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R. Gatto: CONSISTENCY BETWEEN THE $\Delta T = 1/2$ RULE AND THE LOW RATE OF $K^+ \rightarrow \pi^+ + \pi^0 + \gamma$ AS COMPARED TO K^+.

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CONSISTENCY BETWEEN THE $\Delta T = \frac{1}{2}$ RULE AND THE LOW RATE OF $K^+ \to \pi^+ + \pi^0 + \gamma$ AS COMPARED TO $K^+ \to \pi^+ + \pi^0$

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There now seems to be good evidence in favor of the $\Delta T = \frac{1}{2}$ rule for strange particle decays: the predictions which can be derived on the basis of this rule for branching ratios between different decay modes seem in fact to be satisfied[1].

It was realized, however since the early times in which the rule was proposed, that its strict validity could lead to quantitative difficulties for the $K_{\pi 2}$ decay modes. In particular two problems have so far been left unanswered. I shall present them as two separate problems but in fact they concern the same decay mode, namely the mode $K^+ \to \pi^+ + \pi^0$.

Such a mode of decay is forbidden as long as $\Delta T = \frac{1}{2}$ holds. This is very easy to verify. In fact the final state can only have isotopic spin 2, because isotopic spin 0 could not give a total charge of unity and isotopic spin 1 would not lead to a totally symmetric wave function if the final pions must be in a state of angular momentum zero. However, the initial K meson has $T = \frac{1}{2}$ so that to go to $T = 2$ one needs at least $\Delta T = {}^3/_2$.

Now $K^+ \to \pi^+ + \pi^0$ is known to be about two hundred times smaller than $K^0 \to 2\pi$. Its decay rate is thus very low but it is not, however, so low as one would expect from attributing it entirely to the electromagnetic corrections of the $\Delta T = \frac{1}{2}$ rule. The mechanism for $K^+ \to \pi^+ + \pi^0$ would be represented by graphs where a γ is emitted and then absorbed (Fig. 1), and therefore the decay rate would be proportional to $e^4 = \left(\frac{1}{137}\right)^4$ which is a very small factor if compared with the above ratio of 200.

Therefore, there is a problem of discovering the mechanism which makes the rate for $K^+ \to \pi^+ + \pi^0$ so large in the presence of $\Delta T = \frac{1}{2}$, and some suggestions have already been advanced to solve this problem[2].

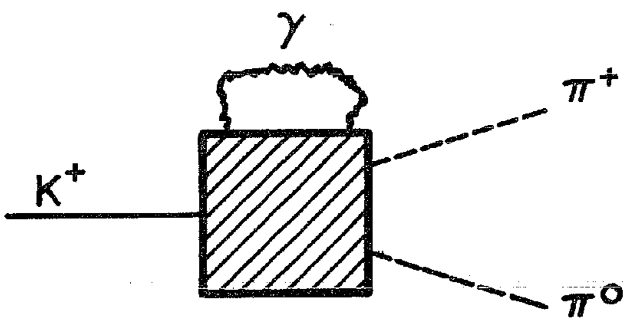

Fig. 1 K^+ decay into two pions.

This is the first of the two problems I mentioned. The second problem is the following.

Suppose you have found an explanation for $K^+ \to \pi^+ + \pi^0$ as obtained from the above graph. Then let us consider $K^+ \to \pi^+ + \pi^0 + \gamma$, i.e. the radiative decay. It may come from graphs of the kind of Fig. 2,

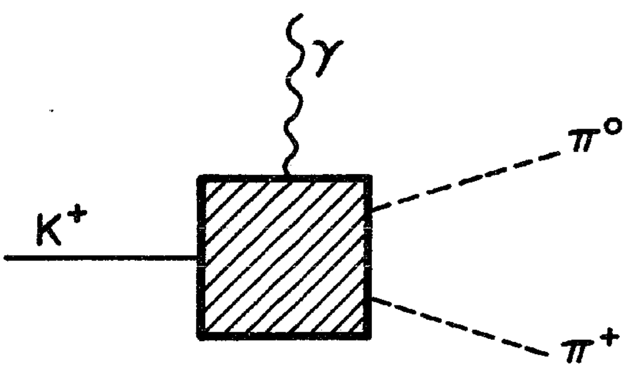

Fig. 2 Radiative K^+ decay.

which are of first order in e and would give a rate proportional to $e^2 = \frac{1}{137}$.

If one could naively argue this way one would conclude that $K^+ \to \pi^+ + \pi^0 + \gamma$ must be more frequent than $K^+ \to \pi^+ + \pi^0$ if $\Delta T = \frac{1}{2}$ holds. This would be in striking contrast with the experiment. Good [3] has in fact shown that present data on $K^+ \to \pi^+ + \pi^0 + \gamma$ may well be explained assuming the process to be due to internal bremsstrahlung during the decay $K^+ \to \pi^+ + \pi^0$.

If $\Delta T = \frac{1}{2}$ holds, the internal bremsstrahlung would be represented from graphs of the type of Fig. 3.

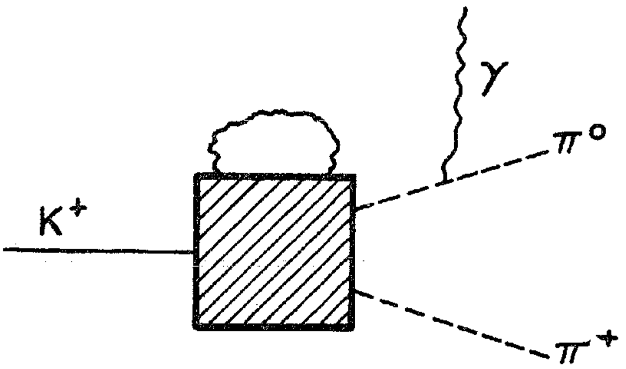

Fig. 3 Radiative K^+ decay.

Its rate contains, therefore, one factor $e^2 = \frac{1}{(137)^2}$ more than the $K^+ \to \pi^+ + \pi^0$ decay rate.

Thus the problem arises of showing that the contribution to $K^+ \to \pi^+ + \pi^0 + \gamma$ from the graphs of the type illustrated in Fig. 2 is not larger (at least not much larger) than the bremsstrahlung contribution. This problem has been considered in Frascati and I wish to report on some calculations that I have made in collaboration with Cabibbo which show that there is indeed no inconsistency between the present data on $K^+ \to \pi^+ + \pi^0 + \gamma$ and $\Delta T = \frac{1}{2}$.

Specifically one can show that the contributions from these graphs are not much larger than the internal bremsstrahlung and that they should indeed be comparable with it in the most explored region of the π^+ spectrum, i.e. in the region between 55 and 75 MeV.

The predictions of the calculations are not unique; there is indeed one parameter which depends on theoretical models for the $K \to 2\pi$ transitions. We have considered a model in which $K \to 2\pi$ proceeds through virtual dissociation of the K-meson into a nucleon and a hyperon, and the hyperon decay interaction is proportional to the derivative of the pion field.

Using this model we find that in the region of the π^+ spectrum between 55 and 75 MeV the number of predicted $K^+ \to \pi^+ + \pi^0 + \gamma$ events is bigger by a factor of 1.6 than the number predicted on the basis of internal bremsstrahlung alone if the interference between the graphs of Fig. 2 and those of Fig. 3 is destructive, or by a factor of 5 if this interference is constructive.

Independent of the model the π^+ spectrum is found to be given by

$$\frac{1}{\omega_0}\frac{d\omega}{d\omega} = \frac{e^2}{4\pi}\frac{2qp}{\pi E\beta}(B + xJ + x^2 D) \tag{1}$$

with

$$B = \frac{2}{q^2}\left[\frac{\omega}{p}\ln\frac{\omega + p}{\mu} - 1\right];$$

$$J = \frac{\sqrt{2}}{M^2}\frac{E}{q}\left[6 - \frac{\mu^2 + 2M\omega}{Mp}\ln\frac{M(\omega+p)-\mu^2}{M(\omega-p)-\mu^2} + \right.$$
$$\left. - \frac{M-4\omega}{p}\ln\frac{M-\omega+p}{M-\omega-p}\right];$$

$$D = \frac{E^2}{M^4}\left[2\frac{\mu^2 + M\omega}{Mp}\ln\frac{M(\omega+p)-\mu^2}{M(\omega-p)-\mu^2} + \right.$$
$$\left. + 4\frac{M-2\omega}{p}\ln\frac{M-\omega+p}{M-\omega-p} - 12\right]$$

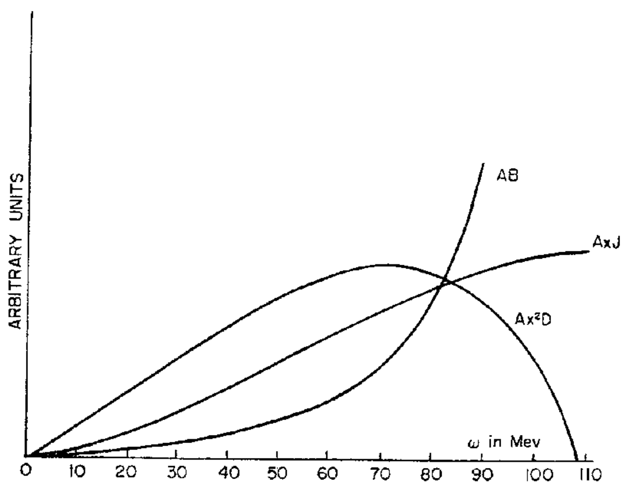

Fig. 4 The π^+ spectrum.

and with the following notations: ω and p are the energy and momentum of the π^+ in the K rest system, μ is the pion mass, and M the K mass; E, q and β are given by

$$E^2 = M^2 + \mu^2 - 2M\omega$$

$$2Eq = M^2 - 2\omega M$$

$$M^2\beta^2 = M^2 - 4\mu^2$$

and ω_0 is the rate for $K^+ \rightarrow \pi^+ + \pi^0$. The parameter x comes out to be 15 in the model we have considered.

In Eq. (1) B is the brehmsstrahlung term corresponding to graphs such as those of Fig. 3, D is the direct term from the graphs of Fig. 2 and J is the interference term. In Fig. 4 are shown the functions AB, AxJ and Ax^2D with $A = qp/E\beta$ for $x = 15$. A comparison with experiment would of course be very important. Apart from the interest relative to the $\Delta T = \frac{1}{2}$ rule, the $K^+ \rightarrow \pi^+ + \pi^0 + \gamma$ process occupies a rather unique place among radiative decays since it is a case in which the direct terms for the decay may be comparable or larger than the brehmsstrahlung contribution.

LIST OF REFERENCES AND NOTES

1. See, for instance, Crawford, F. S. et al. Phys. Rev. Letters **2**, p. 266 (1959).
2. Good, M. L. and Holladay, W. G. Phys. Rev. Letters **4**, p. 138 (1960).
3. Good, M. L. Phys. Rev. **113**, p. 352 (1959).

DISCUSSION

YANG: I would like to comment that the question of the isotopic spin state in the K meson decays as discussed here is a very interesting problem especially since we would like to use a rigorous $\Delta T = \frac{1}{2}$ rule. It will be very desirable, therefore, to have some more accurate measurements of the branching ratio of the K^0.

PRIMAKOFF: May I ask what is known about K^+ decaying into π^+ and one gamma?

GATTO: This is forbidden because the K spin is 0.

PRIMAKOFF: And what about, say, double gamma decay?

GATTO: The rate is very small.

PRIMAKOFF: Yes, but it seems to be down more than would be expected on your model.