Table I. Summary of data on the lifetimes of $M2$ transitions from $d_{3/2}$ hole states in scandium isotopes.

Isotope	Excitation energy (keV)	Observed mean life (μsec)	Conversion coefficient	Partial γ-ray mean life τ_γ (μsec)	Moszkowski estimate, τ_M (μsec)	Ratio τ_γ/τ_M
Sc^{43}	150 ± 3	628 ± 10	0.045	656	3.49	190
Sc^{45}	13 ± 1	(0.44 ± 0.025) × 10^6	330	145 × 10^6	0.6915 × 10^6	210
Sc^{47}	760 ± 20	0.40 ± 0.06	≈0	0.40	0.00098	410

factor. A calculation by Lawson,[11] based on the admittedly somewhat unrealistic assumption that seniority is a good quantum number in this region, predicts that the transition rates should be only one quarter of the single-particle estimate.

*Work performed under the auspices of the U. S. Atomic Energy Commission.

†Permanent address: University of Helsinki, Helsinki, Finland.

[1]J. L. Yntema and G. R. Satchler, Phys. Rev. 134, B976 (1964).

[2]J. B. French, Argonne National Laboratory Report No. ANL-6878, July 1964 (unpublished).

[3]F. J. Lynch, K.-E. Nystén, and R. E. Holland, Bull. Am. Phys. Soc. 9, 79 (1964).

[4]J. L. Yntema and J. R. Erskine, to be published.

[5]G. J. McCallum, A. T. G. Ferguson, and G. S. Mani, Nucl. Phys. 17, 116 (1960).

[6]M. E. Rose, Internal Conversion Coefficients (North-Holland Publishing Company, Amsterdam, 1958).

[7]S. A. Moszkowski, Beta- and Gamma-Ray Spectroscopy, edited by Kai Siegbahn (North-Holland Publishing Company, Amsterdam, 1955).

[8]J. H. Bjerregaard, P. F. Dahl, O. Hansen, and G. Sidenius, Nucl. Phys. 51, 641 (1964).

[9]P. C. Simms, N. Benczer-Koller, and C. S. Wu, Phys. Rev. 121, 1169 (1961).

[10]R. G. Roddick and F. J. Lynch, to be published.

[11]R. D. Lawson, private communication.

SEARCH FOR CP NONCONSERVATION IN K_2^0 DECAYS*

A. Abashian, R. J. Abrams, D. W. Carpenter, G. P. Fisher, B. M. K. Nefkens, and J. H. Smith
Department of Physics, University of Illinois, Urbana, Illinois
(Received 27 July 1964)

Neutral K mesons are especially convenient for studying CP invariance in strangeness-changing decays. The K_1^0 meson, the even CP state, decays into two pions. The K_2^0 meson, the odd state of CP, is not allowed to decay into two pions if CP is conserved. The published experimental upper limit on the $K_2^0 \to \pi^+ + \pi^-$ mode is 0.3% of all K_2^0 decays.[1-5]

In an experiment designed to look primarily at $K_{\mu 3}^0$ and K_{e3}^0 decays, we have also looked for cases of K_2^0 mesons decaying into two pions. The experiment was performed 60 feet from the target in a 30° neutral beam at the Brookhaven AGS. Neutral particles decaying in a vacuum pipe placed in a magnetic field of 10 kG were detected with the counter and spark-chamber arrangement shown in Fig. 1. To trigger the spark chambers, during the portion of the run devoted to $K_{\mu 3}$ decays, a coincidence $ME_1E_2E_3P\bar{A}$ was required. This insured a high probability for selecting $K_{\mu 3}$ events since only about 10% of the pions from the other modes of K_2^0 decay would be able to penetrate the 11 in. of Pb without interacting. The triggering during the K_{e3} portion of the run was the same as before except that the Pb was removed and the bias levels on the E counters raised so that electron showers would trigger the chambers. The E counters consisted of alternate layers of $\frac{1}{8}$-in. plastic scintillator and $\frac{3}{32}$-in. Pb, a total of about two radiation lengths of Pb in each counter.

To analyze the events, a search was made for pictures of the magnet spark chambers which contained two oppositely charged tracks whose intersection point was in the vacuum pipe. The identity of one of these two particles was established as being a muon during the $K_{\mu 3}$ run by observing the range of the particle in the exterior

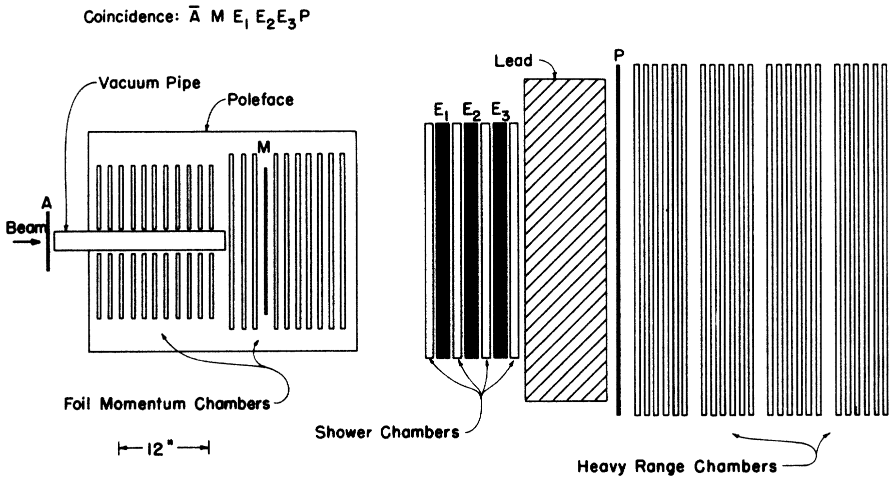

FIG. 1. Detection system. For K_{e3} run, Pb was removed.

range chambers and comparing with its expected range as deduced from the momentum measurement made in the magnet chambers. Electrons were identified during the K_{e3} run by their showering in the Pb scintillation counters and the interspaced spark chambers.

Approximately 4500 V events were found in each of the two runs. Of the 4500 events of the $K_{\mu3}$ run, 1700 were identifiable as true $K_{\mu3}$ events and the remainder were unidentifiable either because the triggering particle was a π or because the μ went out the sides of the range stack before coming to the end of its range. For the K_{e3} run, about 750 events were identifiable as K_{e3}, the remainder again being unidentifiable.

The total of about 9000 V events, irrespective of whether an event was identifiable as a $K_{\mu3}$ or K_{e3} or not, was analyzed under the assumption that the decays were $K_2^0 \to \pi^+ + \pi^-$. With this assumption, the invariant "mass" and the direction D of the composite system relative to the known beam direction could be calculated. If the decay were truly a two-pion decay of the K_2^0, the invariant mass would be the K_2^0 mass of 498 MeV and the angle D would be zero within the experimental angular resolution of about 0.5°.

Figure 2 is a histogram of events selected from the K_{e3} run by the criterion that the invariant mass of the "two-pion" system be close to 498 MeV. There is a very pronounced forward peaking for the unidentifiable events in the bin 500 to 510 MeV. A much less pronounced forward peaking occurs for the corresponding events in the other two bins. Furthermore, only a smooth behavior is observed for those events identifiable as K_{e3} decays. We believe that the calibration of our magnetic field may have been in error by as much as one-half percent and that the 500-to-510 bin could have been as low as 495 to 505 MeV.

Figure 3 is a corresponding set of histograms for events observed in the $K_{\mu3}$ run. Because of the meager statistics, no definite conclusions can be drawn from this data except to say that no marked difference occurs between the unidentifiable events and the identifiable $K_{\mu3}$ events. We cannot rule out the possibility that the effect observed in the K_{e3} run is due to $K_{\mu3}$ decay.

We have examined the effects of labeling a K_{e3} or a $K_{\mu3}$ event as a $K_{\pi2}$ event. The K_{e3} mode cannot give a pronounced forward peaking for invariant masses equal to the K_2^0 mass as verified by our histograms. The $K_{\mu3}$ mode does tend to give a small angle for D when a mass near that of the K_2^0 is taken. This arises from the fact that the μ and π masses are similar, and, in the limiting case of the two masses being equal, choosing an invariant mass equal to the K mass would automatically force D to be equal to zero. Typically, a $\pi\mu\nu$ event in which the assumed $\pi\pi$ reconstructed mass would equal the K_2^0 mass would have a neutrino momentum P_ν^* of 17 MeV/c in the c.m. system. One readily sees that the angle D is given approximately by $\tan^{-1}(P_\nu^* \times \sin\theta^*/P_K)$, where P_K is the K_2^0 momentum in the lab and θ^* is the angle of emission of the neutrino in the c.m. of the K_2^0. Therefore, a typical angle D will be of the order of 0.5° to 1.0° for P_K between 1 and 2 BeV/c. A more exact calcula-

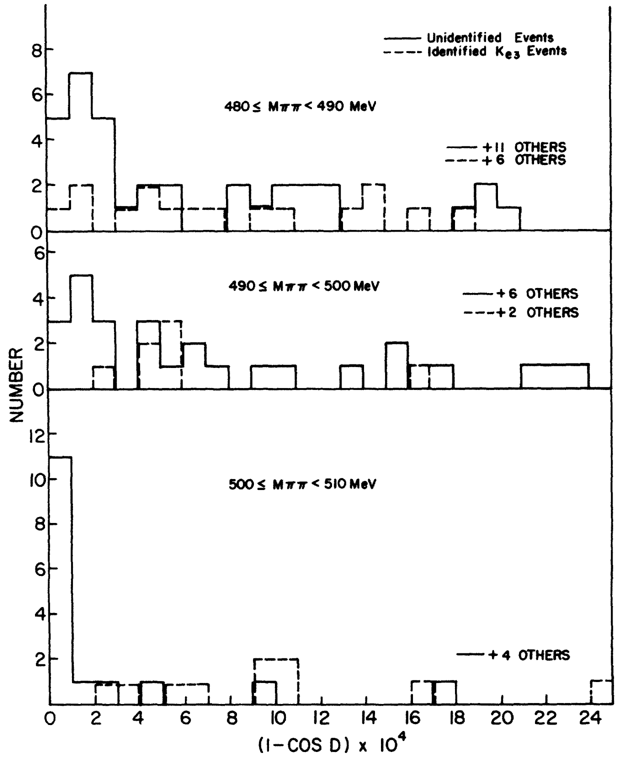

FIG. 2. Angular distribution of reconstructed K_2^0 relative to beam direction for events having a mass near 498 MeV when analyzed assuming the decay is $K_2^0 \rightarrow \pi^+ + \pi^-$. K_{e3} run.

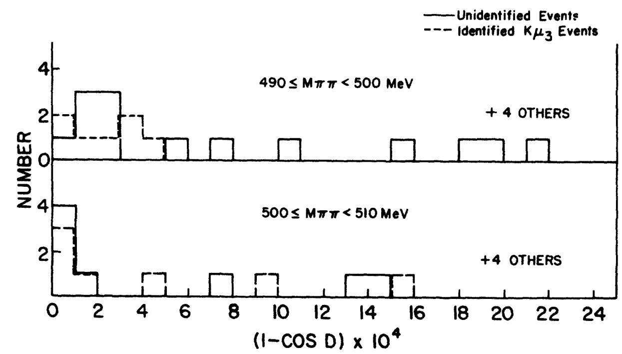

FIG. 3. Angular distribution of reconstructed K_2^0 relative to beam direction for events having a mass near 498 MeV when analyzed assuming the decay is $K_2^0 \rightarrow \pi^+ + \pi^-$. $K_{\mu 3}$ run.

tion gives results in agreement with this rough calculation.

Because of this behavior of $\pi\mu\nu$ events selected in this way, and because of the possible peaking observed in the events of Fig. 3, we prefer to be very cautious about asserting that the pronounced peaking in the 500- to 510-MeV bin of Fig. 2 indicates a $\pi\pi$ decay mode of the K_2^0 meson.

The 11 events shown in the suggestive peak have been analyzed in detail with the following results: (1) There is one event in which the first particle stops in plate 5 and the second in plate 11, whereas their momenta predict that both should penetrate the entire 24 chambers. Neither showers in the shower chambers. Consequently, both particles are identified as pions. The reconstructed invariant mass is 501 MeV; the angle D is 0.29°; and the decay position is in the center of the vacuum pipe more than five K_1^0 mean lives from the nearest regenerator, the $\frac{1}{8}$-in. thick plastic anticoincidence counter. The momentum of the incoming K_2^0 is 1.5 BeV/c. (2) There is one event in which one charged particle stops in plate 15 whereas a muon of this momentum would penetrate the entire 24 chambers. It does not shower. The second particle suffers a sudden 35° scattering in one of the lead electron counters, with no evidence of showering. Therefore, both particles could well be pions. The mass is 506 MeV. D is 0.25°. (3) In three cases there may be some questionable evidence of showering, though not enough to have identified the particle as an electron in normal scanning. (4) In all other cases, although one particle could be identified as a pion, the other left the detecting system or stopped with a range consistent with that of a muon or a pion. In no case did the supposed pion of longest range penetrate more than 2.9 mean free paths of material.

An alternative identity for any $\pi\pi$ event observed would be a $\pi\pi\gamma$ event with a photon of energy less than 10 MeV in the center of mass.

The peak in Fig. 2 constitutes about 0.2 to 0.3 % of all K_2^0 decays. We feel safe in assigning this as an upper limit. In terms of the $K_2^0 \rightarrow \pi^+\pi^-$ to the $K_1^0 \rightarrow \pi\pi$ rate this places an upper limit on CP violation of 5×10^{-6}, with at least a suggestion that CP may actually be violated by this amount.

We would like to acknowledge the help and cooperation of Professor A. Wattenberg for stimulating discussions and the assistance of the staff at the AGS of the Brookhaven National Laboratory.

*This work was supported by the U. S. Atomic Energy Commission.

[1]M. Bardon, K. Lande, L. M. Lederman, and W. Chinowsky, Ann. Phys. (N.Y.) 5, 156 (1958).

[2]D. Neagu, E. O. Okonov, N. L. Petrov, A. M. Rosanova, and V. A. Rusakova, Phys. Rev. Letters 6, 552 (1961).

[3]D. Luers, I. S. Mittra, W. J. Willis, and S. S. Yamamoto, Phys. Rev. Letters 7, 255 (1961).

[4]Rene Turlay, unpublished.

[5]As this manuscript was being prepared, we received a preprint of an article by J. H. Christenson, J. W. Cronin, V. L. Fitch, and R. Turlay [Phys. Rev. Letters 13, 138 (1964)] of an indicated violation of *CP* in K_2^0 decay. We are indebted to the authors for the manuscript before publication.

SIGMA PHOTOPRODUCTION AND DETERMINATION OF THE Σ^+ MAGNETIC MOMENT*†

A. D. McInturff and C. E. Roos
Department of Physics and Astronomy, Vanderbilt University, Nashville, Tennessee
(Received 1 July 1964)

This communication is a report on the current progress in the study of Σ^+ photoproduction near threshold and it includes the first Σ^+ magnetic-moment data.[1] The in-flight decays of the hyperons are observed in nuclear emulsion exposed at the California Institute of Technology electron synchrotron. Details of earlier measurements may be found in the literature.[2-5] A study of the in-flight proton-decay mode of the sigma gives a measurement of the cross section and the mean polarization ($\alpha\bar{P}$) for the reaction

$$\gamma + p \rightarrow K^0 + \Sigma^+. \quad (1)$$

A strong axial pulsed magnetic field focuses the shower electrons along the photon-beam axis. This field reduces the background over an order of magnitude and precesses the sigma spin axis.

The *K*-5 emulsion stacks and the 4.83 g/cm^2 CH_2 target (4×50 mm) were located in a 125-kilogauss pulsed solenoid. The magnet, target, and bremsstrahlung beam were centered on the same line. The beam was collimated to a 1.5-mm radius circular image at the target. The 1280-MeV bremsstrahlung beam was hardened by two radiation lengths of LiH, and had a total exposure energy of 1.68×10^{12} MeV. The stack was exposed parallel to the beam axis with the lower stack surface 2.0 mm from the beam center.

The emulsions were area scanned for in-flight decays with faster secondaries. The charged decay product was required to have at least a 10%->15% lighter ionization than the primary. When the incoming sigma track was darker than 3× plateau a minimum grain difference of 15% was required. The minimum grain count of the proton mode decay was 500 grains/track; the average grain count was over 1000. A minimum angle of 10° between the projected primary and the secondary track was required for a sigma whose kinetic energy was less than 200 MeV (2.3× or darker for primary track). The faster primaries required a minimum difference of 5°. These scan criteria exclude 60% of the $\Sigma^+ \rightarrow p + \pi^0$ decays, but insure that the 40% which are accepted cannot be confused with elastic or inelastic proton scatters. There was an average of approximately 40 scatters per sigma event. A very limited rescan indicated a reasonable detection efficiency (100% for three sigma events).

The earlier data[5] suggested that Reaction (1) could possibly be polarized; therefore the microscope orientation of the present plates was reversed in the middle of scanning to eliminate possible bias.

The kinematics of sigma photoproduction were calculated for hydrogen and are shown in Fig. 1

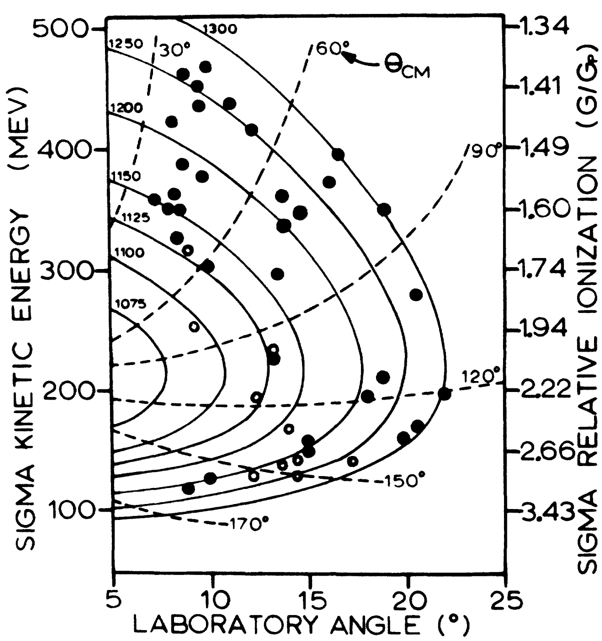

FIG. 1. Sigma photoproduction kinematic curves are shown for hydrogen. The sigma events are plotted on the basis of laboratory angle (degrees) and ionization. The production angle for a sigma in the c.m. system is given by $\theta_{c.m.}$. The present data are shown by closed circles while the earlier events of Roos and Peterson[5] are indicated by open circles.