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$\pi\pi\gamma$ Decay Mode of Neutral K Mesons*

D. STERN
Department of Physics, University of Wisconsin, Madison, Wisconsin
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The decay $K\rightarrow\pi^{+}+\pi^{-}+\gamma$, $\gamma\rightarrow e^{+}+e^{-}$ has been observed in the film of the UCRL 72-in. hydrogen bubble chamber exposed to a beam of 1325-MeV/c momentum negative pions. This event unambiguously fits only the decay mode $K\rightarrow\pi+\pi+\gamma$, but because the K's life span is almost exactly one K_1^0 lifetime it is impossible to say whether it is a direct $\pi\pi\gamma$ or inner bremsstrahlung accompanying normal $K_1^0\rightarrow 2\pi$ decay.

THE decay $K\rightarrow\pi^{+}+\pi^{-}+\gamma$, $\gamma\rightarrow e^{+}+e^{-}$ has been observed in the film of the UCRL 72-in. hydrogen bubble chamber exposed to a beam of 1325-MeV/c momentum negative pions. Figure 1 shows a sketch and a photograph of this event: The incident π^- scatters elastically from a proton at A, proceeds to B where it interacts with another proton to produce a Λ (not seen) and a K which decays at C via the $\pi\pi\gamma$ mode. It is not possible to say whether the γ converts internally or at a point about 3 mm from the decay origin.

ANALYSIS OF $\pi\pi\gamma$ DECAY MODE

The validity of the $\pi\pi\gamma$ interpretation of this event was checked in 2 ways:

(1) The energy of the pion after scattering was determined from the best fit of angles and momenta to an elastic π-p scattering at A. The K momentum at C was calculated using the direction of the neutral track and the angles and momenta of all charged decay products assuming the decay mode $K\rightarrow\pi^{+}+\pi^{-}+e^{+}+e^{-}$. The values of the parameters of the scattered pion and this K meson were then propagated to vertex B where $\pi^{-}+p\rightarrow\Lambda+K$ was the only associated production hypothesis allowed. Table I lists the momenta involved.

(2) The elastic scattering at A was fitted as before. Using the direction of the neutral particle and the now known incident pion momentum at the associated production vertex, the K-meson momentum was calculated assuming both $\pi^{-}+p\rightarrow\Lambda+K$ and $\pi^{-}+p\rightarrow\Sigma+K$. There are two physically allowed momenta in the latter reaction. For each K-meson momentum the decay $K\rightarrow\pi^{+}+\pi^{-}+\gamma$ was attempted with no information assumed about the γ momentum or direction. Only the reaction $\pi^{-}+p\rightarrow\Lambda+K$ gave a K momentum such that this decay mode could be fitted. In this case the γ lies within 8° (less than 2 standard deviations) of the measured electron pair direction. The constrained γ momentum is 86.9±16.3 MeV/c and the algebraic sum of the electrons' momenta is 82.4±3.5 MeV/c. In the K rest frame the γ momentum is 66 MeV/c.

The momentum of the K^0 obtained by method (1) is 749 MeV/c, and by method (2) is 753 MeV/c. With either value the life span of the K in its rest frame is $\tau(K)=(0.98\pm0.05)\times10^{-10}$ sec.

TABLE I. Particle momenta.

Track No.	Identification	Momentum (MeV/c)
1	π^-	1312
3	π^-	1198
4	p	475
5	K^0	750
6	π^-	324
7	π^+	444
8	e^-	43
9	e	39

EXCLUSION OF ALTERNATE DECAY HYPOTHESES

Ignoring the electron pair, the most frequent visible decay mode $K_1^0\rightarrow\pi^{+}+\pi^{-}$ can be excluded even without considering the direction of flight of the K by using the opening angle of the charged pions and their momenta. Further, using the K direction and momentum as determined in method (2), the two tracks which are assumed to be pions will not fit a K_1^0 decay

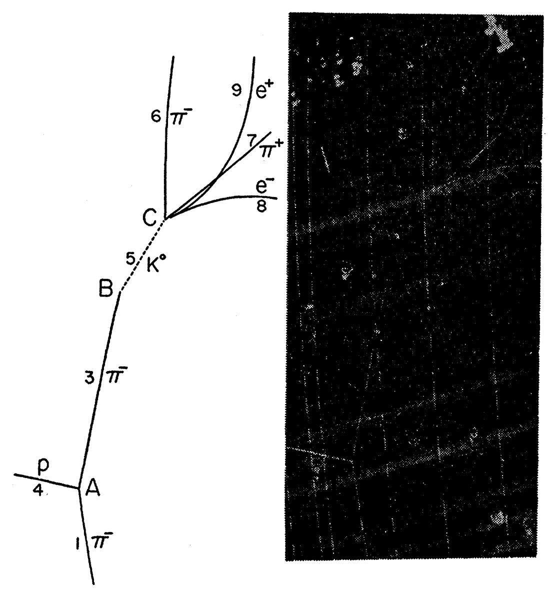

FIG. 1. A photograph with accompanying tracing is shown of a decay of a neutral K into two charged pions and an electron pair.

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TABLE II. Exclusion of small-angle scattering.

	K momentum (calculated) (MeV/c)	$K-\pi$ angle (deg)	Implied momentum (MeV/c)	Measured momentum (MeV/c)
π^-	750	33.2±0.3	371±3	324± 6.5
π^+	750	20.0±0.3	550±4	440±13

even if one assumes that one of these tracks scattered. The contradictions of this assumption are shown in Table II. Although the momentum is a double-valued function of angle at this K momentum, only the closer value is shown.

The three-body τ^0 decay, $K_{1,2}{}^0 \to \pi^+ + \pi^- + \pi^0$, can also be ruled out since the Q of the charged pions alone is 152.6±16 MeV, while that allowed for all 3 pions may not exceed 83.5 MeV.

We next consider the leptonic decays $K \to \pi + \text{lepton} + \nu$, an inner bremsstrahlung giving rise to the electron pair. Again we use the K directions and momentum as determined in method (2). For both muonic decays the neutrino momentum in the lab must be about 15 MeV/c. Assuming that the lepton is an electron, the negative electron predicts the larger neutrino momentum 35 MeV/c. Even in this more probable case, the momentum of the neutron is at the low end of its allowed spectrum, and from phase-space considerations we estimate that the probability that it will be 35 MeV/c or less is less than 3%. Considering the low probability of leptonic decay, the additional factor of $\sim 10^{-3}$ for inner bremsstrahlung, and the extremely low probability for the small neutrino momentum from phase space, we conclude that this interpretation of the event is incorrect.

Finally, we investigate the possibility of the decay at C being $K_1{}^0 \to \pi^0 + \pi^0$; either or both π^0's decaying at the vertex by the normal mode $\pi^0 \to \gamma + \gamma$ or Dalitz decay mode $\pi^0 \to \gamma + e^+ + e^-$. All possible combinations of charged tracks are tabulated in Table III. It is seen that this interpretation is also incorrect.

The interpretation of the decay at C as $\Lambda \to p + \pi + \gamma$ can be excluded by kinematics and by the bubble density of track 7.

TABLE III. Electron pair M^*.

Track No.	$M_{+-}{}^*$ (MeV)	Opening angle
(6, 9)	133	71.5°
(7, 8)	77	37.8°
(6, 7)	330	51.8°
(8, 9)	5.7	8°

CONCLUSIONS

The pion from an elastic scattering at A interacts with a proton at B, and the K from the reaction decays at C. It is possible to rule out all interpretations of the decay except $K^0 \to \pi^+ + \pi^- + \gamma$. CP invariance permits $K_1{}^0 \to \pi^+ + \pi^-$, but forbids $K_2{}^0 \to \pi^+ + \pi^-$. Similarly, CP invariance permits $K_1{}^0 \to \pi^+ + \pi^- + \gamma$, but forbids $K_2{}^0 \to \pi^+ + \pi^- + \gamma$, the γ coming from inner bremsstrahlung.

We calculate the ratio of the decay rate of $K_1{}^0 \to \pi^+ + \pi^- + \gamma$ (the γ having c.m. momentum 65 MeV/c or larger) to the decay rate of $K_1{}^0 \to \pi^+ + \pi^{-1}$:

$$\frac{W(K_1{}^0 \to \pi^+ + \pi^- + \gamma)}{W(K_1{}^0 \to \pi^+ + \pi^-)} \sim \frac{1}{137} \times 0.4 \simeq \frac{1}{350}.$$

Unfortunately, this is not small in the present experiment. We conclude that the event corresponds to the decay, accompanied by an inner bremsstrahlung process, of a $K_1{}^0$ or a direct decay ($K_1{}^0$ or $K_2{}^0$) $\to \pi^+ + \pi^- + \gamma$.

An event of this type has been previously observed in an associated production experiment in the 10-in. Berkeley hydrogen chamber, where a γ ray of $\sim$30 MeV converted externally.[2] Both of the above interpretations also apply to that event.

ACKNOWLEDGMENTS

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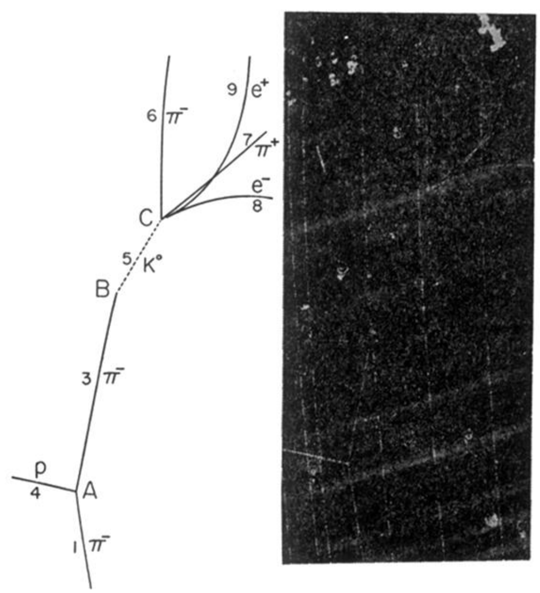
[1] B. Sakita (private communication).
[2] M. L. Good (private communication).



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