

TENSOR POLARIZED DEUTERON CAPTURE BY THE HYDROGEN ISOTOPES

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Data acquisition is now finished for E 234 which measured the angular distribution of the cross section, vector analyzing power  $A_y$  and tensor analyzing power  $A_{yy}$  for the reaction  ${}^2\text{H}({}^2\text{H}, \gamma){}^4\text{He}$  at an incident deuteron energy of 95 MeV. The interesting aspect of this reaction is that the tensor analyzing powers are generated directly by the D-state probability of the residual  ${}^4\text{He}$  nucleus. The reaction was expected to proceed predominantly by E2 radiation since the E1 multipole is forbidden by spin-parity considerations while the M1 transition was expected to be inhibited by isospin selection rules for self conjugate nuclei. Meson exchange currents with explicit isobars should be suppressed since all the particles are isoscalar. These restrictions on the reaction mechanism result in a process uniquely sensitive to a particular piece of the  ${}^4\text{He}$  wavefunction with a clear reaction mechanism; the price paid for this clarity is that the cross section is at most 2 nb/sr in the lab at  $E(d) = 95$  MeV. Since it was impractical to monitor the  ${}^2\text{H}({}^2\text{H}, \gamma){}^4\text{He}$  reaction on-line during the experiment, the  ${}^1\text{H}({}^2\text{H}, \gamma){}^3\text{He}$  reaction was used to set up and monitor the experiment. The tensor analyzing powers of this reaction are also sensitive to the D-state of the  ${}^3\text{He}$  nucleus, enabling us to carry out a useful measurement as well as a detector calibration.

At lower energies this simple picture described the available data very well. The cross section was fit very well by the expected  $\sin^2(2\theta)$  distribution characteristic of an E2 transition.  $T_{20}$  was isotropic<sup>1</sup>, which was expected if the reaction proceeded by E2 radiation and products of two channel

spin 2 matrix elements were ignored<sup>2</sup>. A recent measurement<sup>3</sup> at low energy ( $E(d) = 10$  MeV) of the cross section,  $A_y$ , and  $A_{yy}$  has proven that this simple description is not complete.  $A_y$  is driven by an interference between the E2 and other multipoles and was expected to be small; it was found that  $A_y$  was not small and was comparable in size to  $A_{yy}$ . Additional proof for the contribution of non-E2 strength was found in a Legendre fit to  $A_{yy}$  which required an odd term to fit the data; such terms are not allowed by the pure E2 process<sup>2,3</sup>. Inclusion of the M2 multipole is needed for a complete description.

At higher energies ( $E(d) = 376$  MeV) the available data (cross sections only) are sparse and of generally poor quality due to the very low cross section (typically 20-40 pb/sr). A  $\sin^2(\theta)$  angular distribution (characteristic of an E1 transition) fits these data better than the  $\sin^2(2\theta)$  shape of an E2 transition. One possible explanation is that the deuterons rearrange to form a trinucleon + nucleon system followed by radiative capture. Higher order meson exchange currents could also explain this change in the shape of the cross section<sup>4</sup>. What is clear is that from 10 MeV to 270 MeV a radical change occurs in the reaction mechanism.

Our measurement at 95 MeV extends the polarization measurements to significantly higher energy. The combination of cross section and polarization observables should enable the reaction mechanism to be unraveled, leading to a good determination of the  ${}^4\text{He}$  D-state probability. Our energy is probably not high enough to reach the E1-type region; preliminary

analysis of about 15% of the data shows that we have a deep minimum at 90 degrees.

During the summer of 1985 E 234 completely finished its beam time allocation. Lead glass Cherenkov detectors were used to detect the photon and a plastic scintillator detector telescope detects the coincident helium nucleus (Figure 1). The major technical problem is that the recoil nuclei emerge at small angles relative to the beam axis and the recoil detector must then be able to separate a flood of scattered deuterons from these helium nuclei. Fast timing referenced to the cyclotron RF signal cleanly separates these particles. Figure 2 shows for  ${}^1\text{H}({}^2\text{H},\gamma){}^3\text{He}$  the time of flight in the recoil telescope with and without the conditions for radiative capture events. With timing resolution of 500 psec (FWHM) the background under the radiative capture peak is only about 10% of the radiative capture peak before any

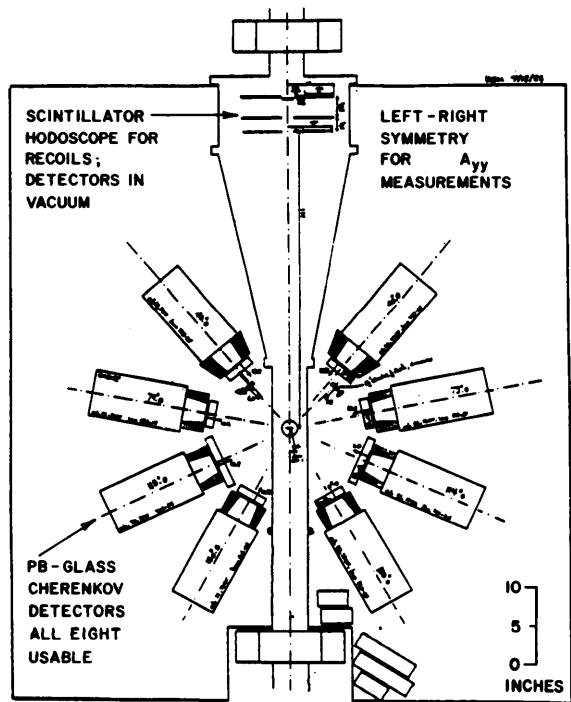
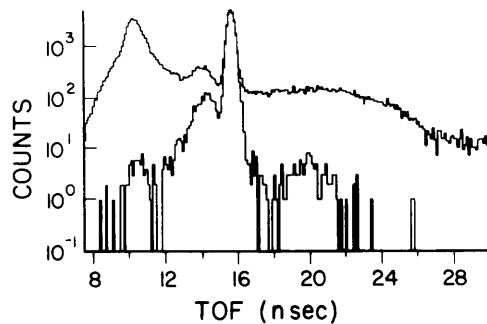


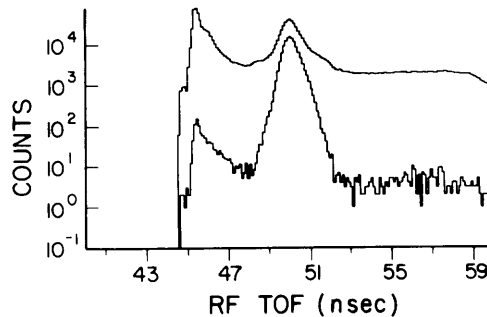
Figure 1. E234 Experimental Apparatus

cuts. While this cross section is about 400 times larger than the  ${}^2\text{H}({}^2\text{H},\gamma){}^4\text{He}$  cross section the preliminary analysis showed that the background can be reduced to better than about 20 pb/sr for the  ${}^2\text{H}({}^2\text{H},\gamma){}^4\text{He}$  process. Figure 2b shows the timing in a lead-glass detector. Most neutron-induced events were eliminated in hardware with a cut on the cyclotron RF signal, which gives the sharp edge on the left of the spectrum. The stability of the RF signal was monitored in a separate "fail-safe" circuit which compared the cyclotron RF signal to the real arrival time of the beam burst at the target. More details of the experiment are given in the 1984 Annual Report.

(a)



(b)



IUCF 2024

Figure 2.  ${}^1\text{H}({}^2\text{H},\gamma){}^3\text{He}$  response spectra: (a) Typical time of flight spectra from the recoil detector. Ungated spectrum overlain by radiative capture gated spectrum. (b) Typical time of flight spectra from the photon detector. Ungated spectrum overlain by radiative capture gated spectrum.

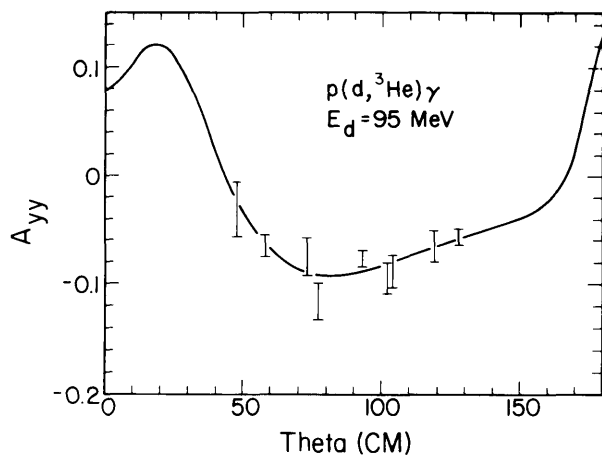
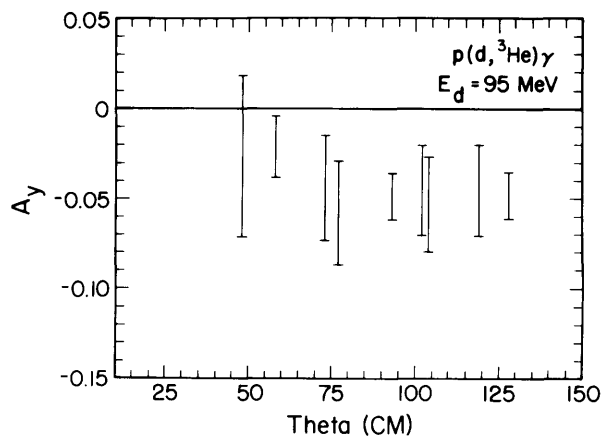
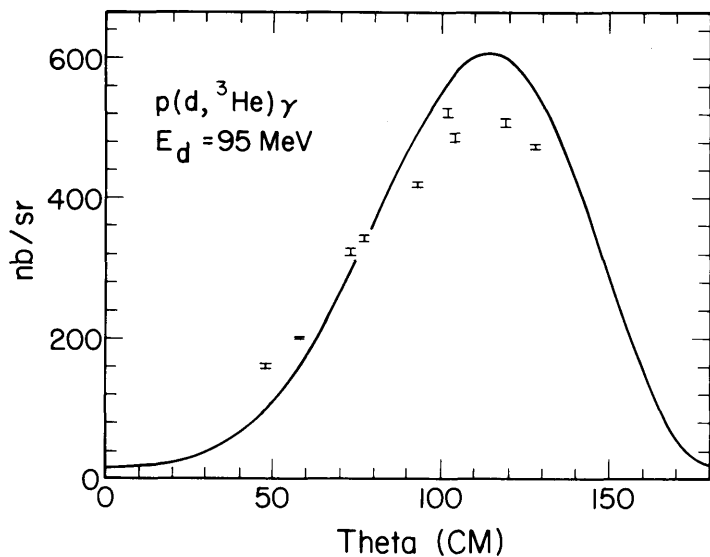


Figure 3. Preliminary results for the  ${}^1\text{H}({}^2\text{H}, \gamma){}^3\text{He}$  reaction at  $E(d) = 95$  MeV. The curves are a result of a PWBA calculation.<sup>6</sup> (a) Differential cross section in the center of momentum system, (b) vector analyzing power  $A_y$ , (c) tensor analyzing power  $A_{yy}$ .

The analysis of the  ${}^1\text{H}({}^2\text{H}, \gamma){}^3\text{He}$  data is almost completed. The data shown in Fig. 3 are preliminary and to be corrected for detector efficiency, reaction effects in the recoil telescope, background subtraction, and other effects. The errors here only include the statistical accuracy of the measurements. PWBA calculations by Arriaga and Santos<sup>6</sup> are shown. These calculations used the same value of the D-S state ratio that gave the best fit to lower energy ( $E(d) = 30$ ) data.<sup>6</sup> Our data will soon be in a form suitable for publication and preprints should be available by April, 1986.

After the  ${}^1\text{H}({}^2\text{H}, \gamma){}^3\text{He}$  analysis is finished, the  ${}^2\text{H}({}^2\text{H}, \gamma){}^4\text{He}$  analysis will begin. Our strategy was that the procedures would be checked in the  ${}^1\text{H}({}^2\text{H}, \gamma){}^3\text{He}$  analysis with its large event rate before the  ${}^2\text{H}({}^2\text{H}, \gamma){}^4\text{He}$  analysis was started. The  ${}^2\text{H}({}^2\text{H}, \gamma){}^4\text{He}$  analysis should be finished by mid-summer, and the final data set should be ready for publication by August 1, 1986.

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