$K_1{}^0$–$K_2{}^0$ Mass Difference*

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A measurement of the magnitude of the $K_1{}^0$–$K_2{}^0$ mass difference yields $(1.5\pm0.2)\hbar/\tau_1 c^2$. The method employed consisted of measuring the time dependence of the $\bar{K}^0$ intensity, in a beam which was initially in a pure K^0 state. The $\bar{K}^0$ intensity was measured by observing nuclear interactions. The K^0 mesons were produced by the charge exchange of K^+ mesons of 800-MeV/c momentum.

I. INTRODUCTION

ALTHOUGH the expected mass difference between the $K_1{}^0$ and $K_2{}^0$ mesons is very small, its determination is of importance because it yields information on weak interactions and determines the rate of conversion of K^0 to $\bar{K}^0$ and vice versa. Treiman and Sachs[1] and Jacobs[2] have pointed out that the magnitude of the mass difference may give information on the character of weak interactions at high energies.

The $K_1{}^0$–$K_2{}^0$ mass difference can be estimated to be about $\hbar/\tau_1 c^2$ if one makes the naive assumption that the mass difference is due to the weak interaction which gives rise to the 2π decay mode for the $K_1{}^0$ and which is excluded for the $K_2{}^0$. We will henceforth refer to the mass difference in units of $\delta=\hbar/\tau_1 c^2$; $\delta c^2 \cong 6\times10^{-6}$ eV. If transitions are allowed where $\Delta S=2$, then Δmc^2 can be expected to be much larger, ~1 eV.[3]

It will be shown in Eq. (3) that, given a mass difference of the order of δ, the interference effects will have a period of the order of four $K_1{}^0$ lifetimes and hence will occur over distances which are readily measurable in laboratory experiments.[4] Several methods have been proposed to measure this mass difference. The method of Treiman and Sachs[1] utilizes the time dependence of the charge asymmetry of leptonic decays; this involves some assumptions on the validity of the $\Delta S=\Delta Q$ rule.[5,6]

A second method is that proposed by Good[7] which depends upon the coherent regeneration of $K_1{}^0$ in a $K_2{}^0$ beam. An experiment utilizing this method has been performed by Good *et al.*[8] where the regeneration effects have been observed and which gives a value of $\Delta m=(0.84_{-0.22}{}^{+0.29})\delta$.

A third proposal, that of Fry and Sachs,[9] depends upon a measurement of the time dependence of the $\bar{K}^0$ component, of an initially pure K^0 beam. The $\bar{K}^0$ component is monitored by the strangeness conserving strong interactions. This method is employed in the experiment described in this paper. Two other experiments have been reported which utilize this method: that of Boldt *et al.*,[10] of limited statistical accuracy; and that of Fitch *et al.*[11] who found a value of $(1.9\pm0.3)\delta$. This latter experiment did not exclude large values of the mass difference.

The interference effects between K^0 and $\bar{K}^0$ are more readily observed if the initial beam consists of either a pure $\bar{K}^0$ or pure K^0 beam. Starting with a pure K^0 beam, the time dependence of the K^0 wave function can be written as follows:

$$\varphi(t)=\frac{1}{\sqrt{2}}\{\theta_1 \exp[\lambda_1(t/2)-i\omega_1 t] +i\theta_2 \exp[\lambda_2(t/2)-i\omega_2 t]\}, \quad (1)$$

where λ_1 and λ_2 are the decay rates, ω_1 and ω_2 are the proper frequences of $K_1{}^0$ and $K_2{}^0$ mesons, respectively, and t is the *proper time* of the K^0 meson. Then writing

$$\theta_1=\frac{1}{\sqrt{2}}(\theta+\bar{\theta}),\quad \theta_2=\frac{1}{\sqrt{2}}(\theta-\bar{\theta}),$$

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[1] S. B. Treiman and R. G. Sachs, Phys. Rev. **103**, 1545 (1956).

[2] R. L. Jacobs, Ph.D. thesis, University of Wisconsin, 1959 (unpublished).

[3] L. B. Okun and B. Pontecorvo, Zhur. Eksptl. i Theoret. Fiz. **32**, 1587 (1957) [translation: Soviet Phys.—JETP **5**, 1297 (1957)]. It has been pointed out by Sheldon L. Glashow [Phys. Rev. Letters **6**, 196 (1961)], that under special conditions where the $\Delta S=2$ coupling is odd under C, it will not give rise to a large $K_1{}^0-K_2{}^0$ mass difference.

[4] That the mass difference might be observable as an interference phenomena, was first discussed by A. Pais and O. Piccioni, Phys. Rev. **100**, 1487 (1957).

[5] It is not necessary that the selection rule $\Delta S=\Delta Q$ be valid in order to find the mass difference from the time distribution of the charge ratio of leptonic decays. The simple formula given by Treiman and Sachs must be modified. Starting from a pure K^0 beam, the intensity of the $\bar{K}^0$ is given by the equation $(1+\chi)^2 \times\exp(-\lambda_1 t)+(1-\chi)^2\exp(-\lambda_2 t)-2(1-\chi^2)\exp(-\lambda_1 t/2)\cos(\Delta\omega t)$ instead of Eq. (2); where $(1+\chi)/(1-\chi)$ is the ratio of $K_1{}^0$ to $K_2{}^0$ amplitudes (see reference 6).

[6] R. P. Ely, W. M. Powell, H. White, M. Baldo-Ceolin, E. Calimani, S. Ciampolillo, O. Fabbri, F. Farini, C. Filippi, H. Huzita, G. Miari, U. Camerini, W. F. Fry, and S. Natali, Phys. Rev. Letters **8**, 132 (1962).

[7] M. L. Good, Phys. Rev. **110**, 550 (1958).

[8] R. H. Good, R. P. Matsen, F. Muller, O. Piccioni, W. M. Powell, H. S. White, W. B. Fowler, and R. W. Birge, Phys. Rev. **124**, 1223 (1961).

[9] W. F. Fry and R. G. Sachs, Phys. Rev. **109**, 2212 (1958).

[10] E. Bolt, D. O. Caldwell, and Y. Pal, Phys. Rev. Letters **1**, 150 (1958).

[11] Val L. Fitch, Pierre A. Piroué, and Roger B. Perkins, Nuovo cimento **22**, 1160 (1961).

one finds for the intensity of the $\bar{K}^0$ component

$$I(\bar{K}_1{}^0 t) = \exp(-\lambda_1 t) + \exp(-\lambda_2 t) - 2\cos(\Delta\omega t)\exp[-(\lambda_1+\lambda_2)t/2]. \quad (2)$$

In this experiment the time is not directly measured, but is calculated from the distance d between the charge exchange and the $\bar{K}^0$ interaction, and the momentum p of the $\bar{K}^0$ meson. One then finds that the number of $\bar{K}^0$ interactions in an interval of time dt is

$$N(t)dt = p/m_0[3\sigma_{\mathrm{C}}(p) + 8\sigma_{\mathrm{H}}(p)]N_0\rho/A \times[1+\exp(-\lambda_1 t) - 2\cos(\Delta\omega t)\exp(-\lambda_1 t/2)]dt, \quad (3)$$

where N_0 is Avogadro's number, ρ is the density of liquid propane, A is its molecular weight, and $\sigma_{\mathrm{H}}(p)$ and $\sigma_{\mathrm{C}}(p)$ are the $\bar{K}^0$ cross section for nuclear interactions for hydrogen and carbon, respectively. t is given by

$$t = dm_0/p. \quad (4)$$

The factor proportional to the momentum in the expression above arises from the fact that the probability of interaction per unit time is proportional to the amount of matter traversed, and this is proportional to the momentum of the $\bar{K}^0$.

In Eq. (2) it has been assumed that the absorption of the beam (and subsequent regeneration) is small. This assumption would seem to be valid in view of the following consideration. The geometrical mean free path in propane is about 120 cm, while the length corresponding to one $K_1{}^0$ lifetime is, on the average, 2 cm. Since most of the information is contained in the first three lifetimes and the beam is attenuated by only 5% over this length, the regeneration is expected to be a small effect. We have also made the approximation that $\lambda_2 = 0$ because $\lambda_2 = \lambda_1/500$. In addition, it is assumed that the weak interactions are invariant under CP. Even though CP may not be conserved in leptonic decays, the $K_1{}^0$ and $K_2{}^0$ states are determined principally by the nonleptonic decay processes involving two pions. The absence[12] of the 2π decay mode of the $K_2{}^0$ is interpreted as verification of this assumption.

A plot of Eq. (2) for several values of the mass difference is shown in Fig. 1. It can be seen that the interference effects are rather large, and that the location of the peak of the distribution is a rapidly varying function of the mass difference.

Preliminary to the experiment reported in detail in this paper, a very similar experiment was performed to test the possibility of proceeding in the manner planned. The experiment consisted of searching for the interactions of $\bar{K}^0$ mesons produced by the charge exchange of K^- mesons of 1.15 BeV/c in the propane chamber. The details of that experiment are given in Appendix I. The value of the $K_1{}^0$–$K_2{}^0$ mass difference can be estimated from those data to be 2δ with a large statistical error.

[12] D. Neagu, E. O. Okonov, N. F. Petrov, A. M. Rosanova, and V. A. Rusakov, Phys. Rev. Letters **6**, 552 (1961).

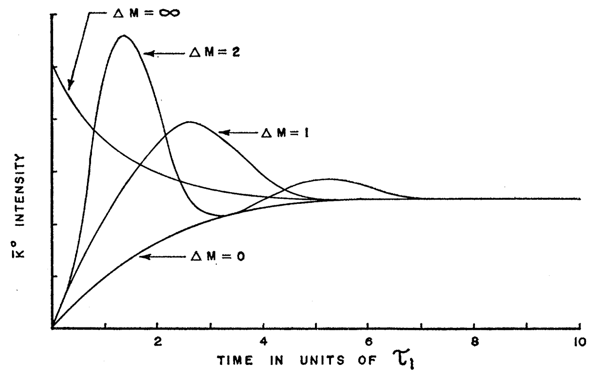

FIG. 1. The intensity of the $\bar{K}^0$ component is shown as a function of time for three values of the mass difference. For $t=0$ the beam is a pure K^0 beam.

II. PROCEDURE

A. K^+ Beam

Because strangeness is conserved in strong interactions, the K^0 and $\bar{K}^0$ components can be generated and monitored by nuclear interactions. In this experiment K^0 mesons are formed by the charge exchange of K^+ mesons in the propane bubble chamber. The K^+ separated beam from the Berkeley Bevatron, which was designed and built by Stork, Goldhaber, Goldhaber, and Ticho,[13] was used as a source of K^+ mesons. The beam momentum, before entering the chamber, was 850 MeV/c (480-MeV kinetic energy) for the portion of the run used in this experiment.

The composition of the separated K^+ beam at 850 MeV/c momentum fluctuated during the run, depending upon the tuning of the magnets. It is estimated that the average ratio of K^+ to π^+ in the beam[13] was larger than 20. The average number of K^+ per pulse was chosen to be about 6. Larger fluxes were obtainable but not used because of the complexity introduced by multiple charge exchanges per frame.

The propane bubble chamber that was used has been described in detail elsewhere.[14] Its dimensions are $31\frac{1}{2}$ in. in length, $21\frac{1}{2}$ in. in width, and $6\frac{1}{2}$ in. in depth. The magnetic field was 13 000 G. The beam, which entered the chamber through a thin window, was nearly parallel, had a width of 10 cm and was located in the median plane of the chamber to within 1 cm.

B. Scanning

About 140 000 frames were scanned specifically for interactions which could be interpreted as production of a Λ or a Σ hyperon. After such an event was found,

[13] A brief discussion of the composition the beam and the experiments utilizing the beam appears in the report: W. Chinowsky, G. Goldhaber, S. Goldhaber, W. Lee, T. O'Halloran, T. Stubbs, W. E. Slater, D. H. Stork, and H. K. Ticho, *Proceedings of the 1960 Annual International Conference on High-Energy Physics at Rochester* (Interscience Publishers, Inc., New York, 1960), pp. 451–455.

[14] W. M. Powell, W. B. Fowler, and L. O. Oswald, Rev. Sci. Instr. **29**, 874 (1958).

the entire frame was searched for all K^+ interactions which could possibly have been a charge exchange; all such origins were recorded. This method was chosen rather than scanning initially for the charge exchange origins, because (1) the latter is much slower and (2) it would tend to produce a bias toward finding events near the K^+ charge exchange origin. Nearly all of the scanning was done by physicists. Due to the uncertainty in the identification of Σ hyperons, none of the events which could be interpreted as Σ decays, have been used. This omission reduced the sample of events by only 20%.

It should be pointed out that the mass difference depends only on the time dependence of the $\bar{K}^0$ interactions and not on a measurement of a cross section and hence it does not depend upon an accurate knowledge of the scanning efficiency, as long as it is independent of the distance. (See Fig. 2.)

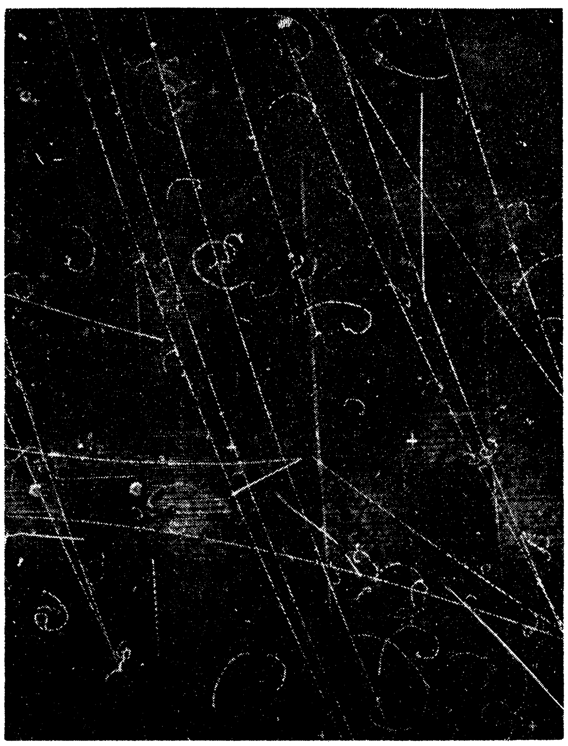

FIG. 2. The photograph shows a K^+ charge exchange followed by a $\bar{K}^0$ interaction. The $\bar{K}^0$ interaction produced by a π^+ and a Λ hyperon.

C. Acceptance Criteria of Events

All neutral "V's" which appeared to be decays of a Λ hyperon, originating from a star in the propane or the origin of a pion, were accepted for measurement. The hyperon production events were taken regardless of the number of possible K^+ charge exchange origins in the picture. The events were measured on a digitized microscope and analyzed with the fog-cloudy-fair system.[15] The neutral "V's" were constrained to fit a Λ decay from the point of the $\bar{\theta}$ interaction (3 constraint fit) and accepted if $\chi^2 \leq 10$. A small number of events were measured directly on the scanning projector. The number of background events included in the accepted sample is estimated to be of the order of, or less than, 5%.

[15] Howard S. White, University of California Radiation Laboratory Report UCRL-9475 (unpublished).

D. Momentum Determination

In order to determine the proper time for each event, it is necessary to know the momentum of the neutral K meson in each case. For this reason a part of the film was scanned for $K_1{}^0$ decays.

Each neutral V was measured and then constrained to fit a $K_1{}^0 \rightarrow \pi^+ + \pi^-$ decay, assuming that the $K_1{}^0$ originated from the nearest K^+ charge exchange vertex. Events giving a $\chi^2 \leq 10$ (3 constraints) were accepted as $K_1{}^0$ decays. A total of 260 such events were accepted. An attempt was made to correlate the measured $K_1{}^0$ momentum with the following characteristics of the K^+ charge exchange: (1) the energy and angle of the fast protons from the K^+ interaction; (2) the total visible energy; (3) the constrained angle between the direction of the K^0 in the lab system, and the direction of the incoming K^+. The only correlation that was found to be significant was (3). (See Fig. 3.)

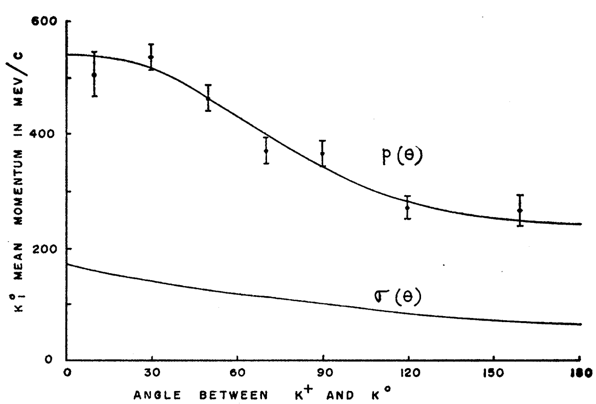

FIG. 3. The K^0 momentum, as a function of angles between K^0 and K^+, is shown above as well as the standard deviation $\sigma(\theta)$ of the momentum.

E. Multiple Origins

For those K^0 interactions where there were more than one possible K^+ charge exchange in the same picture, no satisfactory method was found to correlate the $\bar{K}^0$ interaction with the correct origin. In such cases all origins were considered possible and each origin given a weight dependent upon (a) the inverse square of the distance, (b) the known angular distribution of the $K_1{}^0$ decays from the K^+ origins, and (c) the assumed momentum dependence of the $\bar{K}^0$ cross section for nuclear interaction. Some of the pertinent information on the frequency of possible K^+ charge exchange origins associated with $\bar{K}^0$ interactions is listed in Table I.

TABLE I. Multiplicity of K^+ charge-exchange origins.

No. of origins	1	2	3	4	5	6
No. of $\bar{K}^0$ interactions with N origins	47	47	28	13	5	0

All interactions of incoming particles having the beam momentum were accepted as suitable origins except for those cases where (a) the process could be identified as a K^+ decay or a K^+ scattering and (b) a $K_1{}^0$ decay was associated with the K^+ interaction. Obviously, not all K^+ decays in flight nor K^+ scatterings can be identified, and therefore the origins accepted include some background. As will be discussed later, the inclusion of background origins does not materially affect the experiment. The fraction of false origins is estimated to be $\sim 30\%$.

III. RESULTS

For each event, associated with j possible charge exchange origins, the relative weights W_i, $i=1\cdots j$ were calculated as indicated in Sec. II E, in such a way

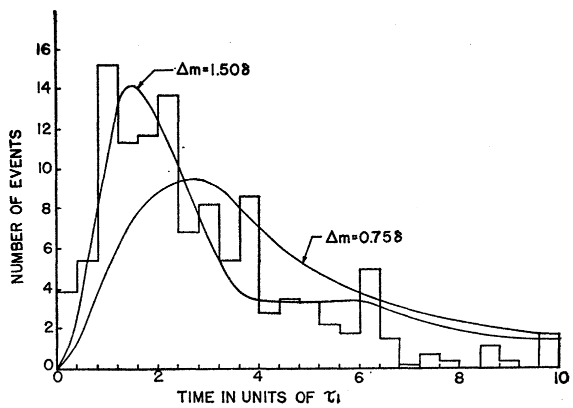

FIG. 4. The time distribution of the $\bar{K}^0$ interactions is compared with the expected distributions for $\Delta M = 0.75\delta$ and 1.50δ.

that $\sum W_i = 1$. The computed times, t^*, were found from $t_i{}^* = d_i m_0 / p_i(\theta)$, where $p_i(\theta)$ is the mean momentum at the angle θ_i for the ith origin, and d_i is the distance to the origin in question. It must be noted that even in the case of only one origin ($j=1$) this calculated time t^* may differ from the actual time of flight by as much as 25% because of the spread in the momentum distribution of the K^0 mesons at any given angle.

It was decided to accept only those $\bar{K}^0$ interactions where there were less than four possible K^+ charge exchanges in the same picture. This reduces the sample of events from 140 to 122. This restriction on multiple origin events was imposed because of the increased probability, for those events with a larger number of origins, to have a false K^+ origin nearby. This accidental association of a false origin tends to increase the measured value of the mass difference.

In Fig. 4 a plot is made of the time distribution of

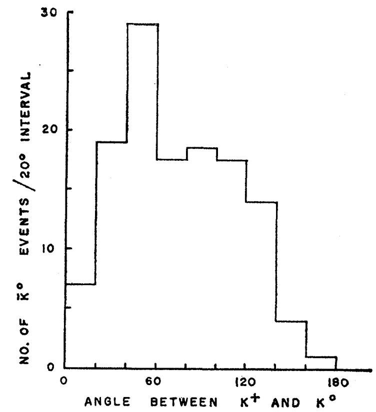

FIG. 5. The angular distribution of the $\bar{K}^0$ events is shown. Only events that occurred in the first 5 τ_1, are included in this distribution. No correction was made for geometrical losses.

these 122 $\bar{K}^0$ interactions. For the cases of multiple origins, all origins were included with their relative weights. Included for comparison are theoretical curves which were calculated by a Monte-Carlo process. These curves incorporate the effects due to the momentum spread of the neutral K mesons, variation of cross section with energy and geometrical losses due to the finite size of the chamber.

The angular distribution of the K^0 which produced the $\bar{K}^0$ interactions is shown in Fig. 5. (The K^0 was assumed to come from the most probable origin.) It is of interest to compare this angular distribution with that of the $K_1{}^0$ decays, which is shown in Fig. 6. Since the mean distance traveled by the $K_1{}^0$ before decay is less than the thickness of the chamber, the loss factor, even at 90° is small and no correction for this effect has been made. If the geometrical loss factors were the same, these two distributions should be the same; however, the loss factor is less for the $K_1{}^0$ than for the $\bar{K}^0$ interactions principally around 90°. In spite of this basic difference, the distributions are remarkably similar.

IV. ANALYSIS

In order to find the best value of the mass difference, the experimental results were compared, by the maximum likelihood method, to a family of curves for the

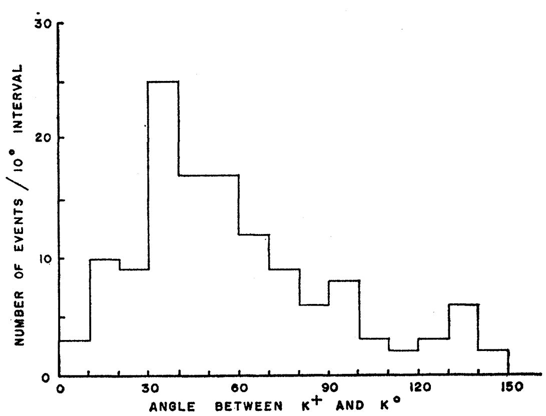

FIG. 6. The angular distribution of $K_1{}^0$ decays is shown.

expected number of $\bar{K}^0$ interactions as a function of time, t^*. These curves were obtained by a Monte-Carlo process. The process simulated the angular and momentum distribution as well as the spacial distribution of the K^0, as inferred from the $K_1{}^0$ decays, and calculated the expected distribution of $\bar{K}^0$ interactions in the chamber as a function of the mass difference.

The following parameters were included in the Monte-Carlo calculation: (1) the value of the $K_1{}^0$–$K_2{}^0$ mass difference; (2) the exponent n in the momentum dependence of the $\bar{K}^0$ cross section, $\sigma(p)=Kp^n$; (3) the length of track L that is required for the recognition of the Λ decay; (4) the fraction F of $\bar{K}^0$ interactions that were caused by neutral K's which originated from outside the propane. In some cases an unrelated charge exchange, in the same picture as the $\bar{K}^0$ interaction, would be incorrectly assumed to be the origin of the neutral meson.

The experimental time distribution has been compared by a maximum likelihood method to a group of curves calculated by the Monte-Carlo process, for various values of Δm. The values of the above parameters used in the Monte-Carlo process are as follows:

$$n=-\tfrac{1}{2},\quad L=6\text{ cm},\quad\text{and}\quad F=0.3.$$

The time distributions of the $\bar{K}^0$ interactions with one, two, and three origins were compared with the curves generated by the Monte-Carlo process containing one, two, and three origins, respectively. The resultant maximum likelihood curve was obtained by taking the product of these three likelihoods. (No significant difference was found between the likelihood curves for the one, two, and three origin groups.) The sample of $\bar{K}^0$ interactions that were used in the maximum likelihood calculation given in Fig. 3 was restricted to events in the first 10 $K_1{}^0$ lifetimes. The results of the likelihood calculation is shown in Fig. 7.

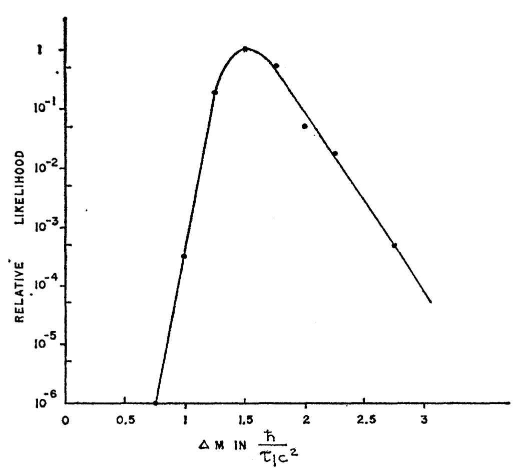

FIG. 7. The relative likelihood for various values of the mass difference in units of $\hbar/\tau_1 c^2$ is shown above.

TABLE II. Parameters used in the Monte-Carlo calculations.

n	L	F
$\left.\begin{matrix}0\\-\frac{1}{2}\\-1\end{matrix}\right\}$	6	0.3
$-\frac{1}{2}$	$\left.\begin{matrix}3\\6\end{matrix}\right\}$	0.3
$-\frac{1}{2}$	6	$\left\{\begin{matrix}0.1\\0.3\\0.7\end{matrix}\right.$

In order to investigate how the relative likelihood depends upon the choice of the parameters n, L, and F, the values listed in Table II were put into the Monte-Carlo calculation. The variation in the value of the mass difference, for values of the above parameters, was found to be less than 0.2δ. This substantiates the unimportance of the inclusion of false charge-exchange origins, such as K^+ decays, K^+ interactions, etc., as well as K^0's from origins outside of the propane.

Although the bulk of the information in the time distribution is contained in the location of the peak, the remainder of the distribution does contain information, principally because of the normalization which is necessary for a comparison with the likelihood curves. The portion of the distribution corresponding to large distances, however, is the most sensitive to the geometrical correlation factor and background effects. For these reasons the data have been analyzed using events which occurred in the time interval 0 to T, where T was varied from 1 to 10 τ_1. No significant variation in Δm with T was found. We consider the results obtained by restricting the time interval to the first 10 τ_1 to be the most significant, as this seems to be the best compromise between loss of data (for small T) and effect of biases (for large T).

The exclusion of large values for the mass difference depends critically upon the absence of events in short time intervals, which corresponds to small distances. It is estimated that, in unfavorable circumstances, the $\bar{K}^0$ interaction point could be distinguished from the point of charge exchange of the K^+ only if they were separated by more than 3 mm. Shorter distances correspond, on the average, to a time interval of less than $0.15\tau_1$. Even for distances less than 3 mm, the $\bar{K}^0$ interaction would be recognized, in many cases, because the Λ hyperon from the interaction would have been seen, indicating that the $\bar{K}^0$ interaction had occurred, even though the two centers may not be resolved. Admittedly, the "V" from the Λ decay would in some cases be falsely assumed to be a $K_1{}^0$ decay and missed in the scanning, but this fraction is not large. The inclusion of events, which might be lost in short time intervals would tend to increase the value of the mass difference, making the discrepancy between our results and that of Good *et al.*[8] even larger.

V. CONCLUSIONS

The presence of the peak in the $\bar{K}^0$ intensity is taken as direct proof of the interference phenomena between the $K_1{}^0$ and $K_2{}^0$ states. The location of the peak gives a mass difference between the $K_1{}^0$–$K_2{}^0$ states of $(1.5\pm 0.2)\delta$ which corresponds approximately to the natural width of the $K_1{}^0$ state (presumably the width of the $K_2{}^0$ is much less because of its longer lifetime). It has been pointed out by Okun and Pontecorvo[3] that the mass difference can be used to test the presence of transitions, real or virtual, where strangeness changes by two units, $\Delta S=2$. If such an interaction exists it would result in a mass difference of about $10^5\delta$. If the mass difference were that large, the expected $\bar{K}^0$ intensity would oscillate so rapidly with time that the individual oscillations could not be detected and the resulting experimental curve would correspond to $\delta=\infty$ (see Fig. 1). The deficiency of events between 0 and 1 τ_1, as well as the peak around between 1 and 2, constitutes the basis for excluding this possibility.

The results of this experiment are in disagreement with that of Good *et al.*,[8] and in agreement with that of Fitch *et al.*[11] The reason for the disagreement with Good *et al.* is not understood.

ACKNOWLEDGMENTS

We wish to thank Professor R. G. Sachs for stimulating our interest in this experiment and for many interesting discussions. Some events were fouud in Padova while scanning the same film for leptonic events. We are grateful to Professor M. Baldo-Ceolin and the whole Padova group for kindly permitting us to use these events and also for many interesting discussions. For the use of the operating, separated K^+ beam we are indebted to Professor D. H. Stork, Professor H. Ticho, Professor G. Goldhaber, and Professor S. Goldhaber. The experiment was made possible by the whole-hearted cooperation of many people associated with the Bevatron accelerator, to whom we owe a big "thanks".

APPENDIX I

If one starts with a pure $\bar{K}^0$ beam; such as obtained from the charge exchange of K^-, then the time dependence of the $\bar{K}^0$ intensity, as a function of the mass difference, is given by the equation:

$$I(\bar{K}^0)=\exp(-\lambda_2 t)+\exp(-\lambda_1 t)+2\cos(\Delta\omega t)\exp(-\lambda_1 t/2). \quad \text{(A1)}$$

To study this time dependence as well as to make a feasibility study for the experiment described in this paper, it was decided to scan the film from a 1.15-BeV/c separated K^- meson beam. The ratio[16] $K^-/\pi^-/\mu^-$ was about 1.5/0.2/4.5 and the average number of K^-/picture was about 2. The film was scanned for events of the type $\bar{K}^0+n\rightarrow\Lambda+\pi$ or $\Sigma+\pi$, whose numbers are proportional to the $\bar{K}^0$ intensity. In order to insure that the events with associated hyperons came from $\bar{K}^0$ interactions rather than hyperon scatterings, only those events were accepted where a charged pion was associated with the presumed $\bar{K}^0$ interaction.

To convert the measured distance, from the K^- charge exchange origin to the $\bar{K}^0$ interaction, into time of flight, it was necessary to estimate the velocity of the $\bar{K}^0$. The velocity of the $\bar{K}^0$ for each event was calculated by assuming that the charge exchange took place on a free proton. A plot of the time distribution of the $\bar{K}^0$ events is shown in Fig. 8. Using the same type of regenerated

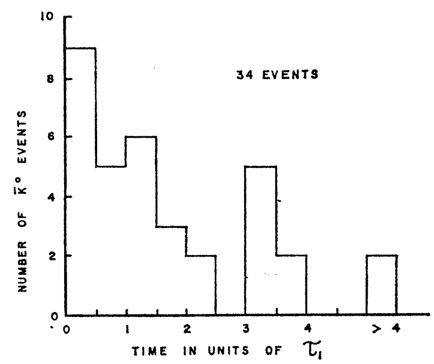

FIG. 8. The time distribution of $\bar{K}^0$ interactions is shown. Note the large fraction of events in the first $K_1{}^0$ lifetime as would be expected from an initial $\bar{K}^0$ beam.

$\bar{K}^0$ intensity curves as used in the K^+–$\bar{K}^0$ experiment, with the time scale changed by the ratio of the beam momenta, the best value of the mass difference was found to be $\sim 2\delta$. Errors are not given because of the low statistics and because several factors are not well known which may introduce biases. Nevertheless, it is important to note that the $\bar{K}^0$ intensity decreases with time (between 0 and 2 τ_1), as expected, and that the results are consistent with the K^+–$\bar{K}^0$ experiment.

[16] L. W. Alvarez, P. Eberhard, M. L. Good, W. Graziano, H. K. Ticho, and S. G. Wojcicki, Phys. Rev. Letters **2**, 215 (1959).

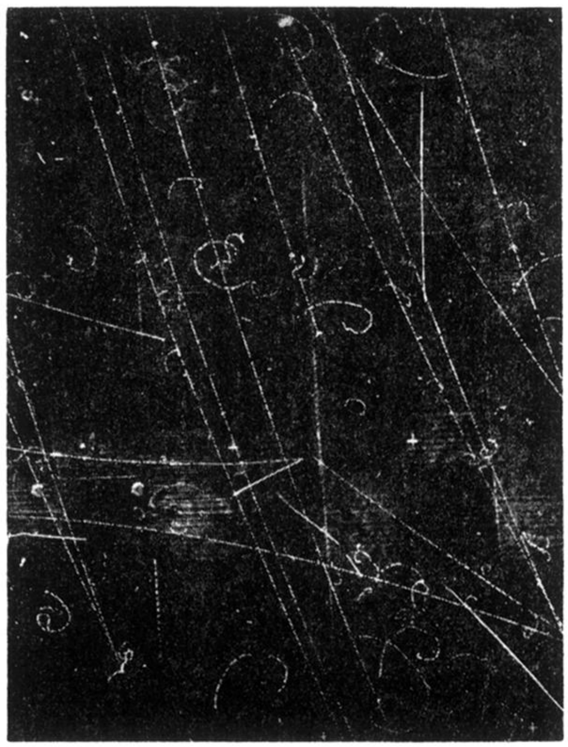

FIG. 2. The photograph shows a K^+ charge exchange followed by a $\bar{K}^0$ interaction. The $\bar{K}^0$ interaction produced by a π^+ and a Λ hyperon.