OBSERVATION OF PHOTOPRODUCED NEUTRAL K MESONS*

J. F. Schivell,† E. Engels, Jr., and A. Entis
Harvard University, Cambridge, Massachusetts

and

J. M. Paterson
Cambridge Electron Accelerator, Cambridge, Massachusetts

and

L. N. Hand‡
Cornell University, Ithaca, New York

and

A. Sadoff
Ithaca College and Laboratory of Nuclear Studies, Cornell University, Ithaca, New York
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Neutral K_L mesons produced by high-energy gamma rays[1,2] have been successfully detected in an experiment performed at the Cambridge Electron Accelerator. The gamma-ray source was produced through bremsstrahlung by 5.5- and 4.25-GeV electrons from the Cambridge Electron Accelerator emergent electron beam. K_L mesons were detected by observing the decay of regenerated K_S mesons in a spark chamber located 100 ft from the production target. Neutral K mesons were observed at 3.5° and 10° from aluminum and at 0°, 2.5°, 3.5°, 6°, and 10° from beryllium, all at the higher electron energy. Further, sufficient data were taken at the lower electron energy for 3.5° from aluminum and 2.5° from beryllium to allow photon-difference spectra to be obtained. In addition, data were taken both with a tungsten target and with no target to allow measurement of backgrounds.

In this Letter we report on the method used to detect the K_L's and on the momentum spectra obtained at 5.5 and 4.25 GeV for photoproduction from a one-radiation-length aluminum target at the nominal production angle of 3.5°.

After passing through a secondary emission monitor, the emergent electron beam struck the target while being deflected in a bending magnet (see Fig. 1). After leaving the target, the electron beam struck a copper beam stop about 2.5 in. from the center line of the neutral beam, which was initially defined by a lead collimator with a 2-in.×2-in. aperture. (The experiments performed with a one-radiation-length tungsten target replacing the aluminum target verified that the contamination of events produced either from the beam stop or by photons leaving the target and striking material downstream was less than 10%.)

Next, the beam passed through a sweeping magnet to remove charged particles. Following the magnet was an 8-in.-thick lead gamma-ray filter. The beam then passed through a hole in the 16-ft-thick concrete shield wall. Following a long drift space, the beam was finally collimated with a 24-in. lead wall with a 4-in.-square hole. This wall stood about 4 ft in front of the detection spark chamber.

Figure 1 also shows the geometry used in the detector. The copper regenerator subtends a solid angle of 1.1×10^{-5} sr at the production target. The spark chamber was triggered whenever the scintillation counters indicated two charged-particle tracks with no charged par-

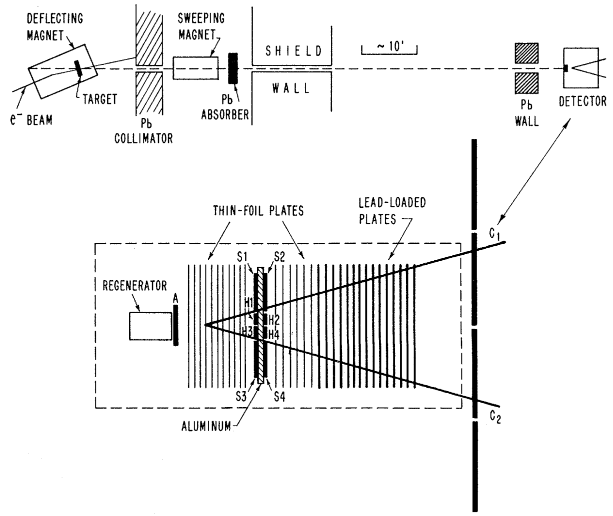

FIG. 1. Experimental apparatus (plan view) and detail of spark chamber and trigger counters.

ticle through A, the anticoincidence counter. No magnetic field was employed and hence no momentum analysis was performed on the individual charged-particle tracks. Because of the relative freedom of this neutral beam from background, it is possible to separate the V's produced in the chamber by transmission regeneration of K_S in the 6-in.-long copper block from background due to $K \rightarrow$ three-body, diffraction-regeneration, nuclear interactions of K's and neutrons, etc. To indicate this separation, Fig. 2 shows a plot of $1-\cos\theta_c$, where θ_c is the angle between the incident beam direction (known to better than 1 mrad) and the plane formed by the two arms of the V. It can be seen that a sharp peak exists, corresponding to the V's coplanar with the incident beam direction. (About $\frac{1}{2}$ of all these events are off scale in the direction of larger angles and form a flat background.) The width of this peak is consistent with our experimental resolution and is approximately $\frac{1}{2}°$ wide, containing about $\frac{1}{4}$ of all events. The lead plates (1.5 radiation lengths total) in the rear of the chamber helped reduce the contamination from K_{e3} and $K_{3\pi}$ events.

If we assume a coplanar V to be a $K_S \rightarrow \pi^+ + \pi^-$, we can calculate the momentum of the K_L from the angles alone. A check on this assumption comes from plotting the distribution of decay vertices in the chamber and comparing this with the distribution expected from the known K_S lifetime. This is also shown in Fig. 2, and it is seen that the contamination of background events is small.

Figures 3(a) and 3(b) show the momentum

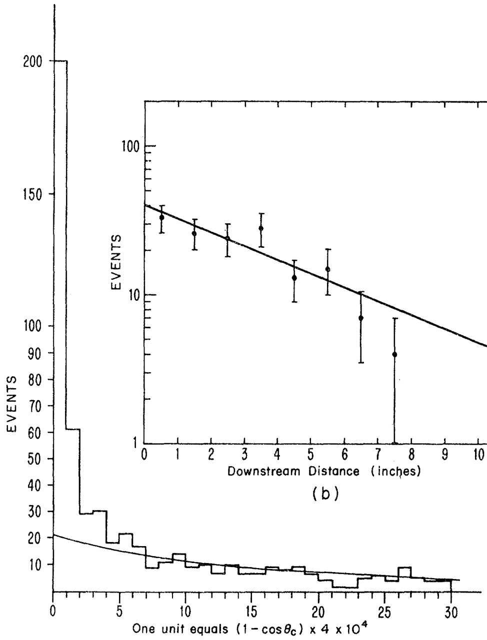

FIG. 2. (a) Event distribution for angle (θ_c) made by the plane of the V with the axis of the apparatus. (b) Distribution of decay vertices. The sample of events consists of those with $2.0 < p_K < 2.2$ GeV/c and $1-\cos\theta_c < \frac{1}{2} \times 10^{-4}$. Numbers of events are corrected for detection efficiency. The solid line is the best fit to the data, which implies a K_S lifetime of 0.95×10^{-10} sec ± 20%.

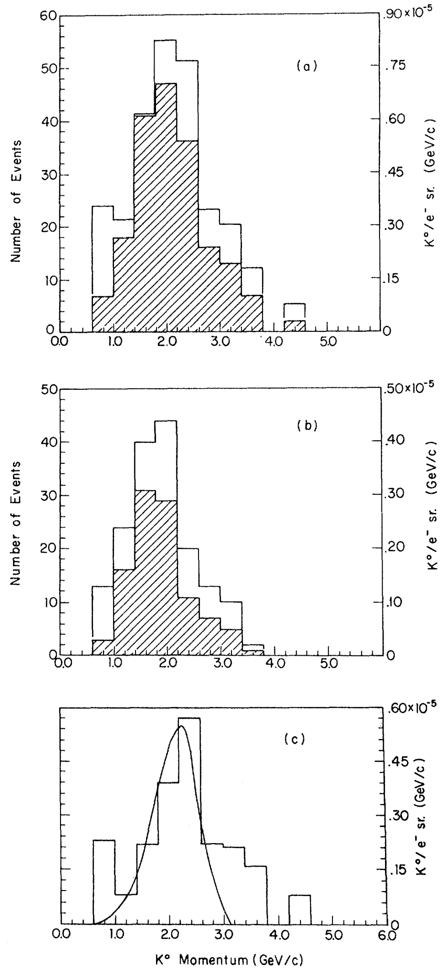

FIG. 3. Momentum spectra of events observed (shaded histogram, left-hand scale) and of yield of K_L, corrected for detection efficiency (open histogram, right-hand scale). Electron beam energies are (a) 5.5 and (b) 4.25 GeV, respectively. (c) Photon-difference yield of K_L (corrected for detection efficiency). The ordinate is in units of 10^{-5} K^0/electron sr (GeV/c). The solid line is the predicted spectrum for K_L via φ production.

spectra of coplanar V's obtained for the two electron beam energies. Both the numbers of events obtained and the deduced yields of K_L at 3.5° are shown. A Monte Carlo calculation has been used to find the geometric efficiency for detection. The regeneration efficiency was obtained by using the measured values of $|f_{21}(0)|^2$, the absolute value of the regeneration amplitude, at 1.1 and 2.7 GeV;[3] for energies above 2.7 GeV, an optical-model calculation was performed to obtain $|f_{21}(0)|^2$, using the measured inelastic cross sections for K^+ and K^- mesons on copper[4] and assuming that $\mathrm{Re}f_{21}(0)$ is small above 2.5 GeV.

One noticeable feature of the spectra is the relative absence of events with momenta greater than 4 GeV/c in the 5.5-GeV data. From this observation we deduce an upper limit for the differential cross section in the center of mass, for incident gammas between 4.5 and 5.5 GeV, of 4×10^{-32} cm^2/sr due to the sum of the following two-body processes: $\gamma+p\rightarrow\Sigma^+ +K^0$, $\gamma+n\rightarrow\Sigma^0+K^0$, $\gamma+n\rightarrow\Lambda^0+K^0$.

Additional data now being analyzed for a production angle of 10° should allow us to shed some light on the process of K^* exchange predicted by Drell.[5] This process should not be apparent in the 3.5° spectrum presented here.

The K_L spectrum for $E_0=5.5$ GeV shows a strong peak in the three bins of the histogram around 2.0 GeV/c (1 bin = 0.4 GeV/c). The position and width of this peak correspond exactly to that predicted for the process of φ-meson photoproduction, followed by the neutral decay mode of the φ into K_S+K_L. The narrow peak predicted is a consequence of the low Q value (12 MeV) for the decay $\varphi\rightarrow K_S+K_L$ and the assumption that $d\sigma(\gamma\varphi)/dt$ is slowly varying with energy, i.e., that φ mesons are produced at increasingly small angles at high energies. Figure 3(b) shows that this peak has shifted and is much smaller at $E_0=4.25$ GeV and Fig. 3(c) gives the difference spectrum which is the result of subtracting the two yield spectra. Except for poorer statistics, this difference spectrum should be more sensitive to the φ-produced neutral K's. We use all of the events in this difference spectrum between 1.0 and 3.0 GeV/c to obtain an upper limit of

$$\sigma_{\gamma\varphi}<0.46\pm0.21\ \mu\mathrm{b}.$$

(The error is combined from a 25% statistical error, an estimated 25% error in absolute efficiency, and a 30% error in calculating the $K_L{}^0$ flux from the decay of φ mesons.)

This limit is to be compared with the Deutsches Elektronen-Synchrotron (DESY) bubble-chamber number[6] for $\sigma_{\gamma+\varphi\rightarrow p+\varphi}=0.22\pm0.07\ \mu$b, averaged over energies from 2.5 to 5.8 GeV. It shows that the cross section for φ production from neutrons is not much larger than that for φ production from protons and implies that at least 50% of the small angle $K_L{}^0$ flux is due to the production and decay of φ mesons.

In order to calculate the yield of K_L from φ photoproduction, a number of assumptions have to be made. A model of diffractive φ photoproduction was used, implying a constant total cross section at high energies and an angular distribution of the form e^{Bt} from the free proton, where t is the momentum transfer and B is a constant. A value[7] of $B=2.5$ (GeV/c)$^{-2}$ was used. The results at 3.5° are insensitive to the exact value of B and the assumption that $B=10$ (GeV/c)$^{-2}$ changes the final answer by only 30%.

Since the production took place from a complex nucleus, there are two additional effects: absorption and the effect of nuclear coherence. We have neglected any correction for the absorption of the φ meson in nuclear matter on the basis that a very low φ-nucleon total cross section is required by the diffraction model of φ production.

Secondly, the effects of nuclear coherence in φ production were estimated by using, in place of the incoherent sum of neutron and proton cross sections, a correction of the form

$$d\sigma(\gamma+A\rightarrow\varphi+A)/d\Omega = [F^2A^2+(1-F^2)A]d\sigma(\gamma+p\rightarrow\varphi+p)/d\Omega.$$

F^2 is the form factor of the nucleus. The correction for coherent effects is +30% in the predicted K^0 yield at 3.5°. This correction is insensitive to the details of the coherent process at these energies.

If this peak in the single K_L spectrum comes from φ photoproduction and not from excitation of a high mass Y^*, for example, it will always remain at slightly under half the available photon energy and will have the predicted width of ±20% from the φ decay kinematics. The peak yield of K_L occurs at $\theta\approx0.216m_\varphi/k$, where k is the average photon energy in the difference spectrum. This optimum angle is independent of the φ angular distribution. The yield at this angle is proportional to $B^{1/2}$, while the yield at 3.5° varies more slowly than $B^{1/2}$.

To summarize, we have reported the initial results of a beam survey of photoproduced K_L mesons. Total yields of 1.3×10^{-5} K^0/electron sr for $1.0<p_K<5.5$ GeV/c were obtained with $E_0=5.5$ GeV at 3.5° from a one-radiation-length aluminum target with an extremely clean beam which appears quite free of neutrons.[8] If we associate the peak in our difference spectrum with the decay of photoproduced φ mesons into K_SK_L, we obtain yields which are in agreement with those predicted from previously published DESY bubble-chamber results. If we use the upper limit of 0.46 μb obtained from the subtracted spectrum, it is possible to account for 84% of the yield from the unsubtracted spectrum at $E_0=5.5$ GeV.

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[4] We would like to thank D. Michael of the Cool group for sending us unpublished data on $K^\pm$ absorption cross sections in copper.

[5] S. D. Drell and M. Jacob, Phys. Rev. 138, B1312 (1965).

[6] German Bubble-Chamber Collaboration, reported at the International Conference on Electron and Photon Interactions at High Energies, Stanford, California, 1967 (to be published).

[7] This value of B is consistent with the observed angular distribution of charged K mesons from the φ in the DESY bubble chamber. (See Ref. 1.)

[8] Rough estimates from our data indicate that neutrons are fewer than several times the number of K_L, and there is no positive evidence for neutron background.

DIPS IN THE ω-EXCHANGE CONTRIBUTION TO $\pi N\to\rho N$

A. P. Contogouris and J. Tran Thanh Van
Laboratoire de Physique Théorique et Hautes Energies, Faculté des Sciences, Orsay, France

and

H. J. Lubatti
Laboratoire de l'Accélérateur Linéaire, Faculté des Sciences, Orsay, France

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In this note we consider a specific combination of the differential cross sections for $\pi^\pm p\to\rho^\pm p$ ($d\sigma_\pm/dt$) and $\pi^-p\to\rho^0n$ ($d\sigma_0/dt$) which, at high energy, isolates the contribution of the ω Regge trajectory. Usual Reggeization rules and Mandelstam analyticity requirements predict that this combination should exhibit pronounced dips at $t\simeq-0.5$ (GeV/c)^2 and $t\simeq0$. Analysis of the existing data at pion incident laboratory momentum $p_0=4$ and 8 GeV/c is found to support these predictions.

To begin with, let $T_\pm$ denote the amplitudes for $\pi^\pm p\to\rho^\pm p$ and T_0 the amplitude for $\pi^-p\to\rho^0n$. Then the following relation, due to the existence of only two isospin states ($I=\frac{3}{2},\frac{1}{2}$), is well known:

$$T_0=2^{-1/2}(T_+-T_-). \tag{1}$$

Next, at high energy, consider an analysis of