CEBAF PROPOSAL COVER SHEET

This Proposal must be mailed to:

CEBAF
Scientific Director's Office
12000 Jefferson Avenue
Newport News, VA 23606

and received on or before 1 October 1991.

A. TITLE:

A STUDY OF LONGITUDINAL CHARGED PION ELECTRO-PRODUCTION IN D2, He3, AND He4

B. CONTACT PERSON:

HAROLD E. JACKSON

ADDRESS, PHONE, AND ELECTRONIC MAIL ADDRESS:

ARGONNE NATIONAL LABORATORY
PHYSICS DIVISION, BLDG 203
9700 S. CASS AVENUE
ARGONNE, IL 60439 BN: B03453@ANLVM

C. IS THIS PROPOSAL BASED ON A PREVIOUSLY SUBMITTED PROPOSAL OR LETT OF INTENT?

[X] YES [ ] NO

IF YES, TITLE OF PREVIOUSLY SUBMITTED PROPOSAL OR LETTER OF INTENT

SAME AS ABOVE

****

(CEBAF USE ONLY) PR-89-011 - COND

Receipt Date 24 SEP 91

Log Number Assigned PR-91-003

By [redacted]

RESEARCH PROPOSAL UPDATE: PR-89-011

A Study of Longitudinal Charged Pion Electroproduction in D2, He3, and He4

K. Coulter, D. F. Geesaman, R. J. Holt, H. E. Jackson (Spokesperson),
S. Kaufman, D. Potterveld, B. Zeidman
Argonne National Laboratory
R. Gilman
Rutgers University
E. Kinney
University of Colorado
J. Mougey
CEBAF
B. Saghai
Centre d'Etudes Nucleaires de Saclay
R. Segel
Northwestern University

Summary

PR-89-011, a proposal to use pion electroproduction to study the nucleon pion coupling in nuclei, was conditionally approved at PAC4. Additional kinematics are presented for measurements at higher invariant masses and a request is made for full approval for an initial run of 500 hours. Issues relating to the data base for the elementary process and the off shell nature of the pion photon system are discussed briefly.

I. Introduction

The proposal, PR-89-011, will use pion electroproduction to probe the properties of the pion field of the nucleon and the extent to which they are modified in nuclei. Measurements of longitudinal charged electro-production will be made along the direction of the momentum transfer where the charge scattering process dominates. A Rosenbluth separation will be performed to obtain the longitudinal cross section, σ_l, which is dominated by scattering of virtual pions into the continuum. By measuring σ_l as a function of momentum transfer, the strength of the pion nucleon coupling in nuclei can be studied as a function of the virtual pion momentum. If current conceptions of pion exchange currents in nuclei are correct, longitudinal electroproduction on bound nucleons will be suppressed at lower momentum transfer and enhanced at higher momentum transfer. However, recent data from Drell Yan studies of antiquark structure functions in nuclei[1,2] suggest that such an enhancement will not occur. If, indeed, the basic pion coupling is observed to be unaltered in multi-nucleon systems, a reformulation of pion-exchange models of the medium and short-range properties of nuclear forces will be required.

The proposal which was presented to PAC4 was a search for nuclear many-body effects in forward-angle pion production by deuterium and the helium isotopes. The experiment was designed to maintain the final state nucleon pairs for the deuteron and ^{3}He in the T=1 state where absorption is suppressed. Measurements would be made at two values of the four momentum transfer, 2.5 and 10.1 fm^{-2} for a single nucleon invariant mass of 1160 MeV. This choice of kinematics was made because under these conditions longitudinal processes dominate and the pion pole term provides the largest contribution to the cross section. In addition, results from a measurement on deuterium carried out at Saclay in kinematics close to Q^2=2.5 fm^{-2} (see attached reprint) suggest the existence of medium modifications of the pion coupling. A productive cycle of measurements at these kinematics would require about 600 hours of beam.

II. Alternative Kinematics

PAC4 recommended consideration of different kinematic regimes, particularly those that maintain the quasi-free nature, but with a pion energy higher than the delta isobar. We discuss here the constraints on kinematic choices and present an alternative set of kinematic conditions which, on balance, offers some advantages over those presented earlier to PAC4. As is evident from the Saclay data for the deuteron, forward angle electroproduction is well described by Fermi-broadened electroproduction on a free proton. Consequently the kinematics for pion production on the proton provides reliable estimates of the average values for kinematic variables in the quasi-free process. Fig. 1 shows the final pion momentum as a function of invariant mass for forward angle pion production on a proton target. To reach higher pion momenta, as suggested in the recommendations of PAC4, measurements must be made at higher invariant mass. However, other aspects of the kinematics must be considered if the objective of the study is to probe the pion coupling over a range of virtual pion momenta. The plan of the proposal is to probe the range of virtual pion momenta of 0.1 to 0.6 GeV/c by varying the four momentum transfer, Q, at a fixed invariant mass. In fig.2 the virtual pion momentum,k, is plotted for various momentum transfers squared, Q^2, as a function of invariant mass for the pion pole process. It is important to note that as the invariant mass increases a larger range of Q^2 is required to cover a given interval of k. Measurements at very high invariant mass, eg W>1.5 GeV, require measurements at $Q^2>1.6$ $(GeV/c)^2$ where pion charge scattering will have a strong dependence on the pion form factor. The measurement proposed avoids this complication.

We propose here a second kinematic configuration for PR-89-011 in which W=1.33 GeV. Measurements will be made for $Q^2= 0.23$ and 0.70 $(GeV/c)^2$, values which correspond to k=0.212 and 0.467 GeV/c respectively. For these kinematics the momenta of the final state pions are .558 and .725 GeV/c. The kinematics for this configuration are shown in Table 1 together with estimated counting rates for a measurement with a deuterium target. The assumptions made with respect to spectrometer properties, beam and target parameters are identical to those in the original proposal.

TABLE 1. Kinematics and Counting Rates

E GeV	ω GeV	θ_ε deg	θ_q deg	W GeV	Q^2 fm^{-2}	p_π GeV/c	ε	coin. rate kcph*	e^- singles rate khz
0.97	0.60	48	21	1.332	6.0	0.56	0.5	2.0	0.7
1.98	0.60	17	31	1.332	6.0	0.56	0.9	54	21
1.46	0.85	53	24	1.332	18.0	0.725	0.5	0.2	0.2
3.02	0.85	19	36	1.332	18.0	0.725	0.9	24	4.4

*kilocounts per hour   ε is the photon polarization parameter.

Although the coincidence rates are much higher for all but the measurement at 1.46 GeV than those proposed earlier, the total number of counts required to obtain a given error in σ_l will be 3 to 4 times as great because of error propagation in the Rosenbluth separation. In the earlier kinematics at W=1.16 GeV the ratio, $R=\sigma_l/\sigma_t \approx 3$, whereas at W=1.33 GeV typically R=0.8. One of the reasons for the earlier choice of W=1.16 was the ease with which the Rosenbluth separation can be made when the longitudinal cross section is large relative to the transverse cross section. We propose to measure relative cross sections with a statistical error of 1%. In this case, the expected error in σ_l will be 5% and 7.5% for the W=1.16 and 1.33 GeV kinematics, respectively.

However, the kinematics of table 1 have several advantages which must be considered. First, the final pion momentum lies in the region immediately above the delta isobar where the total free pion nucleon cross section is lowest. Rescattering effects should be weakest in this case. Second, for these higher pion momenta decay losses in the SOS spectrometer will be less. Third, the Fermi broadening of the pion quasi-free peak will be diminished in direct portion to the increase in the mean pion momentum. Finally, the true to accidental rates are very much improved over the 1:1 values appropriate to the original kinematics.

III. Request for Beam Time

Measurements for two or more invariant masses will be necessary for a conclusive study of pion nucleon coupling in light nuclei using (e,e'π). Such data will provide evidence for the validity of the assumption that the reaction is primarily quasifree production in the "pion pole" mode. The statement of resources required made in the original proposal pertains, regardless of which kinematic configuration is chosen. As in the original case, the estimates of count rate presented here are based on target luminosities which correspond to beam power dissipation in the cryogenic targets in the range of 10-20 watts. This conforms to current planning for cryogenic target capability in Hall C during the first 18 months of operation. It should be noted that, as a result of the excellent true to accidental ratios, measurements in the W=1.33 GeV kinematics could be carried out at much higher luminosities. Using the data from Table 1 , we have made the estimates of beam time shown in Table 2.

TABLE 2. Request for Beam Time (W=1.33 GeV)

Data Acquisition	Q^2=6.0 fm^{-2}		40 hours
	4 targets		
	Q^2=18.0 fm^{-2}		200 hours
	4 targets		
Spectrometer Check-out			100 hours
Overhead/Contingency			160 hours
		total	500 hours

A complete set of measurements covering both kinematics (W=1.16 and 1.33 GeV) will require approximately 1000 hours at the conditions specified. We request at this time approval for an initial phase of measurements of 500 hours. Pending knowledge of the beam energies available at the time of the experiment, we propose to make initial measurements at W=1.16 GeV for a momentum transfer of Q^2=10.1 fm^{-2} and W=1.33 GeV at Q^2=6.0 fm^{-2}. The point at W=1.16 GeV, from the original proposal will probe virtual pion coupling near k=.45 GeV/c, while the point at W=1.33 GeV from the new kinematics will probe the region near k=.21 GeV.

IV. Remaining Issues

Two additional questions were raised by PAC4. The request was made that consideration be given to improving and extending the range of data on charged pion production on the proton. It is an essential element of the planning that absolute measurements be made on the proton. These data will provide additional constraints on the data base in the region of forward angles at and below the delta isobar where information is lacking.

Finally, some concern was expressed about the interpretability of the measurements, given that the struck pion will be significantly off-shell. In response, two points are to be noted. First, the proposal is designed to make measurements in nuclei relative to the process on the free proton. To lowest order, kinematic off-shell effects in the photon pion coupling should cancel in the nuclear target/proton cross section ratios. Second, a measurement of the pion form factor by Bardin et al. [3], using the same reaction we study here, gave results for the pion form factor in agreement with those obtained by studying the scattering of high energy pions [4] off electrons in a hydrogen target.

V. Detector Development

The detector systems planned for the SOS spectrometer are shown in Fig.3. The upper section shows the configuration which will be used for pion measurements. This configuration will include 3 multiplane wirechambers, WC1-WC3, 4 planes of scintillator hodoscopes, S1Y-S2X , a threshold Cerenkov counter, and a shower counter with pre-radiator arranged as shown in the figure. The gas Cerenkov counter is the responsibility of the PR-89-011 collaboration. A conceptual design based on a Freon 114 radiator at STP is presented in Fig. 4.

References

1. D. M. Alde et al., Phys. Rev. Lett. **64**, 2479 (1990).

2. L.L. Frankfurt, L. Mankiewicz, and M. I. Strikman, Z. Phys. **A334**, 343 (1989).

3. G. Bardin et al., Nucl. Phys. **B120**, 45 (1977).

4. S. R. Amendolia et al., Phys. Lett. **146B**, 116 (1984).

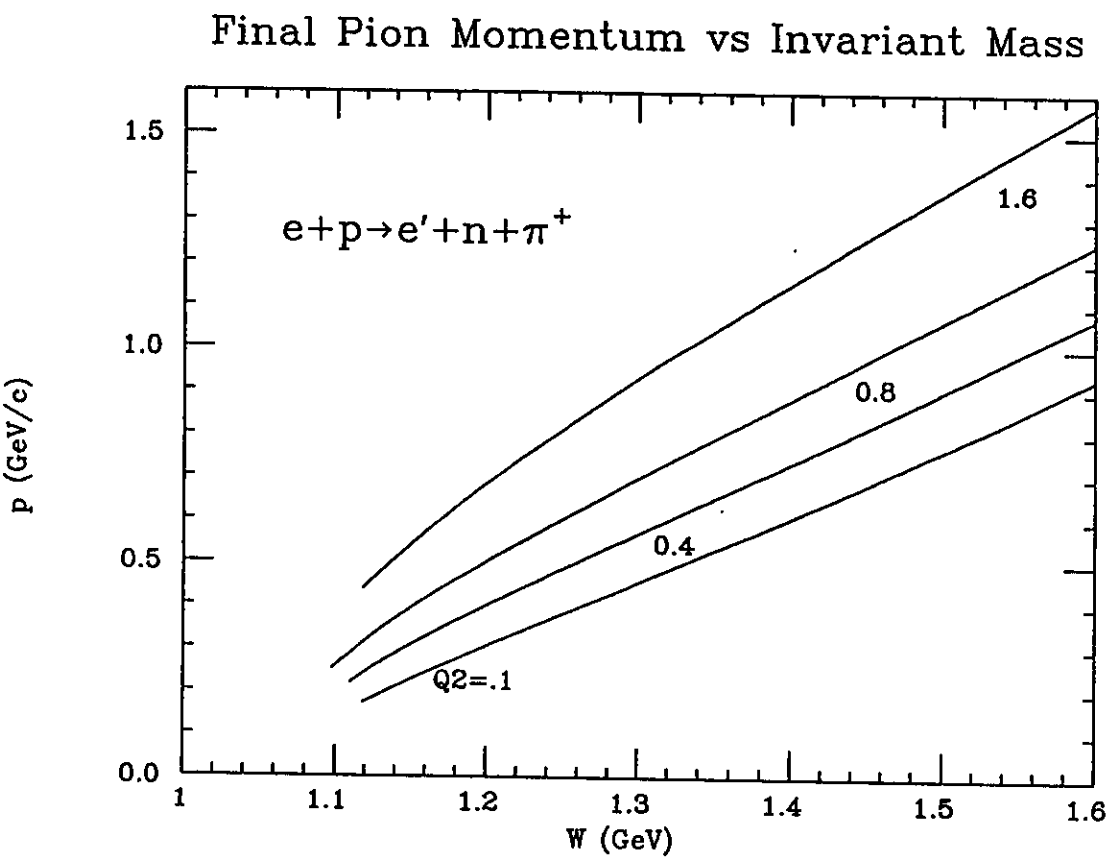
Figure Captions

Figure 1. Final pion momentum as a function of invariant mass for pion electroproduction by free protons in the direction of the virtual photon momentum. The curves correspond to values of Q^2 ranging from 0.1 to 1.6 $(GeV/c)^2$.

Figure 2. Virtual pion momentum, k, as a function of invariant mass, W, for the pion pole term corresponding to pion electroproduction by free protons in the direction of the virtual photon momentum. The curves shown correspond to the same values of Q^2 as in Figure 1. k is equal in magnitude to the momentum transfer to the recoil proton.

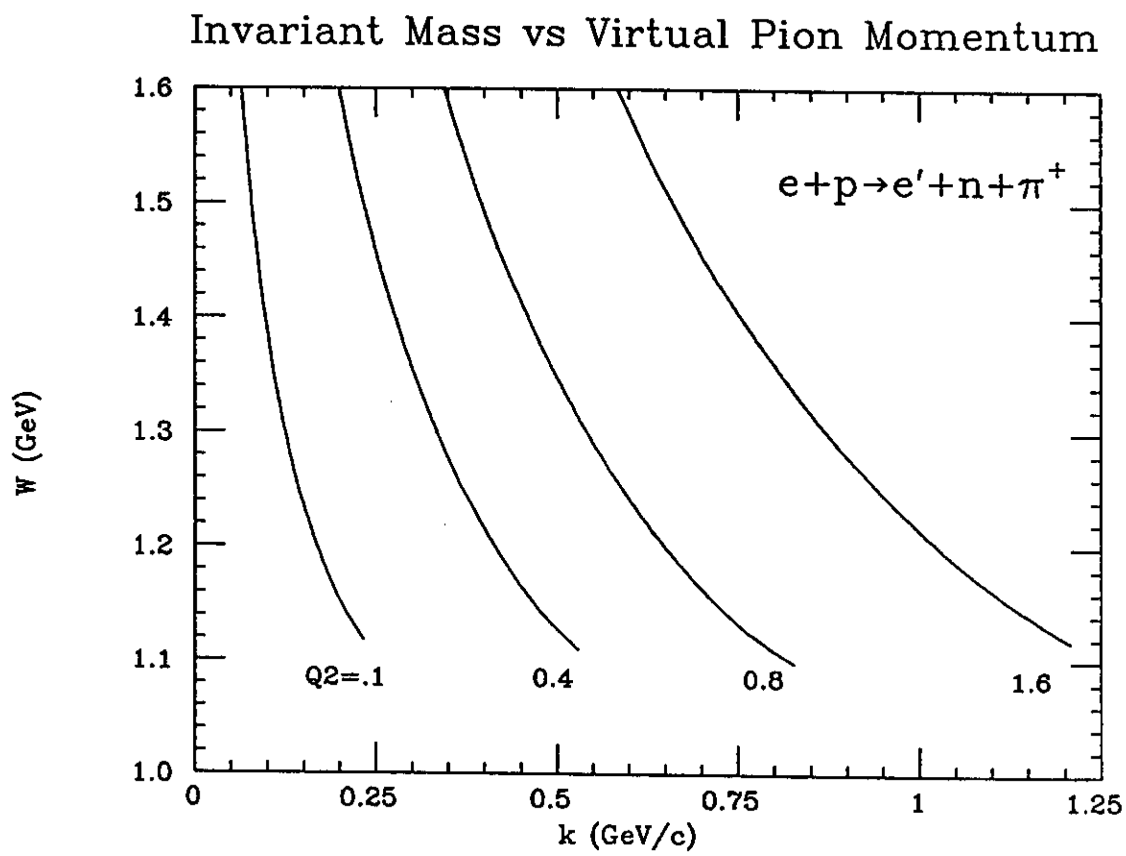
Figure 3. Schematic of the detector packages planned for the SOS spectrometer. The upper section shows the configuration to be used for detecting pions and electrons, while the lower section shows the system to be used for kaon detection.

Figure 4. Schematic of the threshold gas Cerenkov counter to be used in SOS for identifying electrons and positrons. The radiator will be freon 114 at STP.



Final Pion Momentum vs Invariant Mass
$e+p \rightarrow e'+n+\pi^+$
1.6
0.8
0.4
Q2=.1
1.5
1.0
0.5
0.0
p (GeV/c)
1
1.1
1.2
1.3
1.4
1.5
1.6
W (GeV)

Fig. 1



Invariant Mass vs Virtual Pion Momentum
e+p→e'+n+π+
W (GeV)
1.0
1.1
1.2
1.3
1.4
1.5
1.6
k (GeV/c)
0
0.25
0.5
0.75
1
1.25
Q2=.1
0.4
0.8
1.6

Fig. 2

SCHEMATIC DETECTOR PACKAGE

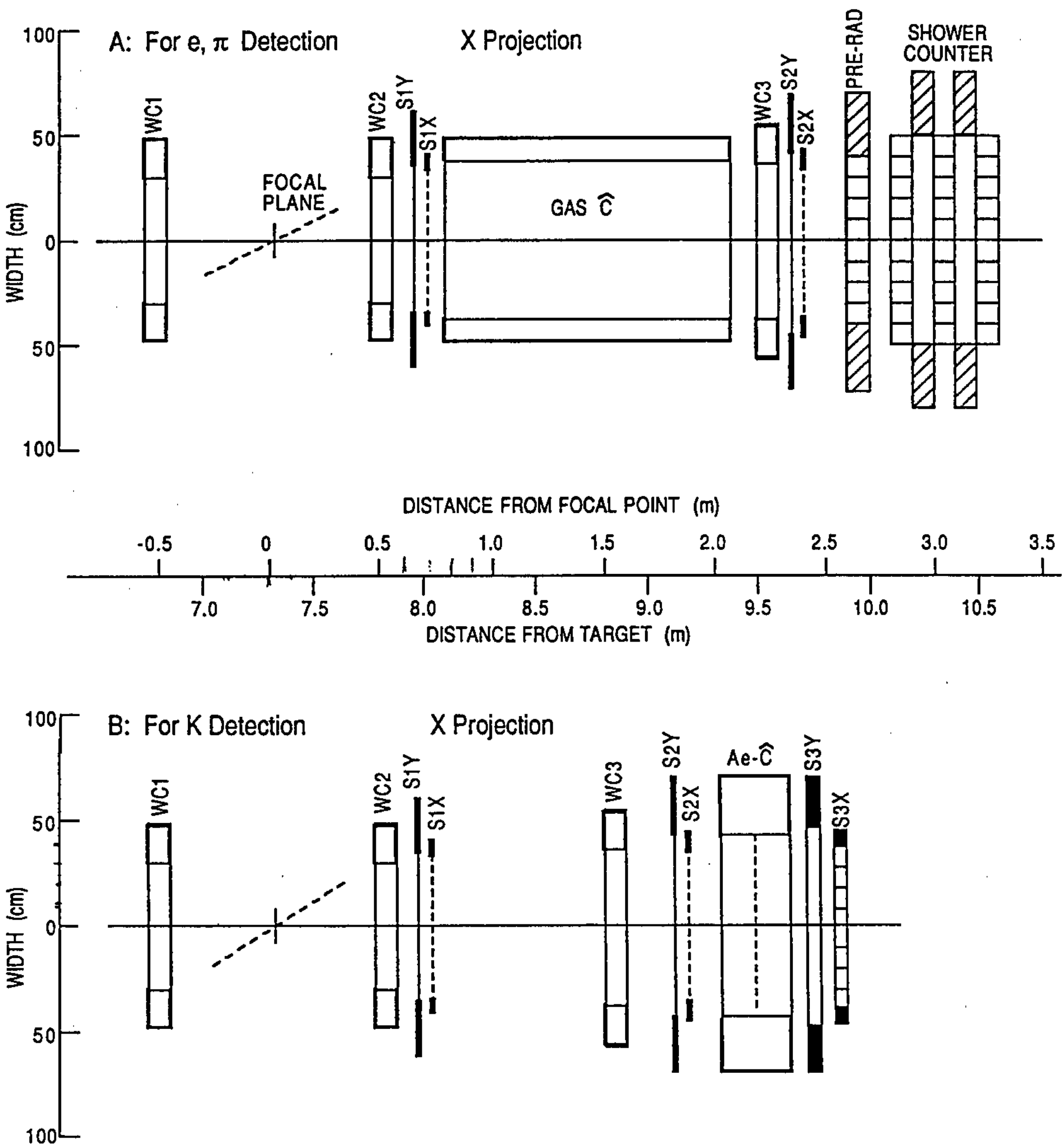
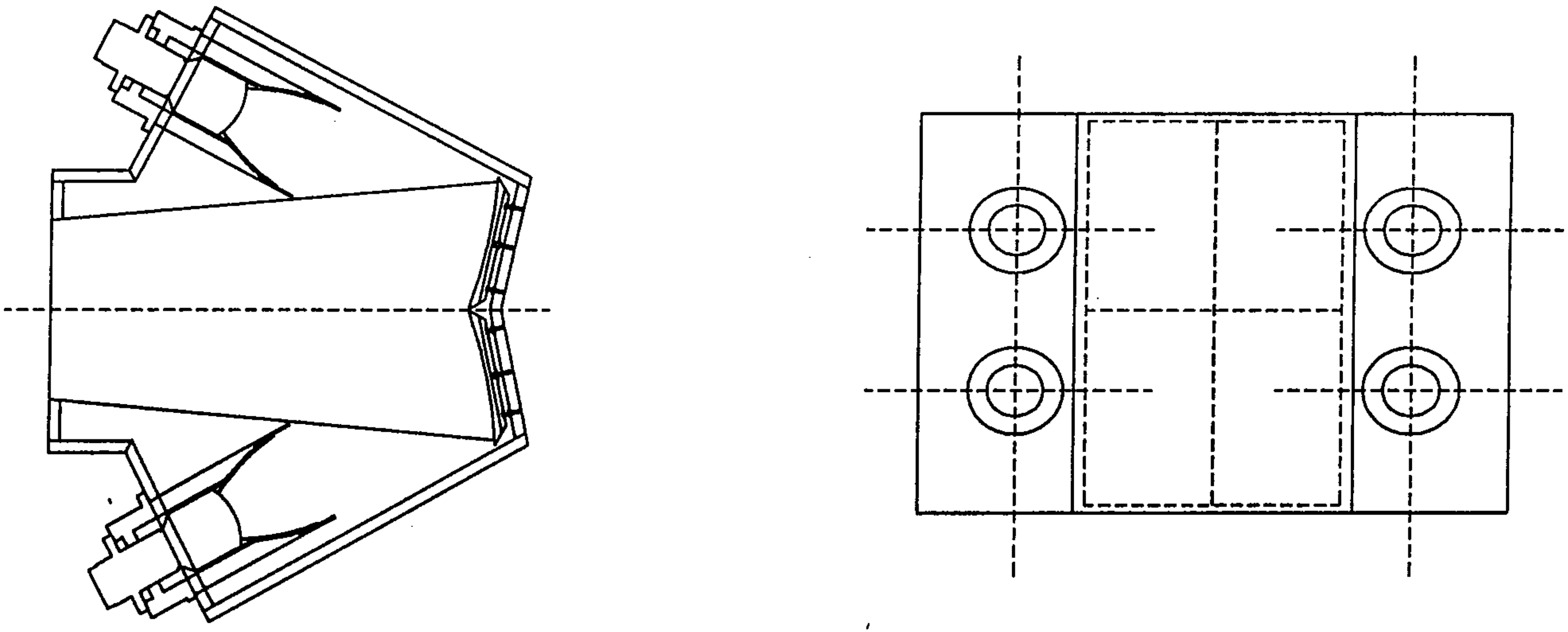


Fig. 3

Schematic of Gas Cerenkov Counter

TOP VIEW

END VIEW



Forward-Angle Charged-Pion Electroproduction in the Deuteron

R. Gilman,[(1)] M. Bernheim,[(2)] M. Brussel,[(3)] J. Cheminaud,[(2)] J.-F. Danel,[(2)] J.-P. Didelez,[(4)] M.-A. Duval,[(4)] G. Fournier,[(2)] R. Frascaria,[(4)] R. J. Holt,[(1)] H. E. Jackson,[(1)] J.-C. Kim,[(5)] E. Kinney,[(1)] J.-M. LeGoff,[(2)] R. Letourneau,[(2)] A. Magnon,[(2)] J. Morgenstern,[(2)] C. Pasquier,[(2)] J. Picard,[(2)] D. Poizat,[(2)] B. Saghai,[(2)] J. Specht,[(1)] P. Vernin,[(2)] and E. Warde[(4)]

[(1)]*Physics Division, Argonne National Laboratory, Argonne, Illinois 60439-4843*

[(2)]*Département de Physique Nucléaire et de Hautes Energies, Centre d'Etudes Nucléaires de Saclay, F91191 Gif-sur-Yvette CEDEX, France*

[(3)]*Department of Physics, University of Illinois, Urbana, Illinois 61801*

[(4)]*Institut de Physique Nucléaire, F91406 Orsay CEDEX, France*

[(5)]*Department of Physics, Seoul National University, Seoul 151, Korea*

(Received 18 August 1989)

A direct experimental determination has been made of the ratio of the forward-angle positive-pion electroproduction cross section for a proton bound in the deuteron with that of a free proton for invariant masses of 1160 and 1232 MeV. A significant quenching of the reaction in the deuteron is observed.

PACS numbers: 25.30.Fj, 13.60.Le, 25.10.+s

To date, evidence for the modification of the structure of the nucleon in nuclear matter has been suggestive but inconclusive. Quark structure functions measured in deep-inelastic lepton scattering show some dependence on target mass.[1] The quenching of longitudinal strength observed[2] in quasifree-electron scattering by medium-mass nuclei has been attributed to modifications in the nucleon form factors.[3] However, studies of the kinematic scaling properties of quasifree-electron scattering[4] at high momentum transfer, where transverse processes dominate, and studies of polarization transfer[5] show no significant differences between properties of bound and free nucleons. Pion electroproduction on nucleons in nuclei is of interest in this regard because of its sensitivity to medium modifications. Under certain kinematic conditions, the longitudinal component can probe directly the charge distribution of the nuclear pion field. The exchange of pions by bound nucleons may modify that pion field. Friman, Pandharipande, and Wiringa[6] have calculated the pion excess in nuclei which results from multinucleon processes. They find a pion excess which is slightly negative for virtual pion momenta of 100–200 MeV, and positive for higher values with a maximum around 400 MeV. One explanation of the "European Muon Collaboration effect" in deep-inelastic lepton scattering by heavy nuclei is an increase in the density of sea quarks in nuclei[7] associated with this pion excess. Ericson and Thomas[8] have pointed out that pion-exchange currents can produce enhanced electron scattering by virtual pions in the region near 400 MeV where Friman, Pandharipande, and Wiringa predict an enhancement of the pion field. Multinucleon processes such as Δ-nucleon scattering and Δ absorption may also modify electroproduction amplitudes through their effect on the propagation of the Δ in nuclear matter. Simple pion rescattering, if sufficiently strong, can also distort production amplitudes.

To explore the use of pion electroproduction as a probe of such processes, we have performed a series of measurements on hydrogen and deuterium. The deuteron was chosen because, as the simplest nuclear system, it is a natural test case for any nuclear model. Observations were made for π^+ production on both targets for two values of the photon-nucleon invariant mass, $W=1160$ and 1232 MeV. π^- production on deuterium was also measured for $W=1160$ MeV. The kinematics corresponding to $W=1160$ MeV were chosen because for this value of W the longitudinal virtual-photon cross section for electroproduction on the proton is more than twice the transverse cross section,[9] and quasifree scattering by virtual pions (the pion-pole term) is the largest longitudinal process. For forward electron-scattering angles such as those of the measurement reported here, the virtual photon has a strong longitudinal polarization, and the corresponding component is 0.6 of the total photon cross section. For the second kinematic configuration, which corresponds to $W=1232$ MeV, the amplitude for Δ production is enhanced. In both cases, the physics issue addressed is the extent to which the basic quasifree-nucleon reaction is modified by the nuclear binding. The choice of the deuteron offered the advantage of use of a single cryogenic target for the two measurements. Because of the identical geometry, a direct comparison can be made of electroproduction on the proton in the deuteron to that of the free proton without the systematic errors common in absolute measurements. The similarity in the scattered-particle spectra for the two targets cancels any systematic effects on the ratio of the cross sections which are related to detector response and pion decay. Except for small corrections, the ratio of deuterium to hydrogen cross sections can be determined from the knowledge of the incoming charge, the target density, and the measured counts, exclusively.

For all measurements, the incident beam energy was

645 MeV and the electron-scattering angle was 36°. Electrons were observed in the Saclay linear electron accelerator (ALS) 900-MeV spectrometer and coincident pions in the ALS 600-MeV spectrometer[10] which was set at 34°, as close as geometry permitted to the direction of the q vector. In the "dip" kinematics corresponding to $W=1160$ MeV the virtual photon is emitted at 30°. In dip kinematics, the scattered-electron energy was 355 MeV, the vector momentum transfer was 412 MeV/c, and the four-momentum transfer squared was 0.0856 $(\text{GeV}/c)^2$. The corresponding quantities in Δ kinematics were 269 MeV, 455 MeV/c, and 0.0656 $(\text{GeV}/c)^2$, respectively. A trigger in the pion arm was determined by coincident scintillators placed to require traversal by all charged particles of a gas Čerenkov counter which was used in anticoincidence to suppress contributions from scattered electrons or positrons. The combined solid angle for the two spectrometers was evaluated by means of a Monte Carlo calculation that utilized their measured magnetic properties and included the effects of pion decay in the particle tracking. The missing-mass spectrum observed for the proton in this configuration is shown in Fig. 1. The spectral shape for the proton provides a measure of the effect of continuum radiative processes. Determination of the absolute cross section provided a check on the spectrometer acceptances used in the data reduction and on the procedures used to correct pion decay in flight and radiative processes. We measured a pion production cross section for the proton at $W=1160$ MeV of $d^3\sigma/d_e\Omega\, d_eE\, d\Omega_\pi=46\pm3$ pb/sr^{2}MeV. This result can be compared with that of Bardin *et al.*[9] and the phase-shift analysis of von Gehlen[11] through the virtual-photon cross section in the center of mass, which is free of extraneous kinematic dependences. Using the notation of Ref. 12, we measure $d\sigma/d\omega=9.7\pm0.5$ μb/sr for the virtual-photon cross section at $W=1160$ MeV. Interpolation of the data of Bardin *et al.* to our kinematics gives 10.7 ± 1.0 μb, in good agreement. The value predicted by the phase-shift analysis is 7.1 μb. The discrepancy here may arise from the lack of data between the pion threshold and the Δ which would constrain the phase shifts in the kinematics of our experiment.

The missing-mass spectrum measured for the deuteron is presented in Fig. 1. Within the accuracy of the data, the shape agrees well with a calculation of quasifree electroproduction on a nucleon described by a standard deuteron wave function including the D-state component.[13] Similar conclusions pertain to the line shape observed for $W=1232$ MeV. For the ratio of the deuteron cross section for positive pions integrated over missing mass to the proton production cross section, we find

$$R=0.80\pm0.05\,,\quad W=1160\,\text{MeV}\,,$$
$$R=0.75\pm0.07\,,\quad W=1232\,\text{MeV}\,.$$

We have also measured the π^+/π^- ratio for deuterium

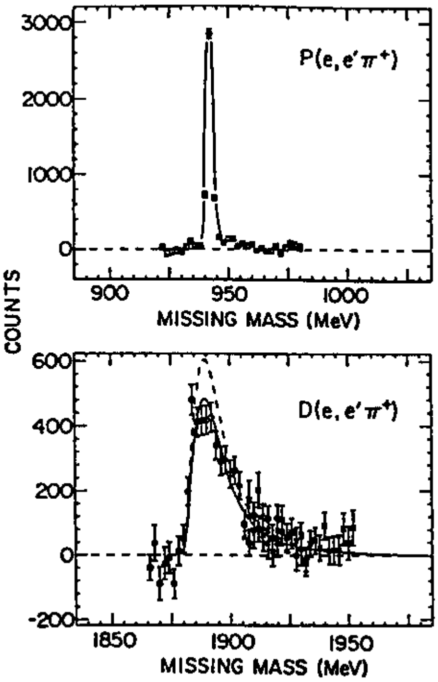


FIG. 1. Missing-mass spectra for an invariant mass of 1160 MeV. The incident electron energy is 645 MeV and the electron-scattering angle is 36°. The circles represent data taken with the pion spectrometer centered on the peak of the pion distribution. The crosses in the deuteron spectrum were taken with the central momentum of the pion spectrometer lowered by 20% in order to observe the strength at higher missing mass. The data have been corrected for the missing-mass acceptance. No corrections have been made for radiative processes. The curve for the hydrogen data is a radiation-broadened monoenergetic peak. The dashed curve in the deuteron data is the radiation-broadened shape calculated for quasifree electroproduction on the proton bound in the deuteron with the same integrated yield as the proton. The solid curve has been renormalized by 0.8 to fit the data.

for $W=1160$ MeV and find 0.94 ± 0.11. The error in this value results primarily from the more limited statistics of the π^- measurement. The deuteron/proton ratios are of particular interest. The decrease of the deuteron cross section compared to the value for a free proton in the same kinematics may signal significant nuclear-medium effects.

Forward-angle quenching may arise from modifications in the $n\to n\pi$ coupling by multinucleon processes in the bound system. Direct pion charge scattering, shown in Fig. 2(a), is believed to be important at forward angles where t-pole processes are favored.[9] In a composite system, this amplitude is modified by the addition of other multinucleon processes such as those of Figs. 2(b) and 2(c). The nucleon rescattering terms, in which the pion is subsequently scattered by the photon into the continuum, can equivalently be considered as medium modifications of the pion propagator for the basic pion-pole term of Fig. 2(a). As mentioned above,

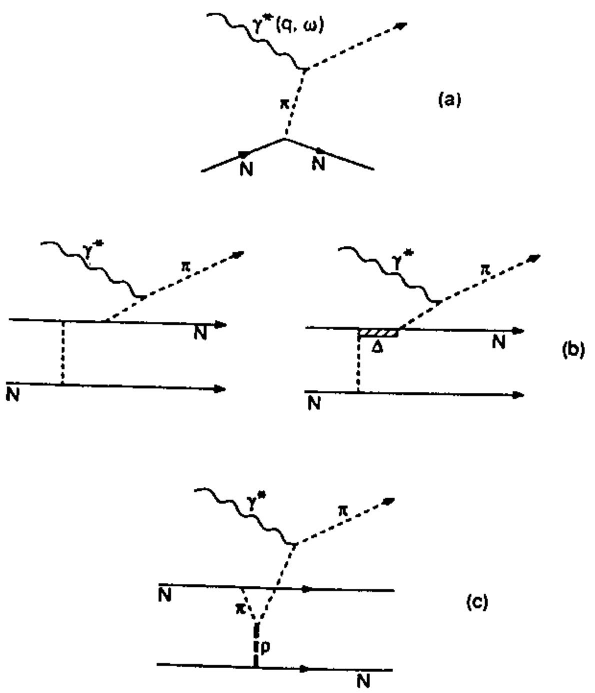


FIG. 2. Electron charge scattering due to the nucleon pion field in (a) lowest-order and (b),(c) multinucleon higher-order charge-scattering processes.

Ericson and Thomas[8] and others have speculated that such higher-order processes can enhance the longitudinal response of the nuclear system in the pion momentum range of 2–3 fm^{-1}. Such an enhancement can be interpreted as a pion excess arising from the exchange processes. At the lower virtual-pion momenta probed at our kinematics, constraints on the final states available to the neutron pair can suppress the reaction. This suppression is the origin of the negative pion excesses which are calculated by Friman, Pandharipande, and Wiringa[6] for pion momenta near 1 fm^{-1}. The forward-angle suppression of electroproduction indicated in our results, particularly at $W=1160$ MeV, may provide the first experimental indications for a significant change in the pion content of nucleons bound in nuclei. At $W=1232$ MeV, in contrast to the data at 1160 MeV, there will be a substantial suppression in the deuteron cross section from Fermi broadening because of the proximity to the peak position of the Δ in the proton. A first-order Born approximation calculation gives a 0.14 decrease due to kinematic broadening. The remainder of the suppression may have its origin in Δ-nucleon final-state interactions.

Another possible source of suppression at forward angles, pion absorption, should not be significant. Recent results on studies of pion absorption in light nuclei[14] imply that absorption should be weak for π^+ production on the deuteron since the final nucleon state is $T=1$. A comparison of the photoabsorption cross section for the deuteron[15] with the photopion cross section provides an upper limit of 5% for pion absorption. In a plane-wave impulse-approximation calculation,[13] inclusion of the Pauli effect on the final *nn* state leads to a 0.08 decrease in the ratio R for both values of W. It remains to be established whether a combination of pion absorption with kinematic broadening and Pauli blocking of final states can explain our observations. It is clear that a systematic study of forward-angle electroproduction will be necessary to establish quantitatively the sensitivity to the pion content. Rosenbluth separations will be needed to isolate the longitudinal cross section in which pionic charge effects are expected to be most prominent. Study of the dependence of the cross section on momentum transfer will be needed to probe the dependence of any enhancement or suppression on virtual-pion momentum. Measurements for a number of light nuclei will provide useful data on the sensitivity of longitudinal electroproduction to nuclear-binding effects.

In summary, we have made the first direct experimental comparison of charged-pion electroproduction by a nucleon bound in a nuclear system with that of the free nucleon. Our data provide strong evidence that, even in the weakly bound deuteron, multinucleon processes alter the electroproduction amplitudes in the forward direction. More detailed studies of the reaction as a function of momentum transfer and target mass will be needed to establish its sensitivity to properties of the nuclear pionic field.

We are grateful to F. Coester, J. M. Laget, and T.-S. H. Lee for extensive discussions of the theory of pion electroproduction, and to A. Godin and co-workers for their efforts in operating the hydrogen-deuterium cryogenic target. This work is supported in part by the U.S. Department of Energy, Nuclear Physics Division, under Contract No. W-31-109-ENG-38.

[1]P. B. Renton, in *Topical Conference on Nuclear Chromodynamics*, edited by J. Qiu and D. Sivers (World Scientific, Singapore, 1988), p. 242.
[2]D. Reffay-Pikeroen *et al.*, Phys. Rev. Lett. **60**, 776 (1988).
[3]G. E. Brown and M. Rho, Phys. Lett. B **222**, 324 (1989).
[4]I. Sick, Comments Nucl. Part. Phys. **18**, 109 (1988).
[5]L. B. Rees *et al.*, Phys. Rev. C **34**, 627 (1986).
[6]B. L. Friman, V. R. Pandharipande, and R. B. Wiringa, Phys. Rev. Lett. **51**, 763 (1983).
[7]E. L. Berger and F. Coester, Phys. Rev. D **32**, 1071 (1985).
[8]M. Ericson and A. W. Thomas, Phys. Lett. **128B**, 112 (1983).
[9]G. Bardin *et al.*, Nucl. Phys. **B120**, 45 (1977).
[10]P. Leconte *et al.*, Nucl. Instrum. Methods **169**, 401 (1980).
[11]G. von Gehlen, Nucl. Phys. **B20**, 102 (1970).
[12]C. J. Bebek *et al.*, Phys. Rev. D **12**, 25 (1976).
[13]T.-S. H. Lee (private communication).
[14]D. Ashery and J. P. Schiffer, Annu. Rev. Nucl. Part. Sci. **36**, 207 (1986).
[15]J. M. Laget, Can. J. Phys. **62**, 1046 (1984).