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DECAY PROPERTIES OF THE A_2(1310) MESON*

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The properties of the A_2 enhancement are determined from the $K\bar{K}$ and $\pi\rho$ decay modes independently. The characteristics of both systems are consistent with the decay of a particle having $I^GJ^P=1^-2^+$.

Existence of a strong $\pi\rho$ enhancement between 1.0 and 1.4 BeV was discovered by Goldhaber et al. in a study of the reaction $\pi^++p\rightarrow\pi^++\pi^++\pi^-+p$ at 3.65 BeV/c.[1] The Aachen-Berlin-Birmingham-Bonn-Hamburg-London(I.C.)-München Collaboration[2] and Chung et al.[3] demonstrated that the enhancement consisted of two peaks: the A_1 at 1080 MeV and the A_2 at 1310 MeV. In addition, Chung et al. reported evidence for existence of a $K\bar{K}$ peak at 1310 MeV; the assignment $I^GJ^P=1^-2^+$ was deduced on the assumption that the $\pi\rho$ and $K\bar{K}$ peaks represented alternative decay modes of the A_2(1310). In several recent studies of the $\pi\rho$ system alone, the assignment $J^P=2^+$ has been favored for the A_2(1310).[4-6] In others, however, assignments $J^P=1^+$ or 2^- have appeared more likely[7-9]; in this case, the $K\bar{K}$ peak represents the decay of a new particle. In the present Letter we attempt to resolve this question by determining quantum numbers independently for the $K\bar{K}$ and $\pi\rho$ peaks; the analysis supports the original assumption of Chung et al.[3]

The film was obtained in the course of a systematic study of π^-p interactions near 3.2 and 4.2 BeV/c in the Lawrence Radiation Laboratory's 72-inch hydrogen bubble chamber. The experimental details are given by Hess[10] and Chung.[11] The observed numbers of events and corresponding cross sections are given in Table I.

The $K\bar{K}$ system has been studied in both $pK^-K_1^0$ and $nK_1^0K_1^0$ final states where the decays $K_1^0\rightarrow\pi^++\pi^-$ were observed; all successfully fitted events in the fiducial volume were used. In contrast, the A_2(1310) represents less than 10% of the $\pi^+\pi^-\pi^-p$ final state, so that useful comparisons are possible only after imposition of stringent selection criteria. For subsequent analysis, $\pi^-\rho^0p$ events are defined as those with at least one $M(\pi^+\pi^-)$ combination in the interval 0.66 to 0.84 BeV. Background due to the sequence $\pi^-+p\rightarrow\pi^-+\pi^-+N^{*++}(1238)\rightarrow\pi^-+\pi^-+\pi^++p$ has been minimized by rejecting events with 1.12 BeV $\leq M(\pi^+p)\leq$ 1.32 BeV and $\Delta_{p\pi^+}^2\leq 1.5$ (BeV/c)^2. In addition, events were

Table I. Final states analyzed.

Final state	Number of events 3.2 BeV/c	Number of events 4.2 BeV/c	Cross section (μb) 3.2 BeV/c	Cross section (μb) 4.2 BeV/c
$p\pi^+\pi^-\pi^-$	6318	2986	1910 ± 80	1920 ± 100
pK^0K^-	228[a]	95[a]	65.1 ± 5.3	65.7 ± 7.9
$nK_1^0K_1^0$	201[b]	68[b]	45.3 ± 4.1	36.6 ± 5.1

[a]$K_1^0\rightarrow\pi^++\pi^-$ decay was observed for these events. The cross sections were corrected for this detection efficiency ($\epsilon\approx\frac{1}{3}$).

[b]Decay of both $K_1^0\rightarrow\pi^++\pi^-$ was observed for these events. The cross sections were corrected for this detection efficiency ($\epsilon\approx 4/9$).

rejected if they fell into the region where the Deck mechanism[12] is strongest, $\Delta_{p\pi^-}^2 \leq 0.55$ $(\mathrm{BeV}/c)^2$ and $\hat{p}_p \cdot \hat{p}_0 \equiv \cos\theta_p \leq -0.8$. Here $\vec{p}_p$ is the momentum of the outgoing proton and $\vec{p}_0$ is the beam direction in the $p\pi^-$ rest frame.[13]

The effective-mass distributions, $M(K\bar{K})$, for the $K\bar{K}$ systems are shown in Fig. 1(a); the $M(\pi^-\rho^0)$ distribution is shown in Fig. 1(d) for events with $\Delta_p^2 \leq 0.65$ $(\mathrm{BeV}/c)^2$. In both cases a good fit is provided by a Breit-Wigner resonance, with $M_0 = 1310 \pm 20$ MeV and $\Gamma = 65 \pm 20$ MeV, above a smooth background. The Δ_N^2 distributions for events in the A_2 interval, 1.24 to 1.38 BeV, are shown separately for $K\bar{K}$ events [Figs. 1(b) and 1(c)] and $\pi^-\rho^0$ events [Figs. 1(e) and 1(f)]. After comparison with control regions we conclude that, within statistics, contributions from the 1310-MeV peak are similar in all cases.

Possible quantum numbers for the $K\bar{K}$ peak at 1310 MeV are readily deduced. Since the decay $K_1^0K_1^0$ is observed, C is +1 and J^P is $(\mathrm{even})^+$. Histograms of decay cosine ($\cos\theta_K$ in the $K\bar{K}$ rest frame) and Treiman-Yang angle are plotted in Fig. 2. The decay cosine distributions for both the $K^-K_1^0$ and $K_1^0K_1^0$ events contain strong $\cos^2\theta$ components, so that J is not equal to zero. Since I is 1 for $K^-K_1^0$, we conclude that $G = (-1)^{J+I} = -1$. Consequently, I^G is 1^- and J^P is 2^+, 4^+, etc. for the $K\bar{K}$ peak

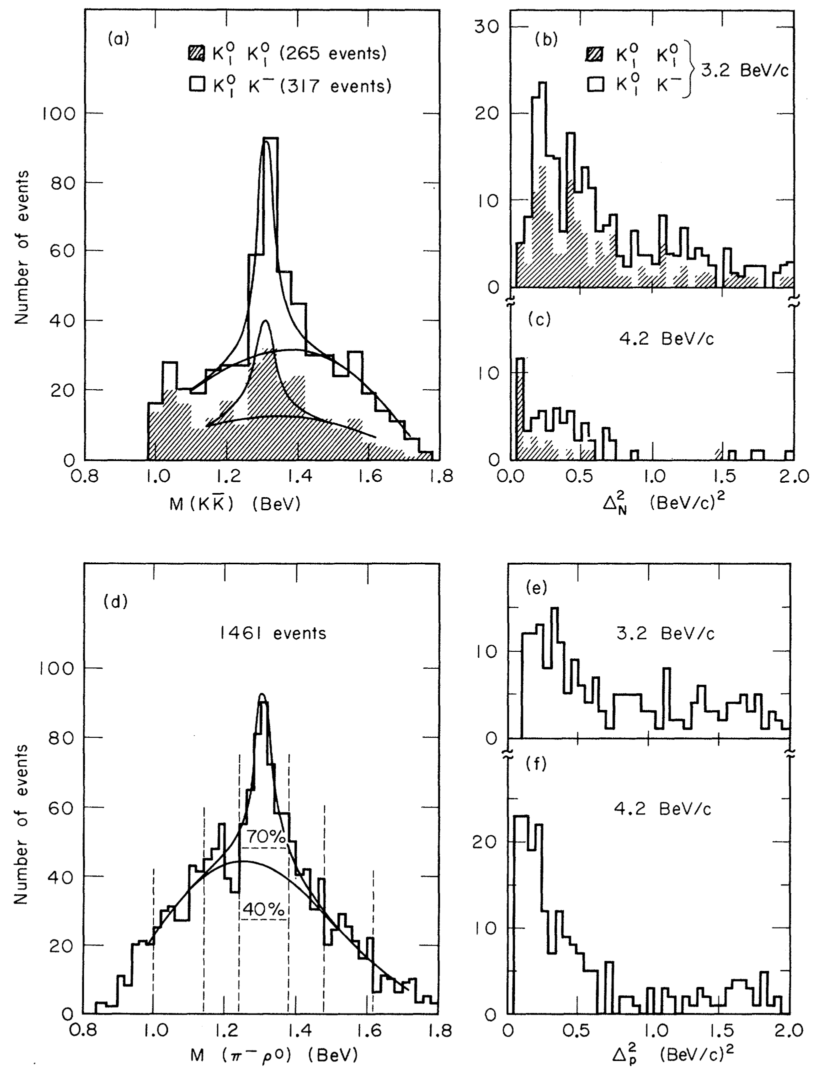

FIG. 1. (a) Effective-mass histogram for the $K\bar{K}$ systems at 3.2 and 4.2 BeV/c. (b), (c) Histograms of Δ_N^2 at 3.2 and 4.2 BeV/c for $K\bar{K}$ events in the A_2 region. (d) Effective-mass histogram for the $\pi^-\rho^0$ system at 3.2 and 4.2 BeV/c. Selections are discussed in the text. (e), (f) Histograms of Δ_p^2 at 3.2 and 4.2 BeV/c for the $\pi\rho$ events in the A_2 region.

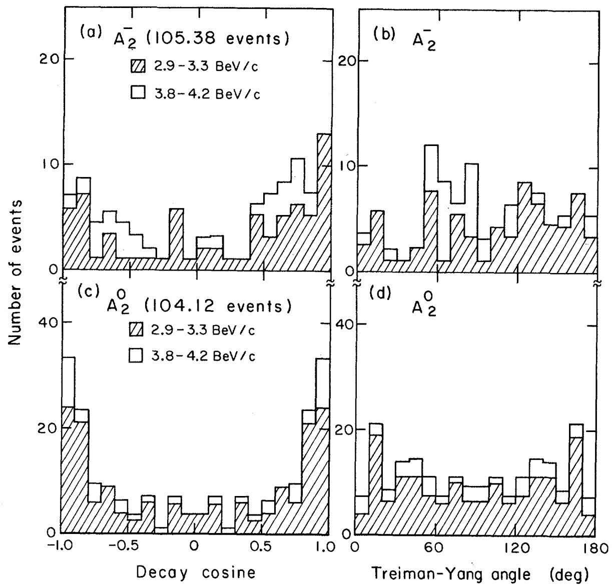

FIG. 2. Histograms of decay cosine ($=\hat{p}_K\cdot\hat{p}_0$ in the A_2 rest frame) and the Treiman-Yang angle for $K\bar{K}$ events in the A_2 region. The A_2^- histogram is shown in (a) and (b) and the A_2^0 in (c) and (d). In (c) and (d) two points have been plotted per event.

at 1310 MeV.

In deducing possible quantum numbers for the $\pi\rho$ system, we note first that the decay $A_2(1310)\rightarrow\pi+\rho$ is allowed, consequently G is -1; in addition, Abolins et al. have shown that $I=1$.[14] To determine the spin and parity, we consider the decay correlations in the A_2 rest frame; we define $\vec{q}$ as the relative momentum of the $\pi^+\pi^-$ pair forming the ρ^0, $\vec{p}$ as the momentum of the third pion, and $\cos\beta\equiv\hat{q}\cdot\hat{p}$. For collinear decays, corresponding to points on the boundary of the Dalitz plot, we have $\cos\beta=\pm1$. For these decays $\psi(3\pi)$ is proportional to $Y_J^M(\hat{q})$, so that P is $-(-1)^J$; consequently, for 3π systems with $P=(-1)^J$, collinear decays are not allowed.[15] Since the parity of the 3π system can be deduced only from the density on the Dalitz plot near the boundaries, a precise estimate of background is crucial; for systems with $P=(-1)^J$, a small residual background of collinear events can lead (erroneously) to the opposite parity assignment.

The $\cos\beta$ distributions are shown in Figs. 3(b), 3(c), and 3(d) for events in the A_2 region and control regions; the strong contribution from the decay $A_2\rightarrow\pi+\rho$ produces the peak at $\cos\beta\simeq0.2$ in Fig. 3(b). Events in the interval 1.24 to 1.38 BeV may be identified as (1) $A_2\rightarrow\pi+\rho$, (2) $\pi\rho$ background, or (3) 3π background. We designate the fraction of events of each type by ϵ_i. The smooth curve in Fig. 1(d) suggests that $\epsilon_2+\epsilon_3=0.6\pm0.1$; the $M(\pi^+\pi^-)$ distribution for the events in the A_2 interval gives $\epsilon_3=0.4\pm0.1$.

For comparison with the experimental data, theoretical $\cos\beta$ distributions[16] for possible J^P assignments were modified by addition of noninterfering background. To examine the dependence of each J^P assignment on background, $\epsilon_2+\epsilon_3$ was varied from 0 to 1. The $\pi\rho$ background was calculated using the matrix element for an s-wave $\pi\rho$ interaction (i.e., $J^P=1^+$ appropriately symmetrized)[17]; a uniform distribu-

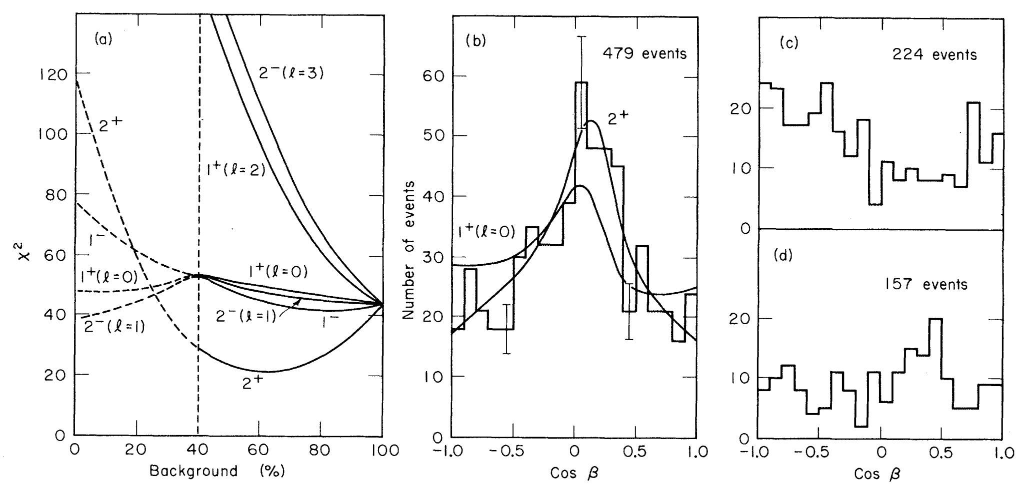

FIG. 3. (a) Variations of χ^2 (19 degrees of freedom) for various J^P assignments for the A_2 as a function of the background level. (b) The $\cos\beta$ distribution in the A_2 region. See text for explanation of the curves. (c) The $\cos\beta$ distribution for the region below the A_2 (1.0 to 1.14 BeV). (d) The same distribution for the region above the A_2 (1.48 to 1.62 BeV).

tion in $\cos\beta$ was assumed for the 3π background. The behavior of χ^2 (for 19 degrees of freedom) is shown in Fig. 3(a) as a function of the assumed background level; the slopes are discontinuous, since we have arbitrarily set $\epsilon_2=0$ for $\epsilon_1 \geq 0.6$. We note that when background is ignored, the most likely assignments are $J^P=1^+(l=0)$ and $J^P=2^-(l=1)$. However, for a realistic background level of 40 to 70%, $J^P=2^+$ represents the only assignment (of those considered) compatible with the data[18]: The fitted distribution is shown in Fig. 3(b) for $\epsilon_1=0.4$. Consequently, for a model with noninterfering background, parsimony requires that we identify the $\pi\rho$ and $K\bar{K}$ peaks as alternative decay modes of an $I^GJ^P=1^-2^+$ state at 1310 MeV; production cross sections are given in Table II. The combined data give $\Gamma(A_2^- \to K+\bar{K})/\Gamma(A_2^- \to \pi+\rho)=0.05 \pm 0.02$; a factor of $\frac{1}{2}$ has been included for the unobserved $\pi^0\rho^-$ decays. The decay $A_2 \to \pi+\eta$ is allowed; some evidence for a peak near 1310 MeV has been reported. We have examined the $M(\pi^-\eta)$ distribution from the $\pi^-(\pi^+\pi^-\pi^0)p$ final state and (after correcting for unobserved decays) estimate $\Gamma(A_2^- \to \pi+\eta)/\Gamma(A_2^- \to \pi+\rho) = 0.12 \pm 0.08$.

Since A_2 events are concentrated at low Δ_N^2 and the decay $A_2 \to \pi+\rho$ is dominant, it is likely that production occurs through ρ exchange. Unmodified, this model predicts a distribution $\cos^2\theta_K \sin^2\theta_K(1+a\cos 2\varphi)$ for the $K\bar{K}$ decay mode, where φ is the Treiman-Yang angle; the $\cos\theta_K$ distributions in Fig. 2 are in strong disagreement with this prediction. Similarly, the model does not account for the observed correlation between the beam direction and the normal to the $\pi\rho$ decay plane.[11] Analogous discrepancies in other reactions involving ρ exchange have been explained by absorption effects.[19]

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[13]This cut reduces the number of events in the mass region below the A_2, but eliminates few events in the A_2 region itself. The analysis was also carried out without this cut, and the conclusions remained un-

Table II. Cross section for A_2 production.

Reaction	Cross section (μb) 3.2 BeV/c	Cross section (μb) 4.2 BeV/c
$\pi^- + p \to A_2^- + p;\ A_2^- \to K^0 + K^-$	18 ± 4	17 ± 5
$\pi^- + p \to A_2^0 + n;\ \ A_2^0 \to K + \bar{K}$	36 ± 10	18 ± 9
$\pi^- + p \to A_2^- + p;\ A_2^- \to \rho^0 + \pi^-$	150 ± 50	175 ± 45

changed. See Ref. 11 for a detailed account.

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[16]We have used a computer program written by R. Diebold, CERN/TC/PROG 64-25, modified for our purpose. As an alternative method for taking background into account, varying amounts of the $\cos\beta$ distribution in the control region were subtracted from the distribution in the A_2 interval. A comparison of the resulting distribution with theoretical curves for various J^P assignments yielded similar results; see Ref. 11 for details.

[17]We thank Dr. Vanya Cocconi (private communication) for informing us that calculated distributions for events produced through the Deck mechanism resemble closely those for a $J^P = 1^+$ system.

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