LFV Higgs Decay

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Workshop on Tau Lepton Physics

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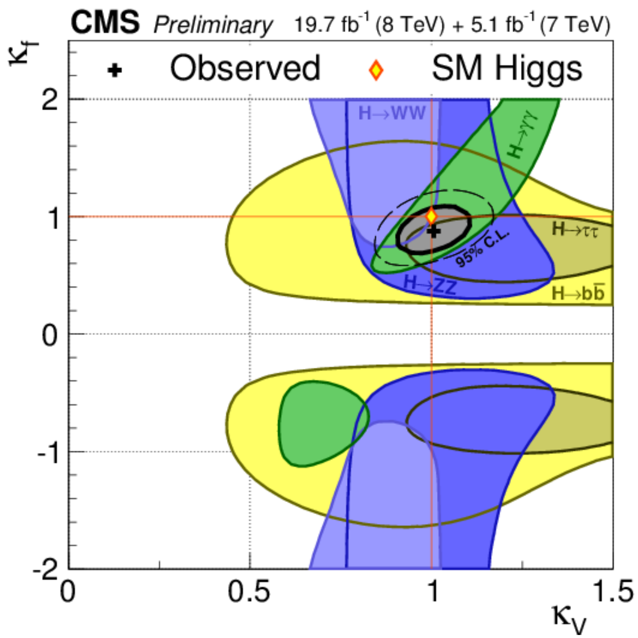
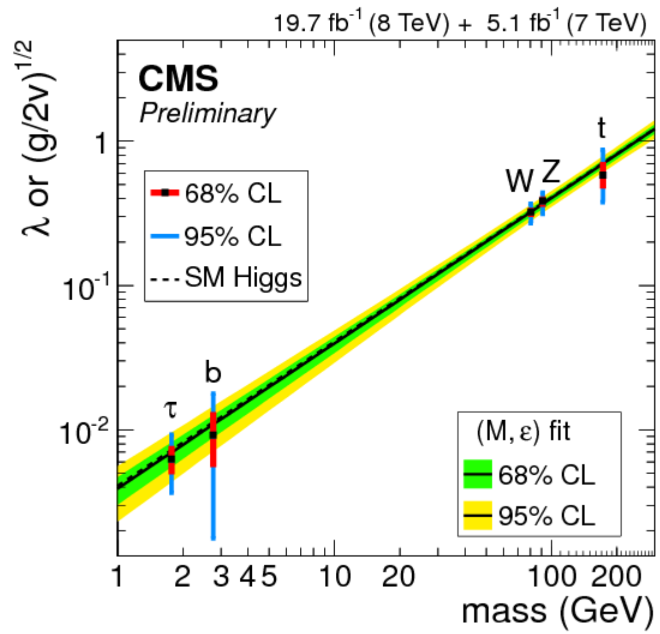
A SM like Higgs boson

Higgs properties compatible with the SM expectations, so far.

Evidence for H $\rightarrow\tau\tau$ by both ATLAS and CMS.

See T. Schwindt & T. Muller talks

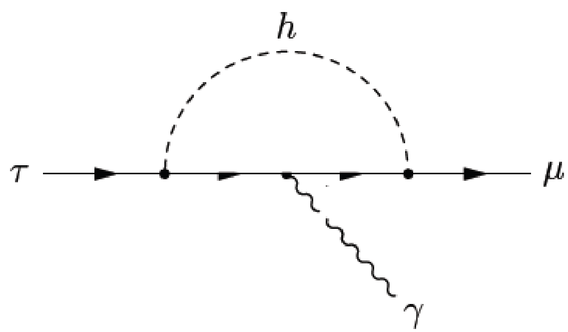


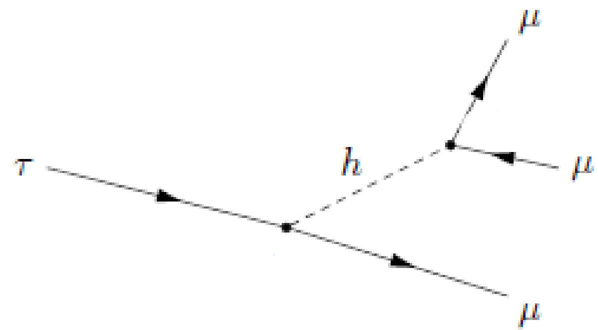


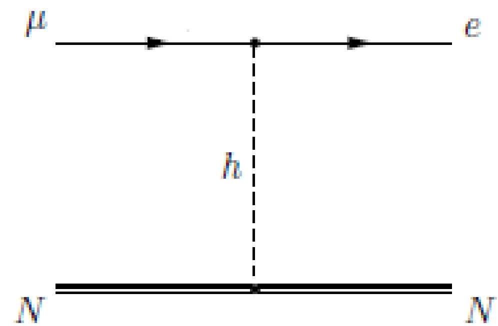
BSM Physics in the lepton sector to generate neutrino masses should induce Lepton Flavour Violating Higgs decay

- Single doublet Higgs field: non-renormalisable operators
- Two Higgs Doublet Model or the NMSSM: renormalisable flavour-changing interactions
- Extra-dimensions, compositeness …

LFV in the Higgs sector







LFV process	Bound on BR (90% CL)	FV Higgs couplings
$\mu \to e\gamma$	5.7×10^{-13} (MEG)	$\sqrt{\lvert Y_{\mu e}\rvert^2 + \lvert Y_{e\mu}\rvert^2} < 3.6 \times 10^{-6}$
$\mu \to eee$	1.0×10^{-12} (SINDRUM)	$\sqrt{\lvert Y_{\mu e}\rvert^2 + \lvert Y_{e\mu}\rvert^2} < 3.1 \times 10^{-5}$
$\mu \to e$ conversion	7.0×10^{-13} (SINDRUM)	$\sqrt{\lvert Y_{\mu e}\rvert^2 + \lvert Y_{e\mu}\rvert^2} < 4.6 \times 10^{-5}$
$\tau \to e\gamma$	3.3×10^{-8} (Babar)	$\sqrt{\lvert Y_{\tau e}\rvert^2 + \lvert Y_{e\tau}\rvert^2} < 1.4 \times 10^{-2}$
$\tau \to eee$	2.7×10^{-8} (Belle)	$\sqrt{\lvert Y_{\tau e}\rvert^2 + \lvert Y_{e\tau}\rvert^2} < 1.2 \times 10^{-1}$
$\tau \to \mu\gamma$	4.4×10^{-8} (Babar)	$\sqrt{\lvert Y_{\tau\mu}\rvert^2 + \lvert Y_{\mu\tau}\rvert^2} < 1.6 \times 10^{-2}$
$\tau \to \mu\mu\mu$	2.1×10^{-8} (Belle)	$\sqrt{\lvert Y_{\tau\mu}\rvert^2 + \lvert Y_{\mu\tau}\rvert^2} < 2.5 \times 10^{-1}$

Goudelis, Lebedev, Park (1111.1715)
Harnik, Kopp, Zupan (1209.1397)
Also:
Blakenburg, Ellis, Isidori (1202.5704)

Strong constraints:
B ($H \to e\mu$) < 2×10^{-8}

Indirect bounds are weak for $Y_{\tau\mu}$

LFV in the Higgs sector

Furthermore, the Higgs is narrow :

$$\frac{\Gamma\,(\tau \to \mu\mu\mu)}{\Gamma\,(\tau \to \mu\nu\nu)} \sim \frac{{Y_{\tau\mu}}^2 {Y_{\mu}}^2}{g^4}$$

$$\frac{\Gamma\,(H \to \tau\mu)}{\Gamma\,(H \to bb)} \sim \frac{{Y_{\tau\mu}}^2}{{Y_b}^2}$$

Searching for LFV Higgs decay on the resonance:

no loop, no additional small Yukawa couplings and direct comparison between Yukawa couplings

$\Rightarrow$ On the resonance is the right place to search for small couplings

$\Rightarrow$ And we know precisely the Higgs mass: M(H) = 125.7 $\pm$0.4 GeV

Direct search for H $\rightarrow\tau\mu$ decays can probe FV Higgs couplings
beyond limits set by LFV tau decays:

Re-interpreting ATLAS H $\rightarrow\tau\tau$ analysis: B(H$\rightarrow\tau\mu$) and B(H$\rightarrow\tau$e) < 13% — Harnik, Kopp, Zupan (1209.1397)

LHC sensitivity with a dedicated search with 20 fb^{-1} @8 TeV : B (H$\rightarrow\tau\mu$) < 4.5 $\times$ 10^{-3} — Davidson, Verdier [1211.1248]

CMS analysis

CMS 2012 data at 8 TeV with =19.7 fb^{-1}

- M_H = 126 GeV
- 2 channels : $H \rightarrow \mu\tau_{had}$ and $H \rightarrow \mu\tau_e$

Take benefit from a high p_T isolated muon to trigger and to distinguish $\mu \leftarrow H$ from $\mu \leftarrow \tau \leftarrow Z$ (or H)

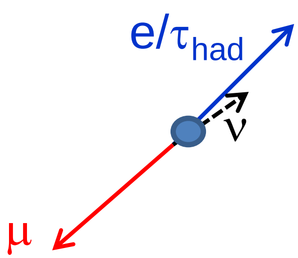
Same strategy as the $H \rightarrow \tau\tau$ analysis:

- Event categories: 0-jet, 1-jet, VBF tag
- Jets: p_T > 30 GeV and $|\eta|$<4.7

See Christian Veelken's talk

Hadronic tau reconstruction with Pflow/HPS algo

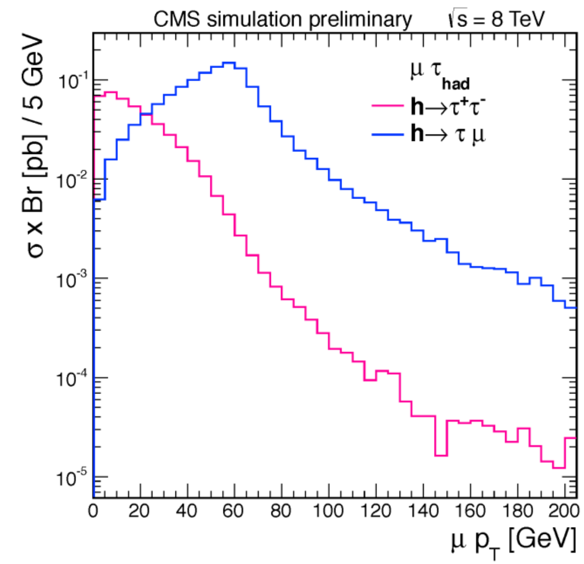
Use the collinear mass: MET collinear with visible tau decay products

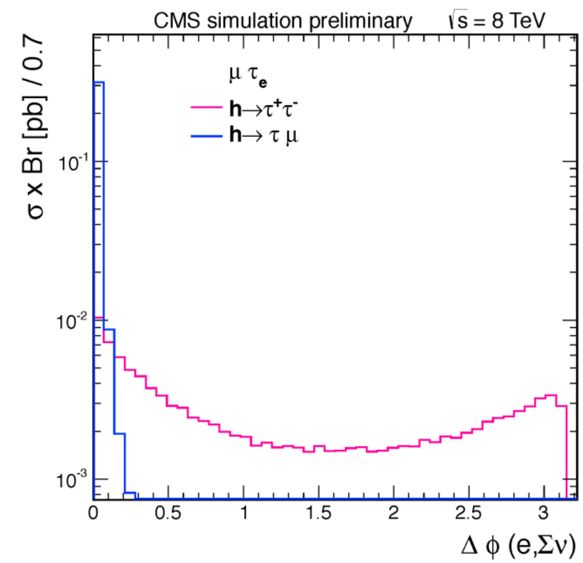


$$\vec{p}_T^{\,\nu} = \vec{E}_T^{\text{miss}} \cdot \hat{p}_T^{\,\tau_{vis}}$$

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

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





See also Aaron Levine @ the poster session

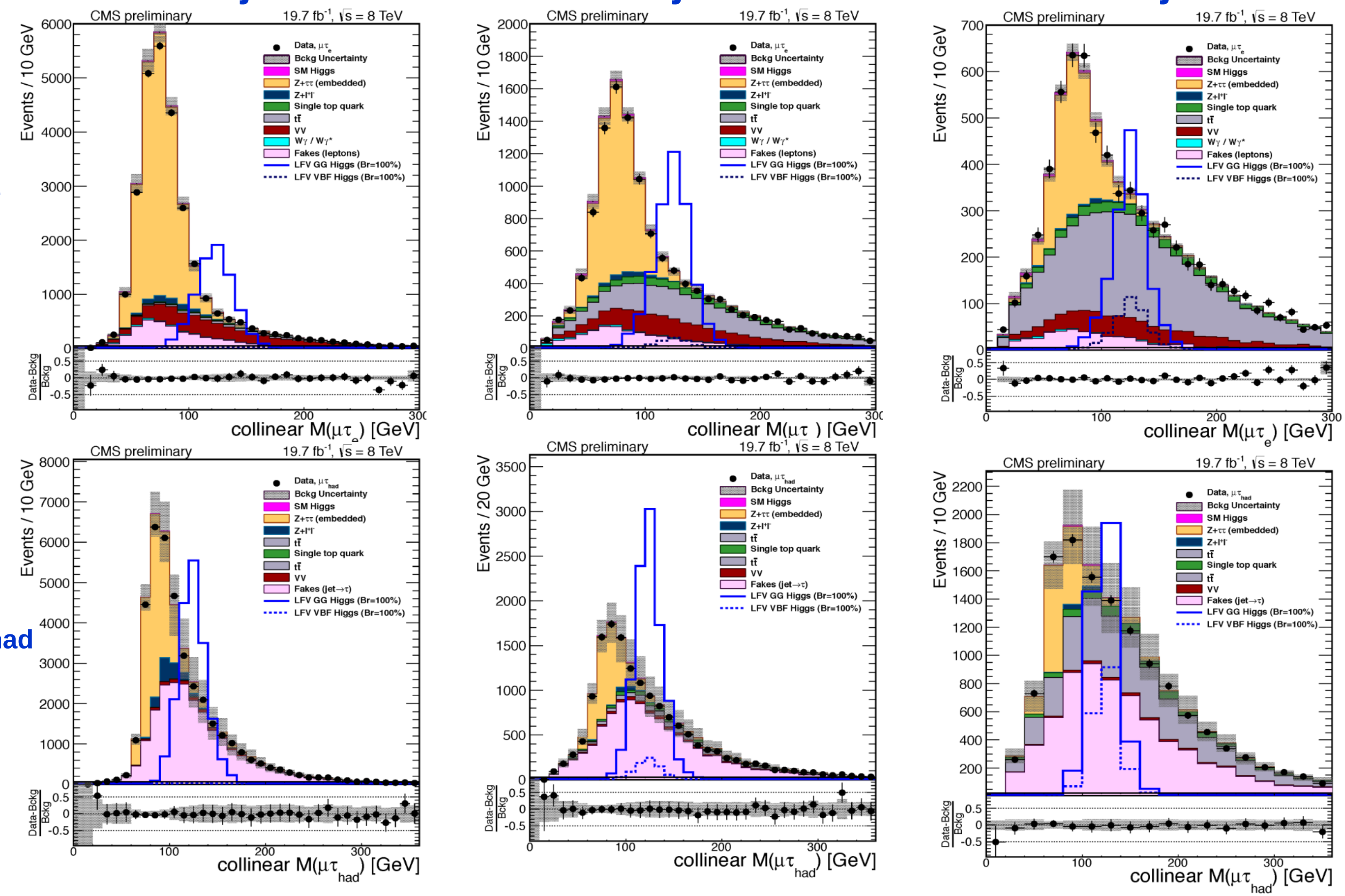
Preselection

Requiring exactly 1 isolated muon and 1 tau candidate with opposite sign

0 jet **1 jet** **2 jets**

H →$\mu\tau_e$

H →$\mu\tau_{had}$



Final selection

Main backgrounds:

- $Z \to \tau\tau$ from embedding technique
- Fake leptons (QCD W+jets): from data
- Other small backgrounds from MC simulations

LFV Higgs signal :

- gluon fusion and VBF with Pythia 8.176

Final selection criteria are optimized for each channel with s/sqrt(s+b) for B ($H \to \tau\mu$) = 10%

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

Analysis blinded in the region: 100 < M_{coll} < 150 GeV

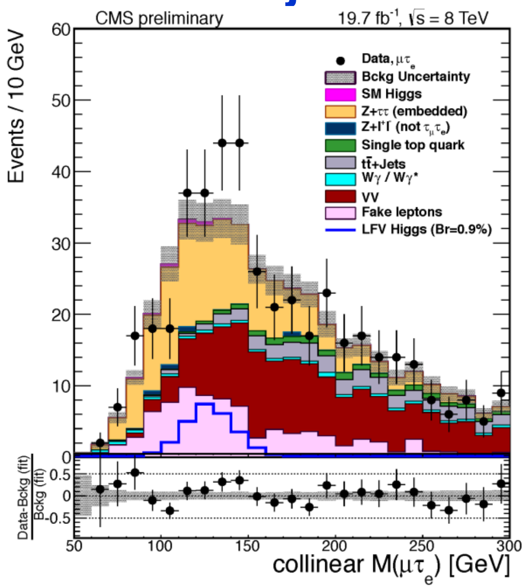
Sample	$H \to \mu\tau_{had}$			$H \to \mu\tau_e$		
	0-jet	1-jet	2-jet	0-jet	1-jet	2-jet
Fakes	1858.1 ± 558.8	362.9 ± 110.0	0.5 ± 0.5	41.5 ± 17.3	16.1 ± 6.8	1.1 ± 0.7
$Z \to \tau\tau$	198.8 ± 11.0	50.5 ± 3.5	0.4 ± 0.2	65.0 ± 3.0	38.6 ± 2.0	1.3 ± 0.2
ZZ, WW	47.0 ± 8.0	14.6 ± 2.6	0.3 ± 0.2	40.8 ± 6.6	21.2 ± 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

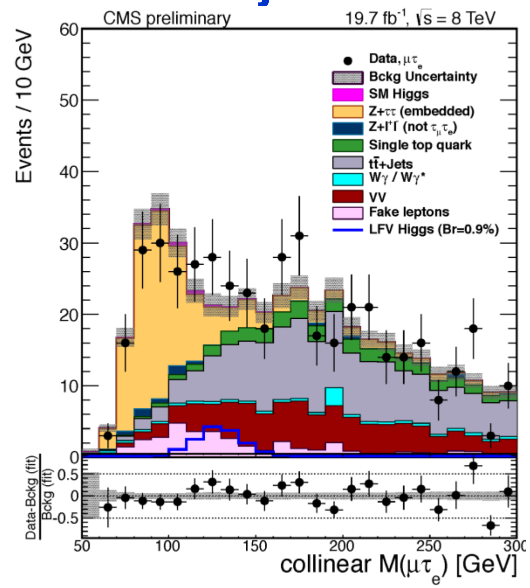
← B ($H \to \tau\mu$) = 0.89 %

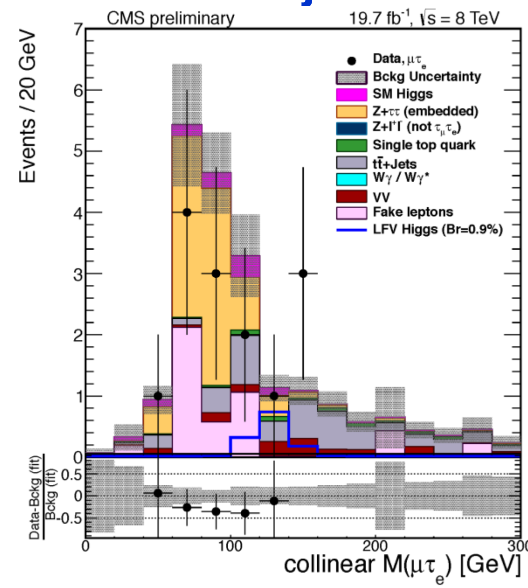
Final selection

	0 jet	1 jet	2 jets

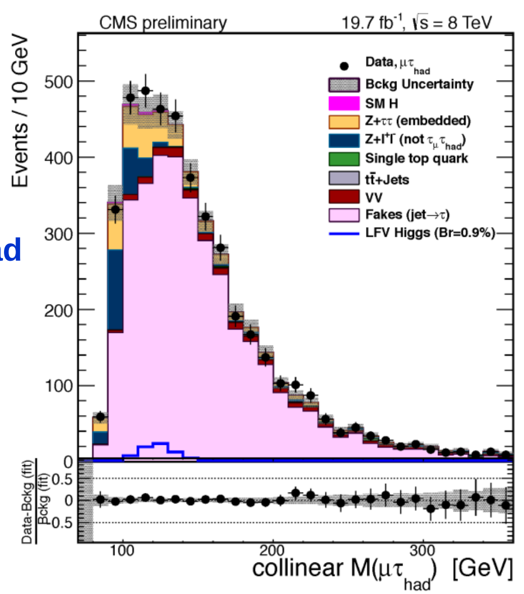
$H \rightarrow \mu\tau_e$

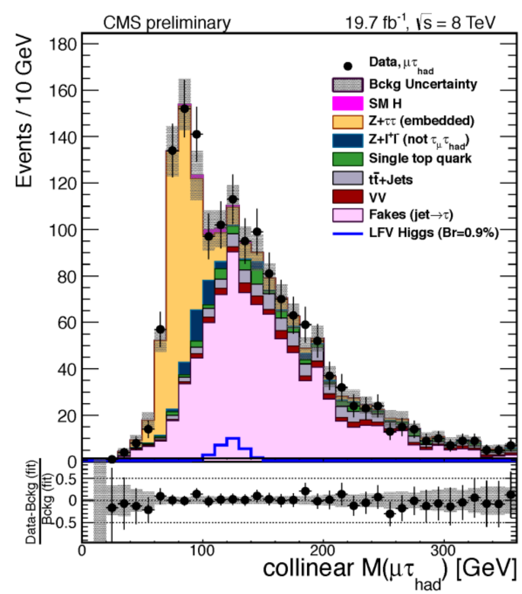


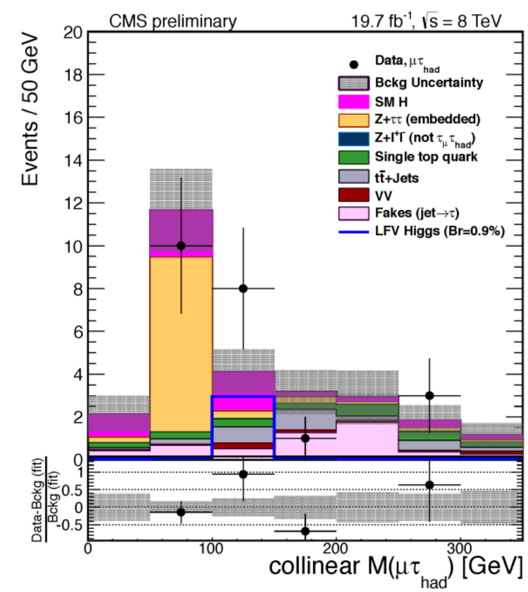




$H \rightarrow \mu\tau_{had}$







Systematic uncertainties

M_{coll} independent systematics

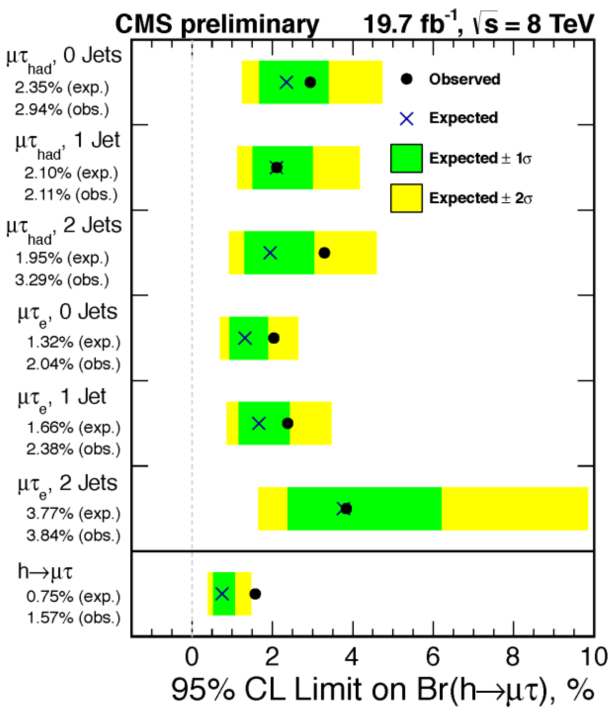
Systematic Uncertainty	$H \to \mu\tau_e$			$H \to \mu\tau_{had}$		
	0-jet	1-jet	2-jet	0-jet	1-jet	2-jet
electron trigger/ID/isolation	3%	3%	3%	-	-	-
muon trigger/ID/isolation	2%	2%	2%	2%	2%	2%
hadronic tau efficiency	-	-	-	9%	9%	9%
luminosity	2.6%	2.6%	2.6%	2.6%	2.6%	2.6%
$Z \to \tau\tau$ background	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%

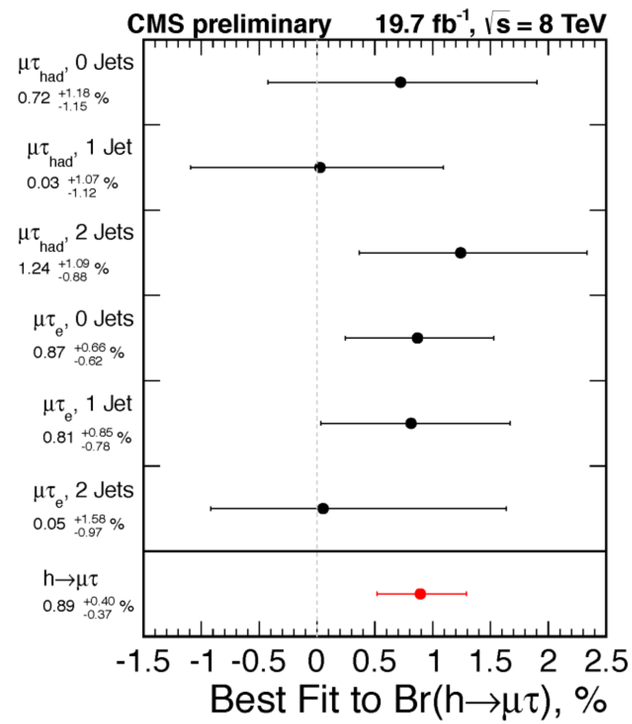
Uncertainty	Gluon-Gluon Fusion			Vector Boson Fusion		
	0-jet	1-jet	2-jet	0-jet	1-jet	2-jet
parton density function	+9.7%	+9.7%	+9.7%	+ 3.6%	+3.6%	+3.6%
renormalization scale	+8 %	+10 %	-30%	+4 %	+1.5%	+2%
underlying event/parton shower	+4%	-5%	-10%	+10%	0%	-1%

M_{coll} dependent systematics

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%	-

Result





Limit @ 95% C.L. on $B(H \to \mu\tau) < 1.57\%$ (0.75% expected)

Background only p-value = 0.007 : 2.46 σ

Best-fit : $B(H \to \mu\tau) = 0.89^{+0.40}_{-0.37}$ %

CMS result

Limit on Yukawa couplings is obtained from the limit on the $H \rightarrow \mu\tau$ branching ratio :

$$L \equiv -[Y_{e\mu}\bar{e}_L\mu_R h + Y_{\mu e}\bar{\mu}_L e_R h] - [Y_{e\tau}\bar{e}_L\tau_R h + Y_{\tau e}\bar{\tau}_L e_R h] - [Y_{\mu\tau}\bar{\mu}_L\tau_R h + Y_{\tau\mu}\bar{\tau}_L\mu_R h]$$

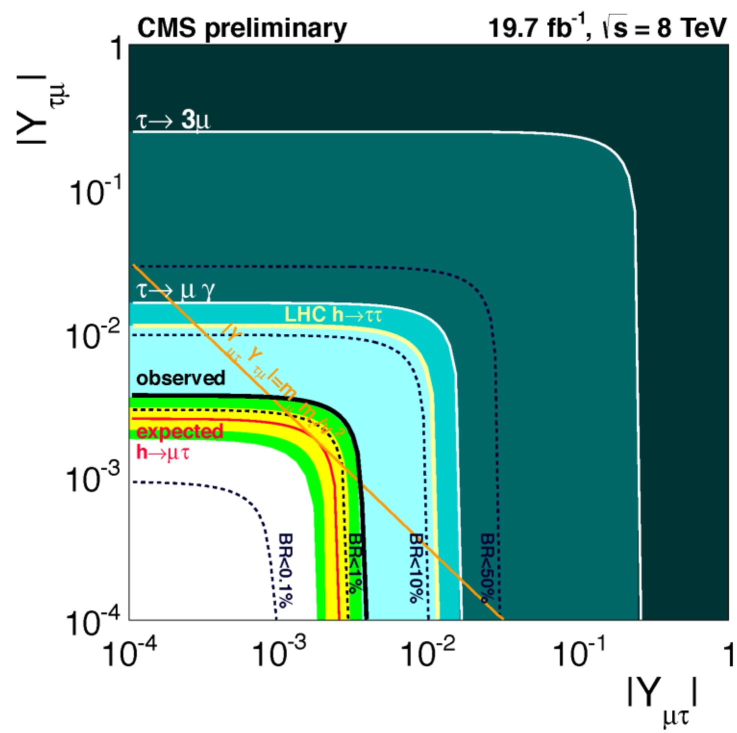
$$B(H \rightarrow \mu\tau) = \frac{\Gamma(H \rightarrow \tau\mu)}{\Gamma(H \rightarrow \tau\mu) + \Gamma_{SM}}$$ with Γ_{SM} = 4.1 MeV

$$\Gamma(H \rightarrow \tau\mu) = \frac{M_H}{8\pi}\left(|Y_{\tau\mu}|^2 + |Y_{\mu\tau}|^2\right)$$ with M_H = 125 GeV

Limit observed at 95% C.L. :

$$\sqrt{|Y_{\tau\mu}|^2 + |Y_{\mu\tau}|^2} < 3.6 \times 10^{-3}$$

Factor 4.4 improvement of the previous limit



Conclusion

First result on direct search for LFV Higgs decay in the $\tau\mu$ channel by CMS

A slight excess is observed : 2.5 σ

Limit @ 95% C.L. on $B(H \to \mu\tau) < 1.57\%$ (0.75% expected)

A factor ~4 improvement compared to $\tau \to \mu\gamma$ limit

This is just the beginning:

A long program is foreseen at the LHC to study precisely the Higgs boson

Higgs cross section will increase by a factor ~2 when going to 13-14 TeV pp collisions

and integrated luminosity $\times 5$ by 2018, $\times 15$ by 2022 and $\times 150$ by 2030