determined two parameters so as to make the contributions of D_{13} and F_{15} in the helicity-$\frac{1}{2}$ state as small as possible for the reaction $\gamma+p\to\pi^++n$.[3] As for $S_{11}(1525)$, the model predicted large and nearly equal amplitudes for two reactions, while we found a large difference, $A(S_{11}(\pi^-))\sim1.5A(S_{11}(\pi^+))$.

We made an attempt to interpret a sharp peak found at 710 MeV for $\gamma+p\to\pi^++n$ as a cusp effect at the η^0 threshold. The dashed curve in Fig. 1(a) shows the shape obtained from our multichannel analysis with a K-matrix formalism.[20] A similar effect for the reaction $\gamma+n\to\pi^-+p$ was estimated to be about half of the one for $\gamma+p\to\pi^++n$, which was too small to be observed with the present energy resolution.

We are grateful to the operating crew of the Institute of Nuclear Study synchrotron for the stable operation of the machine.

[1]R. L. Walker, Phys. Rev. 182, 1729 (1969).

[2]P. E. Scheffler and P. L. Walden, Phys. Rev. Lett. 24, 952 (1970).

[3]L. A. Copley, G. Karl, and E. Obryk, Nucl. Phys. B13, 303 (1969).

[4]L. Hand and C. Schaerf, Phys. Rev. Lett. 6, 229 (1961); C. Schaerf, Nuovo Cimento 44A, 504 (1966).

[5]H. Sasaki, Nucl. Instrum. Methods 76, 100 (1969).

[6]T. Fujii *et al.*, to be published.

[7]D. H. White *et al.*, Phys. Rev. 120, 614 (1960).

[8]G. Fisher *et al.*, Bonn University Report No. PI-1-101, 1970 (unpublished).

[9]J. T. Beale, S. D. Ecklund, and R. L. Walker, California Institute of Technology Report No. CALT-68-108, 1968 (unpublished).

[10]The recent preliminary data of the Orsay-Daresbury group on $\gamma+p\to\pi^++n$ at 180° seem to indicate a steeper decrease toward high energy than ours. E. F. Erickson, private communication.

[11]A. Ito *et al.*, Phys. Rev. Lett. 24, 687 (1970).

[12]Cross sections at 0° were taken from S. D. Ecklund and R. L. Walker, Phys. Rev. 159, 1195 (1967), for $\gamma+p\to\pi^++n$ and from Refs. 3 and 11.

[13]The details of the analysis will be published elsewhere.

[14]Y. C. Chau, R. G. Moorhouse, and N. Dombey, Phys. Rev. 163, 1632 (1967).

[15]N. Barash-Schmidt *et al.*, Rev. Mod. Phys. 41, 109 (1969).

[16]The convention for isospin decomposition used in our analysis is as follows: $\gamma+p\to\pi^++n$, $(\frac{1}{3})^{1/2}A_{3/2}{}^v-(\frac{2}{3})^{1/2}(A_{1/2}{}^v-A_{1/2}{}^s)$; $\gamma+n\to\pi^-+p$, $(\frac{1}{3})^{1/2}A_{3/2}{}^v-(\frac{2}{3})^{1/2}\times(A_{1/2}{}^v+A_{1/2}{}^s)$.

[17]T. Nishikawa *et al.*, Phys. Rev. Lett. 21, 1288 (1968).

[18]R. G. Moorhouse and W. A. Rankin, Nucl. Phys. B23, 181 (1970).

[19]P. Noelle, W. Pfeil, and D. Schwela, Bonn University Report No. PI-2-79, 1970 (unpublished).

[20]S. F. Tuan, Phys. Rev. 139, B1393 (1965).

Coherent Production of High-Mass Meson States in π^+d Collisions at 13 GeV/c*

K. Paler, R. C. Badewitz, H. R. Barton, Jr., D. H. Miller, T. R. Palfrey, Jr., and J. Tebes
Purdue University, Lafayette, Indiana 47907
(Received 21 December 1970)

Evidence is found for the coherent production of high-mass meson states in the 1.6- and 1.9-GeV mass regions. These states are observed, respectively, in the 3π and 5π systems produced in the reactions $\pi^+d\to d\pi^+\pi^+\pi^-$ and $\pi^+d\to d\pi^+\pi^+\pi^+\pi^-\pi^-$ at 13 GeV/c. The spin and parity of the 3π state, identified as the A_3 meson, is determined to be in the series $2^-,3^+,\cdots$ with a dominant $f\pi$ decay.

At present[1] evidence for the coherent production of the A_3 meson[2] has come from an experiment with 16-GeV/c negative pions on Freon.[3] The results from this experiment needed confirmation since a clear peak in the 1.6-GeV region was only observed in the $f^0\pi^-$ effective-mass spectrum and then with small statistics. Evidence from the same experiment for a coherently produced 5π state at about 1.9 GeV was presented by Huson *et al.* and Allard *et al.*[4]

The events considered in this Letter come from a completely analyzed 260 000 picture exposure of the Stanford Linear Accelerator Center 82-in. bubble chamber, filled with deuterium, to a beam of positive pions of 13-GeV/c momentum. Four- and six-prong events have been fitted[5] by the reactions

$$\pi^+d\to np\pi^+\pi^+\pi^-, \tag{1}$$

$$\pi^+d\to np\pi^+\pi^+\pi^+\pi^-\pi^-, \tag{2}$$

respectively. A clear deuteron signal was observed in the proton-neutron effective-mass spectra of both reactions, and events for which this effective mass was less than 1.884 GeV in

Reaction (1) and less than 1.885 GeV in Reaction (2) were classified as events containing ground-state deuterons. These events were then fitted by the reactions

$$\pi^+d\to d\pi^+\pi^+\pi^- \text{ (2016 events)}, \quad (3)$$

$$\pi^+d\to d\pi^+\pi^+\pi^+\pi^-\pi^- \text{ (160 events)}. \quad (4)$$

The contamination in our samples of Reactions (3) and (4) from deuteron "breakup" events was estimated to be less than 10%.

We consider that the requirement of having a ground-state deuteron in the final state ensures the coherence of the production mechanism.[6] Justification for this assertion comes from the fact that the deuteron differential cross section when parametrized by the usual formula, viz.,

$$d\sigma/dt = A\exp(bt_{d,d}), \quad (5)$$

where A and b are constants and $t_{d,d}$ is the deuteron four-momentum transfer, yields a value for b of 30 ± 2 GeV^{-2} for Reaction (3) and 15 ± 5 GeV^{-2} for Reaction (4). Because we have considered only four- and six-prong topologies, there is a cutoff on the deuteron four-momentum transfer for values less than 0.02 GeV^2, i.e., corresponding to unseen deuteron recoils.

In Fig. 1(a) we show the effective-mass distribution of the 3π system produced in Reaction (3). A clear peak is observed in the "A"-meson region (1.0 to 1.3 GeV). This region will not be discussed further. In addition, a distinct enhancement is seen in the 1.6-GeV region, usually associated with the A_3 meson. We show as shaded in Fig. 1(a) the 3π effective-mass spectrum in which the effective mass of at least one of the two possible $\pi^+\pi^-$ combinations was in the f^0 region, i.e., $1.16 < M(\pi^+\pi^-) < 1.32$ GeV.[7] To provide evidence for an f^0 signal we show in Fig. 1(c) the effective-mass distribution for both $\pi^+\pi^-$ combinations. A clear peak is observed at the f^0 mass. The f^0-selection region is indicated in Fig. 1(c). The $f^0\pi^+$ effective-mass distribution shows a clear peak in the 1.6-GeV region and indicates that the 3π enhancement is strongly

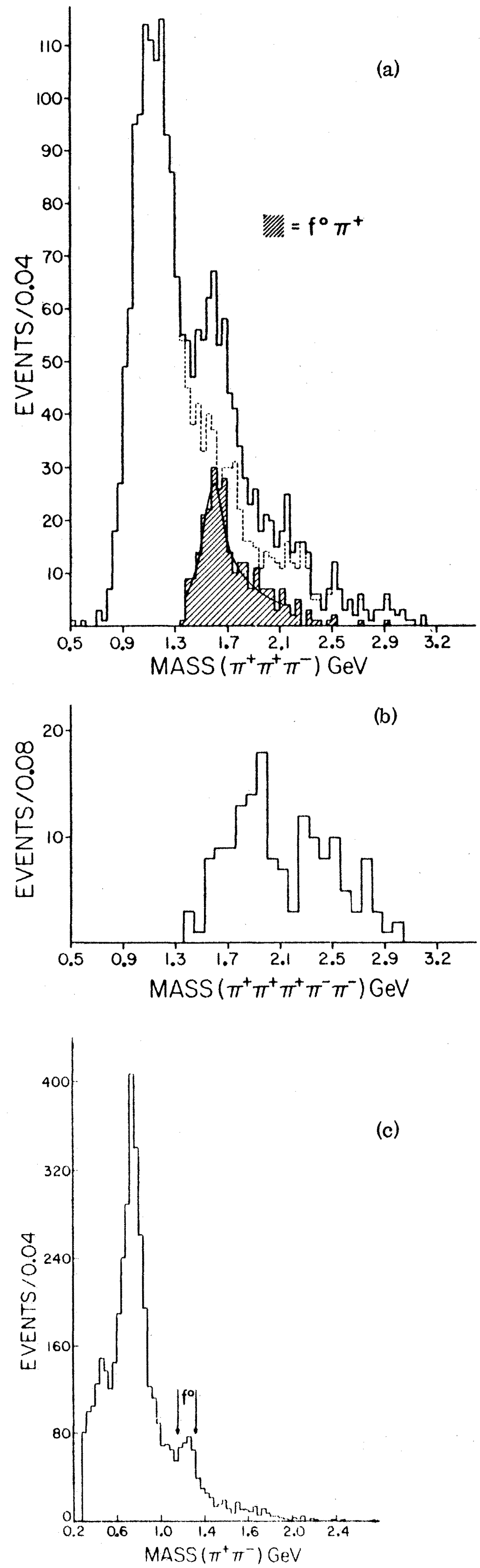

FIG. 1. (a) For the reaction $\pi^+d\to d\pi^+\pi^+\pi^-$, the $(3\pi)^+$ effective-mass distribution. The shaded histogram corresponds to the $f^0\pi^+$ effective-mass distribution with $M_{f0} = 1.16 < M(\pi^+\pi^-) < 1.32$ GeV. The dashed histogram is the result of subtracting the shaded from the unshaded histogram. (b) The $(5\pi)^+$ effective-mass distribution from the reaction $\pi^+d\to d\pi^+\pi^+\pi^+\pi^-\pi^-$. (c) The $\pi^+\pi^-$ effective-mass distribution for the two combinations from the reaction $\pi^+d\to d\pi^+\pi^+\pi^-$.

associated with the $f^0\pi^+$ system. The broken histogram in Fig. 1(a) is the result of subtracting the $f^0\pi^+$ histogram from the 3π histogram and indicates that our data are consistent with this 3π state decaying completely through the $f^0\pi^+$ mode. This strong correlation supports the identification of this 3π state with the A_3.[8]

We have also made a quantitative fit to the 3π Dalitz plot as a function of the 3π mass to determine the branching modes of the A_3. The Dalitz-plot density was fitted by an incoherent sum of ρ^0 and f^0 symmetrized Breit-Wigner functions and an uncorrelated 3π contribution. This simple function was found adequate to describe the data (i.e., all fits had acceptable χ^2 probabilities). The results of these fits are shown in Fig. 2. The only structure observed is in the contribution from the $f^0\pi^+$ final state which has a magnitude and shape which accounts for all the A_3 observed in the 3π spectrum. The $\rho^0\pi^+$ contribution is smooth and initially decreases rapidly and reaches an almost constant value above a 3π mass of about 1.5 GeV. For each 3π mass range the best fit required no contribution from an uncorrelated 3π final state. From these results we obtain the following limits on the branching fractions of the A_3 into $\pi^+\pi^+\pi^-$ of $f^0\pi^+ > 85\%$, $\rho^0\pi^+ < 18\%$, and uncorrelated $\pi^+\pi^+\pi^- < 5\%$ at a 95% confidence level. These branching fractions were calculated using those events in the A_3 region above the smooth background shown in Fig. 2(b).[9] We note that our data do not show the feature of a threshold enhancement in the 3π effective mass for arbitrary $\pi^+\pi^-$ effective-mass regions, in agreement with the results presented by Crennell *et al.*[10]

The fact that this 3π enhancement, which we consider is the A_3, is not observed in Reaction (3) at lower beam momenta[11] could be explained by the minimum deuteron four-momentum transfer (t_{min}) kinematically allowed[12] ($t_{\text{min}} \propto 1/P_{\text{lab}}^2$) at lower beam momenta being larger than that required for coherent production.

A least-squares fit to the $f^0\pi^+$ effective-mass distribution of one Breit-Wigner resonance and a hand-drawn background gives a mass of 1.60 ± 0.05 GeV and a width of 0.220 ± 0.080 GeV. These values are consistent with previously reported values.[2]

We now consider Reaction (4). In Fig. 1(b) we show the 5π effective-mass distribution. An enhancement is seen in the 1.9-GeV region similar to that observed in Ref. 4. For this enhancement there is no significant evidence for it being cor-

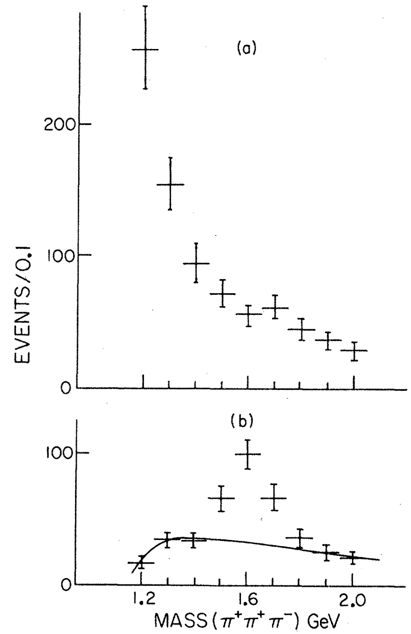

FIG. 2. The number of events corresponding to the amount of (a) $\rho^0\pi^+$ and (b) $f^0\pi^+$ states in the 3π system as a function of the 3π mass.

related with specific subsystems such as $g\pi$, $A_2\rho$, and $\rho\rho\pi$. This, at least in part, is due to the inherent permutational complexity of this 5π system and small statistics. Continuing nomenclature from the A_1 and A_3, we suggest referring to this 1.9-GeV 5π enhancement as the A_5 meson.

We now consider the spin and parity of the A_3 observed in our data. In the following analysis we define the A_3 by $1.48 < M(3\pi) < 1.72$ GeV. The observation of the A_3 in Reaction (3), which is believed to proceed via a diffractive process, implies that the spin and parity of the A_3 is in the unnatural series, i.e., $1^+, 2^-, 3^+ \cdots$, which is in accord with previous spin and parity analyses.[13] For the decay of the A_3 we use the polar and azimuthal distributions, in the Gottfried-Jackson frame, of the normal to the 3π-decay plane. These distributions are shown in Figs. 3(a) and 3(b), respectively. Berman and Jacob[14] have given expressions describing these angular distributions for various spin and parity assignments. We have fitted these distributions to the 1^+, 2^-, and 3^+ spin and parities and find we can rule out the 1^+ assignment for which the fit to the polar distribution gives a χ^2 probability less than 0.01%. The fits to the polar distribution of the 2^- and 3^+ assignments have χ^2 probabilities of 85 and 75%, respectively. The curves show-

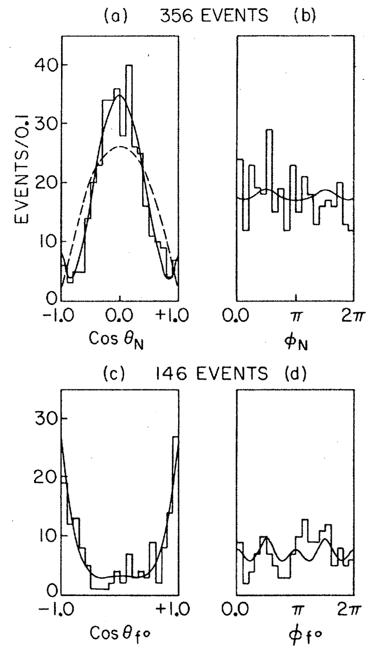

FIG. 3. The decay angular distributions for the reaction $\pi^+d \to d\pi^+\pi^+\pi^-$ in the appropriate Gottfried-Jackson reference frames. (a) Polar distribution of the normal to the 3π-decay plane. The dashed curve is the 1^+ fit and the continuous curve is the 2^- fit. (b) Azimuthal distribution of the normal to the 3π-decay plane. The curve is the 2^- fit. (c) Polar distribution of the direction of the π^+ from the f^0 decay. The curve is a fit to a 2^+ decay. (d) Azimuthal distribution of the direction of the π^+ from the f^0 decay. The curve is a fit to a 2^+ decay.

ing the 1^+ and 2^- fits are shown superimposed on Fig. 3(a). The 3^+ curve is essentially identical to the 2^- curve and is omitted for clarity. The curve on Fig. 3(b) is the 2^- fit.

For the 2^- fit to the A_3 decay distributions we obtain a ρ_{00} of 1.11 ± 0.05 with the other density-matrix elements within three standard deviations of zero. This large value of ρ_{00} indicates total transverse alignment of the A_3 spin with respect to the beam direction.

We shown in Figs. 3(c) and 3(d) the decay distributions, in the Gottfried-Jackson frame, of the decay of the f^0 associated with the A_3. The fitted curves shown in the figures correspond to a fit to the 2^+ decay distribution. The value of ρ_{00} was 0.74 ± 0.07. If the A_3 has natural spin and parity, then the distribution shown in Fig. 3(a) implies a large longitudinal alignment of the spin of such an A_3, and since we only obtain a fit for spin 2 and greater, the exchanged spin would have to be 2, or larger than 2. It is very unlikely that this type of exchange mechanism would dominate such a peripheral interaction. In addition, an A_3 with such a large longitudinal alignment is unlikely to decay into an f^0 with such a large transverse-spin alignment. Hence we feel justified in not considering natural spin and parity assignments for the A_3. Hence we exclude 1^+ and allow 2^-, 3^+, and higher spins. This result is not affected by (a) removing D^{*++} events ($\lesssim 10\%$), (b) removing events in the $\rho^0\rho^0$ and $\rho^0 f^0$ overlap regions of the 3π Dalitz plot, or (c) selecting only f^0 events.

Hence, in conclusion, we have observed a diffractively produced A_3 meson in the reaction $\pi^+d \to d\pi^+\pi^+\pi^-$ and a diffractively produced 5π state, the A_5, in the reaction $\pi^+d \to d\pi^+\pi^+\pi^+\pi^-\pi^-$ at 13 GeV/c. The spin and parity of the A_3 was found to be in the series 2^-, $3^+\cdots$ with a dominant $f\pi$ decay.

It is a pleasure to acknowledge the work and cooperation of the Stanford Linear Accelerator Center personnel. We also wish to thank the members of the Purdue high energy physics group, experimental and theoretical, with whom we have had many informative discussions, and the scanners and measurers at Purdue, without whom this work would not have been possible.

---

*Work supported in part by the U. S. Atomic Energy Commission.

[1]H. Bingham, CERN Report No. D. Ph. II/Phys. 70-60 (to be published).

[2]A. Barbero-Galtieri *et al.*, Rev. Mod. Phys. 42, 87 (1970).

[3]B. Daugeras *et al.*, Phys. Lett. 27B, 332 (1968).

[4]R. Huson *et al.*, Phys. Lett. 28B, 208 (1968); J. F. Allard *et al.*, Nuovo Cimento 46A, 737 (1966).

[5]The TVGP-SQUAW system of programs was used.

[6]We do not observe any D^{*0} and $\lesssim 10\%$ D^{*++}.

[7]The number of events for which both $\pi^+\pi^-$ combinations were in the f^0 region was less than 4% of the total number of f^0 events.

[8]C. Baltay, in Proceedings of the Meeting of the Division of Particles and Fields of the American Physical Society, Austin, Texas, 5-7 November 1970 (to be published).

[9]The values of these limits depend to some extent on the magnitude of the smoothly varying background, but it is clear from Fig. 2 that the dominant decay mode of the A_3 is $f^0\pi^+$ with no obvious $\rho^0\pi^+$ decay.

[10]D. J. Crennell *et al.*, Phys. Rev. Lett. 24, 781 (1970).

[11]M. A. Abolins *et al.*, Phys. Rev. Lett. 15, 125 (1965); B. Eisenstein and H. Gordon, Illinois University Report No. COO-1195-168, 1969 (to be published); A. Forino *et al.*, Phys. Lett. 19, 68 (1969); P. Vander-

hagen *et al.*, Nucl. Phys. B13, 329 (1969); B. J. Deery *et al.*, Phys. Rev. D 3, 635 (1971); G. Vegni *et al.*, Phys. Lett. 19, 526 (1965); A. M. Cnops *et al.*, Phys. Rev. Lett. 21, 1609 (1968).

[12]M. L. Good and W. D. Walker, Phys. Rev. 120, 1857 (1960); L. Stodolsky, Phys. Rev. Lett. 18, 973 (1967); J. J. Veillet *et al.*, in *Proceedings of the Topical Conference on High Energy Collisions of Hadrons, CERN, 1968* (CERN Scientific Information Service, Geneva, Switzerland, 1968), p. 537.

[13]J. Bartsch *et al.*, Nucl. Phys. 137, 345 (1968); C. Caso *et al.*, Lett. Nuovo Cimento 2, 437 (1969).

[14]S. M. Berman and M. Jacob, Phys. Rev. 139, 1023 (1965).

ERRATA

MEASUREMENT OF INSTABILITY GROWTH COEFFICIENTS AND FEEDBACK STABILIZATION IN ELECTRON-HOLE PLASMAS. B. Ancker-Johnson, H. J. Fossum, and A. Y. Wong [Phys. Rev. Lett. 26, 560 (1971)].

The left-hand ordinate in Fig. 4(b) should read 0, 1, 2, 3, 4 instead of 1, 2, 3, 4, 5.

OBSERVATION OF A $T=\frac{1}{2}$ RESONANCE IN ^{3}He BY INELASTIC α-PARTICLE SCATTERING. M. L. Halbert and A. van der Woude [Phys. Rev. Lett. 26, 1124 (1971)].

In this paper we reported the observation of a broad peak in the inelastic α-particle spectrum when ^{3}He was bombarded with 63.7-MeV α particles. We attributed this peak to a resonance in ^{3}He since its energy showed the correct kinematic variation with angle of observation and since we had previously found evidence for such a state from the radiative capture of deuterons by protons.[1]

We now believe that this interpretation of the inelastic α scattering is incorrect. By repeating the measurements at higher energies we found that the apparent excitation energy increases with increasing α-particle energy: At bombarding engies of 63.7, 71.9, and 81.6 MeV the apparent excitation energy is 20.4, ~23, and ~26 MeV, respectively. Although we do not fully understand the mechanism responsible for this peak, it appears to be due to something other than a resonance in ^{3}He. Thus the only evidence we have now for an excited state of ^{3}He is from the excitation function and angular distribution of the radiative capture of deuterons by protons.[1]

[1]A. van der Woude, M. L. Halbert, C. R. Bingham, and B. D. Belt, Phys. Rev. Lett. 26, 909 (1971).