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Mu-e Conversion in the Electroweak-scale Right-handed Neutrino Model

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Abstract

Within the framework of the Electroweak-scale right-handed neutrino (EW-ν_R) model, we calculate the rate for mu-e conversion with a particular aim at the sensitivities of the upcoming experiments, Mu2e (6×10^{-17}) and COMET (3×10^{-17}). Our calculations show a direct relationship between the rate for mu-e conversion and that for $\mu \to e + \gamma$. Upon comparing the projected sensitivities with the present limit from SINDRUM II (6.1×10^{-13}) and including the upper bound on $\mu \to e + \gamma$ (4.2×10^{-13}), we found that approximately only half of the allowed parameter space between the SINDRUM II limit and the sensitivities of Mu2e and COMET is available ($\sim10^{-17}$ –> 10^{-15}).

The Model

EW-ν_R model

A model in which right-handed neutrinos have Majorana masses (M_R) of the order of EW naturally. They can be detected at the LHC. For naturalness, M_R has to be related to the breaking scale of the SM therefore ν_R's cannot be a singlet of the SM. The simplest picture: ν_R is a member of a doublet of SU(2) along with a mirror charged lepton also right-handed => Mirror fermions. Then ν_R's are non-sterile. This model contains 2 Higgses doublets (Φ_2, Φ_{2M}) which give masses to fermions and mirror fermions, 2 triplets (χ, ξ) and one singlet (ϕ_S). The gauge group in this model is the same as SM (i.e $SU(3)_C \otimes SU(2)_W \otimes U(1)_Y$).

Framework — Electroweak-Scale Right-handed Neutrino Model (EW-ν_R)

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Tool — Discrete A_4 Symmetry

Building a neutrino mass model

A_4 symmetry

- Non-Abelian discrete group containing four irreducible representations: Three 1D representations called 1, 1', 1'' and One 3D representation called 3.
- The discrete symmetry group A_4 is widely popular in discussions of neutrino masses and mixings. Usually, it is applied to the charged lepton mass matrix and involves many Higgs doublets (5 or so) which cause potential problems with the 125-GeV scalar [2].
- This symmetry also helps to obtain the experimentally desired form of neutrino mixing matrix: **Pontecorvo–Maki–Nakagawa–Sakata (PMNS)** matrix.

Buiding a neutrino mass model

Let us apply A_4 to the neutrino Dirac mass matrix which involves a Higgs singlet ϕ_S. Under A_4 symmetry, we have an extension to 4 Higgs singlet fields. It is reasonable because of no constraints from the LHC!

Field	$\binom{\nu}{e}_L$	$\binom{\nu}{e^M}_R$	e_R	ν_R^M	ϕ_{0S}	$\tilde{\phi}_{kS}$	Φ_2	Φ_{2M}
A_4	3	3	3	3	1	3	1	1

Assignments of the model's content under A_4

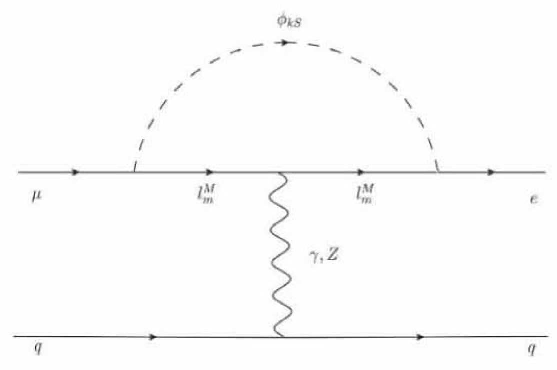
The Dirac neutrino mass matrix:

$$M_\nu^D = \begin{pmatrix} g_{0S}v_0 & g_{1S}v_3 & g_{2S}v_2 \\ g_{2S}v_3 & g_{0S}v_0 & g_{1S}v_1 \\ g_{1S}v_2 & g_{2S}v_1 & g_{0S}v_0 \end{pmatrix} \quad \text{Which can be diagonalized by : } U_{CW}^\dagger = \frac{1}{\sqrt{3}}\begin{pmatrix} 1 & 1 & 1 \\ 1 & \omega^2 & \omega \\ 1 & \omega & \omega^2 \end{pmatrix}$$

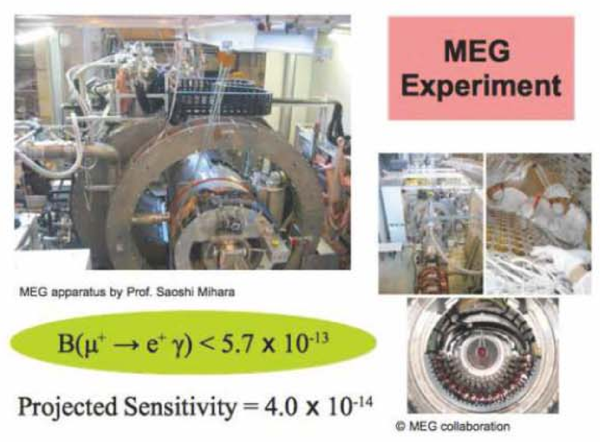
Where v_0, v_1, v_2, v_3 are VEVs of Higgs singlets and U_{CW} are Cabibbo-Wolfeinstein matrix

Mu-e conversion in the model

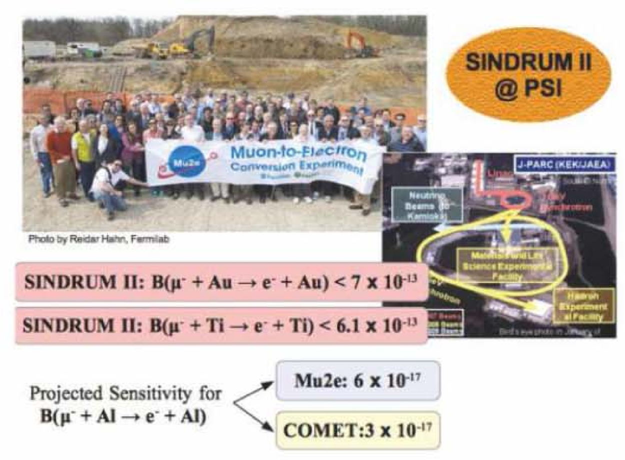
We are able to calculate the amplitude and partial width for the process: $l_i^-(p) \to l_j^-(p') + \gamma(q)$. This work makes full use of the results on mixings developed above. There are many possibilities which depend on the relative sizes of the Yukawa coupling g_{0S} and g_{iS} to the Higgs singlets.



Analysis and Results



Experimental constraints for $\mu \to e\gamma$

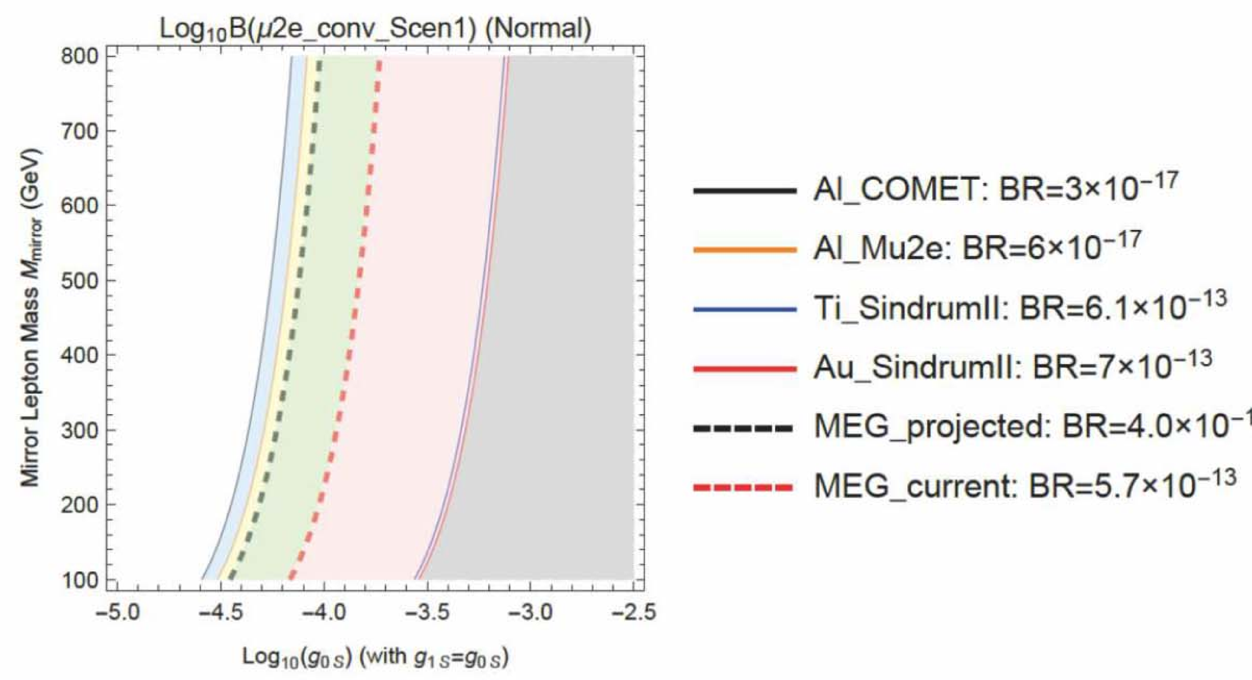


Experimental constraints for $\mu \to e$ conversion

Contributions to the $\mu \to e$ conversion rate include photonic process with an off-shell photon and four-fermion couplings with γ, Z, scalar Higgs and box diagram exchanges. By proving that the main contribution comes from the γ contribution, we are able to find a reasonable relation between $\mu \to e$ conversion and $\mu \to e\gamma$. In order to give you a better visualization, we have a contour plot of $\text{Log}_{10}B(\mu \to e \text{ conv})$ on the (g_{0S}, M_{mirror}) plane, in which we set Yukawa couplings to Higgs singlets to be equal as an example (other cases are considered in the paper [5]).

We have incorporated in experimental data from SINDRUM II, Mu2e and COMET for $\mu \to e$ conversion as well as MEG for $\mu \to e\gamma$. Interestingly, the constraints from $\mu \to e\gamma$ shown as a light green region between two dashed lines exclude the probed region corresponding to couplings > 10^{-4} for the branching ratio of $\mu \to e$ conversion.

Advantages? This specific relation can help save some work on future searches for $\mu \to e$ conversion at Mu2e and J-PARC COMET!



Conclusions

- In our analysis, we are showing that constraints from CLFV processes imply Yukawa couplings < 10^{-3}. Due to small couplings, searches for mirror particles of this model at the LHC would be quite interesting since they might decay outside the beam pipe and inside silicon vertex detectors (displaced vertices).
- We found a relation between $\mu \to e\gamma$ and $\mu \to e$ conversion within a good approximation.
- The current limit from $\mu \to e\gamma$ excludes almost half of the searched region for the branching ratio of $\mu \to e$ conversion. Therefore, our work may help narrow down future searches for $\mu \to e$ conversion at Mu2e and J-PARC COMET within this model.

References

1. P.Q. Hung, PLB 649 (2007)
2. V. Hoang, P.Q. Hung and A.S. Kamat, Nucl. Phys. B 896 (2015) 611
3. P.Q. Hung and T. Le, JHEP 09 (2015) 001
4. P.Q. Hung, T. Le, V.Q. Tran and T.C. Yuan, JHEP 12 (2015) 169
5. P.Q. Hung, T. Le, V.Q. Tran and T.C. Yuan, [arXiv:16xx.xxxxx [hep-ph]]
6. Other references can be found in the above papers.