Inclusive K^+ and K^- Electroproduction

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In inclusive electroproduction, the production ratios of kaons to pions for both charge signs, and of K^+ to K^-, have been measured in the positive-x_F region. The K/π data for a deuterium target display behavior similar to that for a hydrogen target. The K^+/π^+ ratio shows a general rise and the K^-/π^- ratio shows a decrease as x_F increases. For high x_F, K^+/π^+ increases with p_T^2 while K^-/π^- stays flat. The K^+/K^- ratio shows a dramatic rise as x_F increases.

Comparisons of data on the inclusive electroproduction of pions from nucleons with predictions from the quark-parton model have shown striking agreement.[1-6] Some theoretical studies have gone beyond electroproduction of pions and make definite predictions about K/π ratios.[1,6,7] Most of these studies refer to the region where x_F, the longitudinal center-of-mass variable, is positive and valence quarks are expected to dominate. The relative production of K and π mesons is dependent upon specific quark-fragmentation hypotheses, and assumptions about vector-meson production, but it is expected that as x_F is increased, the relative production of K^- will drop and the value of K^+/π^+ will rise to values near 0.5 as seen in high p_T inclusive hadron-hadron interactions. This is due to the prediction that there are no direct fragmentation channels of valence quarks in nucleons into K^- mesons, and the channels that do exist tend to contribute other mesons as well, thereby lowering the likelihood of the K^- occurring at large x_F. To test these ideas it is necessary to measure the relative production of π^+, π^-, K^+, and K^- as a function of x_F.

The results presented here represent the highest energy at which inclusive K^+ data have been reported, and are the only data on inclusive K^- leptoproduction collected to date. This experiment has a further asset in that data on all hadronic types were collected simultaneously with the same equipment.

Although previous reports[8,9] have discussed the apparatus and analysis procedures, a brief summary of the major features of the experiment is useful. A 20.5-GeV electron beam from the Stanford Linear Accelerator Center entered a thin target of either liquid hydrogen or deuterium followed by a magnetic spectrometer designed to have high efficiency for the scattered electron and high momentum, forward-going hadrons produced in a deep inelastic scattering event. The spectrometer employed multiwire proportional chambers, scintillation counters, and lead-scintillator shower counters to detect scattered electrons and produced charged hadrons. A threshold-type Cherenkov counter allowed identification of the final-state hadrons over about 10% of the 60-msr solid angle covered by the detector.

In the analysis, each electron-hadron combination was treated as a separate event. Each event was described by five variables. Two of the variables, Q^2 and s, depend on the scattered electron only and refer to the absolute value of the square of the transverse momentum of the virtual photon and the energy squared of the virtual-photon–nucleon system, respectively. The other three variables are for the hadron in the center of mass. They are x_F, the longitudinal Feynman variable equal to the longitudinal momentum divided by the maximum momentum:

$$x_F = p_l/p_{max}$$

with

$$p_{max} \equiv \tfrac{1}{2}\sqrt{s};$$

p_T^2, the square of the momentum transverse to the virtual-photon direction; and φ, the azimuthal angle of the produced hadron about an axis collinear with the virtual photon. We have integrated over φ ($0-2\pi$) prior to calculating ratios. The range of Q^2 is from 0.5 to 5.0 $(\mathrm{GeV}/c)^2$ with an average of 1.1 $(\mathrm{GeV}/c)^2$, the range of s is from 15 to 31 GeV^2 with an average of 21 GeV^2, and the range of p_T^2 is from 0.0 to 1.0 $(\mathrm{GeV}/c)^2$, with an average of 0.25 $(\mathrm{GeV}/c)^2$.

All results reported here are in the form of K/π or K^+/K^- ratios, and the relative geometrical efficiencies for K^+, K^-, π^+, and π^- are identical except for a factor corresponding to the decay in flight of the kaons. The systematic errors are a small contribution to our total errors.

The Cherenkov counter was operated at four different pressures to provide sensitivity to pions only, pions and kaons, or pions, kaons, and protons over the laboratory momentum range 1.5–14 GeV/c. Two ratios were calculable directly: the fraction of all hadrons which were kaons or protons $[(K+p)/h]$, and the fraction of all hadrons which were protons (p/h). These ratios yielded the K to π ratio:

$$K/h=[(K+p)/h-p/h]F_{\mathrm{decay}},$$

$$\pi/h=1-(K+p)/h,$$

$$\frac{K}{\pi}=\frac{K/h}{\pi/h}.$$

F_{decay} expresses the momentum-dependent correction for the loss of kaons due to their decay in flight and varied from 1.10 to 1.35. There were two additional corrections to π/h and p/h due to (a) a small inefficiency (1.0%) for particles which should have triggered the Cherenkov counter but did not; and (b) a larger effect (3%–25%) producing a spurious signal in the Cherenkov counter when no signal should have been present. Notice that since we have divided kaons by pions, the effects of limited geometrical acceptance are canceled out. Furthermore, since we have at all Q^2 and s, some acceptance at all x_F or p_T^2 values presented, the behavior of the K/π ratio as a function of x_F or p_T^2 is independent of its behavior as a function of Q^2 or s.

Figure 1 shows the ratio K/π versus x_F for both charge signs, and both targets. There are no significant differences between hydrogen and deuterium. Note that as x_F increases, the K^+/π^+ ratios become larger, while the K^-/π^- ratios get smaller. The exception to this is the data at $x_F=0.92$, covering the x_F range from 0.85 to 1.0, where the K/π ratios drop suddenly. This is not unexpected for two reasons. First, this bin includes any diffractive production, which may differ for pions and kaons. Second, we have analyzed all events using the same definition of $p_{\max}$. However, a definition of $p_{\max}$ for kaons which included the effect of the kaon mass and the production of other strange particles would increase the K/π ratios measured in this bin. Such a definition would be model dependent, however, and would be a large effect only for the highest-x_F bin.

The data on K^+ production reported by Bebek *et al.*[10,11] were taken at lower values of s (<9.6 GeV^2) than the data in this paper ($s>15$ GeV^2). Nevertheless, the ratio K^+/π^+ reported there for the highest-s points is compatible with Fig. 1.

Since the high-x_F region is the most interesting, Fig. 2 shows K/π versus p_T^2 for x_F integrated from 0.4 to 1.0. In this plot, data from hydrogen and deuterium have been combined. Here the K^+/π^+ ratio strongly suggests a rise to a value near 0.5, while the K^-/π^- ratio appears to remain flat. Eventually, the quark-parton model should be

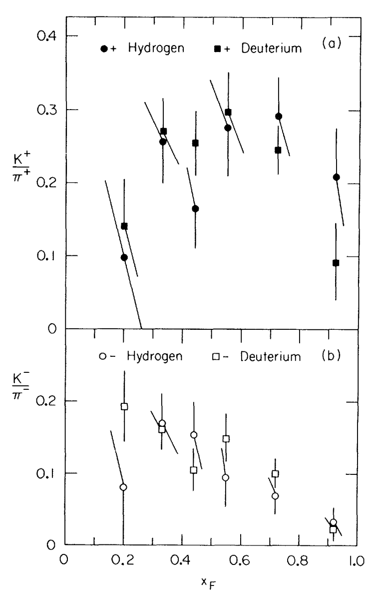

FIG. 1. (a) The ratio of K^+/π^+ for hydrogen (circles) and deuterium (squares) targets as a function of x_F. (b) The ratio of K^-/π^- for the same targets.

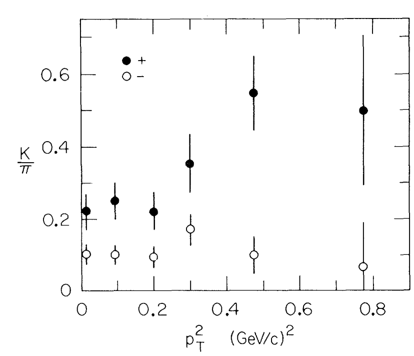

FIG. 2. The ratio of K^+/π^+ and K^-/π^- as a function of p_T^2 for data integrated from 0.4 to 1.0 in x_F. Data from hydrogen and deuterium have been combined.

meson electroproduction. We know of no such predictions but include Fig. 2 in hopes of stimulating some.

None of the models include any contribution from the quasielastic production of vector mesons such as the ρ or φ. In the s and Q^2 range discussed here, these resonances are less important than at lower s and Q^2. In fact, the contribution to the inclusive kaons here from φ production and decay is negligible. However, the ρ does contribute a significant fraction to the pion signal measured in this experiment. The K/π and p/π ratios reported in Ref. 9 were modified for the estimated contribution from ρ production and decay. The ratios reported here have not been corrected for this effect, but the fractional contribution due to the ρ rises from a few percent at $x_F = 0.1$ to approximately 50% at $x_F = 0.9$. If this contribution were subtracted from the π signal before calculating ratios, K^+/π^+ would rise more as a function of x_F while K^-/π^- would become nearly flat. For Fig. 2, the contribution from ρ is limited to p_T^2 less than 0.3 $(\mathrm{GeV}/c)^2$ for x_F greater than 0.4 and if subtracted, would cause the K^+/π^+ to become relatively flat, while K^-/π^- would show able to correctly predict the p_T^2 dependence of a definite decrease as p_T^2 increases.

The ρ subtraction is controversial; furthermore, in quark-model predictions some assumptions have to be made about quark fragmentation into mesons of different strangeness in order to predict K/π. The K^+/K^- ratio is free of these objections, and is shown in Fig. 3 versus x_F. The point at largest x_F has very large error bars, but this ratio is clearly rising as x_F increases. There is a contribution to this rise from kinematics: As x_F approaches 1, it becomes more difficult to produce K^- since it must be created with an antibaryon or low-x_F K^+. This is a large effect only in the highest-x_F bin. It is significant that the results on K^+/K^- reported in a photoproduction experiment[12] at similar s and p_T^2 rise much less than the data shown in Fig. 3 which indicates that the behavior seen in Fig. 3 is not primarily of kinematic origin. Furthermore, when our data for K^+ and K^- are integrated over x_F from 0.4 to 1.0 and analyzed as a function of s, the K^+/K^- ratio is flat to within 30%.

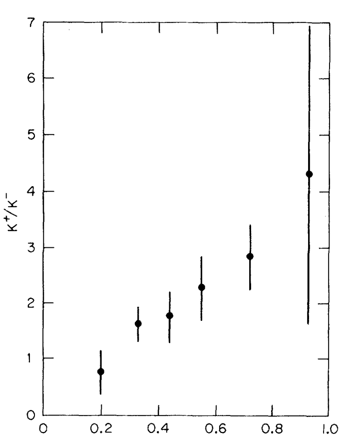

FIG. 3. The ratio of K^+/K^- as a function of x_F. Data from hydrogen and deuterium have been combined.

The only detailed prediction of K/π ratios for electroproduction is that of Seiden[6]; K^+/π^+ is expected to be 0.33 and K^-/π^- is expected to be 0.21 for the x_F range from 0.4 to 0.9. Averaging over both targets for x_F from 0.4 to 0.85, we find the K^+/π^+ ratio to be 0.255 ± 0.020, and the K^-/π^- ratio to be 0.113 ± 0.013. These values are in qualitative agreement; furthermore, this quantitative disagreement should not be interpreted as evidence that the quark-parton model is not capable of correctly predicting these ratios since the prediction was based on u-quark fragmentation only. Fragmentation of the d quark and of quarks in the sea can easily lead to additional π and K mesons which need to be included in any complete calculation.

We conclude that the behavior of the inclusive electroproduction ratios of K/π and K^+/K^- are qualitatively in keeping with the expectations of the quark-parton model.

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