SEARCH FOR T-VIOLATION in $K_{\mu 3}$ DECAY

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We propose a new experiment at the AGS to search for the T-violating polarization of the muon normal to the decay plane of the $K^+ \rightarrow \mu^+ \pi^0 \nu$ decay. Motivated by the need for a stronger CP violation source to account for the baryon asymmetry of the Universe, the experiment aims to search for T-violation beyond the Standard Model. The experiment will be performed with in-flight decays from an intense 2 GeV/c separated $K^+$ beam at the AGS. We expect to analyze $10^9$ events to obtain the sensitivity of $\delta P_t = \pm 0.00013$ at 1 $\sigma$, corresponding to the sensitivity of $\pm 0.0007$ to $\text{Im} \xi$, an improvement by 40 over the present limit.

1 Introduction

We propose a new search for the time reversal violating polarization of the muon normal to the plane of the $K^+ \rightarrow \mu^+ \pi^0 \nu$ decay. The term $\sigma_\mu \cdot (\vec{P}_\pi \times \vec{P}_\mu)$, which is proportional to the projection of the muon polarization out of the decay plane, changes sign upon time reversal; therefore a finite expectation value for this quantity indicates a violation of time reversal invariance. Moreover, since the Standard Model prediction for such polarization is zero, and there is no final state interaction, the observation of T-violation in the $K_{\mu 3}$ decay is a discovery of T-violation beyond the Standard Model. Through the CPT theorem we know that T-invariance is intimately related to CP-invariance. Although the only observed CP-violation in the neutral kaon system can be attributed to the complex phase in the CKM matrix within the Standard Model the true nature of CP-violation is far from being revealed by the current experimental data. It is now accepted that the baryon asymmetry of the universe requires a source of CP violation stronger than that embodied in the CKM matrix. Models of non-standard CP violation that produce the baryon asymmetry could also produce effects observable in the transverse polariza-
tion. Because of the very high sensitivity of the experiment the possibility of discovering unexpected new physics should not be underestimated.

The best previous experimental limits were obtained over 15 years ago with 4 GeV charged kaons at the AGS, yielding a result of $P_T^\mu = 0.0031 \pm 0.0053$. The high intensity kaon beams available now at the AGS makes it possible to improve the limit on the polarization by more than an order of magnitude.

## 2 Detector Design

The experiment will be performed with 2 GeV/c electrostatically seperated charged kaons decaying in flight. The beam intensity will be $2 \times 10^7 K^+$/s/spill with $3 \times 10^{13}$ protons on target every 3.6 sec. Figure 1 shows the plan view of the experiment. The basic workings of the experiment are the same as the experiment in Reference 2. The detailed design is, however, optimized for a high intensity 2 GeV beam. The cylindrically symmetric detector is centered on the kaon beam. The $K_{\mu 3}^+$ decays of interest occur in the decay tank; the photons from the $\pi^0$ decay are detected in the calorimeter; the muon stops in the polarimeter. The decay of the stopped muon is detected in the polarimeter by wire chambers, which are arranged radially with graphite...
wedges that serve as absorber medium. The hit pattern in the polarimeter identifies the muon stop as well as positron direction relative to the muon stop. By selecting events with $\pi^0$ moving along the beam direction and muon moving perpendicular to the beam direction in the $K^+$ center of mass frame, the decay plane coincides with the radial wedges. A non-zero transverse muon polarization causes an asymmetry between the number of muons that decay clockwise versus the number counter-clockwise. To reduce systematic errors, a weak solenoidal magnetic field along the beam direction (70 gauss or an precessing period of $\sim 1\mu s$) with polarity reversal every spill is applied to the polarimeter. The initial muon transverse polarization causes a small shift in the phase of the sinusoidal oscillation in the measured asymmetry. The difference in the asymmetry for the two polarities is proportional to the muon polarization in the decay plane, while the sum is proportional to the muon polarization normal to the decay plane.

Compared to the previous experiment, this experiment has much better background rejection and event reconstruction. The separated $K^+$ beam should greatly reduce the accidental rate. The polarimeter is fine segmented and the analyzing power is higher. The positron signature is defined by the coincidence of signals in a pair of neighboring wedges. The larger calorimeter makes it possible to reconstruct the $\pi^0$ momentum. Together with the muon trajectory, the event can be fully reconstructed. The detector acceptance and background rejection is optimized using GEANT simulation. We expect to obtain 550 events/spill, with up to 20% background. With an analyzing power of over 30%, we expect to reach the statistical sensitivity of $\delta P_t = 1.3 \times 10^{-4}$.

At such a high statistical accuracy, much care has to be taken in reducing systematic errors. We have studied various effects that may give a false signal, such as misalignment within the polarimeter, misalignment among and detector components and the beam, asymmetry in or caused by the precessing field and inefficiencies. We believe that these errors can be made acceptably small by proper construction techniques and by using symmetries of the apparatus to internally cancel the systematic errors. In addition, we will use the T-conserving component of the muon polarization to calibrate the detector analyzing power, and samples of muon stops with no known transverse polarization, such as muons from $K_{\mu2}$ decays, to detect any systematic bias.

The proposal has been submitted to the Laboratory in Aug 1996. If approved and funded, we would like to have the first engineering run in 1998. The physics data taking will take about 2000 hours of running time.

1. M.V.Diwan et al, Search for T-violating Muon Polarization in $K^+ \rightarrow \mu^+\pi^0\nu_\mu$ Decay. AGS Proposal 923
2. S. Blatt, et al, Phys. Rev. D 27, 1056 (1983)