

# *Recent ATLAS Results on Higgs Decaying to Fermions*

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Shandong University

on behalf of the ATLAS collaboration

International Symposium on Higgs Physics

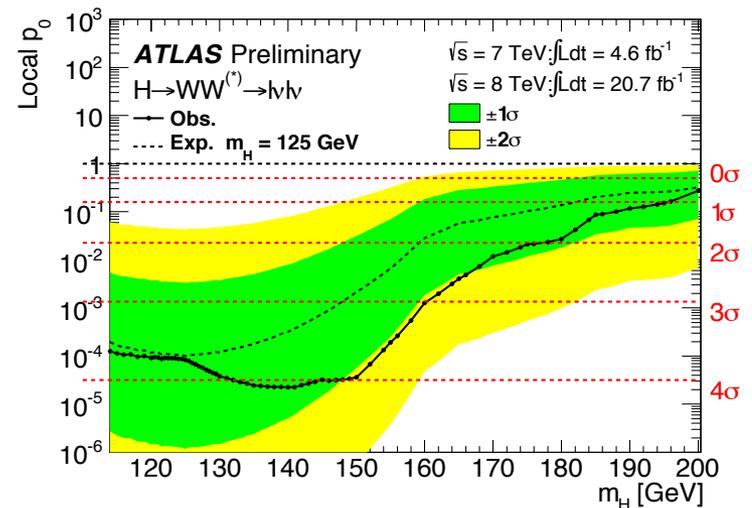
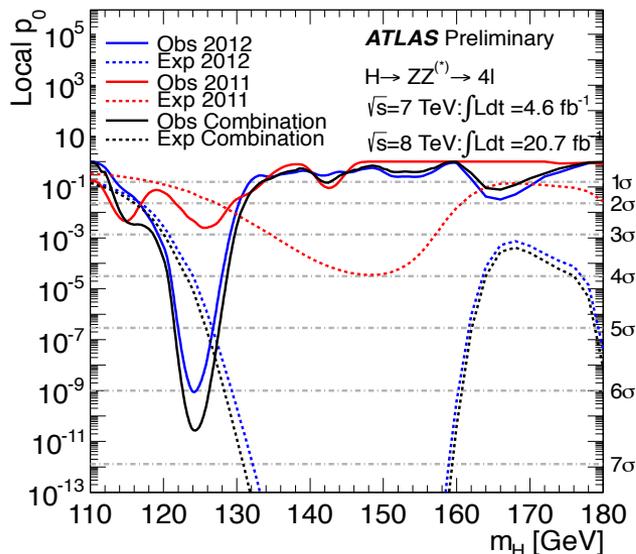
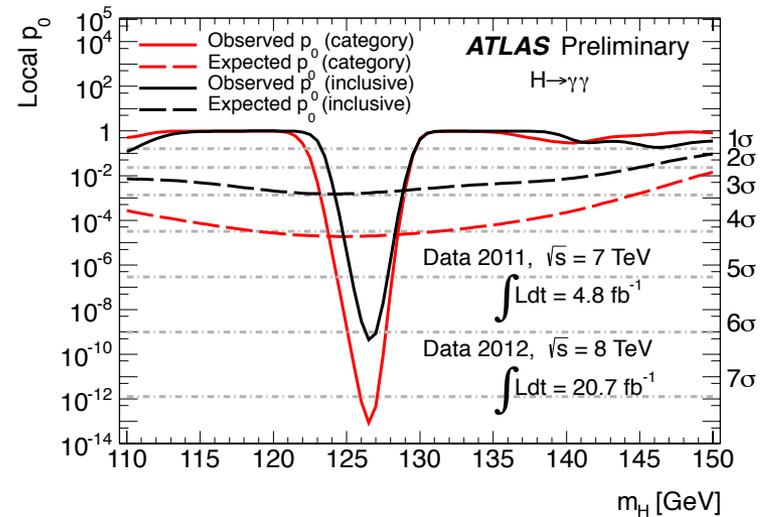
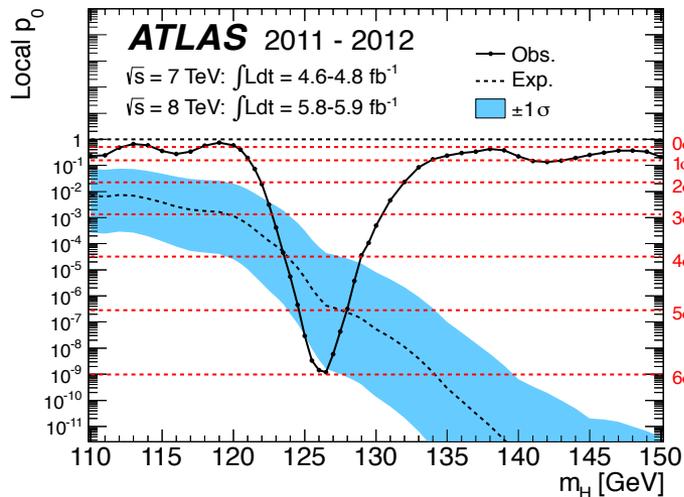
IHEP, Beijing, Aug. 12-16 2013



# Outline

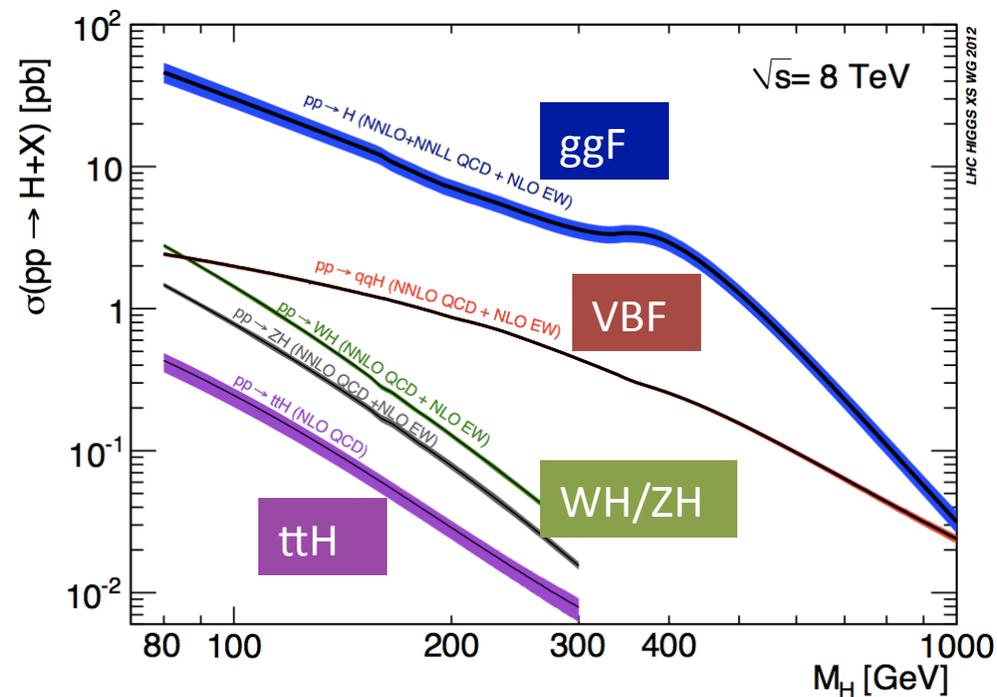
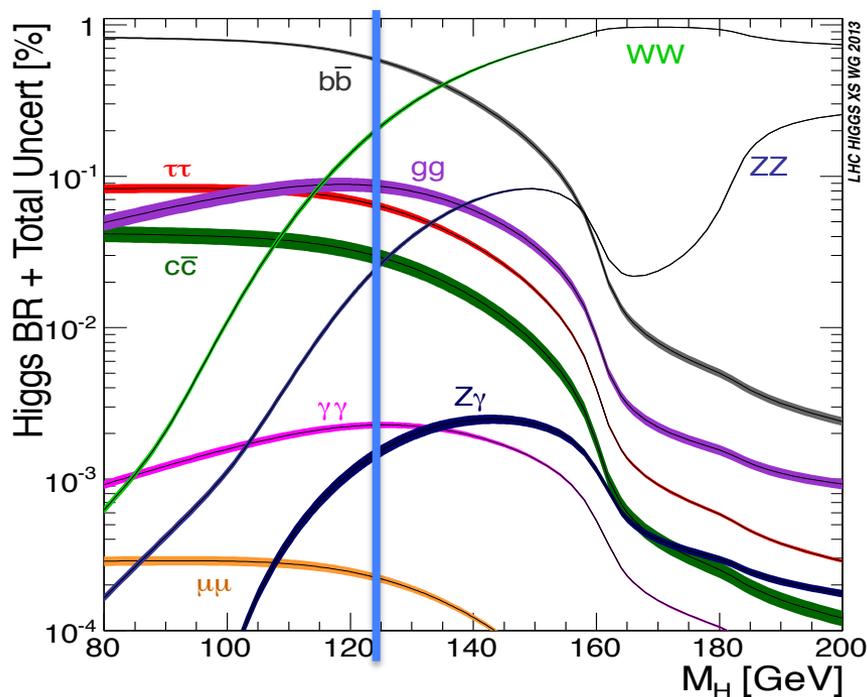
- ✧ Introduction
- ✧ Results from the Higgs decay into  $bb$ 
  - WH/ZH: updated with the full datasets
  - ttH: CONF note with 2011 data
- ✧ Result from the  $H \rightarrow \mu^+ \mu^-$  with 8 TeV data
- ✧ Result from the  $H \rightarrow \tau^+ \tau^-$ 
  - 2012 HCP results reported here
- ✧ Summary

# Introduction: the Observed Boson

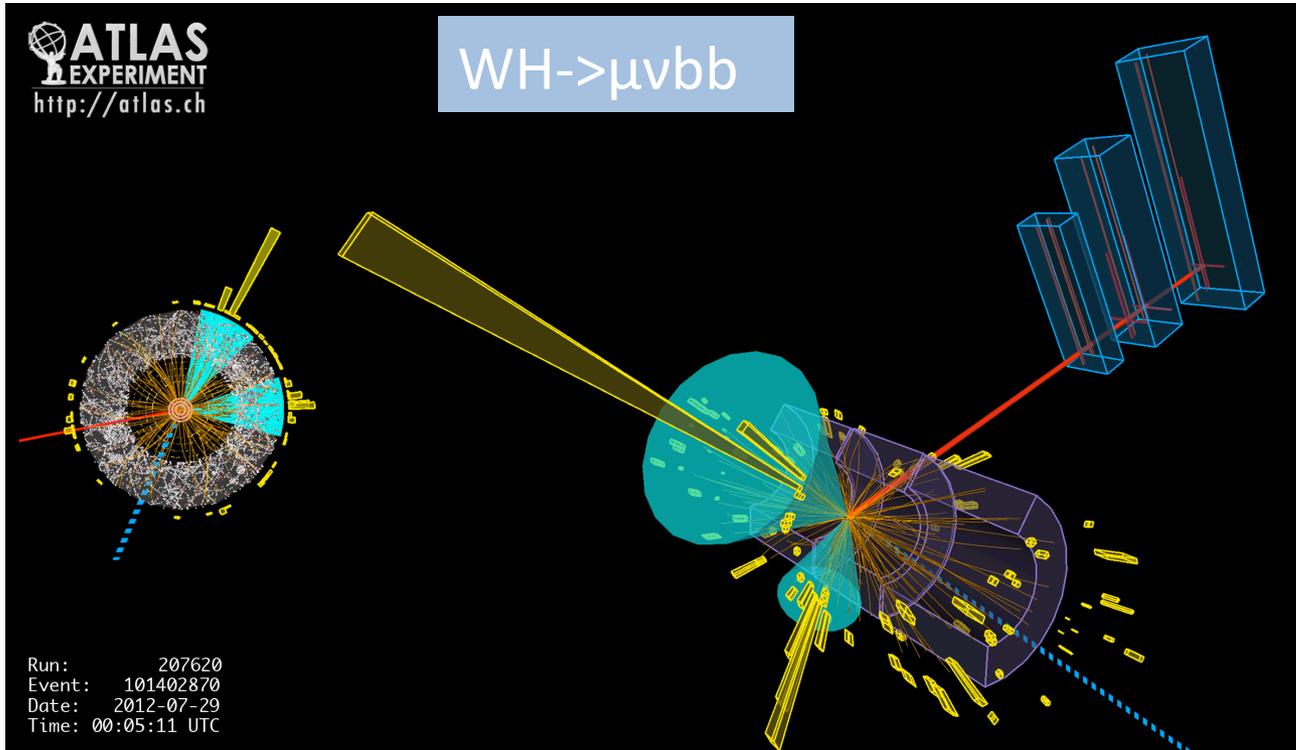


# Introduction: SM Higgs at LHC

- ✧ SM Higgs @125 GeV:  $BR(bb) = 57.7\%$ ;  $BR(\tau\tau) = 6.3\%$ ;  $BR(\mu\mu) = 0.02\%$
- ✧ Searches with fermion final states are important for the Higgs identification and property studies
- ✧ Studies for  $H \rightarrow bb$ :  $WH/ZH$ ,  $t\bar{t}H$ , VBF
- ✧ For  $H \rightarrow \tau\tau$  and  $H \rightarrow \mu\mu$ :  $ggF$ , VBF,  $WH/ZH$



# VH, H->bb @ATLAS



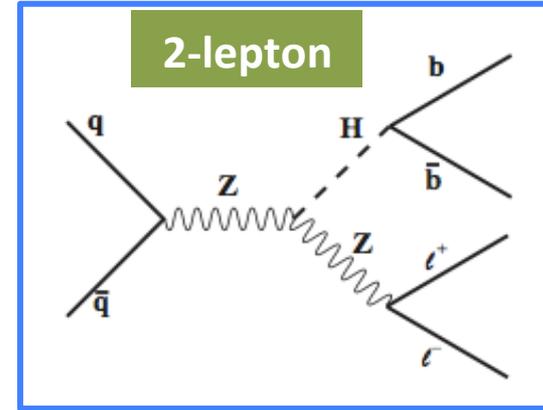
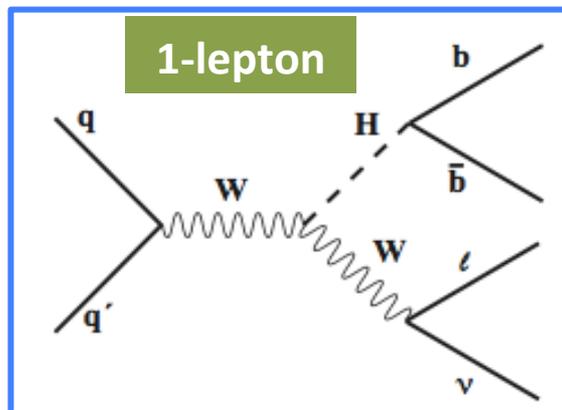
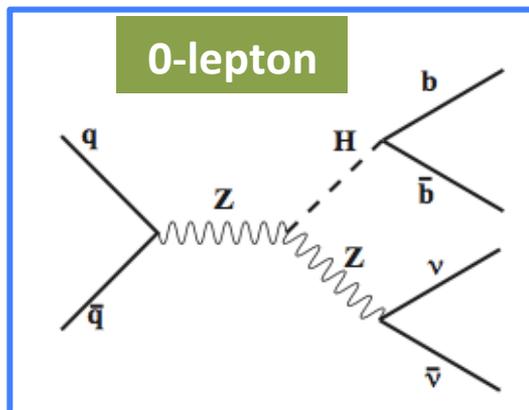
- ✓ Introduction
- ✓ Strategy
- ✓ Backgrounds
- ✓ Systematics
- ✓ Results

✧ **ATLAS-CONF-2013-079** with the full datasets

✧ Previous results:

- ✓  $4.7 \text{ fb}^{-1} + 13.0 \text{ fb}^{-1}$  (8 TeV), [ATLAS-CONF-2012-161](#)
- ✓  $4.7 \text{ fb}^{-1}$  7TeV: [ATLAS-CONF-2012-135](#), [Phys. Lett. B 718 \(2012\) 369-390](#)

# VH, H->bb: Introduction



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 $p_T^{\text{jet}_1} > 45 \text{ GeV}$ $p_T^{\text{jet}_2} > 20 \text{ GeV}$ + $\leq 1$ extra jets	
Missing $E_T$	$E_T^{\text{miss}} > 120 \text{ GeV}$ $p_T^{\text{miss}} > 30 \text{ GeV}$ $\Delta\phi(E_T^{\text{miss}}, p_T^{\text{miss}}) < \pi/2$ $\min[\Delta\phi(E_T^{\text{miss}}, \text{jet})] > 1.5$ $\Delta\phi(E_T^{\text{miss}}, b\bar{b}) > 2.8$	$E_T^{\text{miss}} > 25 \text{ GeV}$	$E_T^{\text{miss}} < 60 \text{ GeV}$
Vector Boson	-	$m_T^W < 120 \text{ GeV}$	$83 < m_{\ell\ell} < 99 \text{ GeV}$

0, 1, 2-leptons

2, 3 jets

MET

W/Z mass

# VH, H->bb: Analysis Strategy

- ✧ Global fit to the  $m_{bb}$  distributions (57 regions)
- ✧ Two types of signal regions (SR) to maximize the sensitivity:  
2-jet and 3-jets in which 2 b-tagged jets (MV1@70%, rejection factors of 5 and 150 against c and light jets)
- ✧ Control regions (CR): 2-jet and 3-jet with 1 b-tagged jet, and the top control region in 2-lepton

Regions	2-jet, 1-tag	3-jet, 1-tag	2-jet, 2-tag	3-jet, 2-tag	Top $e\mu$
<b>0-lep (3 <math>p_T^V</math> bins)</b>	CR	CR	SR	SR	
<b>1-lep (5 <math>p_T^V</math> bins)</b>	CR	CR	SR	SR	
<b>2-lep (5 <math>p_T^V</math> bins)</b>	CR	CR	SR	SR	CR

$p_T^V$ bin (GeV)	0-90 1, 2-lep	90-120 1, 2-lep	120-160 all	160-200 all	> 200 all
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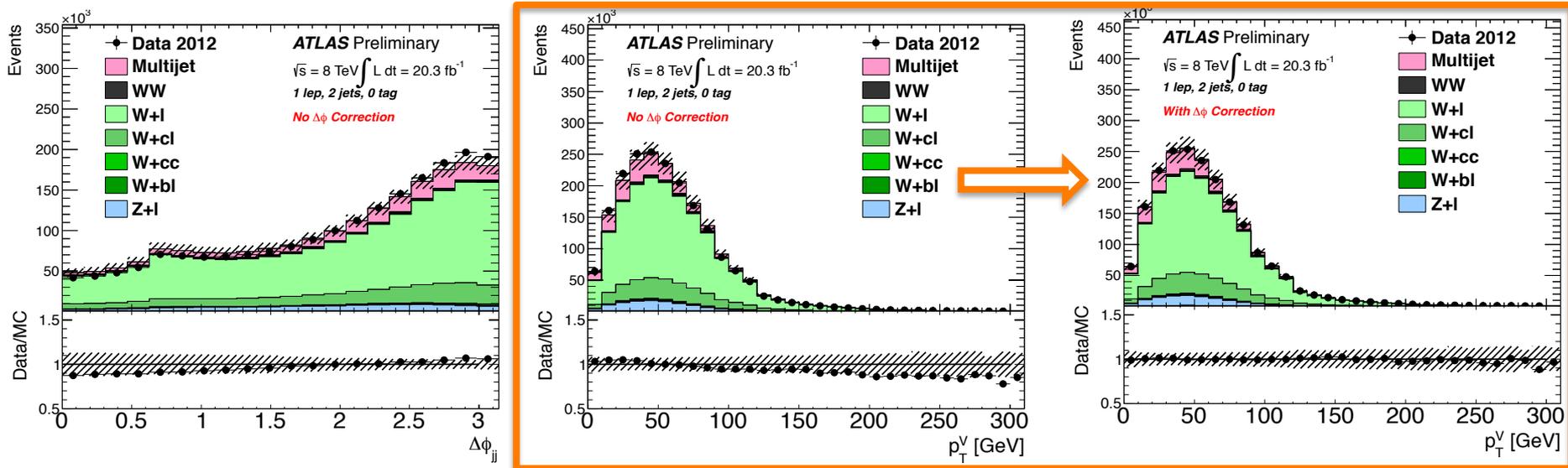
# VH, H->bb: Background Modeling

## ✧ Backgrounds considered:

- **W+heavy-jets, Z+heavy-jets, ttbar**:  $m_{bb}$  from MC, but normalization factors (NF) floating in the final fit to data
- QCD: data-driven, floating in 1-lep, fixed in 0, 2-lep with 100% uncert.
- Di-boson, single-top, W+light-jets, Z+light-jets: MC simulation

## ✧ $\Delta \Phi_{jj}$ correction applied to V+jets MC (Sherpa Leading Order)

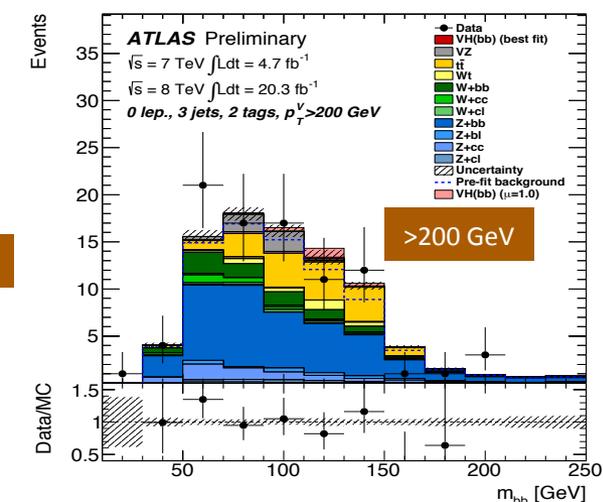
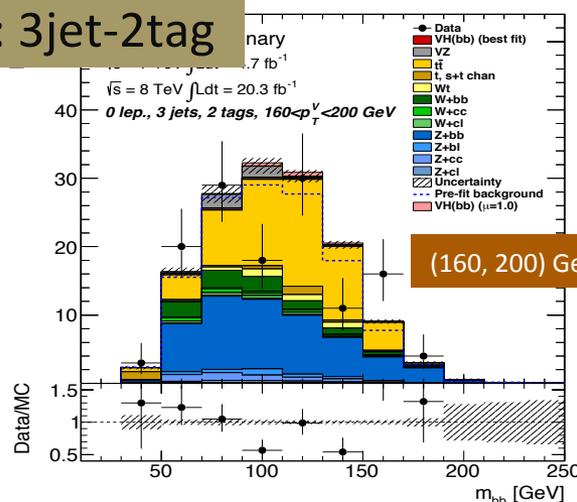
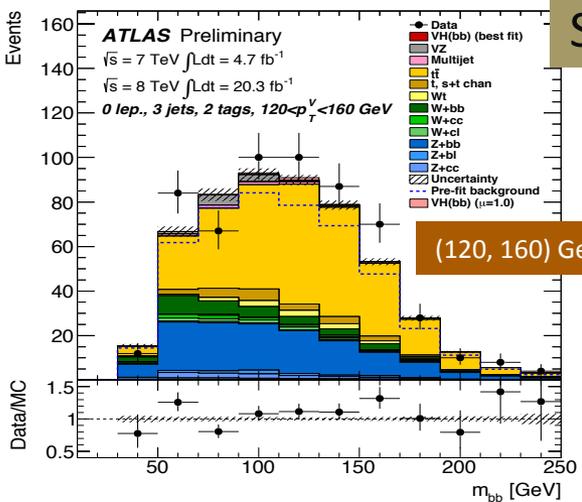
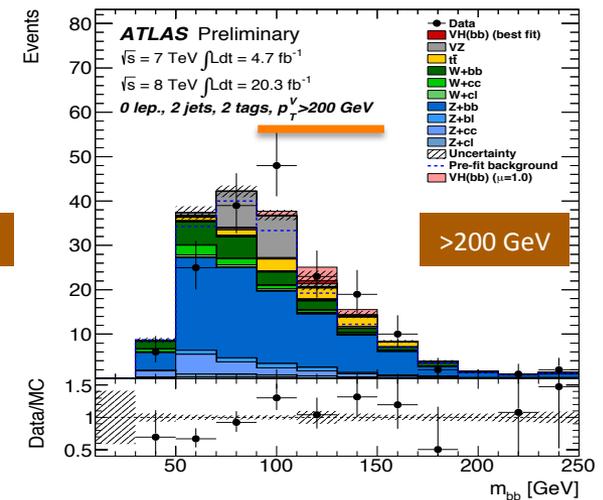
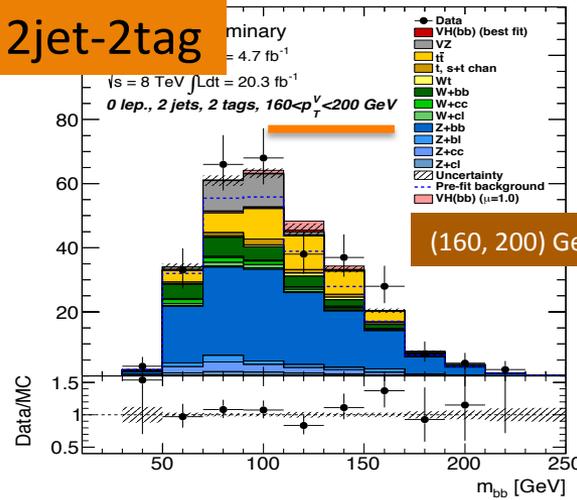
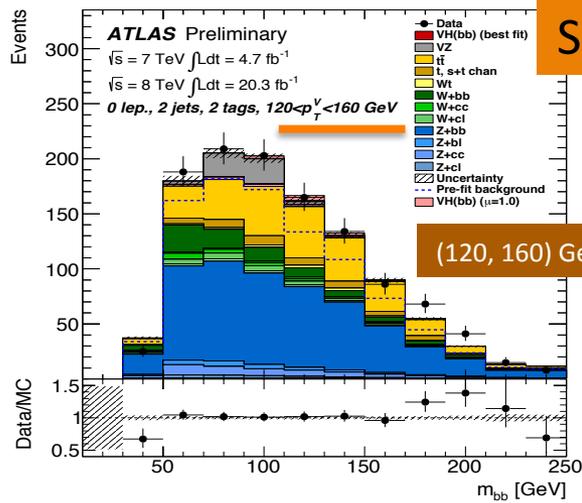
## ✧ Top $p_T$ correction applied at the level of generated top quarks for the ttbar sample (POWHEG + PYTHIA)



# VH, H→bb: Systematic Uncertainties

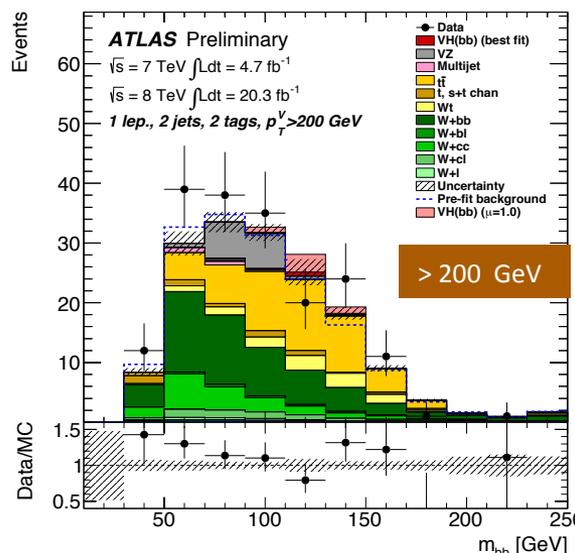
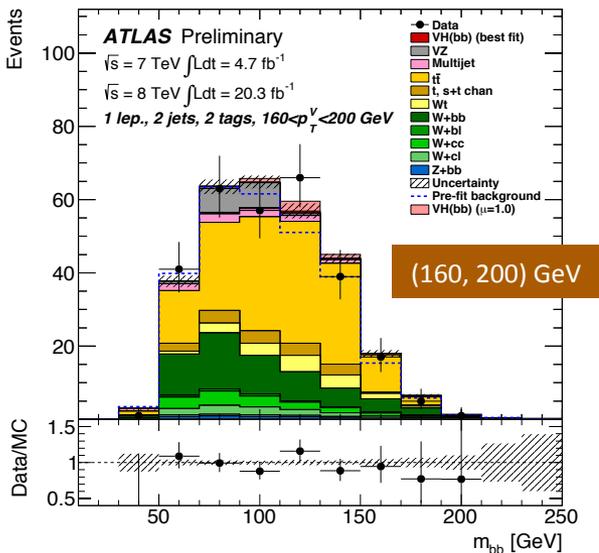
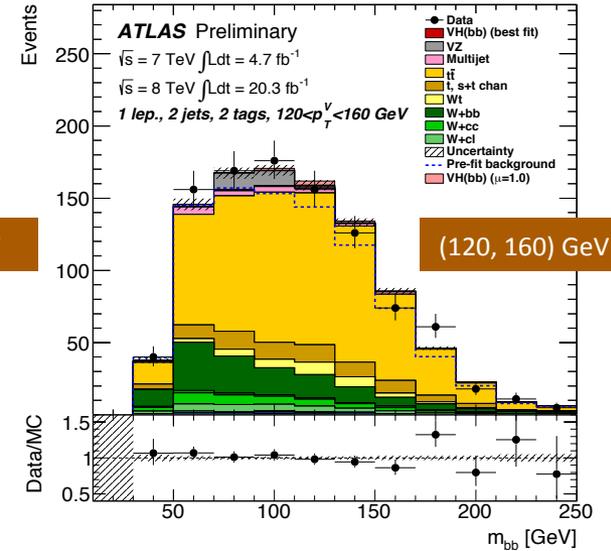
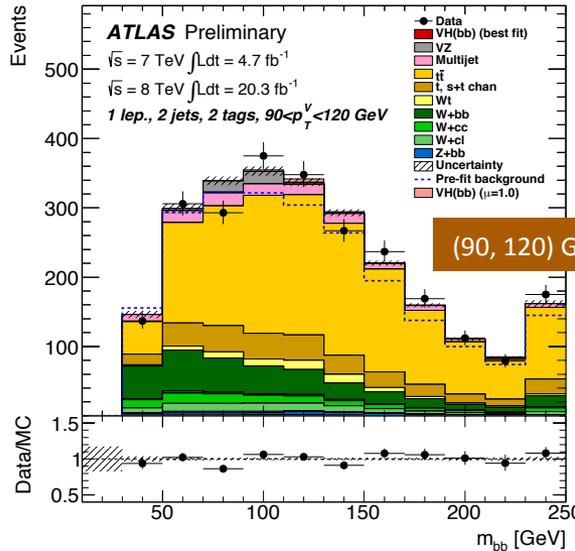
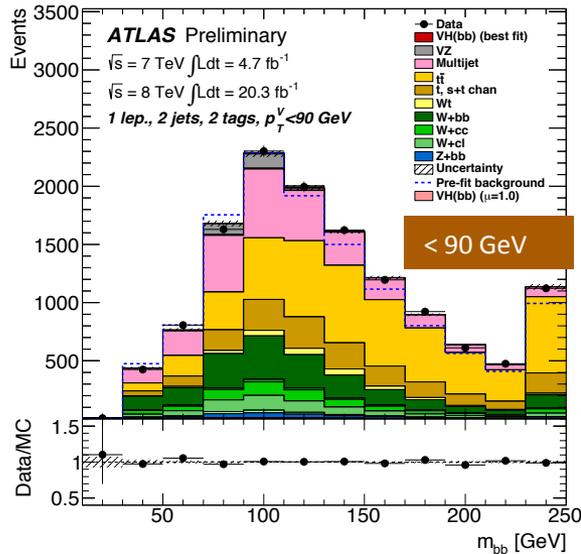
- ✧ Uncertainties on the simulated backgrounds
  - ✓ Main uncertainties: jet multiplicities,  $p_T^V$  distributions, flavor composition, and the  $m_{bb}$  distributions
  - ✓ Estimated as the differences between different generators, or between different tunes of the generator, or data/MC in CRs
- ✧ Experimental uncertainties
  - ✓ Trigger, object reconstruction and identification, energy and momentum calibration and resolution among which the JES and b-tagging efficiencies are the largest ones
  - ✓ Lumi: 1.8% for 7 TeV, and 2.8% for 8 TeV
- ✧ Theoretical uncertainties on the signal: PDFs, BR, renormalization and factorization and acceptance

# 0-lepton: Post-Fit Plots in SRs



Stacked histogram: sum of post-fit backgrounds; Dashed histogram: pre-fit backgrounds

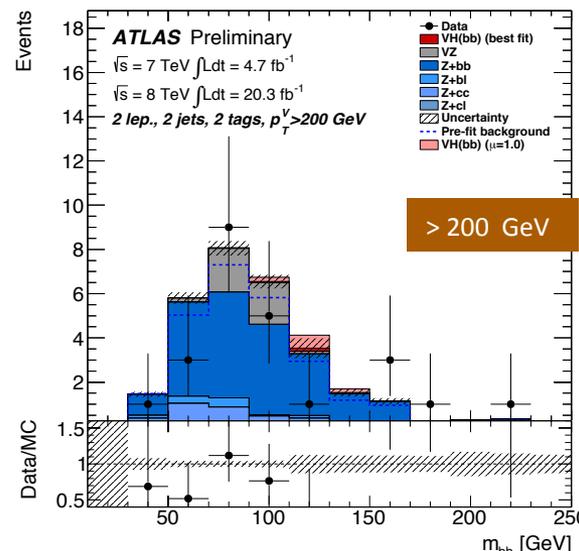
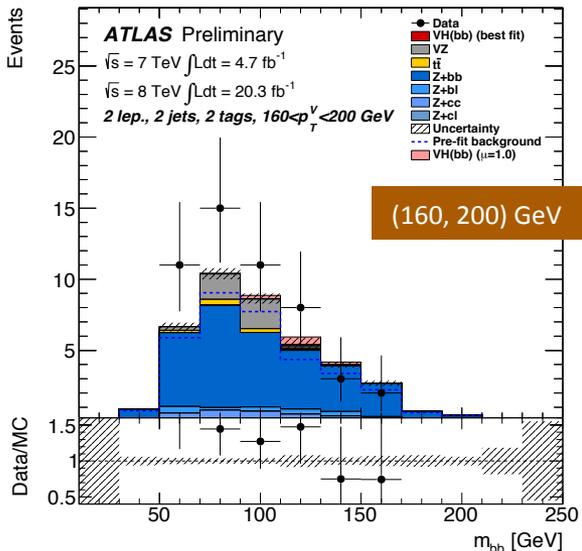
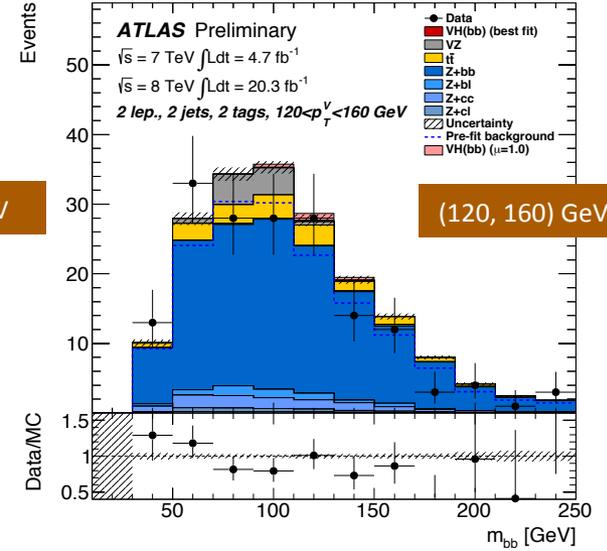
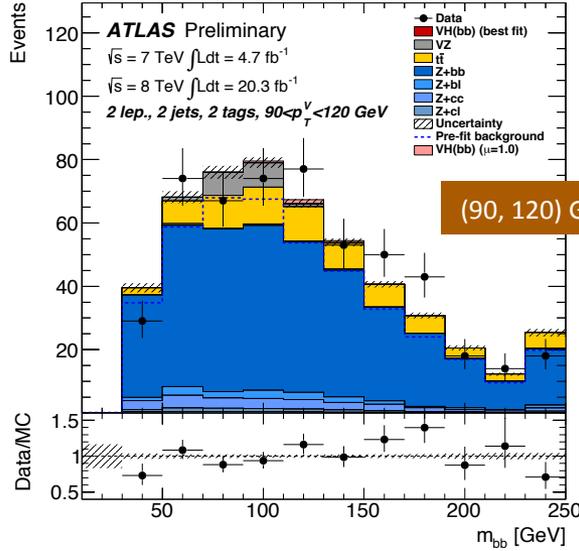
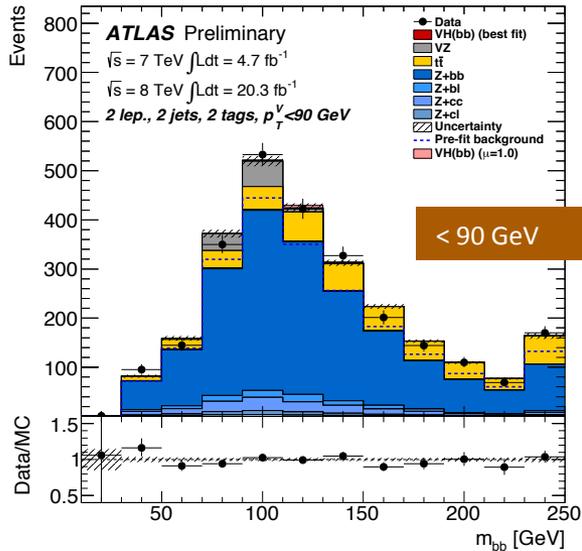
# 1-lepton: Post-Fit Plots (2-jet, 2-tag)



Background contributions change in different  $p_T^V$  bins

3-jet, 2-tag fit in the backup slides

# 2-lepton: Post-Fit Plots (2-jet, 2-tag)

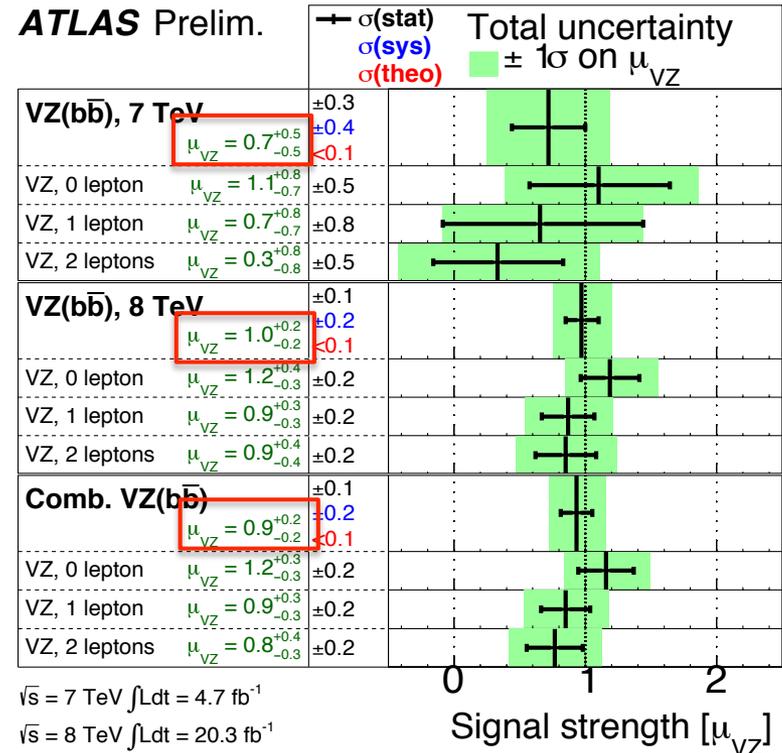
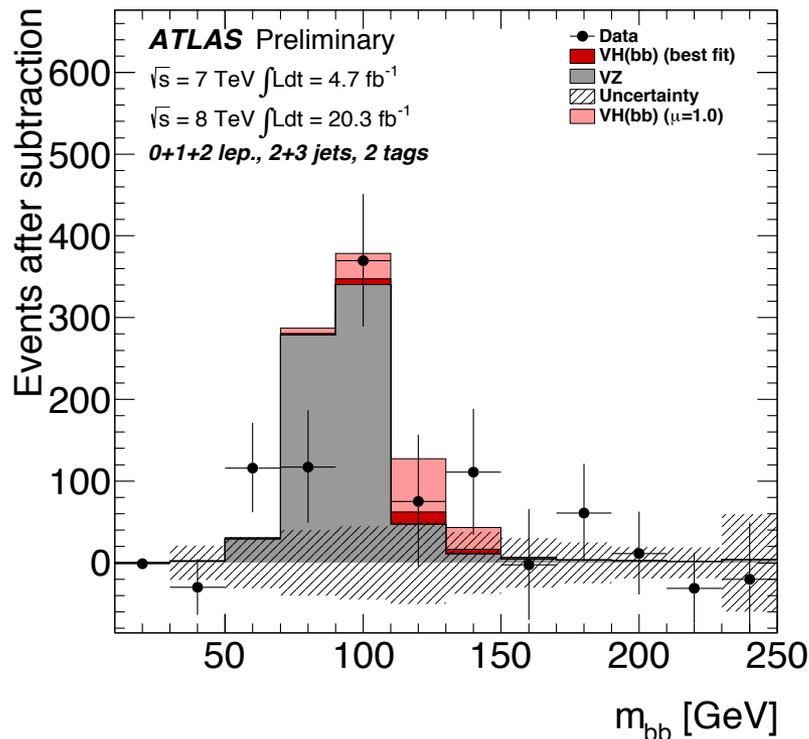


Main background:  
comes from Zbb

3-jet, 2-tag fit in  
the backup slides

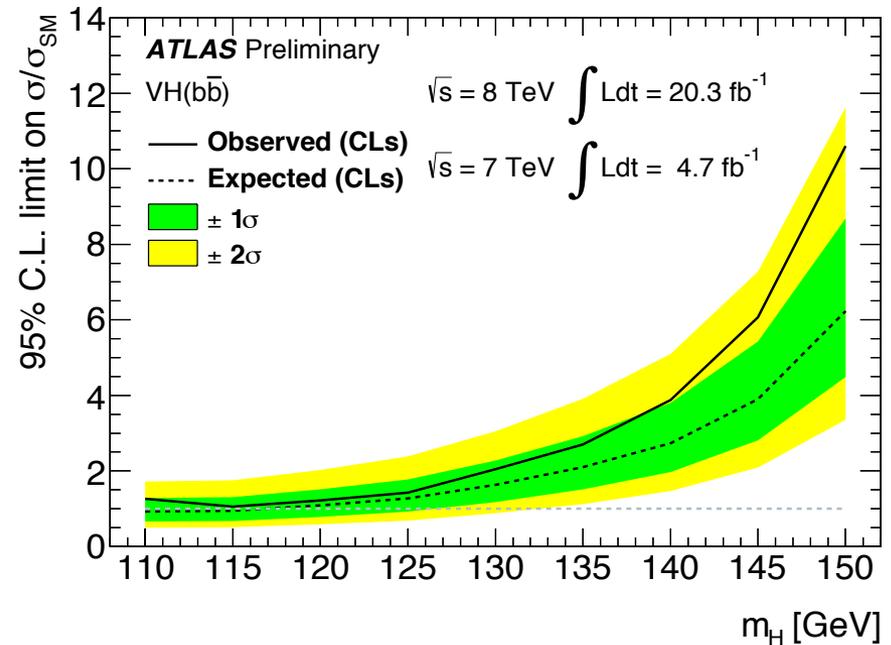
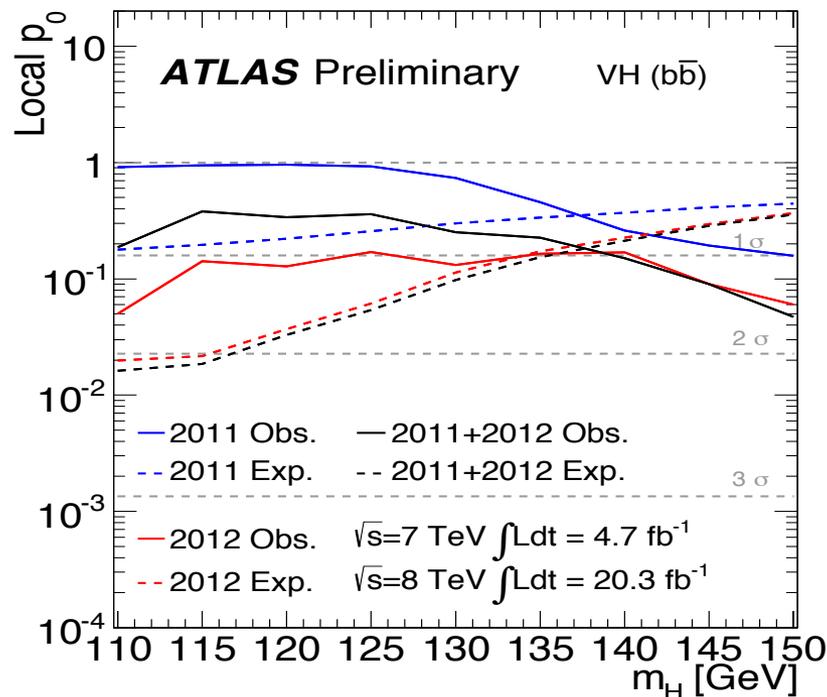
# H->bb: Validation with the VZ Processes

- ✧ Fit with di-boson as signal, NF of di-boson floating, Higgs@125 fixed with 50% uncertainty: **significance observed:  $4.8\sigma$ ; expected:  $5.1\sigma$**
- ✧ Left:  $m_{bb}$  after subtraction of all bkg. except for the di-boson
- ✧ Right:  $\mu_{VZ} = \sigma^{\text{meas.}} / \sigma^{\text{SM}} = 0.9 \pm 0.2$ , consistent with the SM prediction



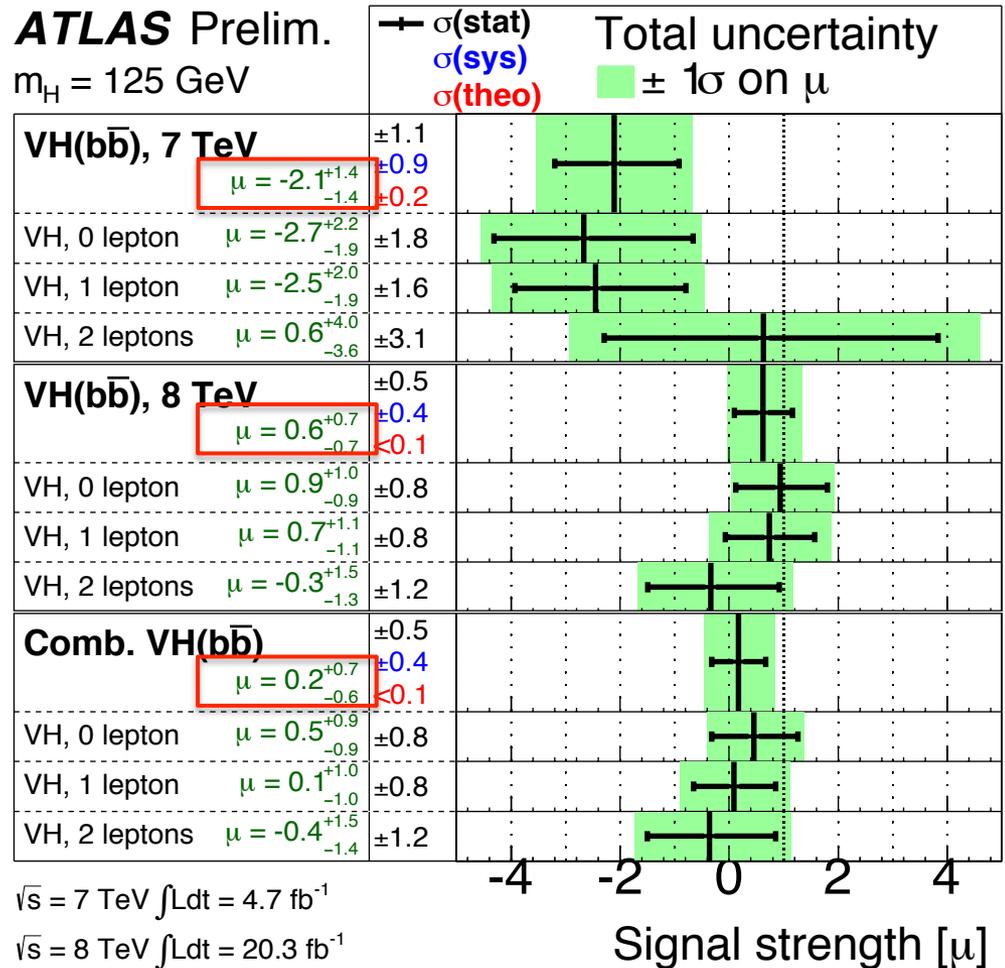
# VH, H->bb: Limit and p0 on SM Higgs

- ✧ Higgs fit with Higgs signal normalization floating, di-boson varied within the uncertainties
- ✧ No significant excess observed
- ✧ For  $m_H=125$  GeV, the upper limit at 95% C.L. is 1.4 times the SM prediction with 1.3 as expected, with the CLs method.



# VH, H->bb: Fit Results for Higgs

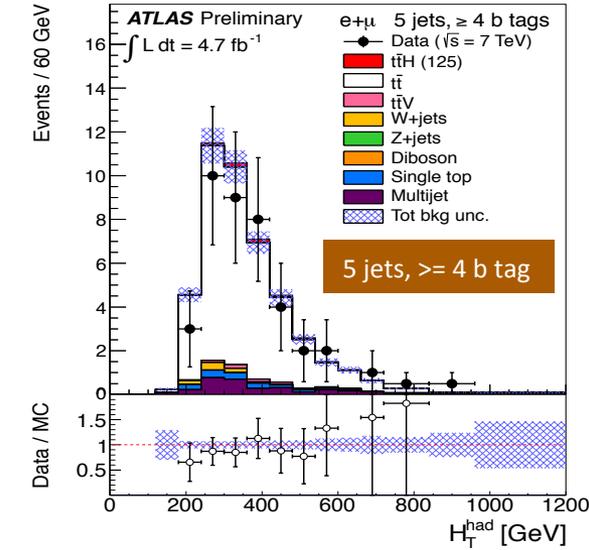
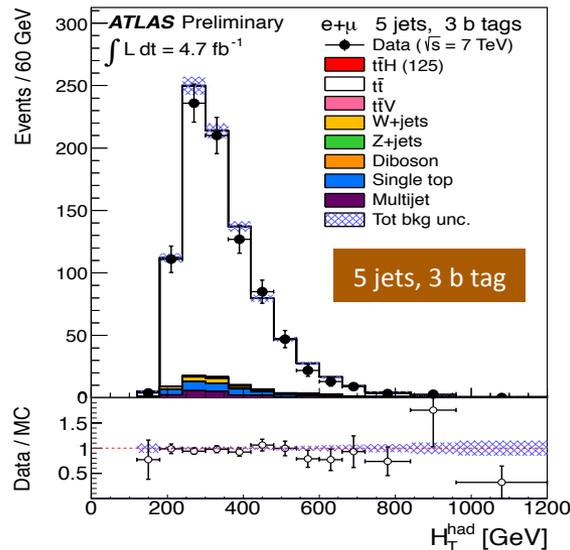
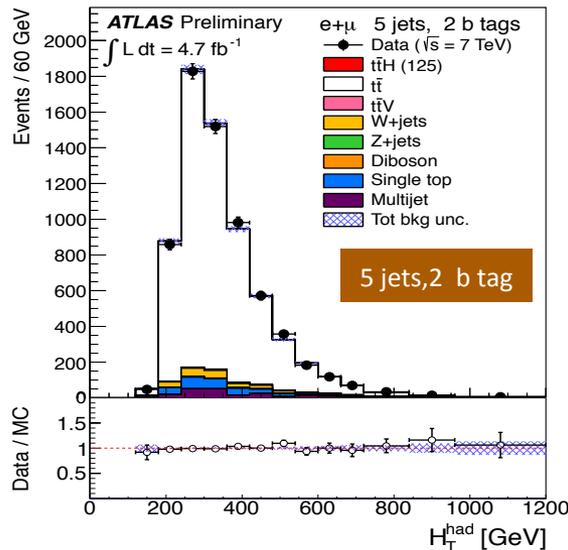
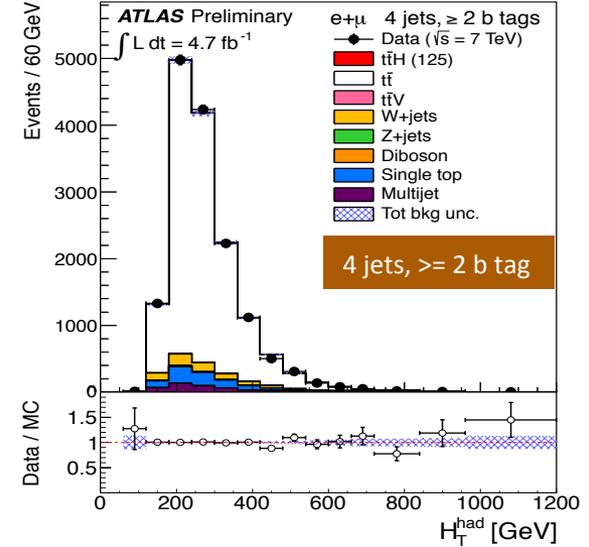
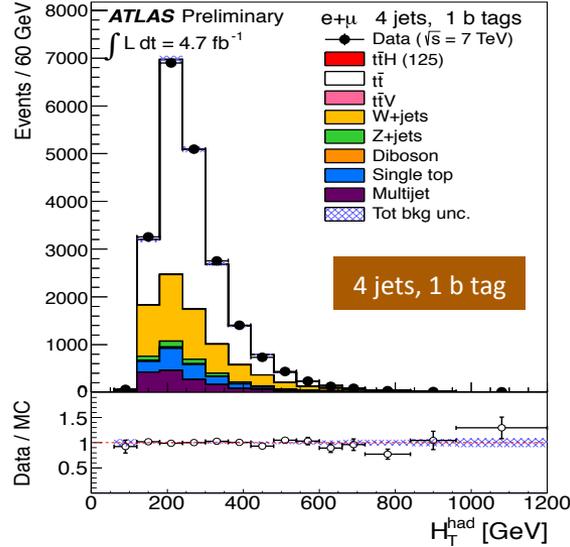
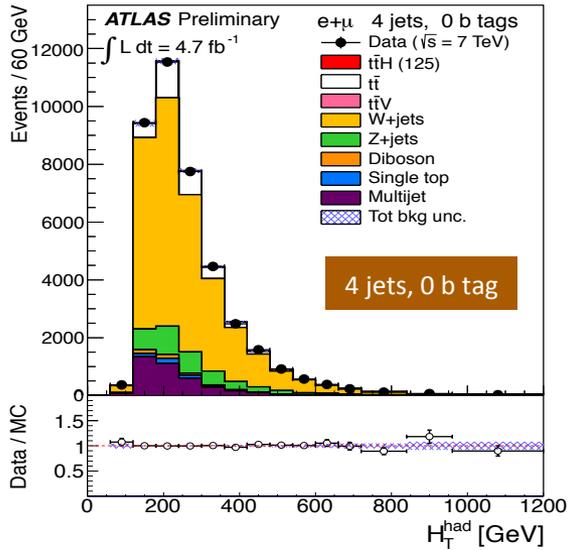
- ✧ Fit results for each year and each channel
- ✧ 7 TeV: deficit w.r.t. the SM expectation
- ✧ 8 TeV indicating excess
- ✧ Final combination:
 
$$\mu = \sigma^{\text{meas.}} / \sigma^{\text{SM}} = 0.2^{+0.7}_{-0.6}$$
- ✧ Results dominated by the statistical uncertainty



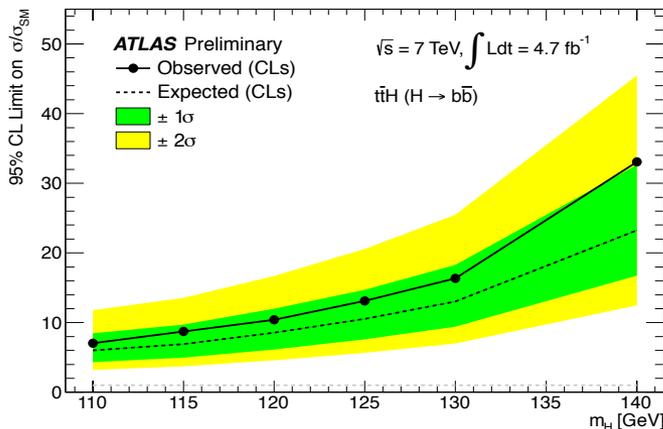
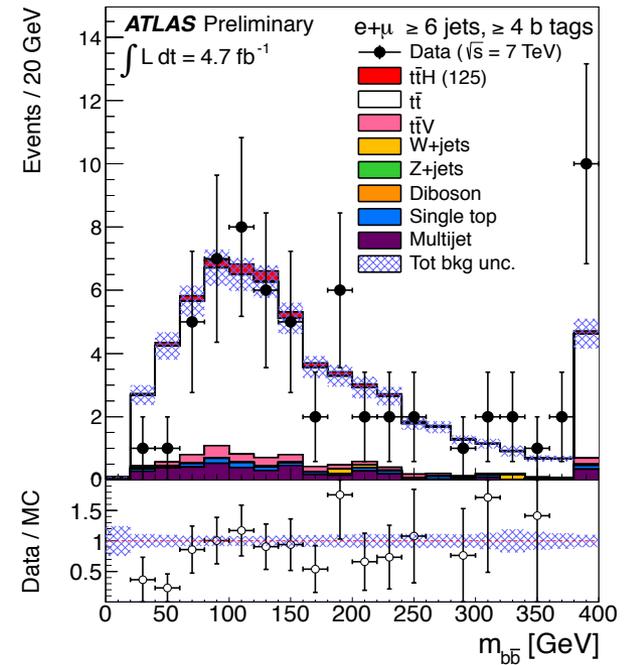
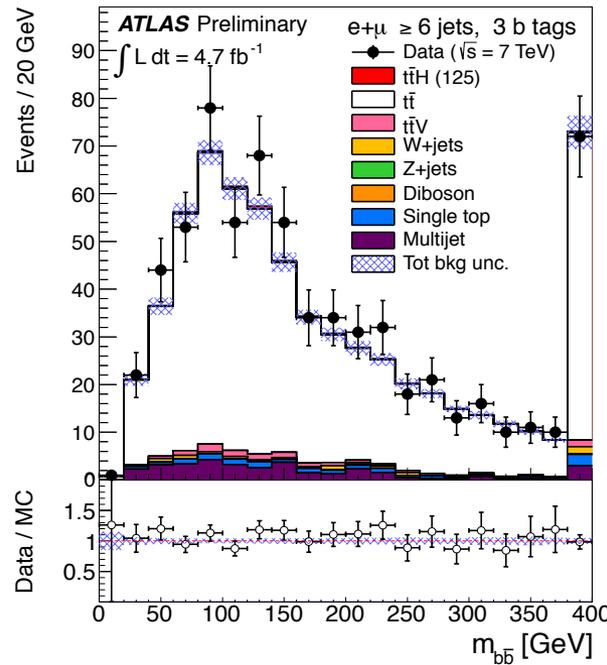
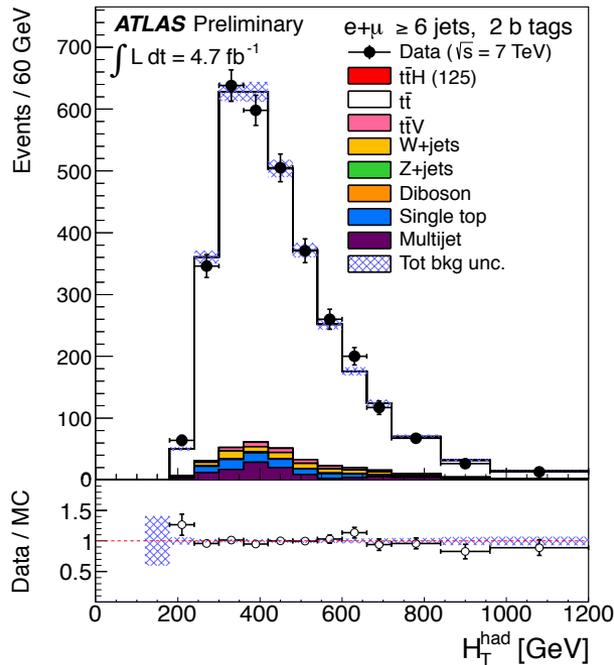
# $t\bar{t}H$ , $H \rightarrow b\bar{b}$ : Introduction

- ✧ Analysis done on 7 TeV of  $4.7 \text{ fb}^{-1}$ : **ATLAS-CONF-2012-135**
- ✧ Topology: one high- $p_T$  isolated  $e/\mu$ , high MET, 6 jets with 4 b's
- ✧ 9 analysis categories: 4 signal regions + 5 control regions
  - 2 with  $m_{bb}$  as discriminant:  $\geq 6$  jets with 3 or  $\geq 4$  b-jets
  - 2 with  $H_T^{\text{had}}$  (scale sum of  $p_T$  of jets): 5 jets with 3 or  $\geq 4$  b-jets
  - 5 with  $H_T^{\text{had}}$  as control regions for background normalization
    - $\geq 6$  jets with 2 b tags; 5 jets with 2 b tags; 4 jets with 0, 1,  $\geq 2$  b tags
- ✧ Background modeling:
  - QCD: data-driven using the “Matrix Method” technique
  - W+jets: shape from MC, normalization based on data (charge asymmetry)
  - Others: MC
- ✧ Main systematic uncertainties: theoretical ones on normalization; heavy flavor fractions; b-tagging efficiency; JES.

# ttH, H->bb: Post-fit Distributions



# $t\bar{t}H$ , $H \rightarrow b\bar{b}$ : Results

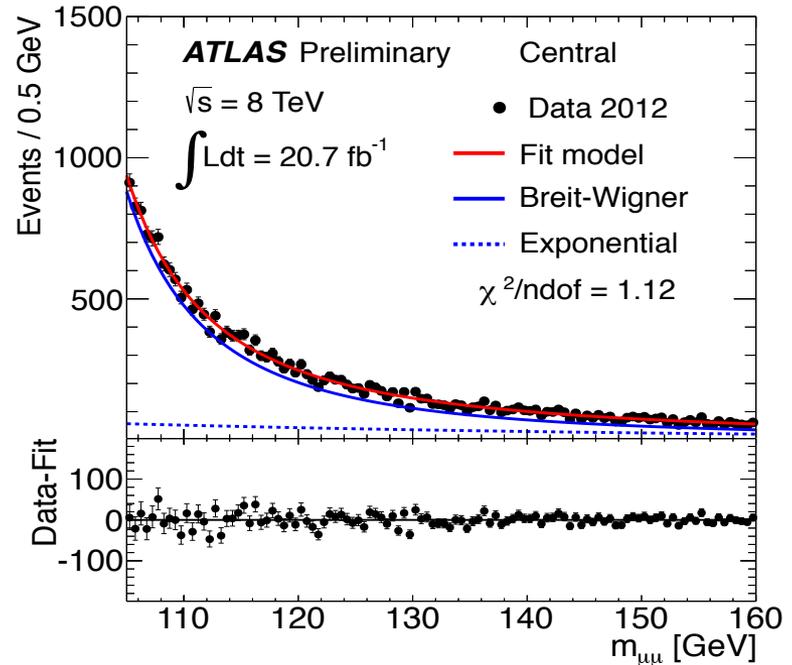
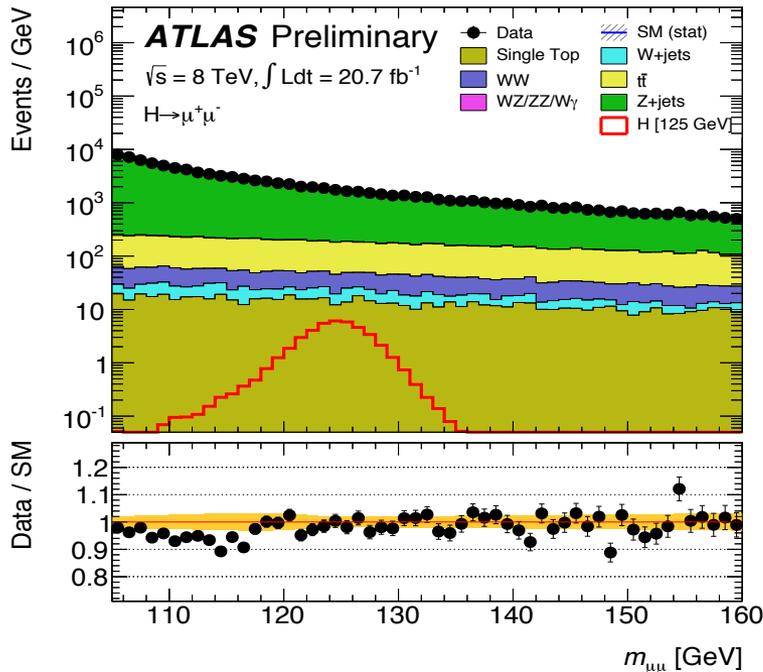


The observed upper limits at 95% C.L. on  $\sigma \times \text{Br}$  is **13.1** times the SM prediction with **10.5** as expected

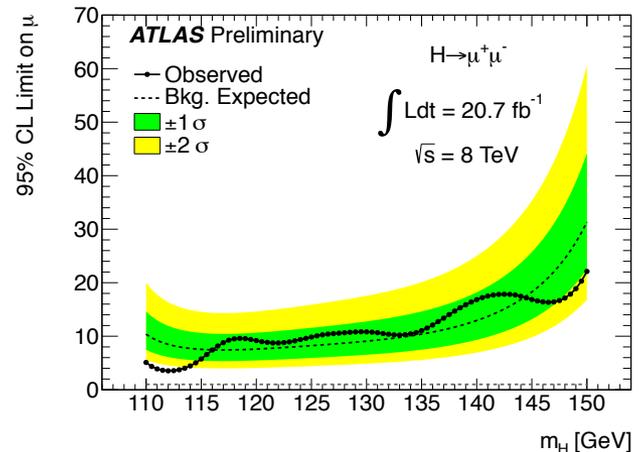
# H- $\mu\mu$ : Introduction

- ✧ Analysis done on 8 TeV of 20.7 fb<sup>-1</sup>: **ATLAS-CONF-2013-010**
  - ✧ Only channel to measure the Higgs coupling to the second generation fermions at the LHC
  - ✧ Clean final-state signature, but very challenging due to tiny S/B
- ✧ Signal: ggF, VBF, and VH modes, with the backgrounds of Z+jets, top, WW, W+jets, and WZ/ZZ/W $\gamma$
- ✧ Selection: exactly two oppositely charged muons ( $p_T^\mu > 25, 15$  GeV)  
 $p_T^{\mu+\mu^-} > 15$  GeV
- ✧ Two categories: central ( $|\eta(\mu_1, \mu_2)| < 1$ ), and non-central
- ✧ Fit the  $m_{\mu+\mu^-}$  with two pdf's for the signal and backgrounds:
  - Signal: sum of the Crystal Ball (CB) and Gaussian (GS)
  - Backgrounds: sum of the Breit-Wigner (BW) and exponential
- ✧ Systematics:
  - Theoretical sources: cross section, BR, generator setting
  - Experimental uncertainties, dominated by the luminosity

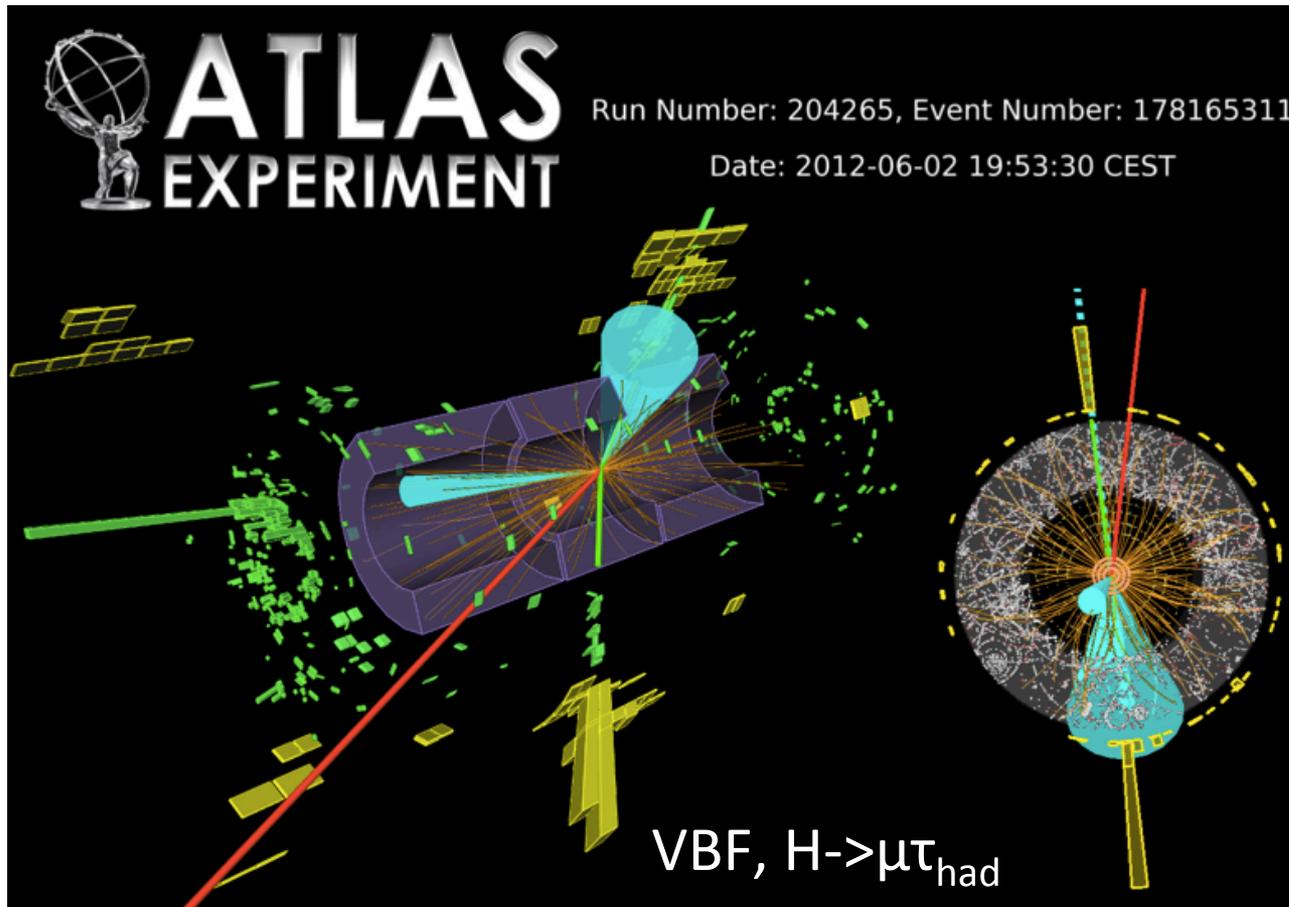
# H $\rightarrow\mu\mu$ : Analysis Result



- ✧ The observed upper limit at the 95% C.L. for Higgs@125 GeV is 9.8 times the SM prediction, with the expected of 8.2
- ✧ More data needed to improve the sensitivity



# H- $\rightarrow$ $\tau\tau$ @ATLAS



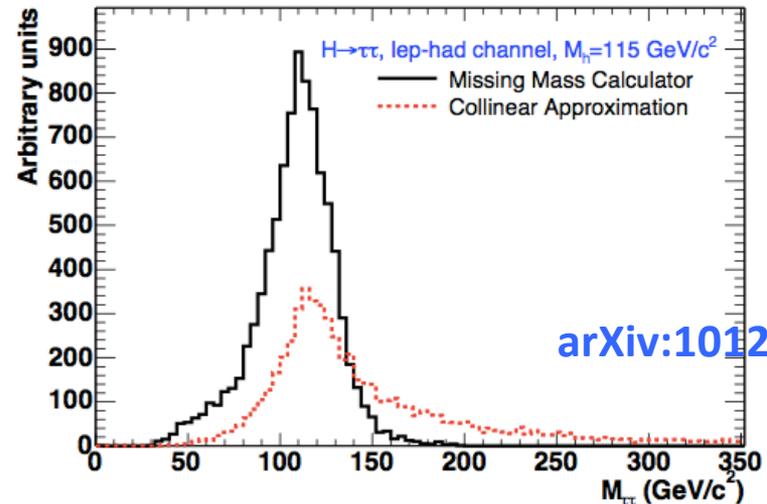
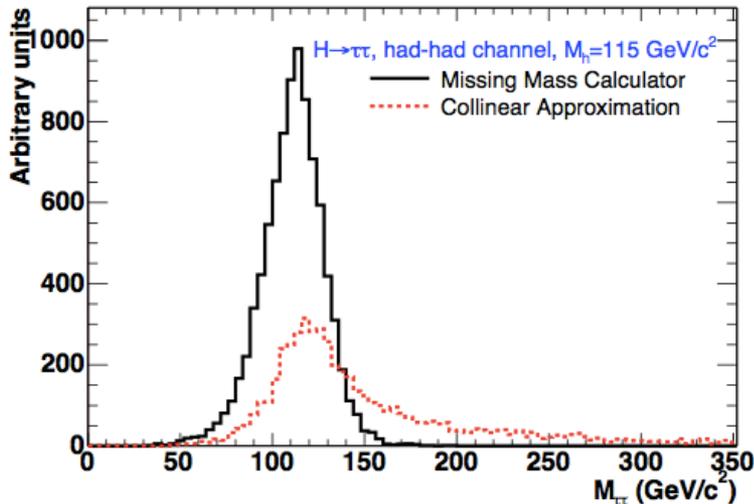
- ✓ Introduction
- ✓ Event selection
- ✓ Backgrounds
- ✓ Systematics
- ✓ Results

✧ ATLAS-CONF-2012-160: 4.6 fb<sup>-1</sup> @7 TeV, 13.0 fb<sup>-1</sup> @8 TeV



# H $\rightarrow$ $\tau\tau$ : Analysis Strategy

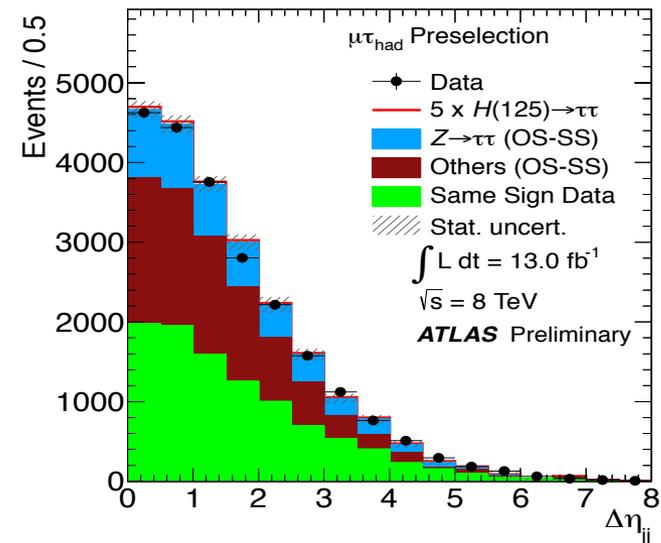
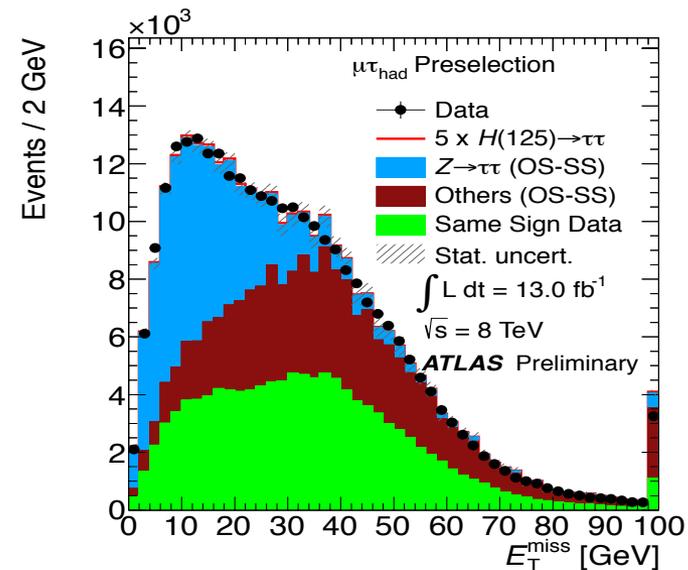
- ✧ Analysis categories motivated by Higgs production modes:
  - **VBF**: 2 forward jets in opposite hemispheres
  - **Boosted**: gg fusion with Boosted Higgs to improve mass resolution
  - **VH**: multi-jet events with different kinematics from VBF
  - **0j/1j**: ggF except from the above
- ✧ Missing Mass Calculator (MMC) with 13-20% mass resolution, used as the final discriminant (except the 7 TeV lep-lep), better than the collinear approximation (more in the back-up)



arXiv:1012.4686

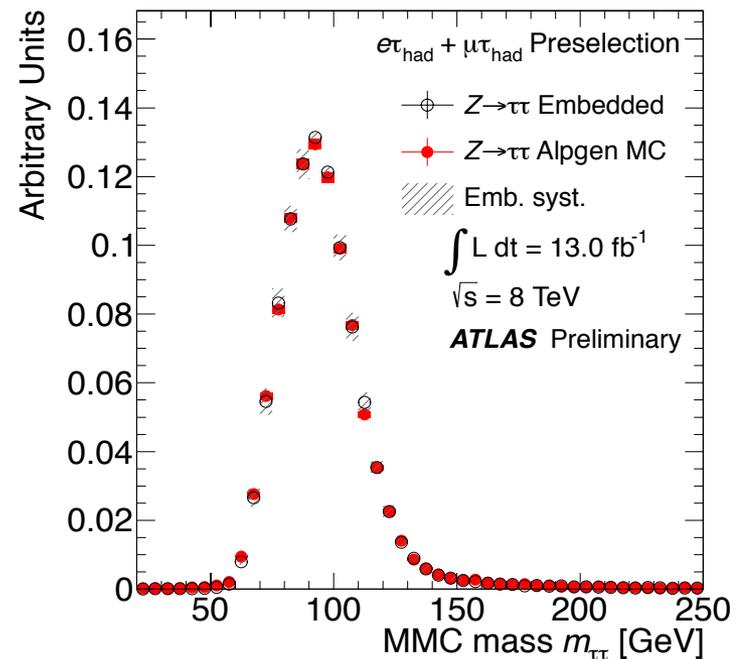
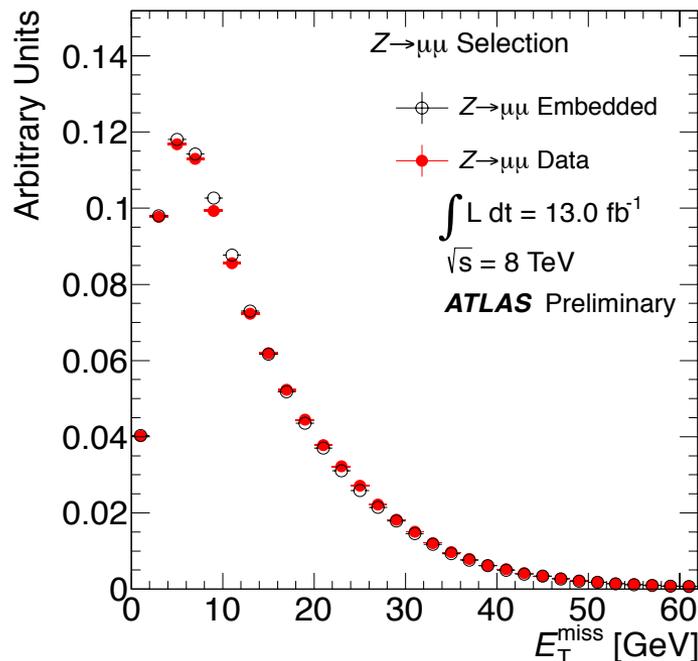
# H → ττ: Event Selection (lep-had)

8 TeV	
<b>VBF Category</b>	<b>Boosted Category</b>
<ul style="list-style-type: none"> <li>▶ <math>p_T^{\ell \text{ had-vis}} &gt; 30 \text{ GeV}</math></li> <li>▶ <math>E_T^{\text{miss}} &gt; 20 \text{ GeV}</math></li> <li>▶ <math>\geq 2</math> jets</li> <li>▶ <math>p_T^{j1} &gt; 40, p_T^{j2} &gt; 30 \text{ GeV}</math></li> <li>▶ <math>\Delta\eta_{jj} &gt; 3.0</math></li> <li>▶ <math>m_{jj} &gt; 500 \text{ GeV}</math></li> <li>▶ centrality req.</li> <li>▶ <math>\eta_{j1} \times \eta_{j2} &lt; 0</math></li> <li>▶ <math>p_T^{\text{Total}} &lt; 30 \text{ GeV}</math></li> <li>▶ <math>p_T^{\ell} &gt; 26 \text{ GeV}</math></li> </ul>	<ul style="list-style-type: none"> <li>▶ <math>p_T^{\ell \text{ had-vis}} &gt; 30 \text{ GeV}</math></li> <li>▶ <math>E_T^{\text{miss}} &gt; 20 \text{ GeV}</math></li> <li>▶ <math>p_T^H &gt; 100 \text{ GeV}</math></li> <li>▶ <math>0 &lt; x_1 &lt; 1</math></li> <li>▶ <math>0.2 &lt; x_2 &lt; 1.2</math></li> <li>▶ Fails VBF</li> </ul>
<ul style="list-style-type: none"> <li>• <math>m_T &lt; 50 \text{ GeV}</math></li> <li>• <math>\Delta(\Delta R) &lt; 0.8</math></li> <li>• <math>\sum \Delta\phi &lt; 2.8</math></li> <li>• <math>b</math>-tagged jet veto</li> </ul>	<ul style="list-style-type: none"> <li>• <math>m_T &lt; 50 \text{ GeV}</math></li> <li>• <math>\Delta(\Delta R) &lt; 0.8</math></li> <li>–</li> <li>• <math>b</math>-tagged jet veto</li> </ul>
<b>1 Jet Category</b>	<b>0 Jet Category</b>
<ul style="list-style-type: none"> <li>▶ <math>\geq 1</math> jet, <math>p_T &gt; 30 \text{ GeV}</math></li> <li>▶ <math>E_T^{\text{miss}} &gt; 20 \text{ GeV}</math></li> <li>▶ Fails VBF, Boosted</li> </ul>	<ul style="list-style-type: none"> <li>▶ 0 jets <math>p_T &gt; 30 \text{ GeV}</math></li> <li>▶ <math>E_T^{\text{miss}} &gt; 20 \text{ GeV}</math></li> <li>▶ Fails Boosted</li> </ul>
<ul style="list-style-type: none"> <li>• <math>m_T &lt; 50 \text{ GeV}</math></li> <li>• <math>\Delta(\Delta R) &lt; 0.6</math></li> <li>• <math>\sum \Delta\phi &lt; 3.5</math></li> <li>–</li> </ul>	<ul style="list-style-type: none"> <li>• <math>m_T &lt; 30 \text{ GeV}</math></li> <li>• <math>\Delta(\Delta R) &lt; 0.5</math></li> <li>• <math>\sum \Delta\phi &lt; 3.5</math></li> <li>• <math>p_T^{\ell} - p_T^{\tau} &lt; 0</math></li> </ul>



# H- $\rightarrow$ $\tau\tau$ : Embedding for Z- $\rightarrow$ $\tau\tau$

- ✧ Z- $\rightarrow$  $\tau\tau$ : important to all the 3 channels, **embedding method** applied to improve modeling of jet/MET variables, reduce the sys. uncertainties, and increase sample statistics
  - Start with Z- $\rightarrow$  $\mu\mu$  events from data, remove muons
  - Embed MC  $\tau$  into the above selected events



# H-> $\tau\tau$ : Background Modeling

## ✧ Lep-lep channel:

- Z-> $\tau\tau$ : shape from embedding, normalized to MC at pre-selection level
- Di-boson: MC, validated with a data control region (CR)
- Z->ee/ $\mu\mu$ , top: MC, normalized to a data CR
- Fake leptons: estimated from a data CR (reverse lepton isolation)

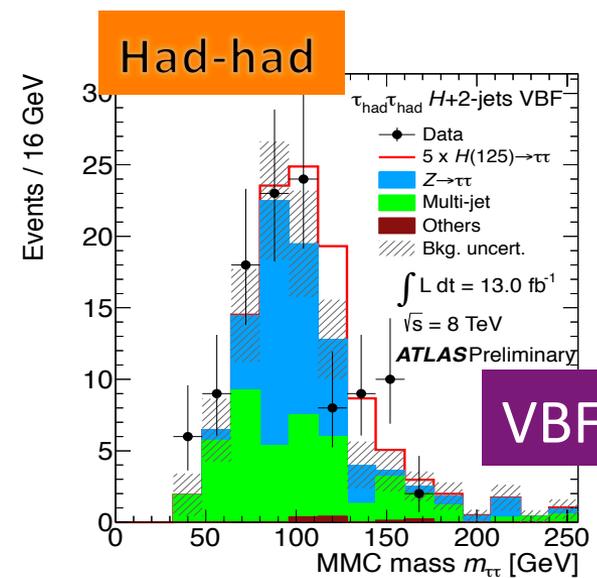
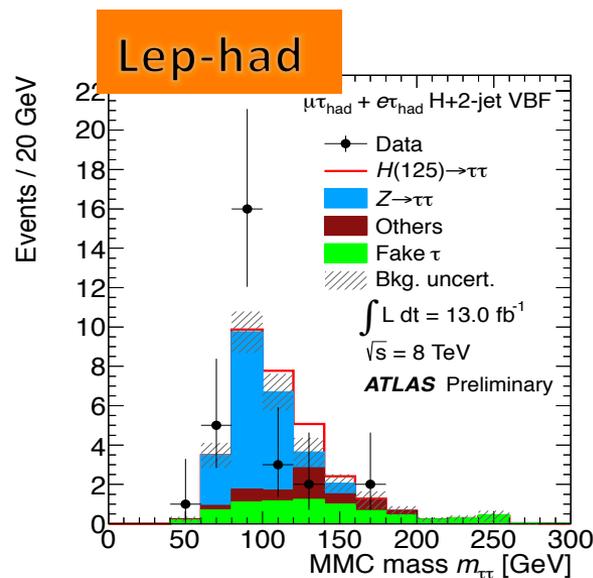
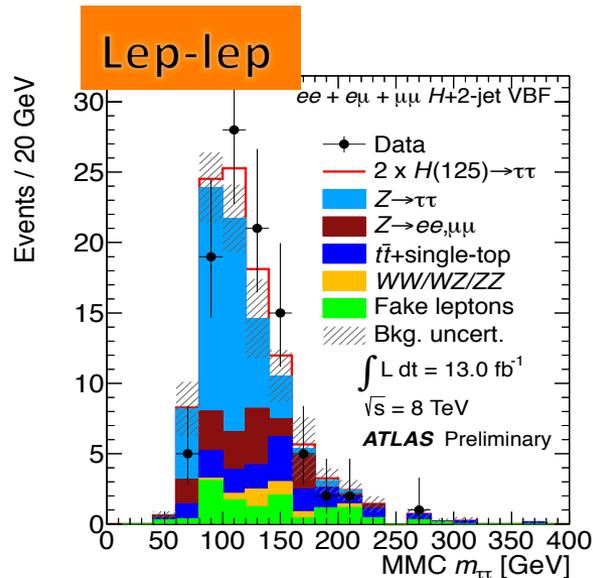
## ✧ Lep-had channel:

- Same sign (SS): primarily multi-jets, estimated from data
- OS-SS background:
  - Z-> $\tau\tau$ : embedding except for VBF (shape from MC, normalized to a CR)
  - Others: top, W+jets, Z->ee/ $\mu\mu$ , di-boson, MC, each normalized to a CR
  - In VBF, the multi-jet and W+jets estimated using a *fake factor*:  $N_{\tau-id}/N_{anti-\tau-id}$

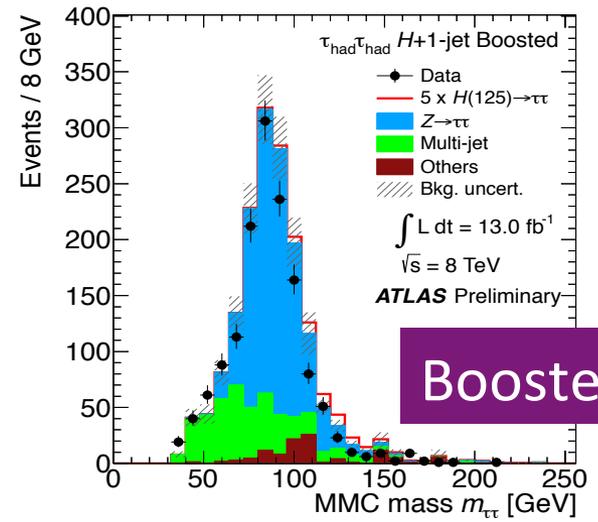
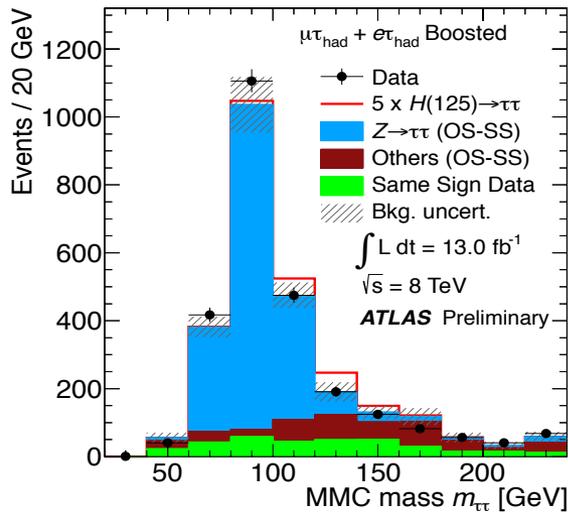
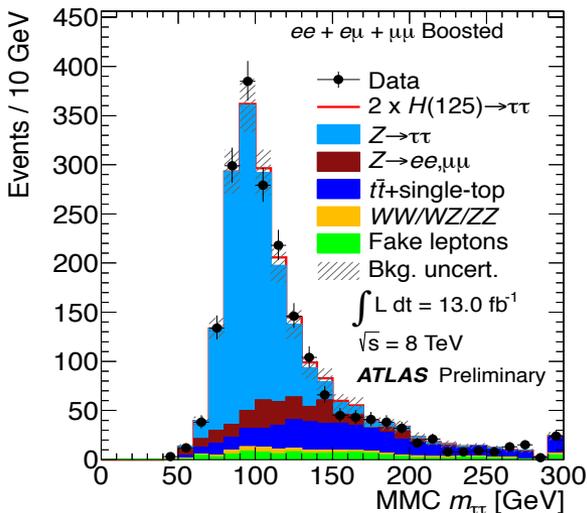
## ✧ Had-had channel:

- Z-> $\tau\tau$ : shape from embedding, normalization from 2D-fit to  $N_{tracks}$  of the two  $\tau_{had}$
- Multi-jets: shape from not-opposite-sign (notOS) in 7 TeV, or with reversed  $\tau_{had}$  ID in 8 TeV, Normalization with same 2D-fit to  $N_{tracks}$
- Others: mainly W-> $\tau\nu$  + jets, shape from MC; fake rate derived from data

# H- $\rightarrow$ $\tau\tau$ : Di-tau Mass after Selections



VBF



Boosted

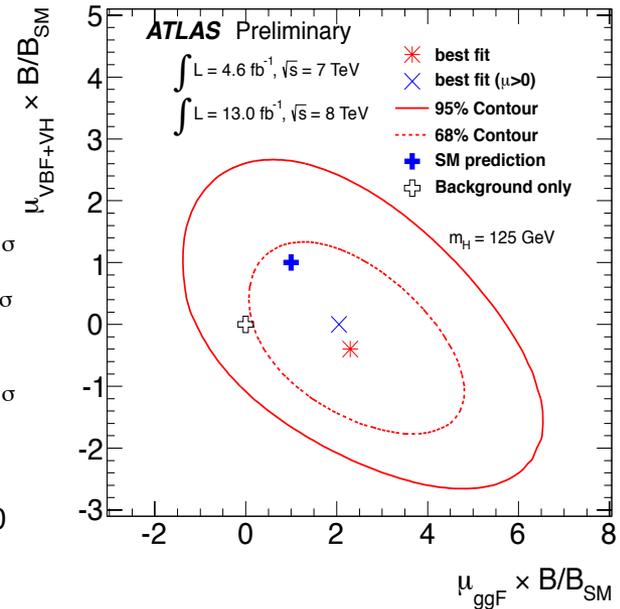
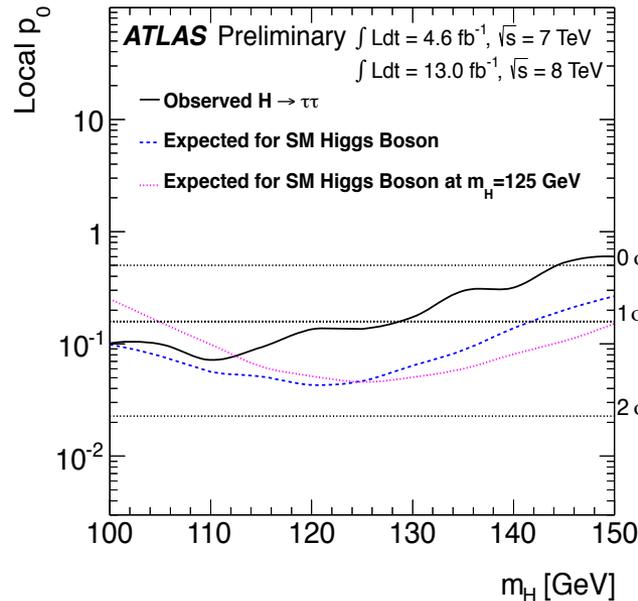
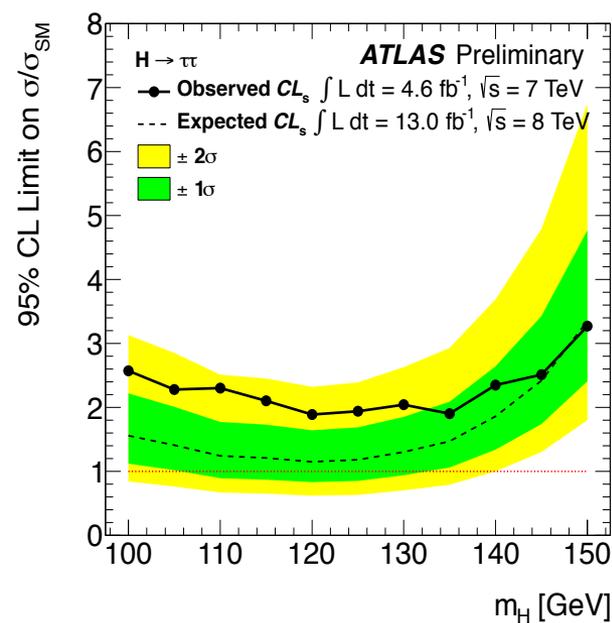
# H- $\rightarrow$ $\tau\tau$ : Systematics

Uncertainty	$H \rightarrow \tau_{\text{lep}}\tau_{\text{lep}}$	$H \rightarrow \tau_{\text{lep}}\tau_{\text{had}}$	$H \rightarrow \tau_{\text{had}}\tau_{\text{had}}$
$Z \rightarrow \tau^+\tau^-$			
Embedding	1–4% (S)	2–4% (S)	1–4% (S)
Tau Energy Scale	–	4–15% (S)	3–8% (S)
Tau Identification	–	4–5%	1–2%
Trigger Efficiency	2–4%	2–5%	2–4%
Normalisation	5%	4% (non-VBF), 16% (VBF)	9–10%
Signal			
Jet Energy Scale	1–5% (S)	3–9% (S)	2–4% (S)
Tau Energy Scale	–	2–9% (S)	4–6% (S)
Tau Identification	–	4–5%	10%
Theory	8–28%	18–23%	3–20%
Trigger Efficiency	small	small	5%

- ✧ Z- $\rightarrow$  $\tau\tau$ : dominated by tau energy scale and normalization
- ✧ Signal: dominated by the theoretical uncertainty
- ✧ Ranges given because of significant variation in the impact on analysis category and signal production mode

# H → ττ: Results

- ✧ No significant excess observed, the upper limit at 95% C.L. for SM Higgs @125 GeV: 1.9 observed with 1.2 as expected
- ✧ The best fitted value of  $\mu$ :  $0.7 \pm 0.7$
- ✧ The observed significance  $1.1\sigma$  with  $1.7\sigma$  as expected
- ✧ Constrained 2-dimentional fit:  $\mu_{ggF} \times B/B_{SM} = 2.1$ ;  $\mu_{VBF+VH} \times B/B_{SM} = 0$



# Summary

No significant excess observed in the searches for the SM Higgs decaying into fermions. For the SM Higgs @125 GeV:

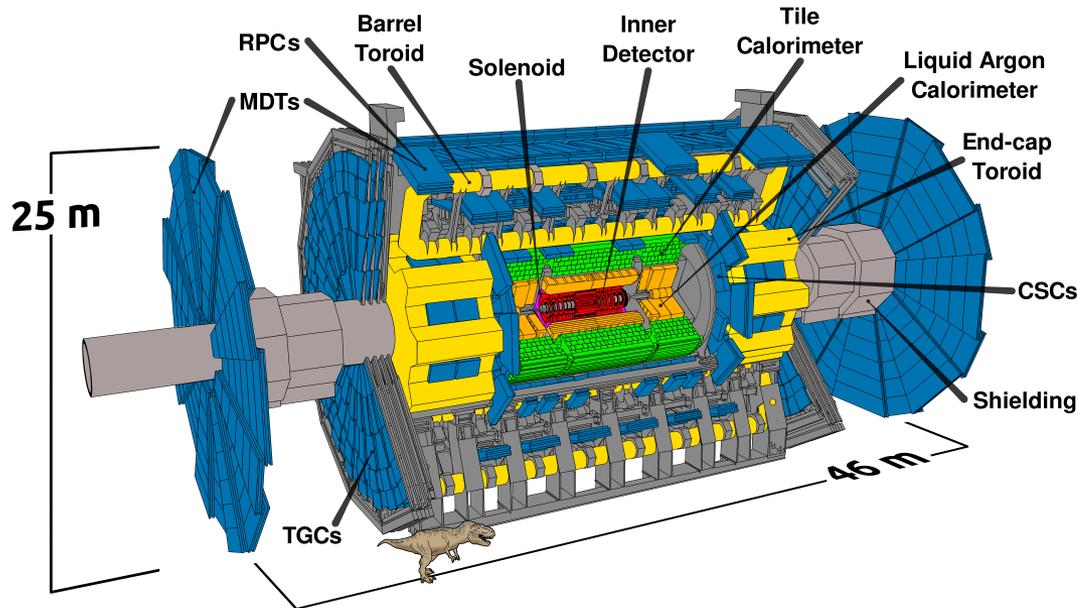
- ✧ Search for Higgs decaying into bb pair using the full datasets in VH production mode: the observed upper limit on  $\mu$  is 1.4 with 1.3 as expected,  $\mu = 0.2 \pm 0.5$  (stat.)  $\pm 0.4$  (syst.)
- ✧ The ttH, H→bb analysis done with 7 TeV dataset: the observed upper limit on  $\mu$  is 13.1 with 10.5 as expected
- ✧ Search in the  $\mu^+\mu^-$  final state with the full 8 TeV data: the upper limit is 9.8 times the SM prediction, with 8.2 as expected
- ✧ For the  $\tau$  with the 7 TeV and 13.0 fb<sup>-1</sup> (8TeV) : the observed upper limit on is 1.9 with 1.2 as expected; the best fit  $\mu = 0.7 \pm 0.7$

Looking forward to the new result from the tau tau, and even the data in 2015!

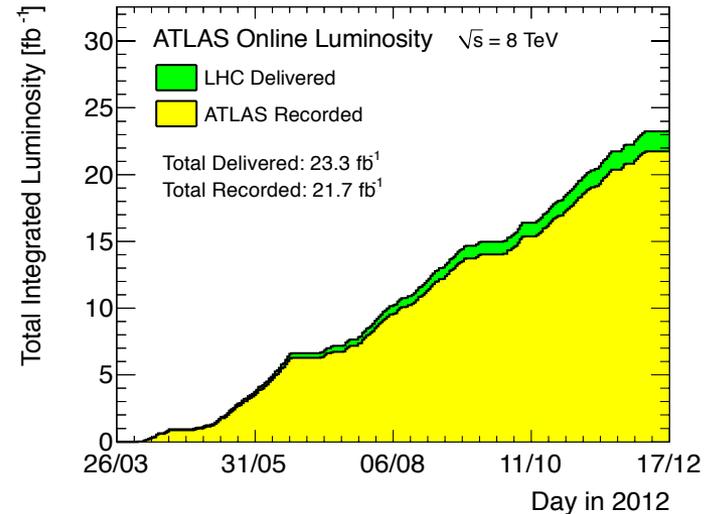
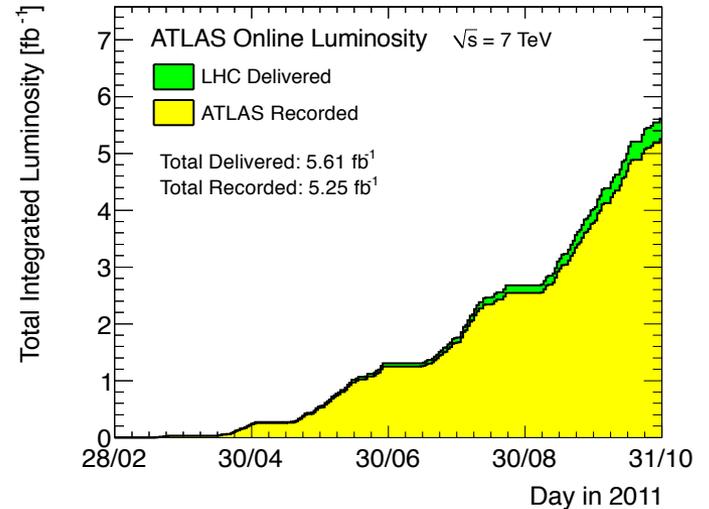
# Thanks!



# Introduction: ATLAS Experiment



- ✧ b-jet and hadronic tau: depending on the Inner Detector with  $|\eta| < 2.5$
- ✧ Datasets recorded:
  - $5.25 \text{ fb}^{-1}$  in 2011 @7TeV
  - $21.7 \text{ fb}^{-1}$  in 2012 @8TeV

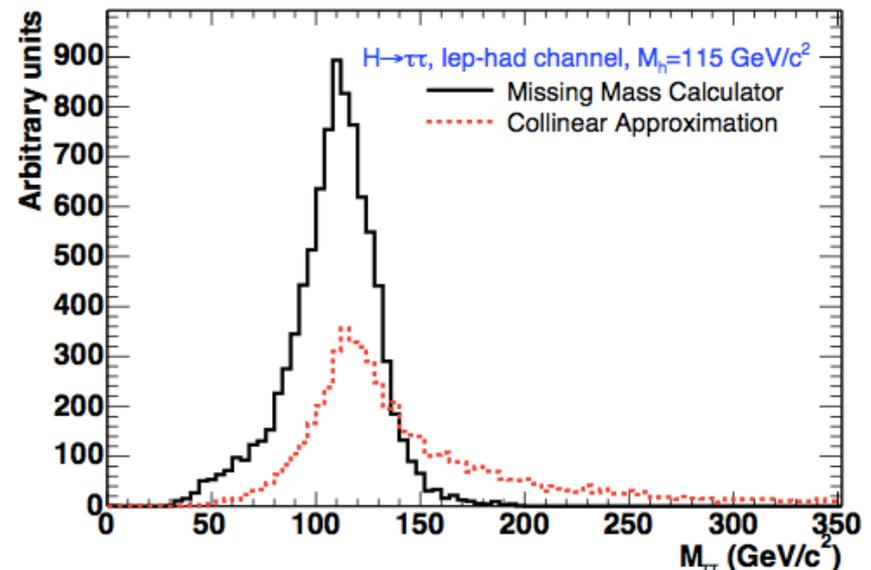
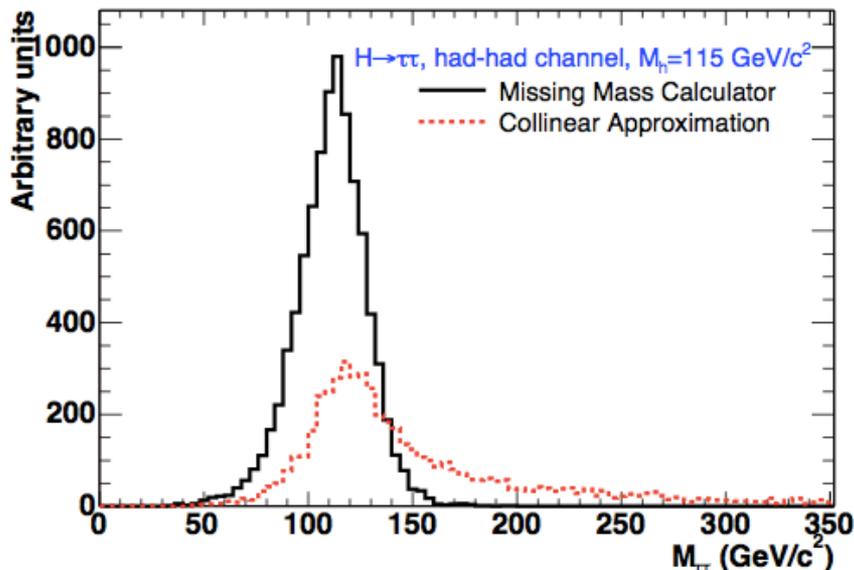


# MMC in arXiv:1012.4686

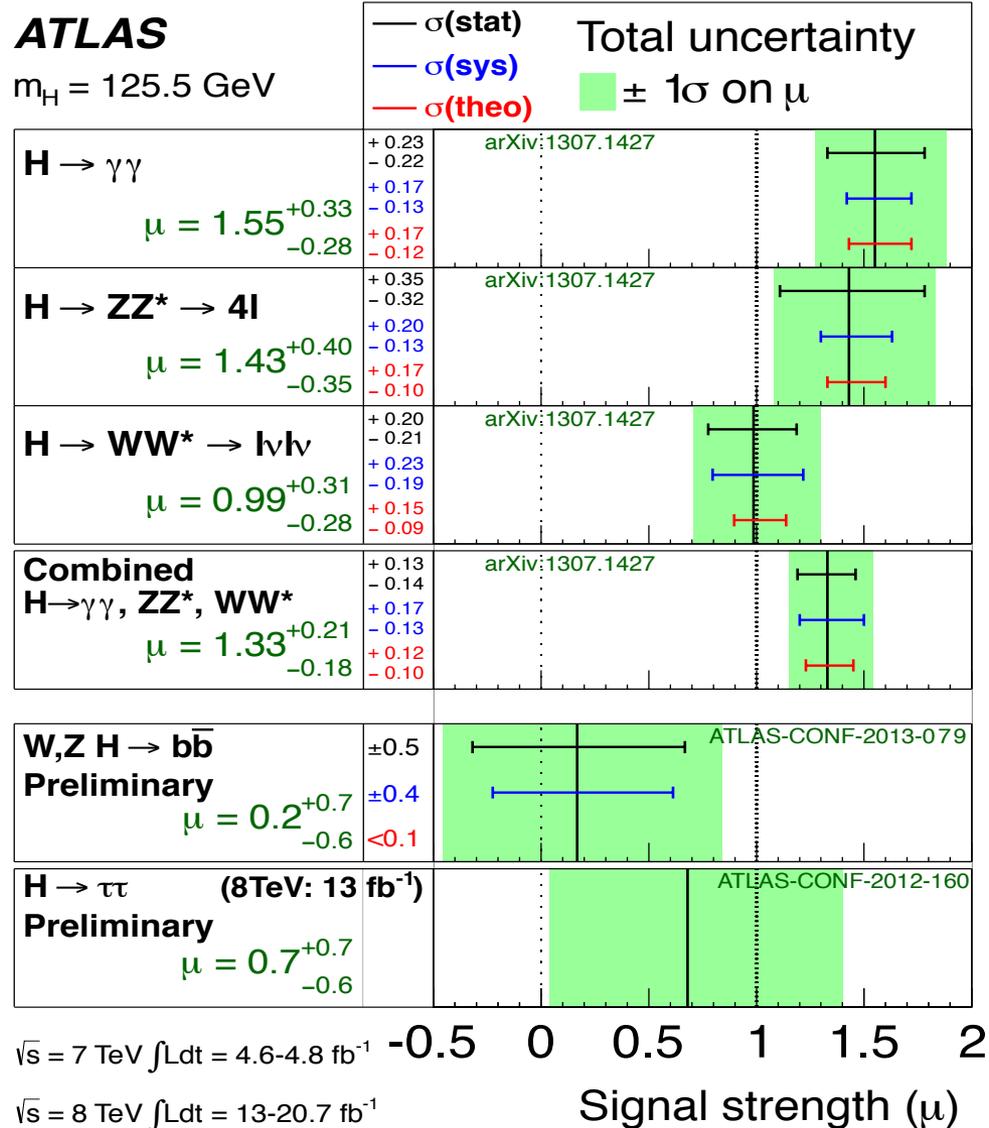
**Collinear mass:** assume momentum of neutrino(s) from a  $\tau$  decay has the same direction as the visible momentum

## Missing Mass Calculator (MMC)

- Reconstruct  $\mathbf{p}^{\text{miss}}$  for each  $\tau$  decay using all kinematic constraints and performing a scan over the undermined variables
- Assign a probability to each outcome based on pdf's from simulated  $\tau$  decays
- Take the mass that maximizes the probability



# Updated Higgs Results



# VH, H->bb: Selection Efficiency of Signals

Table 2: Further topological criteria in  $p_T^V$  intervals. The 0-lepton channel does not use the lowest two  $p_T^V$  intervals.

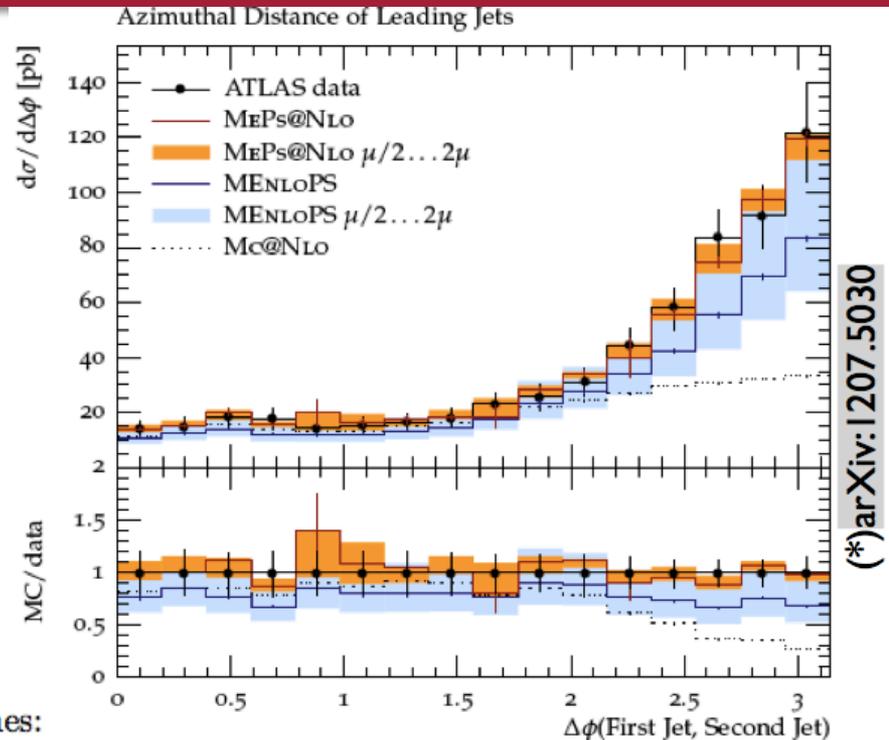
	$p_T^V$ [GeV]	0-90	90-120	120-160	160-200	>200
All Channels	$\Delta R(b, \bar{b})$	0.7-3.4	0.7-3.0	0.7-2.3	0.7-1.8	<1.4
1-lepton	$E_T^{\text{miss}}$ [GeV]	>25				>50
	$m_T^W$ [GeV]	40-120			<120	

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

# VH, H- $\rightarrow$ bb: MC Generators

Process	Generator	$\sigma \times BR$
$WH$	PYTHIA 8.160	
$ZH$	PYTHIA 8.160	
$W \rightarrow \ell\nu$	SHERPA 1.4.1	10.97 nb
$Z/\gamma^* \rightarrow \ell\ell$ $m_{\ell\ell} > 40 \text{ GeV}$	SHERPA 1.4.1	1.24 nb
$Z/\gamma^* \rightarrow \nu\nu$ $m_{\nu\nu} > 5 \text{ GeV}$	SHERPA 1.4.1	6.71 nb
$WW$	HERWIG 6.510	55.43 pb
$WZ$ $66 < m_{\ell\ell} < 116 \text{ GeV}$	HERWIG 6.510	22.69 pb
$ZZ$ $66 < m_{\ell\ell} < 116 \text{ GeV}$	HERWIG 6.510	7.697 pb
Top-quark		
$t\bar{t}$	POWHEG	238.06 pb
$t$ -channel	ACER	87.76 pb
$s$ -channel	POWHEG	5.61 pb
$Wt$ -channel	POWHEG	22.37 pb

# VH, H→bb: p<sub>T</sub> Correction in W+jets



SHERPA predictions are made in three different approaches:

## MC@NLO

NLO+PS matched sample for the  $W + 0$ -jet process using the MC@NLO-like implementation described in [37].

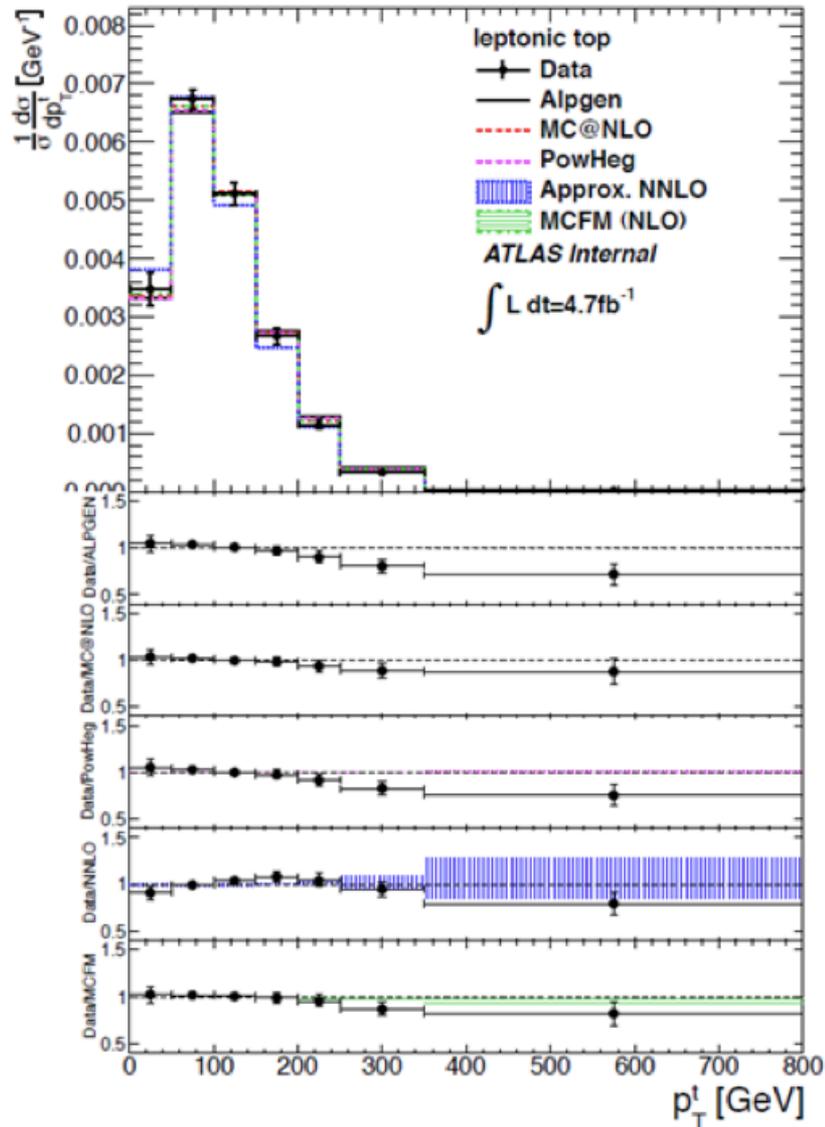
## MENLOPS

The MENLOPS method described in [36] is used to merge an NLO+PS sample for the  $W + 0$ -jet process with tree-level matrix elements for the higher multiplicity  $W + 1, 2, 3, 4$ -jet processes. Here we use this method on top of the  $W + 0$ -jet MC@NLO sample, as described in more detail in a parallel publication.

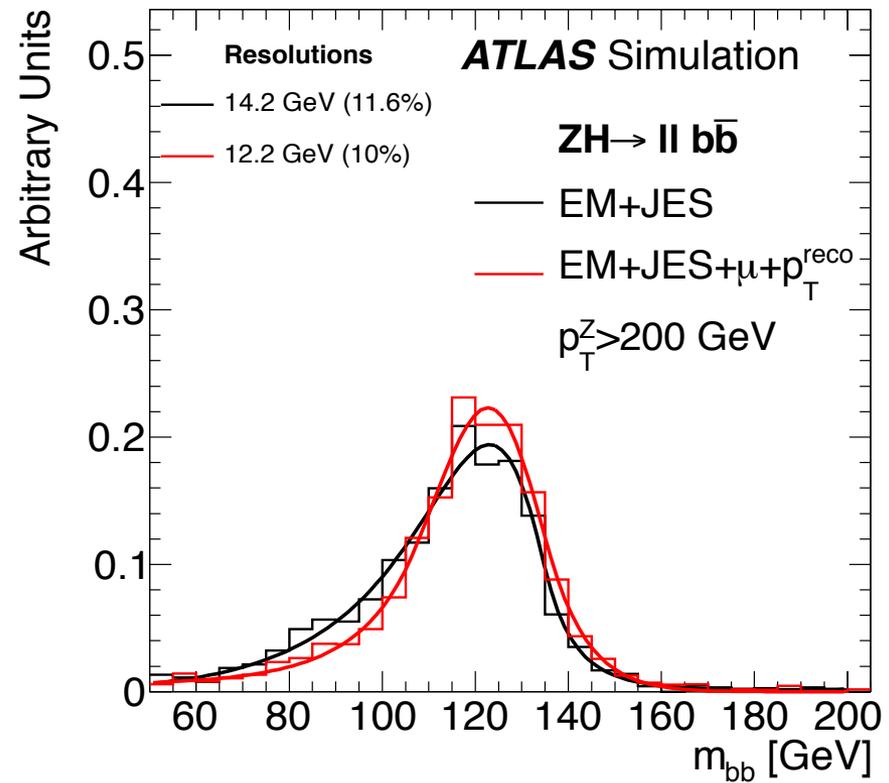
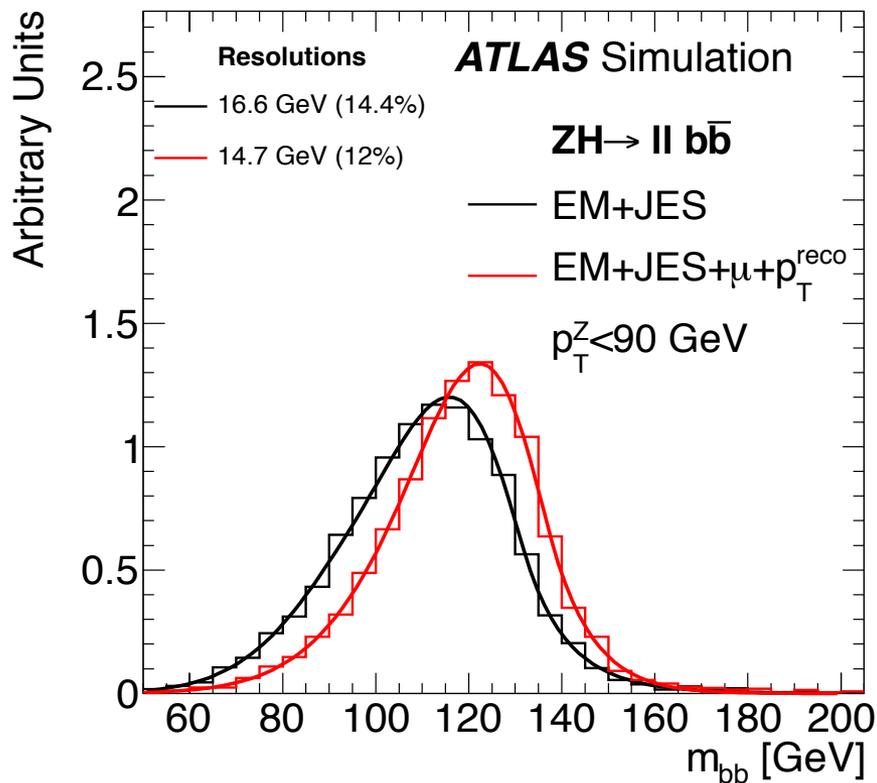
## MEPS@NLO

The MEPS@NLO method was described in Sec. 2 and is used here for the  $W + 0, 1, 2$ -jet processes at NLO. In addition, the  $W + 3, 4$ -jet processes are merged using tree-level matrix elements via the MENLOPS technique.

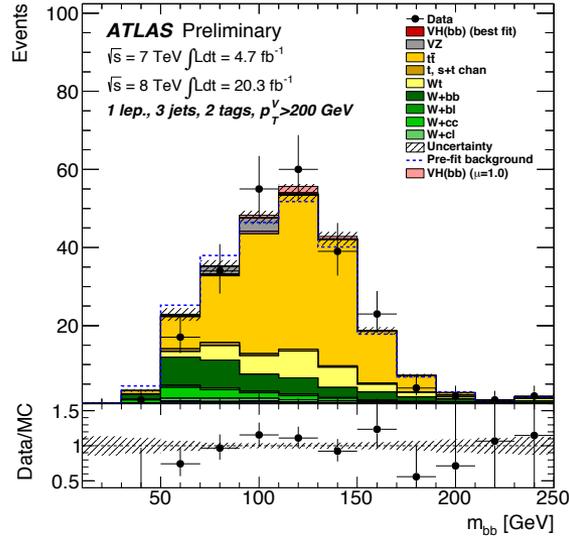
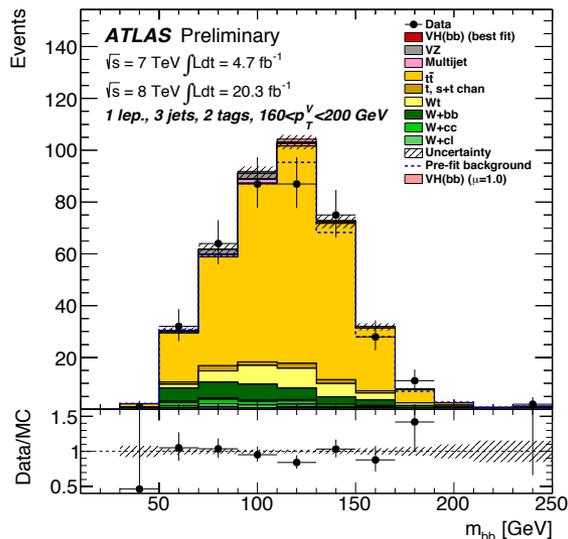
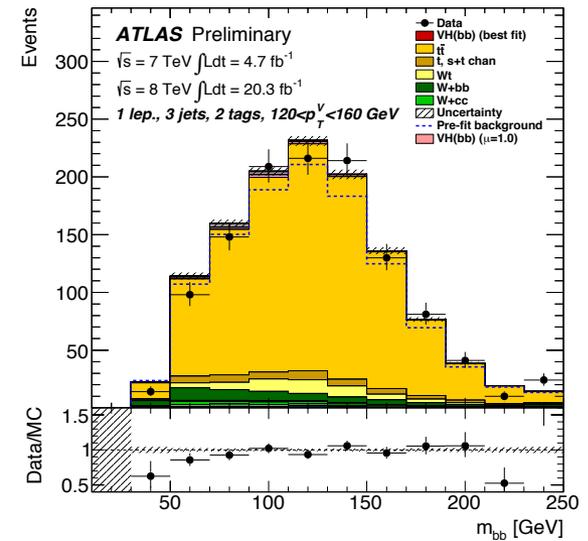
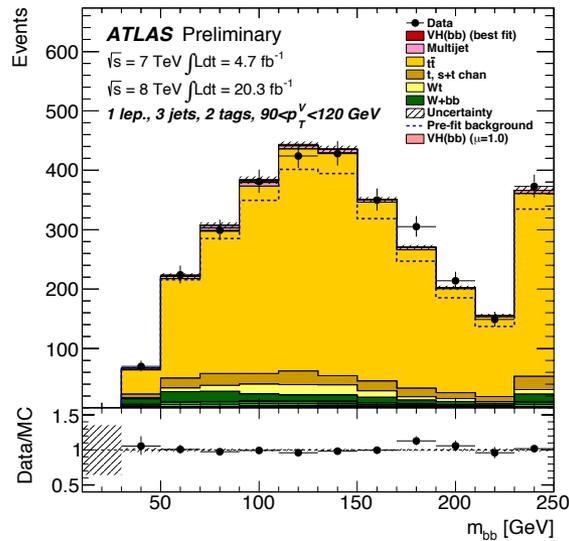
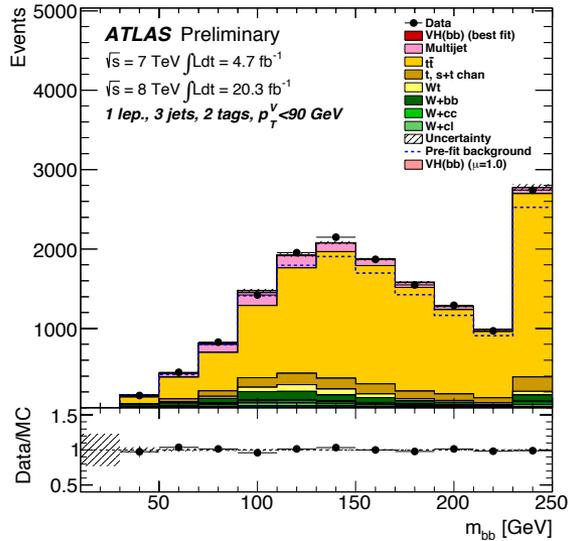
# VH, H->bb: $p_T$ Correction in Top



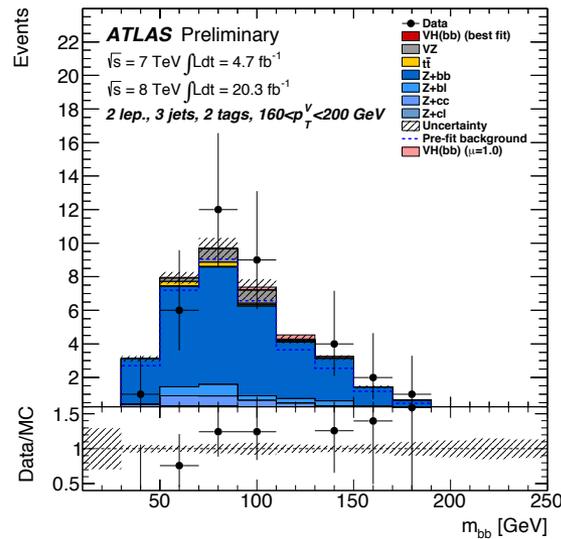
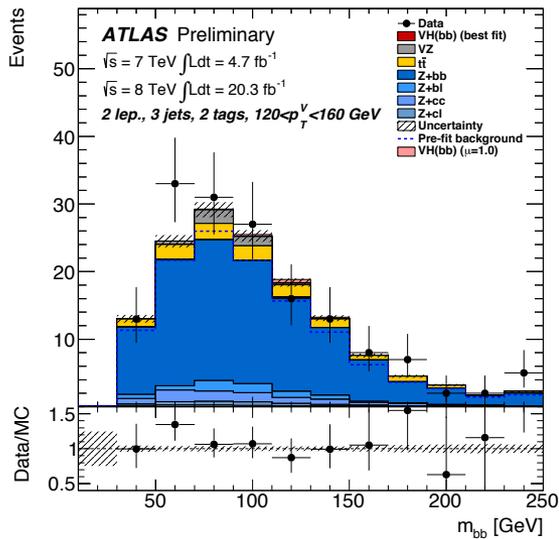
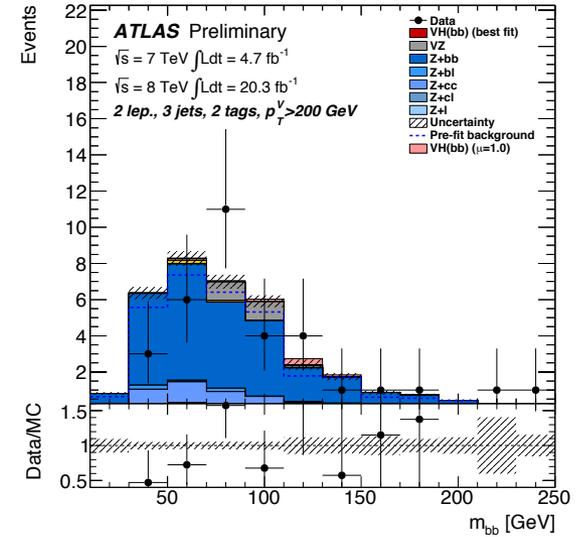
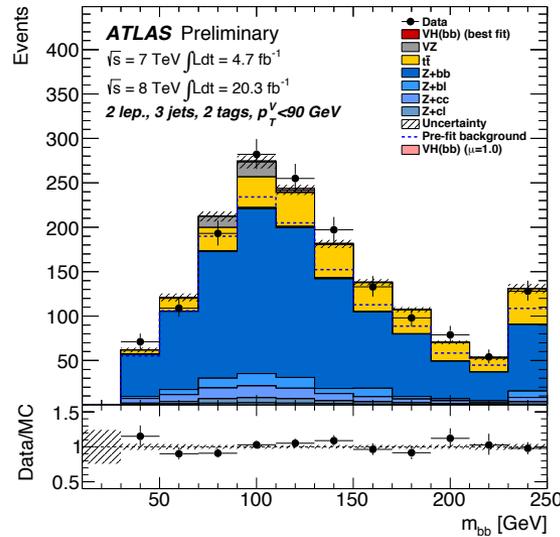
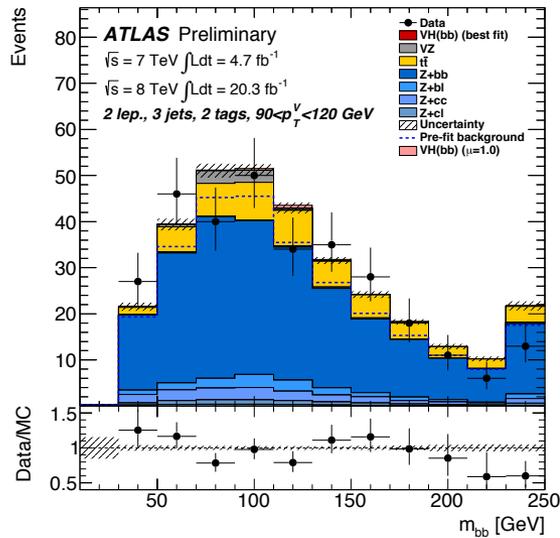
# Improvement on Mass Resolution



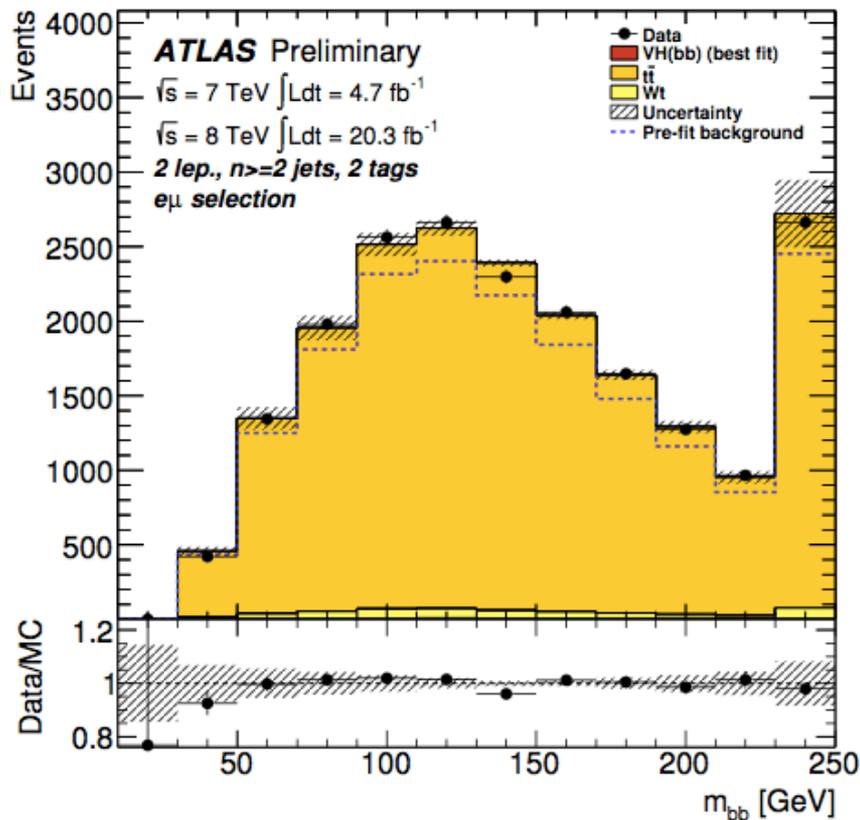
# 1-lepton Post-Fit Plots (3-jet, 2-tag)



# 2-lepton Post-Fit Plots (3-jet, 2-tag)

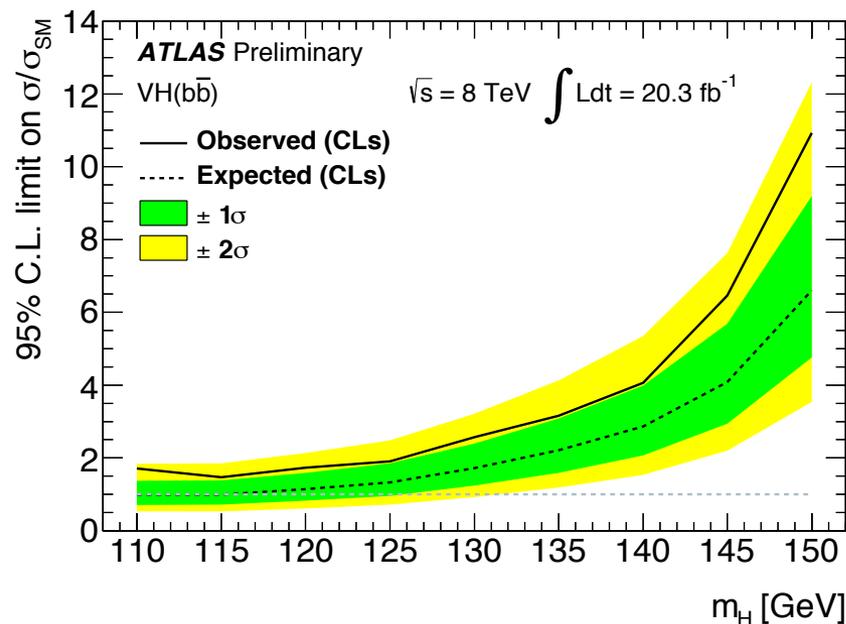
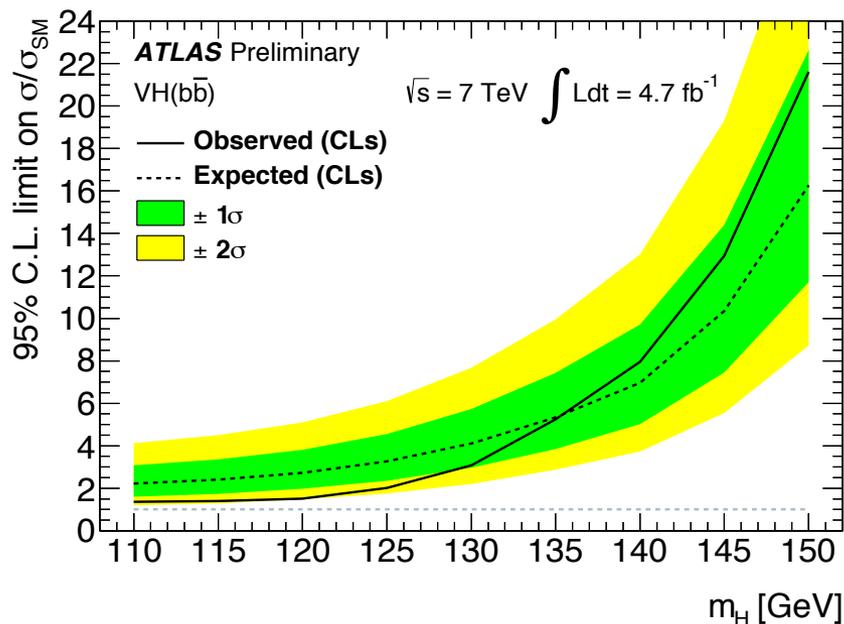


# 2-lepton Post-Fit Plots (Top CR)

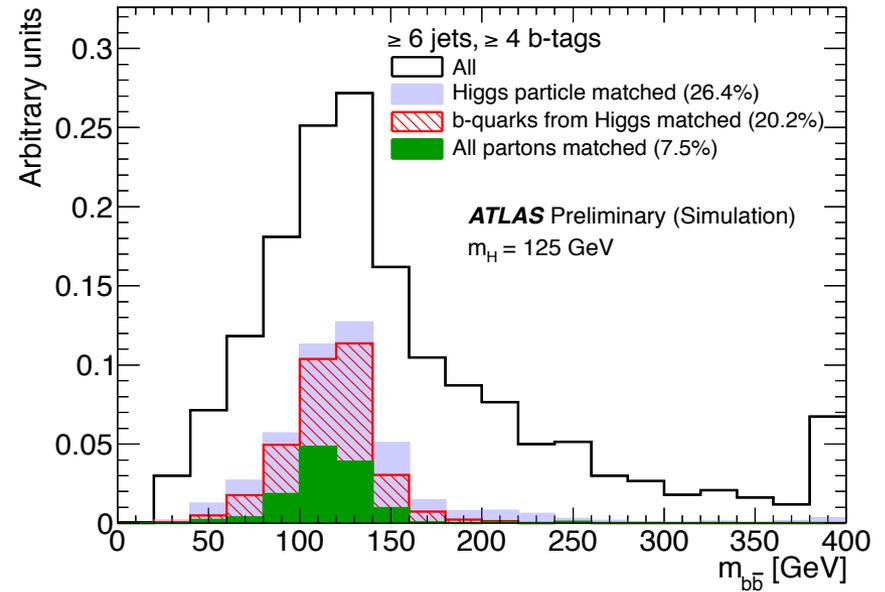
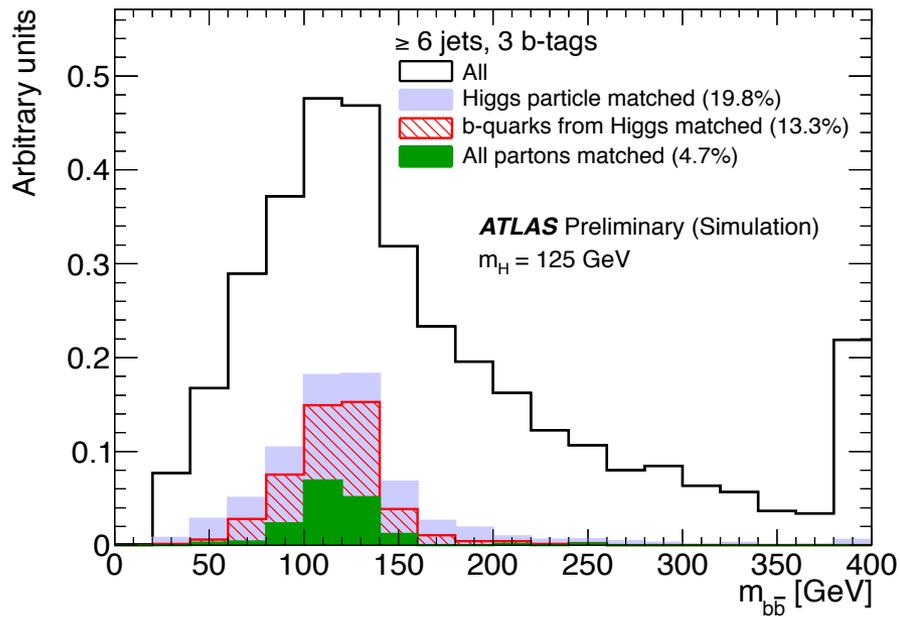


Process	Scale factor
$t\bar{t}$	$1.13 \pm 0.05$
$Wb$	$0.89 \pm 0.15$
$Wcl$	$1.05 \pm 0.14$
$Zb$	$1.30 \pm 0.07$
$Zcl$	$0.89 \pm 0.48$

# Upper Limits of VH in 7 TeV and 8 TeV



# $t\bar{t}H, H \rightarrow b\bar{b}$ : $m_{b\bar{b}}$ Reconstruction



# $t\bar{t}H$ , $H \rightarrow b\bar{b}$ : Post-fit Event Yield

Analysis done on 7 TeV of  $4.7 \text{ fb}^{-1}$ : **ATLAS-CONF-2012-135**

	4 jets, 0 $b$ tags	4 jets, 1 $b$ tags	4 jets, $\geq 2$ $b$ tags	5 jets, 2 $b$ tags	5 jets, 3 $b$ tags
$t\bar{t}H(125)$	$0.20 \pm 0.03$	$1.1 \pm 0.1$	$3.0 \pm 0.2$	$2.7 \pm 0.2$	$2.3 \pm 0.1$
$t\bar{t}$ + jets	$3440 \pm 230$	$12600 \pm 400$	$13040 \pm 160$	$5900 \pm 100$	$837 \pm 24$
$W$ +jets	$28350 \pm 1000$	$5100 \pm 470$	$655 \pm 100$	$210 \pm 50$	$16 \pm 4$
$Z$ +jets	$3700 \pm 600$	$480 \pm 70$	$33 \pm 6$	$16 \pm 4$	$1.1 \pm 0.3$
Single top	$500 \pm 30$	$1380 \pm 70$	$820 \pm 40$	$266 \pm 15$	$31 \pm 2$
Diboson	$411 \pm 50$	$85 \pm 10$	$15 \pm 2$	$3.1 \pm 0.4$	$0.26 \pm 0.05$
$t\bar{t}V$	$12 \pm 3$	$35 \pm 9$	$30 \pm 8$	$32 \pm 9$	$6 \pm 2$
Multijet	$3800 \pm 700$	$1560 \pm 280$	$460 \pm 90$	$210 \pm 50$	$23 \pm 10$
Total bkg.	$40200 \pm 280$	$21240 \pm 200$	$15040 \pm 150$	$6640 \pm 80$	$915 \pm 24$
Data	40209	21248	15066	6653	878

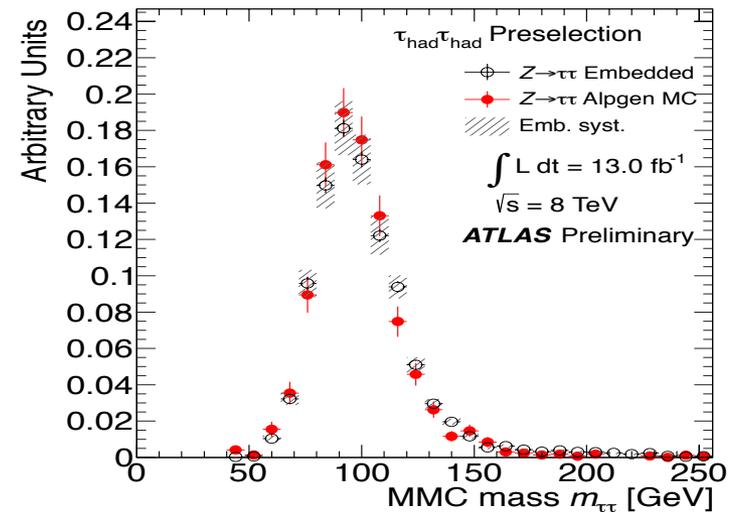
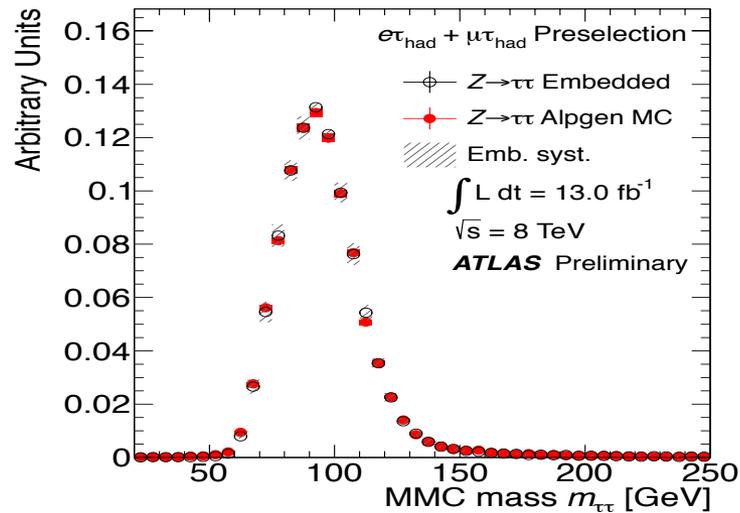
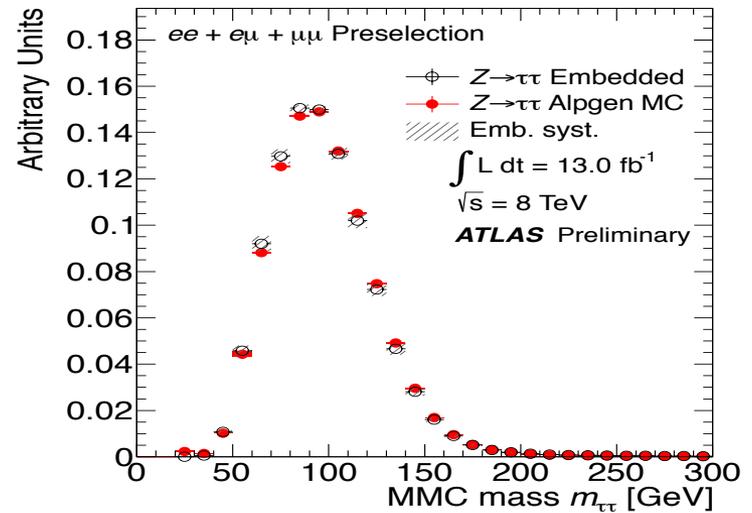
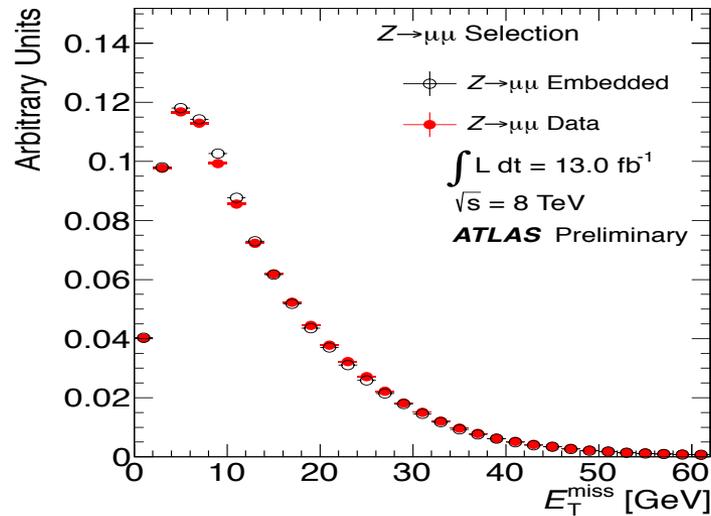
# $t\bar{t}H$ , $H \rightarrow b\bar{b}$ : Post-fit Event Yield

	5 jets, $\geq 4$ $b$ tags	$\geq 6$ jets, 2 $b$ tags	$\geq 6$ jets, 3 $b$ tags	$\geq 6$ jets, $\geq 4$ $b$ tags
$t\bar{t}H(125)$	$0.74 \pm 0.04$	$3.4 \pm 0.2$	$4.0 \pm 0.2$	$2.2 \pm 0.1$
$t\bar{t}$ + jets	$38 \pm 3$	$3030 \pm 90$	$560 \pm 20$	$54 \pm 5$
$W$ +jets	$1.1 \pm 0.4$	$74 \pm 20$	$8 \pm 3$	$0.7 \pm 0.3$
$Z$ +jets	$0.03 \pm 0.01$	$6 \pm 2$	$0.4 \pm 0.2$	$0.01 \pm 0.01$
Single top	$1.6 \pm 0.2$	$92 \pm 7$	$15 \pm 1$	$1.5 \pm 0.2$
Diboson	$0.01 \pm 0.01$	$0.7 \pm 0.1$	$0.09 \pm 0.03$	$0.01 \pm 0.01$
$t\bar{t}V$	$0.8 \pm 0.2$	$45 \pm 10$	$13 \pm 4$	$2.7 \pm 0.7$
Multijet	$3 \pm 2$	$114 \pm 30$	$34 \pm 10$	$4 \pm 3$
Total bkg.	$45 \pm 3$	$3360 \pm 80$	$634 \pm 19$	$62 \pm 5$
Data	41	3340	676	65

# H- $\rightarrow\mu\mu$ : Cross Section and Branch Fraction

$m_H$ [GeV]	gluon fusion			vector boson fusion			BR		
	$\sigma$ [pb]	uncertainty [%]		$\sigma$ [pb]	uncertainty [%]		BR( $H \rightarrow \mu^+\mu^-$ )	uncertainty [%]	
		up	down		up	down		up	down
110	25.04	+15.3	-14.9	1.809	+2.7	-3.0	$2.76 \times 10^{-4}$	+7.0	-6.8
115	22.96	+15.0	-14.9	1.729	+2.7	-3.0	$2.63 \times 10^{-4}$	+6.7	-6.6
120	21.13	+14.8	-14.8	1.649	+2.8	-3.0	$2.44 \times 10^{-4}$	+6.4	-6.3
125	19.52	+14.7	-14.7	1.578	+2.8	-3.0	$2.20 \times 10^{-4}$	+6.0	-5.9
130	18.07	+14.6	-14.6	1.511	+2.8	-2.9	$1.90 \times 10^{-4}$	+5.5	-5.4
135	16.79	+14.4	-14.7	1.448	+2.8	-2.9	$1.55 \times 10^{-4}$	+5.0	-4.9
140	15.63	+14.3	-14.5	1.389	+2.7	-2.9	$1.22 \times 10^{-4}$	+3.7	-3.8
145	14.59	+14.1	-14.4	1.333	+2.8	-2.8	$9.06 \times 10^{-5}$	+3.4	-3.4
150	13.65	+14.1	-14.4	1.280	+2.8	-2.9	$6.19 \times 10^{-5}$	+3.1	-3.2

# H $\rightarrow$ $\tau\tau$ : Embedding Effects

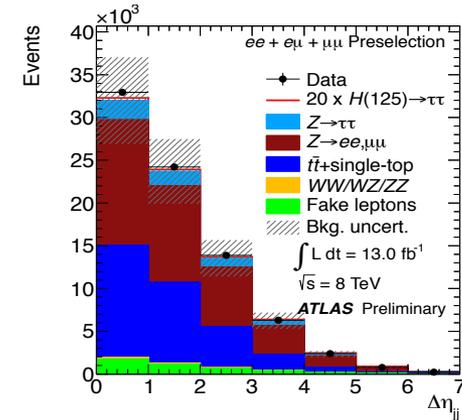
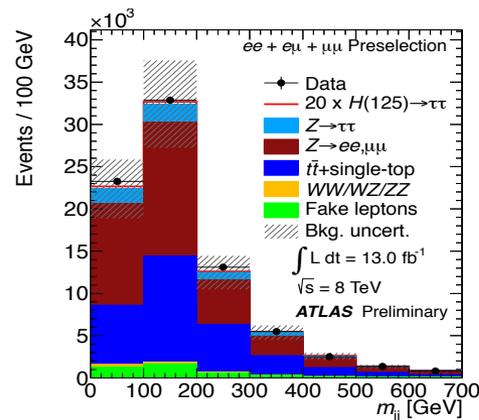
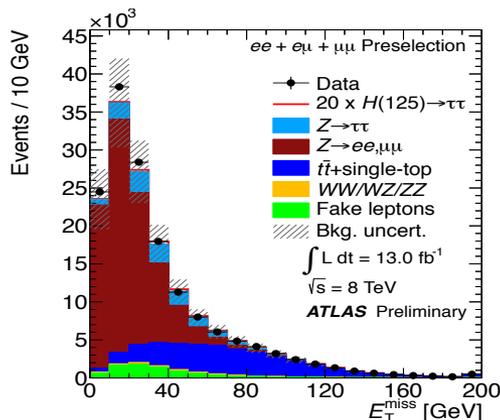


# H → ττ: Event Selection (lep-lep)

2-jet VBF	Boosted	2-jet VH	1-jet
Pre-selection: exactly two leptons with opposite charges			
30 GeV < m <sub>ℓℓ</sub> < 75 GeV (30 GeV < m <sub>ℓℓ</sub> < 100 GeV)			
for same-flavor (different-flavor) leptons, and p <sub>T,ℓ1</sub> + p <sub>T,ℓ2</sub> > 35 GeV			
At least one jet with p <sub>T</sub> > 40 GeV ( JVF <sub>jet</sub>   > 0.5 if  η <sub>jet</sub>   < 2.4)			
E <sub>T</sub> <sup>miss</sup> > 40 GeV (E <sub>T</sub> <sup>miss</sup> > 20 GeV for same-flavor (different-flavor) leptons)			
H <sub>T</sub> <sup>miss</sup> > 40 GeV for same-flavor leptons			
0.1 < x <sub>1,2</sub> < 1			
0.5 < Δφ <sub>ℓℓ</sub> < 2.5			

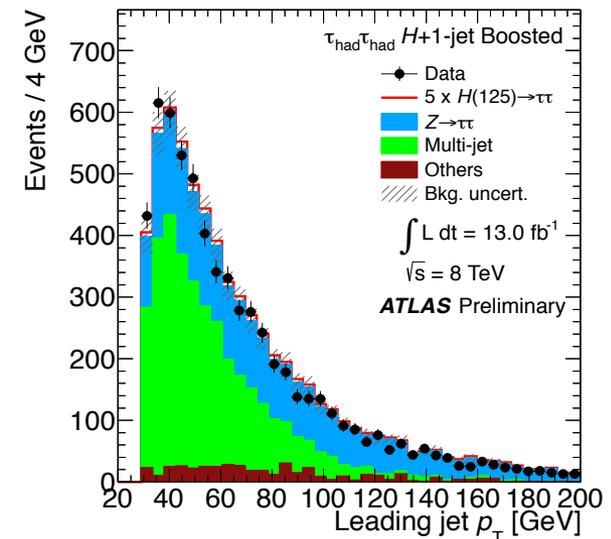
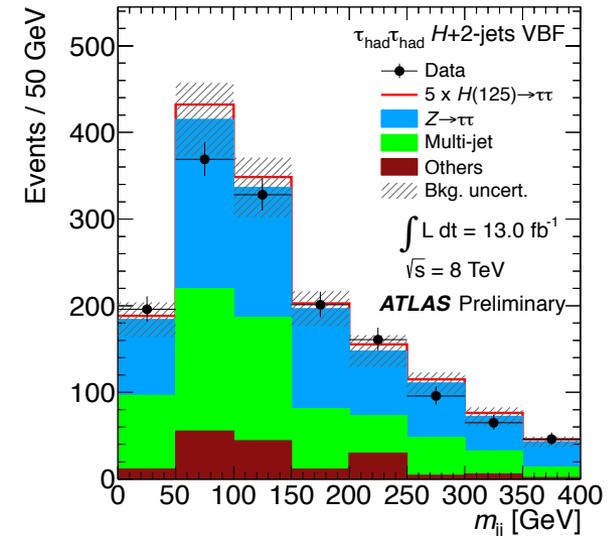
p <sub>T,j2</sub> > 25 GeV (JVF)	excluding 2-jet VBF	p <sub>T,j2</sub> > 25 GeV (JVF)	excluding 2-jet VBF, Boosted and 2-jet VH
Δη <sub>jj</sub> > 3.0	p <sub>T,ττ</sub> > 100 GeV	excluding Boosted	m <sub>ττj</sub> > 225 GeV
m <sub>jj</sub> > 400 GeV	b-tagged jet veto	Δη <sub>jj</sub> < 2.0	b-tagged jet veto
b-tagged jet veto	-	30 GeV < m <sub>jj</sub> < 160 GeV	-
Lepton centrality and CJV	-	b-tagged jet veto	-

0-jet (7 TeV only)
Pre-selection: exactly two leptons with opposite charges
Different-flavor leptons with 30 GeV < m <sub>ℓℓ</sub> < 100 GeV and p <sub>T,ℓ1</sub> + p <sub>T,ℓ2</sub> > 35 GeV
Δφ <sub>ℓℓ</sub> > 2.5
b-tagged jet veto



# H→ττ: Event Selection (had-had)

Cut	Description
Preselection	No muons or electrons in the event Exactly 2 medium $\tau_{\text{had}}$ candidates matched with the trigger objects At least 1 of the $\tau_{\text{had}}$ candidates identified as tight Both $\tau_{\text{had}}$ candidates are from the same primary vertex Leading $\tau_{\text{had-vis}}$ $p_T > 40$ GeV and sub-leading $\tau_{\text{had-vis}}$ $p_T > 25$ GeV, $ \eta  < 2.5$ $\tau_{\text{had}}$ candidates have opposite charge and 1- or 3-tracks $0.8 < \Delta R(\tau_1, \tau_2) < 2.8$ $\Delta\eta(\tau, \tau) < 1.5$ if $E_T^{\text{miss}}$ vector is not pointing in between the two taus, $\min\{\Delta\phi(E_T^{\text{miss}}, \tau_1), \Delta\phi(E_T^{\text{miss}}, \tau_2)\} < 0.2\pi$
VBF	At least two tagging jets, $j_1, j_2$ , leading tagging jet with $p_T > 50$ GeV $\eta_{j1} \times \eta_{j2} < 0$ , $\Delta\eta_{jj} > 2.6$ and invariant mass $m_{jj} > 350$ GeV $\min(\eta_{j1}, \eta_{j2}) < \eta_{\tau_1}, \eta_{\tau_2} < \max(\eta_{j1}, \eta_{j2})$ $E_T^{\text{miss}} > 20$ GeV
Boosted	Fails VBF At least one tagging jet with $p_T > 70(50)$ GeV in the 8(7) TeV dataset $\Delta R(\tau_1, \tau_2) < 1.9$ $E_T^{\text{miss}} > 20$ GeV if $E_T^{\text{miss}}$ vector is not pointing in between the two taus, $\min\{\Delta\phi(E_T^{\text{miss}}, \tau_1), \Delta\phi(E_T^{\text{miss}}, \tau_2)\} < 0.1\pi$ .



# H- $\rightarrow$ $\tau\tau$ : Variable Definitions

✧ In the lep-lep final state:

$$p_{T,\tau\tau} = |\vec{p}_T^{\ell,1} + \vec{p}_T^{\ell,2} + \vec{E}_T^{\text{miss}}|, \quad x_{1,2} = \frac{|p_{\text{vis}1,2}|}{|(p_{\text{vis}1,2} + p_{\text{mis}1,2})|}.$$

✧ In the lep-had final state:

$$p_T^{\text{Total}} = |\vec{p}_T^{\ell} + \vec{p}_T^{\tau\text{had-vis}} + \vec{p}_T^{j1} + \vec{p}_T^{j2} + \vec{E}_T^{\text{miss}}|,$$

$$m_T = \sqrt{2p_T^{\ell}E_T^{\text{miss}}(1 - \cos \Delta\phi)},$$

$$p_T^{\text{H}} = |\vec{p}_T^{\ell} + \vec{p}_T^{\tau\text{had-vis}} + \vec{E}_T^{\text{miss}}|,$$

$$\sum \Delta\phi = |\phi_{\ell} - \phi_{E_T^{\text{miss}}}| + |\phi_{\tau} - \phi_{E_T^{\text{miss}}}|. \quad \Delta(\Delta R) = |\Delta R^{l\tau\text{had-vis}} - \Delta R_{\text{pred}}^{l\tau\text{had-vis}}(p_T^{l\tau\text{had-vis}})|,$$

# H $\rightarrow$ $\tau\tau$ @ATLAS: Results

