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EVIDENCE FOR THE PHOTOPRODUCTION OF $Y=0$ STATES WITH MASSES GREATER THAN 1900 MeV*

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This Letter reports evidence for the existence of $Y=0$ states with masses greater than 1900 MeV obtained from studies of the associated photoproduction of K^+ mesons with neutral $Y=0$ hyperons.[1] The experiments were carried out at the Cambridge electron accelerator. The reactions studied were[1]

$$\gamma + p \rightarrow K^+ + Y^*, \qquad (1)$$

in which the production angle and momentum of the K^+ were measured. Identification of the various $Y=0$ states is based on kinematics and presumes that the reactions proceed primarily through the two-body final states denoted by Eq. (1).[2] This method has been used successfully in the past at photon energies to 1.2 BeV.[3] Its applicability to the higher energies of this experiment is discussed below.

The K^+ mesons were photoproduced on a liquid hydrogen target by an external bremsstrahlung beam from the accelerator and detected by a momentum-velocity analysis system consisting of bending magnets, quadrupole lenses, scintillation counters, and two differential gas Cherenkov counters in series. Measurements are reported for a central momentum of 2.63 BeV/c at two laboratory angles: 5°, with maximum bremsstrahlung energies ranging from 4.0 to 6.0 BeV; and 10°, with maximum bremsstrahlung energies from 3.0 to 6.0 BeV. Complete Cherenkov pressure curves were taken at several of these points to ascertain the contribution of the pion tail to the measured K^+ rates. In no case did this pion background exceed 10%. A typical pressure curve is shown in Fig. 1. Experimental details, as well as a complete analysis of all the data, will appear in a later publication. The present Letter is concerned chiefly with the probable existence of the new, high-mass states.

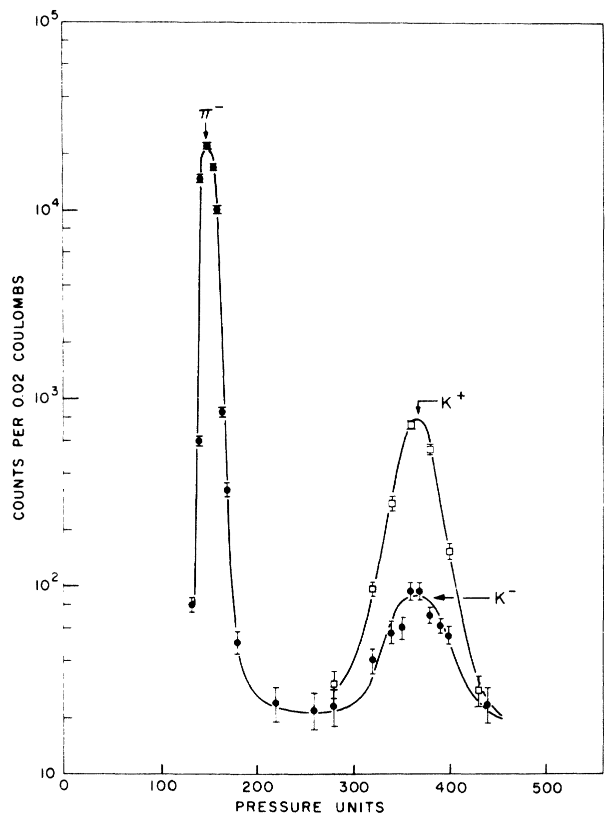

FIG. 1. A representative Cherenkov-counter pressure curve for pions and kaons. Two Cherenkov counters placed along the line of flight of the particles were connected electronically in a coincidence arrangement. The momentum of the particles was 2.63 BeV/c. The difference in widths for the pions and kaons is due to the momentum spread of the particles which was 10%.

Reaction (1) is the simplest Y^* photoproduction process that can be studied experimentally. At the high energies involved in this experiment, it obviously may not be the only mechanism that yields $Y=0$ states. In addition, the measured K^+ rates certainly should contain some contribution from K-pair production. A guide to the relative contributions from reactions with three- or more-body final states can be obtained from the preliminary analysis of the Cambridge bubble chamber photoproduction data for photon energies between 0.5 and 4.8 BeV, and K^+ momenta on the order of 1 BeV/c.[4] This group reports that a majority of their strange-particle–producing events were kinematically consistent with the two-body associated production of a K^+ with a known $Y=0$ state. If this trend continues to momenta around 2.6 BeV/c, one would expect the K^+ yield per equivalent quantum as a function of k_0 to consist of a series of steps (suitably modified by the finite momentum resolution of the detection system and the shape of the bremsstrahlung tip) superimposed upon a rising background. The data presented here are consistent with this view.

Figure 2(a) shows the measured K^+ cross sections per equivalent quantum at 5° and 10° in the laboratory, as a function of peak bremsstrahlung energy, k_0. K^- cross sections are shown on the same figure. These data have been corrected for pion background, decay of the $K^\pm$ in flight, and absorption and scattering effects. An estimate can be made of the contribution to the $K^\pm$ yield by three- (or more-) body production processes involving production of a $K^\pm$ pair, by equating this contribution to the total measured K^- rate. This should include pair production by a variety of mechanisms at these high energies [peripheral, production via $(K\bar{K})$ resonant states, electromagnetic production, etc.], and neglect differences in the final-state interactions for the two charges which could affect the energy and angular distributions. The K^- cross section should also include some contribution from reactions of type (1), in which the Y^* decays to a final state involving a K^-. Since this latter contribution is expected to be appreciable, subtraction of the total K^- from the K^+ yield probably leads to an overestimate of the pair contribution to K^+ production. Figure 2(b) shows these subtracted points. It is interesting to note that after subtraction, the 5° and 10° excitation functions, now attributed principally to two-

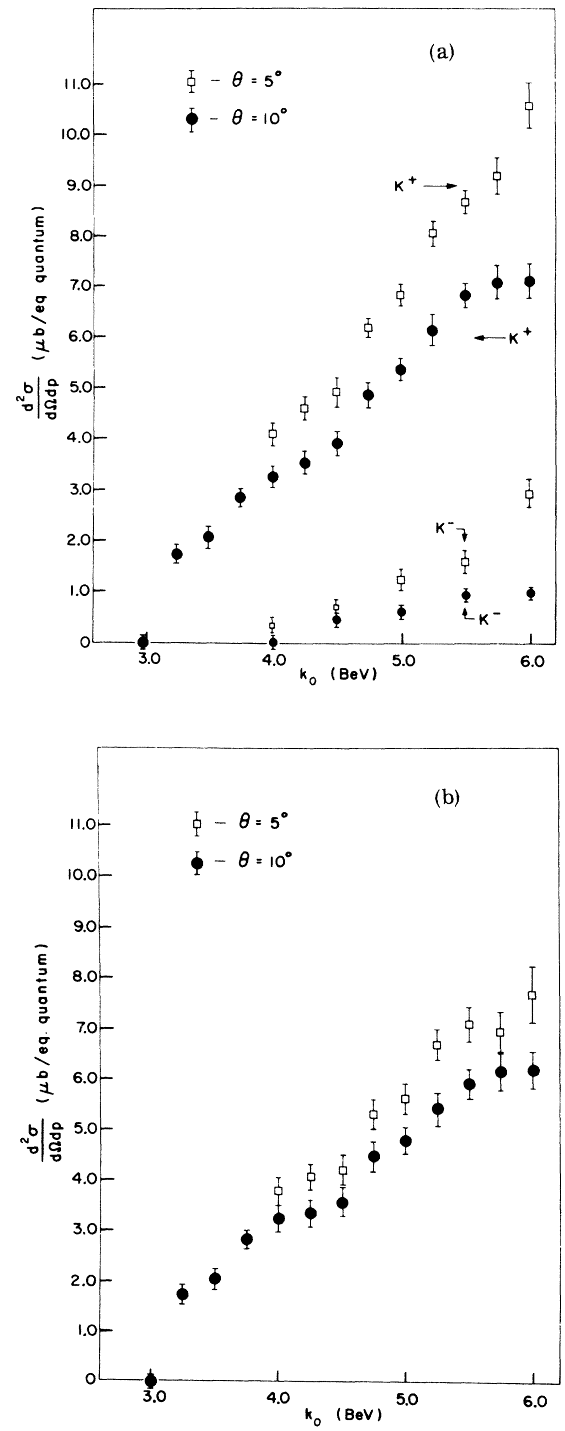

FIG. 2. (a) Measured K^+ and K^- differential cross sections [μb/sr-(BeV/c)-equivalent quantum] as a function of the end-point energy, k_0, of the bremsstrahlung beam, at laboratory angles for the kaons of 5° and 10°, and at a kaon momentum of 2.63 BeV/c. The errors shown are statistical only. (b) Differential K^+ cross sections at $\theta=5°$ and $\theta=10°$ after the measured K^- cross sections have been subtracted.

body production, are more closely similar in shape.

Between 3.0 and 4.5 BeV, two major steps are discernable in these data. With the assumption of a two-body final state, the first appears at a photon energy which would correspond to associated production of Λ^0 and Σ^0 (unresolved in this experiment); the second to the production of $Y^*(1520)$. Possible contributions from the other established $Y=0$ states[1] should all appear at peak bremsstrahlung energies below 4.5 BeV. The continued sharp rise in the cross section above 4.5 BeV suggests either a considerable enhancement in the multibody production cross sections with increasing photon energy, or associated production with higher $Y=0$ states, or both. The flattening in the 10° curves above 5.5 BeV, and in the subtracted 5° curve, favors a major contribution from the latter mechanisms.

The data can be presented in a different form, as in Fig. 3, by making bremsstrahlung subtractions between successive (0.250-BeV intervals) data points. Each bremsstrahlung interval has been converted to a Y^* mass interval by assuming the reaction proceeds only by way of (1). Above 1700 MeV, where the 5° and 10° data overlap, the two yields have been combined. Although the subtraction procedure leads to large statistical uncertainties, the appearance of enhancements in the cross section above 1900 MeV in mass, at both angles at which the data were taken, strongly suggests the existence of $Y=0$ states above 1900 MeV. Further quantitative analysis show that the data are compatible with at least two such states between 1900 and 2400 MeV. A single state has been excluded from consideration for the present because of its unreasonable width. Resolution into more than two states is outside the scope of the available data.

Values for the masses of the new $Y=0$ states were obtained by adopting the following procedure. Assuming the existence of two $Y=0$ states above 1900 MeV, and two-body kinematics, the 5° and 10° data were fitted separately by a least-squares procedure in which the measured masses and widths of the known $Y=0$ states were used, while the masses and widths of the two unknown states and the production cross sections for all states were allowed to vary. For the 10° data all known $Y=0$ states were included, while for the 5° data, which starts at $k_0 = 4$ BeV, only the known $Y^*(1815)$

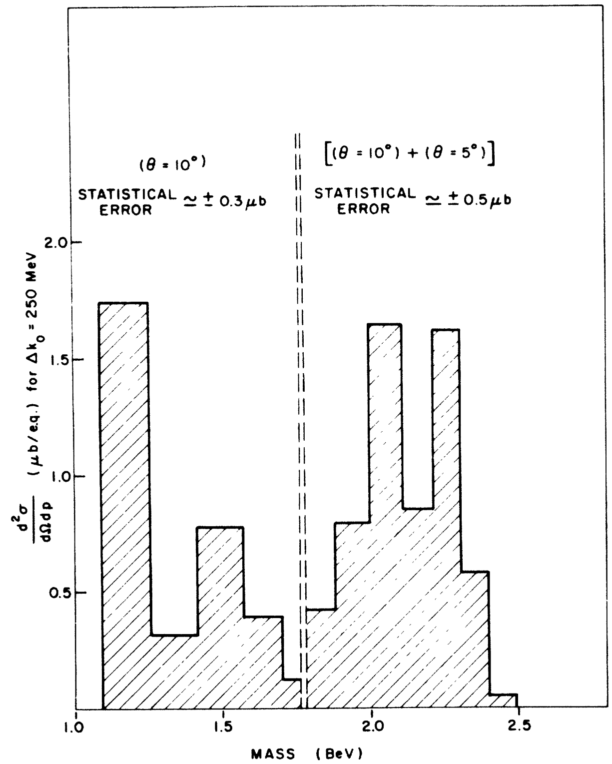

FIG. 3. Differential cross sections [μb/sr-(BeV/c)-equivalent quantum] obtained after making bremsstrahlung subtractions between successive k_0 ($\Delta k_0 = 0.250$ BeV) data points. Each bremsstrahlung interval has been converted to a ($Y=0$) mass interval by assuming that the reaction proceeds only by way of $\gamma + p \rightarrow K^+ + (Y=0)$. The mass interval therefore decreases with photon energy. Above a mass of 1700 MeV where the $\theta = 5°$ and $\theta = 10°$ data overlap they were combined to reduce the statistical error.

state in addition to the two postulated higher states was used in the least-squares fits. A Schiff bremsstrahlung distribution[5] and the measured momentum distribution function of the experimental system were employed in all the calculations.

Although all of the known hyperons were included in the fits, this choice was only arbitrary and not warranted by the statistical accuracy of the data. Since the amount of three- or more-body final-state background is not known, an adequate fit to the data can also be obtained below $k_0 = 4.5$ BeV by considering the dominant contributions of the Λ^0, Σ^0 combination and the $Y^*(1520)$ only, with the addition of a small amount of three-body background. However, the conclusions on the possible existence of new hyperon states are not sensitive to the exact determination of the contributing production processes below $k_0 = 4.5$ BeV, so long as the two-body production mechanism is dominant. The method outlined above was therefore adopted as the fitting procedure. The results are summarized in Table I. For reasons stated above, only the cross sections for the dominant states are statistically meaningful.

The most probable mass values for the two proposed higher mass states obtained by this procedure are $M_1 = 2022 \pm 20$ MeV and $M_2 = 2245 \pm 25$ MeV. The best fits were obtained with widths $\Gamma_1 = 120$ MeV and $\Gamma_2 = 150$ MeV. The uncertainties in the widths are very large, but $\Gamma > 50$ MeV can presently be quoted for both states. It may be noted that the cross sections for these two states are larger than any of the established $Y=0$ states, which may be an indication that more than two states, presently unresolved, are being produced.

The evidence presented here for the existence of new $Y=0$ states relies on having the K^+ mesons photoproduced predominantly in a two-body final-state configuration in association with a $Y=0$ state. As mentioned above, this production mechanism is strongly suggested by the bubble-chamber data[4] at low K^+ momenta, and by these data, at our higher momentum, for the Λ^0 and Σ^0 hyperons. The statistical errors introduced by the bremsstrahlung subtractions make a similar conclusion for the production of the higher mass $Y=0$ states from these data alone uncertain, although for reasons already mentioned, these data favor such a point of view. Further measurements are in progress which will greatly improve the statistical accuracy and the resolution in mass, and extend the search for $Y=0$ states to mass values of 2.9 BeV.

Table I. Differential cross sections for the reaction $\gamma + p \rightarrow K^+ + (Y=0)$ given in μb/sr. Λ^0 and Σ^0 are grouped together, as are $Y^*(1385)$ and $Y^*(1405)$. The momentum of the K^+ meson was 2.63 BeV/c. θ is the laboratory angle of the K^+ mesons.

Y^* (mass in MeV)	$d\sigma/d\Omega$ (μb/sr) $\theta = 5°$	$\theta = 10°$
(1115.4 and 1193.2)		5.4 ± 0.6
(1385 and 1405)		1.4 ± 1.1
1520		3.1 ± 1.0
1660		1.7 ± 1.0
1815	0.9 ± 1.1	1.2 ± 1.7
2022	5.6 ± 1.8	6.5 ± 1.9
2245	9.7 ± 1.9	7.3 ± 1.8

We wish to thank the Cambridge electron accelerator staff for their hospitality and cooperation in the preparation and performance of this experiment. We are also grateful to Mr. Michel Camozzi for his technical assistance with the electronic circuitry.

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[1]Y refers to hypercharge, in accord with the notation of R. H. Dalitz, Ann. Rev. Nucl. Sci. 13, 339 (1963).

[2]If the only contribution to the K^+ cross section is two-body associated production with $Y=0$ states, then the cross section per equivalent quantum plotted as a function of k_0, the end-point energy of an ideal $(1/k)$ bremsstrahlung distribution, would consist of a series of steps at those k_0 corresponding to the production of specific states.

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