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Brief Reports

Brief Reports are accounts of completed research which do not warrant regular articles or the priority handling given to Rapid Communications; however, the same standards of scientific quality apply. (Addenda are included in Brief Reports.) A Brief Report may be no longer than four printed pages and must be accompanied by an abstract.

Analyzing powers for the reaction $\pi^-\vec{p} \to \pi^0 n$ at $T_{\pi^-} = 161$ MeV

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Analyzing powers for the reaction $\pi^-\vec{p} \to \pi^0 n$ were measured at an incident pion energy of $T_{\pi^-} = 161$ MeV with a transversely polarized proton target over the angular range of about 20–60°. The results are well described by calculations based on current sets of πN phase shifts.

Parity and angular momentum conservation play a central role in strongly interacting systems. Thus phase shifts form a convenient parametrization. Partial-wave analysis also is the starting point for computing the properties and locations of πN resonances which are used to test quark models[1] and in Skyrmion-type calculations.[2] For this reason it is important to have an accurate knowledge of the energy-dependent partial-wave amplitudes. Polarization measurements provide a sensitive way of determining those amplitudes.

Until recently analyzing power measurements for the πN charge-exchange reaction have been reported only for incident pion energies above 192 MeV.[3,4] Here we report on the analyzing powers for the reaction $\pi^-\vec{p} \to \pi^0 n$ at an incident pion energy of $T_{\pi^-} = 161$ MeV.

The measurements were made at the Clinton P. Anderson Meson Physics Facility (LAMPF) with a dynamically polarized target and the LAMPF π^0 spectrometer.[5,6] The transversely polarized target consisted of 2.5 cm^3 of frozen 1-mm-diameter beads composed of ethylene glycol OH-$(CH_2)_2$-OH doped with 6×10^{19} molecules/ml of EHBA-Cr$^{(V)}$ (Ref. 7). The carbon was enriched to 99% ^{13}C. The beads were contained in a Teflon basket which was placed in a ^{3}He bath inside a target cavity within a ^{3}He evaporation refrigerator. The target was placed in a uniform magnetic field of 2.5 T and irradiated by microwaves. The magnitude of the target polarization was determined from measurements of the proton nuclear magnetic resonance (NMR) signal which in turn was normalized by using the thermal equilibrium technique.[8] Proton polarization values were typically around 80%.

The measurements were made at the LAMPF Low En-

TABLE I. Angular distribution of the analyzing powers for the $\pi^-\vec{p} \to \pi^0 n$ reaction at T_{π^-} =161 MeV. The errors σ_{A_y} do not include the target polarization uncertainty of 3.9%.

$(\Theta_{\rm lab})^{\rm a}$ (deg)	Monitor error	$(\Theta_{\rm lab})^{\rm b}$ (deg)	Statistical error	$A_y \pm \sigma_{A_y}$
25	0.012	21.8	0.012	0.24±0.017
		27.6	0.015	0.26±0.019
38	0.013	32.3	0.011	0.33±0.017
		37.3	0.013	0.37±0.018
		42.6	0.018	0.44±0.022
55	0.017	50.3	0.013	0.56±0.021
		54.9	0.014	0.60±0.022
		59.5	0.020	0.65±0.026

[a] Angular position of the spectrometer.

[b] Average value of angular bin.

ergy Pion (LEP) channel with an incident pion flux of 1.5 x 10^6 π^-/s and a momentum bite of $\Delta p/p = 0.5\%$. The relative π^- beam intensity was monitored by means of two toroidal current monitors through which the primary proton beam passed and by an ion chamber through which the π^- beam passed.

The data were obtained at three spectrometer positions of 25°, 38°, and 55°. The spectrometer was set at a distance of 1.5 m from the target for the 25° measurements and at 1.0 m for the 38° and 55° measurements. The angular acceptance was about 24° at the 1-m setting and about 18° at 1.5 m. The angular resolution was 6° and the acceptance was divided into three or two bins, respectively, not necessarily of equal width. Two independent sets of measurements were made for the 38° and 55° settings which, in addition, were separated by a considerable time period (approximately one week) to check the reproducibility of the data.

With a target polarization normal to the scattering plane, the analyzing power is given by

$$A_y(\theta) = \frac{N^+ - N^-}{N^+P^- + N^-P^+}, \qquad (1)$$

where N^+ and N^- are the relative scattering yields for the target polarized parallel or antiparallel to the cross product of incoming and outgoing pion momenta, respectively. P^+ and P^- stand for the corresponding target polarization values.

The asymmetries were extracted from the background-subtracted yield spectra by using empirically determined line shapes. Line shapes for the background and signal were derived from separate data obtained with a carbon target and with a polyethylene (CH_2) target. Figure 1 shows a typical excitation energy spectrum. The asymmetries thus obtained from the hydrogen target are listed in Table I.

Most of the uncertainties usually encountered in differential-cross-section measurements (e.g., detector efficiencies, solid angle, absolute beam flux, etc.) cancel out in the expression for $A_y(\theta)$. An estimate of the sys-

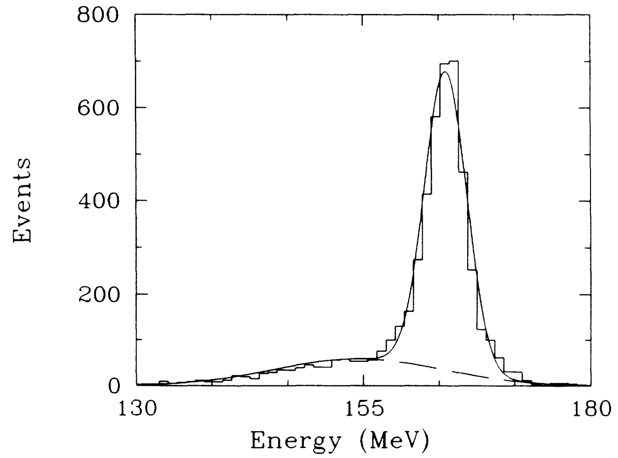

FIG. 1. Excitation-energy spectrum for the 21.8° bin. The background is mainly due to quasifree charge exchange on ^{13}C contained in the target.

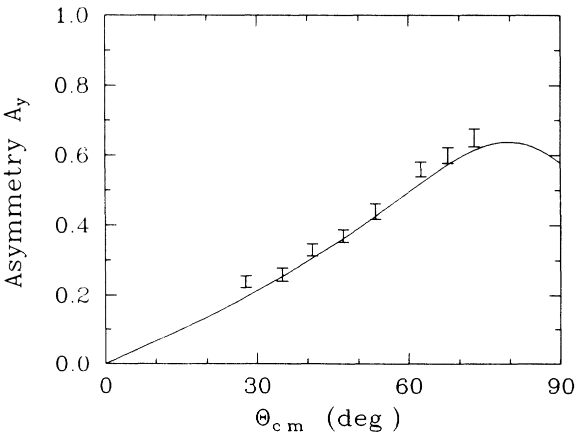

FIG. 2. Analyzing powers for $\pi^-\vec{p} \to \pi^0 n$ at T_{π^-} = 161 MeV. The line represents the results of a calculation with the FA89 phase-shift set. The error bars do not include the target polarization uncertainty of 3.9%.

tematic uncertainty for each angle setting of the spectrometer was obtained from comparisons of the analyzing powers extracted from separate runs with the same polarization orientation. False (nonzero) asymmetries can arise from fluctuations in the counters and scalers used to monitor the relative beam flux, fluctuations in the steering of the beam, and statistical uncertainties associated with the determination of the target polarization. Comparisons were also made between various combinations of similar spin-up and spin-down runs. The weighted mean of the fluctuations in the asymmetries about the average values, hereafter called the monitoring uncertainty, is listed in Table I for each angle setting. It is a random error and applies to all angles binned from a single spectrometer setting.

The statistical error was determined by forming the quadratic sum of the statistical uncertainties in Eq. (1). This procedure gave values for the statistical error of the analyzing powers typically around 0.015. Combining the statistical and systematic uncertainties in quadrature yielded the estimate of the overall uncertainty. There is an additional systematic uncertainty in the target polarization, estimated to be about 3.9%. This uncertainty arises from possible errors in the calibration of the temperature for the thermal equilibrium measurements as well as from biases in estimating the background under the peak in the NMR spectra.

Figure 2 shows our results and compares them with the predictions obtained from phase-shift calculations.[9,10] The FA89 set of phase shifts,[9] which has been constrained to reproduce recent analyzing power data for $\pi\vec{p}$ elastic scattering from $T_{\pi^-} = 98$ to $T_{\pi^-} = 263$ MeV,[11] produces good agreement with the data. The results obtained with older sets of phase shifts, including the Karlsruhe-Helsinki[12] set, are nearly indistinguishable from those shown in Fig. 1. The goodness-of-fit parameter χ^2 for the various sets of phase shifts ranges between 1.5 and 2.0 per degree of freedom. A renormalization of the data by a factor of 0.97, within the overall systematic error, yields a χ^2 per degree of freedom of about 1.0 for the FA89 set, while a renormalization factor of 0.945 produces a minimum χ^2 of 0.66. No revisions in the πN phase shifts near the P_{33} resonance are required by the data reported here.

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[1] J. Carlson, J. B. Kogut, and V. R. Pandharipande, Phys. Rev. D **27**, 2678 (1983).

[2] M. Karliner and M. P. Mattis, Phys. Rev. D **34**, 1991 (1986).

[3] G. Kim *et al.*, Phys. Rev. D **41**, 733 (1990).

[4] J. A. Wightman *et al.*, Phys. Rev. D **36**, 3529 (1987).

[5] H. W. Baer *et al.*, Nucl. Instrum. Methods **180**, 445 (1981).

[6] S. Gilad, Ph.D. thesis, Tel-Aviv University, 1979 .

[7] J. J. Jarmer *et al.*, Nucl. Instrum. Methods A **250**, 576 (1986).

[8] A. Abragam, *The Principles of Nuclear Magnetism* (Clarendon, Oxford, 1961).

[9] R. A. Arndt and L. O. Roper, SAID phase shift analysis program.

[10] R. A. Arndt, J. M. Ford, and L. D. Roper, Phys. Rev. D **32**, 1085 (1985).

[11] M. E. Sevior *et al.*, Phys. Rev. C **40**, 2780 (1989)

[12] R. Koch and E. Pietarinen, Nucl. Phys. **A336**, 331 (1980); G. Höhler, *Pion-Nucleon Scattering*, edited by H. Schopper (Landolt-Börnstein series, Vol. I/9b) (Springer, Heidelberg, 1983).