

# Higgs and Flavor: $H \rightarrow \mu\tau$ search with the CMS experiment



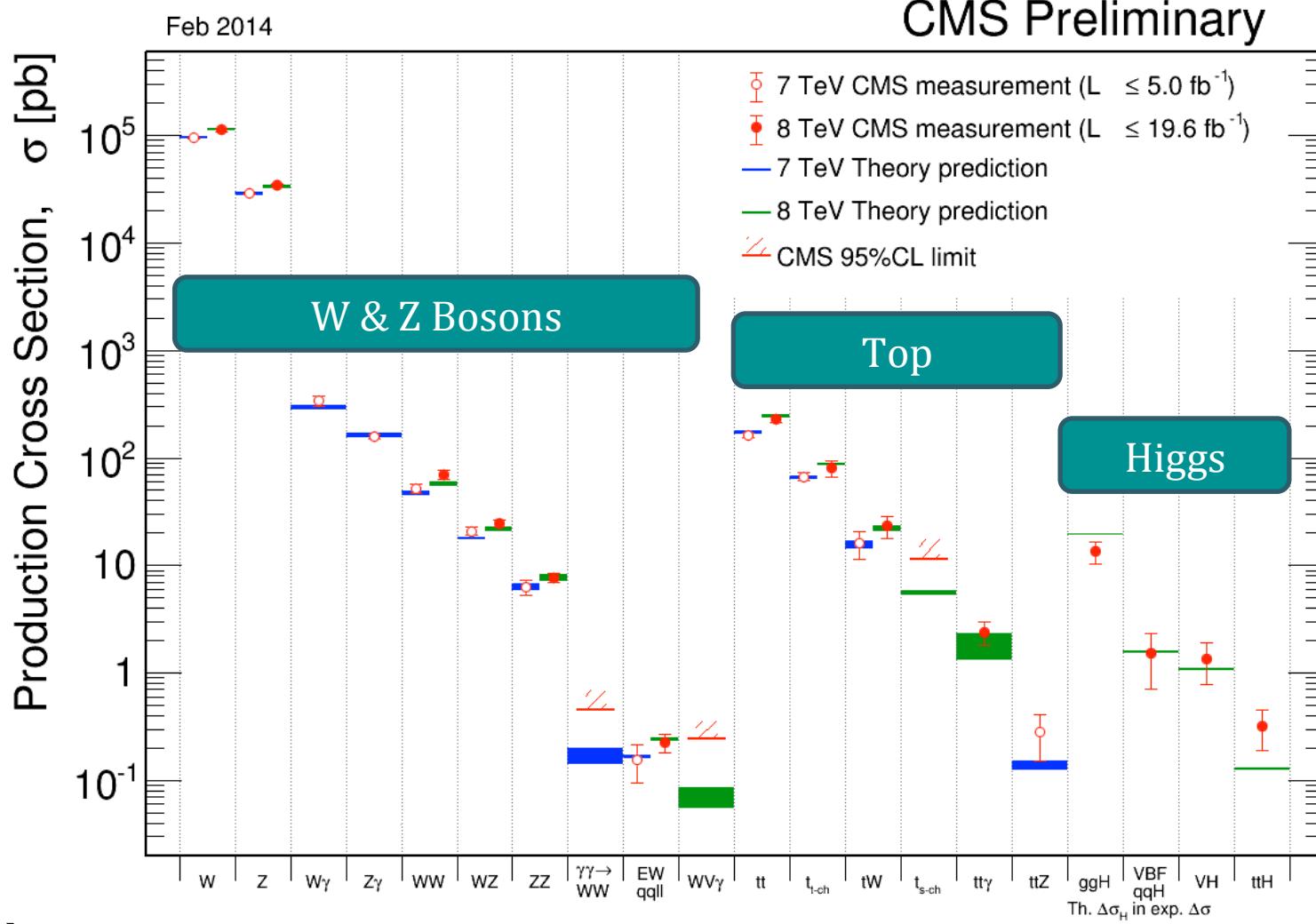
# Introduction

- With the discovery of the Higgs Boson by the ATLAS and CMS collaborations at the LHC, the quest for understanding its properties and decays started
- New physics could arise from unexpected corners
- Exploring the Higgs Flavor sector can hold surprises:
  - BSM models such as double Higgs models or extra dimensions allow LFV decays of the Higgs (for instance, to a  $\mu\tau$  pair)
  - Experimentally, non-LHC bounds on such decays are weak, allowing  $\text{Br}(H \rightarrow \mu\tau, H \rightarrow e\tau) \sim 10\%$ , well within the experimental reach of CMS
- This talk gives a brief overview of the recent CMS Higgs production and decay measurements and summarizes the first direct search for a LFV Higgs Decay, performed with a data sample of  $20 \text{ fb}^{-1}$  @ 8 TeV collected by the CMS experiment



# LHC Run I: The SM

- 2 years of collisions  $\rightarrow 5 \text{ fb}^{-1}$  @ 7 TeV +  $20 \text{ fb}^{-1}$  @ 8 TeV

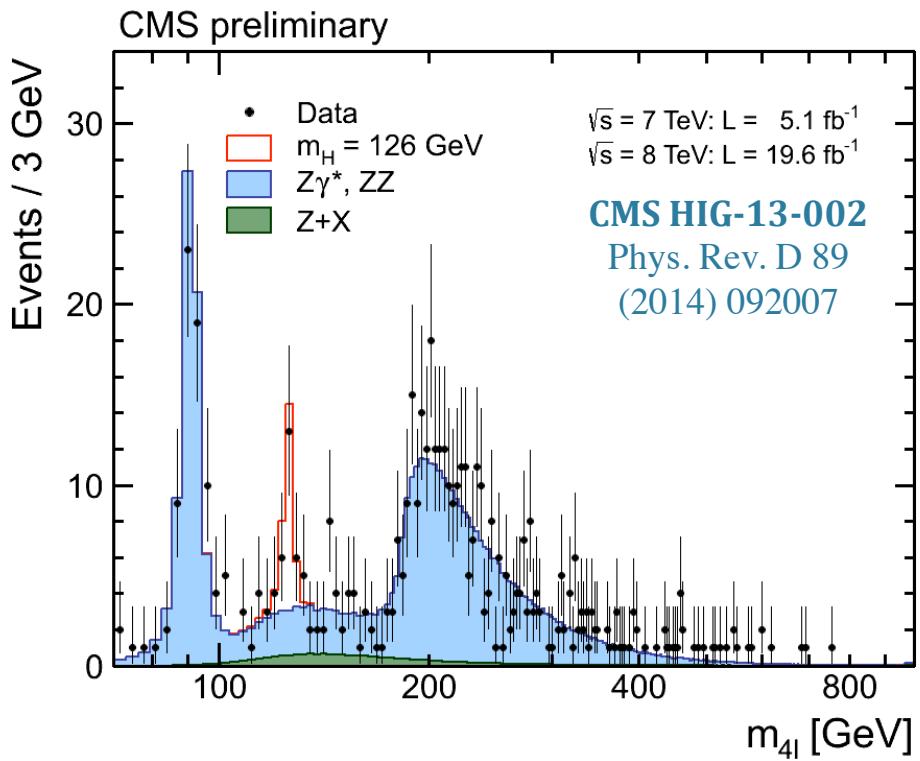


→ 6 orders of magnitude of SM precision physics measurements...

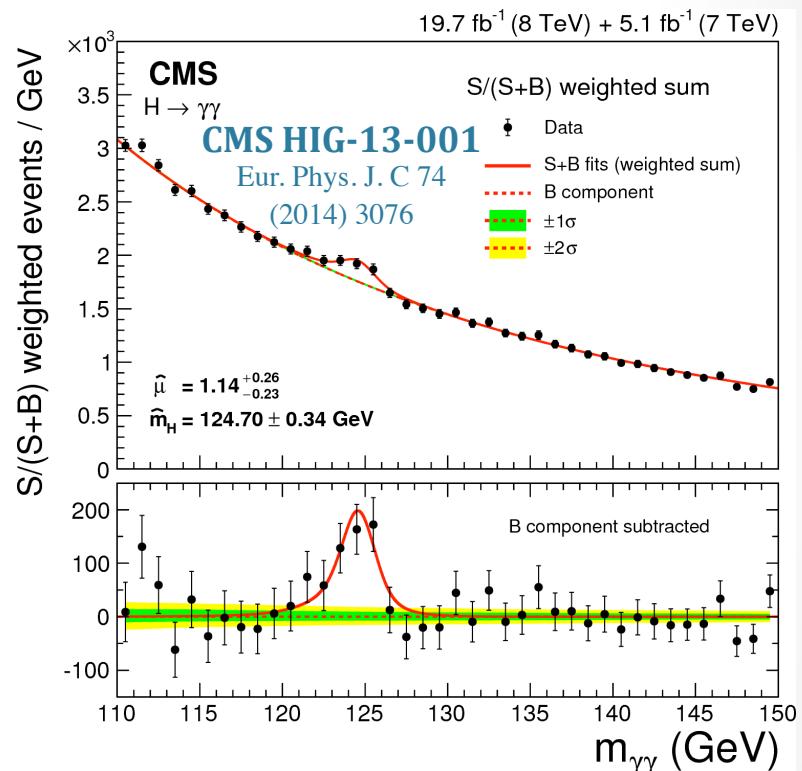


# LHC Run I: The SM

- .. and the discovery of a new particle



$$m_H = 125.03 \pm 0.30 \left[ {}^{+0.26}_{-0.27} (\text{stat.}) {}^{+0.13}_{-0.15} (\text{syst.}) \right] \text{ GeV}$$



But what is it really?

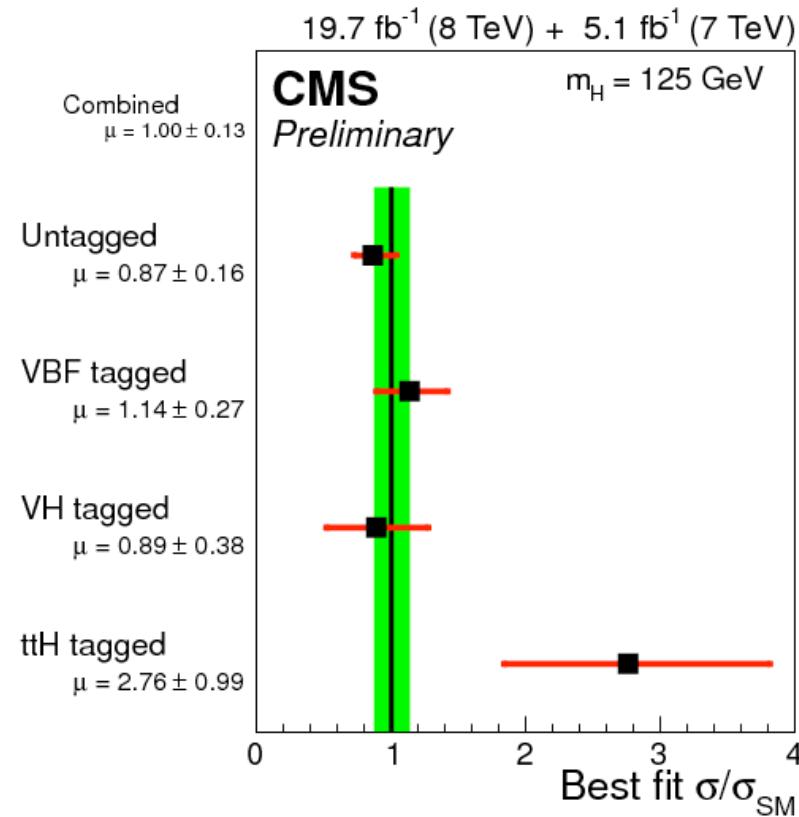
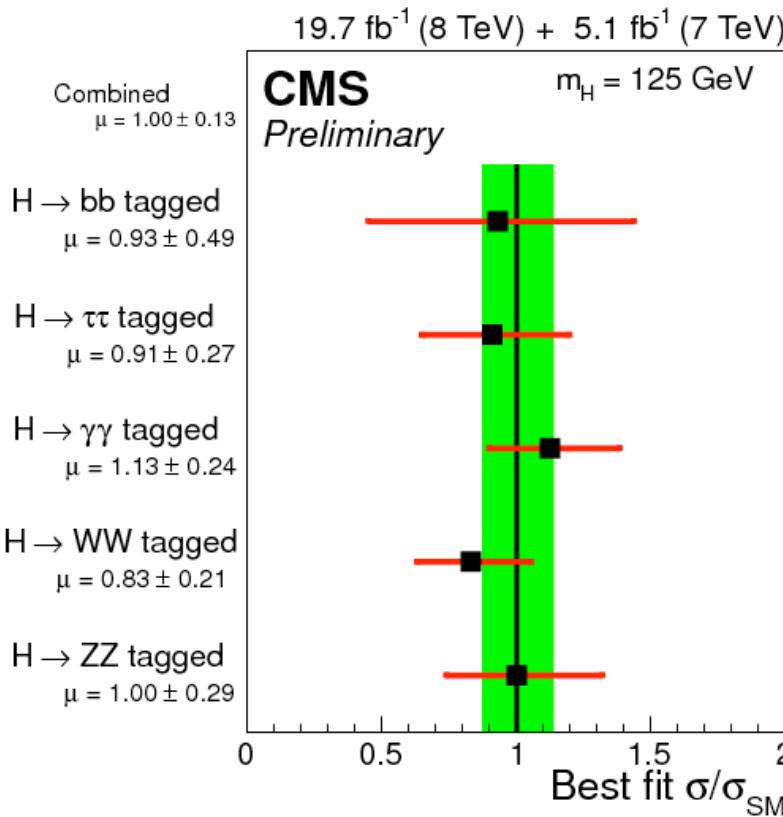
# Is the new boson really the *minimal* SM Higgs?

- Is the ***signal strength***, where seen, at the correct SM level?
  - Is this a ***scalar***, and not a pseudo-scalar or tensor?
  - Does it ***couple*** to the SM particles at appropriate level? t,b, $\tau$ , $\mu$
  - Is this the ***only*** new non-vector boson, and not one of several?
  - Does it ***couple*** unusually ?
- 
- Thanks to its mass of about 125 GeV we will be able to answer many of these questions experimentally ☺
    - Early answers from 2011-12 (Run-1)
    - Preparation for 2015-2017 (Run-2)



# Its signal strength is like the SM predicts...

$$\sigma/\sigma_{\text{SM}} = 1.00 \pm 0.13 \left[ \pm 0.09(\text{stat.})^{+0.08}_{-0.07}(\text{theo.}) \pm 0.07(\text{syst.}) \right]$$

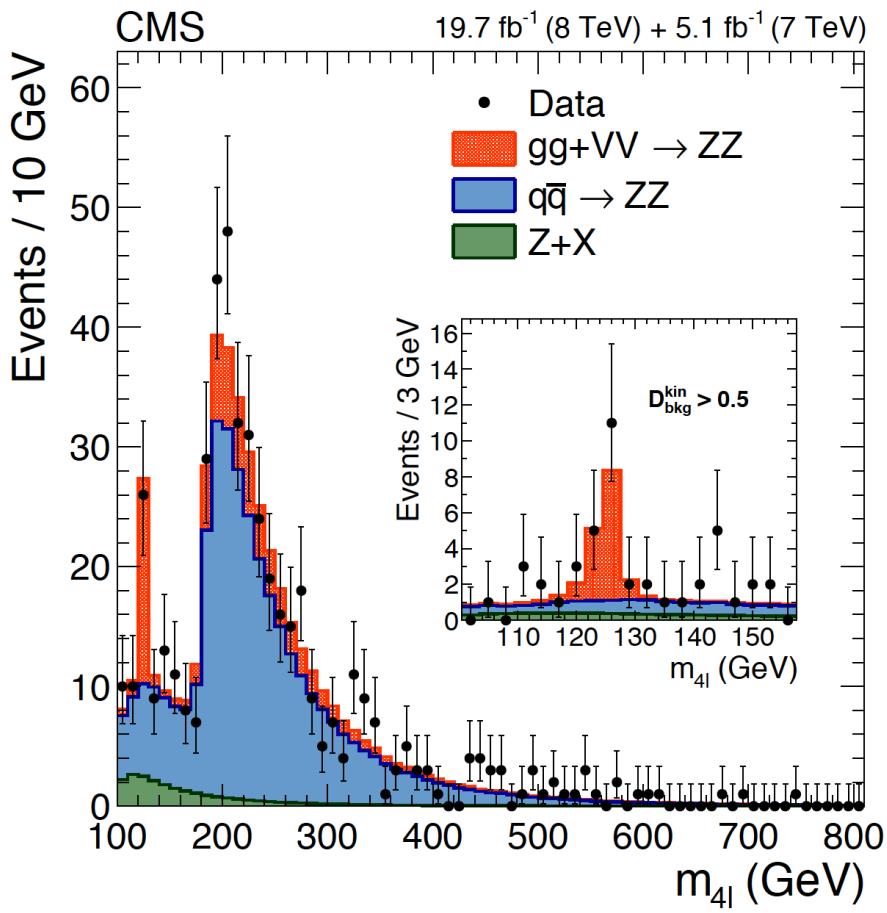


(ttH driven by one channel,  
same sign dimuons)

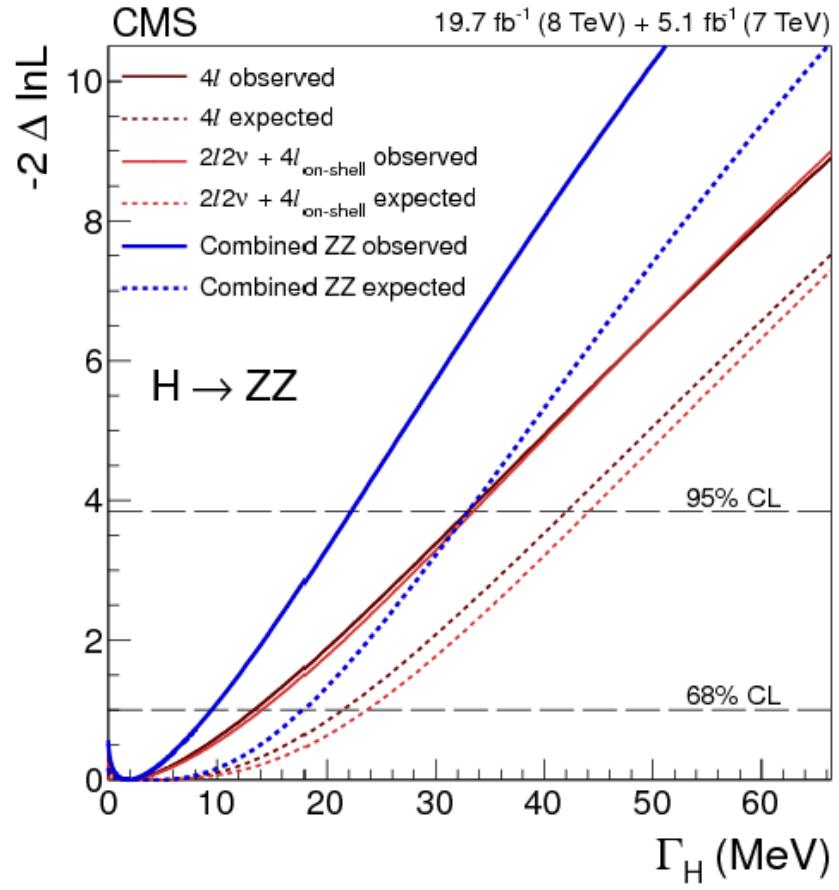


# Its width is as the SM predicts...

- $\Gamma_H$  SM = 4.7 MeV
- $\Gamma_H < 22$  MeV (expected 33 MeV)
- Best Fit:  $\Gamma_H = 1.8^{+7.7}_{-1.8}$  MeV



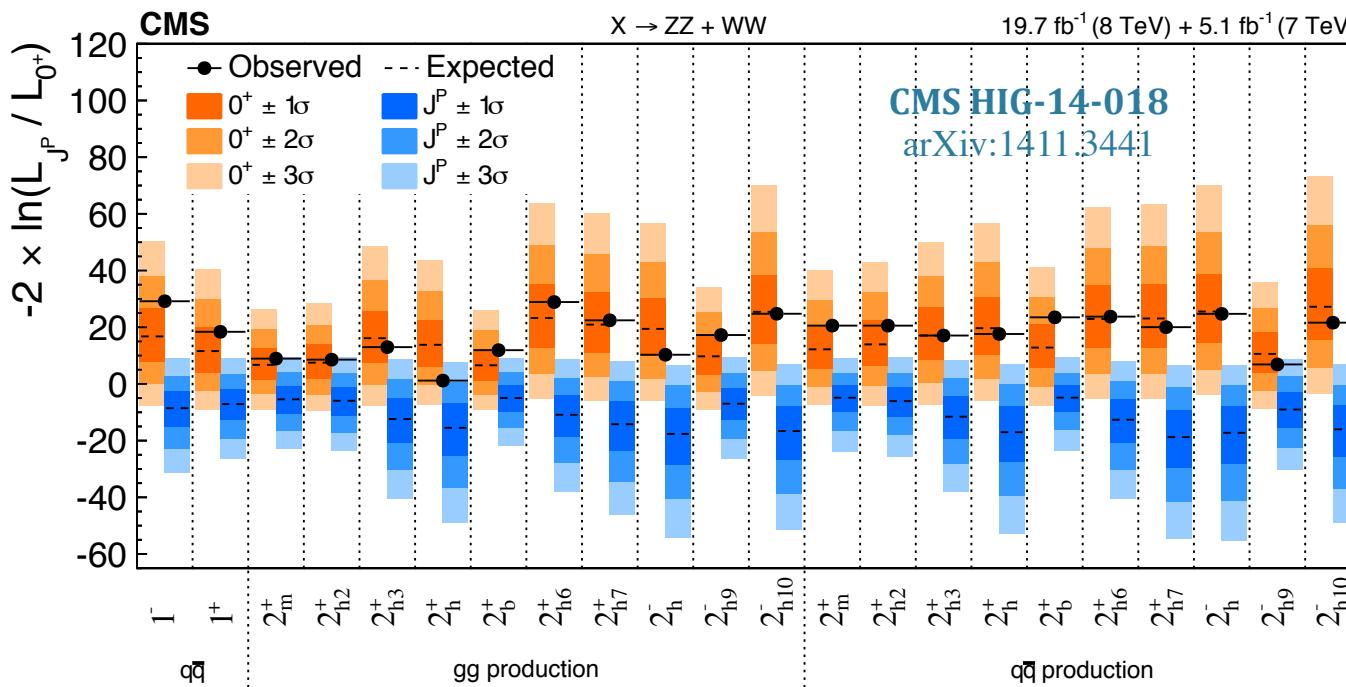
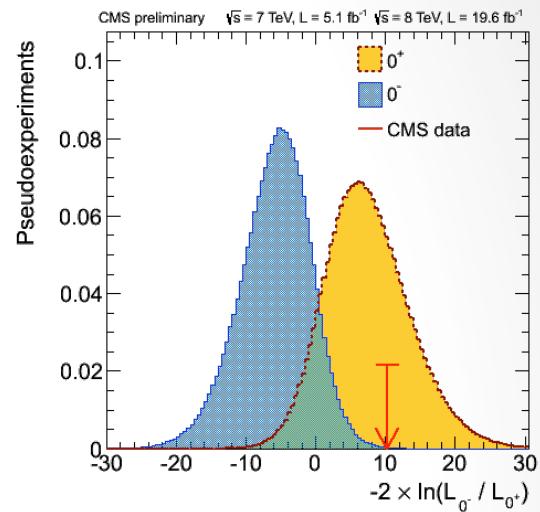
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Phys. Lett. B 736 (2014) 64



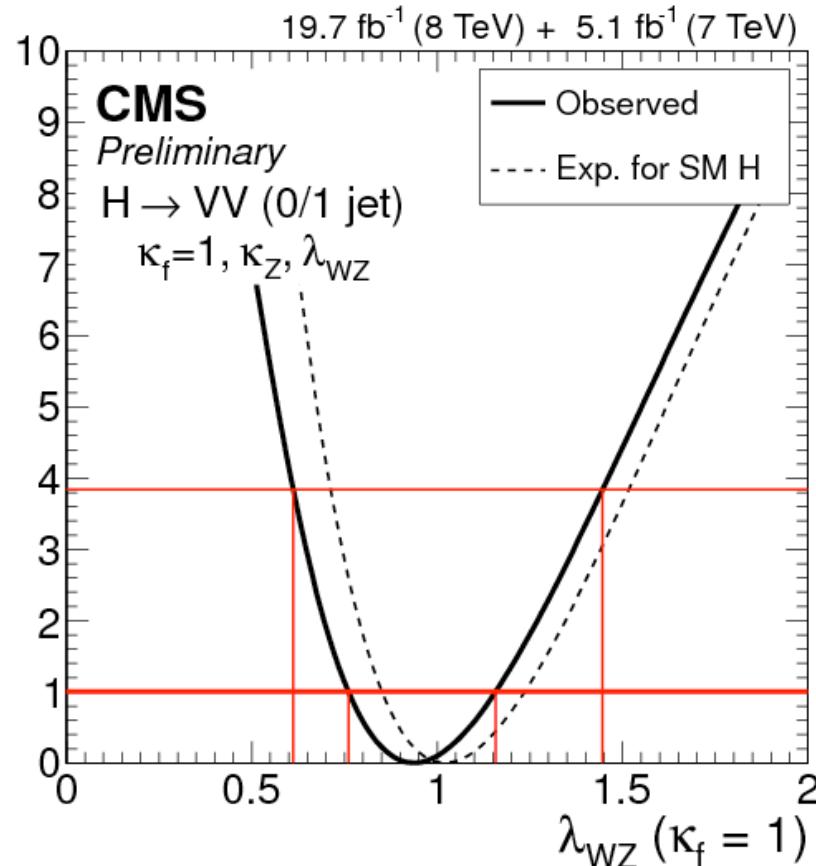
# Its spin is like the SM Higgs

## Boson's one...

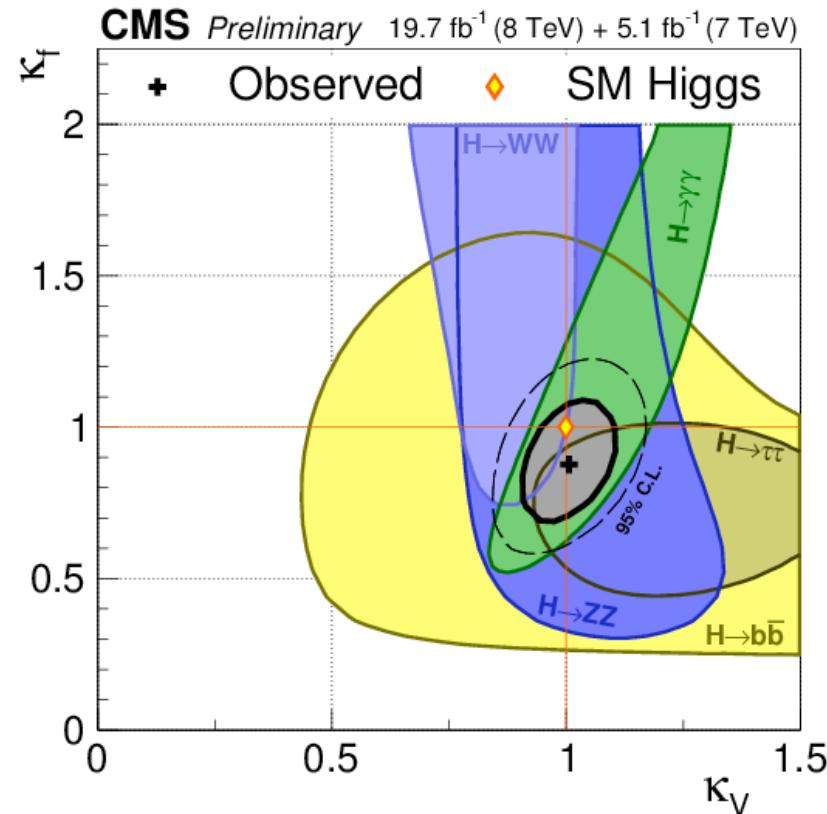
- Spin 1 excluded by observation of  $H\gamma\gamma$
- All tested hypotheses excluded at more than 99.9% CLS ( $HZZ/H\gamma\gamma/HWW$ )
- $J^{PC} = 0^{++}$



# It couples like the SM Higgs Boson...

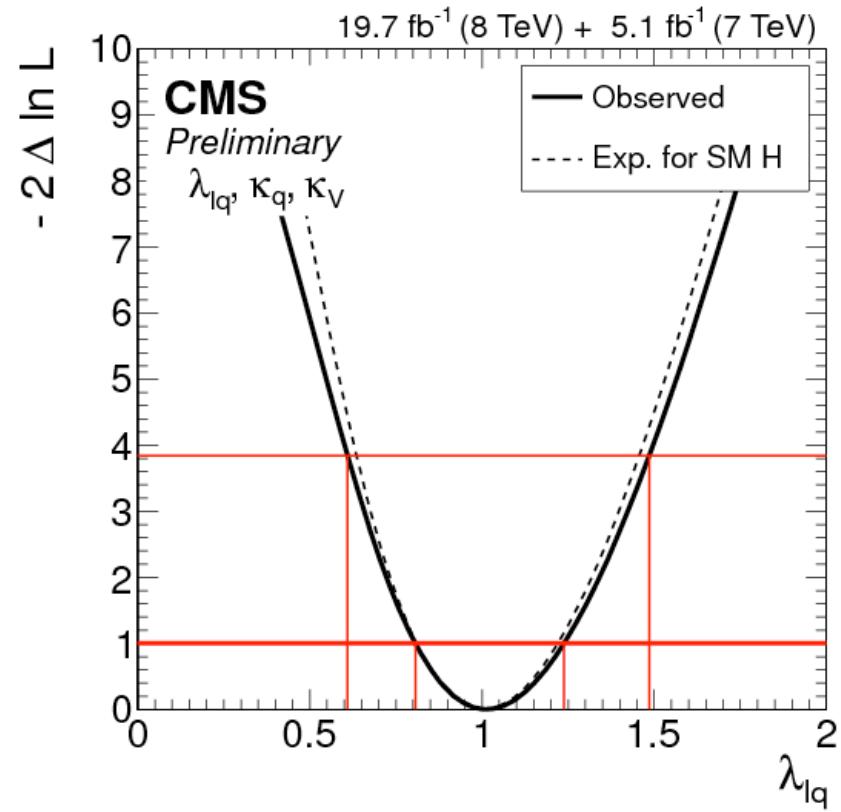
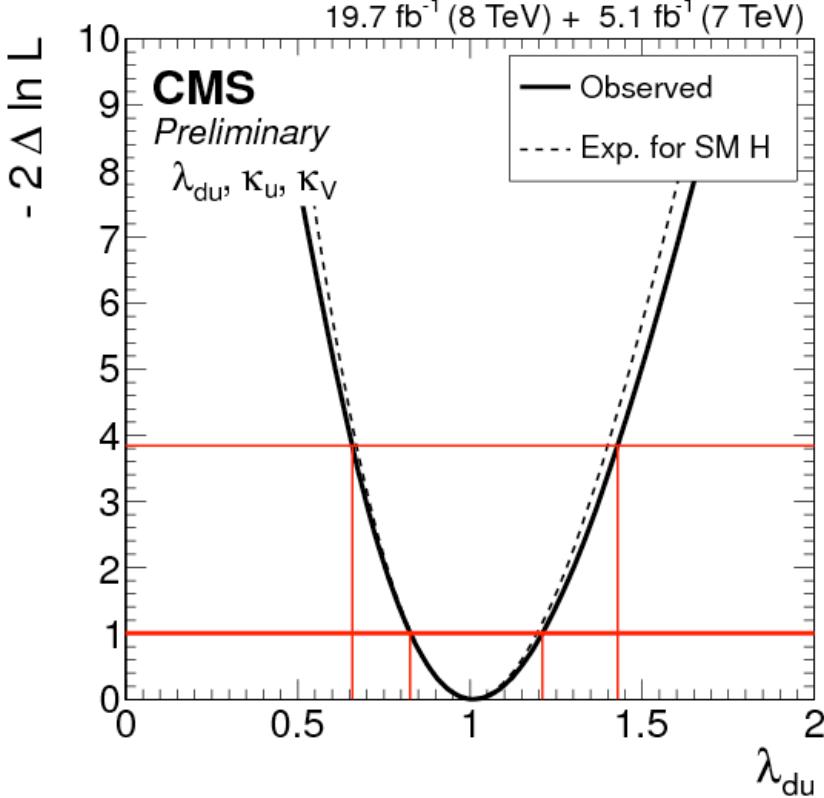


- Symmetry between W and Z couplings



- All decay channels converge around SM expectation

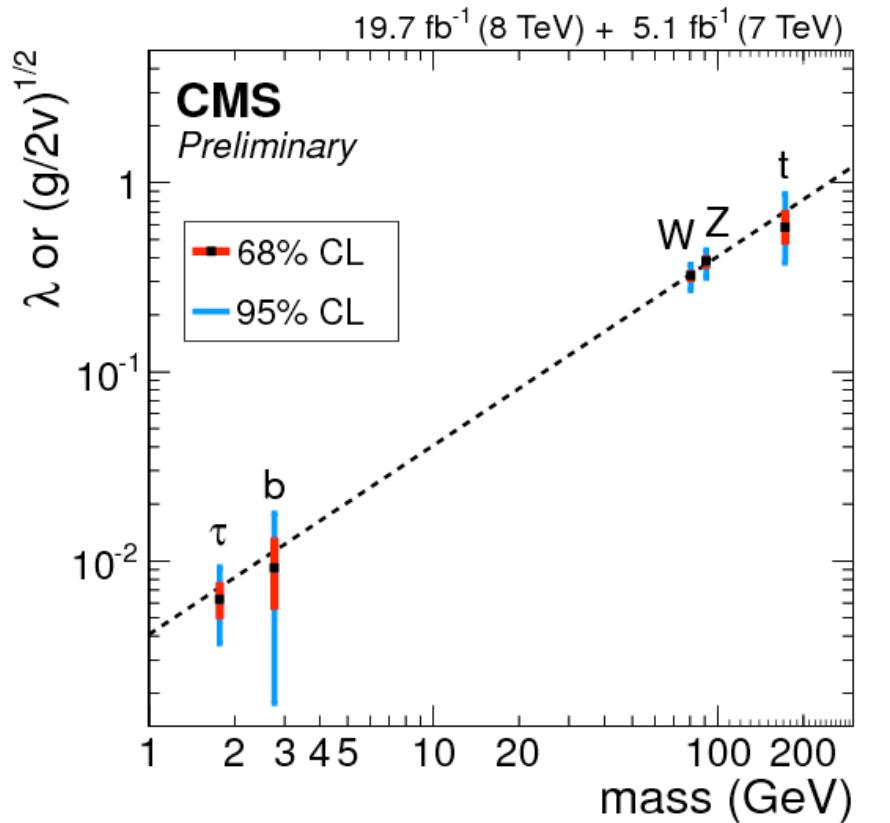
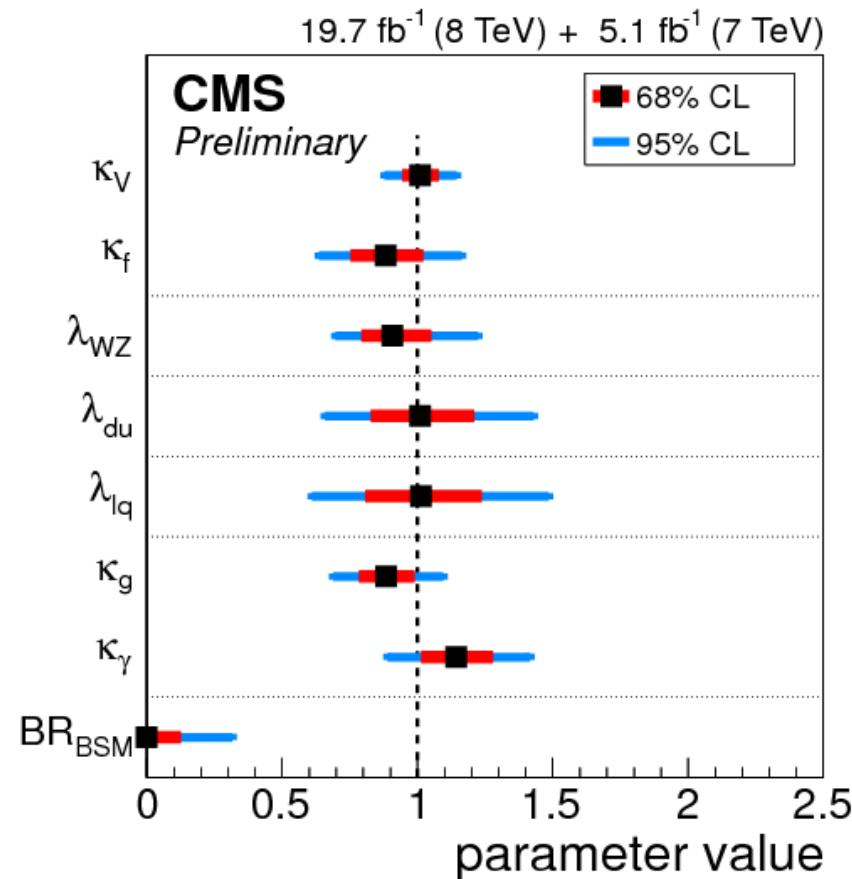
# It couples like the SM Higgs Boson...



- Similar coupling to up-type vs down-type fermions
- Similar coupling to quarks and leptons



# It couples like the SM Higgs Boson...

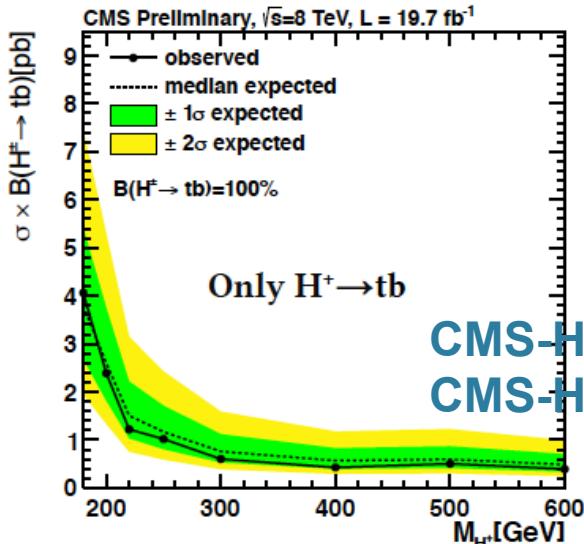
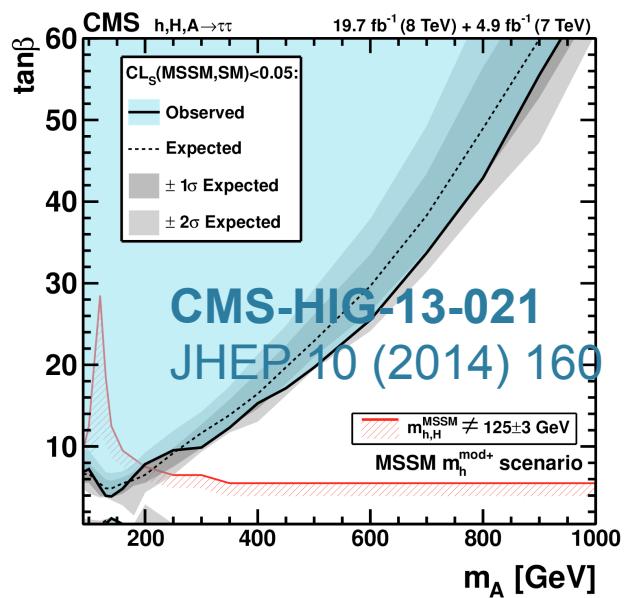
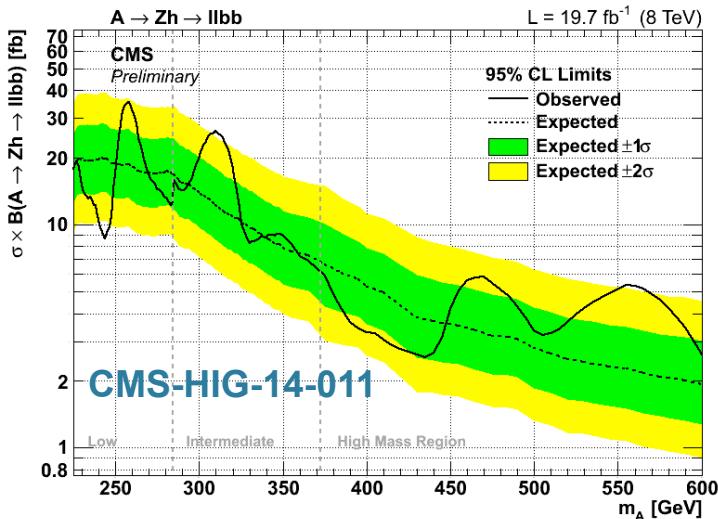


- No significant deviations from SM

# So far, we have not found any other Higgs Boson...

Going beyond the SM: Two Higgs Doublets → Five physical Higgs bosons

¿H, h, A  
H<sup>+</sup>, H<sup>-</sup>?



These are just a few examples, many more signatures being explored

# Is the New Boson really the *minimal* SM Higgs?

- Is the *signal strength*, where  $\sigma$  is the cross-section, at the correct SM level?
- Is this a *scalar*, pseudo-scalar or tensor?
- Does it *couple* to the SM particles at appropriate level? t,b, $\tau$ , $\mu$
- Is this the *only* new non-vector boson, and not one of several?
- Does it ***couple*** unusually (e.g. changing Lepton Flavor?)

No surprises so far.....

- Thanks to its mass of about 125 GeV we will be able to answer many of these questions experimentally ☺
  - Early answers from 2011-12 (Run-1)
  - Preparation for 2015-2017 (Run-2)



WHY LFV?



# Higgs and Flavor

- In the SM, the Yukawa interactions are the only source of the fermion masses:

$$y_{ij} \bar{f}_{L_i} H f_{R_j} = \frac{y_{ij} v}{\sqrt{2}} \bar{f}_{L_i} f_{R_j} + \frac{y_{ij}}{\sqrt{2}} h \bar{f}_{L_i} f_{R_j}$$

mass      ↗      ↗      higgs-fermion interactions

- Both matrices are simultaneously diagonalizable → Lepton Flavor Violating Higgs decays are forbidden in the SM

$$Y = \begin{pmatrix} Y_{ee} & 0 & 0 \\ 0 & Y_{\mu\mu} & 0 \\ 0 & 0 & Y_{\tau\tau} \end{pmatrix}$$



# Higgs and Flavor

- In the SM, the Yukawa interactions are the only source of the fermion masses:

$$y_{ij} \bar{f}_{L_i} H f_{R_j} = \frac{y_{ij} v}{\sqrt{2}} \bar{f}_{L_i} f_{R_j} + \frac{y_{ij}}{\sqrt{2}} h \bar{f}_{L_i} f_{R_j}$$

mass                                  higgs-fermion interactions

- Both matrices are simultaneously diagonalizable → Lepton Flavor Violating Higgs decays are forbidden in the SM

This is not necessarily true anymore in BSM models:

$$\mathcal{L}'_{Y_i} = Y_{ij} h \bar{f}_L^i f_R^j + h.c.$$

- Flavor off-diagonal
- Complex (CP violating)

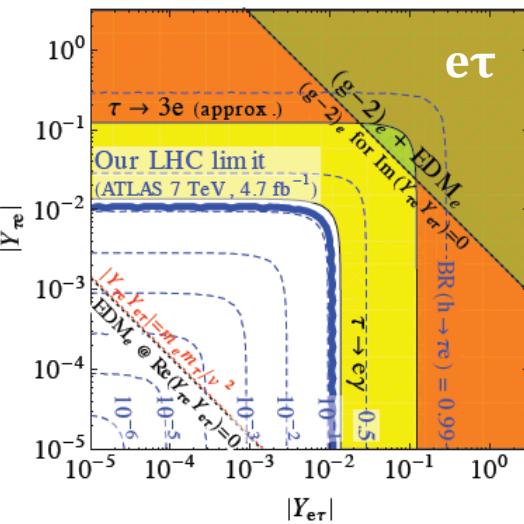
$$Y = \begin{pmatrix} \text{SM values} \\ Y_{ee} & Y_{e\mu} & Y_{e\tau} \\ Y_{\mu e} & Y_{\mu\mu} & Y_{\mu\tau} \\ Y_{\tau e} & Y_{\tau\mu} & Y_{\tau\tau} \end{pmatrix}$$



# Pre-LHC experimental bounds

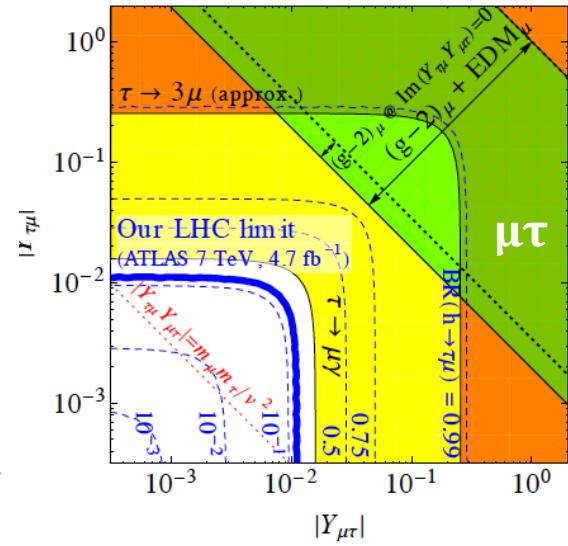
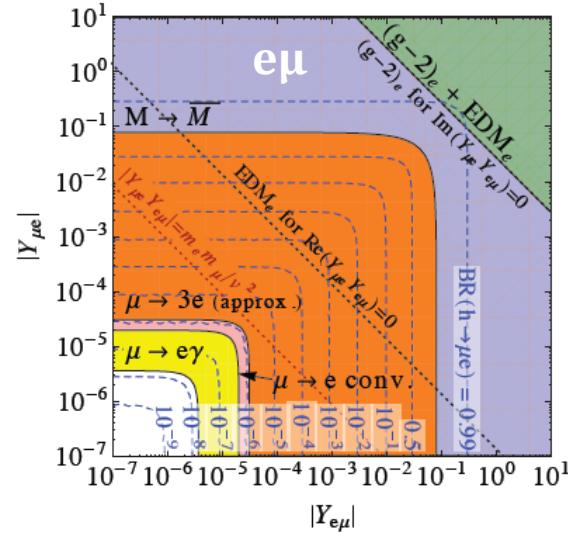
Channel	Coupling	Bound
$\mu \rightarrow e\gamma$	$\sqrt{ Y_{\mu e} ^2 +  Y_{e\mu} ^2}$	$< 3.6 \times 10^{-6}$
$\tau \rightarrow e\gamma$	$\sqrt{ Y_{\tau e} ^2 +  Y_{e\tau} ^2}$	$< 0.014$
$\tau \rightarrow \mu\gamma$	$\sqrt{ Y_{\tau\mu} ^2 +  Y_{\mu\tau} ^2}$	0.016

**Br≤10%**

Without any retuning, a reinterpretation of a LHC  $H \rightarrow \tau\tau$  search yields a  $\text{Br} < 13\%$  limit

arXiv:1209.1397



Naturalness:  $Y_{ij} \leq \frac{\sqrt{m_i m_j}}{v}$

CMS direct search for  $H \rightarrow \mu\tau$



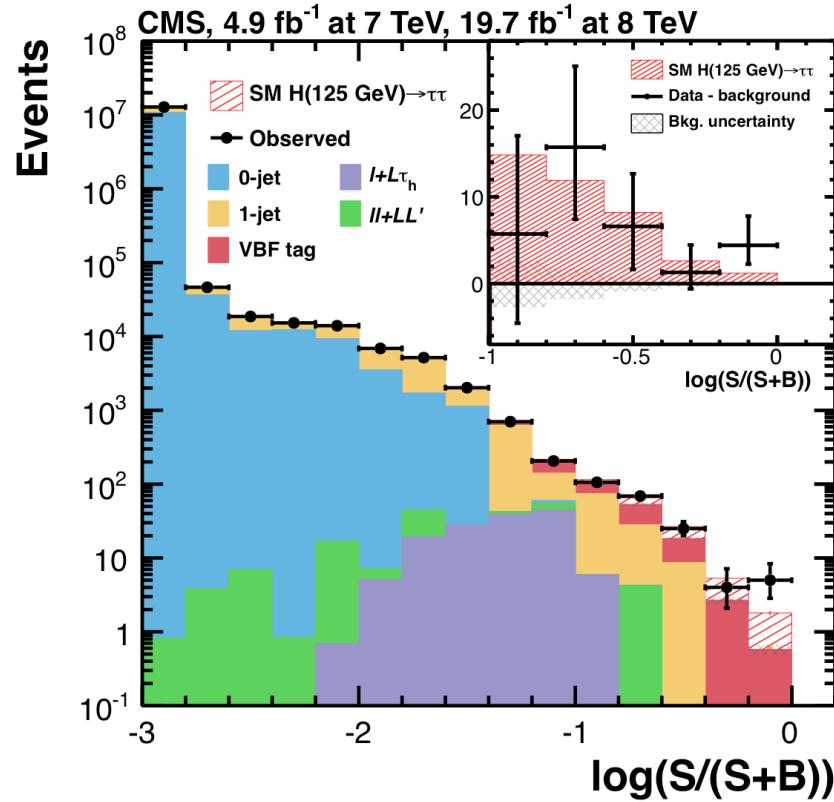
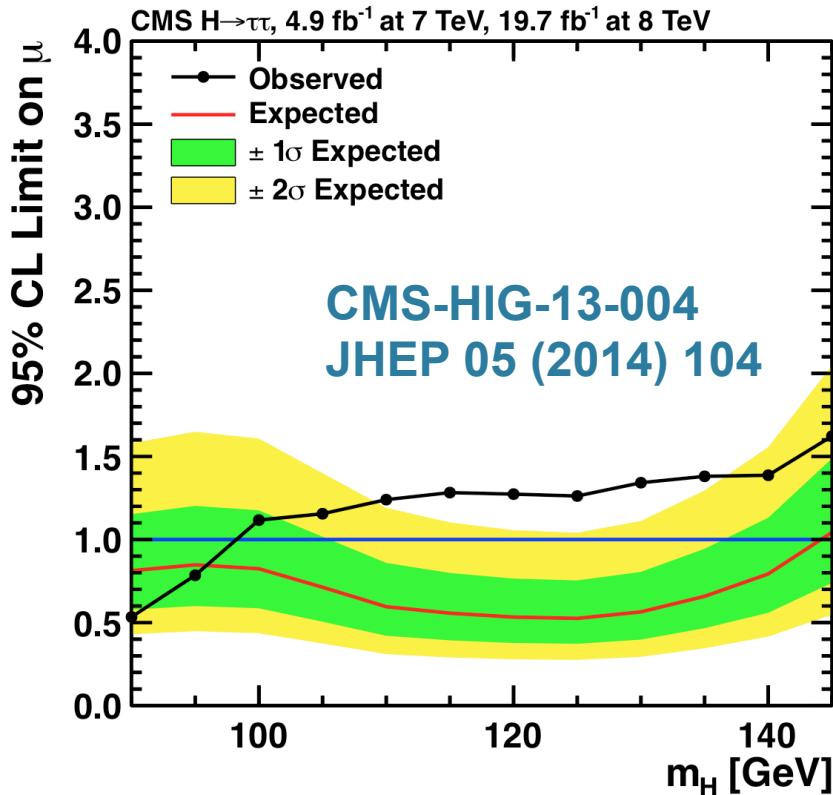
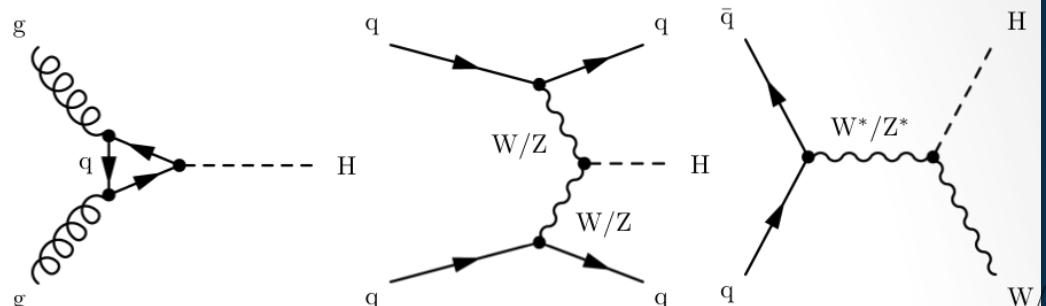
# Higgs Decay to Tau Pairs

Final states VBF + GF:

$$e\mu, \mu\mu, e\tau_h, \mu\tau_h, \tau_h\tau_h$$

Also, VH (WH & ZH):

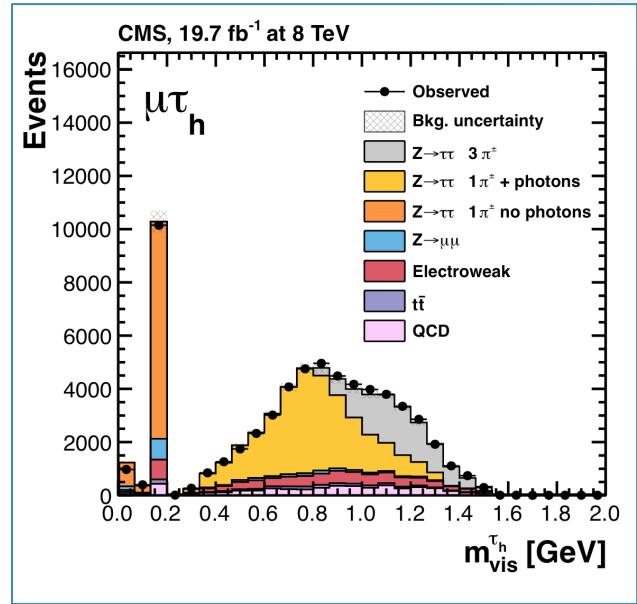
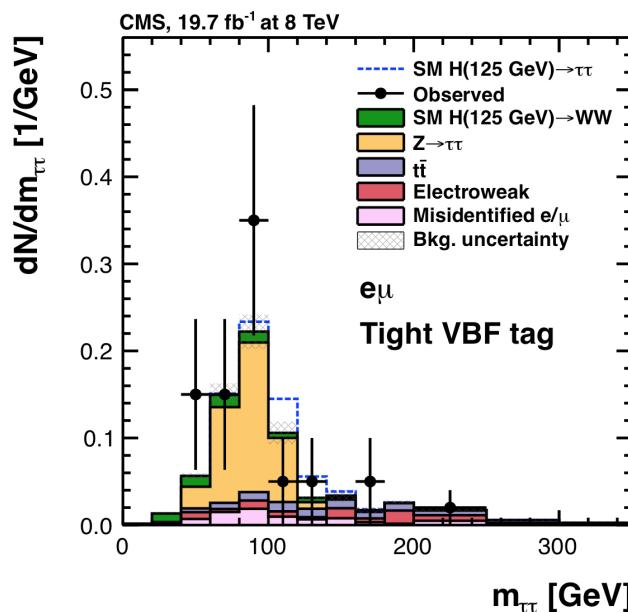
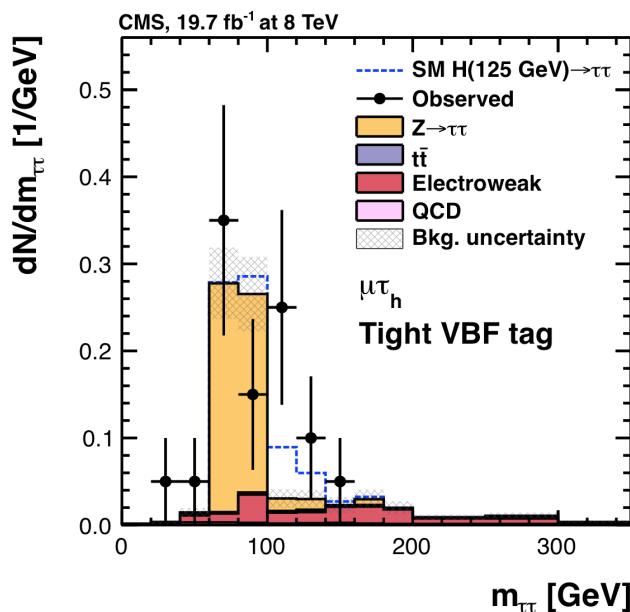
$$\ell\tau_h, \ell\tau_h\tau_h, \ell\ell\tau_h\tau_h$$



Local significance larger than  $3\sigma$  for  $m_H$  values between 115 and 130 GeV

# Higgs Decay to Tau Pairs

- Following the baseline object definition by the CMS SM  $H \rightarrow \tau\tau$  analysis (common building blocks: taus, leptons, jets) allows us to profit from the modeling techniques and systematic studies developed in that context
- Many analysis techniques in common with the SM search



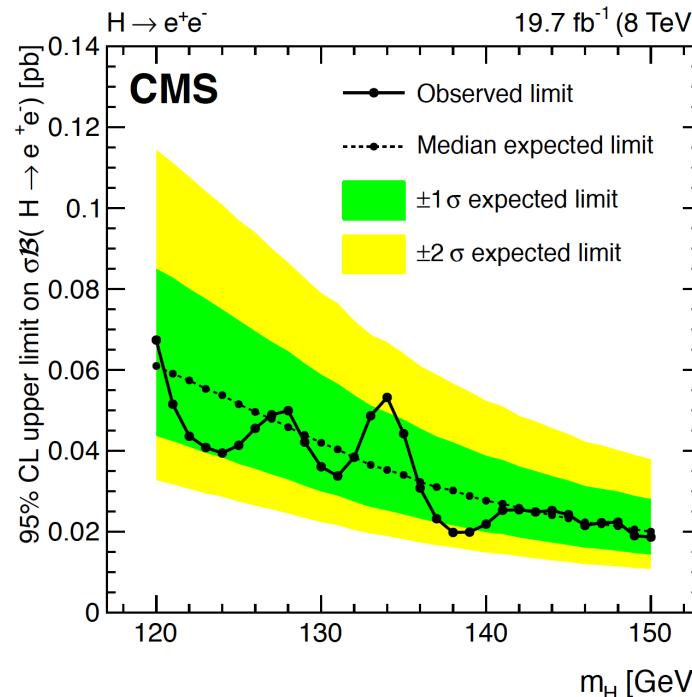
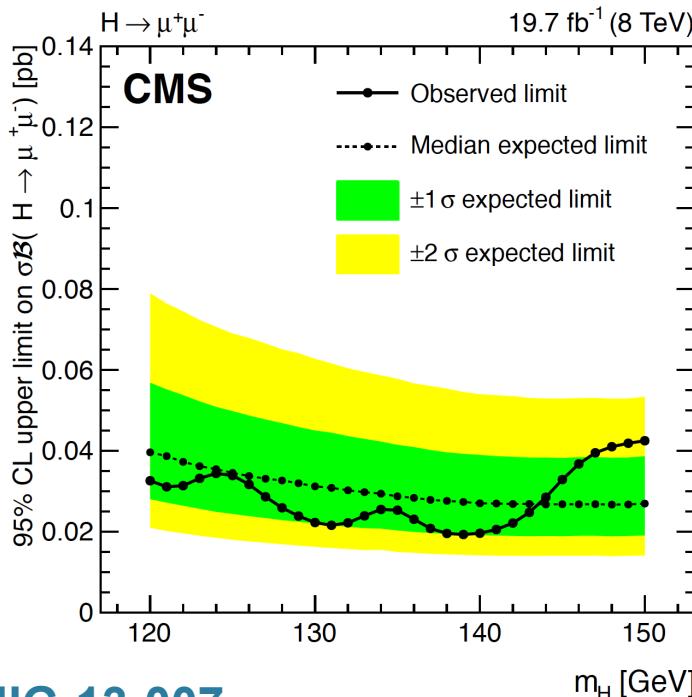
# What about $H\mu\mu$ and $Hee$ ?

- For a Higgs of 125 GeV, the SM predicts:
  - $BR(H\tau\tau)=6.32\%$
  - $BR(H\mu\mu)=0.0219\%$
  - $BR(Hee)=5\times 10^{-9}$



- CMS search:

- $H\mu\mu \rightarrow$  at 95% CL  $\sigma/\sigma_{SM} < 7.4$  (expected  $6.5^{+2.8}_{-1.9}$ )  $\rightarrow$  At 125 GeV, upper limit on the  $Br(H\mu\mu) < 0.0016$
- $Hee \rightarrow Br(Hee) < 0.0019$  ( $3.7 \times 10^5$  times the SM!)

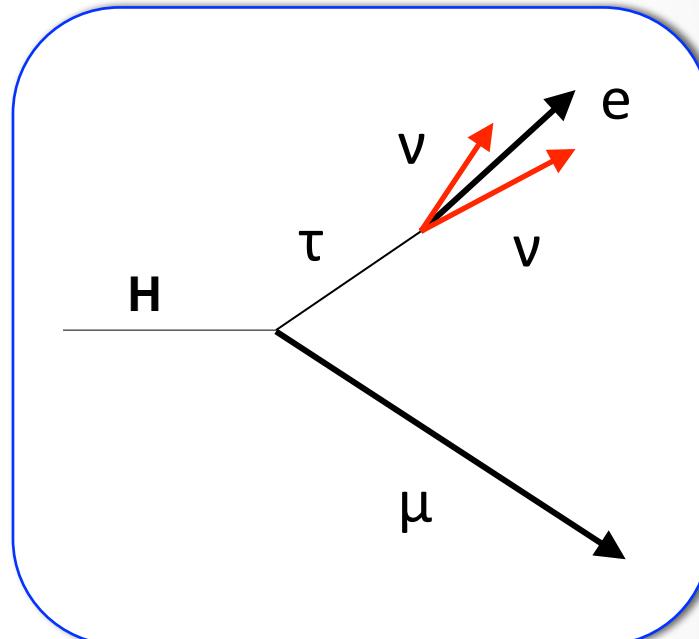
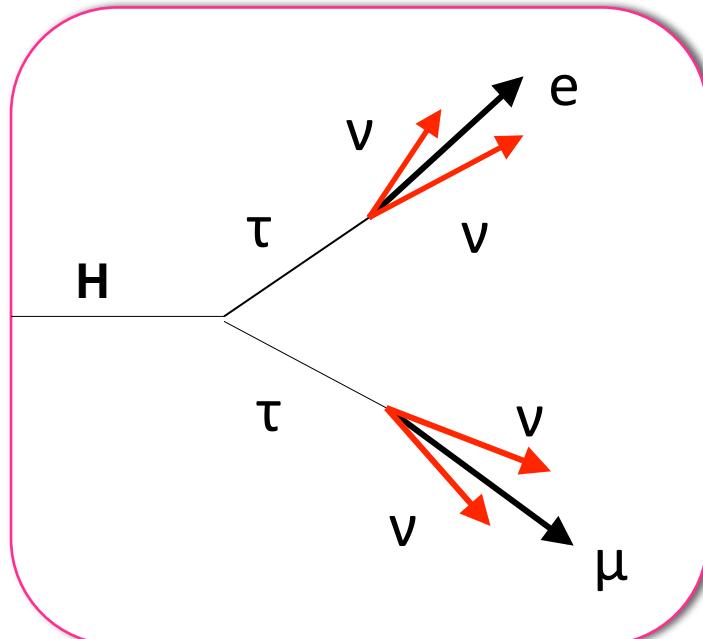


# Comparison of Kinematics

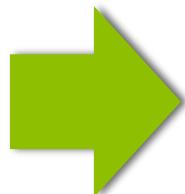
$H \rightarrow \tau\tau$

vs.

$H \rightarrow \mu\tau$



Exploit  
differences in  
event topology



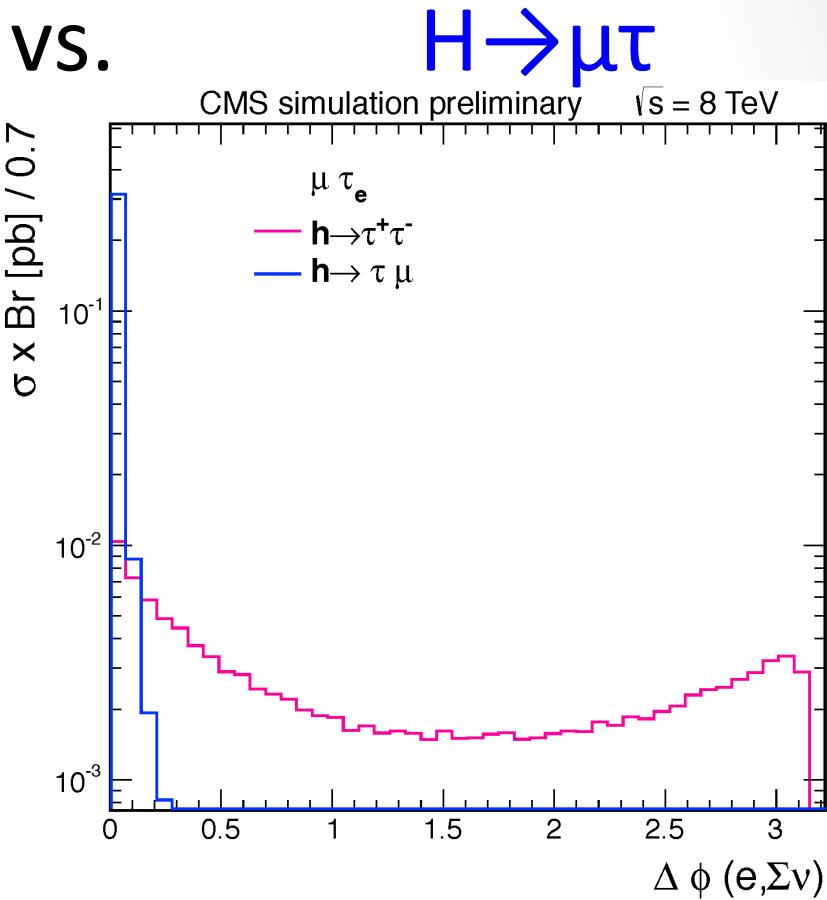
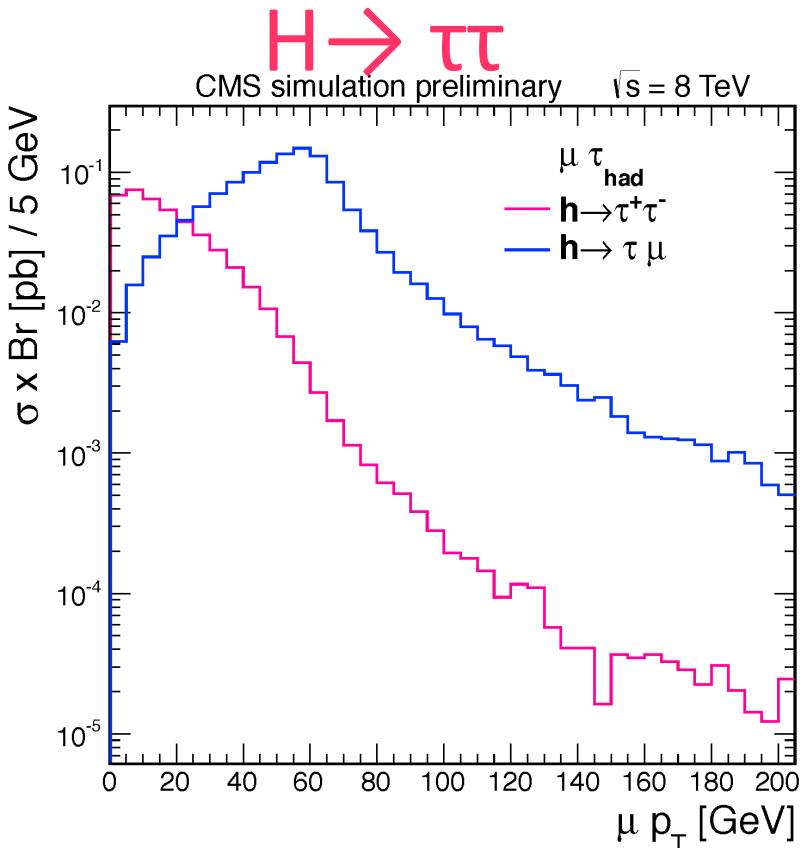
- Harder  $P_T$  spectrum of muons
- Different angular correlations:
  - Electron/Tau<sub>had</sub> – Neutrinos → ~ Collinear
  - Muon - Neutrinos → ~ back to back

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# Comparison of Kinematics



Exploit  
differences in  
event topology



- Harder  $P_T$  spectrum of muons
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  - Electron/Tau<sub>had</sub> – Neutrinos  $\rightarrow$  ~ Collinear
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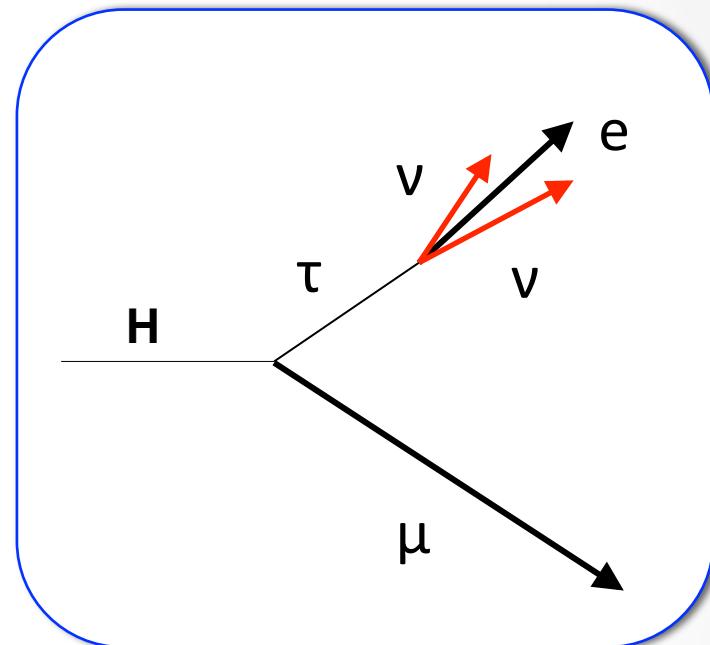
# Mass Reconstruction

- We cannot reconstruct the full Higgs mass from the visible objects
- Using a collinear mass approximation we can improve mass resolution
  - Assume neutrinos are collinear with the tau and define the visible fraction of tau momentum

$$\vec{p}_T^\nu = \vec{E}_T^{\text{miss}} \cdot \hat{\vec{p}}_T^{\tau_{\text{vis}}}$$

$$x_{\tau_{\text{vis}}} = \frac{|\vec{p}_T^{\tau_{\text{vis}}}|}{|\vec{p}_T^{\tau_{\text{vis}}}| + |\vec{p}_T^\nu|}$$

- Like this, the full system mass becomes:



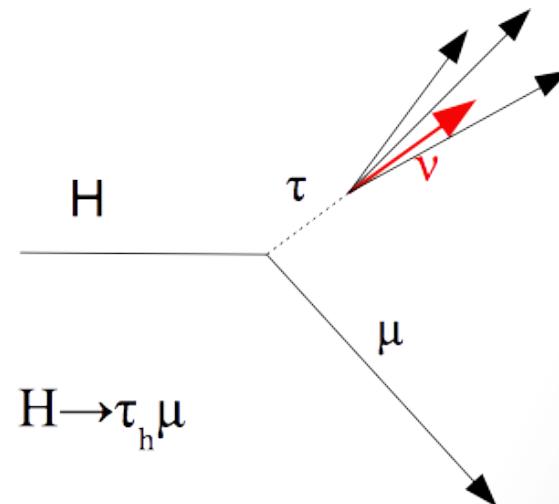
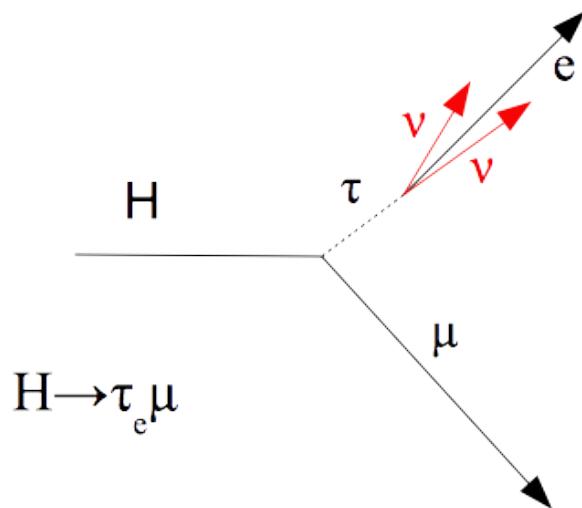
$$M_{\text{collinear}} = \frac{M_{\text{vis}}}{\sqrt{x_{\tau_{\text{vis}}}}}$$



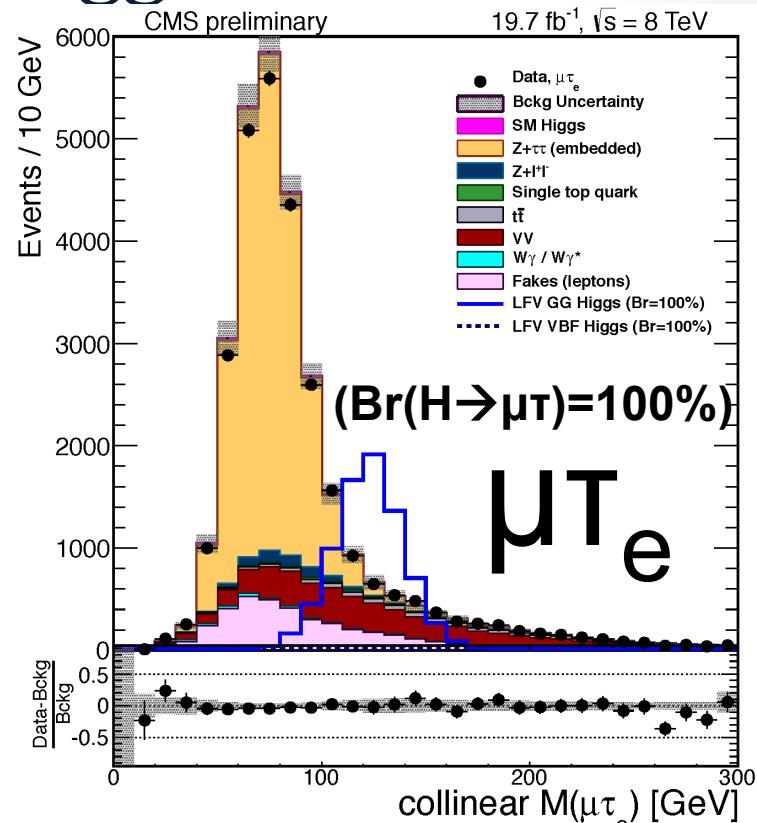
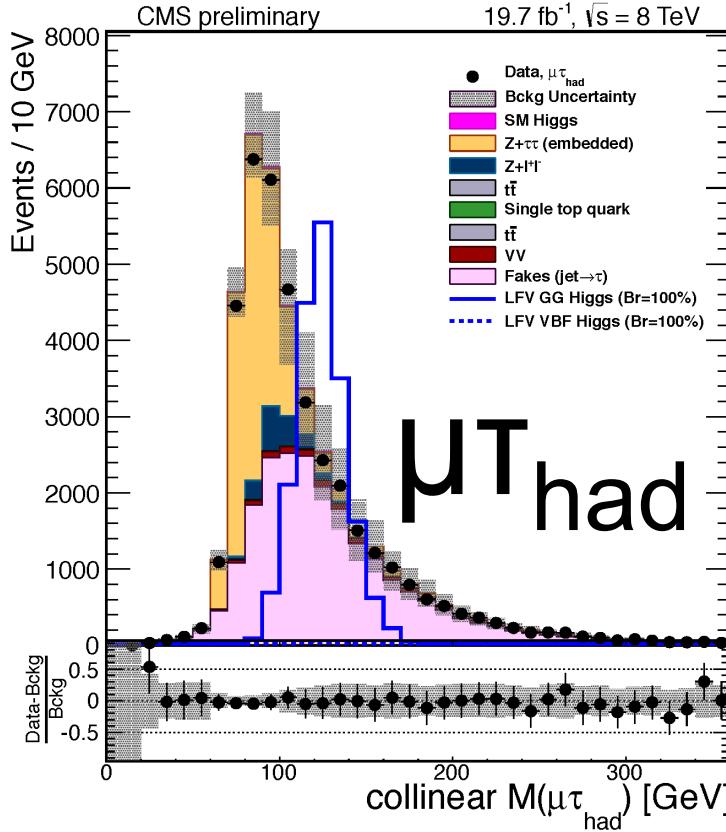
# Base selection in a snapshot

- Two channels:
  - $\mu\tau_{had}$  (triggered by single muon)
  - $\mu\tau_e$  (triggered by muon-electron cross triggers)
- Three categories
  - 0 and 1 jet (dominated by GGF)
  - 2 jets (dominated by VBF)

- 1 Good, Isolated, High  $p_T$  Muon
- 1 Good, isolated low  $p_T$  Electron OR 1 Good, isolated high  $p_T$  tau
- Opposite charge of the  $\mu\tau_{had}$  /  $\mu e$  Pair
- Veto on additional leptons



# Loosely selecting LFV Higgses...



Lead backgrounds:

HTauTau

ZTauTau

Tau-  
Embedding  
technique

SM backgrounds with real tau decays: top, VV

Mididentified Leptons (e, mu, tau)

from MC  
from data

# Full Selection

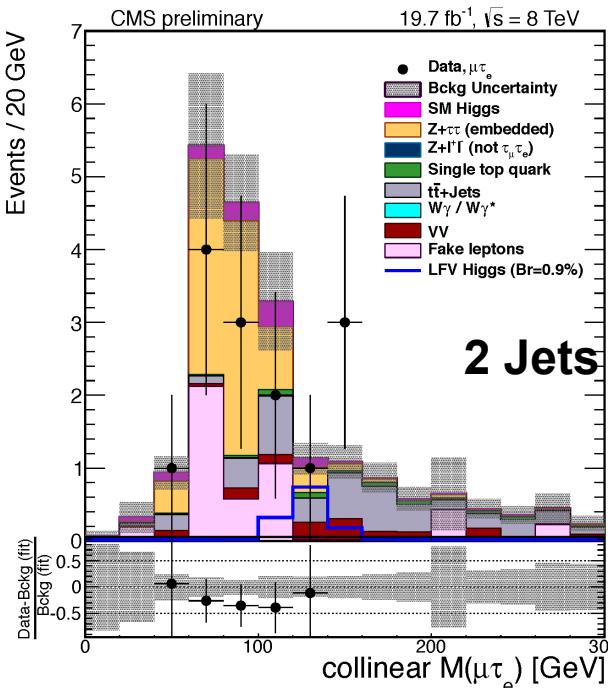
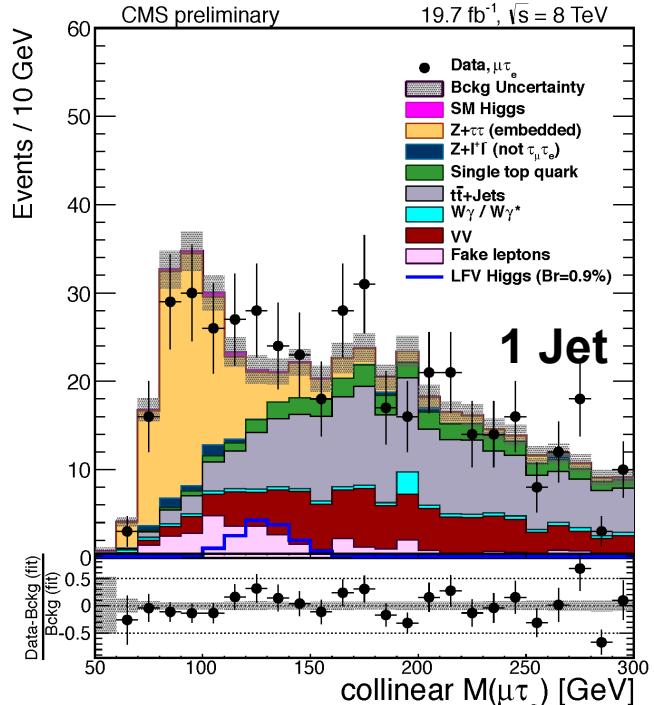
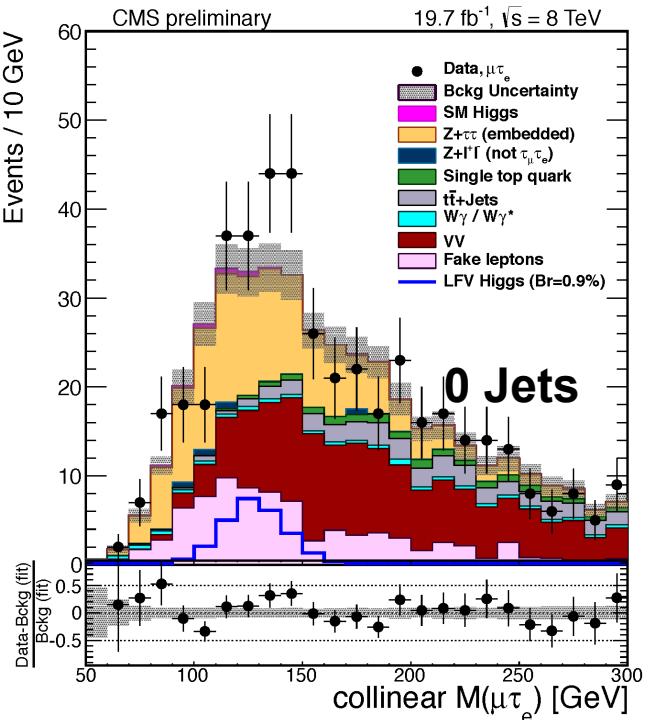
- Greatly improve S/B by applying what we have learned about kinematics → higher muon  $p_T$ , smart angular requirements
- Differentiated by category to account for differences in sample composition in the 0-1-2 Jet bins

Variable	$H \rightarrow \mu\tau_e$			$H \rightarrow \mu\tau_{had}$		
	0-jet	1-jet	2-jet	0-jet	1-jet	2-jet
$p_T^\mu > [\text{GeV}]$	50	45	25	40	35	30
$p_T^e > [\text{GeV}]$	10	10	10	-	-	-
$p_T^\tau > [\text{GeV}]$	-	-	-	35	40	40
$\Delta\phi_{\vec{\mu}-\vec{\tau}_{had}} >$	-	-	-	2.7	-	-
$\Delta\phi_{\vec{e}-\vec{E}_T} <$	0.5	0.5	0.3	-	-	-
$\Delta\phi_{\vec{e}-\vec{\mu}} >$	2.7	1.0	-	-	-	-
$M_T(e) < [\text{GeV}]$	65	65	25	-	-	-
$M_T(\mu) > [\text{GeV}]$	50	40	15	-	-	-
$M_T(\tau) < [\text{GeV}]$	-	-	-	50	35	35

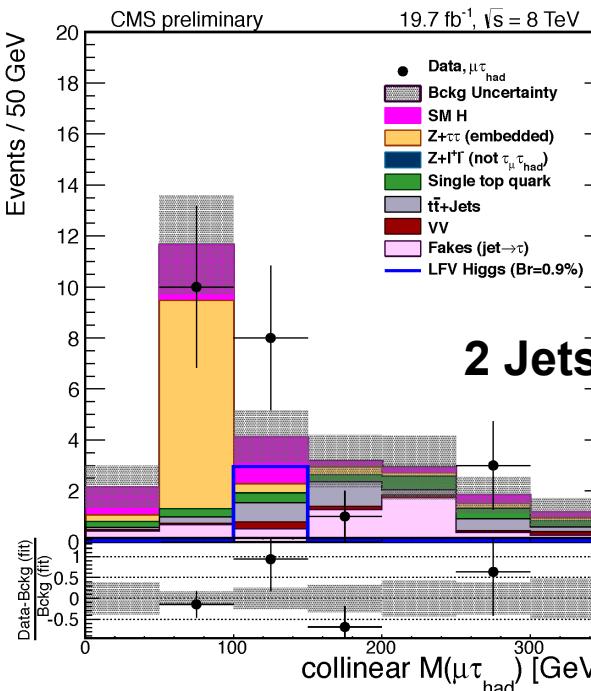
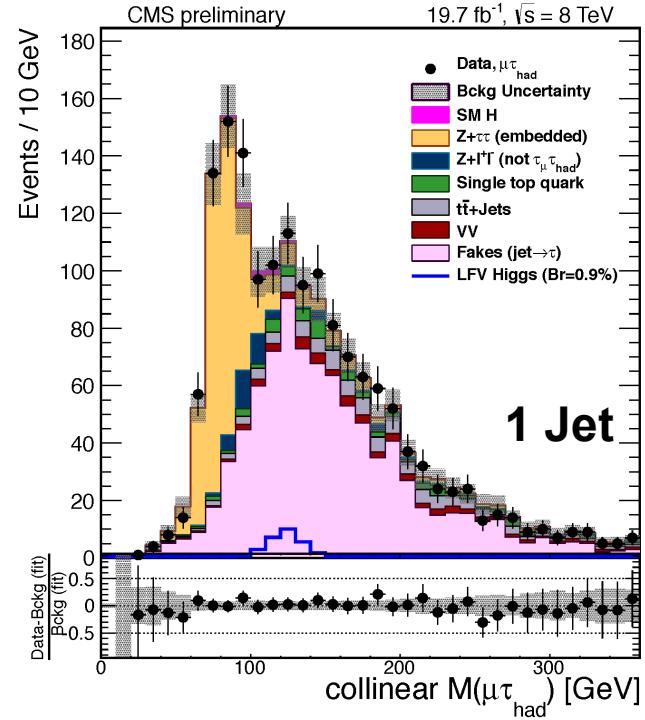
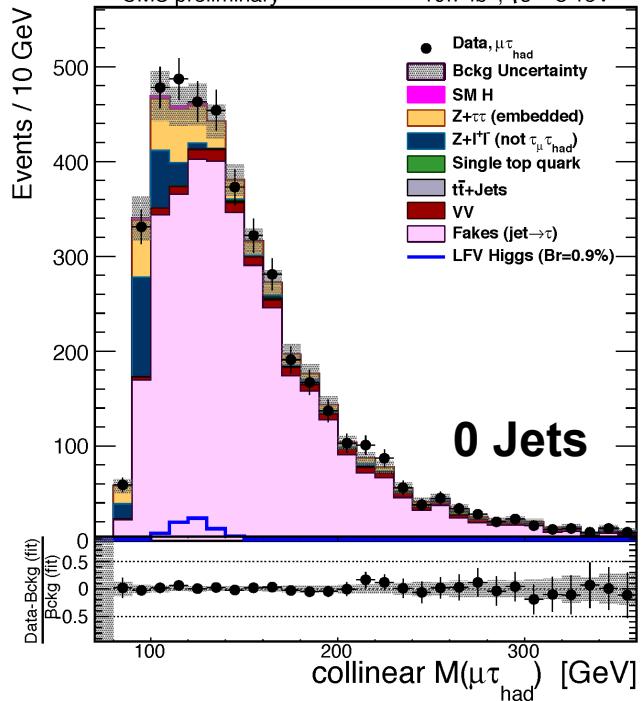




$\mu\tau_e$   
 $(Br(H \rightarrow \mu\tau) = 0.9\%)$



Lead systematic uncertainty:  
background estimation



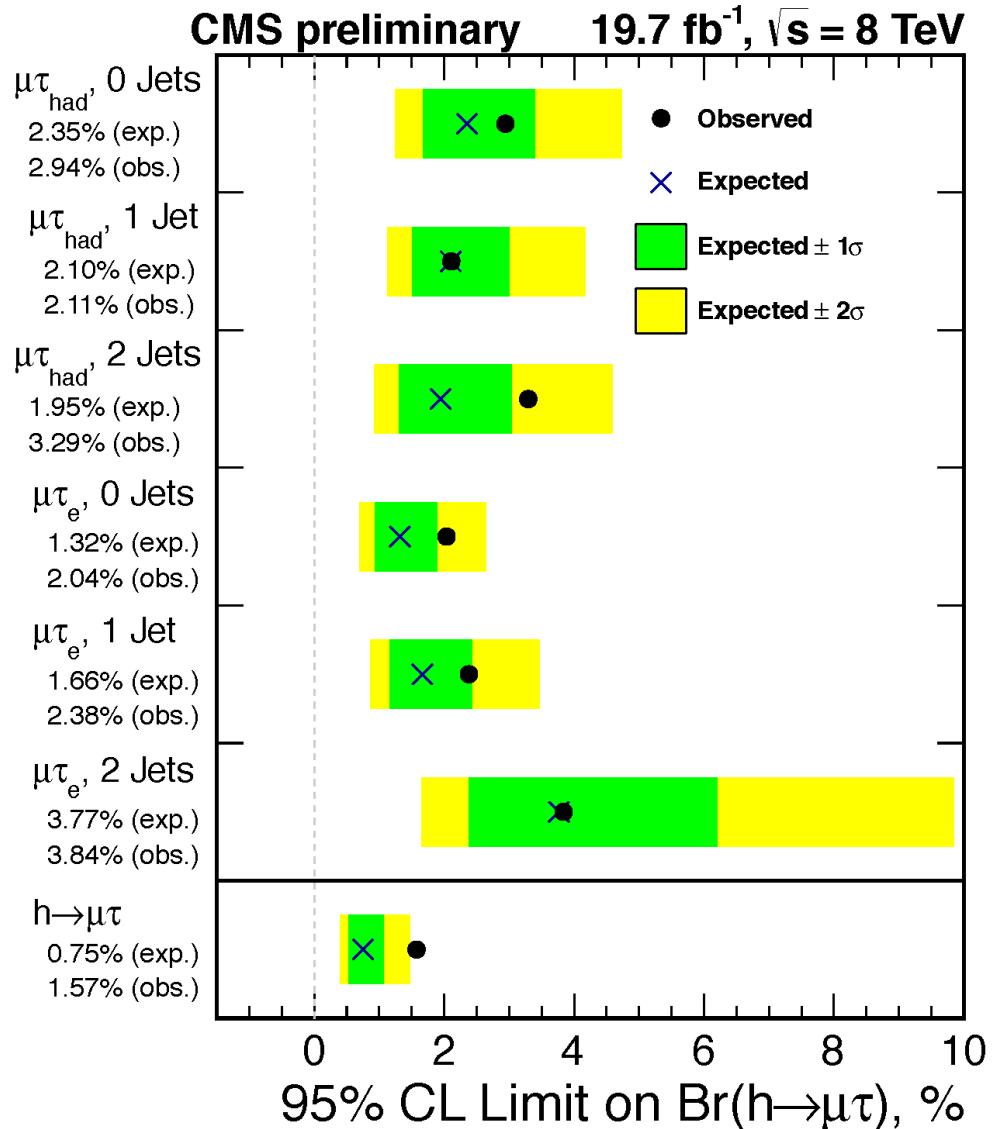
# $\mu\tau_{\text{had}}$

( $\text{Br}(H \rightarrow \mu\tau) = 0.9\%$ )

Lead systematic uncertainty:  
misidentified lepton yield

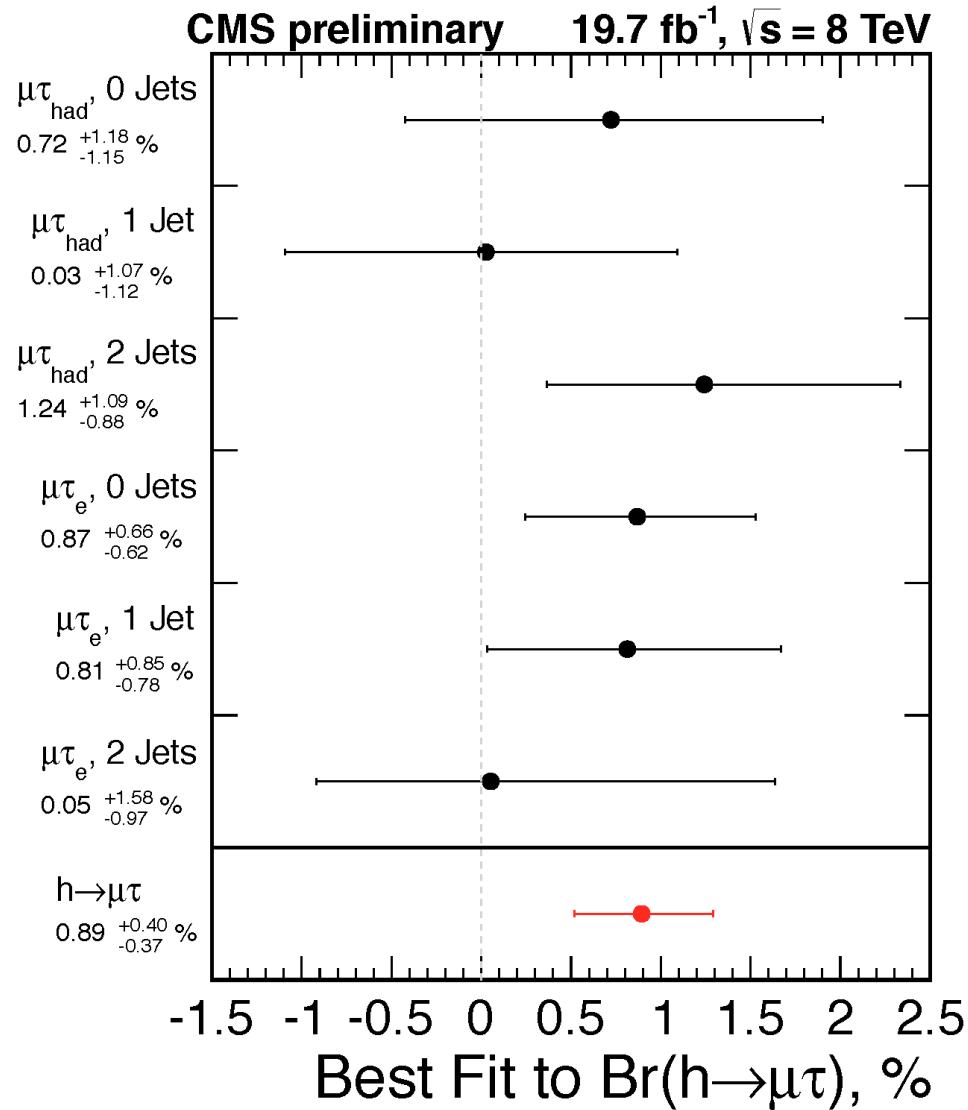
# Observed vs Expected Limits

- Fit to the collinear mass distribution using templates of background and signal shapes
- Systematic uncertainties treated as nuisance parameters in the fit
- Small deviations per category (at most 1sigma)
- Combined they yield a 2.5 sigma deviation from the expected Br Limit



# Best Fit to the Branching Ratio

- Fit to the collinear mass distribution using templates of background and signal shapes
- Systematic uncertainties treated as nuisance parameters in the fit
- Small deviations per category (at most  $\sim 1\sigma$ )



# Interpretation: Off-Diagonal Yukawa couplings

- The width of the LFV Higgs decay can be determined from the LFV Yukawa couplings in the Lagrangian

$$L_V \equiv -Y_{\tau u} \bar{\tau}_L \mu_R h - \dots \Rightarrow \Gamma(h \rightarrow \ell^\alpha \ell^\beta) = \frac{m_h}{8\pi} \left( |Y \ell^\alpha \ell^\beta|^2 + |Y \ell^\beta \ell^\alpha|^2 \right)$$

- Dependence of width on LFV couplings gives dependence of BR on LFV couplings

$$\text{BR}(h \rightarrow \ell^\alpha \ell^\beta) = \frac{\Gamma(h \rightarrow \ell^\alpha \ell^\beta)}{\Gamma(h \rightarrow \ell^\alpha \ell^\beta) + \Gamma_{\text{SM}}}$$

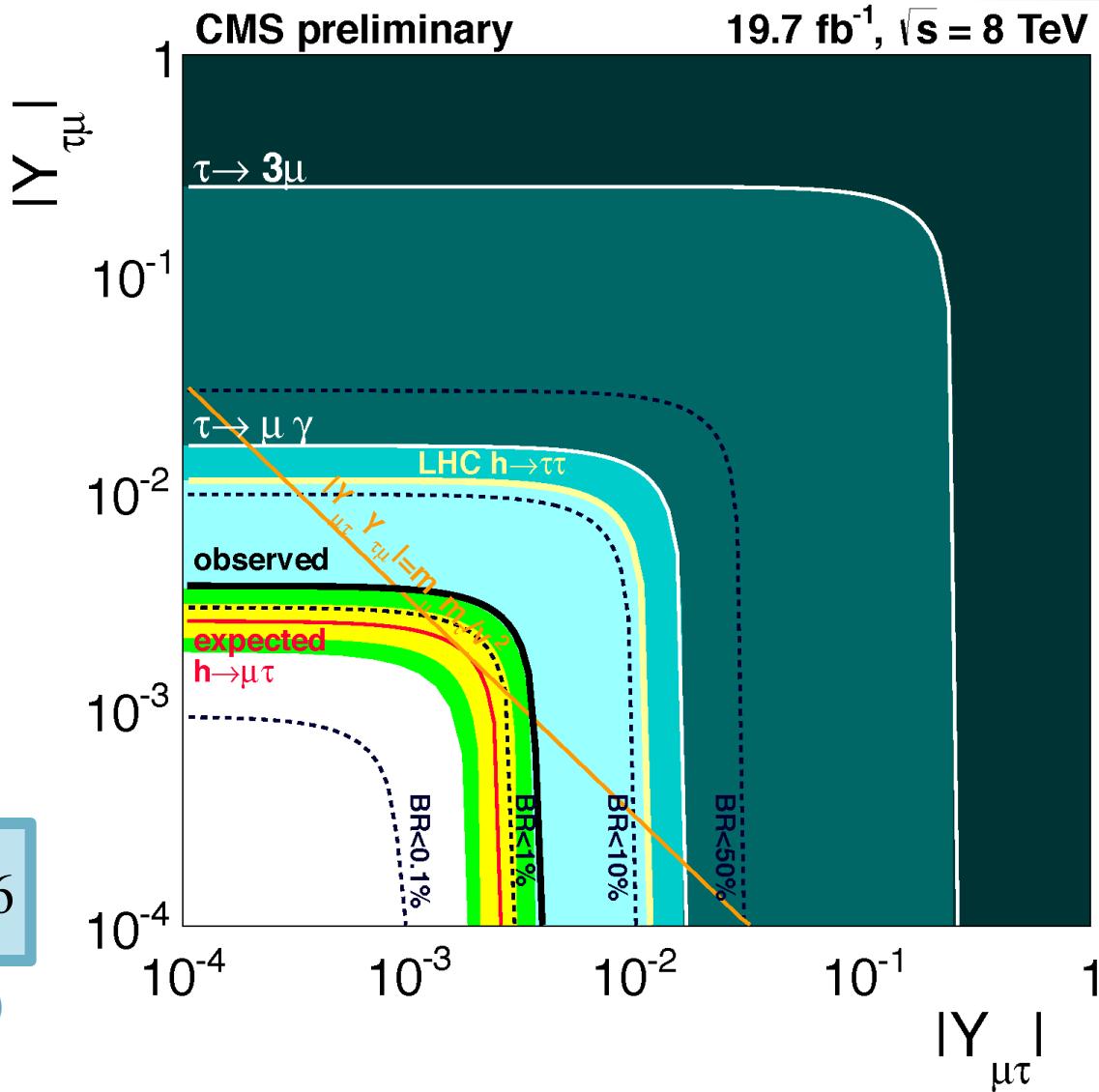
$$\left( |Y_{\mu\tau}|^2 + |Y_{\tau\mu}|^2 \right) = \frac{8\pi}{m_h} \frac{BR(h \rightarrow \mu\tau)\Gamma_{\text{SM}}}{1 - BR(h \rightarrow \mu\tau)}$$



# New limit on $|Y_{\mu\tau}|$

- Already digging into the “natural” regime
- 1 order of magnitude better than the pre-LHC limits

$$\sqrt{|Y_{\mu\tau}|^2 + |Y_{\tau\mu}|^2} < 0.0036 \quad (\text{at 95% CL})$$



## SUMMARY



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- The SM-like Higgs boson discovery opens a era of Higgs precision physics
  - **Comprehensive set of production and decay measurements performed using the 7 and 8 TeV CMS data**
  - Searches in rarer modes become sensitive enough for discovery
- CMS performed the first ever direct search for LFV Higgs decays
  - The branching ratio for LFV decay to  $\mu\tau$  is constrained to be less than 1.57 % (one order of magnitude better than previous experimental constraints)
  - The expected BR limit was 0.75 %
  - A small excess at  $2.5\sigma$  level with p-value of 0.007 is intriguing
    - More data is needed to extract conclusions



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- What next?
  - The LHC Run II @ 13 TeV →  $100 \text{ fb}^{-1}$  is critical
  - Upgrades to accelerator and detector are underway
  - Promising exploration of new physics just around the corner



BACK-UP



# Previous limits on $|Y_{ii}|$

Channel	Coupling	Bound
$\mu \rightarrow e\gamma$	$\sqrt{ Y_{\mu e} ^2 +  Y_{e\mu} ^2}$	$< 3.6 \times 10^{-6}$
$\mu \rightarrow 3e$	$\sqrt{ Y_{\mu e} ^2 +  Y_{e\mu} ^2}$	$\lesssim 3.1 \times 10^{-5}$
electron $g - 2$	$\text{Re}(Y_{e\mu} Y_{\mu e})$	$-0.019 \dots 0.026$
electron EDM	$ \text{Im}(Y_{e\mu} Y_{\mu e}) $	$< 9.8 \times 10^{-8}$
$\mu \rightarrow e$ conversion	$\sqrt{ Y_{\mu e} ^2 +  Y_{e\mu} ^2}$	$< 4.6 \times 10^{-5}$
$M-\bar{M}$ oscillations	$ Y_{\mu e} + Y_{e\mu}^* $	$< 0.079$
$\tau \rightarrow e\gamma$	$\sqrt{ Y_{\tau e} ^2 +  Y_{e\tau} ^2}$	$< 0.014$
$\tau \rightarrow 3e$	$\sqrt{ Y_{\tau e} ^2 +  Y_{e\tau} ^2}$	$\lesssim 0.12$
electron $g - 2$	$\text{Re}(Y_{e\tau} Y_{\tau e})$	$[-2.1 \dots 2.9] \times 10^{-3}$
electron EDM	$ \text{Im}(Y_{e\tau} Y_{\tau e}) $	$< 1.1 \times 10^{-8}$
$\tau \rightarrow \mu\gamma$	$\sqrt{ Y_{\tau\mu} ^2 +  Y_{\mu\tau} ^2}$	0.016
$\tau \rightarrow 3\mu$	$\sqrt{ Y_{\tau\mu}^2 +  Y_{\mu\tau} ^2 }$	$\lesssim 0.25$
muon $g - 2$	$\text{Re}(Y_{\mu\tau} Y_{\tau\mu})$	$(2.7 \pm 0.75) \times 10^{-3}$
muon EDM	$\text{Im}(Y_{\mu\tau} Y_{\tau\mu})$	$-0.8 \dots 1.0$
$\mu \rightarrow e\gamma$	$( Y_{\tau\mu} Y_{\tau e} ^2 +  Y_{\mu\tau} Y_{e\tau} ^2)^{1/4}$	$< 3.4 \times 10^{-4}$

R. Harnik, J.  
Kopp, J. Zupan,

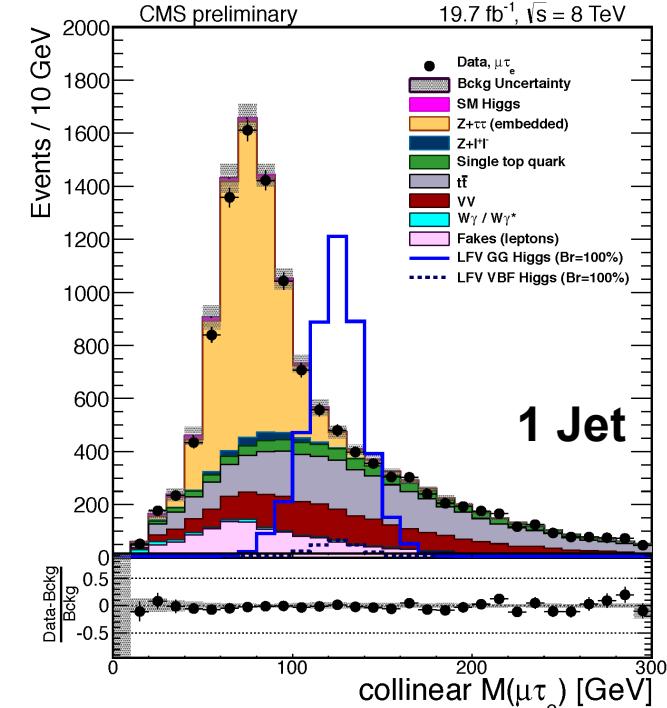
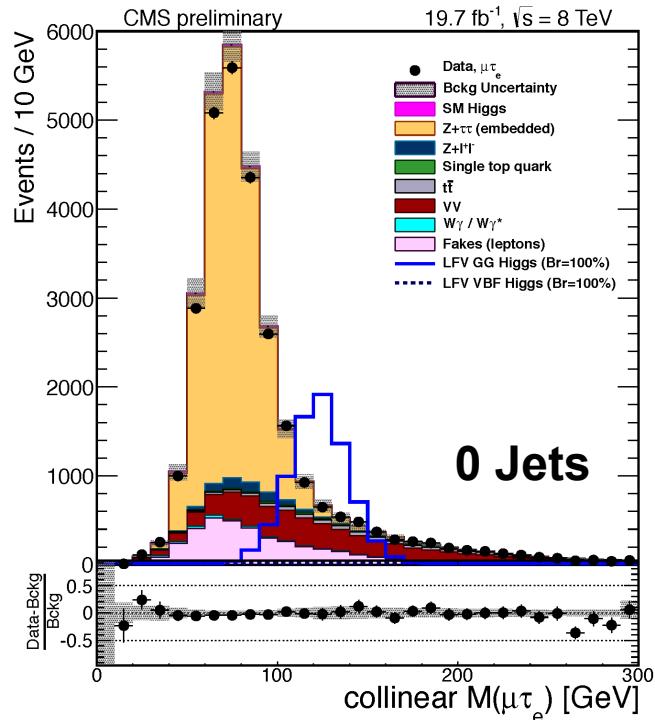
arXiv:1209.1397

(and references  
therein)

# Observed vs Expected Limits

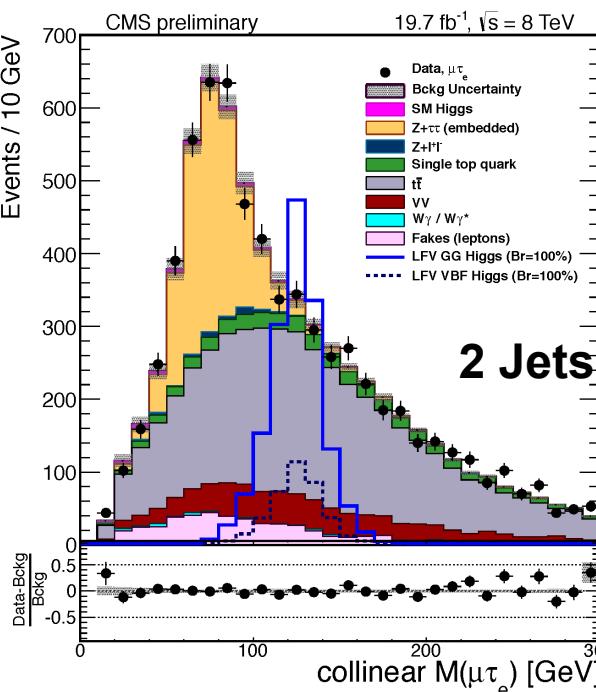
Expected limits			
	0 Jet (%)	1 Jet (%)	2 Jets (%)
$\mu\tau_e$	$< 1.32 (\pm 0.67)$	$< 1.66 (\pm 0.85)$	$< 3.77 (\pm 1.92)$
$\mu\tau_{had}$	$< 2.35 (\pm 1.20)$	$< 2.10 (\pm 1.07)$	$< 1.94 (\pm 0.99)$
$\mu\tau$			$< 0.75 (\pm 0.38)$
Observed limits			
$\mu\tau_e$	$< 2.04$	$< 2.38$	$< 3.84$
$\mu\tau_{had}$	$< 2.94$	$< 2.11$	$< 3.29$
$\mu\tau$			$< 1.57$ <b>Small Excess</b>
Best fit branching fractions			
$\mu\tau_e$	$0.87^{+0.66}_{-0.62}$	$0.81^{+0.85}_{-0.78}$	$0.05^{+1.58}_{-0.97}$
$\mu\tau_{had}$	$0.72^{+1.18}_{-1.15}$	$0.03^{+1.07}_{-1.12}$	$1.24^{+1.09}_{-0.88}$
$\mu\tau$			$0.89^{+0.40}_{-0.37}$





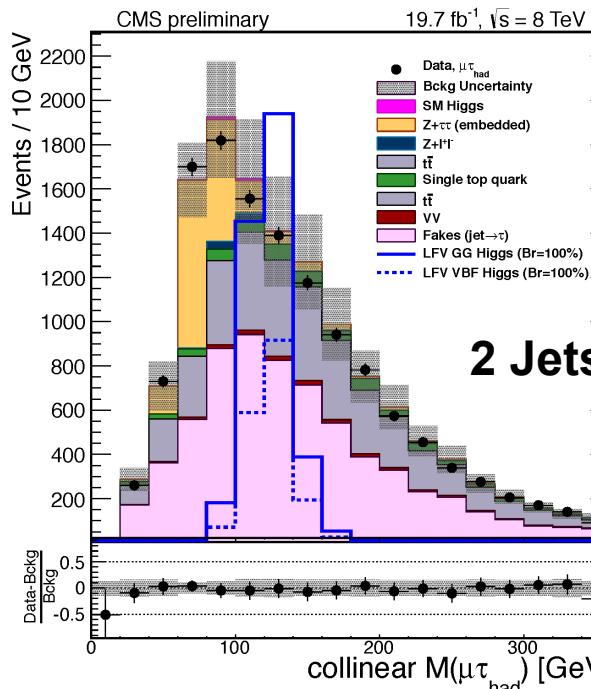
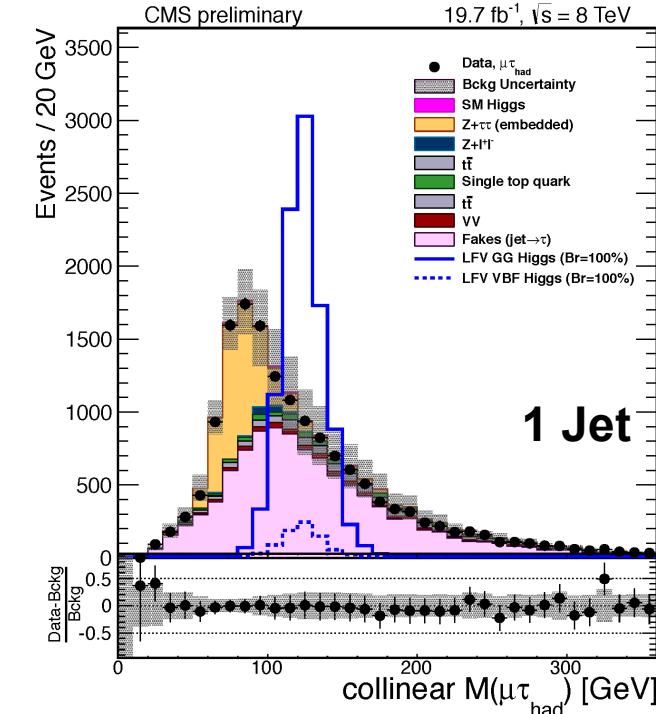
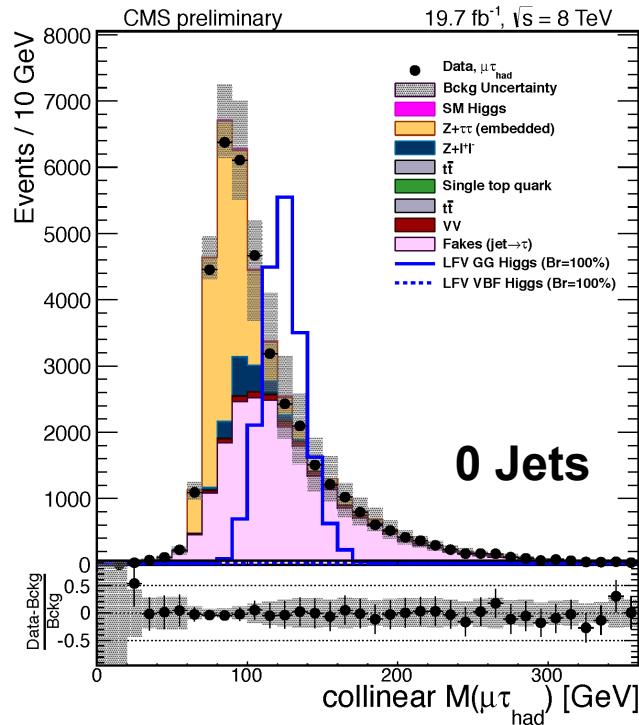
$\mu\tau_e$

Preselection /  
Control Region



$\text{Br}(H \rightarrow \mu\tau) = 100\%$

Excellent data/  
mc agreement



$\text{Br}(H \rightarrow \mu\tau) = 100\%$

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# $\mu\tau_{\text{had}}$

## Preselection / Control Region

# Systematic Uncertainties

- **Background modeling (specially the fake background) is the lead experimental systematic uncertainty**
  - Normalization uncertainty taken either from our data driven estimates or from CMS measurements and correlated between bins
  - Additional uncorrelated uncertainty include to account for potential control region biases
- **The remaining experimental uncertainties (eg: lepton efficiencies) come from dedicated data studies performed centrally in CMS**

Systematic Uncertainty	$H \rightarrow \mu\tau_e$			$H \rightarrow \mu\tau_{had}$		
	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%
$Z \rightarrow \tau\tau$ background	3+3*%	3+5*%	3+10*%	3+5*%	3+5*%	3+10*%
$Z \rightarrow \mu\mu, ee$ background	30%	30%	30%	30%	30%	30%
misidentified muon and electron background	40%	40%	40%	-	-	-
misidentified hadronic tau background	-	-	-	30+10*%	30%	30%
$WW, ZZ + \text{jets}$ background	15%	15%	15%	15%	15%	65%
$t\bar{t} + \text{jets}$ 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%

# Systematic Uncertainties

- Additional experimental systematic uncertainties (effects on the mass resolution and shape):

Systematic	$H \rightarrow \mu\tau_e$	$H \rightarrow \mu\tau_{had}$
Hadronic Tau energy scale	-	3%
Jet Energy scale	3-7%	3-7%
Unclustered energy scale	10%	10 %
$Z(\tau\tau)$ Bias	100%	-

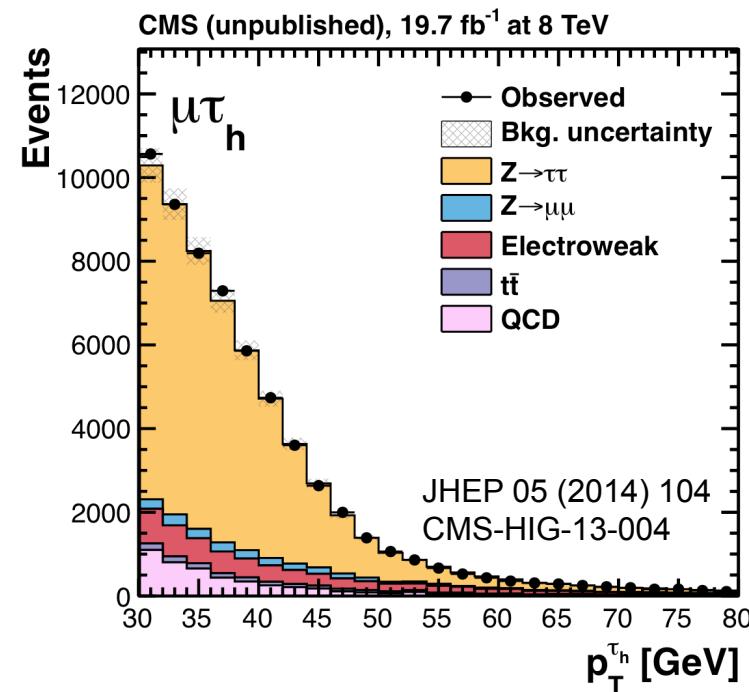
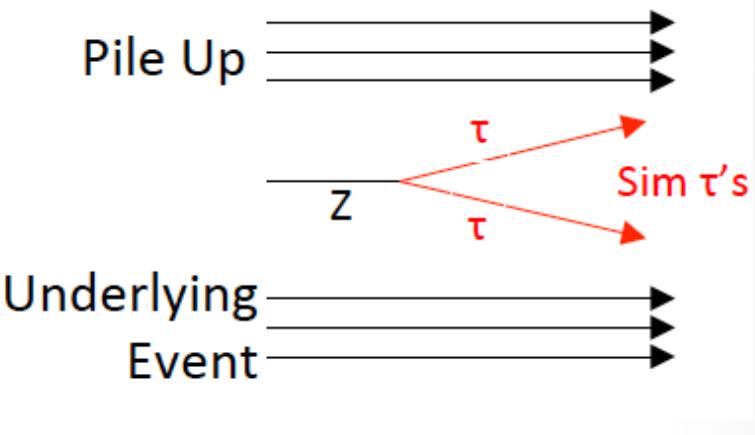
- Theoretical uncertainties:

Uncertainty	Gluon-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%



# $Z \rightarrow \tau\tau$ Modeling

- $Z \rightarrow \tau\tau$  is the dominant background in the  $\mu\tau_e$  channel and significant in the  $\mu\tau_{had}$  channel
- Very similar kinematics to the SM  $H \rightarrow \tau\tau$  & the signal
- Overall 3% yield systematic uncertainty → from  $Z \rightarrow \tau\tau$  cross-section
- Shape modeling using the embedded technique developed by  $H \rightarrow \tau\tau \rightarrow$  exploits the  $20 \text{ fb}^{-1}$  CMS  $Z \rightarrow \mu\mu$  dataset to model key issues like PU, MET → we rely on MC only for the tau decay



# Jet→Lepton misidentification

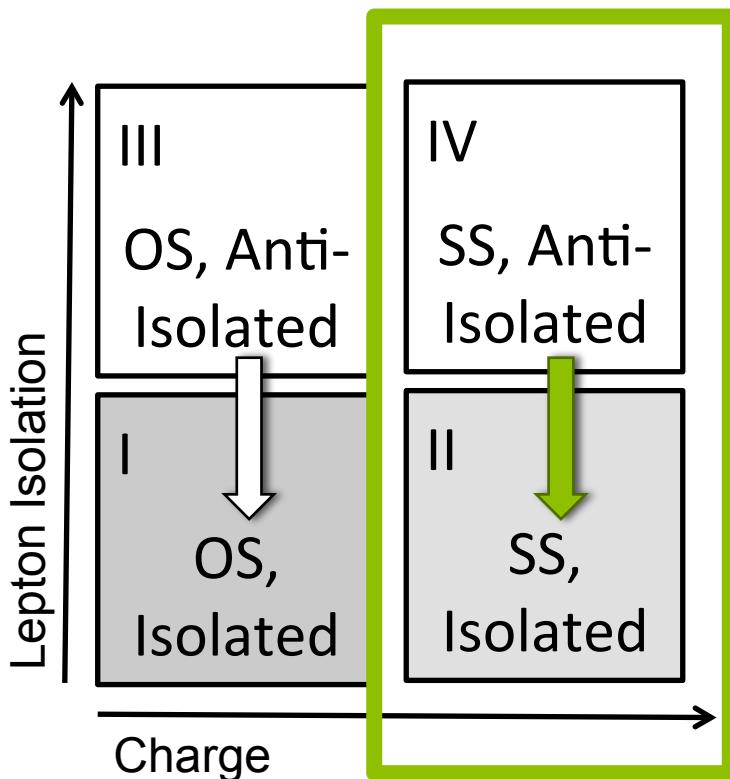
- Leptons can arise from mis-id'ed jets in W+Jets and QCD multijet events → Difficult to model on MC → will be estimated directly on data

- ① **Measure the misidentification rate (fake rate) in an independent  $Z\mu\mu$  sample**
  - ② **Apply this ratio of non-isolated to isolated muons to a data sample with anti-isolation required for one lepton that otherwise fulfills all selection criteria**
  - ③ **Validate on a same sign dilepton sample (no signal)**
- This technique can be applied to obtain Jet→Tau, Jet→Electron, Jet→Muon misidentified lepton contributions

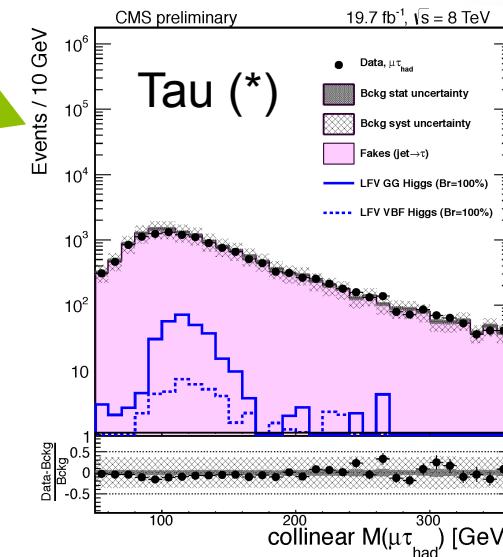
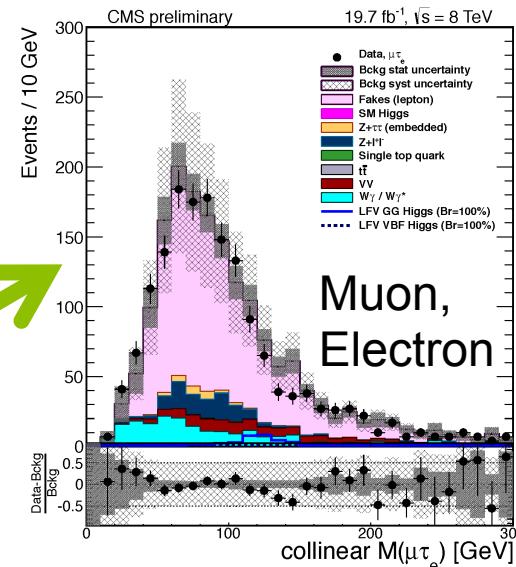


**Shape and yield prediction**  
for fake lepton backgrounds  
(mainly W+Jets)

# Jet $\rightarrow$ Lepton misidentification



Validation based on a SameSign Lepton control sample  
 Conservative uncertainties (yield (30-40%) and shape)  
 Excellent description of the data

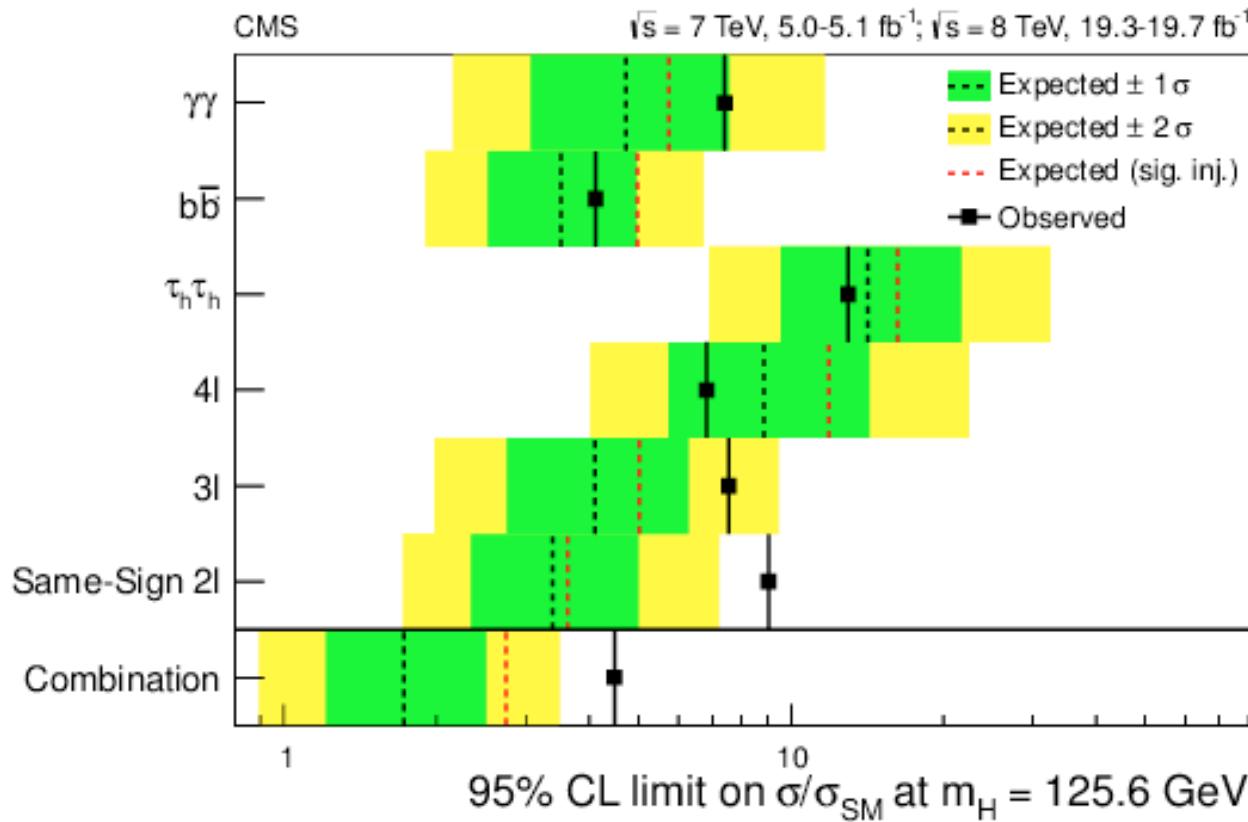


(\* for tau leptons, the anti isolated candidates of regions III and IV are substituted by loosely isolated candidates that fail to pass the strict criteria of regions I and II)

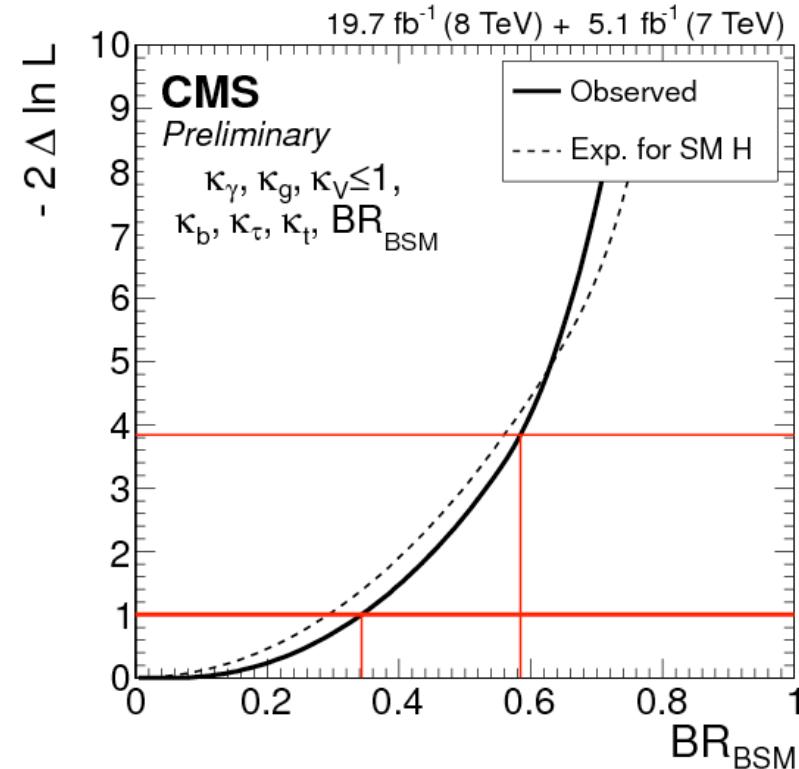
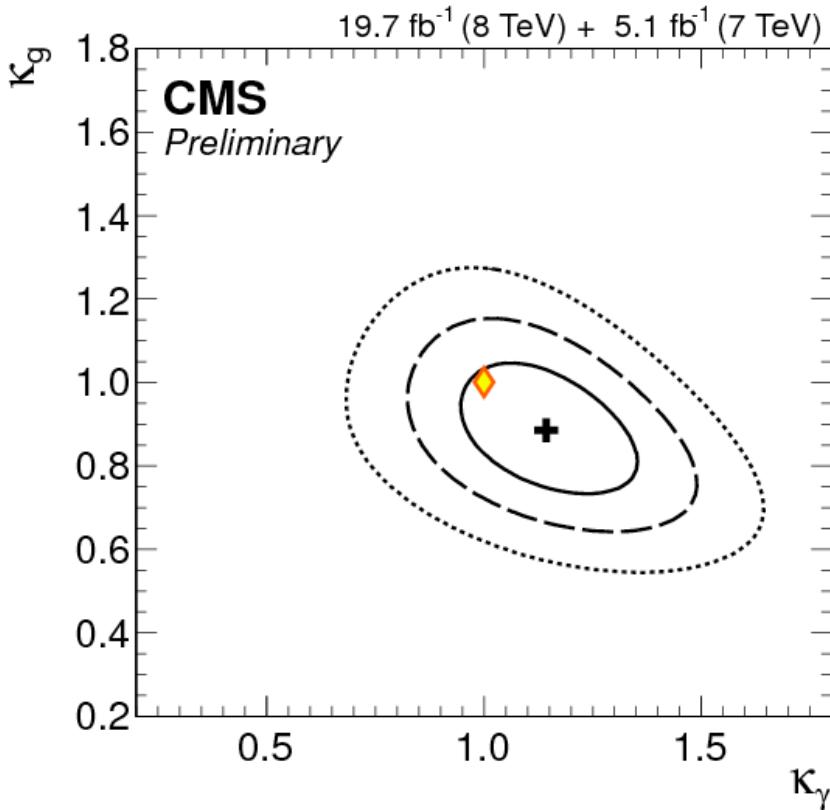


# Coupling to Top Quark

- Observes an excess of  $3.4\sigma$  ( $1.2\sigma$  expected) for  $m_H = 125.6$  GeV, driven by one channel (same sign dimuons)
- Best Fit of the signal strength  $\mu = 2.8^{+1.0}_{-1.9}$



# It couples like the SM Higgs Boson...



- New physics can show up in loop mediated processes
- $\text{BR}(\text{BSM}) < 0.32$  if we fix all tree level couplings to the SM values
- $\text{BR}(\text{BSM}) < 0.58$  for  $\kappa_V \leq 1$

# The Compact Muon Solenoid

## CMS DETECTOR

Total weight : 14,000 tonnes  
Overall diameter : 15.0 m  
Overall length : 28.7 m  
Magnetic field : 3.8 T

STEEL RETURN YOKE  
12,500 tonnes

SILICON TRACKERS  
Pixel (100x150  $\mu\text{m}$ )  $\sim 16\text{m}^2 \sim 66\text{M}$  channels  
Microstrips (80x180  $\mu\text{m}$ )  $\sim 200\text{m}^2 \sim 9.6\text{M}$  channels

SUPERCONDUCTING SOLENOID  
Niobium titanium coil carrying  $\sim 18,000\text{A}$

MUON CHAMBERS  
Barrel: 250 Drift Tube, 480 Resistive Plate Chambers  
Endcaps: 468 Cathode Strip, 432 Resistive Plate Chambers

PRESHOWER  
Silicon strips  $\sim 16\text{m}^2 \sim 137,000$  channels

FORWARD CALORIMETER  
Steel + Quartz fibres  $\sim 2,000$  Channels

CRYSTAL  
ELECTROMAGNETIC  
CALORIMETER (ECAL)  
 $\sim 76,000$  scintillating  $\text{PbWO}_4$  crystals

HADRON CALORIMETER (HCAL)  
Brass + Plastic scintillator  $\sim 7,000$  channels

