THE EXCLUSIVE $p + d \to {}^3\mathrm{He} + 2\pi$ REACTION AT CELSIUS*

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Neutral and charged two-pion production in $p+d \to {}^3\mathrm{He}+2\pi$ reactions has been studied at a proton beam energy of 477 MeV. The total cross section for double pion production is 0.22 ± 0.03 μb. The ratio of the cross sections for the production of charged pion pairs with isospin $T = 1$ and $T = 0$ was determined to be 1.4 ± 0.4.

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Results reported from a measurement by Bellemann *et al.* [1] of the $p + d \to {}^3\mathrm{He} + \pi^+ + \pi^-$ reaction at a centre-of-mass (c.m.) excess energy of $Q_{\pi^+\pi^-} = 70$ MeV are surprising. A relative s-state (*i.e.* isospin $T = 0$) between the two pions is expected, but the result is interpreted as evidence for dominance of production of $\pi^+\pi^-$ pairs in a relative p-state (*i.e.* $T = 1$).

In order to clarify the situation we have made a measurement in which the two possible isospin states of the pion pair could be unambiguously resolved. We have studied the exclusive reactions

$$p + d \to {}^3\mathrm{He} + \pi^0 + \pi^0 \,, \tag{1}$$

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and

$$p + d \rightarrow {}^3\mathrm{He} + \pi^+ + \pi^- \tag{2}$$

as well as the corresponding inclusive reaction at an energy corresponding to $Q_{\pi^0\pi^0} = 37$ MeV and $Q_{\pi^+\pi^-} = 28$ MeV. For reaction (1) the isospin of the pion pair is constrained to $T = 0$ while for reaction (2) two isospin channels, $T = 0$ and $T = 1$, are open.

The CELSIUS accelerator and storage ring [2] at the The Svedberg Laboratory was used for this experiment with an electron-cooled circulating proton beam with a kinetic energy of 477 MeV interacting in a deuterium cluster-jet target. The ^{3}He particles were detected in the zero-degree spectrometer [3]. Charged pions and gamma rays from decaying neutral pions were detected in the forward detector and the central calorimeter of the WASA/PROMICE apparatus respectively [4]. With ΔE-ΔE-E technique ^{3}He particles were selected in coincidence with at least one gamma ray or one charged pion.

In order to determine the relative contribution of $T = 0$ and $T = 1$ pion pairs and the total cross sections, we have fitted the experimental inclusive and exclusive energy spectra of ^{3}He ions by corresponding simulated spectra. For the $T = 0$ channel we assume a constant production amplitude, *i.e.* isotropy and an energy distribution given by phase space. For the $T = 1$ channel a relative p-state is assumed and we use a squared amplitude proportional to $k^2_{\pi\pi} \sin^2 \theta_{\pi\pi}$ [1] where $\boldsymbol{k}_{\pi\pi}$ is the relative momentum in the pion-pion system and $\theta_{\pi\pi}$ the angle between $\boldsymbol{k}_{\pi\pi}$ and the beam axis. For the cross sections we obtained $\sigma(\pi^0\pi^0) = 58 \pm 12$ nb and $\sigma(\pi^+\pi^-) = 162 \pm 22$ nb. Expressed in terms of the $T = 1$ and $T = 0$ contributions to the charged pion cross section we obtain

$$R = \frac{\sigma(\pi^+\pi^-; T = 1)}{\sigma(\pi^+\pi^-; T = 0)} = 1.4 \pm 0.4\,. \tag{3}$$

Experimental and fitted spectra are shown in Fig. 1.

The result for the $T = 0$ channel seems to be consistent with the result for the $p+d \rightarrow {}^3\mathrm{He}+\pi^+ +\pi^-$ reaction studied at 431.5 MeV ($Q_{\pi^+\pi^-} = 0.6$ MeV) by Betker *et al.* [5], where a cross section of $71 \pm 21 \pm 11$ pb was obtained. Extrapolating our $T = 0$ result to the same energy, assuming the cross section to be proportional to phase space (varying approximately as Q^2) we obtain $33 \pm 6 \pm 15$ pb for the charged pion channel. Our results also seem consistent with the findings by Bellemann *et al.* [1] at 546 MeV ($Q_{\pi^+\pi^-} = 70$ MeV). Their integrated cross section for the charged pion channel is 1.34 ± 0.13 μb [6] compared to our extrapolated value of 1.9 ± 0.4 μb, assuming the $T = 1$ cross section to vary approximately proportionally to Q^3. The extrapolated ratio between $T = 1$ and $T = 0$ in the charged pion channel

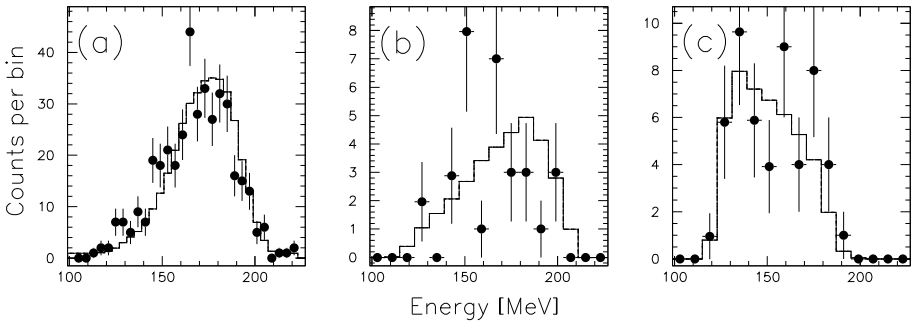

Fig. 1. Experimental energy spectra of ^{3}He particles in the zero-degree spectrometer (filled circles) and the corresponding fitted spectra (histograms). (a) Inclusive data, (b) data from the reaction $p + d \rightarrow {}^3\mathrm{He} + 2\pi^0$ and (c) data from the reaction $p + d \rightarrow {}^3\mathrm{He} + \pi^+ + \pi^-$.

becomes $R = 3.8 \pm 1.0$ at 546 MeV, *i.e.* a strong dominance of the $T = 1$ channel in accordance with interpretation of Bellemann *et al.* [1], Abashian *et al.* [7] measured the inclusive differential cross section of the $p+d \rightarrow {}^3\mathrm{He}+2\pi$ and the pure $T = 1$ $p + d \rightarrow {}^3\mathrm{H} + 2\pi$ reaction for $Q \approx 184$ MeV at 11.8° in the laboratory. From their result, assuming isospin symmetry, we deduce a ratio between the $T = 1$ and $T = 0$ charged-pion differential cross sections of approximately 0.3 for recoil momenta between 1150 and 1300 MeV/c. An extrapolation of our result to the energy of Abashian *et al.* would lead to a predicted ratio of 9 in sharp contrast to the measured value. For the differential cross section in the $T = 0$ channel they measured a value of approximately 28 nb sr^{-1} (MeV/c)$^{-1}$ close to the value 36 ± 7 nb sr^{-1} (MeV/c)$^{-1}$ extrapolated from our data. The $T = 0$ production thus increases smoothly with energy even to this energy whereas the production of $T = 1$ pion pairs has decreased dramatically.

The present result [8] thus ties together existing measurements and a consistent picture emerges for the cross section of the $p + d \rightarrow {}^3\mathrm{He} + 2\pi$ reaction from threshold up to a laboratory energy of 546 MeV. However, in the intermediate energy regime further experiments are called for.

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