LFV 2015 and New Physics

Avelino Vicente
Université de Liège

WIN 2015
MPIK Heidelberg

Introduction

Before the LHC started operating we all hoped for great discoveries...

LHC expectations

LHC results...

Flavor as the road to new physics

The high-energy frontier has brought us the Higgs boson...
but nothing else

Perhaps it is time to explore the high-intensity frontier

$\Longrightarrow$ Flavor physics

Why do we care about LFV?

The observation of LFV [with charged leptons] would be a clear signal of (non-trivial) physics beyond the Standard Model

In fact, most BSM models predict large LFV rates

$$\mathcal{O} = \frac{c_{e\mu}}{\Lambda^2}\,\bar{\mu}e\bar{e}e \quad \Rightarrow \quad \frac{\Lambda}{\sqrt{c_{e\mu}}} \gtrsim 100\,\text{TeV}$$

"The flavor problem"

Why do we care about LFV?

Great experimental perspectives!

LFV Process	Present Bound	Future Sensitivity
$\mu \to e\gamma$	5.7×10^{-13}	6×10^{-14} (MEG)
$\tau \to e\gamma$	3.3×10^{-8}	$\sim 10^{-8} - 10^{-9}$ (B factories)
$\tau \to \mu\gamma$	4.4×10^{-8}	$\sim 10^{-8} - 10^{-9}$ (B factories)
$\mu \to 3e$	1.0×10^{-12}	$\sim 10^{-16}$ (Mu3e)
$\tau \to 3e$	2.7×10^{-8}	$\sim 10^{-9} - 10^{-10}$ (B factories)
$\tau \to 3\mu$	2.1×10^{-8}	$\sim 10^{-9} - 10^{-10}$ (B factories)
μ^-, Au $\to e^-$, Au	7.0×10^{-13}	—
μ^-, SiC $\to e^-$, SiC	—	2×10^{-14} (DeeMe)
μ^-, Al $\to e^-$, Al	—	$10^{-15} - 10^{-17}$ (COMET) $10^{-17} - 10^{-18}$ (Mu2e)
μ^-, Ti $\to e^-$, Ti	4.3×10^{-12}	$\sim 10^{-18}$ (PRISM/PRIME)

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See talks by
Papa and Litchfield

Outline

LFV 2015

(and a little from 2014)

- LFV in low-scale seesaw models
- Higgs LFV decays
- LFV in B meson decays

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Note:
I will not cover the anomaly in R(D*) [not related to LFV]

LFV in low-scale seesaw models

Where lepton physicists meet other lepton physicists

Low-scale seesaw models

[Mohapatra, Valle, 1986]

The Inverse Seesaw

$$-\mathcal{L}_{IS} \supset Y_\nu^{ij} \nu_i^c L_j \tilde{H} + M_{R_{ij}} \nu_i^c S_j + \frac{1}{2} \mu_{S_{ij}} S_i S_j$$

6 additional singlet states: 3 generations of ν^c and 3 generations of S

However, more minimal models are also possible
[Malinsky et al, 2009; Hirsch et al, 2010; Bhupal Dev, Pilaftsis, 2012]

Neutrino masses

[Gonzalez-Garcia, Valle, 1989]

$$\mathcal{M} = \begin{pmatrix} 0 & \frac{1}{\sqrt{2}} Y_\nu^T v & 0 \\ \frac{1}{\sqrt{2}} Y_\nu v & 0 & M_R \\ 0 & M_R^T & \mu_S \end{pmatrix}$$

- Non-zero neutrino masses. In the limit $\mu_S \ll Y_\nu v \ll M_R$:

$$m_\nu \simeq \frac{v^2}{2} Y_\nu^T (M_R^T)^{-1} \mu_S M_R^{-1} Y_\nu$$

- The suppression by μ_S allows to have $Y_\nu \sim \mathcal{O}(1)$ and, at the same time, light singlets.
- Technically natural in the 't Hooft sense: $\mu_S \to 0$ restores lepton number.

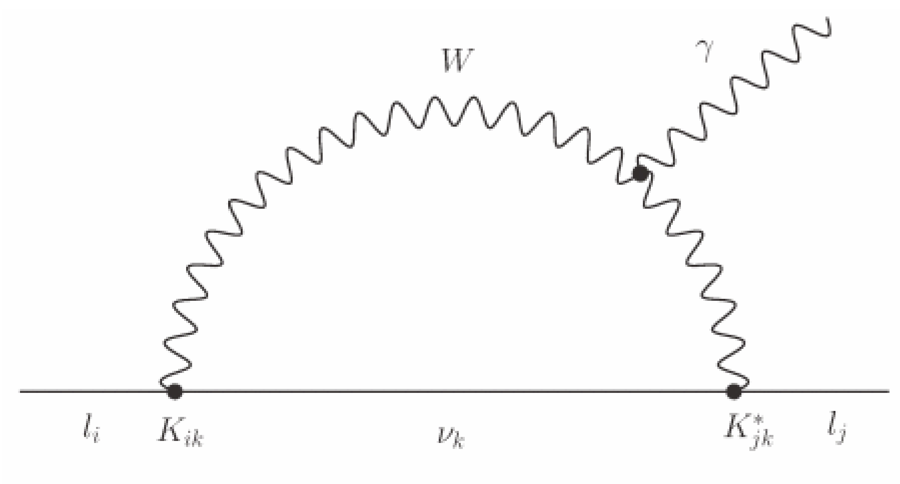
Penguins in the inverse seesaw

[Ilakovac, Pilaftsis, 1995; Deppisch, Valle, 2005]

$$\mathrm{Br}(\mu \to e\gamma) = \frac{\alpha_W^3 s_W^2 m_\mu^5}{256\pi^2 m_W^4 \Gamma_\mu} \left| \sum_k K_{ek} K_{\mu k}^* G_\gamma \left(\frac{m_{\nu k}^2}{m_W^2} \right) \right|^2$$

$$\mathrm{Br}(\mu \to e\gamma)_{\mathrm{MEG}} < 5.7 \cdot 10^{-13}$$

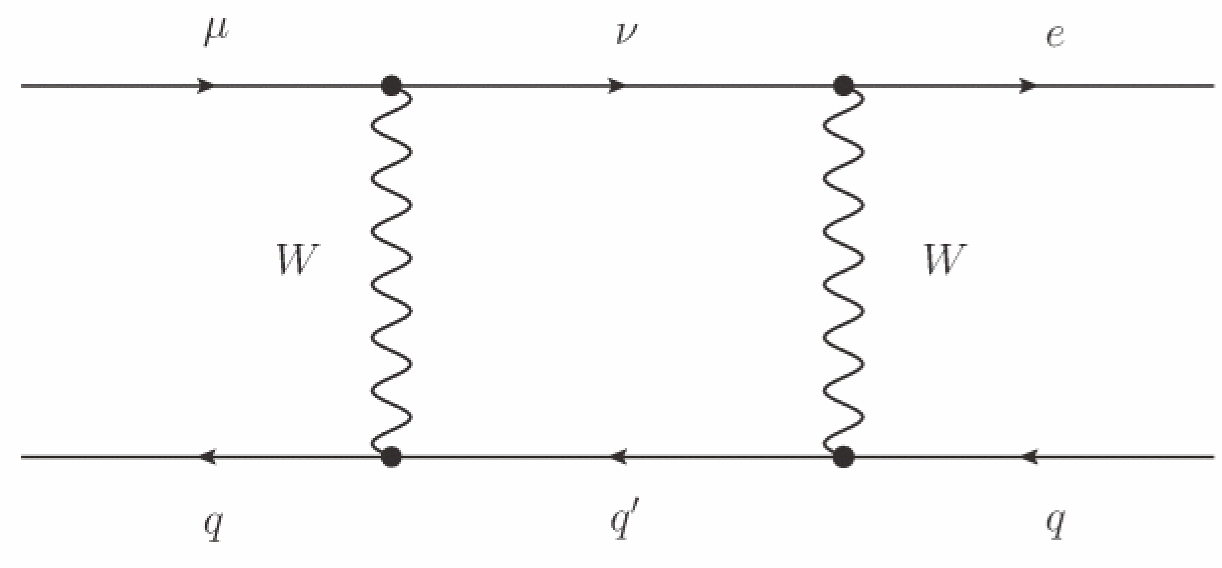
MEG limit
1303.0754



The GIM suppression is spoiled by the sterile neutrinos

Boxes in the inverse seesaw

Furthermore, for $\mu - e$ conversion in nuclei and $\ell_i \to 3\,\ell_j$ ...



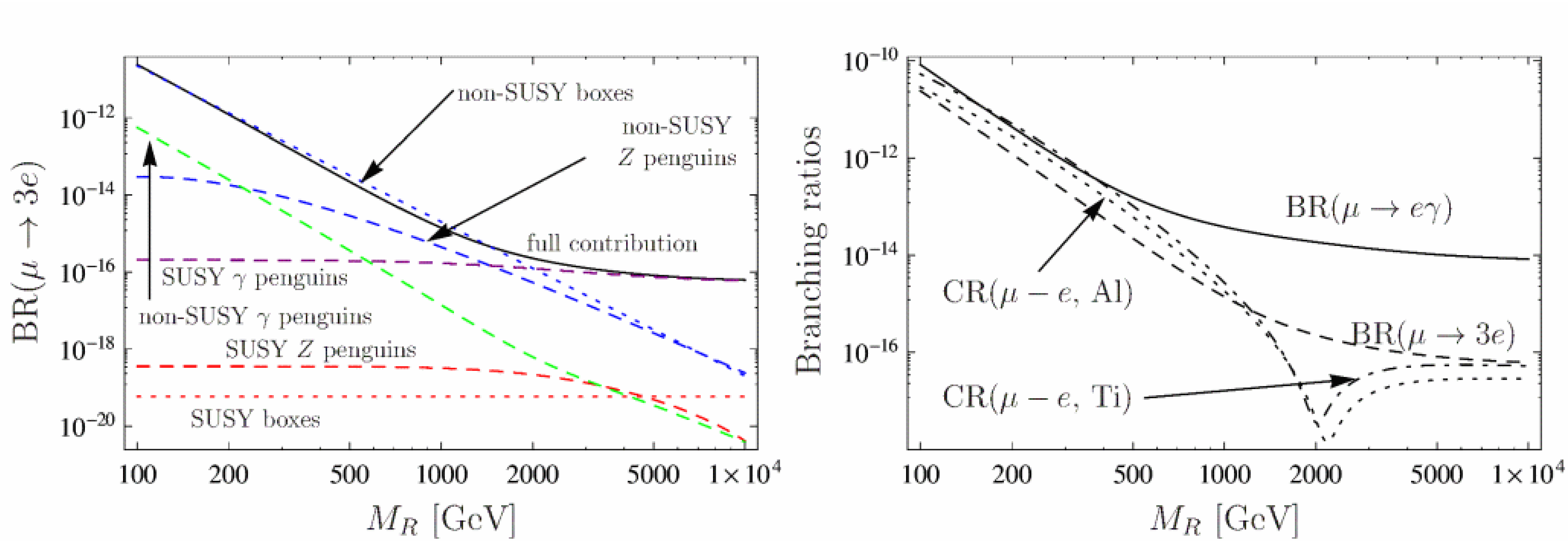
[Ilakovac, Pilaftsis, 2009; Dinh, Ibarra, Molinaro, Petcov, 2012; Alonso, Dhen, Gavela, Hambye, 2013; Ilakovac, Pilaftsis, Popov, 2012]

- Non-supersymmetric contribution
- Relevant for light singlet neutrinos
- Large non-dipole contributions

Low-scale seesaw models

[Abada, Krauss, Porod, Staub, AV, Weiland, 2014]

75 pages paper
First complete study of all SUSY and non-SUSY contributions!



[Same behavior for τ's]

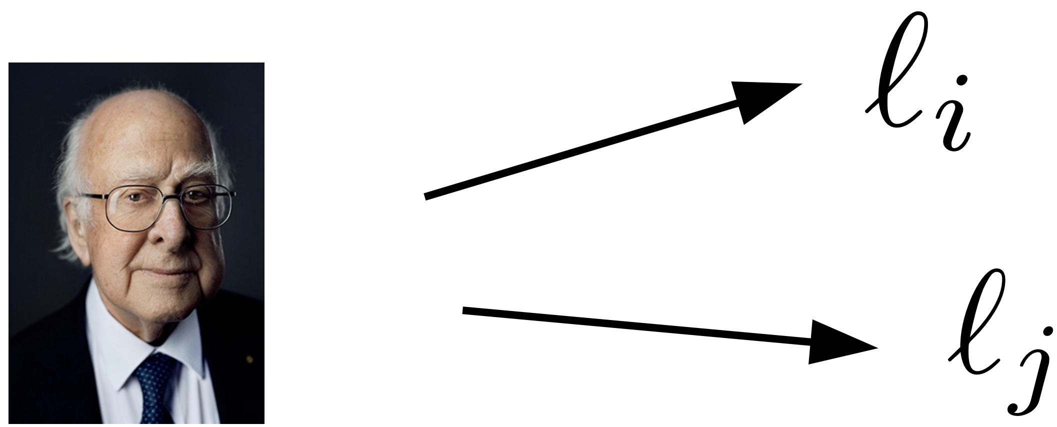
The dipole dominance is broken for low RH neutrino masses

Higgs LFV decays

Where lepton physicists meet collider physicists

Higgs LFV decays

We have discovered the Higgs
However, is there room for non-standard decays?



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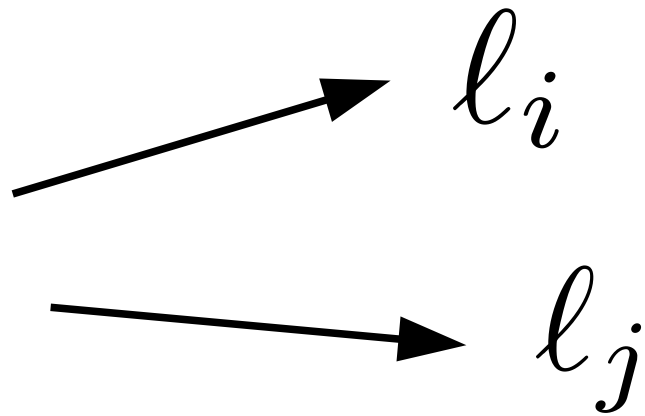

Popular BSM signature: [Blankenburg et al, 2013; Harnik et al, 2013]

LHC sensitivity: $\mathrm{Br} \sim 10^{-3}$ [Davidson, Verdier, 2012]

$20 fb^{-1}$ at $\sqrt{s} = 8\,\mathrm{TeV}$

Early works: [Pilaftsis, 1992; Diaz-Cruz, Toscano, 2000]

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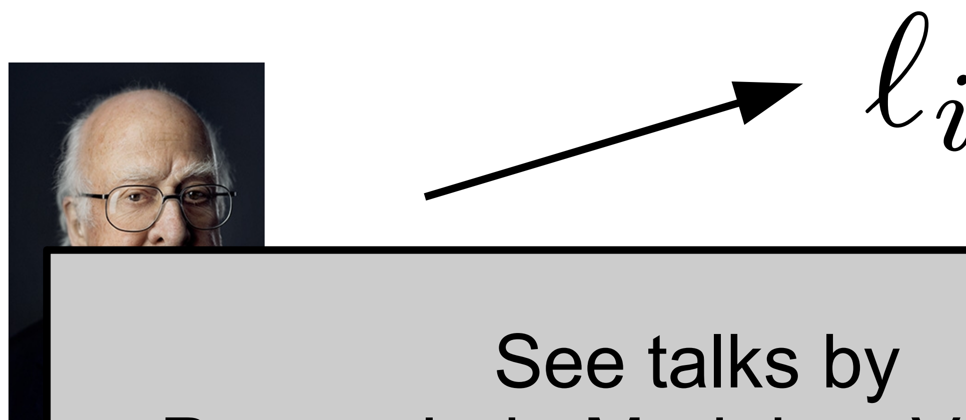

See talks by
Pomarol, de Medeiros Varzielas, Jessop, Dery, Schumacher and Heeck

Popular BSM sign]

LHC sensitivity:

$20 fb^{-1}$ at $\sqrt{s} = 8$ TeV

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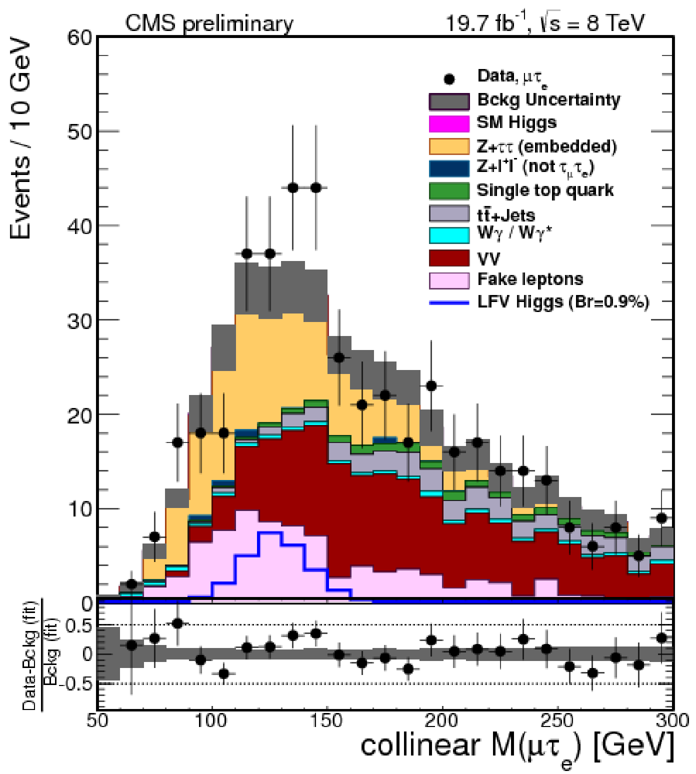
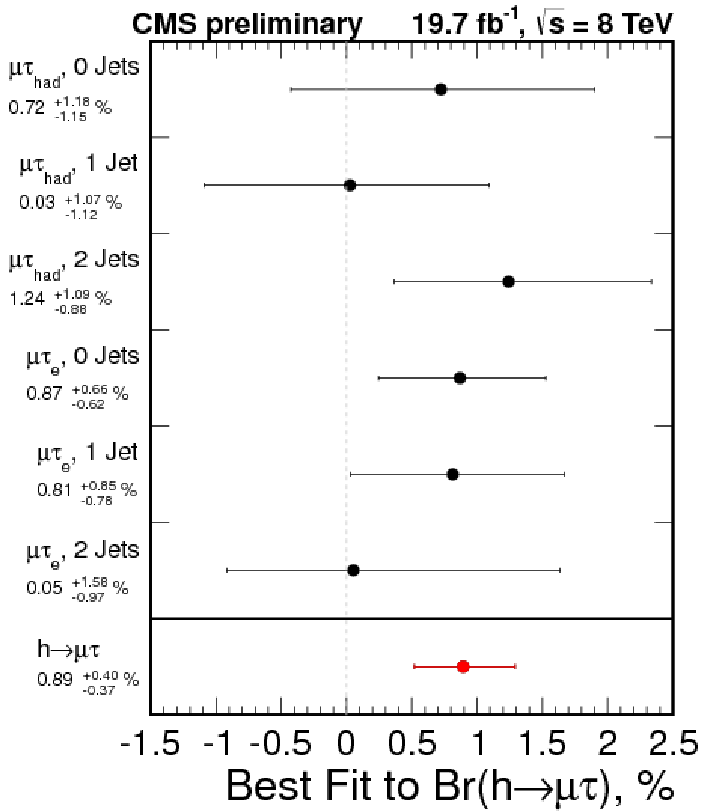
A hint from CMS?

A 2.5σ excess in $h \to \tau\mu$

[CMS-PAS-HIG-14-005, July 2014]

See recent update [arXiv:1502.07400]





$$\mathrm{BR}(h \to \tau\mu) = (0.89^{+0.40}_{-0.37})\%$$

A hint from CMS?

$$\boxed{\mathrm{BR}(h \to \tau\mu) = (0.89^{+0.40}_{-0.37})\%}$$

- Large LFV branching ratio

$$\mathrm{BR}(h \to \tau\bar{\tau})_{\mathrm{SM}} \sim 6\%$$

- Needs more statistics and confirmation from ATLAS
- If taken seriously, any model?

Any model?

DO OR DO NOT
THERE
IS NO
TRY

Flavor constraints seem to preclude any explanation for the CMS excess...

MSSM [Arana-Catania et al, 2013] $\text{BR}(h \to \tau\mu) \lesssim 10^{-4}$

RPV Supersymmetry [Arhrib et al, 2013] $\text{BR}(h \to \tau\mu) \lesssim 10^{-5}$

Vector-like leptons [Falkowski et al, 2014] $\text{BR}(h \to \tau\mu) \lesssim 10^{-5}$

Inverse Seesaw [Arganda et al, 2014] $\text{BR}(h \to \tau\mu) \lesssim 10^{-5}$

No hope?

Vector-like leptons

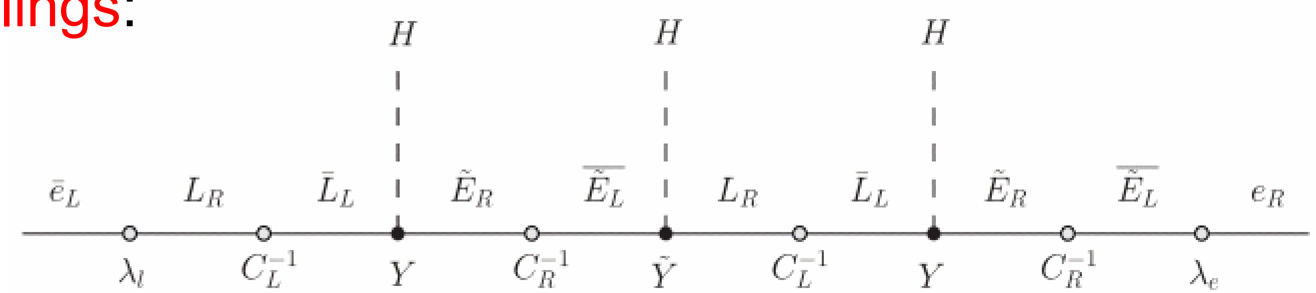
[Falkowski, Straub, AV, 2014]

Model with vector-like leptons
"Composite Higgs inspired"

$$\mathcal{L}_{F,c} = -M\left(\bar{L}C_L L + \tilde{E}C_R\tilde{E}\right) - \left(\bar{L}_L Y \tilde{E}_R H + \bar{L}_R \tilde{Y}\tilde{E}_L H + \text{h.c.}\right)$$

$$\mathcal{L}_{\text{mix}} = M\left(\bar{l}_L \lambda_l L_R + \tilde{E}_L \lambda_e e_R\right) + \text{h.c.}$$

Higgs LFV couplings:

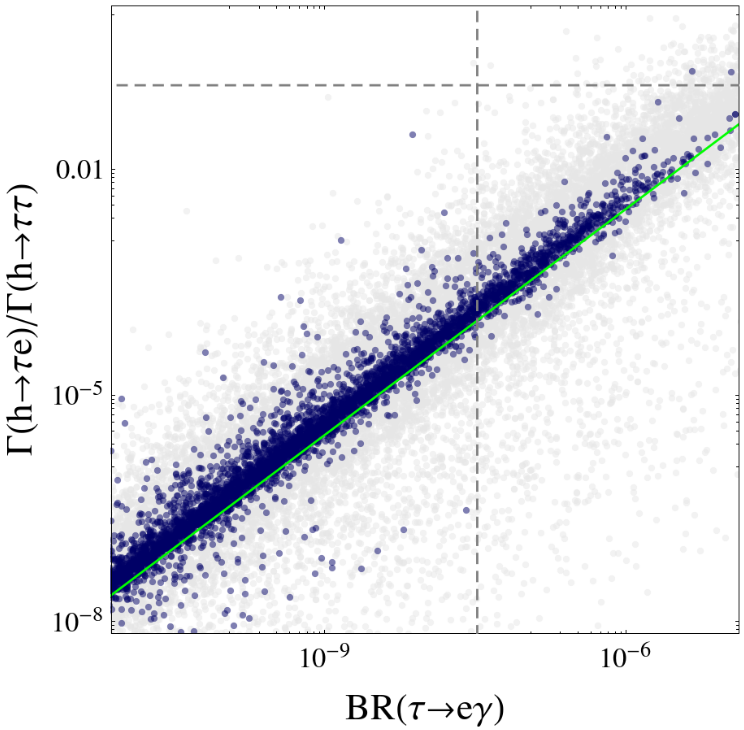


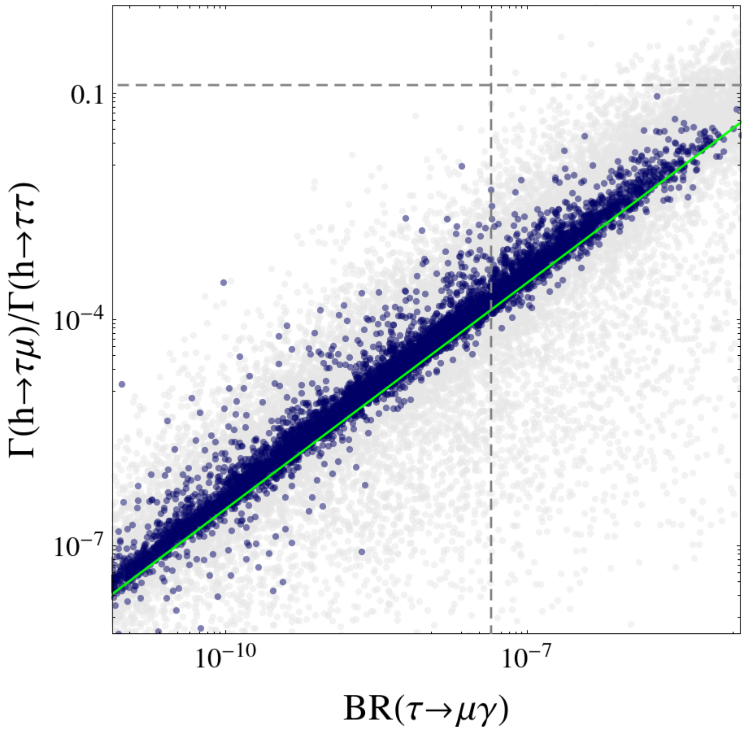
$$\mathcal{L}_{\text{eff}} = -\frac{h}{\sqrt{2}}\bar{e}_L c_{\text{eff}} e_R + \text{h.c.} \qquad c_{\text{eff}} = Y_{\text{eff}} + \frac{v^2}{M^2}\lambda_l C_L^{-1} Y C_R^{-1}\tilde{Y} C_L^{-1} Y C_R^{-1}\lambda_e$$

Vector-like leptons

[Falkowski, Straub, AV, 2014]

$\Rightarrow \text{BR's} \lesssim 10^{-5}$



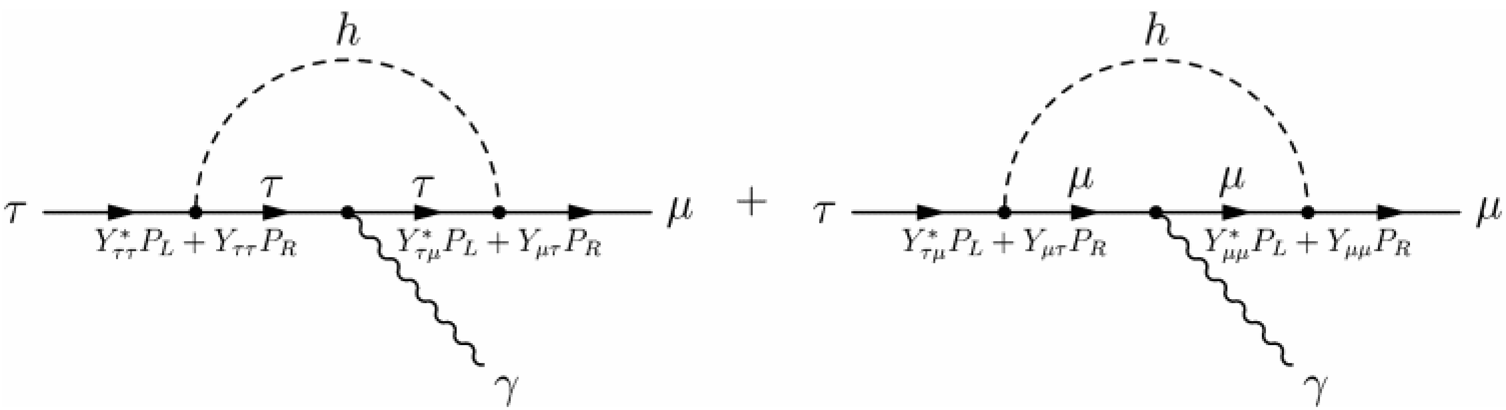


Unfortunately... unobservable at the LHC

A new hope: Type-III 2HDM

[Davidson, Grenier, 2010; Harnik et al, 2013; Kopp, Nardecchia, 2014]

$$\mathcal{L}_Y = m_i \bar{f}_L^i f_R^i - Y_{ij} (\bar{f}_L^i f_R^j + \text{h.c.})$$



[Figure from Harnik et al, arXiv:1209.1397]

A model!

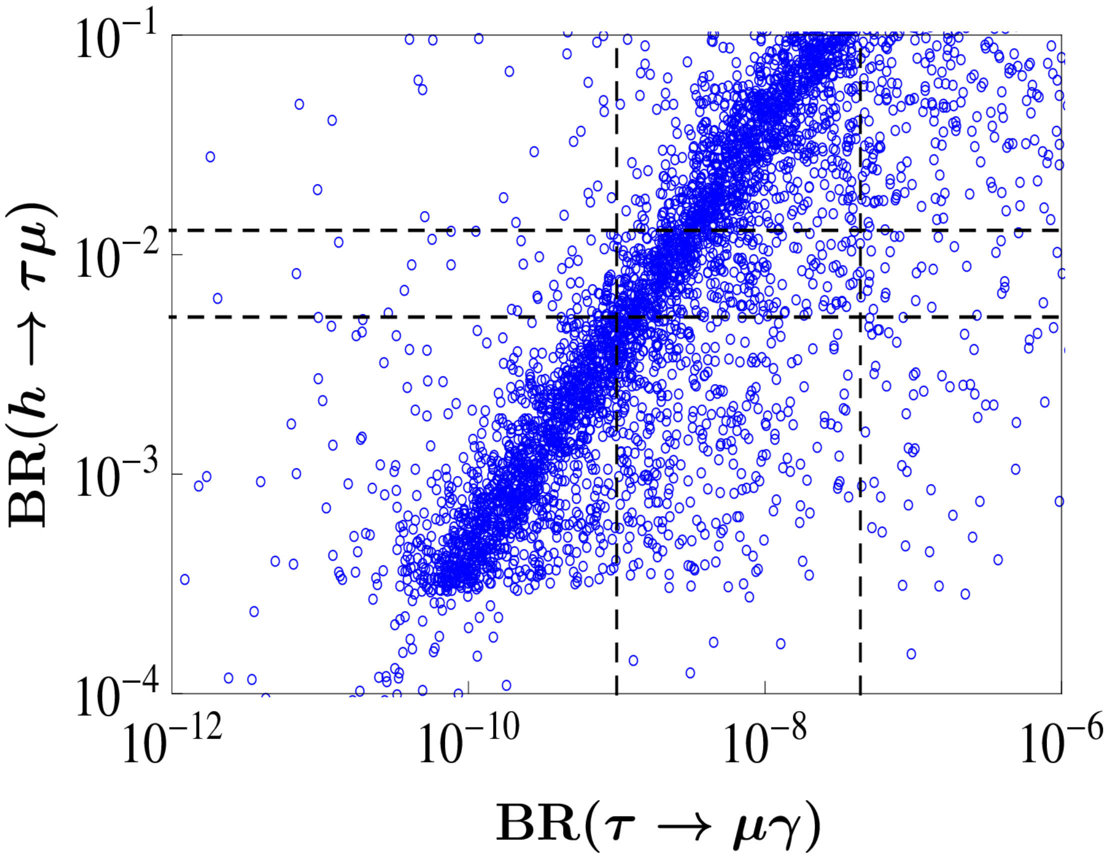
2HDM type III

In *principle*... it is possible to account for the CMS excess!

Higgs LFV couplings and other LFV processes: [Celis et al, 2014]

See also some recipes for model builders: [Dery et al, 2014]

A new hope: Type-III 2HDM



[Aristizabal Sierra, AV, 2014]

Explicit *proof of validity* including the relevant constraints

The signal is consistent with the Sher-Cheng ansatz

$$\rho_{\tau\mu} \simeq \frac{\sqrt{m_\tau m_\mu}}{\langle H \rangle}$$

A flavor symmetry at work?

In this model $\mathrm{BR}(\tau \to 3\,\mu) \simeq 2 \cdot 10^{-3}\,\mathrm{BR}(\tau \to \mu\gamma)$

The observation of $\tau \to 3\,\mu$ at LHCb would exclude this explanation!

Other models?

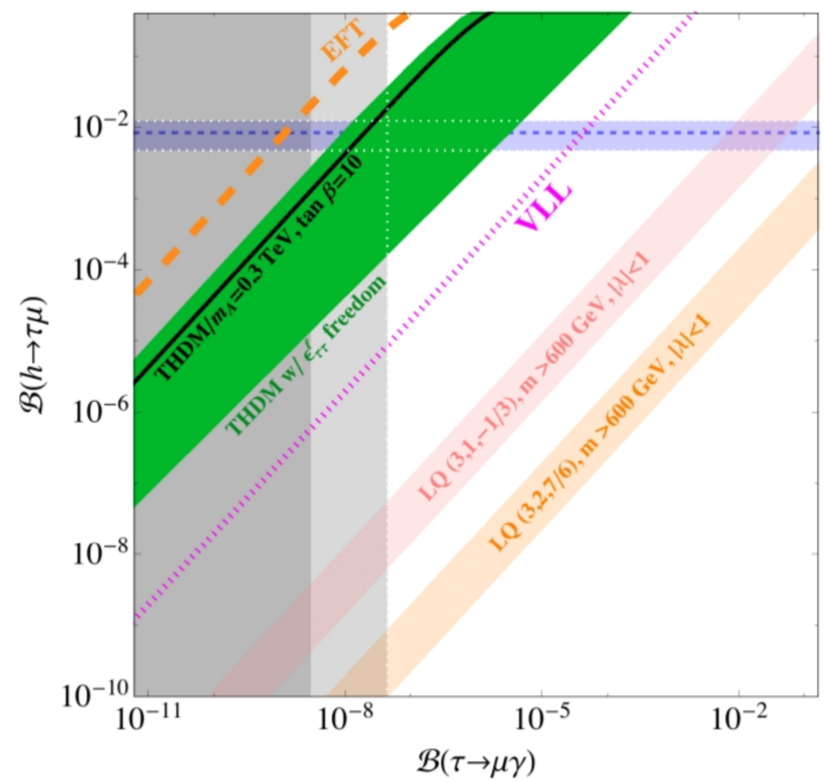
Other models?

[Doršner et al, 2015]

$$\mathcal{O}_6 = \bar{L} H e \left(H^\dagger H \right)$$

$$\mathcal{O}_{\text{dipole}} = \bar{L} H \left(\sigma \cdot F \right) e$$

Same properties under
flavor transformations



[Figure from Doršner et al, arXiv:1502.07784]

- Extended scalar sectors seem to be the only valid scenario

- No way with 1-loop induced Higgs LFV (unless huge fine-tuning!)

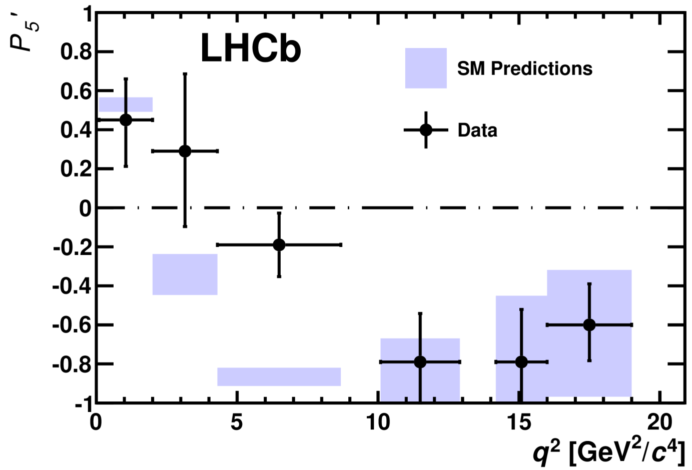
LFV in B meson decays

Where lepton physicists meet quark physicists

The $b \to s$ anomalies

Episode 1

2013 : First anomalies found by LHCb



Episode 2

2014 : Lepton universality violation

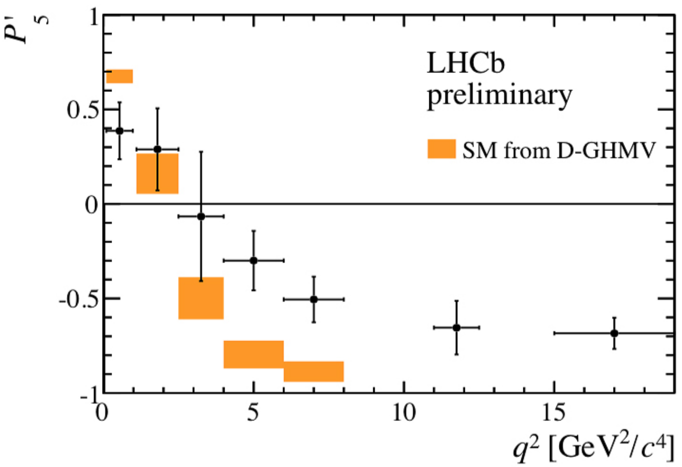
$$R_K = \frac{\text{BR}(B \to K \mu^+ \mu^-)}{\text{BR}(B \to K e^+ e^-)} = 0.745^{+0.090}_{-0.074} \pm 0.036$$

$$R_K^{\text{SM}} = 1.0003 \pm 0.0001$$ [Hiller, Kruger, 2004]

2.6σ away from the SM

Episode 3

2015 : LHCb confirms first anomalies



The $b \to s$ anomalies

Composite Higgs

Buras, Girrbach-Noe, Niehoff, Stangl, Straub

Z' boson

Altmannshofer, Aristizabal Sierra, Buras, Celis, Crivellin, D' Ambrosio, Fuentes-Martín, Gauld, Girrbach-Noe, Goertz, Gori, Haisch, Heeck, Jung, Niehoff, Pospelov, Serôdio, Staub, Straub, Vicente, Yavin

Global fits

Alonso, Altmannshofer, Beaujean, Bobeth, Descotes-Genon, Egede, Ghosh, Grinstein, Hiller, Hurth, Mahmoudi, Martin Camalich, Matias, Nardecchia, Neshatpour, Patel, Petridis, Renner, Schmaltz, Straub, van Dyk, Virto

Other

Calibbi, Crivellin, Greljo, Isidori, Marzocca, Ota

Model building

Leptoquarks

Alonso, Becirevic, Biswas, Chowdhuri, de Medeiros Varzielas, Fajfer, Grinstein, Gripaios, Han, Hiller, Kosnik, Lee, Martin Camalich, Mohanta, Nardecchia, Renner, Sahoo, Schmaltz

$b \to s$ anomalies

Implications - LFV -

Bhattacharya, Boucenna, Civellin, Datta, de Medeiros Varzielas, Glashow, Gripaios, Guadagnoli, Hiller, Hofer, Kane, Lee, London, Matias, Mohanta, Nardecchia, Nierste, Pokorski, Renner, Rosiek, Sahoo, Shivashankara, Tandean, Valle, Vicente

SM uncertainties

Altmannshofer, Bharucha, Descotes-Genon, Ghosh, Hiller, Hofer, Horgan, Hurth, Jaeger, Liu, Lyon, Martin Camalich, Matias, Meinel, Straub, Virto, Wingate, Zwicky

The $b \to s$ anomalies

Composite Higgs

Buras, Girrbach-Noe, Niehoff, Stangl, Straub

Z' boson

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Other

Calibbi, Crivellin, Greljo, Isidori, Marzocca, Ota

Model building

Leptoquarks

Alonso, Becirevic, Bis... Chowdhuri, de Mede... Varzielas, Fajfer, Grins... Gripaios, Han, Hiller, K... Lee, Martin Camalich, M... Nardecchia, Renner, S... Schmaltz

See talks by Nakada, Fleischer, de Medeiros Varzielas, Fuentes-Martín, Hernando Morata, Descotes-Genon and Heeck

...plications ... LFV -

... ucenna, Civellin, Datta, de Medeiros Varzielas, Glashow, Gripaios, Guadagnoli, Hiller, Hofer, Kane, Lee, London, Matias, Mohanta, Nardecchia, Nierste, Pokorski, Renner, Rosiek, Sahoo, Shivashankara, Tandean, Valle, Vicente

SM uncertainties

Descotes-Genon, Ghosh, Hiller, Hofer, Horgan, Hurth, Jaeger, Liu, Lyon, Martin Camalich, Matias, Meinel, Straub, Virto, Wingate, Zwicky

What do we need?

Z' model building

Easiest (but not unique) solution

See also the excellent talks by Javier Fuentes-Martín and Julian Heeck!

List of “ingredients”:

- A Z' boson that contributes to $\mathcal{O}_9$ (and optionally to $\mathcal{O}_{10}$)
- The Z' must have flavor violating couplings to quarks
- The Z' must have non-universal couplings to leptons
- Optional (but highly desirable!): interplay with some other physics

A model with a dark sector

[Aristizabal Sierra, Staub, AV, 2015]

Vector-like = “joker” for model builders

$$SU(3)_c \otimes SU(2)_L \otimes U(1)_Y \otimes U(1)_X$$

Vector-like fermions

Link to SM fermions

$$Q = \left(\mathbf{3}, \mathbf{2}, \frac{1}{6}, 2\right) \qquad L = \left(\mathbf{1}, \mathbf{2}, -\frac{1}{2}, 2\right)$$

Scalars

$$\phi = (\mathbf{1}, \mathbf{1}, 0, 2) \qquad \chi = (\mathbf{1}, \mathbf{1}, 0, -1)$$

$U(1)_X$ breaking

Dark matter candidate

A model with a dark sector

[Aristizabal Sierra, Staub, AV, 2015]

Vector-like = "joker"
for model builders

$$SU(3)_c \otimes SU(2)_L \otimes U(1)_Y \otimes U(1)_X$$

$$\mathcal{L}_m = m_Q \overline{Q} Q + m_L \overline{L} L$$

Vector-like (Dirac) masses

$$\mathcal{L}_Y = \lambda_Q \overline{Q_R} \phi q_L + \lambda_L \overline{L_R} \phi \ell_L + \text{h.c.}$$

VL – SM mixing

Symmetry breaking and dark matter

[Aristizabal Sierra, Staub, AV, 2015]

$$\langle H^0 \rangle = \frac{v}{\sqrt{2}} \qquad \langle \phi \rangle = \frac{v_\phi}{\sqrt{2}}$$

Massive Z' boson: $m_{Z'} = 2 g_X v_\phi$

DM candidate: χ

$$\begin{aligned} \mathcal{V}(\chi) &= m_\chi^2 |\chi|^2 + \frac{\lambda_\chi}{2} |\chi|^4 + \lambda_{H\chi} |H|^2 |\chi|^2 \\ &+ \lambda_{\phi\chi} |\phi|^2 |\chi|^2 + \left(\mu \, \phi \chi^2 + \text{h.c.}\right) \end{aligned}$$

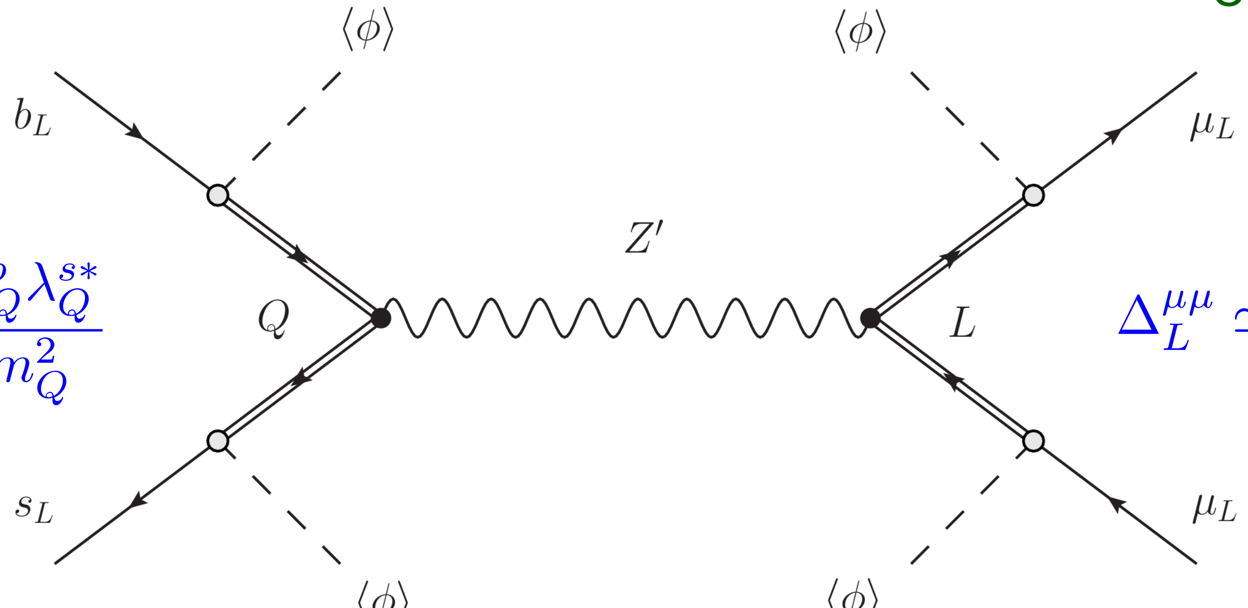
$$\boxed{U(1)_X \to \mathbb{Z}_2}$$

Automatic DM stability

Solving the LHCb anomalies

Similar to
Altmannshofer et al,
Crivellin et al, 2014

$$\Delta_L^{bs} \simeq g_X v_\phi^2 \frac{\lambda_Q^b \lambda_Q^{s*}}{m_Q^2}$$



$$\Delta_L^{\mu\mu} \simeq \frac{2\, g_X |\lambda_L^\mu|^2 v_\phi^2}{2 m_L^2 + |\lambda_L^\mu|^2 v_\phi^2}$$

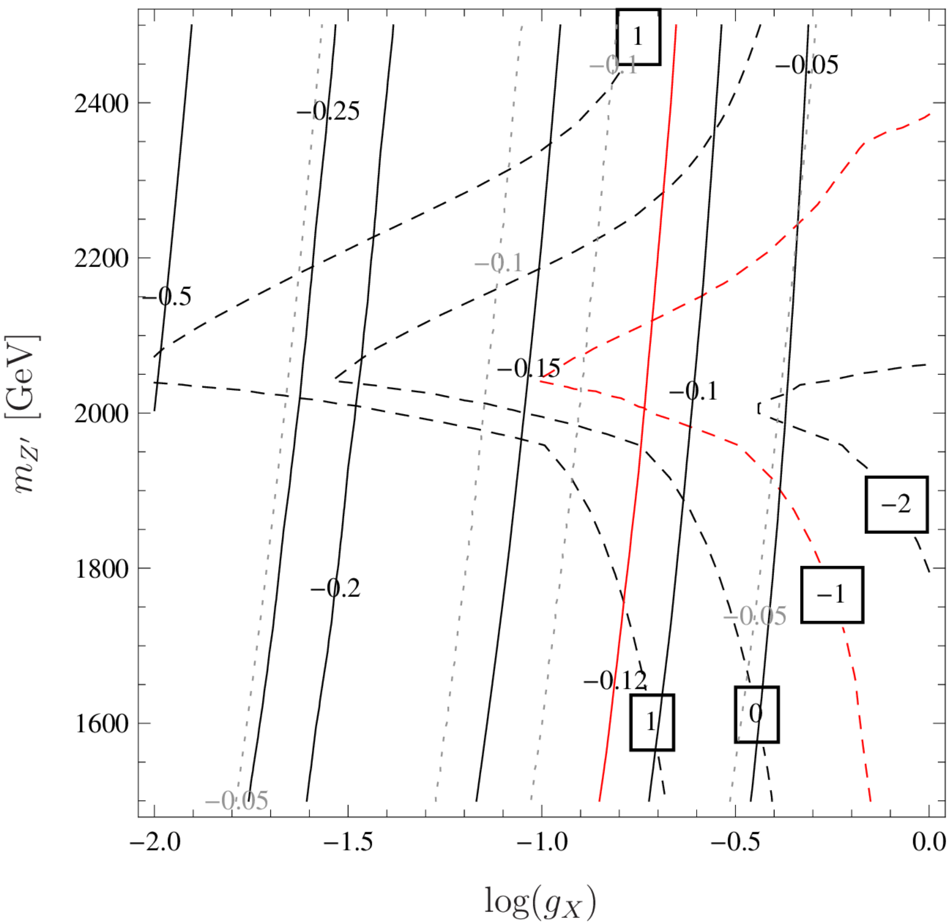
$$\mathcal{O} = (\bar{s}\gamma_\alpha P_L b)\ (\bar{\mu}\gamma^\alpha P_L \mu)$$

Contributions to $\mathcal{O}_{9,10}$

$$C_9^{\rm NP} = -C_{10}^{\rm NP}$$

Dark matter and LHCb anomalies

$C_9^{\rm NP}/C_9^{\rm SM}$ (full) $\log\left(\Omega_{\rm DM} h^2\right)$ (dashed) $C_9^{\rm NP}/C_9^{\rm SM}$ (tree) (dotted gray)



[DM RD Computed with **micrOMEGAs**]

Parameters:

$$\lambda_Q^b = \lambda_Q^s = 0.025$$

$$\lambda_L^\mu = 0.5$$

$$m_Q = m_L = 1 \text{ TeV}$$

$$m_\chi^2 = 1 \text{ TeV}^2$$

- Compatible with flavor constraints (small quark mixings)
- Resonance required to get the correct DM relic density
- Large loop effects for low g_X

LFV in B meson decays

What about LFV?

LFV in B meson decays

What about LFV?

[Glashow et al, 2014]

Lepton universality violation generically implies lepton flavor violation

[See talk by J. Fuentes-Martín for an exception]

Gauge basis | Mass basis

$$\mathcal{O} = \widetilde{C}^Q \, (\bar{q}' \gamma_\alpha P_L q') \, \widetilde{C}^L \, (\bar{\ell}' \gamma^\alpha P_L \ell') \longrightarrow \mathcal{O} = C^Q \, (\bar{q} \gamma_\alpha P_L q) \, C^L \, (\bar{\ell} \gamma^\alpha P_L \ell)$$

$$C^L = U_\ell^\dagger \, \widetilde{C}^L \, U_\ell$$

However: we must have a flavor theory in order to make predictions

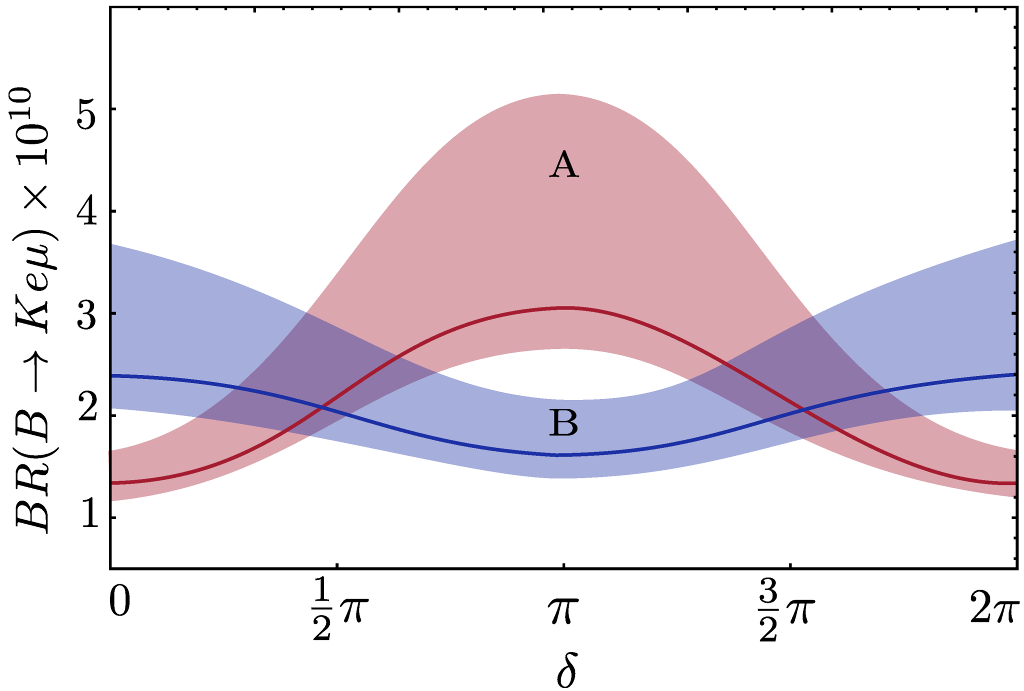
Are the LHCb anomalies related to neutrino oscillations?

Working hypothesis: What if $U_\ell = K^\dagger$? [Boucenna, Valle, AV, 2015]

Neutrino oscillations

Neutrinos ⟷ B-physics

LHCb sensitivity $\sim 10^{-10}$



Lines: BF
Bands: 1σ

LHCb anomalies and flavor symmetries

See talk by Ivo de Medeiros Varzielas for more details

[de Medeiros Varzielas, Hiller, 2015]

symmetry	flavons	Δ assignment
$SU(3)_F \times U(1)_F$	$\langle \phi_{23} \rangle = (0, b, -b)$	$\{\Delta\} = -2$
$A_4 \times Z_3$	$\langle \phi_l \rangle = (u, 0, 0)$	$1, \{\Delta\} = 2$
$A_4 \times Z_3$	$\langle \phi_l \rangle = (u, 0, 0)$	1", $\{\Delta\} = 2$
$1^x, \{\Delta\} = 0$		
$A_4 \times Z_4$	$\langle \phi_l \rangle = (0, u, 0), \xi''$	1', $\{\Delta\} = 2$
$A_4 \times Z_4$	$\langle \phi_l \rangle = (0, u, 0), \xi''$	1", $\{\Delta\} = 2$
$A_4 \times Z_4$	$\langle \phi_l \rangle = (0, u, 0)$	1' , $\{\Delta\} = 2$

$$\lambda = \begin{pmatrix} 0 & \lambda_{d\mu} & 0 \\ 0 & \lambda_{s\mu} & 0 \\ 0 & \lambda_{b\mu} & 0 \end{pmatrix}$$

[Table from de Medeiros Varzielas, Hiller, arXiv:1503.01084]

The rates for the different channels are predicted by the symmetry!

Final remarks

Final remarks

LFV is going to live a golden age

Or perhaps it has already begun?

Whether is new physics or not, only time can tell

In the meantime: let's do some physics and try to learn as much as possible!

Thank you!

Backup slides

$\ell_i \to 3\,\ell_j$ vs $\ell_i \to \ell_j\gamma$

A brief détour...

Experimental limits

$\ell_i \to \ell_j\gamma$	$\ell_i \to 3\,\ell_j$
$\text{Br}(\mu \to e\gamma) < 0.57 \cdot 10^{-12}$	$\text{Br}(\mu \to 3e) < 1.0 \cdot 10^{-12}$
$\text{Br}(\tau \to e\gamma) < 3.3 \cdot 10^{-8}$	$\text{Br}(\tau \to 3e) < 2.7 \cdot 10^{-8}$
$\text{Br}(\tau \to \mu\gamma) < 4.4 \cdot 10^{-8}$	$\text{Br}(\tau \to 3\mu) < 2.1 \cdot 10^{-8}$

LFV : Where to look for?

We should look for LFV everywhere!

ratio	LHT	MSSM (dipole)	MSSM (Higgs)	SM4
$\frac{\mathrm{Br}(\mu^- \to e^- e^+ e^-)}{\mathrm{Br}(\mu \to e\gamma)}$	$0.02 \ldots 1$	$\sim 6 \cdot 10^{-3}$	$\sim 6 \cdot 10^{-3}$	$0.06 \ldots 2.2$
$\frac{\mathrm{Br}(\tau^- \to e^- e^+ e^-)}{\mathrm{Br}(\tau \to e\gamma)}$	$0.04 \ldots 0.4$	$\sim 1 \cdot 10^{-2}$	$\sim 1 \cdot 10^{-2}$	$0.07 \ldots 2.2$
$\frac{\mathrm{Br}(\tau^- \to \mu^- \mu^+ \mu^-)}{\mathrm{Br}(\tau \to \mu\gamma)}$	$0.04 \ldots 0.4$	$\sim 2 \cdot 10^{-3}$	$0.06 \ldots 0.1$	$0.06 \ldots 2.2$
$\frac{\mathrm{Br}(\tau^- \to e^- \mu^+ \mu^-)}{\mathrm{Br}(\tau \to e\gamma)}$	$0.04 \ldots 0.3$	$\sim 2 \cdot 10^{-3}$	$0.02 \ldots 0.04$	$0.03 \ldots 1.3$
$\frac{\mathrm{Br}(\tau^- \to \mu^- e^+ e^-)}{\mathrm{Br}(\tau \to \mu\gamma)}$	$0.04 \ldots 0.3$	$\sim 1 \cdot 10^{-2}$	$\sim 1 \cdot 10^{-2}$	$0.04 \ldots 1.4$
$\frac{\mathrm{Br}(\tau^- \to e^- e^+ e^-)}{\mathrm{Br}(\tau^- \to e^- \mu^+ \mu^-)}$	$0.8 \ldots 2$	~ 5	$0.3 \ldots 0.5$	$1.5 \ldots 2.3$
$\frac{\mathrm{Br}(\tau^- \to \mu^- \mu^+ \mu^-)}{\mathrm{Br}(\tau^- \to \mu^- e^+ e^-)}$	$0.7 \ldots 1.6$	~ 0.2	$5 \ldots 10$	$1.4 \ldots 1.7$
$\frac{\mathrm{R}(\mu\mathrm{Ti} \to e\mathrm{Ti})}{\mathrm{Br}(\mu \to e\gamma)}$	$10^{-3} \ldots 10^{2}$	$\sim 5 \cdot 10^{-3}$	$0.08 \ldots 0.15$	$10^{-12} \ldots 26$

Table taken from Buras et al [arXiv:1006.5356]

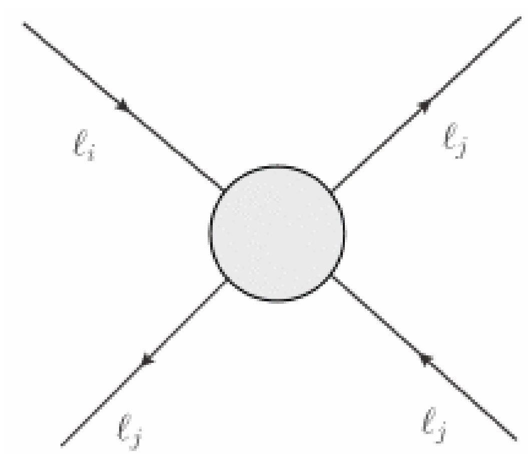
$\ell_i \to 3\,\ell_j$ vs $\ell_i \to \ell_j\gamma$

What contribution dominates $\ell_i \to 3\,\ell_j$?

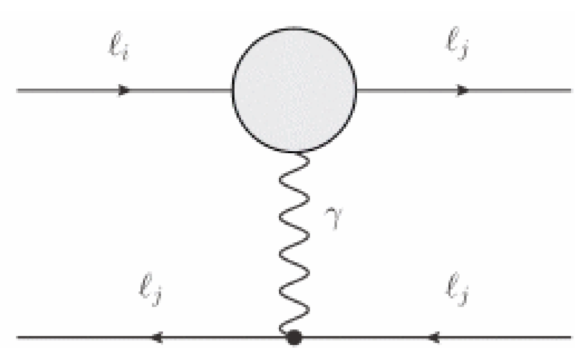
In many models of interest: Photonic dipole contributions

Most popular example: MSSM

[Hisano et al 1996; Arganda, Herrero 2006]



$\simeq$



Dipole dominance

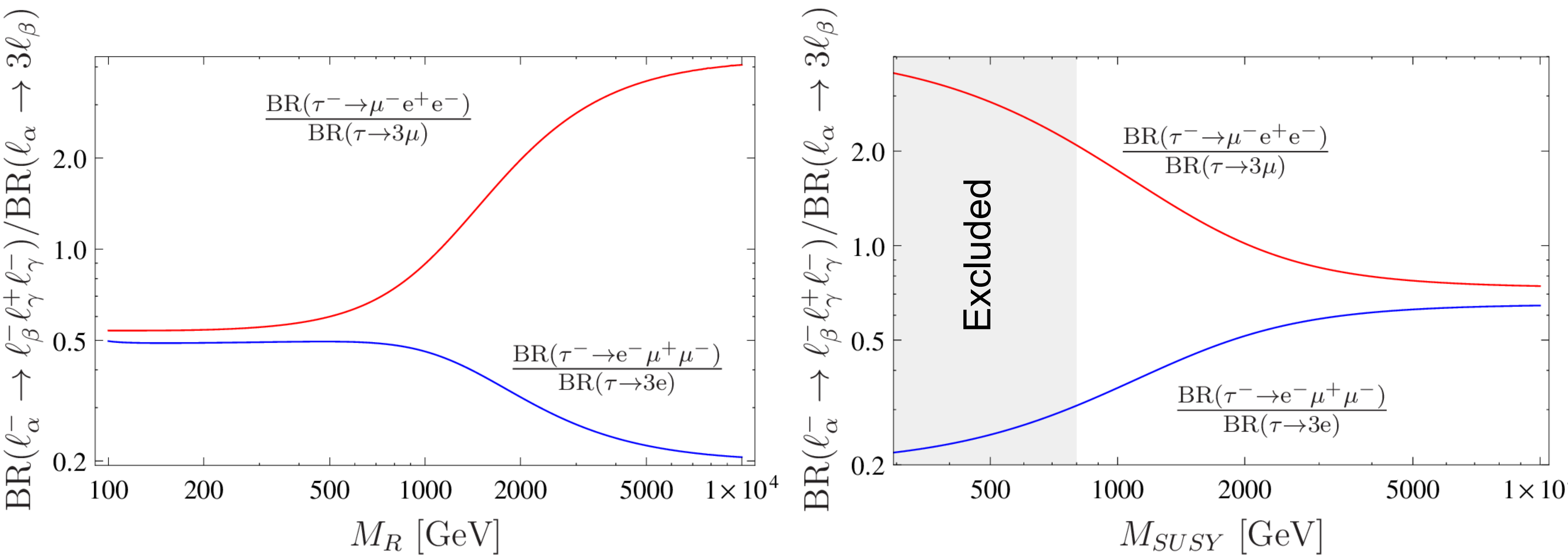
$$\frac{BR(\ell_i \to 3\,\ell_j)}{BR(\ell_i \to \ell_j\gamma)} = \frac{\alpha}{3\pi}\left(\log\frac{m_{\ell_i}^2}{m_{\ell_j}^2} - \frac{11}{4}\right) \Rightarrow \quad BR(\ell_i \to \ell_j\gamma) \gg BR(\ell_i \to 3\,\ell_j)$$

Low-scale seesaw models

[Abada, Krauss, Porod, Staub, AV, Weiland, 2014]

75 pages paper

First complete study of all SUSY and non-SUSY contributions!



Tau LFV decay ratios (LHCb!) provide information on the mass scales

FlavorKit

[Porod, Staub, AV, 2014]

A computer tool that provides automatized analytical and numerical computation of flavor observables. It is based on SARAH, SPheno and FeynArts/FormCalc.

Lepton flavor	Quark flavor
$\ell_\alpha \to \ell_\beta \gamma$	$B^0_{s,d} \to \ell^+ \ell^-$
$\ell_\alpha \to 3\,\ell_\beta$	$\bar{B} \to X_s \gamma$
$\mu - e$ conversion in nuclei	$\bar{B} \to X_s \ell^+ \ell^-$
$\tau \to P\,\ell$	$\bar{B} \to X_{d,s} \nu \bar{\nu}$
$h \to \ell_\alpha \ell_\beta$	$B \to K \ell^+ \ell^-$
$Z \to \ell_\alpha \ell_\beta$	$K \to \pi \nu \bar{\nu}$
	$\Delta M_{B_{s,d}}$
	ΔM_K and ε_K
	$P \to \ell \nu$

Not limited to a single model: use it for the model of your choice

Easily extendable

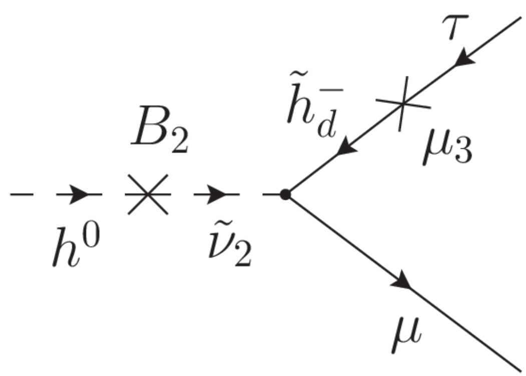
Many observables ready to be computed in your favourite model!

Manual: arXiv:1405.1434
Website: http://sarah.hepforge.org/FlavorKit.html

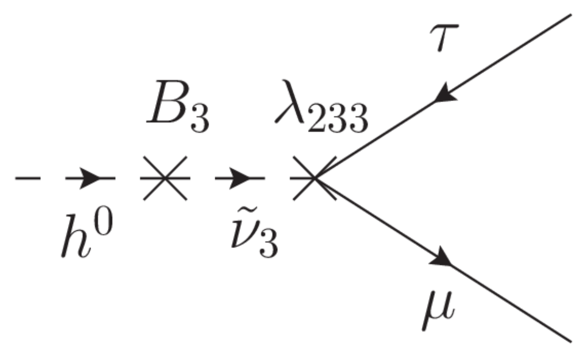
$H \to \mu\tau$ in RPV

[Arhrib, Cheng, Kong, 2013]

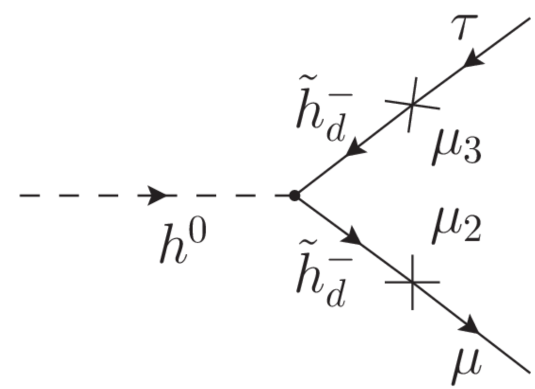
The particles-sparticles mixing induced by RPV lead to
tree-level LFV Higgs decays



$B\epsilon$ contribution



$B\lambda$ contribution

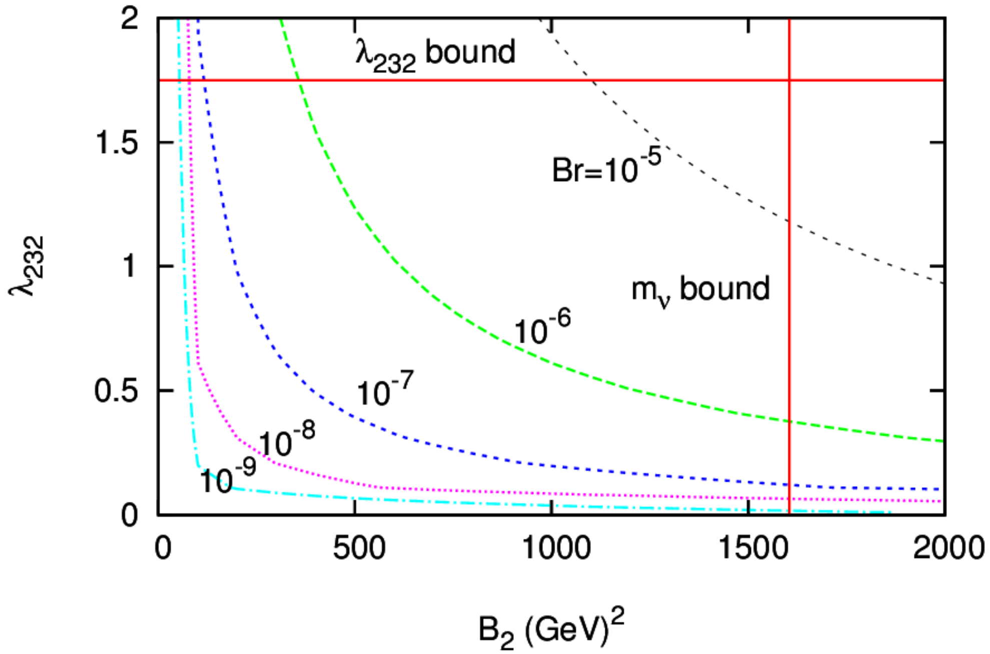


ϵ^2 contribution

Note: $\mathcal{L}_{soft} \supset B\tilde{L}H_u$

$H \to \mu\tau$ in RPV

[Arhrib, Cheng, Kong, 2013]

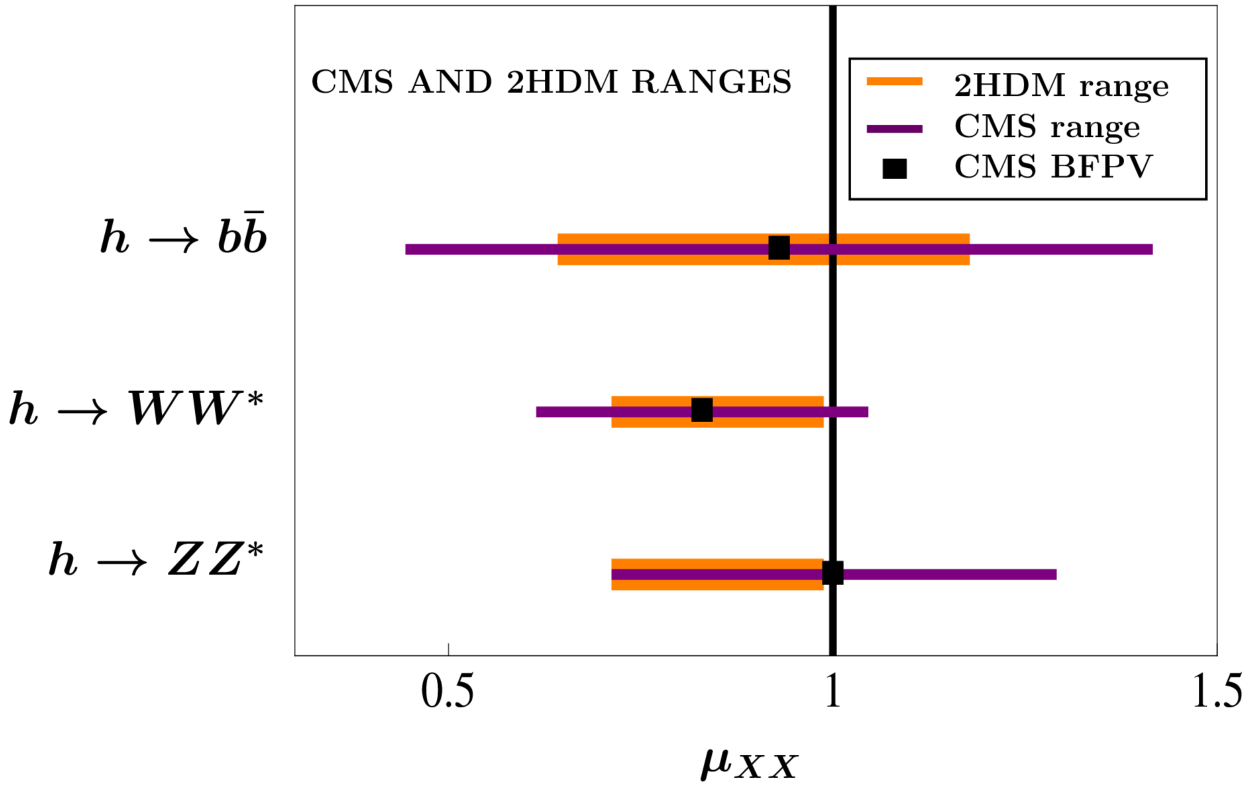


RPV Parameter Combinations	Br with Neutrino Mass $\lesssim 1$ eV Constraint
$B_2\,\mu_3$	1×10^{-15}
$B_3\,\mu_2$	1×10^{-13}
$B_1\,\lambda_{123}$	1×10^{-5}
$B_1\,\lambda_{132}$	3×10^{-5}
$B_2\,\lambda_{232}$	3×10^{-5}
$B_3\,\lambda_{233}$	3×10^{-5}
$\mu_2\,\mu_3$	2×10^{-18}
$B_1\,A^\lambda_{123}$	5×10^{-11}
$B_1\,A^\lambda_{132}$	5×10^{-11}
$B_2\,A^\lambda_{232}$	5×10^{-11}
$B_3\,A^\lambda_{233}$	5×10^{-11}

Again... unobservable at the LHC

A new hope: Type-III 2HDM

[Aristizabal Sierra, AV, 2014]



Signal strengths ranges in the 2HDM
Compatible with all constraints and the CMS signal for $h \to \tau\mu$