The Lepton Flavour Violating Decays of Higgs boson

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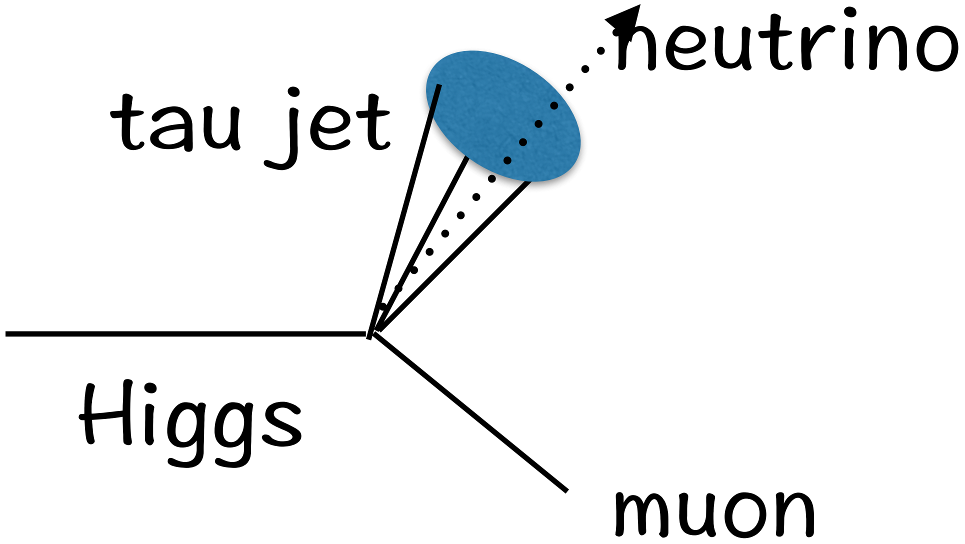
(arXiv:1603.05952)

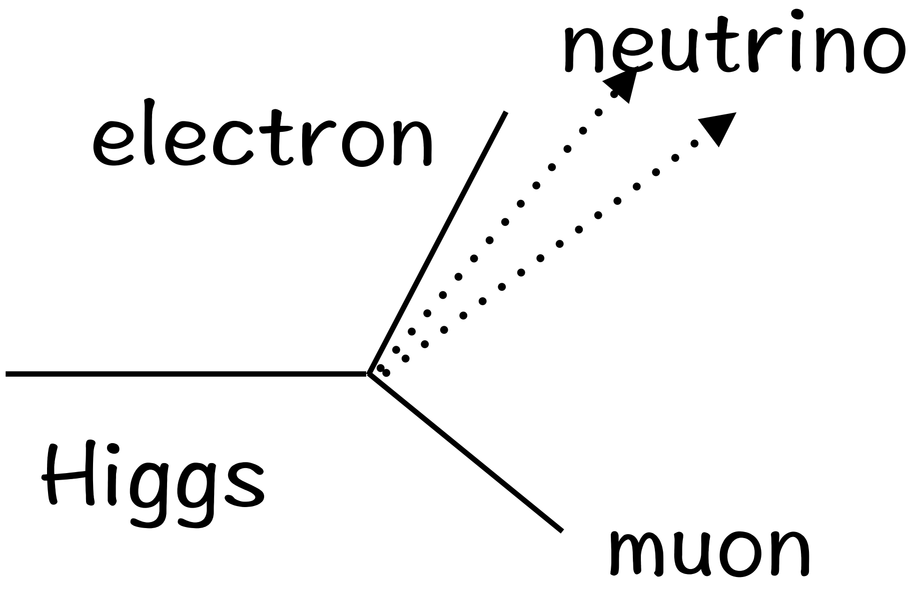
Higgs Tasting Workshop ,
Centro de Ciencias de Benasque Pedro Pascual
Benasque , Spain

CMS H -> mu tau search (8 TeV)

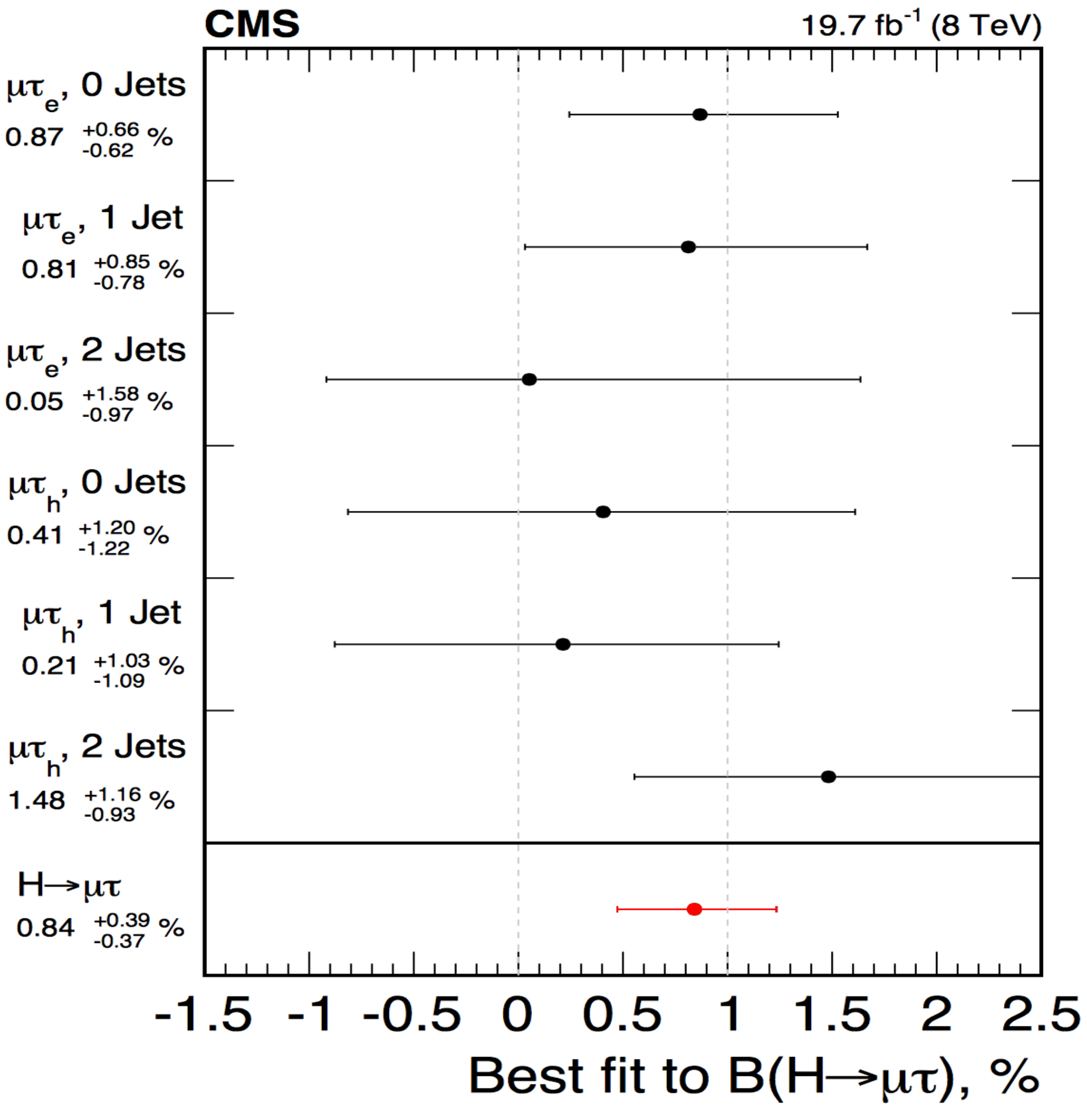
1502.07400



H-> muon + tau jet



H-> muon + electron



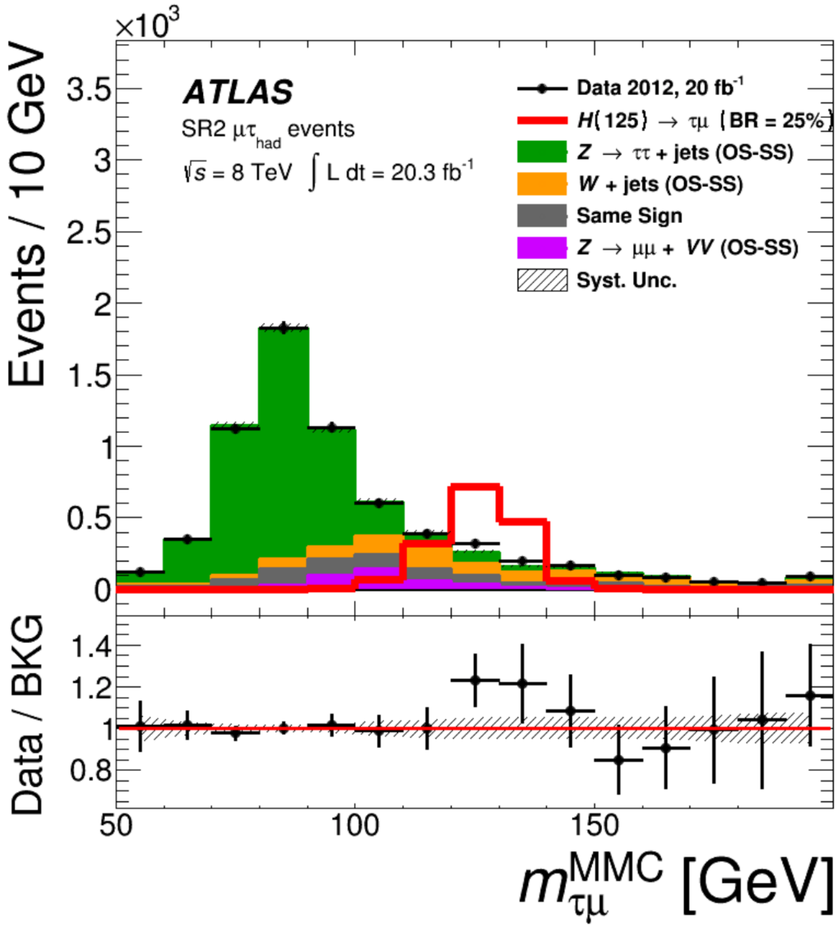
CMS : A slight excess of signal events with a significance of 2.4 sigma is observed (In the collinear mass window 100 -150 GeV)

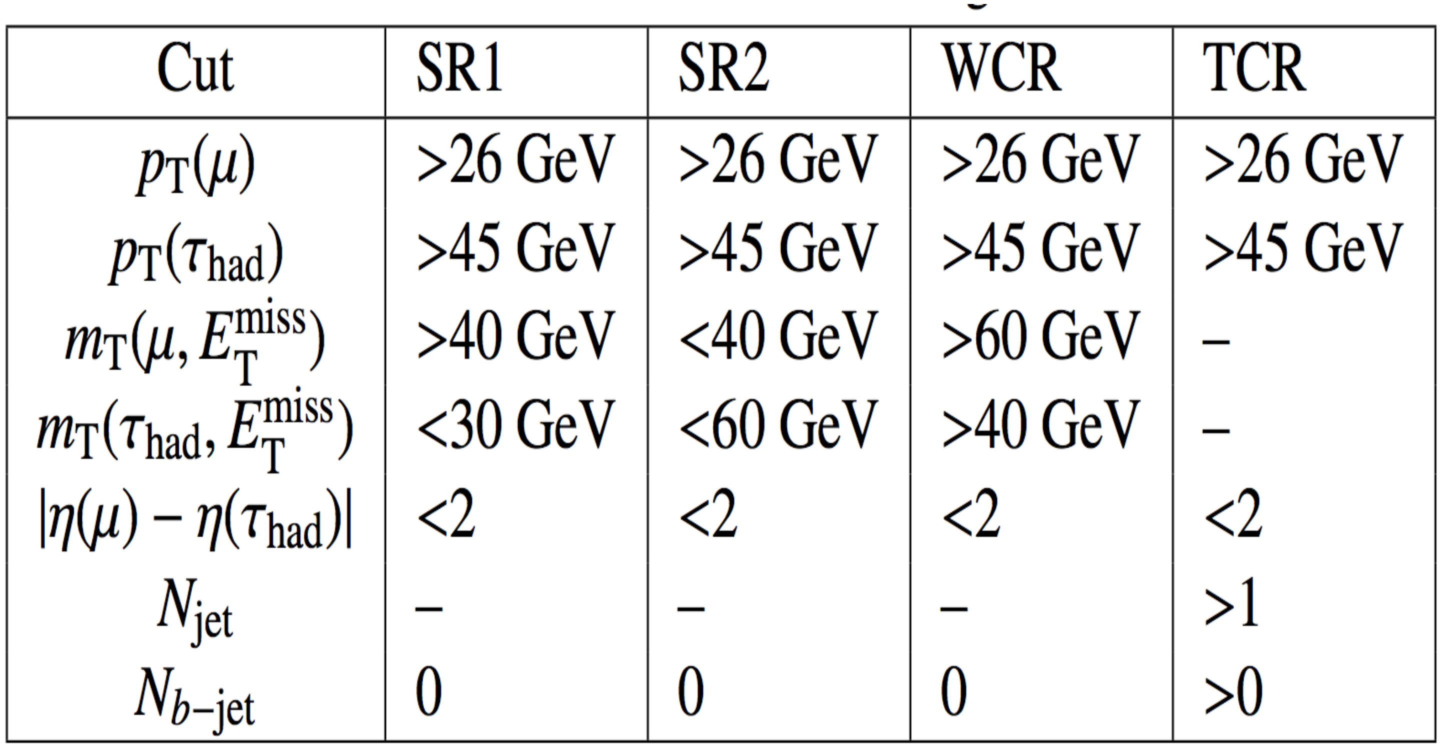
95 % Upper limit on branching (Higgs to Mu tau) = 1.51%

ATLAS H -> mu tau search (8 TeV)

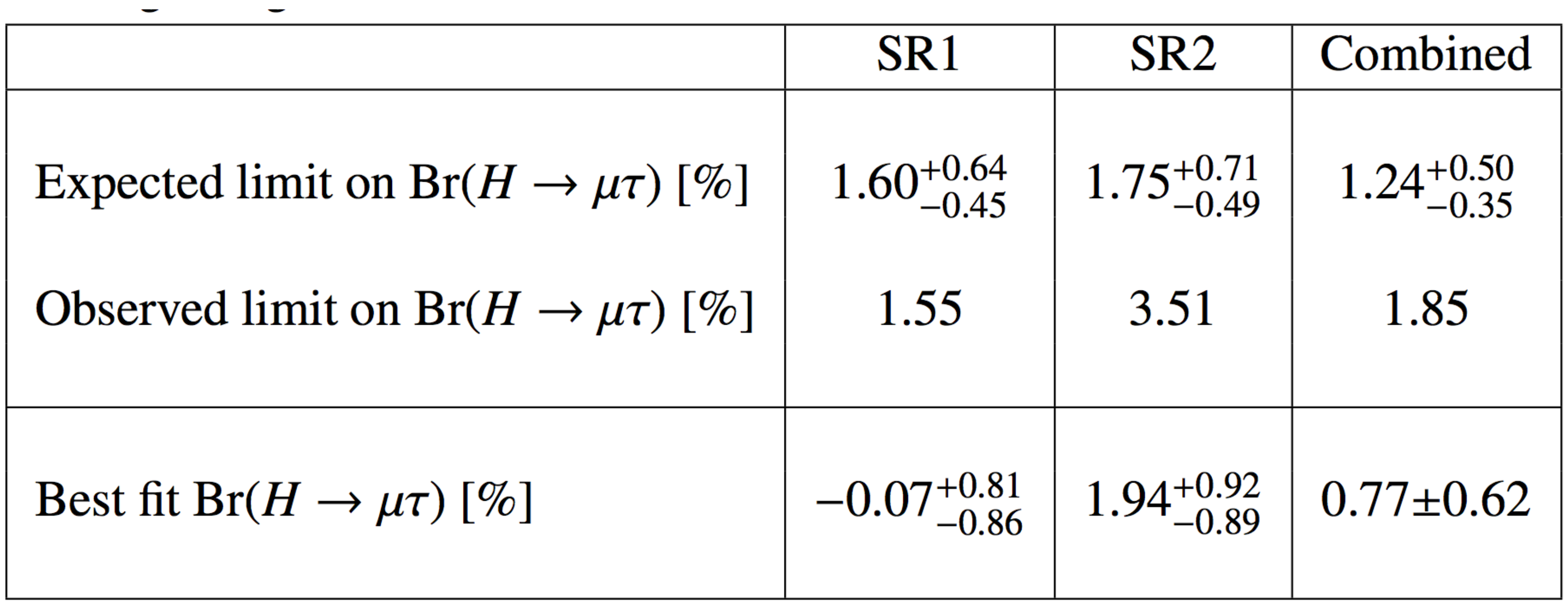
1508.03372

H -> mu + tau_hadronic





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
$N_{b\text{-}jet}$	0	0	0	>0



	SR1	SR2	Combined
Expected limit on Br($H \to \mu\tau$) [%]	$1.60^{+0.64}_{-0.45}$	$1.75^{+0.71}_{-0.49}$	$1.24^{+0.50}_{-0.35}$
Observed limit on Br($H \to \mu\tau$) [%]	1.55	3.51	1.85
Best fit Br($H \to \mu\tau$) [%]	$-0.07^{+0.81}_{-0.86}$	$1.94^{+0.92}_{-0.89}$	0.77±0.62

H -> mu tau/e tau / e mu results (8 TeV)

1604.07730

2016 paper h -> mu tau / e tau

New analyses added :

h -> mu tau_leptonic

h -> e tau_leptonic

h -> e tau_hadronic

combination with hadronic channels

No significant excess

Br(H -> mu tau) < 1.43 % (1604.07730)

Br (H-> e tau) < 1.04 % (1604.07730)

Br(H -> e mu) < 0.036% (CMS-PAS-HIG-14-040)

Effective Lagrangian

$$L_V \equiv -Y_{e\mu}\bar{e}_L\mu_R h - Y_{\mu e}\bar{\mu}_L e_R h - Y_{e\tau}\bar{e}_L\tau_R h - Y_{\tau e}\bar{\tau}_L e_R h - Y_{\mu\tau}\bar{\mu}_L\tau_R h - Y_{\tau\mu}\bar{\tau}_L\mu_R h$$

$Br(\mu \rightarrow e\gamma) < 5.7\times10^{-13}$ $\quad Y_{e\mu} < 1.2\times10^{-6}$

$Br(h \rightarrow e\mu) < 3.6\times10^{-2}$ $\quad Y_{e\mu} < 3.85\times10^{-4}$

H-> e mu: Low energy limit is much better than direct search results

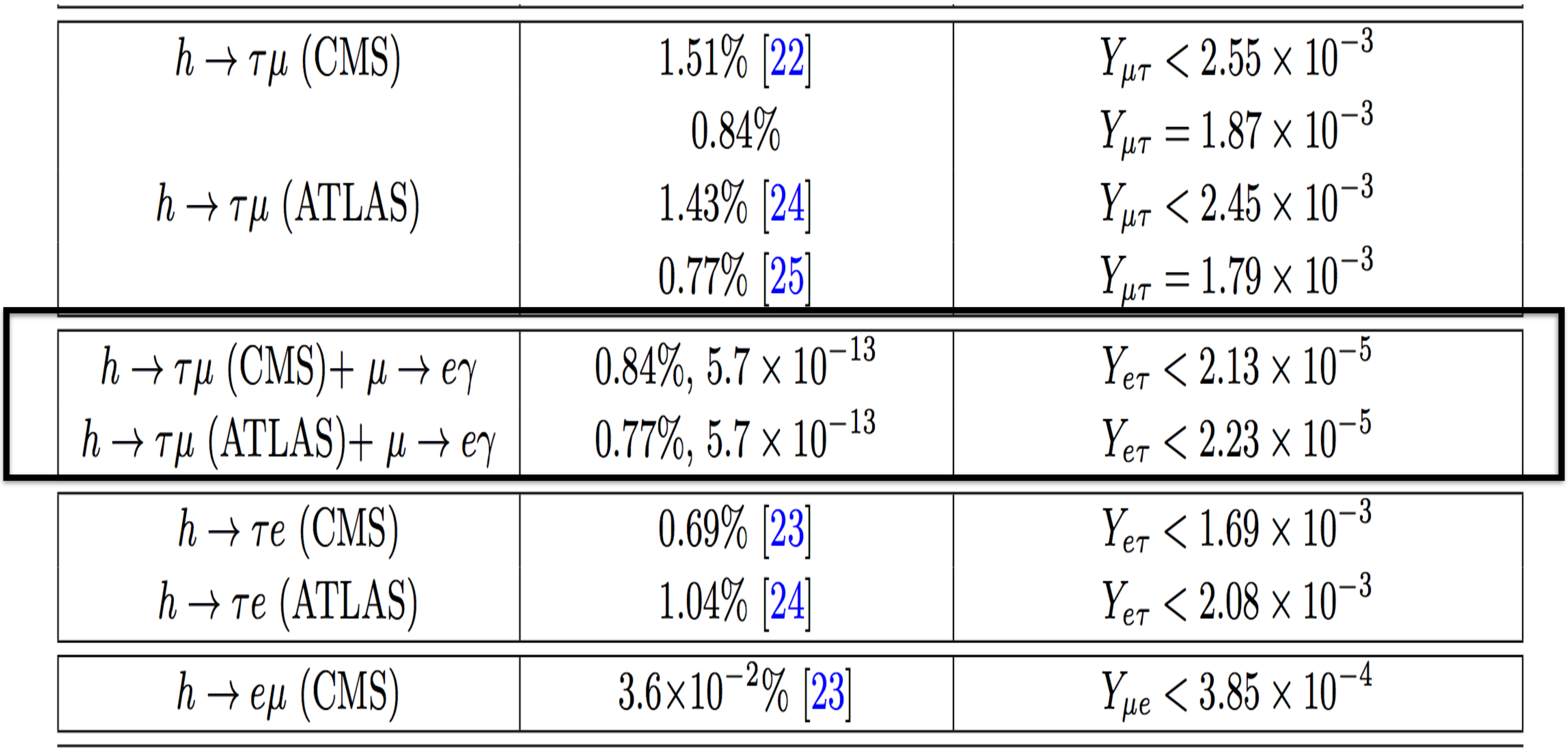
$Br(\tau \rightarrow \mu\gamma) \leq 4.4\times10^{-8}$ $\quad Y_{\mu\tau} < 0.011$

$Br(h \rightarrow \mu\tau) = 1.51\%$ $\quad Y_{\mu\tau} = 2.55\times10^{-3}$

H-> tau mu : Direct search limit is already stronger than low energy bounds

Effective Lagrangian

$$L_V \equiv -Y_{e\mu}\bar{e}_L\mu_R h - Y_{\mu e}\bar{\mu}_L e_R h - Y_{e\tau}\bar{e}_L\tau_R h - Y_{\tau e}\bar{\tau}_L e_R h - Y_{\mu\tau}\bar{\mu}_L\tau_R h - Y_{\tau\mu}\bar{\tau}_L\mu_R h$$



$h \to \tau\mu$ (CMS)	1.51% [22]	$Y_{\mu\tau} < 2.55 \times 10^{-3}$
	0.84%	$Y_{\mu\tau} = 1.87 \times 10^{-3}$
$h \to \tau\mu$ (ATLAS)	1.43% [24]	$Y_{\mu\tau} < 2.45 \times 10^{-3}$
	0.77% [25]	$Y_{\mu\tau} = 1.79 \times 10^{-3}$
$h \to \tau\mu$ (CMS)+ $\mu \to e\gamma$	0.84%, 5.7×10^{-13}	$Y_{e\tau} < 2.13 \times 10^{-5}$
$h \to \tau\mu$ (ATLAS)+ $\mu \to e\gamma$	0.77%, 5.7×10^{-13}	$Y_{e\tau} < 2.23 \times 10^{-5}$
$h \to \tau e$ (CMS)	0.69% [23]	$Y_{e\tau} < 1.69 \times 10^{-3}$
$h \to \tau e$ (ATLAS)	1.04% [24]	$Y_{e\tau} < 2.08 \times 10^{-3}$
$h \to e\mu$ (CMS)	3.6×10^{-2}% [23]	$Y_{\mu e} < 3.85 \times 10^{-4}$

hep-ph : 1202.5704, 1209.1397

H-> e tau Future limit

LHC 14 TeV L = 3000 ifb

- $pp \to h \to e\tau \to ee + \not{E}_T$
- $pp \to h \to e\tau \to \mu e + \not{E}_T$
- $pp \to h \to e\tau \to e\tau_{had} + \not{E}_T$

Madgraph5 + Pythia6 + Delphes3 analysis (cut based + TMVA)

- The transverse mass variable: $M_T(\mu) < 65$ GeV and $M_T(e) > 50$ GeV, where the transverse mass is defined as

$$M_T(\ell) = \sqrt{2 p_T(\ell) \vec{\not{E}}_T (1 - \cos \Delta\phi_{\vec{\ell} - \vec{\not{E}}_T})} \tag{3.3}$$

- The collinear mass variable: 105 GeV $< M^{\mu e}_{collinear} <$ 145 GeV, where the collinear mass is the following,

$$M_h = M_{collinear} = \frac{M_{vis}}{\sqrt{x_{\tau_{vis}}}}, \tag{3.4}$$

with the visible momentum fraction of the τ decay products being, $x_{\tau_{vis}} = \frac{|\vec{p}_T^{\,\tau_{vis}}|}{|\vec{p}_T^{\,\tau_{vis}}| + |\vec{p}_T^{\,\nu}|}$, where $\vec{p}_T^{\,\nu} = |\vec{\not{E}}_T| \hat{p}_T^{\,\tau_{vis}}$

H-> e tau Future limit

LHC 14 TeV L = 3000 ifb

$$e\mu + MET channel: \quad L = 3000 fb^{-1}$$

$$signal(Br(H \rightarrow e\tau) = 0.1\%) \sim 1600 \qquad SM \;\; bkg \sim 48000$$

$$\frac{s}{\sqrt{B}} \sim 2 \;\; for \;\; Br(H \rightarrow e\tau) = 0.03\%$$

$$\frac{s}{\sqrt{B + k^2 B^2}} with \;\; k = 0.1, \;\; \sim 2\sigma \;\; for \;\; Br(h \rightarrow e\tau) = 0.6\%$$

Limit from hadronic channel is weaker than the leptonic channel

Combination will help to strengthen the limit

H-> e mu Future limit

p p -> h -> e mu

- $p_T(e) > 40$ GeV and $p_T(\mu) > 40$ GeV
- $|\eta_e| < 1.479$ and $|\eta_\mu| < 0.8$ (in the barrel)
- $\not{E}_T < 20$ GeV
- 123 GeV $< m_h <$ 127 GeV.

signal = 1435 for Br(H-> e mu) =0.01 % and bkg ~13900

2 sigma w.o systematic uncertainty .0017%

H-> e tau Future limit (ILC 250 GeV)

- $e^+e^- \to Zh, h \to \tau e$, with $Z \to$ $2j$ and $\tau \to e\nu, \mu\nu$ or τ tagged as τ_{had}

Channel	BR % ($\mathcal{S}^{optimal}$)
$e + \mu + \geq 2j + \not{E}_T$	$0.96\ (2\sigma)$
	$3.39\ (5\sigma)$
$2e + \geq 2j + \not{E}_T$	$3.93\ (2\sigma)$
	$> 10\ (5\sigma)$
$e + \tau_{had} + \geq 2j + \not{E}_T$	$0.44\ (2\sigma)$
	$1.54\ (5\sigma)$

Limited by statistics

H-> e tau Future limit (ILC 1TeV)

- $e^+e^- \to \not{E}h, h \to \tau e$, with $\tau \to e\nu, \mu\nu$ or τ tagged as τ_{had}.

Channel	BR % ($\mathcal{S}^{optimal}$)
$e + \mu + \not{E}$	0.63 (2σ)
	1.68 (5σ)
$2e + \not{E}$	2.75 (2σ)
	7.22 (5σ)
$e + \tau_{had} + \not{E}$	0.24 (2σ)
	0.62 (5σ)

Limited by statistics => combination of different channel will improve the limit

H-> mu /e tau low energy Future limits

BELLE II accessible branching

$$Br(\tau \rightarrow \mu\gamma) \sim 10^{-9}$$

$$Y_{\tau\mu} \sim 0.002 \qquad Br(h \rightarrow \tau\mu) \sim 0.5\%$$

Collider limit is comparable/stronger than BELLE II limit

Summary

1. Higgs -> mu tau/ e tau Direct search limit is already better than low energy experimental results

2. ILC limits may not be very different from the LHC limit

Summary

1. Higgs -> mu tau/ e tau Direct search limit is already better than low energy experimental results

2. ILC limits may not be very different from the LHC limit

3. Upper limits on Branchings can be slightly modified in case of non SM production cross section/ decay width

4. Other search channels like ZH , ttH should be studied

(p p -> Zh , h -> tau mu , Z -> l l : 3/4 lepton search)
(p p -> ttH , h -> tau mu : same sign ll, 3/4 l searches)

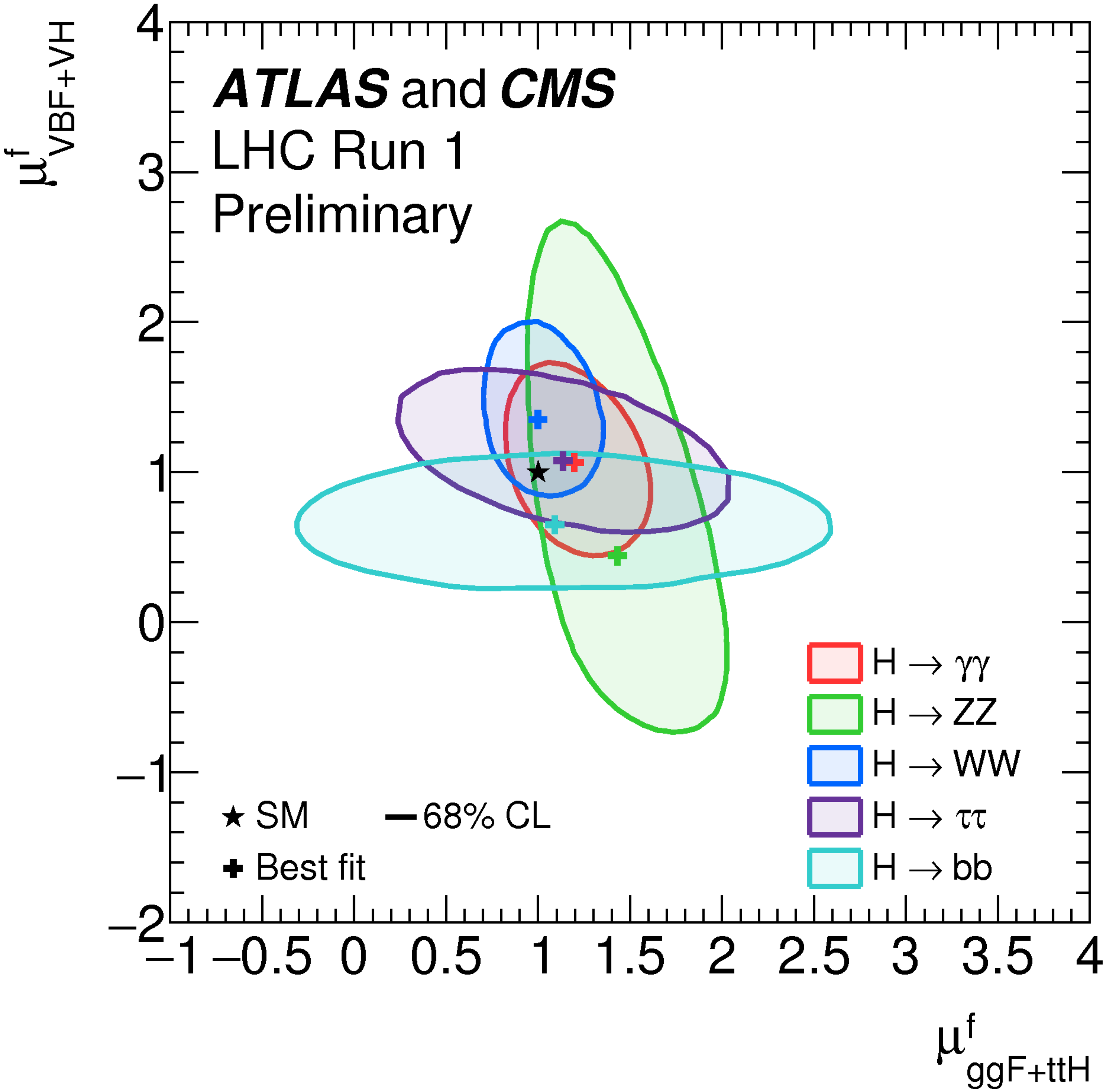
5. Complex coupling/ CP violation ???

Thank you

Effective Lagrangian

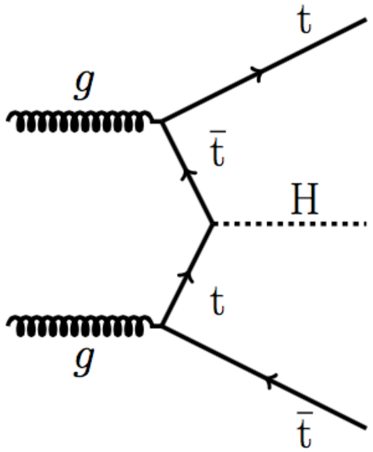
$$L_V \equiv -Y_{e\mu}\bar{e}_L\mu_R h - Y_{\mu e}\bar{\mu}_L e_R h - Y_{e\tau}\bar{e}_L\tau_R h - Y_{\tau e}\bar{\tau}_L e_R h - Y_{\mu\tau}\bar{\mu}_L\tau_R h - Y_{\tau\mu}\bar{\tau}_L\mu_R h$$

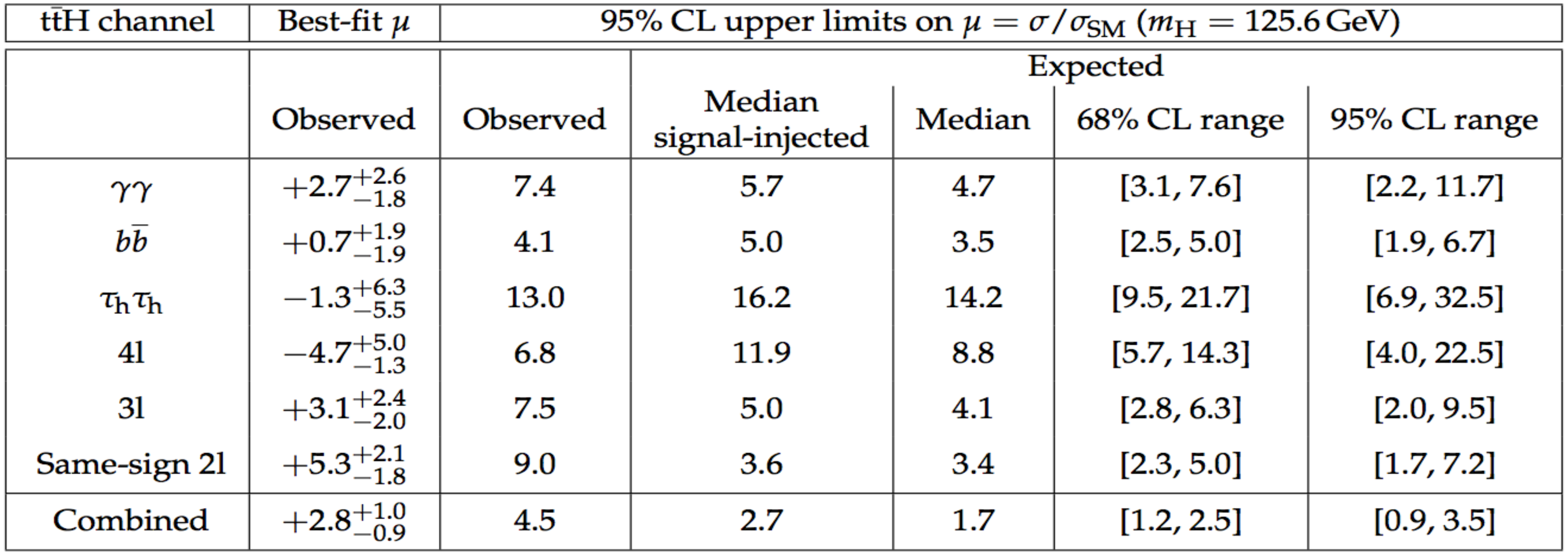
$\tau \to \mu\gamma$	4.4×10^{-8} [70, 71]	$Y_{\mu\tau} < 0.011$
$\tau \to 3\mu$	2.1×10^{-8} [70, 71]	$Y_{\mu\tau} < 0.176$
Muon EDM	$-10 \times 10^{-20} e$ cm $< \lvert d_\mu \rvert < 8 \times 10^{-20} e$ cm [73]	$-0.8 \lesssim \lvert \mathrm{Im}(Y_{\mu\tau}Y_{\tau\mu}) \rvert \lesssim 1.0$
Muon $g-2$	–	$\mathrm{Re}(Y_{\mu\tau}Y_{\tau\mu}) < (2.7 \pm 0.75) \times 10^{-3}$
$\tau \to \mu\gamma$ (f) (Belle-II/super KEKB)	10^{-9} [85]	$Y_{\mu\tau}$ <0.0017
$\tau \to e\gamma$	3.3×10^{-8} [70, 71]	$Y_{e\tau}$ <0.0099
$\tau \to 3e$	2.7×10^{-8} [70, 71]	$Y_{e\tau} < 0.085$
Electron $g-2$	–	$\mathrm{Re}(Y_{e\tau}Y_{\tau e}) < [-2.1, 2.9] \times 10^{-3}$
Electron EDM	$\lvert d_e \rvert \le 0.105 \times 10^{-26}$ e cm	$\lvert \mathrm{Im}(Y_{e\tau}Y_{\tau e}) \rvert < 1.1 \times 10^{-8}$
$\tau \to e\gamma$ (f) (Belle-II/super KEKB)	10^{-9} [85]	$Y_{e\tau}$ <0.00172
$\mu \to e\gamma$	5.7×10^{-13} [70, 71]	$Y_{\mu e} < 1.24 \times 10^{-6}$
$\mu \to 3e$	1.0×10^{-12} [70, 71]	$Y_{\mu e} < 2.19 \times 10^{-5}$
Electron $g-2$	–	$\mathrm{Re}(Y_{e\mu}Y_{\mu e}) < [-0.019, 0.026]$
Electron EDM	$\lvert d_e \rvert \le 0.105 \times 10^{-26}$ e cm	$\lvert \mathrm{Im}(Y_{e\mu}Y_{\mu e}) \rvert < 9.8 \times 10^{-8}$
$\mu \to e$ conversion	–	$Y_{\mu e} < 8.49 \times 10^{-6}$
$M - \bar{M}$ oscillations	–	$\lvert Y_{\mu e} + Y^*_{e\mu} \rvert < 0.079$
$\mu \to e\gamma$ (f) (MEG-II)	4×10^{-14} [84]	$Y_{\mu e} < 3.28 \times 10^{-7}$
$\mu \to e\gamma$	5.7×10^{-13}	$Y_{\mu\tau}Y_{e\tau} < 3.98 \times 10^{-8}$


ATLAS and CMS
LHC Run 1
Preliminary
μ^{f}_{VBF+VH}
$\mu^{f}_{ggF+ttH}$
4
3
2
1
0
−1
−2
−1
−0.5
0
0.5
1
1.5
2
2.5
3
3.5
4
★ SM
— 68% CL
✚ Best fit
H → γγ
H → ZZ
H → WW
H → ττ
H → bb

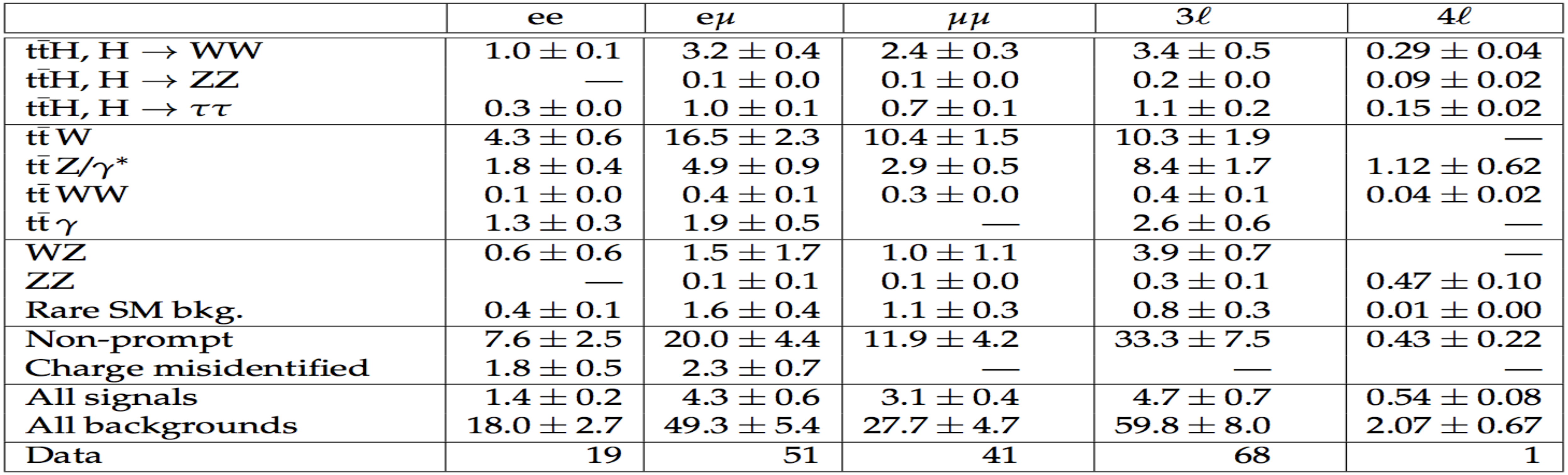
CMS ttH cross section measurement

arXiv:1408.1682





$t\bar{t}$H channel	Best-fit μ	95% CL upper limits on $\mu = \sigma/\sigma_{SM}$ ($m_H = 125.6$ GeV)				
				Expected		
	Observed	Observed	Median signal-injected	Median	68% CL range	95% CL range
$\gamma\gamma$	$+2.7^{+2.6}_{-1.8}$	7.4	5.7	4.7	[3.1, 7.6]	[2.2, 11.7]
$b\bar{b}$	$+0.7^{+1.9}_{-1.9}$	4.1	5.0	3.5	[2.5, 5.0]	[1.9, 6.7]
$\tau_h\tau_h$	$-1.3^{+6.3}_{-5.5}$	13.0	16.2	14.2	[9.5, 21.7]	[6.9, 32.5]
4l	$-4.7^{+5.0}_{-1.3}$	6.8	11.9	8.8	[5.7, 14.3]	[4.0, 22.5]
3l	$+3.1^{+2.4}_{-2.0}$	7.5	5.0	4.1	[2.8, 6.3]	[2.0, 9.5]
Same-sign 2l	$+5.3^{+2.1}_{-1.8}$	9.0	3.6	3.4	[2.3, 5.0]	[1.7, 7.2]
Combined	$+2.8^{+1.0}_{-0.9}$	4.5	2.7	1.7	[1.2, 2.5]	[0.9, 3.5]



	ee	$e\mu$	$\mu\mu$	3ℓ	4ℓ
$t\bar{t}$H, H $\to$ WW	1.0 ± 0.1	3.2 ± 0.4	2.4 ± 0.3	3.4 ± 0.5	0.29 ± 0.04
$t\bar{t}$H, H $\to$ ZZ	—	0.1 ± 0.0	0.1 ± 0.0	0.2 ± 0.0	0.09 ± 0.02
$t\bar{t}$H, H $\to \tau\tau$	0.3 ± 0.0	1.0 ± 0.1	0.7 ± 0.1	1.1 ± 0.2	0.15 ± 0.02
$t\bar{t}$W	4.3 ± 0.6	16.5 ± 2.3	10.4 ± 1.5	10.3 ± 1.9	—
$t\bar{t}$Z/γ^*	1.8 ± 0.4	4.9 ± 0.9	2.9 ± 0.5	8.4 ± 1.7	1.12 ± 0.62
$t\bar{t}$WW	0.1 ± 0.0	0.4 ± 0.1	0.3 ± 0.0	0.4 ± 0.1	0.04 ± 0.02
$t\bar{t}\gamma$	1.3 ± 0.3	1.9 ± 0.5	—	2.6 ± 0.6	—
WZ	0.6 ± 0.6	1.5 ± 1.7	1.0 ± 1.1	3.9 ± 0.7	—
ZZ	—	0.1 ± 0.1	0.1 ± 0.0	0.3 ± 0.1	0.47 ± 0.10
Rare SM bkg.	0.4 ± 0.1	1.6 ± 0.4	1.1 ± 0.3	0.8 ± 0.3	0.01 ± 0.00
Non-prompt	7.6 ± 2.5	20.0 ± 4.4	11.9 ± 4.2	33.3 ± 7.5	0.43 ± 0.22
Charge misidentified	1.8 ± 0.5	2.3 ± 0.7	—	—	—
All signals	1.4 ± 0.2	4.3 ± 0.6	3.1 ± 0.4	4.7 ± 0.7	0.54 ± 0.08
All backgrounds	18.0 ± 2.7	49.3 ± 5.4	27.7 ± 4.7	59.8 ± 8.0	2.07 ± 0.67
Data	19	51	41	68	1

Higgs LFV contribution can be important in muon channels : 1505.02688,
(BB, S. Chakraborty, S. Mukherjee)

ATLAS : best fit value of signal strength in multi-lepton channel $2.1^{+1.4}_{-1.2}$ **(1506.05888)**