H(125) decays to leptons at CMS

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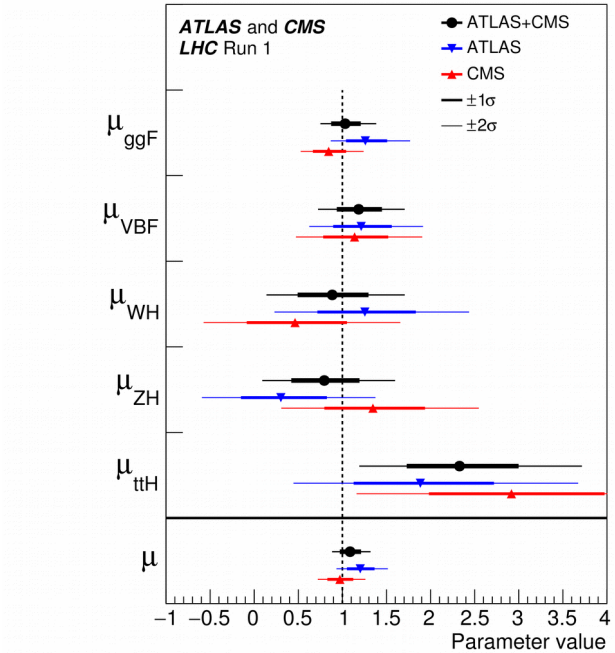
(on behalf of CMS Collaboration)

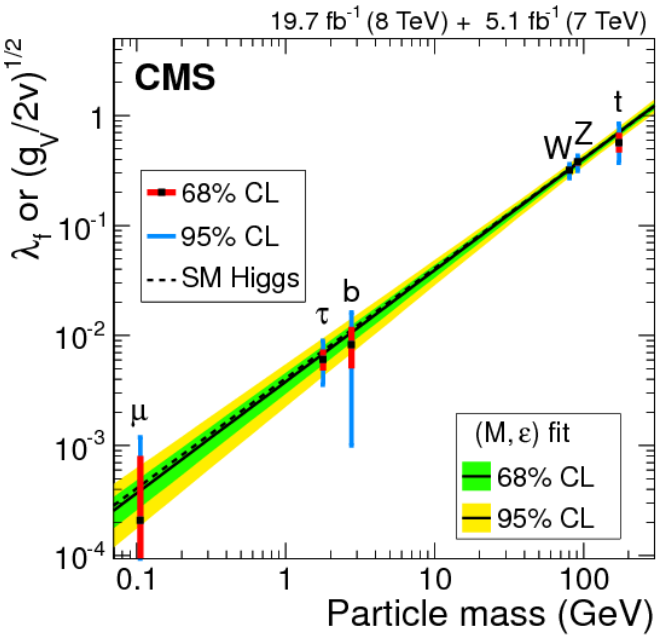
HH Workshop, Orsay 2017/07/24

Leptonic Decays of H(125)

H(125) boson is discovered at 7/8 TeV and rediscovered at 13 TeV

- **at the current level of precision the H(125) properties are consistent with expectations from the SM**
- **But what is the nature of H(125) state?**





Leptonic decays of H(125)

- **probe Yukawa couplings**

  essential for testing mass-coupling relation for fermions

  provide access to CP quantum numbers of H(125)

- **provide directly detectable signatures of new physics**

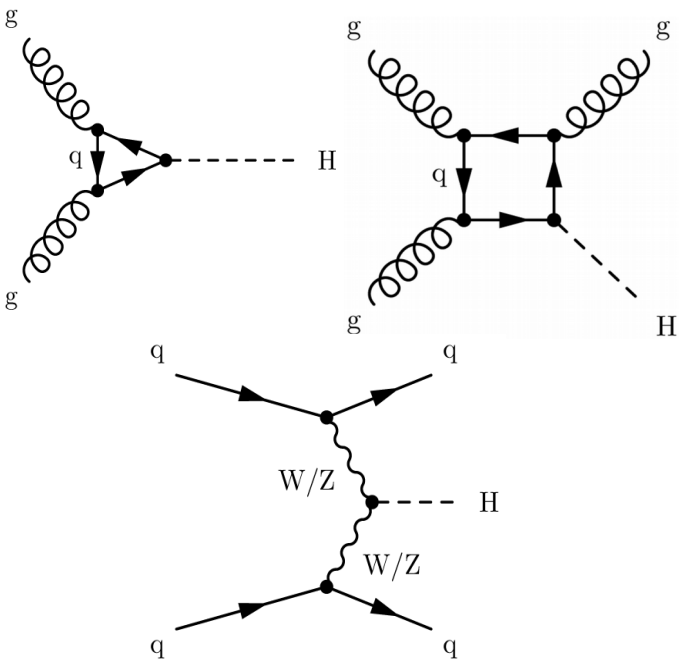
  lepton flavor violating (LVF) decays (covered in separate talk by Fanbo Meng)

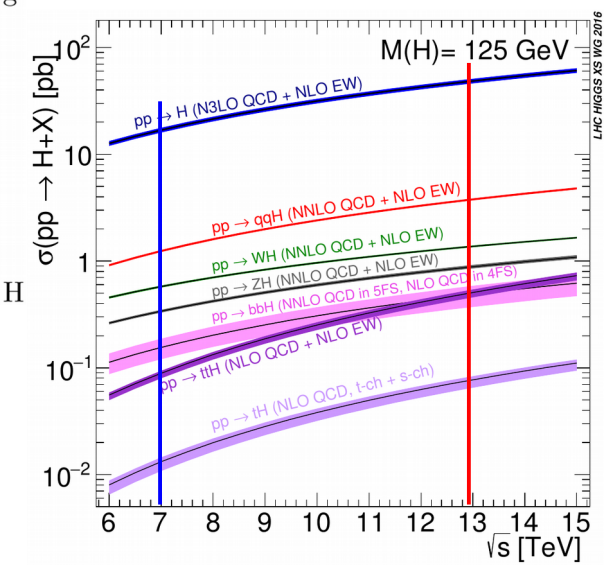
Leptonic decays of H(125) : Results from CMS

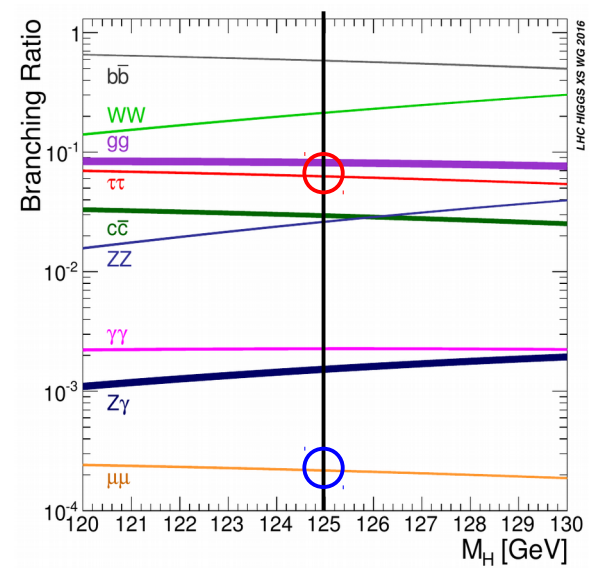
- Main focus on recent results (Run II, 13 TeV)
  - also included results from Run I (7/8 TeV) and projections for the H → μμ search

Analysis	Documentation	Dataset
H → μμ	Phys. Lett. B 744 (2015) 184	Run I, 7/8 TeV (5.0 +19.7 fb^{-1})
H → μμ (projections)	HIG-13-007	14 TeV (up to 1500 fb^{-1})
H → ττ	HIG-16-043	Run II, 35.9 fb^{-1} at 13 TeV

Production modes exploited





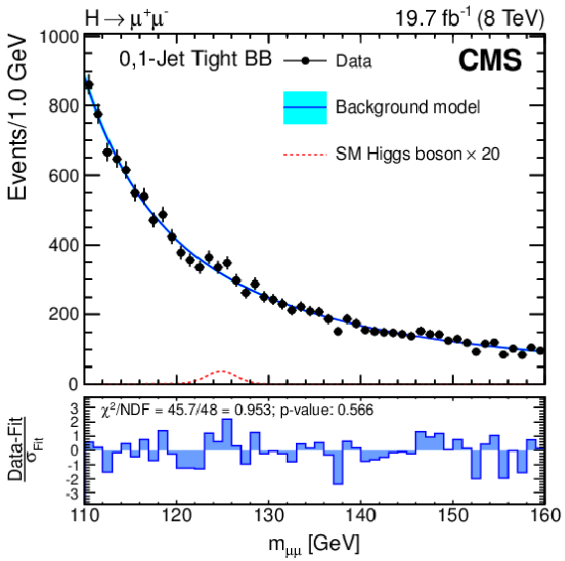


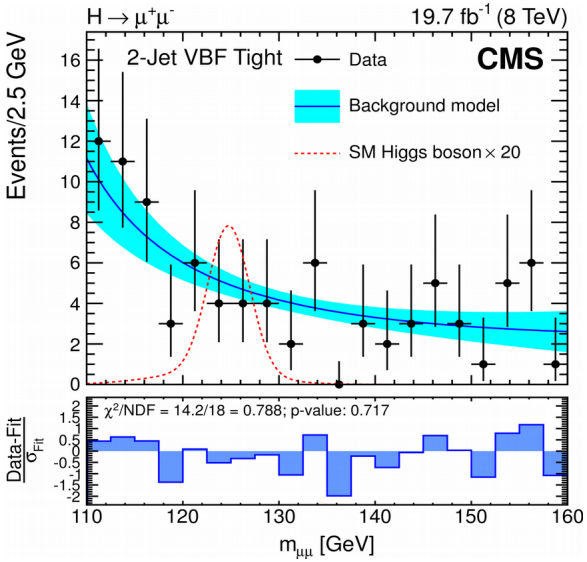
H(125) → μμ

- **access to Yukawa coupling of 2nd generation of fermions**
- **low rate in SM (BR(H → μμ) ≃ 2 x 10^{-4}) but clean signature**

  narrow peak in the $m_{\mu\mu}$ spectrum on top of smoothly falling Z*→μμ background
- **event categorization targeting various production modes**

  based on multiplicity and kinematics of jets accompanying di-muon system
- **further categorization exploiting difference in dimuon mass resolution for muons reconstructed in barrel and endcap**

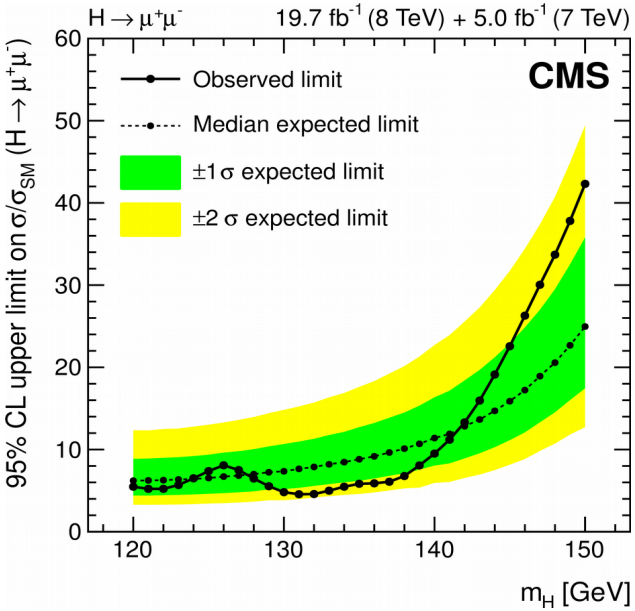




- **Signal extracted by simultaneous fit of the $m_{\mu\mu}$ spectrum in 15 categories**

  maximum-likelihood fit with superposition of analytical parametric functions describing background and signal

H(125) → μμ : Results and Projections



Upper limit on production cross section times BR at m_H = 125 GeV

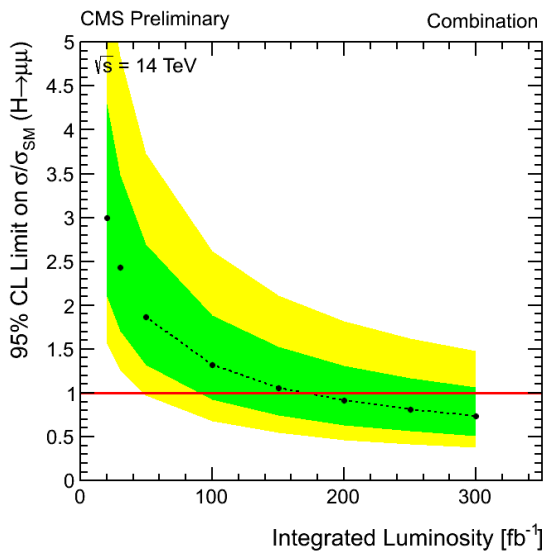
$$\sigma\mathcal{B}/(\sigma\mathcal{B})_{\rm SM} < 7.4 \ (\text{obs.})$$

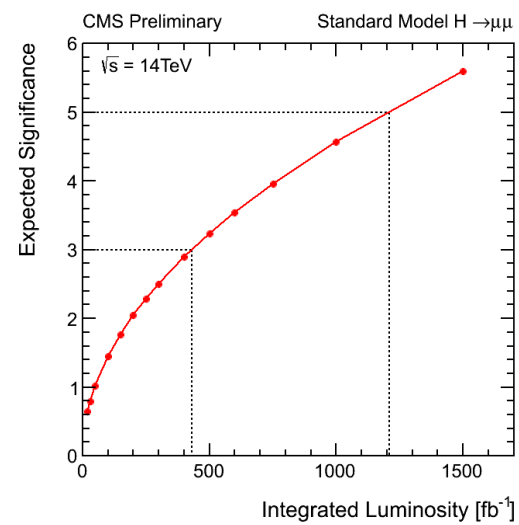
$$\sigma\mathcal{B}/(\sigma\mathcal{B})_{\rm SM} < 6.5 \ (\text{exp.})$$

Fitted value of the signal strength

$$\sigma/\sigma_{\rm SM} = 0.8^{+3.5}_{-3.4}$$

Projections for the H → μμ search





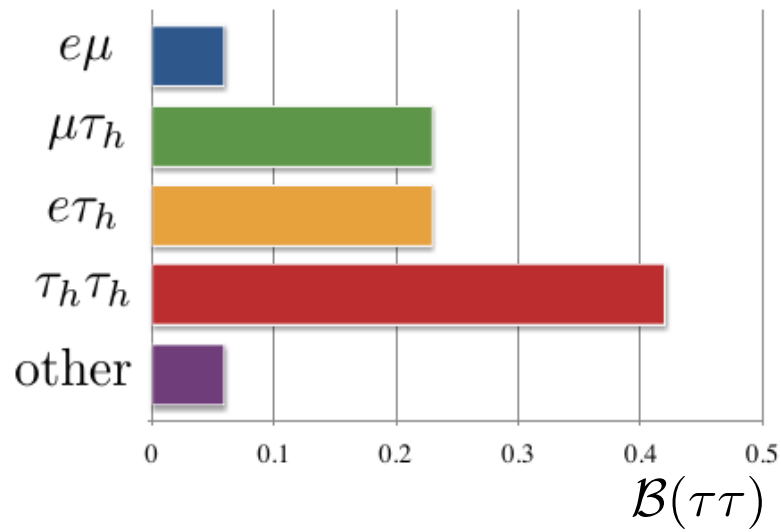
H(125) → ττ

- **second largest branching ratio (BR(H→ττ)=6.3%) among fermionic decays**
- **lower background compared to H → bb**
- **4 final states considered, accounting for 94% of all ττ decays**

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

- **3 event categories targeting different production mechanisms**

  0-jet, VBF, Boosted

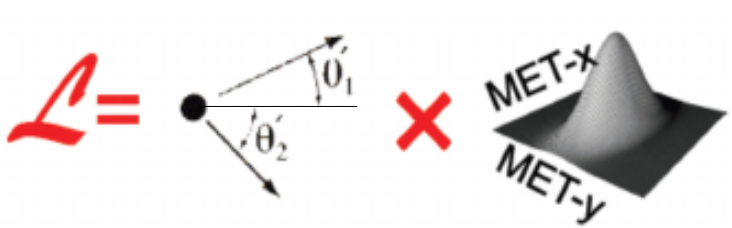


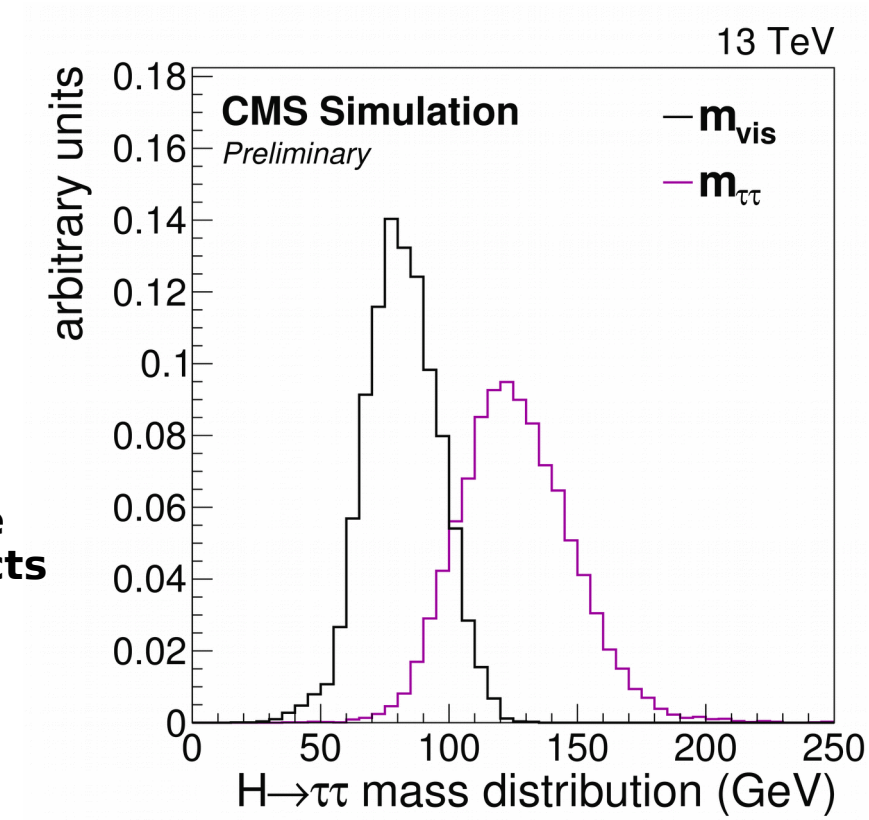
- **In all categories but one signal is extracted from 2-dimensions**

	Selection		
	0-jet	VBF	Boosted
$e\mu$	No jet	2 jets, $m_{jj} > 300$ GeV	Others
$\mu\tau_h$	No jet	≥ 2 jets, $m_{jj} > 300$ GeV, $p_T^{\tau\tau} > 50$ GeV, $p_T^{\tau_h} > 40$ GeV	Others
$e\tau_h$	No jet	≥ 2 jets, $m_{jj} > 300$ GeV, $p_T^{\tau\tau} > 50$ GeV	Others
$\tau_h\tau_h$	No jet	≥ 2 jets, $p_T^{\tau\tau} > 100$ GeV, $\Delta\eta_{jj} > 2.5$	Others
	Variables used for the signal extraction		
$e\mu$	p_T^{μ}, m_{vis}	m_{jj}, $m_{\tau\tau}$	$p_T^{\tau\tau}$, $m_{\tau\tau}$
$\mu\tau_h$	τ_h decay mode, m_{vis}	m_{jj}, $m_{\tau\tau}$	$p_T^{\tau\tau}$, $m_{\tau\tau}$
$e\tau_h$	τ_h decay mode, m_{vis}	m_{jj}, $m_{\tau\tau}$	$p_T^{\tau\tau}$, $m_{\tau\tau}$
$\tau_h\tau_h$	$m_{\tau\tau}$	m_{jj}, $m_{\tau\tau}$	$p_T^{\tau\tau}$, $m_{\tau\tau}$

Di-tau Mass Reconstruction

- **Fully reconstructed di-tau mass is key variable discriminating signal against dominant Z → ττ background**
- **Reconstruction of** $m_{\tau\tau}$ **with dynamic likelihood algorithm**
- **Inputs :** $\vec{p}_{\tau_1}, \quad \vec{p}_{\tau_2}, \quad \vec{p}_{\mathrm{mis}}, \quad \mathrm{cov}(\vec{p}_{\mathrm{mis}})$
- **Estimate of** $m_{\tau\tau}$ **is obtained by maximizing likelihood combining**
  - **matrix elements of tau decays**
  - χ^2 **of** $\vec{p}_{\mathrm{mis}}$ **measurement**

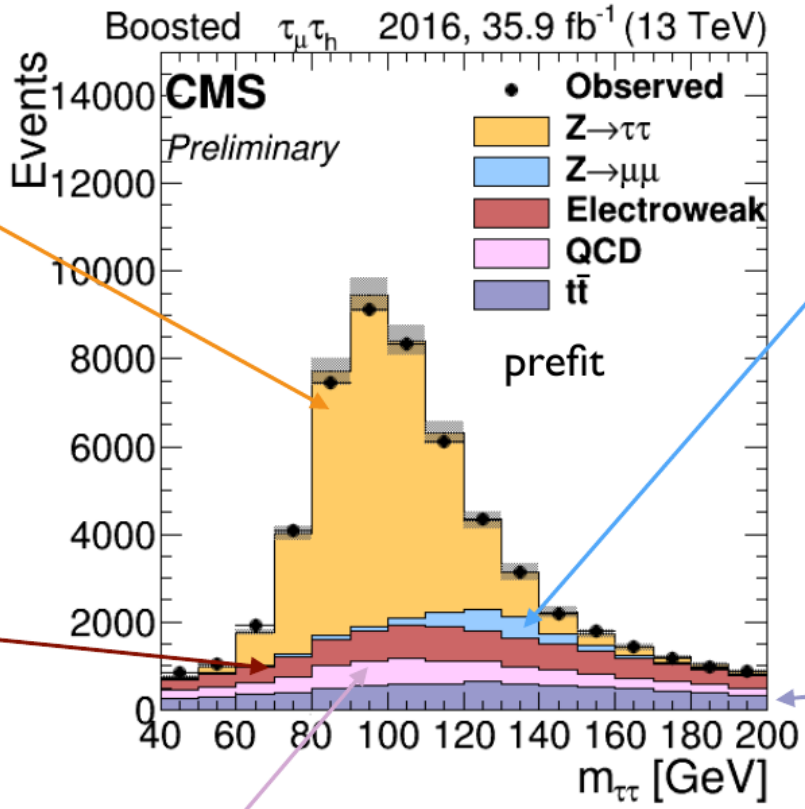




- **Better separation of H → ττ signal and Z → ττ background compared to the invariant mass of visible τ decay products**
  - **the peak position is shifted to the nominal value of resonance mass**
  - **mass resolution : 15-20%**

Background estimation

$Z \to \tau\tau$:
simulation corrected for Z boson kinematics and kinematics of accompanying jets (corrections are derived from $Z \to \mu\mu$ control region)



$Z \to \ell\ell$ with ℓ faking τ_h :
simulation corrected for Z boson and jet kinematics (corrections derived from $Z \to \mu\mu$ control region), additional corrections for $\ell \to \tau_h$ fake rate

W+Jets and VV :
shape estimated from simulation, normalization is determined from high-m_T sideband

QCD multijets :
shape and normalization are estimated from sideband regions (same-sign lepton pairs, relaxed lepton identification/isolation)

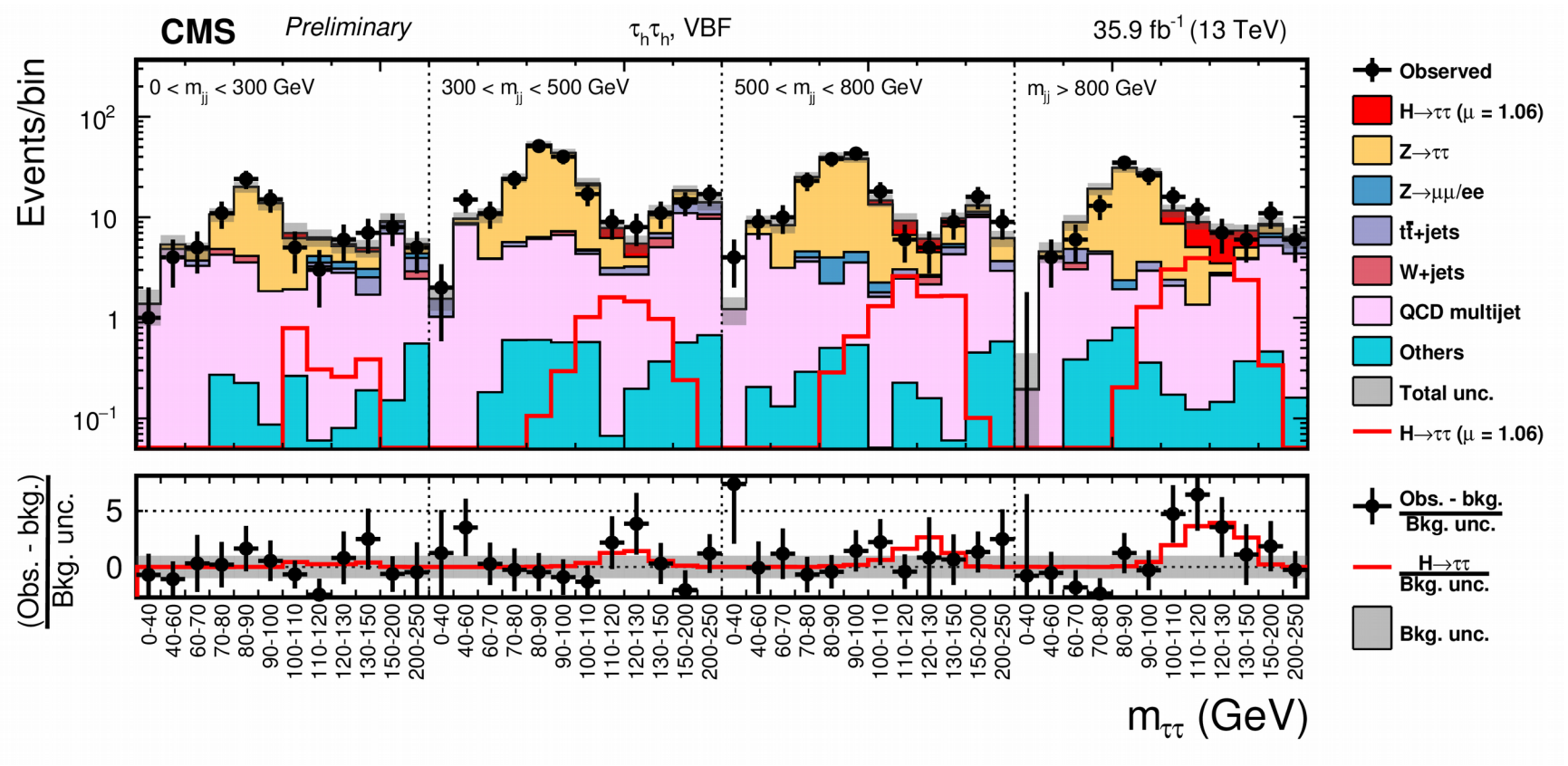
$t\bar{t}$ production :
shape estimate from simulation with corrections for top p_T distributions, dedicated control region in $e\mu$ channel is used to constrain normalization

Signal Extraction

- **Signal is extracted by simultaneous maximum-likelihood fit in 12 channels**

  4 final states ($e\mu$, $e\tau_h$ $\mu\tau_h$, $\tau_h\tau_h$) x 3 event categories (0-jet, VBF, Boosted)

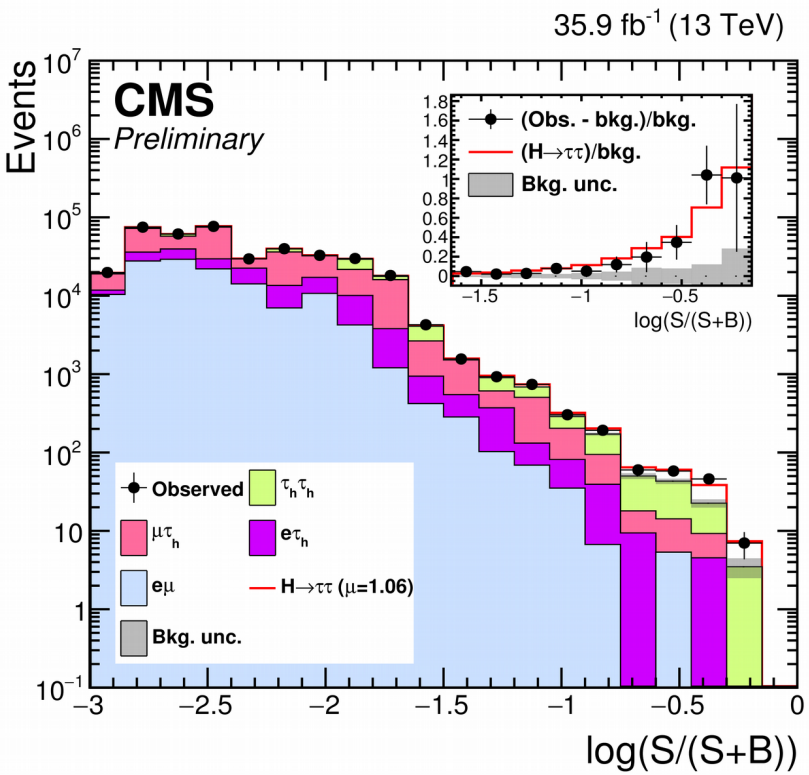
- **Representative example of unrolled postfit 2D distribution : VBF $\tau_h\tau_h$**

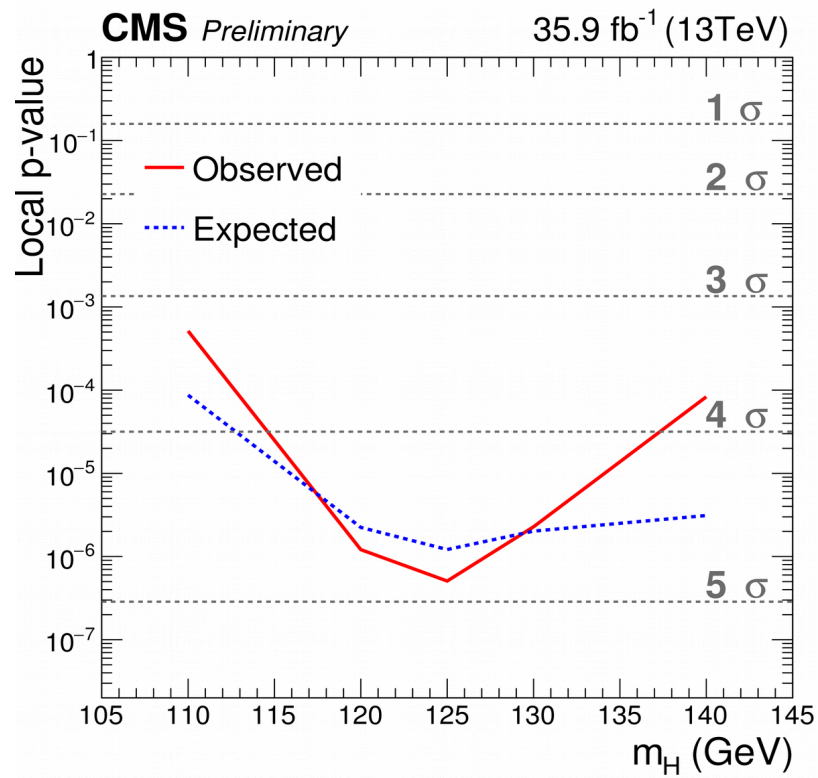


Observation of H → ττ Decays

- **Distribution of event yield in the analysis bins ordered by S/(S+B)**

→ **clearly visible excess in data w.r.t. background-only expectation**



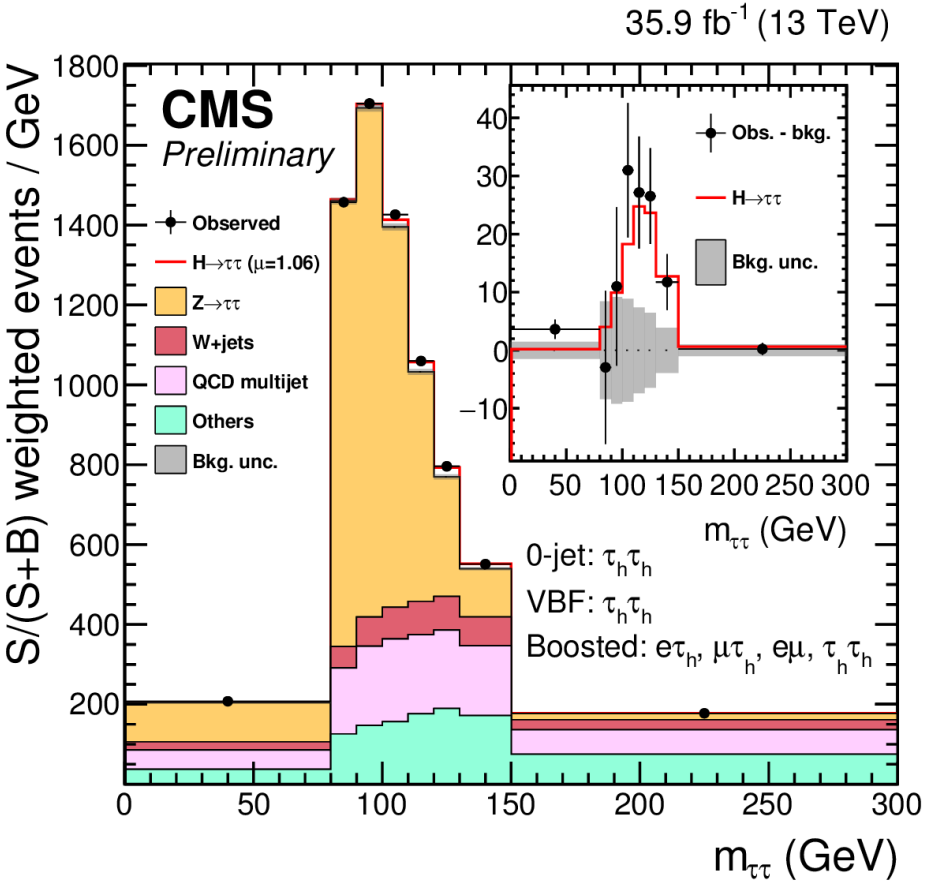


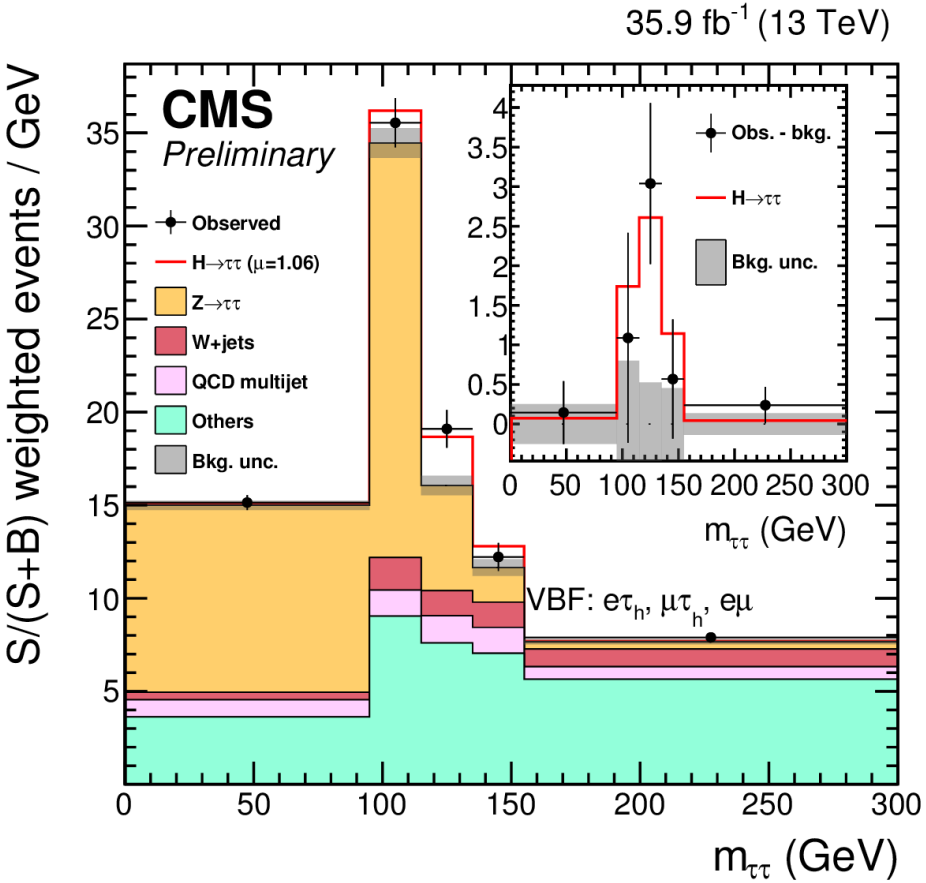
- **obs. (exp.) significance at m_H = 125 GeV**
- $4.9\sigma \quad (4.7\sigma)$ **with Run II data only**
- **Combination with Run I CMS data yields**

$$5.9\sigma \quad (5.9\sigma)$$

- **first observation of Yukawa coupling in single fermionic decay channel at CMS**

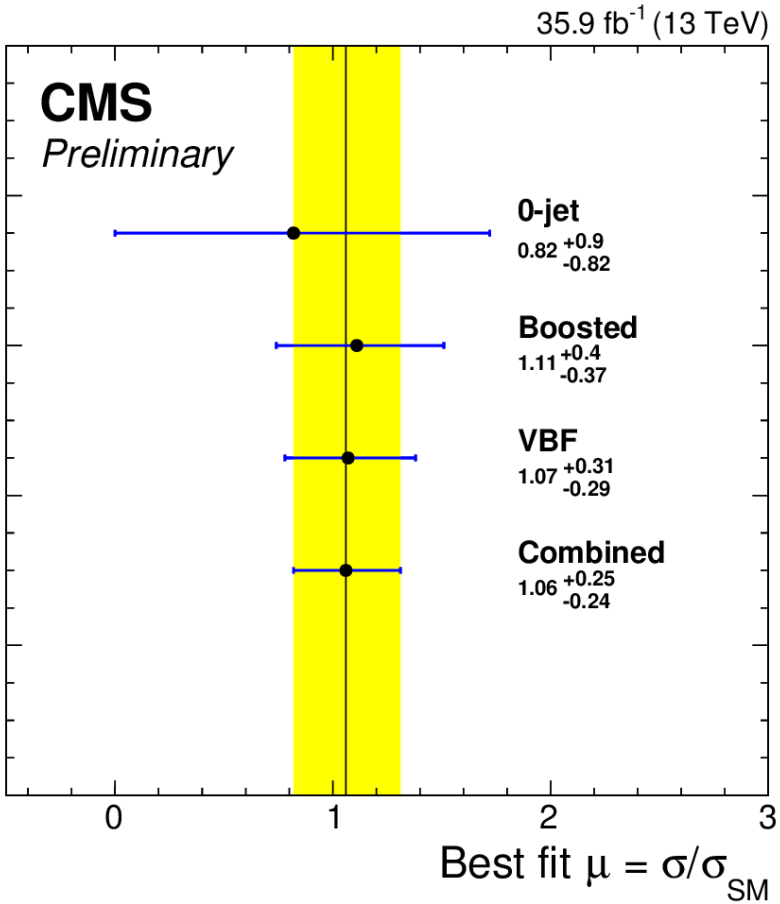
Visualization of signal : $m_{\tau\tau}$ distribution

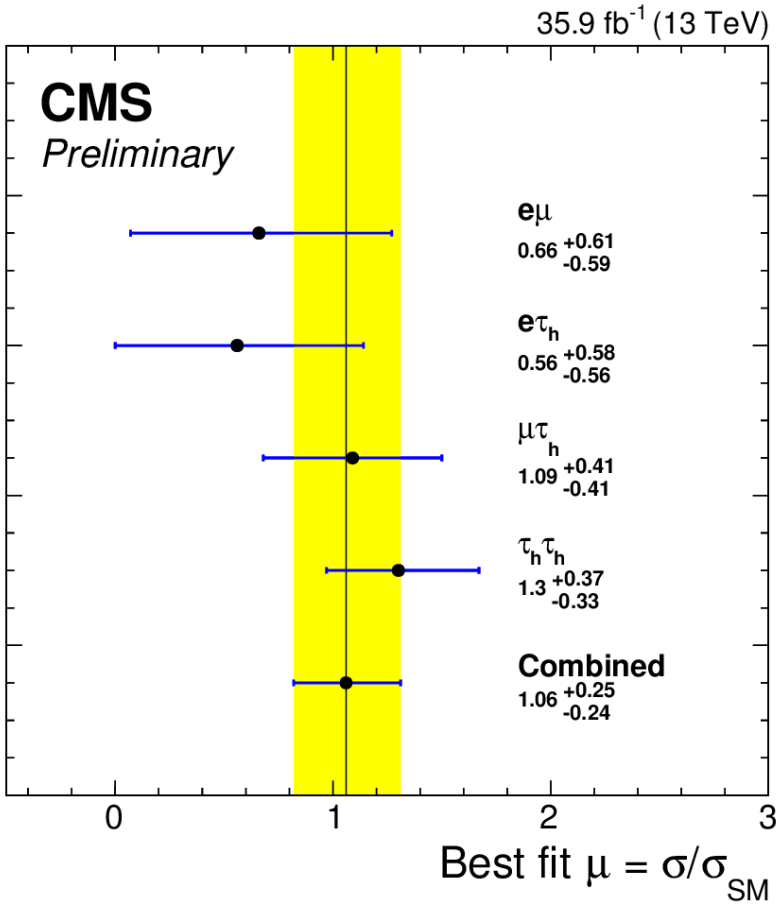




- **Events are weighted by S/(S+B) in bins of second variable of 2D distributions → unbiased mass spectrum**
- **Signal is clearly visible in the distribution of physical observable $m_{\tau\tau}$**

Measurement of the signal strength





- Measurements performed for different production modes and in different final states are compatible with each other and with the expectation for the SM Higgs boson

Measurement of couplings

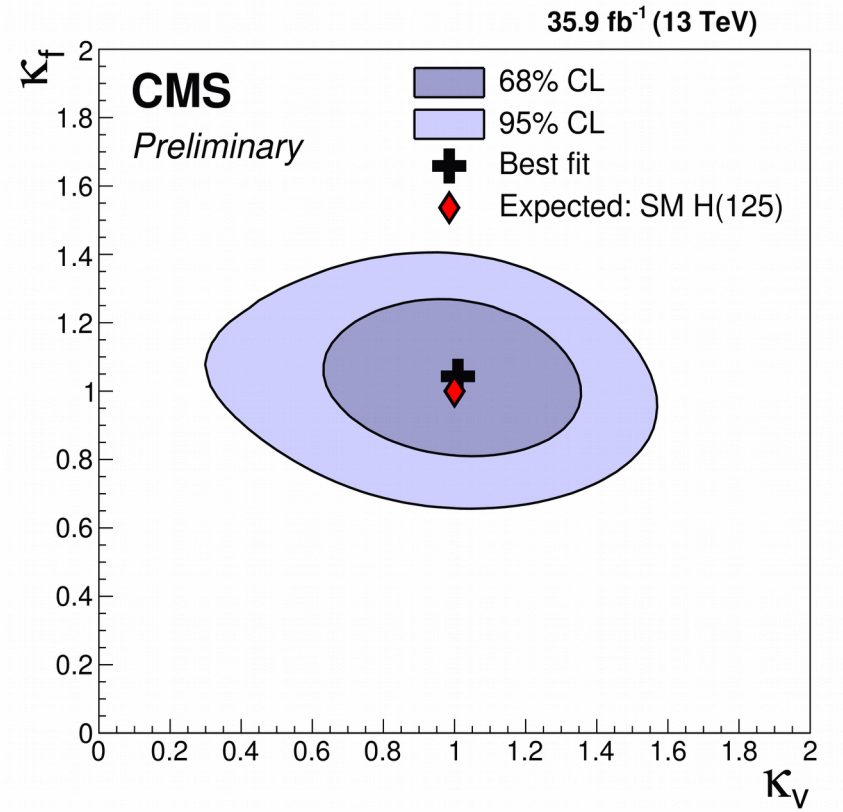
- probing universal coupling modifiers

$$\kappa_f = \frac{g_{Hf\bar{f}}}{g^{SM}_{Hf\bar{f}}}$$

affects gg → H and ttH production rates and H → bb/ττ decay rates

$$\kappa_V = \frac{g_{HVV}}{g^{SM}_{HVV}}$$

affects VBF and VH production rates and H → VV decay rates



- Contribution of VH is added but not targeted with specific category
- Contribution from H → WW (significant in eμ channel, sub-dominant in other channels) is treated as signal
- Measurement of couplings is compatible with SM expectation

Summary

- **H(125) → ττ decay is observed with statistical significance of ~5.9 σ combining data collected at 7, 8 and 13 TeV**
  - **measured H(125) properties in the H → ττ decay channel are consistent with SM expectations**

- **Search for H(125) → μμ decays performed with Run I data collected at 7/8 TeV revealed no signal**
  - **upper limit is set on production cross section times BR(H→μμ)**

$$\sigma\mathcal{B}/(\sigma\mathcal{B})_{\mathrm{SM}} < 7.4 \text{ at } 95\% \text{ CL}$$

  - **search is being currently updated with Run II data collected at 13 TeV**
  - **one needs ~ 400 (1200) fb^{-1} to observe H → μμ decay with statistical significance of 3 (5) standard deviations**

- **Results of measurements in the H → ττ and H → μμ decay channels indicate non-universality of the H(125) coupling to leptons**