Theory Challenges and Opportunities of Mu2e-II

RPF Townhall Meeting

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October 2, 2020

LOI: https://www.snowmass21.org/docs/files/summaries/RF/SNOWMASS21-RF5_RF0-TF6_TF0_Heeck-043.pdf

Introduction

Lepton Flavor Violation (LFV) will have a major role in the next decade because:

- Multiple experiments probing multiple signatures with a significant increase in sensitivity:
  - $\mu \to e\gamma$: MEG II
  - $\mu \to ee\bar{e}$: Mu3e
  - $\mu N \to eN$: Mu2e, COMET, DeeMe
- Sensitive to new particles as heavy as 10^4 TeV (far beyond LHC reach for direct detection)
- Sensitive to many different Beyond the Standard Model (BSM) models

Theoretical inputs for Mu2e(-II)

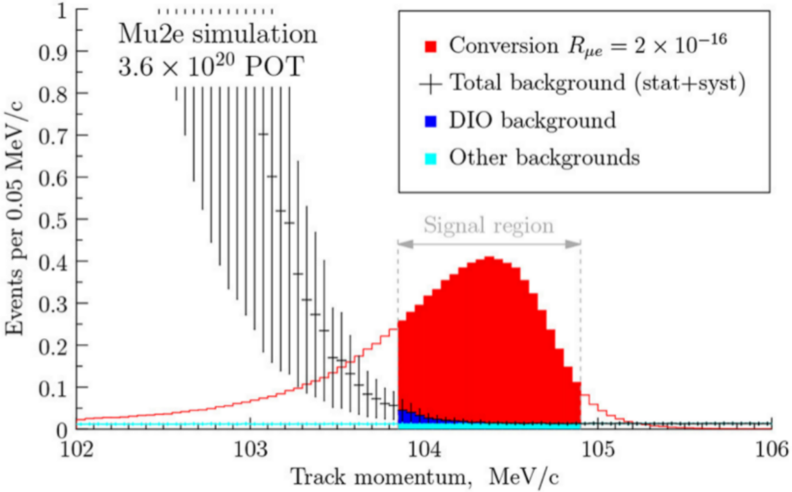
- Decay-In-Orbit (DIO) spectrum calculation for Al target:

$$\frac{m_\mu}{\Gamma_0}\frac{d\Gamma}{dE} \approx 1.24(3) \times 10^{-4} \left(\frac{E_{max} - E}{m_\mu}\right)^{5.023}$$

- Precise calculations are required as DIO are a irreducible SM background
- Need to repeat the calculations for Mu2e-II target material

R. Szafron, and A. Czarnecki, *High-energy electron from the muon decay in orbit: Radiative corrections*, Phys. Lett. B 753 (2016)

DIO spectrum for Al target



Choice of stopping target

- Mu2e(-II) will use a $^{27}_{13}\mathrm{Al}$ stopping target but can use another material if a signal is observed
- Z dependence of the conversion rate on the stopping target material can then distinguish between different BSM models
- 2 contributions: spin-independent (SI) (A^2 rate enhancement) and spin-dependent (SD)

Z dependence

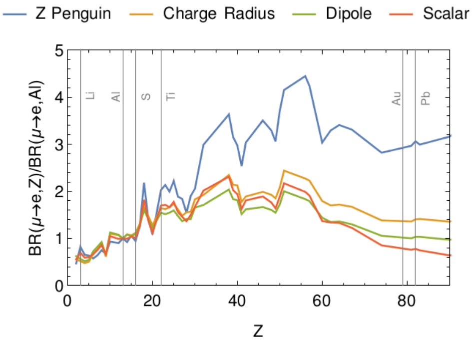


FIG. 1: Z dependence of $\mu \to e$ conversion rates for some example scenarios

R. Kitano, M. Koike and Y. Okada, *Detailed calculation of lepton flavor violating muon electron conversion rate for various nuclei*, Phys. Rev. D 66 (2002)
V. Cirigliano, R. Kitano, Y. Okada and P. Tuzon , *On the model discriminating power of $\mu \to e$ conversion in nuclei*, Phys. Rev. D 80 (2009)

Pros and cons of other materials

Good complementary materials to $^{27}_{13}\mathrm{Al}$:

1. heavy nuclei (Pb, Au)
   - strong signal and good discrimination power
   - short muon lifetime $\rightarrow$ increased pion background
   - low sensitivity to SD contribution
2. another light nucleus $^{7}_{3}\mathrm{Li}$
   - weaker signal and discrimination power
   - long muon lifetime
3. $^{48}_{22}\mathrm{Ti}$
   - similar rate as Al
   - spin-0 $\rightarrow$ no SD contribution
   - can use $^{47}_{22}\mathrm{Ti}$ (spin-5/2) or $^{49}_{22}\mathrm{Ti}$ (spin-7/2) to measure SI contribution

Exotic signals

- $\mu^- \to e^+$:
  - also violate lepton number ($\Delta L = 2$)
  - requires neutrinos to be Majorana particles
  - higher dimensional operators $\to$ more suppressed signal
- $\mu \to eX$ where X is a light new boson (Majoron, axion, Z')
  - weak constraints: BR $\approx 5 \times 10^{-5}$

$\mu \to eX$ electron spectrum shape

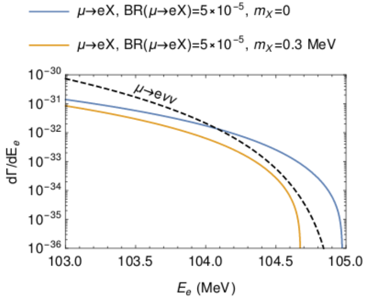


FIG. 2: The tail of $d\Gamma(\mu \to e\nu\nu)/dE_e$ (black, dashed) near the endpoint [27]. Following Ref. [37] we also show the tail of $d\Gamma(\mu \to eX)/dE_e$ corresponding to $BR(\mu \to eX) = 5 \times 10^{-5}$ (just below the current limit [34, 35]) for two values of m_X.

different shape of the electron spectrum tail close to the electron energy $E_{conv} \approx 105\ MeV$:

$$\text{DIO:} \quad \propto (E - E_{conv})^5$$
$$\text{exotic:} \quad \propto (E - E_{conv})^3$$

Summary

- Mu2e and Mu2e-II will achieve remarkable sensitivity to LFV via μ-to-e conversion in nuclei
- The theory group provides precise calculations of SM background, guide the choice of target materials, and explore new physics signatures that can be probed by these experiments