Two–nucleon processes in pion–induced double charge exchange in ^{4}He: A coincidence measurement of the $^4\text{He}(\pi^+, \pi^- p)3p$ reaction.

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ABSTRACT

Inclusive measurements of pion double–charge–exchange in ^{3}He[1] and ^{4}He[2] in the Δ(1232) resonance region suggest the dominance of a two–step sequential single–charge–exchange mechanism involving quasi–free nucleons. To investigate this reaction mechanism, we have observed protons in coincidence with the outgoing pion in $\pi^+ + {}^4\text{He} \rightarrow \pi^- + 4p$ at $T_{\pi^+} = 240$ MeV. Pions were detected in a magnetic spectrometer at $\theta_{\pi^-} = 32°$, while protons were detected in a close–packed array of plastic scintillator telescopes covering $\theta_p = 67.5° - 157.5°$ on the same side of the beam as the spectrometer, and $\theta_p = 22.5° - 157.5°$ on the opposite side. We will present preliminary results for the distributions in energy and angle of the coincident protons.

Two–nucleon correlations have long been a subject of study in nuclear physics, from the point of view of medium modifications to the NN interaction as well as nuclear structure issues. Two–nucleon processes play a large role in the absorption of photons[3] and pions[4, 5, 6] by nuclei. The contributions of these multi–nucleon mechanisms are in many cases difficult to study directly, since these mechanisms are by nature second order and may be obscured by first order processes. Pion–induced double charge exchange (DCX), however, must proceed via interactions with at least two nucleons (since two nucleons must change charge during the reaction) and thus affords the study of two nucleon processes directly.

Over the last decade, the cross section for inclusive DCX has been systematically studied over a range of target mass and beam energy, with emphasis on the energy region near the Δ(1232) resonance[1, 2, 7, 8, 9]. Several distinct features of these data are worthy of mention. The total cross section for DCX as a function of A obeys a scaling law (a function only of A and Z) based on competition between DCX and other channels[9]. Only the helium isotopes differ significantly from this scaling behavior. Despite this apparent universality in the total cross section, there is a distinct change in the appearance of

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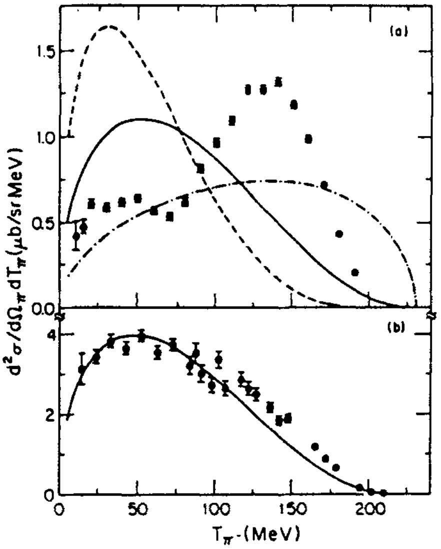

Figure 1: Doubly differential cross sections for the reactions (a) ^{4}He(π^+,π^-)4p [2, 10] and (b) ^{16}O(π^+,π^-)X [8] at incident energy 240 MeV and laboratory angle 25°. The dashed and dot–dashed curves in (a) correspond to the distribution of events in five–body and three–body phase space, respectively, while the solid curves in (a) and (b) correspond to four–body phase space.

differential quantities as a function of A. Figure 1 shows doubly differential cross sections for DCX on ^{4}He and ^{16}O. Whereas the ^{16}O cross section has a shape consistent with a final state described by four–body phase space (*i.e.*, $\pi^+ + {}^{16}\text{O} \rightarrow \pi^- + p + p + {}^{14}\text{O}$), the ^{4}He data are not consistent with any of several phase space descriptions. The behavior of the ^{16}O data are typical of targets heavier than carbon[8], and one sees, with decreasing A, a gradual change to the double–peaked structure of ^{4}He[7].

The double–peaked structure, seen in both helium isotopes[1, 2], qualitatively suggests the dominance of a simple two–step mechanism, consisting of sequential single–charge–exchange (SCX) reactions. In the vicinity of the $\Delta(1232)$ resonance, the SCX cross section will resemble the p-wave $1+3\cos^2\theta$ dependence. At forward angles, DCX events resulting from two large–angle, or two small-angle, SCX events will be favored, resulting in the double–peaked energy spectra observed. To investigate this mechanism in more detail is the purpose of the present investigation. We have chosen to detect recoiling protons resulting from ^{4}He(π^+,π^-)4p in a large solid angle scintillator array, in coincidence with the outgoing pion. This will enable us to identify the contribution of such sequential SCX processes by observing the kinematic signature of each event in more detail.

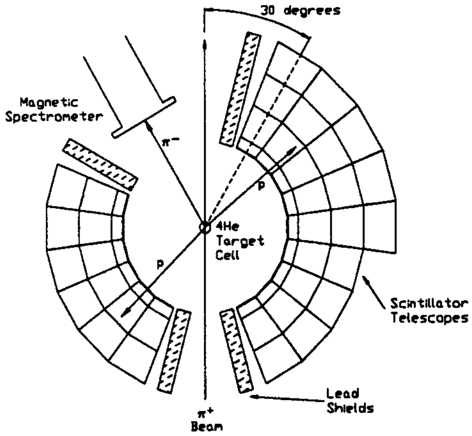

Figure 2: Scale rendering of the experimental setup.

The experiment was performed at the Clinton P. Anderson Meson Physics Facility (LAMPF) on the "P^{3}W" pion beam channel. The beam from the channel was directed onto a 25.4 mm diameter cylindrical liquid helium cell. Outgoing negative pions were detected at $\theta_{\pi^-} = 32^\circ$ in a magnetic spectrometer. The focal plane readout of this spectrometer[1, 2, 7, 8] consisted of wire chambers for tracking, along with a scintillator and Cherenkov detectors for particle identification. Coincident protons were detected in an array of 15 scintillator telescopes (see Fig. 2). The thicknesses of the scintillators in a telescope were, successively, 1, 25, 75, 75, and 75 mm. Only the telescopes at the forward angles had five elements. Those telescopes with four (five) elements could stop protons of 150 (200) MeV, while the lowest detectable proton energy was about 20 MeV (due largely to energy losses in the helium target). The solid angle of each proton telescope was 100 msr.

The solid angle of the spectrometer was measured by observing pions elastically scattered from hydrogen nuclei in a 25.4 mm diameter cylinder of CH positioned below the helium cell — this CH target was accessed by raising the cryogenic target arm within the scattering chamber. An angular distribution of such data also served to calibrate the in-beam ion chamber which measured the flux of beam particles.

Figure 3 shows some preliminary results. In addition to the coincidence data of interest, we also collected an inclusive sample at $\theta_{\pi^-} = 32^\circ$ for T_{π^-} from 30 to 190 MeV (Fig. 3(a)). We selected two points in this distribution at which to take coincidence data, near the peaks of the low- and high-energy structures, $T_{\pi^-} = 45$ and 135 MeV. One result of those data is shown in Fig. 3(b), an angular distribution of coincident protons, for $T_{\pi^-} = 45$ MeV. The

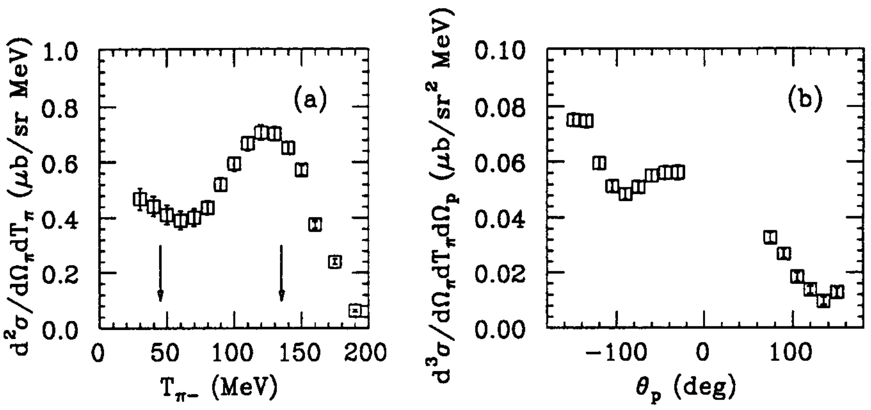

Figure 3: Preliminary results: (a) Inclusive yield for ^{4}He(π^+, π^-) at $T_{\pi^+} = 240$ MeV and $\theta_{\pi^-} = 32°$. The arrows indicate the energies at which the coincidence data were taken. (b) Angular distribution of coincident protons for $T_{\pi^-} = 45$ MeV. Positive proton angles are on the same side of the beam as the pion spectrometer.

analysis of the coincidence data is well underway and will be presented, along with comparisons to calculations.

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