Proc. Sixth Int. Symp. Polar. Phenom. in Nucl. Phys., Osaka, 1985
J. Phys. Soc. Jpn. 55 (1986) Suppl. p. 918-919

4.2 Analyzing Powers for the $^{13}C(\vec{p},\pi^{\pm})$ Reactions at T_p = 200 MeV.

E. Korkmaz, W.W. Jacobs, T.G. Throwe, S.E. Vigdor,
M.C. Green[†], P.L. Jolivette[††], and J.D. Brown[†††]

Indiana University Cyclotron Facility, Bloomington, Indiana 47405, U.S.A.
[†] Physics Division, Argonne National Laboratory, Argonne, Illinois 60439, U.S.A.
[††] Department of Physics, Hope College, Holland, Michigan 49423, U.S.A.
[†††] Department of Physics, Princeton University, Princeton, New Jersey 08544, U.S.A.

Analyzing power (A_y) measurements for exclusive $(\vec{p},\pi^{\pm})$ reactions have proved very useful for investigating the pion production mechanism. Studies near threshold have revealed several apparent A_y signatures[1-4] -- of quite different nature for $(\vec{p},\pi^-)$ and $(\vec{p},\pi^+)$ -- of the dominant role of a two-nucleon mechanism (TNM -- $NN \rightarrow NN\pi$ inside the nucleus). The most striking feature of the $(\vec{p},\pi^-)$ data is the strong variation in A_y with final state, epitomized by the change in sign observed[1] between $^{12}C(\vec{p},\pi^-)^{13}O_{g.s.}$ and $^{13,14}C(\vec{p},\pi^-)^{14,15}O_{g.s.}$, confirming TNM expectations.[1] Furthermore, $(\vec{p},\pi^-)$ transitions[2,3] to $0\hbar\omega$ 2p-1h "stretched" states show a unique A_y pattern independent of target mass,[2] but differing substantially from lower-spin results. In contrast, $(\vec{p},\pi^+)$ data are most remarkable for the absence of any systematic state-dependence in A_y behavior: most transitions have A_y similar (after transformation to the nucleon-nucleus c.m.) to that observed near threshold for the free $\vec{p}p \rightarrow d\pi^+$ process.[4]

Differences between $(\vec{p},\pi^-)$ and $(\vec{p},\pi^+)$ results are qualitatively explained by a TNM. In this model a (p,π^-) transition between given initial- and final-state (2p-1h) configurations proceeds via $pn \rightarrow pp\pi^-$ with a target neutron from a specific shell model orbital. These restrictions, combined with structure or mechanism (e.g., short-range interaction) constraints on the final-state protons' coupling, often fix the preferred relative spin and orbital orientations of the interacting nucleons.[1,3] Distorted waves then may give a strong state-dependent contribution to A_y, superimposed on any A_y intrinsic to the (unmeasured) $\vec{p}n \rightarrow pp\pi^-$ process.[1,3] The spin system is much less constrained for most (p,π^+) transitions, in part because several NN isospin (T_f) channels can contribute: $pp \rightarrow (np)_{Tf=0}\pi^+$, $pp \rightarrow (np)_{Tf=1}\pi^+$, $pn \rightarrow nn\pi^+$. Even assuming the first of these amplitudes to be dominant inside a nucleus, as it is known to be in free NN interactions near threshold,[5] typical (p,π^+) transitions involve nucleons from a variety of orbitals (since a final-state nucleon can refill holes left by the struck nucleon, in contrast to $pn \rightarrow pp\pi^-$). These multiple reaction paths should average over different spin couplings, washing out state-dependent effects and leaving the intrinsic A_y of the dominant $NN \rightarrow NN\pi$ process as the primary contribution in (p,π^+).

To compare $(\vec{p},\pi^+)$ and $(\vec{p},\pi^-)$ reactions under similar conditions, and to investigate further the influence of the fundamental $NN \rightarrow NN\pi$ channels on their A_y behavior, we have measured $d\sigma/d\Omega(\theta)$ and $A_y(\theta)$ for $^{13}C(\vec{p},\pi^{\pm})$ populating the mirror nuclei ^{14}C and ^{14}O at $E_x \leq 25$ MeV. More strong states are seen in the (p,π^+) spectra than in (p,π^-), in accord with expectations based on the coherence of multiple (p,π^+) amplitudes vs. the highly restricted TNM path for all (p,π^-) transitions. The (p,π^+)-(p,π^-) comparison aids identification of populated states since their relative strength in $(\vec{p},\pi^-)$ is dominated by momentum-matching considerations;[6] thus, apparent mirror peaks strong in both spectra probably indicate high-spin 2p-1h (with respect to ^{13}C) states. We concentrate here on A_y for continuum regions in both spectra and for several discrete $(\vec{p},\pi^+)$ transitions. Among the latter are two states in ^{14}C not previously identified: one at E_x=14.87 MeV, to which we assign $J^{\pi}=5^-$ on the basis of the $(\vec{p},\pi^{\pm})$ results in conjunction with other A=14 studies; and a second at E_x=23.2 MeV, discussed below.

The most striking general feature of the observed analyzing powers is the overall negative A_y (characteristic of free $\vec{p}p \rightarrow d\pi^+$) for both the continuum and nearly all discrete states in $^{13}C(\vec{p},\pi^+)$, illustrated in Fig. 1 by the spin-difference spectrum that is a nearly perfect reflection of the spin-sum spectrum. This behavior persists with angle, as revealed by the strikingly similar $A_y(\theta)$ results for two (~1 MeV wide) representative continuum regions (Fig. 3) and three strong discrete transitions (Fig. 2a). The few exceptional $(\vec{p},\pi^+)$ transitions for which A_y deviates significantly from this trend are highlighted in Figs. 1c and 2b, and discussed below. Spin-difference spectra for the $^{13}C(\vec{p},\pi^-)$ reaction (not shown) reveal much more state-to-state variations in A_y than are observed for $(\vec{p},\pi^+)$, again in agreement with the expectations outlined above. However, continuum regions of the $(\vec{p},\pi^-)$ spectrum do show a stable A_y distribution (see Fig. 3), which is furthermore quite similar to continuum $(\vec{p},\pi^-)$ data on ^{18}O, ^{26}Mg, and ^{48}Ca targets.[7] The continuum presumably averages over state-dependent contributions of opposite sign, and it is tempting to interpret these $A_y(\theta)$ results as reflections of the intrinsic $\vec{p}n \rightarrow pp\pi^-$ behavior. The observed sign difference in Fig. 3 between A_y for the $(\vec{p},\pi^{\pm})$ continua might then arise from the different angular momentum coupling of the final-state nucleon pairs which accompany their opposite isospin couplings (T_f=0 mainly for (p,π^+) vs. T_f=1 for (p,π^-)).

Since the $\vec{p}p \rightarrow d\pi^+$ analyzing power appears to dominate in $A(\vec{p},\pi^+)A+1$, anomalous $A_y(\theta)$ may signal transitions which proceed primarily via normally weak (i.e., T_f=1) NN $\rightarrow$ NNπ isospin channels. Data for two such anomalous cases are shown in Fig. 2b. The anomaly for the 10.74-MeV 4^+ state is not surprising, since this state is believed to be predominantly a two-neutron excitation from the ^{14}C ground state, accessible in (p,π^+) only via $pn \rightarrow nn\pi^+$ on the $p_{1/2}$ target neutron. The cross section observed for this state is indeed comparable in magnitude to that for its mirror counterpart in $^{13}C(p,\pi^-)$, which would proceed by the charge-symmetric process $pn \rightarrow pp\pi^-$. The strongest (p,π^+) transition with anomalous A_y behavior is that to the sharp E_x=23.2-MeV state. A natural explanation for all its observed features, except the large yield (an order of magnitude greater at forward angles than the strongest (p,π^-) transitions), is that it has T=2 and therefore cannot be populated via $pp \rightarrow (np)_{Tf=0}\pi^+$. If this interpretation is correct, we are seeing evidence for an unexpectedly strong enhancement of normally weak NN $\rightarrow$ NNπ isospin channels inside the nucleus. An alternative explanation (also incomplete) is that it is a T=1 state of maximal spin accessible in (p,π^+) -- namely, $|^{13}C \times (\pi p_{3/2})^{-1}(\pi d_{5/2})(\nu d_{5/2})\rangle_{7^+}$ -- where the strongly constrained angular momentum coupling produces a large state-dependent modification of $A_y(\theta)$. We are initiating other reaction studies to test these hypotheses.

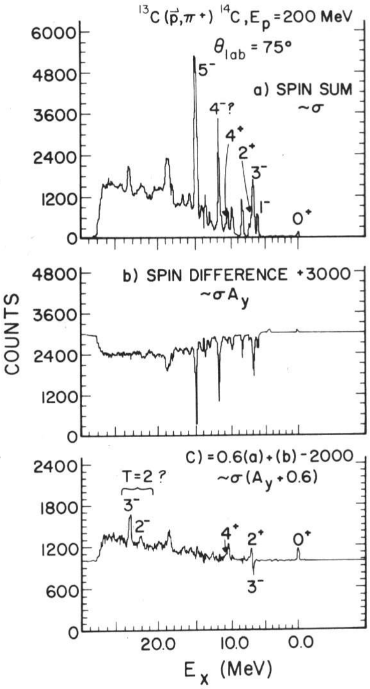

Fig. 1. Spin sum and spin difference $(\vec{p},\pi^+)$ spectra.

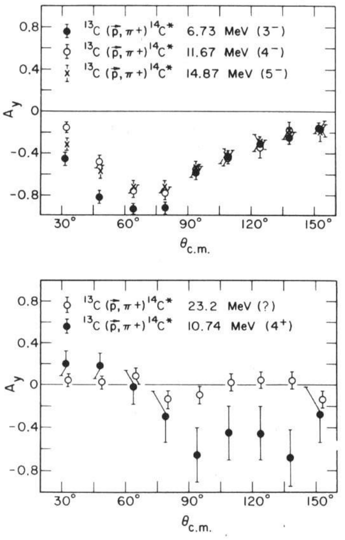

Fig. 2. Analyzing power for $(\vec{p},\pi^+)$ transitions to selected discrete states.

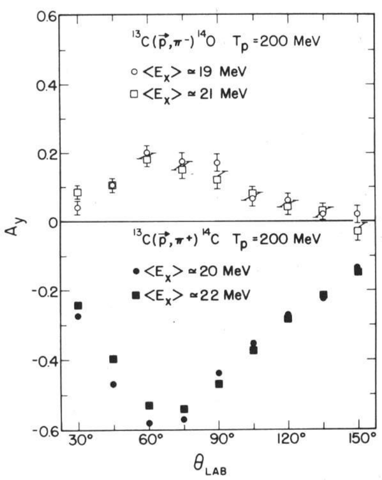

Fig. 3. Analyzing power for the $^{13}C(\vec{p},\pi^{\pm})$ continua.

References

1) W.W. Jacobs et al., Phys. Rev. Lett. 49, 855 (1982).
2) M.C. Green et al., Phys. Rev. Lett. 53, 1893 (1984).
3) H. Toki and K.I. Kubo, Phys. Rev. Lett. 54, 1203 (1985); Vigdor et al., ibid, 1204.
4) E.G. Auld et al., Phys. Rev. Lett. 41, 462 (1978).
5) B.J. VerWest and R.A. Arndt, Phys. Rev. C 25, 1979 (1982).
6) S.E. Vigdor et al., Phys. Rev. Lett. 49, 1314 (1982).
7) J.J. Kehayias, Ph.D. thesis, Indiana University, 1983; T.G. Throwe, ibid, 1984.