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Several authors have proposed the existence of new particles and $\pi - \pi$ resonances.[1-5] Along these lines we are studying the reactions

$$p + d \rightarrow \begin{cases} He^3 + \pi^0 & (1a) \\ He^3 + \omega^0 & (1b) \\ He^3 + \pi^+ + \pi^- & (1c) \\ He^3 + \pi^0 + \pi^0 & (1d) \end{cases}$$

$$p + d \rightarrow \begin{cases} H^3 + \pi^+ & (2a) \\ H^3 + \omega^+ & (2b) \\ H^3 + \pi^+ + \pi^0 , & (2c) \end{cases}$$

where ω may be a particle of mass intermediate between that of a π meson and a K meson. Our first experiment consists of measuring at a fixed laboratory-system angle of 11.7 deg the He^3 momentum spectrum from 1.0 Bev/c to 1.6 Bev/c for incident proton energies ranging from 624 Mev to 743 Mev.

Figure 1 is a schematic drawing of the experimental arrangement. Protons extracted from the 184-inch cyclotron impinged upon a Y-shaped gaseous deuterium target operated at a pressure of 320 psi and at liquid-nitrogen temperature. He^3 nuclei produced at an angle of 11.7 ± 0.2 deg passed through the collimators C_2 through C_4 into

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the magnet spectrometer and were detected by scintillation counters S_1 through S_7. Q_1, an 8-inch triplet quadrupole magnet, focused the particles initially at f_1, and Q_2 (a lens similar to Q_1) focused them finally at S_3. The slit at f_1 was 0.5-in. wide at full proton energy of 743 Mev and 2.0 in. at reduced proton energies, thereby yielding momentum bites of ± 0.6% and ± 2.5%, respectively.

Identification of He^3 was made by requirements of momentum, time of flight, range, and dE/dx in S_3. For He^3 momenta greater than 1200 Mev/c, $S_1S_2S_3S_4S_5\bar{S}_6\bar{S}_7$ coincidences were required, while below 1100 Mev/c, $S_1S_3S_4\bar{S}_6\bar{S}_7$ were required. The momentum interval between 1100 and 1200 Mev/c was measured with both arrangements to check that they agreed. Backgrounds were measured by using H_2 gas of the same stopping power as the D_2 in the target. The backgrounds thus measured agreed with target-empty measurements when corrections were made for energy losses. At the full proton energy, the backgrounds were always less than 1% of the maximum counting rates. However at reduced energies they amounted to as much as 20% of the peak rate because the greater dimensions of the incident proton beam due to scattering in the energy degrader increased the production of He^3 in the walls of the target.

Figure 2 shows the He^3 momentum spectra corrected for energy loss and for the change in momentum bite, Δ p, with momentum p. The assigned errors are statistical and constitute the major part of the error. Each spectrum has a high-momentum peak due to single π^0 production and a lower-momentum continuum associated with double meson production. The solid curves drawn for the π^0 peaks are the calculated momentum-resolution functions of the system, normalized to the area under the experimental points.

For comparing the continua with theory, we have chosen a simple phase-space calculation as a first approximation. The expression used for the phase-space volume element ϕ_s is

$$\phi_s = \frac{d^2 \rho}{dp_3 d\Omega} = \frac{p_3^2}{\omega_3} \sqrt{\frac{t-4}{t}}, \qquad (3)$$

where ρ is the relativistically invariant three-body phase-space volume, ω_3 and p_3 are the total energy and momentum of the He^3, respectively, and t is the square of the total energy of the two pions in their own c.m. in units of the pion mass. The dashed curves drawn in the continua are these calculations fitted by the method of least squares to all of the experimental points.

It is clear that these calculations alone cannot reproduce the peaks that occur in the continua. We have investigated some of the conventional mechanisms for extending these calculations: for example, the effects of Bose statistics for the two pions, pion-nucleon interaction, and final-state wave function for the He^3 nucleus. Our crude calculations of these effects do not give quantitative agreement with the data. We have therefore attempted to fit only that part of the data outside the peaks with ϕ_s; the results are shown as the solid curves in Fig. 2. In Fig. 3, Δ, the differences between the data and the solid curves of Fig. 2 have been plotted as a function of He^3 momentum. The curves are the calculated resolution functions for a particle or a resonance of zero width and located according to kinematics for a mass or total energy of 310 Mev. The areas under the curves have been normalized to the areas under the points.

Some caution must be exercised before firm conclusions are drawn about the rather broad observed peak at full energy, as contrasted to the more narrow distribution expected. First, since the peak resides so close to the sharply changing edge of the continuum, the subtraction is sensitive to errors in momentum settings and the exact shape of ϕ_s.

Second, the data have been lumped over many runs, so that errors in settings from run to run tend to smear out any narrow peaks. We think that it is unlikely that these two possibilities are the entire explanations for the width observed. We therefore fitted the widths of the peaks with a simple Breit-Wigner one-level formula with experimental resolution folded in. The results of these calculations gave, for the natural line width, $\Gamma_{BW} = 10 \pm 6$ Mev. No definite conclusion on the line width can be drawn at this time.

Information on the isotopic spin assignments for the particle or resonance may be obtained from a study of Reactions (2a), (2b), and (2c), which proceed via pure I = I production. Figure 4 shows our attempts to measure these reactions at the highest proton energy. Because our spectrometer was designed for the He^3 measurements, we had to degrade the H^3 with Be to a momentum of 800 Mev/c. The small number of points and the large errors assigned are results of the large backgrounds and low counting rates. Experimentally, we find that the ratio of the cross sections of 2a/(2b + 2c) is about 2.3:1. We expect from charge independence the same ratio for the I = 1 part of 1a/(1b+ 1c) or 1a/peaks if the He^3 peaks are I = 1 and the remainder of the continuum is I = 0. From our fits, we find the ratio 1a/peaks to be 1.9:1. Thus, within the large errors involved, an I = 1 assignment for the peak is possible.

Upon the suggestion of Professor Chew we attempted to fit the full-energy He^3 data with a combination of an S-wave (I = 0) ϕ_s and a P-wave (I = 1) resonant ϕ_p given by

$$\phi_p = c_1 \, \phi_s \left(\frac{t-4}{t}\right) |F_\pi|^2 , \qquad (4)$$

$$|F_\pi|^2 = \left\{ (t-t_r)^2 + (t-4)^3 \Gamma^2/t \right\}^{-1} ,$$

where $\sqrt{t_r}$ is the position of the resonance in units of the meson mass and Γ is a parameter appearing in the expression for the pion form factor F_π of Frazer and Fulco.[3] We obtained reasonable agreement for $c_1 \approx 3$, $t_r = 5.0 \pm 0.2$, and $\Gamma = 1.0$ to 2.0. These values of t_r and Γ do not agree with those of Frazer and Fulco, who predict t_r between 12 and 16 and $\Gamma = 0.4$ in fitting the nucleon form factors and magnetic moments.

In concluding, we can summarize the following:

1. The data are inconsistent with the relativistically invariant phase space assumed. The discrepancy appears in the form of a narrow peak which kinematically behaves like a system with a mass or total energy of 310 ± 10 Mev. The natural line width of this system is not more than about 16 Mev.

2. Plausible explanations of the line are the existence of a new neutral particle or a resonant $\pi - \pi$ system. The possible isotopic spin assignments are I = 1 or I = 0. The H^3 data crudely support the I = 1 assignment.

3. Alternate explanations may be possible although we have not found any in quantitative agreement with the data. Further experimental work, particularly on the H^3 reactions, is clearly essential. Our present conclusions therefore must be regarded as tentative.

A more complete discussion of the experiment and any new results will be forthcoming shortly in a more extensive article.

We would like to thank Professor Geoffrey Chew, Professor Kenneth Watson, and Professor Emilio Segrè for several enlightening discussions of the experiment and the results. We also wish to thank Mr. Morris Pripstein for his assistance during the early phases of the experiment, and Mr. James Vale and the cyclotron crew for their cooperation.

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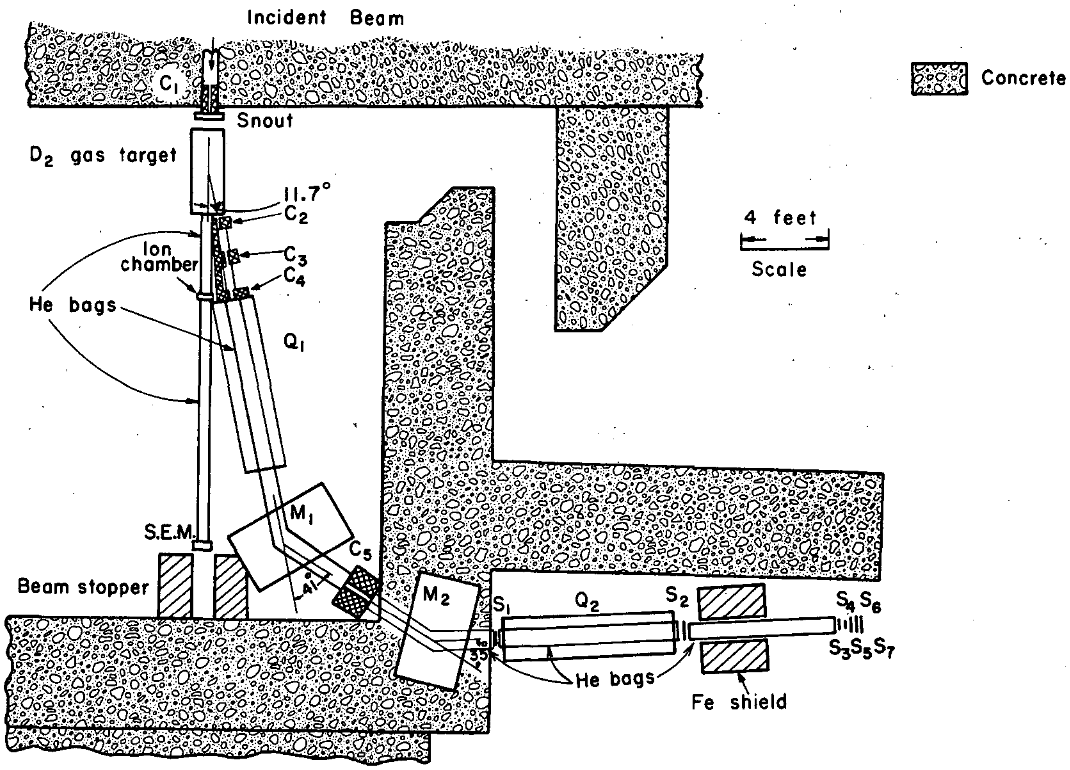
Figure Captions

Fig. 1. Experimental arrangement.

Fig. 2. He^3 momentum spectra for various incident proton energies. (See text for description of curves.) Ordinate scale is correct to within a factor of two.

Fig. 3. Difference between He^3 data and solid curves of Fig. 2 for various incident proton energies. (See text for description of curves).

Fig. 4. H^3 momentum spectrum for incident proton energy of 743 Mev. Ordinate scale is arbitrary.



MU-21004

Fig. 1.

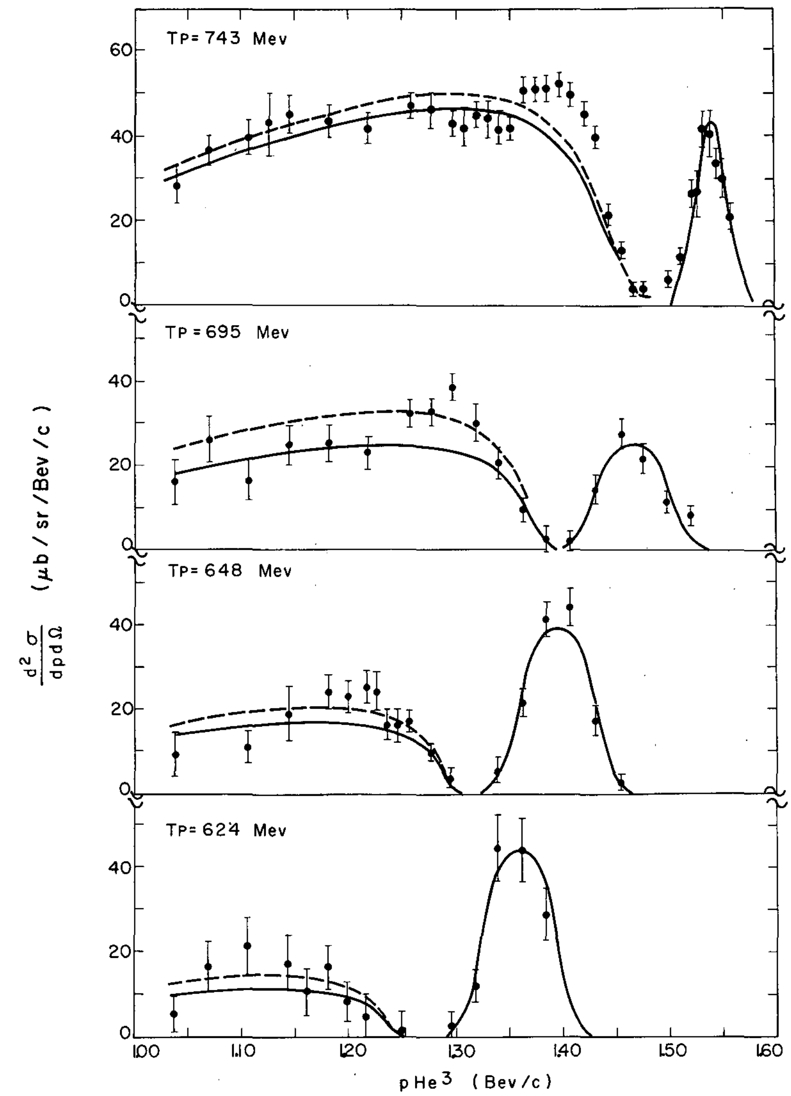
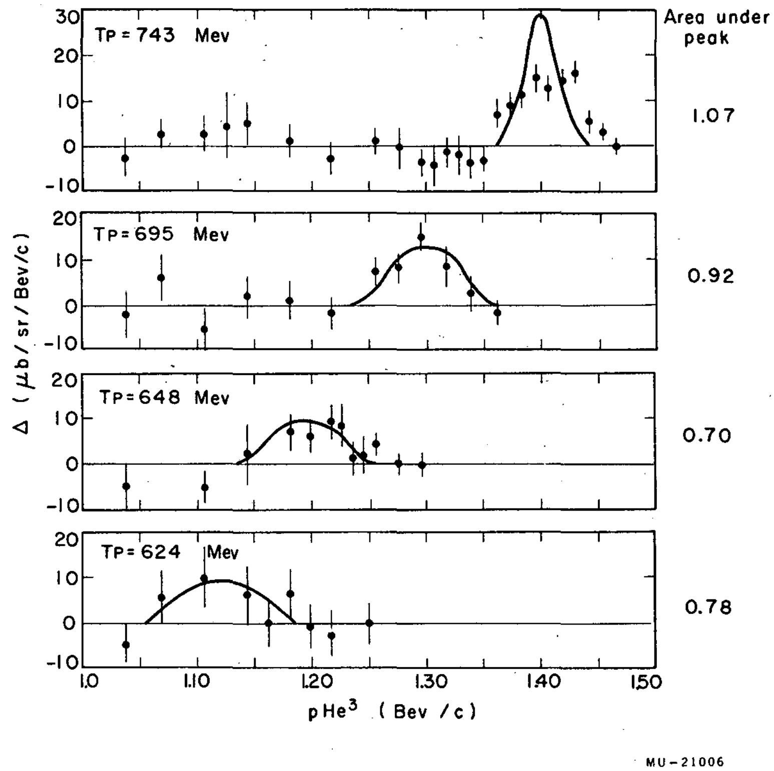

TP= 743 Mev
TP = 695 Mev
TP= 648 Mev
TP= 624 Mev
60
40
20
0
1.00
1.10
1.20
1.30
1.40
1.50
1.60
$\frac{d^2\sigma}{dp\,d\Omega}$ (μb / sr / Bev / c)
pHe3 (Bev/c)
MU-21005

Fig. 2.



Area under peak
TP = 743 Mev
1.07
TP = 695 Mev
0.92
TP = 648 Mev
0.70
TP = 624 Mev
0.78
Δ (μb / sr / Bev/c)
30
20
10
0
-10
1.0
1.10
1.20
1.30
1.40
1.50
pHe³ (Bev / c)
MU-21006

Fig. 3.

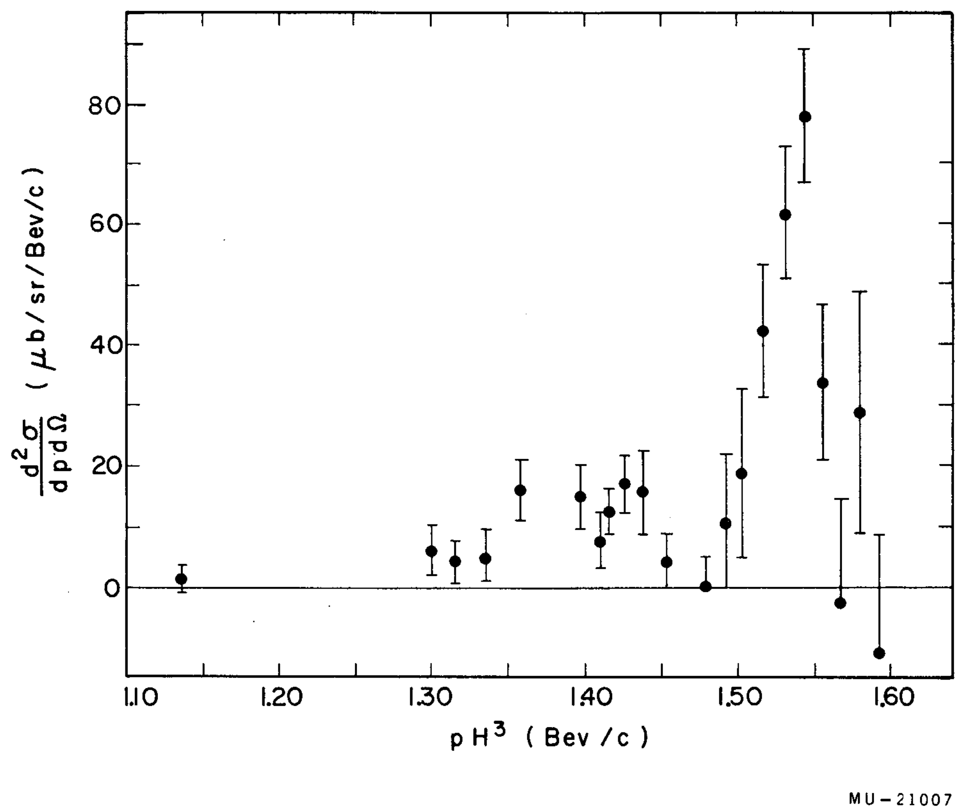

80
60
40
20
0
$\frac{d^2\sigma}{dp\,d\Omega}$ (μb/sr/Bev/c)
1.10
1.20
1.30
1.40
1.50
1.60
pH³ (Bev /c)
MU-21007

Fig. 4.