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STUDY OF STRUCTURE IN THE "A_2(1300)" REGION IN π^-p INTERACTIONS AT 6 GeV/c*†

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In a bubble-chamber experiment we have observed a splitting of the "A_2(1300)" similar to that observed in the CERN missing-mass experiment. Analysis of the $K_1^0K_1^0$ system indicates that there are two different resonances in the "A_2" region.

Recent data on the mass spectrum of negative bosons (X^-) produced in the reaction $\pi^-p \to pX^-$, where X^- can decay into one or three charged particles plus possible neutrals, showed structure in the mass region of the A_2(1300) meson.[1,2] This structure consisted of a splitting of the A_2^- into two peaks with masses (m) and full widths (Γ) of $m_1 = 1274 \pm 16$, $\Gamma_1 = 29 \pm 10$ and $m_2 = 1320 \pm 16$, $\Gamma_2 = 35 \pm 10$ MeV. In this note, we report the observation in a bubble-chamber experiment of a similar splitting of the A_2^- peak in the reaction $\pi^-p \to p\pi^-$ + missing mass (MM) at 6 GeV/c. In addition, investigation of the $K\bar{K}$ mass spectrum in the A_2 region reveals a narrow $K_1^0K_1^0$ enhancement centered at the higher A_2^- peak (m_2) with a width of 21_{-6}^{+10} MeV. These observations suggest that there are two resonances with different spin and parity in the "A_2" mass region.

The data were obtained from a 6-GeV/c π^-p exposure of 230 000 pictures in the Brookhaven National Laboratory (BNL) 80-in. liquid-hydrogen bubble chamber. About $\frac{3}{5}$ of the events were measured by the BNL flying-spot digitizer and the rest by conventional measuring machines. The size of the event samples for the four reactions studied are shown below:

Reaction	Number of events
(1) $\pi^-p \to p\pi^-$MM (elastic events excluded)	10 319
(2) $\to nK_1^0K_1^0$	183
(3) $\to K_1^0K_1^0$ + neutrals	206
(4) $\to pK^-K_1^0$	199

The protons in Reaction (1) have been unambiguously identified for this analysis. This requirement is equivalent to an effective four-momentum transfer cut to the protons $t_{p\to p}$ of ≤ 2 GeV^2. We also required visible K_1^0 decays in Reactions (2)-(4).

Figure 1(a) is a display of the effective mass of X^- as a function of the laboratory proton momentum (P_p) and angle (θ_p) at 6 GeV/c. For the purpose of our subsequent analysis of the X^- mass spectrum in the "A_2" region, we define limits of P_p in region II identical to those in the 1965 CERN missing mass-spectrometer experiment at 6 GeV/c.[1] Adjacent regions I and III are chosen with the same range of P_p as that of region II [see Fig. 1(a)]. We have also selected a region "M" which simulates the "tapered-absorber" selection of the same experiment. Figures 1(b)-1(d) are effective-mass spectra in 40-MeV bins of the X^- (π^- + MM) in regions I, II, and III, respectively. A marked enhancement centered about 1.3 GeV with a width of about 100 MeV is clearly seen in Fig. 1(c). The mass and width of this enhancement are similar to the accepted values for the conventional "A_2" meson.[3] We observe little or no "A_2" production in either region I, probably because of the large Deck-like background at low $t_{p\to p}$ values, or region III, because of lack of A_2 production at high $t_{p\to p}$ values. A study of the experimental mass resolution (Γ_{exp}) of π^- + MM yields 12 ± 3 MeV in region I, 10 ± 2 MeV in region II, and 14 ± 3 MeV in region III.[4] We therefore present the X^- effec-

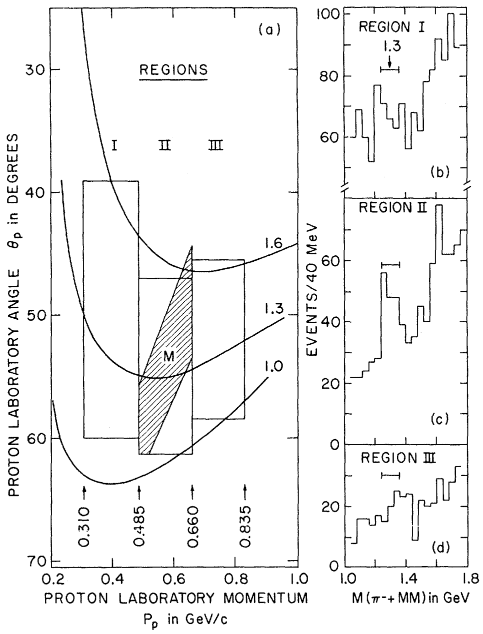

FIG. 1. (a) Proton laboratory momentum (P_p) versus angle (θ_p) for the reaction $\pi^- p \rightarrow pX^-$ at 6 GeV/c. Smooth curves correspond to different X^- effective masses as shown. Regions I-III are defined by cuts in P_p and θ_p plane. Region M is a cut identical to Ref. 2. (See text for details.) (b)-(d) Effective-mass distributions of X^- in 40-MeV bin size for regions I-III.

tive mass in 10-MeV bins as shown in Fig. 2 in order to investigate the fine structure in the "A_2" mass region. We observe in Fig. 2(b) a significant dip of the order of 10 MeV wide at the same position (1297 MeV) as obtained in the CERN experiment.[2] One- and two-resonance fits were made for the X^- mass spectrum using a background as shown in Fig. 2(b). Values for the mass and width obtained from the two-resonance fit are $m_1 = 1269 \pm 5$ with $\Gamma_1 = 24 \pm 10$ and $m_2 = 1315 \pm 5$ with $\Gamma_2 = 12 \pm 10$ MeV; the one resonance fit gives $m = 1287 \pm 10$ with $\Gamma = 94^{+30}_{-20}$. The two-peak fit is better, although not significantly, than the one-peak fit. However, the similarities between our values from the fits[5] and those from previous experiments[2] are striking. For the purpose of completeness, we present in Fig. 3(a) the X^- mass spectrum in the "M" region in order to simulate the "tapered-absorber" conditions of the 1965 CERN experiment.[1] Next we examine the properties of these two objects which we shall refer to as A_2^L (L for low) for m_1 and A_2^H (H for high) for m_2 from the various decay modes.

(1) $\eta(550)\pi$.—A strong $\eta \rightarrow$ neutrals signal is observed in the MM spectrum[6] for the π^- + MM mass region from 1250 to 1350 MeV in regions II and III (not I) as seen in the inserts in Fig. 2.[7] Contributions from $\eta\pi$ events in the X^- region are shaded in Figs. 2(b) and 2(c). Within the limited statistics, there seems to be an equal amount of $\eta\pi$ events in the A_2^L and the A_2^H in region II.

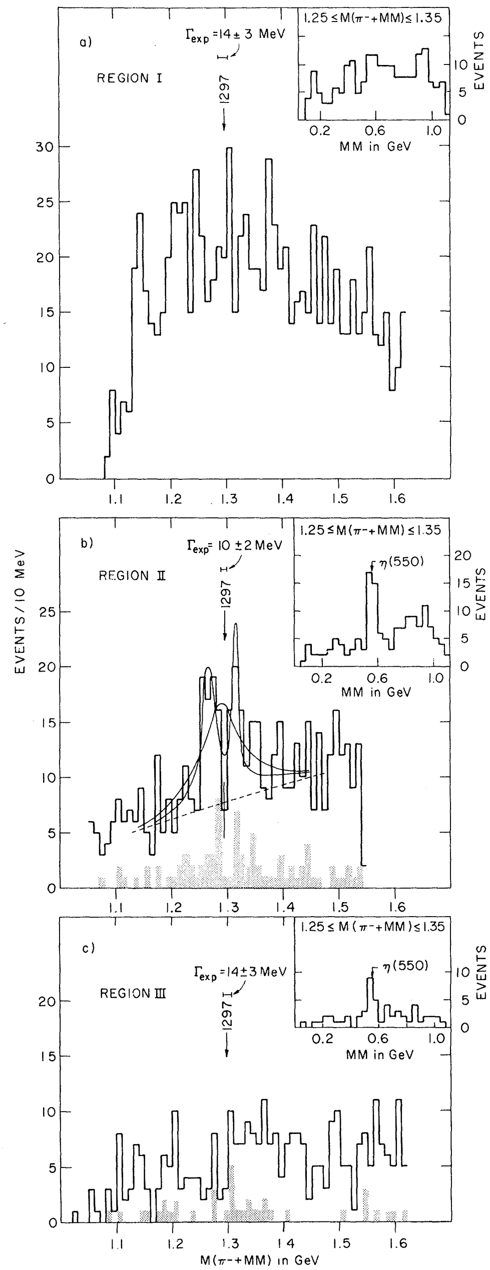

FIG. 2. (a)-(c) Effective-mass distributions of X^- in 10-MeV bin size for regions I-III. The smooth curves in (b) represent one- and two-resonance fits to the X^- mass spectrum in the "A_2" region. The MM projections in the "A_2" region as indicated are also shown in the inserts of (a)-(c). The shaded areas in the effective-mass plots are $\eta(550)\pi$ events.

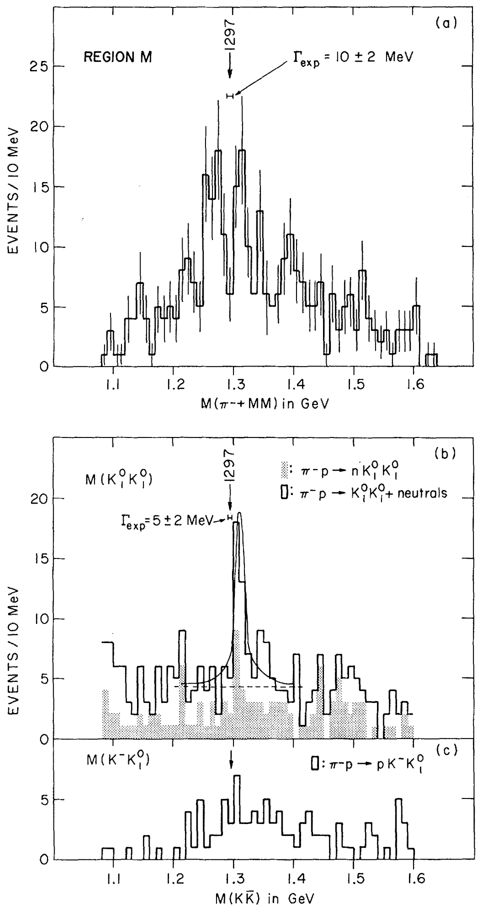

FIG. 3. (a) Effective-mass distributions of X^- for region M. (b) Effective-mass distribution of $K_1^0K_1^0$ in Reactions (2)-(3). The shaded area includes events from Reaction (2) only. (c) Effective-mass distribution of $K^-K_1^0$ in Reaction (4).

It is interesting to note that in region III there is an absence of events (including $\eta\pi$ events) in A_2^L and an excess in A_2^H even though no clear "A_2" signal is seen. This suggests that the $t_{p\to p}$ distribution of the A_2^H is less steep than that of the A_2^L.

(2) π^-MM.–If we assume that the π^- + MM (excluding $\eta\pi$) events in the "A_2" region (1.25-1.35 GeV) originate from the $\rho^-\pi^0$ decay mode of the "A_2," we obtain a value of $(\eta\pi/\rho\pi)^-$ to be $29_{-6}^{+7}\%$, which is in agreement with the currently accepted value. Within statistics the same branching ratio is obtained from both the A_2^L and A_2^H.

(3) $K\bar{K}$.– Figures 3(b) and 3(c) show $K\bar{K}$ mass spectra from Reactions (2) + (3) and (4). A narrow $K_1^0K_1^0$ peak at 1311 MeV is observed in both Reactions (2) and (3). A sharp change in the $K_1^0K_1^0$ decay angular distribution also occurs at the mass of the peak from an isotropic distribution to a forward-backward peaking. The experimental resolution for the $K_1^0K_1^0$ mass is 5 ± 2 MeV. From the Breit-Wigner fit, the mass and width of the $K_1^0K_1^0$ peak are 1311 ± 5 MeV and 21_{-6}^{+10} MeV, respectively.[8] These values are in remarkable agreement with those of A_2^H (m_2 = 1315 ± 5 with Γ_2 = 12 ± 10 MeV). The $K_1^0K_1^0$ mass value disagrees with that of A_2^L by more than six standard deviations.[9] A double-pole explanation[10] of the splitting in the A_2 mass region suggests the existence of a narrow resonance ($\Gamma \lesssim 3$ MeV) such as $K\bar{K}$, centered at the position of the dip (1297). Our experimental width ($20\pm_6^{10}$ MeV) and mass (1311 ± 5) of the $K_1^0K_1^0$ peak are both inconsistent with such a $K\bar{K}$ assumption by ~3 standard deviations. Limited statistics in the $K^-K_1^0$ mass spectrum preclude a determination of a definitive decay rate[11] of the A_2^H into $K^-K_1^0$. However the majority of $K^-K_1^0$ events in the "A_2" region do center above 1.3 GeV.[12]

We present our conclusions as follows:

	A_2^L	A_2^H	Origin
m, Γ	1269 ± 5,	1315 ± 5, 12 ± 10	π^- + MM
	24 ± 10	1311 ± 5, 21_{-6}^{+10}	
I^G, J^P	1^-, ?	1^-, even$^{\text{even}}$	$\eta(550)\pi^-$, $K_1^0K_1^0$

In summary we suggest that (a) A_2^L and A_2^H are distinct and different resonances and (b) A_2^H has the same properties as the "conventional" $I^G = 1^-$ and $J^P = 2^+$ "A_2" meson.[13] For the A_2^L only $I^G = 1^-$ is well established from the present investigations. However, from the $\eta(550)\pi$ decay mode one can obtain a series of $J^P = 0^+, 2^+, \cdots$ and $1^-, 3^-, \cdots$. The absence of a $\bar{K}K$ decay mode for A_2^L may indicate $J^P = 1^-, 3^-, \cdots$, since the $I^G = 1^-$ and $J^P = 1^-, 3^-, \cdots$ states do not couple with $\bar{K}K$ systems.

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‡On leave of absence from the Weizmann Institute of Science, Rehovoth, Israel.

[1]F. Lefebvres et al., Phys. Letters 19, 434 (1965).

[2]G. Chikovani et al., Phys. Rev. Letters 25B, 44 (1967); W. Kienzle, in Proceedings of Informal Meeting on Experimental Meson Spectroscopy, Philadelphia, April, 1968 (to be published).

[3]See an experimental compilation by A. H. Rosenfeld et al., Rev. Mod. Phys. 40, 77 (1968), and references therein.

[4]The major contribution to the error in the effective mass of π^- + MM comes from the uncertainty of the incident beam momentum. Errors introduced by measurements and Coulomb scattering of the recoil protons in the laboratory momentum range ~0.3-0.9 GeV/c are of the order of 5 MeV.

[5]All mass-spectrum fits have been made with a linear background. A quadratic background gives essentially the same results. The fits with two incoherent Breit-Wigner shapes never succeed in reproducing the pronounced dip observed between the peaks. A larger width is obtained for Γ_2 if higher $t_{p\to p}$ values (0.2-0.6 GeV^2) are included, giving $\Gamma_2 \simeq 50 \pm 25$ MeV.

[6]The error in the missing mass comes from errors in measurements of the fast π^- and recoil-proton tracks. It is about 35 ± 15 MeV.

[7]Since we see no ω(780) signal in the MM spectrum (see Fig. 2 inserts), we conclude that the A_2^L does not contain $\omega\pi$ events and hence cannot be due to the B meson.

[8]Unlike the π^- + MM system in Reaction (1), the $K_1^0K_1^0$ system in Reactions (2) and (3) is not complicated by large background due to other final-state interactions; therefore no cuts are introduced in the $K_1^0K_1^0$ mass histogram.

[9]Since the f^0(1260) meson can decay into $K_1^0K_1^0$ system, interference between the $I=0$ f^0 meson and the $I=1$ "A_2" meson is possible; however, this is unlikely since results from similar experiments at different energies do show a similar narrow $K_1^0K_1^0$ peak centered above 1.3 GeV. See, for example, S. U. Chung et al., Phys. Rev. Letters 12, 621 (1964); and Richard I. Hess, thesis, University of California Radiation Laboratory Report No. UCRL-16832, 1966 (unpublished).

[10]K. E. Lassila and P. V. Ruuskanen, Phys. Rev. Letters 19, 762 (1967); A Goldhaber, private communication.

[11]The triangle inequality is satisfied within statistics for the A_2^H (1300-1330 MeV) produced in the reactions $\pi^-p \to K^-K_1^0p$ and $K_1^0K_1^0n$, and $\pi^+p \to K^+K_1^0p$ at 6 GeV/c.

[12]This is also observed in other similar experiments. See, for example, Gerson Goldhaber, in Proceedings of Thirteenth International Conference on High-Energy Physics, Berkeley, 1966 (University of California Press, Berkeley, Calif., 1967), p. 125. See also Richard I. Hess, Ref. 9. The author gave a mass and width of "A_2^-" $\to K^-K_1^0$ as 1317.2 ± 4.0 and 47 ± 18 MeV, and pointed out the difficulty to assign a consistent width between "A_2^-" $\to K^-K_1^0$ and "A_2^-" $\to \rho^0\pi^-$ from the same experiment. See S. U. Chung, thesis, University of California Radiation Laboratory Report No. UCRL-16881, 1966 (unpublished).

[13]$J^P = 0^+$ assignment is ruled out by the observation of the $\rho\pi$ decay mode of the "conventional" A_2 meson.

STUDY OF A_2^- in $\pi^-p \to \pi^-p\eta^0$ AT 5 BeV/c*

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We report a study of the reaction $\pi^-p \to \pi^-p\eta^0 \to \pi^-p\pi^+\pi^-\pi^0$ at 5.0 BeV/c, which gives clear evidence for $A_2^- \to \eta^0\pi^-$. The observed branching ratio is $R = (A_2^- \to \eta^0\pi^-)/[A_2^- \to (\rho\pi)^-] = 0.23 \pm 0.08$, and the observed polarization of the A_2 is $2\rho_{11} \simeq 1, \rho_{1-1} = \rho_{-11} \simeq 0.5$. We also obtain evidence for $A_2^- \to X^0\pi^-$ with an observed branching ratio of $(A_2^- \to X^0\pi^-)/[A_2^- \to (\rho\pi)^-] = 0.07 \pm 0.03$.

The A_2 meson resonance at 1300 MeV is known to decay primarily by $\rho\pi$, $\eta\pi$, and $K\bar{K}$ modes.[1] The decay branching ratios are still uncertain, and the spin and parity determination rests primarily on the $K\bar{K}$ mode. Recently a structure in the A_2 has been reported,[2] indicating that the A_2 may be composed of two peaks. In our data with poorer statistics, we do not observe a splitting, and we therefore have treated all the data together.

A total of 172 η^0 events were observed in 55 000 four-prong events obtained in the 72-in. hydrogen bubble chamber at the Lawrence Radiation Laboratory. These events were selected from $\pi^-p \to \pi^-p\pi^+\pi^-\pi^0$ events chosen by the following criteria: (a) Each event had to be compatible kinematically ($\chi^2 < 10$ for the one-constraint hypothesis) and by ionization with the $\pi^-p \to \pi^-p\pi^+\pi^-\pi^0$ hypothesis. (b) Events which were also compatible with $\pi^-p \to \pi^-p\pi^+\pi^-$ ($\chi^2 < 40$ for the four-con-