RAPID COMMUNICATIONS

PHYSICAL REVIEW D VOLUME 36, NUMBER 11 1 DECEMBER 1987

Rapid Communications

The Rapid Communications section is intended for the accelerated publication of important new results. Since manuscripts submitted to this section are given priority treatment both in the editorial office and in production, authors should explain in their submittal letter why the work justifies this special handling. A Rapid Communication should be no longer than 3½ printed pages and must be accompanied by an abstract. Page proofs are sent to authors, but, because of the accelerated schedule, publication is not delayed for receipt of corrections unless requested by the author or noted by the editor.

Analyzing power for $\pi^- p$ charge exchange and a test of isospin invariance up to η threshold

J. A. Wightman, A. D. Eichon,* G. J. Kim, A. Mokhtari,† and B. M. K. Nefkens
Department of Physics, University of California, Los Angeles, California 90024

W. J. Briscoe
Department of Physics, George Washington University, Washington, D.C. 20052

D. H. Fitzgerald
Los Alamos National Laboratory, Los Alamos, New Mexico 87545

M. E. Sadler
Department of Physics, Abilene Christian University, Abilene, Texas 79699
(Received 4 May 1987)

The analyzing power for $\pi^- p \rightarrow \pi^0 n$ has been measured at five incident momenta from 547 to 687 MeV/c using a transversely polarized target. Data were obtained with scintillation counters at 10 angles simultaneously covering the range $-0.9 \leq \cos\theta^{\pi}_{\mathrm{c.m.}} \leq 0.9$. Our results and those of Kim *et al.* are used for a model-independent test of isospin invariance which is based on the triangle inequalities applied to the transversity-up as well as the transversity-down cross sections. No evidence is found of isospin violation.

Using just rotational invariance and parity, one can show that πN elastic scattering is described completely by two independent amplitudes: the non-spin-flip amplitude f and the spin-flip amplitude g. This implies that there are two independent scattering cross sections, transversity-up $\sigma_\uparrow$ and transversity-down $\sigma_\downarrow$, defined as

$$d\sigma_\uparrow = |f+ig|^2 = d\sigma(1+A_N) ,$$

$$d\sigma_\downarrow = |f-ig|^2 = d\sigma(1-A_N) ,$$

where $d\sigma$ is the unpolarized differential cross section and A_N is the analyzing power measured with a transversely polarized target. The transversity cross sections are not measured directly but are calculated from $d\sigma$ and A_N. Transversity-up (-down) refers to the case where the proton polarization and the normal to the scattering plane are parallel (antiparallel).

Isospin invariance gives rise to the triangle inequalities for $\pi^\pm p$ elastic and $\pi^- p$ charge-exchange (CEX) scattering cross sections. The two transversity cross sections result in two sets of inequalities each of which is a model-independent test of isospin invariance. The inequalities are

$$\tfrac{1}{2}[(d\sigma_\uparrow^+)^{1/2} - (d\sigma_\uparrow^-)^{1/2}]^2 \leq d\sigma_\uparrow^0 \leq \tfrac{1}{2}[(d\sigma_\uparrow^+)^{1/2} + (d\sigma_\uparrow^-)^{1/2}]^2 , \quad (1a)$$

$$\tfrac{1}{2}[(d\sigma_\downarrow^+)^{1/2} - (d\sigma_\downarrow^-)^{1/2}]^2 \leq d\sigma_\downarrow^0 \leq \tfrac{1}{2}[(d\sigma_\downarrow^+)^{1/2} + (d\sigma_\downarrow^-)^{1/2}]^2 , \quad (1b)$$

where the superscript labels the different πp channels, $\pm$ for $\pi^\pm p$ elastic and 0 for CEX.

A violation of the triangle inequalities for the transversity-down cross sections at $p_\pi = 687$ MeV/c and $\cos\theta = -0.8$ has been reported by the Leningrad group.[1] However, the input data came from three different groups who were not working at the same beam momenta. Alder *et al.*[2] have tested the triangle inequalities using their own CEX analyzing-power data at $p_\pi = 351$, 408, and 427 MeV/c and found no violation. Their energy-independent partial-wave analysis did find a difference of $(2.0 \pm 0.4)^\circ$ in the phase of the P_{33} wave measured in $\pi^+ p$ and $\pi^- p$ scattering at $p_\pi = 408$ MeV/c. This small violation of isospin invariance appears only in this wave. For unpolarized data, the two sets of inequalities in (1) reduce to a single set; Comiso *et al.*[3] tested isospin invariance over the range $p_\pi = 239$ to 371 MeV/c and found no violation.

Many models of strong interactions allow for violation of isospin invariance, albeit a small one. Models based on meson exchange accommodate isospin breaking by isovector–isoscalar-meson mixing,[4] primarily π^0-η and ρ-ω. A good energy region in which to test the π^0-η mechanism is the vicinity of the η production threshold, which is barely accessible at LAMPF. Cutkosky[5] studied π^0-η mixing via the S_{11} (1540) and obtained effects as large as 20% in backward direction when assuming maximum interference. Calculations using the quark model as a basis include breaking of isospin invariance as a consequence of the mass difference between the u and d quarks that is non-Coulombic in origin. Estimates of this difference are generally 3–5 MeV which, compared to a constituent mass of a few hundred MeV, leads one to expect that the violation will be small. The effect of the quark mass difference can be enhanced somewhat in certain cases as in the region of Δ-resonance production.

We report measurements of the analyzing power A_N in $\pi^- p$ charge exchange. The experiment was performed at the Clinton P. Anderson Meson Physics Facility (LAMPF), using the P^3 channel. The central beam momenta and momentum bites [% full width at half maximum (FWHM)] were 547 [1.3], 586 [2.4], 625 [1.6], 657 [4.0], and 687 [5.3] MeV/c. The momenta are the same as the ones used in our previous measurements of the differential cross sections for $\pi^\pm p$ elastic scattering[6] and CEX[7] and A_N in the elastic channels.[8] The central beam momentum of the P^3 channel is known to $\pm 0.3\%$ from extensive time-of-flight[9] and range measurements.[10] Our experimental setup is shown in Fig. 1, and details are given in Ref. 11.

The target material, propanediol, was contained in a cylinder, 2 cm in diameter and 4 cm long, oriented with its axis along the beam direction. Free protons in the target were dynamically polarized transverse to the scattering plane. The target polarization was typically 82% with an overall systematic uncertainty of $\pm 3\%$. The major source of background in this experiment was the carbon in the propanediol. Background measurements were made by replacing the propanediol beads with graphite beads of approximately the same density.

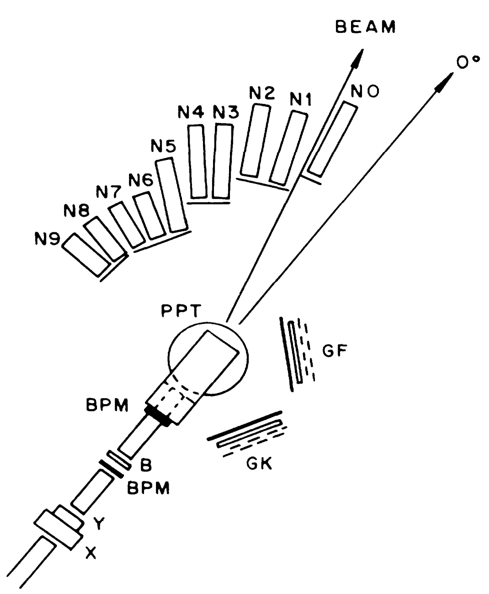

FIG. 1. Experimental setup for the A_N(CEX) measurements.

Recoil neutrons were detected in 10 pairs of scintillation counters covering the range $-0.9 \le \cos\theta^\pi_{\text{c.m.}} \le 0.9$. All the counters were cylinders 7.6 cm in diameter; counters N6–N9 were 19.1 cm long, and N0–N5 were 45.7 cm long. These lengths were chosen to give a high detection efficiency 25%–35%, without compromising the timing resolution, which was 1.5–5 ns. To have sufficient temporal separation between the prompt events and the CEX neutrons, flight paths of different lengths were used, ranging from 2.5 m for N9 (slowest) to 4 m for N0 (fastest). Thin scintillation counters were used to veto charged-particle events.

Photons from $\pi^0 \rightarrow 2\gamma$ decay were detected in two photon detectors: GF and GK. Only one of the photons was required in the event trigger. The spatial distribution of single photons from π^0 decay is peaked along the direction of the π^0. This allowed us to match kinematically GF with N5–N9 and GK with N0–N4. Each photon detector consisted of a lead converter sheet 9.5 mm thick (1.7 radiation lengths), a multiwire proportional chamber (MWPC) measuring 100 cm $\times$60 cm, and a hodoscope comprised of eight overlapping, double-ended counters. Eight thin, overlapping scintillation counters in front of the lead converter were used to veto charged-particle events. The hodoscope counters provided the signal for a photon and the timing of the master event trigger. A photon trigger consisted of a signal in at least one hodoscope counter and no signal in the veto counters; the MWPC information was only used off line.

CEX candidate events required a coincidence between a beam particle, a neutron, and a photon trigger. For each event, pulse height and timing information of each scintillator was recorded along with the position of each photon shower in the MWPC's.

The number of valid CEX events was extracted from the neutron time-of-flight (TOF) spectra after cuts had been applied. Typical signal-to-background ratios ranged from 3:1 for N9 to 1:4 for N0. The analyzing power was calculated from

$$A_N = \frac{N_\downarrow - N_\uparrow}{P_t(N_\downarrow + N_\uparrow - 2B)} , \qquad (2)$$

where P_t is the target polarization, $N_\downarrow$ and $N_\uparrow$ are the normalized yields for target spin down and up, respectively, and B is the background yield from the carbon target. In the analysis, cuts were applied in successive passes to the beam TOF, neutron pulse height, photon TOF, neutron and photon multiplicities of the event, and the spatial distribution of the photons in the photon hodoscope. For each pass, the analyzing power and its uncertainty were calculated; we found the results of each pass to be consistent with the previous one. The neutron peak in each time-of-flight (TOF) histogram was contaminated by a small number of radiative capture ($\pi^- p \rightarrow \gamma n$) events which can have an A_N opposite in sign to that of CEX. These events are co-planar, and the spatial distribution cuts removed them with only a small loss of valid CEX events.

Since (2) is a ratio of numbers of events or, alternatively, cross sections, many factors such as counter efficiency cancel. Only a relative normalization is required, and this was taken with respect to $N_\uparrow$. Both the $\uparrow/\downarrow$ and $\uparrow/B$ normalization factors were calculated from off-time events at times later than the CEX neutrons in the neutron TOF spectra. As a comparison, the normalization factors were also calculated from the prompt events in the TOF spectra and from the scaled singles in each neutron counter. The consistency of the results of all three determinations gives an error in $\uparrow/\downarrow$ of $\pm 1\%$ and of $\pm 5\%$ for $\uparrow/B$, except at 687 MeV/c where we used an error in $\uparrow/B$ of $\pm 10\%$.

We present our data on $A_N(\pi^- p \rightarrow \pi^0 n)$ in Figs. 2(a)–2(e) and include the VPI 1986 partial-wave-analysis (PWA) results[12] for comparison. The error bars on the data points represent the statistical uncertainties and the uncertainties in the background subtraction but do not include the 3% systematic uncertainty in the target polarization. The angular interval due to the finite size of the counters and target cell and the deflection of the incident beam in the field of the PPT magnet is 3°–4° in the center of mass. A comparison of the 547, 586, and 625 MeV/c data with the recent PWA's[12–14] will be made by Kim *et al.*[15] whose substantially smaller errors allow for a more definitive statement regarding them. The CEX data of Ref. 15 is a high statistics background to the radiative capture ($\pi^- p \rightarrow \gamma n$) reaction of the experiment, but it covers a limited angular range.

Our results are compared with the Rutherford[16] A_N (CEX) data at the incident energies nearest to ours in Figs. 2(c)–2(e). The agreement is not satisfactory. A downward shift of about 5% in the beam momenta quoted by the Rutherford group would greatly improve the agreement with our data. If the Rutherford data at higher energies are systematically in error as well, it would have important consequences for the masses of several πN resonances because of the prominent role of the Rutherford data in the PWA's. Also, the Rutherford A_N data at 675 MeV/c shows a peculiar spike at $\cos\theta = -0.08$ not seen in our data. The absence of this spike is significant because it appears that the spike is the origin of the violation of isospin invariance reported by the Leningrad group.

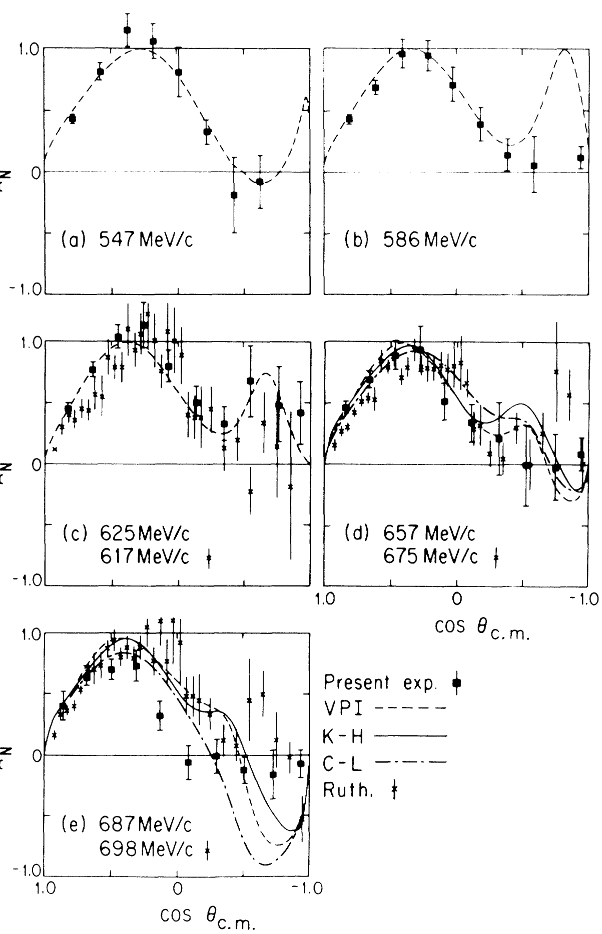

FIG. 2. Comparison of the present A_N(CEX) measurements with those of Ref. 16 (Rutherford) and three recent PWA's of Ref. 12 (VPI), Ref. 13 (K-H), and Ref. 14 (C-L).

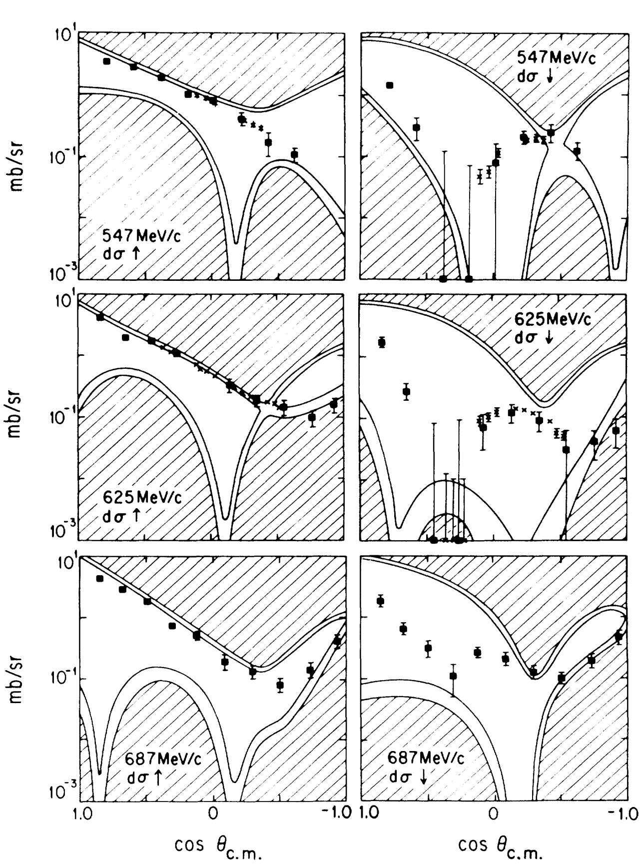

FIG. 3. The CEX transversity cross sections and a test of isospin invariance using the triangle inequalities. The squares are from the present experiment, and the ×'s are from Ref. 15.

Our A_N(CEX) results and those of Ref. 15 have been combined with the cross-section data of Borcherding[7] to obtain the CEX transversity-up and transversity-down cross sections. They are compared in Fig. 3 with the triangle inequality limits at $p_\pi = 547$, 625, and 687 MeV/c, which we determined earlier.[8] The isospin-forbidden regions are marked by stripes; the uncertainties in the limits are indicated by a band. Our CEX data support the validity of isospin invariance for the transversity-up as well as transversity-down cross sections.

The transversity-up CEX cross sections in forward direction are close to the upper limit of the isospin-allowed values, whereas the transversity-down CEX cross sections are far from the boundaries. This illustrates the enhanced sensitivity to testing isospin invariance afforded by the polarized case over the unpolarized one. In the backward direction, both the up and down CEX cross sections are close to the lower limit of the isospin boundary. Reference 13 predicts the angular and momentum dependence of the saturation of the upper and lower isospin bounds, and comparison of these predictions with Fig. 3 finds qualitative agreement with the total or near saturation of both the upper and lower bounds. This is the most recent prediction from a PWA and shows a large angular interval for the saturation of either bound for momenta in the range of 200–500 MeV/c only.

In conclusion, we state that there is no evidence for isospin violation in the region where π^0-η mixing is expected to be important and where the Leningrad group reported a violation earlier. This violation is traced to a bump in the A_N(CEX) data of the Rutherford group which is not seen in our experiment. The absence of a violation shows that the condition of maximal interference used in Ref. 5 is not satisfied, thus demonstrating that π^0-η mixing is not a large effect at the threshold for η production and below.

We thank J. E. Simmons and the Los Alamos National Laboratory P-Division for the loan of the PPT and J. G. J. Boissevain and J. A. Holt for helping to set it up. One of the authors (W.J.B.) wishes to acknowledge the support of the George Washington University Committee on Research and the National Science Foundation, while another (M.E.S.) acknowledges the support of the Research Council at Abilene Christian University. This work was supported in part by the U.S. Department of Energy.

---

*Deceased.

†Present address: Department of Physics, George Washington University, Washington, DC 20052.

[1] V. S. Bekrenev et al., Nucl. Phys. **A364**, 515 (1981).

[2] J. C. Alder et al., Phys. Rev. D **27**, 1040 (1983).

[3] J. C. Comiso et al., Phys. Rev. D **12**, 738 (1975).

[4] E. M. Henley and G. A. Miller, in *Mesons in Nuclei*, edited by M. Rho and D. Wilkinson (North-Holland, Amsterdam, 1979), pp. 405–434.

[5] R. E. Cutkosky, Phys. Rev. Lett. **88B**, 339 (1979).

[6] M. E. Sadler et al. Phys. Rev. D **35**, 2718 (1987).

[7] F. O. Borcherding, Ph.D. thesis, UCLA, 1982; and (unpublished).

[8] A. Mokhtari et al., Phys. Rev. D **35**, 810 (1987).

[9] D. Roeder and R. J. Macek, Los Alamos National Laboratory Report No. LA-7268-PR, 1977, pp. 31–32.

[10] W. J. Briscoe et al., Nucl. Instrum. Methods **197**, 277 (1982).

[11] J. A. Wightman, Ph.D. thesis, UCLA, 1987.

[12] R. A. Arndt, L. D. Roper, and J. Ford, SP86 analysis from SAID computer program (unpublished).

[13] G. Höhler, F. Kaiser, R. Koch, and E. Pietarinen, *Handbook of Pion-Nucleon Scattering* (Physics Data, No. 12-1) (Fachsinformationszentrum, Karlsruhe, 1979).

[14] R. E. Cutkosky, C. P. Forsyth, R. E. Hendrick, and R. L. Kelly, Phys. Rev. D **20**, 2839 (1979).

[15] G. J. Kim et al. (unpublished).

[16] R. M. Brown et al., Nucl. Phys. **B144**, 287 (1978).