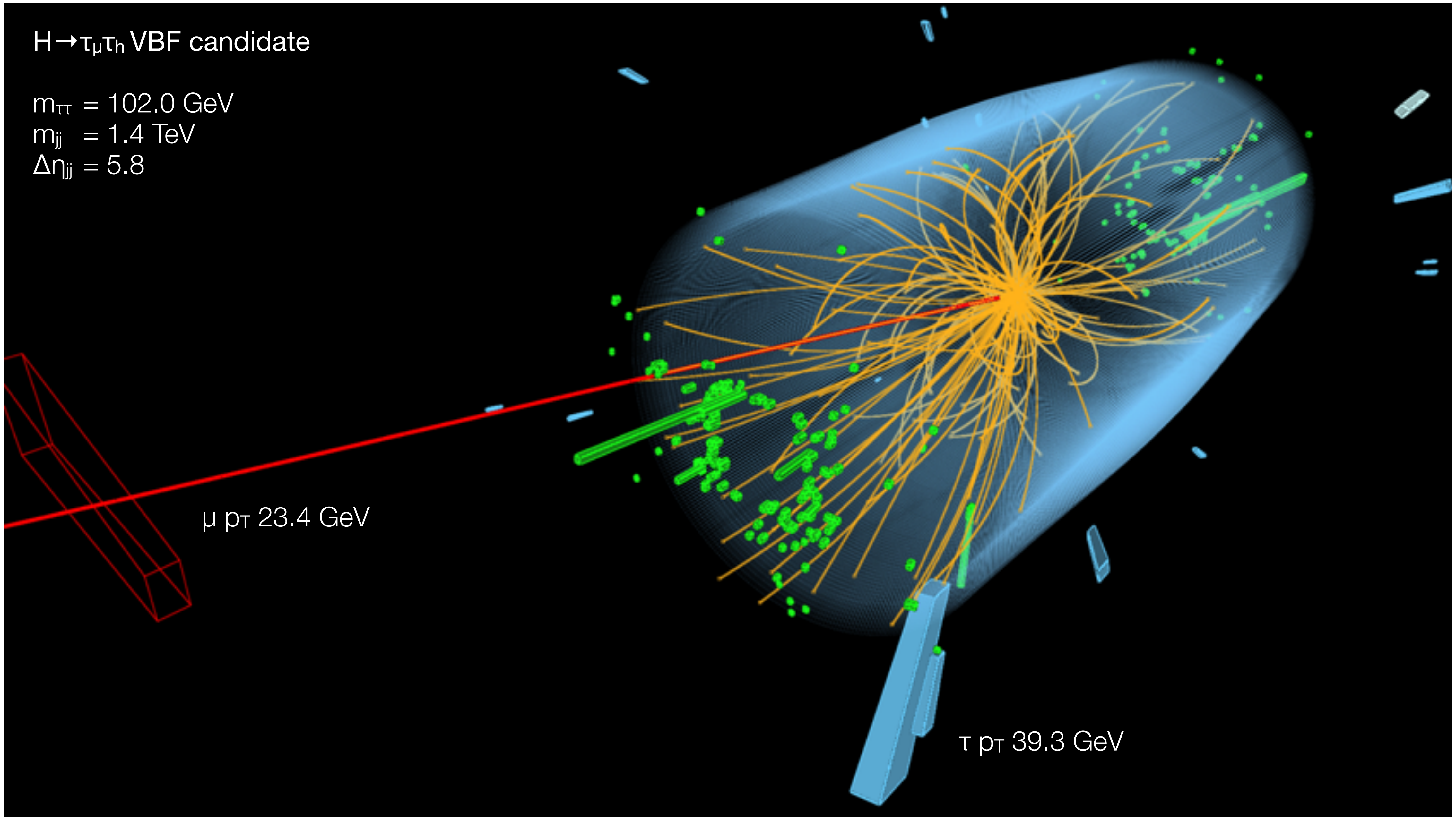
Rencontres de Moriond EW 2014
21/3/2014 - La Thuile



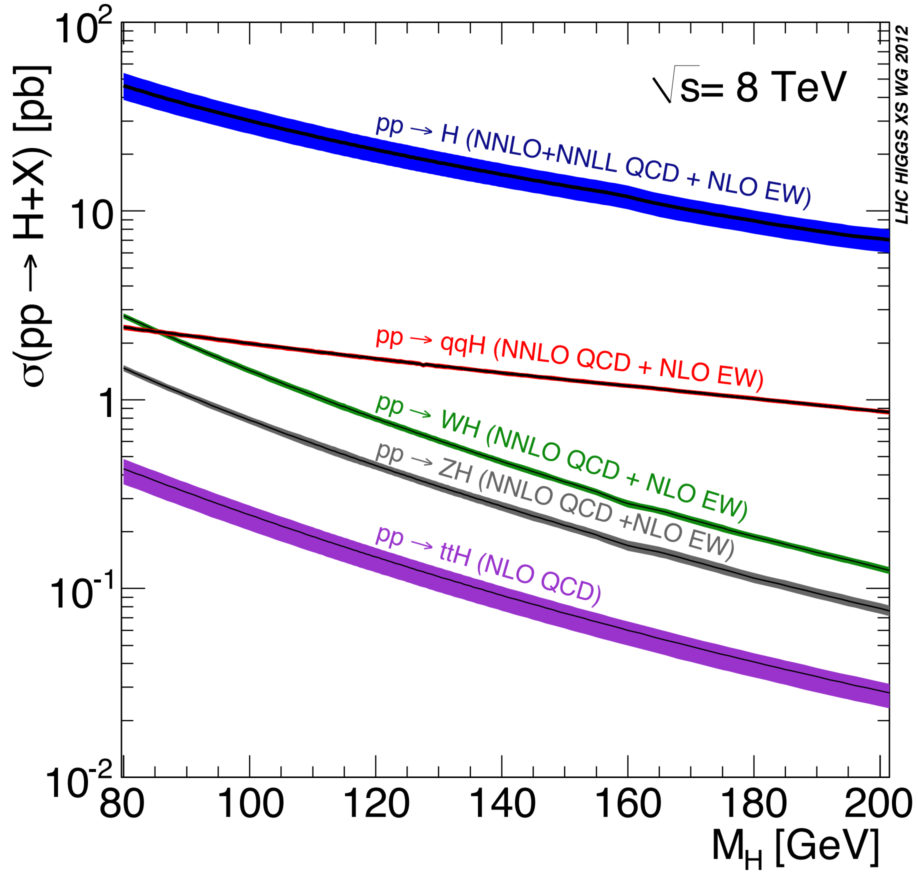
Evidence of the SM Higgs in the decay channel into τ leptons

http://arxiv.org/abs/arXiv:1401.5041
https://twiki.cern.ch/twiki/bin/view/CMSPublic/Hig13004PubTWiki

Riccardo Manzoni
on behalf of the CMS collaboration

Analysis strategy

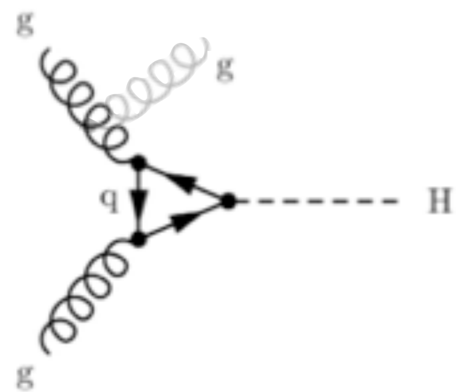
Full CMS Run I data analyzed: 4.9 fb^{-1} @ 7 TeV, 19.7 fb^{-1} @ 8 TeV

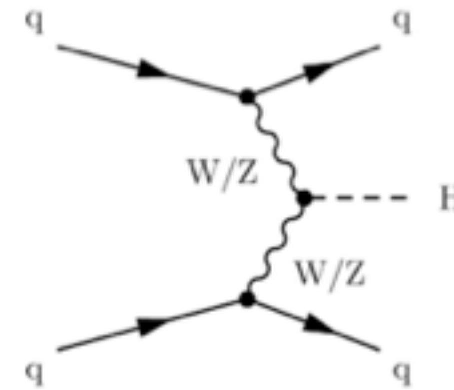


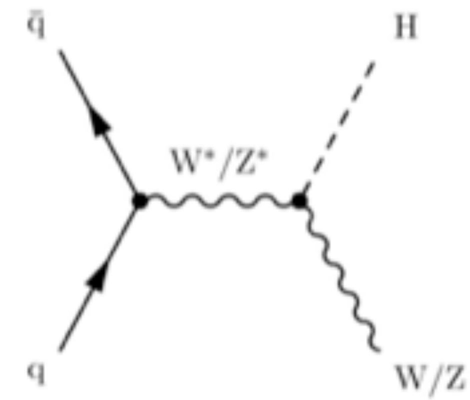
Events are classified in exclusive categories

to enhance sensitivity to the dominant Higgs production processes

gluon fusion, Vector Boson Fusion, W/Z-associated production





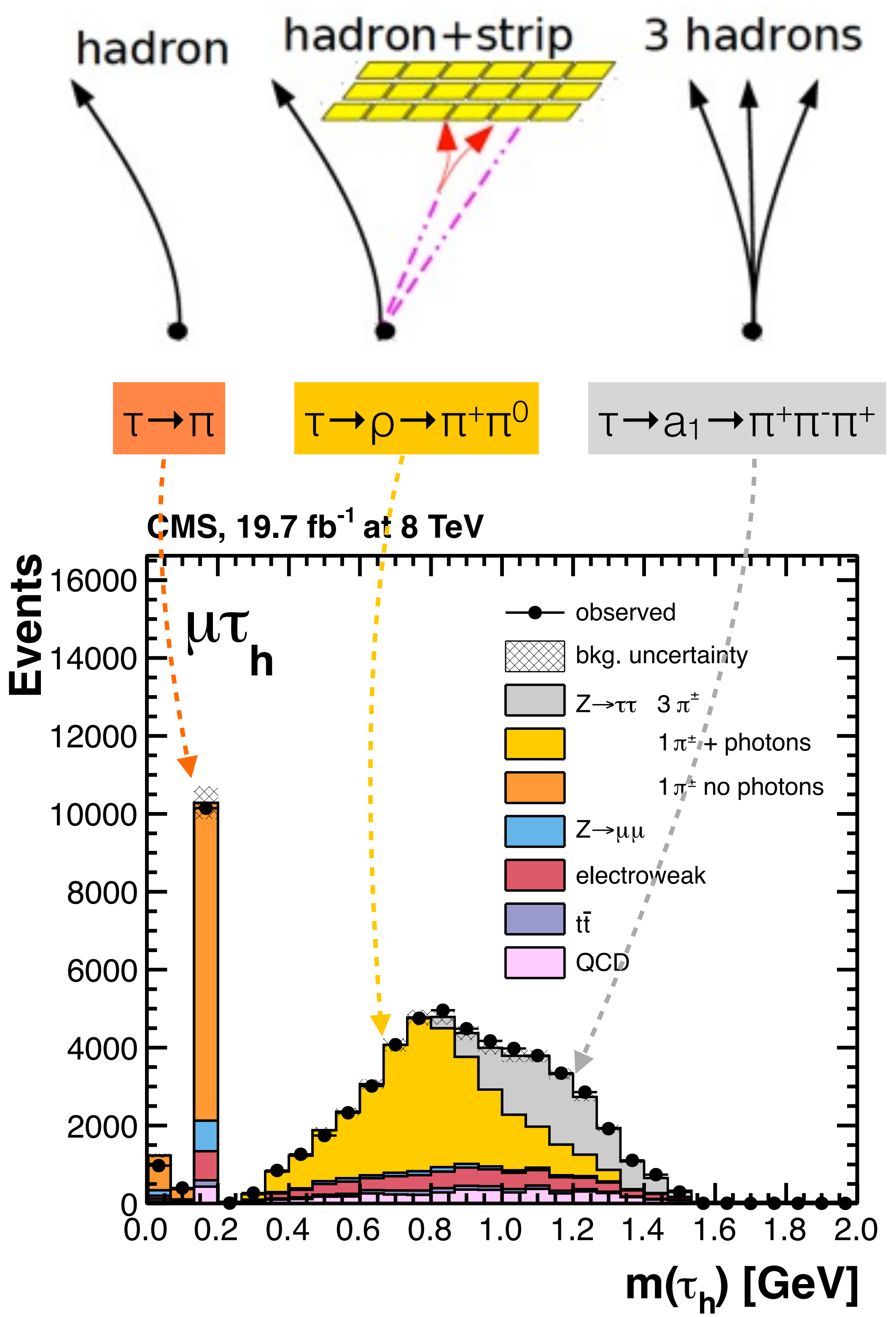


0/1 jet	2 jet (VBF)	VH

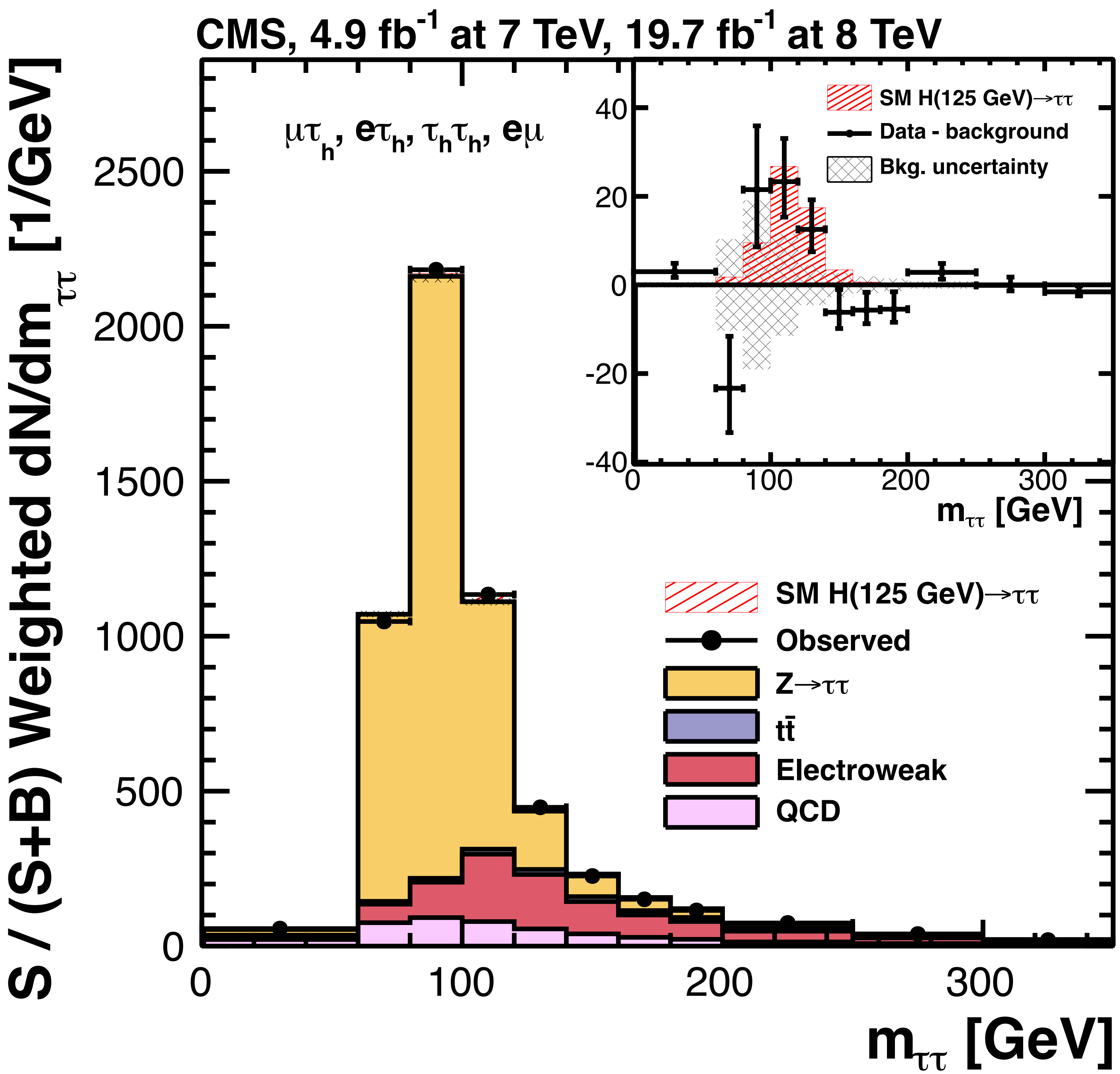
- all di-τ final states ($\mu\tau_h$, $e\tau_h$, $\tau_h\tau_h$, eμ, μμ, ee) analyzed
- **shape analysis**
  - di-tau invariant mass $m_{\tau\tau}$ (SVfit algorithm)
- **categories with low S/B constrain nuisance parameters**

Physics objects

- **Particle Flow reconstruction**
  - combines infos from all sub-detectors
  - produces a collection of unambiguous, stable particles
- **electrons, muons**
- **hadronically-decaying taus**
  - HPS algorithm reconstructs the different decay modes
- **jets**
  - multivariate discriminant against Pile Up
- **multivariate E_T^{miss} regression**
  - discriminates signal from bkgs (W+Jets, ttbar)
  - used to estimate the invariant mass of parent boson (SVfit algorithm)



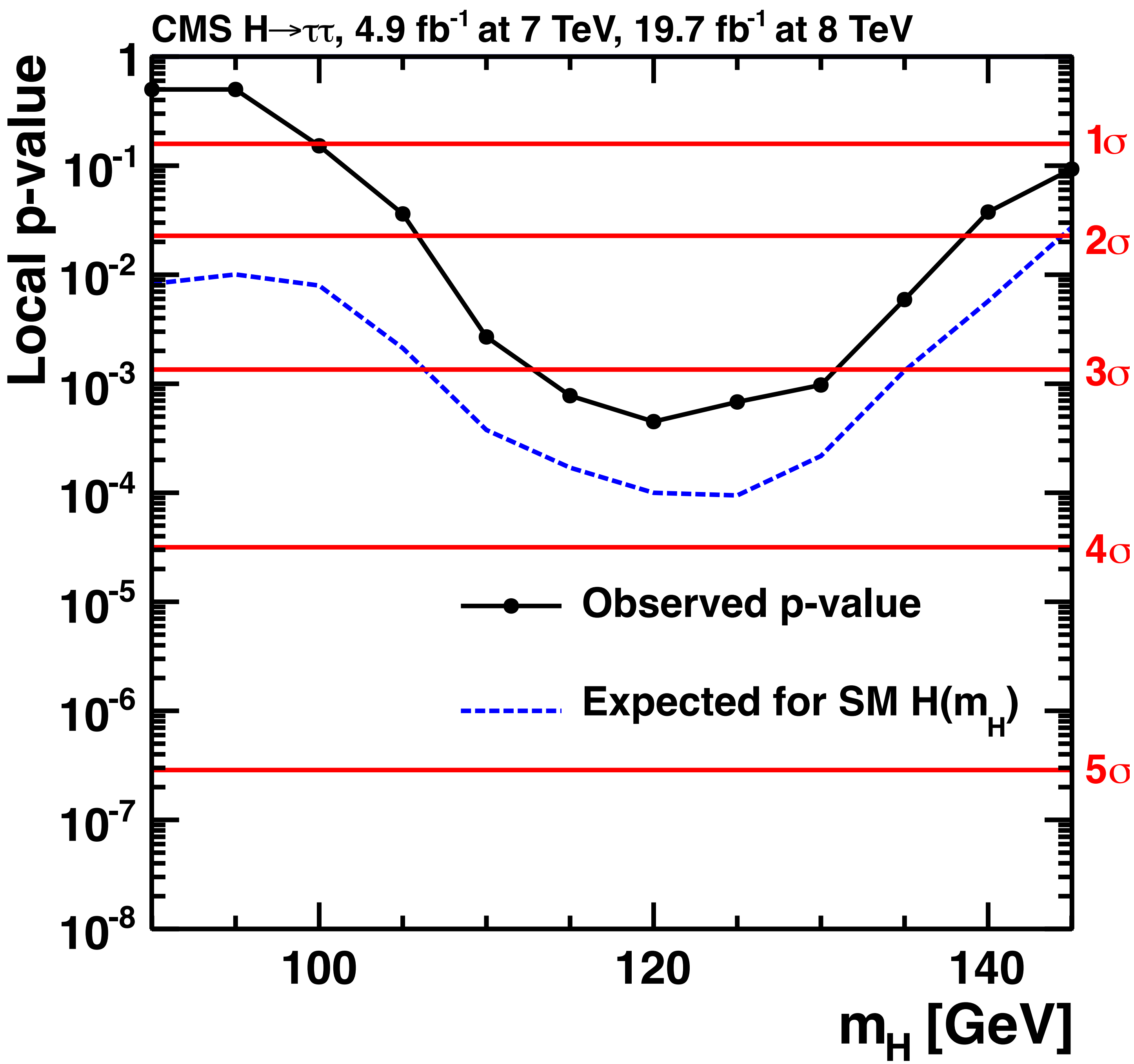
Combined mass distribution



Weighted *each $m_{\tau\tau}$ distribution* of each category of each channel by S/(S+B) in 68% region around Higgs mass peak

Excess compatible with Higgs signal at m_H = 125 GeV

Significance and *p*-value



At m_H = 125 GeV

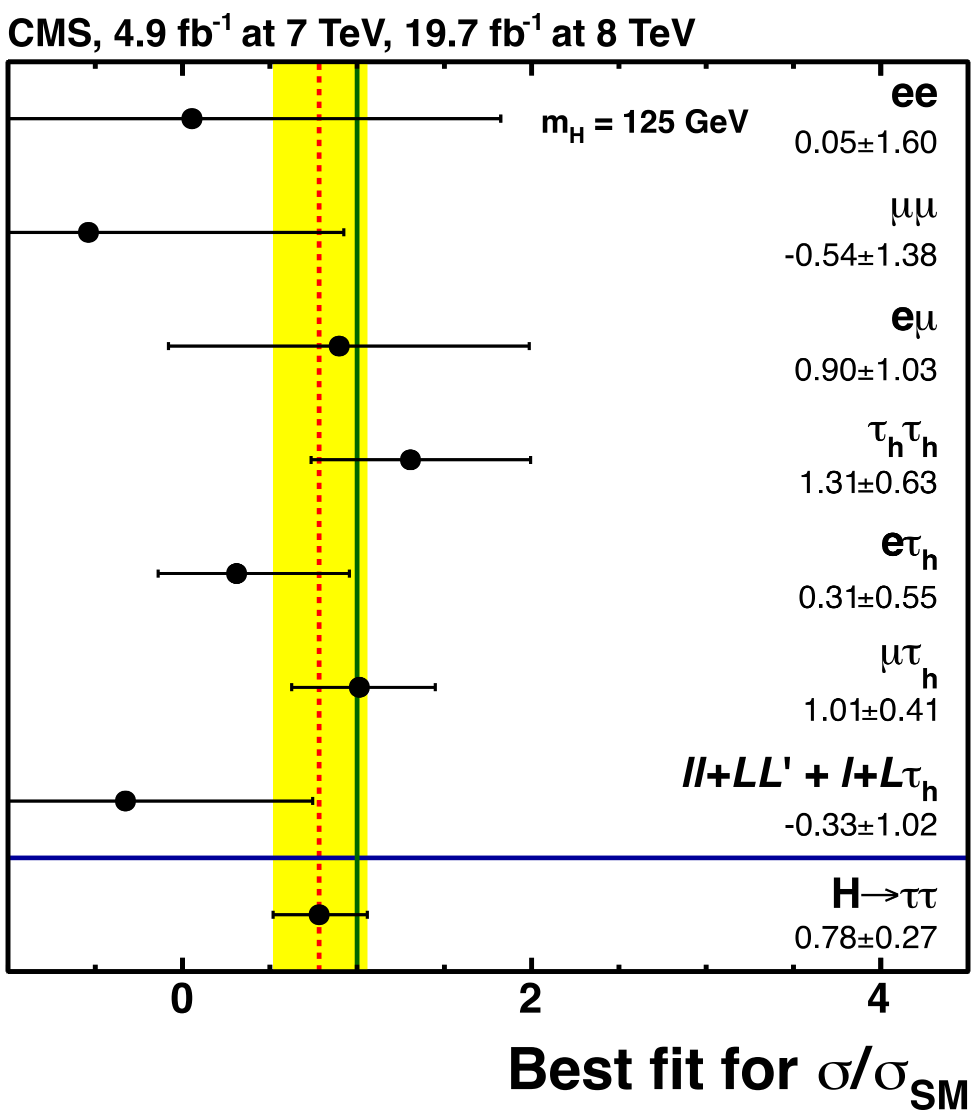
obs. 3.20 σ (exp. 3.73 σ)

Max at m_H = 120 GeV

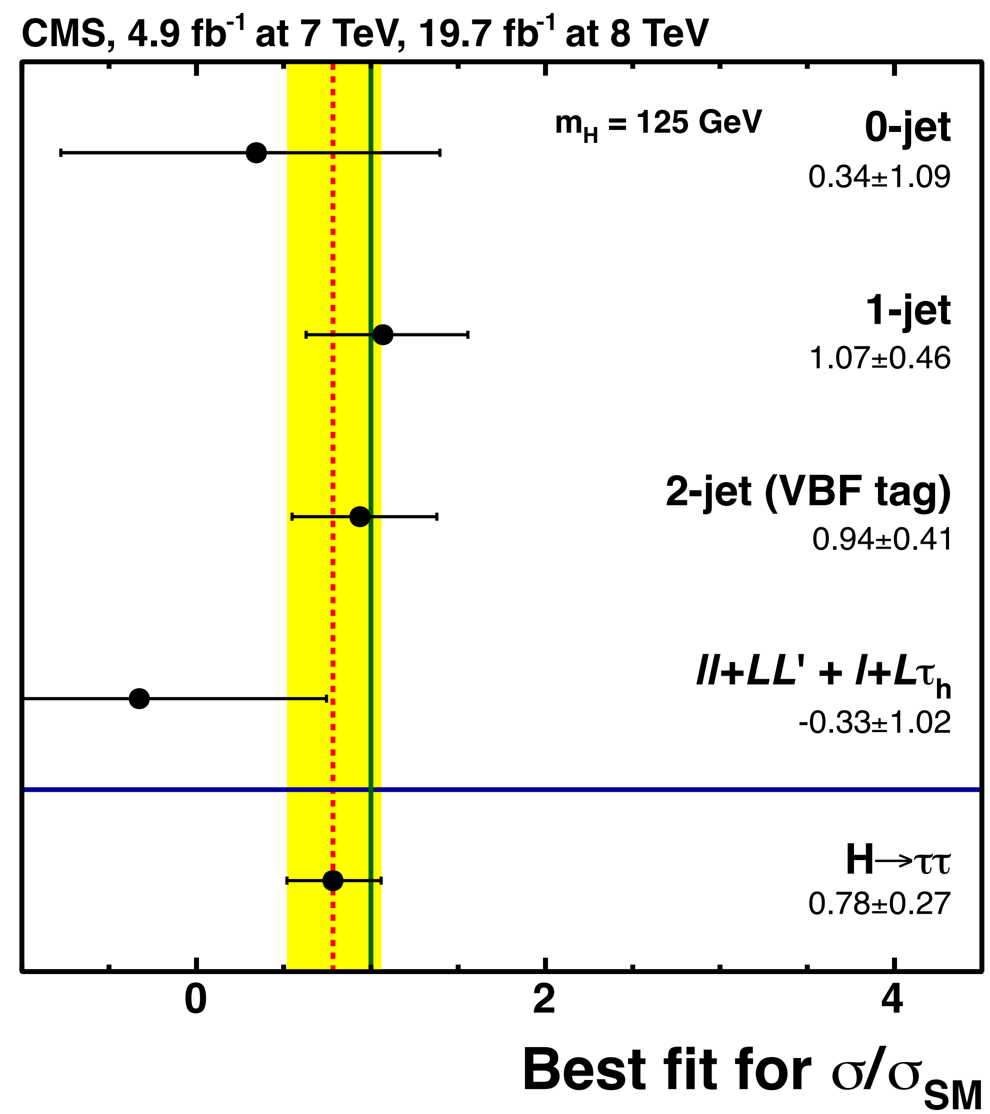
obs. 3.32 σ (exp. 3.72 σ)

Signal strength for m_H = 125 GeV

per channel

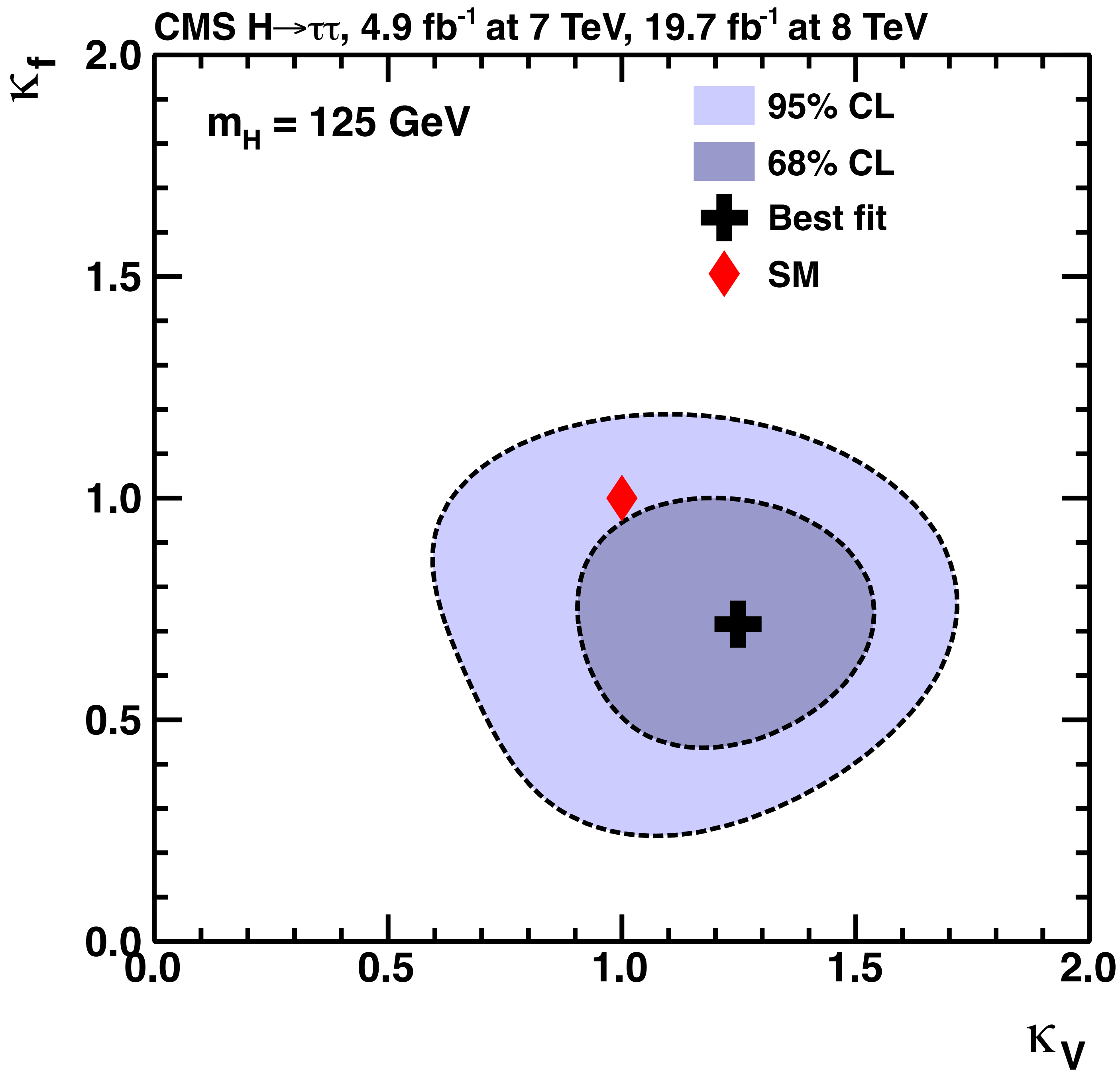


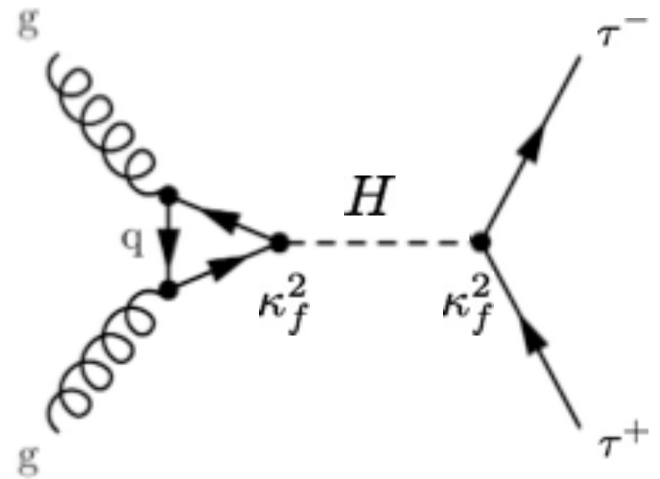
per category



Best-fit μ = 0.78 ± 0.27

Properties: couplings

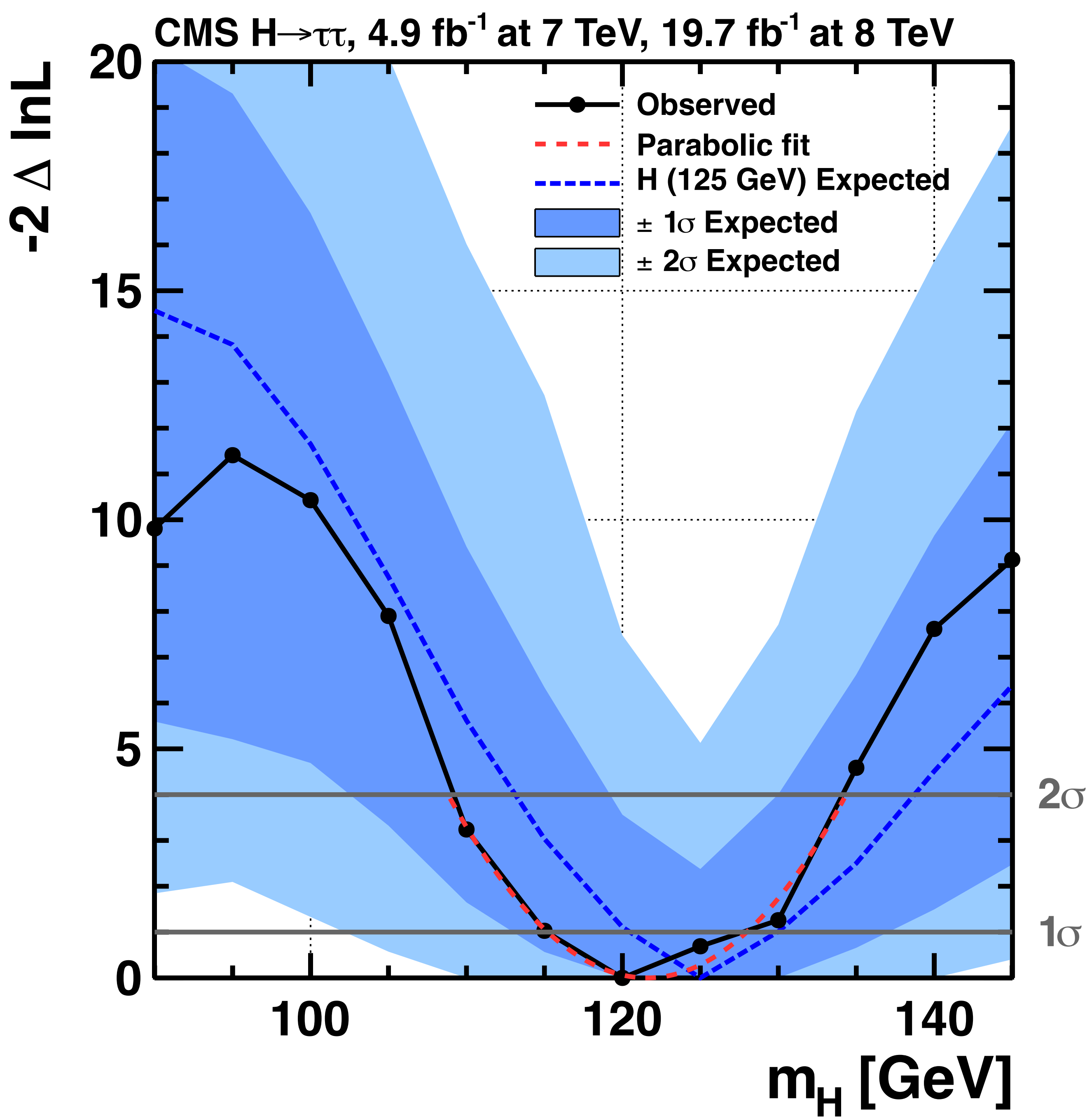




H →ττ channel very sensitive to k_f

k_f measured with 30% precision

Properties: mass



Best-fit mass

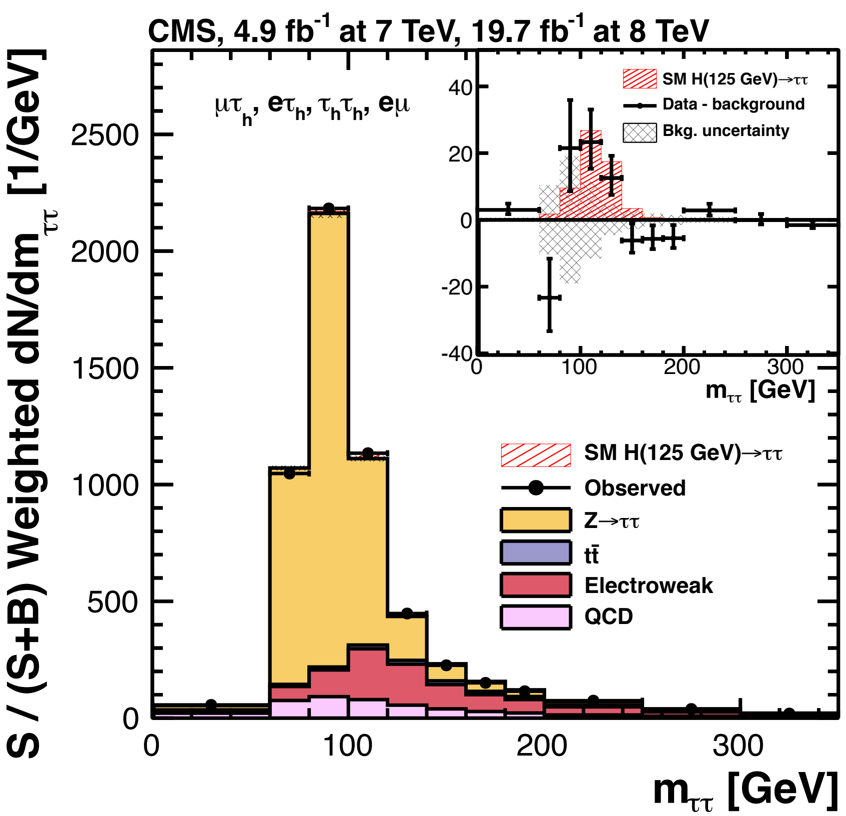
m_H = 122 ± 7 GeV

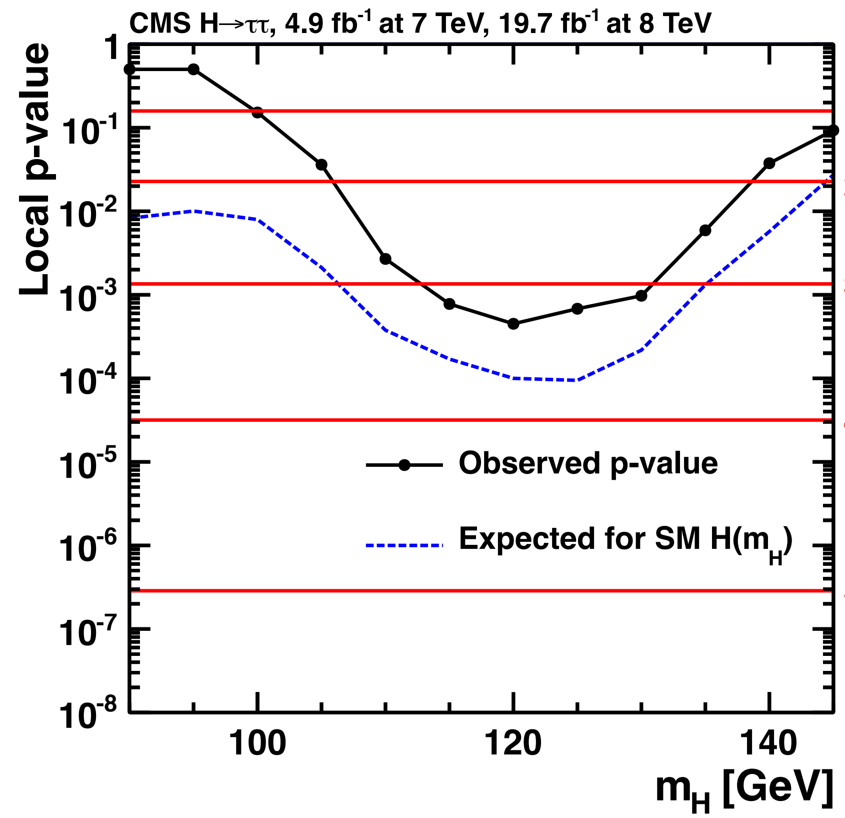
Compatible with

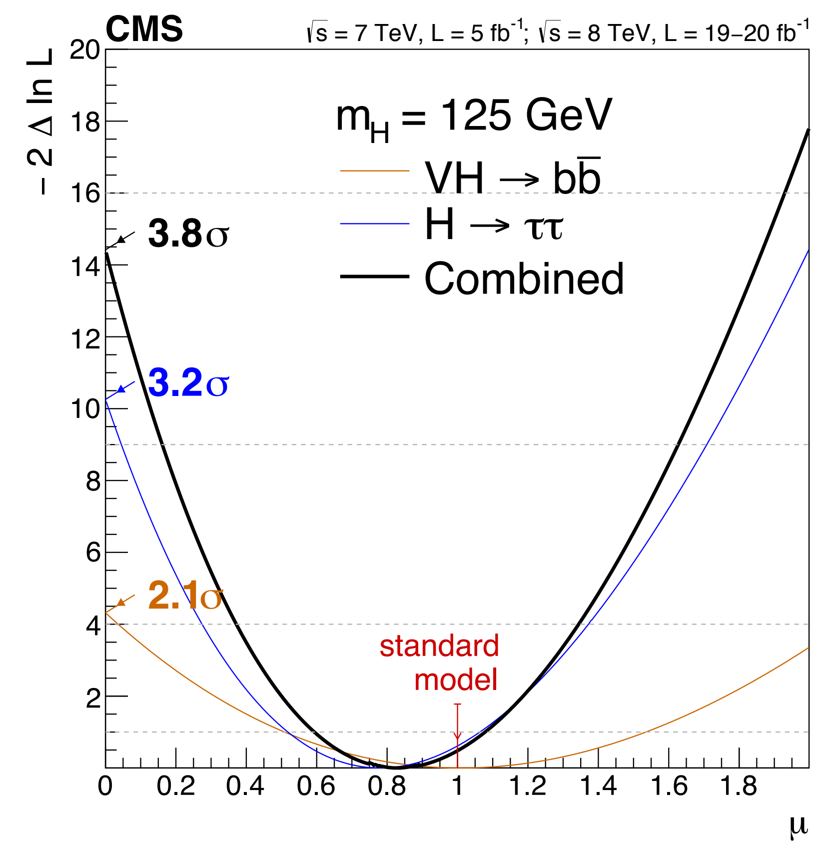
SM Higgs at m_H = 125.6 GeV

Conclusions

http://arxiv.org/abs/1401.6527







$m_H = 125$ GeV

H→ττ

obs. 3.2 σ (exp. 3.7 σ)

H→ττ + VH→bb̄

obs. 3.8 σ (exp. 4.4 σ)

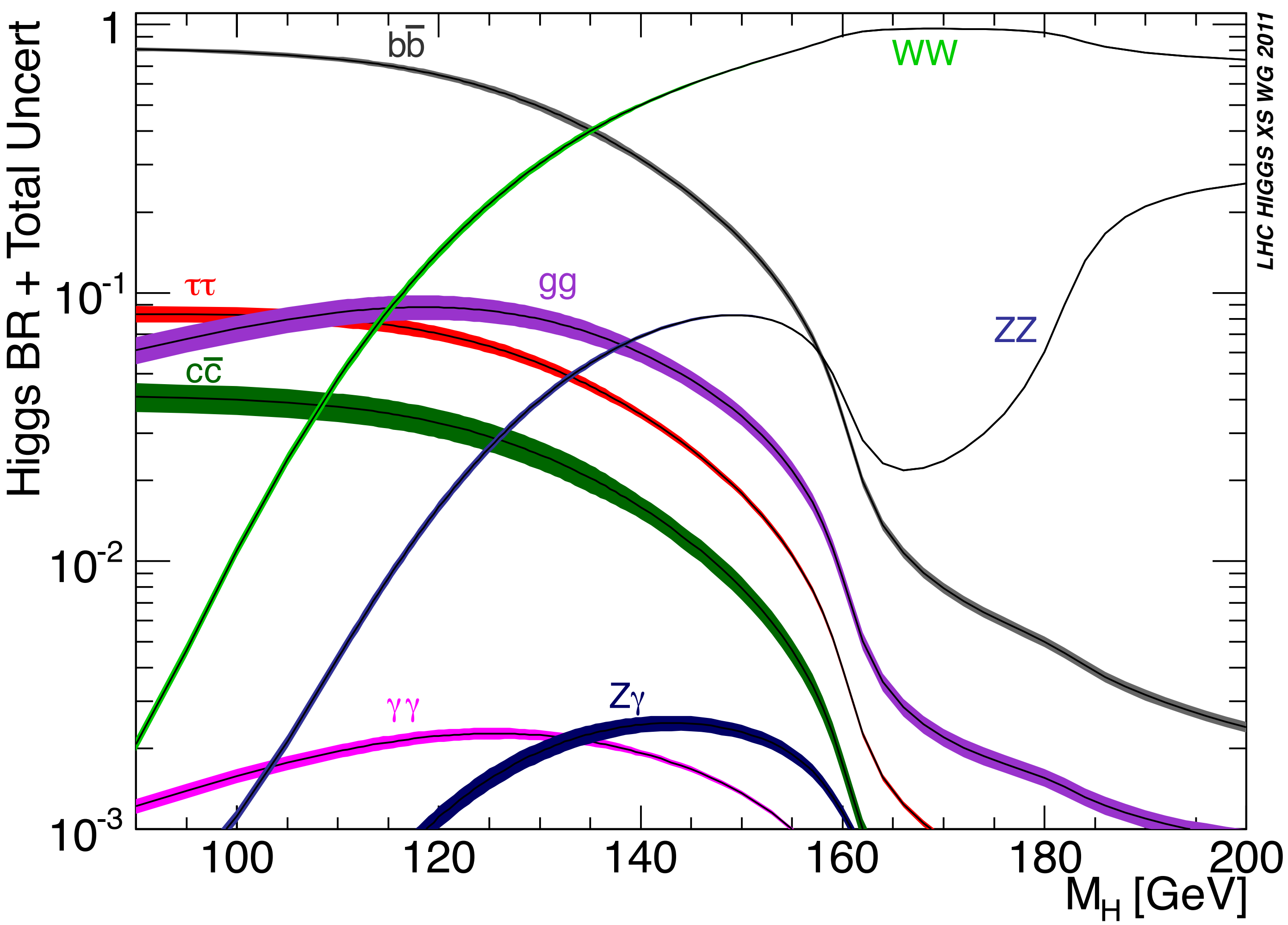
Evidence for H→ττ

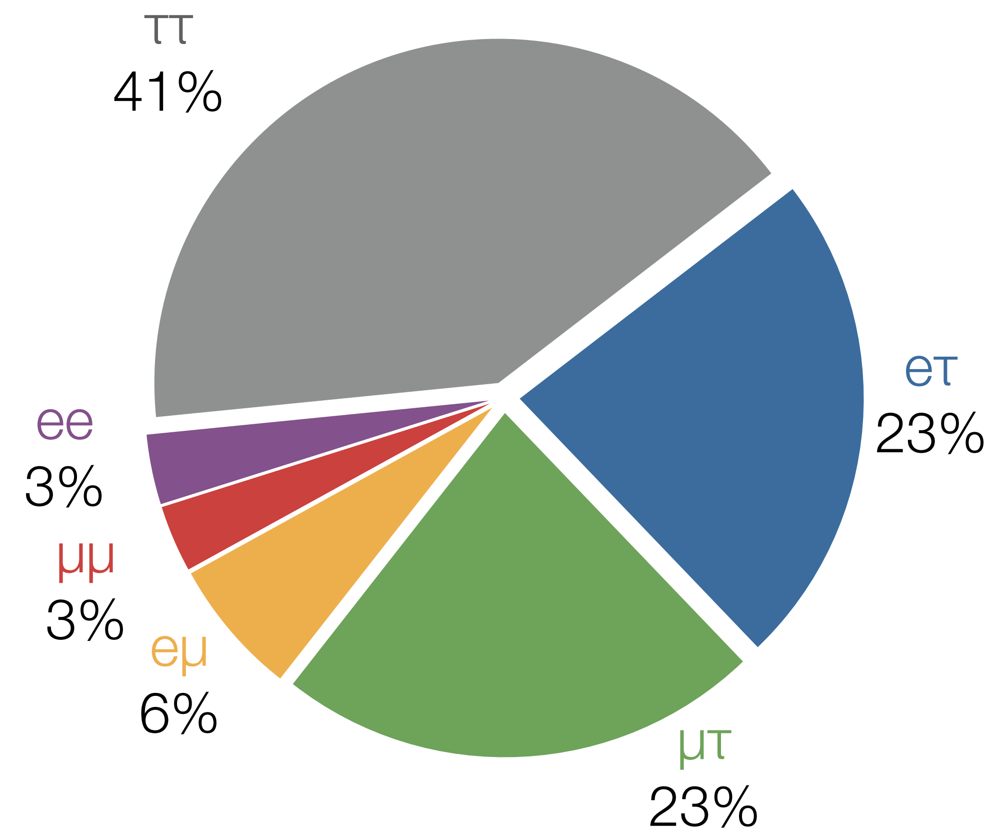
Evidence for H→fermions (H→ττ + VH→bb̄)

Compatible with SM Higgs, $m_H = 125.6$ GeV

Backup

H→ττ branching ratios



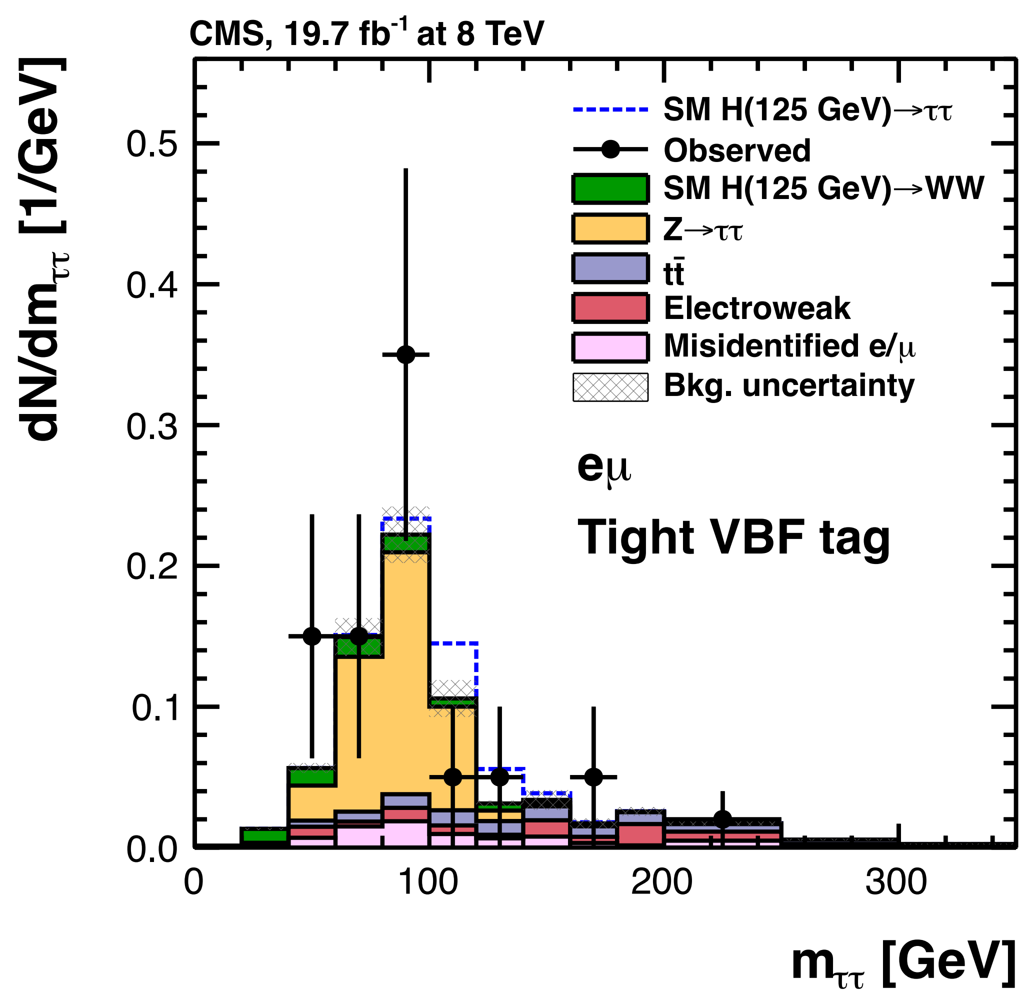


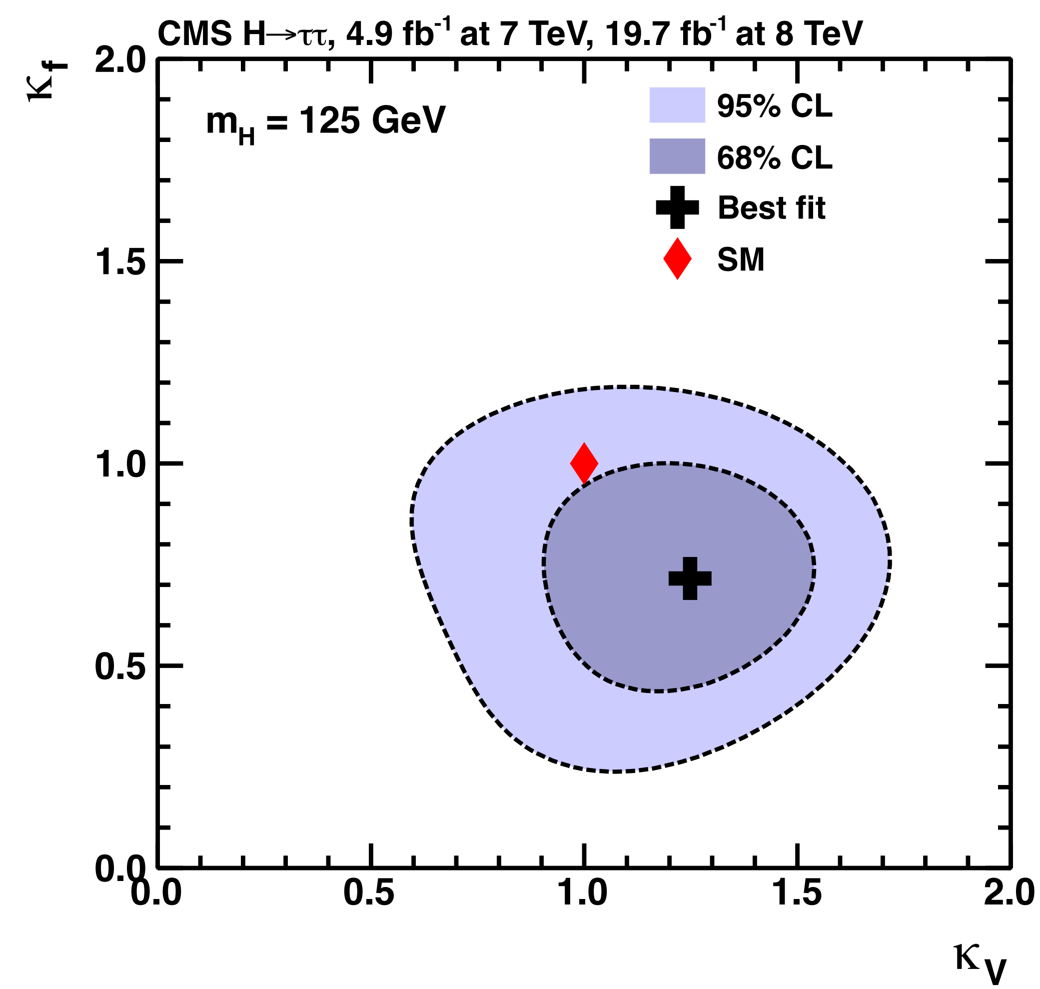
- Sizable **BR(H→ττ)** at low m_H (6.3% at m_H = 125 GeV)
- All 6 final states analyzed (in non-VH categories)

Treatment of H→WW

Goal of the analysis is to measure H→ττ

- H→WW can decay in the same final states and pass the selection
  - especially evident in eμ VBF, negligible otherwise
- HWW at m_H = 125 GeV considered as a background throughout (except for couplings)
- HWW at m_H = 125 GeV considered as part of the signal for k_V vs. k_f
- k_V constraint mostly from HWW in eμ VBF k_V^2 (production) * k_V^2 (decay)





Kinematic selections

	Channel	HLT requirement	Lepton selection		
non VH	$\mu\tau_h$	$\mu(12\text{–}18)$ & $\tau_h(10\text{–}20)$	$p_T^{\mu} > 17\text{–}20$ $p_T^{\tau_h} > 30$	$\lvert\eta^{\mu}\rvert < 2.1$ $\lvert\eta^{\tau_h}\rvert < 2.4$	$R^{\mu} < 0.1$ $I^{\tau_h} < 1.5$
	$e\tau_h$	$e(15\text{–}22)$ & $\tau_h(15\text{–}20)$	$p_T^{e} > 20\text{–}24$ $p_T^{\tau_h} > 30$	$\lvert\eta^{e}\rvert < 2.1$ $\lvert\eta^{\tau_h}\rvert < 2.4$	$R^{e} < 0.1$ $I^{\tau_h} < 1.5$
	$\tau_h\tau_h$ (2012 only)	$\tau_h(35)$ & $\tau_h(35)$ $\tau_h(30)$ & $\tau_h(30)$ & jet(30)	$p_T^{\tau_h} > 45$	$\lvert\eta^{\tau_h}\rvert < 2.1$	$I^{\tau_h} < 1$
	$e\mu$	$e(17)$ & $\mu(8)$ $e(8)$ & $\mu(17)$	$p_T^{\ell_1} > 20$ $p_T^{\ell_2} > 10$	$\lvert\eta^{\mu}\rvert < 2.1$ $\lvert\eta^{e}\rvert < 2.3$	$R^{\ell} < 0.1\text{–}0.15$
	$\mu\mu$	$\mu(17)$ & $\mu(8)$	$p_T^{\mu_1} > 20$ $p_T^{\mu_2} > 10$	$\lvert\eta^{\mu_1}\rvert < 2.1$ $\lvert\eta^{\mu_2}\rvert < 2.4$	$R^{\mu} < 0.1$
	ee	$e(17)$ & $e(8)$	$p_T^{e_1} > 20$ $p_T^{e_2} > 10$	$\lvert\eta^{e}\rvert < 2.3$	$R^{e} < 0.1\text{–}0.15$
WH	$\mu + \mu\tau_h$	$\mu(17)$ & $\mu(8)$	$p_T^{\mu_1} > 20$ $p_T^{\mu_2} > 10$ $p_T^{\tau_h} > 20$	$\lvert\eta^{\mu}\rvert < 2.4$ $\lvert\eta^{\tau_h}\rvert < 2.3$	$R^{\mu} < 0.1\text{–}0.2$ $I^{\tau_h} < 2$
	$e + \mu\tau_h$ / $\mu + e\tau_h$	$e(17)$ & $\mu(8)$ $e(8)$ & $\mu(17)$	$p_T^{\ell_1} > 20$ $p_T^{\ell_2} > 10$ $p_T^{\tau_h} > 20$	$\lvert\eta^{e}\rvert < 2.5$ $\lvert\eta^{\mu}\rvert < 2.4$ $\lvert\eta^{\tau_h}\rvert < 2.3$	$R^{\ell} < 0.1\text{–}0.2$ $I^{\tau_h} < 2$
	$\mu + \tau_h\tau_h$	$\mu(24)$	$p_T^{\mu} > 24$ $p_T^{\tau_{h,1}} > 25$ $p_T^{\tau_{h,2}} > 20$	$\lvert\eta^{\mu}\rvert < 2.1$ $\lvert\eta^{\tau_h}\rvert < 2.3$	$R^{\mu} < 0.1$ $I^{\tau_h} < 2\text{–}3$
	$e + \tau_h\tau_h$	$e(20)$ & $\tau_h(20)$ $e(22)$ & $\tau_h(20)$	$p_T^{e} > 24$ $p_T^{\tau_{h,1}} > 25$ $p_T^{\tau_{h,2}} > 20$	$\lvert\eta^{e}\rvert < 2.1$ $\lvert\eta^{\tau_h}\rvert < 2.3$	$R^{e} < 0.1\text{–}0.15$ $I^{\tau_h} < 2$

Kinematic selections

ZH

Resonance	HLT requirement	Lepton selection		
$Z \to \mu\mu$	$\mu(17)\,\&\,\mu(8)$	$p_T^{\mu_1} > 20$ $p_T^{\mu_2} > 10$	$\lvert\eta^{\mu}\rvert < 2.4$	$R^{\mu} < 0.3$
$Z \to ee$	$e(17)\,\&\,e(8)$	$p_T^{e_1} > 20$ $p_T^{e_2} > 10$	$\lvert\eta^{e}\rvert < 2.5$	$R^{e} < 0.3$
$H \to \mu\tau_h$		$p_T^{\mu} > 10$ $p_T^{\tau_h} > 15$	$\lvert\eta^{\mu}\rvert < 2.4$ $\lvert\eta^{\tau_h}\rvert < 2.3$	$R^{\mu} < 0.3$ $I^{\tau_h} < 2$
$H \to e\tau_h$		$p_T^{e} > 10$ $p_T^{\tau_h} > 15$	$\lvert\eta^{e}\rvert < 2.5$ $\lvert\eta^{\tau_h}\rvert < 2.3$	$R^{e} < 0.2$ $I^{\tau_h} < 2$
$H \to \tau_h\tau_h$		$p_T^{\tau_h} > 15$	$\lvert\eta^{\tau_h}\rvert < 2.3$	$I^{\tau_h} < 1$
$H \to e\mu$		$p_T^{\ell} > 10$	$\lvert\eta^{e}\rvert < 2.5$ $\lvert\eta^{\mu}\rvert < 2.4$	$R^{\ell} < 0.3$

Background estimates

$Z \to \tau\tau$

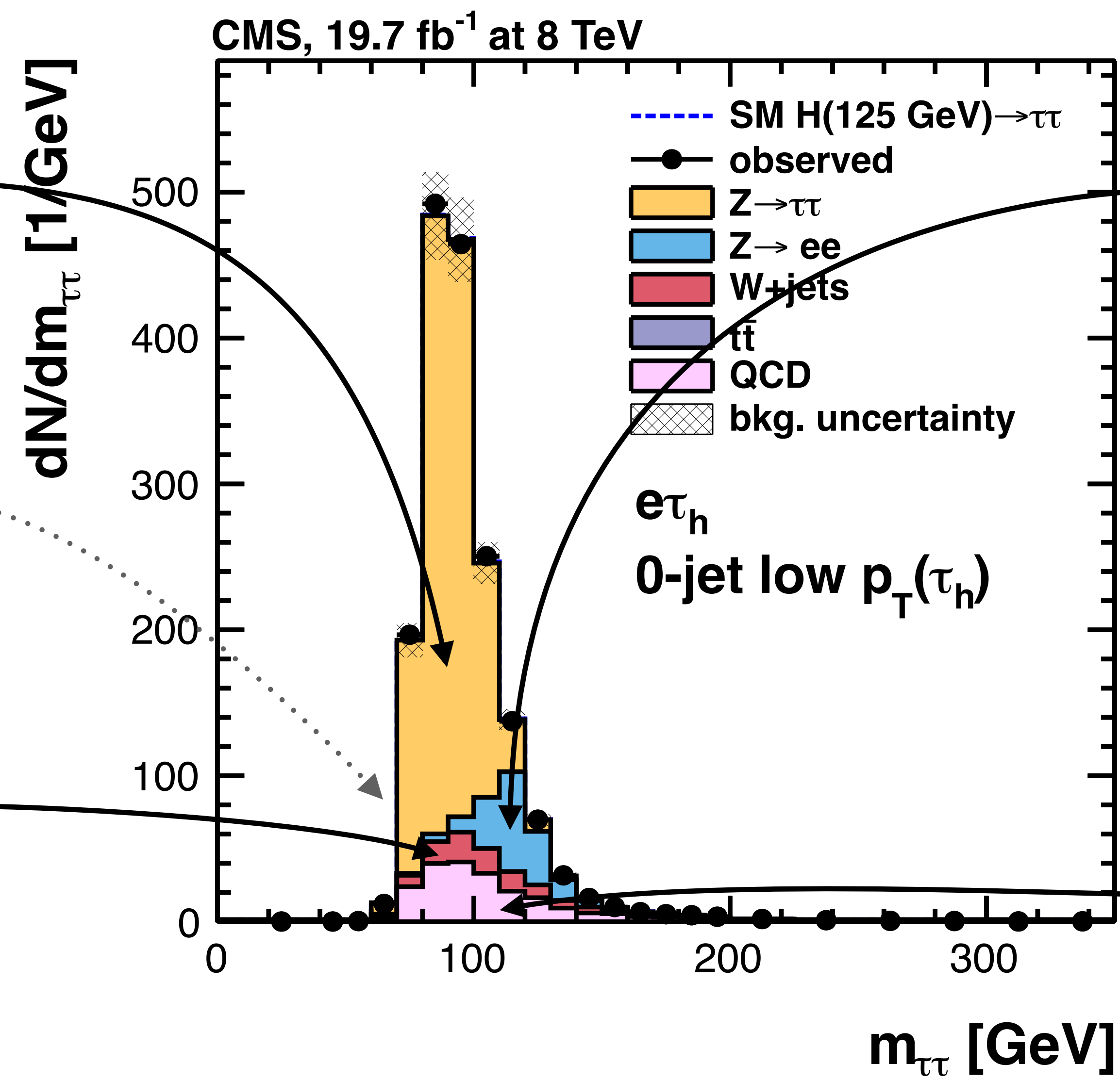
embedded sample
no MET scale and JES unc., since these are data events

$t\bar{t}$

shape MC
norm SF from eμ sideband with ≥1 *b*jet and high MET

W+Jets

shape MC
norm high m_T sideband



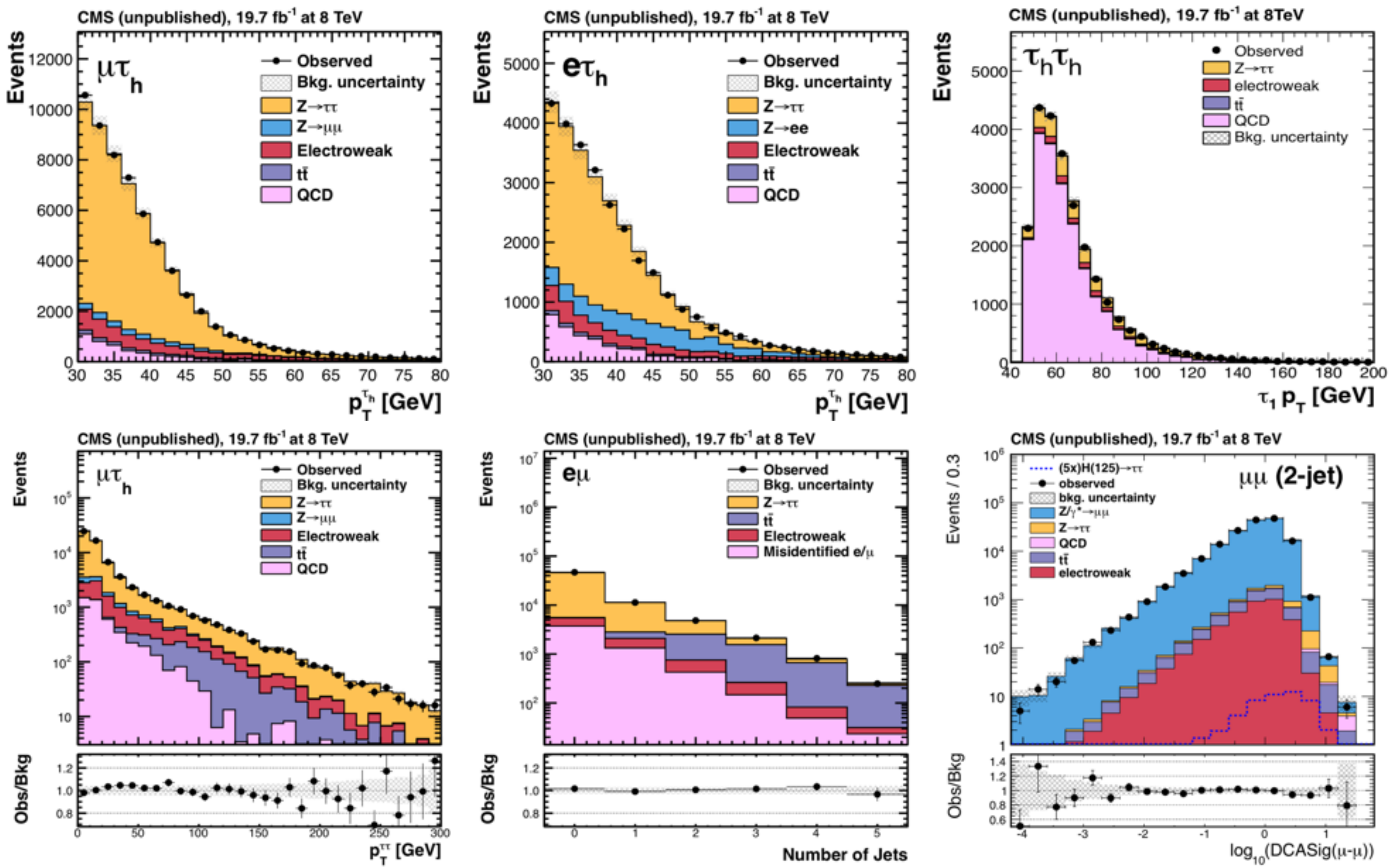
$Z \to ee/\mu\mu$
(μτ,eτ channels)
shape MC
norm SF from T&P in data

$Z \to ee/\mu\mu$
(ee/μμ channels)
shape MC
norm Z→ll enriched sideband

QCD
shape & norm
control regions in data, defined using di-τ charge and isolation

The most relevant backgrounds are derived from data or normalized using data sidebands

Excerpt of control plots

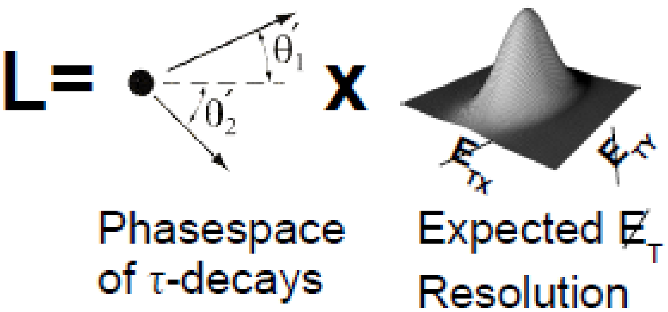


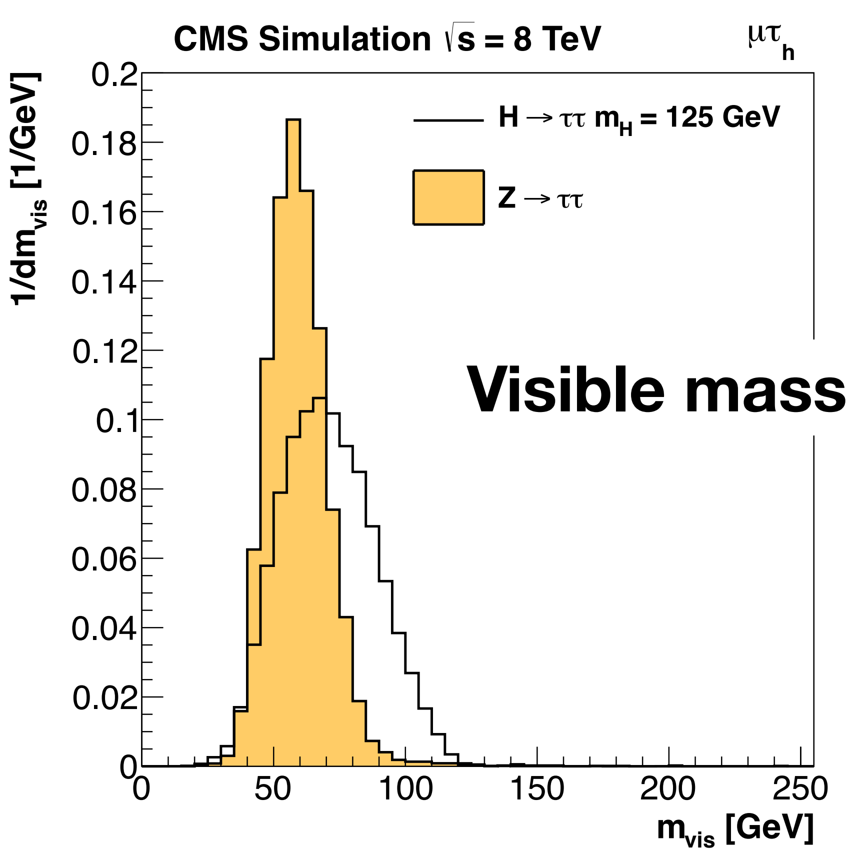
Systematics

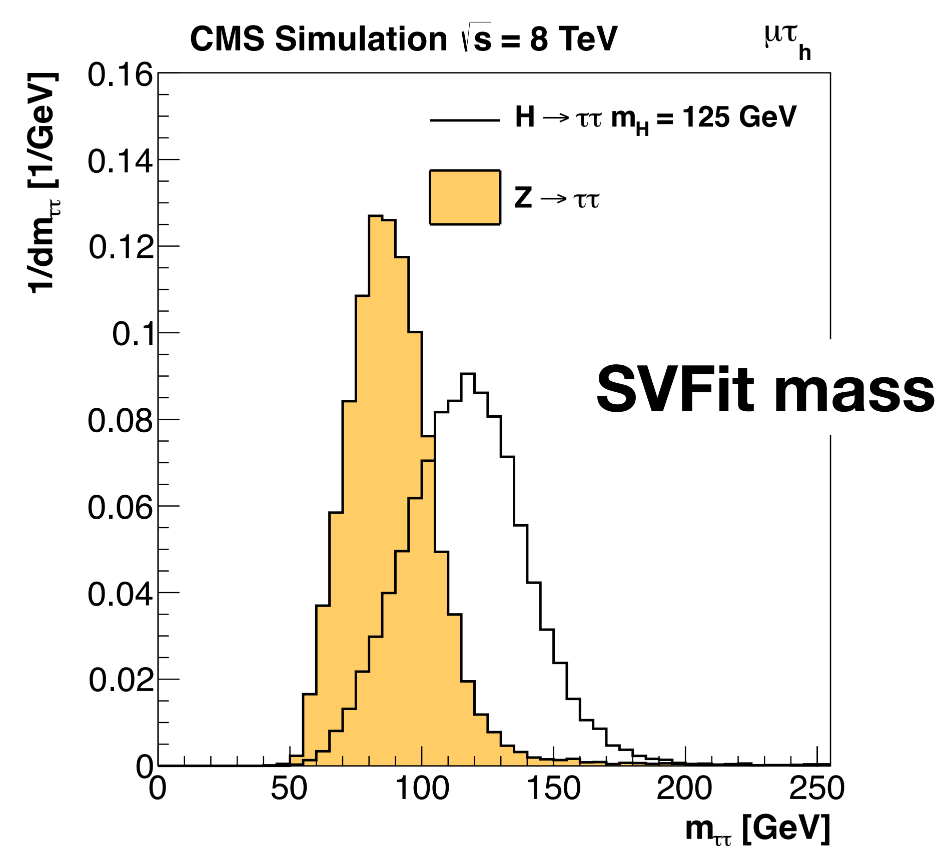
Uncertainty	Affected processes	Change in acceptance
Tau energy scale	signal & sim. backgrounds	1–29%
Tau ID (& trigger)	signal & sim. backgrounds	6–19%
e misidentified as τ_h	$Z \to ee$	20–74%
μ misidentified as τ_h	$Z \to \mu\mu$	30%
Jet misidentified as τ_h	$Z + \text{jets}$	20–80%
Electron ID & trigger	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. $W + \text{jets}$	$W + \text{jets}$	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

di-τ mass reconstruction (SVFit)

- Kinematic **maximum likelihood fit to estimate mass of ττ system**
- Estimated on event-by-event basis using four-momenta of visible decay products, E_x^{miss}, E_y^{miss}, and expected E_T^{miss} resolution
- **10-20% resolution** on reconstructed $m_{\tau\tau}$ depending on channel/category

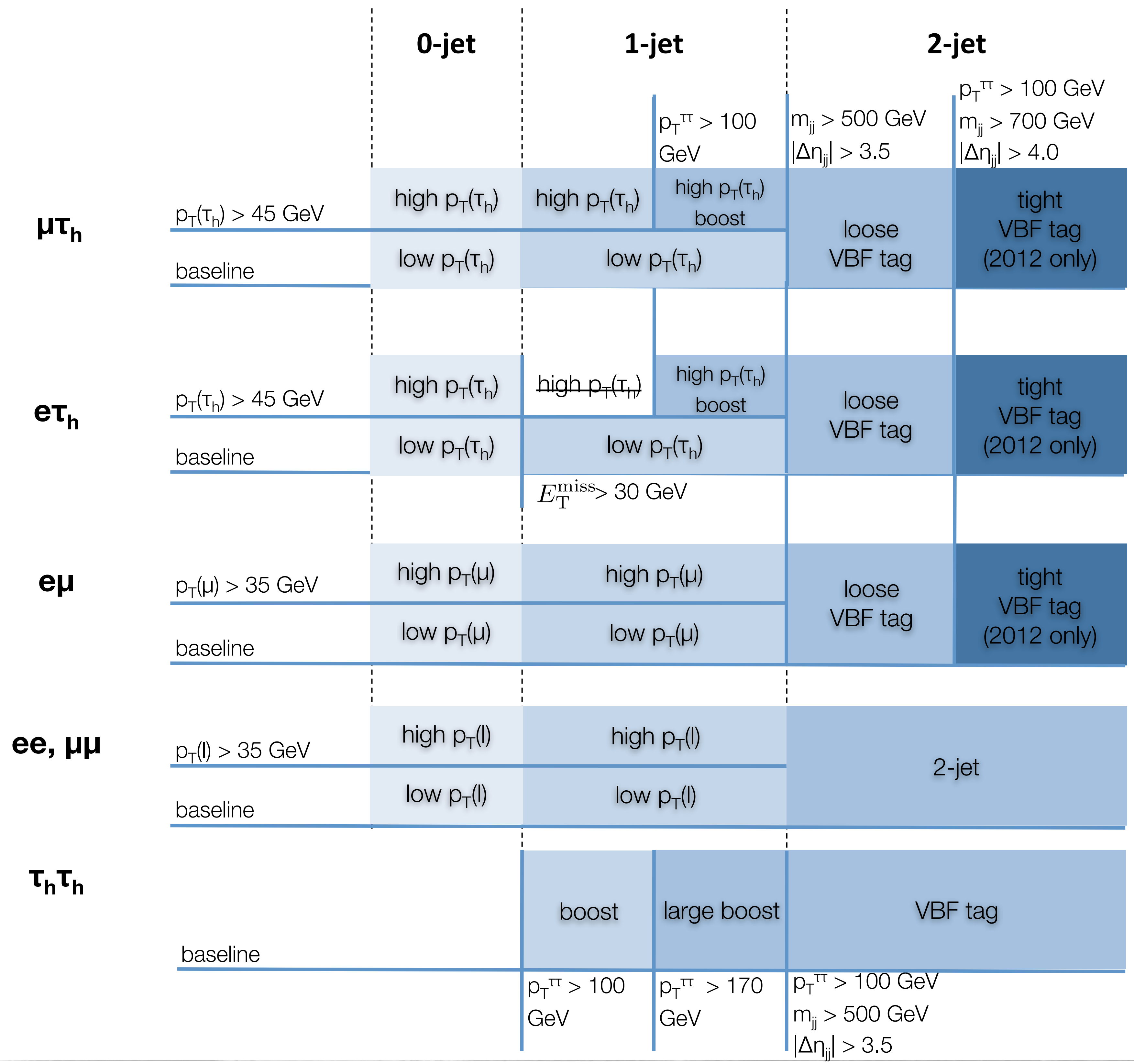






SVFit di-τ mass is used as mass discriminator for the statistical interpretation for $\mu\tau_h$, $e\tau_h$, $e\mu$, $\tau_h\tau_h$ channels

Event classification @ 8 TeV

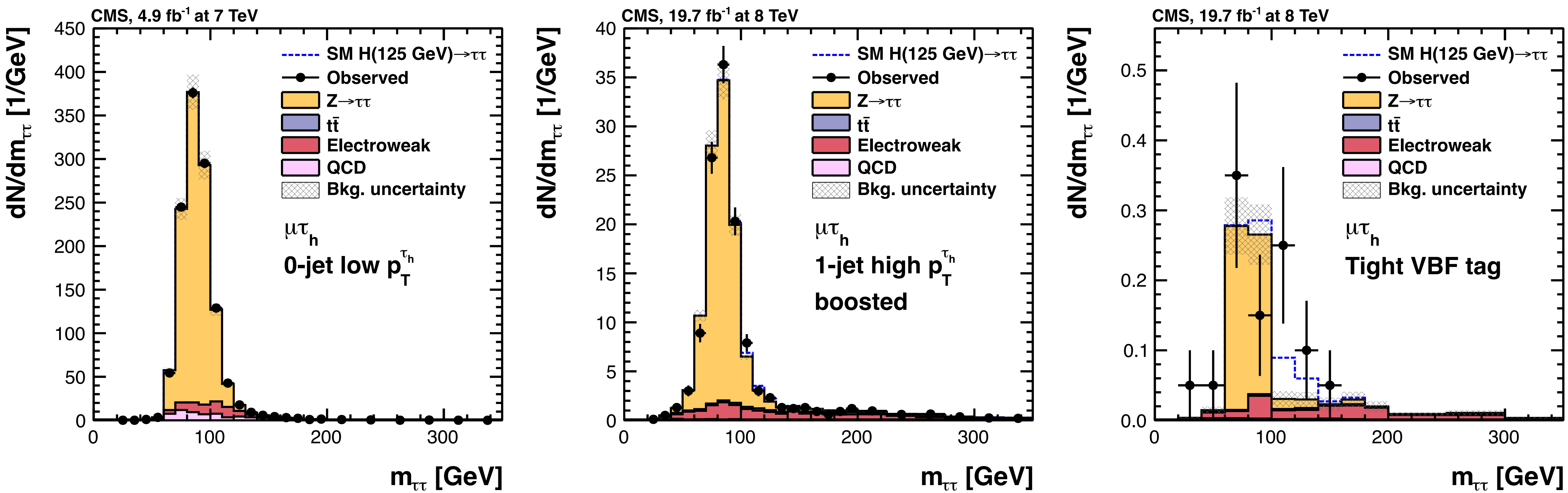


Higgs candidate transverse momentum

$$p_T^{\tau\tau} = |\vec{p}_T(L) + \vec{p}_T(L') + E_T^{miss}|$$

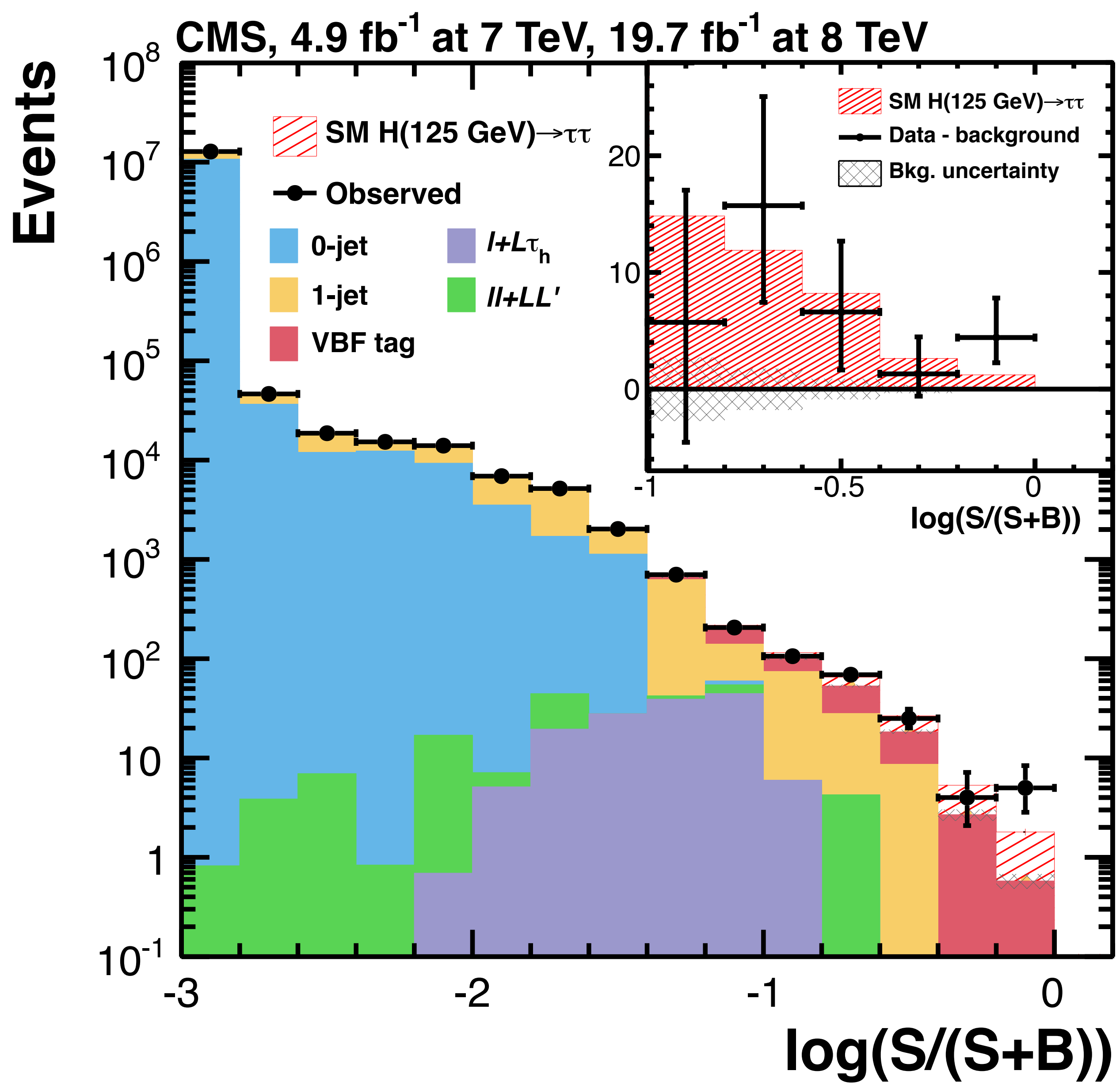
Mass distributions: μτh as a benchmark

0 jet | 1 jet | 2 jet (VBF)



- **0-jet** categories have large statistics but low S/B and thus provide good constraints for the main uncertainties
  - Tau ID efficiency
  - Tau Energy Scale
    further constrained within the uncertainties of the method in slide 3
- **1-jet** (boosted) categories show better $m_{\tau\tau}$ resolution and good sensitivity
- **2-jets** (VBF) categories show low bkg contamination and good S/B

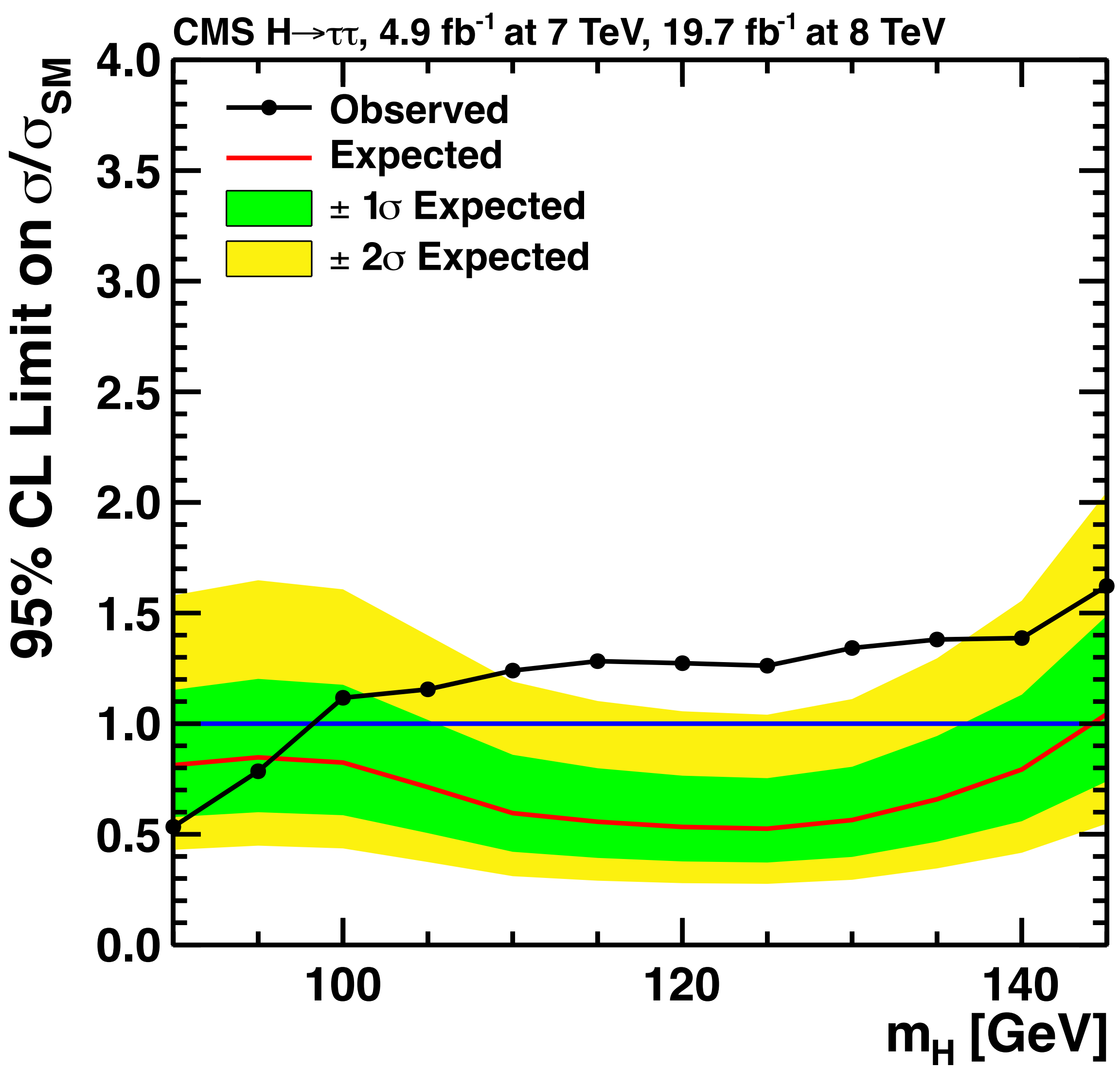
Combined mass distribution



Combined observed and predicted distributions of the decimal logarithm log(S/(S+B)) in each bin of the final $m_{\tau\tau}$, m_{vis}, or discriminator distributions obtained in all event categories and decay channels

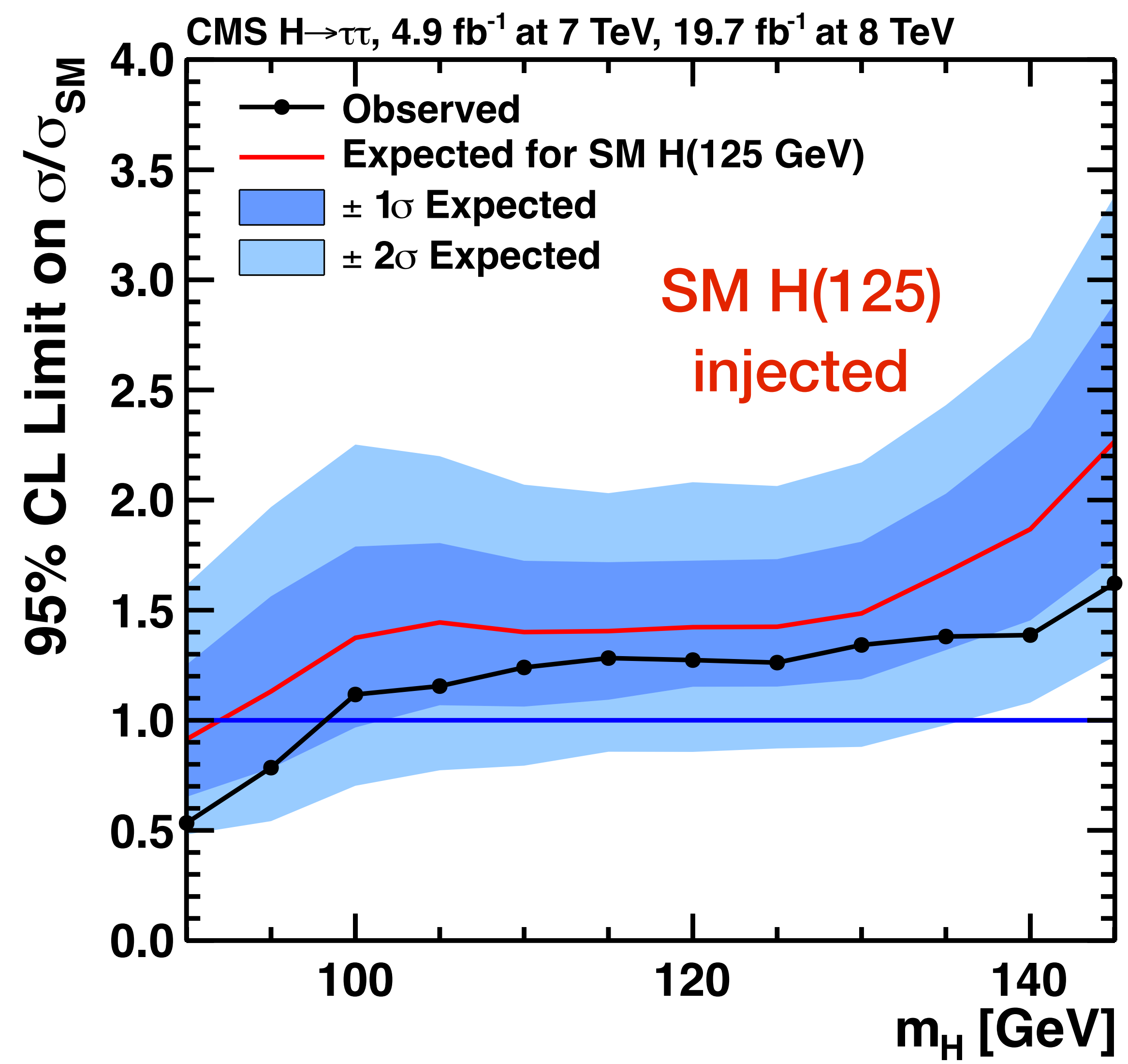
Excess compatible with SM Higgs signal at m_H = 125 GeV

Limits



background only expected

0.53 x σ_{SM} at m_H = 125 GeV



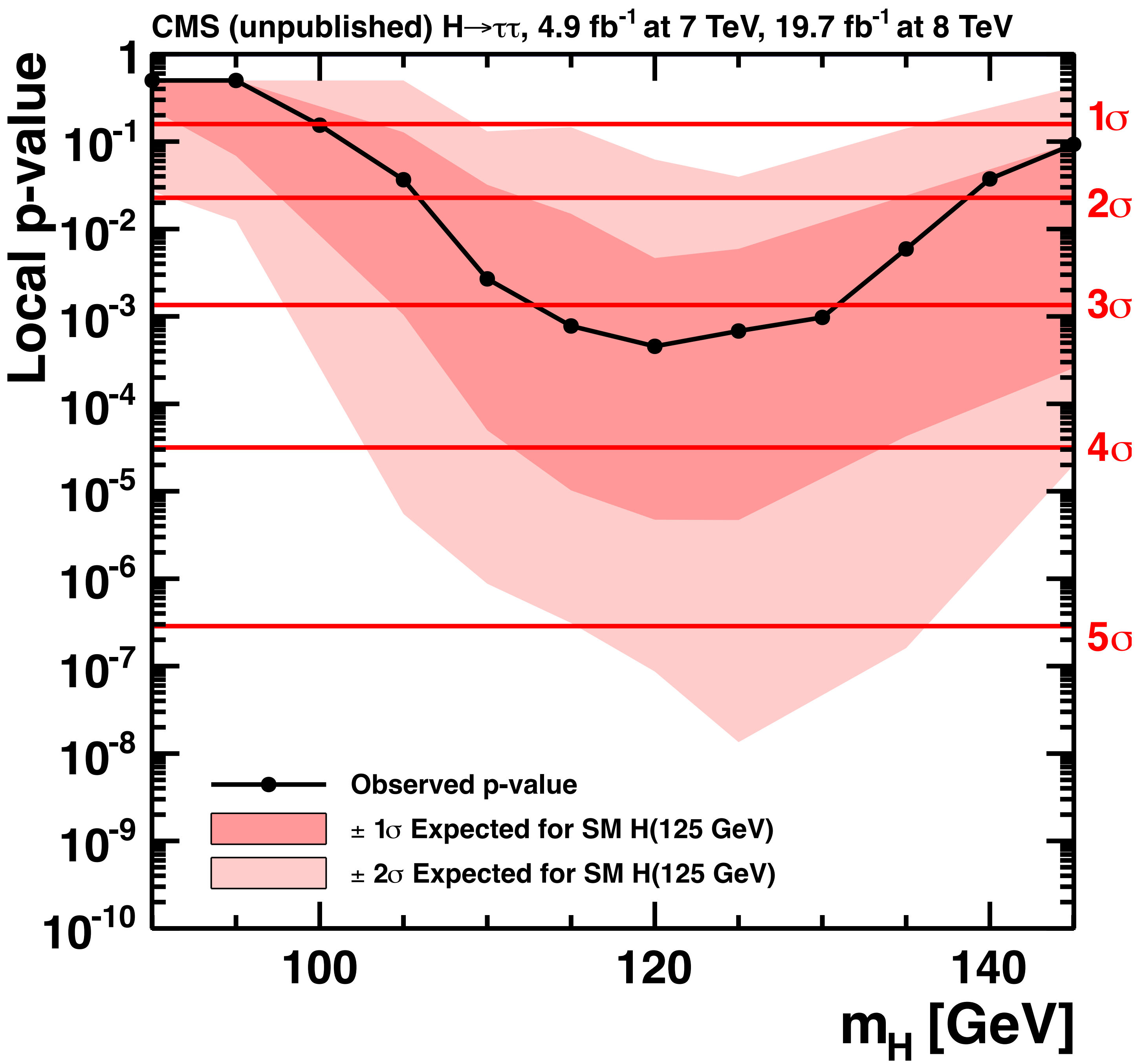
SM H(125) + background expected

1.42 x σ_{SM} at m_H = 125 GeV

Observed limit is 1.26 x σ_{SM} at m_H = 125 GeV

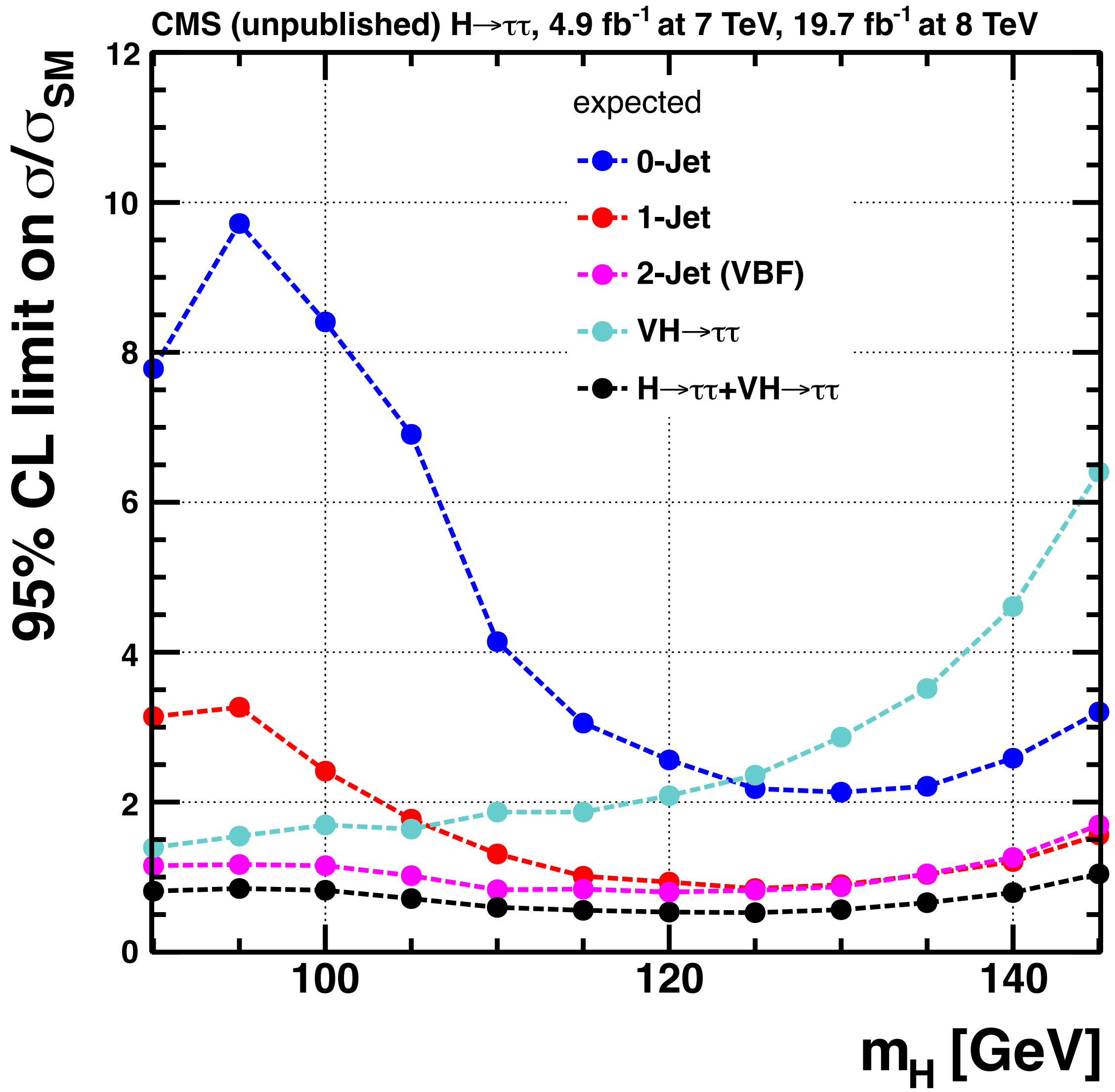
Excess compatible with SM Higgs signal at m_H = 125 GeV

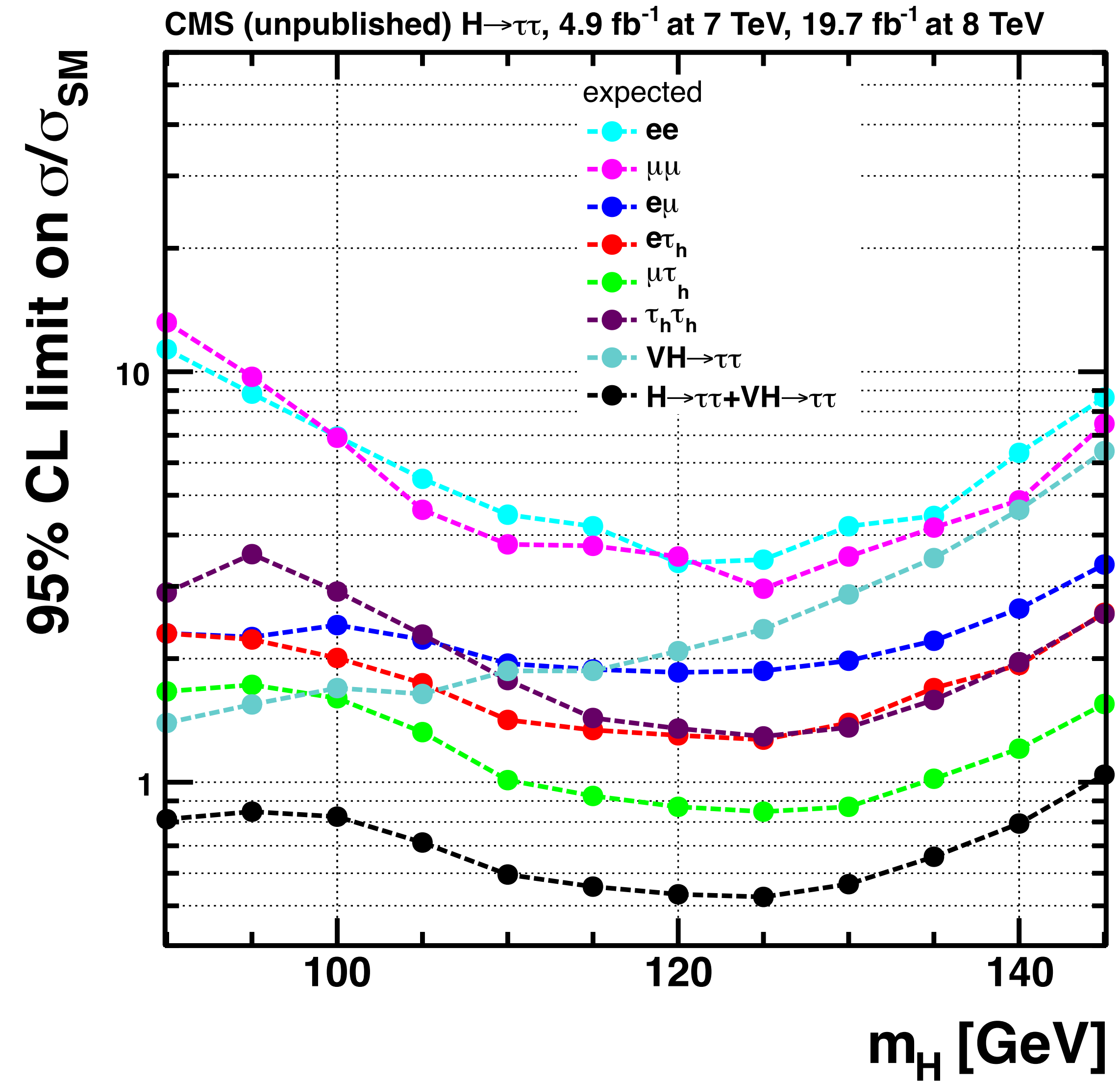
Expected significance



The observed significance (solid line) is compared to the uncertainty bands on the expectation for a SM Higgs boson with m_H = 125 GeV.

Expected sensitivity



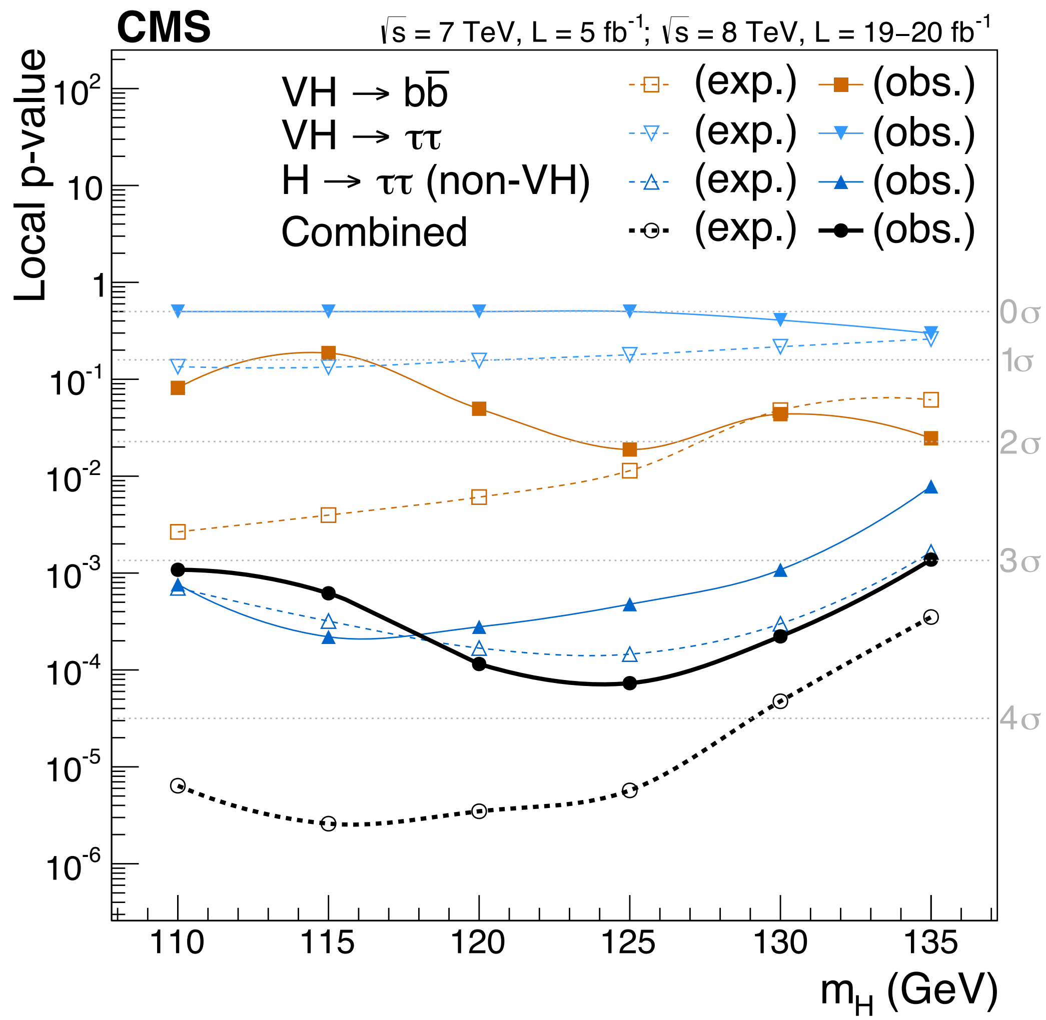


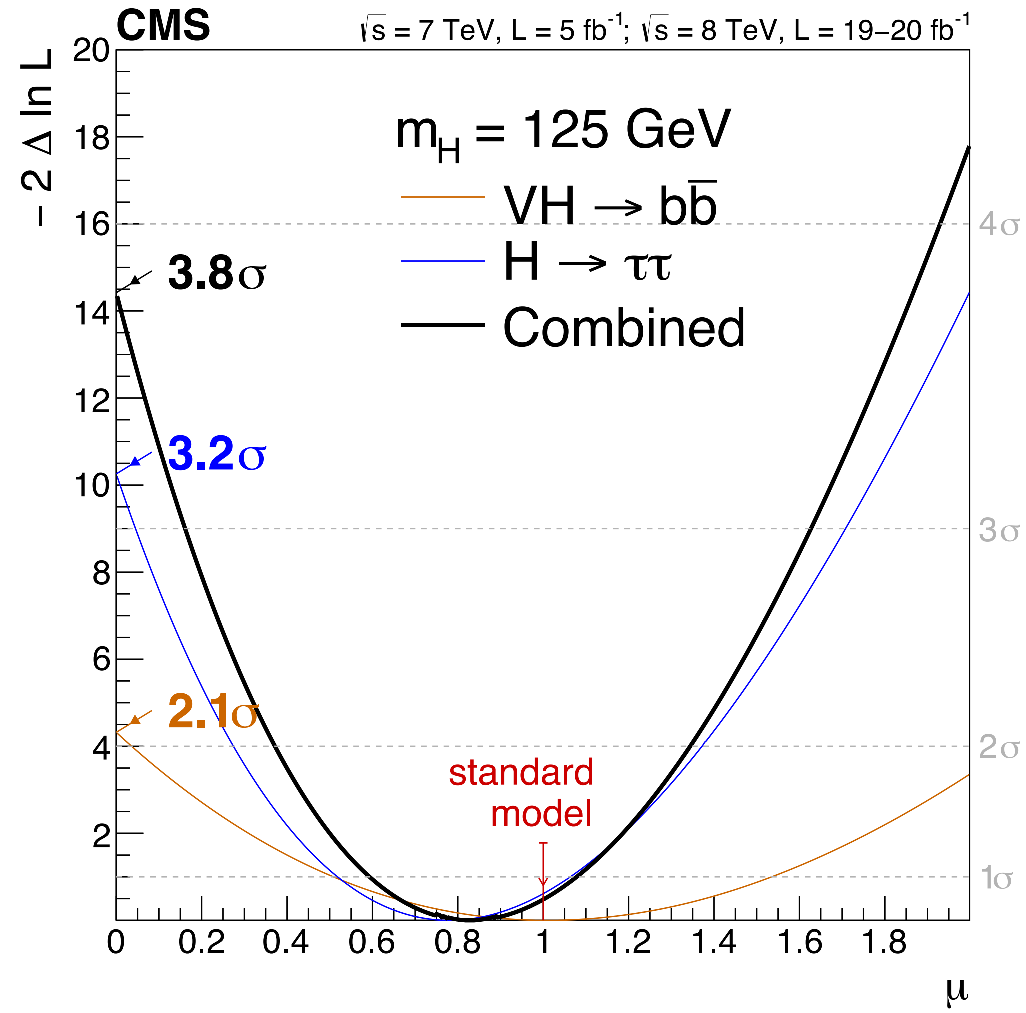
- 1-Jet and 2-Jets (VBF) have approximatively the same sensitivity for $m_H > 110$ GeV
- VH contributes significantly for $m_H < 110$ GeV

- Approaching sensitivity to SM Higgs in single channels
  - exp. limit $m_H = 125$ GeV
    - $\mu\tau_h$ 0.86 x σ_{SM}
    - $e\tau_h$ 1.28 x σ_{SM}
    - $\tau_h\tau_h$ 1.29 x σ_{SM}

H→ττ and VH→bb̄ combination

http://arxiv.org/abs/1401.6527
https://twiki.cern.ch/twiki/bin/view/CMSPublic/Hig13033PubTWiki





channel m_H = 125 GeV	significance		best fit μ
	expected	observed	
VH→bb	2.3	2.1	1.0 ± 0.5
H→ττ	3.7	3.2	0.78 ± 0.27
combined	4.4	3.8	0.83 ± 0.24

evidence of Higgs couplings to down type fermions