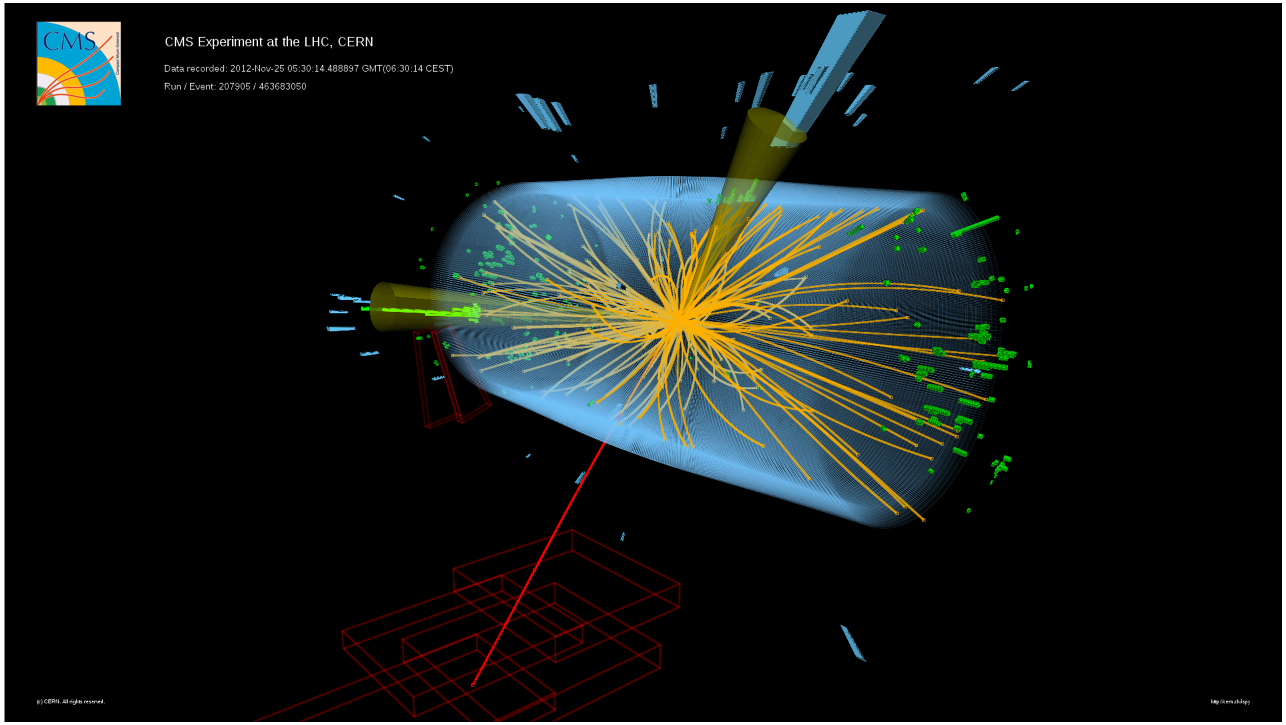


Searches for Higgs bosons decaying to lepton pairs with the CMS detector

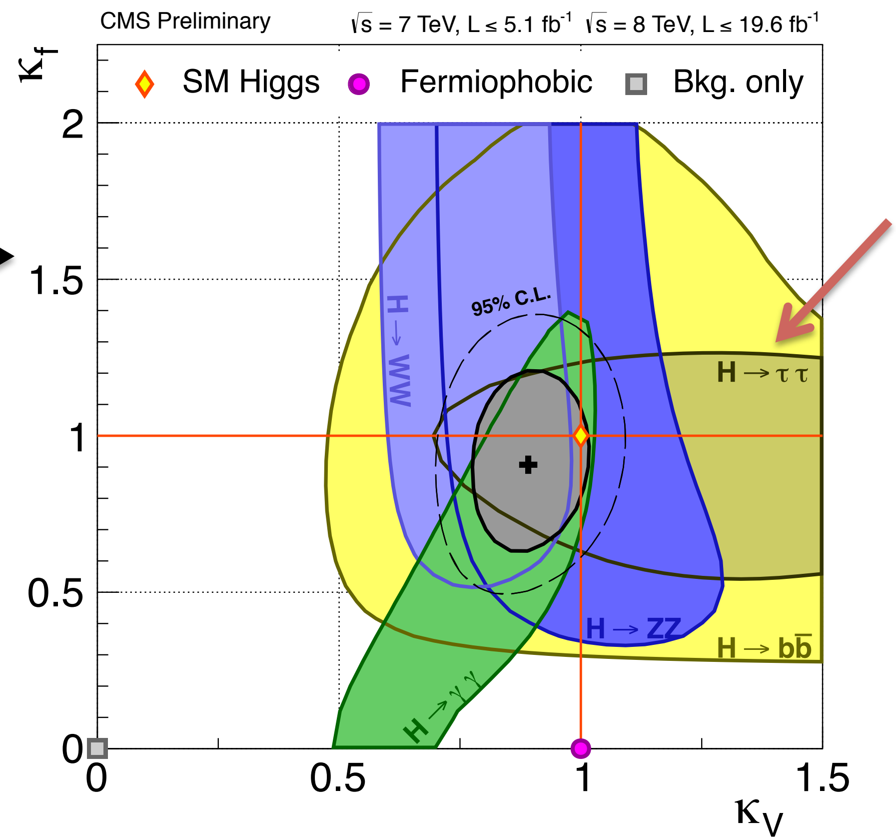
Jan Steggemann (CERN)
on behalf of the CMS collaboration

4 July 2014

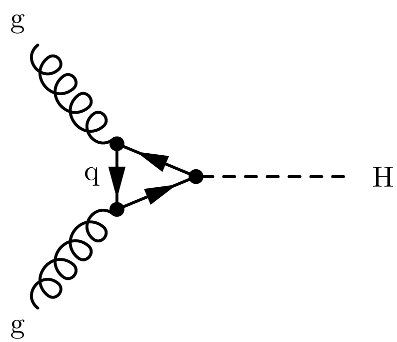
Motivation

- Does the Higgs boson decay to leptons/fermions? (H⟶ττ)
- Measurement of fermionic and bosonic couplings (H⟶ττ)
- Enhanced decay rate to 2nd generation leptons? (H⟶μμ)
- **Lepton flavour violation? (H⟶μτ) – new result!**

Higgs couplings as of Moriond 2013

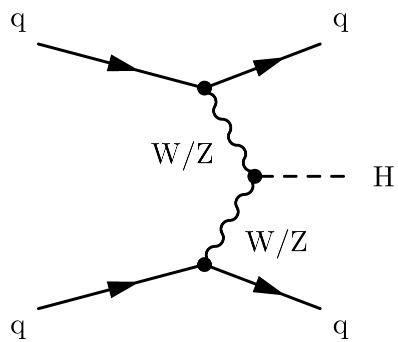


Higgs Production and Event Categories



Gluon fusion (87%)

0-jet/≥1-jet

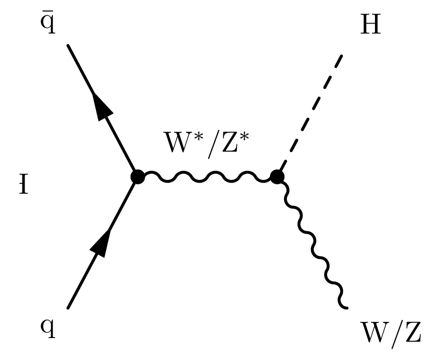


VBF (7%)

2-jet/VBF tag

(2 jets with rapidity gap, no central jet)

All analyses



WH/ZH (6%) **H→ττ**

VH

(additional muons/ electrons from Z/W boson decay)

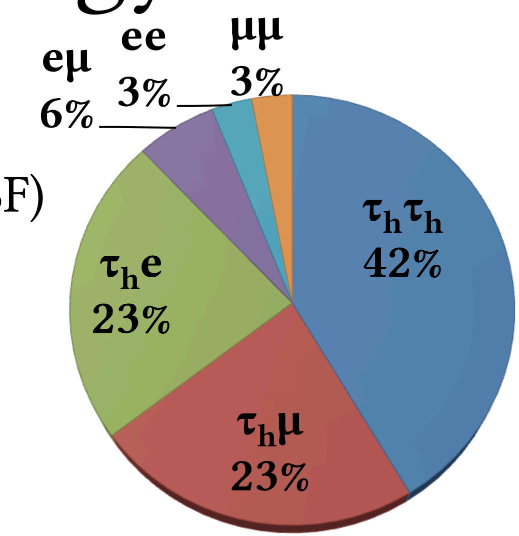
Higgs decay branching fractions to leptons

- **H→ττ: 6.3%**; H→μμ = 0.02% (m_H = 125 GeV)
- H→τμ: < 10% (exp.)

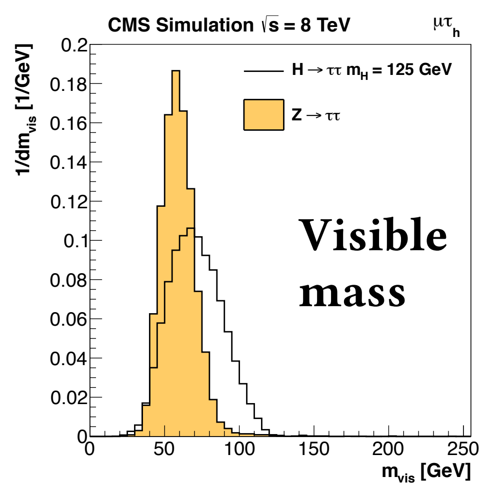
JHEP05(2014)104

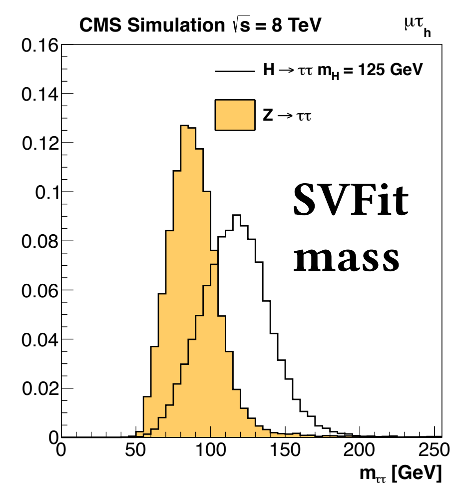
Search for H→ττ: Strategy

- Include **all 6 di-tau decay channels**
  - 0-jet, 1-jet, and VBF-tag categories (gluon fusion & VBF)
  - In addition, l+ττ (WH) and ll+ττ (ZH) final states



- Observable: reconstructed di-tau mass with resolution of 10-20%
  - Maximum likelihood fit using di-tau decay products and missing energy



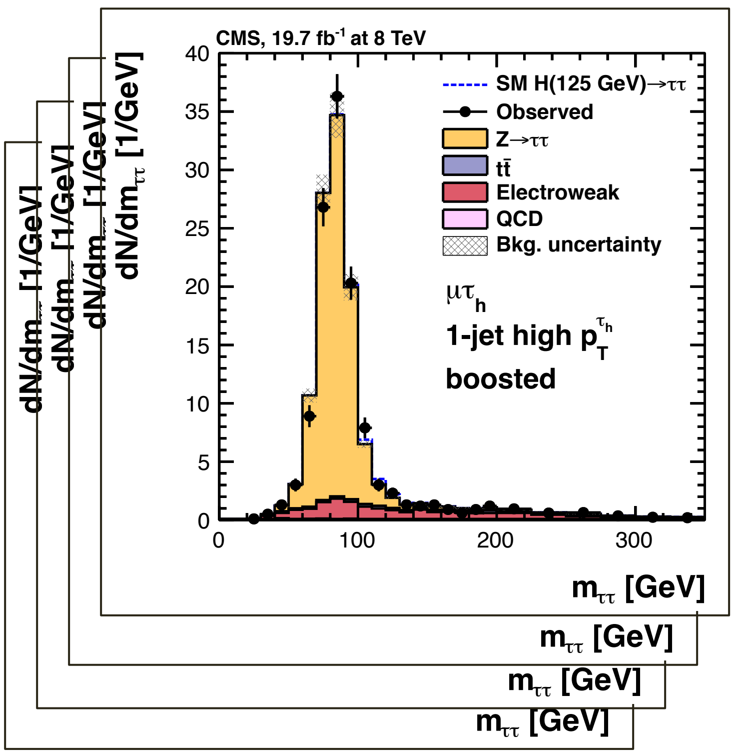


- Optimisation
  - Further divide events in categories based on lepton p_T, di-tau p_T, and VBF-jet properties

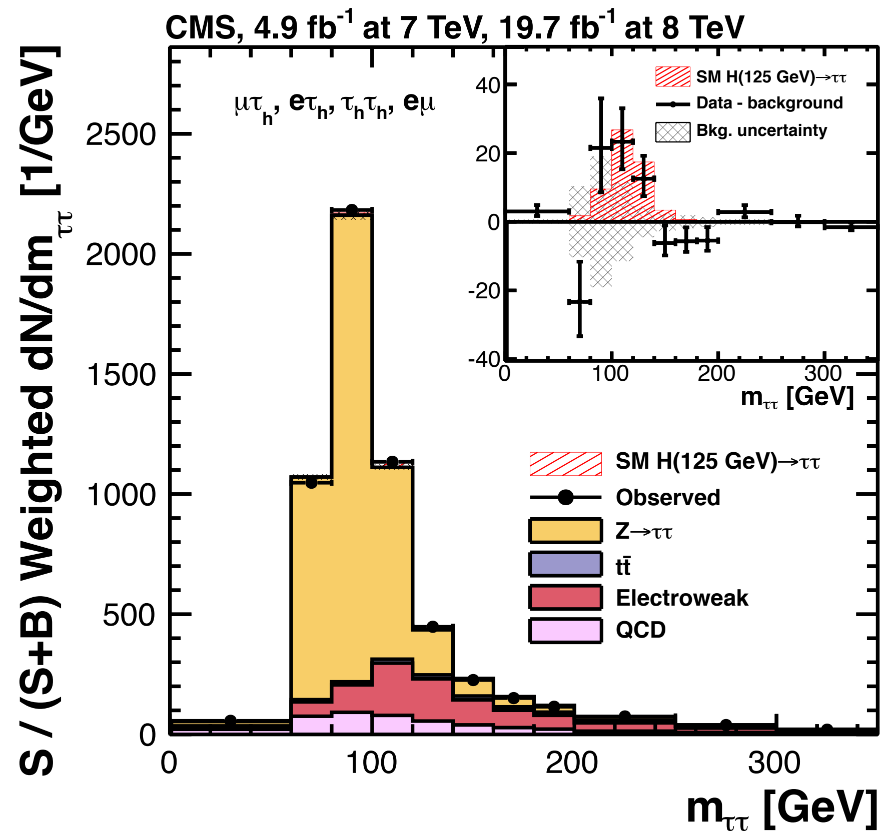
Challenges

- Excellent control of all backgrounds
- Experimental: missing energy, forward jets, **hadronic tau identification**

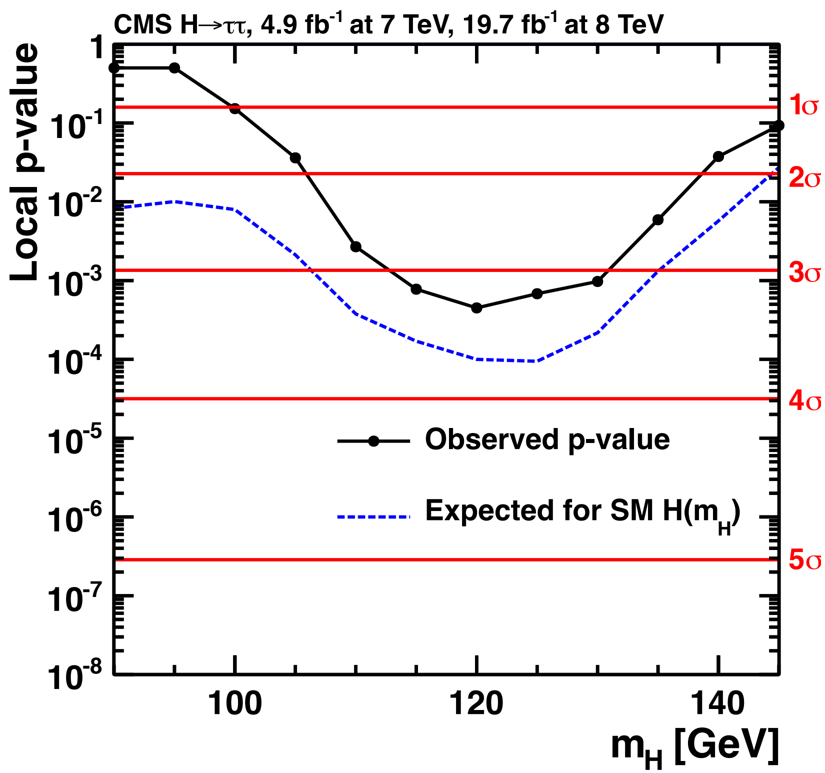
τ_h reconstruction efficiency

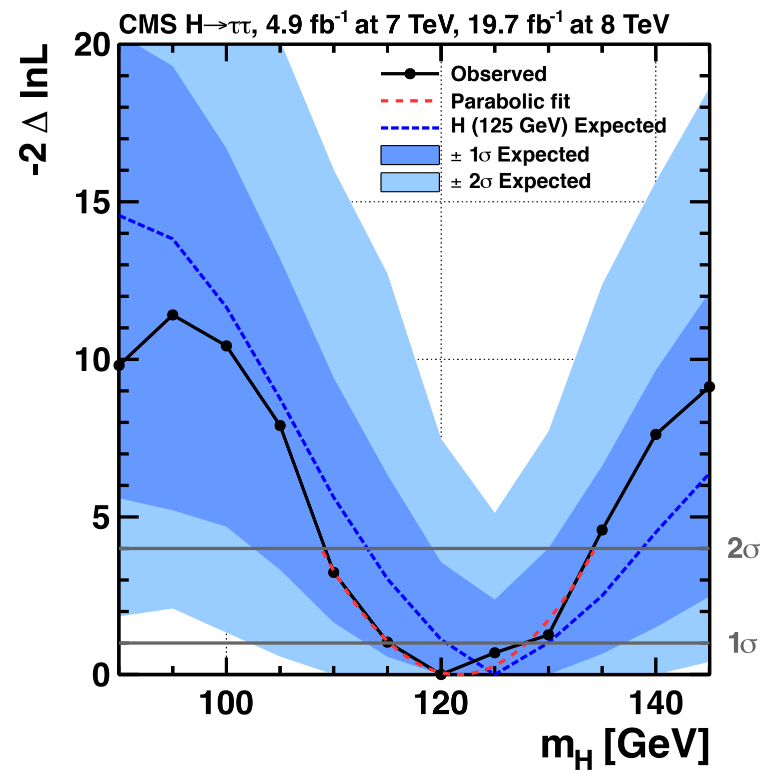


τ_h energy scale



Significance and mass

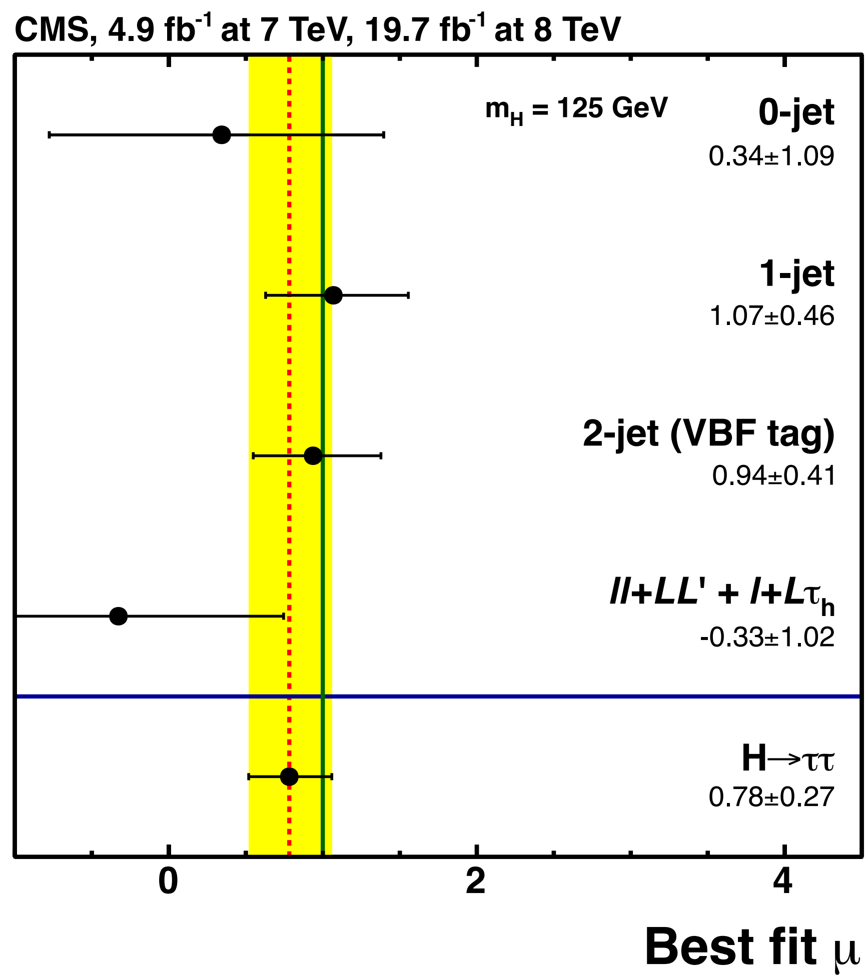




- **3.2 sigma evidence for H→ττ decays** (3.7 expected) at m_H = 125 GeV
- Mass: 122 ± 7 GeV – compatible with 125 GeV

Signal strength by jet/lepton multiplicity

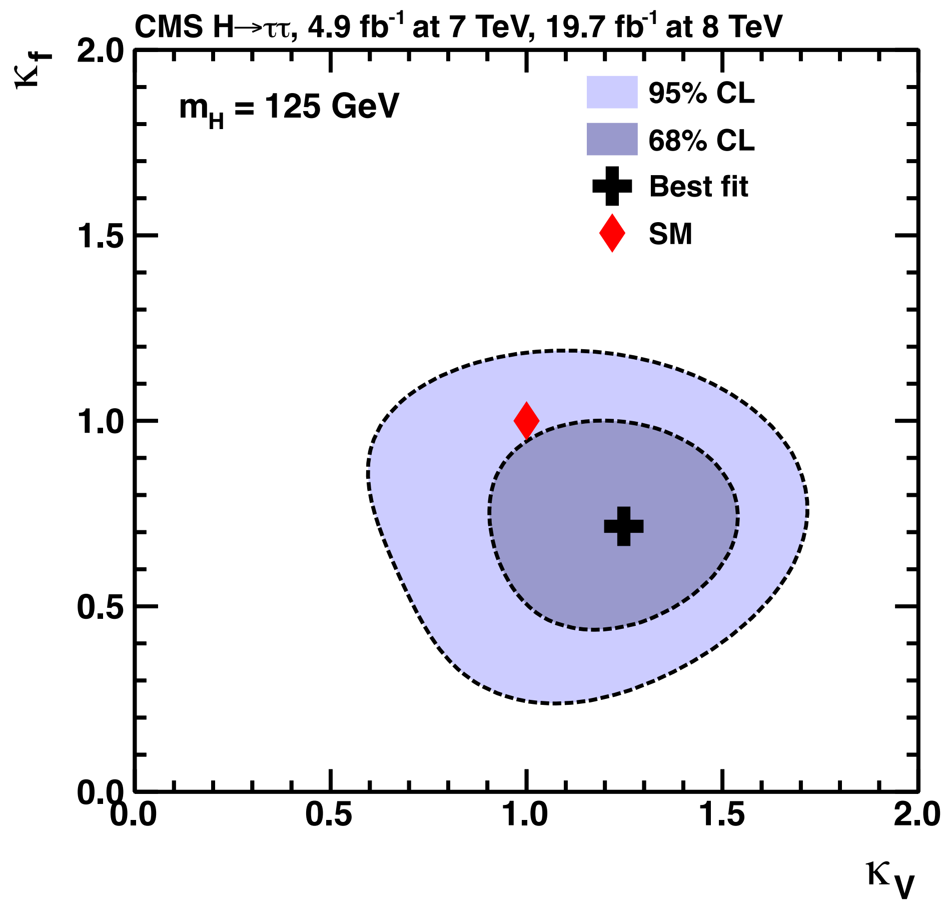
- Most of the sensitivity from VBF and 1-jet categories
  - 0-jet category constrains backgrounds and tau energy scale
- **Best fit signal strength modifier μ = 0.78 ± 0.27**



Couplings

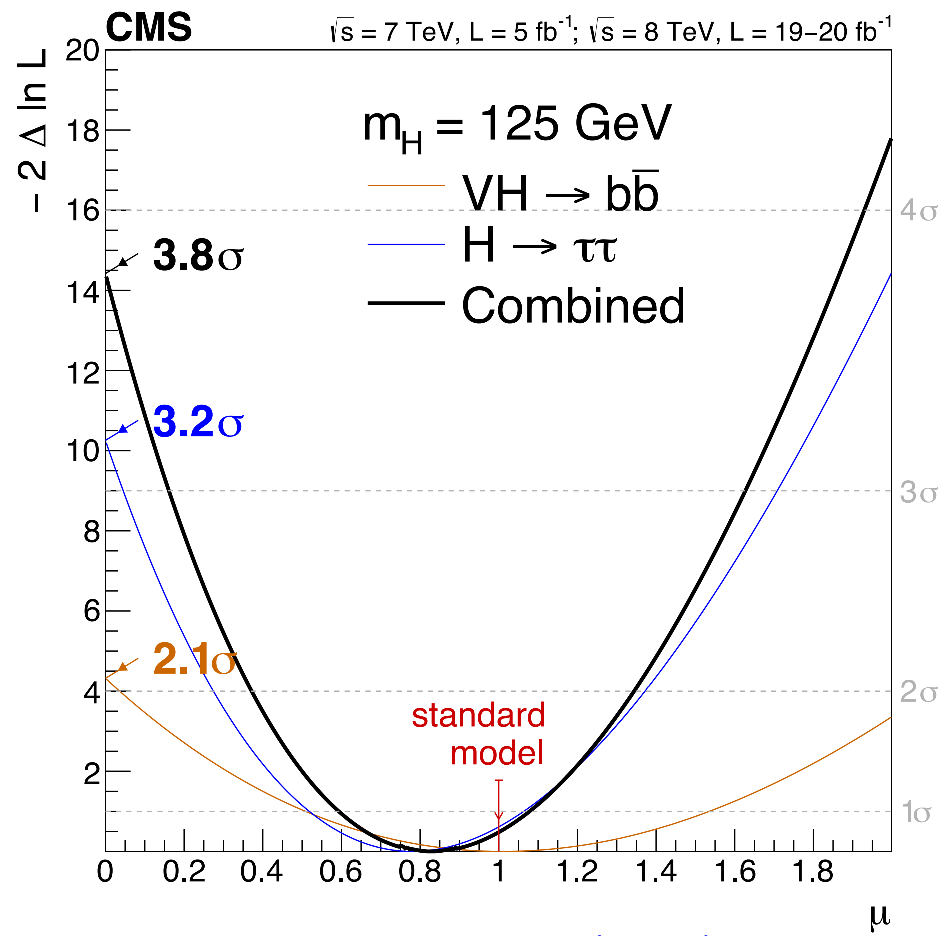
- Constraints on fermionic and bosonic couplings
  - **compatible with SM expectation**
- Sensitivity to bosonic coupling from VBF production and H⟶WW decays (in particular in eμ channel)

H⟶WW decays treated as signal



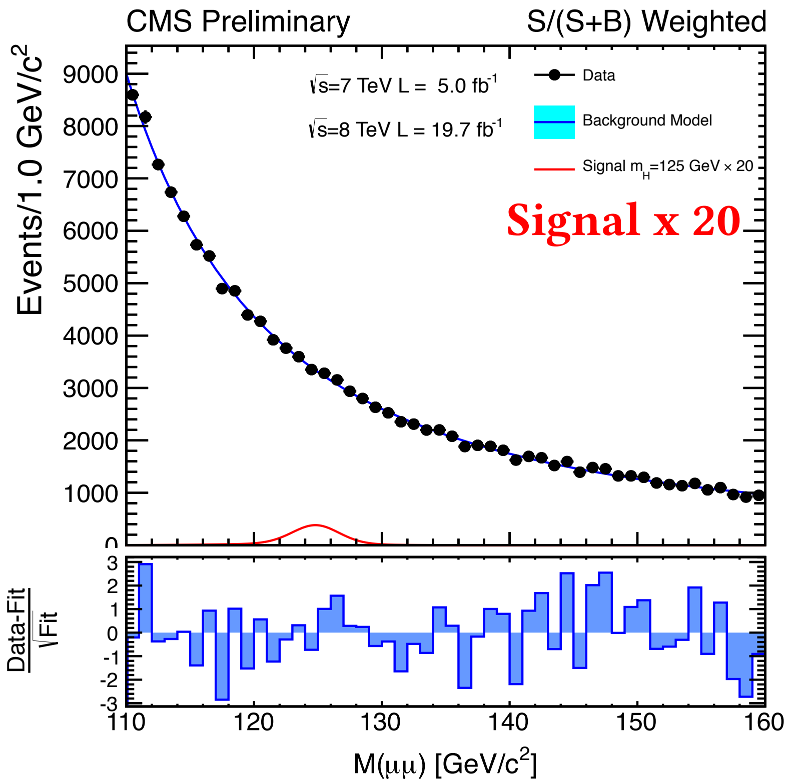
Higgs decays to fermions

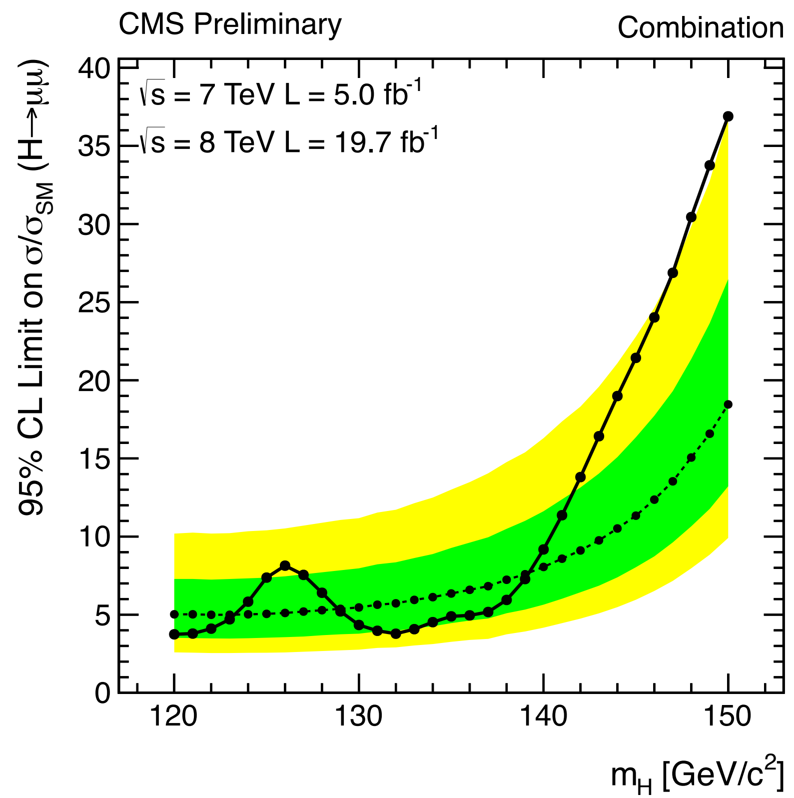
- Combination with VH⟶bb (previous talk)
- Observed (expected) combined significance of 3.8 (4.4) sigma
- Best-fit signal strength $\mu = 0.83 \pm 0.24$
- **Evidence for direct decay of the Higgs boson to fermions**



Nature Physics 10 (2014)
Advance online publication

Search for H⟶μμ





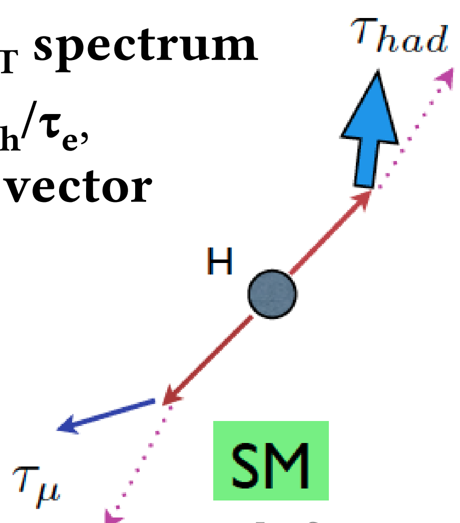
- Fit of parameterised background & signal shapes in various event categories
- Observed limit: μ(H⟶μμ) < 7.4 x SM expectation (5.1 expected)
  - Similar results in H⟶ee channel
- **As expected, Higgs boson decays to leptons are not universal**

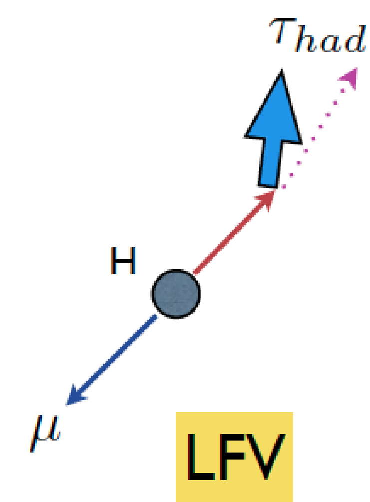
NEW RESULT

CMS-PAS-HIG-14-005

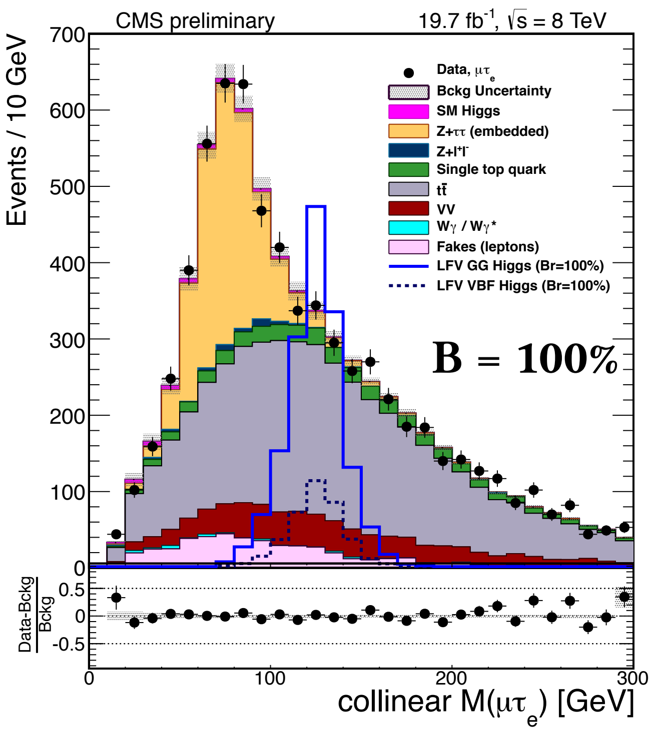
Search for H→μτ

- Previous best limits on B(H→μτ) <~ 10% from reinterpretation of LHC H→ττ searches and from τ→μγ arXiv:1209.1397
  - **Can do better with first dedicated search**
- Consider hadronic (τ_h) and electron (τ_e) tau decays
- Same basic event selection and jet categories as SM H→ττ analysis (0-jet, 1-jet, VBF-tag)
- Differences in kinematics
  - **Harder muon p_T spectrum**
  - **Δϕ between μ, τ_h/τ_e, missing energy vector**

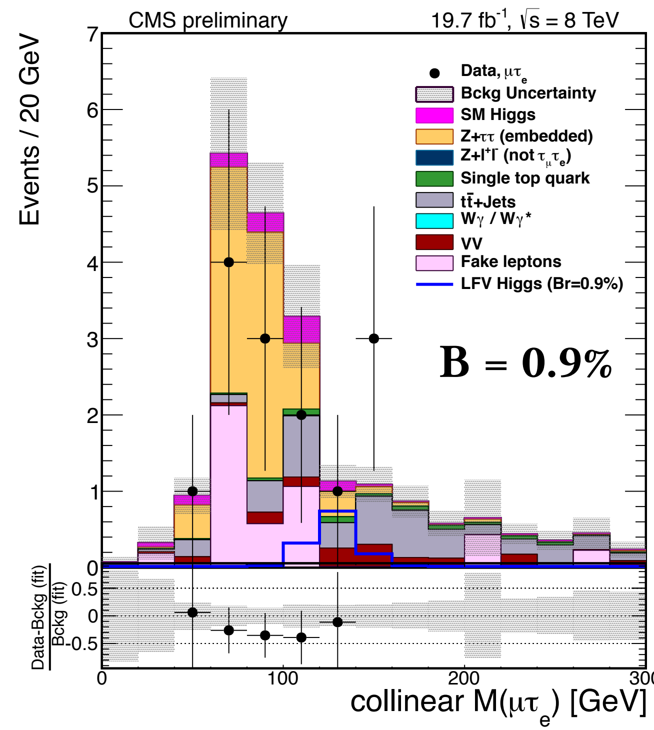




Observable and final selection



$\mu\tau_e$ VBF-tag pre-selection



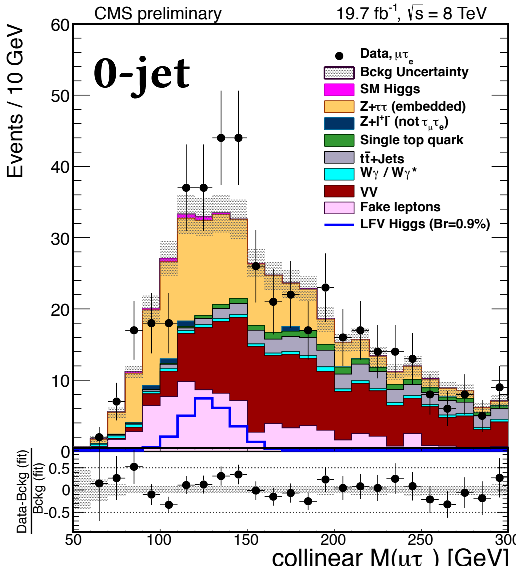
$\mu\tau_e$ VBF-tag final selection

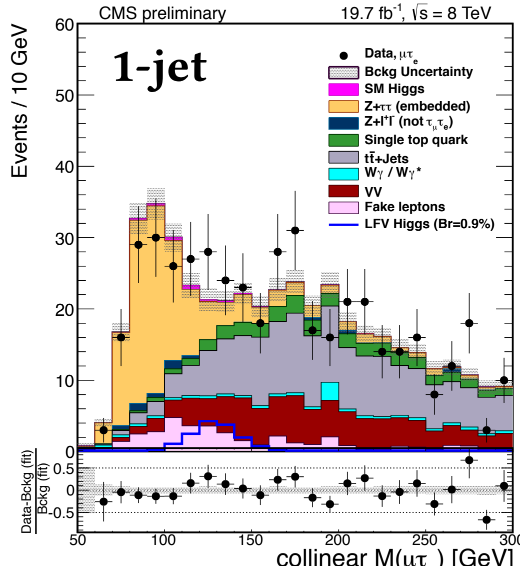
- Collinear approximation to reconstruct Higgs boson mass
- **Optimise selection for each category** based on various kinematic variables

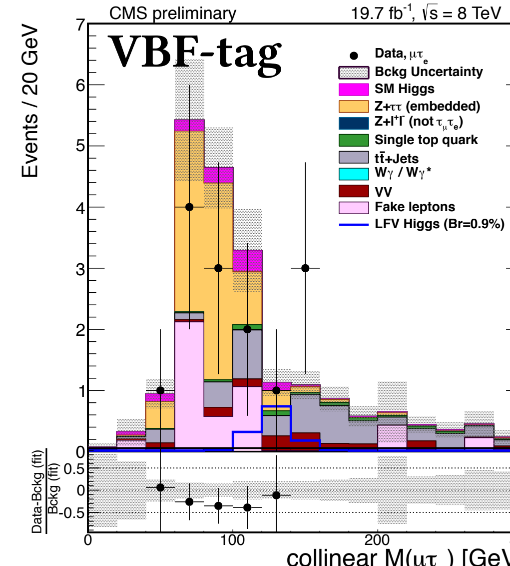
Final collinear mass distributions

B = 0.9%

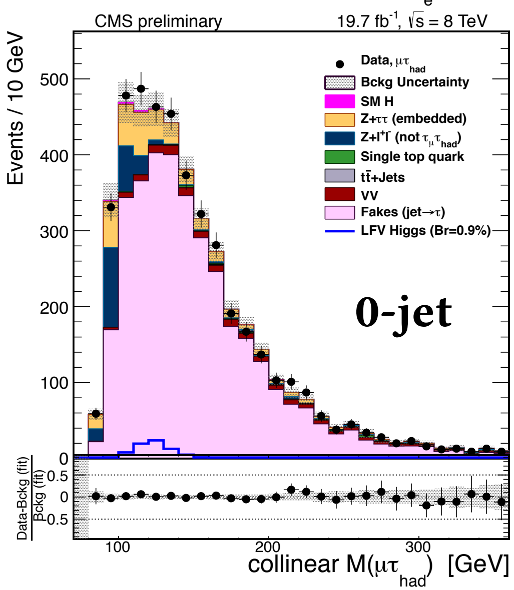
$\mu\tau_e$

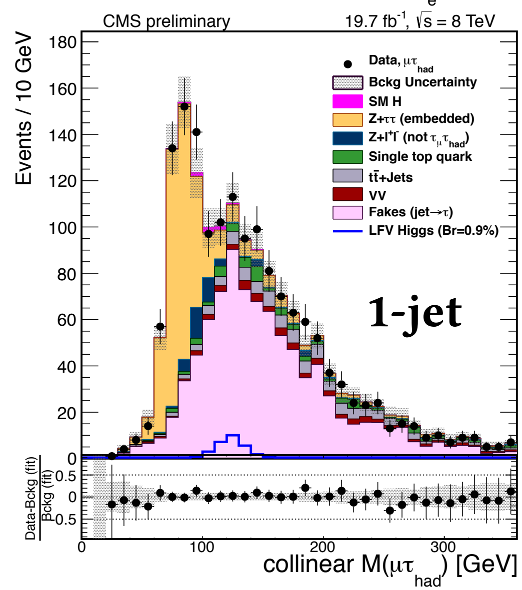


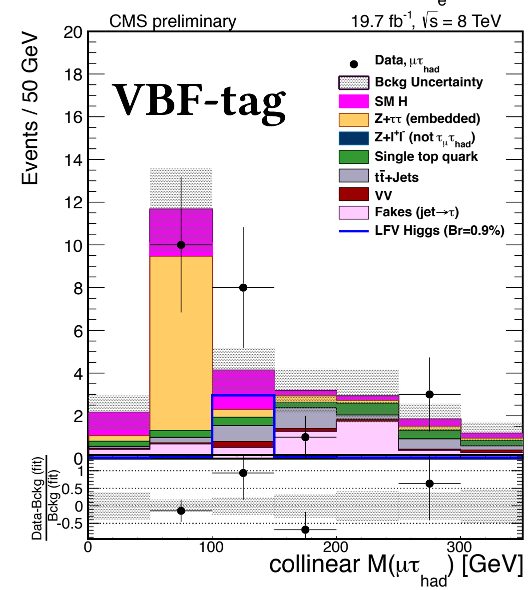




$\mu\tau_h$

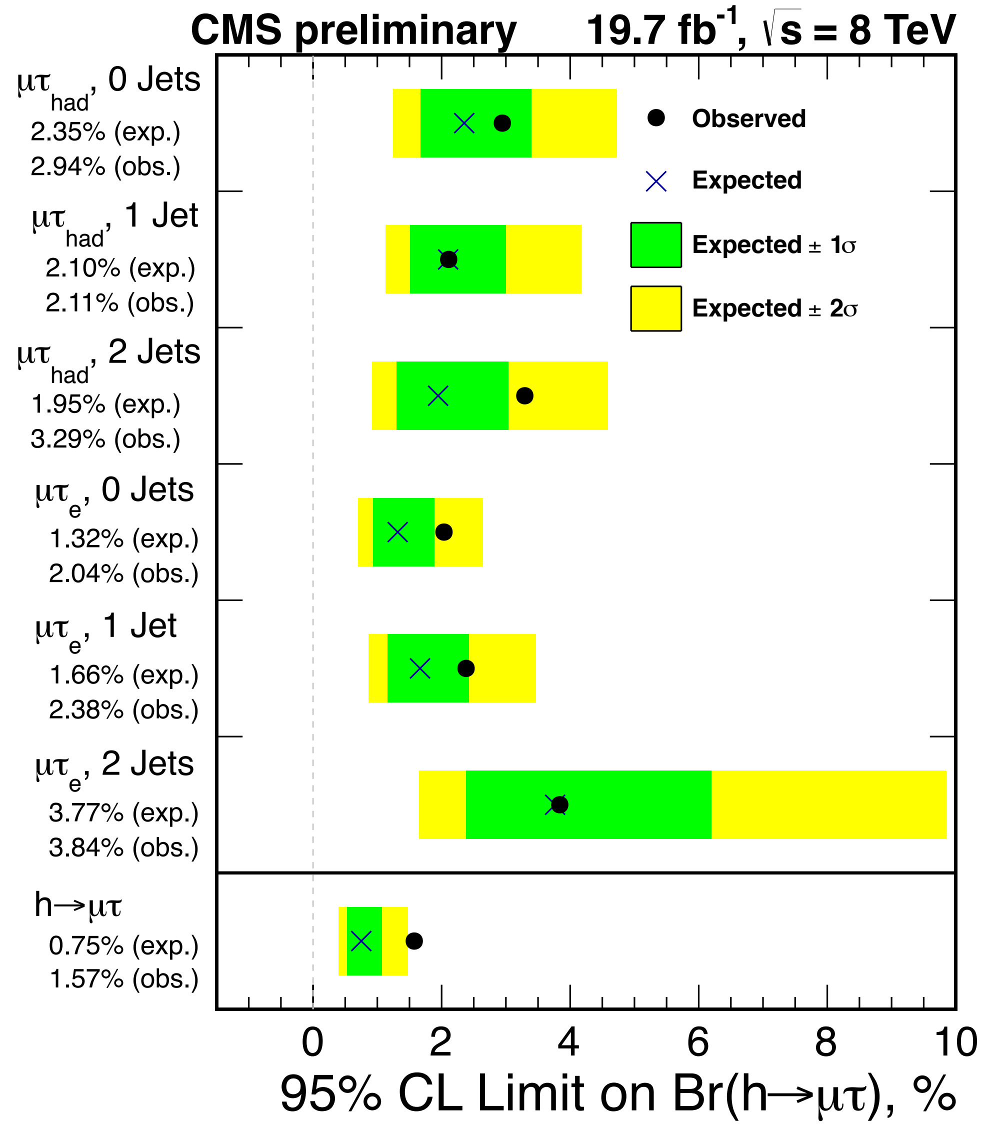






Limits on H⟶μτ branching ratio

- Comparable sensitivity from all channels
- Observed limit 1.57% (exp. 0.75%)
- **Large improvement of previous limits**
- **Background-only p-value of 0.007 (2.46σ)**
  - Best-fit $B(H\to\mu\tau) = 0.89^{+0.40}_{-0.37}\%$

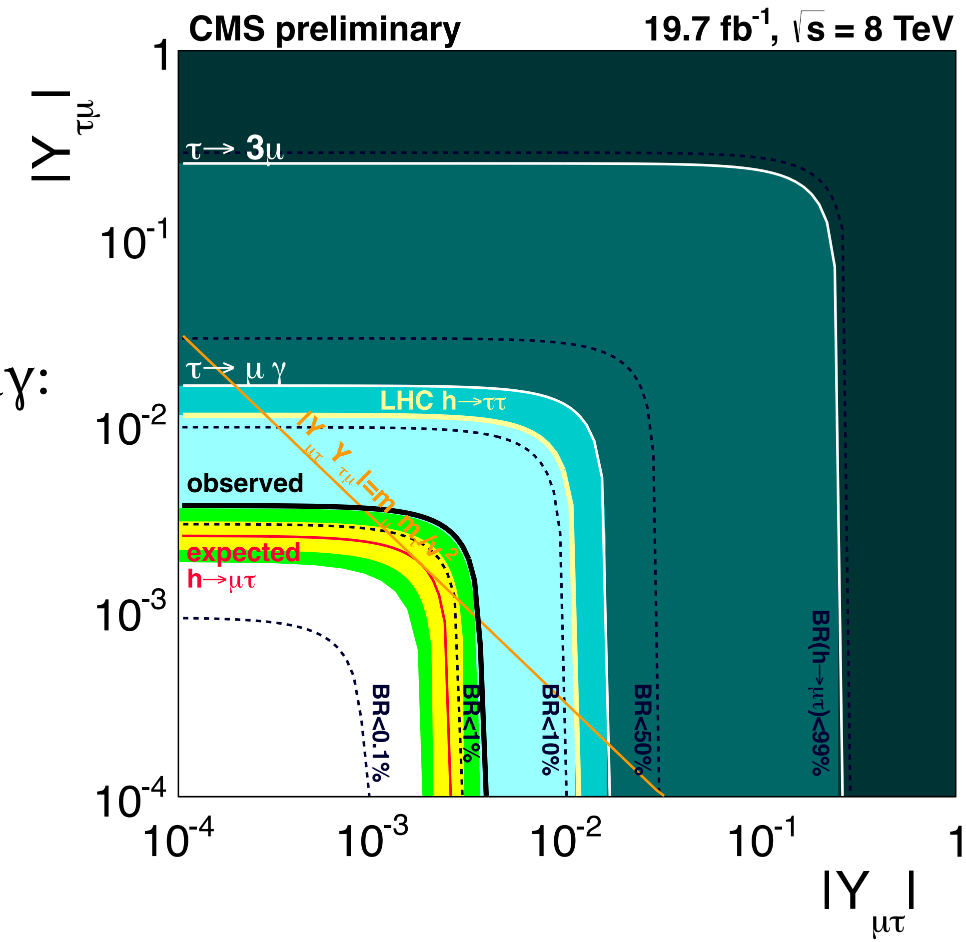


Limits on Yukawa couplings

- Translate branching ratio limits to limits on Yukawa couplings

- Previous best limit from τ⟶μγ:
  $\sqrt{|Y_{\mu\tau}|^2 + |Y_{\tau\mu}|^2} < 0.016$
- Observed limit:
  $\sqrt{|Y_{\mu\tau}|^2 + |Y_{\tau\mu}|^2} < 0.0036$

- **Large improvement of previous limits**

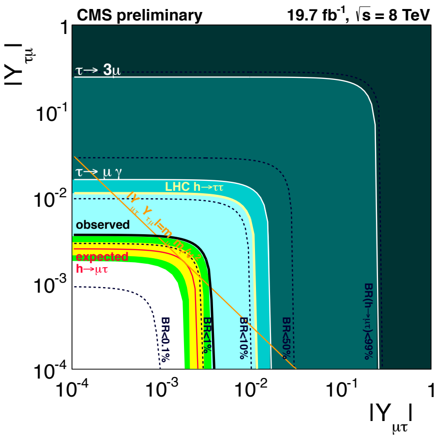


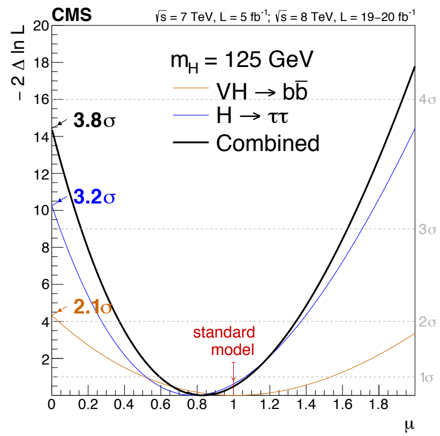
Conclusion

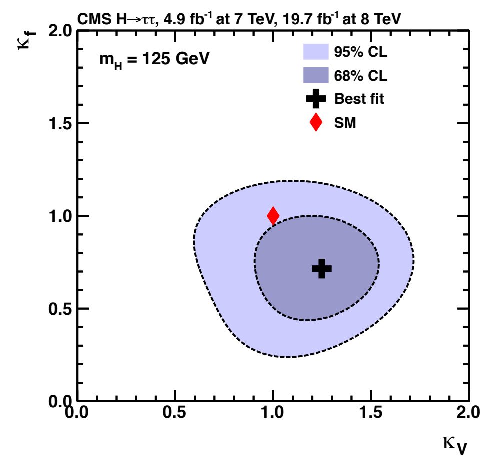
- Tight constraints on lepton-flavour violating Higgs boson decays

- Evidence for Higgs boson decays to taus (and fermions)

- Precise measurements of Higgs boson couplings to fermions and bosons







Backup

Bibliography

- CMS Collaboration, “Evidence for the 125 GeV Higgs boson decaying to a pair of tau leptons”, JHEP (2014): http://dx.doi.org/10.1007/JHEP05(2014)104
- CMS Collaboration, "Evidence for the direct decay of the 125 GeV Higgs boson to fermions”, Nature Physics (2014): http://dx.doi.org/10.1038/nphys3005
- CMS Collaboration, “Search for the standard model Higgs boson in the dimuon decay channel in pp collisions at sqrt(s) = 7 and 8 TeV, CMS-PAS-HIG-13-007 (2013): http://cds.cern.ch/record/1606831?ln=en
- CMS Collaboration, “Search for Lepton Flavor Violating Decays of the Higgs Boson”, CMS-PAS-HIG-14-005 (2014)

LFV: Systematic uncertainties

Experimental:

Systematic	$H \to \mu\tau_e$			$H \to \mu\tau_{had}$		
	0-jet	1-jet	2-jet	0-jet	1-jet	2-jet
Electron Trigger/ID/Isolation	3%	3%	3%	-	-	-
Muon Trigger/ID/Isolation	2%	2%	2%	2%	2%	2%
Hadronic Tau efficiency	-	-	-	9%	9%	9%
Luminosity	2.6%	2.6%	2.6%	2.6%	2.6%	2.6%
$Z \to \tau\tau$ Background	3+3*%	3+5*%	3+10*%	3+5*%	3+5*%	3+10*%
$Z \to \mu\mu, ee$ Background	30%	30%	30%	30%	30%	30%
muon and electron fake background	40%	40%	40%	-	-	-
Hadronic Tau fake background	-	-	-	30+10*%	30%	30%
$WW, ZZ + jets$ background	15%	15%	15%	15%	15%	65%
$t\bar{t} + jets$ background	10 %	10 %	10+10*%	10 %	10 %	10+33*%
$W + \gamma$ background	100 %	100 %	100 %	-	-	-
B-tagging veto	3%	3%	3%	-	-	-
Single Top production background	10 %	10 %	10 %	10 %	10 %	10%

From theory:

Uncertainty	Gluon Fusion			Vector Boson Fusion		
	0-jet	1-jet	2-jet	0-jet	1-jet	2-jet
Parton Density Function	+9.7%	+9.7%	+9.7%	+ 3.6%	+3.6%	+3.6%
Renormalization Scale	+8 %	+10 %	-30%	+4 %	+1.5%	+2%
Underlying Event/Parton Shower	+4%	-5%	-10%	+10%	0%	-1%

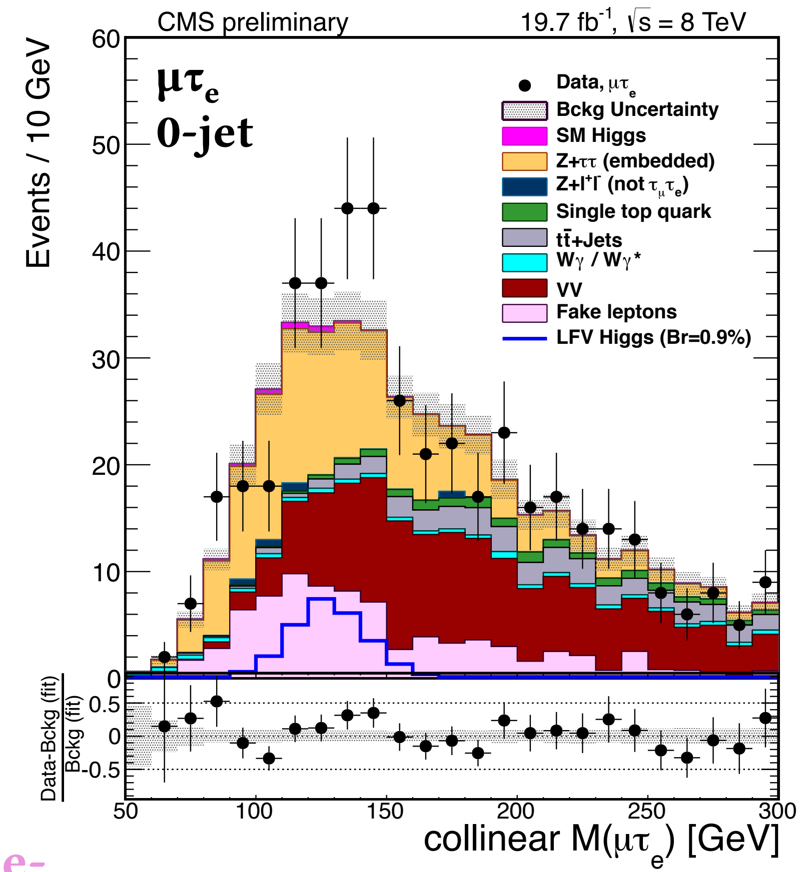
Shape-altering:

Systematic	$H \to \mu\tau_e$	$H \to \mu\tau_{had}$
Hadronic Tau energy scale	-	3%
Jet Energy scale	3-7%	3-7%
Unclustered energy scale	10%	10 %
$Z(\tau\tau)$ Bias	$1 \pm 1\%$	-

LFV: Background estimation

$Z \to \tau\tau$:
Embedded event sample based on $Z \to \mu\mu$ data

W+jets/Multijet:
Fake rate method based on anti-isolated event sample, $Z \to ll$ data sample & same-sign control region



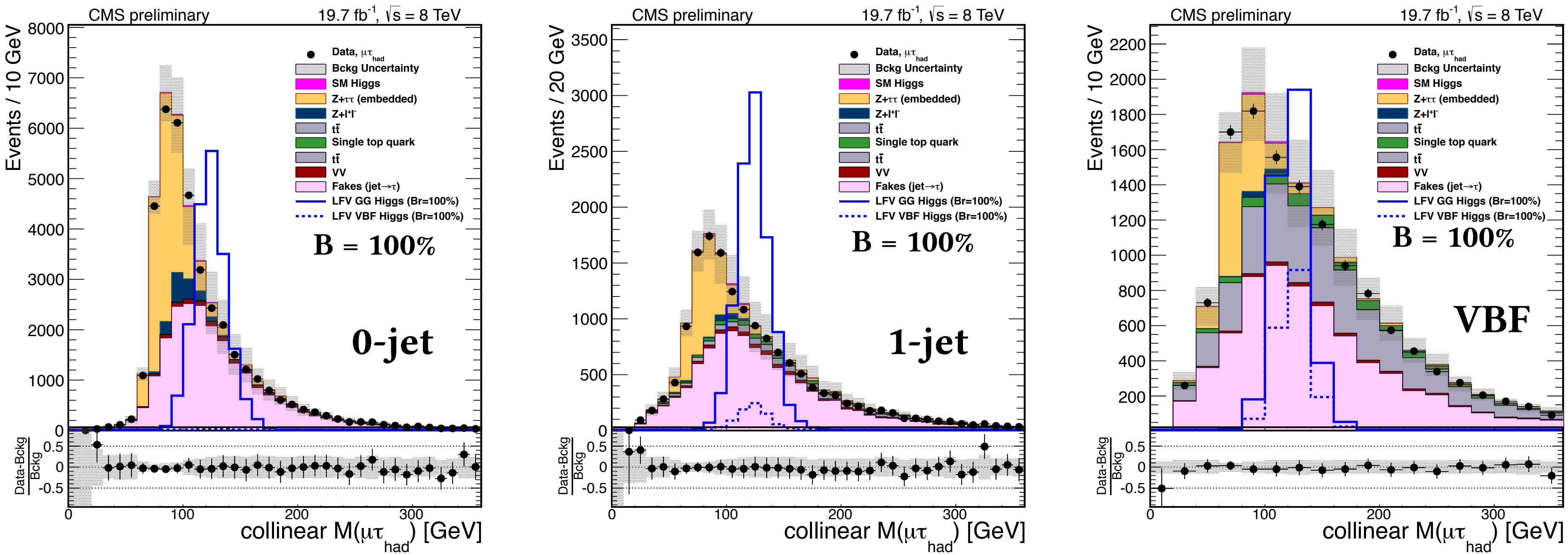
SM Higgs/$Z \to ll$/W+γ/diboson/single top: Simulation

ttbar:
Shape from simulation, normalisation from control region

Largest backgrounds estimated from data

LFV: Background checks

- Test agreement of simulation in
  - Pre-selection region and
  - Intermediate region (tighter selection closer to final selection criteria)
- Collinear mass distributions in $\mu\tau_h$ channel after pre-selection



LFV: Background checks

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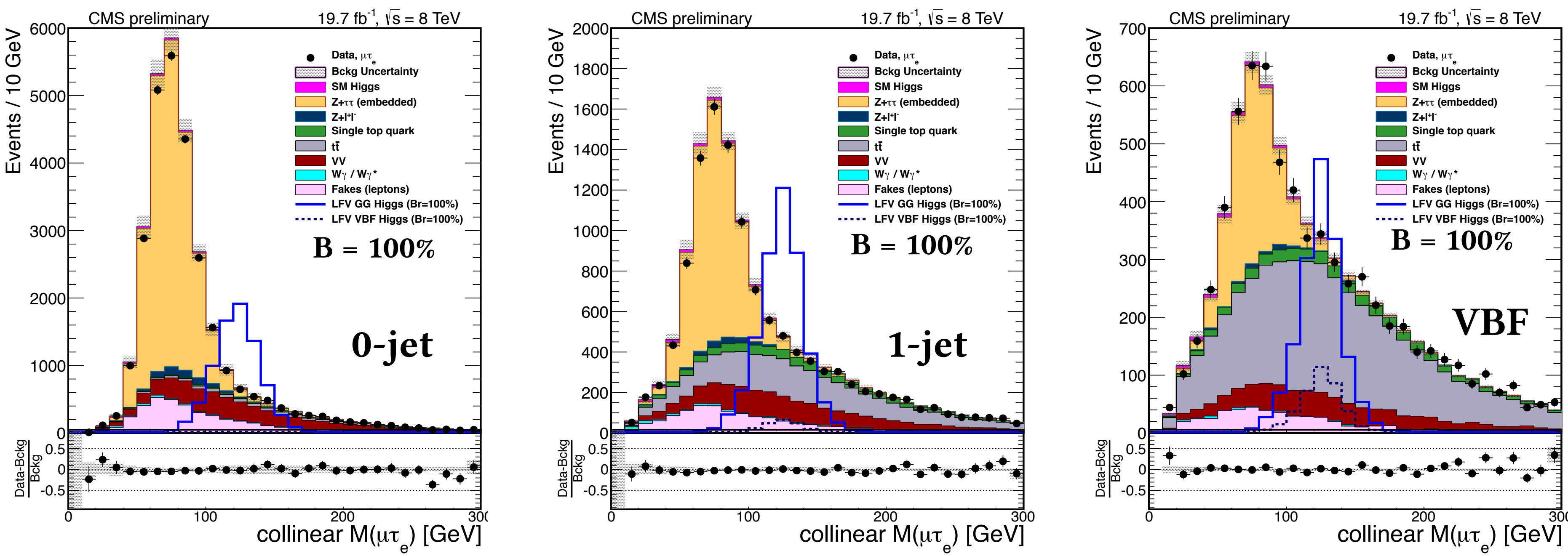
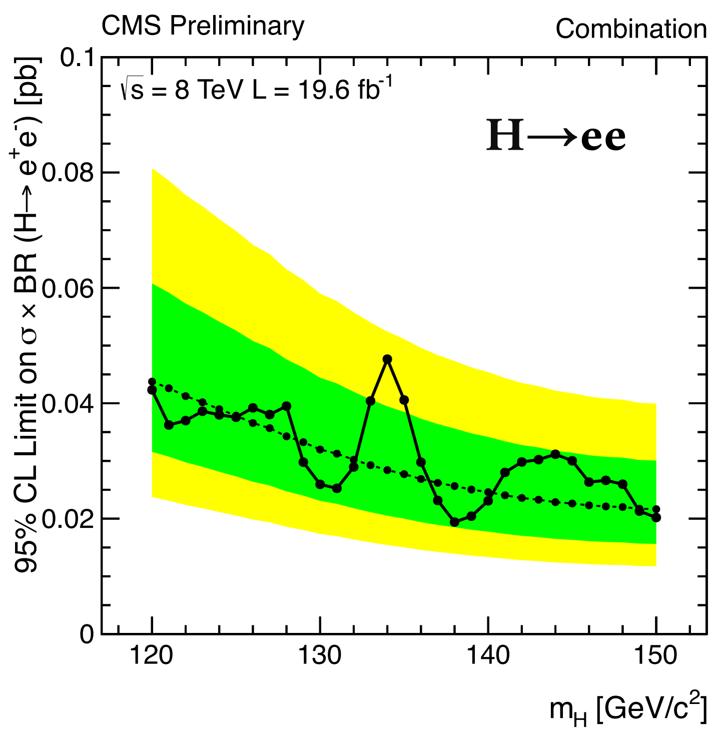
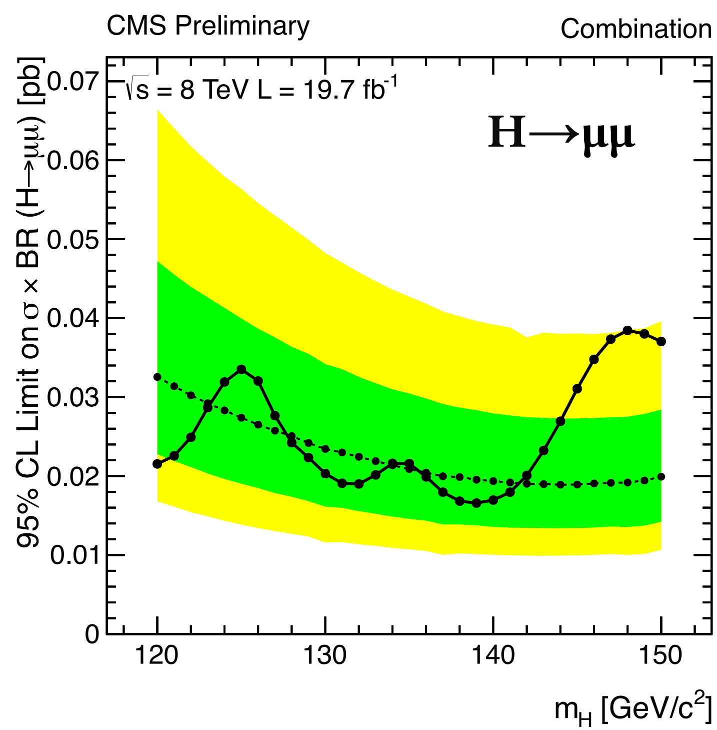


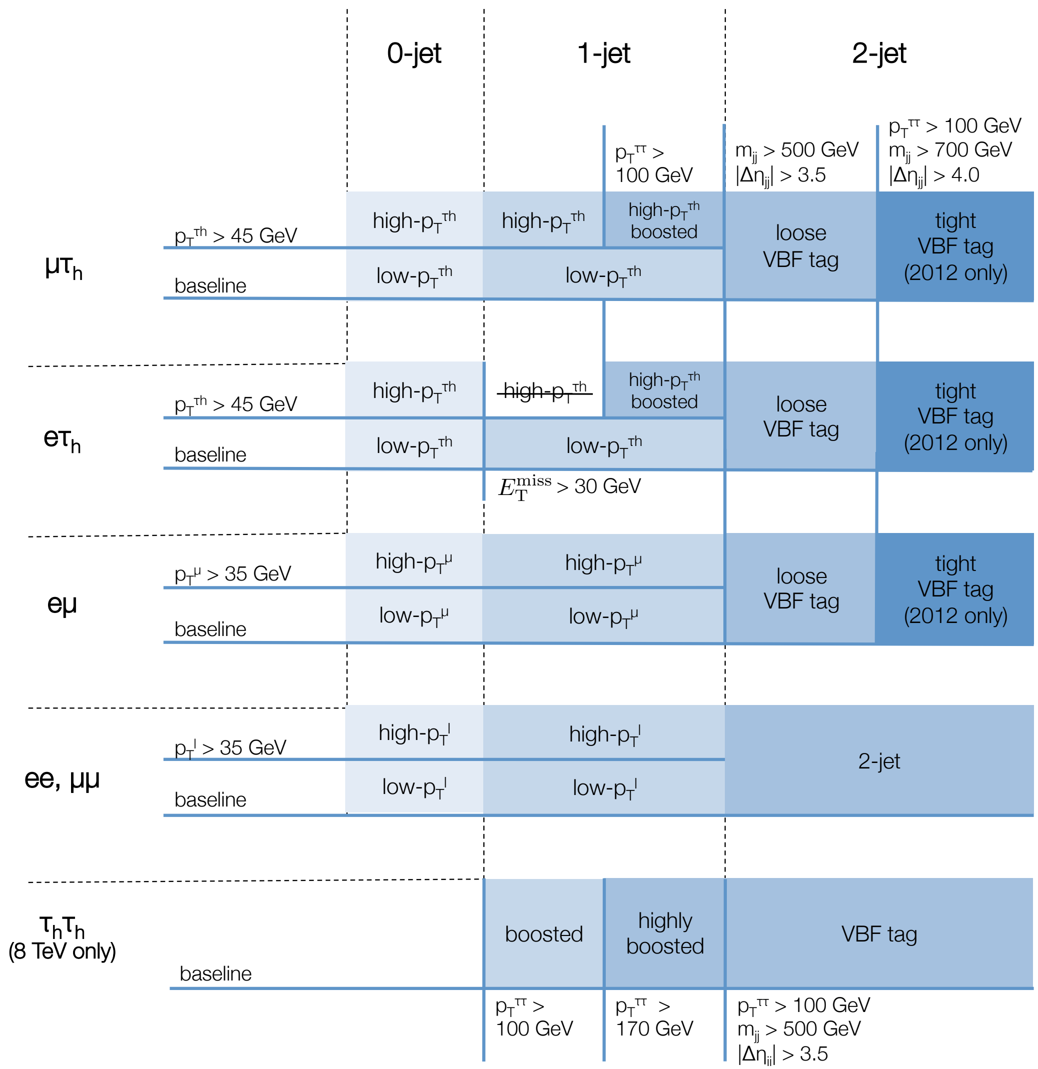
H→μμ and H→ee

- Similar analysis performed in H→ee decay channel
- Yields comparable exclusion limits to H→μμ channel
- Further evidence that Higgs boson does not couple to all leptons with same strength

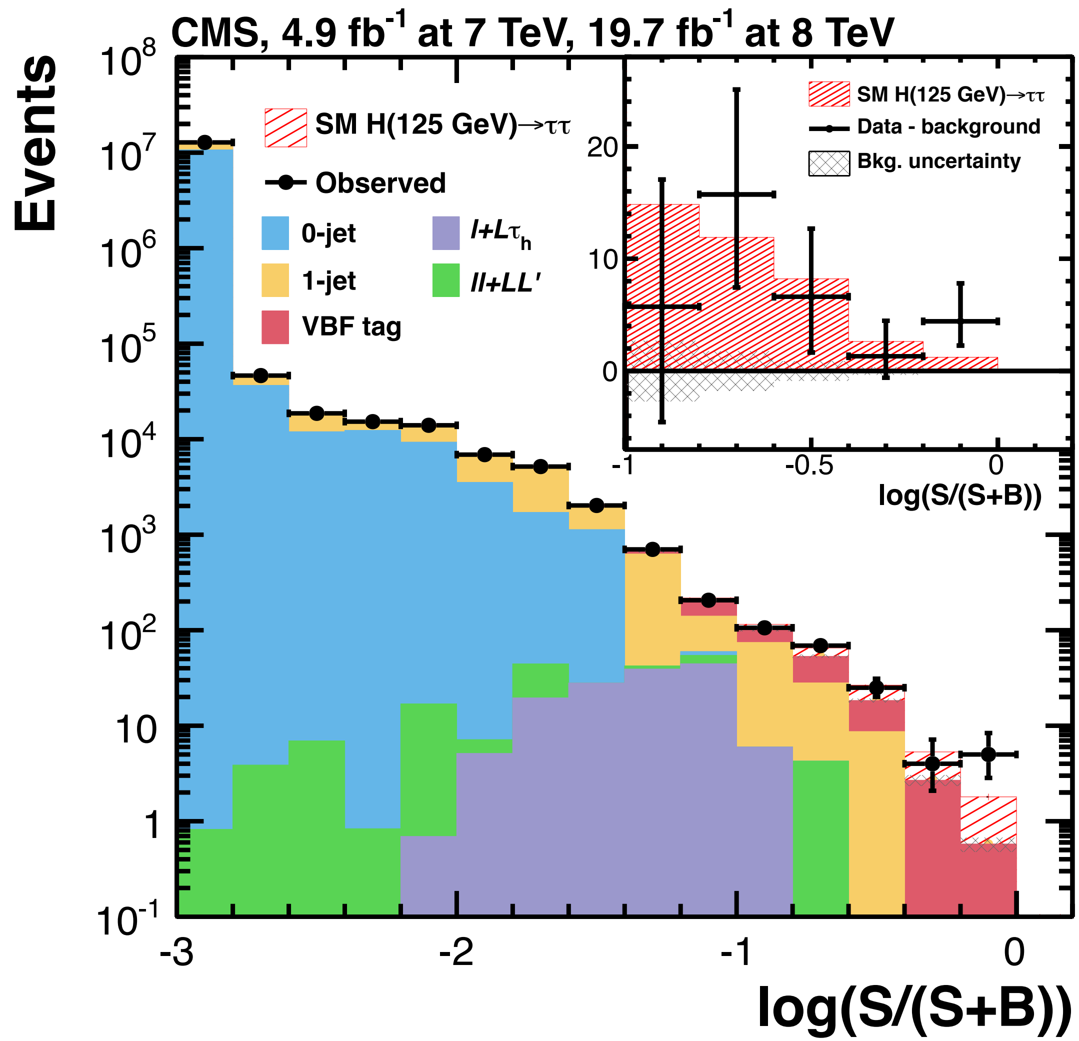




H→ττ: Event categories



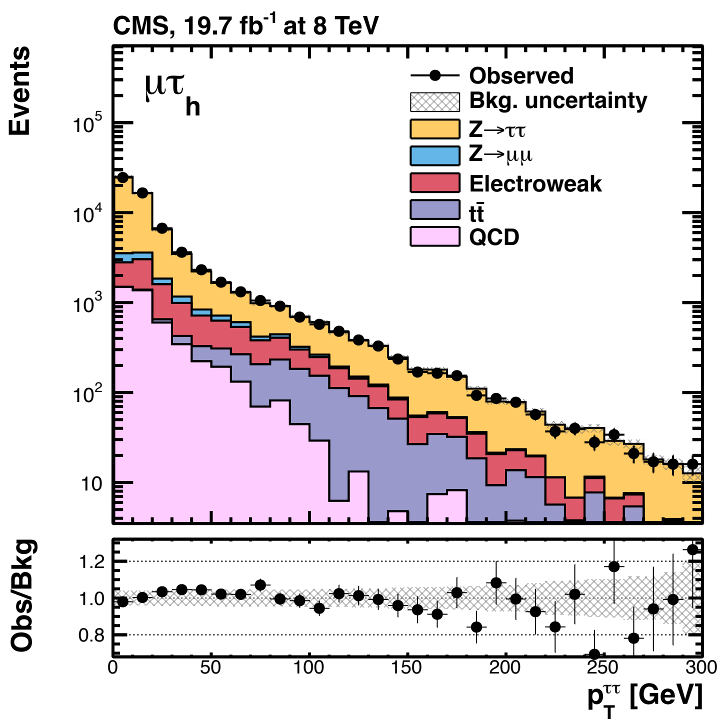
H→ττ: distribution of log(S/(S+B))

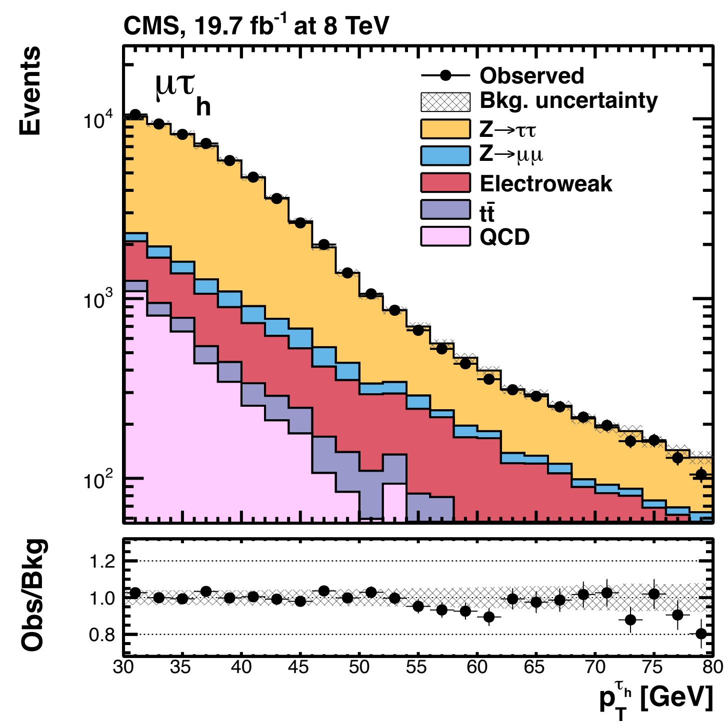


S/(S+B) in each bin of the final discriminator distributions

$H \to \tau\tau$: Distributions used in event categorisation

- p_T di-tau p_T system
- p_T of hadronically decaying tau
- Shown for inclusive event selection





$H \rightarrow \tau\tau$: event selection

- Reconstructed mass of hadronically decaying tau in 1-prong and 3-prong decay modes to determine tau energy scale
- Transverse W boson mass: reject and estimate W+jets background