EVIDENCE FOR THE 2π DECAY OF THE K₂⁰ MESON*†

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This Letter reports the results of experimental studies designed to search for the 2π decay of the K₂⁰ meson. Several previous experiments have served to set an upper limit of 1/300 for the fraction of K₂⁰'s which decay into two charged pions. The present experiment, using spark chamber techniques, proposed to extend this limit.

In this measurement, K₂⁰ mesons were produced at the Brookhaven AGS in an internal Be target bombarded by 30-BeV protons. A neutral beam was defined at 30 degrees relative to the circulating protons by a 1 1/2-in. × 1 1/2-in. × 48-in. collimator at an average distance of 14.5 ft. from the internal target. This collimator was followed by a sweeping magnet of 512 kG-in. at -20 ft. and a 6-in. × 6-in. × 48-in. collimator at 55 ft. A 1 1/2-in. thickness of Pb was placed in front of the first collimator to attenuate the gamma rays in the beam.

The experimental layout is shown in relation to the beam in Fig. 1. The detector for the decay products consisted of two spectrometers each composed of two spark chambers for track delineation separated by a magnetic field of 178 kG-in. The axis of each spectrometer was in the horizontal plane and each subtended an average solid angle of 0.7 × 10⁻⁵ steradians. The spark chambers were triggered on a coincidence between water Cherenkov and scintillation counters positioned immediately behind the spectrometers.

When coherent K₁⁰ regeneration in solid materials was being studied, an anticoincidence counter was placed immediately behind the regenerator. To minimize interactions K₂⁰ decays were observed from a volume of He gas at nearly STP.

The analysis program computed the vector momentum of each charged particle observed in the decay and the invariant mass, m*, assuming each charged particle had the mass of the charged pion. In this detector the Kₑ93 decay leads to a distribution in m* ranging from 280 MeV to ~536 MeV; the K₁μ3, from 280 to ~516; and the K₁π3, from 280 to 363 MeV. We emphasize that m* equal to the K₀ mass is not a preferred result when the three-body decays are analyzed in this way. In addition, the vector sum of the two momenta and the angle, θ, between it and the direction of the K₂⁰ beam were determined. This angle should be zero for two-body decay and is, in general, different from zero for three-body decays.

An important calibration of the apparatus and data reduction system was afforded by observing the decays of K₁⁰ mesons produced by coherent regeneration in 43 gm/cm² of tungsten. Since the K₁⁰ mesons produced by coherent regeneration have the same momentum and direction as the K₂⁰ beam, the K₁⁰ decay simulates the direct decay of the K₂⁰ into two pions. The regenerator was successively placed at intervals of 11 in. along the region of the beam sensed by the detector to approximate the spatial distribution of the K₂⁰'s. The K₁⁰ vector momenta peaked about the forward direction with a standard deviation of 3.4 ± 0.3 milliradians. The mass distribution of these events was fitted to a Gaussian with an average mass 498.1 ± 0.4 MeV and standard deviation of 3.6 ± 0.2 MeV. The mean momentum of the K₂⁰ decays was found to be 1100 MeV/c. At this momentum the beam region sensed by the detector was 300 K₁⁰ decay lengths from the target.

For the K₂⁰ decays in He gas, the experimental distribution in m* is shown in Fig. 2(a). It is compared in the figure with the results of a Monte Carlo calculation which takes into account the nature of the interaction and the form factors involved in the decay, coupled with the detection efficiency of the apparatus. The computed curve shown in Fig. 2(a) is for a vector interaction, form-factor ratio f⁻/f⁺ = 0.5, and relative abundance 0.47, 0.37, and 0.16 for the Kₑ93, K₁μ3, and K₁π3, respectively. The scalar interaction has been computed as well as the vector interaction.
with a form-factor ratio $f^-/f^+ = -6.6$. The data are not sensitive to the choice of form factors but do discriminate against the scalar interaction.

Figure 2(b) shows the distribution in $\cos \theta$ for those events which fall in the mass range from 490 to 510 MeV together with the corresponding result from the Monte Carlo calculation. Those events within a restricted angular range ($\cos \theta > 0.9995$) were remeasured on a somewhat more precise measuring machine and recomputed using an independent computer program. The results of these two analyses are the same within the respective resolutions. Figure 3 shows the results from the more accurate measuring machine. The angular distribution from three mass ranges are shown; one above, one below, and one encompassing the mass of the neutral $K$ meson.

The average of the distribution of masses of those events in Fig. 3 with $\cos \theta > 0.99999$ is found to be $499.1 \pm 0.8$ MeV. A corresponding calculation has been made for the tungsten data resulting in a mean mass of $498.1 \pm 0.4$. The difference is $1.0 \pm 0.9$ MeV. Alternately we may take the mass of the $K^0$ to be known and compute the mass of the secondaries for two-body decay. Again restricting our attention to those events with $\cos \theta > 0.99999$ and assuming one of the secondaries to be a pion, the mass of the other particle is determined to be $137.4 \pm 1.8$. Fitted to a Gaussian shape the forward peak in Fig. 3 has a standard deviation of $4.0 \pm 0.7$ milliradians to be compared with $3.4 \pm 0.3$ milliradians for the tungsten. The events from the He gas appear identical with those from the coherent regeneration in tungsten in both mass and angular spread.

The relative efficiency for detection of the three-body $K^0_d$ decays compared to that for decay to two pions is 0.23. We obtain $45 \pm 9$ events in
the forward peak after subtraction of background
out of a total corrected sample of 22,700 $K_s^0$ de-
cays.

Data taken with a hydrogen target in the beam
also show evidence of a forward peak in the $\cos\theta$
distribution. After subtraction of background,
45 ± 10 events are observed in the forward peak
at the $K^0$ mass. We estimate that ~10 events can
be expected from coherent regeneration. The
number of events remaining (35) is entirely con-
sistent with the decay data when the relative tar-
get volumes and integrated beam intensities are
taken into account. This number is substantially
smaller (by more than a factor of 15) than one
would expect on the basis of the data of Adair
et al.4

We have examined many possibilities which
might lead to a pronounced forward peak in the
angular distribution at the $K^0$ mass. These in-
clude the following:

(i) $K_s^0$ coherent regeneration. In the He
gas it is computed to be too small by a factor of ~10^6 to
account for the effect observed, assuming reason-
able scattering amplitudes. Anomalously large
scattering amplitudes would presumably lead to
exaggerated effects in liquid H2 which are not
observed. The walls of the He bag are outside
the sensitive volume of the detector. The spatial
distribution of the forward events is the same as
that for the regular $K_s^0$ decays which eliminates
the possibility of regeneration having occurred
in the collimator.

(ii) $K_{\mu 3}$ or $K_{e 3}$ decay. A spectrum can be
constructed to reproduce the observed data. It
requires the preferential emission of the neutrino
within a narrow band of energy, ±4 MeV, cen-
tered at 17 ± 2 MeV ($K_{\mu 3}$) or 39 ± 2 MeV ($K_{e 3}$).
This must be coupled with an appropriate angular
correlation to produce the forward peak. There
appears to be no reasonable mechanism which
can produce such a spectrum.

(iii) Decay into $\pi^+\pi^-\gamma$. To produce the highly
singular behavior shown in Fig. 3 it would be
necessary for the $\gamma$ ray to have an average ener-
gy of less than 1 MeV with the available energy ex-
ceeding 209 MeV. We know of no physical
process which would accomplish this.

We would conclude therefore that $K_s^0$ decays to
two pions with a branching ratio $R = (K_s^0 - \pi^+\pi^-)/
(K_s^0 - all$ charged modes) = (2.0 ± 0.4)×10^{-3} where
the error is the standard deviation. As empha-
sized above, any alternate explanation of the ef-
effect requires highly nonphysical behavior of the
three-body decays of the $K_s^0$. The presence of a
two-pion decay mode implies that the $K_s^0$ meson
is not a pure eigenstate of $CP$. Expressed as
$K_s^0 = 2^{-1/2}[\langle K_s^0 - K^0 \rangle + \epsilon \langle K_s^0 + K^0 \rangle]$ then $|\epsilon|^2 \approx R_T^2 \tau_1 \tau_2$
where $\tau_1$ and $\tau_2$ are the $K_s^0$ and $K_s^0$ mean lives
and $R_T$ is the branching ratio including decay to
two $\pi^0$. Using $R_T = 3 R$ and the branching ratio
quoted above, $|\epsilon| \approx 2.3 \times 10^{-3}$.

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