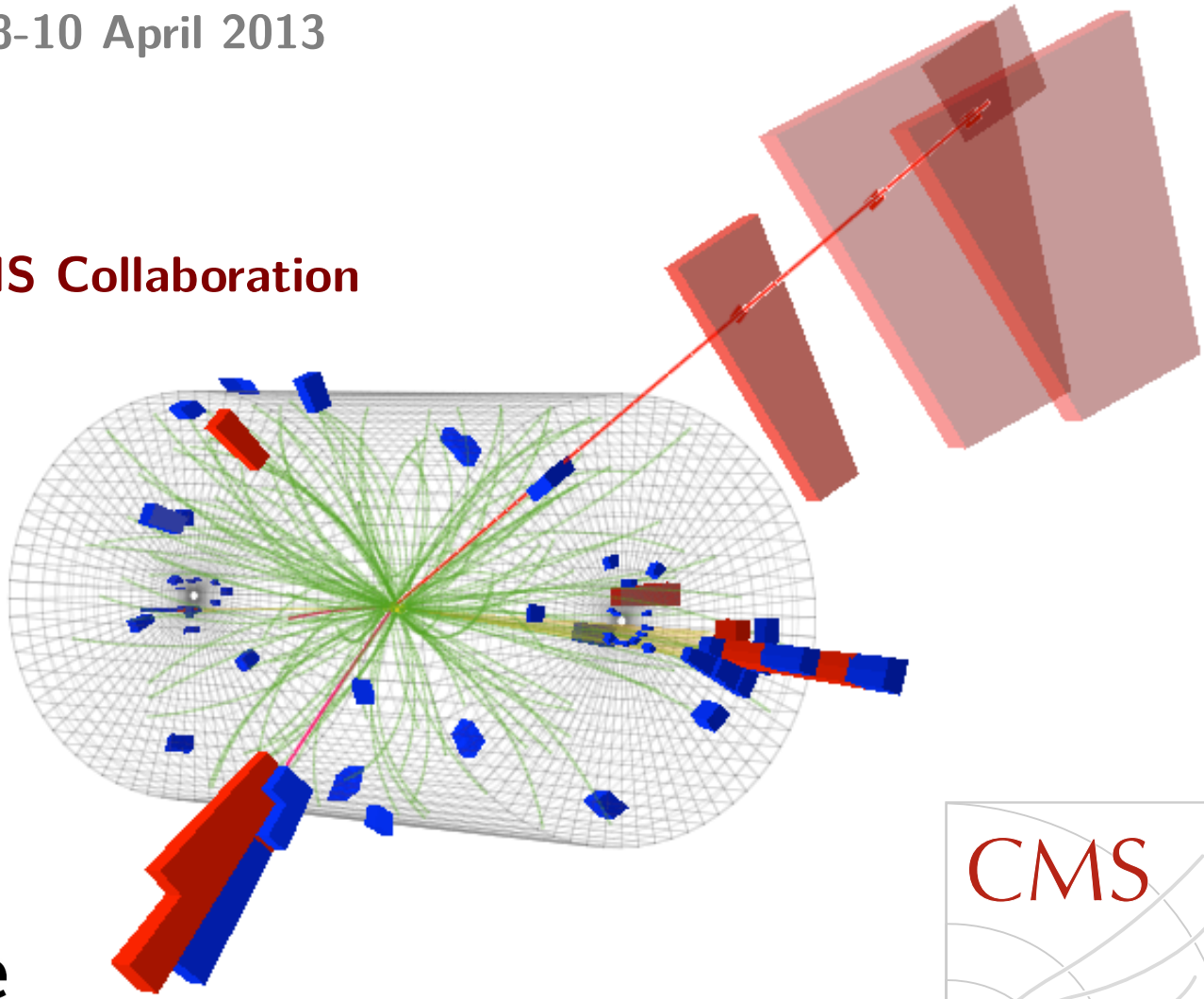
Search for the Standard Model Higgs boson decaying to tau leptons with the CMS detector

Institute of Physics, 8-10 April 2013

Andrew Gilbert

on behalf of the CMS Collaboration



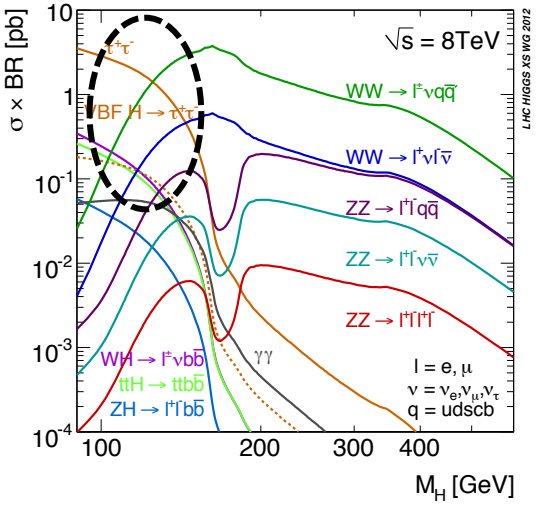
Imperial College
London

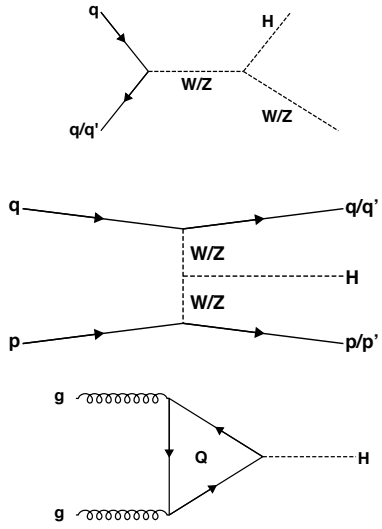
CMS
Compact Muon Solenoid

Introduction

- Higgs-like boson discovered July 2012: does it decay to fermions?

- $H \rightarrow \tau\tau$ has high σ X BR for a low mass Higgs
- Able to probe all Higgs production mechanisms
- However large backgrounds from $Z \rightarrow \tau\tau$, W+jets, QCD

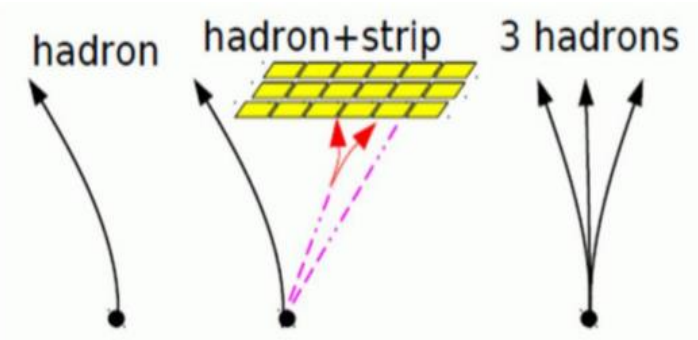




- Present latest $H \rightarrow \tau\tau$ result with full 2011 (4.9 fb^{-1}) + 2012 (19.4 fb^{-1}) datasets: **CMS-PAS-HIG-13-004**
- Analysis performed with 5 final states: $\mu\tau_h$ $\mu\mu$ $e\tau_h$ $e\mu$ $\tau_h\tau_h$
  - Final results shown also include WH/ZH$\rightarrow\tau\tau$ analysis: CMS-PAS-HIG-12-053

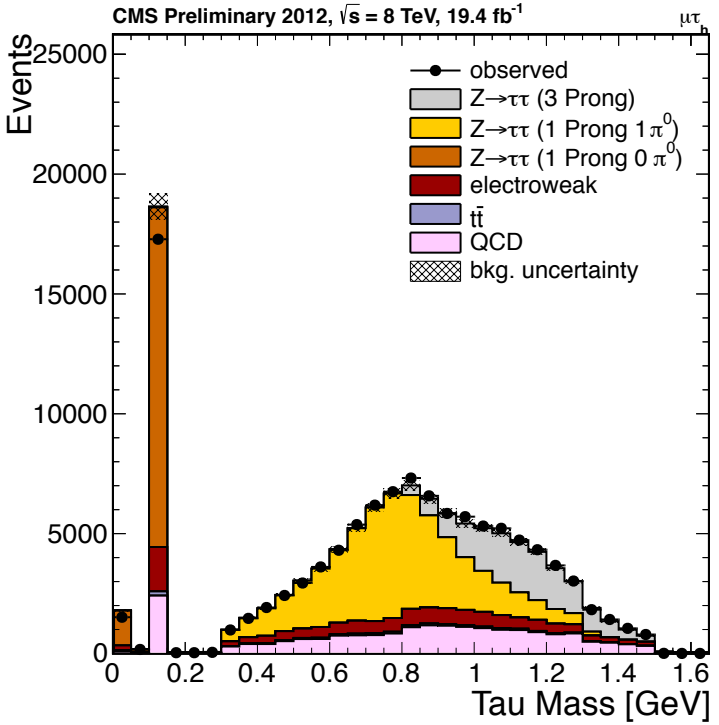
Hadronic Tau Reconstruction

- Uses **particle flow** - optimally combine all detector output to reconstruct and classify particles in the event (e.g. charged hadrons, electrons, muons, neutral hadrons, photons)
- Reconstruct different decay modes of the tau
- Use the tau mass to calibrate the energy scale



$\pi^{\pm}$ $\rho^{\pm} \rightarrow \pi^{\pm}\pi^{0}$ $a_1 \rightarrow \pi^{\pm}\pi^{\mp}\pi^{\pm}$

$a_1 \rightarrow \pi^{\pm}\pi^{0}\pi^{0}$



Analysis Strategy

1) **Require isolated and well-identified leptons to suppress background from fakes (e.g. QCD)**

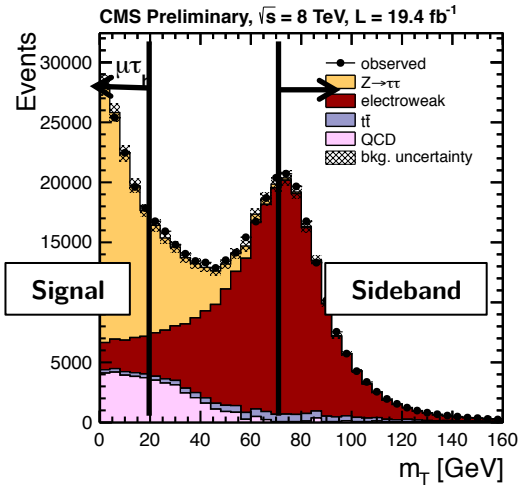
2) **Topological cuts to suppress backgrounds further (e.g. m_T for $\mu\tau_h$, $e\tau_h$ to suppress W+jets)**

3) **Split events into mutually exclusive categories based on:**
   - **jet multiplicity**
   - **τ_h p_T**

4) **Simultaneous binned max-likelihood fit of $m_{\tau\tau}$ distribution in all channels & categories**

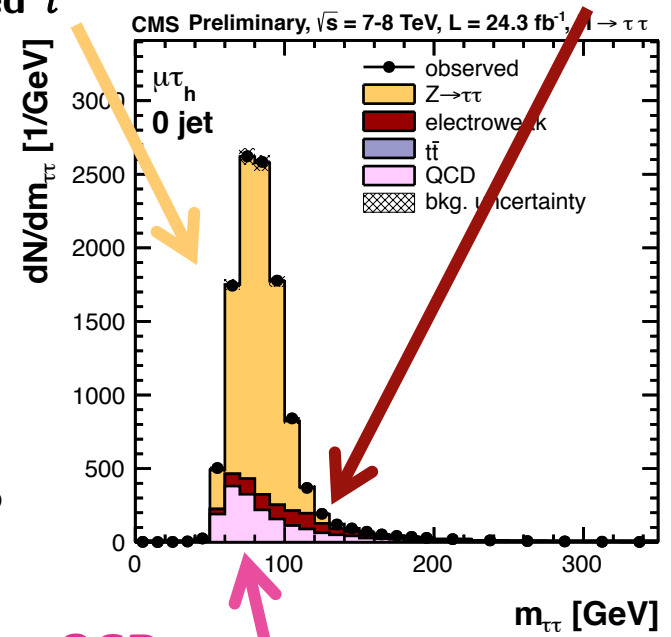
$Z\rightarrow\tau\tau$

- Embedding: **$Z\rightarrow\mu\mu$** events in data replacing μ with **simulated τ**



W+jets

- Normalisation from sideband in data



QCD

- Shape & normalisation from same-sign data

Event Categories

$\mu\tau_h$, $\mu\mu$, $e\tau_h$, $e\mu$

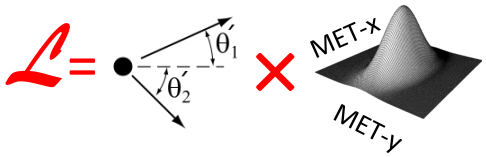
	0-Jet	1-Jet	2-jet (Vector-boson fusion)
Low τ p_T	**Large background**: **no fit for signal**. Constrains uncertainties in other categories	To select signal events where H recoils against jet ($p_T > 30$ GeV)	Enhances VBF Higgs Production Central Jet Veto ($p_T > 30$ GeV) $m_{jj} > 500$ GeV $\Delta\eta_{jj} > 3.5$
High τ p_T	**Large background**: **no fit for signal**. Constrains uncertainties in other categories	Benefit from Lepton p_T and jet requirement – better $\tau\tau$ mass resolution	

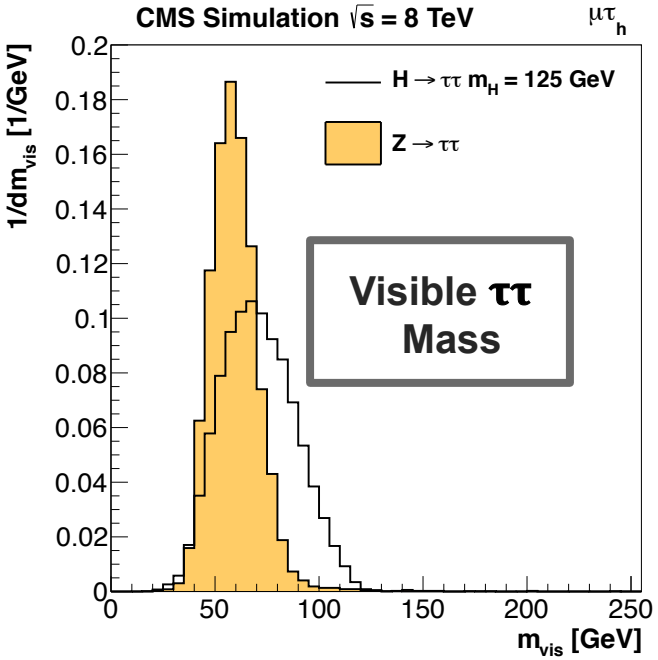
$\tau_h\tau_h$

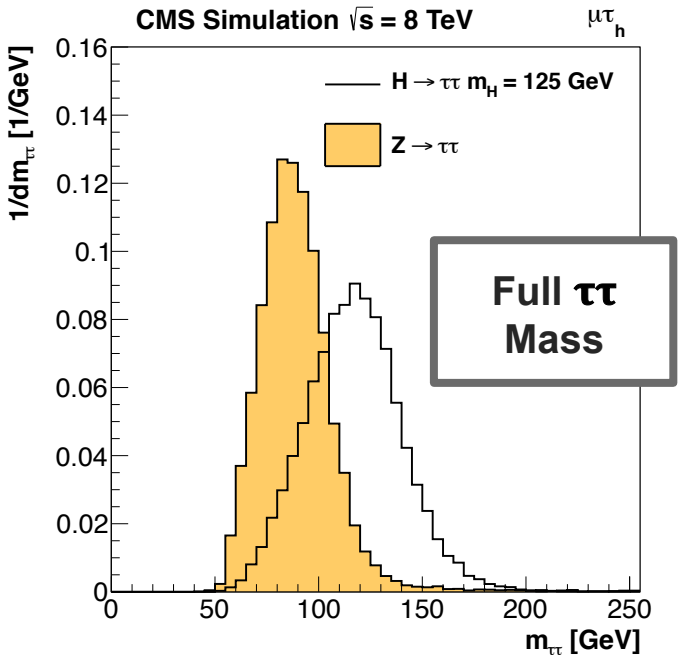
	$p_T(H) > 140$ GeV to suppress QCD background	$p_T(H) > 110$ GeV $m_{jj} > 250$ GeV $\Delta\eta_{jj} > 2.5$

Di-tau Mass Reconstruction

- Always have at least one neutrino when tau decays
- Use an event-by-event likelihood-based estimate of full di-tau mass
  - Input is lepton four-momenta, E_T^{miss} and expected E_T^{miss} res.
  - Mass resolution is 15-20%, and gives better separation of Z/H



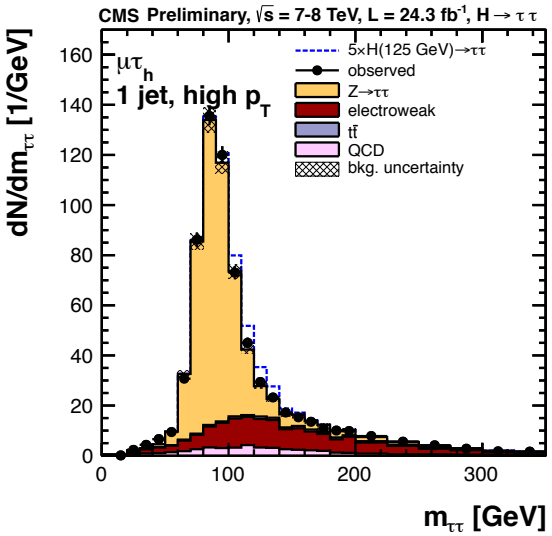


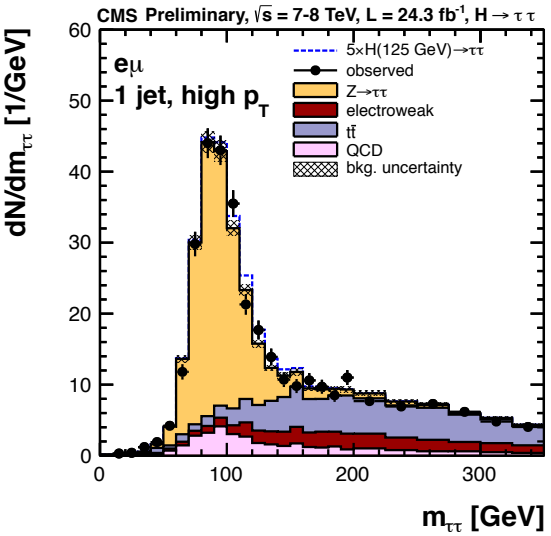


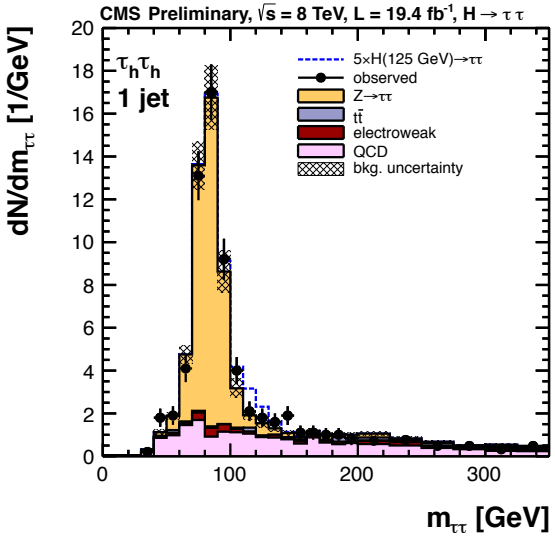
$M_{\tau\tau}$ Distributions: 1-jet, high p_T

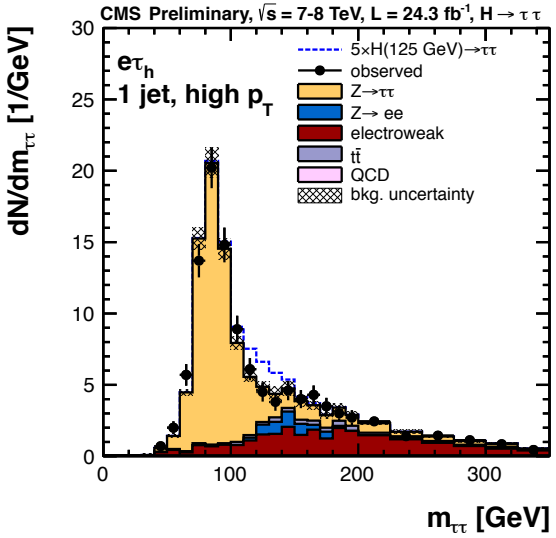
Second most sensitive category

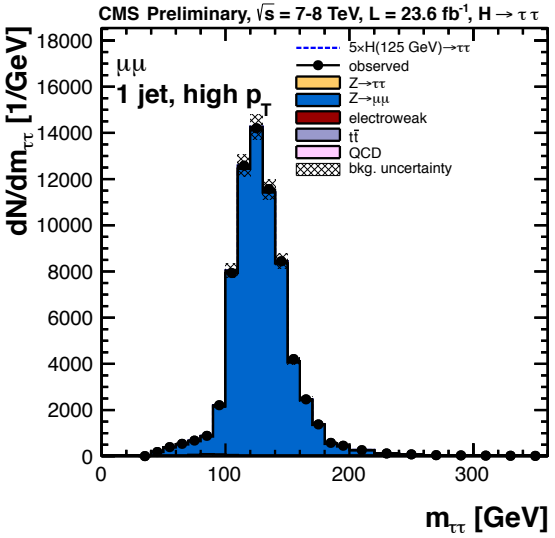
- Jet and high p_T requirements improve mass resolution and increase expected S/B







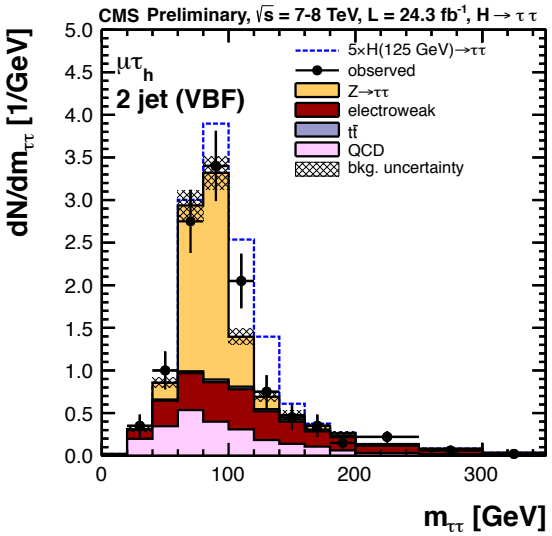


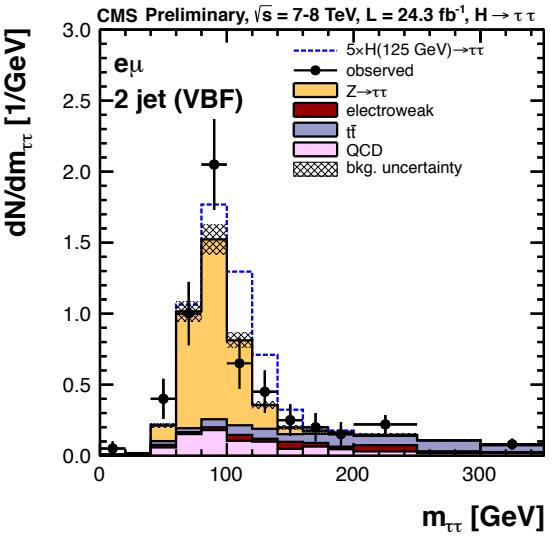


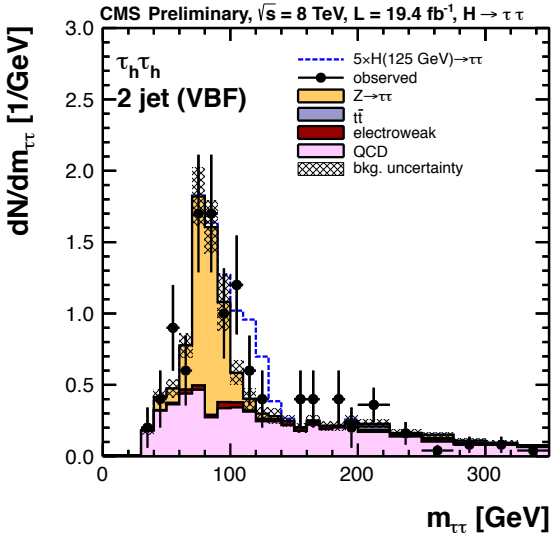
$M_{\tau\tau}$ Distributions: 2-jet (VBF)

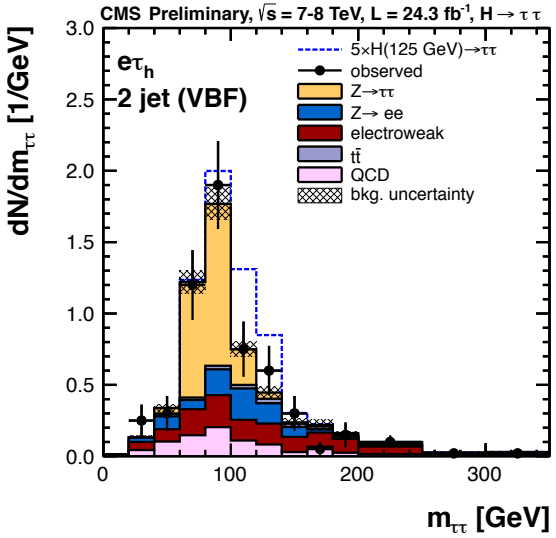
Most sensitive category

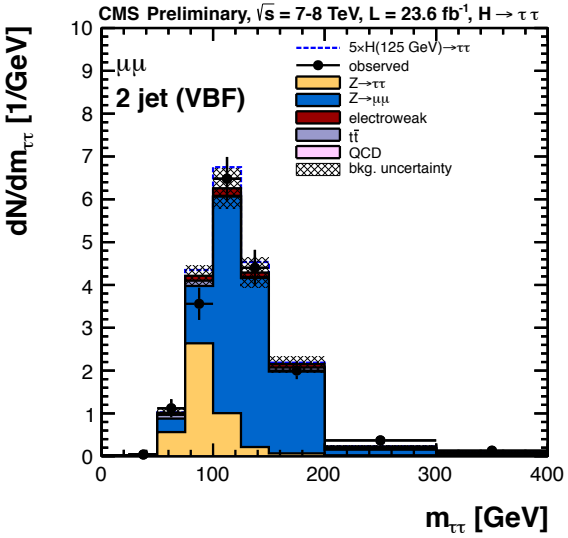
- Enhances contribution from vector-boson fusion production









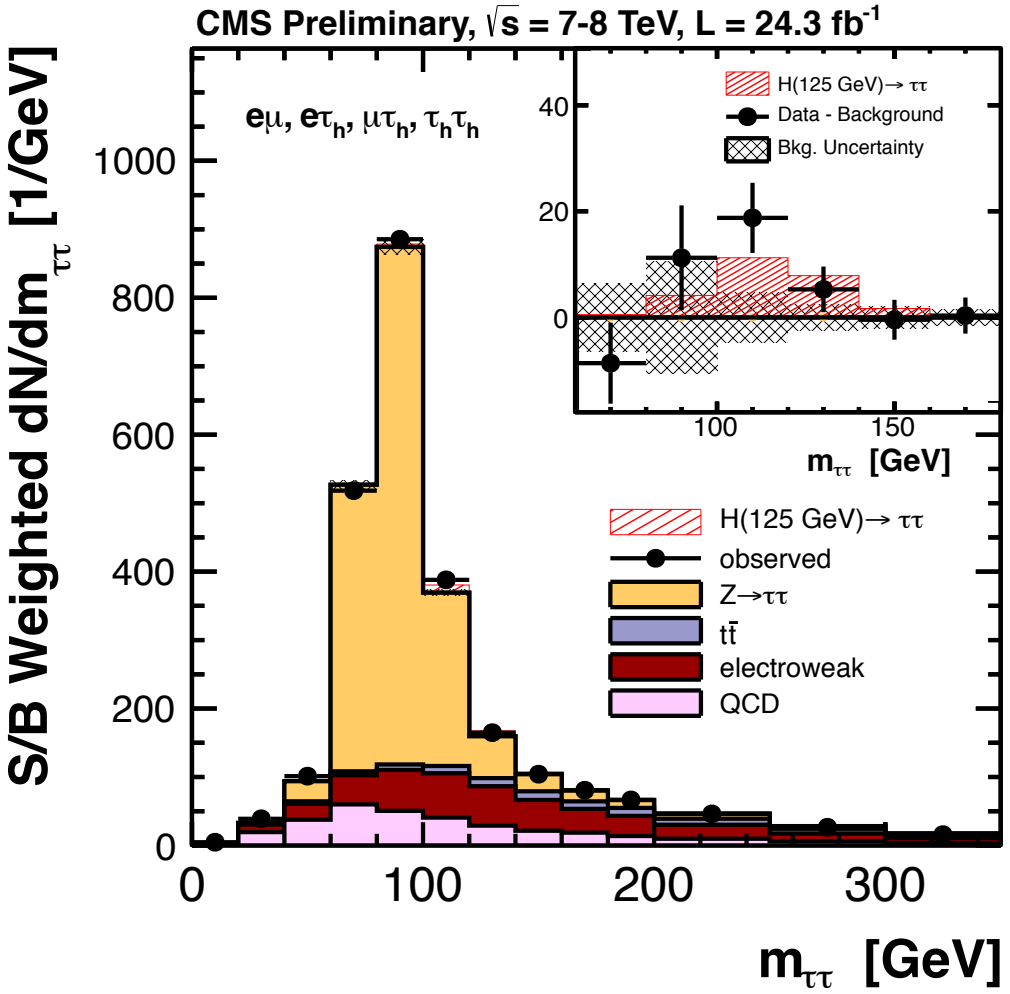


$M_{\tau\tau}$ Distributions: 1-jet + VBF

- Combine channels and categories, weighting each by

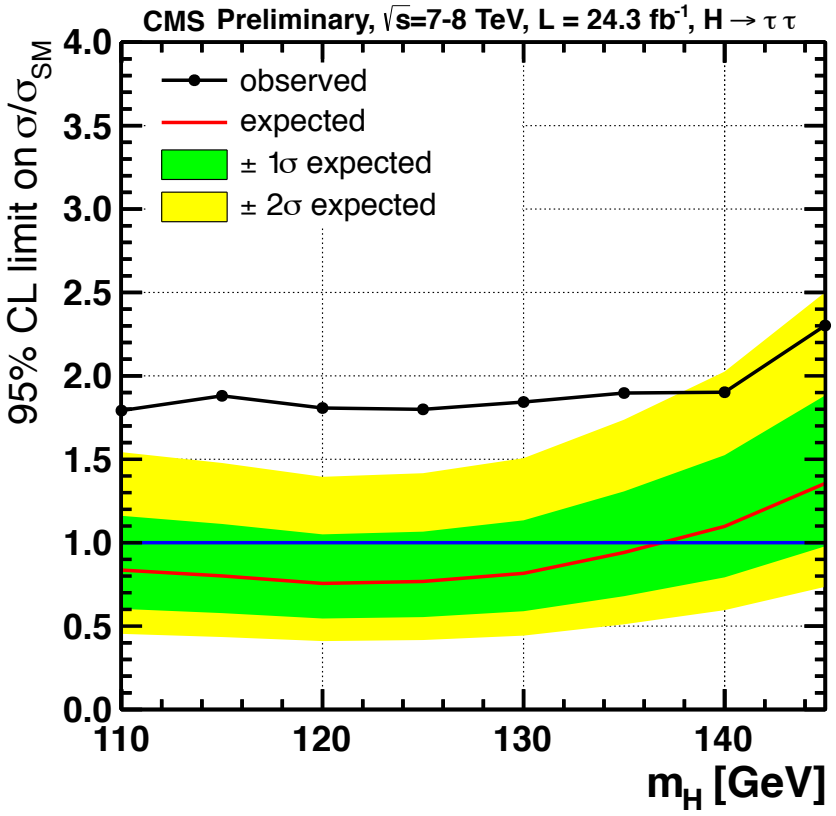
$$\frac{\text{expected signal (S)}}{\text{fitted background (B)}}$$

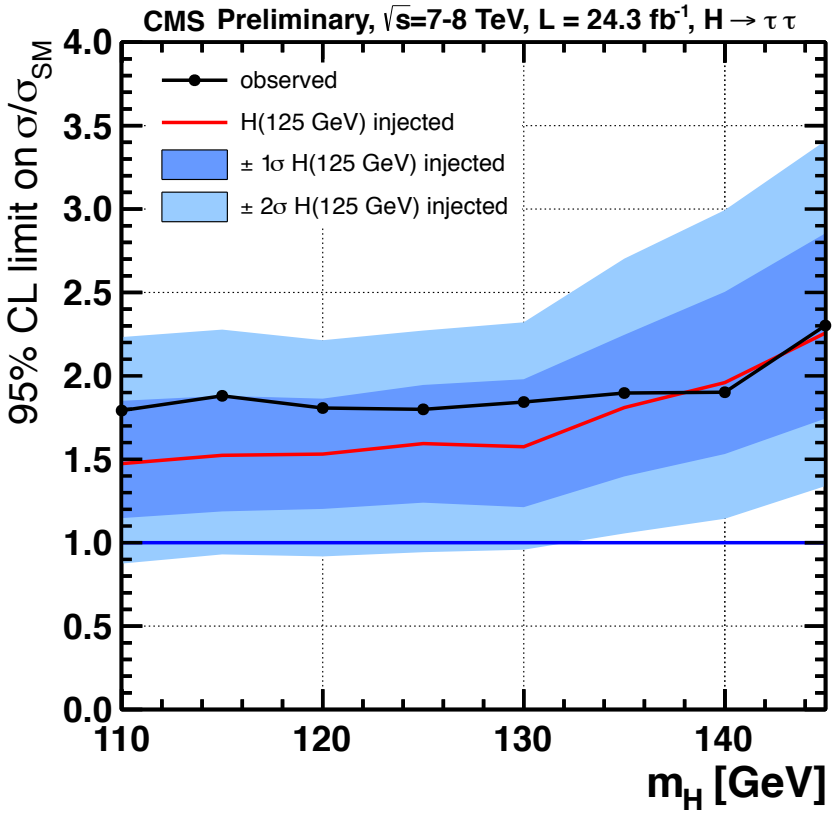
- Calculated in a window around peak for a 125 GeV Higgs



Limits

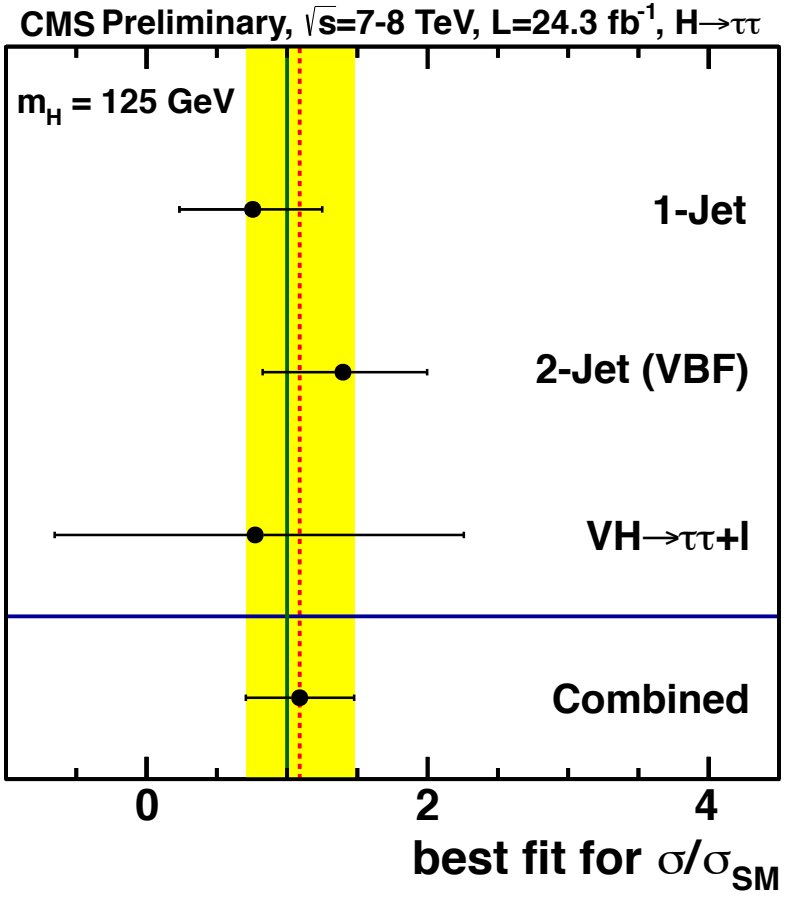
- Combining all channels (including ZH/WH analysis)
- Left: Expected exclusion limit of 0.76 x SM, observe 1.81 x SM
- Right: Expected limit in the presence of a 125 GeV SM Higgs signal

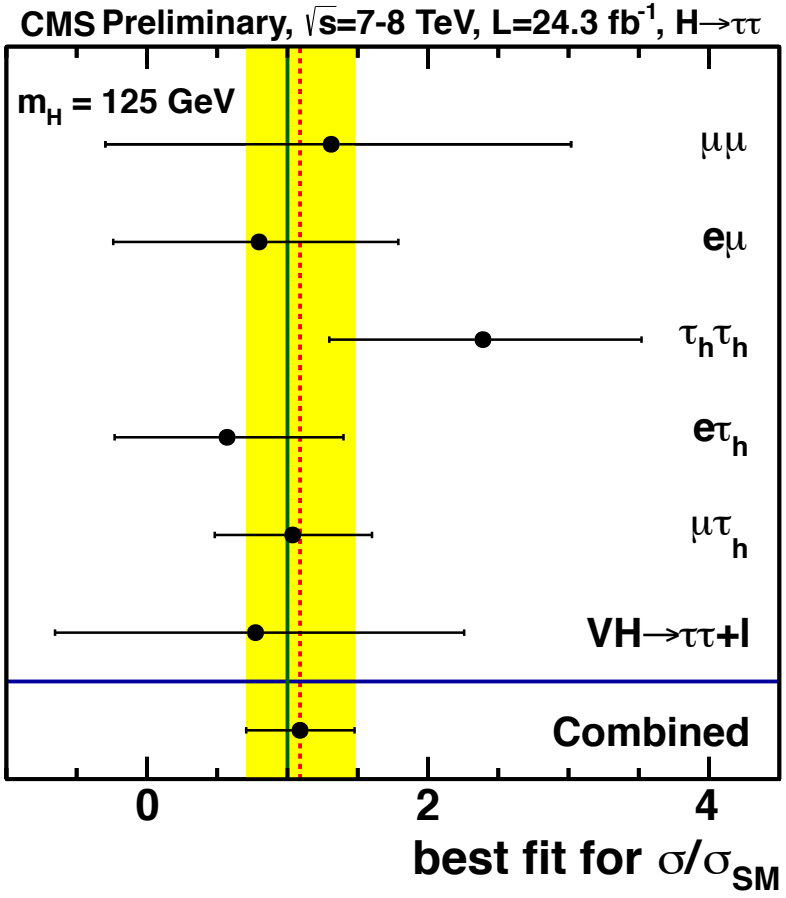




Signal Strength

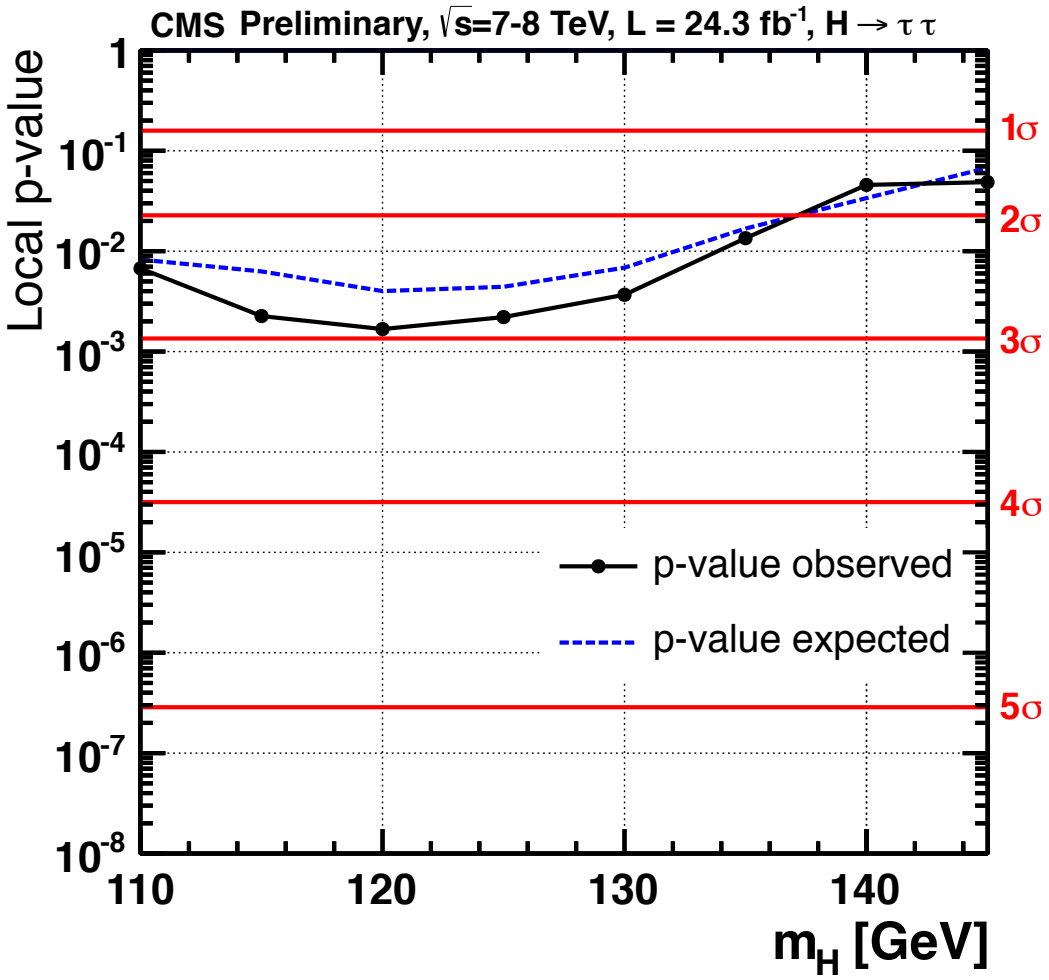
- Best-fit signal strength by category (left) and channel (right)
- Combined best-fit $\hat{\mu} = 1.1 \pm 0.4$





Significance & Conclusion

- Observe a broad excess over the m_H search range, compatible with the expectation from a 125 GeV SM Higgs boson
- Maximum local significance of 2.93σ at 120 GeV. 2.85σ observed (2.62σ expected) at 125 GeV
- Strong indication that the new boson decays to taus



Backup

Missing Energy Reconstruction

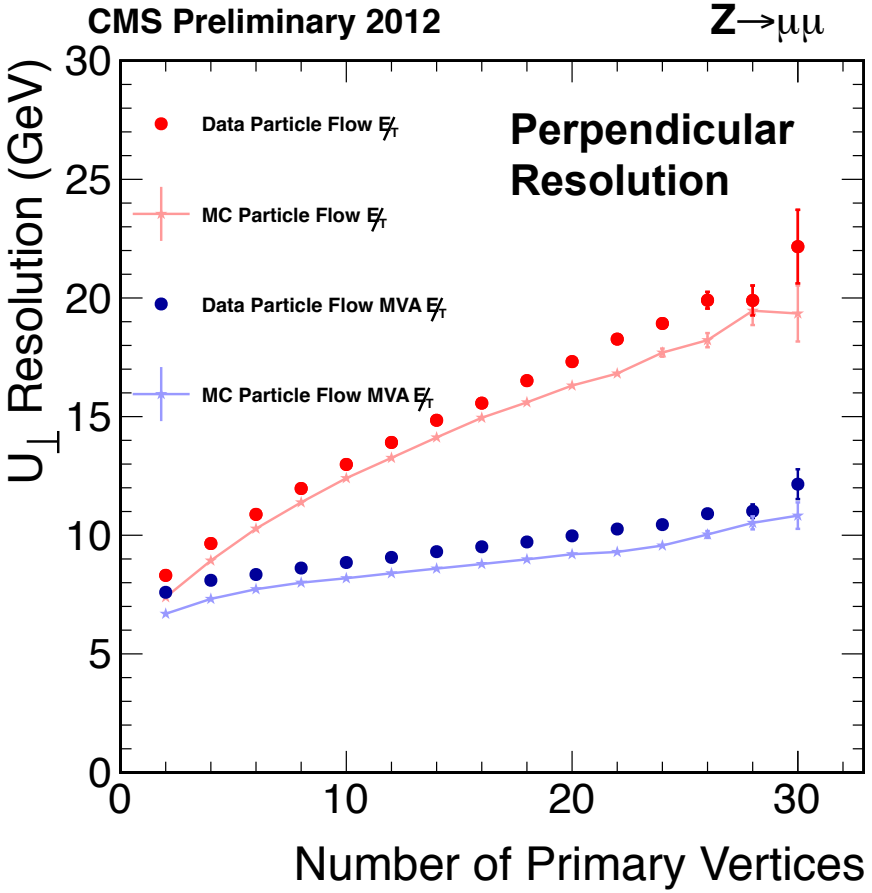
- Missing transverse energy also based on particle flow

- However the E_T^{miss} resolution degrades with increased pileup

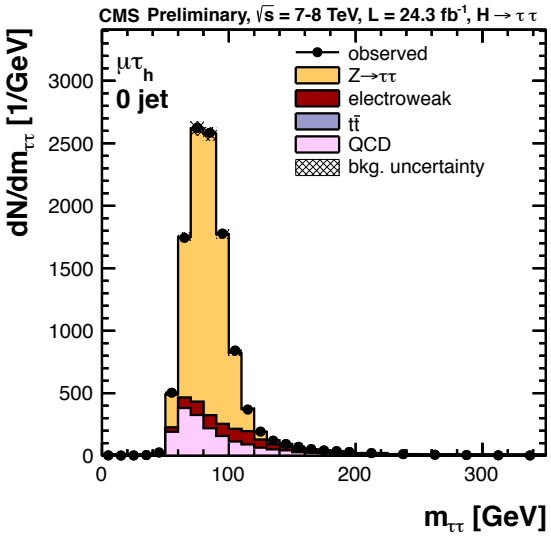
  ~<19> interactions in 2012

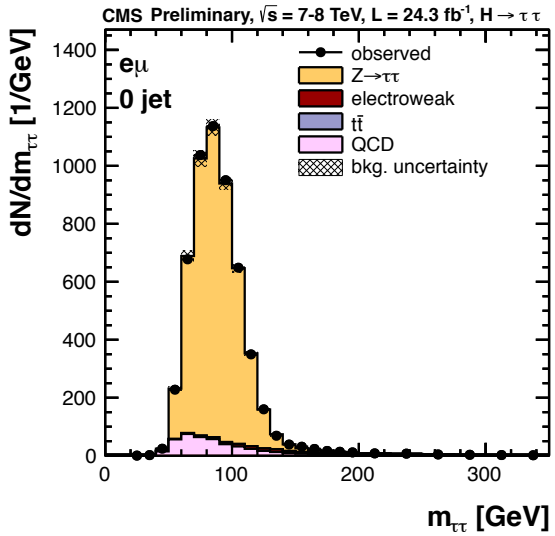
- Solution uses a BDT regression which uses 5 different E_t^{miss} hypotheses as input

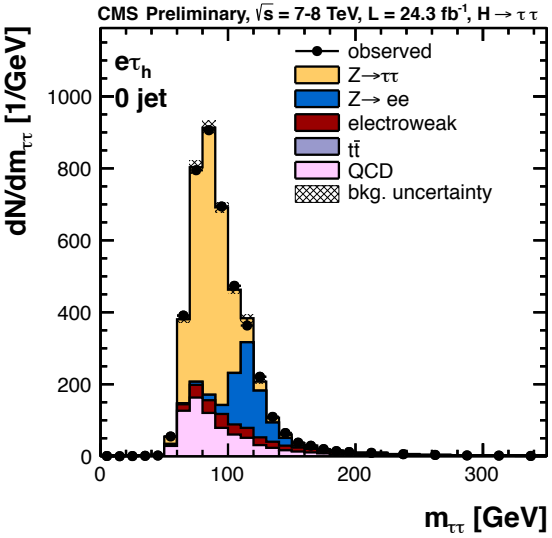
- Resolution less sensitive to pileup: compare components of the recoil to the hard scatter (e.g. in Z→μμ): **particle-flow** vs **mva regression**

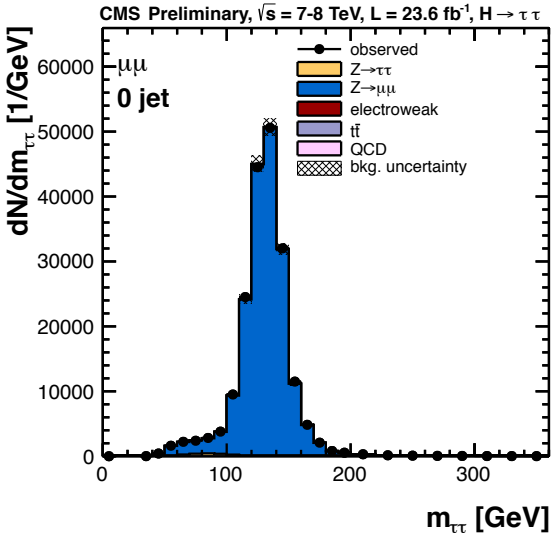


$M_{\tau\tau}$ Distributions: 0-jet

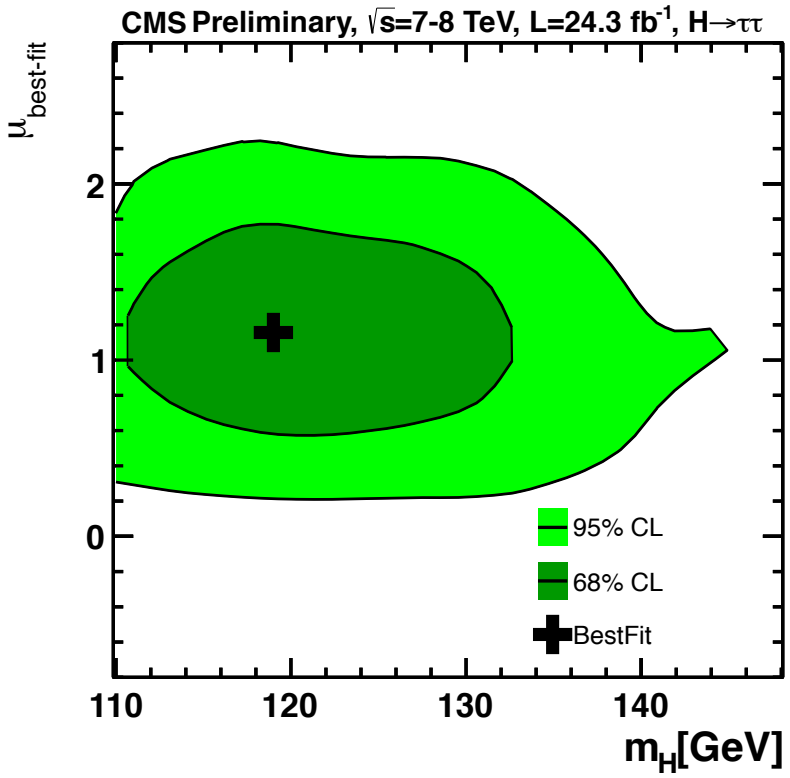


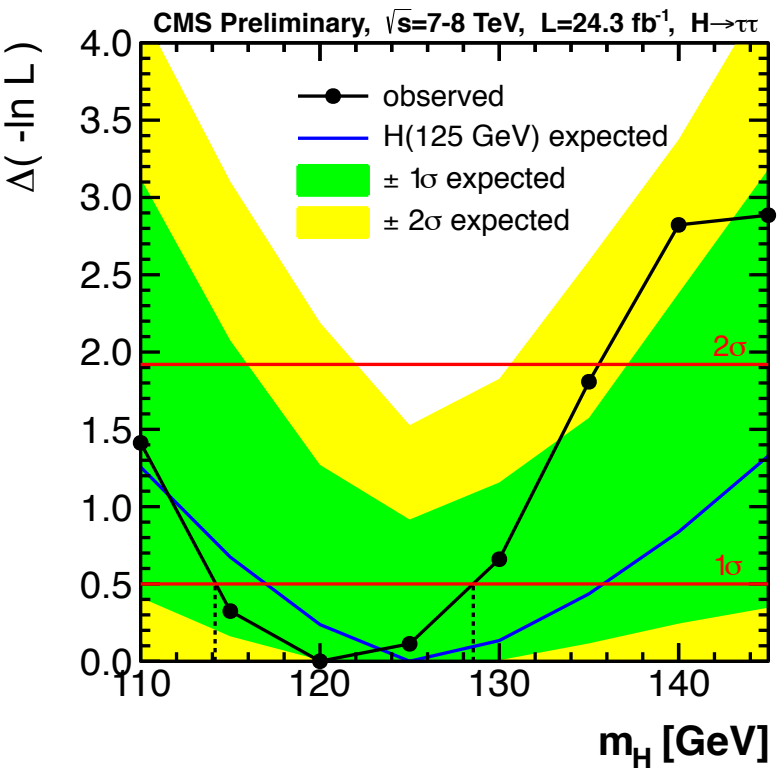




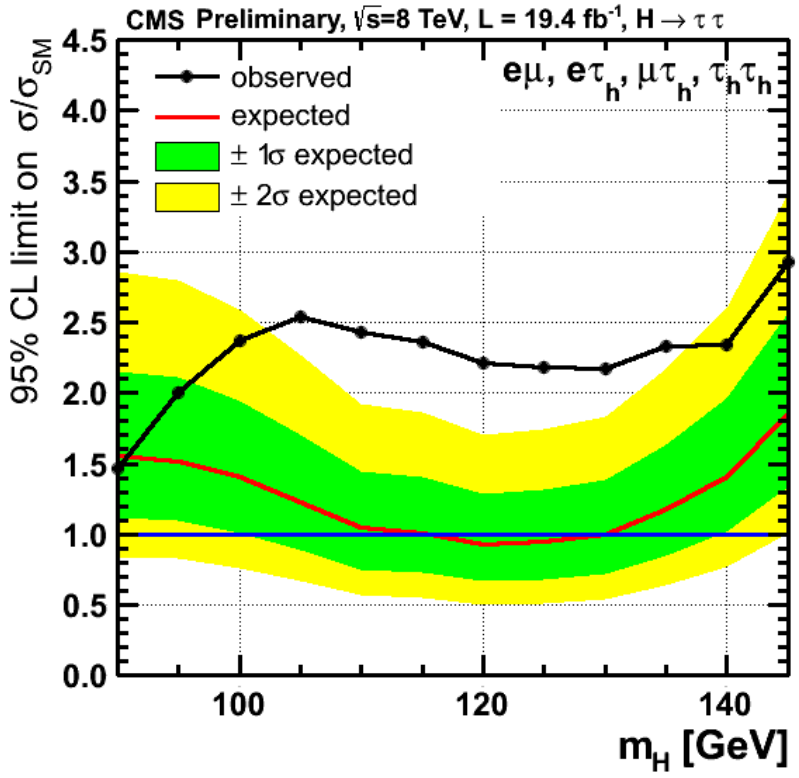


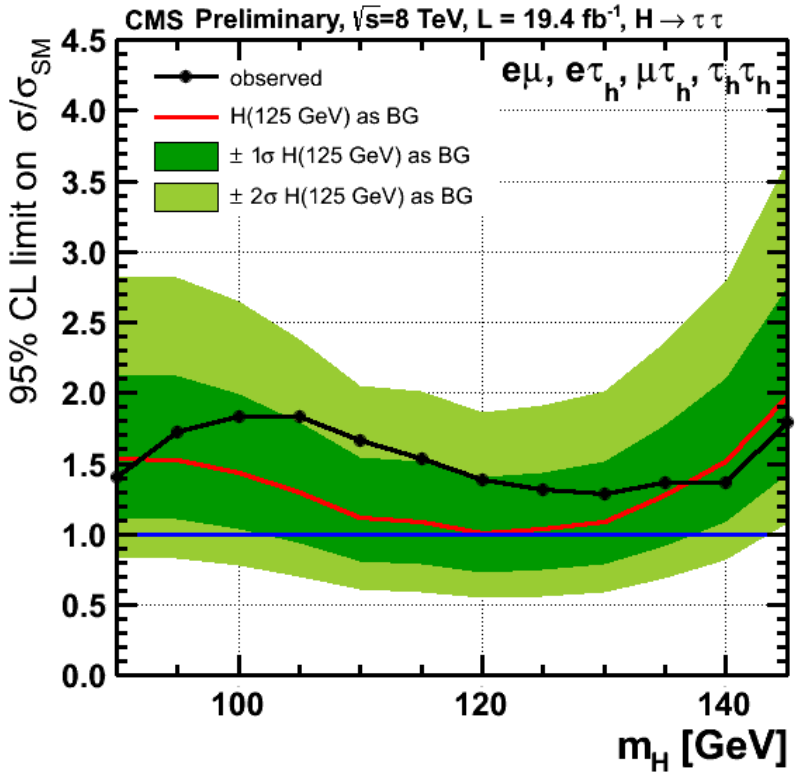
Mass Scan


CMS Preliminary, √s=7-8 TeV, L=24.3 fb-1, H→ττ
μbest-fit
2
1
0
95% CL
68% CL
BestFit
110
120
130
140
mH[GeV]


CMS Preliminary, √s=7-8 TeV, L=24.3 fb-1, H→ττ
Δ(-ln L)
4.0
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0.0
observed
H(125 GeV) expected
± 1σ expected
± 2σ expected
2σ
1σ
110
120
130
140
mH [GeV]

Extension to Lower Mass





Systematic Uncertainties

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 (†*)	$\pm 3\%$	$\pm 3\%$	$\pm 3\%$	$\pm 3\%$
$Z \to \tau\tau$ 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. $Z \to \ell\ell$: e fakes τ_h (†)	$\pm 20\%$	$\pm 20\%$	$\pm 36\%$	$\pm 22\%$
Norm. $Z \to \ell\ell$: μ fakes τ_h (†)	$\pm 30\%$	$\pm 30\%$	$\pm 30\%$	$\pm 30\%$
Norm. $Z \to \ell\ell$: 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 (†*)	-	-	$\pm 2-8\%$	$\pm 2-8\%$
$\mu_r/\mu_f(gg \to H)$ (†*)	-	-	$\pm 10\%$	$\pm 30\%$
$\mu_r/\mu_f(qq \to H)$ (†*)	-	-	$\pm 4\%$	$\pm 4\%$
$\mu_r/\mu_f(qq \to VH)$ (†*)	-	-	$\pm 4\%$	$\pm 4\%$
UE & PS (†*)	-	-	$\pm 4\%$	$\pm 4\%$

Expected Limits