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Search For Anomalous Photopion Production from Helium[*]

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This letter reports an experiment on the photoproduction of charged pions from He^4 which indicates that π^- and π^+ photoproduction proceed through similar nuclear mechanisms. Our results are at variance with the interpretation and part of the evidence presented by Argan et al,[1] who in a helium cloud chamber investigated final state interactions in the reactions

$$\gamma + He^4 \rightarrow \pi^+ + \left[H^4 \right] \rightarrow \pi^+ + H^3 + n \quad , \qquad (1)$$

$$\gamma + He^4 \rightarrow \pi^- + He^3 + p \quad . \qquad (2)$$
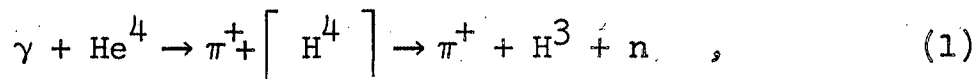
On the basis of a strong angular correlation between the π^+ and the H^3 of reaction (1), they conclude that a substantial fraction of π^+ photoproduction goes through an intermediate state of H^4, whereas this state is not prominent in the mirror system of reaction (2), presumably because of Coulomb effect. They assigned to the state an isotopic spin T = 1. A later paper suggested T = 2. [2] This latter assignment prompted a search for n^4 [3] and for a bound state in He^4 [4], both unsuccessful. The existence of H^4 has been discussed by Werntz and Brennan [5] in relation to an excited 0^+ state of He^4 at 20 MeV. [6]

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The effect of a strong H^4 level can be observed in
a counter experiment if the yield of positive photopions at
fixed angle and momentum is recorded as a function of the
peak bremsstrahlung energy. A discrete intermediate state of
the system should show up as a step in the yield curve, since
the state can be produced by photons in a narrow energy interval
only.[7]

In our experiment a 2" diameter cylinder of liquid
helium was irradiated with a collimated bremsstrahlung beam
from the 300 MeV University of Illinois betatron. Photopions
of about 117 MeV/c momentum were selected by a magnet which
could be rotated about the target. The target and magnet were
those previously used by Robinson et al.[8] in a π^+ photopro-
duction experiment on hydrogen. The pions were counted in a
plastic scintillator telescope which consisted of two dE/dx
counters, each 1/8" thick, followed by a scintillator 3-1/2"
thick in which the pions stopped. The momentum interval
accepted ($\Delta p/p = 6\%$, half width at half max.) was defined by
the position and width of the second dE/dx counter placed
along the focal plane of the magnet. Standard transistorized
electronics were used with the coincidence resolving time set
at 30 nsec.

In order to adjust the thresholds of the dE/dx
counters, the trigger level of the stopping counter was set
sufficiently high that only stars from negative pions could
count. It was then possible to set the dE/dx counters to
count all these pions, but to reject a large fraction of the

incidents electrons. With the trigger levels of the dE/dx
counters adjusted in this fashion the pulse height distribution
in the stopping counter showed clearly resolved electron and
pion peaks. The trigger level was set between these peaks.
On the basis of tests with CH_2, Be, and Pb targets we believe
our electron contamination to be 1% at the highest energies and
to be known rather well. There was also about a 4% background
from the target walls. Both these have been subtracted from
all our data. We estimate that our counting efficiency for
pions is above 95%. No corrections have been made for this
inefficiency or for decay muons.

With this apparatus we have measured the yield of
116.3 MeV/c π^+ mesons from hydrogen at 30° in the laboratory
as a function of peak bremsstrahlung energy, k_o. The results
are shown in Figure 1a along with the curve to be expected
from a pion momentum interval of $\pm$ 6%.

Figures 1b-1d show the yield of 117.2 MeV/c π^- and
116.0 MeV/c [9/] π^+ mesons from helium at the three laboratory
angles of 30°, 80°, and 120° as a function of k_o. The gentle
slope in the π^- and π^+ production curves—in contrast to the
steep slope of the π^+ curve on hydrogen—is characteristic of
"many body final state" production of the pion. Such a slope
can be predicted from the momentum distribution of the nucleons
inside helium. (See, for example, Lax and Feshbach.[10/]) The
momentum transfers to the nucleus at threshold are 117, 220,
and 290 MeV/c respectively. An inspection of Figures 1b-1d
shows that the π^+ production is qualitatively the same as the

π^- production save for a nearly constant ratio characteristic

of the difference in photoproduction from neutrons and protons.

In Figure 2 we have plotted the ratio of the π^- and

π^+ yields as a function of the difference between peak brems-

strahlung and reaction threshold energies. The threshold energies

for π^- and π^+ production differ by about 1.8 MeV due to the

different masses of the recoil nuclei and 0.7 MeV due to the

above mentioned difference in pion momenta. To obtain the

ratio, the π^- data for each k_o have been corrected by the

resulting difference of 1.1 MeV. At high energies these ratios

do not differ significantly from the theoretical values 1.25,

1.33, and 1.52 respectively, which are expected for free neutrons

and protons at the same angles and the same pion momentum.[11,12]

To find the influence of a strong H^4 state on the

π^-/π^+ ratio, we first have to account for the different Coulomb

interactions in the final states of reactions (1) and (2).

The main effect comes from the He^3-p system. At photon energies

just above threshold it is produced in a state of low relative

velocity, so that the Coulomb wave function differs strongly

from that of a free particle system. Following Moravcsik we

have calculated the suppression factor as a ratio of the squares

of the distorted and undistorted wave functions, averaged over

the nuclear volume.[13] The effect of the Coulomb interactions

of the π^- and π^+ meson is smaller and roughly independent of

photon energy. Using the same method we find a 1% suppression

of reaction (1) and a 3% enhancement of (2). Taking all of

these Coulomb effects into account we expect the π^-/π^+ ratios shown by the solid curves of Figure 2.

If part of the π^+ production goes through a narrow H^4 final state its activation function will be that of hydrogen in Figure 1(a), corrected for mass and binding energy of the nucleus. In calculating the dashed curves we have assumed that 20% of the π^+ production (at 270 MeV) proceeds through this H^4 channel, whereas the remainder is proportional to our experimental π^- production, divided by the calculated π^-/π^+ ratio. We consider the agreement of our data with the solid curves as somewhat fortuitous, in view of the approximate nature of the calculations. It seems, however, that a large admixture of H^4-production is inconsistent with these data.

It has been pointed out [14,15] that some of the main features of Argan's [1] experiment can be explained without the assumption of an H^4 production. While these arguments do not exclude the possible influence of an H^4 final state, one of our results, the symmetry in the corrected π^- and π^+ yields, requires that every nuclear final state interaction that affects reaction (1) must also be present in reaction (2). The gentle slope of our activation functions 1(b)-(d), however, indicates that neither reaction contains any appreciable part of two-body final state production.

Our data show more 116 MeV/c pions in backward than in forward directions. This is not necessarily in disagreement with the forward peaking found by Argan [1] and calculated by von Hippel, et al.[15] At fixed pion momentum the backward

angles favor higher photon energies where the expected cross section is higher, and for photon energies with which we are concerned the matrix element is not isotopic as assumed by von Hippel, but is strongly peaked backwards.

A comparison of our results with photopion production on other light nuclei shows several similarities. The π^-/π^+ ratio from carbon [7] shows the same angular dependence and far enough above threshold even the same absolute value as that reported here. Also the photoproduction on He^3 [16], B^{11} [17], and C^{12} [18] where the "two body final state" channel has been investigated by the detection of H^3, C^{11}, Be^{11}, N^{12}, and B^{12} respectively, shows that only a small fraction (< 15%) of the pions are produced through this channel. We do not find that helium is different in this respect.

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well does not change the π^-/π^+ ratio significantly, if the
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Figure 1.   (a) π^+ yield from hydrogen at 30° in the laboratory (b), (c), and (d) π^+ and π^- yields from He^4 at 30°, 80°, and 120° in the laboratory. The yield is given in pions detected per MeV of beam energy per nucleus per cm^2. The magnet accepts an interval of momentum, which, when translated to photon energy gives the magnet acceptance function shown in (a).

Figure 2. π^-/π^+ ratio from He^4 at laboratory angles of 30°, 80°, and 120°. The solid curves are those to be expected from production from free neutrons and protons with only coulomb interactions in the final state. The dashed curves are those to be expected if 20% of the π^+ production goes via a sharp inter- mediate state of H^4 close to threshold.
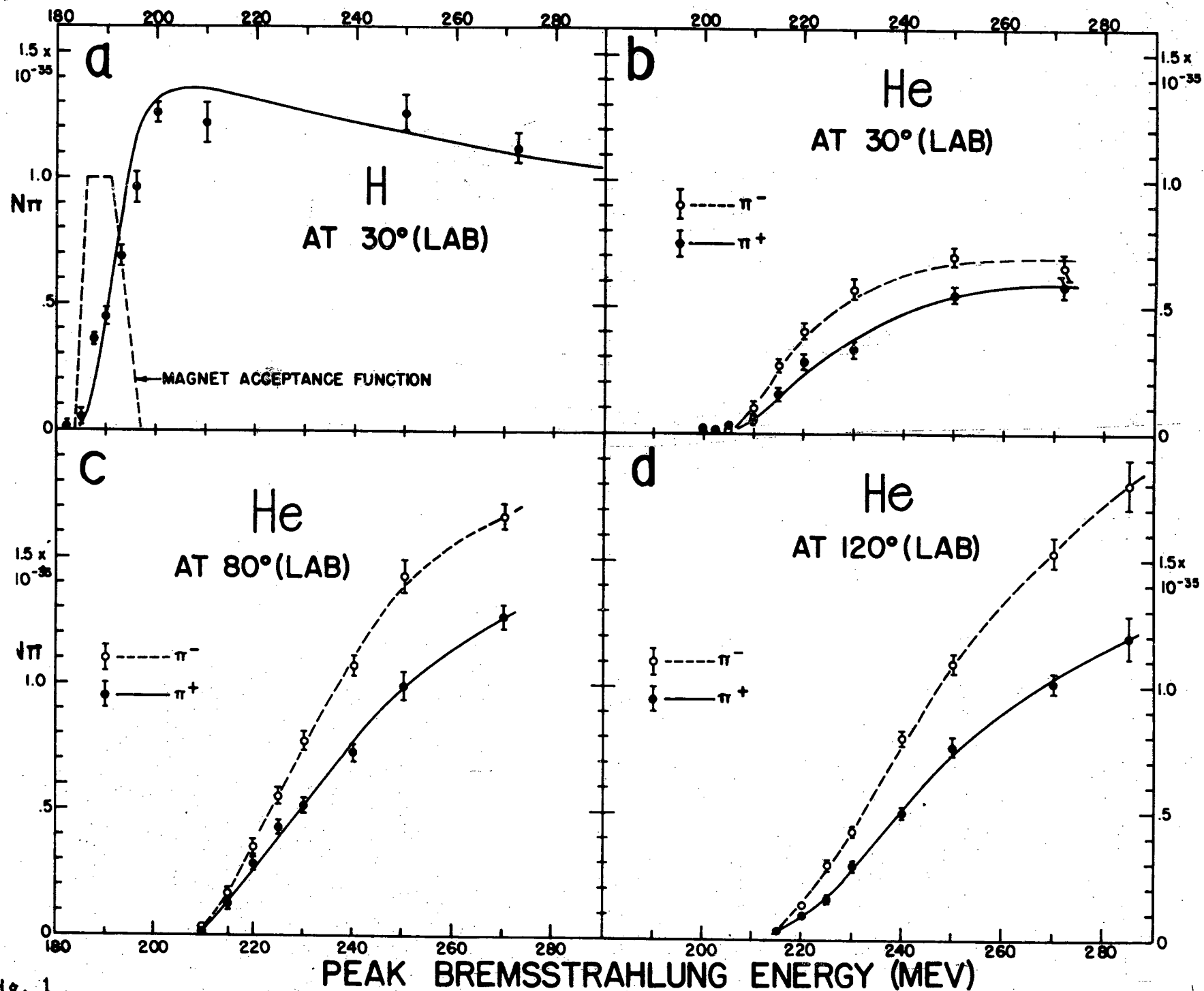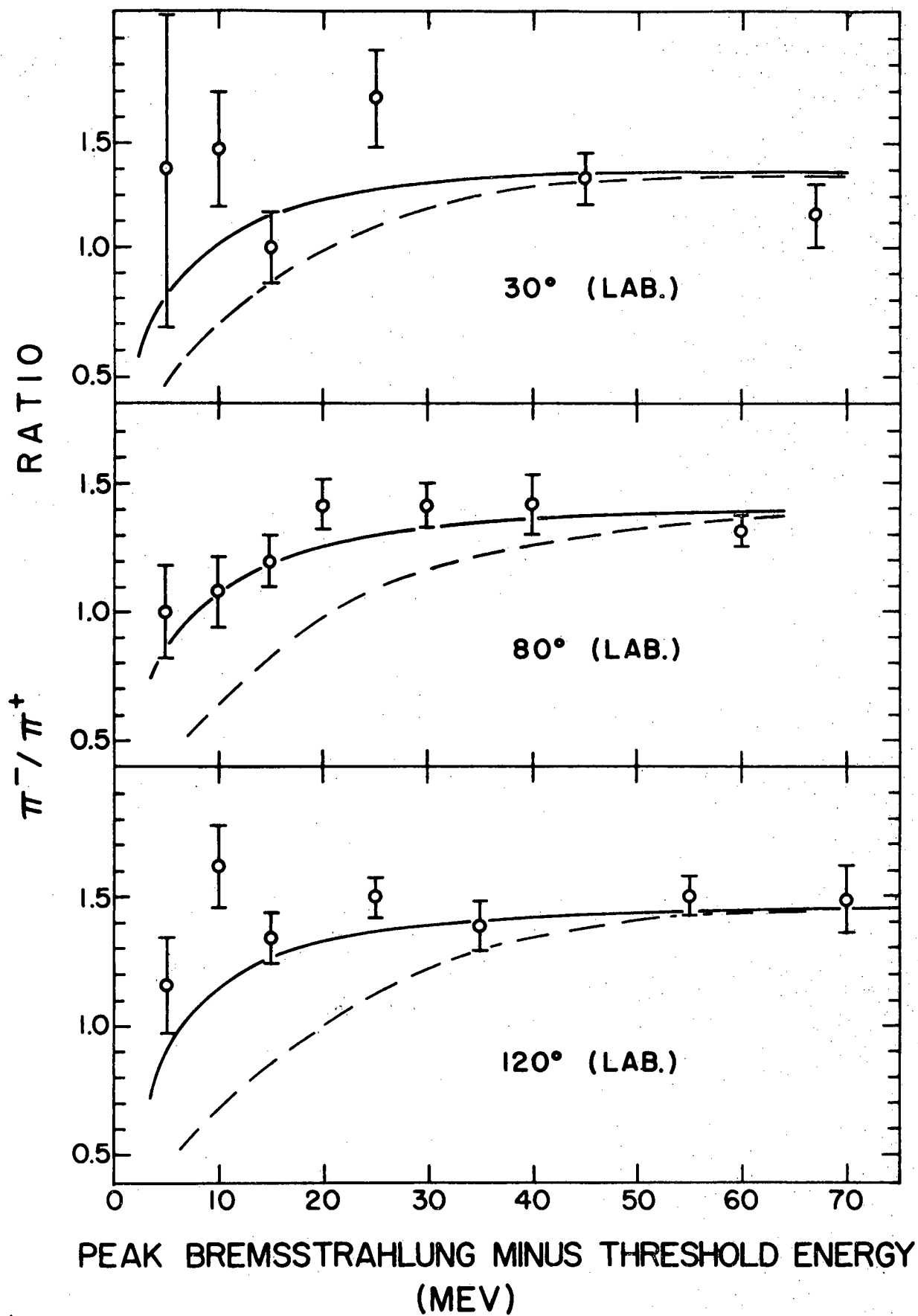
Fig. 1

Fig. 2

PEAK BREMSSTRAHLUNG MINUS THRESHOLD ENERGY (MEV)