LA-UR -91-2857

LA-UR--91-2857

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The Proceedings of the International Workshop on Pions in Nuclei, Peniscola, Spain, June 3-8, 1991

Los Alamos

Los Alamos National Laboratory
Los Alamos, New Mexico 87545

QUASIFREE POLARIZATION-TRANSFER MEASUREMENTS IN THE $(\vec{p},\vec{n})$ REACTION AT 495 MeV

J.B. McClelland, T.A. Carey, L.J. Rybarcyk, W. Sailor, and T.N. Taddeucci
Los Alamos National Laboratory, Los Alamos, New Mexico 87545

X.Y. Chen and D. Mercer
University of Colorado, Boulder Colorado 80309

S. DeLucia, B. Luther, D.G. Marchlenski, and E.R. Sugarbaker
Ohio State University, Columbus, Ohio 43210

J. Rapaport
Ohio University, Athens, Ohio 45701

E. Gülmez and C. Whitten Jr.
University of California, Los Angeles, California 90024

C.D. Goodman and Y. Wang
Indiana University Cyclotron Facility, Bloomington, Indiana 47405

W.P. Alford
University of Western Ontario, London, Ontario, Canada N6A 3K7

ABSTRACT

A complete set of polarization transfer observables for quasifree scattering in the $(\vec{p},\vec{n})$ reaction at 495 MeV is reported. Measurements were carried out on CD_2, natural carbon, and calcium targets at a momentum transfer of 1.72 fm^{-1} using the new Neutron Time-of-Flight facility at LAMPF. The spin-longitudinal and spin-transverse responses are extracted from the data. The ratio of these responses are compared to DWIA-RPA calculations in which the particle-hole interaction is taken to be of the form $g'+\pi+\rho$. No evidence for these RPA correlations is seen in the data at this momentum transfer.

1. Introduction

Recently there has developed a growing body of data concerning excitations of high-lying continuum modes by a variety of probes (e, π, p, n, d, ^{3}He,..., heavy ions). Continuum scattering in the quasifree region should be a particularly incisive tool for studying how the nucleus responds via intrinsically nucleonic degrees of freedom to spin, isospin, and large energy and momentum transfers. Although signatures of shell structure, such as low-lying discrete states and giant resonances, disappear in this sector, the nucleus should continue to respond collectively through the action of the residual particle-hole interaction. This collectivity will manifest itself not in sharp states or resonances, but in the gross features of the spectrum, such as shifts in the position and magnitude of the quasifree peak and deviations of spin observables or of the derived spin-response functions from the free-nucleon values. The very (non)existence of such collectivity is directly connected to the form and magnitude of the spin-isopin-dependent parts of the residual interaction, and hence to the basic underlying degrees of freedom in the nuclear system.

A unique spin-isospin sensitivity is provided by the nucleon charge-exchange reactions such as (p,n), which provides a solely isovector probe of the nuclear response. Until recently, only limited polarization-transfer data were available, none above 200 MeV. The new Neutron Time-of-Flight (NTOF) facility[1] at LAMPF now provides such a capability up to 800 MeV.

By measuring complete sets of polarization-transfer (PT) observables for quasifree scattering, the spin-longitudinal and spin-transverse nuclear responses can be extracted[2,3]. The spin-transverse response can be compared to transverse electron scattering, while the spin-longitudinal response is unique to those probes coupling longitudinally to the spin of the nucleon, such as nucleon scattering or semi-hadronic processes.

The contrast between the spin-longitudinal and spin-transverse responses should provide a sensitive test of particle-hole correlations in the nucleus.[4] In particular, if the form of the interaction is taken to be $g'+\pi+\rho$, one expects to observe an enhancement and softening of the longitudinal response and a quenching and hardening of the transverse responses with respect to the free response using reasonable values of g' of 0.6 to 0.7. This produces sizable differences in the ratio of these responses for quasifree scattering.

In addition to providing information on the particle-hole interaction away from $q=0$ momentum transfer, these types of measurements are also sensitive to effects due to relativistic dynamics and serve to define the form of the effective NN interaction. Nucleon charge-exchange measurements are very complementary to (p,p') in that they sample very different parts of the interaction in these models, particularly the treatment of the pion.[5]

2. The Experiment

A complete set of PT observables for quasifree scattering on ^{2}H, C, and Ca at a momentum transfer of 1.72 fm^{-1} was taken at 495 MeV with the new NTOF facility at LAMPF. Spin precession equipment at the ion source and in the high-energy beamlines provided all three polarization directions (s,n,l) at the NTOF target. The average beam intensity was 78 nA with an average polarization of 52% and a pulse separation of 200 nsec. The neutron detectors were positioned at 200 meters from the NTOF target. Areal densities of 0.78, 1.0, and 1.0 gm/cm^2 were used for the CD_2, natural carbon, and calcium targets respectively. The overall system resolution for this experiment was about 1 MeV (FWHM).

The neutron detection system was comprised of four segmented scintillator planes approximately 1.0 x 1.0 x 0.1 m^3. The segmentation provided essentially ten 1.0 x 0.1 x 0.1 m^3 cells per plane, viewed on both ends by photomultiplier tubes. The front two and one of the rear planes were constructed of a thin stainless steel tank filled with liquid scintillator (Bicron BC517S), with the segmentation provided by optical isolator panels in the scintillator. This particular liquid scintillator has a high hydrogen-to-carbon ratio of 1.?:1, useful for neutron polarimetry, where the free and quasifree scatterings in the scintillator provide the analyzing reaction. The fourth plane was of similar design but instead used plastic scintillator. The neutron polarimeter was calibrated near 492 MeV using the $^{14}C(\vec{p},\vec{n})^{14}N$ reaction to the 0^+ state at 2.31 MeV at zero degrees. This 0^+ to 0^+ transition provides a "neutron beam" at the detectors of known polarization since the longitudinal spin-transfer coefficient D_{LL} is equal to unity. Therefore, the neutron polarization is equal to the proton beam polarization, which is well determined in the high-energy beamline polarimeters. In order to resolve the state of interest, it was necessary to longitudinally focus the beam at the NTOF detectors using a technique which utilizes unused acceleration modules in the linac when operating at energies below 800 MeV. This provides a longitudinal phase rotation to minimize the contribution of the energy spread in the beam to the neutron energy resolution.[6] An additional normalization near 430 MeV was provided by using the $P=A_y$ relation for quasifree scattering from deuterium. Both the (n,n) elastic and (n,p) charge-exchange scatterings in the front planes contribute to the measured asymmetry.

The high-energy calibrations were extrapolated to the range of energies appropriate to the quasifree scattering, 350 to 450 MeV, using a Monte Carlo simulation of the detection system acceptance and the energy dependence of the free (n,n) and (n,p) phase-shift values for cross section and analyzing power. A calibration at lower energy is expected to take place this year to confirm the extrapolation methods and any rate dependences might effect the calibration. At present we ascribe a 5-10% systematic uncertainty in the individual polarization transfer observables due to calibration uncertainties. Otherwise, all errors quoted are statistical only.

Data for the quasifree scattering were sorted into 10-MeV bins from 30 to 150 MeV in neutron energy loss.

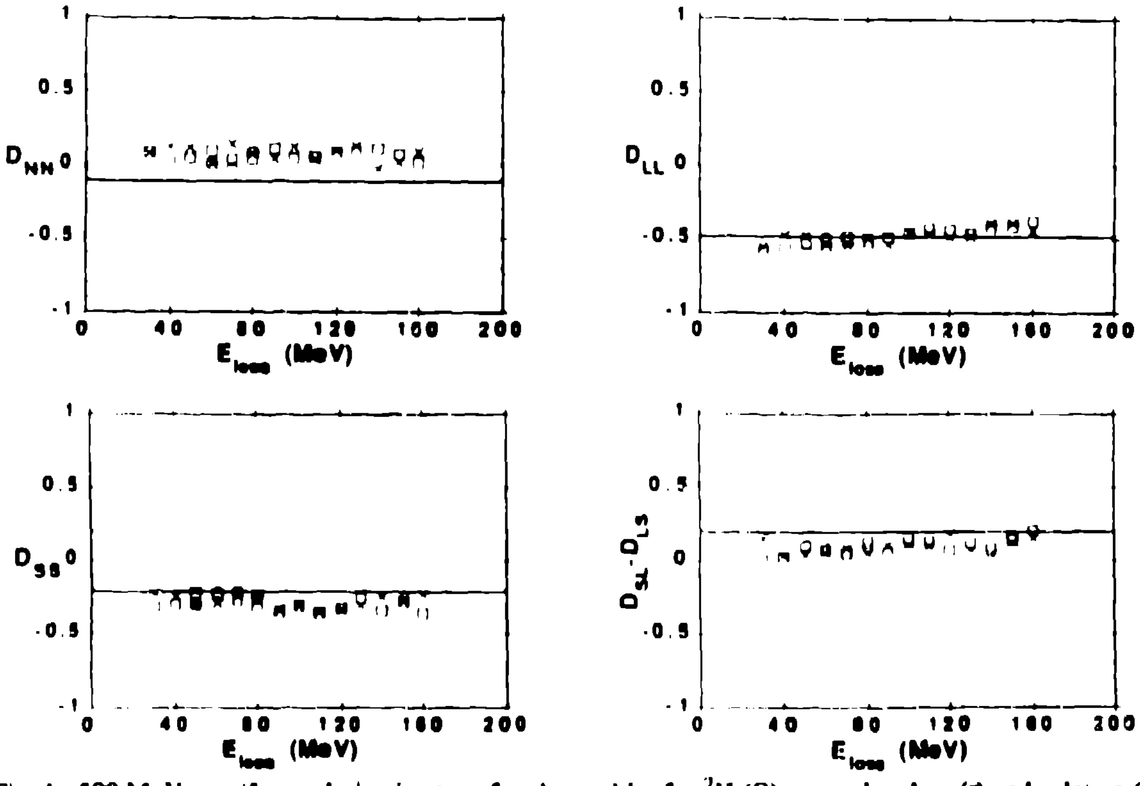

Fig. 1. 500 MeV quasifree polarization transfer observables for ^2H (O), natural carbon (□) and calcium (x). Solid lines are SM90 phase shift values.

3. Analysis

Fig. 1 shows the PT observables relevant to R_L and R_T obtained for ^2H (extracted from the CD_2 runs), natural carbon, and calcium over the peak of quasifree scattering, together with a recent phase shift solution for free NN scattering. Notable in these data is the fact that there is no significant difference in any given PT observables for the three targets as a function of energy loss. Inasmuch as the extracted responses are linear combinations of these observables, it is already apparent in the raw data that no significant differences between the nuclear and "free" deuterium values.

In order to extract further information from the data, it is necessary to take advantage of the connection of PT observables to the nuclear response functions. It has been shown that in the plane-wave limit and assuming NN kinematics, the following linear combinations can be constructed which are related to the spin-longitudinal and spin-transverse response functions:[2,3]

$$D_q = \tfrac{1}{4}\left[1 + D_{qq} - D_{nn} - D_{pp}\right] = \frac{R_L|\delta|^2}{I} \approx \tfrac{1}{4}\left[1 - D_{NN} + (D_{SS} - D_{LL})\sec\theta_L\right]$$

$$D_p = \tfrac{1}{4}\left[1 - D_{qq} - D_{nn} + D_{pp}\right] = \frac{R_T|\varepsilon|^2}{I} \approx \tfrac{1}{4}\left[1 - D_{NN} - (D_{SS} + D_{LL})\sec\theta_L\right] \tag{1}$$

where R_L (R_T) is the spin-longitudinal (spin-transverse) response

$$\hat{q} = \frac{\vec{k}_f - \vec{k}_i}{\left|\vec{k}_f - \vec{k}_i\right|} \qquad \hat{n} = \frac{\vec{k}_i \times \vec{k}_f}{\left|\vec{k}_i \times \vec{k}_f\right|} \qquad \hat{p} = \hat{q} \times \hat{n} \tag{2}$$

are the center of mass coordinates and

$$\hat{N} = \frac{\vec{k}_i \times \vec{k}_f}{\left|\vec{k}_i \times \vec{k}_f\right|} \qquad \hat{L} = \hat{k}_i \qquad \hat{S} = \hat{N} \times \hat{L} \tag{3}$$

and θ_L are laboratory quantities, with k_i and k_f being the initial and final momenta respectively. δ ad ε are the spin-longitudinal and spin-transverse amplitudes of the NN scattering matrix given by

$$\begin{aligned} M(q) = \alpha - i\gamma\left\{(\sigma^1 \bullet \hat{n}) + (\sigma^2 \bullet \hat{n})\right\} + \\ \beta(\sigma^1 \bullet \hat{n})(\sigma^2 \bullet \hat{n}) + \delta(\sigma^1 \bullet \hat{q})(\sigma^2 \bullet \hat{q}) + \varepsilon(\sigma^1 \bullet \hat{p})(\sigma^2 \bullet \hat{p}) \end{aligned} \tag{4}$$

This analysis was used in our previous experiment[7] using the $(\vec{p},\vec{p}')$ reaction at the same energy and momentum transfer as the present experiment. There too, no differences were found for medium to heavy nuclei as compared to deuterium. The $(\vec{p},\vec{p}')$ reaction, however, brings in the isoscalar response and further corrections to the data had to be made in order to extract the isovector responses. Only the isovector responses contribute to the present experiment using the $(\vec{p},\vec{n})$ reaction.

Distortions can in principle destroy the equivalence in Eq. 1. In order to quantify the effects of distortion, a comparison was made between the ratio of the true spin-longitudinal (R_L) and spin-transverse (R_T) responses as a function of neutron excitation energy and the ratio of response as derived from Eq. 1. All quantities were obtained from the DWIA-RPA calculations of reference 8 using the $g'+\pi+\rho$ model for the interaction with a value of g' equal to 0.7. Although not identical, the true ratio of responses (R_L/R_T) is reasonably approximated by those extracted from Eq. 1, particularly in the region of the peak for quasifree scattering. In any case, large enhancements in both ratios are predicted between the RPA correlated and uncorrelated results. In all that follows, we will compare data and theory on the same basis. That is to say, using the linear combinations of PT observables as measured in the experiment and as predicted in the theory.

4. Results and Discussion

Fig. 2 shows our preliminary results for the ratio of spin-longitudinal to spin-transverse response functions for carbon and calcium. Also shown are DWIA calculations from reference 8 for the same quantities with and without RPA correlations. Our data are in good agreement with the calculations without RPA correlations.

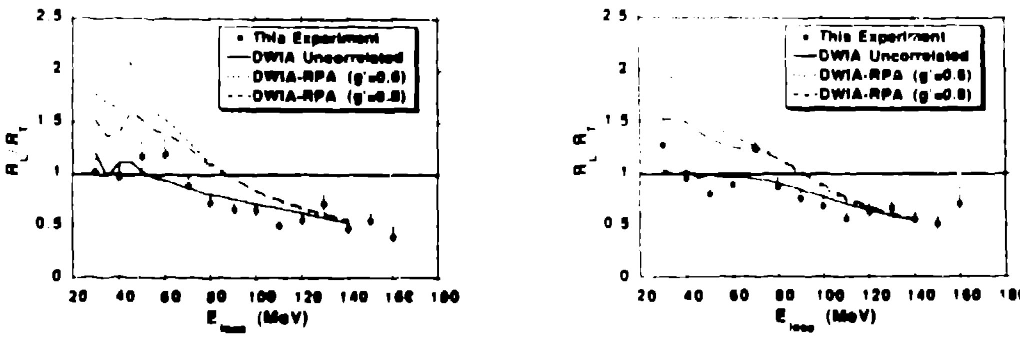

Fig. 2. Ratio of spin-longitudinal to spin-transverse responses for carbon (left) and calcium (right). Calculations are from reference 8.

While these results are compelling evidence for lack of enhancement due to RPA correlations, there are several qualifying points to be made. While the ratio of responses without RPA correlations is in good agreement with our data, the individual PT observables vary somewhat in the degree of agreement. Proper attention must be paid to the transformation of observables from the center of mass to laboratory frames and the proper frame in which to evaluate the NN amplitudes. These investigations are underway. Further refinements will be required before a definitive statement can be made. Other forms of the interaction can also be tested against the data. Work is now in progress towards this end.

Further data taking is planned in upcoming runs at different momentum transfers in order to map out the momentum dependence of our result.

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