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THE FINAL RESULT OF THE T-VIOLATION EXPERIMENT KEK-E246

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ABSTRACT

We have been carrying out a measurement of transverse muon polarization in the $K^+ \to \pi^0 \mu + \nu (K^+_{\mu 3})$ to deduce the parameter $Im\xi$, a quantitative estimate of breakdown of Time reversal invariance in this decay. From a cumulative data sample of nearly 12 million events, we deduced $P_T = -0.0017 \pm 0.0023(stat) \pm 0.0011(syst)$ or the T-violation parameter $Im\xi = -0.0053 \pm 0.0071(stat) \pm 0.0036(syst)$ which correspond to upper limits of $|P_T| < 0.005$ and $Im\xi < 0.016$ (95% confidence limit).

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1 Introduction

Though several dedicated investigations in different decays and reactions spreading over four decades have been carried out, the CP violation is found only in neutral mesons, specifically in neutral K and B mesons. Also, it is very disconcerting to note that one finds direct evidence of T-violation only in neutral K mesons. Our experiment was motivated to look for direct evidence of breakdown of Time reversal in a charged Kaon (K^+) system. The experiment was based on the physics principle suggested by J. J. Sakurai [1)] that the transverse muon polarization in the three-body decay of $K^+ \to \pi^0 \mu^+ \nu$ will be finite if the Time reversal invariance symmetry is broken. Earlier, groups at Brookhaven [2)] measured this channel with a negative result. In the meantime, there have been several model arguments in the frameworks of Multi Higgs and Supersymmetry etc., [3)] which gave reasons to consider that non-zero P_T may be just within reach of present-day experiments.

2 Experiment

This experiment was carried out at the 12 GeV proton synchrotron of the KEK-High Energy Accelerator Research Organization, Tsukuba, Japan. It was designed to take advantage of azimuthal symmetry of the 12-sector superconducting toroidal spectrometer. A large acceptance photon calorimeter of 768 CsI crystals, an active target of of 256 scintillators were built. Also built were 12 drift chamber tracking systems and muon polarimeters, one set for each of the toroidal magnet sectors were built. The system is thoroughly described in Macdonald et al. [4)] and a cross sectional diagram of the system is shown in figure 1.

Briefly, the low momentum K^+ beams were passed through energy degrader and stopped in the active scintillating fiber target. The momentum tracking of charged particles is done. The polarization of muons of $K^+_{\mu 3}$ are determined by the direction of decay positrons. For each gap in the spectrometer, a pair of paddles served to measure asymmetry in the positrons emitted in the clockwise and counter clockwise directions. Summation over the 12 sectors played an important role. Also, we note that the transverse polarization is written as $P_T = \vec{s}_\mu \cdot (\vec{p}_\pi \times \vec{p}_\mu)/|\vec{p}_\pi \times \vec{p}_\mu|$ and necessitates asymmetry measurements transverse to the decay plane. One recognizes that the transverse

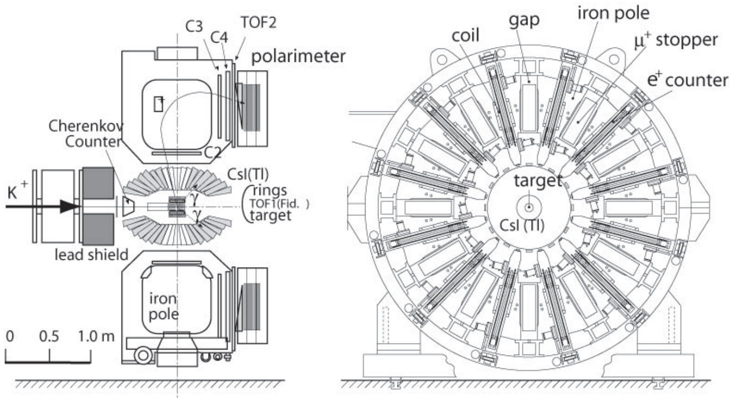

Figure 1: *Cross section side view and end view of the spectrometer. Kaon beams entering from the left.*

polarization is of opposite sign for the forward going pions to that of backward going pions. Thus the events of forward going pions and backward going pions have opposite sign for the asymmetry. We exploit this feature to double the signal. It also serves as a powerful means to cancel the systematic errors.

The experiment ran over about 4 years, and the data were grouped into three periods of (I) 1996-97, (II)1998 and (III) 1999-2000. The first result from the earliest runs were published in Abe etal [5] Since then, the data volume almost tripled and we also refined our analysis procedures as we better understood the system. The final results are in press. [6]

The data analysis was carried out by two independent teams, who set their own even selection criteria and off-line analysis apart from some basic principles. To make maximum use of the data set, π^0 identification relied on events where both the photons (2γ) were detected and and also those with a single photon (1γ) of energy $E_\gamma > 70MeV$ was detected. There was asmall, but non-negligible amount of uncommon events in the two analysis due to slight differences in the cut criteria between the two analyses. We thus categorized them as common (A1.A2)events, and two sets of ($\overline{A1} \cdot A2$ and $A1 \cdot \overline{A2}$) uncommon events and separately for the 2γ and 1γ types. The time spectra integrated between 20 ns to 6 μs after subtraction of the constant background was used as a measure of the positron yields. The main background was due to the $K^+ \to \pi^+\pi^0$ and the subsequent decay of π^+ mesons. The estimated background contamination was included in the systematic error.

The P_T was calculated as the $P_T = A_T/(\alpha_{int} < \cos\theta_T >)$

where A_T is the asymmetry, α is analyzing power and $< cos\theta_T >$ is the angular attentuation factor. The analyzing power is not constant over the 'y' coordinate of the polarimeter. We could calibrate the y-dependence of the analyzing power using the positron asymmetry $A_N(y)$ associated with the normal polarization. The absolute value of the analyzing power was deduced from the Monte Carlo simulation result. We obtained an analyzing power of $\alpha_{int} = 0.271 \pm 0.027$. The $P_T(y)$ thus calculated was found to be nearly constant with slight but opposite-sign gradients for the 2γ and 1γ. We believe this dependence has its origins in the differences in kinematics of muon stopping distributions for the 2γ from that of 1γ types. We have checked the sector dependence of the measured asymmetries and found it to be insignificant.

3 Result

The T-violation parameter $Im\xi$ was obtained from the measured transverse polarization P_T using the conversion factors $\Phi = 0.327$ and 0.287 for the 2γ and 1γ events respectively. This value is what we have employed in our earlier analyses [5]. The left side of figure 2 shows an ideogram of the results of $Im\xi$ for the six sets of events as labelled in the figure. There is considerable overlap between the separate values; the average value is $< Im\xi > = 0.0053 \pm 0.0071$, consistent with zero.

Almost all the systematic errors cancel as we sum over the 12 sectors and double ratio of forward and backward going π^0 are used. However, a few errors

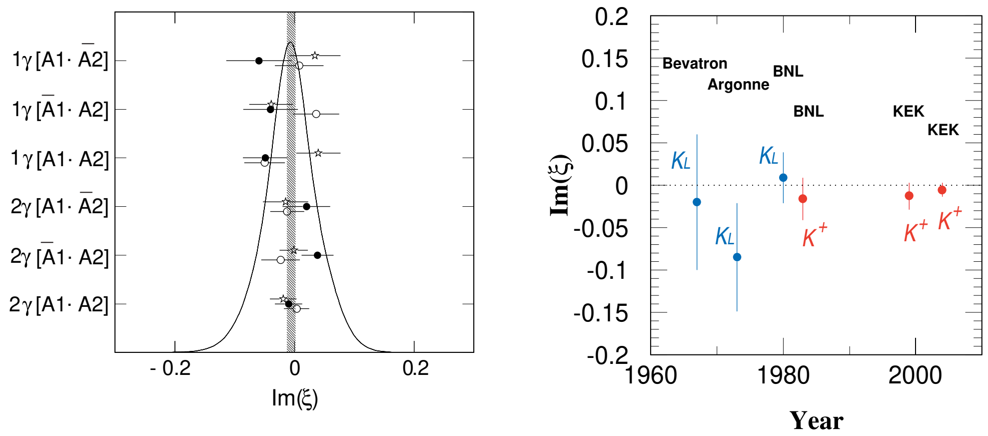

Figure 2: *The ideogram(left) shows the results of analyses six sets of data. Our present result(KEK-2004) is compared with earlier works(right).*

remain. The principal sources are due to misalignment of $\vec{B}$ fields and the muon multiple scattering etc. Altogether, they amounted to less than 10^{-3} and thus the statistical uncertainty is the main contributing factor in our errors.

It is of interest to compare our result with earlier measurements. The right portion of figure2 shows that we achieved about a factor of three improvement over the previous K^+ decay measurement. It is much more improved compared to the polarization measurements in the neutral kaon decays.

4 Summary and Conclusions

A dedicated experiment of the T-violation test by the KEK-PS-E246 collaboration in the $K^+_{\mu 3}$ has attained a higher precision than the experiments so far. The result does not warrant the occurence of light Higgs ($M < 100GeV$). It revealed that in the model frame work of Garisto and Kane, [3] the d-quark contribution to the neutron electric dipole moment is about an order of magnitude smaller than the current experimental limit of $d_n < 6 * 10^{-26}$.

Our collaboration has plans to push this limit by another order of magnitude further at the new high intensity proton machine of 50 GeV under construction at J-PARC, Tokaimura, Japan. The motivations for this project are clear. The high intensity, high quality kaon beams at J-PARC in conjunction with an optimum detector system will allow us to push the experimental limit very close to the estimates of standard model incorporating the final state interactions. This improved precision will allow us to offer stringent constraints of the extensions of standard model. There are plans to upgrade the current detector and/or build a more powerful detector to achieve this limit [7].

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