STUDY OF THE $\pi\rho$ SYSTEM IN THE REACTION $\pi^- + p \to \pi^- + \rho^0 + p$ AT 8 GeV/c†

N. M. Cason, J. W. Lamsa, N. N. Biswas, I. Derado,* T. H. Groves, V. P. Kenney, J. A. Poirier, and W. D. Shephard
Department of Physics, University of Notre Dame, Notre Dame, Indiana
(Received 24 March 1967)

In the reaction $\pi^- + p \to \pi^- + \rho^0 + p$ at 8 GeV/c, we find that the A_1 can be explained as a kinematic effect due to a Deck-type mechanism, but only if both π and ρ exchanges are included. We also present evidence for a possible $\pi^-\rho^0$ resonance at 1190 MeV with a width of 17 MeV.

The A_1 meson has continued to be a puzzle despite the fact that Shen et al.[1] showed clearly that the Deck effect[2] is important in the A_1 region. The problem is that the A_1 peak produced at higher incident momenta has not been reproduced by the Deck calculations.[3] The calculations yield curves which are too broad, thus leaving an excess of events in the A_1 region which can then be interpreted as a resonance sitting on top of a broad Deck-type background. The present work demonstrates that this excess of events can be explained by a Deck-type mechanism including π and ρ exchange, and that no A_1 resonance is needed.

Measurements of 9900 selected four-prong events, produced in the Brookhaven National Laboratory 80-inch hydrogen bubble chamber at a beam momentum of 8 GeV/c, led to 1832 events which were consistent with the reaction

$$\pi^- + p \to \pi^- + \pi^- + \pi^+ + p \tag{1}$$

on the basis of kinematic fitting and ionization.[4] The events were further required to have the square of their missing mass between −0.02 and +0.02 GeV².

The general features of Reaction (1) are quite similar to those observed[5] at 6 and 7 GeV/c. Both $N^{*++}(1236)$ and ρ^0 production are prominent, and ρ^0 production is very peripheral. In order to select events corresponding to the reaction

$$\pi^- + p \to \pi^- + \rho^0 + p, \tag{2}$$

the following cuts were introduced: (a) $|t_{pp}| < 0.5$ (GeV/c)², (b) $M(\pi^+p)$ outside the interval 1.140 to 1.349 GeV, and (c) $0.660 < M(\pi^-\pi^+) < 0.860$ GeV, where t_{pp} is the square of the four-momentum transfer from the target proton to the final proton, $M(\pi^+p)$ is the π^+p invariant mass, and $M(\pi^-\pi^+)$ is the invariant mass of the π^+ and either π^-.[6]

Figure 1(a) shows the $\pi^-\rho^0$ effective-mass distribution for these events. There is a broad shoulder in the A_1 region, a rather sharp peak at 1190 MeV, hereafter called the $A_{1.5}$, and a peak corresponding to the A_2 meson. In the following analysis, we have fitted the data with background curves using Deck-type models in order to distinguish between kinematic peaks and resonances.

The procedure used in searching for the correct background curve involved the following Monte Carlo technique. We first attempted to fit the background with a Deck effect based on π exchange followed by πp elastic scatter-

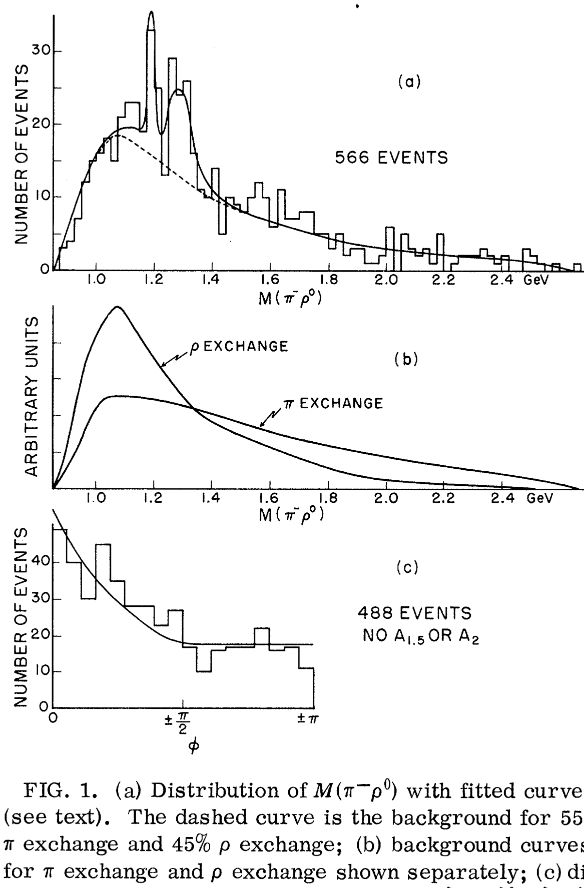

FIG. 1. (a) Distribution of $M(\pi^-\rho^0)$ with fitted curve (see text). The dashed curve is the background for 55% π exchange and 45% ρ exchange; (b) background curves for π exchange and ρ exchange shown separately; (c) distribution of the Treiman-Yang angle $\varphi = (\vec{\pi}_{in}\times\vec{p}^0)\cdot(\vec{p}\times\vec{\pi}^-)/|\vec{\pi}_{in}\times\vec{p}^0||\vec{p}\times\vec{\pi}^-|$ with the curve for 55% π exchange and 45% ρ exchange.

ing. The Monte Carlo events were required to reproduce the experimental $\pi^- p$ effective mass distribution and the distribution of the four-momentum transfer from the incident track to the ρ meson.[7] If one then specifies the angle between the incoming proton and the outgoing proton, the effective mass of the $\pi^-\rho^0$ system is fixed. We required that this angular distribution correspond to that for real $\pi^- p$ elastic scattering[8] which is a function of the $\pi^- p$ effective mass. The resulting distribution is insufficiently peaked in the low $\pi^-\rho^0$-mass region to explain the data.

We have, in a similar way, computed a background curve based on ρ^0 exchange followed by $\rho^0 p$ elastic scattering. This calculation uses as input the $\rho^0 p$ effective-mass distribution and the distribution of $t_{\pi^-\pi^-}$, the four-momentum transfer from the incident π^- to the final π^-. For the $\rho^0 p$ elastic-scattering angular distributions we have put in an exponential t_{pp} dependence, which can be justified by the fact that almost all the events have a high $\rho^0 p$ invariant mass.[9] The resulting curve is more peaked than the π^- exchange curve and is, in fact, too peaked to fit the data.

In order to see if some combination of π exchange and ρ exchange is justified, we have examined the Treiman-Yang angular distribution shown in Fig. 1(c). This is the angle in the laboratory system between the normal to the plane including the incident pion and the ρ^0, and the normal to the $\pi^- p$ plane. This distribution should be isotropic for π exchange if absorption effects are ignored; it is clearly anisotropic. Our Monte Carlo events for ρ^0 exchange are similarly nonisotropic. Another indication that ρ^0 exchange is present is that the scattergram of $t_{\pi^-\rho^0}$, the momentum transfer from the incident π^- to the ρ^0, vs $t_{\pi^-\pi^-}$ shows two bands corresponding to low $t_{\pi^-\rho^0}$ and low $t_{\pi^-\pi^-}$. If one assumes π exchange for events with $t_{\pi^-\rho^0} < t_{\pi^-\pi^-}$ and ρ^0 exchange for events with $t_{\pi^-\pi^-} < t_{\pi^-\rho^0}$, the ratio of 55% π exchange to 45% ρ exchange is obtained.

For the analysis to follow the events were so divided and the Monte Carlo techniques described above were separately applied: π exchange to the events with lower $t_{\pi^-\rho^0}$ and ρ exchange to the events with lower $t_{\pi^-\pi^-}$. The smooth curve in Fig. 1(c) is based on this model and agrees well with the angular distribution observed.

The maximum-likelihood fit to the $\pi^-\rho^0$ mass distribution, assuming three Breit-Wigner resonances combined with the background curve corresponding to 55% π exchange and 45% ρ exchange, is shown as the solid curve in Fig. 1(a). The dashed curve shows the background contribution; the π exchange and ρ exchange distributions are shown separately in Fig. 1(b). The intensities, masses, and widths of the three resonances were varied simultaneously. The values obtained are shown in Table I. The χ^2 value of the fit is 25.5 for 27 mass intervals.[10] We conclude that no A_1 resonance is required to fit the data when both π and ρ exchanges are included.

Our Monte Carlo analysis is, of course, not a theory, and such a model cannot be considered complete until one can reproduce the data by a theoretical calculation with no experimental data as input. The results are in such good agreement with the data, however, that we feel the substance of the model may very well explain the A_1 effect in Reaction (1).

Finally, we wish to comment on the peak in the $\pi\rho$ spectrum at 1190 MeV. A peak at this mass is all the more significant since one expects a valley between the A_1 effect and the A_2. The fit to the $\pi\rho$ mass distribution summarized in Table I shows this peak as a three-standard-deviation effect. This suggests the existence of a resonance

Further evidence on this point is given in Fig. 2 which shows the distributions in the Jackson angle, the angle between the incident π^- and the outgoing π^- in the $\pi^-\rho^0$ center of mass, for various regions of the $\pi^-\rho^0$ effective mass. The smooth curves are maximum-likelihood fits of the form $A + B\cos\theta + C\cos^2\theta$. It seems clear that the distribution becomes more peaked fore and aft in the region 1150 to 1225 MeV. This lends credence to the hypothesis that $A_{1.5}$ mass peak is not a statistical fluctuation. The

Table I. Parameters of the maximum-likelihood fit to the $\pi\rho$ mass distribution.

	Mass (MeV)	Width[a] (MeV)	Percentage of events in resonance
A_1	⋯	⋯	0.07 ± 0.05
$A_{1.5}$	1190 ± 4	17^{+12}_{-6}	4.1 ± 1.4
A_2	1288 ± 14	84^{+30}_{-20}	11.6 ± 3.2

[a]No correction has been made for our experimental resolution which is about 8 MeV in the A region.

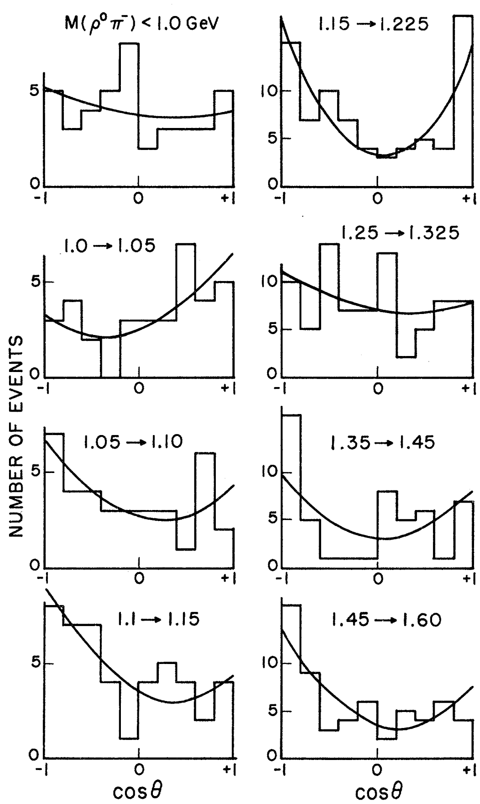

FIG. 2. Distributions in the angle between the incident π^- and the outgoing π^- in the $\pi^-\rho^0$ center of mass, for various $M(\pi\rho)$ intervals. The intervals are chosen to center on the $A_{1.2}$ and the A_2 regions. The curves are maximum-likelihood fits of the form $A+B\cos\theta +C\cos^2\theta$.

mass and width of this peak, interpreted as a resonance, along with those of the A_2 are shown in Table I. The $\pi^-\rho^0$ decay mode indicates a state of negative g parity and isospin of one or two.

We wish to thank Brookhaven National Laboratory and its staff members for their cooperation and assistance in performing the experiment. We are grateful for the assistance of Mr. John B. Annable and Mr. Robert J. Schlentz. The cooperation of the Notre Dame Computing Center is appreciated. Finally, we would like to thank our scanning staff for their excellent work.

†Research supported in part by the National Science Foundation.

*On leave at Stanford Linear Accelerator Center, Stanford, California.

[1]B. C. Shen, G. Goldhaber, S. Goldhaber, and J. A. Kadyk, Phys. Rev. Letters 15, 731 (1965).

[2]R. T. Deck, Phys. Rev. Letters 13, 169 (1964); U. Maor and T. A. O'Halloran, Jr., Phys. Letters 15, 281 (1965).

[3]Aachen-Berlin-CERN Collaboration, M. Deutschmann, R. Steinberg, H. Weber, W. Woischnig, C. Grote, J. Klugow, K. Lanius, R. Leiste, S. Nowak, A. Białas, V. T. Cocconi, O. Czyzewski, P. F. Dalpiaz, E. Flaminio, J. D. Hansen, H. Hromadnik, G. Kellner, and D. R. O. Morrison, Phys. Letters 22, 112 (1966); Orsay-Milan-Saclay-Berkeley Collaboration, J. F. Allard, D. Drijard, J. Hennessy, R. Huson, A. Lloret, J. Six, J. J. Veillet, G. Bellini, M. di Corato, E. Fiorini, P. Negri, M. Rollier, J. Crussard, J. Ginestet, A. Tran, H. H. Bingham, C. Farwell, W. B. Fretter, H. J. Lubatti, and K. Moriyasu, Nuovo Cimento 46A, 737 (1966).

[4]Only those four-prong events with at least one positive track with ionization greater than minimum were measured. This selection is equivalent to a momentum-transfer cut at about 1.2 $(\mathrm{GeV}/c)^2$. Since we make a momentum-transfer cut at 0.5 $(\mathrm{GeV}/c)^2$, no bias is introduced by the ionization criteria.

[5]V. E. Barnes, W. B. Fowler, K. W. Lai, S. Orenstein, D. Radojičić, M. S. Webster, A. H. Bachman, P. Baumel, and R. M. Lea, Phys. Rev. Letters 16, 41 (1966); N. M. Cason, Phys. Rev. 148, 1282 (1966).

[6]If both $\pi^-\pi^+$ combinations satisfy the third criterion, then the pair closest to 760 MeV is chosen to be the ρ^0 when such a choice is required.

[7]These distributions had the $A_{1.5}$ and A_2 removed.

[8]P. M. Ogden, D. E. Hagge, J. A. Helland, M. Banner, J. F. Detoeuf, and J. Teiger, Phys. Rev. 137, B1115 (1965); J. A. Helland, C. D. Wood, T. J. Devlin, D. E. Hagge, M. J. Longo, B. J. Moyer, and V. Perez-Mendez, Phys. Rev. 134, B1079 (1964); V. Cook, B. Cork, W. R. Holley, and M. L. Perl, Phys. Rev. 130, 762 (1963); M. L. Perl, L. W. Jones, and C. C. Ting, Phys. Rev. 132, 1252 (1963).

[9]80 % of the events had $M(p\rho^0)$ greater than 2.6 GeV. The angular distribution used was assumed to be identical to that for π^-p elastic scattering at high energies, namely $\exp(9.6t+3.3t^2)$ (see Perl et al., Ref. 8). This seems justified since the angular distributions for πp, Kp, and pp elastic scattering are very similar at these energies as noted in N. N. Biswas, N. M. Cason, I. Derado, V. P. Kenney, J. A. Poirier, and W. D. Shephard, Phys. Rev. Letters 18, 273 (1967).

[10]It is important to point out that our use of the Monte Carlo technique has not guaranteed that our $\rho^0\pi^-$ spectrum will be reproduced. One might assume that no freedom is left when so much experimental information is input to the calculation. However, neither pure π nor pure ρ exchange alone fits the data, whereas if all freedom has been removed, both would fit the data.