SM Higgs in Fermion Decay Modes (CMS)

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On behalf of the CMS collaboration

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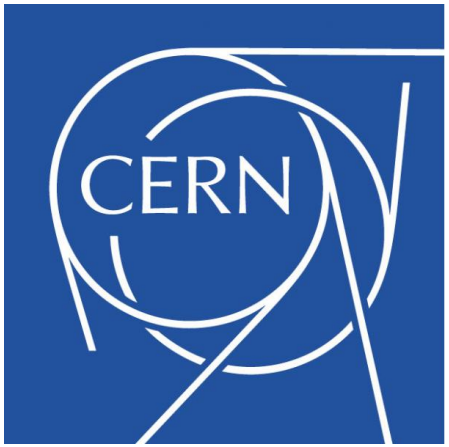
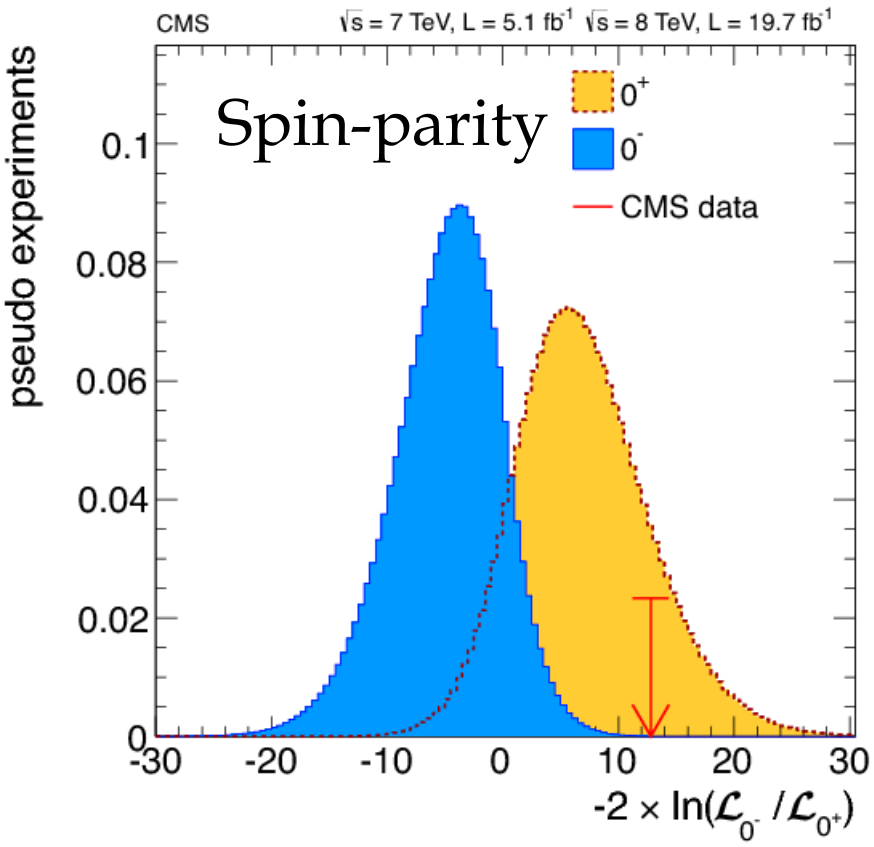
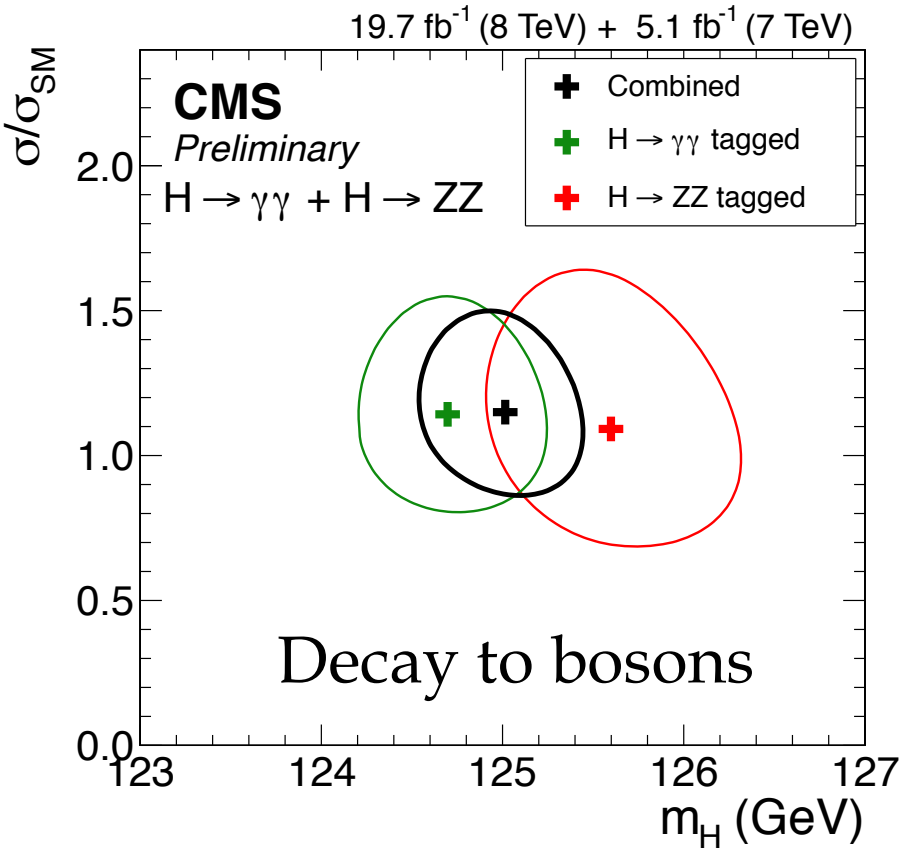


Physics Motivation

- ATLAS/CMS discovered new boson at 125 GeV
  - Property measurements consistent with SM Higgs boson



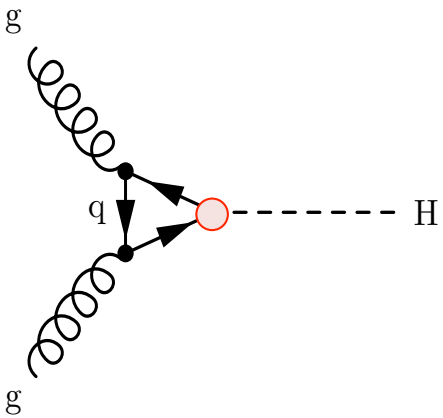


- Q : Is a new Higgs boson responsible for the fermion mass ?

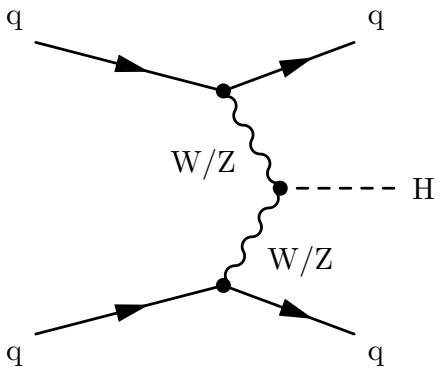
  → **Search for Higgs boson in fermion decay mode**

Analysis Strategy

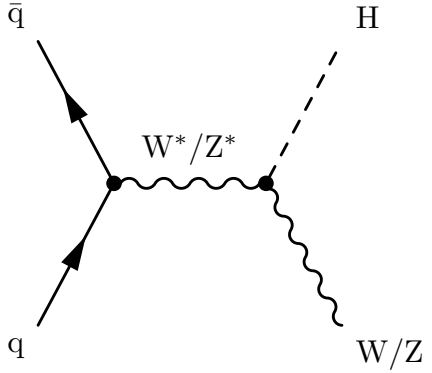
- Search for events with H(125) including fermion coupling (t, b, τ, μ) at one of the vertex



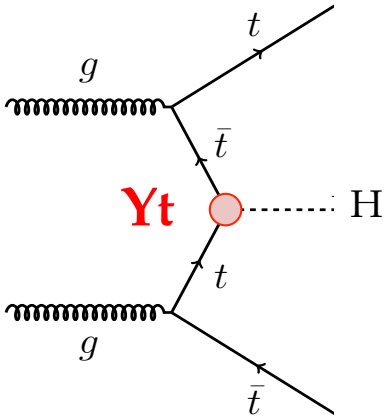
Gluon fusion :
ggH (19pb)



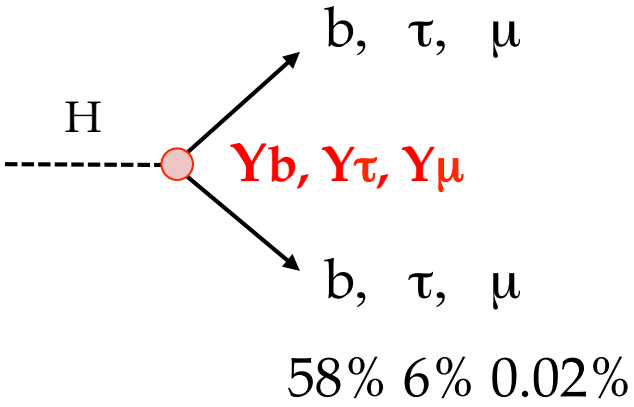
Vector boson fusion :
VBF (1.6pb)



VH (1.1pb)



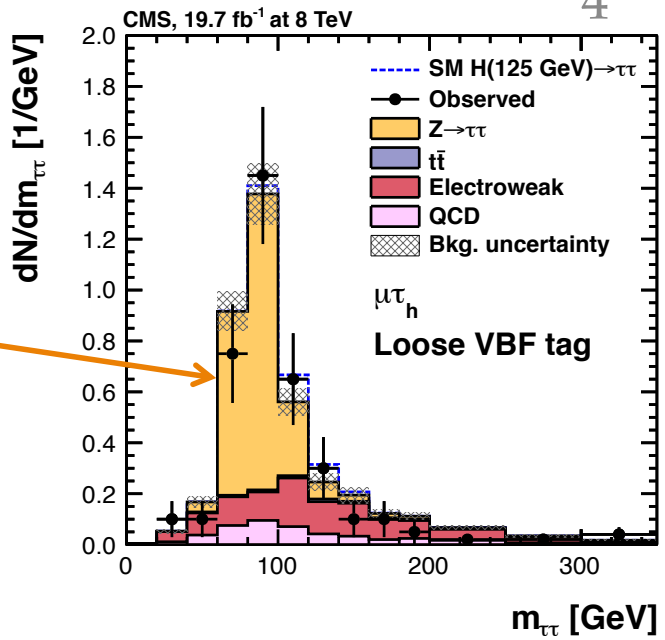
ttH (0.1pb)



	Production	Decay
Tau (Yτ)	ggH, VBF , VH	**H → ττ**
Bottom (Yb)	VH	**H → bb**
Top (Yt)	**ttH**	H → ττ, bb, WW, ZZ, γγ
Muon (Yμ)	Inclusive	**H → μμ**

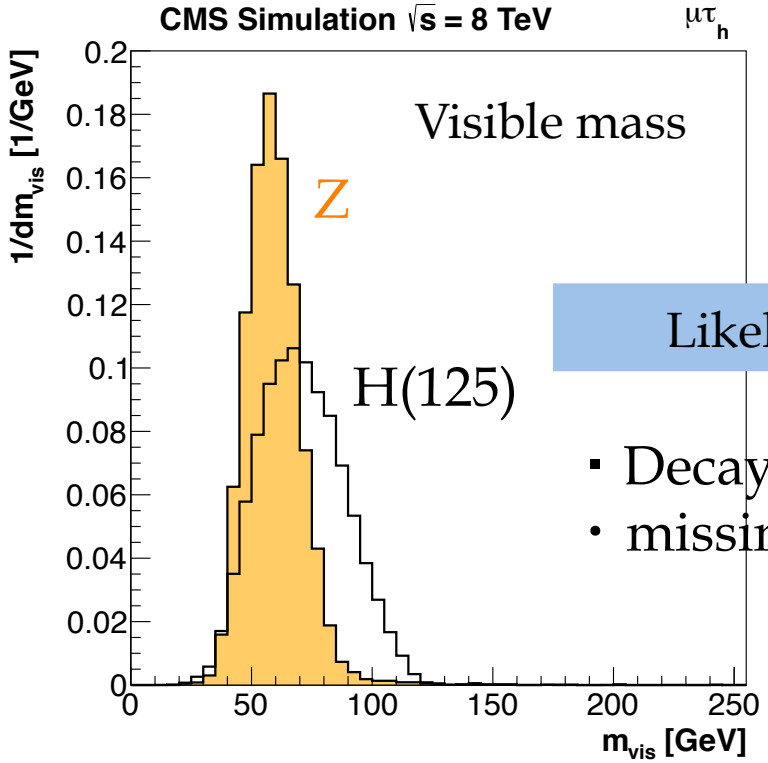
Search for H → ττ

- Find broad excess of $m_{\tau\tau}$ distribution on top of $Z \rightarrow \tau\tau$ backgrounds



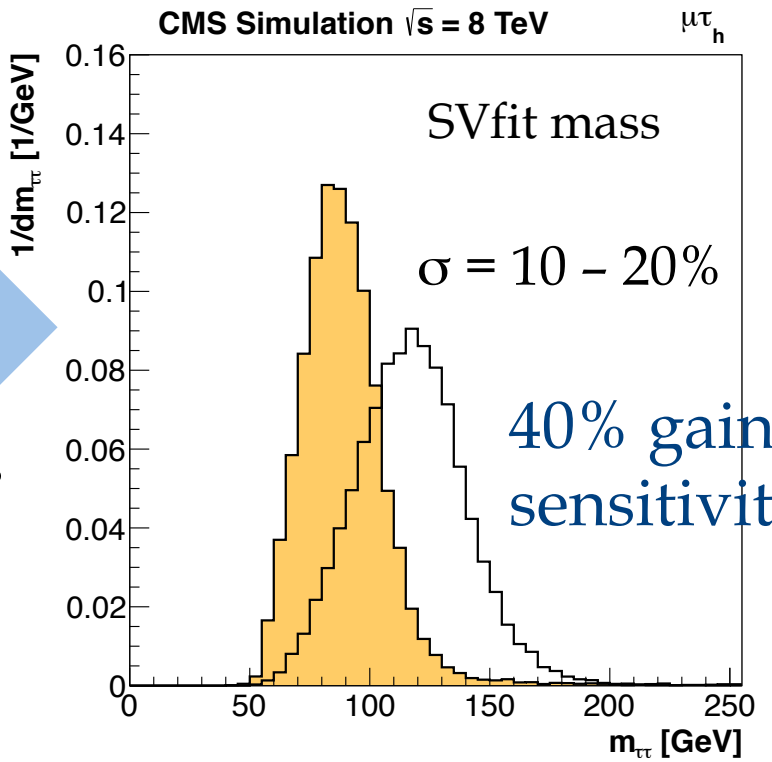
✓ Control of all backgrounds from data

✓ Better Z & H(125) separation in $m_{\tau\tau}$



Likelihood

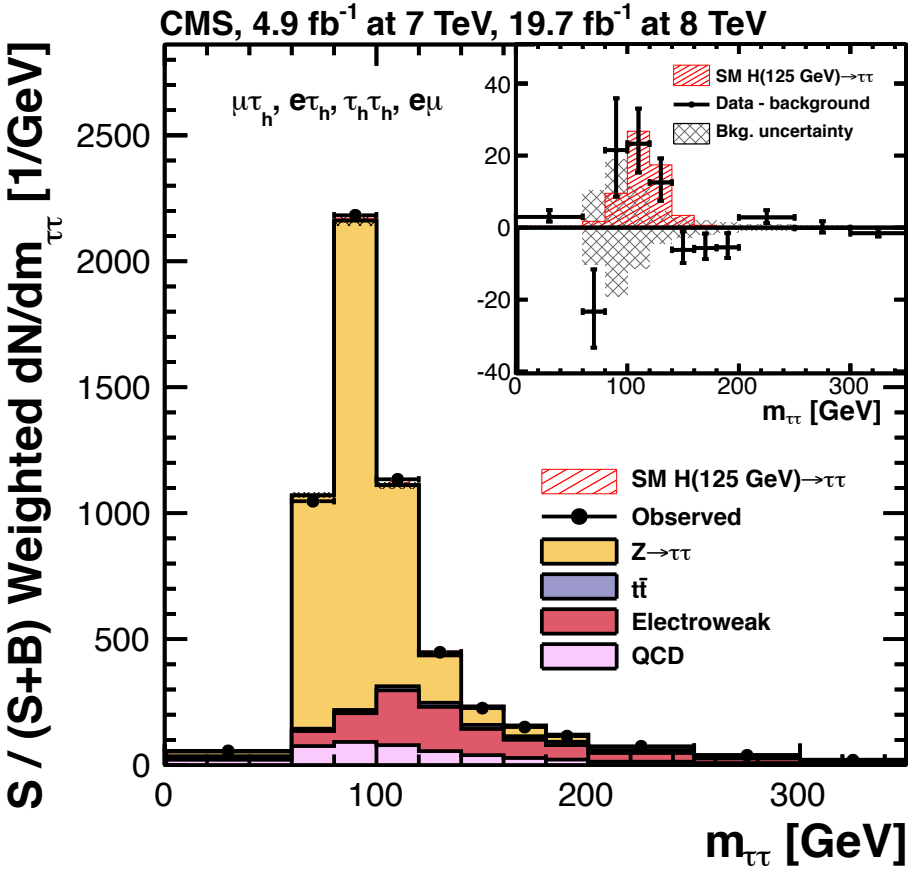
- Decay products
- missing E_T

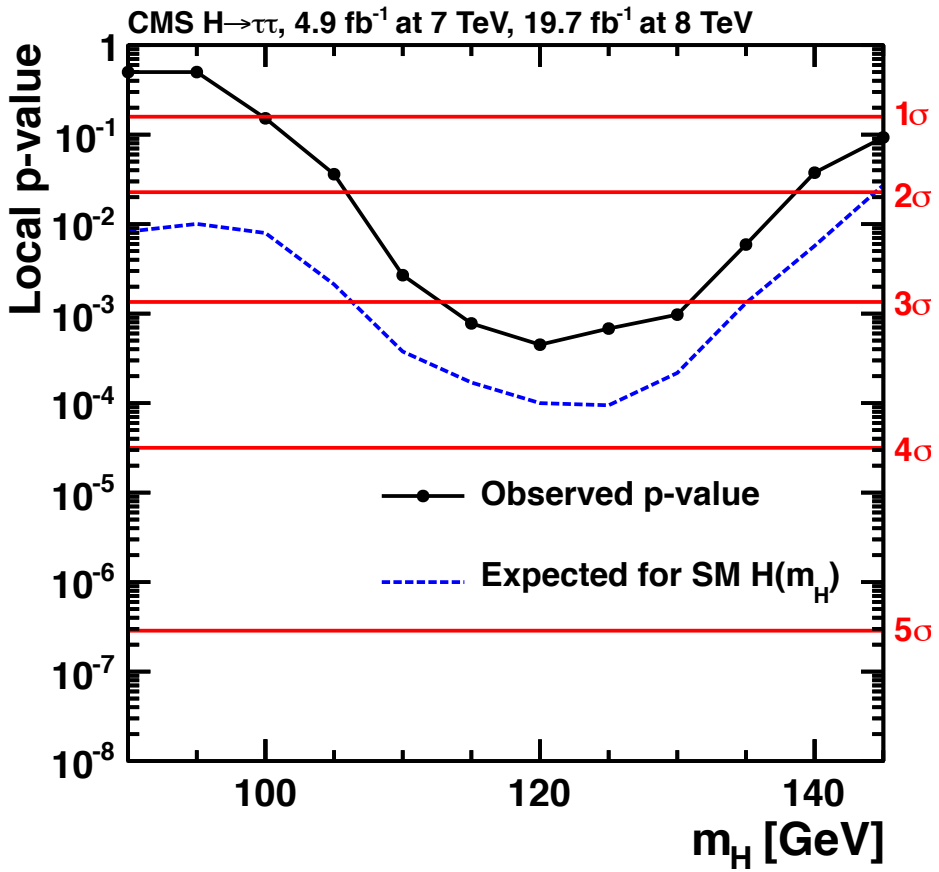


40% gain in sensitivity

$H \rightarrow \tau\tau$: Results (4.9 + 19.7 fb^{-1})

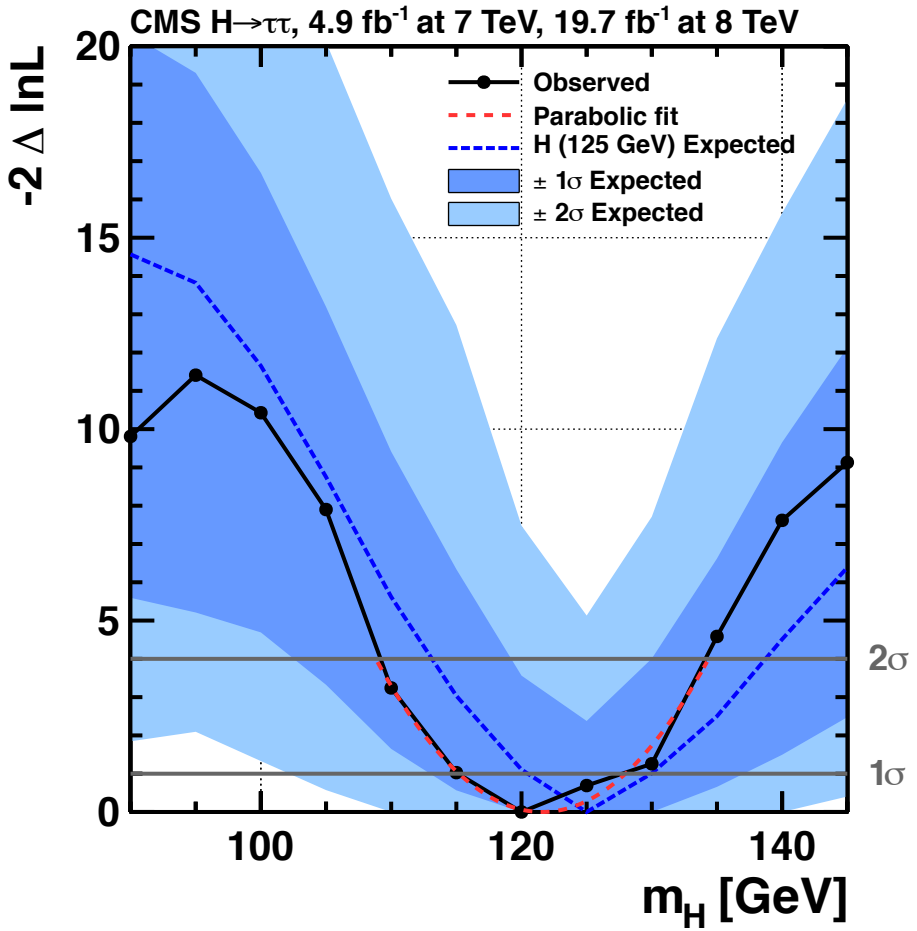
- Fit to $m_{\tau\tau}$ in 6 di-tau final states ($\tau_e\tau_h$, $\tau_\mu\tau_h$, $\tau_\mu\tau_e$, $\tau_e\tau_e$, $\tau_\mu\tau_\mu$, $\tau_h\tau_h$) categorized by # jet, lepton p_T, $p_T^{\text{di-tau}}$ to raise sensitivity

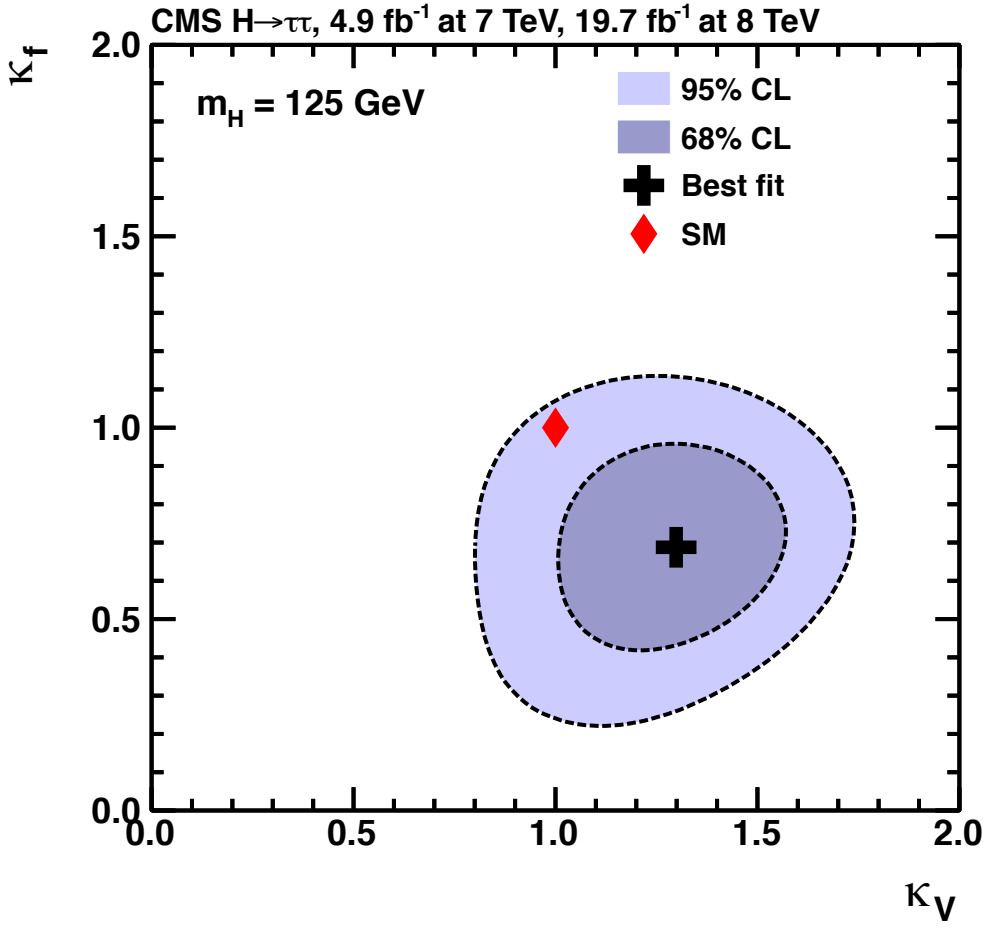




3.2σ (exp 3.7σ) with $\mu = \sigma/\sigma_{SM} = 0.78 \pm 0.27$ at 125 GeV

$H \rightarrow \tau\tau$: Mass and Couplings





$m_H^{\text{best fit}} = 122 \pm 7$ GeV

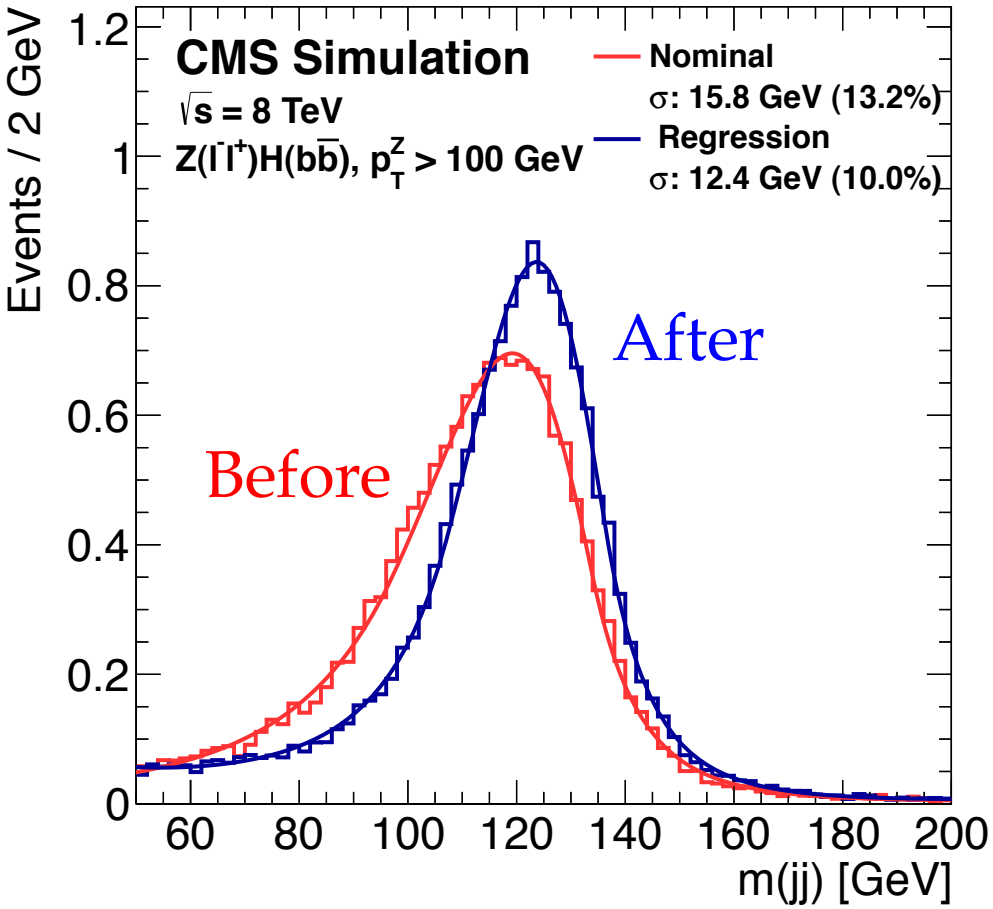
Assume : $\kappa_W = \kappa_Z$ and $\kappa_t = \kappa_b = \kappa_\tau$

Compatible with 125.0 ± 0.3 GeV measured by γγ and ZZ

Coupling compatible with SM (coupling ∝ m_f)

Search for VH(bb)

- Large background → focus on W($l\nu$)H, Z(ll, $\nu\nu$)H
- Construct BDT score as a final discriminant
  - Input : m_{jj}, b-tag discriminant score, # jet, kinematics

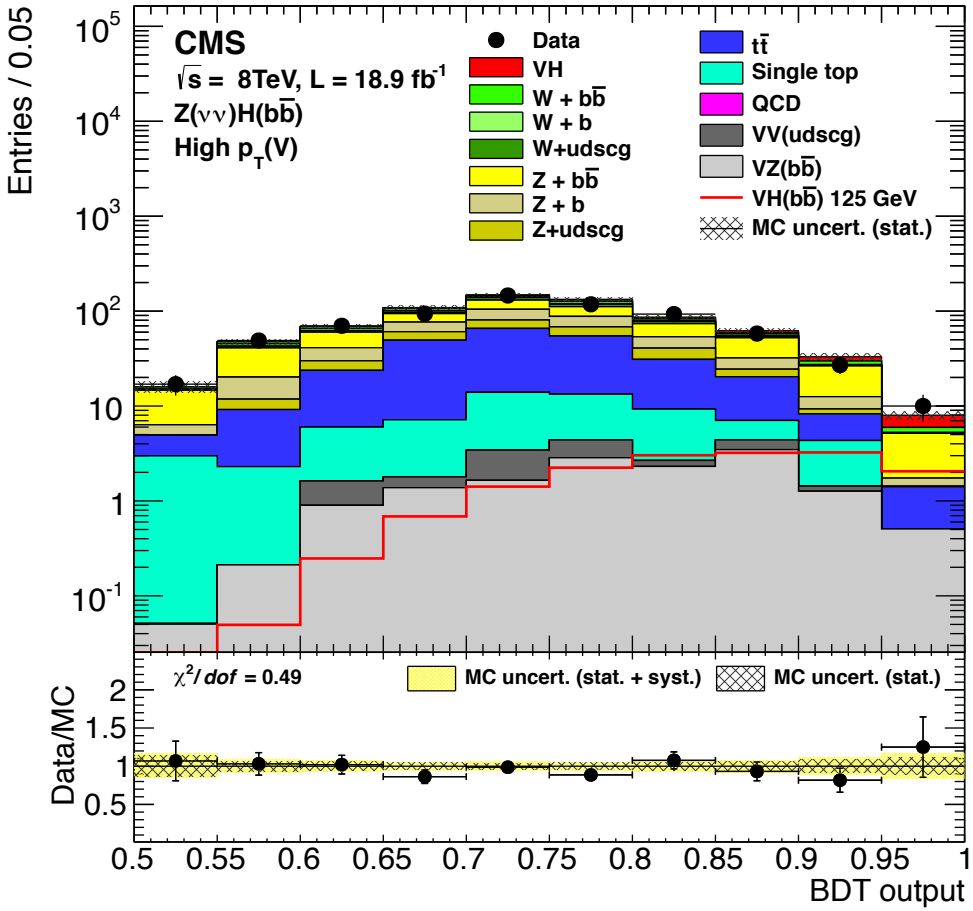


- Improve m_{jj} resolution using MVA trained on VH signal with jet structure and b-tag variables
- 10 – 20% gain in sensitivity

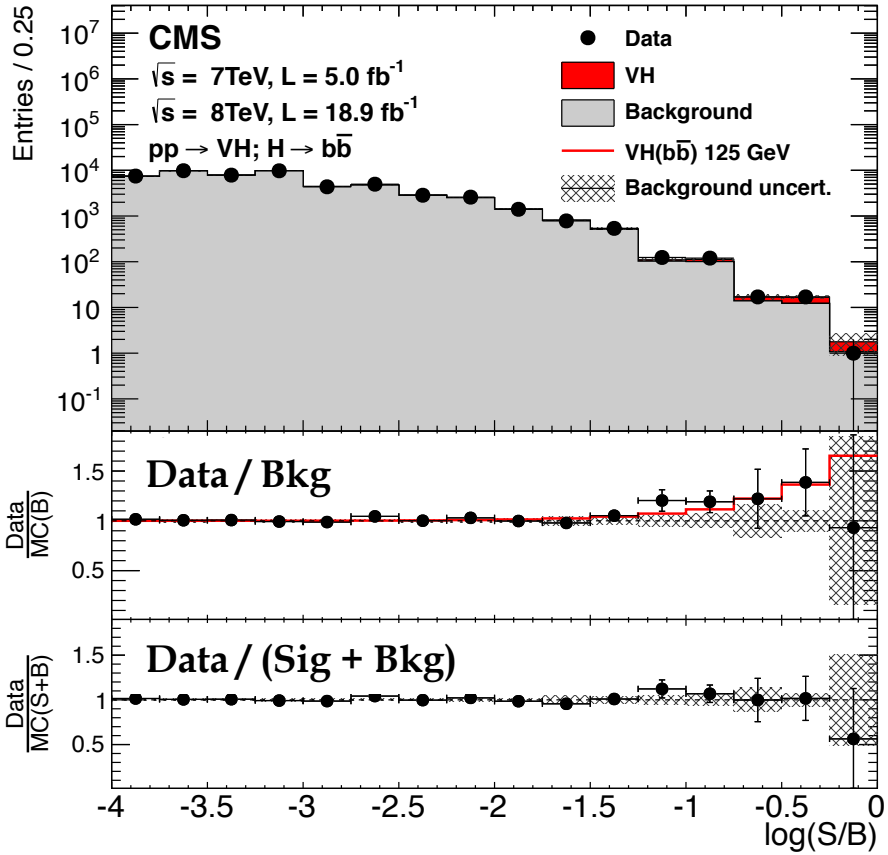
VH(bb) : Results (5.0 + 18.9 fb^{-1})

- Simultaneous fit to BDT in 14 different categories
  - Categorization by p_T^{jj}, i.e Higgs boson p_T

Z(νν)H(bb) in p_T^{jj} > 170 GeV

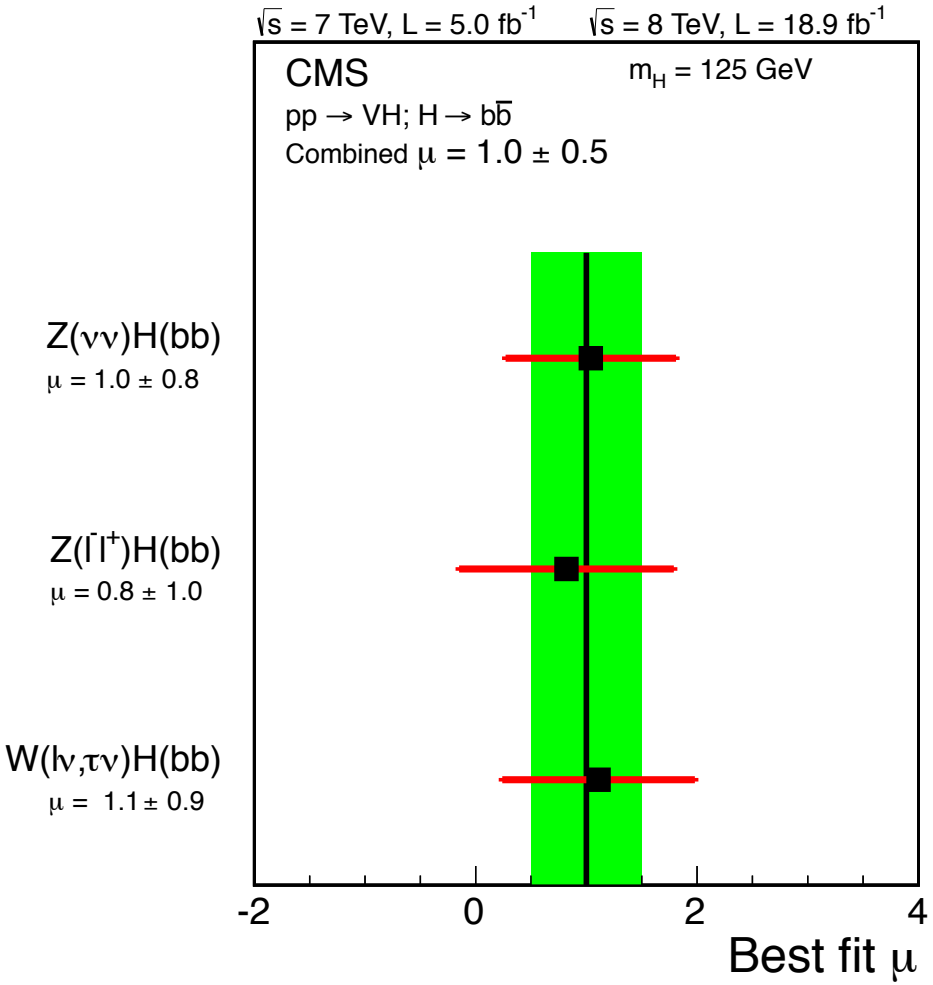


Combination (sorted by S/B)

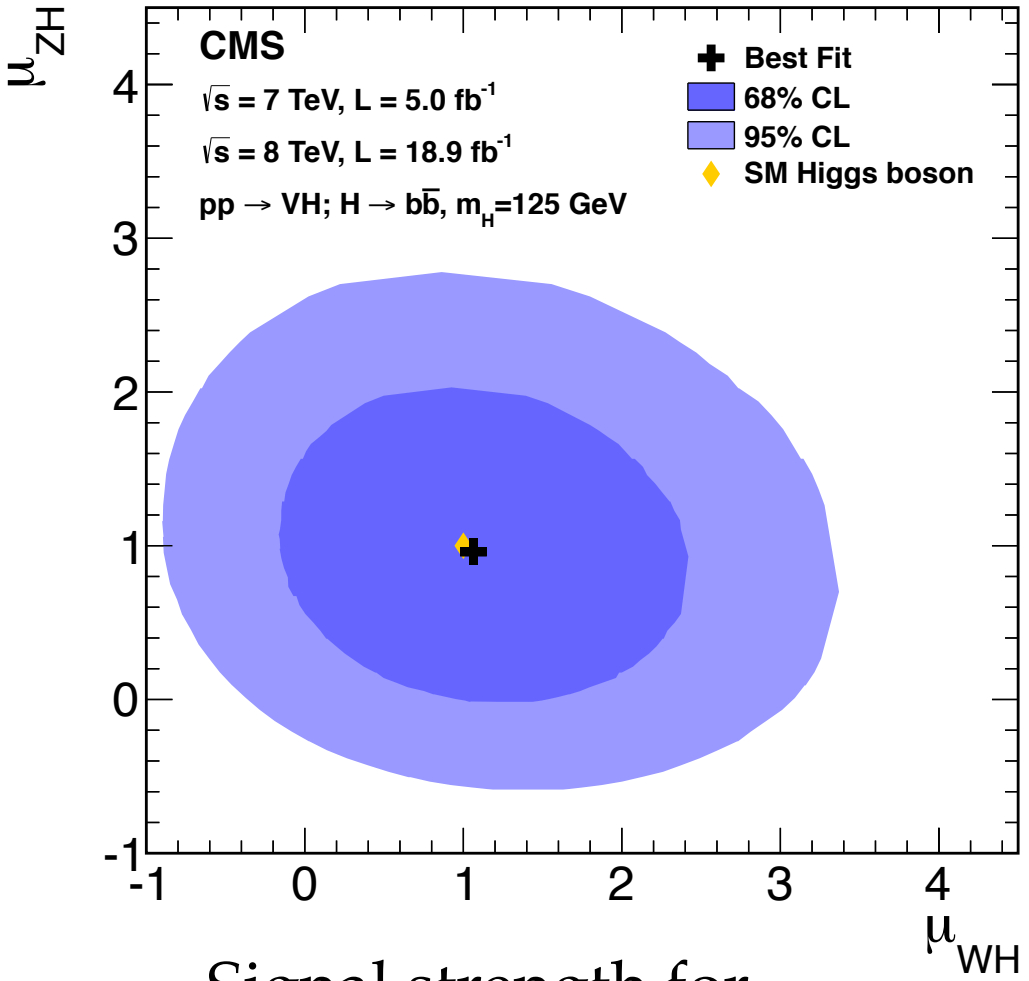


Obs. 2.1σ (Exp. 2.1σ)

VH(bb) : μ and Couplings



Combined μ = 1.0 ± 0.5

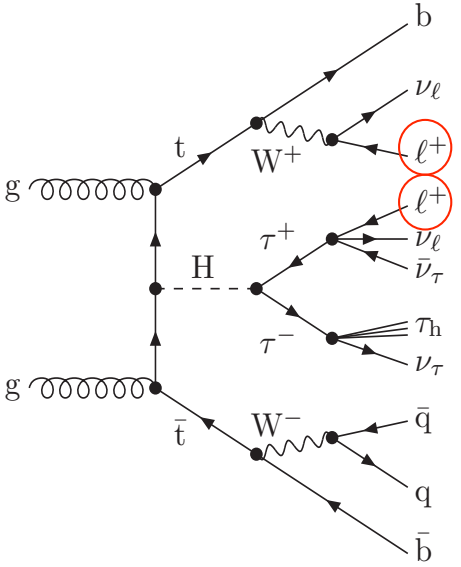


Signal strength for
WH and ZH production

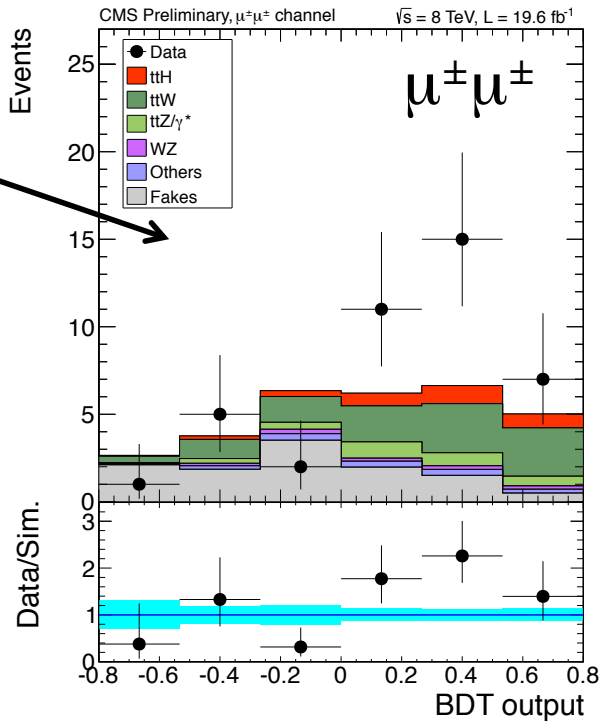
Signal strength and couplings consistent with SM

Search for ttH (19.6 fb^{-1})

- Exploit ≥ 1 lepton from tt decay
  - H → WW, ZZ, $\tau_l\tau_h$: Multi-lepton
  - H → bb, $\tau_h\tau_h$: Fermion
  - H → γγ : Photon



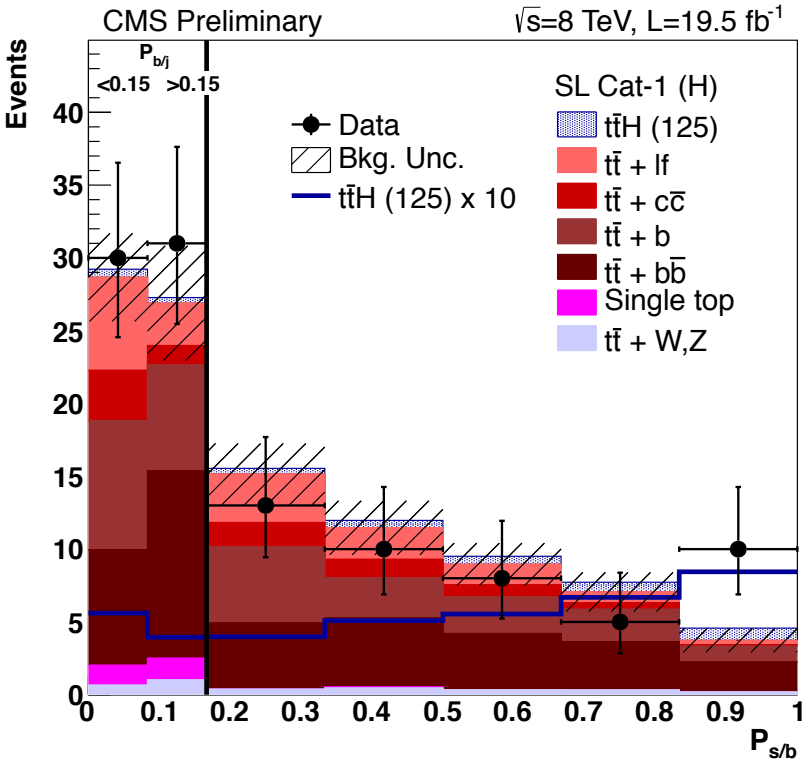
channel	Signal strength
ttH + Multi-lepton	$3.94^{+1.70}_{-1.44}$
ttH + H → $\tau_h\tau_h$	$-1.33^{+6.08}_{-3.60}$
ttH + H → bb	$0.65^{+1.85}_{-1.81}$
ttH + H → γγ	$2.67^{+2.41}_{-1.73}$
Combined	$\mathbf{2.76^{+1.05}_{-0.92}}$

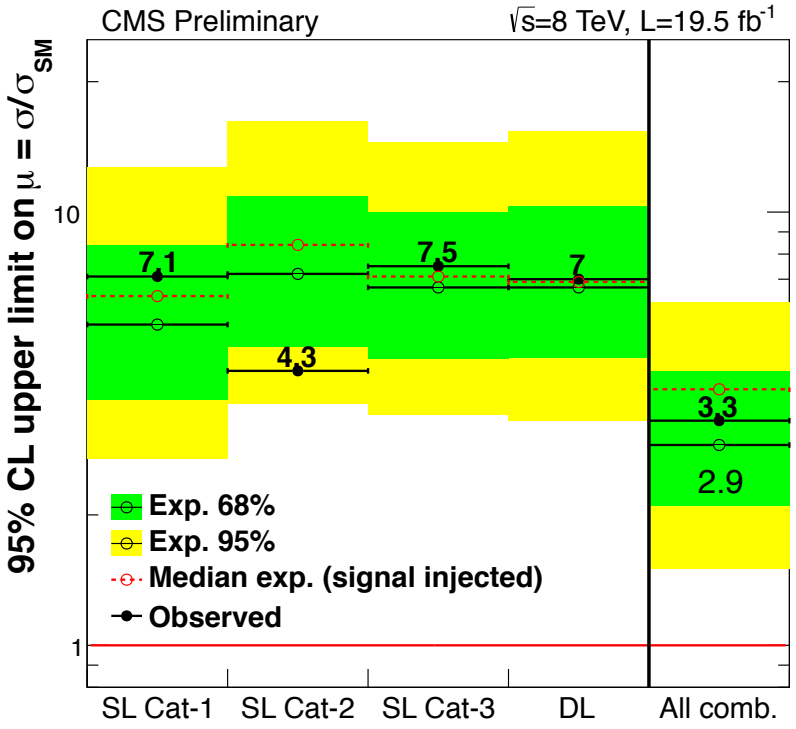


Signal strength compatible with SM (μ=1) at 2σ level

ttH + H → bb : New method

- Matrix element method
  - Assign signal and background probability to each event using matrix element information
  - Likelihood ratio $P_{s/b}$ used for signal extraction

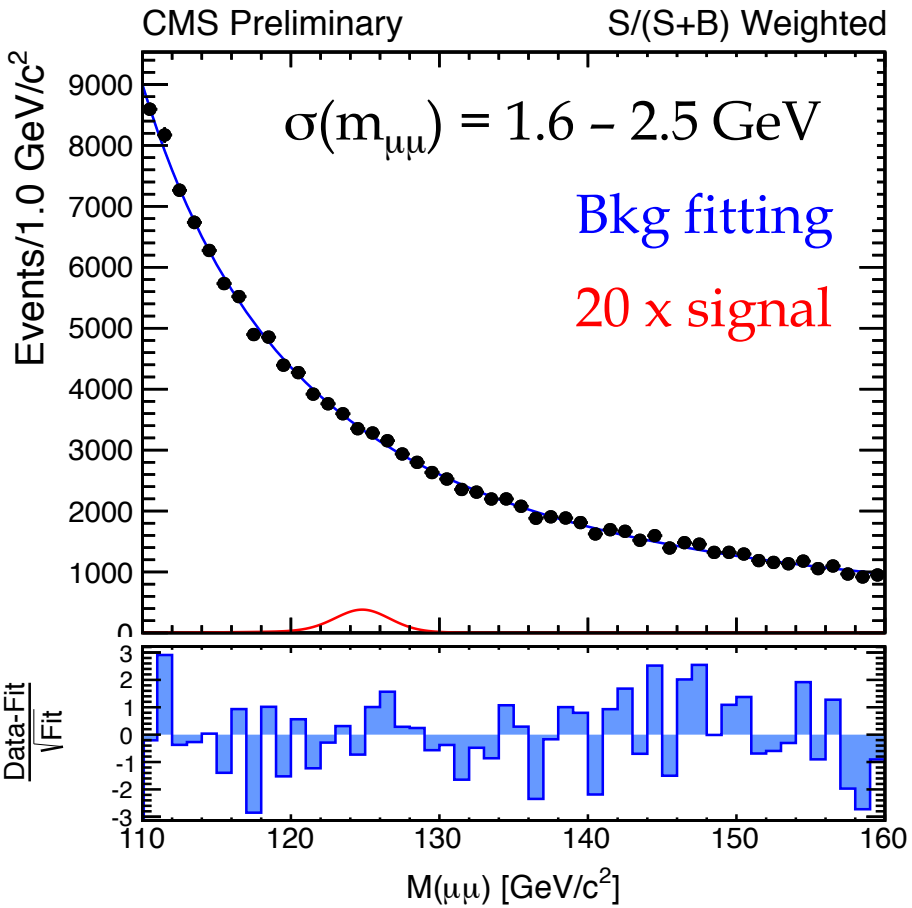


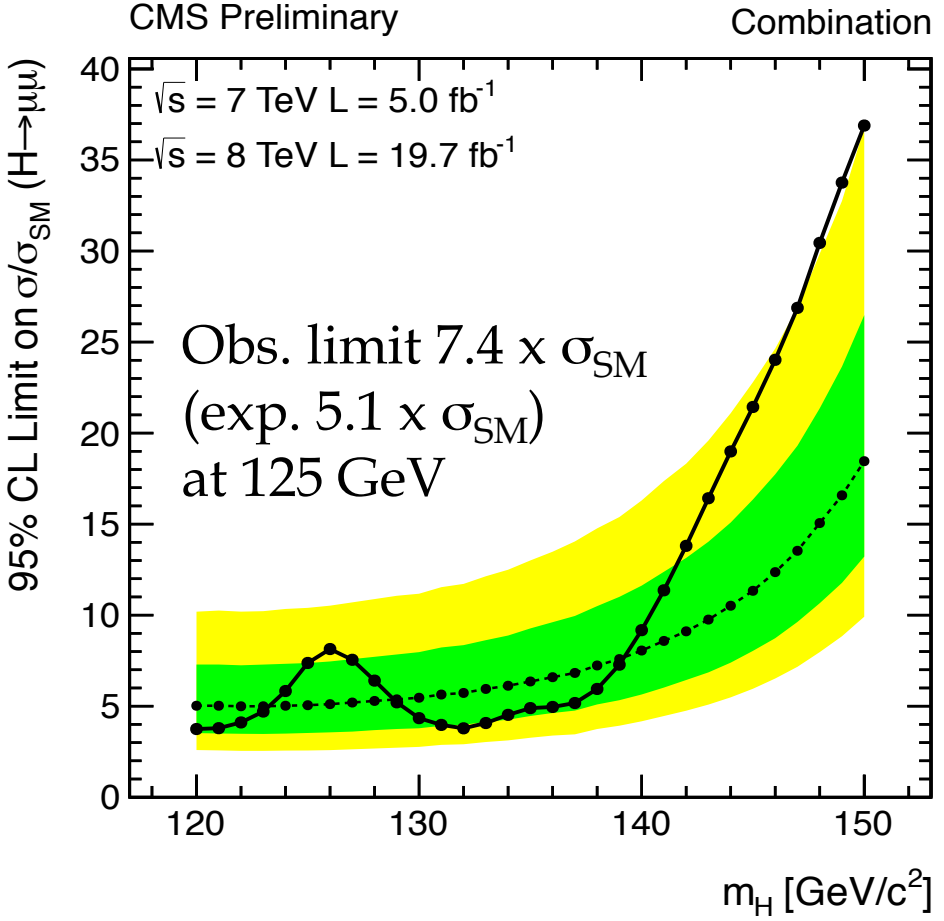


20% improvement from previous analysis (exp. limit 3.7 → 2.9)

Search for H → μμ (5.0 + 19.7 fb^{-1})

- Signal extraction by fitting $m_{\mu\mu}$ distribution, categorized by # jet, η^{μ} and $p_T^{\mu\mu}$

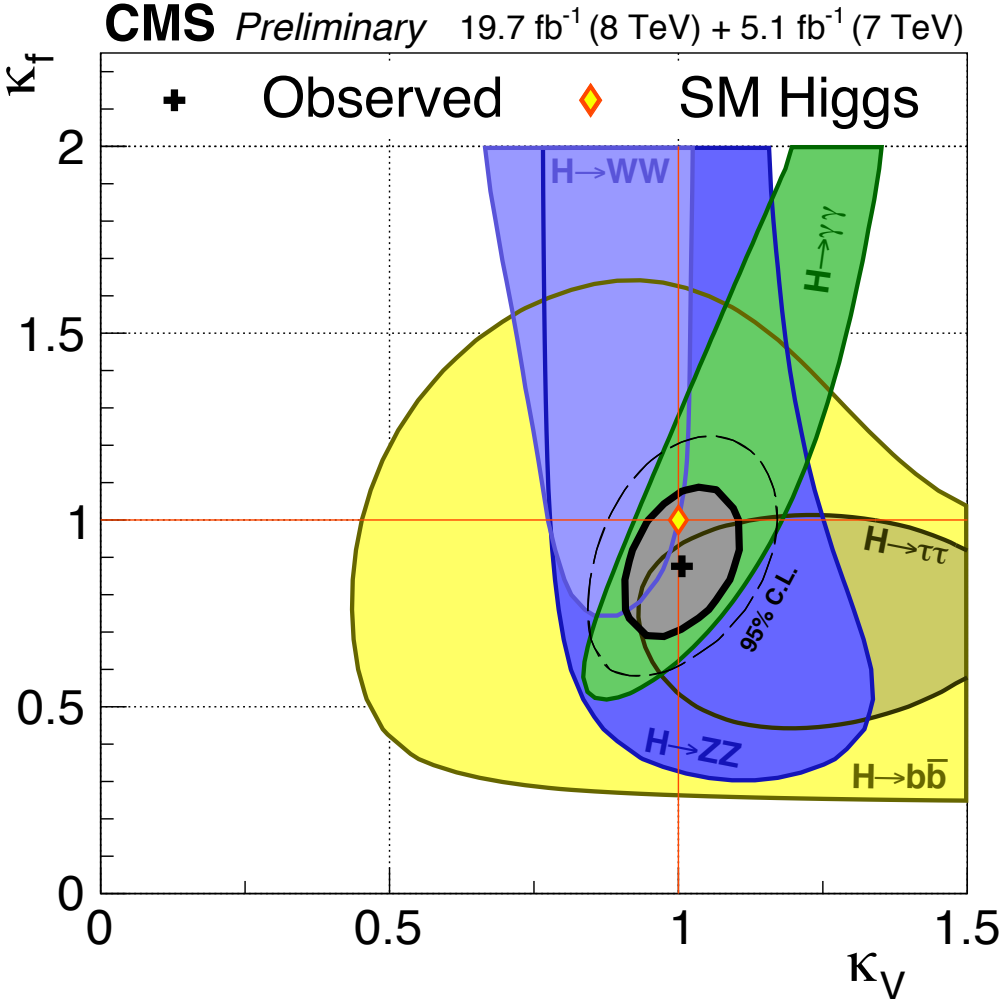


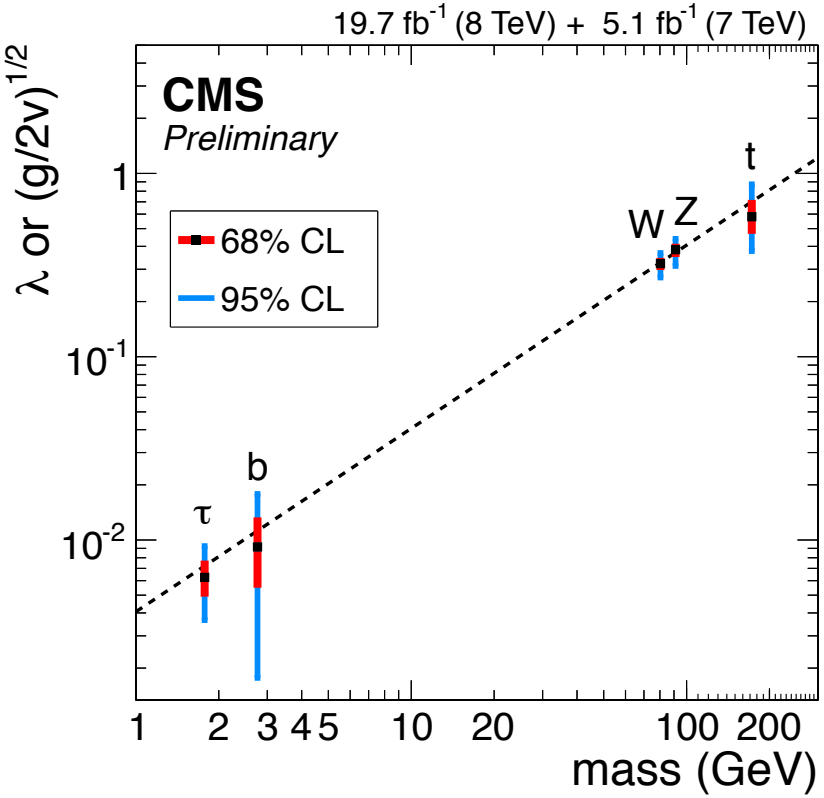


Limited by statistics. Higgs decay Br. is not same with ττ

Combination

- H → bb and H → ττ results are combined
  - Observed significance 3.8σ (Exp. 4.4σ)
  - Combined signal strength μ = 0.83 ± 0.24





$$\lambda_f = \kappa_f (m_f/v)$$

$$\sqrt{g_V/2v} = \sqrt{\kappa_V}(m_V/v)$$

Summary

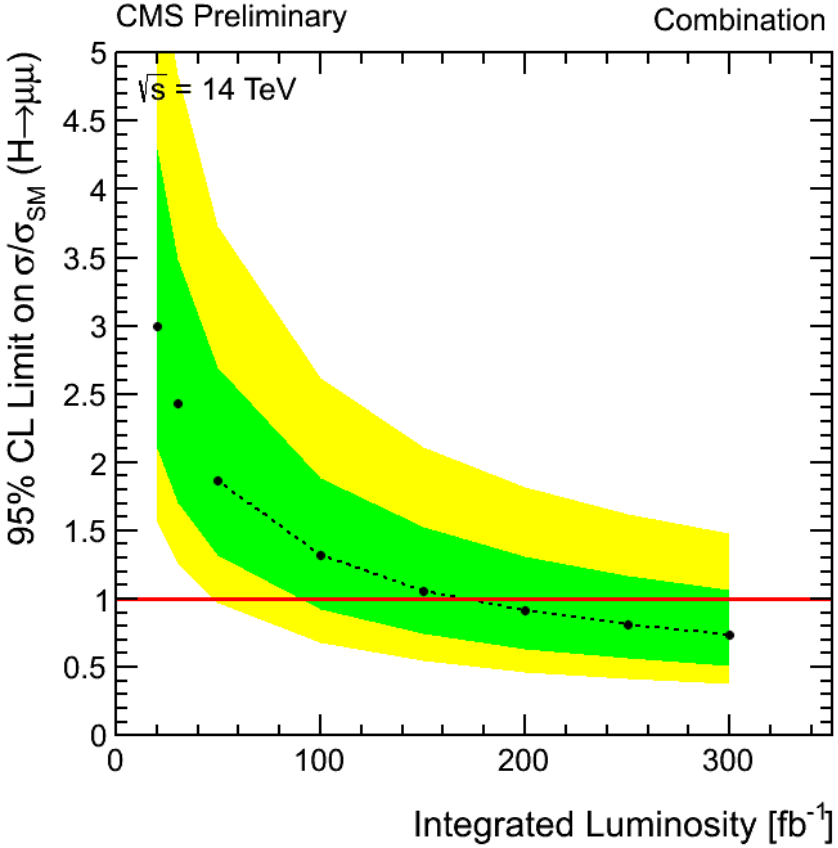
	dataset	μ	Results	Paper
$H \rightarrow \tau\tau$	4.9 + 19.7	0.8 ± 0.3	3.2σ (3.7σ)	JHEP 05 (2014) 104 PRD 89, 012003 Nature, NPHYS3005
VH(bb)	5.0 + 19.5	1.0 ± 0.5	2.1σ (2.1σ)	
			3.8σ (4.4σ)	
ttH	19.6	$2.76\ ^{+1.05}_{-0.92}$	limit $\mu = 4.3$ (1.8)	CMS-PAS-HIG-14-010 12-035, 13-019, 13-020
$H \rightarrow \mu\mu$	5.0 + 19.7	-	limit $\mu = 7.4$ (5.1)	CMS PAS HIG-13-007

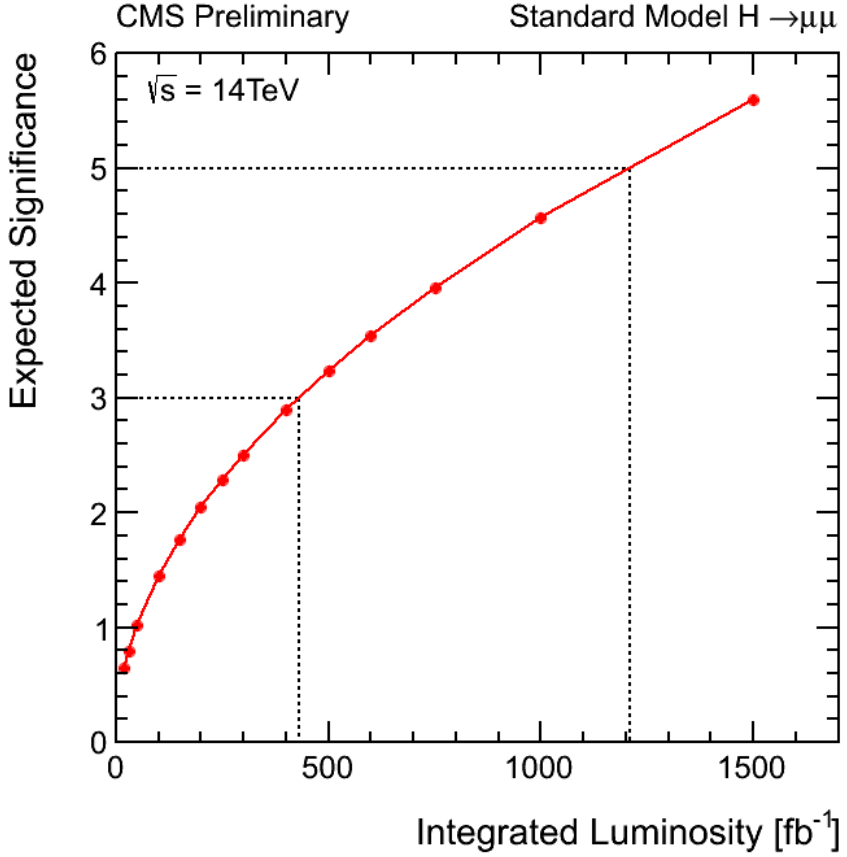
- **Evidence of H(125) decaying into fermions**
  - Looks to be SM Higgs boson although there is plenty of room for deviation
- Most analysis limited by stat. Stay tune in 2015

Spare slide

H → μμ : Future prospect

- Analysis projection to √s = 14 TeV
  - Cross-sections are scaled to 14 TeV
  - All uncertainties use the same values as 8 TeV

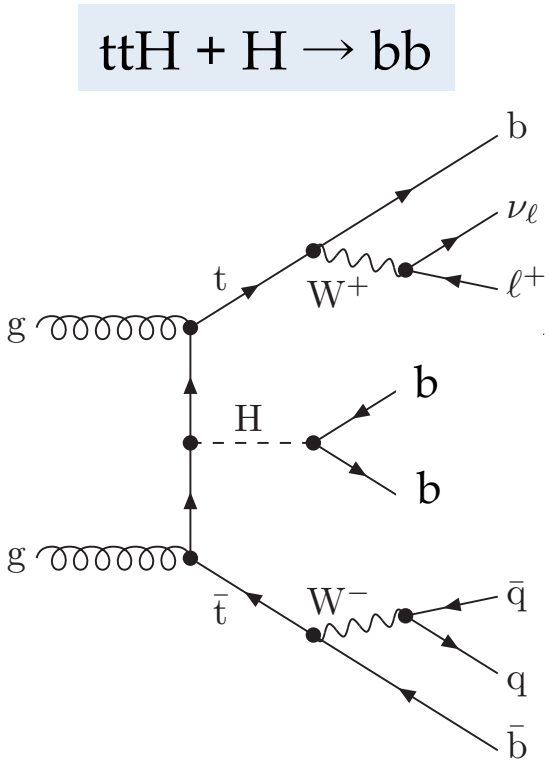


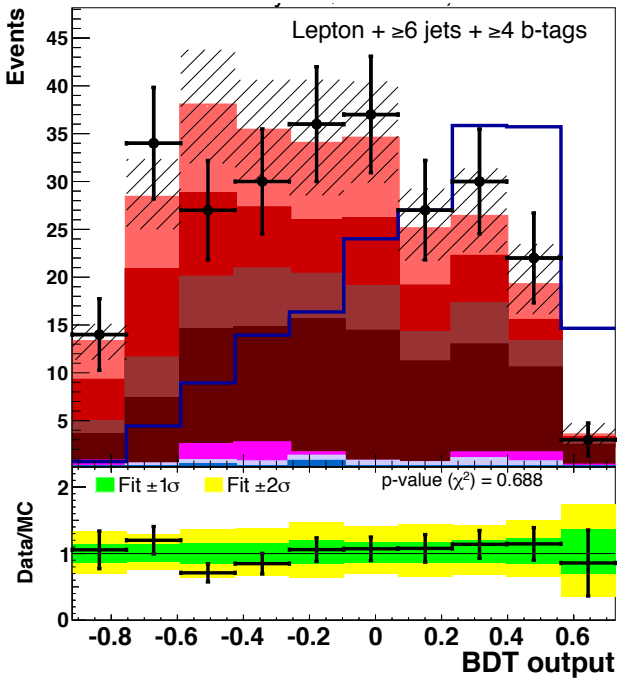


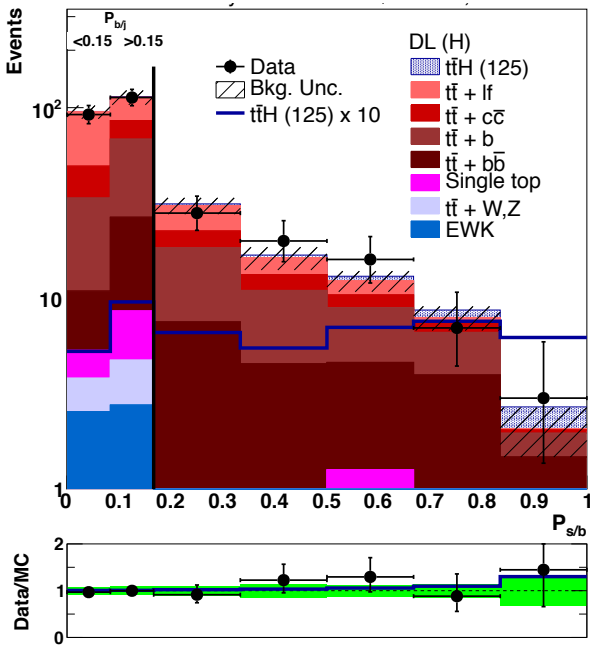
- 3σ evidence with 450/fb, leading to $\sigma(k_\mu) \sim 20 - 30\%$

Search for ttH + H → bb (19.5 fb^{-1})

- bb in coincidence with semi-leptonic tt decay
  - 1 lepton + 6 jets (4 b-tagged)
- Alternative analysis with matrix element method
  - Assign signal and bkg. probability ($P_{s/b}$) density to each event
  - Likelihood ratio of $P_{s/b}$ used to extract the signal



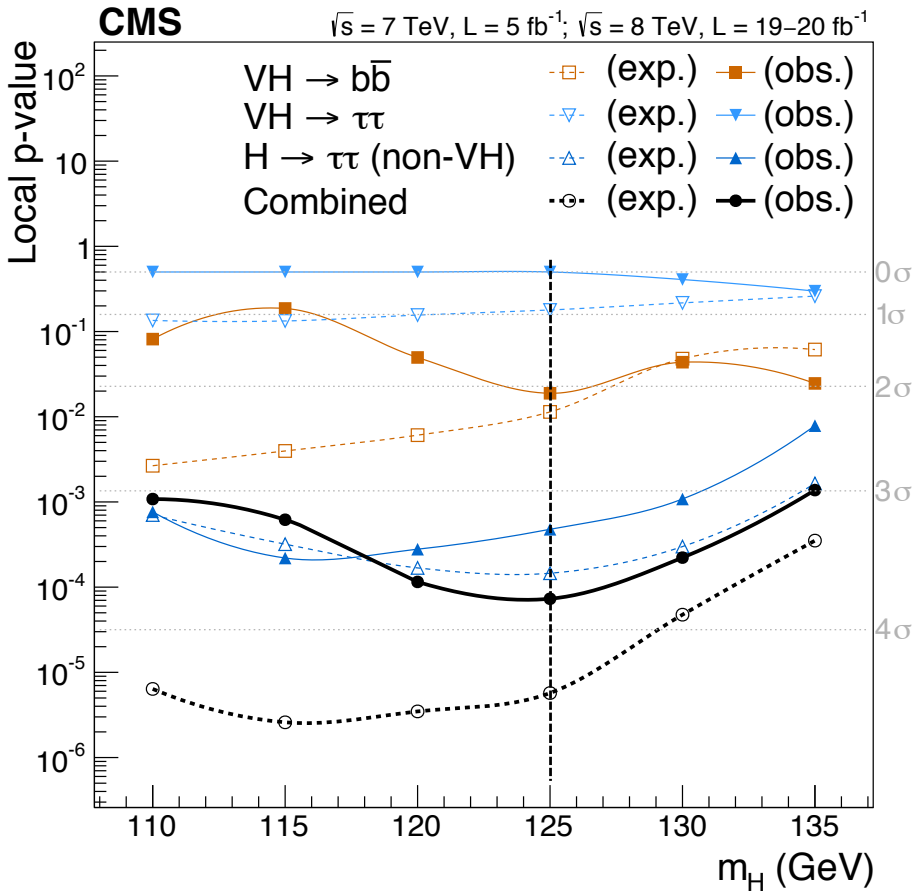




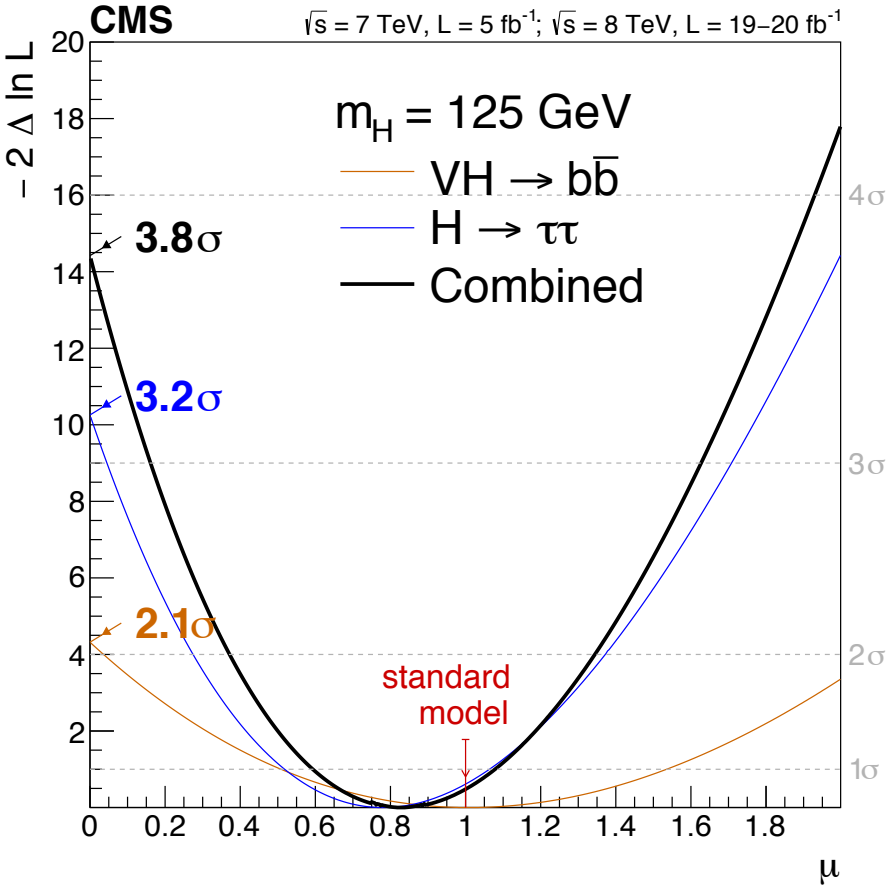
Similar sensitivity between 2 methods

Combination (5.0 + 19 - 20 fb^{-1})

- H → bb and H → ττ results are combined



Obs. significance 3.8 (exp. 4.4)



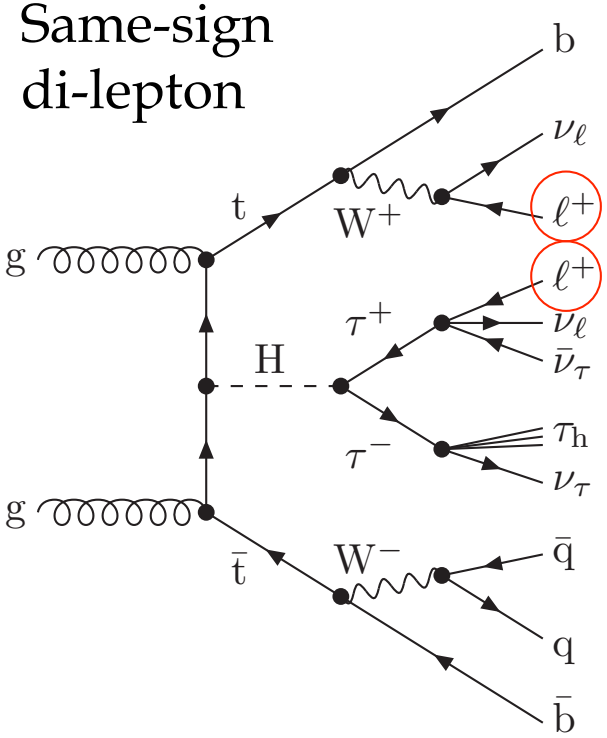
Signal strength μ = 0.83 ± 0.24

Evidence for the direct decay of 125 GeV Higgs boson to fermions

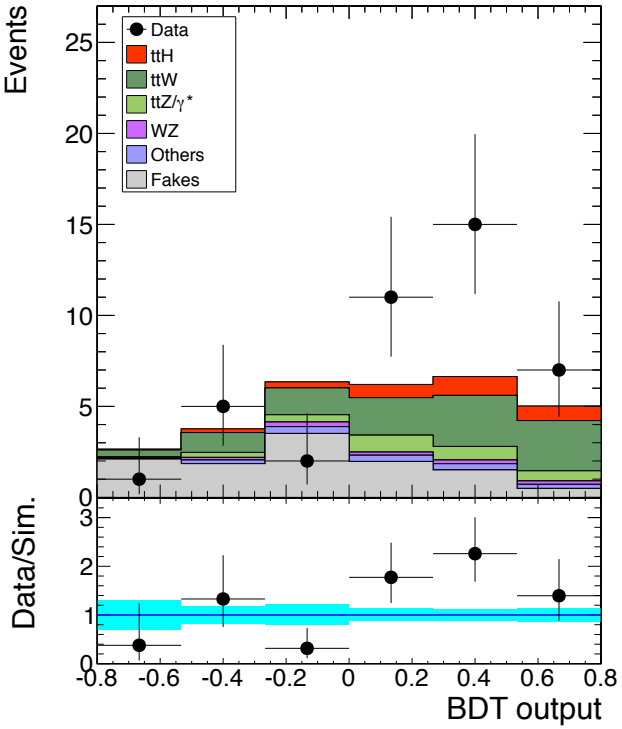
Search for ttH (19.6 fb^{-1})

- Shape analysis of BDT (input : lepton p_T, η, kinematics)
  - simultaneous fit of different jet and b-tag multiplicities
- Di- or Semi-leptonic tt decay is used to increase S/B
- Irreducible ttV background validated in control region

ttH + H → ττ
Same-sign
di-lepton



$\mu^\pm\mu^\pm$ channel



$e^\pm\mu^\pm$ channel