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TWO-PION DECAY OF THE K_2^0 MESON*

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The existence of the decay $K_2^0 \to \pi^+ + \pi^-$ was first observed by Christenson et al.[1] They determined the branching ratio, R, of this mode compared to all charged decay modes of the K_2^0 as $(2.0 \pm 0.4) \times 10^{-3}$ at a K_2^0 momentum of 1.1 GeV/c. This Letter reports the preliminary results of an experiment at Nimrod in which the two-pion decay mode is clearly distinguished from the background of three-body decays of the K_2^0, confirming the earlier observation.[1] The branching ratio R is found to be $(2.08 \pm 0.35) \times 10^{-3}$ averaged over the K_2^0 momentum spectrum which extends from 1.5 to 5.0 GeV/c. A comparison of this result with that of Christenson et al.[1] rules out a variation of the branching ratio with the square of the K_2^0 total energy. Such a variation has been suggested on the basis of an interaction of the K_2^0 meson with a long-range vector field.[2,3]

A neutral beam taken at zero degrees from an internal target (6 in. of copper) emerges from the shield wall. A lead converter 2 in. thick and a sweeping magnet remove γ rays and their charged products from the beam. The resulting neutral beam is 17 cm wide and 8 cm high (base widths) at entry to a vacuum chamber 40 m from the machine target. The minimum inner dimensions of the vacuum chamber are 45 cm wide and 20 cm high, its length is 5 m, and the entrance and exit windows are of Mylar (0.01 in. thick).

The charged products of decay of K_2^0's within the vacuum chamber are momentum analyzed by two spectrometer systems each comprising four sonic spark chambers and a bending magnet. All the spark chambers are triggered by a six-fold coincidence of scintillation counters. The sonic chamber data, consisting of scalar readings from which the coordinates of the sparks can be determined, are recorded on magnetic tape and later analyzed by an Orion computer. The spark chambers determine particle positions to an accuracy of ±0.3 mm.[4]

Each event is analyzed to find the decay point (x_0, y_0, z_0), the mass M_0, the momentum P_0, and the direction of motion θ_0 (with respect to the beam direction) of the decaying particle. The assumption is made that the decay is to two bodies only, both being π mesons. Only decays occurring within a fiducial volume 16 cm wide, 10 cm high, and 460 cm in length, were accepted, thus ensuring that all decays took place well within the vacuum chamber. The apparatus has an estimated mass resolution $\delta M_0 = \pm 3$

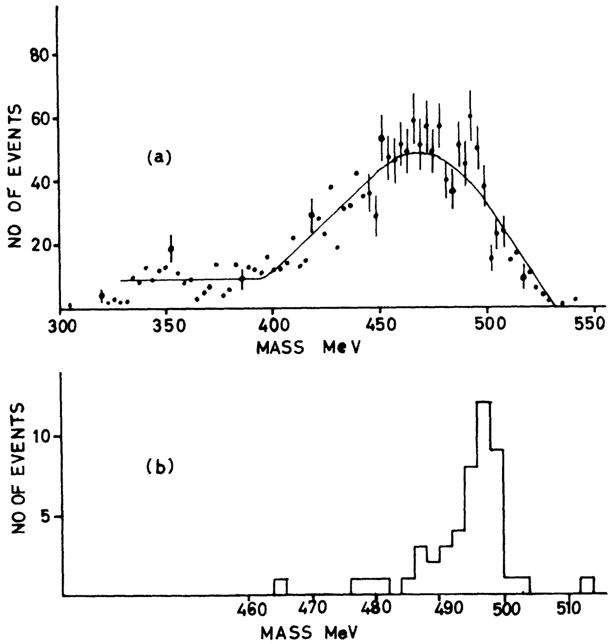

FIG. 1. Distribution of the apparent mass M_0 of the decaying particle, assuming that the two decay products are π mesons. (a) With no restriction on the angle θ_0. (b) With θ_0 restricted to values 0-2 mrad; note that the horizontal scale has been expanded in comparison with Fig. 1(a).

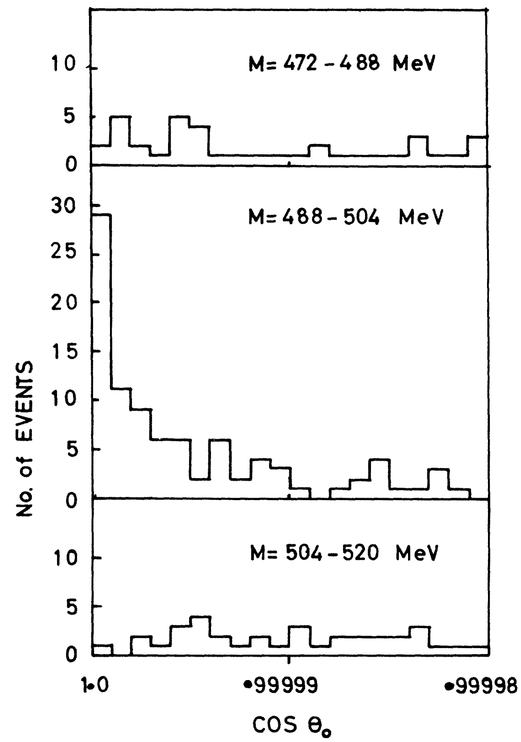

FIG. 2. Distribution in $\cos\theta_0$ for particles in the mass intervals as shown.

MeV and an angular resolution $\delta\theta_0 = \pm 2$ mrad (standard deviations) for decays to $\pi^+ + \pi^-$. The data presented in Figs. 1 and 2 were obtained with 80 000 Nimrod pulses (2 days effective running time) at an intensity of 5×10^{11} protons/pulse incident upon the internal target. Figure 1(a) shows the mass distribution, placing no restrictions on the angle θ_0. The broad peak from $M = 365$ MeV to $M = 530$ MeV results from the leptonic decays $K_{\mu 3}$ and K_{e3} which, having been analyzed as two body decays, give a spectrum of masses. The peak from 320 to 363 MeV is from the decay $K_2^0 \to \pi^+ + \pi^- + \pi^0$. The solid curve is the result of a Monte-Carlo calculation on the $K_{\pi 3} + K_{e3} + K_{\mu 3}$ modes, which is discussed below. The experimental data fit well to the predicted mass plot for three-body decays. Figure 1(b) shows the mass distribution for events with $\theta_0 \leq 2$ mrad, a restriction which implies that the two detected particles are coplanar with the incoming K_2^0 and have no net transverse momentum. This discriminates against most of the three-body decays, but two-body decays should be accepted. A narrow peak has been observed having a full width at half-height of 5 MeV, and centered at a mass of 497 MeV. This is equal to the mass of the K meson within the accuracy of calibration of the magnets of $\frac{1}{2}\%$. This result is strong evidence for the decay $K_2^0 \to 2\pi$. The peak at 497 MeV is also evident in the general mass plot [Fig. 1(a)]. The data are displayed in a different manner in Fig. 2. Here the number of detected events is plotted against $\cos\theta_0$ for three different mass ranges. A sharp peak is seen in the mass range containing the K_2^0 mass, in contrast to the flat distributions seen in the adjacent mass ranges above and below. The Monte-Carlo calculation for the three-body decays shows no such peaking in the $\cos\theta_0$ plot. The first interval used in the plot of $\cos\theta_0$ corresponds to the angular range 0-1.4 mrad.

After correction for background, there are 54 events in the forward peak. The decay points of these events occur throughout the fiducial volume and lie within the known region of K_2^0 flux. The distribution of points along the beam direction is consistent with the lifetime of the K_2^0 meson and completely inconsistent with that of the K_1^0. The possibility of these events arising from K_1^0 regeneration in the walls of the vacuum tank is ruled out, because such events would have values of $\theta_0 > 10$ mrad. Moreover the fiducial volume requirements were relaxed to include the regions close to the walls of the vacuum chamber and no decay points were found close to the walls. We conclude therefore that these events are examples of the decay $K_2^0 \to \pi^+ + \pi^-$

The experiment has been simulated by a Monte-Carlo calculation for the charged decay modes $K\pi 2$, $K\pi 3$, $Ke3$, and $K\mu 3$, assuming a momentum spectrum of the K_2^0's calculated from yield measurements of K^+ and K^- measured at Nimrod.[5] The published branching ratios[6] for $K_{\pi}3$, $K_e 3$, and $K_{\mu}3$ of 12%, 38%, and 27% have been used and a V-A interaction for the leptonic modes (with a ratio of the form factors $f^-/f^+ = 0.5$) has been assumed. The 3π decay spectrum was taken to be proportional to phase space. The geometry of the apparatus and all the selection criteria that were applied to the experimental data were used.

Histograms were obtained for the predicted spectra of detected events from each mode as a function of M_0, θ_0, P_0, and P_K (the K-meson momentum). In particular a comparison was made between the P_0 spectrum of the leptonic decays obtained in the experiment, and that calculated. This comparison is a sensitive test of the shape of the K_2^0 momentum spectrum fed into the Monte-Carlo calculation. Some modification of the K_2^0 spectrum was necessary to obtain exact agreement with the P_0 spectrum determined experimentally, and this modified K_2^0 momentum spectrum has been used in further calculations. Geometrical efficiencies for detecting each decay mode $K_{\pi}2$, $K_{\mu}3$, and $K_e 3$, averaged over the K_2^0 momentum spectrum and the fiducial decay volume, were obtained from the Monte-Carlo calculation:

$$\epsilon_{\pi 2} = 1.4 \times 10^{-3}, \quad \epsilon_{\mu 3} = 1.0 \times 10^{-4},$$

$$\epsilon_{e3} = 0.9 \times 10^{-4}.$$

The number of events observed in the present experiment were

$$N_{\pi 2} = 54 \pm 9; \quad N_{l3} = 1440 \pm 50.$$

From these figures the branching ratio

$$R = (2.08 \pm 0.35) \times 10^{-3}$$

is obtained. It should be remarked that the value of R changes by only 5% if the original K_2^0 spectrum is used, although the individual efficiencies change by a factor of 1.5. This is due to the fact that the efficiencies $\epsilon_{\pi 2}$, $\epsilon_{\mu 3}$, and $\epsilon_{e 3}$ vary with momentum in a very similar way.

If the branching ratio R is proportional to the square of the total energy of the K_2^0 meson[2,3] and we use the result of Christenson et al.,[1] $(2.0 \pm 0.4) \times 10^{-3}$ at an effective momentum of 1.1 GeV/c, we would expect a value of R of $(13.4 \pm 3.0) \times 10^{-3}$. The error is predominantly determined by the scaling up of the error in R from Christenson et al.'s experiment and to a lesser extent by the uncertainty in our K_2^0 momentum spectrum. We have taken no account of the spread in energy of the K_2^0 mesons in the former experiment.

We, therefore, confirm that the K_2^0 meson decays into two charged pions in vacuum; and, further, we conclude that the decay rate is not proportional to the square of the total energy of the K_2^0 meson. Thus the source of apparent CP violation in this decay mode lies elsewhere than in the long-range vector field.[2,3]

As an alternative to CP violation, it has been suggested[7,8] that the decay $K_2^0 \to 2\pi$ can be explained by assuming the existence of a new particle K_3^0 with the same mass as the K_2^0 and decaying into two pions, but with a different lifetime. Assuming that the K_2^0 and K_3^0 are produced at the machine target and that the K_3^0 momentum spectrum at production is similar in shape to that of the K_2^0, we deduce from the present data that the lifetime is longer than 10^{-8} sec.

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