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ABSTRACT

Excited and multineutron final states have been studied in the reaction $\pi^- + He^4$. An excited state of helium is detected at 32±1 MeV. Upper limits on the existence of bound trineutrons and tetraneutrons are established. Large distortions from phase-space predictions are observed in the 3-n spectrum.

In an experimental study using 140±0.5-MeV negative pions incident on He^4 we have measured the following reactions:

$$\pi^- + He^4 \rightarrow \pi^- + He^{4*} \qquad (1)$$

$$\pi^- + He^4 \rightarrow \pi^+ + 4n \qquad (2)$$

$$\pi^- + He^4 \rightarrow p + 3n. \qquad (3)$$

In each case, the specific final state was determined uniquely for a range of kinematical conditions by detecting the charged particle and determining its mass by a combination of time-of-flight measurements, with vector momentum determination in a magnetic field.

In this experiment we used a high-resolution magnetic spectrometer consisting of a 40- by 90-cm pole C magnet with three pairs of magnetostrictive readout wire chambers [1] placed around the open sides of the magnet in order to determine the input and output trajectories of the charged particles from reactions (1) through (3). A 10-cm-long liquid-helium target was placed 1 m from the magnet, and the mean angle of detection of the charged particles was 20 deg relative to the incident π^-. The energy resolution of the system was 1 MeV for pions and 0.6 MeV for protons.

The study of reaction (1) shows one inelastic peak located at 32±1 MeV relative to the elastic scattering peak as shown in fig. 1. This level can have a T spin of 0, 1, or 2. In a previous experiment Charpak et al. [2] discovered a 30-MeV level formed in the reaction $\pi^+ + Li^6 \rightarrow 2p + He^{4*}$. This level is quite wide and overlaps ours, and while the authors considered it as a manifestation of peripheral reactions, Tang [3] in a subsequent paper argues for the existence of a $T = 0$ level at ≈ 30 MeV. Measday and Palmieri [4] present arguments for the existence of a T = 1 contribution to the level at that energy. Since corresponding states in Li^4 and H^4 have been observed, [5, 6] and since there is evidence against the existence of a tetraneutron (n^4), as discussed below, we feel that the assignment of T = 1 to this level is most probable.

By reversing the spectrometer we simultaneously looked at the π^+ and protons from reactions (2) and (3). In the π^+ case, the 1-MeV resolution achieved in this experiment allowed careful search for a tetraneutron. For an assumed binding energy between -10 MeV and 10 MeV, an upper limit of $1.38 \pm 0.69 \times 10^{-34}$ cm^2/sr-MeV is set for tetraneutron formation under the given conditions.

The π^+ energy spectrum, fig. 2, is in agreement with that obtained by Jean et al. [7] in that the best fit corresponds to two neutrons interacting through a $^1S_0$ potential, with the interaction of the other not being strong enough to affect the spectrum appreciably. Our method of measurement does not allow us to determine whether the two neutrons in the $^1S_0$ state were produced by double charge exchange or were spectators.

A search for the existence of trineutrons (n^3) was performed by taking many points near the proton energy spectrum threshold [reaction (3)]. In this case, the upper limit in the cross section for formation of a trineutron with a binding energy between 5 and -5 MeV is determined to be $7.5 \pm 4.5 \times 10^{-33}$ cm^2/sr-MeV.

As seen in fig. 3, the proton spectrum shows a pronounced peaking at 130 MeV. This corresponds to an energy of 53 MeV for the three neutrons in the center of mass. No data were taken for proton energies lower than 80 MeV in the center of mass, since below this energy other competing channels are possible and render the kinematics nonunique.

The comparison of immediate interest is made with respect to phase space (curve A) and phase space altered by the $^1S_0$ interaction between two of the neutrons in the final state (curve B). The results are shown normalized to equal areas. It is easy to see that the spectra shown differ widely from that observed. Addition of a final-state interaction between the proton and one (or more) of the neutrons will shift its spectrum towards the low-energy end, contrary to what is seen. As a purely phenomenological fit we used a Breit-Wigner-like resonance among the three neutrons, assuming the "decay" of the p-3n system to go through an $\ell = 1$ channel. This makes the width a factor of the relative momentum cubed (curve C).

A possibility to consider is that we are dealing with a direct reaction mechanism. In this case, the high-energy protons would arise from π^- absorption by p-p pairs, producing a proton and a neutron which share the energy of the pion, and two other neutrons that are spectators and carry energies of the order of their Fermi momenta in the α nucleus. Were this to be a purely two-body absorption, we would expect the proton to carry about 122 MeV in the c.m. system; this is lower than the observed most probable proton energy of 130 MeV. The width of this peak (caused by the internal energy of the target nucleons) should be approximately 20 MeV, narrower than the observed width. Since this mechanism does not seem to match the data, we should consider the possibility that the observed effects are due to a three-body interaction.

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FIGURE LEGENDS

Fig. 1. π^- spectrum.

Fig. 2. π^+ spectrum. The energy scale changes to 1 MeV steps near threshold.

Fig. 3. Proton spectra. The Breit-Wigner fit is for a 3-n system unbound by 15 MeV, and a width $\Gamma = 65 \times 10^{-8} k^3$.

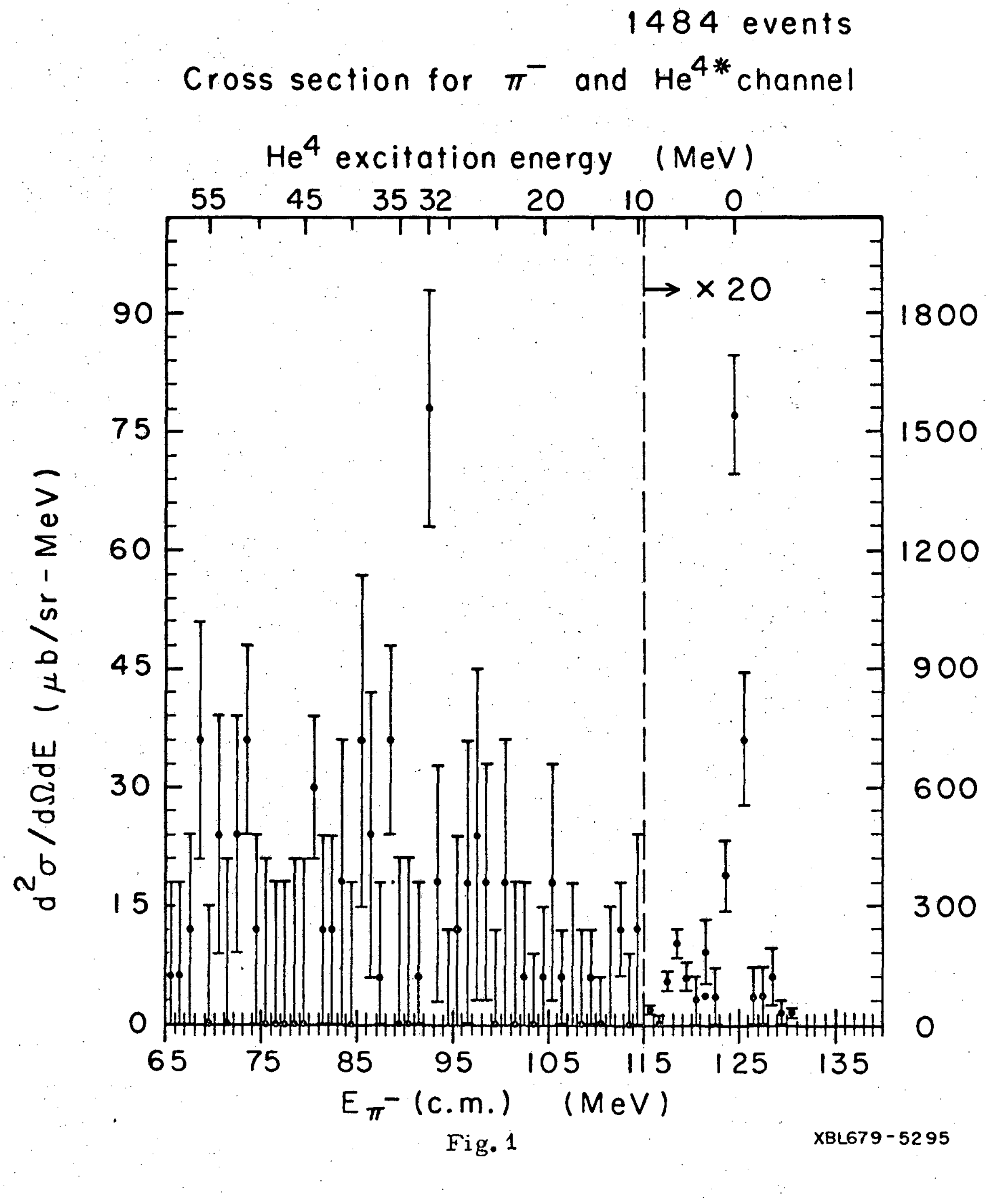

Fig. 1

XBL679-5295

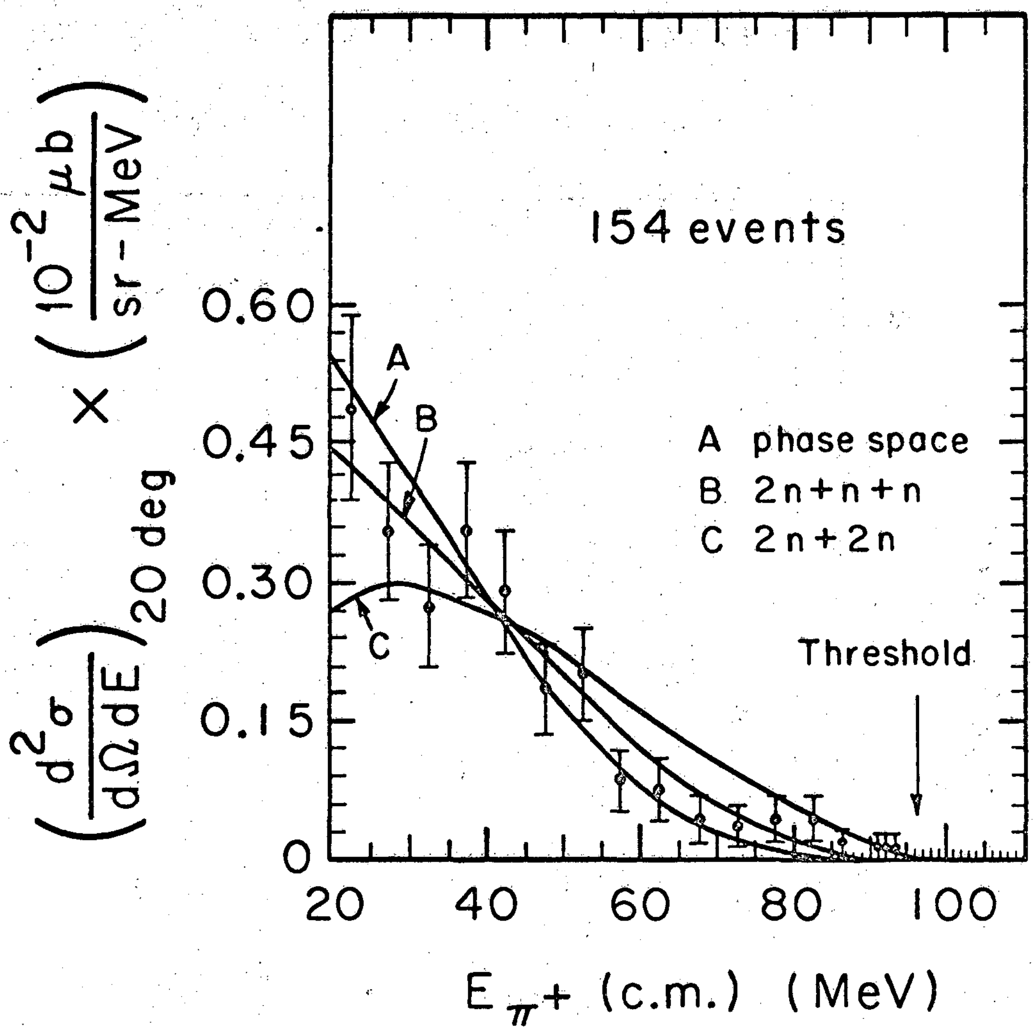

Fig. 2 XBL679-5294

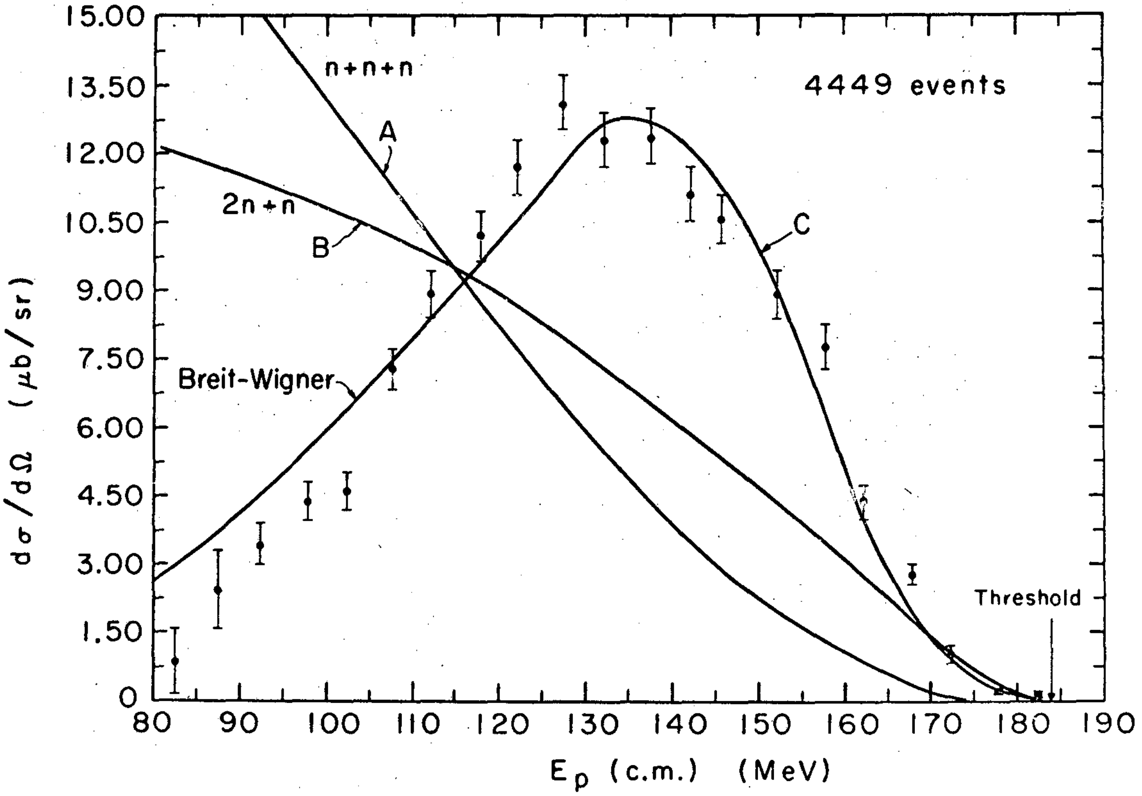

Fig. 3

XBL676-3298-A