EVIDENCE FOR TWO-NUCLEON PROCESSES IN A(p,π)A+1

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In the currently favored "two-nucleon" models of pion production, the pion production mechanism involves the explicit interaction of the incident nucleon with a target nucleon. However there have been very little experimental data which bear directly on the question of how many nucleons actively participate in the production mechanism (i.e., without requiring comparison with detailed, and as yet unavailable, model calculations). While trying to identify simple, yet general signatures of N-N production processes which might be exhibited in selected (p,π) transitions, we were led to focus on the little studied (p,π^-) reaction. Unlike (p,π^+), the (p,π^-) reaction viewed as a N-N process is quite restrictive, since the proton must interact with a target neutron ($p+n \rightarrow p+p+\pi^-$), whose shell model orbital is then uniquely determined if the configurations of both initial and final (2 particle [protons] - 1 hole [neutron]) states are known. These restrictions in fact make the (p,π^-) reaction easier to understand and interpret than (p,π^+). From this viewpoint we predicted on general grounds (not specific to a particular 2-nucleon mechanism), a systematic sign difference in near threshold (p,π^-) analyzing powers between transitions involving target neutrons from $j_>=\ell+1/2$ versus $j_<=\ell-1/2$ orbitals. Under more stringent assumptions, a simple scaling of the (p,π^-) cross section across an isotopic series of targets was also expected.

Measurements of cross sections and analyzing powers[1] for $^{12,13,14}C(p,\pi^-)^{13,14,15}O$ have borne out these simple N-N signatures. The distributions as presented recently in the literature[2] are shown in Fig. 1. The analyzing power data in the top part of the figure show a clear j-dependence (sign difference) for transitions involving the interaction with $j_<=\ell-1/2$ [$^{13,14}C(p,\pi^-)$] versus $j_>=\ell+1/2$ [$^{12}C(p,\pi^-)$] target neutrons.

The cross section data in the lower part of the figure exhibit the expected scaling, which would be a factor of two in a simple shell model picture as one effectively doubles the number of available $p_{1/2}$ target neutrons in going from ^{13}C to ^{14}C. We note that although the $^{13,14}C(p,\pi^-)$ cross section distributions are very similar, as expected, the $^{12}C(p,\pi^-)$ distribution, which involves interaction with a $p_{3/2}$ target neutron, has a distinctly different shape. The latter distribution was remeasured during this past year because of uncertainties about the solid angle acceptance in the original measurements (some of the first made with the QQSP pion spectrometer). Presently, it is in good agreement with the shape and overall magnitude of previous results from the literature[3] obtained at a slightly higher bombarding energy and hence slightly higher pion energy than the $\langle E_\pi \rangle \cong 40$ MeV used for the present studies.

These simple experimental tests exhibit N-N signatures in nuclear pion production which are not expected in general for production processes involving more than two nucleons. Thus, the results obtained for the carbon isotopes support the view that it is two-nucleon processes which dominate in (p,π) near threshold. During the past year we have attempted to

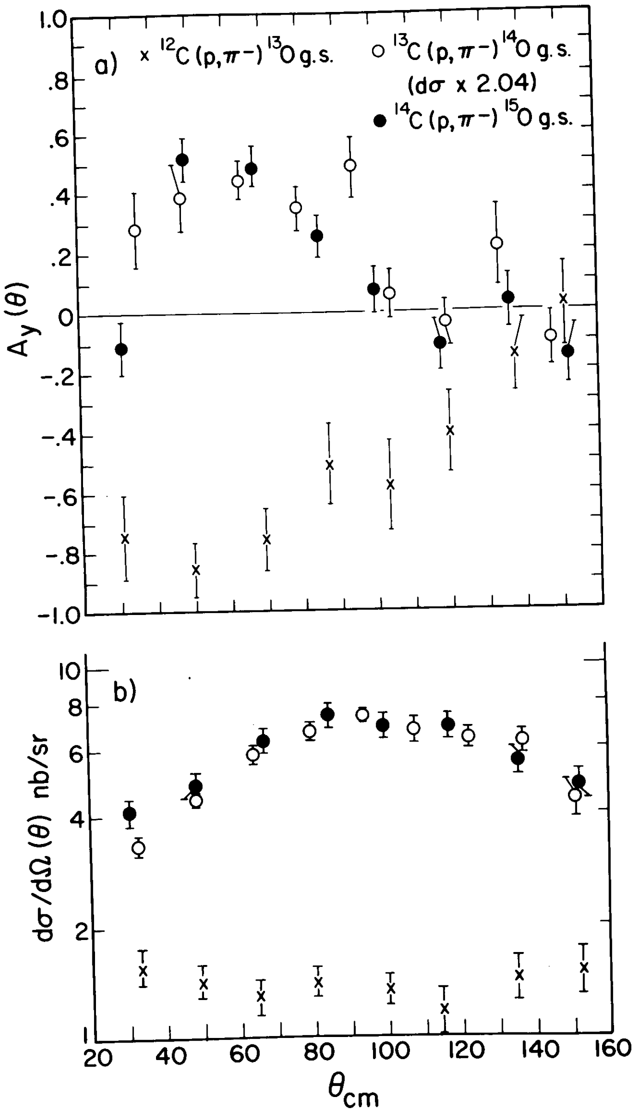

Figure 1. Cross section and analyzing power angular distributions for $^{12}C(p,\pi^-)^{13}O$g.s.(Δj=3/2$^-$), $^{13}C(p,\pi^-)^{14}O$g.s.(Δj=1/2$^-$), and $^{14}C(p,\pi^-)^{15}O$g.s.(Δj=1/2$^-$).

push these studies further in two ways.

First, it is interesting to speculate with regard to simple N-N signatures how the charge symmetric fundamental processes $p+n \rightarrow p+p+\pi^-$ and $p+n \rightarrow n+n+\pi^+$ would be reflected in a comparison of the (p,π^-) and (p,π^+) reactions. This can be accomplished by suitable target selection (closed neutron shell and an empty corresponding proton shell) if one observes 2p-1h final states whose spin and parity are determined by a hole in the last-filled neutron shell. In the simplest picture, the comparison between the two nuclear production processes would be dominated by the charge symmetry of the fundamental contributing two-nucleon amplitudes. In practice of course, transformation to the p-nucleus c.m. frame, damping of the nuclear form factor at the larger angles (larger momentum transfer), and Coulomb differences in the exit channel interaction complicate this comparison. However, if the two-nucleon production mechanism is dominant, one should expect qualitative features of the comparison to remain. The two reactions should have average cross sections of similar magnitude; a strong forward peaking in the angular distribution for one should be reflected in a backward-peaking for the other. It is also possible that the implications of symmetry principles for the contributing two-nucleon amplitudes may be more simply reflected in a comparison of the analyzing powers. For example, charge symmetry implies that the sign of the analyzing power for $pn \rightarrow nn\pi^+$ at backward angles (in the pn c.m.) should be opposite in sign to that for $pn \rightarrow pp\pi^-$ at forward angles (and vice versa).

The lightest targets for such a comparison of (p,π^-) and (p,π^+) are ^{14}C and ^{48}Ca. We attempted to determine the feasibility of using ^{48}Ca as a target by measuring the $^{48}Ca(p,\pi^-)^{49}Ti$(g.s.) cross section. Unfortunately we discovered that the ground state cross section is very small (~300 pb/sr, at θ_{lab}=30° and T_p=205 MeV), and hence not a very practical transition for study. (However, it was during this run that we observed a very large strength concentration for this target (~53 nb/sr) near E_x=4.0 MeV, whose origin and systematics[4] are discussed in accompanying contributions to this section of the report.) In the case of ^{14}C, the other possible target, the (p,π^-) cross section and analyzing powers for the ground state (1/2-) transition are shown in Fig. 1. However, the corresponding "charge symmetric transition," $^{14}C(p,\pi^+)^{15}C$(1/2-, 3.105 MeV), is difficult to measure in this case. Not only is there in general a higher level of background events in the QQSP spectrometer for (p,π^+) versus (p,π^-), but the specific transition of interest is inhibited, compared to normal (p,π^+) transitions to neighboring states, because of the specificity of the reaction path expected to populate this state. The first problem was addressed by employing a more stringent pion identification scheme. An absorber with a calculated wedge shape (to account for the various pion trajectories as a function of focal plane position) was inserted in the focal plane detector stack to energetically degrade the pions so that they would stop in the second scintillator. The third scintillator was then used as a hardware veto. Conventional NIM electronics modules were used to look for "pileup" pulses in the second scintillator resulting from the pion decay into muons. This pileup condition was used to stop a TAC (started by the normal QQSP start signal) which could be added to the pion identification condition in software. The scheme provides excellent pion identification, although its efficiency using conventional NIM modules is only 50-60%. The second problem is exacerbated by the isotopic composition of the present ^{14}C target, which is 33% ^{12}C. In our test runs so far, positive pions from neighboring ^{13}C and ^{15}C residual states, as well as possible residual ^{14}C continuum contributions obscure the state of interest at the level of several nb/sr. It is possible that a ^{14}C target of higher isotopic purity will make these measurements possible in the future.

A second avenue of pursuit in these studies was to look for other cases where the j-dependence, as observed for (p,π^-) in the carbon isotopes, might be exhibited. The $^{54}Cr(p,\pi^-)^{55}Fe$ reaction to the ground state (3/2-), 0.411-MeV (1/2-), 0.931-MeV (5/2-), and 1.36-MeV (7/2-) states was picked for study since it provided several $j=\ell\pm1/2$ states (neutron hole in a ^{56}Fe core) in a narrow band of excitation from the same target. As an additional feature, it was thought possible that states of high spin (up to 19/2-) arising from $(f_{7/2})^3$ configurations at $E_x < 6.5$ MeV in ^{55}Fe might be strongly populated in this reaction. Unfortunately, neither of these expectations was fulfilled. For the low-lying states (where the two final protons are coupled to spin zero in the residual nucleus), very small cross sections were observed. In retrospect, and after further systematic measurements,[4] this now appears to be a general feature of (p,π^-) to such states except for fairly light targets. A similar suppression has been been observed in pion absorption measurements and attributed,[5] at least in part, to the fact that angular momentum, parity, and isospin conservation forbid the $p+n \rightarrow (pp)_{0+} + \pi^-$ reaction from proceeding through an even parity (in particular, an s-wave) ΔN intermediate state. The fact that we didn't observe any strong population of the high-spin states for this target fits in well with the general systematics recently observed,[4] though not understood in detail, for population of high-spin two-particle one-hole transitions in the (p,π^-) reaction.

In summary, our search for experimental evidence for N-N processes in $A(p,\pi)A+1$ has met with success, although additional examples of the type we have discussed will be hard to come by because of the observed suppression of the cross section when the two final protons are coupled to low spin in the residual nucleus. On the other hand, the observation of the strong and selective population of high-spin states in (p,π^-) also has an explanation[4] in terms of the underlying fundamental N-N processes. Further investigation of the systematics of these states and the associated continuum region are of great current interest.

1) IUCF Scientific and Technical Report 1981, p. 43.

2) W.W. Jacobs, T.G. Throwe, S.E. Vigdor, M.C. Green, J.R. Hall, H.O. Meyer, W.K. Pitts, and M. Dillig, Phys. Rev. Lett. 49, 855 (1982).

3) B. Hoistad, P.H. Pile, T.P. Sjoreen, R.D. Bent, M.C. Green, and F. Soga, Phys. Lett. 94B, 315 (1980).

4) S.E. Vidgor, T.G. Throwe, M.C. Green, W.W. Jacobs, R.D. Bent, J.J. Kehayias, W.K. Pitts, and T.E. Ward, Phys. Rev. Lett. 49, 1314 (198); see also p. 75 of this report.

5) D. Ashery et al., Argonne National Laboratory report ANL-81-79 (1982) p. 8.