New Limit on T-violating Parameters in Kaon Decays

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Abstract: A search for a T-violating transverse muon polarization (P_T) in $K^+ \to \pi^0\mu^+\nu$ decay was carried out in the experiment E246 at the KEK-PS. The Standard model (SM) predicts vanishing value of the polarization ($< 10^{-7}$), so an observation of non-zero P_T at the current experimental sensitivity level would be a definite signature of new physics beyond SM. The preliminary result of the analysis of the 1996-1998 data is presented here: $P_T = (-3.3\pm3.7(stat)\pm0.9(syst))\times10^{-3}$, which corresponds to the T-violation parameter $\mathrm{Im}(\xi) = (-0.9 \pm 1.2(stat) \pm 0.3(syst)) \times 10^{-2}$. There is no evidence for T-violation in $K_{\mu3}$ at the current level of sensitivity.

1. Introduction

This talk is about a search for T-violation in the decay $K^+ \to \pi^0\mu^+\nu$ ($K^+_{\mu3}$). The Lorentz invariant matrix element of this decay can be written as

$$M = (G_F/2)sin\theta_C[f_+(q^2)(p_K + p_\pi)^\lambda + f_-(q^2)(p_K - p_\pi)^\lambda][\bar{u}_\mu\gamma_\lambda(1-\gamma_5)u_\nu], \tag{1.1}$$

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where G_F is the Fermi constant, θ_C - the Cabibbo angle, p_K and p_π are 4-momenta of the kaon and pion, respectively, and q is the 4-momentum transfer to leptons. It includes two hadronic form factors[1] f_- and f_+ which should be relatively real in the case of T-invariance: $\mathrm{Im}(\xi) = 0$, where $\xi \equiv f_-(q^2)/f_+(q^2)$ [1].

On the other hand, the only observable related to T-violation in $K^+_{\mu 3}$ decay is a transverse muon polarization P_T defined as a muon polarization component normal to the decay plane: $\mathrm{P}_T = \vec{s}_\mu \cdot (\vec{p}_{\pi^0} \times \vec{p}_{\mu^+})/|\vec{p}_{\pi^0} \times \vec{p}_{\mu^+}|$, where $\vec{s}_\mu$ is the muon spin, $\vec{p}_{\pi^0}$ and $\vec{p}_{\mu^+}$ are the π^0 and μ^+ momentum vectors, respectively. It's known that P_T is proportional to $\mathrm{Im}(\xi)$: $\mathrm{P_T} \sim m_\mu \cdot m_K \cdot \mathrm{Im}(\xi)$, where m_μ and m_K are muon and kaon masses, so by measuring the transverse polarization, one gets an information on T-violation.

What level of $\mathrm{P_T}$ should be expected from a theoretical point of view? The Standard Model (SM) predicts zero, or $< 10^{-7}$ [4], which is far below the current experimental sensitivity. A contribution of the final state interactions (FSI) was found to be below the 10^{-5} level [5], so this decay presents a good opportunity to search for new physics beyond SM. Indeed, some extensions to the SM, such as multi Higgs doublet models, supersymmetrical models with/without R-parity violation (SUSY), and leptoquark models predict $\mathrm{P}_T < 10^{-2}$ [6].

The previous experiment carried out at BNL almost 20 years ago found no evidence for T-violation: $\mathrm{P}_T = (-3.1 \pm 5.3) \times 10^{-3}$, which corresponds to $\mathrm{Im}(\xi) = (-1.6 \pm 2.5) \times 10^{-2}$ [7]. The latest result on transverse polarization was published by our group two years ago (1996-1997 data): $\mathrm{P}_T = (-4.2 \pm 4.9(stat) \pm 0.9(syst)) \times 10^{-3}$ and $\mathrm{Im}(\xi) = (-1.3 \pm 1.6(stat) \pm 0.3(syst)) \times 10^{-2}$ [8], obtained from only one third of the data collected. Here our new result based on increased statistics including the 1998 data set is presented.

2. Experimental Technique

The main feature of our experiment is the use of *stopped* kaons which allows detection of decay particles from a wide kinematic range. Kaons with 660 MeV/c momentum are identified by a Čerenkov detector, degraded and stopped in an active target made of 256 scintillating fibers (Fig 1, a). A decay muon passes through the target, ring hodoscope, magnetic spectrometer with three proportional chambers (C2, C3, C4) and enters a muon polarimeter consisting of a copper degrader, pure aluminium stopper and positron counters. The neutral pion almost instantly decays into two photons which are detected by a CsI(Tl) calorimeter comprised of 768 crystal modules [9].

The experimental setup consists of 12 azimuthally symmetric sectors, which correspond to the gaps in the superconducting toroidal magnet (Fig 1, b). Each of 12 polarimeters has two positron counters detecting e^+s from the muon decays in clockwise (*cw*) and counter-clockwise (*ccw*) directions (Fig. 2). The difference in the number of hits between these two counters is an asymmetry representing the transverse polarization P_T of interest.

[1] The matrix element (1.1) doesn't include explicitly any exotic terms, since our recent study of $K^+ \to \pi^0 e^+ \nu$ (K^+_{e3}) decays shows that, first, scalar f_S and tensor f_T form factors are consistent with zero [2] and, second, there is no deviation from μ-e universality [3].

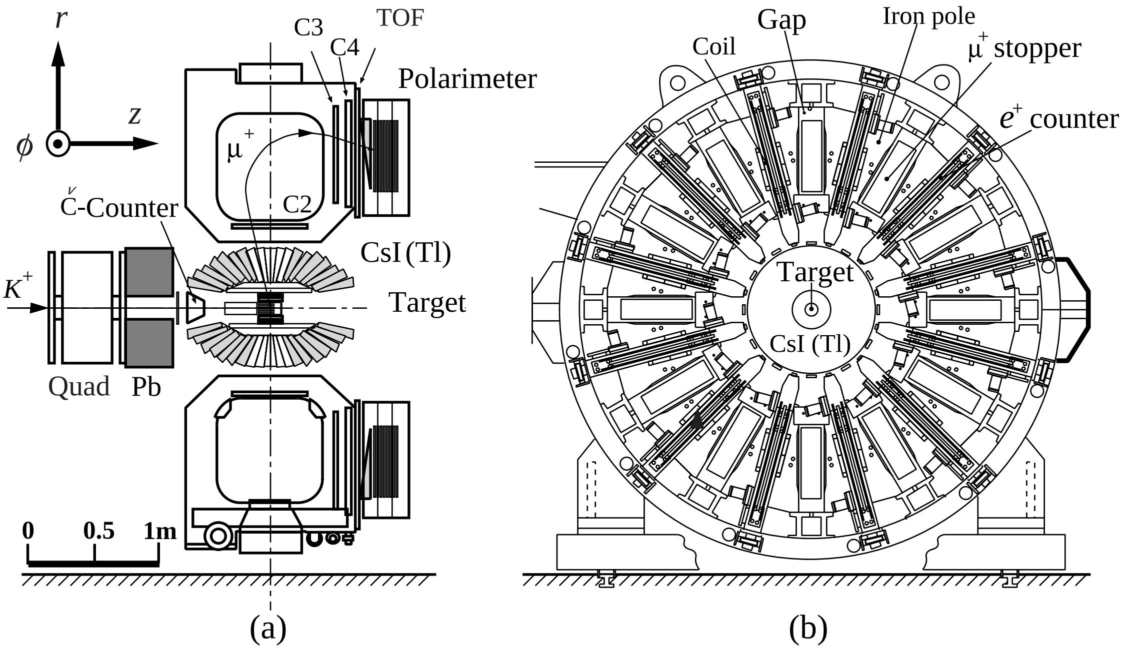

Figure 1: E246 experimental setup; (a) cross section side view, (b) end view.

With decays of stopped kaons events are divided into two classes: with *backward-* (*bwd*), and *forward-* (*fwd*) going pions (with respect to the initial kaon beam direction). Since events with opposite π^0 directions have opposite signs of P_T, combining of the events with *fwd-* and *bwd-*going pions increases the sensitivity to P_T ("double ratio"). It also reduces the effect of various geometrical factors whose contribution to P_T is independent of the π^0 direction ("*fwd/bwd* cancellation").

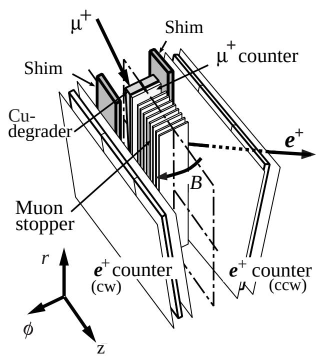

Figure 2: Muon polarimeter of each sector consists of copper degrader, aluminium stopper and two plastic positron counters (clockwise and counter-clockwise with respect to the muon).

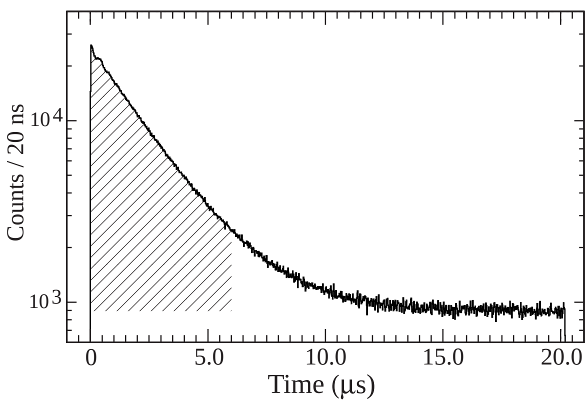

Figure 3: Positron time spectrum of all good events (sum of 2γ and 1γ). The hatched region is the analyzed signal region after subtraction of the constant background.

In order to minimize the background level a number of kinematic cuts were applied. The 2.6 MeV/c momentum resolution (σ at 205 MeV/c) of the spectrometer allows the momentum cut to be set as high as possible and reject most of $K^+ \to \pi^+\pi^0$ events. $K^+ \to e^+\pi^0\nu$ events are eliminated by means of time-of-flight. Neutral pions from the $K_{\mu3}$ are identified either by two photons in CsI(Tl) by means of the invariant mass $M_{\gamma\gamma}$ cut 75 $MeV/c^2 < M_{\gamma\gamma} <$ 160 MeV/c^2 ("2γ-events"), or by one detected photon with an energy $E_\gamma >$ 70 MeV when the second photon has escaped detection ("1γ-events"). A selection of events with *fwd* (*bwd*)-going π^0s is achieved by applying the proper polar angle cut: $\theta_{\pi^0} < 70°$ for *fwd* and $\theta_{\pi^0} > 110°$ for *bwd*, where θ_{π^0} is the angle between the π^0 momentum and the kaon beam axis (Z-axis).

3. Systematics and Results

After selecting $K_{\mu3}$ events the number of hits N_{cw} (N_{ccw}) in the signal regions (from 20 ns to 6μs) of the positron counter time spectra is determined (Fig. 3). The T-violation asymmetry A_T is then extracted as

$$\mathrm{A}_T = \frac{1}{4}\left[\frac{(N_{cw}/N_{ccw})_{fwd}}{(N_{cw}/N_{ccw})_{bwd}} - 1\right]. \tag{3.1}$$

Then, the transverse polarization P_T is obtained as $\mathrm{P}_T = \mathrm{A}_T/(\alpha\langle cos\theta_T\rangle)$, where the geometrical attenuation factor $\langle cos\theta_T\rangle$ is calculated by Monte Carlo simulations, and the analyzing power $\alpha = 0.197 \pm 0.005$ is extracted using events with transverse-going pions (Fig. 4) for which the polarimeter measures the T-even in-plane muon polarization

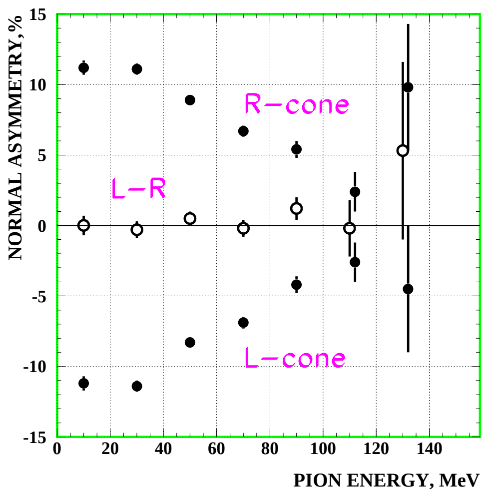

Figure 4: Normal asymmetry A_N vs π^0 energy. In this case the kaon decay plane is perpendicular to Z-axis, π^0 goes either in the right (R) or left (L) cone with respect to the muon direction. The events with opposite π^0 directions have opposite signs of A_N.

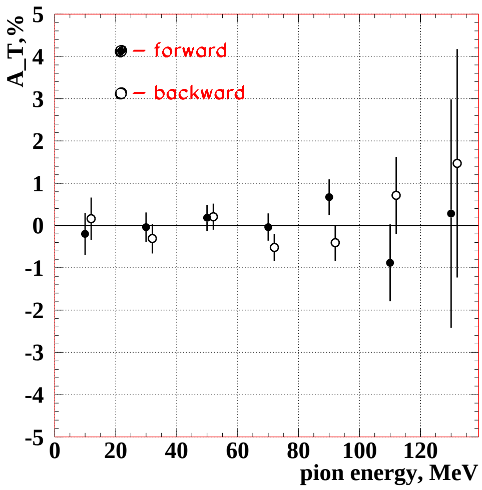

Figure 5: Transverse asymmetry A_T vs π^0 energy. Empty circles present the events with backward going π^0; black circles – "forward" events.

Source of error	$\mathbf{\Delta P_T \times 10^{-4}}$
CsI(Tl) misalignment	1.6
Decay plane rotation	2.2
Misalignment of positron counters	2.3
MWPC ϕ-offset	2.5
K^+ stopping distribution	< 3.0
Analysis	3.8
Fringing field asymmetry	6.1
Total	**9.2**

Table 1: Main systematic errors

$P_N(\perp p_\mu)$. T-violation parameter $\mathrm{Im}(\xi)$ is calculated then as $\mathrm{Im}(\xi) = \mathrm{P}_T/\Phi$, where $\Phi \approx 0.3$ is a kinematic factor obtained from the analysis of the $K_{\mu 3}$ Dalitz-plot. The 12-fold rotational symmetry and fwd/bwd cancellation allow most of the systematic errors to be suppressed by a factor of 20–30, so that the resulting uncertainty of P_T due to the systematics is $\Delta\mathrm{P}_T(syst) = 9 \times 10^{-4}$ (Table 1) which is much smaller than the statistical error. A check of the instrumental systematics is demonstrated in Fig. 5 where the dependence of the asymmetry A_T on the π^0-energy is plotted. As in the case of the normal asymmetry A_N (Fig. 4) there is no visible systematic shift for A_T.

Two thirds of all the data collected during 1996-2000 runs have been analyzed by this time ($\sim 7.2 \times 10^6 K_{\mu 3}$ events). Our preliminary result shows no T-violation in $K^+_{\mu 3}$ at the current experimental sensitivity: $\mathrm{P}_T = (-3.3 \pm 3.7(stat) \pm 0.9(syst)) \times 10^{-3}$ and $\mathrm{Im}(\xi) = (-0.9 \pm 1.2(stat) \pm 0.3(syst)) \times 10^{-2}$.

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