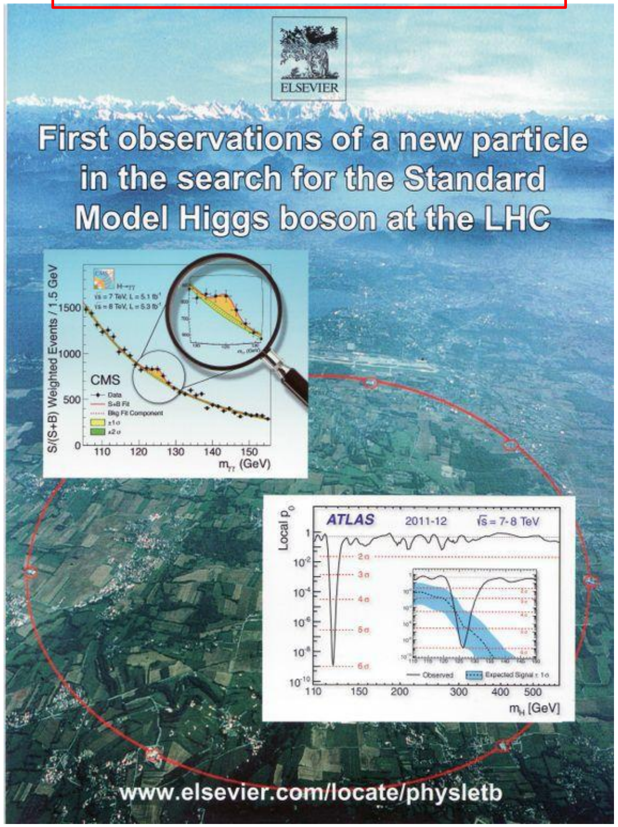
Search for the Standard Model Higgs Boson in the $H \rightarrow bb$ and $H \rightarrow \tau\tau$ decay modes with the ATLAS detector

A. Farilla (INFN)
On behalf of the ATLAS Collaboration

Kruger 2012

H → bb and H → ττ in ATLAS

Phys. Lett. B 716 (2012)



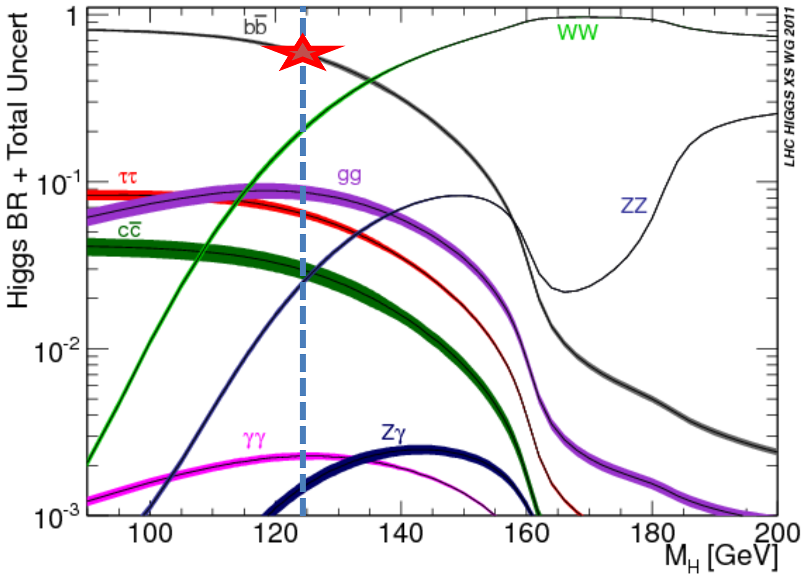
- ❖ The Higgs particle has been observed for the first time at LHC (by the ATLAS and CMS experiments) through its decays into boson pairs (ZZ, γγ, WW)

- ❖ But what about the Higgs decays into fermions?

- ❖ H → bb and H → ττ decays : important to establish the properties of the Higgs Boson in the fermionic sector!

- ❖ This talk:
  ATLAS results for 4.7 fb^{-1} $\sqrt{s}$ = 7 TeV (2011) & 13 fb^{-1} $\sqrt{s}$ = 8 TeV (2012)
- ❖ ATLAS published results already available for 4.7 fb^{-1} $\sqrt{s}$ = 7 TeV (2011) :
  - http://arxiv.org/abs/1207.0210 (H → bb)
  - http://link.springer.com/article/10.1007%2FJHEP09%282012%29070 (H →ττ)

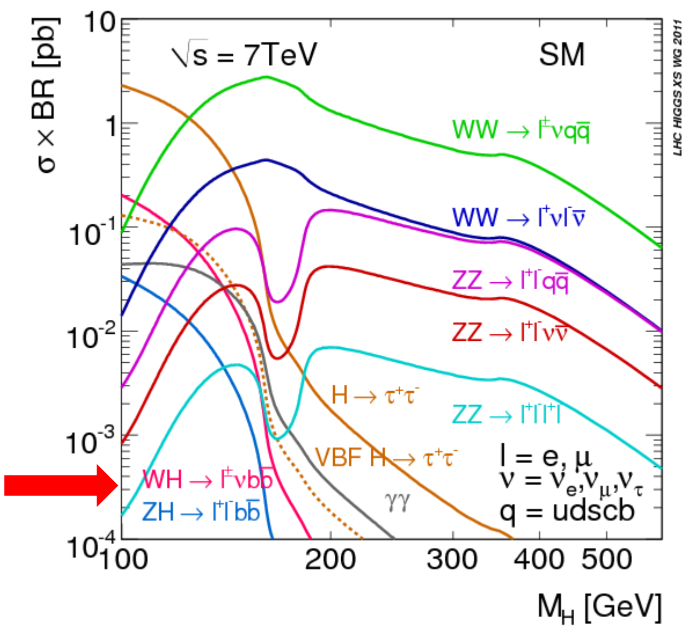
Higgs decay to b-quark pair



- High branching ratio
- For m_H = 125 GeV BR(H → bb) ~ 58%

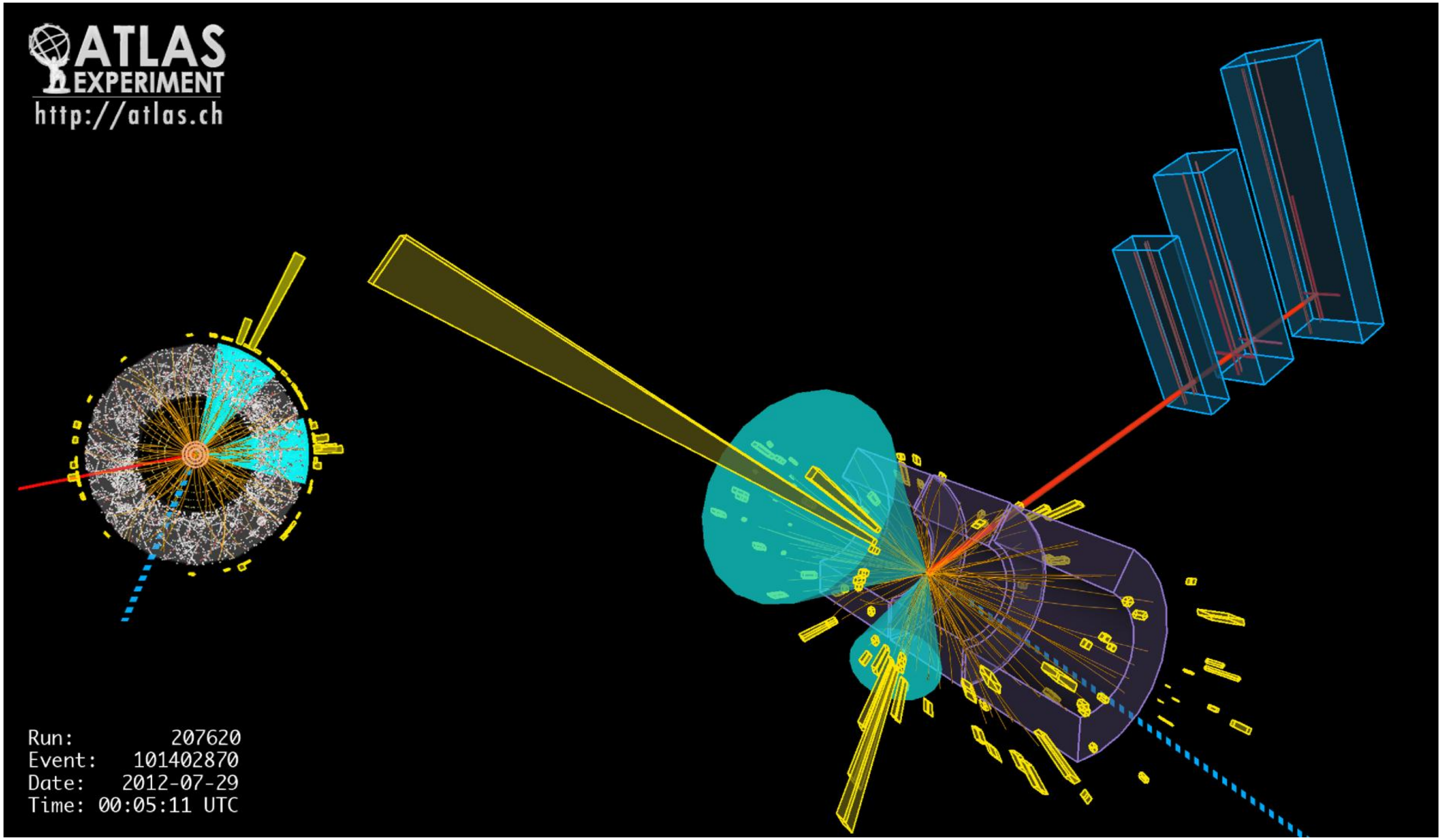
- The search for H → bb is performed in associated production with W/Z boson to clean the sample from the huge multijet background and have a clean signature for triggering

- The multijet background is reduced at the price of a lower event yield: the cross section of VH associated production is ~10 times smaller than the main Higgs production mode (gluon-gluon fusion)

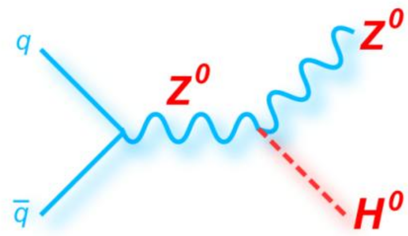


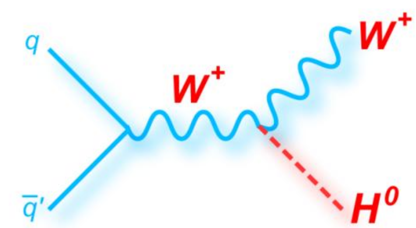
Event Display

Higgs boson candidate with one selected muon



Search/Analysis Strategy





- ❖ Search for Higgs to b-pair in associated production with a Z or $W^{\pm}$ boson:
- ❑ Better background rejection, good signature for triggering

- ❖ The analysis is divided into three channels (based on lepton multiplicity):
- ❑ Two (llbb), one (lνbb) or zero (ννbb) charged lepton (l=e or μ)

- ❖ Cuts common to all channels:
- ❑ Two or three jets : first jet $p_T > 45$ GeV, other jets $p_T > 20$ GeV
- ❑ Two b-tags: 70% efficiency per tag (mistag ~1%)

ZH → llbb

- Two leptons
- $E_T^{miss} < 60$ GeV
- $83 < m_Z < 99$ GeV
- Single & di-lepton trigger

WH → lνbb

- One lepton
- $E_T^{miss} > 25$ GeV
- $40 < m_T^W < 120$ GeV
- Single lepton trigger

ZH → ννbb

- No leptons
- $E_T^{miss} > 120$ GeV
- E_T^{miss} trigger

Analysis Overview

- Signal over Background ratio increases with p_T^{bb}
- To enhance the sensitivity, the analysis is categorised as a function of p_T^V
- 16 signal categories:
  - 0-lepton: E_T^{miss} [120-160] [160-200] [>200] GeV (2 jets or 3 jets)
  - 1 & 2 leptons: $p_T^{W/Z}$ [0-50], [50-100], [100-150], [150-200], [>200] GeV
- Recent important improvements:
  - Cuts are optimized for each category (~30% increase in sensitivity)
  - Muon energy (p_T>4 GeV) added for b-jets (~10% increase in resolution)
  - Additional ttbar based b-tagging calibration (~50% reduction in systematics)

Background and MC

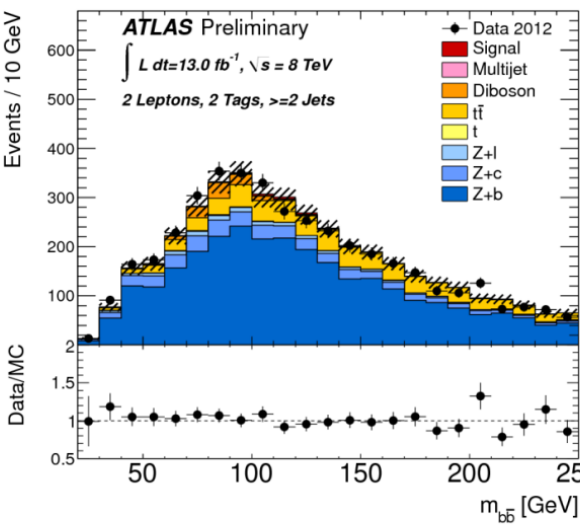
- Signal — WH/ZH Pythia8
- Multijet — Data Driven
- Diboson — WW/WZ/ZZ Herwig
- ttbar — MC@NLO
- Single top — Acer/MC@NLO
- W+b — Powheg
- W+c/light jets — Alpgen
- Z+b/c/light jets — Alpgen/Sherpa

❖ Background shapes from simulation and normalised using flavour and data fit

❖ Multijet bkg determined by data-driven tecniques

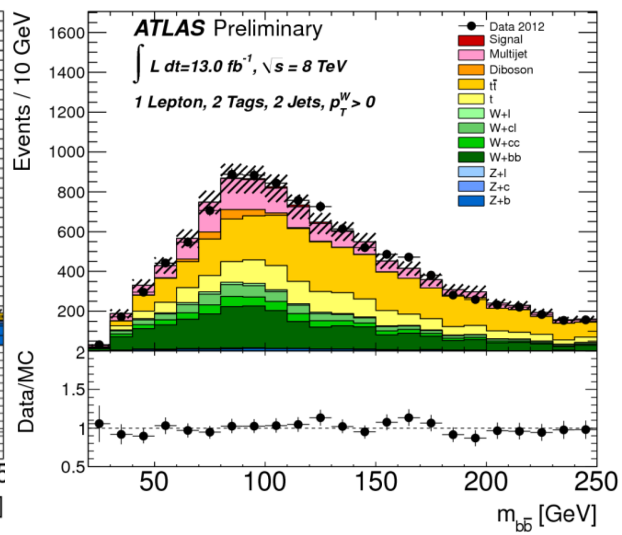
❖ WZ/ZZ (with Z→ bb) bkg normalisation and shape from simulation

2 leptons



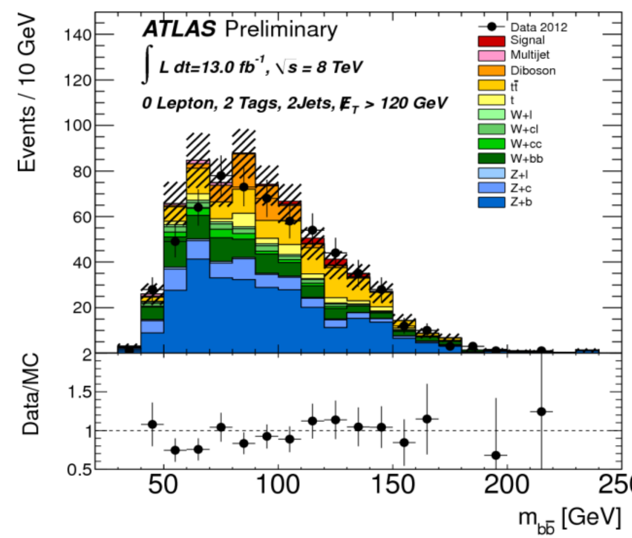
Z+jets

1 lepton



Top/W+jets

0 lepton



Z+jets/W+jets/Top

Background and flavours fit

Events with 0,1 and 2 b-jets have different flavour contribution: this allows to fit the normalisation of the several components

- **Flavour maximum likelihood fit to signal and control regions:**
  - Determine V+jets (b/c/light) and top scale factors
  - One scale factor applied for each bkg
  - Scale factors are consistent for the 7 TeV and 8 TeV data samples (Z+c factor changes due to different MC treatment)

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

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

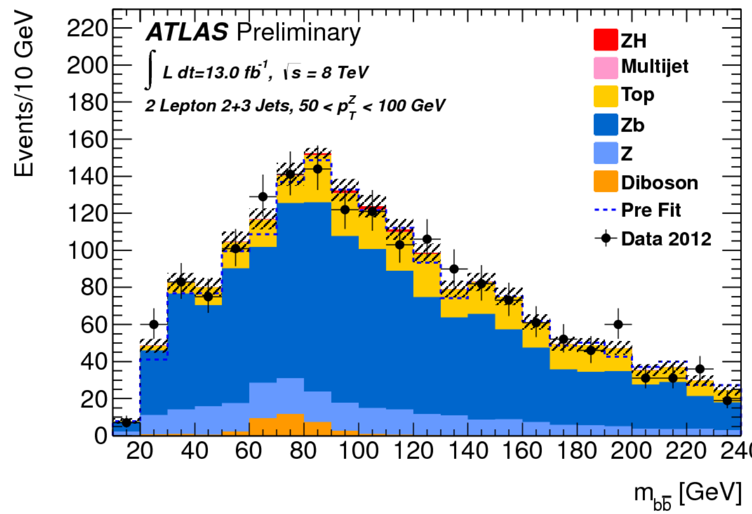
- **Almost all SF ~1 : the MC simulation is performing very well !**
- **Improved understanding of background in recent analysis:**
  - Analyzing the 8 TeV data we discovered that the V p_T spectrum falls more rapidly in data than expected from MC
  - W + jets and Z + jets: 5-10% correction required
  - Top bkg: 15% correction required

Examples of m_{bb} distributions

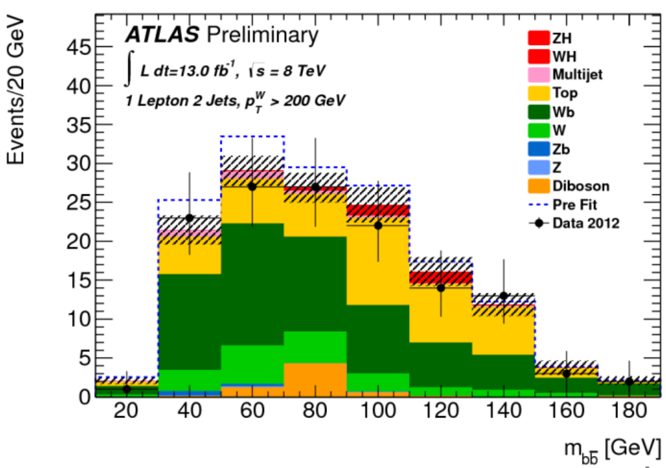
- In this slide: three examples of final m_{bb} in specific bins of p_T^Z , p_T^W , E_t^{miss}
  (more plots in backup slides)

- Full m_{bb} distribution is used in the limit setting procedure

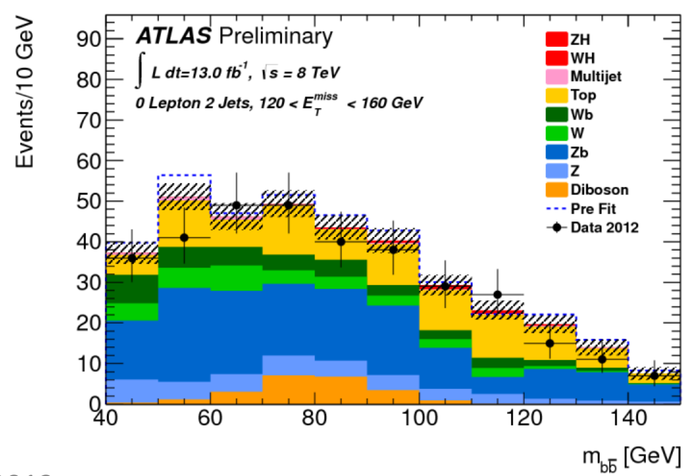
2 leptons ($50 < p_T^Z < 100$ GeV)



1 lepton ($p_T^W > 200$ GeV)



0 lepton ($120 < E_T^{miss} < 160$ GeV)

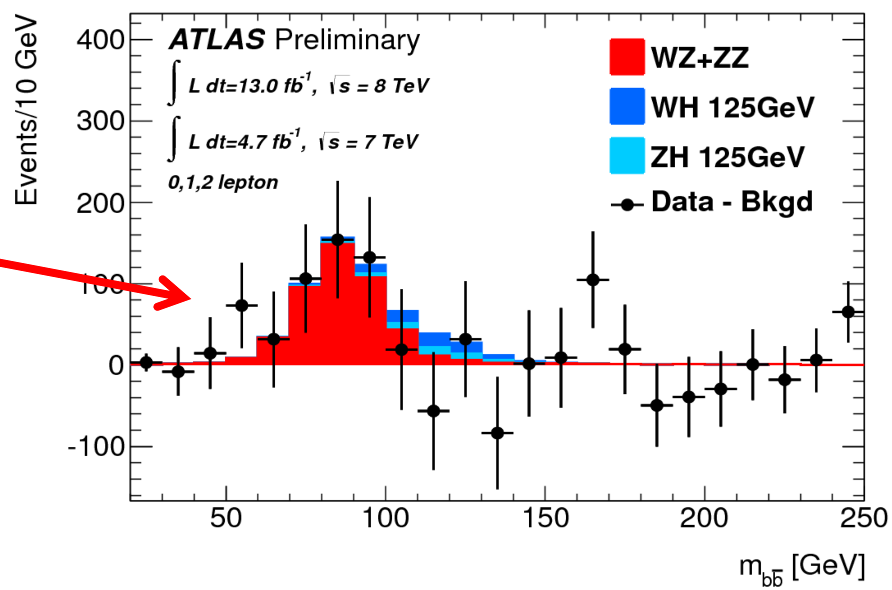


Diboson Production

- WZ & ZZ production with Z →bb:
  - Signature similar to VH with H →bb but cross section 5 times larger

- Perform a separate fit to search diboson events and to validate the analysis:
  - Profile likelihood fit performed (with full systematics)
  - All backgrounds (except diboson) subtracted
  - All lepton channels combined, no separation in p_T^V bins

- Diboson peak clearly visible in the data



- Result in agreement with SM:
  - $\sigma/\sigma_{SM} = \mu_D = 1.09 \pm 0.20$ (stat) ± 0.22 (sys)
  - Significance = 4.0 σ

Systematics Uncertainties

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

- **Main theoretical uncertainties:**
  - W/Z+jet m_{bb} (20%) and V p_T (5-10%)
  - Single top/top normalisation
  - W+c/W+jets (30%), Z+c/z+jets (30%)
  - Diboson (11%)
  - BR(H →bb) @m_H=125 GeV

Background systematics

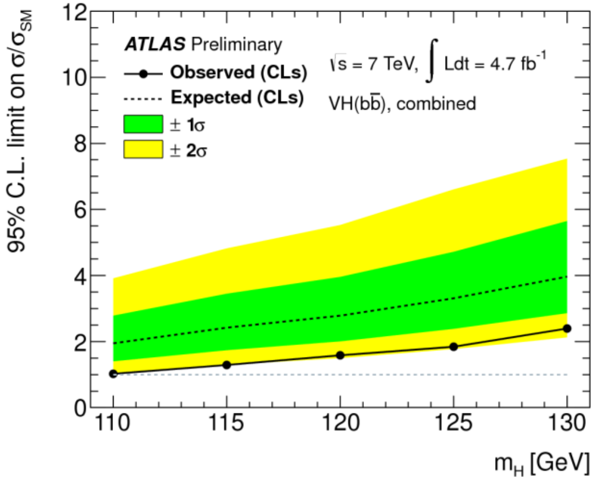
Uncertainty [%]	0 lepton	1 lepton	2 leptons
b-tagging	6.5	6.0	6.9
c-tagging	7.3	6.4	3.6
light tagging	2.1	2.2	2.8
Jet/Pile-up/E_T^{miss}	20	7.0	5.4
Lepton	0.0	2.1	1.8
Top modelling	2.7	4.1	0.5
W modelling	1.8	5.4	0.0
Z modelling	2.8	0.1	4.7
Diboson	0.8	0.3	0.5
Multijet	0.6	2.6	0.0
Luminosity	3.6	3.6	3.6
Statistical	8.3	3.6	6.6
Total	25	15	14

Signal systematics

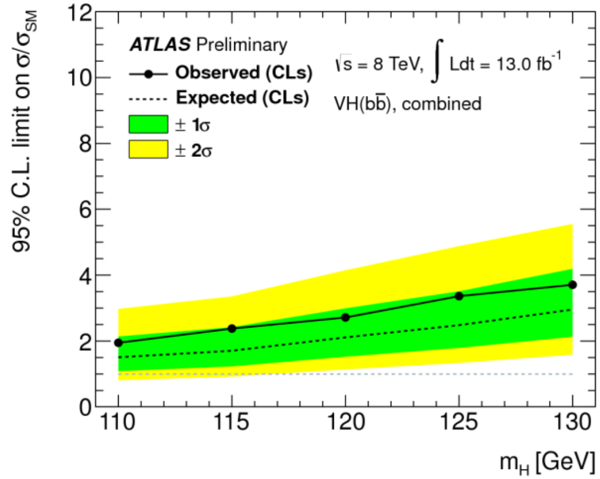
Uncertainty [%]	0 lepton		1 lepton	2 leptons
	ZH	*WH*	*WH*	*ZH*
b-tagging	8.9	9.0	8.8	8.6
Jet/Pile-up/E_T^{miss}	19	25	6.7	4.2
Lepton	0.0	0.0	2.1	1.8
$H \to bb$ BR	3.3	3.3	3.3	3.3
VH p_T-dependence	5.3	8.1	7.6	5.0
VH theory PDF	3.5	3.5	3.5	3.5
VH theory scale	1.6	0.4	0.4	1.6
Statistical	4.9	18	4.1	2.6
Luminosity	3.6	3.6	3.6	3.6
Total	24	34	16	13

Results

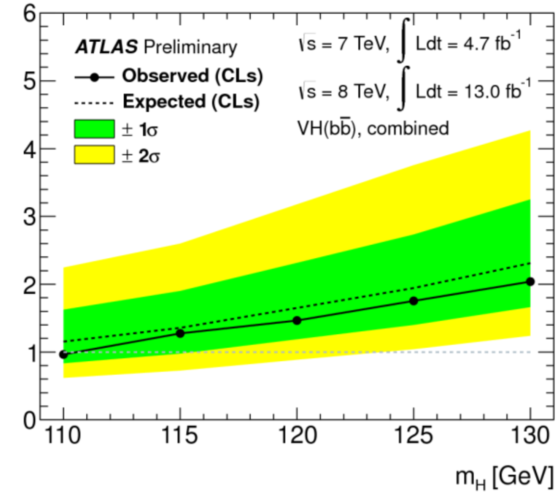
2011



2012



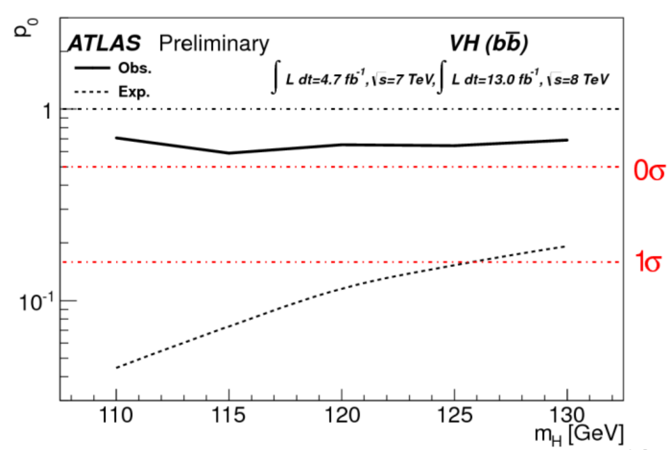
2011 & 2012



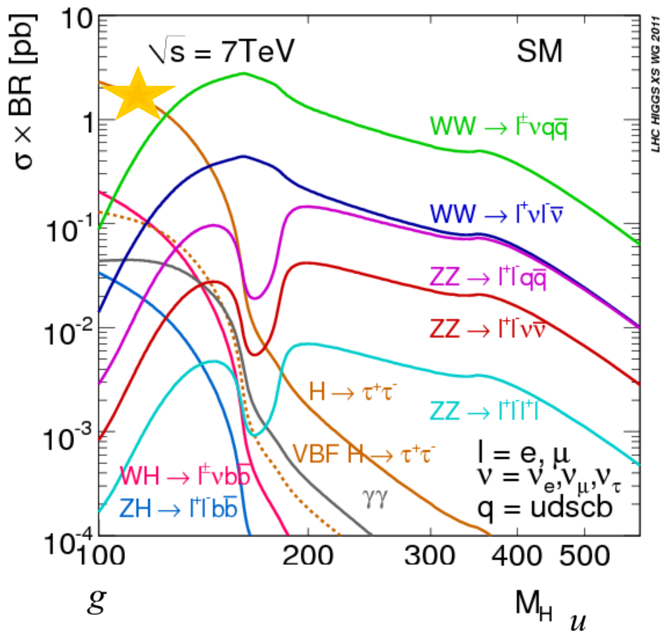
❖Combined results (2011&2012):

- Use standard CLs profiling method
- Fit full m_{bb} distribution
- Observed (expected) limit at m_H = 125 GeV:

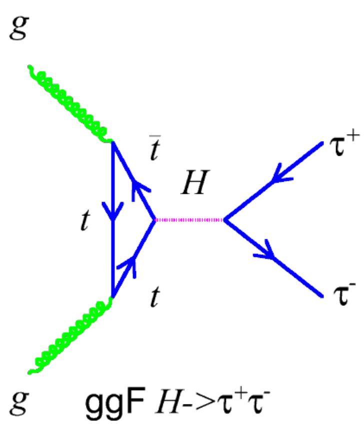
  1.8 (1.9) x SM prediction
- Observed (expected) p0 value: 0.64 (0.15)
- $\sigma/\sigma_{SM} = \mu = -0.4 \pm 0.7$ (stat) $\pm$ 0.8 (syst)
- No significant excess observed

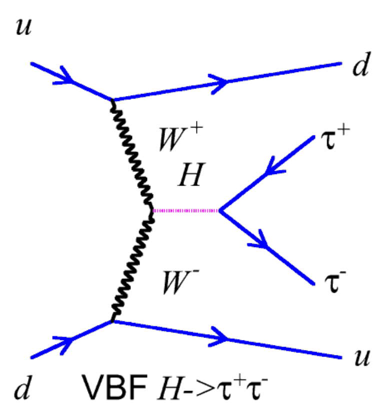


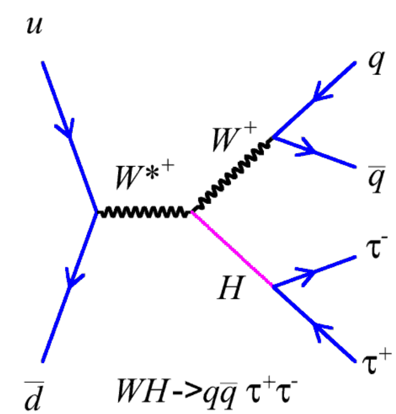
Higgs decay to τ-lepton pair



- $H \rightarrow \tau\tau$ is one of the leading decay modes for m_H = 125 GeV
- Very important to establish the couplings to the fermions
- Three Higgs production processes are considered in this search: ggF, VBF, VH
- VBF has the highest sensitivity thanks to its signature (2 high-p_T jets with high $\Delta\eta_{jj}$ and high m_{jj})



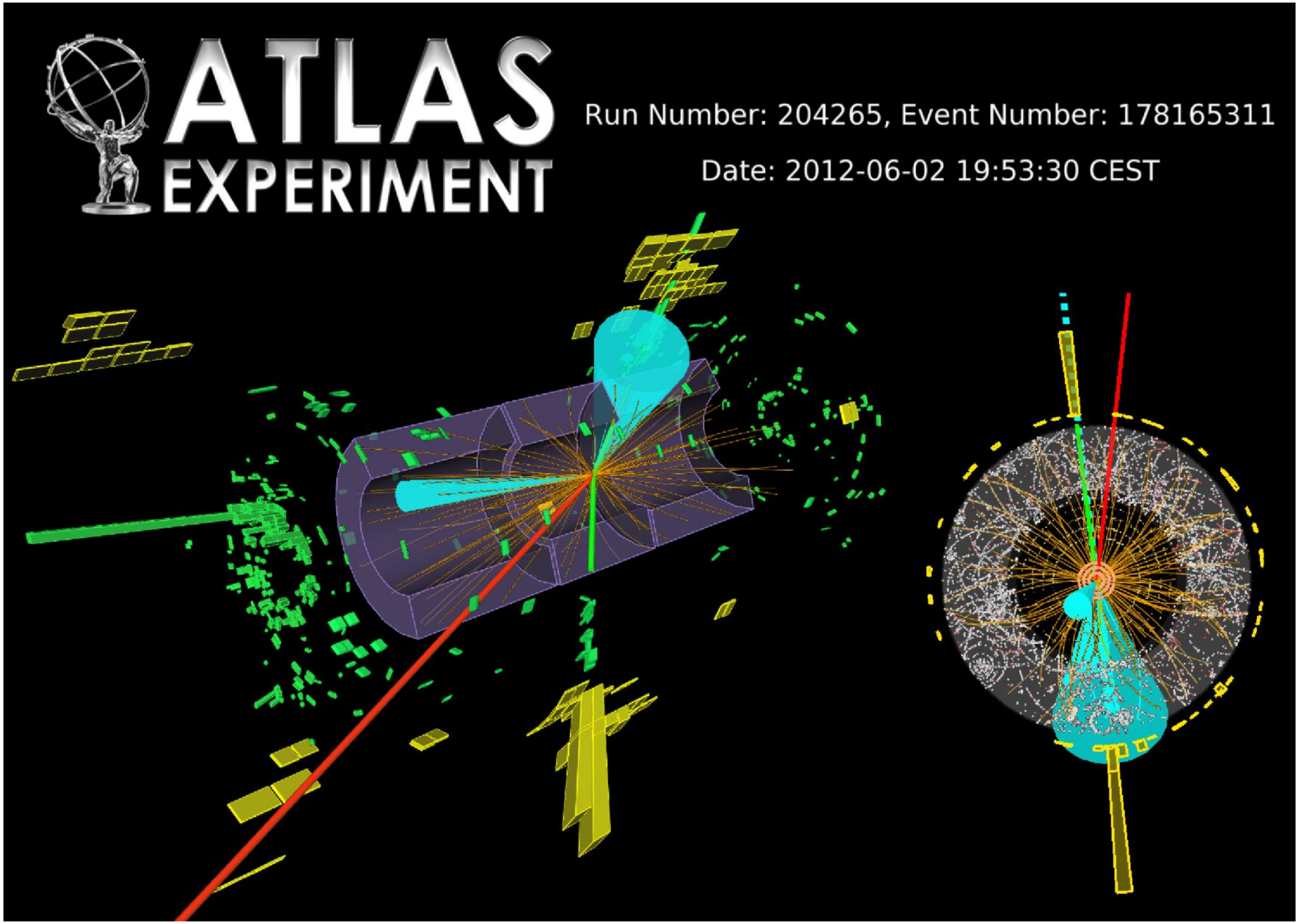




We select only hadronic decays of V

Event display (VBF category)

$H \rightarrow \tau_{lep} \tau_{had}$, with $\tau \rightarrow \mu\nu\nu$



Analysis Categories (8 TeV)

❖ Analysis divided into channels based on τ decays

❖ In each channel the search is optimized separately in a set of (mutually exclusive) analysis categories, which differ by number of jets (0,1 or 2 jets) and kinematic features

❖ Categories for 8 TeV data:

- $H \rightarrow \tau_{lep} \tau_{lep}$ (BR ~12.4%) 2-jets VBF , Boosted, 2-jet VH, 1-jet
- $H \rightarrow \tau_{lep} \tau_{had}$ (BR ~ 45.6%) 2-jets VBF, Boosted, 1-jet, 0-jet
- $H \rightarrow \tau_{had} \tau_{had}$ (BR ~ 42%) 2-jets VBF, Boosted

❖ Quite similar categories for 7 TeV data
(more details in the backup slides)

❖ In each channel and category the final discriminant (used for limit setting) is the invariant mass of the τ-pair $m_{\tau\tau}$

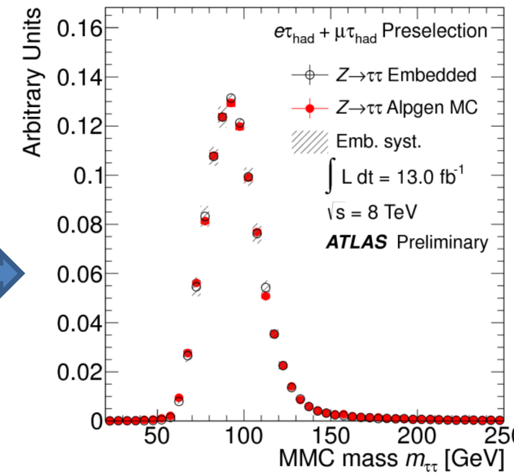
- $m_{\tau\tau}$ reconstructed with the Missing Mass Calculator using measured momenta, E_T^{miss} and the simulated distribution of the opening angle between visible and missing momenta

Background estimation

❖ The main background for all analysis categories is due to $Z \rightarrow \tau\tau$ process

❖Data driven estimation of $Z \rightarrow \tau\tau$:

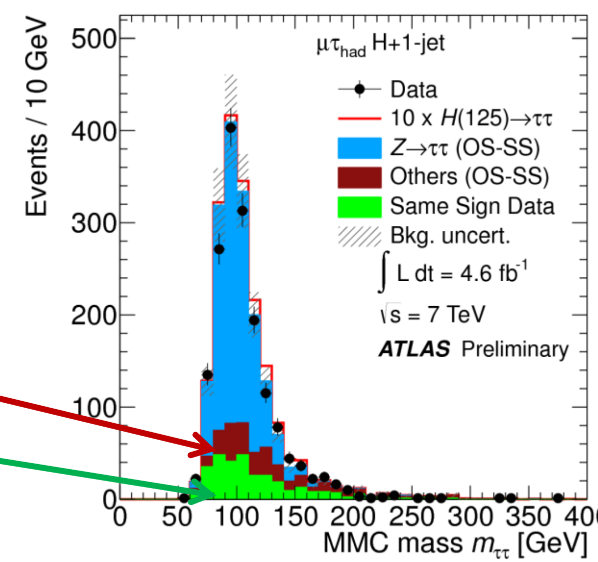
- Use $Z \rightarrow \mu\mu$ data and replace the μ's with τ's from MC simulation (τ-embedded)
- All other objects (jets, underlying event, etc) are obtained from data
- Good agreement between data and MC



❖For VBF lep-had category the estimation of $Z \rightarrow \tau\tau$ is performed with high statistic MC samples with jet-selection cuts at generator level (VBF-filter), plus correction and normalization from data

❖Other background sources:

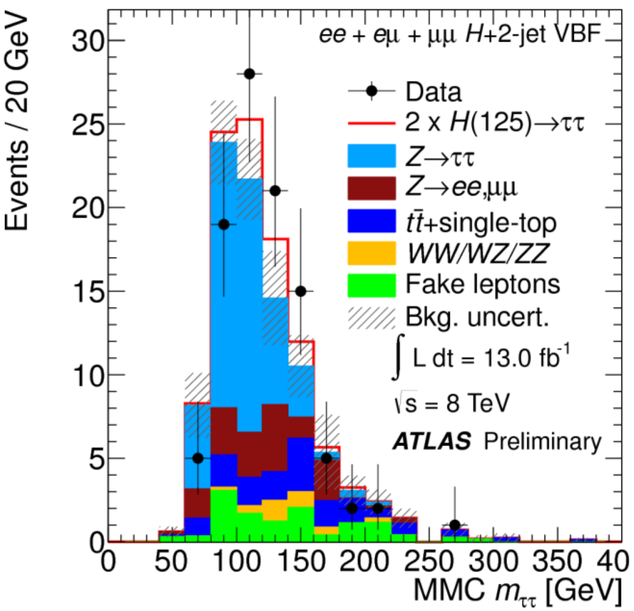
- Z ($\rightarrow ee/\mu\mu$) + jets, Top, di-boson (estimated from MC + corrections from data)
- Multijet and W+ jets (data driven estimation)



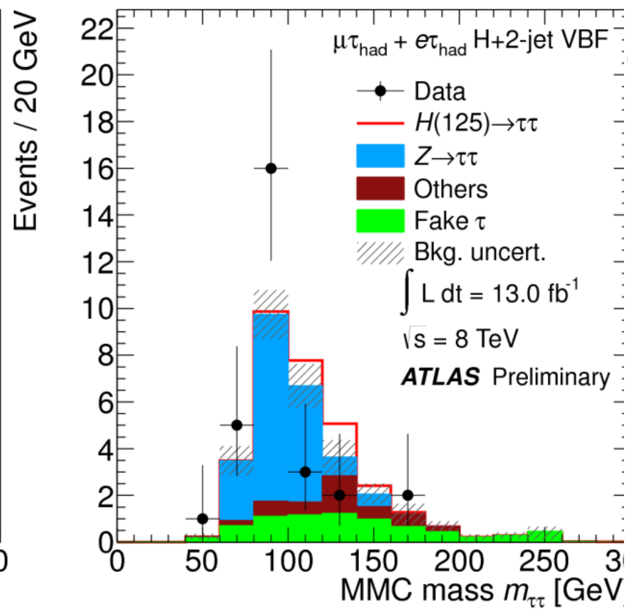
Results for VBF: $m_{\tau\tau}$

- ❖VBF category has the highest sensitivity
- ❖Limited statistics but good S/B ratio
- ❖In this slide: results for 8 TeV data (more plots in the backup slides)

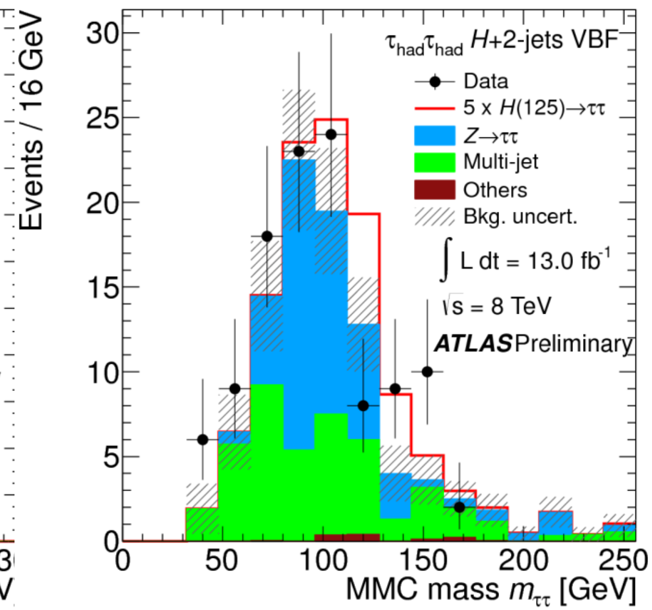
lep-lep



lep-had



had-had

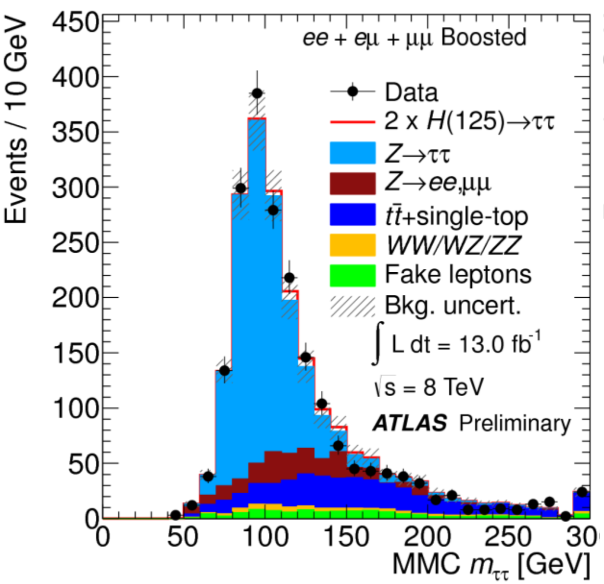


Results for Boosted: $m_{\tau\tau}$

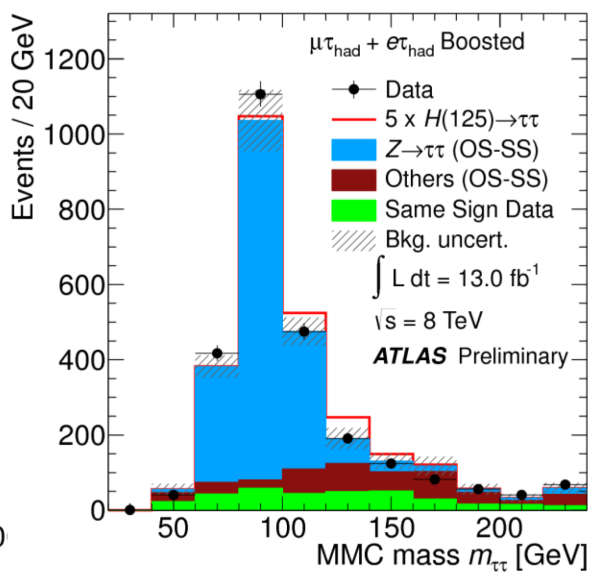
❖ **Boosted category has the best sensitivity among non-VBF categories**

❖ **In this slide: results for 8 TeV data (more plots in the backup slide)**

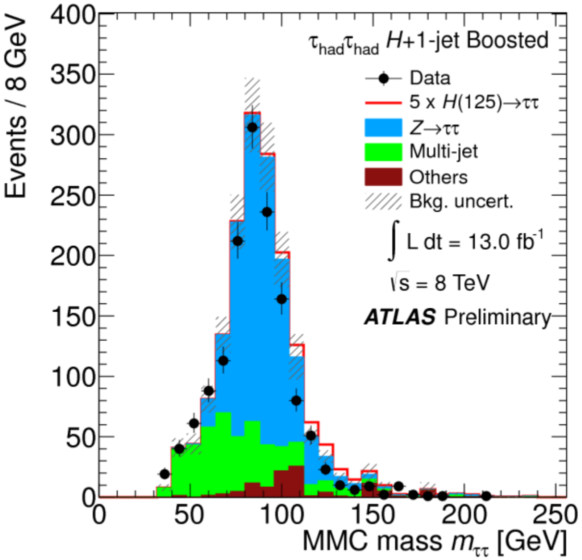
lep-lep



lep-had



had-had



Systematics uncertainties

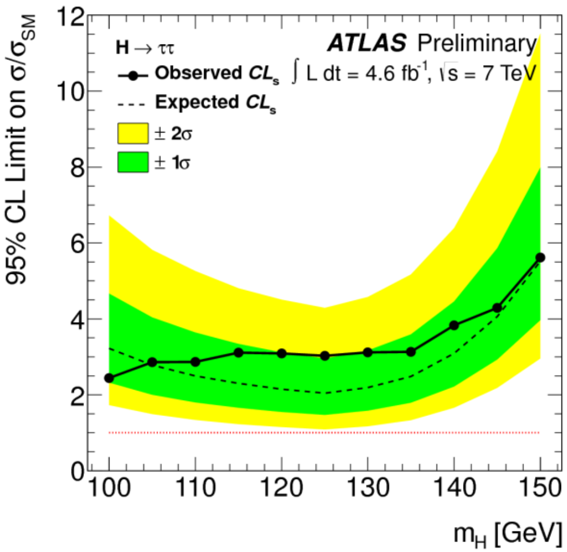
- Main systematic uncertainties for $Z \to \tau\tau$ Background and the Signal
- Dominant systematic : Embedding, τ Energy Scale, Jet Energy Scale

Uncertainty	$H \to \tau_{\rm lep}\tau_{\rm lep}$	$H \to \tau_{\rm lep}\tau_{\rm had}$	$H \to \tau_{\rm had}\tau_{\rm had}$
$Z \to \tau^+\tau^-$			
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	4.7%	4% (non-VBF), 16% (VBF)	9-10%
Signal			
Jet Energy Scale	1.0-5.0% (S)	3-9% (S)	2-4% (S)
Tau Energy Scale	-	2-9% (S)	4-6% (S)
Tau Identification	-	4-5%	10%
Theory	7.9-28%	18-23%	3-20%
Trigger Efficiency	small	small	5%

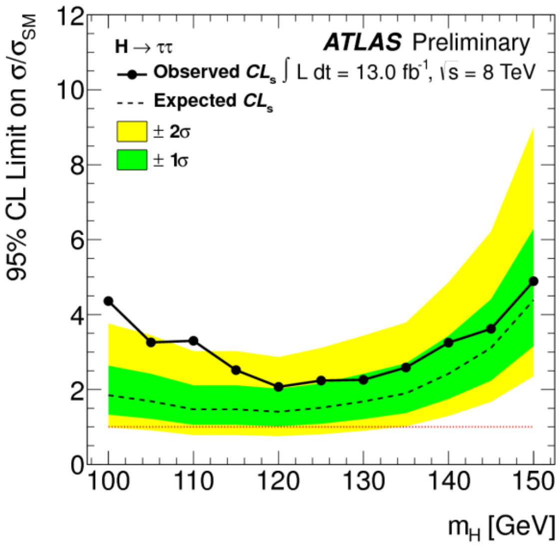
Uncertainties with (S) are also applied bin-by-bin (affect the shape of the final distribution)

Results

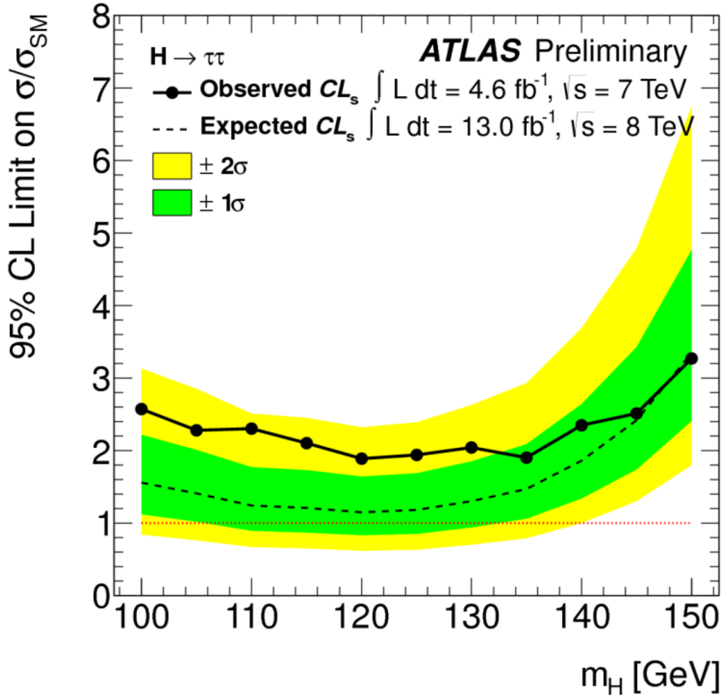
2011



2012



2011 & 2012



❖**Combined results (2011&2012):**

- Use standard CLs profiling method
- Fit full $m_{\tau\tau}$ distribution

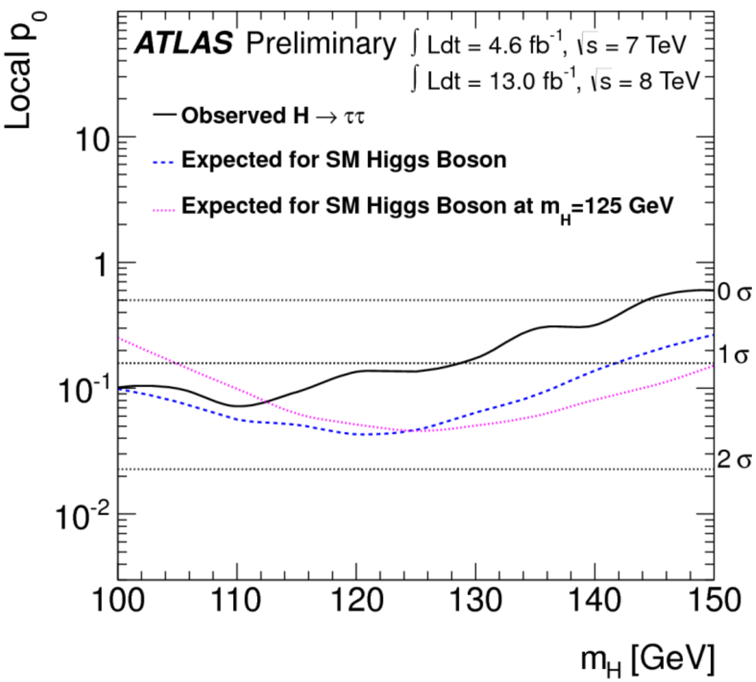
- Observed (expected) limit at m_H = 125 GeV:

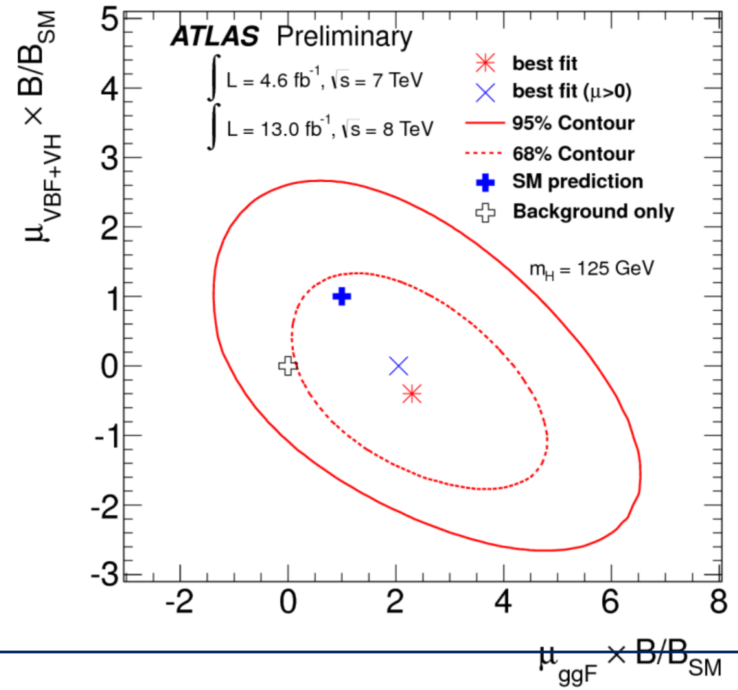
  1.9 (1.2) x SM prediction

- $\sigma/\sigma_{SM} = \mu = 0.7 \pm 0.7$

- No significant excess observed

Results





Observed (expected) p0 value:

1.1σ (1.7σ) for m_H = 125 GeV

- **Contour plot obtained introducing, in the likelihood function, signal strenght parameters $\mu_i = \sigma_i / \sigma_{i,SM}$ for each production mode ggF, VBF, VH (μ_{VBF} and μ_{VH} are combined since they both depend on the VVH coupling)**

- **Not enough sensitivity to probe SM Higgs against the background only prediction, but provides good constraint in VBF and ggF plane**

Conclusions

- Updated ATLAS results on $H \rightarrow bb$ and $H \rightarrow \tau\tau$ are now available for 4.7 fb^{-1} at $\sqrt{s}$ = 7 TeV (in 2011) and 13 fb^{-1} at $\sqrt{s}$ = 8 TeV (in 2012)

- For $H \rightarrow bb$ @ m_H = 125 GeV:
μ = -0.4 ±0.7 (stat) ± 0.8 (syst)
Observed (expected) p0 value: 0.64 (0.15)

- For $H \rightarrow \tau\tau$ @ m_H = 125 GeV:
μ = 0.7 ± 0.7
Observed (expected) p0 value: 0.135 (0.047)

- No excess observed yet for $H \rightarrow bb$ and $H \rightarrow \tau\tau$

- Including the new data sample of ~10 fb^{-1} at $\sqrt{s}$ = 8 TeV collected by ATLAS in the last weeks could provide new insights into these two extremely interestings Higgs decays

Backup Slides

Backup

H→bb: Expected and Observed events

	0-lepton, 2 jet			0-lepton, 3 jet			1-lepton					2-lepton				
Bin	E_T^{miss} [GeV]						p_T^W [GeV]					p_T^Z [GeV]				
	120-160	160-200	>200	120-160	160-200	>200	0-50	50-100	100-150	150-200	> 200	0-50	50-100	100-150	150-200	>200
ZH	2.9	2.1	2.6	0.8	0.8	1.1	0.3	0.4	0.1	0.0	0.0	4.7	6.8	4.0	1.5	1.4
WH	0.8	0.4	0.4	0.2	0.2	0.2	10.6	12.9	7.5	3.6	3.6	0.0	0.0	0.0	0.0	0.0
Top	89	25	8	92	25	10	1435	2276	1120	147	43	230	310	84	3	0
$W+c,l$	30	10	5	9	3	2	576	585	209	36	17	0	0	0	0	0
$W+b$	35	13	13	8	3	2	774	778	288	77	64	0	0	0	0	0
$Z+c,l$	35	14	14	8	5	8	17	17	4	1	0	201	231	91	12	15
$Z+b$	144	51	43	41	22	16	50	63	13	5	1	1010	1182	469	75	51
Diboson	23	11	10	4	4	3	53	59	23	13	7	37	39	16	6	4
Multijet	3	1	1	1	1	0	893	522	68	14	3	12	3	0	0	0
Total Bkg.	361 ± 29	127 ± 11	98 ± 12	164 ± 13	63 ± 8	42 ± 5	3810 ± 150	4310 ± 86	1730 ± 90	297 ± 27	138 ± 14	1500 ± 90	1770 ± 110	665 ± 47	97 ± 12	72 ± 12
Data	342	131	90	175	65	32	3821	4301	1697	297	132	1485	1773	657	100	69

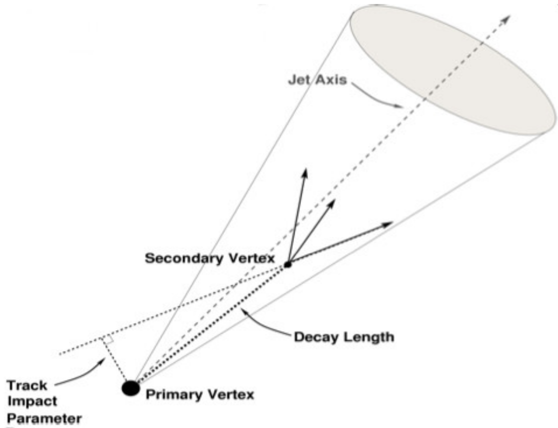
Backup

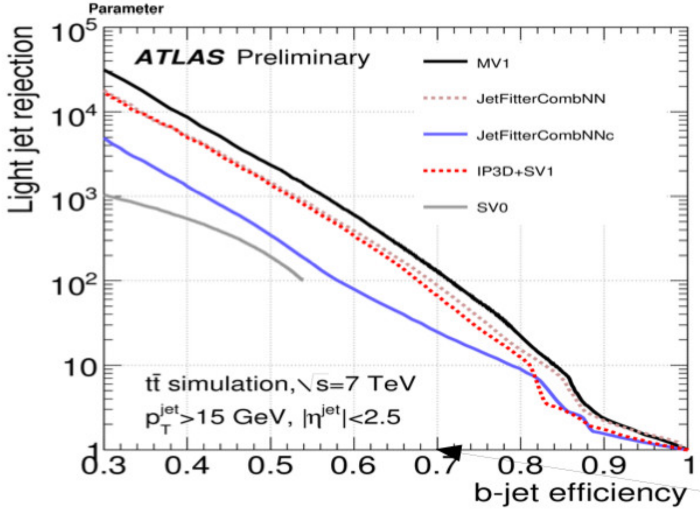
H →bb : Selection cuts

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

Backup

B-tagging



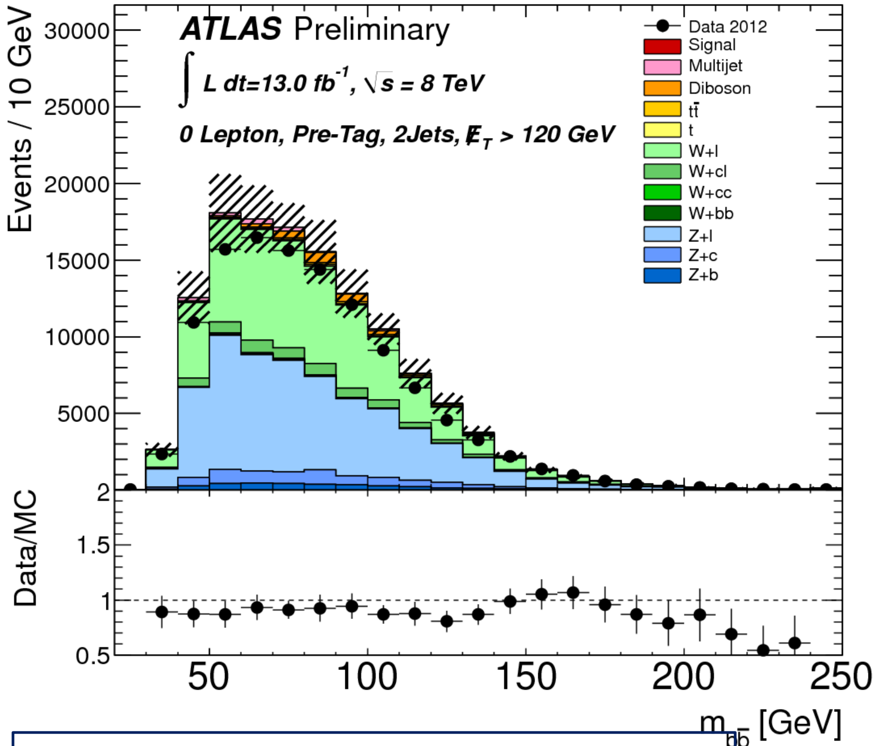


- Algorithms to identify heavy flavour content in reconstructed jets
- Impact parameter of tracks in jet
  - **IP3D** uses track weights based on longitudinal and transverse IP significance
- Displaced secondary vertex
  - **SV1** reconstructs inclusive displaced vertex
  - **JetFitter** reconstructs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

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

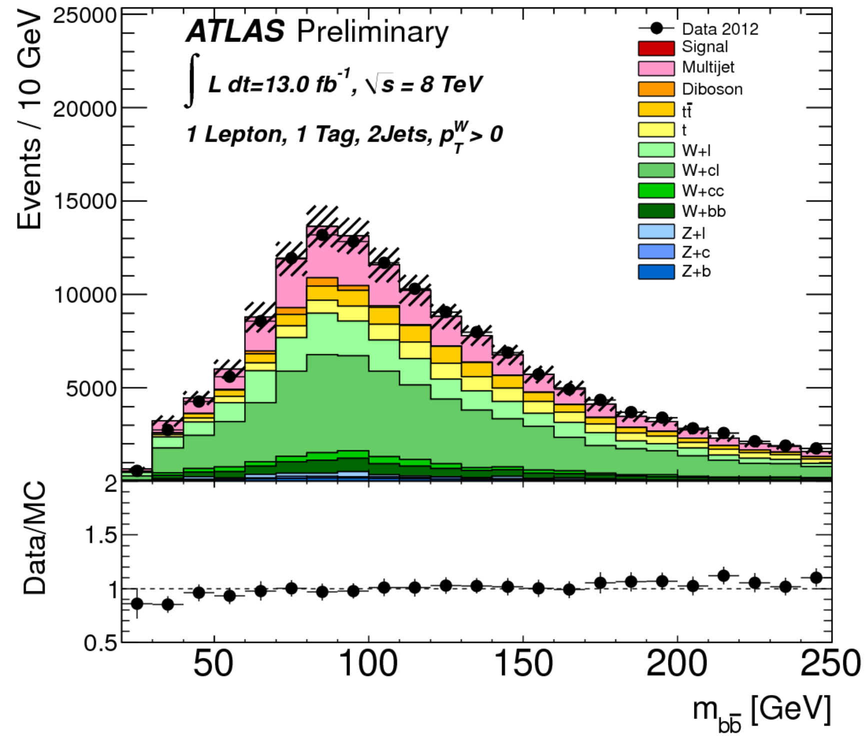
Backup

H→ bb: Flavour Fit Results



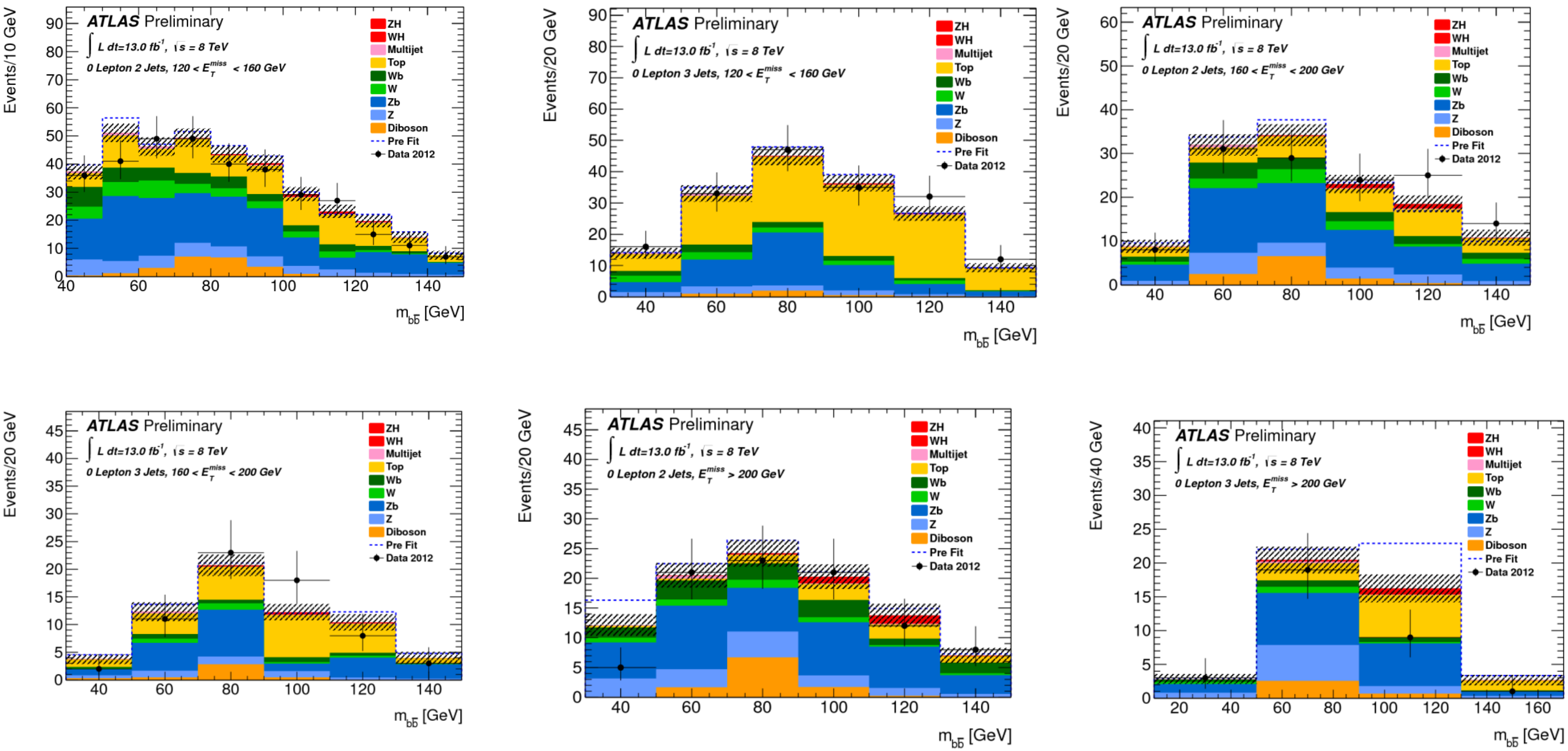
Pre b-tag : sum of 0-tag, 1-tag control region and 2-tag signal region

1-tag control region



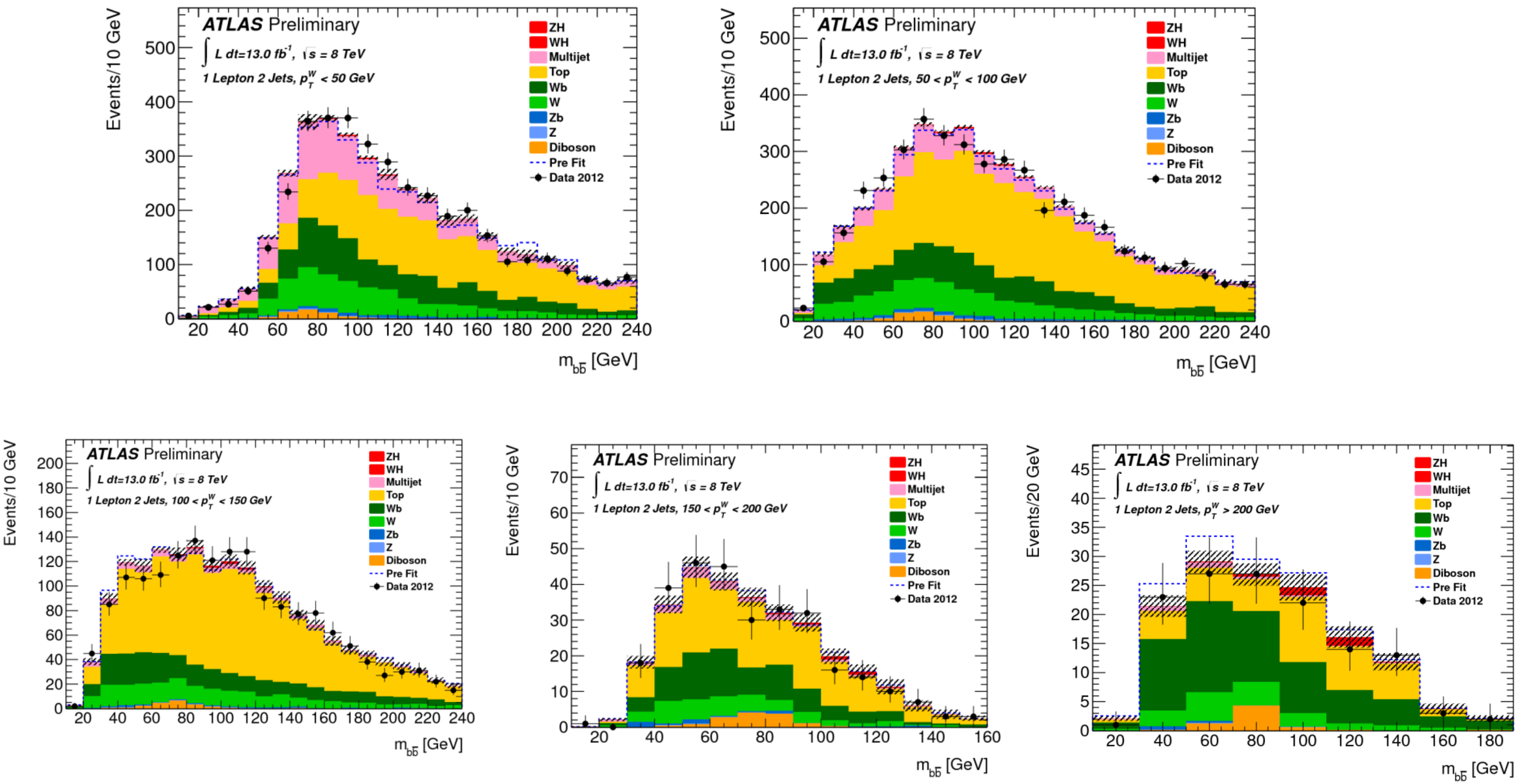
Backup

H → bb: m_{bb} distribution for the six categories of zero lepton analysis



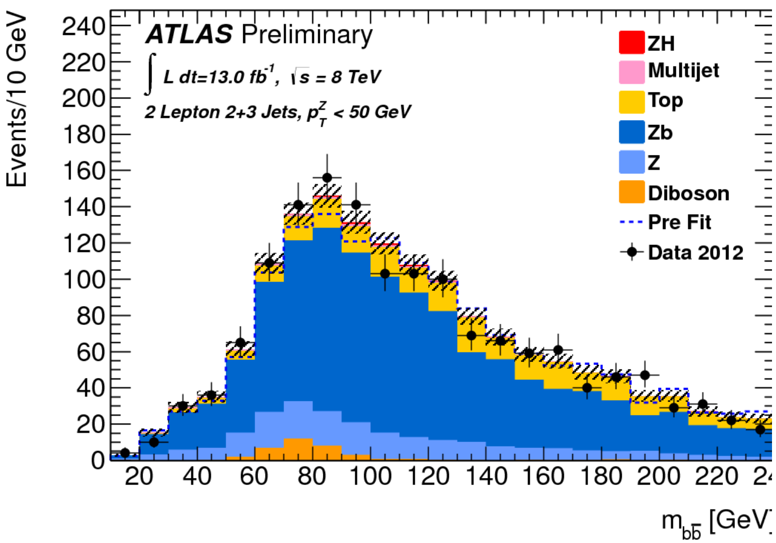
Backup

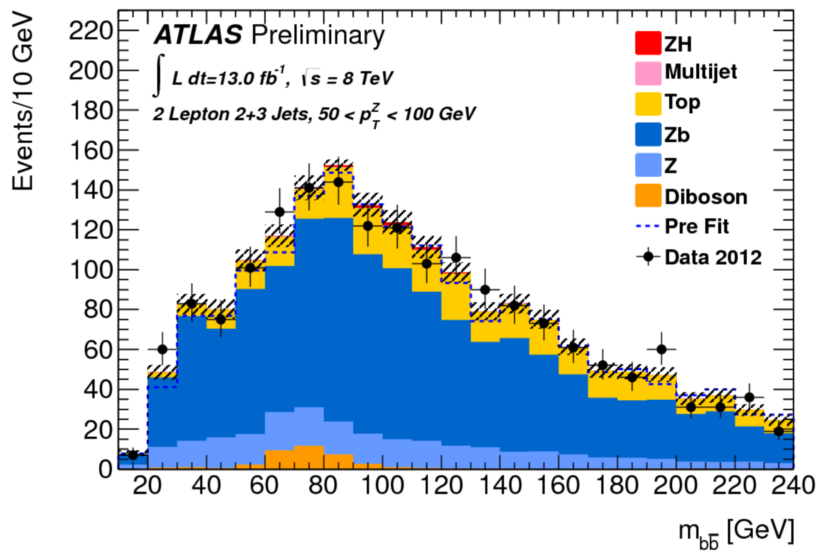
H→ bb: m_{bb} distribution for the five categories of one lepton analysis

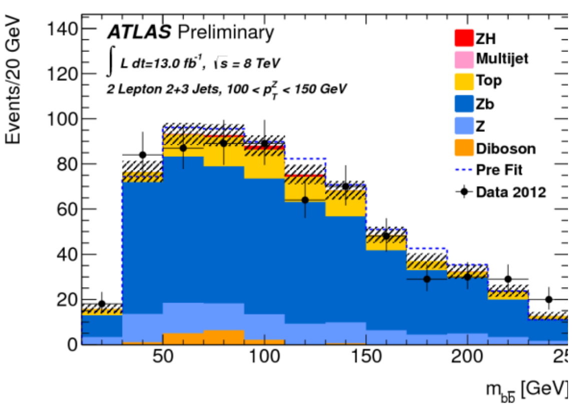


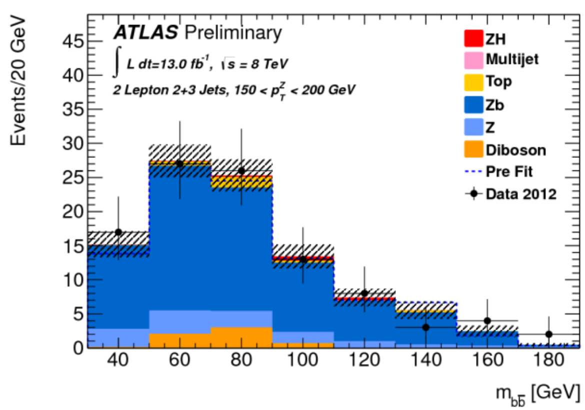
Backup

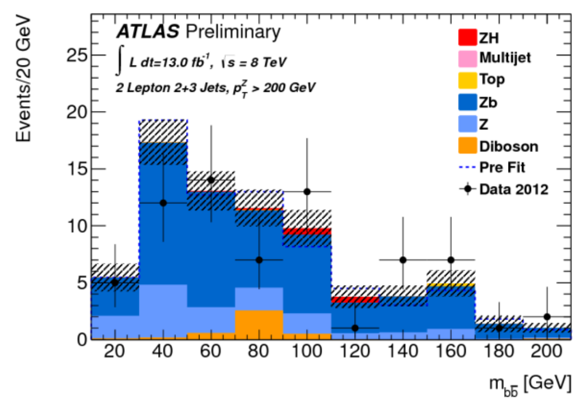
H→ bb: m_{bb} distribution for the five categories of 2 leptons analysis











Backup

τ_{had} identification

- Hadronic decays of τ leptons: one or three charged hadrons plus a neutrino and possibly neutral hadrons giving a collimated jet with few associated tracks

- The visible decay products are combined in τ_{had} candidates

- Jets for τ_{had} candidates are re-calibrated to account for the different calorimeter response to hadronic τ-decays w.r.t. hadronic jets

- Multivariate analysis based on Boosted Decision Tree (BDT) is performed to reject mis-identified τ_{had} jets (tracking and calorimeter information is used by BDT)

- Loose, medium and tight τ_{had} candidates are found with efficiencies of 60%, 50% and 30% respectively and jet mis-identification probability < 1%

- Selection of τ_{had} candidates: $|\eta| < 2.5$, $p_T > 20$ GeV, one or three associated tracks (with $p_T > 1$ GeV) within $\Delta R < 0.2$ around the τ_{had} direction and a total charge of ±1 computed from the associated tracks.

Backup

$H \rightarrow \tau\tau$: $m_{\tau\tau}$ reconstruction with Missing Mass Calculator (MMC)

- MMC is a more sophisticated version of the collinear approximation

- Main improvement : require that the relative orientations of the ν's and the other decay products are consistent with mass and kinematics of a τ decay

- This is achieved by maximasing a probability defined in the kinematically allowed phase space region

- This results in very high reconstruction efficiency (>99%) and 13-20% resolution in $m_{\tau\tau}$, depending on event topology and final state

- Collinear approximation (used for lep-lep 7 TeV data with at least 1 jet) : for high p_T τ's we can assume that the ν direction is along the visible decay products

- For lep-lep data at 7 TeV with 0-jets the effective mass $m_{\tau\tau}^{eff}$ (the invariant mass of the di-lepton and E_T^{miss} system) is used since the performance of the collinear approximation is not optimal when the τ-decay products are back-to-back in the transverse plane

Backup

H → ττ : Event Selection for lep-had channel

7 TeV		8 TeV	
VBF Category	Boosted Category	VBF Category	Boosted Category
▹ $p_T^{\tau_{\text{had-vis}}} > 30$ GeV	–	▹ $p_T^{\tau_{\text{had-vis}}} > 30$ GeV	▹ $p_T^{\tau_{\text{had-vis}}} > 30$ GeV
▹ $E_T^{\text{miss}} > 20$ GeV	▹ $E_T^{\text{miss}} > 20$ GeV	▹ $E_T^{\text{miss}} > 20$ GeV	▹ $E_T^{\text{miss}} > 20$ 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.	–
▹ $\eta_{j1} \times \eta_{j2} < 0$	–	▹ $\eta_{j1} \times \eta_{j2} < 0$	–
▹ $p_T^{\text{Total}} < 40$ GeV	–	▹ $p_T^{\text{Total}} < 30$ GeV	–
–	–	▹ $p_T^{\ell} > 26$ 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
▹ $E_T^{\text{miss}} > 20$ GeV	▹ $E_T^{\text{miss}} > 20$ GeV	▹ $E_T^{\text{miss}} > 20$ GeV	▹ $E_T^{\text{miss}} > 20$ 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
• $\Delta(\Delta R) < 0.6$	• $\Delta(\Delta R) < 0.5$	• $\Delta(\Delta R) < 0.6$	• $\Delta(\Delta R) < 0.5$
• $\sum \Delta\phi < 3.5$	• $\sum \Delta\phi < 3.5$	• $\sum \Delta\phi < 3.5$	• $\sum \Delta\phi < 3.5$
–	• $p_T^{\ell} - p_T^{\tau} < 0$	–	• $p_T^{\ell} - p_T^{\tau} < 0$

Backup

$H \rightarrow \tau\tau$: Examples of Event Yield for $\tau_\mu \tau_{had}$ channel

7 TeV

Process	Events	
	0-Jet	1-Jet
$gg \rightarrow H$ (125 GeV)	4.6 ± 0.2 ± 1.1	6.4 ± 0.2 ± 1.2
VBF H (125 GeV)	0.04 ± 0.00 ± 0.01	1.35 ± 0.03 ± 0.09
WH (125 GeV)	0.03 ± 0.01 ± 0.00	0.40 ± 0.03 ± 0.03
ZH (125 GeV)	0.01 ± 0.00 ± 0.00	0.26 ± 0.02 ± 0.02
$Z/\gamma^* \rightarrow \tau\tau$ embedded (OS-SS)	$(0.88 \pm 0.01 \pm 0.17)\times10^3$	$(1.20 \pm 0.02 \pm 0.17)\times10^3$
Diboson (OS-SS)	2.3 ± 0.3 ± 0.4	9.1 ± 1.2 ± 0.8
$Z/\gamma^* \rightarrow \ell\ell$ (OS-SS)	10 ± 3 ± 2	13 ± 3 ± 4
Top (OS-SS)	0.5 ± 0.2 ± 0.1	92 ± 3 ± 14
W boson + jets (OS-SS)	65 ± 11 ± 6	$(0.15 \pm 0.02 \pm 0.02)\times10^3$
Same sign data	60 ± 8 ± 3	$(0.31 \pm 0.02 \pm 0.02))\times10^3$
Total background	$(1.01 \pm 0.02 \pm 0.17)\times10^3$	$(1.78 \pm 0.03 \pm 0.18)\times10^3$
Observed data	958	1701

8 TeV

Process	Events	
	0-Jet	1-Jet
$gg \rightarrow H$ (125 GeV)	34.3 ± 0.9 ± 8.0	46 ± 1 ± 11
VBF H (125 GeV)	0.47 ± 0.06 ± 0.04	8.5 ± 0.3 ± 0.6
WH (125 GeV)	0.09 ± 0.04 ± 0.01	2.4 ± 0.2 ± 0.2
ZH (125 GeV)	0.11 ± 0.03 ± 0.01	1.3 ± 0.1 ± 0.1
$Z/\gamma^* \rightarrow \tau\tau$ (OS-SS)	$(7.13 \pm 0.04 \pm 0.48)\times10^3$	$(6.14 \pm 0.04 \pm 0.45)\times10^3$
Diboson (OS-SS)	10.5 ± 0.7 ± 0.9	30 ± 1 ± 3
$Z/\gamma^* \rightarrow \ell\ell$ (OS-SS)	$(0.10 \pm 0.02 \pm 0.02)\times10^3$	$(0.12 \pm 0.02 \pm 0.03)\times10^3$
Top (OS-SS)	10.4 ± 2.3 ± 0.6	$(1.03 \pm 0.03 \pm 0.05)\times10^3$
W boson + jets (OS-SS)	$(0.51 \pm 0.09 \pm 0.04)\times10^3$	$(1.0 \pm 0.1 \pm 0.14)\times10^3$
Same sign data	$(1.03 \pm 0.03 \pm 0.07)\times10^3$	$(3.27 \pm 0.06 \pm 0.24)\times10^3$
Total background	$(8.8 \pm 0.1 \pm 0.5)\times10^3$	$(11.6 \pm 0.1 \pm 0.5)\times10^3$
Observed data	8300	11373

Backup

H → ττ : Event Selection for had-had channel

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 $\tau_{\text{had-vis}}$ $p_T > 40$ GeV and sub-leading $\tau_{\text{had-vis}}$ $p_T > 25$ GeV, $\|\eta\| < 2.5$
	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_T^{miss} vector is not pointing in between the two taus, min $\left\{\Delta\phi(E_T^{\text{miss}}, \tau_1), \Delta\phi(E_T^{\text{miss}}, \tau_2)\right\} < 0.2\pi$
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^{miss} vector is not pointing in between the two taus, min $\left\{\Delta\phi(E_T^{\text{miss}}, \tau_1), \Delta\phi(E_T^{\text{miss}}, \tau_2)\right\} < 0.1\pi$.

Backup

❖Backgroud estimation for H $\rightarrow\tau\tau$ (lep-lep channel):

- Top contribution estimated from MC and corrected using data in top-enriched Control Region (CR)
- Fake lepton contribution obtained from data with a template method using a CR in which lepton isolation requirement is reversed (template from p_T distribution of the sub-leading lepton)
- Diboson contribution estimated from MC and validated in a 3-lepton CR enriched with WZ events

❖Backgroud estimation for H $\rightarrow\tau\tau$ (had-had channel):

- Data driven estimation of the dominant bck (Z $\rightarrow\tau\tau$ and multijet) both for normalisation and shape
- Two-dimensional template fit to track multiplicity distributions
- Template modelled by the simulation for Z $\rightarrow\tau\tau$ and from same-sign (SS) data for multijet

Backup

❖ **Backgroud estimation for H $\rightarrow\tau\tau$ (lep-had channel):**

- Bckg estimation (except VBF category) based on assumption that for multijet the shape of $m_{\tau\tau}$ in signal region is the same for opposite-sign (OS) and same-sign (SS) events after all kinematic cuts (except charge requirement)

- The number of SS events and the shape of $m_{\tau\tau}$ derived from CR obtained by inverting the OS requirement

- SS sample dominated by multijet but contain contribution from other bckg: for these bck OS-SS terms are required to cover any excess of OS components over SS components

- W+jets bckg normalised to data using bckg-enriched CR

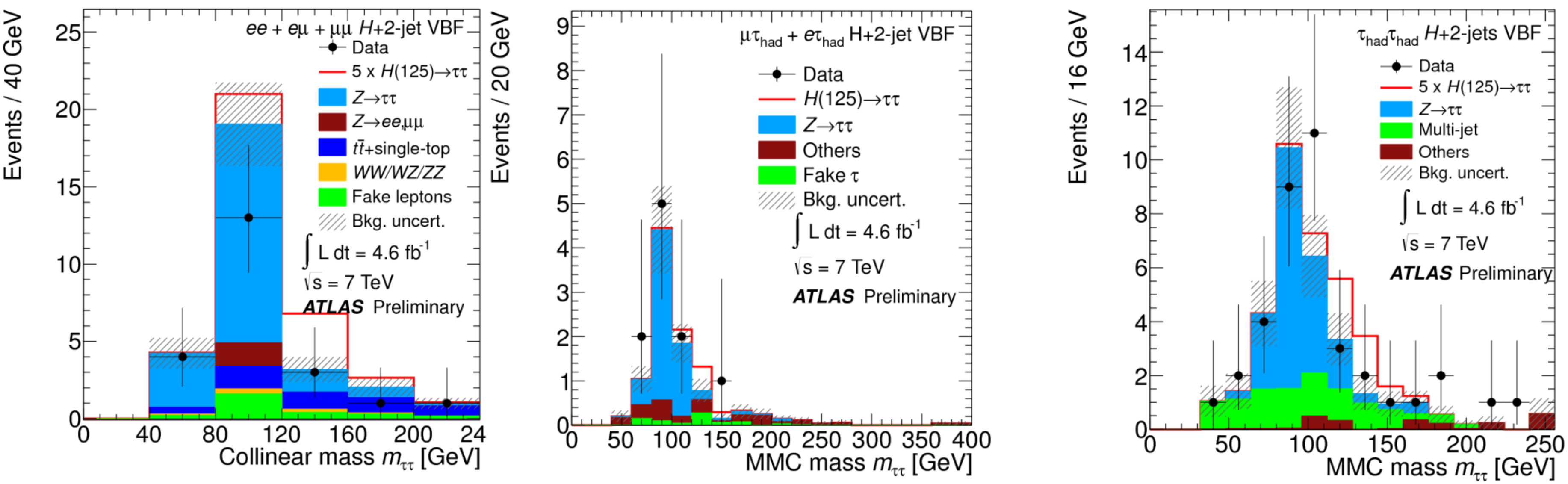
- For VBF category W+jet and multijet bckg estimated using a Fake Factor $F = N_{id} / N_{anti\text{-}id}$

Backup

H→ ττ: Results for VBF

- VBF category has the highest sensitivity
- Limited statistics but good S/B ratio
- In this slide: results for 7 TeV data

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



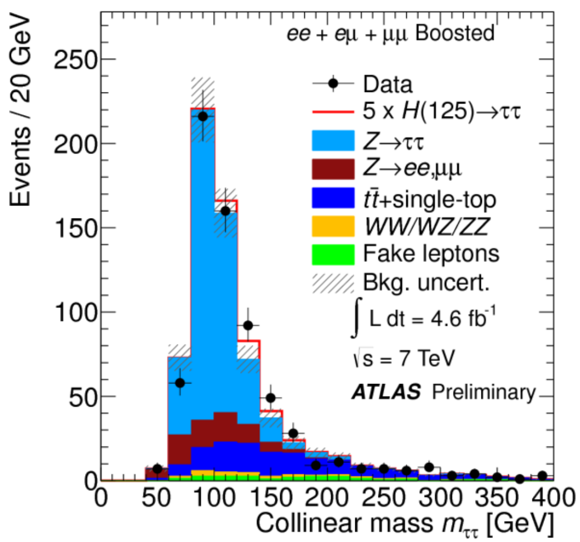
Backup

H →ττ: Results for Boosted

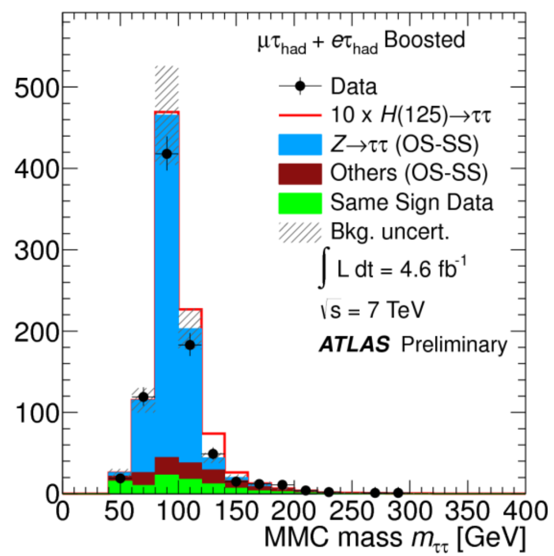
❖ Boosted category has the best sensitivity among non-VBF categories

❖ In this slide: results for 7 TeV data

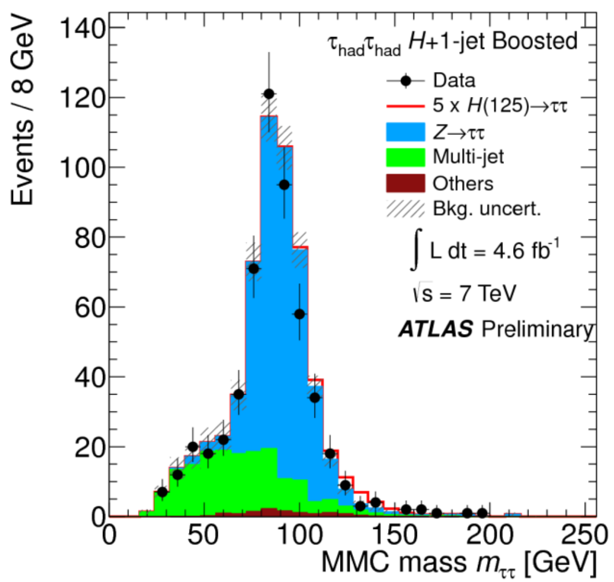
lep-lep



lep-had



had-had



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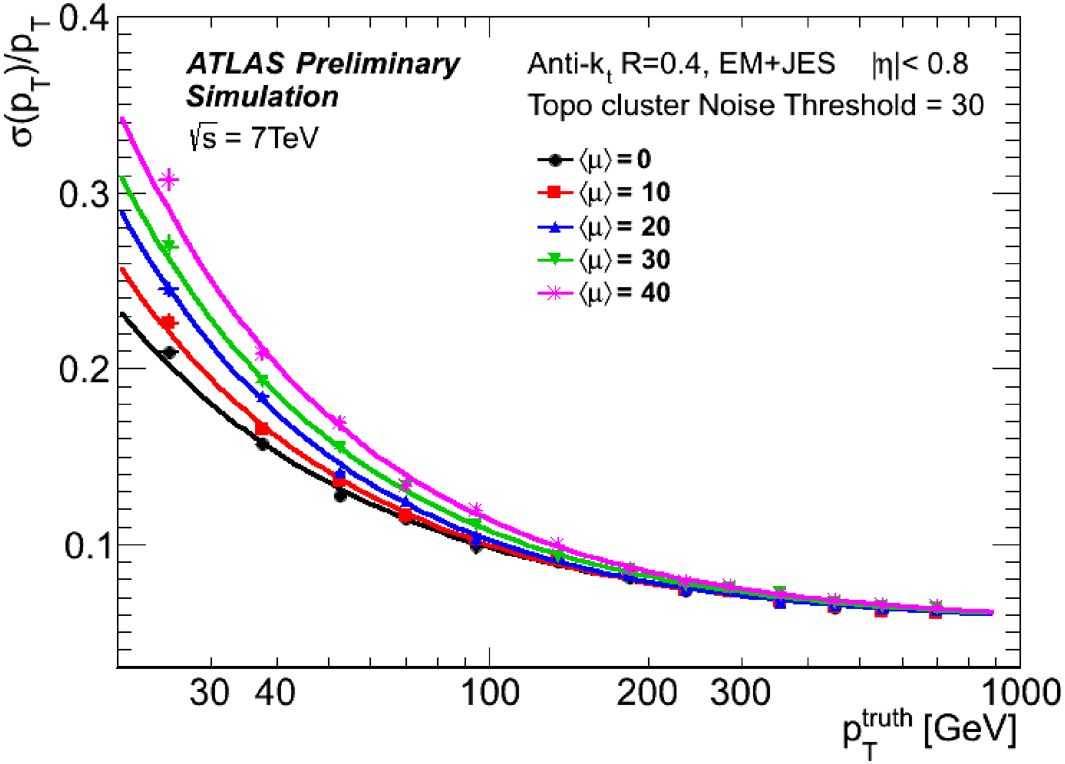
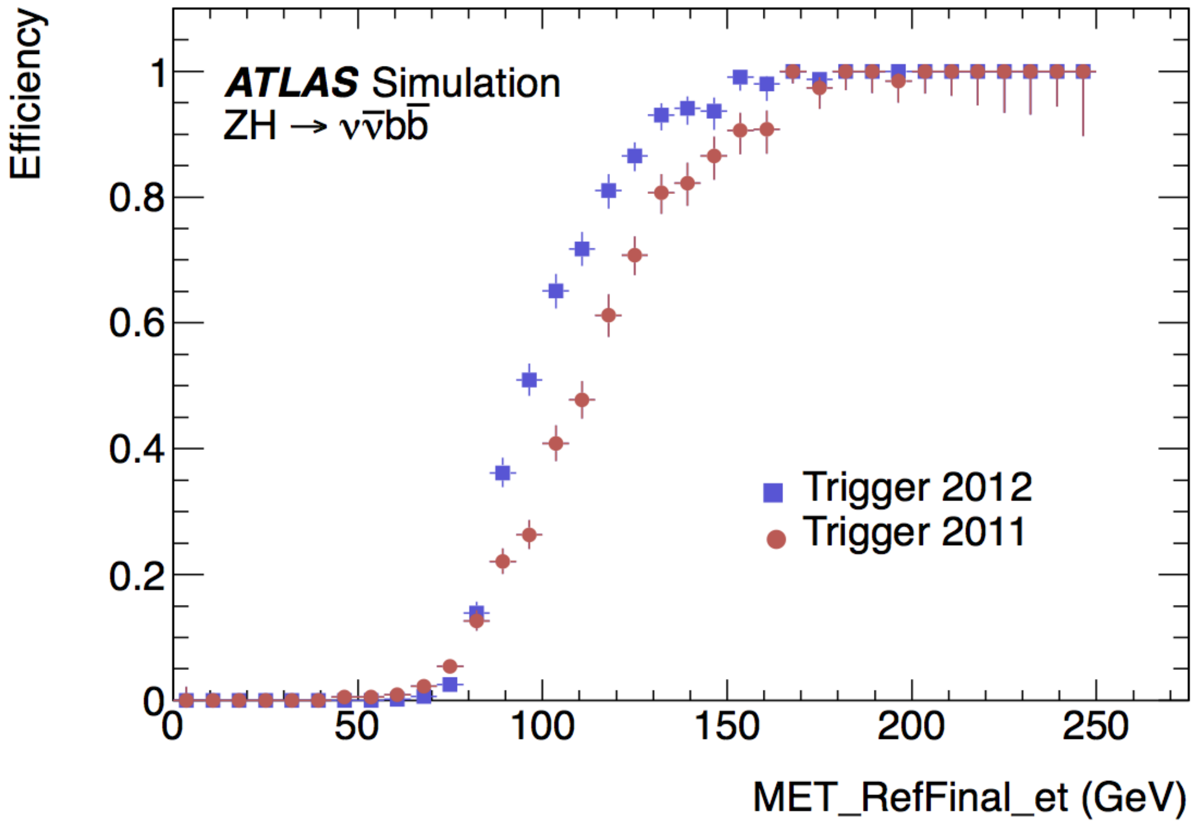


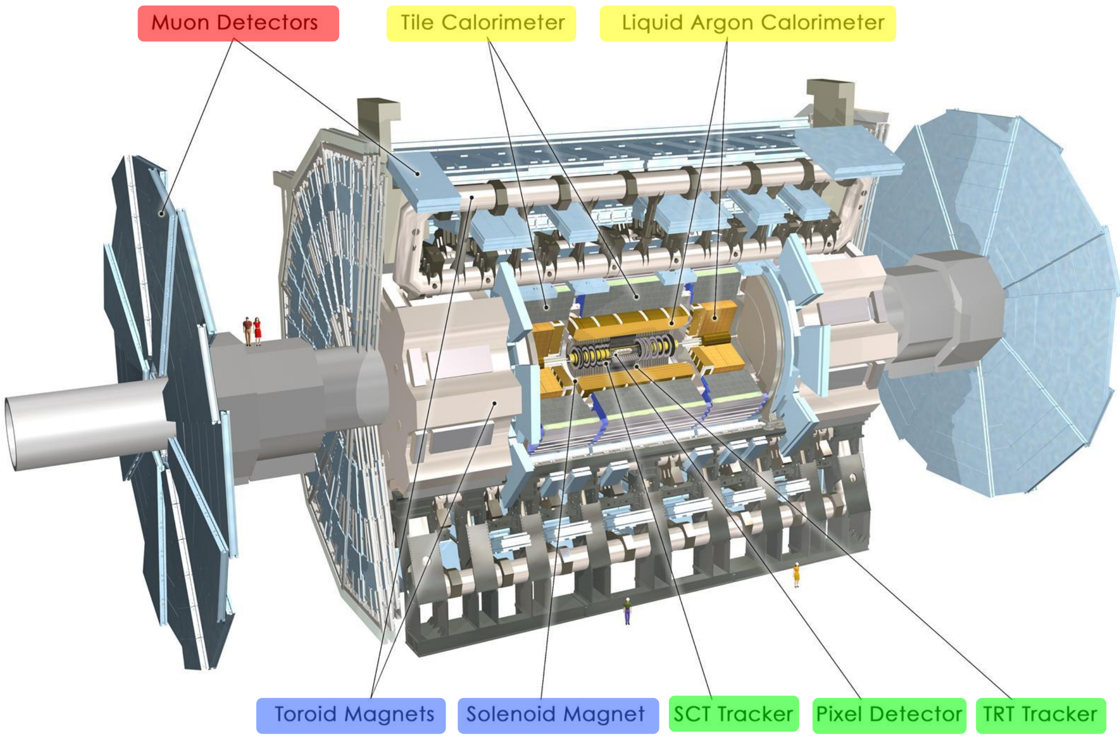
Jet energy resolution for samples with different values of <μ>, the mean number of pile-up interactions per bunch crossing.

Backup



The improvement in the turn-on curve for simulated pp → ZH → νν̄bb (using Pythia and m_H = 120 GeV) using either the lowest unprescaled trigger chain in 2011 (L1 XE50 → L2 xe55 noM → xe60 verytight noMu) or in 2012 (L1 XE40 BGRP7 → L2 xe45T → xe80T tclcw loose) are shown.

The ATLAS detector components



The Magnet system:
Four Superconducting magnets:
1 Central Solenoid
3 Air core Toroids

The Inner Detector

EM and hadronic Calorimeters

The Muon Spectrometer

Subdetector	Required resolution	η coverage Measurement	Trigger
Tracking	$\sigma_{p_T}/p_T = 0.05\% p_T \oplus 1\%$	± 2.5	
EM calorimetry	$\sigma_E/E = 10\%/\sqrt{E} \oplus 0.7\%$	± 3.2	± 2.5
Hadronic calorimetry (jets)			
Barrel and Endcap	$\sigma_E/E = 50\%/\sqrt{E} \oplus 3\%$	± 3.2	± 3.2
Forward	$\sigma_E/E = 100\%/\sqrt{E} \oplus 10\%$	$3.1 - 4.9$	$3.1 - 4.9$
Muon spectrometer	$\sigma_{p_T}/p_T = 10\%$ at $p_T = 1$ TeV	± 2.7	± 2.4