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An active polarimeter system for the TREK experiment at J-PARC

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An experiment to search for a T-violating muon polarization in $K^+ \rightarrow \pi^0\mu^+\nu$ decay at J-PARC is currently being prepared. The most essential component in this experiment is the active polarimeter for the determination of the μ^+ and e^+ tracks to reduce the systematic error to below the 10^{-4} level. The active polarimeter consists of muon stopper plates with gaps which function as multi-wire drift chambers. For the position determination in each gap, normal drift time and charge division analyses are employed in the beam and the radial directions, respectively.

In order to check the performance of the polarimeter chamber, we constructed a 1/5 prototype model and carried out a test experiment at the Fuji Test Beam Line (FTBL) in KEK. The chamber efficiency integrated over the entire chamber volume was obtained to be higher than 99.5%. The most probable straight line was obtained by a least-squares-method from the observed hit positions. The position resolution of each layer was determined from the width of (fit$-$data) residual distribution to be 2mm in σ. The chamber efficiency and position resolution are good enough to perform the TREK experiment using a polarimeter chamber based on the current design.

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1. Introduction

Time reversal symmetry (T) has long been a subject of interest, since it implies the microscopic reversibility of motion. In modern quantum field theories, it has received renewed attention as a discrete symmetry of space/time along with charge conjugation and parity reflection.

The transverse muon polarization (P_T) in $K^+ \to \pi^0\mu^+\nu$ ($K_{\mu3}$) with T-odd correlation is a clear signature of T-violation [1]. P_T in $K_{\mu3}$ has the advantage that the final state interactions (FSI) are very small. This effect is only from higher order loop levels and can be accurately calculated to be $P_T \leq 10^{-5}$ [2]. However, the most important feature of a P_T study is the fact that the contribution to P_T from the Standard Model (SM) is nearly zero ($P_T \sim 10^{-7}$). Therefore, in a P_T search we can investigate new physics beyond the SM [3]. Several candidate theories can give rise to sizable P_T ($\sim 10^{-3}$ or even $\sim 10^{-2}$), eg., multi-Higgs doublet model, leptoquark model, and SUSY with R-parity violation and s-quark mixing have been studied. The physics potential of a P_T search in terms of the discovery of new physics along with the power to constrain the various exotic models has been shown to be competitive with other experiments being planned or prepared.

2. Active polarimeter in the TREK experiment

At the KEK-PS, the E246 collaboration performed a search for P_T in $K_{\mu3}$ decay using a stopped K^+ beam in conjunction with a superconducting toroidal spectormeter, as shown in Fig. 1. An upper limit $P_T = -0.017 \pm 0.0023(stat) \pm 0.0011(syst)$ has been published [4]. A new experiment to improve the sensitivity of P_T down to 10^{-4} is now being prepared at J-PARC with reasonable upgrading of the previous E246 system (TREK) [5, 6]. The most essential detector component in the TREK experiment is the active polarimeter which is used to determine the μ^+ and e^+ tracks and obtain the transverse muon polarization from the e^+ asymmetry in azimuthal direction, as shown in Fig. 2. Systematic errors due to imperfections in the experimental conditions will be drastically suppressed in TREK, compared to the passive polarimeter which measured just the incoming μ^+ and the outgoing e^+ in E246. This new polarimeter has been designed to measure P_T primarily as the azimuthal e^+ asymmetry, although asymmetry components in other directions corresponding to different π^0 kinematics will also be possible to analyze pending a more elaborate systematic study.

The active polarimeter consists of muon stopper plates with gaps which function as multi-wire drift chambers. Fig. 2 shows the schematic configuration of the polarimeter with the new muon spin-holding magnet. The plates are arranged in the azimuthal direction along which we measure the left/right asymmetry of the e^+ emission, and the sense wires are strung in the radial direction. The wire arrangement is adopted to be a staggered structure with a large aspect ratio of 2. For the position determination, normal drift chamber and charge division analyses are applied in the beam(z) and the radial(r) directions, respectively.

3. The 1/5 prototype chamber and the test experiment at FTBL

According to a Monte Carlo simulation, the position resolution along the wire direction is required to be better than 2mm in σ. In order to check the performance of the position determination by the charge division, we constructed a 1/5 prototype chamber and performed a test experiment at

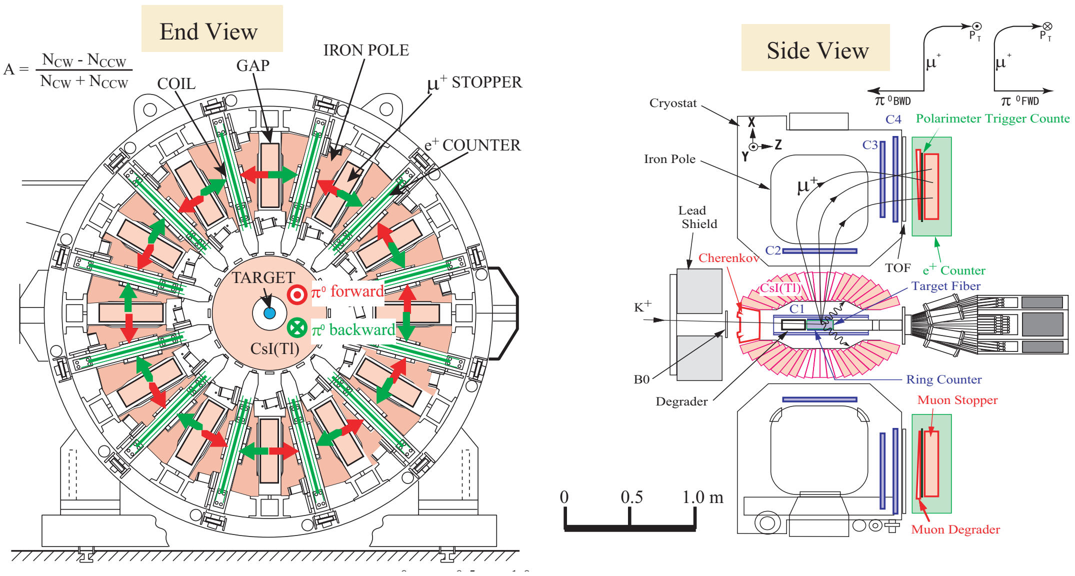

Figure 1: Cross sectional end and side views of the TREK setup. The momentum vectors of charged particles and π^0s are determined by the Toroidal spectrometer and the CsI(Tl) calorimeter, respectively. By tagging forward and backward going π^0 events, P_T can be measured as the e^+ asymmetry in the azimuthal direction.

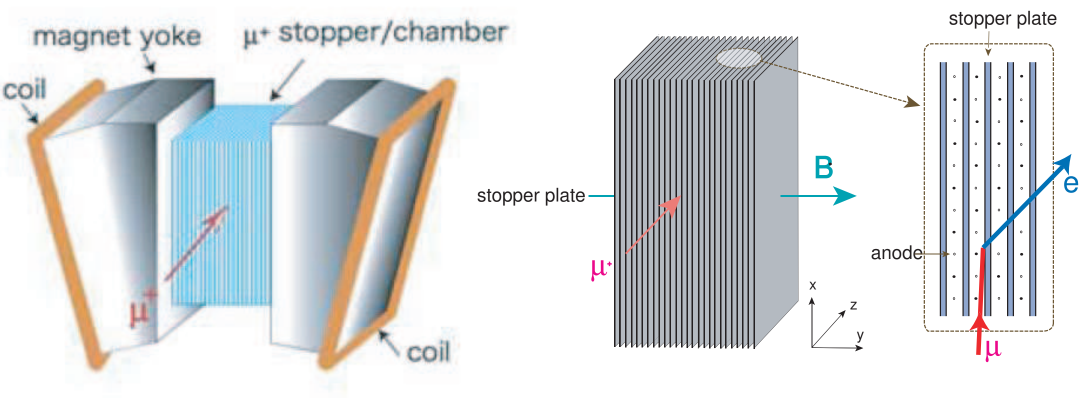

Figure 2: The schematic configuration of the polarimeter with the muon spin-holding magnet. The active polarimeter consists of muon stopper plates with gap multi-wire drift chambers. For the position determination, normal drift time and charge division analyses are employed in the beam and radial directions, respectively.

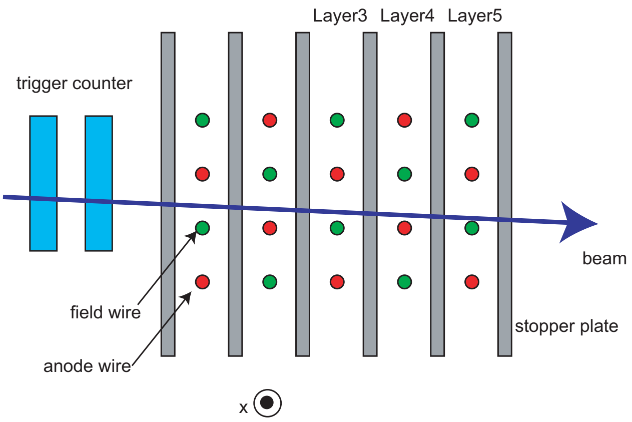

Figure 3: The schematic configuration of the efficiency and position resolution determinations. The efficiency was obtained by requiring L3 and L5 hits and then checking for signals from L4. The particle hit positions in layers 1, 3, and 4 were calculated using event-by-event data, and the position resolution was obtained from the width of the residual distribution (fit−data) in each layer.

the Fuji Test Beam Line (FTBL) in KEK [9]. The 1/5 prototype chamber had a 5- layer structure. The stopper plates were 2.5mm in thickness and the gap between the plates was 8 mm. The resistive wires used in this experiment were SUS304 ($\phi = 20\mu$m) for the first layer and Stablohm800 ($\phi = 20\mu$m) for the other layers. The wire length was 65 cm and the total resistance was 1.9 kΩ for SUS304 and 2.54 kΩ for Stablohm800. The wire ends were connected to pre-amplifiers (amplifier/discriminator) and the output signals were thus obtained. A mixed gas of Ar (50%) and ethane (50%) was used as the operating gas. Two plastic scintillation counters were located in front of the chamber to generate a trigger signal. The main purpose of the test experiment was to check (1) the detection efficiency and (2) the performance of the position determination using the charge division method.

4. Results of the test experiment

4.1 Detection efficiency

The chamber inefficiency introduces a local asymmetry for the e^+ response in the polarimeter, which would introduce a finite systematic effect for the P_T measurement. Since the polarimeter chamber has a wire structure with a large aspect ratio, we have to take care of, in particular, events where the charged particle passes far from the sense wire.

The detection efficiency was determined by requiring Layer3 (L3) and Layer5 (L5) hits and then checking for signals from Layer4 (L4), as shown in Fig. 3. Fig. 4(a) shows the efficiency distribution as a function of the distance from the sense wire to the particle hit position on L4. The detection efficiency integrated over the entire chamber volume is about 99.8%. On the other hand, the detection efficiencies when the particles pass close to the field wire (far from the sense wire) were determined by changing the beam hit position along the wire direction, as shown in Fig. 4(a). Even for such a special case, the efficiency was still greater than 95%. Taking into count

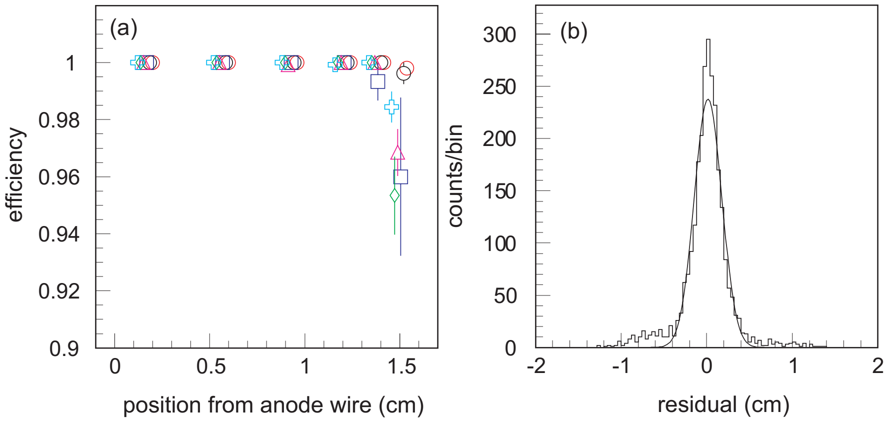

Figure 4: Results of the test experiment: (a) chamber efficiency as a function of the particle hit position from the sense wire, (b) typical spectrum of the (fit−hit) residual distribution. The beam positions are +5cm(red circle), −5cm(black circle), +5cm(red triangle), −5cm(tetra), +15cm(square), and −15cm(diamond). The peak width of the residual distribution was regarded as the position resolution.

these results, the systematic error due to wire inefficiencies was estimated from the Monte Carlo simulation to be better than 10^{-4}.

4.2 Position resolution obtained by charge division

Fig.5 shows schematic view of (a) the charge division method and (b) an equivalent electric circuit of the system. The collected charge in the virtual capacitors is discharged through the resistances. Experimentally time-integrated currents are observed as Q_1 and Q_2 charges, respectively. In the coordinates where x is the distance of the particle hit position from the center ($x = 0$ is center), x is written as,

$$\frac{x}{Z} = \frac{1}{2}(1+\frac{r_1+r_2}{R})\frac{Q_1-Q_2}{Q_1+Q_2} - \frac{r_1-r_2}{2R}, \tag{4.1}$$

where r_1 and r_2 are the input impedances of the pre-amplifiers [7, 8]. R and Z are the total resistance and the total length of the anode wire, respectively. From Eq.(4.1), the wire length can be regarded to be extended due to the input impedance of amplifiers. In other words, the resolution of x becomes a factor of $1+(r_1+r_2)/R$ worse than that of $1/2\cdot(Q_1-Q_2)/(Q_1+Q_2)$.

The particle hit positions in layers 1, 3, 4, and 5 were calculated on an event-by-event basis using Eq.(4.1). Then, the most probable straight line was determined by the least-squares-method. The beam energy was sufficiently high (2 GeV) that we can neglect scattering effects. The position resolution was obtained from the width of the residual distribution (fit−data) in each layer, as shown in Fig. 5(b). The typical position resolution was 2mm in σ, which is good enough to perform the experiment using such a chamber with a charge division readout system.

5. Summary

We are currently preparing a new experiment to search for a finite P_T effect in the $K_{\mu 3}$ decay at J-PARC. The P_T sensitivity will be improved to be better than 10^{-4}. The most essential detector

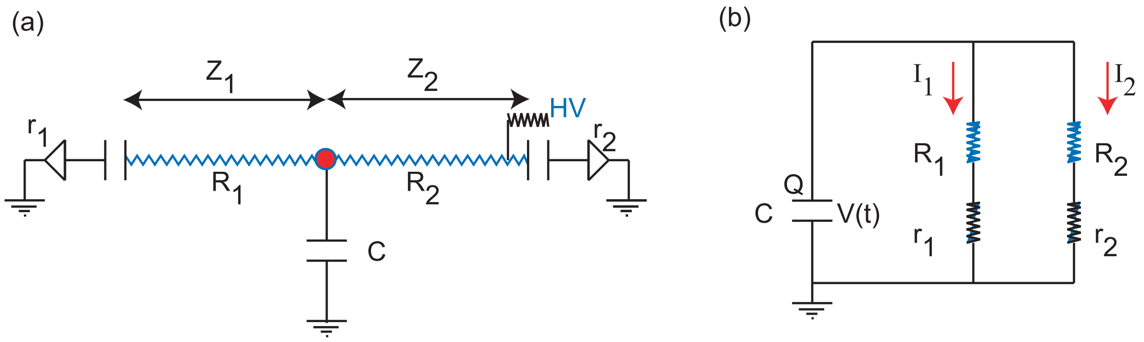

Figure 5: (a) Schematic view of the charge division method. The distances from the avalanche to the wire ends are Z_1 and Z_2, and the corresponding resistances of the wires are R_1 and R_2. The input impedances of the amplifiers are r_1 and r_2. (b) An equivalent electric circuit for the charge division system. The collected charge in the capacitors is discharged through the resistances.

component in the TREK experiment is the active polarimeter to determine the μ^+ and e^+ tracks and obtain P_T from the e^+ asymmetry. The active polarimeter consists of muon stopper plates with gaps which function as multi-wire drift chambers. For the position determination in each gap, normal drift chamber and charge division analyses are applied in beam(z) and radial(r) directions, respectively.

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