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RARE K DECAYS AND LIMITS ON NEW FORCES

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ABSTRACT

We reconsider the possible detection of hyperphotons (γ_Y) in the decay mode, $K_L \to \pi^+\pi^-\gamma_Y$. We find it to have certain advantages over $K^+ \to \pi^+\gamma_Y$ in setting limits on new forces coupling to hypercharge. The prospects for studying this decay mode in the near future are discussed.

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The connection has been made previously by numerous authors[1-5] between new forces and rare decays of K mesons. In his original paper Weinberg[1] considered the decay

$$K^o \rightarrow \pi^+\pi^-\gamma_Y. \qquad (1)$$

However, most recent interest has focussed on the process

$$K^+ \rightarrow \pi^+\gamma_Y. \qquad (2)$$

Reaction (2) is attractive because the analogous mode with an ordinary photon is forbidden (by angular momentum conservation), and because it is a kinematically simple (2-body) process. In addition there are[6,7] very sensitive searches for the decay

$$K^+ \rightarrow \pi^+a^o, \qquad (3)$$

where a^o is any light invisible neutral particle.

There has, however, been some disagreement among the several recent calculations of reaction (2), as can be seen in Table 1 of Reference 8. These differences stem from two sources: Off-mass-shell extrapolations connecting the weak amplitude $<\pi^+|H_W|K^+>$ to the rate of $K_S \rightarrow \pi^+\pi^-$, and inclusion of non-pole diagrams.

We will address this discrepancy elsewhere; here we wish to point out that reaction (1), while more difficult to isolate experimentally, is more straightforward to calculate. Therefore it merits reconsideration as a way to study the existence of new forces coupling to hypercharge. Below we summarize the pros and cons of reaction (1) and compare its sensitivity to new forces with that of reaction (2).

With regard to the calculation of the branching ratio of reaction (1) we show in detail elsewhere[9] that : a) the non-pole terms are relatively small in comparison to the pole term, unlike the case of reaction (2), and b) the computation of the pole term varies by at most a factor two over a broad range of models. Therefore, measurements of reaction (1) can lead to limits on new forces which are much better defined than those derived from reaction (2). In addition to being more straightforward to calculate, reaction (1) is also comparable in sensitivity to reaction (1). If we compare the branching ratios of the two processes[2-5,9] we find that for given values of the range and coupling strength of the hypercharge force,

$$0.07 \lesssim \frac{B.R.(K_L \to \pi^+\pi^-\gamma_Y)}{B.R.(K^+ \to \pi^+\gamma_Y)} \lesssim 5.0, \tag{4}$$

where the broad range is due to uncertainty in the denominator as mentioned previously.

With regard to the experimental difficulties associated with reaction (1), note first that since the hyperphoton escapes detection,[2] signal events will appear to be 2π events with invariant mass < m_K and which have missing transverse momentum. Note also that

$$K_L \to \pi^+\pi^-\gamma \tag{5}$$

is allowed (and measured),[10] although CP-suppressed. Backgrounds can arise from reaction (5) and from

$$K_L \to \pi^+\pi^-\pi^o, \tag{6}$$

where the photon(s) escape detection. Similarly, semileptonic K_L decays,

$$K_L \to \pi^{\pm} \ell^{\mp} \nu, \quad (7)$$

where the lepton is misidentified as a pion, is a potential source of background events. Consequently, an experiment designed for a high sensitivity search for hyperphotons in reaction (1) must have extremely efficient photon and lepton detection. However, the present and future detectors designed for CP-violation studies and ultra-rare K_L decay searches (for example, $K_L \to \pi^o e^+ e^-$) must meet the same requirements. Further, the next generation of such detectors will be designed for single-event sensitivity of 10^{-12} to 10^{-13}. This is one to two orders of magnitude beyond what the current K^+ or K_L experiments can achieve. It seems likely, therefore, reaction (1) may provide the most stringent test of the existence of hyperphotons in the foreseeable future.

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