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PHOTOPRODUCTION OF $K^+\Lambda$ AND $K^+\Sigma^0$ FROM HYDROGEN FROM 5 TO 16 GeV*

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Cross sections for the reactions $\gamma p \to K^+\Lambda$ and $\gamma p \to K^+\Sigma^0$ have been measured at squared four-momentum transfer $(-t)$ from 0.005 to 2 GeV^2, at photon energies 5, 8, 11, and 16 GeV. For $-t > 0.2$ GeV^2 each of the K^+ cross sections is about $\frac{1}{3}$ of the π^+n photoproduction cross section, having nearly the same energy and momentum-transfer dependence. The K^+ cross sections fall off at small $|t|$, however, in contrast to the sharp forward spike seen in π^+n; this leads to a disagreement with an SU(3) prediction for $-t < 0.1$ GeV^2. The ratio of $K^+\Sigma^0$ to $K^+\Lambda$ cross sections is typically between 0.5 and 1.0.

Cross sections for the reactions $\gamma p \to K^+\Lambda$ and $\gamma p \to K^+\Sigma^0$ were measured simultaneously with $\gamma p \to \pi^+n$ using the Stanford Linear Accelerator Center 20-GeV magnetic spectrometer.[1] This extends work done previously at other laboratories in the few GeV range.[2-5] The experimental apparatus has been described previously.[6]

The measured K^+ yields were corrected for K^+ decay; detection inefficiencies in the shower counter, range hodoscope, and Čerenkov counters; absorption in detectors; dead time and accidental coincidences; and empty-target yields. The errors given in the figures reflect only the counting statistics folded with a 5% error to account for fluctuating systematics. In addition, there is an overall uncertainty in normalization of ±10%.

Cross sections were obtained by measuring K^+ yields produced by photons near the end point of the bremsstrahlung spectrum. For each event, a missing mass was calculated for a photon energy equal to the bremsstrahlung end-point energy. The yield as a function of missing mass then has a step at the Λ mass plus a second step, beginning at the Σ^0 mass. The shape of the steps is a reflection of the bremsstrahlung spectrum[7] and the variation of the cross section with energy, folded with the finite experimental resolution. The resolution was accurately determined from the step in the π^+n reaction measured at the same time; it was typically 0.04 GeV^2 (standard deviation), in units of missing-mass squared, compared with a separation of 0.18 GeV^2 between the Λ and Σ^0 steps. The position of the Λ and Σ^0 steps was computed from the measured position of the π^+n step which agreed with the position expected from the calibration of the beam and spectrometer momenta to better than 0.3%. The cross sections were obtained by least-squares fitting the height of the Λ and Σ^0 steps. To represent background processes a polynomial in missing-mass squared was included beginning at the threshold for $\gamma p \to K^+\Lambda\pi^0$.

The results of the cross-section measurements are given in Figs. 1 and 2. Both K reactions fall exponentially for $-t > 0.5$ GeV^2 approximately as $e^{(3.0\pm 0.2)t}$, similar to the $\gamma p \to \pi^+n$ cross sections. At smaller $|t|$, the K^+ cross sections become flat in t and then decrease as $-t$ goes towards zero, markedly different from π^+n,

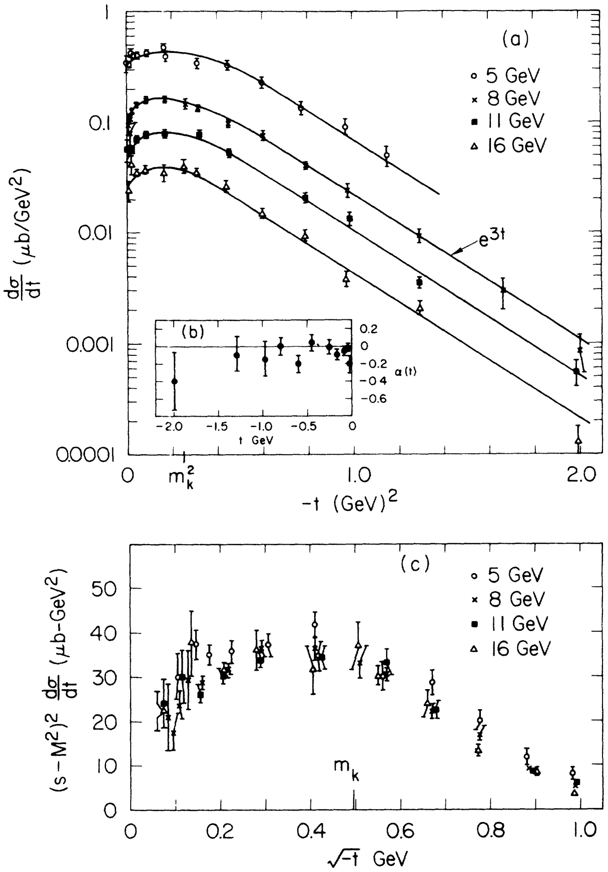

FIG. 1. Results for $\gamma p \rightarrow K^+\Lambda$. (a) $(d\sigma/dt)$ vs t; the curves are drawn by hand to guide the eye. (b) Energy dependence given by $\alpha(t)$ (see text) vs t. (c) $(s-M^2)^2 \times d\sigma/dt$ vs $\sqrt{-t}$ showing the small-$|t|$ behavior of the cross section.

where a sharp spike was seen for $-t<m_\pi^2$.

The energy dependence of the cross section at fixed t is conveniently parametrized by

$$d\sigma/dt=\beta(t)(s-M^2)^{2\alpha(t)-2}, \tag{1}$$

where M is the proton mass, s the square of the c.m.-system energy, and β is a function only of t. The values of α obtained for $\gamma p \rightarrow K^+\Lambda$, using only the cross sections at 8, 11, and 16 GeV, are shown in Fig. 1(b); α remains close to zero and thus defies interpretation as a single dominant Regge trajectory with a normal slope of 1 GeV^{-2}.

The total cross sections for $K^+\Lambda$ and $K^+\Sigma^0$ photoproduction can be approximated by integrating the forward differential cross sections, neglecting the large-$|t|$ regions which presumably contribute a few percent or less. This gives

$$\sigma_{tot}=[(6\pm 1)/k^2]\ \mu\text{b} \tag{2}$$

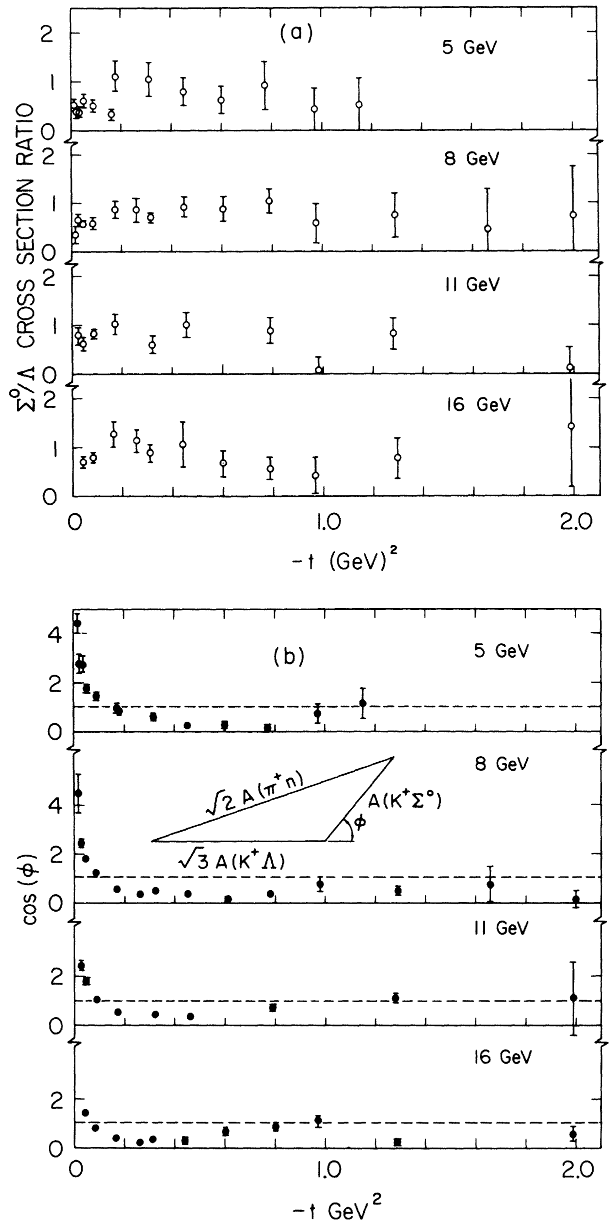

FIG. 2. (a) The ratio $[d\sigma(\gamma p \rightarrow K^+\Sigma^0/dt][d\sigma(\gamma p \rightarrow K^+\Lambda)/dt]^{-1}$ vs t. (b) Cos(φ) vs $-t$ calculated from Eq. (4) assuming the validity of the SU(3) triangle shown. Values of $|\cos\varphi|>1$ demonstrate a violation of the SU(3) prediction.

(k is the lab photon energy in GeV) for each process, the Λ cross section tending to be slightly higher than the Σ^0 cross section. Our Λ cross section ties on well with the values obtained by the DESY bubble-chamber group,[2] Eq. (2) being valid down to $k=1.5$ GeV. The Σ^0 cross section does not tie on well; the bubble-chamber group observed only three events in the range $k=2.0$-

5.8 GeV, a factor of 4 less than expected from Eq. (2).

The forward π^+n data have been fitted by theoretically assuming the pion to conspire at $t=0$ with a trajectory of opposite parity[8,9] as well as by assuming evasive π exchange interfering with other conspiring mechanisms.[10-12] In the case of the K^+ reactions, the smallness of the cross sections at small $|t|$ allows good fits to the data with either evasion or conspiracy for K^+ exchange.[9] Frøyland[13] has fitted the $K^+\Lambda$ cross section with an evasive K^+ trajectory and a conspiring K-P cut.

The $K^+\Sigma^0$ cross section, however, requires an additional trajectory. If K^+ exchange were the only contribution to both $K^+\Lambda$ and $K^+\Sigma^0$ photoproduction, the coupling constants

$$(g_{K\Lambda n}{}^2/4\pi) = 16.0 \pm 2.5,$$

$$(g_{K\Sigma n}{}^2/4\pi) = 0.3 \pm 0.5 \qquad (3)$$

calculated using dispersion relations[14] would give a $\Sigma^0\Lambda$ ratio of less than 0.1 which disagrees with the data. Hence some other exchange must contribute significantly, at least to the $K^+\Sigma^0$ reaction. In order to fit the $\Sigma^0\Lambda$ ratio as well as the $K^+\Lambda$ cross section, Ball, Frazer, and Jacob[8] included an evasive K^* trajectory along with a conspiring K^+ exchange. By varying the amount of K^* exchange, they fit the ratio near $t=-0.3$ and predict a falloff as t goes from -0.05 to zero, due to the vanishing of the K^* exchange at $t=0$. The data are consistent with such a falloff, but do not provide a stringent test.

SU(3) predicts the following relation among photoproduction amplitudes[15]:

$$\sqrt{2}A(\pi^+n) = -\sqrt{3}A(K^+\Lambda) - A(K^+\Sigma^0). \qquad (4)$$

Letting φ be the unknown phase between the $K^+\Lambda$ and $K^+\Sigma^0$ amplitudes, we have the following relation among cross sections:

$$2\frac{d\sigma}{dt}(\pi^+n) = 3\frac{d\sigma}{dt}(K^+\Lambda) + \frac{d\sigma}{dt}(K^+\Sigma^0) + 2\cos\varphi\left[3\frac{d\sigma}{dt}(K^+\Lambda)\frac{d\sigma}{dt}(K^+\Sigma^0)\right]^{1/2}. \qquad (5)$$

Previous photoproduction data[4] between 3.4 and 4 GeV for $0.2 < -t < 0.8$ GeV^2 give values for $|\cos\varphi|$ less than unity. The values of $\cos\varphi$ calculated from our data are shown in Fig. 2(b). The data are consistent with the SU(3) relation Eq. (4) except for small $|t|$, where the violation is simply related to the fact that the K^+ cross sections fall off while the π^+ increases. This violation at small $|t|$ may well be related to the large π-K mass difference.

The ratio of $K^+\Sigma^0$ to $K^+\Lambda$ photoproduction has been predicted using the quark model plus SU(6).[16,17] For baryon spin flip, as required by angular-momentum conservation for photoproduction at zero degrees, $R = [d\sigma(K^+\Sigma^0)/dt][d\sigma(K^+\Lambda)/dt]^{-1} = 1/27$ is predicted, while for arbitrary mixtures of spin flip and spin nonflip, the prediction $R \leq \frac{1}{3}$ is obtained. Neither of these predictions agrees with the data. An SU(6)$_W$ model,[18] however, predicts a ratio in good agreement with the data by including the 405-dimensional representation which is not present in the quark model.

The vector-dominance model can be used to relate $K^+\Lambda$ photoproduction to $K^-p \rightarrow V^0\Lambda$ if one assumes invariance of the amplitude under s-u crossing. In the Regge model this assumption requires that the interference between trajectories of opposite signature be negligible. Davier[19] has discussed this point and compared our 5 GeV with the K^-p data of R. Ammar et al.[20]; he finds that the photoproduction cross section is a factor of 2 or more times that expected from the simple model (a similar discrepancy results for Δ^{++} photoproduction[6]). If one assumes the validity of the vector-dominance model, these results indicate that interference between trajectories of opposite signature is indeed important.

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PHOTOPRODUCTION OF MUON PAIRS AT 7-9 GeV *

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The photoproduction of wide-angle muon pairs from carbon has been measured in order to test the validity of quantum electrodynamics at small distances. The data extend to a muon-pair invariant mass of about 1150 MeV and is consistent with quantum electrodynamics.

It has been noted[1] that if the presently accepted theory of quantum electrodynamics (QED) were to fail, one would expect to see a deviation from the predicted cross section for lepton-pair photoproduction at large angles and for wide-angle bremsstrahlung. Several experiments have looked for a deviation from the well-known Bethe-Heitler formula (BH) with electron pairs,[2] muon pairs,[3] or wide-angle bremsstrahlung.[4] Some of the early results indicated a breakdown of QED, but most of the recent data agree with QED. We report here on the results of a muon-pair photoproduction experiment which extends to a higher invariant pair mass than most of the previous experiments. Our results are consistent with QED.

The process studied was

$$\gamma + \mathrm{C} \to \mathrm{C} + \mu^+ + \mu^-. \qquad (1)$$

The photons were produced by 10-GeV electron bremsstrahlung at the Cornell University Wilson Synchrotron Laboratory. The apparatus is shown in Fig. 1. Muons produced in a 6.55-g/cm^2 carbon target were detected in pairs by hodoscopes H_L and H_R which spanned horizontal production angles from 4.0 to 8.0 deg in eight equal steps. The vertical dimensions of the hodoscopes were twice the horizontal. Each hodoscope consisted of two planes of vertical and two planes of horizontal counters. The front horizontal and vertical planes defined the angular bins while the rear planes, which were somewhat larger, resolved ambiguities due to random coincidences and knock-on electrons. The range in iron of each muon was determined by means of the eight range counters R_L(1-4) and R_R(1-4). Thus, the energy range[5] from 3.38 to 4.68 GeV per muon was covered in three steps. Trigger counters T_L and T_R were used to reduce accidentals. 54 in. of aluminum in front of the hodoscopes served to attenuate the large flux of pion pairs. Iron packs behind the hodoscopes further attenuated to a negligible level those pions which did not decay.

The data were recorded on magnetic tape by a

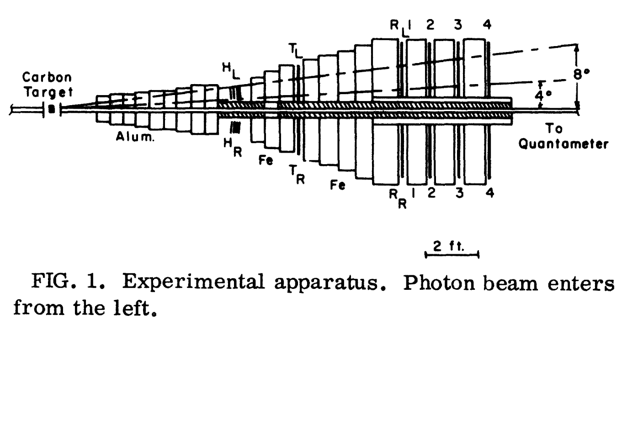

FIG. 1. Experimental apparatus. Photon beam enters from the left.