Standard Model $H \to \tau\tau$ in CMS

LHC Physics Discussion
June 10, 2013

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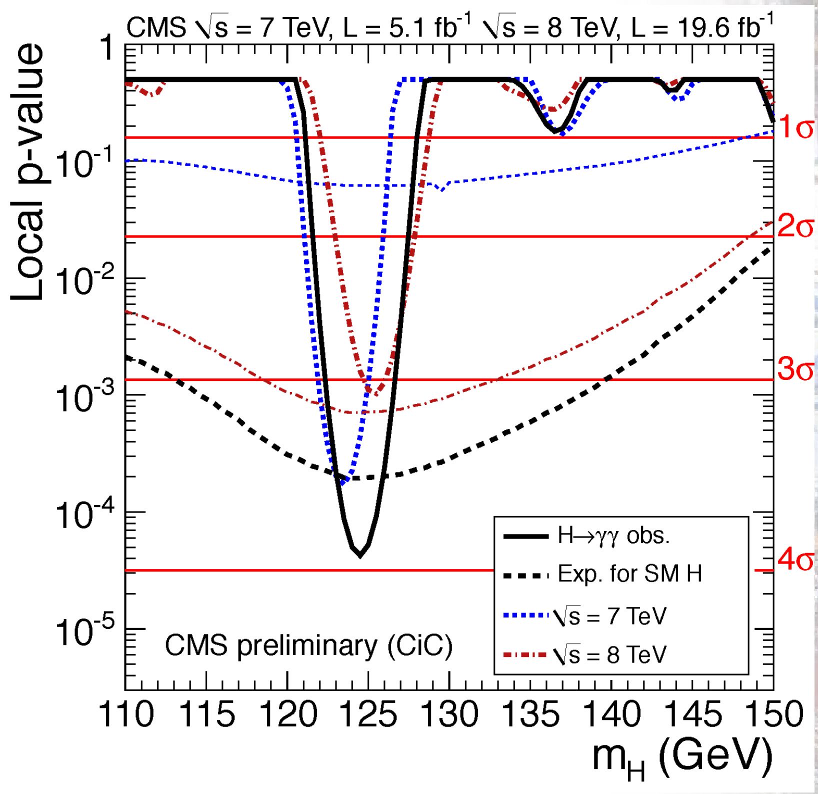
for the DESY Higgs group

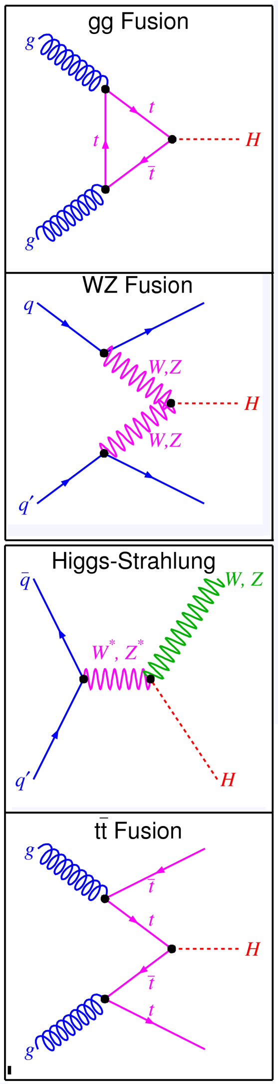
Motivation

- A Higgs has been found at a mass of 125 GeV
  - Signals have been seen in $H \to \gamma\gamma$, $H \to ZZ$, $H \to WW$
- Properties need to be measured!
  - Mass
  - Spin/CP
  - Does it couple to fermions?
    - With the rates predicted by the SM?
  - ...

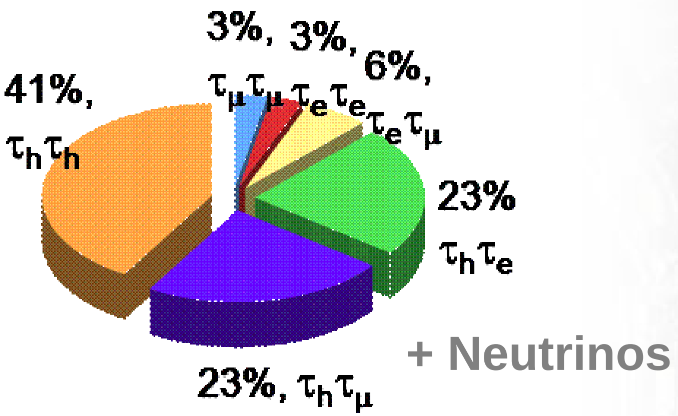
HIG-13-001

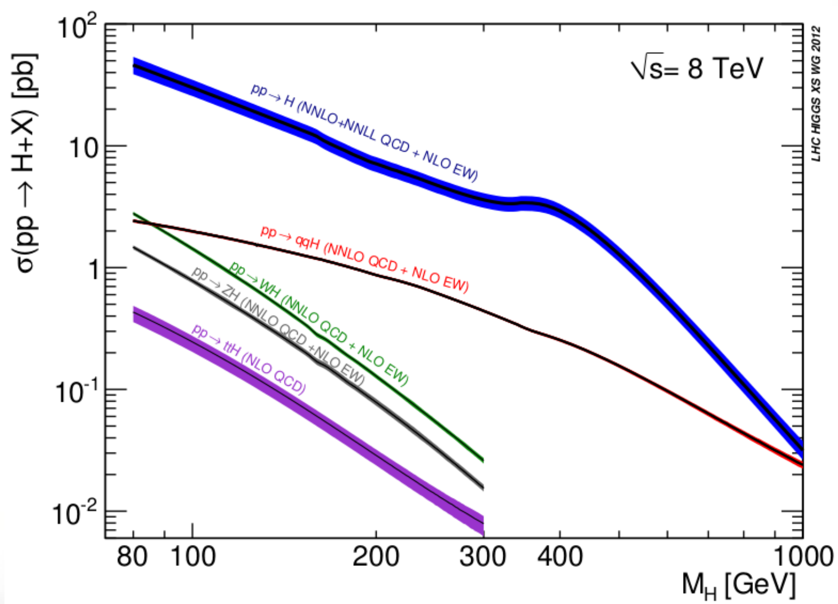


Higgs Production and Decay



ττ





From an Analysis Point of View

- Many different final states!

$$(H, qqH, WH, ZH, ttH) \otimes (ee, e\mu, \mu\mu, e\tau_h, \mu\tau_h, \tau_h\tau_h)$$

= 30 channels!

blue = Preliminary Results published by CMS

- **Many channels** to analyze with
  - Different final states
  - Different backgrounds
  - Different systematics
  - Different sensitivity
- All need to be **combined** for the final result

Analysis Strategy

- Individual analyses differ greatly from channel to channel, but the **basic idea** is the same:
  1. Trigger and Object Selection
  2. Background Rejection
  3. Background Modelling
  4. Event Categorization
  5. Look whether we see a **bump in the di-tau mass**
     - (or in some more complicated MVA discriminant)

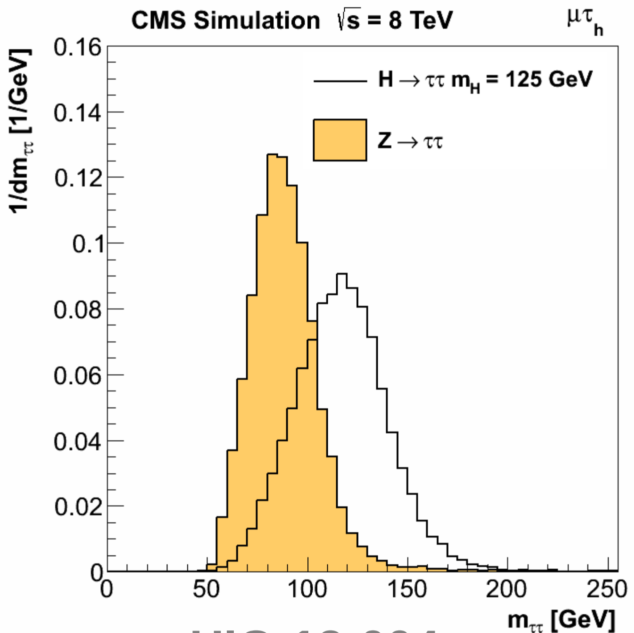
Data analyzed:

$4.9 fb^{-1}$ at $\sqrt{s} = 7$ TeV

$19.4 fb^{-1}$ at $\sqrt{s} = 8$ TeV

Di-τ mass reconstruction

- Undetected neutrinos lead to **underestimation** of the di-τ mass
- Likelihood-based method: Find mass which is **most compatible** with:
  - E_T^{miss} + E_T^{miss} uncertainty (event-by-event)
  - Visible decay products
  - Tau decay matrix element
- Mass resolution: **15-20%**



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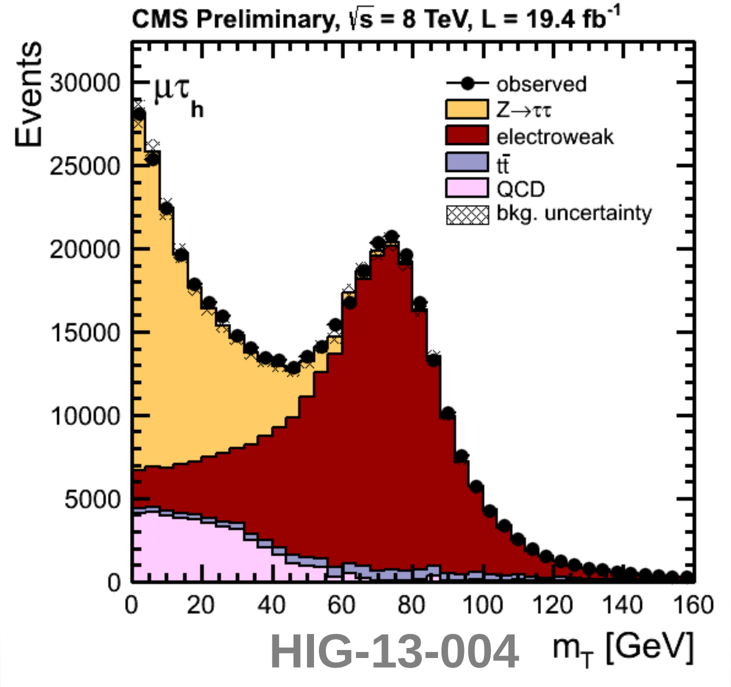
Background Rejection

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



Background Estimation

- **Remaining backgrounds** must be estimated
  - Take as much from **data** as possible, to reduce systematics

Z → ττ:

Normalized to measured Z cross section
Shape from embedded data events

Z → ee/μμ:

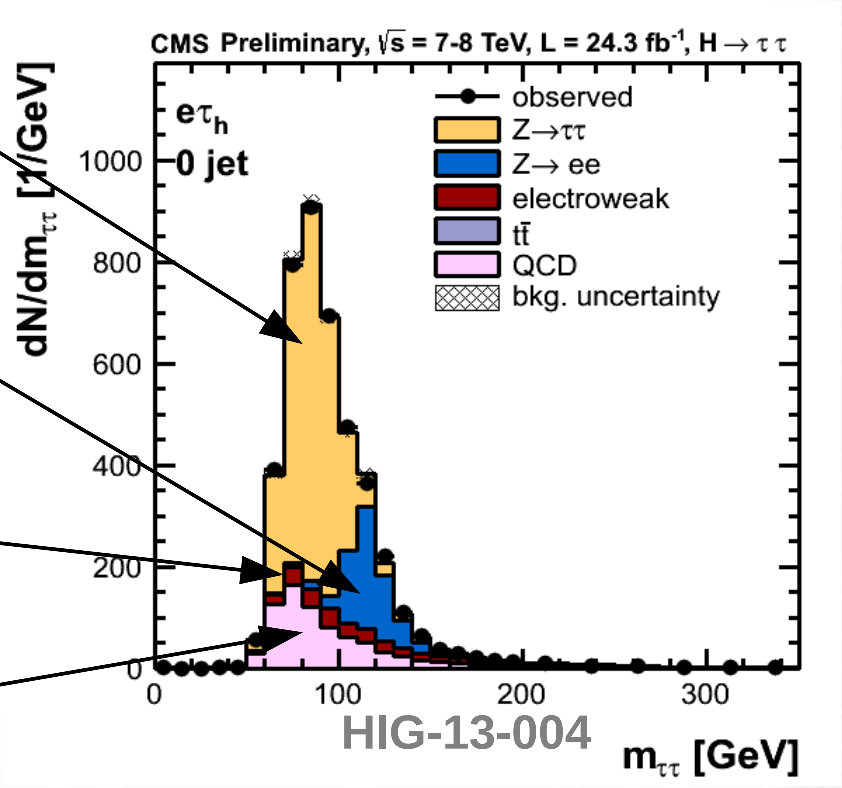
Normalization from fit to data in 0-jet "sideband"
Shape from Simulation

W + Jets:

Normalized to data in high mT sideband
Shape from Simulation

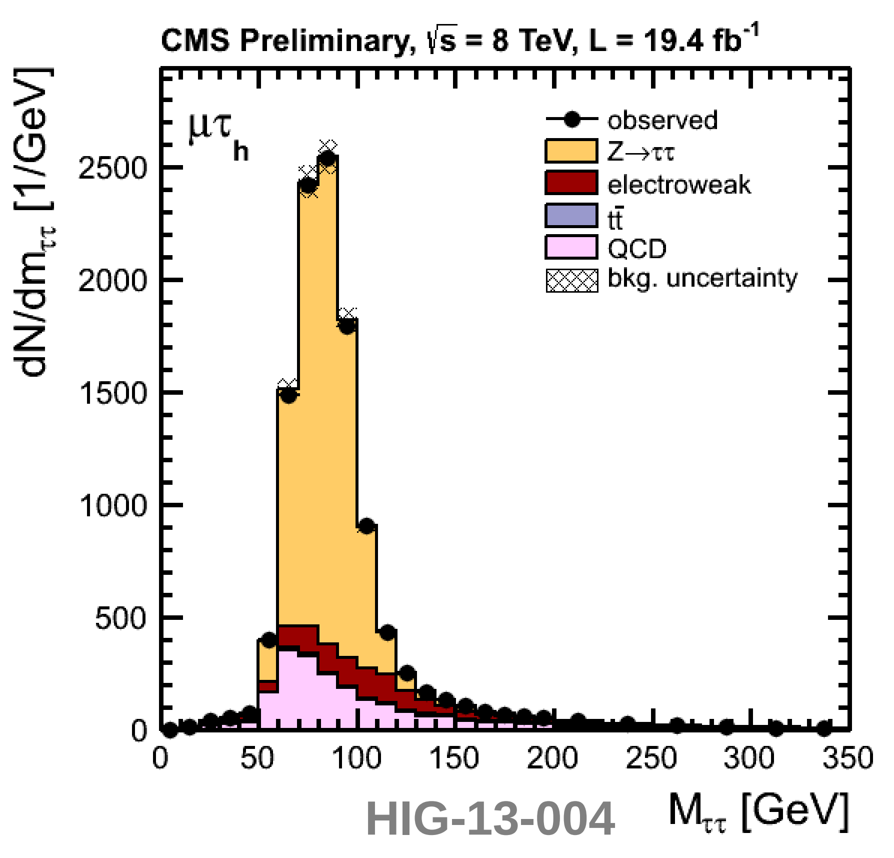
QCD Multijet:

Shape and **Normalization** from Same Sign data



Event Categorization

- Even after background rejection a **substantial fraction** of background remains
- Split events in categories with higher S/B, to improve sensitivity:
  - VBF (ττ + 2 Jets)
  - 1Jet (ττ + 1 Jet)
  - 0Jet (ττ + 0 Jets)



Event Categorization (2)

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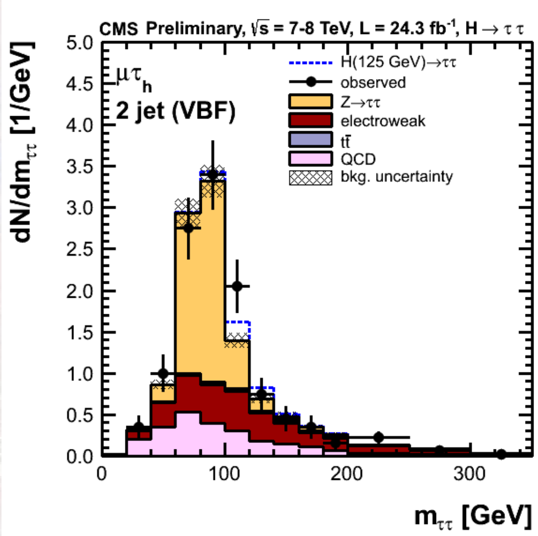
VBF:

M_{jj} > 500 GeV

$|\Delta\eta_{jj}|$ > 3.5

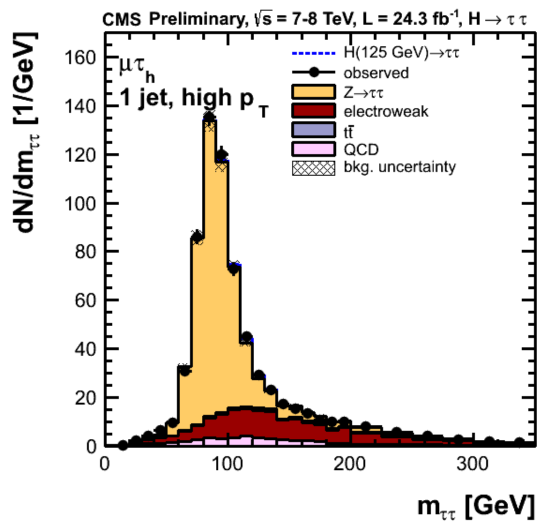


- Low event statistics
- High S/B

1 Jet:

Jet p_T > 30 GeV

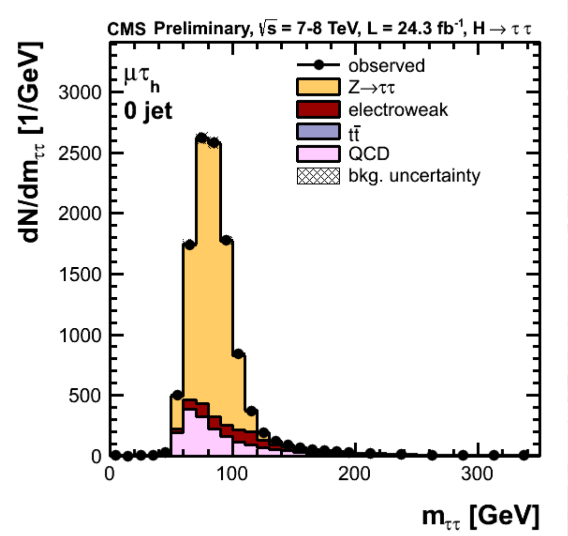
1 τ > 40 GeV



- Exploit boost of the Higgs system:
  - Better mass resolution

0 Jets:

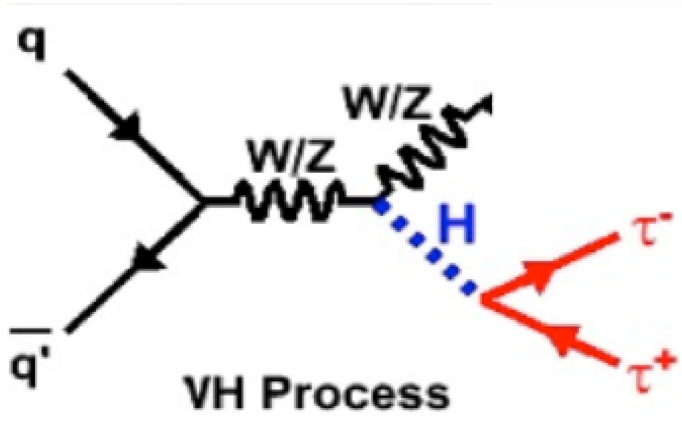
No jet > 30 GeV



- Low S/B
- Important for Constraining Nuisance Parameters

Associated Production

- So far did not talk about: WH, ZH
- More than 2 leptons in the event
- Easy to trigger
- Low SM Background
- But: Low cross section → Low statistics



Individual channels in CMS:

WH: $e\mu\tau_h$, $\mu\mu\tau_h$, $e\tau_h\tau_h$, $\mu\tau_h\tau_h$

ZH: $eee\mu$, $eee\tau_h$, $ee\mu\tau_h$, $ee\tau_h\tau_h$, $e\mu\tau_h\tau_h$, $e\mu\mu\tau_h$, $\mu\mu\tau_h\tau_h$, $\mu\mu\mu\tau_h$

Requires dedicated analysis strategy!

Backgrounds in VH

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

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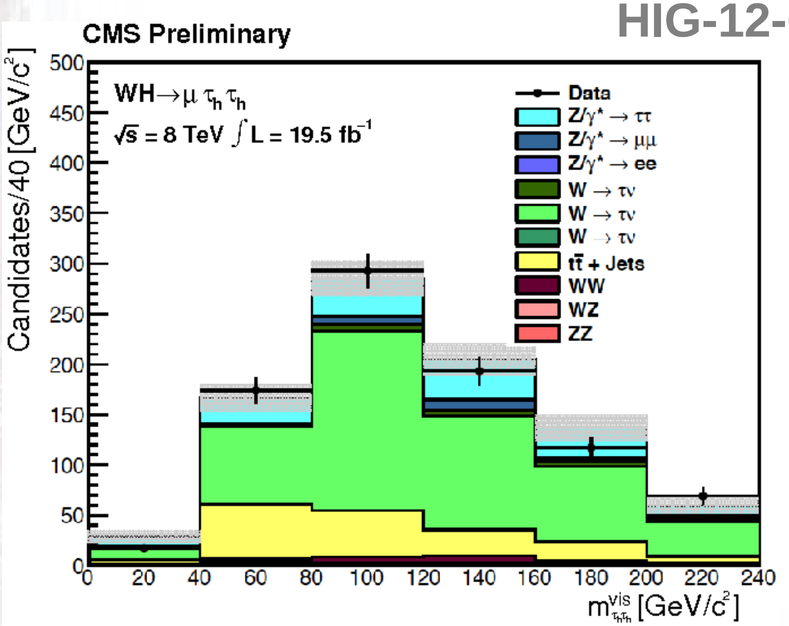

Reducible backgrounds in $\mu\tau_h\tau_h$

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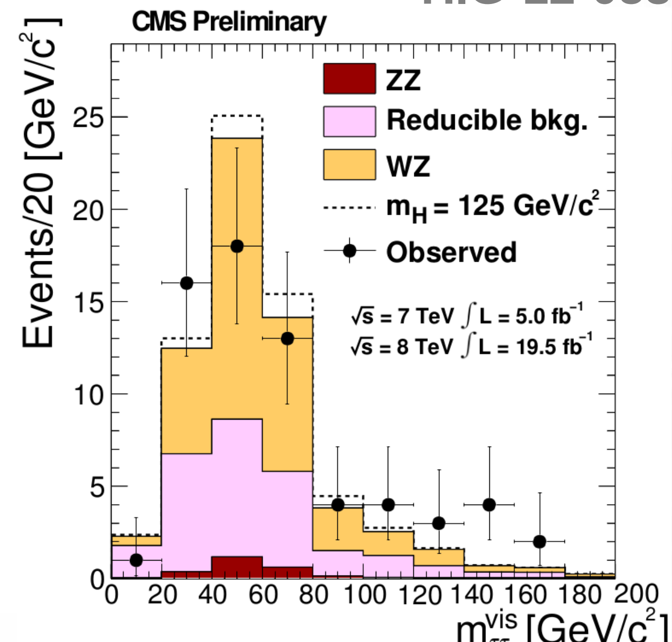

Mass plot in $\mu\mu\tau_h/e\mu\tau_h$

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

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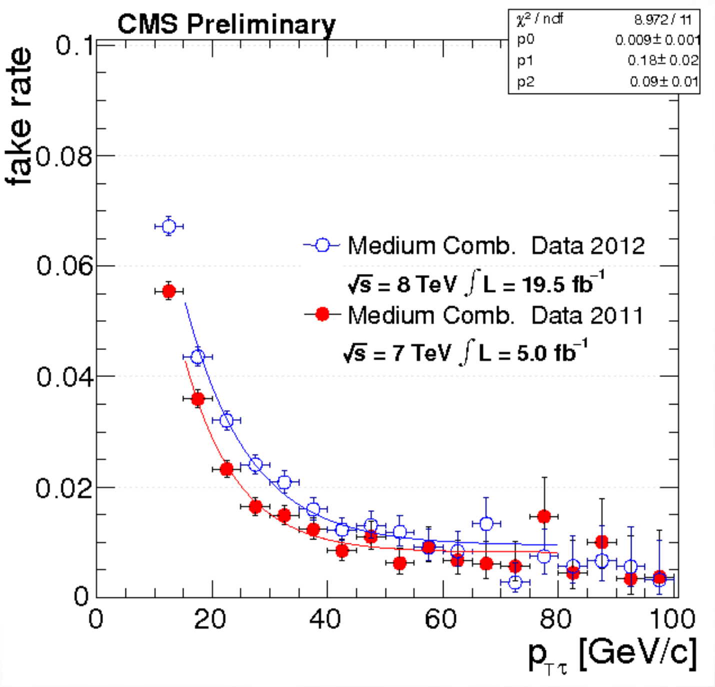

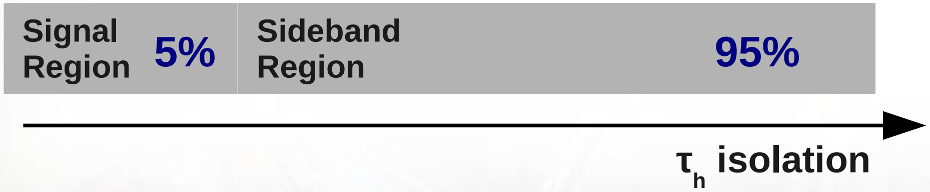

Expected Limit

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

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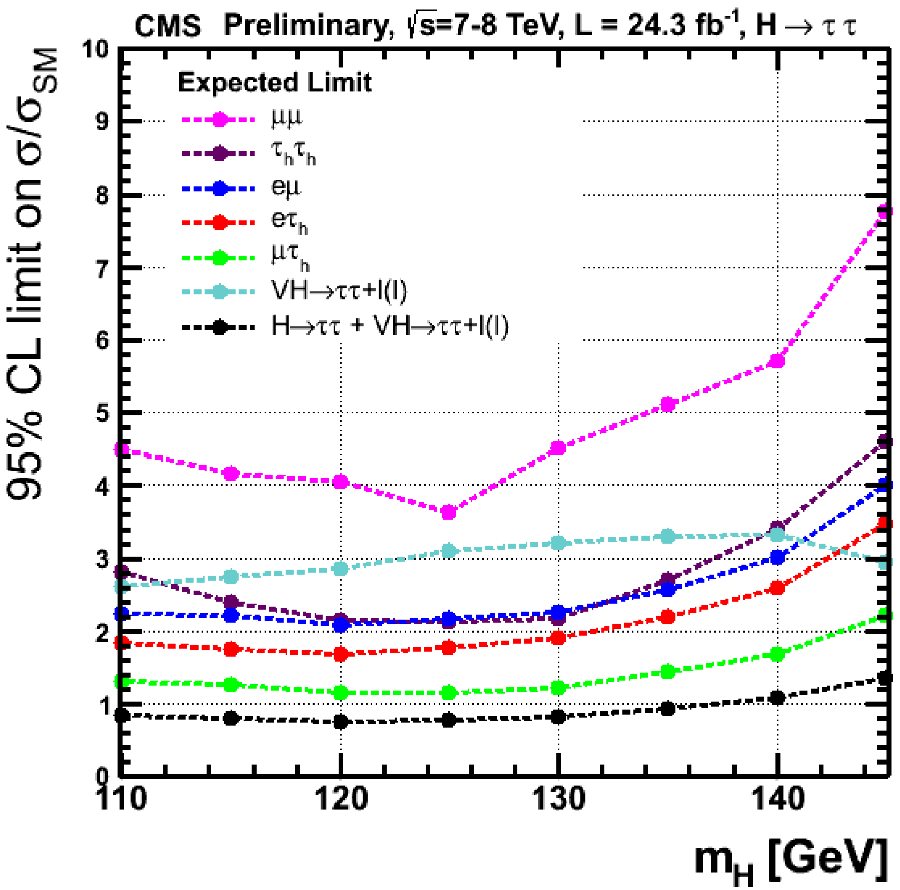
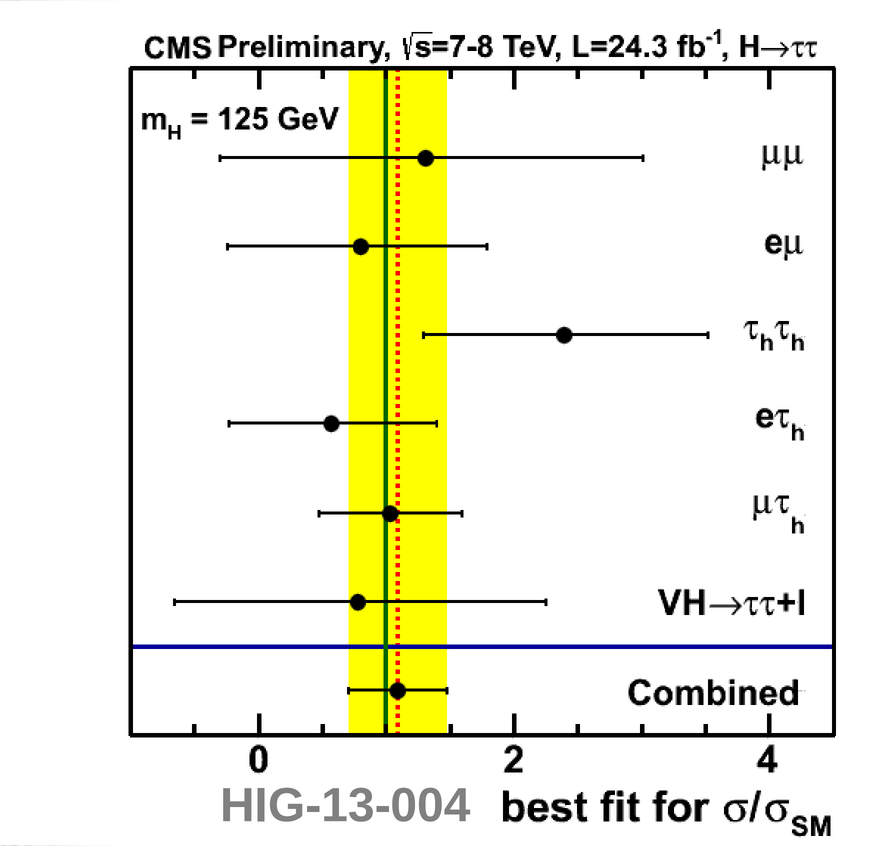
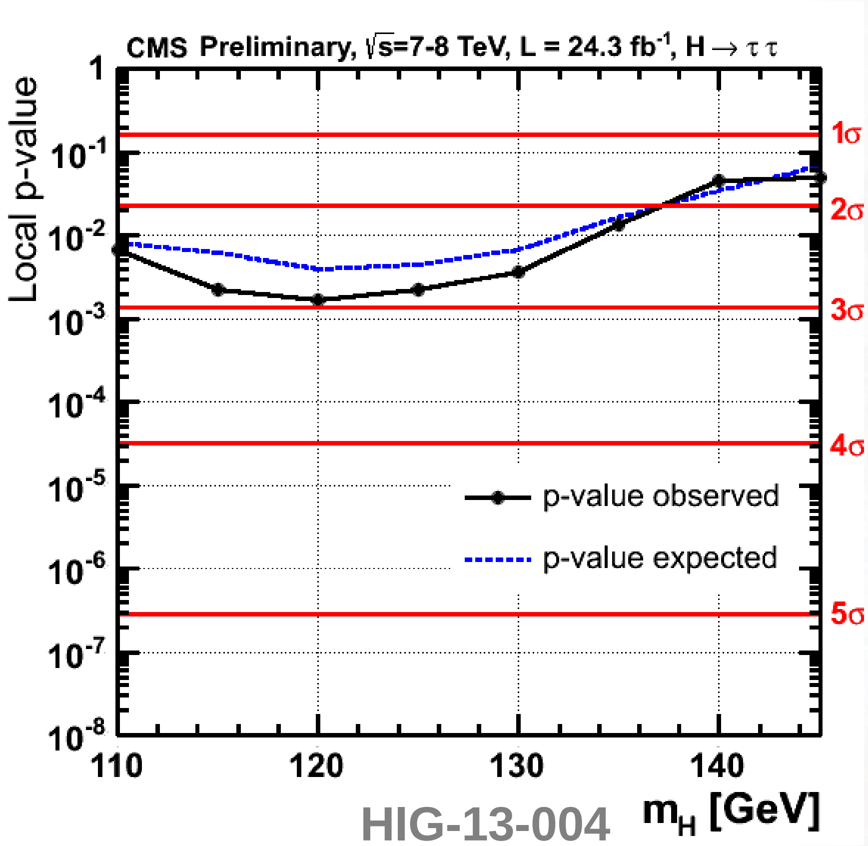


Only combination of channels is sensitive to SM Higgs

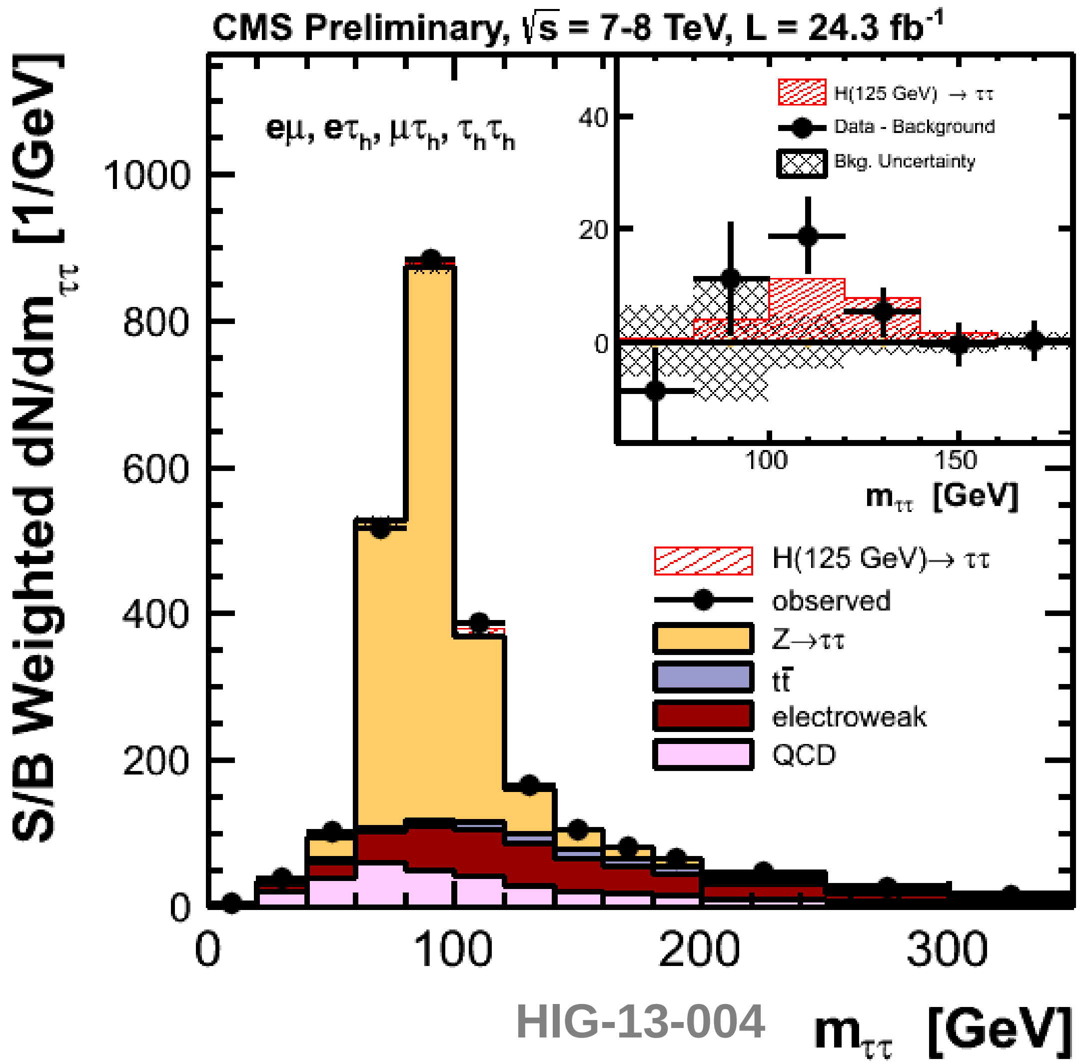
Combined Result





Broad excess with a significance of 2.9σ is observed
Consistent with SM Higgs Hypothesis

The Mass Bump



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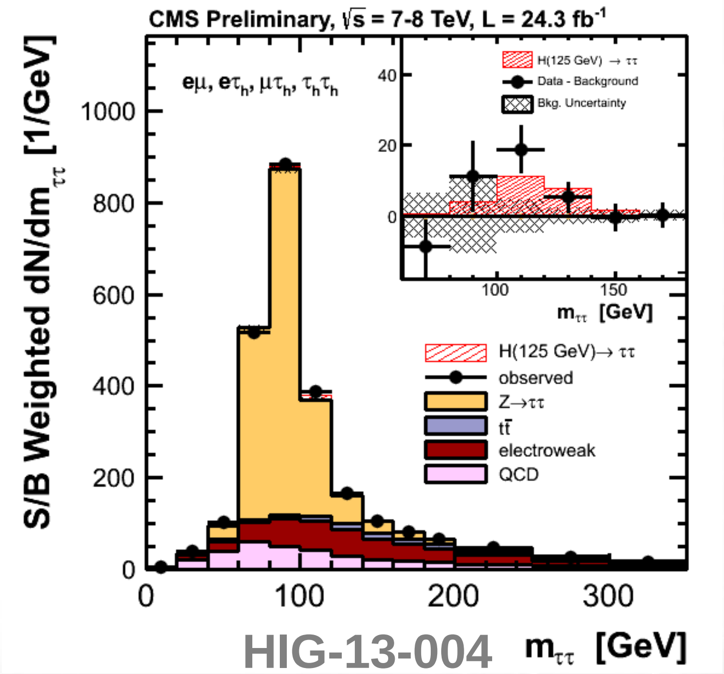
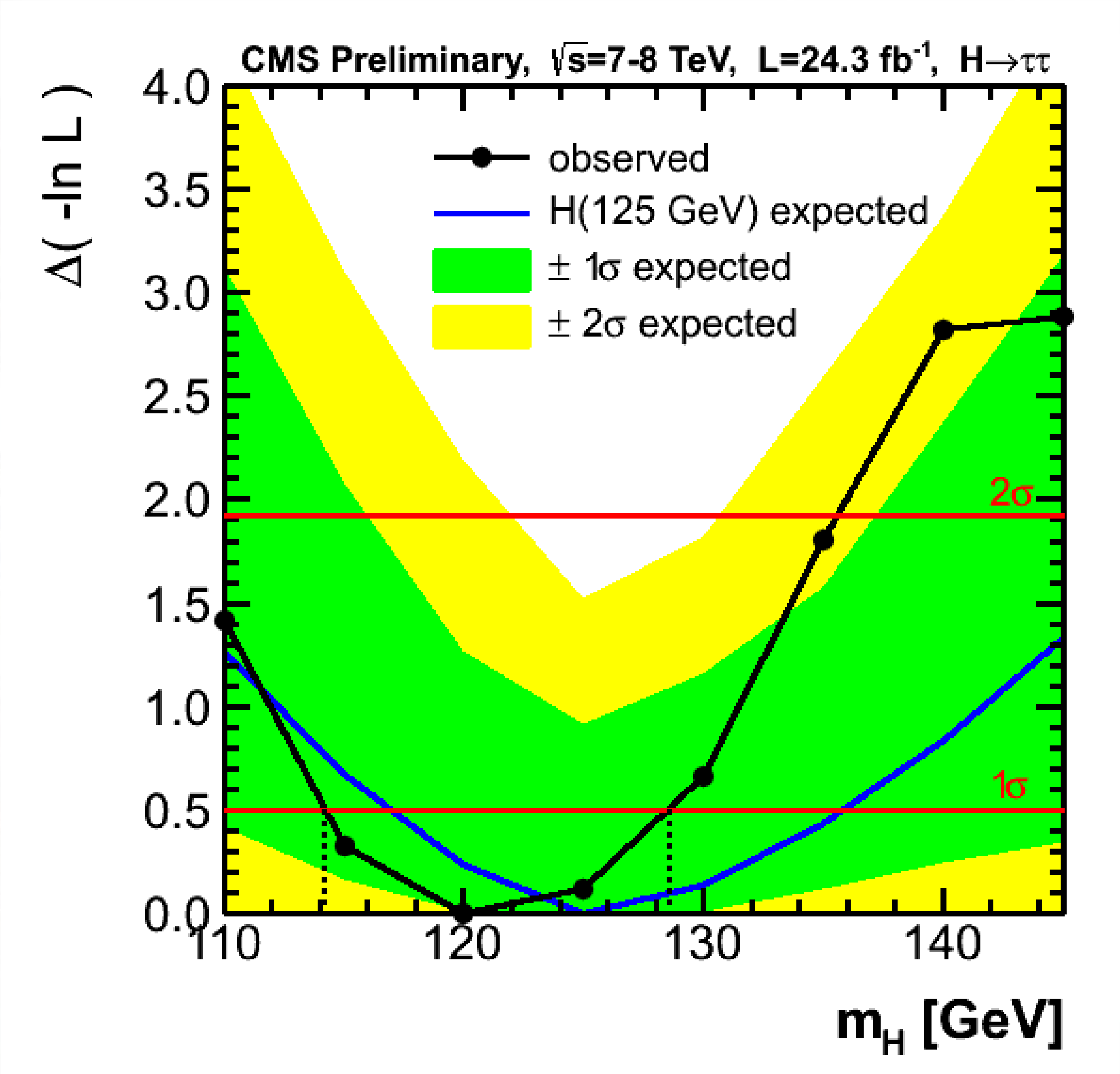
Conclusions

- **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 2.9σ significance!
- Presented results are **Preliminary**
  - Analysis strategy unchanged since HCP
    - Higher statistics allow finer categorization
  - **Final publication** for later this year is in preparation
    - With even more final states analyzed



Backup

Constraint on Higgs Mass

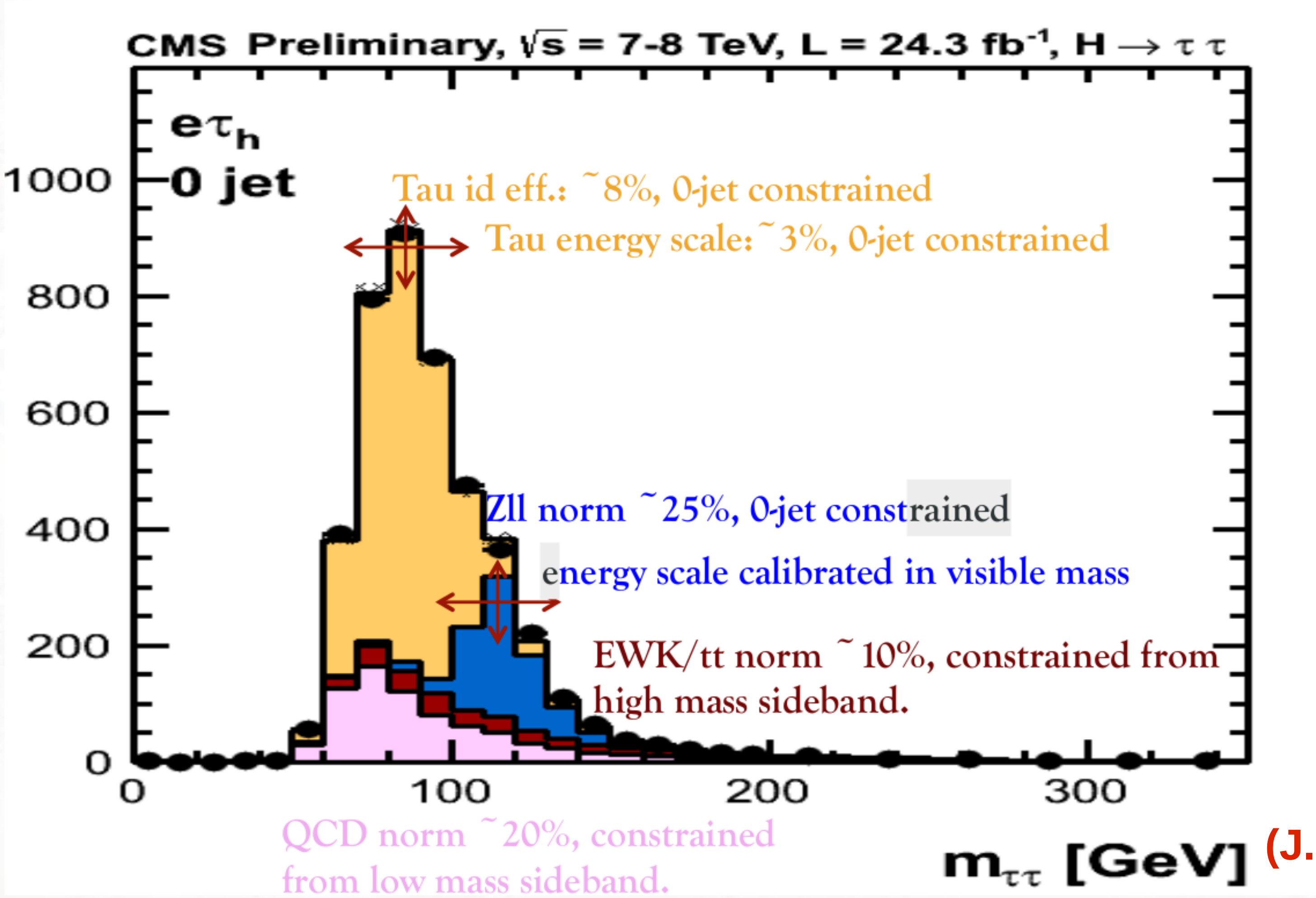


$m_H = 120^{+9}_{-7}$ GeV

(syst. + stat.)

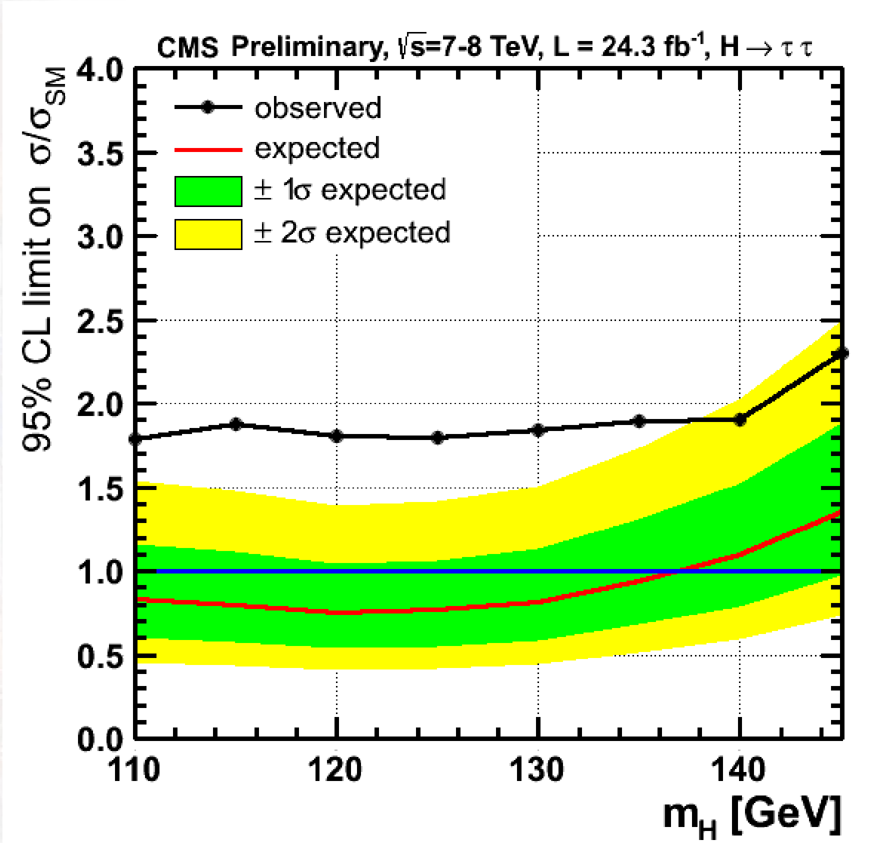
Systematics

on one slide

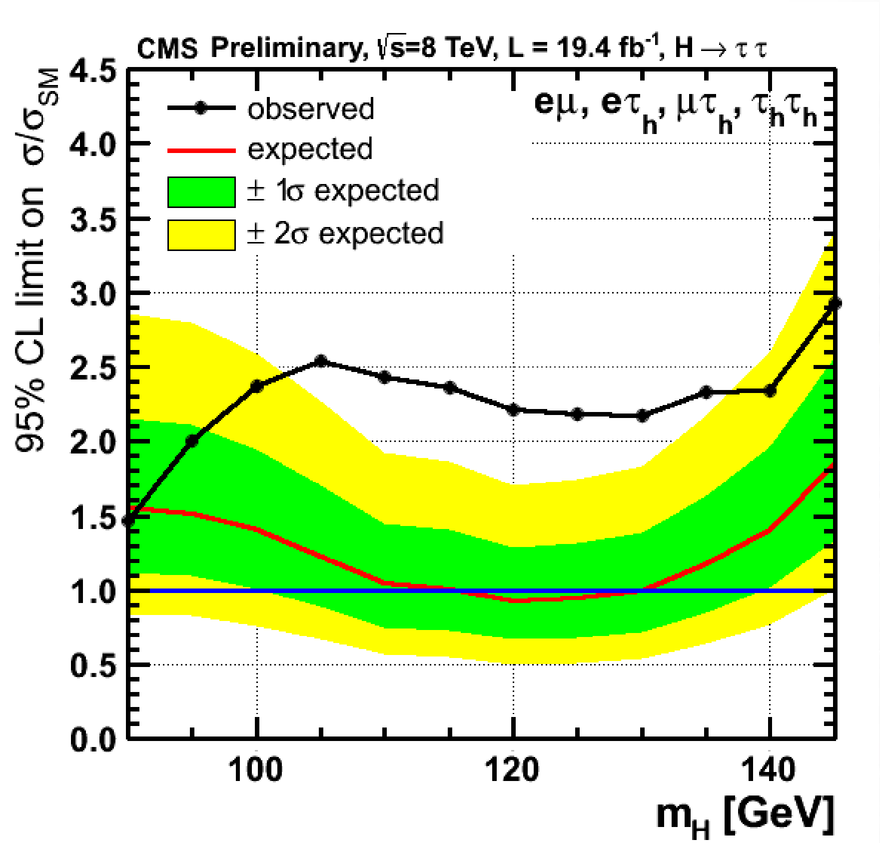


(J. Benitez)

Combined Exclusion Limit



Full combination of all channels



Extended to low mass (8 TeV data and most significant channels only)