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Charged Pion Electroproduction on H,^2H, and ^3He

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On behalf of the NucPi Collaboration

A series of measurements of single pion electroproduction on the proton, deuteron, and ^3He was completed recently at Jefferson Laboratory by the NucPi Collaboration. The goal was a determination of the longitudinal cross section in parallel kinematics by means of a Rosenbluth separation, and a search for target-mass dependent effects. Longitudinal pion electroproduction should be sensitive to nuclear pion currents because of the dominance of the pion-pole process for charged-pion emission in the direction of the virtual photon. The mass dependence of the longitudinal cross section should provide insight into the absence of any enhancement of sea quark distributions in nuclei as measured in deep-inelastic scattering. Data have been obtained at $Q^2 = 0.4\ GeV^2$, for $W = 1.15$ and $W = 1.6\ GeV$. from H,^2H, and ^3He, and for a range of values of Q^2 on H and ^2H at $W = 1.9\ GeV$. Preliminary results for separated longitudinal and transverse cross sections are presented and implications for understanding nuclear pion exchange currents are discussed.

1. Introduction

According to the simplest models of the nucleon-nucleon force, pion-exchange currents in nuclei should give rise to a mass-dependent enhancement[1] of the nuclear pion charge distribution. Longitudinal pion electroproduction should be sensitive to nuclear pion currents because of the dominance of the pion-pole process for charged-pion emission in the direction of the virtual photon. If current conceptions of pion-exchange currents in nuclei are correct, longitudinal electroproduction will be suppressed at lower momentum transfers and enhanced at higher momentum transfers. These currents should also manifest themselves in quark-antiquark distribution functions[2,3] as observed in deep-inelastic scattering(DIS) on nuclei. However, analysis of parton distribution functions shows no evidence for any mass enhancements of sea quarks. Recent data from Drell-Yan studies[4] which probe directly the quark- antiquark sea, show no mass dependence. These results suggest that a reformulation of pion-exchange models of the medium- and short-range properties of nuclear forces may be required. In an attempt to probe exchange currents directly, we have carried out a series of measurements of single-charged-pion electroproduction on the proton, deuteron, and ^3He at TJNAF. The goal is to measure the longitudinal cross section in parallel kinematics by means of a Rosenbluth separation, and to search for target-mass dependent effects. The results from these measurements should provide insight into the absence of any enhancement of sea quark distributions in nuclei as measured in DIS.

DISCLAIMER

2. Measurements

The single π electroproduction cross section for the free proton has the form

$$\frac{d\sigma}{d\Omega_{e'}dE_{e'}d\Omega_\pi^*} = \Gamma[\frac{d\sigma_t}{d\Omega_\pi^*} + \epsilon^l\frac{d\sigma_l}{d\Omega_\pi^*} + \sqrt{2\epsilon_l(1+\epsilon)}\frac{d\sigma_{lt}}{d\Omega_\pi^*}cos\phi_\pi^* + \epsilon\frac{d\sigma_{tt}}{d\Omega_\pi^*}cos2\phi_\pi^*]$$

where ϵ is the transverse polarization and $\epsilon_l = \frac{q^2}{\omega^2}\epsilon$ the longitudinal polarization of the virtual photon. The pion angles θ_π^* and ϕ_π^* are defined in the center-of-mass frame. For forward electroproduction, ie. $\theta_\pi^* = 0$, the pion pole process which corresponds to scattering by the pion field, is known[5] to

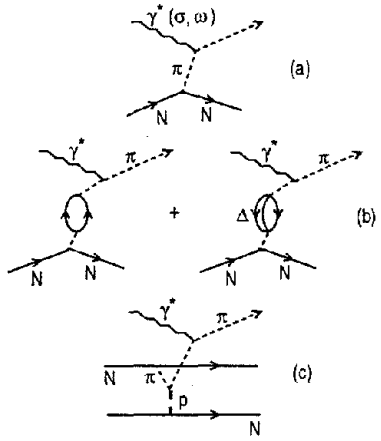

Fig.1 *Electron charge scattering due to the nucleon pion field in lowest order(a) and from multinucleon higher order processes(bc).*

dominate. To the extent that this dominance is valid, $\frac{d\sigma_L}{d\Omega_\pi^*}(\theta_\pi^* = 0)$ provides a direct probe of the basic $n \rightarrow n\pi$ coupling. Multinucleon processes, which can be related to the nuclear pion excess will modify this cross section in nuclear targets. The pole process is shown in Fig.1a, and multinucleon processes which may modify the pole amplitude are shown in Fig. 1b,c. It is useful to view these effects as modifications of the elementary $n \rightarrow n\pi$ coupling in nuclear matter. Consequently, a direct comparison of the longitudinal cross section per nucleon in the nuclear targets with the experimental value for the free nucleon will provide evidence for the presence of multinucleon effects which can be related to the nuclear pion excess. The deuteron and ^3He are particularly interesting systems for which microscopic calculations of these multinucleon contributions may be possible. The measurements were carried out at Jefferson Lab in Feb-April 1998 using the Hall C facility. 0.845 to 3.245 GeV electrons were scattered from high-density cryo-targets. The scattered electrons were observed in the High Momentum Spectrometer in coincidence with pions observed in a short orbit spectrometer. The kinematic conditions, shown in table 1, correspond to momentum transfers for which, in one case, the electroproduction is expected to be quenched ($p_{recoil} \approx 0.200\ GeV/c$), and a second, in which according to the standard pion-exchange model of nuclear forces, one expects a substantial enhancement ($p_{recoil} \approx 0.400\ GeV/c$). In the forward direction only $\frac{d\sigma_L}{d\Omega_\pi^*}$ and $\frac{d\sigma_L}{d\Omega_\pi^*}$ contribute to $\frac{d\sigma}{d\Omega_{e'}dE_{e'}d\Omega_\pi^*}$. Measurements were made at kinematics corresponding to two virtual photon polarizations for each momentum transfer in order to use the data to carry out a Rosenbluth separation of the transverse and longitudinal cross sections.

Table 1
Kinematic Conditions for JLAB experiment E91-003

E	ω	Θ_e	Θ_q	W	Q^2	p_π	ϵ	p_{recoil}
GeV	*GeV*	*deg*	*deg*	*GeV*	GeV/c^2	*GeV/c*		*GeV/c*
0.845	0.46	66.87	27.11	1.150	0.396	0.327	0.43	0.451
1.645	0.46	26.04	41.94	1.150	0.396	0.327	0.86	0.451
1.645	1.108	39.33	15.46	1.600	0.400	1.079	0.49	0.197
3.245	1.108	13.79	23.54	1.600	0.400	1.079	0.89	0.197
2.446	1.879	38.40	10.01	1.950	0.600	1.856	0.37	0.180
3.549	1.879	18.31	14.87	1.950	0.600	1.856	0.74	0.180
2.669	1.957	36.60	11.45	1.950	0.750	1.929	0.43	0.210
3.549	1.957	21.00	15.47	1.950	0.750	1.929	0.70	0.210
3.007	2.410	56.33	10.50	1.950	1.600	2.326	0.27	0.400
4.045	2.410	28.49	16.63	1.950	1.600	2.326	0.63	0.400

3. Results

The general features of the deuterium and ^3He pion spectra in missing mass, are typical of quasifree scattering. An example of the data obtained is shown in Fig.2 in which the missing mass spectra for π^+ and π^- production on ^3He are compared. The π^+ yield was divided by 2 in order to make a direct comparision of the π^+ production on the protons in ^3He with π^- production on the neutron. For the π^+ production, in addition to the quasifree component which appears to be the same as for π^-, there is a sharp peak corresponding to coherent production leading to a triton in the final state. The forward angle electroproduction cross section integrated over missing mass, $\frac{d^3\sigma}{d\omega d\Omega_e d\Omega_\pi} = \int \Gamma_v [\frac{d^2\sigma_t}{dM d\Omega_\pi} + \epsilon \frac{d^2\sigma_l}{dM d\Omega_\pi}] dM$ provides the most direct basis for comparing quasifree electroproduction with production on the free nucleon. The ratio of this cross section to that of the proton is a robust indicator of any mass dependence. The ratio of the luminosity normalized pion yields corrected for experimental acceptance, $\frac{d^3\sigma_A}{d^3\sigma_p} \equiv \frac{(N^{\pi^+}{}_A/q_A)/exp\_accept_A}{(N^{\pi^+}{}_p/q_p)/exp\_accept_p}$, was used to estimate the cross section ratio. Unseparated cross section ratios measured for two invariant masses are presented in Table 2. The first kinematics correspond to a recoil momentum of 0.197 *GeV* in the region where a quenching of the cross section is expected. The second kinematics correspond to 0.450 *GeV* where an enhancement could occur. The data of Table 2 show an apparent quenching of the nuclear cross sections at each measured point. However, these data must be corrected for the trivial modification of the nuclear cross sections which comes from the kinematic effects of the Fermi momenta of the target nucleons. The physics quantity of basic interest is the longitudinal charged pion electroproduction cross section for the proton bound in the deuteron and ^3He measured relative to the cross section for the free proton. To extract this quantity, the experimental measured coincidence

yield is simulated in a Monte Carlo calculation(SIMC) using a realistic model of the

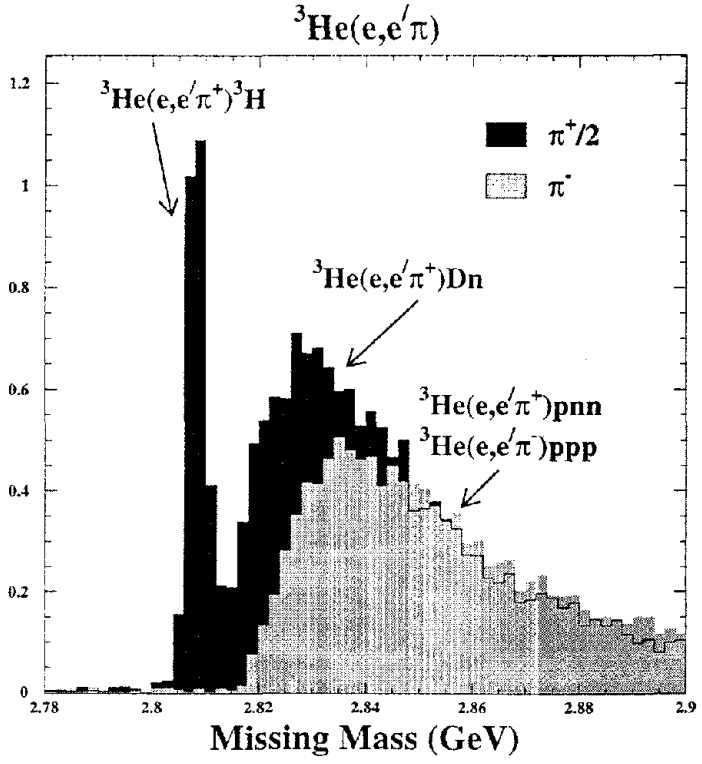

Fig.2 *The Missing Mass Spectra for π^+ and π^- electroproduction on ^3He with $W = 1.6$ GeV, $Q^2 = 0.40$ GeV^2.*

experiment. The effects of spectrometer response, radiation, nucleon Fermi motion, and kinematic variation of the primary nucleon cross section are included in the simulation. The measured data are compared with the simulation. The input data are refined and the process iterated until the best fit is obtained. The extracted experimental cross section is then defined as $\sigma(Q_0^2, W_0, \Theta_{cm}) = \sigma_{model}(Q_0^2, W_0, \Theta_{cm}) * (data)/(SIMC)$. To avoid corrections for the coherent contributions, $^3He(e, e'\pi^+)T/Dn$, to the π^+ spectrum measured for ^3He, the π^- spectrum corrected by the measured π^+ to π^- ratio measured for σ_l in the deuteron is used to estimate quasifree π^+ production in ^3He. The resulting extracted cross section ratios are shown in Fig.3.

Table 2
Unseparated cross section ratios for deuterium and ^3He

Kinematics	Target	$d^3\sigma_A^{\pi^+}/d^3\sigma_p$	$d^3\sigma_A^{\pi^-}/d^3\sigma_p$
$W = 1.6GeV$	proton	1	
$\epsilon = 0.89$	deuteron	0.85 ± 0.04	0.83 ± 0.04
$p_r = 0.197GeV$	^3He	(0.60 ± 0.05)	0.59 ± 0.04
$W = 1.15GeV$	proton	1	
$\epsilon = 0.86$	deuteron	0.95 ± 0.03	0.91 ± 0.03
$p_r = 0.451GeV$	^3He	(0.79 ± 0.03)	0.75 ± 0.02

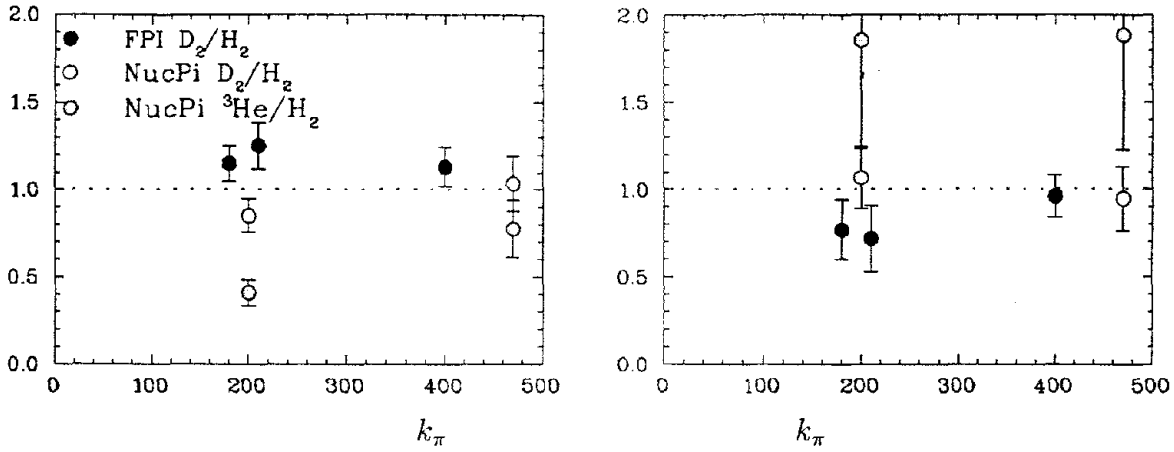

Fig.3 *The measured ratios of $d\sigma_l/d\Omega_\pi$ and $d\sigma_t/d\Omega_\pi$ for single $\pi+$ electroproduction on the deuteron and ^3He to the free proton cross section*

4. Discussion

Within the precision of the measurements summarized in Table 1, there is no indication of multinucleon contributions. The measured values of the $d\sigma_l/d\Omega_\pi$ ratios cluster around one, with the exception of the point for ^3He at 0.197 GeV. The transverse ratios for the deuteron also cluster near one, while the results for ^3He are substantially greater than one. However, the errors for the latter points are unavoidably large because the corresponding $d\sigma_t/d\Omega_\pi$ are small relative to $d\sigma_l/d\Omega_\pi$. There is no evidence in these data for a measurable enhancement of $d\sigma_l/d\Omega_\pi$ in either target. The quenching observed in earlier measurements[6] on the deuteron at $k_\pi = 0.2$ GeV is present in the deuteron data for $W = 1.6$ GeV and appears stronger in ^3He, ie ≈ 0.4, but this trend is absent in the data for $W = 1.95$ GeV. Qualitatively, these data are consistent with conclusions drawn from earlier work on DIS. There is no experimental evidence for a measurable pion excess. More precise interpretation on the data presented here will require detailed theoretical estimates of the contributions expected from the exchange currents in the deuteron and ^3He.

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References

1. B.L. Friman, V.R.Pandharipande, and R.B. Wiringa, Phys. Rev. Lett. **51**, 763 (1983).
2. H. Jung, and G.A. Miller, Phys. Rev. **C41**, 659 (1990).
3. G.F. Bertsch, L. Frankfurt, and M. Strikman, Science **259**, 773 (1993).
4. D.M.Alde et al., Phys. Rev. Lett. **64**, 2479 (1990).
5. G. Bardin et al., Nucl. Phys. **B120**, 45 (1977).
6. R. Gilman et al., Phys. Rev. Lett. **64**, 622 (1990)