



Search for Higgs to $\tau\tau$ at ATLAS & CMS

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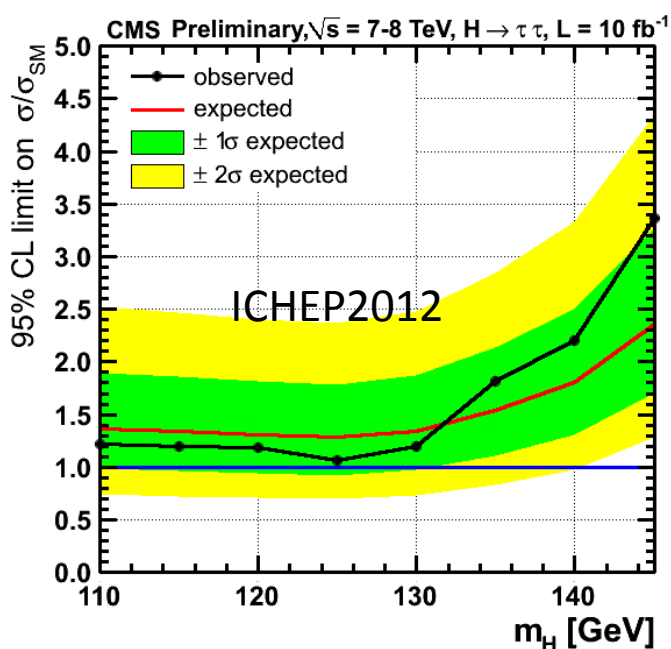
IRFU/SPP, CEA, Saclay

(On behalf of ATLAS & CMS Collaboration)



Introduction

- A Higgs boson was discovered by ATLAS & CMS (July 2012)
 - Driven by high resolution channels : $H \rightarrow \gamma\gamma$, $H \rightarrow ZZ \rightarrow 4\ell$
 - Supported by $H \rightarrow WW \rightarrow 2\ell 2\nu$
- No excess was observed in fermionic channels
 - Results were compatible with background only hypothesis



Why Higgs to $\tau\tau$?

- Most sensitive channel to probe lepton couplings
 - Important to establish SM predictions
- Large enhancement of production rates in BSM models (MSSM etc..)

What has Changed from ICHEP2012 ?

- Added more data
- Improved object reconstruction
- Improved analysis technique

ATLAS-CONF-2012-160, CMS-PAS-HIG-13-004



French Contribution

➤ Strong involvement of LLR/IN2P3, SPP/IRFU in CMS $H \rightarrow \tau\tau$ analysis

- Developments of HLT triggers with taus
- Tau reconstruction, identification, and commissioning
- Di-tau mass reconstruction
- Analysis design & optimization
- Contribution to final result ($e\tau_h$, $\mu\tau_h$ channel)

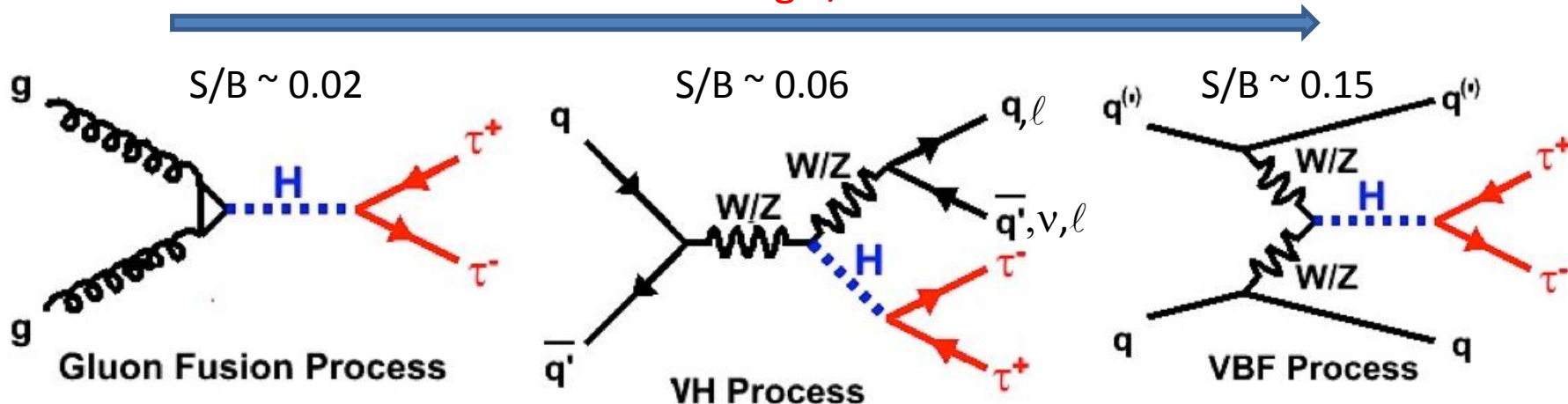
➤ LAL, Orsay in ATLAS $H \rightarrow \tau\tau$ analysis

- Di-Tau mass reconstruction & involvement in the analysis



Analysis Overview

Increasing S/B



Reducing and controlling backgrounds is the key
Analysis divided into various channels

ATLAS

$ee, \mu\mu, e\mu, \tau\tau, e\tau, \mu\tau$

Gluon Fusion + VBF

Associated production (VH)

$\ell\tau\tau, \ell\ell\tau\tau, \ell\ell\tau$ ($W/Z \rightarrow \ell\nu/\ell\ell, H \rightarrow \tau\tau$)

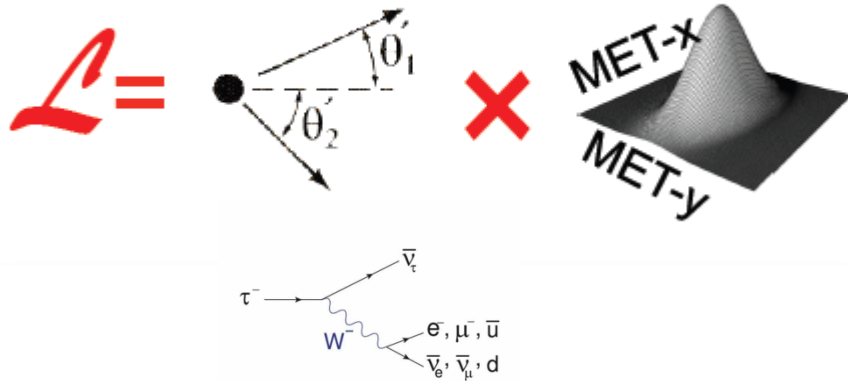
CMS

$\mu\mu, e\mu, \tau\tau, e\tau, \mu\tau$



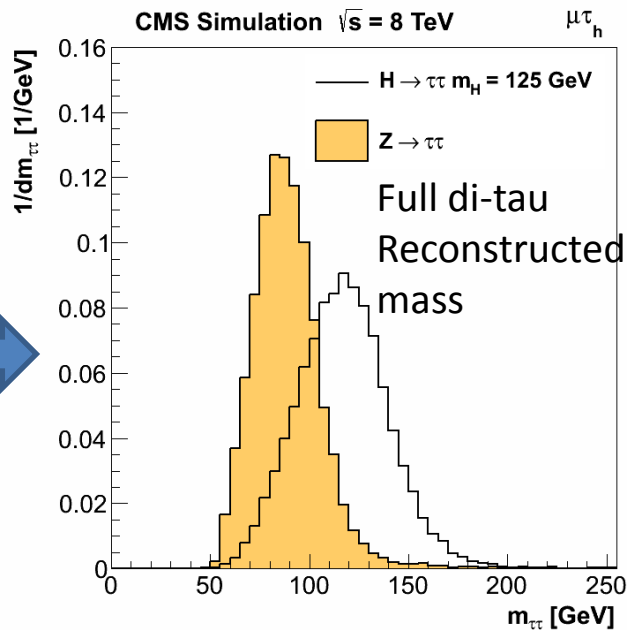
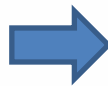
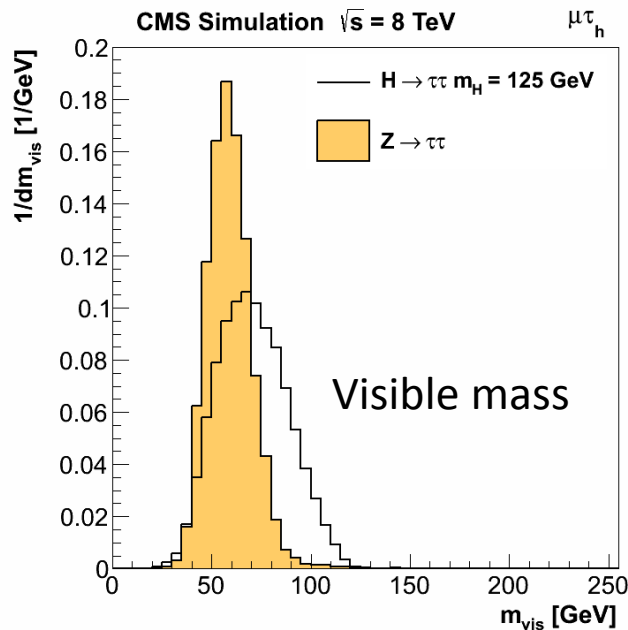
di-Tau Mass Reconstruction

SVFit



➤ Mass of τ Lepton pair reconstructed via Likelihood technique, based on:

- τ decay Kinematics
- Compatibility of reconstructed E_T^{miss} with Neutrino hypotheses
- Exact Matrix Element used for $\tau \rightarrow \ell \nu \nu$
- Phase-Space is used for $\tau \rightarrow \pi$
- Nuisance parameters are integrated out



A similar di-tau mass reconstruction is used by ATLAS with similar performance

MMC : Missing Mass Calculator

[arxiv:1012.4686](https://arxiv.org/abs/1012.4686)



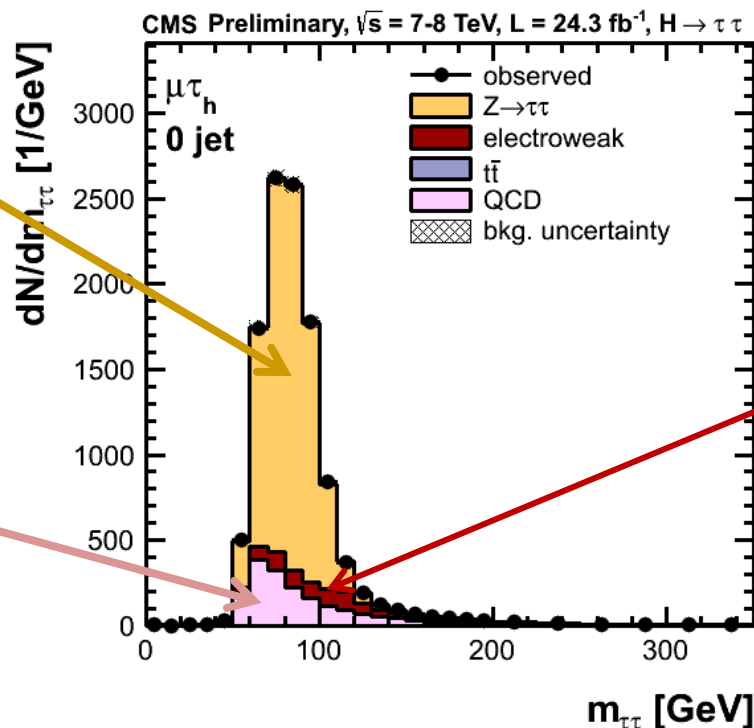
Anatomy of the Analysis

Z- $\tau\tau$

Estimated using τ
embedded Z- $\mu\mu$
events

QCD

Estimated using
SS data



EWK

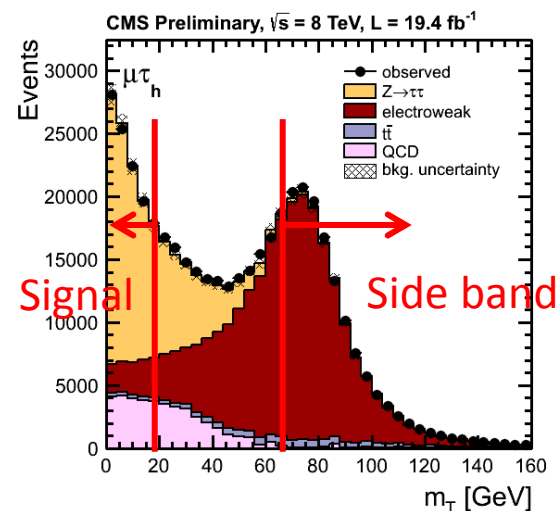
Mostly W+jets
Measured from high
 m_τ sideband

Preselection :

- Events selected with well identified and isolated leptons, τ_h
- Topological cuts applied (m_τ etc..) depending on the channel

Systematic uncertainties

- Yield uncertainty
- Shape uncertainty from:
 - τ energy scale
 - statistical uncertainty in each bin





Event Categories

➤ VBF

- 2 Jets
- Large M_{jj} ($> \sim 500$ GeV)
- Large difference in pseudorapidity ($\Delta\eta_{jj} > \sim 3.5$)
- Central Jet Veto
 - No jets in between two tagging jets

➤ 1 Jet

- ≥ 1 Jets
- Failing VBF

CMS

The sensitivity of 0/1 Jet category improved by dividing into Low and High p_T tau categories

➤ 0 Jet

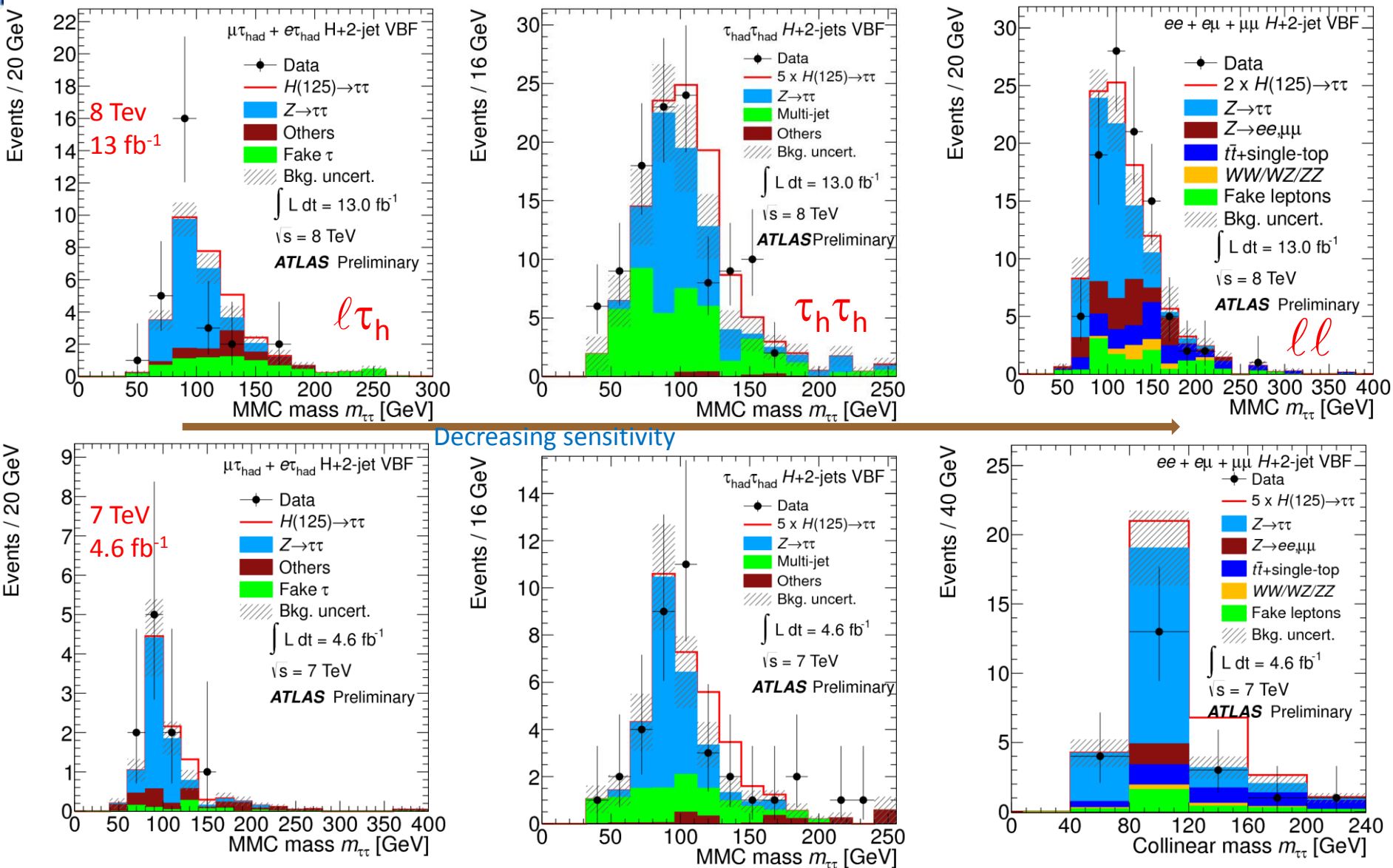
- Mostly constrains lepton and tau systematic uncertainties
- Leptonic channels only

Details are in backup



$M_{\tau\tau}$ Distribution (ATLAS)

VBF (2-Jet) : Most sensitive category





$M_{\tau\tau}$ Distribution

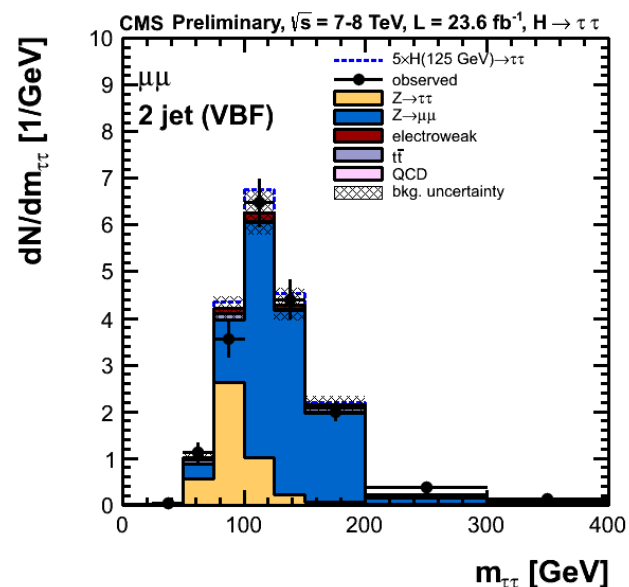
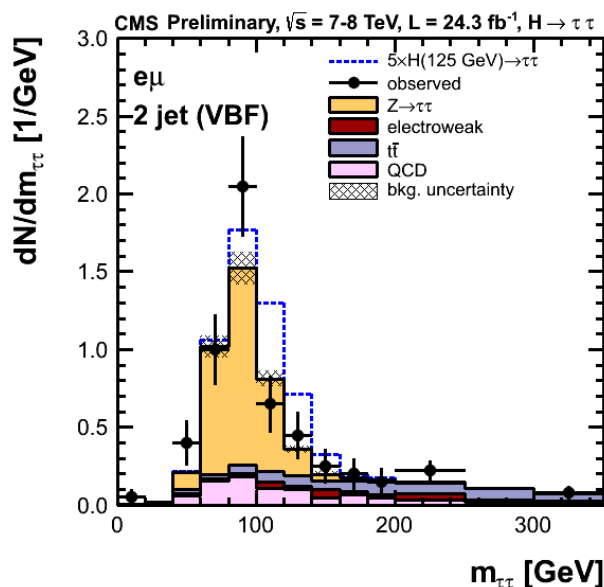
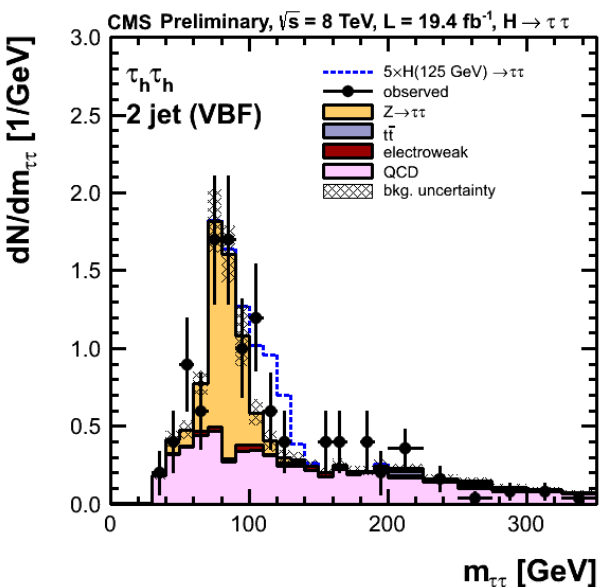
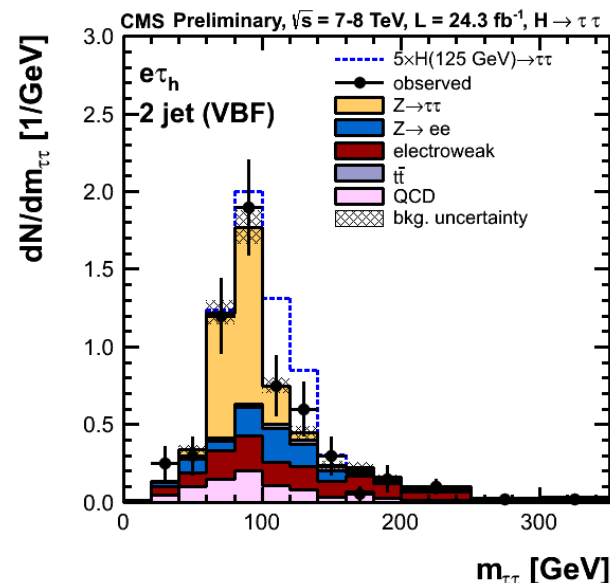
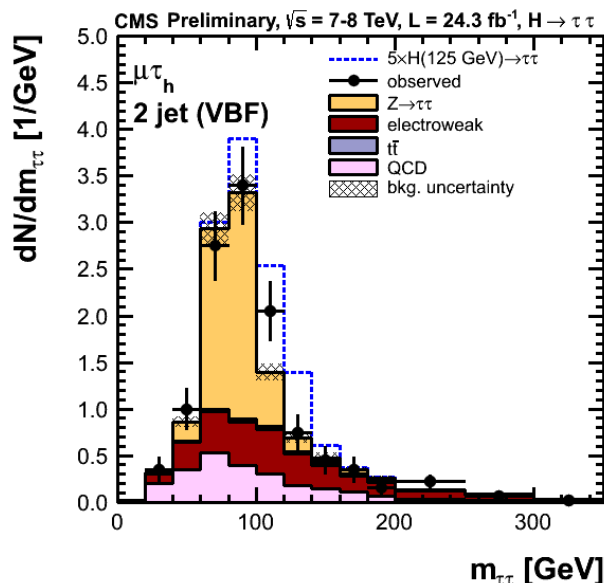
CMS

7 TeV : 4.9 fb⁻¹

8 TeV : 19.4 fb⁻¹

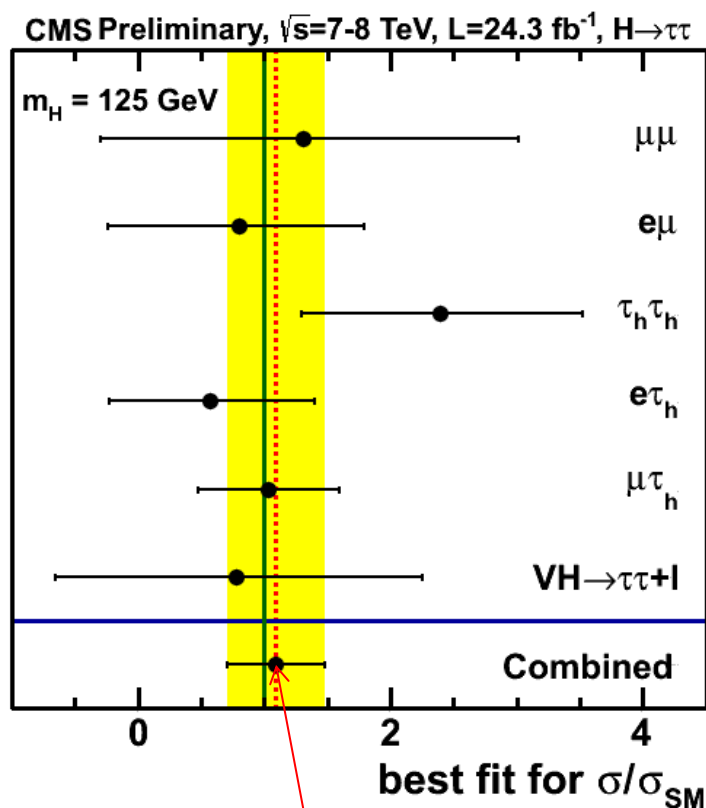
VBF (2-jet)

- Enhancement of VBF signal
- Highest S/B

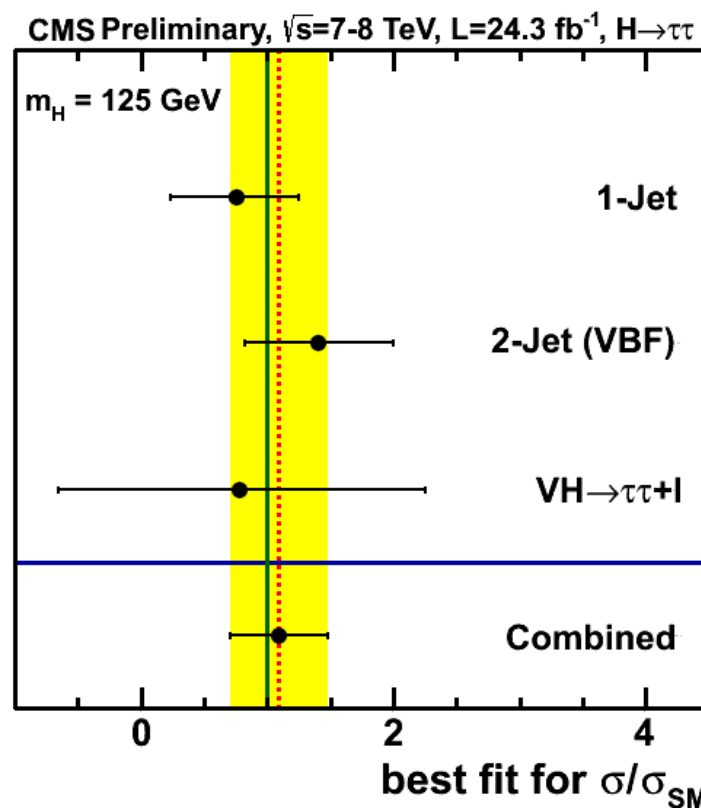




Signal Strength $\sigma/\sigma_{\text{SM}}$



Best fit $\sigma/\sigma_{\text{SM}} = 1.1 \pm 0.4$



Results consistent among all channels and categories

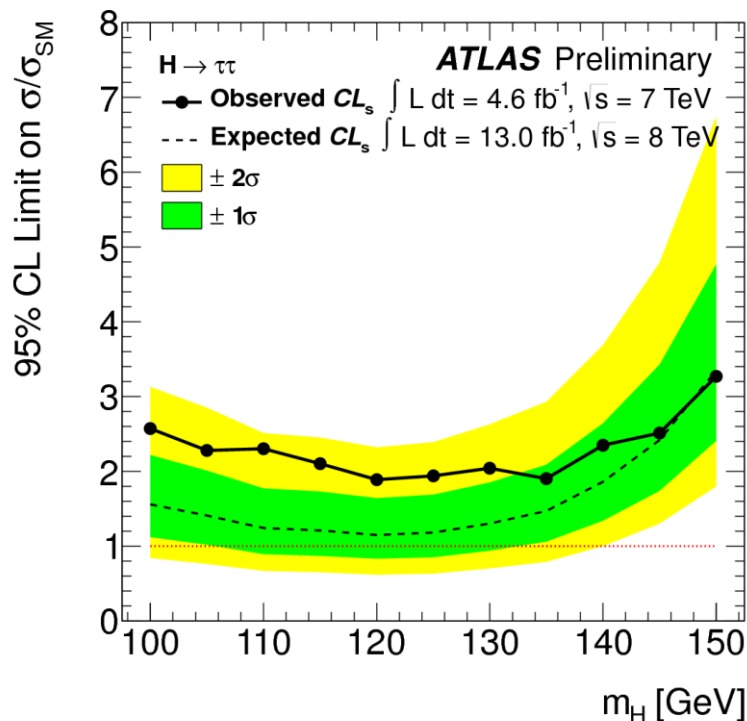


SM Results

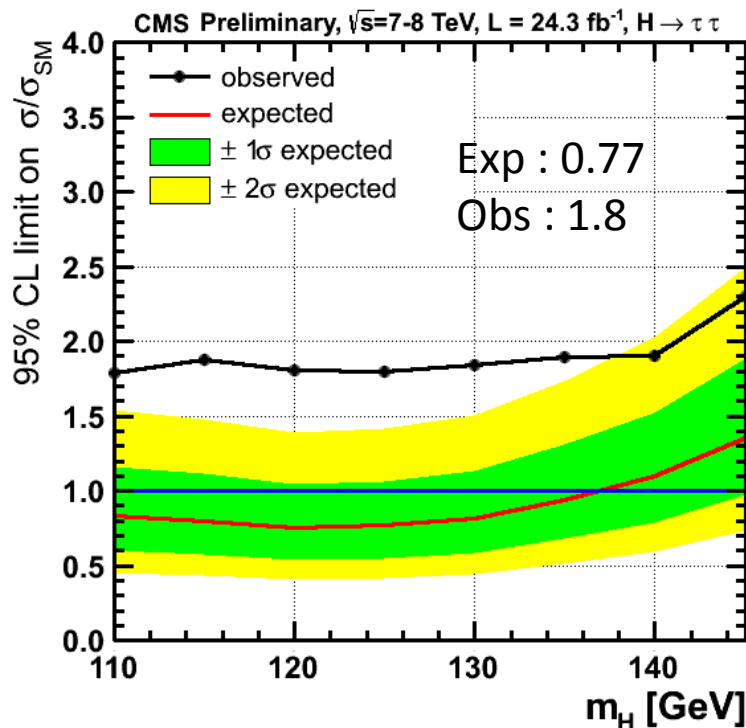
Results combining all channels and categories

ATLAS : 17.6 fb⁻¹

CMS : 24.3 fb⁻¹



At 125 :
 The expected/observed Limit 1.2/1.9



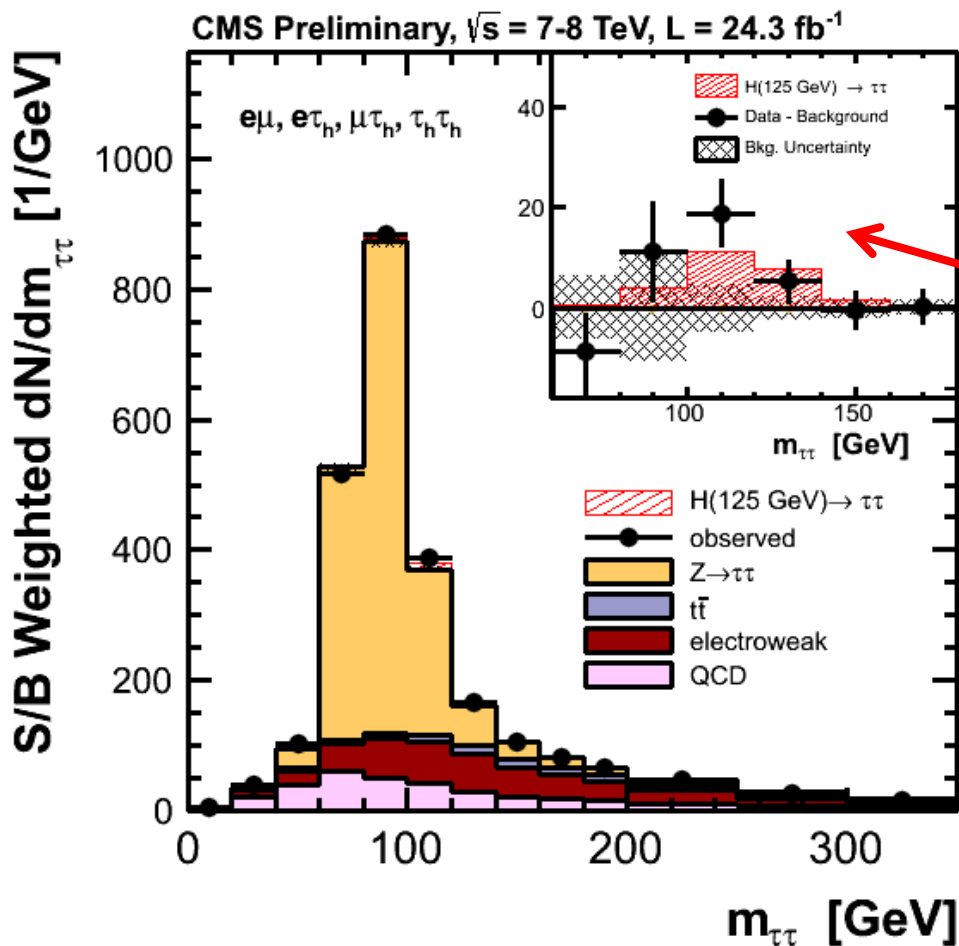
At 125 :
 The expected/observed Limit **0.77/1.81**
Observation of flat excess

The observation compatible with S+B hypothesis for a Higgs boson of mass 125 GeV



Compatibility of the Higgs Signal

Combined 1 Jet and VBF



Each category in each channel are combined with weight of S/B.

Data – Background

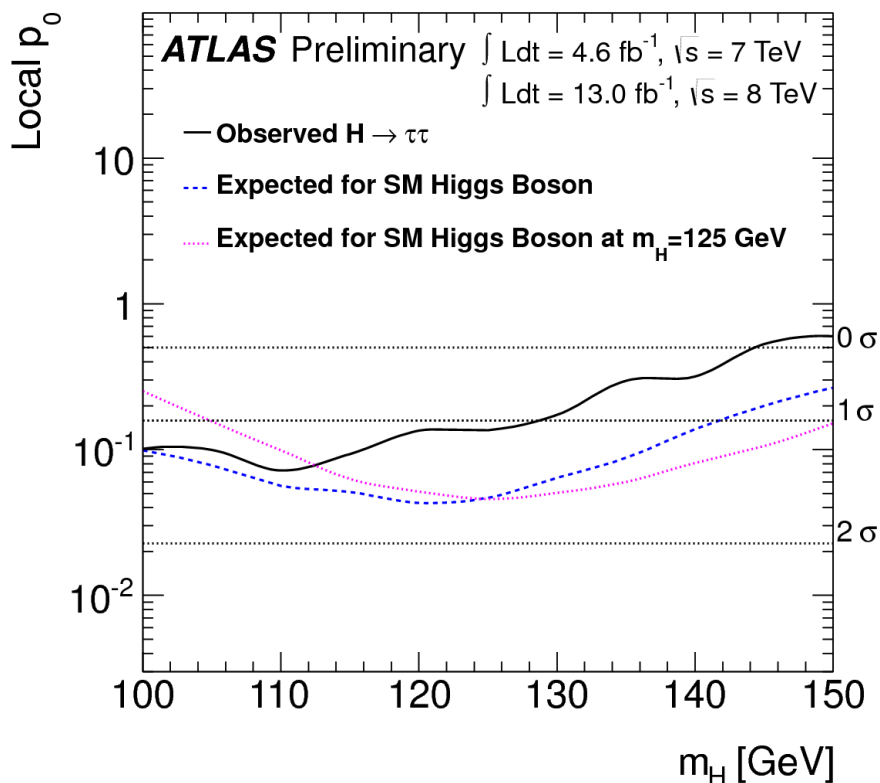
the region around 50 – 150 GeV

Excess is compatible with the expectation for a SM Higgs boson at $m_H = 125\text{ GeV}$



Significance

ATLAS : 17.6 fb⁻¹

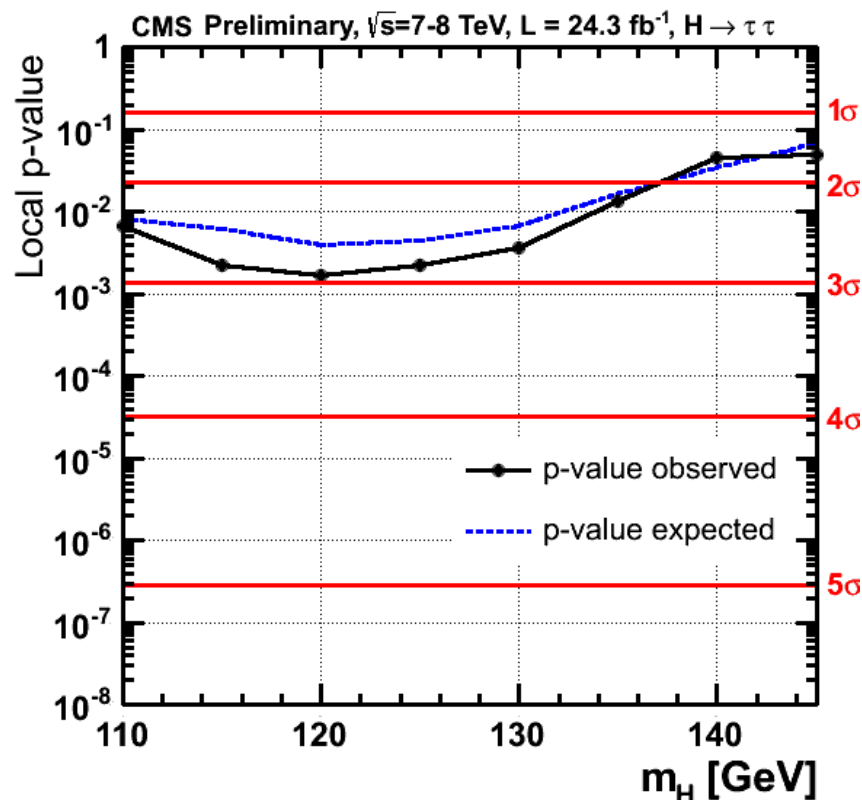


Maximum Significance of 1.5 σ at 110 GeV

The Expected/Observed significance

@ 125 GeV : 1.7 σ / 1.1 σ

CMS : 24.3 fb⁻¹



Maximum Significance of 2.93 σ at 120 GeV

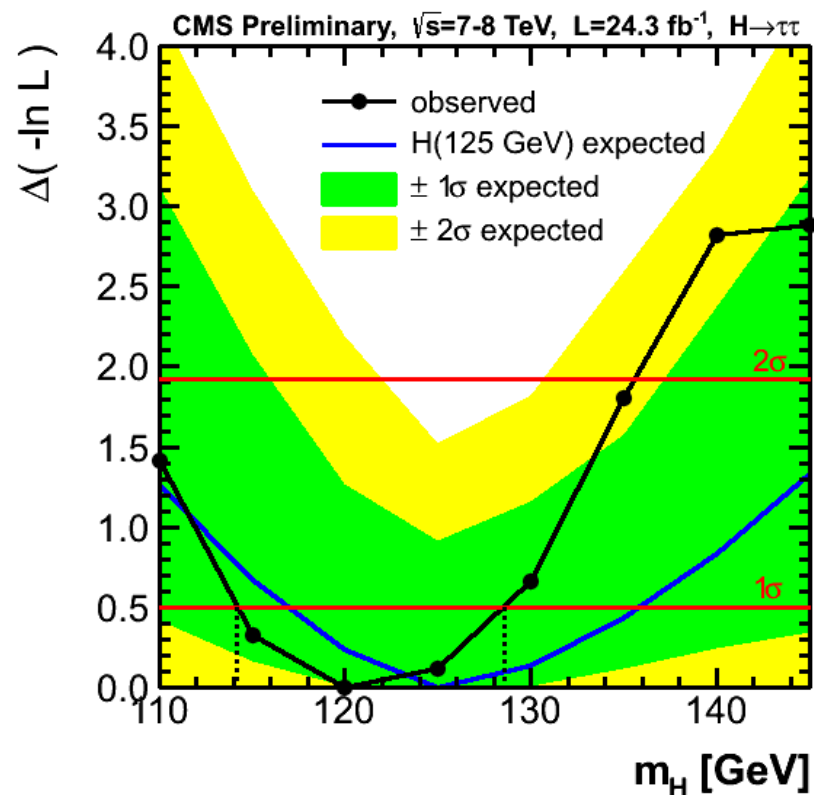
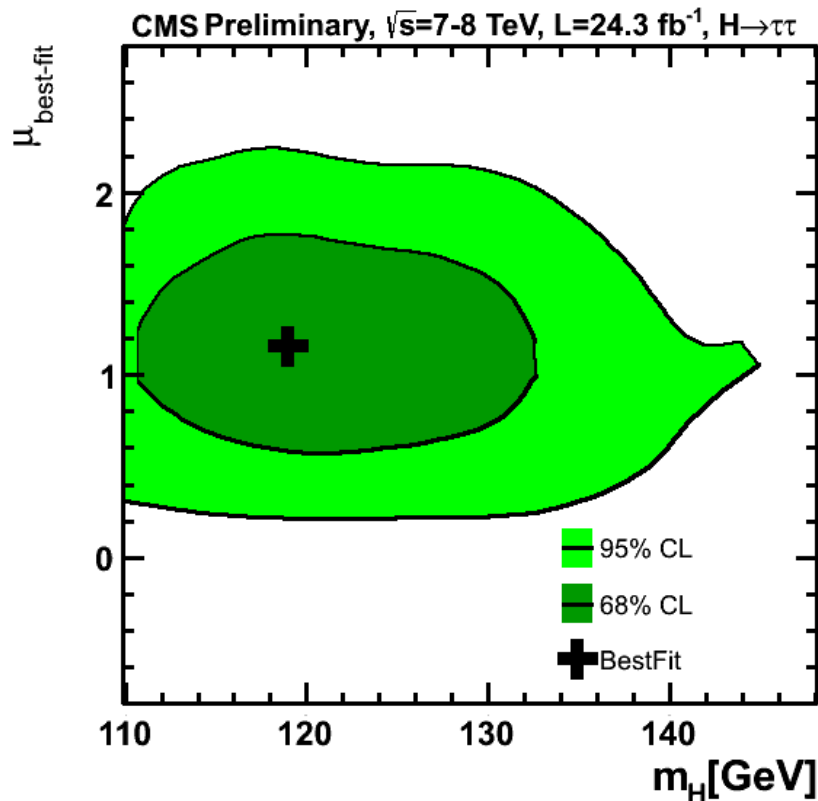
The Expected/Observed significance

@ 125 GeV : 2.62 σ / 2.82 σ

First indication of the new boson coupling to taus as expected from the SM Higgs boson



Mass Measurement



Best Fit Mass : 120^{+9}_{-7} (stat+syst) GeV

Compatible with $m_H(ZZ) = 125.8 \pm 0.5$ GeV, $m_H(\gamma\gamma) = 125.4 \pm 0.5 \pm 0.6$



Summary

- ATLAS has an observed significance of 1.1σ , based on 17fb^{-1} of data
 - Results with full data is expected to be available soon

- CMS has observed a signal in $H \rightarrow \tau\tau$ channel with a **significance of 2.93σ** , based on 24fb^{-1} of data
 - First indication that the new boson couples to taus as the SM Higgs boson
 - The Higgs mass in $H \rightarrow \tau\tau$ channel is compatible with resonance of $m_H \sim 125 \text{ GeV}$ observed in diboson channels ($\gamma\gamma$, ZZ , WW)

- Plans :
 - Re-optimization of the analysis (selection categories etc..)
 - Expect to have further improvements with current data.
 - Produce results for MSSM Higgs with full $7\text{TeV}+8\text{TeV}$ data.
 - Higgs boson Properties measurements (coupling, CP properties etc..)

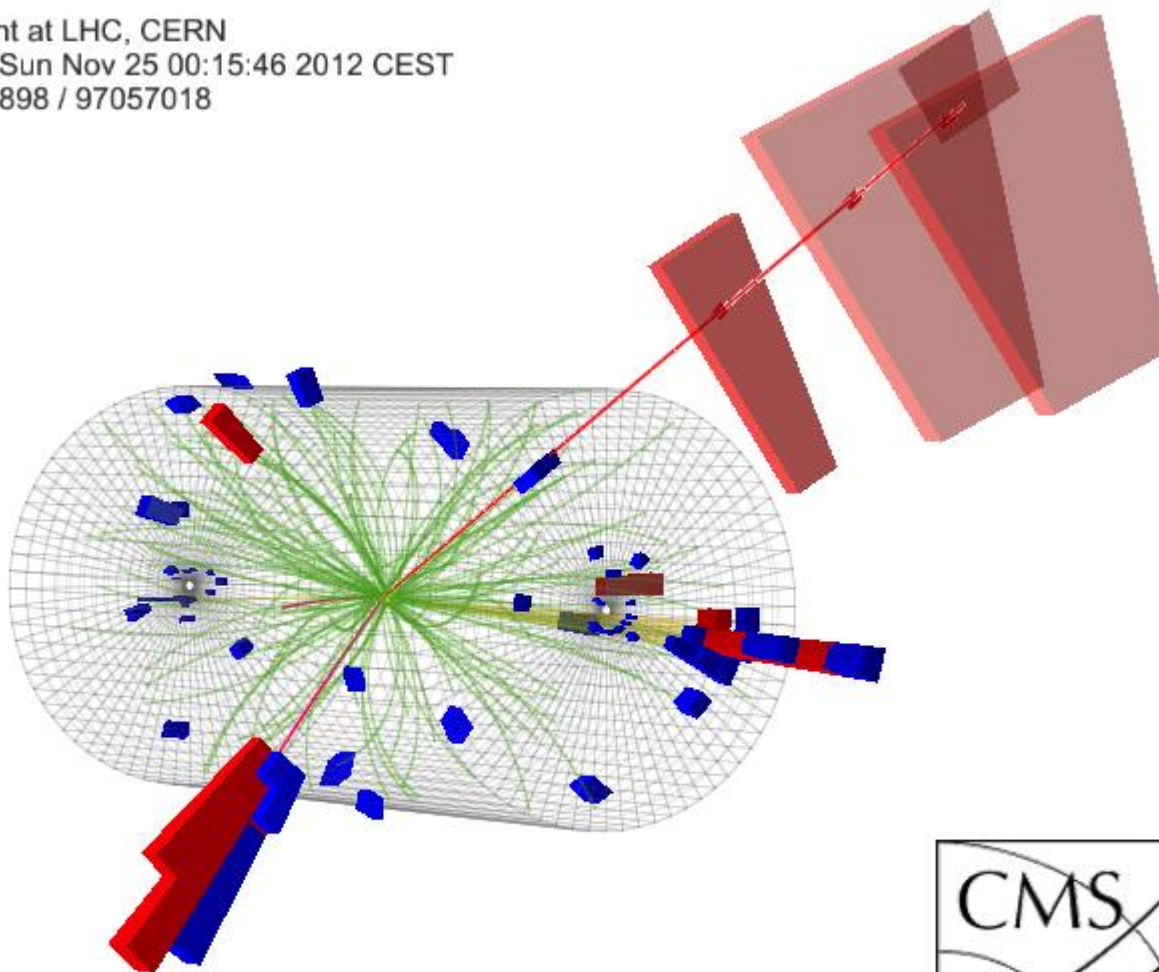


Backup



A $\mu\tau$ VBF candidate

CMS Experiment at LHC, CERN
Data recorded: Sun Nov 25 00:15:46 2012 CEST
Run/Event: 207898 / 97057018





Event Categories (**ATLAS**)

Categories by Number of jets

$ee, \mu\mu, e\mu, e\tau, \mu\tau$

0 jet

$e\tau, \mu\tau$ channel
for 7 & 8 TeV
 $e\mu$ channel for
only 7 TeV

1 jet

events failing 2
jet categories
 $M_{\tau\tau j} > 225$ GeV

Boosted

2 jets and not falling
to VBF
 $p_T(H) > 100$ GeV
(vector sum of
leptons and E_{miss})

VBF

$\Delta\eta(jj) > 3.0$
 $M_{jj} > 500$ (400) GeV
Central Jet Veto
Cut on sum Pt
($\ell, \tau, \text{jet}, E_{\tau}^{\text{miss}}$)
Lepton centrality

Additional VH category for $ee, \mu\mu, e\mu$

2 jet VH

2 jet events not falling to
VBF and boosted
categories
 $\Delta\eta(jj) < 2.0$
 $30 \text{ GeV} < M_{jj} < 160 \text{ GeV}$

Boosted

At least one jet with
large p_T and not
falling to VBF
 $DR(\tau_1, \tau_2) < 1.9$

$\tau_h\tau_h$

VBF

$\Delta\eta(jj) > 2.6$
 $M_{jj} > 350$ GeV
Lepton centrality

★ Cuts on leptons, jets, E_{τ}^{miss} are dependent on channels
 E_{τ}^{miss} cut applied in almost all categories
b-tag veto applied to all categories



Event Categories (CMS)

Enrich Signal wrt to Z->tt background

Number of Jets (Jet $p_T > 30$ GeV)

$\mu\mu, e\mu, e\tau, \mu\tau$

Lepton (τ for $\ell\tau$) p_T

0jet, Low p_T

High Background
Constrains Fit

1Jet, Low p_T

Signal Enhancement
wrt Z

0jet, high p_T

Lepton p_T spectrum is
harder from Higgs
Reduce QCD

1Jet, high p_T

Enhancement from both
lepton and jet
(better mass resolution)

VBF (2 jet)

- $\geq 2\text{Jet}$
- Central Jet veto
- $m(jj) > 500$ GeV
- $|\Delta\eta(jj)| > 3.5$

Tau (muon in $e\mu$) > 40 (35) GeV
for high p_T category.

$\tau_h\tau_h$

1Jet

1 jet, high $p_T(H)$
requirement

VBF (2 Jet)

2 jets,
high $p_T(H)$ requirement,
 $m(jj) > 250$ GeV,
 $|\Delta\eta(jj)| > 2.5$



Event Categories (CMS)

Enrich Signal wrt to Z->tt background

Number of Jets (Jet $p_T > 30$ GeV)

$\mu\mu, e\mu, e\tau, \mu\tau$

**Do not Fit
for signal**

**Propagate
Constraint from
0 jet**

1Jet, Low p_T
Signal Enhancement
wrt Z

1Jet, high p_T
Enhancement from both
lepton and jet
(better mass resolution)

VBF (2 jet)

- $\geq 2\text{Jet}$
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1Jet
1 jet, high $p_T(H)$
requirement

$\tau_h \tau_h$

VBF (2 Jet)
2 jets,
high $p_T(H)$ requirement,
 $m(jj) > 250$ GeV,
 $|\Delta\eta(jj)| > 2.5$



VH Categories (CMS)

W/Z decay to leptons

WH $\rightarrow \ell \tau \tau$

ZH $\rightarrow \ell \ell \tau \tau$

1 Hadronic τ

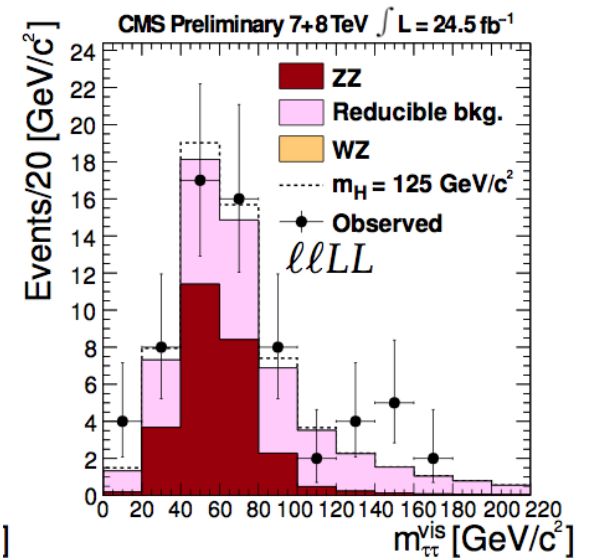
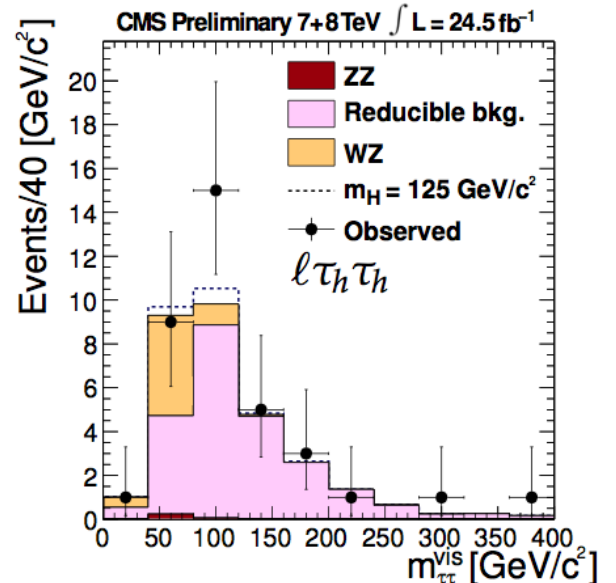
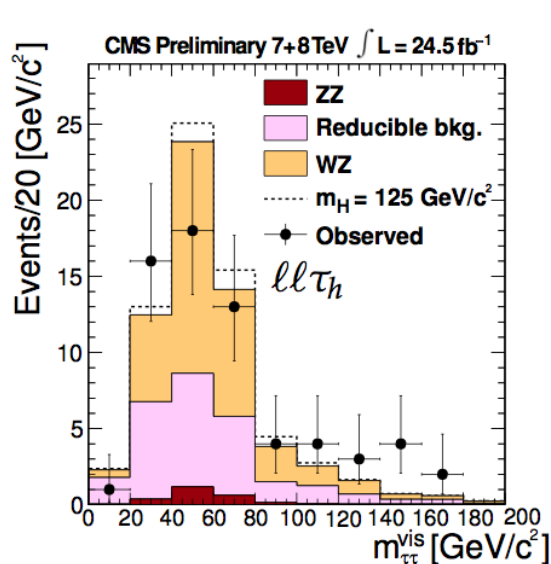
$\tau e^{\pm} \mu^{\pm}$
 $\tau \mu^{\pm} \mu^{\pm}$

2 Hadronic τ

$\tau \tau e$
 $\tau \tau \mu$

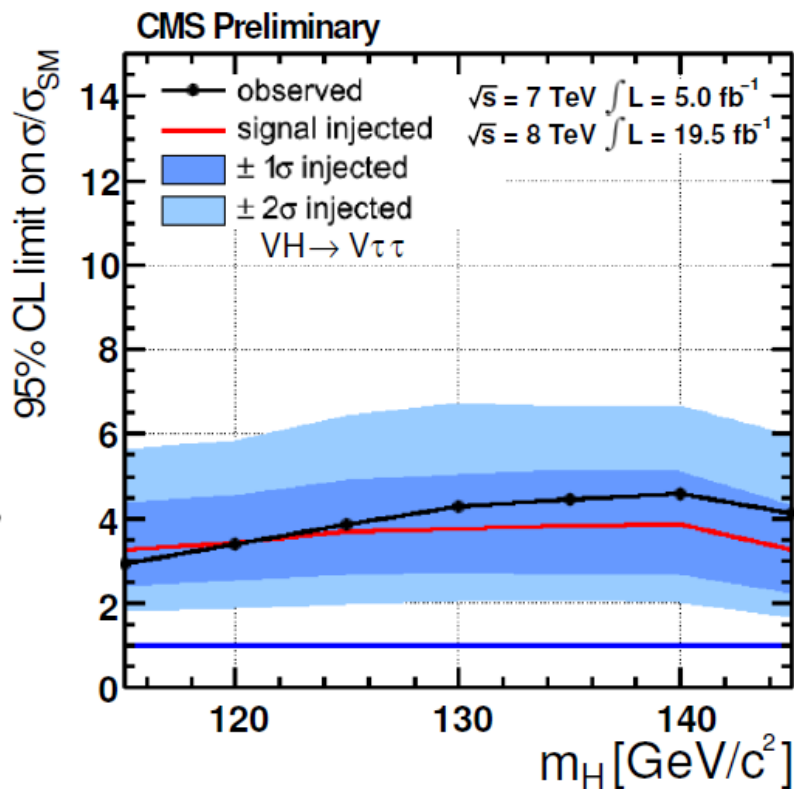
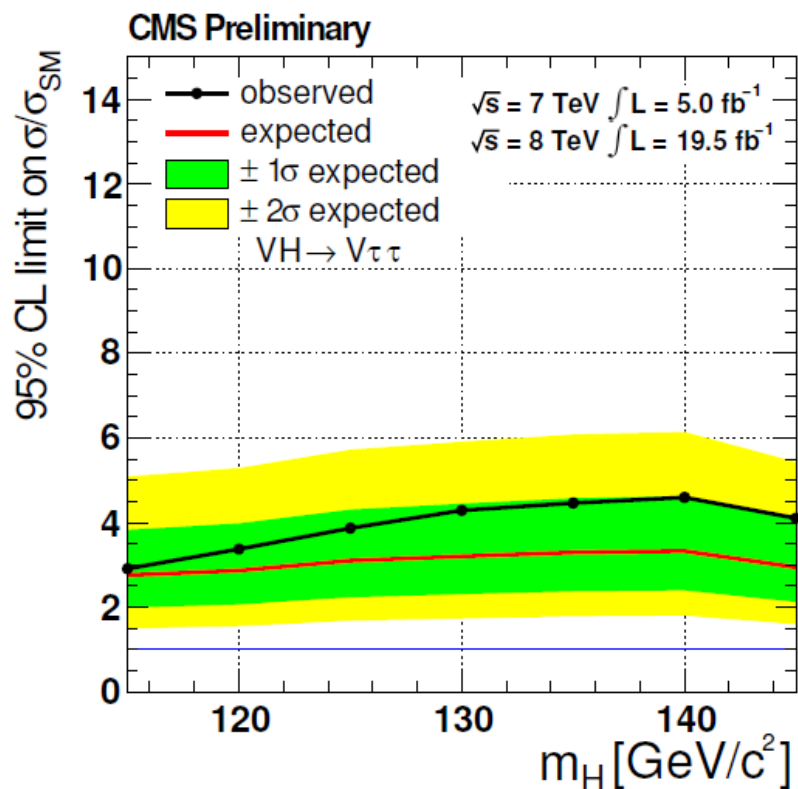
$ee/\mu\mu$ + All possible combinations

VH, $H \rightarrow WW \rightarrow \tau + X$ is also included in the channel



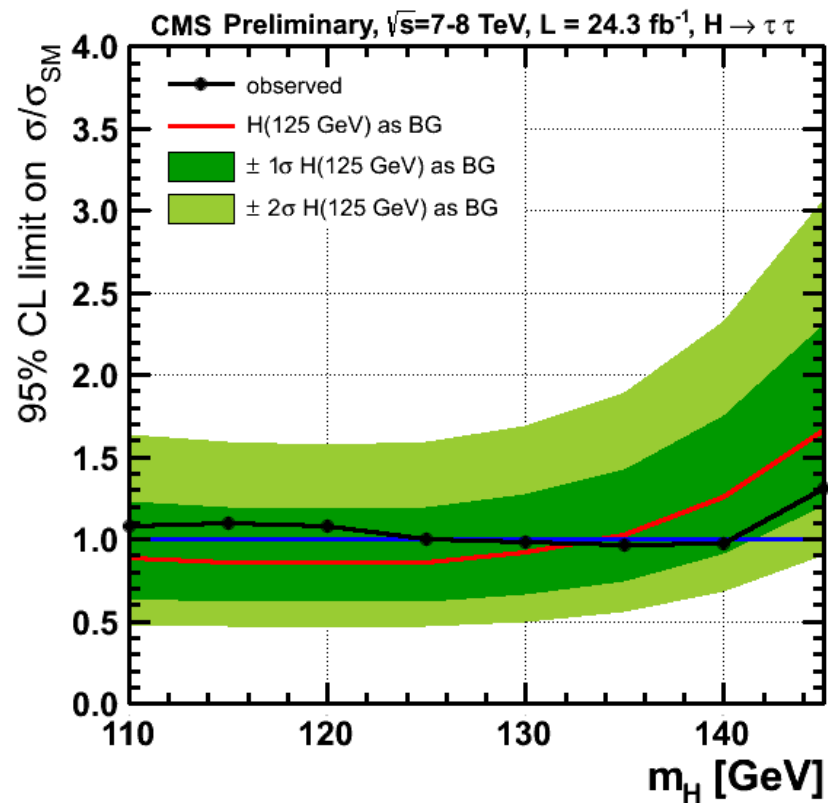
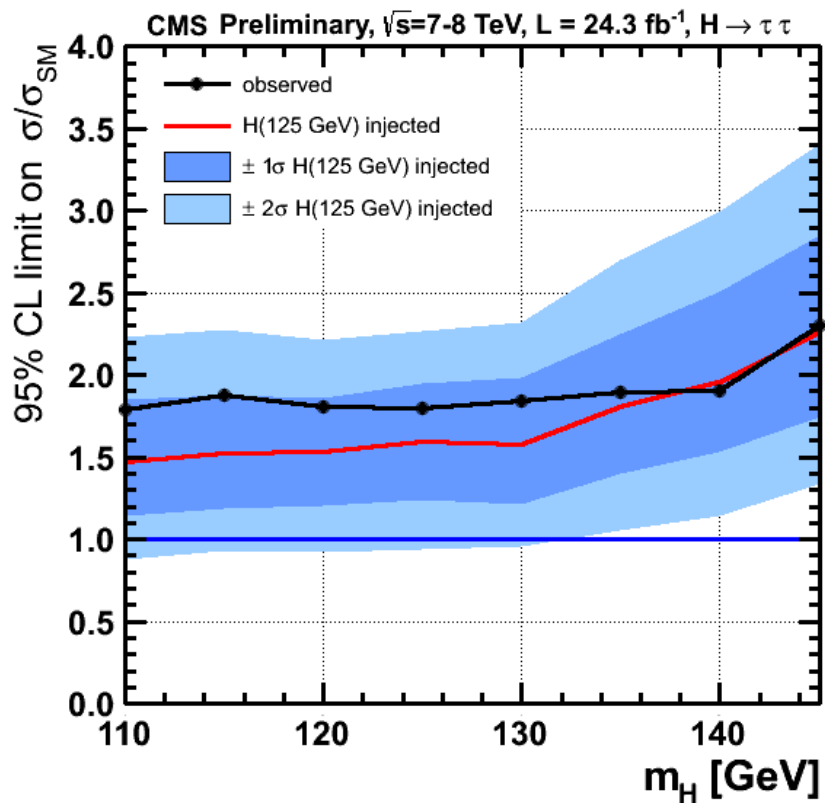


VH Exclusion Limit



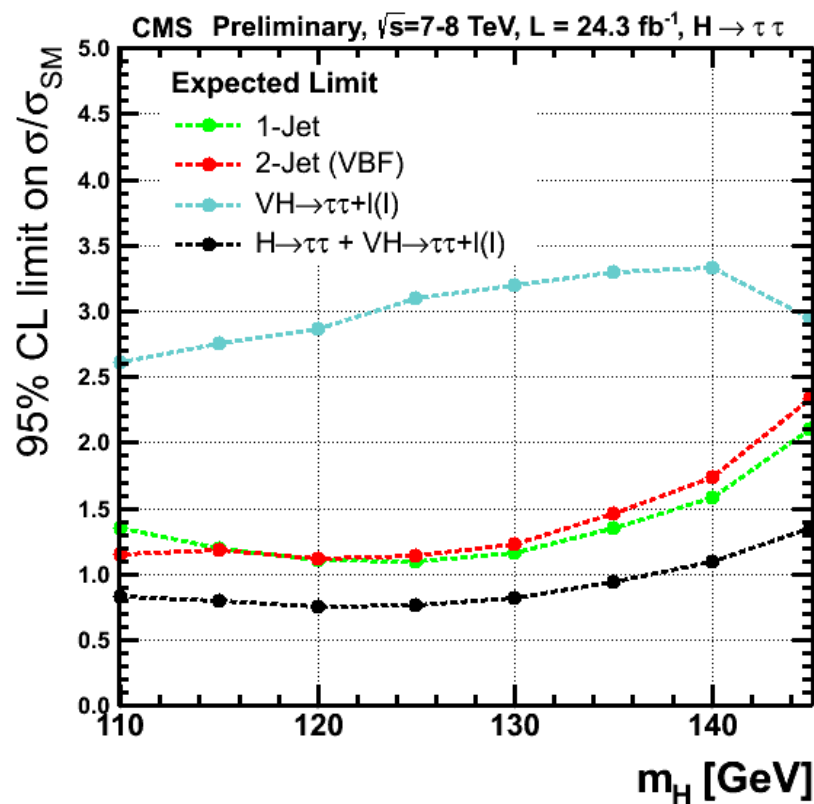
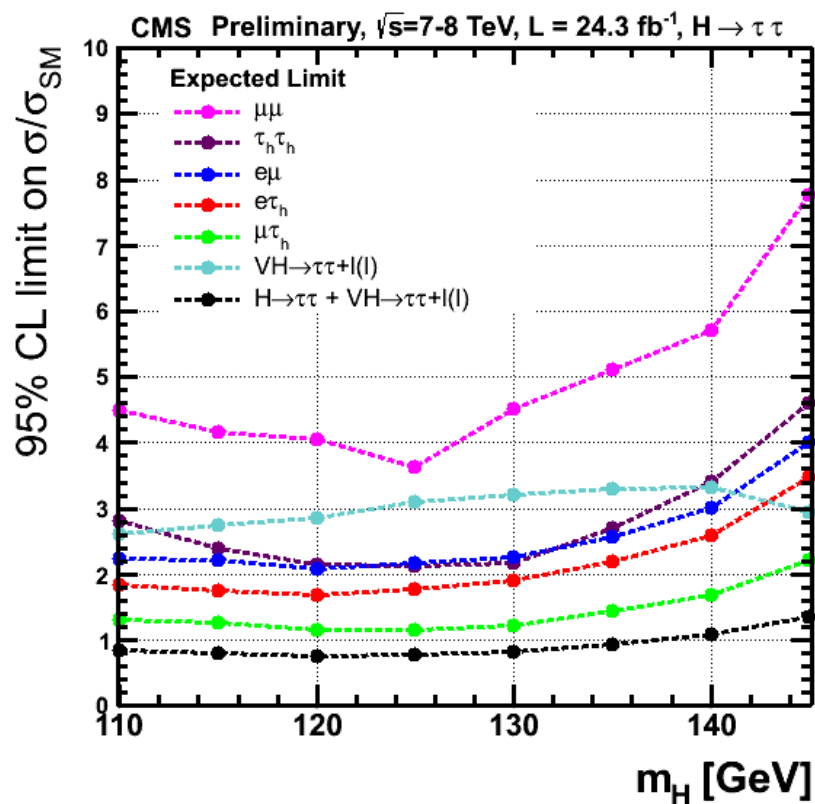


Exclusion



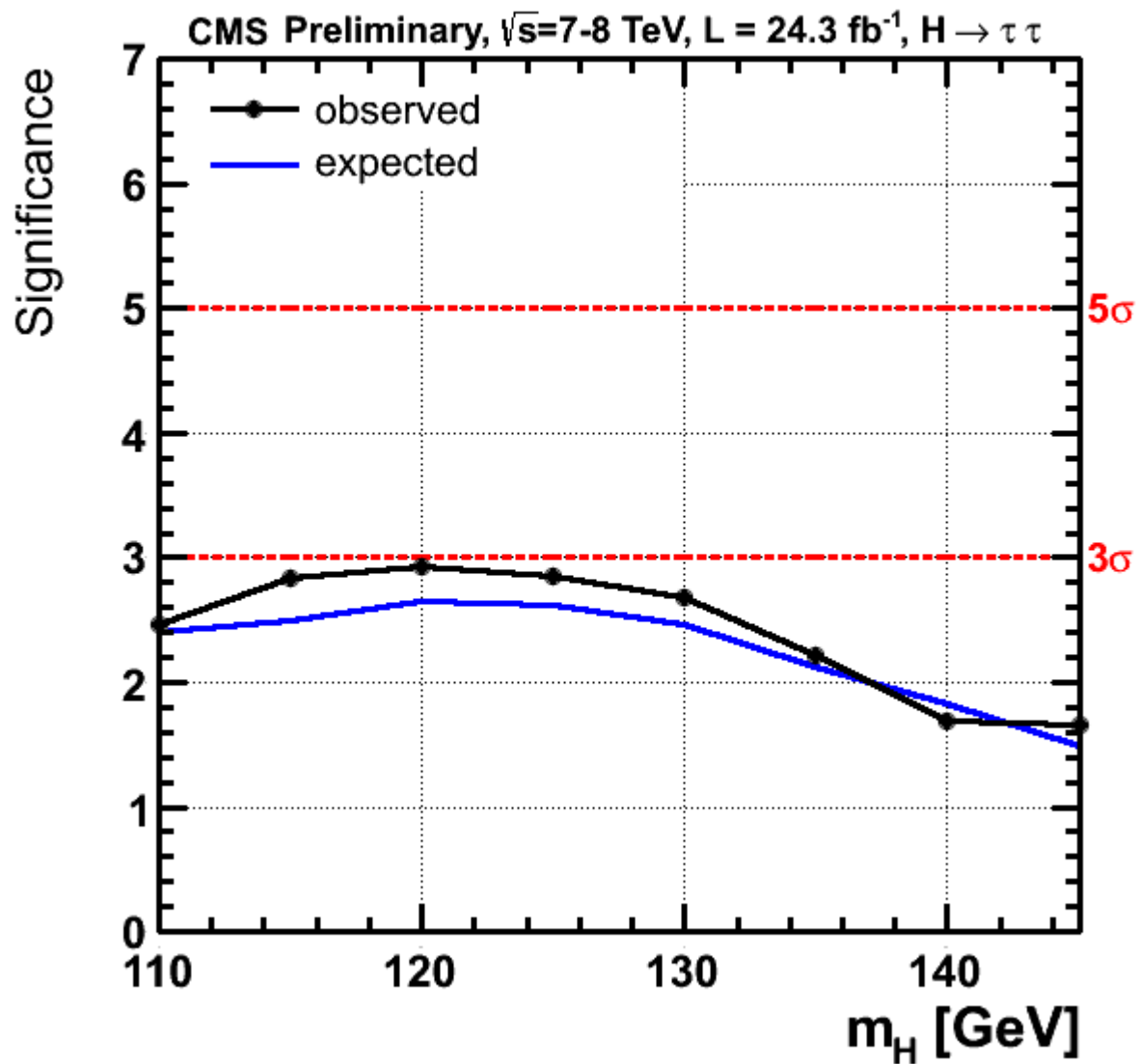


Sensitivity by Channel & Category



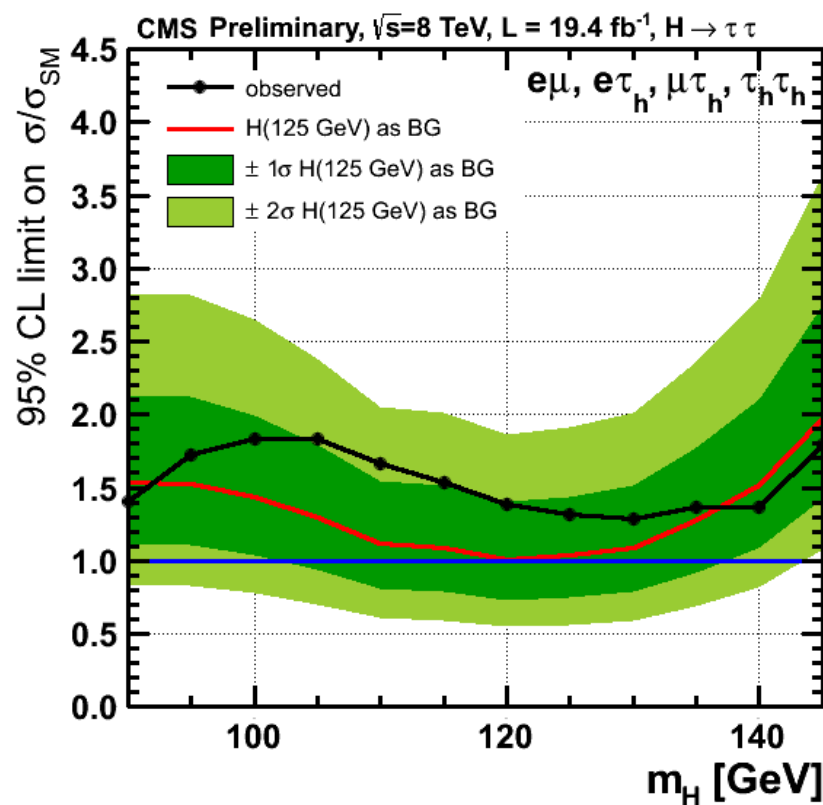
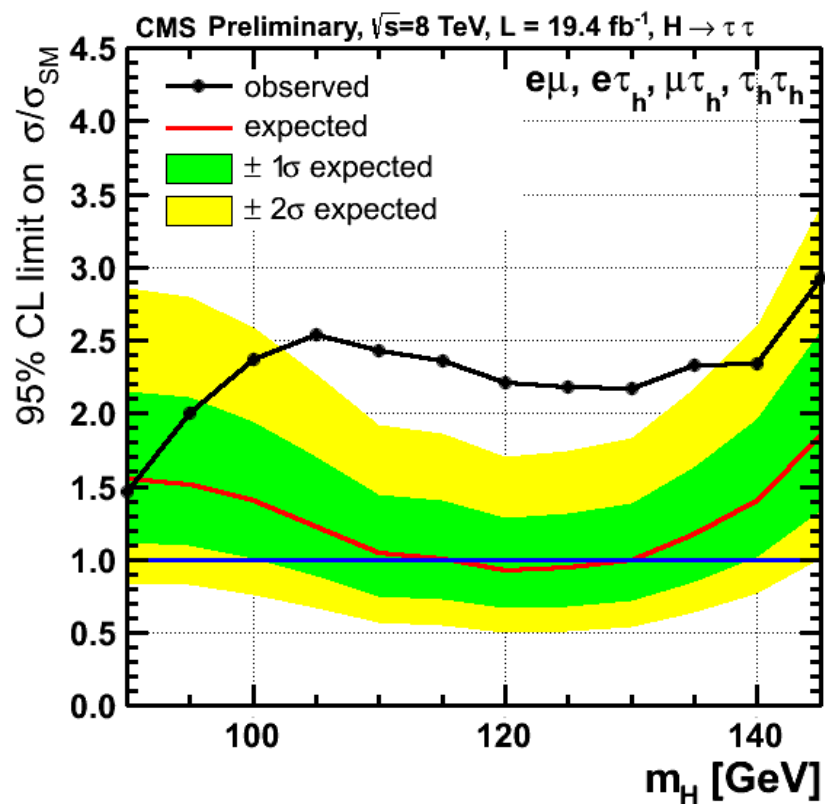


Significance





Limits at low mass





Uncertainties

The (*) symbol indicates correlation between separate channels.

The (†) symbol indicates correlation between separate categories

Experimental Uncertainties		Propagation into Event Categories		
Uncertainty	Uncert.	0-Jet	1-Jet	VBF
Electron ID & Trigger (*)	$\pm 2\%$	$\pm 2\%$	$\pm 2\%$	$\pm 2\%$
Muon ID & Trigger (*)	$\pm 2\%$	$\pm 2\%$	$\pm 2\%$	$\pm 2\%$
Tau ID & Trigger (†)	$\pm 8\%$	$\pm 8\%$	$\pm 8\%$	$\pm 8\%$
Tau Energy Scale (†)	$\pm 3\%$	$\pm 3\%$	$\pm 3\%$	$\pm 3\%$
Electron Energy Scale (†)	$\pm 1\%$	$\pm 1\%$	$\pm 1\%$	$\pm 1\%$
JES (Norm.) (†*)	$\pm 2.5 - 5\%$	$\mp 3 - 15\%$	$\pm 1 - 6\%$	$\pm 5 - 20\%$
MET (Norm.) (†*)	$\pm 5\%$	$\pm 5 - 7\%$	$\pm 2 - 7\%$	$\pm 5 - 8\%$
b-Tag Efficiency (†*)	$\pm 10\%$	$\mp 2\%$	$\mp 2 - 3\%$	$\mp 3\%$
Mis-Tagging (†*)	$\pm 30\%$	$\mp 2\%$	$\mp 2\%$	$\mp 2 - 3\%$
Norm. Z production (†*)	$\pm 3\%$	$\pm 3\%$	$\pm 3\%$	$\pm 3\%$
Z $\rightarrow \tau\tau$ Category	$\pm 3\%$	$\pm 0 - 5\%$	$\pm 3 - 5\%$	$\pm 10 - 13\%$
Norm. $t\bar{t}$ (†* ex.vbf)	$\pm 10\%$	$\pm 10\%$	$\pm 10\%$	$\pm 12 - 33\%$
Norm. Diboson (†* ex. vbf)	$\pm 15 - 30\%$	$\pm 15 - 30\%$	$\pm 15 - 30\%$	$\pm 15 - 100\%$
Norm. QCD Multijet	$\pm 6 - 32\%$	$\pm 6 - 32\%$	$\pm 9 - 30\%$	$\pm 19 - 35\%$
Lumi 7 TeV (8 TeV)	$\pm 2.2(4.2)\%$	$\pm 2.2(4.2)\%$	$\pm 2.2(4.2)\%$	$\pm 2.2(4.2)\%$
Norm. W+jets	$\pm 10 - 30\%$	$\pm 20 - 27\%$	$\pm 10 - 33\%$	$\pm 12.4\% - 30\%$
Norm. Z $\rightarrow \ell\ell$: e fakes τ_h (†)	$\pm 20\%$	$\pm 20\%$	$\pm 36\%$	$\pm 22\%$
Norm. Z $\rightarrow \ell\ell$: μ fakes τ_h (†)	$\pm 30\%$	$\pm 30\%$	$\pm 30\%$	$\pm 30\%$
Norm. Z $\rightarrow \ell\ell$: jet fakes τ_h	$\pm 20\%$	$\pm 20\%$	$\pm 20\%$	$\pm 40\%$

Theory Uncertainties (SM)		Propagation into Limit Calculation		
Uncertainty	Uncert.	0-Jet	1-Jet	VBF
PDF (†*)	-	-	$\pm 2 - 8\%$	$\pm 2 - 8\%$
$\mu_r/\mu_f(gg \rightarrow H)$ (†*)	-	-	$\pm 10\%$	$\pm 30\%$
$\mu_r/\mu_f(qq \rightarrow H)$ (†*)	-	-	$\pm 4\%$	$\pm 4\%$
$\mu_r/\mu_f(qq \rightarrow VH)$ (†*)	-	-	$\pm 4\%$	$\pm 4\%$
UE & PS (†*)	-	-	$\pm 4\%$	$\pm 4\%$



$M_{\tau\tau}$ Distribution

CMS

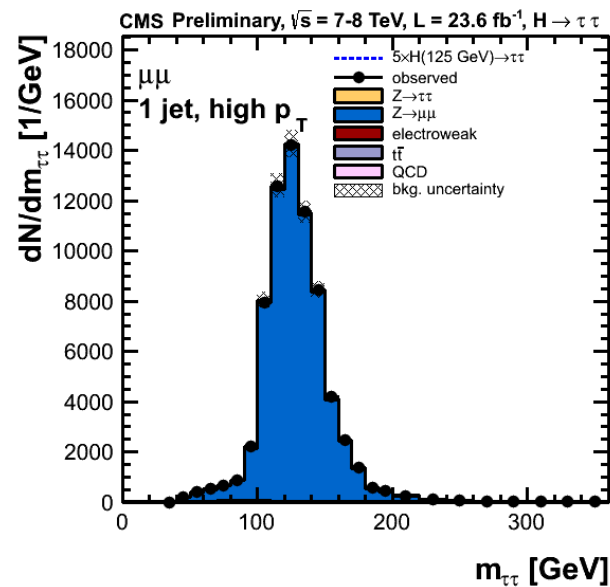
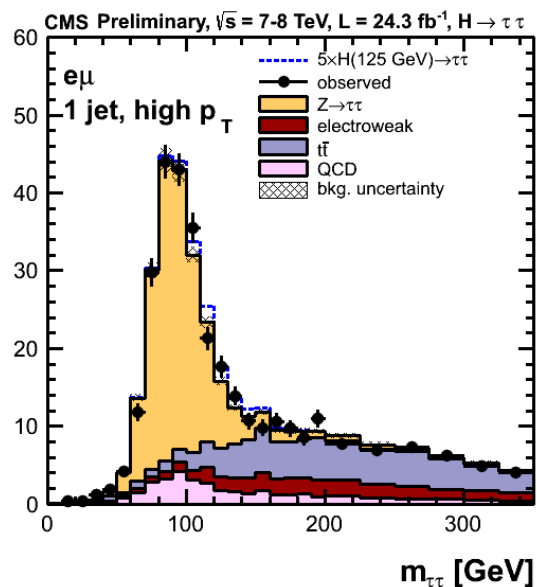
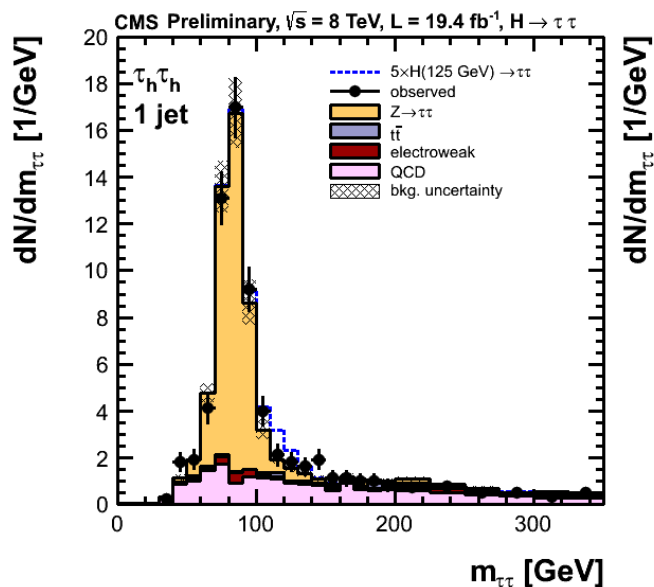
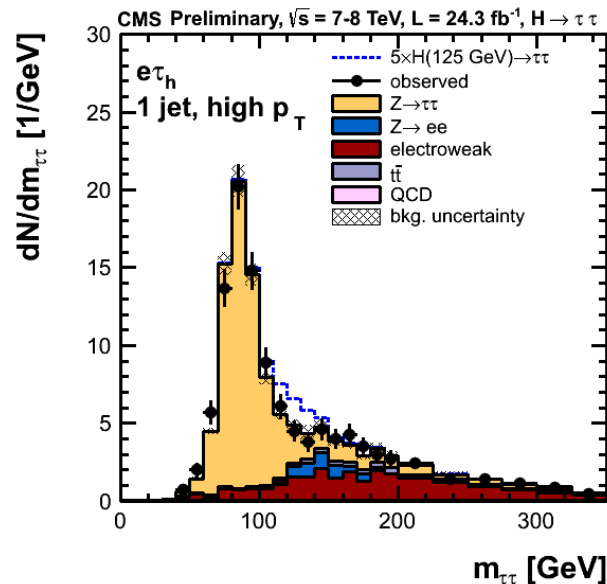
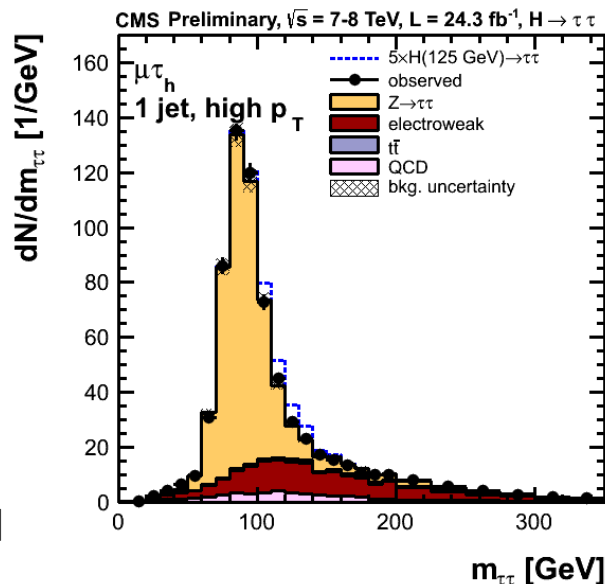
7 TeV : 4.9 fb⁻¹

8 TeV : 19.4 fb⁻¹

1Jet , High Pt

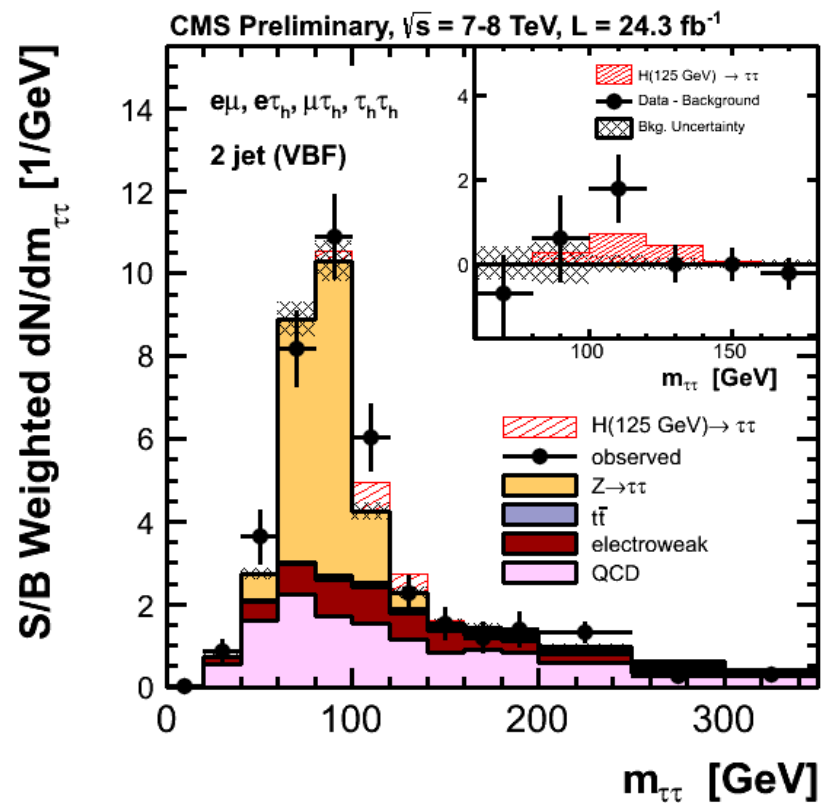
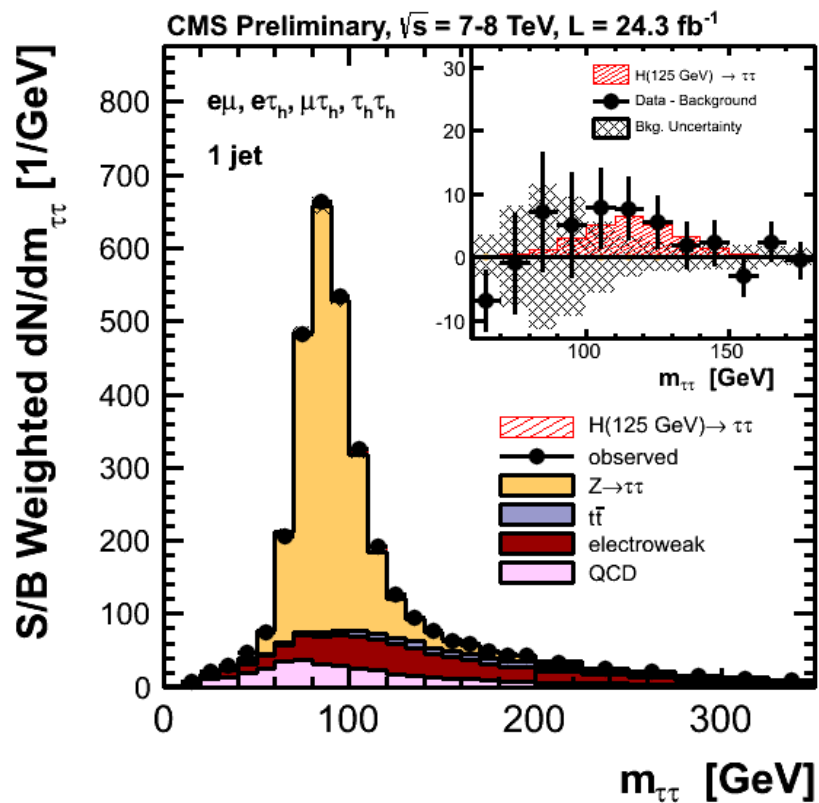
2nd best Category

Enhances Gluon Fusion signal



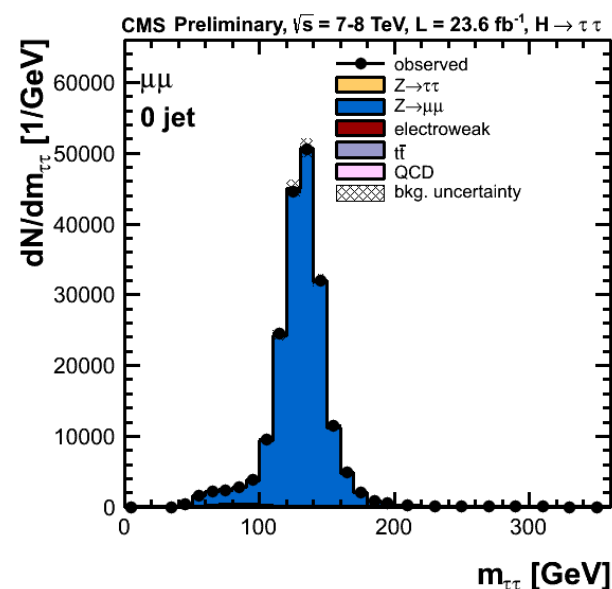
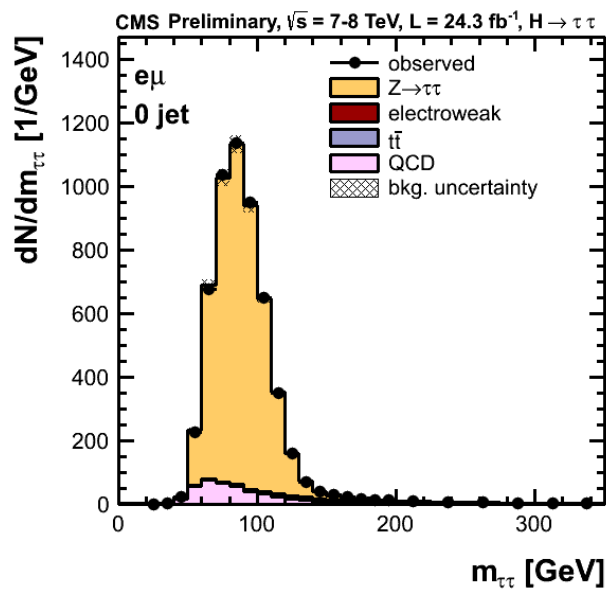
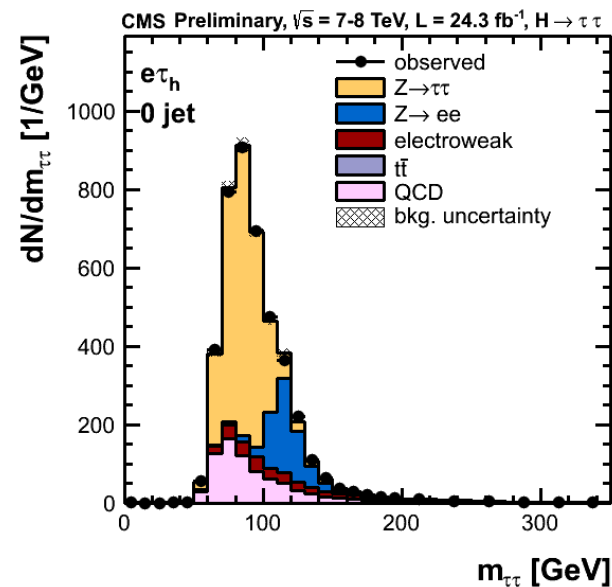
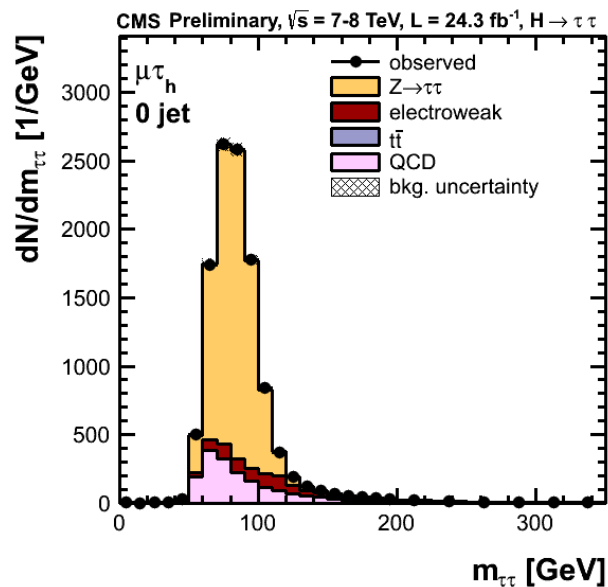


Combined 1 Jet & VBF



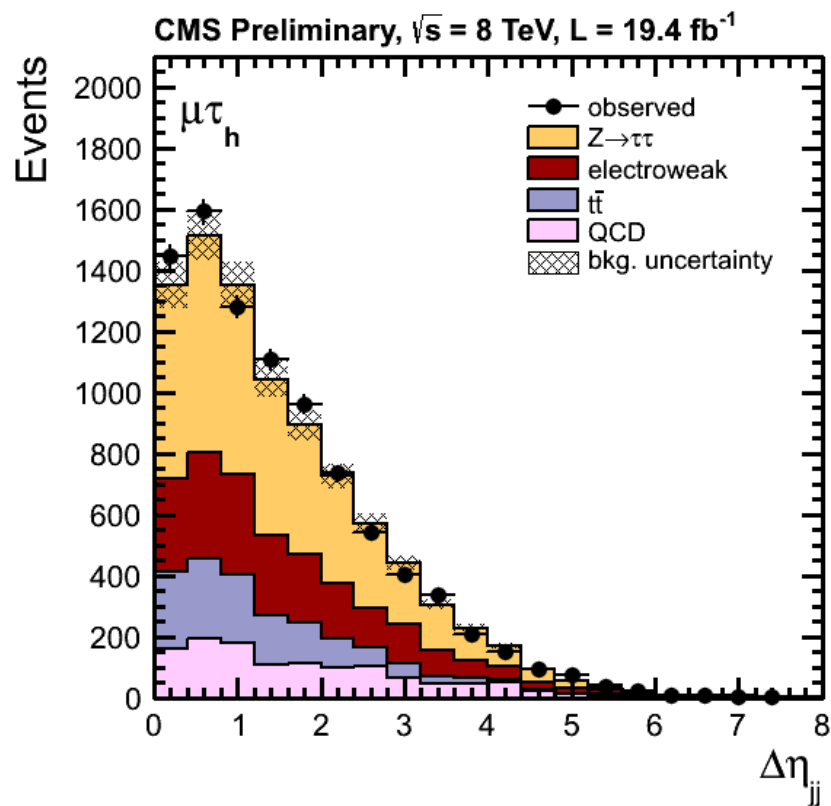
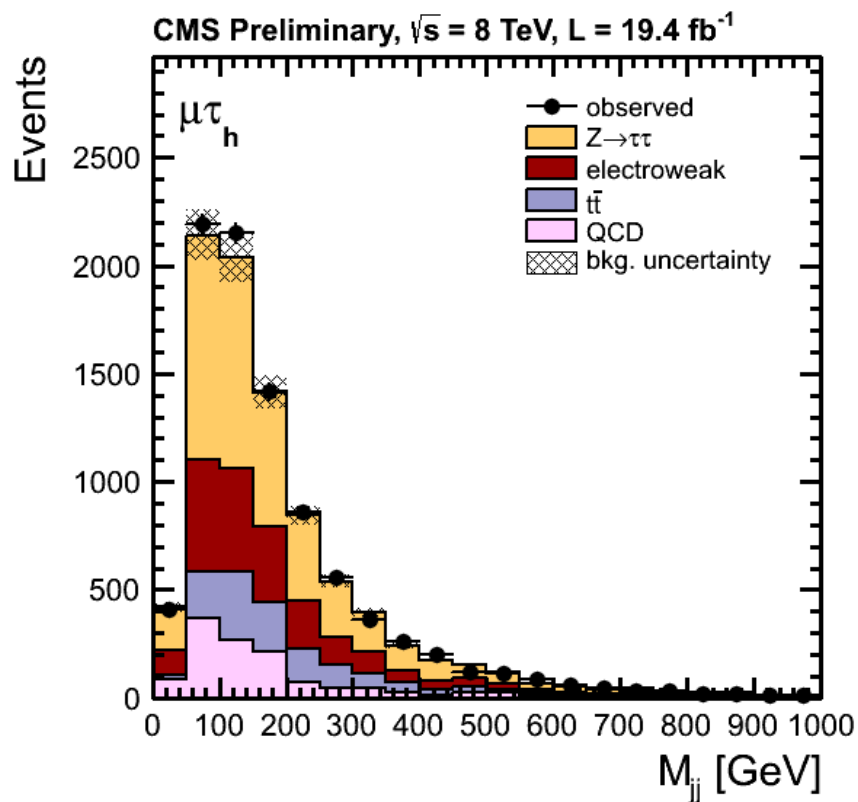


0 jet



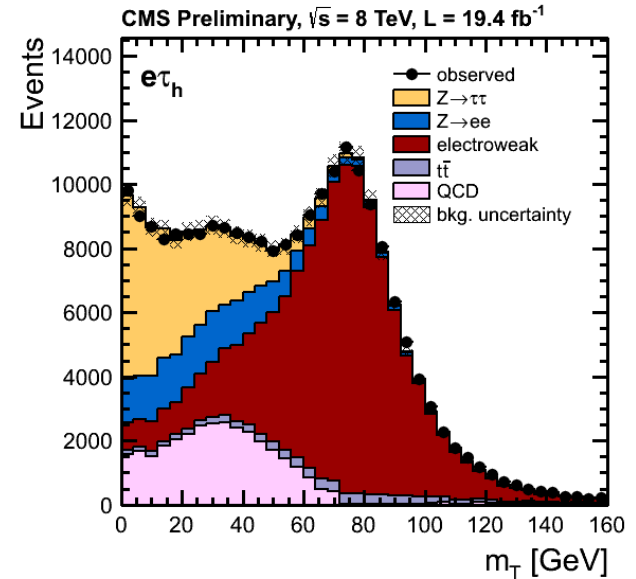
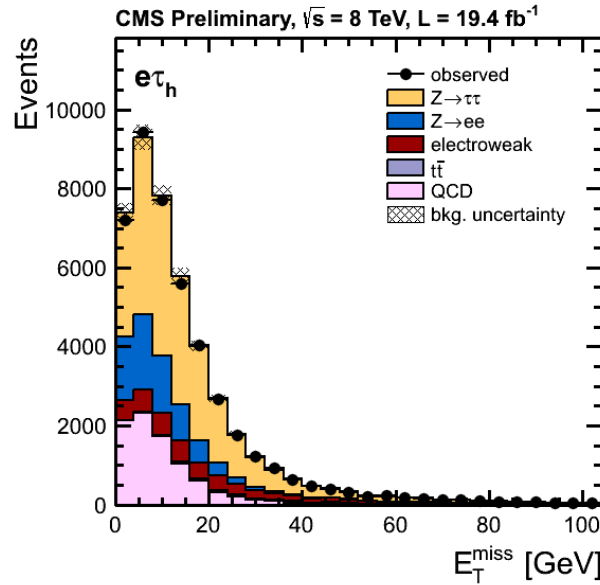
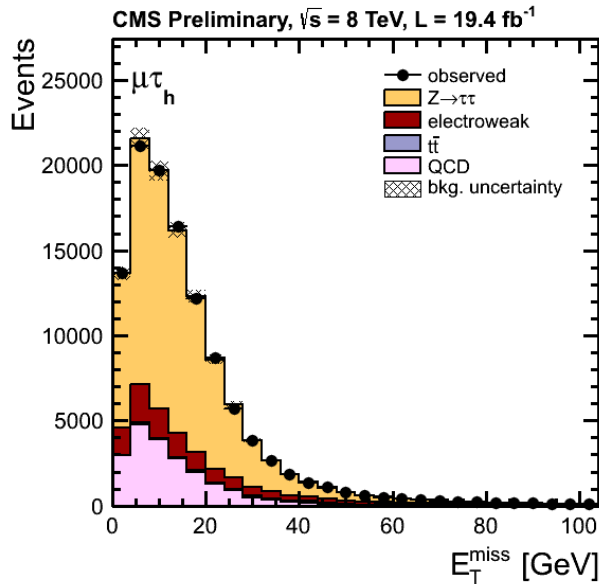


VBF Variables





MET

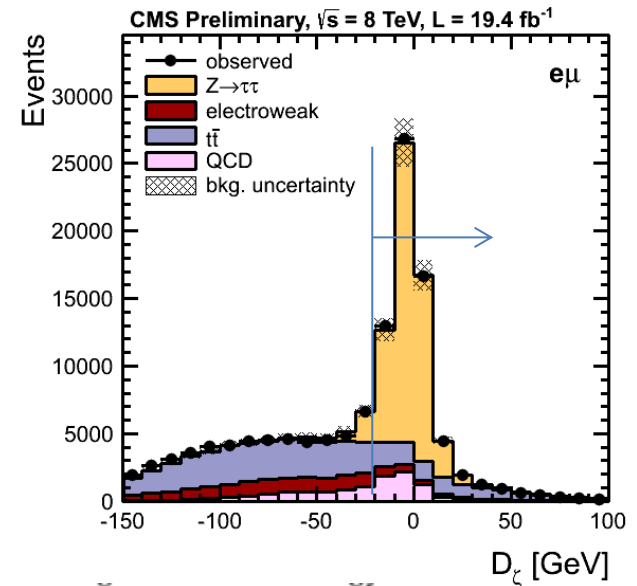
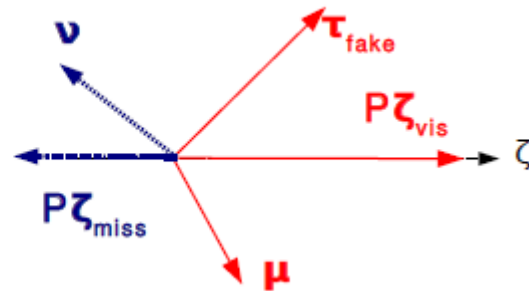
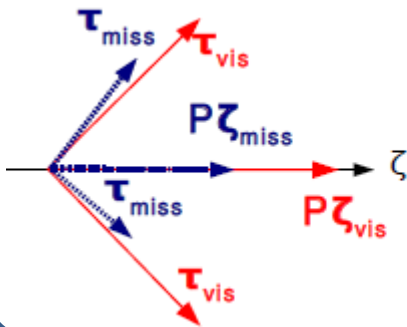


$$P_{\zeta}^{vis} = p_{T,1} \cdot \zeta + p_{T,2} \cdot \zeta$$

$$P_{\zeta} = P_{\zeta}^{vis} + E_T^{miss} \cdot \zeta$$

H \rightarrow $\tau\tau$

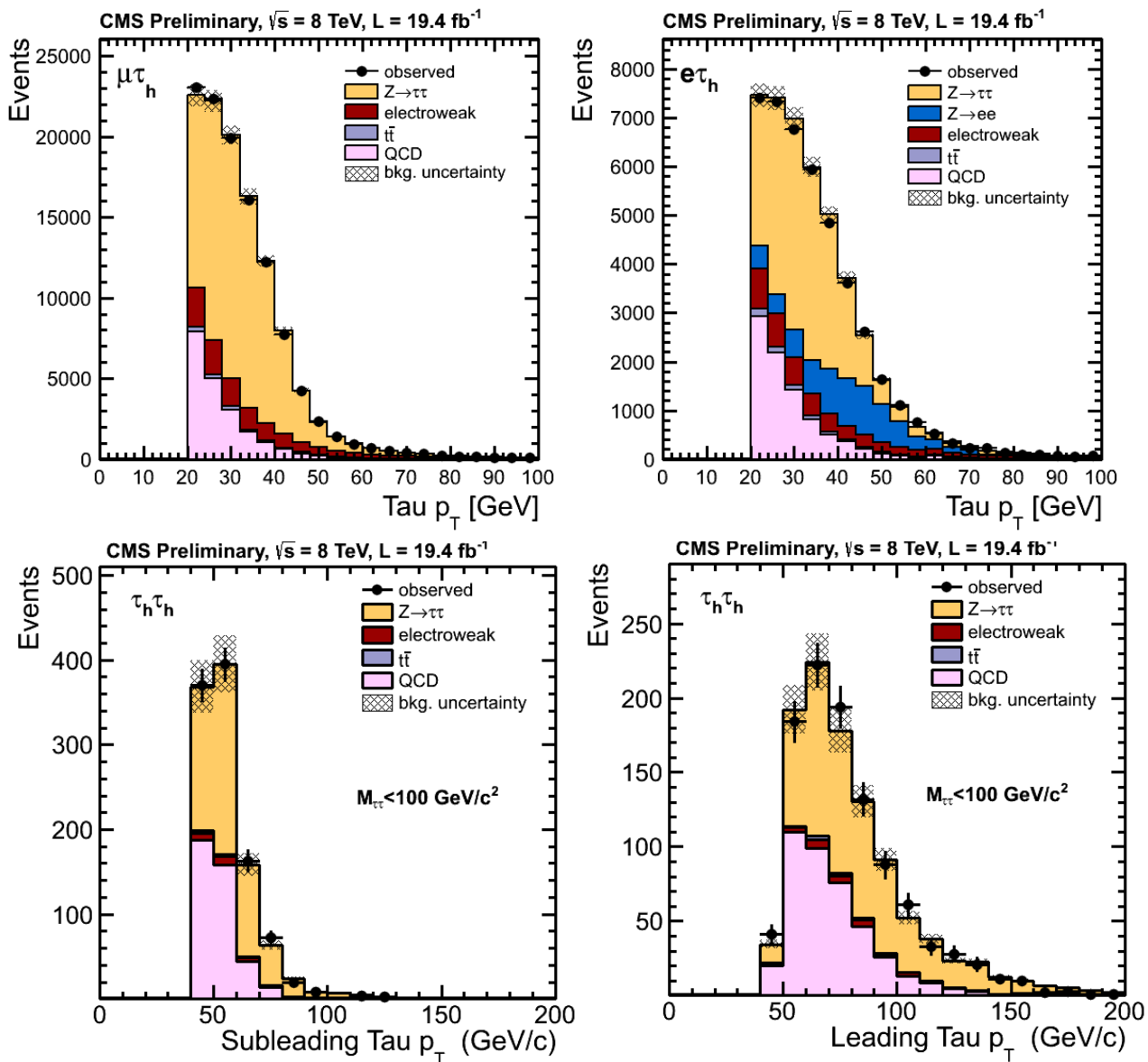
W+Jets



$$D_{\zeta} \equiv \tilde{p}_{\zeta} - 0.85 \cdot p_{\zeta}^{vis} > \sim -20 \text{ GeV}$$

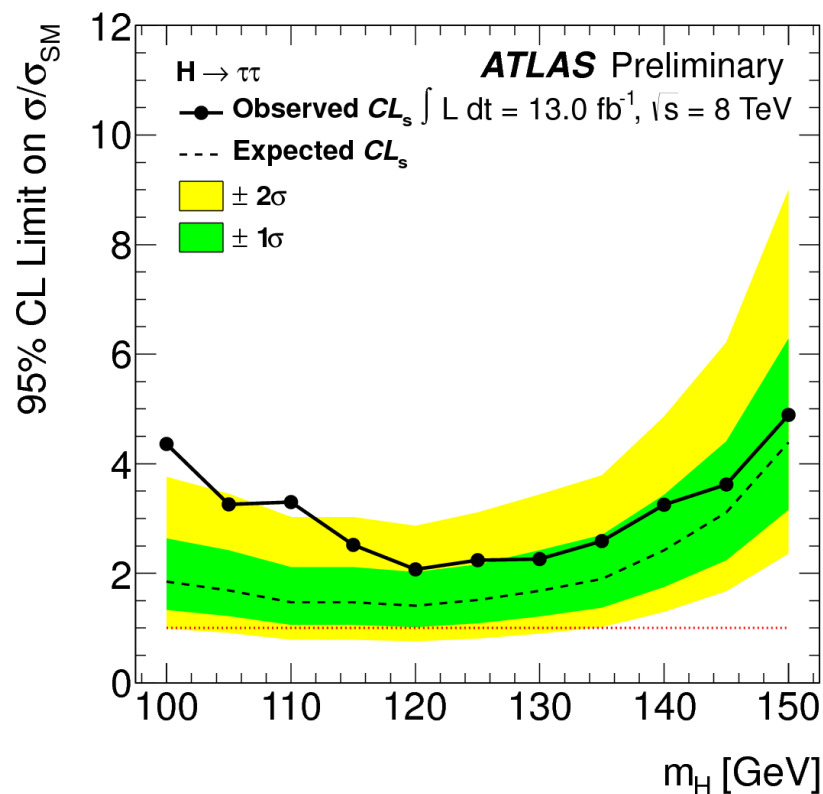
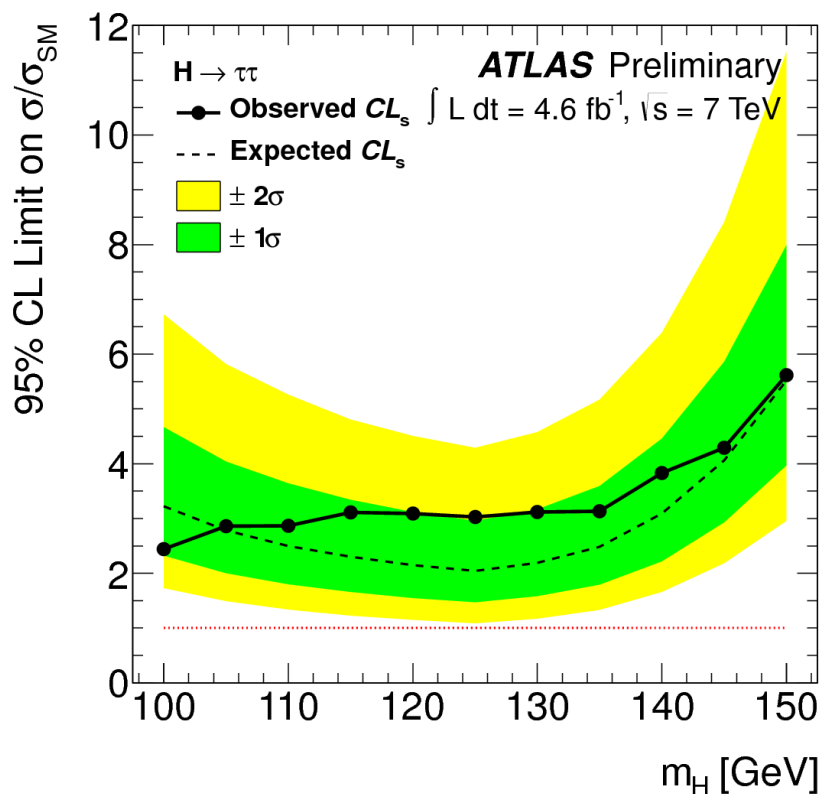


Tau





Limits by Period



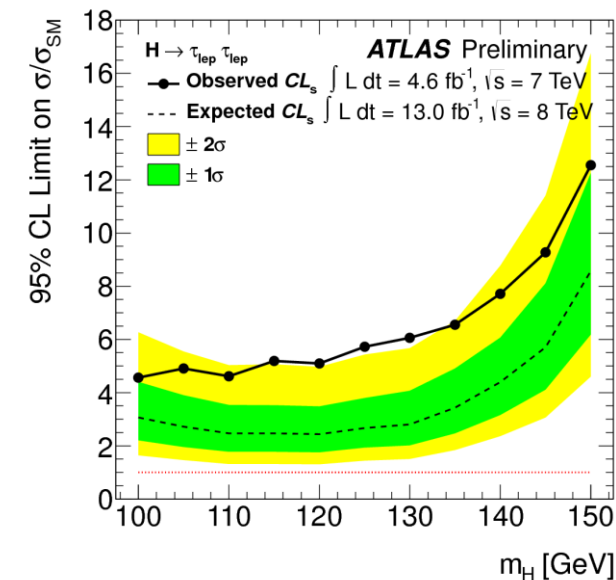
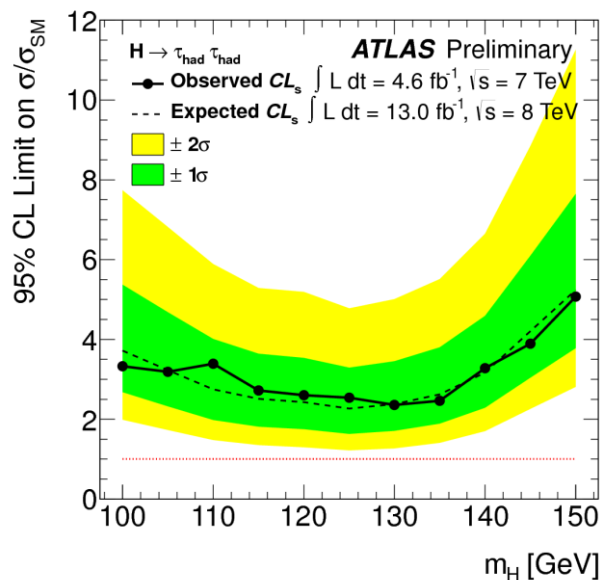
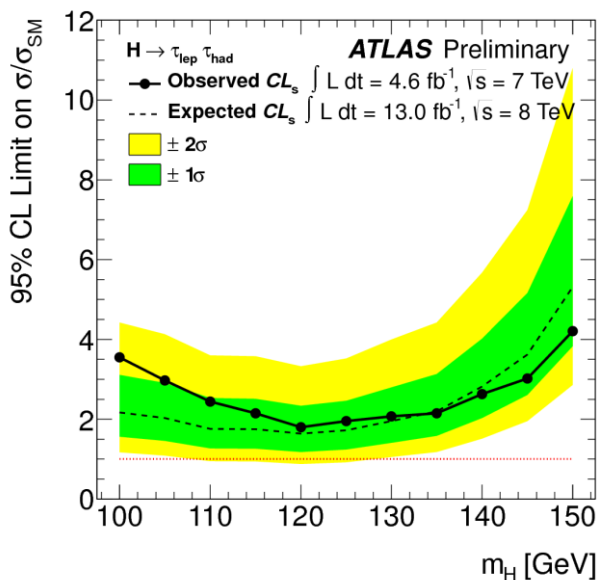
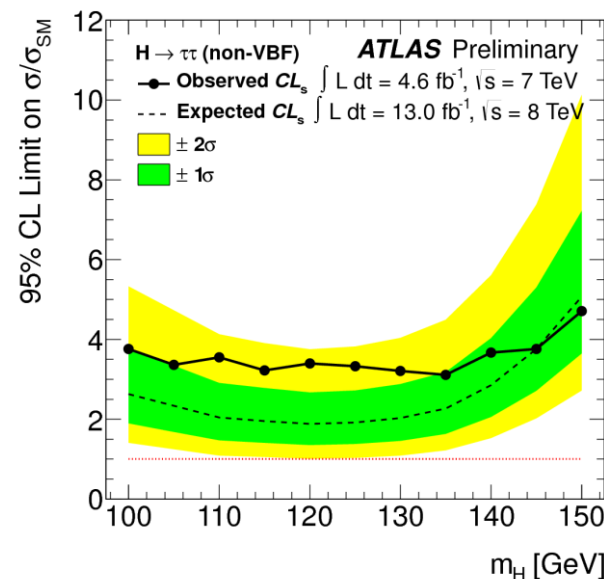
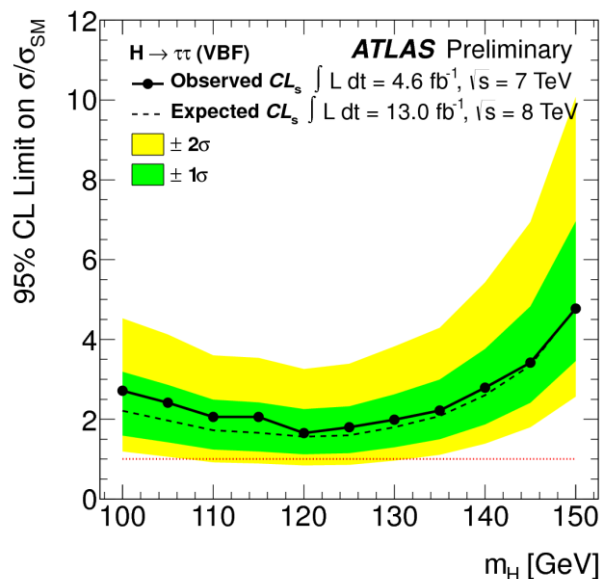


Limits

Limits by Category

And

By Channel





Event Yields (CMS)

$\mu\tau_h$

Process	0-Jet	1-Jet high p_T	VBF
$Z \rightarrow \tau\tau$	84833 ± 1927	4686 ± 232	109 ± 11
QCD	18313 ± 478	481 ± 38	48 ± 7
EWK	8841 ± 653	1585 ± 153	63 ± 9
$t\bar{t}$	11 ± 1	155 ± 11	5 ± 1
Total Background	111998 ± 2090	6908 ± 281	225 ± 16
$H \rightarrow \tau\tau$	- \pm -	73 ± 13	11 ± 2
Observed	112279	7011	240

Signal Eff.

$gg \rightarrow H$	-	$1.99 \cdot 10^{-3}$	$8.51 \cdot 10^{-5}$
$qq \rightarrow H$	-	$4.09 \cdot 10^{-3}$	$3.46 \cdot 10^{-3}$
$qq \rightarrow Ht\bar{t}$ or VH	-	$3.00 \cdot 10^{-3}$	$1.60 \cdot 10^{-5}$

$\tau_h\tau_h$

Process	1-Jet	VBF
$Z \rightarrow \tau\tau$	428 ± 90	47 ± 28
QCD	210 ± 31	61 ± 10
EWK	41 ± 9	4 ± 1
$t\bar{t}$	29 ± 6	2 ± 2
Total Background	709 ± 95	114 ± 30
$H \rightarrow \tau\tau$	9 ± 4	4 ± 2
Observed	718	120

Signal Eff.

$gg \rightarrow H$	$2.52 \cdot 10^{-4}$	$4.99 \cdot 10^{-5}$
$qq \rightarrow H$	$5.93 \cdot 10^{-4}$	$1.20 \cdot 10^{-3}$
$qq \rightarrow Ht\bar{t}$ or VH	$9.13 \cdot 10^{-4}$	$3.59 \cdot 10^{-5}$

$e\tau_h$

Process	0-Jet	1-Jet high p_T	VBF
$Z \rightarrow \tau\tau$	25161 ± 708	792 ± 62	47 ± 6
QCD	7706 ± 307	3 ± 0.3	17 ± 4
EWK	9571 ± 510	365 ± 53	44 ± 6
$t\bar{t}$	4 ± 0.5	47 ± 4	4 ± 1
Total Background	42443 ± 924	1207 ± 82	113 ± 9
$H \rightarrow \tau\tau$	- \pm -	15 ± 3	5 ± 1
Observed	42481	1217	117

Signal Eff.

$gg \rightarrow H$	-	$3.94 \cdot 10^{-4}$	$3.33 \cdot 10^{-5}$
$qq \rightarrow H$	-	$1.10 \cdot 10^{-3}$	$1.78 \cdot 10^{-3}$
$qq \rightarrow Ht\bar{t}$ or VH	-	$8.30 \cdot 10^{-4}$	$1.46 \cdot 10^{-6}$

$e\mu$

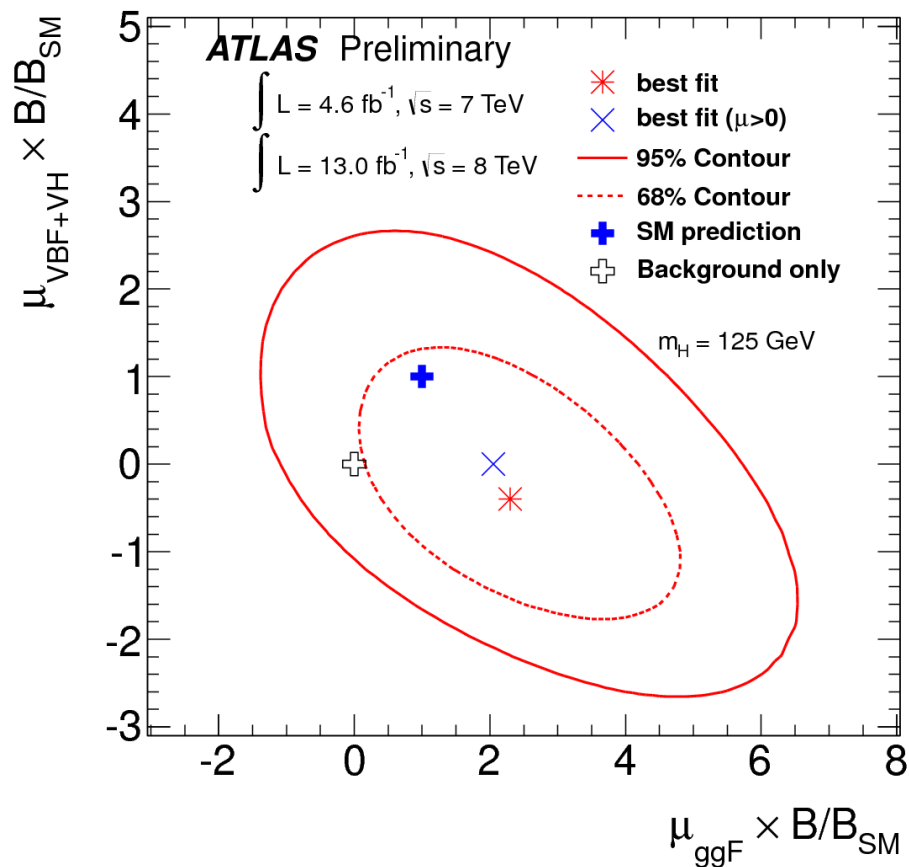
Process	0-Jet	1-Jet high p_T	VBF
$Z \rightarrow \tau\tau$	48882 ± 1282	1830 ± 105	61 ± 6
QCD	4374 ± 249	395 ± 36	19 ± 2
EWK	1185 ± 89	461 ± 44	7 ± 1
$t\bar{t}$	74 ± 5	1100 ± 66	19 ± 2
Total Background	54514 ± 1309	3785 ± 137	105 ± 7
$H \rightarrow \tau\tau$	- \pm -	23 ± 4	5 ± 0.6
Observed	54694	3774	118

Signal Eff.

$gg \rightarrow H$	-	$6.04 \cdot 10^{-4}$	$3.27 \cdot 10^{-5}$
$qq \rightarrow H$	-	$1.37 \cdot 10^{-3}$	$1.80 \cdot 10^{-3}$
$qq \rightarrow Ht\bar{t}$ or VH	-	$1.38 \cdot 10^{-3}$	$1.32 \cdot 10^{-5}$



Properties (ATLAS)





ATLAS Categories ($\ell\ell$)

Table 2: The categorization of the $H \rightarrow \tau_{\text{lep}}\tau_{\text{lep}}$ analysis. The JVF cut is $|JVF| > 0.75$ for 7 TeV data, the lepton centrality is not applied for 7 TeV analysis, and the 0-jet category is not used for 8 TeV data analysis.

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



ATLAS Categories ($\ell\tau$)

Table 3: Event requirements applied in the different categories of the $H \rightarrow \tau_{\text{lep}}\tau_{\text{had}}$ analysis. Requirements marked with a triangle (\triangleright) are categorization requirements, meaning that if an event fails that requirement it is still considered for the remaining categories. Requirements marked with a bullet (\bullet) are only applied to events passing all categorization requirements in a category; events failing such requirements are discarded.

7 TeV		8 TeV	
VBF Category	Boosted Category	VBF Category	Boosted Category
<ul style="list-style-type: none"> $\triangleright p_T^{\tau_{\text{had-vis}}} > 30 \text{ GeV}$ $\triangleright E_T^{\text{miss}} > 20 \text{ GeV}$ $\triangleright \geq 2 \text{ jets}$ $\triangleright p_T^{j1}, p_T^{j2} > 40 \text{ GeV}$ $\triangleright \Delta\eta_{jj} > 3.0$ $\triangleright m_{jj} > 500 \text{ GeV}$ $\triangleright \text{centrality req.}$ $\triangleright \eta_{j1} \times \eta_{j2} < 0$ $\triangleright p_T^{\text{Total}} < 40 \text{ GeV}$ – 	<ul style="list-style-type: none"> – $\triangleright E_T^{\text{miss}} > 20 \text{ GeV}$ $\triangleright p_T^H > 100 \text{ GeV}$ $\triangleright 0 < x_1 < 1$ $\triangleright 0.2 < x_2 < 1.2$ $\triangleright \text{Fails VBF}$ – – – – 	<ul style="list-style-type: none"> $\triangleright p_T^{\tau_{\text{had-vis}}} > 30 \text{ GeV}$ $\triangleright E_T^{\text{miss}} > 20 \text{ GeV}$ $\triangleright \geq 2 \text{ jets}$ $\triangleright p_T^{j1} > 40, p_T^{j2} > 30 \text{ GeV}$ $\triangleright \Delta\eta_{jj} > 3.0$ $\triangleright m_{jj} > 500 \text{ GeV}$ $\triangleright \text{centrality req.}$ $\triangleright \eta_{j1} \times \eta_{j2} < 0$ $\triangleright p_T^{\text{Total}} < 30 \text{ GeV}$ $\triangleright p_T^\ell > 26 \text{ GeV}$ – 	<ul style="list-style-type: none"> $\triangleright p_T^{\tau_{\text{had-vis}}} > 30 \text{ GeV}$ $\triangleright E_T^{\text{miss}} > 20 \text{ GeV}$ $\triangleright p_T^H > 100 \text{ GeV}$ $\triangleright 0 < x_1 < 1$ $\triangleright 0.2 < x_2 < 1.2$ $\triangleright \text{Fails VBF}$ – – – –
<ul style="list-style-type: none"> $\bullet m_T < 50 \text{ GeV}$ $\bullet \Delta(\Delta R) < 0.8$ $\bullet \sum \Delta\phi < 3.5$ – 	<ul style="list-style-type: none"> $\bullet m_T < 50 \text{ GeV}$ $\bullet \Delta(\Delta R) < 0.8$ $\bullet \sum \Delta\phi < 1.6$ – 	<ul style="list-style-type: none"> $\bullet m_T < 50 \text{ GeV}$ $\bullet \Delta(\Delta R) < 0.8$ $\bullet \sum \Delta\phi < 2.8$ $\bullet b\text{-tagged jet veto}$ 	<ul style="list-style-type: none"> $\bullet m_T < 50 \text{ GeV}$ $\bullet \Delta(\Delta R) < 0.8$ – $\bullet b\text{-tagged jet veto}$
1 Jet Category	0 Jet Category	1 Jet Category	0 Jet Category
<ul style="list-style-type: none"> $\triangleright \geq 1 \text{ jet}, p_T > 25 \text{ GeV}$ $\triangleright E_T^{\text{miss}} > 20 \text{ GeV}$ $\triangleright \text{Fails VBF, Boosted}$ 	<ul style="list-style-type: none"> $\triangleright 0 \text{ jets } p_T > 25 \text{ GeV}$ $\triangleright E_T^{\text{miss}} > 20 \text{ GeV}$ $\triangleright \text{Fails Boosted}$ 	<ul style="list-style-type: none"> $\triangleright \geq 1 \text{ jet}, p_T > 30 \text{ GeV}$ $\triangleright E_T^{\text{miss}} > 20 \text{ GeV}$ $\triangleright \text{Fails VBF, Boosted}$ 	<ul style="list-style-type: none"> $\triangleright 0 \text{ jets } p_T > 30 \text{ GeV}$ $\triangleright E_T^{\text{miss}} > 20 \text{ GeV}$ $\triangleright \text{Fails Boosted}$
<ul style="list-style-type: none"> $\bullet m_T < 50 \text{ GeV}$ $\bullet \Delta(\Delta R) < 0.6$ $\bullet \sum \Delta\phi < 3.5$ – 	<ul style="list-style-type: none"> $\bullet m_T < 30 \text{ GeV}$ $\bullet \Delta(\Delta R) < 0.5$ $\bullet \sum \Delta\phi < 3.5$ $\bullet p_T^\ell - p_T^\tau < 0$ 	<ul style="list-style-type: none"> $\bullet m_T < 50 \text{ GeV}$ $\bullet \Delta(\Delta R) < 0.6$ $\bullet \sum \Delta\phi < 3.5$ – 	<ul style="list-style-type: none"> $\bullet m_T < 30 \text{ GeV}$ $\bullet \Delta(\Delta R) < 0.5$ $\bullet \sum \Delta\phi < 3.5$ $\bullet p_T^\ell - p_T^\tau < 0$



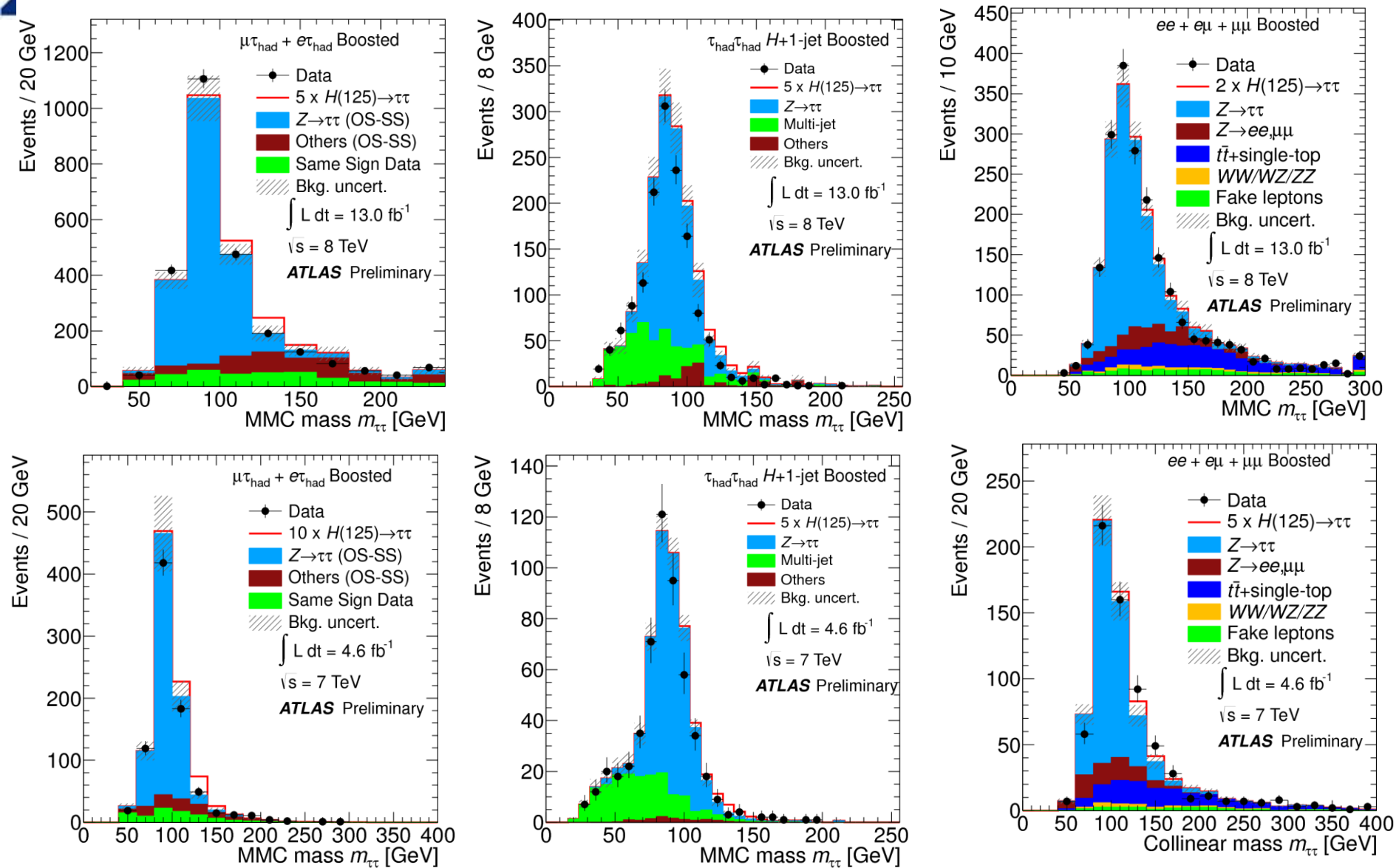
ATLAS Categories ($\tau\tau$)

Table 4: Summary of the event selection and categories for the $H \rightarrow \tau_{\text{had}}\tau_{\text{had}}$ channel.

Cut	Description
Preselection	<p>No muons or electrons in the event</p> <p>Exactly 2 medium τ_{had} candidates matched with the trigger objects</p> <p>At least 1 of the τ_{had} candidates identified as tight</p> <p>Both τ_{had} candidates are from the same primary vertex</p> <p>Leading $\tau_{\text{had-vis}}$ $p_T > 40$ GeV and sub-leading $\tau_{\text{had-vis}}$ $p_T > 25$ GeV, $\eta < 2.5$</p> <p>τ_{had} candidates have opposite charge and 1- or 3-tracks</p> <p>$0.8 < \Delta R(\tau_1, \tau_2) < 2.8$</p> <p>$\Delta\eta(\tau, \tau) < 1.5$</p> <p>if E_T^{miss} vector is not pointing in between the two taus, $\min\{\Delta\phi(E_T^{\text{miss}}, \tau_1), \Delta\phi(E_T^{\text{miss}}, \tau_2)\} < 0.2\pi$</p>
VBF	<p>At least two tagging jets, j_1, j_2, leading tagging jet with $p_T > 50$ GeV</p> <p>$\eta_{j1} \times \eta_{j2} < 0$, $\Delta\eta_{jj} > 2.6$ and invariant mass $m_{jj} > 350$ GeV</p> <p>$\min(\eta_{j1}, \eta_{j2}) < \eta_{\tau1}, \eta_{\tau2} < \max(\eta_{j1}, \eta_{j2})$</p> <p>$E_T^{\text{miss}} > 20$ GeV</p>
Boosted	<p>Fails VBF</p> <p>At least one tagging jet with $p_T > 70(50)$ GeV in the 8(7) TeV dataset</p> <p>$\Delta R(\tau_1, \tau_2) < 1.9$</p> <p>$E_T^{\text{miss}} > 20$ GeV</p> <p>if E_T^{miss} vector is not pointing in between the two taus, $\min\{\Delta\phi(E_T^{\text{miss}}, \tau_1), \Delta\phi(E_T^{\text{miss}}, \tau_2)\} < 0.1\pi$.</p>

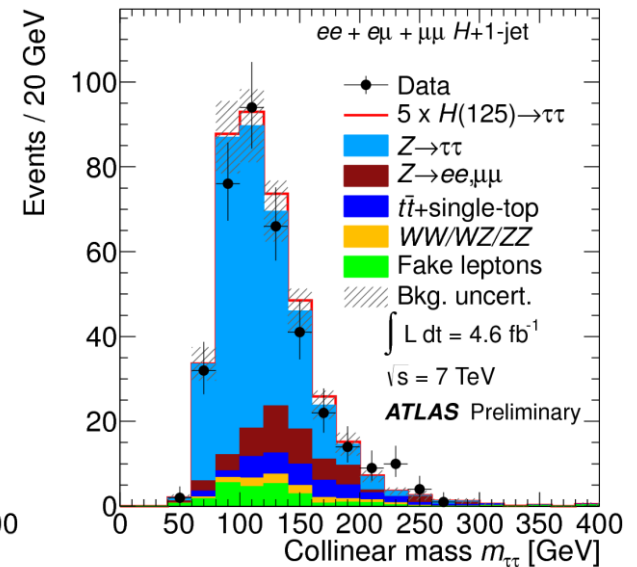
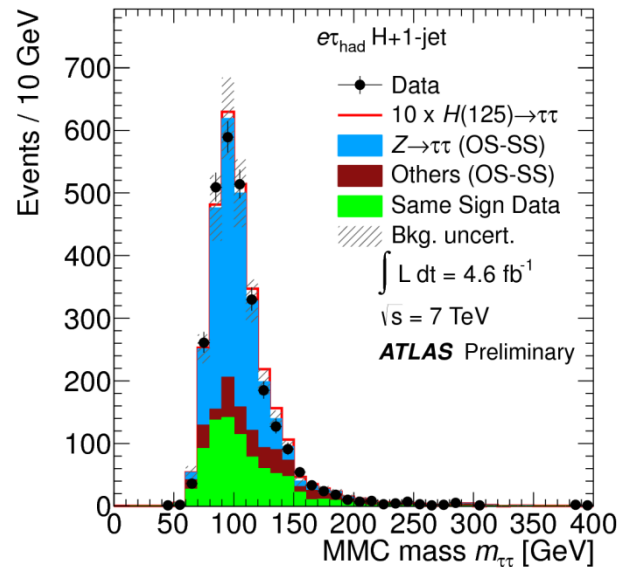
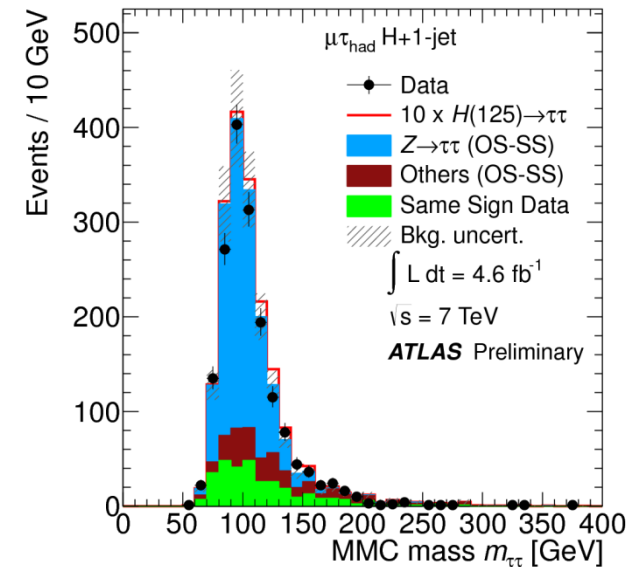
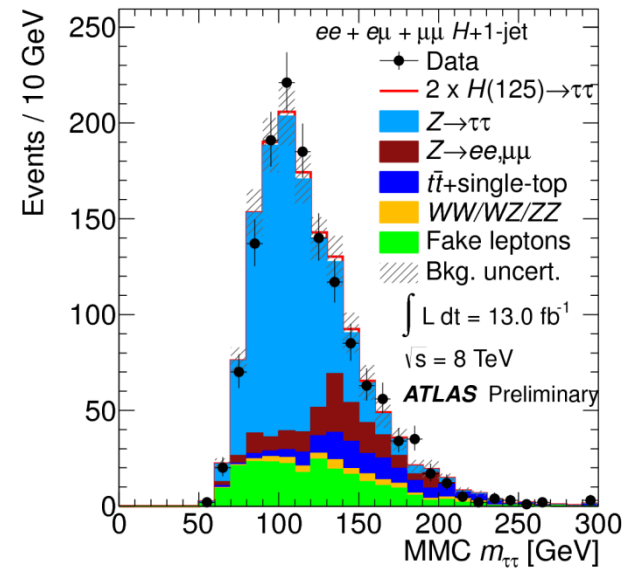
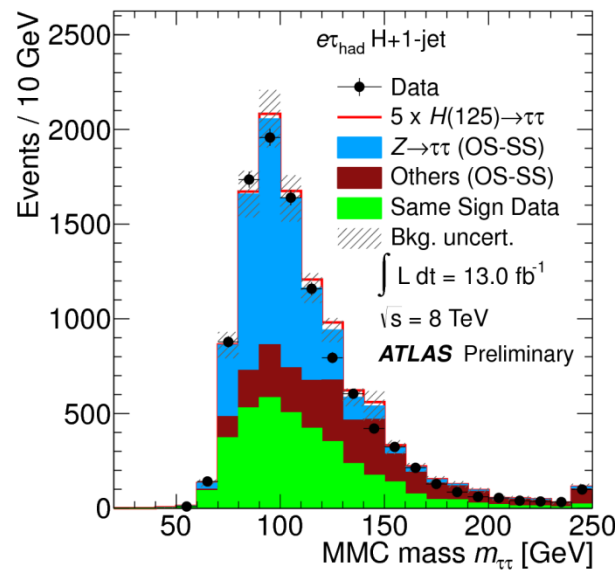
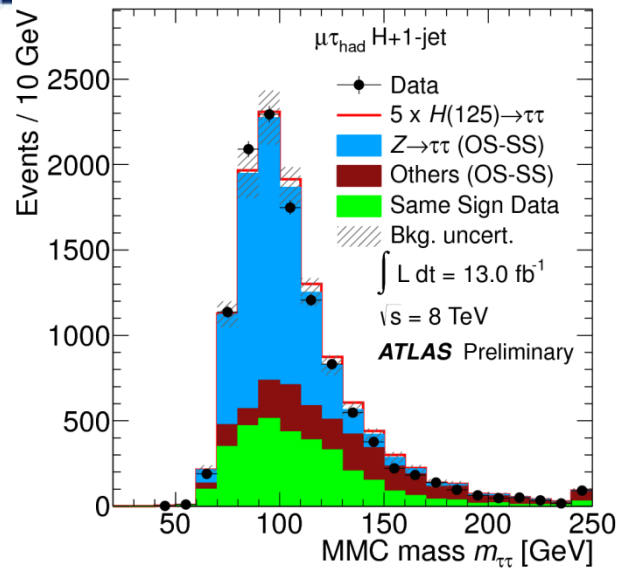


Boost (ATLAS)



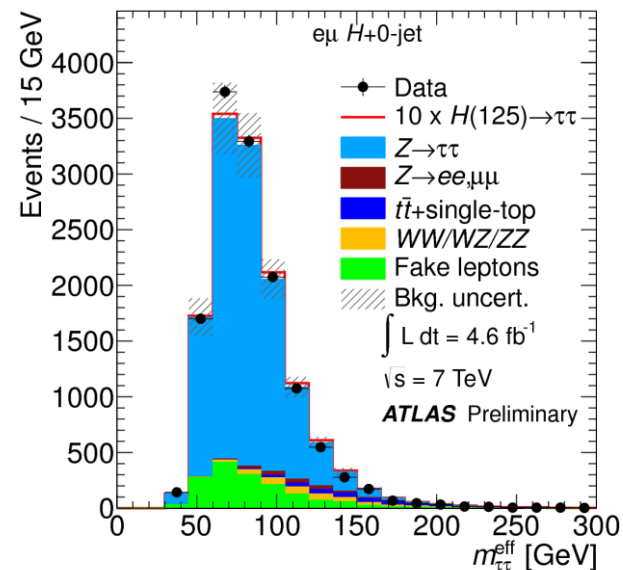
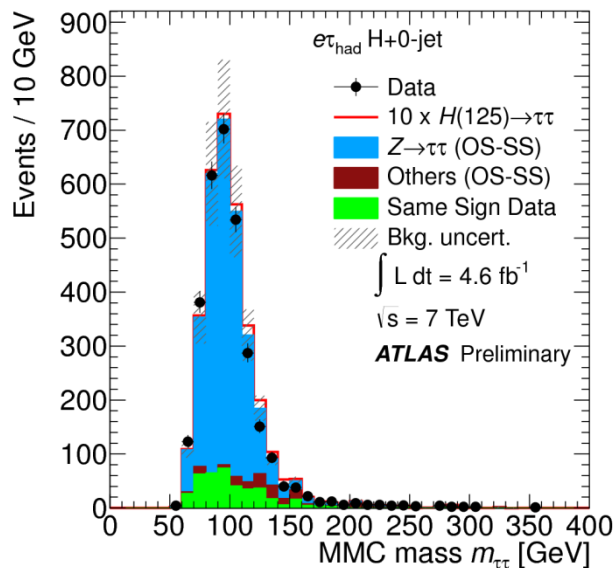
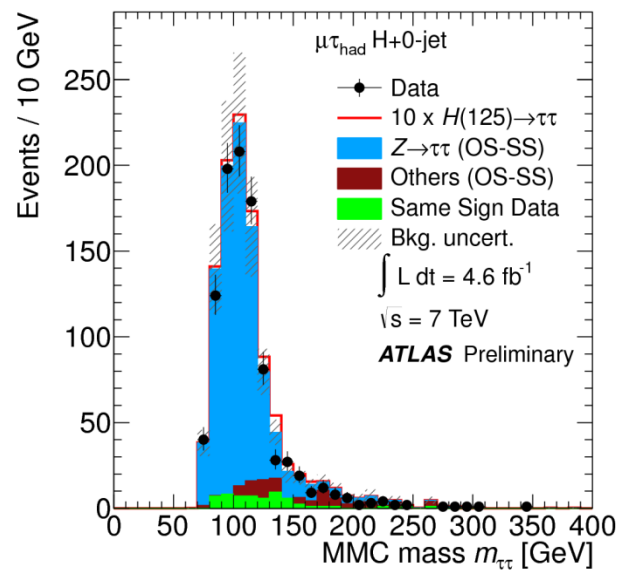
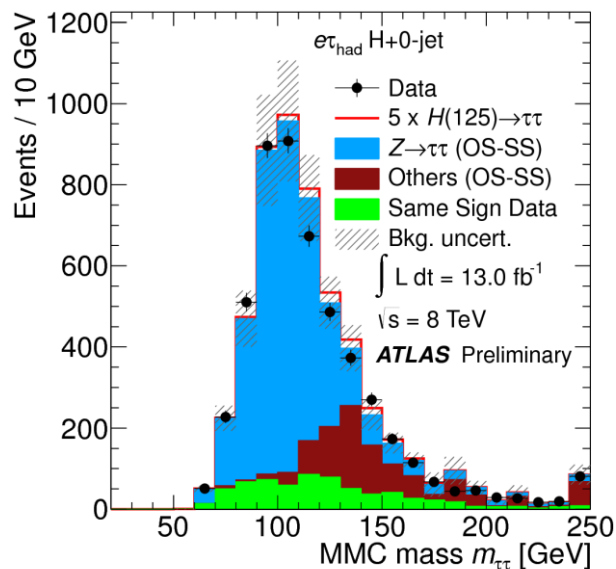
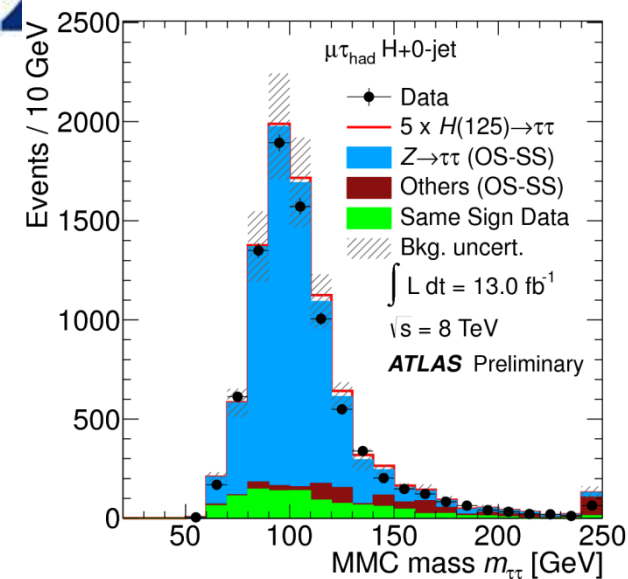


1 jet (ATLAS)





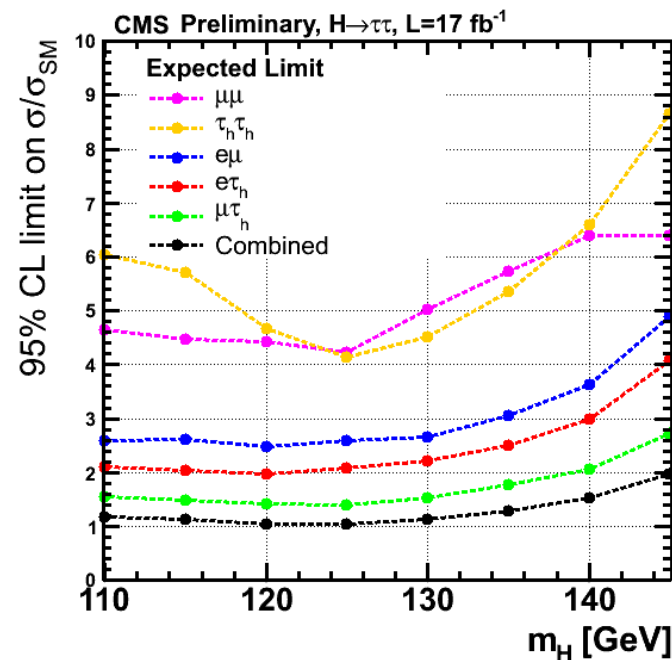
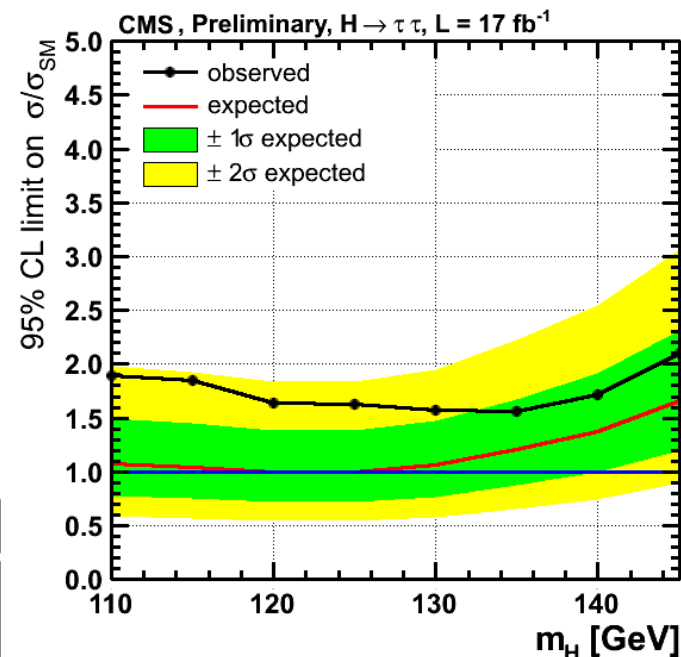
0 jet (ATLAS)





Past CMS results

SM Higgs	Significance					
m_H [GeV]	-2σ	-1σ	Median	$+1\sigma$	$+2\sigma$	Observed
110	0.50	1.32	2.25	2.99	3.55	1.68
115	0.59	1.30	2.33	3.12	3.68	1.74
120	0.70	1.53	2.49	3.18	3.78	1.49
125	0.61	1.47	2.45	3.19	3.74	1.50
130	0.54	1.41	2.32	3.08	3.66	1.17
135	0.39	1.23	2.10	2.79	3.40	0.76
140	0.30	1.01	1.89	2.60	3.10	0.67
145	0.23	0.81	1.65	2.30	2.77	0.73





Analysis Strategy

MSSM Categories

Non-bTag

≤ 1 jet with $p_T > 30$ GeV,
< 1 b-Tagged Jet with p_T
> 20 GeV

Dominated by ggH

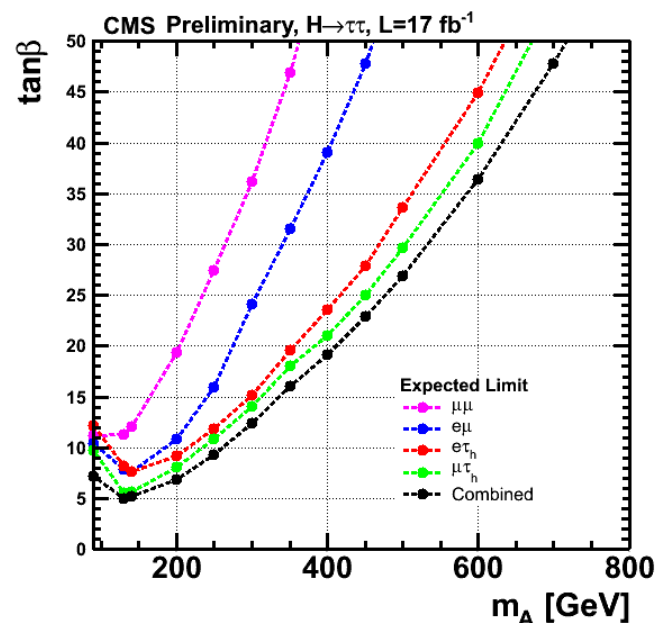
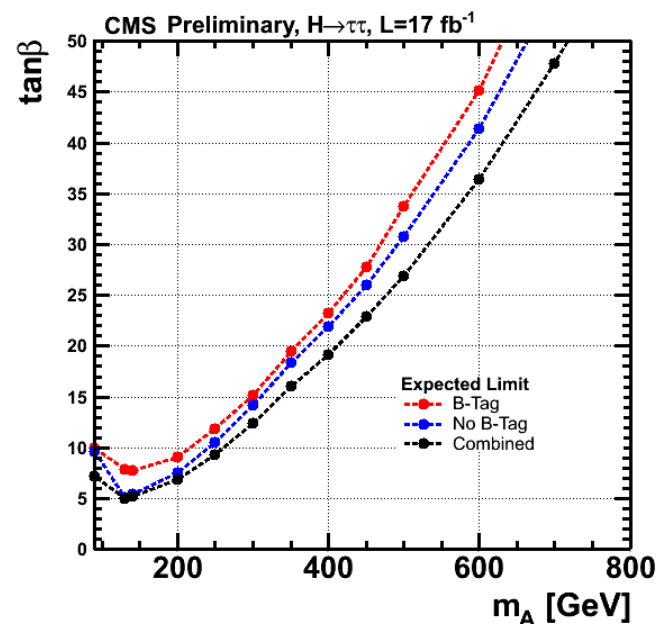
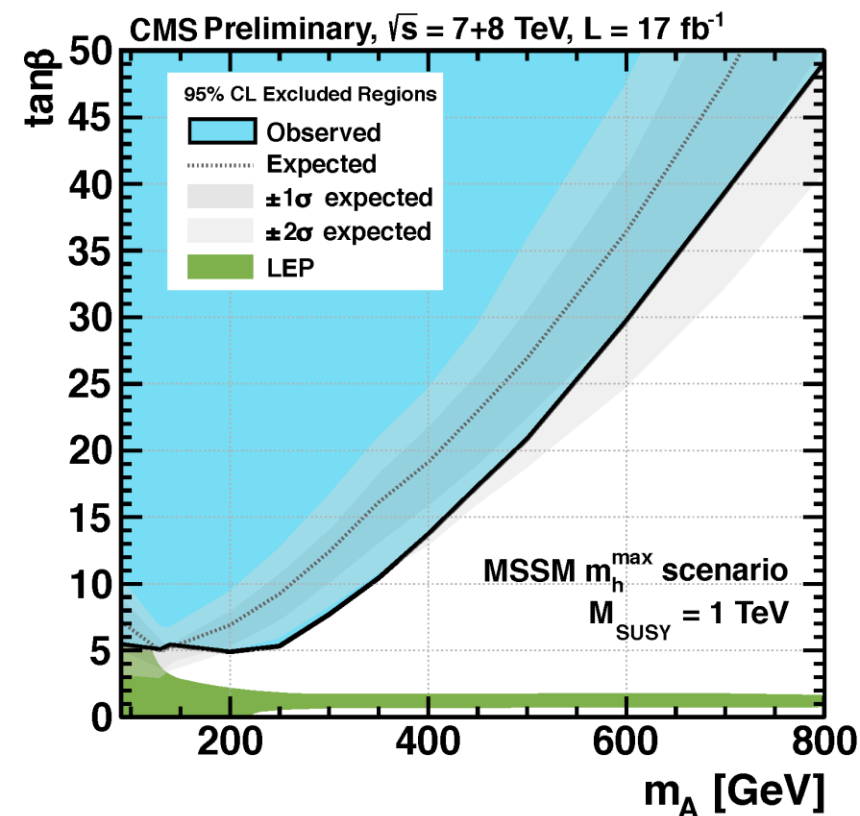
b-Tag

≤ 1 jet with $p_T > 30$ GeV,
 ≥ 1 b-Tagged Jet with p_T
> 20 GeV

Dominated by bbH



MSSM Results





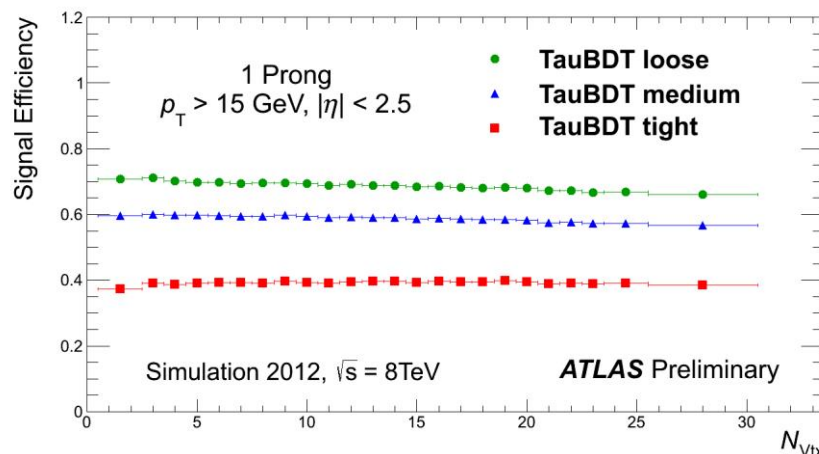
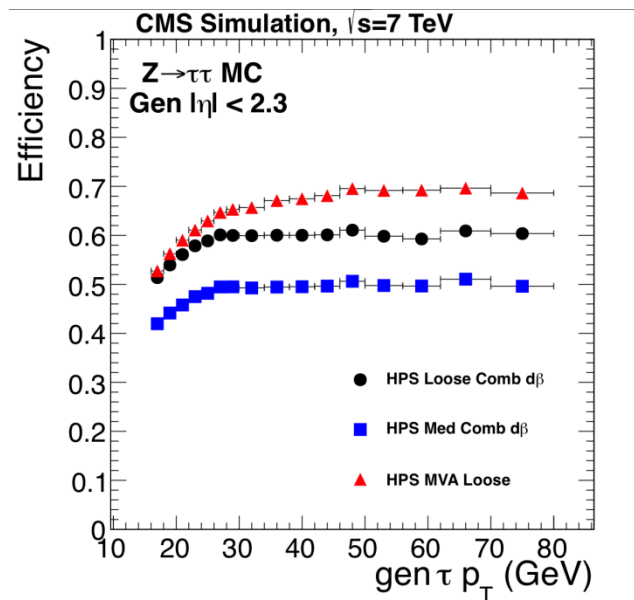
τ_h Identification

CMS :

- Decay Mode based τ_h identification using Particle flow objects :
charged hadrons + photons
- MVA Isolation :
 - Isolation p_T summed in rings around tau
 - BDT trained against jet $\rightarrow \tau$ fakes

ATLAS :

- Reconstruction seeded by anti-kt jets($R=0.4$)
 - calibrated 3D topological clusters
 - good quality tracks with $p_T > 1$ GeV
- discriminating variables
 - Multivariate discriminants combining information from calorimeter and tracking.

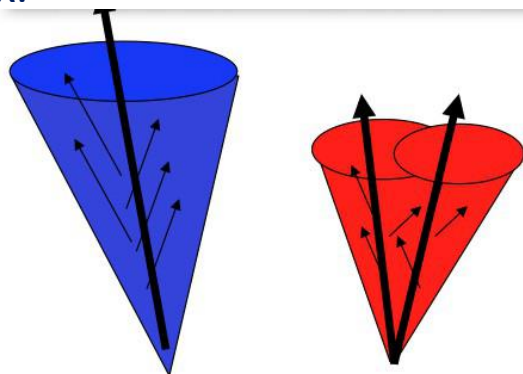


More details in the Talk by Colin Bernet & Poster by Ivo Naranjo Fong



Jets

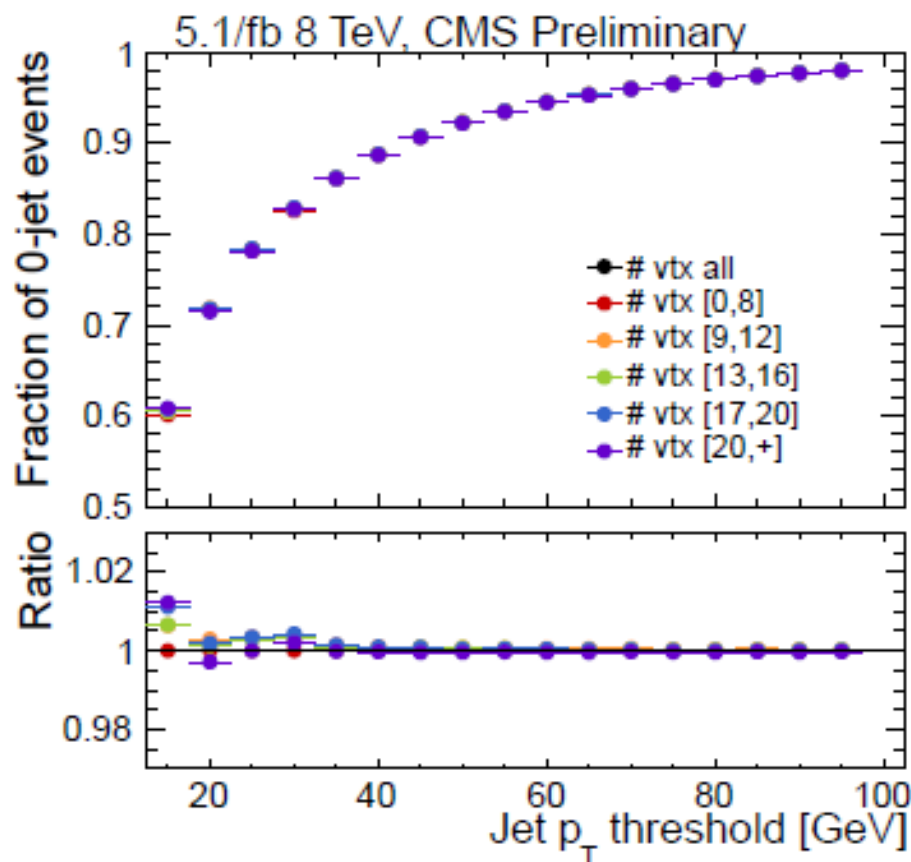
- Jet production rate grows rapidly with pileup
- **CMS** : **MVA discriminant** against pileup jets, exploiting shape and tracking variables
- **ATLAS** : Use **Jet Vertex Fraction (JVF)** defined as the fraction of sum p_T of tracks in a jet assigned to PV to the sum p_T of tracks assigned to any vertex.



Typical jet

Pileup jet

B-Tagging : Lifetime based b-tagger combining secondary vertex and track impact parameter information





Missing Transverse Momentum

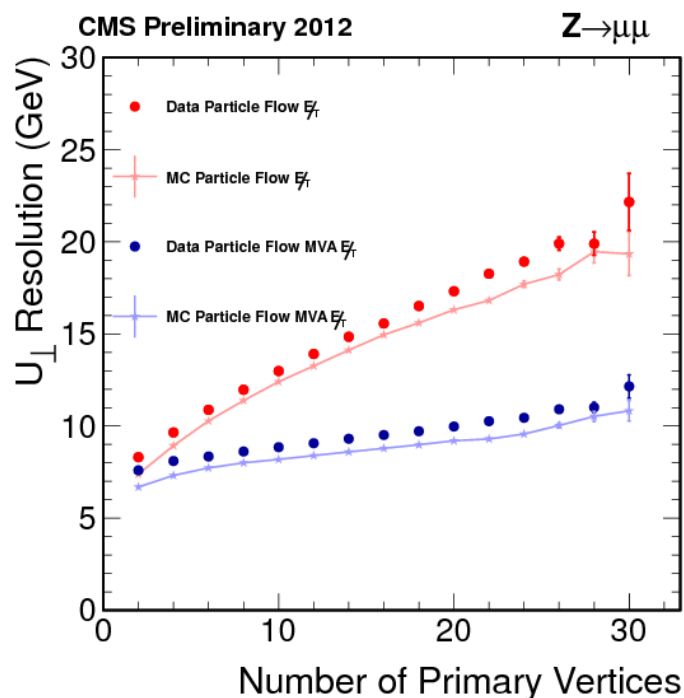
CMS

MVA Regression to compute best MET

Constructed out of 5 best METs (Recoils)

Significant Improvement in MET resolution and pileup dependency

Key to separate signal from background, improve di-tau mass reconstruction



ATLAS

Pile-up mitigation of MET

Using Jet-Vertex-Fraction (JVF) and soft-term-vertex-fraction (STVF)

STVF : ratio of sum pT of tracks associated to primary vertex and all tracks outside reconstructed objects

