CMS Experiment at LHC, CERN
Data recorded: Sun Nov 25 00:15:46 2012 CEST
Run/Event: 207898 / 97057018

CMS results on the SM H boson decaying to a pair of *taus*

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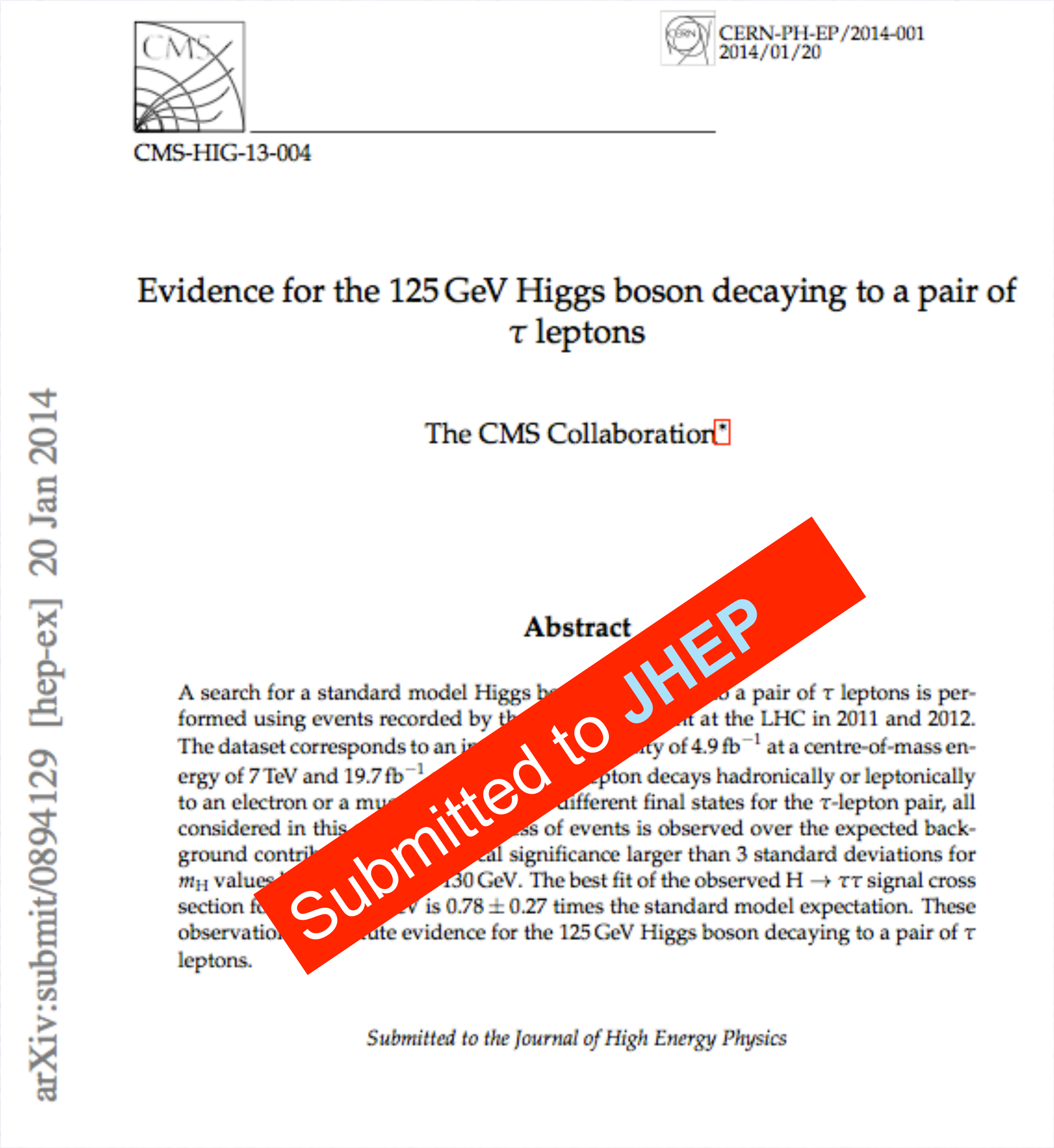
H boson Mini Workshop, Brussels, Jan. 2014



CERN-PH-EP/2014-001
2014/01/20

CMS-HIG-13-004

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

The CMS Collaboration[*]

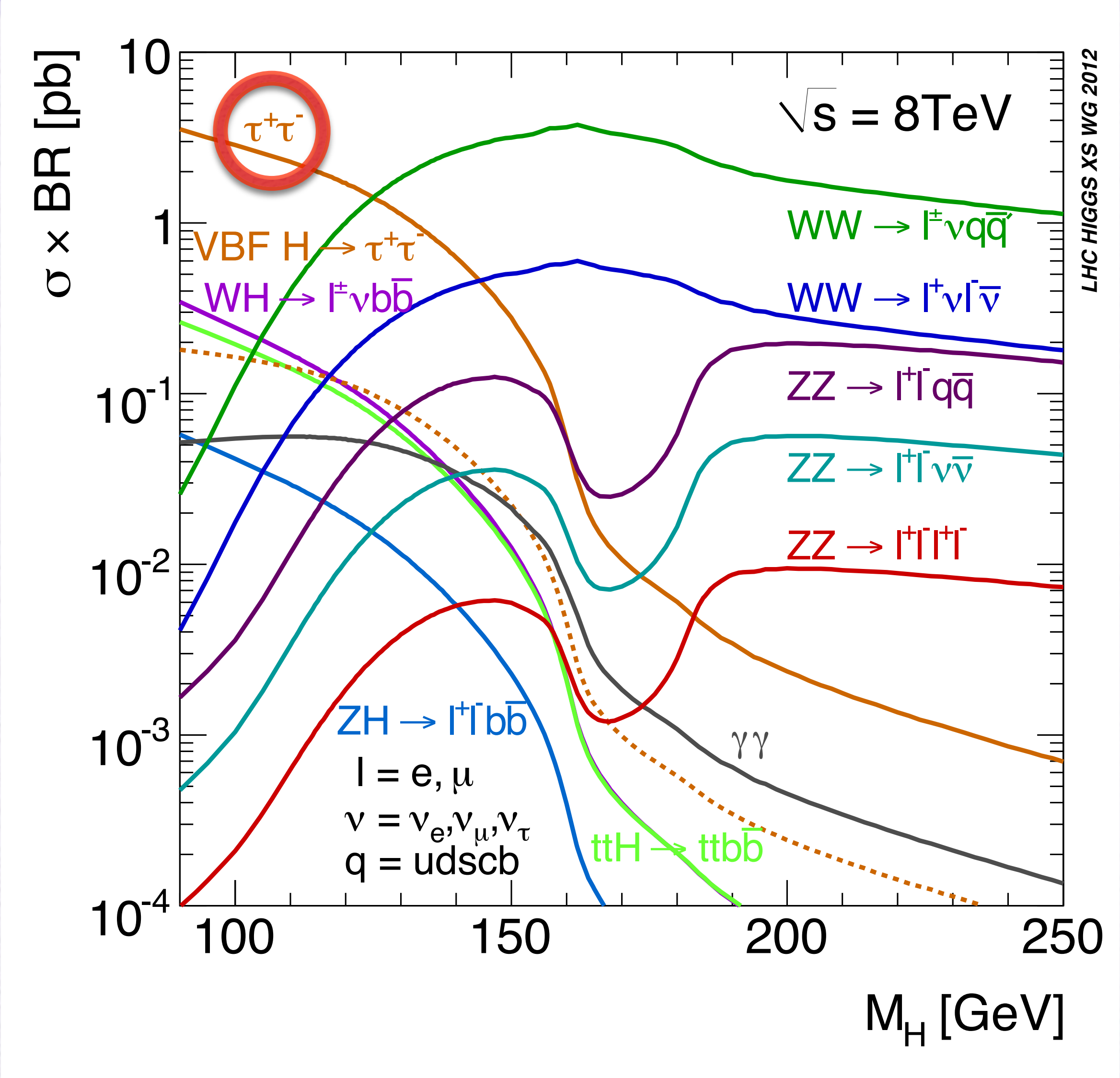
Abstract

A search for a standard model Higgs b[illegible] a pair of τ leptons is performed using events recorded by th[illegible] at the LHC in 2011 and 2012. The dataset corresponds to an i[illegible]ity of 4.9 fb^{-1} at a centre-of-mass energy of 7 TeV and 19.7 fb^{-1} [illegible]pton decays hadronically or leptonically to an electron or a mu[illegible] different final states for the τ-lepton pair, all considered in this [illegible]ss of events is observed over the expected background contri[illegible]al significance larger than 3 standard deviations for m_H values [illegible]130 GeV. The best fit of the observed $H \to \tau\tau$ signal cross section fo[illegible] is 0.78 ± 0.27 times the standard model expectation. These observatio[illegible]te evidence for the 125 GeV Higgs boson decaying to a pair of τ leptons.

Submitted to JHEP

Submitted to the Journal of High Energy Physics

Cross section x Branching Ratios of Decay Modes



Search for a tau pair Challenges and methods

Significant Branching Ratio (~ 6%) at low mass

Challenges:

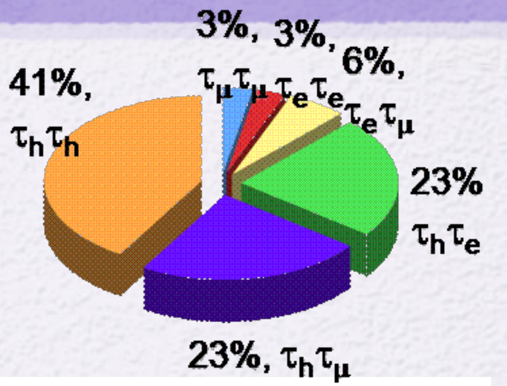
- Reconstruction of different tau decay modes: Hadronic tau (τ_h) reconstruction
- Reconstruction of di-τ mass (presence of ν's)

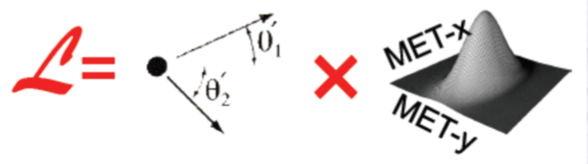
Improve sensitivity:

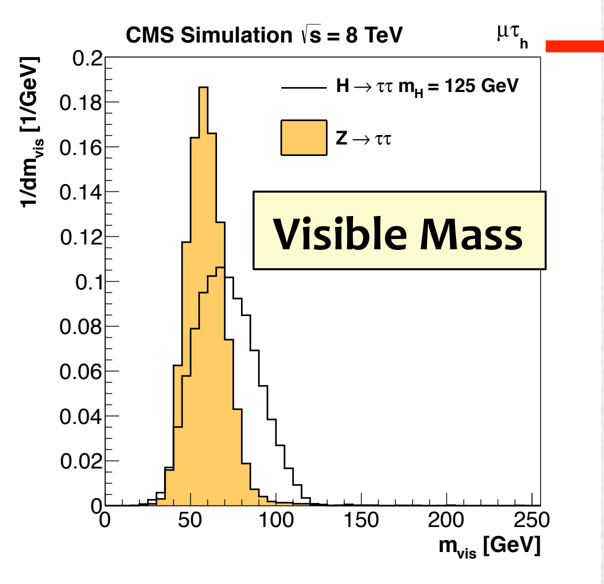
- Different categories based on jet/lepton multiplicity and τ p_t
- Optimized τ_{had}-isolation and e, $\mu \rightarrow \tau_{had}$ fake rejection
- Using MVAMet

di-τ Mass Reconstruction

- Determine invariant mass of di-**τ** system with maximum likelihood method.
- marginalize the unobserved neutrinos d.o.f.
- Inputs: four-vector information of visible leptons, x- and y- component of MET and MET resolution

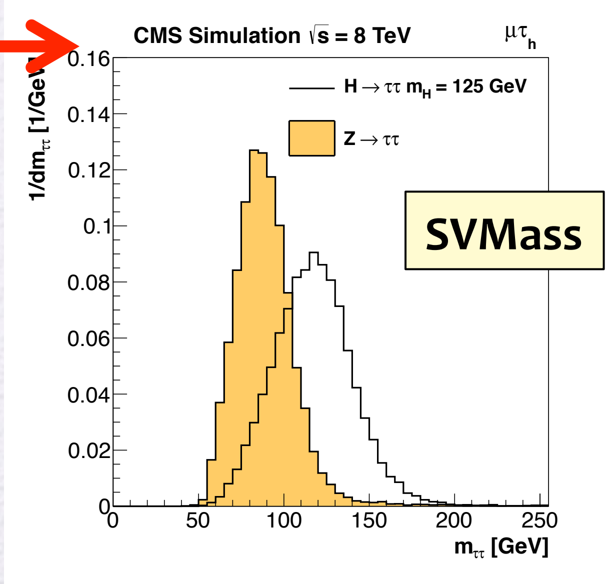






Visible Mass

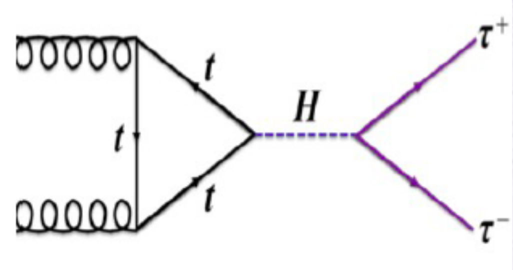
- Improve the Mass resolution (15-20%)
- Increase Z/H separation
- Impact on Limit/Sign. ~ 30%



SVMass

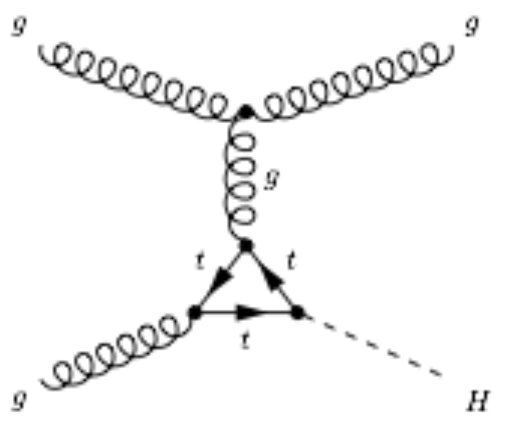
H$\to\tau\tau$ Categorization

0-jet



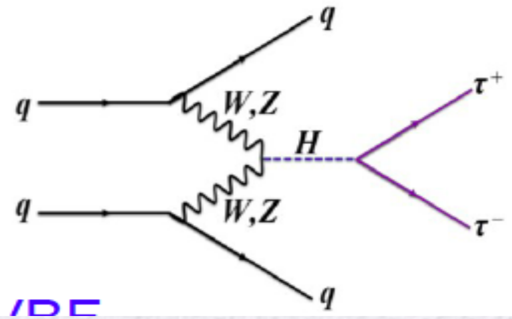
Background dominated
allows to control systematics uncertainties
(nuisances in fit)

1-jet



Enhanced gluon-fusion contribution
Boosted H → collinear H decay products →
better Mass resolution

2-jet

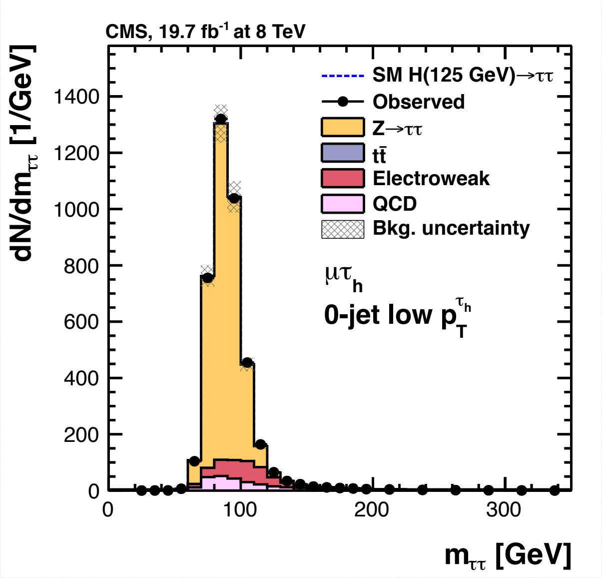


Vector Boson Fusion (VBF)
(best S/B) in all categories→ still divide this category
to tight and loose VBF
Tight VBF is the most sensitive channel

$H \to \tau\tau \to \mu\tau_h$

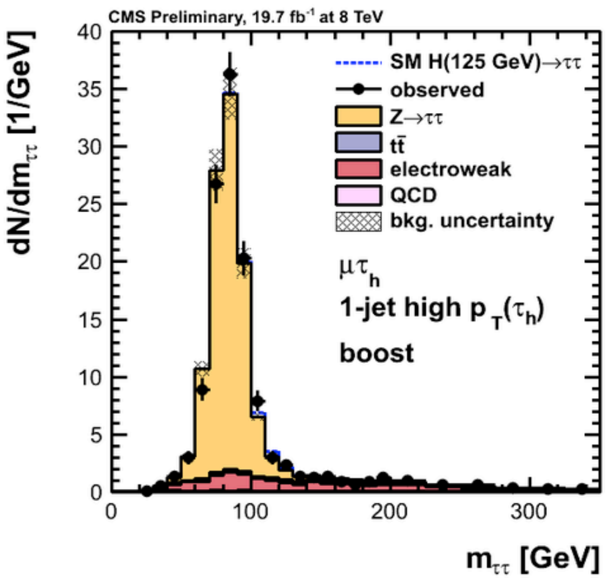
$\mu\tau_h$: most sensitive channel

0-jet
low $p_t(\tau_h)$



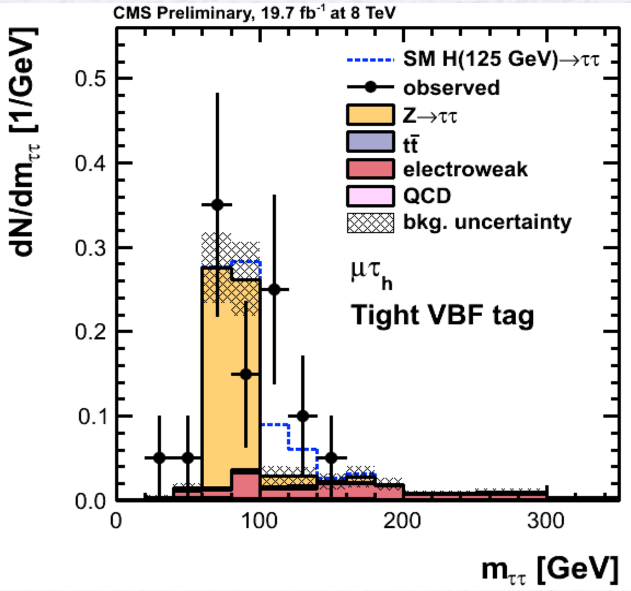
$p_t(\tau_h) < 45$ GeV

1-jet
high $p_t(\tau_h)$ boost



$p_t(\tau_h) > 45$ GeV
$p_t^{\tau\tau} > 100$ GeV

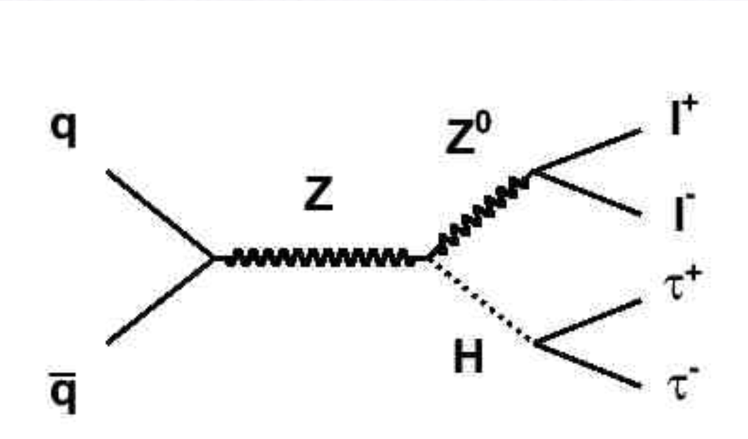
2-jet
tight VBF tag

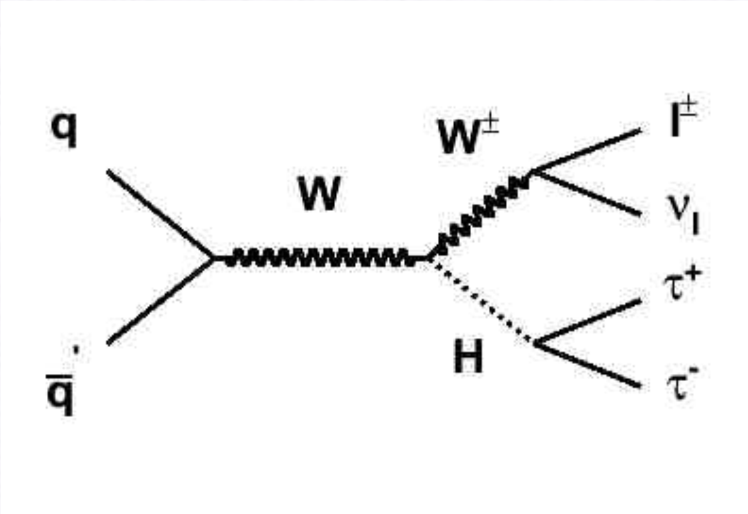


$M_{jj} > 700$ GeV, $|Dh_{jj}| > 4$
$p_t^{\tau\tau} > 100$ GeV

Associated Production

New categories including extra leptons

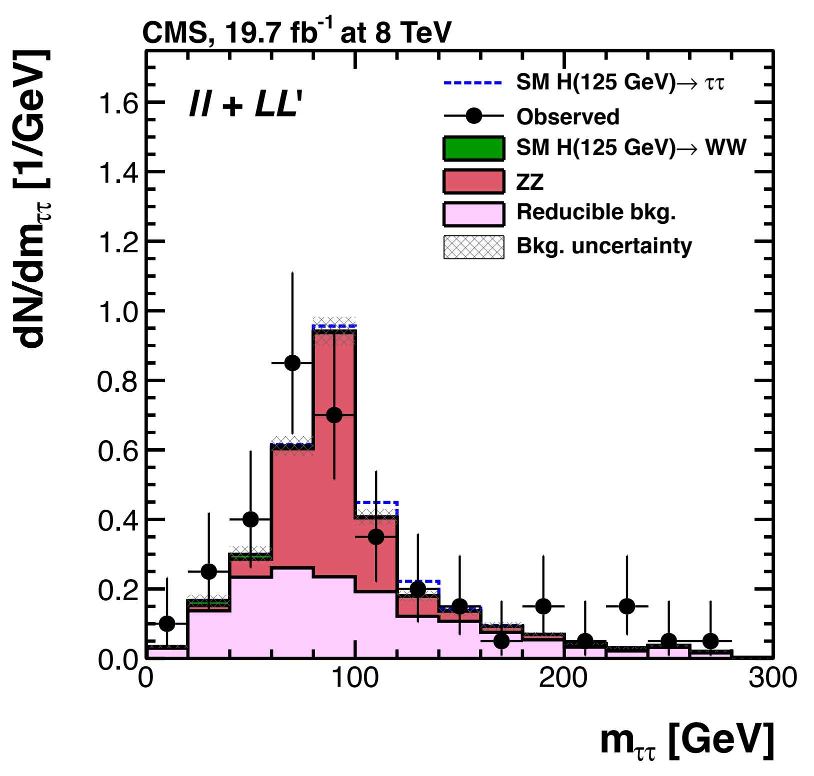




Collaboration between ULB and UCL

ZH→Zττ

$$Z \rightarrow (\mu\mu, ee) H \rightarrow (\tau_h\tau_h, \tau_h\mu, \tau_h e, e\mu)$$



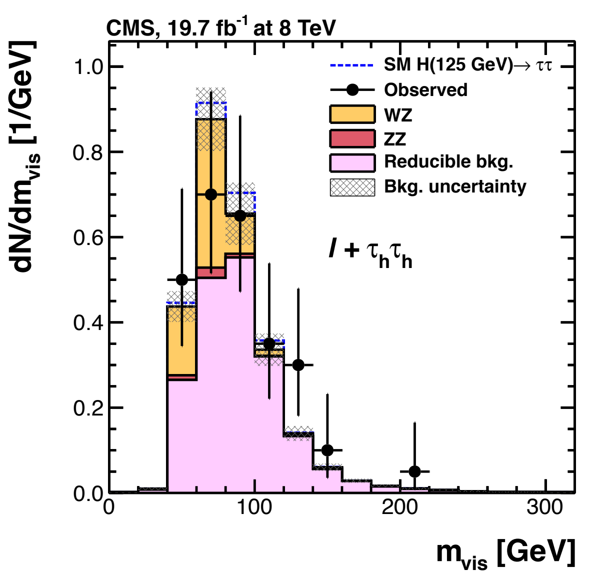
- Reducible BG:Z+jets, ttbar, … : Estimated from data using fake rate method
- Irreducible BG: ZZ for ZH: Estimated from MC

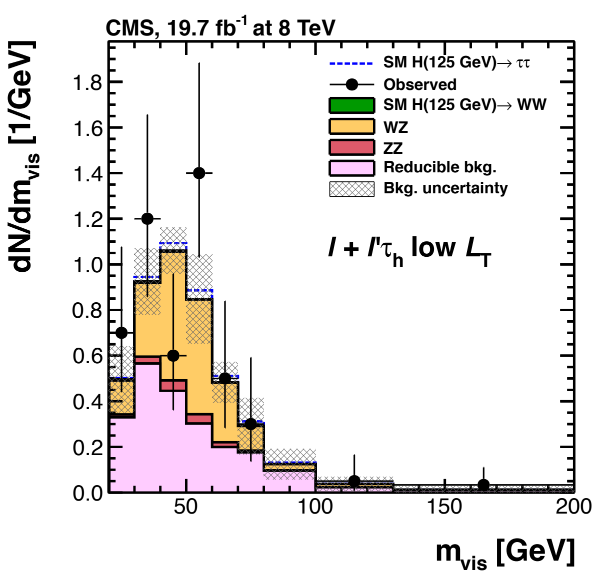
WH→Wττ

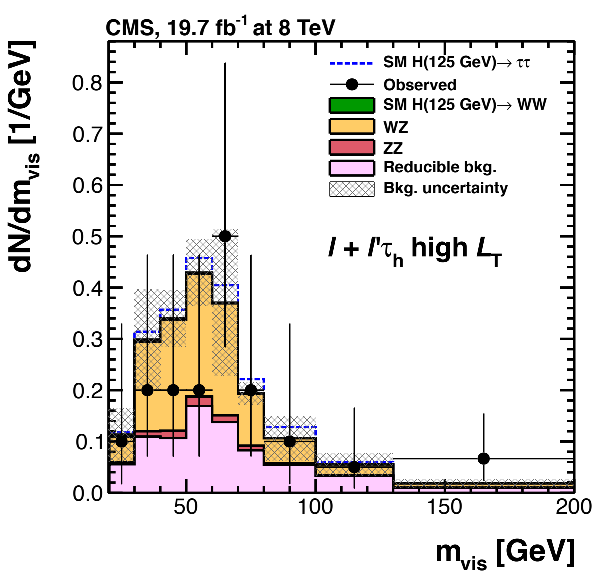
- Reducible BG:W/Z+jets, ttbar, … : Estimated from data using fake rate method
- Irreducible BG: WZ for WH : Estimated from MC
- Two categories (based on the scalar sum of the Pt of 3 leptons in semi-leptonic channel)

$W \rightarrow (\mu\nu, e\nu) H \rightarrow (\tau_h \tau_h)$

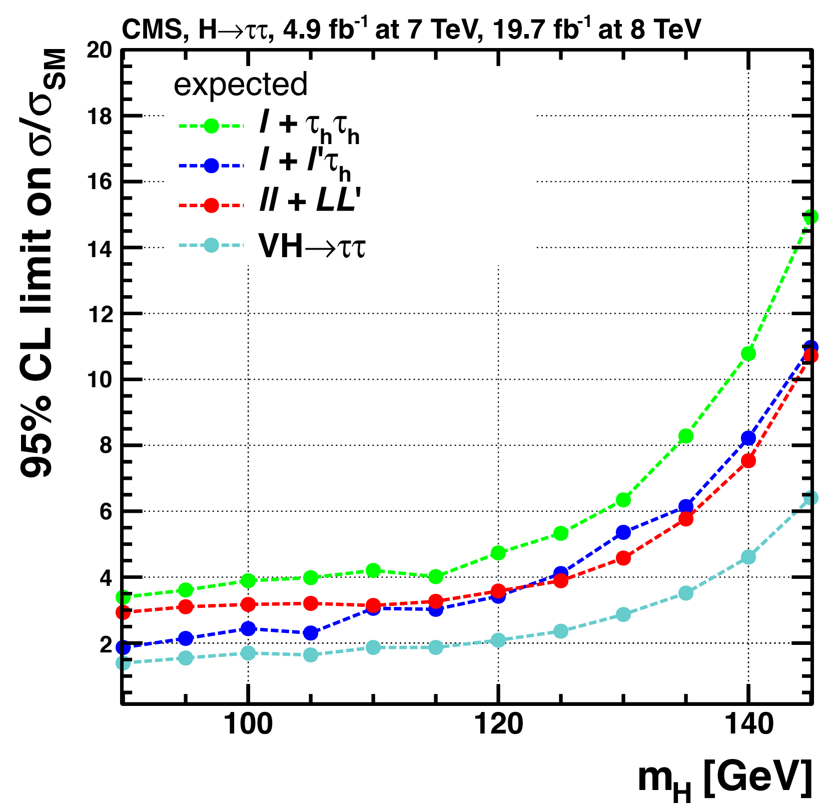
$W \rightarrow (\mu\nu) H \rightarrow (\tau_h \mu, \tau_h e)$

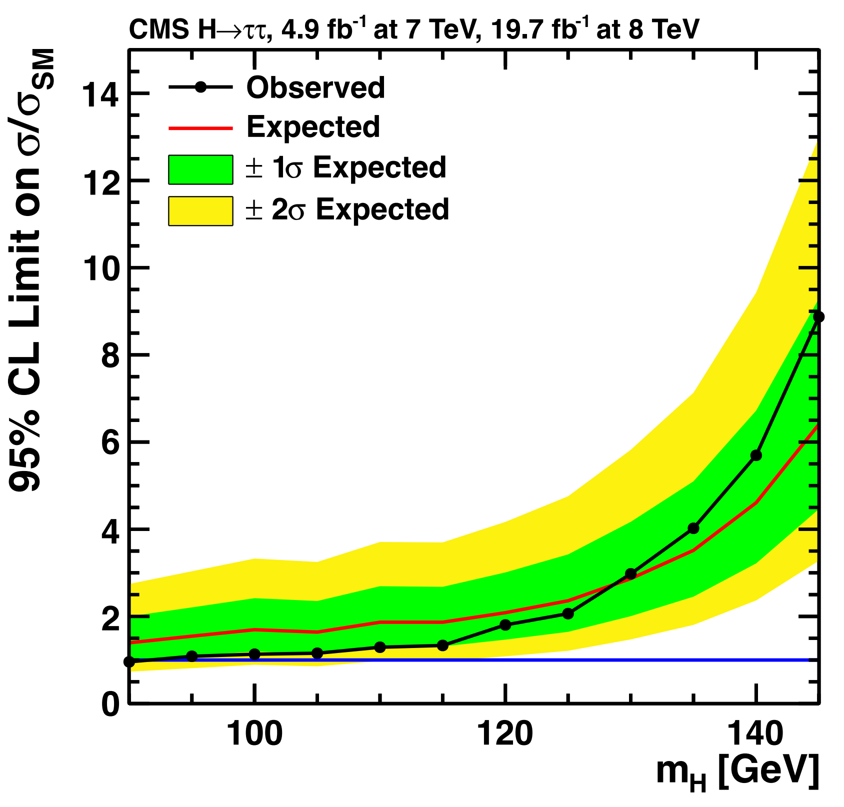




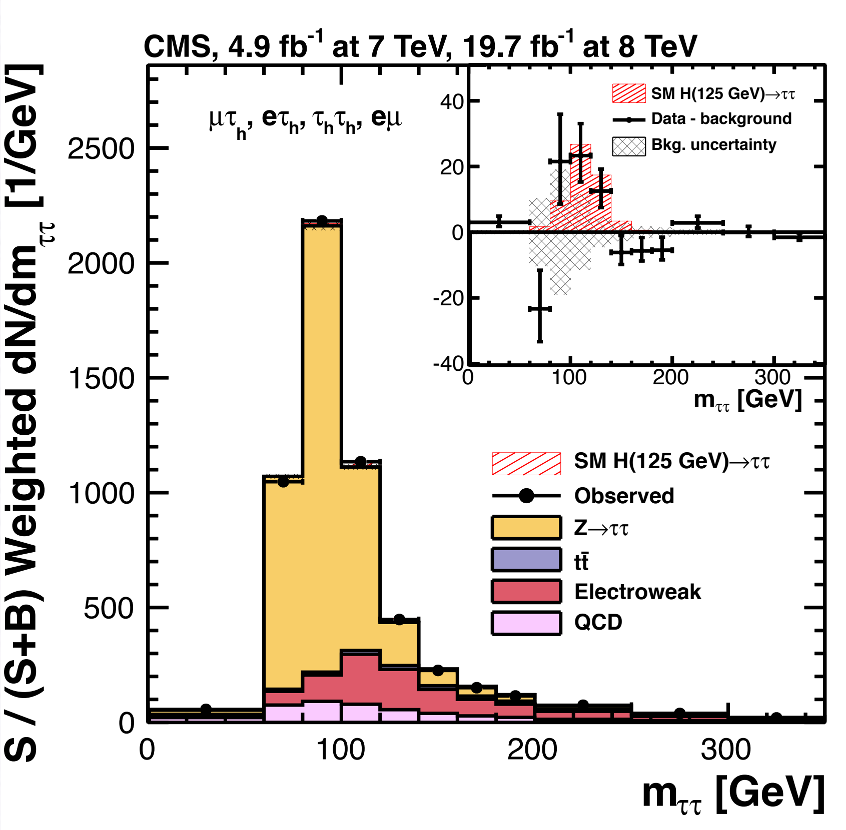


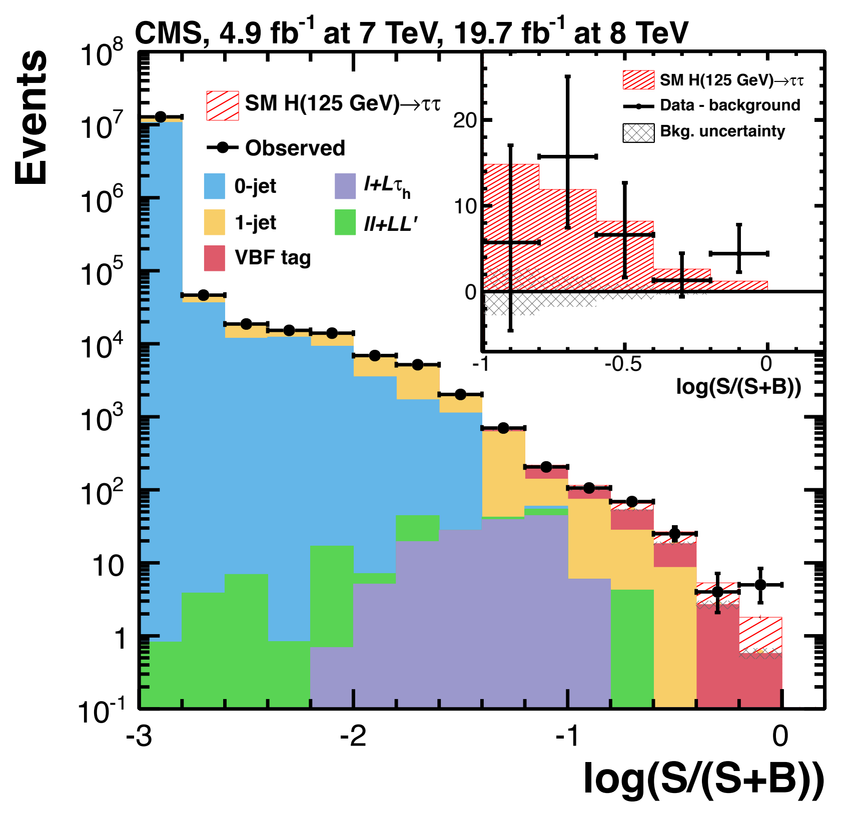
VH Limits


CMS, H→ττ, 4.9 fb^{-1} at 7 TeV, 19.7 fb^{-1} at 8 TeV
95% CL limit on σ/σ_{SM}
expected
$l + \tau_h\tau_h$
$l + l'\tau_h$
$ll + LL'$
VH→ττ
20
18
16
14
12
10
8
6
4
2
100
120
140
m_H [GeV]


CMS H→ττ, 4.9 fb^{-1} at 7 TeV, 19.7 fb^{-1} at 8 TeV
95% CL Limit on σ/σ_{SM}
Observed
Expected
± 1σ Expected
± 2σ Expected
14
12
10
8
6
4
2
0
100
120
140
m_H [GeV]

H→ττ: Combined Mass

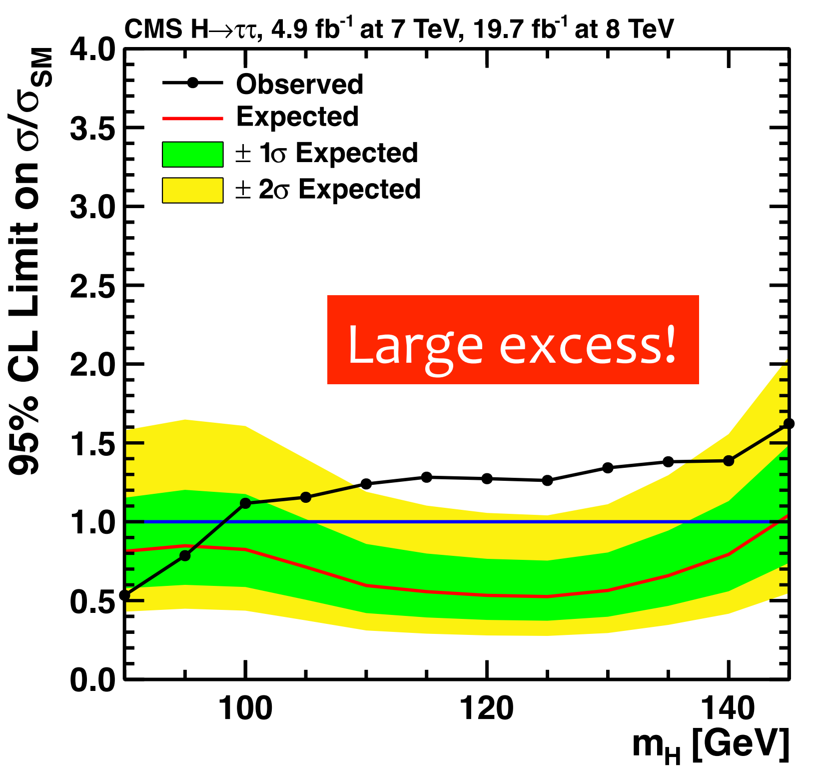




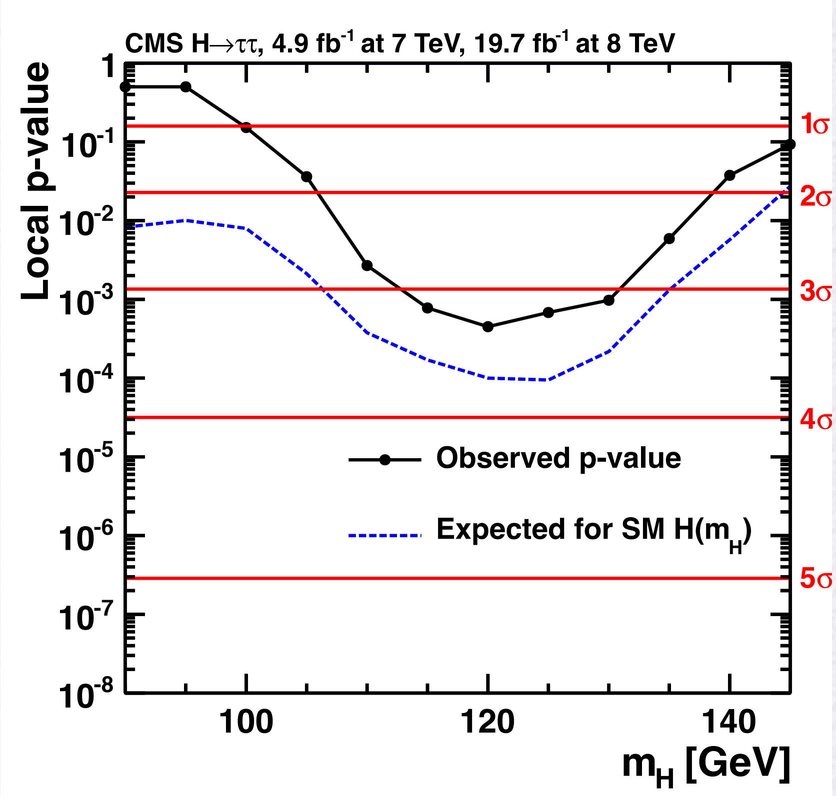
Weighted by S/(S+B) using 68% region around the $m_{\tau\tau}$ peak

Calculate S/(S+B) in every bin of the mass distributions of every event category and channel

Evidence for a $H\to\tau\tau$ signal!



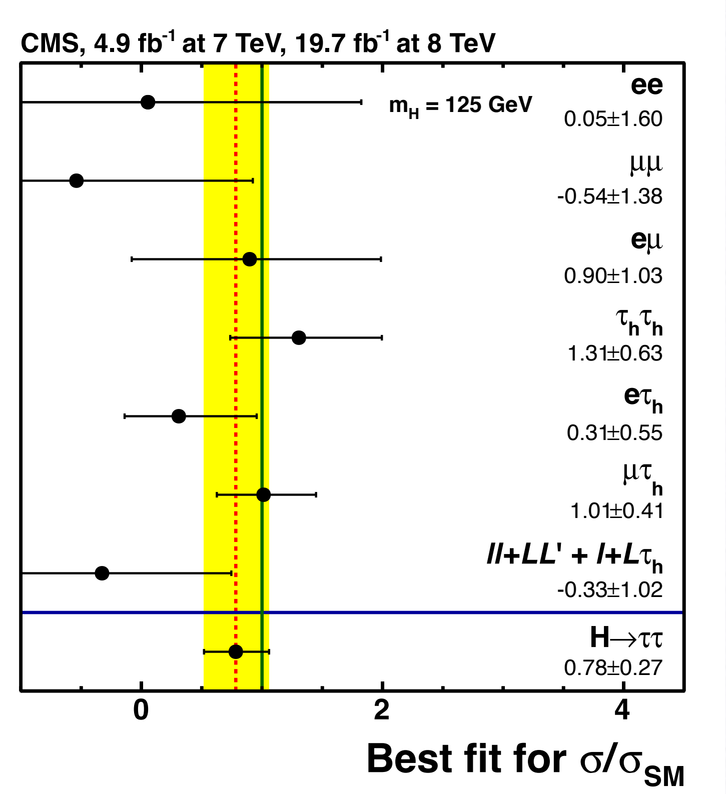
Large excess!

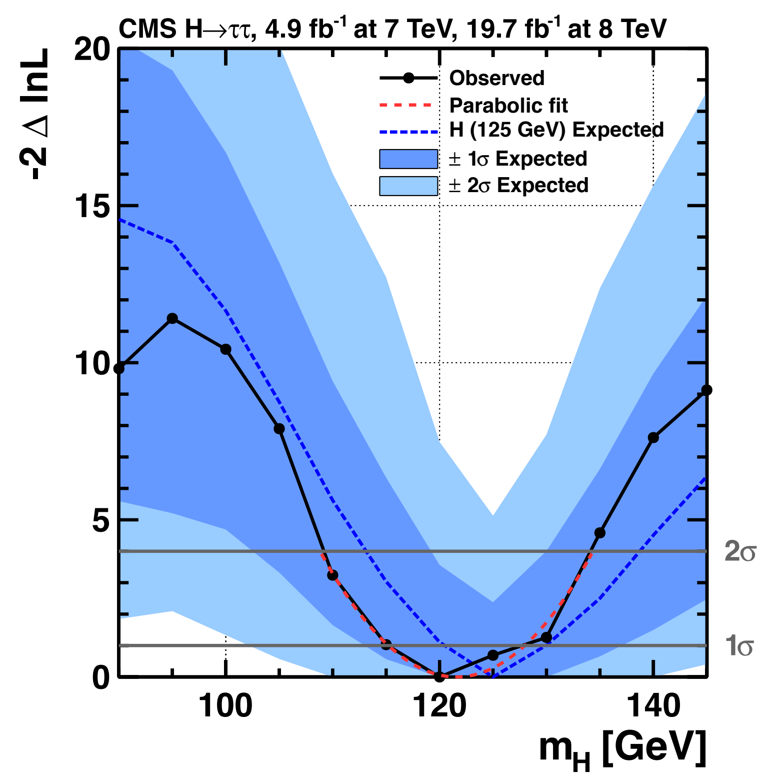


$H\to WW@125$ is treated as background, motivated by the bosonic discovery

>3σ of $H\to\tau\tau$ decays for M_H between 115 and 130 GeV

μ Values and Mass

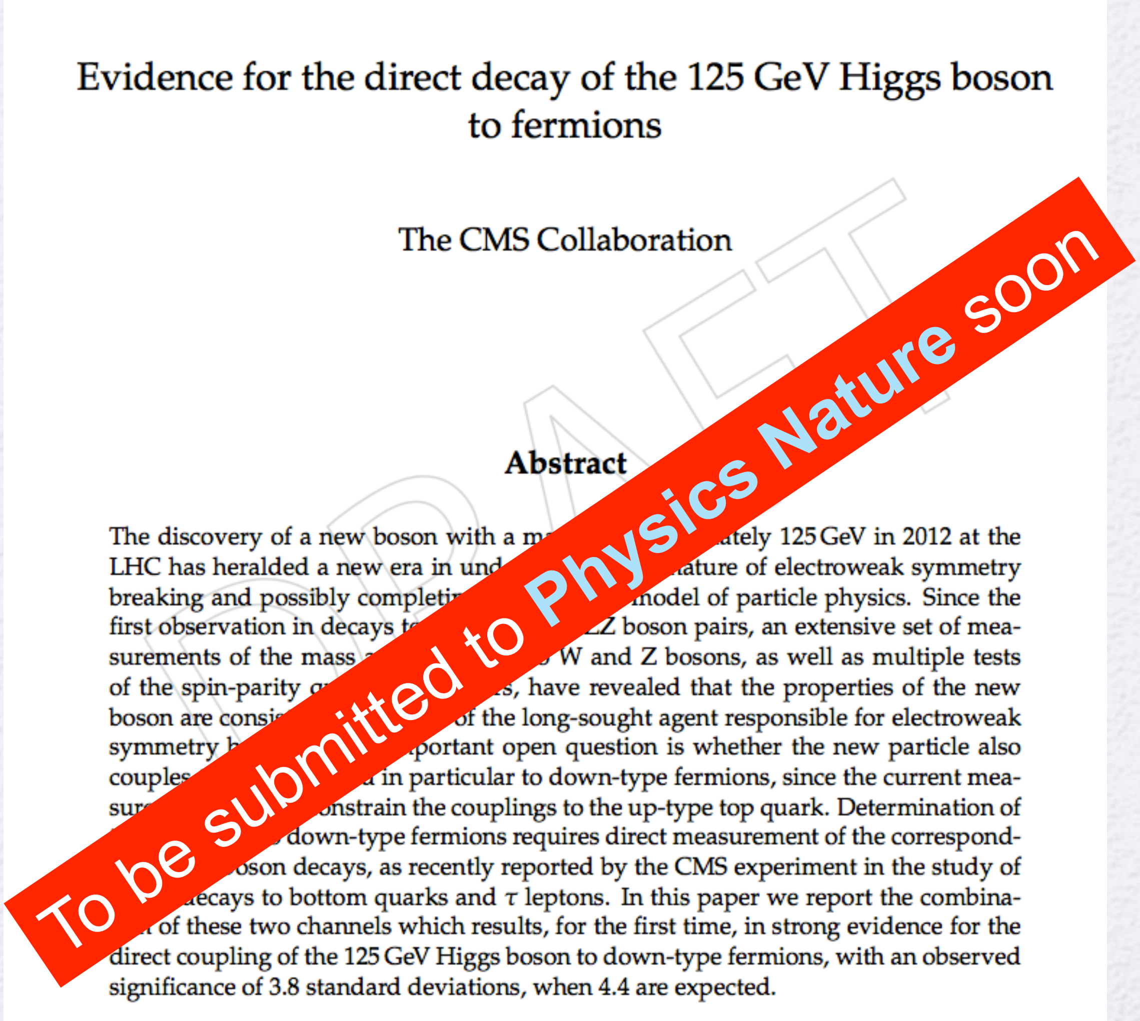




$\mu = 0.78 \pm 0.27$

$M_H = 122 \pm 7$ GeV

Combination of SM H→ττ and H→bb in CMS



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

The CMS Collaboration

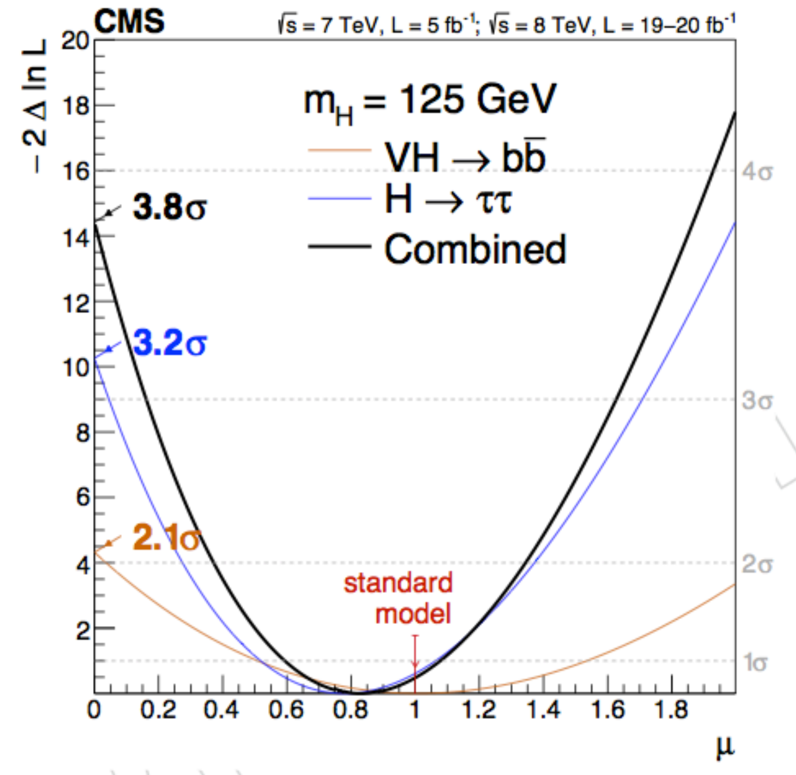
Abstract

The discovery of a new boson with a m ately 125 GeV in 2012 at the
LHC has heralded a new era in und ature of electroweak symmetry
breaking and possibly completi model of particle physics. Since the
first observation in decays t Z boson pairs, an extensive set of mea-
surements of the mass a W and Z bosons, as well as multiple tests
of the spin-parity q s, have revealed that the properties of the new
boson are consi of the long-sought agent responsible for electroweak
symmetry b portant open question is whether the new particle also
couples in particular to down-type fermions, since the current mea-
sur onstrain the couplings to the up-type top quark. Determination of
down-type fermions requires direct measurement of the correspond-
oson decays, as recently reported by the CMS experiment in the study of
ecays to bottom quarks and τ leptons. In this paper we report the combina-
of these two channels which results, for the first time, in strong evidence for the
direct coupling of the 125 GeV Higgs boson to down-type fermions, with an observed
significance of 3.8 standard deviations, when 4.4 are expected.

To be submitted to Physics Nature soon

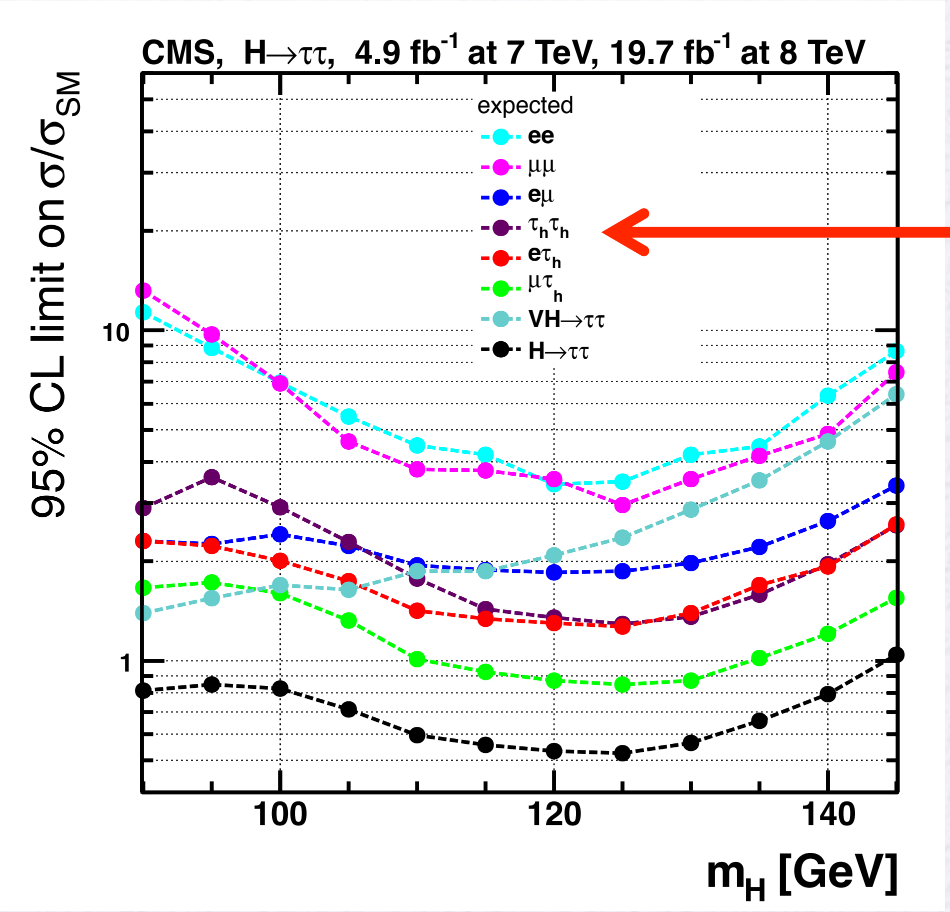
H→ττ & H→bb: Combination @ 125 GeV

Channel M_H= 125 GeV	Significance		m
	Expected	Observed	
VH→bb	2.3 s	2.1s	1.0±0.5
H→ττ	3.7s	3.2s	0.78±0.27
Combination	4.4s	3.8s	0.83±0.24



3.8 σ: strong evidence of fermionic Higgs decays!

Future Plan

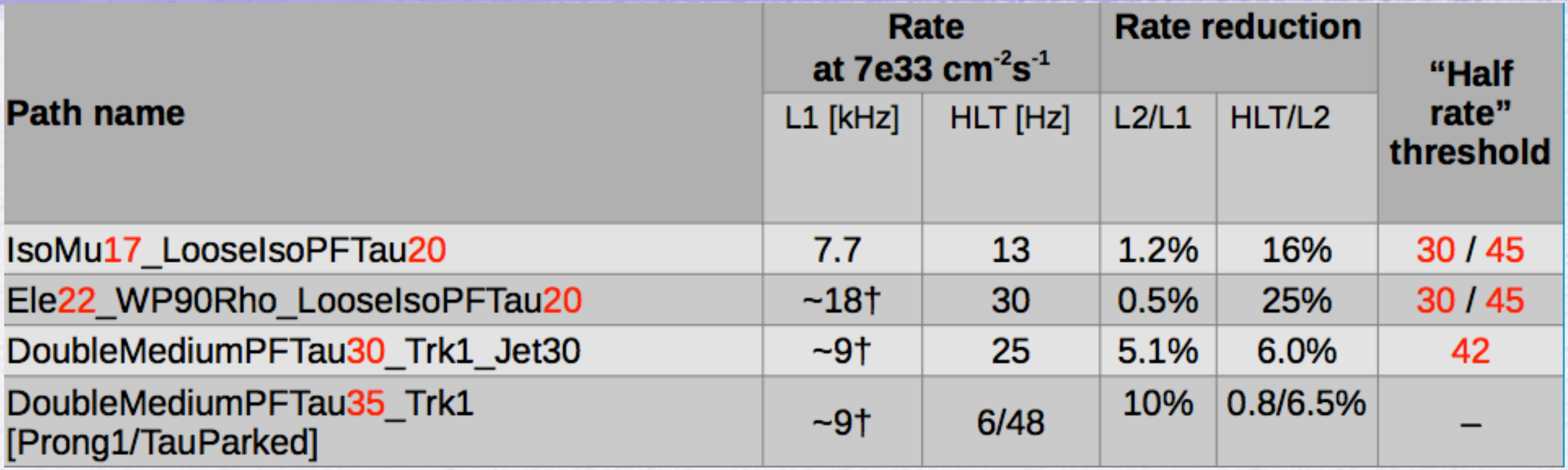


Search for di-tau in fully hadronic channel
Both interesting in SM and BSM for high masses

We have some ideas for improving the search, but …

… the main challenge for 2015 is **trigger**

Trigger overview for 2015



Path name	Rate at 7e33 $cm^{-2}s^{-1}$		Rate reduction		"Half rate" threshold
	L1 [kHz]	HLT [Hz]	L2/L1	HLT/L2	
IsoMu17_LooseIsoPFTau20	7.7	13	1.2%	16%	30 / 45
Ele22_WP90Rho_LooseIsoPFTau20	~18†	30	0.5%	25%	30 / 45
DoubleMediumPFTau30_Trk1_Jet30	~9†	25	5.1%	6.0%	42
DoubleMediumPFTau35_Trk1 [Prong1/TauParked]	~9†	6/48	10%	0.8/6.5%	–

- Minimal requirement is to reduce current rate by 2 to compensate increase of

luminosity and energy (they give factor of ~4)

- "Half rate" thresholds
  - ~30GeV for lepton (vs 20 GeV now), and ~45 GeV for tau (vs 20-30 GeV now)
  - => Z-candle basically killed, also H125 affected

Foreseen improvements to Tau@HLT (from M.Bluj)

New L1 tau (Pascal talk)

- The baseline algorithm for τ identification is a 2 × 1 ECAL plus HCAL tower cluster. Both isolated and non-isolated τ are identified; ($E_\tau - E_{iso}/E_\tau < 0.2$) as the e/γ triggers.

Options for Id:

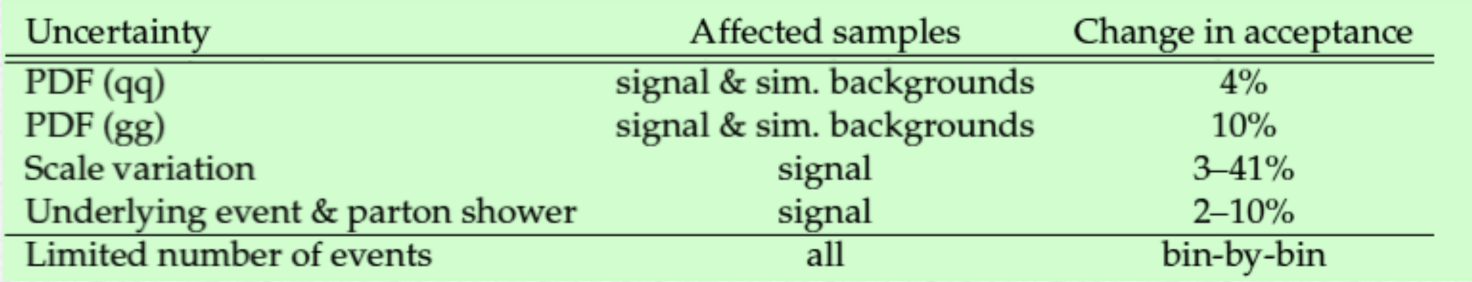
- Improve simple and fast track finding:
  - Use shrinking cone (high efficiency for low Pt, suppressed rate)
  - Improved track counting (e.g. 1 or 3 tracks) → track quality to be studied

Options for Isolation:

- Currently: veto candidates with tracks with Pt>1.5(1.0) GeV in isolation ring for a loose(medium) isolation wp
- Tight isolation track quality criteria
  - ≥8 hits and ≥3 pixel hits => should be relaxed
- Check ECal for isolation → PU correction needed (rho)
  - Is it useful in high PU condition (<PU>~50)?

BACKUP

H→tt: Theoretical uncertainties



Uncertainty	Affected samples	Change in acceptance
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	bin-by-bin

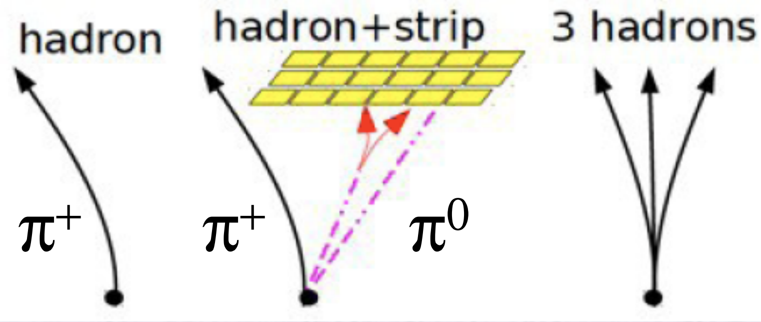
Uncertainty on signal acceptance in each category due to:

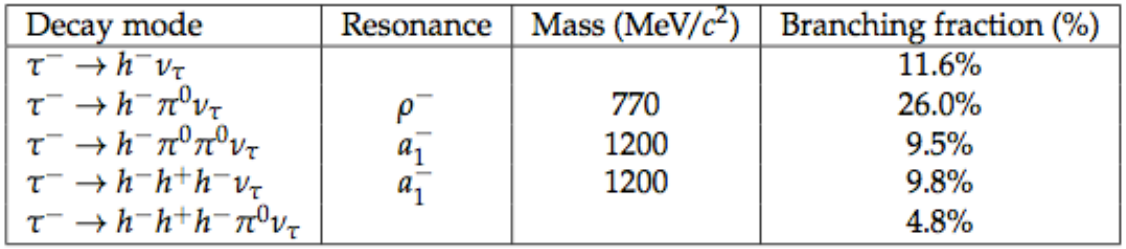
- PDF: take envelope of variation from CT10, MSTW and NNPDF sets
- Scale μ_F and μ_R: applied on total cross section and as a modified p_t spectrum
- Parton shower modeling: difference in acceptance between CMS (Z2*) and ATLAS (AUET2) tunes
- p_T Matching: vary Powheg threshold for the additional NLO jet
- ggH MC Comparison: compare default Powheg NLO to Madgraph, Powheg+MINLO and aMC@NLO

Re-weight Higgs p_T to NNLO Hres distribution in gluon-fusion samples

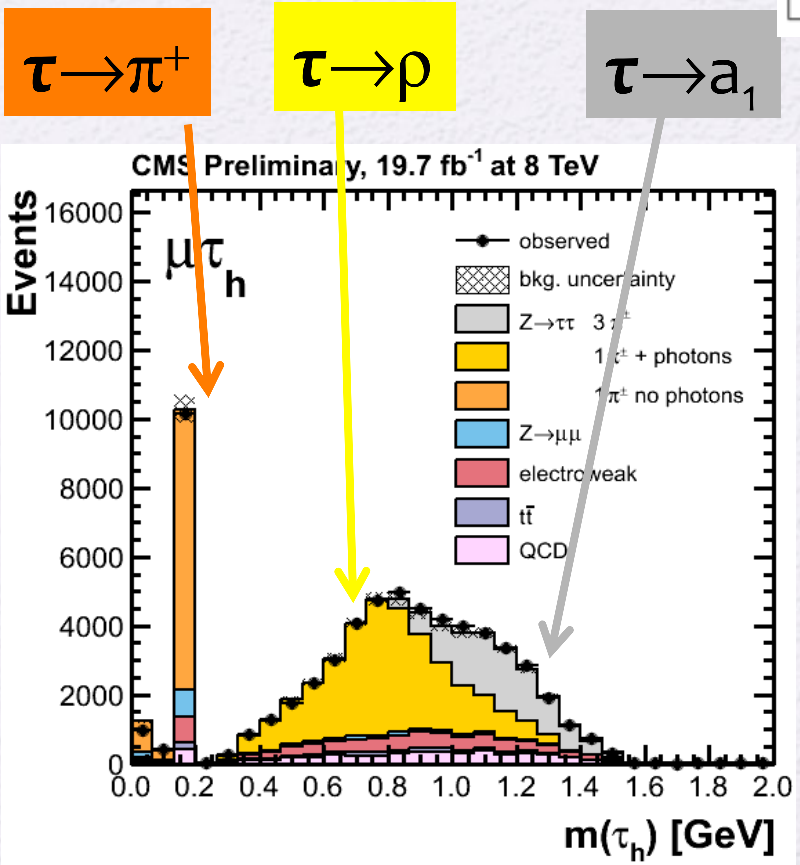
→ Uncertainty covered by shape systematic on signal templates

Hadronic τ 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%



Tau reconstruction: hadron+strip

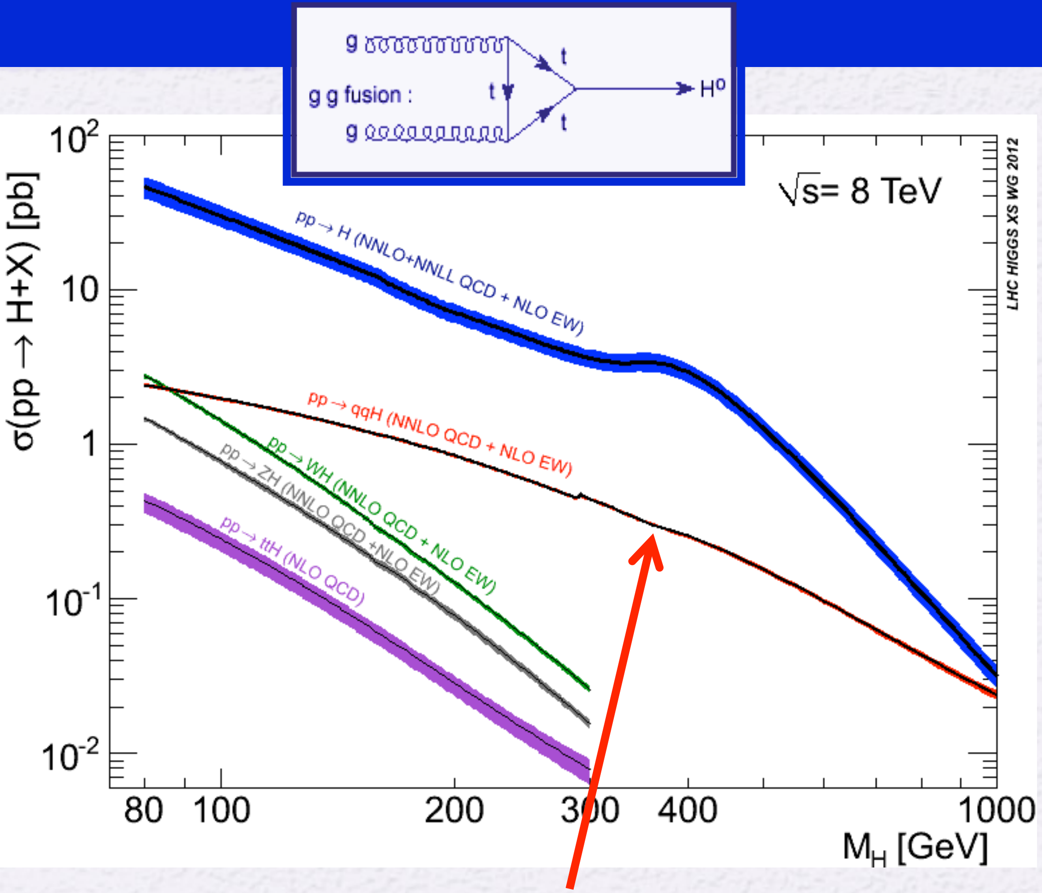
Particle-flow based algorithm to reconstruct different hadronic tau decay modes

τ_h identification:

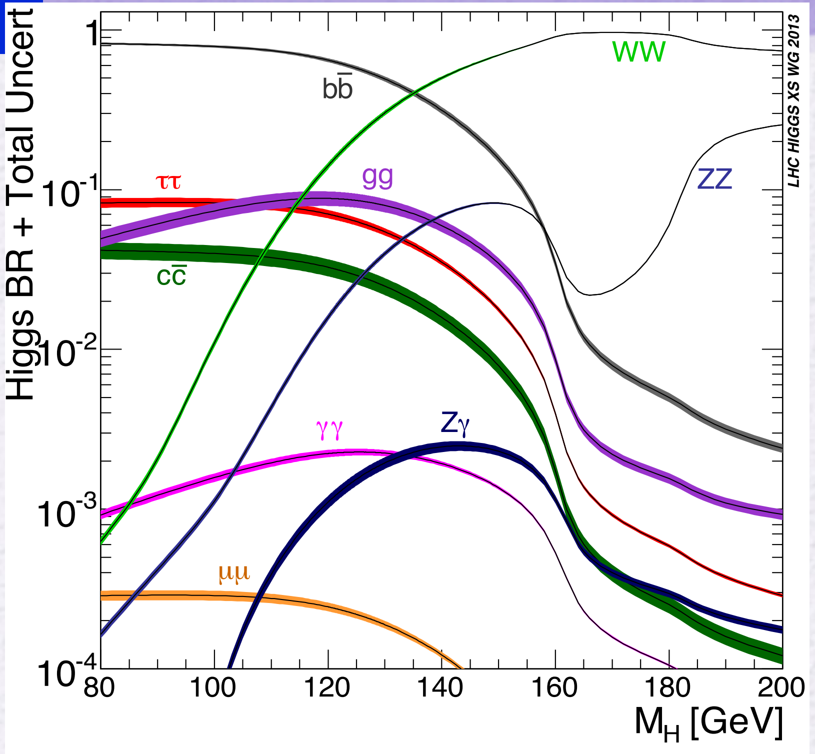
- efficiency ~ 60%
- fake rate ~ 1%

Standard Model Higgs Production @LHC

gluon-gluon fusion dominant production



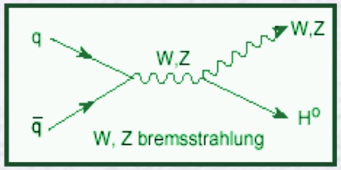
Branching Ratio



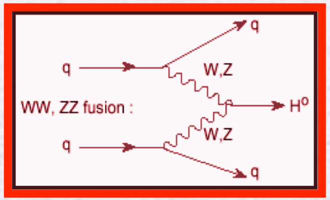
Fermionic decay modes:

- ➢ bb
- ➢ $\tau\tau$
- ➢ μμ, ee

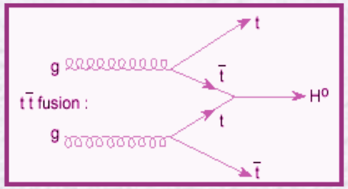
ttH



Higgs Strahlung

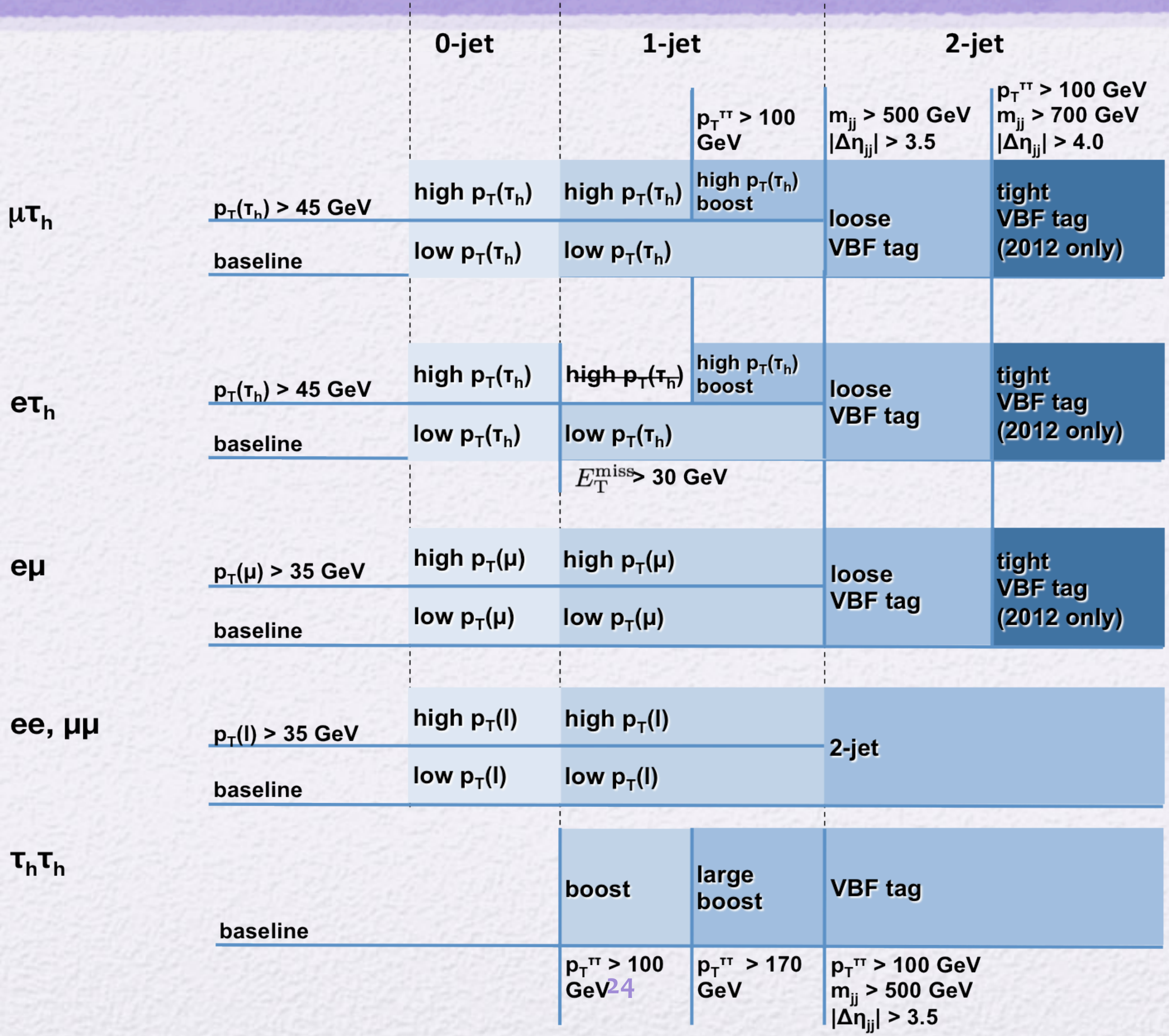


Vector boson fusion



ttH

H→ττ categories



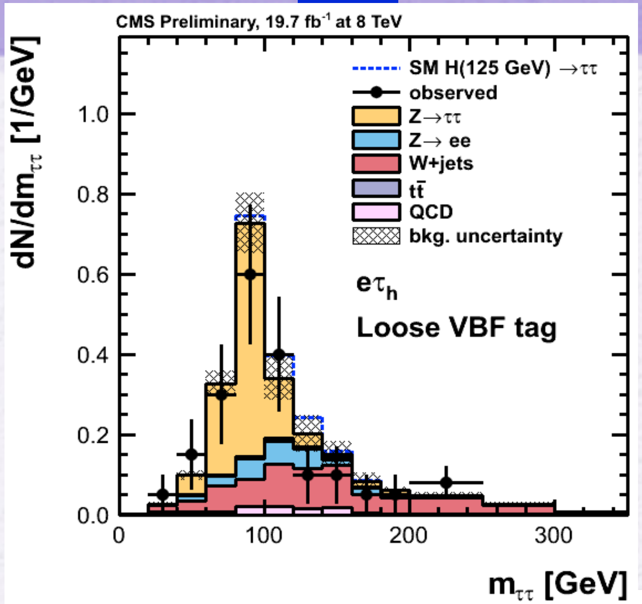
		0-jet	1-jet		2-jet	
				$p_T^{\tau\tau}$ > 100 GeV	m_{jj} > 500 GeV $\lvert\Delta\eta_{jj}\rvert$ > 3.5	$p_T^{\tau\tau}$ > 100 GeV m_{jj} > 700 GeV $\lvert\Delta\eta_{jj}\rvert$ > 4.0
$\mu\tau_h$	$p_T(\tau_h)$ > 45 GeV	high $p_T(\tau_h)$	high $p_T(\tau_h)$	high $p_T(\tau_h)$ boost	loose VBF tag	tight VBF tag (2012 only)
	baseline	low $p_T(\tau_h)$	low $p_T(\tau_h)$			
$e\tau_h$	$p_T(\tau_h)$ > 45 GeV	high $p_T(\tau_h)$	~~high $p_T(\tau_h)$~~	high $p_T(\tau_h)$ boost	loose VBF tag	tight VBF tag (2012 only)
	baseline	low $p_T(\tau_h)$	low $p_T(\tau_h)$ E_T^{miss} > 30 GeV			
$e\mu$	$p_T(\mu)$ > 35 GeV	high $p_T(\mu)$	high $p_T(\mu)$		loose VBF tag	tight VBF tag (2012 only)
	baseline	low $p_T(\mu)$	low $p_T(\mu)$			
ee, μμ	$p_T(l)$ > 35 GeV	high $p_T(l)$	high $p_T(l)$		2-jet	
	baseline	low $p_T(l)$	low $p_T(l)$			
$\tau_h\tau_h$	baseline		boost	large boost	VBF tag	
			$p_T^{\tau\tau}$ > 100 GeV	$p_T^{\tau\tau}$ > 170 GeV	$p_T^{\tau\tau}$ > 100 GeV m_{jj} > 500 GeV $\lvert\Delta\eta_{jj}\rvert$ > 3.5	

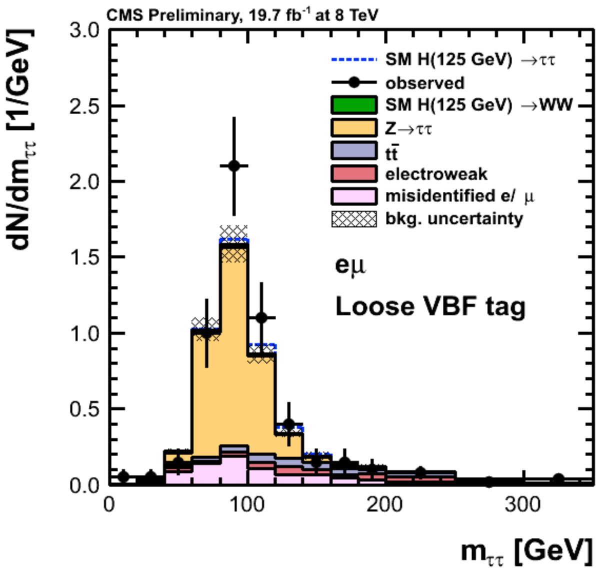
H→ττ: VBF tag

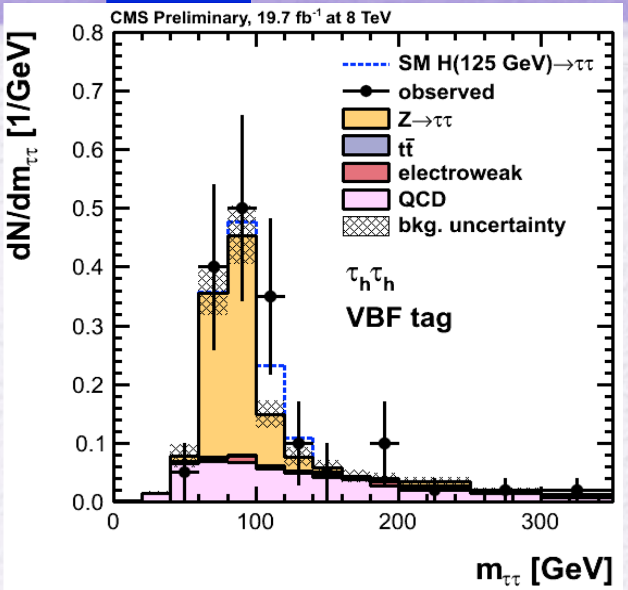
eτ

eμ

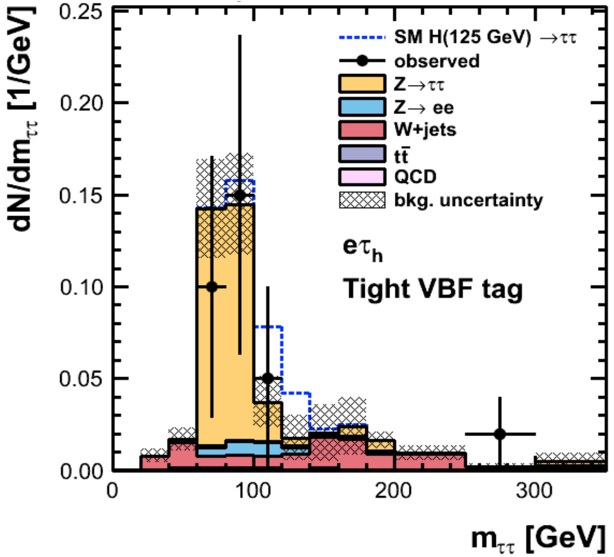
$\tau_h\tau_h$

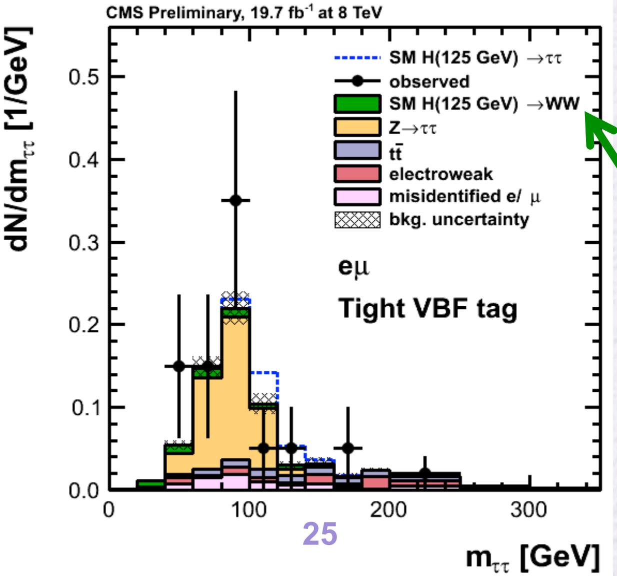






$\tau_h\tau_h$: no tight-VBF





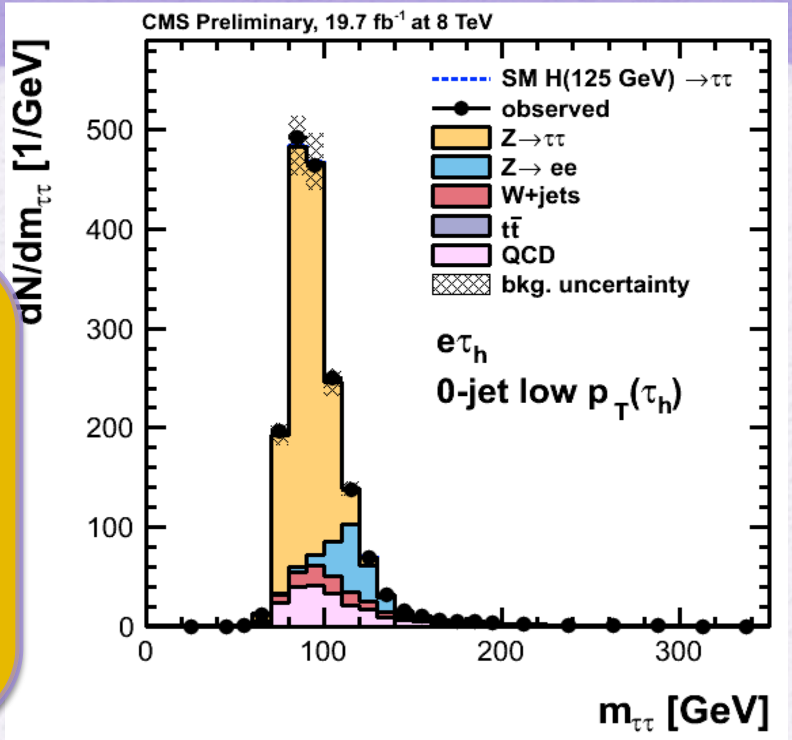
eμ:
H→WW contribution!

H→WW is treated as background to probe fermionic decay contribution

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

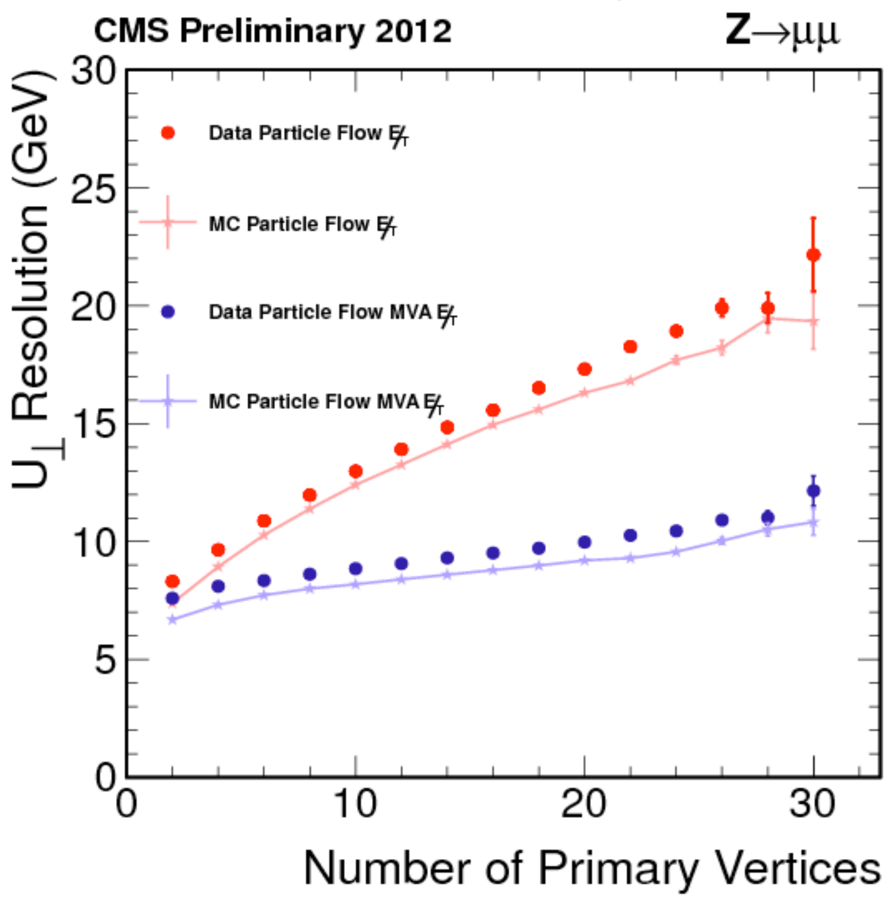
ttbar:
- Normalization from em b-tag control region
- Shape from MC

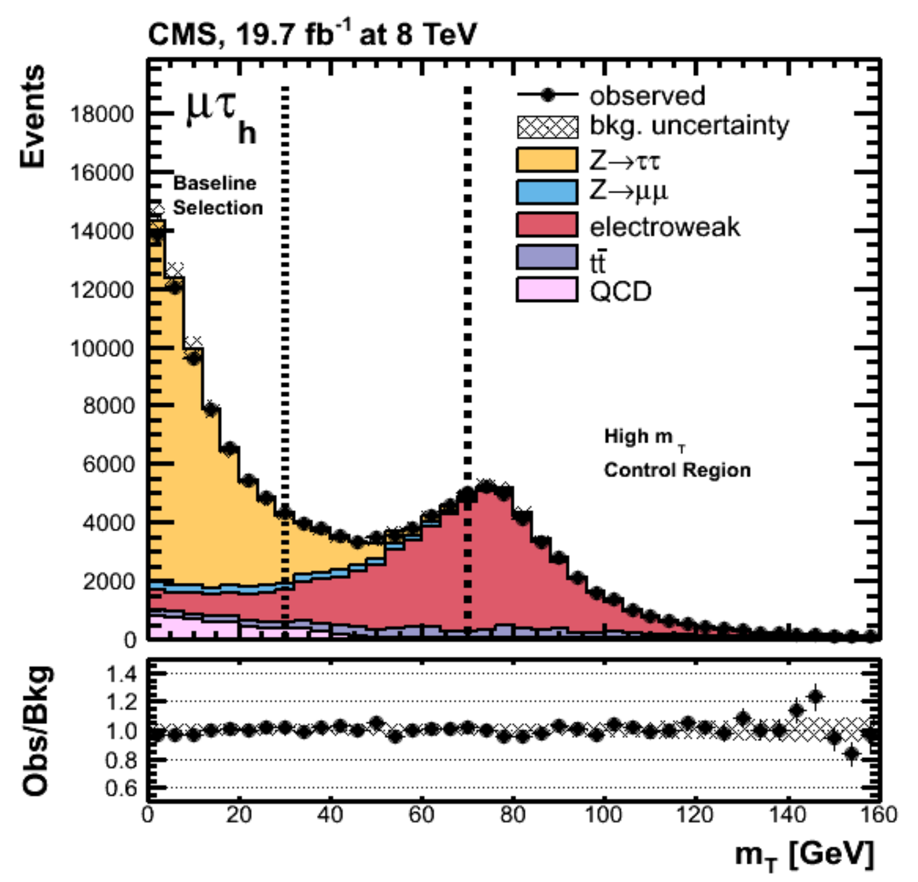
Z→ee/μμ
- Normalization scale factor from tag-and-probe in data
- Shape from MC

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

H→tt: control of W+jet background

Multivariate E_T^{miss} regression





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