LFV Higgs and Z-boson decays: a portal to new physics at the LHC

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Why Lepton Flavor Violation?

Neutral LFV observed in Neutrino Oscillations!!!

Neutrino Oscillations $\Longrightarrow$ BSM for neutrino masses

$$nLFV \xrightarrow{\text{New Neutrino Physics}} cLFV$$

LFV in the SM and beyond

- Forbidden in SM if theory renormalizable [R. Harnik *et al.*, JHEP03(2013)026].
- Occurs naturally in extended Higgs sectors without abandoning renormalizability [Bjorken, Weinberg, PLB38(1977)622].
- Also arises in BSM models: heavy neutrinos [Ilakovac, Pilaftsis, NPB437(1995)491], SUSY [Díaz-Cruz, Toscano, PRD62(2000)116005], composite Higgs boson [Agashe, Contino, PRD80(2009)075016], flavor symmetries [H. Ishimori *et al.*, arXiv:1003.3552], RS models [Pérez, Randall, JHEP01(2009)077]...
- If BSM particles heavier than 100 GeV, EFT can describe LFV interactions integrating out new heavy states [Bélusca-Maïto and Falkowski, EPJC76(2016)514]

Intense search program for cLFV

LFV transitions	LFV Present Bounds (90%CL)	Future Sensitivities
BR($\mu \to e\gamma$)	4.2×10^{-13} (MEG 2016)	6×10^{-14} (MEG-II)
BR($\tau \to e\gamma$)	3.3×10^{-8} (BABAR 2010)	10^{-9} (BELLE-II)
BR($\tau \to \mu\gamma$)	4.4×10^{-8} (BABAR 2010)	10^{-9} (BELLE-II)
BR($\mu \to eee$)	1.0×10^{-12} (SINDRUM 1988)	10^{-16} Mu3E (PSI)
BR($\tau \to eee$)	2.7×10^{-8} (BELLE 2010)	$10^{-9,-10}$ (BELLE-II)
BR($\tau \to \mu\mu\mu$)	2.1×10^{-8} (BELLE 2010)	$10^{-9,-10}$ (BELLE-II)
BR($\tau \to \mu\eta$)	2.3×10^{-8} (BELLE 2010)	$10^{-9,-10}$ (BELLE-II)
CR($\mu - e$, Au)	7.0×10^{-13} (SINDRUM II 2006)	
CR($\mu - e$, Ti)	4.3×10^{-12} (SINDRUM II 2004)	10^{-18} PRISM (J-PARC)
CR($\mu - e$, Al)		3.1×10^{-15} COMET-I (J-PARC)
		2.6×10^{-17} COMET-II (J-PARC)
		2.5×10^{-17} Mu2E (Fermilab)

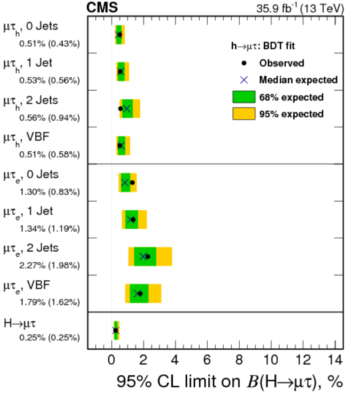
Bounds on	LEP(95%CL)	ATLAS(95%CL)	CMS(95%CL)
BR($Z \to \mu e$)	1.7×10^{-6}	7.5×10^{-7} PRD90(2014)072010	
BR($Z \to \tau e$)	9.8×10^{-6}	5.8×10^{-5} arXiv:1804.09568	
BR($Z \to \tau\mu$)	1.2×10^{-5}	1.3×10^{-5} arXiv:1804.09568	
BR($H \to \mu e$)	-		3.5×10^{-4} PLB763(2016)472
BR($H \to \tau e$)	-	1.04×10^{-2} EPJC77(2017)70	6.1×10^{-3} arXiv:1712.07173
BR($H \to \tau\mu$)	-	1.43×10^{-2} EPJC77(2017)70	2.5×10^{-3} arXiv:1712.07173

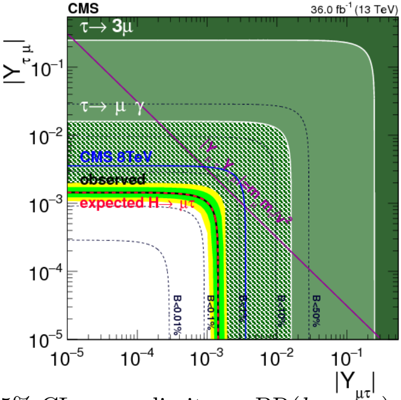
CMS found 2.4σ excess: $\mathrm{BR}(H \to \tau\mu) = 0.84^{+0.39}_{-0.37}\%$ (95% C.L.) [PLB749(2015)337]

ATLAS found 1.3σ excess: $\mathrm{BR}(H \to \tau\mu) = 0.77 \pm 0.62\%$ (95% C.L.) [arXiv:1508.03372]

2.3σ excess: $\mathrm{BR}(Z \to \tau e) = (3.3^{+1.5}_{-1.4}) \times 10^{-5}$ (95% C.L.) [arXiv:1804.09568]

Focus on LFV Higgs and Z-boson decays at the LHC

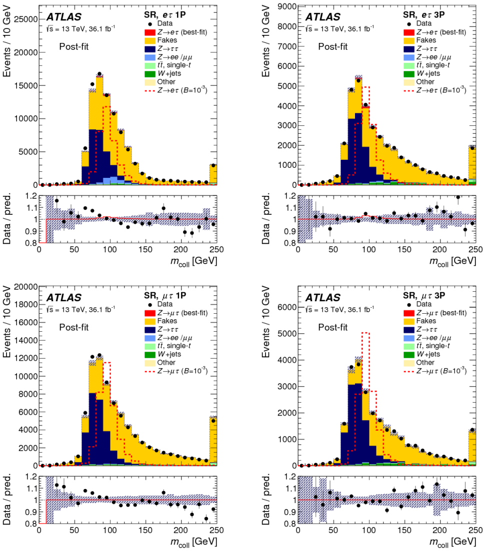




- Left panel: Observed and expected 95% CL upper limits on $\mathrm{BR}(h \to \tau\mu)$ for each individual category and combined by BDT fit analysis. No excess over background expectation is observed, excluding 2.4σ excess at 8 TeV.
- Right panel: Constraints on $\mathrm{BR}(h \to \tau\mu)$ interpreted in terms of tree-level LFV Yukawa couplings derived from BDT analysis:

$$\sqrt{|Y_{\mu\tau}|^2 + |Y_{\tau\mu}|^2} < 1.43 \times 10^{-3}\,.$$

LHC searches for LFV Z-boson decays



- m_{coll}: invariant mass of ℓ-$\tau_{\text{had-vis}}$-ν system, where ν comes from τ decay, assumed to have momentum equal in transverse plane to measured E_T^{miss} and collinear in η with τ candidate.
- Best fit value $\text{BR}(Z \to \mu\tau) = (-0.1)^{+1.2}_{-1.2} \times 10^{-5}$ consistent with zero.
- $\text{BR}(Z \to e\tau) = (3.3)^{+1.5}_{-1.4} \times 10^{-5}$ slightly fluctuating to positive values.
- Exclusion upper limits using CL_S method are set:
  $\text{BR}(Z \to e\tau) < 5.8 \times 10^{-5}$ and
  $\text{BR}(Z \to \mu\tau) < 2.4 \times 10^{-5}$.
- 2.3σ excess significance in $e\tau$ channel.
- Combination with 8-TeV analysis set $\text{BR}(Z \to \mu\tau) < 1.3 \times 10^{-5}$.

Some theoretical predictions...

LFV Higgs and Z decays from heavy neutrino loops

Type-I seesaw model

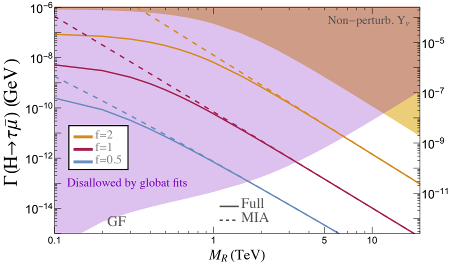
$$\left.\begin{array}{l} M \sim 1\text{ TeV} \Rightarrow Y_\nu \ll 1 \\ Y_\nu \sim 1 \Rightarrow M \sim 10^{14}\text{ GeV} \end{array}\right\} \begin{array}{c}\text{Suppressed}\\ \text{Pheno}\end{array}$$

Low-scale seesaw models

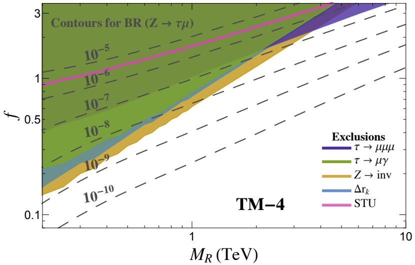
$$\left.\begin{array}{l} M \sim 1\text{ TeV} \\ Y_\nu \sim 1 \end{array}\right\} \begin{array}{c}\text{Enhanced}\\ \text{Pheno}\end{array}$$

- Maximum rates: $\mathrm{BR}(H \to \tau\mu) \sim 10^{-8}$ and $\mathrm{BR}(Z \to \tau\mu) \sim 10^{-7}$.
- Similar results for τ-e transitions.
- $H(Z) \to \mu e$ even more constrained by $\mu \to e\gamma$ and $\mu \to eee$.
- If ATLAS and CMS excesses confirmed, seesaw models cannot account for these LFV rates.

[Arganda *et al.*, PRD95(2017)095029]

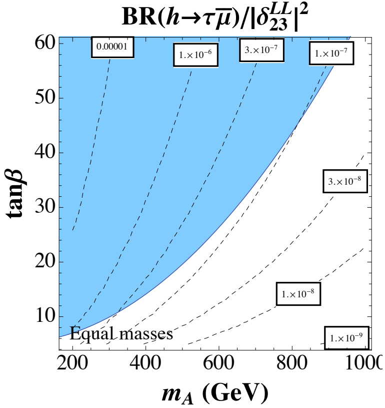


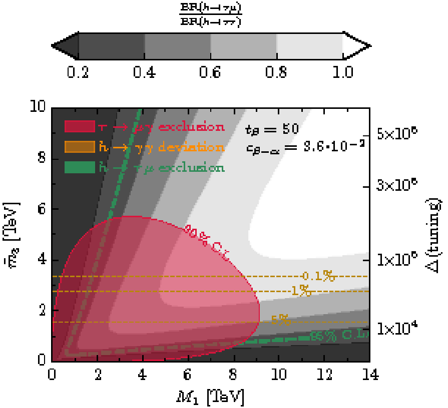
[Herrero *et al.*, PRD95(2017)075028]



LFV Higgs decays from slepton loops in the MSSM

[Arganda *et al.*, JHEP1603(2016)055] [Nir *et al.*, JHEP1604(2016)162]

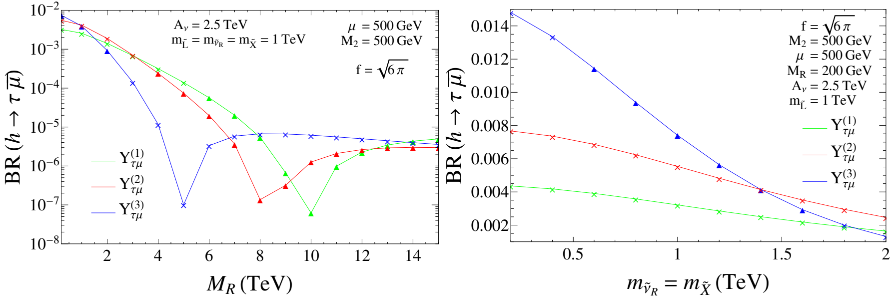




- Left panel: $M_{\mathrm{SUSY}} = 4$ TeV to ensure agreement with $\tau \to \mu\gamma$. Largest rates of $\mathcal{O}(10^{-7})$ out of the reach of the LHC.
- Right panel: if ATLAS and CMS had established that $R_{\tau\mu/\tau\tau} \lesssim 0.01$, the R-parity conserving MSSM would have been excluded.

LFV Higgs decays from slepton/sneutrino loops in supersymmetric low-scale seesaw models

[Arganda *et al.*, PRD93(2016)055010]



- $\times$: excluded by $\tau \to \mu\gamma$. ▲: allowed.
- Different behavior as a function of the seesaw and SUSY scale if it is dominated by chargino or neutralino loops.
- $\text{BR}(h \to \tau\mu) \sim 10^{-2}$ allowed by LFV radiative decays.
- **Possible explanation of the CMS and ATLAS excess.**

Conclusions

LFV Higgs and Z-boson decays are clear evidence of new physics and/or powerful tools to discriminate among BSM models in competition

- Seesaw models cannot account by themselves for LFV rates larger than 10^{-8}-10^{-7} (not testable at the LHC). If ATLAS and CMS excesses on $h \to \tau\mu$ confirmed, no low-scale seesaw model can be responsible for this LFV.
- MSSM excluded if $h \to \tau\mu$ had been established at the percent level.
- Supersymmetric realizations of seesaw models can give rise to large LFV Higgs boson decay rates allowed by data.
- 2HDM can accommodate large LFVHD in agreement with th/exp constraints, including muon g-2 [Omura *et al.*, PRD94(2016)055019].
- Constraints allow sizable rates in EFT for $h \to \tau\mu$ and $h \to \tau e$, but not simultaneously large [Bélusca-Maïto and Falkowski, EPJC76(2016)514].