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MEASUREMENT OF THE DECAY RATE OF $K_2^0 \to \pi^0 + \pi^0$ †*

James W. Cronin, Paul F. Kunz, Winthrop S. Risk, and Paul C. Wheeler
Palmer Physical Laboratory, Princeton University, Princeton, New Jersey

(Received 28 November 1966)

An experiment to measure the decay rates $R(K_2^0 \to \pi^0 + \pi^0)$ and $R(K_2^0 \to \gamma + \gamma)$ is in progress at the Princeton-Pennsylvania Accelerator (PPA). With a small fraction of the expected data analyzed, we find that we can draw a significant conclusion from the value we obtain for the decay rate $R(K_2^0 \to \pi^0 + \pi^0)$.

It has been pointed out by many authors[1] that a comparison of the decay rate $R(K_2^0 \to \pi^0 + \pi^0)$ with the well established CP-nonconserving decay rate[2] $R(K_2^0 \to \pi^+ + \pi^-)$ can lead to definite conclusions about the source of the CP violation in the decay of the K_2^0 into two pions. In particular a difference in the amplitude ratio

$$|\eta_{00}| = [R(K_2 \to \pi^0 + \pi^0)/R(K_1 \to \pi^0 + \pi^0)]^{1/2}$$

from

$$|\eta_{+-}| = [R(K_2^0 \to \pi^+ + \pi^-)/R(K_1^0 \to \pi^+ + \pi^-)]^{1/2}$$

is direct evidence that there is a CP-nonconserving $|\Delta I| \geqslant \frac{3}{2}$ amplitude in the decay $K_2^0 \to \pi + \pi$.

Our technique of measurement uses the fact that the energy spectrum of the γ rays from $K_2^0 \to \pi^0 + \pi^0$ extends to significantly higher energies than the major background $K_2^0 \to 3\pi^0$ in the K_2^0 center-of-mass system. In this system the energy distribution of single γ rays from $K_2^0 \to 2\pi^0$ extends from 19 to 229 MeV in a uniform spectrum. The spectrum of γ rays from $K_2^0 \to 3\pi^0$ approaches an upper limit of 165 MeV with zero slope. The observation of a small shelf beyond this upper limit is evidence of $K_2^0 \to 2\pi^0$, and the comparison of the height of this shelf with the number of γ rays from $K_2^0 \to 3\pi^0$ gives a direct measure of the ratio $R(K_2^0 \to 2\pi^0)/R(K_2^0 \to 3\pi^0)$.

Figure 1 shows a plan view of the apparatus. A beam of K_2^0 was produced by bombarding with 3-BeV protons an internal Pt target 1.5 in. long. The K_2^0 beam was defined by a tapered collimator placed at 90° to the incident proton beam. The 6-in. × 6-in. aperture at 10 ft from the target gave a nominal beam size of 12 in. × 12 in. at the detector, 20 ft from the target. Typical intensities were 5×10^4 K_2^0's/sec at a mean momentum of 250 MeV/c and 5×10^7 neutrons/sec with mean momentum of 400 MeV/

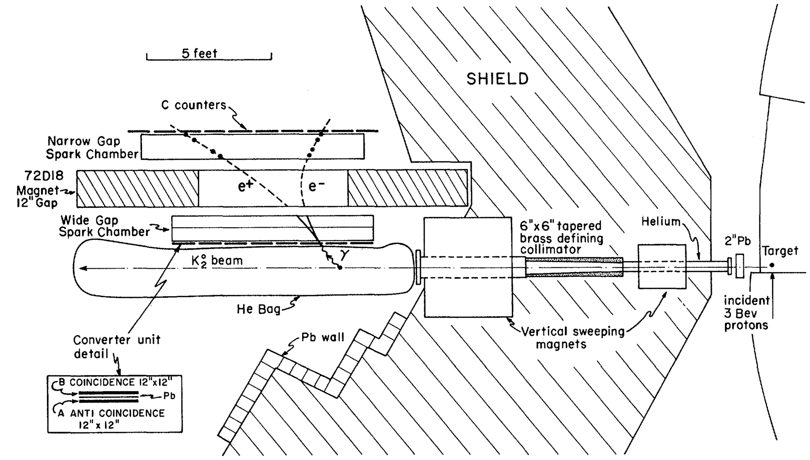

FIG. 1. Plan view of experimental apparatus.

c. Most of the neutrons were below the π^0 production threshold. Two sweeping magnets, each with $\int Bdl = 6\times10^5$ G cm, swept the beam free of charged particles. Two inches of lead were inserted to filter the γ-ray component of the beam. The decay region was enclosed with a helium bag for most of the runs, and the beam channel was filled with helium.

A pair spectrometer was used to observe the laboratory energies of γ rays emitted at large angles with respect to the K_2^0 beam. The γ rays converted in a 0.02-in.-thick Pb radiator sandwiched between two 12-in. × 12-in. × $\frac{1}{4}$-in. scintillation counters A and B. Eight such converting units were placed along the length of the beam. The converted electrons were observed in a wide-gap spark chamber 8 ft long × 14 in. high × 12 in. deep and then were deflected by a 72-in. × 18-in. magnet with a $\int Bdl = 1.4\times10^5$ G cm. Beyond the magnet was a conventional narrow-gap spark chamber with a row of ten 12-in. × 24-in. counters (C) behind it. The total thickness of the spark-chamber system between the counters was 0.12 g/cm^2. An event was triggered by a coincidence between $(\overline{A}B)$ and any two nonadjacent C counters. Stereo views of both chambers were recorded on a single frame. The momentum of the K_2^0 meson was measured by recording with an oscilloscope the time of flight of the K_2^0 between the production target and the detector. The beam of the PPA during this experiment was delivered on the target in 1.5-nsec wide bunches, 67 nsec apart. Knowledge of the K momentum allowed us to transform all γ rays to the center-of-mass system. The trigger rate was 7 counts/min. About 1 count/min was an event which showed an electron-positron pair. This rate was in agreement with the rate computed using the PPA beam survey.[3] Most of these γ rays were expected to be from $K_2^0 \to 3\pi^0$. The data here represent about 2000 such decays.

The detection efficiency and resolution of the pair spectrometer have been carefully calculated with Monte Carlo techniques. Ingredients in the calculation include consideration of bremsstrahlung loss and multiple scattering in the converter, multiple scattering in the foils and gas of the spark chamber, variation of conversion efficiency with the incident γ-ray energy and angle, and errors in the determination of the K momentum by time of flight. Another ingredient in the calculation is the K_2^0 momentum spectrum of the beam. This was directly measured in a previous PPA experiment.[4]

The detection efficiency of the pair-spectrometer as a function of center-of-mass γ-ray energy is zero below 100 MeV and rises linearly thereafter. The efficiency for detection of a single γ ray from $K_2^0 \to 3\pi^0$ is $(13.4 \pm 0.5)\,\%$ of the efficiency for detection of a single γ ray from $K_2^0 \to 2\pi^0$. This result assumes that the Dalitz plot for $K_2^0 \to 3\pi^0$ is uniform. The energy resolution of the apparatus for a monoenergetic γ ray is about 4% full width at half-maximum and there is a net downward shift of 1.6 % due to bremsstrahlung energy loss. In the wide-gap chamber the curvature of each track in the fringe field of the magnet permits an unambiguous correspondence between the tracks on either side of the magnet. Thus the momentum of the electron or positron can be measured independently of the multiple scattering in the converter. The energy resolution is significantly improved by this technique. The resolution can be directly observed if a sufficient number of events of the type $K_2{}^0 \to \gamma + \gamma$ can be seen, since this decay gives a monoenergetic 249-MeV γ ray in the center-of-mass system.

The events were measured in a two-stage process to speed the analysis. First, angles of deflection of the electron and positron were measured in the top view only and momenta calculated directly, without detailed reconstruction or consideration of the variation of the magnetic field integral. This rapid measurement yielded the γ-ray laboratory energy with 5% accuracy. With the rapid measurement we could not detect the effect of scattering off pole tips or make any careful check that each track was continuous. Of the 2000 events measured by rapid analysis, events with laboratory energies greater than 154 MeV were then subjected to remeasurement with full spatial reconstruction, and transformed to the center-of-mass system.

About 65% of these events survived the fine analysis. Events were eliminated if either of the tracks hit the pole pieces or did not intersect properly when extrapolated through the magnet. Two percent of the events were eliminated which did not come from the beam volume. Events were selected to have K momenta between 150 and 450 MeV. This requirement eliminated the possibility of ambiguities in momentum which occur if an event has appreciable probability of being associated with two different proton bunches on the target.

The energy spectrum of the events which passed the fine analysis is plotted in Fig. 2. The solid lines drawn are the Monte Carlo curves of the distribution expected for $K_2{}^0 \to 2\pi^0$ and $K_2{}^0 \to 2\gamma$. The large peak below 150 MeV is the spectrum of $K_2{}^0 \to 3\pi^0$ cut off by the requirement that the laboratory energy exceed 154 MeV. The shelf of $2\pi^0$ events and the 2γ peak are clearly evident. The width of the 2γ peak indicates our resolution calculations are essentially correct. Detailed Monte Carlo calculations for the tail of the $3\pi^0$ distribution show that its contribution to the γ spectrum above 180 MeV is completely negligible. The appearance of the data also supports this conclusion. There are four events in the region from 260 to 400 MeV which constitute a true background. The origin of these events is uncertain.

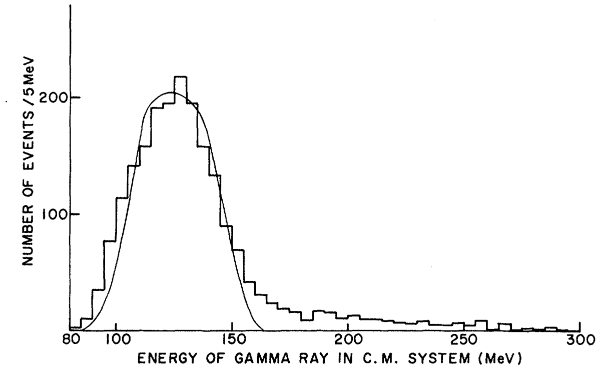

FIG. 2. Distribution in $E_{\text{c.m.}}$ for events measured with the fine analysis for γ-ray energies greated than 154 MeV in the laboratory. There is an event at $E_{\text{c.m.}} = 365$ MeV not shown on the figure. The solid lines are the expected distributions from the Monte Carlo calculations.

Tests were made to establish that the events were coming from the decay of particles in the beam and not from interactions of either the neutron constituent or the $K_2{}^0$'s themselves. Neutron interactions are expected to produce, by production of low energy π^0's, a γ-ray spectrum which would be similar to the $K_2{}^0 \to 3\pi^0$ spectrum. $K_2{}^0$'s in the beam can interact to produce by charge exchange $K^\pm$ which can decay in flight to $\pi^\pm\pi^0$ giving a background in the region of the $2\pi^0$ γ rays. To check these backgrounds, 15% of the data was taken with air in the decay region instead of helium. The interaction probability is five times greater in air than in helium. There was no observed change in the over-all rate of detection of γ rays to a precision of 6%. There was no observed change in the rate of events in the range $170 < E_{\text{c.m.}} < 230$ with a precision of 25%. (We denote $E_{\text{c.m.}}$ as the center-of-mass γ energy.) A second check was made to demonstrate that events were not being produced by interactions in the converting counter sandwich itself. Lucite squares $\frac{1}{4}$ in. × 12 in. × 12 in. were inserted in the converter sandwich between the anticoincidence and the lead. There was no change in the over-all rate to a precision of 5%. There was no change in the rate for events in the range $170 < E_{\text{c.m.}} < 230$ to a precision of 15%. Estimates of the possible magnitude of these effects place them to be entirely negligible, confirming the experimental checks. The possibility of K^+ leaking through the sweeping magnets is completely negligible.

The wall facing the apparatus may serve as a source of γ rays produced by the interaction of stray high-energy neutrons. The material of the wall was changed from concrete to lead with no observed change in total rate. All data runs were made with a lead wall.

In short, experimentally or by estimation, we can find no background which significantly alters the conclusion that the γ-ray spectrum comes from the three decay modes considered. (A fraction of idientified $3\pi^0$ γ rays come from $K_2{}^0 \to \pi^+ + \pi^- + \pi^0$ which has essentially the same spectrum as the $3\pi^0$ γ rays.) The only other physical process which could confuse the analysis is $K_2{}^0 \to \pi^+ + \pi^- + \gamma$. The end point of its γ spectrum is at 171 MeV, and the branching ratio is estimated to be <0.3% of all decay modes. The mode $K_2{}^0 \to \pi^0 + \pi^0 + \gamma$ is a quadrupole transition and is unlikely.

Figure 3 shows the entire center-of-mass spectrum measured with the rapid analysis system. The Monte Carlo calculation of the energy spectrum fits the data quite well, and the various spatial distributions of the events are also in agreement with what is expected. For normalization purposes one quarter of the film was measured with both analysis systems. It was found that $(64 \pm 4)\%$ of the rapid analysis events with $E_{\text{c.m.}} < 160$ MeV pass the fine analysis.

The events with $E_{\text{c.m.}} < 160$ MeV contain a negligible amount of $2\pi^0$ events and hence are $3\pi^0$ events. In the rapid analysis we observed 1992 events with $E_{\text{c.m.}} < 160$ MeV, which gives 1290 ± 80 events, had all the events been measured with the slow program. Alternately, the fraction of $3\pi^0$ events computed by Monte Carlo to be above 154 MeV in the lab is 0.138 ± 0.007. The 193 events in the $3\pi^0$ peak of Fig. 2 give 1400 ± 125 $3\pi^0$ events, had all the events been measured with the fine analysis. We take as the number of $3\pi^0$ events observed the average of these two determinations. Correcting for the fraction of events $K_2{}^0 \to \pi^+ + \pi^- + \pi^0$ we find a total of 1160 ± 90 $3\pi^0$ events.

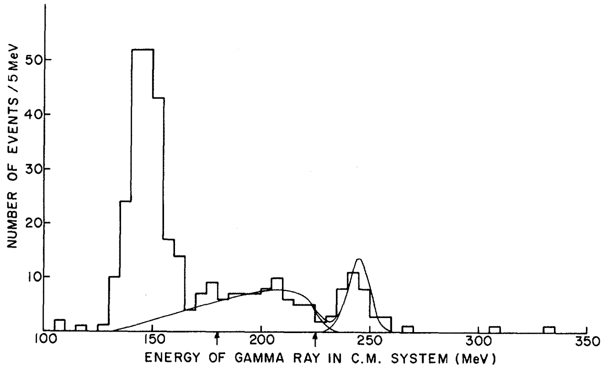

FIG. 3. Distribution in $E_{\text{c.m.}}$ for all events measured with the rapid analysis system. The solid line is the distribution expected from the Monte Carlo calculation for $K_2{}^0 \to 3\pi^0$.

The interval $180 < E_{\text{c.m.}} < 225$ MeV contains 61 events. The computed resolution indicates that there are two events expected in this interval from the tail of the 2γ peak. Using the four events beyond 260 MeV as a guide, we estimate two events of this type to be in the interval. The fraction of $2\pi^0$ events expected to lie in this interval is computed to be 52.3%, leading to a total number of 109 ± 15 $2\pi^0$ events corresponding to the 1160 ± 90 $3\pi^0$ events. Considering that $3\pi^0$ events yield six γ rays per decay and $2\pi^0$ events, four γ rays per decay, we find the ratio

$$\frac{R(K_2{}^0 \to \pi^0 + \pi^0)}{R(K_2{}^0 \to \pi^0 + \pi^0 + \pi^0)} = \frac{(6)(109 \pm 15)(0.134 \pm 0.005)}{(4)(1160 \pm 90)(1)} = (1.89 \pm 0.31) \times 10^{-2}.$$

Using the branching ratio $R(K_2{}^0 \to 3\pi^0)/R(K_2{}^0 \to \text{charged modes}) = 0.30 \pm 0.033$ given by Trilling,[5] we find a ratio

$$\frac{R(K_2{}^0 \to \pi^0 + \pi^0)}{R(K_2{}^0 \to \text{charged modes})} = (5.7 \pm 1.1) \times 10^{-3}.$$

This is to be compared with the current world average[6] for the ratio

$$\frac{R(K_2{}^0 \to \pi^+ + \pi^-)}{R(K_2{}^0 \to \text{charged modes})} = (1.96 \pm 0.12) \times 10^{-3}.$$

The 33 events under the $K_2{}^0 \to \gamma + \gamma$ peak lead to a branching ratio

$$\frac{R(K_2{}^0 \to \gamma + \gamma)}{R(K_2{}^0 \to \text{all modes})} = (7.4 \pm 1.6) \times 10^{-4}.$$

This result disagrees with the value $(1.3 \pm 0.6) \times 10^{-4}$ found by Criegee et al.[7]

We find $|\eta_{00}| = (4.9 \pm 0.5) \times 10^{-3}$ which is conclusively different from $|\eta_{+-}| = (1.94 \pm 0.09) \times 10^{-3}$. We have searched for large systematic errors and have not succeeded in finding any which is larger than the statistical error. We therefore conclude that a $|\Delta I| \geq \frac{3}{2}$ transition contributes significantly to the CP-nonconserving decay $K_2{}^0 \to \pi + \pi$. The experiment is still in progress, and we hope to reduce substantially the error of $|\eta_{00}|$ in the future.

We wish to thank the staff and crew of the PPA for their able and continuing support of this experiment. Mr. John Liu, Mr. Richard Bower, and Mr. Melvin Shochet assisted in the early stages of preparation of the experiment. Professor G. T. Reynolds gave many helpful suggestions during the design stage. We are grateful for the excellent analysis programs written by Mr. James Pilcher. Thanks go to the staff of the Elementary Particles Laboratory for their part in construction of the apparatus, and to our able scanners. Finally, we would like to acknowledge many valuable discussions with Professors Val L. Fitch, Sam B. Treiman, and Pierre Piroué.

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†Work supported by the U. S. Office of Naval Research, Contract No. Nonr-1858(06).

*This work made use of computer facilities supported in part by a National Science Foundation Grant No. NSF-GP 579.

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SUM RULES FOR BARYON RESONANCE WIDTHS

Bunji Sakita*
University of Wisconsin, Madison, Wisconsin

and

Kameshwar C. Wali†
Argonne National Laboratory, Argonne, Illinois

(Received 14 November 1966)

Recently sum rules[1] for strong interactions have been derived on the basis of a dispersion-theoretic approach. In such derivations, one makes assumptions[2] concerning the high-energy behavior of scattering amplitudes, which specify the convergence properties of the relevant dispersion relations. If the dispersion integral is approximated by a sum consisting of intermediate resonant states, the masses and widths of different resonances are related. Thus AFRF consider $\rho\pi$ forward scattering and show that

$$g_{\varphi\rho\pi}^{\;2}=0;\quad g_{\omega\rho\pi}^{\;2}=4g_{\rho}^{\;2}\pi\pi/m_{\rho}^{\;2}. \tag{1}$$

The interesting feature of relations (1) is that they are the well-known coupling-constant relations[3] that follow from the considerations of higher symmetries. This suggests the possibility that some of the results of higher symmetries can be derived from certain dynamical requirements. With this point of view, we consider meson-baryon scattering within the framework of SU(3) symmetry and discuss the relations between masses and widths of baryonic resonances with different total angular momentum J.

The invariant amplitudes $A(\nu,t)$ and $B(\nu,t)$ in meson-baryon scattering have different asymptotic behavior.[4] Thus, if $A(\nu,t)\xrightarrow[\nu\to\infty]{}\nu^{\alpha(t)}$, $B(\nu,t)\xrightarrow[\nu\to\infty]{}\nu^{\alpha(t)-1}$. In a Regge-pole model, $\alpha(t)$ refers to the dominant Regge trajectory in the crossed $P+\overline{P}\to B+\overline{B}$ t channel. Now, from our present knowledge of the meson mass spectrum, it is reasonable to assume that $\alpha(t)<0$ $(t\leqslant0)$ for $\underline{27}$, $\underline{10}$, $\underline{10}^*$ trajectories. Conse-