Search for LFV Higgs decays at CMS

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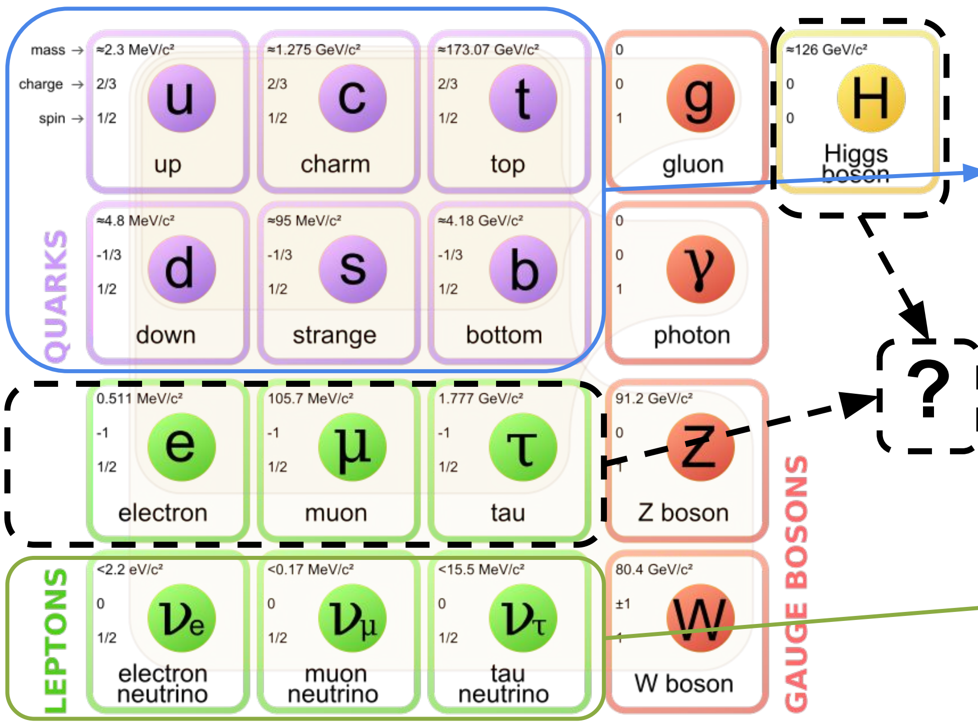
Outline: LFV Higgs decays @ CMS

- Short Motivation
- 8 TeV: H→eμ, H→eτ, H→μτ a
- 13 TeV: Run-II update for Moriond
- 13 TeV: Tau polarization
- Summary

Why Charged Lepton Flavor Violation (CLFV)?



CKM matrix - quark sector

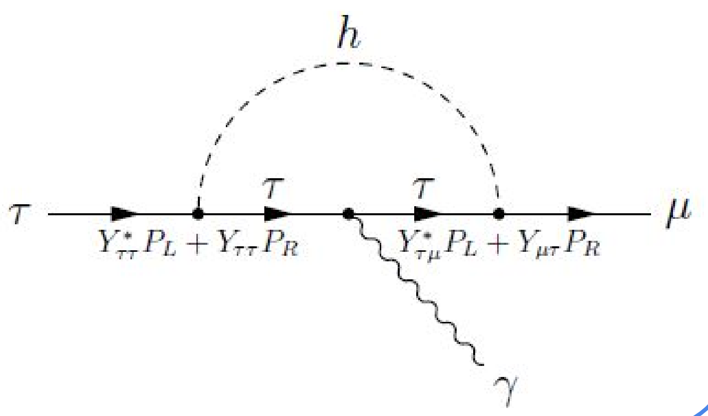
$$\begin{pmatrix} d' \\ s' \\ b' \end{pmatrix} = \begin{pmatrix} V_{ud} & V_{us} & V_{ub} \\ V_{cd} & V_{cs} & V_{cb} \\ V_{td} & V_{ts} & V_{tb} \end{pmatrix} \begin{pmatrix} d \\ s \\ b \end{pmatrix} = V_{CKM} \begin{pmatrix} d \\ s \\ b \end{pmatrix}$$

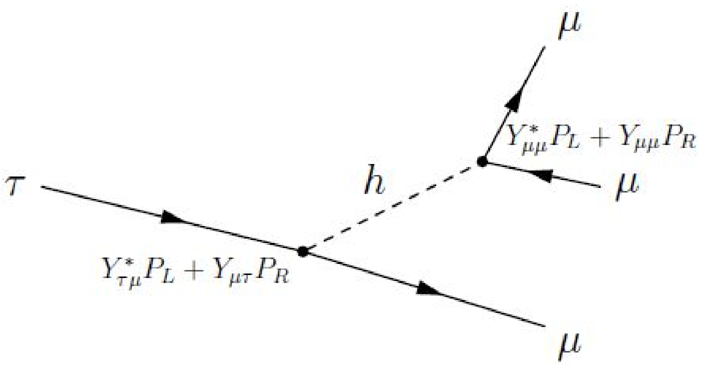
Higgs: CLFV couplings?

PMNS matrix - neutrino sector

$$\begin{bmatrix} \nu_e \\ \nu_\mu \\ \nu_\tau \end{bmatrix} = \begin{bmatrix} U_{e1} & U_{e2} & U_{e3} \\ U_{\mu 1} & U_{\mu 2} & U_{\mu 3} \\ U_{\tau 1} & U_{\tau 2} & U_{\tau 3} \end{bmatrix} \begin{bmatrix} \nu_1 \\ \nu_2 \\ \nu_3 \end{bmatrix}.$$

Constraints from low energy measurements

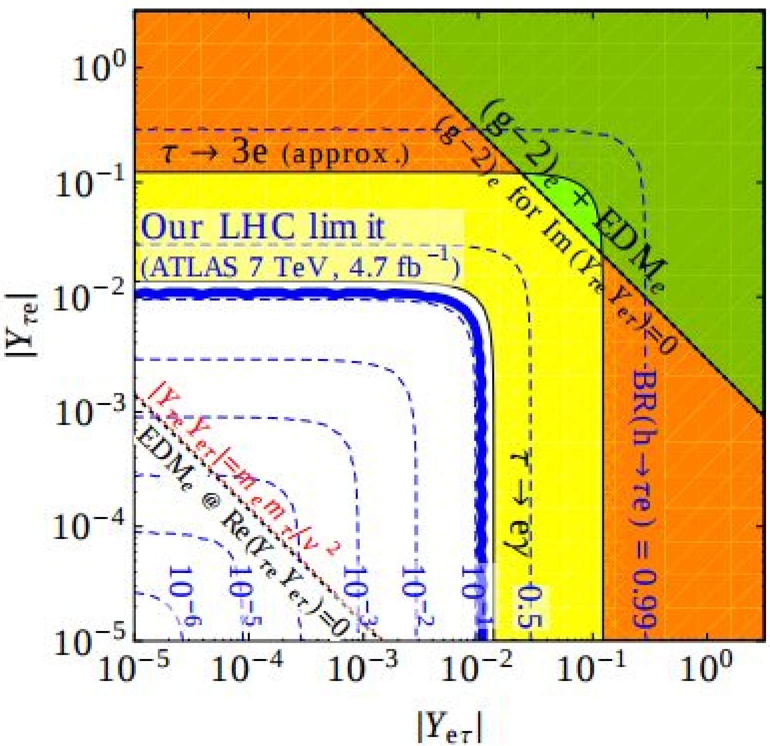


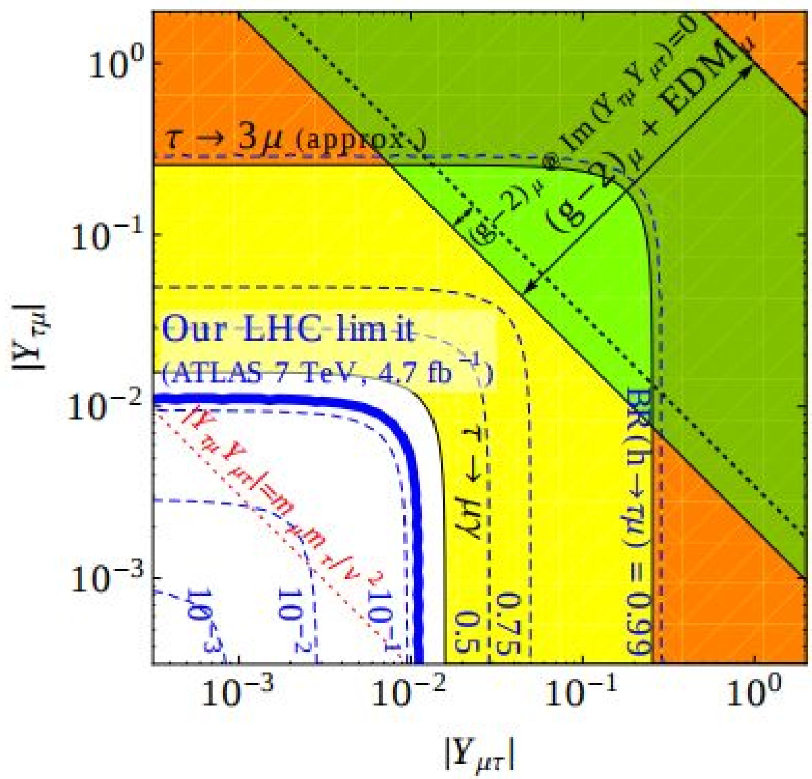


Channel	Coupling	Bound
$\mu \to e\gamma$	$\sqrt{\lvert Y_{\mu e}\rvert^2 + \lvert Y_{e\mu}\rvert^2}$	$< 3.6 \times 10^{-6}$
$\mu \to 3e$	$\sqrt{\lvert Y_{\mu e}\rvert^2 + \lvert Y_{e\mu}\rvert^2}$	$\lesssim 3.1 \times 10^{-5}$
electron $g-2$	$\mathrm{Re}(Y_{e\mu}Y_{\mu e})$	$-0.019 \ldots 0.026$
electron EDM	$\lvert\mathrm{Im}(Y_{e\mu}Y_{\mu e})\rvert$	$< 9.8 \times 10^{-8}$
$\mu \to e$ conversion	$\sqrt{\lvert Y_{\mu e}\rvert^2 + \lvert Y_{e\mu}\rvert^2}$	$< 4.6 \times 10^{-5}$
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
$\tau \to 3\mu$	$\sqrt{\lvert Y_{\tau\mu}^2 + \lvert Y_{\mu\tau}\rvert^2}$	$\lesssim 0.25$
muon $g-2$	$\mathrm{Re}(Y_{\mu\tau}Y_{\tau\mu})$	$(2.7 \pm 0.75) \times 10^{-3}$
muon EDM	$\mathrm{Im}(Y_{\mu\tau}Y_{\tau\mu})$	$-0.8 \ldots 1.0$
$\mu \to e\gamma$	$(\lvert Y_{\tau\mu}Y_{\tau e}\rvert^2 + \lvert Y_{\mu\tau}Y_{e\tau}\rvert^2)^{1/4}$	$< 3.4 \times 10^{-4}$

Harnik, Kopp, Zupan, JHEP 1303 (2013) 026 (2013-03-05)

Constraints from low energy measurements



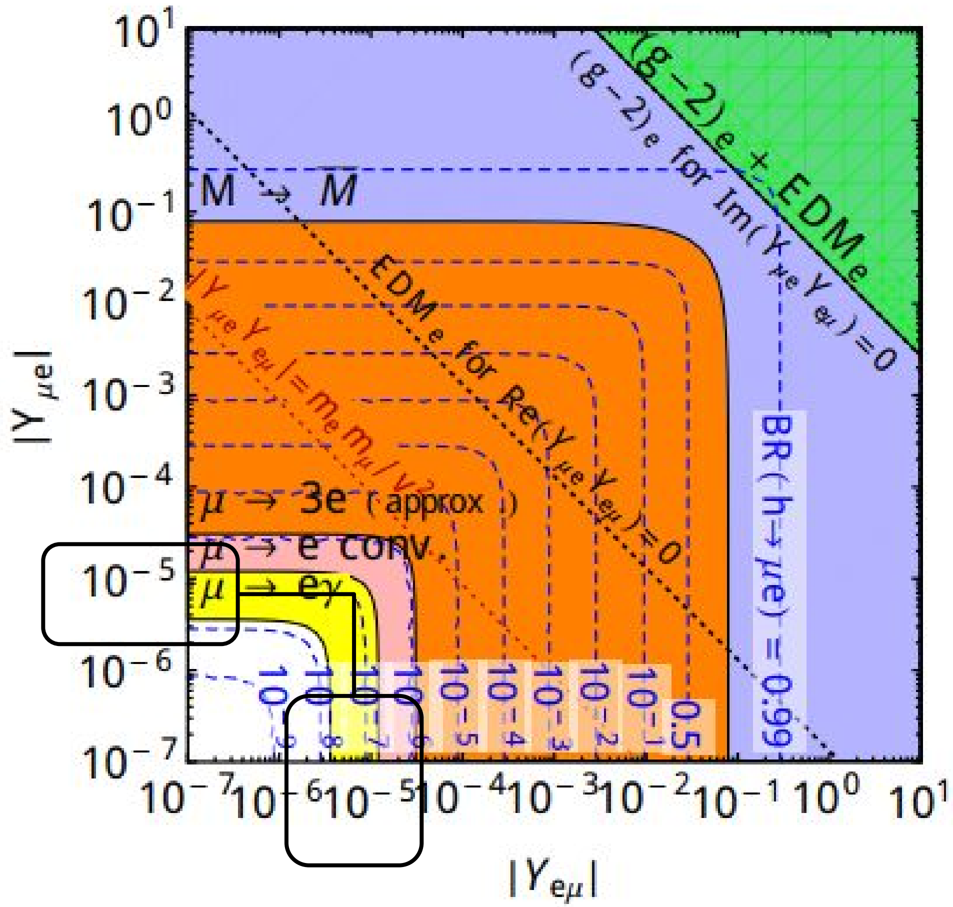


Harnik, Kopp, Zupan, JHEP 1303 (2013) 026 (2013-03-05)

Constraints from low energy measurements

H→eμ:

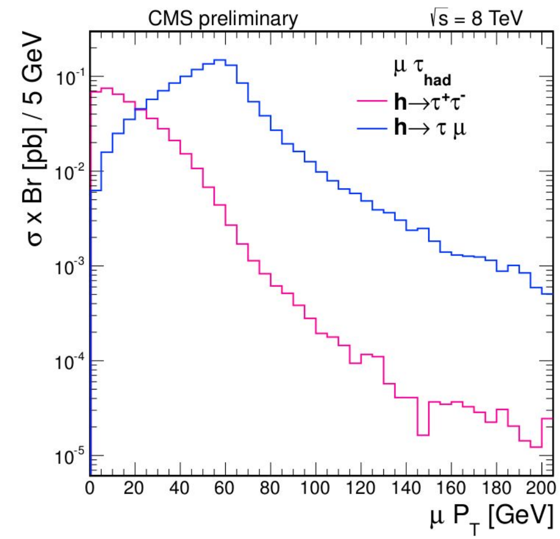
- Limit on the BR(H→eμ) in the order of 10^{-8}
- No chance at the LHC!



Harnik, Kopp, Zupan, JHEP 1303 (2013) 026 (2013-03-05)

H→μτ : Overview

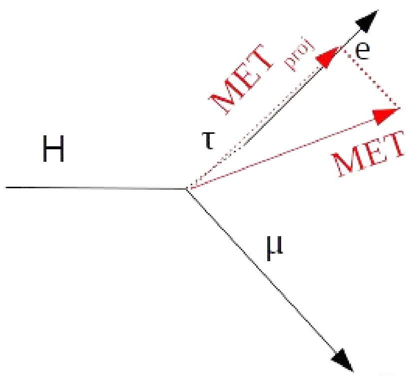
- 2 channels: leptonic tau (e) and hadronic tau decays
- GGF and VBF production considered: 0,1 and 2-Jet categories
- Dilepton (eμ) and/or SingleMuon trigger
- Kinematic cuts to enhance S/B ratio



Variable	$H \to \mu\tau_e$			$H \to \mu\tau_h$		
[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	—	—	—	—

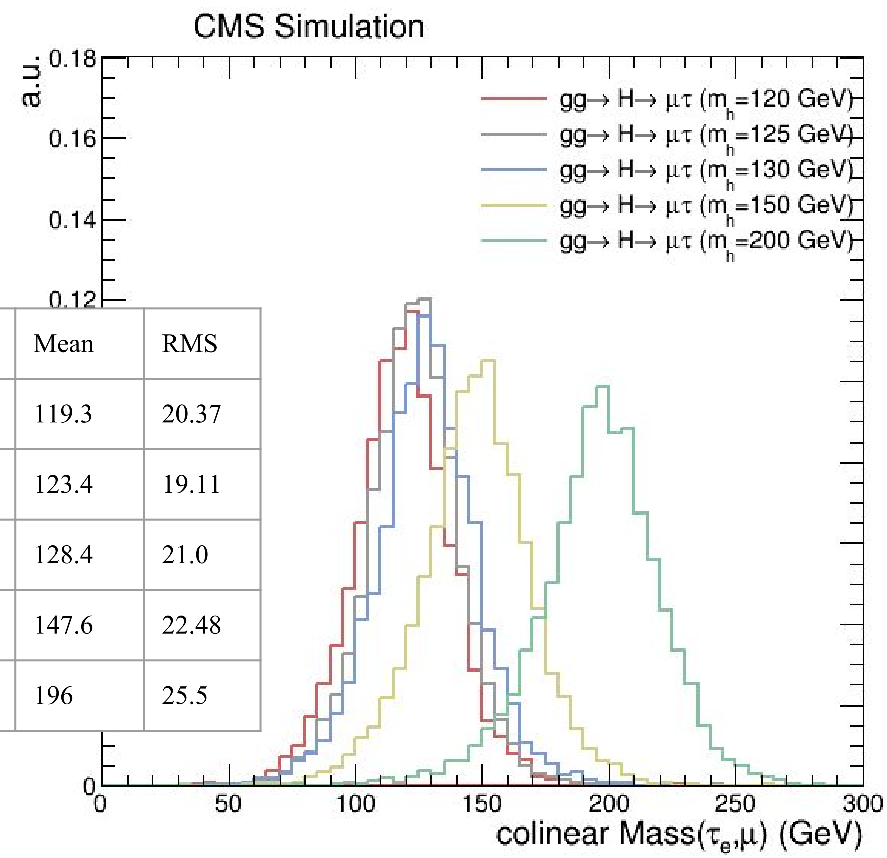
H→μτ: mass reconstruction

- Collinear mass approximation (projection method)
- Assumption: neutrinos are collinear with the tau directions and thus with the lepton (e/μ)



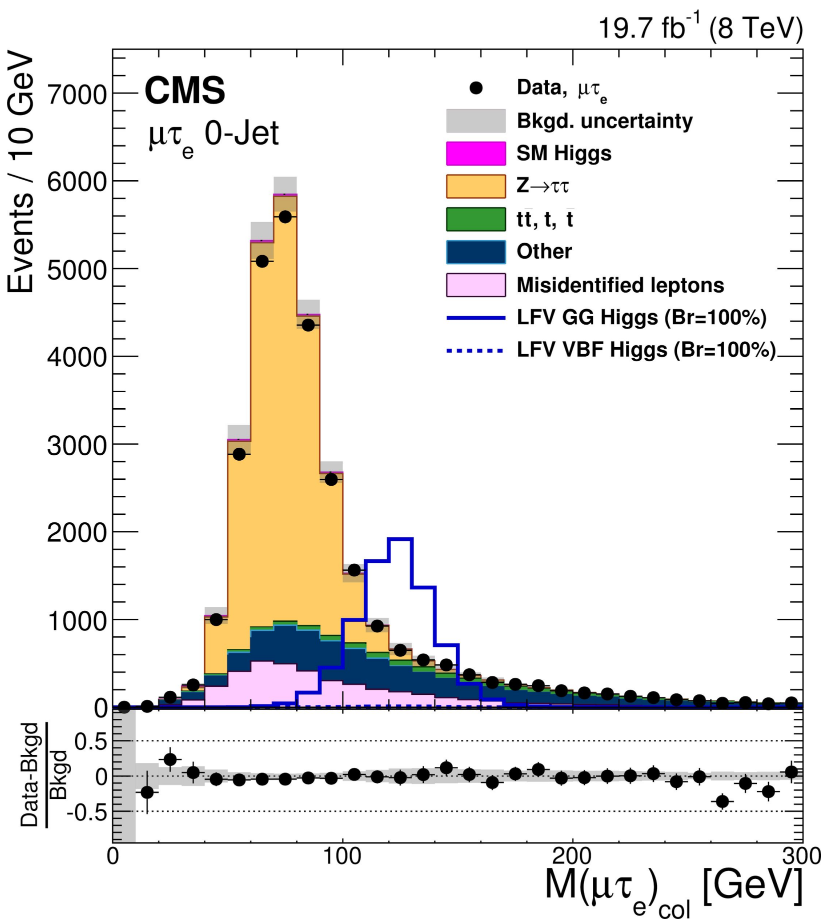
$$M_{colMass} = \frac{M_{vis}}{\sqrt{x_{\tau_e}}}, \quad x_{\tau_e} = \frac{P_T^{\tau_e}}{P_T^{\tau_e} + MET_{proj}}$$

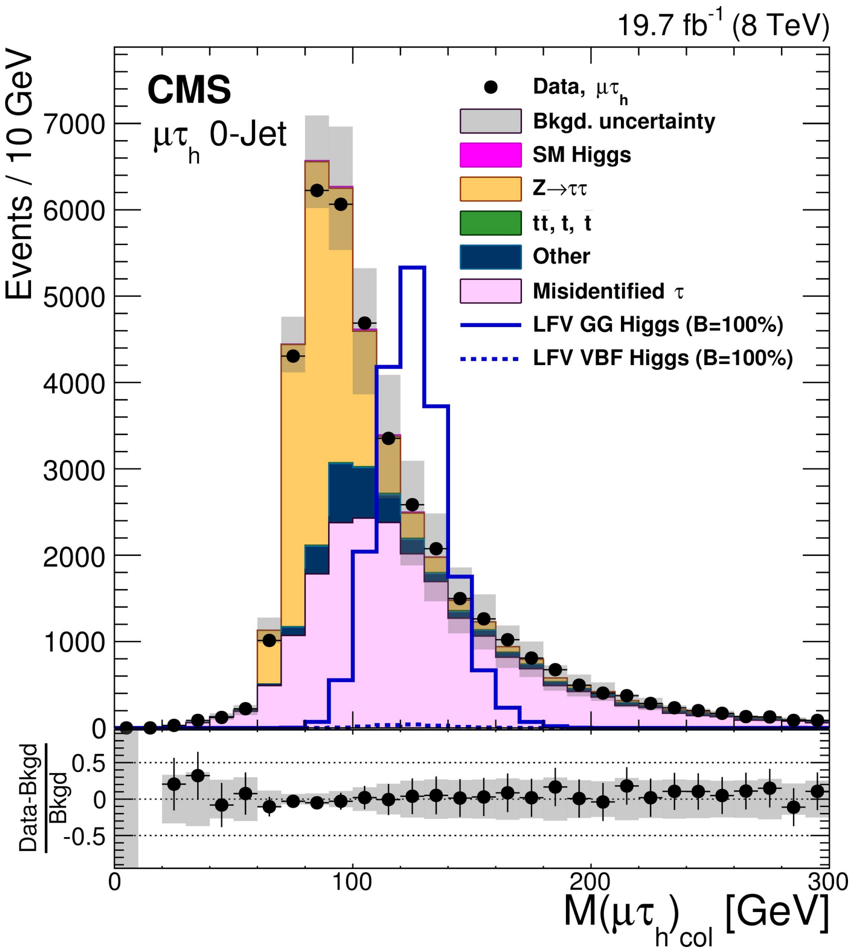
$$MET_{proj} = \frac{E_x^{miss} \cdot P_x^{\tau_e} + E_y^{miss} \cdot P_y^{\tau_e}}{P_T^{\tau_e}}$$



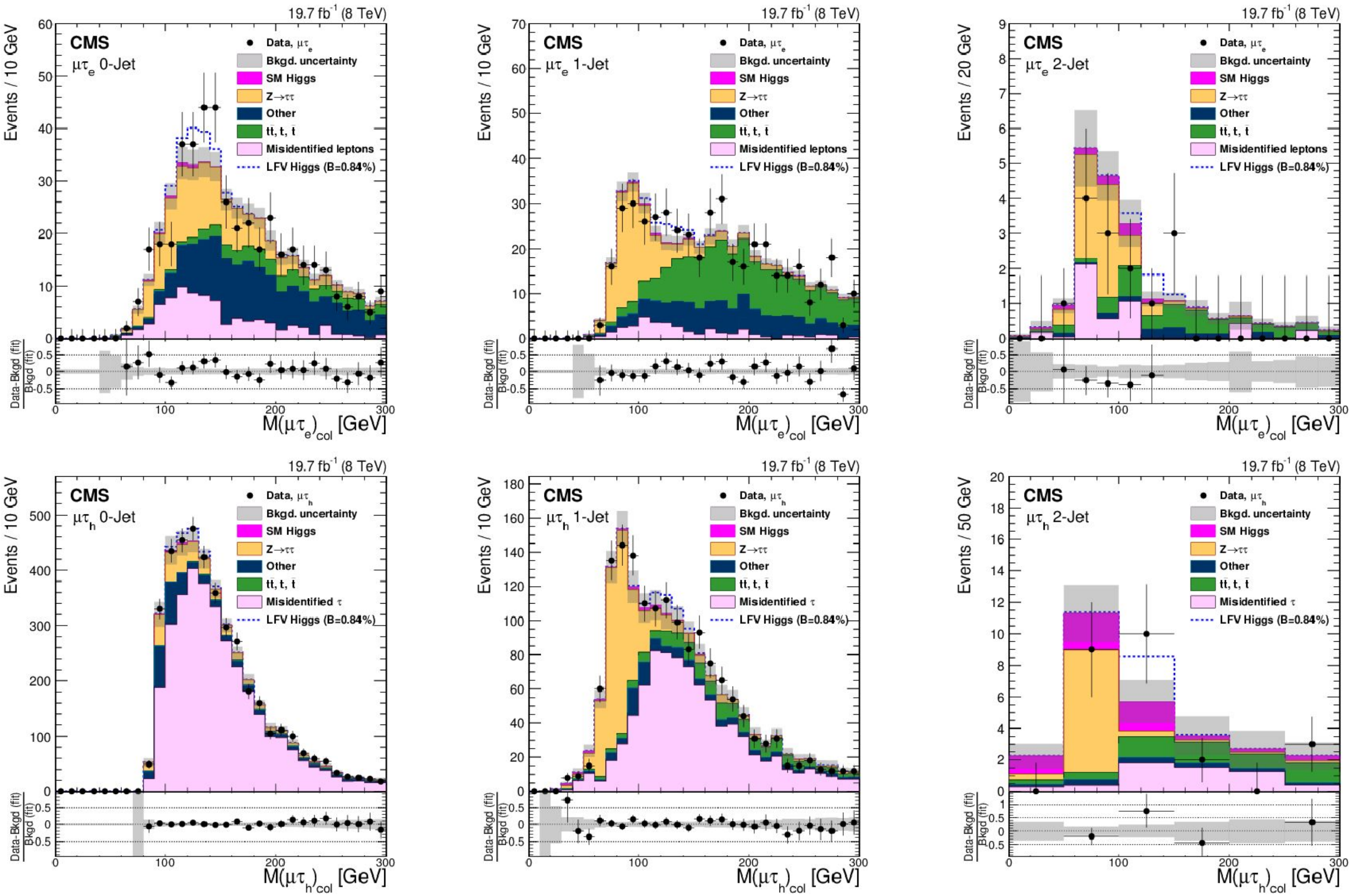
Mass	Mean	RMS
120	119.3	20.37
125	123.4	19.11
130	128.4	21.0
150	147.6	22.48
200	196	25.5

H→μτ: background composition





H→μτ: results



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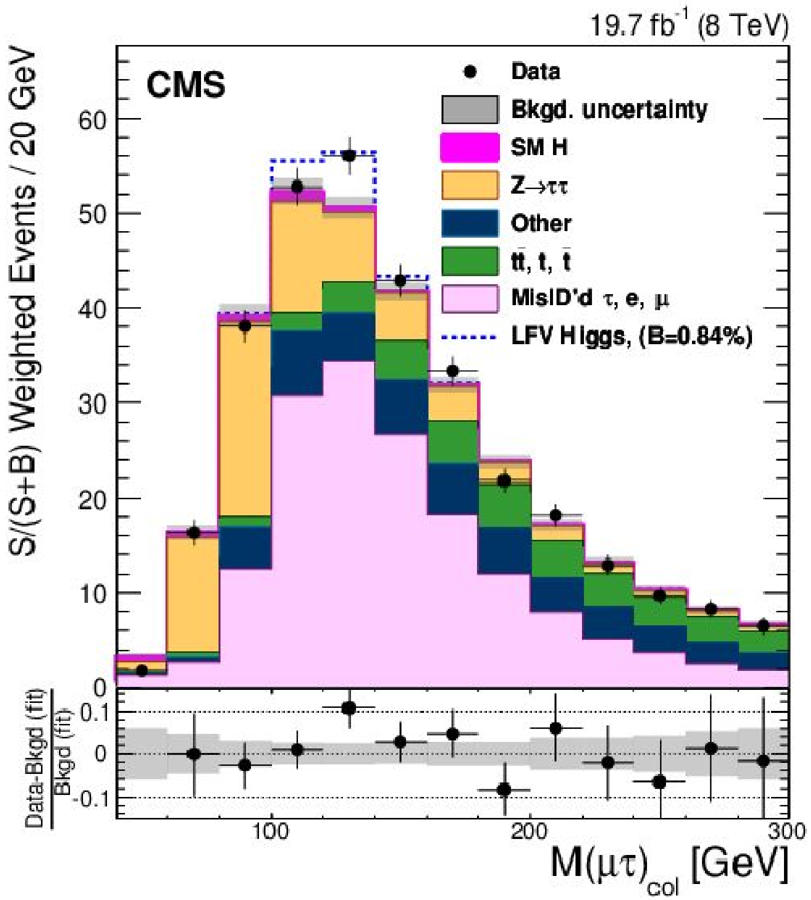
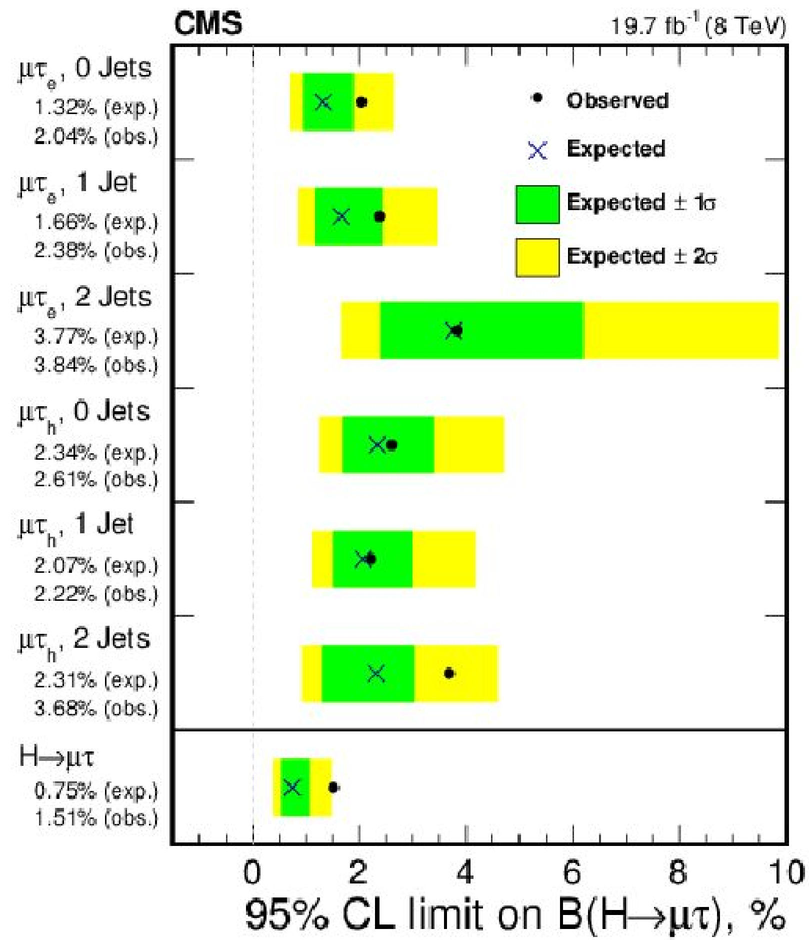
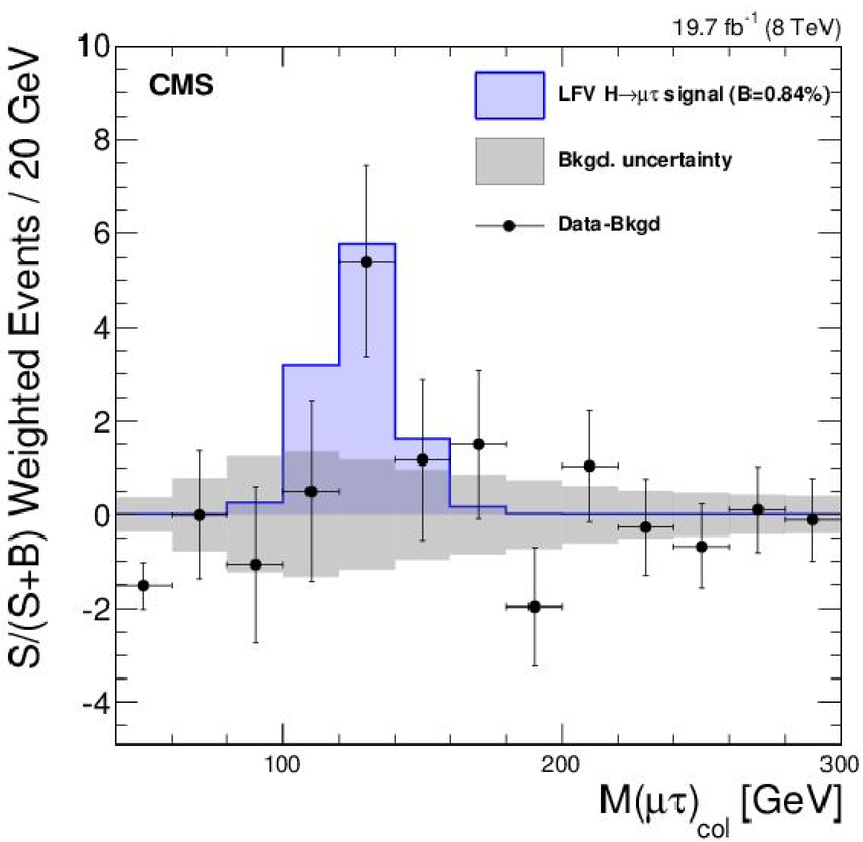
H→μτ: results

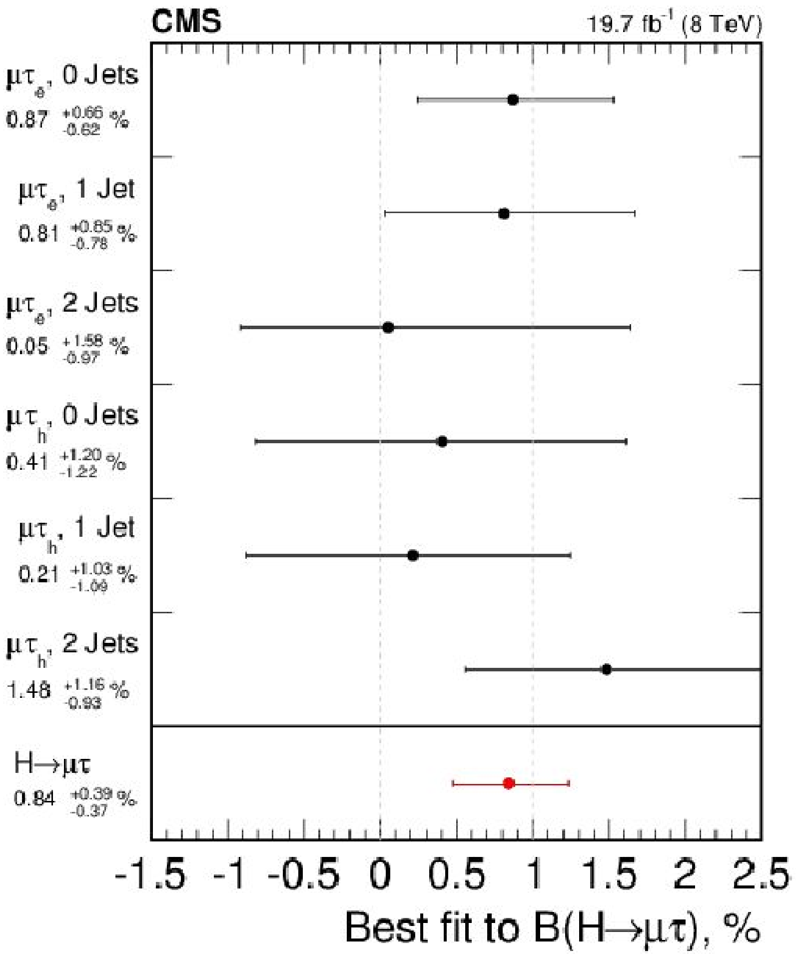

19.7 fb^{-1} (8 TeV)
CMS
Data
Bkgd. uncertainty
SM H
Z→ττ
Other
tt̄, t, t̄
MisID'd τ, e, μ
LFV Higgs, (B=0.84%)
S/(S+B) Weighted Events / 20 GeV
Data-Bkgd (fit) / Bkgd (fit)
M(μτ)$_{col}$ [GeV]


CMS
19.7 fb^{-1} (8 TeV)
μτ$_e$, 0 Jets
1.32% (exp.)
2.04% (obs.)
μτ$_e$, 1 Jet
1.66% (exp.)
2.38% (obs.)
μτ$_e$, 2 Jets
3.77% (exp.)
3.84% (obs.)
μτ$_h$, 0 Jets
2.34% (exp.)
2.61% (obs.)
μτ$_h$, 1 Jet
2.07% (exp.)
2.22% (obs.)
μτ$_h$, 2 Jets
2.31% (exp.)
3.68% (obs.)
H→μτ
0.75% (exp.)
1.51% (obs.)
Observed
Expected
Expected ± 1σ
Expected ± 2σ
95% CL limit on B(H→μτ), %

H→μτ: Signal?



CMS
19.7 fb^{-1} (8 TeV)
LFV H→μτ signal (B=0.84%)
Bkgd. uncertainty
Data-Bkgd
S/(S+B) Weighted Events / 20 GeV
M(μτ)$_{col}$ [GeV]



CMS
19.7 fb^{-1} (8 TeV)
$\mu\tau_e$, 0 Jets
0.87 $^{+0.66}_{-0.62}$ %
$\mu\tau_e$, 1 Jet
0.81 $^{+0.85}_{-0.78}$ %
$\mu\tau_e$, 2 Jets
0.05 $^{+1.58}_{-0.97}$ %
$\mu\tau_h$, 0 Jets
0.41 $^{+1.20}_{-1.22}$ %
$\mu\tau_h$, 1 Jet
0.21 $^{+1.03}_{-1.09}$ %
$\mu\tau_h$, 2 Jets
1.48 $^{+1.16}_{-0.93}$ %
H→μτ
0.84 $^{+0.39}_{-0.37}$ %
Best fit to B(H→μτ), %

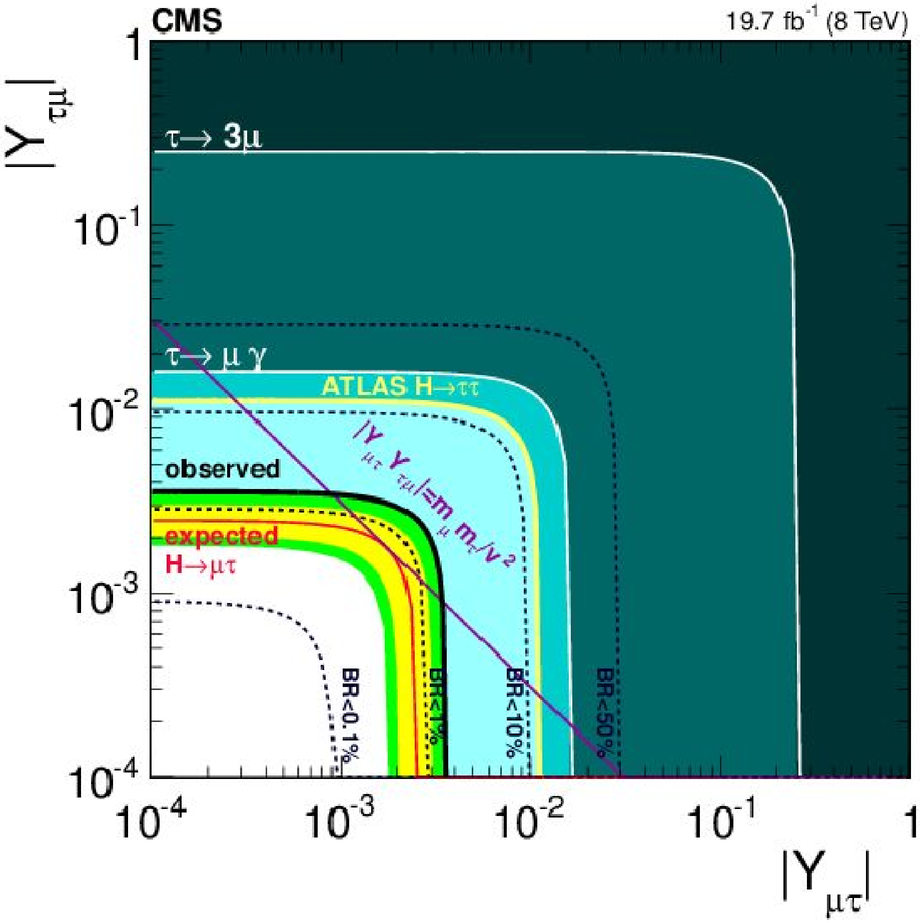
H→μτ: interpretation

- Limit on BR can be reinterpreted as a limit on the corresponding flavor violating yukawa coupling

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

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

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



Assumptions:

- SM Higgs decay width ΓSM=4MeV
- At most one of non-standard decay mode of the higgs is significant compared to SM decay width

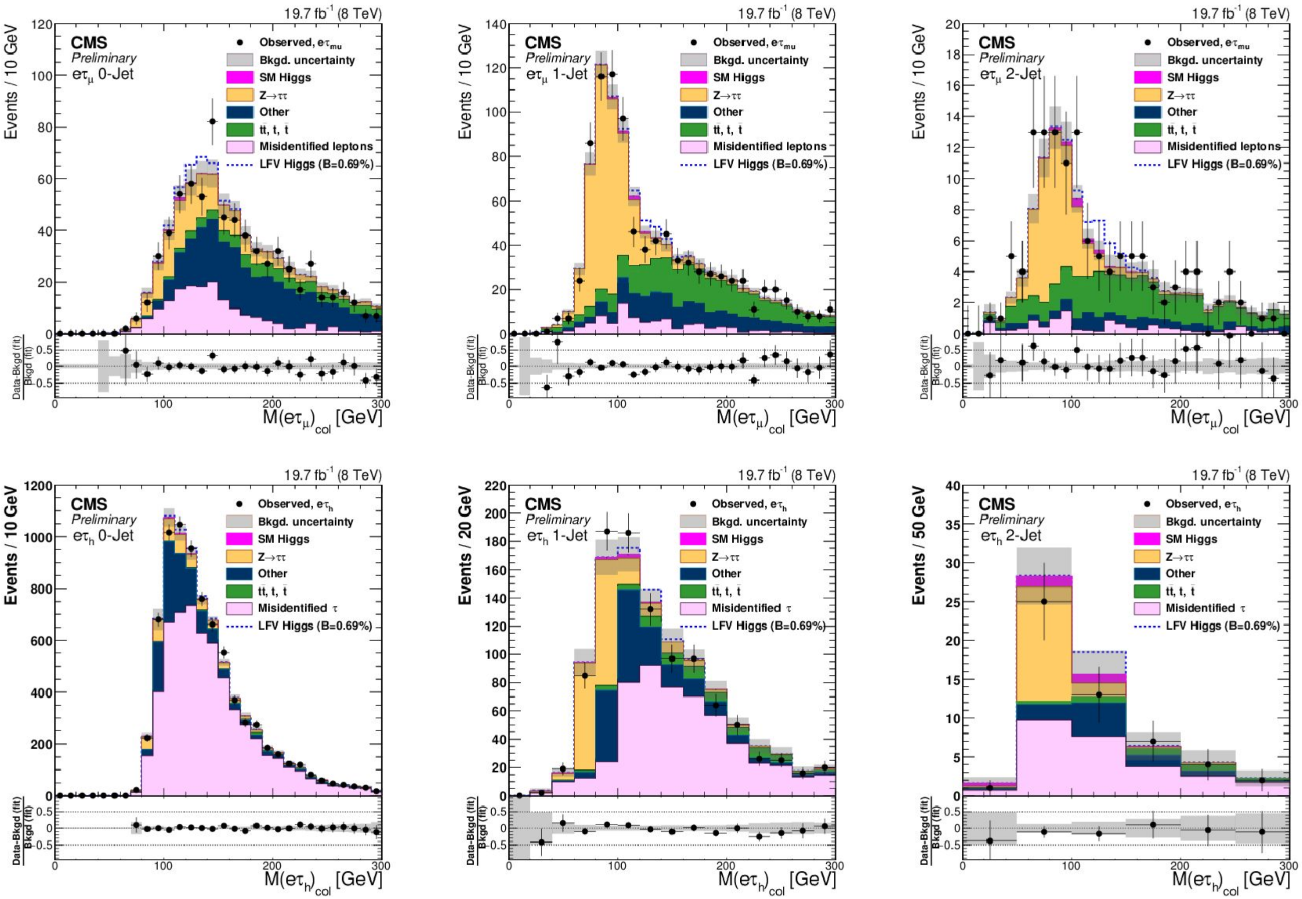
CMS-PAS-HIG-14-040

H→eτ: overview

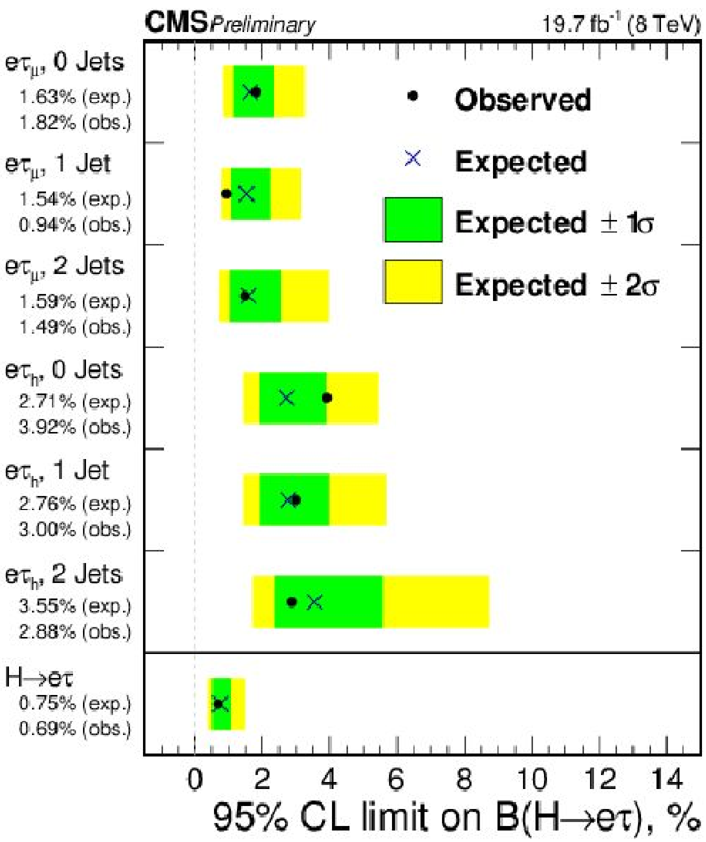
- Analogous to H→μτ analysis:
- 2 channels: leptonic (μ) and hadronic tau decays
- GGF and VBF production channels: 0, 1 and 2-Jet categories

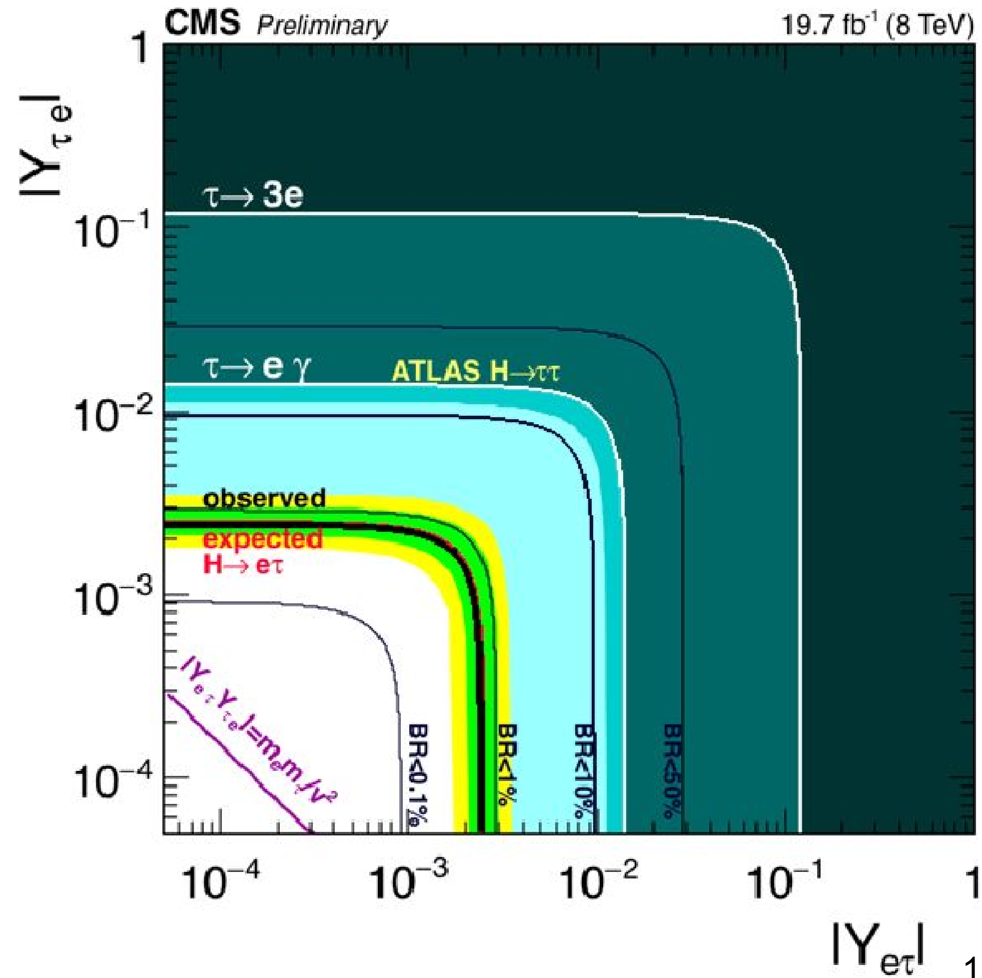
Variable		$H \to e\tau_\mu$			$H \to e\tau_h$		
		0-jet	1-jet	2-jet	0-jet	1-jet	2-jet
p_T^e	(GeV)	> 50	> 40	> 40	> 45	> 35	> 35
p_T^μ	(GeV)	> 15	> 15	> 15	-	-	-
$p_T^{\tau_h}$	(GeV)	-	-	-	> 30	> 40	> 30
$M_T(\mu)$	(GeV)	-	< 30	< 40	-	-	-
$M_T(\tau_h)$	(GeV)	-	-	-	< 70	-	< 50
$\Delta\phi_{\vec{p}_{T,e}-\vec{p}_{T,\tau_h}}$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

H→eτ results


19.7 fb-1 (8 TeV)
CMS
Preliminary
eτμ 0-Jet
eτμ 1-Jet
eτμ 2-Jet
eτh 0-Jet
eτh 1-Jet
eτh 2-Jet
Observed, eτmu
Observed, eτh
Bkgd. uncertainty
SM Higgs
Z→ττ
Other
tt, t, t̄
Misidentified leptons
Misidentified τ
LFV Higgs (B=0.69%)
Events / 10 GeV
Events / 20 GeV
Events / 50 GeV
Data-Bkgd (fit) / Bkgd (fit)
M(eτμ)col [GeV]
M(eτh)col [GeV]

H→eτ results


CMS Preliminary
19.7 fb⁻¹ (8 TeV)
eτμ, 0 Jets
1.63% (exp.)
1.82% (obs.)
eτμ, 1 Jet
1.54% (exp.)
0.94% (obs.)
eτμ, 2 Jets
1.59% (exp.)
1.49% (obs.)
eτh, 0 Jets
2.71% (exp.)
3.92% (obs.)
eτh, 1 Jet
2.76% (exp.)
3.00% (obs.)
eτh, 2 Jets
3.55% (exp.)
2.88% (obs.)
H→eτ
0.75% (exp.)
0.69% (obs.)
Observed
Expected
Expected ± 1σ
Expected ± 2σ
0 2 4 6 8 10 12 14
95% CL limit on B(H→eτ), %


CMS Preliminary
19.7 fb⁻¹ (8 TeV)
|Y_τe|
τ→ 3e
τ→ e γ
ATLAS H→ττ
observed
expected
H→ eτ
|Y_eτ Y_τe|=m_e m_τ/v²
BR<0.1%
BR<1%
BR<10%
BR<50%
|Y_eτ|

H→eμ: overview

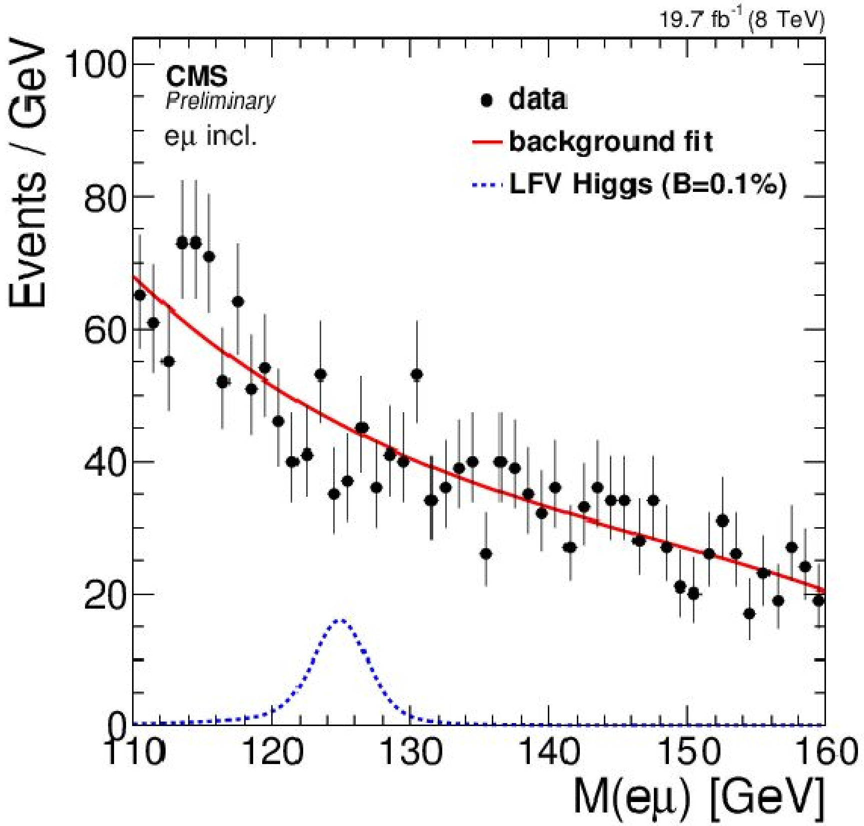
- Dilepton trigger (e,μ)
- GGF and VBF production: 0,1 and 2 Jet category
- Split in Barrel and Endcap region (resolution)
- Low MET in the events is required
- Background: 'simple' fit of the dilepton invariant mass distribution $m_{e\mu}$=[110,160]
- Fit-Function: function with lowest 'bias' in each category is chosen

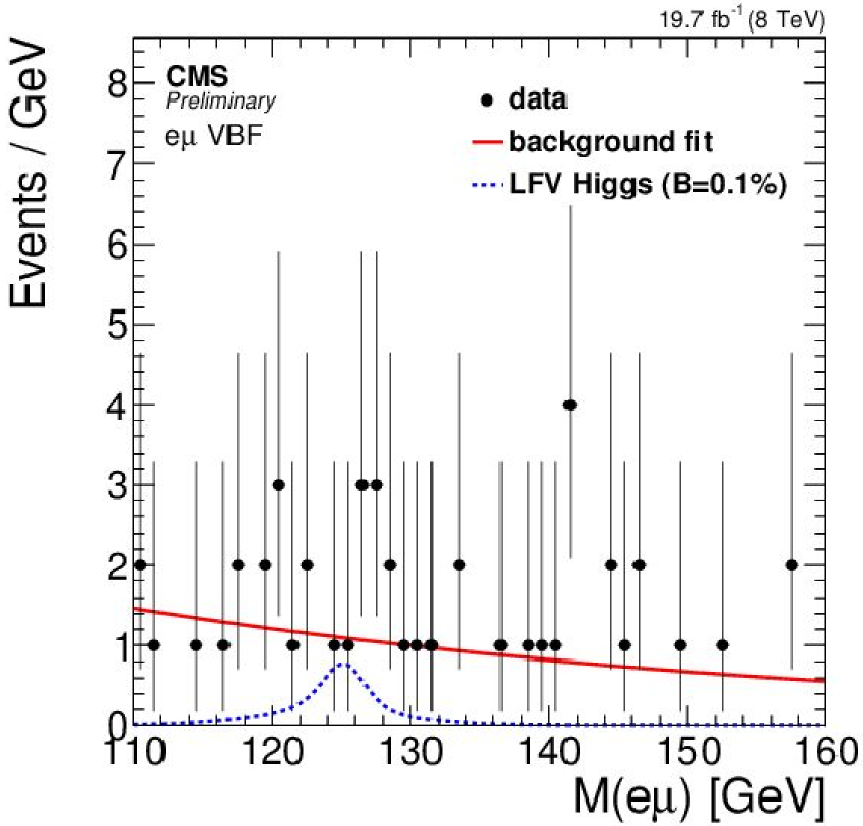
Category		Number of jets	Lepton p_T (GeV)	E_T^{miss} (GeV)	B-tag
0	EB-MB	0	> 25	< 30	-
1	EB-MB	1	> 22	< 30	< 0.38
2	EB-MB	2	> 25	< 25	$< 0.38, < 0.48$
3	EB-ME	0	> 20	< 30	-
4	EB-ME	1	> 22	< 20	< 0.48
5	EB-ME	2	> 20	< 30	$< 0.51, < 0.57$
6	EE-(MB or ME)	0	> 20	< 30	-
7	EE-(MB or ME)	1	> 22	< 20	< 0.48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

Category	Selected function	Selected order	Bias
0	Polynomial	4	10.8 ± 1.0 %
1	Polynomial	4	4.6 ± 1.1 %
2	Power law	1	7.6 ± 1.0 %
3	Polynomial	4	4.8 ± 1.1 %
4	Exponential	1	7.4 ± 1.0 %
5	Exponential	1	8.4 ± 1.0 %
6	Polynomial	4	13.8 ± 1.4 %
7	Power law	1	12.6 ± 1.0 %
8	Polynomial	4	7.7 ± 1.1 %
9	Exponential	1	< 0.1 %
10	Exponential	1	< 0.1 %

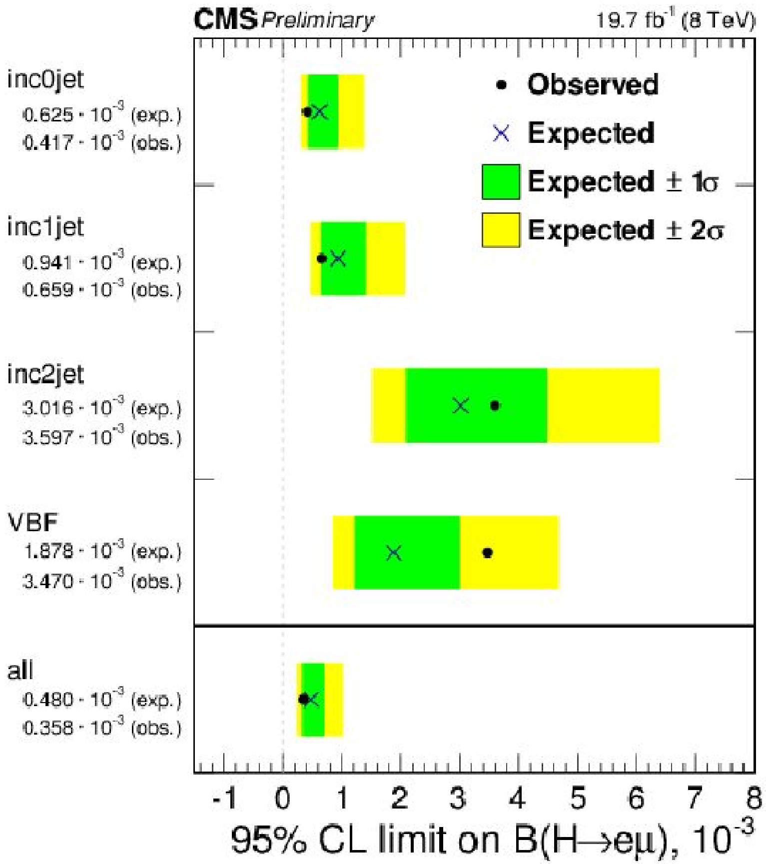
CMS-PAS-HIG-14-040

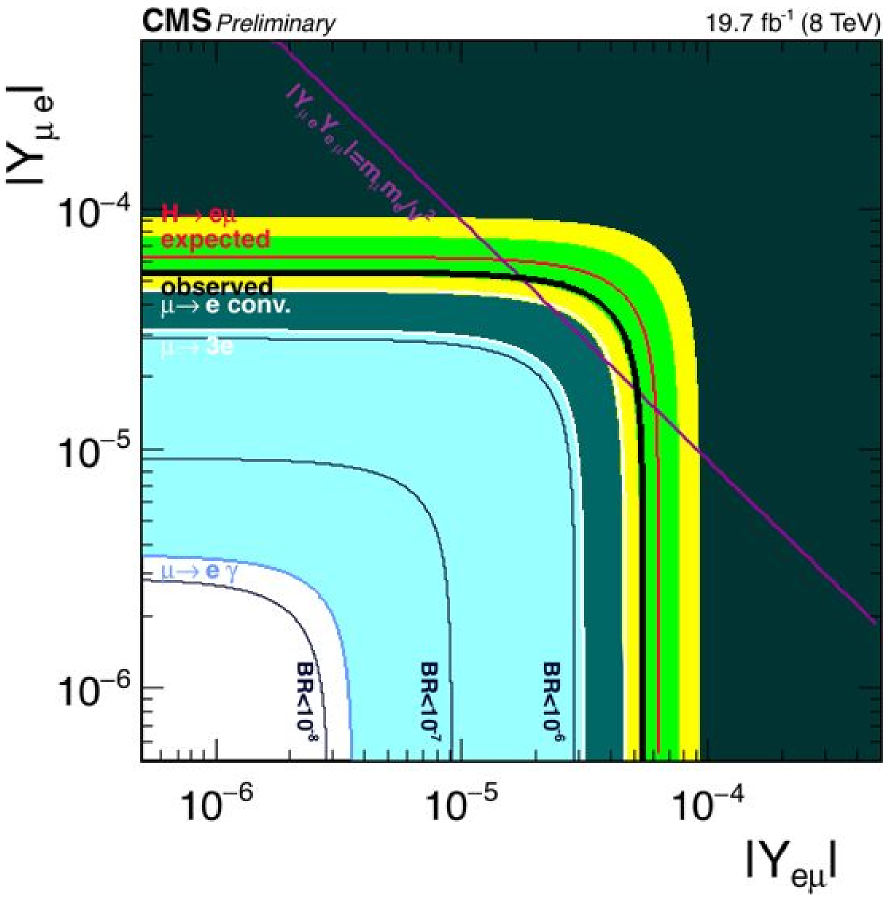
H→eμ: results


19.7 fb^{-1} (8 TeV)
CMS
Preliminary
eμ incl.
data
background fit
LFV Higgs (B=0.1%)
Events / GeV
M(eμ) [GeV]

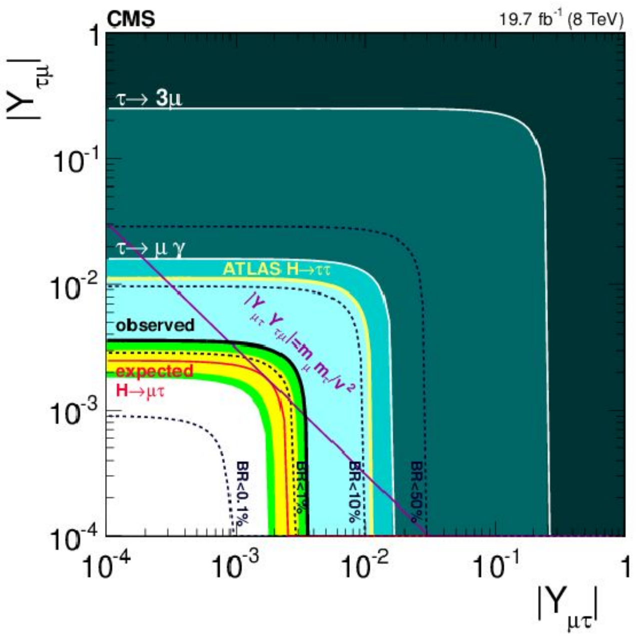

19.7 fb^{-1} (8 TeV)
CMS
Preliminary
eμ VBF
data
background fit
LFV Higgs (B=0.1%)
Events / GeV
M(eμ) [GeV]

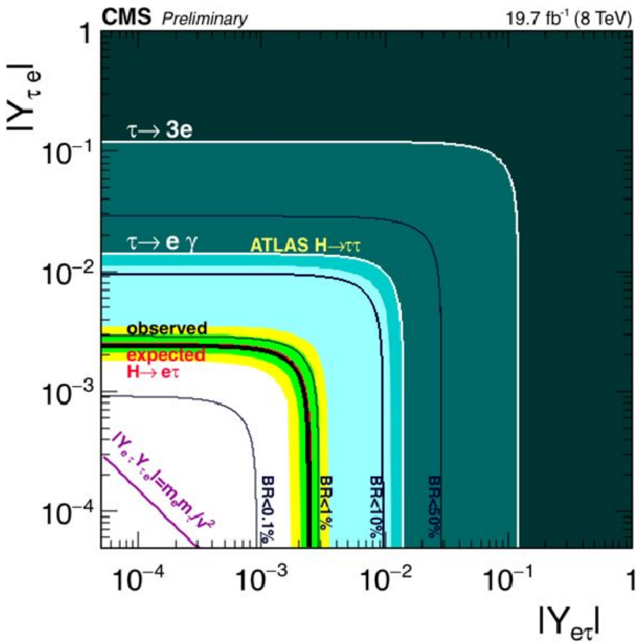
H→eμ: results

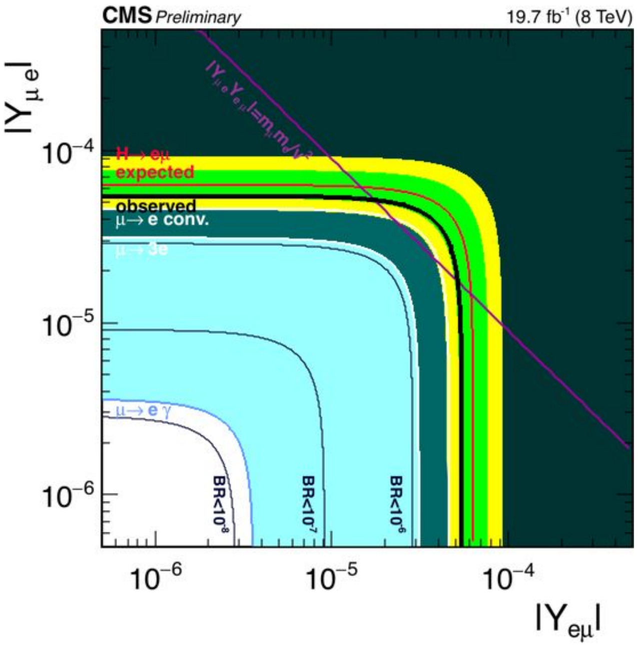

CMS Preliminary
19.7 fb-1 (8 TeV)
inc0jet
0.625 · 10-3 (exp.)
0.417 · 10-3 (obs.)
inc1jet
0.941 · 10-3 (exp.)
0.659 · 10-3 (obs.)
inc2jet
3.016 · 10-3 (exp.)
3.597 · 10-3 (obs.)
VBF
1.878 · 10-3 (exp.)
3.470 · 10-3 (obs.)
all
0.480 · 10-3 (exp.)
0.358 · 10-3 (obs.)
Observed
Expected
Expected ± 1σ
Expected ± 2σ
95% CL limit on B(H→eμ), 10-3


CMS Preliminary
19.7 fb-1 (8 TeV)
|Yμe|
|Yeμ|
H→eμ
expected
observed
μ→e conv.
μ→3e
μ→e γ
BR<10-8
BR<10-7
BR<10-6

LFV Higgs @ 8TeV: summary



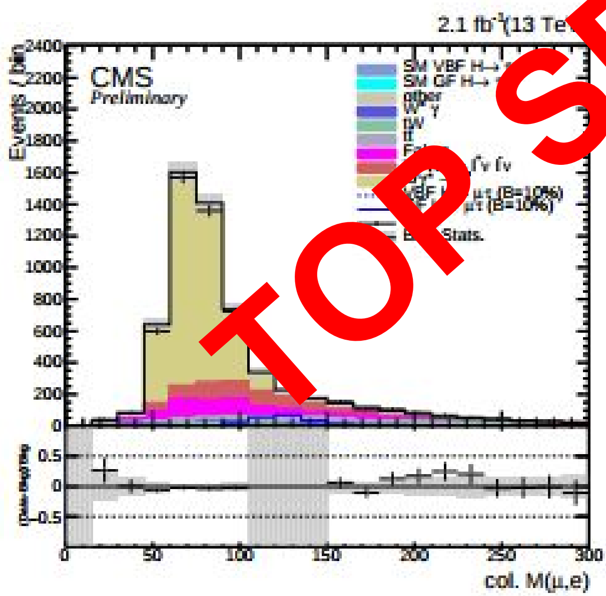


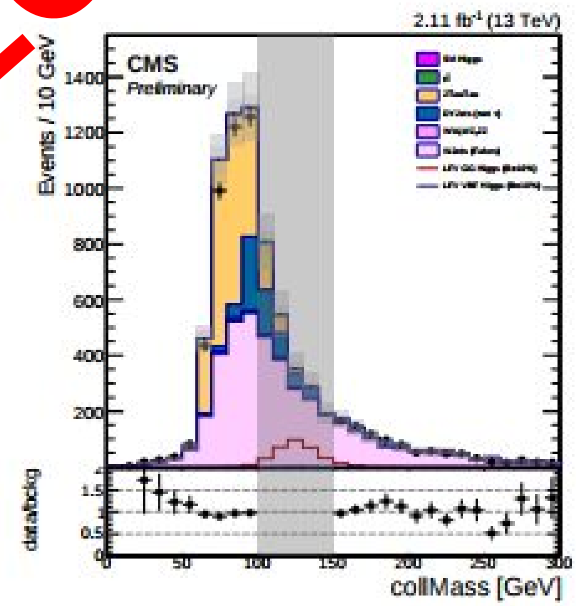


LFV Higgs decays @ 13 TeV

- Reload of 8 TeV analysis for Moriond (hopefully)
- No changes to the analysis strategy for the 2.1fb^{-1} reload (H→μτ only): same cuts (except VBF category, due to statistics)

TOP SECRET!





LFV Higgs decays @ 13 TeV

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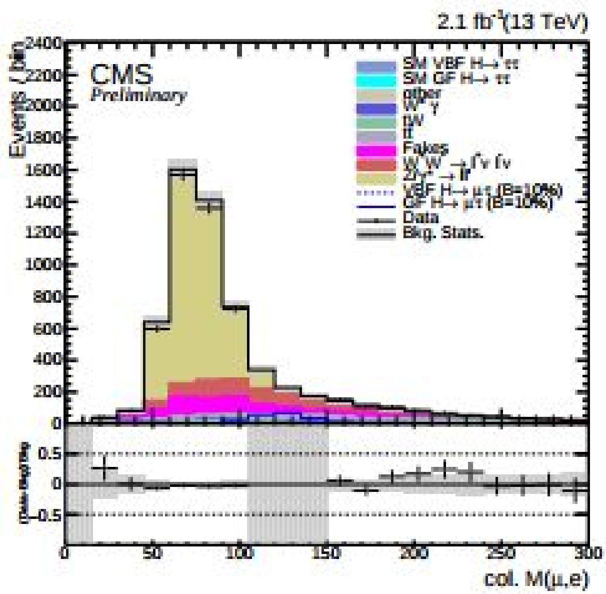
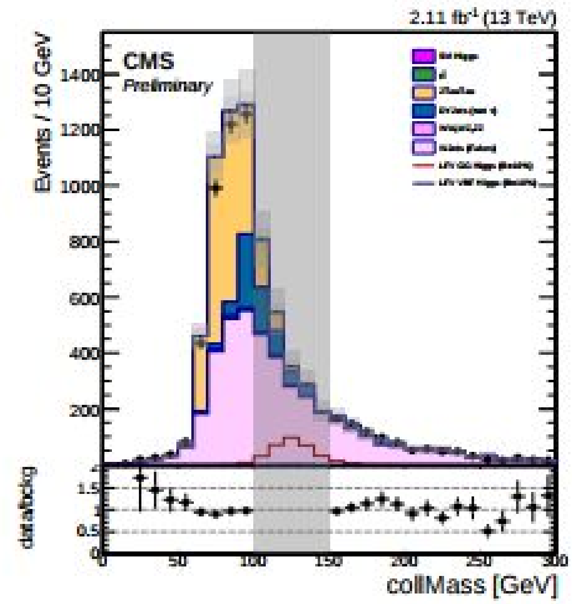
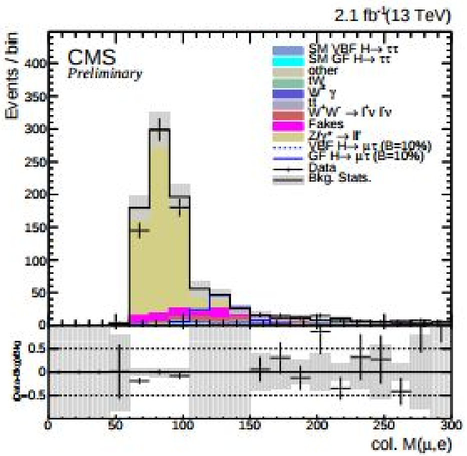
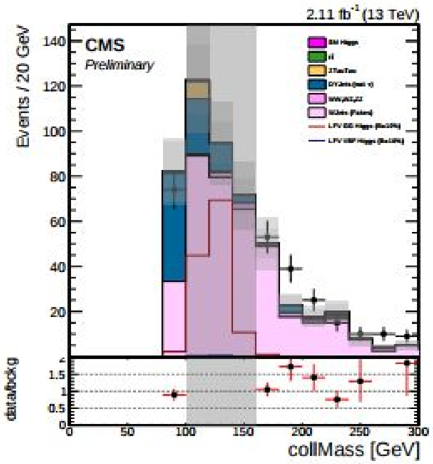




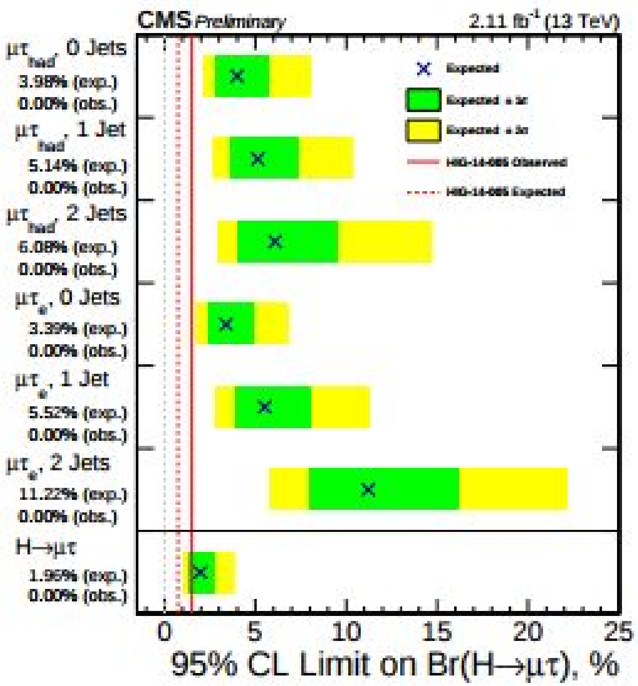
Overall good agreement after baseline selection! Still blinded!

LFV Higgs decays @ 13 TeV





Very preliminary expected limits!

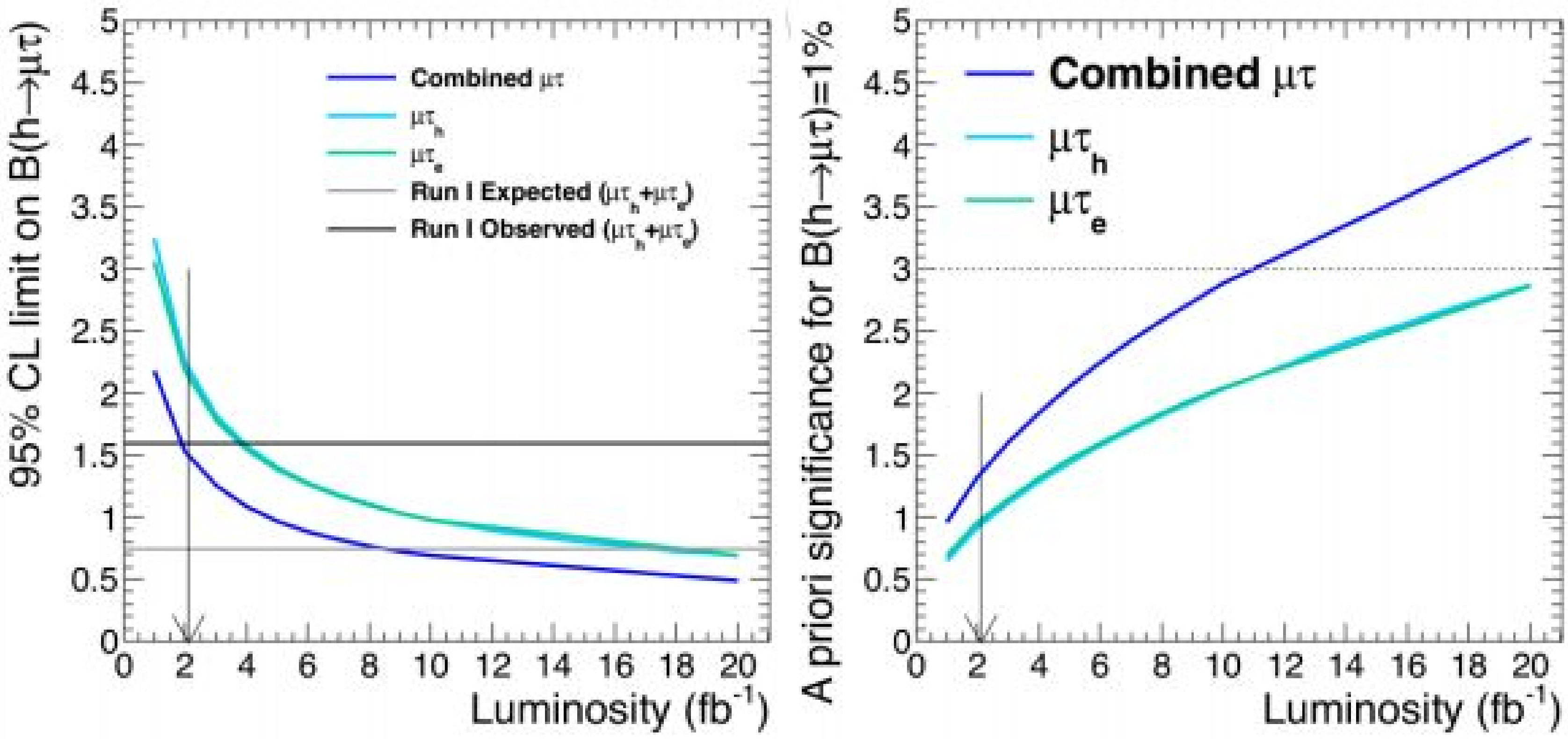


Expected limit is in the order of 2% on the BR(H→μτ): 0.75% exp. (1.57% obs.) limit from Run-I!

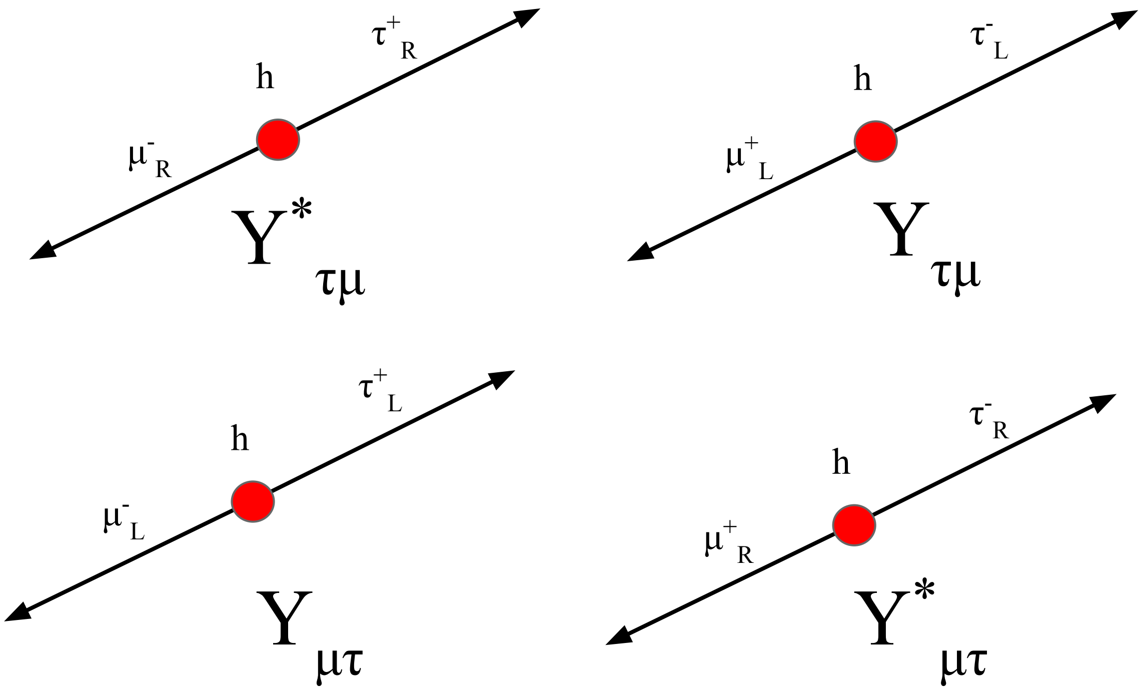
2.1fb^{-1} update: no gain in terms of BR limit with the Moriond update expected!

Prospects for H→μτ at 13 TeV

Very preliminary combination!



Prospects using the tau polarization



$Y_{\mu\tau}$ vs $Y_{\tau\mu}$: extracting $r=Y_{\mu\tau}/Y_{\tau\mu}$

- If the excess is a true signal and if it will be confirmed in 13 TeV, we can do interesting physics!
- Extracting the ratio of $r=Y_{\mu\tau}/Y_{\tau\mu}$!
- **How to:**
  - Assume m_{higgs}=125GeV and colinearity of the tau decay products: reconstruct the full tau 4-vec
  - Extract visible energy fraction(x) of tau decay products with respect to the full tau-4vec
  - Fit templates of x for $Y_{\mu\tau}$ and $Y_{\tau\mu}$

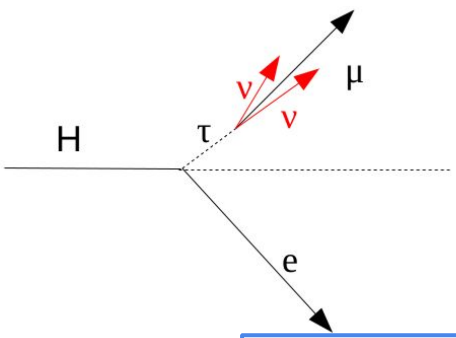
Reconstruct full tau 4-vec

Note: first approximation - neglect tau mass!

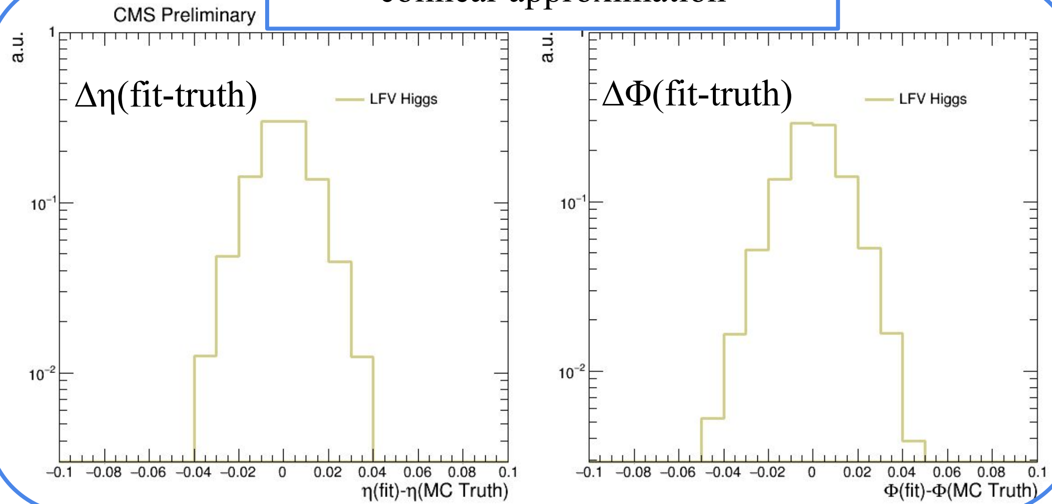
$$M^2=(p_\tau+p_e)^2=p_\tau^2+p_e^2+2\,p_\tau\,p_e=2\,p_\tau\,p_e=2\boxed{\alpha\,p_\mu}\,p_e$$

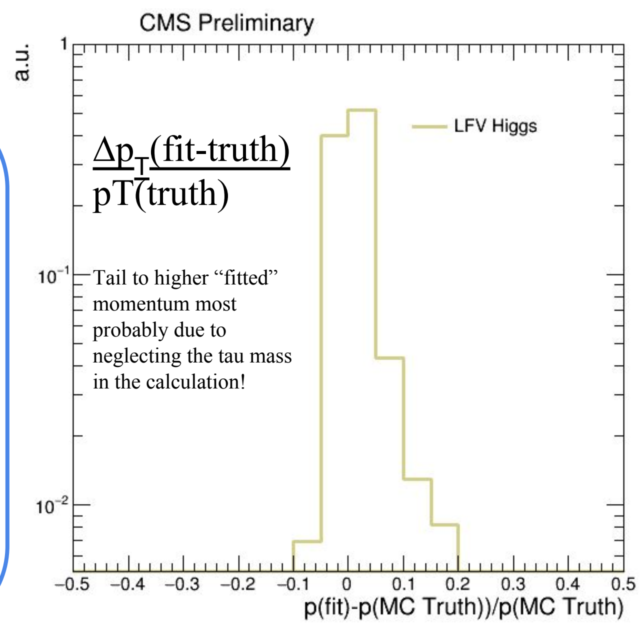
$$\alpha=\frac{M_{Higgs}^2}{2(E_\mu\times E_e+\vec{p}_\mu\times\vec{p}_e)}$$

colinear approx. + neglecting tau mass!

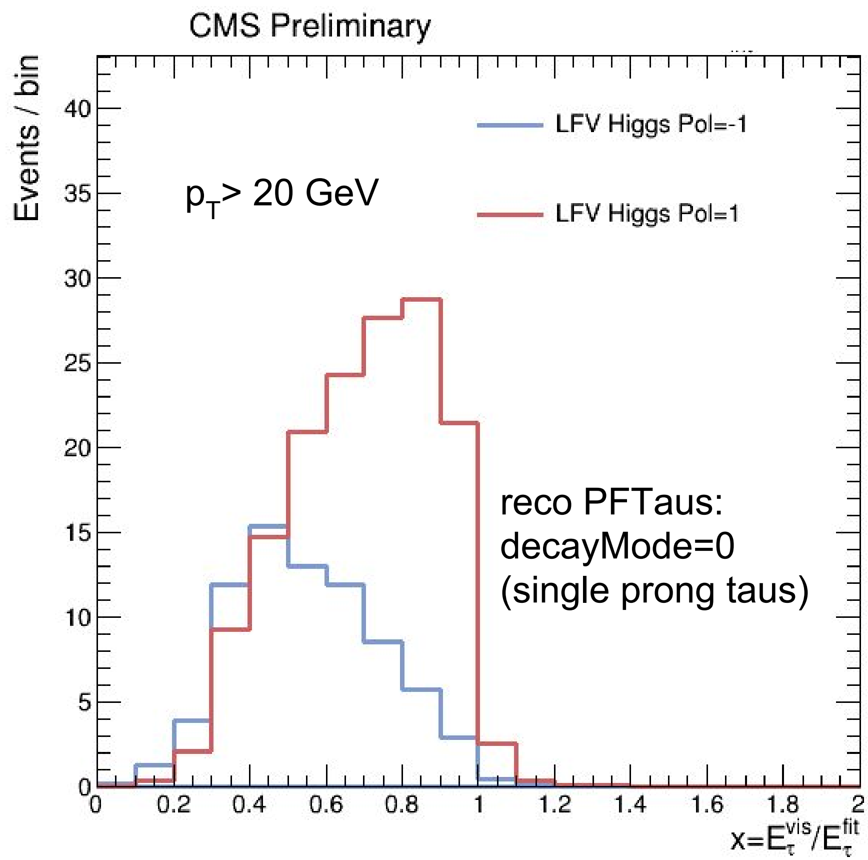


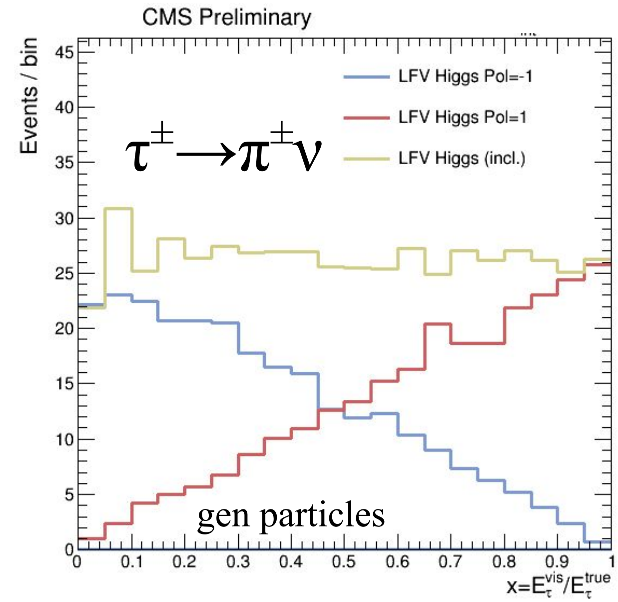
colinear approximation

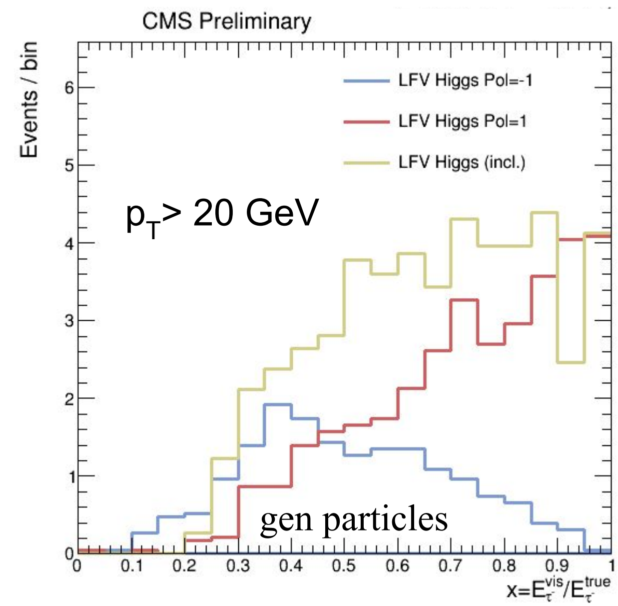




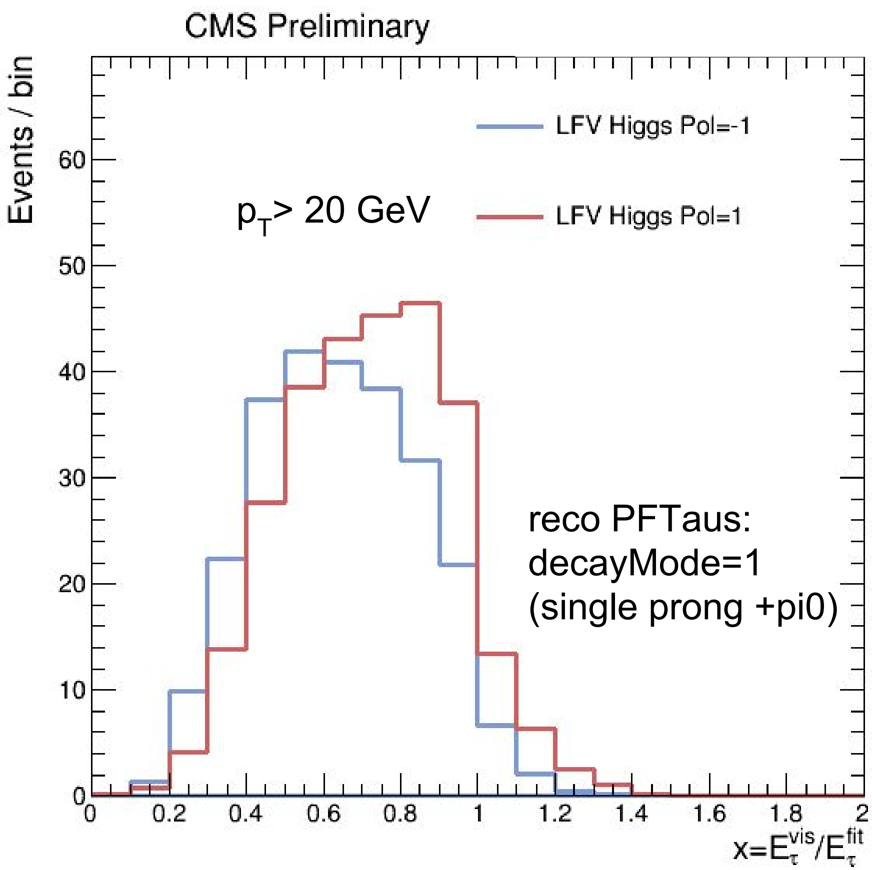
$Y_{\mu\tau}$ vs $Y_{\tau\mu}$: templates

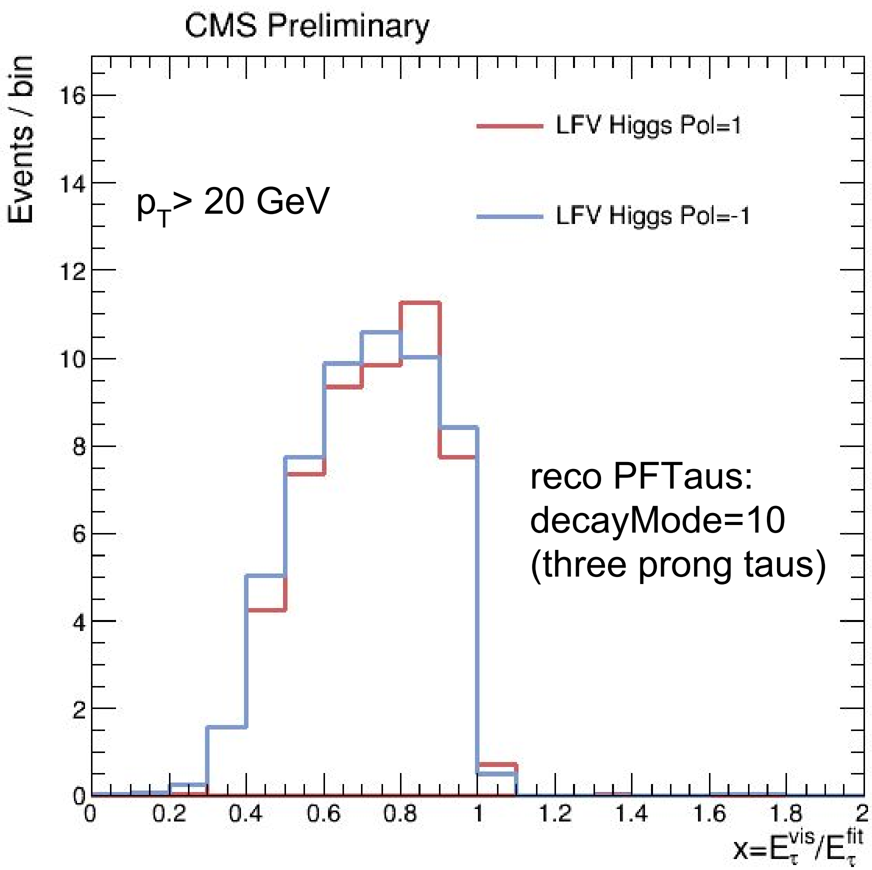






$Y_{\mu\tau}$ vs $Y_{\tau\mu}$: templates

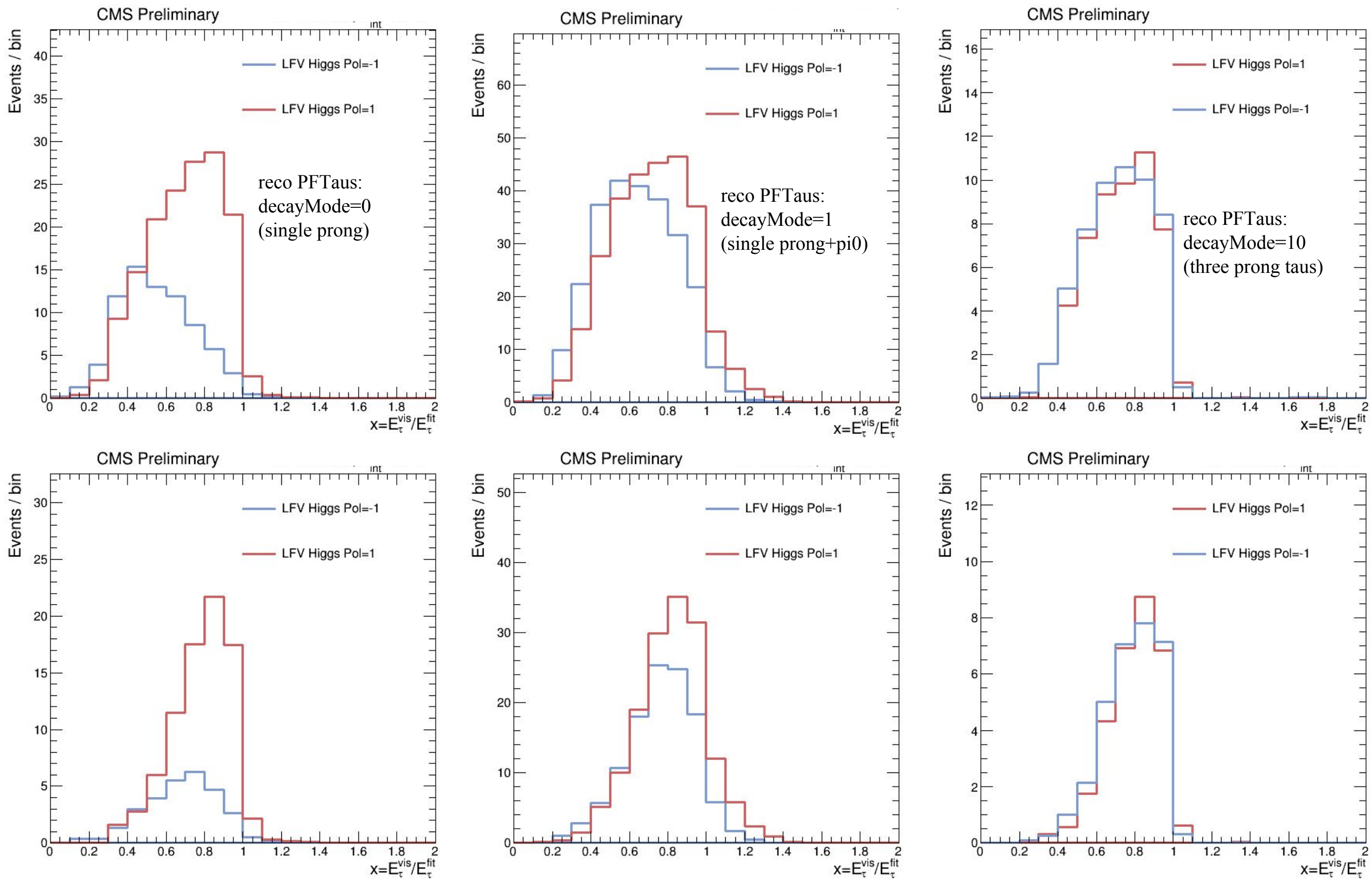




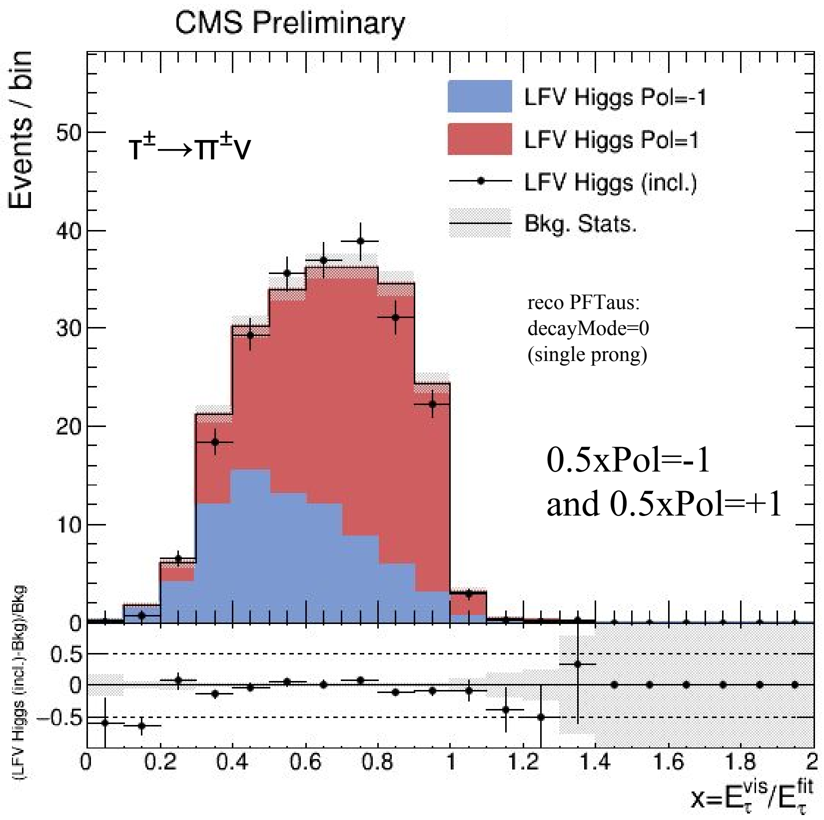
$Y_{\mu\tau}$ vs $Y_{\tau\mu}$: templates p_T>20 vs p_T> 40

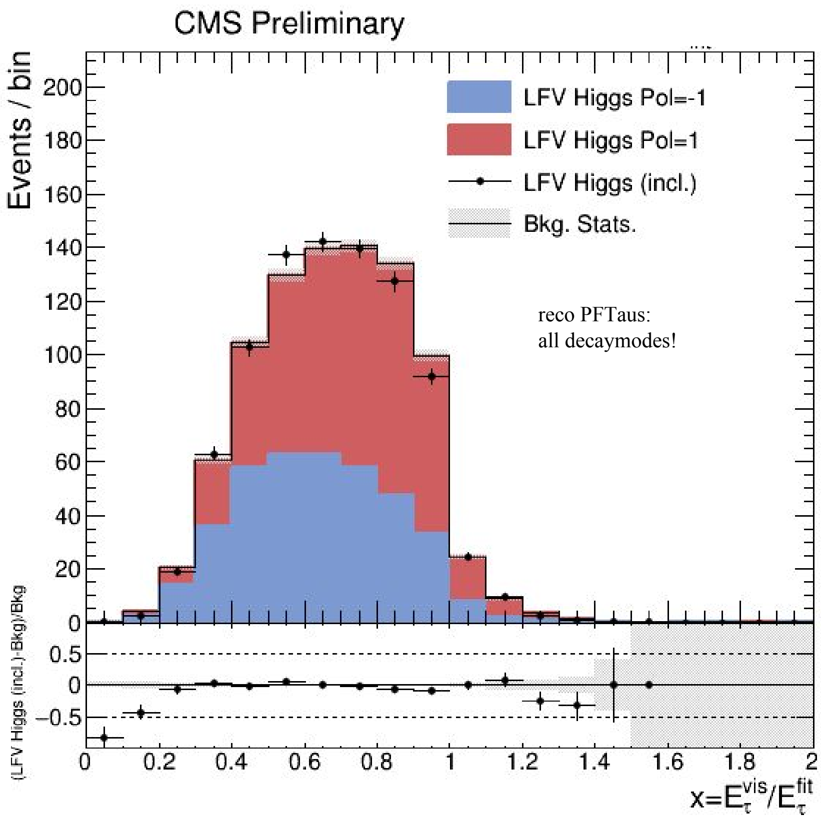
$p_T > 20$

$p_T > 40$



$Y_{\mu\tau}$ vs $Y_{\tau\mu}$: extracting the ratio (test)





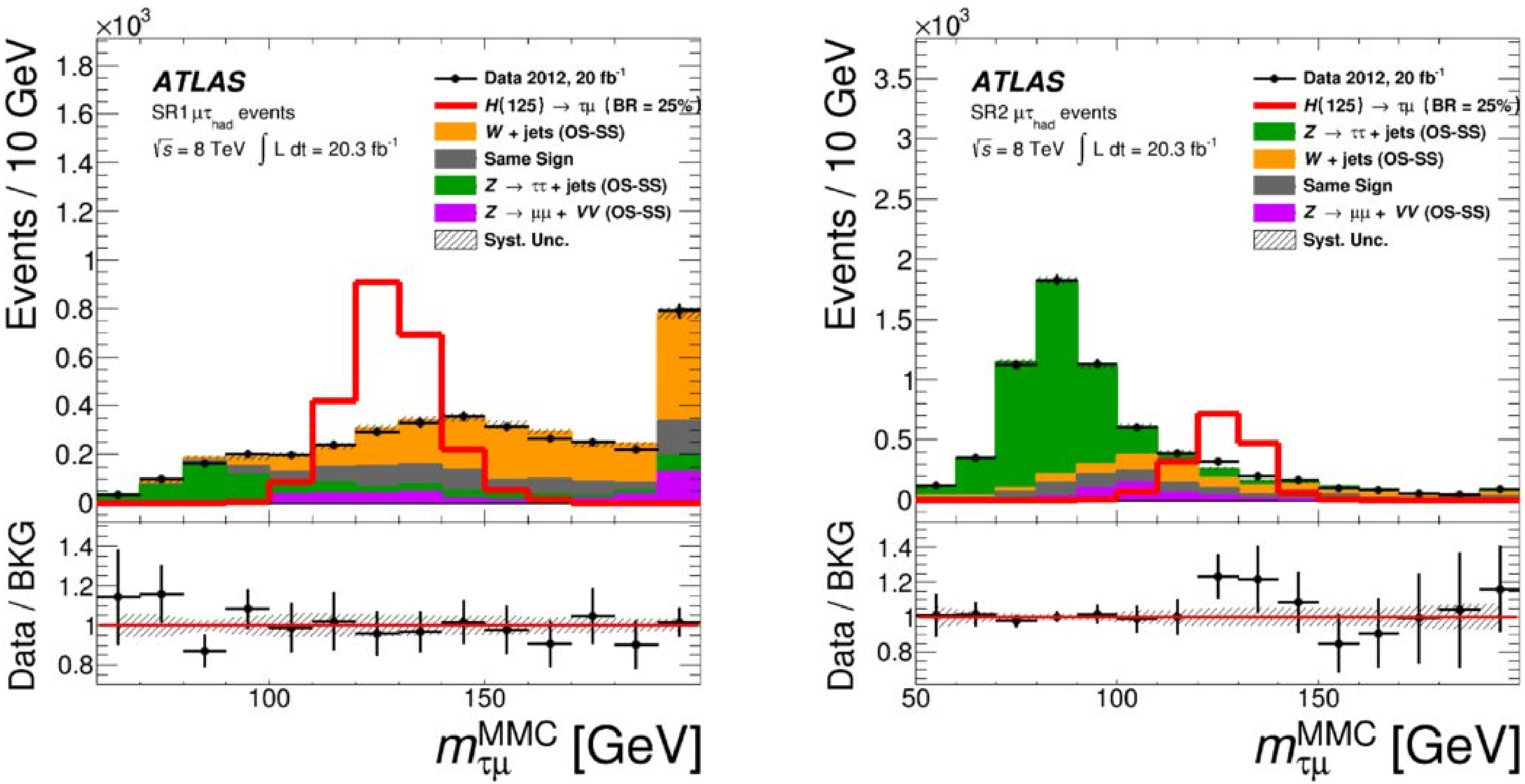
Summary

- All possible LFV Higgs couplings has been tested in 8 TeV
- Small excess (2.4σ) observed in the H→μτ channel.

  (ATLAS: 2 channels; 1 channel similar excess other channel no excess!)
- 13 TeV: Moriond update on track, but no surprises or answer on the excess expected.
- Various improvements (like tau polarisation as a discriminant) planned for the end-of-year update.
- High mass LFV A/H search on the list to be done.

arXiv:1508.03372

Atlas: H→μτ analysis



Best Fit Point for the combination of both channels: Br(H→μτ)=0.77%