NEUTRAL $\pi\rho$ ENHANCEMENTS PRODUCED IN 8-GeV/c π^+d INTERACTIONS*

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Enhancements in the A region and at 1.670 GeV are observed decaying into $\pi\rho$. The A_1 enhancement is not well described by a simple charge-exchange Deck effect. The isoscalar character of the 1.670-GeV enhancement is confirmed.

Previous studies[1] at 5.1 GeV/c of the channel $\pi^+d \to \pi^+\pi^-\pi^0 pp$ indicated an enhancement in the A_1 region which was interpreted as a charge-exchange Deck effect.[2] In addition, the existence of an isoscalar $\pi\rho$ enhancement of mass 1.636 GeV was suggested, although the isospin assignment has not been considered conclusive.[3] The analysis presented here confirms the existence of an isoscalar $\pi\rho$ resonance of mass 1.670 ± 0.02 GeV and width 0.10 ± 0.04 GeV and shows that the enhancement in the A_1 mass region is not described well by a Deck effect.

From the measurement of 56 000 three- and four-prong events produced in an exposure of the Brookhaven National Laboratory 80-in. deuterium bubble chamber to a beam of 8-GeV/c π^+ mesons, we have identified[4] approximately 4100 events fitting the channel $\pi^+d \to \pi^+\pi^-\pi^0 pp$.

Figure 1(a) shows the $\pi^+\pi^-\pi^0$ mass distribution from this channel; η, ω, and A_2 resonances are evident, and also there are enhancements in the A_1 mass region and at a mass of about 1.670 GeV which we refer to as the $\varphi(1670)$. Figure 1(b) shows the results of a ρ selection; evidently the A_1, A_2, and $\varphi(1670)$ are predominantly $\pi\rho$ enhancements. We confine this paper to a discussion of the A_1 and $\varphi(1670)$ enhancements and first discuss the $\varphi(1670)$.

From a fit of Breit-Wigner distributions and a smooth hand-drawn background to Fig. 1(b) we obtain a mass and width for the $\varphi(1670)$ of 1.670 ± 0.02 GeV and 0.10 ± 0.04 GeV in agreement with the previous measurement.[1] The cross section for production of this enhancement is 19 ± 5 μb.

The isospin of the $\varphi(1670)$ may be determined from its decay branching ratios into ρ^+, ρ^-, and ρ^0; a $\pi^0\rho^0$ decay mode in particular rules out isospin 1. In Fig. 2(a) the $\pi\rho$ mass distribution is shown for a ρ^0 selection and a clear peak is present in the $\varphi(1670)$ region, which persists when ρ^- and ρ^+ events are removed.[5] From Fig. 2(b), which shows that ρ^0 is produced in the $\varphi(1670)$ region, and the increase in signal-to-background ratio when a ρ^0 selection is made, we conclude that the $\varphi(1670)$ has a $\rho^0\pi^0$ decay mode and hence has isospin 0 or 2.

The number of events decaying $\rho^+\pi^- + \rho^-\pi^+$ and $\rho^0\pi^0$ are 58 ± 15 and 30 ± 10, respectively; this is consistent with isospin 0 and eliminates isospins 1 and 2 by approximately 3 standard deviations.

An attempt was made to determine the spin and parity of the $\varphi(1670)$ assuming an isospin of zero by fitting the mass distribution in the three ρ bands. The character of the background in the $\varphi(1670)$ region was determined by Dalitz-plot fits above and below the enhancement. It was found that the background was well described by 75% phase space and 25% incoherent $\pi\rho$ with the ρ as-

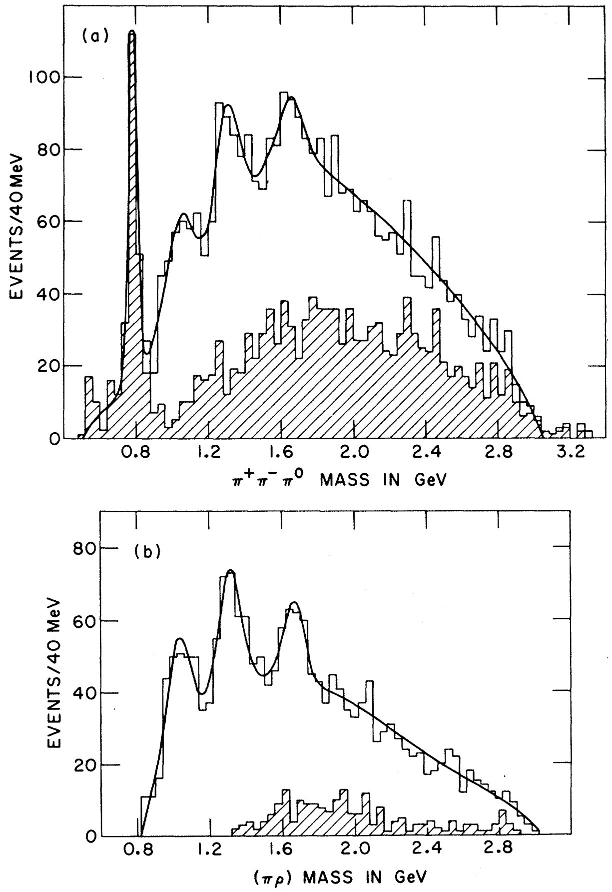

FIG. 1. (a) $\pi^+\pi^-\pi^0$ mass spectrum with $N^{*+}(1236)$ removed. The shaded area corresponds to the further removal of $\pi\rho$ events. (b) $(\pi\rho)^0$ mass spectrum with N^{*+} removed. The $\pi^0 f^0$ mass spectrum is shown shaded.

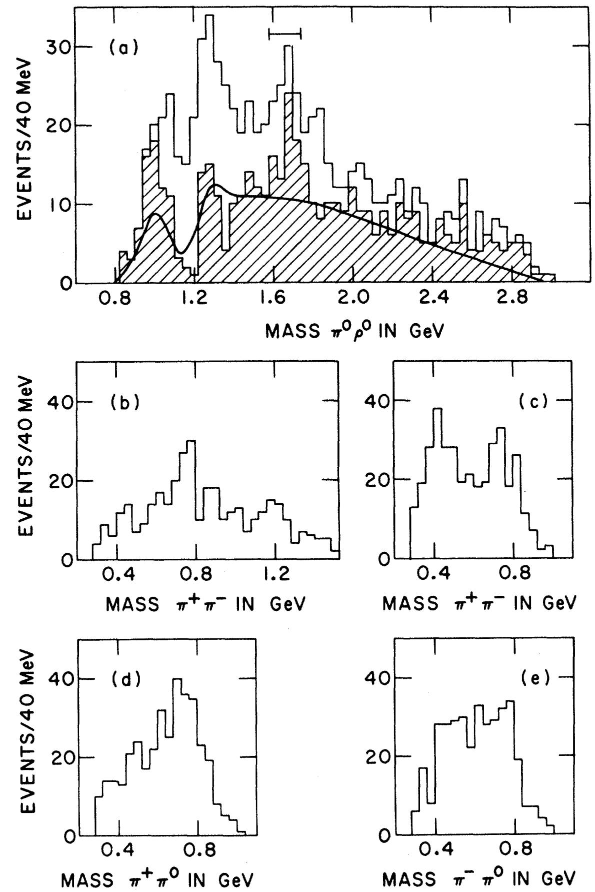

FIG. 2. (a) The $\pi^0\rho^0$ mass spectrum with $N^{*+}(1236)$ removed. Shown shaded is the $\pi^0\rho^0$ mass spectrum with ρ^- and ρ^+ also removed. The solid curve shows the expected distribution for the background. (b) $\pi^+\pi^-$ mass distribution for the $\varphi(1670)$ region, 1.580-1.740 GeV. (c), (d), (e) Respectively, the $\pi^+\pi^-$, $\pi^+\pi^0$, and $\pi^-\pi^0$ mass spectra for the A_1 region 0.940-1.2 GeV.

sumed to appear equally in all charge states. The χ^2 of a fit, with six degrees of freedom, of this background and different fractions of 0^-, $1^\pm$, and $2^\mp$ states to the sum of the mass spectra in the three ρ bands is shown in Fig. 3. Figure 1(b) shows that the fraction of resonance in the $\varphi(1670)$ region is about 0.3. From Fig. 3 it may be seen that with this fraction of resonance 0^- is least likely (fit probability 0.001%) and 1^+ and 2^- are most favored (fit probability 50%). 0^- is also made unlikely by the fact that the angular distribution of the normal to the 3π plane shows an increase in the amount of Y_2^0 moment in the $\varphi(1670)$ region with no indication in the odd moments. From this we conclude that the $\varphi(1670)$ has spin 1 or greater.

We have searched for other decay modes of the $\varphi(1670)$ by both removing ρ^{+-0} events [Fig. 1(a)] and selecting f events [Fig. 1(b)]; for both selections no enhancement in the $\varphi(1670)$ region is observed, indicating that its dominant 3π decay mode is $\pi\rho$. This observation, independently of the isospin assignment, shows that the $\varphi(1670)$ is different from the $A_3^\pm$ in that the latter enhancement has a strong πf and a weak $\pi\rho$ decay mode.[6] No significant enhancements in the $\varphi(1670)$ region are observed in the 5π or $\omega\pi\pi$ mass distribution from $\pi^+d \rightarrow pp\pi^+\pi^+\pi^-\pi^-\pi^0$. The branching ratio for 5π to 3π decays is estimated to be 10 $\pm$ 10%.

In addition we are able to rule out isovector exchange as the production mechanism for the A_3^+ since the observed cross section for this state in the reaction $\pi^+n \rightarrow n\pi^+\pi^+\pi^-$ would result in an A_3^0 production cross section of about 80 μb in our experiment. The predominance of small momentum transfers between the incident pion and the A_3^+ strongly suggests that the A_3^+ is diffractively produced.

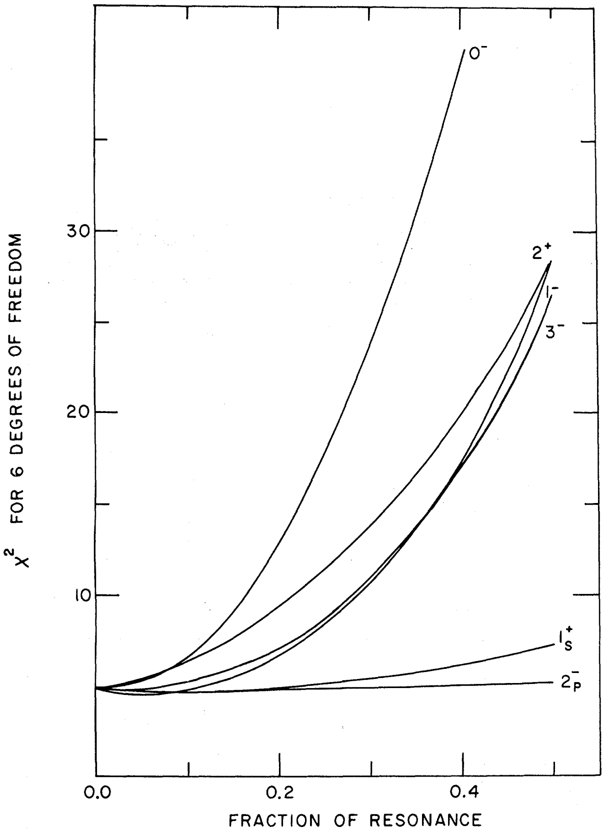

FIG. 3. χ^2 for six degrees of freedom from a fit of the ρ-band mass distribution for the $\varphi(1670)$ as a function of the fraction of resonance for the spins and parities shown.

We consider next the enhancement in the A_1 region. Two points may be noted: (a) The enhancement is present before ρ selection and (b) there is negligible production of φ or χ^0 in this experiment. Hence, we conclude that while the A_1 enhancement is associated with ρ production, it is not merely a kinematic effect due to ρ selection nor is it due to φ or misfitted χ^0 decays.

Earlier analyses[7] have shown that the $(\pi\rho)^+$ enhancement in the A_1 region in both coherent and incoherent πd interactions is well described by a Deck effect; it is therefore appropriate to consider this model in the present case. A simple charge-exchange Deck mechanism with π^+ and π^0 exchange[8] would suggest that the $\pi^+\pi^0$ and $\pi^+\pi^-$ mass spectra in the A_1 region would be identical. As may be seen from Fig. 2, this is not the case; more ρ^+ than ρ^0 is present (the probability that the mass spectra originate from the same distribution is 1.5%). The cross section for $\pi\rho$ production in the A_1 region is also in disagreement with the model. If it is assumed that the relative cross sections of the charge-exchange and non-charge-exchange Deck effects are in the ratio of the charge-exchange to elastic π-p scattering, the cross section for $(\pi\rho)^0$ production is predicted[9] to be about one tenth of that for $(\pi\rho)^+$ production in the same mass range. Experimentally, the cross section for $(\pi\rho)^0$ is about twice that predicted by this model.

The above discussion shows that the charge-exchange Deck model is not adequate to explain completely the A_1^0 region at 8 GeV/c.[10]

From the proportion of charged and neutral ρ's, no particular isospin state appears to dominate this enhancement; in this connection we examine the possibility of A_1^0 production by ρ exchange in this channel. If it is assumed that the A_1^0 enhancement discussed here is produced by isovector exchange, a background of $\leq 15\%$ of nondiffractively produced $\pi^+\rho^0$ is predicted to be present in the predominantly diffractive A_1^+ region in π-nucleon interactions. A nondiffractive background of this magnitude is not in disagreement with our previous analysis,[7] and consequently it is interesting to speculate that the A_1^0 enhancement is due to the interference of approximately equal amounts of an isospin-1 object, which may or may not have the same characteristics as the diffractively produced A_1^+ region, and an isoscalar background. The possibility that this background is a resonant state[11] cannot be ruled out.

In conclusion, we have confirmed the existence of an isoscalar $\pi\rho$ resonance of mass 1.670 ± 0.02 GeV, width 0.10 ± 0.04 GeV, negative G parity, and spin 1 or greater; we have also shown that the enhancement in the A_1 region is inconsistent with being due only to a charge-exchange Deck effect.

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[1]N. Armenise, B. Ghidini, V. Picciarelli, A. Romano,

A. Forino, R. Gessaroli, L. Lendinara, G. Quareni, A. Quareni-Vignudelli, A. Cortacci, M. G. Dagliana, G. DiCaporiacco, G. Parrini, M. Barrier, J. Laberrigue-Frolow, and J. Quinquard, Phys. Letters 26B, 336 (1968).

[2]R. T. Deck, Phys. Rev. Letters 13, 169 (1964). The references to the A_1 region in the present paper refer to an enhancement in the mass region 1.0-1.2 GeV irrespective of width.

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

[4]Events were measured on the Brookhaven National Laboratory flying-spot digitizer and Oak Ridge National Laboratory and Pennsylvania conventional measuring machines. The events had at least one uniquely identified proton and fitted the channel of interest with a fit probability greater than 10%. The resolution in the $\pi^+\pi^-\pi^0$ mass varied from ±15 MeV in the ω region to ±25 MeV in the $\varphi(1670)$ region.

[5]The smooth curve on Fig. 2(a) results from the distribution obtained when ρ^0 is selected and the $\rho^+\rho^-$ removed from the smooth background distribution used in the fit of Fig. 1(b). It was assumed that the Dalitz-plot distribution for the background was uniform. The curve drawn is approximately normalized each side of the $\varphi(1670)$; a normalization factor of 1.1 is needed showing that the assumption of a uniform background is reasonably accurate.

[6]C. Case et al., Nuovo Cimento 54A, 983 (1968); C. Baltay et al., Phys. Rev. Letters 20, 887 (1968); J. Bartsch et al., Nucl. Phys. B7, 345 (1968). Charged A_3 production in the reaction $\pi^+N \to A_3^+N$ similarly exhibits in this experiment a dominant π^+f^0 decay mode.

[7]A. M. Cnops et al., Phys. Rev. Letters 21, 1609 (1968), and to be published.

[8]If ρ exchange were allowed, ρ^- formation could occur and the $\pi^+\pi^-$ and $\pi^+\pi^0$ mass systems need not be identical, but the model would still be unsatisfactory since the additional diagrams would imply more ρ^0 than ρ^+ production if they are assumed to have similar phases.

[9]The calculation and experimental test were made excluding π-nucleon masses less than 1.7 GeV and the shape of the 3π distributions were assumed to be the same. This results in an over estimate of the charge-exchange Deck cross section in the A_1 region since the charge-exchange peak will be broadened due to the reduced slope of the differential cross section in charge-exchange scattering compared with elastic scattering.

[10]A further argument against a Deck-effect interpretation is that the A_1^0 region cross section has fallen by a factor 2 in going from 5.1- to 8-GeV/c incident energy. A charge-exchange Deck calculation would suggest a slower fall since the cross section depends on the allowed πN phase space.

[11]H. Harari, in Proceedings of the Fourteenth International Conference on High Energy Physics, Vienna, Austria, September, 1968 (CERN Scientific Information Service, Geneva, Switzerland, 1968). This mixture of isospin states is chosen to enhance ρ^+ and reduce the ρ^- relative to ρ^0 in the A_1 region.

HIGH-ENERGY MUON-PROTON SCATTERING: ONE-PHOTON EXCHANGE TESTS*

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Muon-proton elastic scattering has been studied in the range $0.15 < q^2 < 0.85$ (GeV/c)^2 with μ^+ and μ^- beams of 6 and 11 GeV/c and a μ^- beam of 17 GeV/c. Cross sections have been determined with uncertainties as small as 2%. Rosenbluth straight-line plots and comparisons of the μ^+ and μ^- cross sections show no deviation from the one-photon exchange approximation.

Electron-proton elastic-scattering experiments are consistent with a one-photon–exchange approximation to the electromagnetic interaction between the two particles.[1] The present experiment used muons to study this interaction with the objectives of extending the previous tests to the very high energies available at the alternating-gradient synchrotron (AGS) and of searching for deviations from the theory due to a possible μ-e universality breakdown. A detailed discussion of the μ-e comparison is presented in the next Letter.