

INCLUSIVE  
 $K^+$  AND  $K^-$  ELECTROPRODUCTION\*

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ABSTRACT

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  $K/\pi$  data for a deuterium target display behavior similar to that for a hydrogen target. The  $K^+/\pi^+$  ratio shows a general rise and the  $K^-/\pi^-$  ratio shows a decrease as  $x_F$  increases. For high  $x_F$ ,  $K^+/\pi^+$  increases with  $p_T^2$  while  $K^-/\pi^-$  stays flat. The  $K^+/K^-$  ratio shows a dramatic rise as  $x_F$  increases.

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Comparisons of data on the inclusive electroproduction of pions from nucleons with predictions from the quark-parton model have shown striking agreement<sup>1-6</sup>. Some theoretical studies have gone beyond electroproduction of pions and make definite predictions about  $K/\pi$  ratios<sup>1,6,7</sup>. 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  $\pi$  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  $K^+/\pi^+$  will rise to values near 0.5 as seen in high  $p_T$  inclusive hadron-hadron interactions. To test these ideas it is necessary to measure the relative production of  $\pi^+$ ,  $\pi^-$ ,  $K^+$ , and  $K^-$  as a function of  $x_F$ .

The results presented here represent the highest energy at which inclusive  $K^+$  data has 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<sup>8,9</sup> 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 Cerenkov 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 transverse momentum squared 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:

$$x_F = \frac{p_\ell}{p_{\max}}$$

with

$$p_{\max} \equiv \frac{\sqrt{s}}{2} ;$$

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

All results reported here are in the form of  $K/\pi$  or  $K^+/K^-$  ratios, and the relative geometrical efficiencies for  $K^+$ ,  $K^-$ ,  $\pi^+$ , and  $\pi^-$  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 Cerenkov 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 to 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  $\pi$  ratio:

$$\frac{K}{h} = \left( \frac{K+p}{h} - \frac{p}{h} \right) F_{\text{decay}}$$

$$\frac{\pi}{h} = 1 - \frac{K+p}{h}$$

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

$F_{\text{decay}}$  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  $\pi/h$  and  $p/h$  due to a) a small inefficiency (1.0%) for particles which should have triggered the Cerenkov counter but did not; and b) a larger effect (3 - 25%) producing a spurious signal in the Cerenkov counter when no signal should have been present.

Fig. 1 shows the ratio  $K/\pi$  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  $K^+/\pi^+$  ratios become larger, while the  $K^-/\pi^-$  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  $K/\pi$  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  $p_{\text{max}}$ . However, a definition of  $p_{\text{max}}$  for kaons which included the effect of the kaon mass and the production of other strange particles would increase the  $K/\pi$  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 in Ref. 10 and 11 were taken at lower values of  $s$  ( $< 9.6 \text{ GeV}^2$ ) than the data in this paper ( $s > 15 \text{ GeV}^2$ ). Nevertheless, the ratio  $K^+/\pi^+$  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  $K/\pi$  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  $K^+/\pi^+$  ratio strongly suggests a rise to a value near 0.5, while the  $K^-/\pi^-$  ratio appears to remain flat.

None of the models include any contribution from the quasi-elastic production of vector mesons such as the  $\rho$  or  $\phi$ . 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  $\phi$  production and decay is negligible. However, the  $\rho$  does contribute a significant fraction to the pion signal measured in this experiment. The  $K/\pi$  and  $p/\pi$  ratios reported in Ref. 9 were modified for the estimated contribution from  $\rho$  production and decay. The ratios reported here have not been corrected for this effect, but the fractional contribution due to the  $\rho$  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  $\pi$  signal before calculating ratios,  $K^+/\pi^+$  would rise more as a function of  $x_F$  while  $K^-/\pi^-$  would become nearly flat. For Fig: 2, the contribution from  $\rho$  is limited to  $p_T^2$  less than  $0.3 \text{ (GeV/c)}^2$  for  $x_F$  greater than 0.4, and if subtracted, would cause the  $K^+/\pi^+$  to become relatively flat, while  $K^-/\pi^-$  would show a definite decrease as  $p_T^2$  increases.

The  $\rho$  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  $K/\pi$ . 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 at similar  $s$  and  $p_T^2$  <sup>12</sup> 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  $\pm 30\%$ .

The only detailed calculation of  $K/\pi$  ratios for electroproduction is that of Seiden<sup>6</sup>;  $K^+/\pi^+$  is expected to be 0.33 and  $K^-/\pi^-$  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  $K^+/\pi^+$  ratio is  $0.255 \pm 0.020$ , and the  $K^-/\pi^-$  ratio is  $0.113 \pm 0.013$ . This quantitative disagreement should not be interpreted as evidence that the quark-parton model is not capable of correctly predicting these ratios: The calculation of Ref. 6 was based on u quark fragmentation only.

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

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## FIGURE CAPTIONS

1. a) The ratio of  $K^+/\pi^+$  for hydrogen (circles) and deuterium (squares) targets as a function of  $x_F$ .  
b) The ratio of  $K^-/\pi^-$  for the same targets.
2. The ratio of  $K^+/\pi^+$  and  $K^-/\pi^-$  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.
3. The ratio of  $K^+/K^-$  as a function of  $x_F$ . Data from hydrogen and deuterium have been combined.



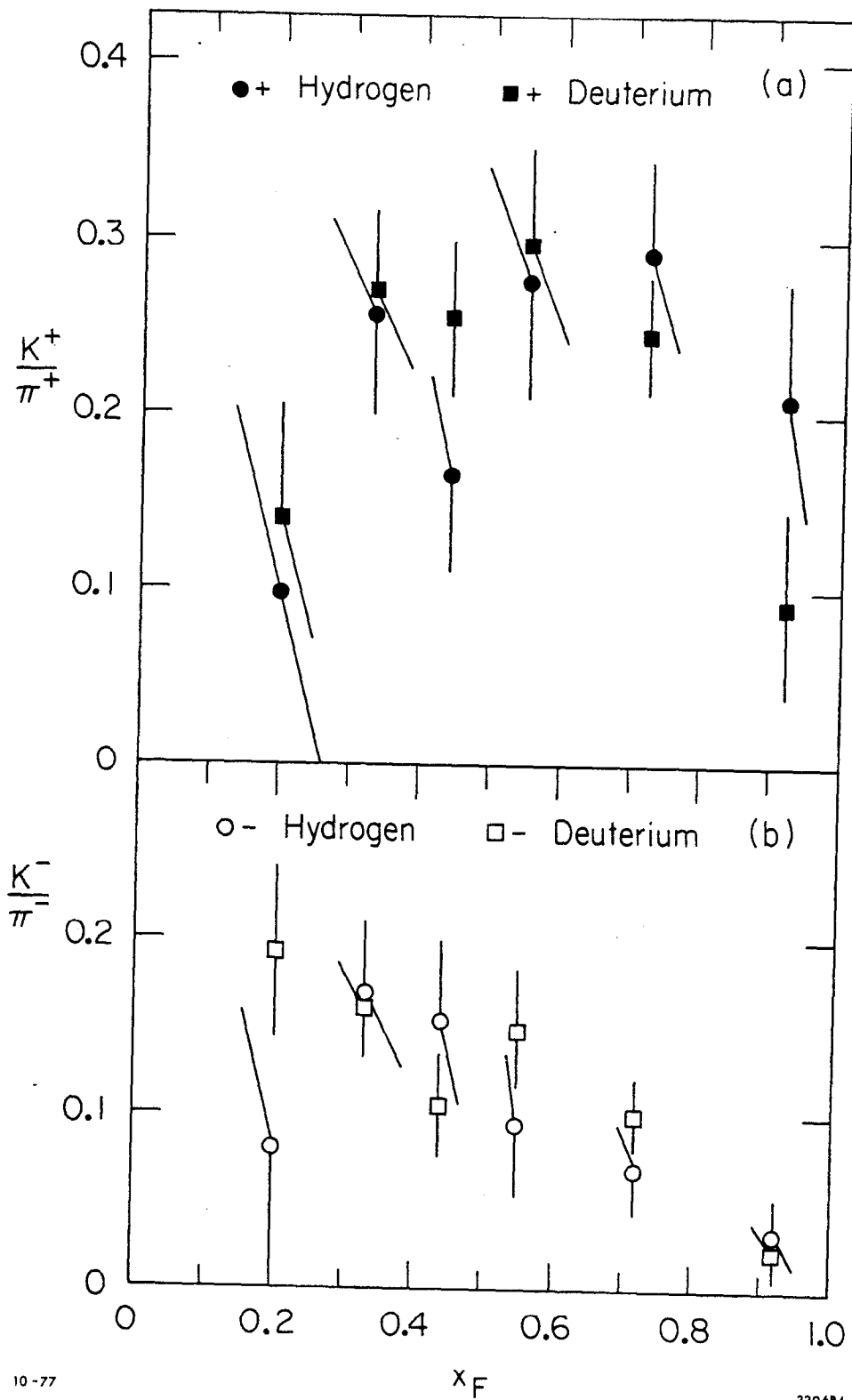


Fig. 1

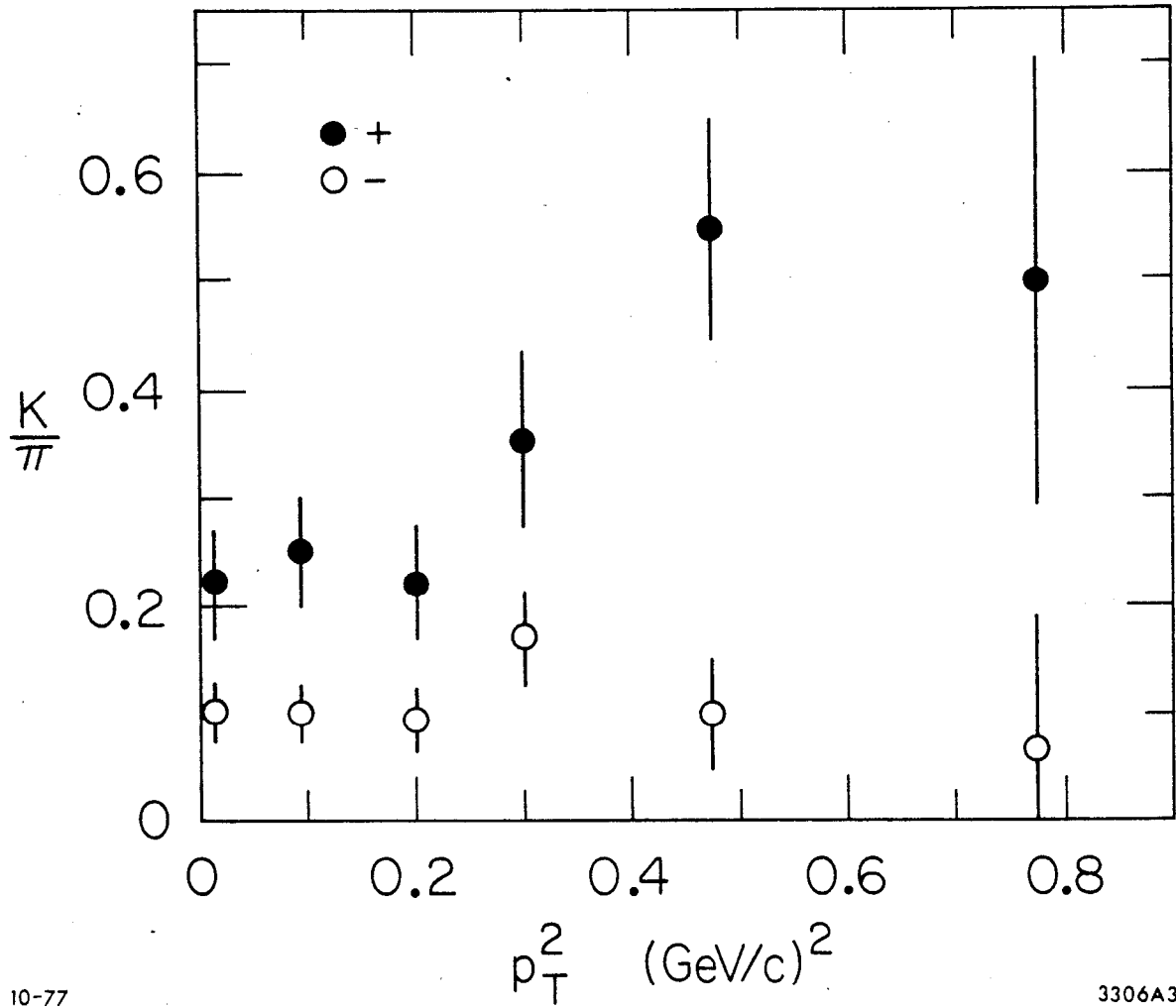


Fig. 2

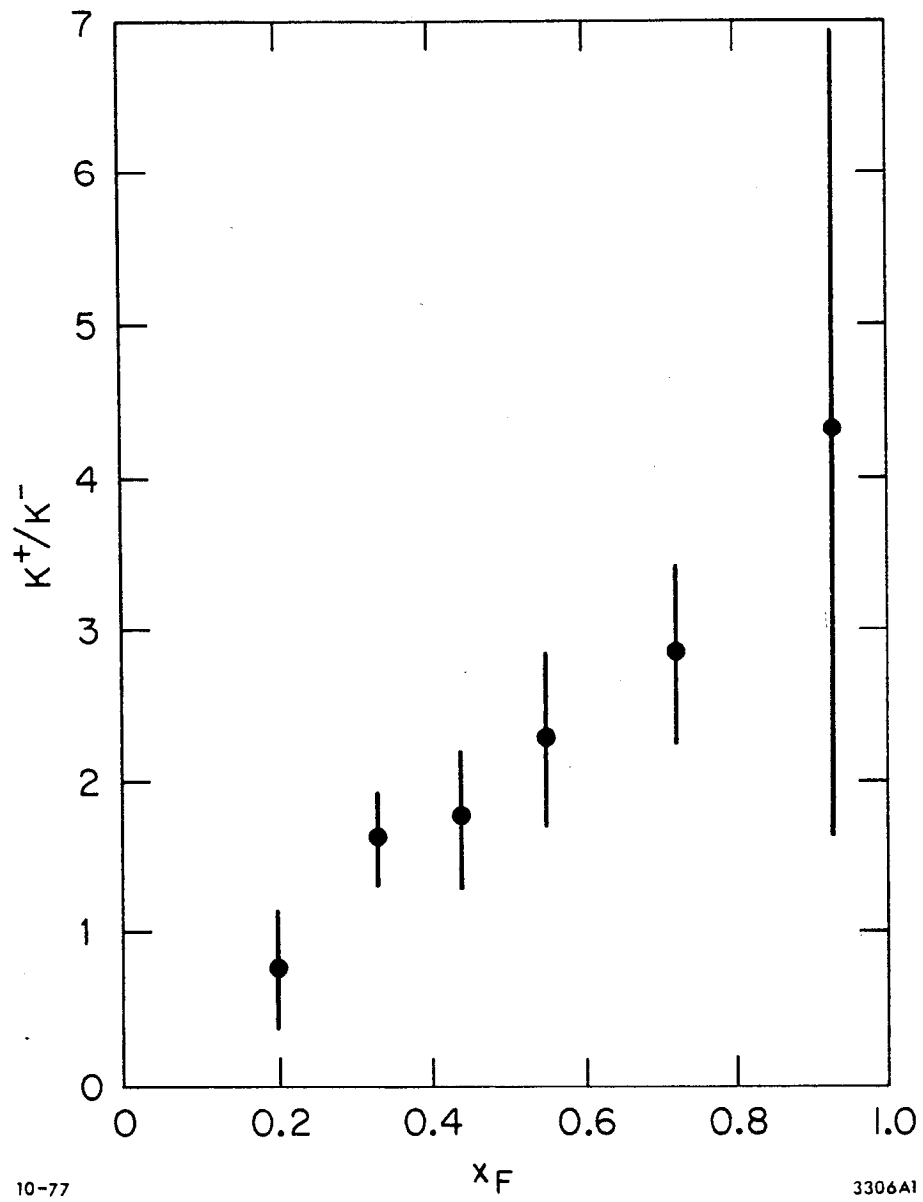


Fig. 3