Theory of Charged Lepton Flavour Violation

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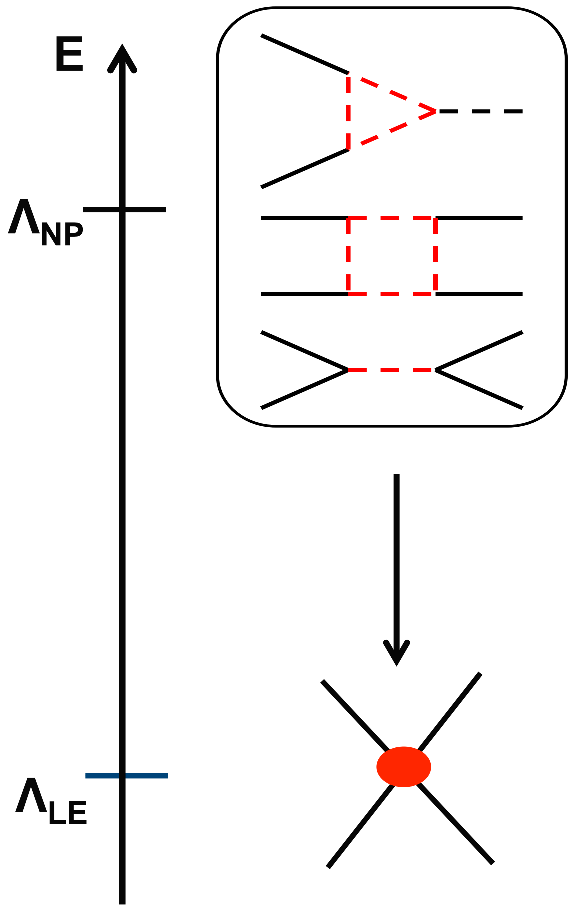
Outline

1. Introduction and Motivation
2. Charged Lepton-Flavour Violation: Model discriminating power of muons and tau channels
3. Ex: Non-Standard LFV couplings of the Higgs boson
4. Conclusion and Outlook

1. Introduction and Motivation

1.1 Why study charged leptons?

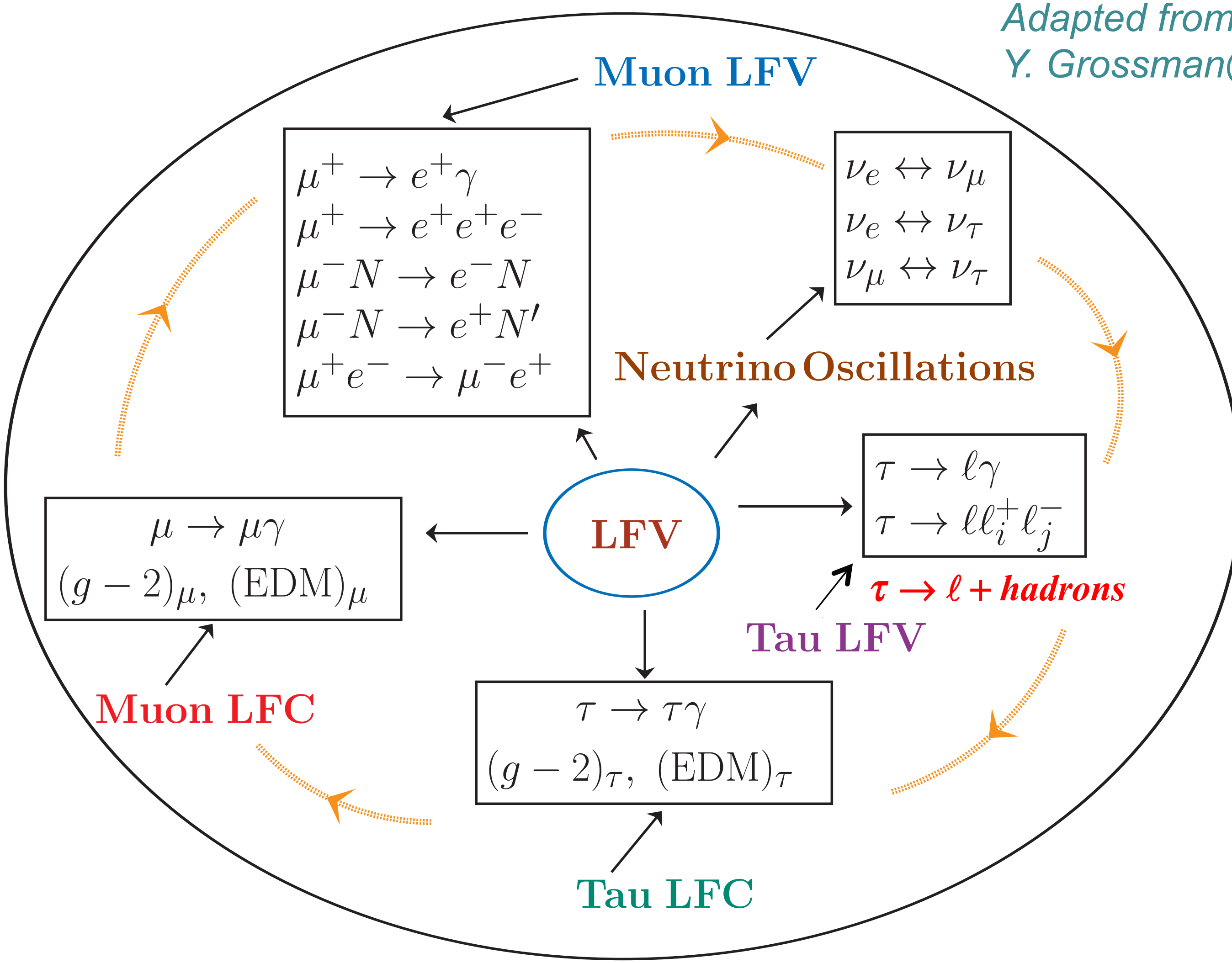


- In the quest of New Physics, can be sensitive to very high scale:
  - Kaon physics: $\frac{s\bar{d}s\bar{d}}{\Lambda^2} \Rightarrow \Lambda \gtrsim 10^5$ TeV
    [ε_K]
  - Charged Leptons: $\frac{\mu\bar{e}f\bar{f}}{\Lambda^2} \Rightarrow \Lambda \gtrsim 10^4$ TeV
    [$\mu \rightarrow e\gamma$]
- At low energy: lots of experiments e.g., *MEG*, *COMET*, *Mu2e*, *E-969, BaBar*, *BelleI-II*, *BESIII, LHCb* ⇨ huge improvements on measurements and bounds obtained and more expected
- In many cases no SM background: e.g., LFV, EDMs
- For some modes accurate calculations of hadronic uncertainties essential

⇨ Charged leptons very important to look for *New Physics*!

1.2 The Program

Adapted from Talk by Y. Grossman@CLFV2013



2. Charged Lepton-Flavour Violation

- Neutrino oscillations are the first evidence for lepton flavour violation

- How about in the charged lepton sector?

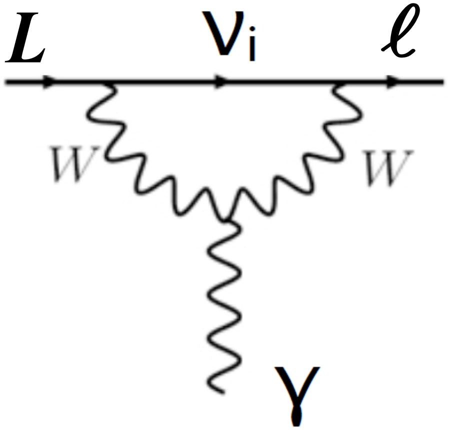
- In the *SM* with massive neutrinos effective CLFV vertices are tiny due to GIM suppression ⇒ *unobservably small rates!*

E.g.: $\mu \to e\gamma$

$$Br(\mu \to e\gamma) = \frac{3\alpha}{32\pi}\left|\sum_{i=2,3} U^*_{\mu i} U_{ei} \frac{\Delta m^2_{1i}}{M^2_W}\right|^2 < 10^{-54}$$

Petcov'77, Marciano & Sanda'77, Lee & Sh

$$\left[Br(\tau \to \mu\gamma) < 10^{-40}\right]$$



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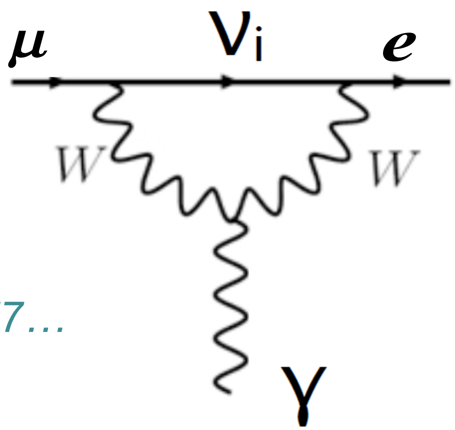


Petcov'77, Marciano & Sanda'77, Lee & Shrock'77…

$$\left[Br(\tau \to \mu\gamma) < 10^{-40} \right]$$

- Extremely *clean probe of beyond SM physics*

2.1 Introduction and Motivation

- In New Physics scenarios CLFV can reach observable levels in several channels

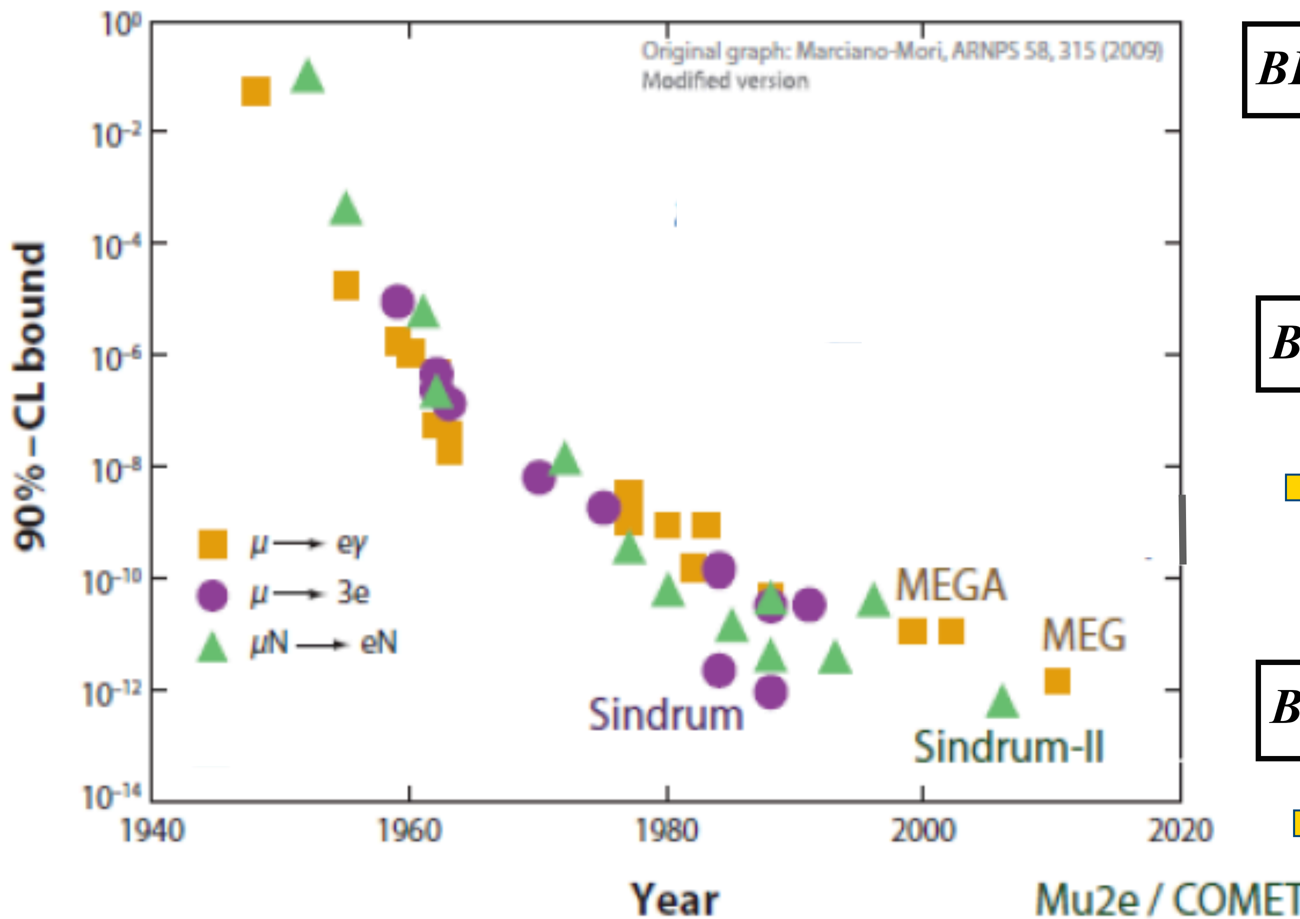
Talk by D. Hitlin @ CLFV2013

		$\tau \to \mu\gamma$	$\tau \to \ell\ell\ell$
SM + ν mixing	Lee, Shrock, PRD 16 (1977) 1444 Cheng, Li, PRD 45 (1980) 1908	Undetectable	
SUSY Higgs	Dedes, Ellis, Raidal, PLB 549 (2002) 159 Brignole, Rossi, PLB 566 (2003) 517	10^{-10}	10^{-7}
SM + heavy Maj ν_R	Cvetic, Dib, Kim, Kim , PRD66 (2002) 034008	10^{-9}	10^{-10}
Non-universal Z'	Yue, Zhang, Liu, PLB 547 (2002) 252	10^{-9}	10^{-8}
SUSY SO(10)	Masiero, Vempati, Vives, NPB 649 (2003) 189 Fukuyama, Kikuchi, Okada, PRD 68 (2003) 033012	10^{-8}	10^{-10}
mSUGRA + Seesaw	Ellis, Gomez, Leontaris, Lola, Nanopoulos, EPJ C14 (2002) 319 Ellis, Hisano, Raidal, Shimizu, PRD 66 (2002) 115013	10^{-7}	10^{-9}

- But the sensitivity of particular modes to CLFV couplings is model dependent
- Comparison in muonic and tauonic channels of branching ratios, conversion rates and spectra is model-diagnostic

2.2 CLFV processes: muon decays

- Several processes: $\mu \to e\gamma,\ \mu \to e\bar{e}e,\ \mu(A,Z) \to e(A,Z)$



MEG'16

$$BR(\mu \to e\gamma) < 4.2\times 10^{-13}$$

$\Rightarrow 6\times 10^{-14}$

Sindrum

$$BR(\mu \to eee) < 1.0\times 10^{-12}$$

$\Rightarrow 10^{-15} - 10^{-16}$ *Mu3e*

Sindrum II

$$BR^{Ti}_{\mu-e} < 4.3\times 10^{-12}$$

$\Rightarrow 10^{-16} - 10^{-17}$

Mu2e/COMET

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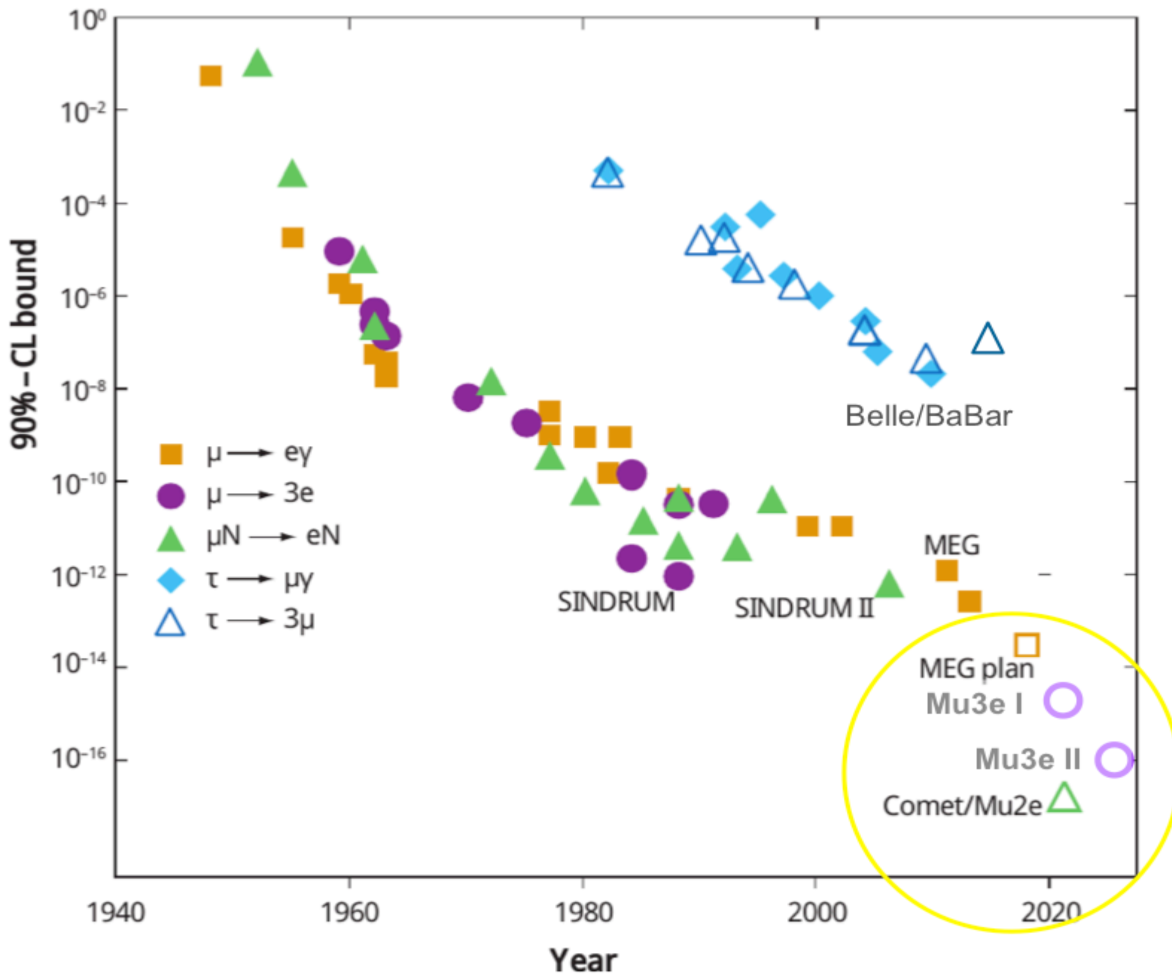

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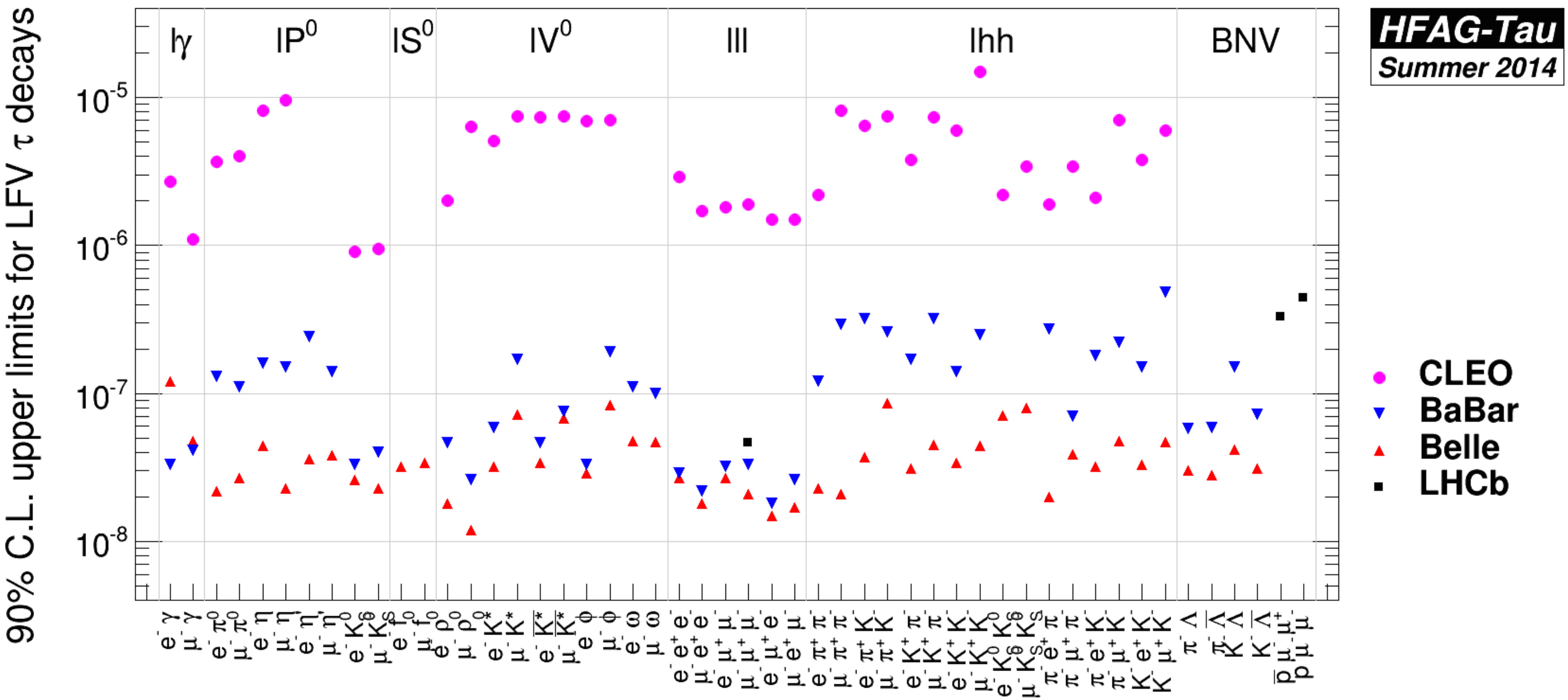
- Several processes: $\tau \to \ell\gamma,\ \tau \to \ell_\alpha \bar{\ell}_\beta \ell_\beta,\ \tau \to \ell Y$ ↖ $P,\ S,\ V,\ P\bar{P}, \ldots$



- 48 LFV modes studied at Belle and BaBar

2.2 CLFV processes: tau decays

Belle II Physics Book'18
HL-LHC&HE-LHC'18

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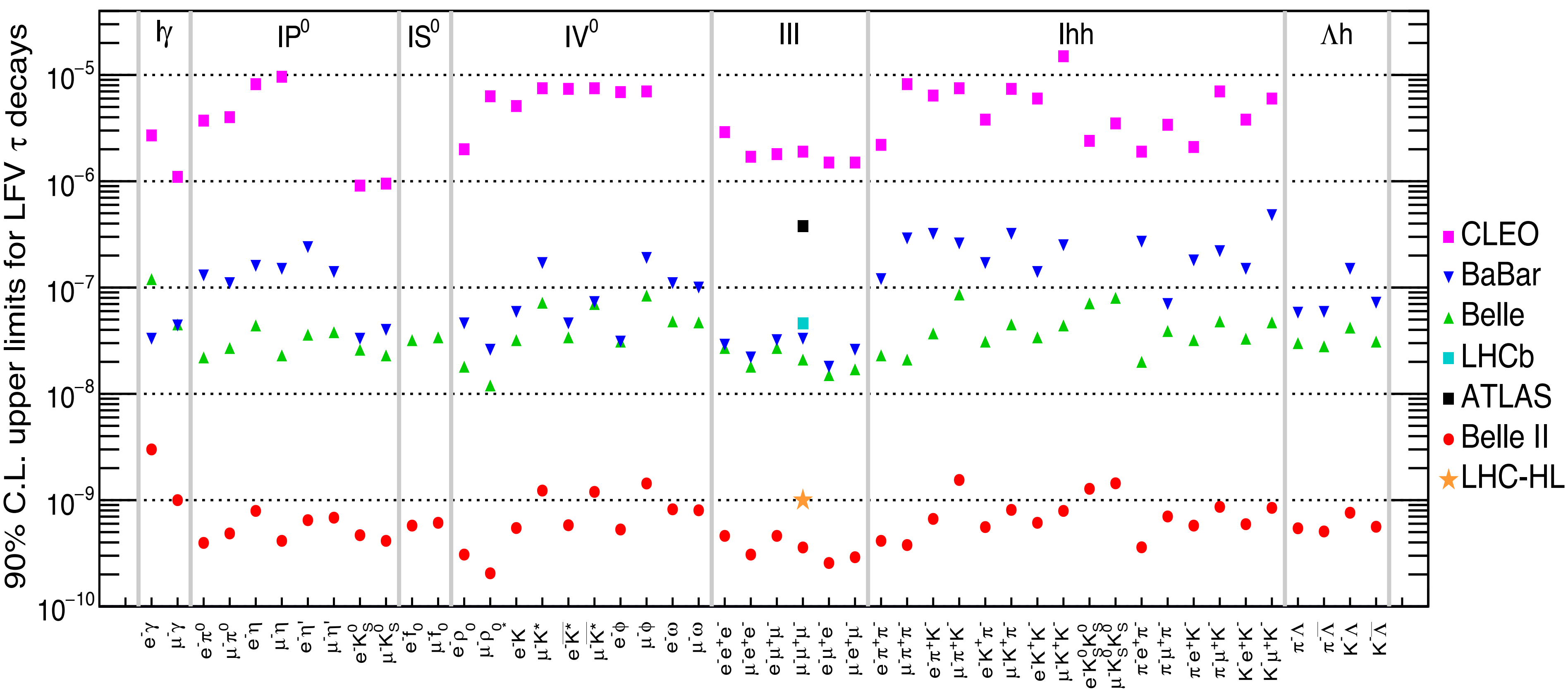
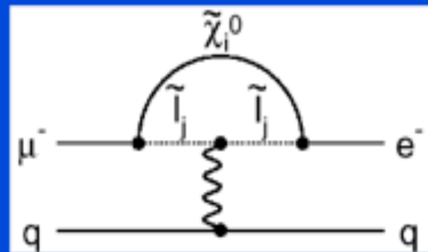


- Expected sensitivity 10^{-9} or better at *LHCb, Belle II, HL-LHC?*

A multitude of models…

Supersymmetry

Predictions at 10^{-15}

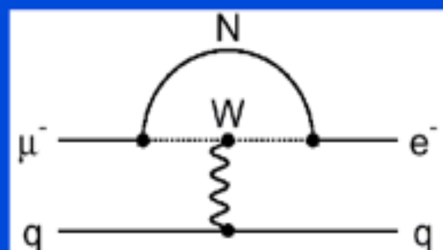


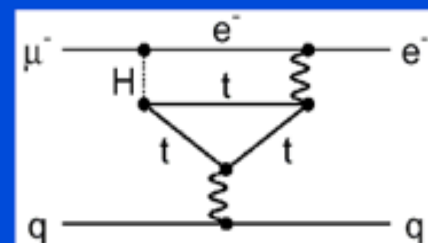
Compositeness

$\Lambda_c = 3000$ TeV

Heavy Neutrinos

$\left|U^*_{\mu N} U_{eN}\right|^2 = 8 \times 10^{-13}$





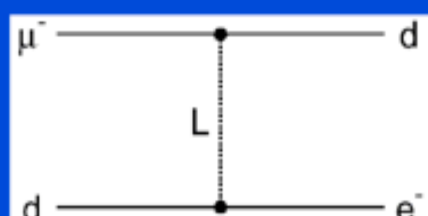
Second Higgs doublet

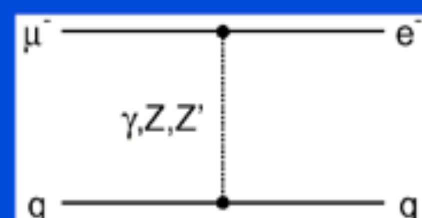
$g_{H_{\mu e}} = 10^{-4} \times g_{H_{\mu\mu}}$

Leptoquarks

$M_L =$

$3000\sqrt{\lambda_{\mu d}\lambda_{ed}}$ TeV/c^2





Heavy Z', Anomalous Z coupling

$M_{Z'} = 3000$ TeV/c^2

$B(Z \to \mu e) < 10^{-17}$

After W. Marciano

James Miller, 2006

2.3 Effective Field Theory approach

$$\mathcal{L} = \mathcal{L}_{SM} + \frac{C^{(5)}}{\Lambda} O^{(5)} + \sum_i \frac{C_i^{(6)}}{\Lambda^2} O_i^{(6)} + \dots$$

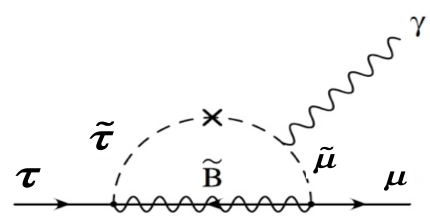
See e.g.
Black, Han, He, Sher'02
Brignole & Rossi'04
Dassinger, Feldmann, Mannel, Turczyk'07
Matsuzaki & Sanda'08
Giffels et al.'08
Crivellin, Najjari, Rosiek'13
Petrov & Zhuridov'14
Cirigliano, Celis, E.P.'14

- Build all D>5 LFV operators:

  - Dipole:

$$\mathcal{L}_{eff}^{D} \supset -\frac{C_D}{\Lambda^2} m_\tau \bar{\mu} \sigma^{\mu\nu} P_{L,R} \tau F_{\mu\nu}$$

e.g.



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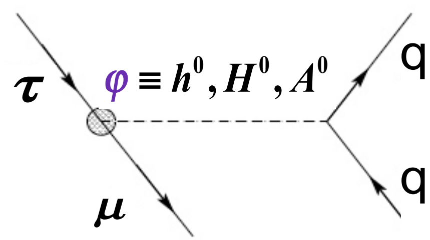
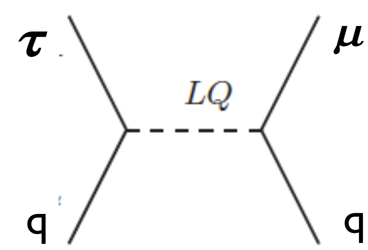
  - Lepton-quark (Scalar, Pseudo-scalar, Vector, Axial-vector):

$$\mathcal{L}_{eff}^{S,V} \supset -\frac{C_{S,V}}{\Lambda^2} m_\tau m_q G_F \bar{\mu}\, \Gamma P_{L,R} \tau\, \bar{q} \Gamma q$$

e.g.



$\Gamma \equiv 1$



$\Gamma \equiv \gamma^\mu$

.

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  - Integrating out heavy quarks generates *gluonic operator*

$$\frac{1}{\Lambda^2} \bar{\mu} P_{L,R} \tau Q \bar{Q} \rightarrow \mathcal{L}_{eff}^{G} \supset -\frac{C_G}{\Lambda^2} m_\tau G_F \bar{\mu} P_{L,R} \tau\; G_{\mu\nu}^{a} G_a^{\mu\nu}$$

Importance of this operator emphasized in *Petrov & Zhuridov'14*

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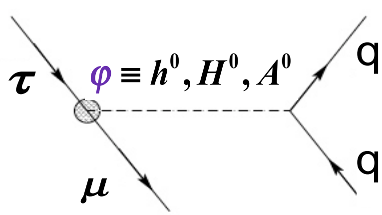

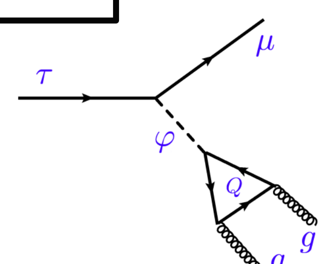

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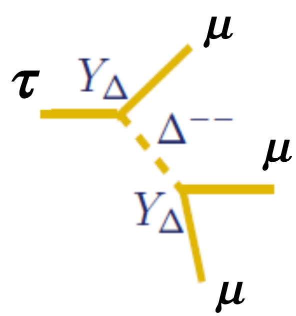
  - 4 leptons (Scalar, Pseudo-scalar, Vector, Axial-vector): $\mathcal{L}_{eff}^{4\ell} \supset -\frac{C_{S,V}^{4\ell}}{\Lambda^2} \bar{\mu}\, \Gamma P_{L,R} \tau\; \bar{\mu}\, \Gamma P_{L,R} \mu$

$\Gamma \equiv 1, \gamma^\mu$

e.g.



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  - Lepton-gluon (Scalar, Pseudo-scalar): $\mathcal{L}_{eff}^{G} \supset -\frac{C_G}{\Lambda^2} m_\tau G_F \bar{\mu} P_{L,R}\tau\ G_{\mu\nu}^{a} G_{a}^{\mu\nu}$
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$\Gamma \equiv 1, \gamma^\mu$

- Each UV model generates a *specific pattern* of them

2.4 Model discriminating power of muon processes

- Summary table:

Cirigliano@Beauty2014

	$\mu \to 3e$	$\mu \to e\gamma$	$\mu \to e$ conversion
$O^{4\ell}_{S,V}$	✓	–	–
O_D	✓	✓	✓
O^q_V	–	–	✓
O^q_S	–	–	✓

- The notion of "*best probe*" (process with largest decay rate) is *model dependent*

- If observed, compare rate of processes
  ⇒ key handle on *relative strength* between operators and hence on the *underlying mechanism*

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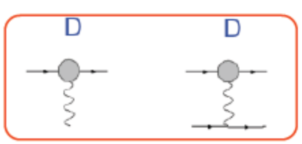
O^q_S	–	–	✓

- $\mu \to e\gamma$ vs. $\mu \to 3e$ ⇨ relative strength between *dipole* and *4L* operators

$$\frac{\Gamma_{\mu\to 3e}}{\Gamma_{\mu\to e\gamma}} = \frac{\alpha}{4\pi}\, I_{\rm PS} \left(1 + \sum_i \frac{c_i^{(\rm contact)}}{c^{(\rm dipole)}} \right)$$



6×10^{-3}

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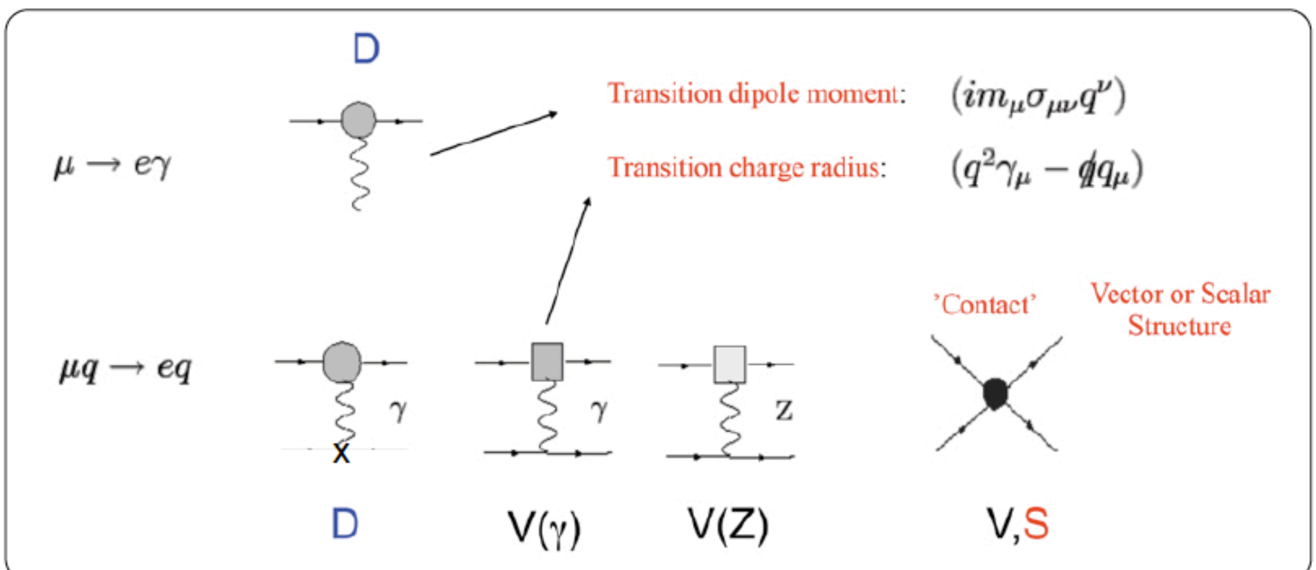
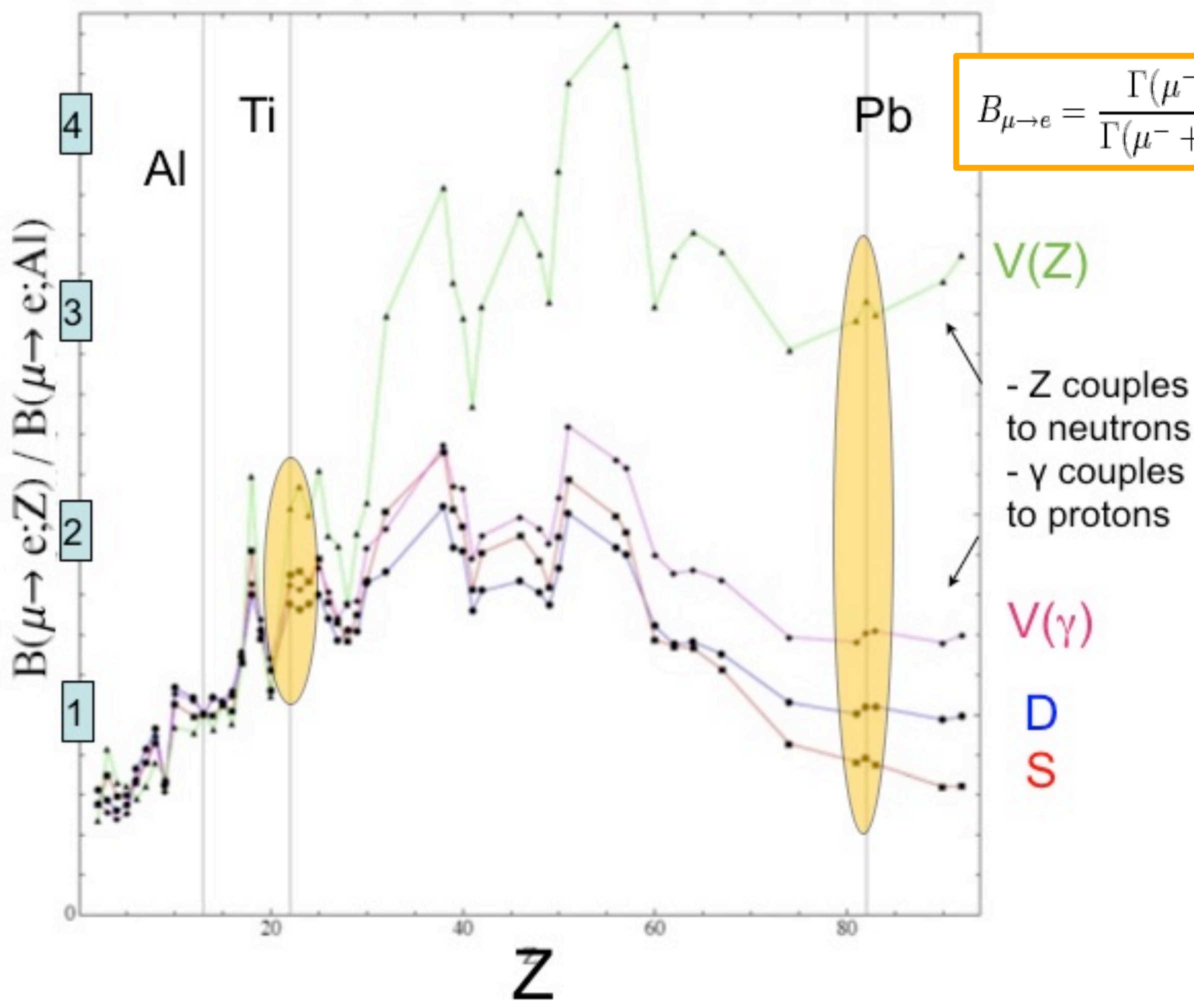
- *$\mu \to e\gamma$* vs. *$\mu \to e$ conversion* ⇨ relative strength between *dipole* and *quark* operators



BR for $\mu \rightarrow$ e conversion

- For *$\mu \rightarrow$e conversion,* target dependence of the amplitude is different for V,D or S models

Cirigliano, Kitano, Okada, Tuzon'09



$$B_{\mu\to e} = \frac{\Gamma(\mu^- + (Z,A) \to e^- + (Z,A))}{\Gamma(\mu^- + (Z,A) \to \nu_\mu + (Z-1,A))}$$

2.5 Model discriminating power of Tau processes

- Summary table:

Celis, Cirigliano, E.P.'14

	$\tau \to 3\mu$	$\tau \to \mu\gamma$	$\tau \to \mu\pi^+\pi^-$	$\tau \to \mu K\bar{K}$	$\tau \to \mu\pi$	$\tau \to \mu\eta^{(\prime)}$
$O_{S,V}^{4\ell}$	✓	–	–	–	–	–
O_D	✓	✓	✓	✓	–	–
O_V^q	–	–	✓ (I=1)	✓(I=0,1)	–	–
O_S^q	–	–	✓ (I=0)	✓(I=0,1)	–	–
O_{GG}	–	–	✓	✓	–	–
O_A^q	–	–	–	–	✓ (I=1)	✓ (I=0)
O_P^q	–	–	–	–	✓ (I=1)	✓ (I=0)
$O_{G\tilde{G}}$	–	–	–	–	–	✓

- In addition to leptonic and radiative decays, *hadronic decays* are very important ⇒ sensitive to large number of operators!

- But need reliable determinations of the hadronic part: form factors and *decay constants* (e.g. f_η, $f_{\eta'}$)

2.5 Model discriminating power of Tau processes

- Summary table: *Celis, Cirigliano, E.P.'14*

	$\tau \to 3\mu$	$\tau \to \mu\gamma$	$\tau \to \mu\pi^+\pi^-$	$\tau \to \mu K\bar{K}$	$\tau \to \mu\pi$	$\tau \to \mu\eta^{(\prime)}$
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O_D	✓	✓	✓	✓	–	–
O^q_V	–	–	✓ (I=1)	✓(I=0,1)	–	–
O^q_S	–	–	✓ (I=0)	✓(I=0,1)	–	–
O_{GG}	–	–	✓	✓	–	–
O^q_A	–	–	–	–	✓ (I=1)	✓ (I=0)
O^q_P	–	–	–	–	✓ (I=1)	✓ (I=0)
$O_{G\tilde{G}}$	–	–	–	–	–	✓

- Form factors for $\tau \to \mu(e)\pi\pi$ determined using *dispersive techniques*
- Hadronic part: *Donoghue, Gasser, Leutwyler'90*

Moussallam'99
Daub et al'13
Celis, Cirigliano, E.P.'14

$$H_\mu = \langle \pi\pi | \left(V_\mu - A_\mu\right) e^{iL_{QCD}} | 0 \rangle = \left(Lorentz\ \text{struct.}\right)^i_\mu F_i(s)$$

with

$$s = \left(p_{\pi^+} + p_{\pi^-}\right)^2$$

- 2-channel unitarity condition is solved with I=0 S-wave ππ and KK scattering data as input

$$\mathrm{Im} F_n(s) = \sum_{m=1}^{2} T^*_{nm}(s)\sigma_m(s)F_m(s)$$

$$n = \pi\pi, K\bar{K}$$

2.5 Model discriminating power of Tau processes

Celis, Cirigliano, E.P.'14

- Two handles:
  - Branching ratios: $$R_{F,M} \equiv \frac{\Gamma(\tau \to F)}{\Gamma(\tau \to F_M)}$$ with F_M dominant LFV mode for model M
  - Spectra for > 2 bodies in the final state:

$$\frac{dBR(\tau \to \mu\pi^+\pi^-)}{d\sqrt{s}}$$ and $$dR_{\pi^+\pi^-} \equiv \frac{1}{\Gamma(\tau \to \mu\gamma)} \frac{d\Gamma(\tau \to \mu\pi^+\pi^-)}{d\sqrt{s}}$$

2.6 Model discriminating of BRs

- Studies in specific models

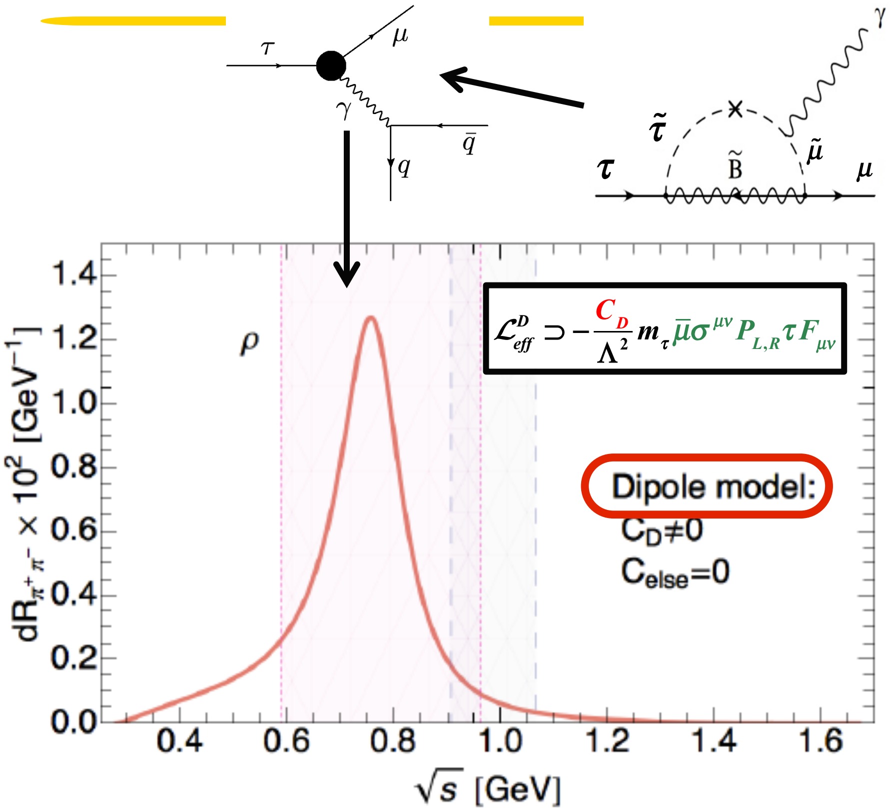
Buras et al.'10

ratio	LHT	MSSM (dipole)	MSSM (Higgs)	SM4
$\frac{\mathrm{Br}(\mu^-\to e^-e^+e^-)}{\mathrm{Br}(\mu\to e\gamma)}$	$0.02\ldots1$	$\sim 6\cdot10^{-3}$	$\sim 6\cdot10^{-3}$	$0.06\ldots2.2$
$\frac{\mathrm{Br}(\tau^-\to e^-e^+e^-)}{\mathrm{Br}(\tau\to e\gamma)}$	$0.04\ldots0.4$	$\sim 1\cdot10^{-2}$	$\sim 1\cdot10^{-2}$	$0.07\ldots2.2$
$\frac{\mathrm{Br}(\tau^-\to\mu^-\mu^+\mu^-)}{\mathrm{Br}(\tau\to\mu\gamma)}$	$0.04\ldots0.4$	$\sim 2\cdot10^{-3}$	$0.06\ldots0.1$	$0.06\ldots2.2$
$\frac{\mathrm{Br}(\tau^-\to e^-\mu^+\mu^-)}{\mathrm{Br}(\tau\to e\gamma)}$	$0.04\ldots0.3$	$\sim 2\cdot10^{-3}$	$0.02\ldots0.04$	$0.03\ldots1.3$
$\frac{\mathrm{Br}(\tau^-\to\mu^-e^+e^-)}{\mathrm{Br}(\tau\to\mu\gamma)}$	$0.04\ldots0.3$	$\sim 1\cdot10^{-2}$	$\sim 1\cdot10^{-2}$	$0.04\ldots1.4$
$\frac{\mathrm{Br}(\tau^-\to e^-e^+e^-)}{\mathrm{Br}(\tau^-\to e^-\mu^+\mu^-)}$	$0.8\ldots2$	~ 5	$0.3\ldots0.5$	$1.5\ldots2.3$
$\frac{\mathrm{Br}(\tau^-\to\mu^-\mu^+\mu^-)}{\mathrm{Br}(\tau^-\to\mu^-e^+e^-)}$	$0.7\ldots1.6$	~ 0.2	$5\ldots10$	$1.4\ldots1.7$
$\frac{\mathrm{R}(\mu\mathrm{Ti}\to e\mathrm{Ti})}{\mathrm{Br}(\mu\to e\gamma)}$	$10^{-3}\ldots10^{2}$	$\sim 5\cdot10^{-3}$	$0.08\ldots0.15$	$10^{-12}\ldots26$

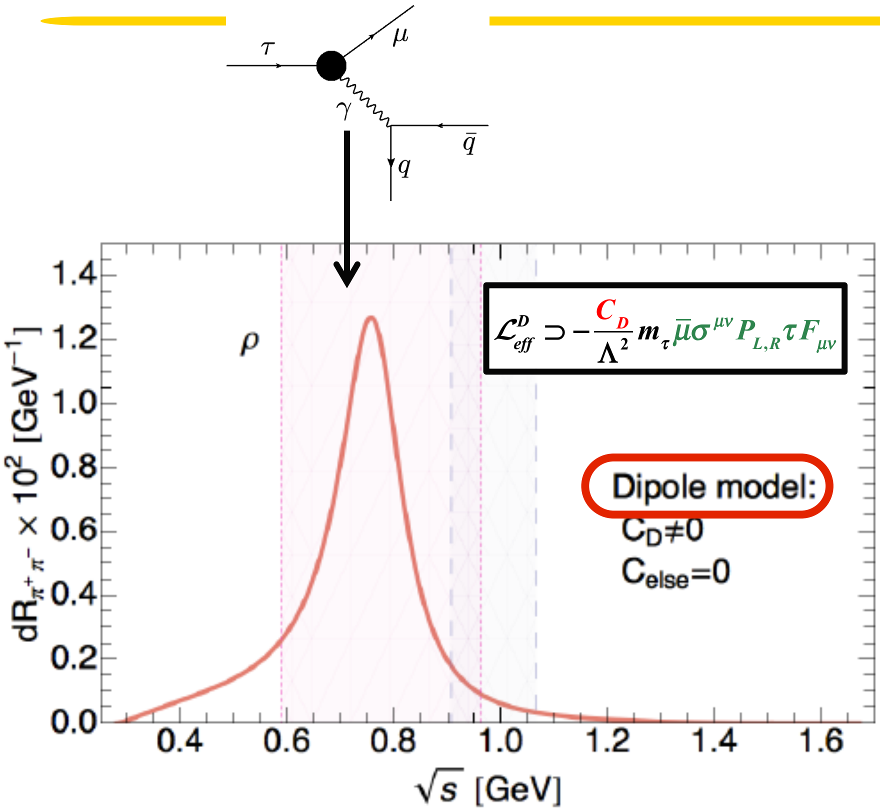
⇨ Disentangle the *underlying dynamics* of NP

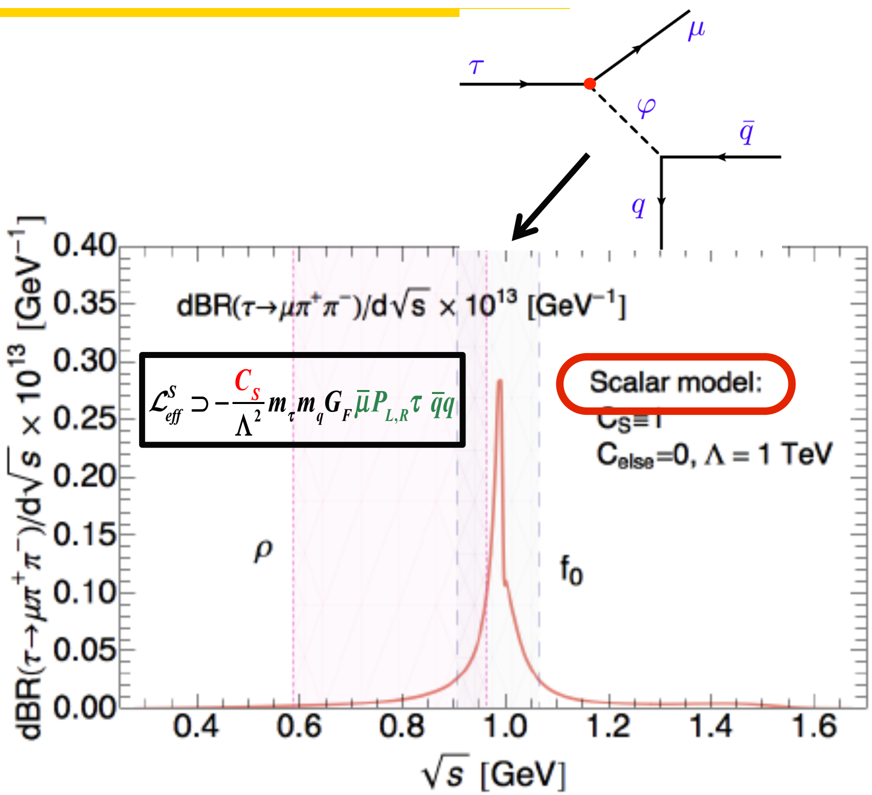
2.7 Discriminating power of $\tau \to \mu(e)\pi\pi$ decays

Celis, Cirigliano, E.P.'14

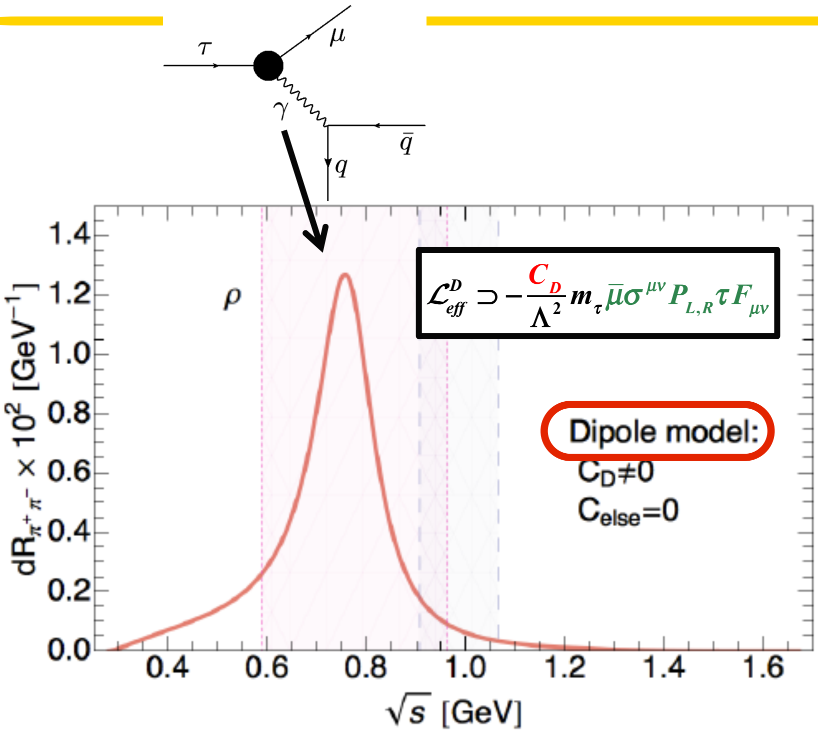


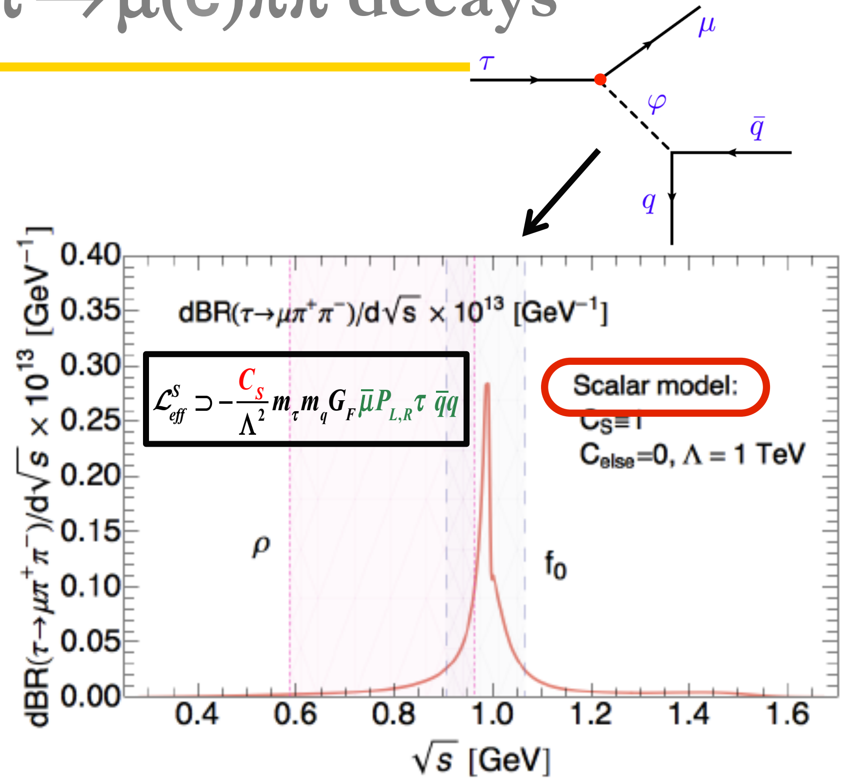
2.7 Discriminating power of τ→μ(e)ππ decays

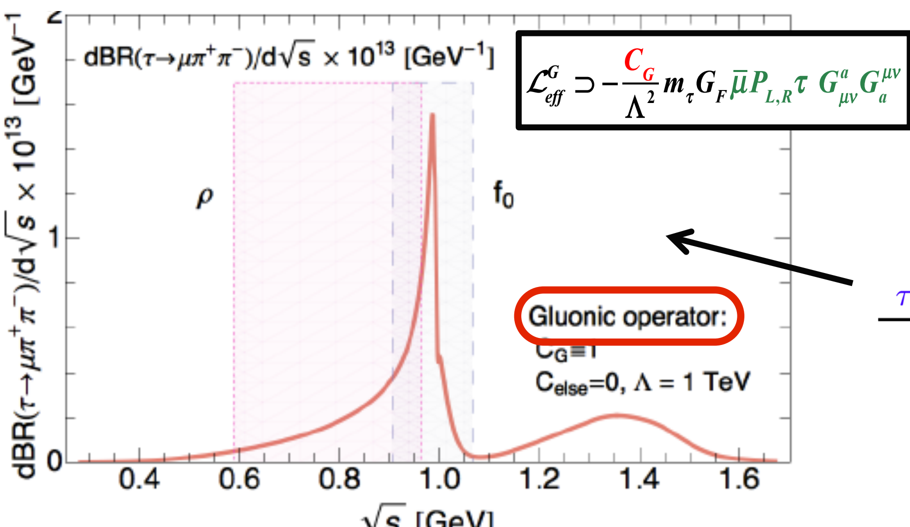


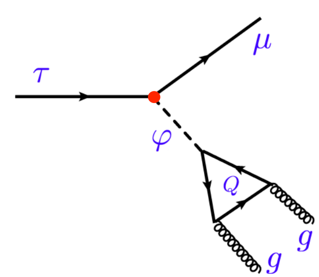


2.7 Discriminating power of τ→μ(e)ππ decays









Different distributions according to the *operator!*

3. Ex: Charged Lepton-Flavour Violation and Higgs Physics

3.1 Non standard LFV Higgs coupling

- $$\Delta\mathcal{L}_Y = -\frac{\lambda_{ij}}{\Lambda^2}\left(\bar{f}_L^i f_R^j H\right) H^\dagger H$$ ⇒ $$-Y_{ij}\left(\bar{f}_L^i f_R^j\right) h$$

In the SM: $Y_{ij}^{h_{SM}} = \frac{m_i}{\text{v}}\delta_{ij}$

Goudelis, Lebedev, Park'11
Davidson, Grenier'10
Harnik, Kopp, Zupan'12
Blankenburg, Ellis, Isidori'12
McKeen, Pospelov, Ritz'12
Arhrib, Cheng, Kong'12

$$\mathcal{L}_Y = -m_i \bar{f}_L^i f_R^i - h\left(Y_{e\mu}\bar{e}_L\mu_R + Y_{e\tau}\bar{e}_L\tau_R + Y_{\mu\tau}\bar{\mu}_L\tau_R\right) + \ldots$$

- Arise in several models *Cheng, Sher'97, Goudelis, Lebedev,Park'11*
  Davidson, Grenier'10

Cheng, Sher'97

- Order of magnitude expected ⇒ No tuning: $|Y_{\tau\mu}Y_{\mu\tau}| \lesssim \frac{m_\mu m_\tau}{v^2}$

- In concrete models, in general further parametrically suppressed

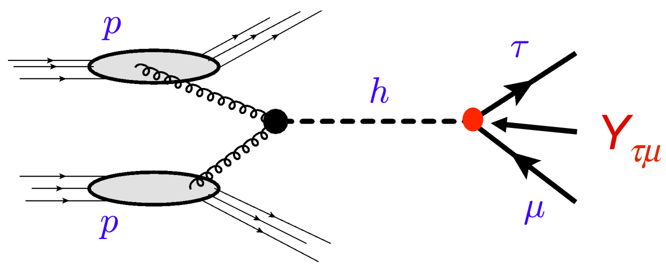
3.1 Non standard LFV Higgs coupling

- $$\Delta\mathcal{L}_Y = -\frac{\lambda_{ij}}{\Lambda^2}\left(\bar{f}_L^i f_R^j H\right) H^\dagger H$$ $\Rightarrow$ $$-Y_{ij}\left(\bar{f}_L^i f_R^j\right) h$$

In the SM: $Y_{ij}^{h_{SM}} = \frac{m_i}{v}\delta_{ij}$

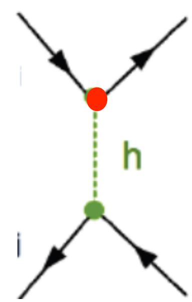
Goudelis, Lebedev, Park'11
Davidson, Grenier'10
Harnick, Koop, Zupan'12
Blankenburg, Ellis, Isidori'12
McKeen, Pospelov, Ritz'12
Arhrib, Cheng, Kong'12

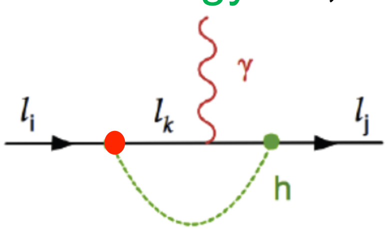
- High energy : LHC

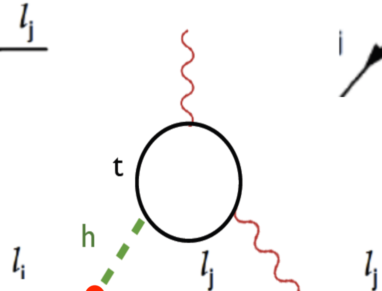


Hadronic part treated with perturbative QCD

- Low energy : D, S operators







3.1 Non standard LFV Higgs coupling

- $\Delta\mathcal{L}_Y = -\frac{\lambda_{ij}}{\Lambda^2}\left(\bar{f}_L^i f_R^j H\right) H^\dagger H$ ⇒ $-Y_{ij}\left(\bar{f}_L^i f_R^j\right) h$

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Goudelis, Lebedev, Park'11
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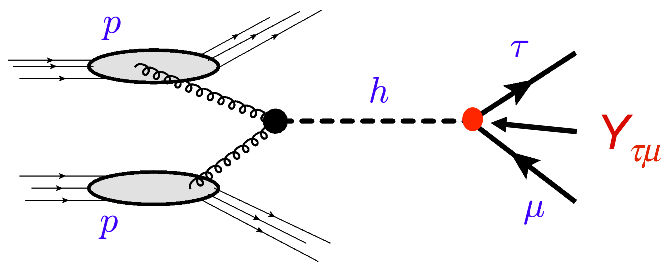
McKeen, Pospelov, Ritz'12
Arhrib, Cheng, Kong'12

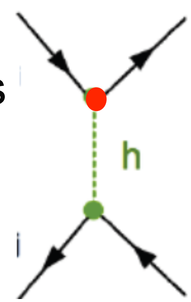
- High energy : LHC

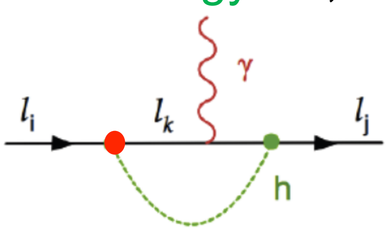


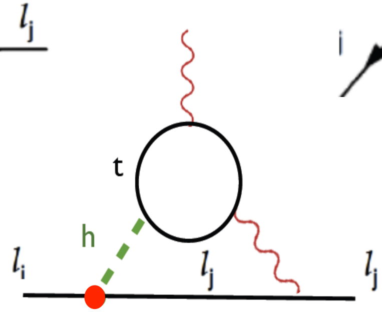
Hadronic part treated with perturbative QCD

Reverse the process

- Low energy : D, S, G operators







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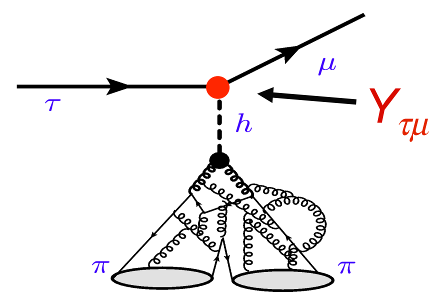
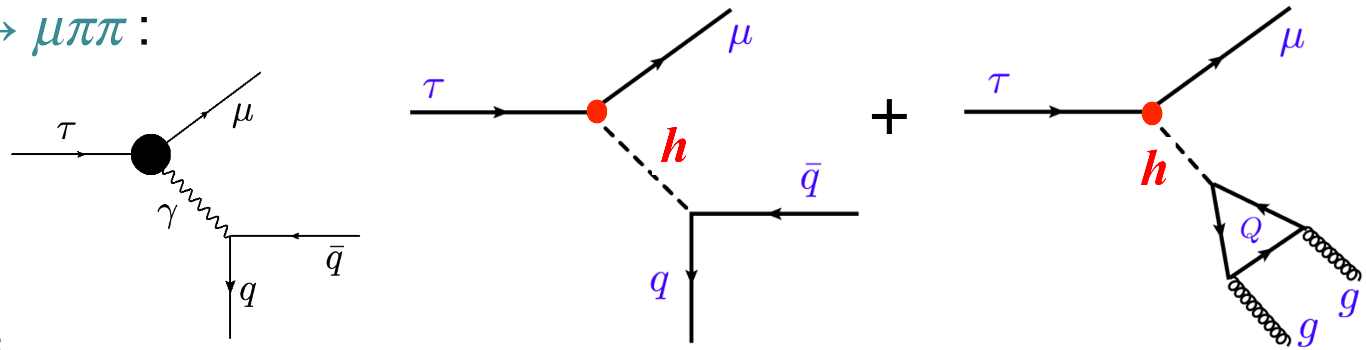
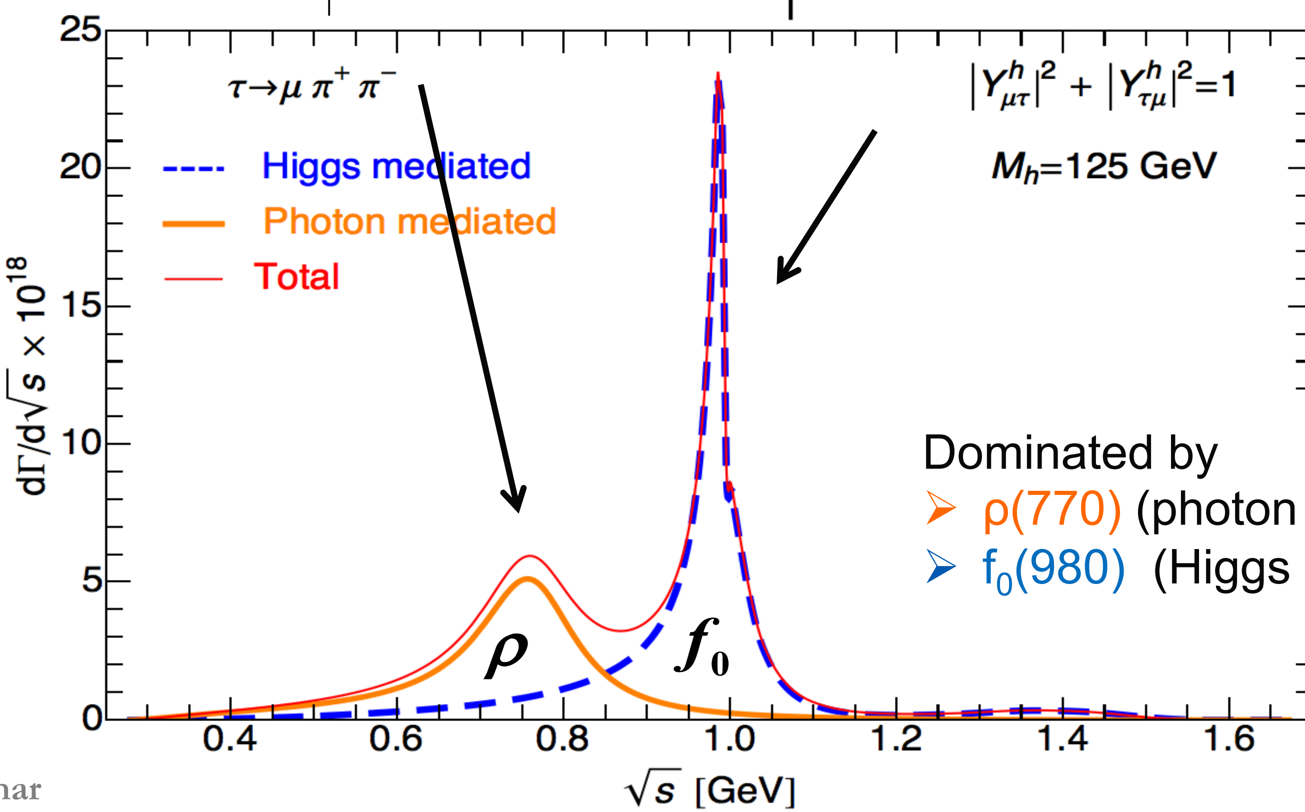


Hadronic part treated with non-perturbative QCD

3.2 Constraints in the τμ sector

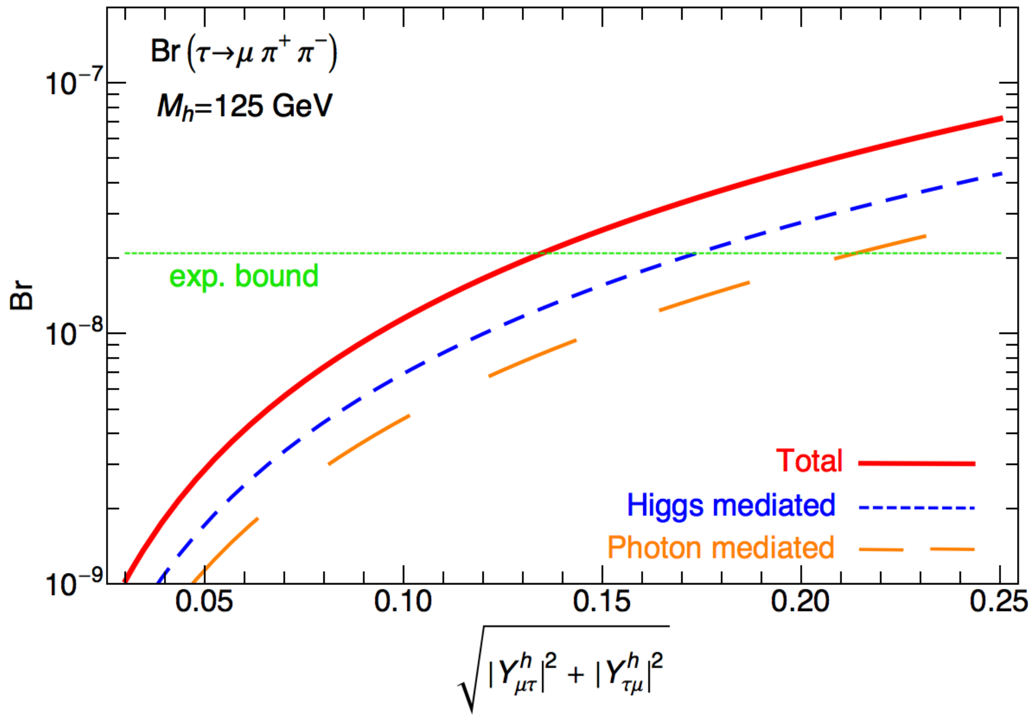
- At low energy
  - $\tau \to \mu\pi\pi$:





Dominated by
- ρ(770) (photon mediated)
- $f_0(980)$ (Higgs mediated)

3.2 Constraints in the τμ sector



Bound:

$$\sqrt{\left|Y^h_{\mu\tau}\right|^2 + \left|Y^h_{\tau\mu}\right|^2} \leq 0.13$$

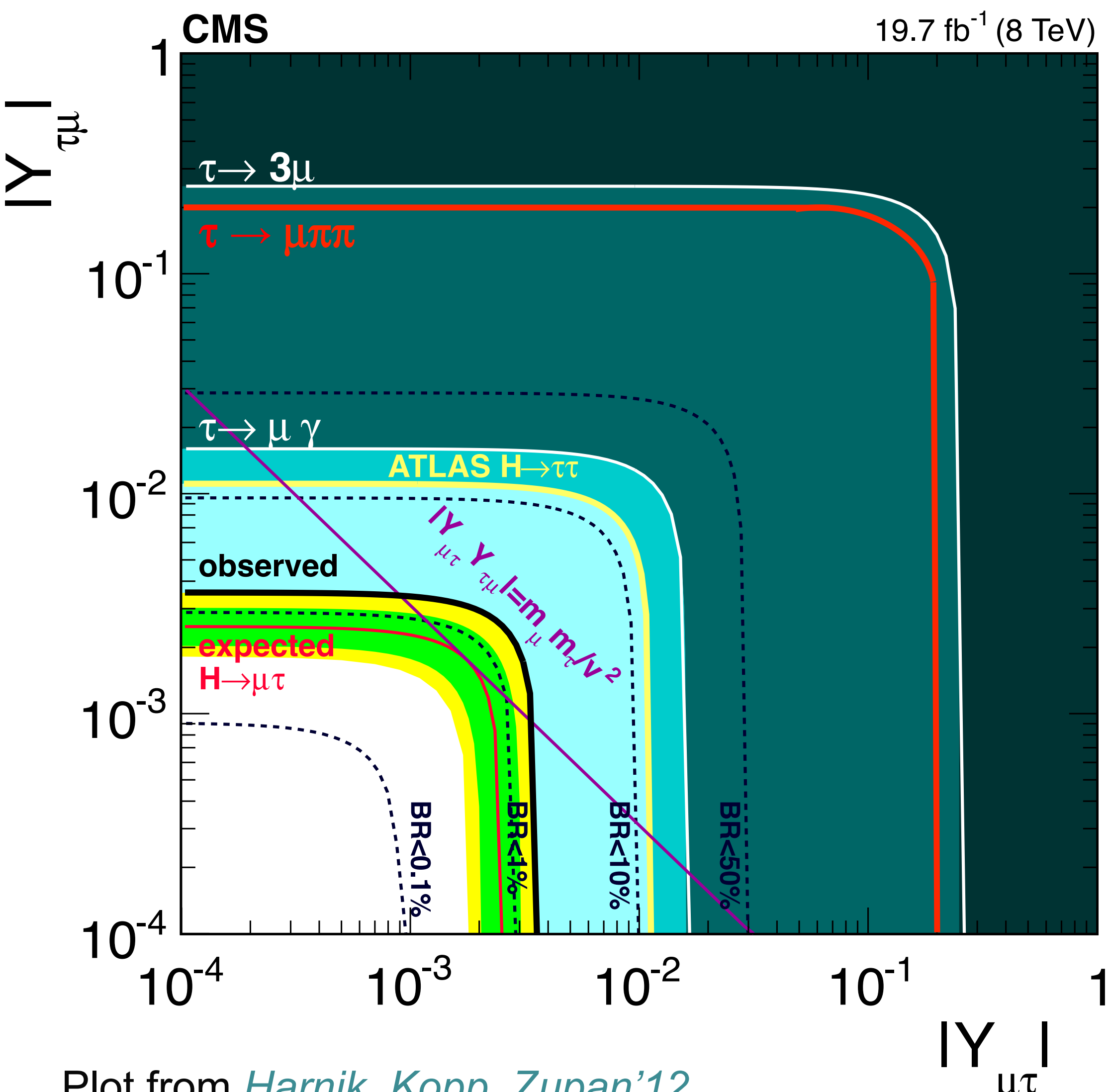
Process	(BR × 10^8) 90% CL	$\sqrt{\|Y^h_{\mu\tau}\|^2 + \|Y^h_{\tau\mu}\|^2}$	Operator(s)
$\tau \to \mu\gamma$	< 4.4 [88]	< 0.016	Dipole
$\tau \to \mu\mu\mu$	< 2.1 [89]	< 0.24	Dipole
$\tau \to \mu\pi^+\pi^-$	< 2.1 [86]	< 0.13	Scalar, Gluon, Dipole
$\tau \to \mu\rho$	< 1.2 [85]	< 0.13	Scalar, Gluon, Dipole
$\tau \to \mu\pi^0\pi^0$	< 1.4 × 10^3 [87]	< 6.3	Scalar, Gluon

Less stringent but more robust handle on LFV Higgs couplings

?

Belle'08'11'12 except last from *CLEO'97*

3.2 Constraints in the τμ sector



Plot from *Harnik, Kopp, Zupan'12* updated *by CMS'15*

- Constraints from LE:
  - $\tau \to \mu\gamma$: best constraints but loop level
    ➡ sensitive to UV completion of the theory
  - $\tau \to \mu\pi\pi$: tree level diagrams
    ➡ robust handle on LFV
- Constraints from HE: *LHC* wins for τμ!
- Opposite situation for μe!
- For LFV Higgs and nothing else: LHC bound

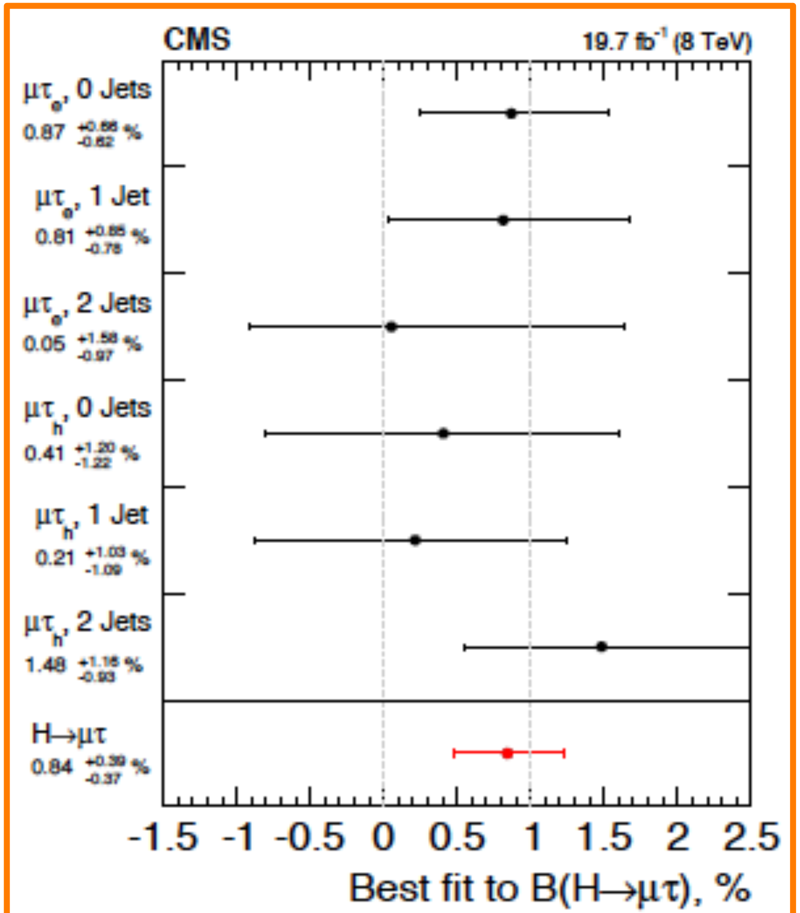
➡ $BR(\tau \to \mu\gamma) < 2.2 \times 10^{-9}$

$BR(\tau \to \mu\pi\pi) < 1.5 \times 10^{-11}$

3.3 Hint of New Physics in h → τμ?

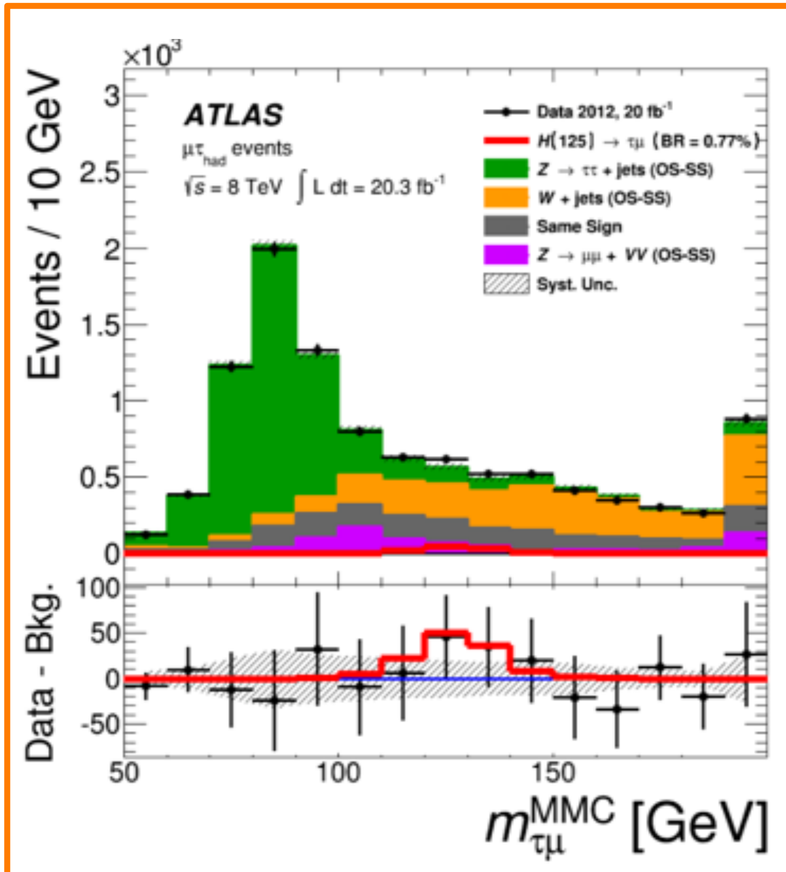
$BR(h \to \tau\mu) = (0.84^{+0.39}_{-0.37})\%$ @2.4σ

CMS'15



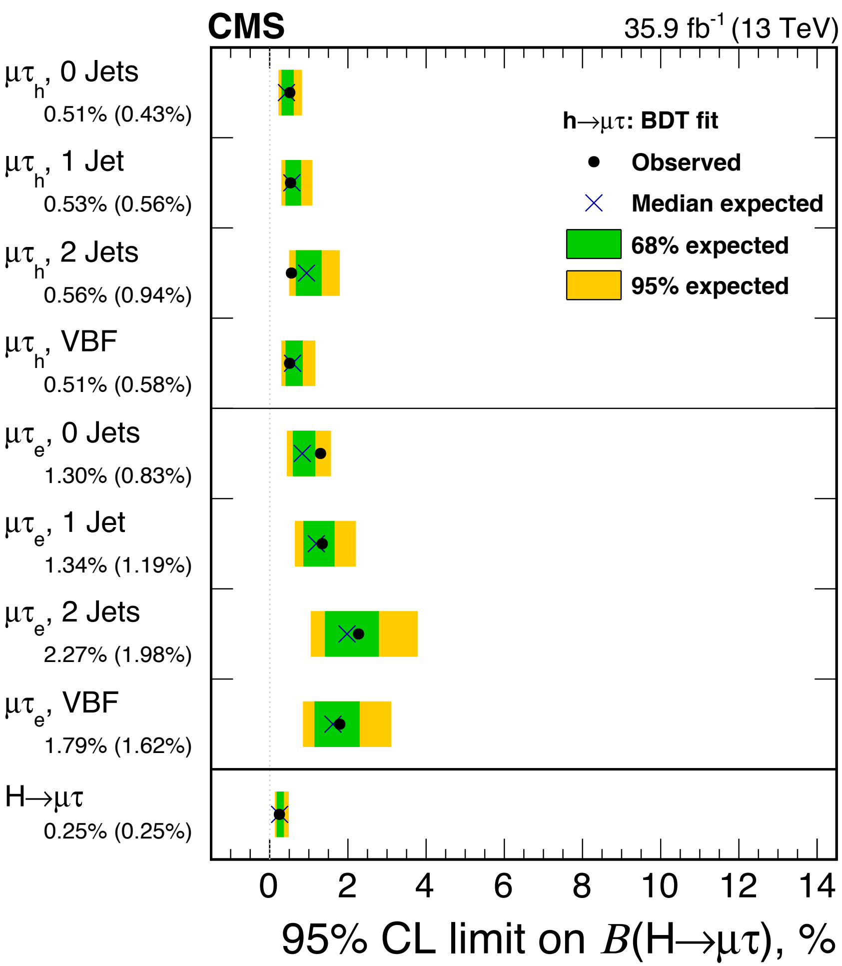
$BR(h \to \tau\mu) = (0.53 \pm 0.51)\%$ @1σ

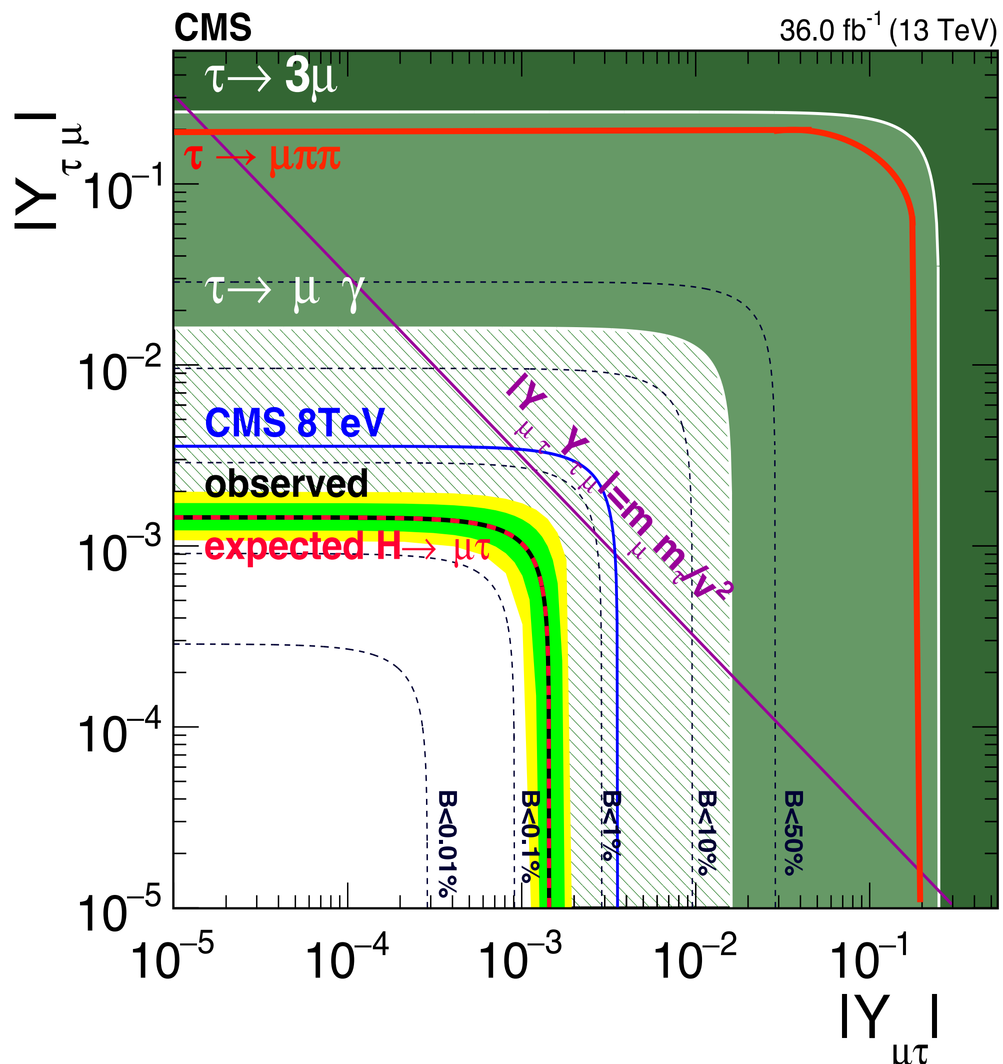
ATLAS'15



3.3 Hint of New Physics in $h \rightarrow \tau\mu$?

CMS'17

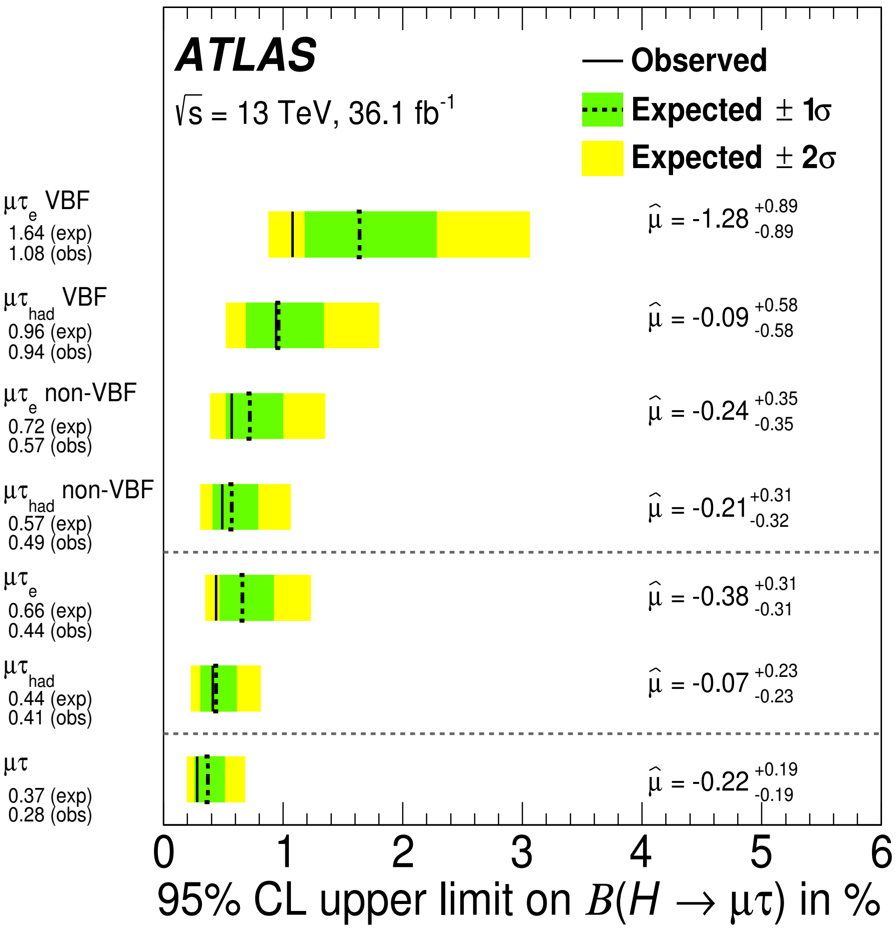


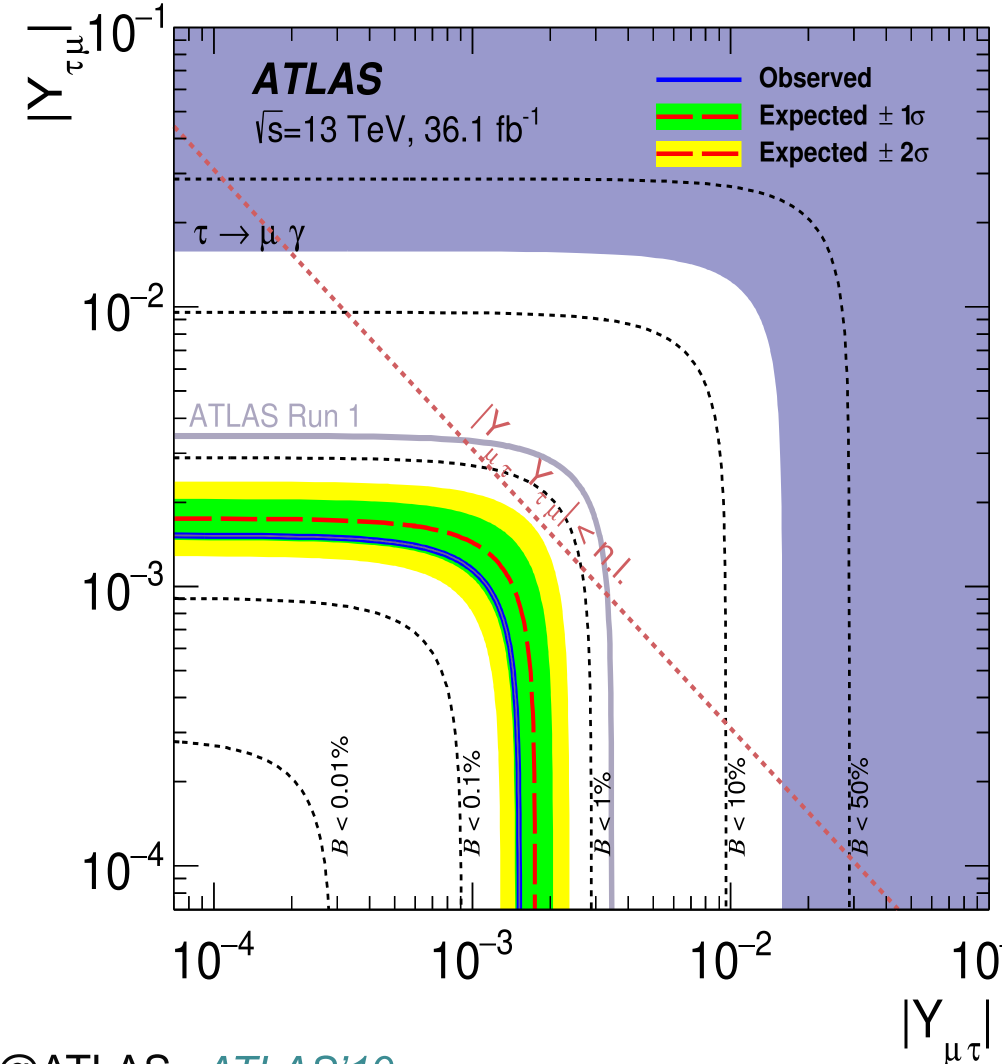


$\Rightarrow$ $BR(h \rightarrow \tau\mu) = (0.25 \pm 0.25)\%$ 13 TeV@CMS CMS'17

3.3 Hint of New Physics in h → τμ?

ATLAS'19



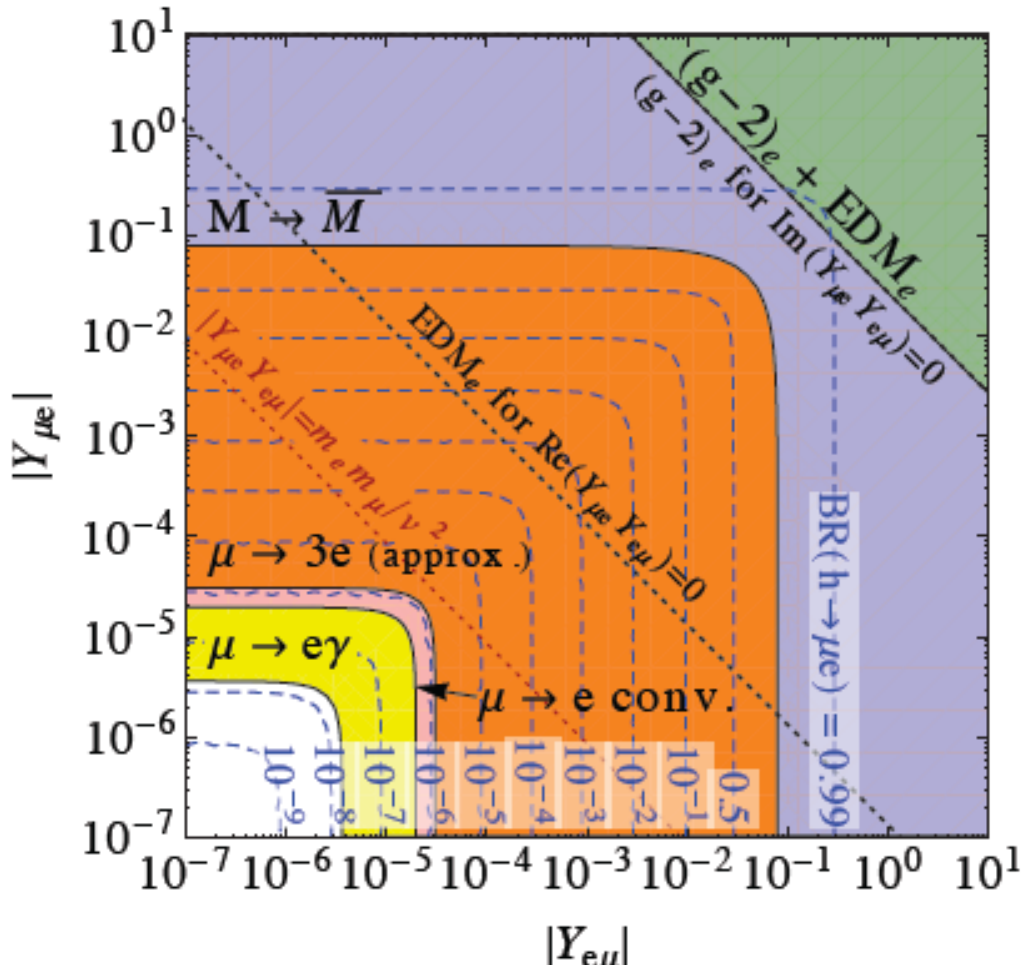


➡ $BR(h \to \tau\mu) \leq 0.28\%$ 13 TeV@ATLAS ATLAS'19

3.4 Constraints in the μe sector

- Constraints from Higgs decay (LHC) vs. low energy LFV and LFC observables

Harnik, Kopp, Zupan'12



- Best constraints coming from *low energy*: $\mu \to e\gamma$

MEG'13

$$BR(\mu \to e\gamma) < 5.7\ 10^{-13}$$

⇒ $BR(h \to \mu e) < 10^{-7}$

4. Conclusion and Outlook

Summary

- Direct searches for new physics at the TeV-scale at LHC by ATLAS and CMS ⇨ energy frontier

- Probing new physics orders of magnitude beyond that scale and helping to decipher possible TeV-scale new physics requires to work hard on the *intensity* and *precision frontiers*

- *Charged leptons* offer an important spectrum of possibilities:
  - ➢ LFV measurements have SM-free signal
  - ➢ Current experiments and mature proposals promise orders of magnitude sensitivity improvements
  - ➢ In addition to leptonic and radiative decays ⇨ hadronic decays important, e.g. $\tau \to \mu(e)\pi\pi, \mu N \to eN$
  - ➢ New physics models usually strongly correlate these sectors

Summary

- Direct searches for new physics at the TeV-scale at LHC by ATLAS and CMS ⇨ energy frontier

- Probing new physics orders of magnitude beyond that scale and helping to decipher possible TeV-scale new physics requires to work hard on the *intensity* and *precision frontiers*

- *Charged leptons* offer an important spectrum of possibilities:
  - We show how CLFV decays offer an excellent model discriminating tools giving indications on
    - the *mediator* (operator structure)
    - the *source of flavour breaking* (comparison $\tau\mu$ vs. τe vs. μe)

- Interplay low energy and collider physics: LFV of the Higgs boson

- Several experimental programs:
  MEG, Mu3e, COMET, *Mu2e*, *Belle II*, *BESIII, LHCb, LHC-HL*