Search for a SM H boson decaying to taus and produced in association with a vector boson

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Results from:

Evidence for the 125 GeV Higgs boson decaying to a pair of τ leptons

The CMS Collaboration*

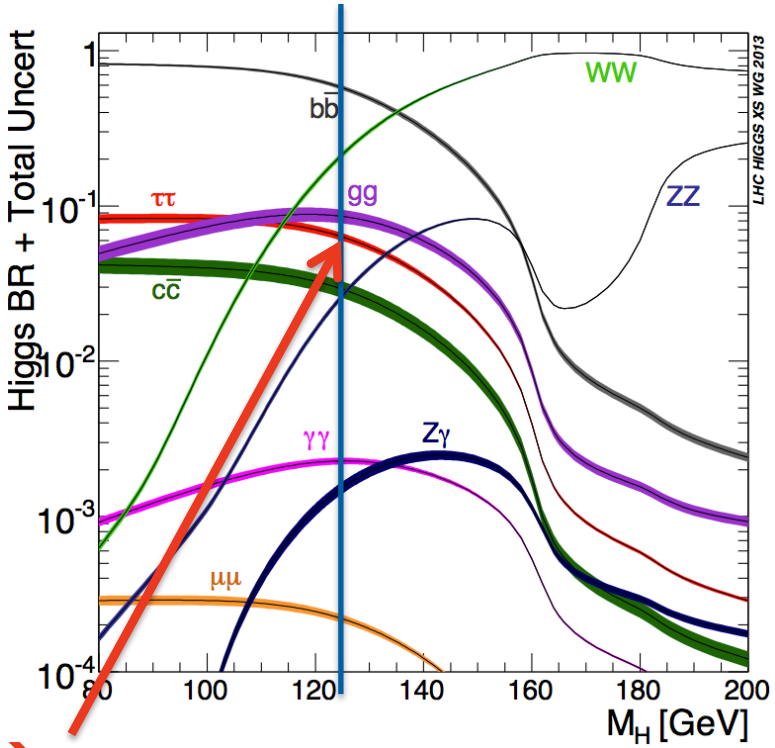
Submitted to JHEP, arXiv:1401:5041v1

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

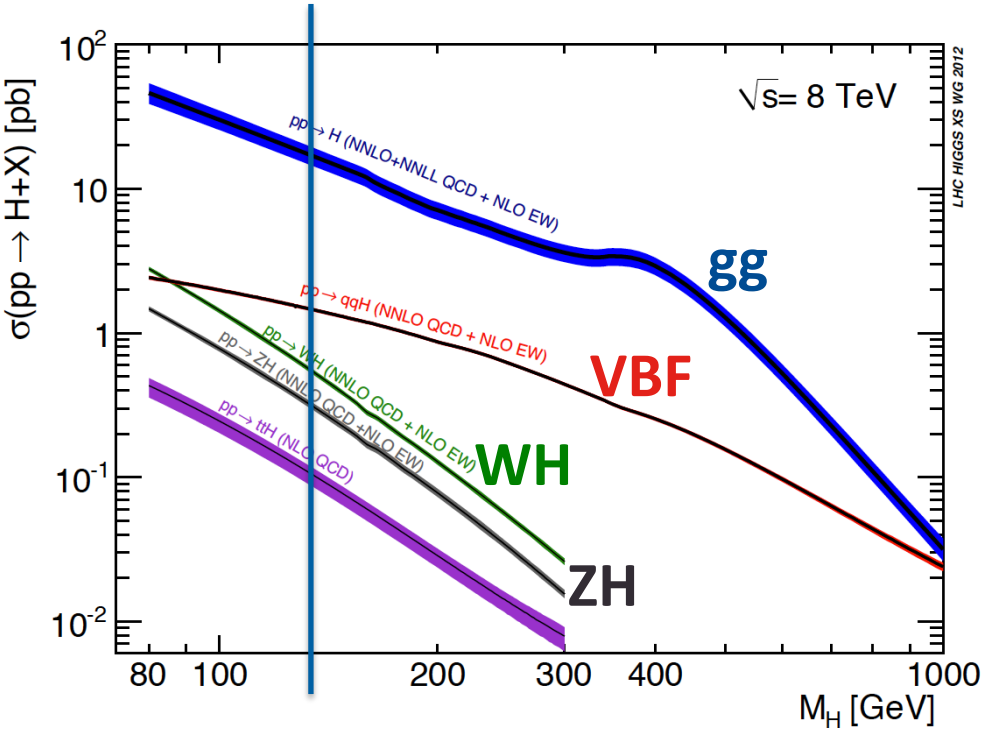
The CMS Collaboration*

Submitted to Nature Physics, arXiv:1401:6527v1

Motivation



H→ττ

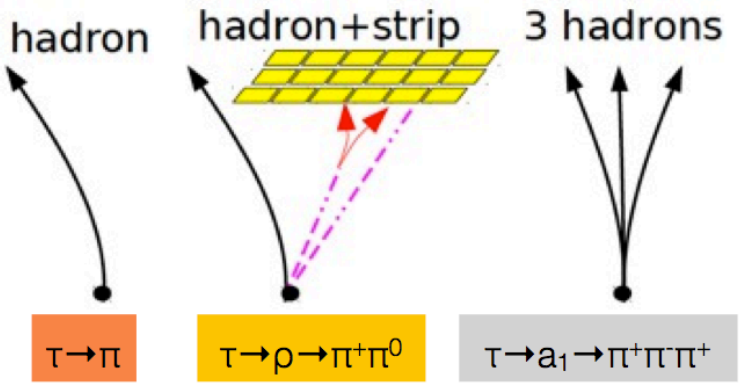


- Does the H boson couple to fermions?
- Does it couple to fermions through Yukawa couplings?
- Can it be produced in association with a vector boson?

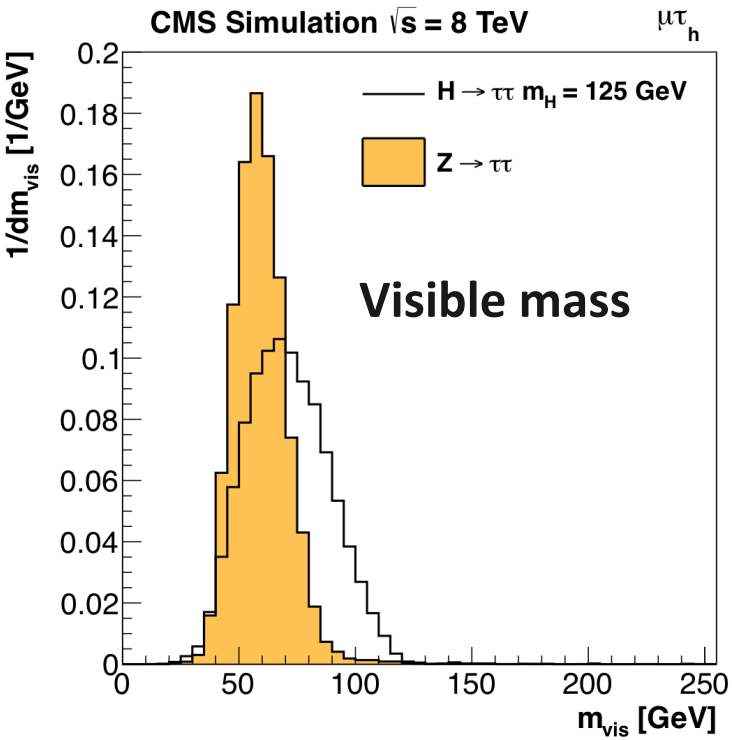
Hadronic tau (τ_h) reconstruction

Decay mode	Resonance	Mass (MeV/c^2)	Branching fraction (%)
$\tau^- \to h^- \nu_\tau$			11.6%
$\tau^- \to h^- \pi^0 \nu_\tau$	ρ^-	770	26.0%
$\tau^- \to h^- \pi^0 \pi^0 \nu_\tau$	a_1^-	1200	9.5%
$\tau^- \to h^- h^+ h^- \nu_\tau$	a_1^-	1200	9.8%
$\tau^- \to h^- h^+ h^- \pi^0 \nu_\tau$			4.8%

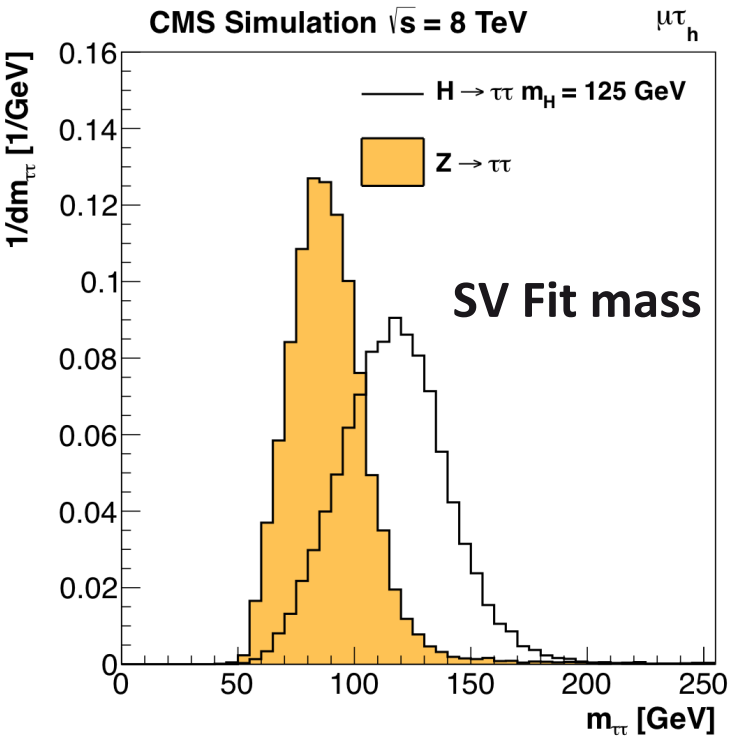
- Hadrons Plus Strips (HPS) algorithm:
  - Decay mode finding: based on number of charged hadrons + EM strips compatible with intermediate resonance mass
  - Isolation: cut-based or MVA-based



H mass reconstruction



Invariant mass of visible decay products

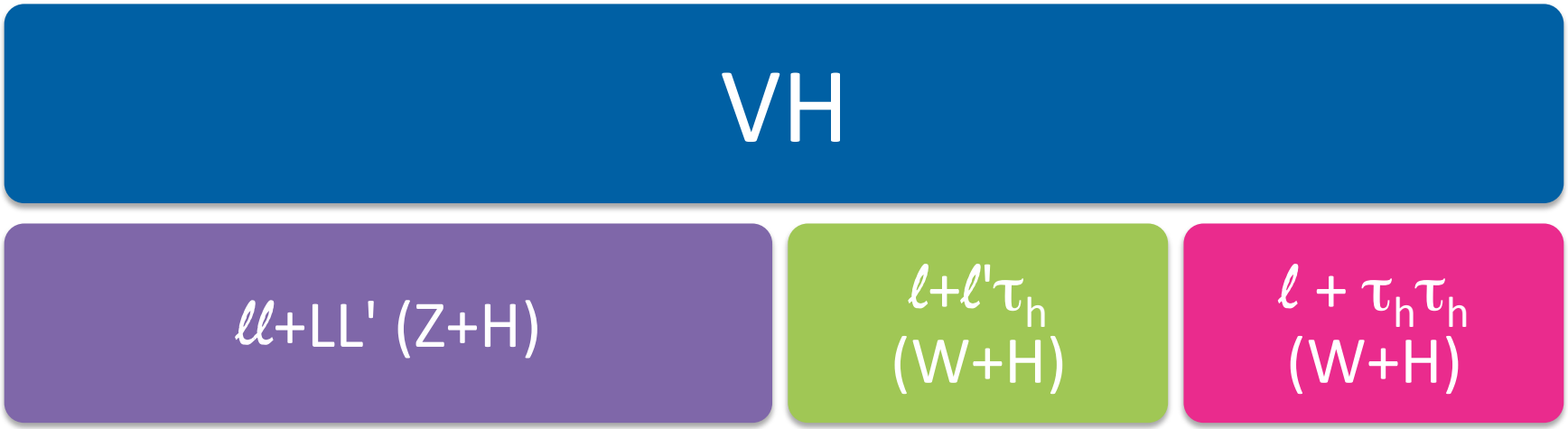


Kinematic event-by-event maximum likelihood with visible four-momenta, MET and MET resolution

- Improved H→ττ/Z→ττ separation
- Improved mass resolution

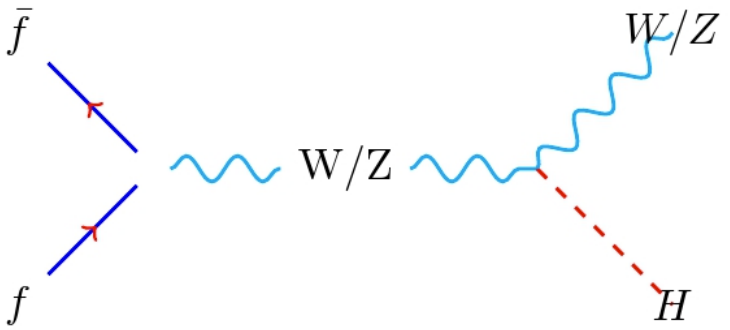
→ Up to **30%** effect on limit

VH analysis structure

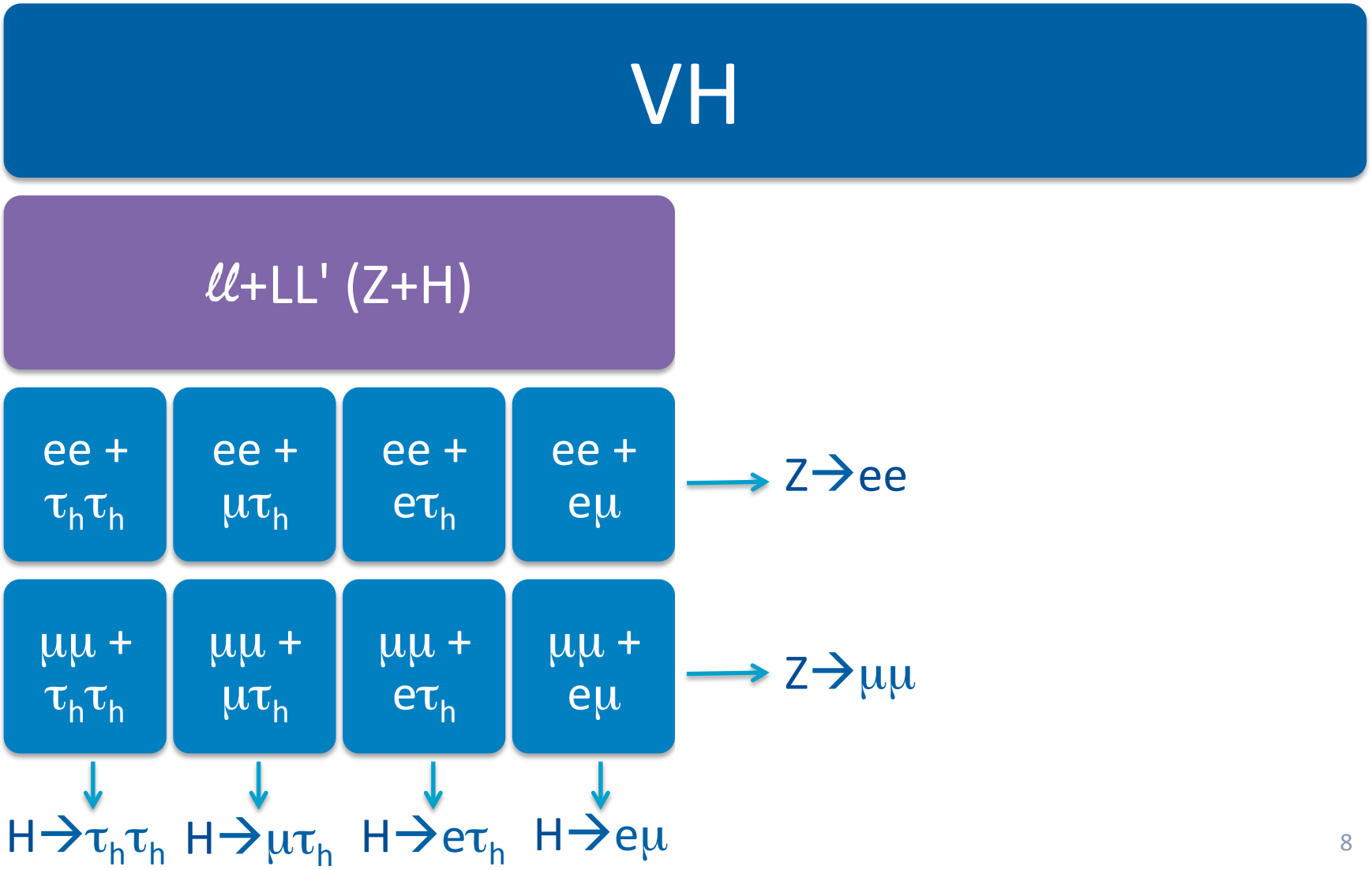


Selection overview

- Trigger:
  - DoubleMu, DoubleEle, SingleMu, Ele+Mu, Ele+Tau, …
- Vector boson selection:
  - 1 or 2 loosely identified and isolated electron or muon, compatible with a W or a Z boson
- H selection:
  - 2 identified and isolated OS leptons
- Additional requirements:
  - b-jet veto, extra lepton veto
  - Other cuts depending on final state



ZH analysis ($\ell\ell$+LL')



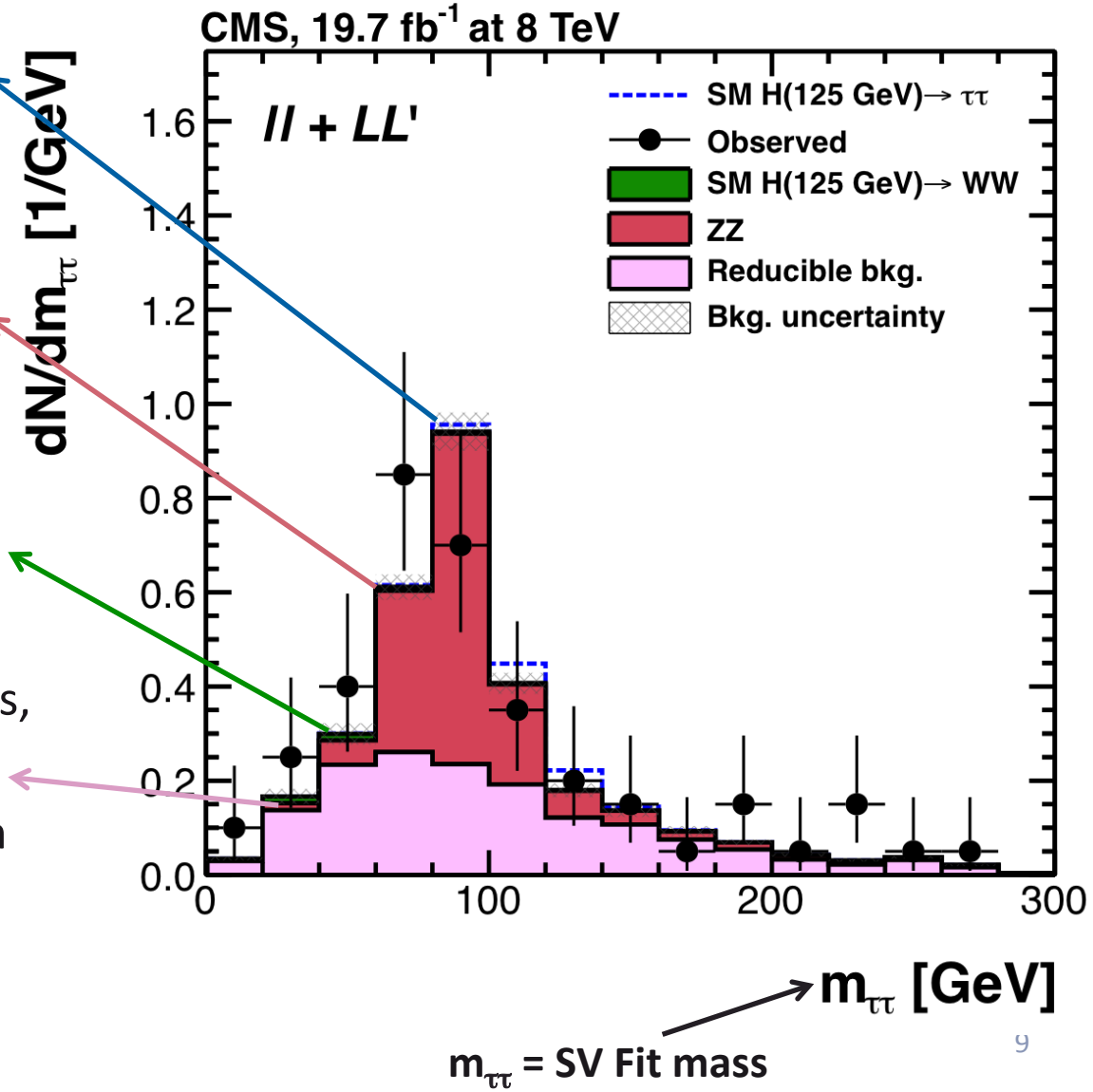
$\ell\ell$+LL' overview

- **ZH→Zττ**: signal
- **ZZ**: irreducible

  Estimated from MC
- **H→WW**: irreducible

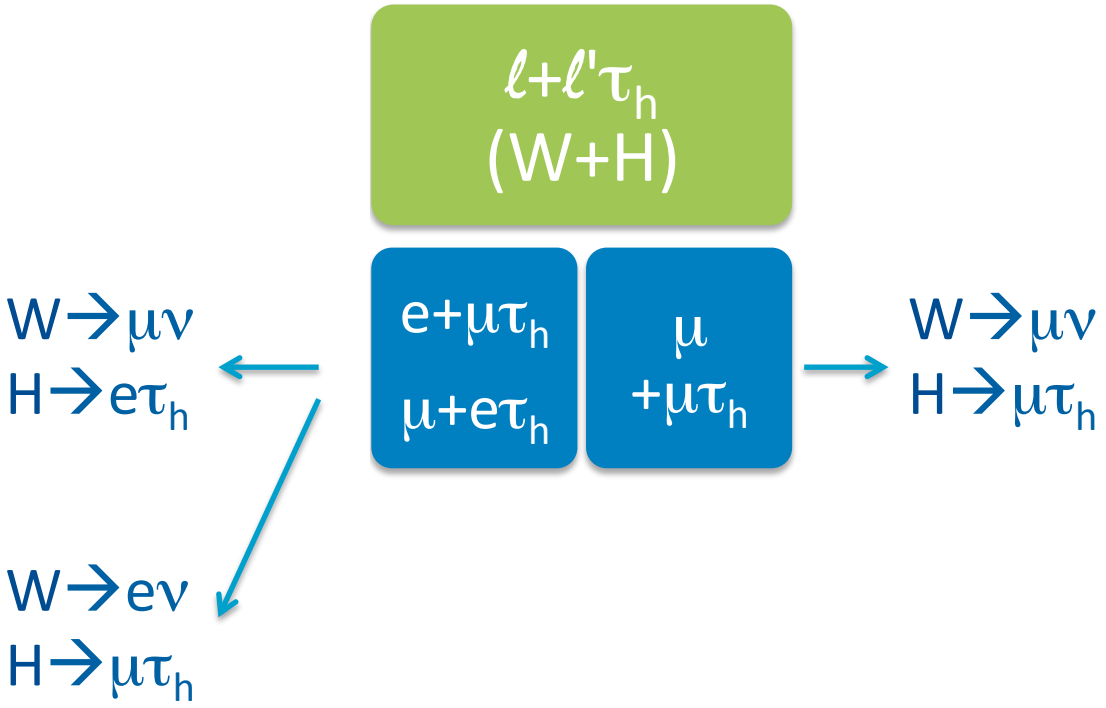
  Considered as background
- **Reducible**: Z+jets, WZ+jets, ttbar, …

  Estimated from data with fake rate method



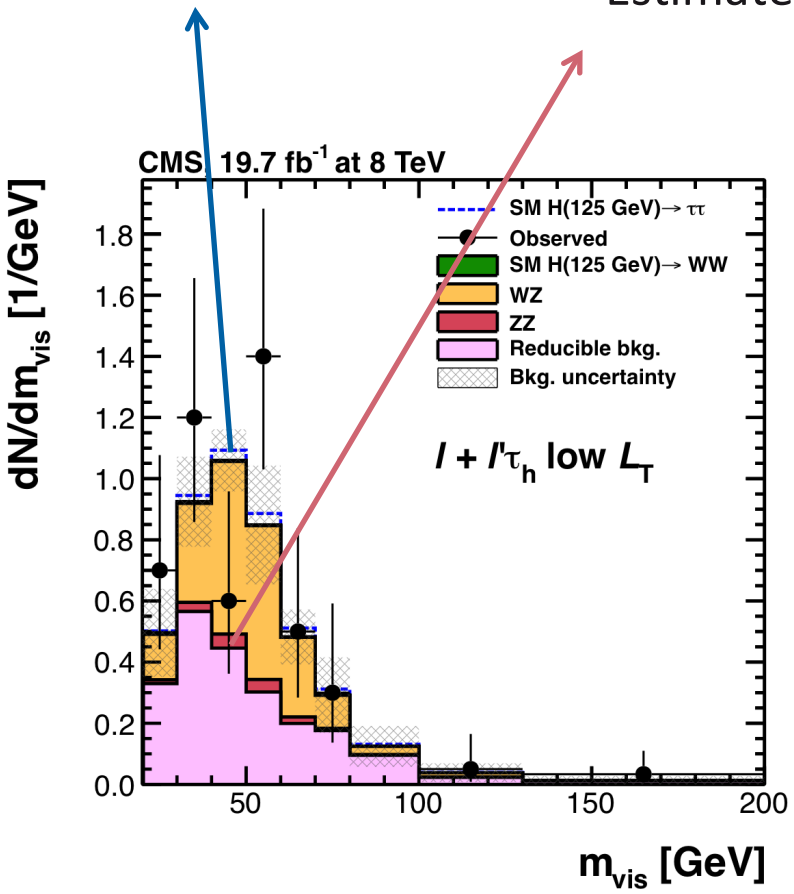
WH semi-leptonic analysis ($\ell+\ell'\tau_h$)

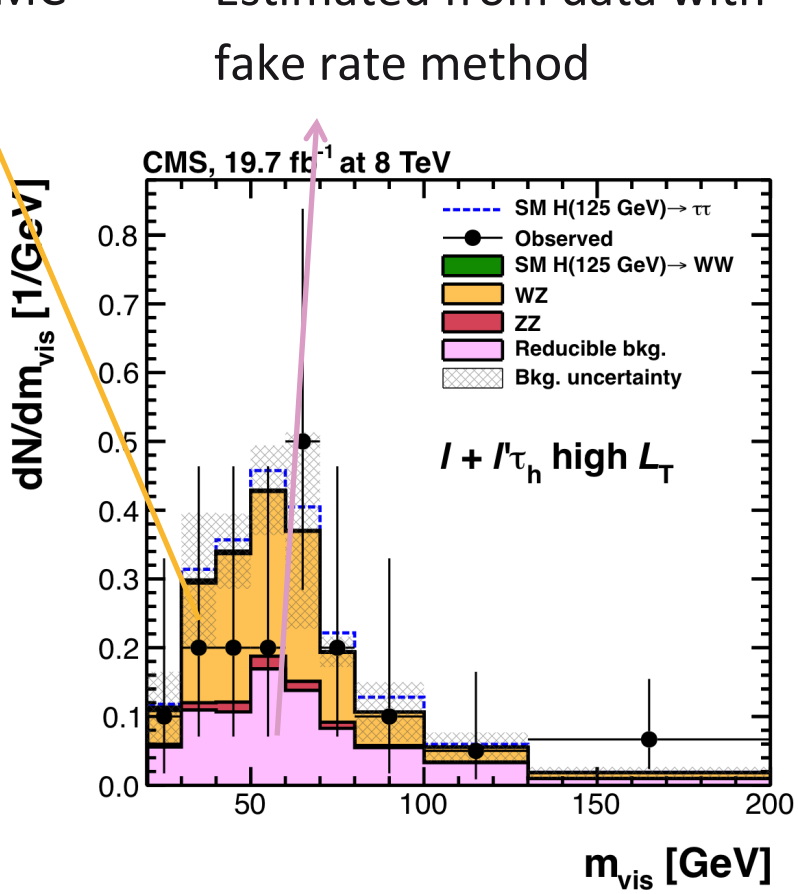
VH



$\ell+\ell'\tau_h$ overview

- **WH→Wττ**: signal
- **ZZ/WZ**: irreducible
  Estimated from MC
- **Reducible**: Z+jets, W+jets, ttbar, QCD, …
  Estimated from data with fake rate method

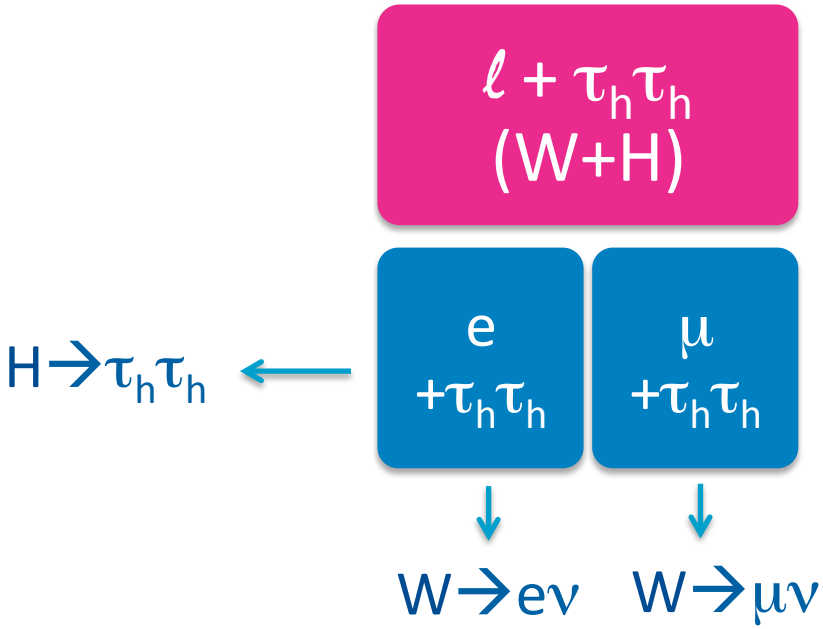




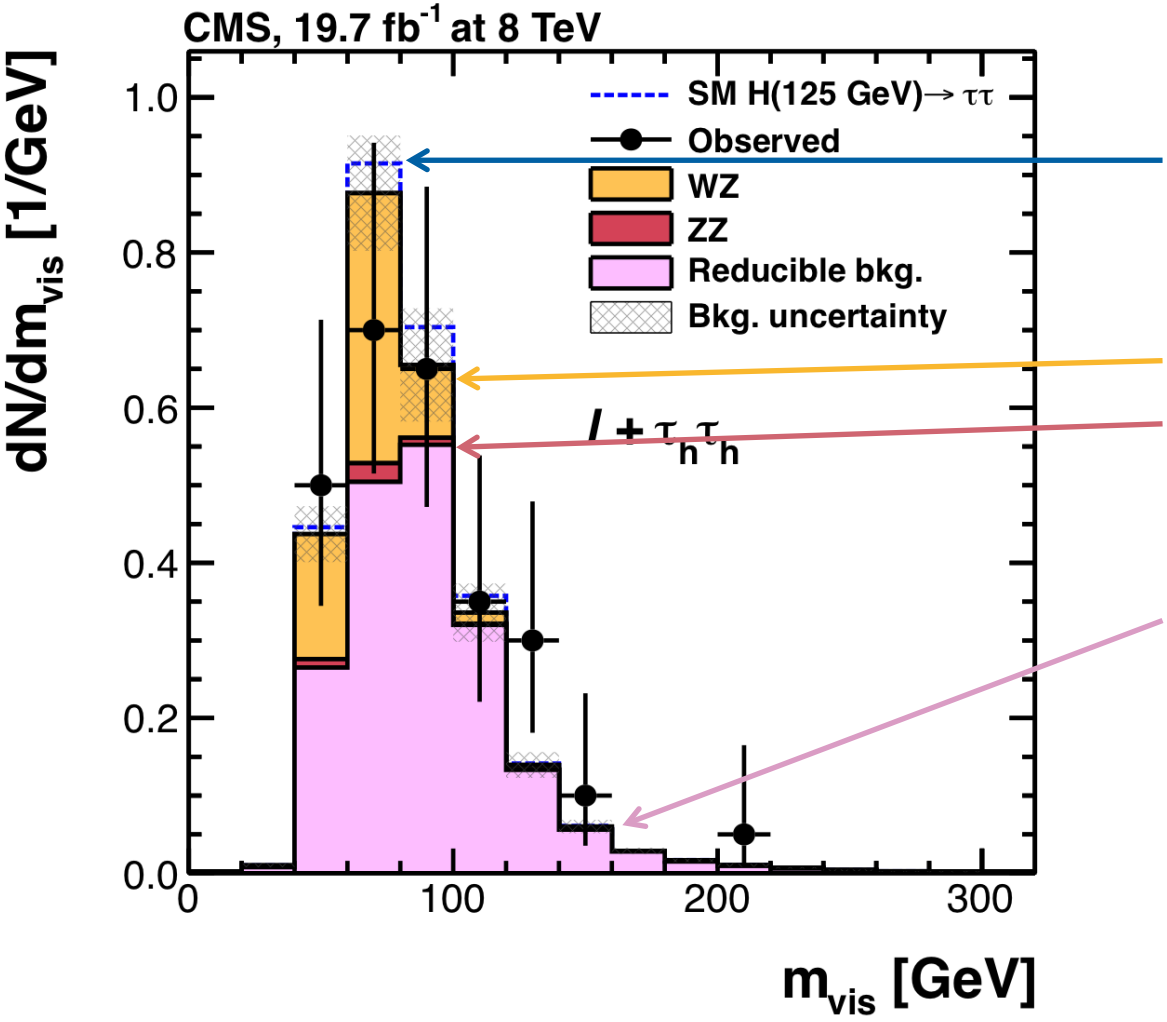
- 2 categories: L_T>130 GeV or L_T<130 GeV *(L_T: scalar pT sum of all leptons)*
- SS light leptons

WH fully-hadronic analysis ($\ell+\tau_h\tau_h$)

VH



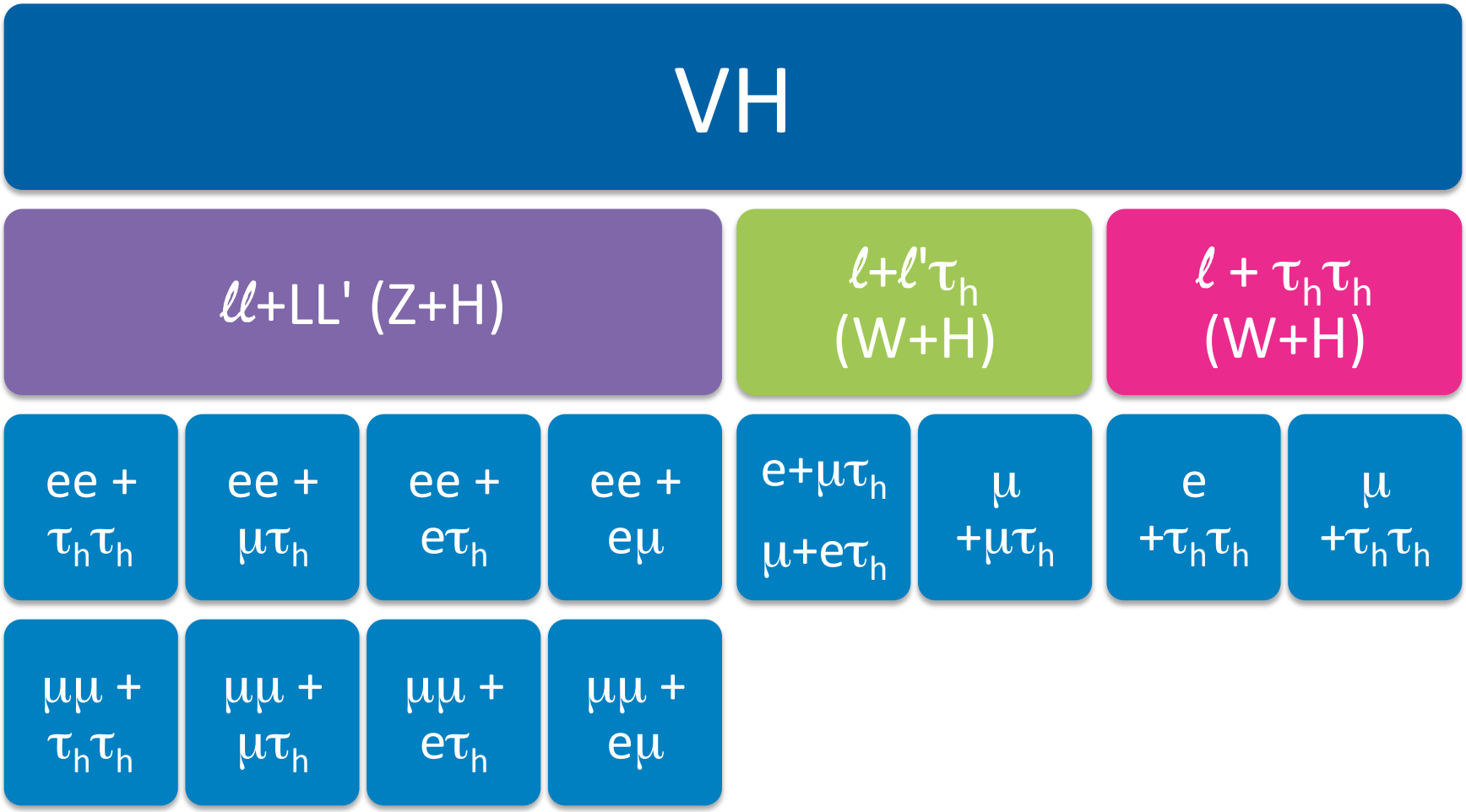
$\ell+\tau_h\tau_h$ overview



- **WH→Wττ**: signal
- **ZZ/WZ**: irreducible
  Estimated from MC
- **Reducible**: Z+jets, W+jets, QCD, …
  Estimated from data with fake rate method

- MVA discrimination against reducible background

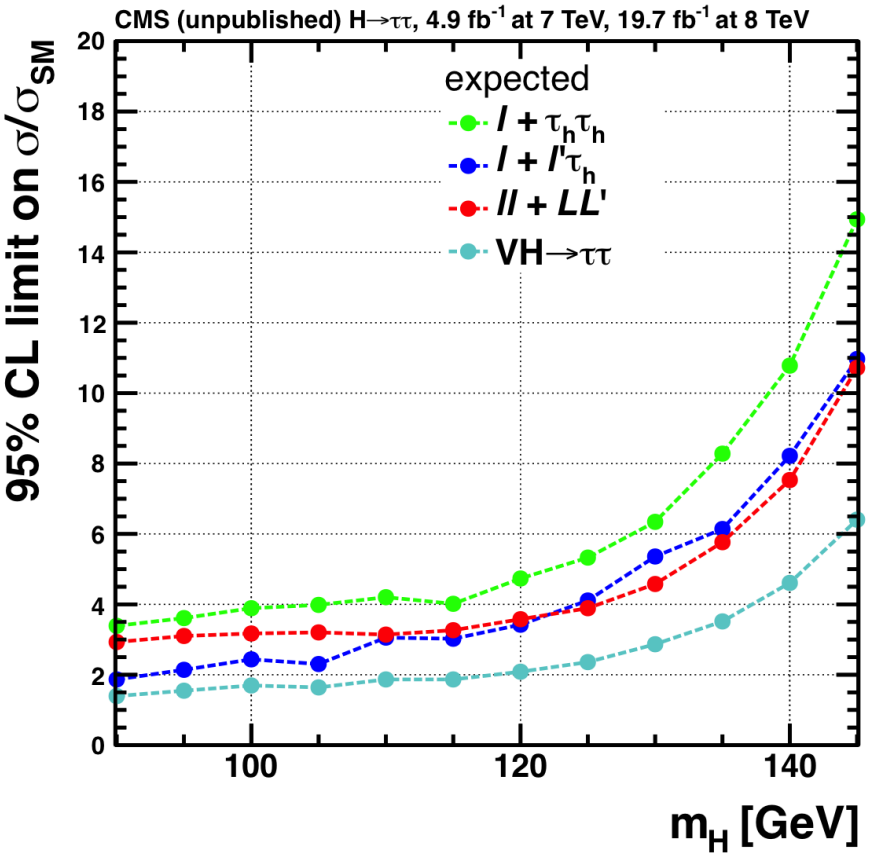
VH combination

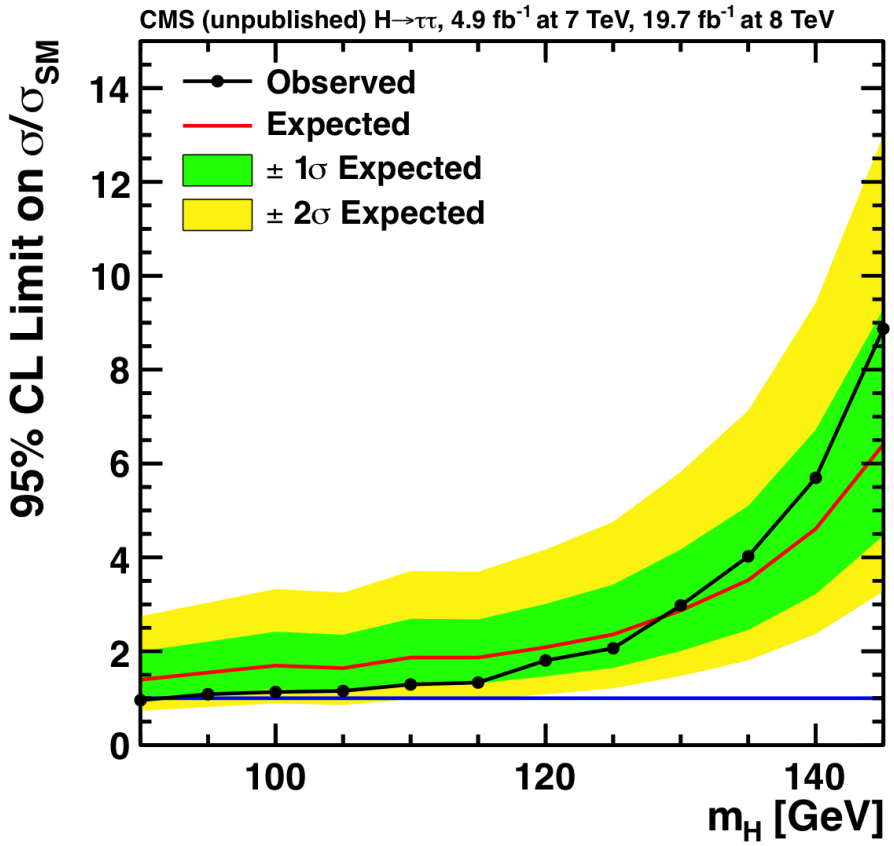


Systematics

Light lepton ID/iso/trigger	2-6%
Tau ID	6%
Tau energy scale	shape
Normalization WZ/ZZ	4-8%
Normalization reducible background	15-30%
Shape reducible background	shape
Limited number of events	shape

VH exclusion limit

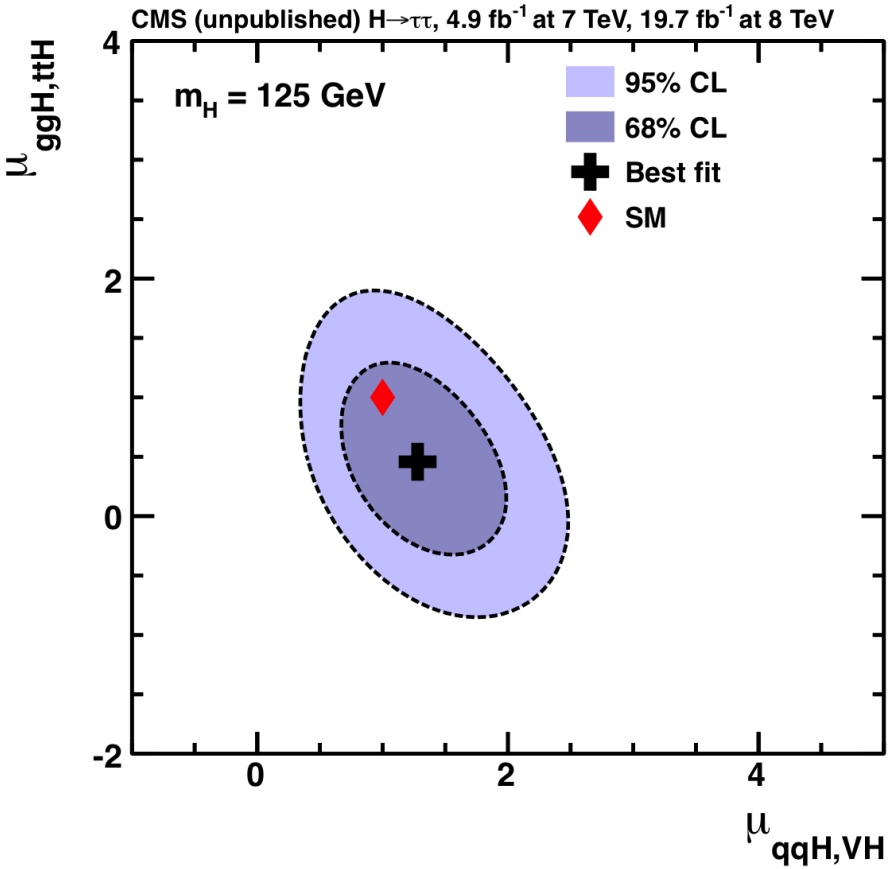




- At m_H= 125 GeV:
  - 2.36 (exp)
  - 2.06 (obs)

VH contribution to H→ττ analysis

- ~5% increase in sensitivity
- H coupling to fermions $\mu_{qqH,VH}$ measurement

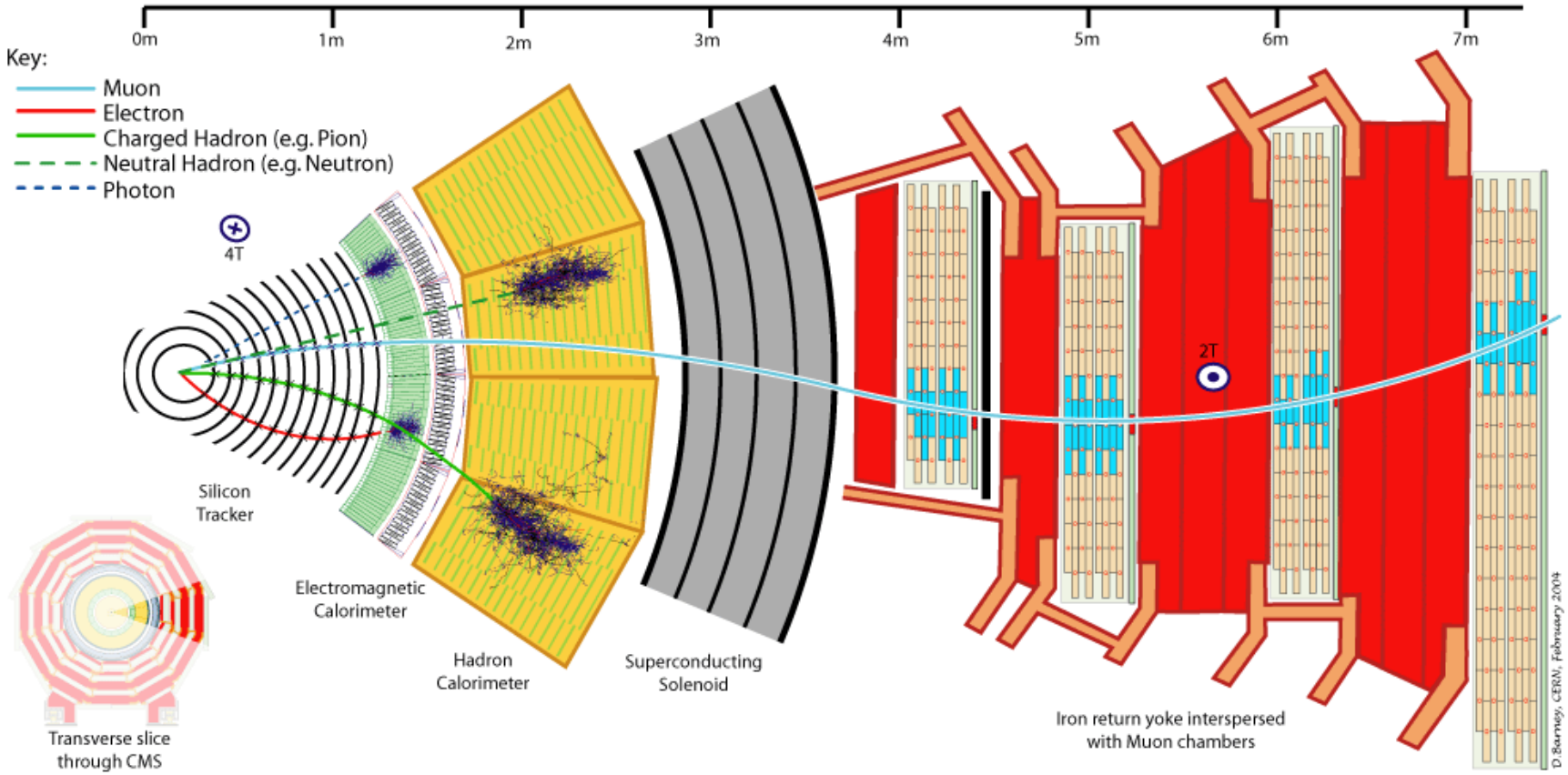


Conclusion

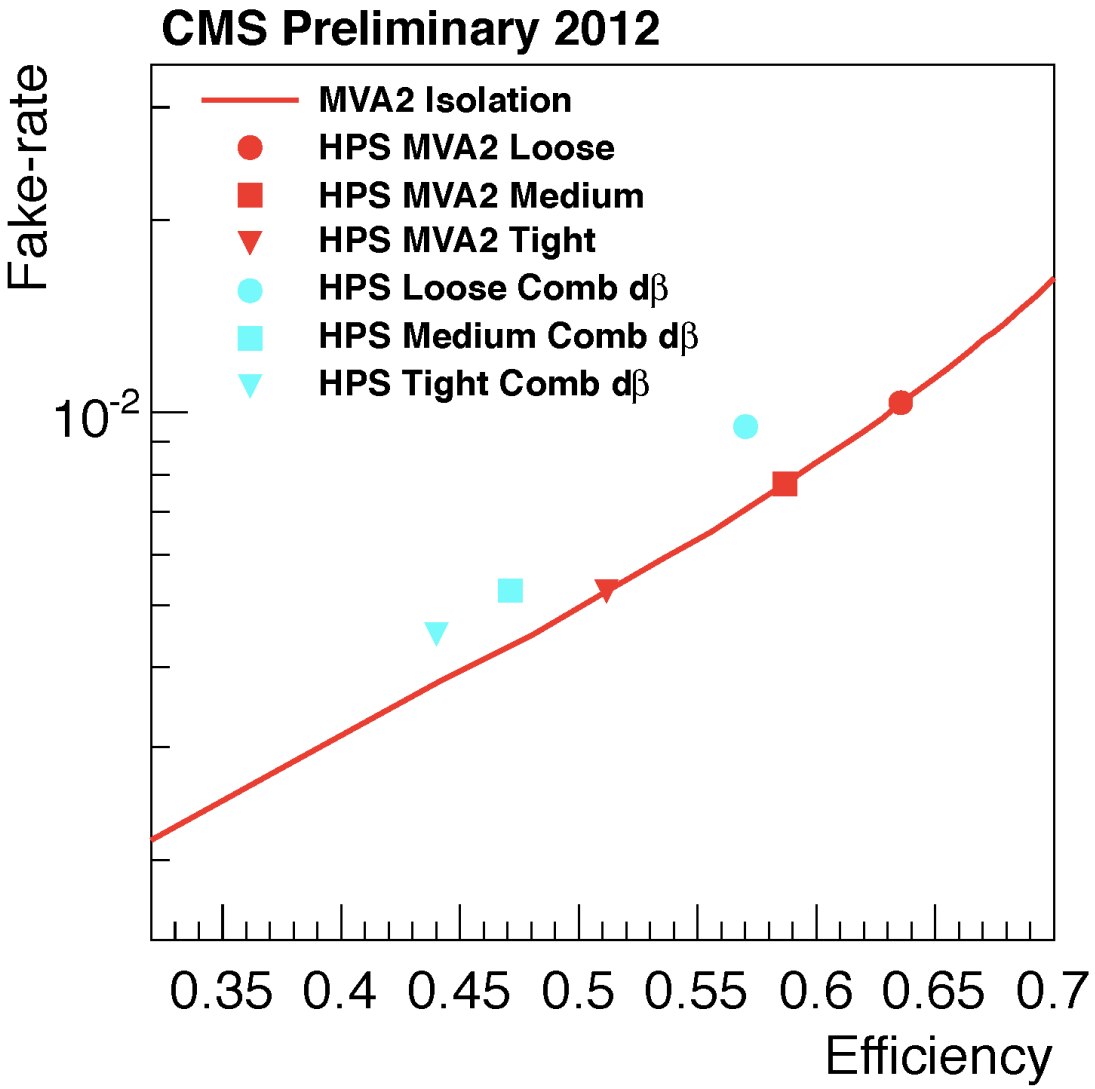
- Search for a SM H boson in VH→Vττ channel:
  - 5% increase in sensitivity in H→ττ analysis
  - Probing H associated production mode
- Contribution to the **evidence** for a SM H boson decaying to tau leptons
- Exclusion limits: **2.36** (exp) **2.06** (obs)
- Looking forward to reaching SM sensitivity in Run 2!

BACKUP

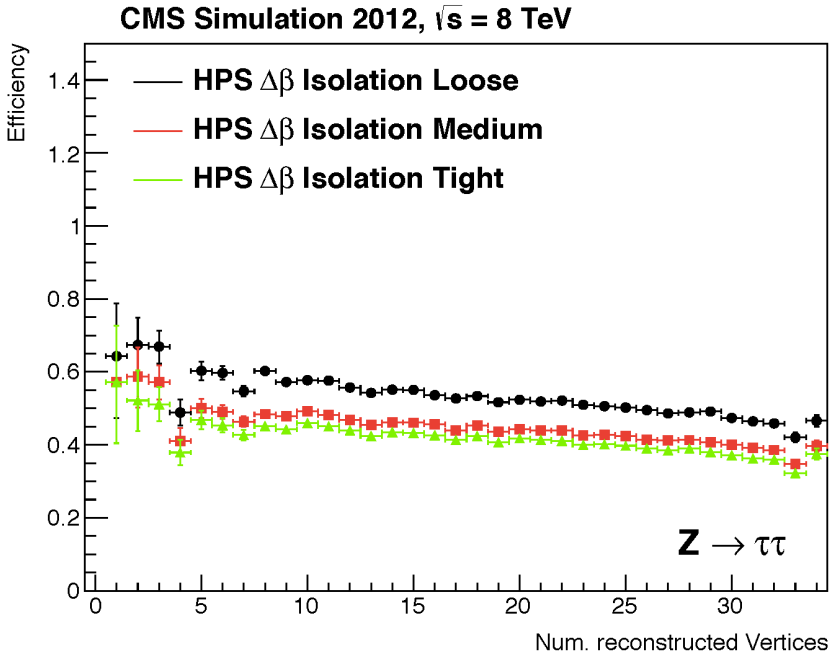
CMS detector

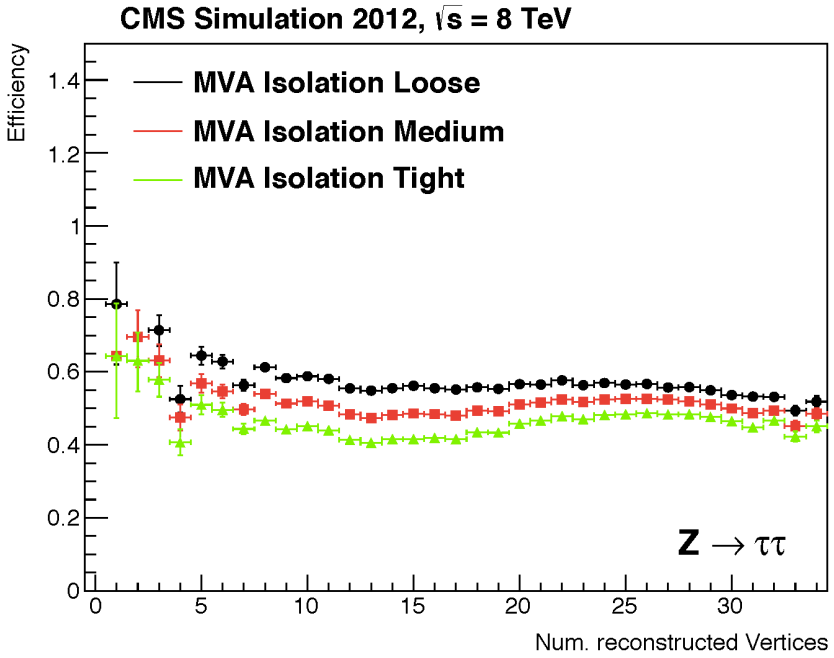


Tau ID performance

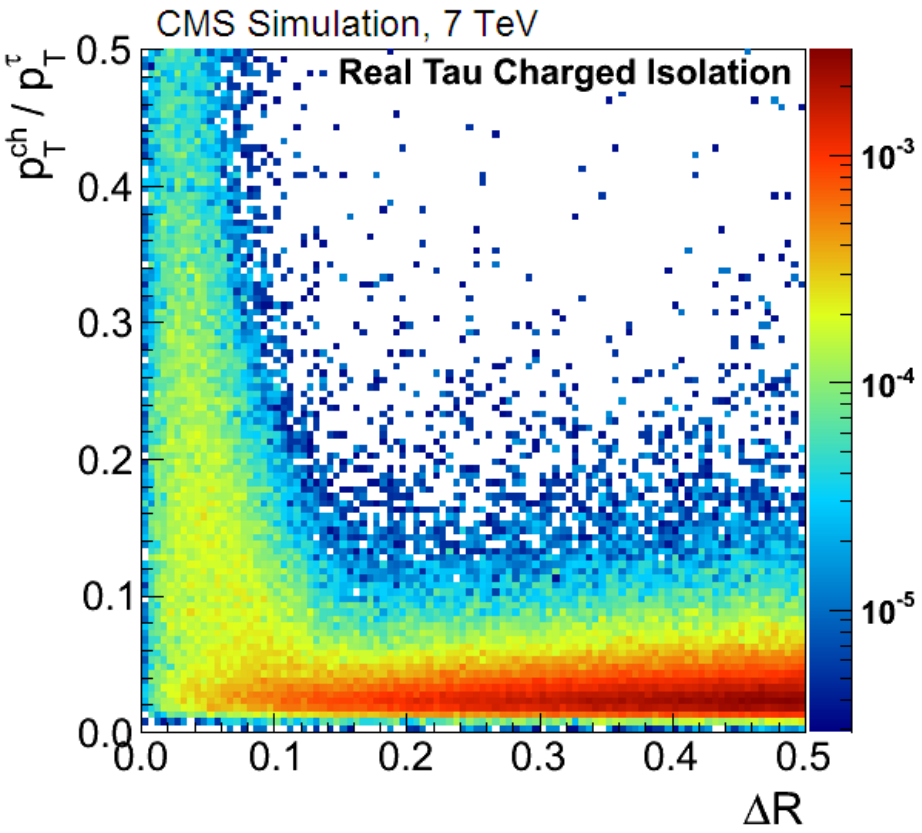


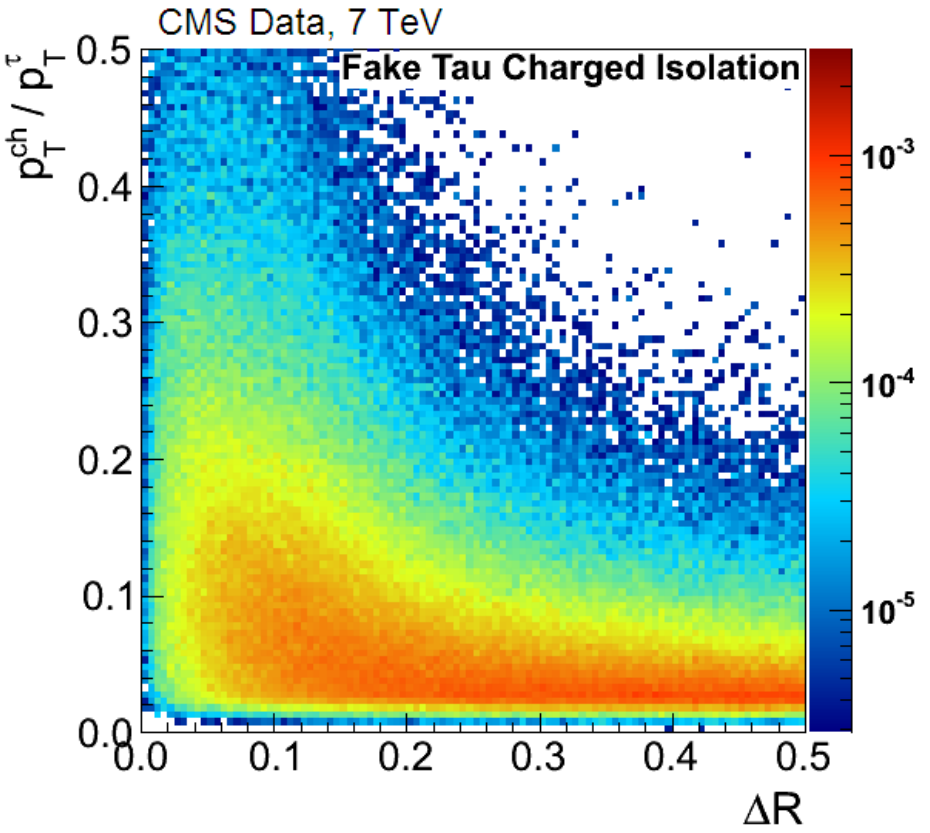
Tau ID performance





Tau ID performance





$\ell+\ell'\tau_h$ / $\ell+\tau_h\tau_h$ lepton selection

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

$\ell\ell$+LL' lepton selection

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

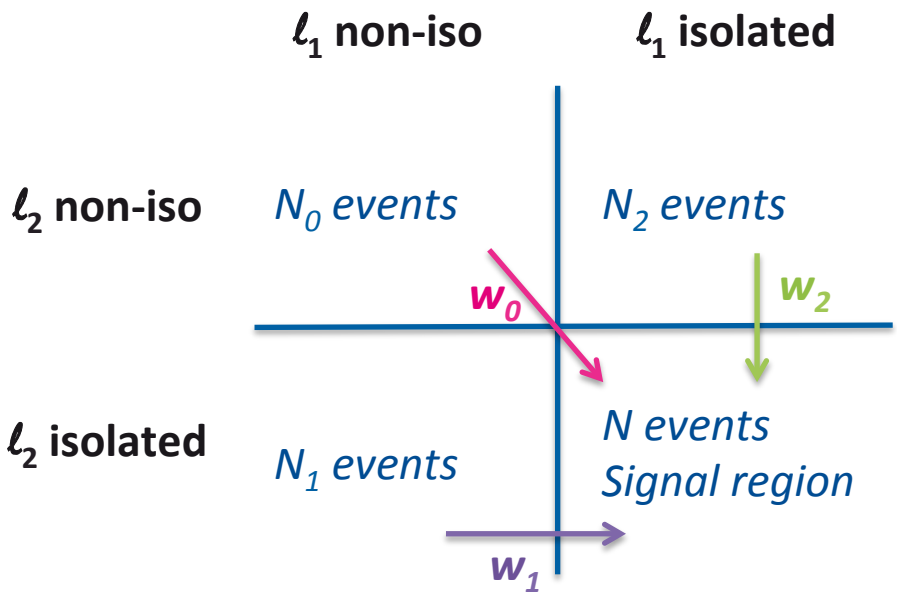
Event category	Signal	Background	Data	$\frac{S}{S+B}$
$\ell\ell + LL'$				
$\mu\mu + \mu\tau_h$ 7 TeV	0.111 ± 0.005	2.4 ± 0.3	2	0.103
$\mu\mu + \mu\tau_h$ 8 TeV	0.427 ± 0.021	10.5 ± 0.6	12	0.092
$ee + \mu\tau_h$ 7 TeV	0.087 ± 0.004	1.5 ± 0.1	2	0.135
$ee + \mu\tau_h$ 8 TeV	0.385 ± 0.018	7.6 ± 0.4	11	0.149
$\mu\mu + e\tau_h$ 7 TeV	0.078 ± 0.004	2.2 ± 0.1	1	0.092
$\mu\mu + e\tau_h$ 8 TeV	0.293 ± 0.014	12.2 ± 0.6	8	0.081
$ee + e\tau_h$ 7 TeV	0.075 ± 0.004	2.2 ± 0.1	4	0.077
$ee + e\tau_h$ 8 TeV	0.279 ± 0.013	10.2 ± 0.5	13	0.063
$\mu\mu + \tau_h\tau_h$ 7 TeV	0.073 ± 0.006	0.8 ± 0.1	0	0.195
$\mu\mu + \tau_h\tau_h$ 8 TeV	0.285 ± 0.022	5.8 ± 0.4	4	0.150
$ee + \tau_h\tau_h$ 7 TeV	0.061 ± 0.004	1.1 ± 0.1	1	0.127
$ee + \tau_h\tau_h$ 8 TeV	0.260 ± 0.020	4.8 ± 0.4	9	0.148
$\mu\mu + e\mu$ 7 TeV	0.051 ± 0.002	1.0 ± 0.1	3	0.100
$\mu\mu + e\mu$ 8 TeV	0.202 ± 0.008	5.1 ± 0.3	9	0.105
$ee + e\mu$ 7 TeV	0.045 ± 0.002	1.0 ± 0.0	1	0.077
$ee + e\mu$ 8 TeV	0.185 ± 0.007	4.0 ± 0.2	4	0.082
$\ell + \tau_h\tau_h$				
$\mu + \tau_h\tau_h$ 7 TeV	0.35 ± 0.03	4.1 ± 0.4	2	0.098
$\mu + \tau_h\tau_h$ 8 TeV	1.57 ± 0.12	35.2 ± 2.1	38	0.054
$e + \tau_h\tau_h$ 7 TeV	0.23 ± 0.02	2.7 ± 0.2	0	0.101
$e + \tau_h\tau_h$ 8 TeV	0.87 ± 0.08	16.5 ± 1.1	15	0.062
$\ell + \ell'\tau_h$				
$\mu + \mu\tau_h$ 7 TeV	0.33 ± 0.02	3.2 ± 0.4	2	0.090
$\mu + \mu\tau_h$ low L_T 8 TeV	0.72 ± 0.03	20.7 ± 2.2	19	0.046
$\mu + \mu\tau_h$ high L_T 8 TeV	0.72 ± 0.02	8.4 ± 1.3	7	0.102
$e + \mu\tau_h/\mu + e\tau_h$ 7 TeV	0.47 ± 0.03	6.2 ± 1.0	6	0.074
$e + \mu\tau_h/\mu + e\tau_h$ low L_T 8 TeV	0.92 ± 0.03	24.6 ± 3.2	30	0.041
$e + \mu\tau_h/\mu + e\tau_h$ high L_T 8 TeV	1.15 ± 0.04	13.9 ± 2.0	11	0.109

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	$Z +$ 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%
$E_{\mathrm{T}}^{\mathrm{miss}}$ scale	signal & sim. backgrounds	1–12%
$\varepsilon_{\text{b-tag}}$ b jets	signal & sim. backgrounds	up to 8%
$\varepsilon_{\text{b-tag}}$ 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. $W +$ jets	$W +$ 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

Fake rate method

- Reducible backgrounds have at least one fake lepton.
- Fake rate *f* measured in a signal-free region.
- Non isolated/identified leptons reweighted by *w=f/(1-f).*



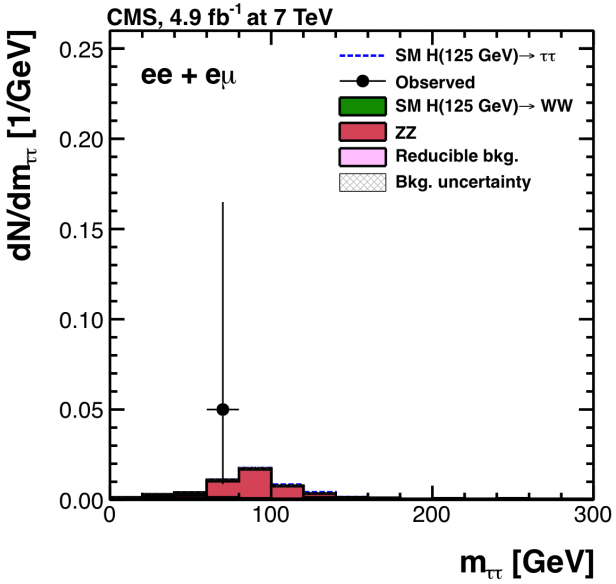
$$w_0 = f_1 f_2 / [(1-f_1)(1-f_2)]$$

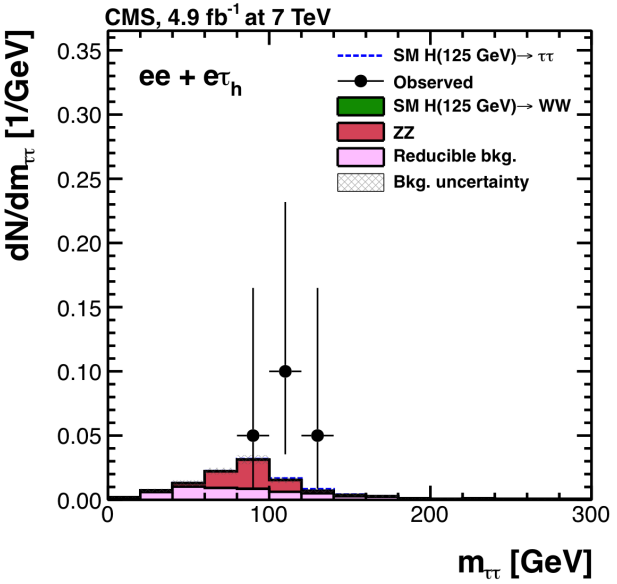
$$w_1 = f_1 / (1-f_1)$$

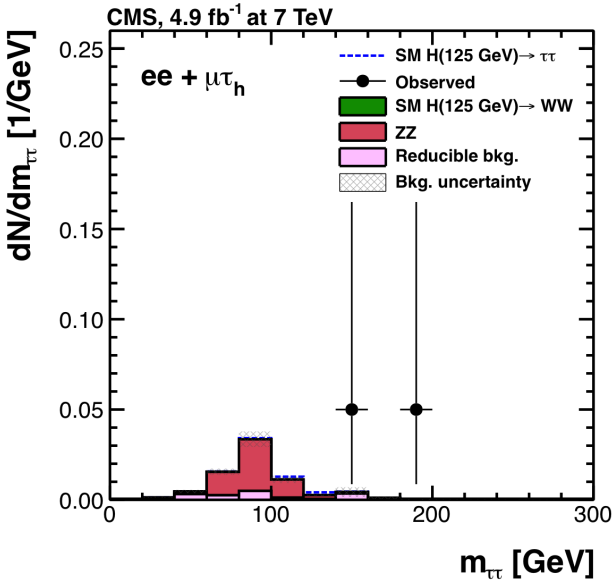
$$w_2 = f_2 / (1-f_2)$$

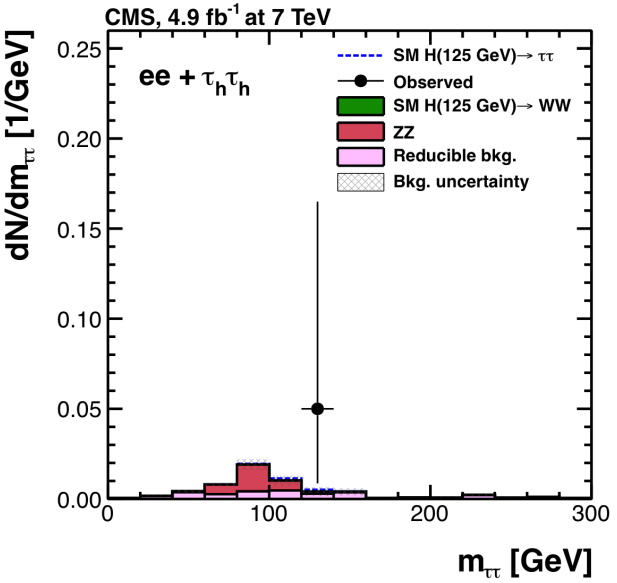
$$N = N_1 w_1 + N_2 w_2 - N_0 w_0$$

Mass plots – 7 TeV

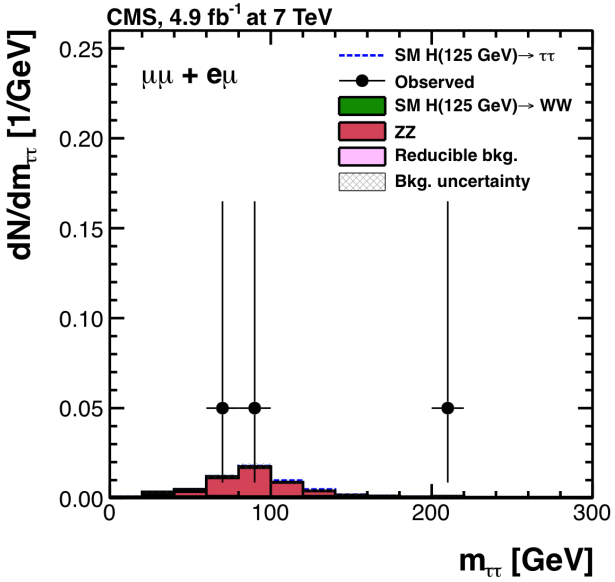


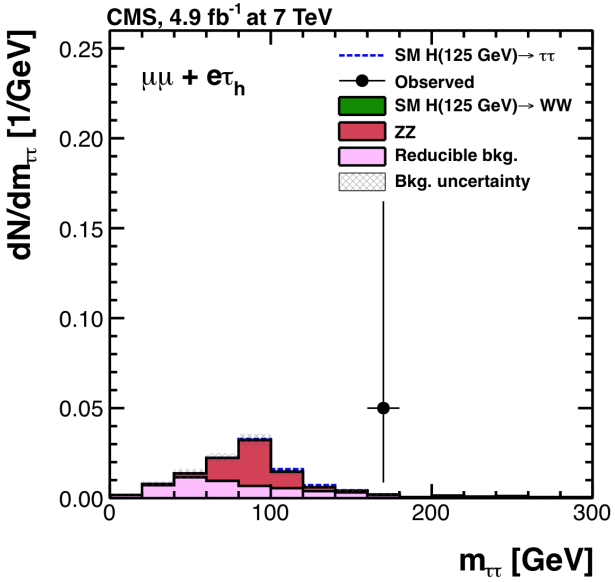


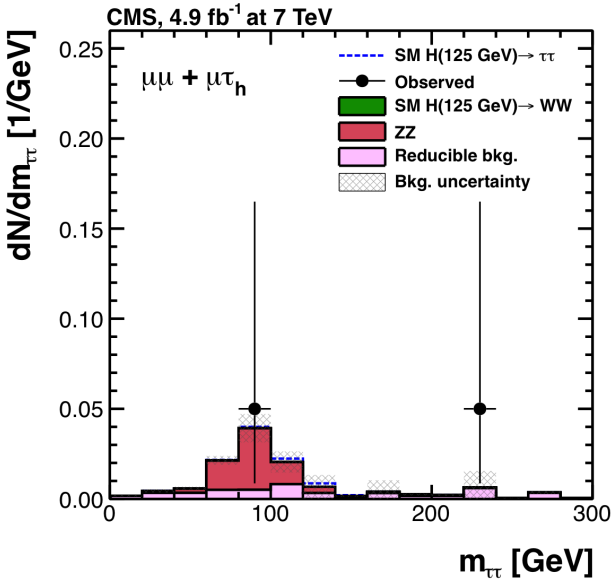


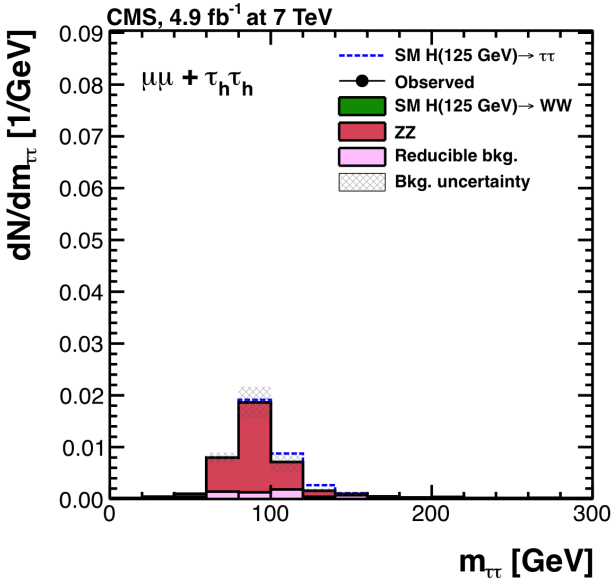


Mass plots – 7 TeV

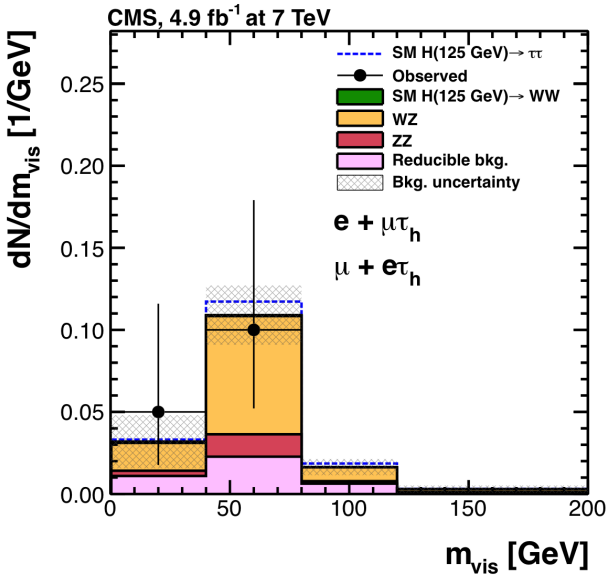


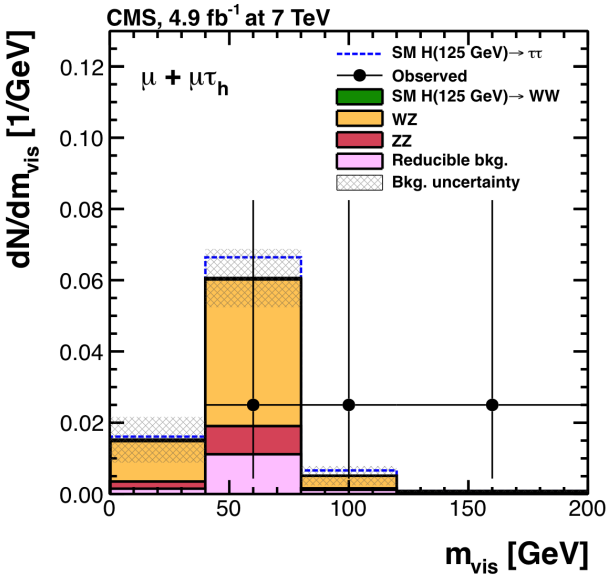


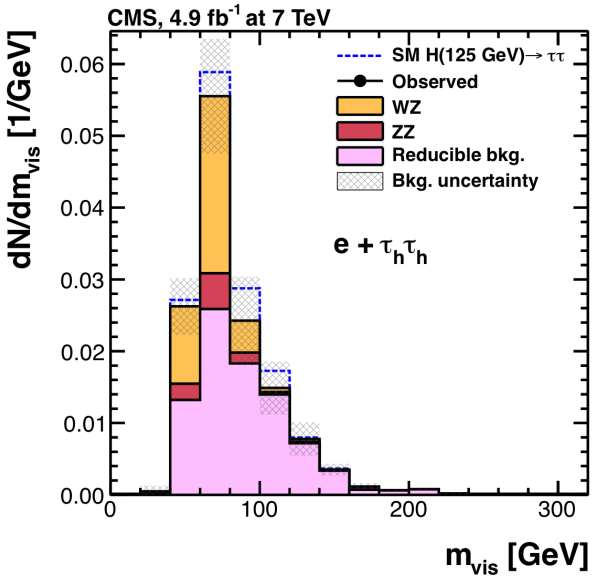


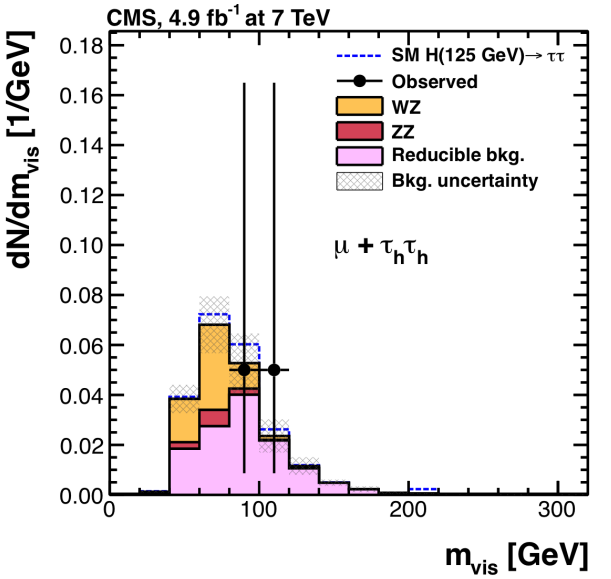


Mass plots – 7 TeV

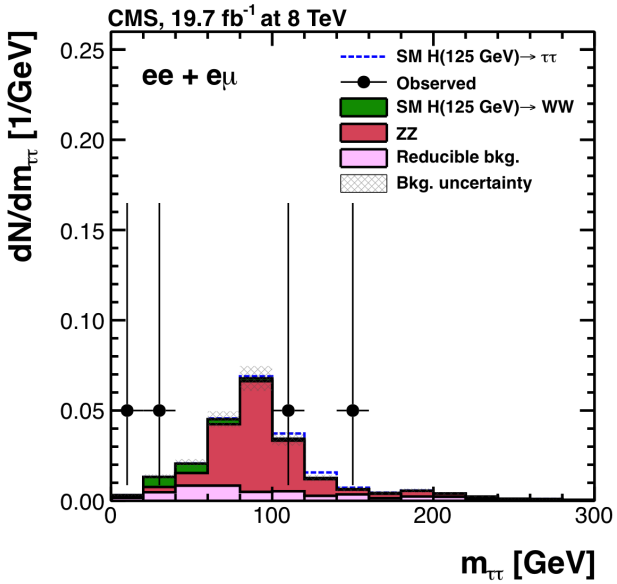


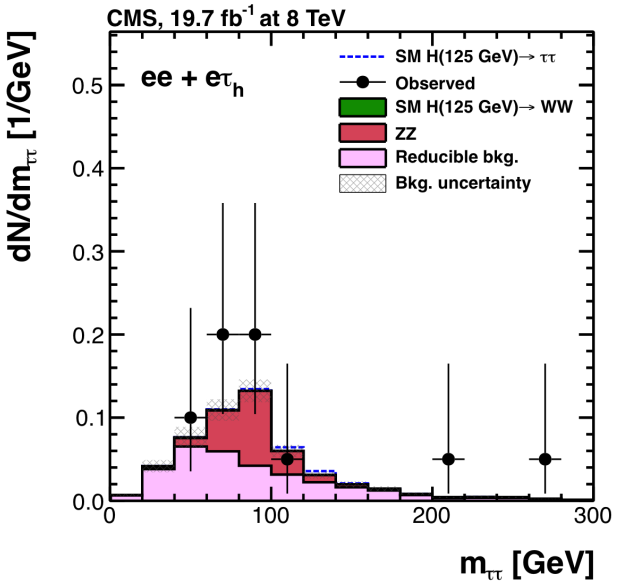


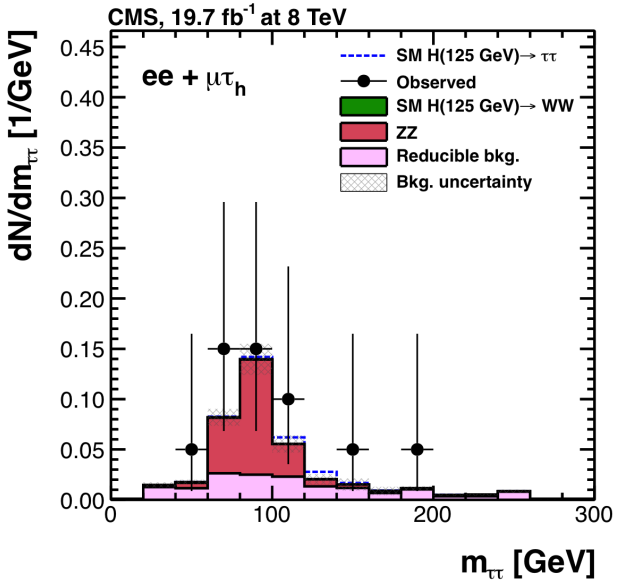


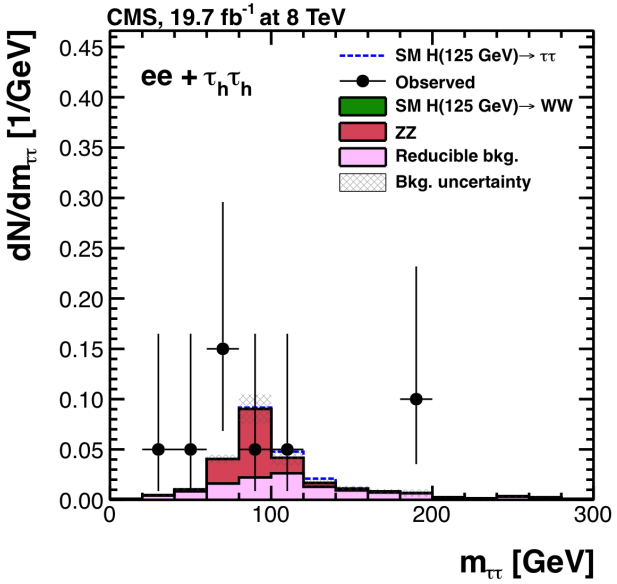


Mass plots – 8 TeV

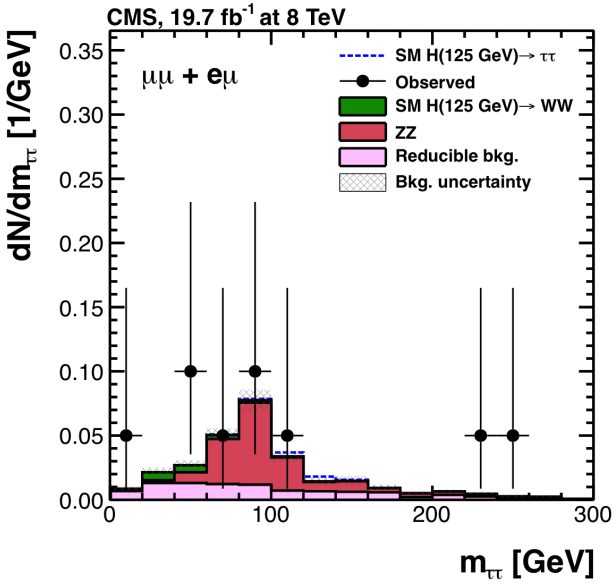


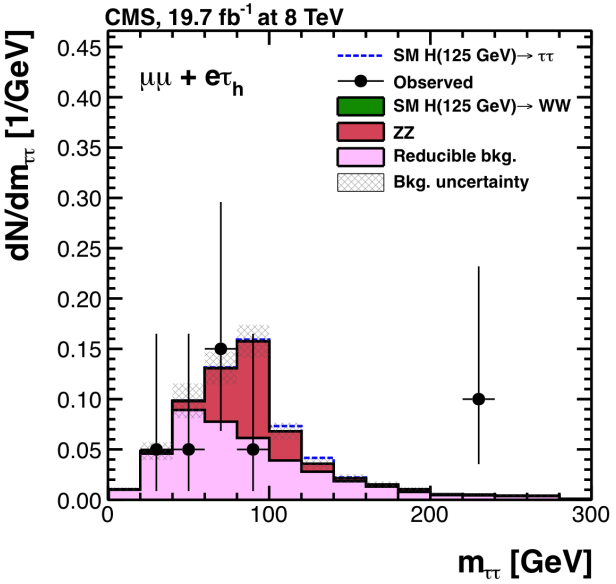


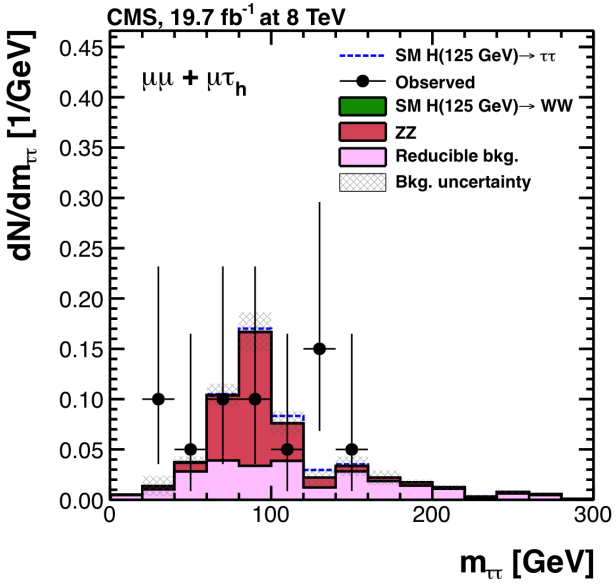


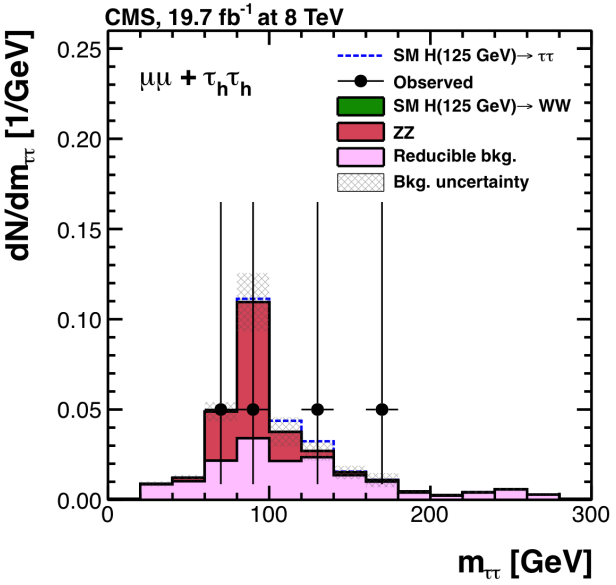


Mass plots – 8 TeV

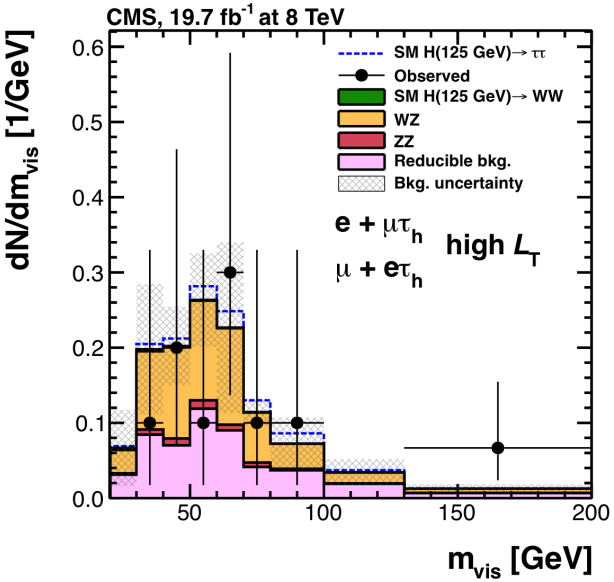


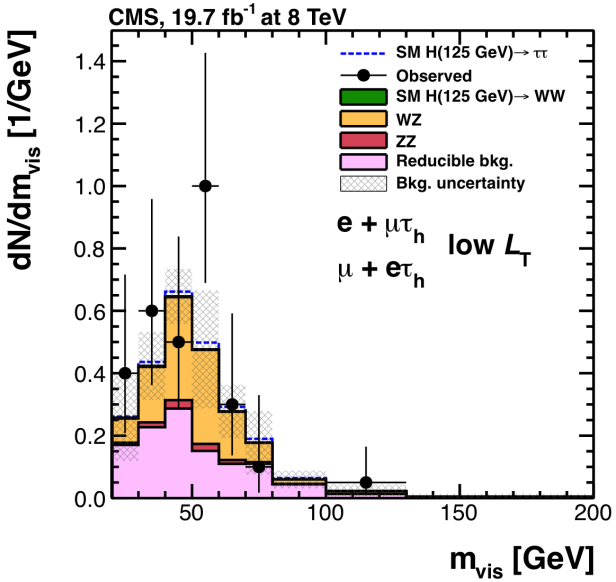


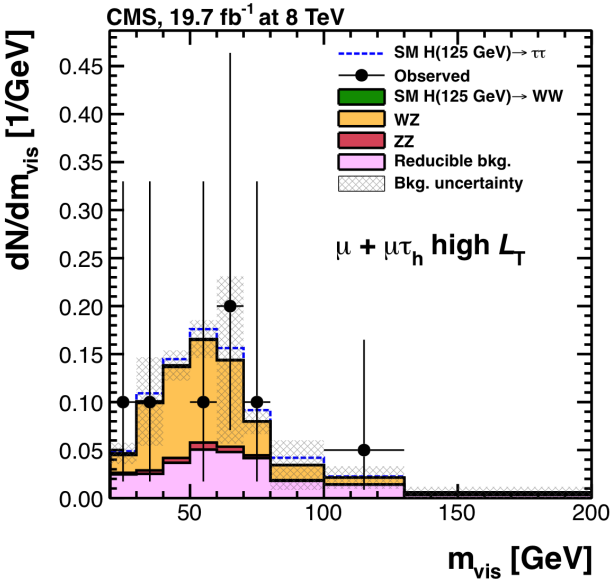


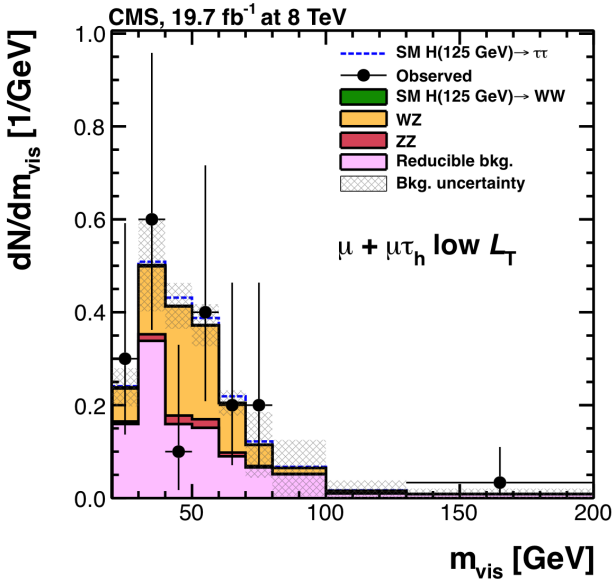


Mass plots – 8 TeV

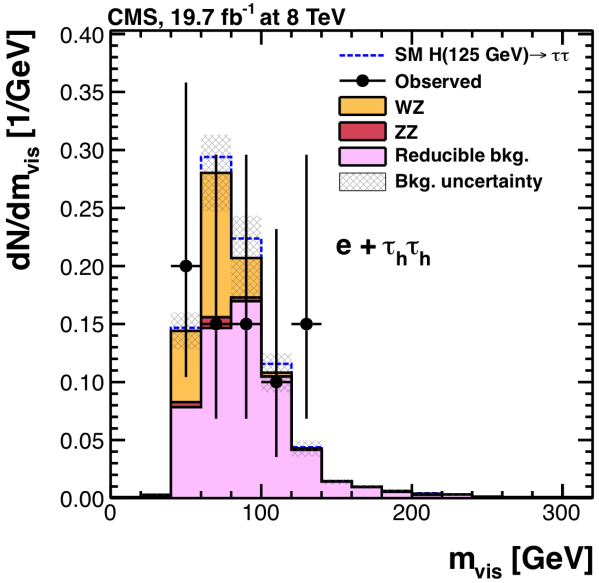


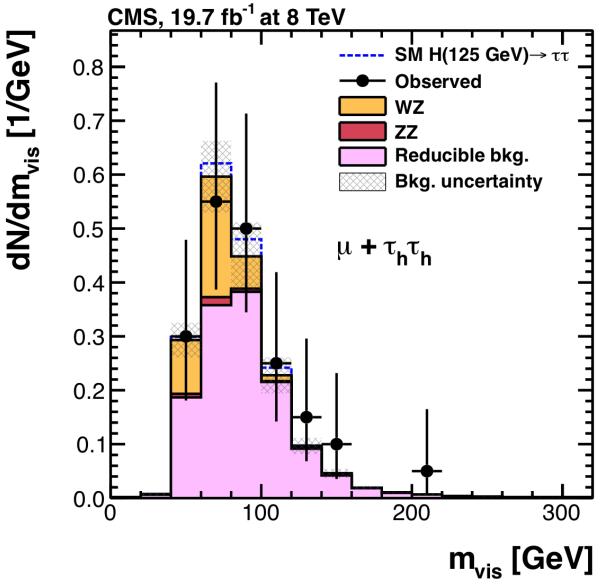




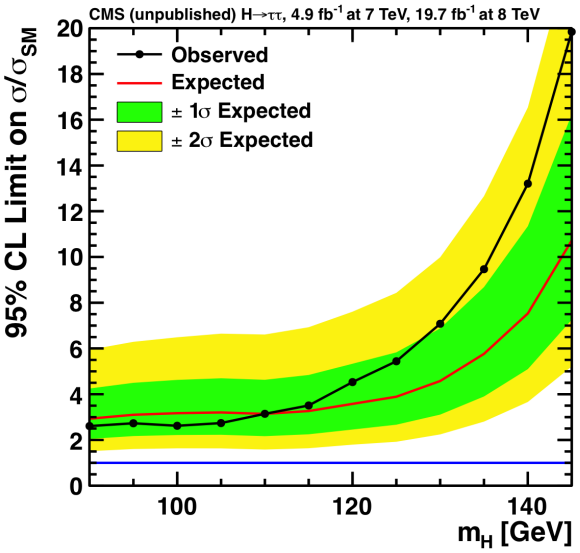


Mass plots – 8 TeV

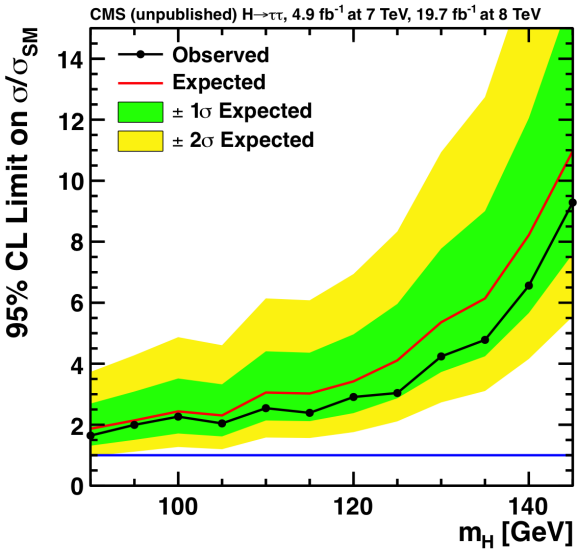




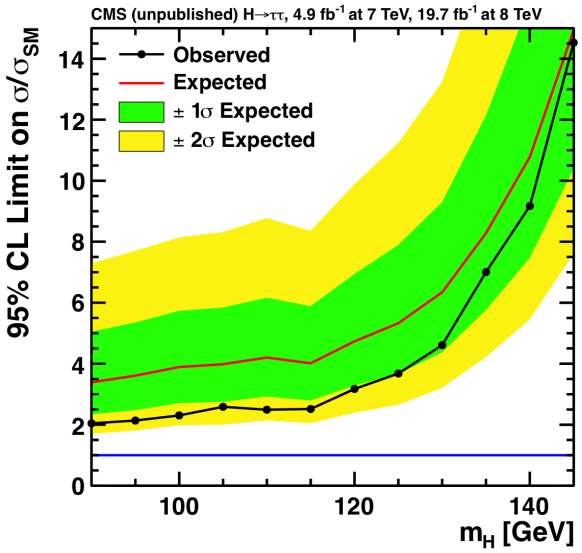
Limits



ll+LL'



l+l'τ_h



l+$\tau_h\tau_h$

Signal strength