$^{12}C(p,\pi^+n)$ COINCIDENCE MEASUREMENT

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A current focus of the IUCF pion production program is on understanding the extent to which $A(p,\pi^{\pm})$ reactions can be viewed as resulting from quasifree $NN \rightarrow NN\pi$ processes in the nucleus.[1,2] Evidence in favor of a quasifree mechanism is particularly striking for $(\vec{p},\pi^+)$ reactions on nuclei, where observed analyzing powers for continuum production, and for nearly all strong transitions to discrete residual states as well, are similar in magnitude, sign, and angular dependence to results for $\vec{p}p \rightarrow d\pi^+$, when the latter are transformed to the nucleon-nucleus reference frame.[1] These "canonical" analyzing powers $[A_y(\theta)]$ are large and negative over most of the angle range. In $(\vec{p},\pi^+)$ measurements for several 1p-shell target nuclei,[1,3] however, we have observed typically one, sometimes two, strong anomalous transitions -- to relatively sharp states at high excitation ($E_x \sim$ 14-23 MeV) -- with $A_y \simeq 0$ at all angles. It is important to understand the nature of the anomalous final states, since these transitions may provide a clue essential to a more complete understanding of pion production from nuclei.

One plausible speculation[1] concerning the anomalous states is that they are isospin-mixed. A (p,π^+) transition to a $T_>$ state in the final nucleus would involve a $\Delta T=3/2$ amplitude, which is known[1] from $(\vec{p},\pi^-)$ studies to be characterized by A_y of opposite sign, but also by much smaller magnitude, than typical $\Delta T=1/2$ amplitudes. A suitable $T_> - T_<$ admixture could conceivably account for the observed analyzing powers, cross section magnitudes, and widths of the anomalous final states. Furthermore, the anomalous transition in $^{12}C(p,\pi^+)$ is to a state (or states) in ^{13}C at E_x=21.4 MeV, where previous $^{13}C(\pi^{\pm},\pi^{\pm\prime})$ results[4] have suggested the existence of $7/2^+$ or $9/2^+$ states with possible isospin mixing as well.

In order to try to distinguish between the mixed-isospin and other possible (e.g., very high spin $T_<$ state, see Ref. 1) interpretations for the anomalous (p,π^+) transitions, we have undertaken a measurement of $^{12}C(p,\pi^+n)$ coincidence yields at a bombarding energy of 200 MeV. The aim is to look for evidence of the sequential decay of the 21.4-MeV state in ^{13}C. If the state is predominantly a $7/2^+$, T=3/2 state (as suggested by the pion inelastic scattering results and shell model calculations[4]), we would expect a dominant decay branch (via $d_{5/2}$ neutron emission) to the 15.11-MeV 1^+, T=1 state in ^{12}C, while a T=1/2 state of similar configuration would decay preferentially to the 2^+, T=0 (4.44 MeV) or 1^+, T=0 (12.71 MeV) states. An isospin-mixed parent state might have significant decay branches to both T=0 and T=1 ^{12}C states. Such a coincidence measurement is very difficult given the small absolute (p,π^+) near-threshold cross sections (~ a few hundred nb/sr for the strongest transitions), even with the large solid angle and excellent particle identification of the QQSP magnetic spectrometer for the pions (e.g., see Ref. 5). However, the real-to-accidental ratio should be enhanced for the events of interest, because we are searching for coincidences between relatively sharp peaks in both the pion and neutron spectra.

During 1986 we had two test runs to optimize the detection apparatus, angle pairs, shielding against room background, electronics, and acquisition software for the coincidence experiment. The detector system has evolved toward the use of 7 liquid scintillator (NE213) counters for the low-energy neutrons, each a cylinder of 5" diameter and 5" depth (yielding detection efficiency > 35% for the neutrons of interest), in coincidence with π^+ detected at θ_{lab}=30° in the QQSP. We had originally planned to detect the pions at 0°, where the interpretation of the π-n angular correlation is considerably simplified (since the recoiling ^{13}C nucleus must then be populated in m_J=±1/2 substates only). However, our hope that the strongly forward-peaked (p,π^+) cross section angular distribution (see Ref. 1) would continue to rise toward 0° was not borne out by measurements, and the sensitivity of the apparatus to the quality of the beam tune was magnified at 0° by the possibility of producing room background neutrons when the primary beam would strike parts of the QQSP vacuum can or the beam pipe leading to the Faraday cup. In the present configuration, the neutron detectors are at a distance of 1.9 m from the ^{12}C target (providing adequate time-of-flight resolution for our purposes), and they span an angle range from ~ 25° to ~ 50° in the ^{13}C rest frame for the decay neutrons of interest. At these forward angles, we take advantage of a laboratory frame boost in the neutron energies, which are as low as 1.3 MeV in the ^{13}C rest frame (for decay of the 21.4-MeV state to the 15.11-MeV state in ^{12}C).

Performance of this coincidence measurement places stringent demands on the quality of the pulse-shape discrimination (PSD) obtained with, and on the dynamic range of, the liquid scintillator electronics, and much of the work in the test runs has addressed these issues. The PSD is critical because the singles (and hence, the accidental coincidence) rate of room background photons (uncorrelated with the cyclotron RF signal) in the time range of interest for the neutrons is about one order of magnitude greater than the low-energy neutron rate. The dynamic range problem is presented by searching for relatively rare low pulse-height events in the presence of a very high singles rate from elastically and inelastically scattered protons, which produce ~ 100 times more light in the liquid scintillators than do the neutrons of interest.

We have obtained excellent PSD, all the way down to our 0.4 MeV electron-equivalent threshold, with a simple electronics scheme, wherein we route the anode signal from each scintillator phototube into two separate charge-integrating ADC's, with separate gates generated by the same constant fraction discriminator (CFD). The timing and width of the two gates are chosen so as to integrate only the rising portion of each pulse in one ADC, and only the falling portion in the second, giving pulse heights E_1 and E_2, respectively. The representative PSD spectrum in Fig. 1 shows the distribution of events with respect to the summed pulse height ($E_1 + E_2$) and a pulse-shape parameter derived from $(E_2 - E_1)/(E_2 + E_1)$. The dynamic range problem has been handled in part by use of an open-sided sweeping (dipole) magnet to deflect scattered protons, headed for the liquid scintillators, toward more forward angles. In this way, the highest proton rate seen by any of the liquid scintillators corresponds to elastic scattering at $\theta_{lab} \simeq 35°$. In addition, we have found it necessary to veto events for a long time period (~ 350 ns) following arrival of any very large pulse for a given scintillator (even if the pulse itself is subjected to a fast charged-particle veto from the plastic scintillator placed in front of

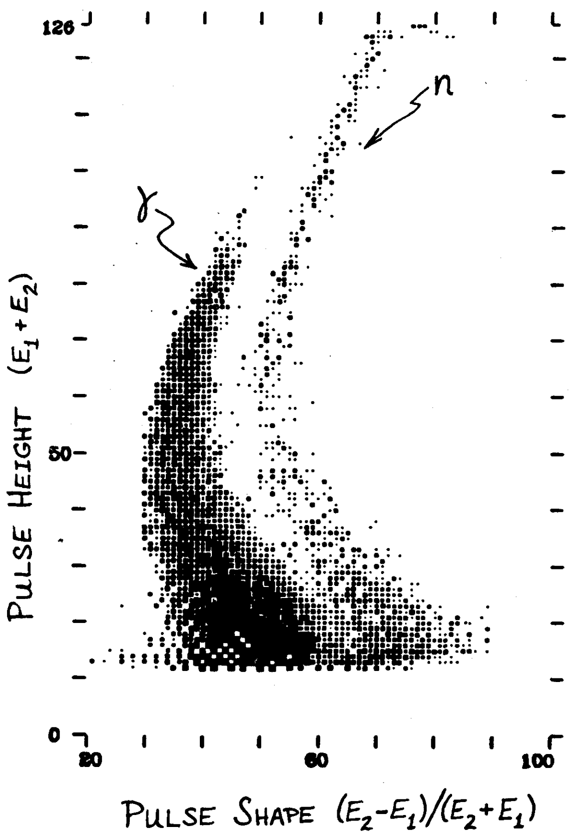

Figure 1. Representative n-γ pulse-shape discrimination (PSD) spectrum obtained with NE213 scintillators detecting reaction products from 200 MeV bombardment of a 51 mg/cm^2 ^{12}C target. The pulse shape parameter plotted on the horizontal axis is $(E_2-E_1)/(E_2+E_1)$, where E_1 and E_2 correspond to the integrated charge in the rising and falling portions, respectively, of the liquid scintillator linear pulses. The PSD resolution is very good all the way down to the 0.4 MeV electron-equivalent threshold.

the liquid counter), since otherwise the very-low-threshold CFD will "retrigger" on the extreme tails of such pulses, producing spurious groups in the pulse-shape spectra. The dead time introduced by such "retrigger" vetoing was reduced to a couple of percent by the installation of the sweeping magnet.

We now have a working detector setup suitable for obtaining reasonable (> 2:1 for $\gtrsim$ 50% neutron decay branches) real-to-accidental coincidence ratios with 10-20 nA of 200 MeV protons incident on a ~ 50 mg/cm^2 ^{12}C target. We aim to take production data during 1987. During production runs, we will simultaneously acquire π^+-n coincidences corresponding to low-lying residual states in ^{13}C, which are known to have ~ 100% neutron decay branches to the ^{12}C ground state. The ^{12}C(p,π^+n) data for these states will provide a built-in efficiency calibration for our investigation of decay branches from the 21.4-MeV state.

1) E. Korkmaz, et al., Phys. Rev. Lett. 58, 104 (1987).

2) S.E. Vigdor, W.W. Jacobs, and E. Korkmaz, Phys. Rev. Lett. 58, 840 (1987).

3) S. Aziz, et al., this report p. 61.

4) S.J. Seestrom-Morris et al., Phys. Rev. C 26, 594 (1982).

5) H. Breuer et al., IUCF Scientific and Technical Report 1982, p. 80.