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SIGN OF THE K_L-K_S MASS DIFFERENCE*

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The sign of the ($K_L{}^0$-$K_S{}^0$) mass difference has been measured by studying the time distribution of scattered neutral K mesons, using K^0's from the reaction $K^+ + d \rightarrow K^0 + p + p$. We obtain $m(K_L) > m(K_S)$.

We have measured the sign of the K_L-K_S mass difference by observing the time distribution of neutral scattered K's in the Brookhaven National Laboratory 30-inch bubble chamber filled with deuterium. We find $m(K_L) - m(K_S) = (0.64 \pm 0.18)(\hbar/c^2) \times 10^{10}$, i.e., $m(K_L) > m(K_S)$.

The experiment was performed at the alternating-gradient synchrotron (AGS) where the bubble chamber was exposed to a 600-MeV/c separated K^+ beam. In a systematic search for K^0 decays in 300 000 pictures, we have identified about 10 000 events of the type

$$K^+ + d \rightarrow K^0 + p + p. \tag{1}$$

The sign of the mass difference has been obtained by observing the elastic scattering of K^0's, produced in the above reaction, and the subsequent K_S decay after the K^0 scattering.[1] The intensity for these reactions

$$\begin{Bmatrix} \bar{K}^0 \\ K^0 \end{Bmatrix} + d \rightarrow \begin{Bmatrix} \bar{K}^0 \\ K^0 \end{Bmatrix} + p + n, \atop \qquad\qquad\qquad \llcorner\!\rightarrow \pi^+ + \pi^-, \tag{2}$$

is given by

$$F(t, t', \Delta m) = I(t, \Delta m) e^{-\lambda s t'},$$

where

$$I(t, \Delta m) = |f_1(t)(A+B) + f_2(t)(A-B)|^2 + |f_1(t)(A'+B') + f_2(t)(A'-B')|^2.$$

Here $f_1 = \exp[-(\lambda_1/2 + im_1)t]$, $f_2 = \exp[-(\lambda_2/2 + im_2)t]$, A and B are the K^0 and $\bar{K}^0$ nucleon spin-nonflip amplitudes, and A' and B' are the K^0 and $\bar{K}^0$ nucleon spin-flip amplitudes, respectively. The time from production of the K^0 to the scattering is t; t' is the time from scattering to the K_S decay; $\Delta m = m(K_L) - m(K_S)$; λ_S and λ_L are the K_S and K_L decay rates.[2]

The pictures were scanned for V's independent of production origin. The bulk of the pictures were scanned twice giving a combined scanning efficiency of $(98 \pm 1)\%$. All events were required to be within a suitably chosen fiducial volume. For all V's the following criteria had to be satisfied: (a) The dip angles of both the neutral and charged tracks were less than 70°; (b) the distance of a V from the production origin or recoil was greater than 3 mm; and (c) the errors in the measured momenta were less than the values of the momenta. All frames in which the V's fitted a free $K^0 \rightarrow \pi^+ + \pi^-$ (one constraint), but could not be associated with any production vertex (three constraints) were examined for possible recoil protons of length greater than 2 mm. In this manner a sample of 72 scattered K^0 events was obtained, in which each event satisfied kinematics at the production, interaction, and decay vertices.

The production kinematics limit the K^0 momentum to the range 100 to 600 MeV/c. Figure 1(a) shows the observed distribution of incident K^0 momenta for Reaction (2). The typical momentum for the interacting K^0 is around 450 MeV/c. The K^0 lifetime for our 72 scattered events is $(0.83 \pm 0.10) \times 10^{-10}$ sec.

To establish whether the K^0 interacted with the proton or the neutron in Reaction (2), we assumed that the slower nucleon was the spectator. To facilitate this decision we accepted only events in which the incident K^0 momentum is greater than 200 MeV/c. A scatter plot of the laboratory momentum of the two nucleons is shown in Fig. 1(b). The spectator momentum distribution is in agreement with that predicted by the Hulthén wave function. Removal of the events in the overlap region within the bands in Fig. 1(b) does not alter the conclusions of the analysis. Of the 72 events which survive the selection criteria, there are 20 neutron

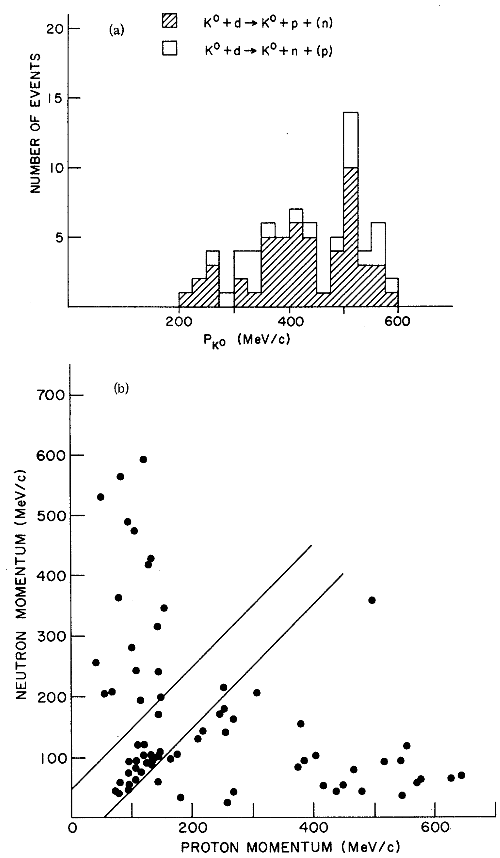

FIG. 1. (a) Momentum distribution of incident K^0's. (b) Scatter plot of the momentum of the proton against the momentum of the neutron in the laboratory system for the reaction

$$\binom{K^0}{\bar{K}^0}+d \to \binom{K^0}{\bar{K}^0}+p+n.$$

(spectator proton) and 52 proton events.

After separating the events into these two categories, we determine the sign of the mass difference in the following way. For each event, the phase shifts and amplitudes A and B appropriate to the kinematic information at the K^0 interaction were obtained. For the K^0 nucleon phase shifts, the results of the S, P, D partial-wave analysis by Stenger et al.[3] were used. For the $\bar{K}^0$-nucleon amplitudes the S-wave solutions of Kim[4] and Sakitt et al.[5] and the P- and D-wave solutions of Watson et al.[6] were used. These amplitudes, A_i and B_i, and the time, t_i, for each event were used to construct the likelihood function

$$\mathcal{L}(\Delta m)=\prod_i \left\{ \frac{I_i(t_i, \Delta m)}{\int_{t_i^{\min}}^{t_i^{\max}} I(t, \Delta m)\,dt} \right\}. \qquad (3)$$

The limits in the denominator, $t_i^{\min}$ and $t_i^{\max}$, are the times which correspond to the minimum and maximum observable distances in the cham-

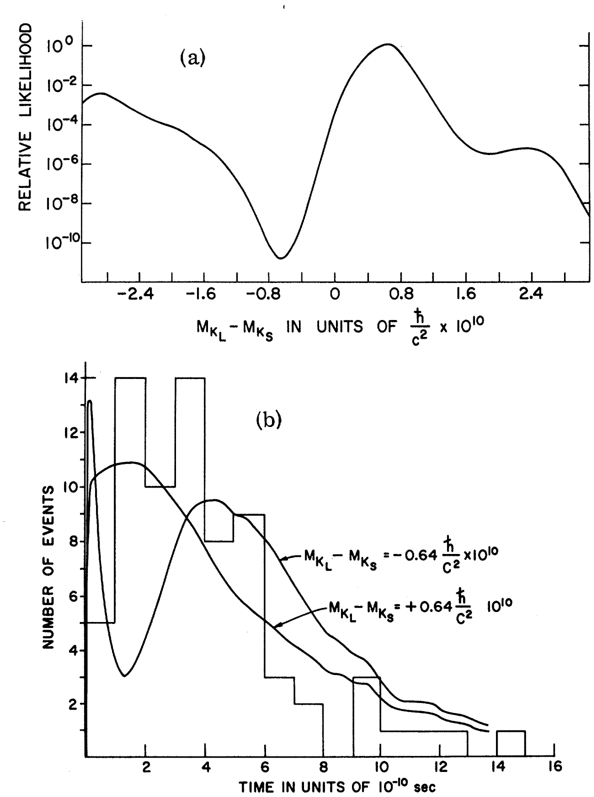

FIG. 2. (a) Plot of the relative likelihood function of $m(K_L)-m(K_S)$. (b) Observed time distribution of scattered neutral K's. The solid curves are the expected distributions.

ber for the ith event. A plot of this likelihood function is shown in Fig. 2(a). From the graph we obtain $m(K_L)-m(K_S)=(0.64\pm0.18)(\hbar/c^2)\times10^{10}$. This result does not include the effect of uncertainties in the phase shifts. Varying the phase shifts within their experimental errors shifts the likelihood peak by less than 20% and does not alter the conclusions of the analysis.

If the magnitude of the mass difference is assumed $[|\Delta m|=0.64(\hbar/c^2)\times10^{10}]$, the normalized intensities $I(t,+\Delta m)$ and $I(t,-\Delta m)$ as functions of time, for each event, can be calculated. The normalized curves can then be added to give the time distribution which is expected for that particular choice of sign of the mass difference. These curves and the observed data are shown in Fig. 2(b). As can be seen from these curves, $m(K_L)>m(K_S)$ is a better fit to the data. This result agrees with the results from a regeneration experiment[7] and a scattered K experiment.[8]

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