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Search for the Higgs boson in fermionic channels using the ATLAS detector

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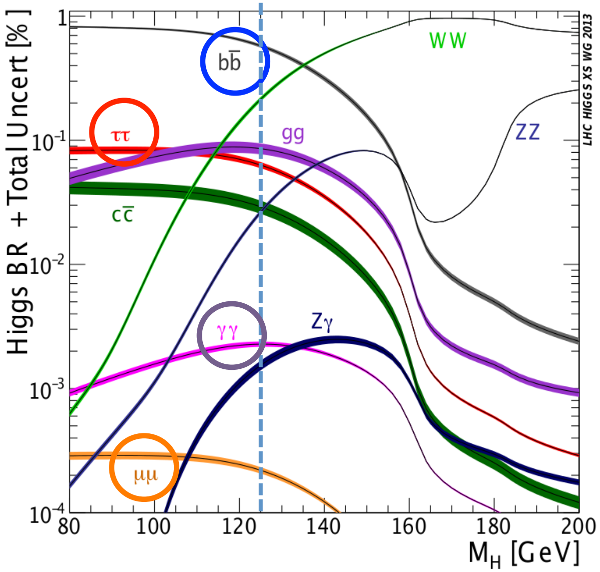
On behalf of the ATLAS collaboration

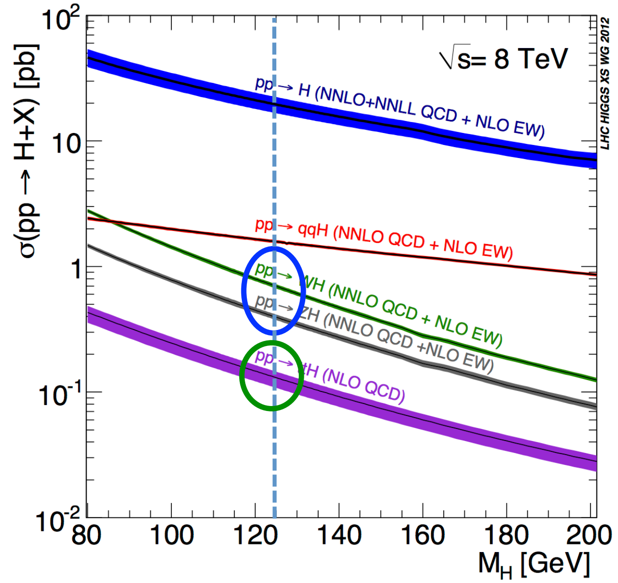
Probing Higgs couplings to fermions

- The discovery and the properties measurements of the Higgs boson particle has been driven mainly by analyses exploiting bosonic decay modes ($H \rightarrow \gamma\gamma$, $H \rightarrow ZZ \rightarrow 4l$, $H \rightarrow WW \rightarrow l\nu l\nu$)

- *A direct measurement of Higgs fermionic couplings* is crucial to:
  - further investigate the nature of the discovered particle
  - test for potential beyond-SM contributions
  - investigate the role of top quark in the EWSB mechanism



Large variety of production and decay modes to test



Br($H \rightarrow bb$): VH, ttH

Br($H \rightarrow \tau\tau$): all production modes

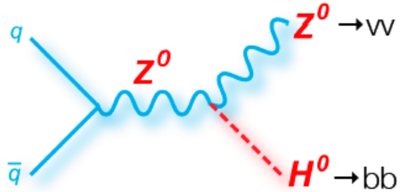
Top Yukawa coupling: ttH($H \rightarrow bb$), ttH($H \rightarrow \gamma\gamma$)

Rare decays: $H \rightarrow \mu\mu$, ZH($H \rightarrow$ inv.)

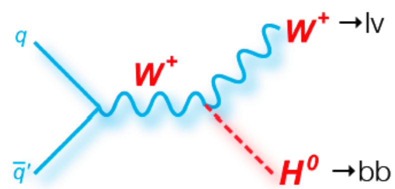
H→bb: VH

VH (H→bb): strategy

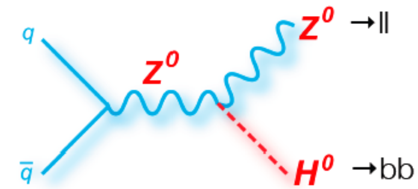
- Multiple leptonic decays of the vector boson: easy triggering and reduction of multi-jet background



Zero lepton: ZH



One lepton: WH



Two leptons: ZH

- Binning in *vector boson p_T* (Vp_T) reconstructed from missing E_T and leptons: further cut optimization (dR_{jj}) and increase in sensitivity

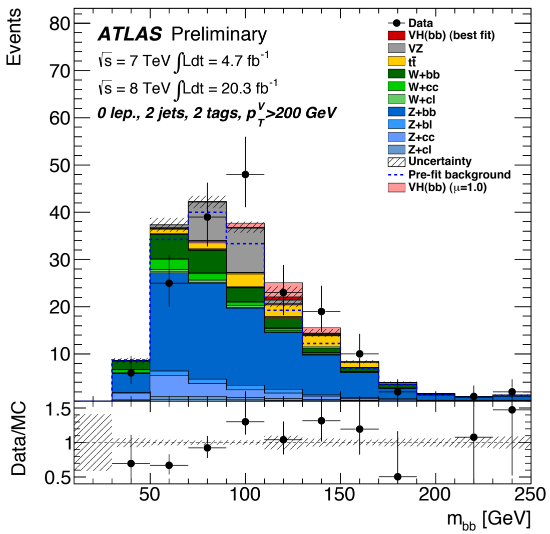
- Simultaneous fit to 3 channels in multiple Vp_T bins and jet and b-tag multiplicities:
  - helps normalizing backgrounds
  - controls effect of systematic uncertainties
  - isolates categories with very different S/sqrt(B)

		2 jets 1 tag	3 jets 1 tag	2 jets 2tags	3 jets 2 tags	top CR	top emu CR
X 3 Vp_T bin	0 lepton	*norm. only*	*norm. only*	*shape*	*shape*	-	-
X 5 Vp_T bin	1 lepton	*norm. only*	*norm. only*	*shape*	*Shape*	inverting cut on M_{ll}	e-mu pair with same analysis cuts
X 5 Vp_T bin	2 leptons	*norm. only*	*norm. only*	*shape*	*shape*	*norm. only*	*norm. only*

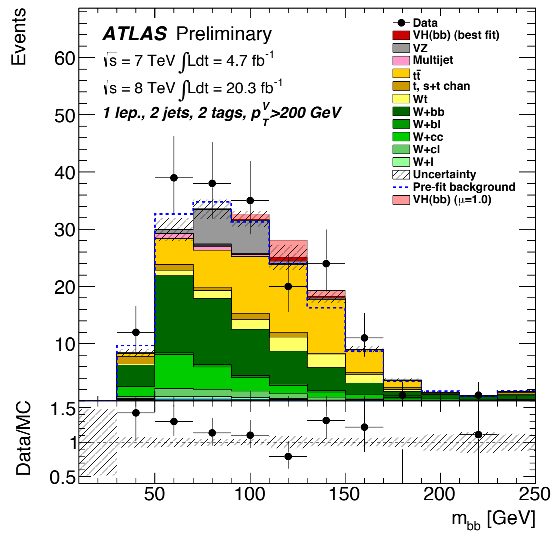
VH (H→bb): discriminant

◆ In 2 tags signal regions: m_{bb} shape information used for signal extraction

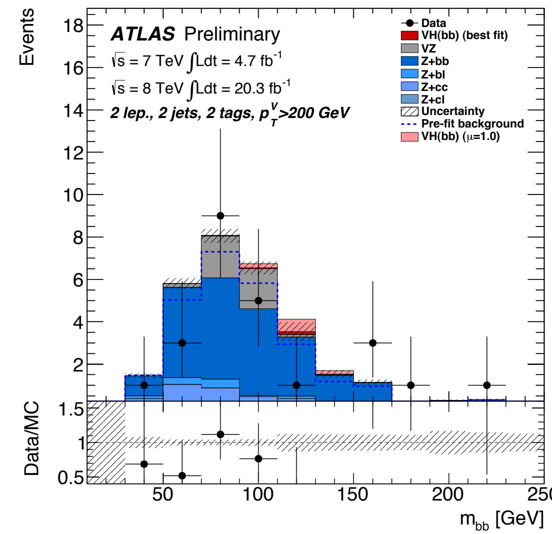
Zero lepton



One lepton



Two leptons



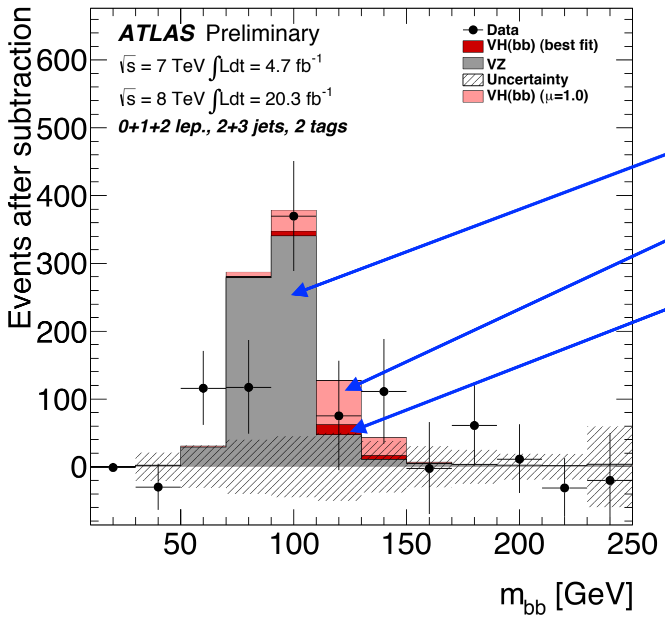
◆ Normalization of main backgrounds (*ttbar*, *W+HF*, *Z+HF*) free-floating in the fit:

✧ systematics for extrapolation across regions extracted from MC studies (different generators, ISR, parton shower)

✧ correcting MC for data/MC mis-modelling: top p_T , $\Delta\phi_{jj}$ in V+jets

◆ Largest systematics uncertainties: *ttbar modelling, b-tagging*

VH (H→bb): result



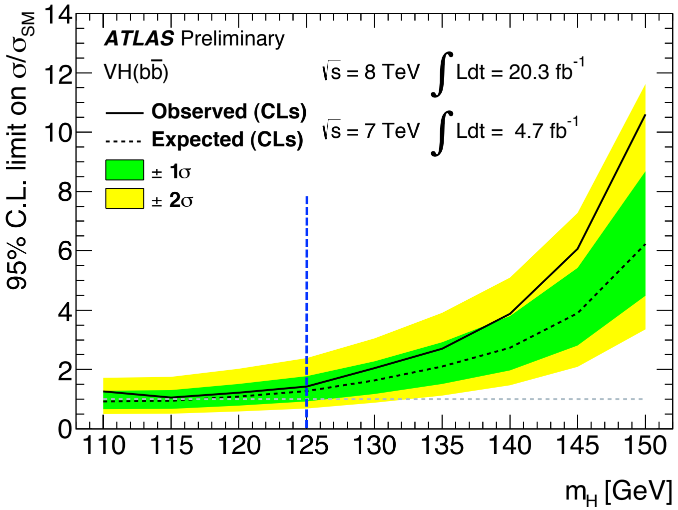
- Data with subtracted MC prediction (but di-bosons):
  - VZ(Z→bb) contribution: ~5 s.d. evidence. (μ_{VZ} =0.9±0.2)
  - nominal VH contribution
  - VH from best fit: $\mu = \frac{\sigma_{meas}}{\sigma_{SM}}$
- No significant excess observed above background-only predictions

- 95% CL limit on σ/σ_{SM}:

observed σ/σ_{SM} = 1.4

expected σ/σ_{SM} = 1.3

@ m_H=125 GeV



- Best-fit signal strength:

μ=0.2 ± 0.5 (stat.) ± 0.4 (sys.)

@ m_H=125 GeV

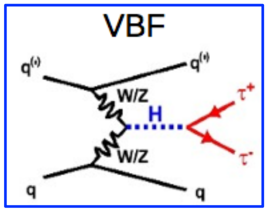
Compatibility with μ=0 : 36%

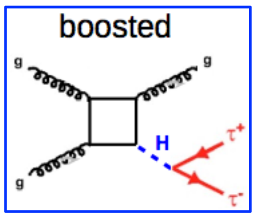
Compatibility with μ=1 : 11%

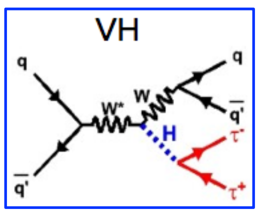
$H \rightarrow \tau\tau$

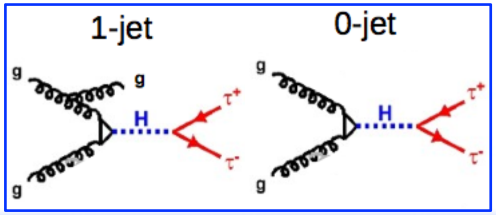
$H \rightarrow \tau\tau$: strategy

- Possibility to trigger/identify all the di-τ decay mode (*τ_{lep}-τ_{lep}, τ_{lep}-τ_{had}, τ_{had}-τ_{had}*)
- Define *different categories* to exploit changing S/B, sensitivity to background composition and *targeting multiple Higgs production modes*









lep-lep | *lep-had* | *had-had*

VBF category: 2jets with large rapidity separation and large m_{jj}

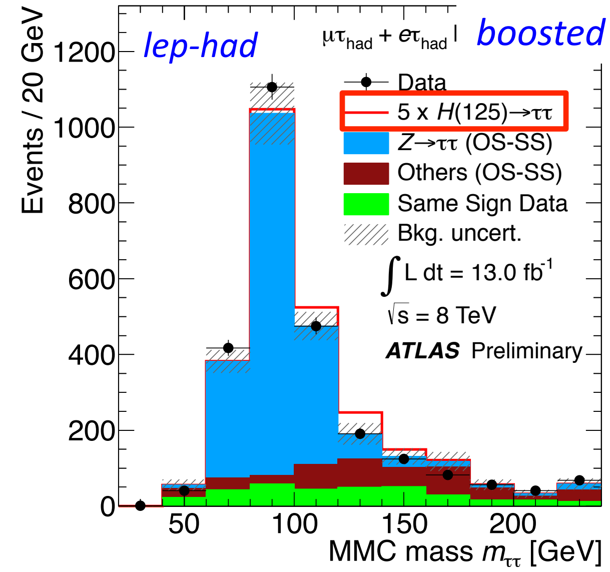
Boosted: *not VBF* and large Higgs p_T or hard jets. Takes advantage to the better $m_{\tau\tau}$ resolution at high p_T

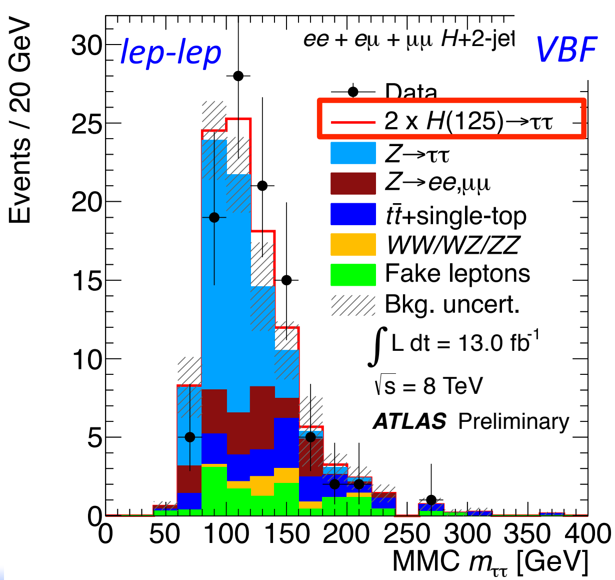
VH: (not VBF and boosted) and 2 jets close in dR and m_{jj} in W-mass window

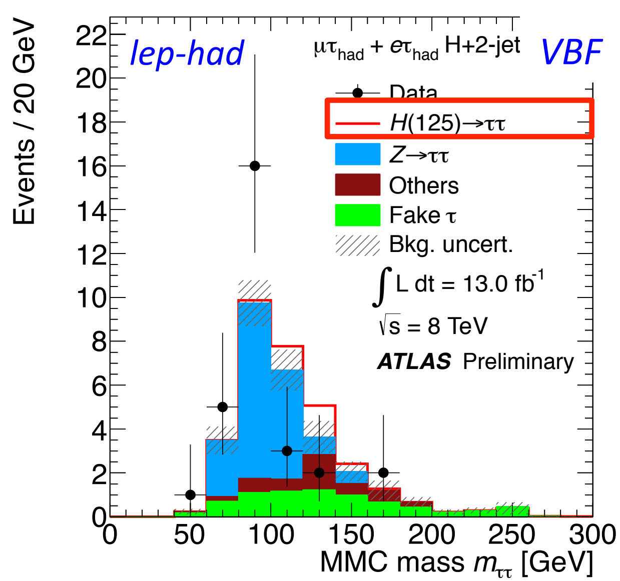
1-jet/0jets : (not VBF, boosted or VH) >=1 or 0 additional jet in the event with p_T>25-30 GeV. For lep-had, e and μ channel are considered separately

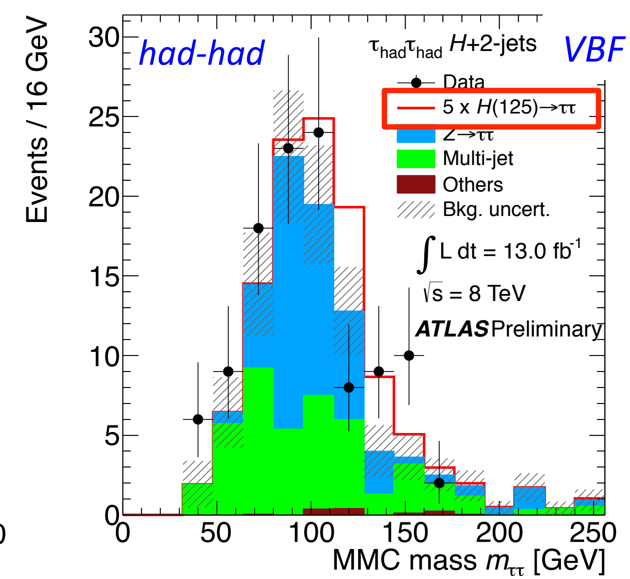
decreasing sensitivity

- Discriminant: $m_{\tau\tau}$ from *Missing Mass Calculator (MMC)*:
  - reconstruction of neutrino direction from kinematic constraints and template from MC τ decays
  - resolution ~ 13-20% (better resolution for high p_T and τ_{had})
- Main (irreducible) background: *$Z \rightarrow \tau\tau$ modelled with embedding*
  - replacing μ in $Z \rightarrow \mu\mu$ data events with τ decay from MC.









$H \to \tau\tau$: limits

- Approaching sensitivity to SM Higgs production
- Local p_0 @ m_H=125 GeV:

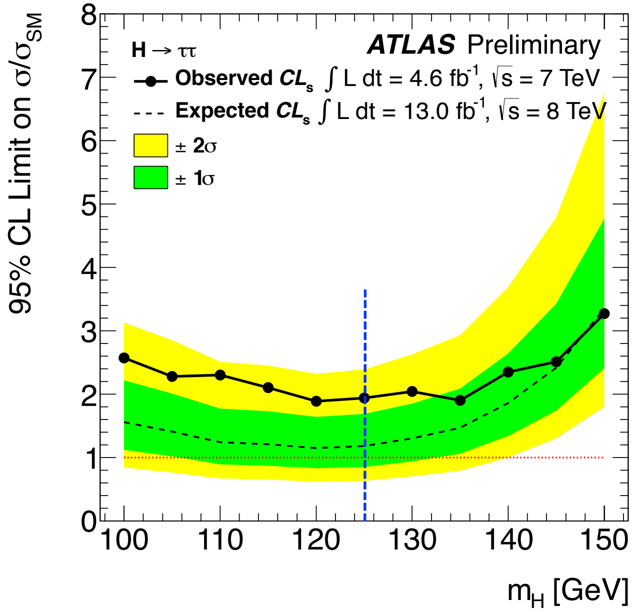
  1.1 s.d. observed, 1.7 s.d. expected

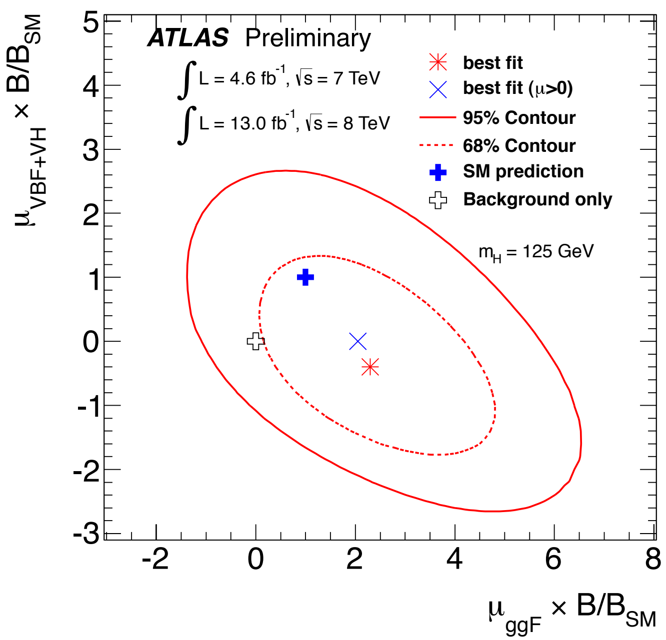
- 95% CL limit on σ/σ_{SM}:

  @ m_H=125 GeV

  observed σ/σ_{SM} = 1.9

  expected σ/σ_{SM} = 1.2





- Best-fit value for signal strength:

  $\mu = 0.7 \pm 0.7$

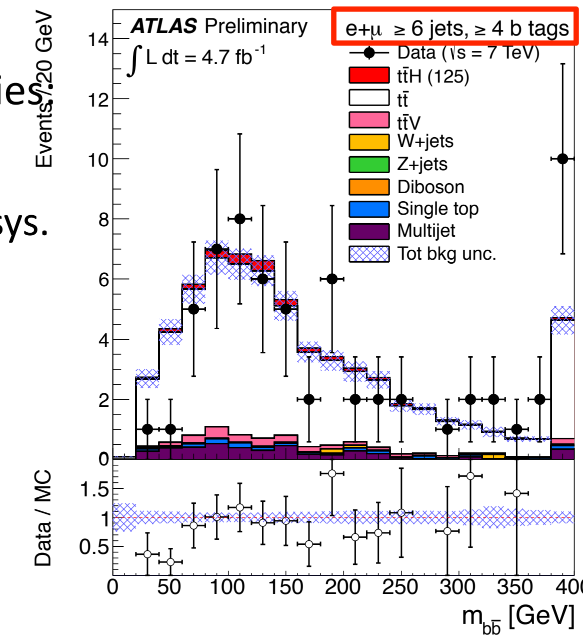
- Testing compatibility for production modes:
  - *$\mu_{ggF} \times BR(H\to\tau\tau)/BR_{SM}(H\to\tau\tau) = 2.4$*
  - *$\mu_{VBF+VH} \times BR(H\to\tau\tau)/BR_{SM}(H\to\tau\tau) = -0.4$*
  - consistent with the SM Higgs (but also no Higgs hypothesis) within 1 s.d. contour

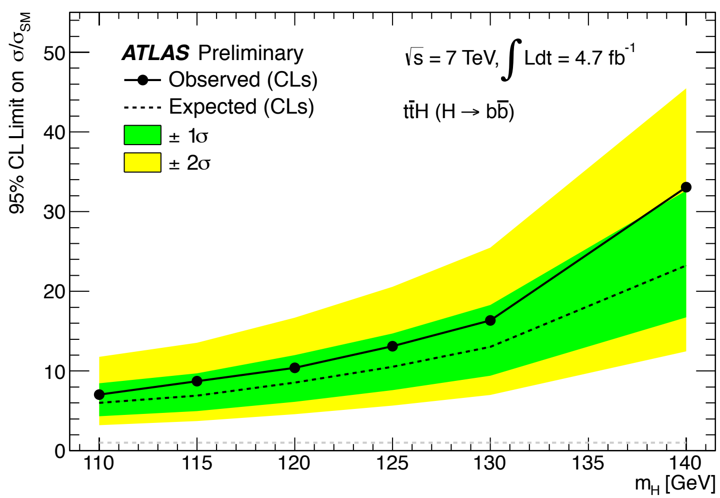
ttH: H→bb and H→γγ

ttH (H→bb)

- Using l+jets ttbar decay topology: 1 lept, MET, ≥6 jets, ≥4 tags
- Separate analysis in categories according to jet and b-tag multiplicities
  - signal enriched: 5 / ≥6 jets , 3 tags / ≥4 tags
  - signal depleted: used for background normalization, constraining of sys.
- Discriminant variables:
  - ≥6 jets , 3 tags / ≥4 tags : m_{bb} from kinematic reconstruction
  - other: H_T^{had} = scalar sum of jet p_Ts
- Main challenge: understanding of the ttbar(+HF) background

post-fit plot





- 95% CL limit on σ/σ_{SM}:

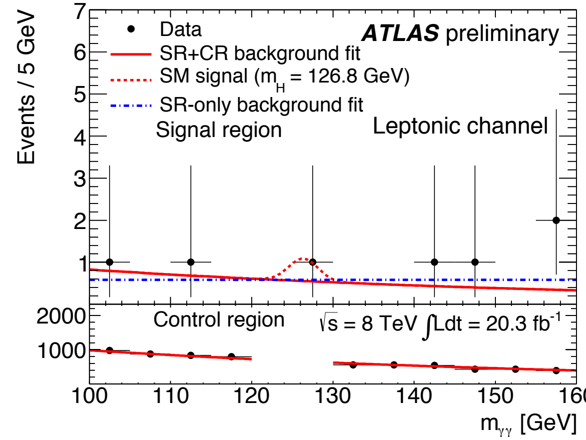
@ m_H=125 GeV

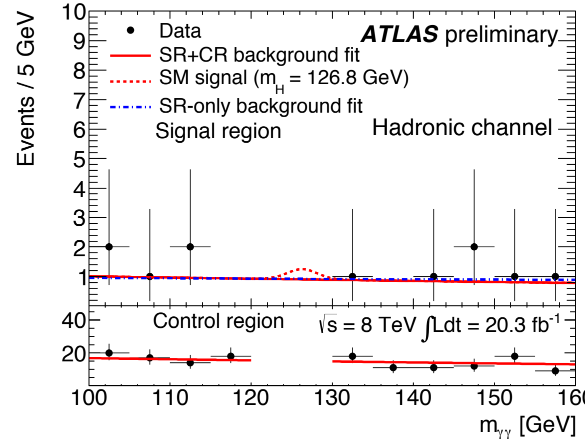
observed σ/σ_{SM} = 13.1
expected σ/σ_{SM} = 10.5

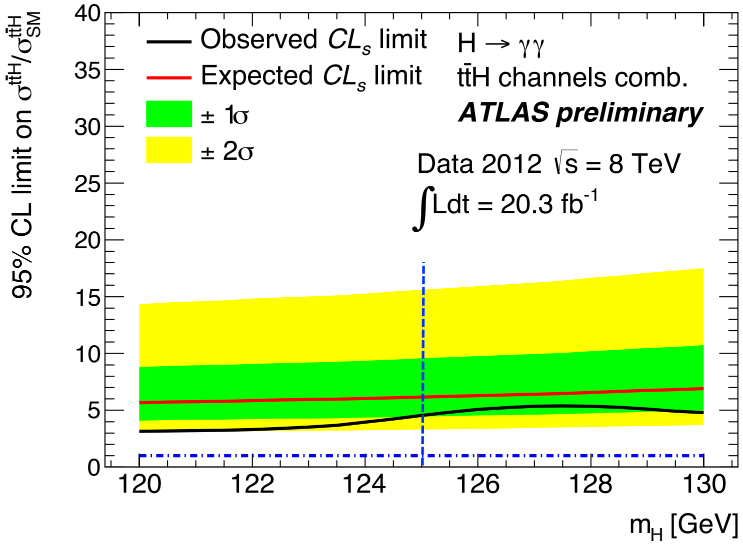
- Large impact of systematics (ttbar+HF, JES, tagging):
  - *sensitivity degradation by 70%*

ttH (H→γγ)

- 2 high-p_T isolated photons (as in main H→$\gamma\gamma$ analysis)
- Targeting both leptonic and fully-hadronic ttbar decay modes
- Optimized selection *to increase ttH purity* over other H production modes (>80%):
  - *Lep: ≥1 lep, MET, ≥1 tag : S/B ~ 0.5*
  - *Hadr: ≥6jets, ≥2tags : S/B ~ 0.2*
- Background estimated from exponential fit to both signal and control regions.







- 95% CL limit on σ/σ_{SM}:

@ m_H=125 GeV

observed σ/σ_{SM} = 5.3

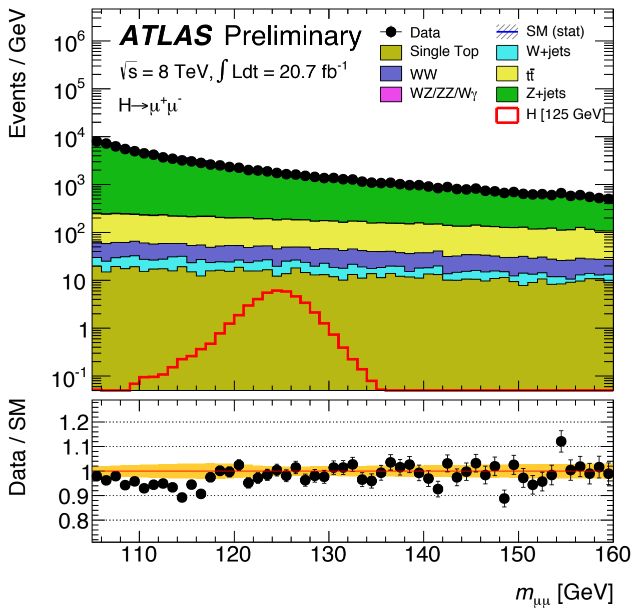
expected σ/σ_{SM} = 6.4

- contrary to ttH (H→bb), impact of systematics is small
- analysis still statistically limited

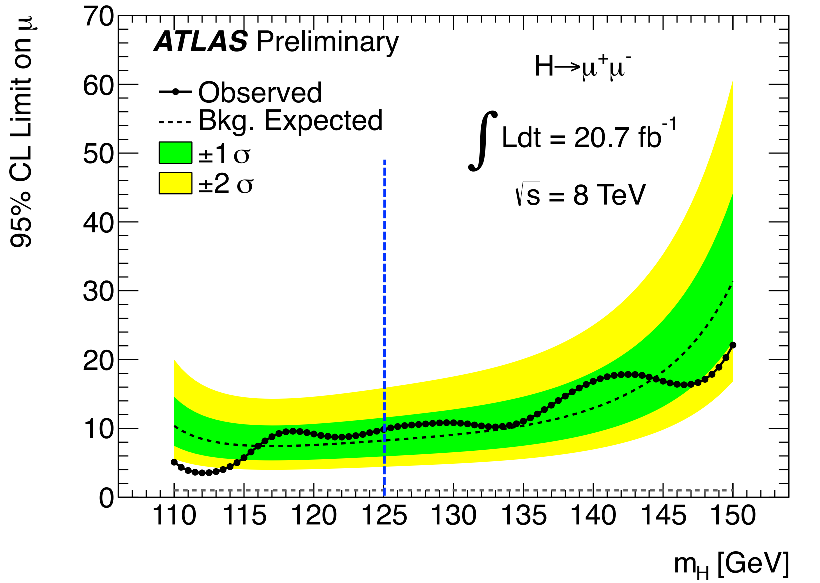
Rare decays: H→μμ , ZH(H→invisible)

$H\rightarrow\mu\mu$

- *Very clean signature but very low BR (10^{-4})*
  - BR could be enhanced by new physics contribution
- Exactly 2 opposite-sign isolated muons:
  - $p_{T\,(\mu1)}$>25 GeV , $p_{T\,(\mu2)}$> 25 GeV
  - $p_{T(\mu\mu)}$ > 15 GeV (against DY)
  - categorize events according to di-muon mass resolution (2 muons with |eta|<1, at least 1 forward muon)



- Main background: $Z/\gamma^*\rightarrow\mu\mu$



- Analytical description of the background (Breit-Wigner+exponential) validated in MC and control regions
- 95% CL limit on σ/σ_{SM}:

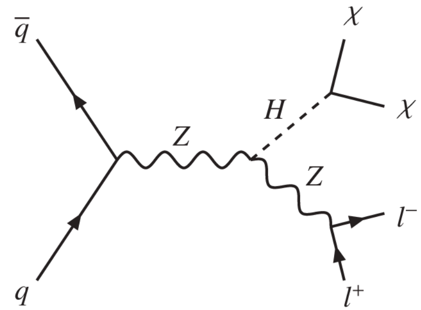
@ m_H=125 GeV

observed σ/σ_{SM} = 9.8

expected σ/σ_{SM} = 8.2

ZH (H→invisible)

- *$Br(H \rightarrow ZZ \rightarrow 4\nu)$ is too small to be detected, looking for enhancement due to possible BSM effects*



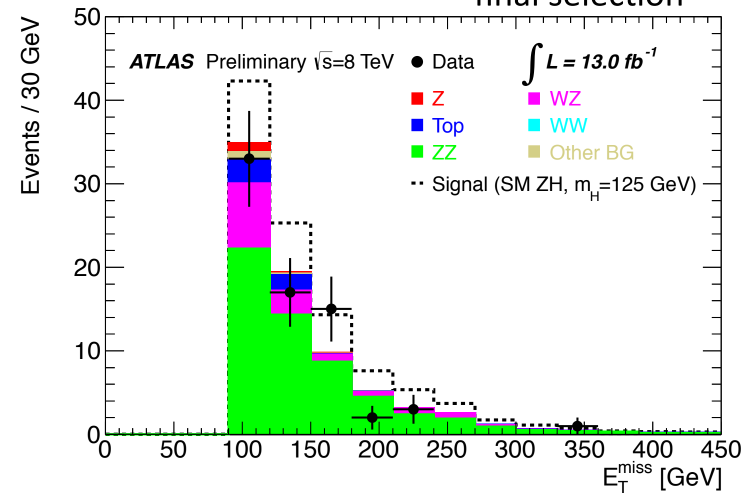
- Exploiting Z+H production:
  - ee, μμ events within Z mass window
  - missing transverse energy > 90 GeV
  - jet veto
  - additional kinematic/topological cuts

- Main background after selection: $ZZ \rightarrow ll\nu\nu$

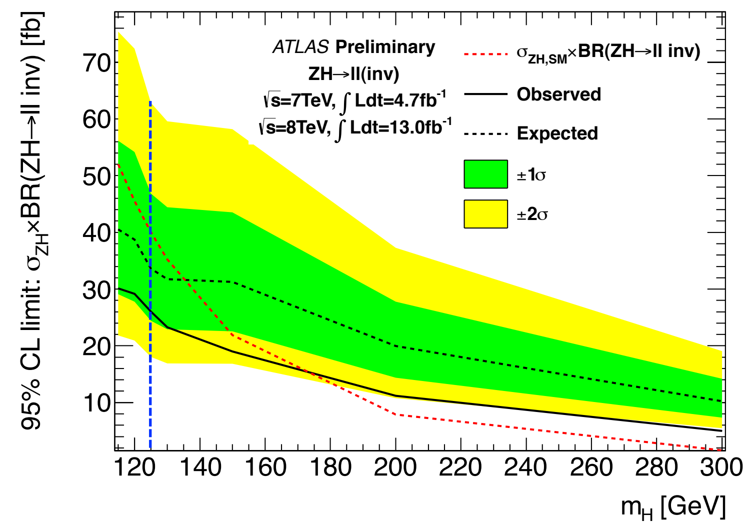
- No excess over background prediction
- Setting limit on Br(Higgs→invisible). For m_H=125 GeV:

observed Br(H→inv) < 65%	*@ 95% CL*	*assuming SM ZH production rate*
expected Br(H→inv) < 84%		

final selection



model independent limit



Summary and conclusions

- Rich program of analyses in the fermionic Higgs sector at ATLAS

- No significant excess observed over background-only expectations :
  - *VH ($H\rightarrow bb$)*: 4.7 fb^{-1} at 7 TeV + 20.9 fb^{-1} at 8 TeV : *obs. (exp.) σ/σ_{SM} limit = 1.4 (1.3)*
  - *$H\rightarrow \tau\tau$*: 4.7 fb^{-1} at 7 TeV + 13 fb^{-1} at 8 TeV : *obs. (exp.) σ/σ_{SM} limit = 1.9 (1.2)*
  - *ttH ($H\rightarrow bb$)*: 4.7 fb^{-1} at 7 TeV : *obs. (exp.) σ/σ_{SM} limit = 13.3 (10.5)*
  - *ttH ($H\rightarrow \gamma\gamma$): 20.9* fb^{-1} at 8 TeV : *obs. (exp.) σ/σ_{SM} limit = 5.3 (6.4)*
  - *$H\rightarrow \mu\mu$*: 20.7 fb^{-1} at 8 TeV : *obs. (exp.) σ/σ_{SM} limit = 9.8 (8.2)*
  - *$H\rightarrow$invisible*: 13 fb^{-1} at 8 TeV : *obs. (exp.) Br($H\rightarrow$invisible) limit = 65% (84%)*

- $H\rightarrow bb$ and $H\rightarrow \tau\tau$ sensitivity is approaching the SM value
- Aiming at a combination with bosonic decay mode for ttH
- Full dataset is being analyzed for the missing analyses
- More sophisticated techniques (MVA) are being explored in order to increase the sensitivity

……. stay tuned ……….

References

- *VH (H→bb)*: *ATLAS-CONF-2013-079*

  https://atlas.web.cern.ch/Atlas/GROUPS/PHYSICS/CONFNOTES/ATLAS-CONF-2013-079/

- *ttH (H→bb)*: *ATLAS-CONF-2012-135*

  https://atlas.web.cern.ch/Atlas/GROUPS/PHYSICS/CONFNOTES/ATLAS-CONF-2012-135/

- *ttH (H→$\gamma\gamma$)*: *ATLAS-CONF-2013-080*

  https://atlas.web.cern.ch/Atlas/GROUPS/PHYSICS/CONFNOTES/ATLAS-CONF-2013-080/

- *H→$\tau\tau$* : *ATLAS-CONF-2012-160*

  https://atlas.web.cern.ch/Atlas/GROUPS/PHYSICS/CONFNOTES/ATLAS-CONF-2012-160/

- *H→$\mu\mu$* : *ATLAS-CONF-2013-010*

  https://atlas.web.cern.ch/Atlas/GROUPS/PHYSICS/CONFNOTES/ATLAS-CONF-2013-010/

- *ZH (H→inv)*: *ATLAS-CONF-2013-011*

  https://atlas.web.cern.ch/Atlas/GROUPS/PHYSICS/CONFNOTES/ATLAS-CONF-2013-011/

Back-Up

VH(bb): full selection

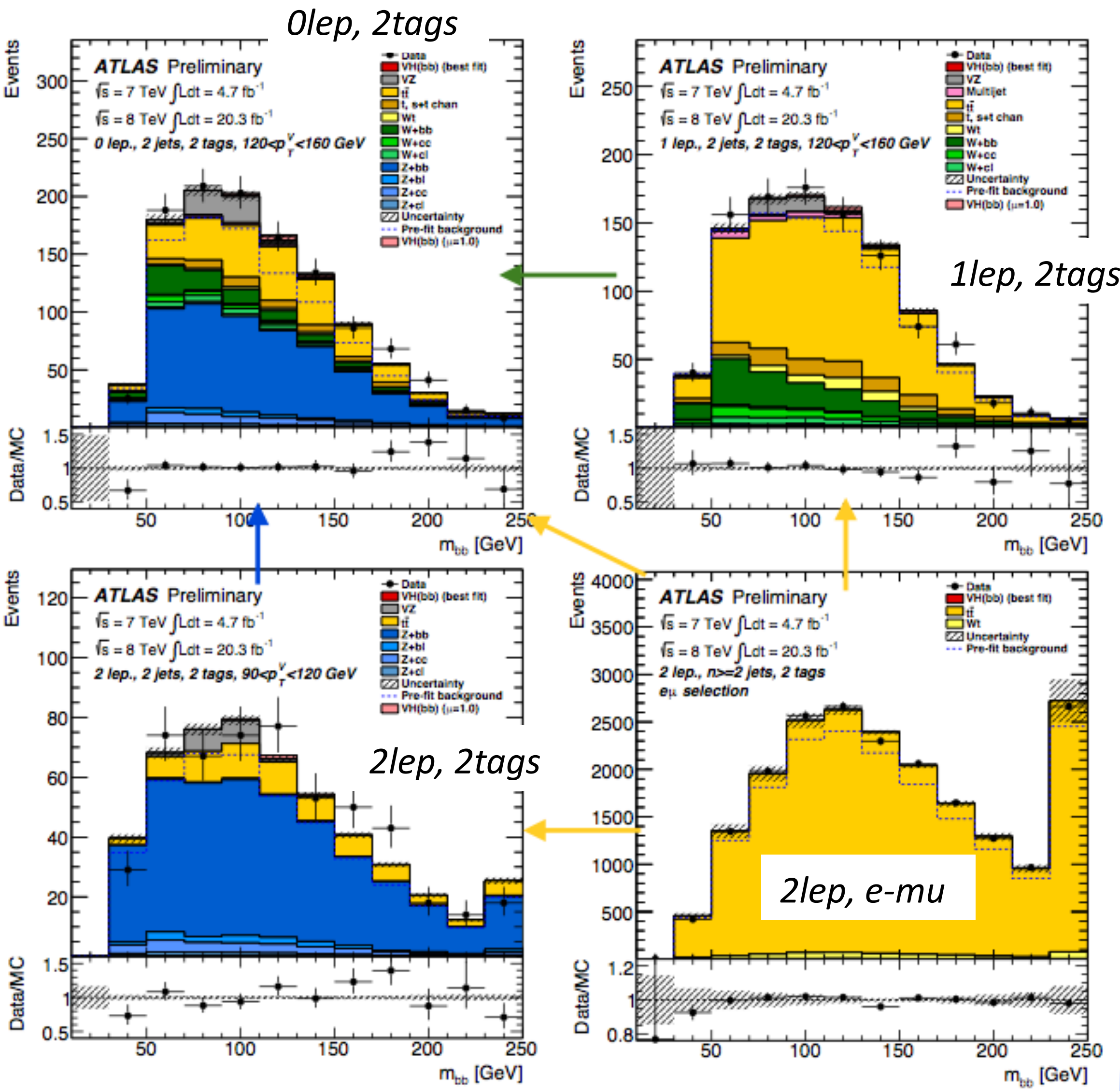
Object	0-lepton	1-lepton	2-lepton
Leptons	0 loose leptons	1 tight lepton + 0 loose leptons	1 medium lepton + 1 loose lepton
Jets	2 b-tags $p_T^{jet_1} > 45$ GeV $p_T^{jet_2} > 20$ GeV $+ \leq 1$ extra jets		
Missing E_T	$E_T^{miss} > 120$ GeV $p_T^{miss} > 30$ GeV $\Delta\phi(\boldsymbol{E}_T^{miss}, \boldsymbol{p}_T^{miss}) < \pi/2$ $\min[\Delta\phi(\boldsymbol{E}_T^{miss}, \text{jet})] > 1.5$ $\Delta\phi(\boldsymbol{E}_T^{miss}, b\bar{b}) > 2.8$	$E_T^{miss} > 25$ Gev	$E_T^{miss} < 60$ GeV
Vector Boson	-	$m_T^W < 120$ GeV	$83 < m_{\ell\ell} < 99$ GeV

- p_T^V dependent cuts

	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^{miss} [GeV]	>25				>50
	m_T^W [GeV]	40-120			<120	

$m_H = 125$ GeV at 8 TeV				
$(W/Z)(H \to b\bar{b})$	Cross-section × BR [fb]	Acceptance [%]		
		0-lepton	1-lepton	2-lepton
$Z \to \ell\ell$	15.3	0.0	0.9	8.4
$W \to \ell\nu$	130.2	0.2	3.3	-
$Z \to \nu\nu$	45.5	2.5	-	-

- Interplay between channels for background normalization

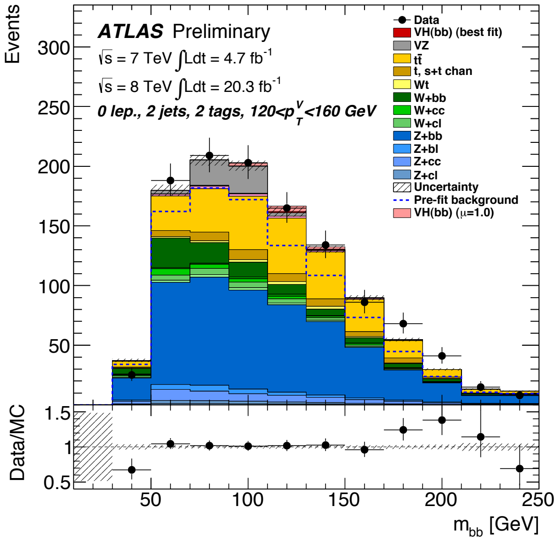


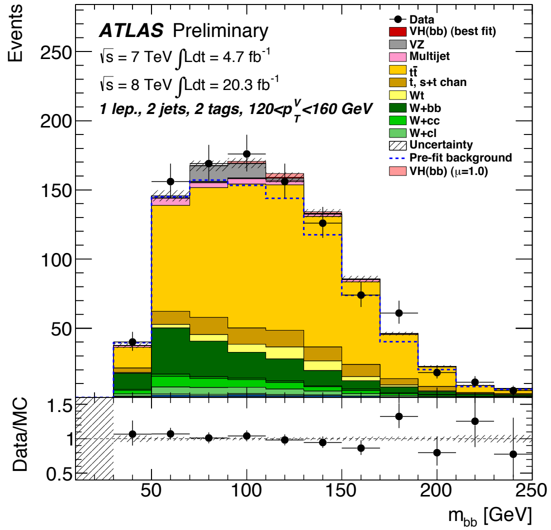
- Scale factors returned by the fit for free-floating backgrounds

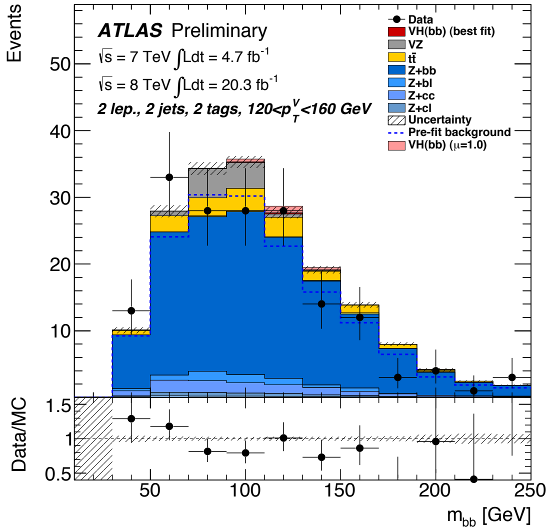
Process	Scale factor
$t\bar{t}$	1.13 ± 0.05
Wb	0.89 ± 0.15
Wcl	1.05 ± 0.14
Zb	1.30 ± 0.07
Zcl	0.89 ± 0.48

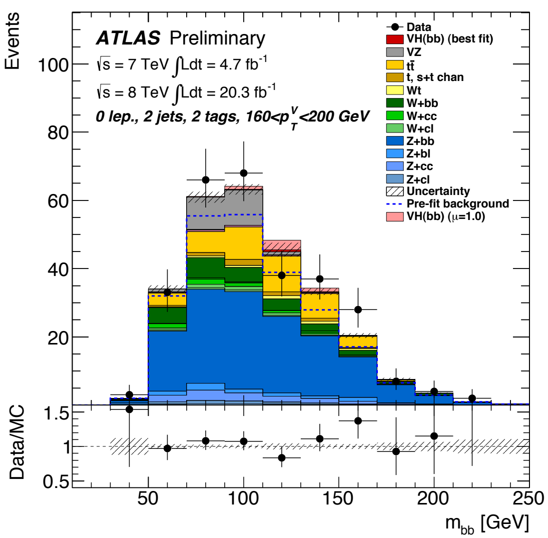
VH (H→bb): plots

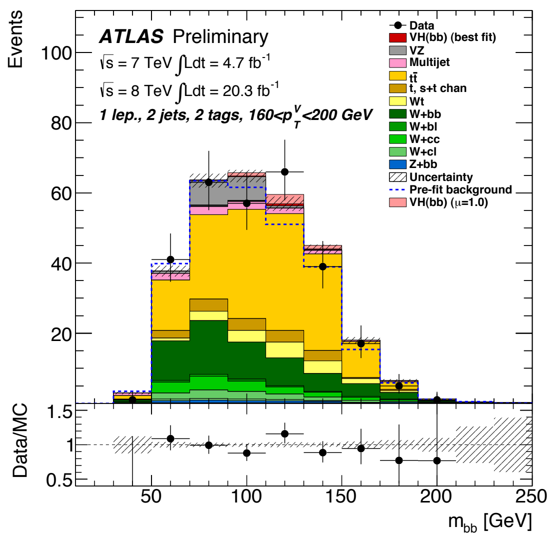
- Other Vp_T regions

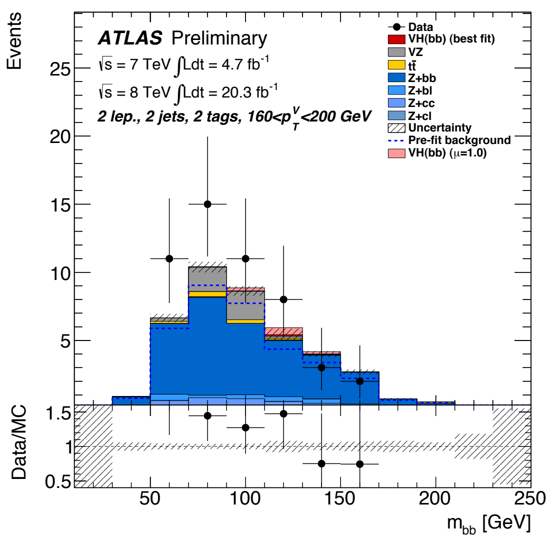






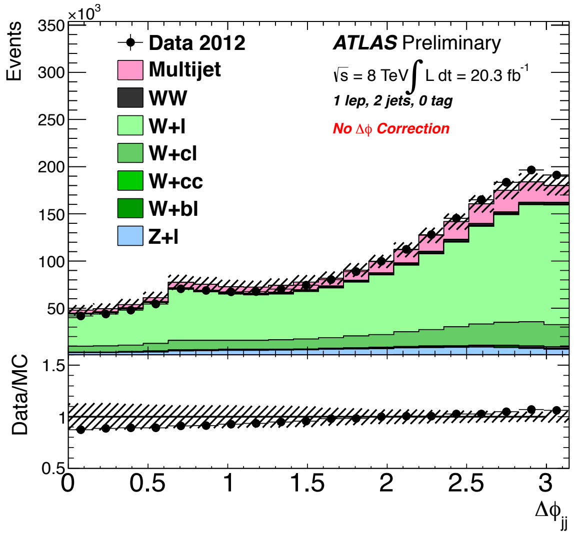


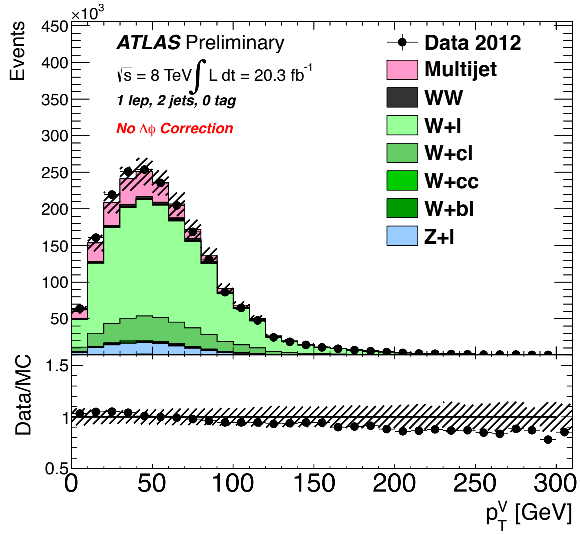


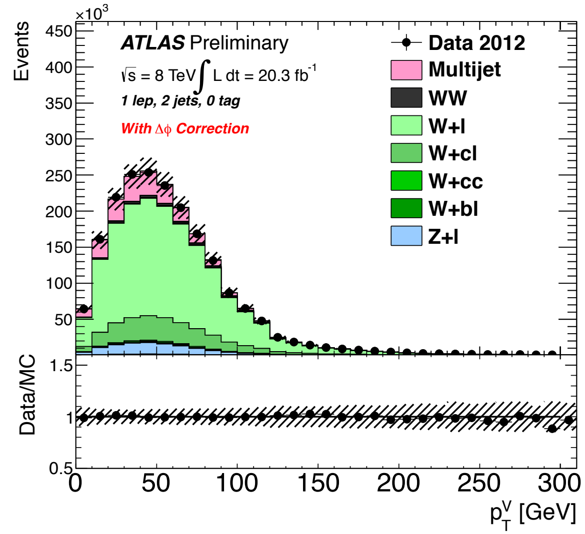


VH: V+jets modelling

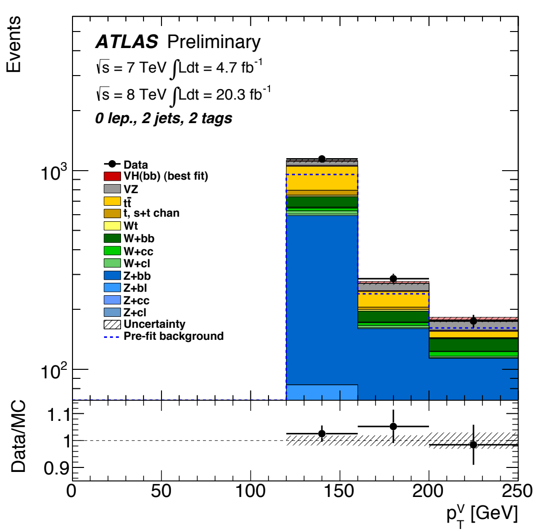
- DeltaPhi_jj correction extracted from 0tag region: correlated with VpT

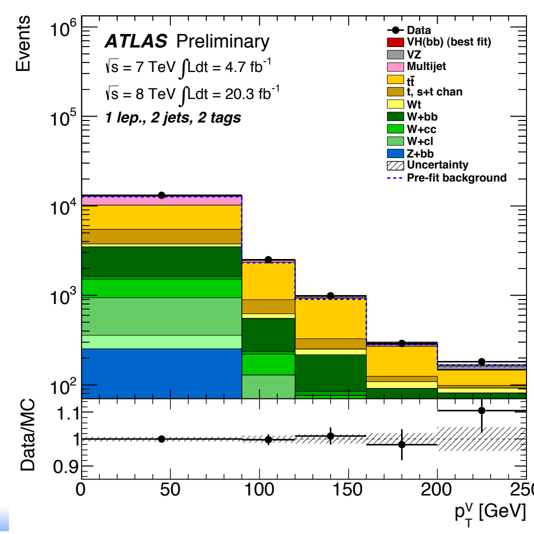


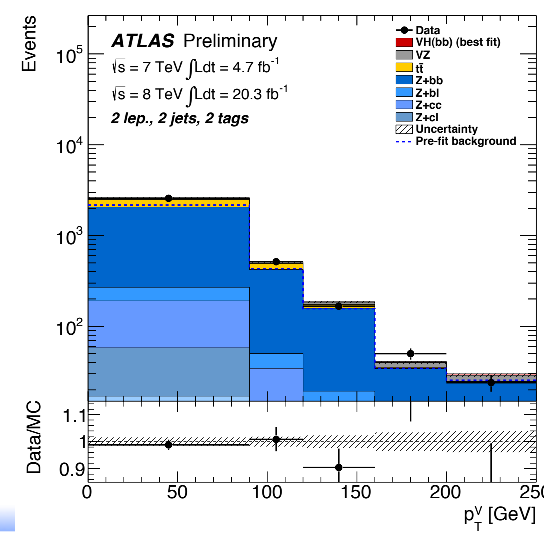




- Vp_T distribution after global fit

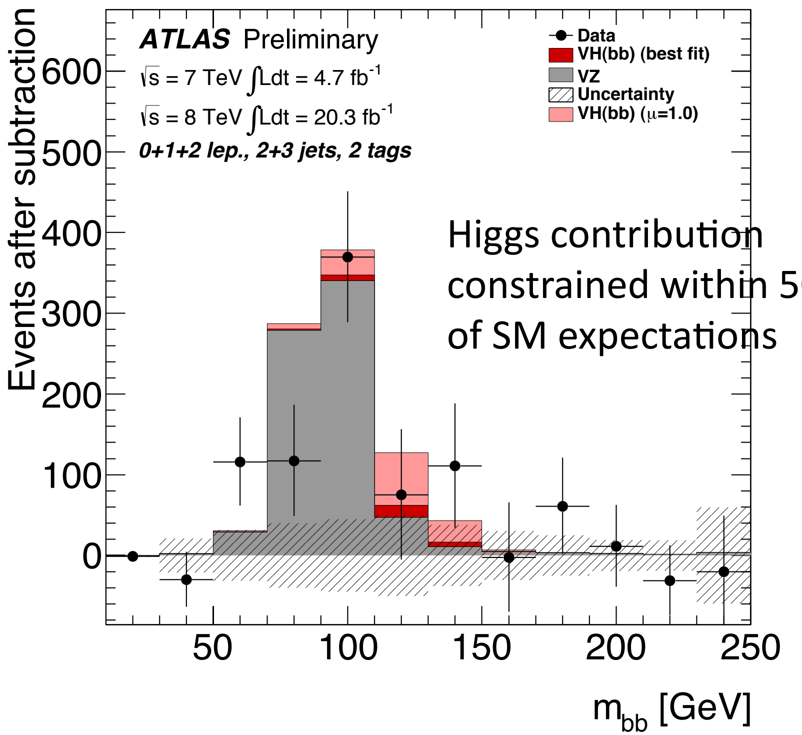




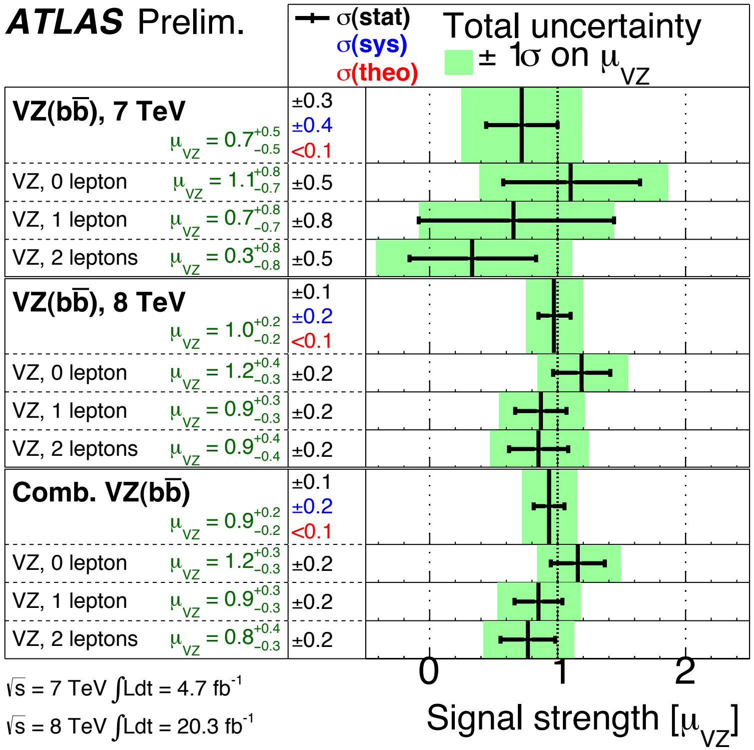


VH (H→bb): Dibosons validation

- Validate analysis techniques by measuring WZ,ZZ with Z→bb : ~5 times bigger than expected signal

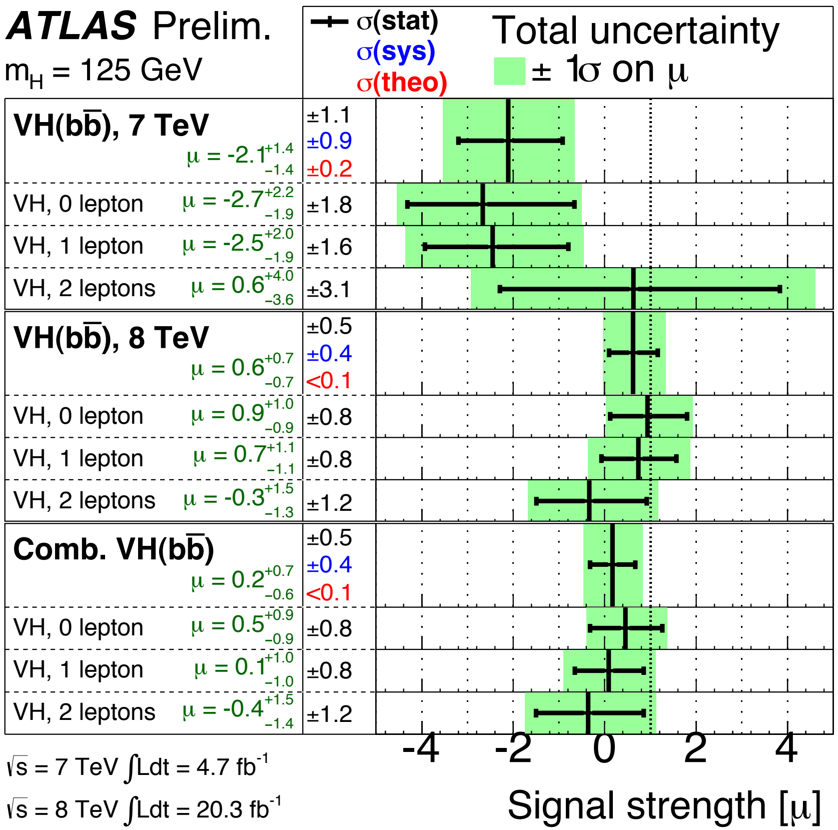


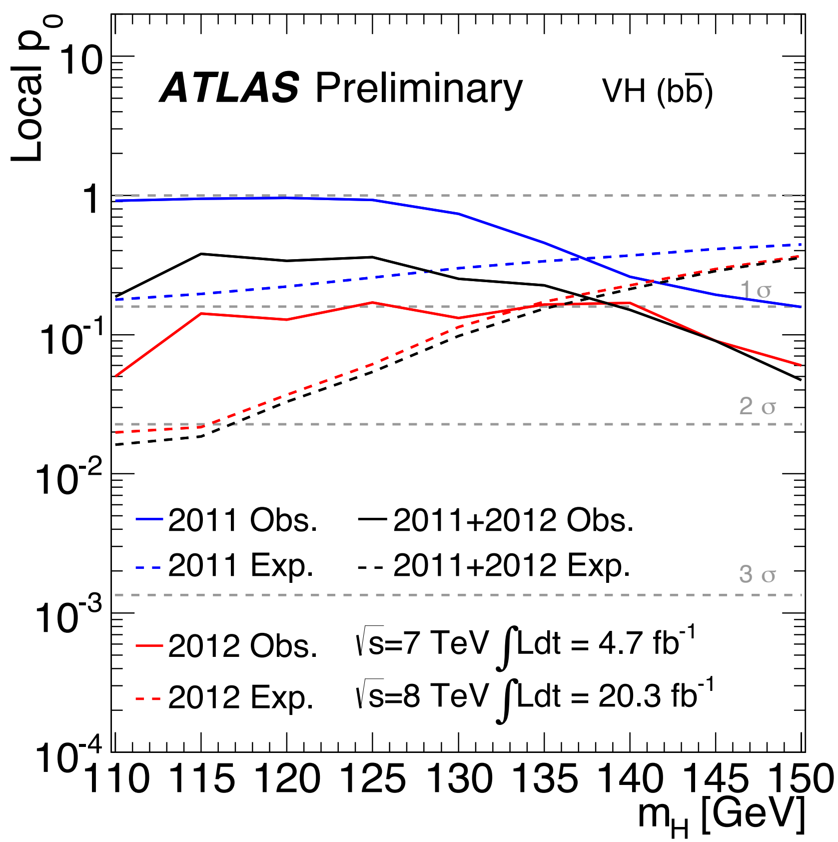
Higgs contribution constrained within 50% of SM expectations



- $\mu_{VZ} = 0.9 \pm 0.2$
- 4.8 (5.1) observed (expected) significance

VH (H→bb): result (2)





- 1 s.d. excess in 2012 data at m_H=125 GeV, excess at higher masses too
- deficit in 7 TeV data already observed in previous analysis leads to a small excess in combined result at m_H=125 GeV

$H \to \tau\tau$: lep-lep selection

2-jet VBF	Boosted	2-jet VH	1-jet
Pre-selection: exactly two leptons with opposite charges			
$30\ \text{GeV} < m_{\ell\ell} < 75\ \text{GeV}$ ($30\ \text{GeV} < m_{\ell\ell} < 100\ \text{GeV}$) for same-flavor (different-flavor) leptons, and $p_{T,\ell 1} + p_{T,\ell 2} > 35\ \text{GeV}$			
At least one jet with $p_T > 40\ \text{GeV}$ ($\lvert JVF_{\text{jet}}\rvert > 0.5$ if $\lvert\eta_{\text{jet}}\rvert < 2.4$)			
$E_{\text{T}}^{\text{miss}} > 40\ \text{GeV}$ ($E_{\text{T}}^{\text{miss}} > 20\ \text{GeV}$) for same-flavor (different-flavor) leptons			
$H_{\text{T}}^{\text{miss}} > 40\ \text{GeV}$ for same-flavor leptons			
$0.1 < x_{1,2} < 1$			
$0.5 < \Delta\phi_{\ell\ell} < 2.5$			
$p_{T,j2} > 25\ \text{GeV}$ (JVF)	excluding 2-jet VBF	$p_{T,j2} > 25\ \text{GeV}$ (JVF)	excluding 2-jet VBF, Boosted and 2-jet VH
$\Delta\eta_{jj} > 3.0$	$p_{T,\tau\tau} > 100\ \text{GeV}$	excluding Boosted	$m_{\tau\tau j} > 225\ \text{GeV}$
$m_{jj} > 400\ \text{GeV}$	b-tagged jet veto	$\Delta\eta_{jj} < 2.0$	b-tagged jet veto
b-tagged jet veto	–	$30\ \text{GeV} < m_{jj} < 160\ \text{GeV}$	–
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 $30\ \text{GeV} < m_{\ell\ell} < 100\ \text{GeV}$ and $p_{T,\ell 1} + p_{T,\ell 2} > 35\ \text{GeV}$			
$\Delta\phi_{\ell\ell} > 2.5$			
b-tagged jet veto			

H→ττ: lep-had selection

7 TeV		8 TeV	
VBF Category	Boosted Category	VBF Category	Boosted Category
▸ $p_T^{\tau_{had\text{-}vis}}$ >30 GeV	–	▸ $p_T^{\tau_{had\text{-}vis}}$ >30 GeV	▸ $p_T^{\tau_{had\text{-}vis}}$ >30 GeV
▸ E_T^{miss} >20 GeV	▸ E_T^{miss} >20 GeV	▸ E_T^{miss} >20 GeV	▸ E_T^{miss} >20 GeV
▸ ≥ 2 jets	▸ $p_T^H > 100$ GeV	▸ ≥ 2 jets	▸ $p_T^H > 100$ GeV
▸ $p_T^{j1}, p_T^{j2} > 40$ GeV	▸ $0 < x_1 < 1$	▸ $p_T^{j1} > 40$, p_T^{j2} >30 GeV	▸ $0 < x_1 < 1$
▸ $\Delta\eta_{jj} > 3.0$	▸ $0.2 < x_2 < 1.2$	▸ $\Delta\eta_{jj} > 3.0$	▸ $0.2 < x_2 < 1.2$
▸ $m_{jj} > 500$ GeV	▸ Fails VBF	▸ $m_{jj} > 500$ GeV	▸ Fails VBF
▸ centrality req.	–	▸ centrality req.	–
▸ $\eta_{j1} \times \eta_{j2} < 0$	–	▸ $\eta_{j1} \times \eta_{j2} < 0$	–
▸ $p_T^{Total} < 40$ GeV	–	▸ $p_T^{Total} < 30$ GeV	–
–	–	▸ p_T^{ℓ} >26 GeV	–
• m_T <50 GeV	• m_T <50 GeV	• m_T <50 GeV	• m_T <50 GeV
• $\Delta(\Delta R) < 0.8$	• $\Delta(\Delta R) < 0.8$	• $\Delta(\Delta R) < 0.8$	• $\Delta(\Delta R) < 0.8$
• $\sum \Delta\phi < 3.5$	• $\sum \Delta\phi < 1.6$	• $\sum \Delta\phi < 2.8$	–
–	–	• b-tagged jet veto	• b-tagged jet veto
1 Jet Category	0 Jet Category	1 Jet Category	0 Jet Category
▸ ≥ 1 jet, p_T >25 GeV	▸ 0 jets p_T >25 GeV	▸ ≥ 1 jet, p_T >30 GeV	▸ 0 jets p_T >30 GeV
▸ E_T^{miss} >20 GeV	▸ E_T^{miss} >20 GeV	▸ E_T^{miss} >20 GeV	▸ E_T^{miss} >20 GeV
▸ Fails VBF, Boosted	▸ Fails Boosted	▸ Fails VBF, Boosted	▸ Fails Boosted
• m_T <50 GeV	• m_T <30 GeV	• m_T <50 GeV	• m_T <30 GeV
• $\Delta(\Delta R) < 0.6$	• $\Delta(\Delta R) < 0.5$	• $\Delta(\Delta R) < 0.6$	• $\Delta(\Delta R) < 0.5$
• $\sum \Delta\phi < 3.5$	• $\sum \Delta\phi < 3.5$	• $\sum \Delta\phi < 3.5$	• $\sum \Delta\phi < 3.5$
–	• $p_T^{\ell} - p_T^{\tau} < 0$	–	• $p_T^{\ell} - p_T^{\tau} < 0$

H→ττ: had-had selection

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

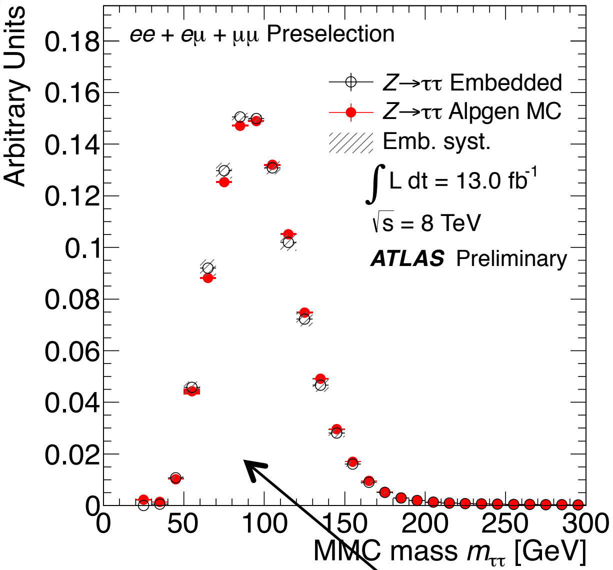
$H \rightarrow \tau\tau$: backgrounds

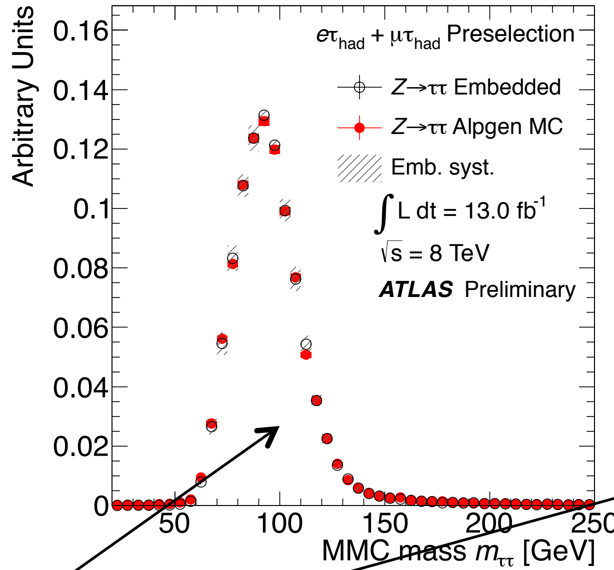
- Each channel affected by different backgrounds !!

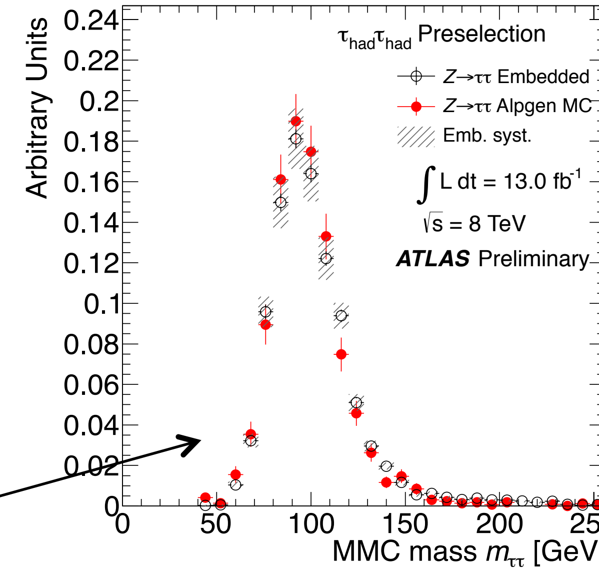
bkgd	τ_{lep}-τ_{lep}	τ_{lep}-τ_{had}	τ_{had}-τ_{had}	Rejection cut	estimation
$Z \rightarrow \tau\tau$	x	x	x	irreducible	Embedding: replacing μ in Z→μμ data events with tau decay from MC. Normalization from control region
ttbar	x	x		b-tag veto	shape from MC, normalization from control region (b-tag)
Z→ee,μμ	x			Mll<75 GeV	shape from MC, normalization from control region (low MET, high Mll)
QCD multi-jet	x	x	x		SS events and reverted tauID
Z→ee, e→τ_{had}		x			Shape from MC, normalized from control regions. Using add-on factors to take into account the OS-SS contribution
Z→ll+j, j→τ_{had}		x			
W→lν+j , j→τ_{had}		x		mT	
W→lν+j , j→*l*	x				from data: reversing lepton isolation

- Dominant systematics are Embedding, Tau Energy Scale and Jet Energy Scale.

H→ττ: embedding validation

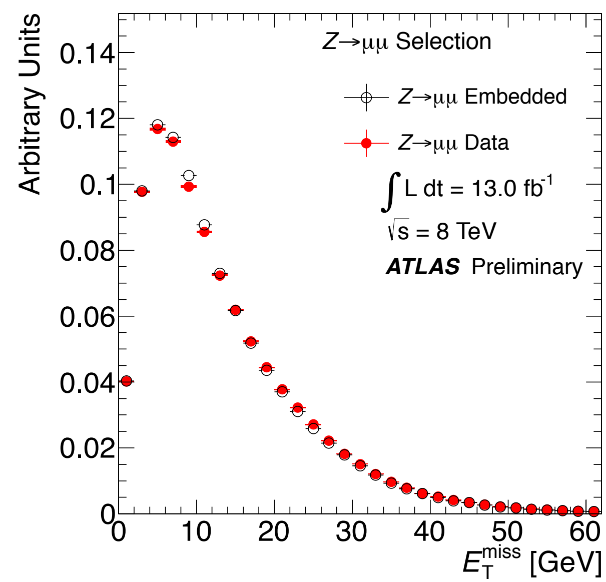




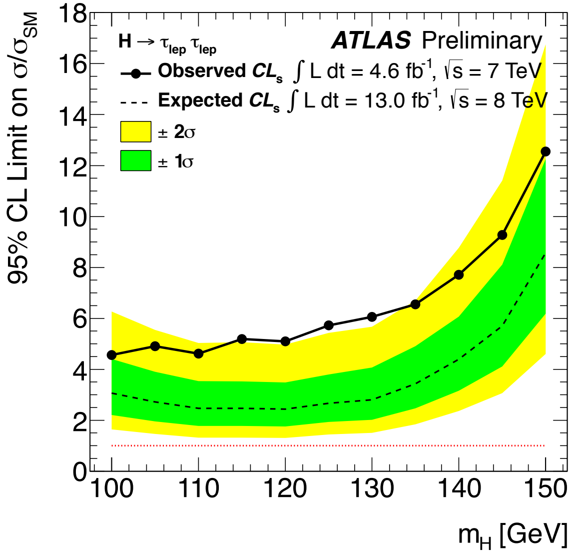


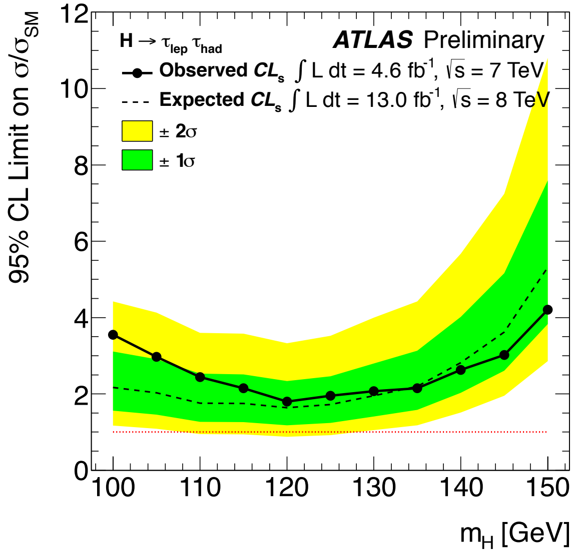
- Embedding MC validation: comparison of embedded data with Z→ ττ mc

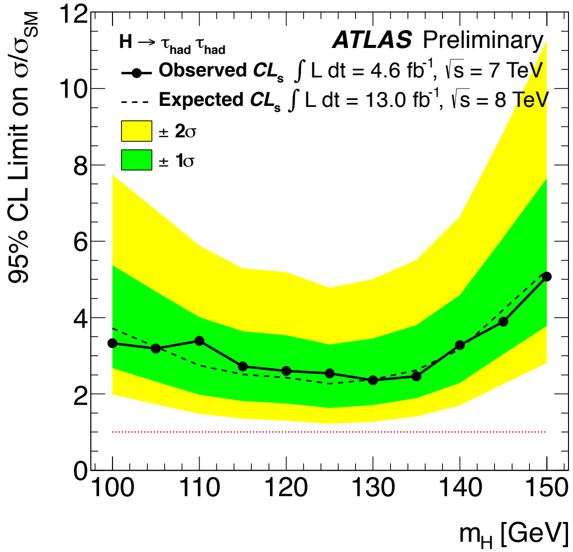
- Verifying embedding procedure by embedding with muons (instead of taus) and comparing to the original data



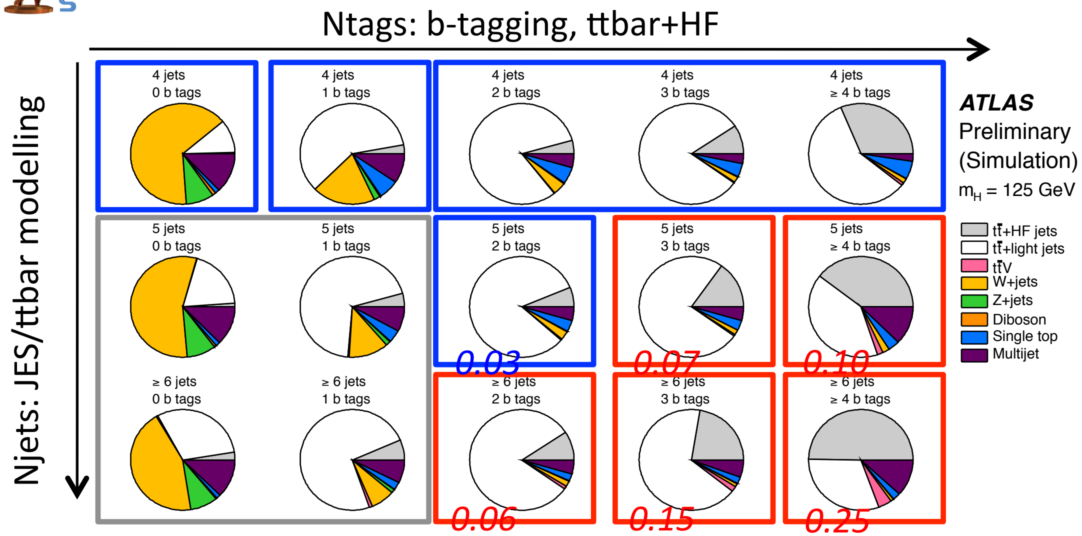
H→ττ: limits for each decay mode





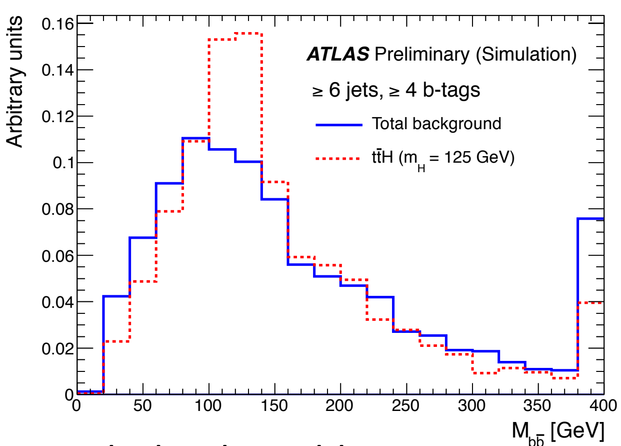


ttH(bb): categories and variables



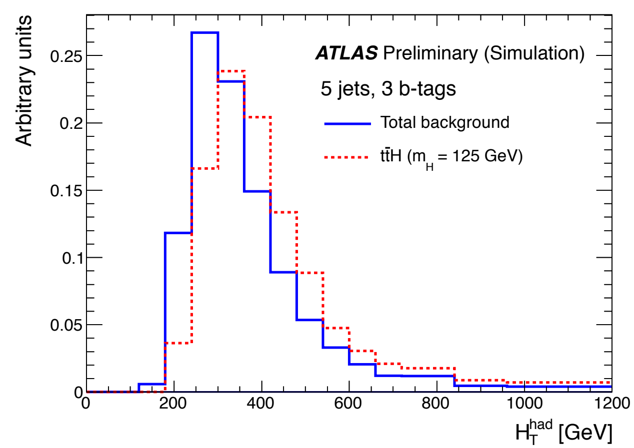
- Different Njet regions: controlling the effect of JES and ttbar modelling
- Different Ntag regions: controlling the effect b-tag and ttbar+HF

- *$m_{b\bar{b}}$ = invariant mass of two tagged jets not assigned to ttbar*



- mass peak clearly visible
- tails are due to incorrectly reconstructed events

- *H^T_{had} = scalar sum of jet p_Ts*

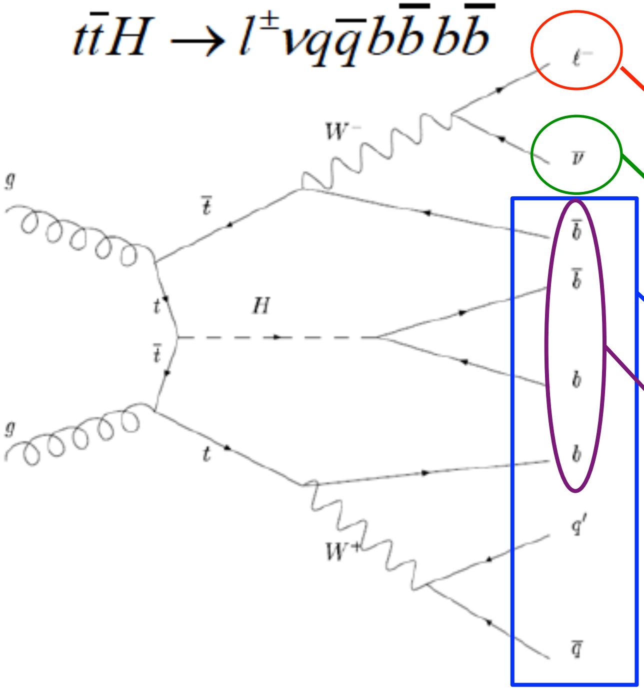


- large sensitivity to JES uncertainties, ttbar MC modelling systematics

ttH(bb): selections

- Exploiting lepton+jets (electron or muon) ttbar decay topology Br ~ 30%:
  - *using lepton to trigger / suppress multijet background*
  - *reasonably high BR (some contribution from dilepton events)*

$$t\bar{t}H \rightarrow l^{\pm}\nu q\bar{q}b\bar{b}b\bar{b}$$



- *Typical signal event looks like:*
  - exactly 1 well isolated lepton (electron or muon)
  - large missing transverse energy from escaping neutrino
  - at least 6 jets
  - at least 4 jets identified as coming from b-quarks (tagged)

- Due to b-tagging algorithm efficiency and kinematic acceptance of jets:
  - *significant leakage of signal in lower jet and b-tag multiplicity regions*

ttH(bb): selections (2)

- *ttbar identification requires good performance from all the ATLAS sub-detectors*

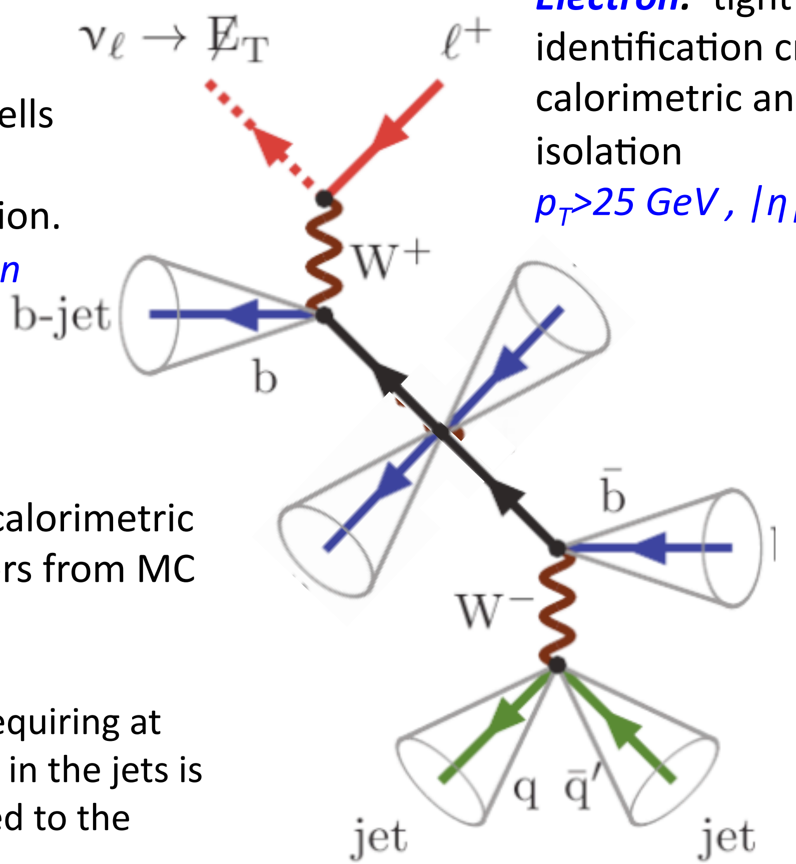
Transverse mass from lepton and neutrino.
Use to reduce QCD background
M_{wT} >35 GeV ele, E_T^{miss}+M_{wT}>60 GeV muon

***E_T^{miss}**: vector sum of calo cells energy deposits+muons.*
Object dependent calibration.
E_T^{miss}>20 (35) GeV for muon (electron) channel

Lepton selection

Electron: 'tight' identification criteria+ calorimetric and track isolation
p_T>25 GeV , |η|< 2.47

Muon: combining info in inner tracker and muon spectrometer. Track and calorimetric isolation
p_T>20 GeV , |η|< 2.5

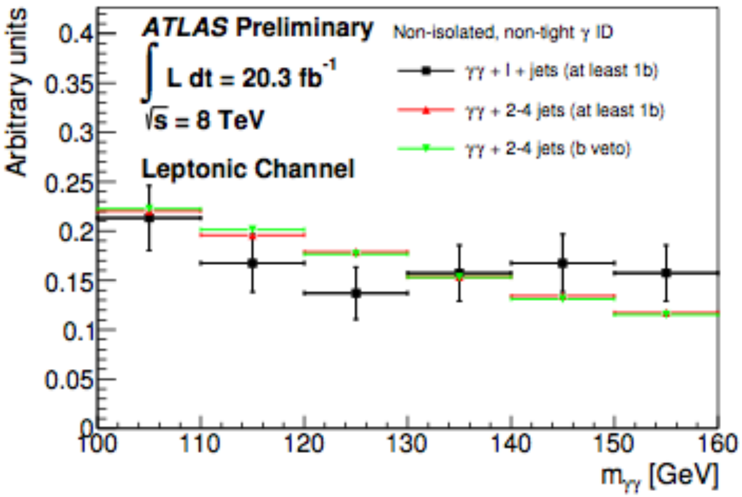


Jets: anti-kt (R=0.4) from calorimetric clusters. (eta-p_T corr. factors from MC for calibration).
p_T>25 GeV, |η|<2.5
Against pile-up condition: requiring at least 75% of sum p_T of track in the jets is coming from track associated to the primary vertex

b-Jets: multivariate tagger using information from:
reconstructed secondary vertex,
tracks impact parameter
Working point: *70%* efficiency for jet from b-quarks, *<1%* mistag rate

ttH (H→γγ)

- Main background is jet mis-identified as photons
- Shape validated in control regions by reverting photon ID



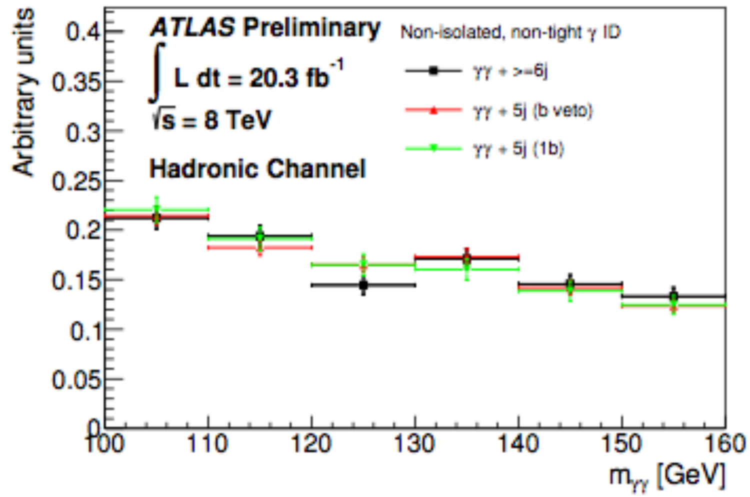
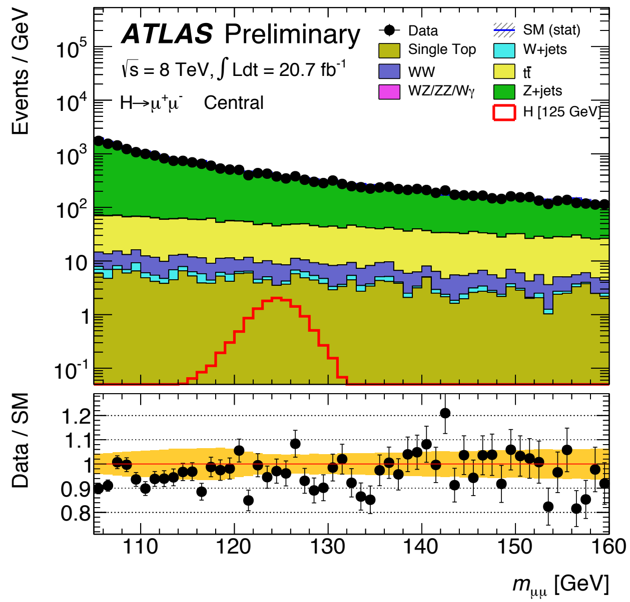


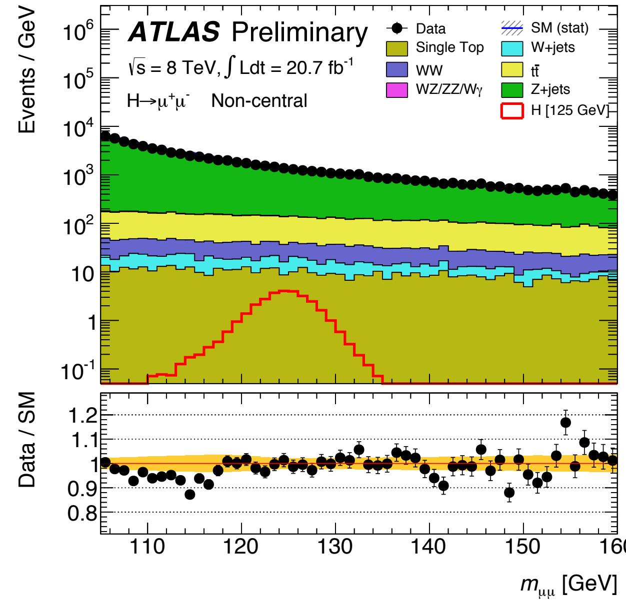
Table 5: Observed and expected 95% CL limits on the $t\bar{t}H$ production cross section times $H \to \gamma\gamma$ branching ratio relative to the SM expectation at $m_H = 126.8$ GeV.

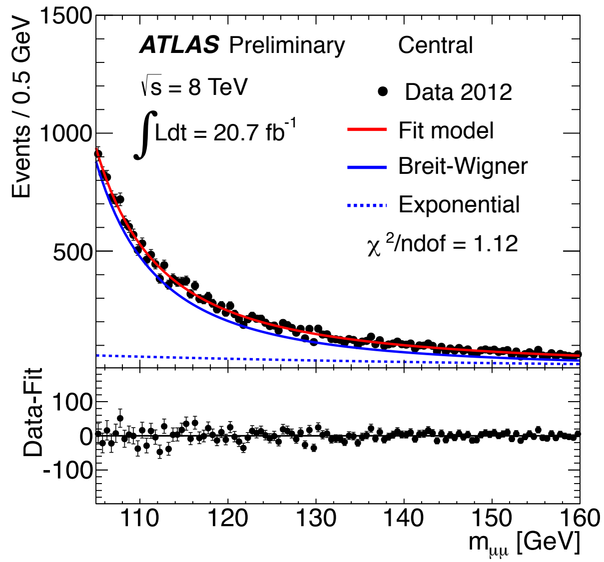
	Observed limit	Expected limit	$+2\sigma$	$+1\sigma$	-1σ	-2σ
Combined (with systematics)	5.3	6.4	16.2	9.9	4.6	3.4
Combined (statistics only)	5.0	6.0	13.5	8.9	4.3	3.2
Leptonic (with systematics)	9.0	8.4	21.9	13.2	6.1	4.5
Leptonic (statistics only)	8.5	8.0	18.8	12.1	5.7	4.3
Hadronic (with systematics)	8.4	13.6	36.4	21.6	9.8	7.3
Hadronic (statistics only)	7.9	12.6	29.1	18.9	9.1	6.8

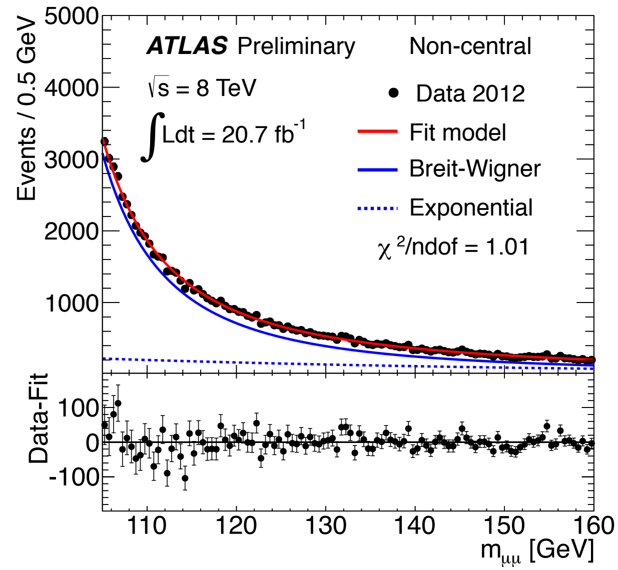
$H \rightarrow \mu\mu$

- *Two |eta| category regions separated*

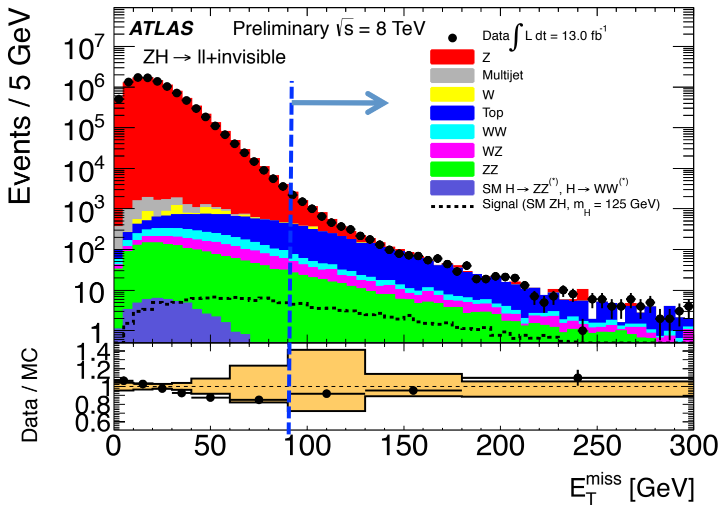


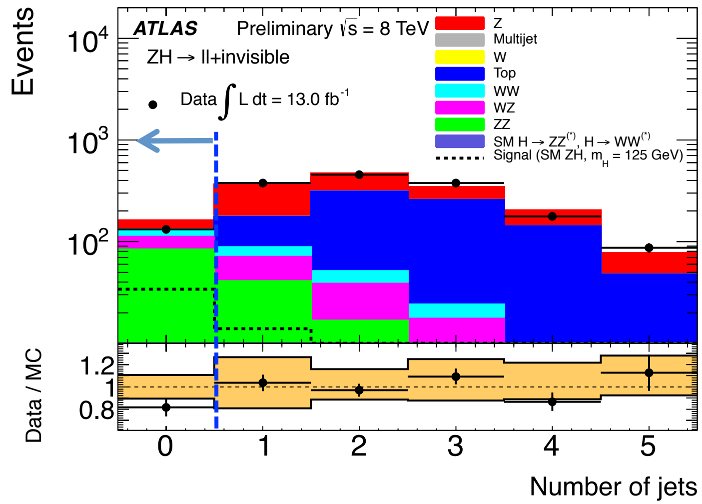




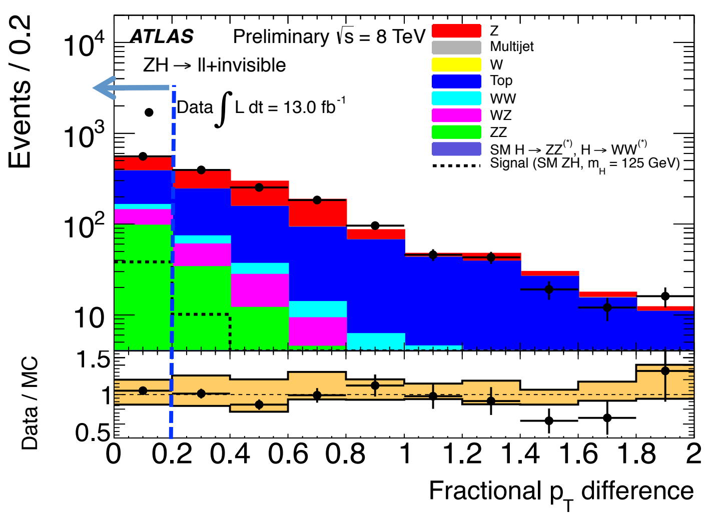


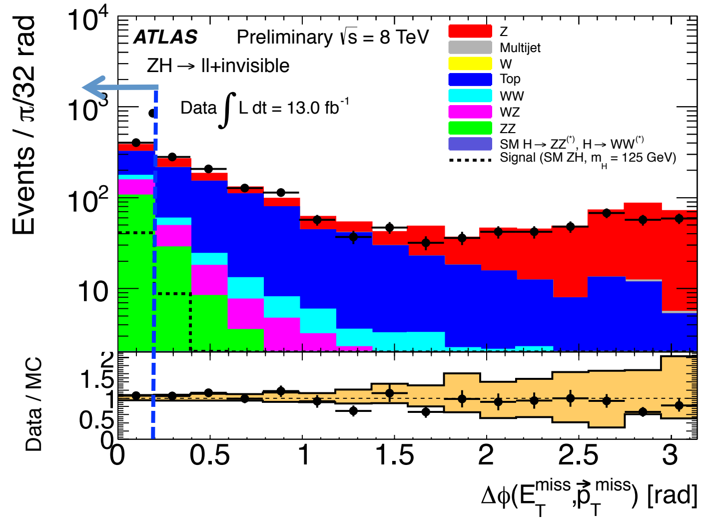
ZH (H→invisible): selection





Pre-selection





- Variables used for ABCS background estimation