SLAC-PUB-1870
January 1977
(T/E)

A TEST OF THE QUARK PARTON MODEL WITH DATA FROM ELECTROPRODUCTION OF PIONS*

J. F. Martin

Stanford Linear Accelerator Center
Stanford University, Stanford, California 94305

L. S. Osborne

Department of Physics and Laboratory for Nuclear Science
Massachusetts Institute of Technology, Cambridge, Massachusetts 02139

ABSTRACT

We derive some simple ratios obtained from $\pi^{\pm}$ yields from protons and neutrons. These ratios, when tested against data, confirm predictions of quark parton models.

(Submitted to Phys. Rev. Letters.)

*Work supported in part by the Energy Research and Development Administration.

It has been pointed out by several authors[1, 2] that a measurement of the relative production of $\pi^{\pm}$ and π^{0} mesons from lepton-nucleon collisions can be related to the parameters of quark parton models. The use of isotopic spin reflection decreases the number of unknowns to the point that one can measure these parameters. In this paper, we derive some new relations for relative yields and compare all these with recent experimental data on electroproduction.

Concentrating on only π^{+} and π^{-}, we write the following general expressions:

$$\pi_p^+ = u_p q_u^2 D_u^+ + d_p q_d^2 D_d^+ + \beta \tag{1a}$$

$$\pi_p^- = u_p q_u^2 D_u^- + d_p q_d^2 D_d^- + \beta \tag{1b}$$

$$\pi_n^+ = u_n q_u^2 D_u^+ + d_n q_d^2 D_d^+ + \beta \tag{1c}$$

$$\pi_n^- = u_n q_u^2 D_u^- + d_n q_d^2 D_d^- + \beta \tag{1d}$$

where $\pi_i^{\pm} \equiv$ yield of $\pi^{\pm}$ mesons from a struck hadron, i = p or n (proton or neutron);[3] $u_i, d_i \equiv$ relative probability that a u or d quark was present to strike;[3] $q_{u(d)} \equiv$ charge of the u(d) quark; $D_{u(d)}^{\pm} \equiv$ the fragmentation function for quark u(d) giving rise to a $\pi^{\pm}$ meson; $\beta \equiv$ contribution to the yield from the vacuum quarks. We assume, naturally, that this contribution is charge- and source-symmetric.

π, u, D, and β can be differential in all experimental variables, which are, for the

1. electron: E_0 - electron energy, $-q^2$ - 4-momentum transfer, and ν - electron energy loss (or a combination of these such as $x = q^2/2m\nu = 1/\omega$ or $y = \nu/E_0$).

2. hadron: in addition to the above and in the hadron center-of-mass system with the collision axis taken in the direction of the momentum of the

virtual photon, $z = p_\ell/p_{\ell\,max}$, $p_\perp^2$ = (transverse momentum)^2, and ϕ = azimuthal angle ($\phi = 0$ is toward electron).

Isotopic spin reflection gives,

$$D_u^+ = D_d^- \equiv D_1 \qquad D_u^- = D_d^+ \equiv D_2$$
$$u_p = d_n \equiv u_1 \qquad u_n = d_p \equiv u_2 \tag{2}$$

We form the following sums and differences:

$$A' = \left(\pi_p^+ + \pi_p^-\right) + \left(\pi_n^+ + \pi_n^-\right) \tag{3a}$$

$$A = A' - 4\beta \tag{3b}$$

$$B = \left(\pi_p^+ + \pi_p^-\right) - \left(\pi_n^+ + \pi_n^-\right) \tag{3c}$$

$$C = \left(\pi_p^+ - \pi_p^-\right) + \left(\pi_n^+ - \pi_n^-\right) \tag{3d}$$

$$D = \left(\pi_p^+ - \pi_p^-\right) - \left(\pi_n^+ - \pi_n^-\right) \tag{3e}$$

Note that the β term cancels in the last three equations.

We also define a ratio,

$$R = A/A' \tag{4}$$

This ratio gives the fractional contribution to the π yields from valence quarks. It could, in principle, be measured from the y distributions in neutrino events,[4, 5] but this data is not yet sufficiently accurate for use.

Expressions A through D in terms of Eqs. (1) are all products of sums and differences of the numbers q_i, u_i, D_i; for example

$$B = \left(q_u^2 - q_d^2\right)(u_1 - u_2)(D_1 + D_2) \tag{5}$$

By taking appropriate ratios we can solve for three expressions relating measurable yields to functions of the fractions q_u^2/q_d^2, u_1/u_2, and D_1/D_2 alone. These

functions, however, include R.

$$r_1' = B\cdot C/A\cdot D = B\cdot C/R\cdot A'\cdot D = \left(q_u^2 - q_d^2\right)^2/\left(q_u^2 + q_d^2\right)^2 \tag{6a}$$

$$r_2' = B\cdot D/A\cdot C = B\cdot D/R\cdot A'\cdot C = (u_1 - u_2)^2/(u_1 + u_2)^2 \tag{6b}$$

$$r_3' = C\cdot D/A\cdot B = C\cdot D/R\cdot A'\cdot D = (D_1 - D_2)^2/(D_1 + D_2)^2 \tag{6c}$$

We can also get three ratios each of which eliminates one of the three above fractions (Eq. (5)) and does <u>not</u> involve R.

$$r_4 = D/C = \left[(u_1 - u_2)/(u_1 + u_2)\right]\left[\left(q_u^2 + q_d^2\right)/\left(q_u^2 - q_d^2\right)\right] \tag{7a}$$

$$r_5 = D/B = \left[\left(q_u^2 + q_d^2\right)/\left(q_u^2 - q_d^2\right)\right]\left[(D_1 - D_2)/(D_1 + D_2)\right] \tag{7b}$$

$$r_6 = B/C = \left[(u_1 - u_2)/(u_1 + u_2)\right]\left[(D_1 + D_2)/(D_1 - D_2)\right] \tag{7c}$$

Equation (7a) is a recasting of Eq. (4.11) in GRZ.[2] A simple quark model would require r_1' to be independent of all variables, r_2' and r_4 to be dependent on x and independent of the emitted hadron variables, and r_3 and r_5 to be independent of x. Equivalent expressions can be derived for neutrino interactions.

The experimental determination of r_i requires good statistics and small systematic uncertainties. A recent electroproduction experiment allows their calculation.[6] Particle identification was provided by a gas Čerenkov counter for a subset of the data (~1/6). We have corrected the total hadron samples by removing an average K and p contribution as measured in the identified sub-sample. For data with $x > .2$ there is insufficient data and we use the correction for smaller x; we observe no appreciable change in this correction for x between .02 and .2. The error bars in the figures reflect statistical uncertainty as well as systematic uncertainties from beam normalization and K-p corrections. The data is summed over $p_\perp$, $.3 < z < .85$, and ϕ excluding a region near the beam

pipe where background contamination might be possible. In Fig. 1 we plot r_1 ($=Rr_1'$) and the value of $R_1 = |q_u/q_d|$ (effective) derived from it assuming R=1. Our result is clearly compatible with $q_u = 2e/3$ and $q_d = -e/3$ for large x.[7] Shown also is the deviation from 2 expected from vacuum quark contributions using two published parametrizations.[8,9]

From the above we feel justified in accepting the charge ratio as -2 and using this number in Eqs. (7a) and (7b) to find u_1/u_2 (i.e., u_v/d_v) and $\eta = \bar{D}_1/\bar{D}_2$ $(0.3 < z < 0.85)$. These are plotted in Figs. 2 and 3 respectively. We see that u_v/d_v is <u>not</u> a constant with respect to x. It clearly falls below the expected average value of 2 at low x and is consistent with a number greater than 2 at large x.[10] We also note that η is independent of x even in the small x region where the vacuum quarks contribute appreciably to the cross section.

In summary, we have derived expressions which allow us to calculate the parameters of a general quark model directly from experimental data. We find that the ratio of up to down quark charge is consistent with -2 and that the ratio of the fragmentation functions, D_i, is independent of x. The majority to minority quark ratio is not a constant with x, falling well below 2 at small x.

The authors wish to thank their collaborators on SLAC Experiment E-97[6] for making the data possible. They particularly thank D. Roth for his contribution to the data analysis.

REFERENCES

1. J. T. Dakin and G. J. Feldman, Phys. Rev. D 8, 2862 (1973).
2. M. Gronau, F. Ravndal, and Y. Zarmi, Nucl. Phys. B 51, 611 (1973).
3. These π functions are proportional to cross sections, not yields per scattered electron.
4. C. H. Llewellyn Smith, Physics Reports, Vol. 3C, No. 5 (1972).
5. XVII International Conference on High Energy Physics, London, 1974 (The Science Research Council, Rutherford Laboratory, Chilton, Didcot, United Kingdom).
6. J. F. Martin et al., Stanford Linear Accelerator Center preprint SLAC-PUB-1766 (1976). Some results from Experiment E-97 are published in this preprint and Phys. Letters B (to be published).
7. The drama of this result is that there would have been no a priori expectation that complicated expressions of hadron yields would give rise to a result such as the integer, 2 as found for R_1.
8. T. Kuti and V. F. Weisskopf, Phys. Rev. D 4, 3418 (1971), and R. McElhaney and S. F. Tuan, Phys. Rev. D 8, 2267 (1973).
9. Listed by R. Blankenbecler et al., Stanford Linear Accelerator Center preprint SLAC-PUB-1531 (1975) and attributed to G. Farrar, G. Chu, and J. Gunion. See also J. F. Gunion, Phys. Rev. D 10, 242 (1974), and Glenys R. Farrar, Nucl. Phys. B 77, 429 (1974).
10. A. Bodek et al., Phys. Rev. D 7, 1362 (1973). The "disappearance" of the minority quark at large x ($d_v \to 0$) is the usual explanation for the νW_2 of neutron to proton going to a ratio smaller than 2/3.

FIGURE CAPTIONS

1. (a) A comparison of r_1, defined in the text, with data from Ref. 6. From r_1, we have also calculated the ratio, R_1. This is shown in (b). The solid line is the expectation from Ref. 9, the dashed line from Ref. 8.

2. A plot of u_v/d_v (u_1/u_2) from the data of Ref. 6 and using Eq. (7a). We have set $q_u^2/q_d^2 = 4$. The solid (dashed) line is the expectation from Ref. 9(8).

3. A plot of η as a function of x. η is the ratio of $\bar{D}_1$ to $\bar{D}_2$, i.e., D_1 and D_2 averaged over z from z=0.3 to 0.85 and over ϕ and $p_\perp^2$.

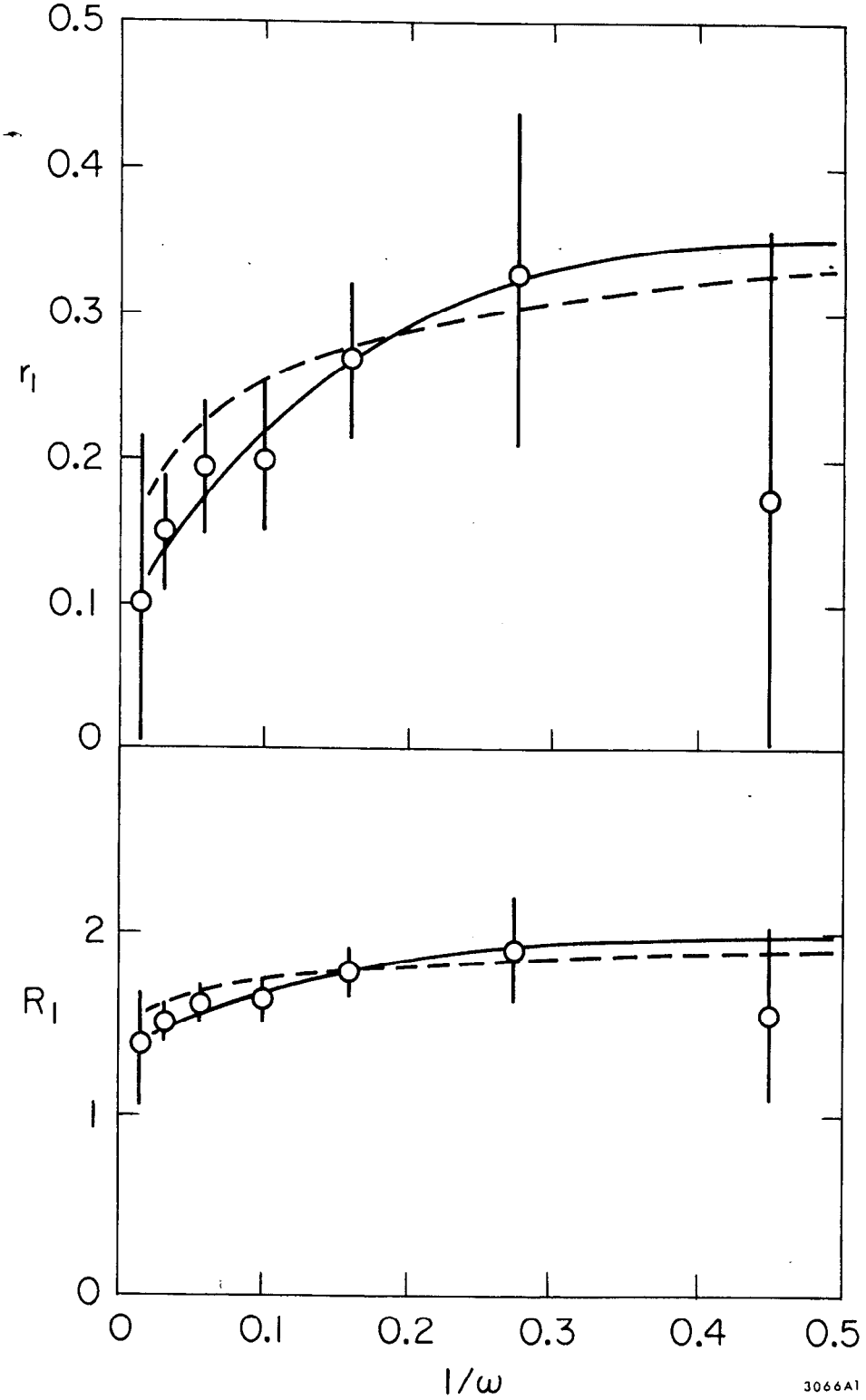

Fig. 1

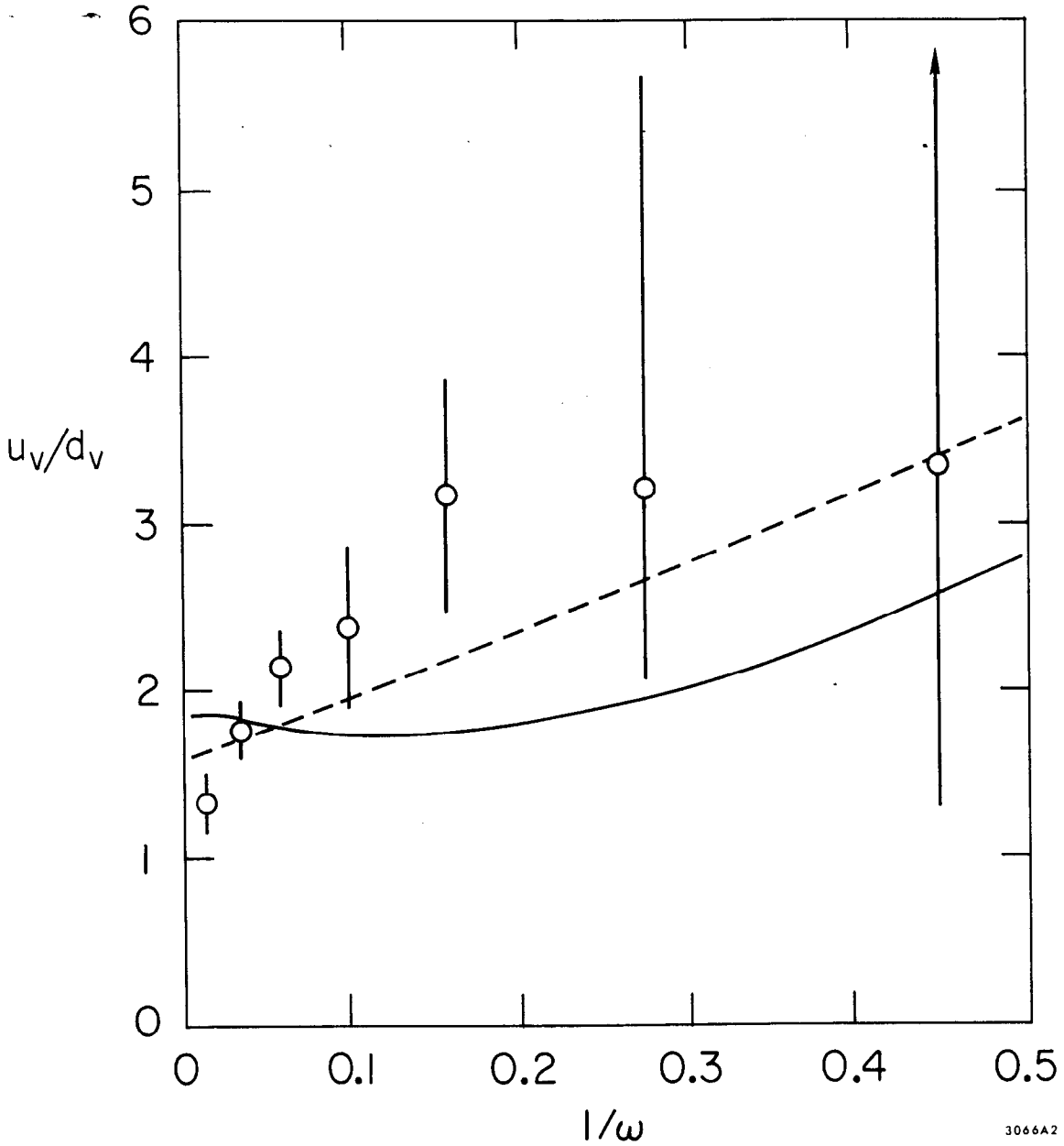

Fig. 2

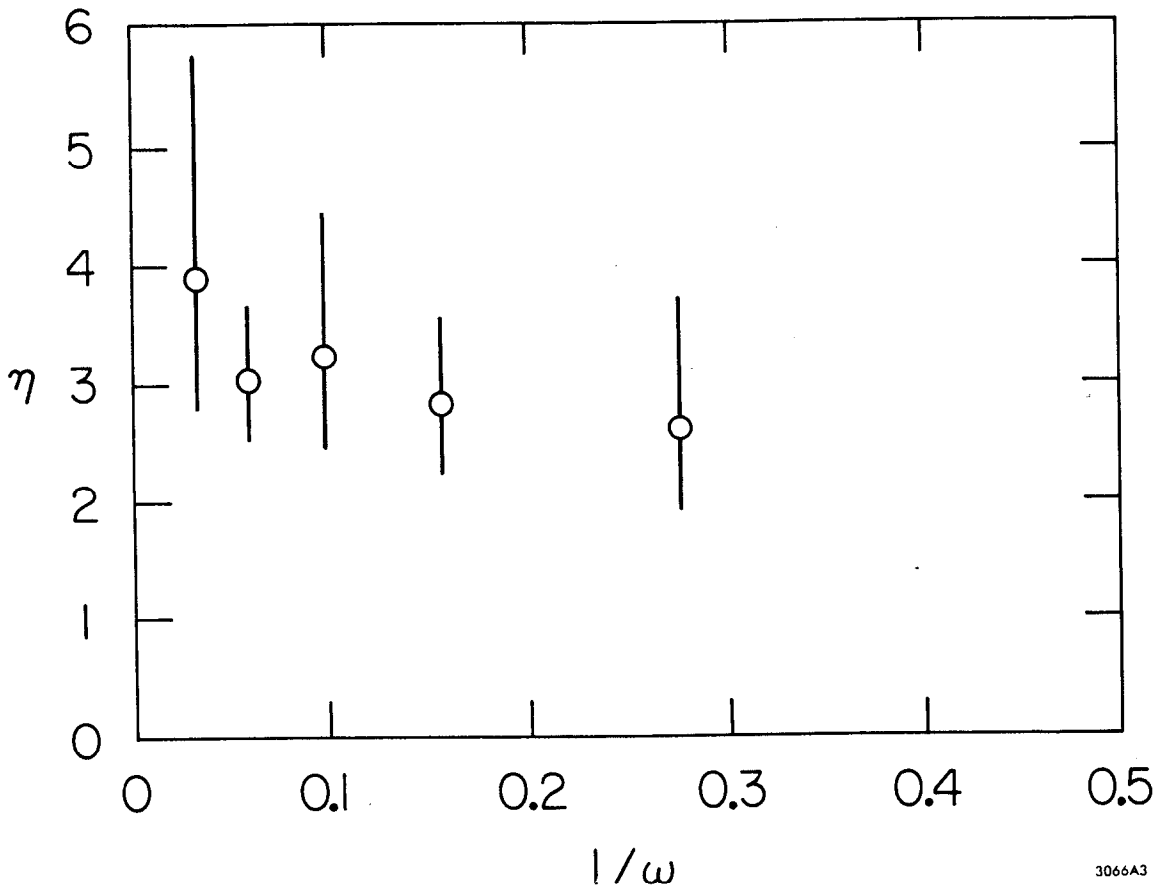

Fig. 3