Study of Pion Exchange in the Reaction $\pi p \to \rho N$ at 6 GeV/c*

J. Michael Scarr and Kwan-Wu Lai
Brookhaven National Laboratory, Upton, New York 11973
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We have observed a dip at $-t \simeq 0.5$ GeV^2 in $(\rho_{00}{}^H d\sigma/dt)(\pi p \to \rho N)$ for ρ^-, ρ^0, and ρ^+ at 6 GeV/c. The dominant contribution to $(\rho_{00}{}^H d\sigma/dt)(\pi p \to \rho N)$ is from π exchange.

In the study of $\pi^- p \to \rho^- p$, $\pi^- p \to \rho^0 n$, and $\pi^+ p \to \rho^+ p$ at 6 GeV/c, we have observed that

$$\tfrac{1}{2}\rho_{00}{}^H \frac{d\sigma}{dt}(\rho^0) \simeq \rho_{00}{}^H \frac{d\sigma}{dt}(\rho^-) \simeq \rho_{00}{}^H \frac{d\sigma}{dt}(\rho^+)$$

for $|t| < 1.4$ GeV^2 in the s-channel helicity frame. This indicates that $I = 1$ exchange gives the dominant contributions to $\rho_{00}{}^H$. Furthermore, a break is observed in the $(\rho_{00}{}^H d\sigma/dt)(\rho)$ for all three reactions at $-t \simeq 0.5$ GeV^2. This observation is consistent with the dual absorption model[1] where a zero is predicted at $-t \simeq 0.5$ GeV^2 for the imaginary part of the amplitude which behaves like $J_1(r\sqrt{-t})$ with an interaction radius $r \simeq 1$ F. This break cannot be explained by the nonsense wrong-signature (NSWS) zero of the pion trajectory in the context of the Regge-pole model.[2]

The data used for this analysis come from 6-GeV/c π^- and π^+ exposures of the Brookhaven National Laboratory (BNL) 80-in. hydrogen bubble chamber. Both exposures were measured on the BNL flying-spot digitizer and the data were treated identically. There are 3097 events in the $\pi^-\pi^0 p$ final state, 4998 events in the $\pi^-\pi^+ n$ final state, and 2060 events in the $\pi^+\pi^0 p$ final state. The details of the analysis have been described earlier.[3]

Figures 1(a) to 1(c) show the differential cross sections and Figs. 1(d) to 1(f) show the density-matrix elements $\rho_{00}{}^H$ for ρ^-, ρ^0, and ρ^+, respectively.[4] These density-matrix elements receive

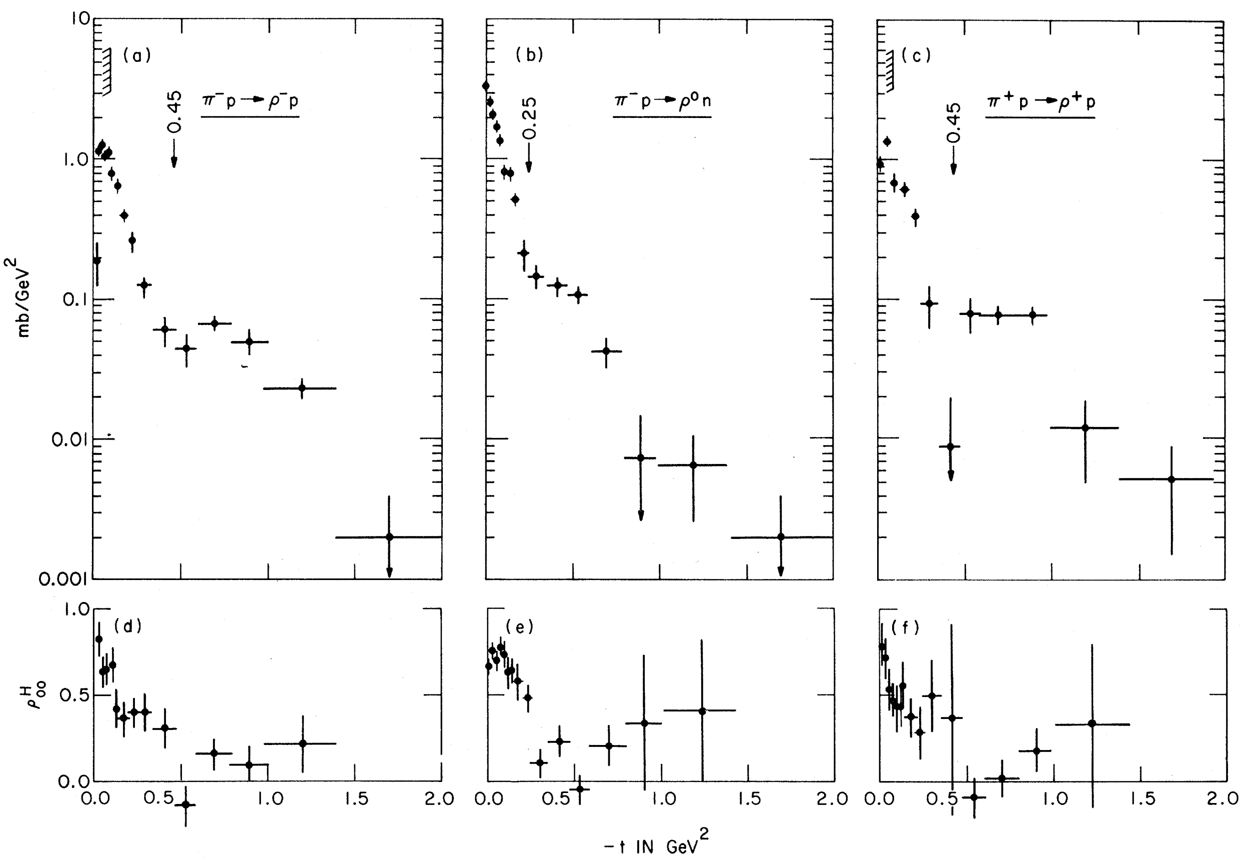

FIG. 1. (a)–(c) Differential cross sections as shown; cross-hatched area indicates $|t| < 0.1$ GeV^2, where there is a loss of $\rho^\pm$ events (see Ref. 3). (d)–(f) Density-matrix elements in the s-channel frame versus t.

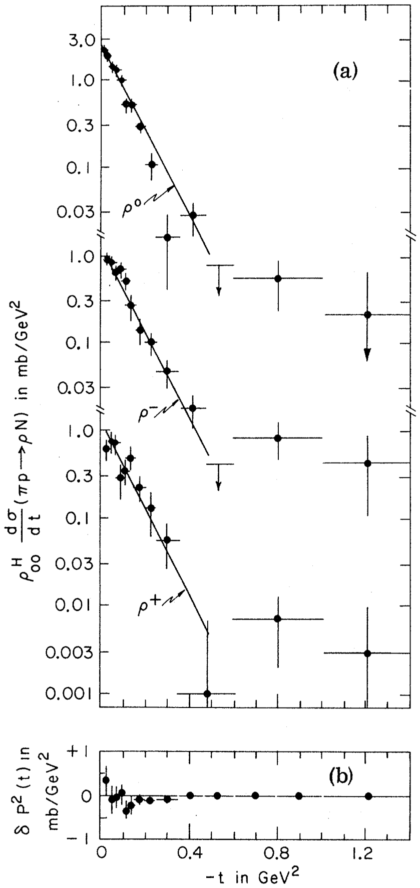

FIG. 2. (a) The product of $(\rho_{00}{}^H d\sigma/dt)(\pi p \to \rho N)$ for ρ^0, ρ^-, and ρ^+. (b) The size of the $I=0$ contribution, $\delta P^2(t)$, to $(\rho_{00}{}^H d\sigma/dt)(\pi p \to \rho N)$, where $\delta P^2(t) = (\rho_{00}{}^H d\sigma/dt)(\pi^- p \to \rho^0 n) - (\rho_{00}{}^H d\sigma/dt)(\pi^- p \to \rho^- p) - (\rho_{00}{}^H d\sigma/dt)(\pi^+ p \to \rho^+ p)$. See text for details.

contributions only from the unnatural parity exchanges, namely, π and possibly A_1. For the subsequent analysis, we assume that only the contribution from pion exchange is dominant.[5] Figure 2(a) shows the product $(\rho_{00}{}^H d\sigma/dt)(\rho)$ for all three charges of ρ's. Two features should be noted here.

(1) All three distributions of $\rho_{00}{}^H d\sigma/dt$ are similar in shape out to $-t \approx 1.4$ GeV^2 despite the fact that the behaviors of $d\sigma/dt$ and $\rho_{00}{}^H$ for $\rho^\pm$ are very different from those of ρ^0. The solid lines in Fig. 2(a) are drawn with the same slope but with the normalization of 2:1:1 for ρ^0:ρ^-:ρ^+, and represent the data well. The size of the $I=0$ exchange contribution to $(\rho_{00}{}^H d\sigma/dt)(\rho)$ can be seen by examining the expression $\delta P^2(t) = (\rho_{00}{}^H d\sigma/dt)(\rho^0) - (\rho_{00}{}^H d\sigma/dt)(\rho^-) - (\rho_{00}{}^H d\sigma/dt)(\rho^+)$. We observe that $\delta P^2(t) \approx 0$ as shown in Fig. 2(b). This observation indicates that $(\rho_{00}{}^H d\sigma/dt)(\rho)$ extracts the

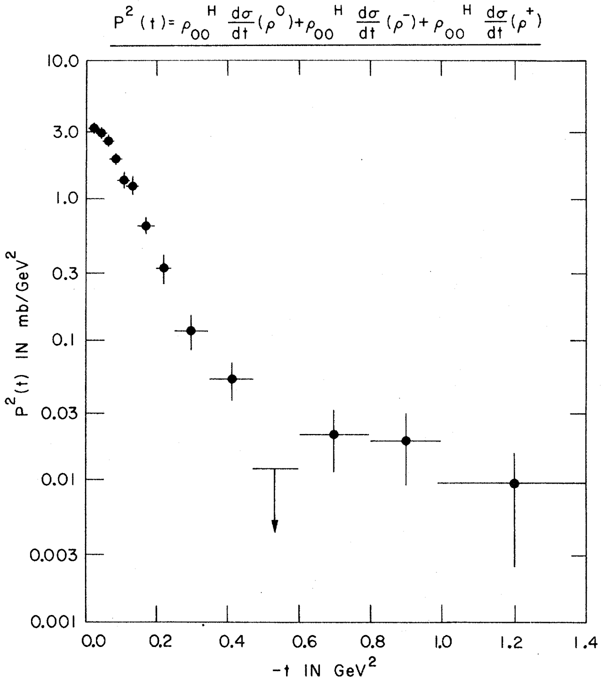

FIG. 3. Combined $(\rho_{00}{}^H d\sigma/dt)(\pi p \to \rho N)$ as shown.

isospin-1 exchange in the t channel even though there are large contributions of $I=0$ exchange in ρ^+ and ρ^- production. In other words, there is little, if any, $I=0$ contribution from unnatural-parity exchange to $(\rho_{00}{}^H d\sigma/dt)(\rho)$.

(2) A break in $(\rho_{00}{}^H d\sigma/dt)(\rho)$ at $-t \simeq 0.5$ GeV^2 exists in *all* three charges of ρ production.

To enhance the statistical significance of the break at $-t \simeq 0.5$ GeV^2 for all three charges of ρ, we combine the products of $(\rho_{00}{}^H d\sigma/dt)(\rho)$ for all three charges of ρ forming $P^2(t)$ as shown in Fig. 3. The break is evident. To the extent that $P^2(t)$ represents the contribution of pion exchange, charge-conjugation invariance requires only spin-nonflip contributions at the $N\bar{N}$ vertex in the t channel.[6] Under $s \leftrightarrow t$ crossing,[7] this gives rise to the complete dominance of spin-flip ($n=1$) contributions in the s channel at the $N\bar{N}$ vertex for $|t| > \mu^2$ at this energy. Therefore, $(\rho_{00}{}^H d\sigma/dt)(\rho)$ is the square of a single s-channel helicity amplitude, with total helicity flip, n, of 1 unit.

For the dual absorption model, the imaginary part of the amplitude with a single unit of helicity flip should behave as $J_1(r\sqrt{-t})$ with the second zero occurring at $-t \simeq 0.5$ GeV^2 for an interaction radius $r \simeq 1$ F. A dip in $(\rho_{00}{}^H d\sigma/dt)(\rho)$ is observed in this position for the unnatural parity exchange, which also indicates that the real part of the amplitude cannot be large at $-t \sim 0.5$ GeV^2. Since the dip does not occur at the expected position of the NSWS zero of the pion trajectory, the dual absorption model does not predict the behavior of the real part of the amplitude.[8] It is, however, reasonable to expect a large contribution to the real part from the pion pole in the small-t region. Thus, the $J_1(r\sqrt{-t})$ behavior is not observed at the small-t region ($|t| \lesssim 0.2$ GeV^2).[9]

To summarize, the break observed in this experiment for the pion exchange[10] is difficult to explain by the usual Regge-pole model, since the NSWS zero for the pion is expected at $-t \simeq 1$ GeV^2, unlike the ρ exchange in $\pi^- p \to \pi^0 n$ and ω exchange in $\pi p \to \rho N$ where the NSWS zeros occur where $J_1(r\sqrt{-t})$ also expects a zero. Our result suggests that the dual absorption model may be extended to the unnatural parity exchange.[11]

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[1]H. Harari, Phys. Rev. Lett. 26, 1400 (1971).

[2]For a critical review of the experimental and theoretical situation see for example, G. C. Fox, *Phenomenology in Particle Physics* (California Institute of Technology, Pasadena, Calif., 1971), p. 703. For a recent experimental result at 2.67 GeV/c, see W. Michael and G. Gidal, Phys. Rev. Lett. 28, 1475 (1970).

[3]See, for example, D. J. Crennell *et al.*, Phys. Rev. Lett. 27, 1674 (1971); D. J. Crennell *et al.*, Phys. Rev. Lett. 18, 323 (1967).

[4]To determine the differential cross sections, fits were made to the $\pi\pi$ mass spectra in each t interval using a fixed mass and width obtained from the total sample. No correction has been made to ρ_{00}^H for S-wave effects. Assuming the S wave present is $\leq 20\%$ in intensity, the corrections to ρ_{00}^H are ~ 0.05 which is less than the statistical errors of ρ_{00}^H. In calculating the density-matrix elements, the 3% contamination of ρ^+ events by Δ^{++} events has been corrected for by subtracting conjugate Δ^{++} events in the Dalitz plot.

[5]The assumption of the dominance of π exchange is consistent with our experimental observation that the value of Reρ_{10}^H obtained in this experiment (to be published) reaches the maximum allowed value of $[\frac{1}{2}\rho_{00}(\rho_{11} - \rho_{1-1})]^{1/2}$. This limit is given, for example, by J. Daboul, Nucl. Phys. B4, 180 (1967). Any significant A_1 exchange contribution would be expected to destroy this relationship since both the amplitude phase and spin-flip characteristics differ from those for π exchange.

[6]See, for example, G. A. Ringland and R. L. Thews, Phys. Rev. 170, 1569 (1968).

[7]T. L. Trueman and G. C. Wick, Ann. Phys. (New York) 26, 322 (1964).

[8]See Ref. 1. This indicates that absorptive effects in the $n=1$ amplitude for pion exchange are important. This differs from vector and tensor exchanges where little or no absorption is required for helicity-flip amplitudes.

[9]In addition, for the very forward region ($|t| < \mu^2$), $\rho_{00}^H d\sigma/dt$ is no longer pure helicity flip ($n=1$), but also contains contributions from nonflip $n=0$ amplitudes.

[10]For A_1 exchange, charge-conjugation invariance requires only spin-flip contributions at the $N\bar{N}$ vertex in the t channel. This requires the complete dominance of the helicity nonflip ($n=0$) contribution to $\rho_{00}^H d\sigma/dt$ for A_1 exchange. Appreciable A_1 exchange would, therefore, tend to destroy the observed dip structure at $-t \sim 0.5$ GeV^2.

[11]Even though this dip is suggested from the strong-cut model in this reaction, dips at $-t \sim 0.5$ GeV^2 are also predicted for other processes such as $(\rho_{00}^H d\sigma/dt)(\pi^- p \to \omega n)$. Because of the absence of any structure in $\pi^- p \to \omega n$ at $-t \simeq 0.5$ GeV^2, the strong-cut model certainly loses much of its attractiveness. For a detailed comparison among the known models, see Ref. 2.