Search for the Lepton Flavor Violating Higgs decay H → τμ

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SM Coupling Structure

SM: NO LFV H Decays!

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

General MHDM: flavor violating decays allowed (tree level)

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

Similar for quark sector → Problem!
No FCNC observed so far!

- **3+X solutions to solve this problem:**
  - 2HDM Type-I: impose a discrete symmetry to couple only one doublet to fermions
  - 2HDM Type-II: impose a discrete symmetry to couple Q=2/3 quarks to one doublet and Q=-1/3 quarks to the other
  - 2HDM Type-III: no discrete symmetries are introduced, but phenomenological constraints on the flavor changing couplings $L_Y = -Y^a_{ij} \left(\bar{f}^i_L f^j_R \right) h^a + h.c.$

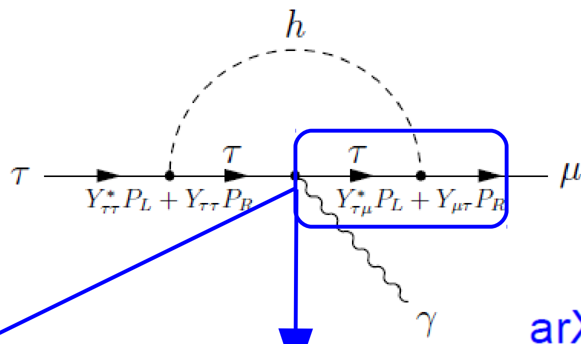
ad hoc introduction

2HDMs: Coupling Structure

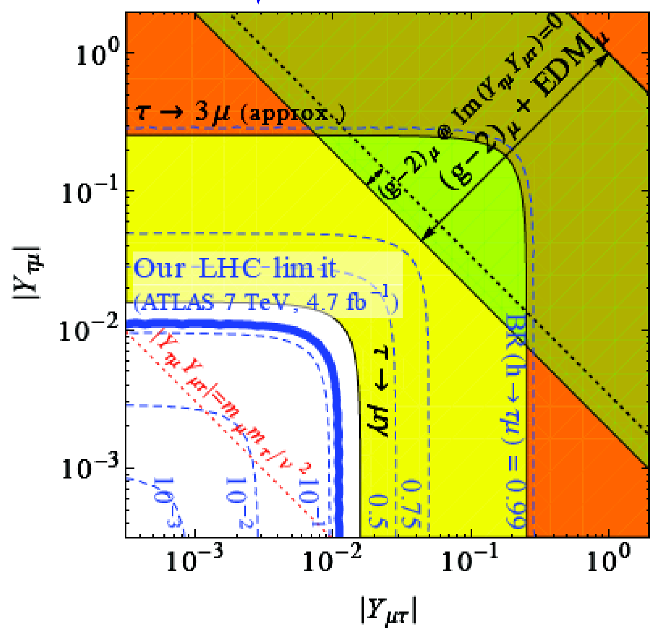
$$Y_{ll'} \propto m_l m_{l'}$$

SM values

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



arXiv:1209.1397

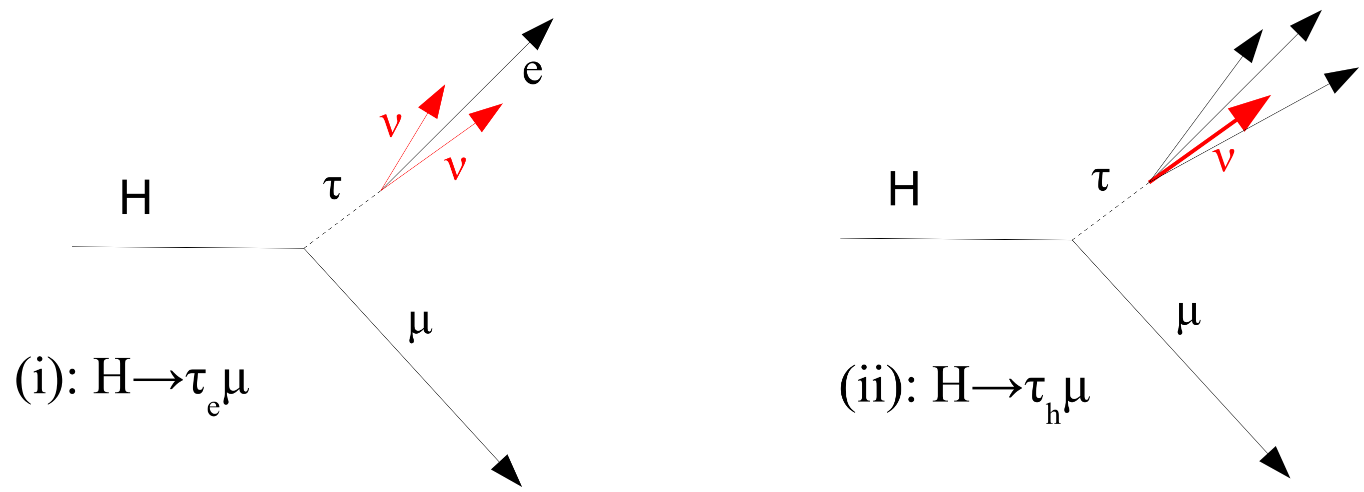


Flavor Violating Higgs Decays. Roni Harnik, Joachim Kopp, Jure Zupan. Sep 2012 FERMILAB-PUB-12-498-T

The $Y_{\mu\tau}$ coupling is constraint by low energy measurements!
But still a BR($H \rightarrow \mu\tau$) ≈ 10% **was** still allowed!

Introduction

- Search for exotic higgs decays: lepton flavor violating decays
- Not expected in the SM, but “perfectly” allowed within general 2HDMs



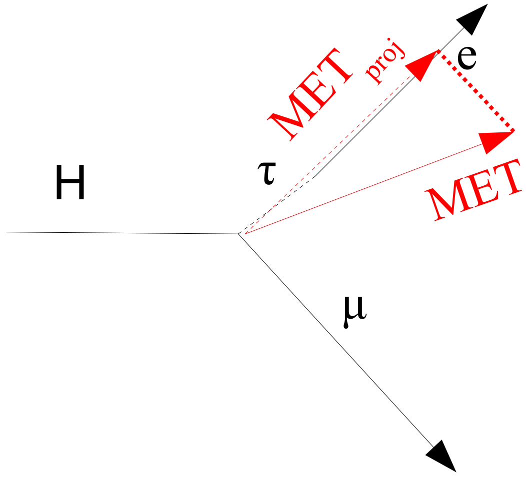
- Assumptions: m_{Higgs}=125 GeV (no Look-elsewhere effect)

General methodology and collinear mass approximation

- **2 channels: H→$\tau_h\mu$ and <u>H→$\tau_e\mu$</u>**
- <u>Split each channel into exclusive 0,1,2 Jets categories:</u>
  - 0 and 1 Jet categories are mostly sensitive to gluon-gluon production mode
  - 2 Jet category corresponds to VBF Higgs production
- <u>Mass reconstruction:</u>
  - Collinear mass approximation (projection method)
  - Assumption: neutrinos are collinear with the tau directions and thus with the lepton (e/μ)

$$M_{colMass} = \frac{M_{vis}}{\sqrt{x_{\tau_e}}}, \; x_{\tau_e} = \frac{P_T^{\tau_e}}{P_T^{\tau_e} + MET_{proj}}$$

$$MET_{proj} = \frac{E_x^{miss} \cdot P_x^{\tau_e} + E_y^{miss} \cdot P_y^{\tau_e}}{P_T^{\tau_e}}$$

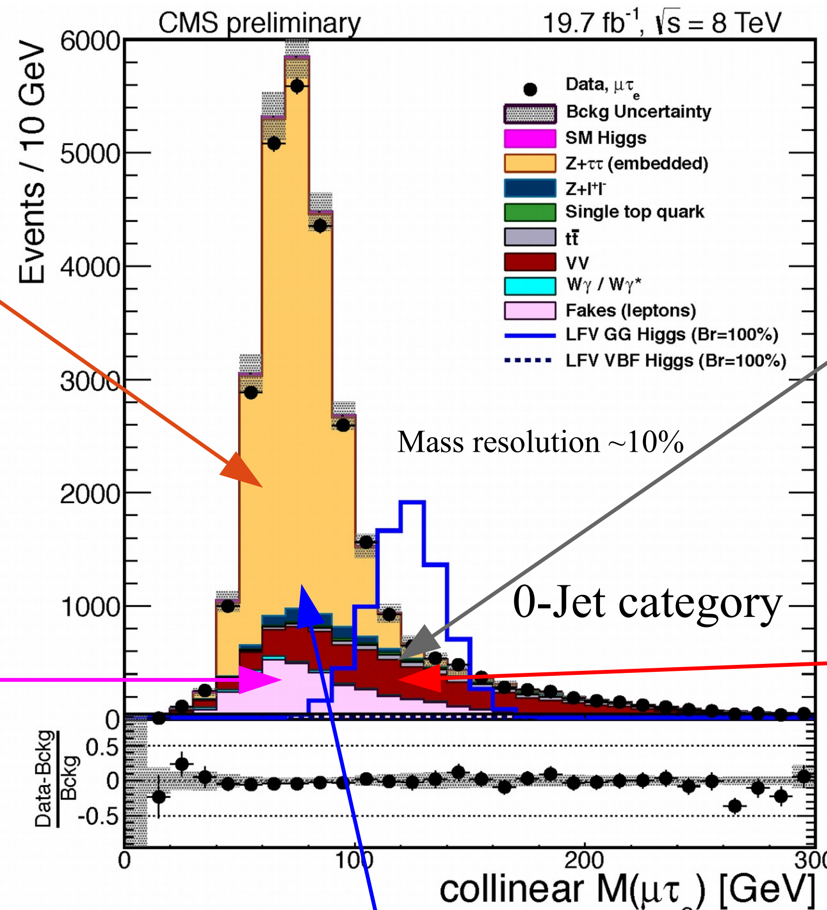


Background Summary: $H \rightarrow \mu\tau_e$

$Z \rightarrow \tau\tau$:
- Normalization from MC simulation
- Shape: PFEmbedding Method

W+Jets/QCD Multijets:
- Fakerate Method
- Shape from Anti-isolated lepton events

Estimated from data!

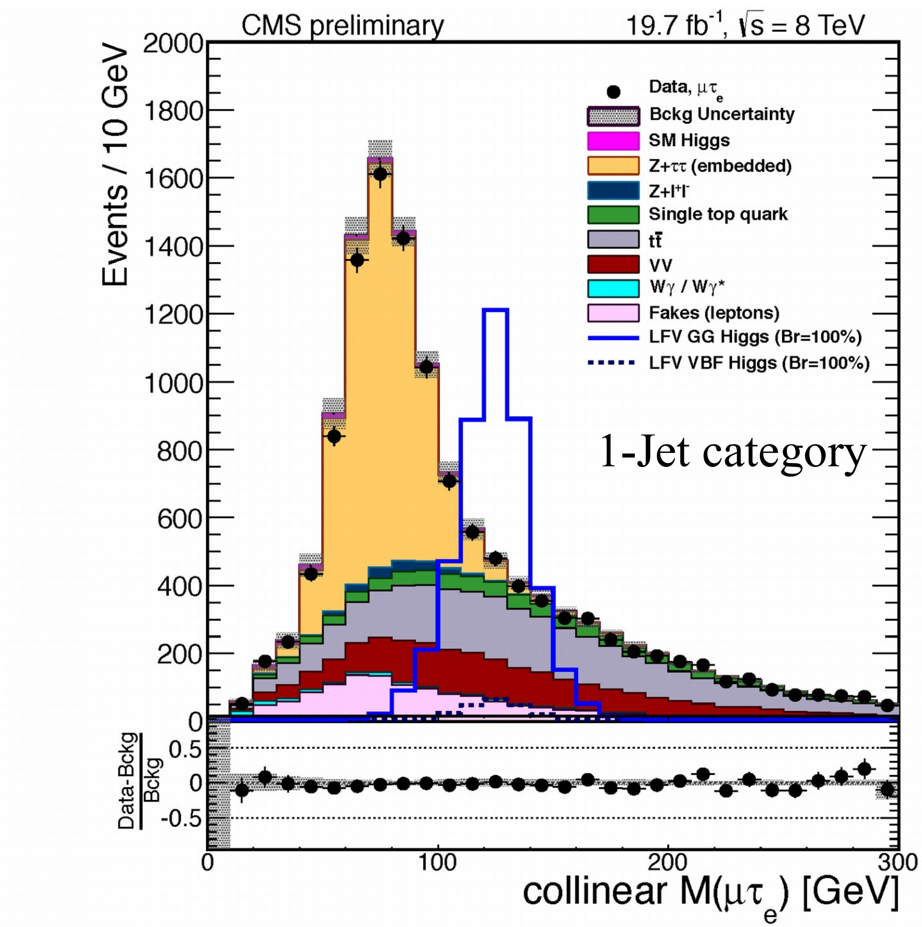


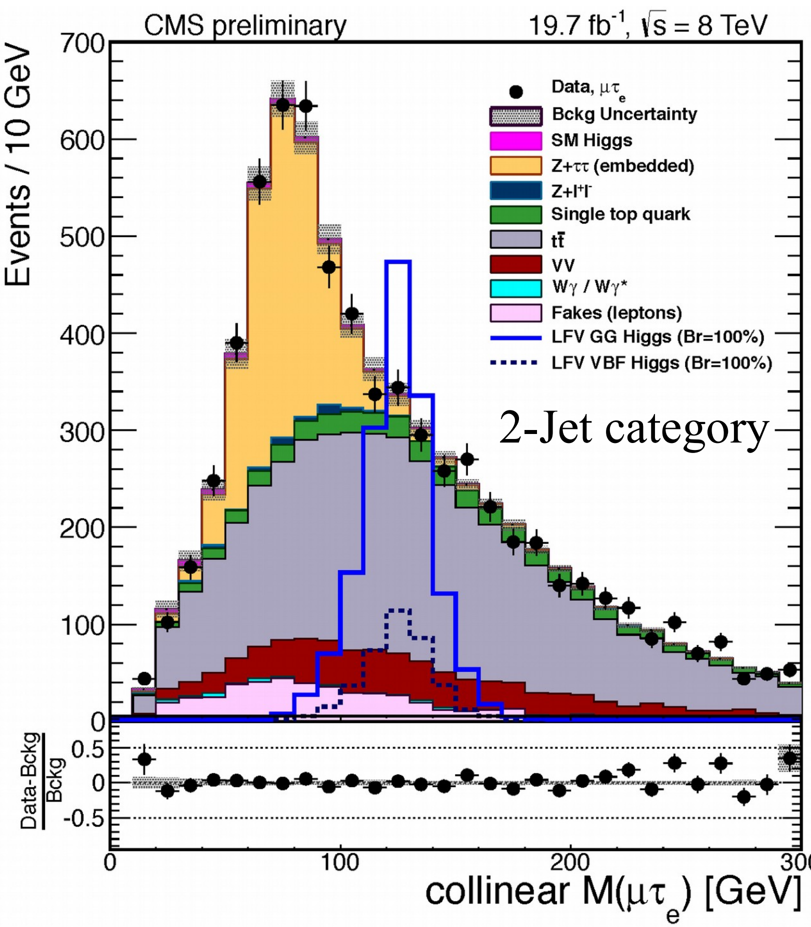
ttbar:
- Shape from MC simulations
- Normalization from control region

WW+Jets:
- Normalization(NLO) and shape from MC simulations

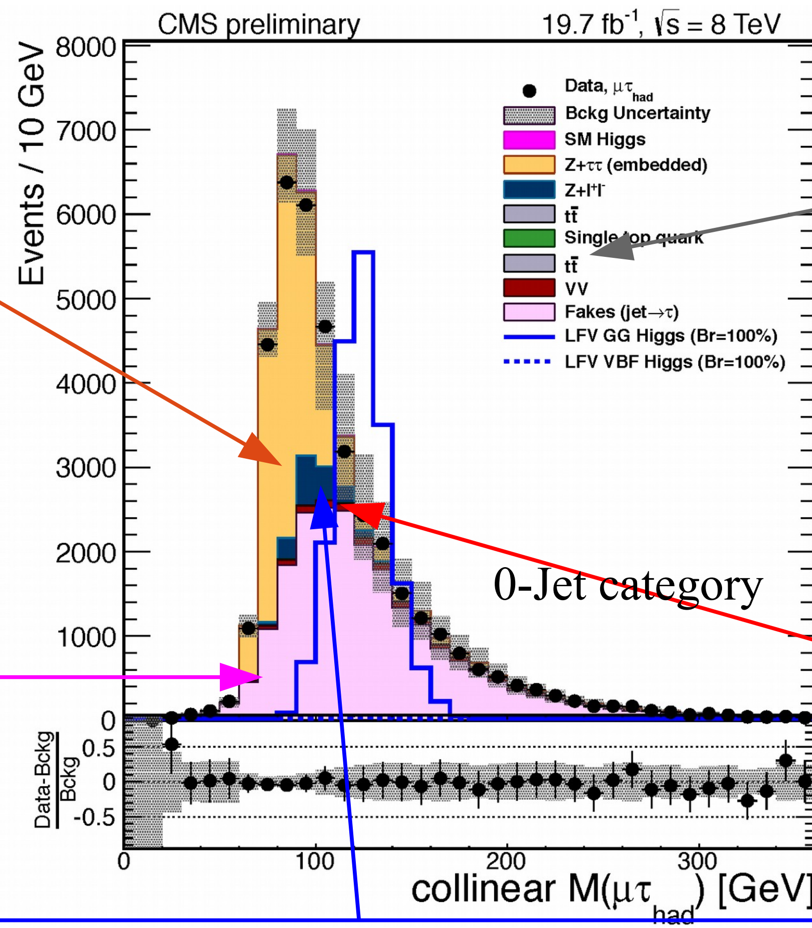
Wjets+γ(*), SingleTop,...:
- Normalization and shape from MC simulation

Background Summary: $H \rightarrow \mu\tau_e$





Background Summary: H → $\mu\tau_h$



Z → ττ:
- Normalization from MC simulation
- Shape: PFEmbedding Method

W+Jets/QCD Multijets:
- Fakerate Method
- Shape from Anti-isolated tau events

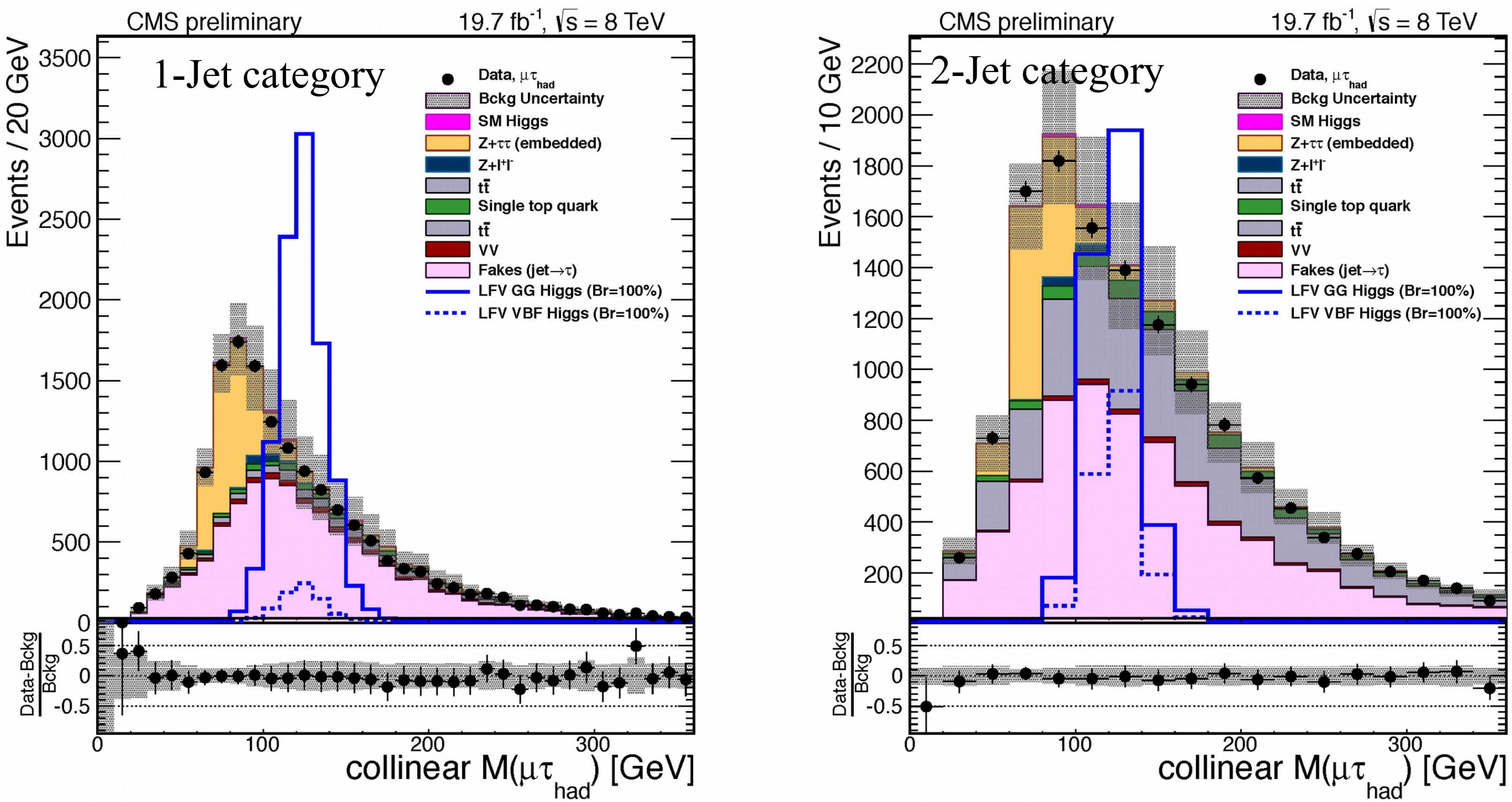
Estimated from data!

ttbar:
- Shape from MC simulations
- Normalization from control region

WW+Jets:
- Normalization(NLO) and shape from MC simulations

DY → ll, SingleTop,...:
- Normalization and shape from MC simulation

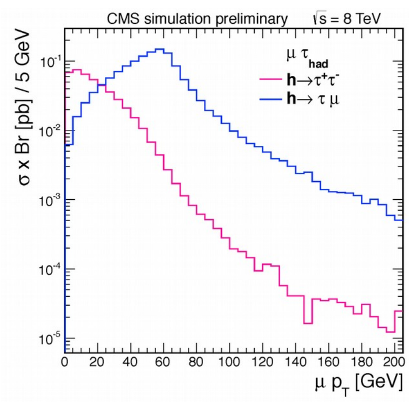
Background Summary: $H \rightarrow \mu\tau_h$

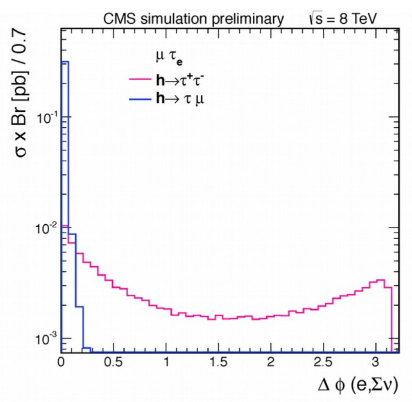


Signal Region

Signal region cuts optimized for S/√(S+B)

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





#Events in the Mcoll Higgs window: 100-150 GeV

Sample	$H \to \mu\tau_{had}$			$H \to \mu\tau_e$		
	0-jet	1-jet	2-jet	0-jet	1-jet	2-jet
Fakes	1858.1 ± 558.8	362.9 ± 110.0	0.5 ± 0.5	41.5 ± 17.3	16.1 ± 6.8	1.1 ± 0.7
$Z \to \tau\tau$	198.8 ± 11.0	50.5 ± 3.5	0.4 ± 0.2	65.0 ± 3.0	38.6 ± 2.0	1.3 ± 0.2
ZZ, WW	47.0 ± 8.0	14.6 ± 2.6	0.3 ± 0.2	40.8 ± 6.6	21.2 ± 3.5	0.7 ± 0.2
$W\gamma$	–	–	–	2.0 ± 2.1	1.9 ± 1.9	–
$Z \to ee$ or $\mu\mu$	94.5 ± 25.2	17.6 ± 6.7	0.1 ± 0.1	1.6 ± 0.8	1.8 ± 0.8	–
$t\bar{t}$	2.5 ± 0.6	24.3 ± 3.2	0.7 ± 0.3	4.8 ± 0.7	30.0 ± 3.4	1.8 ± 0.3
$t, \bar{t}$	2.7 ± 1.2	19.9 ± 3.9	0.4 ± 0.5	1.9 ± 0.2	6.8 ± 0.8	0.2 ± 0.1
SM Higgs background	7.0 ± 1.3	4.9 ± 0.7	1.9 ± 0.7	1.9 ± 0.3	1.6 ± 0.2	0.6 ± 0.1
Sum of backgrounds	2210.4 ± 559.6	494.7 ± 110.4	4.3 ± 1.1	159.4 ± 18.9	118.1 ± 8.9	5.6 ± 0.9
LFV Higgs signal	69.7 ± 17.0	29.7 ± 6.7	3.0 ± 1.0	24.2 ± 5.7	13.6 ± 3.1	1.2 ± 0.4
data	2255.0 ± 47.5	506.0 ± 22.5	8.0 ± 2.8	180.0 ± 13.4	128.0 ± 11.3	6.0 ± 2.4

BR(H → μτ)=0.9%

Signal Region & Uncertainties

M_{coll} independent uncertainties

Systematic Uncertainty	$H \to \mu\tau_e$			$H \to \mu\tau_{had}$		
	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%
misidentified muon and electron background	40%	40%	40%	-	-	-
misidentified hadronic tau 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%

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%

M_{coll} dependent uncertainties

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	100%	-

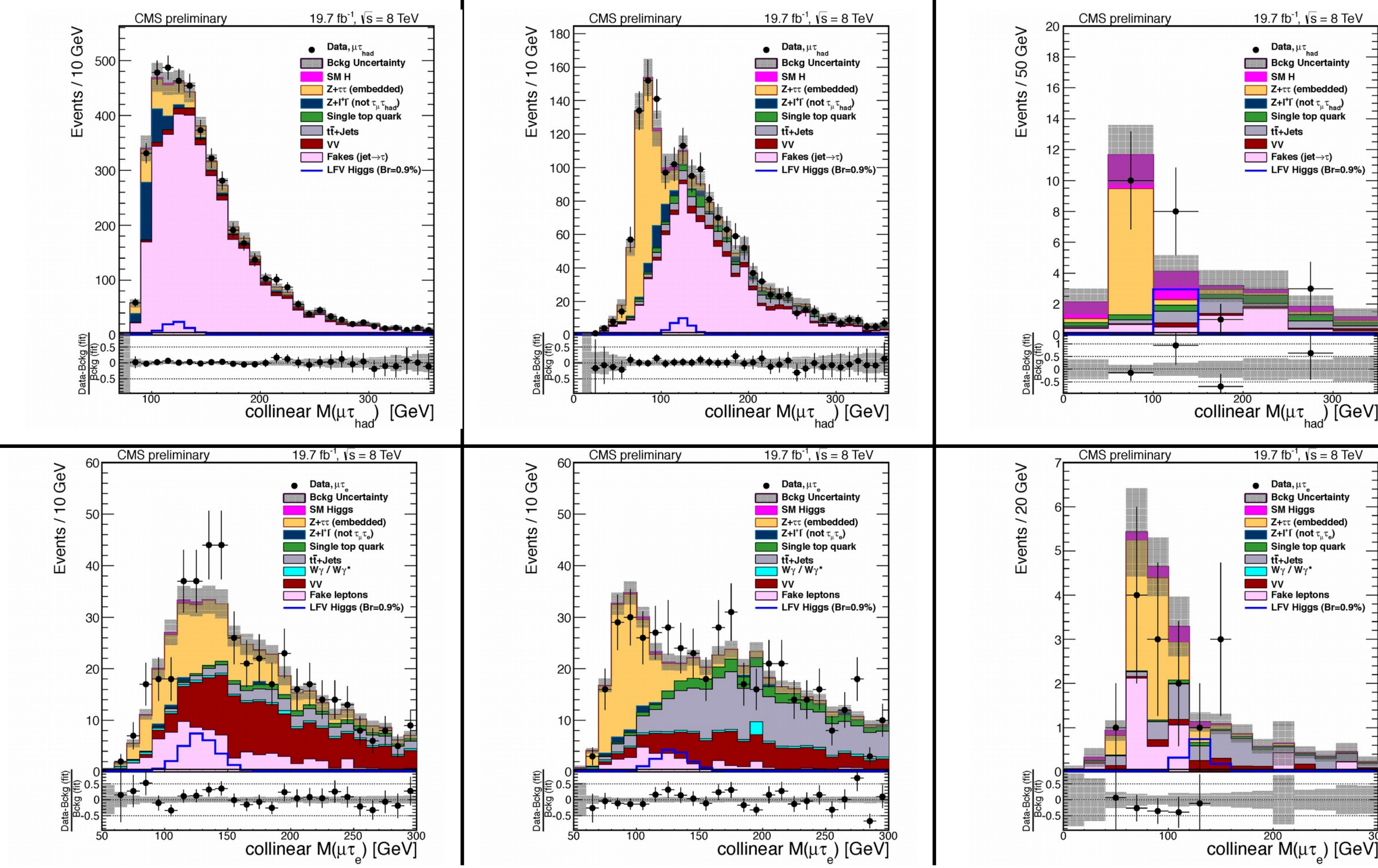
Results

6 channels: (τ_h, τ_e) x (0,1,2 Jet Cat.) are combined for current expected limits

	0-Jet Category	1-Jet Category	2-Jet Category

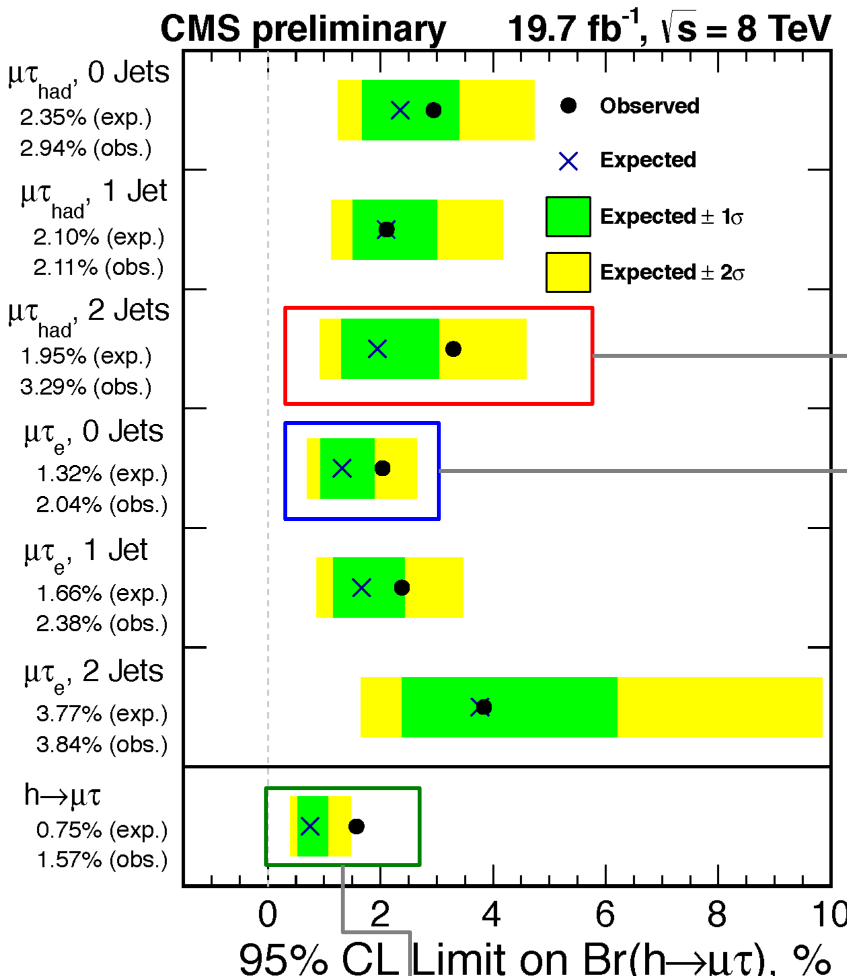
$H \rightarrow \tau_h \mu$

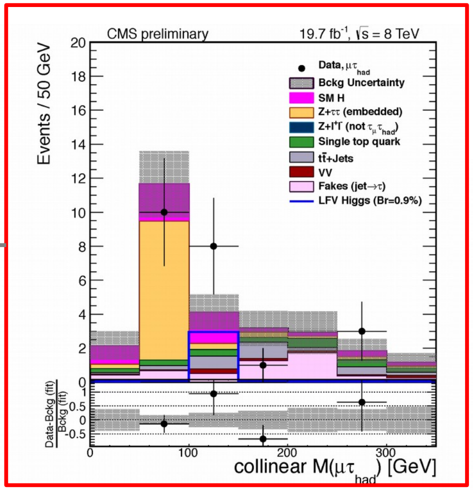
$H \rightarrow \tau_e \mu$

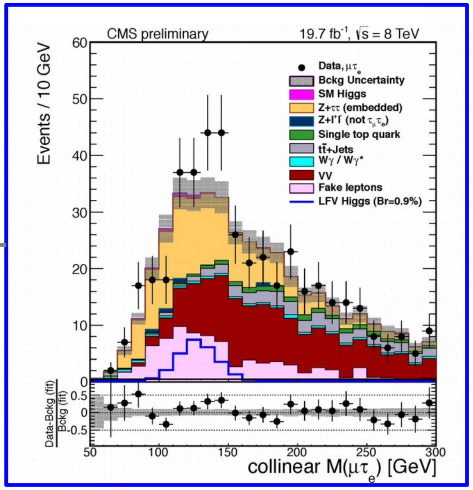


Post-Fit plots: global maximum likelihood fit!

Results

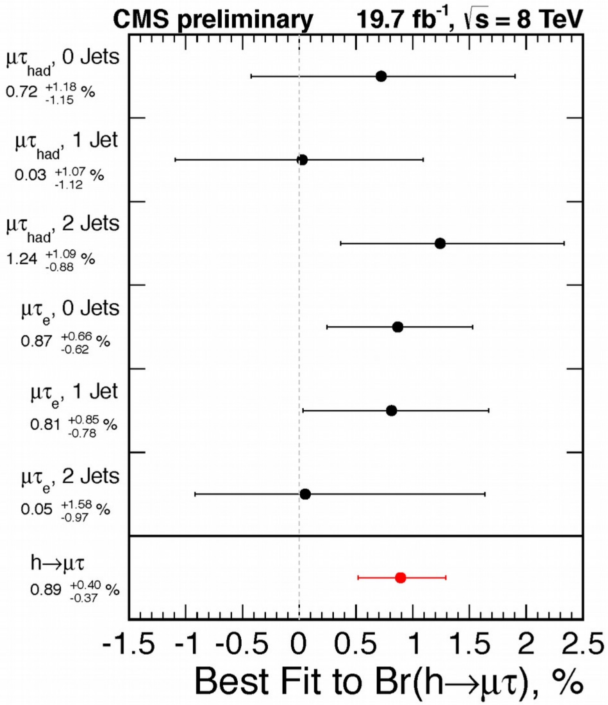






~2.5σ excess?

Assume to be Signal:



Best-Fit:

BR($h\to\mu\tau$) ~ 0.9 ±0.40

Limit on BR($h\to\mu\tau$) = 1.57% (0.75 expected)!

Interpretation

- The limit on the BR(H → τμ) can be reinterpreted as an limit on the corresponding flavor violating Yukawa coupling, following (arXiv:1209.1397):

$$BR(h \to l^{\alpha} l^{\beta}) = \frac{\Gamma(h \to l^{\alpha} l^{\beta})}{\Gamma(h \to l^{\alpha} l^{\beta}) + \Gamma_{SM}}$$

With the the decay width

$$\Gamma(h \to l^{\alpha} l^{\beta}) = \frac{m_h}{8\pi} \left(|Y_{l^{\alpha} l^{\beta}}|^2 + |Y_{l^{\beta} l^{\alpha}}|^2 \right)$$

$$l^{\alpha,\beta} = e, \mu, \tau \; with \; l^{\alpha} \neq l^{\beta}$$

- <u>Assumptions:</u>
  - SM Higgs width is Γ_{SM}=4.1 MeV for a 125 GeV Higgs
  - At most one of the non-standard decay mode of the Higgs is significant compared to SM decay width

Limit on Yukawa Coupling

- The limit

$$BR(H \to \tau\mu) < 1.57\%$$

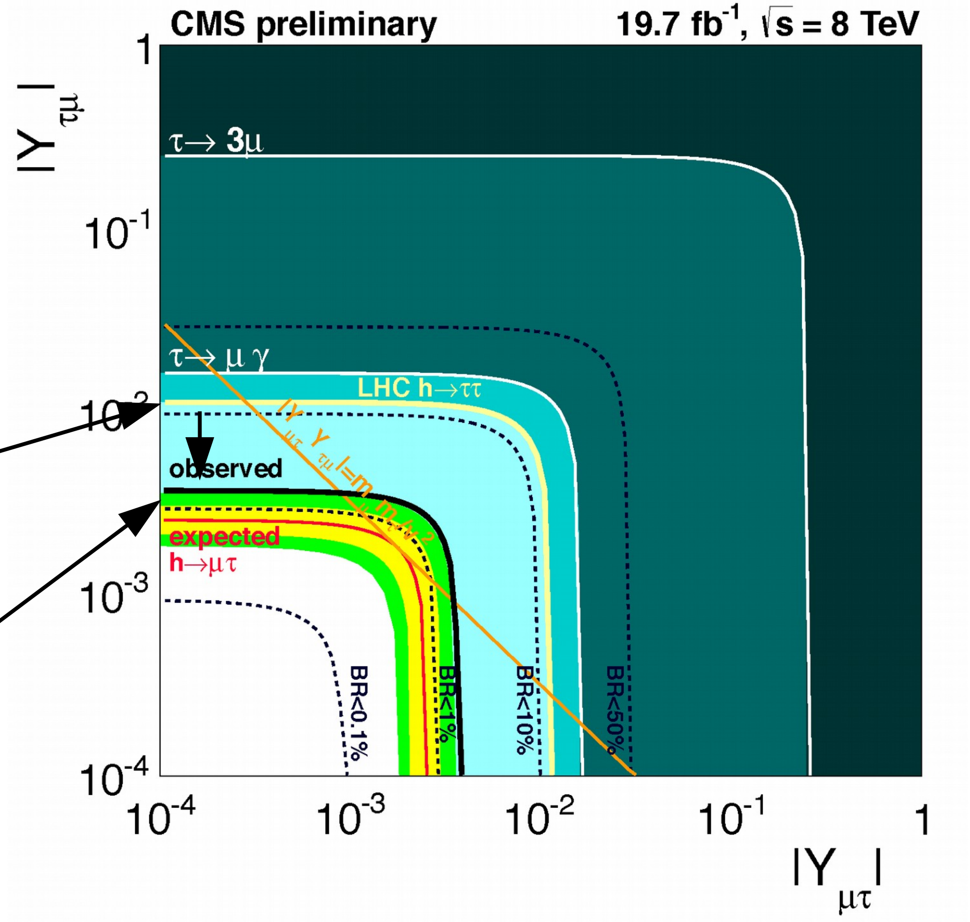
can be reinterpreted as

$$\sqrt{|Y_{\mu\tau}^2| + |Y_{\tau\mu}^2|} < 0.0035$$

$$\left(\tau \to \mu\gamma : \sqrt{|Y_{\mu\tau}^2| + |Y_{\tau\mu}^2|} < 0.016\right)$$

Pre-LHC-CMS Limit

CMS LFVHiggs Limit



Summary

- First dedicated LFV Higgs search @ LHC
- Limit on LFV $H \rightarrow \tau\mu$ branching ratio: BR<1.57%
- Interpretation of the result in terms of a limit on the corresponding Yukawa coupling

https://twiki.cern.ch/twiki/bin/view/CMSPublic/Hig14005TWiki