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Structure in the $\omega\pi\pi$ System at the A_2 Mass Region

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Evidence is presented for an enhancement in the $\omega\pi\pi$ mass spectrum at the A_2 mass region in π^+p interactions at 5 GeV/c. Assuming this effect to be the A_2, we calculate the decay rate relative to the $\rho\pi$ decay mode and obtain the results 0.29 ± 0.08 and 0.10 ± 0.04 for the two final states $A_2^0\Delta^{++}$ and A_2^+p, respectively. Possible explanations of the discrepancy between these numbers are suggested.

Some evidence has been recently presented for the possible decay of the A_2 meson into $\omega\pi\pi$,[1-4] in either the neutral or charged mode. In this note we present results on both decay modes observed in the study of the final states $A_2^0\Delta^{++}$ and A_2^+p in the reactions

$$\pi^+p \to \pi^+p\pi^+\pi^-\pi^0, \quad (1)$$

$$\pi^+p \to \pi^+p\pi^+\pi^-\pi^+\pi^-\pi^0, \quad (2)$$

$$\pi^+p \to p\pi^+\pi^+\pi^-, \quad (3)$$

$$\pi^+p \to p\pi^+\pi^+\pi^-(\mathrm{MM}), \; (\mathrm{MM}) \geq 2\pi^0, \quad (4)$$

at 4.93 GeV/c. The data come from a complete subsample of ~320 000 pictures, which is ~40% of the final sample of a high-statistics experiment taken at the Stanford Linear Accelerator Center 82-in. hydrogen bubble chamber. More experimental details are presented elsewhere.[5]

In Fig. 1(a) we present the $\pi_2^+\pi^-\pi^0$ mass distribution of Reaction (1) for events having $M(p\pi_1^+)$ in the Δ^{++} region (1.16–1.28 GeV). In Fig. 1(b) the plot of $M(\pi^+\pi^-\pi^0)$ in the final state $\Delta^{++}\pi^+\pi^-\pi^+\pi^-\pi^0$ of Reaction (2) with the same Δ^{++} cut shows strong ω production. Defining "ω events" by the

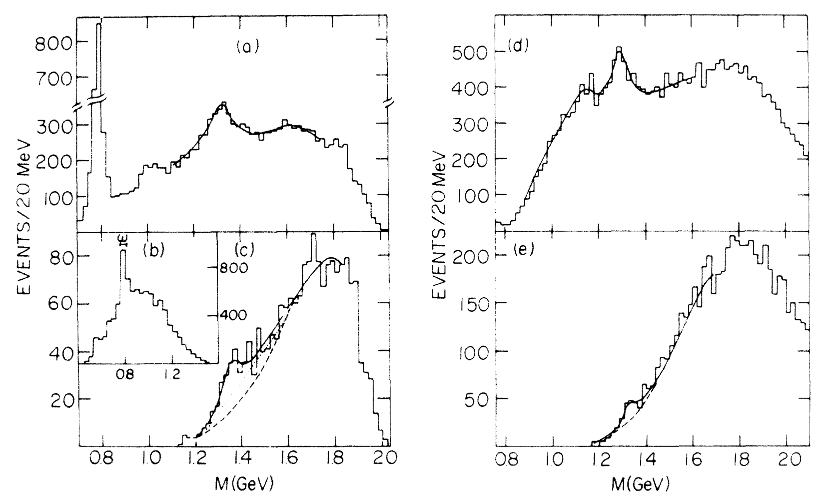

Fig. 1. (a) $M(\pi^+\pi^-\pi^0)$ in the reaction $\pi^+p \to \Delta^{++}\pi^+\pi^-\pi^0$. The curve is the best fit to A_2^0 and hand-drawn background. (b) $M(\pi^+\pi^-\pi^0)$ in the reaction $\pi^+p \to \Delta^{++}\pi^+\pi^+\pi^-\pi^-\pi^0$ (four combinations per event). (c) $M(\omega\pi^+\pi^-)$ in the reaction $\pi^+p \to \Delta^{++}\omega\pi^+\pi^-$. The solid curve is the best fit to A_2^0 and phase space. The background in the A_2^0 region is described by two extremes: The dashed curve is pure phase space (fit 1 in Table I) and the dotted curve is a hand-drawn straight line (fit 4 in Table I). (d) $M(\pi^+\pi^+\pi^-)$ in Reaction (3). The curve is the best fit to A_1^+, A_2^+, and hand-drawn background. (e) $M(\omega\pi^+\pi^0)$ in Reaction (4) with cuts to enhance the ω as described in text. The solid curve is the best fit to A_2^+ and phase space. The dashed curve is phase space in the A_2^+ region.

TABLE I. Results of several fits for the mass combination $M(\omega\pi^+\pi^-)$ in Reaction (2) with various types of background estimation. Errors are statistical only.

Fit no.	Type of background	Mass (MeV)	Width (MeV)	Events in A_2^0	$\omega\pi\pi/\rho\pi$ branching ratio
1	Pure PS	1335 ± 9	130 ± 26	174 ± 18	0.36 ± 0.05
2	Peripheral (e^{2t}) PS	1334 ± 9	78 ± 26	112 ± 19	0.23 ± 0.04
3	Polynomial modified PS	1335 ± 11	120 ± 42	155 ± 27	0.32 ± 0.06
4	Hand drawn (straight line)	1331 ± 11	104 ± 36	116 ± 20	0.24 ± 0.05

cut $0.76\le M(\pi^+\pi^-\pi^0)\le 0.81$ GeV we show in Fig. 1(c) the $\omega\pi^+\pi^-$ mass distribution of Reaction (2) recoiling against Δ^{++}. We have fitted the mass distributions of Figs. 1(a) and 1(c) with a nonrelativistic Breit-Wigner shape and background. A hand-drawn curve was used to describe the background in Fig. 1(a). For the $\Delta^{++}\omega\pi^+\pi^-$ final state[6] we tried a relativistically invariant phase space (PS) as well as peripheral ($\sim e^{2t}$) PS, PS modified by a polynomial function, and hand-drawn curves of several shapes to describe the background.

Table I describes the results of several fits with various types of background estimation. In each case we give the best values for the mass M and width Γ of the resonance. The significance of the effect lies between 3.3 and 6.3 standard deviations (sd) depending on the background assumption. All fits yield stable values[7] for M (~ 1335 MeV), and Γ values varying between 78 and 130 MeV. The dashed (dotted) curve in Fig. 1(c) describes a typical low- (high-) background estimation under the resonance corresponding to fit 1 (fit 4) in Table I. The solid curve describes the overall fit 1 and is not much different from the other fits 2–4.

Assuming the $\omega\pi^+\pi^-$ effect to be an A_2, we calculated the decay rate relative to the $\rho^\pm\pi^\mp$ decay mode. To do this we have used fixed values for the mass (1335 MeV) and width[8] (100 MeV). After applying correction factors for the ω tail (1.23) and for unseen decay modes of the ω (1.12), we obtained for the various fits the number of events in the $A_2^0\to\omega\pi^+\pi^-$ and the branching ratios as shown in Table I. The errors are statistical only. In the absence of precise knowledge about the shape of the background, we average between the above mentioned results and, including the systematic uncertainties in the error, we quote as best estimate for the branching ratio the value $\Gamma(A_2^0\to\omega\pi\pi)/\Gamma(A_2^0\to\rho\pi)=0.29\pm 0.08$. This ratio is somewhat higher than most of the previously reported results.[1-4]

We have further investigated the identification of the $\omega\pi^+\pi^-$ effect with that of the A_2 meson by comparing the amount of A_2^+ produced in Reaction (3) to that of Reaction (4). To enhance the $\omega\pi_2^0$ component in the zero-constraint process $\pi^+p\to\omega\pi_2^+\pi_2^0p$, $\omega\to\pi_1^+\pi^-\pi_\omega^0$, we have used a method[9] that assumes only two π^0's, π_ω^0 and π_2^0, in the missing-mass final state (4) and that the ω has zero width.[10] Expressing in the $\omega\pi_2^0$ rest frame the absolute value for the momenta of each π^0 and the cosine of the angle between their directions in terms of measurable quantities, we require the following cuts: $|\vec{p}(\pi_2^0)|^2>0$, $|\vec{p}(\pi_\omega^0)|^2>0$, and $|\cos[\vec{p}(\pi^0),\vec{p}(\pi_\omega^0)]|\le 1$. In addition we have required the mass of the $(\mathrm{MM})\pi_2^+$ combination to be less than 1.3 GeV. This requirement does not throw away any $\omega\pi^+\pi_2^0$ events in the A_2 region but does cut out much of the background. The $\pi^+\pi^+\pi^-(\mathrm{MM})$ mass plot for the events satisfying the above mentioned requirements is shown in Fig. 1(e). We observe a 4 sd signal centered at $M=1315\pm 8$ MeV and with a width of 70 ± 24 MeV after we have fitted the signal by $\pi^+p\pi^+\pi^-\pi^0\pi^0$ phase-space with the above mentioned cuts and a Breit-Wigner resonance.

To get the number of A_2^+'s produced in Reaction (3), we have fitted the $\pi^+\pi^+\pi^-$ mass spectrum by A_1 and A_2 nonrelativistic Breit-Wigner shapes and a hand-drawn background [see Fig. 1(d)]. By correcting for unseen decay modes of the ω and for the $A_2^+\to\rho^+\pi^0$, $\rho^+\to\pi^+\pi^0$ unseen decay mode, we obtain a branching ratio (assuming that the $\omega\pi^+\pi^0$ signal comes from a decay mode of the A_2 with fixed values of $M=1310$ MeV and $\Gamma=100$ MeV) of[11] $\Gamma(A_2^+\to\omega\pi\pi)/\Gamma(A_2^+\to\rho\pi)=0.10\pm 0.04$ which is consistent with a previously obtained result for the charged A_2.[2]

Figures 2(a), 2(b), and 2(d) show the dN/dt' distributions of $A_2^0\Delta^{++}$ and A_2^+p in Reactions (1), (2), and (4), respectively. They were obtained by fitting the mass distributions separately at

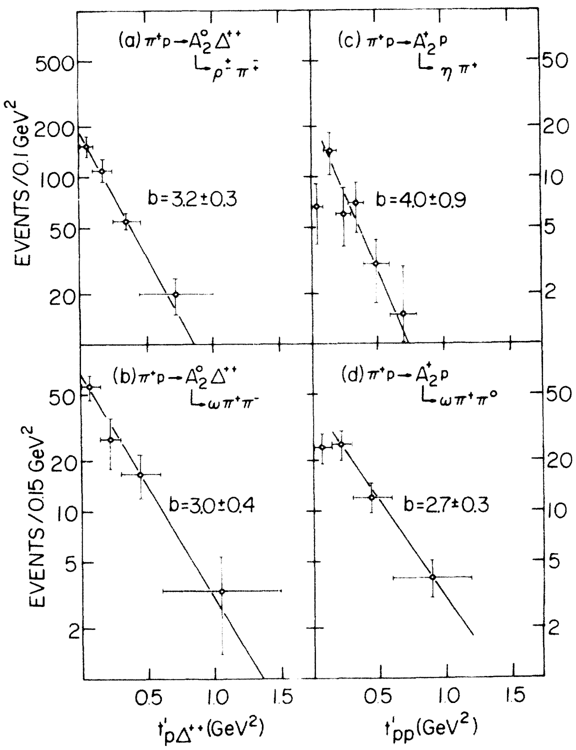

FIG. 2. (a)–(d) Production angular distributions in the forward direction for the final states $A_2{}^0\Delta^{++}$, $A_2{}^+p$ in various decay modes of A_2. Straight lines are fits to $A\exp(-bt')$ with slopes b as given.

the various t' intervals assuming fixed M and Γ values for the A_2 as obtained in each case for the total t' region. The straight lines correspond to $A\exp(-bt')$ fits with slopes b as given in the figure. Since no reliable slope can be extracted for $A_2{}^+p$ via the $\rho\pi$ decay mode of the A_2 because of the A_1 tail,[5] we present in Fig. 2(c) the dN/dt' distribution for the final state $pA_2{}^+$, $A_2{}^+\to\eta_c\pi^+$, $\eta_c\to\pi^+\pi^-\pi^0$ produced in Reaction (1), where the $A_2{}^+$ signal (not shown) is almost background free.

In conclusion, we have simultaneously seen significant signals in both the neutral and charged $M(\omega\pi\pi)$ states. However, the decay rate (assuming the signals to be A_2) relative to $\rho\pi$ differ by $\gtrsim 2$ sd. We also note that the value of the mass in the neutral state is higher by ~ 2 sd than the accepted value[8] of the A_2 while the $A_2{}^+$ mass is consistent with it.

It is quite possible that the above discrepancies are due to statistical fluctuations or to some unknown systematic biases.[7] However, we wish to point out that another way to resolve these disagreements is to assume that there exists an $I=0$ state[12] with a mass slightly higher than that of the A_2, which decays strongly into $\omega\pi\pi$. This hypothesis could explain the high values obtained for both the decay rate and the mass of the $\omega\pi^+\pi^-$ effect.[13] No evidence for this hypothesis can be found from the production distributions (Fig. 2), which look similar for both decay modes of $A_2{}^0$ and $A_2{}^+$.

We wish to thank the Stanford Linear Accelerator Center and the crew of the 82-in. hydrogen bubble chamber for their assistance in obtaining the exposure. We are grateful to our engineers, technicians, programmers, and scanners for their devoted efforts in operating our measuring facility and the data reduction system. Thanks are also due to Professor A. Engler for fruitful discussions.

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[5]Y. Eisenberg *et al.*, "Study of $\pi^+p\to$ Quasi-Two-Body Reactions at 5 GeV/c" (to be published).

[6]In order to check that the effect at ~ 1300 MeV is due to $\omega\pi\pi$ rather than to the 5π background, we plotted the $M(\pi^+\pi^-\pi^0)$ for the various $2\pi^+2\pi^-\pi^0$ mas intervals. Each plot was fitted to determine the number of ω's present. Though the errors are large, the results are consistent with the entire $\omega\pi\pi$ signal coming from true ω events rather than from the 5π background.

[7]We have searched for a possible bias which could explain the high mass value for the $\omega\pi^+\pi^-$ effect but found none. In fact the ω mass [Fig. 1(b)] turns out to be 784 ± 2 MeV, exactly as given by T. A. Lasinski *et al.* [Rev. Mod. Phys. 45, S1 (1973)] so that a systematic mass shift for the $\omega\pi\pi$ system is improbable.

[8]Lasinski *et al.*, Ref. 7.

[9]G. Mikenberg, Weizmann Institute Report No. WIS-74/3-Ph, 1974 (to be published).

[10]Less than 5% of true ω's are lost due to the experimental width in the ω region in the missing-mass channel.

[11]We have tried several background shapes for the fit of the $\omega\pi^+\pi^0$ mass distribution, including invariant phase space as above and various hand-drawn curves. The branching ratio is obtained by averaging the results of these fits and the error includes the systematic uncertainties.

[12]Note that there are two $I=0$, $J^{PC}=1^{+-}$ states that can decay into $\omega\pi\pi$ which are still missing in a simple quark model.

[13]High values for the mass and the decay rate of the $\omega\pi^+\pi^-$ effect in the A_2 region, consistent with our results, are also reported in Ref. 3.