tral function are assumed to be negligible [see S. Mandelstam and Ling-Lie Wang, Phys. Rev. 160, 1490 (1967)].

[6]It is assumed that the ω couples to the sense-sense channels at $\alpha = 0$.

[7]D. R. O. Morrison, presented in the Proceedings of the International Conference on Elementary Particles, Heidelberg, Germany, 1967 (to be published).

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[9]The combination $X(s,t)$ can be written in a form identical to that of Eq. (14) of Ref. 4. This form contains correctly a factor $|t|$ in the contribution of F_-. The presence of this factor can also be concluded by means of the factorization theorem (Ling-Lie Wang, private communication quoted in Ref. 8).

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EVIDENCE FOR A_1^0 PRODUCTION IN K^-p INTERACTIONS AT 4.6 AND 5.0 BeV/c*

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(Received 14 September 1967)

The A_1 effect has been reported previously only in the $I_3 = \pm 1$ states[1-12] decaying by $\rho^0\pi^\pm$. In those reactions in which it has been seen (mainly of the type $\pi N \rightarrow \pi\pi\pi N$ above 2.5 BeV/c), it is characteristically associated with events exhibiting very low four-momentum transfer from the target to the final-state proton. In reactions of this type at high momenta, the background contribution of the Deck effect[13-15] must be considered. In some cases the $\rho^0\pi^\pm$ mass distribution appears to require an additional resonance structure near 1080 MeV superposed on the Deck background. In other situations the Deck effect alone (possibly requiring both π and ρ exchange[16]) seems adequate to fit the data.

Evidence is presented in this report for the observation of a $\rho^\pm\pi^\mp$ enhancement at 1060 ± 15 MeV with a width of 120 ± 15 MeV in the reaction $K^-p \rightarrow K^-\pi^-\pi^+p\pi^0$ at incident K^- momenta of 4.6 and 5.0 BeV/c. This is interpreted as the A_1^0 on the basis of mass, width, and decay modes. Also, the experimentally determined spin and parity for this effect are consistent with previous investigations of the charged A_1.

Approximately 5800 measured four-prong events from 60 000 frames of K^- interactions in hydrogen in the Brookhaven National Laboratory 80-inch bubble chamber were processed to obtain a 1305-event sample for the reaction

$$K^-p \rightarrow K^-\pi^-\pi^+p\pi^0.$$

Kinematic fits to all constrained final states were tried. Events included in the sample were required to have an ionization-consistent fit to this reaction hypothesis with $\chi^2 < 5.0$. A 5-to-1 χ^2 probability ratio was used to choose among multiple fits satisfying the above criteria. Remaining ambiguous fits were included in the sample; however, comparison with a sample of unique fits indicates that possible contamination from incorrectly assigned fits does not affect the results presented here. Restrictions on missing mass and beam particle parameters were also imposed. The contamination from all sources is estimated at less than 18%.[17] The cross section for this reaction is 0.7 ± 0.1 mb.

In its general features this final state is rather complicated. There are strong signals for N^{*++} (15 ± 4%) and $\bar{K}^{*0}$ (22 ± 4%). Also, K^{*-} (9 ± 3%), N^{*+} (7 ± 2%), ρ^- (5.5 ± 2%), and ρ^+ (8 ± 3%) are evident. The gross $\pi^+\pi^-\pi^0$ distribution [Fig. 1(a)] indicates strong ω^0 production (17 ± 4%), some η^0 (3 ± 1.5%), and, of specific interest in this report, an enhancement in the region of 1060 MeV. This latter effect is not accounted for by the appropriate 3π phase space. Possible distortion in the background due to kinematic reflection of strong resonance production in other channels, specifically $K^-\pi^+$ and $p\pi^+$, has been examined by displaying the $\pi^+\pi^-\pi^0$ distribution for Monte-Carlo-generated phase-space events weighted on the experimental $K^-\pi^+$ and $p\pi^+$ mass distributions. In the case of the 3π spectrum there is no significant difference between the weighted and un-

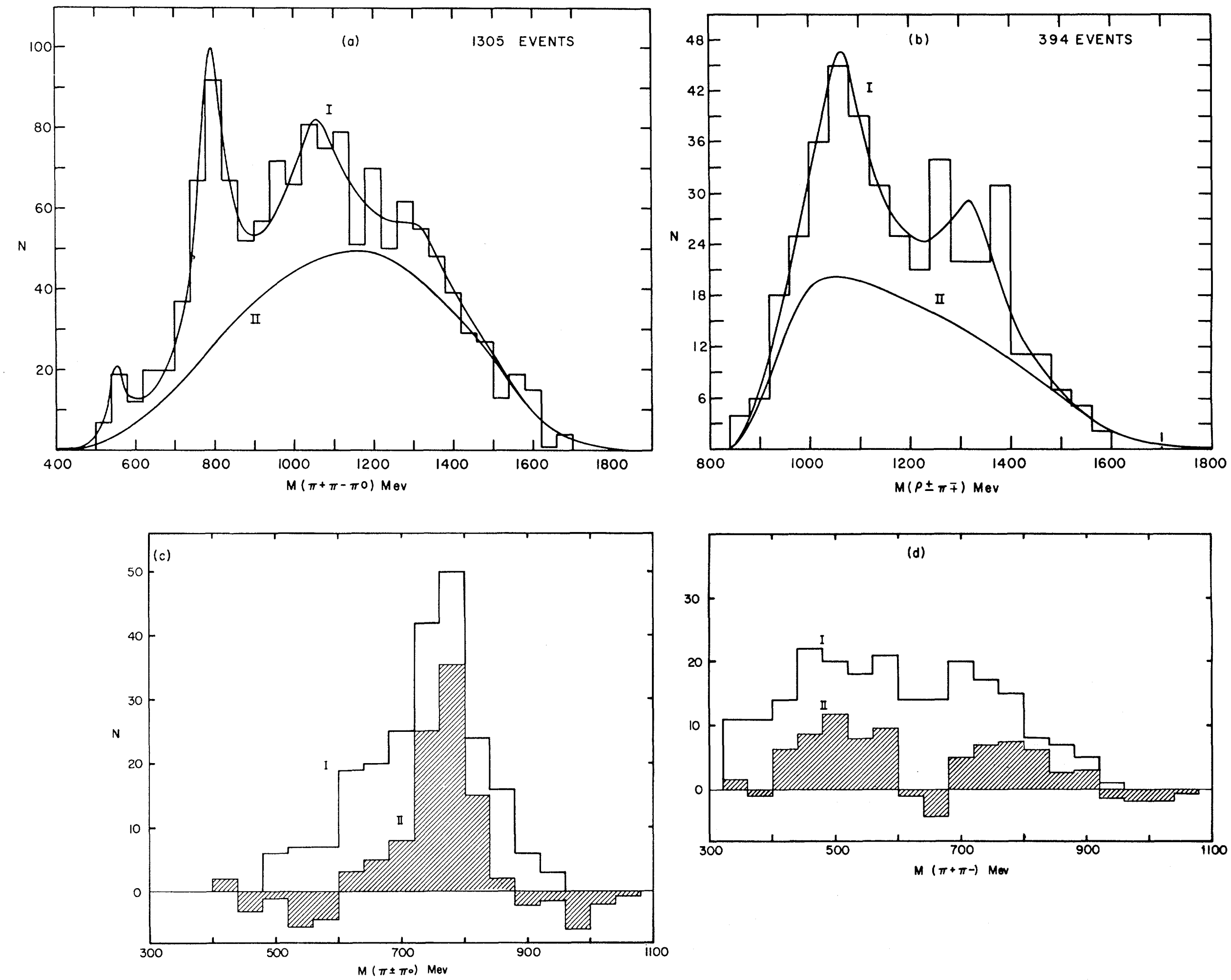

FIG. 1. $A_1{}^0$ production and decay $K^-p \rightarrow K^-\pi^-\pi^+p\pi^0$. (a) Gross $\pi^+\pi^-\pi^0$ mass distribution. Curve I is a maximum-likelihood fit using Breit-Wigner resonance functions for the η^0, ω^0, $A_1{}^0$, and $A_2{}^0$. Curve II is the weighted phase-space contribution for this fit. (b) $\pi^+\pi^-\pi^0$ mass distribution for events with $\pi^+\pi^0$ and/or $\pi^-\pi^0$ mass in 760 $\pm$ 60 MeV band. Curve I is a maximum-likelihood fit using Breit-Wigner resonance functions for the $A_1{}^0$ and the $A_2{}^0$. Curve II is the weighted phase-space contribution for this fit. (c) $\pi^\pm\pi^0$ mass distribution obtained by folding a $\pi^+\pi^0$-$\pi^-\pi^0$ mass-scatter plot along the diagonal and projecting onto the axis perpendicular to the superposed ρ bands. I is the histogram for all events with $\pi^+\pi^-\pi^0$ mass in $A_1{}^0$ region (1060$\pm$60 MeV). II is histogram I corrected for background (Ref.18). (d) $\pi^+\pi^-$ mass distribution. I is for all events with $\pi^+\pi^-\pi^0$ mass in $A_1{}^0$ region (1060 $\pm$60 MeV). II is histogram I corrected for background (Ref. 18).

weighted curves. A maximum-likelihood analysis of the gross 3π distribution using the weighted phase-space background and including Breit-Wigner resonance functions only for the η^0 and ω^0 gives a rather poor fit. The χ^2 is 73, corresponding to a probability of 20% for a larger χ^2. The addition of resonance functions for a possible effect near 1060 MeV (with fixed intrinsic width of 120 MeV) and for the $A_2{}^0$ leads to a considerably better fit. The χ^2 is 52, which gives a probability of 80%. The mass for the added resonance structure near 1060 MeV is adjusted to 1057 MeV, and its contribution is about 150 events or 11$\pm$3% of the total. The curve for this fit is shown in Fig. 1(b). Evidence for the $A_2{}^0$ is not striking from a visual examination of this distribution, but there is a suggestion of a weak enhancement in the 1300-MeV region. We know of no reason for excluding the possible contribution of the $A_2{}^0$; however, the quality of the fit is not very sensitive to the presence of the A_2. In any case it is clear, from the gross 3π distribution alone, that there is a significant effect in the region of 1060 MeV which is well accounted for in terms of a resonance structure of mass around 1060 MeV and width 120 MeV. We cannot rule out a small contribution from the φ meson (which is reported to have a 3π decay mode[1]), but the enhancement we see is too broad and centered at too high a mass to involve an appreciable amount of φ. On the basis of the fits discussed here, the partial cross section for the 1060-MeV effect is estimated to be 85 ± 25 μb.

The association of this enhancement with the ρ meson is apparent from Fig. 1(b), which shows the $\rho^\pm\pi^\mp$ mass distribution, in which the 1060-MeV effect is relatively much enhanced. A maximum-likelihood fit to this distribution using the appropriate selected, weighted, phase-space background with Breit-Wigner resonance functions for the 1060-MeV effect (Γ fixed at 120 MeV but with variable mass) and for the A_2^0 (Γ and mass fixed at 90 and 1327 MeV, respectively) yields for the 1060-MeV effect a mass of 1064 ± 15 MeV and a relative contribution of 25%. The absolute intensity of the 1060-MeV effect in the $\rho^\pm\pi^\mp$ distribution is consistent with that obtained from the fits to the gross distribution if it is assumed that all charged 3π decay modes of this effect involve $\rho^\pm\pi^\mp$. The need for additional structure in the $\rho^\pm\pi^\mp$ mass spectrum beyond that of the phase-space background is indicated by the difference in χ^2 probabilities for the two-resonance fit and a simple normalized-phase-space fit. In the latter case the probability is 25% while in the former it is 50%. However, unlike the case of the gross distribution, the absolute contribution of this effect is here more sensitive to the presence of the A_2^0 and to variations in the A_2^0 mass and width. Also, the A_2^0 contribution in the $\rho^\pm\pi^\mp$ distribution is noticeably greater than that in the gross distribution, whereas it should be smaller. We can only attribute this to the differing shape of the phase-space background in the two cases and to uncertainties in the nature of the effects in the 1300-MeV region. There does appear to be some structure in this region in the $\rho^\pm\pi^\mp$ spectrum as well as in the gross distribution, but it is not clear whether it is properly attributed to the A_2^0 or to this plus other effects. It is reasonable to expect that such effects will play a relatively more important role in the $\rho^\pm\pi^\mp$ spectrum than in the gross distribution. The inclusion of a resonance of mass and width appropriate for the A_2^0 provides at least a rough way of accounting for such structure as well as a means of fixing an upper limit on the A_2^0 contribution.

The symmetric nature of the decay of the 1060-MeV effect into $\rho^+\pi^-$ and $\rho^-\pi^+$ has been checked by counting events in the 1060 ± 60 MeV band for selection on ρ^+ and ρ^-, respectively. The ratio of the $\rho^+\pi^-/\rho^-\pi^+$ decays is 1.0 ± 0.2, consistent with unity. A strong confirmation of this correlation between the 1060-MeV 3π peak and $\rho^\pm$ is provided in Fig. 1(c), which displays the projection of a $\pi^+\pi^0$-$\pi^-\pi^0$ mass-scatter plot which has been folded along the diagonal for events in the 1060 ± 60 MeV 3π band. An appropriate background subtraction has been made.[18] The dominant ρ signal is a striking feature of this distribution.[19] On the other hand, the $\pi^+\pi^-$ mass distribution after background correction,[18] Fig. 1(d), shows no clear evidence for a ρ^0 signal. The ρ^+ and ρ^- intensities found from fits to the gross $\pi^+\pi^0$ and $\pi^-\pi^0$ distributions are consistent, within error limits, with the estimated contributions due to $\rho^\pm\pi^\mp$ decay of the 1060-MeV effect and any possible A_2^0. There is evidence also for excess ρ^+ arising from other sources.

Insofar as its 3π charged decay modes are concerned, the 1060-MeV effect exhibits the characteristics of an $I=1$ state. Since in this respect, as well as in its mass and width, this effect has properties consistent with those of the A_1, it will be referred to as the A_1^0 in the following discussion.

The center-of-mass angular distribution for the A_1^0 events[20] is presented in Fig. 2(a). A general forward peaking is evident, but it is not a sharp effect. A more striking behavior is noted in the center-of-mass angular distribution for the proton associated with the A_1^0 events [Fig. 2(b)]. The backward peak is quite sharp here, much more so than for events whose $\rho^\pm\pi^\mp$ mass lies either above or below the A_1^0 region. There is a strong indication here that the A_1^0 is produced via a process in which the target proton is only peripherally involved. The distribution in four-momentum transfer between the target and final-state proton (not shown here) exhibits a sharp rise at low t values, not inconsistent with this point of view. However, the low four-momentum transfer characteristics of a possible periph-

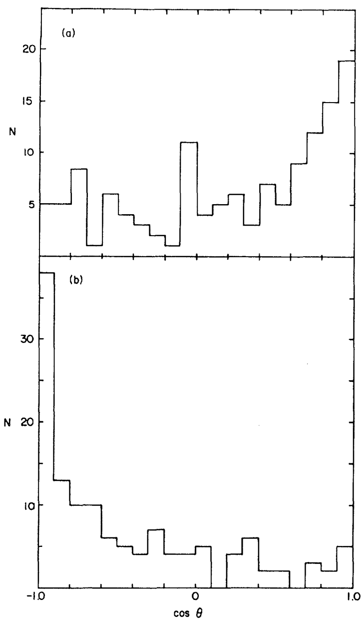

FIG. 2. (a) Center-of-mass angular distribution of A_1^0. (b) Recoil proton for A_1^0 events. All events have $\pi^+\pi^-\pi^0$ mass in A_1^0 region (1060 ± 60 MeV) and $\pi^+\pi^0$ and/or $\pi^-\pi^0$ in ρ bands (760 ± 60 MeV).

eral mechanism involved here would be significantly distorted by the kinematic cutoff.

As we have indicated previously, the Deck mechanism has been invoked in some cases to explain $\rho\pi$ enhancements near threshold in $\pi N \to \pi\pi\pi N$ reactions, and it is frequently suggested that the A_1 is not a true resonance but only a kinematic enhancement arising from a Deck-type process. It is obvious that no strict charge analog of the Deck effect can lead to A_1^0 production in the reaction considered here. Other more complicated processes which might conceivably produce such enhancements in our data have been considered. Without attempting to catalog and discuss here all of these various diagrams, we note that we can find no reasonable processes which in simple charge variations can lead to equal enhancements in both the $\rho^+\pi^-$ and $\rho^-\pi^+$ spectra but produce no effect in $\rho^0\pi^0$.

To make statements about the spin and parity (J^P) of the A_1^0, the Berman and Jacob analyses of sequential and direct three-body decays are used. For the sequential decay $A_1^0 \to \rho\pi$, $\rho \to \pi\pi$, the experimental quantity $R \equiv \int I(\theta, \varphi, \theta', \varphi')[5\cos^2\theta' - 1]d\Omega' d\Omega$ being nonzero implies the parity of the A_1^0 is $(-1)^{J+1}$ (unnatural parity).[21] Here θ and φ are the decay angles of the ρ meson in the A_1^0 rest frame in the coordinate system of Jackson[22] and θ', φ' are the decay angles of one of the pions in the $\rho \to \pi\pi$ decay in the ρ rest frame, while $I(\theta, \varphi, \theta', \varphi')$ is the experimental decay angular distribution for the A_1^0 decay expressing the probability of obtaining the ρ meson at angles θ, φ with the π meson at θ', φ'.

Using a sample of 119 events in the ρ-meson bands of the A_1^0 Dalitz plot excluding the overlap region, and making an appropriate background correction, the value $R = 1.7 \pm 0.5$ is obtained implying unnatural parity for the A_1^0 in agreement with previous reports.[3-6] The background is estimated by assuming that the decay angular distribution for background events is essentially the same as that for events outside the ρ bands (127 events, each event used twice), and that in the ρ bands the ratio of the number of true events to background events is 1.[23]

The theoretical angular distributions in the polar angle of the normal to the A_1^0 decay plane for spin hypotheses[24] 0^- [$I(\beta) \sim$ const] and 1^+ [$I(\beta) \sim (1+\rho_{00}) + (1-3\rho_{00})\cos^2\beta$] are fitted to the background corrected data by the method of least squares. Here ρ_{00} is an A_1^0 spin-density matrix element referred to the beam direction in the A_1^0 rest frame. The theoretical curves and the data are shown in Fig. 3. The best fit for the 1^+ hypothesis is obtained with $\rho_{00} = 1$. The χ^2 probabilities for the 0^- and 1^+ fits are 43 and 98%, respectively. While this re-

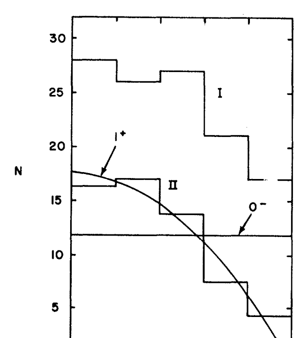

FIG. 3. Angular distribution in the cosine of the polar angle (see text) of the normal to the A_1^0 decay plane. Histogram I, no background correction; histogram II, with background correction; solid curves, theoretical predictions for the A_1^0 spin hypotheses 0^- and $1^+(\rho_{00}=1)$ normalized to histogram II (see Ref. 24). The histograms were symmetrical before folding.

sult does not permit a good discrimination between 0^- and 1^+, it is clearly consistent with the previously favored 1^+ assignment.[4-6]

The A_1^0 spin-parity analysis is being continued, but it is not anticipated that a definitive choice between the assignments 1^+, 2^-, and 3^+ will be possible with our present data.

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*Work supported by the U. S. Atomic Energy Commission under Contract No. W-7405-eng-82 at the Ames Laboratory, and at the University of Colorado under Contract No. AT(11-1)1537.

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[17]Background in the complete 1305-event sample from π^--induced reactions (due to π^- beam impurity) has been estimated from δ-ray scans of the film and published data on $\pi^- p$ reactions at comparable beam momentum. Background due to events with $\bar{K}^0$ or Λ^0 (or Σ^0) is estimated on the basis of studies of a sample of four-prong-one-V events treated as four prongs. Though the data subset considered in the present report is of the order of magnitude of the estimated total background, a consideration of characteristics of possible contaminating reactions indicates that the impurity in this subset is relatively no greater than in the complete sample, i.e., less than 18%.

[18]The background is formed from a suitably normalized sum of two distributions selected in one case on 3π masses above the 1060 ± 60 MeV band (1180 ± 40 MeV) and in the other on masses below this band (940 ± 40 MeV).

[19]Folding the $\pi^+\pi^0$-$\pi^-\pi^0$ scatter plot about its diagonal and projecting onto an axis perpendicular to the superposed ρ bands would not in general provide the most suitable method for superposing the two bands for the $\rho\pi$ decay of an arbitrary resonance. However, in this case the ρ^+,ρ^- resonance overlap region lies near the edge of the scatter plot and is relatively depopulated. Here this procedure does effectively clarify the $\rho\pi$ decay mode and with a minimum of distortion.

[20]By A_1^0 events we refer to events with $\pi^+\pi^-\pi^0$ mass in the A_1^0 region (1060 ± 60 MeV) and with $\rho^+\pi^-$ and/or $\rho^-\pi^+$ mass in the ρ region (760 ± 60 MeV).

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