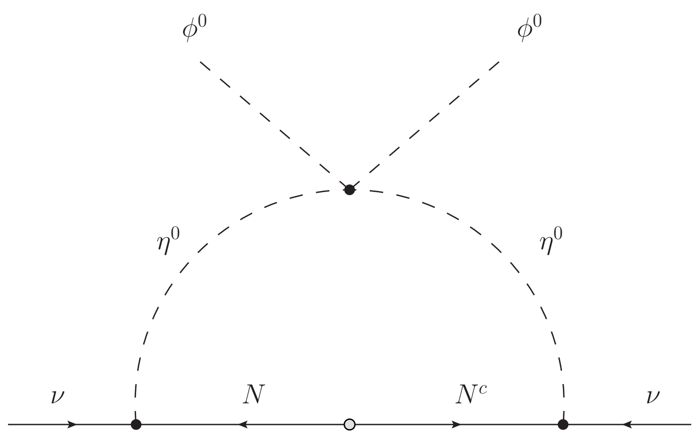
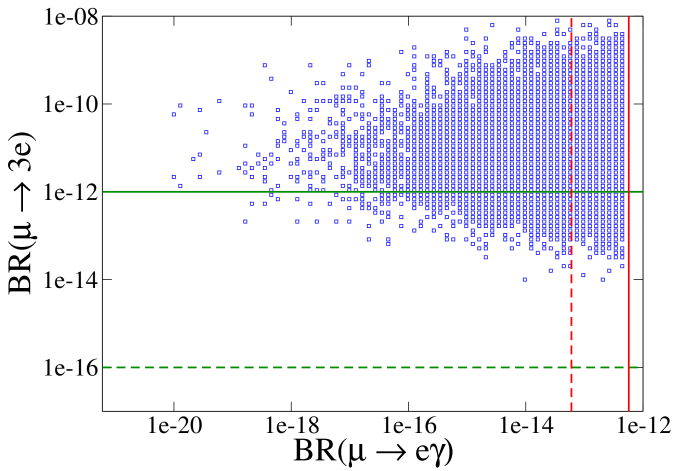
Dark matter, lepton flavor violation and 1-loop neutrino masses





Based on JHEP 1502 (2015) 144,
JCAP 1407 (2014) 015, JCAP 1304 (2013) 044

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2015

New physics is required to account for neutrino masses and the dark matter

Both are strongly supported by data

ν: oscillations
dm: cosmology/astronomy

But not much is known about them

origin of M^ν
dm properties

And it's not clear what this new physics is

??

Most new physics models try to address at least one of these two issues

Many scenarios could account for the DM

SUSY, UED, minimal models

Different mechanisms to explain ν masses

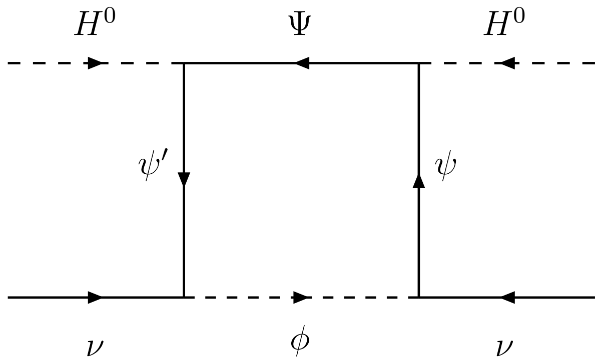
Seesaw, loops, flavor symmetries

Could dark matter and M_ν be related?

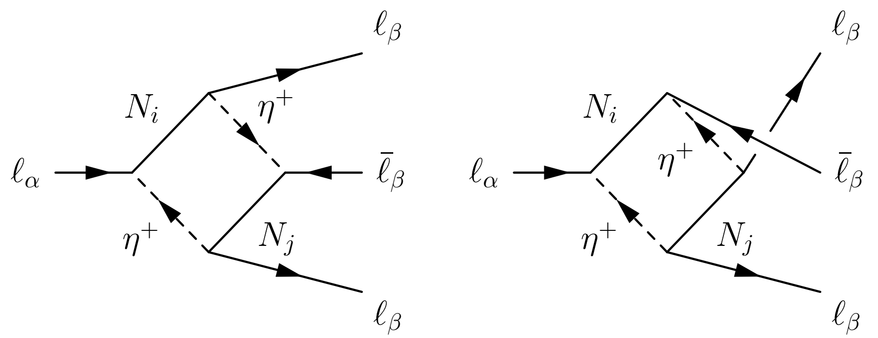
Can both be explained by physics at the TeV scale?

I will discuss models that generate ν masses at 1-loop and that can explain the dark matter

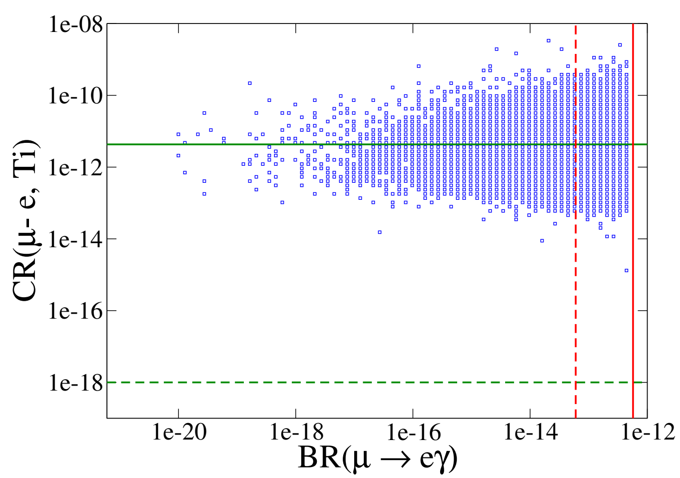
1. The general framework



2. A specific model

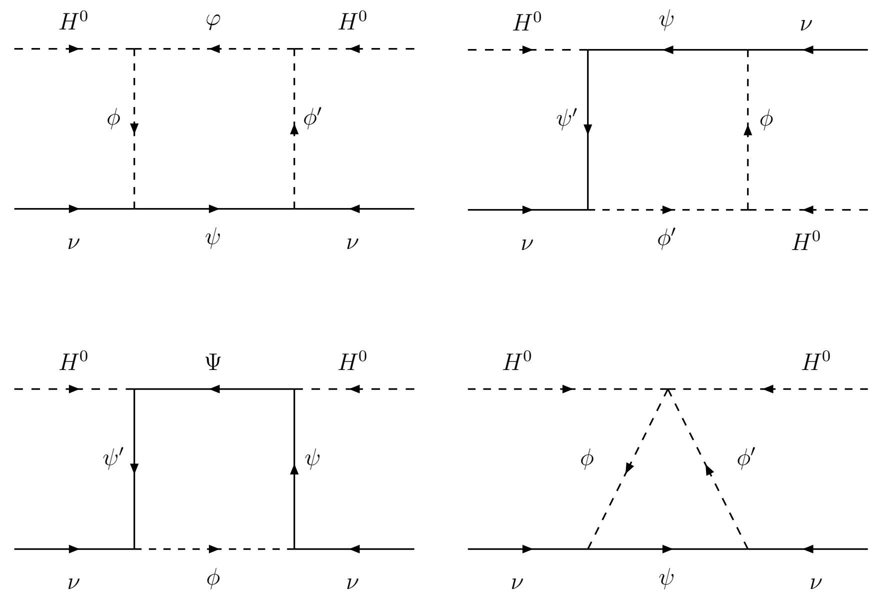


3. Numerical results



The possible 1-loop realizations of the Weinberg operator are already known

Only 4 different topologies exist



The new fields transform as 1, 2 or 3 of SU(2)

Bonnet, Hirsch, Ota, Winter (2012)

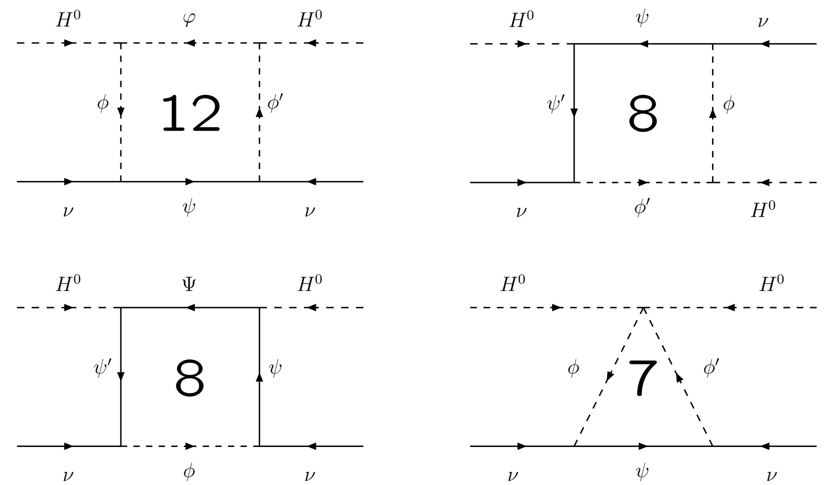
They give rise to $\sim$ 30 new field configurations

Modulo the hypercharge

We obtained the full list of minimal models of 1-loop ν masses and dark matter

All fields in the loop are odd under a Z_2	DM stability
A neutral particle should be present	$Y = -2T_3$ Few viable possibilities
It must be consistent with current experiments	Direct detection bounds $DM \to$ TeV masses

We found only 35 models compatible also with dark matter



All (half) admit scalar (fermionic) dark matter

Several contain exotic particles

Collider searches

They contain less than 4 different new fields

Simple!

Lepton flavor violating processes may provide strong constraints on these models

LFV Process	Present Bound	Future Sensitivity
$\mu \to e\gamma$	5.7×10^{-13}	6×10^{-14}
$\tau \to e\gamma$	3.3×10^{-8}	$\sim 3 \times 10^{-9}$
$\tau \to \mu\gamma$	4.4×10^{-8}	$\sim 3 \times 10^{-9}$
$\mu \to eee$	1.0×10^{-12}	$\sim 10^{-16}$
$\tau \to \mu\mu\mu$	2.1×10^{-8}	$\sim 10^{-9}$
$\tau^- \to e^-\mu^+\mu^-$	2.7×10^{-8}	$\sim 10^{-9}$
$\tau^- \to \mu^-e^+e^-$	1.8×10^{-8}	$\sim 10^{-9}$
$\tau \to eee$	2.7×10^{-8}	$\sim 10^{-9}$
$\mu^-, \mathrm{Ti} \to e^-, \mathrm{Ti}$	4.3×10^{-12}	$\sim 10^{-18}$
$\mu^-, \mathrm{Au} \to e^-, \mathrm{Au}$	7×10^{-13}	
$\mu^-, \mathrm{Al} \to e^-, \mathrm{Al}$		$10^{-15} - 10^{-18}$
$\mu^-, \mathrm{SiC} \to e^-, \mathrm{SiC}$		10^{-14}

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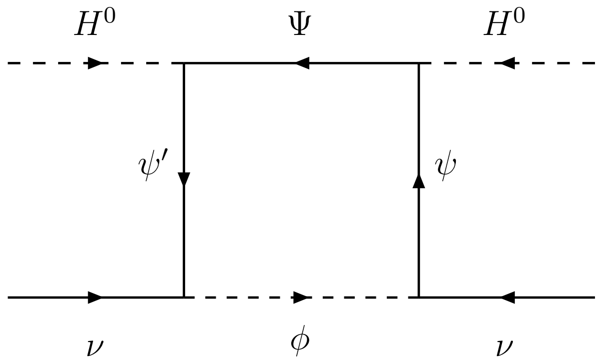

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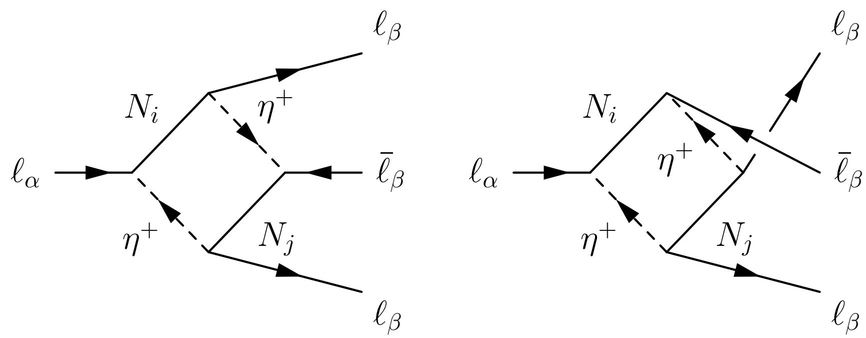

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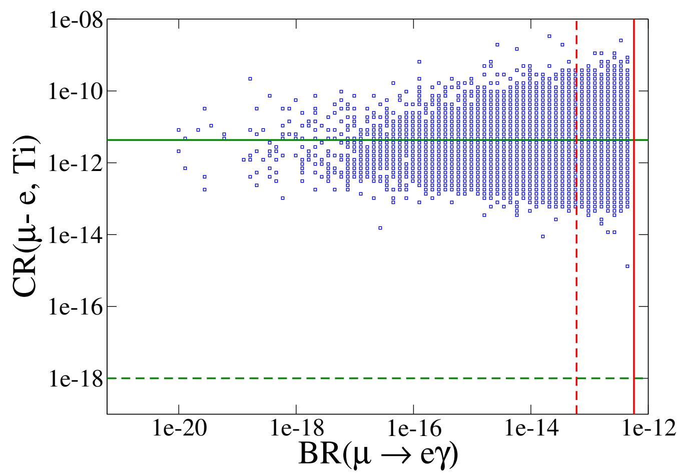


The simplest and best known model of 1-loop ν masses and dm is the radiative seesaw

It contains only two new fields

Ma, 2006

$H_2 = \begin{pmatrix} H^{\pm} \\ H^0 + iA^0 \end{pmatrix}$, N_i

They are odd under a Z_2 symmetry

To prevent FCNC and stabilize the dm

It has been studied extensively

dark matter, ν's, collider

In this model, neutrino masses are generated radiatively at the 1-loop level

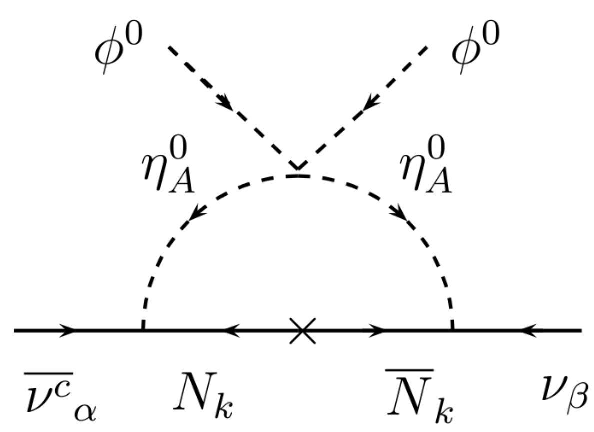
There is no Dirac mass term for neutrinos

$$\boldsymbol{y_{ij}\, L_i N_j H_2 + M_N N N}$$

Lepton number violation requires $\lambda_5 \neq 0$

$$\boldsymbol{\frac{\lambda_5}{2}\left[(H_1^\dagger H_2)^2 + (H_2^\dagger H_1)^2\right]}$$

Neutrinos acquire masses at 1-loop



Current neutrino data can be accommodated within this model

$\mathcal{M}^{\nu}$ has a very simple structure

$$\mathcal{M}^{\nu}_{\alpha\beta} \sim \frac{\lambda_5}{16\pi^2}\frac{y_{\alpha i}y_{\beta i}v^2}{M_{N_i}} \times f\left(\frac{M^2_{N_i}}{M^2_{\eta^0}}\right)$$

The ν mass scale can be obtained

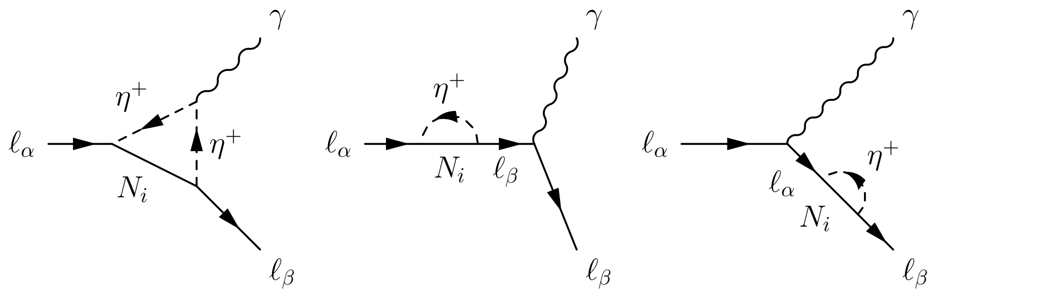
$$\lambda_5 y^2_{ij} \sim 10^{-10}\text{-}10^{-11}$$

Enough free parameters to account for the data

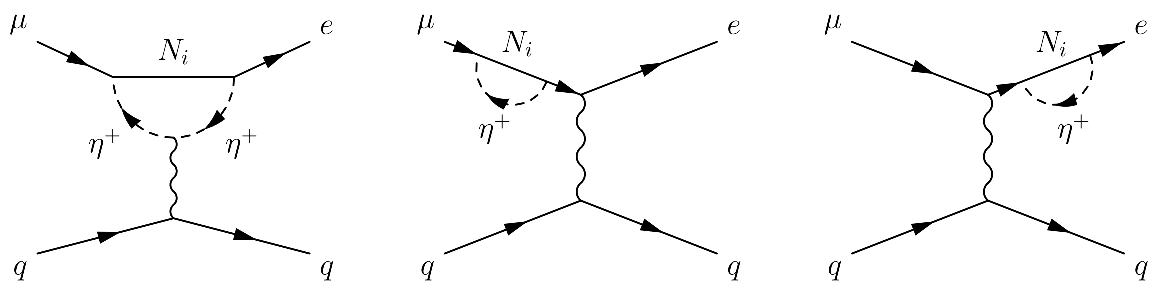
At least 2 N's

Lepton flavor violating processes are also induced at one-loop

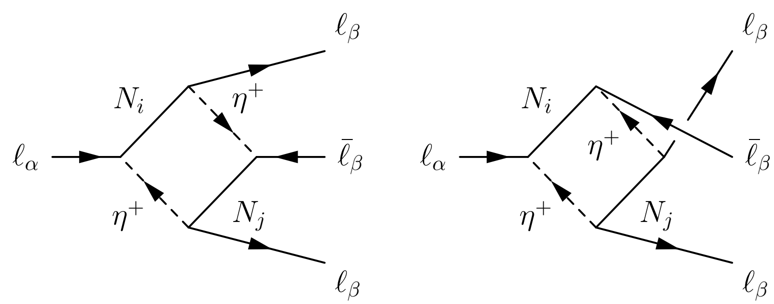
They are mediated by the charged scalar



They depend on y_{ij} but not on λ_5



Relevant constraints for $y_{ij} \sim \mathcal{O}(0.1 - 1)$



In this model the dark matter particle can be a scalar or a fermion

It contains two dark matter candidates

H^0: WIMP
N_1: WIMP or FIMP

Ω_{H^0} tends to be smaller than Ω_{dm}

$H^0 H^0 \to W^+ W^-$

Ω_{N_1} tends to be larger than Ω_{dm}

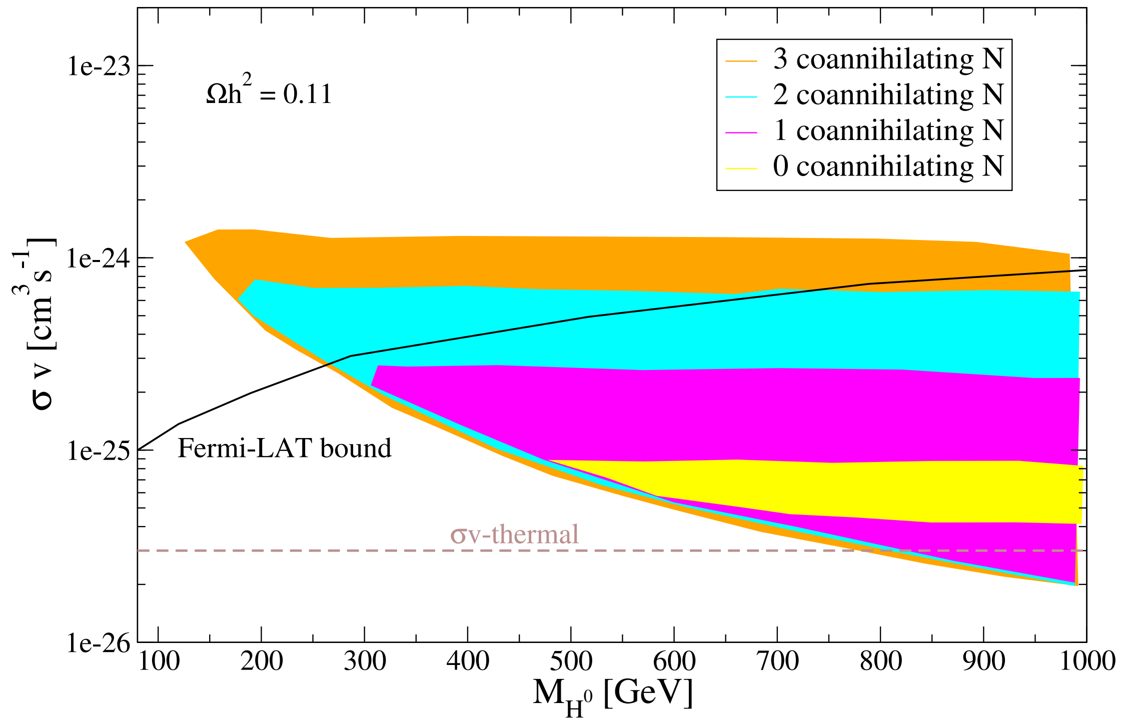
Large Yukawa couplings
Compatible with LFV?

For scalar dark matter the phenomenology resembles that of the inert doublet

Viable regions feature $M_{H^0} \gtrsim 500$ GeV

H^0-N coannihilations may change this picture

No correlation with LFV or ν masses



The lightest singlet fermion is a leptophilic dark matter candidate

It does not couple to quarks at tree-level

No direct detection bounds

It annihilates into leptons

$\sigma(NN \to \ell\bar{\ell}) \propto y^4$
$\Omega_{dm} \Rightarrow \mathcal{O}(1)$ Yukawas

Strong correlation with LFV and ν masses

is it viable?

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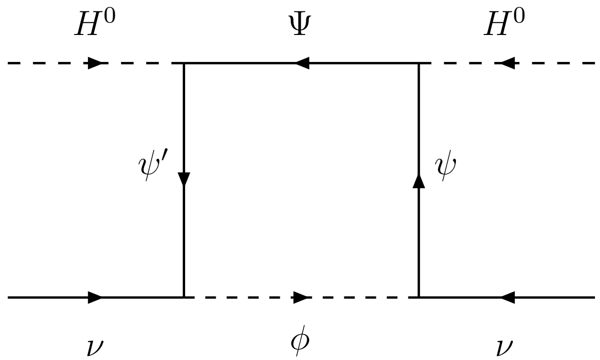

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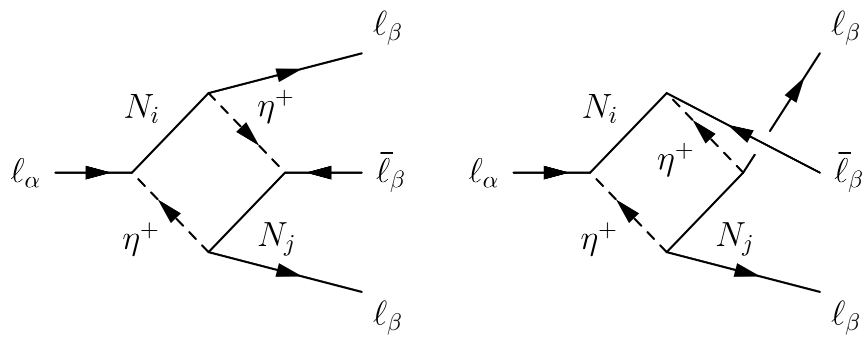

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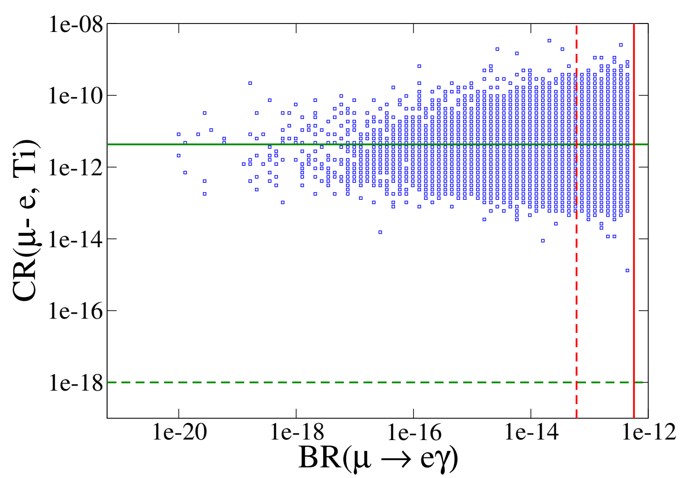


We studied the parameter space of this model and obtained a large sample of viable points

We used the most general form of the Yukawas

$y_{ij} \rightarrow$ Casas-Ibarra

We took into account all relevant constraints

Dark matter: (co)annihilation
EW data, colliders,...

We computed the rates for different LFV processes

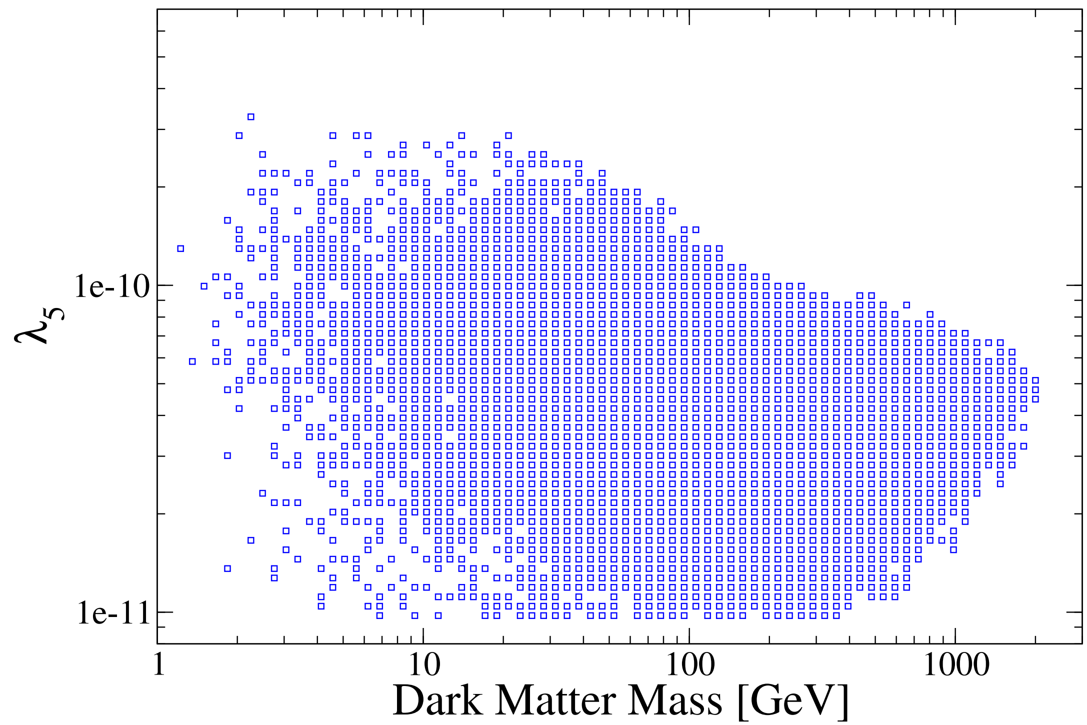
$\underline{\mu \rightarrow e\gamma}, \mu \rightarrow 3e, CR(\mu\text{-}e)$
$\tau \rightarrow \mu\gamma, \tau \rightarrow e\gamma, \tau \rightarrow 3\mu$

Dark matter and neutrino masses imply that λ_5 has to be tiny

It is never larger than about 3×10^{-10}

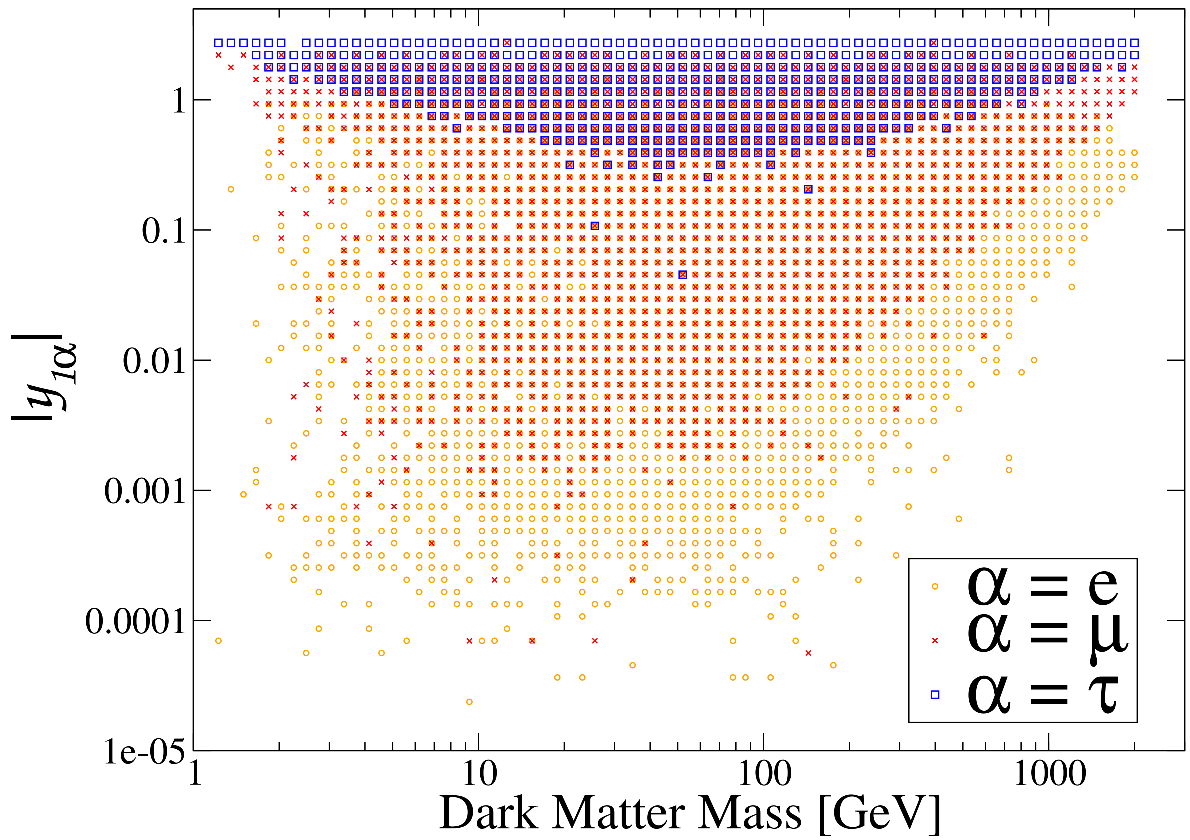
This is technically natural (t'Hooft)

The two neutral scalars are degenerate



The dark matter annihilates dominantly into third family leptons

$\mu \to e\gamma$ requires small $y_{1e}, y_{1\mu}$



The Yukawas satisfy $|y_{1e}| \lesssim |y_{1\mu}| \lesssim |y_{1\tau}|$

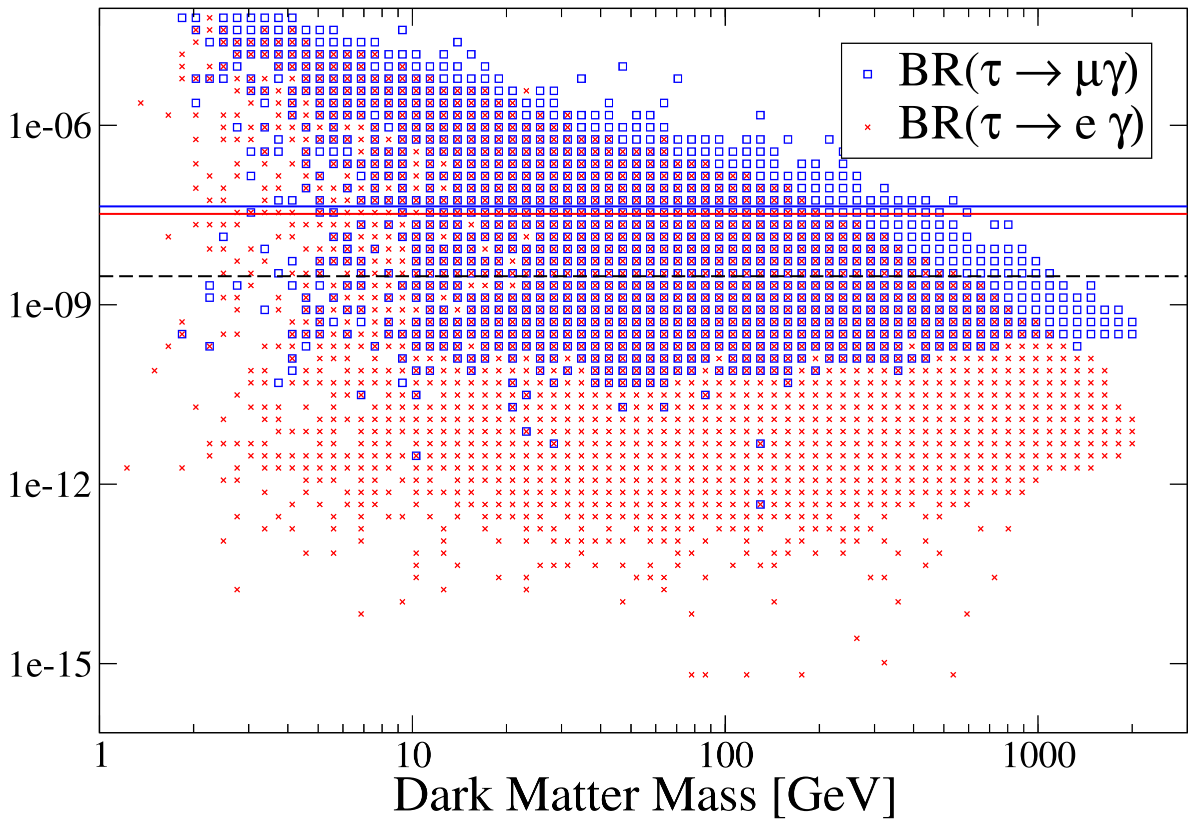
No viable models for $M_{N_1} \gtrsim 2$ TeV

Current bounds on LFV τ decays can be violated

They are more relevant at low dm masses

Viable models remain for all values of M_{N_1}

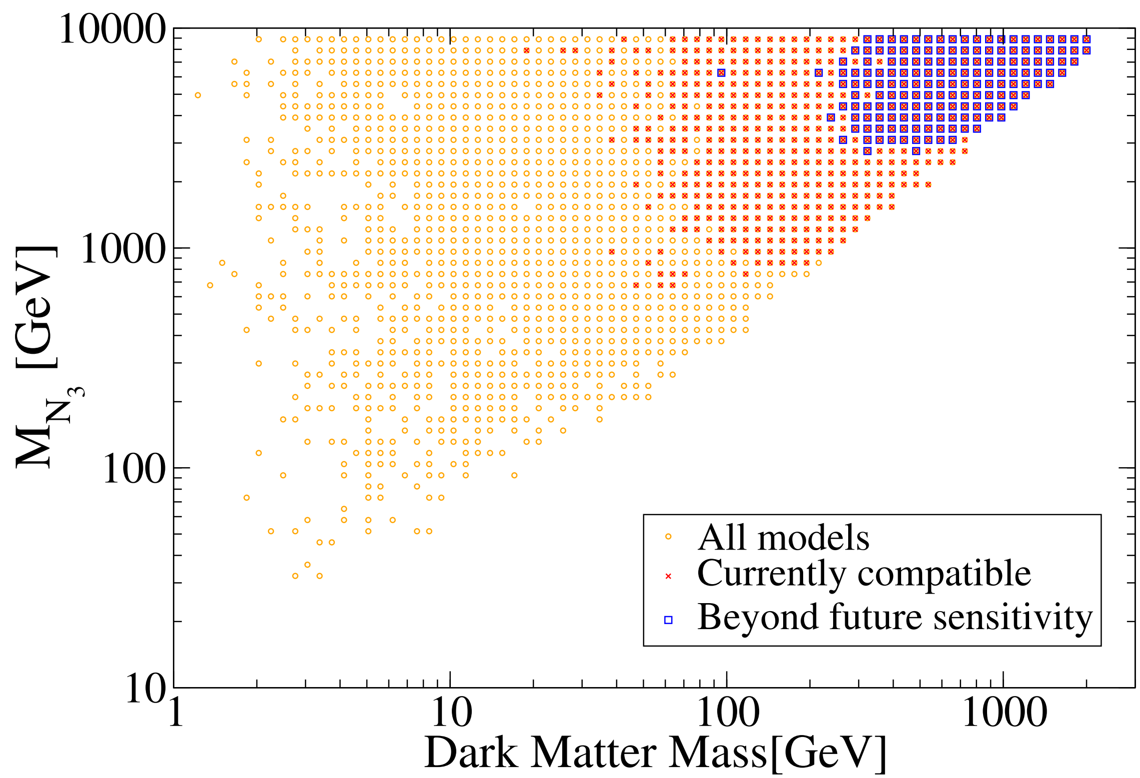
Future experiments can exclude more models



Significant regions of the parameter space can be probed via LFV τ decays

$M_{N_3} \lesssim 700$ GeV is already excluded

Future experiments may rule out $M_{N_3} \lesssim 3$ TeV

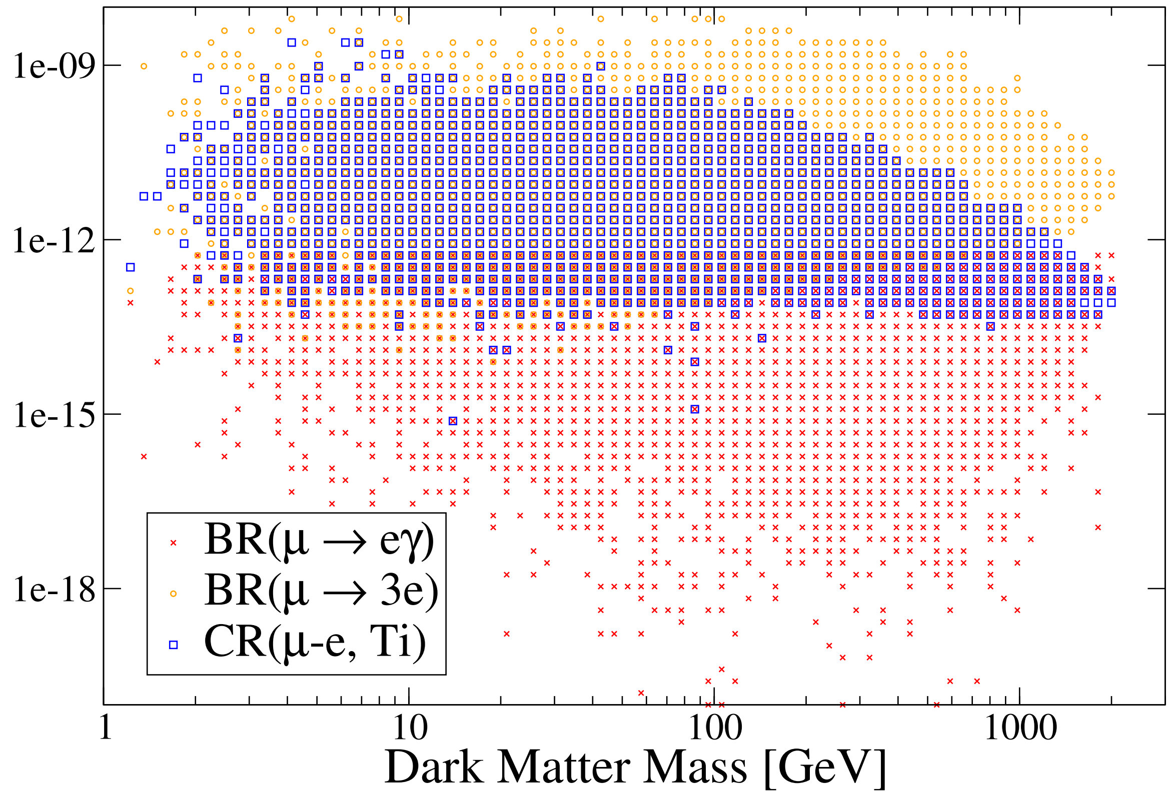


Models consistent with $\mu \to e\gamma$ can be excluded by $\mu \to 3e$ and μ-e conversion

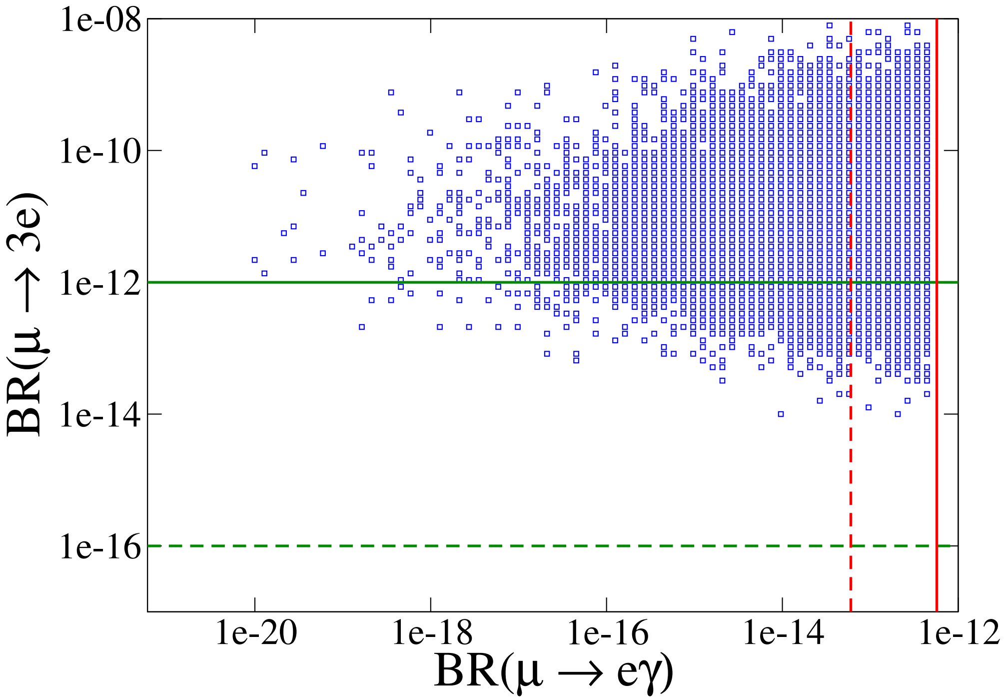
BR($\mu \to 3e$) may be above 10^{-9}

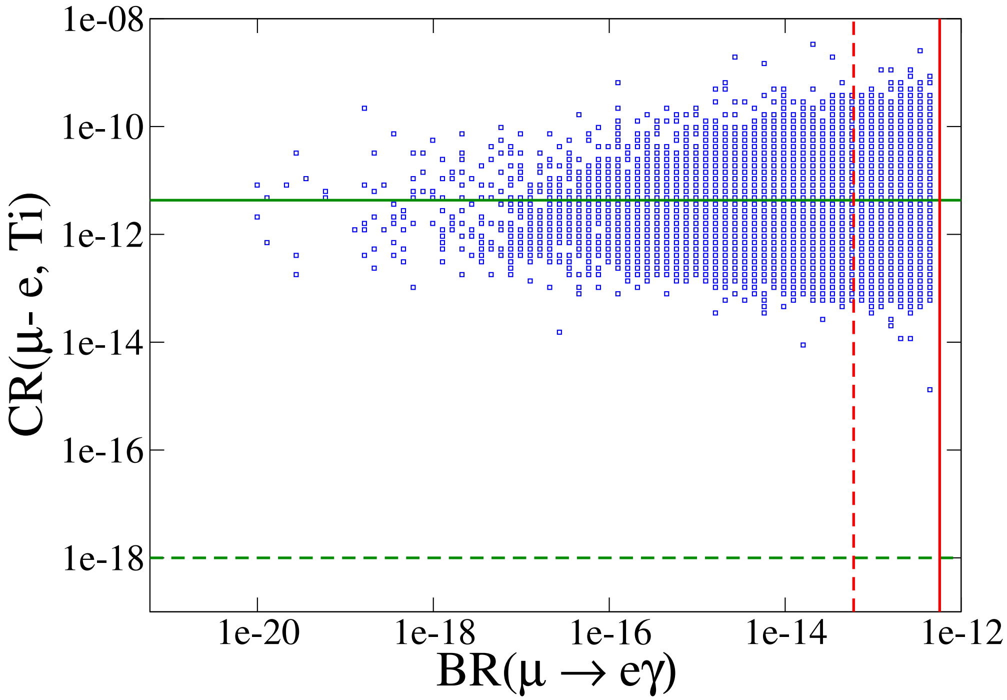
BR($\mu \to e\gamma$) can be quite suppressed

Not so with $\mu \to 3e$ and μ-e conversion



This scenario will be easily and entirely probed by future LFV experiments





The dark matter constraint can also be satisfied via coannihilations with the scalars

When $M_{H_2} - M_{N_1}$ is small

$$\Delta m \lesssim 20\%$$

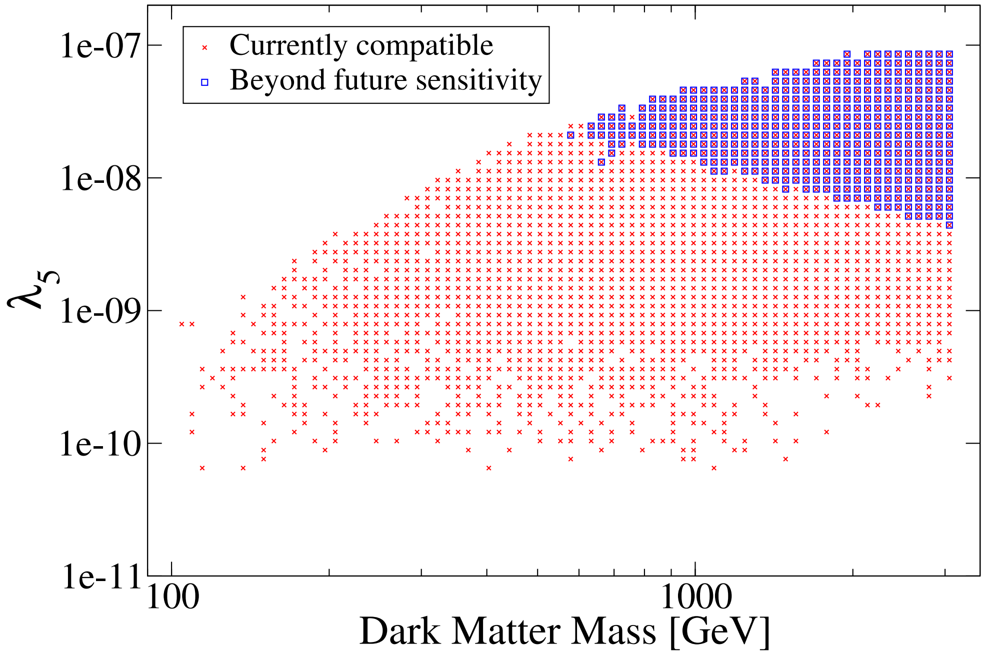
Final states contain a single lepton

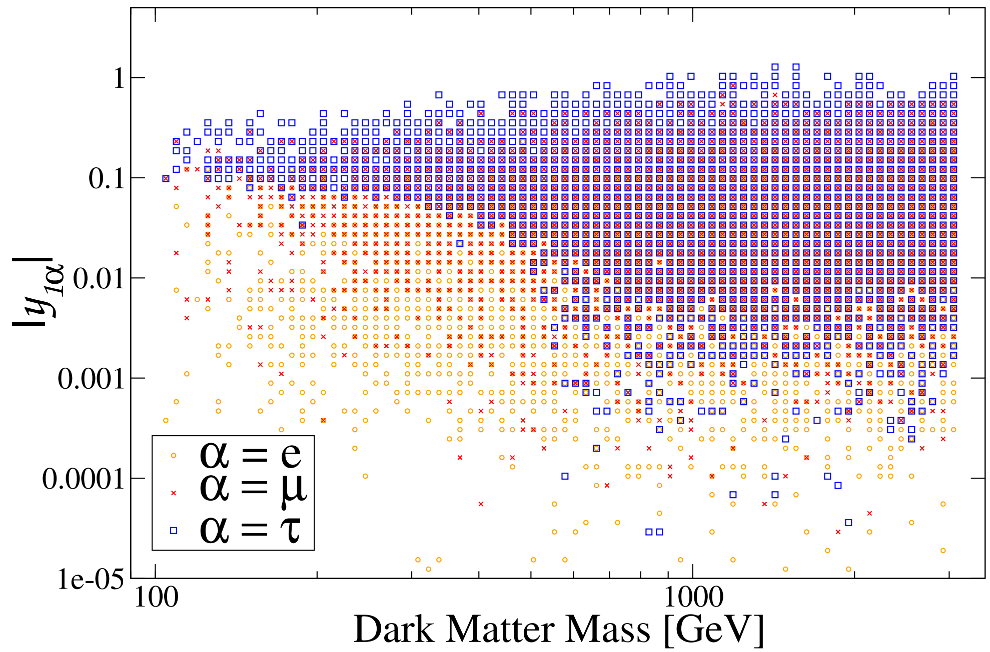
$$N_1 H^0 \to \nu Z,\ \ell^- W^+, \ell^+ W^-$$
$$N_1 H^+ \to \ell^+ \gamma, \ell^+ Z, \nu W^+$$

The coannihilation rate tends to be larger

$$\sigma \propto y^2$$

Coannihilations allow λ_5 to be larger and the Yukawas to be smaller

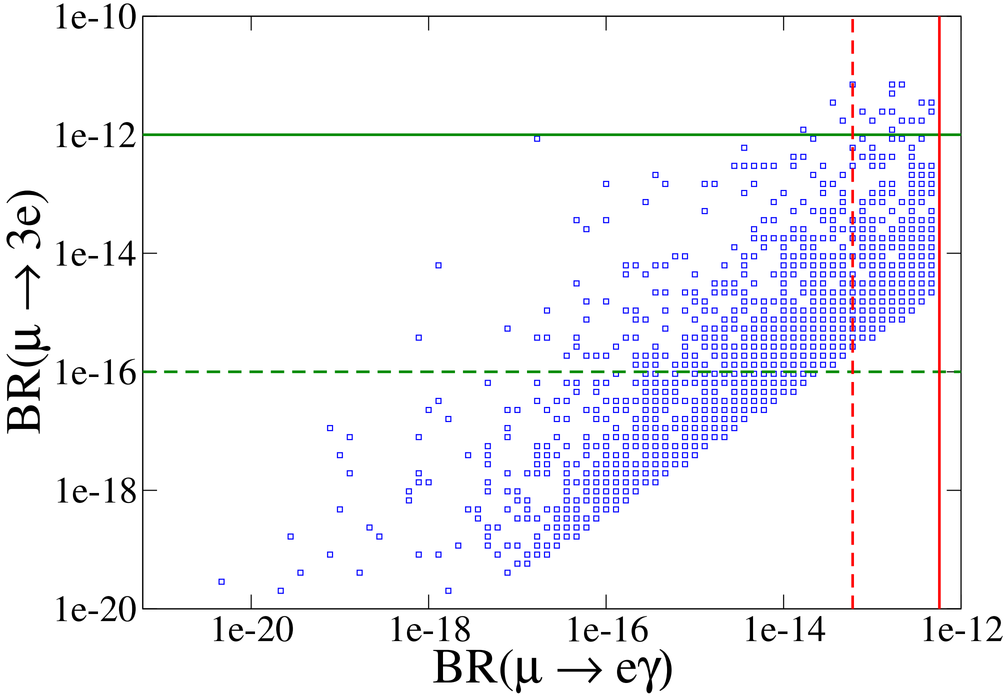


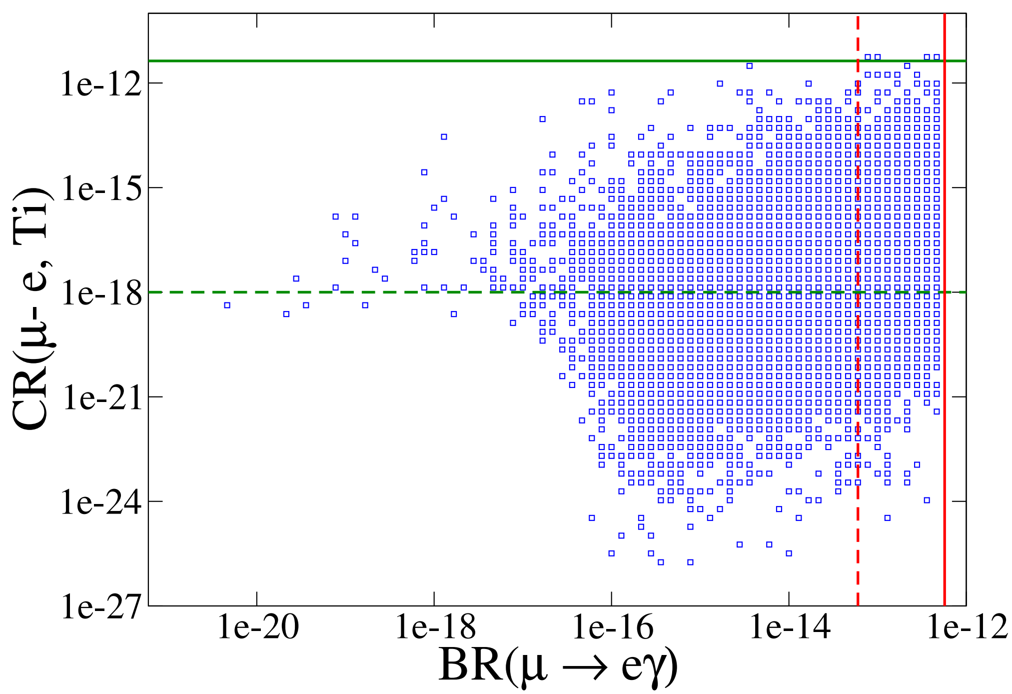


λ_5 varies between 10^{-10} and 10^{-7}

$y_{1\tau}$ can be suppressed for large M_{N_1}

Even in this case future LFV experiments will probe a large fraction of the parameter space





Models of 1-loop neutrino masses and dark matter feature a very rich phenomenology

They are simple and well motivated

They give rise to strong correlations

They can be tested via LFV experiments