Pion Charge Exchange on Tritium

P. Glodis, H. Brändle, R. Haddock, I. Kostoulas, N. Matz, B. Nefkens, W. Plumlee, and O. Sander
University of California, Los Angeles, California 90024

and

J. Pratt, R. Sherman, F. Shively, and J. Spencer
Los Alamos Scientific Laboratory, Los Alamos, New Mexico 87545

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Measurements of the differential cross section for pion charge exchange on ^{3}H have been carried out at incident pion momenta of 232 and 252 MeV/c. The results are compared with several theoretical predictions and also with charge-independence bounds determined from elastic-scattering cross sections obtained in the same experiment.

The isospin doublet ^{3}H, ^{3}He provides an experimentally accessible test of charge symmetry through comparison of the differential cross sections for mirror reactions such as $^3\mathrm{H}(\pi^\pm,\pi^\pm)^3\mathrm{H}$ and $^3\mathrm{He}(\pi^\mp,\pi^\mp)^3\mathrm{He}$, or $^3\mathrm{H}(\pi^+,\pi^0)^3\mathrm{He}$ and $^3\mathrm{He}(\pi^-,\pi^0)^3\mathrm{H}$. Measurements of the differential cross section for pion charge exchange ($d\sigma_0$) and the π^+ and π^- elastic differential cross sections ($d\sigma_+$ and $d\sigma_-$) on a given three-nucleon target allow a test of charge independence based on the triangle inequality

$$\tfrac{1}{2}(d\sigma_+^{1/2}-d\sigma_-^{1/2})^2 \leq d\sigma_0 \leq \tfrac{1}{2}(d\sigma_+^{1/2}+d\sigma_-^{1/2})^2.$$

The three-nucleon system is also an attractive testing ground for models of π-nucleus interactions. The $A=3$ wave functions are sufficiently well known to encourage calculations of pion-scattering processes and the results of these calculations[1-5] indicate a high sensitivity to theoretical assumptions.

Eisenberg and Mandelzweig[1] have calculated the angle-integrated cross section for the reaction $^3\mathrm{H}(\pi^+,\pi^0)^3\mathrm{He}$ using Glauber multiple-scattering theory. They find that, relative to the single-scattering (impulse) approximation, inclusion of pion rescattering results in the elimination of the pronounced resonant-energy dependence and a reduction of the total charge-exchange cross section by as much as 70%. The importance of the spin-flip amplitude is expected to be large. Landau[2] has pointed out the role of the $\Delta(1232)$ intermediate state in emphasizing the spin-flip contribution of the unpaired nucleon. This effect is seen in the calculation by Sparrow[3] of the charge-exchange differential cross section which is dominated by the resonant spin-flip amplitude at center-of-mass angles near 90°. Lohs and Mandelzweig[4] have investigated the sensivity of π-^{3}H differential cross sections to the parametrization of the elementary pion-nucleon amplitudes and find it to be substantial for large-angle scattering in both the elastic and charge-exchange reactions. In general, various authors emphasize different effects and, especially where experimental results are lacking, the range of competing theoretical predictions is large.

We report here on the first results of an experiment, performed at the Clinton P. Anderson Meson Physics Facility (LAMPF), designed to survey pion scattering from tritium and ^{3}He in the $\Delta(1232)$ resonance region. This Letter presents our measurements of the differential cross section for pion charge exchange on tritium at 232 and 252 MeV/c. The data cover the angular range from 110° to 140° in the center-of-mass system because our experimental technique is based on the detection of the recoiling ^{3}He nucleus. Despite this limitation, the data are of sufficient accuracy to discriminate between several calculations in our energy range.

The experimental arrangement, shown in Fig. 1, consists of a two-arm coincidence spectrometer and a cryogenic tritium gas target. A charge-exchange trigger is defined by the detection of a recoiling nucleus in coincidence with one of the photons from the presumed π^0 decay. The track of the recoiling nucleus is defined by two sets of multiwire proportional chambers (MWPC's). These chambers operate in a low-pressure (5 Torr) pentene-gas environment and present a minimum amount of mass to the recoiling particle. They have essentially no sensitivity to minimum-ionizing particles and yet are 100% efficient for helium nuclei in the energy range of this experiment. In addition, the time resolution of these low-pressure chambers is significantly better than that of standard multiwire chambers. Following the recoil chambers, a thick scintillator, also in the low-pressure environment, serves as a stopping counter for the ^{3}He. The pulse-

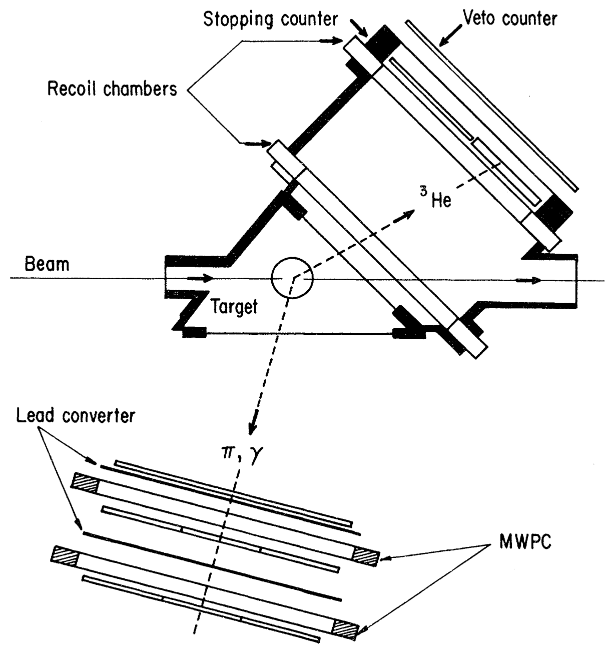

FIG. 1. The University of California, Los Angeles, double-arm spectrometer. The 15-cm-diam cylindrical target flask located in the center of the triangular vacuum box contains 80 000 Ci of tritium gas at a temperature of 38 K.

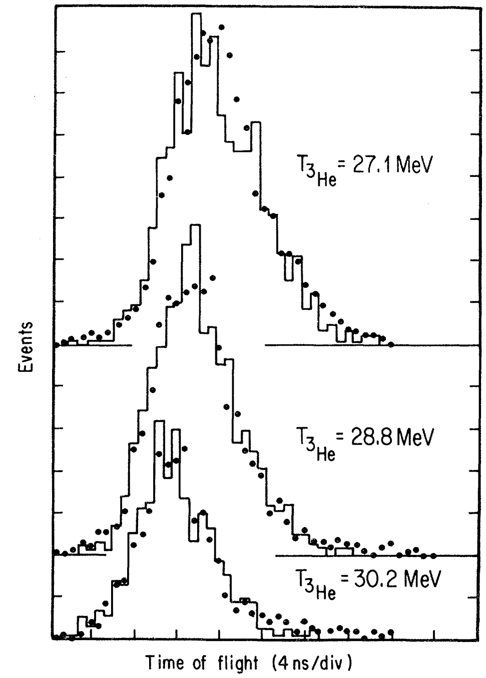

FIG. 2. Recoil time-of-flight spectra for elastic events from the reaction $^3He(\pi^+, \pi^+)^3He$ (lines) compared with time-of-flight spectra for pion charge exchange $^3H(\pi^+, \pi^0)^3He$ (solid circles). The equivalent shape of the two distributions at each recoil energy demonstrates the absence of significant background in the charge-exchange data.

height and timing information from that counter are recorded for each event. The recoil spectrometer is completed by a final plane of scintillators which act as a fast-particle veto.

The photon detector consists of an intial plane of scintillators which provides a charged-particle veto followed by two photon-detection packages. Each package consists of a 1-radiation-length lead-sheet converter, a conventional MWPC, and a final plane of scintillators to provide a clean timing signal. The photon-detection array spans a range of 30° in laboratory angle and can be pivoted about the target center to cover the range of angles between 60° and 130°.

The incident pion flux is measured with an ionization chamber in the beam following the target and two scintillator telescopes on either side of the beam which monitor muons from pion decay in flight in the space immediately preceding the target.[5] Time-of-flight and range measurements were used to confirm nominal beam momenta (± 1%) and to establish beam compositions.

In the analysis of the data, the event coordinates from the low-pressure chambers are used to establish the direction of the recoiling nucleus and an approximate target-interaction point. Events originating upstream or downstream of the target are eliminated at this stage.

The solid angle of the photon array does not allow the detection of both π^0 decay photons simultaneously. Since the coordinates for one γ are missing, the event is not overconstrained on the basis of the measured angular information and time-of-flight and recoil pulse-height data are used to unambiguously identify the charge-exchange events. In this respect, one of the important features of this experiment is the ability to calibrate the response of the recoil detectors. This is done using elastic-scattering data taken with a ^{3}He-filled target. The elastic events, in which both the recoiling nucleus and scattered pion are detected, are overconstrained and allow us to obtain, for ^{3}He's of a given energy, the time of flight and pulse-height response of the stopping counter and recoil MWPC's. Since the angle-energy corelation of the recoil ^{3}He is the same in both the charge-exchange and elastic reactions, this provides a convincing calibration for the charge-exchange events. The equivalence of the time-of-flight spectra for several ^{3}He recoil energies for the ^{3}He elastic and ^{3}H charge-exchange data samples is shown in Fig. 2. For each recoil energy we have normalized the elastic and charge-exchange distributions to the same number of events.

Final number of events are determined from the charge-exchange time-of-flight distributions after the subtraction of an appropriately normalized target-empty sample to eliminate a small number of spurious events originating in the target walls. In the calculation of the cross section, the acceptance of the γ arm is calculated for each center-of-mass angular bin using a Monte Carlo simulation of π^0 decay. Averaged over the angular range of our data, about 25% of the π^0 decays result in a detectable photon conversion in the array.

The center-of-mass differential cross sections at our two energies are shown in Fig. 3. As a test of the validity of charge independence we compare our charge-exchange data to the triangle-inequality limits derived from our preliminary $\pi^\pm$-^{3}H elastic-scattering results obtained in the same experiment.[6] Our data fall within the shaded bound in Fig. 3 in support of the applicability of charge independence to the π-^{3}H system. Note that the data are close to the lower limit implying dominance of one of the isospin amplitudes or a 180° phase degeneracy.

Comparison is also made with the first-order optical-model calculation of Landau,[2] two Glauber-model calculations by Lohs and Mandelzweig,[4] and a multiple-scattering-theory calculation using separable π-N t matrices by Hess and Gibson.[7] All of the calculations show the expected falloff of the cross section with increasing momentum transfer as a result of the nucelar form factor. Another feature common of the calculations is that the inclusion of the large spin-flip contribution from the unpaired photon effectively fills in the spin-nonflip s-p minimum seen, for example, in π-^{3}H elastic scattering.[6] The data appear to favor the optical-model calculation by Landau.

Landau[8] has also calculated the charge-exchange cross section at energies above the resonance where a comparison is possible at several energies with the ^{3}He$(\pi^-,\pi^0)^3$H data of Källne *et al.*[9] The agreement becomes poorer at the two highest energies where the experimental cross section is not falling as rapidly as predicted.

Because of the safety precautions necessary with a tritium target, the running of our experiment required a special and costly effort by

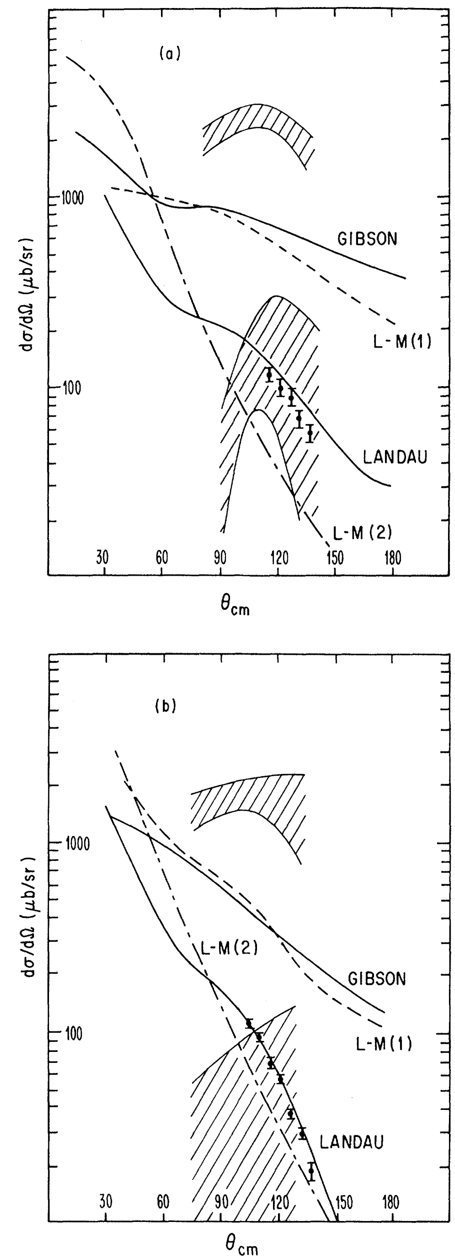

FIG. 3. Measured $d\sigma/d\Omega$ for the reaction ^{3}H$(\pi^+,\pi^0)^3$He. (a) 232 MeV/c (131 MeV) and (b) 252 MeV/c (148 MeV). The errors shown are statistical only. The shaded areas represent upper and lower limits on the charge-exchange reaction derived from elastic-scattering results assuming charge independence. Comparison is made at each energy with theoretical predictions by Hess and Gibson (at 232 and 252 MeV/c), Lohs and Mandelzweig (at 233 and 256 MeV/c), and Landau (at 233 and 253 MeV/c).

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Triton *s*-Wave Asymptotic Normalization Constants

E. P. Harper, D. R. Lehman, and F. Prats
Department of Physics, The George Washington University, Washington, D. C. 20052

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The n-d and n-$(np)_{s=0}$ triton s-wave asymptotic normalization constants are calculated from a realistic one-boson-exchange model of the NN interaction. Both parameters are calculated from integral relations which make the analytic continuation to the pole unambiguous. The values obtained are $C_t^2 = 2.60$ and $C_s^2 = -0.69$.

The subject of triton asymptotic normalization constants has received considerable attention in the literature recently.[1] Apart from the accepted usefulness of these quantities in the analysis of direct reactions[2] involving tritions, it has been proposed that these numbers provide a discriminating test of triton wave functions obtained from realistic models of the NN interaction.[3] The purpose of this Letter is to present the values of the $^3H \to n + d$ and $^3H \to n + (np)_{s=0}$ s-wave asymptotic normalization constants, designated C_t and C_s, respectively, calculated from a one-boson-exchange (OBE) representation of the NN interaction. To our knowledge, it represents the first calculation of C_s^2 with a realistic NN potential[4] and the first OBE-model calculation of C_t^2.[5] Furthermore, we stress that the C_s^2 defined unambiguously by analytic continuation to the second-sheet pole has not yet been extracted from experiment and a method to do it remains an open problem. Also, we show how to calculate the quantity called $C(^3H, d^*n)$—the "effective" $^3H \to n + (np)_{s=0}$ asymptotic normalization—by Plattner, Bornand, and Viollier (PBV)[6] and give its value as predicted from our wave functions.

The OBE model of the NN interaction which we use is one developed by Holinde and Machleidt.[7] This interaction gives an excellent account of the low-energy NN parameters ($a_s = -23.83$ fm, $r_{0s} = 2.703$ fm, $\epsilon_s = 67.6$ keV; $a_t = 5.50$ fm, $r_{0t} = 1.87$ fm, $\epsilon_d = 2.225$ MeV) and the NN phase shifts. Moreover, it leads to a somewhat better description of the triton than does the Reid soft-core potential (RSC).[8] With the OBE interaction effective in the $^1S_0$ and $^3S_1$-$^3D_1$ states, solving the complete set of Faddeev equations, we get $E_3 = 7.38$ MeV for the ^3H binding energy and a triton charge form factor in marginally better agreement with the data. This ^3H wave function, including all its components, we normalize and use in the calculations.

The asymptotic normalization constant C_t is de-

