Searches for Standard Model Higgs to bb and $\tau\tau$ in ATLAS

Jike Wang (Academia Sinica)

On Behalf of the ATLAS Collaboration

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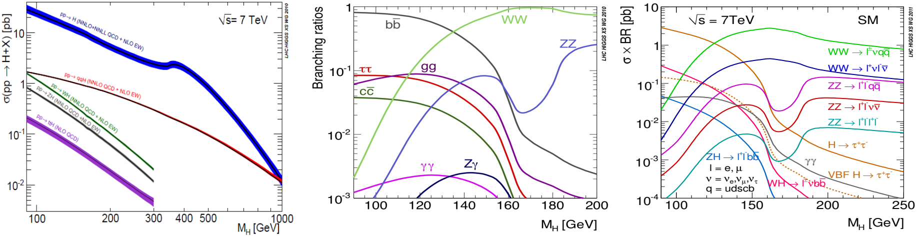
Higgs Production



$\mathbf{H \to bb}$:

- $H \to bb$ has the largest BR (at 125 GeV)
- Due to the huge backgrounds present in the dominant production process $gg \to H \to bb$, the analysis reported here is restricted to Higgs boson production in association with a vector boson (W/Z)
- The vector boson provides an additional final state signature, allowing for significant background suppression.

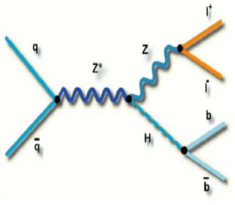
$\mathbf{H \to \tau\tau}$:

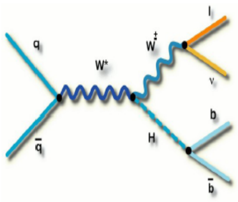
- $H \to \tau\tau$ has the largest $\sigma \times BR$ (at 125 GeV)
- The $H \to \tau\tau$ search covers all the Higgs production mechanisms (except $t\bar{t}H$): gluon gluon fusion, vector boson fusion and the VH associated production

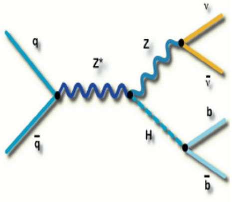
$\mathbf{H} \rightarrow \mathbf{bb}$

The results are based on 4.6-4.7 fb^{-1} of 2011 data collected by ATLAS at $\sqrt{s}$ = 7 TeV

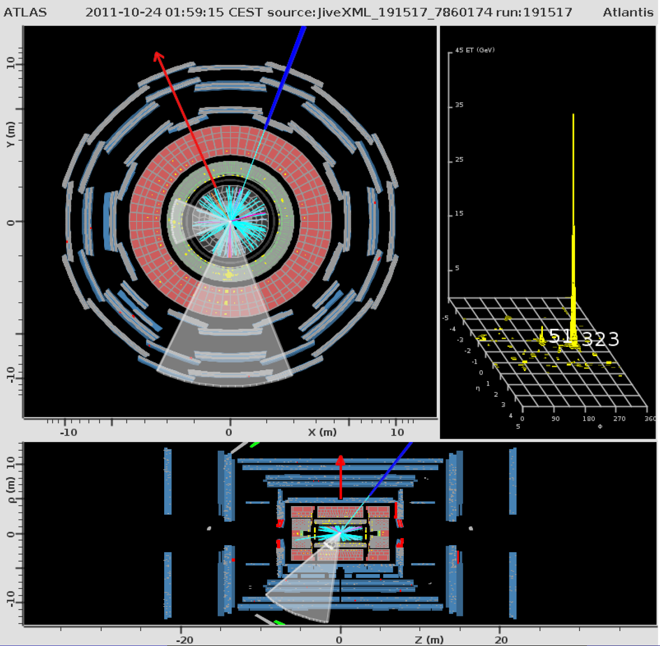
Three channels, 11 subchannels







H $\rightarrow$ bb (A $WH \rightarrow \ell\nu b\bar{b}$ Candidate)



$b-$Jet Reconstruction in ATLAS

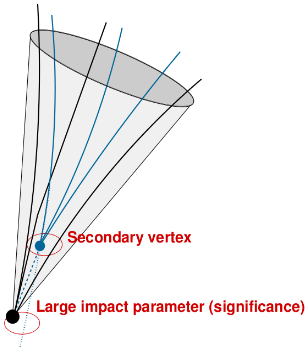
Introduction:

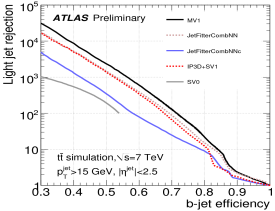
- b-tagging is an extremely important tool to separate a heavy flavor signal (top, Higgs, SUSY, etc.) from backgrounds.
- Identify decays of b-hadrons in jets by presence of:
  - tracks with large impact parameter (IP) and IP significance
  - secondary decay vertex

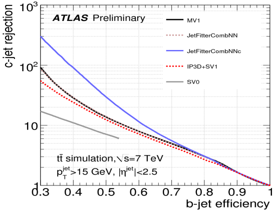
Algorithms:

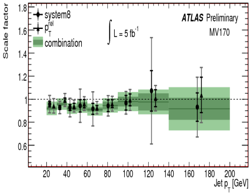
- IP-based algorithms: use PDFs in transverse and longitudinal IP significance.
- Secondary vertex-based algorithms:
  - SV1 reconstructs inclusive SV
  - JetFitter reconstructs full weak ($b \to c \to X$) decay chain
- Combinations (NN based): MV1 (JetFitterCombNN+IP3D+SV)

$H \to bb$ use: MV1 ϵ^{b-jet}~70%, ϵ^{c-jet}~20%, ϵ^{l-jet}<1%









Channels and Selections

Three channels considered: $WH \to \ell\nu b\bar{b}$, $ZH \to \ell^+\ell^- b\bar{b}$, $ZH \to \nu\bar{\nu}b\bar{b}$

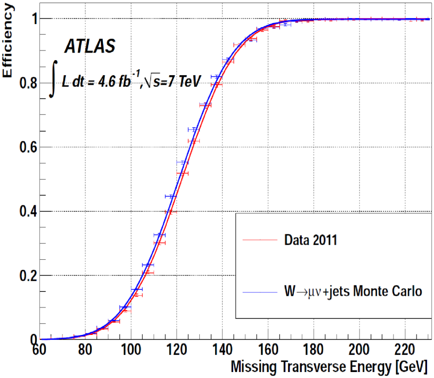
- Jets are reconstructed from energy clusters in the calorimeter using the anti-kt algorithm with R=0.4. Pileup corrections on jet energies are applied.
- Require at least 75% of the summed transverse momentum of inner detector tracks associated with the jet are compatible with originating from the primary vertex.
- $E_{\mathrm{T}}^{\mathrm{miss}}$: vector sum of the transverse momentum vectors associated with clusters of energy reconstructed in the calorimeters with $|\eta| <$4.9
- $p_{\mathrm{T}}^{\mathrm{miss}}$: used in $ZH \to \nu\bar{\nu}b\bar{b}$ only, is calculated from the vector sum of the transverse momenta of inner detector tracks associated with the primary vertex

$\mathbf{WH \to \ell\nu b\bar{b}}$	$\mathbf{ZH \to \ell^+\ell^- b\bar{b}}$	$\mathbf{ZH \to \nu\bar{\nu}b\bar{b}}$
p_{T}^{b-jet1} >45 GeV, p_{T}^{b-jet2} >25 GeV; $\Delta R_{b-jet1,b-jet2}$ >0.7 for p_{T}^{V} <200 GeV		
single-lepton trigger	single-lepton + di-electron trigger	$E_{\mathrm{T}}^{\mathrm{miss}}$ trigger with 70 GeV threshold
p_{T}^{l} >25 GeV, 1 lepton	p_{T}^{l} >20 GeV, 2 leptons	p_{T}^{l} >10 GeV, 0 lepton
$E_{\mathrm{T}}^{\mathrm{miss}}$ >25 GeV	$E_{\mathrm{T}}^{\mathrm{miss}}$ <50 GeV	$E_{\mathrm{T}}^{\mathrm{miss}}$ >120 GeV
m_T^W >40 GeV	83 GeV< m_{ll} <99 GeV	-
2 good jets, 2 b-jets	2 or 3 good jets, 2 b-jets	2 good jets, 2 b-jets
loose jets/leptons veto	-	-

Triggers

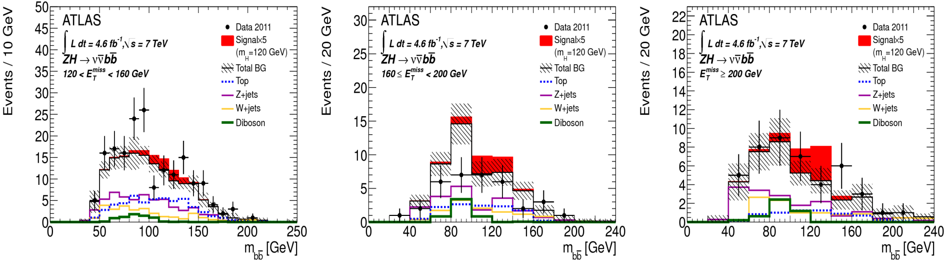
- **The lepton trigger:**
  - The efficiency relative to the offline selection, is close to 100% for $ZH \to e^+e^-bb$ and $WH \to e\nu bb$
  - It is around 95% for the $ZH \to \mu^+\mu^-bb$ channel and 90% for the $WH \to \mu\nu bb$ channel, due to the lower azimuthal angular coverage of the muon trigger chambers with respect to the precision tracking chambers.

- **The $E_{\mathrm{T}}^{\mathrm{miss}}$ trigger:**
  - Has a threshold of 70 GeV and an efficiency above 50% for $E_{\mathrm{T}}^{\mathrm{miss}} > 120$ GeV. The efficiency exceeds 99% for $E_{\mathrm{T}}^{\mathrm{miss}} > 170$ GeV
  - The efficiency curve is measured in a sample of $W \to \mu\nu$ + jet events collected using muon triggers
  - The simulation predicts the trigger efficiency to be 5% higher than that in data for 120 GeV $< E_{\mathrm{T}}^{\mathrm{miss}} <$160 GeV and agrees for $E_{\mathrm{T}}^{\mathrm{miss}} > 160$ GeV
  - A correction factor of 0.95 ± 0.01 is therefore applied to the MC in the lower $E_{\mathrm{T}}^{\mathrm{miss}}$ region, and no trigger efficiency correction is applied elsewhere



To maximize the searching sensitivity, all three channels are further divided into several p_T^W or p_T^Z bins (Unit: GeV), then in total 11 sub-channels:

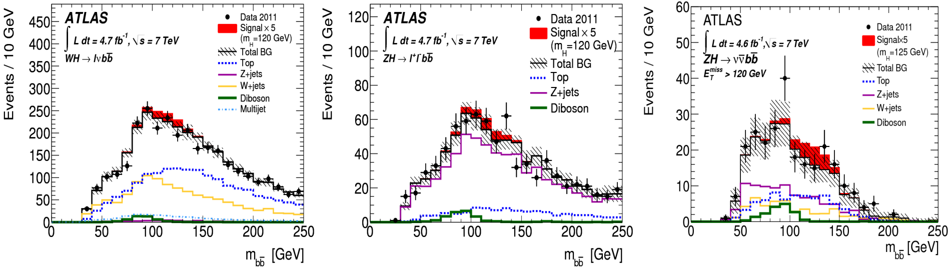
- $WH \to \ell\nu b\bar{b}$ and $ZH \to \ell^+\ell^- b\bar{b}$: 4 p_T^W/p_T^Z bins [0-50, 50-100, 100-200, $>$200]
- $ZH \to \nu\bar{\nu}b\bar{b}$: 3 E_T^{miss} bins [120-160, 160-200, $>$200]
  For $ZH \to \nu\bar{\nu}b\bar{b}$, different cut-optimizations have been done for different E_T^{miss} bins, respectively. The final optimized cuts based on: $\Delta R_{b1,b2}$, $\Delta\phi(V,bb)$, $min(\Delta\phi(E_T^{miss}, jets))$ and $\Delta\phi(E_T^{miss}, p_T^{miss})$



(Above are m_{bb} of the three E_T^{miss} bins in $ZH \to \nu\bar{\nu}b\bar{b}$ channel)

Main Backgrounds

$WH \to \ell\nu b\bar{b}$: Top and $W(lv)+jets$; $ZH \to \ell^+\ell^- b\bar{b}$: $Z(ll)+jets$ and Top; $ZH \to \nu\bar{\nu}b\bar{b}$: $Z(vv)+jets$, Top and $W(lv)+jets$

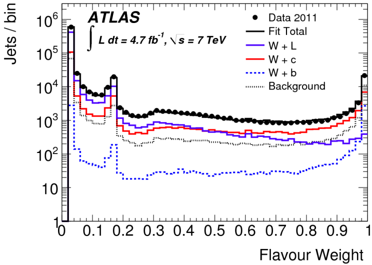


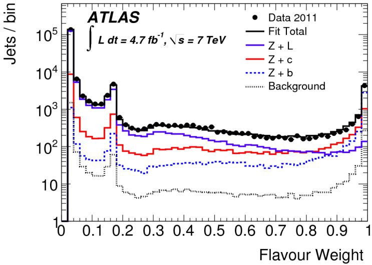
The BG m_{bb} shape from MC, the normalization from simultaneously fitting to data (SR regions excluded)

- $WH \to \ell\nu b\bar{b}$: Top and W+jet scale factors from m_{bb} sidebands + WH top control region
- $ZH \to \ell^+\ell^- b\bar{b}$: Top and Z+jet scale factors from m_{bb} sidebands + ZH top control region
- $ZH \to \nu\bar{\nu}b\bar{b}$: The scale factors are propagated from the other two channels and then are carefully checked in many dedicated control regions

$W/Z + jets$ Backgrounds: Flavor Composition Determination

- The flavor composition of the W/Z+jet samples: $W/Z + b$, $W/Z + c$ and $W/Z + l$
- The relative normalizations of the three components are adjusted by fitting the distribution of the b-tagging weight ω found in MC simulation to the distribution found in control data samples dominated by W/Z+jet events.
- The relative normalizations are determined before the overall normalizations.



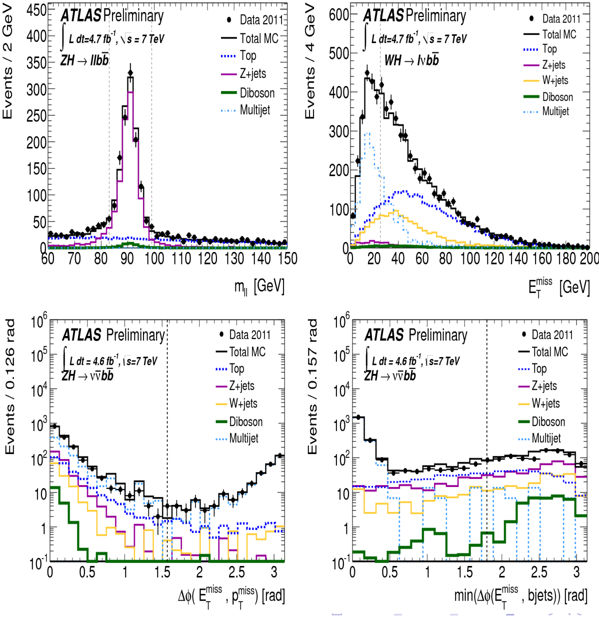


The b-tagging weight for both jets without applying the b-tagging cut for the $WH \to \ell\nu b\bar{b}$ (left) and $ZH \to \ell^+\ell^- b\bar{b}$ (right). The full line shows the result of the fit with the normalization of the c and l MC templates treated as free.

Multi-jet background

- $ZH \to \ell^+\ell^- b\bar{b}$ ($WH \to \ell\nu b\bar{b}$): **multi-jet templates from looser lepton ID (anti-isolation), then estimate based on fitting to m_{ll} (E_T^{miss})**

- $ZH \to \nu\bar{\nu}b\bar{b}$: **ABCD method. Based on two un-correlated variables:** $min(\Delta\phi(E_T^{\text{miss}}, jets))$ **and** $\Delta\phi(E_T^{\text{miss}}, p_T^{\text{miss}})$



Main Background Uncertainties

bin	$ZH \to \ell^+\ell^- bb$ p_T^V [GeV] 0-50	50-100	100-200	>200	$WH \to \ell\nu bb$ p_T^V [GeV] 0-50	50-100	100-200	>200	$ZH \to \nu\bar{\nu}bb$ p_T^V [GeV] 120-160	160-200	>200
Components of the relative systematic uncertainties of the background [%]											
b-tag eff	1.4	1.0	0.3	4.8	0.9	1.3	0.9	7.2	4.1	4.2	5.5
BG norm	3.6	3.4	3.6	3.8	2.7	1.8	1.8	4.5	2.7	2.2	3.2
jets/E_T^{miss}	2.1	1.2	2.7	5.1	1.5	1.4	2.1	9.5	7.7	8.2	12.1
leptons	0.2	0.3	1.1	3.4	0.1	0.2	0.2	1.7	0.0	0.0	0.0
luminosity	0.2	0.1	0.2	0.4	0.1	0.1	0.1	0.2	0.2	0.5	0.7
pileup	0.9	1.6	0.5	1.3	0.1	0.2	0.8	0.5	1.6	2.5	3.0
theory	5.2	1.3	4.7	14.9	2.2	0.3	1.6	14.8	2.9	4.0	7.7
total BG	6.9	4.3	6.6	17.3	3.9	2.7	3.4	19.6	9.7	10.6	16.0

- **B-tagging efficiency: 1$\sim$7%**
  - The overall normalization uncertainty cancels out when fitting BGs to data, but the effect of distortions on m_{bb} has been carefully treated
- **Background normalization (statistical error from the fitting): 2$\sim$5%**
- **Jet energy scale,resolution and E_T^{miss}: 2$\sim$12%**
- **Theory uncertainty: 1$\sim$15%**
  - Mainly from m_{bb} and p_T^W/p_T^Z modeling in W/Z+jets

Total background uncertainty up to 20%; the highest p_T^W/p_T^Z bins have the best sensitivity, but have the biggest uncertainties as well

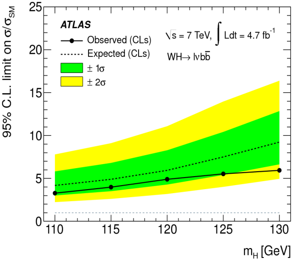
Main Signal Uncertainties

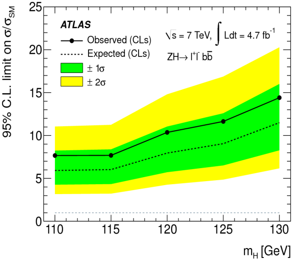
bin	$ZH \to \ell^+\ell^- bb$ p_T^V [GeV] 0-50	50-100	100-200	>200	$WH \to \ell\nu bb$ p_T^V [GeV] 0-50	50-100	100-200	>200	$ZH \to \nu\bar{\nu}bb$ p_T^V [GeV] 120-160	160-200	>200
Components of the relative systematic uncertainties of the signal [%]											
b-tag eff	6.4	6.4	7.0	13.7	6.4	6.4	7.0	12.1	7.1	8.2	9.2
jets/E_T^{miss}	4.9	3.2	3.5	5.5	5.8	4.6	3.7	3.3	7.3	5.1	6.3
leptons	0.9	1.2	1.7	2.6	3.0	3.0	3.0	3.2	0.0	0.0	0.0
luminosity	3.9	3.9	3.9	3.9	3.9	3.9	3.9	3.9	3.9	3.9	3.9
pileup	0.5	1.1	1.8	2.2	1.2	0.3	0.3	1.6	0.2	0.2	0.0
theory	4.6	3.6	3.3	5.3	4.4	4.7	5.0	8.0	3.3	3.3	5.6
total signal	10.1	9.1	9.6	16.5	11.4	10.8	11.0	16.0	11.8	11.4	13.4

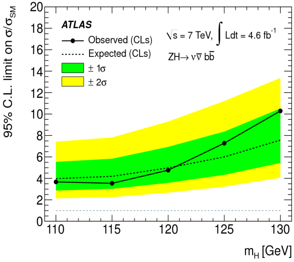
- **B-tagging efficiency: 6∼14%**
- **Jet energy scale, resolution and E_T^{miss}: 3∼7%**
- **Theory uncertainty: 3∼8%**
  - EW NLO corrections are now applied differentially in p_T^W/p_T^Z in all three analyses for the WH and ZH signals
  - inclusive uncertainties (on the overall cross-section)
  - differential uncertainties (mainly from rejecting events with three or more jets)

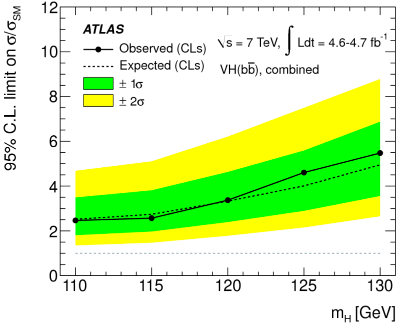
Total signal uncertainty: 9∼17%

$\mathrm{H} \to \mathrm{bb}$ Final Limits









- The observed (expected) upper limits (at the 95% confidence level) on the cross section times the branching ratio are **between 2.5 (2.5) and 5.5 (4.9)** times the SM prediction, in the mass range 110-130 GeV.
- $WH \to \ell\nu b\bar{b}$ and $ZH \to \nu\bar{\nu}b\bar{b}$ are the most sensitive channels

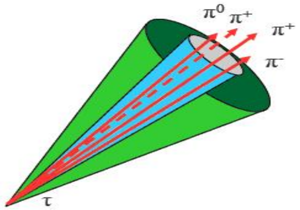
$\mathbf{H} \rightarrow \tau\tau$

The results are based on 4.7 fb^{-1} of 2011 data collected by ATLAS at $\sqrt{s}$ = 7 TeV

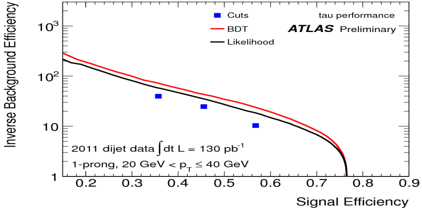
Three channels, 12 subchannels

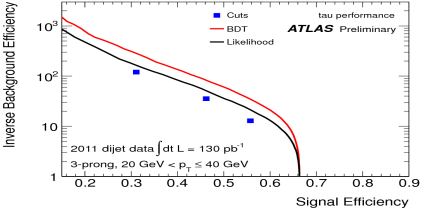
$\mathbf{H} \rightarrow \tau_{\mathbf{lep}}\tau_{\mathbf{lep}}$ 12.4%	$\mathbf{H} \rightarrow \tau_{\mathbf{lep}}\tau_{\mathbf{had}}$ 45.6%	$\mathbf{H} \rightarrow \tau_{\mathbf{had}}\tau_{\mathbf{had}}$ 42.0%

Phenomenology of tau decays		
leptonic 35.2%	1 prong 49.5%	3 prong 15.2%
$\tau^- \rightarrow e^- \bar{\nu}_e \nu_\tau$ ...	$\tau^- \rightarrow \pi^- \pi^0 \nu_\tau$ ...	$\tau^- \rightarrow \pi^- \pi^- \pi^+ \nu_\tau$ ...



- τ_{had} are characterized by the presence of one or three charged hadrons accompanied by a ν and possibly neutral hadrons.
- Results in a collimated shower profile in the calorimeters and only a few nearby tracks. The visible decay products are combined into candidates.
- The rejection of jets is performed by a Boosted Decision Tree that uses both tracking and calorimeter information.
- The identification is optimized to be 50% efficient while the misidentification probability is below 1%.

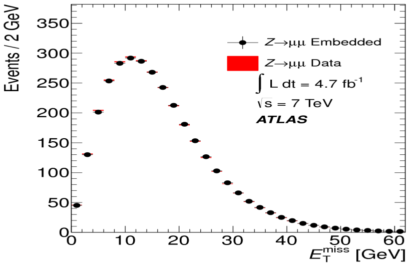


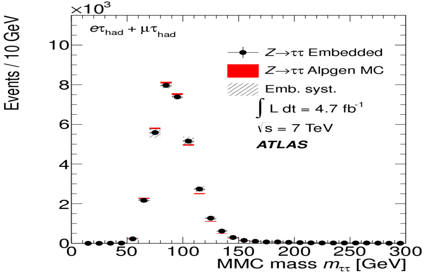


Three mass reconstruction methods:

- **effective mass**: $m_{eff} = (p_l^+ + p_l^- + E_{\mathrm{T}}^{\mathrm{miss}})^2$ (used in $H \rightarrow \tau_{lep}\tau_{lep}$+0-jet)
- **collinear mass**: $m_{\tau\tau} = \frac{m_{ll}/m_{hh}}{\sqrt{x_1 \cdot x_2}}$ (used in $H \rightarrow \tau_{lep}\tau_{lep}$+$\geq 1$ jets, $H \rightarrow \tau_{had}\tau_{had}$)
- **MMC (Missing Mass Calculator)**: use measured momentum, $E_{\mathrm{T}}^{\mathrm{miss}}$ and simulated distributions of the opening angles between visible and missing momentum

$Z \rightarrow \tau\tau$ is the main BG in all the channels. This BG is modeled in a data-driven way. Muons in $Z \rightarrow \mu\mu$ data events are replaced with simulated τ decay from TAULA to simulate the shape of this BG, which are then normalized to MC predictions. Below are two validation plots:



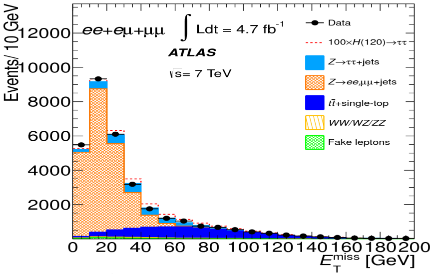


Four subchannels. The main BGs are: $Z \rightarrow \tau\tau$ and fake-leptons for the 0-jet channel; $Z \rightarrow \tau\tau$ and Top for the other jet channels.

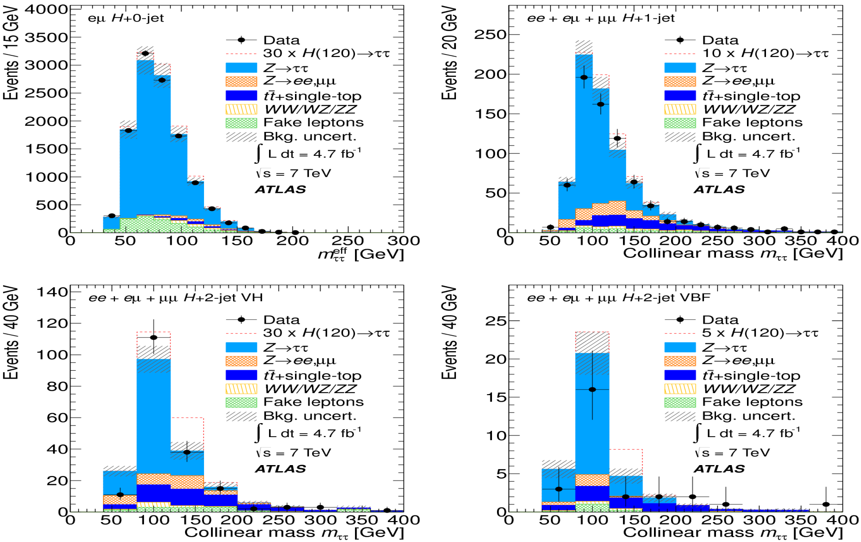
H + 0-jet	H + 1-jet	H + 2-jet VH	H + 2-jet VBF
30 GeV$< m_{e\mu} <$100 GeV, 30 GeV$< m_{ee,\mu\mu} <$70 GeV; Single lepton and di-lepton trigger			
$e\mu$, $\Delta\phi_{e\mu}$ >2.5, $H_T^l = p_T^{l1} + p_T^{l2} + E_T^{miss}$ <120 GeV	$E_T^{miss} >$ 20(40) GeV for $e\mu$, $(ee,\mu\mu)$, $0.5 < \Delta\phi_{ll} < 2.5$, $0 < x_1, x_2 < 1$		
no p_T >40 GeV jet	$\geq$ 1jet with p_T >40 GeV no bjet with p_T >25 GeV $M_{\tau\tau j} > 225$ GeV	p_T >40(25) GeV no bjet with p_T >25 GeV $\Delta\eta_{jj} < 2.0$ $M_{jj} < 120$ GeV	$\geq$ 1jet with p_T >40 GeV no bjet with p_T >25 GeV $\Delta\eta_{jj} > 3.0$ $M_{jj} > 350$ GeV

Backgroud estimation:

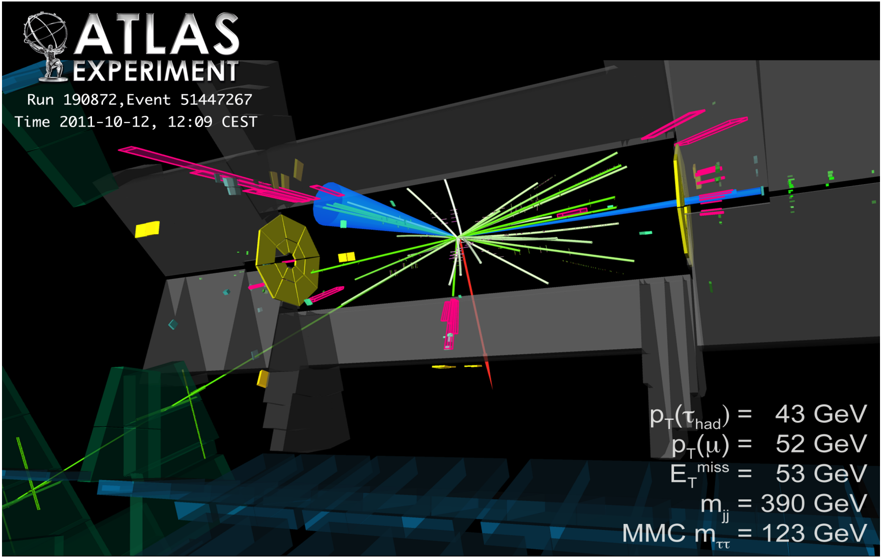
- $Z \rightarrow \tau\tau$ BG: τ embedded $Z \rightarrow \mu\mu$ data
- Top: shape from MC, normalization from control regions (CR) by inverting H_T^l for the H+0-jet; by inverting the b-jet selection for the H+1/2-jet
- Fake-leptons (not originate from the decay of a τ or the leptonic decay of a W/Z): normalization and shape are obtained from data using a CR in which the lepton isolation requirement is reversed, from fitting of the p_T distribution of the sub-leading lepton



The E_T^{miss} plot shows data and MC agreement



Channels	H + 0-jet	H + 1-jet	H + 2-jet VH	H + 2-jet VBF
Signal Composition (ggH:VBF:VH %)	95:2:3	72:21:7	56:7:37	19:80:1

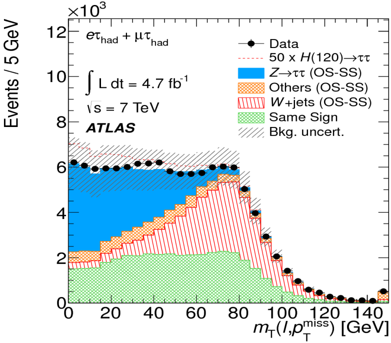

ATLAS EXPERIMENT
Run 190872,Event 51447267
Time 2011-10-12, 12:09 CEST
$p_T(\tau_{had})$ = 43 GeV
$p_T(\mu)$ = 52 GeV
E_T^{miss} = 53 GeV
m_{jj} = 390 GeV
MMC $m_{\tau\tau}$ = 123 GeV

Four subchannels. The main BGs are: $Z \to \tau\tau$ and the Same-Sign

H + 0-jet		**H + 1-jet**	**H + 2-jet VBF**
The single electron (muon) trigger			
$E_{\mathrm{T}}^{\mathrm{miss}}$ <20 GeV	$E_{\mathrm{T}}^{\mathrm{miss}}$ >20 GeV	$E_{\mathrm{T}}^{\mathrm{miss}}$ >20 GeV	$E_{\mathrm{T}}^{\mathrm{miss}}$ >20 GeV
$(e\mu)$ separated no p_{T} >25 GeV jet		$(e\mu)$ separated $\geq$ 1jet with p_{T} >25 GeV not VBF	$(e \oplus \mu)$ combined 2 jets, p_{T} >25 GeV $\Delta\eta_{jj}$ >3.0, m_{jj} >300 GeV

Define: $m_T = \sqrt{2 \cdot p_{\mathrm{T}}^{l} E_{\mathrm{T}}^{\mathrm{miss}}(1 - cos\Delta\phi)}$

Signal Region: m_T <30 GeV

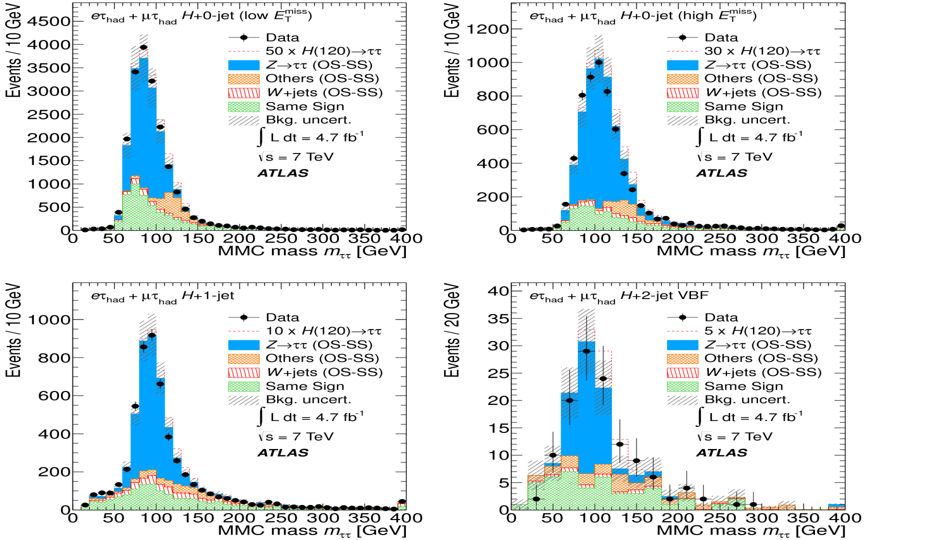


BG modeling:

$$n_{OS}^{bkg} = n_{SS}^{all} + n_{OS-SS}^{W+jets} + n_{OS-SS}^{Z\to\tau\tau} + n_{OS-SS}^{other}$$

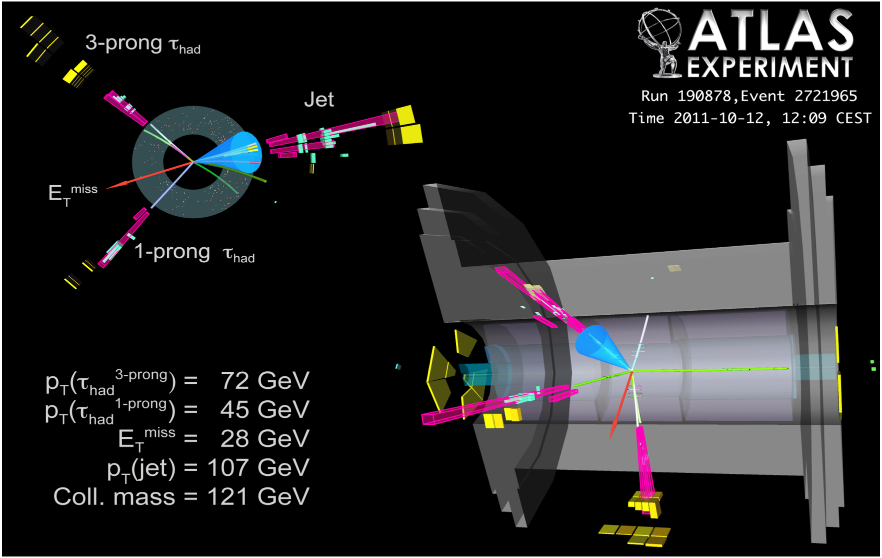
- Same Sign (SS): applying the signal region selections, but requiring that the light lepton and the τ_{had} candidate have the same charge
- n_{OS-SS}^{W+jets}: from CR with m_T >50 GeV
- $n_{OS-SS}^{Z\to\tau\tau}$: from the τ-embedded $Z \to \mu\mu$ sample in data

$H \rightarrow \tau_{lep}\tau_{had}$



Channels	H + 0-jet (low E_T^{miss})	H + 0-jet (high E_T^{miss})	H + 1-jet	H + 2-jet VBF
Signal Composition (ggH:VBF:VH %)	98:1:1	98:1:1	76:14:10	29:70:1

$H \to \tau_{had}\tau_{had}$



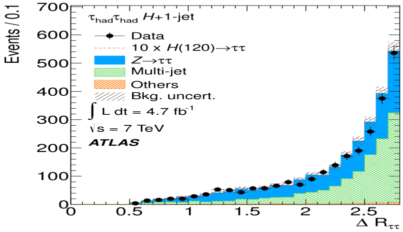
Only a single H + 1-jet category is defined. The dominant BGs are $Z \rightarrow \tau\tau$ and multi-jet

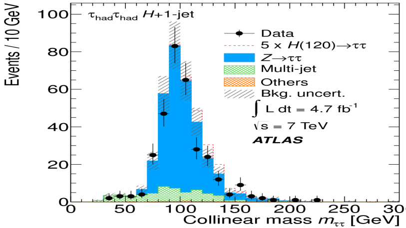
Signal region selections:

- Pass double-hadronic τ trigger (the thresholds are 29GeV and 20GeV respectively)
- Charged light lepton veto. Two identified opposite charge τ_{had} candidates with p_T >35 GeV and p_T >25 GeV. $0 < x_1, x_2 < 1$
- $E_T^{miss} > 20$ GeV and the 1-jet p_T >40 GeV
- $\Delta R_{\tau,\tau}$ <2.2 and $m_{\tau\tau j}$ >225 GeV

Background estimation:

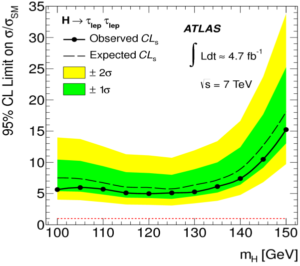
- The data-driven control sample: two τ_{had} that pass the hadronic selections and $0 < x_1, x_2 < 1$ and $\Delta R_{\tau,\tau}$ <2.8
- $m_{\tau\tau}$ <100 GeV, to avoid the signal contamination
- The $Z \rightarrow \tau\tau$ and multi-jet contribution is estimated by the two-dimensional track multiplicity fitting technique.
- The tracks associated to the τ_{had} candidates are counted in the cone defined by $\Delta R < 0.6$

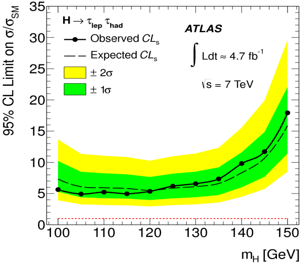


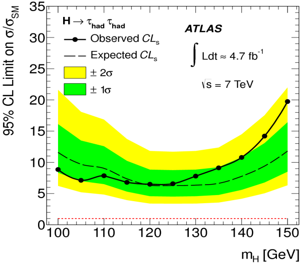


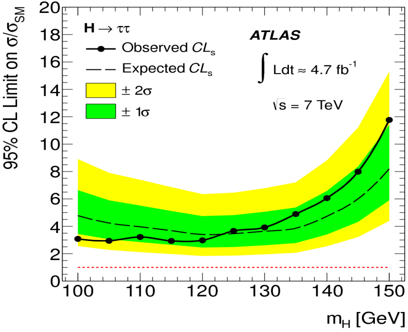
Signal Composition (ggH:VBF:VH %)	59:29:12

$\mathrm{H} \rightarrow \tau\tau$ Final Limits









- The observed (expected) upper limits on the cross section times the branching ratio are **between 2.9 (3.4) and 11.7 (8.2)** times the SM prediction, in the mass range 100-150 GeV.
- The most sensitive categories are the H + 1-jet category in the $H \rightarrow \tau_{had}\tau_{had}$ channel, the H +2-jet VBF category in the $H \rightarrow \tau_{lep}\tau_{had}$ channel and the H + 2-jet VBF category in the $H \rightarrow \tau_{lep}\tau_{lep}$ channel.

Summary

$\mathbf{H \to bb}$:

- No evidence for Higgs boson production is observed in the mass range 110-130 GeV. Paper submitted to **PLB: arXiv:1207.0210**
- The observed (expected) upper limits: between 2.5 (2.5) and 5.5 (4.9)
- In the near future: adding 2012 data based results, NN based b-jet energy scale improvement, lower BG theory uncertainty, MV based analysis, etc.

$\mathbf{H} \to \tau\tau$:

- No significant excess over the expected background is observed in the Higgs boson mass range of 100-150 GeV. Paper submitted to **JHEP: arXiv:1206.5971**
- The observed (expected) upper limits: between 2.9 (3.4) and 11.7 (8.2)
- In the near future: tighter VBF cut, Boost Higgs categories and additional triggers, etc.