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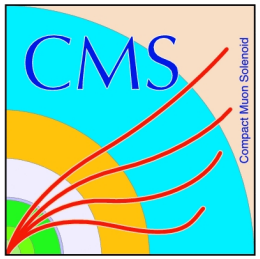


# Evidence for the 125 GeV Higgs boson decaying to a pair of tau leptons at CMS

IoP Meeting: Royal Holloway, University of London
8th April 2014

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*on behalf of the CMS Collaboration*

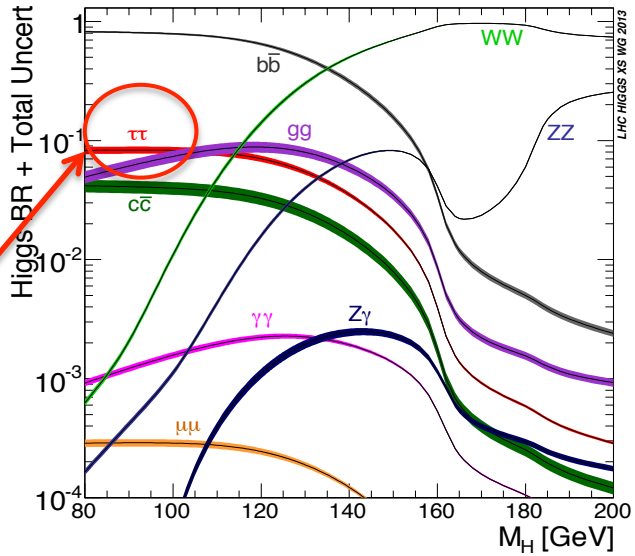
# Outline

- Introduction
- Analysis Overview
  - Event separation
  - Backgrounds
  - Mass reconstruction
- Expected limits
- Results
  - Observed limits
  - Best fit signal strength
  - S/B plots
  - Significance
  - Mass scan
- Summary

# Introduction

- July 2012: observation of a new boson by the ATLAS and CMS experiments, with $m_H$ ~ 125 GeV.
- Observation made in the bosonic decay modes: WW, ZZ and γγ. Question remains: **Does it decay to fermions?**
- **H→ττ** has high (~7%) branching ratio at low Higgs masses, but also large backgrounds from Z→ττ, W+jets, QCD and others.

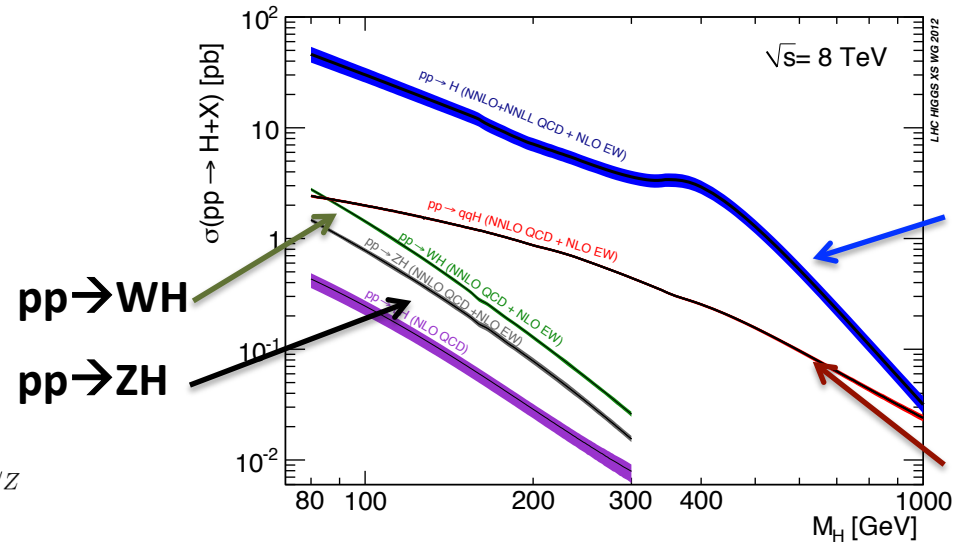
**H branching ratios (BR):**



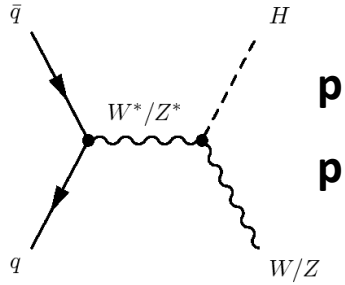

→ Study final state with **H→ττ**

# Introduction

**H cross sections (σ):**




**associated production**

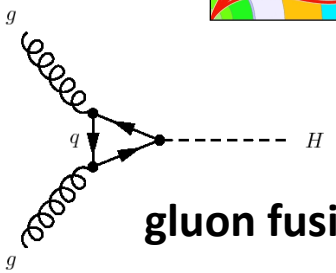



**pp→WH**

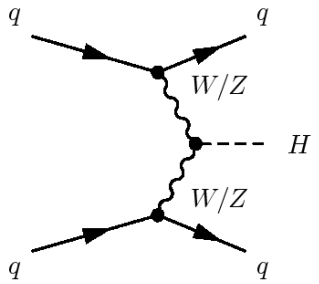
**pp→ZH**

**pp→H**

**pp→qqH**




**gluon fusion**




**VBF**

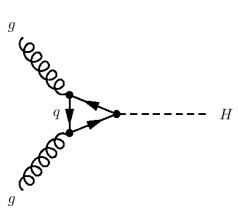
Target Higgs production modes: includes **gluon fusion** (pp→H), **VBF** (pp→qqH) and **associated production** (pp→W/ZH)

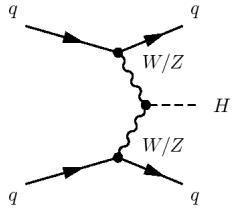
- Results in this talk are the latest CMS H→ττ analysis with the full dataset from 2011 (7 TeV) and 2012 (8 TeV) for a recent paper: arXiv:1401.5041

# Analysis Overview: Events

- Select events in `**channels**' based on all possible final states of the two τ's: **eτ$_h$**, **μτ$_h$**, **eμ**, **τ$_h$τ$_h$**, **μμ** and **ee**, where τ$_h$ = a tau decaying hadronically.
- Further split into `**categories**' to separate events of different S/B and enhance selection of the different Higgs production modes:
  - 1-jet sensitive to ggH, 2-jet for VBF and dedicated (separate) VH analysis.
  - 0-jet background dominated: helps control backgrounds and their uncertainties.

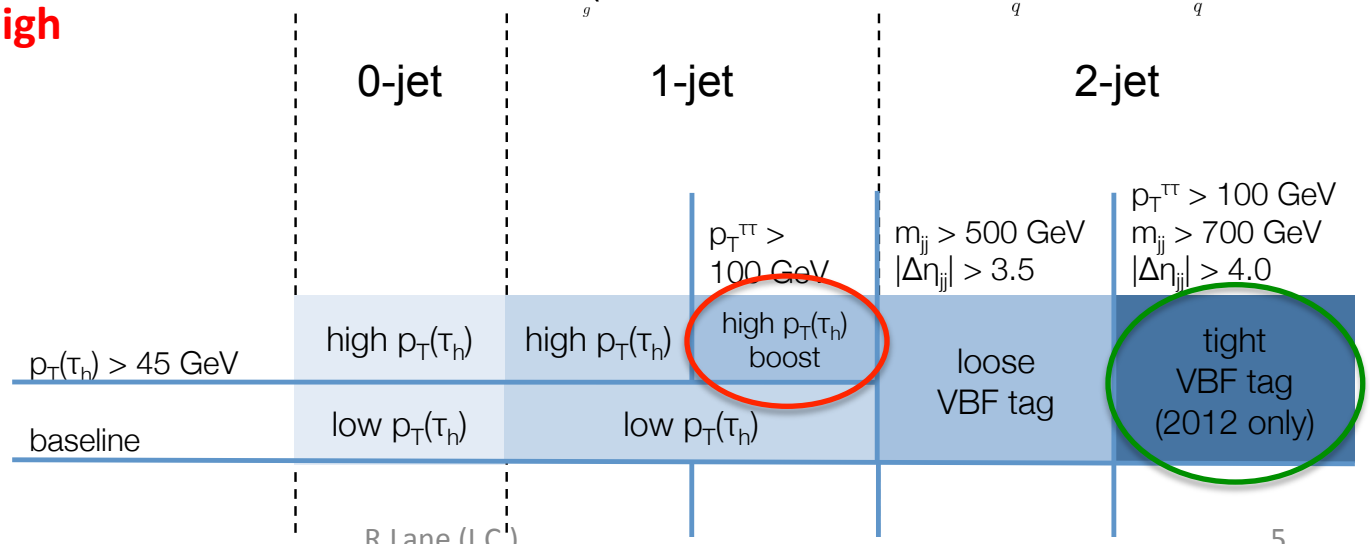
Most signal sensitive categories: "**tight VBF**" and "**1 jet high boost**" categories




**Most sensitive channel**

μτ$_h$

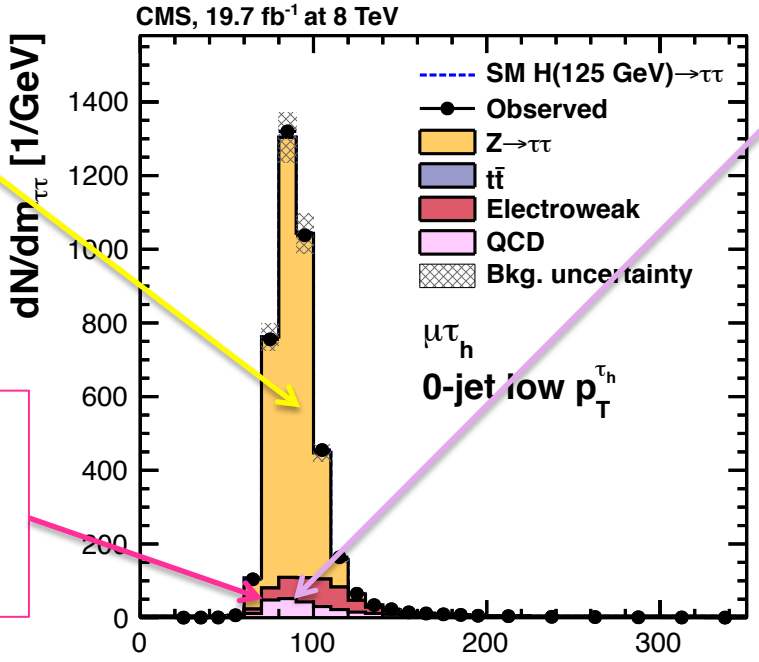


# Analysis Overview: Backgrounds

- Use data driven methods for background estimation.
- Plot of $m_{\tau\tau}$ in background dominated category shows major contributions:

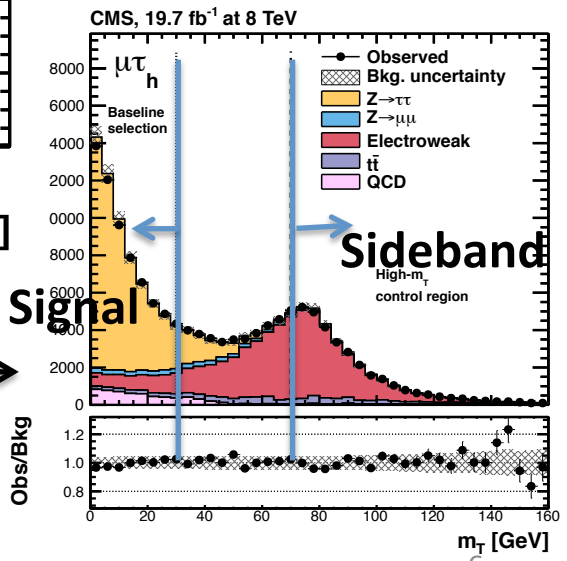
**$Z \rightarrow \tau\tau$**
Uses $Z \rightarrow \mu\mu$ **data embedded** with simulated $\tau$'s.

**EWK (W+jets)**
Normalization from **high $m_T$ sideband in data**.
Shape from MC.




**QCD**
Measured in **same-sign control region**.

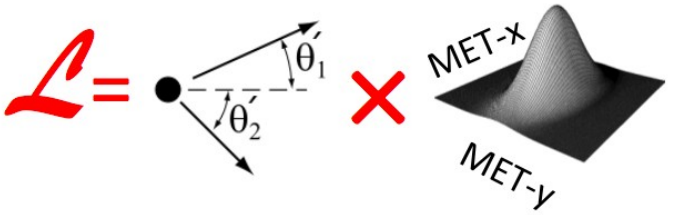
$m_T$ = transverse mass between lepton and $E_T^{miss}$



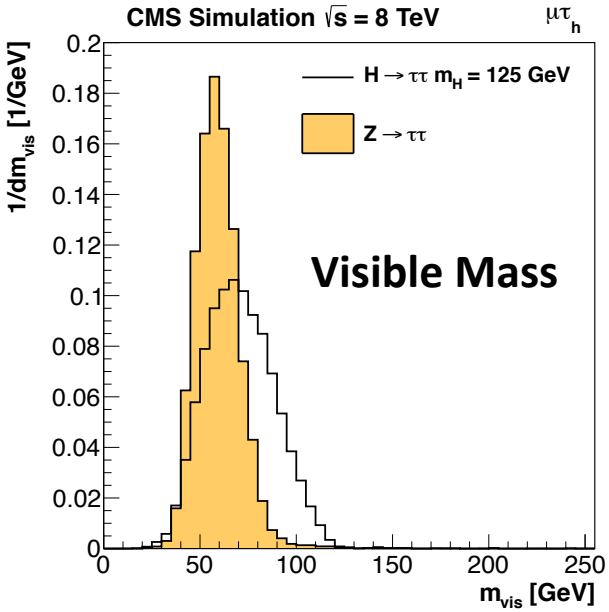

**Strategy:**

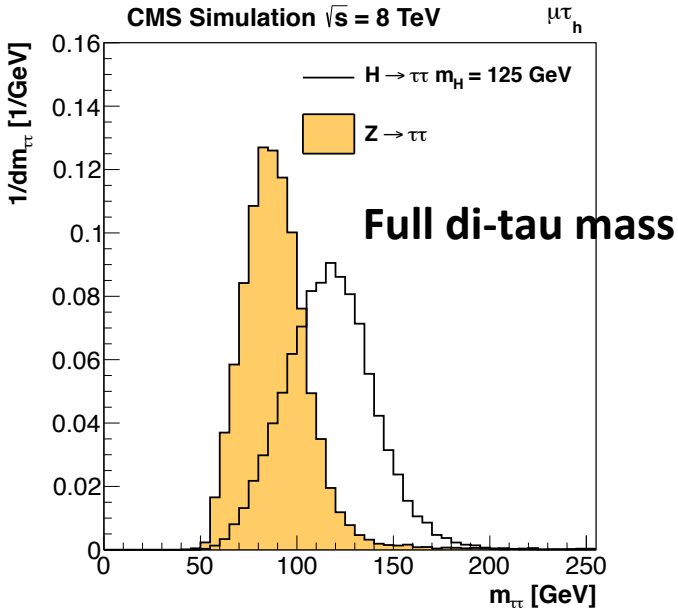
- **Suppress QCD with isolated leptons.**
- **$m_T$ < 30 GeV cut to suppress W+Jets.**
- **Extract signal from binned maximum-likelihood fit to $m_{\tau\tau}$. Combine channels and categories.**

# $m_{\tau\tau}$ Reconstruction




- Always have at least one neutrino from tau decays.
- Can construct "visible mass" using just the visible products, or use a likelihood based approach to reconstruct the full mass of the tau pair.
- Mass resolution 15-20%, and gives better separation of Z/H:

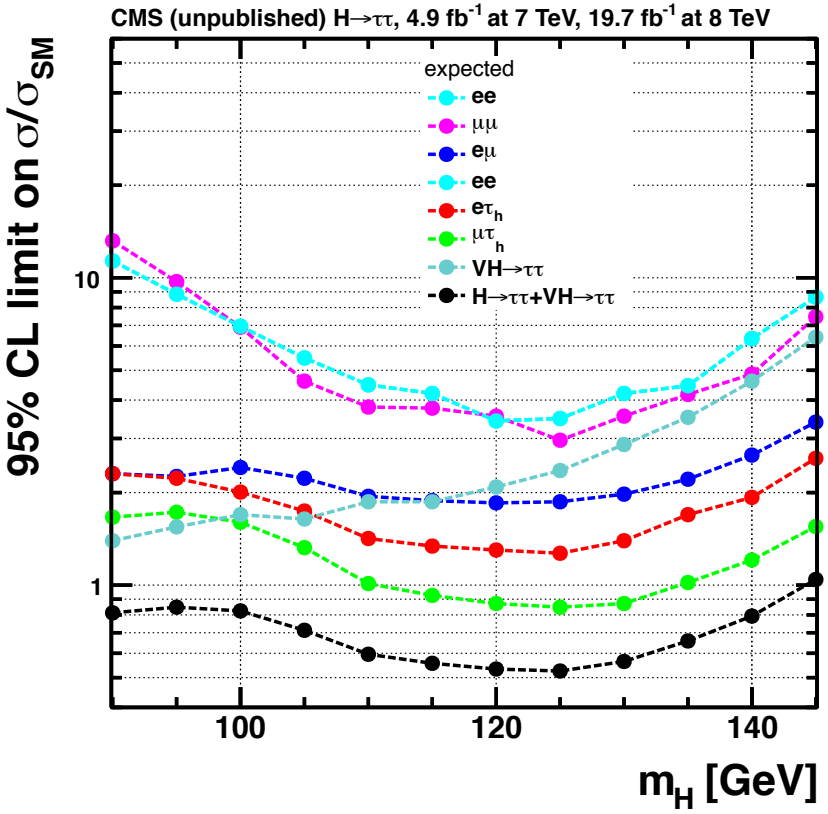


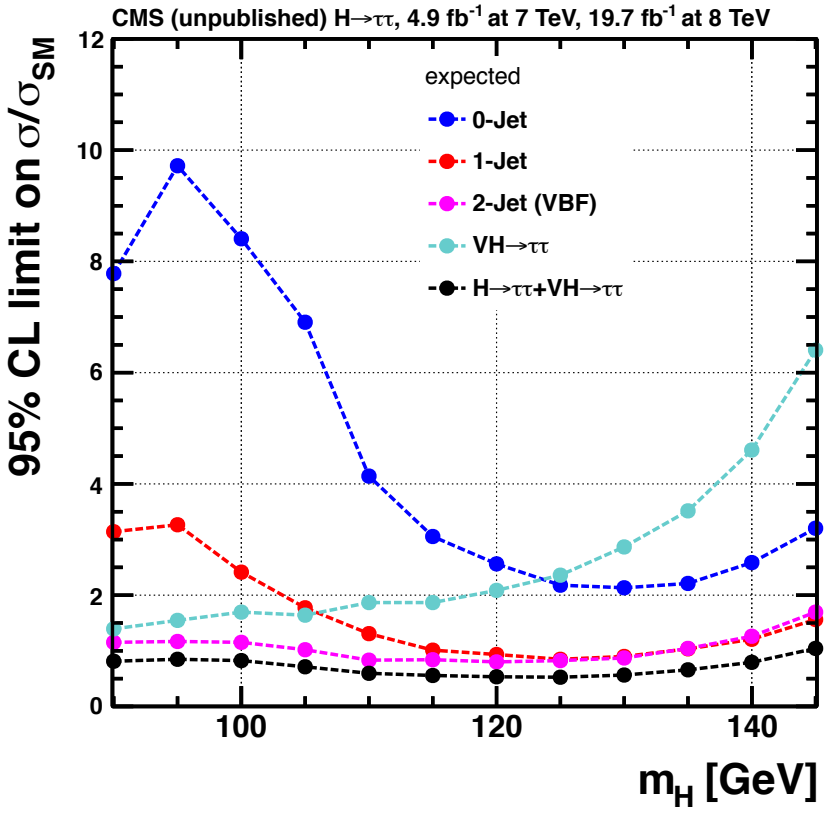

- Signal extracted from fit to $m_{\tau\tau}$.
- Analysis blinded in signal sensitive region: $100 < m_{\tau\tau} < 150$ GeV.

# Expected Limits

**NOTE: Associated production VH also included in final combination.**



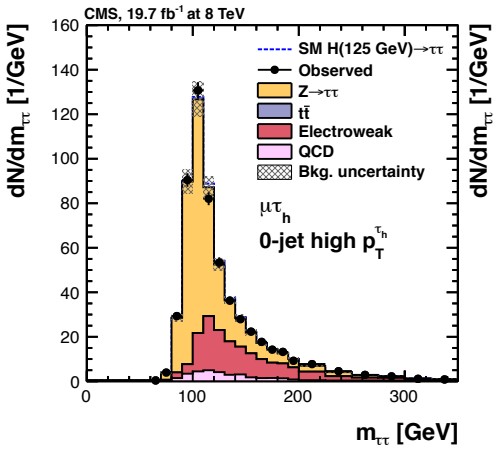

**Split by channel**

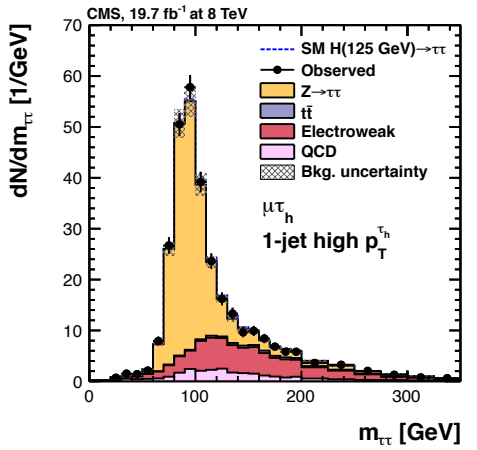


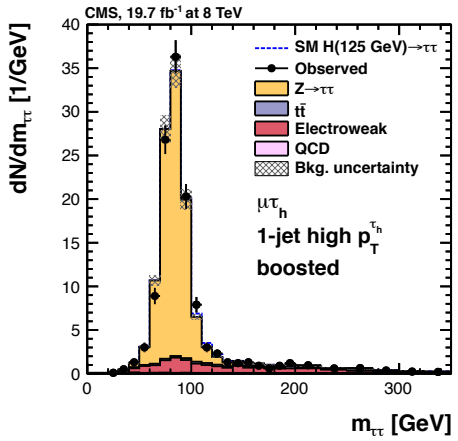

**Split by category**

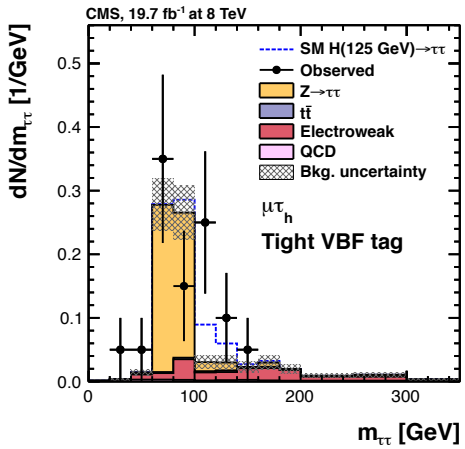
For combination, expected limit at 125 GeV is 0.53 → within standard model sensitivity

# Results: Post-fit Mass Distributions

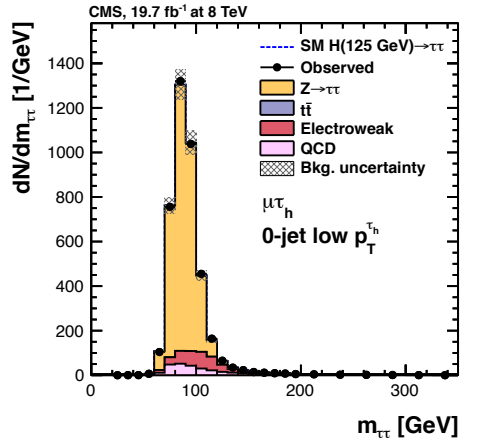


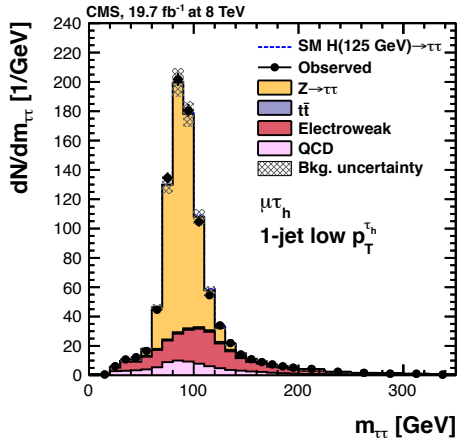



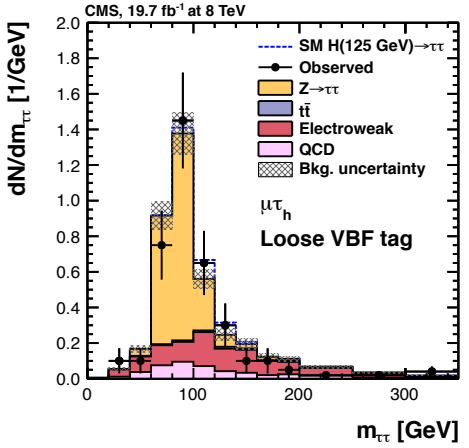




**0-jet** **1-jet** **VBF**

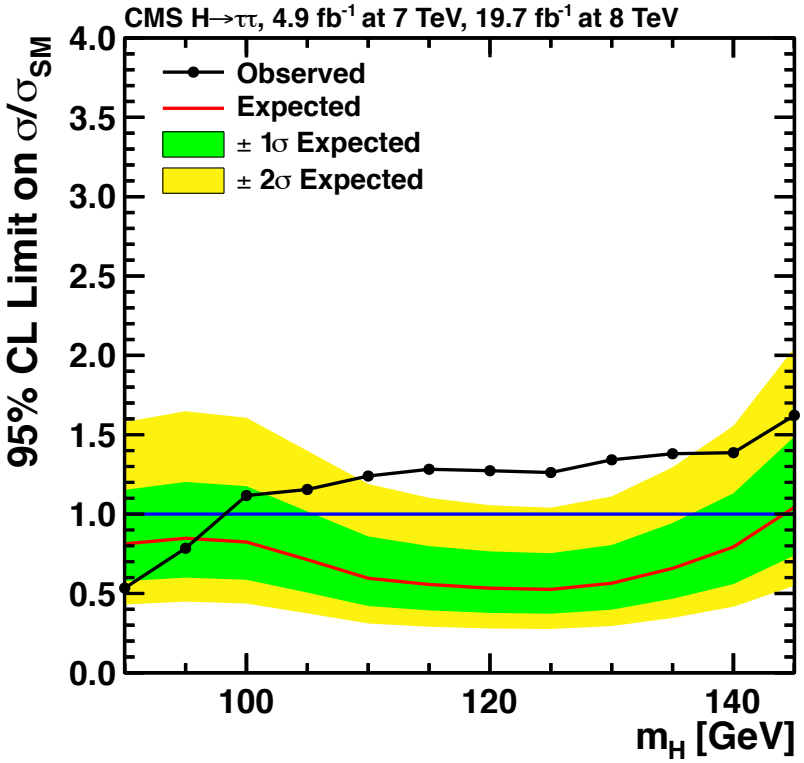


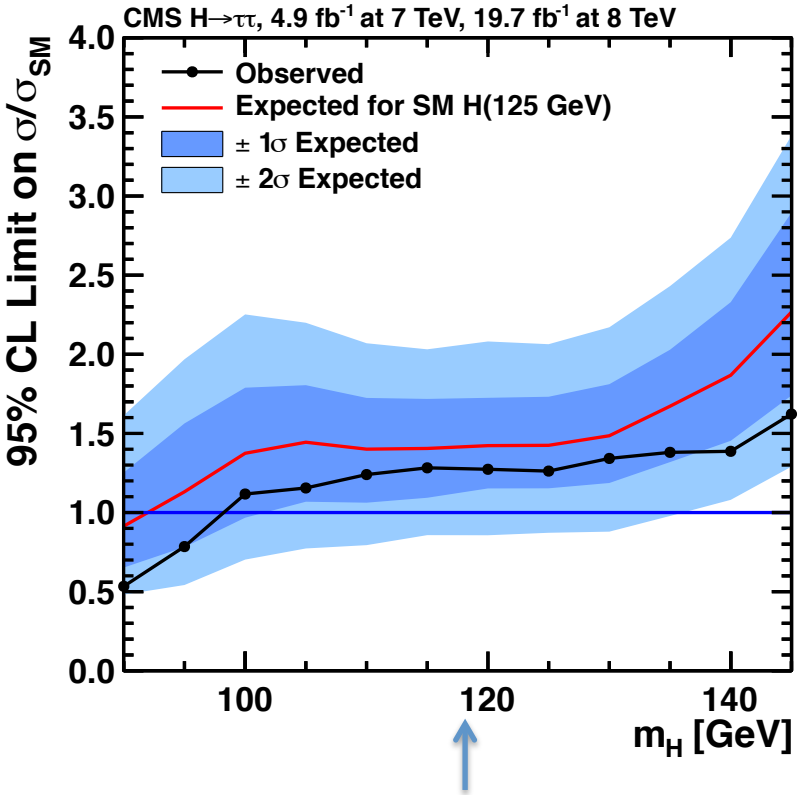




**Increasing sensitivity**

# Results: Observed Limit



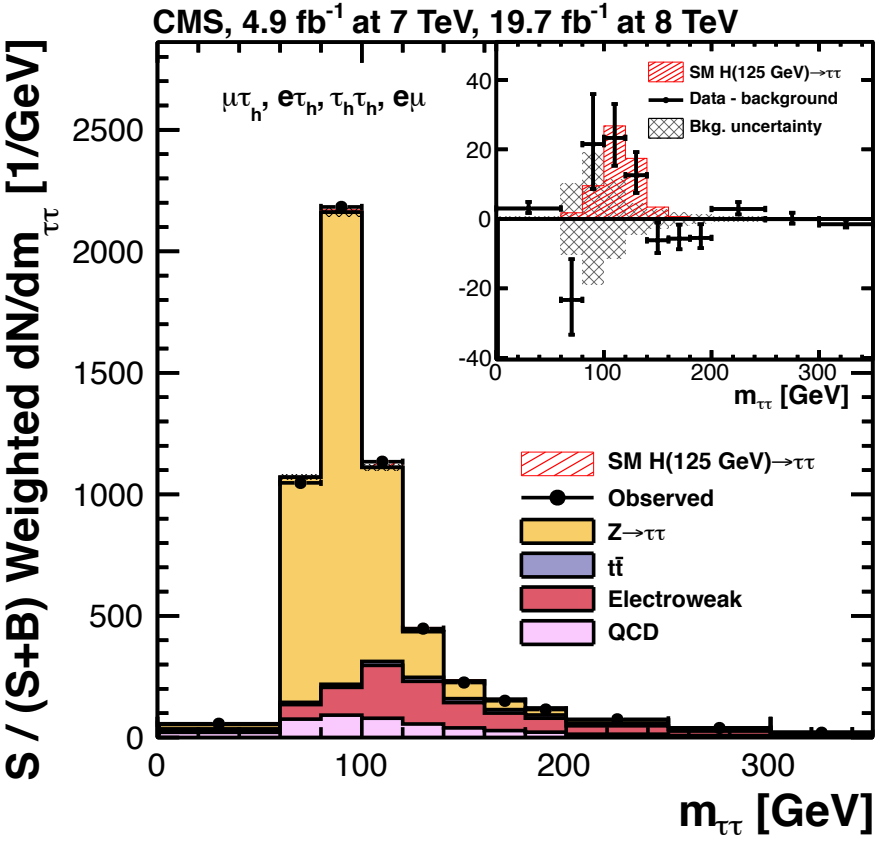




**Excess of events** over background only expectation.

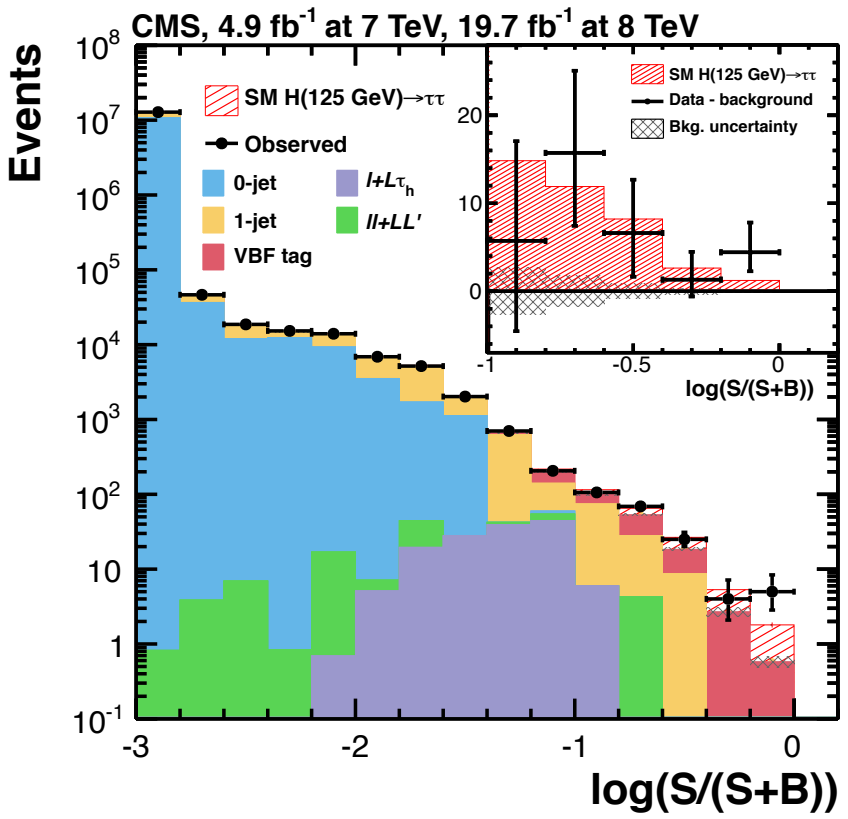
Observed (expected) limit at 125 GeV is 1.26 (0.53)

Band generated from toys with 125 GeV Higgs injected.

# Results: S/B plots

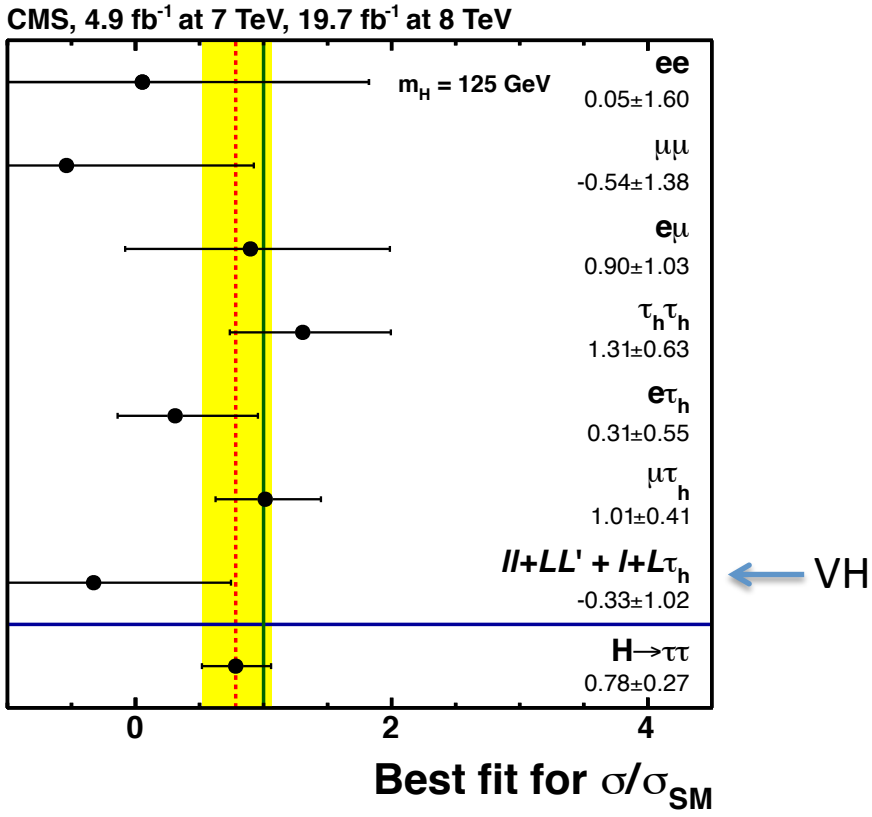



Combined mass plot, weighting by expected S/(S+B). Includes $e\tau_h$, $\mu\tau_h$, $e\mu$, $\tau_h\tau_h$ channels

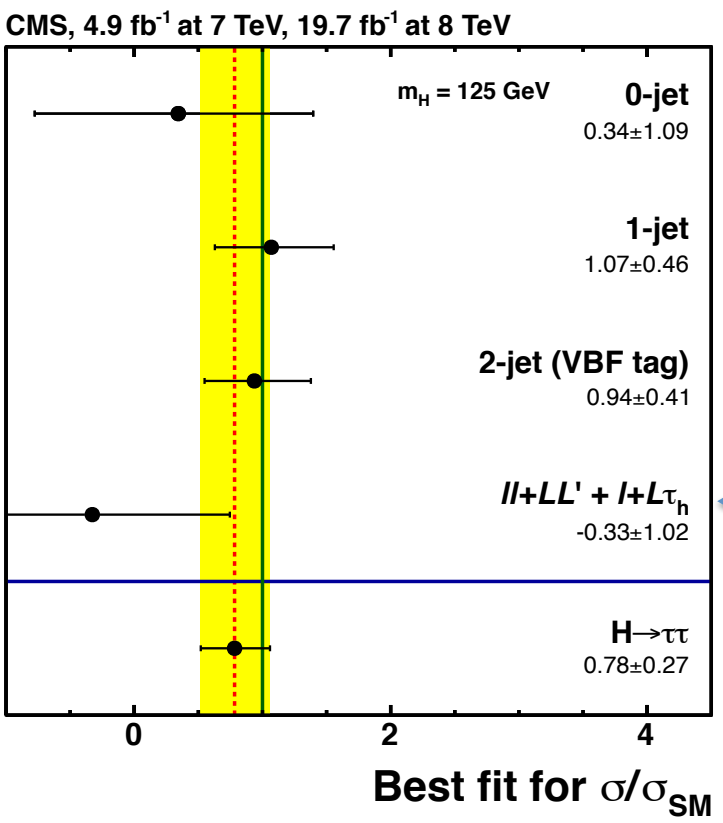



Arranging events in bins of S/(S+B), and highlighting the contributions of the different categories. Includes all channels.

# Results: Signal Strength




VH



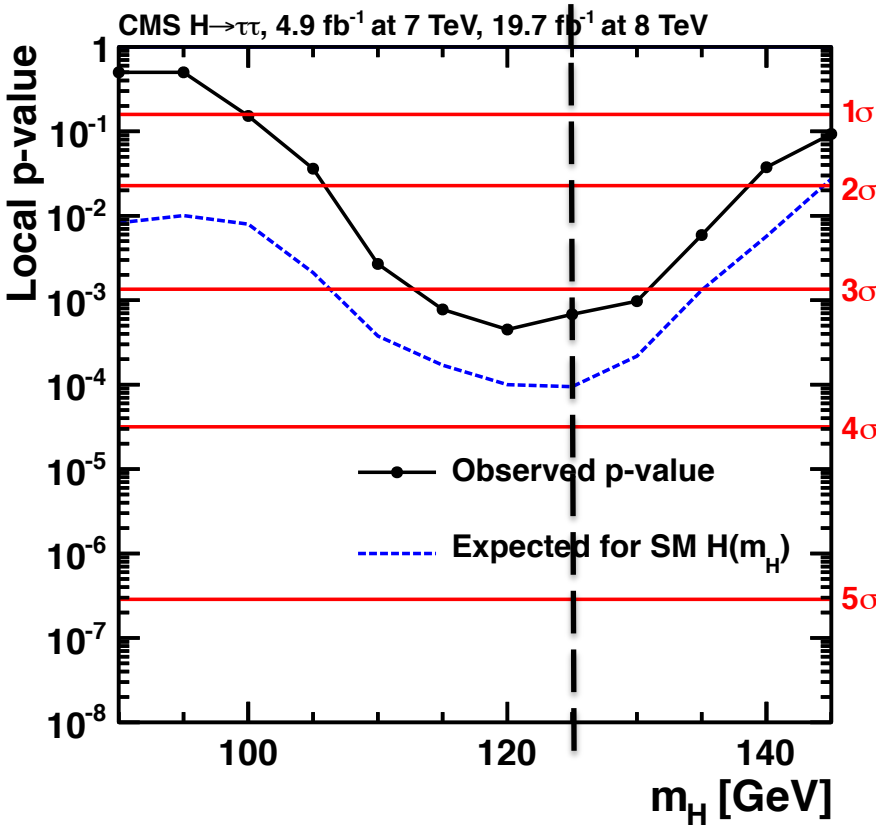

VH

**Split by channel**

**Split by category**

Best fit μ = 0.78 ± 0.27

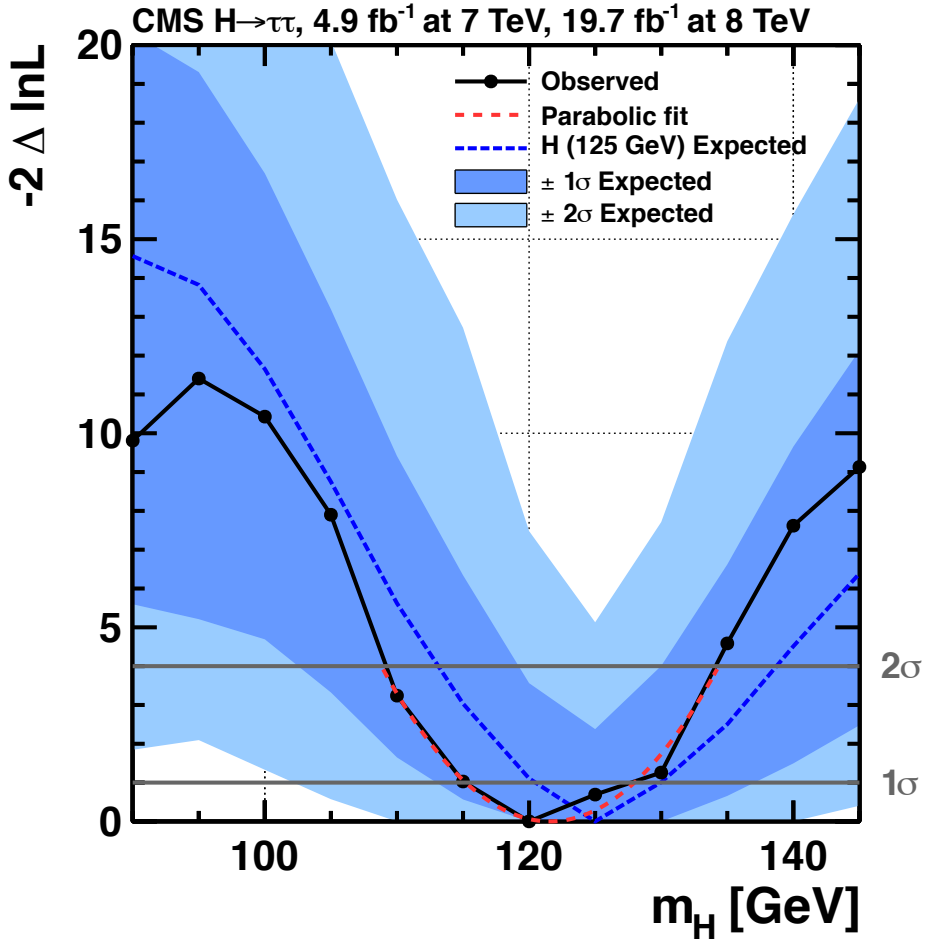
# Results: Significance




Observed (expected) significance at 125 GeV is **3.2σ** (3.7σ).

> 3σ → "evidence" for H→ττ

# Results: Mass Scan




Likelihood distribution shows observed best fit mass compared with the expectation for a 125 GeV Higgs.

We fit a parabola to extract the best fit mass.

**Best fit mass = 122 ± 7 GeV**

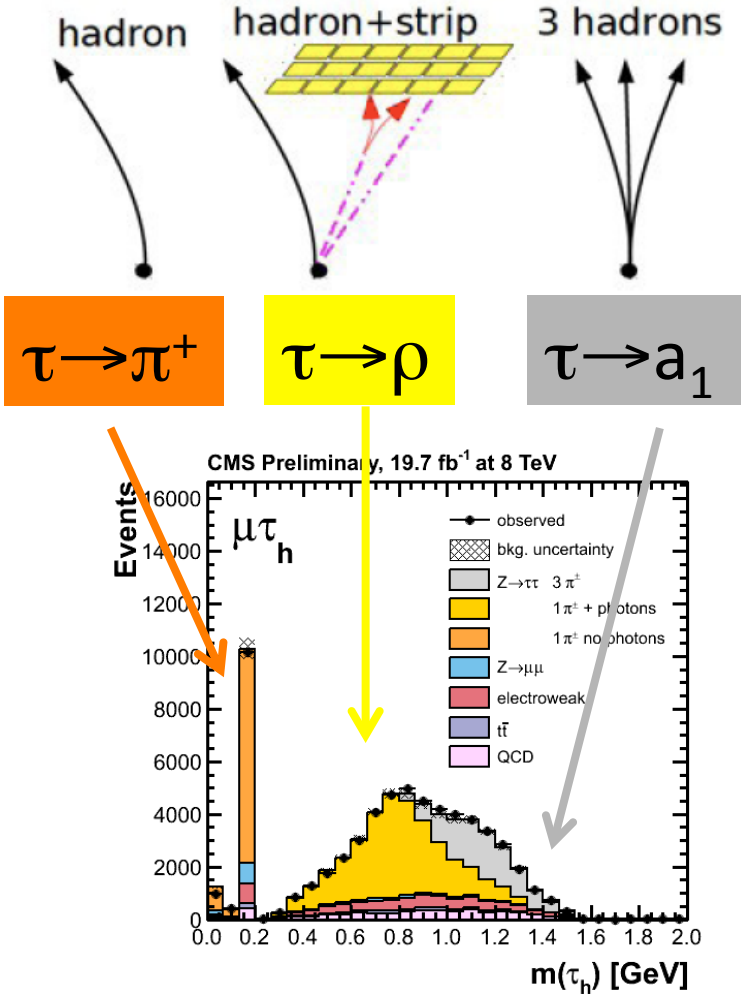
# Summary

- A search has been performed in the H→ττ final state using the complete 2011 and 2012 dataset from the CMS detector.
- An excess of events above the expectation from backgrounds has been seen.
- This excess corresponds to an observed significance of 3.2σ compared with 3.7σ expected for 125 GeV Higgs, meaning we have **> 3σ evidence for H→ττ**.
- This excess is compatible with the particle observed in the bosonic decay modes:
  - **$\mu = 0.78 \pm 0.27$**, with all channels and categories consistent.
  - Best fit mass **$m_H = 122 \pm 7$ GeV**.

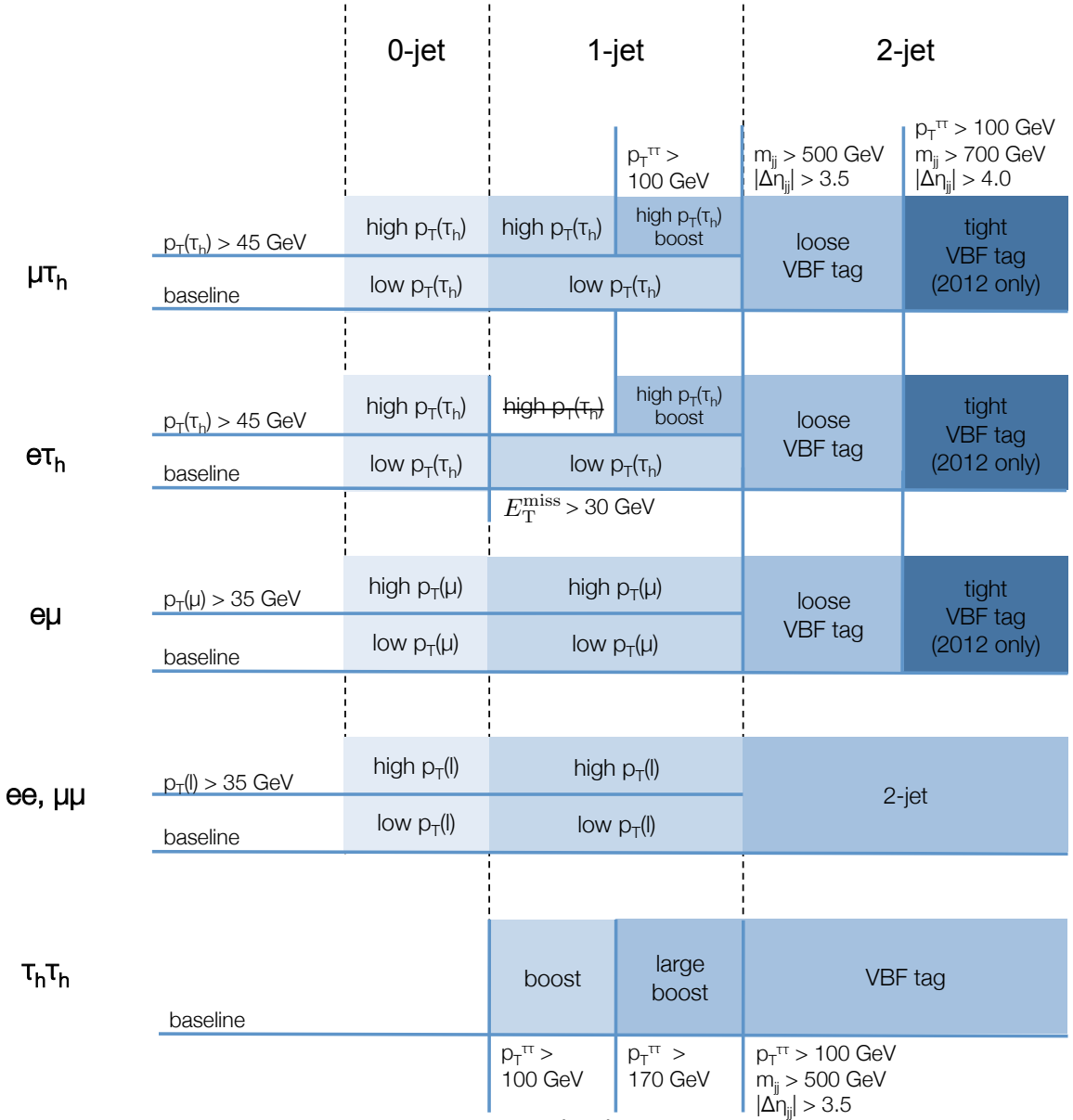
# Backup

# Hadronic taus

- "Particle Flow" used to combine information from all sub-detectors to classify all candidate particles in an event.
- This information is used to reconstruct all the different decay modes of the tau
- Mass distribution used to control energy scale in each decay mode.



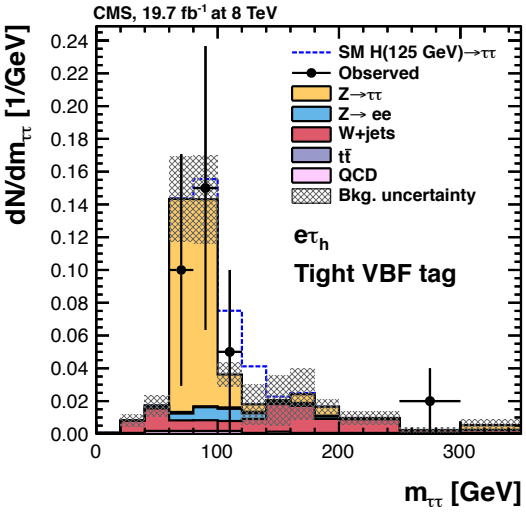
# Categories for all channels

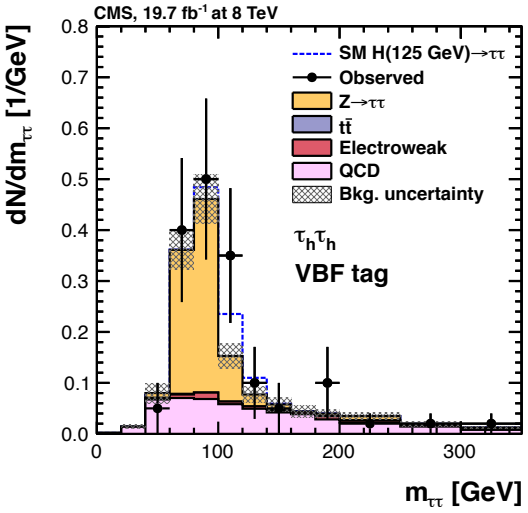


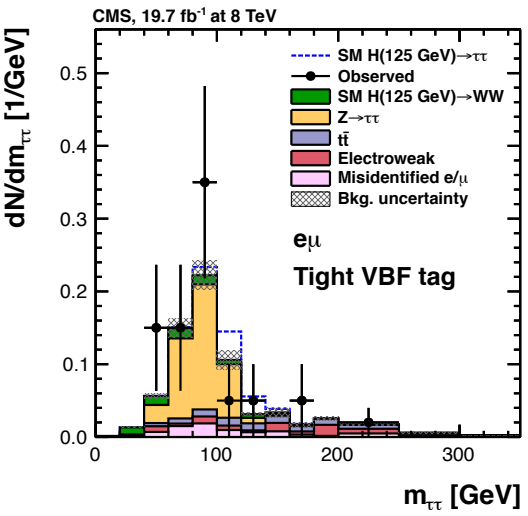
# Systematics

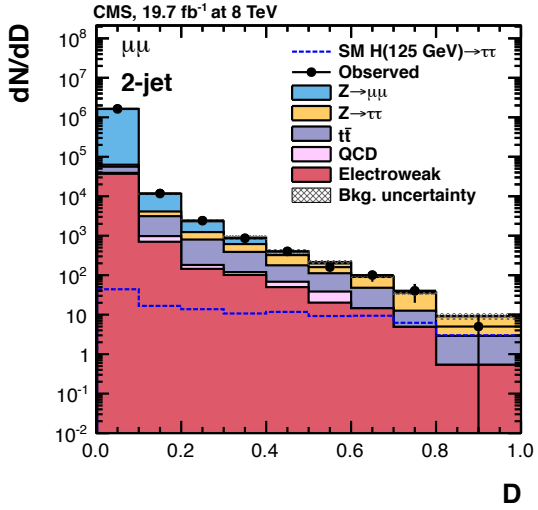
| Uncertainty | Affected processes | Change in acceptance |
|---|---|---|
| Tau energy scale | signal & sim. backgrounds | 1–29% |
| Tau ID (& trigger) | signal & sim. backgrounds | 6–19% |
| e misidentified as $\tau_h$ | $Z \to ee$ | 20–74% |
| $\mu$ misidentified as $\tau_h$ | $Z \to \mu\mu$ | 30% |
| Jet misidentified as $\tau_h$ | $Z + jets$ | 20–80% |
| Electron ID & trigger | signal & sim. backgrounds | 2–6% |
| Muon ID & trigger | signal & sim. backgrounds | 2–4% |
| Electron energy scale | signal & sim. backgrounds | up to 13% |
| Jet energy scale | signal & sim. backgrounds | up to 20% |
| $E_T^{miss}$ scale | signal & sim. backgrounds | 1–12% |
| $\varepsilon_{b\text{-tag}}$ b jets | signal & sim. backgrounds | up to 8% |
| $\varepsilon_{b\text{-tag}}$ light-flavoured jets | signal & sim. backgrounds | 1–3% |
| Norm. Z production | Z | 3% |
| $Z \to \tau\tau$ category | $Z \to \tau\tau$ | 2–14% |
| Norm. $W + jets$ | $W + jets$ | 10–100% |
| Norm. $t\bar{t}$ | $t\bar{t}$ | 8–35% |
| Norm. diboson | diboson | 6–45% |
| Norm. QCD multijet | QCD multijet | 6–70% |
| Shape QCD multijet | QCD multijet | shape only |
| Norm. reducible background | Reducible bkg. | 15–30% |
| Shape reducible background | Reducible bkg. | shape only |
| Luminosity 7 TeV (8 TeV) | signal & sim. backgrounds | 2.2% (2.6%) |
| PDF (qq) | signal & sim. backgrounds | 4–5% |
| PDF (gg) | signal & sim. backgrounds | 10% |
| Norm. ZZ/WZ | ZZ/WZ | 4–8% |
| Norm. $t\bar{t} + Z$ | $t\bar{t} + Z$ | 50% |
| Scale variation | signal | 3–41% |
| Underlying event & parton shower | signal | 2–10% |
| Limited number of events | all | shape only |

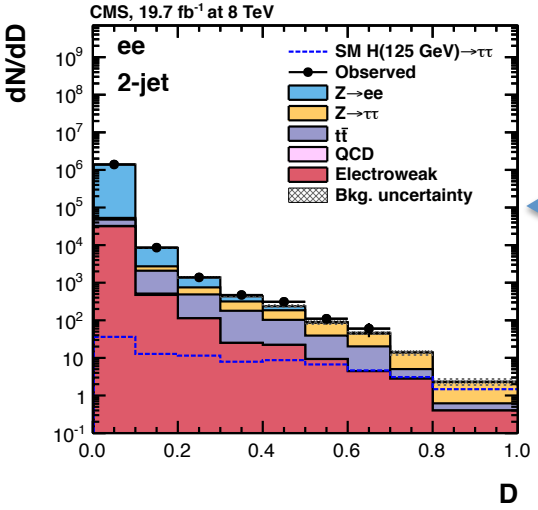
# H→ττ CMS VBF Mass Plots



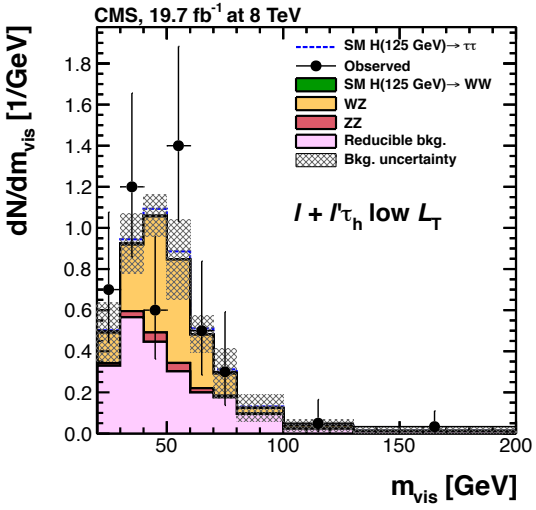



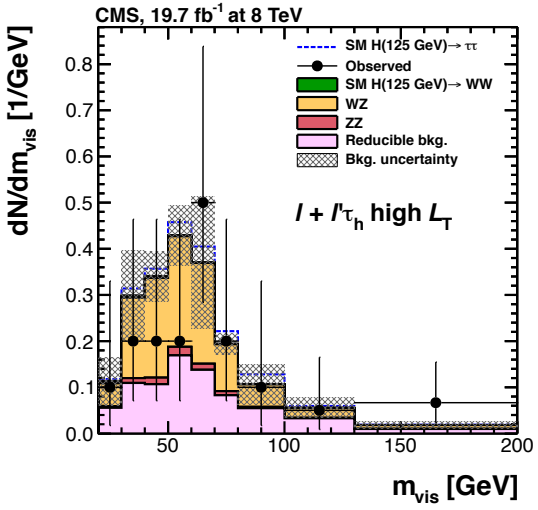



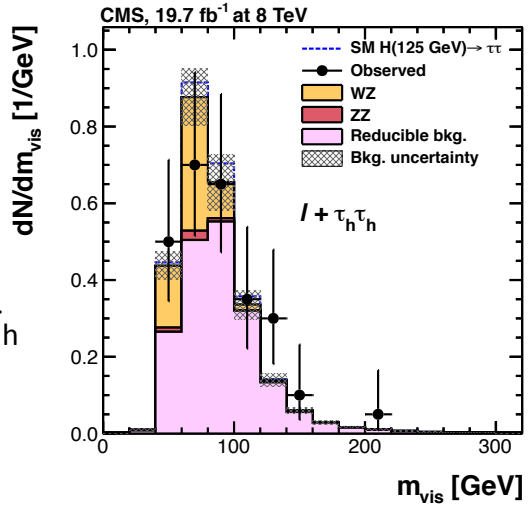

μμ and ee channels use BDT discriminator

# H→ττ CMS VH channels

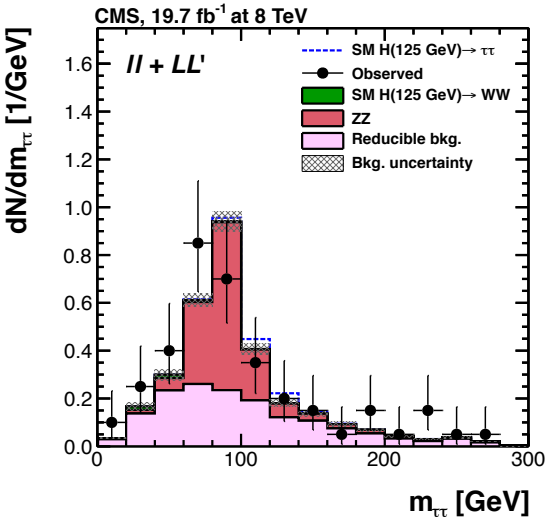



WH,H→lτ$_h$



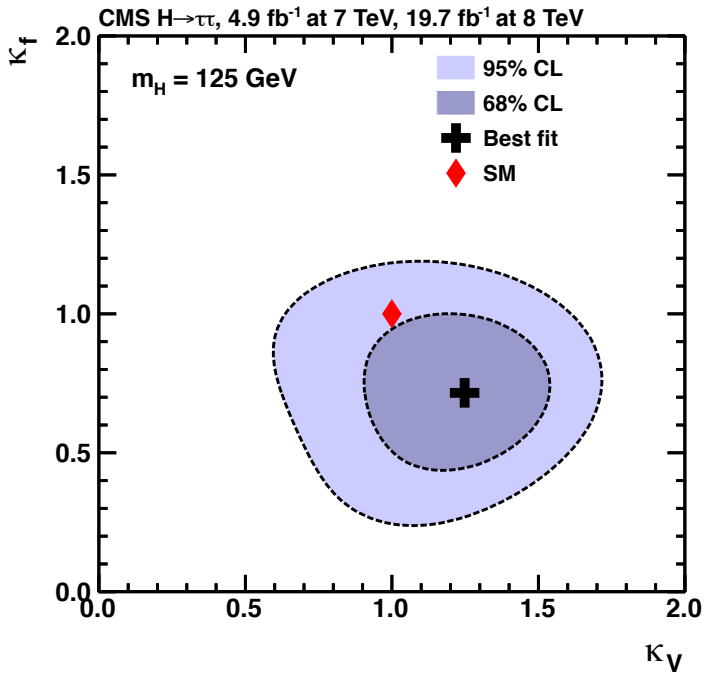

WH,H→τ$_h$τ$_h$




ZH

# Results: Couplings

**H→WW treated as signal in this plot:**




**Couplings compatible** with SM predictions