

Evidence for the 125 GeV Higgs boson decaying to Taus

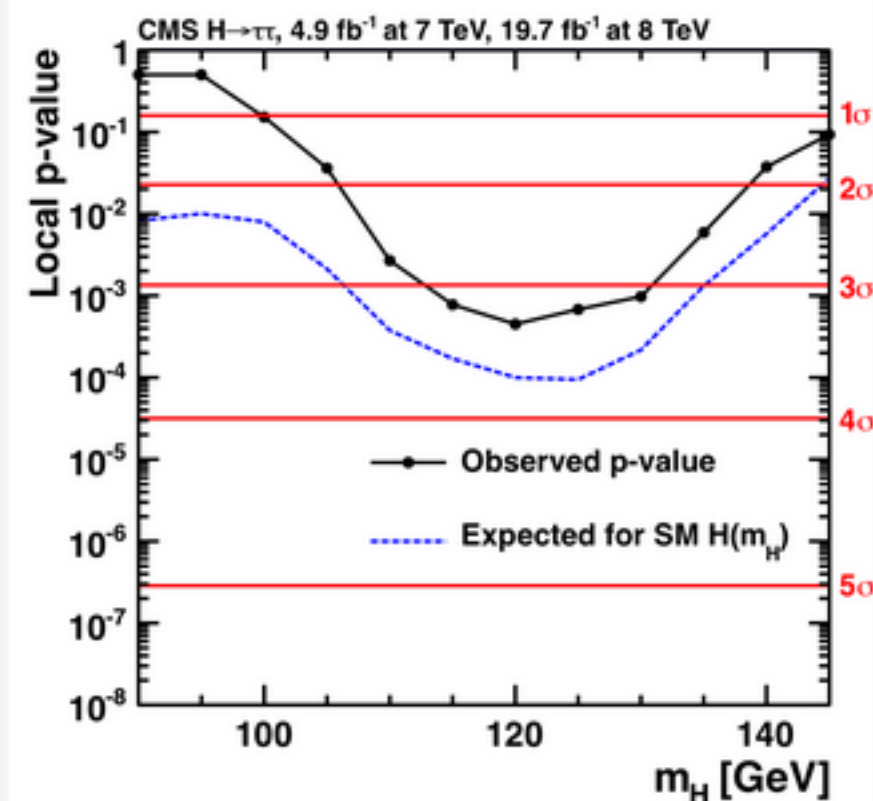
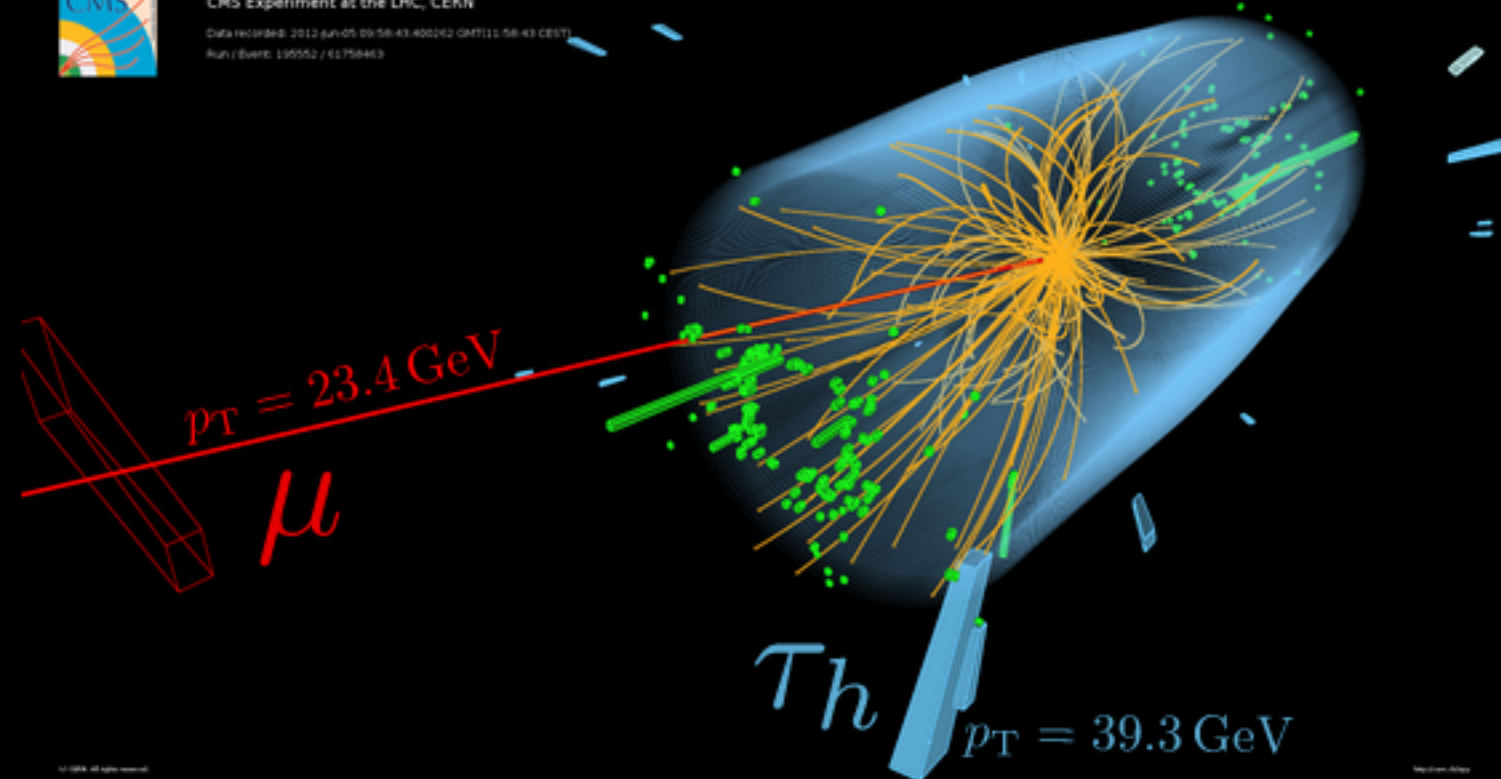
Thomas Müller on behalf of the CMS Collaboration | September 18th, 2014

INSTITUTE OF EXPERIMENTAL NUCLEAR PHYSICS (IEKP, KIT)



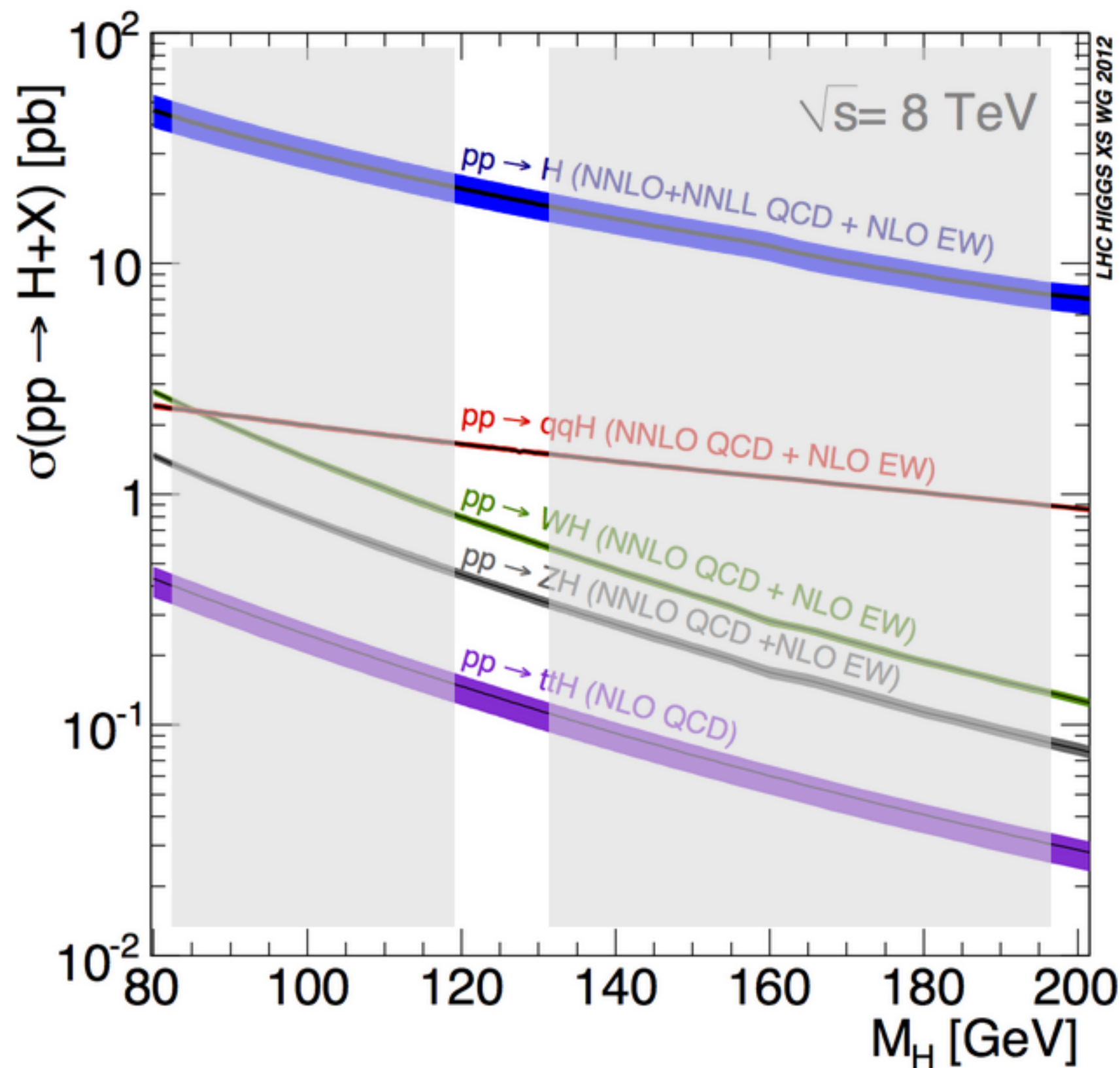
CMS Experiment at the LHC, CERN

Data recorded: 2012 Jun 05 09:58:43-400242 GMT(11:58:43 CEST)
Run / Event: 19552 / 6175843



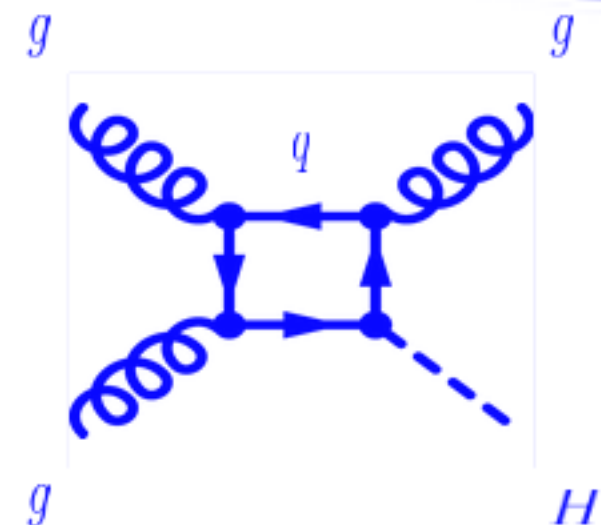
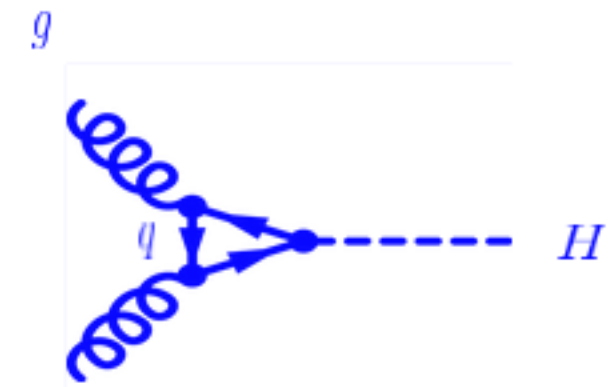
Higgs Bosons at the LHC

Production



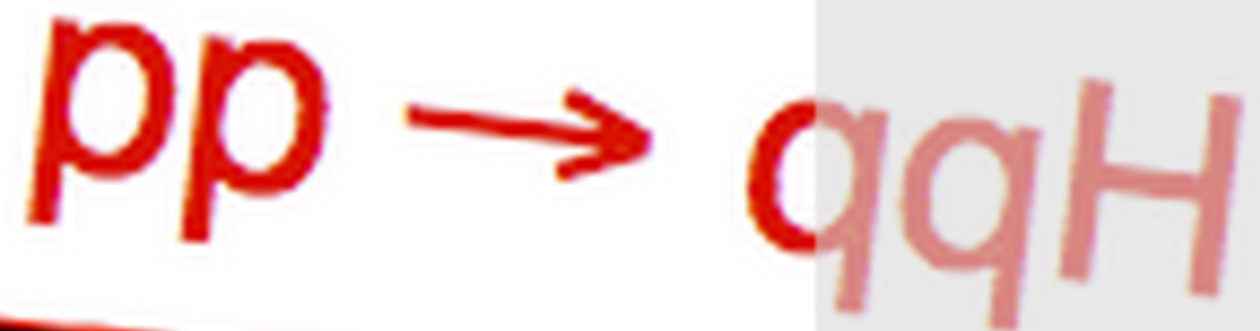
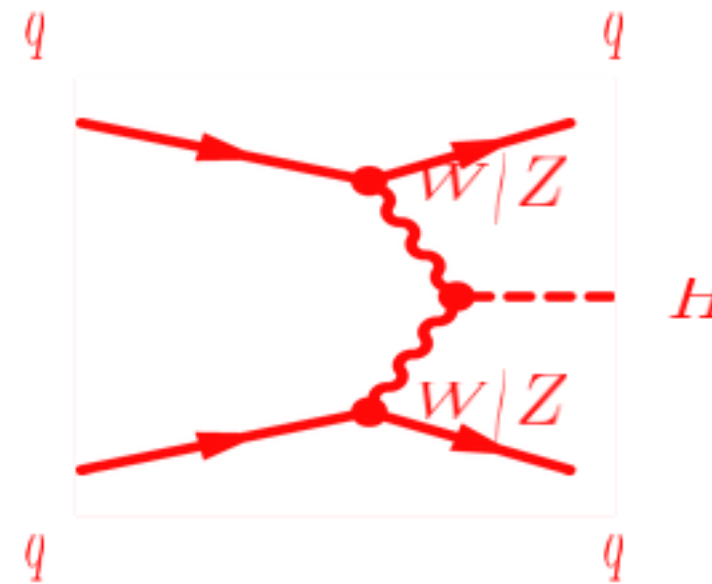
Gluon Fusion

- ▶ Largest cross section



Vector Boson Fusion (VBF)

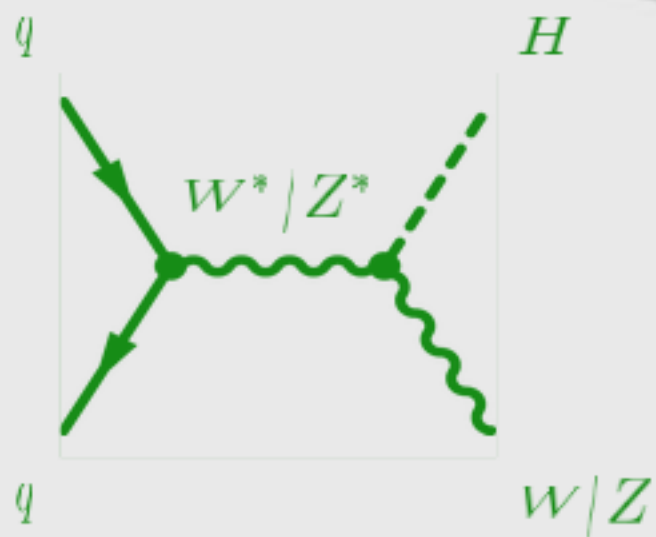
- ▶ Good distinction from SM background processes



Associated Production

$pp \rightarrow WH$

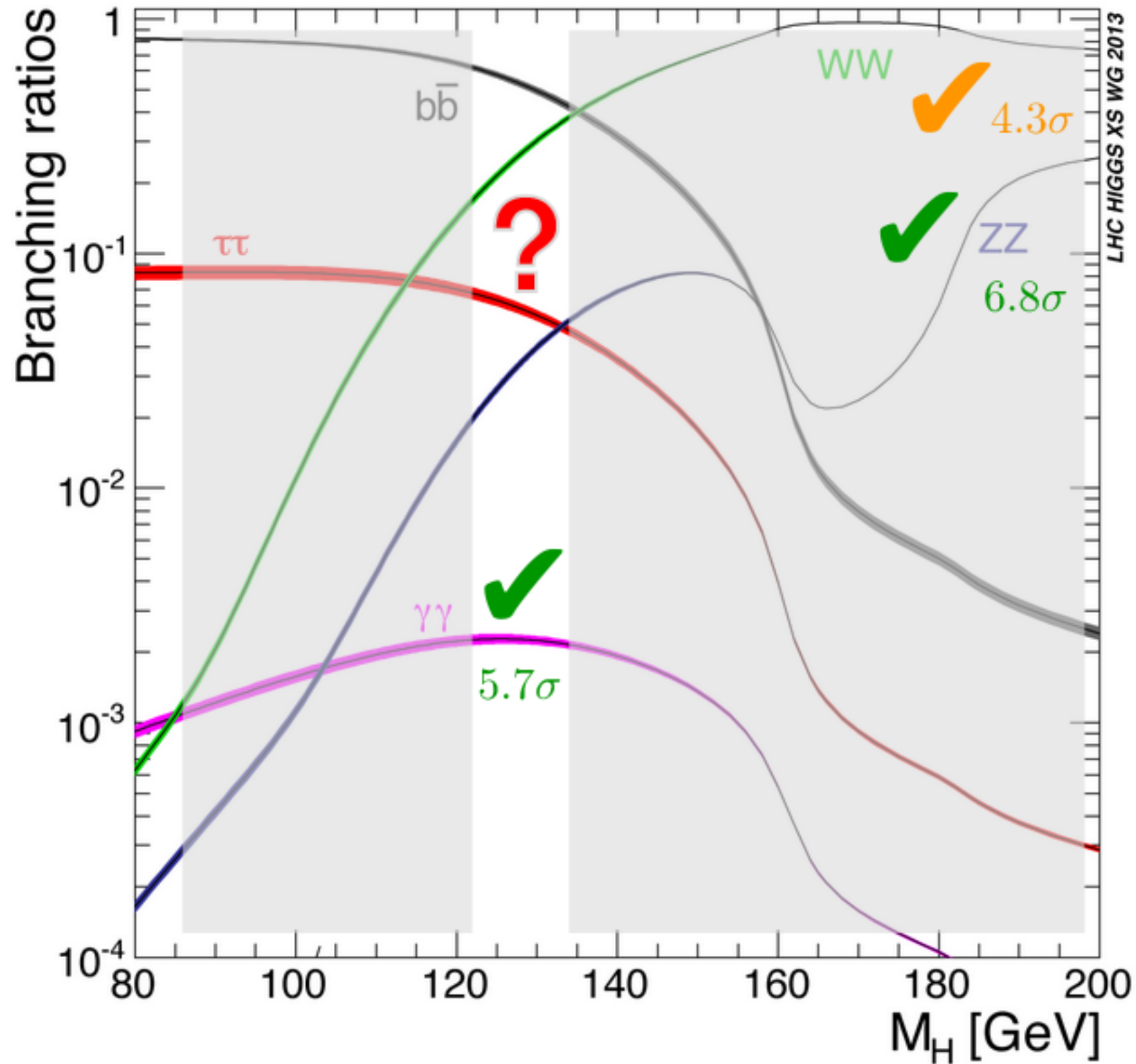
$pp \rightarrow ZH$



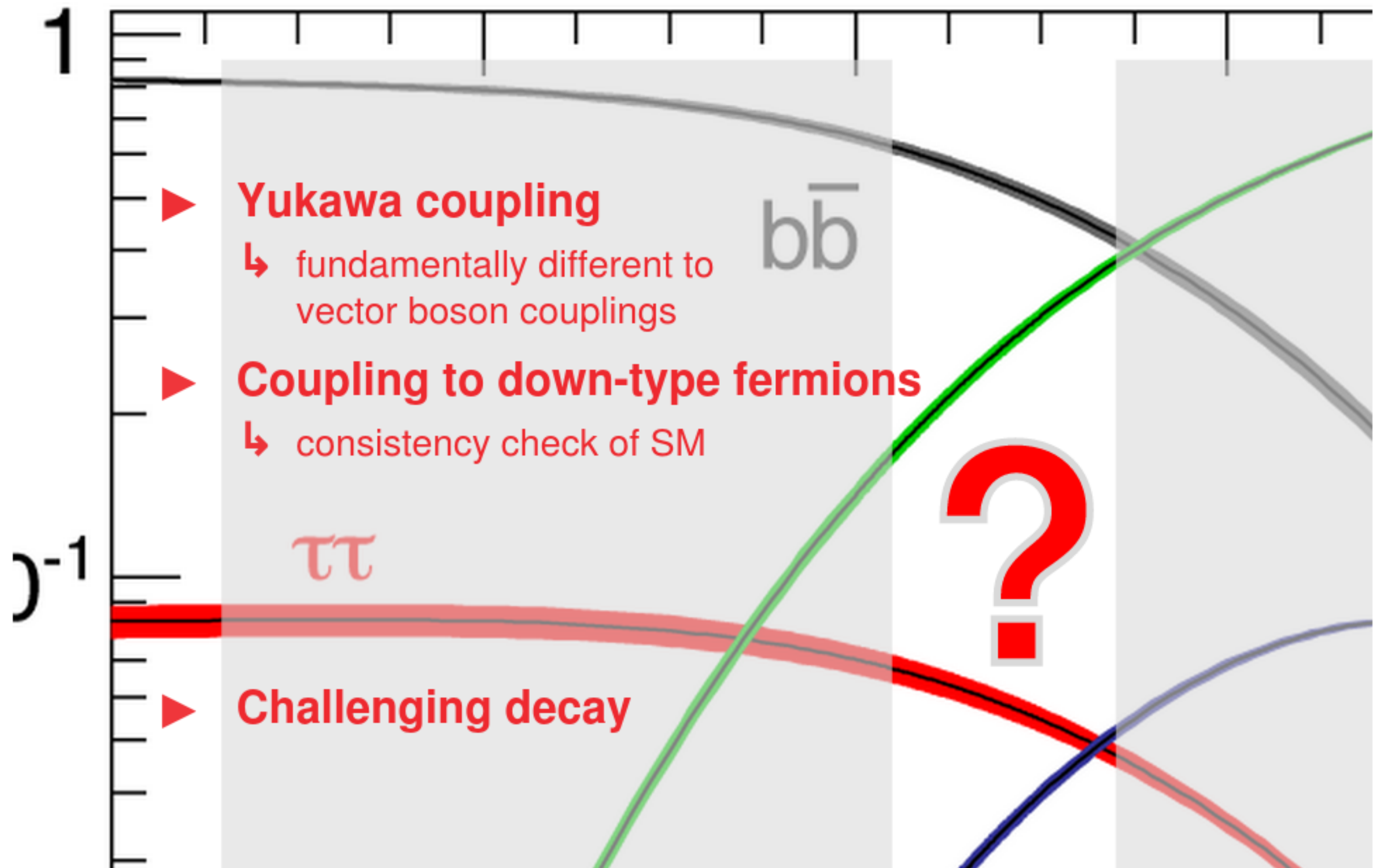
► Small cross section

Higgs Bosons at the LHC

Decay



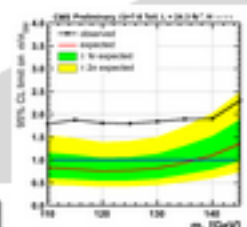
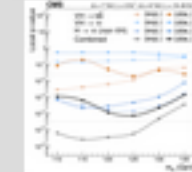
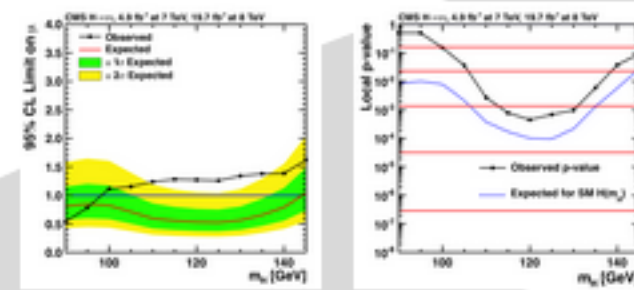
Higgs Bosons at the LHC



Timeline – Fermionic Higgs Decays

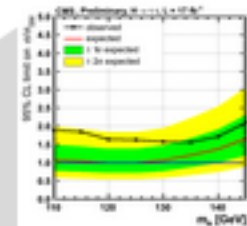
January 2014

Januar, 2014

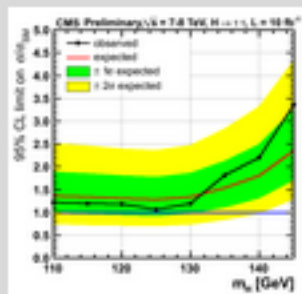


Moriond, March 2013

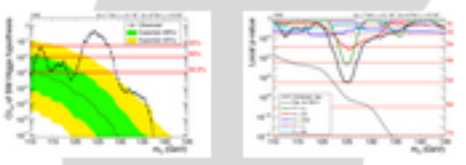
HCP, November 2012



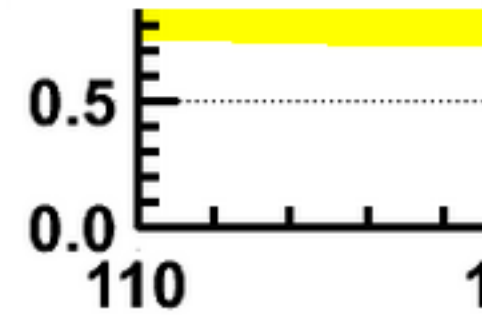
ICHEP, July 2012



July 4, 2012

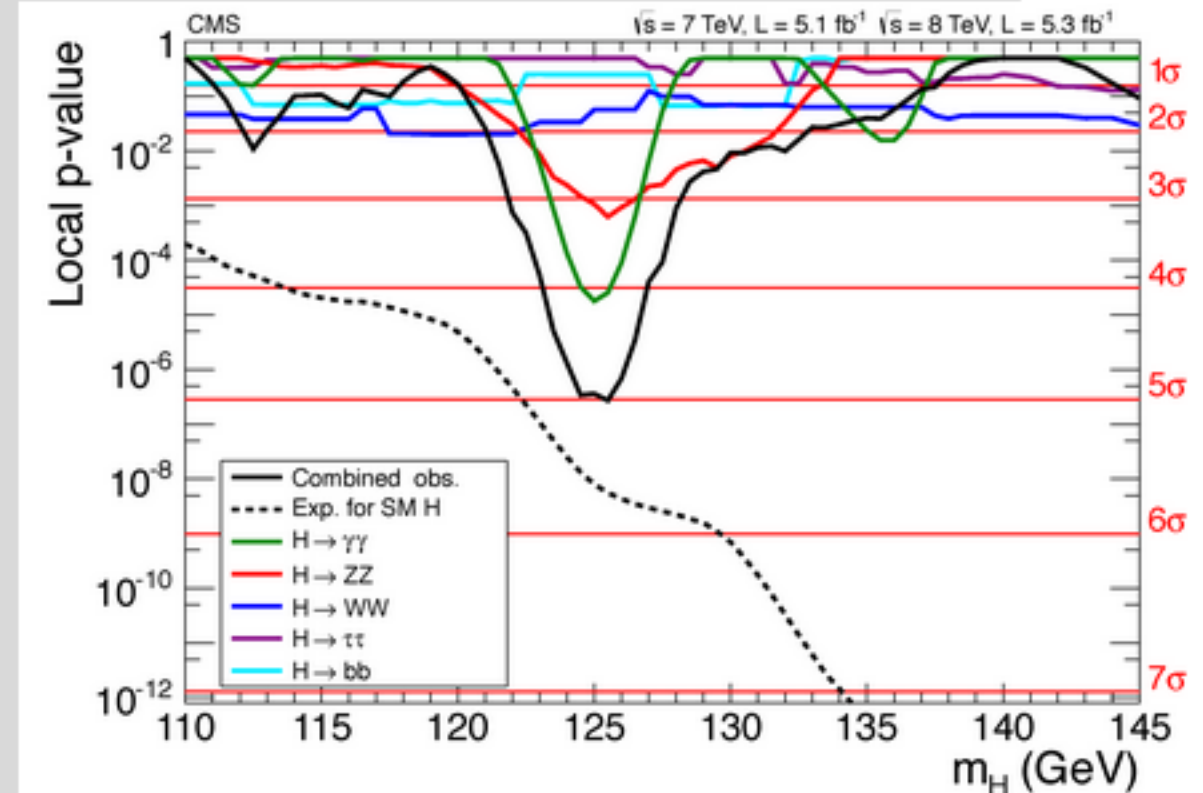
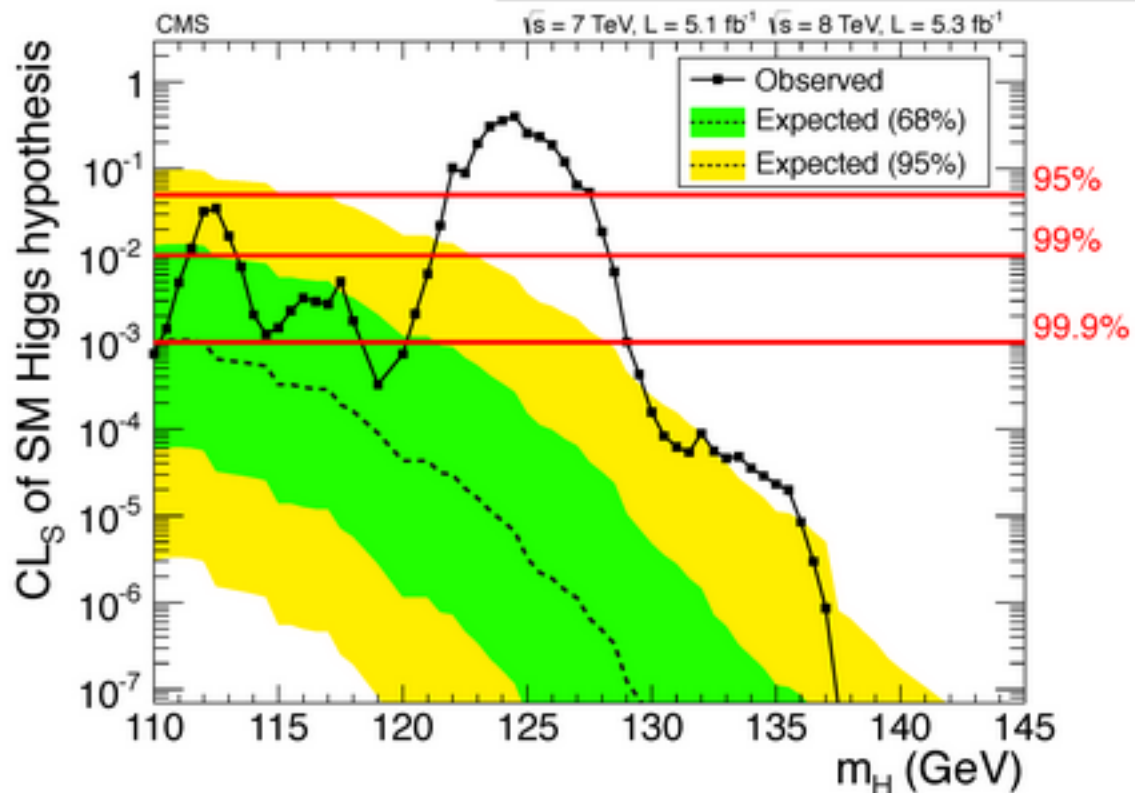


Timeline – Fermionic Higgs Decays



July 4, 2012

Observation of 125 GeV resonance

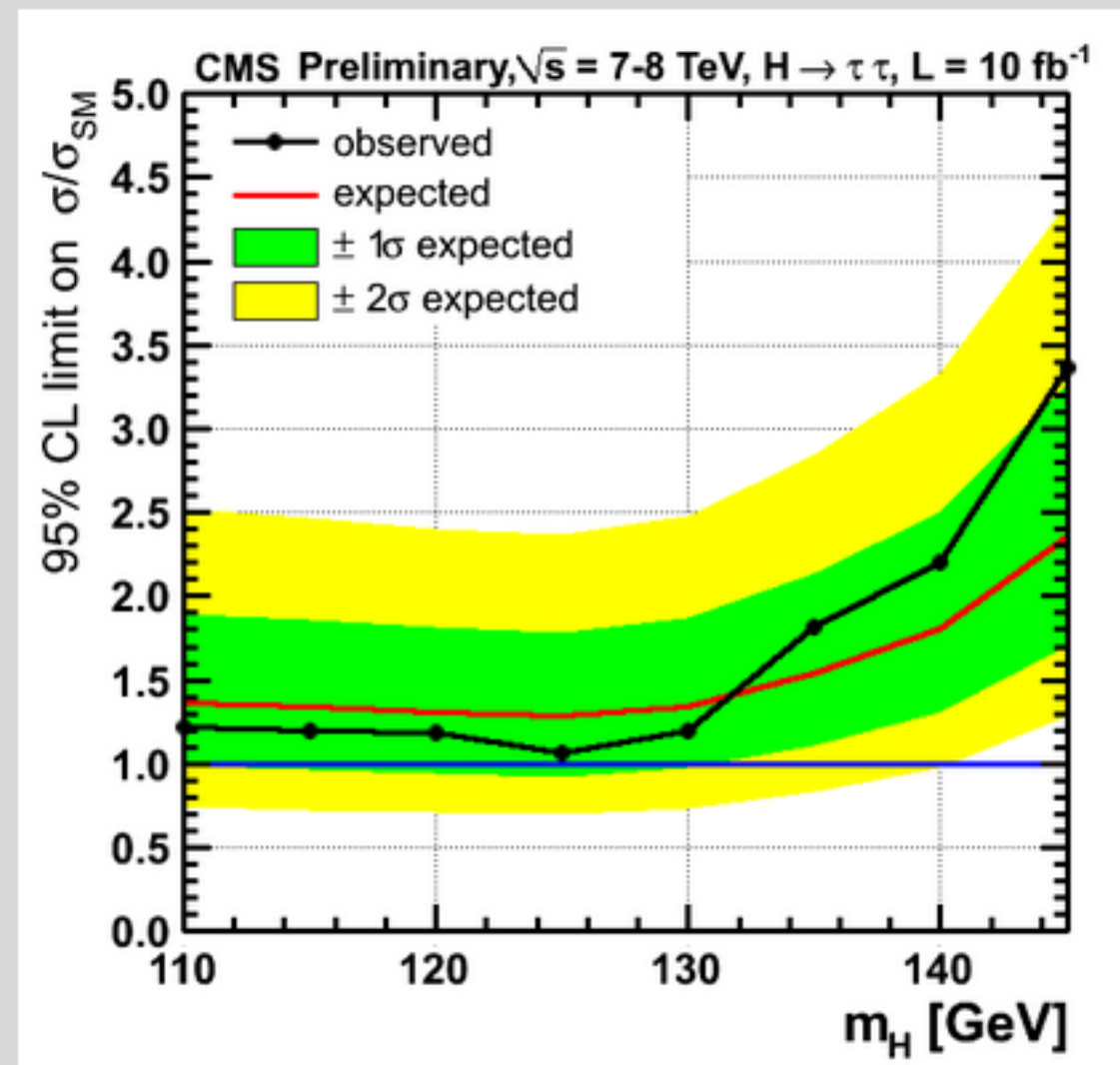


Timeline – Fermionic Higgs Decays

ICHEP, July 2012

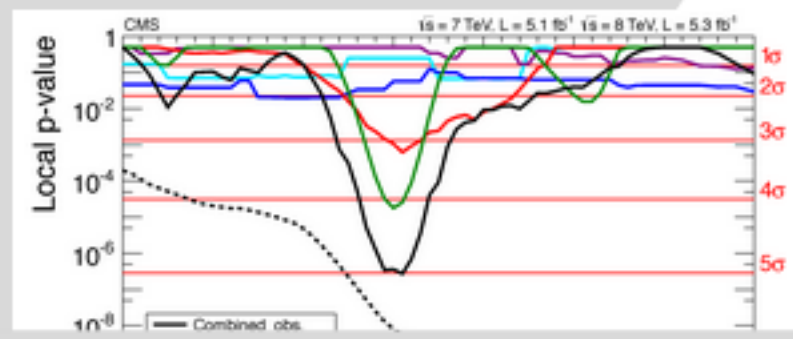
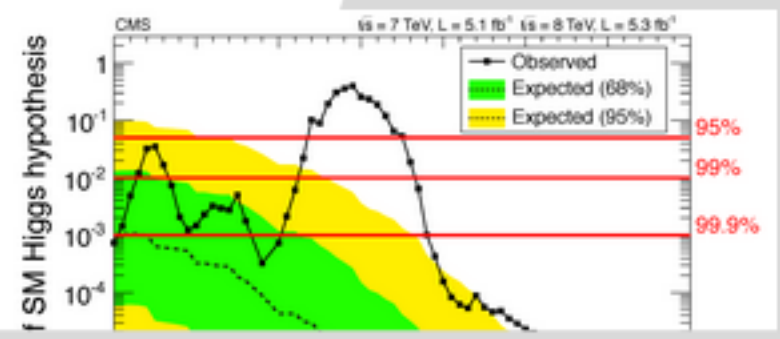
Data deficit in the $\tau\tau$ channel:

95% CL exclusion at 125 GeV of $\sigma BR(H \rightarrow \tau\tau) > 1.06 \sigma_{SM} BR$



July 4, 2012

Observation of 125 GeV resonance



Timeline – Fermionic Higgs Decays

Deviation from SM?
Hint at new physics?

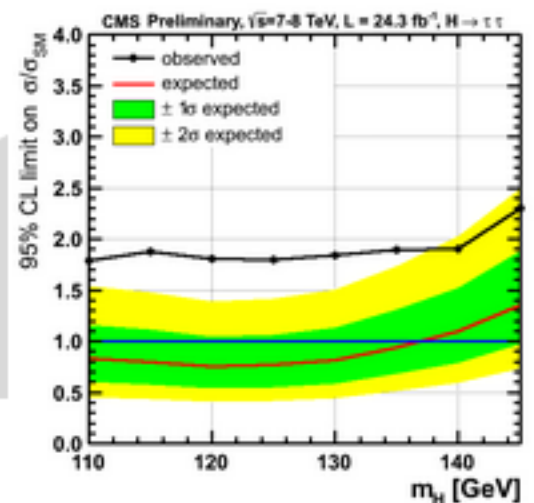
Four fermion generations?
Fermiophobic Higgs?

ICHEP, July 2012

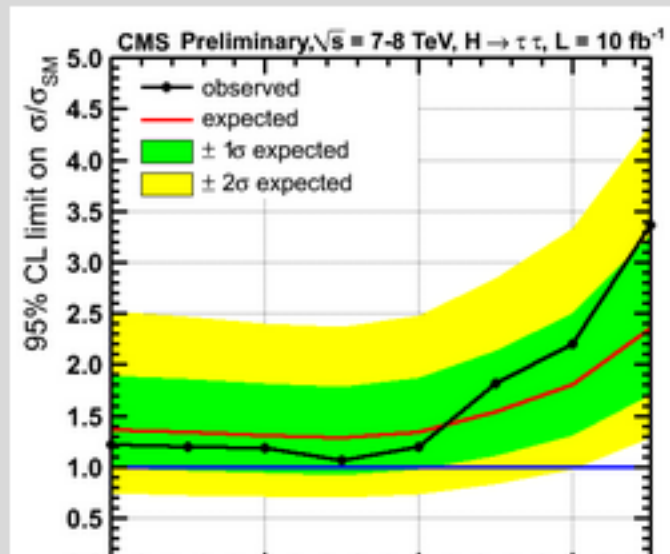
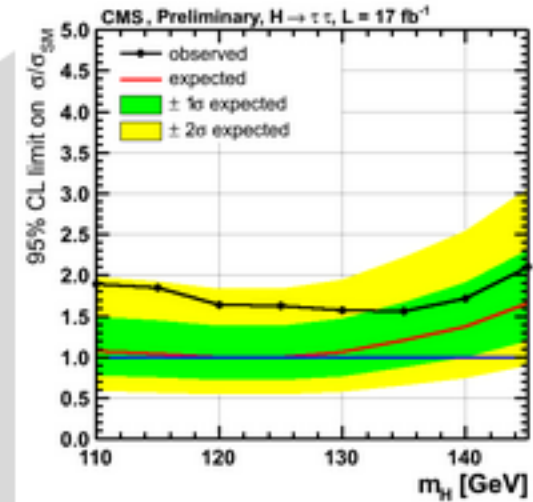
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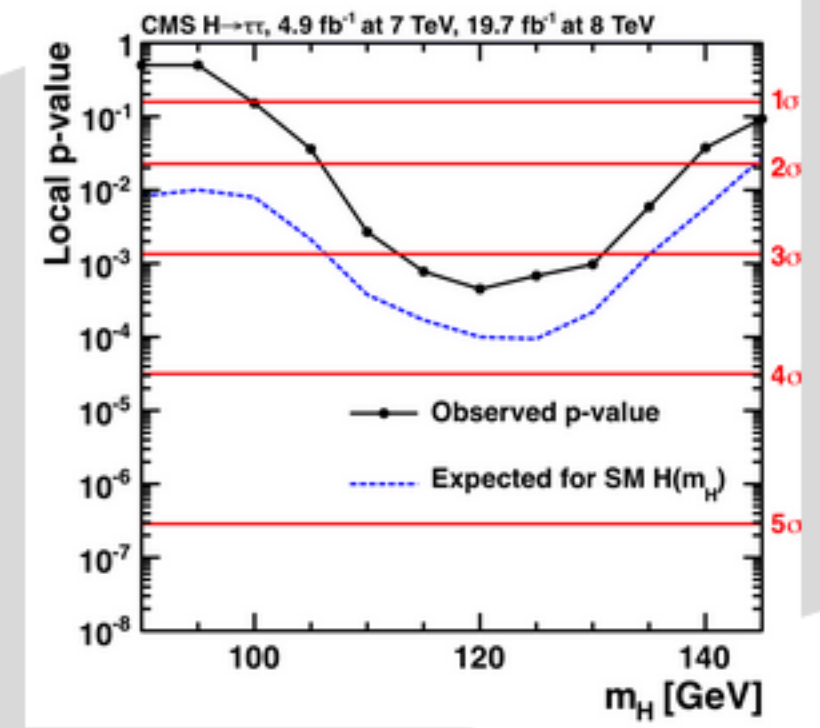
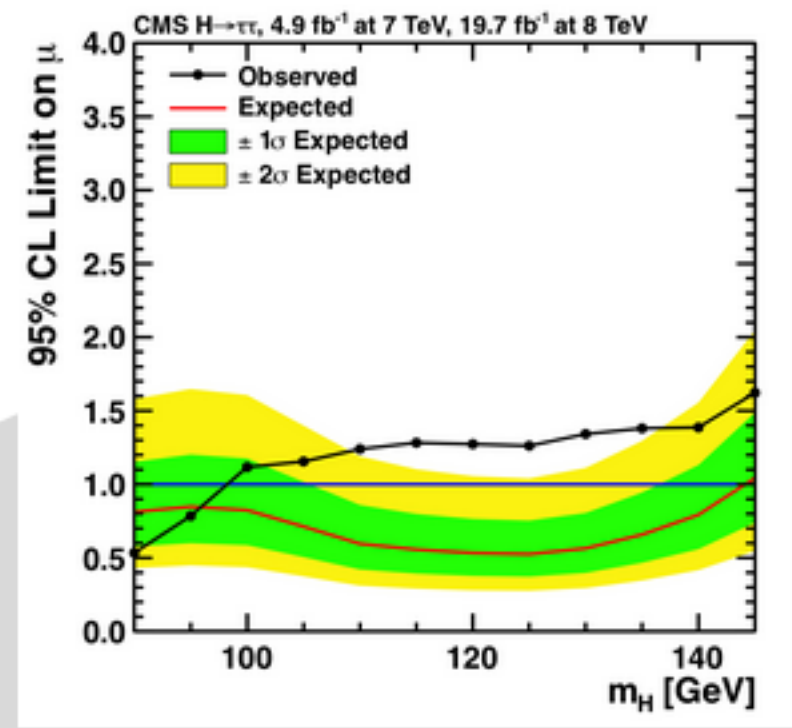
Moriond, March 2013



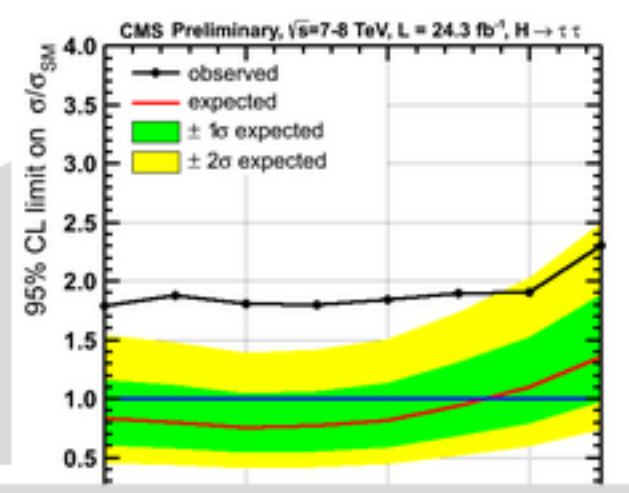
Timeline – Fermionic Higgs Decays

January 2014

Strong evidence for H(125) → ττ



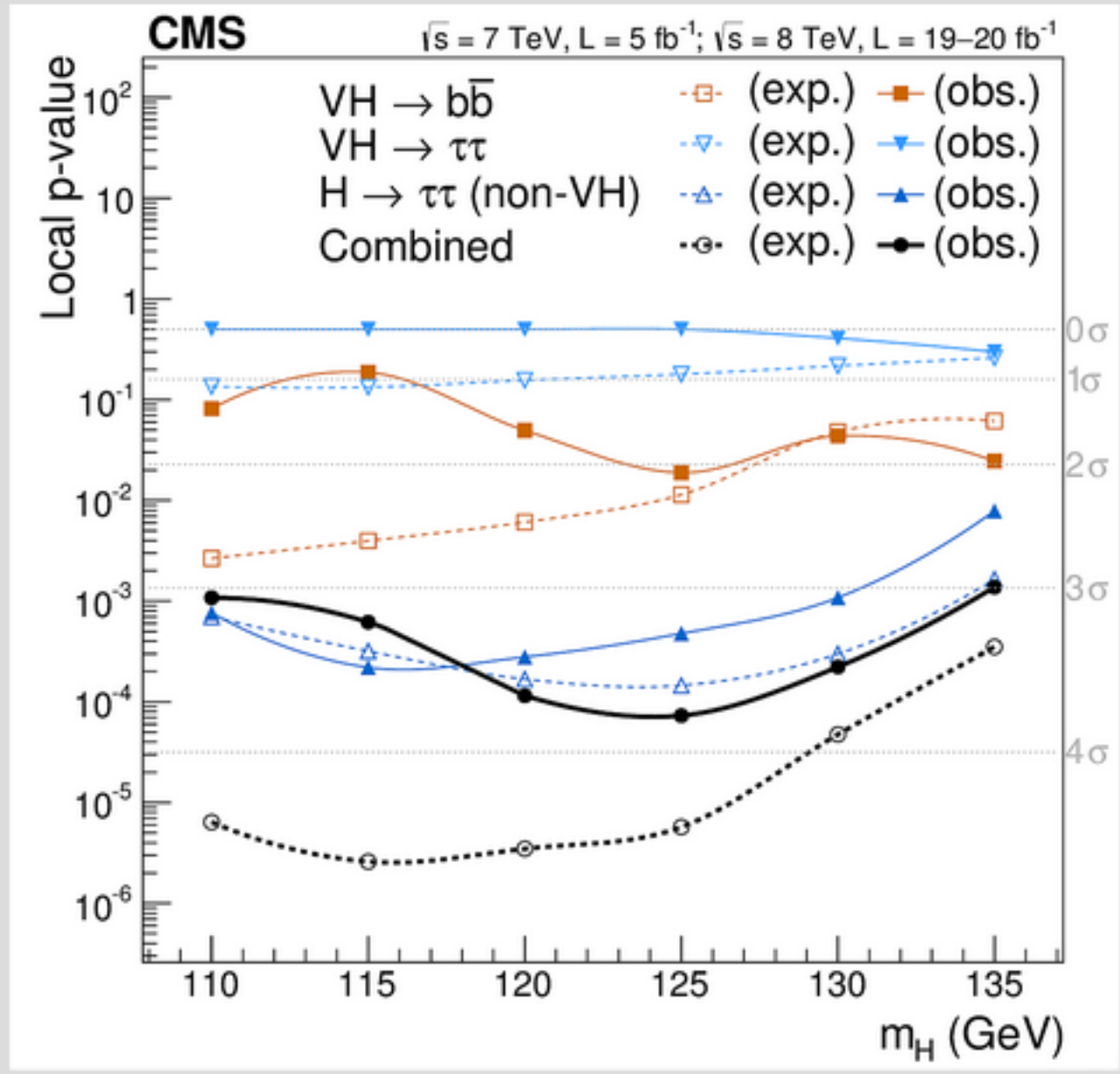
Significance of 3.2 σ
at 125 GeV

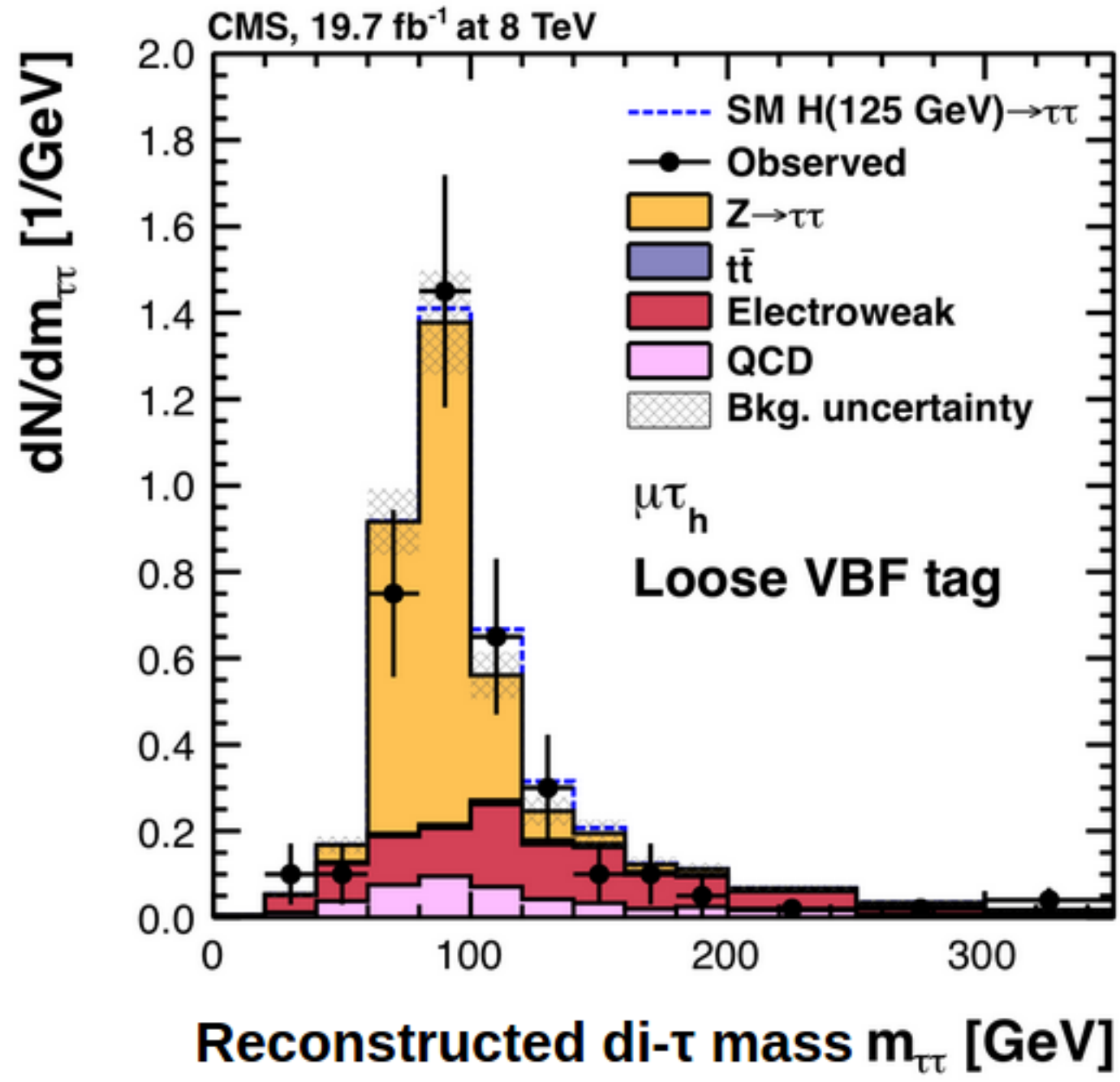


Januar, 2014

Combination with $H \rightarrow b\bar{b}$ shows:

Higgs couples to down-type fermions!





Observable

- ▶ Reconstructed di- τ mass
- ▶ Mass of visible decay products
 - ↳ WH channels
- ▶ Multivariate Discriminator (BDT)
 - ↳ ee and $\mu\mu$ channels

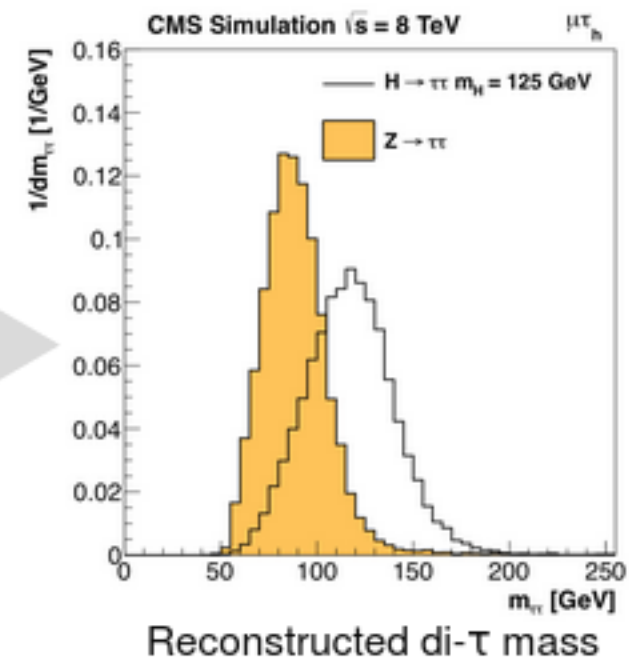
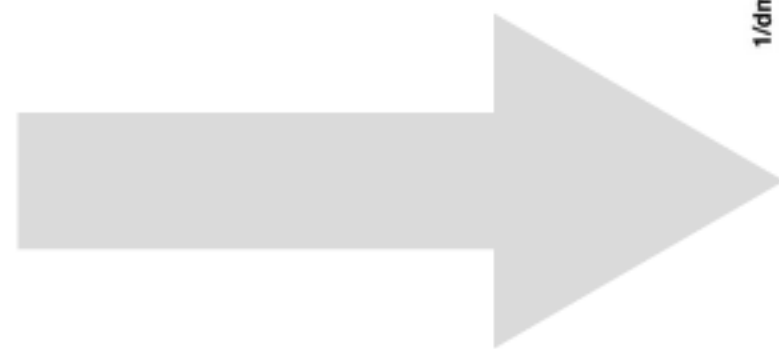
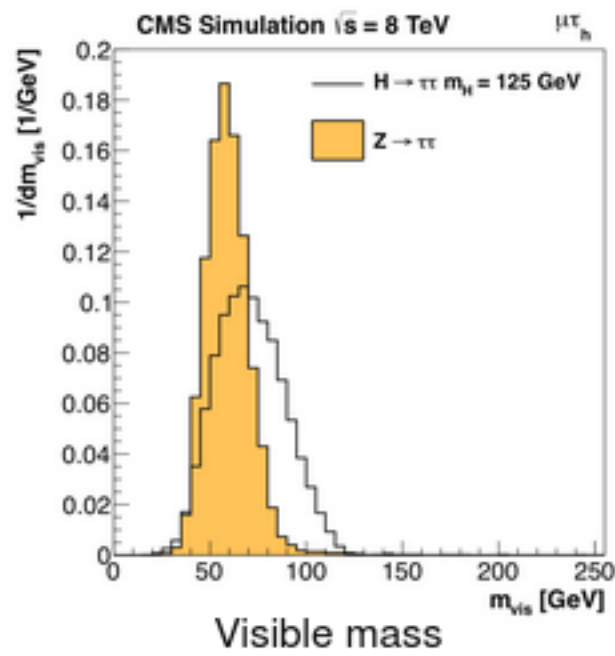
Reconstructed di- τ mass $m_{\tau\tau}$

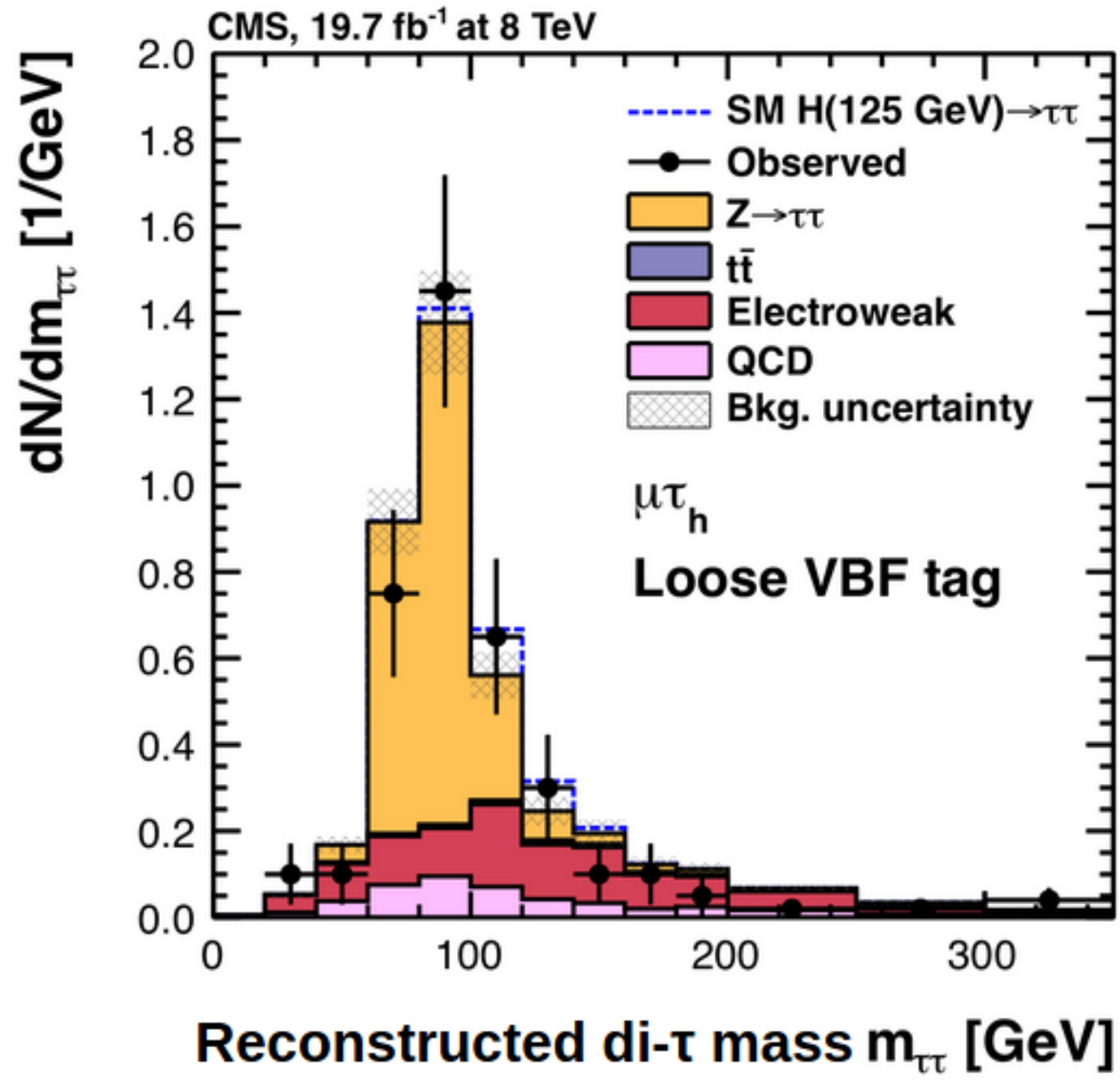
Likelihood maximation

Measured momenta of decay products

Phase space information from matrix element

Reconstructed missing transverse energy



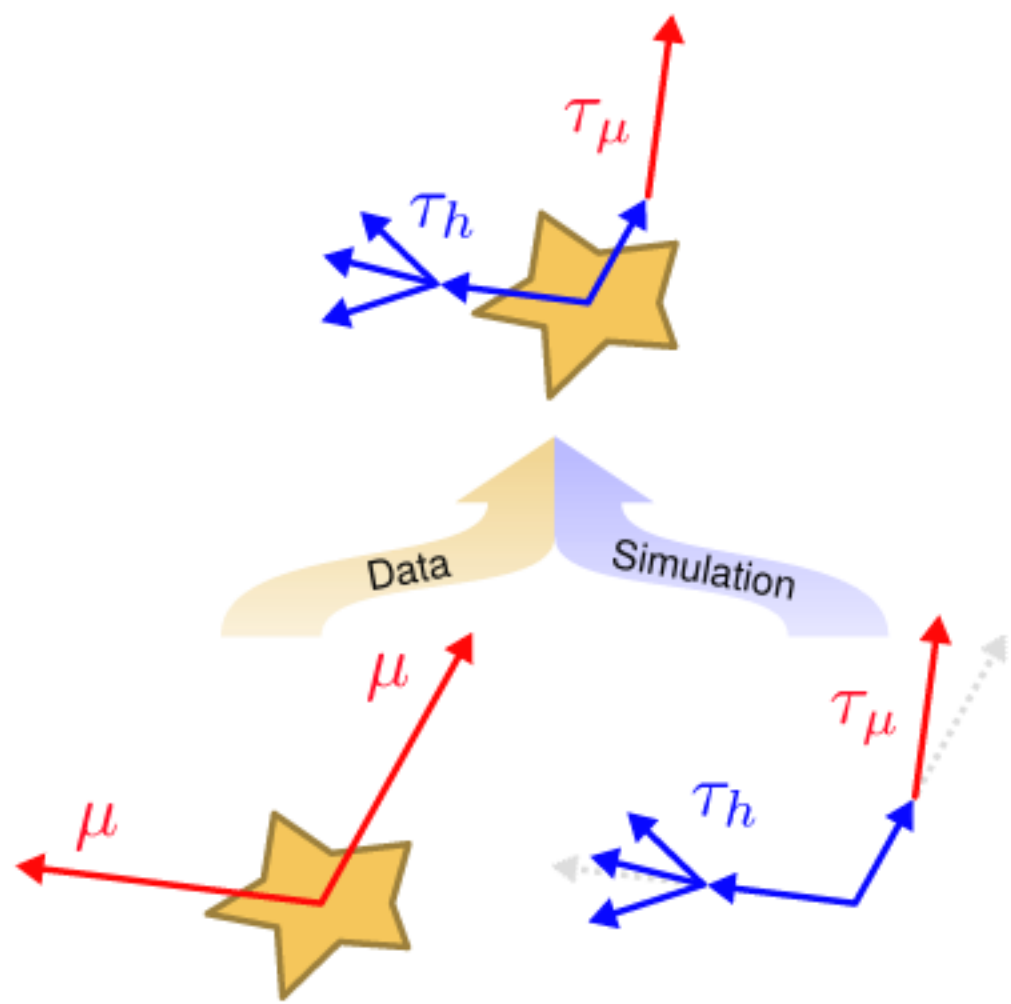


Observable

- ▶ Reconstructed di- τ mass
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Analysis Overview

$$Z \rightarrow \tau\tau$$



Main irreducible background

Data-driven estimation using **embedding technique**

$\mu\mu$ (data) \Rightarrow $\tau\tau$ (simulation)

Take pile-up and underlying event from data

Reduce systematic uncertainties

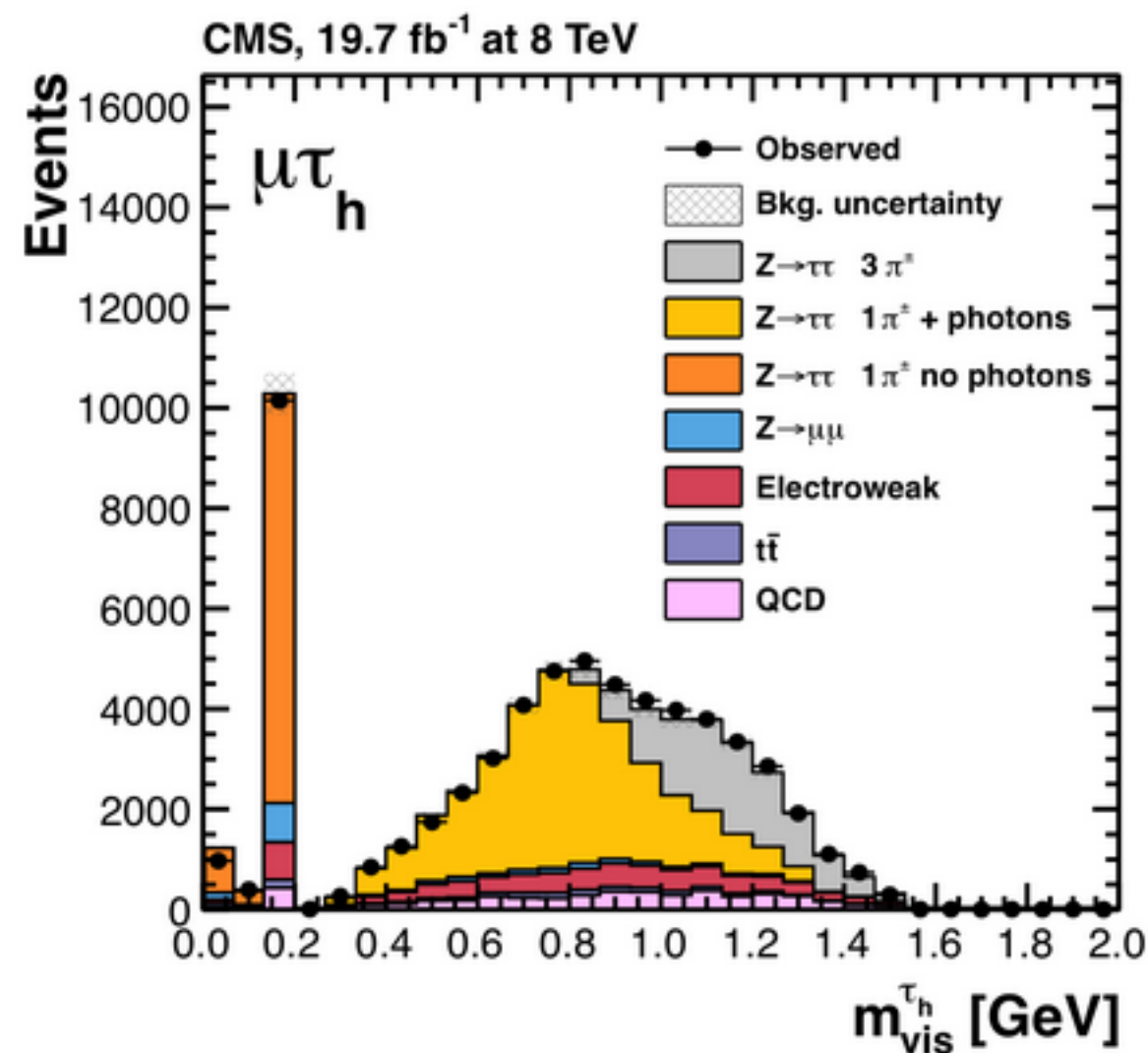
Systematic Uncertainties

- ▶ Experimental uncertainties affecting hadronically decaying taus
 - ↳ Tau energy scale derived from template fit of τ mass: 3% per τ (shape and normalisation)
 - ↳ Tau identification and trigger efficiency: 6-10% per τ (normalisation) 20-80% for misidentified taus

- ▶ Further experimental and theoretical uncertainties



Uncertainties treated as nuisance parameter in global fit



Event Categorisation

0 Jets

- ↳ Dominated by background
- ↳ Constrains systematic uncertainties affecting background contributions

1 Jet

- ↳ Higgs boson recoils against jet
- ↳ Improved resolution of missing transverse energy and mass

2 Jets, VBF tagged

- ↳ Jets characterised by large dijet mass and gap in η
- ↳ Low background expectation from SM processes

VH

- ↳ Additional W/Z in final state, required to decay leptonically
- ↳ Dedicated analysis

Gluon Fusion

VBF

All 6 $\tau\tau$ final states covered

Final State	Percentage
$\tau\tau$	42%
$e\mu$	6%
$\mu\mu$	3%
$e\tau$	3%
$\mu\tau$	23%
$e\tau$	23%

+ VH modes

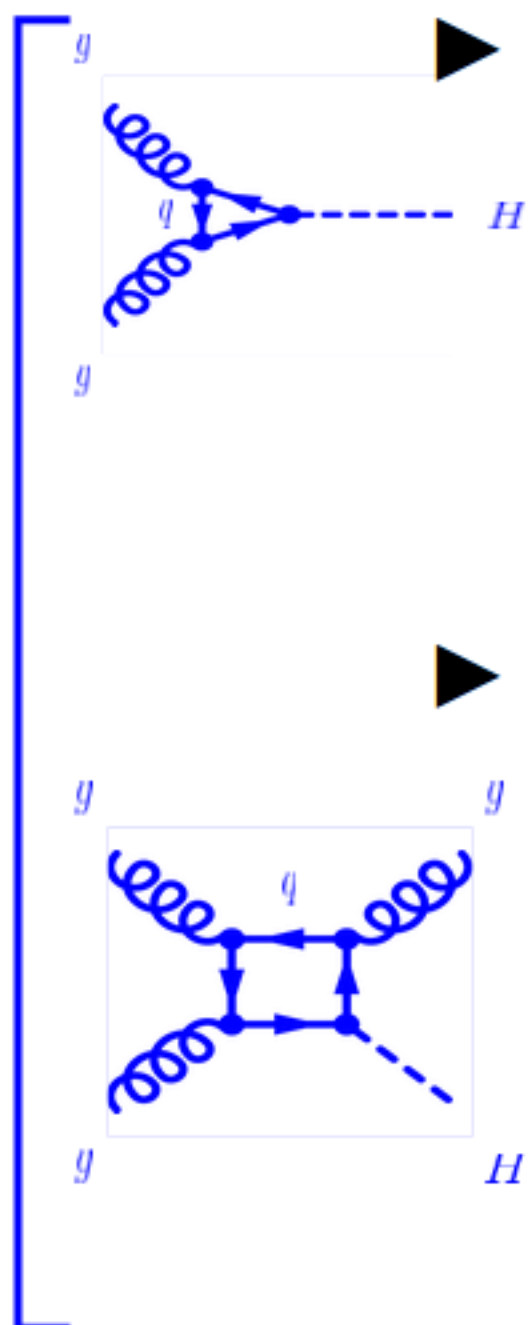
Further optimisation

- ↳ categorisation by lepton and di- τ p_T and di-jet quantities

~80 event categories

Event Categorisation

Gluon Fusion

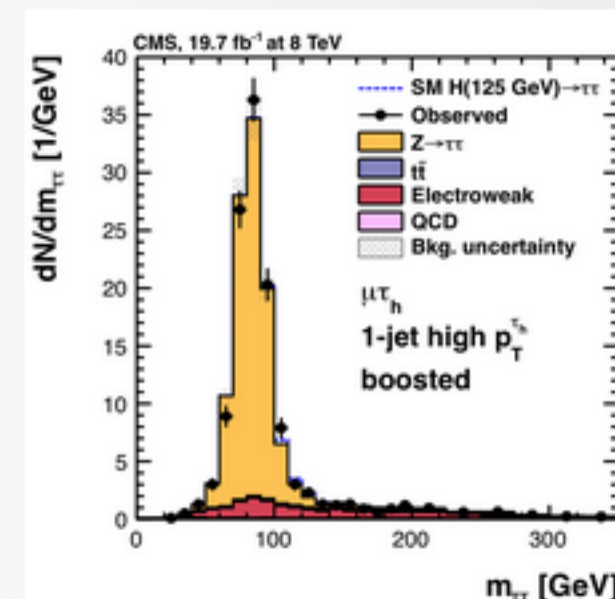
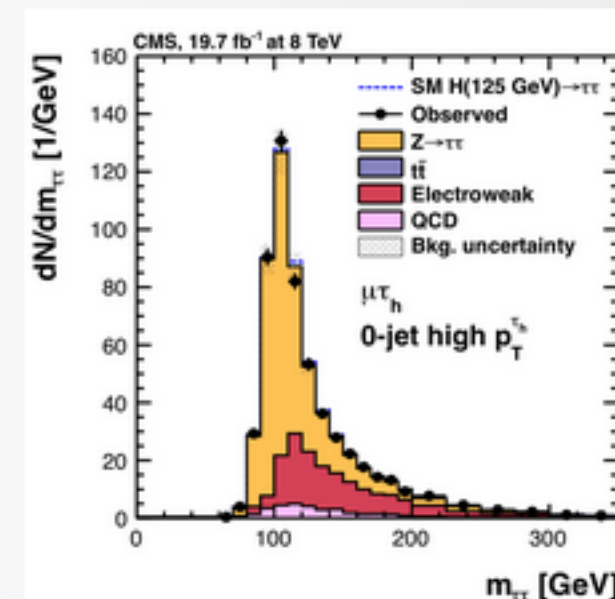


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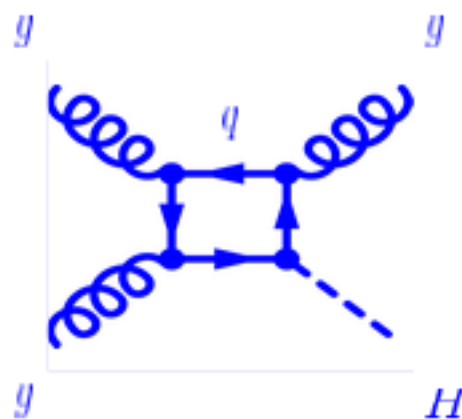
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Event Categorisation

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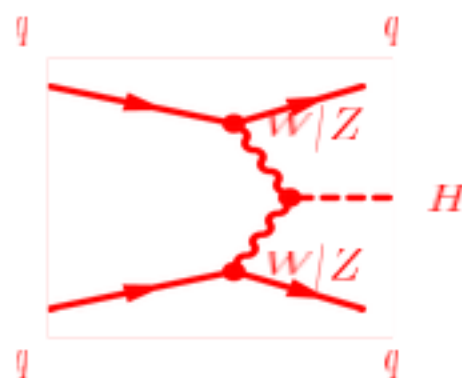
background contributions

1 Jet

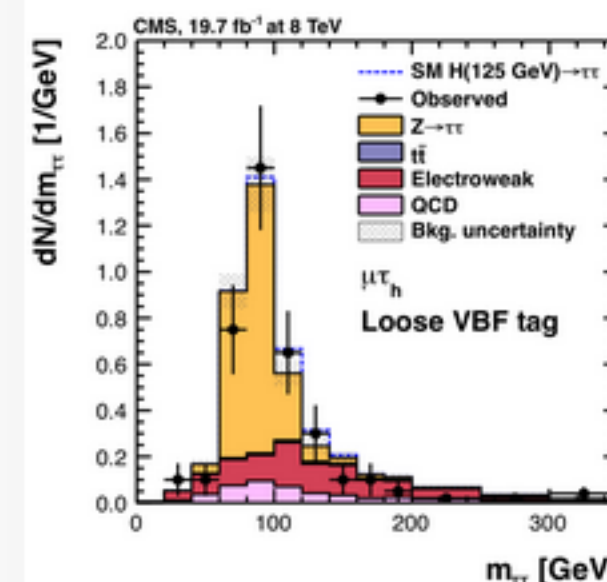
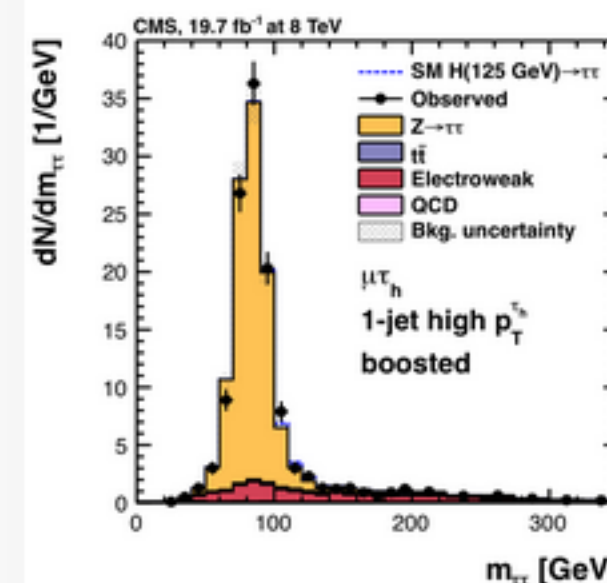
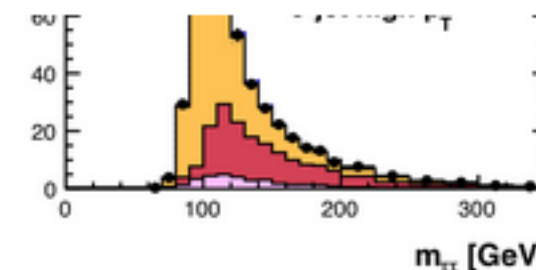
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2 Jets, VBF tagged

VBF

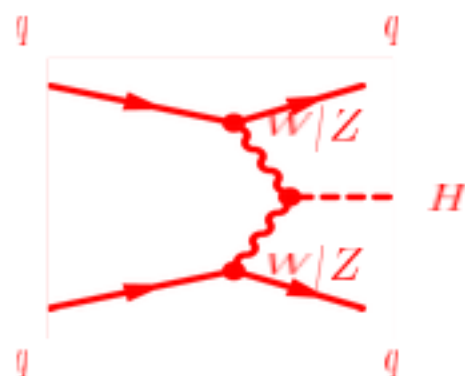


- ↳ Jets characterised by large dijet mass and gap in η
- ↳ Low background expectation from SM processes



Event Categorisation

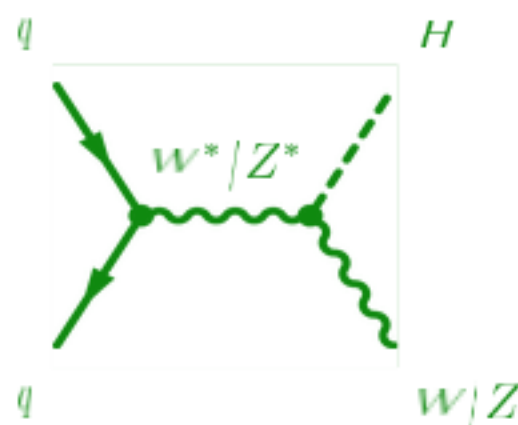
VBF



▶ 2 Jets, VBF tagged

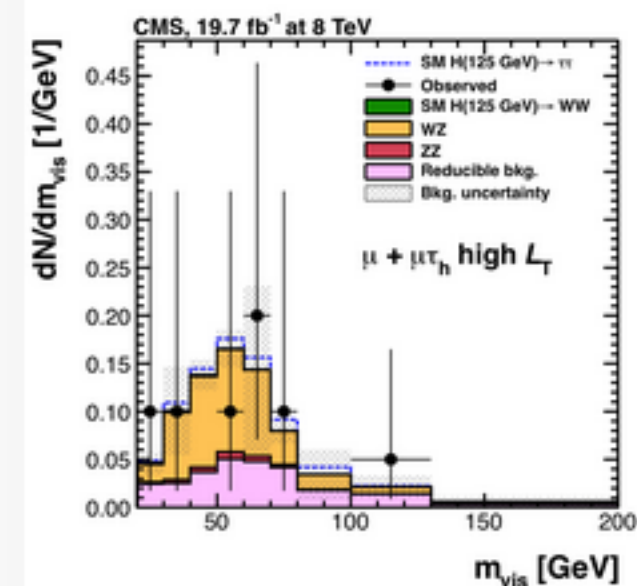
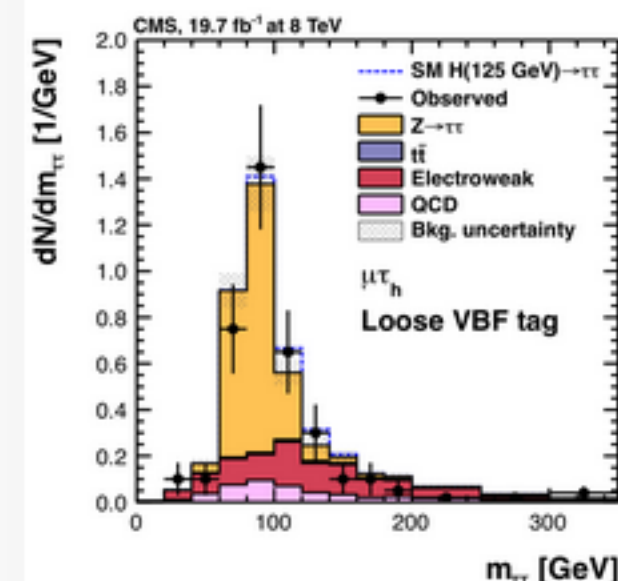
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VH

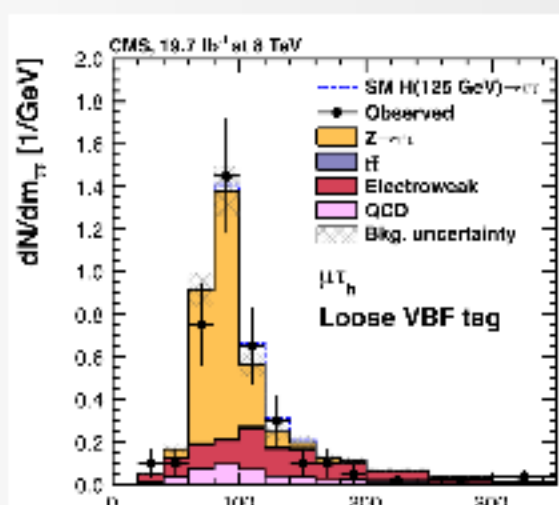
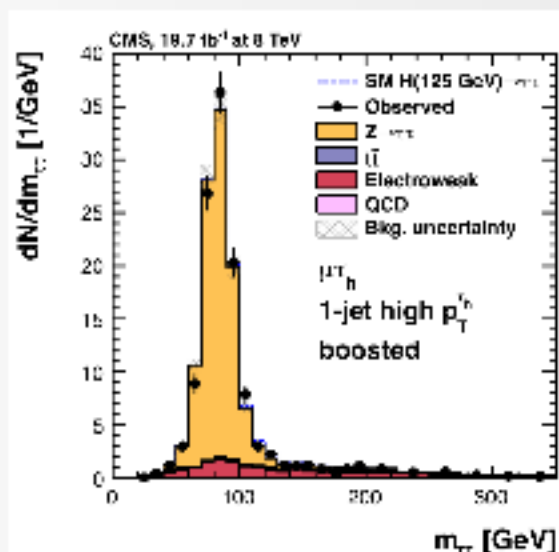
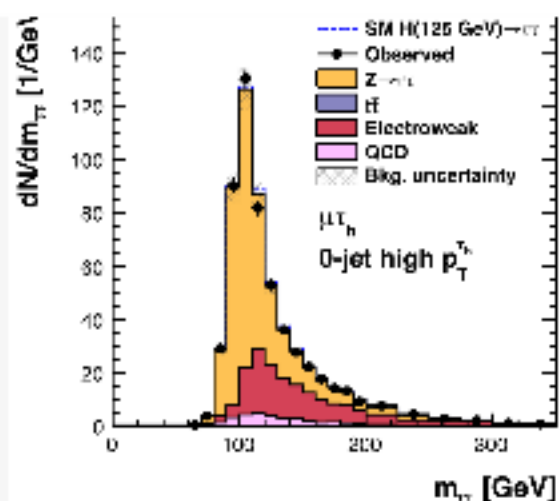


▶ VH

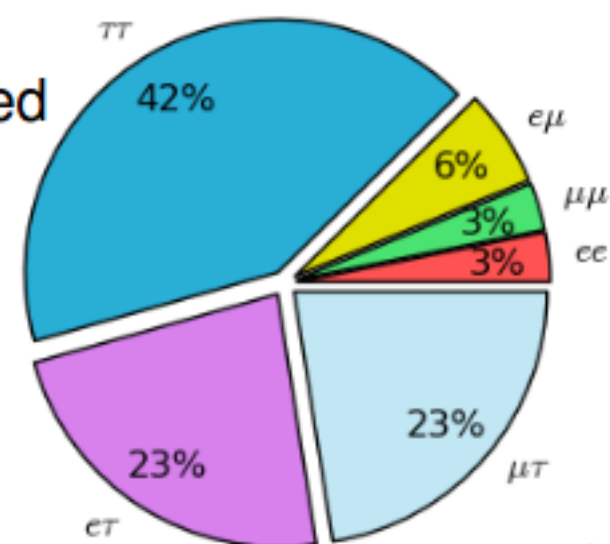
- ↳ Additional W/Z in final state, required to decay leptonically
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Event Categorisation



► All 6 $\tau\tau$ final states covered



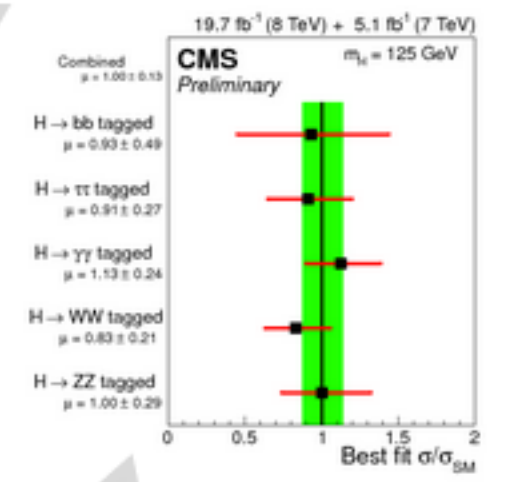
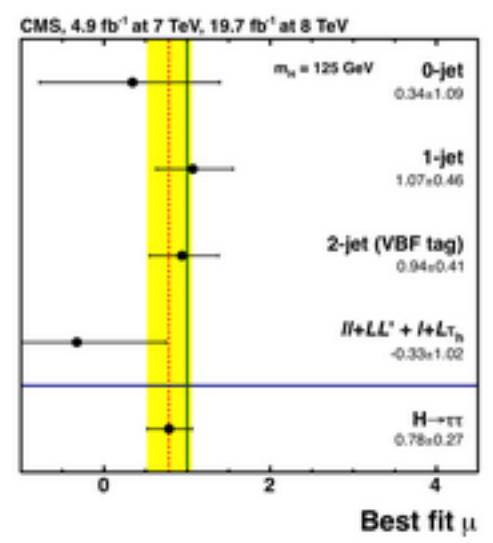
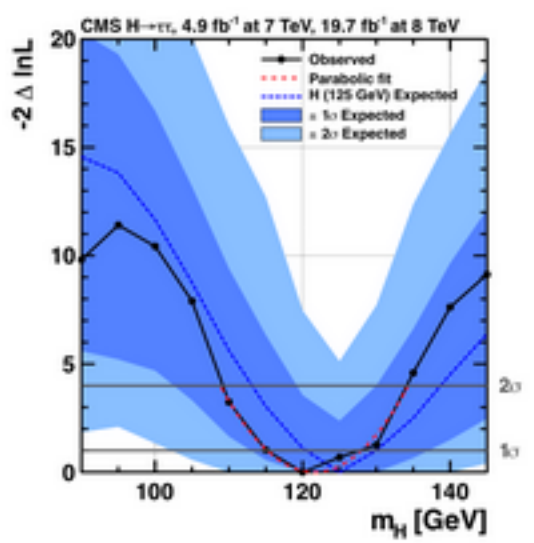
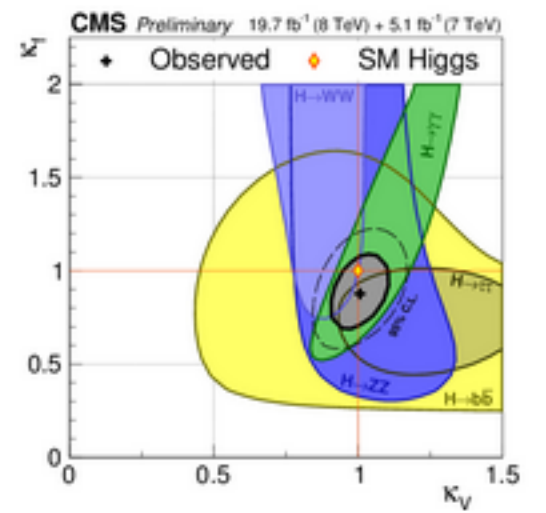
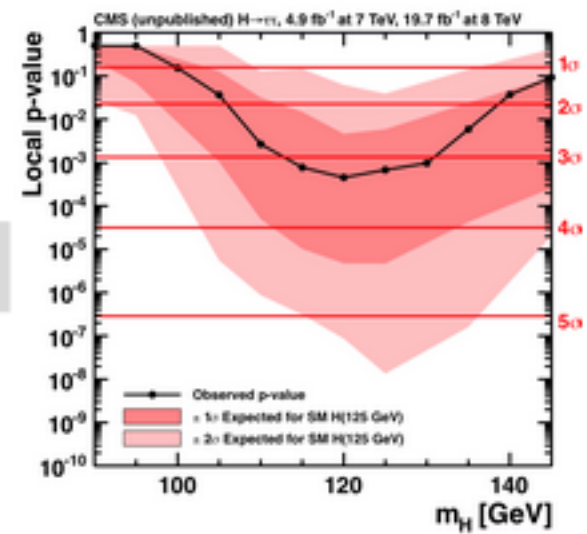
+ VH modes

► Further optimisation

↳ categorisation by lepton and di- τ p_T and di-jet quantities

~80 event categories

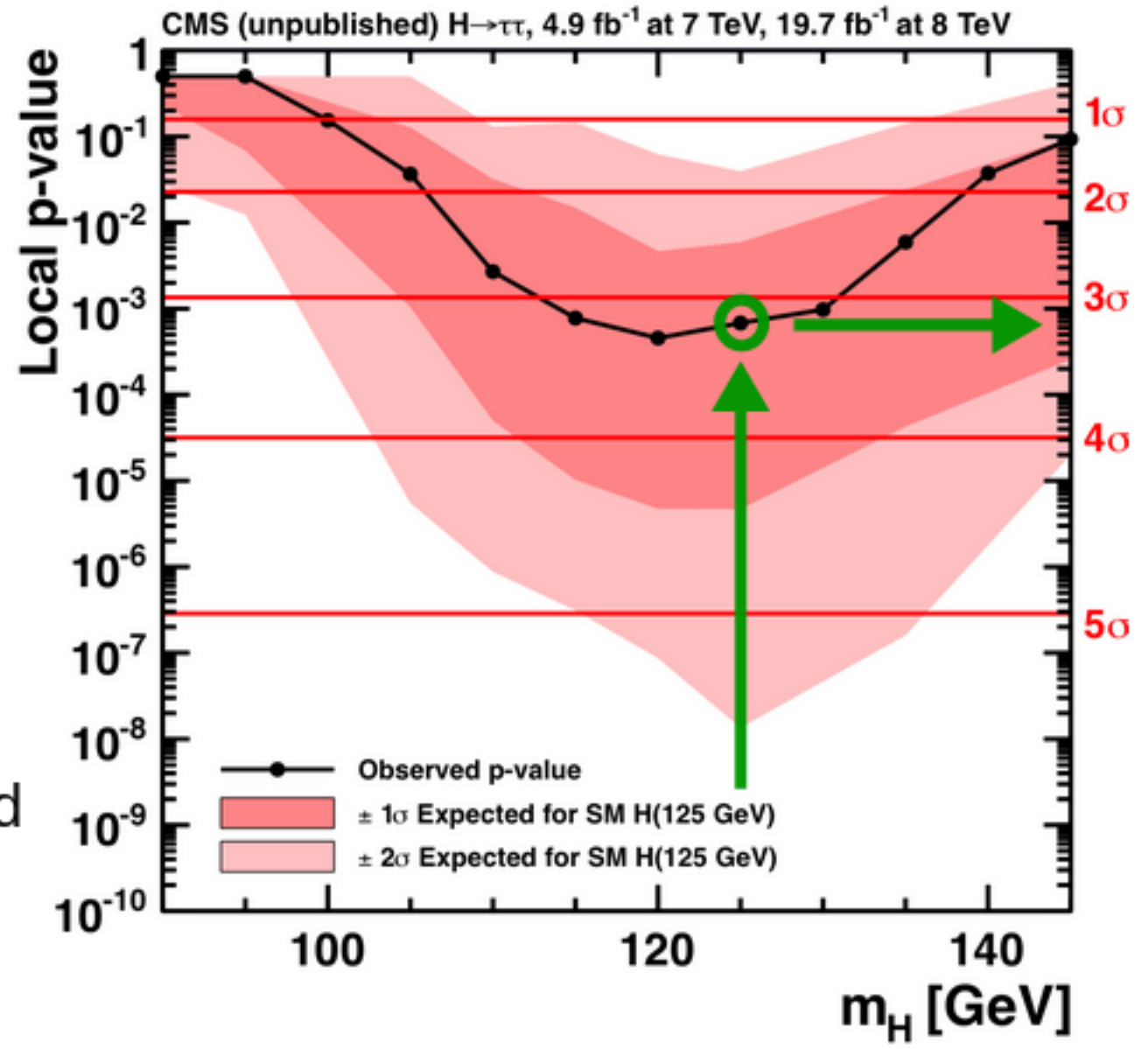
Statistical Inference – Results



Statistical Inference – Results

▶ 3.2 σ significance at 125 GeV

↳ compatible with SM expectation



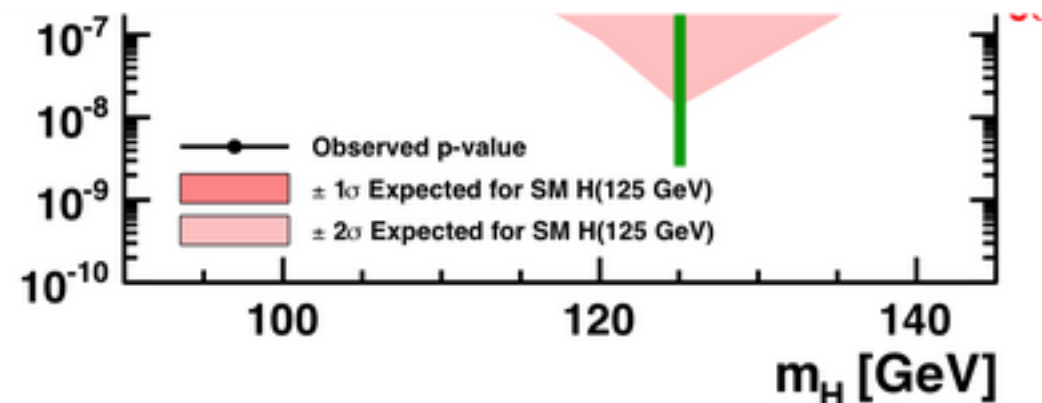
▶ Broad excess observed around 120 GeV

due to mass resolution of 10-20%

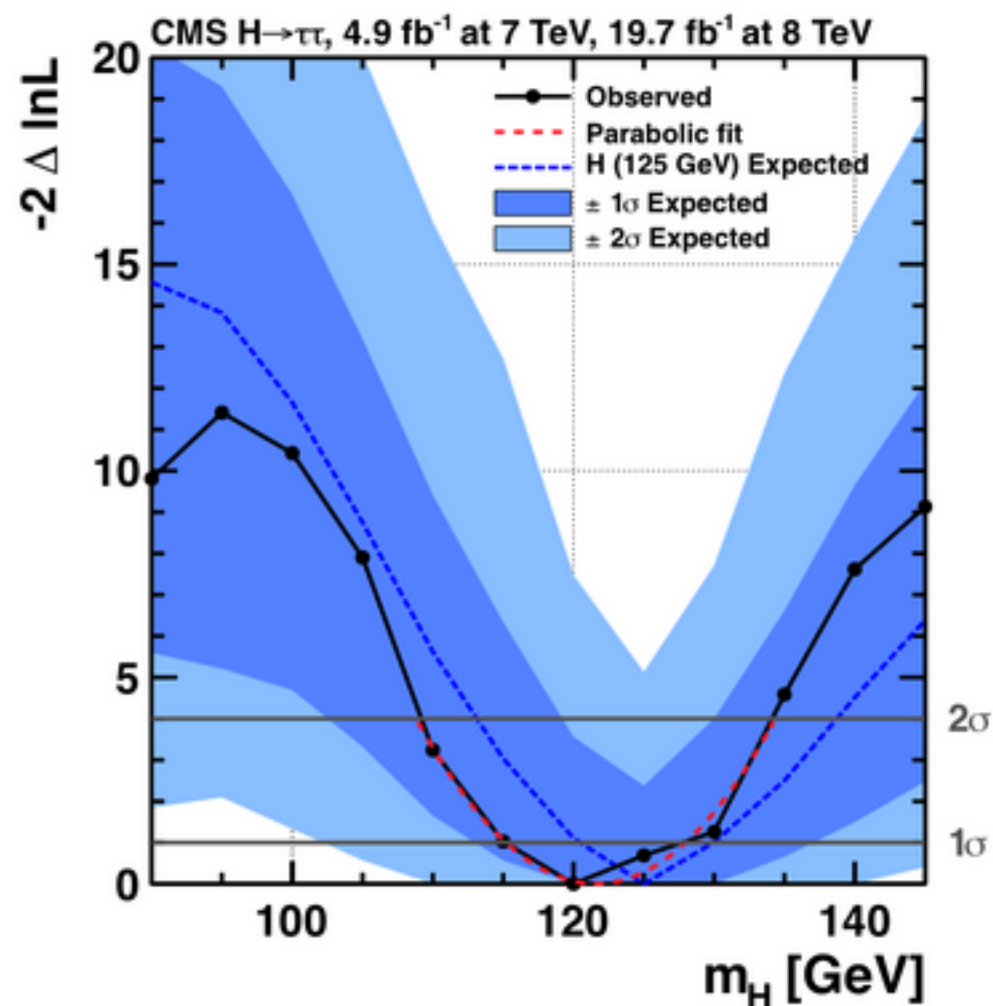
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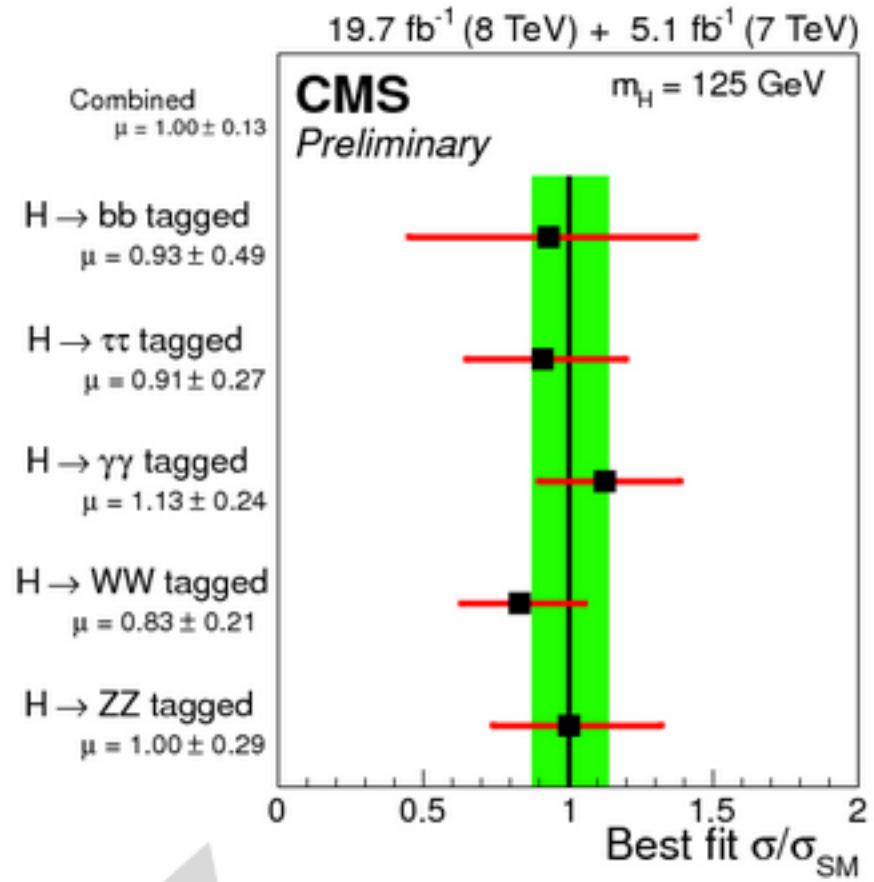
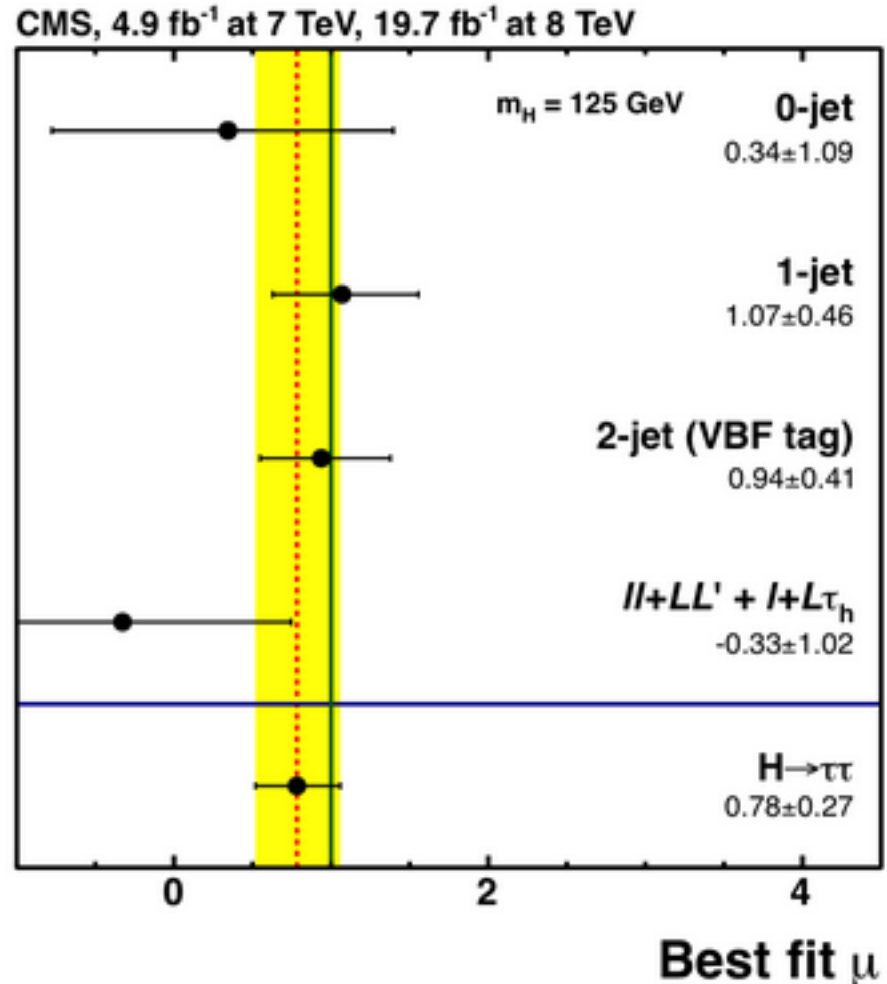
► Mass scan:
 $m_H = 122 \pm 7$ GeV

↳ compatible with result from
high precision channels

Statistical Inference – Results

- ▶ Signal strength $\mu = 0.78 \pm 0.27$
- ↳ compatible with SM expectation ($\mu=1$)

largest sensitivity



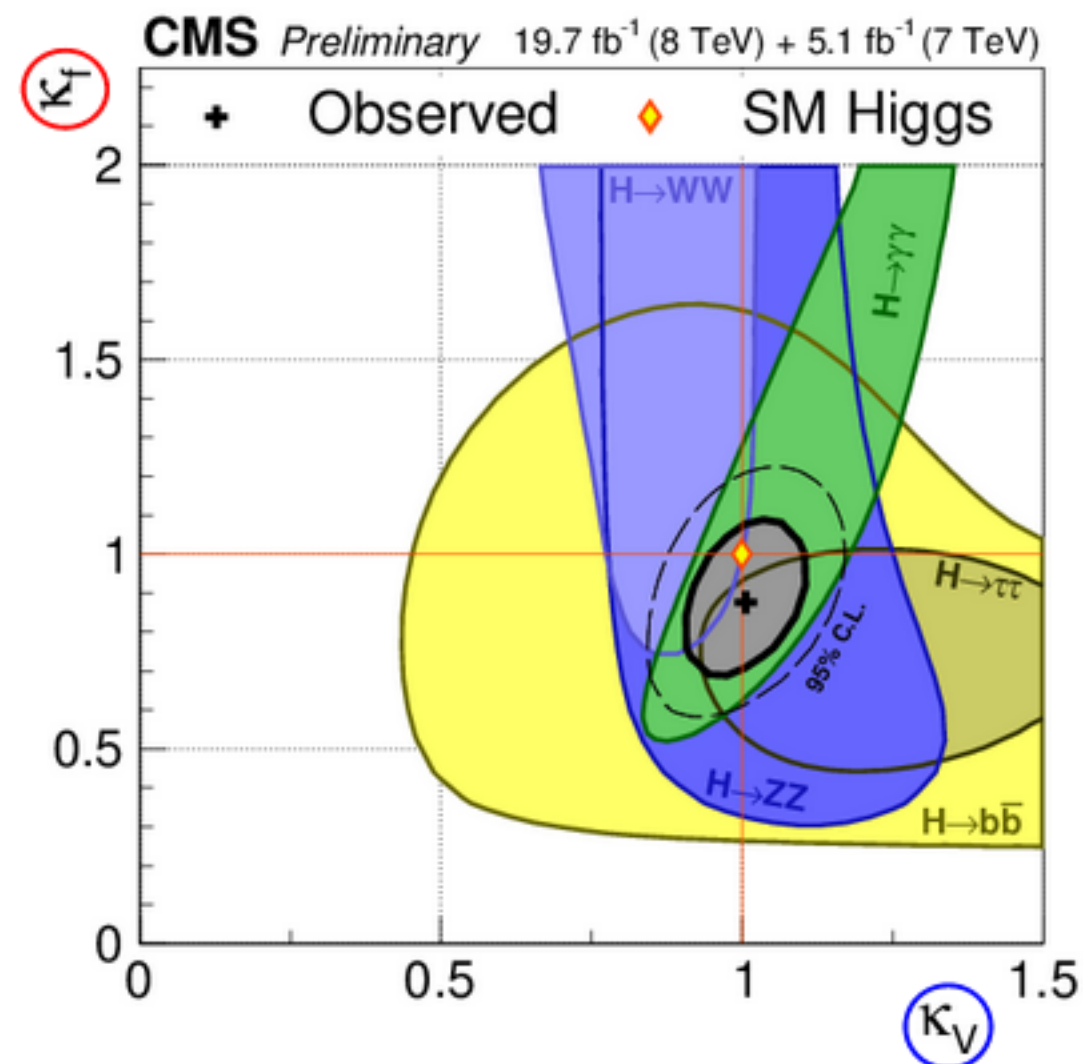
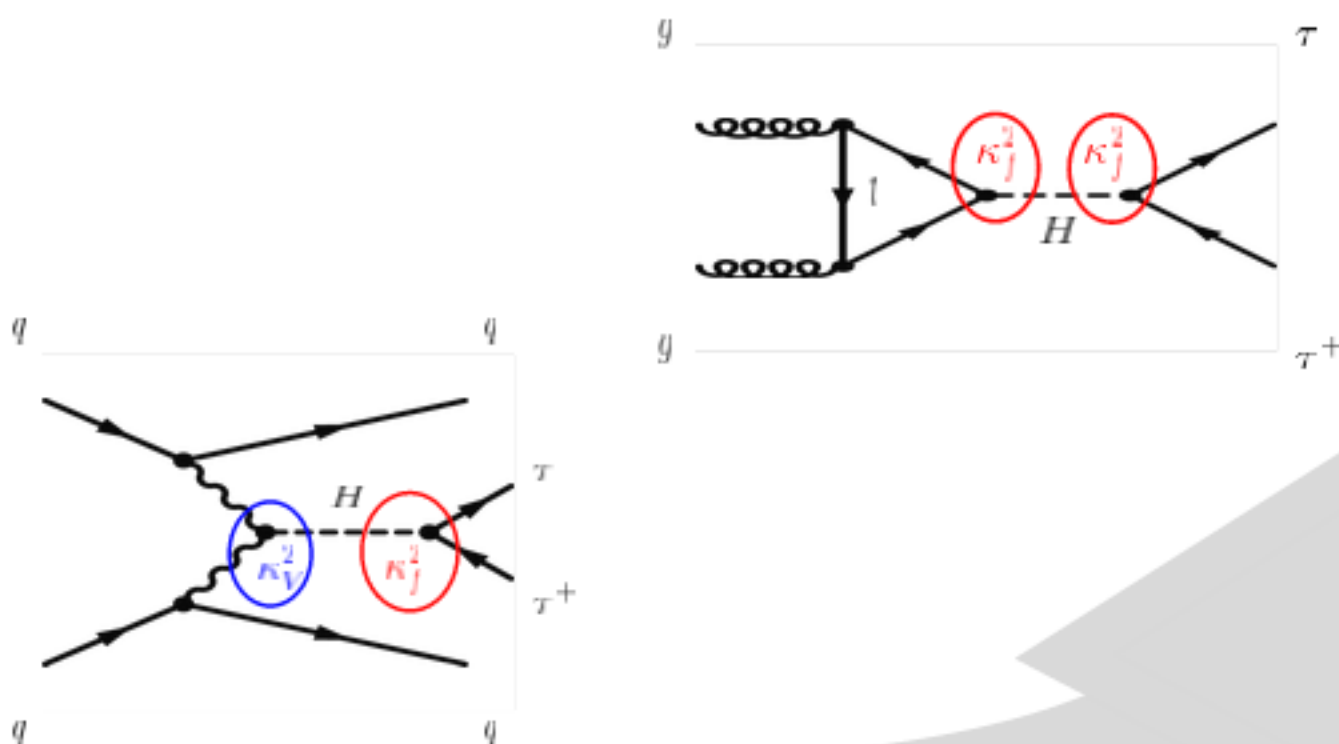
VH

▶ Higgs boson couples to mass

Statistical Inference – Results

► Fermionic coupling measured up to 30%

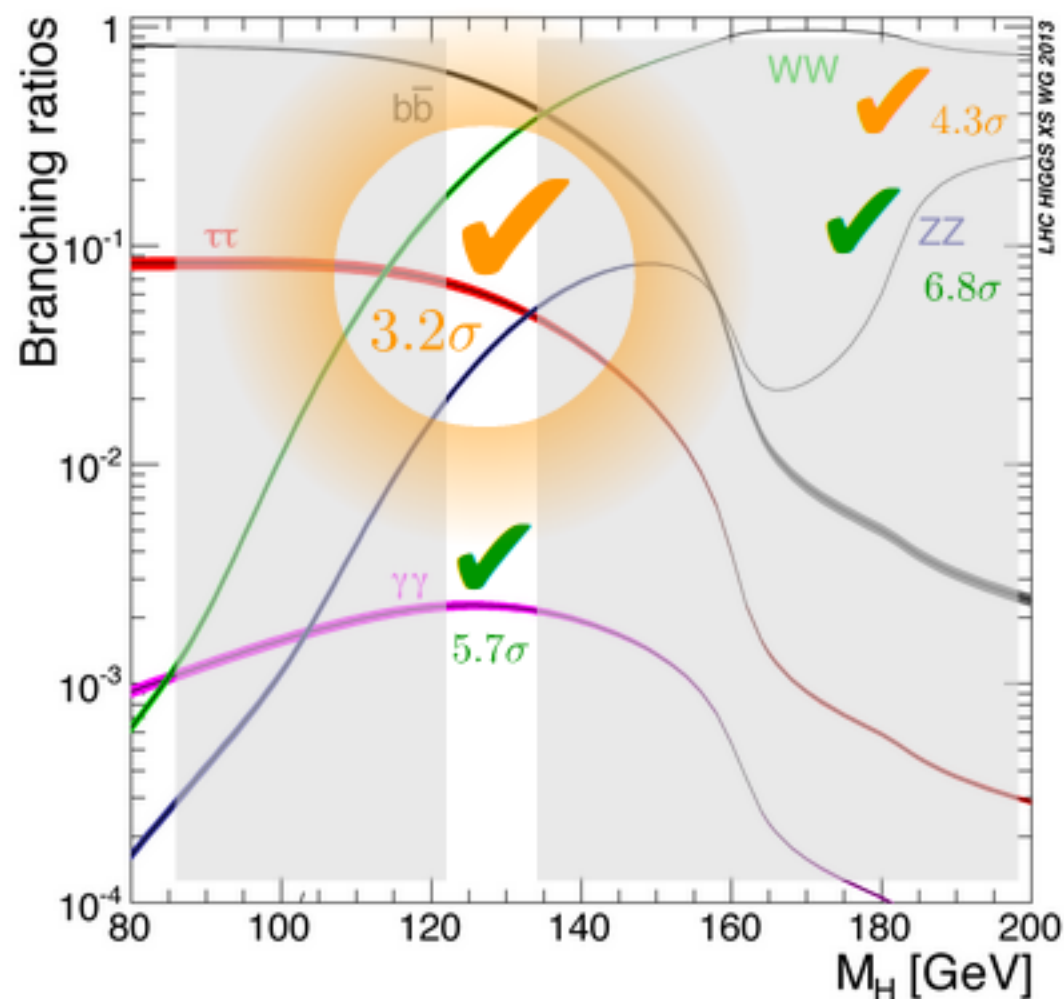
↳ compatible with SM expectation



► Fermionic coupling mainly constrained by $H \rightarrow \tau\tau$ analysis

Summary and Outlook

- ▶ CMS $H \rightarrow \tau\tau$ analysis performed on full dataset from first data-taking period at the LHC
 - ↳ Published: Journal of High Energy Physics 05 (2014) 104
- ▶ Evidence for Higgs bosons decaying into τ leptons
- ▶ All measurements compatible with the SM expectation within their uncertainties



▶ Open questions:

- ↳ Observation in next data-taking period
- ↳ Is there more than one Higgs boson?
- ↳ Small deviations from SM in couplings?
- ↳ CP measurement

► References

- ↳ **Evidence for the 125 GeV Higgs boson decaying to a pair of τ leptons, CMS Collaboration, JHEP 05 (2014) 104**
- ↳ Evidence for the direct decay of the 125 GeV Higgs boson to fermions, CMS Collaboration, Nature Phys. 10 (2014) 557-560
- ↳ Measurement of the properties of a Higgs boson in the four-lepton final state, CMS Collaboration, Phys. Rev. D 89, 092007
- ↳ Measurement of Higgs boson production and properties in the WW decay channel with leptonic final states, CMS Collaboration, JHEP 01 (2014) 096
- ↳ Observation of the diphoton decay of the Higgs boson and measurement of its properties, CMS Collaboration, arXiv:1407.0558 [hep-ex]
- ↳ Observation of a new boson at a mass of 125 GeV with the CMS experiment at the LHC, CMS Collaboration, Phys. Lett. B 716 (2012) 30-61
- ↳ Search for a standard model Higgs bosons decaying to tau pairs in pp collisions, CMS Collaboration, CMS-PAS-HIG-12-018
- ↳ Search for the standard model Higgs boson decaying to tau pairs, CMS Collaboration, CMS-PAS-HIG-12-043
- ↳ Search for the standard-model Higgs boson decaying to tautau, CMS Collaboration, CMS-PAS-HIG-13-004
- ↳ LHC Higgs Cross Section Working Group