Search for new physics using a precision measurement of the $K_{e2}/K_{\mu 2}$ branching ratio

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Abstract. A new experiment at J-PARC proposes to test lepton universality and search for new physics beyond the Standard Model (SM) by measuring the ratio, $R_K = \Gamma(K^+ \to e^+\nu_e)/\Gamma(K^+ \to \mu^+\nu_\mu)$ with an accuracy of 0.25%. Experiment E36 will use a stopped K^+ beam, a 12-sector iron-core superconducting toroidal magnet, and a 768 element CsI(Tl) calorimeter which will provide completely different systematics than the existing in-flight CERN NA62 and KLOE experiments.

Keywords: Kaon Decay, Lepton Universality, BSM
PACS: 11.30.Hv, 12.60.Fr, 13.20.Eb

INTRODUCTION

High precision electroweak measurements have long been used as stringent tests of Standard Model (SM) predictions and any deviations from these predictions will indicate new physics. The semi-leptonic kaon decay $K^+ \to l^+\nu_l$ (K_{l2}) is one of the best channels to perform such tests since lepton universality is one of the basic assumptions in the SM. By measuring the branching ratio of the electric (K_{e2}) and muonic ($K_{\mu 2}$) decay modes the hadronic form factor in K_{l2} decay cancels out, and the helicity suppression in K_{e2} greatly enhances the sensitivity to new physics. The SM prediction, R_K^{SM} can be computed with very high accuracy [1],

$$R_K^{SM} = \frac{\Gamma(K^+ \to e^+\nu_e[\gamma])}{\Gamma(K^+ \to \mu^+\nu_\mu[\gamma])} = \frac{m_e^2}{m_\mu^2}\left(\frac{m_K^2 - m_e^2}{m_K^2 - m_\mu^2}\right)^2 (1+\delta_r) = (2.477 \pm 0.001) \times 10^{-5} \quad (1)$$

where δ_r is a correction due to the internal bremsstrahlung process (IB), which unlike the structure dependent process (SD), is included in R_K^{SM}.

Recently, a minimal SUSY extension of the SM (MSSM) with R parity has been considered [2] as a candidate for the new physics to be tested by R_K. A charged Higgs-mediated SUSY LFV contribution, as shown in Fig. 1, can be strongly enhanced by emitting a τ neutrino after mixing in the right-handed slepton sector. The dominant contribution is predicted to be

$$\Delta R_K^{LFV}/R_K^{SM} = \frac{m_K^4}{M_{H^+}^4} \cdot \frac{m_\tau^2}{m_e^2}\, |\Delta_R^{31}|^2 \tan^6\beta \quad (2)$$

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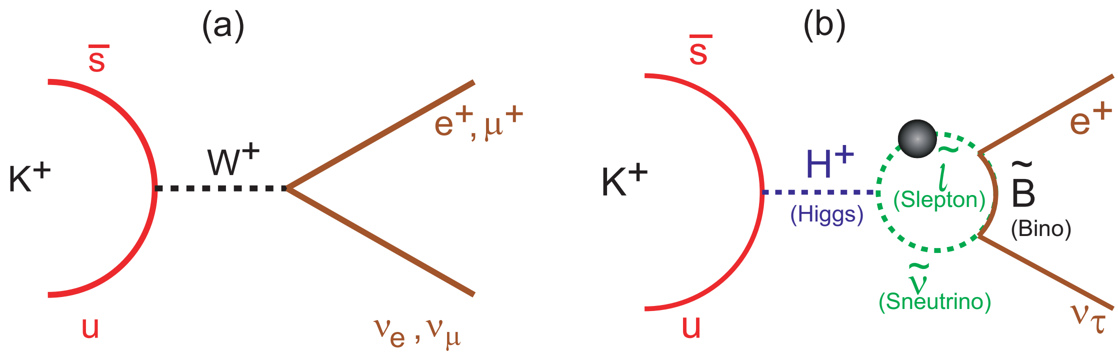

FIGURE 1. Contributions to R_K from (a) SM and (b) LFV SUSY. A charged Higgs-mediated LFV SUSY contribution can be strongly enhanced by the emission of a τ neutrino.

where M_H is the charged Higgs mass and Δ_R^{31} is the term induced by the exchange of a Bino and a slepton. Taking $\Delta_R^{31} = 5 \times 10^{-4}$, $\tan\beta = 40$, and $M_H = 500$ GeV, $\Delta R_K^{LFV} = 0.013 \times R_K^{SM}$ can be reached. Thus, it is possible to reach a contribution at the percent level thanks to the possible LFV enhancements arising in SUSY models.

The current world average is $R_K = (2.488 \pm 0.009) \times 10^{-5}$ based on the recent NA62 [3, 4] and KLOE [5] in-flight decay experiments. Our proposed stopped K^+ decay experiment aims to obtain a factor of two improvement in the combined systematic and statistical uncertainty.

R_K MEASUREMENT USING STOPPED KAONS AT J-PARC

The new E36 experiment will be performed with the TREK apparatus at J-PARC using a stopped K^+ beam (see Fig. 2). The $K_{e2}(p_{e^+} = 247$ MeV/c) and $K_{\mu 2}(p_{\mu^+} = 236$ MeV/c) events will be detected using the TREK 12-sector toroidal spectrometer [6]. In order to compare the experimental R_K value with the SM prediction the internal bremsstrahlung process in radiative $K^+ \to e^+ \nu_e \gamma (K_{e2\gamma}^{IB})$ and $K^+ \to \mu^+ \nu_\mu \gamma (K_{\mu 2\gamma}^{IB})$ decays must be included in the K_{e2} and $K_{\mu 2}$ samples, respectively. The $R_K = \Gamma(\tilde{K}_{e2})/\Gamma(\tilde{K}_{\mu 2})$ value can be derived from the number of accepted events $(\tilde{N}), \tilde{K}_{e2} = K_{e2} + K_{e2\gamma}^{IB}$ and $\tilde{K}_{\mu 2} = K_{\mu 2} + K_{\mu 2\gamma}^{IB}$ events, corrected for the detector acceptance. The acceptance ratio can be computed by Monte Carlo but it will also be measured using the $K_{\mu 3}$ spectrum at a reduced B field. Charged particles emitted from the active scintillating fibre target will be tracked and momentum analyzed using one GEM detector and three MWPCs in each toroidal sector at B=1.4 T. Momentum cuts at 228 and 215 MeV/c will be used to remove the $K^+ \to \pi^0 e^+ \nu_e (K_{e3})$ and $K^+ \to \pi^0 \mu^+ \nu_\mu (K_{\mu 3})$ backgrounds, respectively. Particle ID will be carried out using (1) aerogel Cherenkov counters surrounding the target, (2) by TOF between counters located just outside the target and at the exits of the magnet sectors, and (3) by lead glass counters (PGC) placed behind the TOF2 counters.

The analysis procedure will be exactly identical for both K_{e2} and $K_{\mu 2}$ except for the particle identification in order to reduce the systematic error due to the analysis. The structure dependent (SD) background events will be rejected using the CsI(Tl) data. The

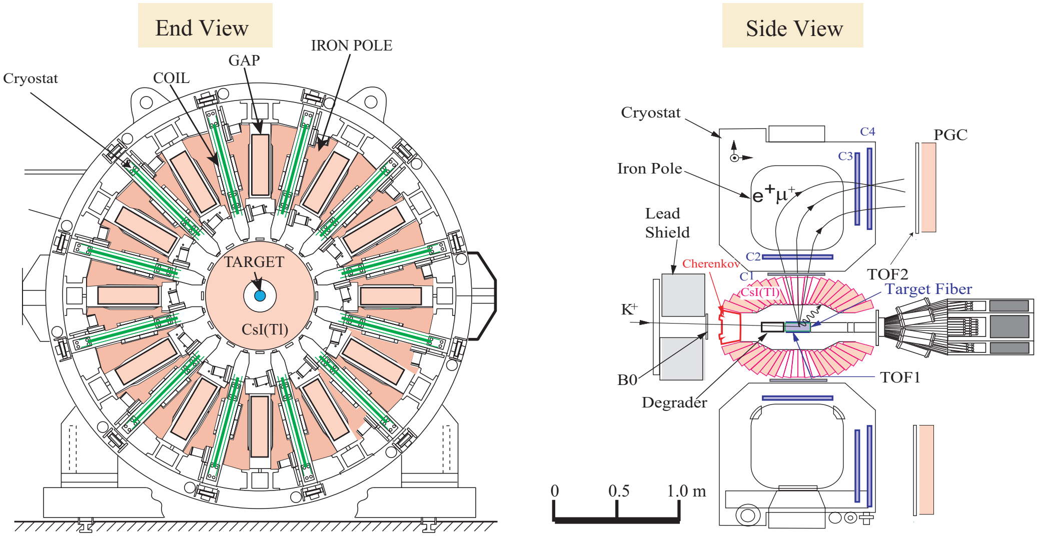

FIGURE 2. End- and side-views of the TREK detector system at J-PARC.

statistical error of the R_K value will be dominated by that of the accepted K_{e2} events. Assuming a J-PARC main ring power of 30 kW we expect a K^+ beam intensity of $\sim$200 kHz at the target position. Hence the number of accumulated K_{e2} events after 50 days of data collection will be $\sim 250 \times 10^3$ corresponding to a statistical error of $\Delta R_K \sim 0.0054$ $(\Delta R_K/R_K \sim 0.2\%)$. We have simulated the systematic errors due to (1) the uncertainty of the detector acceptance ratio, (2) the performance of the CsI(Tl) calorimeter and the PID systems, (3) the chamber inefficiencies, (4) the subtraction of the SD backgrounds, (5) the π^0 backgrounds from K_{e3} and $K_{\mu 3}$ decays, and (6) the imperfect reproducibility of the experimental conditions. The total systematic error is estimated to be $\Delta R_K/R_K = 0.15\%$ after adding all items in quadrature. The statistical error can be reduced even further with more beam time. Data collection is planned to start in the fall of 2014.

ACKNOWLEDGMENTS

This work is supported in part by the NSERC and NRC in Canada, the KAKEN-HI Grants-in-Aid for Scientific Research in Japan, the DOE and NSF in the US, and in Russia by the Ministry of Science and Technology.

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