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Search for Charged Lepton Flavor Violating Higgs decays at the LHC

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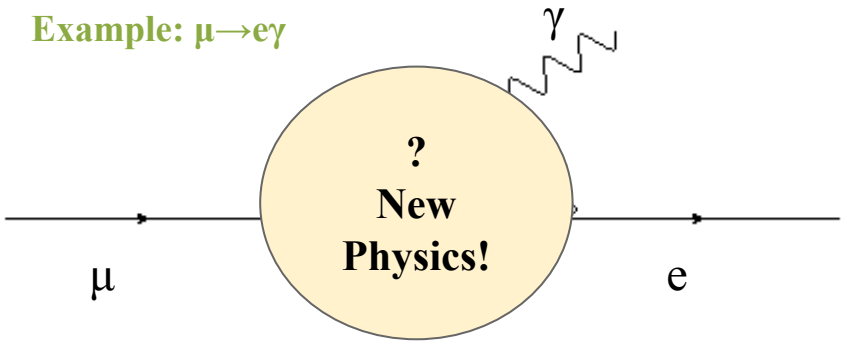
Motivation: CFLV at LHC

- **Lepton Flavor Number (L) is not conserved** →Neutrino Oscillation!
- Charged-Lepton-Flavor violation (CLFV): no SM contribution, hence clear signature for **New Physics**!



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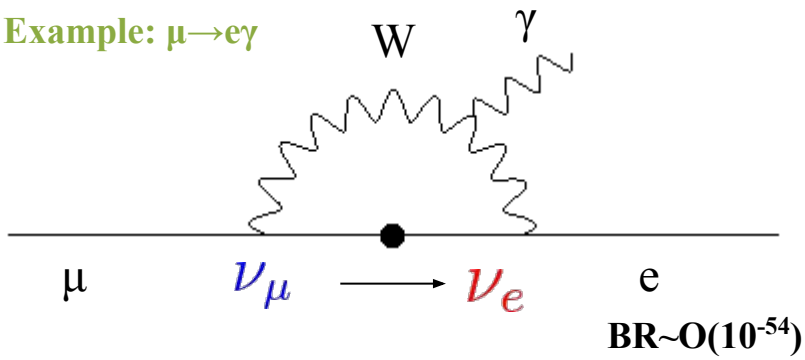

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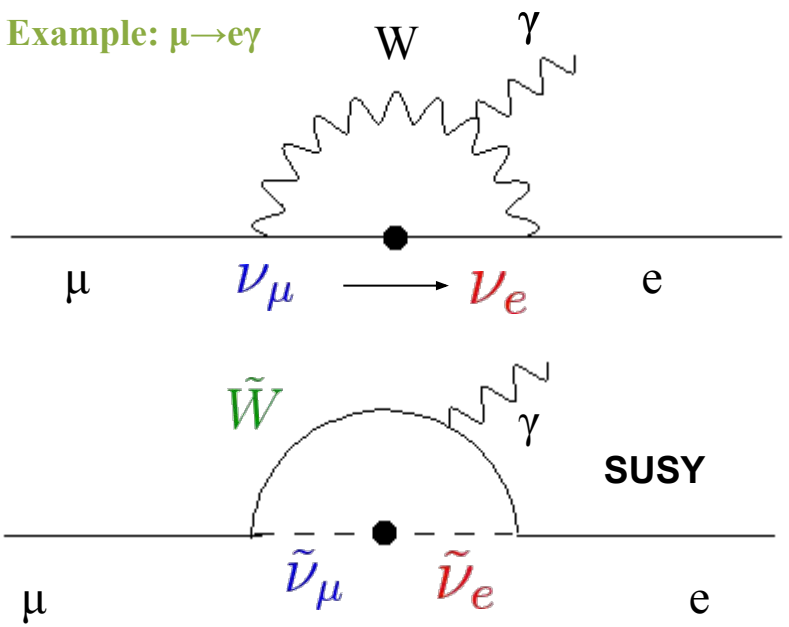
- Examples for NP contribution: SUSY



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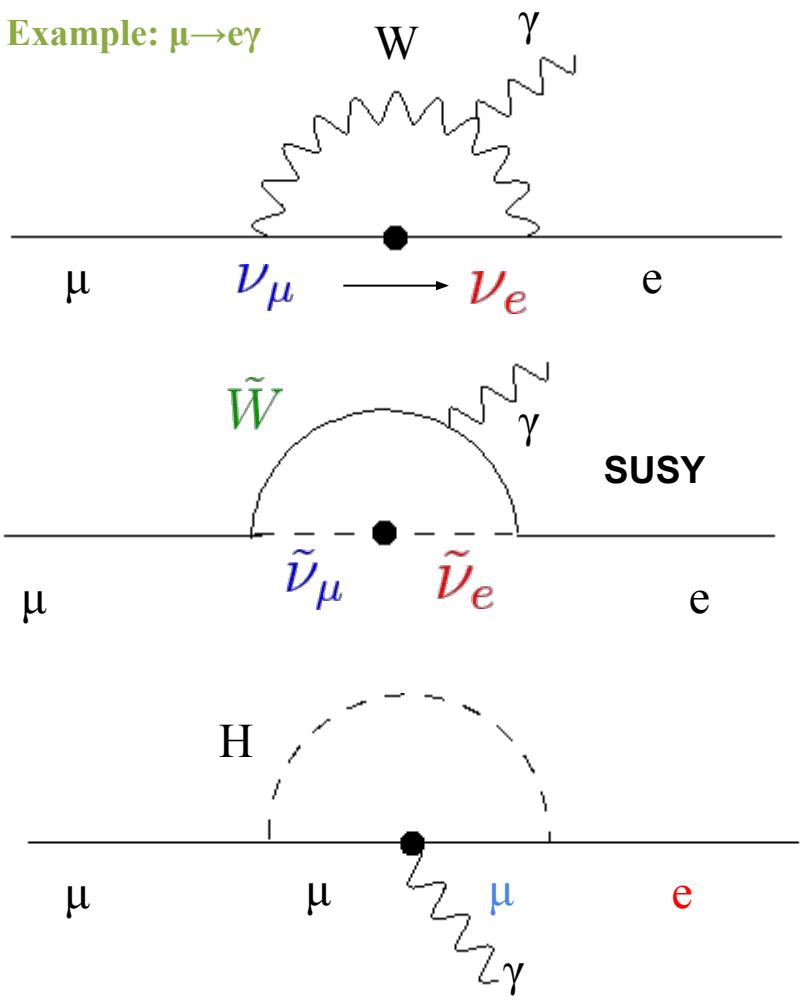
- Charged-Lepton-Flavor violation (CLFV): no SM contribution, hence clear signature for **New Physics (NP)**!
- Examples for NP contribution: SUSY, Heavy Neutrinos, Leptoquarks, Z', **Higgs**,...



Search for CLFV Higgs decays

In general two Higgs-Doublet models (2HDMs):

- ***CFLV Higgs coupling are possible!***
- Typically one need to introduce an additional symmetry to suppress flavor changing neutral currents (FCNC)...
- **LHC-RunII: exploit the full yukawa-matrix, not "only" the diagonal entries!**

SM values

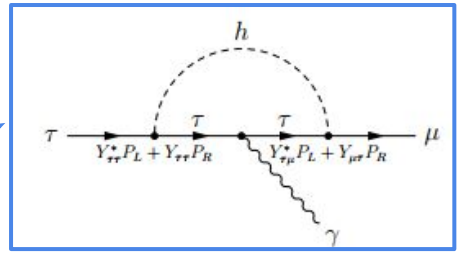
$$Y = \begin{pmatrix} Y_{ee} & Y_{e\mu} & Y_{e\tau} \\ Y_{\mu e} & Y_{\mu\mu} & Y_{\mu\tau} \\ Y_{\tau e} & Y_{\tau\mu} & Y_{\tau\tau} \end{pmatrix}$$

Harnik, Kopp, Zupan, arXiv:1209.1397

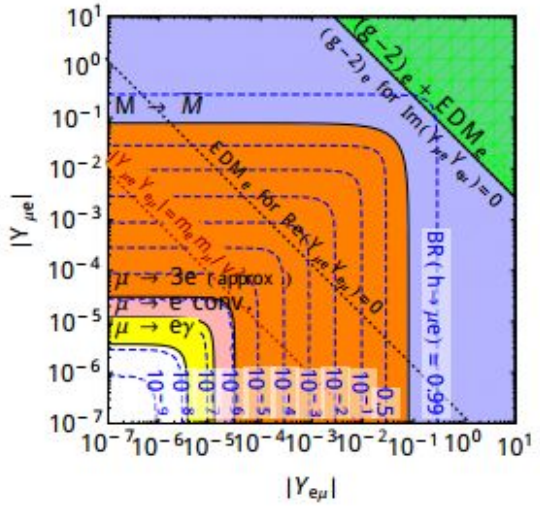
Search for CLFV Higgs decays

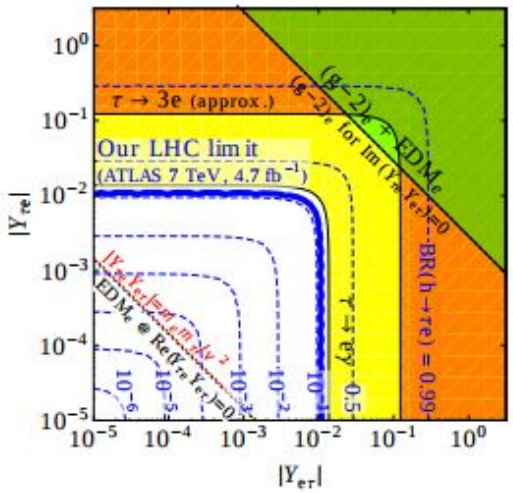
Pre-LFC bounds on LFV Higgs couplings

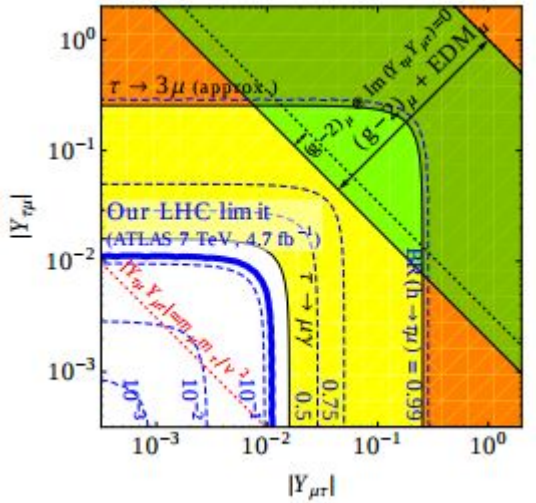
Channel	Coupling	Bound
$\mu \to e\gamma$	$\sqrt{\lvert Y_{\mu e}\rvert^2 + \lvert Y_{e\mu}\rvert^2}$	$< 3.6 \times 10^{-6}$
$\mu \to 3e$	$\sqrt{\lvert Y_{\mu e}\rvert^2 + \lvert Y_{e\mu}\rvert^2}$	$\lesssim 3.1 \times 10^{-5}$
electron $g-2$	$\mathrm{Re}(Y_{e\mu}Y_{\mu e})$	$-0.019 \ldots 0.026$
electron EDM	$\lvert\mathrm{Im}(Y_{e\mu}Y_{\mu e})\rvert$	$< 9.8 \times 10^{-8}$
$\mu \to e$ conversion	$\sqrt{\lvert Y_{\mu e}\rvert^2 + \lvert Y_{e\mu}\rvert^2}$	$< 1.2 \times 10^{-5}$
M-$\bar{M}$ oscillations	$\lvert Y_{\mu e} + Y^*_{e\mu}\rvert$	< 0.079
$\tau \to e\gamma$	$\sqrt{\lvert Y_{\tau e}\rvert^2 + \lvert Y_{e\tau}\rvert^2}$	< 0.014
$\tau \to 3e$	$\sqrt{\lvert Y_{\tau e}\rvert^2 + \lvert Y_{e\tau}\rvert^2}$	$\lesssim 0.12$
electron $g-2$	$\mathrm{Re}(Y_{e\tau}Y_{\tau e})$	$[-2.1 \ldots 2.9] \times 10^{-3}$
electron EDM	$\lvert\mathrm{Im}(Y_{e\tau}Y_{\tau e})\rvert$	$< 1.1 \times 10^{-8}$
$\tau \to \mu\gamma$	$\sqrt{\lvert Y_{\tau\mu}\rvert^2 + \lvert Y_{\mu\tau}\rvert^2}$	0.016
$\tau \to 3\mu$	$\sqrt{\lvert Y^2_{\tau\mu} + \lvert Y_{\mu\tau}\rvert^2}$	$\lesssim 0.25$
muon $g-2$	$\mathrm{Re}(Y_{\mu\tau}Y_{\tau\mu})$	$(2.7 \pm 0.75) \times 10^{-3}$
muon EDM	$\mathrm{Im}(Y_{\mu\tau}Y_{\tau\mu})$	$-0.8 \ldots 1.0$
$\mu \to e\gamma$	$(\lvert Y_{\tau\mu}Y_{e\tau}\rvert^2 + \lvert Y_{\mu\tau}Y_{\tau e}\rvert^2)^{1/4}$	$< 3.4 \times 10^{-4}$

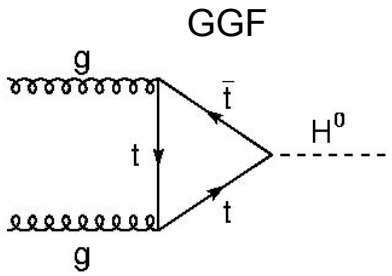


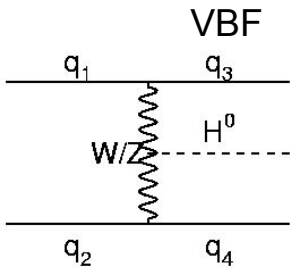
Pre-LHC constraints:
B(H→μτ/eτ)~O(10%)
are still allowed!





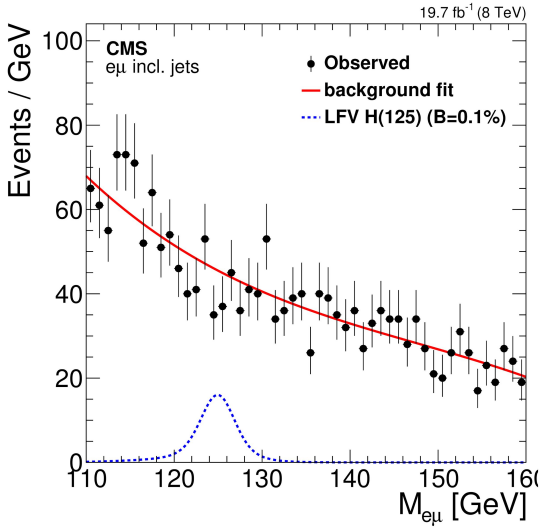


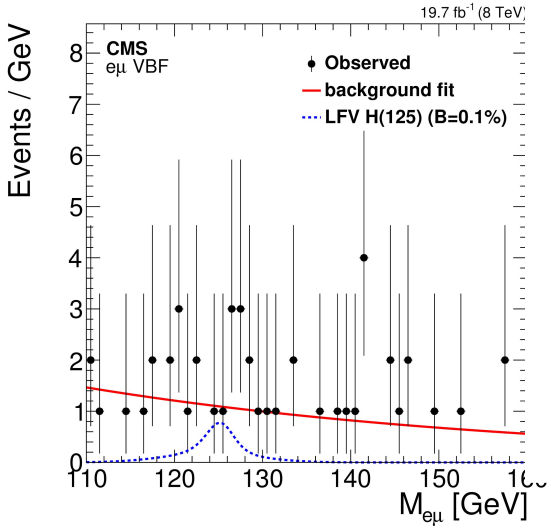


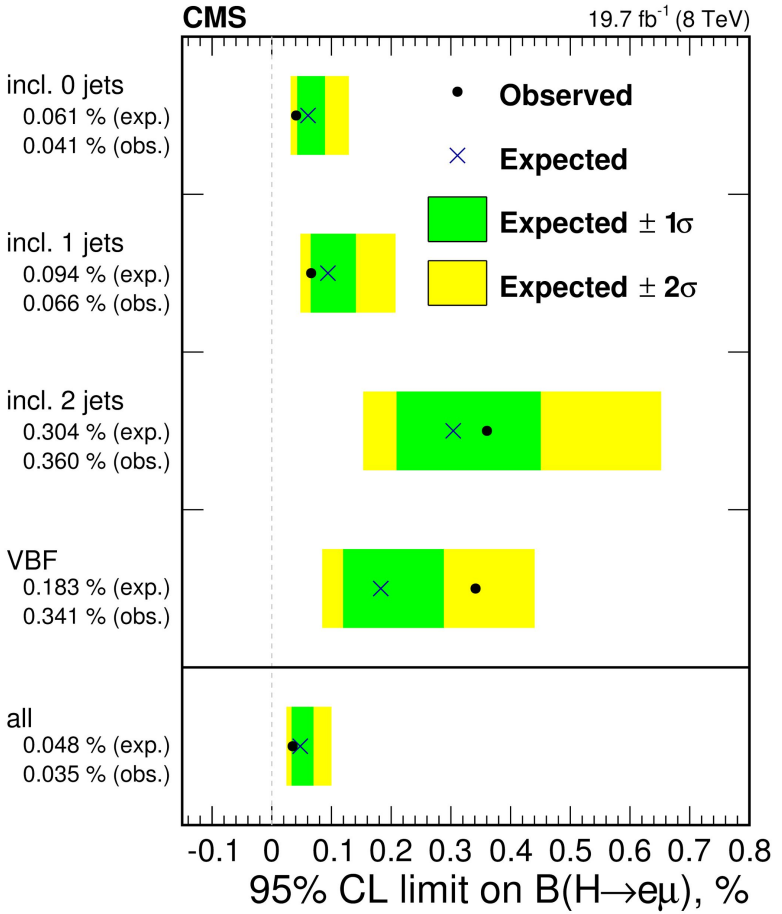


Search for H→eμ

- Dilepton: e+μ with opposite sign
- GGF and VBF production: 0,1 and 2 Jet category
- Low MET in the events is required
- Background: 'smooth' fit of the dilepton invariant mass distribution $m_{e\mu}$=[110,160]







arXiv:1607.03561

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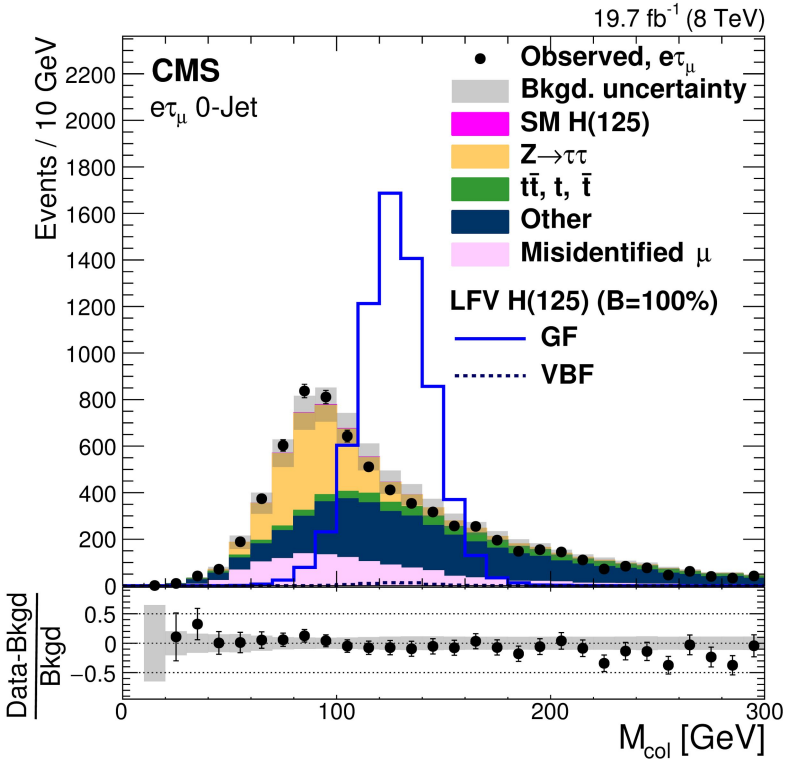
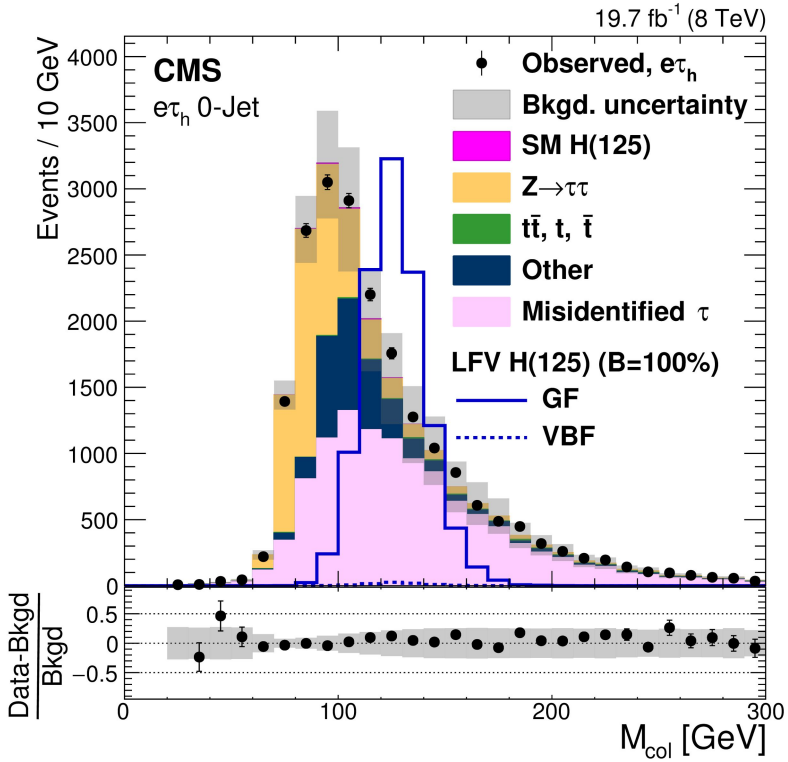
Search for H→eτ

- 2 channels: leptonic tau (μ) and hadronic tau decays
- GGF and VBF production channels: 0, 1 and 2-Jet categories



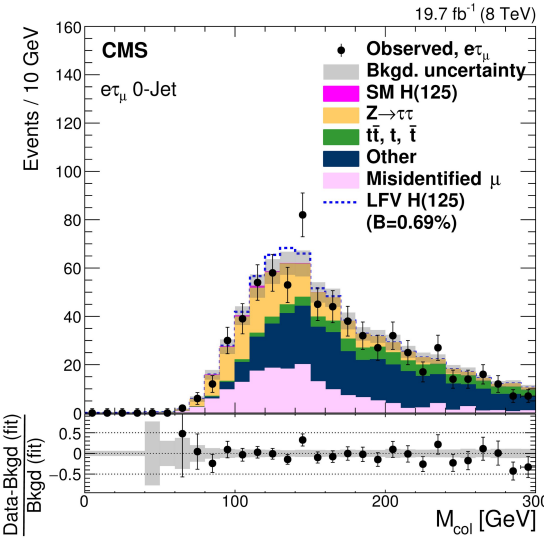


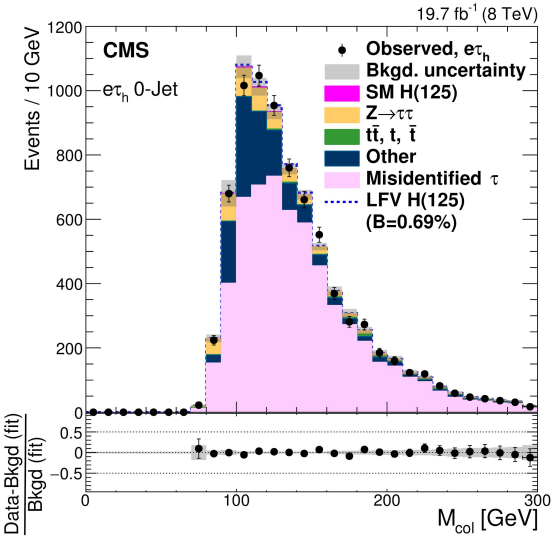
Misidentified lepton and **Z→ττ** background estimated from data!

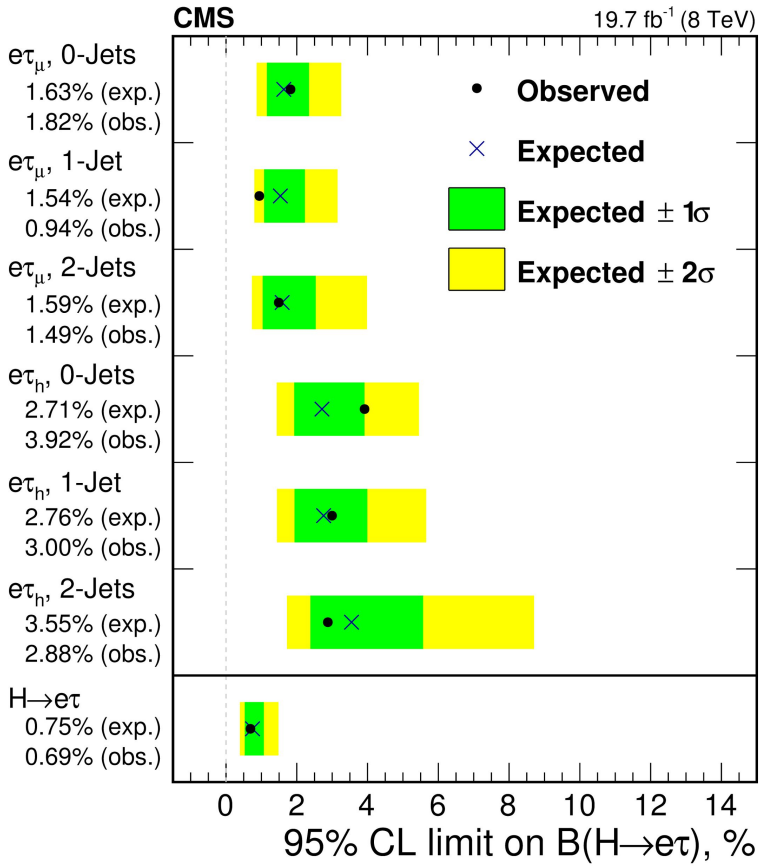
Search for H→eτ

- Kinematic cuts to enhance S/B ratio

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





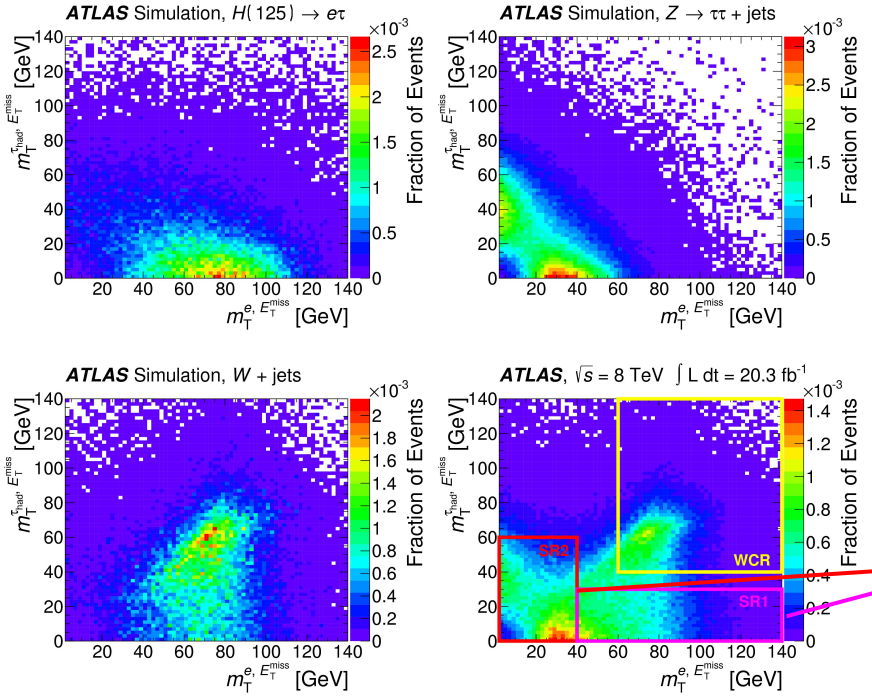


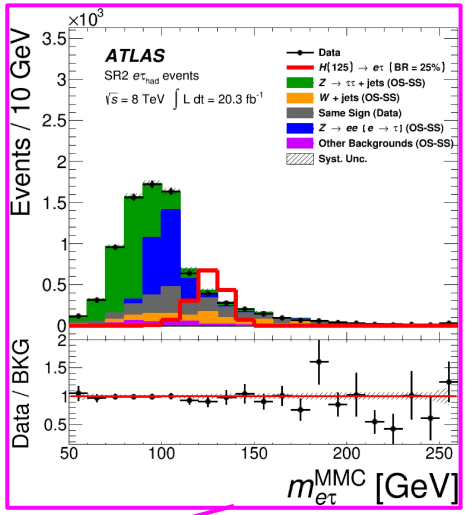
arXiv:1607.03561

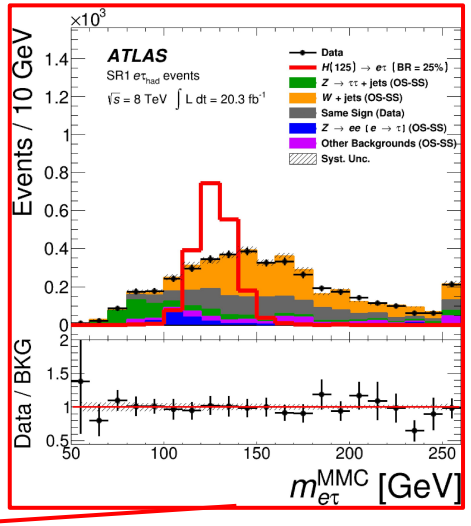
arXiv:1604.07730

Search for H→eτ$_{had}$

- 2 channels: leptonic tau (μ) and hadronic tau decays
- GGF and VBF production channels considered
- SR defined in 2D plane of m_T(e,MET) and $m_T(\tau_{had}$,MET)







QCD and Z→ττ background estimated from data!

Search for $H \to e\tau_\mu$

- SRs: kinematic cuts and jet multiplicity
- Fully data driven background estimation!
- Flavour symmetric backgrounds estimated by switching cuts on μ↔e

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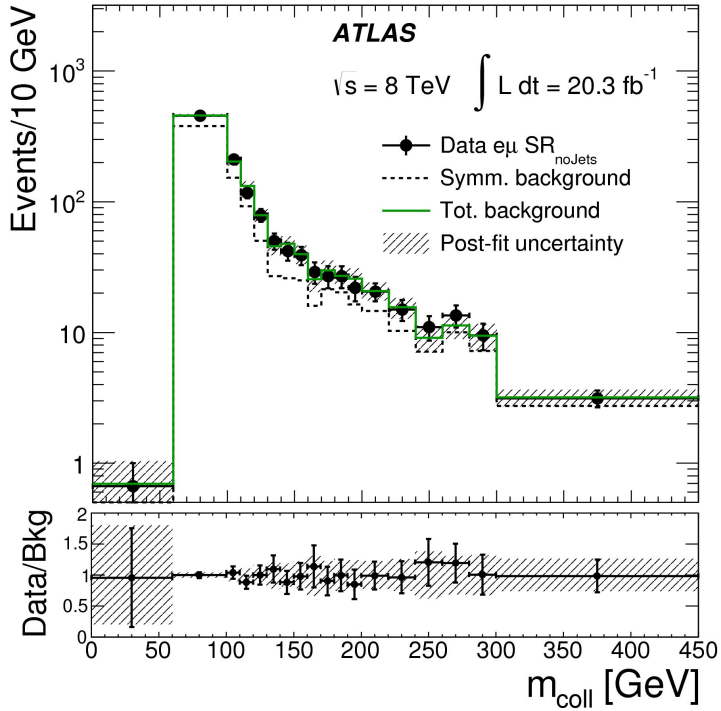
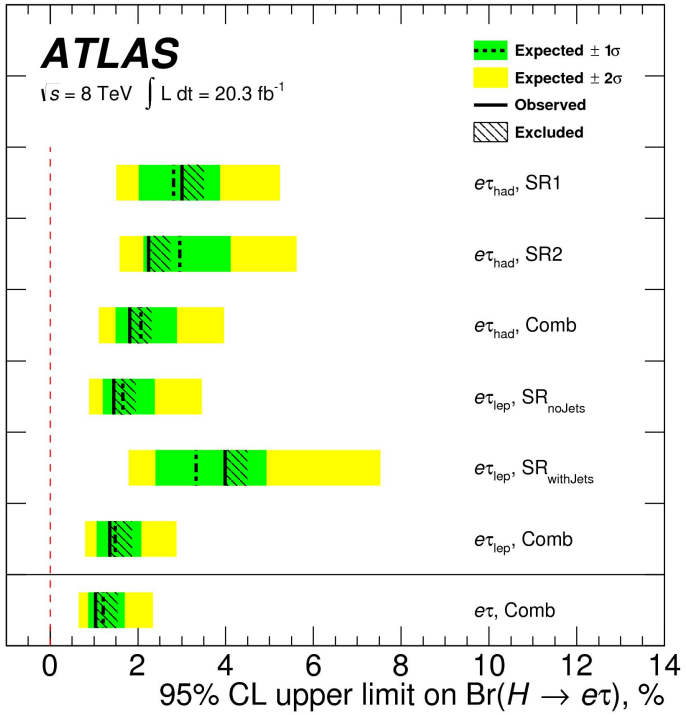
	SR_{noJets}	$SR_{withJets}$
Light leptons	$e^{\pm}\mu^{\mp}$	$e^{\pm}\mu^{\mp}$
τ leptons	veto	veto
Central jets	0	≥ 1
b-jets	0	0
$p_T^{\ell_1}$	$\geq 35GeV$	$\geq 35GeV$
$p_T^{\ell_2}$	$\geq 12GeV$	$\geq 12GeV$
$\lvert\eta^e\rvert$	≤ 2.4	≤ 2.4
$\lvert\eta^\mu\rvert$	≤ 2.4	≤ 2.4
$\Delta\phi(\ell_2, E_T^{miss})$	≤ 0.7	≤ 0.5
$\Delta\phi(\ell_1, \ell_2)$	≥ 2.3	≥ 1.0
$\Delta\phi(\ell_1, E_T^{miss})$	≥ 2.5	≥ 1.0
$\Delta p_T(\ell_1, \ell_2)$	$\geq 7GeV$	$\geq 1GeV$





Search for H→μτ

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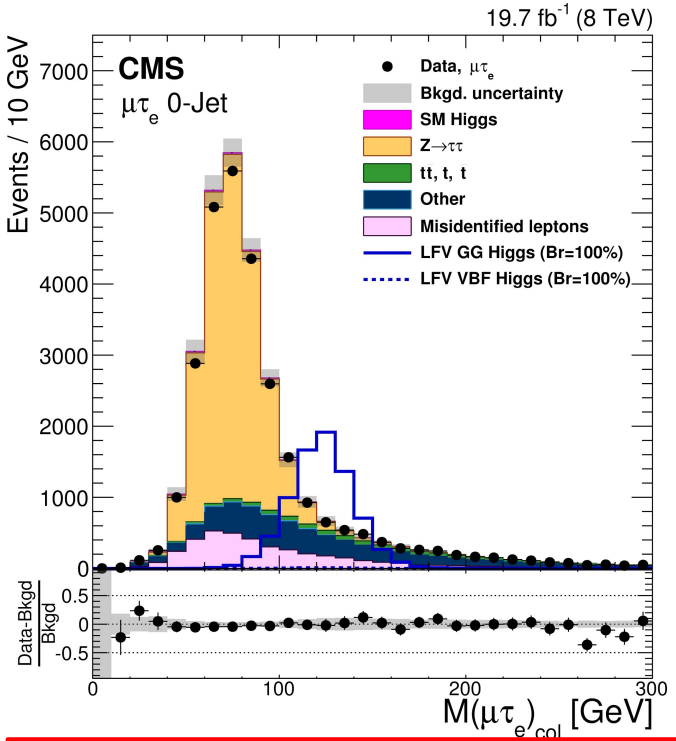

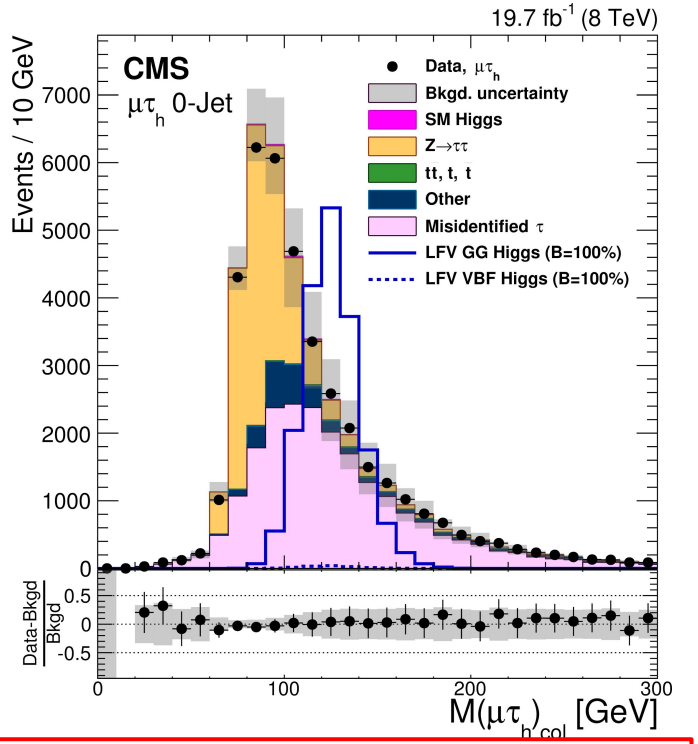

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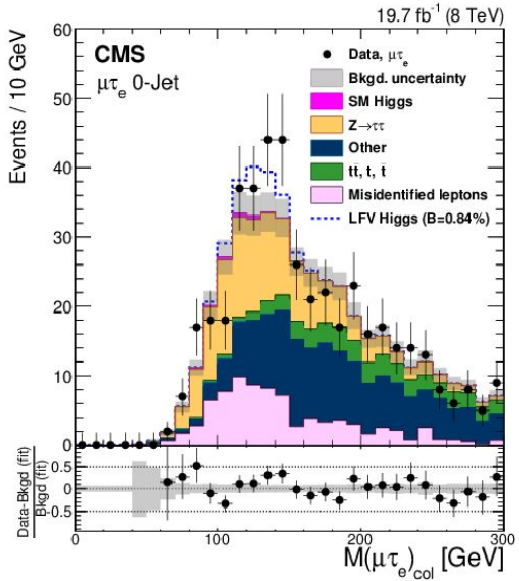
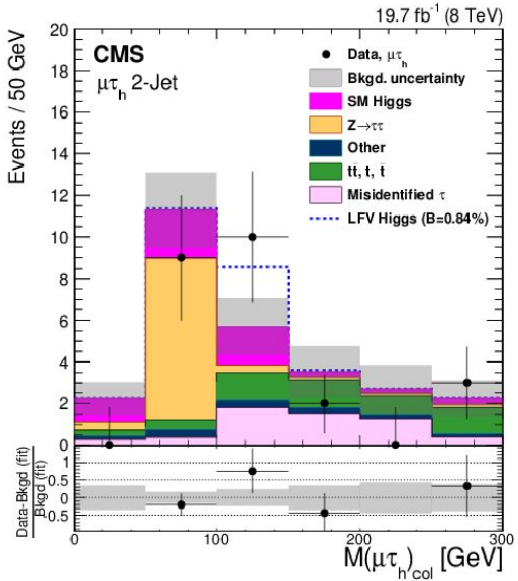
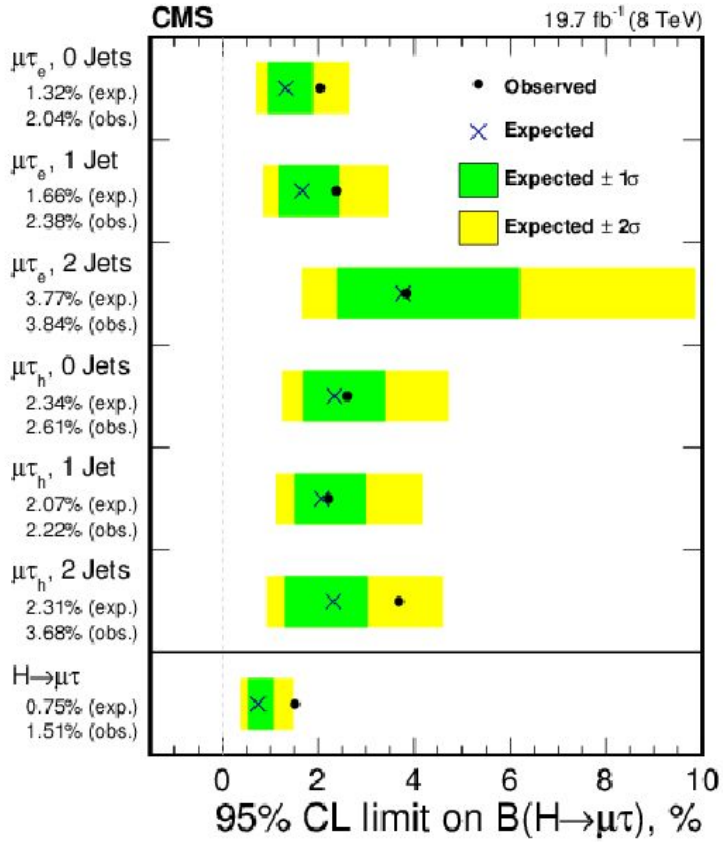
[GeV]	0-jet	1-jet	2-jet	0-jet	1-jet	2-jet
$p_T^\mu >$	50	45	25	45	35	30
$p_T^e >$	10	10	10	—	—	—
$p_T^\tau >$	—	—	—	35	40	40
$M_T^e <$	65	65	25	—	—	—
$M_T^\mu >$	50	40	15	—	—	—
$M_T^\tau <$	—	—	—	50	35	35
[radians]						
$\Delta\phi_{\vec{p}_T^\mu - \vec{p}_T^{\tau_h}} >$	—	—	—	2.7	—	—
$\Delta\phi_{\vec{p}_T^e - \vec{E}_T^{miss}} <$	0.5	0.5	0.3	—	—	—
$\Delta\phi_{\vec{p}_T^e - \vec{p}_T^\mu} >$	2.7	1.0	—	—	—	—







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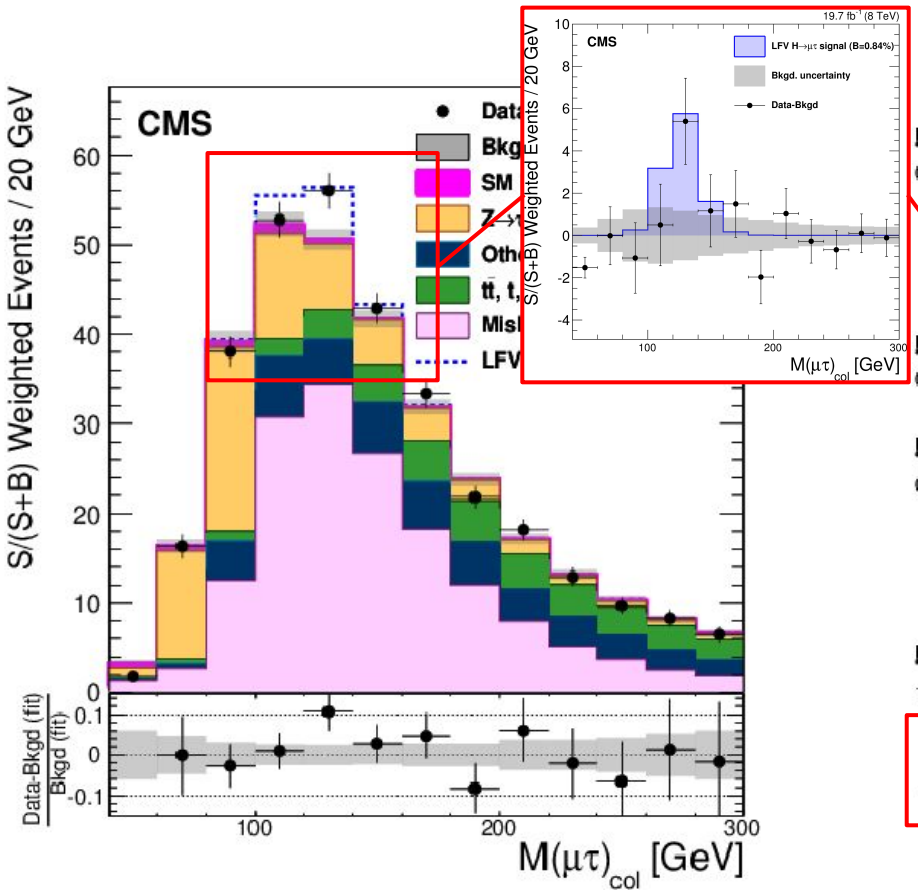
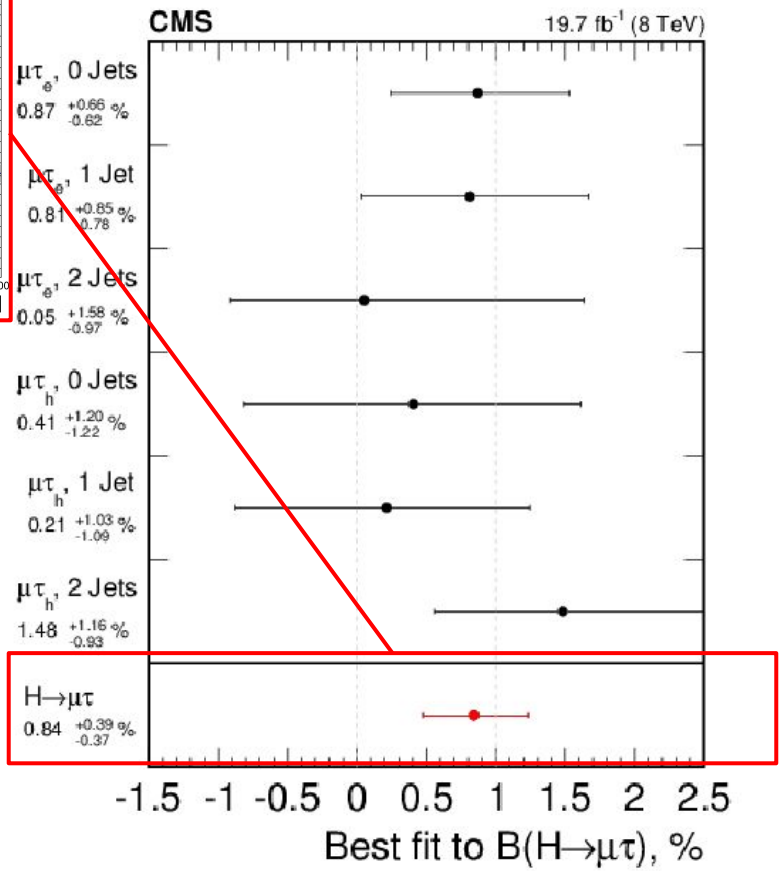
Search for H→μτ

Excess: ~2.4σ excess
Best Fit B(H→μτ)=0.84±0.39%





JHEP11(2015)211

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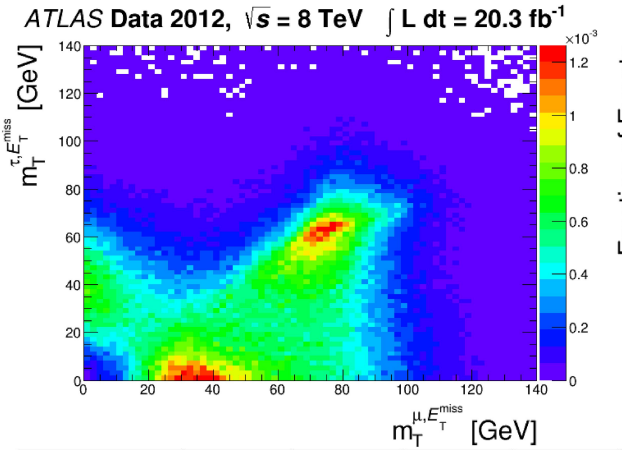
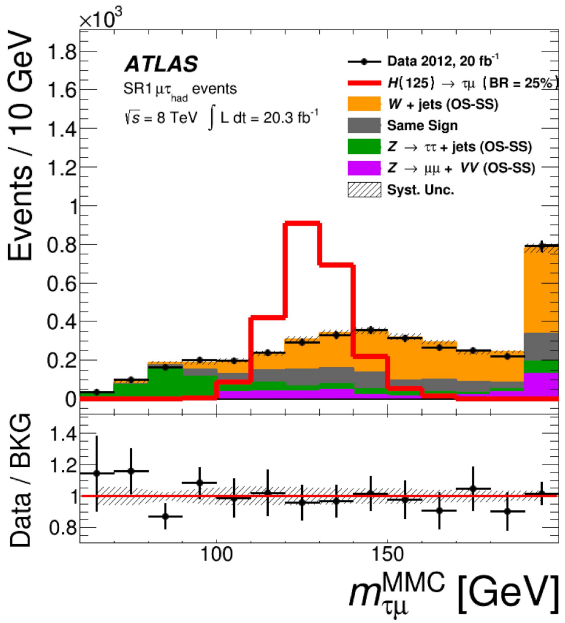
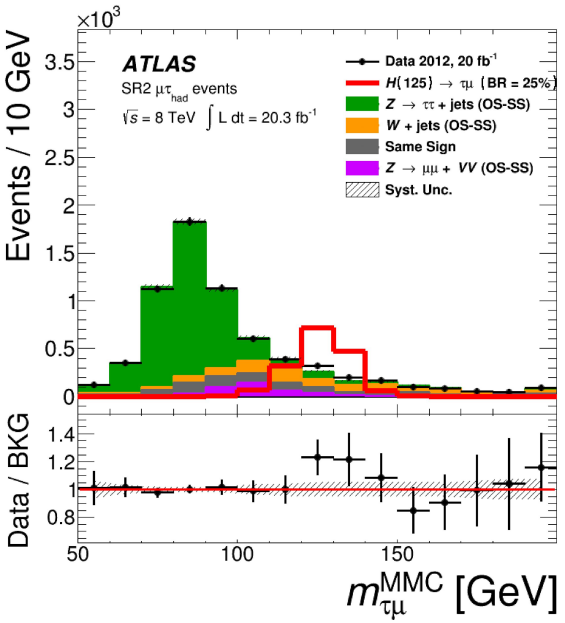


Cut	SR1	SR2	WCR	TCR
$p_T(\mu)$	>26 GeV	>26 GeV	>26 GeV	>26 GeV
$p_T(\tau_{had})$	>45 GeV	>45 GeV	>45 GeV	>45 GeV
$m_T(\mu, E_T^{miss})$	>40 GeV	<40 GeV	>60 GeV	–
$m_T(\tau_{had}, E_T^{miss})$	<30 GeV	<60 GeV	>40 GeV	–
$\lvert\eta(\mu) - \eta(\tau_{had})\rvert$	<2	<2	<2	<2
N_{jet}	–	–	–	>1
N_{b-jet}	0	0	0	>0





QCD and Z→ττ background estimated from data!

Search for $H \to \mu\tau_e$

- SRs: kinematic cuts and jet multiplicity
- Fully data driven background estimation!
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arXiv:1604.07730

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$\Delta\phi(\ell_1, E_T^{miss})$	≥ 2.5	≥ 1.0
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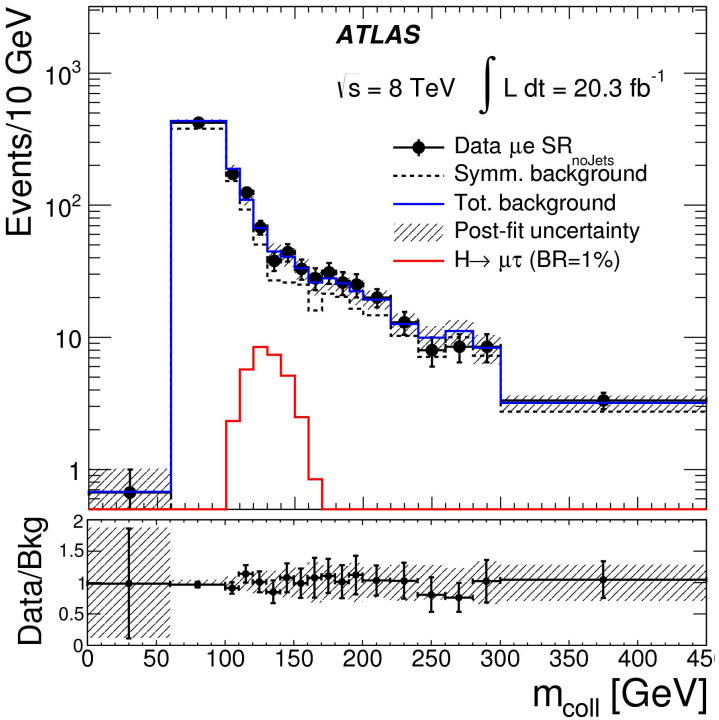
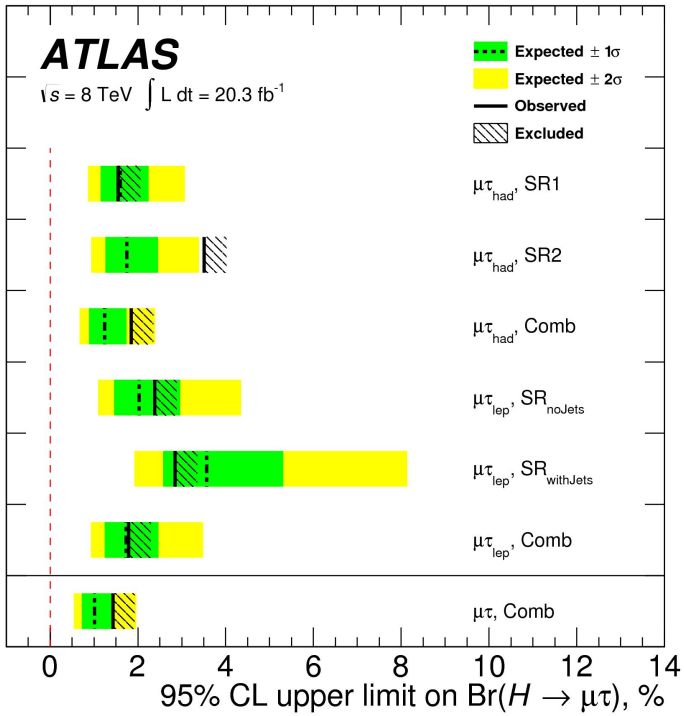
Similar to $H \to e\tau_\mu$ search!





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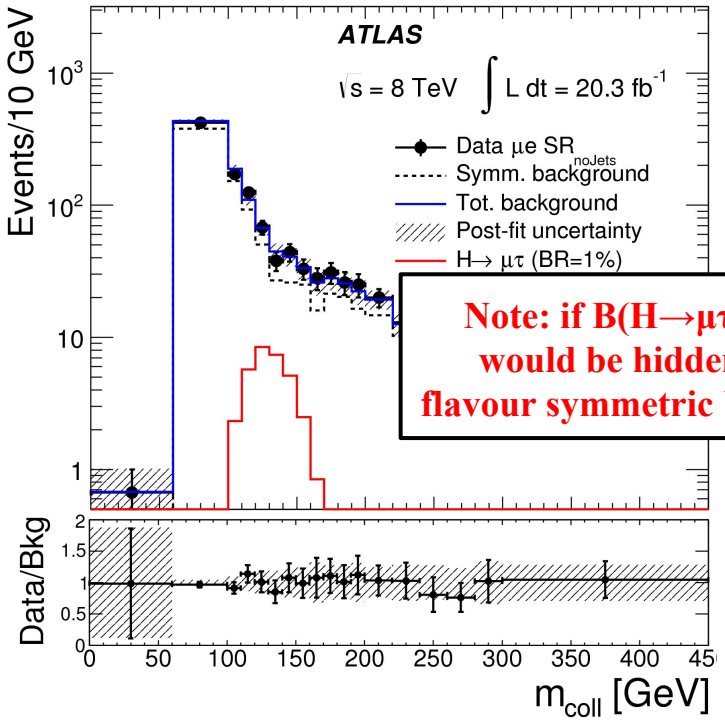
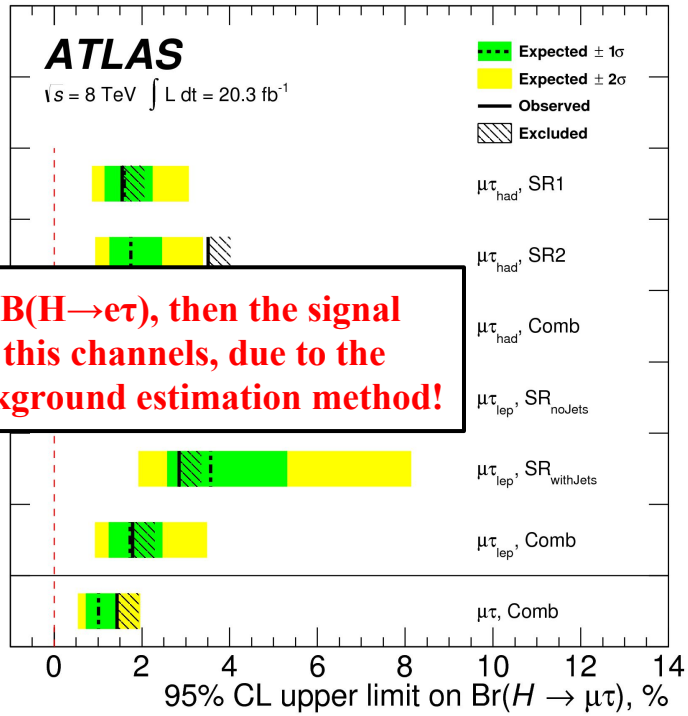
$\Delta p_T(\ell_1, \ell_2)$	$\geq 7GeV$	$\geq 1GeV$

Similar to H→eτ$_\mu$ search!

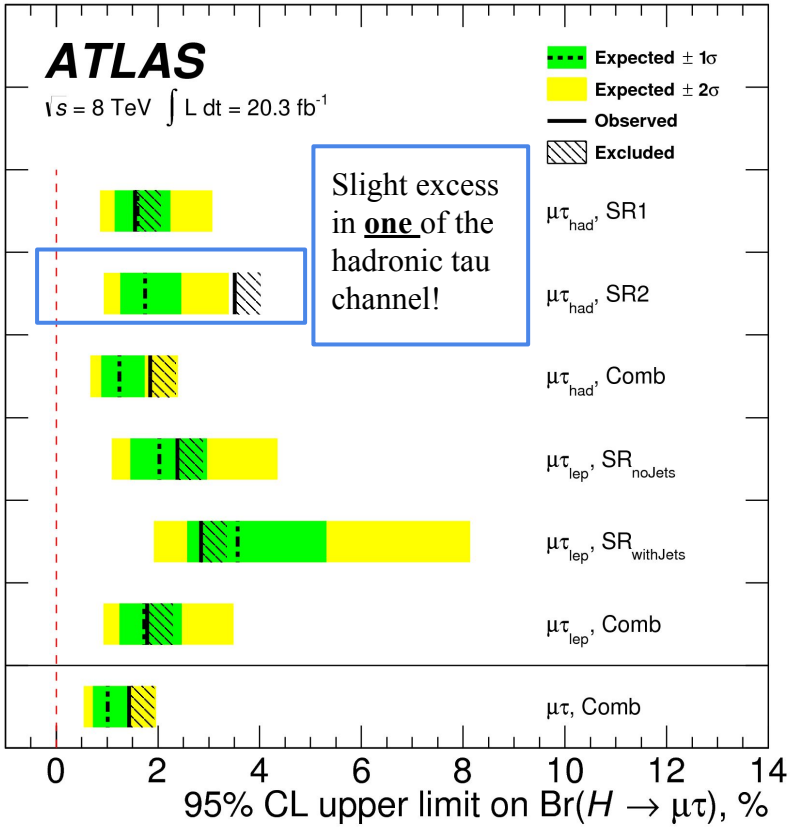


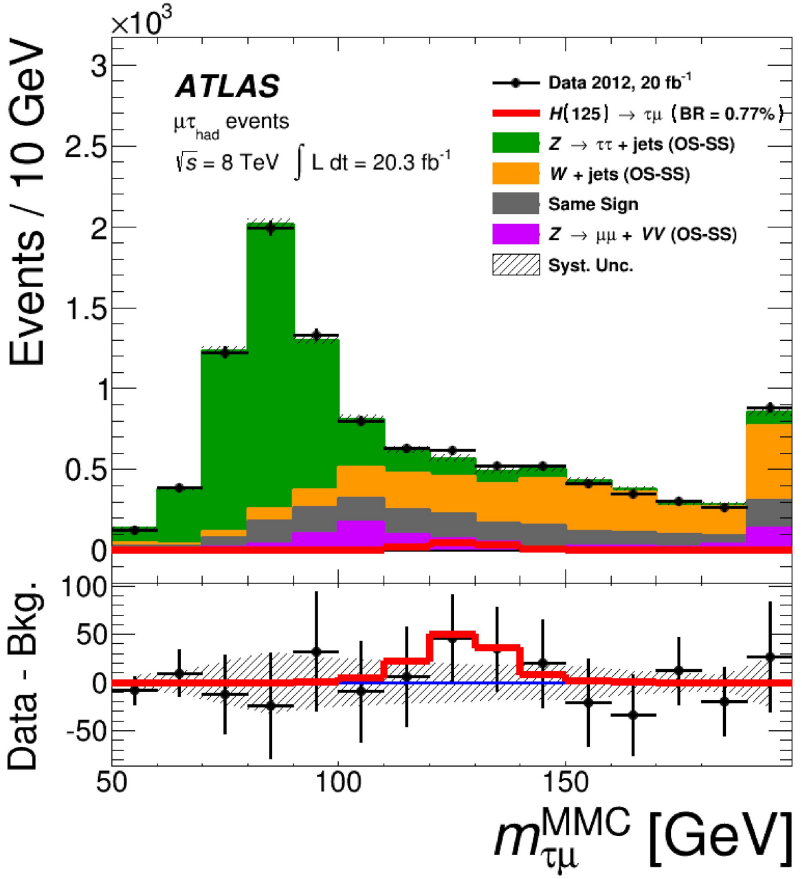


Note: if B(H→μτ)==B(H→eτ), then the signal would be hidden in this channels, due to the flavour symmetric background estimation method!

arXiv:1604.07730

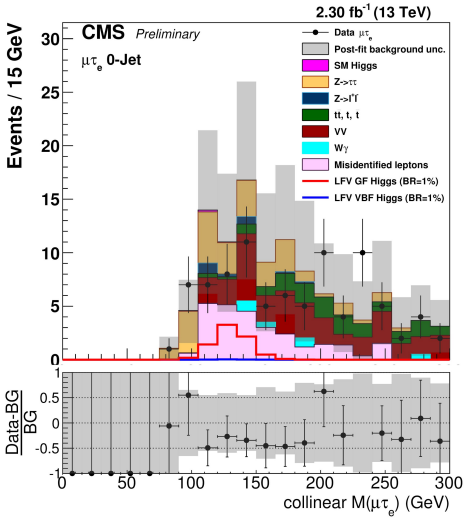
Search for H→μτ

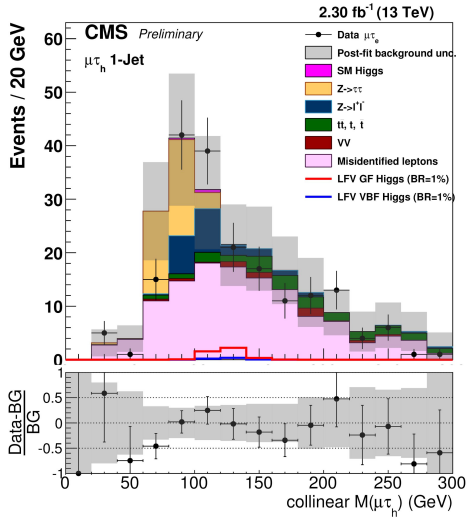


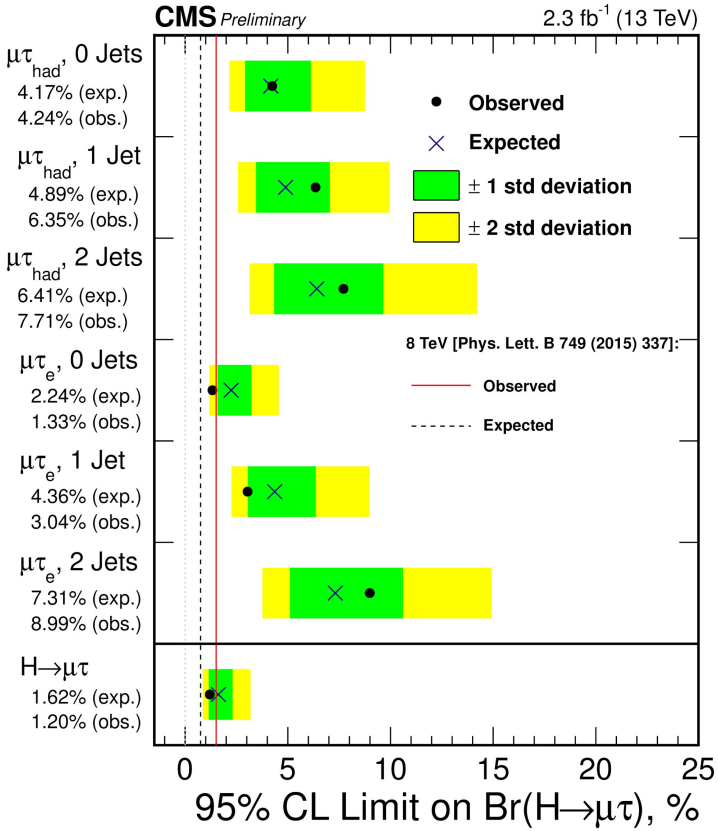


Search for H→μτ @ 13TeV!

- Repetition of 8 TeV CMS H→μτ analysis: no change of strategy and kinematic cuts
- **Slight excess of 8 TeV analysis could not be confirmed so far, but also not excluded!**
- Updated B(H→μτ) Limit: B(H→μτ)<1.2% observed (1.62% expected)

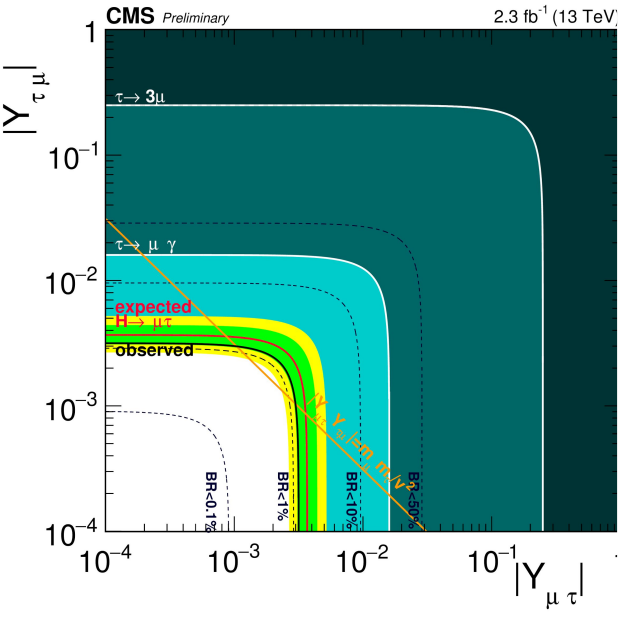


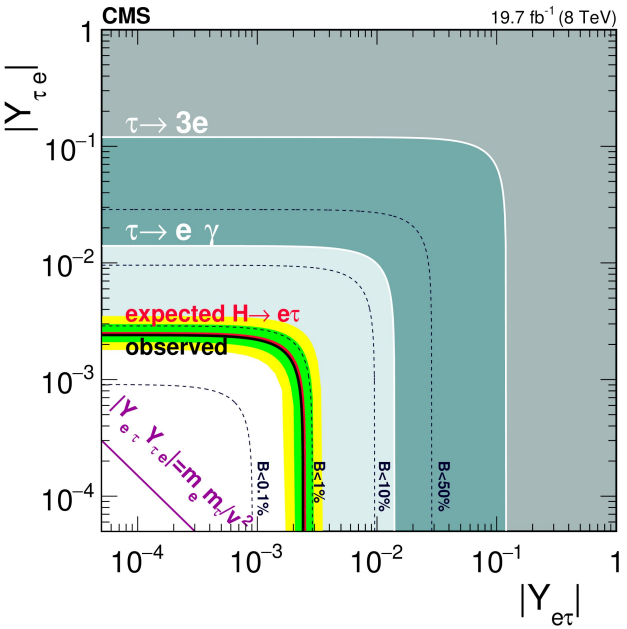


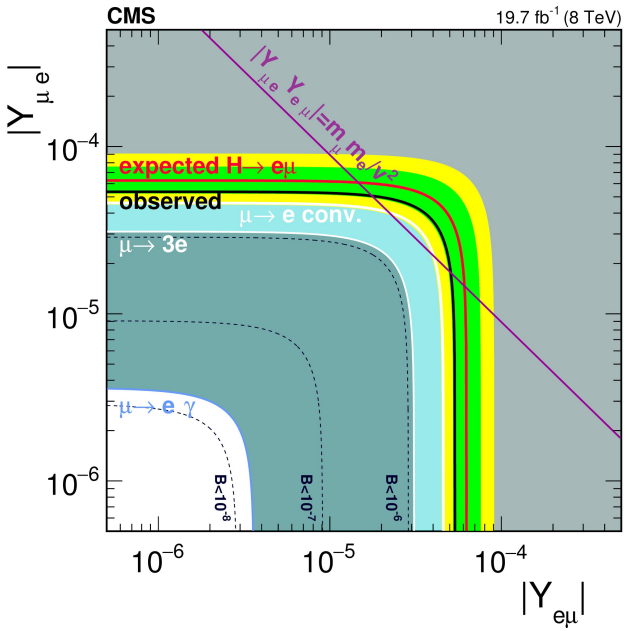


CMS-PAS-HIG-16-005

LFV Higgs Summary







Expect major update by end of the year for the Atlas and CMS Analysis!

Conclusion

- All possible CLFV Higgs couplings has been investigated at CMS+ATLAS!
- Limits improved by one order of magnitude with respect to previous limits
- Slight excess in 8 TeV not yet confirmed or ruled out at 13 TeV → full 206 data set will reveal if excess was true!
- More interesting results on general CLFV searches (SUSY, EXO, Z, ...) available as well!

http://cms-results.web.cern.ch/cms-results/public-results/publications/

https://twiki.cern.ch/twiki/bin/view/AtlasPublic

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