A STUDY OF THE DECAY MODE $K_L^0 \rightarrow \pi^+ \pi^- \pi^0$ ***MASTER**

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ABSTRACT

The decay process $K_L^0 \rightarrow \pi^+ \pi^- \pi^0$ has been studied in the 3^0 K_L^0 beam at the Stanford Linear Accelerator Center using a wire chamber magnetic spectrometer. The three pion decay was separated from leptonic decays using kinematics and muon identification. The average detection efficiency is 58.5% with a variation of less than 10% over the Dalitz plot. For a matrix element expressed as

$$|M|^2 = 1 + 2 a_0 \frac{M_K}{M_\pi^2} (2 T_0 - T_{\max}) + \beta_0 \frac{M_K}{M_\pi^2} (2 T_0 - T_{\max})^2$$

we find $a_0 = -0.257 \pm 0.005$. The squared term is consistent with zero.

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The 3π decay of the K meson is of interest because little is known concerning the dynamics of the decay. However, using a given parameterization of the matrix element, useful relations concerning the $\Delta I = 1/2$ rule and the Callan-Treiman¹ relations can be tested.

The matrix element governing the decay of a pseudoscalar meson into three pseudoscalar mesons is usually expanded in a power series in the kinetic energy of one of the decay mesons; in this case, the π^0 .

$$M \simeq 1 + a_0 \frac{M_K}{M_{\pi^+}^2} (2 T_0 - T_{\max}) \dots \quad (1)$$

where

M_K = mass of the K meson

M_{π^+} = mass of the π^+ meson

T_0 = kinetic energy of the π^0 in the K rest frame

$T_{\max}$ = $2/3 Q$ value of the 3π decay

a_0 = a parameter of the expansion

If we terminate the series after one term then the square of the matrix element will contain terms in $(2 T_0 - T_{\max})$ and $(2 T_0 - T_{\max})^2$.

We fit the expression

$$|M|^2 \simeq 1 + 2 a_0 \frac{M_K}{M_{\pi^+}^2} (2 T_0 - T_{\max}) + \beta_0 \frac{M_K^2}{M_{\pi^+}^4} (2 T_0 - T_{\max})^2 \quad (2)$$

This treatment is consistent with previous experiments.²

We also expand the matrix element in terms of the kinetic energies of the charged pions and obtain

$$|M|^2 \simeq 1 + 2 a_{\pm} \frac{M_K}{M_{\pi^+}^2} (2 T_{\pm} - T_{\max}) + \beta_{\pm} \frac{M_K^2}{M_{\pi^+}^4} (2 T_{\pm} - T_{\max})^2 \quad (3)$$

A wire spark chamber magnetic spectrometer was used to obtain 36,000 $K_L^0 \rightarrow \pi^+ \pi^- \pi^0$ events at SLAC. A schematic of the apparatus is shown in Figure 1. K_L^0 decays occurred in a 1 m long decay volume bounded by an anti-coincidence counter upstream and a time of flight counter downstream. The directions of the charged decay products were measured in a set of six 1 m x 1 m double-plane magnetostrictive wire spark chambers. After the particles traversed a 10.5 kg-m bending magnet, a second set of 1 m x 2 m wire spark chambers was used to determine the trajectories. The spark chamber trigger consisted of:

- (1) no count in the anti-coincidence counter
- (2) a count in the time of flight counter

and

- (3) two charged particles in the array of trigger counters downstream of the last wire spark chamber.

Muons were identified by their ability to penetrate 19" of lead and 5" of steel. Information from the muon identifiers was recorded on magnetic tape for each event but they did not participate in the spark chamber trigger.

Analysis of the data yielded 300,000 events with a pair of charged particles of opposite sign with a reconstructed vertex within the decay volume. $K_L^0 \rightarrow \pi^+ \pi^- \pi^0$ events were selected from the sample by requiring that:

- (1) neither charged particle penetrates the lead-steel barrier.
- (2) the transverse momentum of each charged track be less than 133 Mev/c, the kinematic limit in the 3π decay mode.
- (3) the transverse momentum P_T of the charged pair be consistent with 3π decay.

and

- (4) the kinematic variable

$$P_o'^2 = \frac{(M_K^2 - M_\pi^2 - M_{12}^2)^2 - 4(M_\pi^2 M_{12}^2 + P_T^2 M_K^2)}{4(P_T^2 + M_{12}^2)}$$

where M_{12} is the invariant mass of the charged particle pair

interpreted as $\pi^+ \pi^-$;

be between -7.0×10^3 and $+ 33.0 \times 10^3$ (Mev/c)².

A Monte Carlo calculation incorporating the geometry of the apparatus and the known beam spectrum, as obtained from a measurement of regeneration in copper, was carried out to obtain the acceptance of 3π events and the effects of contamination from leptonic decays.

Figure 2 shows the quantity $P_O'^2$ for all events. The shaded events are those satisfying cuts (1), (2), and (3) above. The shoulder at negative $P_O'^2$ is an indication of the contamination in the data due to leptonic decays. We have fitted this shoulder by a Monte Carlo calculation, as is shown by the solid curve in figure 2. The fitted values were 3.7% K_{e3} and 7.4% $K_{\mu 3}$ contamination remaining in the $K_{3\pi}$ region $-7 \times 10^3 \leq P_O'^2 \leq + 33 \times 10^3$ (Mev/c)².

Figure 3 shows the energy spectrum of the neutral pion. Each point is obtained by dividing the number of events by the acceptance of phase space as obtained from the Monte Carlo calculation. A fit to the linear matrix element squared, corrected for remaining leptonic background, yields a value of $a_0 = -.257 \pm .005$. The correction for the backgrounds was $+.020$. Radiative corrections have not been made to the data.

Because of the high (≈ 5 Gev/c) average momentum of the beam we have not determined the energy of the K_L^0 's by time of flight. Hence for the charged pion spectra we have high and low K^0 momentum solutions arising from the well known 0-c ambiguity. Figure 4 shows the spectra of the charged pions divided by Monte Carlo calculated phase space for both the high and low K_L^0 solutions. Table I gives the results of our fits to the matrix elements (1), (2) and (3).

It is expected that if the matrix element as given in equation (2) the slopes a_0 and $a_{\pm}$ will be related by

$$\frac{a_0}{a_{\pm}} = -2 .$$

We find

$$\frac{a_0}{a_{\pm}} = -1.93 \pm 0.14$$

where we have used our average $a_{\pm} = 0.133 \pm .01$

Comparison with $\Delta I = 1/2$ predictions

The $\Delta I = 1/2$ rule predicts:

$$a_0(+ - 0) = a_+(+ 00)$$

$$a_0(+ - 0) = -2a_-(++-)$$

where the quantities in parenthesis refer to the charges of the pions. Using ^{2, 3}

$$a_+(+00) = -0.26 \pm 0.02$$

and

$$a_-(++-) = 0.100 \pm 0.0036$$

we find

$$\frac{a_0(+ - 0)}{a_+(+00)} = 0.99 \pm 0.09$$

and

$$\frac{a_0(+ - 0)}{a_-(++-)} = -2.57 \pm 0.05.$$

Comparison with Current Algebra Predictions

Several authors ^{1, 4, 5} have used the algebra of currents to make predictions relating $K \rightarrow 3\pi$ amplitudes to $K \rightarrow 2\pi$ amplitudes. Using the most recent amplitudes these relations would predict a slope of

$$a_0 = -0.22$$

for the neutral pion spectrum.

The amplitudes for $K_L \rightarrow \pi^+ \pi^- \pi^0$ are also predicted ^{1, 4, 5} to vanish when the four momentum of the charged pions vanish, $q(\pi^{\pm}) = 0$.

Using our average slope of

$$a_{\pm} = 0.133 \pm 0.01$$

and the extrapolation procedure of Nefkens ⁵ we find the amplitude

$$A[q(\pi^{\pm}) = 0] = -0.005 \pm 0.07.$$

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FIGURES

1. Schematic of the experimental apparatus.
2. $P_O'^2$ for all events. Shaded events satisfy all cuts for 3π except the $P_O'^2$ cut. The line shows the Monte Carlo calculation of the leptonic contamination of the $K\pi_3$ events.
3. Spectrum of the neutral pion. Each point is the number of events divided by phase space. Normalization is obtained from

$$dN/d\phi = 1 \text{ at } T_{\pi^0} = T_{\max}/2.$$

4. Spectrum of the charged pions for each of the K^0 momentum solutions.

TABLE I

$$|M|^2 = 1 + 2a_{\pm 0} (M_K/M_{\pi} + 2) (2T_0 - T_{\max}) + \beta_{\pm 0} (M_K^2/M_{\pi} + 4) (2T_0 - T_{\max})^2$$

	<u>Result</u>	
	<u>a</u>	<u>β</u>
1. Neutral Pion Energy Spectrum (a_0)	$-.257 \pm .005$	$-.023 \pm .014$
2. Positive Pion Energy Spectrum (High Solution a_{++})	$.108 \pm .010$	$-.007 \pm .025$
3. Positive Pion Energy Spectrum (Low Solution a_{++})	$.128 \pm .012$	$-.054 \pm .030$
4. Negative Pion Energy Spectrum (High Solution a_{-+})	$.146 \pm .010$	$-.005 \pm .025$
5. Negative Pion Energy Spectrum (Low Solution a_{-+})	$.150 \pm .013$	$-.057 \pm .033$

All fits are performed on the data with background subtracted. The errors are statistical.

Fig. 1 JHU-7016 and JHU-7018

Fig. 2 JHU-7018

Fig. 4 JHU-7018