Searches for Lepton Flavour Violating Higgs Decays at CMS

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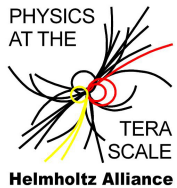
on behalf of the CMS Collaboration

University of Hamburg



Physics at the Terascale

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Desy Hamburg

18.11.2015

Higgs couplings to leptons

LFV Higgs boson decays can be introduced by flavour violating Yukawa interactions.

$$\mathcal{L}_Y = -m_i \bar{f}_L^i f_R^j - Y_{ij}(\bar{f}_L^i f_R^j) + \text{h.c.} + ...$$

Yukawa coupling matrix:

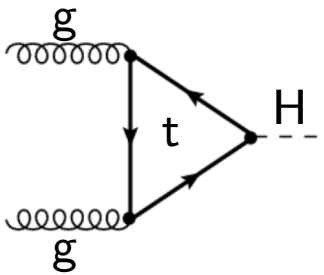
$$Y = \begin{pmatrix} Y_{ee} & Y_{e\mu} & Y_{e\tau} \\ Y_{\mu e} & Y_{\mu\mu} & Y_{\mu\tau} \\ Y_{\tau e} & Y_{\tau\mu} & Y_{\tau\tau} \end{pmatrix}$$

SM	$Y_{ij} = \frac{m_i}{v}\delta_{ij}$
2HDM	$Y_{ll'} \propto m_l m_{l'}$

$Y_{e\tau}$ is constrained by low energy measurements, still allowing $B(H \to e\tau) \approx 10\%$.

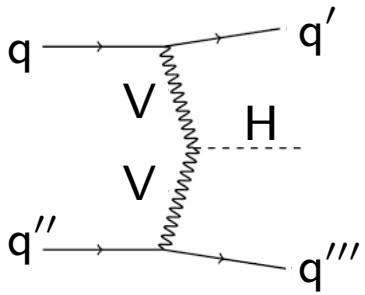
Channels and categories

Higgs production:



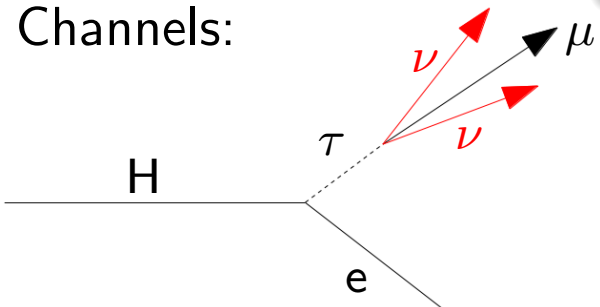
GGF

VBF

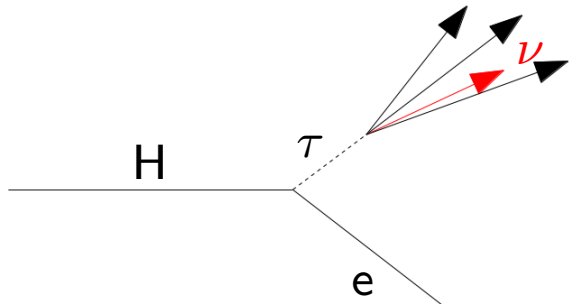


$m_H = 125$ GeV

Channels:



i) leptonic: $H \to e\tau_\mu$



ii) hadronic: $H \to e\tau_h$

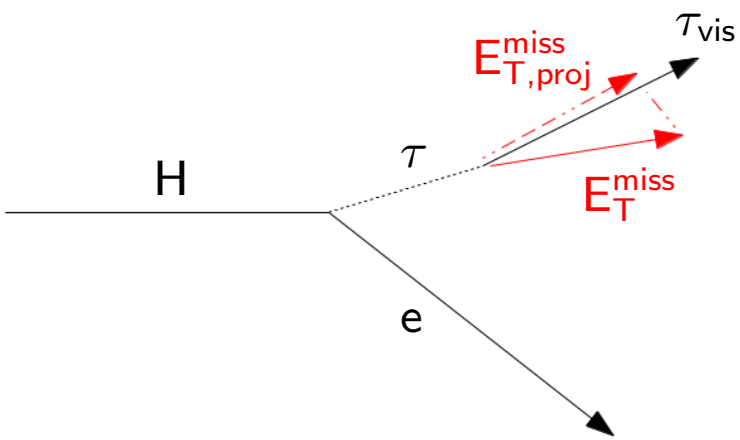
Three exclusive jet-categories:

- 0 Jet: GGF Higgs production
- 1 Jet: GGF Higgs production
- 2 Jet: enriched with VBF events

Collinear mass approximation

Mass reconstruction

- Assumption: neutrinos are collinear with tau direction and thus with the visible tau decay products
- Collinear mass: invariant mass of neutrinos+electron+visible tau decay products



Neutrino momentum:

$$\vec{p}_T^{\,\nu} = \vec{E}_T^{\,miss} \cdot \hat{p}_T^{\,\tau_{vis}} \qquad (1)$$

Fraction of the τ momentum carried by the visible τ decay products:

$$x_{\tau_{vis}} = \frac{|\vec{p}_T^{\,\tau_{vis}}|}{|\vec{p}_T^{\,\tau_{vis}}| + |\vec{p}_T^{\,\nu}|} \qquad (2)$$

Higgs mass:

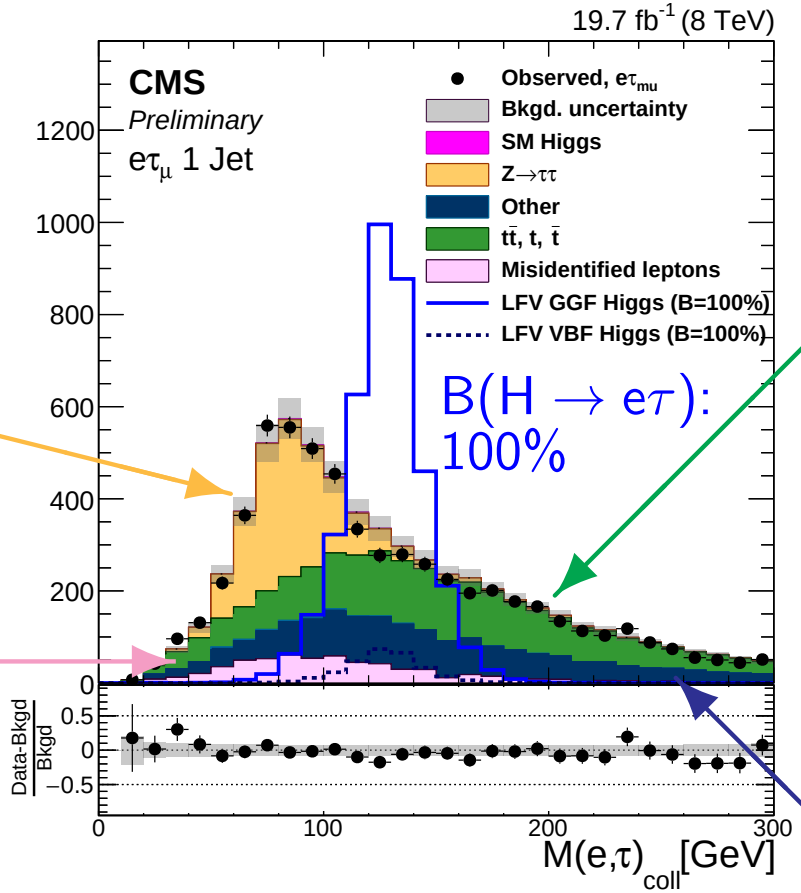
$$M_H = M_{col} = \frac{M_{vis}}{\sqrt{x_{\tau_{vis}}}} \qquad (3)$$

Background processes

From data:

$Z \to \tau\tau$:
- Normalization: MC
- Shape: PF-Embedding

Misidentified leptons:
- jets misidentified as leptons
- W+Jets/QCD multijets
- Shape: isolation sideband



$t\bar{t}$:
- Normalization: control region
- Shape: MC

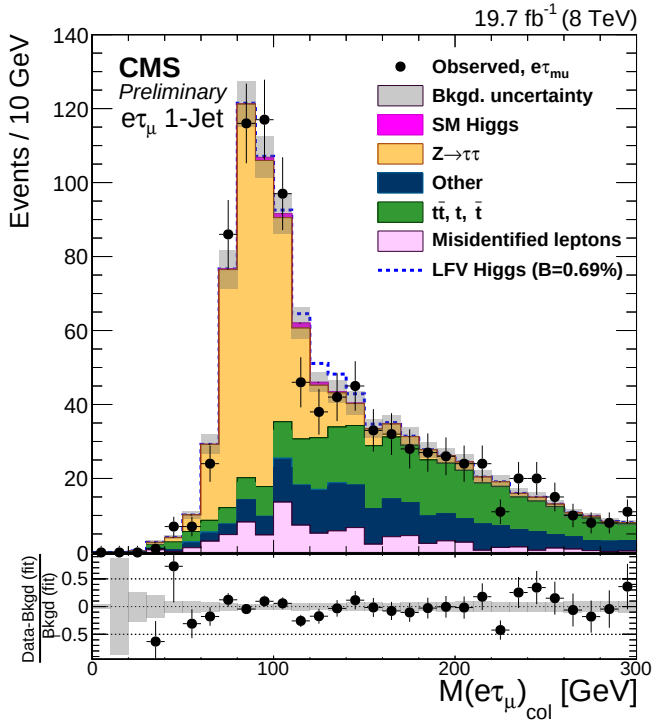
$t, \bar{t}$:
- Normalization and shape: MC

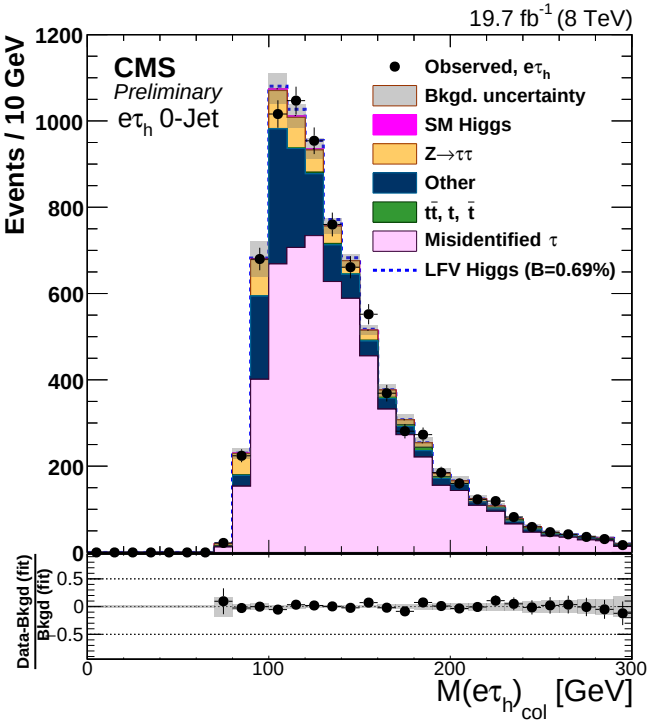
Other:
- WW, ZZ+jets, $Z \to ee$, $Z \to \mu\mu$, $W\gamma$+jets
- Normalization and shape: MC

SM Higgs:
- GGF $H \to \tau\tau$
- VBF $H \to \tau\tau$

Analysis details

- Signal region: $100 < M_{col} < 150$ GeV
- The analysis was performed "blinded" in the signal region.
- The event selection has been optimized for $S/\sqrt{S+B}$, where S and B are the expected signal and background event yields in the signal region, assuming $B(H \to e\tau) = 1\%$.

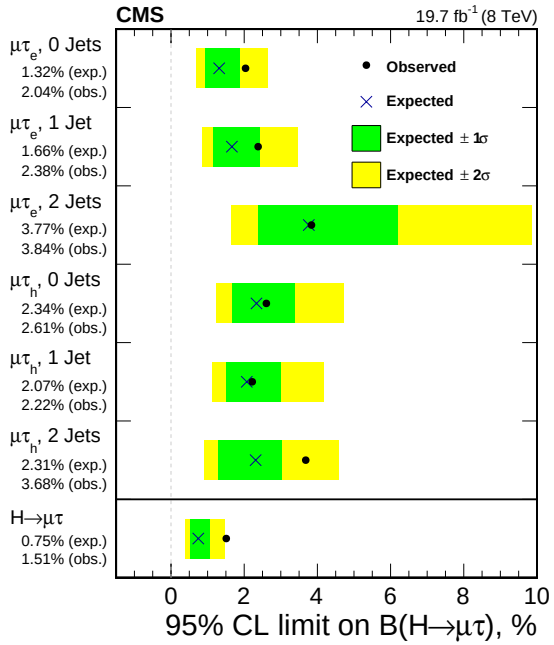




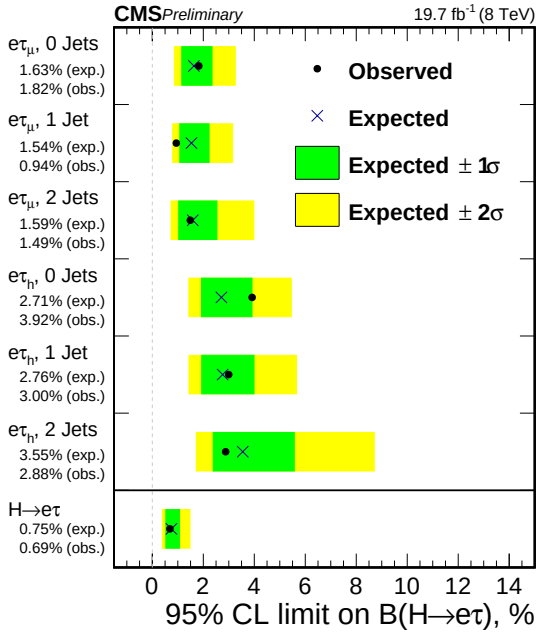
Upper limits on the LFV branching fractions

These limits are the first direct limits for LFV Higgs decays:

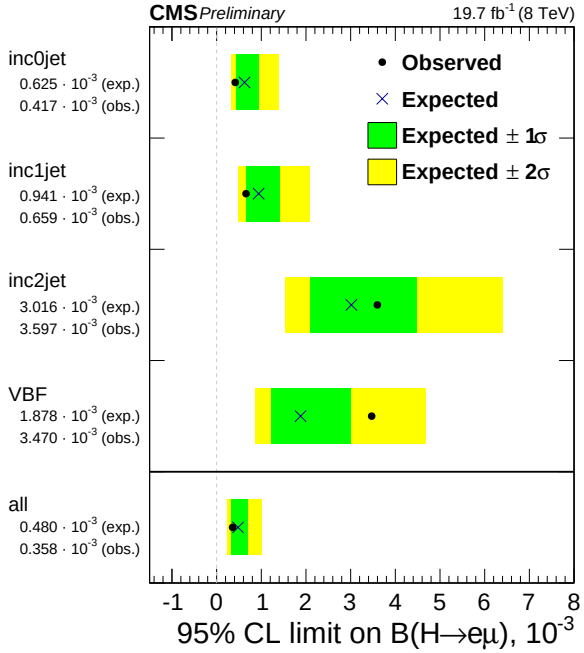
$\mu\tau$
Phys.Lett. B 749 (2015)



$e\tau$
CMS PAS HIG-14-040



$e\mu$
CMS PAS HIG-14-040



Observed upper limits on the LFV branching fractions:

$B(H \to \mu\tau) < 1.51\%$ **$B(H \to e\tau) < 0.69\%$** **$B(H \to e\mu) < 0.036\%$**

Yukawa couplings

Decay width: $\Gamma(H \to \ell^\alpha \ell^\beta) = \frac{m_H}{8\pi}(|Y_{\ell^\alpha \ell^\beta}|^2 + |Y_{\ell^\beta \ell^\alpha}|^2)$

Branching fraction: $B(H \to \ell^\alpha \ell^\beta) = \frac{\Gamma(H \to \ell^\alpha \ell^\beta)}{\Gamma(H \to \ell^\alpha \ell^\beta) + \Gamma_{SM}}$

With $\ell^\alpha, \ell^\beta = e, \mu, \tau$ and $\ell^\alpha \neq \ell^\beta$

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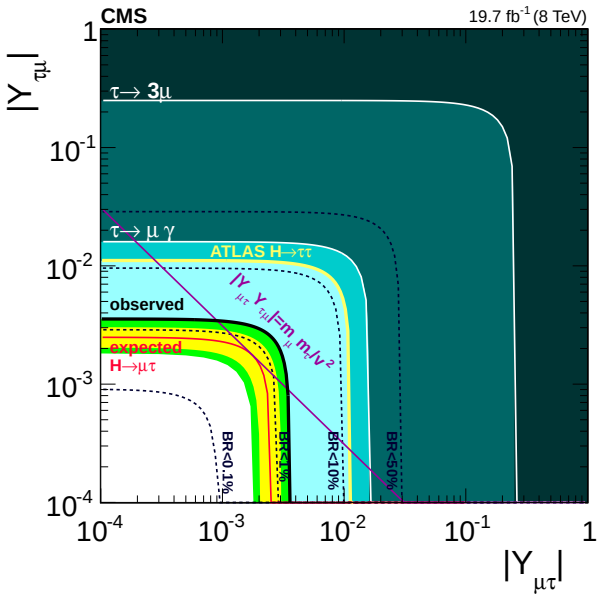

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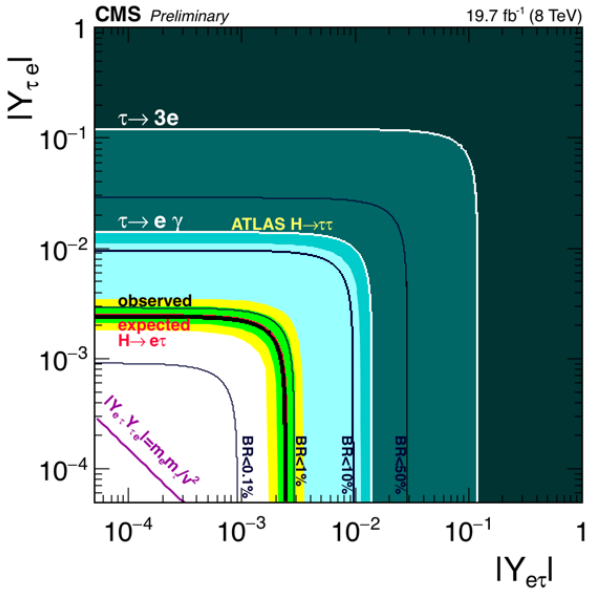
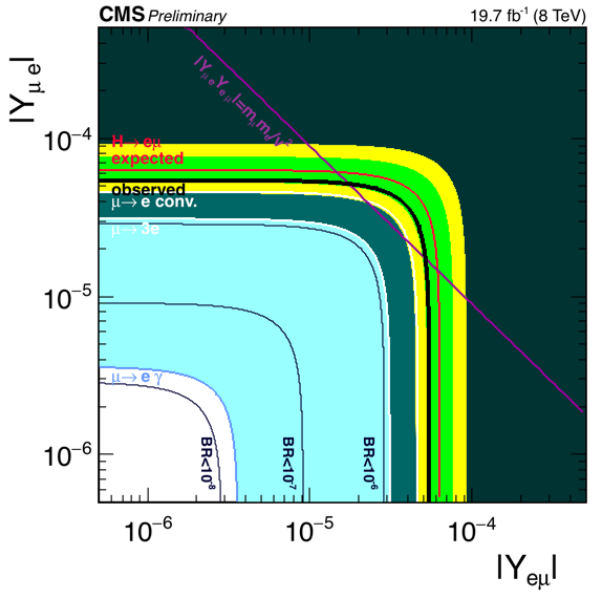


CMS PAS HIG-14-040



$\sqrt{|Y_{\mu\tau}|^2 + |Y_{\tau\mu}|^2} < 3.6 \times 10^{-3}$ $\sqrt{|Y_{e\tau}|^2 + |Y_{\tau e}|^2} < 2.41 \times 10^{-3}$ $\sqrt{|Y_{e\mu}|^2 + |Y_{\mu e}|^2} < 5.43 \times 10^{-4}$

Search for LFV H $\rightarrow \mu\tau$ decays

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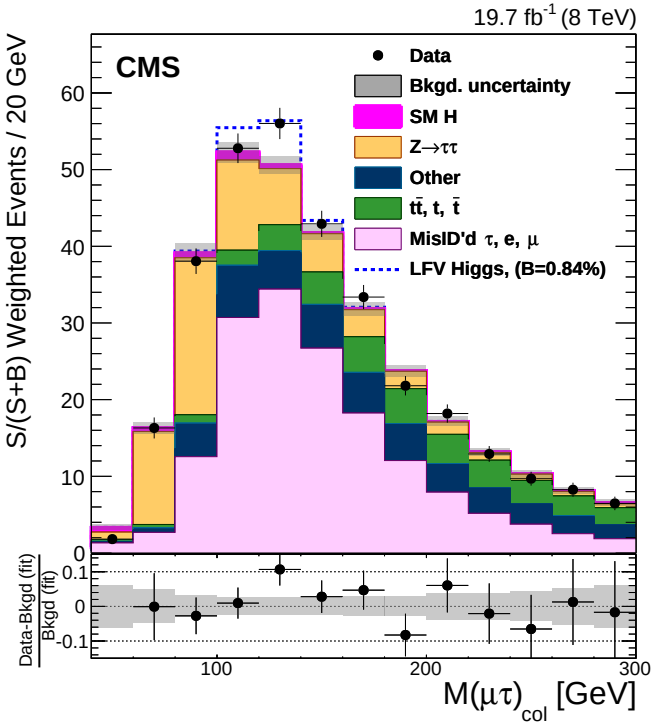
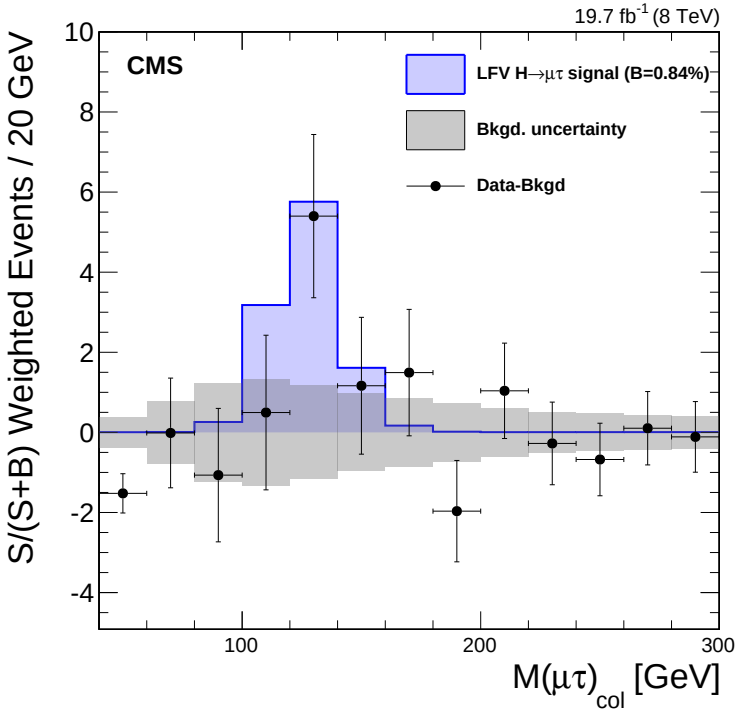
Slight excess of events with a local significance of 2.4 σ is observed.

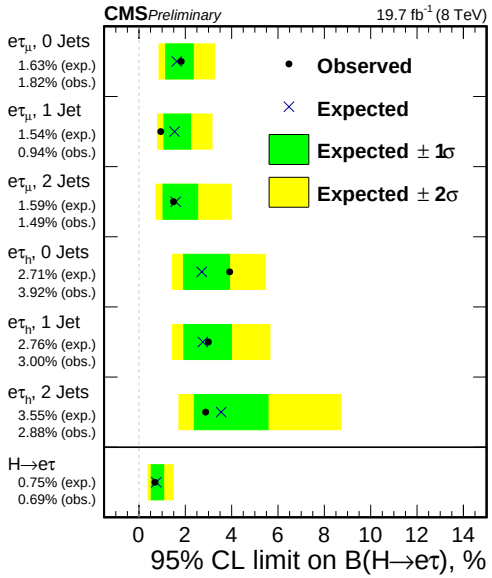


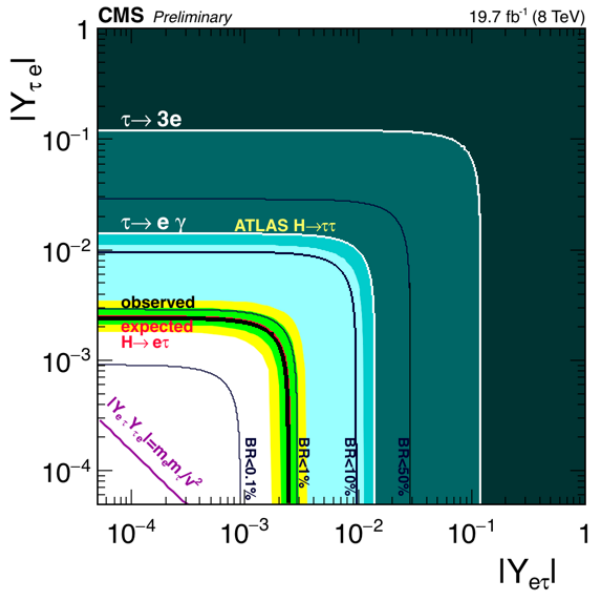


The best fit branching fraction is $B(H \rightarrow \mu\tau) = (0.84^{+0.39}_{-0.37})\%$.

Summary

- First direct search for LFV H $\rightarrow$ eτ decays.
- No evidence is found.
- Observed upper limit: B(H $\rightarrow$ eτ) $<$ 0.69%.
- The limit is used to constrain the $|Y_{e\tau}|$ Yukawa coupling.
- New limits are an order of magnitude better than the old indirect ones[1].
- Slight excess of events (2.4σ) is observed in the $\mu\tau$ channel.





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[1] indirect limits: Roni Harnik, Joachim Kopp, Jure Zupan, "Flavor Violating Higgs Decays" arXiv 1209.1397

Thank you for your attention!

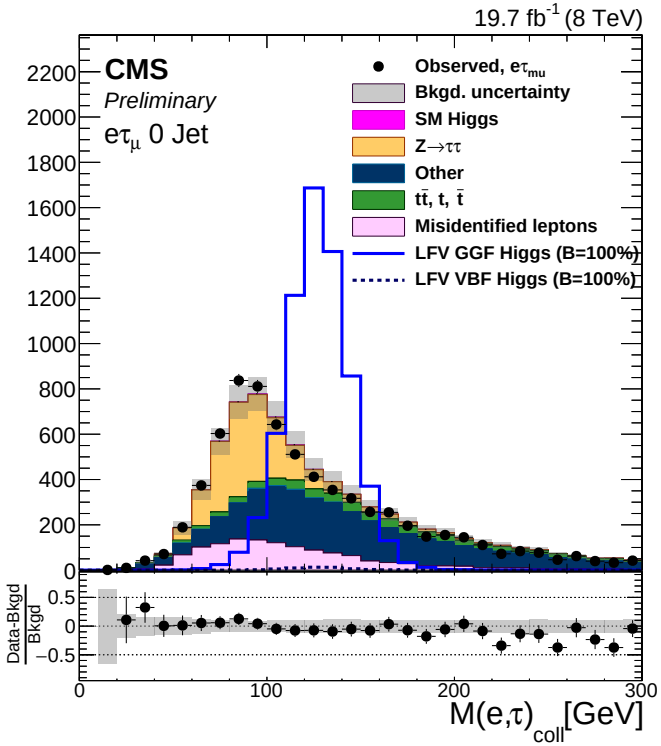
References

- $H \to e\tau / H \to e\mu$:
  The CMS Collaboration: "Search for lepton-flavour-violating decays of the Higgs boson to $e\tau$ and $e\mu$ at $\sqrt{s} = 8$ TeV", CMS PAS HIG-14-040
- $H \to \mu\tau$:
  The CMS Collaboration: "Search for lepton-flavour-violating decays of the Higgs boson" Phys.Lett. B 749 (2015) 337-362 arXiv:1502.07400 [hep-ex]
- R. Harnik, J. Kopp, and J. Zupan: "Flavor Violating Higgs Decays", JHEP 1303 (2013) 026, arXiv:1209.1397

PF-Embedding

The $Z \to \tau\tau$ background is estimated using an embedding technique. Key features of the event topology such as the jets, missing energy and underlying events are taken directly from data.

1. Select $Z \to \mu\mu$ events from data.
2. Replace muons with simulated τ decays.
3. Normalize the embedded $Z \to \tau\tau$ sample by comparing to Monte Carlo simulation.



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Misidentified leptons

Misidentified leptons:

- W+jets
- QCD multijets

	Opposite Sign	Same Sign
$S(\ell_1)$, $S'(\ell_2)$	Region III	Region IV
$S(\ell_1)$, $S(\ell_2)$	Region I	Region II

Ratio of tight isolated $S(\ell_1)$ to loose isolated leptons $S'(\ell_1)$:

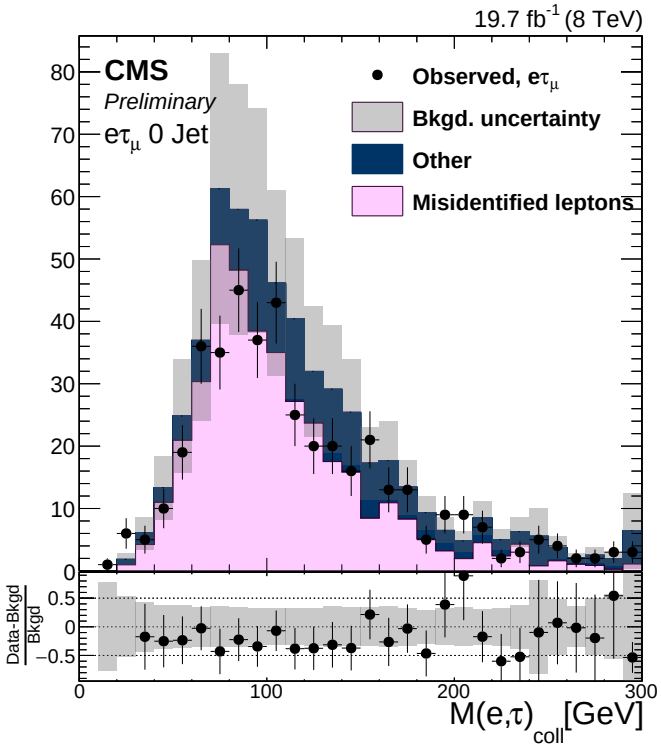
- $H \to e\tau_\mu$: $Z \to \mu\mu$+X events

$$f_\mu = \frac{N[Z(\mu\mu)+\mu(\text{tight})]}{N[Z(\mu\mu)+\mu(\text{loose})]}$$

- $H \to e\tau_h$: $Z \to ee + X$ events

$$f_\tau = \frac{N[Z(ee)+\tau(\text{tight})]}{N[Z(ee)+\tau(\text{loose})]},$$

$$f_e = \frac{N[Z(ee)+e(\text{tight})]}{N[Z(ee)+e(\text{loose})]}$$



Selection criteria requirements on the kinematic variables

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Optimized for $S/\sqrt{S+B}$, where S and B are the expected signal and background event yields in the signal region, assuming $B(H \to e\tau) = 1\%$.

Variable		$H \to e\tau_\mu$			$H \to e\tau_h$		
		0-jet	1-jet	2-jet	0-jet	1-jet	2-jet
p_T^e	(GeV)	> 50	> 40	> 40	> 45	> 35	> 35
p_T^μ	(GeV)	> 15	> 15	> 15	-	-	-
$p_T^{\tau_h}$	(GeV)	-	-	-	> 30	> 40	> 30
$M_T(\mu)$	(GeV)	-	< 30	< 40	-	-	-
$M_T(\tau_h)$	(GeV)	-	-	-	< 70	-	< 50
$\Delta\phi_{\vec{p}_{T,e}-\vec{p}_{T,\tau_h}}$	(radians)	-	-	-	> 2.3	-	-
$\Delta\phi_{\vec{p}_{T,\mu}-\vec{E}_T^{\text{miss}}}$	(radians)	< 0.8	< 0.8	-	-	-	-
$\Delta\phi_{\vec{p}_{T,e}-\vec{p}_{T,\mu}}$	(radians)	-	> 0.5	-	-	-	-

2 Jets:

- $H \to e\tau_h$: $M(jj) > 400$ GeV, $|\eta| > 2.3$
- $H \to e\tau_\mu$: $M(jj) > 200$ GeV, $|\eta| > 3$

Collinear mass

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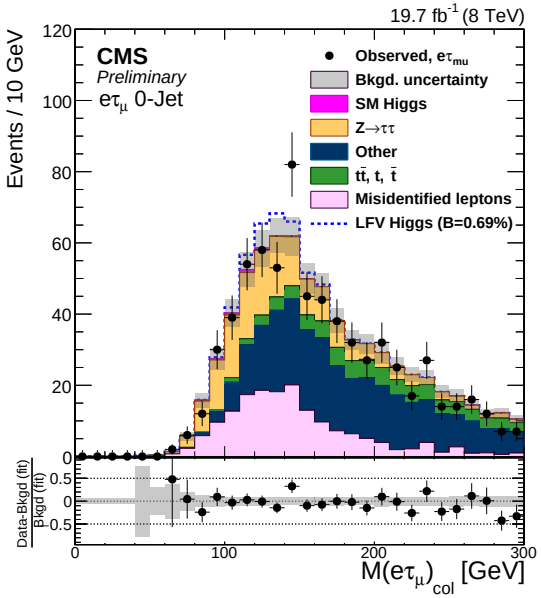
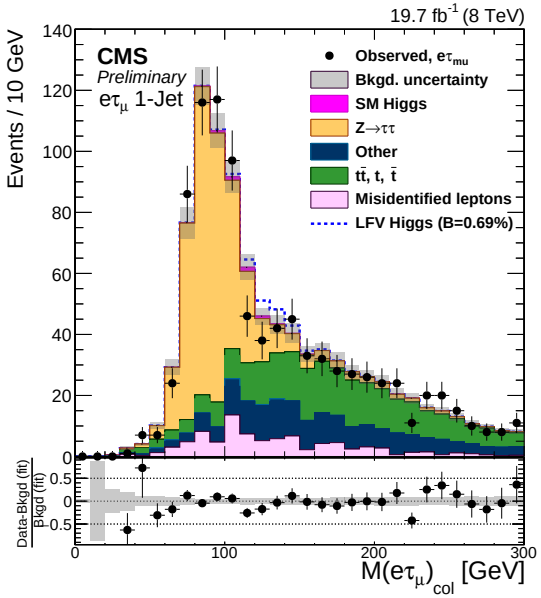
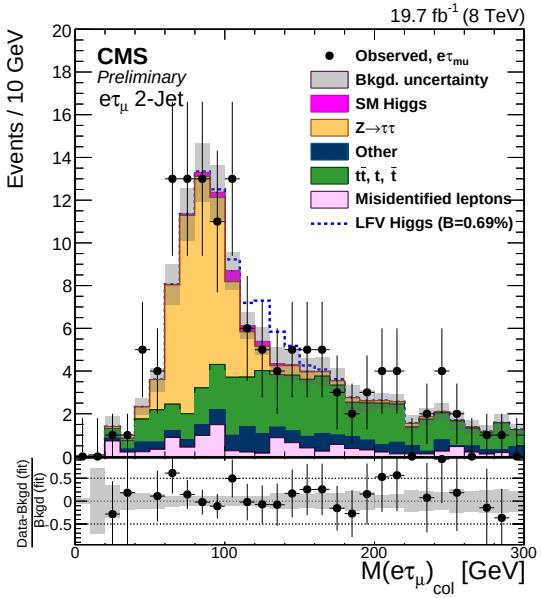
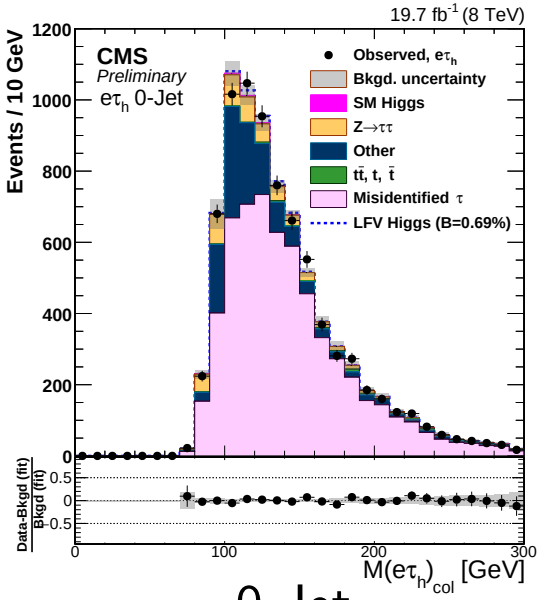
$H \rightarrow \tau_\mu$



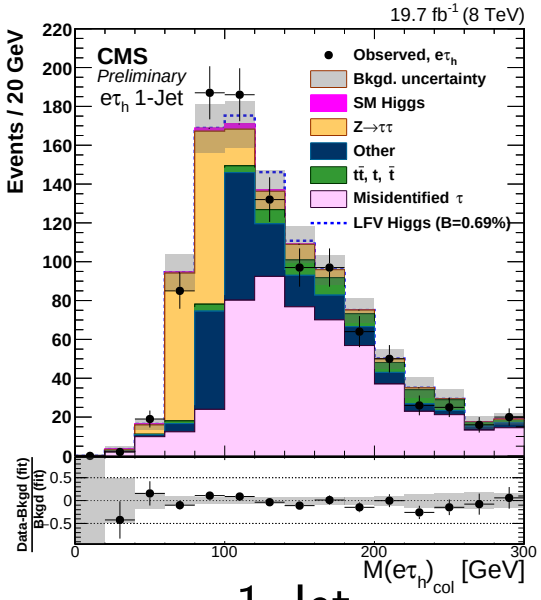




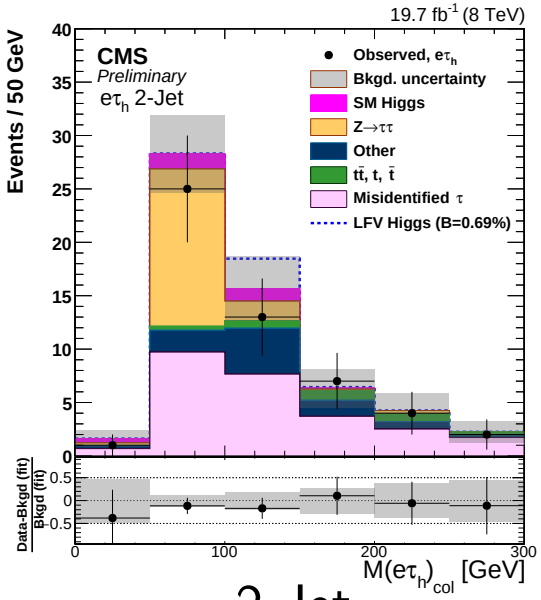
$H \rightarrow \tau_h$



0-Jet



1-Jet



2-Jet

Search for LFV H $\rightarrow$ eμ decays

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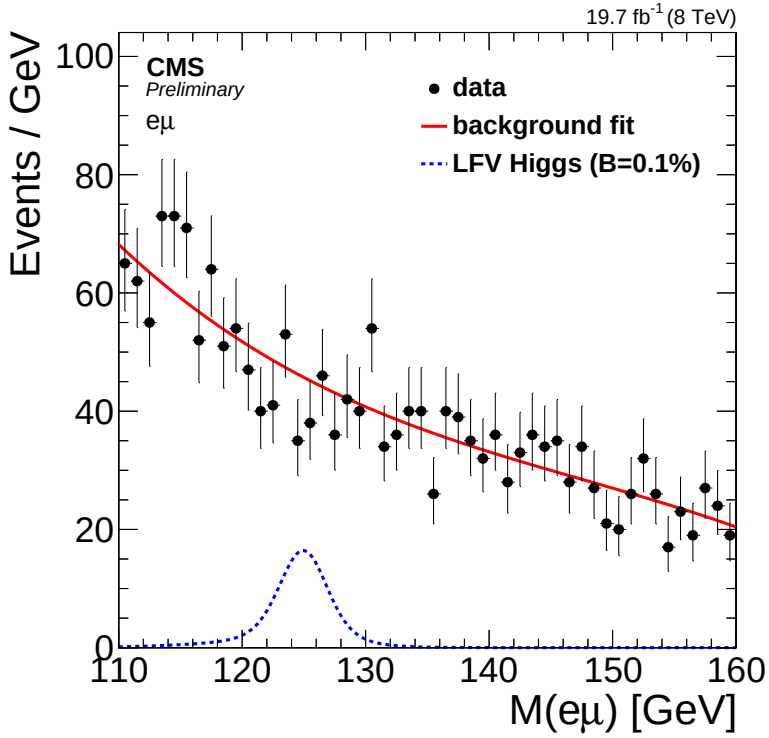
- Categorization of events according to lepton kinematic and number of jets.
- The background is estimated fitting data over the mass range 110 to 160 GeV.
- Background parametrization from several groups of simple analytical functions: polynomials, sums of exponentials and sums of power law functions.
- The simulated signal is used to fit a sum of two Gaussians in each selection category and production mechanism (GGF and VBF).



Selection criteria requirements on the kinematic variables

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Categories according to:

- EB/EE: electron in the calorimeter barrel/endcap:
  $|\eta_e| < 1.479 / |\eta_e| < 1.566$
- MB/ME: muon in the muon detector barrel/endcap
  $|\eta_\mu| < 0.8 / |\eta_\mu| > 0.8$

Category		Number of jets	Lepton p_T (GeV)	E_T^{miss} (GeV)	B-tag
0	EB-MB	0	> 25	< 30	-
1	EB-MB	1	> 22	< 30	< 0.38
2	EB-MB	2	> 25	< 25	$< 0.38, < 0.48$
3	EB-ME	0	> 20	< 30	-
4	EB-ME	1	> 22	< 20	< 0.48
5	EB-ME	2	> 20	< 30	$< 0.51, < 0.57$
6	EE-(MB or ME)	0	> 20	< 30	-
7	EE-(MB or ME)	1	> 22	< 20	< 0.48
8	EE-(MB or ME)	2	> 20	< 30	$< 0.51, < 0.57$
VBF					
9	Tight	2	> 22	< 30	$< 0.58, < 0.244$
10	Loose	2	> 22	< 25	$< 0.62, < 0.30$