Title

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TEST OF ISOTOPIC SPIN CONSERVATION IN STRONG INTERACTIONS FROM AN EXPERIMENT LIMIT ON $\sigma(d + d \to He^4 + \pi^0)$*

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To test the validity of isotopic spin (I-spin) conservation, the reaction

$$d + d \to He^4 + \pi^0 \tag{1}$$

was looked for at the Berkeley 184-inch cyclotron. This strong interaction requires a change in I-spin from zero to one (since the I-spin of d and He^4 are zero and the ordinary π^0 is one) and is therefore forbidden by the conservation law. Preliminary results of our investigation have been published.[1] On the basis of a more comprehensive data analysis to be described below, we obtain an upper limit for the differential cross section of this reaction, in the center-of-mass system, of

$$\frac{d\sigma^{c.m.}}{d\Omega} (d + d \to He^4 + \pi^0) < 1.5 \times 10^{-34} \text{ cm}^2/\text{sr}. \tag{2}$$

at about $\Theta_{c.m.} = 90$ deg. The data are consistent with no π^0 production. By comparing this upper limit with the theoretical prediction of the cross section obtained by assuming that I-spin need not be conserved,[2] we conclude that I-spin is at least 99.6% conserved. The reaction

$$d + d \to He^4 + \gamma \tag{3}$$

was also looked for at $\Theta_{c.m.} = 65$-deg; we obtain an upper limit for this cross section in the center of mass system of

$$\frac{d\sigma^{c.m.}}{d\Omega} \ (d + d \rightarrow He^4 + \gamma) < 3.5 \times 10^{-34} \ cm^2/sr. \qquad (4)$$

The kinematics for reactions (1) and (3) for incident deuterons of 460 Mev laboratory kinetic energy are shown in Fig. 1. The experimental arrangement is shown in Fig. 2. Slits of lead were placed between the target and the first quadrupole to fix the lab angle of the alpha particles at 8.7 $\pm$ 0.6 deg (indicated in Fig. 1) and to prevent the alpha-selecting magnet system from seeing the deuteron beam as it passed through the windows of the gas target. In order to accept the alphas from reaction (1) which are produced in the above lab angle interval, the magnet system was designed to have a momentum bite of approximately $\pm$ 6%. To minimize energy loss and multiple scattering, the entire path length of the alphas was in vacuum except for regions in the immediate vicinity of the target and the counters.

The target was 37.5-in. long, 6-in. in diameter, with 1/32-in. thick aluminum entrance and exit windows. It was filled with gas to a pressure of 390 psi (absolute) at liquid-nitrogen temperature. Fillings of hydrogen and deuterium were alternated.

The alpha particles were identified by means of effective momentum selection (p/Z), time of flight and range (i.e., T_1, T_2, T_4, Abs., $\bar{A}_1$), and dE/dx (i.e. lower level discrimination of the pulse heights of T_3 and T_4). The pulses from every counter of the telescope were recorded on a four-gun oscilloscope for each event. The electronics were tuned up by means of an alpha beam from the cyclotron and consistency checks were made periodically during the experiment. The R counter, shown in Fig. 2, was not used during the data-taking runs but was allowed to remain in position as part of the absorber arrangement.

The cross-section for deuterons on carbon,

$$\frac{d^2\sigma}{d\Omega dp} (d + C^{12} \rightarrow He^4 + \text{residue}) \qquad (5)$$

was also measured by using the CH_2-H_2 subtraction technique. The result is 0.38×10^{-30} cm^2/sr-Mev/c for alpha particles of 1060 Mev/c lab momentum and lab angle of 8-2/3 deg. With the CH_2 target we could show that our electronics did not saturate even though the production cross section for alpha particles and the background of deuterons were larger than with the deuterium target in place.

The data runs were cycled among four settings: the system set for 1275 Mev/c alphas produced at target center to observe reaction (1), and then for 1427 Mev/c alphas to observe reaction (3), first with deuterium and then with hydrogen in the target. The setting for 1275 Mev/c alphas was sensitive to the production of a neutral particle with a mass of 120 to 155 Mev while that for 1427 Mev/c was sensitive to a mass of 0 to 110 Mev. The calculations of the cross sections for reactions (1), (3), and (5) were, in reference 1, based on the data counts recorded by the electronics and included an error in the calculation of the solid angles. Since then, a comprehensive analysis of the oscilloscope film was undertaken. From these pictures the pulse height distribution and the timing of each counter output was measured. The traces were calibrated by triggering the oscilloscope from time of flight coincidence circuits set for (a) protons, (b) deuterons, and (c) He^3's while using a scattered deuteron beam from the cyclotron; alpha calibration was obtained while using a scattered alpha beam from the cyclotron. A scan of the data film shows that all the events have a timing corresponding to that of alphas or deuterons (for a given magnetic rigidity, these particles have the same velocity); moreover, no pulses from the anti-counter, A_1, are seen. Thus, all the events have the timing and range of alphas.

However, an analysis of the pulse heights of the counters showed that only a small fraction of these events were, in fact, alphas. These pulse height distributions for the system set for reaction (1), are shown in Fig. 3. The spectra for the D_2 and H_2 target data were the same, within statistics, and have been combined in Fig. 3. The pulse height data are based on a scan of approximately one-third of all the events. The spectra of the data for reaction (3) show the same effect. The pulse height spectrum for counter T_1 shows that it was sagging badly since it was located in a region of high background. For purposes of time-of-flight coincidences, however, T_1 was shown to be counting alphas efficiently. The T_2 spectrum has two well separated peaks with the higher pulse-height peak position coinciding with that of the alpha calibration peak, and the lower peak coinciding with calibrated deuteron spectrum. The outputs of T_1, T_3, and T_4 are correlated with that of T_2: for the events in which the T_2 pulse height corresponds to that of alphas, the outputs of T_3 and T_4 also correspond to that for alphas, while for those events which have a deuteron pulse-height in T_2 the pulse-height distribution for T_3 and T_4 are peaked about a pulse-height lower than that for alphas. The low pulse height edge of the distributions in T_3 and T_4 correspond to the lower-level discriminator cut-off.

The pulse height information indicates that most of the events which the electronics recorded as alphas were really deuterons. Since the timing of all the events was the same, the deuterons must have interacted near the final counters to produce particles which gave a large pulse-height in T_3 and T_4 and which had insufficient range to reach the anti counter, A_1. The only material in the beam upstream from and near the final counters was the R counter (0.063-in. plastic scintillator) and a 0.010-in. thick mylar window of the vacuum system. Further analysis shows that this effect must be due to singly charged particles

(H^3, protons or inelastic deuterons) produced in a deuteron-carbon reaction in this material. Because of the very large number of deuterons scattered down our channel (see Table I) this effect dominated the alpha counting rate determined by the electronics.

The number of true alpha counts, determined from a scan of all the film data, is listed in Table I.

Table I. Counts per 10^{13} incident deuterons.

$P(He^4)$ Mev/c	Alpha Counts* (Oscilloscope Film Data)		Deuteron Counts** (Electronics Data)	
	D_2 Target	H_2 Target	D_2 Target	H_2 Target
1275 (π^0)	12.7 ± 0.77	9.1 ± 0.65	63×10^3	44×10^3
1427 (γ)	15.5 ± 1.10	10.5 ± 0.82	62×10^3	44×10^3

*Errors are statistical

**Counter telescope was not plateaued for counting deuterons; therefore, numbers should be considered only as indicative.

Since the conservation of baryon number forbids the production of alpha particles from d-p collisions, the hydrogen data were treated as background and subtracted from the deuterium data to yield the net He^4 signal from d-d collision. However, this signal is to be considered an upper limit for the following reasons:

1. It was experimentally determined that an alpha particle beam scatters into our channel preferentially from deuterium. Thus alpha contamination of the beam from the cyclotron or from deuteron interactions before the target would provide a net D_2-H_2 counting rate.

2. Deuterons also scatter into our system preferentially from deuterium (see Table I). Thus if some of the deuterons interacted at the target walls to produce alphas, a net positive yield of alphas would result from a D_2-H_2 subtraction.

3. Further data at different momenta (not shown in Table I) provide additional information on the background. The results of an analysis of these data are consistent with zero yield from reaction (1). We find, therefore, no evidence of non-conservation of isotopic spin. This also means that no evidence was found for the existence of the reaction $d + d \rightarrow He^4 + \pi^o_o$, where the π^o_o is a neutral meson of zero isotopic spin with a rest mass in the interval 120 to 155 Mev. If the π^o_o exists, then this reaction, which is a strong interaction, would not be forbidden by I-spin conservation and therefore should have been detected.

To get a firm upper limit for reaction (1), we assumed that the alpha counts determined from the oscilloscope film and listed in Table I for the D_2 target minus those from the H_2 target were due entirely to reaction (1). A new limit for the differential cross section in the center-of-mass angle interval $\Theta_{c.m.} = 97 \pm 14$ deg was then calculated and the value is

$$\frac{d\sigma^{c.m.}}{d\Omega} (d + d \rightarrow He^4 + \pi^o) < 1.5 \times 10^{-34} \text{ cm}^2/\text{sr}. \tag{2}$$

for incident deuterons of 460 Mev laboratory kinetic energy. This value is a two standard deviation limit, the standard deviation being 0.27×10^{-34} cm^2/sr. This value is also an upper limit on the cross section for the production of a π^o_o of the same mass as that of the ordinary π^o. To get an upper limit on the degree of non-conservation of I-spin in strong interactions, we compare the value in (2) with the theoretical prediction[2] for the cross section at our energies, $\frac{d\sigma^{Th.}}{d\Omega} = (380 \pm 50) \times 10^{-34}$ cm^2/sr, which was computed with the assumption that I-spin need not be conserved. From this ratio, increased by two standard deviations we find that the probability of non-conservation of I-spin is < 0.4%, or alternatively, that I-spin in strong interactions is at least 99.6% conserved. The limit for reaction (3), mentioned previously, was obtained in the same manner from the oscilloscope film data in Table I and is a two standard deviation limit, the standard deviation being 0.61×10^{-34} cm^2/sr.

*Work done under the auspices of the U. S. Atomic Energy Commission.

[1]John A. Poirier and Morris Pripstein, Phys. Rev. 122, 1917 (1961).

[2]K. R. Greider, Phys. Rev., 122, 1919 (1961).

Figure Captions

Fig. 1. Angle vs. momentum of He^4 (lab).

Fig. 2. Experimental arrangement.

Fig. 3. Pulse height spectra determined from oscilloscope film.

▨ - Experimental Data.

◈ - Spectrum for events in which T_2 pulse height occurs in lower peak (i.e. T_2 p.h. ≤ 0.9 cm).

Histogram is the spectrum for events in which T_2 pulse height occurs in higher peak (i.e. T_2 p.h. ≥ 1.0 cm). Arrows indicate medians of the calibration pulse height spectra for d's and He^4's obtained with d and He^4 beams, respectively, from the cyclotron.

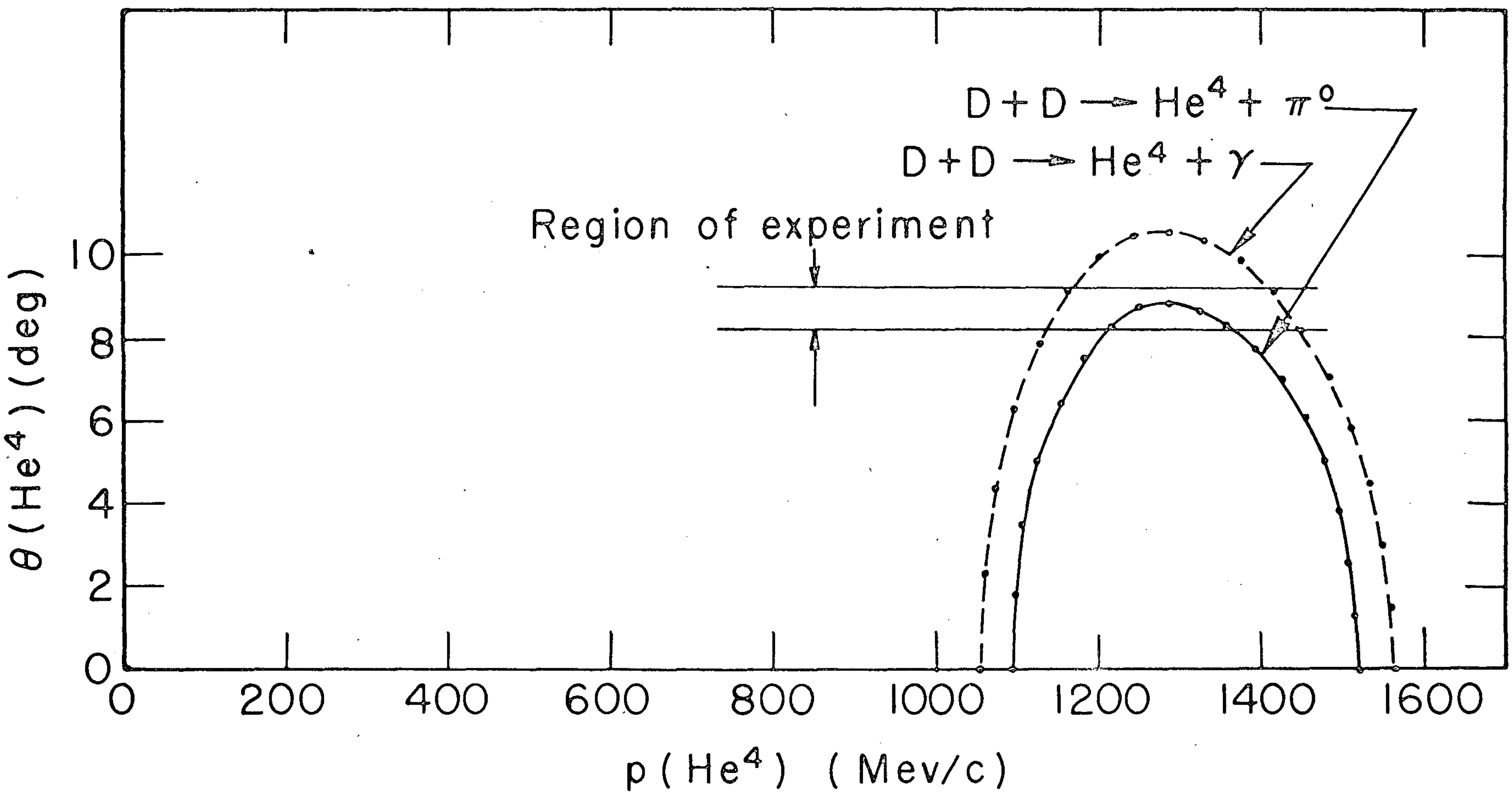

Fig. 1

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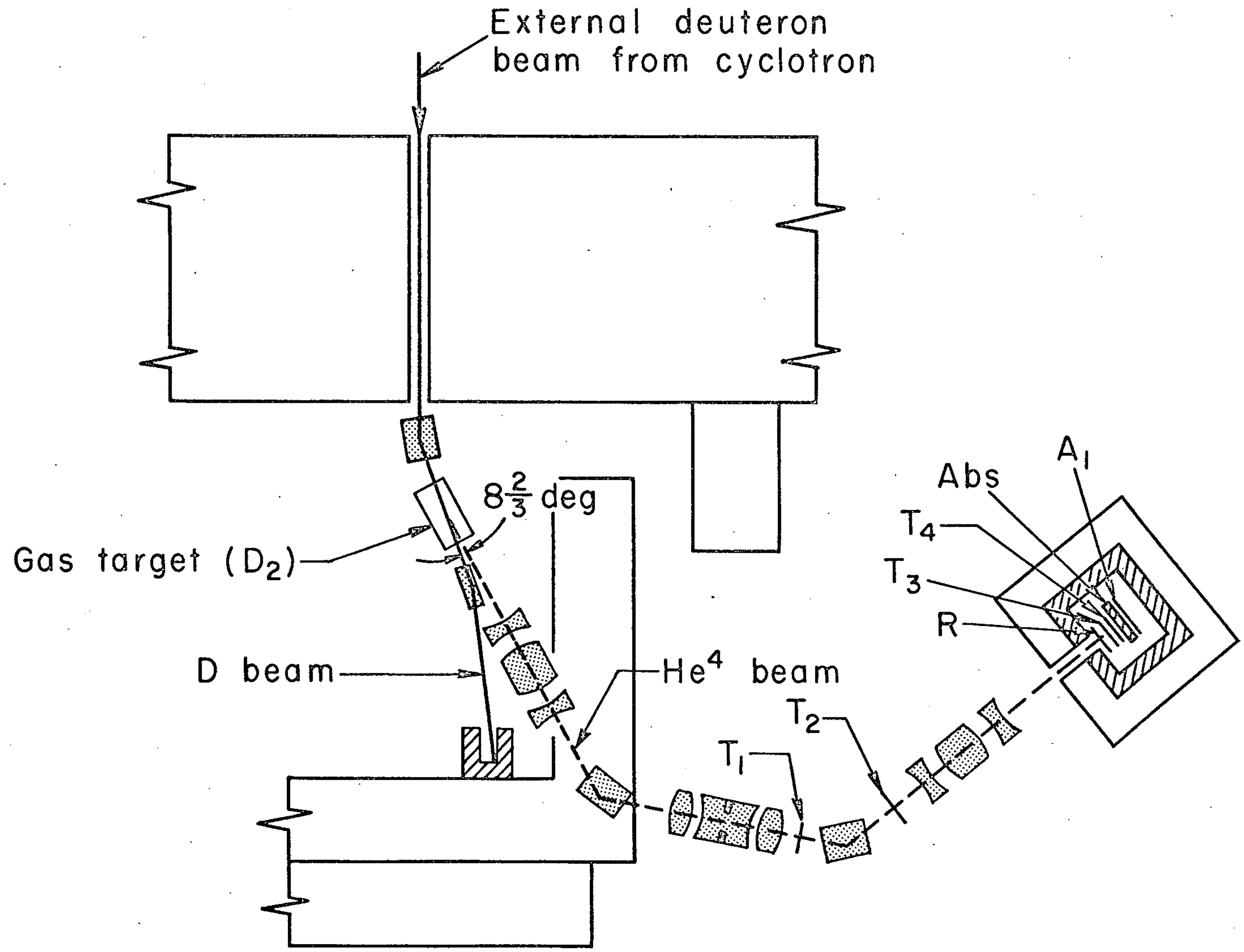
External deuteron beam from cyclotron
8 2/3 deg
Gas target (D2)
D beam
He4 beam
T1
T2
T3
T4
Abs
A1
R
MU-22452

Fig. 2

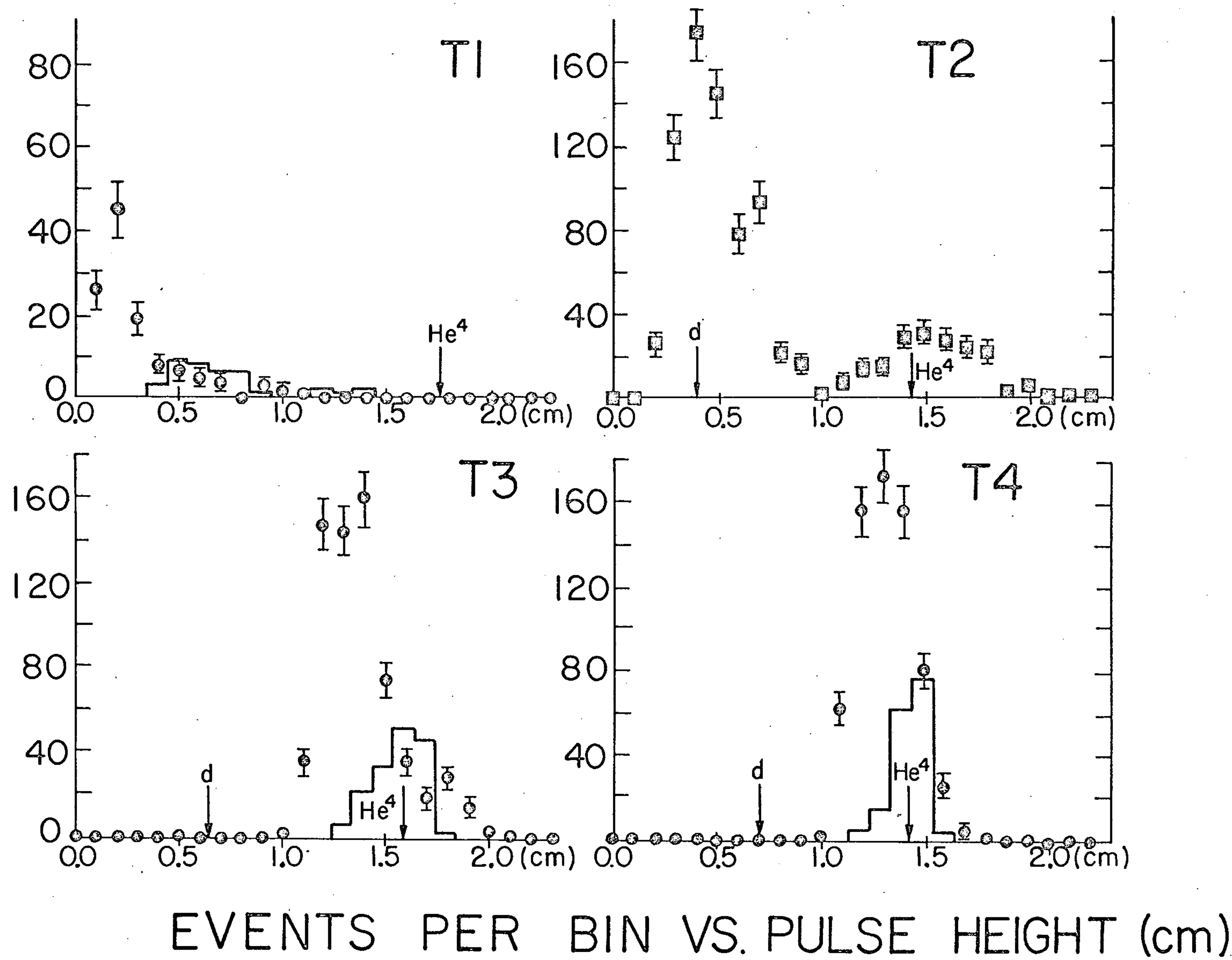

Fig 3

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