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

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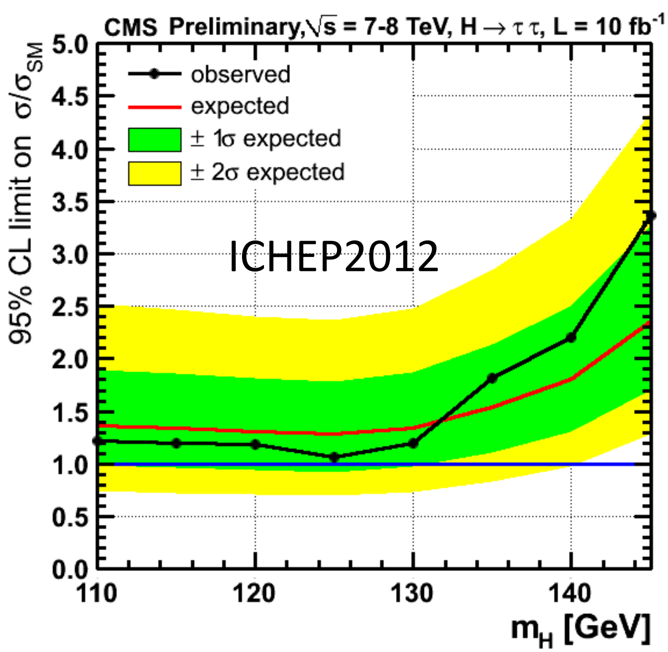
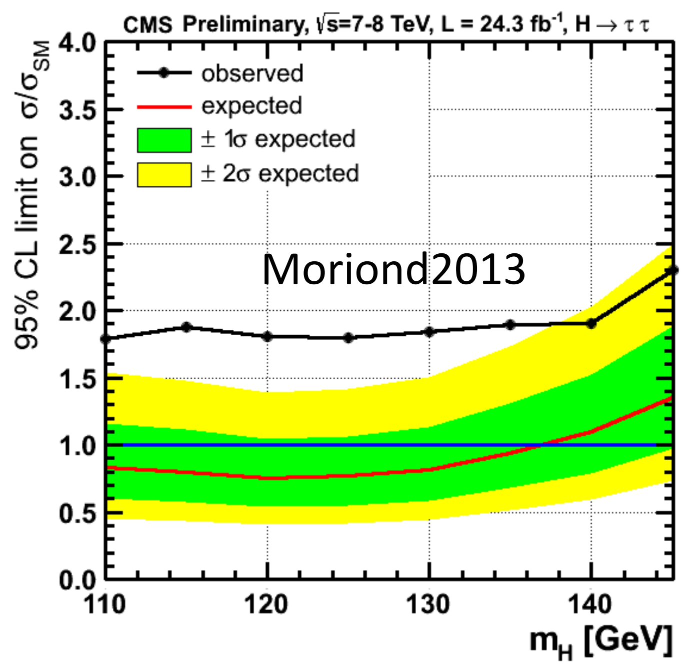
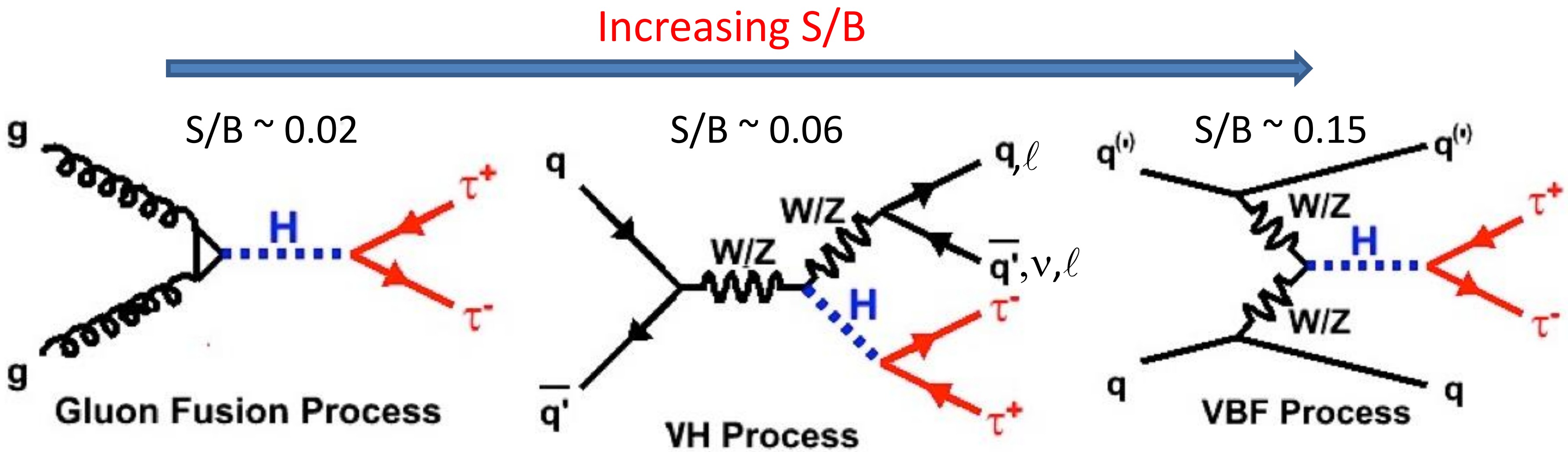
Introduction

- 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..)





Analysis Overview



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

Gluon Fusion + VBF

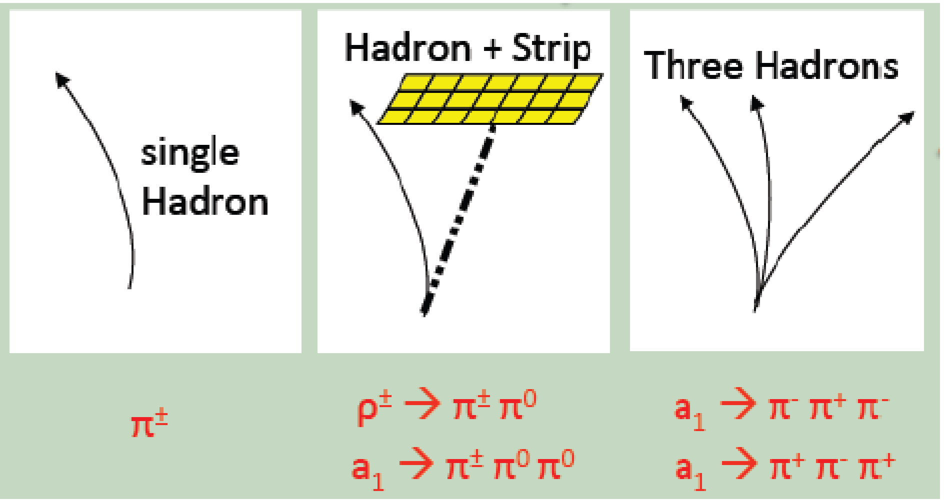
μμ,eμ,ττ,eτ,μτ

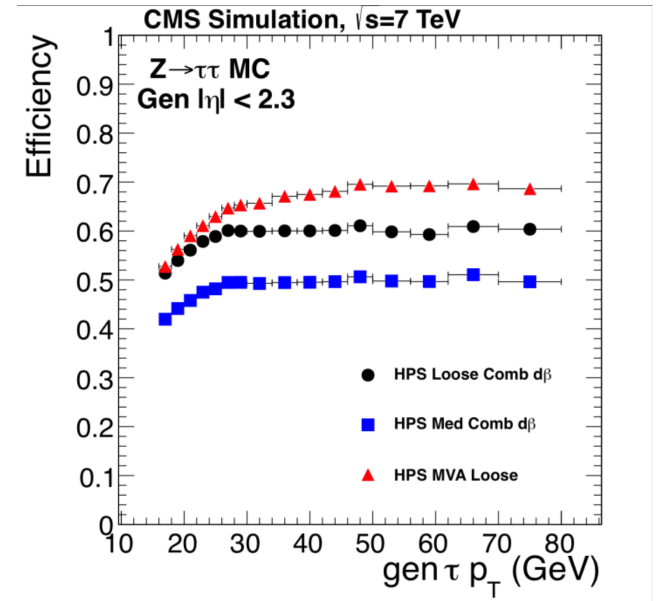
Associated production (VH)

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

τ_h Identification

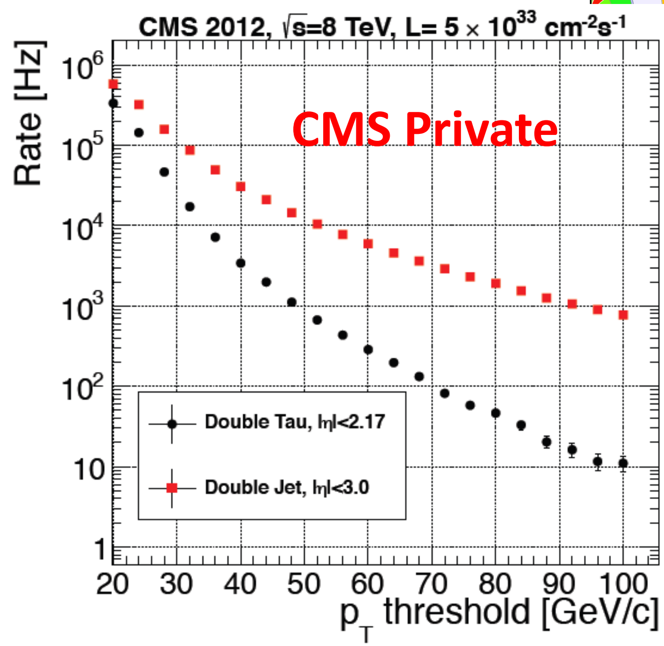
- Decay Mode based τ_h identification using Particle flow objects : charged hadrons + photons
- π^0s reconstructed as ECAL strips to take into account photon conversions in large tracker material (full silicon tracker)
- MVA Isolation : (Used in Moriond2013)
  - Isolation p_T summed in rings around tau
  - BDT trained against jet -> τ fakes
- CutBased isolation : (using for final paper)
  - New cut based isolation tuning the parameters of the isolation tracks
  - Correction for event pile-up
- Discrimination Against Leptons :
  - Electron is reconstructed as a perfect 1 prong tau
  - MVA discriminant against electron using electron ID variables

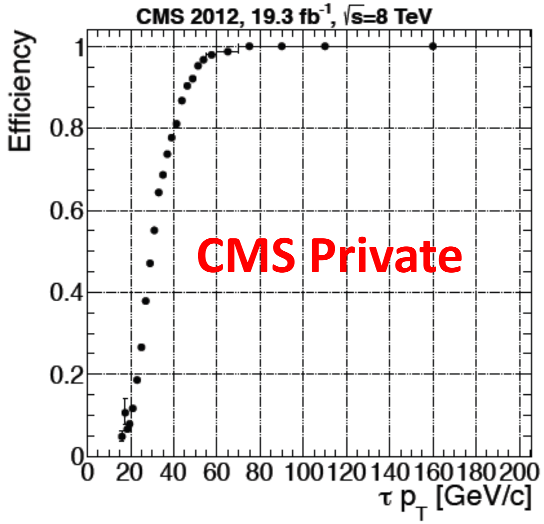


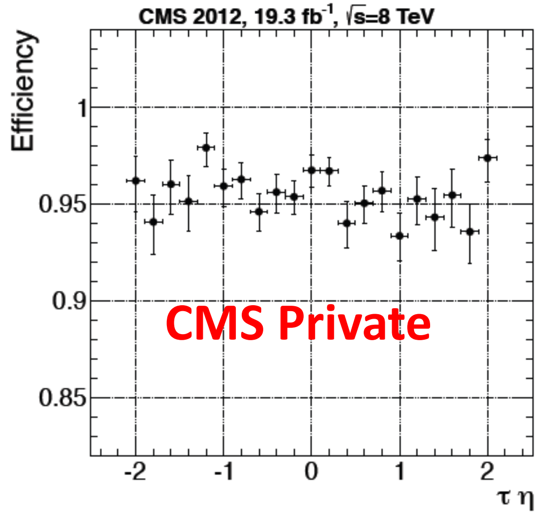


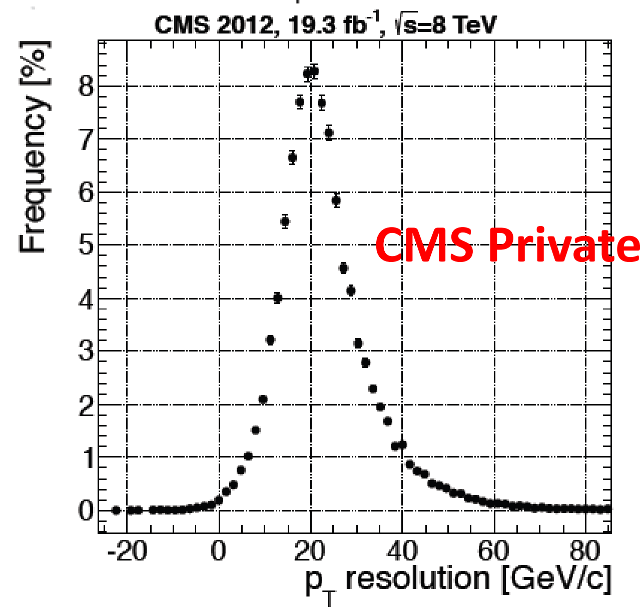
Trigger Selection (Level-1)

- Used only in Double-Hadronic Tau Trigger
- L1 Seed : di-tau (pT>44 GeV) OR di-jet (pT > 64 GeV)
- Quite relaxed tau-tagging at Level-1 => large rate



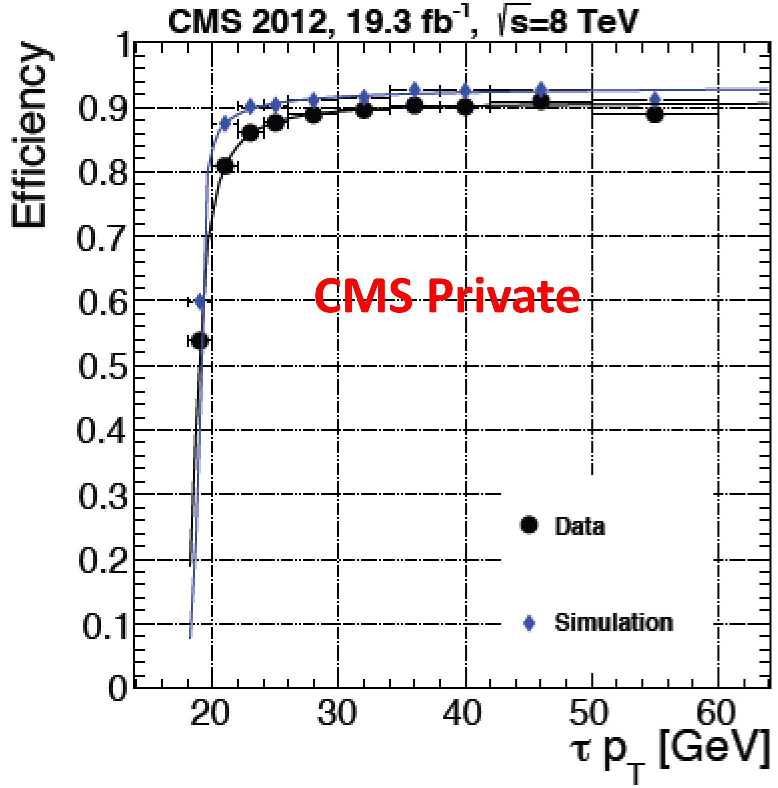


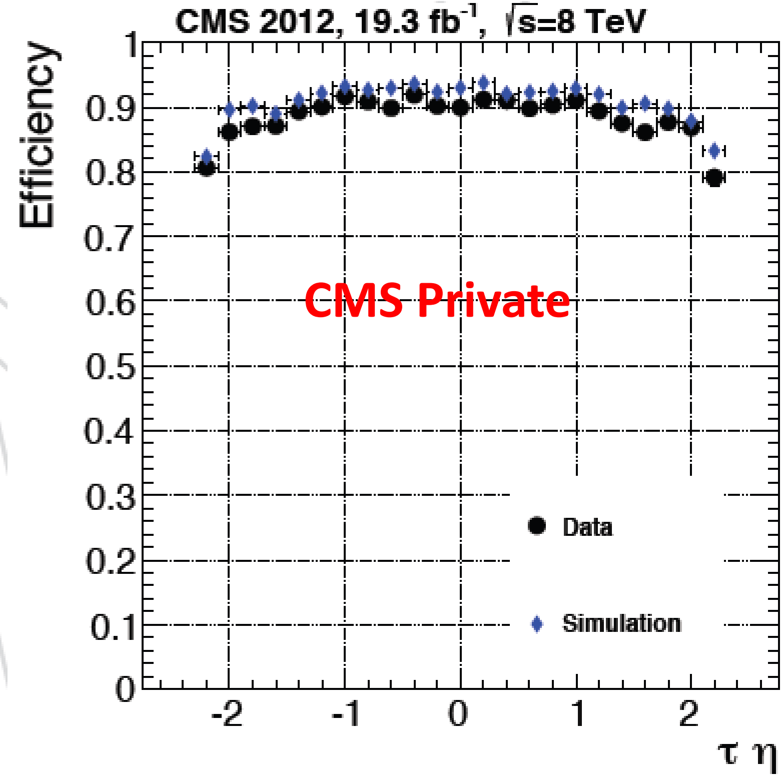




Trigger Selection (High Level Trigger)

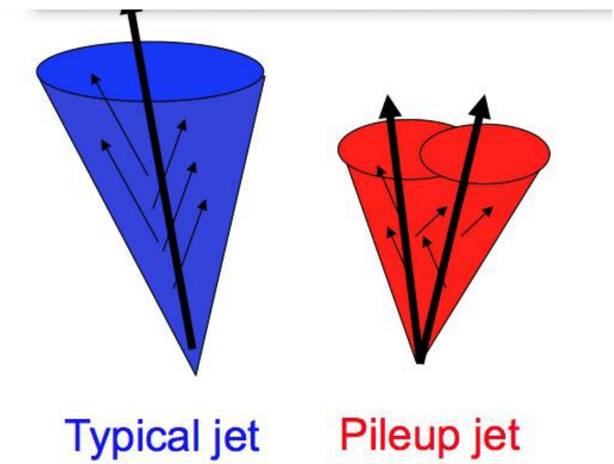
- Events selected using 3 type of triggers that reconstruct hadronic tau decay
  - Muon + Tau, Electron + Tau , Double-Tau
- Use particle-flow to reconstruct hadronic tau decay at HLT
- A simple cone based algorithm is employed => high efficiency, but higher rate due to fake taus, Also higher CPU time due to Pflow (iterative tracking)



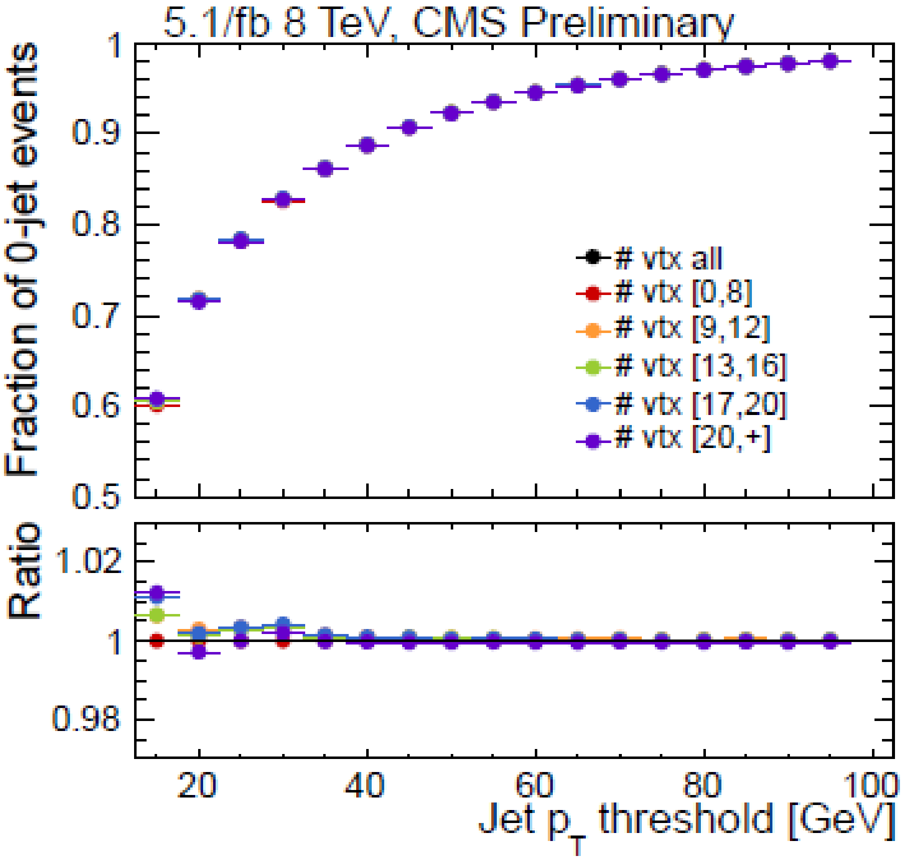


Jets

- Jet production rate grows rapidly with pileup
- MVA discriminant against pileup jets, exploiting shape and tracking variables



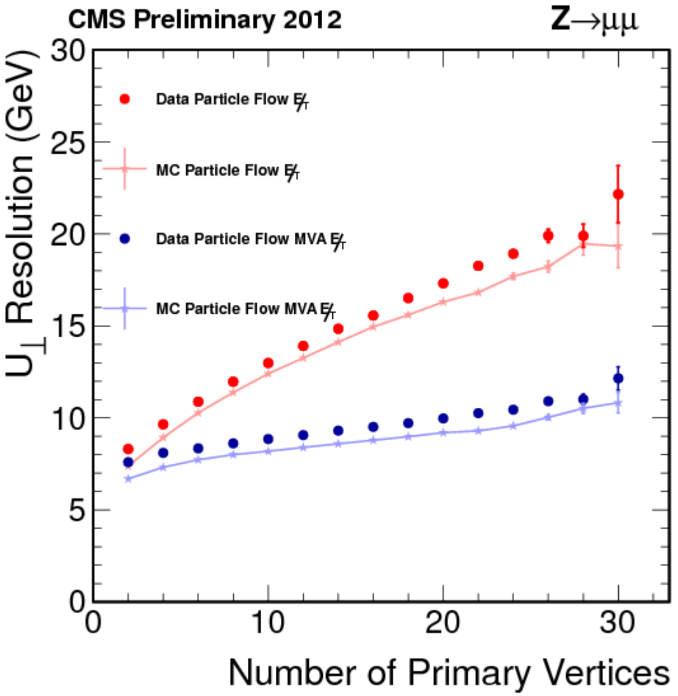
B-Tagging : Lifetime based b-tagger combining secondary vertex and track impact parameter information



Missing Transverse Momentum

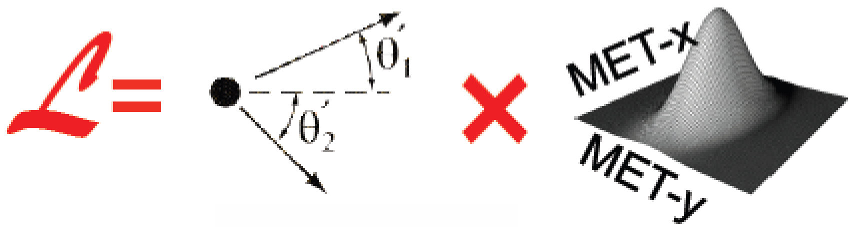
MVA Regression to compute best MET

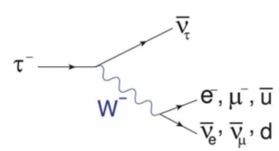
- Constructed out of 5 best METs (Recoils)
- Significant Improvement in MET resolution and pileup dependency
- Key to separate signal from background, improve di-tau mass reconstruction



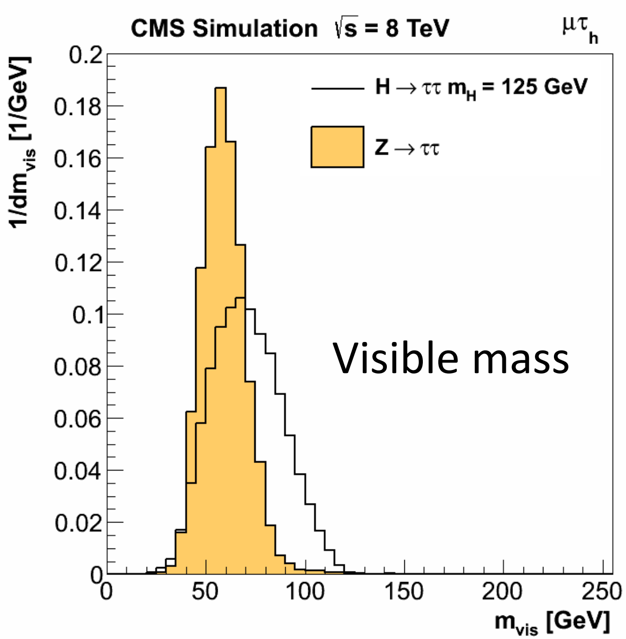
di-Tau Mass Reconstruction

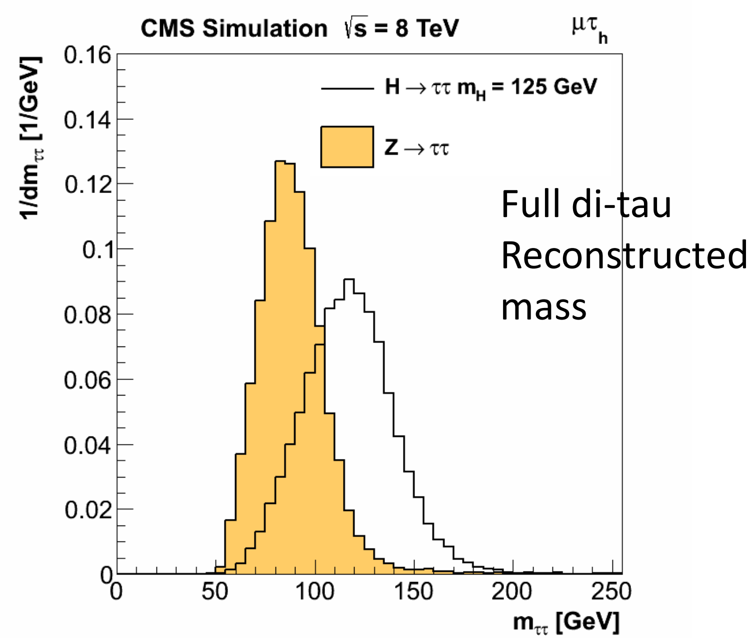
SVFit





- 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

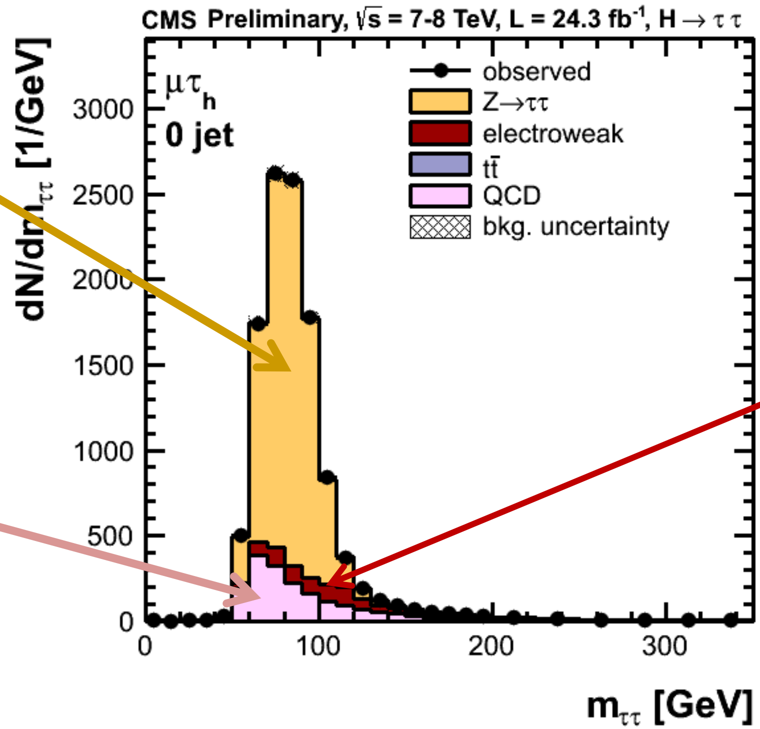




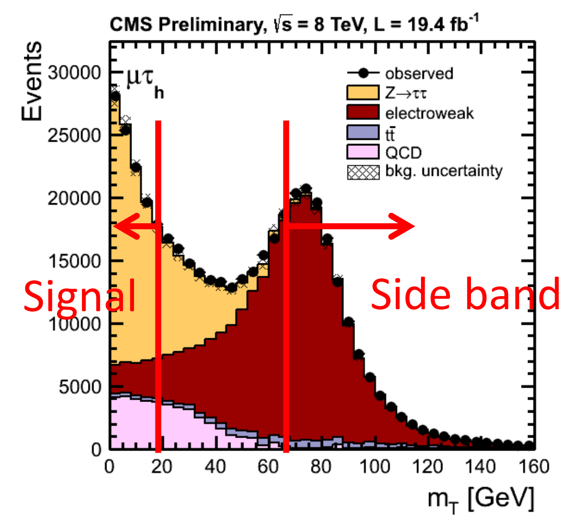
Anatomy of the Analysis

Z->ττ
Estimated using τ embedded Z->μμ events

QCD
Estimated using SS data



EWK
Mostly W+jets
Measured from high m_T sideband



Preselection :

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

Systematic uncertainties

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

Event Categories

Enrich Signal wrt to Z->tt background

Jet p_T > 30 GeV

Lepton (τ for $\ell\tau$) p_T

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

0jet, Low pT
High Background
Constrains Fit

1Jet, Low pT
Signal Enhancement
wrt Z

VBF (2 jet)

- ≥ 2Jet
- Central Jet veto
- m(jj) > 500 GeV
- |$\Delta\eta$(jj)| > 3.5

0jet, high pT
Lepton pT spectrum is
harder from Higgs
Reduce QCD

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

$\tau_h\tau_h$

Tau (muon in eμ) > 40 (35) GeV for high p_T category.

1Jet
1 jet, high pT(H)
requirement

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

Event Categories

Enrich Signal wrt to Z->tt background

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

Jet p_T > 30 GeV

Lepton (τ for $\ell\tau$) p_T

Do not Fit for signal

Propagate Constraint from 0 jet

<u>1Jet, Low pT</u>
Signal Enhancement wrt Z

<u>1Jet, high pT</u>
Enhancement from both lepton and jet (better mass resolution)

<u>VBF (2 jet)</u>

- ≥ 2Jet
- 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.

$\tau_h\tau_h$

<u>1Jet</u>
1 jet, high pT(H) requirement

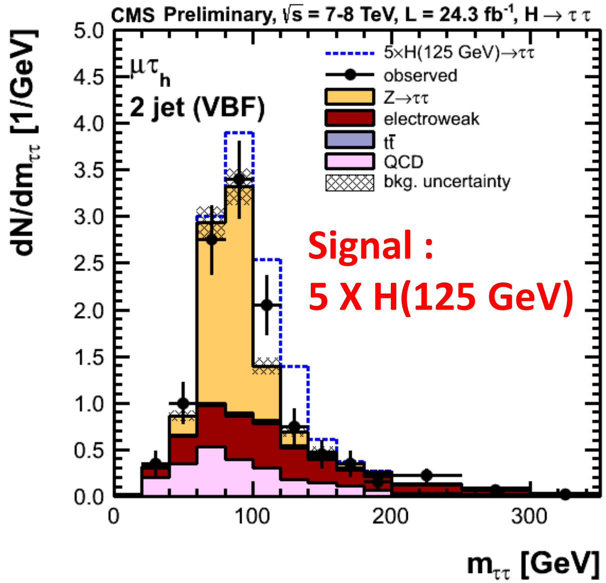
<u>VBF (2 Jet)</u>
2 jets,
high $p_T(H)$ requirement,
$m(jj) > 250$ GeV,
$|\Delta\eta(jj)| > 2.5$

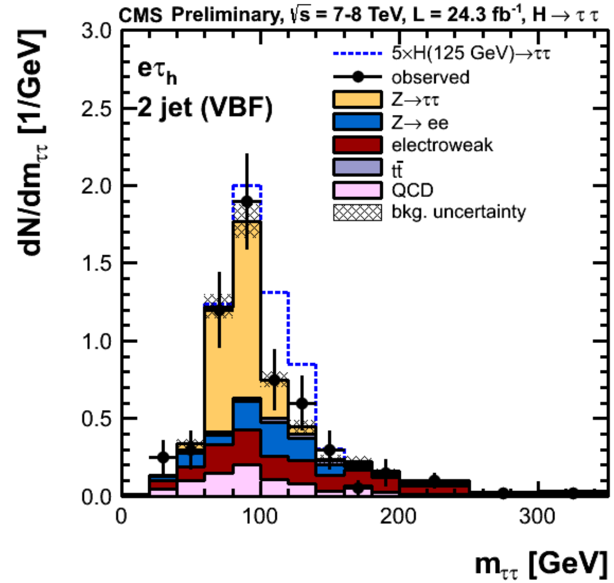
$M_{\tau\tau}$ Distribution

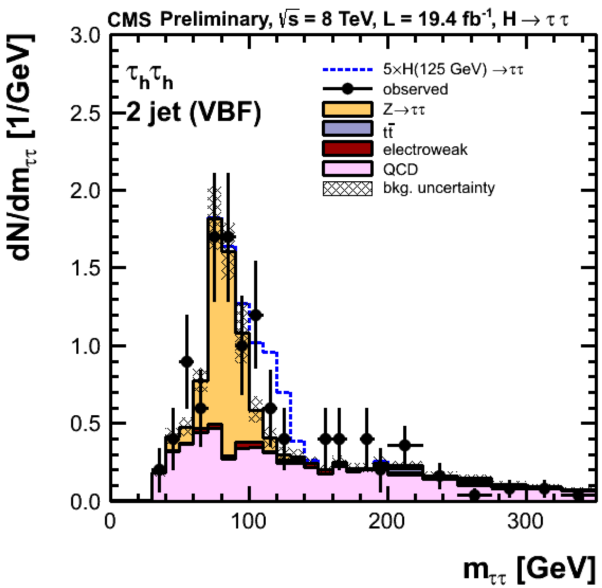
7 TeV : 4.9 fb^{-1}
8 TeV : 19.4 fb^{-1}

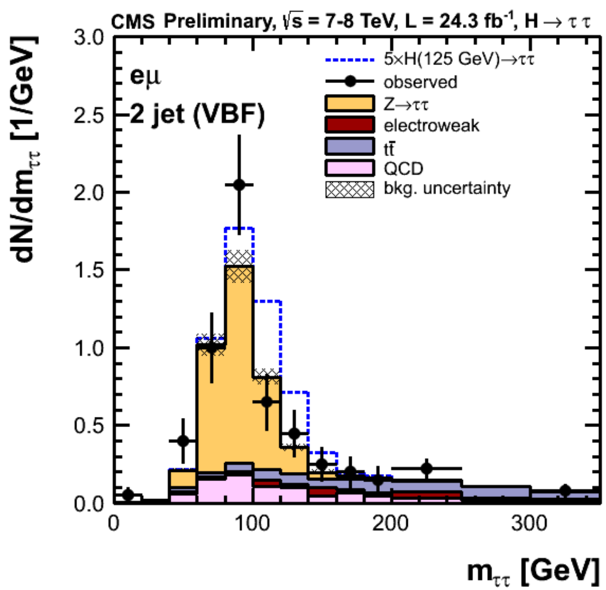
VBF (2-jet)

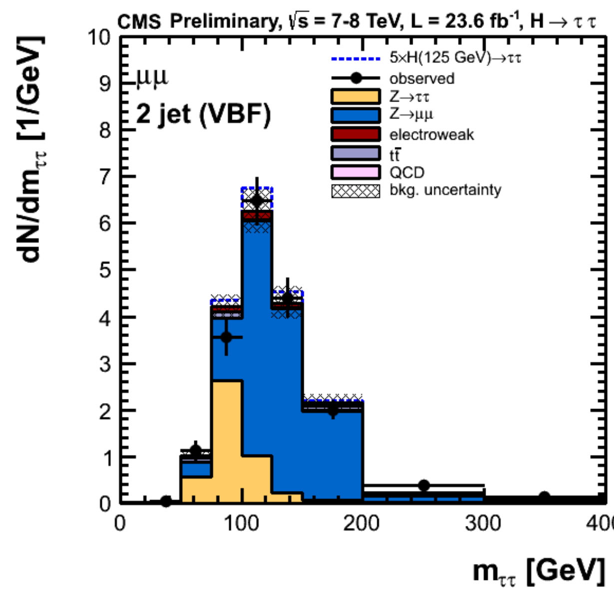
- Enhancement of VBF signal
- Highest S/B





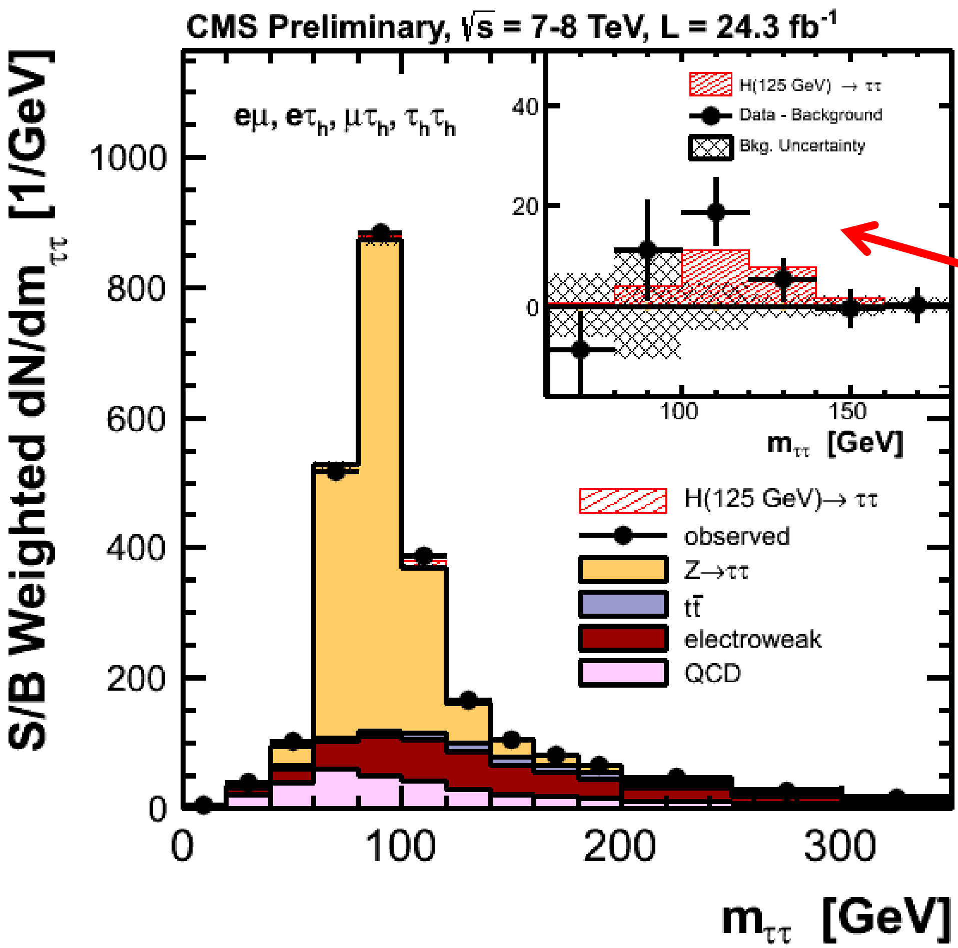






Compatibility of the Higgs Signal

Combined 1 Jet and VBF

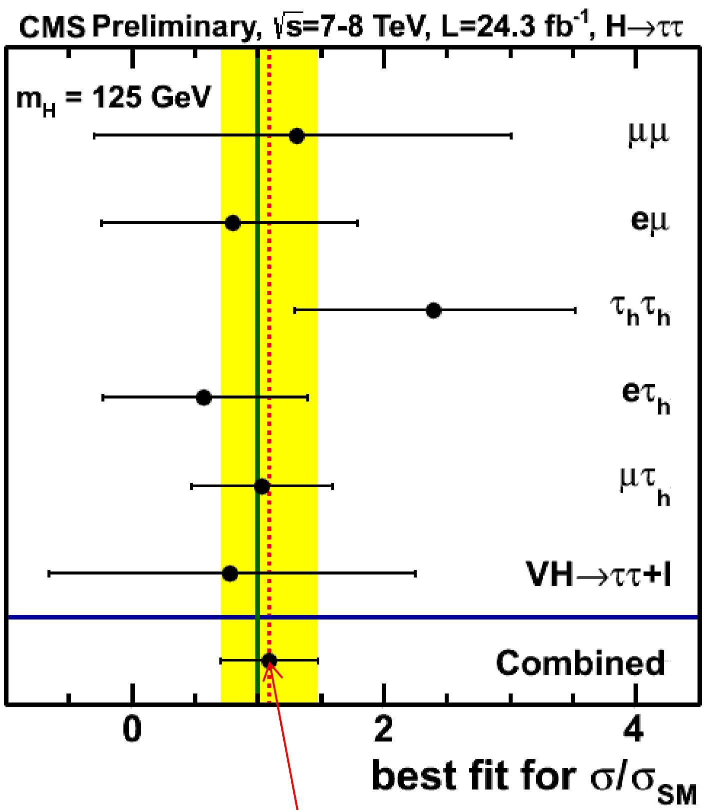


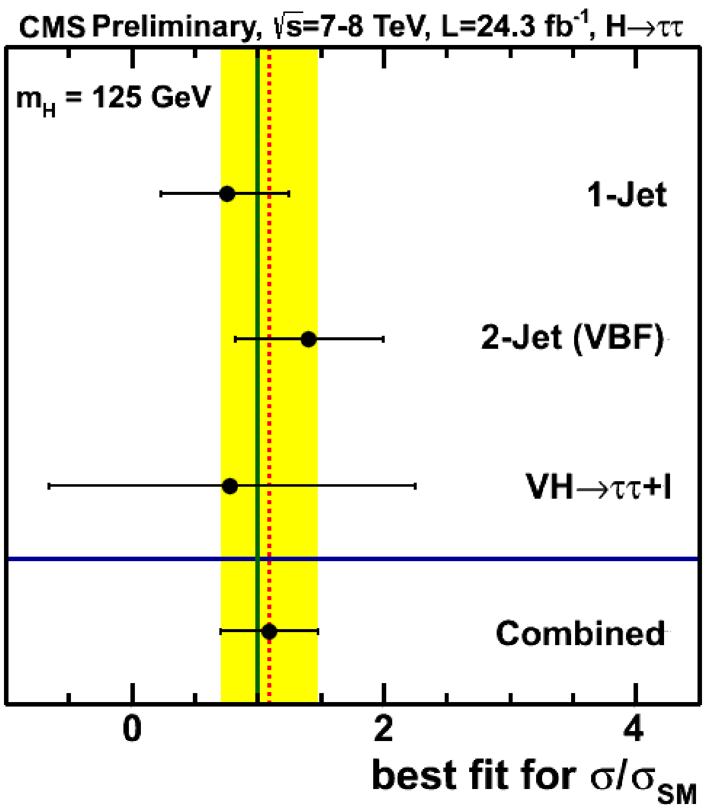
Each category in each channel are combined with weight of S/B.

Data – Background

the region around 50 – 150 GeV

Signal Strength σ/σ_{SM}





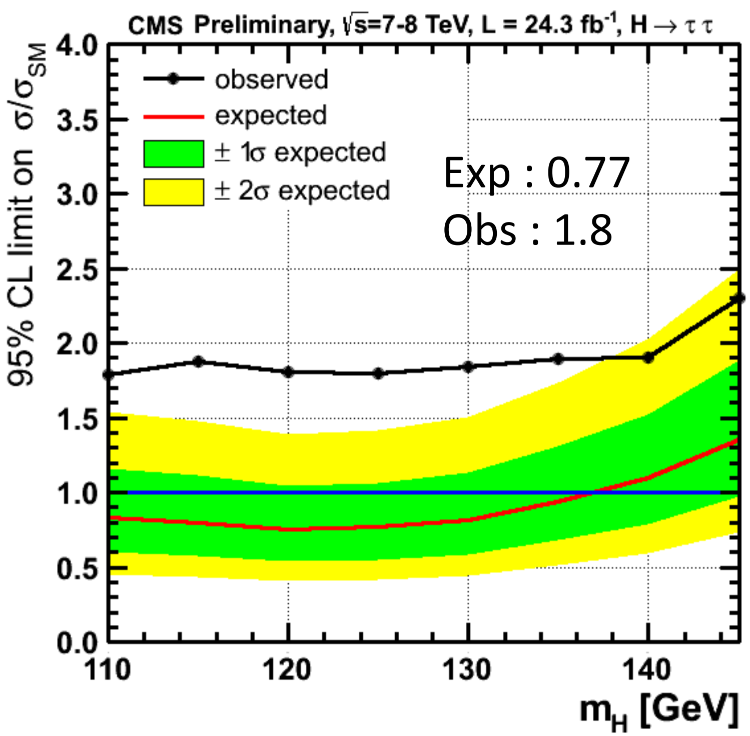
Best fit σ/σ_{SM} = 1.1 +/- 0.4

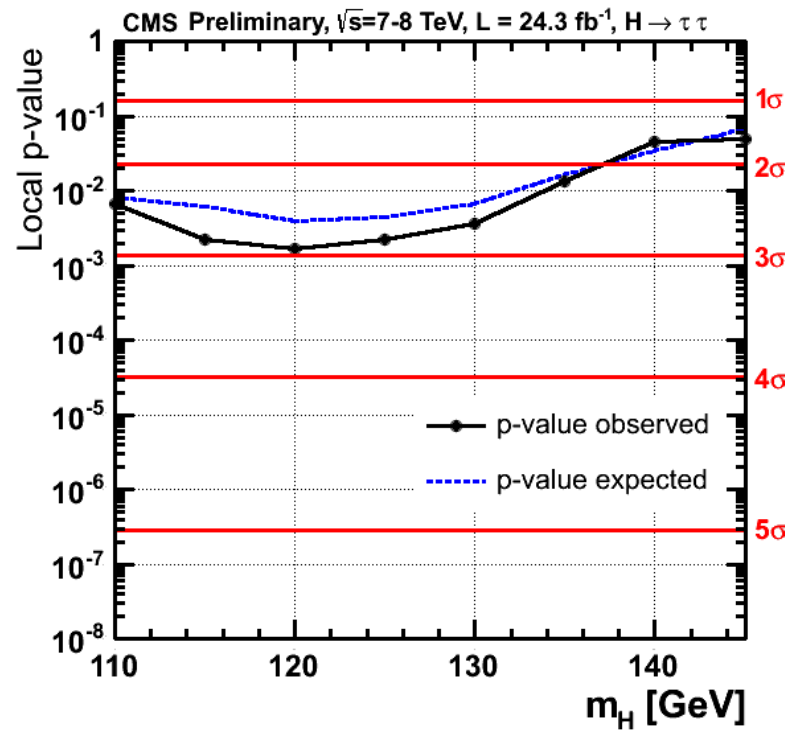
Results consistent among all channels and categories

SM Results

Results combining all channels and categories

24.3 fb-1





At 125 :

The expected/observed Limit **0.77/1.81**

Observation of flat excess

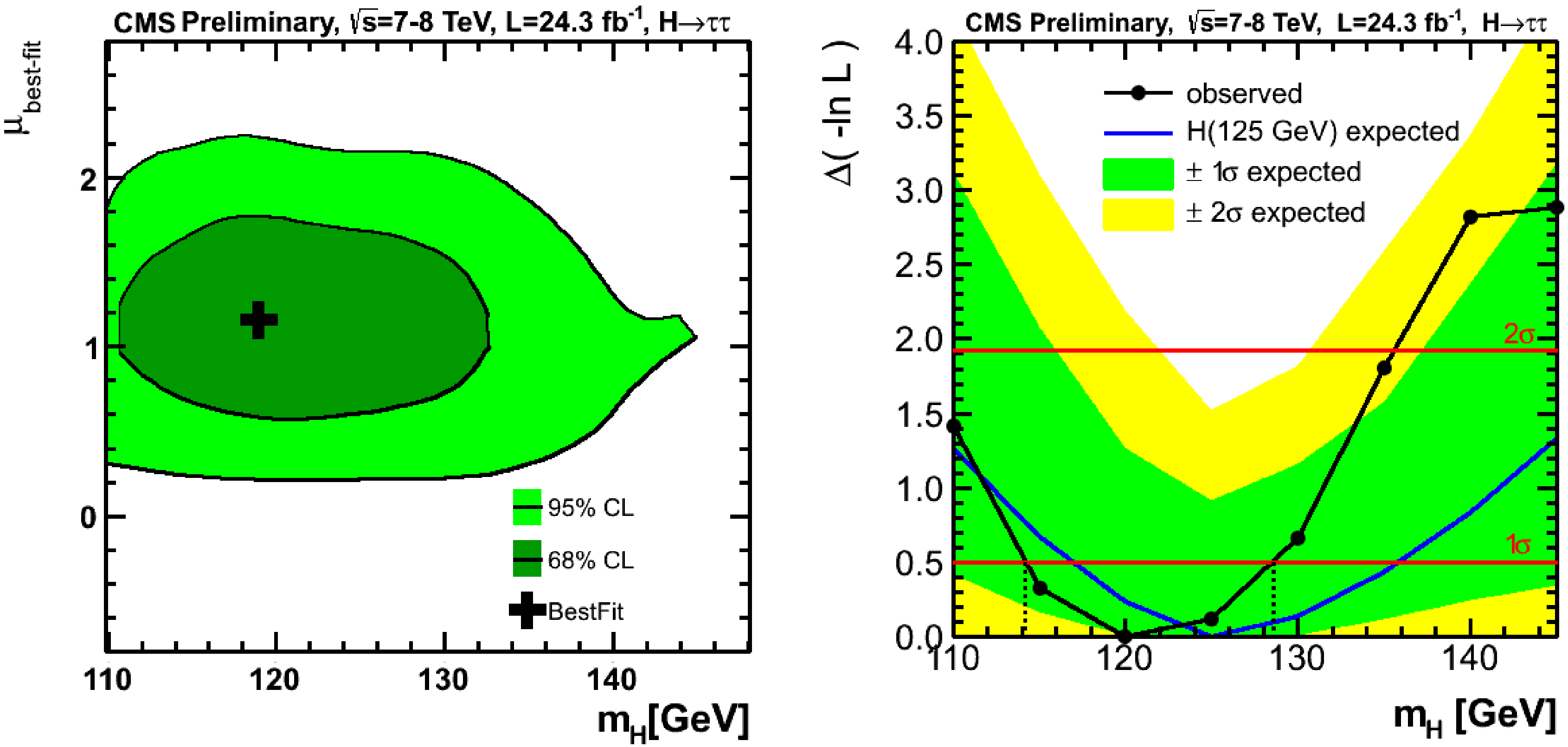
Maximum Significance of **2.93 σ at 120 GeV**

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

- CMS observes an excess in the search for $H\rightarrow\tau\tau$ with a **significance of 2.9 σ**, based on 24 fb^{-1} of data, which is consistent with the expected signal for a 125-GeV Higgs boson
  - 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 ~ 125 GeV observed in diboson channels ($\gamma\gamma$, ZZ, WW)

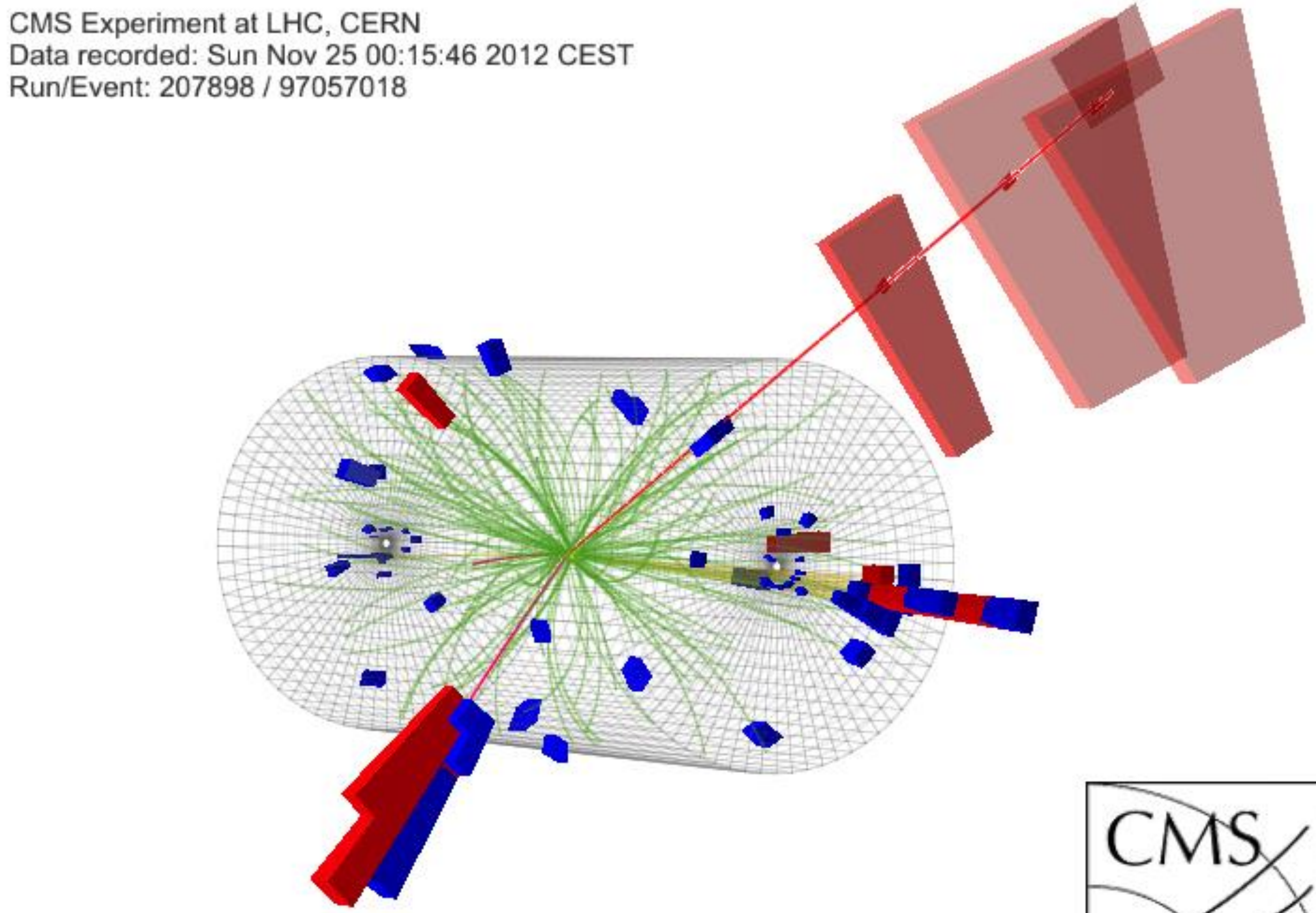
- Current Progress for final paper :
  - Re-optimized categories, selection cuts, tau identification
    - Expected significance above 3σ
  - Analysis have been un-blinded in major channels
  - Final results in another few weeks

IRFU Contribution

- Strong involvement of IRFU along with LLR/IN2P3 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 ($e\tau_h$, $\mu\tau_h$ [8 TeV] channel)

Backup

A μτ VBF candidate



VH Categories

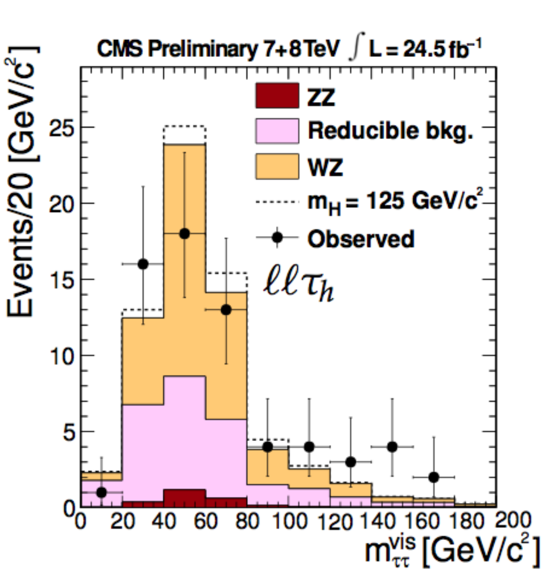
W/Z decay to leptons

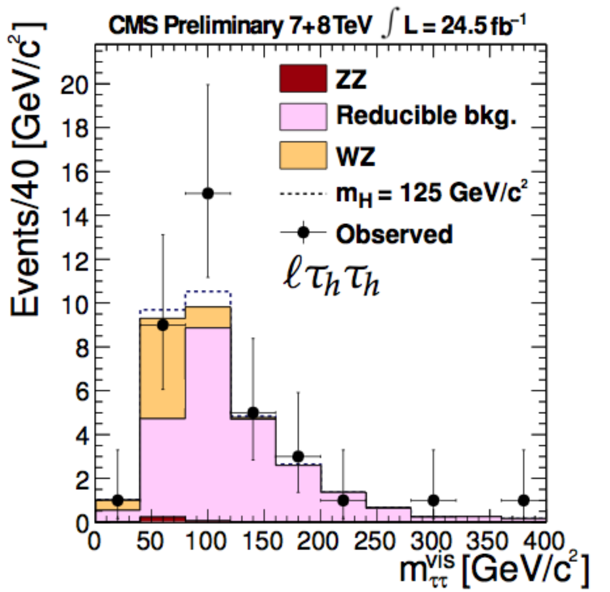
WH -> $\ell\,\tau\tau$

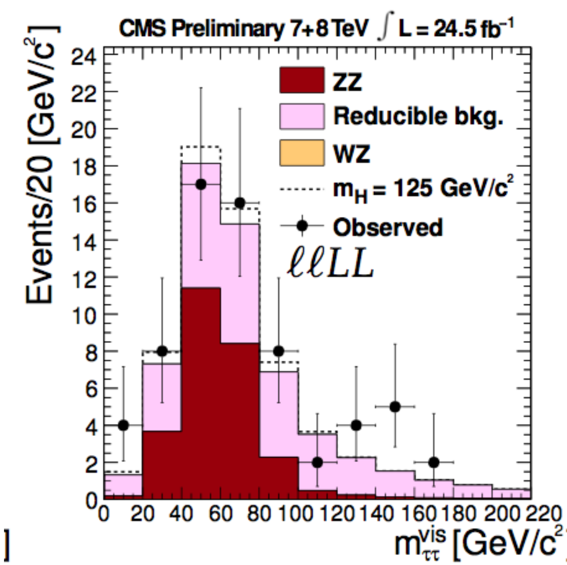
ZH -> $\ell\ell\tau\tau$

1 Hadronic τ	2 Hadronic τ	ee/$\mu\mu$+ All possible combinations
$\tau e^{\pm}\mu^{\pm}$	$\tau\tau e$	
$\tau\mu^{\pm}\mu^{\pm}$	$\tau\tau\mu$	

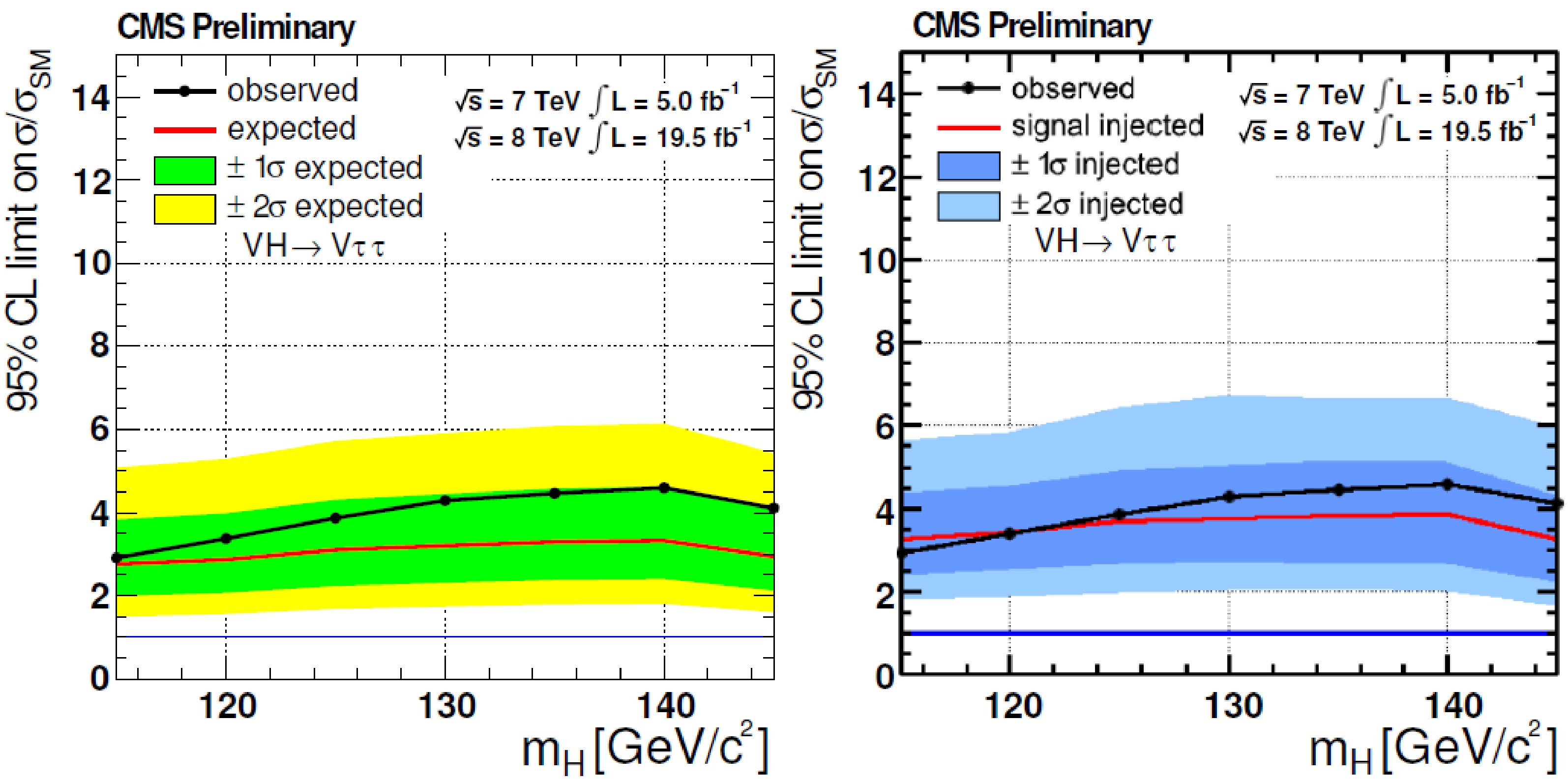
VH, H->WW-> τ + X is also included in the channel



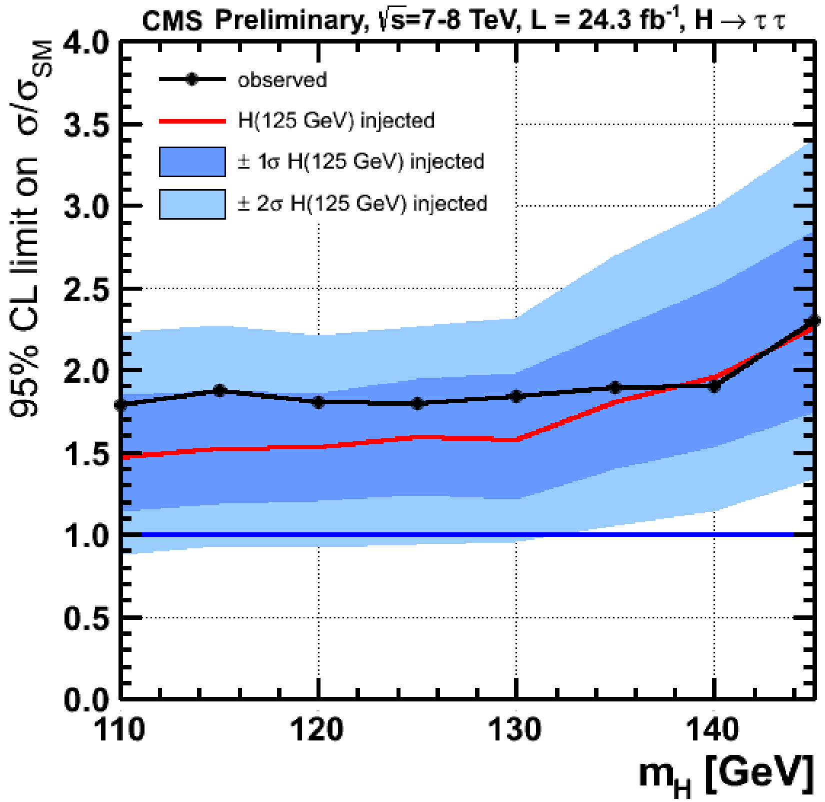




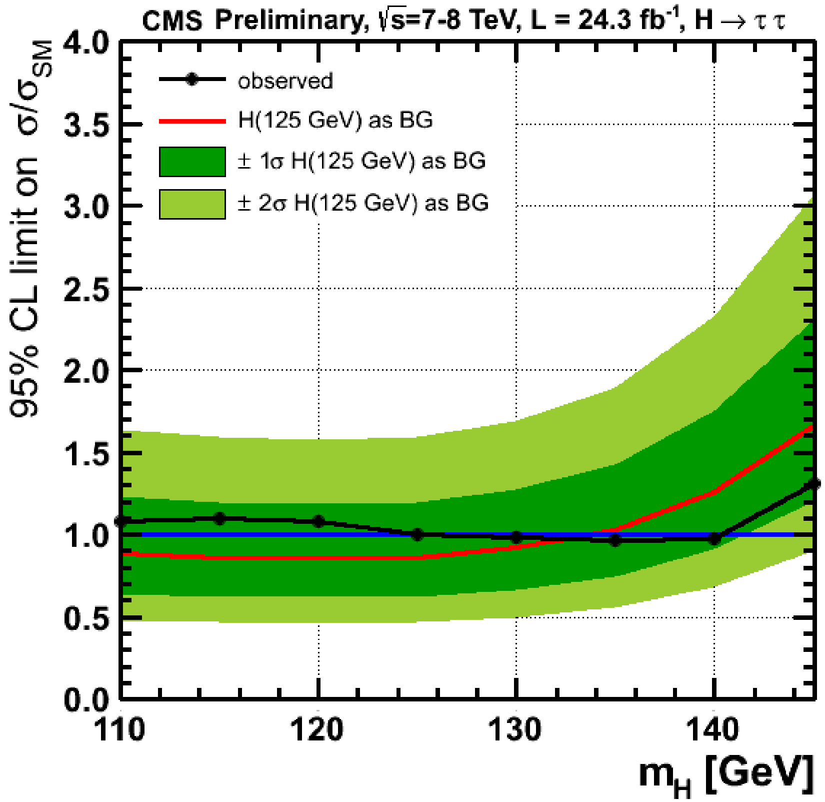
VH Exclusion Limit



Exclusion

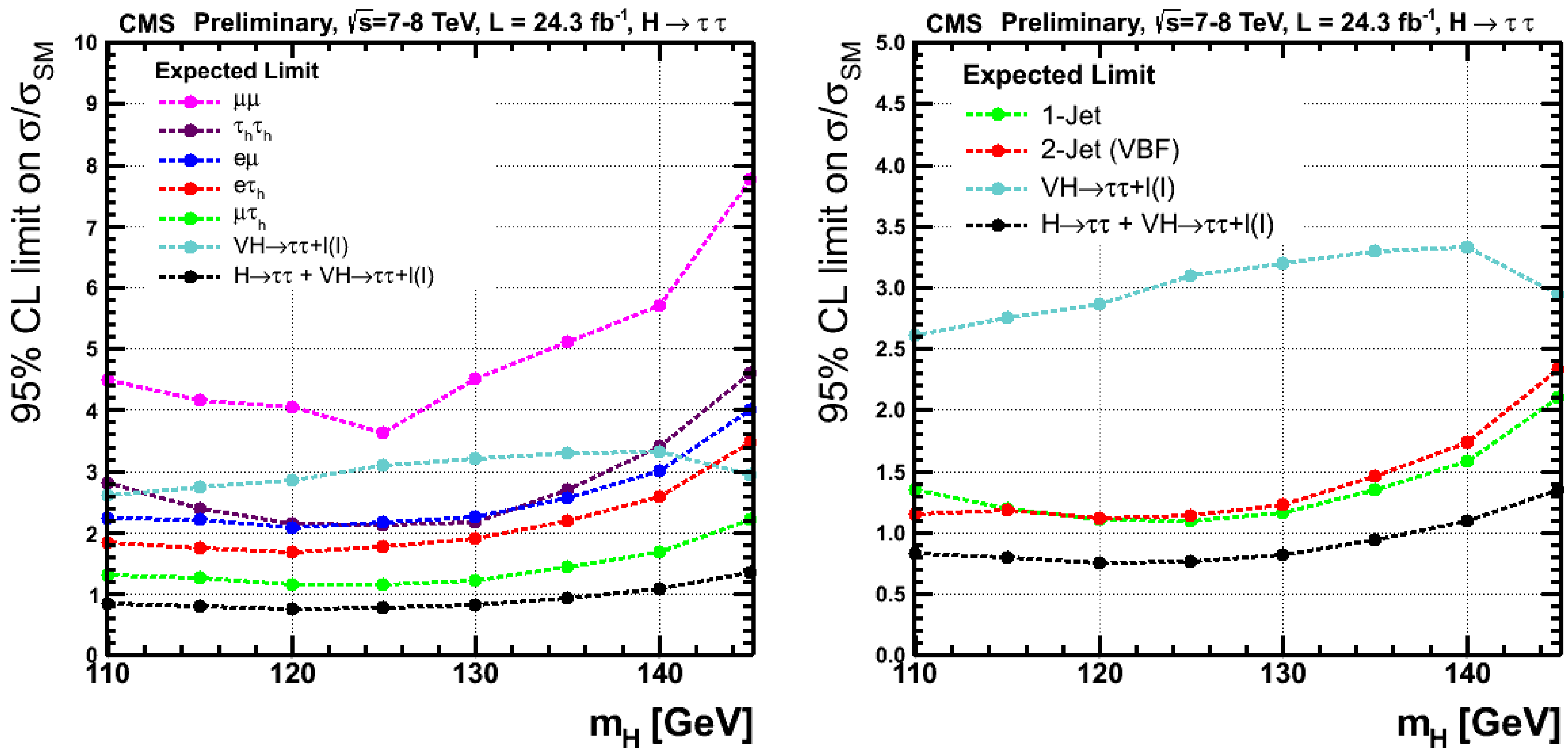


CMS Preliminary, √s=7-8 TeV, L = 24.3 fb⁻¹, H → τ τ
95% CL limit on σ/σSM
observed
H(125 GeV) injected
± 1σ H(125 GeV) injected
± 2σ H(125 GeV) injected
mH [GeV]

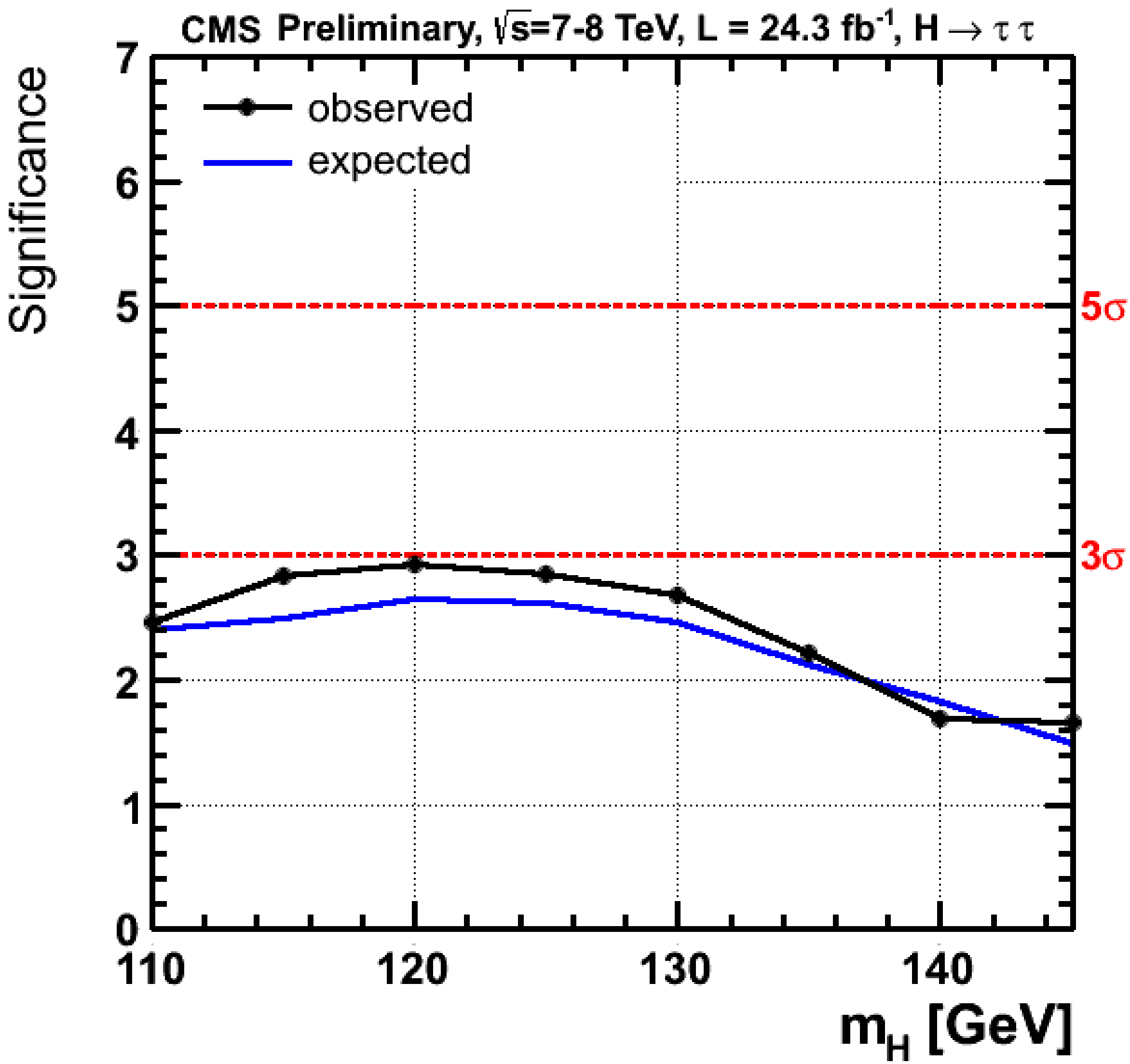


CMS Preliminary, √s=7-8 TeV, L = 24.3 fb⁻¹, H → τ τ
95% CL limit on σ/σSM
observed
H(125 GeV) as BG
± 1σ H(125 GeV) as BG
± 2σ H(125 GeV) as BG
mH [GeV]

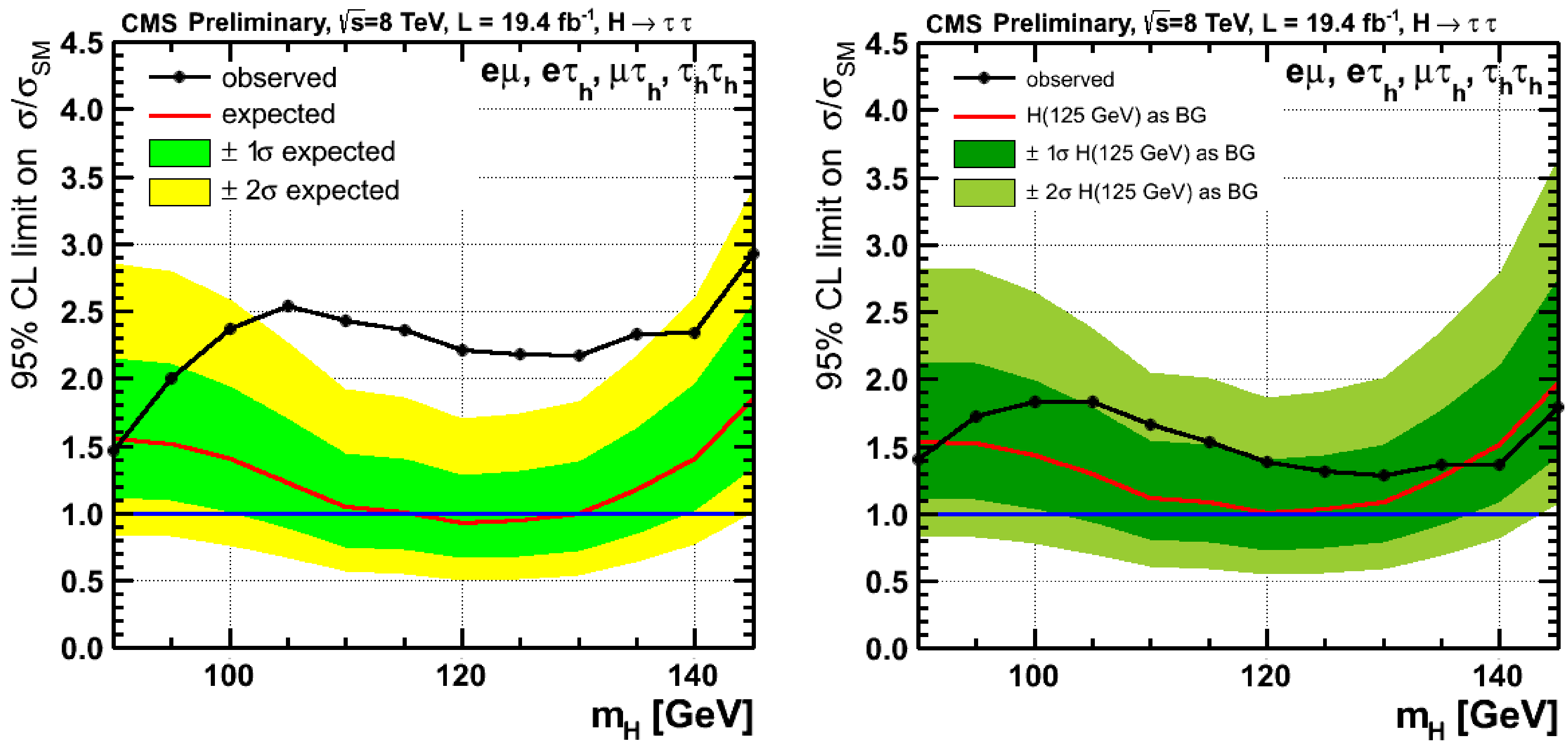
Sensitivity by Channel & Category



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

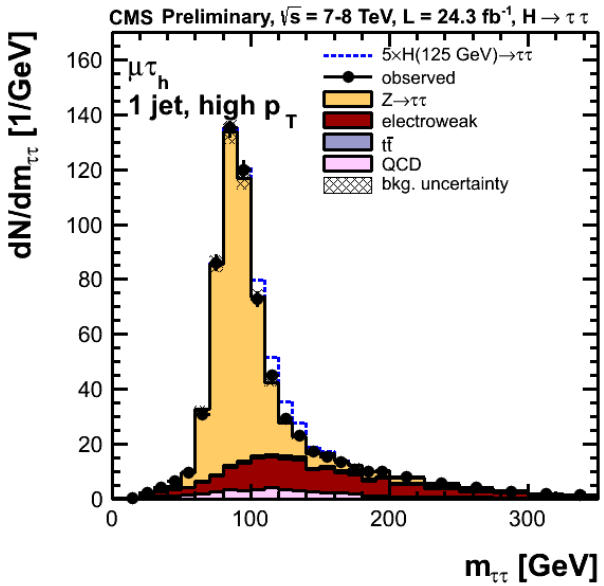
Theory Uncertainties (SM)		Propagation into Limit Calculation		
Uncertainty	Uncert.	*0-Jet*	*1-Jet*	*VBF*
PDF (†*)	-	-	±2 – 8%	±2 – 8%
$\mu_r/\mu_f(gg \to H)$ (†*)	-	-	±10%	±30%
$\mu_r/\mu_f(qq \to H)$ (†*)	-	-	±4%	±4%
$\mu_r/\mu_f(qq \to VH)$ (†*)	-	-	±4%	±4%
UE & PS (†*)	-	-	±4%	±4%

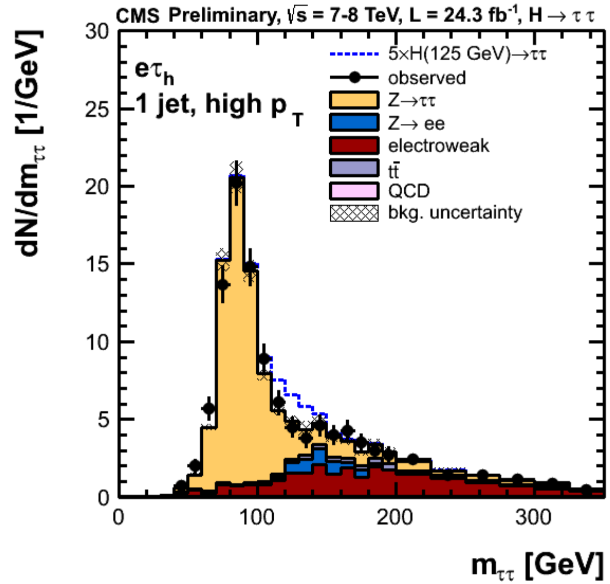
$M_{\tau\tau}$ Distribution

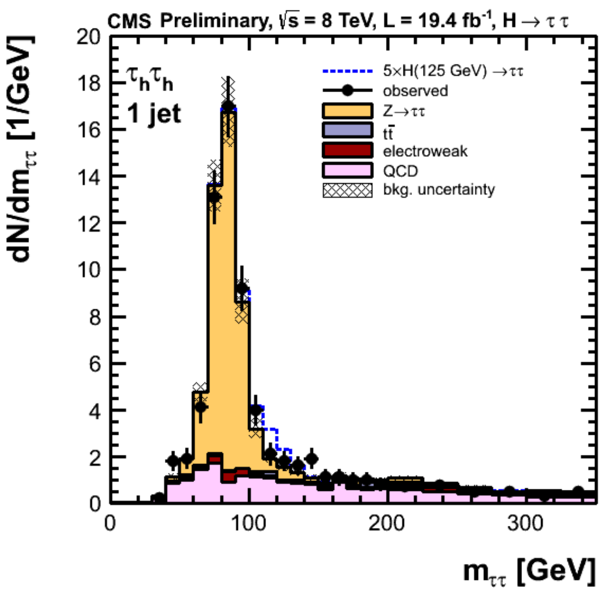
7 TeV : 4.9 fb-1
8 TeV : 19.4 fb-1

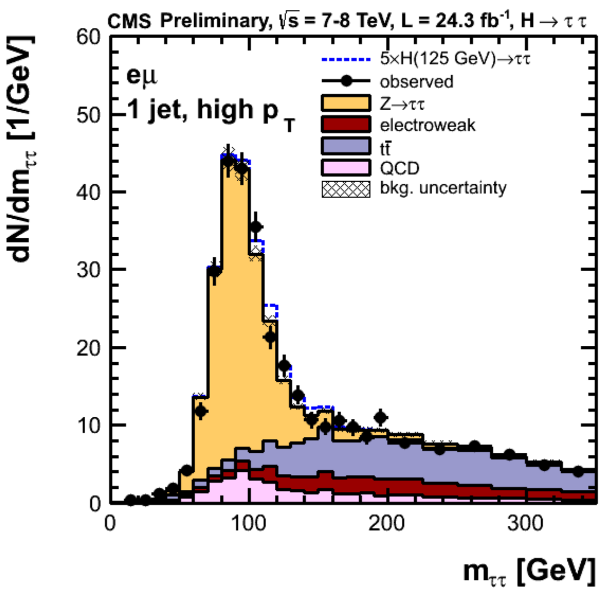
1-Jet , High Pt
2nd best Category

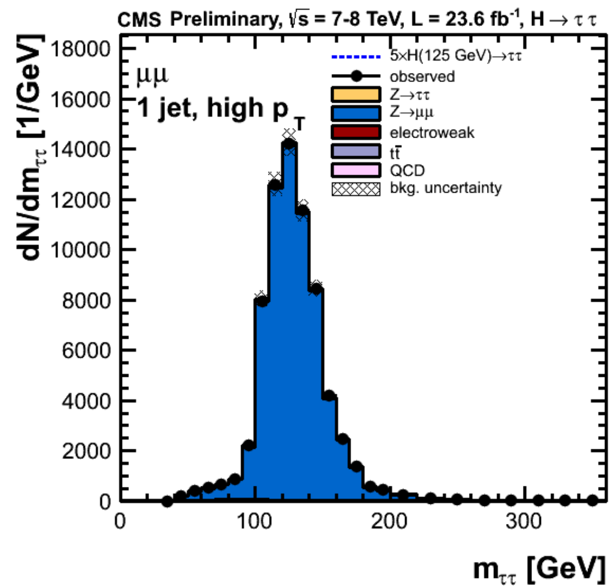
Enhances Gluon Fusion signal



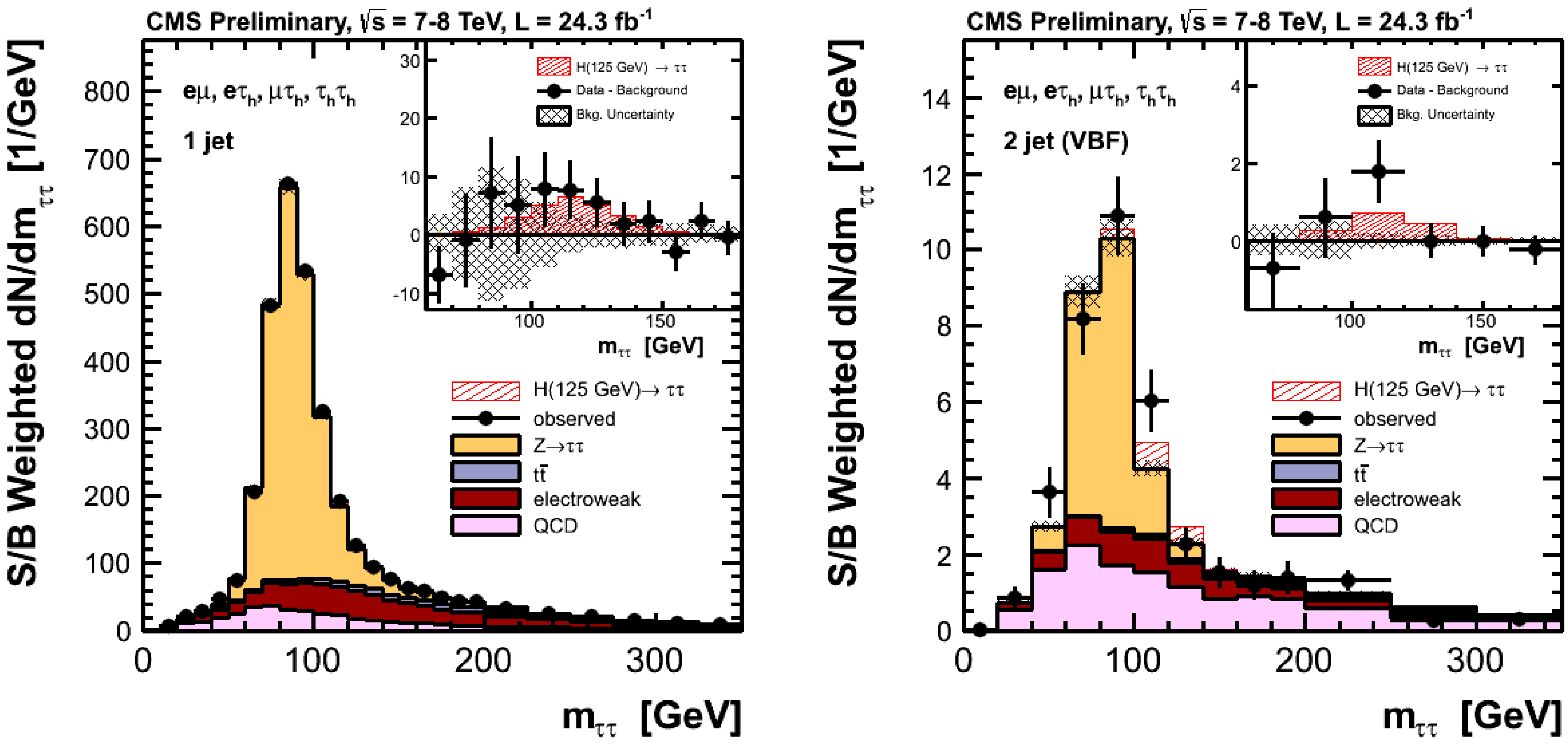




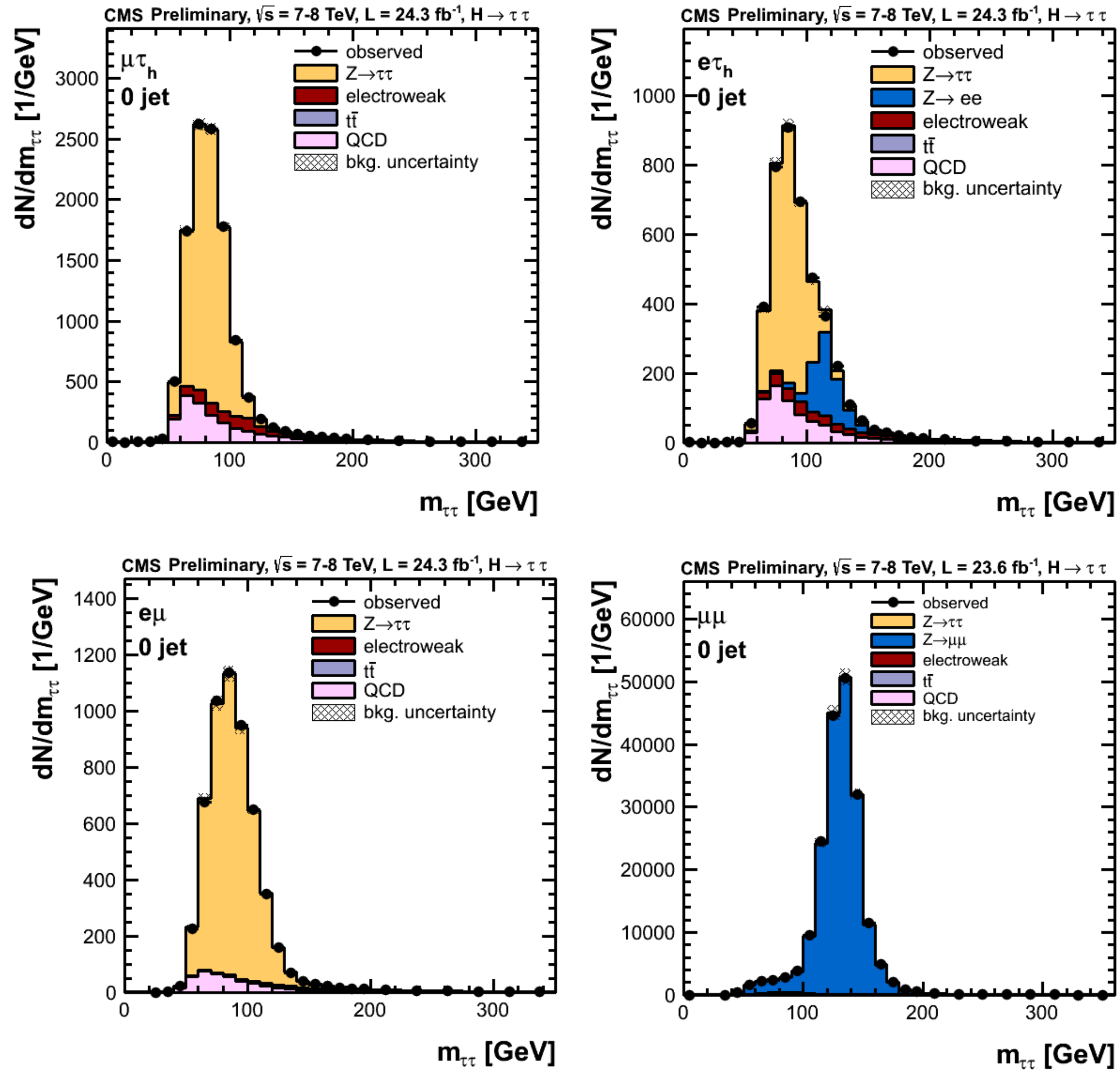




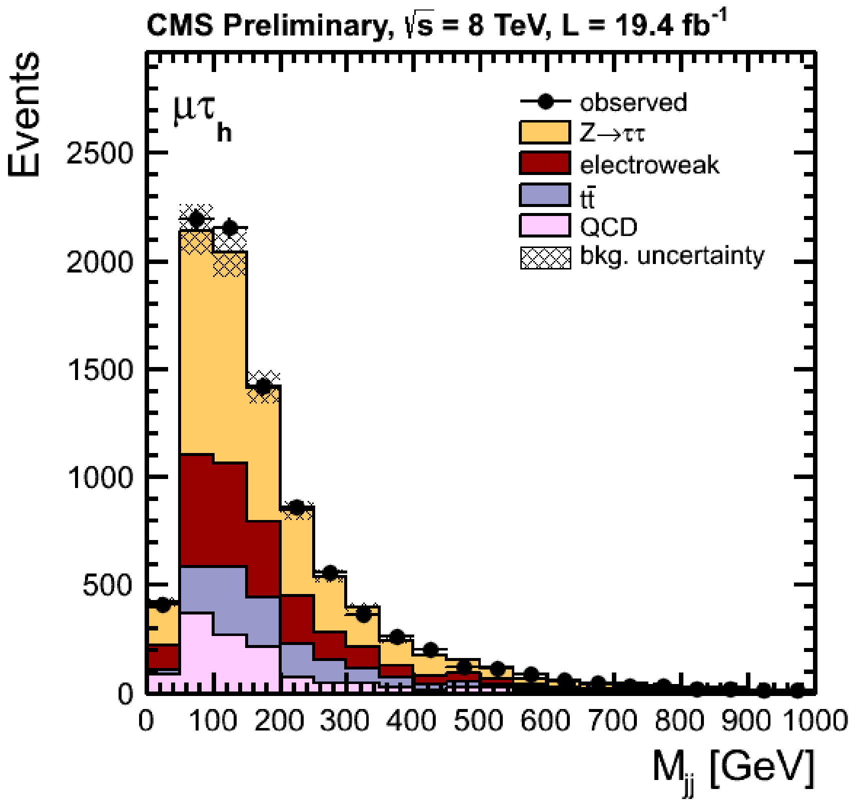
Combined 1 Jet & VBF

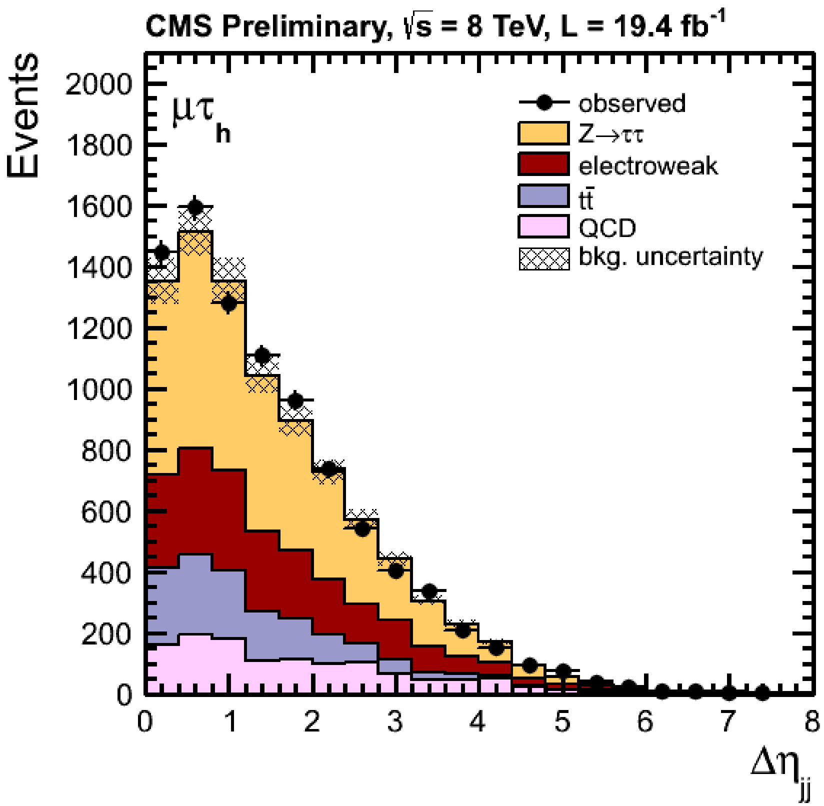


0 jet

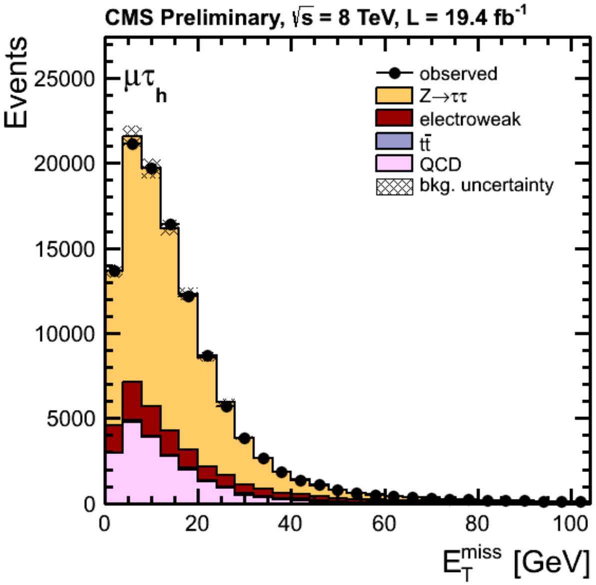

CMS Preliminary, √s = 7-8 TeV, L = 24.3 fb-1, H → τ τ
μτh
0 jet
observed
Z→ττ
electroweak
tt̄
QCD
bkg. uncertainty
dN/dmττ [1/GeV]
mττ [GeV]
CMS Preliminary, √s = 7-8 TeV, L = 24.3 fb-1, H → τ τ
eτh
0 jet
observed
Z→ττ
Z→ ee
electroweak
tt̄
QCD
bkg. uncertainty
dN/dmττ [1/GeV]
mττ [GeV]
CMS Preliminary, √s = 7-8 TeV, L = 24.3 fb-1, H → τ τ
eμ
0 jet
observed
Z→ττ
electroweak
tt̄
QCD
bkg. uncertainty
dN/dmττ [1/GeV]
mττ [GeV]
CMS Preliminary, √s = 7-8 TeV, L = 23.6 fb-1, H → τ τ
μμ
0 jet
observed
Z→ττ
Z→μμ
electroweak
tt̄
QCD
bkg. uncertainty
dN/dmττ [1/GeV]
mττ [GeV]

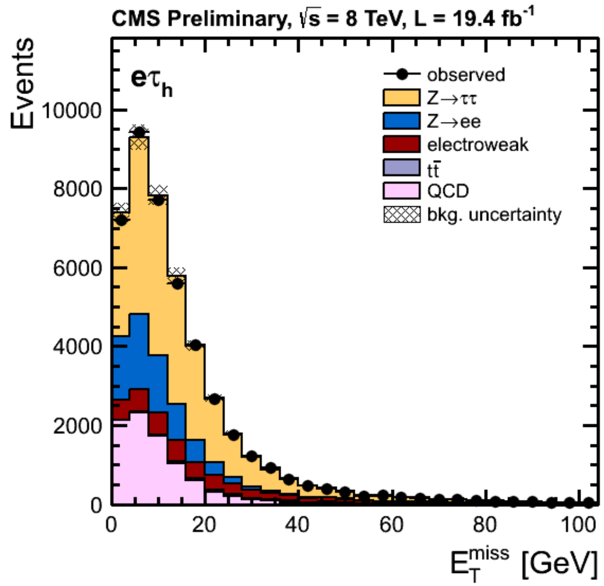
VBF Variables

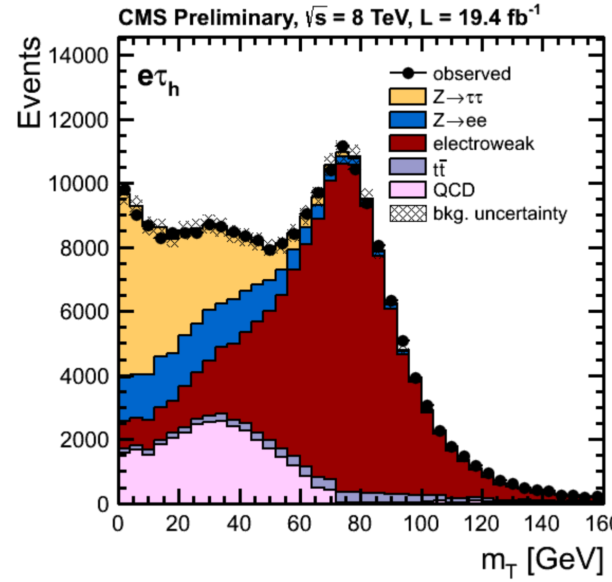




MET

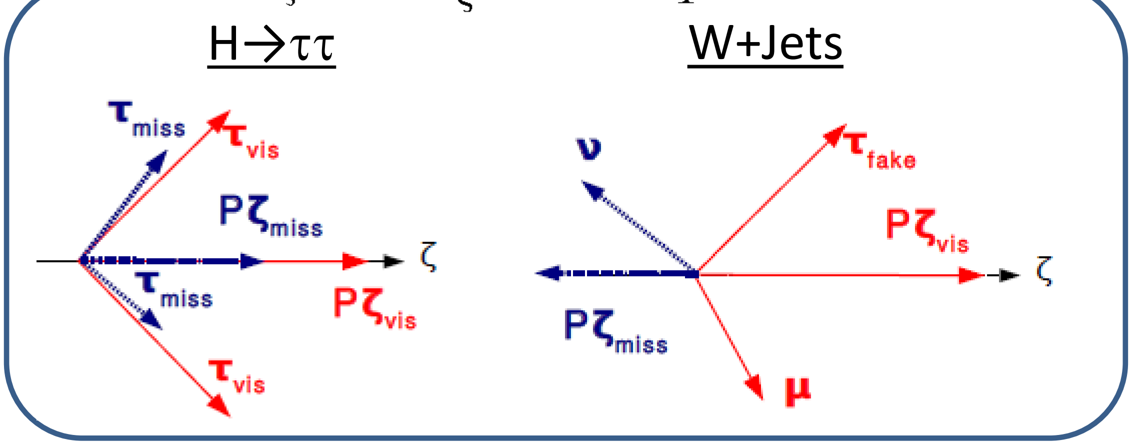


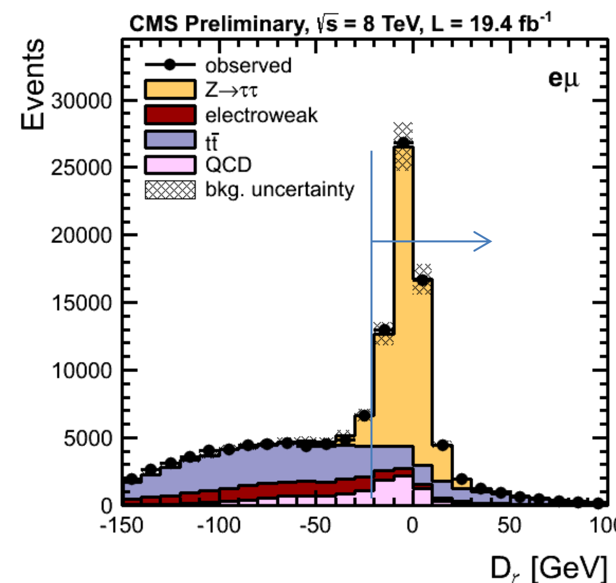




$$P_\zeta^{vis} = p_{T,1} \cdot \zeta + p_{T,2} \cdot \zeta$$

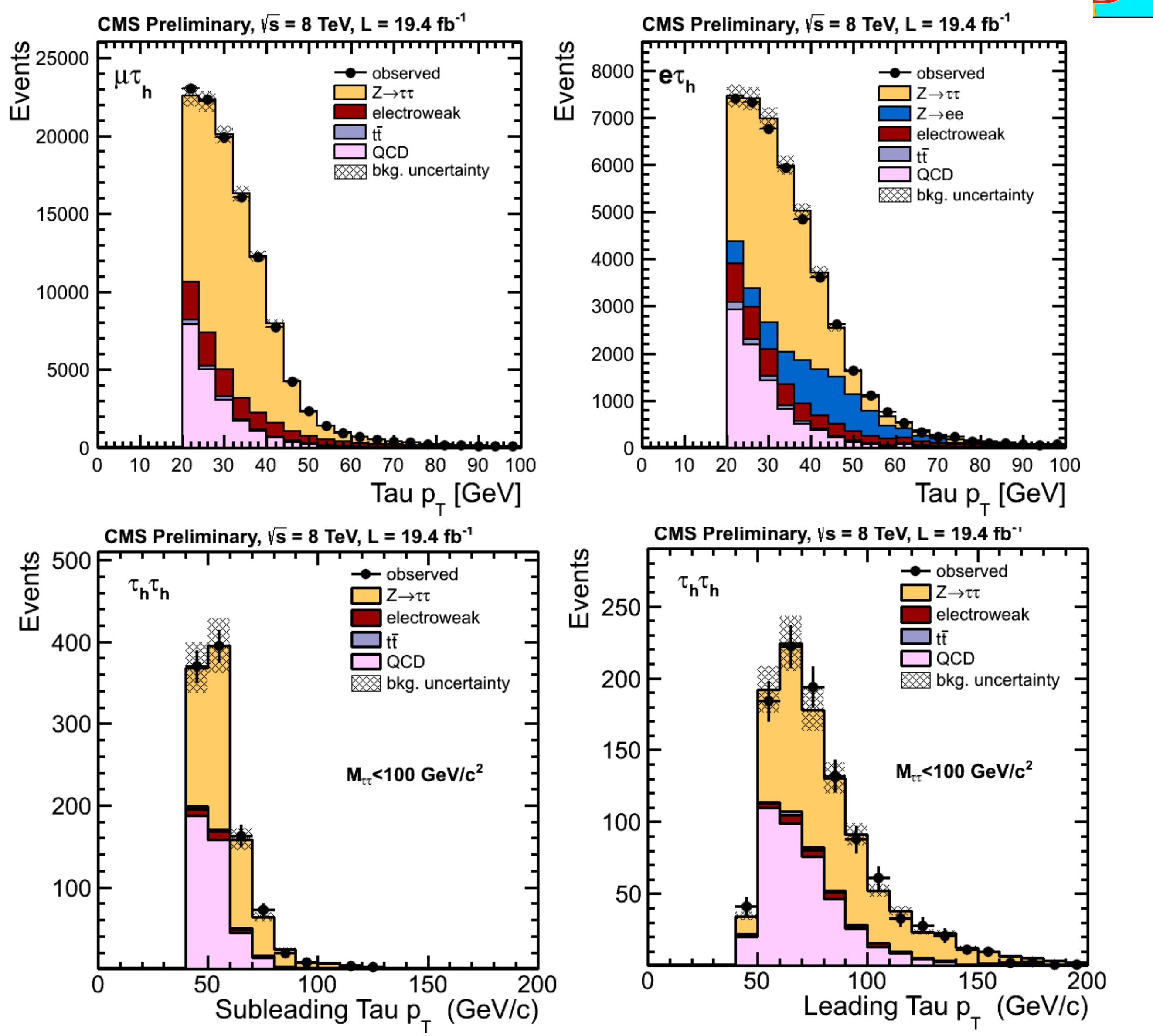
$$P_\zeta = P_\zeta^{vis} + E_T^{miss} \cdot \zeta$$





$$D_\zeta \equiv \not{p}_\zeta - 0.85 \cdot p_\zeta^{vis} > -20 \text{ GeV}$$

Tau



CMS Preliminary, √s = 8 TeV, L = 19.4 fb⁻¹
μτh
observed
Z→ττ
electroweak
tt̄
QCD
bkg. uncertainty
Events
Tau pT [GeV]
eτh
Z→ee
τhτh
Mττ<100 GeV/c²
Subleading Tau pT (GeV/c)
Leading Tau pT (GeV/c)

Event Yields (CMS)

$\mu\tau_h$

Process	0-Jet	1-Jet high p_T	VBF
$Z\to \tau\tau$	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
$H\to \tau\tau$	- ± -	73 ± 13	11 ± 2
Observed	112279	7011	240

Signal Eff.

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

$e\tau_h$

Process	0-Jet	1-Jet high p_T	VBF
$Z\to \tau\tau$	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
$H\to \tau\tau$	- ± -	15 ± 3	5 ± 1
Observed	42481	1217	117

Signal Eff.

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

$\tau_h\tau_h$

Process	1-Jet	VBF
$Z\to \tau\tau$	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
$H\to \tau\tau$	9 ± 4	4 ± 2
Observed	718	120

Signal Eff.

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

$e\mu$

Process	0-Jet	1-Jet high p_T	VBF
$Z\to \tau\tau$	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
$H\to \tau\tau$	- ± -	23 ± 4	5 ± 0.6
Observed	54694	3774	118

Signal Eff.

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

Analysis Strategy

MSSM Categories

Non-bTag

$\leq$ 1 jet with p_T > 30 GeV,
< 1 b-Tagged Jet with p_T > 20 GeV
Dominated by ggH

b-Tag

$\leq$ 1 jet with p_T > 30 GeV,
$\geq$ 1 b-Tagged Jet with p_T > 20 GeV
Dominated by bbH

MSSM Results