SLAC-PUB-1766
June 1976
(T/E)

PARTICLE RATIOS IN INCLUSIVE ELECTROPRODUCTION FROM HYDROGEN AND DEUTERIUM

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ABSTRACT

We present a high statistics study of particle ratios in electroproduction of forward hadrons. The π^+/π^- ratios for a proton target rise monotonically to a value of $2.4 \pm .2$ at Q^2 of $3(\mathrm{GeV}/c)^2$ and for a neutron target average $1.16 \pm .04$ from Q^2 of .35 to $3(\mathrm{GeV}/c)^2$. We report the first data on electroproduction of $\bar{p}$, and measure the cross sections of $K^\pm$, p, and $\bar{p}$ relative to pions as a function of Q^2.

*Work supported by the Energy Research and Development Administration.

†Work supported by U.S. National Science Foundation.

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(Submitted to Physics Letters)

In the past, hadron production in virtual photon-nucleon collisions has proved stimulating,[1-3] especially in the current-fragmentation, or "forward", region. In a previous electroproduction experiment[2] the positive to negative hadron ratio from a proton target was shown to increase markedly with Q^2 and there were indications that the corresponding ratio from a neutron target was greater than unity. If this behavior were established for that subset corresponding to produced pions, it would yield a strong constraint on theoretical models, lending support to fractionally-charged quark models of the nucleons.[3] Also, although no explicit predictions have been published, the fraction of forward hadrons which are K's, p's, and $\bar{p}$'s must be crucially related to the dynamics of current-fragmentation. However, all experiments to date have been too limited in energy, statistics, and/or particle identification to establish conclusively the Q^2 behavior of electroproduced forward hadrons by particle type. In this paper, we are able to report data providing mass identification and high counting rates of final state hadrons, as well as interaction energies high enough to avoid production thresholds.

The data were taken at the Stanford Linear Accelerator Center (SLAC) on an apparatus which has been previously described.[4] We detected scattered electrons and any accompanying charged hadrons produced by 20.5 GeV electrons incident on a 4 cm target of either liquid hydrogen or deuterium. Downstream of an 11 kG-m analyzing magnet, an array of multi-wire proportional chambers, scintillation counters, and lead-lucite shower counters subtended an acceptance of about $\pm$ 200 mr vertically and +(-)33 mr to +(-)115 mr horitzontally. In one portion of the apparatus subtending about one-sixth of our solid angle, the shower counters were displaced further downstream and a threshold, variable pressure, gas Cerenkov counter was installed. The integrated incident flux of 10^{14} electrons was divided roughly equally into 16 data blocks corresponding to all combinations of the two targets, the two magnet polarities, and four different gas presssures. The trigger required only the detection of a scattered electron with energy greater than 3 GeV.

From a total of 12×10^6 triggers, 1.9×10^6 scattered electrons survived track and shower cuts and 5×10^5 of these were associated with detected hadrons. For each combination of a scattered electron and produced hadron, we calculated the following variables: $-Q^2$ and ν, the mass-squared and energy of the virtual photon; s, the square of the energy of the virtual photon-nucleon system (the center-of-mass system, CM); and the scaling variable, $x = Q^2/2M\nu$, where M is the proton mass. For the hadron in the CM, we use φ, its azimuthal angle about the axis of the virtual photon; p_t^2, its transverse momentum squared (relative to the virtual photon); and z_ℓ, the ratio of its longitudinal momentum to the maximum possible.

Defining each combination as an event, we found the invariant differential cross sections:

$$\frac{1}{\sigma} E \frac{d^3\sigma}{dp^3} = \frac{2E}{p_{max}} \frac{d\sigma(q^2,s)}{dp_t^2 d\varphi dx} \frac{1}{\sigma_{tot}(q^2,s)}$$

where E and p_{max} refer to the energy and maximum possible momentum of the hadron in the CM system, and σ_{tot} is the cross section for the scattered electron only, as determined within our geometry.

The data reported here have been restricted to a range of 15-31 $(\text{GeV})^2$ in s, and the hadrons were further restricted to be in the range 0-0.64 $(\text{GeV/c})^2$ in p_t^2 and 0.4-0.85 in z_ℓ in order to emphasize the current-fragmentation region. The differential cross sections were integrated over all variables except Q^2 to obtain $d\sigma/dQ^2$.

After subtracting for production from the target walls, the cross sections for a neutron target were found by analyzing the data resulting from a subtraction of hydrogen from deuterium. We have corrected the data for several systematic effects, but the symmetry of the apparatus and running conditions ensured that the effects of these corrections on the ratios reported here were small: for target wall production, 1-6%; for geometric acceptance, 0-5%; for chamber inefficiency, < 0.5%; for chamber and counter deadtime, < 0.5%; for electron misidentification and losses, 0-3%; and for radiative effects on σ_{tot}, < 2.5%. The combined effect of these corrections on the ratios averaged ~ 2.6% and was uncorrelated with any physics variable. The conventional deuterium corrections for shadowing and smearing were not applied since we have divided our observed double-arm counts by our observed single-arm counts to obtain $d\sigma/dQ^2$. From the resulting production cross sections for hydrogen and deuterium, we have estimated hadron absorption within the deuteron; a correction for this would increase the π^+/π^- ratios for neutrons by less than 1%.

Exclusive ρ^0 production is analogous to an elastic channel, but the ρ^0 decay pions are a major contaminant to the inclusive pion spectrum. To study only the dynamics of inclusive pion production, we estimated the contribution from ρ decays and subtracted it from the data. This estimate was based on rhos as observed in our apparatus and agreed with published cross sections.[5] The correction varied with Q^2 from 0 to 23% for proton target ratios and from 0 to 8% for neutron target ratios.

Pions were identified as any hadrons producing a signal in the Cerenkov counter within the proper momentum range. The π^+ and π^- cross sections were found by multiplying the hadron cross sections by the fraction of hadrons entering the Cerenkov counter which proved to be pions. In a similar procedure, p and $\bar{p}$ cross sections employed that fraction of hadrons which did not produce a signal within the proper momentum range, correcting for Cerenkov counter inefficiency ($1.0 \pm .2\%$). Finally, the $d\sigma/dQ^2$ for $K^+(K^-)$ were obtained by subtracting the $d\sigma/dQ^2$ for $p(\bar{p})$ and $\pi^+(\pi^-)$ found in this way from the cross sections for all hadrons. Errors shown are mainly statistical; an estimated 2.5% systematic error is included in all ratios.

Figure 1 shows the ratio of positive to negative particle cross sections for all hadrons and for pions. Although the pion ratios are generally less than the hadron ratios, the characteristic features of the hadrons remain. For a neutron target, the pion ratios favor a gradual rise with Q^2, with an error weighted average of $1.16 \pm .04$ for the whole Q^2 range.

Figure 2 shows only the π^+/π^- ratios for a proton target and neutron target, binned as a function of x.

Figure 3 shows K^+/π^+, K^-/π^-, p/π^+, and $\bar{p}/\pi^-$ ratios for a proton target and a deuteron target. In addition, we have extracted these ratios from a report on forward photoproduction at comparable s, p_t, and z_ℓ[6] and show those values at $Q^2 = 0$ in Figs. 1 and 3. These $Q^2 = 0$ ratios also include a correction for rho photoproduction. The subtraction had no effect on the π^+/π^- ratio for neutron target, increased the π^+/π^- ratio for proton target by about 10%, and increased the ratios in Fig. 3 by about 50%.

In summary, we have presented a high-statistics measurement of the relative production of pions, kaons, p, and $\bar{p}$ in high energy electron scattering from proton and neutron targets. The data show that the ratio of π^+ to π^- in the forward direction rises with Q^2 for a proton target, and is greater than 1.0 for a neutron, in quantitative agreement with predictions from a specific quark model of the nucleons.[3] We show that $\bar{p}$ is produced in significant numbers, and measure the K^+/π^+, K^-/π^-, p/π^+, and $\bar{p}/\pi^-$ production ratios as a function of Q^2. These latter ratios are similar for a proton and a deuteron target, and in combination with data from photoproduction appear to be increasing with Q^2.

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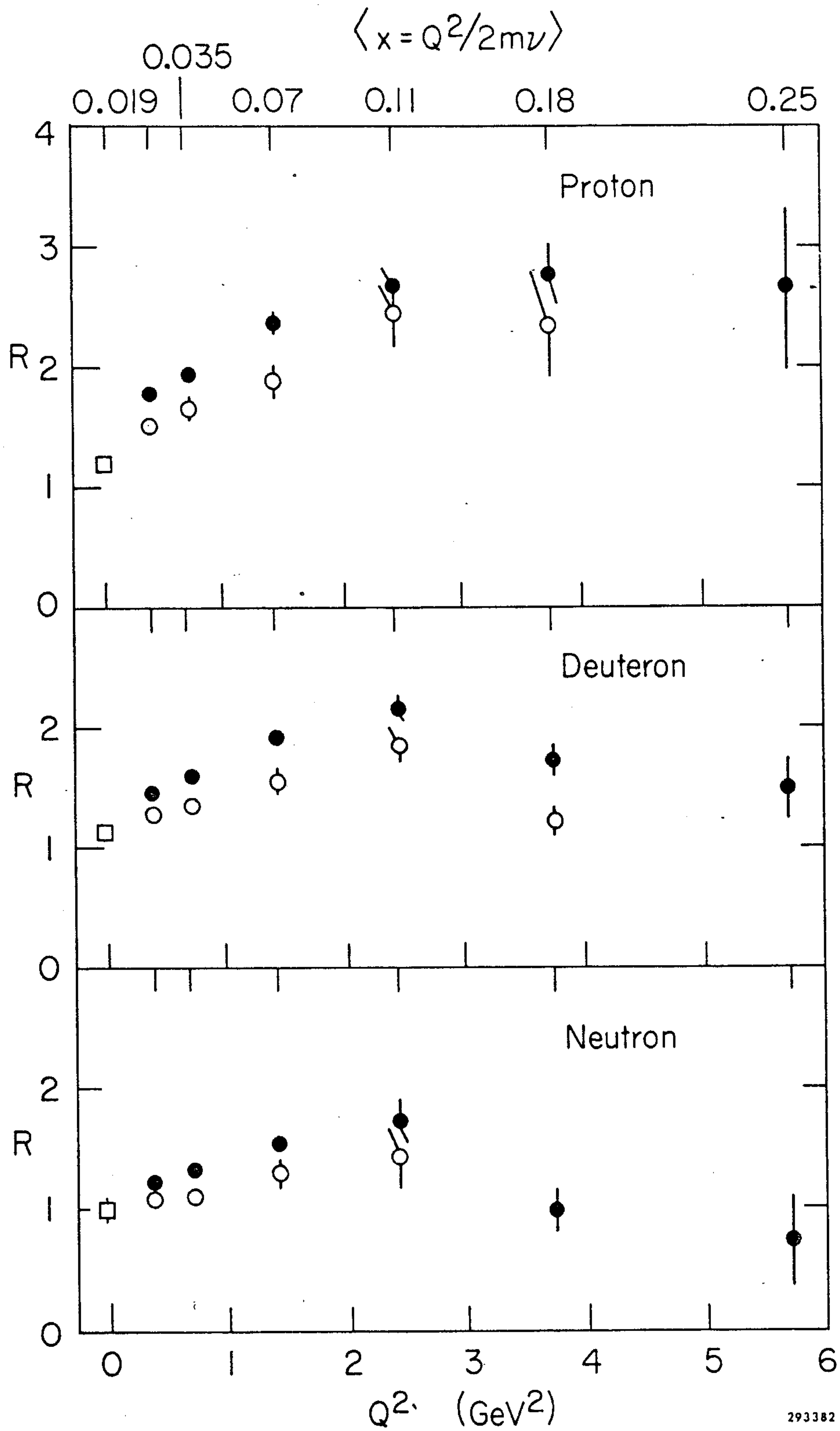
FIGURE CAPTIONS

Fig. 1 Charge ratios for three targets as a function of Q^2. Neutron data were derived from proton and deuteron results as described in text. Filled symbols correspond to all hadrons and open symbols to pions only. Open squares at $Q^2 = 0$ are from ref. (6).

Fig. 2 Charge ratios for pions as a function of the scaling variable x. Here the filled symbols are for proton target results, and open symbols are for a neutron target.

Fig. 3 Production ratios for proton target and deuteron target. a) K^+ divided by π^+, b) K^- divided by π^-, c) p divided by π^+, and d) $\bar{p}$ divided by π^-. Filled circles refer to proton target and crosses to deuteron target. The points at $Q^2 = 0$ are from ref. (6); filled symbols refer to proton target and open symbols to deuteron target.



⟨x = Q²/2mν⟩
0.019
0.035
0.07
0.11
0.18
0.25
Proton
Deuteron
Neutron
R
0
1
2
3
4
5
6
Q² (GeV²)
293382

Fig. 1

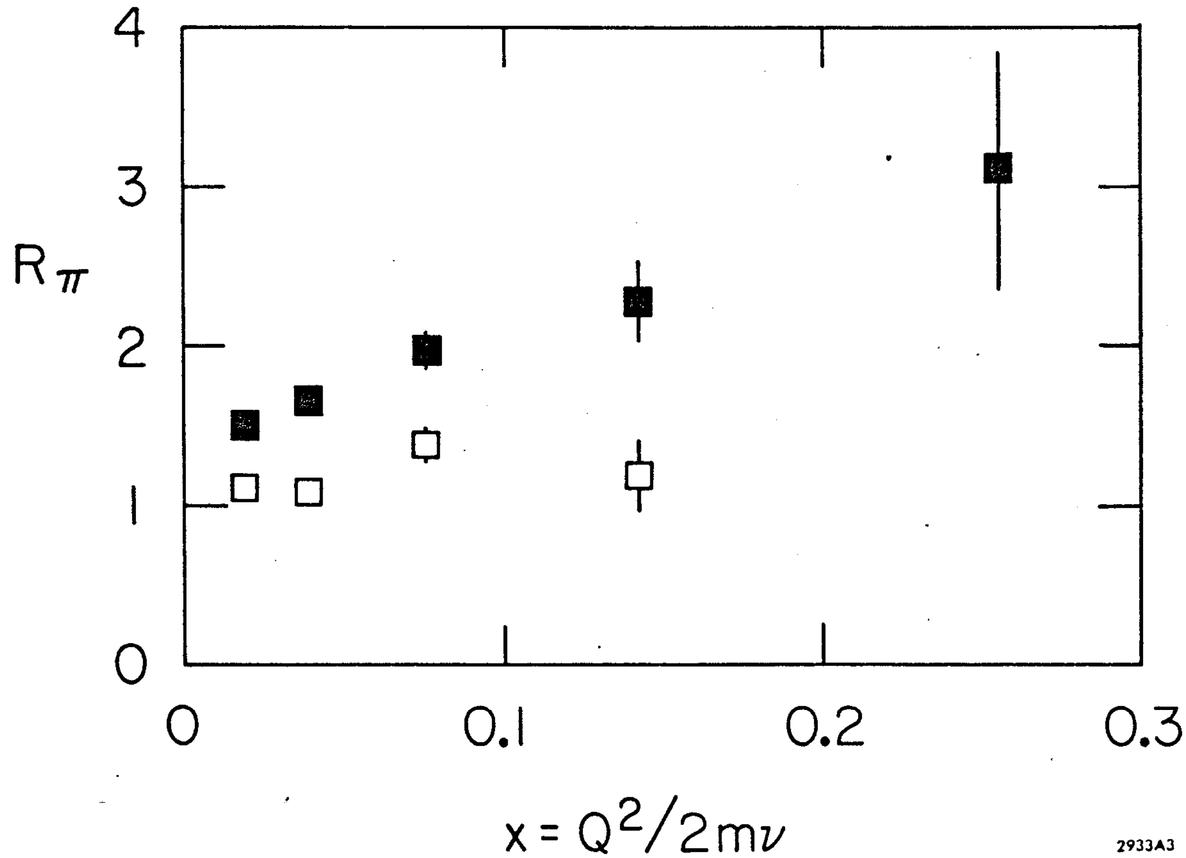


Fig. 2

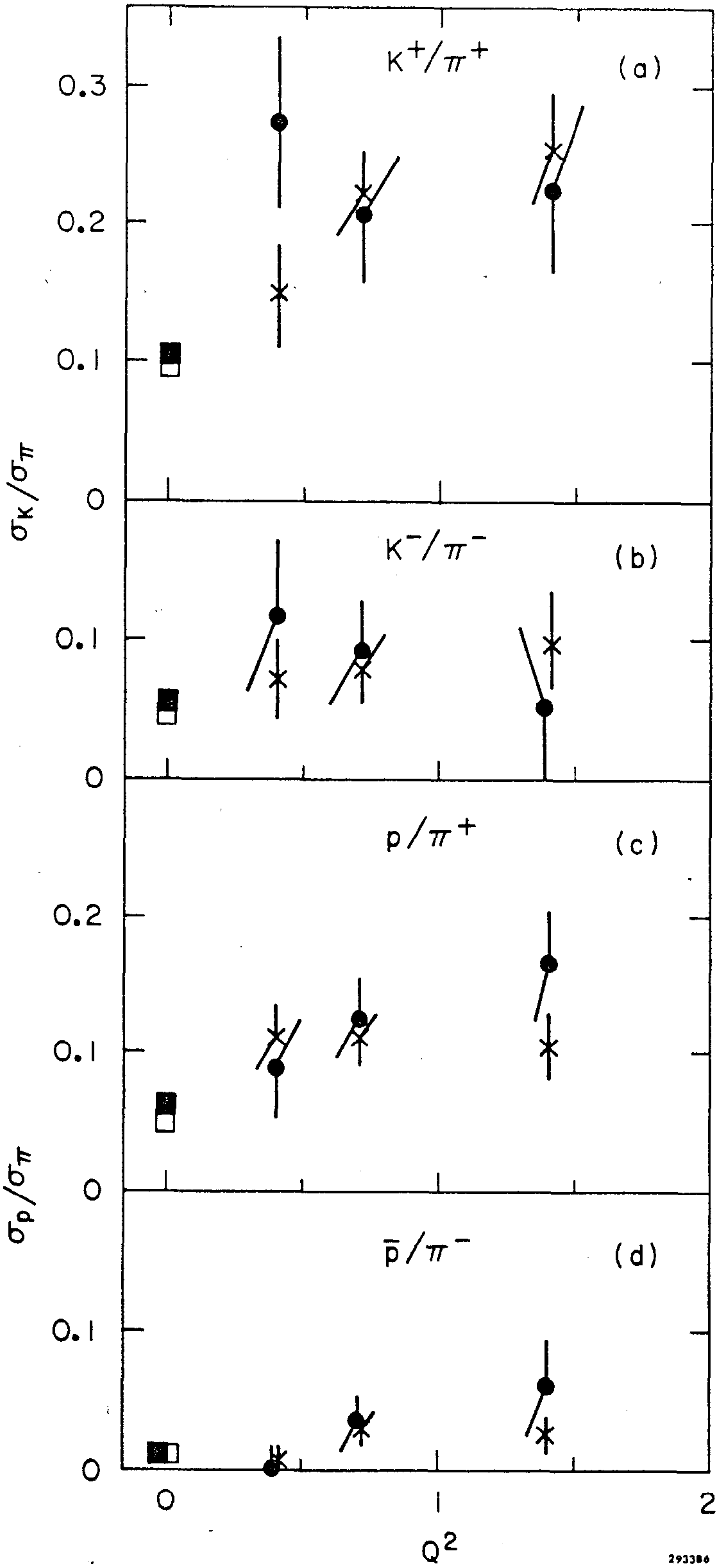


Fig. 3