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

Coo-1428-290

MASTER

K. Palar, R. C. Badewitz, H. R. Barton, Jr., D. H. Miller,
T. R. Palfrey, Jr., and J. Tebes.

Purdue University, Lafayette, Indiana 47907

ABSTRACT

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 $\pi^+d \rightarrow d\pi^+\pi^+\pi^-$ and $\pi^+d \rightarrow d\pi^+\pi^+\pi^-\pi^-$ at 13 GeV/c. The spin-parity of the 3π state, identified as the A_3 meson, is determined to be in the series $2^-, 3^+ \dots$ with a dominant $\pi\pi$ decay.

✓ Work supported in part by the U.S. Atomic Energy Comm.

This report was prepared as an account of work sponsored by the United States Government. Neither the United States nor the United States Atomic Energy Commission, nor any of their employees, nor any of their contractors, subcontractors, or their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness or usefulness of any information, apparatus, product or process disclosed, or represents that its use would not infringe privately owned rights.

DISTRIBUTION OF THIS DOCUMENT IS UNLIMITED

DISCLAIMER

This report was prepared as an account of work sponsored by an agency of the United States Government. Neither the United States Government nor any agency Thereof, nor any of their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or any agency thereof. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or any agency thereof.

DISCLAIMER

Portions of this document may be illegible in electronic image products. Images are produced from the best available original document.

At present¹ evidence for the coherent production of the A_3 meson² 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 in reference 4.

The events considered in this letter come from a completely analysed 260,000 picture exposure of the SLAC 82" bubble chamber, filled with deuterium, to a beam of positive pions of 13 GeV/c momentum. Four and six prong events have been fitted⁵ to the reactions:

$$\pi^+d \rightarrow n\pi^+\pi^+\pi^- \quad (1)$$

and $\pi^+d \rightarrow n\pi^+\pi^+\pi^+\pi^- \quad (2)$

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 in reaction 2 were classified as events containing ground state deuterons. These events were then fitted to the reactions:

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

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

The contamination in our samples of reactions 3 and 4 from deuteron "break-up" events was estimated to be less than 10%.

We consider 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 parameterized by the usual formula, viz:

$$d\sigma/dt = Ae^{bt_{d,d}} \quad (5)$$

where A and b are constants and $t_{d,d}$ is the deuteron four-momentum transfer, yields a value for b of $30 \pm 2 \text{ GeV}^{-2}$ for reaction 3 and $15 \pm 5 \text{ GeV}^{-2}$ for

reaction 4. Because we have considered only four and six prong topologies there is a cut off on the deuteron four-momentum transfer for values less than 0.02 GeV^2 , i.e. corresponding to unseen deuteron recoils.

In figure 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 shaded in figure 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. $1.16 < M(\pi^+\pi^-) < 1.32 \text{ GeV}$.⁷ To provide evidence for an f^0 signal we show in figure 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 figure 1(c). The $f^0\pi^+$ effective mass distribution shows a clear peak in the 1.6 GeV region and indicates the 3π enhancement is strongly associated with the $f^0\pi^+$ system. The broken histogram in figure 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 to an incoherent sum of ρ^0 and f^0 symmetrized Briet-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 figure 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 95% C.L. These branching fractions were calculated using those events in the A_3 region above the smooth background shown in figure 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 in reference 10.

The fact that this 3π enhancement, which we consider is the A_3 , is not observed in reaction 3 at lower beam momenta¹¹ could be explained by the minimum deuteron four-momentum transfer ($t_{\min}$) kinematically allowed ($t_{\min} \propto 1/P_{\text{LAB}}^2$)¹² 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 figure 1(b) we show the 5π effective mass distribution. An enhancement is seen in the 1.9 GeV region similar to that observed in reference 4. For this enhancement there is no significant evidence for it being correlated with specific sub-systems 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-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 parity of the A_3 is in the unnatural series, i.e. 1^+ , 2^- , 3^+, which is in accord with previous spin 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 figures 3(a) and 3(b) respectively. Berman and Jacob¹⁴ have given expressions describing these angular distributions for various spin-parity assignments. We have fitted these distributions to the 1^+ , 2^- and 3^+ spin 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 $10^{-2}\%$. The fits to the polar distribution of the 2^- and 3^+ assignments have χ^2 probabilities of 85% and 75% respectively. The curves showing the 1^+ and 2^- fits are shown superimposed on figure 3(a). The 3^+ curve is essentially identical to the 2^- curve and is omitted for clarity. The curve on figure 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 3 S.D. of zero. This large value of ρ_{00} indicates total transverse alignment of the A_3 spin with respect to the beam direction.

We show in figures 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 parity, then the distribution shown in figure 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-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 ($\leq 10\%$)
- b) removing events in the $\rho^0\rho^0$ and ρ^0f^0 overlap regions of the 3π Dalitz plot.
- c) selecting only f^0 events.

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

It is a pleasure to acknowledge the work and cooperation of the SLAC personnel, the members of the Purdue High Energy Physics Group, experimental and theoretical, with whom we have had many informative discussions, and finally the Purdue scanners and measurers, without whom this work would not have been possible.

REFERENCES AND FOOTNOTES

1. H. Bingham, CERN Preprint/D.Ph.II/Phys. 70-60.
2. Particle Data Group, Review of Modern Physics 42, (1970) 87.
- B** 3. Daugeras et al., Physics Letters 27B, (1968) 332.
- GR.** 4. Huson et al., Physics Letters 28B, (1968) 208.
- J.F.** 5. Allard et al., ~~Physics Letters~~ 46A, (1966) 737. *Nuovo Cimento*
5. The TVGP-SQUAW system of programs was used.
6. We do not observe any D^{*0} and $\leq 10\%$ 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, Meson Review at APS-DPP Meeting, Austin, Texas, Nov. 5-7, 1970.
9. The values of these limits depend to some extent on the magnitude of the smoothly varying background, but it is clear from figure 2 that the dominant decay mode of the A_2 is $f^0\pi^+$ with no obvious $\rho^0\pi^+$ decay.
- D.J.** 10. Crennell et al., Phys. Rev. Letters 24, (1970) 781.
- M.A.** 11. Abolins et al., Phys. Rev. Letters 15, (1965) 125.
- B. Eisenstein and H. Gordon, Illinois University Preprint C00-1195-168 (1969).
- A** Forino et al., Physics Letters 19, (1969) 68.
- R** Vanderhagen et al., Nuclear Physics B13, (1969) 329.
- B.J.** Deery et al., Physical Review 3, (1971) 635.
- G** Vegni et al., Physics Letters 19, (1965) 526.
- A.M.** Cnops et al., Phys. Rev. Letters 21, (1968) 1609.
12. M. L. Good and W. D. Walker, Physical Review 120, (1960) 1857.
- L. Stodolsky, Phys. Rev. Letters 18, (1967) 973.
- J.J.** Veillet et al., CERN Conference on High Energy Collisions 1, (1968) 537.
- J.** Bartsch et al., Nuclear Physics 137, (1968) 345.
- C.** Caso et al., Letters al Nuovo Cimento 2, (1969) 437.
14. S. M. Berman and M. Jacob, Physical Review 139, (1965) 1023.

FIGURE CAPTIONS

Figure 1. For the reaction $\pi^+ d \rightarrow d\pi^+\pi^+\pi^-$.

- a) The $(3\pi)^+$ effective mass distribution. The shaded histogram corresponds to $f^0\pi^+$ effective mass distribution with $M_{f^0} = 1.16 < M(\pi^+\pi^-) < 1.32$ GeV. The dashed histogram is the result of subtracting the shaded histogram from the unshaded histogram.
- b) The $(5\pi)^+$ effective mass distribution from the reaction $\pi^+ d \rightarrow d\pi^+\pi^+\pi^+\pi^-$.
- c) The $\pi^+\pi^-$ effective mass distribution for the 2 combinations from the reaction $\pi^+ d \rightarrow d\pi^+\pi^+\pi^-$.

Figure 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.

Figure 3. The decay angular distributions for the reaction $\pi^+ d \rightarrow d\pi^+\pi^+\pi^-$ 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.

Fig 1

Fig 2

Fig 3

(a) 356 EVENTS (b)

(c) 146 EVENTS (d)