ESTIMATE OF THE RELATIVE PROBABILITY FOR THE $K_2^0 \rightarrow 3\pi^0$ DECAY

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The probability for $K_2^0 \rightarrow 3\pi^0$ decay relative to that for all K_2^0-meson decays into charged particles is obtained experimentally and found to be (0.24 ± 0.08).

THERE is every reason for expecting the decay $K_2^0 \rightarrow 3\pi^0$, which is also allowed by CP invariance, to exist along with the decay $K_2^0 \rightarrow \pi^+\pi^-\pi^0$. The selection rule $|\Delta I| = 1/2$ predicts here a definite ratio for the probabilities of these two decays [1]:

$$W(K_2^0 \rightarrow \pi^+\pi^-\pi^0)/W(K_2^0 \rightarrow 3\pi^0) = 0.55.$$

An experimental determination of this ratio cannot in itself serve as a sufficiently effective means of observing a mixture of the transitions $|\Delta I| = 3/2$, since this ratio proves to be not very sensitive to $|\Delta I| = 3/2$ transitions (see, for example [2]). However, an estimate of the relative probability of $K_2^0 \rightarrow 3\pi^0$ makes it possible to determine the absolute probabilities of different types of K_2^0-meson decays and by the same token check on other consequences of the $|\Delta I| = 1/2$ selection rule.

The first experimental indications of the existence of the $K_2^0 \rightarrow 3\pi^0$ decay were obtained with the proton synchrotron of the Joint Institute for Nuclear Research with the aid of a cloud chamber, in which Dalitz pairs from the decay $K_2^0 \rightarrow 3\pi^0$ were observed. In this work, on the basis of four registered events, a crude estimate was made of the relative probability of this type of decay: $W(K_2^0 \rightarrow 3\pi^0)/\Sigma W_i(K_2^0) = 0.18 \pm 0.09$. Recently there were registered at Saclay (in a bubble chamber with a heavy liquid) two events which can be interpreted as $K_2^0 \rightarrow 3\pi^0$ decays. A second group of workers exposed a freon bubble chamber to the beam of neutral particles from the Joint Institute of Nuclear Research proton synchrontron. In a preliminary report by this group [4], data are presented on some events with emergence of four or five γ quanta from a single point, which are most likely to be the results of $K_2^0 \rightarrow 3\pi^0$ decay.

In the present work, as in our earlier one [3], the $K_2^0 \rightarrow 3\pi^0$ decay was registered by the Dalitz pairs observed in a one-meter cloud chamber placed in a beam of neutral particles from the proton synchrotron. The general experimental setup was described earlier [5]. In our preliminary communication [6], owing to a systematic error in the selection of the Dalitz pairs, we overestimated the relative probability of the $K_2^0 \rightarrow 3\pi^0$ decay. The main selection criterion was the scattering angle, which, as was already explained, was measured with appreciable systematic error in the small-angle range. For this reason, a noticeable number of conversion pairs were included with the number of selected Dalitz pairs.

In the subsequent reduction, more stringent selection criteria were applied to the selected events, in order to ensure a maximum reliability of the identification of the Dalitz pairs from the $K_2^0 \rightarrow 3\pi^0$ decay. For Dalitz-pair analysis, the only V^0 events selected were those satisfying the following six conditions:

(1) The length l of the projection of the tracks on the horizontal plane is not less than 4 cm.

(2) The momentum of one of the decay products does not exceed 80 Mev/c and that of the second—100 Mev/c; the tracks of both decay products correspond to electron tracks in density.

(3) The vertex of the "fork" lies in a well illuminated region.

(4) The angle of emission θ_t of the particle being investigated (determined by the direction of the total momentum of the decay products relative to the axis of the neutral beam) is not less than 20°.

(5) The scattering angle of the decay products ω does not exceed 70°.

(6) The vertex of the "fork" is not more than 4 cm away from the end walls of the chamber and the plate.

A triple scanning of 15,000 stereo photographs provided a visual selection of all the cases which could be electron-positron pairs. In one of the scannings templates were used to measure the

Momentum and angular characteristics of Dalitz pairs

Number of event	P_+, MeV/c	P_-, MeV/c	θ_l, deg	ω, deg	T_+/T_{el}	T_-/T_{el}
7—69	50±3	40±3	116±1	8±2	0.98±0.18	1.00±0.15
8—246	45±4	34±4	71±1	34±2	1.10±0.16	0.85±0.17
11—54	22±4	85±5	56±2	16±2	0.80±0.12	0.80±0.10
14—39	93±6	30±2	146±1	2±2	0.97±0.10	~1
17—98	73±4	26±2	75±1	17±2	0.74±0.15	0.73±0.15
19—35	81±5	60±4	49±1	19±2	~1	~1
31—89	17±1	8±0.5	39±1	10±3	~1	~1
36—4	16±1	60±4	34±1	7±1	0.83±0.18	1.10±0.20
44—74	50±3	33±2	77±1	20±4	0.86±0.14	~1
58—35	30±6	61±4	51±2	42±4	~1	~1
64—122	29±2	103±18	33±2	3±1	~1	~1

projection of the radius of curvature on the plane of the photograph. If the projection of both momenta on the plane of the photograph exceeded 150 MeV/c, then such a V^0 event was measured on a reprojector or a UIM-21 measuring microscope. The first selection criterion ($l \geq 4$ cm) should ensure in this case selection of all the events in which the momenta of the decay products lie in the region of interest to us.

Limitation of the decay-product momenta (second condition) is due to the fact that the identification of the electron and positron in the V^0 event was based on the density of track blackening. Within the indicated momentum selection limits, we could distinguish by ionization the pair electrons from the muons and pions in the $K_{\mu 3}$ and $K_{\pi 3}$ decays.

For ionization measurements to be reliable, it is very important that the tracks lie in the well illuminated region (third condition). The dimensions of this region were determined from measurements of the density of the tracks which cross the entire illuminated region of the chamber, and also from the distribution in height of the vertices of all the observed V^0 decays. The ionization measurements were made with a microphotometer by comparing the density of the track with the density of one of the "background" electrons located alongside.

The measurement error did not exceed 15%. It was determined experimentally from the mean-square scatter in the relative density of the tracks of 24 identified electrons in the momentum interval 60—100 MeV/c; $T_e/T_{min} = 1.35 \pm 0.18$ [1)].

For purposes of calibration, measurements were made of the densities of the pion tracks from K_{e3} decays [2)]. They yielded for the average ratio of the track density of pions with momenta in the interval 80—100 MeV/c and for the background electron tracks a value $T_\pi/T_e = 1.40 \pm 0.26$.

As can be seen from the table above, in most cases the decay products are uniquely identified from their track density as electrons. In some cases, owing to unfavorable background conditions, the density was estimated visually. Case 64—122 was identified as an electron-positron pair from the "dip" in momentum on passing through the lead plate. Only in one case, 14—39, is there a small probability that the positive-particle track can belong to a pion. However, as can be seen from further analysis, this probability reduces to a minimum by introducing an additional criterion.

The electron-positron pairs can imitate with maximum probability those K_{e3} decays in which the electron is identified by measuring the track density ($p < 80$ MeV/c), and the pion momentum lies in the boundary region. We have observed only two K_{e3} decays in which the pion momenta lie within the indicated limits, and the densities of the pion tracks turned out to be noticeably higher than the electron track density. This experimental fact agrees well with the results of a simulation of the spatial and momentum configurations in K_{e3} decays, carried out by the Monte Carlo method assuming the V-A interaction variant. Out of the 500 simulated K_{e3} decays, in only one were the momenta of both decay products in the region under investigation. A characteristic feature here was that the scattering angles of the meson and the electron, in events in which the momenta of the decay products did not exceed 150 MeV/c, exceeded 80°.

Thus, if we introduce for the selection of Dalitz pairs an additional criterion which limits the scattering angle ($\omega \leq 70°$), then by the same token we exclude the possible K_{e3}-decay admixture which may result from error in the ionization measurement. On the other hand, by specifying this selection criterion, we greatly reduce the

1)We used for comparison tracks the tracks of muons with momenta 600–800 MeV/c.

2)The K_{e3} decays were identified by the change in the momentum of the secondary particles on passing through a lead plate [3].

probability of imitation of a Dalitz pair by electron scattering events.

Calculations show that the number of elastic and inelastic scatterings of electrons with momenta $p > 10$ MeV/c by angles $> 110°$ (which corresponds to an angle $\omega \leq 70°$) does not exceed 0.1 under our conditions. The limitation of the scattering angle does not lead to an appreciable decrease in the number of Dalitz pairs, since the overwhelming number of all pairs lies in the interval $\omega \leq 70\%$.

The fourth condition ($\theta_t > 20°$) has made it possible to reduce to a minimum the admixture of electron-positron pairs produced as a result of the conversion of the γ quanta of the beam, without appreciably reducing the number of registered Dalitz pairs. Indeed, under our conditions the average relative probability for a γ quantum from the beam to be converted at an angle $\theta_t > 20°$ amounts to < 0.01. At the same time, as shown by estimates, the interval $\theta_t < 20°$ receives only about 5% of the Dalitz pairs from the $K_2^0 \rightarrow 3\pi^0$ decays[3)].

We have registered approximately 200 decays of Λ^0 hyperons produced in the plate and also in the front and rear walls of the chamber. It is obvious that with this number of $\Lambda^0 \rightarrow p + \pi^-$ decays we can expect the appearance of Dalitz pairs as a result of the $\Lambda^0 \rightarrow n + \pi^0$ decay (of the order of one pair). In order to suppress the possible admixture due to this process, it is necessary to satisfy the sixth condition, which excludes from consideration the working regions of the chamber adjacent to the plate and the walls. If the width of this region is chosen equal to 4 cm (which corresponds on the average to two Λ^0 particle ranges for energies of the K_2^0 mesons registered in our experiment), then the possible admixture of Dalitz pairs from this decay will be of the order of 0.1. This also eliminates possible Dalitz pairs from the neutral decay of the regenerative K_1^0 mesons.

As a result, 11 electron-positron pairs satisfying all the foregoing criteria were selected. For these events we plotted the distribution with respect to the parameter $(m_\gamma/m_{\pi^0})^2$, where m_γ represents the effective mass of the converting virtual γ quantum: $m_\gamma^2 = 2(E_1E_2 - p_1p_2 \cos \omega + m_e^2)$. This distribution was compared with the theoretical one calculated for the internal-conversion pairs by Kroll and Wada [7] and subsequently confirmed experimentally [8].

It follows from the plot of Fig. 1 that the experimental distribution agrees well with the distribution expected for Dalitz pairs. On the other hand, an analogous comparison for 30 pairs from the external conversion of γ quanta of the beam shows a sharp contradiction. This means that the overwhelming majority of the 11 selected pairs are Dalitz pairs.

This is also confirmed by an estimate of the possible number of pairs from the conversion of γ quanta not connected with the beam in the gas of the chamber, which could make a noticeable contribution after using all the selection criteria. Under our conditions such γ quanta can result from the following processes:

1) Decays of π^0 mesons produced in the chamber walls and in the plate (we can neglect the production of π^0 mesons in the gas of the chamber).

2) Decays of K_2^0 mesons with emission of π^0 mesons (γ quanta), among which the most intense is the $K_2^0 \rightarrow 3\pi^0$ decay.

The possible contribution from these two sources was estimated by the Monte Carlo method. In the first case the decay of π^0 mesons produced in the plate and in the walls of the chamber was simulated. In this simulation, we used the angular and momentum distributions of the π^- mesons produced by the nuclei of the chamber gas. In each case the fate of the γ quanta from the π^0 decay was traced either to the point of conversion, or to the point of emergence from the working volume of the chamber. The total number of such π^0 mesons was estimated from the number of π^- mesons in the stars, with allowance for the difference in the production probabilities.

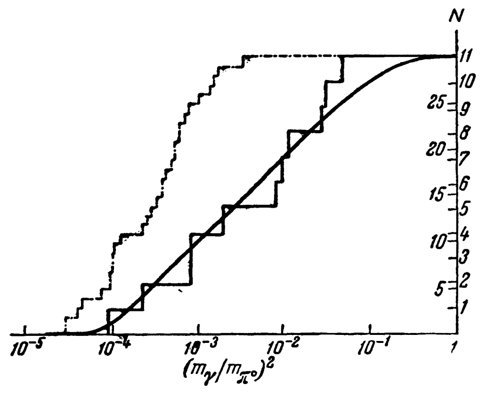

FIG. 1. Integral distribution of events with respect to the parameter $(m_\gamma/m_{\pi^0})^2$: continuous curve—theoretical distribution, continuous staircase curve—experimental distribution of Dalitz pairs, dash-dot—experimental distribution of conversion pairs.

3)It is obvious that the smaller the number of pairs originating in this way relative to the number of registered decays the smaller will be the admixture of these pairs. Under the conditions of our experiment, this ratio was on the order of 2%, which is 10–15 times smaller than in [3].

For both the processes under consideration, we obtained the probability of γ quantum conversion in the working volume of the chamber under the condition that the electron-positron pair satisfies the selection criteria. It was assumed that any division of the γ quantum energy between the electron and the positron is of equal probability. The result of the calculation shows that the expected admixture of conversion pairs from the π^0 mesons produced in the walls and in the plate, and from the $K_2^0 \to 3\pi^0$ decay, amounts to 1.3 ± 0.5 pairs[4)].

Under the conditions of our experiment there were no appreciable sources of Dalitz pairs except the $K_2^0 \to 3\pi^0$ decay. This process could be imitated only by Dalitz pairs from the decays of π^0 mesons produced by neutrons on the nuclei of the chamber gas in "prongless" stars. However, this effect was very small in our case, owing to the small neutron energy ($\overline{E}_n \sim 100$ MeV). Among the several tens of thousands of interactions of the neutrons in the chamber gas we observed only approximately 50 stars with π^- meson production. There was not observed a single star with emission of a Dalitz pair, which could result from the decay of a π^0 meson occurring in the star in accordance with the Dalitz scheme. It must be kept in mind here that the cross section for the production of a π^0 meson by a neutron on an argon nucleus in a "prongless" star is at least one order of magnitude smaller than the cross section for the analogous process accompanied by emission of charged nuclear disintegration products. Thus, the possible admixture due to the process under consideration is known to be less than 0.1 pair, and can be completely neglected. The contribution to the number of Dalitz pairs from the $\Lambda^0 \to n + \pi^0$ decay can also be neglected, insofar as we exclude from consideration, as already indicated, those regions of the chamber where the overwhelming number of Λ^0 hyperons decay.

The only source of Dalitz pairs worthy of consideration is, under our conditions, the decay of K_2^0 particles into π^0 mesons with subsequent decay in accordance with the Dalitz scheme $\pi^0 \to \gamma + (e^+e^-)$. Inasmuch as the decay of K_2^0 to $\pi^+\pi^-$ is forbidden or at least strongly suppressed, it has very low probability. The expected probabilities of the K_2^0 decays into neutral particles with emission of a γ quantum (for example, $K_2^0 \to \pi^0\pi^0\gamma$) are also very low.

In this connection we must point out that we did not register a single $K_2^0 \to \pi^+\pi^-$ (e^+e^-) decay, and at the same time observed four decays of type[5]

$$K_2^0 \to \pi^+\pi^-\pi^0 \begin{smallmatrix}\nearrow e^+e^- \\ \searrow \gamma\end{smallmatrix} . \quad (1)$$

There is thus every reason for assuming the Dalitz pairs under consideration to be the result of the $K_2^0 \to 3\pi^0$ decay.

Let us compare the scattering-angle distribution of the 11 selected pairs with the distribution calculated under the assumption that the only possible source of Dalitz pairs is the $K_2^0 \to 3\pi^0$ decay (the latter distribution was obtained by the Monte Carlo method, and will be discussed in detail below). From the plot of Fig. 2 we see that the experimental and calculated distributions are in good agreement. We must also point out that the average value of the scattering angle in these 11 cases (16°) is close to the average value of the scattering angle (12°) in the Dalitz pairs produced in decay (1), a value obtained from the 12 cases registered to date.

The theoretical distributions with respect to ω/ω_0 [$\omega_0 = (E_1 + E_2) m_e/E_1E_2$] for the Dalitz pairs from the $K_2^0 \to 3\pi^0$ decays and for the conversion pairs [9] differ strongly. With the number of conversion electron-positron pairs being small under the conditions of our experiments, this difference can be used to estimate the possible number of Dalitz pairs. In this case the need for introducing a correction for the admixture of "nonbeam" conversion pairs disappears. Using the experimental distribution of all the electron-positron pairs in two regions ($\omega/\omega_0 < 6$ and $\omega/\omega_0 > 6$) and comparing it with the calculated distributions, we obtain for the Dalitz pairs in the conversion

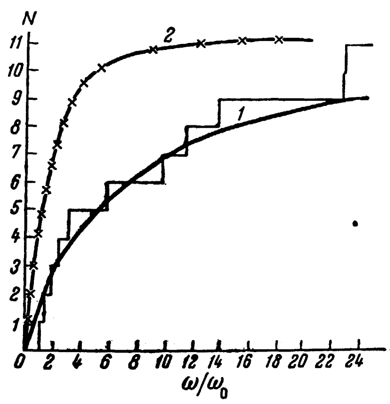

FIG. 2. Integral distribution of events by scattering angle (ω/ω_0): curve 1—calculated distribution for Dalitz pairs from the $K_2^0 \to 3\pi^0$ decay, curve 2—theoretical distribution for conversion pairs, staircase curve—experimental distribution for Dalitz pairs.

[4)]The calculation error is given here.

pairs a value $N_D = 8$ and $N_c = 33$, which is in good agreement with the result obtained above.

To estimate the total number of $K_2^0 \rightarrow 3\pi^0$ decays it is necessary to introduce corrections connected with the selection criteria employed. Calculation of all these corrections is by the Monte Carlo method.

For the calculations we have used the distribution over the parameters x and y, given in the paper of Kroll and Wada [7]

$$F(x, y)\,dx\,dy \sim \frac{1}{x}\left(1-\frac{x^2}{m_\pi^2}\right)^3\left(1+y^2+\frac{4m_e^2}{x^2}\right)dx\,dy,$$

and also the distribution of the pion momenta in the K-meson rest system

$$\Phi(q)\,dq \sim q^2\sqrt{1-\frac{4m_\pi^2}{(M-\varepsilon)^2-q^2}} \times\left\{(M-\varepsilon)^2-\frac{1}{3}q^2\left[1-\frac{4m_\pi^2}{(M-\varepsilon)^2-q^2}\right]\right\}dq,$$

where $x = m_\gamma$ is the summary mass of the electron and positron, $y = |p_+ - p_-|/(E^+ + E^-)$ ($p_\pm$ and $E_\pm$ are respectively the momenta and energies of the positron and electron), m_π is the π^0-meson mass, m_e the electron mass, q and e the momentum and energy of the π^0 meson, and M the K_2^0 meson mass. The latter distribution has been obtained from the statistical theory of multiple particle production. Since we do not have the exact spectrum of the K_2^0-momenta, we used in the calculations the momentum (p_K = 450 MeV/c), averaged over the identified K_{e3} decays.

Calculation has shown that 0.67 of all the Dalitz pairs have electrons with momenta in the intervals $p_1 < 80$ and $p_2 < 100$ MeV/3. The same value for K_2^0 mesons with momenta 350 and 550 MeV/c and for K_2^0 mesons uniformly distributed over the momenta in the interval 300—600 MeV/c is respectively 0.71, 0.62 and 0.67. Thus, the correction depends relatively little on the form of the energy spectrum of the K_2^0 mesons and is close to 0.67 in value.

The relative fraction of pairs with scattering angle $\leq 70°$ amounts to 0.94, and the fraction of the pairs with scattering angle $\geq 20°$ is 0.96. We also calculated a number of pairs in which the lengths of both tracks projected on the horizontal plane exceeded 4 cm. The fraction of such events is 0.75 of the total number.

As a result of taking into account all these corrections, and also the probabilities of the formation of a Dalitz pair in the $K_2^0 \rightarrow 3\pi^0$ decay (which is equal to 0.037), we obtain a value 580 ± 200) for the number of $K_2^0 \rightarrow 3\pi^0$ decays.[5)]

To distinguish the number of the decays of K_2^0 mesons to charged particles from the number of Λ^0 events registered, we have excluded Λ^0 decays (5.5%), $\pi \rightarrow \mu$ decays (1.5%) and conversion electron-positron pairs. To reliably register the K_2^0-meson decays, the same selection criteria were applied to these decays as to the Dalitz pairs with respect to the track lengths. Calculation has shown that this criterion is satisfied by 0.69 of all the K_2^0 decays.

It was found as a result that in that volume of the chamber in which the Dalitz pairs were registered, there are 2400 ± 240 K_2^0-meson decays to charged particles, and the relative probability of the decay to neutral particles is

$$W(K_2^0 \rightarrow 3\pi^0)/W(K_2^0 \rightarrow \text{all charged}) = 0.24 \pm 0.08.$$

The small number of registered Dalitz pairs did not enable us to observe any difference in the efficiencies of the visual registration of the Dalitz pairs and the K_2^0 meson decays, so that in calculating the ratio presented above, these efficiencies were assumed to be equal.

If we use the data of Luers et al. [10], in which the relative probability of the $K_2^0 \rightarrow \pi^+\pi^-\pi^0$ decay was estimated, we can obtain for the ratio of the two decays

$$R_1 = W(K_2^0 \rightarrow \pi^+\pi^-\pi^0)/W(K_2^0 \rightarrow 3\pi^0) = 0.56 \pm 0.21,$$

which agrees within the limits of error with the selection rule $|\Delta I| = 1/2$ ($R_1 = 0.55$). A comparison of the absolute probabilities of the decays $K_2^0 \rightarrow 3\pi$ and $K^+ \rightarrow 3\pi$ yields

$$R_2 = W(K_2^0 \rightarrow 3\pi)/W(K^+ \rightarrow 3\pi) = 0.77 \pm 0.34.$$

The appreciable statistical error does not make it possible to speak, for the time being, of the presence of any discrepancy whatever. It must also be emphasized that in order to obtain the experimental ratio we have used the average K_2^0-meson lifetime, which is presently known with a high degree of uncertainty.

In conclusion we wish to thank the proton synchrotron crews, whose precise work enabled us to set up this project. We are deeply grateful to B. M. Pontecorvo, who called attention to the possibility of investigating $K_2^0 \rightarrow 3\pi^0$ decay by means

5)The error cited is determined essentially by the poor statistics. The possible error, after introducing corrections, is connected with the lack of final data concerning the spectrum of the K_2^0 mesons, and does not influence greatly the error in the final result.

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