The Time Reversal Experiment with Kaons (TREK) at J-PARC

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Abstract. The Time Reversal Experiment with Kaons (TREK) at J-PARC aims to find CP violation beyond the Standard Model in the semi-leptonic $K^+_{\mu 3}$ decay mode by measuring the T-violating transverse polarization P_T of outgoing muons. TREK makes use of the intense kaon beam at J-PARC stopped in a target and employs an optimized setup with excellent control of systematic uncertainties. The sensitivity at J-PARC is improved by a factor of 20 compared to the current uncertainty for P_T, well in the predicted range of various New Physics models. An overview of the planned experiment and current status will be presented.

Keywords: time reversal symmetry violation, transverse muon polarization, kaon decay
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Despite its great successes in recent years culminating in the 2008 Nobel Prize decision, which was announced during this symposium, the Standard Model is widely believed to be incomplete as it leaves many fundamental questions unanswered such as the mechanism of baryogenesis and electroweak symmetry breaking. Experimentally, it is of greatest importance to find evidence for New Physics beyond the Standard Model in accessible observables. Electroweak theory allows to link T-odd observables (which change sign under time reversal transformation) to time reversal symmetry breaking, which can be interpreted as clear indication of New Physics. The CPT theorem then allows to connect T violation to CP violation. The transverse polarization P_T of muons in stopped K^+ decays in the $\mathrm{K}^+_{\mu 3}$ mode $\mathrm{K}^+ \to \mu^+ \pi^0 \nu_\mu$ is such a long-recognized example [1] and is depicted in Fig. 1.

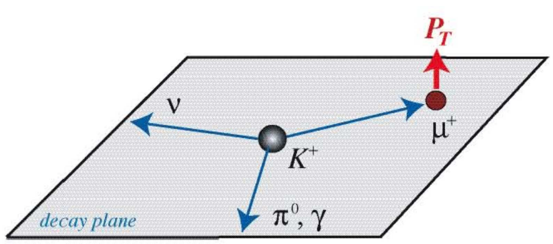

FIGURE 1. Transverse muon polarization P_T in $K^+_{\mu 3}$ decays at rest.

The Standard Model prediction for P_T is extremely small, of order 10^{-7}, arising from higher-order loop contributions. Final-state interaction in the semi-leptonic mode is precisely calculable and does not exceed 10^{-5} in the $\mathrm{K}^+_{\mu 3}$ channel. On the other hand, models involving New Physics such as multi-Higgs doublet models, leptoquark models or supersymmetric models with R-parity breaking or s-quark mixing give rise to finite values of P_T ranging from 10^{-4} to 10^{-2}.

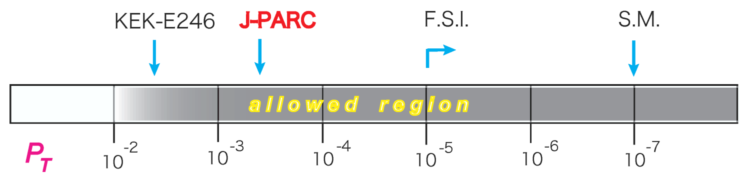

FIGURE 2. Sensitivity of P_T to New Physics. Also marked are the 90% confidence limits achieved by E-246 and projected for TREK.

The proposed Time Reversal Experiment with Kaons (TREK) at J-PARC [2] will be sensitive to P_T to the order 10^{-4}, thereby improving the current limit on P_T by a factor 20 and probing deeply inside the window of New Physics in this channel.

Experimentally, P_T can be measured by polarimetry of muons after identifying the $K^+_{\mu 3}$ decay mode in stopped K^+ decays. The kinematics of this decay is completely determined by measuring energy and angle of the outgoing μ^+ (using a toroidal magnetic field and spatially sensitive tracking detectors) and the π^0 (using a large-acceptance CsI(Tl) calorimeter). In a second step, the transverse polarization of the outgoing muon is determined in a muon polarimeter based on the measured direction of emitted positrons in stopped $\mu^+ \rightarrow e^+ \nu_e \bar{\nu}_\mu$ decays.

The proposed experiment TREK at J-PARC reuses most of the existing setup of the predecessor experiment E-246 at KEK-PS shown in Fig. 3, which had resulted in the current upper limit of $P_T < 5 \cdot 10^{-3}$ (90% C.L.) [3]. The superconducting toroidal magnetic spectrometer has twelve sectors equally instrumented. The rotational symmetry of the arrangement helps reducing systematic uncertainties.

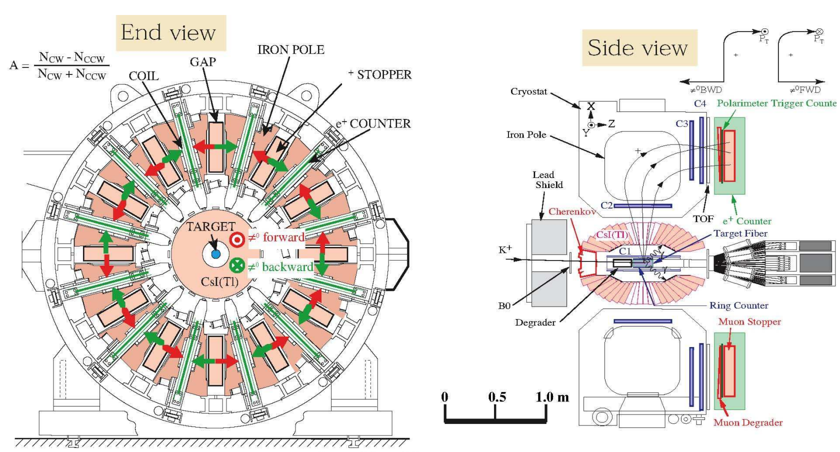

FIGURE 3. Schematic drawing of the E-246 apparatus to be reused by TREK in end view (left) and side view (right). The T-violating asymmetry is recorded from different positron count rates in clockwise and counterclockwise direction. Distinguishing between forward and backward pions corresponds to flipping of the decay plane, leading to a sign change of the asymmetry.

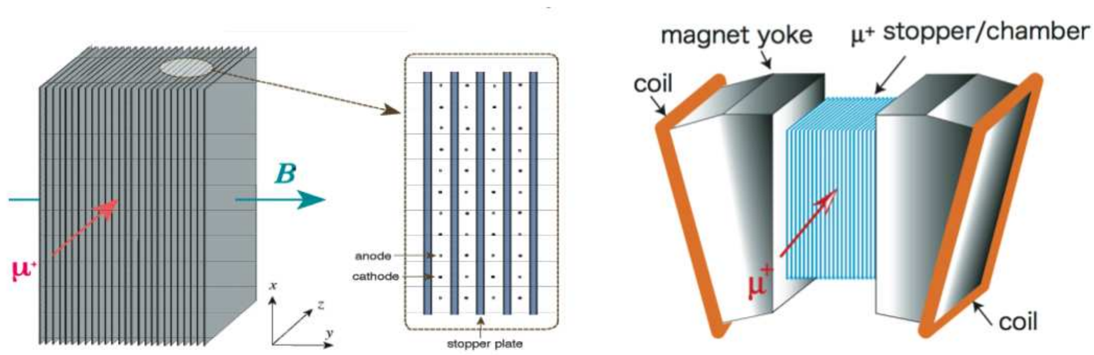

FIGURE 4. Schematic layout of the active muon polarimeter for TREK.

The previous E-246 system will be upgraded to meet the requirements of statistical and systematic uncertainties of TREK. The higher kaon beam intensity at J-PARC in combination with an increased acceptance of the upgraded setup with a newly designed active muon polarimeter will improve the statistical error by a factor 20 to 10^{-4} in less than one year of running time. While the previous passive polarimeter consisted of a stack of muon stoppers between simple plastic scintillators to count the clockwise and counterclockwise emitted positrons, the new active muon polarimeter (see Fig. 4) uses aluminum stopping plates parallel to the muon path, with the intermediate space between the plates designed as a wire chamber. This design results in a substantially larger solid angle acceptance to detect the decay positrons with good angular and certain energy resolution. In addition, a dedicated homogeneous holding field is used to ensure a polarization alignment relative to the field.

The higher count rates in TREK require a faster readout of the CsI(Tl) calorimeter, which will be based on avalanche photo diodes (APD) with new current amplifiers. The kaon stopping target has been redesigned with smaller diameter and higher segmentation by using a bundle of 432 scintillating fibers each 3 mm thick, resulting in 7.5 cm diameter. Promising tests of performance and radiation hardness have been conducted with multi-pixel photon counters (MPPC) as a novel fiber readout technology.

It has been demonstrated with detailed simulations that the systematic uncertainties can be reduced to $< 10^{-4}$. Alignments of tracking elements and the polarimeter will be calibrated with real tracks. The tracking capability for charged particles will be improved near the target region in order to identify and suppress backgrounds from charged pion tracks decaying in flight which resemble true $K^+_{\mu 3}$ events and which can cause spurious asymmetries. Identifying this class of events is only possible by adding near-target tracking elements in the field-free inner region of the toroid, which requires robust technology in the high-rate environment given. Therefore, the charged tracking upgrade will be based on the novel Gas Electron Multiplier (GEM) technology [4]. It is envisioned to construct a cylindrical GEM tracking detector (C0) surrounding the target assembly inside the CsI(Tl) calorimeter barrel, as well as additional planar GEM elements (C1) to cover the muon gaps outside the barrel in each of the twelve sectors. In addition, it is considered to fill previous large air gaps with He bags to reduce multiple scattering effects. The anticipated tracking upgrade for TREK is illustrated in Fig. 5.

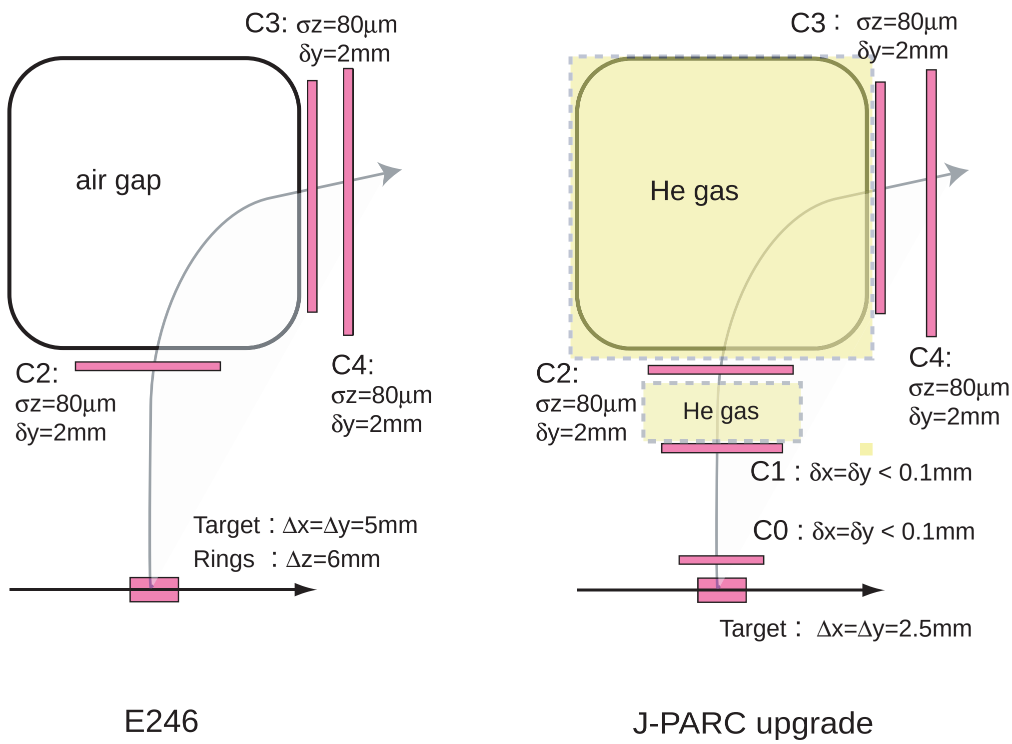

FIGURE 5. Proposed upgrade of the charged-particle tracking system.

In summary, a new generation of experimental search for T-violating transverse muon polarization in stopped-kaon decays has been proposed with TREK at J-PARC. The sensitivity of TREK will improve the current upper limit of P_T by at least a factor 20. The proposed experiment uses the previous E-246 apparatus after applying upgrades to various components.

ACKNOWLEDGMENTS

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