Inclusive K_S^0 and Λ Electroproduction

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Cross sections for inclusive electroproduction of K_s^0's and Λ's have been measured. The K_s^0 results are combined with data from electron-positron annihilation and charged K electroproduction to give information on quark fragmentation into strange particles. The longitudinal- and transverse-momentum distributions for Λ's are compared with those of electroproduced protons.

Deep-inelastic electron-proton scattering is commonly interpreted as the scattering of virtual photons of mass $-Q^2$ and energy ν from the constituents of the proton, the quarks. Within this context, the forward-going hadrons are viewed as the fragments of the quark struck by the virtual photon. This approach has been successful in relating the pion yields in electroproduction with those in neutrino scattering and electron-positron annihilation.[1,2] Tests of the quark fragmentation picture down to and even below, the Q^2 and ν ranges of this experiment have been surprisingly successful.[1-3] Measurements of the electroproduction of K_s^0's can add considerably to our knowledge. In particular, when they are combined with other kaon production data, information can be obtained about the breaking of SU(3) in the formation of new quark-antiquark pairs.

The pictures which have been developed for the target fragments, hadrons from the remaining two-quark system, have been less specific. Measurements of proton and Λ electroproduction give information about these fragments, and together they allow study of systematic trends.

In this Letter we report the first measurements of Λ and K_s^0 electroproduction. The experiment was performed in an 11.5-GeV electron beam at the Wilson Synchrotron Laboratory at Cornell University. The beam was incident on a 9-cm-long by 1.5-cm-diam liquid hydrogen target located inside a streamer chamber which provided charged-particle detection over nearly the full 4π solid angle. The chamber had a sensitive volume of $100\times60\times45$ cm^3 and was placed in a homogeneous magnetic field of 1.65 T. Scattered electrons above 2.5 GeV in momentum were detected and identified with shower counters (14 radiation lengths) and counter hodoscopes placed behind the streamer chamber on both sides of the beam (Fig. 1). The electron detection and identification efficiency rose from approximately 70% at 2.5 GeV to 85% above 5 GeV. Events triggered by a π^- which appeared to be an electron constituted approximately 5% of the data at 2.5 GeV and less than 1% at greater than 4 GeV. Proportional chambers in the trigger arms were used to improve the momentum and angular resolutions of the scattered electron and forward hadrons.

A total of 130 000 inelastic-electron-scattering events were observed in the kinematic region $0.5 < Q^2 < 6$ GeV^2 and center-of-mass energy, W, up

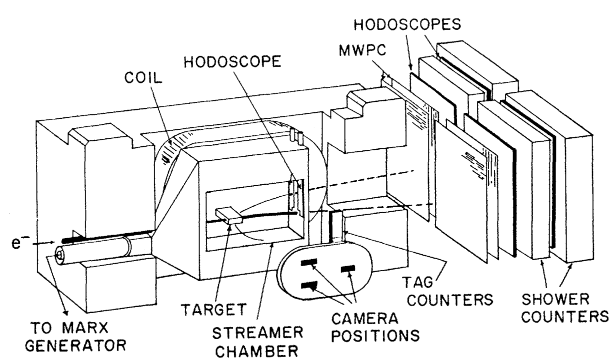

FIG. 1. The experimental apparatus. The event trigger was a coincidence between the hodoscopes and shower counters in one of the trigger arms. The TAG counters vetoed events produced by the electron radiating a high-energy γ ray in the target.

to 4.2 GeV. Events were measured either manually or with a flying-spot digitizer and reconstructed using the CERN bubble chamber program THRESH. The results in this Letter come from 60% of the total data sample, most of which was scanned in a special scan in which events with a neutral V were selected. The electron acceptance of this special scan and the random scanning efficiency for events with neutral V's (0.80 ± 0.04) were determined using several independent scans. The total inelastic-electron-scattering cross section determined from our data agees with that measured in single-arm experiments.[4]

The major sources of neutral V's in our experiment were Λ and K_s^0 decays and photon conversion. Any neutral V with an invariant mass of less than 90 MeV when the prongs were assumed to be an electron and positron was considered a photon. Study of the data showed that $(7\pm1)\%$ of the Λ's and $(2\pm1)\%$ of the K_s^0's were lost due to misidentification as photons.

Once the photons were eliminated, Λ's and K_s^0's were identified on the basis of the invariant masses of the decay products. Approximately 35% of the Λ's were ambiguous with K_s^0's. Phase-space calculations showed that such ambiguities are much more probable for true Λ's than for true K_s^0's. This was verified experimentally by assigning $\bar{p}$ and π^+ masses to the decay products of possible K_s^0's. If we assume $\bar{\Lambda}$ production to be negligible, the number of such decays identified as $\bar{\Lambda}$'s measures the number of K_s^0's also identified as Λ's. This number was found to be small, and consequently all of the ambiguous events were identified as Λ's. This procedure leads to a 3% contamination of the Λ sample with K_s^0's and a $(6\pm2)\%$ loss of K_s^0's.

The largest single correction to the data was for undetected decays. Decays occurring in the target or its surrounding vacuum vessel, or in the beam tube downstream of the target, were not observed. In addition, the region close to the target was often obscured by δ electrons. Using the measured positions of the interaction and decay vertices, the probability of a decay in the obscured region was calculated, and events were weighted according to this probability. The resultant correction, typically a factor of 3, was momentum dependent.

Additional small corrections, $(7\pm3)\%$, were made for losses in the data reduction chain, and the cross sections were also corrected for decay modes into neutral particles. We estimate the overall uncertainty in our normalization to be $\pm15\%$, this error being mainly systematic.

In Fig. 2(a) we present $(1/\sigma)d\sigma/dz$ [$z=E(K_s^0)/\nu$] for K_s^0 electroproduction. The mean values of Q^2, W, and x ($=Q^2/2M\nu$) are 1.45 GeV^2, 3.15 GeV, and 0.14, respectively. For comparison we show the data of Burmester *et al.*[5] and Lüth *et al.*[6] for K_s^0 production in electron-positron annihilation. The results of Ref. 6 include data above the charm threshold, while the data of Ref. 5 are below this threshold. The large difference between the electroproduction and annihilation cross sections is unexpected in the quark fragmenation model if current parametrizations of the fragmenation functions are used.[7,8] For example, using the Field and Feynman[7] fragmentation functions to calculate the integral of $(1/\sigma)d\sigma/dz$ for $z>0.3$ gives 0.11 for annihilation and 0.046 for electroproduction. The measurements give 0.081 ± 0.019[5] and 0.013 ± 0.002, respectively.

To explain both our results and the storage ring data, the fragmentation of u quarks into K_s^0's must be much less probable than the fragmentation of s quarks into K_s^0's. There are six independent fragmentation functions for quarks into K mesons[7]; however, K_s^0 production in both annihilation and electron scattering depends on only three combinations of these six functions. These combinations, which by convention are defined for charged-K production,[7] are $K_d=D_u^{K^0}+D_u^{\bar{K}^0}$ ($=D_d^{K^+}+D_d^{K^-}$), $K_u=D_d^{K^0}+D_d^{\bar{K}^0}$, and $K_s=D_s^{K^0}+D_s^{\bar{K}^0}$, where we denote the fragmentation func-

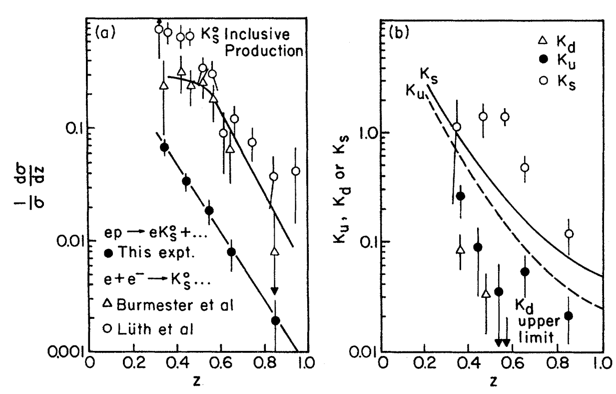

FIG. 2. (a) Comparison of the z distributions of K_s^0's produced in electron scattering and electron-positron annihilation. The Burmester *et al.* data are at a center-of-mass energy, $\sqrt{s}$, of 3.6 GeV, and the Lüth *et al.* data cover a range in $\sqrt{s}$ of 3.4 to 4.0 GeV. The electron scattering data are for $Q^2>0.5$ GeV^2 and $\nu>3.5$ GeV. The lines show the results of the fragmentation function calculation. (b) Quark fragmentation functions for K^0 and $\bar{K}^0$ determined in this work compared with those of Field and Feynman shown by the curves.

tion for quark q to fragment into hadron h as D_q^h. These three combinations are also sufficient to describe the sum of K^+ plus K^- production in annihilation and in electron scattering. We have combined our data with annihilation data[5,6,9] and charged-K electroproduction data[10] to calculate K-meson fragmentation functions.[11] The results are shown in Fig. 2(b) where they are compared with the Field and Feynman functions. The ratio of K_u to $D_d^{\pi^+} + D_d^{\pi^-}$ is a measure of the probability of producing an $s\bar{s}$ pair versus a $u\bar{u}$ pair in the quark jet cascade. Using the results of the calculation described above, we find this ratio to be 0.13 ± 0.03 for $z > 0.3$, indicating considerably stronger SU(3) breaking than expected.[7]

The transverse-momentum distribution for electroproduced K_s^0's (Fig. 3) is similar to that for other electroproduced hadrons.[12] It is exponential in $P_\perp^2$ with a slope corresponding to an average transverse momentum of 0.43 ± 0.03 GeV. The z dependence of the average transverse momentum (Fig. 3) is consistent with that observed for charged hadrons.[12]

In Fig. 4 we present the longitudinal- and transverse-momentum distributions for Λ electroproduction. The quantities plotted are the integrals of the invariant structure function

$$F(x_F, P_\perp^2) = \frac{E^*}{P_{max}^*} \frac{1}{\pi\sigma} \frac{d^2\sigma}{dx_F dP_\perp^2},$$

wbere the asterisk denotes center-of-mass quantities and $x_F = P_\parallel^*/P_{max}^*$. As expected, most Λ's are produced in the target fragmentation region.

Figure 4(a) shows that the Λ structure function is qualitatively similar to the proton electroproduction structure function[13]; some of the discrepancy at negative x_F can be attributed to uncertainties in the proton data.

In the quark fragmentation picture, the quark struck by the virtual photon fragments into hadrons by producing quark-antiquark pairs from the vacuum. One end of this quark-antiquark chain combines with the two-quark system left behind in the original interaction, thus producing the final-state baryon. In our x range it is a reasonable approximation that the two-quark system is either a ud or a uu pair. By considering the branching ratios of the low-mass baryons which could be formed when such pairs combine with a u, d, or s quark, we estimate that the ratio of the probabilities of combining with an s versus a u quark is 1.5 ± 0.2 times the Λ-to-proton ratio. The result for the ratio of probabilities is 0.15 ± 0.03, consistent with the SU(3) breaking deduced from the meson fragmentation functions.

The transverse-momentum distribution for electroproduced Λ's is exponential in $P_\perp^2$ with a slope of 4.2 ± 0.3 GeV^{-2}. This slope is in good agreement with the measured slope for electroproduced protons,[14] and we see no variation with Q^2 or x_F. We conclude that the momentum distributions of the final-state baryon are not strongly affected by changing it from a proton to a Λ.

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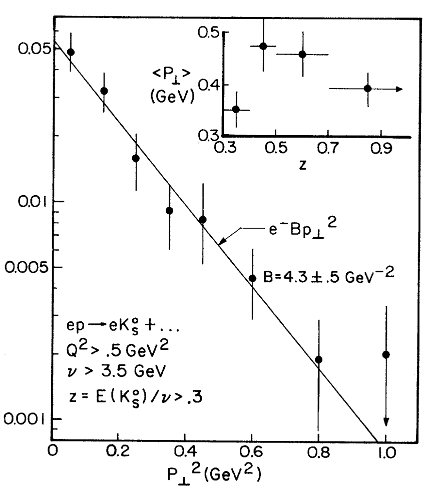

FIG. 3. Transverse-momentum dependence for electroproduced K_s^0's. The inset shows the average transverse momentum vs z.

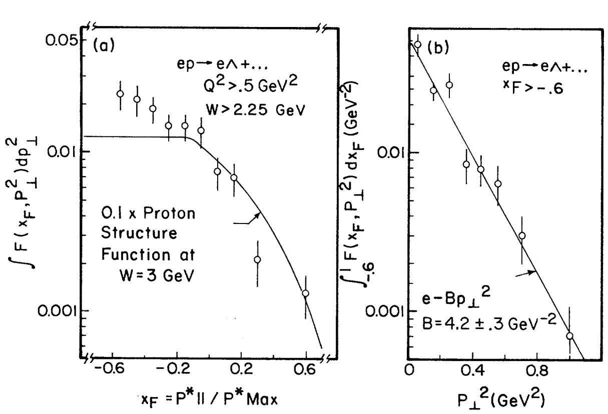

FIG. 4. Momentum distributions for Λ electroproduction. (a) x_F distribution. The data are compared with a smoothed representation of the proton structure function (Ref. 13). (b) Transverse-momentum distribution.

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Yang's Parity Test for the New Spin-0 Mesons

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Yang's parity test for general spin-0 mesons applied to the decay sequence $X\to\varphi\varphi\to(K^+K^-)(K^+K^-)$ leads to maximal parity signature. The correlation function for the azimuthal angle between the two $\varphi\to K^+K^-$ decay planes is given by $1+\beta\cos2\varphi$, where $\beta=-1$ for pseudoscalar X, and $1\geqslant\beta\geqslant0$ for scalar X.

The state $X(2.85)$ first seen at DORIS[1] may, at last, also have been observed in a hadronic π^-p reaction.[2] The properties of the X state remain to this day a mystery. The observed decay into 2γ rules out a spin-1 assignment[3] for the X. The allowed spin-0 assignment leaves open the issue of a scalar versus a pseudoscalar nature under parity.

By obvious analogy with the π^0,[4] it might seem that, short of an actual observation of X into $\pi^+\pi^-$ or K^+K^-, a definitive test of its parity must await a study of its internal conversion into Dalitz pairs.[5] However, we have found, much to our pleasant surprise, that Yang's parity test,[4] when applied to the decay sequence

$$X\to2\text{ (vector mesons)}\to2\text{ (boson pairs)},$$

unlike the case with fermion pairs, leads to maximal parity signatures. If $X\to\varphi\varphi$ decay exists, then the correlation function for the azimuthal angle between the two $\varphi\to K^+K^-$ decay planes is given by

$$1+\beta\cos2\phi, \tag{1}$$

with

$$\beta=-1\text{ for pseudoscalar }X \tag{2}$$

and

$$1\geqslant\beta\geqslant0\text{ for scalar }X, \tag{3}$$

in the boson case. For comparison, the result for the sequence $X\to\varphi\varphi\to2(e\bar{e})$ is[6]

$$\beta=-0.25\text{ for pseudoscalar }X \tag{4}$$

and

$$0.25\geqslant\beta\geqslant0\text{ for scalar }X, \tag{5}$$

in the fermion case. A signature as maximal as that given by Eq. (2) should help considerably toward confirming the belief among some that X is