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Scalar-transverse separation of electroproduced $K^+\Lambda$ and $K^+\Sigma^0$ final states*

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We present evidence for a large scalar contribution to the cross section for the reaction $ep \to eK^+\Lambda$. No evidence for a scalar contribution is found for the reaction $ep \to eK^+\Sigma^0$. This is reminiscent of the results for the π^+n and $\pi^+\Delta^0$ final states.

In two earlier articles on K^+ electroproduction by some of the authors it was conjectured that there was a significant contribution to the $K^+\Lambda$ cross section from scalar virtual photons.[1,2] The evidence for this was the initial increase in $d\sigma/d\Omega_K$ from photoproduction at small values of the virtual-photon mass squared, $-Q^2$. The $K^+\Sigma^0$ final state was also observed in the earlier experiments[1,2] and no evidence was found for a similar scalar contribution to the cross section. In the experiment reported here three of the earlier (W, Q^2) data points were repeated with the photon polarization parameter, ϵ, in the range $0.35<\epsilon<0.50$. This is to be compared with the earlier ϵ range $0.80<\epsilon<0.95$. W is the virtual-photon–target-nucleon center-of-mass energy and the three (W, Q^2) points were (2.15 GeV, 1.2 GeV^2), (2.65, 2.0), and (2.65, 3.3). Data were taken with a hydrogen target for all three points and with a deuterium target for the first two points. Figure 1 shows the electron and hadron magnetic spectrometers that were used to collect the data. A lead-Lucite shower counter and a threshold Freon Čerenkov counter served to identify the electrons. Pions were eliminated by a threshold Freon Čerenkov counter when their momenta were greater than 1.8 GeV. Kaons were separated from pions and protons below 1.8 GeV and from protons above 1.8 GeV by time of flight. Maximum kaon momentum was limited to 4.6 GeV because kaons began to trigger the pion Čerenkov counter. The data have been corrected for random coincidences (~1%), electronics dead time (~5%), target-wall background (~1%), absorption in counters (~5%), and electron misidentification (~1%). Kaon decay losses were simulated in the Monte Carlo acceptance determination of the apparatus.

The two reactions observed in this experiment are

$$e+p \to e+K^+ +\Lambda\,, \tag{1a}$$

$$e+p \to e+K^+ +\Sigma^0\,. \tag{1b}$$

It is usual to treat reactions (1) as the virtual-photoproduction processes

$$\gamma_v + p \to K^+ + \Lambda\,, \tag{2a}$$

$$\gamma_v + p \to K^+ + \Sigma^0\,, \tag{2b}$$

where the virtual photon's mass squared $-Q^2$, energy ν, direction, and polarization parameter ϵ are tagged by detecting the scattered electron. The cross sections for reactions (1) and (2) are related by[3]

$$\frac{d\sigma}{d\Omega_e dE' d\Omega_K} = \Gamma \frac{d\sigma}{d\Omega_K}\,, \tag{3}$$

where Γ is the "flux" of virtual photons. The cross section for reaction (2) can be expressed in the general form

$$\frac{d\sigma}{d\Omega_K} = A + \epsilon C + \epsilon B \cos 2\phi + \left[\frac{\epsilon(\epsilon+1)}{2}\right]^{1/2} D\cos\phi\,. \tag{4}$$

In terms of laboratory variables, ϵ is given by

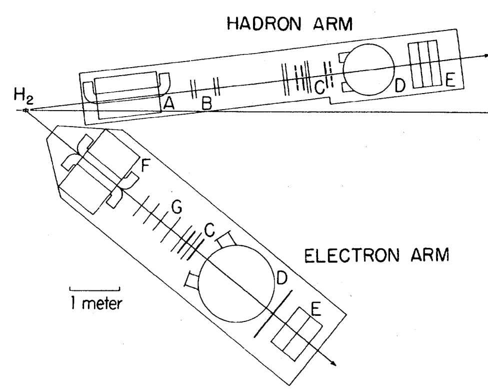

FIG. 1. A schematic view of the apparatus. A and F: bending magnets; B: multiwire proportional counters; C: scintillation counters; D: Freon Čerenkov counters; E: lead-Lucite shower counters; G: wire-spark chambers.

TABLE I. $K^+\Lambda$ results from this experiment and earlier measurements at high ϵ.

θ_K^* bin	W (GeV)	Q^2 (GeV^2)	ϵ	$d\sigma/d\Omega$ (nb)
<15°	2.19	1.18	0.94	269 ± 17
<15°	2.10	1.20	0.47	207 ± 19
<15°	2.66	2.00	0.82	137 ± 13
<15°	2.65	1.98	0.35	109 ± 15
<15°	2.51	3.46	0.85	97 ± 29
<15°	2.61	3.30	0.40	94 ± 36

$$\epsilon = \left[1 + 2\frac{(\nu^2 + Q^2)}{Q^2}\tan^2\theta_e/2\right]^{-1},$$

where θ_e is the angle through which the incident electron is scattered. The virtual-photon–target-nucleon center-of-mass angular spherical coordinates for the detected K^+ are θ^*, the polar angle between the photon and kaon, and ϕ, the azimuthal angle between the electron scattering plane and the photon-kaon plane. A, B, C, and D are the respective contributions from unpolarized transverse photons, scalar photons, the interference between transverse amplitudes, and the interference between transverse and scalar amplitudes. In the results presented here ϕ has been averaged such that only the A and C terms survive. Because we now have data at the same W and Q^2 for two values of ϵ, a separation of the A and C terms can be made.

The extraction of $K^+\Lambda$ and $K^+\Sigma^0$ cross sections from the data was similar to that of the earlier experiments. $d\sigma/d\Omega_K$ was binned in missing-mass squared assuming the reaction

$$\gamma_v + p \rightarrow K^+ + \text{anything}. \tag{5}$$

This spectrum was then fit to the sum of two Gaussians (reflecting the apparatus resolution) folded with a radiative tail. The distance between the two Gaussians was fixed to be the known Λ-Σ^0 mass-squared difference; the mass position of the Λ was not fixed. A fit was made for the Λ mass and the amplitudes of the two peaks. These amplitudes are the radiatively corrected cross sections (4) shown in Tables I and II for $\theta_K^* < 15°$ along with the earlier results. To increase the Λ statistics from a proton target we have combined our hydrogen and deuterium data (low-ϵ data only). The Σ^0 results are from a hydrogen target only.

TABLE II. $K^+\Sigma^0$ results from this experiment and earlier measurements at high ϵ.

θ_K^* bin	W (GeV)	Q^2 (GeV^2)	ϵ	$d\sigma/d\Omega$ (nb)
<15°	2.19	1.18	0.94	40 ± 11
<15°	2.10	1.20	0.47	43 ± 18
<15°	2.66	2.00	0.82	6 ± 6
<15°	2.66	2.00	0.34	15 ± 11
<15°	2.51	3.46	0.85	5 ± 8
<15°	2.61	3.30	0.40	17 ± 23

TABLE III. Separation results for $K^+\Lambda$ final state.

θ_K^* bin	W (GeV)	Q^2 (GeV^2)	ϵ_1	ϵ_2	$\frac{A+\epsilon_1 C}{A+\epsilon_2 C}$	$\frac{C}{A}$
<15°	2.14	1.19	0.94	0.47	1.34 ± 0.15	$1.10^{+0.94}_{-0.60}$
<15°	2.65	1.99	0.82	0.35	1.28 ± 0.15	$0.75^{+0.60}_{-0.44}$
<15°	2.56	3.38	0.85	0.40	1.02 ± 0.50	$0.05^{+2.10}_{-0.80}$

Tables III and IV show the separation results for A and C in terms of their ratio $R = C/A$. The low- and high-ϵ results have been corrected to their average W, Q^2 values according to the functions[1]

$$\frac{p_K^{\mathrm{c.m.}}}{W(W^2 - M^2)}\frac{1}{(Q^2 + 2.67)^2} \tag{6a}$$

and Λ's and

$$\frac{p_K^{\mathrm{c.m.}}}{W(W^2 - M^2)}\frac{1}{(Q^2 + 0.79)^2} \tag{6b}$$

for Σ^0's. This correction was at most 2% for any cross section.

Before discussing the results for R we must consider the effects of the relative systematic uncertainties of the two sets of data. The overall systematic error in this experiment is estimated to be at the most ±7%. Both spectrometers were checked with elastic-electron scattering and the mean ratios of the measured elastic scattering cross sections to the average of the world data for the electron and hadron arms were 0.972 ± 0.010 and 0.993 ± 0.004, respectively. The estimated systematic error in the high-ϵ data with which these data were combined to separate the scalar and transverse terms is ±7%. The spectrometers used in the earlier experiments were also checked with elastic-electron scattering measurements.

TABLE IV. Separation results for $K^+\Sigma^0$ final state.

θ_K^* bin	W (GeV)	Q^2 (GeV^2)	ϵ_1	ϵ_2	$\frac{A+\epsilon_1 C}{A+\epsilon_2 C}$	$\frac{C}{A}$
<15°	2.14	1.19	0.94	0.47	0.93 ± 0.47	$-0.14^{+1.56}_{-0.61}$
<15°	2.66	2.00	0.82	0.34	0.40 ± 0.50	$-0.88^{+0.69}_{-0.41}$
<15°	2.56	3.38	0.85	0.40	0.30 ± 0.64	$-0.96^{+0.83}_{-0.40}$

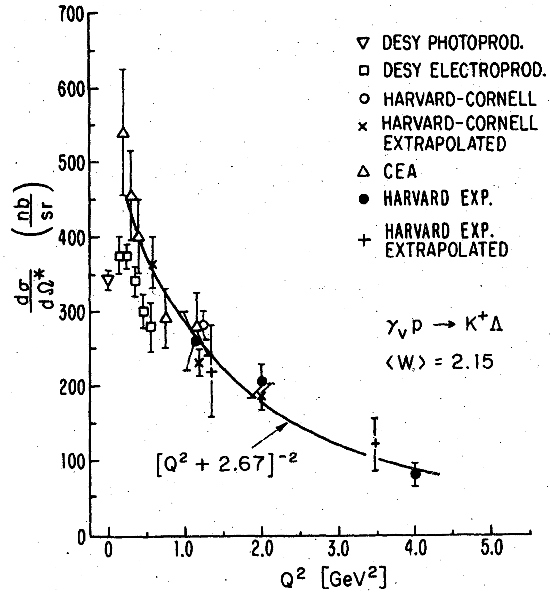

FIG. 2. The Q^2 dependence of the $K^+\Lambda$ cross section reproduced from Ref. 2. The data for the CEA (Ref. 1), Harvard-Cornell (Ref. 4), and Harvard (Ref. 2) electroproduction measurements are for $\theta^* < 15°$. The DESY electroproduction data (Ref. 5) are for $\theta^* < 25°$ and the DESY photoproduction data (Ref. 6) are for $\theta^* = 25°$. The solid curve is a dipole fit to the data with $\theta^* < 15°$.

The mean ratios of the measured elastic scattering cross sections to the average of the world data for the electron and hadron arms were 0.994 ± 0.009 and 0.998 ± 0.009, respectively. The same Faraday cup was used in both experiments. The radiative corrections in the two experiments were nearly the same and the error in the cross section due to the uncertainty in the correction is estimated to be less than 2%. Since the spectrometer systems were quite similar and the procedures for the data analysis were almost identical, the systematic errors are correlated. It is estimated that the overall systematic uncertainty in A and C is ±7% and that the additional error in the ratio R due to the uncorrelated portion of the systematic error is ±3%.

Table III shows that R is consistent with there being a sizable contribution to the $K^+\Lambda$ cross section from scalar photons. This is also consistent with the initial rise in the cross section at low Q^2 as seen in Fig. 2, which is reproduced from Ref. 2. Also shown in Fig. 2 are data from the other reported measurements of kaon electroproduction[1,2,4,5] and one measurement of kaon photoproduction.[6] Table IV shows the results for R for the $K^+\Sigma^0$ cross section. In contrast to the $K^+\Lambda$ cross section, there is no evidence for a longitudinal contribution to the $K^+\Sigma^0$ cross section. This is consistent with the observed monotonic decrease in the cross section seen in Ref. 1 for $Q^2 = 0$ to $Q^2 = 4$ GeV^2. The analogy of the two low-lying K^+ final states with the two low-lying π^+ states, $\pi^+ n$ and $\pi^+\Delta^0$ is striking. In the $\pi^+ n$ case, the lower of the two resonances, there is a substantial scalar contribution[7] while for the higher resonance, $\pi^+\Delta^0$, there is no evidence for any scalar contribution.[8]

In conclusion, by a direct separation of scalar and transverse cross sections, evidence has been obtained for a significant contribution to the $K^+\Lambda$ electroproduction cross sections due to scalar photons similar to that found for the $\pi^+ n$ final state. The $K^+\Sigma^0$ final state, like the $\pi^+\Delta^0$, does not show evidence for a scalar contribution.

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