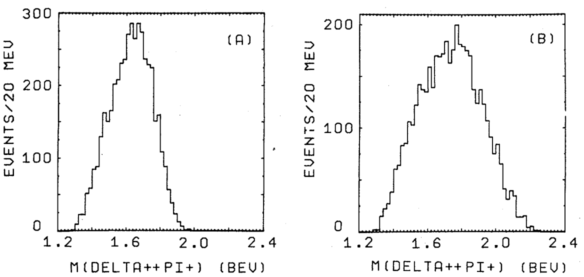

FIG. 2. $\Delta^{++}(1236)\pi^+$ mass spectrum for $|t|$ (beam to π^-) less than 0.6 $(\mathrm{BeV}/c^2)^2$. Δ^{++} is defined as 1120 $\mathrm{MeV}/c^2 < M(p\pi^+) < 1320\ \mathrm{MeV}/c^2$. (a) Events in beam momentum interval I. (b) Events in interval II.

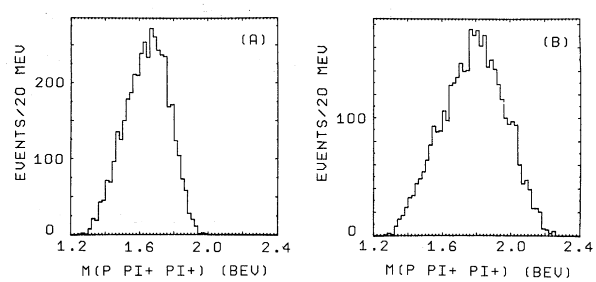

FIG. 3. $p\pi^+\pi^+$ mass spectrum for $|t|$ (beam to π^-) less than 0.6 $(\mathrm{BeV}/c^2)^2$, and $\Delta^{++}\rho^0$ events excluded. Δ^{++} is defined as in Fig. 2; ρ^0 is defined as 710 $\mathrm{MeV}/c^2 < M(\pi^+\pi^-) < 810\ \mathrm{MeV}/c^2$. (a) Events in beam momentum interval I; (b) Events in interval II.

However, in this case the meson would have to be doubly charged. A more likely exchange mechanism for production of an $I=\frac{5}{2}$ baryon in these reactions would be $I=\frac{3}{2}$ baryon exchange. We have also made cuts corresponding to production by baryon exchange, and we see no enhancement. Finally we note that we have examined the $p\pi^+\pi^+$ mass spectrum at each of our momentum settings separately, and we find no evidence for an enhancement at any of them.

In conclusion, we see no evidence for a narrow ($\Gamma \leq 60\ \mathrm{MeV}/c^2$) resonance in the mass range 1500-2000 MeV/c^2. The 40-μb production cross section reported by Benvenuti, Marquit, and Oppenheimer would correspond to a 6-standard-deviation enhancement in either of our beam momentum intervals.

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[1]A. Benvenuti, E. Marquit, and F. Oppenheimer, Phys. Rev. Letters 22, 970 (1969).

[2]M. Banner et al., in Proceedings of the International Conference on Elementary Particles, Heidelberg, Germany, 1967, edited by H. Filthuth (North-Holland Publishing Company, Amsterdam, The Netherlands, 1968), p. 112. Note added in proof.— Banner et al. now interpret their data as showing no structure identifiable as an $I=\frac{5}{2}$ baryon resonance (M. Banner et al., to be published).

OBSERVATION OF $A_1^{+,0}$ PRODUCTION IN K^+p INTERACTIONS AT 12.7 GeV/c †

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We observed statistically significant peaks in the charged and neutral three-pion mass spectra at the position of the A_1 in the reactions $K^+p \to K^{0,+}p\pi^+\pi^-\pi^{+,0}$ at 12.7 GeV/c. We discuss the possible interpretation of these peaks.

The A_1 meson has generally been observed as a low-mass enhancement in the charged tri-pion mass spectrum produced in the reaction[1]

$$\pi^\pm p \to \pi^\pm\pi^+\pi^- p. \quad (1)$$

In this reaction the events in the $A_1^\pm$ enhancement have highly peripheral characteristics and several nonresonant diffractive production mechanisms have been proposed to explain the observed charged three-pion mass enhancement characterizing the A_1 region.[2] It has thus never been clearly established whether the A_1 should be regarded as a true resonant state or considered to be a kinematic reflection of some particular production mechanism.[3]

Recently there have been indications of A_1 production in channels other than Reaction (1).[4] In this note we present evidence for the production of a state with the properties of the A_1 in the reactions[5]

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

$$K^+p \to K^+p\pi^+\pi^-\pi^0. \quad (3)$$

Our data are taken from a 7-event/μb exposure of the Brookhaven National Laboratory 80-in. bubble chamber to rf-separated 12.7-GeV/c K^+ mesons produced at the alternating-gradient synchrotron. We report on a study of 381 events from Reaction (2) and 3497 events from Reaction (3).[6]

Figure 1(a) displays the $\pi^+\pi^+\pi^-$ mass spectrum for Reaction (2) while in Fig. 1(b) we present the $\pi^+\pi^-\pi^0$ mass spectrum for Reaction (3). The curves drawn on these figures represent polynomial fits to the data [in Fig. 1(b) a Gaussian was included at the ω^0 mass]. The quality of these fits was relatively insensitive to the order of the fitted polynomial, and on the basis of the curves shown we conclude that both peaks are statistically significant. Throughout the remainder of this Letter we will refer to these peaks as the A_1^+ and the A_1^0.[7]

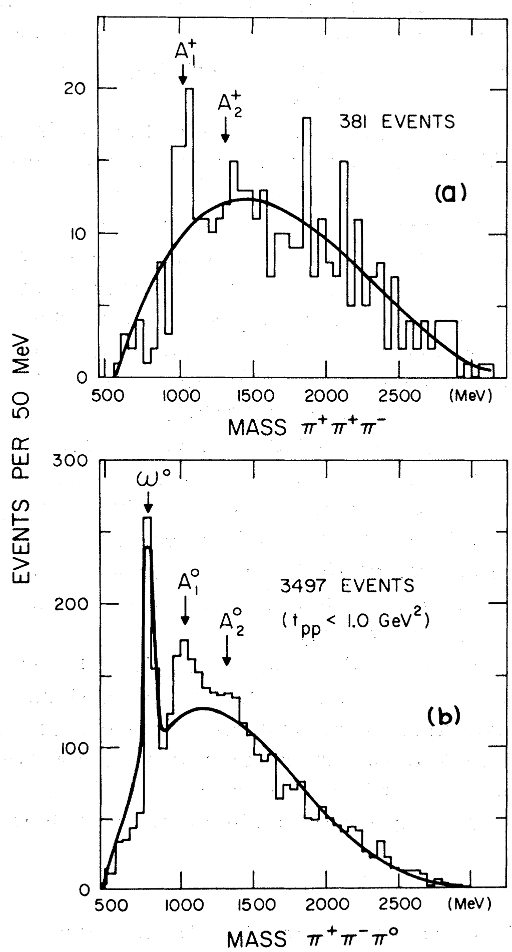

FIG. 1. (a), (b) The three-pion mass spectra for events in Reactions (2) and (3), respectively. The smooth curves represent polynomial fits to the data (see text).

We have investigated the possibility that the A_1^0 peak might arise from φ^0 production, through an analysis of the reaction

$$K^+p \to K^+pK^+K^-. \tag{4}$$

We observed that about 50% of Reaction (4) was indeed accounted for by the reaction

$$K^+p \to K^+p\varphi^0 \quad \llcorner K^+K^-. \tag{5}$$

The cross section for Reaction (5) is 15 ± 4 μb. The three-pion branching rate of the φ^0 is small[8] and we conclude that the φ^0 can account for only about 30 events near 1020 MeV in the $\pi^+\pi^-\pi^0$ mass distribution of Fig. 1(b), and hence cannot explain the observed peak in our data.

The spin and parity of the φ is 1^-, while that of the A_1 is thought to be 1^+. The normalized Dalitz plot consisting of $\pi^+\pi^-\pi^0$ events coming from the φ^0 would tend to show a concentration of events in the center and a vanishing near the boundaries. In contrast, a 1^+ state would not display this behavior.[9] In Fig. 2(a) we present the $\pi^+\pi^-\pi^0$ mass spectrum for those events located near the periphery of the Dalitz plot while Fig. 2(b) displays the tri-pion mass spectrum for those events located in the central area of the

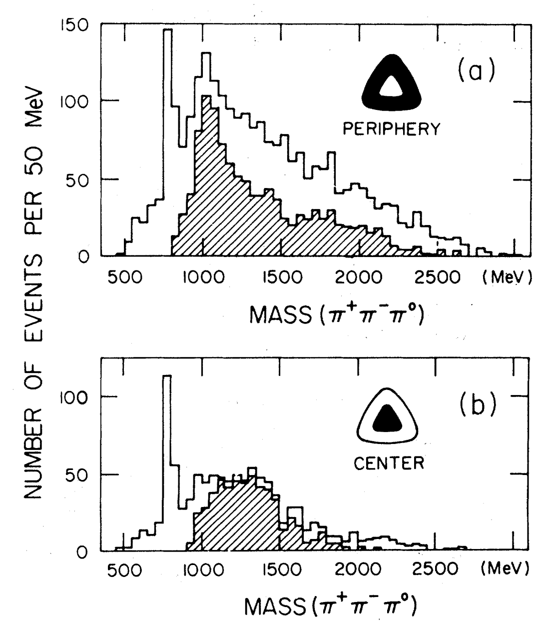

FIG. 2. (a), (b) Three-pion mass spectra for Reaction (3) for those events which populate the periphery and the center of the normalized three-pion Dalitz plot, respectively. The cross-hatched region corresponds to the requirement that a charged ρ meson be present.

$\pi^+\pi^-\pi^0$ Dalitz plot.[10] We note that for the region definitions employed, the two mass distributions contain equal amounts of ω^0 ($J^P = 1^-$) while the peak at the A_1^0 mass comes primarily from the peripheral regions of the Dalitz plot.[11] This result also argues against a φ^0 interpretation for the observed peak and suggests its identification as a meson in the J^P series $0^-, 1^+, 2^-, \cdots$.

The cross-hatched events in Fig. 2 contain at least one charged ρ; it is clear that this selection enhances the A_1^0 peak. Since this effect may be at least partially due to kinematics, we have also investigated the ρ structure of the A_1^0 events through a simple method of background subtraction. We divided the three-pion mass spectrum in the vicinity of the A_1^0 into two regions: a peak region centered on the A_1^0 and a control region consisting of events taken from immediately below and above this peak region. Any differences between the characteristics of events in the central region and those in the control region were attributed to the presence of the A_1^0 signal in the peak region.[12]

In Fig. 3(a) we present the sum of the $\pi^+\pi^0$ and the $\pi^-\pi^0$ di-pion decay distributions for those events in the peak region,[13] while in Fig. 3(b) we display this combined distribution for the control region; the $\pi^+\pi^-$ di-pion decay distributions for the peak and control regions are presented in Figs. 3(c) and 3(d), respectively. The curves drawn on Figs. 3(b) and 3(d) represent polynomial fits to these distributions; these same curves have been drawn on Figs. 3(a) and 3(c) as an estimate of the contribution from the background under the A_1^0 peak. Based upon the difference between Figs. 3(a) and 3(c) we can conclude that we are not observing the decay of an $I=2$ $\rho\pi$ system since this would require twice as much neutral as charged ρ in Figs. 3(a) and 3(c). If we further assume that the charged and neutral three-pion peaks in Fig. 1 represent the same state then we can conclude that this state is an $I=1$ $\rho\pi$ resonance—in agreement with previous analyses of the A_1 meson.

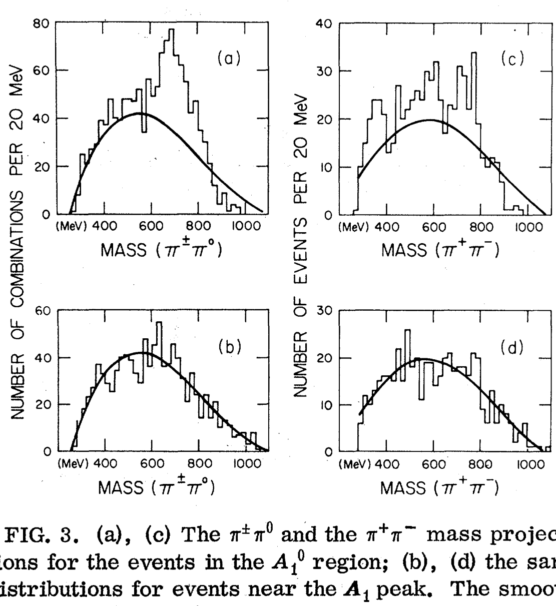

FIG. 3. (a), (c) The $\pi^{\pm}\pi^0$ and the $\pi^+\pi^-$ mass projections for the events in the A_1^0 region; (b), (d) the same distributions for events near the A_1 peak. The smooth curves in (b) and (d) are polynomial fits to the background data. These same curves are superimposed on the A_1^0 spectra in (a) and (c).

Using the same subtraction technique we have also investigated other significant characteristics of the events in the A_1^0 peak. These may be summarized as follows: (1) There is essentially no $K^{*0}(890)$ or $K^{*+}(890)$ associated with the A_1^0 peak. (2) There is essentially no $K^{*0}(1420)$ or $K^{*+}(1420)$ associated with the A_1^0 peak. [This includes two-body as well as three-body decays of the $K^*(1420)$.] (3) There is essentially no $\Delta^{++}(1236)$ associated with the A_1^0 signal.

The A_1^0 events are produced peripherally in Reaction (3) with the proton-to-proton momentum-transfer distribution exhibiting an exponential slope of 6 ± 2 GeV^{-2}. The momentum transfers from the beam K^+ to the final-state K^+ and to the A_1^0 also tend to accumulate at small values but with smaller exponential slopes. Finally, the $K^+A_1^0$ mass distribution is characterized by a general enhancement in the region of small $K^+A_1^0$ effective mass (1550 to 2000 MeV).

In summary, we conclude that we observe the production of the A_1^+ and A_1^0 mesons in Reactions (2) and (3), respectively. Our observed A_1 position is 1030 ± 20 MeV and our estimate of the A_1 width is 120 ± 30 MeV.[14] Our A_1 production cross sections are ~20 and ~40 μb in Reactions (2) and (3), respectively.

We thank Dr. B. Forman, Dr. A. C. Melissinos, and Dr. T. Yamanouchi for their contributions in the early stages of this experiment. We express our gratitude to the Brookhaven National Laboratory personnel and to the Rochester scanning/measuring group for their efforts on our behalf.

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[1]See G. Goldhaber, in Meson Spectroscopy, edited by C. Baltay and A. H. Rosenfeld (W. A. Benjamin, Inc., New York, 1968). See also B. French, in Proceedings of the Fourteenth International Conference on High Energy Physics, Vienna, Austria, September, 1968 (CERN Scientific Information Service, Geneva, Switzerland, 1968).

[2]For a description of some of the mechanisms investigated see M. L. Ioffredo et al., Phys. Rev. Letters 21, 1212 (1968), and references given therein to previous work.

[3]Recent theoretical speculations concerning the concept of duality have diluted the significance of such a distinction. It is no longer clear whether a "kinematic reflection" of a particular production mechanism (t-channel effect) is not just an alternative description of a resonant state (s-channel effect). See for example R. Dolen, D. Horn, and C. Schmid, Phys. Rev. 166, 1768 (1968).

[4]R. E. Juhala et al., Phys. Rev. Letters 19, 1355 (1967); G. Alexander et al., University of California Radiation Laboratory Report No. UCRL-18786, 1969 (to be published).

[5]Although Reactions (2) and (3) are quite different from Reaction (1), the observation of an A_1 peak in such processes is still subject to many of the ambiguities characterizing Reaction (1). For example, we have investigated the process of K dissociation into a real ρ and a virtual K^* with the subsequent dissociation of the K^* into a real pion and virtual K which then diffractively scatters off the target proton. Using a multi-Regge exchange calculation we have been able to produce a relatively narrow (~200 MeV) $\pi\rho$ mass peak near 1 GeV. Nevertheless, we feel that from an experimental point of view the most economical explanation at present for our data is resonance production, and this is the point of view which we are taking in this Letter. This does not preclude the possibility that a theory based on diffractive production mechanisms may ultimately prove to be most useful in describing the A_1 phenomenon (see Ref. 3).

[6]The sample of events from Reaction (3) was obtained from the measurement of about 20 000 four-prongs. Of these, approximately 6500 were unselected events while the remainder were preselected on the scanning table to enrich the yield of low-momentum protons. The data presented in the text for Reaction (3) were restricted to the region of proton-to-proton momentum transfers of <1.0 GeV^2; no momentum-transfer preselection of any kind was carried out for the sample of events from Reaction (2). We estimate that the background from event misidentification is less than 10% in Reaction (2) and less than 20% in Reaction (3).

[7]The statistics available in Reaction (2) do not permit a meaningful study of the A^+ state. We have however, ascertained that the characteristics of the A_1^+ peak are generally compatible with those which we report for the A_1^0 events.

[8]J. E. Augustin et al., Phys. Letters 28B, 517 (1969); also, Particle Data Group, University of California Radiation Laboratory Report No. UCRL 8030, 1969 (unpublished). We use the rate $(\varphi^0\to\pi^+\pi^-\pi^0)/(\varphi^0\to K^+K^-)=0.36$.

[9]For an $I=1$ $\pi^+\pi^-\pi^0$ system, the $J^P=1^-$, 2^+, 3^-, $\cdots$ series gives zeros at the boundary of the Dalitz plot, while for the $J^P=0^-$, 1^+, 2^-, 3^+, $\cdots$ series the density at the boundary of the Dalitz plot remains finite [see, for example, C. Zemach, Phys. Rev. 133, B1201, (1964)].

[10]We have employed the Dalitz-plot regions initially defined by G. Goldhaber, S. Goldhaber, J. A. Kadyk, and B. C. Shen, Phys. Rev. Letters 15, 118 (1965), in their study of the B meson. A normalized parameter $\lambda=|\vec{P}_+\times\vec{P}_-/Q^2|^2$ is defined (where $\vec{P}_+$ and $\vec{P}_-$ are the three-momenta of the π^+ and π^- mesons, respectively, and Q is the mass excess of the three-pion system). The central region of the Dalitz plot is then specified by the condition $\lambda>0.067$ and corresponds to about 30% of the total area on the Dalitz plot. The remainder of the events are assigned to the periphery. Such a cut on the Dalitz plot would equally partition a set of events arising from the decay of a simple 1^- matrix element of the form $|\vec{P}_+\times\vec{P}_-|^2$.

[11]We have used a program written by Dr. D. Griffiths to study the characteristics of an $I=1$, $J^P=1^+$ resonance. This program is based on the formulation of W. R. Frazer et al., Phys. Rev. 136, B1207 (1964), and takes into account interfering ρ bands in the $\pi\rho$ decay of a three-pion state. This program predicts that a neutral $I=1$, $J^P=1^+$ state should populate the periphery of the Dalitz plot 75% of the time. Our experimental results are consistent with this prediction.

[12]Such a subtraction technique ignores any interference between signal and background. The region definitions employed were: peak region, 940 to 1140 MeV; control region, 840 to 940 MeV plus 1140 to 1240 MeV.

[13]The positively and negatively charged di-pion decay distributions were completely consistent with one another and we have therefore added them together. The low mass observed for the ρ peak in Fig. 3 can be qualitatively understood on the basis of the kinematics of the $\pi\rho$ decay of a low-mass system.

[14]We estimate our experimental resolution at the A_1 mass to be ~10 MeV in Reaction (2), and ~30 MeV in Reaction (3).