decay. This fact strongly indicates that the four gamma rays are indeed to be attributed to a particle of strangeness +1. (3) On the basis of the known θ_2^0 lifetime,[6] less than one of our ten events can be attributed to a neutral decay mode of the θ_2^0. Although these considerations leave little doubt as to the fact that the four-gamma events do arise from neutral θ_1^0 decay modes, some question may remain as to whether these decay modes are indeed of the type $\theta_1^0 \to \pi^0 + \pi^0$ followed by $\pi^0 \to 2\gamma$ or whether perhaps some of the gammas are produced directly in the decays. If one knows how to pair the gammas belonging to the same π^0, it is possible to compute the θ^0 mass from the observed directions of the θ^0 and the four gammas, thus making a direct check that the decay scheme $\theta_1^0 \to \pi^0 + \pi^0$ has really been observed. Unfortunately the results of this calculation are quite sensitive even to small measurement errors. Making use of the lower limit for the energy of each gamma ray imposed by the visible ionization loss of its associated electron shower, however, we were able to pick assignments of gamma rays which made the kinematics for the decays consistent with the mode $\theta_1^0 \to \pi^0 + \pi^0$ followed by $\pi^0 \to 2\gamma$ for both π^0's. We therefore believe that the decay scheme $\theta_1^0 \to 2\pi^0$ is the most likely interpretation of the events, although on the basis of our data such schemes as $\theta_1^0 \to \pi^0 + 2\gamma$ or $\theta_1^0 \to 4\gamma$ cannot be ruled out.

Work is in progress on other aspects of the experiment, including branching ratios for neutral decay of Λ^0 and θ^0.

We wish to express our gratitude to the staff of the Lawrence Radiation Laboratory for making this work possible, and especially to our many friends at the Bevatron who helped us very much during this experiment.

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EXPERIMENT ON CHARGE INDEPENDENCE IN PION INTERACTIONS

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Although the existing experimental results in pion physics are consistent with the assumption of charge independence of pion-nucleon forces, the statistical accuracy of the data leads to an uncertainty of ±15% in quantitative tests of the concept.[1] Direct experimental tests[2] offer the possibility of substantially reducing this uncertainty before being limited by the accuracy of theoretical calculations of the Coulomb and mass difference effects in the specific reactions studied.

The present paper describes an experiment at 600-Mev proton energy on the reactions

$$p + d \to \mathrm{H}^3 + \pi^+,$$

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

for which (apart from Coulomb and mass corrections) the charge independence hypothesis predicts the ratio of the differential cross sections to be 2 at any c.m. angle. The c.m. energy of the emerging pions is 220 Mev, well above the $(\frac{3}{2},\frac{3}{2})$ resonance. The cross sections are compared by detecting only the recoiling nuclei, which are identified by momentum and time-of-flight selection, with pulse-height analysis as an additional check.

A sketch of the experimental arrangement is given in Fig. 1. The 600-Mev proton beam traverses a 2-cm thick liquid deuterium target with 0.1-mm thick Mylar windows and then a secondary emission chamber monitor. The solid angle for the scattering is defined by a 2×3 cm^2 tungsten collimator, 4 cm thick, which is placed 500 cm from the target at an angle of 11.3° to the incident proton beam. Of the H^3 and He^3 nuclei transmitted, the higher energy group, corresponding to 52° in

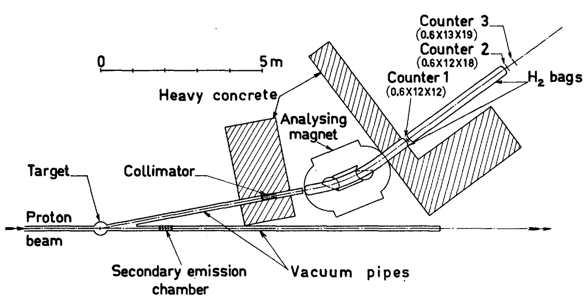

FIG. 1. Experimental arrangement. The counter dimensions are given in cm.

the c.m. system, was measured. A few properties of these particles are given in Table I. The particles passed by the collimator are analyzed by a magnet, the current in which is adjusted to bend the beam of either the H^3 or the He^3 nuclei over 26° into a telescope of three scintillation counters. The separation between counter 1, just after the magnet, and the pair of counters 2 and 3 is 400 cm. The signal from counter 1 is delayed by a cable of a length corresponding to the time of flight of the H^3 and He^3 nuclei over this 400-cm path and triple coincidences are recorded simultaneously with two coincidence circuits, one with 5.5 mμsec and the other with 4.0 mμsec resolution. The selectivity of this momentum–time-of-flight system ensures that no particles with a mass number different from three can be counted if they come directly from the target, i.e., are not scattered in or after the collimator. The identity of the counted particles is confirmed by recording, from one of the counters, the amplitude of the pulses that give rise to triple coincidences. These pulses are split and fed through two fast gates in parallel, each triggered by a different coincidence circuit. The output of each gate is recorded on a separate multichannel pulse-height analyzer. By taking the

Table I. Properties of the H^3 and He^3 nuclei counted in the present experiment. The range and energy loss are for plastic scintillator, the time of flight for 400-cm pathlength.

	T (Mev)	pc/Z (Mev)	Time of flight (mμsec)	Range (g cm^{-2})	Energy loss (Mev cm^2 g^{-1})
H^3	300	1332	31.1	23.2	7.2
He^3	300	666	31.1	5.8	28.9

data from the well-defined H^3 and He^3 peaks of the pulse-height spectra (shown for He^3 in Fig. 2), particles of the wrong charge and accidentals producing small pulse heights are eliminated.

Measurements on H^3 are alternated with He^3 runs. The thickness of counter 1 is reduced from 6 to 1.5 mm for the He^3 measurements to equalize the multiple scattering for both kinds of particles. Other effects of the larger multiple scattering of He^3 are negligibly small, as the trajectory of the heavy particles goes through vacuum from the target to the analyzing magnet and from there on through hydrogen.

The main difficulty of the experiment is the very small cross section of the reactions which, at the angle considered, is 14 μb/sterad for H^3. Three H^3 particles are counted for every 10^{11} protons in our geometry, whereas the number of protons and deuterons scattered into the same solid angle is a factor of 10^4 higher. Most of these particles are removed by the analyzing magnet, but Fig. 3, which gives the relative number of triple coincidences as a function of the delay in counter 1, shows that the time-of-

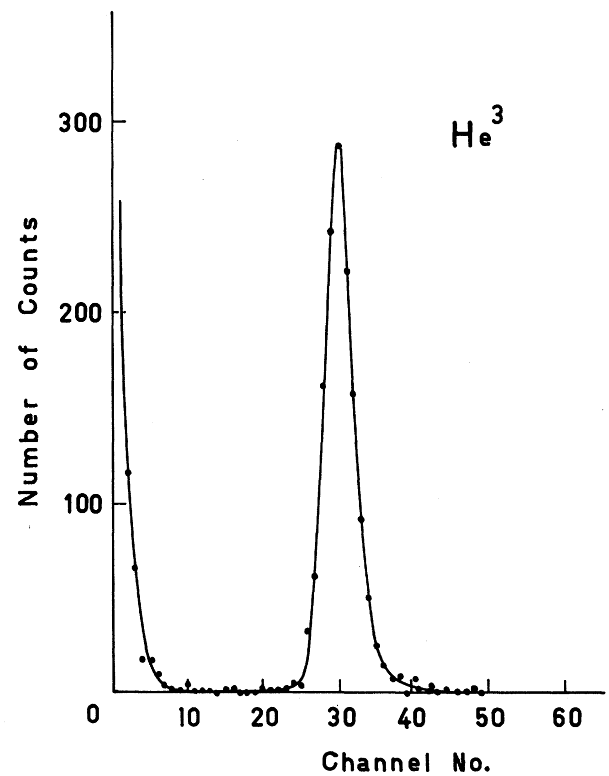

FIG. 2. Pulse-height spectrum in counter 2, gated by triple coincidences, for He^3 settings. The number of counts is given per channel for 8×10^{13} incident protons.

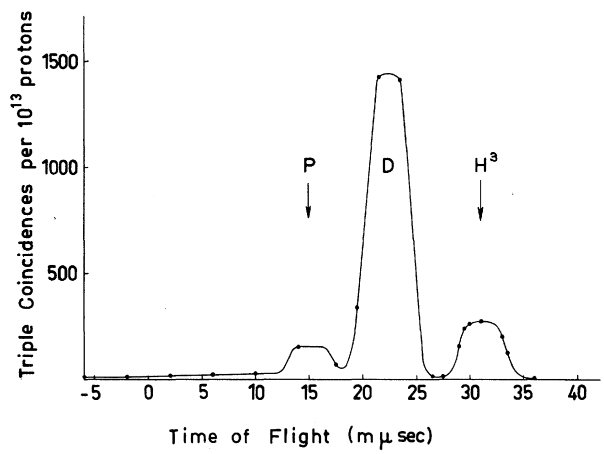

FIG. 3. Time-of-flight curve for H^3 settings.

flight selection still has to discriminate against rather a large number of deuterons.

The direct proton beam crosses the experimental room in a vacuum pipe but nevertheless contributes most to the background in the counters, approximately one thousand singles for each heavy particle recorded, notwithstanding the heavy shielding. To avoid corrections for accidental coincidences, the measurements have been made with a proton beam of 2×10^{10} protons per second, one-fifth of the maximum intensity.

The results of the counting, with their statistical errors, are listed in Table II. The value for the ratio of the measured cross sections following from these numbers is 2.29 ± 0.05.

In addition to the statistical uncertainty, possible sources of systematic errors must be considered. The reliability of the result depends mainly on two assumptions: first, that all the H^3 and He^3 nuclei, passing through the collimator, are counted and secondly, that all the recorded counts with the correct pulse height originate in H^3 and He^3 nuclei going through the three counters. To test the validity of these assumptions all measurements were repeated under marginal conditions. When the delay in counter 1 was set off from its correct value by an amount equal to the resolving time of the coincidence circuits, less than 1% of the counting rate was left. In the ratio this effect can be neglected. When the counters 2 and 3 were shifted together by their own width in the horizontal direction, the counting rate dropped to less than 1% of the central position value. The corresponding figure after vertical movement was at most 2% for both H^3 and He^3. Depending on their origin these marginal counts would have to be added to or subtracted from the measured numbers, leading to a negative or positive correction of (2 ± 2.8)% in the ratio. As this origin is unknown (the counts might be due to multiply scattered H^3 and He^3 nuclei or to other scattered particles with the correct time of flight) no corrections were applied, but the uncertainty was expressed in an additional error to the ratio of 4%. Other sources of uncertainty are the drift in the monitor and possible deviations from 100% efficiency of the counting system, each contributing a 1% error.

Table II. Results of the experiment. The number of counts is given for 10^{13} incident protons. The errors include only counting statistics.

	H^3	He^3
Full target	279.8 ± 2.6	136.2 ± 1.6
Empty target	16.1 ± 1.1	21.2 ± 1.2
Full - empty	263.7 ± 2.8	115.0 ± 2.0

After transformation to the c.m. system and combining the errors in quadrature, the final result for the ratio of the cross sections at a c.m. angle of 52° is

$$R=2.26\pm0.11.$$

The difference between this result and the value 2 predicted by isotopic spin considerations alone is somewhat larger than the 4% which, according to a preliminary calculation by Köhler,[3] should be added for Coulomb and mass corrections. Measurement of the ratio at a different angle is now planned.

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