Elias Coniavitis

ATLAS collaboration

Search for SM H→ττ with the ATLAS detector

Partikeldagarna

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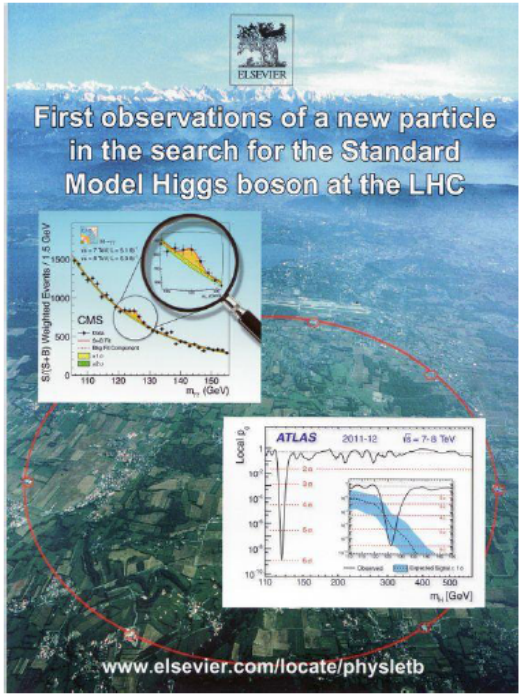
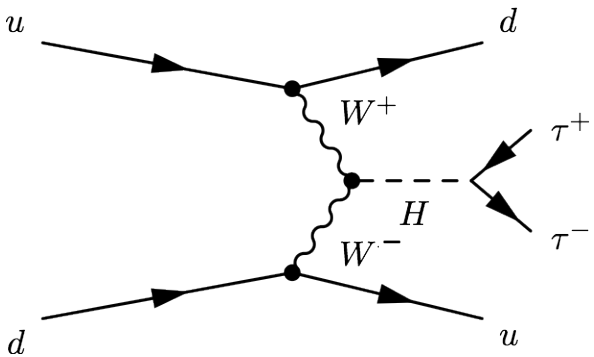
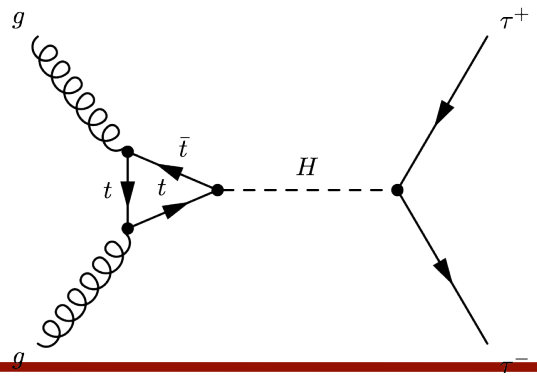
UPPSALA
UNIVERSITET

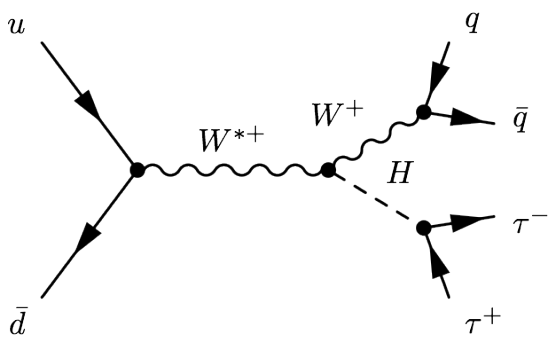
H→ττ

- Last summer: Historical observation!
- But what have we observed?
  - We know it couples to bosons
  - It probably couples to quarks (ggF production and γγ decay through quark-loop)
  - But what about leptons?
- Need H→ττ to check if our particle behaves like a SM-Higgs…



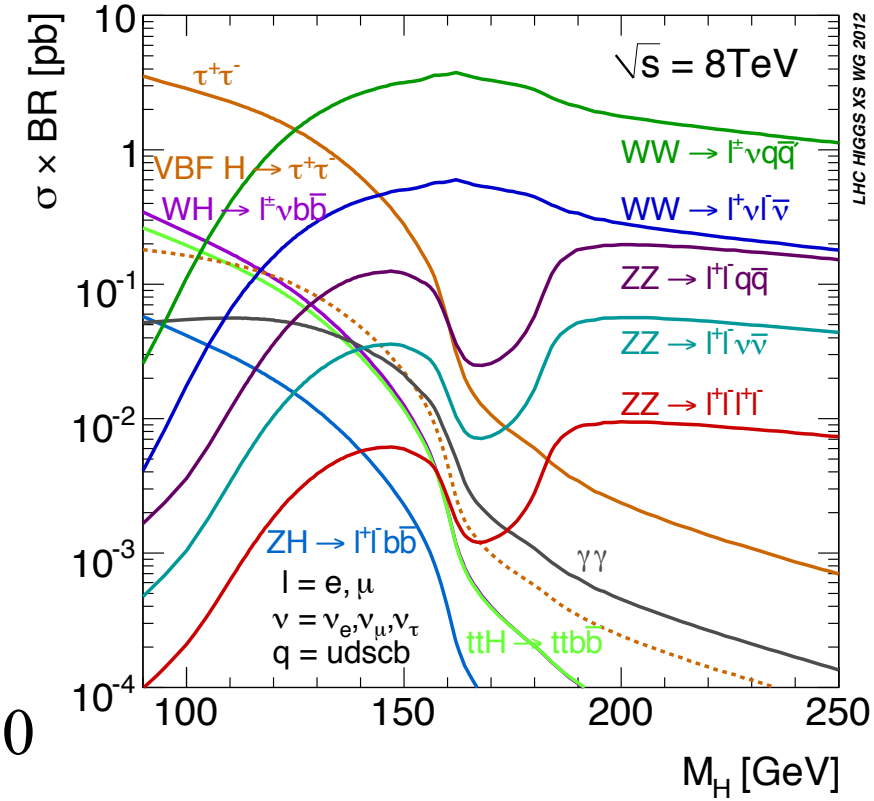






H→ττ in ATLAS

- Separate cut-based analysis for each of three different decay modes:
  - Lep-lep: ee/μμ/eμ+4ν
  - Lep-had: $e\tau_{had}/\mu\tau_{had}+3\nu$
  - Had-had: $\tau_{had}\tau_{had}+2\nu$
- Combine all channels, to search for H→ττ signature
- Results presented using 4.6fb^{-1} for 7 TeV and 13 fb^{-1} for 8 TeV data
- More details: ATLAS-CONF-2012-160



Uppsala involvement in H→ττ lep-had channel:
Henrik Öhman, Elias Coniavitis

Categorization

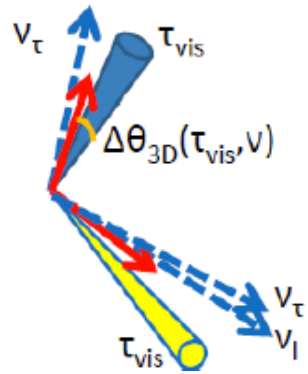
Lep-lep	Lep-had	Had-had
VBF (large $\Delta\eta_{jj}$, m_{jj})	VBF (large $\Delta\eta_{jj}$, m_{jj})	VBF (large $\Delta\eta_{jj}$, m_{jj})
Boosted (large p_T^H)	Boosted (large p_T^H)	Boosted (high-p_T jet)
VH (m_{jj}~$m_{Z/W}$)	≥1j	
≥1j	0j	
0j*		

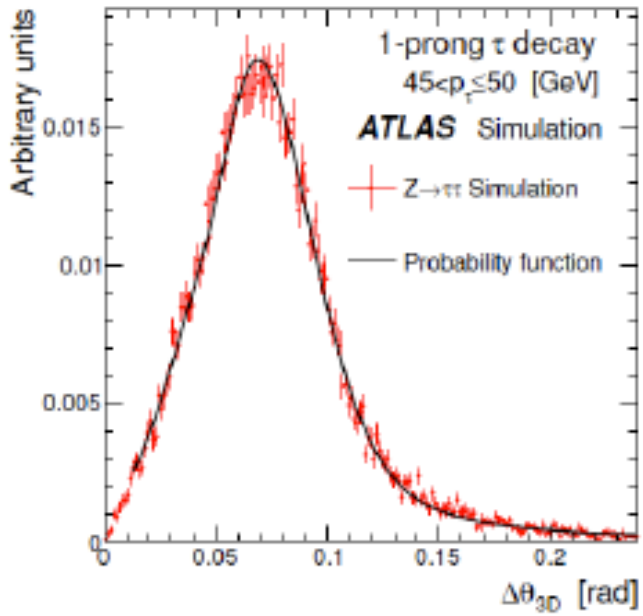
- Light-lepton flavors merged in analysis channels, except for Lep-had 1j and 0j categories
- Exact cuts applied detailed in backup slides

*: Only used for 7 TeV dataset

Di-tau Mass Reconstruction

- Reconstructing invariant mass of ditau system not straightforward, due to the presence of neutrinos in the tau decay
- MMC method used to estimate ditau invariant mass
  - Exception: lep-lep in 7 TeV (used collinear approx)
- Scan all points in parameter space and calculate $m_{\tau\tau}$, then evaluate probability of this τ-decay, given measured observables
  - Additional scan over E_x^{miss} and E_y^{miss}. E_T^{miss} resolution drives performance of the method.

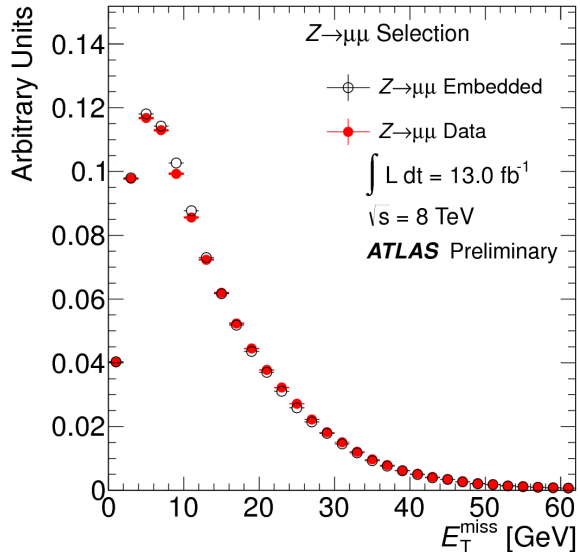


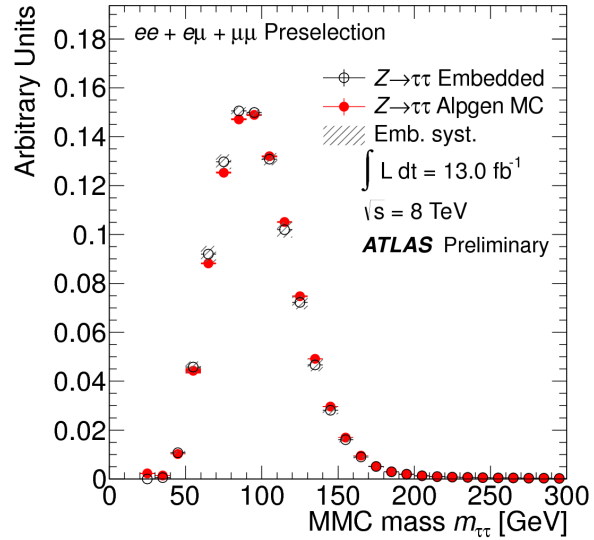


Background Estimation: $Z \rightarrow \tau\tau$

- Embedding procedure:
  - Select $Z \rightarrow \mu\mu$ events in data
  - Replace muons with simulated taus with same kinematics
- Major advantage: Only tau decays are from Monte Carlo, the rest (jets, pile-up, …) comes from data
- Normalization:
  - Lep-lep: using simulation
  - Lep-had, had-had: from data in low $m_{\tau\tau}$ window
- Method validation
  - By embedding muons instead of taus and comparing to data
  - By comparing to Monte Carlo

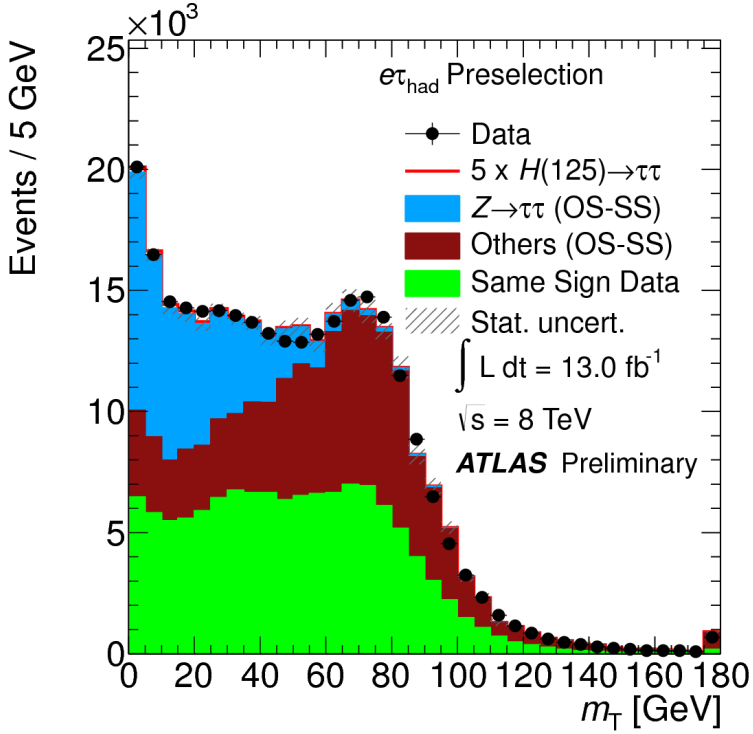
- Lep-had VBF category uses high-statistics VBF-filtered Monte Carlo samples instead
  - Rescaled to data using $Z \rightarrow ll$ events with VBF selection





Background Estimation: Others

- Lep-had: Use same-sign events, rescaled by factor accounting for difference between same sign (SS) and opposite sign (OS).
- For backgrounds with OS/SS asymmetry calculate OS-SS component, to add on top

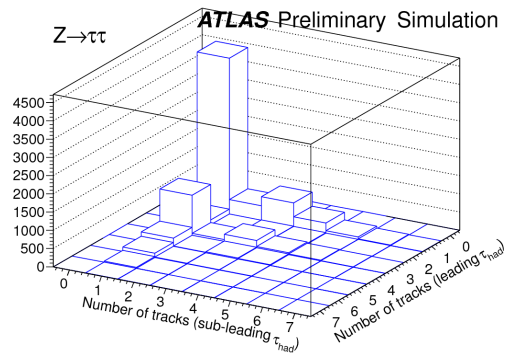


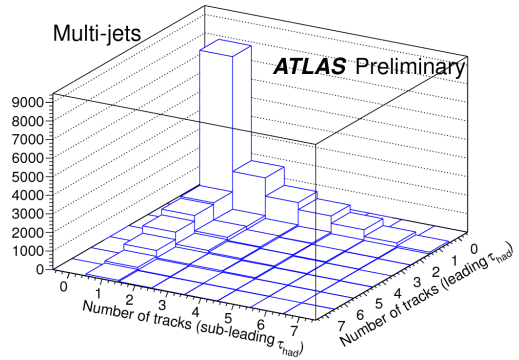
- W+jets: Shapes from Monte Carlo; normalization from control region of large transverse mass
- Z→ee: Monte Carlo-based , rescaled using e→τ fake-rate from dedicated Z→ee study, verified in m_{ee}~m_Z conrol region.
- Top: Shapes from Monte Carlo; normalization from control region of 2 jets, at least one b-tagged
- Other backgrounds from Monte Carlo corrected for trigger and identification efficiencies etc measured in data

Background Estimation: Others

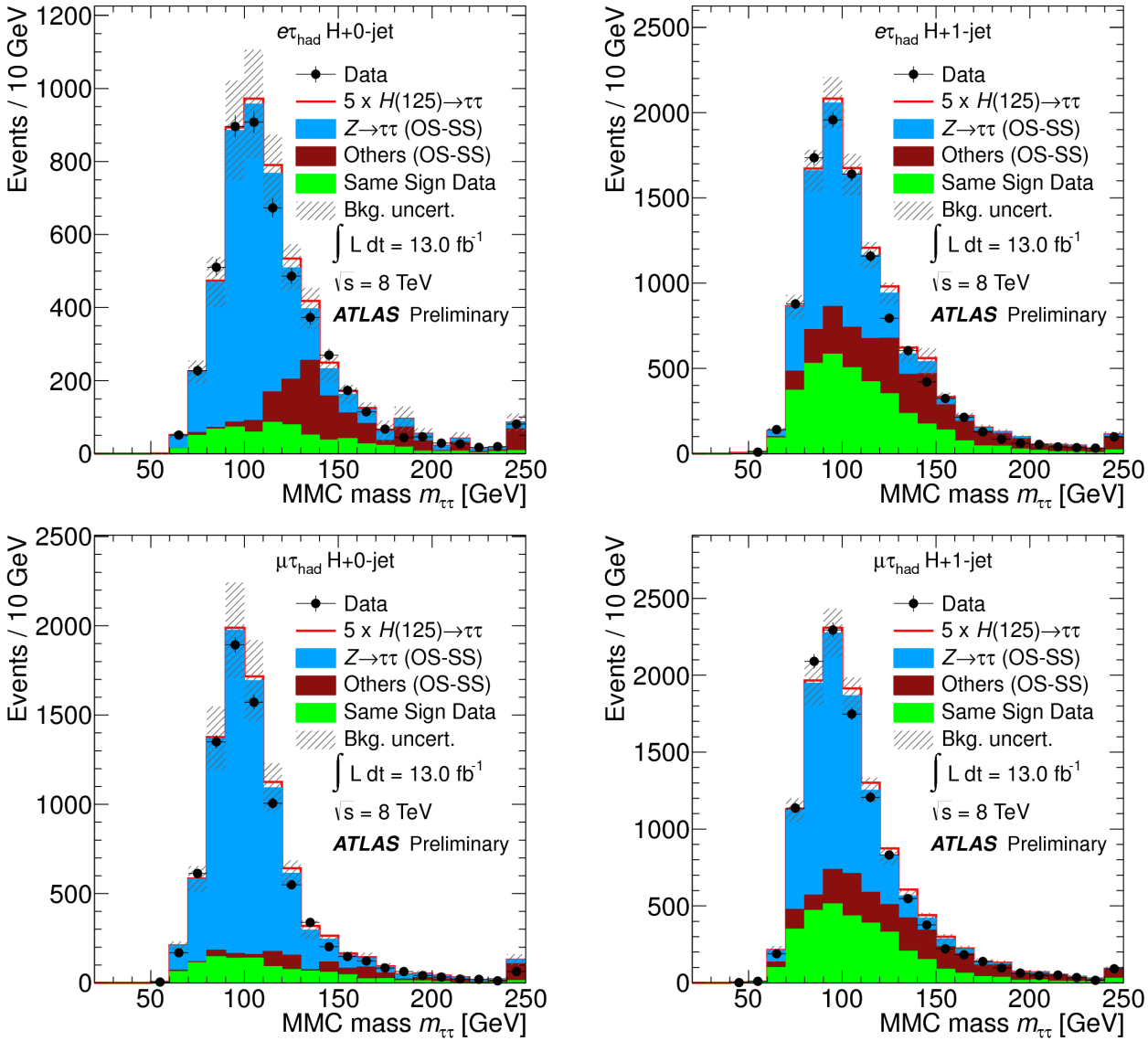
- Lep-had VBF category: use sample of inverted tau-identification (higher stats) for multijets & W+jets estimate rescaled with correction factors from control regions
  - Loose lepton isolation region for multijets
  - High transverse mass region for W+jets
  - Uncertainty on relative composition dominant systematic for this background estimate

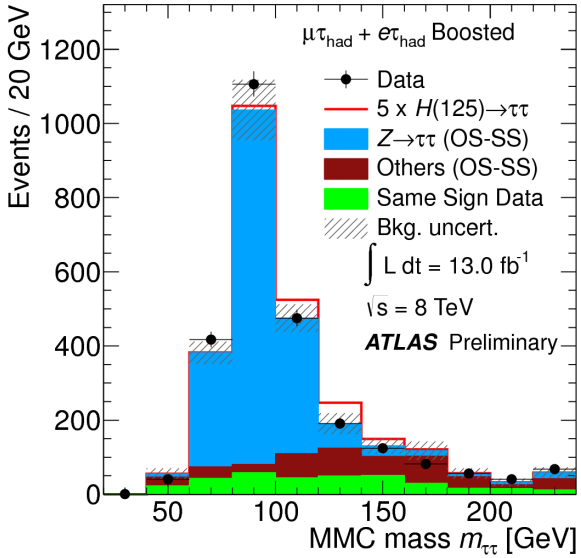
- Lep-lep, had-had: Fake-τ backgrounds estimated with template fits
  - $Z \rightarrow ll$ background in lep-lep obtained using control regions of different E_T^{miss} and m_{ll} requirements.
  - Other important backgrounds from Monte Carlo





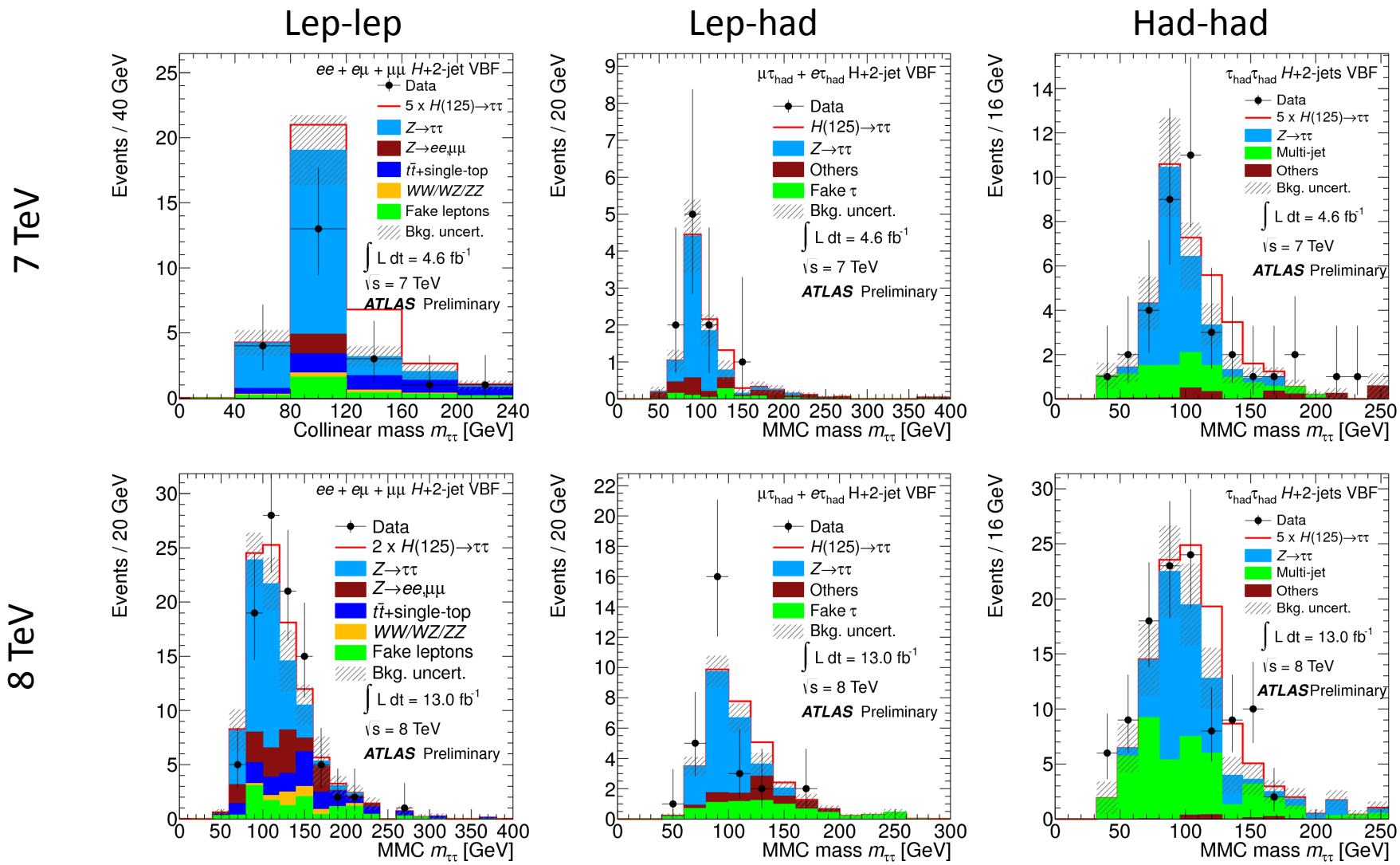
Lep-had Mass Distributions (8 TeV)





(For mass distributions in these categories for 7 TeV see backup slides)

VBF Mass Distributions



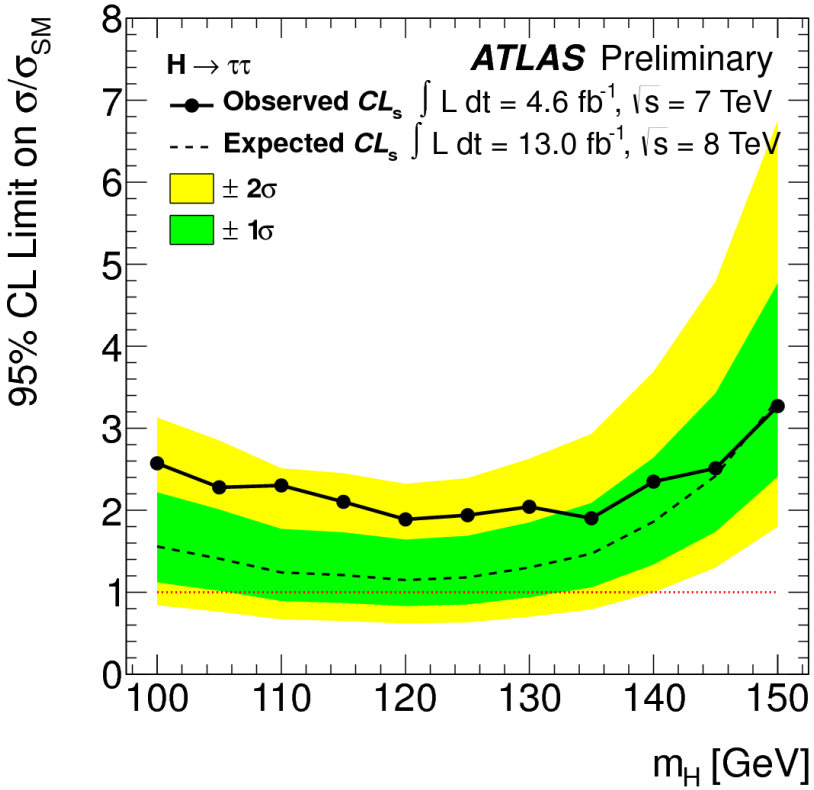
Systematic Uncertainties

- Most important experimental systematic uncertainties come from Embedding, Tau and Jet Energy Scale. Both normalization and shape effect considered for these.

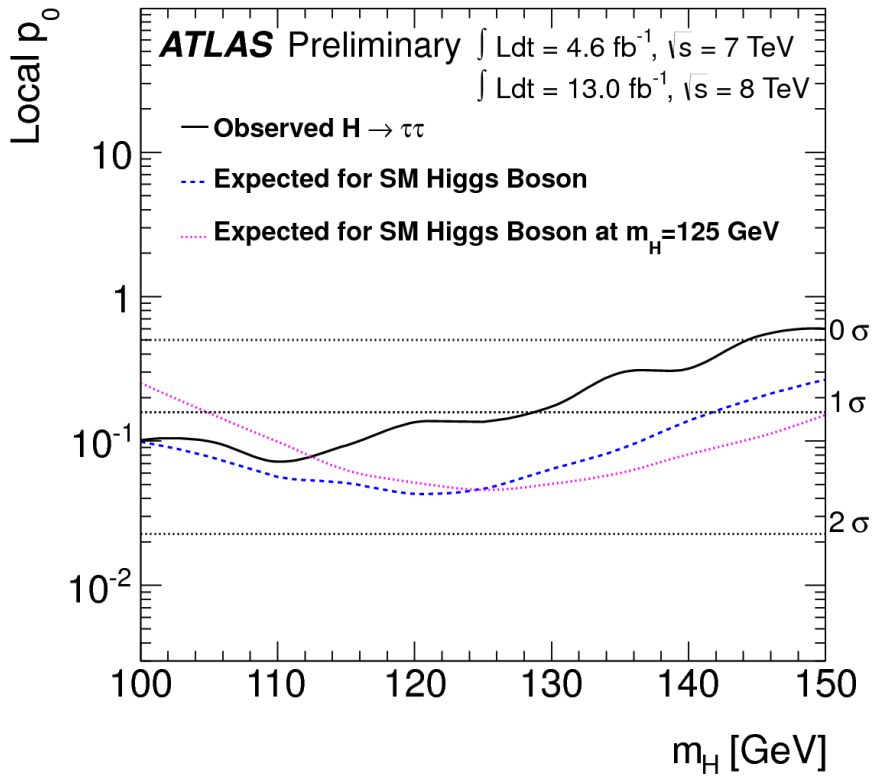
Uncertainty	$H \to \tau_{lep}\tau_{lep}$	$H \to \tau_{lep}\tau_{had}$	$H \to \tau_{had}\tau_{had}$
		$Z \to \tau^+\tau^-$	
Embedding	1–4% (S)	2–4% (S)	1–4% (S)
Tau Energy Scale	–	4–15% (S)	3–8% (S)
Tau Identification	–	4–5%	1–2%
Trigger Efficiency	2–4%	2–5%	2–4%
Normalisation	5%	4% (non-VBF), 16% (VBF)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

Combined Results

- Using profile likelihood
- Di-τ invariant mass distribution as discriminant



m_H=125 GeV: expected 1.2 x σ_{SM}
observed 1.9 x σ_{SM}

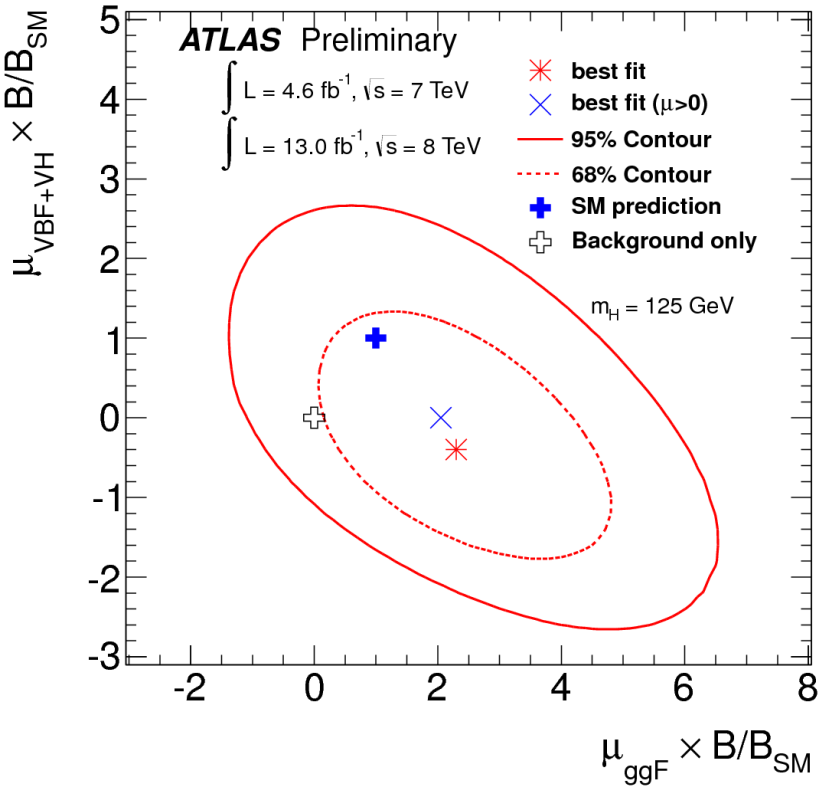


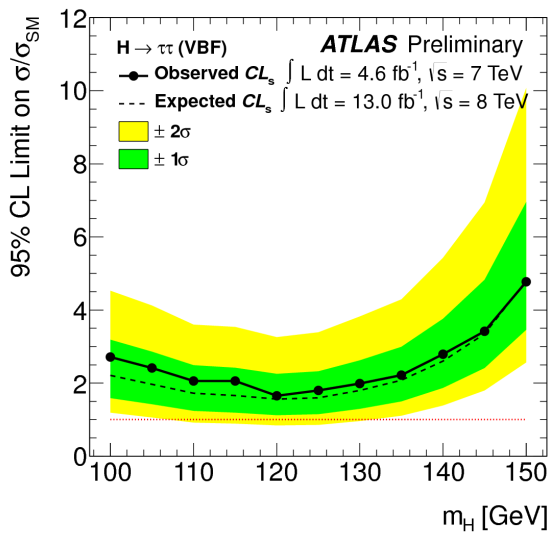
m_H=125 GeV: exp. local sign. 1.7σ
obs. local sign. 1.1σ

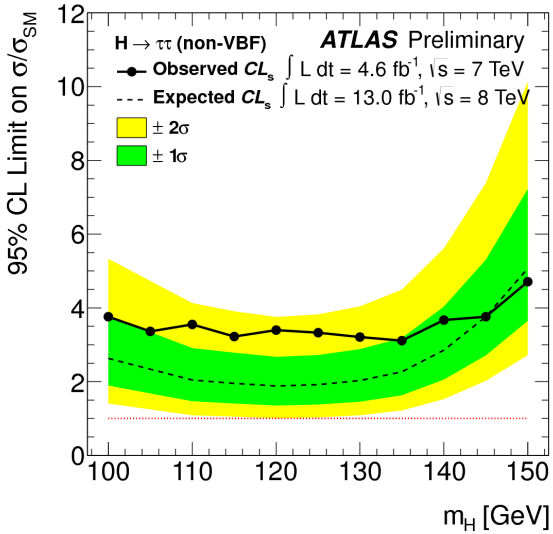
➢ Best fit value for signal strength (μ) is **0.7 ± 0.7**

Combined Results

- $H \rightarrow \tau\tau$ can be sensitive to different production modes
- Introduce separate μ for each production mode.
  - VBF and VH combined since both depend on VVH coupling of SM.
  - Fit μ_{VBF+VH}, μ_{ggF} with fixed mass (m_H=125 GeV)





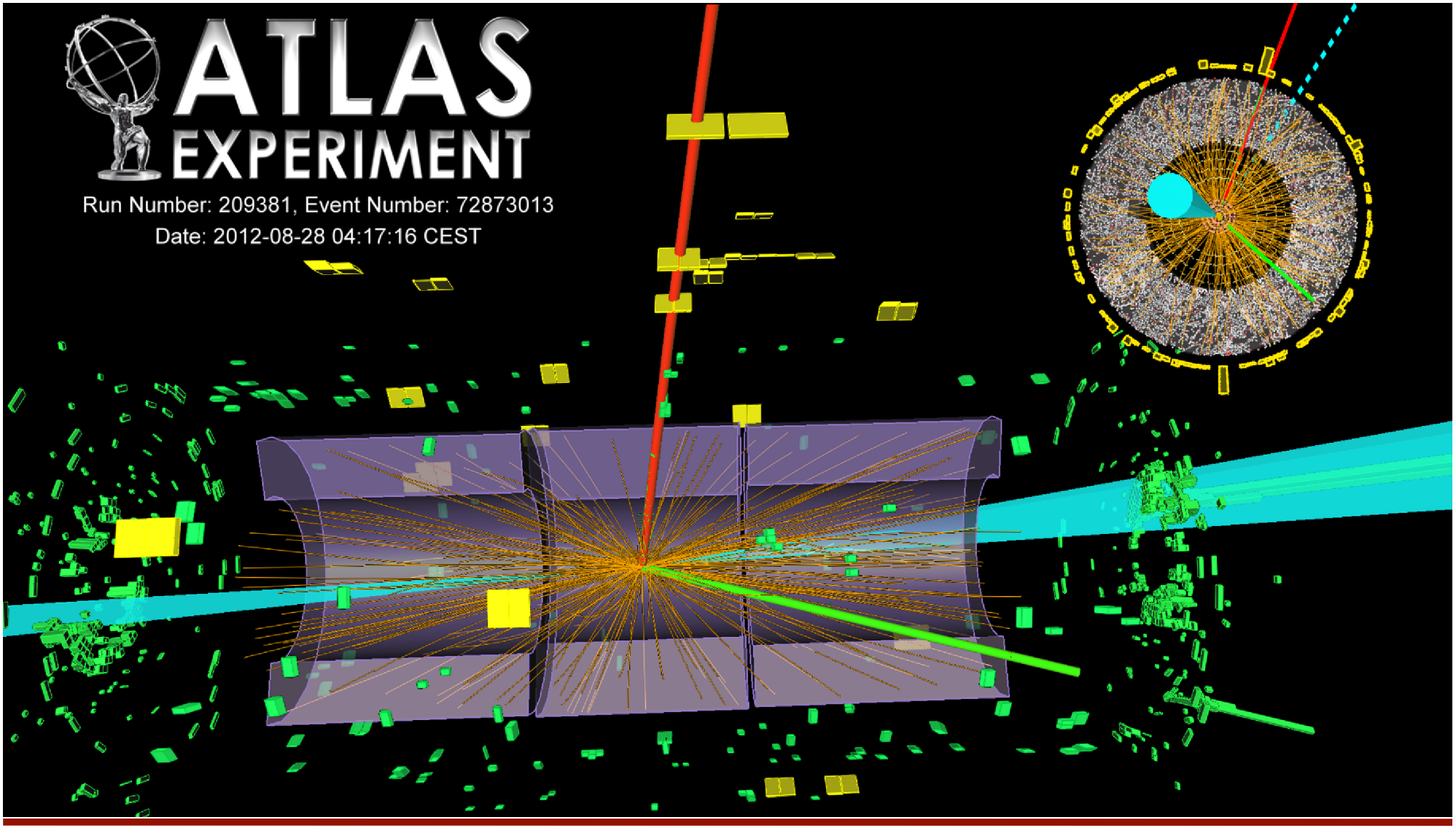


➢ Result is consistent both with SM Higgs, and background-only hypothesis
- Best fit for (μ_{VBF+VH}xB/B_{SM}, μ_{ggF}xB/B_{SM}) is (-0.4, 2.4)

Summary

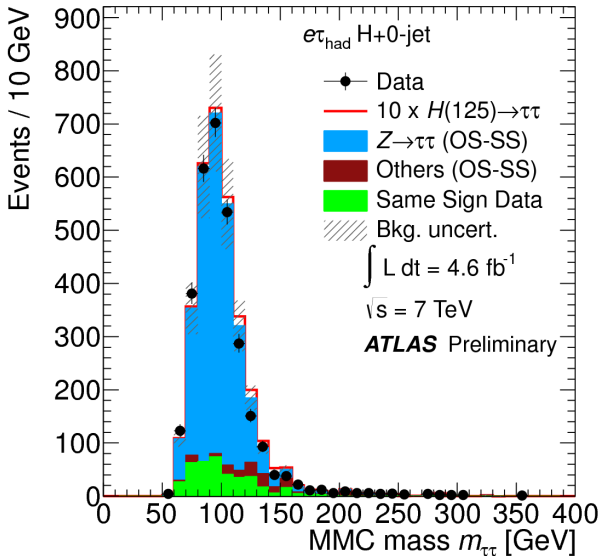
- Analysed 4.6fb^{-1} of 7 TeV data and 13 fb^{-1} of 8 TeV data
- Expected sensitivity now very close to $1x\sigma_{SM}$
  - Observed 95% CL limit is $1.9x\sigma_{SM}$ for mH=125 GeV (expected (μ=0) is $1.2x\sigma_{SM}$)
  - Observed local significance 1.1σ (expected (μ=1) is 1.7σ)
- Best fit value for signal strength is 0.7 ± 0.7
- Results in ($\mu_{VBF+VH}xB/B_{SM}$, $\mu_{ggF}xB/B_{SM}$) plane consistent both with SM Higgs and background-only hypothesis
- Further analysis improvements + more collected data: Stay tuned!

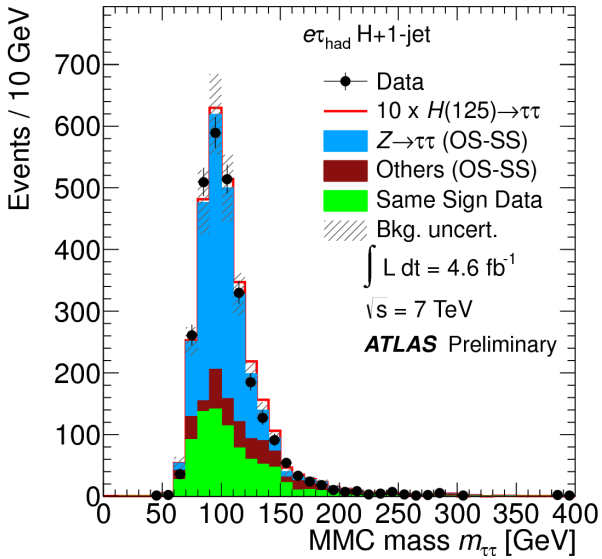
Event Display

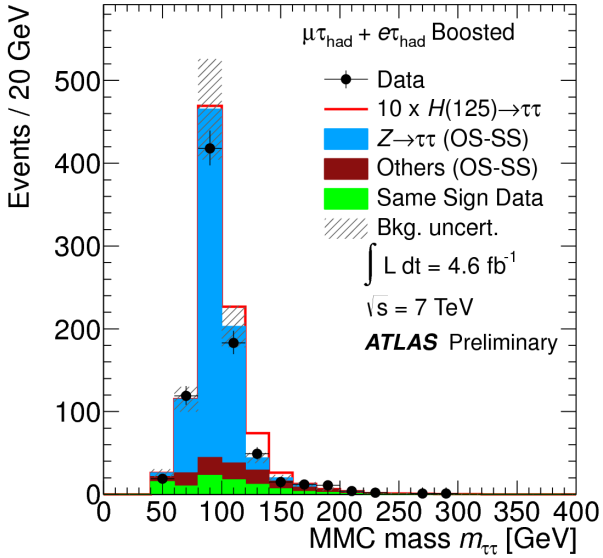


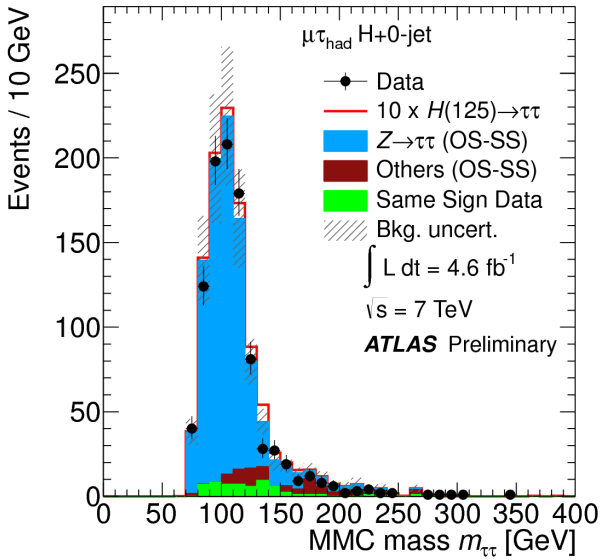
Backup Slides

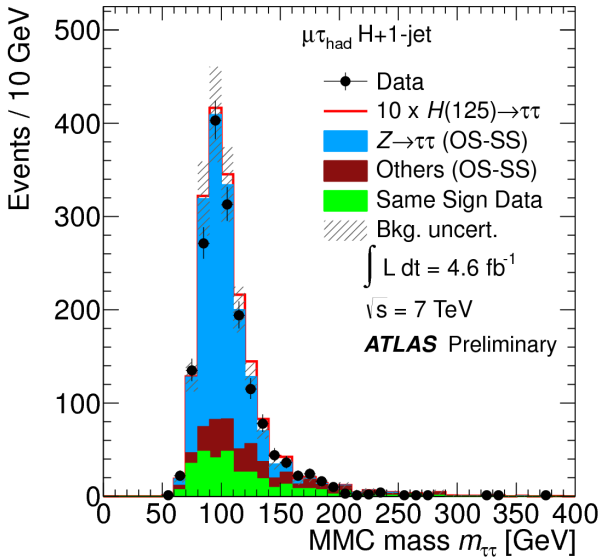
Lep-had Mass Distributions (7 TeV)



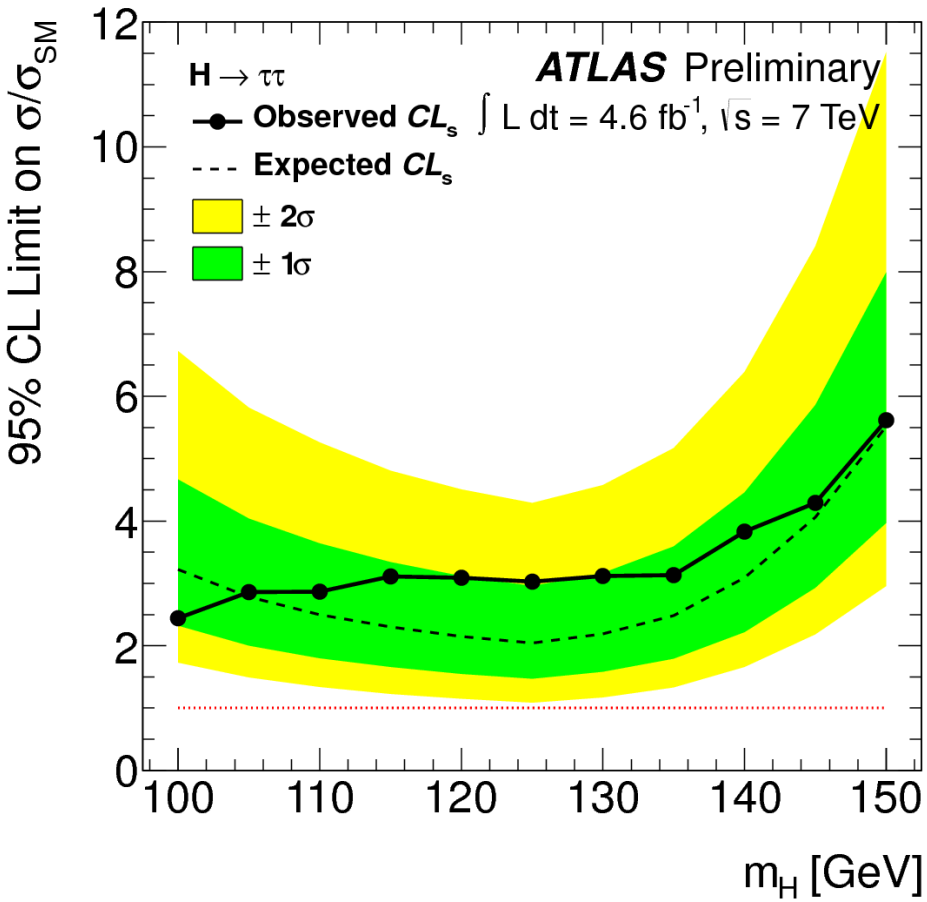




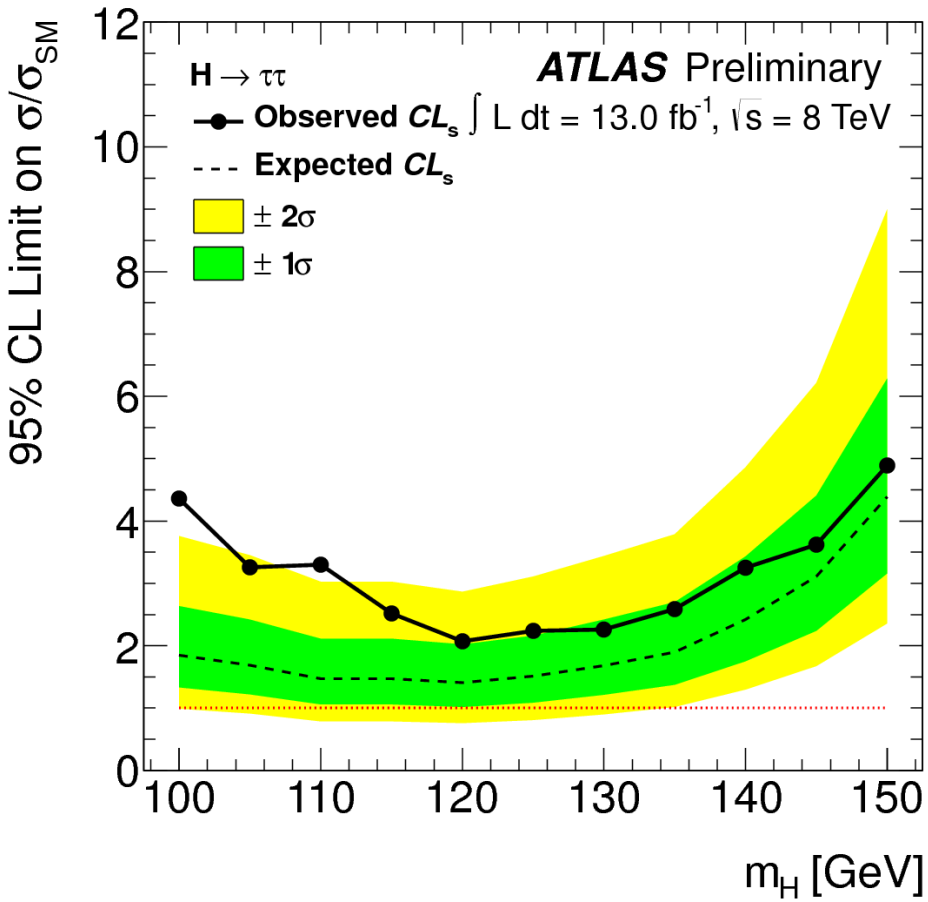




Limits for 7/8 TeV



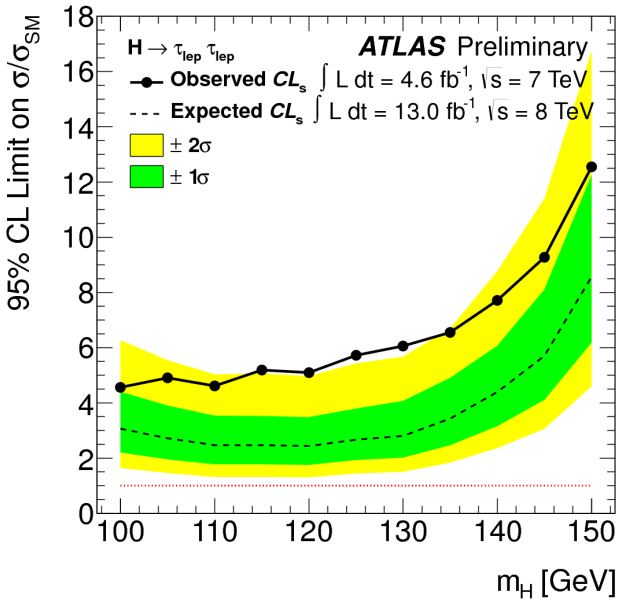
7 TeV



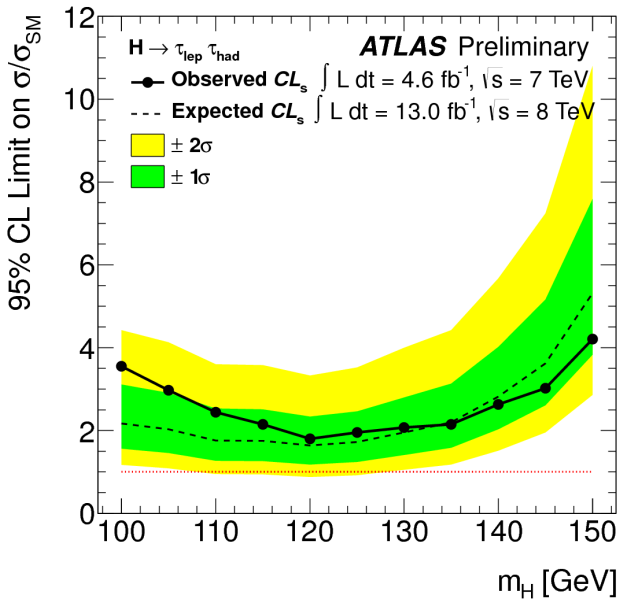
8 TeV

Limits by Category

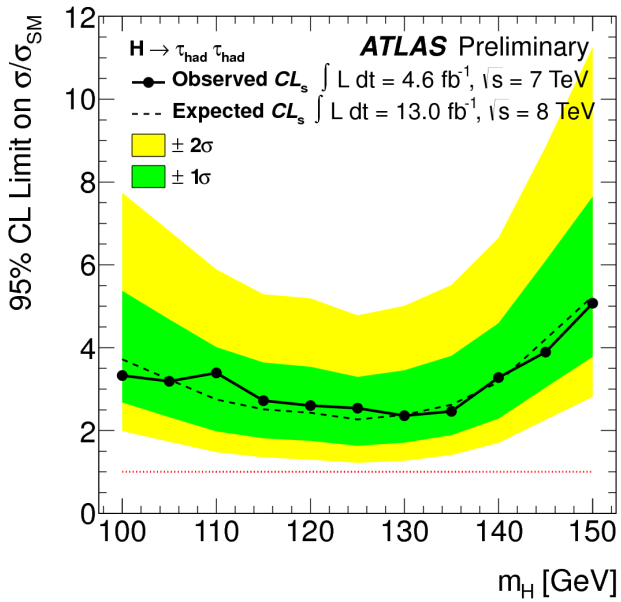
Lep-lep



Lep-had



Had-had



Lep-lep Cuts Summary

2-jet VBF	Boosted	2-jet VH	1-jet
Pre-selection: exactly two leptons with opposite charges			
30 GeV $< m_{\ell\ell} <$ 75 GeV (30 GeV $< m_{\ell\ell} <$ 100 GeV) for same-flavor (different-flavor) leptons, and $p_{T,\ell 1} + p_{T,\ell 2} >$ 35 GeV			
At least one jet with $p_T >$ 40 GeV ($\lvert JVF_{\rm jet}\rvert > 0.5$ if $\lvert\eta_{\rm jet}\rvert < 2.4$)			
$E_{\rm T}^{\rm miss} >$ 40 GeV ($E_{\rm T}^{\rm miss} >$ 20 GeV) for same-flavor (different-flavor) leptons			
$H_{\rm T}^{\rm miss} >$ 40 GeV for same-flavor leptons			
$0.1 < x_{1,2} < 1$			
$0.5 < \Delta\phi_{\ell\ell} < 2.5$			
$p_{T,j2} >$ 25 GeV (JVF)	excluding 2-jet VBF	$p_{T,j2} >$ 25 GeV (JVF)	excluding 2-jet VBF, Boosted and 2-jet VH
$\Delta\eta_{jj} > 3.0$	$p_{T,\tau\tau} >$ 100 GeV	excluding Boosted	$m_{\tau\tau j} >$ 225 GeV
$m_{jj} >$ 400 GeV	b-tagged jet veto	$\Delta\eta_{jj} < 2.0$	b-tagged jet veto
b-tagged jet veto	–	30 GeV $< m_{jj} <$ 160 GeV	–
Lepton centrality and CJV		b-tagged jet veto	
0-jet (7 TeV only)			
Pre-selection: exactly two leptons with opposite charges			
Different-flavor leptons with 30 GeV $< m_{\ell\ell} <$ 100 GeV and $p_{T,\ell 1} + p_{T,\ell 2} >$ 35 GeV			
$\Delta\phi_{\ell\ell} > 2.5$			
b-tagged jet veto			

Lep-had Cuts Summary

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^{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
• $\Delta(\Delta R) < 0.6$	• $\Delta(\Delta R) < 0.5$	• $\Delta(\Delta R) < 0.6$	• $\Delta(\Delta R) < 0.5$
• $\sum \Delta\phi < 3.5$	• $\sum \Delta\phi < 3.5$	• $\sum \Delta\phi < 3.5$	• $\sum \Delta\phi < 3.5$
–	• $p_T^{\ell} - p_T^{\tau} < 0$	–	• $p_T^{\ell} - p_T^{\tau} < 0$

Had-had Cuts Summary

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, $\lvert\eta\rvert < 2.5$
	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 $E_{\text{T}}^{\text{miss}}$ vector is not pointing in between the two taus, $\min\left\{\Delta\phi(E_{\text{T}}^{\text{miss}}, \tau_1), \Delta\phi(E_{\text{T}}^{\text{miss}}, \tau_2)\right\} < 0.2\pi$
VBF	At least two tagging jets, j_1, j_2, leading tagging jet with $p_{\text{T}} > 50$ GeV
	$\eta_{j1} \times \eta_{j2} < 0$, $\Delta\eta_{jj} > 2.6$ and invariant mass $m_{jj} > 350$ GeV
	$\min(\eta_{j1}, \eta_{j2}) < \eta_{\tau 1}, \eta_{\tau 2} < \max(\eta_{j1}, \eta_{j2})$
	$E_{\text{T}}^{\text{miss}} > 20$ GeV
Boosted	Fails VBF
	At least one tagging jet with $p_{\text{T}} > 70(50)$ GeV in the 8(7) TeV dataset
	$\Delta R(\tau_1, \tau_2) < 1.9$
	$E_{\text{T}}^{\text{miss}} > 20$ GeV
	if $E_{\text{T}}^{\text{miss}}$ vector is not pointing in between the two taus, $\min\left\{\Delta\phi(E_{\text{T}}^{\text{miss}}, \tau_1), \Delta\phi(E_{\text{T}}^{\text{miss}}, \tau_2)\right\} < 0.1\pi$.

Lep-had Event Yields (7 TeV)

Process	e-had Events 0-Jet	e-had Events 1-Jet	μ-had Events 0-Jet	μ-had Events 1-Jet
$gg \to H$ (125 GeV)	9.4 ± 0.3 ± 2.3	8.7 ± 0.2 ± 1.8	4.6 ± 0.2 ± 1.2	6.4 ± 0.2 ± 1.3
VBF H (125 GeV)	0.09 ± 0.01 ± 0.01	1.68 ± 0.03 ± 0.15	0.04 ± 0.00 ± 0.01	1.35 ± 0.03 ± 0.12
VH (125 GeV)	0.05 ± 0.01 ± 0.01	0.73 ± 0.04 ± 0.07	0.03 ± 0.01 ± 0.00	0.67 ± 0.04 ± 0.06
$Z/\gamma^* \to \tau\tau$ embedded (OS-SS)	(2.57 ± 0.03 ± 0.44)×10^3	(1.63 ± 0.02 ± 0.24)×10^3	(0.88 ± 0.01 ± 0.17)×10^3	(1.20 ± 0.02 ± 0.17)×10^3
Diboson (OS-SS)	2.1 ± 0.6 ± 0.3	12.2 ± 1.3 ± 1.1	2.3 ± 0.3 ± 0.4	9.1 ± 1.2 ± 0.8
$Z/\gamma^* \to \ell\ell$ (OS-SS)	47 ± 5 ± 12	34 ± 5 ± 8	10 ± 3 ± 2	13 ± 3 ± 4
Top (OS-SS)	0.7 ± 0.2 ± 0.2	121 ± 3 ± 19	0.5 ± 0.2 ± 0.1	92 ± 3 ± 14
W boson + jets (OS-SS)	116 ± 15 ± 6	(0.24 ± 0.02 ± 0.03)×10^3	65 ± 11 ± 6	(0.15 ± 0.02 ± 0.02)×10^3
Same sign data	(0.40 ± 0.02 ± 0.06)×10^3	(0.82 ± 0.04 ± 0.04)×10^3	60 ± 8 ± 3	(0.31 ± 0.02 ± 0.02))×10^3
Total background	(3.13 ± 0.04 ± 0.44)×10^3	(2.85 ± 0.04 ± 0.25)×10^3	(1.01 ± 0.02 ± 0.17)×10^3	(1.78 ± 0.03 ± 0.18)×10^3
Observed data	3064	2828	958	1701

Process	Events Boosted	Events VBF
$gg \to H$ (125 GeV)	4.1 ± 0.1 ± 1.0	0.17 ± 0.03 ± 0.06
VBF H (125 GeV)	1.52 ± 0.03 ± 0.13	0.87 ± 0.02 ± 0.15
VH (125 GeV)	0.86 ± 0.04 ± 0.08	<0.001
$Z/\gamma^* \to \tau\tau$ †	(0.70 ± 0.02 ± 0.10)×10^3	6.5 ± 0.6 ± 1.5
Diboson †	8.4 ± 0.7 ± 0.8	0.12 ± 0.06 ± 0.03
$Z/\gamma^* \to \ell\ell$ †	3.7 ± 1.3 ± 1.0	0.8 ± 0.3 ± 1.0
Top †	52 ± 2 ± 9	1.2 ± 0.3 ± 0.1
W boson + jets (OS-SS)	41 ± 7 ± 8	–
Same sign data	90 ± 10 ± 5	–
Fake-$\tau_{\text{had-vis}}$ backgrounds	–	0.8 ± 0.2 ± 0.4
Total background	(0.90 ± 0.02 ± 0.10)×10^3	9.5 ± 0.8 ± 1.9
Observed data	834	10

Lep-had Event Yields (8 TeV)

Process	e-had Events 0-Jet	e-had Events 1-Jet	μ-had Events 0-Jet	μ-had Events 1-Jet
$gg \to H$ (125 GeV)	25.9 ± 0.8 ± 6.1	37.3 ± 0.9 ± 8.4	34.3 ± 0.9 ± 8.0	46 ± 1 ± 11
VBF H (125 GeV)	0.30 ± 0.05 ± 0.04	7.8 ± 0.3 ± 0.5	0.47 ± 0.06 ± 0.04	8.5 ± 0.3 ± 0.6
VH (125 GeV)	0.27 ± 0.05 ± 0.03	3.5 ± 0.2 ± 0.2	0.20 ± 0.05 ± 0.02	3.7 ± 0.2 ± 0.3
$Z/\gamma^* \to \tau\tau$ (OS-SS)	$(3.59 \pm 0.03 \pm 0.278)\times10^3$	$(4.50 \pm 0.04 \pm 0.37)\times10^3$	$(7.13 \pm 0.04 \pm 0.48)\times10^3$	$(6.14 \pm 0.04 \pm 0.45)\times10^3$
Diboson (OS-SS)	9.9 ± 0.7 ± 0.9	27 ± 1 ± 2	10.5 ± 0.7 ± 0.9	30 ± 1 ± 3
$Z/\gamma^* \to \ell\ell$ (OS-SS)	$(0.41 \pm 0.04 \pm 0.13)\times10^3$	$(0.28 \pm 0.07 \pm 0.14)\times10^3$	$(0.10 \pm 0.02 \pm 0.02)\times10^3$	$(0.12 \pm 0.02 \pm 0.03)\times10^3$
Top (OS-SS)	8 ± 2 ± 1	$(1.00 \pm 0.02 \pm 0.03)\times10^3$	10.4 ± 2.3 ± 0.6	$(1.03 \pm 0.03 \pm 0.05)\times10^3$
W boson + jets (OS-SS)	$(0.48 \pm 0.07 \pm 0.04)\times10^3$	$(1.32 \pm 0.12 \pm 0.12)\times10^3$	$(0.51 \pm 0.09 \pm 0.04)\times10^3$	$(1.0 \pm 0.1 \pm 0.14)\times10^3$
Same sign data	$(0.66 \pm 0.03 \pm 0.03)\times10^3$	$(3.68 \pm 0.06 \pm 0.18)\times10^3$	$(1.03 \pm 0.03 \pm 0.07)\times10^3$	$(3.27 \pm 0.06 \pm 0.24)\times10^3$
Total background	$(5.16 \pm 0.09 \pm 0.31)\times10^3$	$(10.8 \pm 0.2 \pm 0.5)\times10^3$	$(8.8 \pm 0.1 \pm 0.5)\times10^3$	$(11.6 \pm 0.1 \pm 0.5)\times10^3$
Observed data	5012	10409	8300	11373

Process	Events Boosted	Events VBF
$gg \to H$ (125 GeV)	20.3 ± 0.7 ± 5.1	0.5 ± 0.1 ± 0.3
VBF H (125 GeV)	5.3 ± 0.2 ± 0.3	2.5 ± 0.2 ± 0.4
VH (125 GeV)	2.7 ± 0.2 ± 0.2	<0.001
$Z/\gamma^* \to \tau\tau$ †	$(1.78 \pm 0.03 \pm 0.11)\times10^3$	17 ± 2 ± 6
Diboson †	12.2 ± 0.9 ± 1.0	0.6 ± 0.3 ± 0.4
$Z/\gamma^* \to \ell\ell$ †	18 ± 9 ± 4	1.7 ± 0.5 ± 1.2
Top †	111 ± 8 ± 33	2.0 ± 0.7 ± 1.0
W boson + jets (OS-SS)	$(0.27 \pm 0.06 \pm 0.04)\times10^3$	–
Same sign data	$(0.34 \pm 0.02 \pm 0.01)\times10^3$	–
Fake-$\tau_{\text{had-vis}}$ backgrounds	–	7.6 ± 0.7 ± 3.8
Total background	$(2.53 \pm 0.07 \pm 0.13)\times10^3$	29 ± 2 ± 7
Observed data	2602	29

Lep-lep Event Yields

7 TeV

	$ee + \mu\mu + e\mu$				
	VBF category	Boosted category	VH category	1-jet category	0-jet category
$gg \to H$ (125 GeV)	$0.20 \pm 0.04 \pm 0.07$	$3.5 \pm 0.2 \pm 0.4$	$0.4 \pm 0.1 \pm 0.1$	$2.0 \pm 0.1 \pm 0.8$	$25 \pm 1 \pm 4$
VBF H (125 GeV)	$1.05 \pm 0.03 \pm 0.10$	$0.90 \pm 0.03 \pm 0.05$	$0.05 \pm 0.01 \pm 0.01$	$0.56 \pm 0.02 \pm 0.01$	$0.97 \pm 0.03 \pm 0.06$
VH (125 GeV)	0.0	$0.71 \pm 0.03 \pm 0.09$	$0.20 \pm 0.01 \pm 0.02$	$0.14 \pm 0.01 \pm 0.02$	$0.63 \pm 0.02 \pm 0.04$
$Z/\gamma^* \to \tau\tau$ embedded	$20 \pm 2 \pm 2$	$(0.41 \pm 0.01 \pm 0.02) \times 10^3$	$113 \pm 5 \pm 8$	$272 \pm 8 \pm 41$	$(10.71 \pm 0.05 \pm 0.07) \times 10^3$
$Z/\gamma^* \to \ell\ell$	$1.5 \pm 0.6 \pm 0.6$	$77 \pm 7 \pm 6$	$27 \pm 4 \pm 9$	$45 \pm 5 \pm 24$	$(0.17 \pm 0.01 \pm 0.01) \times 10^3$
Top	$4.8 \pm 0.5 \pm 0.6$	$132 \pm 3 \pm 6$	$27 \pm 1 \pm 6$	$31 \pm 2 \pm 10$	$284 \pm 4 \pm 15$
Diboson	$0.8 \pm 0.1 \pm 0.2$	$17.4 \pm 0.7 \pm 0.6$	$4.3 \pm 0.4 \pm 1.0$	$12 \pm 1 \pm 3$	$347 \pm 3 \pm 20$
Backgrounds with fake leptons	$2.7 \pm 0.3 \pm 0.9$	$22 \pm 3 \pm 4$	$19 \pm 3 \pm 6$	$24 \pm 3 \pm 10$	$(1.56 \pm 0.02 \pm 0.40) \times 10^3$
Total background	$29 \pm 3 \pm 2$	$(0.66 \pm 0.01 \pm 0.02) \times 10^3$	$190 \pm 7 \pm 15$	$(0.38 \pm 0.01 \pm 0.05) \times 10^3$	$(13.07 \pm 0.06 \pm 0.41) \times 10^3$
Observed data	28	673	176	371	13214

8 TeV

	$ee + \mu\mu + e\mu$			
	VBF category	Boosted category	VH category	1-jet category
$gg \to H$ (125 GeV)	$1.3 \pm 0.2 \pm 0.4$	$12.4 \pm 0.6 \pm 2.9$	$2.5 \pm 0.3 \pm 0.6$	$7.0 \pm 0.5 \pm 1.6$
VBF H (125 GeV)	$3.63 \pm 0.10 \pm 0.02$	$3.36 \pm 0.09 \pm 0.30$	$0.21 \pm 0.03 \pm 0.02$	$1.82 \pm 0.07 \pm 0.18$
VH (125 GeV)	$0.01 \pm 0.01 \pm 0.01$	$2.20 \pm 0.05 \pm 0.22$	$0.64 \pm 0.03 \pm 0.09$	$0.44 \pm 0.02 \pm 0.05$
$Z/\gamma^* \to \tau\tau$ embedded	$47 \pm 2 \pm 1$	$(1.24 \pm 0.01 \pm 0.08) \times 10^3$	$393 \pm 7 \pm 26$	$(0.86 \pm 0.01 \pm 0.06) \times 10^3$
$Z/\gamma^* \to \ell\ell$	$14 \pm 3 \pm 2$	$(0.21 \pm 0.02 \pm 0.04) \times 10^3$	$(0.08 \pm 0.01 \pm 0.02) \times 10^3$	$(0.16 \pm 0.01 \pm 0.03) \times 10^3$
Top	$15 \pm 2 \pm 3$	$(0.39 \pm 0.01 \pm 0.07) \times 10^3$	$87 \pm 4 \pm 23$	$117 \pm 5 \pm 18$
Diboson	$3.6 \pm 0.8 \pm 0.6$	$55 \pm 3 \pm 10$	$15 \pm 1 \pm 4$	$40 \pm 3 \pm 7$
Backgrounds with fake leptons	$12 \pm 2 \pm 3$	$102 \pm 7 \pm 23$	$86 \pm 4 \pm 16$	$230 \pm 8 \pm 52$
Total background	$91 \pm 5 \pm 5$	$(2.01 \pm 0.03 \pm 0.12) \times 10^3$	$(0.66 \pm 0.02 \pm 0.05) \times 10^3$	$(1.40 \pm 0.02 \pm 0.08) \times 10^3$
Observed data	98	2014	636	1405

Had-had Event Yields

$H \to \tau_{had}\tau_{had}$	7 TeV analysis (4.6 fb^{-1})		8 TeV analysis (13.0 fb^{-1})	
	VBF category	Boosted category	VBF category	Boosted category
$gg \to H$ (125 GeV)	0.36 ± 0.06 ± 0.12	2.4 ± 0.2 ± 0.7	1.0 ± 0.1 ± 0.3	8.2 ± 0.4 ± 1.8
VBF H (125 GeV)	1.12 ± 0.04 ± 0.18	0.68 ± 0.03 ± 0.07	3.01 ± 0.09 ± 0.48	1.98 ± 0.07 ± 0.30
VH (125 GeV)	<0.02	0.61 ± 0.05 ± 0.06	<0.05	1.4 ± 0.2 ± 0.2
$Z/\gamma^* \to \tau\tau$ embedded	20 ± 2 ± 3	392 ± 9 ± 12	50 ± 4 ± 6	1080 ± 20 ± 110
W/Z boson+jets	1.5 ± 0.7 ± 0.4	5 ± 1 ± 1	0.4 ± 0.4	90 ± 20 ± 30
Top	1.0 ± 0.2 ± 0.2	3.0 ± 0.3 ± 0.5	1.4 ± 1.0	21 ± 3 ± 5
Diboson	0.10 ± 0.07 ± 0.02	4.4 ± 0.6 ± 0.7	<0.01	<0.5
Multijet	10.2 ± 0.9 ± 5.0	156 ± 6 ± 30	44 ± 5 ± 7	420 ± 20 ± 60
Total background	32.5 ± 2.2 ± 5.9	561 ± 11 ± 32	96 ± 6 ± 9	1607 ± 37 ± 130
Observed data	38	535	110	1435