Search for a Neutral Boson in a Two-Body Decay of $K^+ \to \pi^+ X^0$

T. Yamazaki, T. Ishikawa, T. Taniguchi, T. Yamanaka, T. Tanimori, R. Enomoto, A. Ishibashi, S. Sato, Y. Akiba, M. Iwasaki, and T. Fujii
Department of Physics and Meson Science Laboratory, Faculty of Science, University of Tokyo, Bunkyo-ku, Tokyo 113, Japan

and

R. S. Hayano and S. Schnetzer
National Laboratory for High Energy Physics, Oho-machi, Tsukuba-gun, Ibaraki 305, Japan
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The momentum spectrum of the π^+ in stopping K^+ decays was measured by use of a high-resolution magnetic spectrometer to search for a discrete peak due to a neutral boson X^0 in a two-body decay $K^+ \to \pi^+ X^0$. An upper bound of the branching ratio $R(K^+ \to \pi^+ X^0)$ is presented for the mass range of X^0 from 10 to 300 MeV/c^2.

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In this Letter we present the first result of an experiment to look for a hitherto unknown neutral boson (hereafter called X^0) from a discrete line in a two-body decay mode $K^+ \to \pi^+ X^0$.[1] The high-resolution experiment presented here was carried out as a byproduct of the previous $K_{\mu 2}$ experiment to search for heavy neutrinos.[2]

Theoretically, various types of light pseudoscalar particles have been proposed, such as the axion[3] and the majoron,[4] but have not been found up to date. However, all the experiments done so far to search for the axion, a^0, were based on the assumption that the mass of a^0 is sufficiently small ($\lesssim 5$ MeV) so that it does not decay promptly. For example, the constraint on the $K^+ \to \pi^+ a^0$ mode (upper limit $=3.8\times 10^{-8}$), as given by Asano *et al.*,[5] was obtained from the nonexistence of events of the $K^+ \to \pi^+ \nu\bar{\nu}$ type by use of a photon veto, and thus can be applied only to a light axion. The decay time of the a^0 is estimated to be 10^{-9} sec for $m_a \simeq 1$ MeV and becomes shorter proportionally to m_a^{-5} with the increase of the mass, where both $a^0 \to \gamma\gamma$ and $\to e^+e^-$ modes are equally probable.[3] The present method to look for a discrete line in a high-resolution spectrum without a photon veto allows the detection of a massive particle with subsequent photon emission, and thus it provides a more general and sensitive search.

The experimental procedures were the same as described in Ref. 2. The charged particles from the decay of K^+'s stopped in thin layers of plastic scintillators were momentum analyzed by a magnetic spectrometer, which had a broad momentum range (100–250 MeV/c), a high momentum resolution ($\Delta p/p \simeq 0.5\%$ full width at half maximum) and a large solid angle (max 150 msr). The range and the time of flight of the charged particles were measured to discriminate π^+ from others.

The π^+ spectrum obtained is shown in Fig. 1 together with the spectrum of all the charged particles. In this π^+ spectrum we selected pions rather severely with the sacrifice of the efficiency; the 205-MeV/c $\pi^+\pi^0$ peak (branching ratio $R=0.21$) is reduced by a factor of 2, while the 236-MeV/c $\mu^+\nu$ peak ($R=0.64$) is suppressed by 10^3. No photon veto was applied to either one of the spectra. These histograms were constructed by assuming all the particles to be pions when the energy-loss correction in the counters was converted to the momentum. Thus, the momentum of the 235.5-MeV/c $\mu^+\nu$ peak is slightly shifted upward. The resolution at the 205-MeV/c peak is 2.4 MeV/c full width at half maximum, and expected to increase gradually to 3.5 MeV/c at 120 MeV/c.

A small peak at 214 MeV/c in the spectrum of all the particles was interpreted as being due to the μ^+ arising from the extreme forward decay in flight of the 205-MeV/c π^+ in the spectrometer. A Monte Carlo simulation reproduced this bumplike structure, and actually, this peak disappeared after the π^+ selection. A bump below 125 MeV/c comes from the 3π decay. The lower tail below the 205-MeV/c peak may include a contribution due to the radiative decay $\pi^+\pi^0\gamma$ ($R=2.8\times 10^{-4}$). A broad continuous part observed between 125 and 200 MeV/c is attributed to the strong interactions of the 205-MeV/c π^+ inside the stopping counters. The origin of the energy loss of π^+ of this energy is mainly due to quasifree scattering of π^+ by the nucleons inside ^{12}C,[6] and the back-scattering contribution is very large. Since we used multilayered plastic scintillators as the target, it was impossible to re-

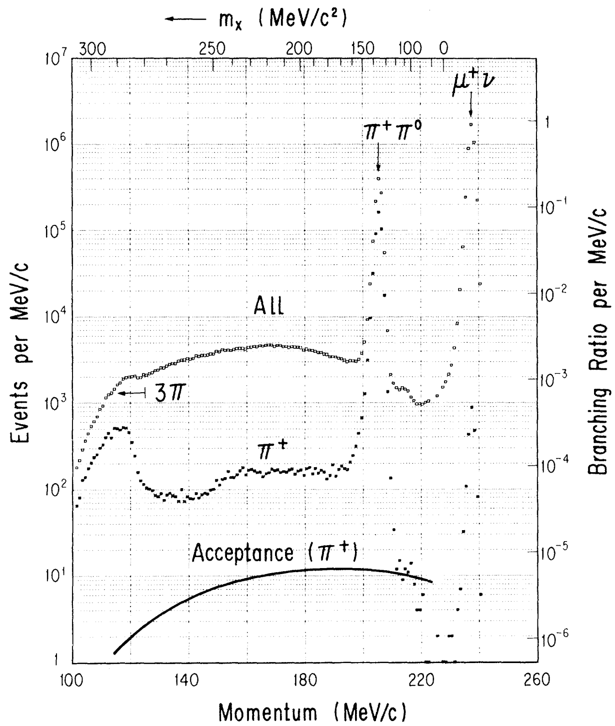

FIG. 1. Momentum spectra of all the particles (open squares) as well as of π^+ (closed squares). The momentum dependence of the acceptance (relative) for π^+ is also shown.

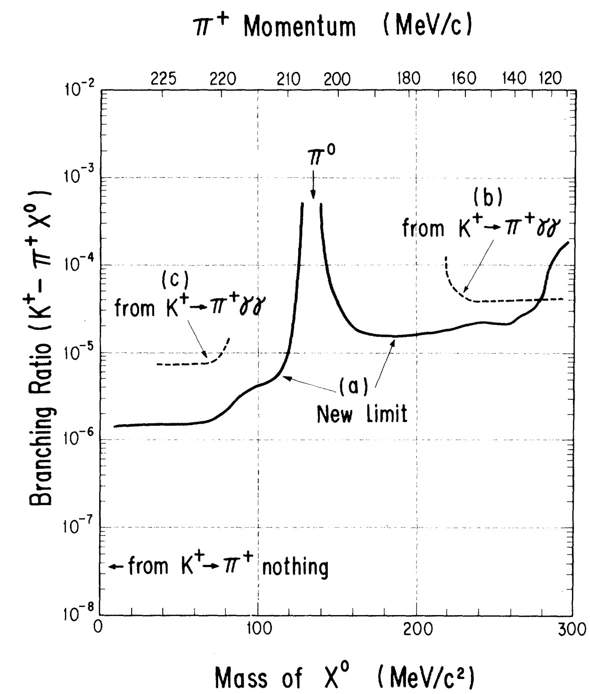

FIG. 2. The new limit (90% confidence) on $R(K^+ \to \pi^+ X^0)$ obtained in the present experiment is shown versus the hypothetical mass of X^0. The broken curves are indirect bounds from the $K^+ \to \pi^+\gamma\gamma$ experiments by Abrams *et al.* (Ref. 7) in the heavier-mass region (b) and by Asano *et al.* (Ref. 8) in the lighter-mass region (c). Also shown is the zero-mass limit which comes from the "$K^+ \to \pi^+ +$nothing" type experiment by Asano *et al.* (Ref. 5).

move this background. Its spectral profile can well be reproduced from the known inelastic cross sections.

Now, we examine the spectrum to look for an anomalous line. The scale for the mass of X^0 is shown in the upper part of the spectrum. The spectrum shows no distinct peak. Thus, we estimate the upper limit of a discrete peak at each momentum according to the same procedure as in the case of the muon spectrum.[2] The following formula was used to obtain the 90%-confidence-level limit:

$$N(p) = 1.28[2\pi^{1/2}\sigma(p)n(p)]^{1/2}$$
$$= 1.70[2\sigma(p)n(p)]^{1/2},$$

where $n(p)$ is the number of events per MeV/c and $\sigma(p)$ is the momentum resolution (standard deviation) in MeV/c. This estimation is valid as long as the spectrum is smooth. This number was then corrected for the relative acceptance with respect to the 205-MeV/c peak. The total number of the peak events was 4.5×10^5.

A diagram of the observed constraint on the upper limit of the ratio $R(K^+ \to \pi^+ X^0)$ vs m_X is shown in Fig. 2. Because of the high-resolution spectroscopy achieved here, this result covers a wide mass region up to 300 MeV except for the narrow range around the π^0 mass. In Fig. 2 are also shown indirect constraints obtained from (b) $K^+ \to \pi^+\gamma\gamma$ in the region $p_\pi^{\text{c.m.}} < 205$ MeV/c,[7] (c) $K^+ \to \pi^+\gamma\gamma$ in the region $p_\pi > 205$ MeV/c.[8] The upper limit[5] on (d) $K^+ \to \pi^+ a^0$ that can be applied to the low-mass region is also indicated in the figure.

The present study has shed a new light on the search for a neutral boson and established a new constraint on the branching ratio versus its mass in a wide range (5–300 MeV). An experiment of improved resolution together with photon correlation to further illuminate this problem is under way at KEK.

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