Microwave Conversion and Neutrino Magnetic Moment in Effective Theory

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Abstract

Lepton flavor violating (LFV) phenomena, such as neutrinoless double beta decay, are very sensitive to possible physics beyond the Standard Model (SM). Using effective field theory we parametrize new physics signatures in LFV phenomena, and get bounds for particular models, e.g., ones with leptoquarks (LQ).

Motivation

LFV is forbidden in the SM (without neutrino masses) by flavor symmetry. However it may occur at either tree or loop level in many SM extensions, which provides important clues to test them. Effective theory is a general framework for description of the effects of all these models.

In wide class of models $\nu_\mu \rightarrow \nu_\tau$ conversion in nuclear media is enhanced by large logarithms comparing with $\nu_e \rightarrow \nu_\mu$ [1].

Present bound on model $\nu_\mu \rightarrow \nu_\tau$ conversion ratio is [2]

$$\delta_{\mu \tau} = \frac{\Gamma(\nu_\mu \rightarrow \nu_\tau)}{\Gamma(\nu_\mu \rightarrow \nu_e)} < 2 \times 10^{-11} \quad (\text{capture}),$$

while Mu2e sensitivity goal is $5 \times 10^{-13}$ [3].

The strongest present limit on NMM [4]

$$\rho_{\mu \tau} < 5 \times 10^{-12} \rho_{\mu \mu},$$

and $\rho_{\mu \tau} \approx 5 \times 10^{-12}$ MeV c$/\text{cm}^2$ is the order of magnitude weaker than Eq. (2).

Such high sensitivity of present experiments on $\nu_\mu \rightarrow \nu_\tau$ conversion and NMMs is rather important in the new physics searches.

In the SM, minimally extended to include neutrino masses, the diagonal and transition NMMs are Refs. [5] and [6].

$$\left| \langle \delta \nu_\mu \rangle \right| \leq 10^{-24} \quad (\text{capture})$$

and $\left| \langle \delta \nu_{\mu \tau} \rangle \right| \leq 10^{-22} \quad (\text{capture})$, respectively.

We can neglect the lepton flavor violating terms in the NMMs and get the following bounds on the diagonal and transition neutrino mass differences:

$$\Delta m_{\mu \mu} \lesssim 10^{-10} \text{eV},$$

$$\Delta m_{\mu \tau} \lesssim 10^{-12} \text{eV},$$

which are consistent with experimental data.

Microwave conversion

$\nu_\mu \rightarrow \nu_\tau$ conversion can be described by the effective theory with the operators of dimension 5 and 6 [1]. However the operators of dim. 7, involving two gluonic tensors [10], may be important since gluonic couplings to nucleons are not suppressed, and the new physics couplings to heavy quarks are not well constrained.

We consider the flavor changing Lagrangian

$$\mathcal{L}_{\mu \tau}^{\text{FC}} = \frac{\lambda}{4} \overline{\nu}_\mu \gamma_\mu \Gamma_{\mu \tau} \nu_\tau + \text{H.c.},$$

where $\lambda$ is a scale parameter for $\nu_\mu \rightarrow \nu_\tau$ conversion.

Models with leptoquarks

The bounds in Table 2 can be used for restricting the physical parameters of particular models, e.g., models with LQs. The general renormalizable, $\beta$ and $\gamma$ conserving, and $\mathcal{SU}(2) \times \mathcal{SU}(2)$ invariant LQ-lepton-quark interactions are given in Refs. [14, 15, 16].

The scalar (S) and vector (V) $\mathcal{L}$ interactions relevant for the Lagrangian in Eq. (4) are

$$\mathcal{L}_{\mu \tau}^{\text{S}} = \lambda_{\mu \tau} S_{\mu \tau} \nu_\mu \nu_\tau + \lambda_{\mu \tau} V_{\mu \tau} \nu_\mu \nu_\tau + \text{H.c.},$$

$$\mathcal{L}_{\mu \tau}^{\text{V}} = \lambda_{\mu \tau} V_{\mu \tau} \nu_\mu \nu_\tau + \lambda_{\mu \tau} S_{\mu \tau} \nu_\mu \nu_\tau + \text{H.c.},$$

where we omit flavor indices, the subindices $0$ and $1/2$ indicate $SU(2)$ singlet and doublet LQ, respectively, and couplings $\lambda$ are assumed to be real. These LQ interactions induce the effective vertices of the form of Eq. (12). By further matching with Eq. (5), assuming that only the couplings $\lambda$ for a single quark flavor are nonzero at a time, for the common scales $M_S$ and $M_V$ of scalar

Table 2: Upper bounds on the couplings $\lambda_{\mu \tau}$

We note that Eq. (23) reproduces the leading order in the exact result, which can be derived in the case of scalar LQs, and is given for the exact expressions of diagonal NMMs.

We note that the bound on $\lambda_{\mu \tau}$ from $\nu_\mu \rightarrow \nu_\tau$ scattering, derived in [44], is comparable with the respective bound in Table 3.

Table 3: Upper bounds on the couplings $\lambda_{\mu \tau}$

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References