  - Need external constraint on the top Yukawa coupling



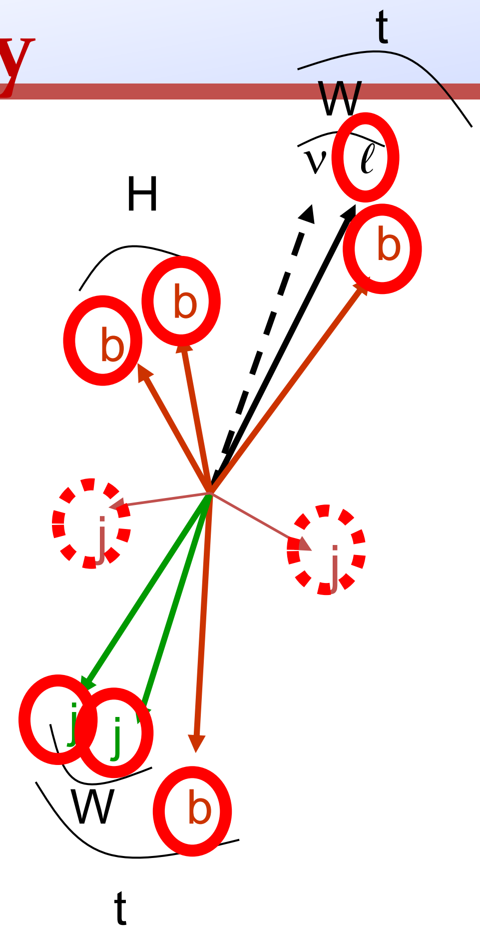


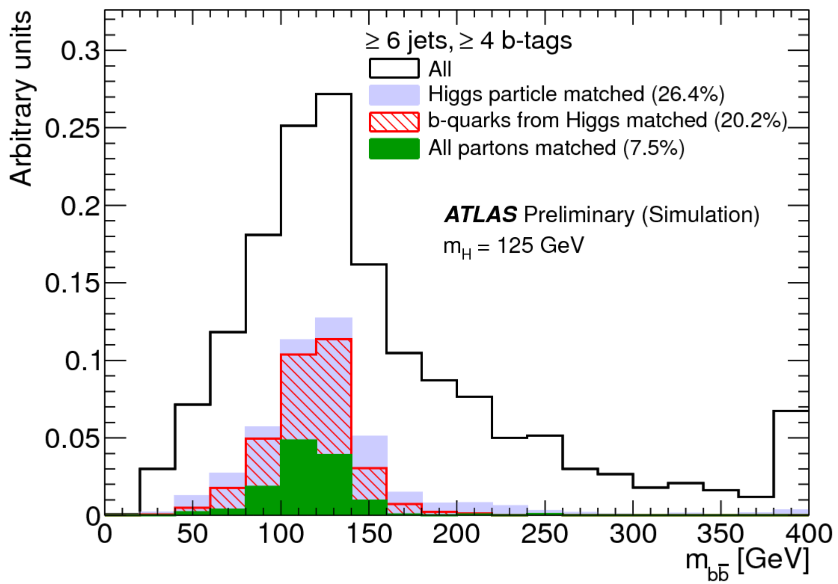
- The ttH channel is the only way to have a direct constrain on the top Yukawa coupling at the LHC
- ttH(H->bb) channel originally thought to be better than VH channels
  - Complex final stat allows better bkg separation
  - Recent studies showed that this channel is very challenging



ttH(H->bb) General Strategy

- Selection in a nutshell (1-lepton channel)
  - Exactly one lepton
  - 6 or more jets
  - 4 b-jets
- Try to reconstruct top quarks
  - Using kinematic fit
  - The two remaining b-jets are used to form the Higgs boson

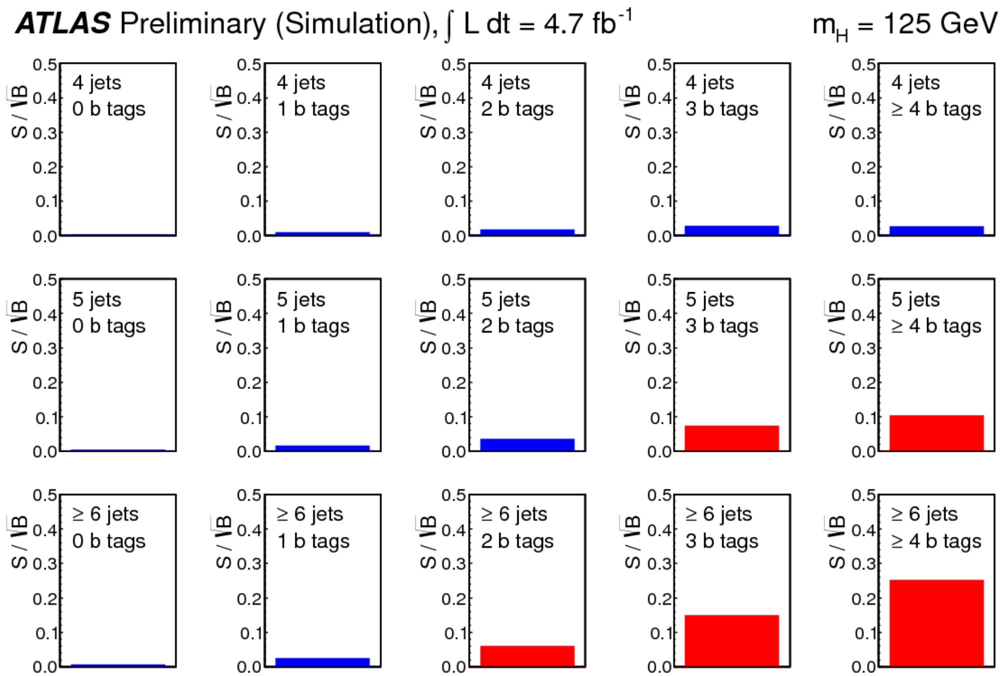


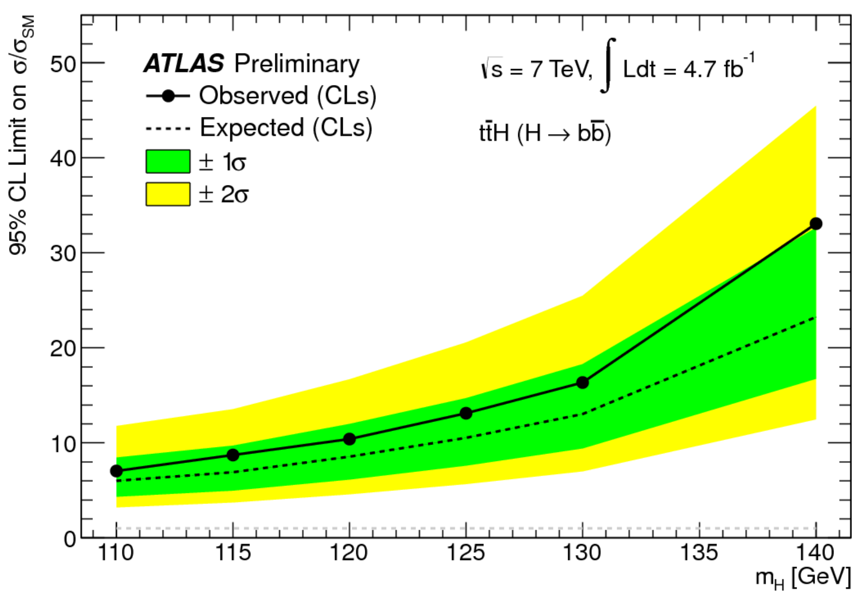


- Main problems
  - tt+jets modeling
  - Solving jet combinatorics

ttH(H->bb) Current ATLAS results

- Likelihood fit including several regions
  - Highest sensitivity with 6 jets 4 b-tag
  - Decreases with decreasing number of jets/b-tags
  - HT used rather than m(bb) in region with nJets<6





- Current ATLAS results
  - Using only 7 TeV data
  - Observed: 13.1 @125 GeV
  - Expected: 10.5 @125 GeV
- Channel not accessible with current collected data
  - More important in 2014

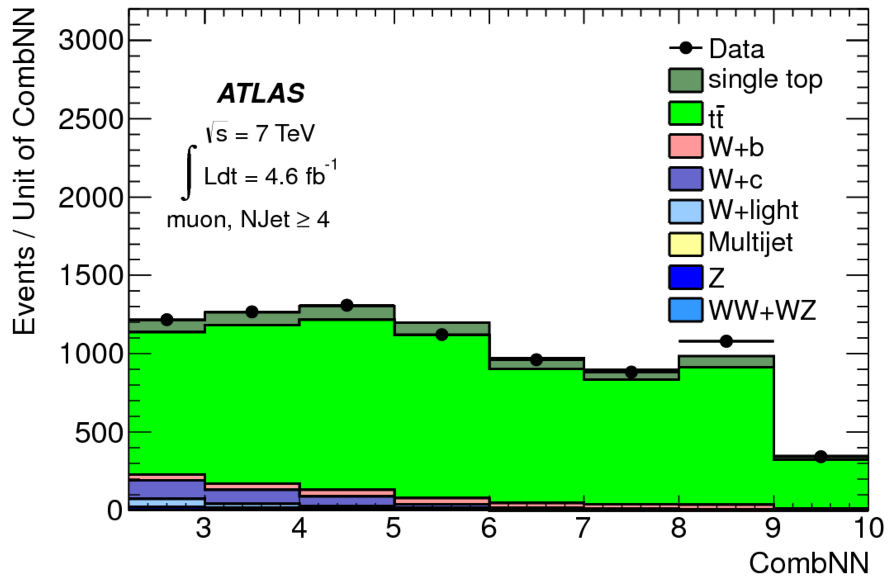
Conclusion

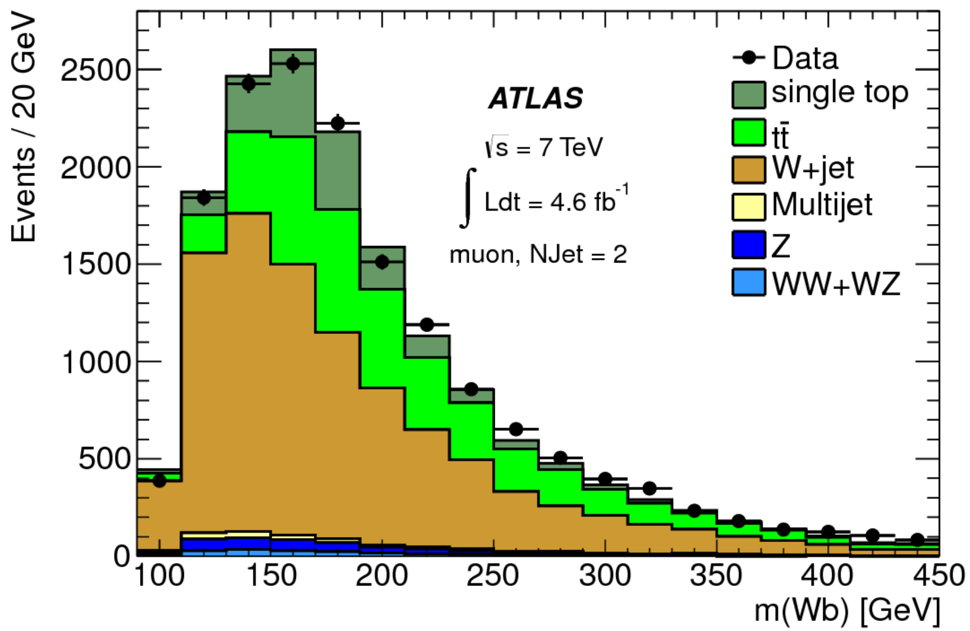
Conclusion

- Atlas continues to test pQCD and current MC generators using W+heavy flavor events
  - Wb cross section already measured: aim for more differential measurements
  - Wc cross section measurement on the way
- 2013: the year of H->bb (and H->ττ)
  - Very important to establish the presence of the SM Higgs boson
  - Limits from ATLAS and CMS already close to 1 (with 2/3 of 2012 data)
  - Goal to achieve better performance leading to the discovery (or exclusion) of Higgs to bbbar
- ttH channel very important with 2014 data
  - Mandatory to increase sensitivity to new physics in the loop contribution to the production and decay of the Higgs boson
  - Challenging channel with complex final state
  - Need to improve the reconstruction purity of such a complex final state

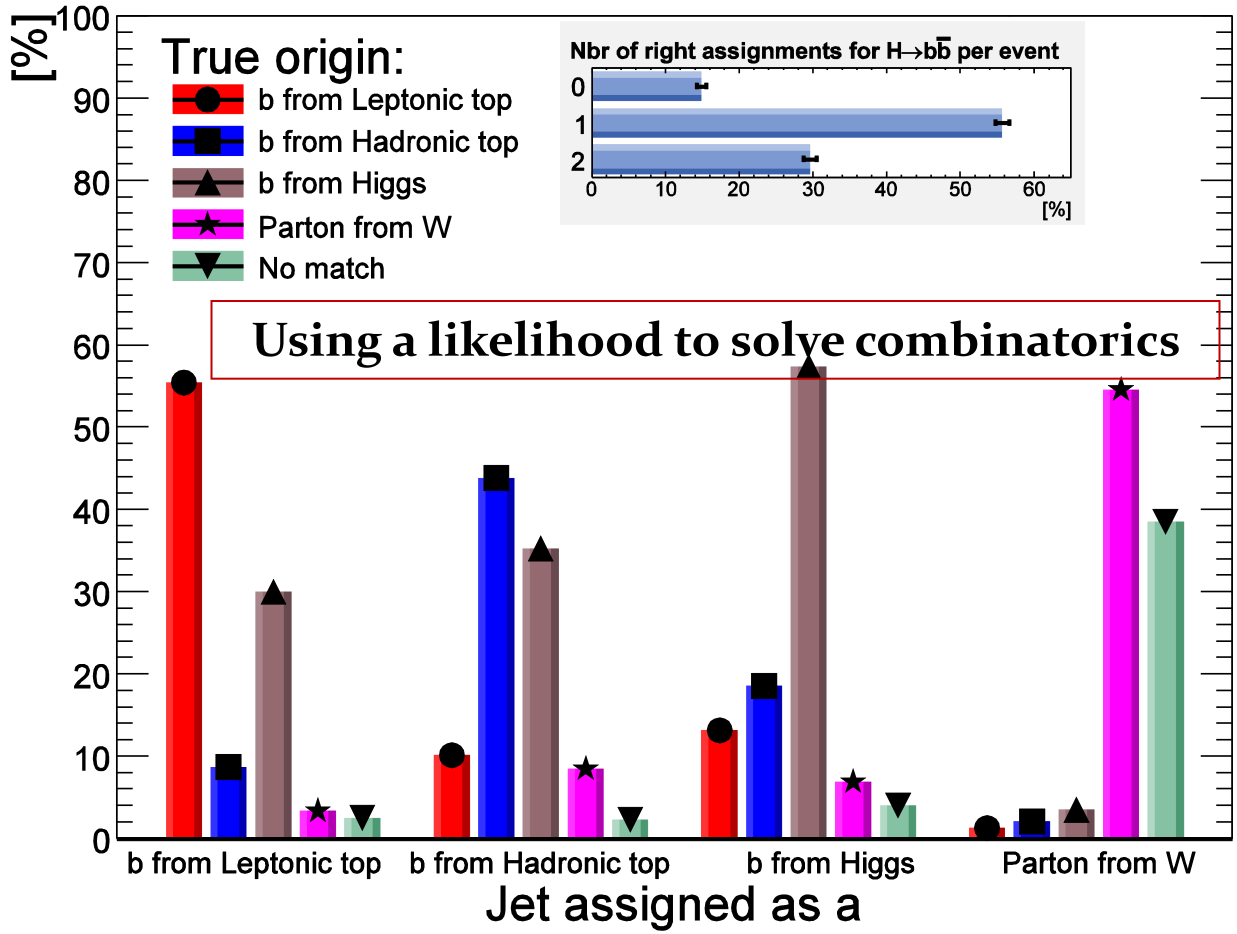
Extra Slides

W+b-jets: Other Backgrounds



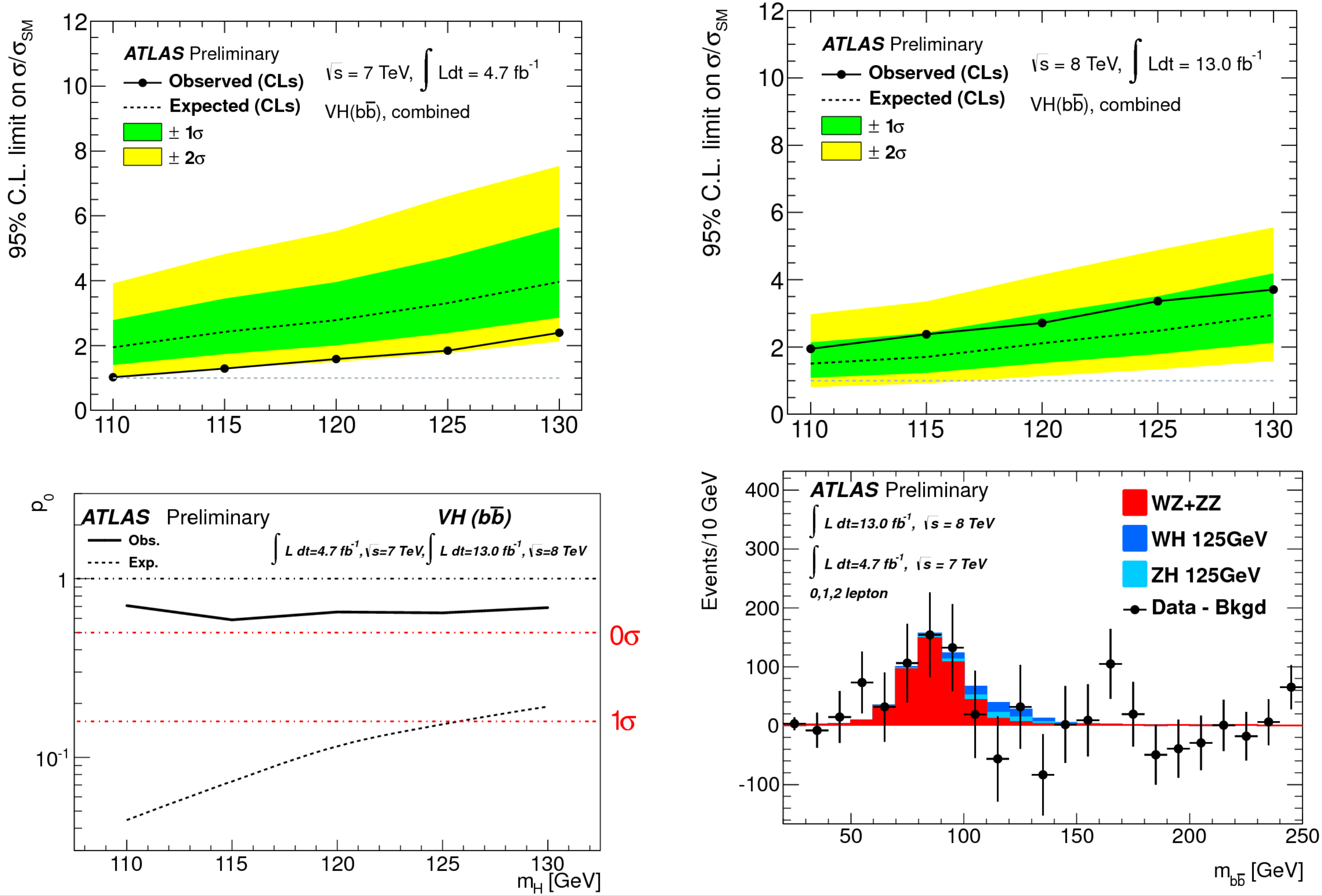


ttH(H->bb) Lessons from CSC

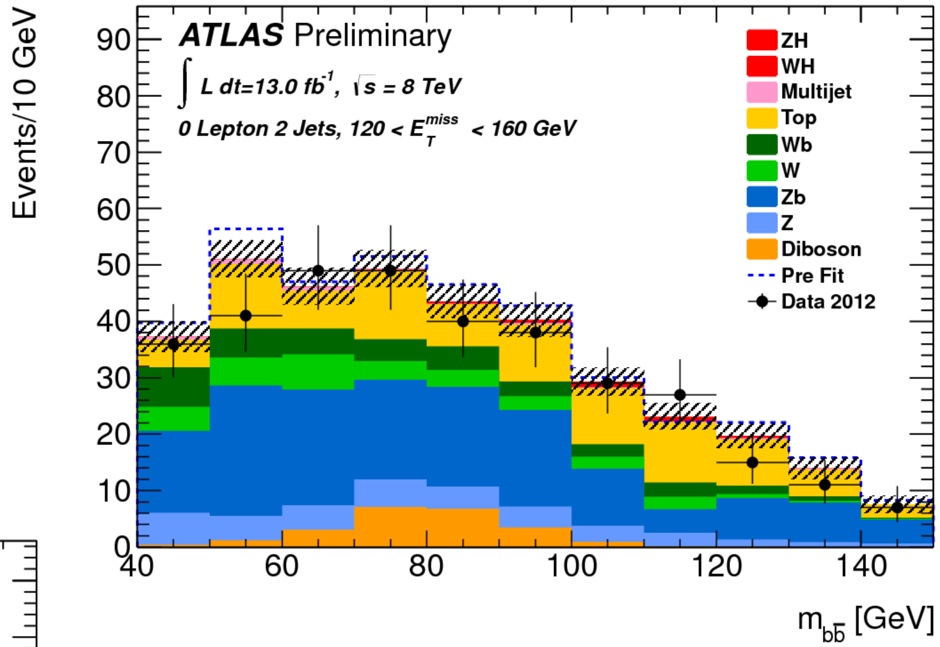


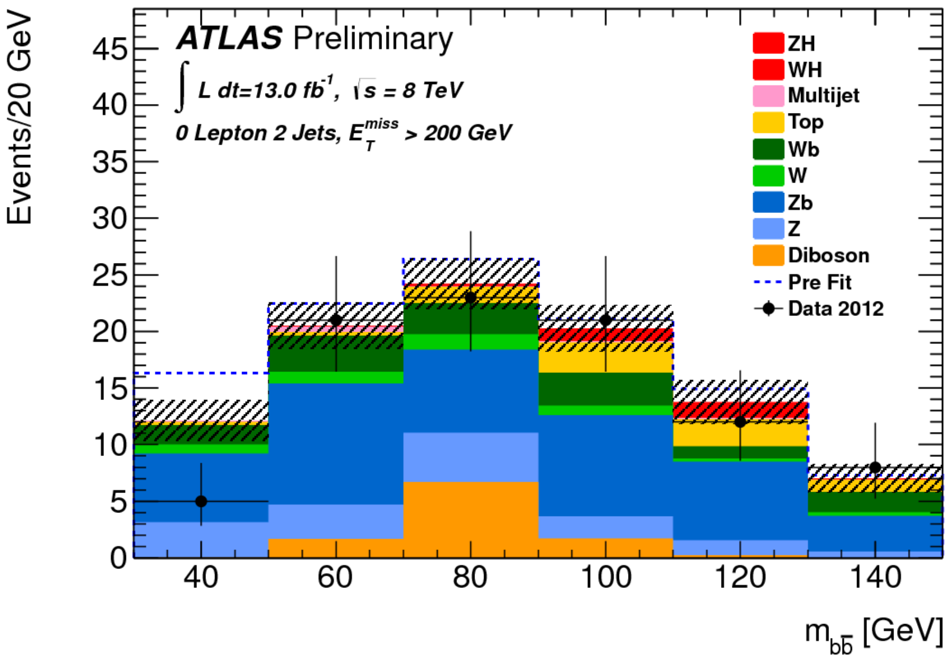
- Higgs boson mainly formed by one jet from the Higgs and one from either top quarks
- Frequently missing second jet from W

VH results


ATLAS Preliminary
Observed (CLs)
Expected (CLs)
± 1σ
± 2σ
√s = 7 TeV, ∫ Ldt = 4.7 fb-1
VH(bb̄), combined
95% C.L. limit on σ/σSM
√s = 8 TeV, ∫ Ldt = 13.0 fb-1
VH(bb̄), combined
p0
VH (bb̄)
Obs.
Exp.
∫ L dt=4.7 fb-1, √s=7 TeV, ∫ L dt=13.0 fb-1, √s=8 TeV
0σ
1σ
mH [GeV]
Events/10 GeV
∫ L dt=13.0 fb-1, √s = 8 TeV
∫ L dt=4.7 fb-1, √s = 7 TeV
0,1,2 lepton
WZ+ZZ
WH 125GeV
ZH 125GeV
Data - Bkgd
mbb̄ [GeV]

M(bb) 0-lepton


ATLAS Preliminary
∫ L dt=13.0 fb^{-1}, √s = 8 TeV
0 Lepton 2 Jets, 120 < E_T^{miss} < 160 GeV
ZH
WH
Multijet
Top
Wb
W
Zb
Z
Diboson
Pre Fit
Data 2012
Events/10 GeV
$m_{b\bar{b}}$ [GeV]


ATLAS Preliminary
∫ L dt=13.0 fb^{-1}, √s = 8 TeV
0 Lepton 2 Jets, E_T^{miss} > 200 GeV
ZH
WH
Multijet
Top
Wb
W
Zb
Z
Diboson
Pre Fit
Data 2012
Events/20 GeV
$m_{b\bar{b}}$ [GeV]