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LIMIT ON THE $K^+ \to \pi^+ + \gamma + \gamma$ DECAY RATE*

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The branching ratio for the process $K^+ \to \pi^+ + \gamma + \gamma$ is shown by a counter–spark-chamber experiment to be less than 4×10^{-5} of all decay modes, assuming a phase-space pion energy spectrum. A limit of 4×10^{-6} is established for the process $K^+ \to \pi^+ + \gamma$. The apparatus was sensitive to pions in the kinetic energy range 117-127 MeV.

M. Chen et al.[1] have reported a search for the process

$$K^+ \to \pi^+ + \gamma + \gamma \tag{1}$$

using apparatus which was sensitive to pions of kinetic energy 60 to 90 MeV (kinematic limit = 127 MeV). They set an upper limit of 1.1×10^{-4} for the branching ratio into this decay mode. We report here a search for the same process with an apparatus which was sensitive for π^+ above 117 MeV. Assuming a phase-space model for the decay, i.e.,

$$d\Gamma(K\pi\gamma\gamma)/dE_\pi = \lambda P_\pi, \tag{2}$$

where λ is a constant, we obtain a limit of 4×10^{-5} on the branching ratio.

The significance of this search has been discussed by Chen et al.[1] Briefly, they point out that a limit on (1) may be interpreted as a limit on the off-the-mass-shell behavior of the $K^+ \to \pi^+ + \pi^0$ amplitude. It has been suggested that the $|\Delta T| = \frac{1}{2}$ law may be exact, and that $K^+ \to \pi^+\pi^0$ may occur because the π^+-π^0 mass difference prevents the $\pi^+\pi^0$ from being in a pure $T=2$ state. If we imagine that the two gamma rays from the process $K^+ \to \pi^+\gamma\gamma$ come from a virtual π^0 intermediate state, then for our energy range the π^+-$(\gamma\gamma)$ mass difference is much greater than the π^+-π^0 mass difference. According to this picture the rate for $K^+ \to \pi^+\gamma\gamma$ may be greatly enhanced.[2-5]

Our experiment has been performed in conjunction with a search[6] for the process $K^+ \to \pi^+ + \nu + \bar{\nu}$. The experiment depends on the fact that no observed K^+ decay at rest produces a π^+ with an energy greater than that from $K^+ \to \pi^+\pi^0$ [T_π = 109 MeV; branching ratio (b.r.) = 0.21]. In order to produce a π^+ of higher energy the K^+ must decay into a π^+ and a neutral system with rest mass less than that of the π^0. If we neglect decays into four or more particles, the only possibilities are $K^+ \to \pi^+e^+e^-$ (b.r. < 2.5×10^{-6}),[7] $K^+ \to \pi^+\nu\nu$ (b.r. < 1.2×10^{-6}),[6] and Reaction (1) [or (3)]. The last two reactions may give pions with energies up to 127 MeV. Hence the fact that we observe no π^+ emitted with energy between 117 and 127 MeV accompanied by high-energy γ's in the opposite hemisphere is sufficient to exclude the process $\pi^+\gamma\gamma$.

The techniques for identifying stopping K^+ and π^+ and for measuring the energy of the π^+ were identical to those used in the $K^+ \to \pi^+\nu\bar{\nu}$ experi-

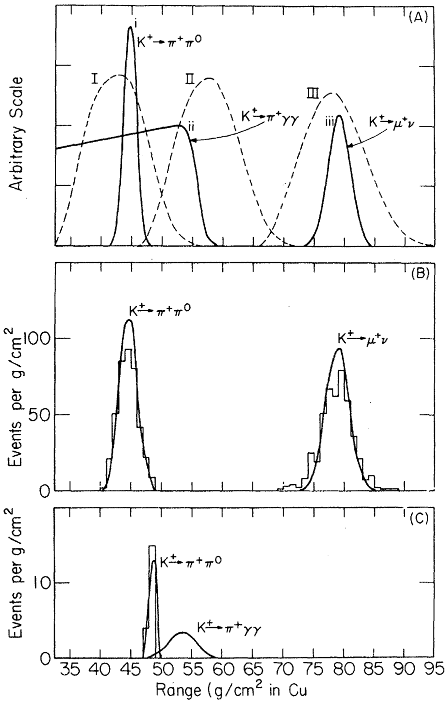

FIG. 1. Range distributions. (a) Calculated distributions for K^+ decays into (i) $\pi^+\pi^0$, (ii) $\pi^+\gamma\gamma$ (phase space), and (iii) $\mu^+\nu$, with straggling and small-angle multiple scattering taken into account. Dashed curves I, II, and III show detector efficiencies for different absorber thicknesses. (b) Expected event distributions for $\pi^+\pi^0$ and $\mu^+\nu$ (curves I and III folded into i and iii) and corresponding observed distributions (histograms). (c) Expected $\pi^+\pi^0$ and "$\pi^+\gamma\gamma$" distributions (curves) for absorber corresponding to curve II, (a), and observed "$\pi^+\gamma\gamma$" distribution (histogram—no "$\pi\gamma\gamma$" events above $\pi^+\pi^0$ curve).

ment.[6] But in the search for $K^+\to\pi^+\gamma\gamma$ we required that the π^+ signal be accompanied by a γ signal from one or both of the lead-glass Čerenkov counters in the hemisphere opposite the π^+ detection system. Tests of the Čerenkov counters showed an inefficiency for π^0 decay gammas of 6×10^{-4} (see Ref. 6).

Our event distributions and sensitivity curves for the processes $K^+\to\pi^+\pi^0$, $K^+\to\mu^+\nu$, and $K^+\to\pi^+\gamma\gamma$ are shown in Fig. 1.

No $K^+\to\pi^+\gamma\gamma$ events were observed. Assuming a phase-space spectrum (2), if one event had been found the branching ratio would have been 1.8×10^{-5}. Accordingly we set a 90% confidence limit (c.l.)

$$\frac{\Gamma(K^+\to\pi^+\gamma\gamma)}{\Gamma(\text{all modes})}=4\times10^{-5}.$$

The vector-meson–dominant model[8,9] and the η-pole model[10] both predict branching ratios much lower than we have been able to set in this experiment.

We can also set limits on the $K^+\to\pi^+ + (n+2)\gamma$, but since the phase-space spectrum is $d\Gamma/dE = \lambda P_\pi(E_M-E_\pi)^n$ (where E_M is the maximum energy of π^+), our experiment becomes less sensitive as n increases. For $n=1$, $\Gamma(K^+\to\pi^+ +3\gamma)/\Gamma(K^+\to\text{all})<3\times10^{-4}$(90% c.l.).

F. Seleri has proposed a model[11] in which the K^+ has spin $\frac{1}{2}$ and the strangeness-changing weak interactions violate angular momentum conservation. His model would allow the process

$$K^+\to\pi^+ +\gamma. \qquad (3)$$

He predicts a branching ratio into this mode of 2×10^{-4}. We would be especially sensitive to this decay mode since the π^+ would be produced in the region of maximum detector efficiency [see curve II, Fig. 1(a)]. Our limit on (3) (90% c.l.) is

$$\frac{\Gamma(K^+\to\pi^+ +\gamma)}{\Gamma(\text{all modes})}=4\times10^{-6}.$$

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