Higgs Fermionic Properties at CMS

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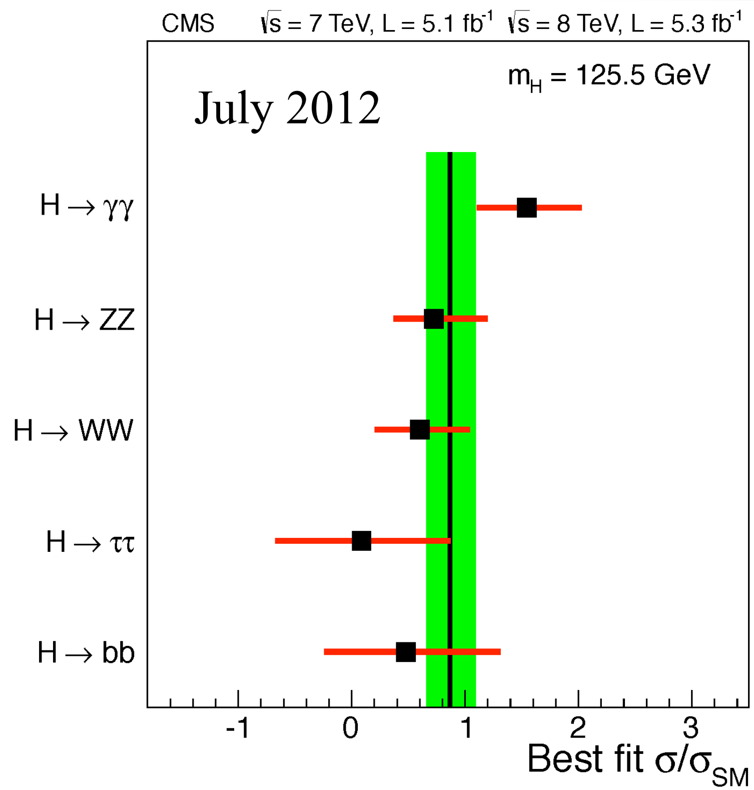
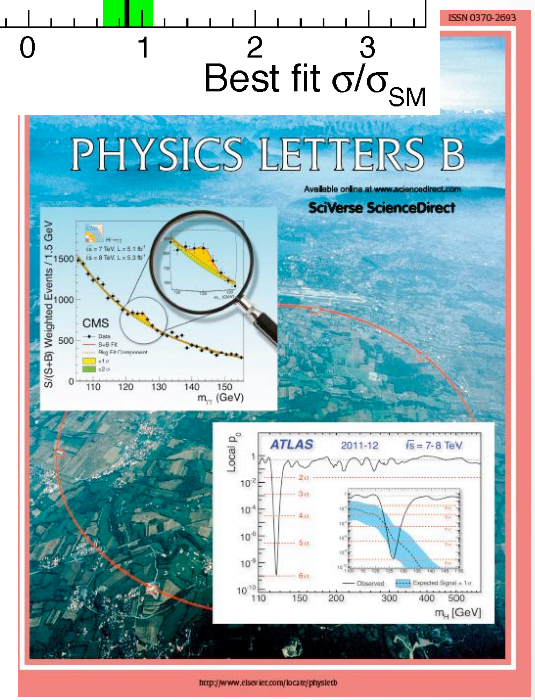
La Thuile 2014

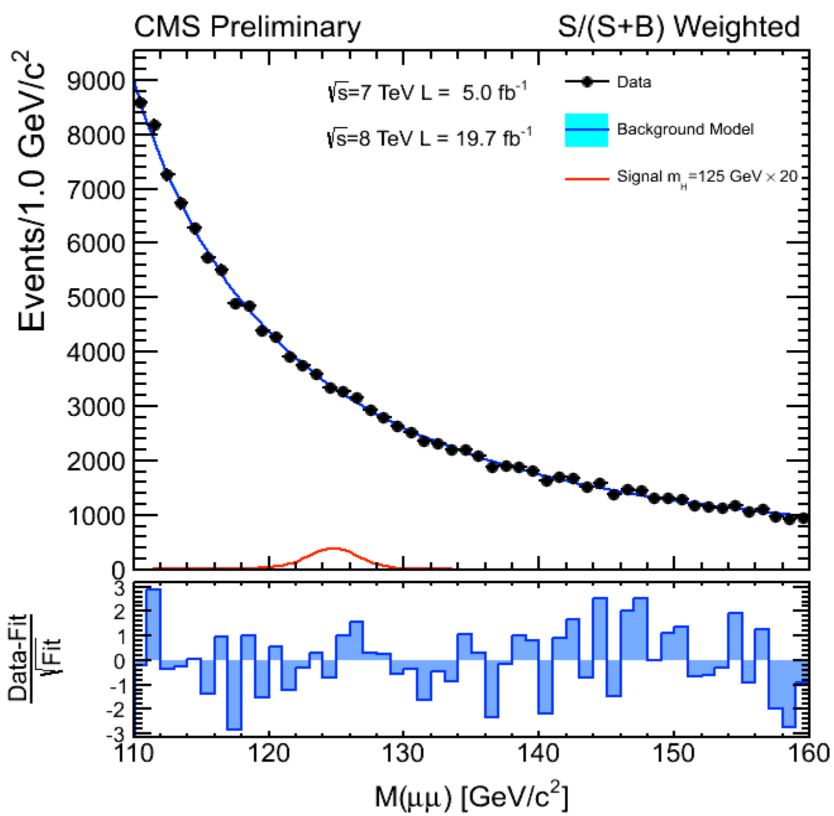
Introduction

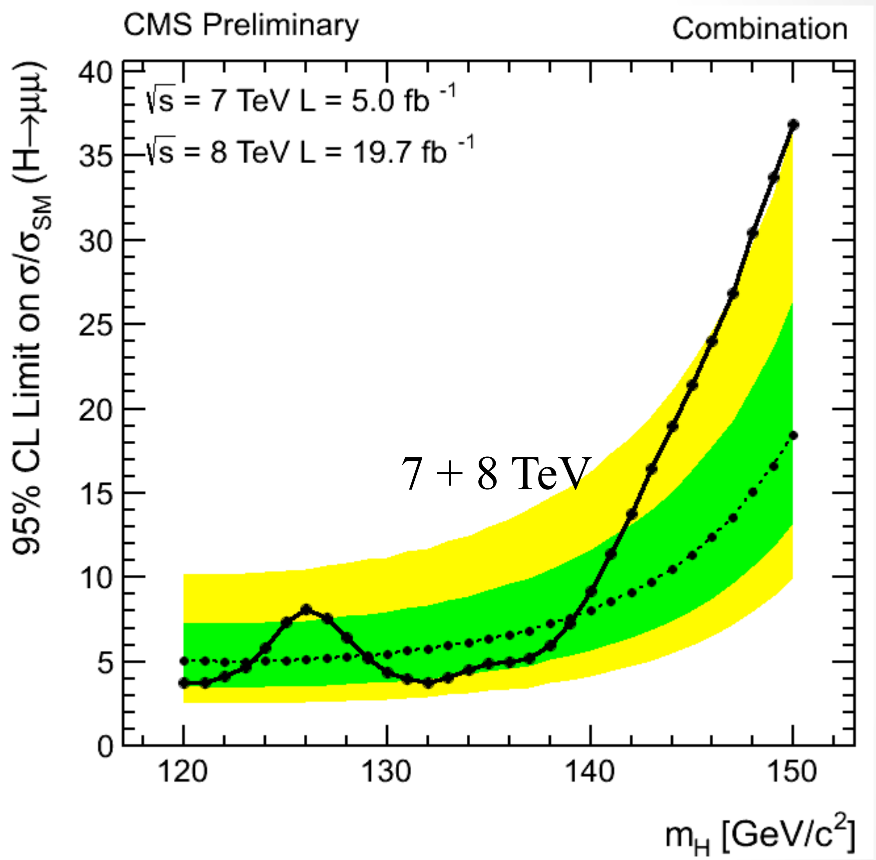
- Observation of new boson dates back to July 2012
  - Evidence in decays to γγ, ZZ, WW
  - No significant excess for ττ, bb
- **Does this new boson couple to fermions?**
  - **Is the coupling proportional to their mass?**
- Will discuss today searches for H→μμ, ee, bb, ττ
  - Will also briefly discuss ttH searches





$H \rightarrow \mu\mu$ search

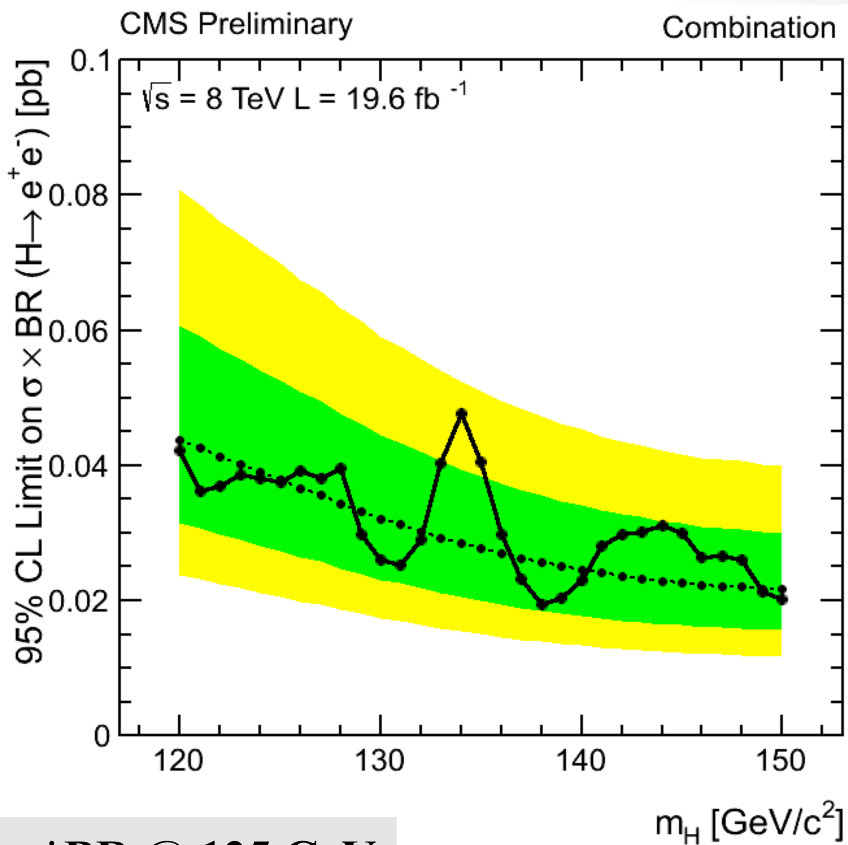




- SM predicts tiny branching fraction (2.2×10^{-4} @ $m_H = 125$ GeV)
- Search done in categories in η^{μ}, $p_t^{\mu\mu}$, jet multiplicity
- Observed limit 7.4 X SM vs. 5.1 expected at $m_H = 125$ GeV

H→ee search

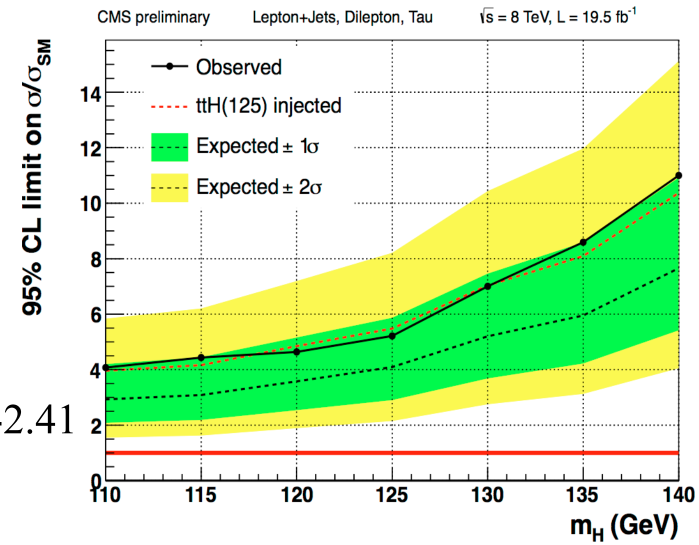
- Branching fraction even smaller then μμ:
  - BR(H →ee) ~2x10^{-5}*BR(H→μμ)
- Done in different categories based on η^e and di-jet tagged
- No significant excess in search region



- H(125)→ee/μμ summary (@8 TeV)

CHN	Obs. Limit 95% σ*BR @ 125 GeV
H→ee	0.038 pb
H→μμ	0.034 pb

ttH

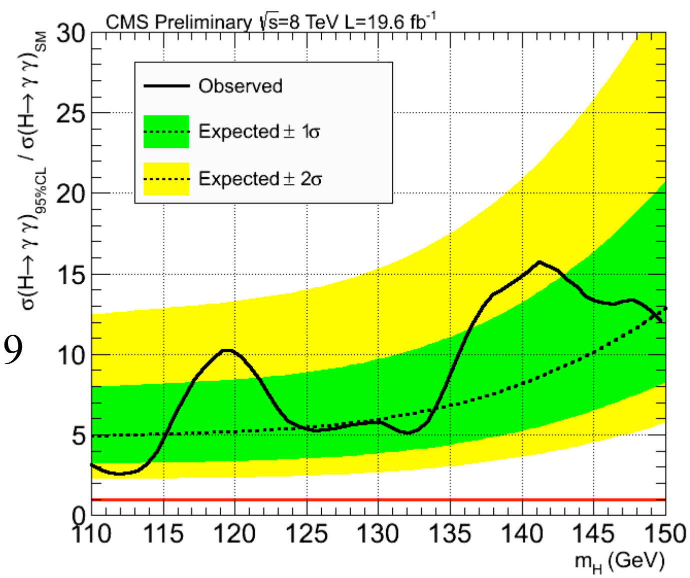


ttH(bb/ττ)

- CMS PAS HIG-13-019
- $\mu_{ttH} = 0.85^{+2.47}_{-2.41}$

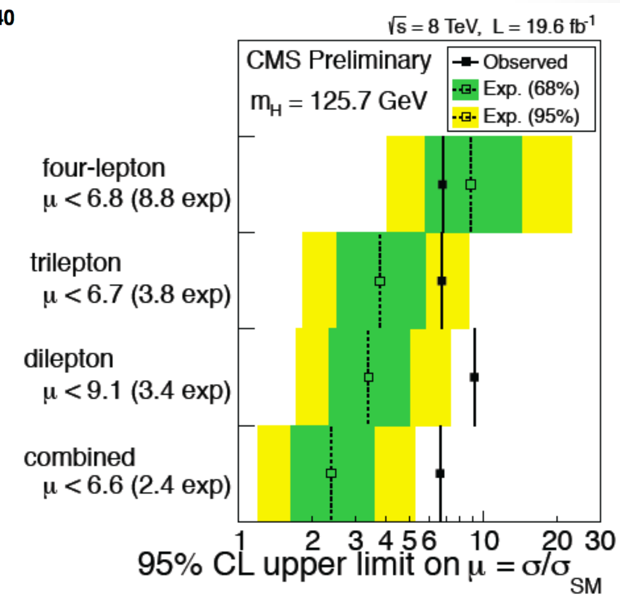
ttH (multi-leptons)

- CMS PAS HIG-13-020
- $\mu_{ttH} = 3.7^{+1.6}_{-1.4}$



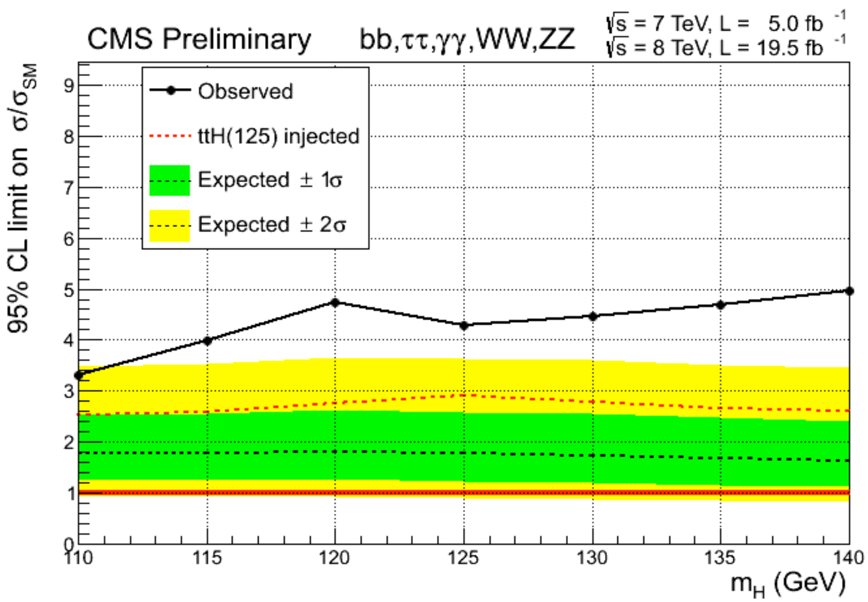
ttH(γγ)

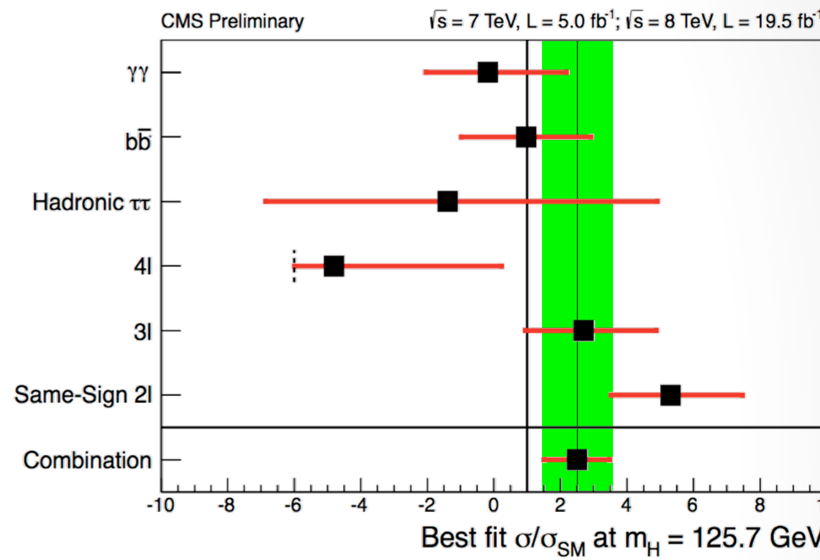
- CMS PAS HIG-13-015
- $\mu_{ttH} = -0.2^{+2.4}_{-1.9}$



ttH search: combination

CMS PAS HIG-13-019

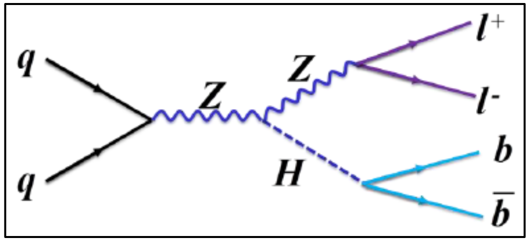


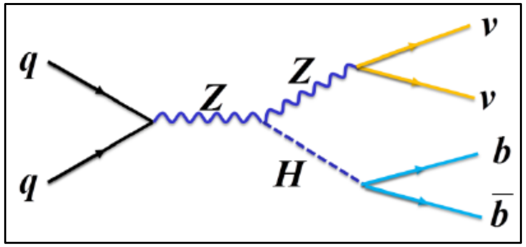


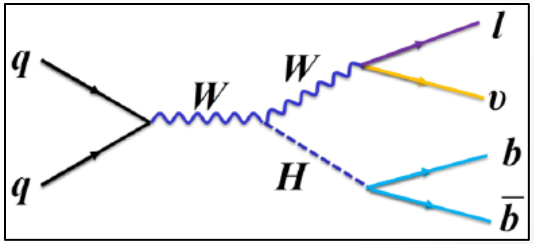
- Combination of 3 independent ttH analyses
- Observed limit @ m_H = 125 GeV 4.3Xσ_{sm} vs 2.9 expected
- Best fit $\mu_{ttH} = 2.5^{+1.1}_{-1.0}$
- Hint of direct coupling to top quarks

H→bb Analysis Overview

- Large Branching Fraction at $m_H = 125$ GeV
  - Large SM backgrounds
  - B-Tagging presents challenges at the LHC
- Analysis done in 6 topologies:
  - Z(ll)H(bb), Z(νν)H(bb), W(lν)H(bb)
- Published to arXiv:1310.3687 (Oct 2013) and Phys. Rev. D (Jan 2014)
- CMS also has a VBF H→bb analysis CMS-PAS-HIG-13-011

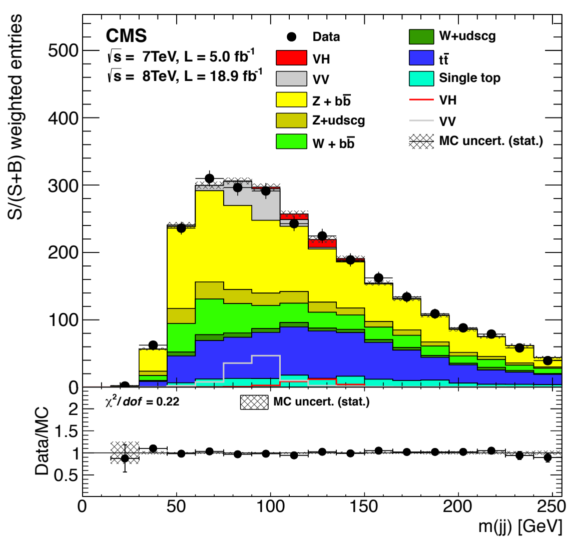


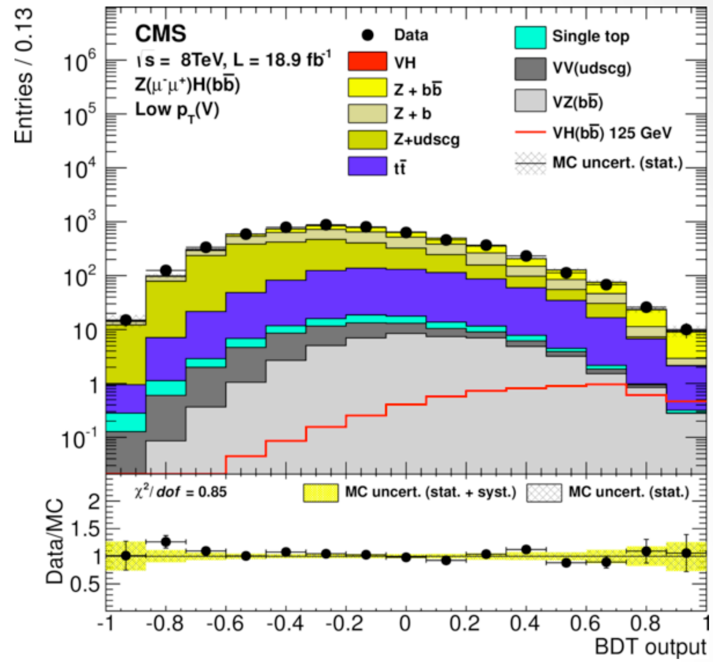


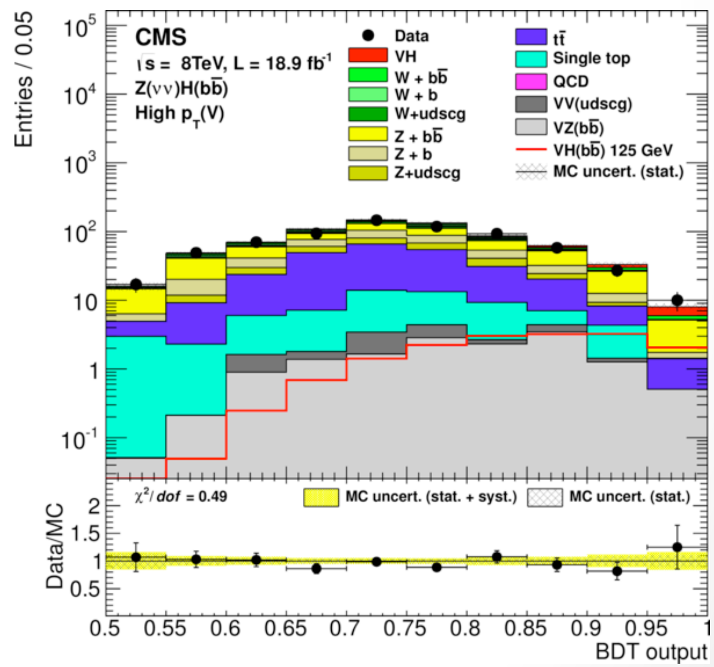


H→bb

- BDT Inputs include kinematics, b-tag information, angles
- Categorized based on $p_t(V)$ for each channel
- As a cross check to the BDT analysis an analysis fitting to m_{jj} is done

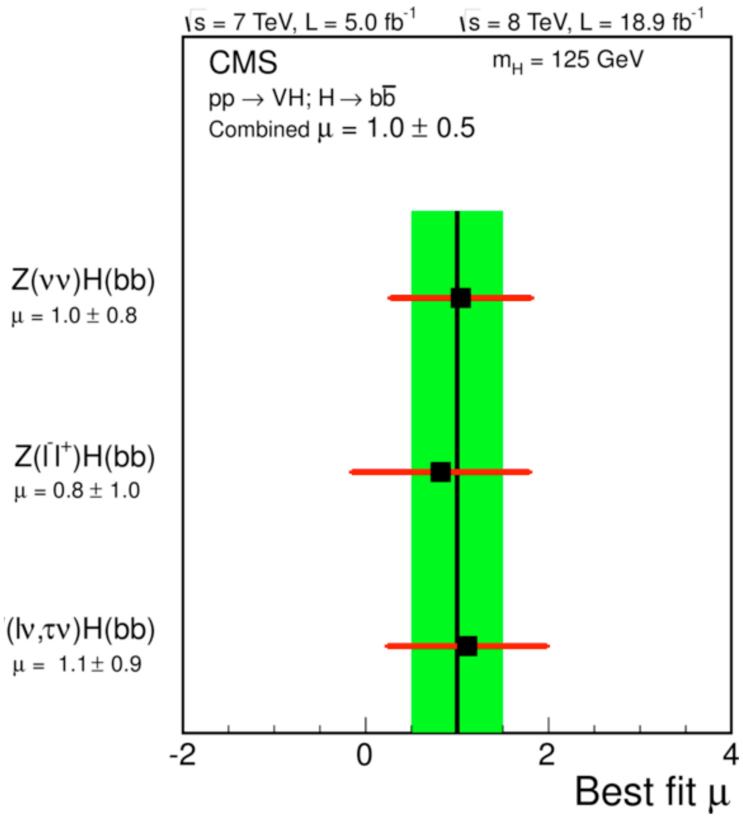


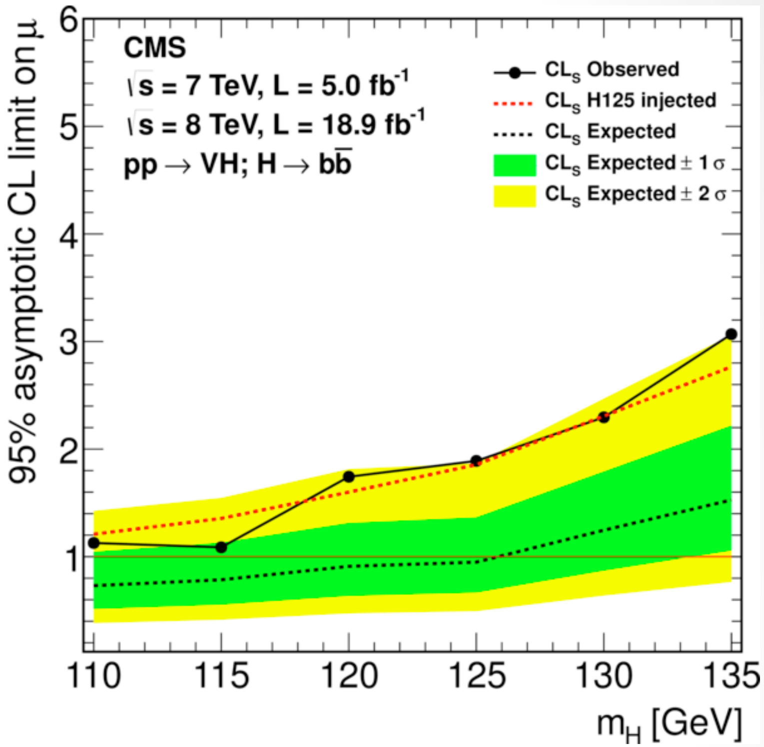




H→bb Results

- 2.1 σ excess is observed at m_H = 125 GeV consistent with the expectation for a SM Higgs

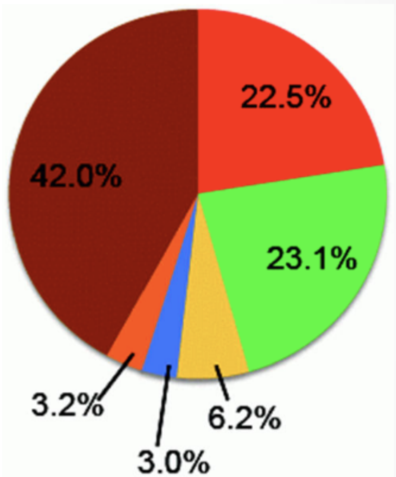


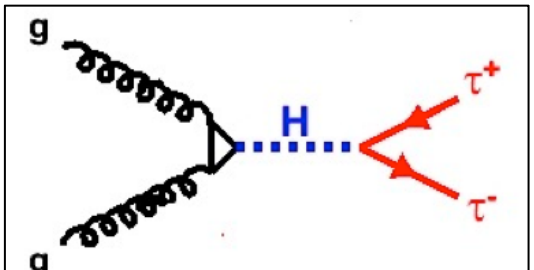


- Best fit μ = 1.0 ± 0.5
  - Consistent in Z(νν)H, Z(ll)H and WH channels

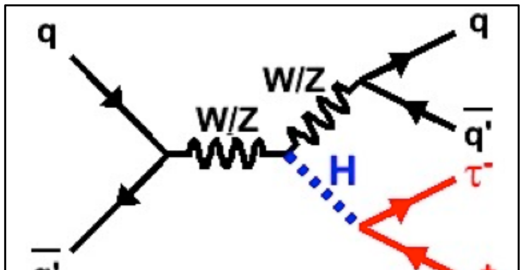
H→ττ Analysis Overview

- Overall search includes 19.7 (4.9) fb^{-1} @ $\sqrt{s}$ = 8 TeV (7 TeV) of LHC data taken with CMS
- Covers 3 leading production modes ggF, VBF, VH
- All ττ decay modes included
  - $\tau_\mu\tau_h$, $\tau_e\tau_h$, $\tau_h\tau_h$, $\tau_\mu\tau_e$, $\tau_\mu\tau_\mu$, $\tau_e\tau_e$
- Submitted to arXiv:1401.5041 and JHEP Jan. 2014

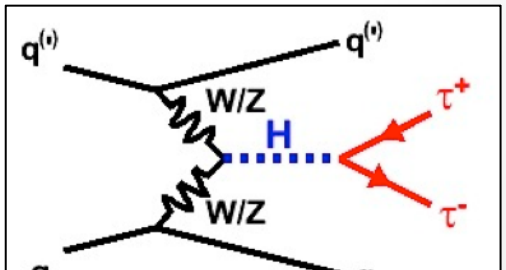




Gluon Fusion Process

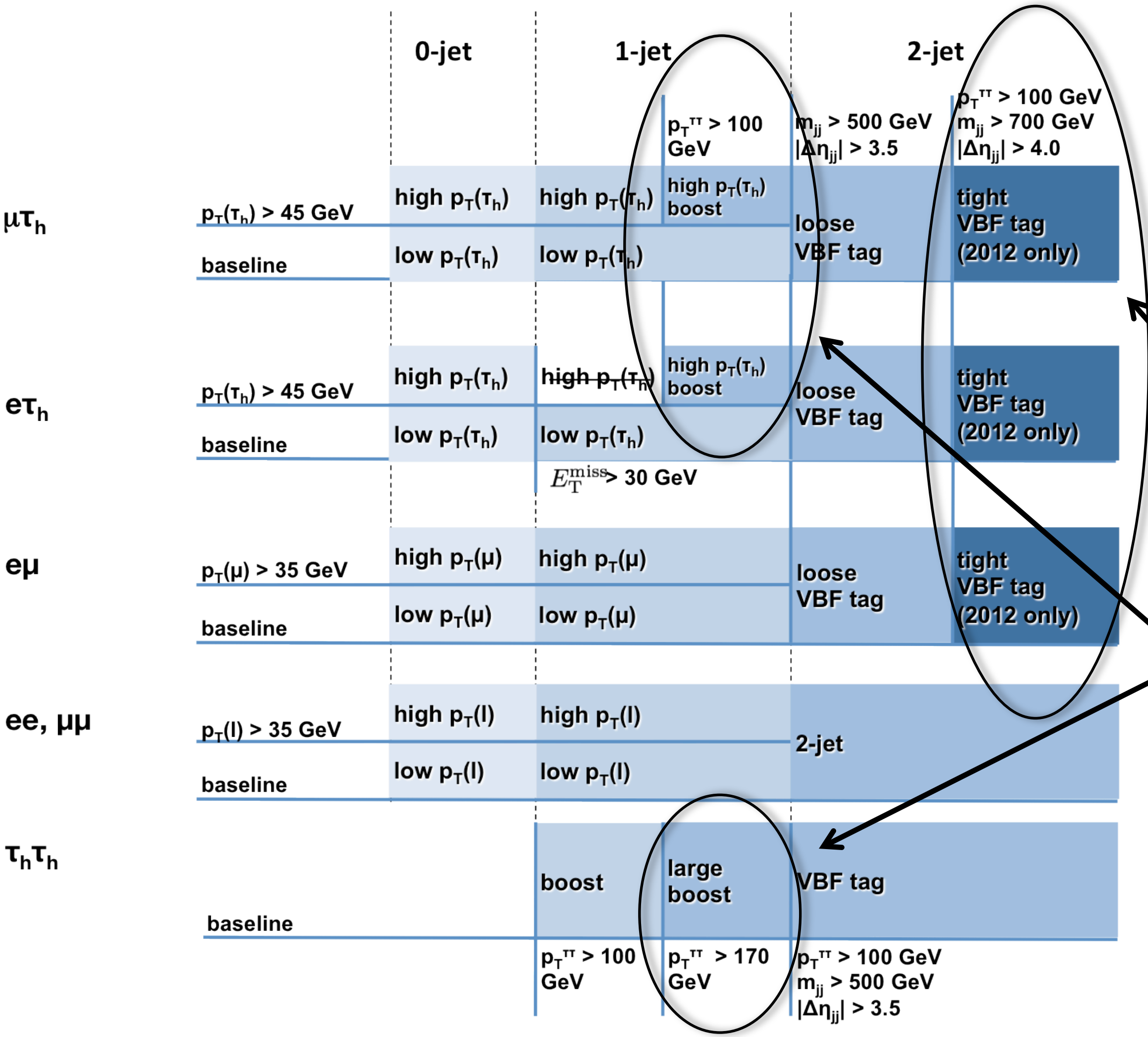


VH Process



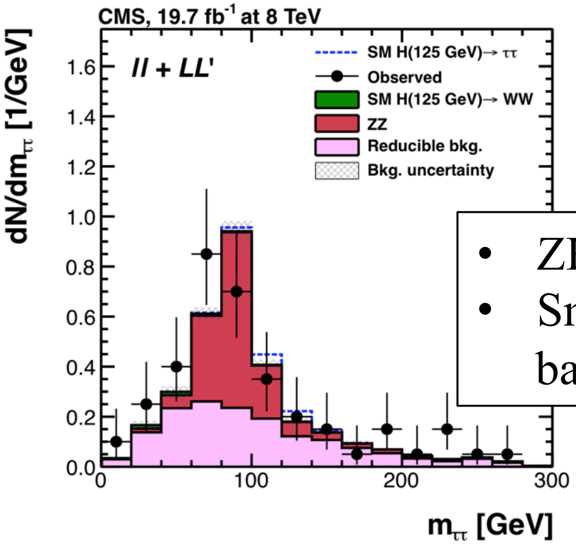
VBF Process

Search Categories (Non-VH)



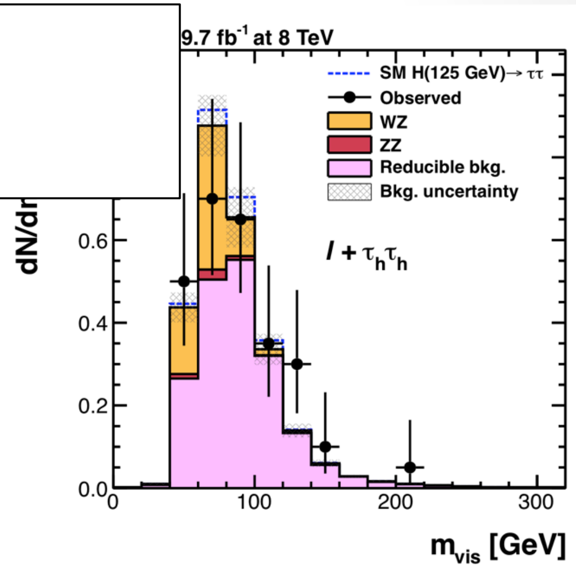
- Events split into categories
  - Boost Significance
  - Enhance production modes
- High sensitivity VBF Modes
- Boosted modes
  - Initial state gluon radiates a jet

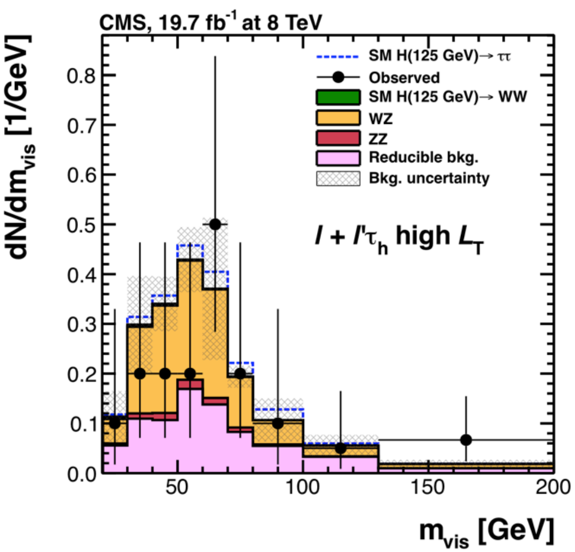
Dedicated VH Channels

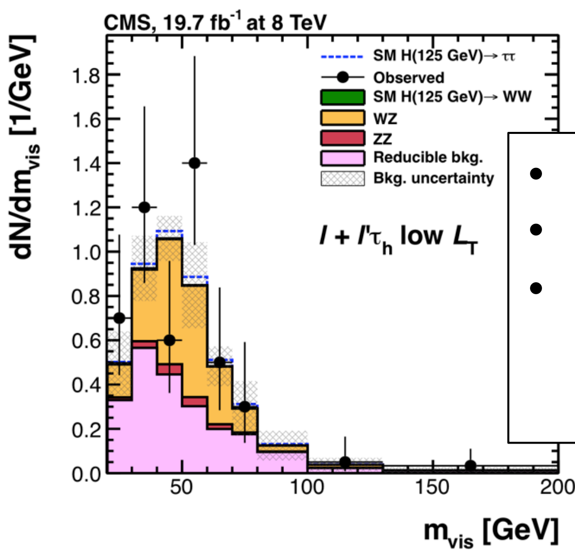


- ZH→2l2τ
- Small signal and background yields

- WH→l2τ_h
- Large QCD Background

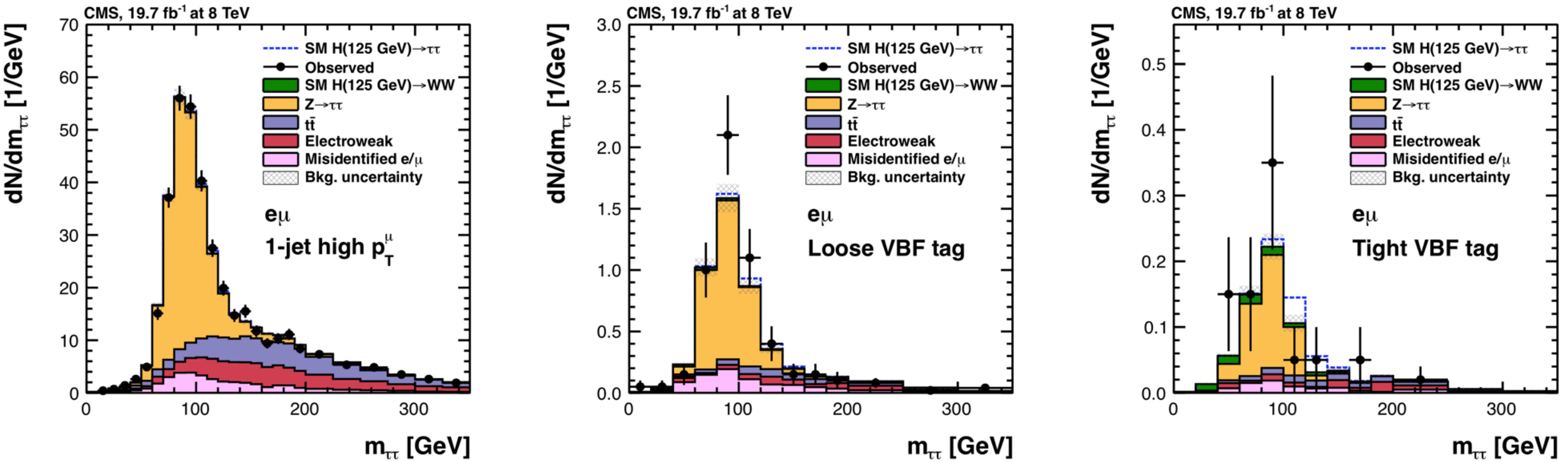






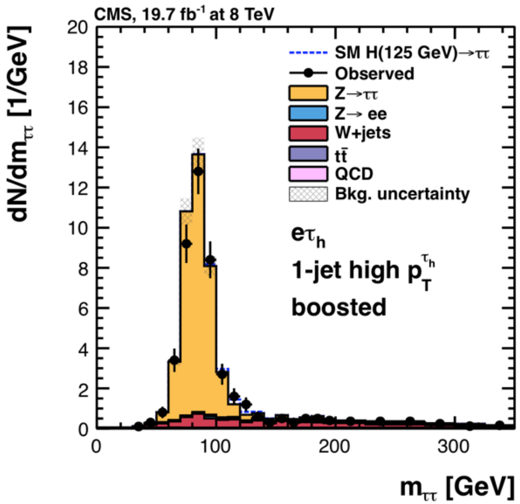
- WH→l$\tau_l\tau_h$
- lτ_l must be same charge
- Split into categories based on L_T:
  - $L_T = p_T^{l} + p_T^{\tau l} + p_T^{\tau h}$

$\tau_e\tau_\mu$ Channel

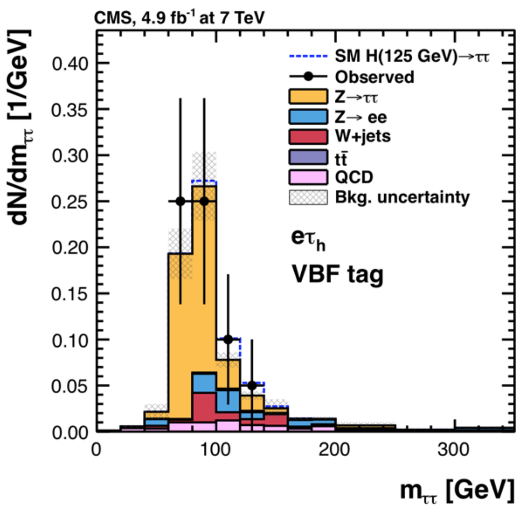


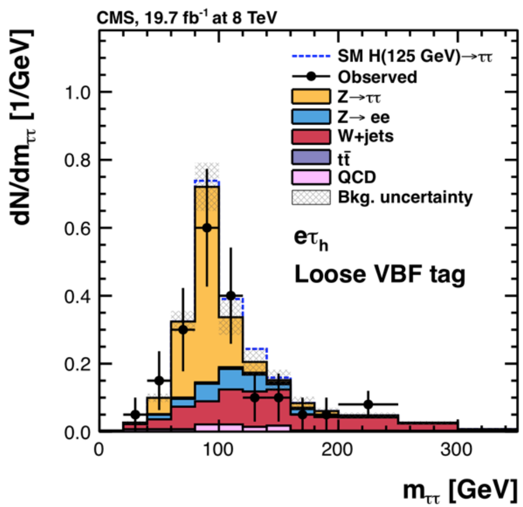
- Very clean channel
  - ttbar background reduced with a BDT
- Small branching ratio
- SM H→WW background in Tight VBF category

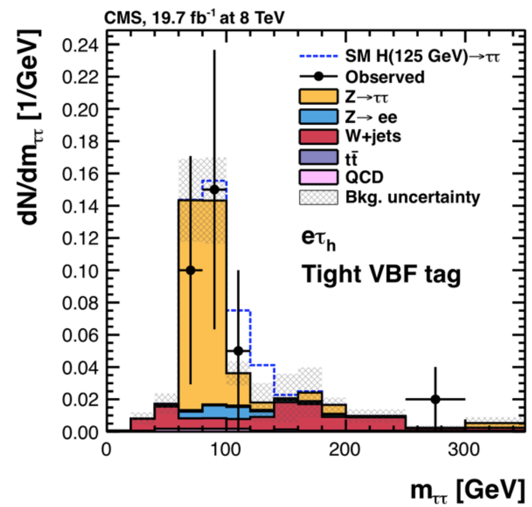
$\tau_e\tau_h$ Channel



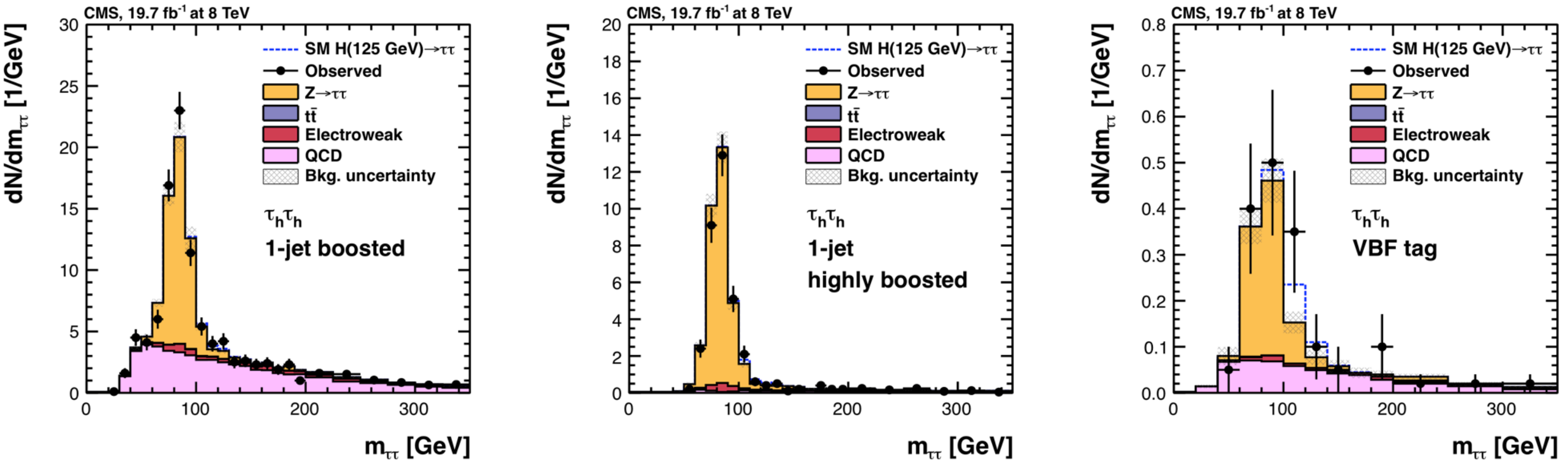
- Tricky Z→ee background
  - e→τ fakes
  - With fake MET peaks in signal region
- QCD Multi-jet background is also problematic
  - Tighter cuts reduces signal yields





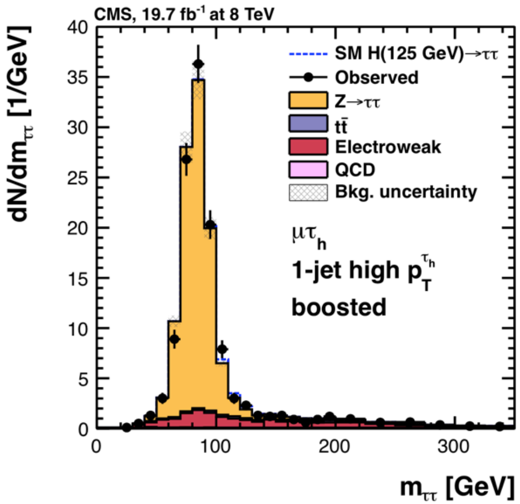


$\tau_h \tau_h$ Channel

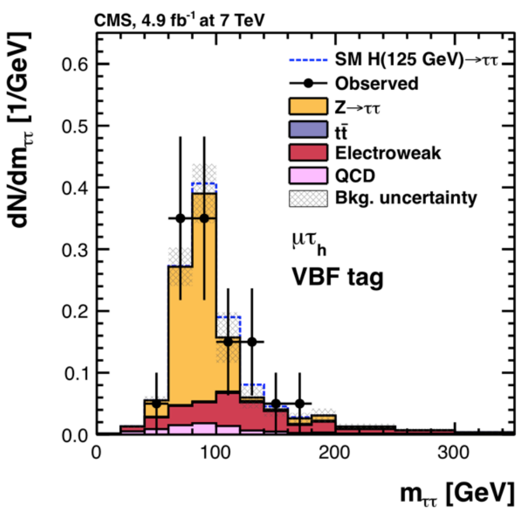


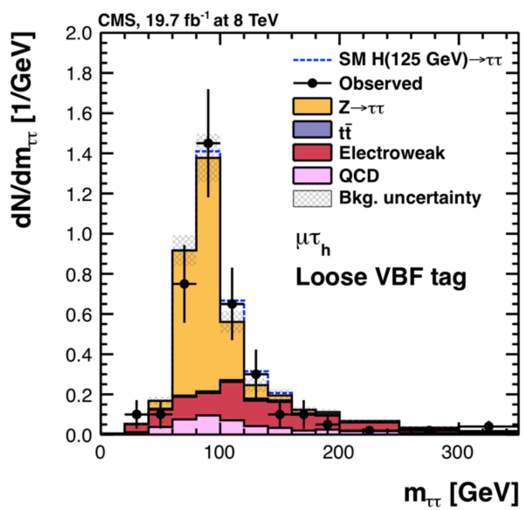
- 7 TeV analysis not done due to trigger thresholds
- Highest branching ratio
- QCD multi-jet background is large

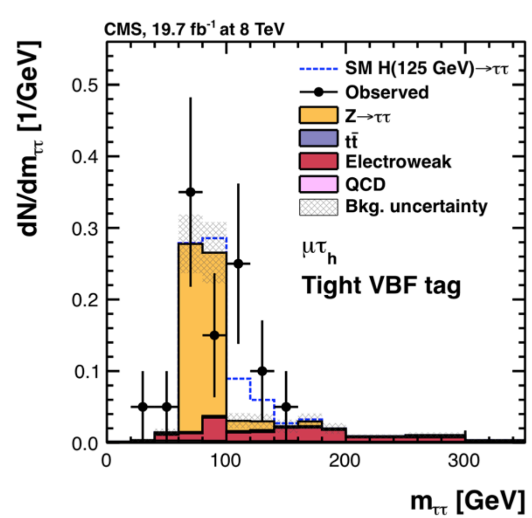
$\tau_\mu\tau_h$ Channel



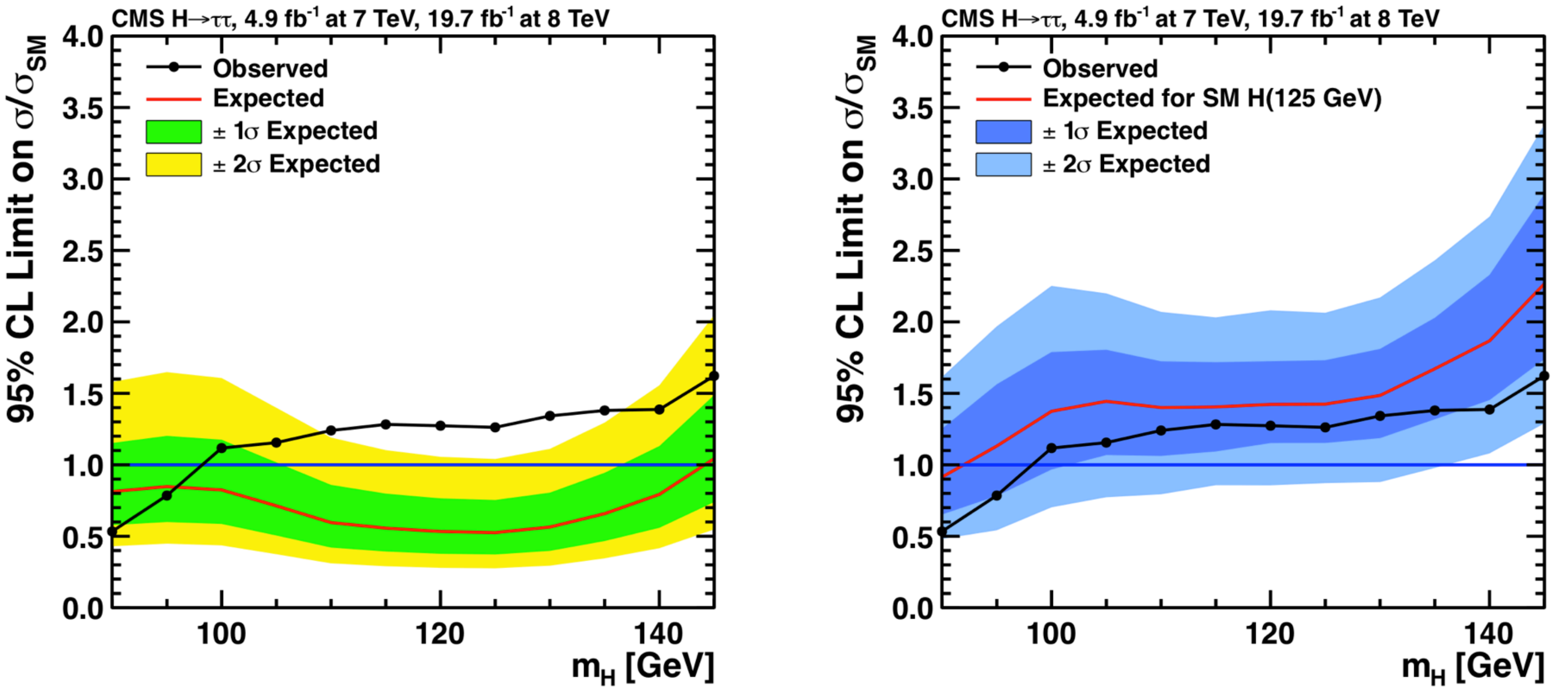
- Most sensitive channel
- Smaller QCD/Z→ll backgrounds then $\tau_e\tau_h$
- S/B ~ 1 in VBF tight signal region





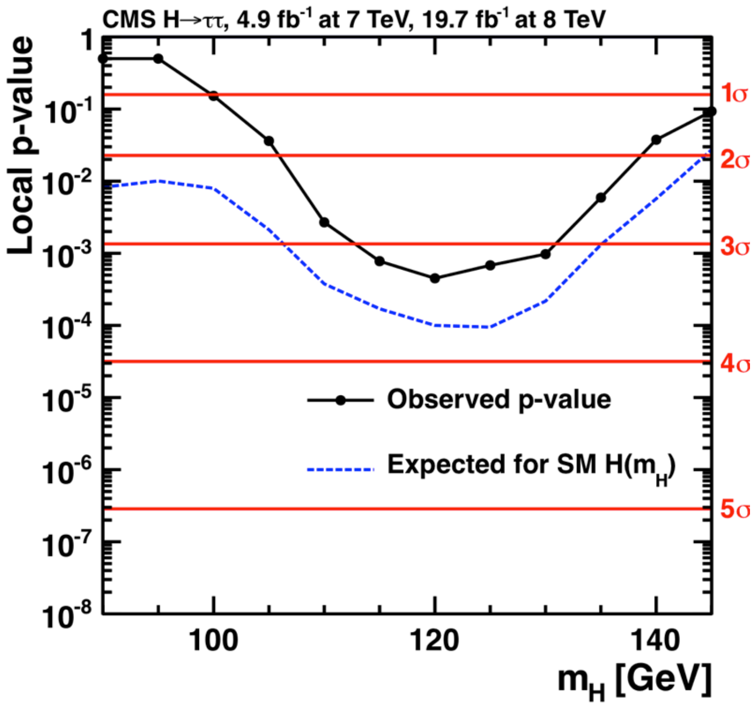


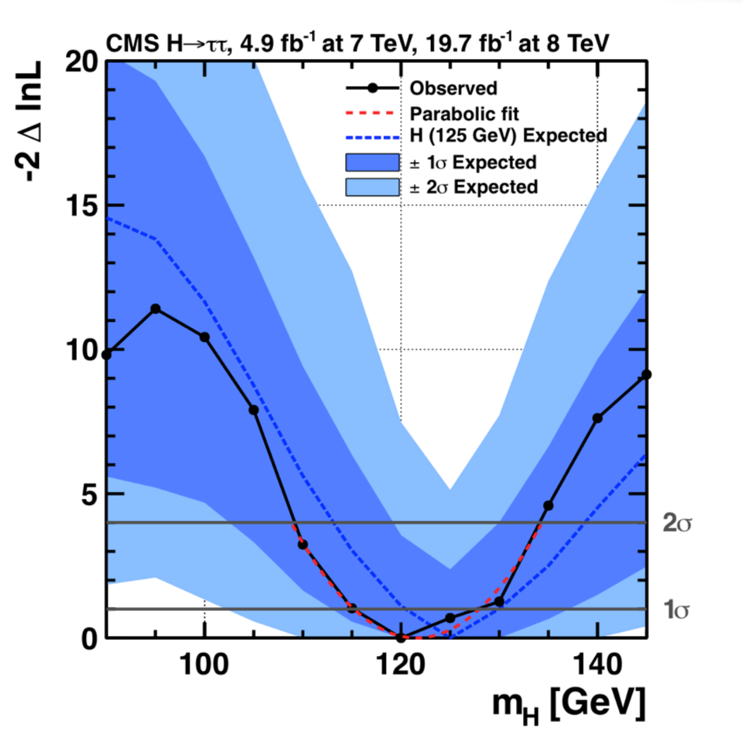
Exclusion Limits



- Clear presence of an excess of events that is compatible with SM Higgs expectation.

Properties of the Excess

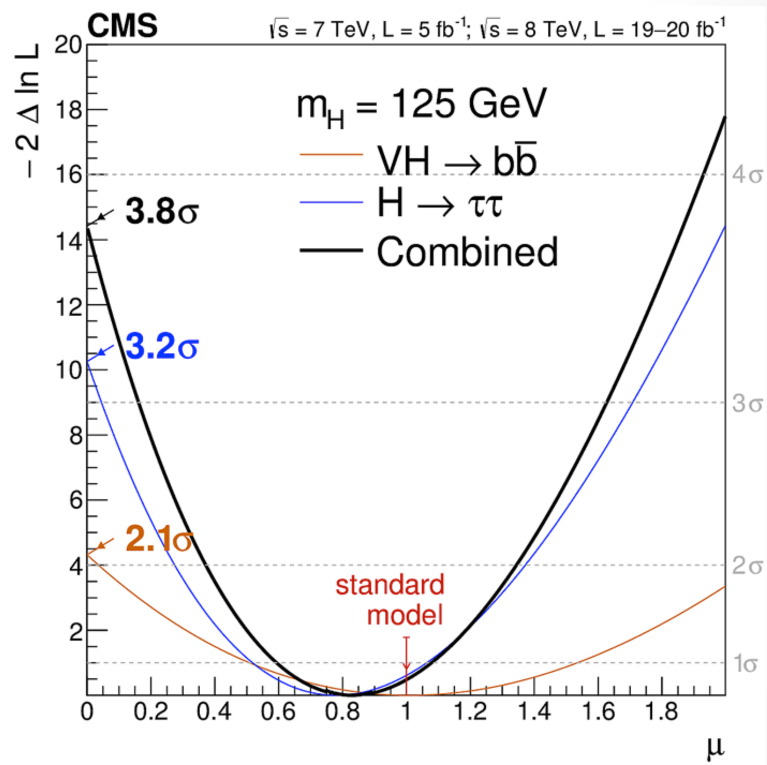




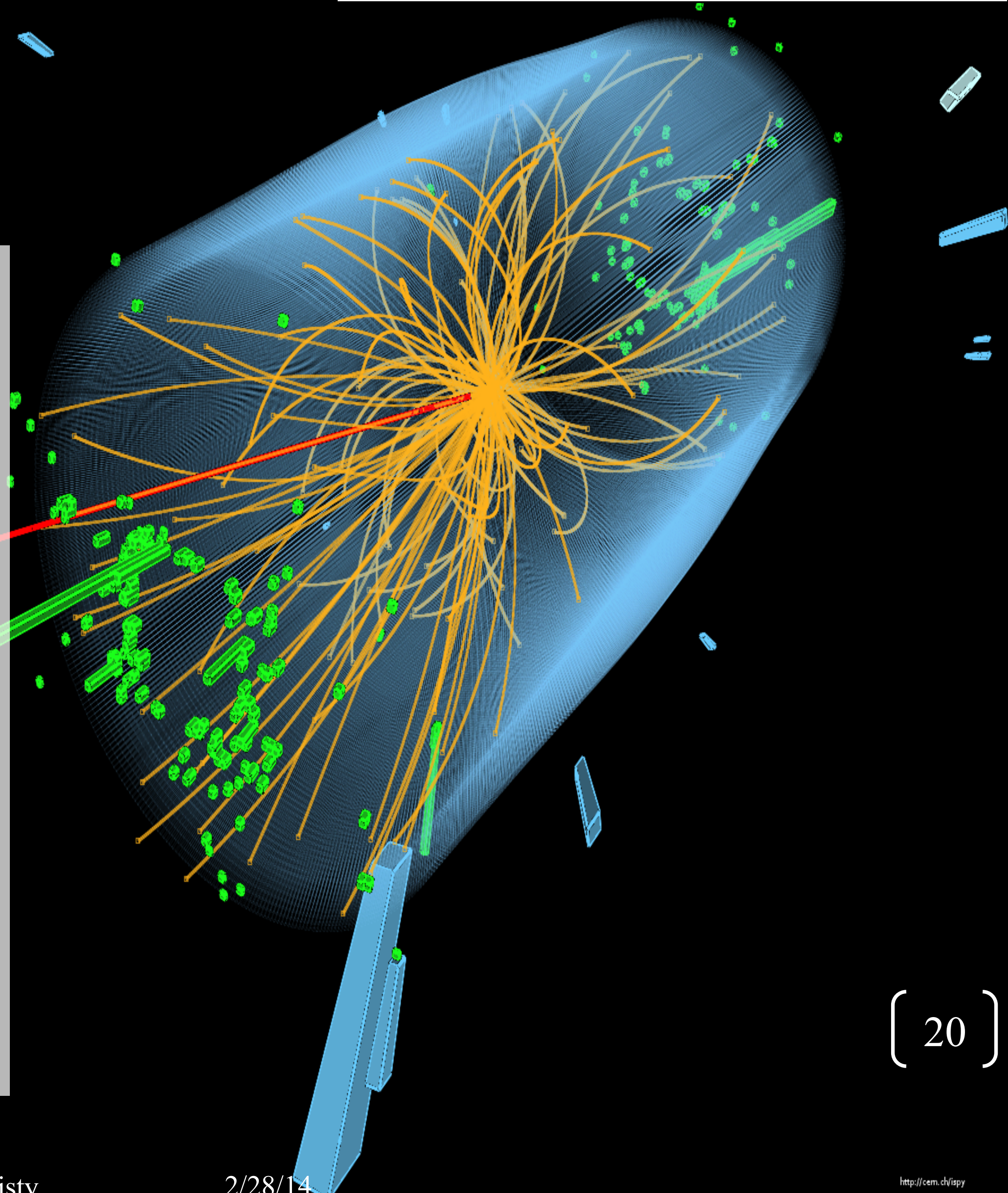
- Excess of 3.2 σ observed compared (M_H = 125 GeV) to 3.7 σ expected
- Scan of negative log likelihood difference gives a mass measurement of 122 ± 7 GeV
    - Compatible with more sensitive mass measurements in ZZ,γγ searches
- Best fit μ = 0.78 ± 0.27 (@ m_H = 125 GeV)

Combination bb/ττ

- Combination of VH(bb) and H→ττ searches
- Submitted to arXiv:1401.6527 and Nature Physics Jan 2014
- Combined excess of 3.8 σ for M_H = 125 GeV compared to an expectation of 4.4 σ
- Best fit μ = 0.83 ± 0.24
- Strong evidence for H(125) decays to fermions



Channel	Significance (σ)		Best-fit
(m_H = 125 GeV)	Expected	Observed	μ
VH → $b\bar{b}$	2.3	2.1	1.0 ± 0.5
H → $\tau\tau$	3.7	3.2	0.78 ± 0.27
Combined	4.4	3.8	0.83 ± 0.24



Summary

- CMS has well rounded searches covering Higgs Fermionic properties
- Hint of direct coupling of Higgs to top quarks
- 3.2 σ excess is observed over the background expectation for $H \rightarrow \tau\tau$
  - Best fit $\mu = 0.78 \pm 0.27$
- Strong evidence for Higgs decays to fermions of 3.8 σ (Combination of bb/ττ searches)
  - Best fit $\mu = 0.83 \pm 0.24$
- No significant evidence for decays to ee/μμ
  - Strong evidence for flavor non-universality

BACKUP

Acceptance

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

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

Yields (1)

Event category	SM Higgs ($m_H = 125\,\mathrm{GeV}$) ggH	VBF	VH	Σ signal	Background	Data	$\frac{S}{S+B}$	σ_{eff} (GeV)
$\mu\tau_h$								
0-jet low-$p_T^{\tau_h}$ 7 TeV	23.1	0.2	0.1	23.5 ± 3.4	11950 ± 590	11959	0.002	17.4
0-jet low-$p_T^{\tau_h}$ 8 TeV	83.0	0.8	0.4	85.0 ± 11.0	40800 ± 1900	40353	0.003	16.3
0-jet high-$p_T^{\tau_h}$ 7 TeV	17.5	0.2	0.2	17.9 ± 2.6	1595 ± 83	1594	0.022	15.1
0-jet high-$p_T^{\tau_h}$ 8 TeV	66.2	0.7	0.6	67.5 ± 9.3	5990 ± 250	5789	0.020	15.2
1-jet low-$p_T^{\tau_h}$ 7 TeV	9.1	1.6	0.8	11.5 ± 1.7	2020 ± 120	2047	0.012	18.8
1-jet low-$p_T^{\tau_h}$ 8 TeV	36.0	6.0	3.0	45.0 ± 6.0	9030 ± 360	9010	0.010	18.6
1-jet high-$p_T^{\tau_h}$ 7 TeV	7.7	1.1	0.6	9.4 ± 1.3	796 ± 39	817	0.033	19.1
1-jet high-$p_T^{\tau_h}$ 8 TeV	29.6	4.3	2.4	36.3 ± 4.6	3180 ± 130	3160	0.029	19.7
1-jet high-$p_T^{\tau_h}$ boosted 7 TeV	2.6	0.8	0.5	3.9 ± 0.6	282 ± 16	269	0.054	17.7
1-jet high-$p_T^{\tau_h}$ boosted 8 TeV	11.5	2.9	2.0	16.5 ± 2.6	1265 ± 62	1253	0.072	17.2
VBF tag 7 TeV	0.2	1.3	–	1.6 ± 0.1	22 ± 2	23	0.14	19.6
Loose VBF tag 8 TeV	1.1	3.4	–	4.5 ± 0.4	81 ± 7	76	0.17	17.0
Tight VBF tag 8 TeV	0.3	2.0	–	2.4 ± 0.2	15 ± 2	20	0.49	18.1
$e\tau_h$								
0-jet low-$p_T^{\tau_h}$ 7 TeV	11.8	0.1	0.1	12.0 ± 1.8	6140 ± 320	6238	0.002	16.4
0-jet low-$p_T^{\tau_h}$ 8 TeV	33.4	0.3	0.2	34.0 ± 4.6	16750 ± 750	17109	0.002	15.8
0-jet high-$p_T^{\tau_h}$ 7 TeV	11.1	0.1	0.1	11.3 ± 1.7	1159 ± 62	1191	0.015	14.3
0-jet high-$p_T^{\tau_h}$ 8 TeV	31.4	0.3	0.3	32.1 ± 4.4	4380 ± 170	4536	0.010	15.4
1-jet low-$p_T^{\tau_h}$ 7 TeV	3.1	0.6	0.3	4.0 ± 0.6	366 ± 25	385	0.029	19.6
1-jet low-$p_T^{\tau_h}$ 8 TeV	9.1	1.8	1.0	11.9 ± 1.6	1200 ± 56	1214	0.025	16.5
1-jet high-$p_T^{\tau_h}$ boosted 7 TeV	1.2	0.3	0.2	1.8 ± 0.3	150 ± 9	167	0.089	15.5
1-jet high-$p_T^{\tau_h}$ boosted 8 TeV	5.1	1.4	0.9	7.5 ± 1.1	497 ± 27	476	0.11	15.5
VBF tag 7 TeV	0.2	0.7	–	0.9 ± 0.1	14 ± 2	13	0.24	15.9
Loose VBF tag 8 TeV	0.6	1.8	–	2.4 ± 0.2	45 ± 4	40	0.14	16.7
Tight VBF tag 8 TeV	0.3	1.3	–	1.6 ± 0.1	9 ± 2	7	0.51	16.2
$\tau_h\tau_h$								
1-jet boosted 8 TeV	7.2	2.1	1.0	10.3 ± 1.7	1133 ± 49	1120	0.054	15.2
1-jet highly-boosted 8 TeV	5.6	1.6	1.2	8.4 ± 1.2	380 ± 23	366	0.14	13.1
VBF tag 8 TeV	0.5	2.4	–	3.0 ± 0.3	29 ± 4	34	0.32	14.3
$e\mu$								
0-jet low-p_T^{μ} 7 TeV	20.8	0.2	0.2	21.1 ± 3.0	11320 ± 260	11283	0.002	24.4
0-jet low-p_T^{μ} 8 TeV	70.3	0.7	0.7	71.7 ± 9.6	40410 ± 830	40381	0.002	23.6
0-jet high-p_T^{μ} 7 TeV	7.5	0.1	0.1	7.8 ± 1.1	1636 ± 55	1676	0.007	22.7
0-jet high-p_T^{μ} 8 TeV	24.0	0.2	0.5	24.7 ± 3.3	6000 ± 150	6095	0.006	20.7
1-jet low-p_T^{μ} 7 TeV	9.0	1.6	1.0	11.7 ± 1.5	2475 ± 74	2482	0.009	23.7
1-jet low-p_T^{μ} 8 TeV	40.6	6.5	3.7	50.8 ± 6.1	10910 ± 250	10926	0.007	23.8
1-jet high-p_T^{μ} 7 TeV	4.7	1.0	0.6	6.2 ± 0.8	928 ± 37	901	0.015	23.3
1-jet high-p_T^{μ} 8 TeV	18.0	3.4	2.6	23.9 ± 2.9	4040 ± 110	4050	0.014	23.1
Loose VBF tag 7 TeV	0.2	1.0	–	1.2 ± 0.1	19 ± 1	12	0.13	23.0
Loose VBF tag 8 TeV	0.6	2.6	–	3.3 ± 0.3	99 ± 6	112	0.054	23.5
Tight VBF tag 8 TeV	0.2	1.5	–	1.6 ± 0.1	14 ± 1	17	0.31	17.8

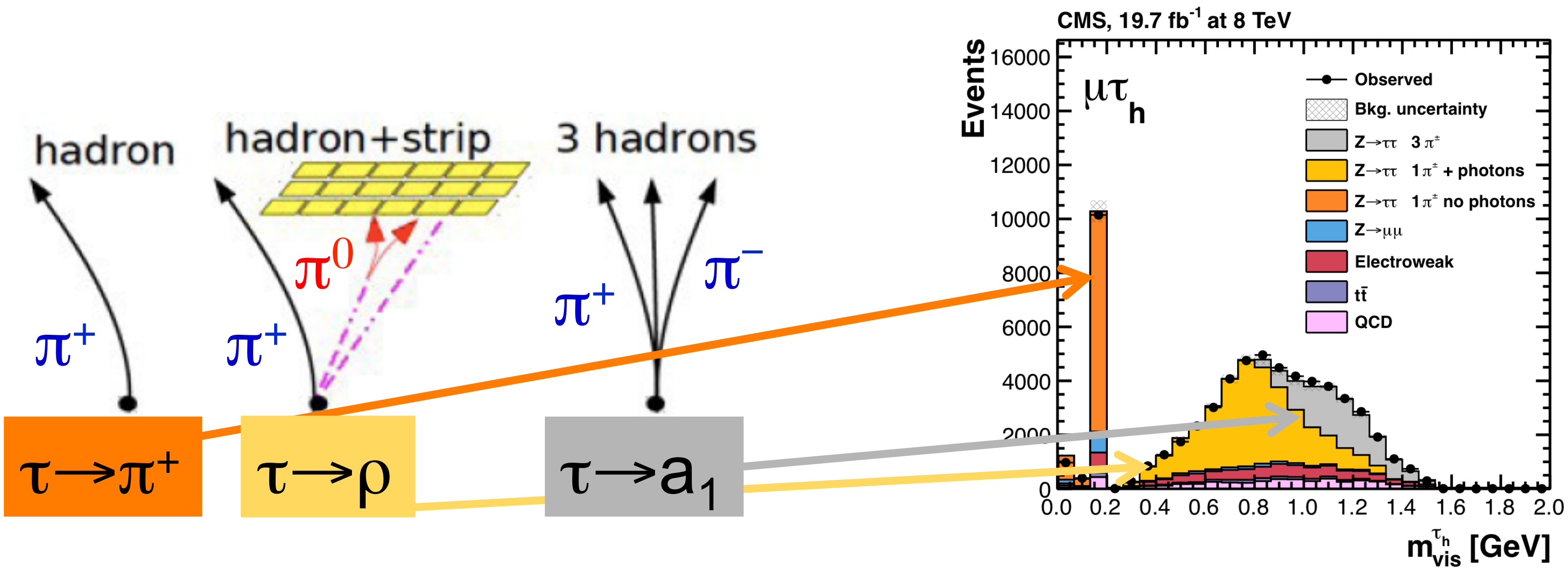
Yields (2)

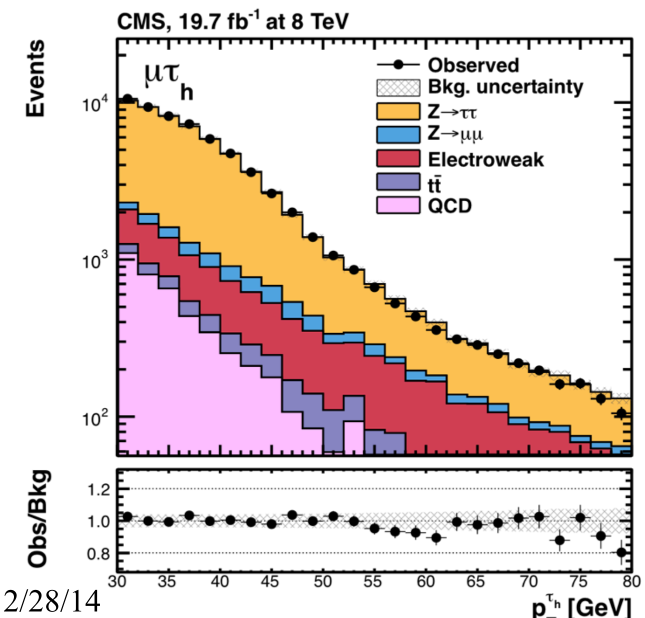
Event category	SM Higgs ($m_H = 125$ GeV) ggH	VBF	VH	Σ signal	Background	Data
$\mu\mu$						
0-jet low-p_T^{μ} 7 TeV	8.0	0.1	0.1	8.2 ± 1.2	266200 ± 1400	266365
0-jet low-p_T^{μ} 8 TeV	25.4	0.3	0.6	26.4 ± 3.8	873200 ± 2600	873709
0-jet high-p_T^{μ} 7 TeV	5.5	0.1	0.3	5.9 ± 0.8	982900 ± 2100	982442
0-jet high-p_T^{μ} 8 TeV	30.6	0.4	3.5	34.6 ± 4.6	3775700 ± 3100	3776365
1-jet low-p_T^{μ} 7 TeV	2.5	0.4	0.3	3.2 ± 0.4	18680 ± 180	18757
1-jet low-p_T^{μ} 8 TeV	7.0	1.0	0.6	8.6 ± 1.1	40900 ± 360	40606
1-jet high-p_T^{μ} 7 TeV	3.7	1.4	1.9	7.0 ± 0.6	233600 ± 1200	234390
1-jet high-p_T^{μ} 8 TeV	15.1	2.2	4.4	21.7 ± 2.3	646000 ± 2500	646549
2-jet 7 TeV	1.4	0.2	0.7	2.4 ± 0.3	33260 ± 350	33186
2-jet 8 TeV	6.3	3.9	2.6	12.8 ± 1.4	164100 ± 1400	164469
ee						
0-jet low-p_T^{e} 7 TeV	3.6	–	0.1	3.7 ± 0.5	190900 ± 1000	190890
0-jet low-p_T^{e} 8 TeV	14.3	0.2	0.3	14.7 ± 2.2	519440 ± 700	519376
0-jet high-p_T^{e} 7 TeV	4.0	–	0.5	4.5 ± 0.6	819900 ± 1700	820035
0-jet high-p_T^{e} 8 TeV	22.3	0.3	2.5	25.1 ± 3.4	3225000 ± 2000	3225144
1-jet low-p_T^{e} 7 TeV	1.5	0.2	0.1	1.8 ± 0.2	10268 ± 97	10300
1-jet low-p_T^{e} 8 TeV	4.6	0.6	0.3	5.5 ± 0.7	26570 ± 180	26604
1-jet high-p_T^{e} 7 TeV	2.4	0.4	0.6	3.4 ± 0.4	144900 ± 740	144945
1-jet high-p_T^{e} 8 TeV	11.7	1.9	3.2	16.9 ± 1.8	560000 ± 1900	560104
2-jet 7 TeV	1.6	0.6	0.4	2.6 ± 0.4	35800 ± 280	35796
2-jet 8 TeV	5.0	2.8	1.6	9.4 ± 1.1	140000 ± 1200	140070

Yields 3

Event category	Signal	Background	Data	$\frac{S}{S+B}$
$\ell\ell + LL'$				
$\mu\mu + \mu\tau_{\mathrm{h}}$ 7 TeV	0.111 ± 0.005	2.4 ± 0.3	2	0.103
$\mu\mu + \mu\tau_{\mathrm{h}}$ 8 TeV	0.427 ± 0.021	10.5 ± 0.6	12	0.092
$\mathrm{ee} + \mu\tau_{\mathrm{h}}$ 7 TeV	0.087 ± 0.004	1.5 ± 0.1	2	0.135
$\mathrm{ee} + \mu\tau_{\mathrm{h}}$ 8 TeV	0.385 ± 0.018	7.6 ± 0.4	11	0.149
$\mu\mu + \mathrm{e}\tau_{\mathrm{h}}$ 7 TeV	0.078 ± 0.004	2.2 ± 0.1	1	0.092
$\mu\mu + \mathrm{e}\tau_{\mathrm{h}}$ 8 TeV	0.293 ± 0.014	12.2 ± 0.6	8	0.081
$\mathrm{ee} + \mathrm{e}\tau_{\mathrm{h}}$ 7 TeV	0.075 ± 0.004	2.2 ± 0.1	4	0.077
$\mathrm{ee} + \mathrm{e}\tau_{\mathrm{h}}$ 8 TeV	0.279 ± 0.013	10.2 ± 0.5	13	0.063
$\mu\mu + \tau_{\mathrm{h}}\tau_{\mathrm{h}}$ 7 TeV	0.073 ± 0.006	0.8 ± 0.1	0	0.195
$\mu\mu + \tau_{\mathrm{h}}\tau_{\mathrm{h}}$ 8 TeV	0.285 ± 0.022	5.8 ± 0.4	4	0.150
$\mathrm{ee} + \tau_{\mathrm{h}}\tau_{\mathrm{h}}$ 7 TeV	0.061 ± 0.004	1.1 ± 0.1	1	0.127
$\mathrm{ee} + \tau_{\mathrm{h}}\tau_{\mathrm{h}}$ 8 TeV	0.260 ± 0.020	4.8 ± 0.4	9	0.148
$\mu\mu + \mathrm{e}\mu$ 7 TeV	0.051 ± 0.002	1.0 ± 0.1	3	0.100
$\mu\mu + \mathrm{e}\mu$ 8 TeV	0.202 ± 0.008	5.1 ± 0.3	9	0.105
$\mathrm{ee} + \mathrm{e}\mu$ 7 TeV	0.045 ± 0.002	1.0 ± 0.0	1	0.077
$\mathrm{ee} + \mathrm{e}\mu$ 8 TeV	0.185 ± 0.007	4.0 ± 0.2	4	0.082
$\ell + \tau_{\mathrm{h}}\tau_{\mathrm{h}}$				
$\mu + \tau_{\mathrm{h}}\tau_{\mathrm{h}}$ 7 TeV	0.35 ± 0.03	4.1 ± 0.4	2	0.098
$\mu + \tau_{\mathrm{h}}\tau_{\mathrm{h}}$ 8 TeV	1.57 ± 0.12	35.2 ± 2.1	38	0.054
$\mathrm{e} + \tau_{\mathrm{h}}\tau_{\mathrm{h}}$ 7 TeV	0.23 ± 0.02	2.7 ± 0.2	0	0.101
$\mathrm{e} + \tau_{\mathrm{h}}\tau_{\mathrm{h}}$ 8 TeV	0.87 ± 0.08	16.5 ± 1.1	15	0.062
$\ell + \ell'\tau_{\mathrm{h}}$				
$\mu + \mu\tau_{\mathrm{h}}$ 7 TeV	0.33 ± 0.02	3.2 ± 0.4	2	0.090
$\mu + \mu\tau_{\mathrm{h}}$ low L_{T} 8 TeV	0.72 ± 0.03	20.7 ± 2.2	19	0.046
$\mu + \mu\tau_{\mathrm{h}}$ high L_{T} 8 TeV	0.72 ± 0.02	8.4 ± 1.3	7	0.102
$\mathrm{e} + \mu\tau_{\mathrm{h}}/\mu + \mathrm{e}\tau_{\mathrm{h}}$ 7 TeV	0.47 ± 0.03	6.2 ± 1.0	6	0.074
$\mathrm{e} + \mu\tau_{\mathrm{h}}/\mu + \mathrm{e}\tau_{\mathrm{h}}$ low L_{T} 8 TeV	0.92 ± 0.03	24.6 ± 3.2	30	0.041
$\mathrm{e} + \mu\tau_{\mathrm{h}}/\mu + \mathrm{e}\tau_{\mathrm{h}}$ high L_{T} 8 TeV	1.15 ± 0.04	13.9 ± 2.0	11	0.109

Hadronic τ reconstruction

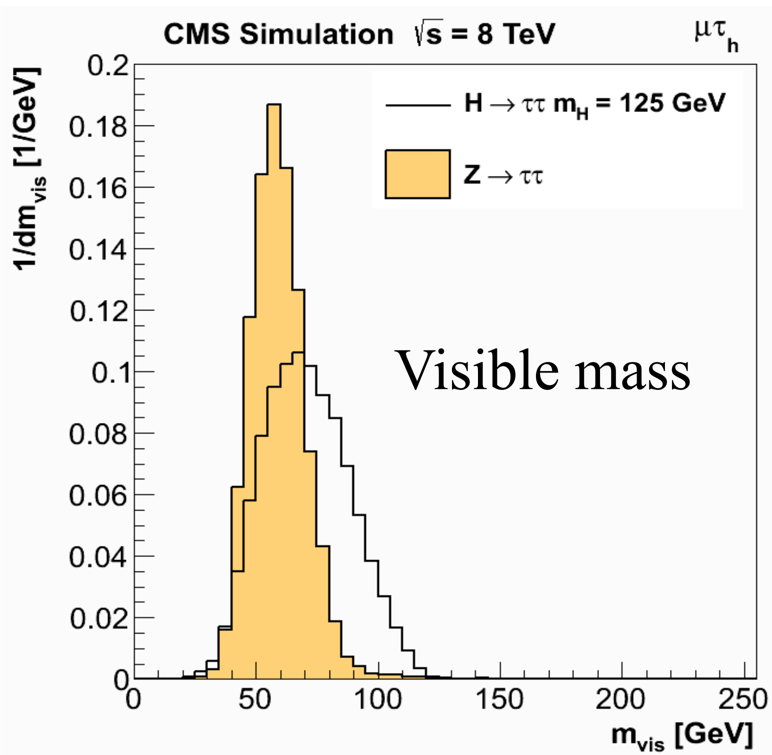


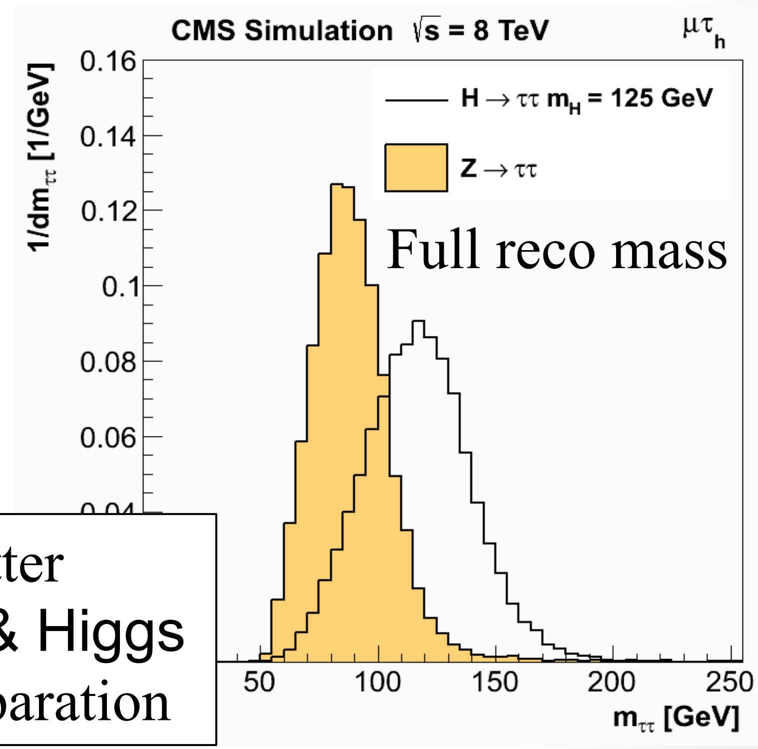


- Tau reconstruction: hadron+strip Particle-flow based algorithm to reconstruct different hadronic tau decay modes
- τ_h identification: efficiency ~ 60% for jet fake rate ~ 1%
- The τ_h mass distribution used to control the tau energy-scale within 3%

$H\to\tau\tau$: mass reconstruction

- Di-tau mass estimation uses visible decay products & missing E_T in a maximum likelihood fit
- The mass resolution is ~ 10-20% depending on channel/category

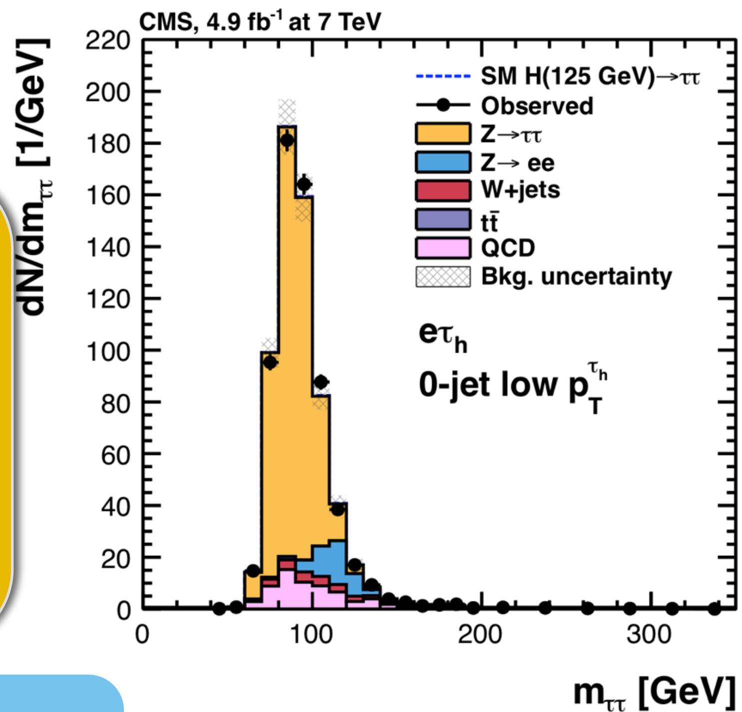




better
Z & Higgs
separation

H→ττ: background estimation

[All normalizations are data-driven]()



Z→ττ:

embedded samples
No MET/JES scale uncertainties
Shape estimation and correction for selection efficiencies

W+jets:

- Normalization from high m_T control region
- Shape from MC

ttbar:

- Normalization from eμ b-tag control region
- Shape from MC

Z→ee/μμ

- Normalization scale factor from tag-and-probe in data
- Shape from MC

QCD:

- Normalization from ratio of same-sign(SS) to opposite-sign (OS) data events
- Shape from SS data events

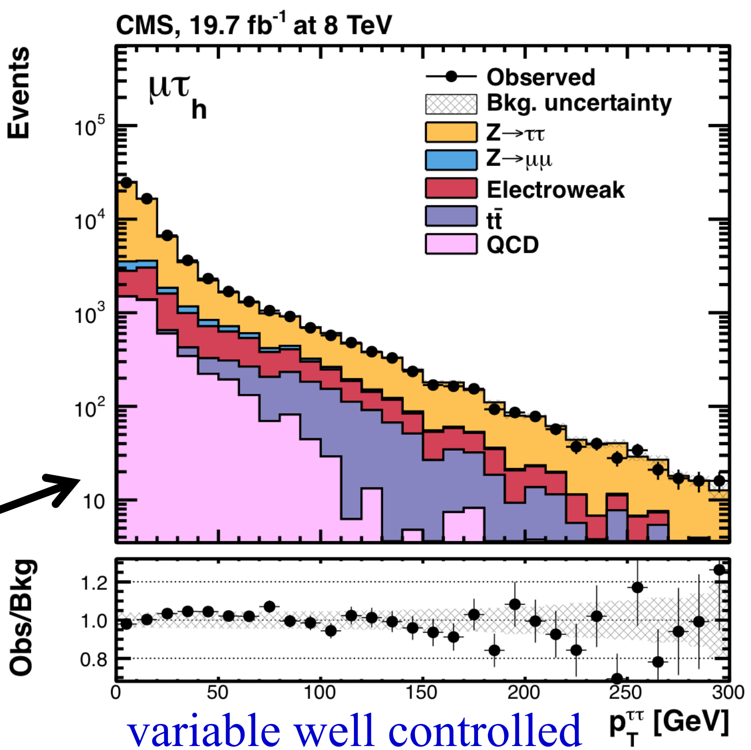
$H \to \tau\tau$: Event categorization

Highest sensitivity categories utilize $p_t^{\tau\tau}$

- 1-jet: high $p_t(\tau_h)$ boost
  $p_t(\tau_h) > 45$ GeV, $p_t^{\tau\tau} > 100$ GeV
- 2-jet: tight VBF tag
  $M_{jj} > 700$ GeV, $|\Delta\eta_{jj}| > 4$, $p_t^{\tau\tau} > 100$ GeV

$$p_t^{\tau\tau} = | \vec{p}_t(L_1) + \vec{p}_t(L_2) + \vec{E}_T^{miss} |$$

L_1, L_2 : two final state leptons



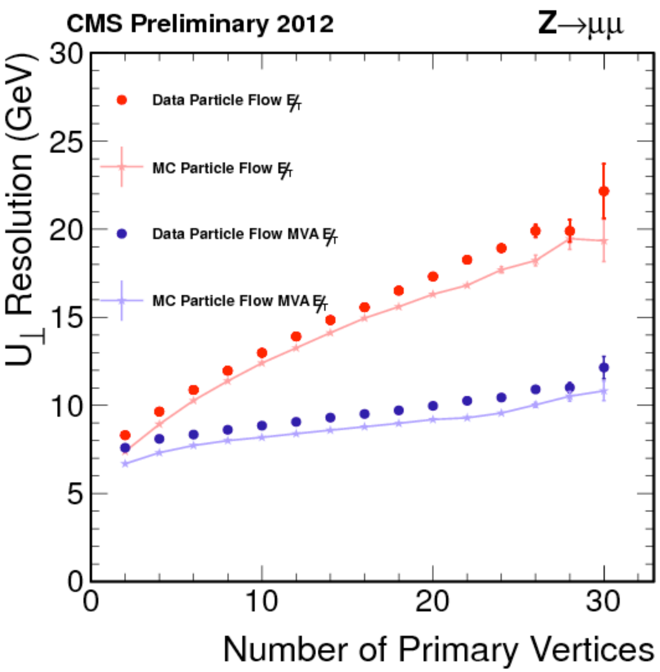
variable well controlled

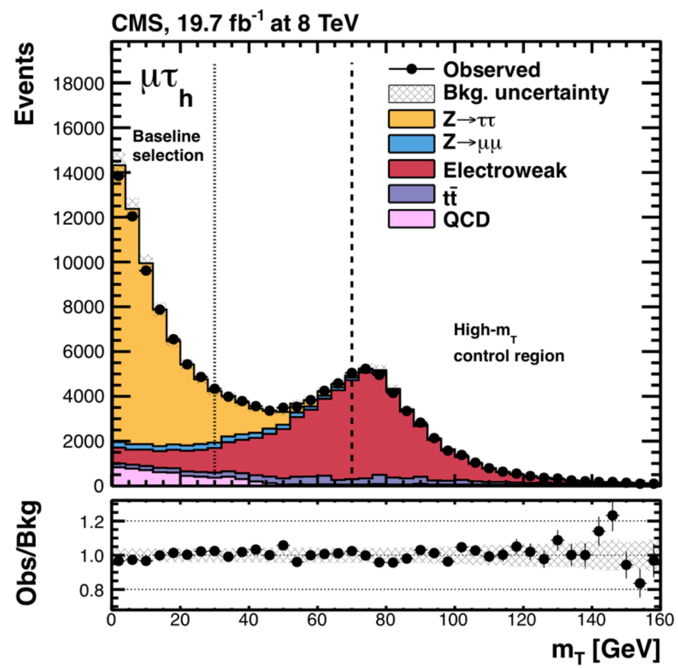
Systematics

- Summary of systematic uncertainties
- τ_h E-Scale
  - Shape Uncertainty
- Background Normalization
  - Vary by category/ channel
- Theory Uncertainties
- Bin-By-Bin Stat uncertainties

Uncertainty	Affected Processes	Change in acceptance
Tau energy scale	signal & sim. backgrounds	shape
e misidentified as τ	$Z \to ee$	20-74%
μ misidentified as τ	$Z \to \mu\mu$	30%
Jet misidentified as τ	Z+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	shape
Jet energy scale	signal & sim. backgrounds	0-20%
MET scale	signal & sim. backgrounds	1-12%
Eff. b-jets	signal & sim. backgrounds	0-8%
Eff. 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+jets	W+jets	10-100%
Norm. $t\bar{t}$	$t\bar{t}$	8-35%
Norm. di-boson	di-boson	15%-45%
Norm. QCD multijet	QCD multijet	6-70%
Shape QCD multijet	QCD multijet	shape
Luminosity 7 TeV (8 TeV)	signal & sim. backgrounds	2.2% (2.6%)
PDF (qq)	signal & sim. backgrounds	4%
PDF (gg)	signal & sim. backgrounds	10%
Scale variation	signal	3-41%
Underlying event & parton shower	signal	2-10%
Limited number of events	all	shape bin-by-bin

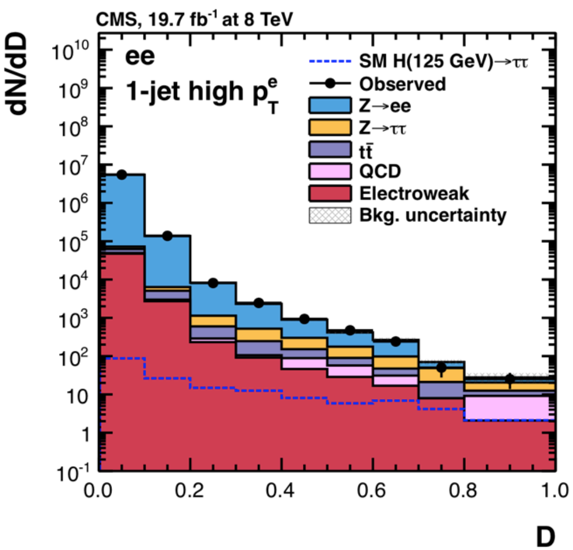
MET and control of W+Jets Background

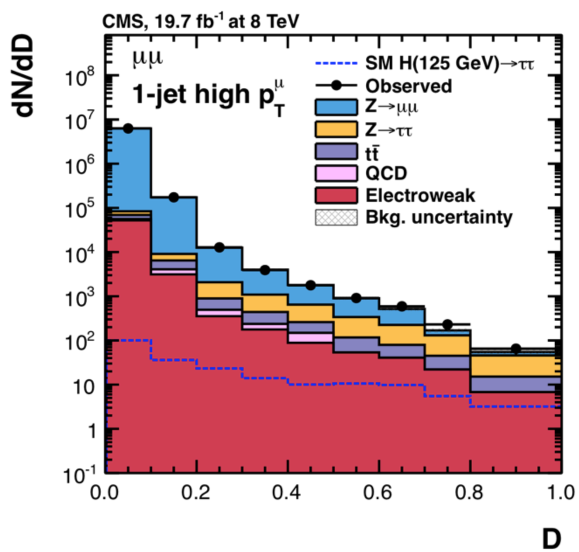




- E_T^{miss}: significant improvement in resolution and dependence on pileup
- Crucial for H→ττ analysis: $m_{\tau\tau}$ reconstruction and separation of signal from W+jets background using $m_T(\mu, E_T^{miss})$ selections

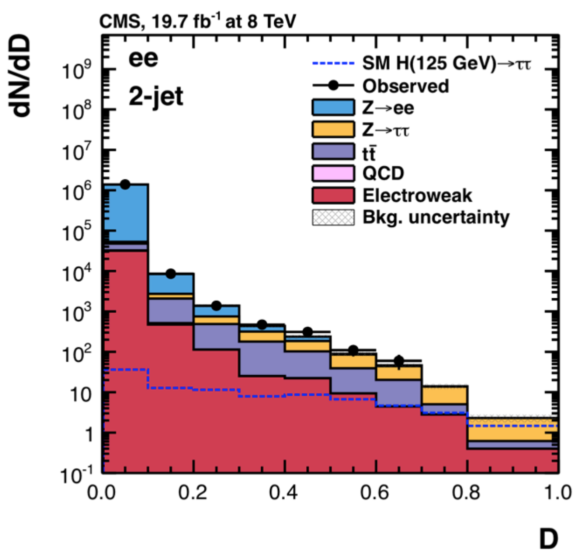
$\tau_e\tau_e/\tau_\mu\tau_\mu$ Channels

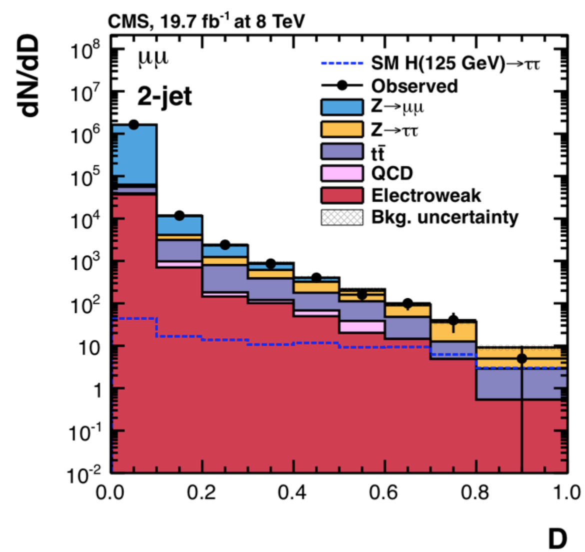




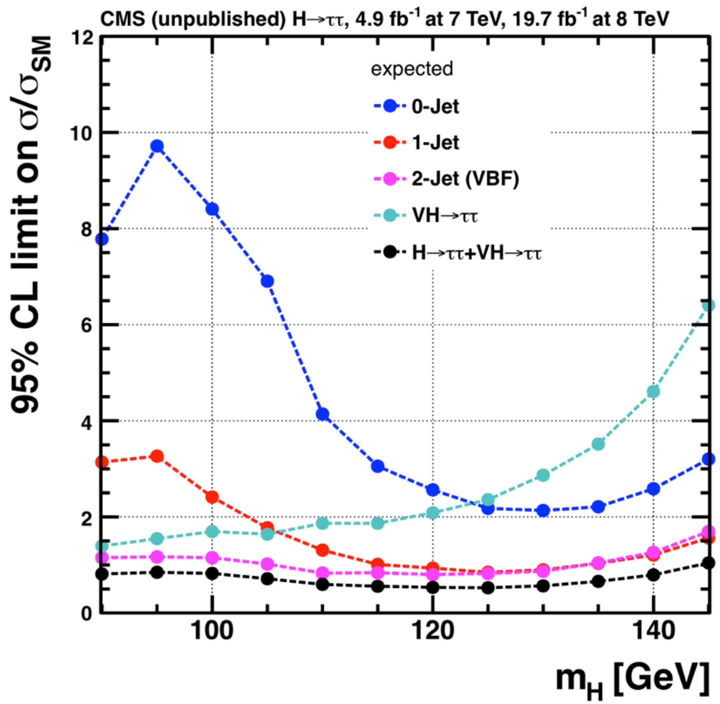
- Large Z→ll background
- Small ττ branching ratios

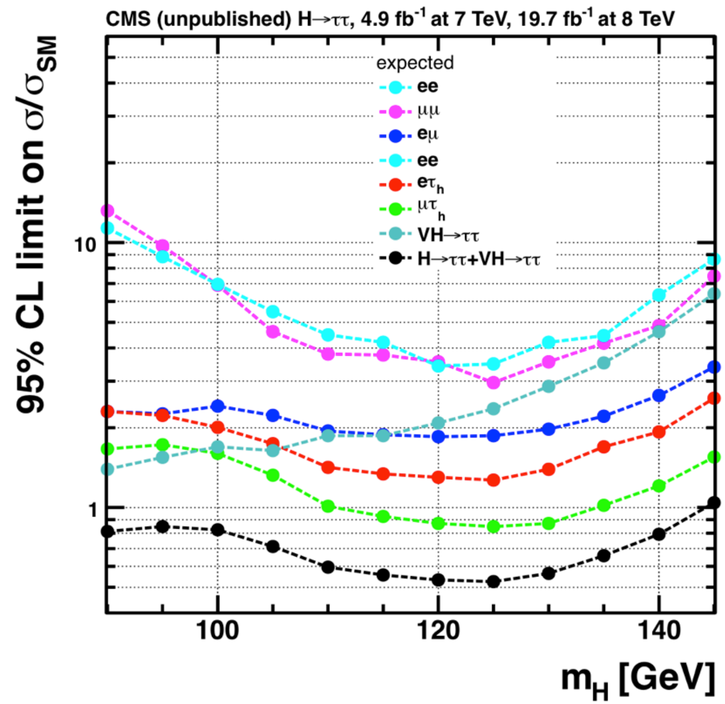
- Analysis fits to BDT distribution
- BDT includes kinematic variables including: $M_{\tau\tau}$, M_{vis}





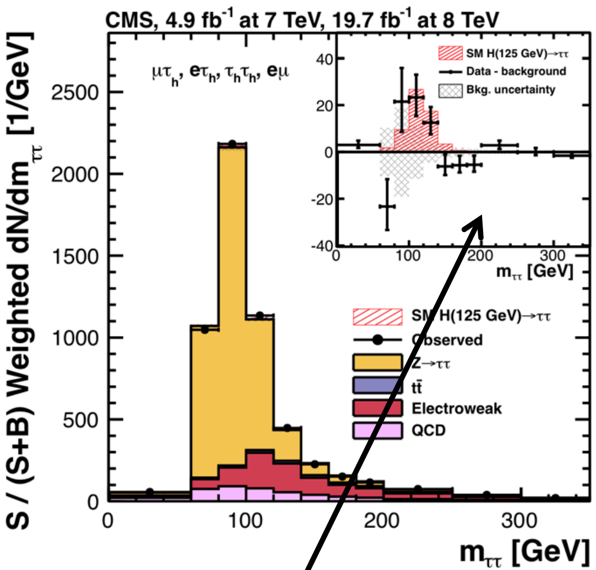
Expected Sensitivity

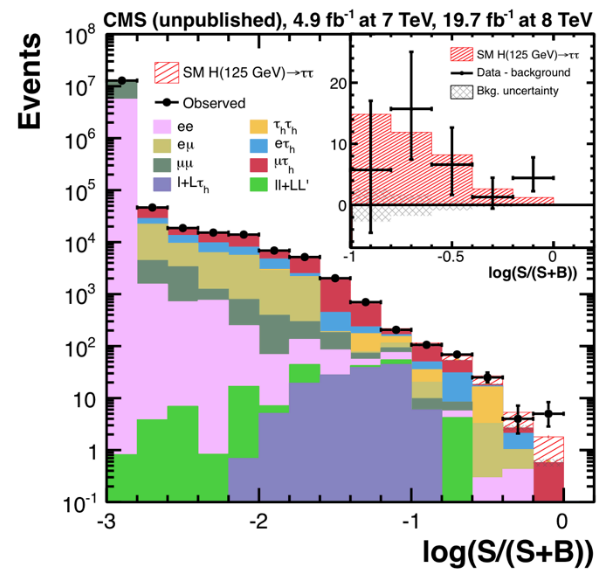


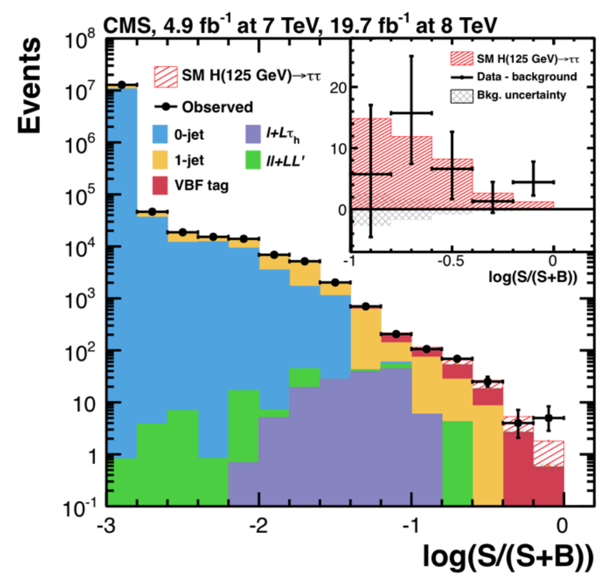


- $\tau_\mu\tau_h$ is the most sensitive channel
- VBF/Boost highest sensitivity categories
  - Good Mass Resolution and smaller backgrounds

Significance Weighted

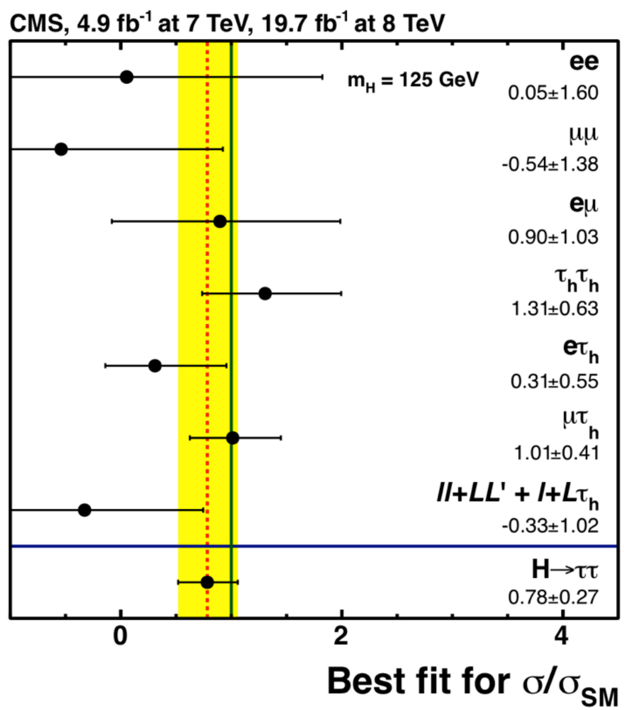


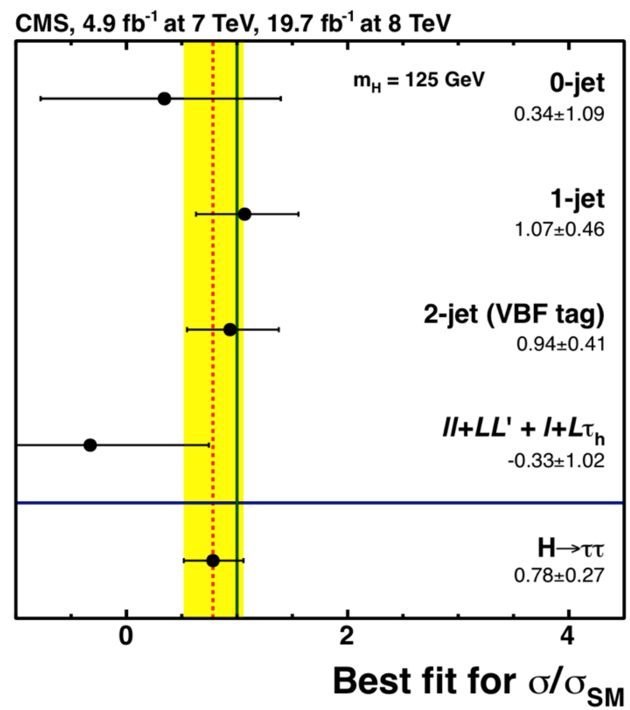




- Inset shows difference between observed data and expected background – compared to SM H (125) expectation

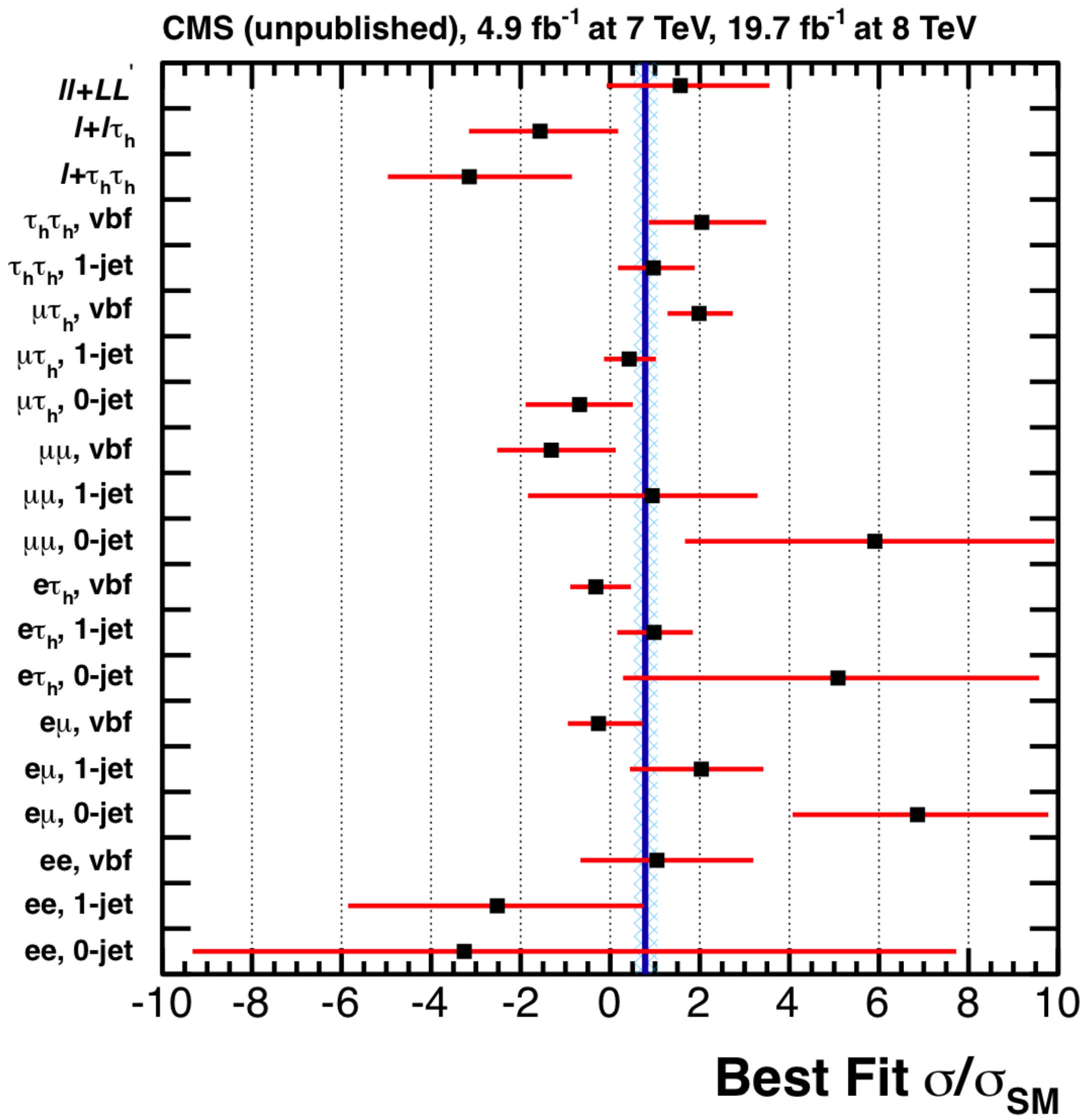
Best Fit



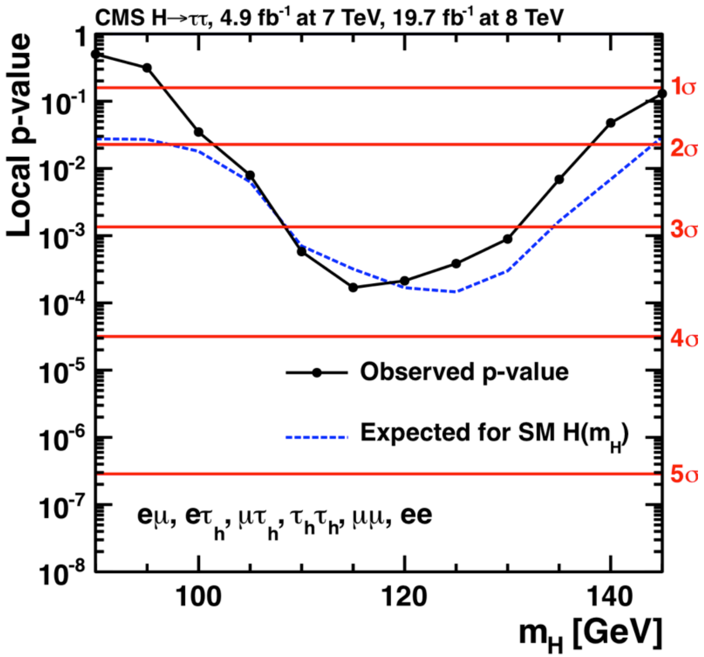


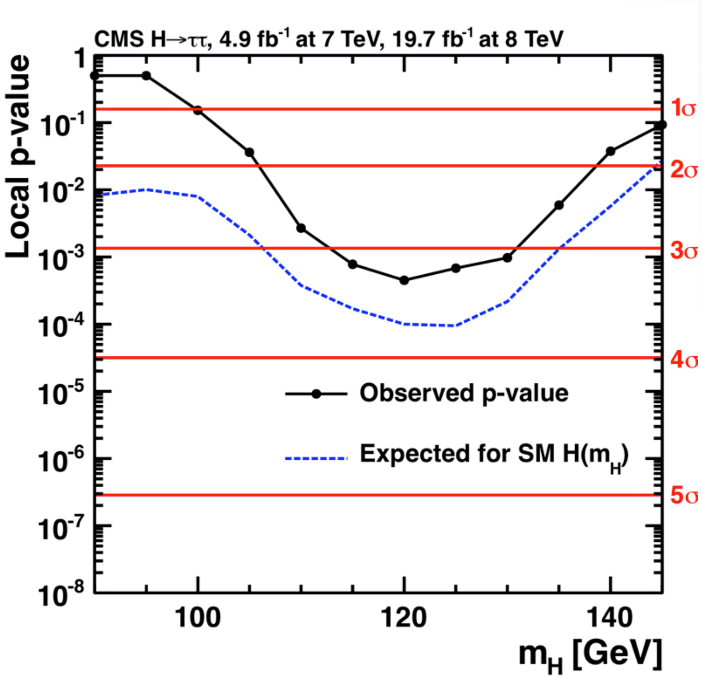
- Overall best fit $\mu = 0.78 \pm 0.27$
- Standard model like couplings

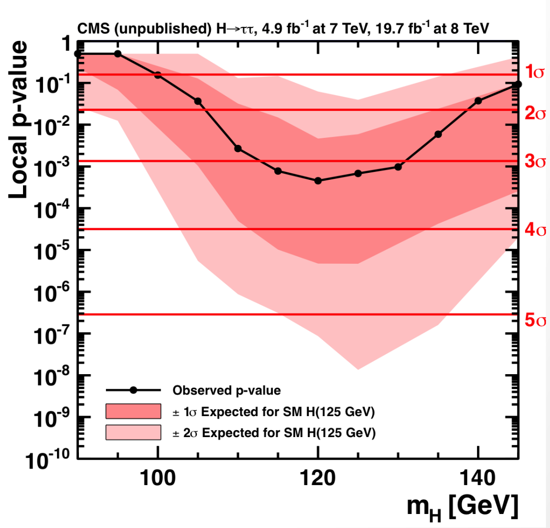
Best Fit Breakdown



Significance

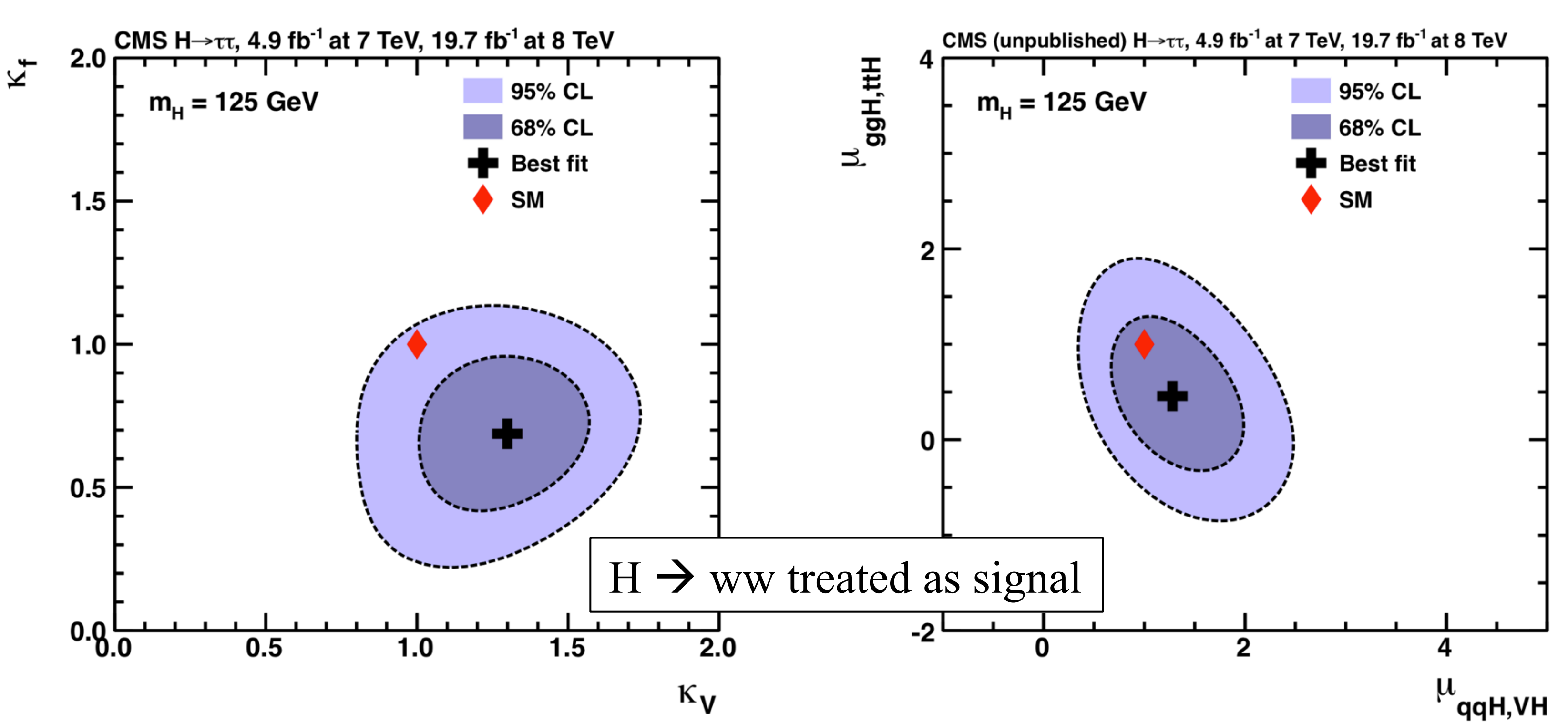






- Excess of 3.2 σ observed compared (M_H = 125 GeV) to 3.7 σ expected
  - Slightly larger in the case VH is excluded (3.4 σ observed)
- 0.07% chance of background only hypothesis

Couplings



H → ww treated as signal

- Couplings are compatible with SM expectation

Vector and fermion couplings grouped

κ_V: $\kappa_W = \kappa_Z$ κ_F: $\kappa_t = \kappa_b = \kappa_\tau = \kappa_g$