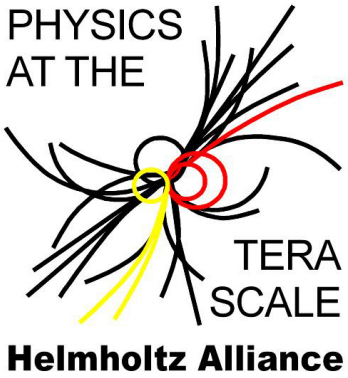
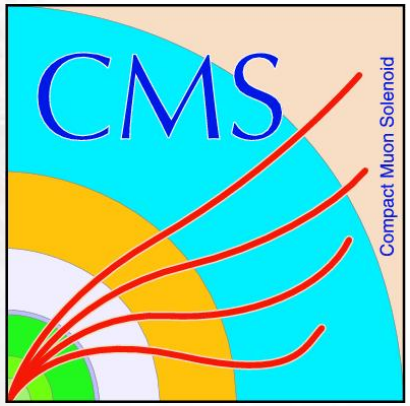
Search for Standard Model H → ττ with CMS



Terascale Alliance Meeting
December 03, 2013

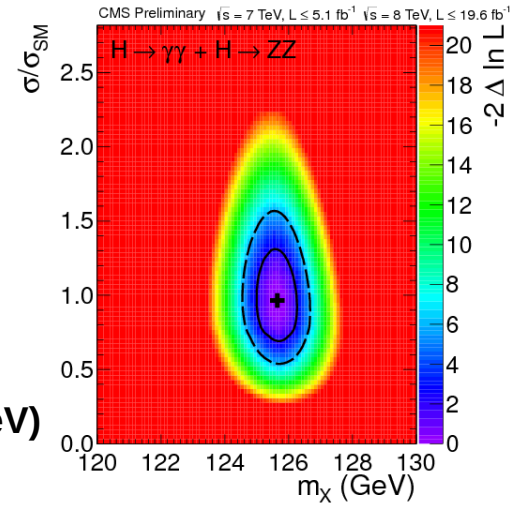
Armin Burgmeier (DESY)
for the CMS H → ττ group

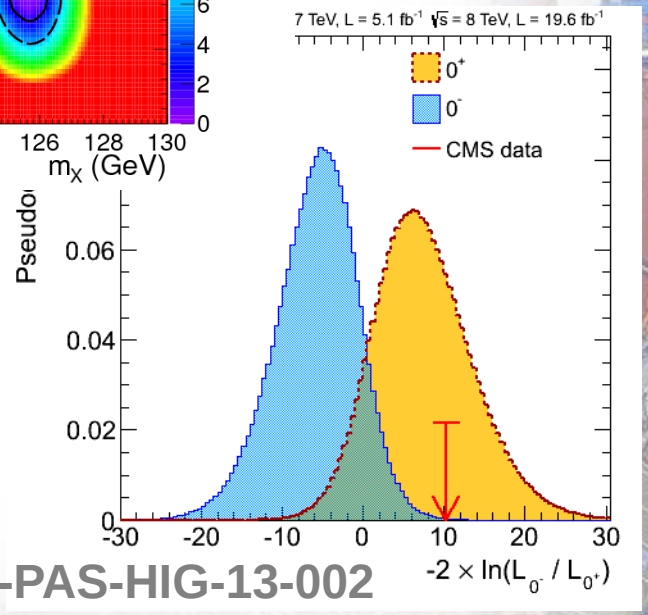


Motivation

- A **Higgs has been found** at a mass of 125 GeV
  - Signals have been seen in
    H → γγ (3.2σ),
    H → ZZ (6.7σ),
    H → WW (3.9σ)
- **Properties** need to be measured!
  - Mass **(m_H = 125.7 ± 0.3 (stat.) ± 0.3 (syst.) GeV)**
  - Spin/CP **(e.g. CP = -1 excluded at >3σ)**
  - Coupling to fermions?
    - Fundamentally different than coupling to bosons
    - Only indirect evidence so far

CMS-PAS-HIG-13-005





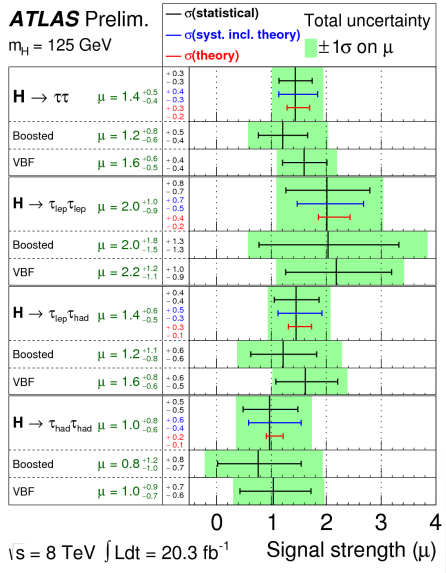
CMS-PAS-HIG-13-002

Current Status in H → ττ

Preliminary result presented in November 2013

ATLAS-CONF-2013-108

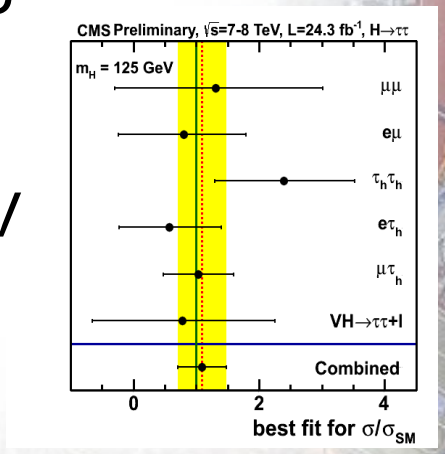
- BDT based analysis with 8 TeV data
- Observed: 4.1σ
- $\mu = 1.4^{+0.5}_{-0.4}$
- Optimized for $m_H = 125$, no mass scan (yet)



Preliminary result presented in March 2013

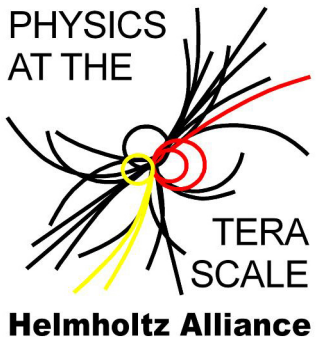
CMS-PAS-HIG-13-004

- Cut-based analysis with 7+8 TeV data
- Observed: 2.94σ
- μ = 1.1 ± 0.4
- $m_H = 120^{+9}_{-7}$ GeV

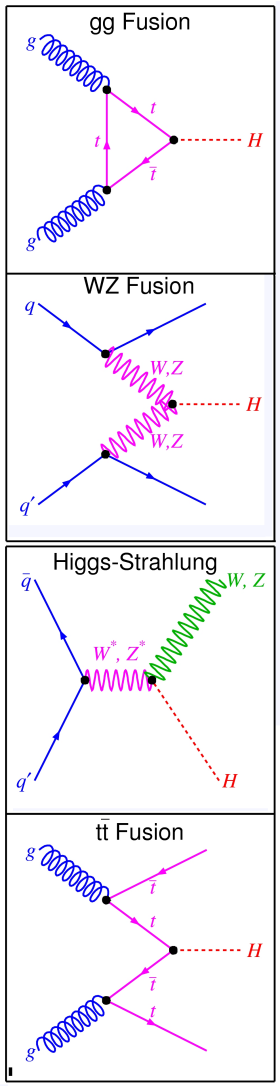


German Contributions

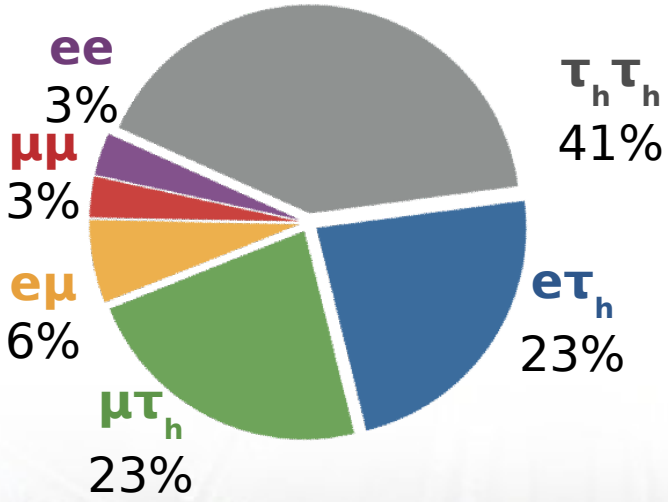
- Joint effort from KIT/DESY in **ee, μμ** final states
- Joint effort from DESY/Aachen in **WH → $l\tau_h\tau_h$** final states
- **Combination** and Statistical Interpretation of all channels
  - Cross check with indepedent tool (Theta)
- ATLAS/CMS/Theory working group: **$m_{\tau\tau}$ group**
  - Very fruitful inter-experiment collaboration
  - Bi-annual 2-day workshops
  - Development and discussion of analysis tools, such as
    - Polarization sensitive variables
    - Background estimation methods

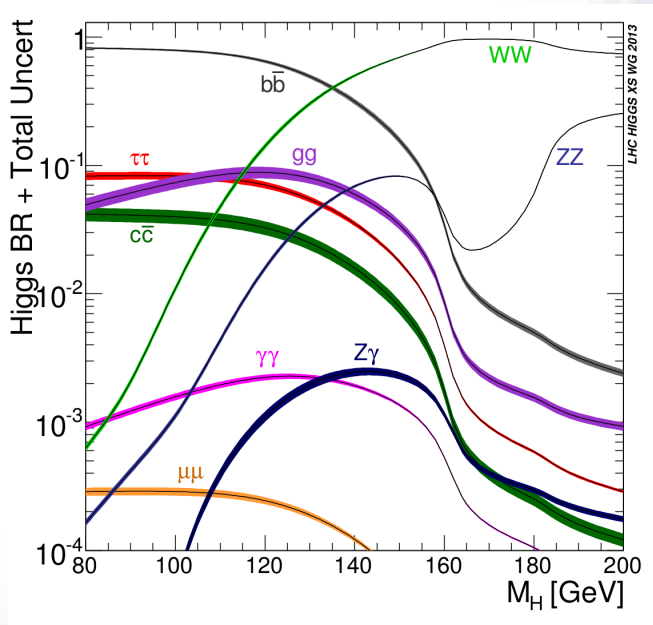


Higgs Production and Decay



- 4 **Production Mechanisms**
  - H, qqH, VH, $t\bar{t}$H
- 5 main **decay channels** at low mass
  - H → $b\bar{b}$, H → WW, H → ZZ, H → ττ, H → γγ
- ττ decay has 6 **final states**:





Analysis Strategy

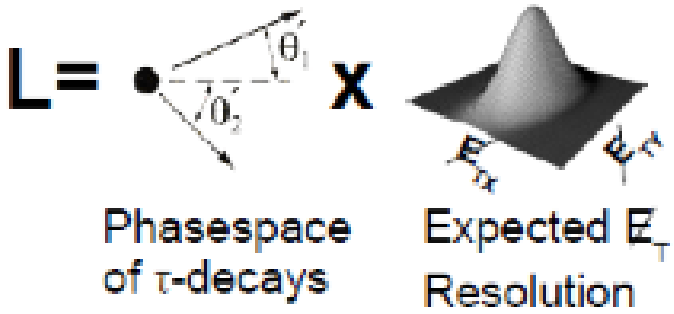
- Goal: Measure coupling of Higgs to ττ
- Final states with **2 leptons**: e, μ or τ_h (More than two leptons in VH)
- Light leptons from tau decays are **soft**
  - Need **low p_T thresholds** (→ cross triggers)

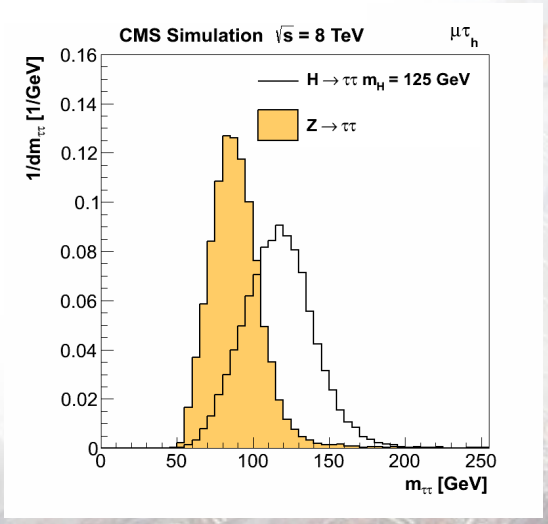
Channel	Offline p_T Threshold
$\mu\tau_h$	$p_T(\mu) > 20$ GeV, $p_T(\tau_h) > 30$ GeV
$e\tau_h$	$p_T(e) > 24$ GeV, $p_T(\tau_h) > 30$ GeV
$\tau_h\tau_h$	$p_T(\tau_h) > 45$ GeV
ee, eμ, μμ	$p_T(l_1) > 20$ GeV, $p_T(l_2) > 10$ GeV

- Isolated leptons to suppress e.g. QCD multijet events with jets misidentified as leptons
- $M_T(l, E_T^{miss}) < 30$ GeV to suppress W+Jets events

Di-tau mass reconstruction

- Use di-tau mass as **discriminating variable**
- Undetected neutrinos lead to **underestimation** of the di-τ mass
- Likelihood-based method to find mass which is **most compatible** with:
  - Tau decay kinematics
  - Visible decay products
  - E_T^{miss} + uncertainty
- Mass resolution:
  - 10% to 20% (depending on final state)

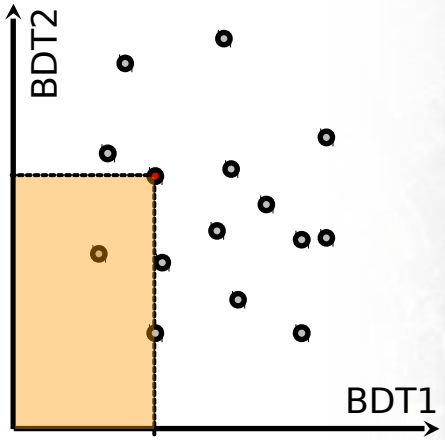


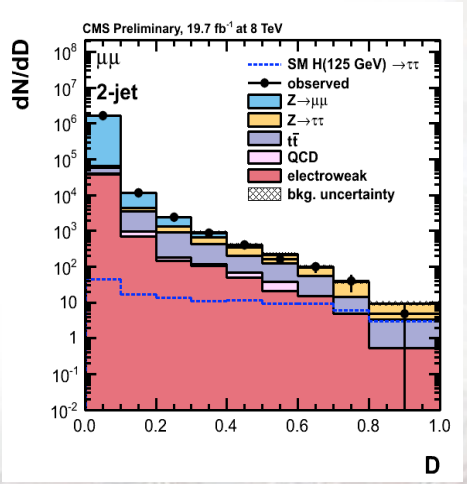


Same Flavor Dilepton Channels

- Different analysis strategy
- No τ_h reconstruction needed
- Additional **direct Z → ll** background
- Train **two BDTs**
  - BDT1: Separate Z → ll from Z/H → ττ
  - BDT2: Separate Z → ττ from H → ττ

$$D_{\mathrm{cat}} = \int_0^{\mathrm{BDT}_1} \int_0^{\mathrm{BDT}_2} f_{\mathrm{cat}}^{\mathrm{sig}}(\mathrm{BDT}_1', \mathrm{BDT}_2')\, \mathrm{dBDT}_1'\, \mathrm{dBDT}_2'$$

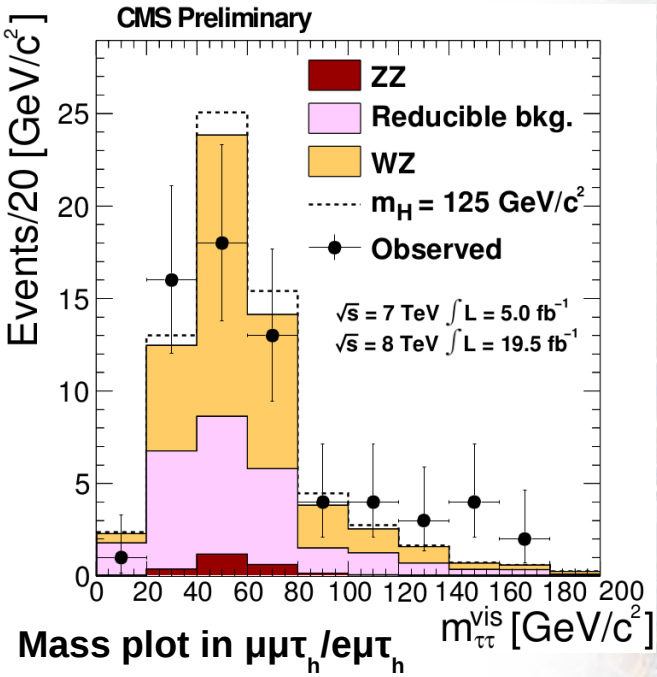




Associated Production

CMS-PAS-HIG-12-053

- More than 2 leptons in the event
- Easy to **trigger**
- Low SM Background
- But: Low cross section
- WZ/ZZ is **irreducible background**
- Other background has **fake leptons**
  - estimated from **data**



Mass plot in $\mu\mu\tau_h$/$e\mu\tau_h$

Updated VH analyses are still being finalized and will be combined with Non-VH channels for the legacy paper

Concentrate on non-VH in the following

Most Important Backgrounds

- Take as much from **data** as possible (e.g. **correct modelling** of interference of inclusive and VBF Z production)

Z → ττ:

Normalized to measured cross section, **Shape** from embedded data events

Z → ee/μμ:

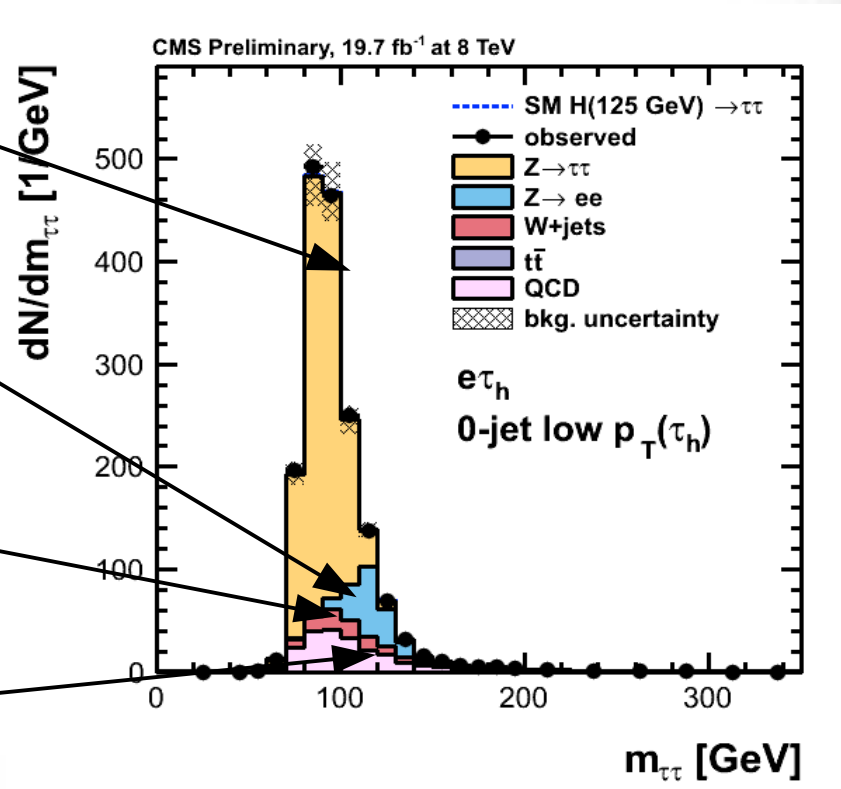
Shape and **Normalization** from fit to data in 0-jet category

W + Jets:

Normalized to data in high mT sideband, **Shape** from Simulation

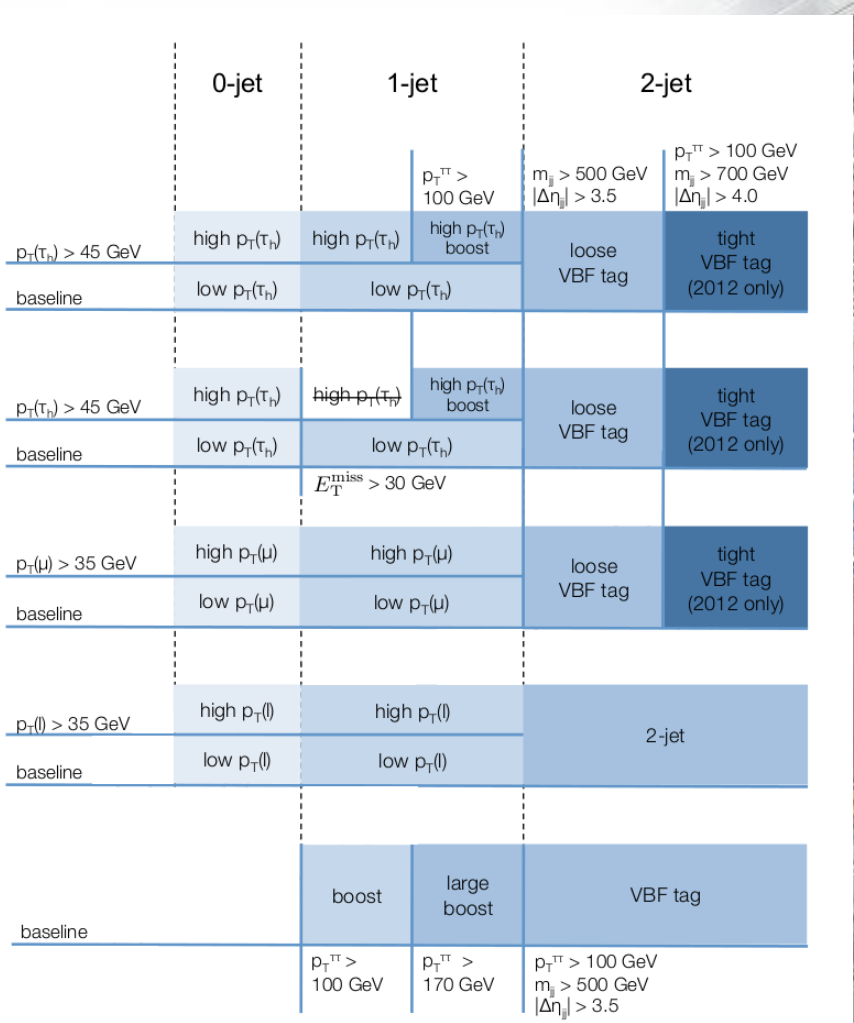
QCD Multijet:

Shape and **Normalization** from Same Sign data



Event Categorization

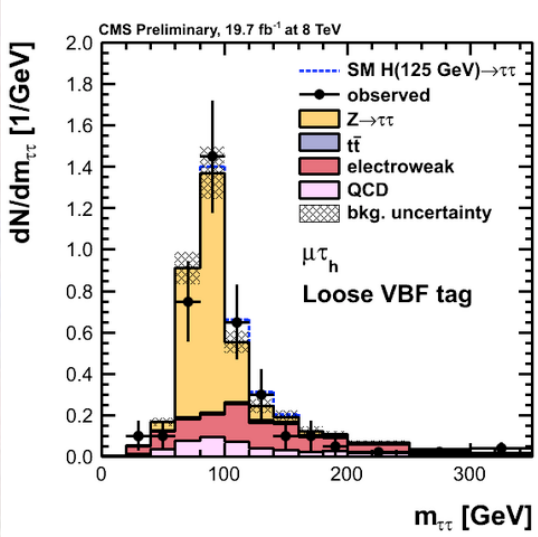
- Use full event kinematics to **categorize events**, based on
  - jet multiplicity
  - $p_T^{\tau\tau} = |\vec{p}_T(L) + \vec{p}_T(L') + E_T^{miss}|$
  - $p_T(\tau_h / \tau_l)$
- **Re-optimized** since Moriond result
- Improves **overall sensitivity**
- Less categories in the 7 TeV data
- **58 categories** in total
  - Fit for signal in all of them



Categories in 8 TeV

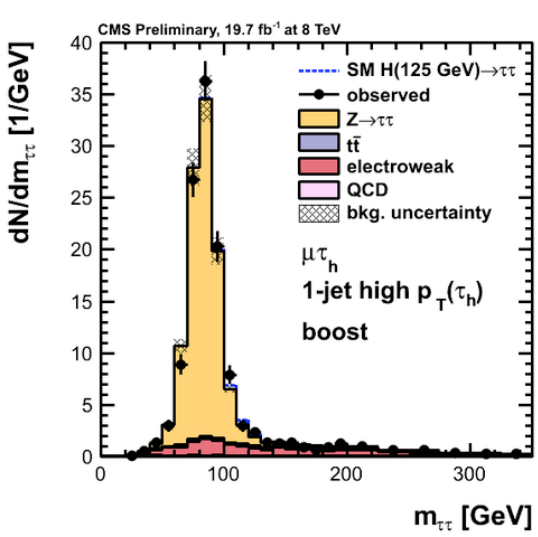
Example Di-Tau Mass Plots

VBF:



- Low event statistics
- High S/B

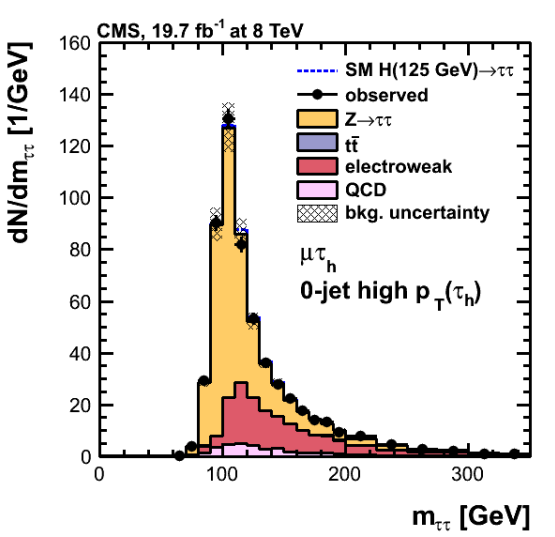
1 Jet:



- Exploit boost of the Higgs system: Improved mass resolution

0 Jets:

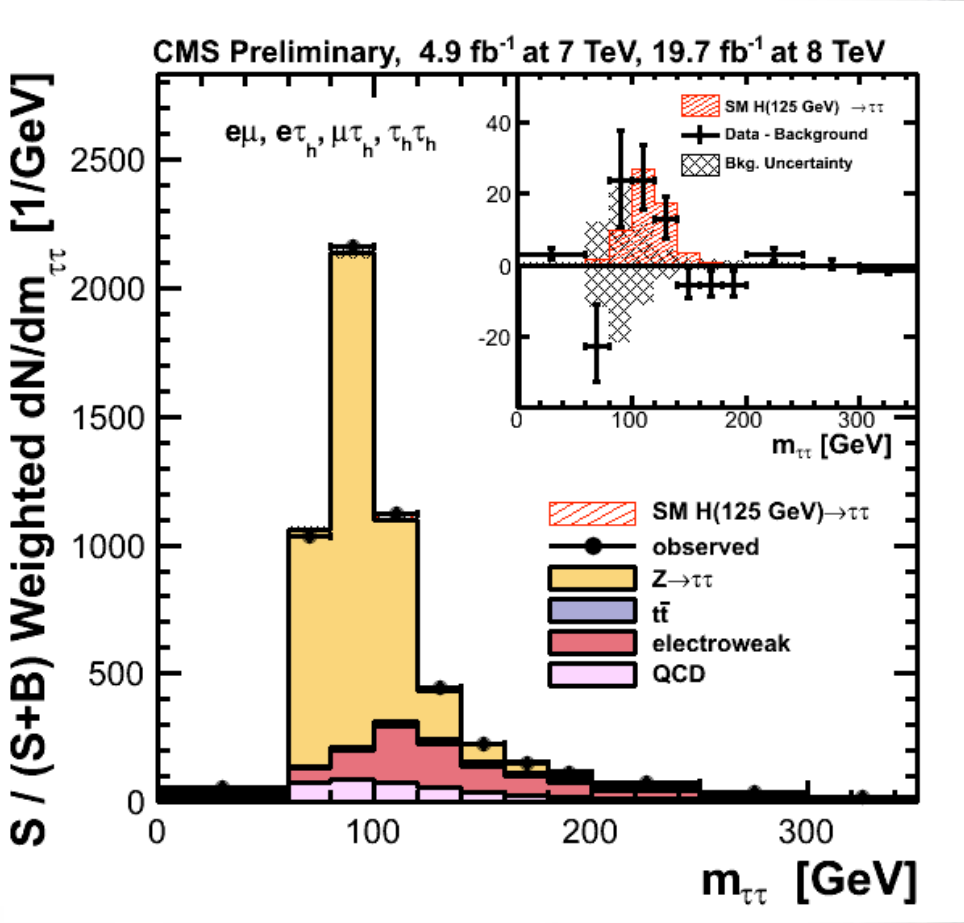
$\mu\tau_h$ channel



- Low S/B
- Important for Constraining Nuisance Parameters

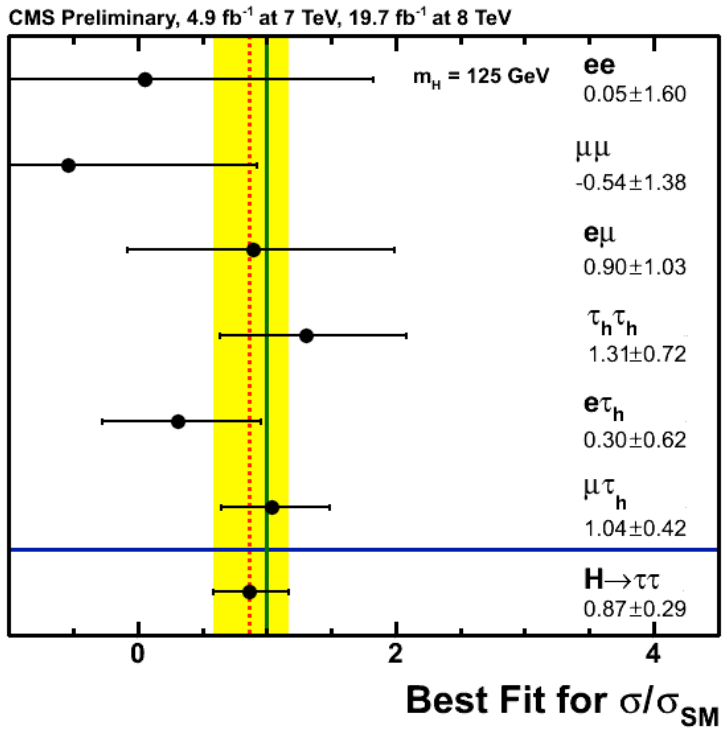
S/B Weighted Di-Tau Mass

- Signal starts to build up in all channels and categories
- Combine all events in one plot
- Each event is **weighted with S/(S+B)** in its respective category

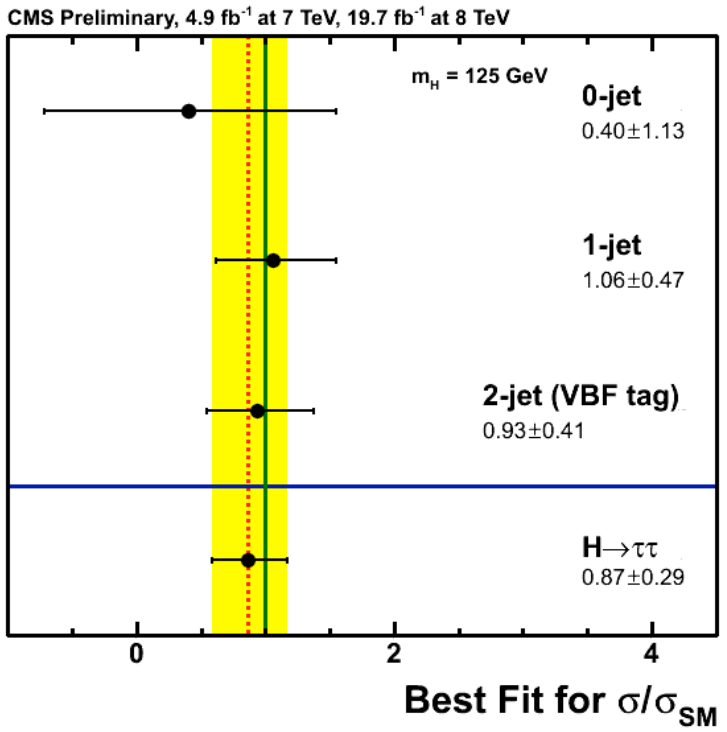


Best Fit Signal Strength

By channel:



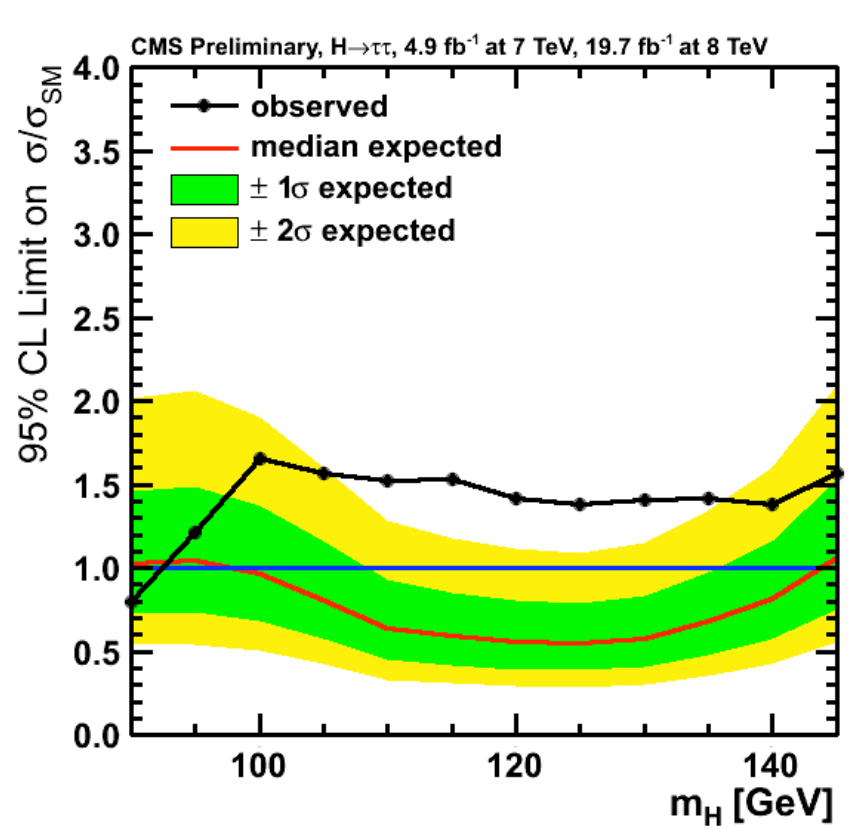
By category:



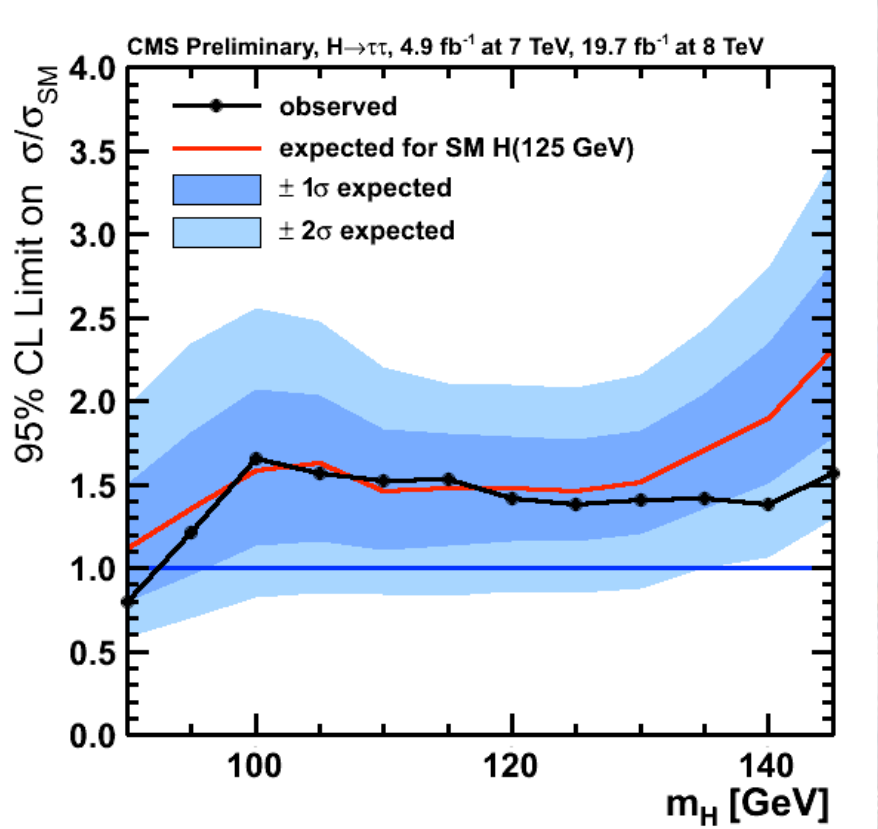
- Important nuisance parameters **shared** between channels and categories (**constrained** by high statistics categories in global fit)
- Best fit **μ = 0.87 ± 0.29**

Expected Exclusion Limits

Background only:

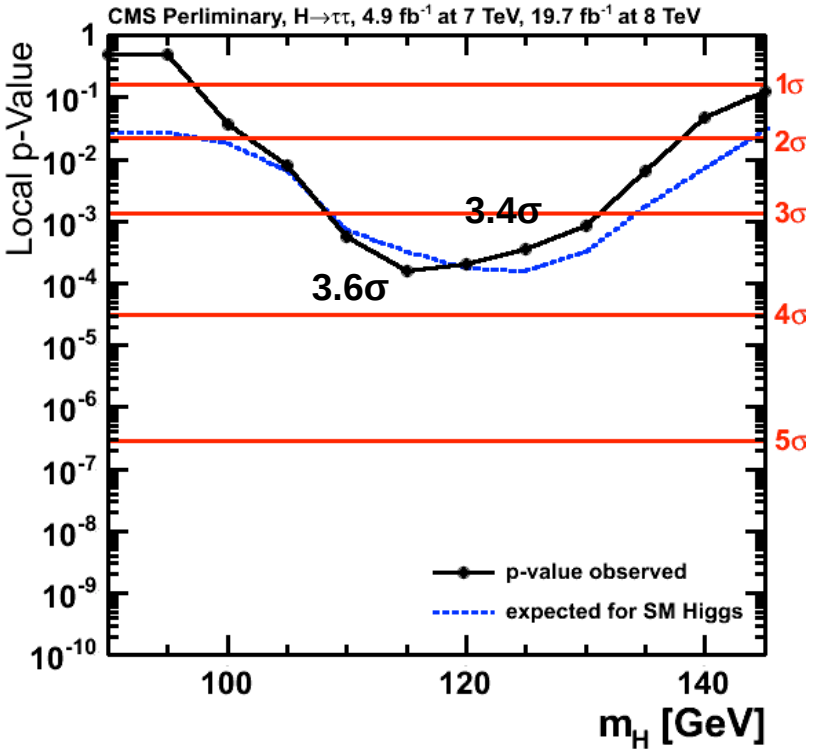


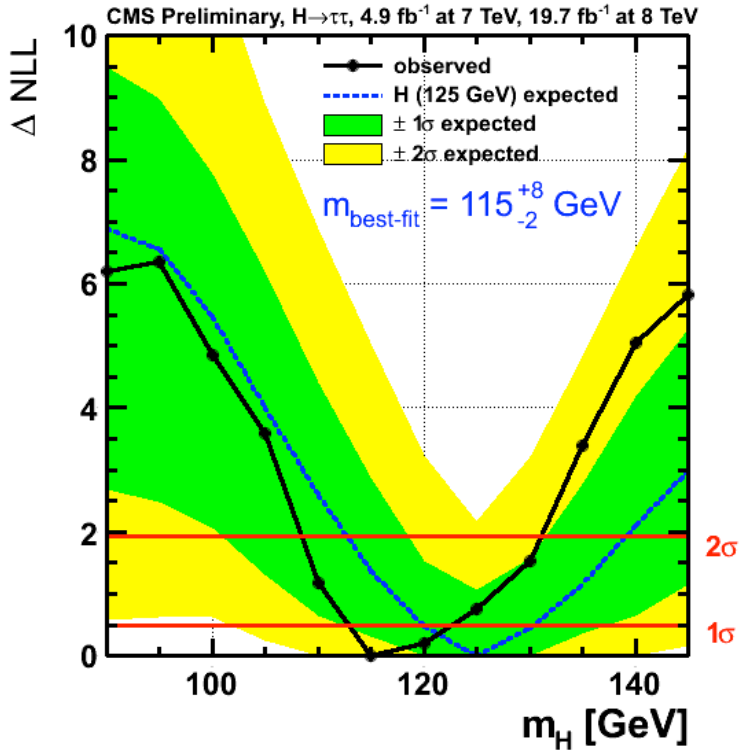
1x SM + Background:



- Excess is **compatible with SM Higgs** boson hypothesis over wide mass range

p-value and Mass Scan

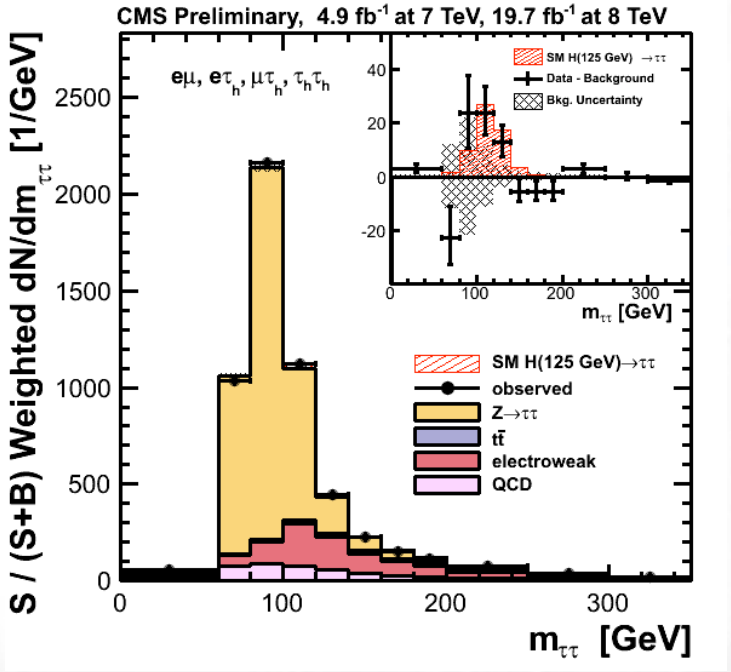




- Largest **observed significance** (3.59σ) at m_H = 115 GeV
- **Mass scan**: **$m_H = 115^{+8}_{-2}$ GeV**

Conclusions

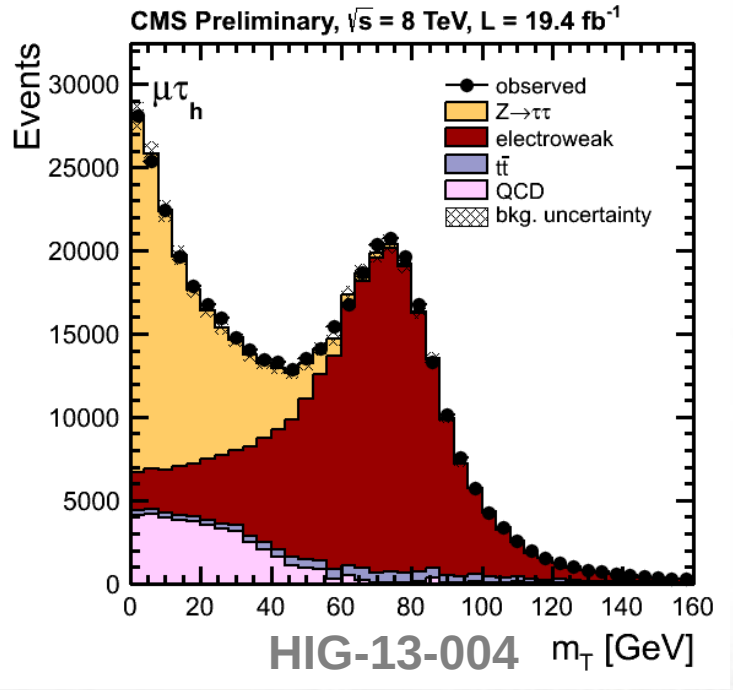
- **SM Higgs Results** in the ττ channel have been presented
  - Analysis is complex due to high backgrounds and the **combination of many channels** and categories
- CMS sees an **excess around 125 GeV** at **3.6σ** significance!
- Analysis has been **optimized** since Preliminary Moriond result
  - VH channels to be added
  - **Final publication** within the next days



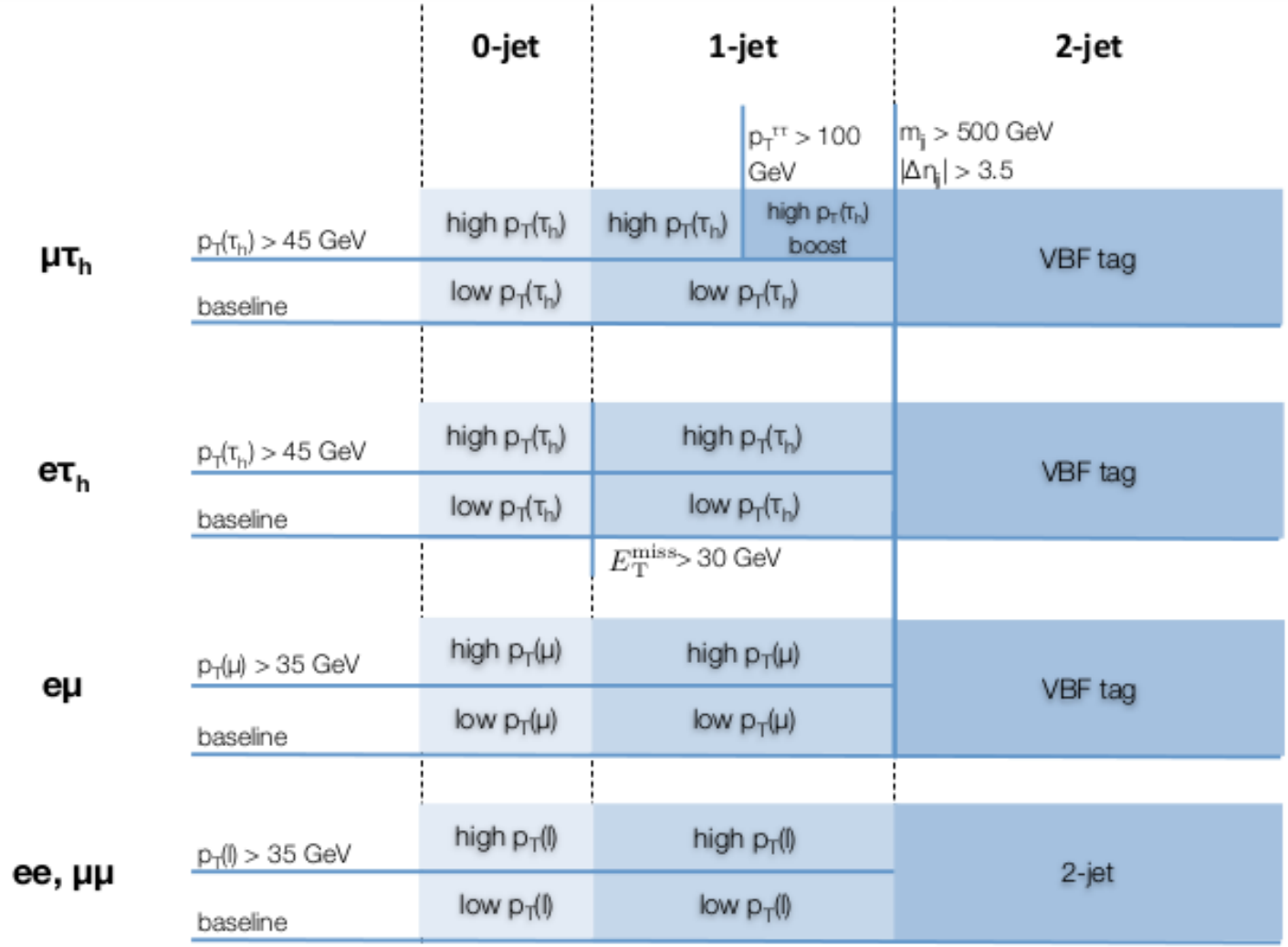
Backup

Background Rejection

- Very channel specific in general
  - Differentiate between
    - Irreducible backgrounds (same final state)
    - Reducible backgrounds (one or more objects misidentified)
- Main backgrounds:
  - $Z \rightarrow \tau\tau$
  - $Z \rightarrow ee/\mu\mu$
  - W + Jets
  - QCD Multijet
  - $t\bar{t}$

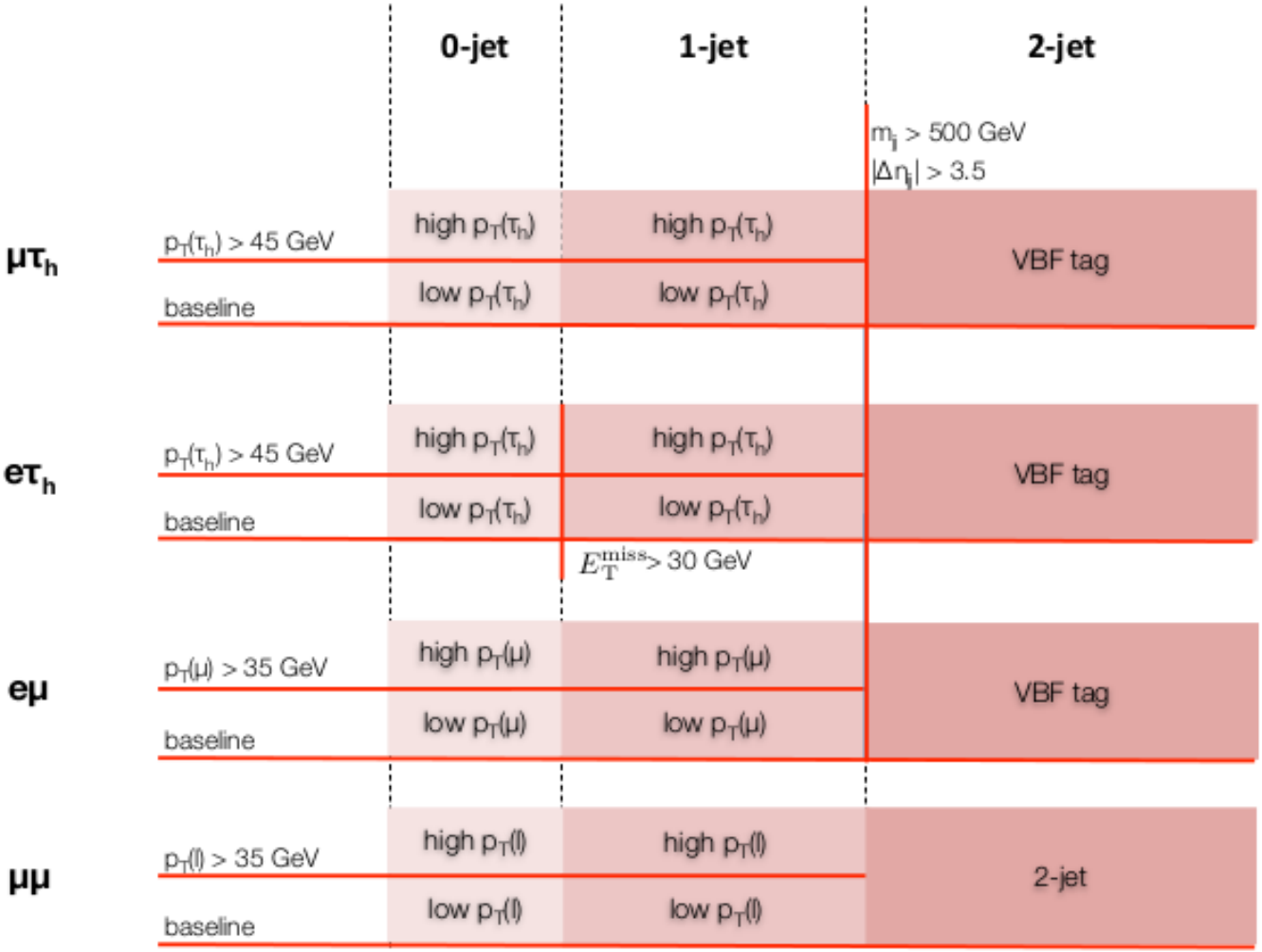


Event Categorization at 7 TeV



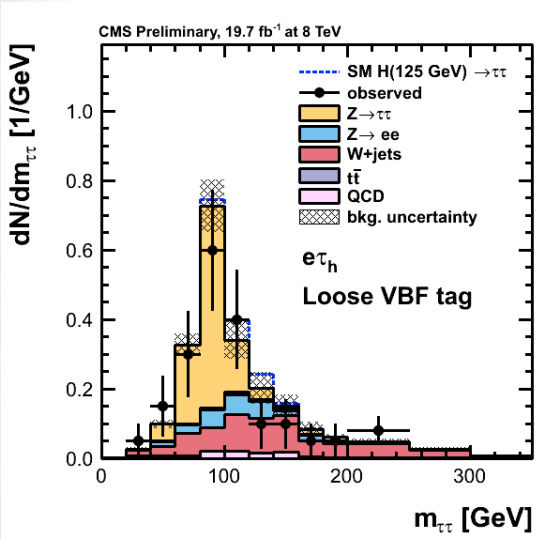
Event Categorization at Moriond 8 TeV

Event Categorization at Moriond 7 TeV



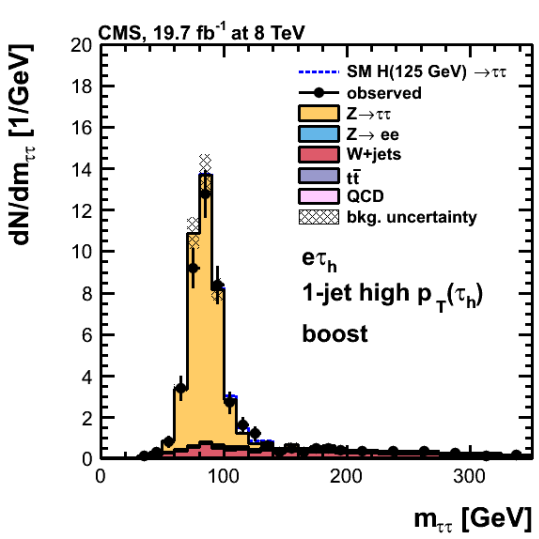
Di-Tau Mass Distributions ($e\tau_h$)

VBF:



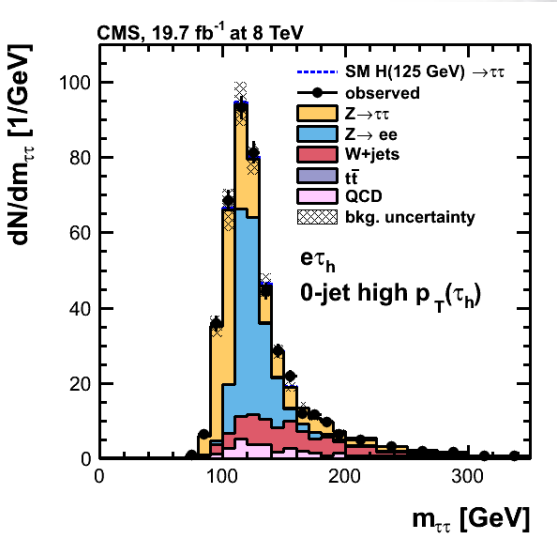
- Low event statistics
- High S/B

1 Jet:



- Exploit boost of the Higgs system: Improved mass resolution

0 Jets:

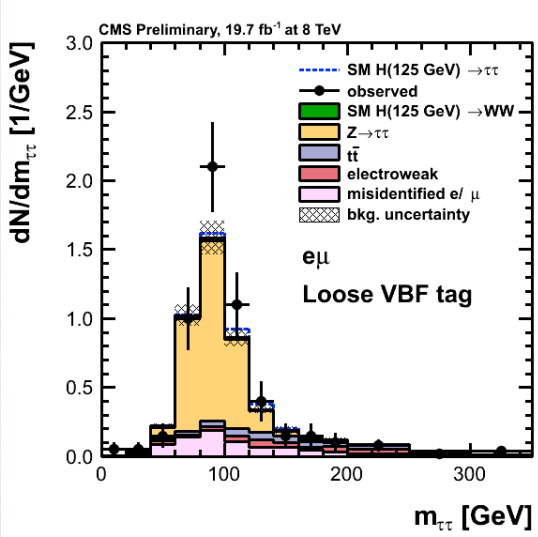


- Low S/B
- Important for Constraining Nuisance Parameters

$e\tau_h$ channel

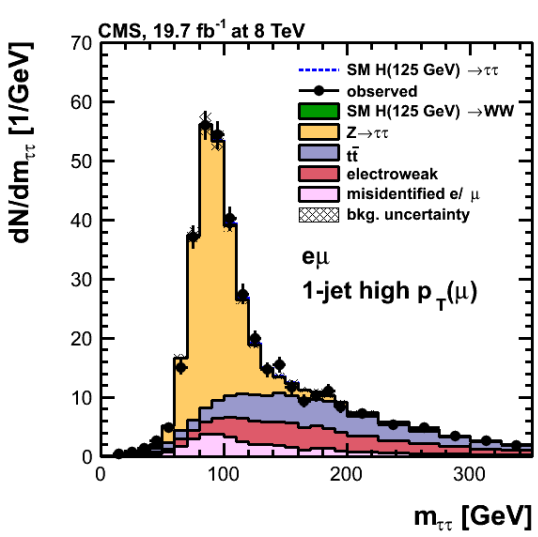
Di-Tau Mass Distributions (eμ)

VBF:



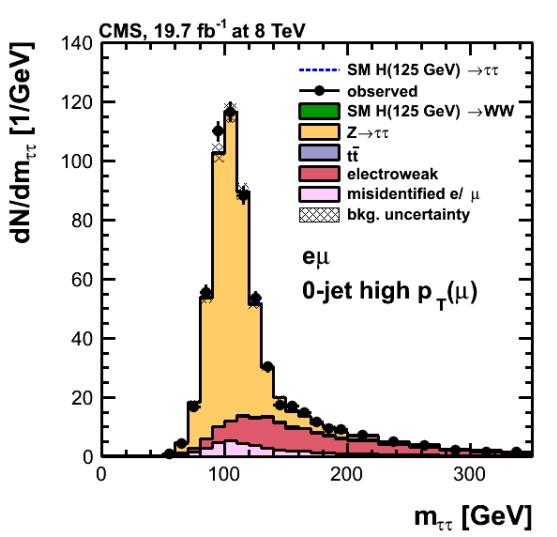
- Low event statistics
- High S/B

1 Jet:



- Exploit boost of the Higgs system: Improved mass resolution

0 Jets:

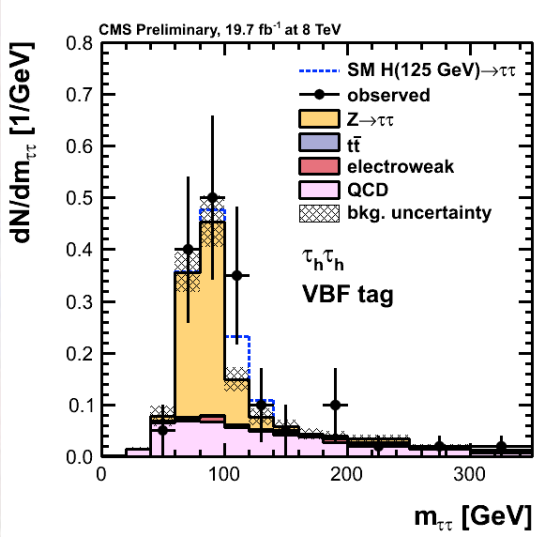


- Low S/B
- Important for Constraining Nuisance Parameters

eμ channel

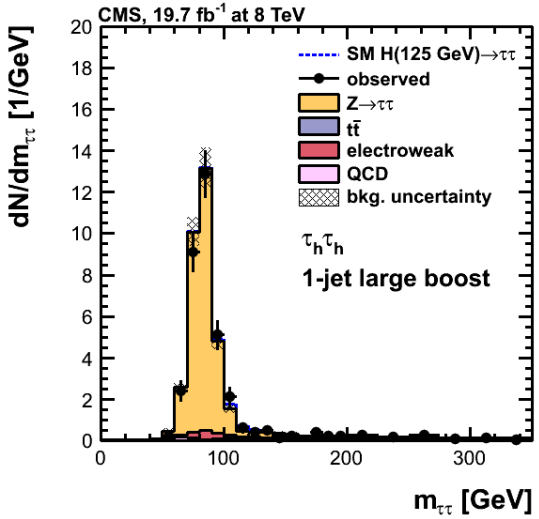
Di-Tau Mass Distributions ($\tau_h\tau_h$)

VBF:



- Low event statistics
- High S/B

1 Jet:



- Exploit boost of the Higgs system: Improved mass resolution

0 Jets:

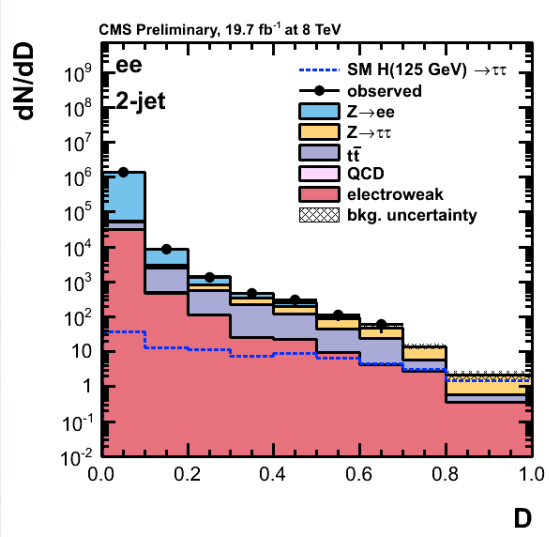
No 0-Jet category due to trigger requirements in this channel

- ~~Low S/B~~
- ~~Important for Constraining Nuisance Parameters~~

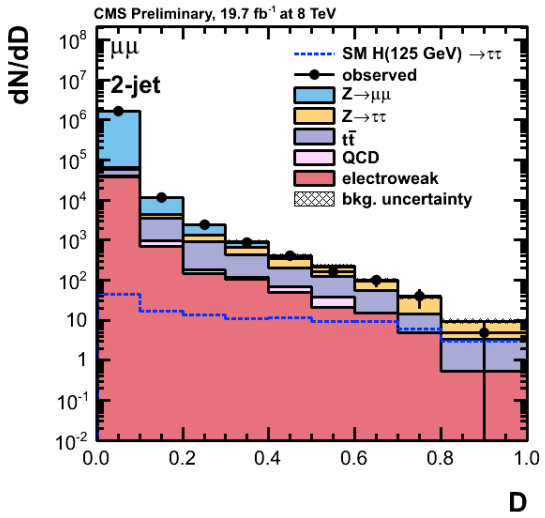
$\tau_h\tau_h$ channel

Comb. BDT Distributions (mm/ee)

ee VBF:

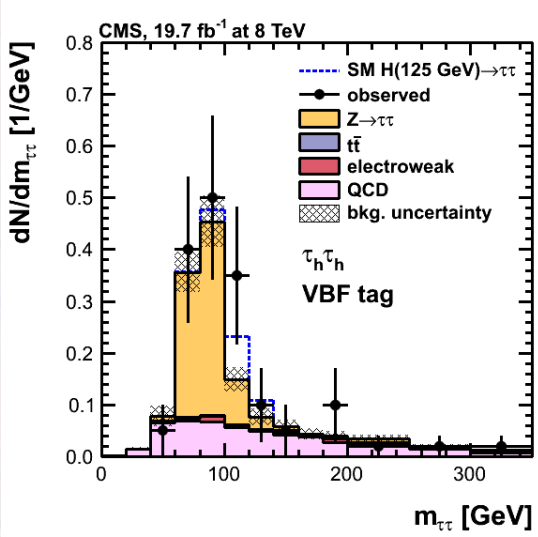


mm VBF:



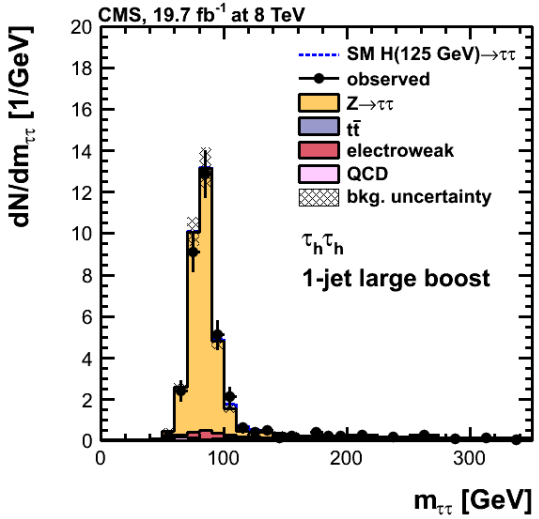
Di-Tau Mass Distributions ($\tau_h\tau_h$)

VBF:



- Low event statistics
- High S/B

1 Jet:



- Exploit boost of the Higgs system: Improved mass resolution

0 Jets:

No 0-Jet category due to trigger requirements in this channel

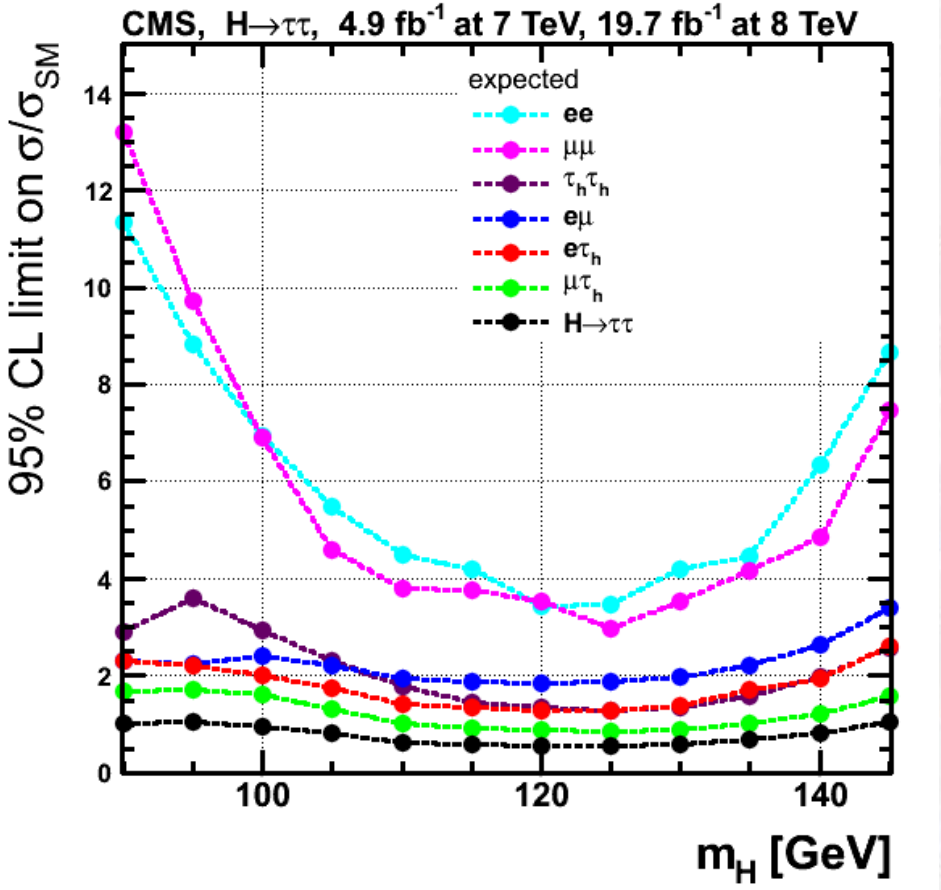
- ~~Low S/B~~
- ~~Important for Constraining Nuisance Parameters~~

$\tau_h\tau_h$ channel

Expected Limit by Channel

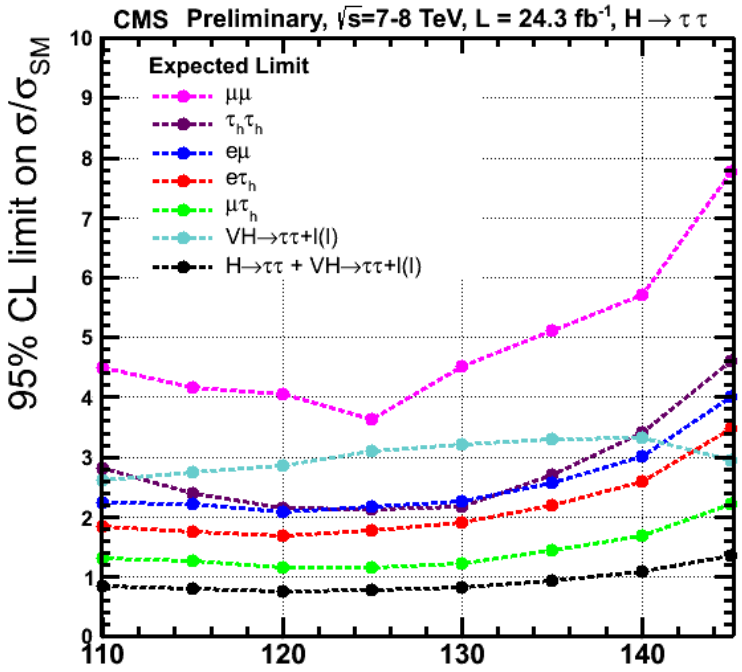
- **Combine all channels** and categories for statistical interpretation
- 95% C.L. Frequentist **Exclusion Limits** are set with the CLs method

HIG-13-004

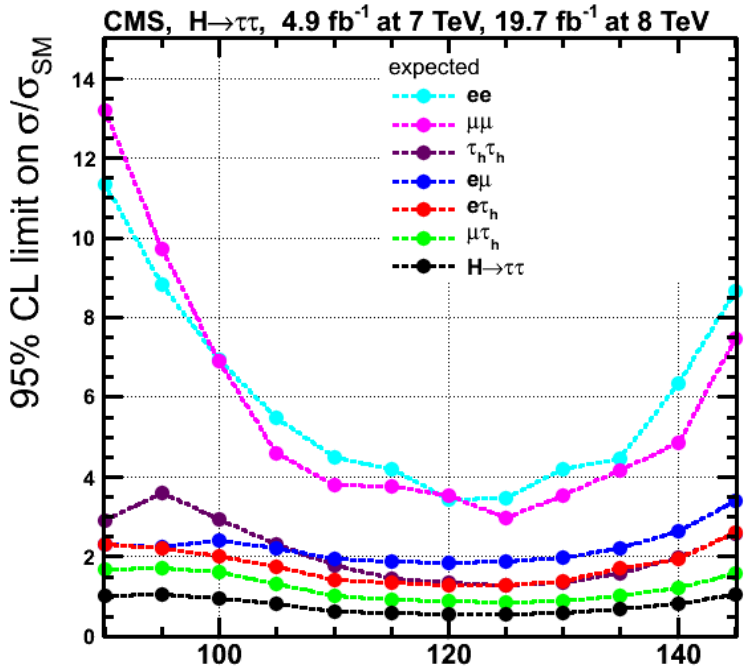


Only combination of channels is sensitive to SM Higgs

Improvement in sensitivity

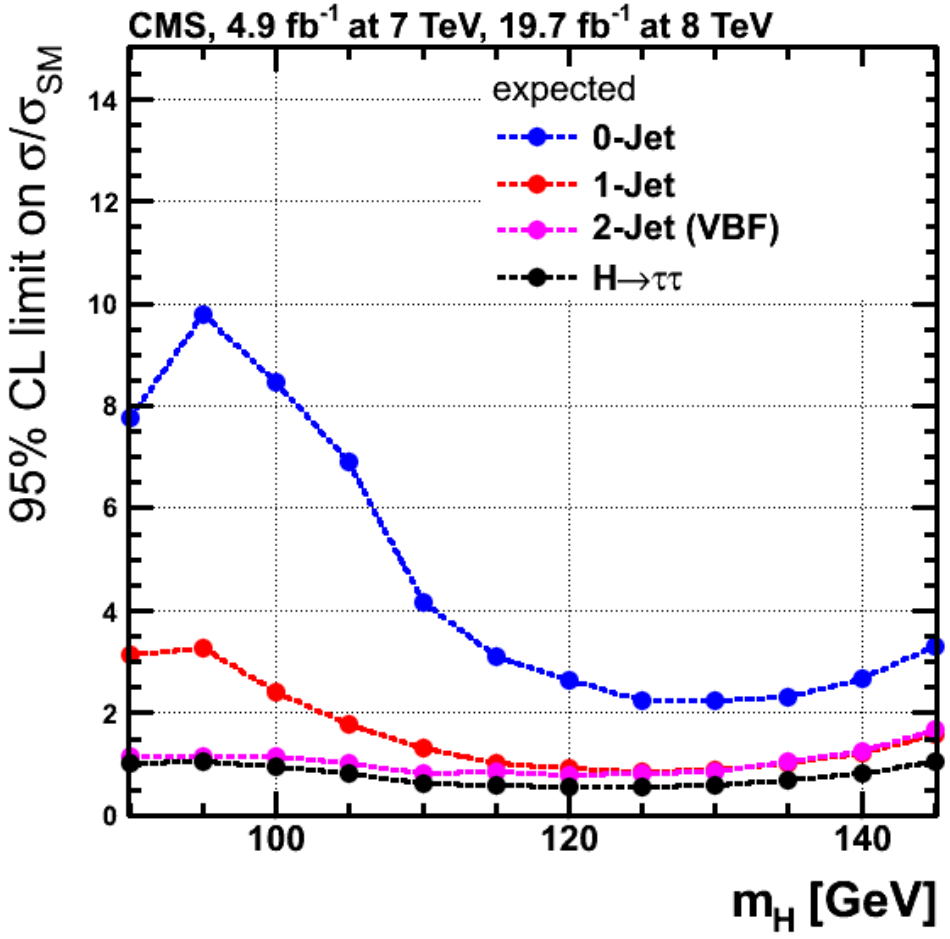


Moriond 2013

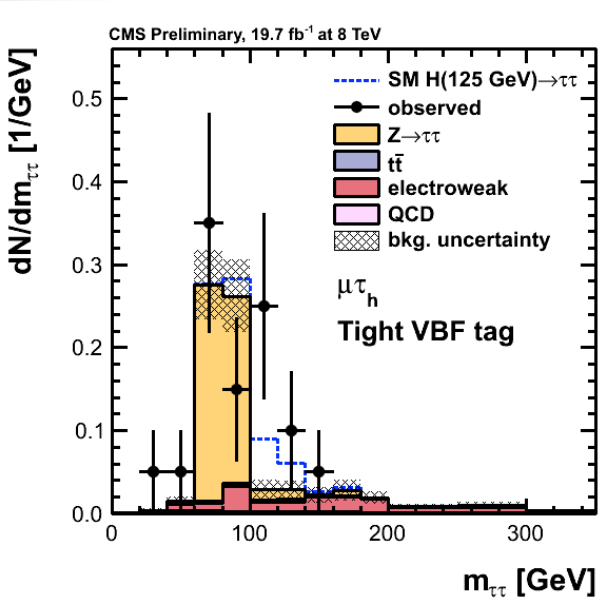


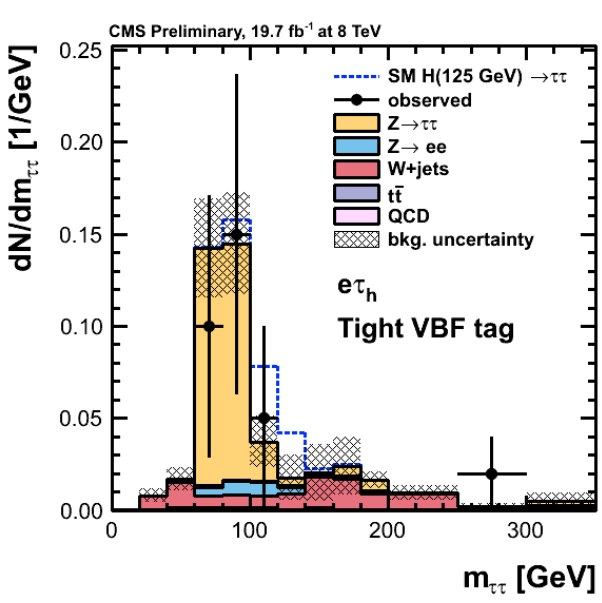
Current Analysis

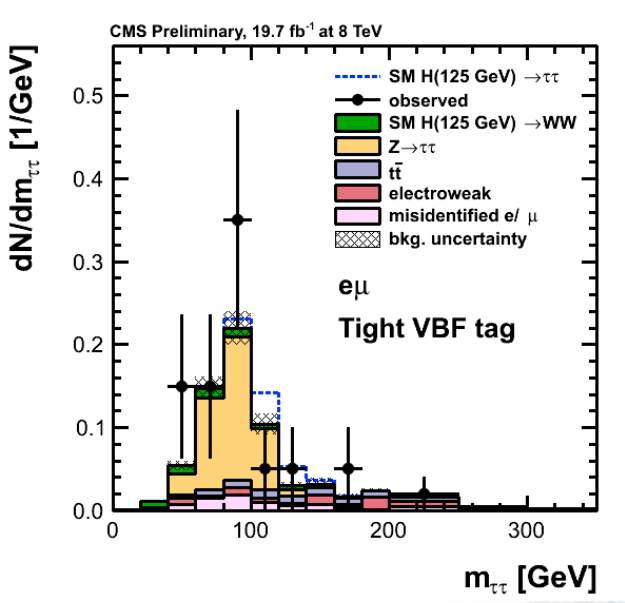
Expected Limit By Category



Tight VBF Category

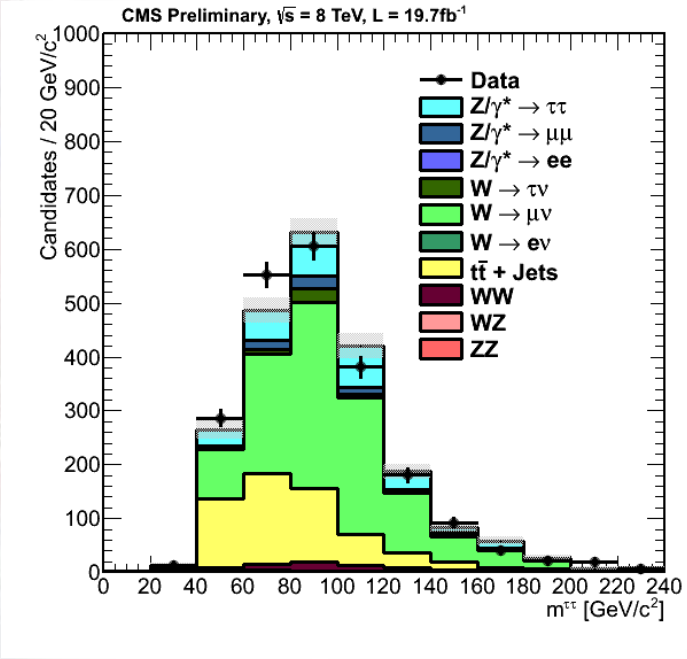




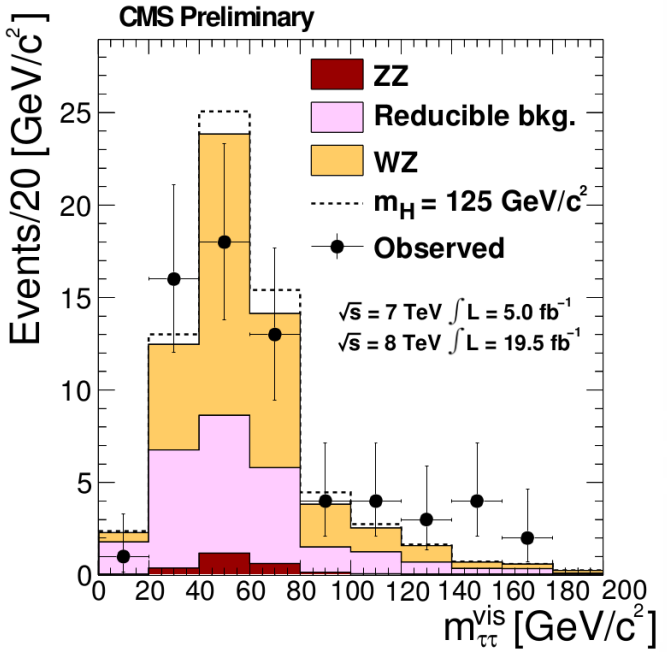


Backgrounds in VH

- **Major Backgrounds** from:
  - Di-boson WZ/ZZ production (irreducible)
  - W + Jets, Z + Jets, $t\bar{t}$ + Jets (reducible)



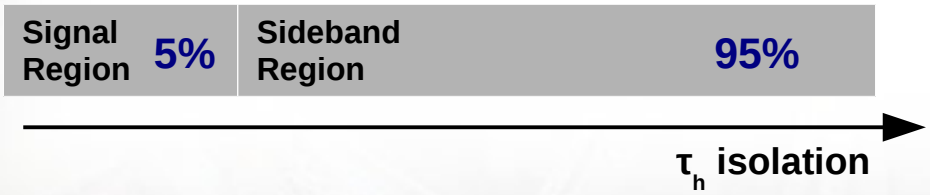
Reducible backgrounds in $\mu\tau_h\tau_h$

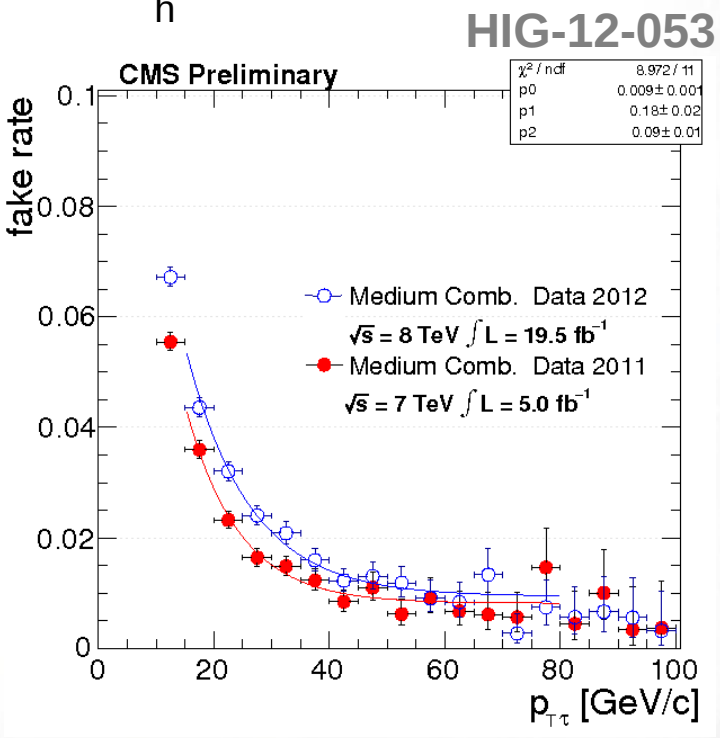


Mass plot in $\mu\mu\tau_h$/$e\mu\tau_h$

Background Estimation in VH

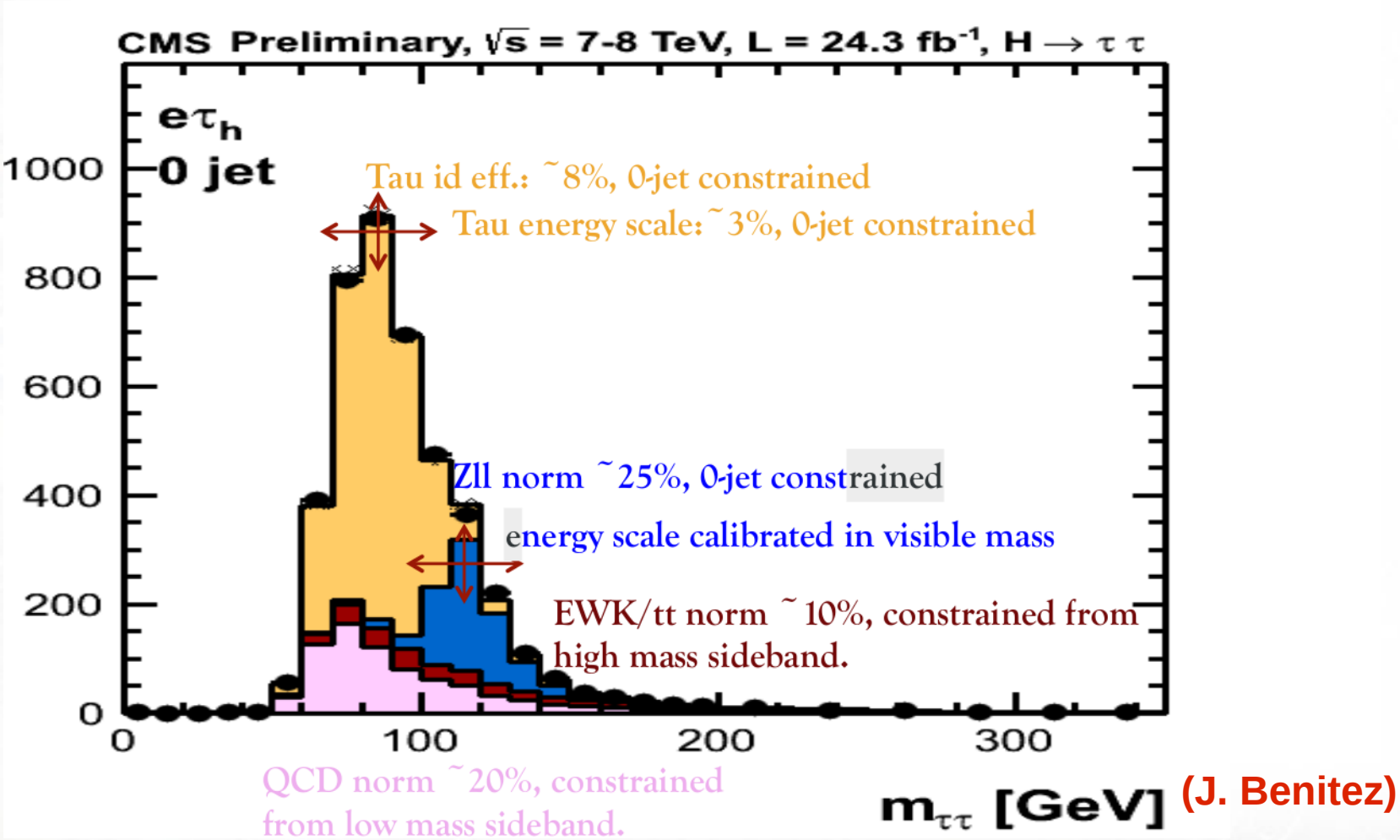
- Reducible backgrounds are estimated with **Fake Rate Method**
- Invert the ID cut of the object which is misidentified (Sideband)
  - For example, isolation for jet → τ_h Fakes
- **Measure probability** for a jet to pass the ID cut (”Fake Rate”)
- Scale events in the sideband region with the probability that they pass the ID





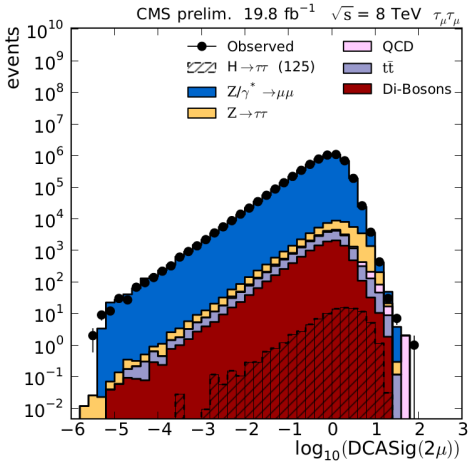
Systematics

on one slide

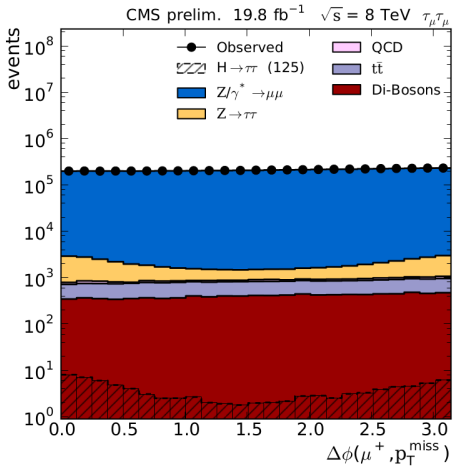


(J. Benitez)

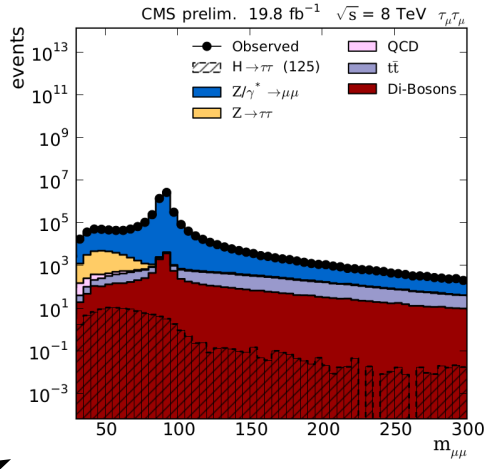
BDT Input Variables



Distance of closest approach between muons



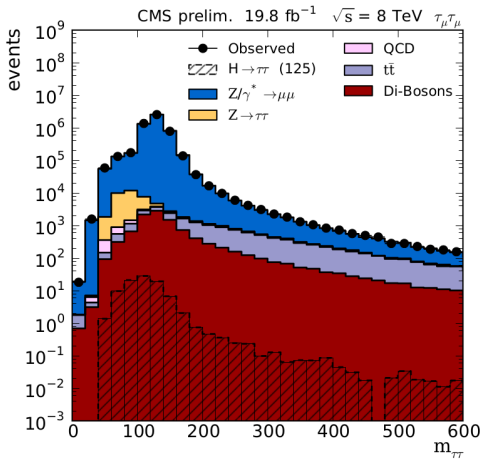
Δφ(E$^{T}_{miss}$, μ$^+$)



Dimuon mass

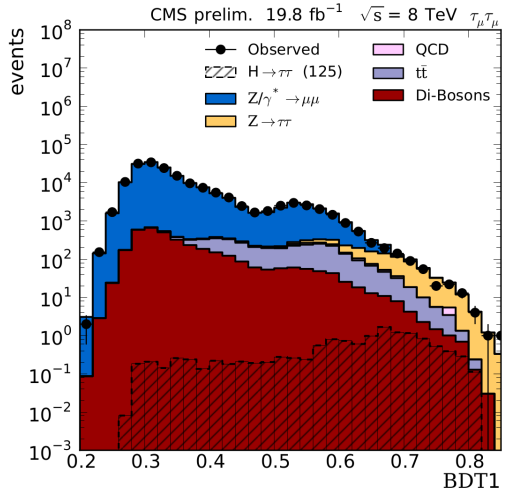
Against Z → μμ

Against Z → ττ



Reconstructed di-tau mass

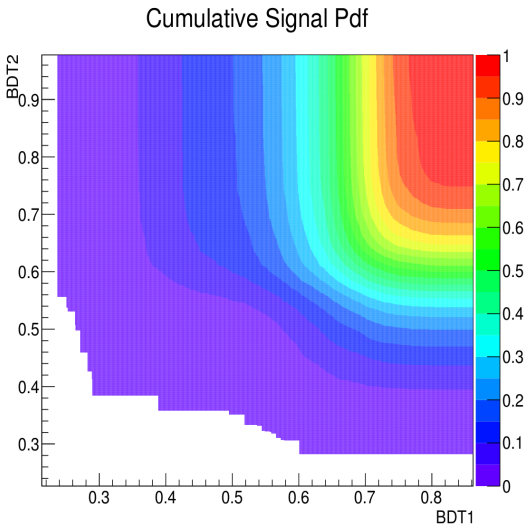
Combination of BDTs

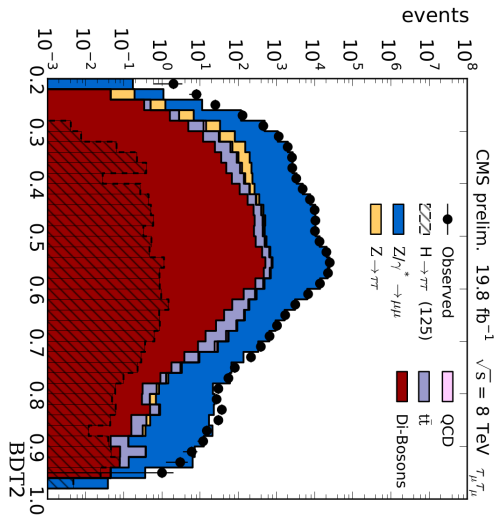


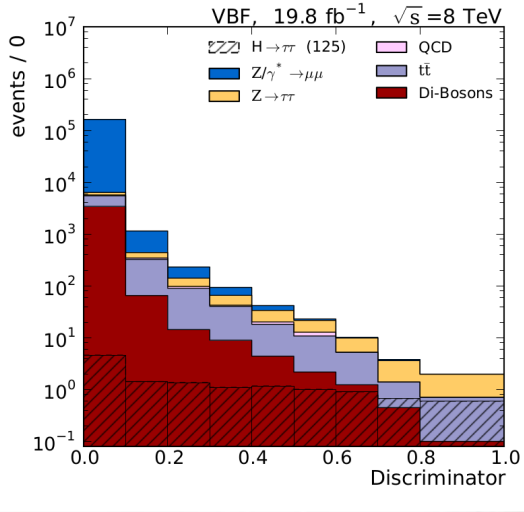
Create **2D PDF** f^{sig}_{cat} from BDT outputs of signal events

Final discriminator:

$$D_{\mathrm{cat}} = \int_0^{\mathrm{BDT}_1} \int_0^{\mathrm{BDT}_2} f^{\mathrm{sig}}_{\mathrm{cat}}(\mathrm{BDT}'_1, \mathrm{BDT}'_2)\, \mathrm{dBDT}'_1\, \mathrm{dBDT}'_2$$

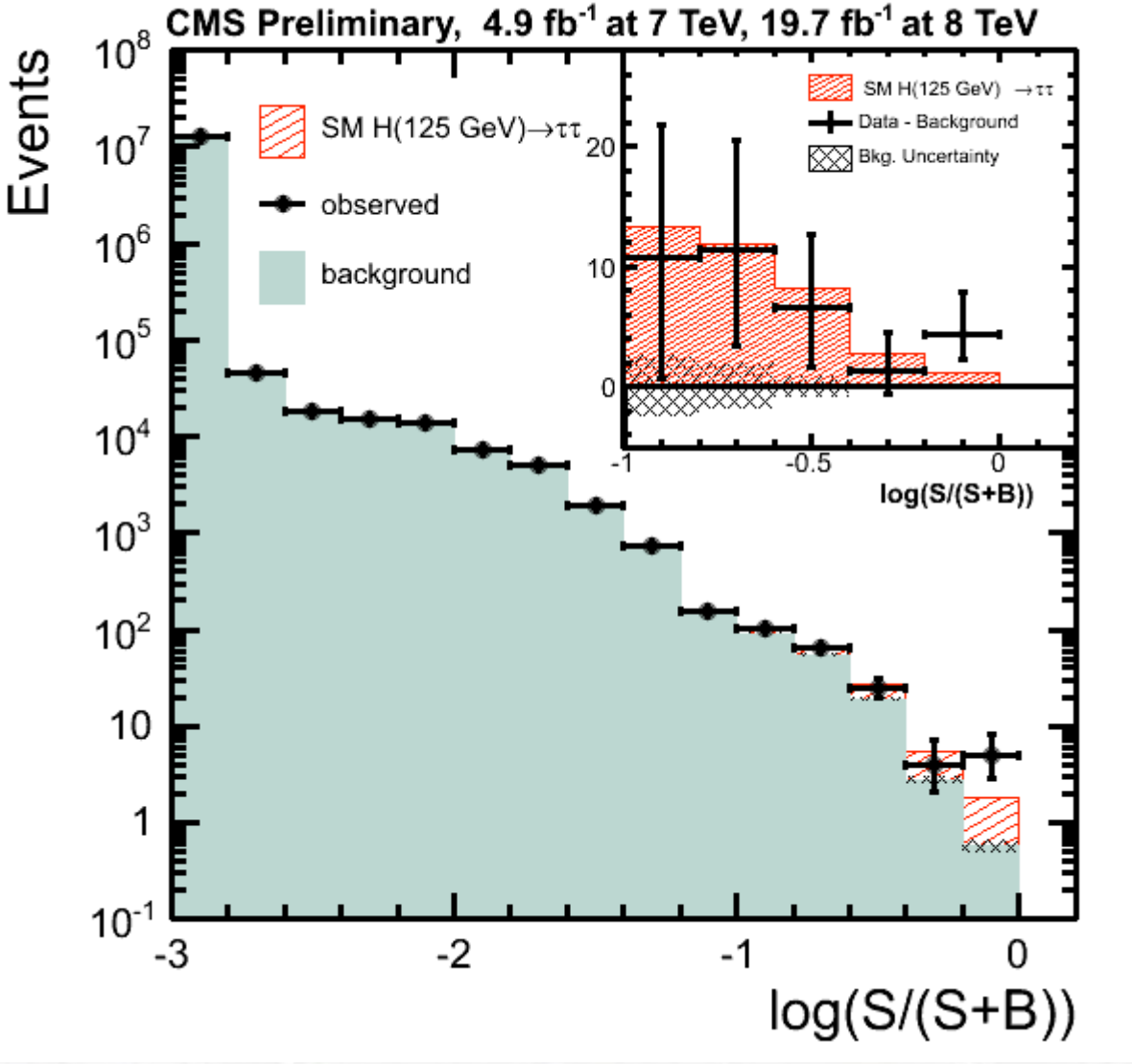




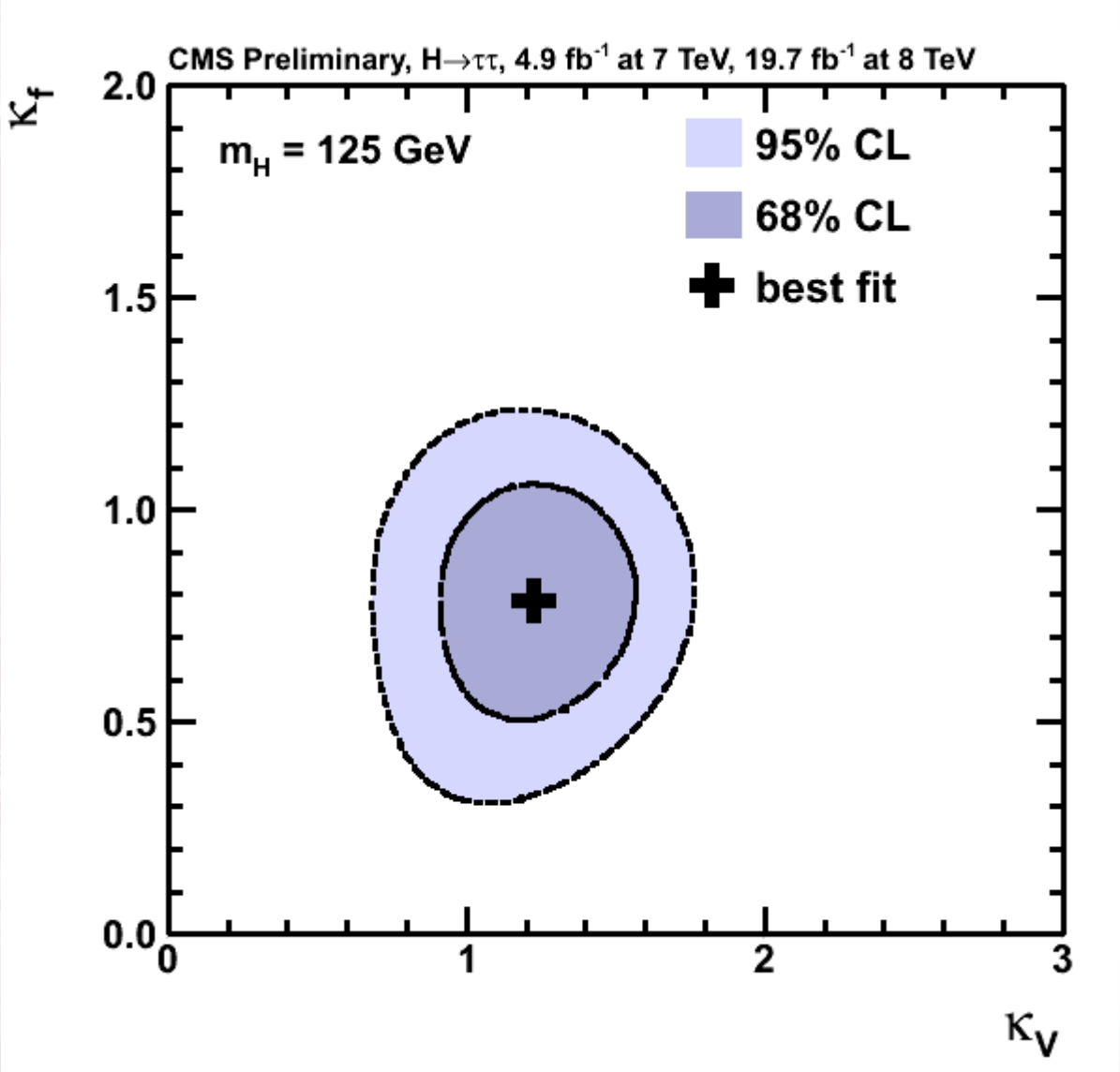


Work in Progress

S/(S+B) plot with all analysis bins



cV-cF



H → WW treated as signal

Contraint in κ_V comes from eμ VBF