Search for the Higgs boson in $\tau^+\tau^-$ channel using the ATLAS detector

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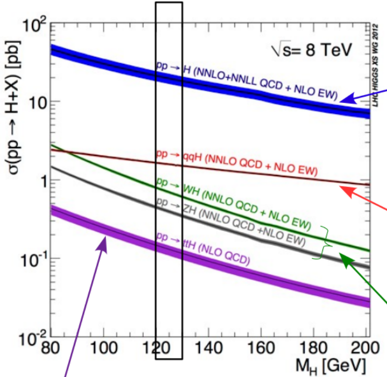
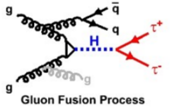
Motivation and Introduction

- LHC's first big discovery was of "a" Higgs boson.
- Observed, so far, only in decays to bosons.

- $\tau^+\tau^-$ is the most promising mode in which to observe direct decay to fermions.
- Potential contribution to couplings measurements, VBF production mode measurements, CP (eventually).
- Challenging mode! No public result yet on full 2011+2012 ATLAS datasets.
- This presentation: full 2011 dataset ($4.6 fb^{-1}$) and $13 fb^{-1}$ of 2012 data (ATLAS-CONF-2012-160).

SM Higgs Production



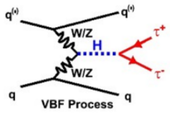


Gluon Fusion (~19pb)

Dominant process.

Can exploit high p_T Higgs,

or association with jets. ✓



Vector Boson Fusion (~1.5pb)

Has the cleanest signature

(two high-energy jets with

large rapidity separation). ✓

Associate with W/Z

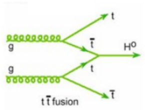
Adds little signal, but is very

important to study Higgs

coupling to weak bosons.

Here only hadronic decays

of W/Z are considered. ✓



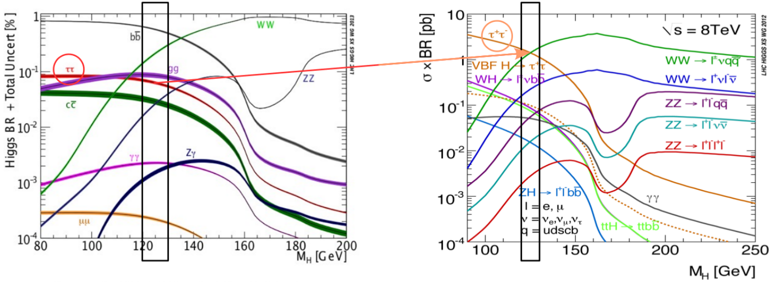
Associate with $t\bar{t}$

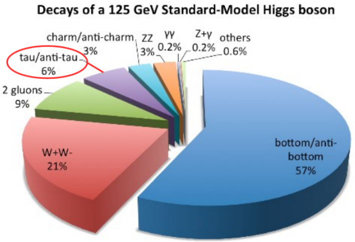
Relatively small

cross-section.

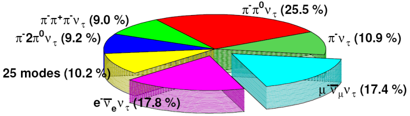
Not considered. ✗

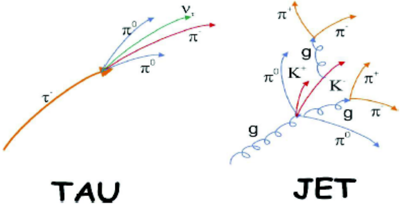
SM Higgs Decay





- Highest BR among the leptons.
- Low overall BR compensated by ability to use all decay modes.
- Presence of neutrinos in final state makes full kinematic reconstruction impossible.





Identifying hadronic τ Decays

- Hadronic decays are a well-collimated collection of charged and neutral pions.
- BDT-based τ_{had} ID:
  - 60%(40%) efficiency for medium (tight)
  - 2-3% (0.5%) jet acceptance.

For this reason, the tau-tau channel is actually many channels, classified by the decay of the tau: $\tau_\ell\tau_\ell$, $\tau_\ell\tau_{\text{had}}$, $\tau_{\text{had}}\tau_{\text{had}}$.

Analysis Strategy

- BR for each mode:
  - $H \to \tau\tau \to \tau_\ell \tau_\ell + 4\nu$ (12%)
  - $H \to \tau\tau \to \tau_\ell \tau_{\mathrm{had}} + 3\nu$ (46%)
  - $H \to \tau\tau \to \tau_{\mathrm{had}} \tau_{\mathrm{had}} + 2\nu$ (42%)
- Separate analyses **in each decay mode** allows optimization for different background compositions.
- Define analysis **categories** motivated by Higgs production modes:
  - **VBF:** target VBF topology by requiring 2 forward jets in opposite hemispheres.
  - **Boosted:** target ggF topology with Boosted Higgs to improve mass resolution.
  - **VH:** target VH, multi-jet events with different kinematics from VBF.
  - **1j/0j:** catch-all categories seeking ggF.

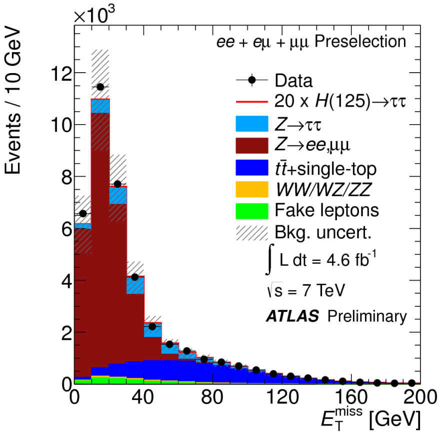
Special Considerations

- In all modes, neutrinos limit mass resolution. Use Missing Mass Calculator (MMC) to achieve 13-20% resolution.
- Use data-driven background models where possible.
- $Z \to \tau\tau$ is an important background to all decay modes. Use **embedding**:
  - Start with $Z \to \mu\mu$ data events, remove muons.
  - Embed MC τ in the data events.

  Improves modeling of jet/met variables, reduces systematic uncertainties, increases sample sizes!!

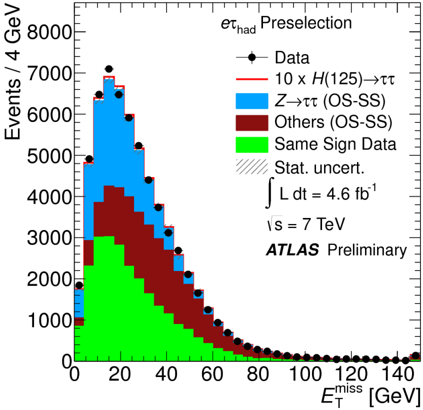
Important Backgrounds to $\tau_\ell \tau_\ell$

- $Z \rightarrow \tau\tau$ **:** embedding
- $Z \rightarrow ee, \mu\mu$**:** MC normalized in data control region.
- **Top:** MC normalized in data control region.
- **Di-bosons:** MC normalized in data control region.
- **Fake Leptons:** shape from data control (reverse lepton isolation), normalized to data.



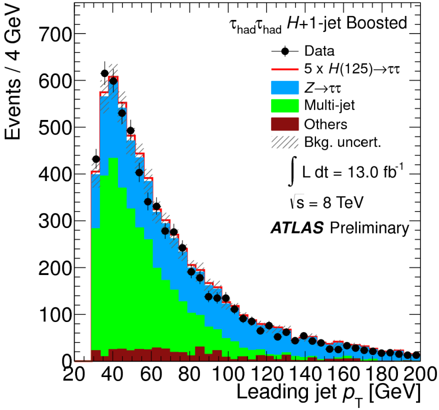
Important Backgrounds to $\tau_\ell \tau_{\rm had}$

- **$Z \to \tau\tau$:** embedding
- **Others:** Top, W+jets, $Z \to \ell\ell$, di-bosons. From MC, each normalized in data control regions.
- **Same Sign:** Primarily multi-jets.



Important Backgrounds to $\tau_{\rm had}\tau_{\rm had}$

- $Z \to \tau\tau$ **:** embedding
- **Multi-jets:** shape from not-opposite-sign (notOS) data. Normalized by fitting track distribution.
- **Others:** Shape from MC. Fake rate derived from data samples. Dominated by $W \to \tau\nu +$ jets.



(Cascading) Selection Criteria - VBF

Category	Selection	$\tau_\ell\tau_\ell$	$\tau_\ell\tau_{\mathrm{had}}$	$\tau_{\mathrm{had}}\tau_{\mathrm{had}}$
VBF	$p_T(j1) >$ (GeV)	40	40	50
	$p_T(j2) >$ (GeV)	25	40	30
	$\Delta\eta_{j1,j2} >$	3.0	3.0	2.6
	$\eta(j1) \times \eta(j2) <$	-	0	0
	$M_{j1,j2} >$(GeV)	400	500	350
	$P_T^{tot} <$ (GeV)	-	30	-
	centrality	yes	-	yes
	$\sum \Delta\phi <$	-	2.8	-
	CJV	yes	-	-

- Differing background composition and sample sizes lead to different optimal settings per decay mode.
- Events which fail VBF get passed to the next categories...

(Cascading) Selection Criteria - Boosted

Category	Selection	$\tau_\ell \tau_\ell$	$\tau_\ell \tau_{\rm had}$	$\tau_{\rm had} \tau_{\rm had}$
Boosted	Higgs P_T(GeV)	100	100	-
	$p_T(j1) >$ (GeV)	40	-	70
	x_1	-	0-1	-
	x_2	-	0.2-1.2	-
	$\not{E}_T \phi$ centrality	-	-	yes
	$\Delta R_{\tau,\tau} <$	-	-	1.9

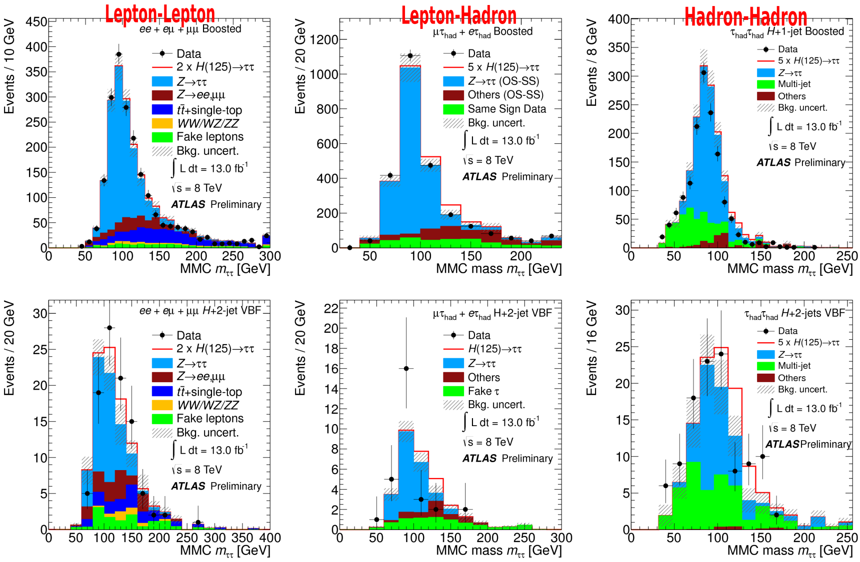
- Targeted to ggF.
- Boosted Higgs provides better mass resolution.
- Events which fail Boosted get passed to the next categories...

(Cascading) Selection Criteria - the rest

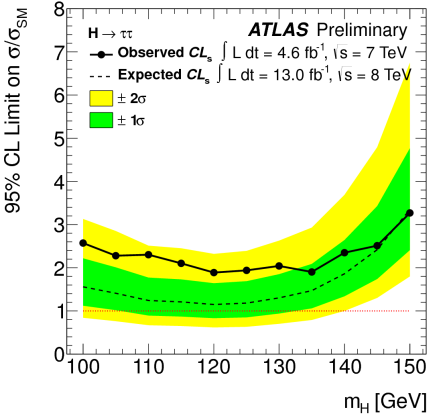
Category	Selection	$\tau_\ell \tau_\ell$	$\tau_\ell \tau_{\rm had}$	$\tau_{\rm had} \tau_{\rm had}$
VH	$p_T(j2) >$ (GeV)	25	-	-
	$\Delta\eta_{j1,j2} <$	2.0	-	-
	$M_{j1,j2}$(GeV)	30-160	-	-
1j	$p_T(j1) >$ (GeV)	40	30	30
	$\Delta(\Delta R) <$	-	0.6	-
	$\sum \Delta\phi <$	-	3.5	-
	$M_{\tau,\tau,j} >$(GeV)	225	-	-
0j	$\Delta\phi_{\ell\ell} >$	2.5	-	-
	$\Delta(\Delta R) <$	-	0.5	-
	$\sum \Delta\phi <$	-	3.5	-
	$P_T(\ell) - P_T(\tau) <$	-	0	-

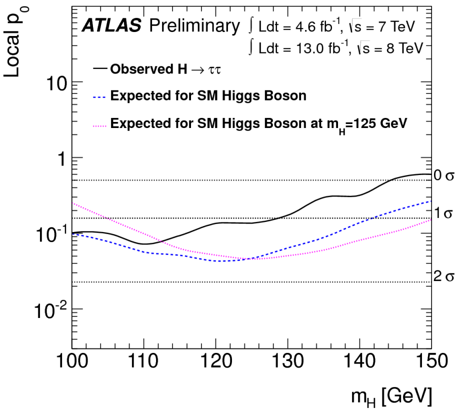
- These three categories are the weakest.

Final Discriminant: Di-Tau Mass



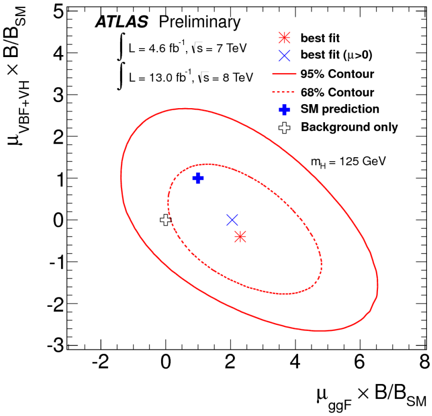
Results: limits and local p_0





Summary and Conclusions

- First results from di-tau channels with full 2011 dataset and $13 fb^{-1}$ of 2012 data.
- Not yet sensitive enough to say anything definitive about Higgs decays to tau.
- Ongoing analysis of full 2012 dataset with more sophisticated techniques expected to improve sensitivity.
- More interesting measurements to come with Run-I data once sensitivity improves!



EXTRA SLIDES

Preselection and Common Criteria (2012)

$\tau_\ell \tau_{\rm had}$

- exactly one lepton
- b-veto (VBF,Boosted)
- one medium tau (> 20GeV)
- OS lepton and tau
- $\not{E}_T > 20$GeV
- $p_T(\tau) > 30$GeV (VBF, Boosted)
- $m_T < 50$ (< 30 for 0j)
- $\Delta(\Delta R) < 0.8$ (VBF, Boosted)

$\tau_\ell \tau_\ell$

- $p_T(j1) > 40$GeV
- b-veto (> 25GeV)
- $0.1 < x_1, x_2 < 1.0$
- $0.5 < \Delta\phi_{\ell\ell} < 2.5$
- exactly 2 OS leptons

$\tau_{\rm had} \tau_{\rm had}$

- 2 OS $\tau_{\rm had}$ (one medium, one tight)
- 0 light charged leptons
- $\not{E}_T > 20$GeV
- $P_T(\tau_1) > 40$, $P_T(\tau_2) > 25$
- $0.8 < \Delta R(\tau, \tau) < 2.8$
- $\Delta\eta < 1.5$

Systematics

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%

7 TeV Triggers

Channel	Trigger	Trigger p_T Threshold (GeV)	Offline p_T Threshold (GeV)
		7 TeV	
$H \rightarrow \tau_{lep}\tau_{lep}$	single electron	${p_T}^{e} > 20-22$	electron p_T 2 GeV above trigger threshold ${p_T}^{\mu} > 10$
	single muon	${p_T}^{\mu} > 18$	${p_T}^{\mu} > 20$ ${p_T}^{e} > 15$
	di-electron	${p_T}^{e1} > 12$ ${p_T}^{e2} > 12$	${p_T}^{e1} > 15$ ${p_T}^{e2} > 15$
	di-muon	${p_T}^{\mu1} > 15$ ${p_T}^{\mu2} > 10$	${p_T}^{\mu1} > 16$ ${p_T}^{\mu2} > 10$
	$e-\mu$ combined	${p_T}^{e} > 10$ ${p_T}^{\mu} > 6$	${p_T}^{e} > 15$ ${p_T}^{\mu} > 10$
$H \rightarrow \tau_{lep}\tau_{had}$	single electron	${p_T}^{e} > 20-22$ $-$	${p_T}^{e} > 25$ ${p_T}^{\tau_{\text{had-vis}}} > 20$
	single muon	${p_T}^{\mu} > 18$ $-$	${p_T}^{\mu} > 25$ ${p_T}^{\tau_{\text{had-vis}}} > 20$
	combined $e + \tau_{\text{had-vis}}$	${p_T}^{e} > 15$ ${p_T}^{\tau_{\text{had-vis}}} > 16-20$	$17 < {p_T}^{e} < 25$ ${p_T}^{\tau_{\text{had-vis}}} > 25$
$H \rightarrow \tau_{had}\tau_{had}$	combined two τ_{had}	${p_T}^{\tau_{\text{had-vis}}} > 29$ ${p_T}^{\tau_{\text{had-vis}}} > 20$	${p_T}^{\tau_{\text{had-vis}}} > 40$ ${p_T}^{\tau_{\text{had-vis}}} > 25$

8 TeV Triggers

		8 TeV	
$H \rightarrow \tau_{lep}\tau_{lep}$	single electron	${p_T}^e > 24$	${p_T}^e > 25$ ${p_T}^\mu > 10$
	di-electron	${p_T}^{e1} > 12$ ${p_T}^{e2} > 12$	${p_T}^{e1} > 15$ ${p_T}^{e2} > 15$
	di-muon	${p_T}^{\mu1} > 18$ ${p_T}^{\mu2} > 8$	${p_T}^{\mu1} > 20$ ${p_T}^{\mu2} > 10$
	$e - \mu$ combined	${p_T}^e > 12$ ${p_T}^\mu > 8$	${p_T}^e > 15$ ${p_T}^\mu > 10$
$H \rightarrow \tau_{lep}\tau_{had}$	single electron	${p_T}^e > 24$ –	${p_T}^e > 26$ ${p_T}^{\tau_{had\text{-}vis}} > 20$
	single muon	${p_T}^\mu > 24$ –	${p_T}^\mu > 26$ ${p_T}^{\tau_{had\text{-}vis}} > 20$
	combined $e + \tau_{had\text{-}vis}$	${p_T}^e > 18$ ${p_T}^{\tau_{had\text{-}vis}} > 20$	$20 < {p_T}^e < 26$ ${p_T}^{\tau_{had\text{-}vis}} > 25$
	combined $\mu + \tau_{had\text{-}vis}$	${p_T}^\mu > 15$ ${p_T}^{\tau_{had\text{-}vis}} > 20$	$17 < {p_T}^\mu < 26$ ${p_T}^{\tau_{had\text{-}vis}} > 25$
$H \rightarrow \tau_{had}\tau_{had}$	combined two τ_{had}	${p_T}^{\tau_{had\text{-}vis}} > 29$ ${p_T}^{\tau_{had\text{-}vis}} > 20$	${p_T}^{\tau_{had\text{-}vis}} > 40$ ${p_T}^{\tau_{had\text{-}vis}} > 25$

$\tau_\ell \tau_\ell$ Cuts

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 ($\lvert JVF_{\mathrm{jet}} \rvert > 0.5$ if $\lvert \eta_{\mathrm{jet}} \rvert < 2.4$)			
$E_{\mathrm{T}}^{\mathrm{miss}} >$ 40 GeV ($E_{\mathrm{T}}^{\mathrm{miss}} >$ 20 GeV) for same-flavor (different-flavor) leptons			
$H_{\mathrm{T}}^{\mathrm{miss}} >$ 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

$\tau_\ell \tau_{\rm had}$ Cuts

7 TeV		8 TeV	
VBF Category	Boosted Category	VBF Category	Boosted Category
▹ $p_{\rm T}^{\tau_{\rm had\text{-}vis}}$ >30 GeV	–	▹ $p_{\rm T}^{\tau_{\rm had\text{-}vis}}$ >30 GeV	▹ $p_{\rm T}^{\tau_{\rm had\text{-}vis}}$ >30 GeV
▹ $E_{\rm T}^{\rm miss}$ >20 GeV	▹ $E_{\rm T}^{\rm miss}$ >20 GeV	▹ $E_{\rm T}^{\rm miss}$ >20 GeV	▹ $E_{\rm T}^{\rm miss}$ >20 GeV
▹ ≥ 2 jets	▹ $p_{\rm T}^{\rm H} > 100$ GeV	▹ ≥ 2 jets	▹ $p_{\rm T}^{\rm H} > 100$ GeV
▹ $p_{\rm T}^{j1}, p_{\rm T}^{j2} > 40$ GeV	▹ $0 < x_1 < 1$	▹ $p_{\rm T}^{j1} > 40$, $p_{\rm T}^{j2}$ >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.	–
▹ $\eta_{j1} \times \eta_{j2} < 0$	–	▹ $\eta_{j1} \times \eta_{j2} < 0$	–
▹ $p_{\rm T}^{\rm Total} < 40$ GeV	–	▹ $p_{\rm T}^{\rm Total} < 30$ GeV	–
–	–	▹ $p_{\rm T}^{\ell}$ >26 GeV	–
• $m_{\rm T}$ <50 GeV	• $m_{\rm T}$ <50 GeV	• $m_{\rm T}$ <50 GeV	• $m_{\rm T}$ <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, $p_{\rm T}$ >25 GeV	▹ 0 jets $p_{\rm T}$ >25 GeV	▹ ≥ 1 jet, $p_{\rm T}$ >30 GeV	▹ 0 jets $p_{\rm T}$ >30 GeV
▹ $E_{\rm T}^{\rm miss}$ >20 GeV	▹ $E_{\rm T}^{\rm miss}$ >20 GeV	▹ $E_{\rm T}^{\rm miss}$ >20 GeV	▹ $E_{\rm T}^{\rm miss}$ >20 GeV
▹ Fails VBF, Boosted	▹ Fails Boosted	▹ Fails VBF, Boosted	▹ Fails Boosted
• $m_{\rm T}$ <50 GeV	• $m_{\rm T}$ <30 GeV	• $m_{\rm T}$ <50 GeV	• $m_{\rm T}$ <30 GeV
• $\Delta(\Delta R) < 0.6$	• $\Delta(\Delta R) < 0.5$	• $\Delta(\Delta R) < 0.6$	• $\Delta(\Delta R) < 0.5$
• $\sum \Delta\phi < 3.5$	• $\sum \Delta\phi < 3.5$	• $\sum \Delta\phi < 3.5$	• $\sum \Delta\phi < 3.5$
–	• $p_{\rm T}^{\ell} - p_{\rm T}^{\tau} < 0$	–	• $p_{\rm T}^{\ell} - p_{\rm T}^{\tau} < 0$

$\tau_{\rm had}\tau_{\rm had}$ Cuts

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

$\tau_\ell \tau_\ell$ Yields (8 TeV)

	$ee + \mu\mu + e\mu$			
	VBF category	Boosted category	*VH* category	1-jet category
$gg \to H$ (125 GeV)	1.3 ± 0.2 ± 0.4	12.4 ± 0.6 ± 2.9	2.5 ± 0.3 ± 0.6	7.0 ± 0.5 ± 1.6
VBF *H* (125 GeV)	3.63 ± 0.10 ± 0.02	3.36 ± 0.09 ± 0.30	0.21 ± 0.03 ± 0.02	1.82 ± 0.07 ± 0.18
VH (125 GeV)	0.01 ± 0.01 ± 0.01	2.20 ± 0.05 ± 0.22	0.64 ± 0.03 ± 0.09	0.44 ± 0.02 ± 0.05
$Z/\gamma^* \to \tau\tau$ embedded	47 ± 2 ± 1	$(1.24 \pm 0.01 \pm 0.08)\times10^3$	393 ± 7 ± 26	$(0.86 \pm 0.01 \pm 0.06)\times10^3$
$Z/\gamma^* \to \ell\ell$	14 ± 3 ± 2	$(0.21 \pm 0.02 \pm 0.04)\times10^3$	$(0.08 \pm 0.01 \pm 0.02)\times10^3$	$(0.16 \pm 0.01 \pm 0.03)\times10^3$
Top	15 ± 2 ± 3	$(0.39 \pm 0.01 \pm 0.07)\times10^3$	87 ± 4 ± 23	117 ± 5 ± 18
Diboson	3.6 ± 0.8 ± 0.6	55 ± 3 ± 10	15 ± 1 ± 4	40 ± 3 ± 7
Backgrounds with fake leptons	12 ± 2 ± 3	102 ± 7 ± 23	86 ± 4 ± 16	230 ± 8 ± 52
Total background	91 ± 5 ± 5	$(2.01 \pm 0.03 \pm 0.12)\times10^3$	$(0.66 \pm 0.02 \pm 0.05)\times10^3$	$(1.40 \pm 0.02 \pm 0.08)\times10^3$
Observed data	98	2014	636	1405

$\tau_\ell \tau_{\rm had}$ Yields (8 TeV)

Process	Events	
	Boosted	VBF
$gg \rightarrow H$ (125 GeV)	$20.3 \pm 0.7 \pm 5.1$	$0.5 \pm 0.1 \pm 0.3$
VBF H (125 GeV)	$5.3 \pm 0.2 \pm 0.3$	$2.5 \pm 0.2 \pm 0.4$
VH (125 GeV)	$2.7 \pm 0.2 \pm 0.2$	<0.001
$Z/\gamma^* \rightarrow \tau\tau^\dagger$	$(1.78 \pm 0.03 \pm 0.11)\times 10^3$	$17 \pm 2 \pm 6$
Diboson †	$12.2 \pm 0.9 \pm 1.0$	$0.6 \pm 0.3 \pm 0.4$
$Z/\gamma^* \rightarrow \ell\ell^\dagger$	$18 \pm 9 \pm 4$	$1.7 \pm 0.5 \pm 1.2$
Top †	$111 \pm 8 \pm 33$	$2.0 \pm 0.7 \pm 1.0$
W boson + jets (OS-SS)	$(0.27 \pm 0.06 \pm 0.04)\times 10^3$	–
Same sign data	$(0.34 \pm 0.02 \pm 0.01)\times 10^3$	–
Fake-$\tau_{\text{had-vis}}$ backgrounds	–	$7.6 \pm 0.7 \pm 3.8$
Total background	$(2.53 \pm 0.07 \pm 0.13)\times 10^3$	$29 \pm 2 \pm 7$
Observed data	2602	29

$\tau_{\rm had}\tau_{\rm had}$ Yields

$H \to \tau_{\rm had}\tau_{\rm had}$	7 TeV analysis (4.6 $\rm fb^{-1}$) VBF category	7 TeV analysis (4.6 $\rm fb^{-1}$) Boosted category	8 TeV analysis (13.0 $\rm fb^{-1}$) VBF category	8 TeV analysis (13.0 $\rm fb^{-1}$) 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