Observation of a Dip Due to $I=0$ t-Channel Exchange in the Reaction $\pi N \to A_2 N$ at 4.5 and 6 GeV/c*

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In the reaction $\pi^- p \to A_2^- p$, we observe a dip in the differential cross section at $t \approx 1.2$ GeV^2. Analysis in terms of t-channel contributions from isospin-0 and -1, natural- and unnatural-parity exchanges suggest that the dip is mainly due to natural-parity, $I=0$ exchange.

The production of A_2 can be analyzed in terms of the isospins (I) and natural (N) parity and unnatural (U) parity t-channel exchanges. For $I=0$, P (Pomeron) (N), f^0 (N), and η (U) are allowed, whereas for $I=1$, ρ (N) and B (U) can be exchanged [Fig. 1(a) inset]. In this Letter, we present the data of 4.5 and 6 GeV/c $\pi^- p \to A_2^- p$ for

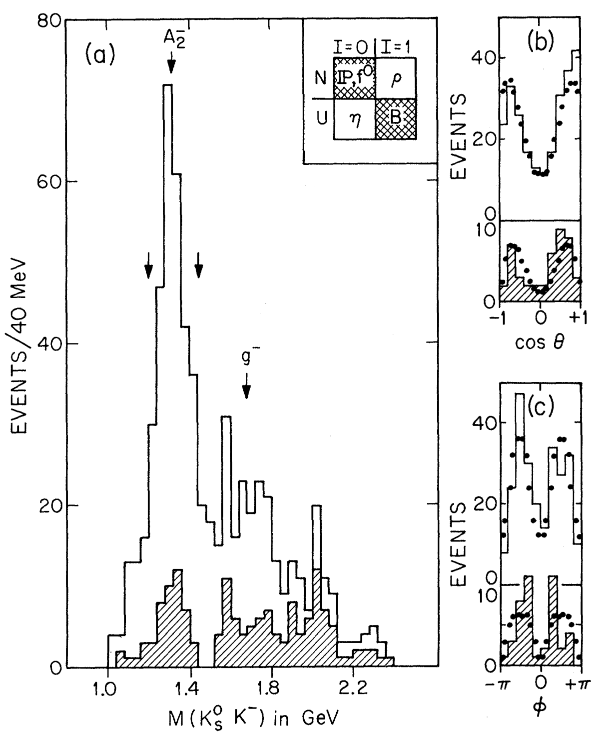

FIG. 1. (a) $K_s^0 K^-$ mass spectrum from the reaction $\pi^- p \to K_s^0 K^- p$ at 4.5 and 6 GeV/c with events in the $\Lambda(1520)$ removed. (b),(c) Decay distributions for the $A_2^- \to K_s^0 K^-$ in the Gottfried-Jackson frame. Shaded areas are for events in the high-t region. Solid points indicate best fit to the data.

$A_2^- \to K_s^0 K^-$. Our analysis from this reaction and other relevant reactions ($\pi^+ n \to A_2^0 p$ and $\pi^+ p \to A_2^+ p$) allows us to separate the contributions due to $I+0$ and $I=1$, and N- and U-parity exchanges in the t-channel. A dip is observed at $t \approx 1.2$ GeV^2 and can for example be interpreted as the nonsense wrong-signature zero (NSWSZ) of the f^0 trajectory in the context of the Regge-pole model. In addition to the f^0 contribution, the B exchange seems to dominate in the $I=1$ and U-parity contribution.

The data for this study come from a series of bubble-chamber exposures (this experiment) with details presented elsewhere[1] and other published[2] and unpublished experiments[3] (See Table I). Since normalizations are important for this analysis, we have calculated the cross sections in a consistent way for our experiment. The procedure is to (1) determine $A_2^\pm \to \rho^0 \pi^\pm$ production cross sections from the $\pi^+\pi^-\pi^\pm$ modes by using the University of Illinois partial-wave analysis program,[4] (2) obtain the total A_2 production cross sections by appropriate corrections from $\rho\pi$ to include all modes,[5] and (3) obtain the shapes of the differential cross sections and density-matrix elements from the $A_2^\pm \to K_s^0 K^\pm$ modes, where the normali-

TABLE I. A_2 data.

	p_{lab} (GeV/c)	Modes used	$\sigma(A_2 \to \text{all})$ (μb)
A_2^-	4.5	$K_s^0 K^-$	159 ± 25
	6	$\rho^0\pi^-$ $K_s^0 K^-$	$\cdots$
A_2^0	6 [a]	$\rho^\pm \pi^\mp$	90 ± 15
A_2^+	6	$\rho^0 \pi^+$	132 ± 23
	7.1 [b]	$K^0 K^+ \eta\pi^+$	$\cdots$

[a] Ref. 2. [b] Ref. 3.

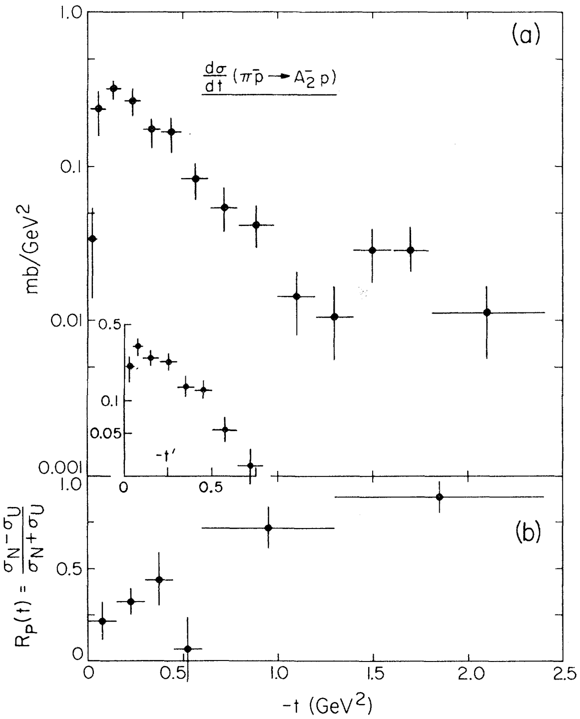

FIG. 2. (a) $d\sigma/dt$ for A_2^- production (corrected for all decay modes). Inset shows the same distribution in t'. (b) Ratios of contributions from σ_N and σ_U exchanges.

zations come from step (2). We use the $K_s^0K^\pm$ modes[6] because of small background in the $A_2^\pm$ region (<20%) as illustrated in Fig. 1(a) for the $K_s^0K^-$ mass spectrum with $\Lambda(1520) \to K^-p$ removed.[7] Since our study of the differential cross sections extends to the high-t region, to check the quality of the data, we present events with $|t| > 1.0$ GeV^2 in Fig. 1(a) in the shaded area. A clear A_2^- signal is seen. Decay angular distributions in $\cos\theta$ and Φ (Gottfried-Jackson frame) in the A_2^- rest frames are also shown in Figs. 1(b) and 1(c). Both t regions show slightly different angular distributions but both are characteristic of a resonance.

In Fig. 2(a) we show the differential cross section of $\pi^-p \to A_2^-p$ as obtained from the $A_2^- \to K_s^0K^-$ events at 4.5 and 6 GeV/c normalized to the cross section at 6 GeV/c as shown in Table I. A forward ($t \approx 0$) dip is observed. The distribution in $t' = t - t_{\min}$ is also shown in the inset of Fig. 2(a). This forward dip, which has been reported before,[8] is associated with the s-channel spin-flip contribution to the A_2 production, and thus we will not discuss it further. However, we see another dip at $|t| \approx 1.2$ GeV^2 followed by a second maximum centered at about 1.8 GeV^2. To understand this structure, we first examine the $J^P = 2^+$ spin density-matrix elements as a function of t. We use a maximum-likelihood fit to the $K_s^0K^-$ decay angles in the Gottfried-Jackson frame. To separate the N- and U-parity contributions, we use the definitions $\rho_N = (\rho_{11} + \rho_{1\,-1}) + (\rho_{22} - \rho_{2\,-2})$ and $\rho_U = \rho_{00} + (\rho_{11} - \rho_{1\,-1}) + (\rho_{22} + \rho_{2\,-2})$; thus $d\sigma_{N(U)}/dt = \rho_{N(U)}\, d\sigma/dt$. Figure 2(b) displays the ratio

$$R_P(t) = \left(\frac{d\sigma_N}{dt} - \frac{d\sigma_U}{dt}\right) \Big/ \left(\frac{d\sigma_N}{dt} + \frac{d\sigma_N}{dt}\right)$$

as a function of t. $R_P(t) = 1$ (-1) implies all N- (U-) parity contribution. It is evident that all values of $R_P(t)$ are greater than 0 for the whole t range, and approach 1 for the high-t region, indicating that the differential cross section for N-parity exchange is dominant over that for U-parity exchange, particularly at the high-t region ($|t| > 1.0$ GeV^2). Thus the structure in the differential cross section at the high-t region mainly comes from the N-parity exchange. Since there are two possible isospins $I = 0$ (P and f^0) and $I = 1$ (ρ) in the N-parity contribution, we now proceed to separate the isospin exchange in the t channel.

We consider the $I_t = 0$ (a_0) and $I_t = 1$ (a_1) t-channel amplitudes to describe the A_2 production:

$$f(\pi^\pm p \to A_2^\pm p) = \tfrac{1}{2}a_1 \mp (1/\sqrt{6})a_0, \quad (1)$$

$$f(\pi^+n \to A_2^0 p) = (1/\sqrt{2})a_1, \quad (2)$$

and

$$\sigma_{I_t=1} = \int |a_\perp|^2\, dt = 2\sigma(\pi^+n \to A_2^0p),$$

$$\sigma_{I_t=0} = \int |a_0|^2\, dt = 3[\sigma(\pi^-p \to A_2^-p) + \sigma(\pi^+p \to A_2^+p) - \sigma(\pi^+n \to A_2^0p)],$$

and the isospin interference term ($I_t = 0, 1$)

$$2\int \mathrm{Re}(a_1{}^* a_0)\, dt = \sqrt{6}\,[\sigma(\pi^-p \to A_2^-p) - \sigma(\pi^+p \to A_2^+p)].$$

We evaluate the above expressions at 6 GeV/c using (1) A_2^- data as described before, (2) A_2^0 data from Ref. 2, and (3) A_2^+ data obtained from the normalization from Table I and the shape of the differential cross section from Ref. 3 with the use of the $K_s^0K^+$ and $\eta\pi^+$ modes. Figure 3(a) shows $d\sigma(\pi N\to A_2N)_{I_t=0}/dt$ and Fig. 3(b) shows $d\sigma(\pi N\to A_2N)_{I_t=1}/dt$ (all solid points) as the results of the isospin separation. We note that the $I_t=0$ contribution is dominant over the $I_t=1$ contribution, particularly evident in the high-t region. It is again interesting to display the ratio

$$R_I(t')=\left(\frac{d\sigma_0}{dt'}-\frac{d\sigma_1}{dt'}\right)\bigg/\left(\frac{d\sigma_0}{dt'}+\frac{d\sigma_1}{dt'}\right)$$

in Fig. 3(c), and $R_I(t')\approx 1$ for the high-t' region, and there appears very little or no interference as shown in Fig. 3(d).

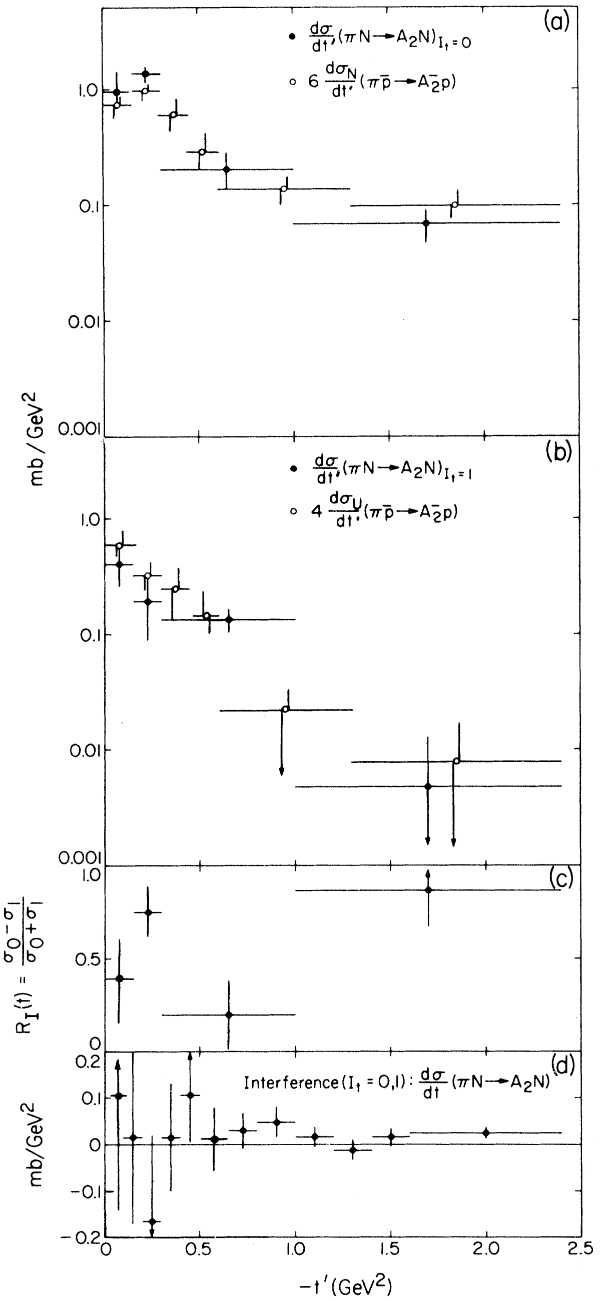

FIG. 3. (a) Contributions to the A_2 production from σ_0 (solid points) compared with σ_N in A_2^- production (open points). (b) Contributions to the A_2 production from σ_1 (solid points) compared with σ_U in A_2^- production (open points). (c) Ratios of contributions from σ_0 and σ_1 exchanges. (d) Interference term between $I=0,1$ amplitudes in the t-channel exchange.

To examine further the dominance of $I_t=0$ and N-parity exchange to the available t range in this experiment, we note from Eq. (1) that $\sigma(\pi^-p\to A_2^-p)=\frac{1}{4}\sigma_1+\frac{1}{6}\sigma_0$ since the isospin interference is negligible. Furthermore $\sigma(\pi^-p\to A_2^-p)=\sigma_N+\sigma_U$, and therefore $\sigma_N+\sigma_U=\frac{1}{4}\sigma_1+\frac{1}{6}\sigma_0$. Thus it is interesting to investigate whether a separation of isospin contributions is equivalent to a separation of N- and U-parity exchanges (i.e., $6\sigma_N=\sigma_0$ and $4\sigma_U=\sigma_1$). From this experiment, we obtain $\sigma_0=603\pm111$ μb, $6\sigma_N=666\pm114$ μb, $\sigma_1=180\pm30$ μb, and $4\sigma_U=192\pm40$ μb for all t regions. The agreements between $6\sigma_N$ and σ_0 as well as $4\sigma_U$ and σ_1 are impressive. This is further illustrated in differential cross sections, namely, $6d\sigma_N(\pi^-p\to A_2^-p)/dt'$ compared with $d\sigma(\pi N\to A_2N)_{I_t=0}/dt'$ and $4d\sigma_U(\pi^-p\to A_2^-p)/dt'$ compared with $d\sigma(\pi N\to A_2N)_{I_t=1}/dt'$ as shown in Figs. 3(a) and 3(b). It is evident that not only cross sections but also differential cross sections are in good agreement between $I_t=0$ and N-parity contributions as well as $I_t=1$ and U-parity contributions. With the assumption that N- and U-parity amplitudes as well as $I_t=0,1$ amplitudes do not interfere, an equality between $4\sigma_U=\sigma_1$ implies that ρ contribution is negligible if one can assume that the η exchange in the $A_2^\pm$ production is small.[9] In this case, the B exchange would dominate the $I_t=1$ amplitude.

Thus our analysis shows that the differential cross sections for $A_2^\pm$ productions at the moderate-to-high-t region are due to contributions from the $I=0$ and N-parity exchange. This implies that only P and/or f^0 are responsible for the exchange in this t region [Fig. 1(a) inset]. It is, however, unlikely for the P to make important contributions in the high-t region, and therefore it is natural to ascribe the structure (the dip at $|t|\approx 1.2$ GeV^2) to the f^0 exchange. To further speculate on f^0 trajectory, when a degenerate f^0-ω trajectory is extended to the $-t$ region, it intersects with $\alpha(t)=0$ at $t=-0.4$ GeV^2 and $\alpha(t)=-1$ at $t=-1.3$ GeV^2. The zero at $t=-0.4$ GeV^2 can be interpreted as the NSWSZ for ω which has been observed experimentally by Crennell *et al.*[10] in isolation of ω exchange from the ρ production from an earlier analysis of this experiment. The zero at $t=-1.3\ \mathrm{GeV}^2$ may be associated with the NSWSZ for f^0 which has been observed here from the present analysis.

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[1]D. J. Crennell *et al.*, Phys. Lett. 35B, 185 (1971). K.-W. Lai, in *Phenomenology in Particle Physics—1971,* edited by C. B. Chin, G. C. Fox, and A. J. G. Hey (California Institute of Technology Press, Pasadena, Calif., 1971), p. 257.

[2]J. Diaz *et al.*, Phys. Rev. Lett. 32, 260 (1974).

[3]F. Buhl *et al.*, private communication.

[4]The $\rho^0\pi^\pm$ events in the $J^P=2^+$ (D wave) state was estimated in the mass interval 1.2–1.44 GeV. In the fit, density-matrix elements ($\rho_{00},\rho_{1\,-1},\rho_{11}$) were treated as free parameters but all subjected to the positivity constraints. Corrections have been made for background 2^+ events and for the mass interval cut. See G. Ascoli *et al.*, Phys. Rev. Lett. 25, 962 (1970), for details of the method.

[5]We used the value $A_2\to\rho\pi/A_2\to$ all $=72.4\to2.1\%$ [T. A. Lasinski *et al.*, Rev. Mod. Phys., Suppl. 45, S1 (1973)] which has been affected the least by discoveries of other new but minor modes of A_2. See Ref. 2.

[6]For A_2^+ we used also the shape of $d\sigma/dt$ of the $\eta\pi^+$ mode which is also characterized by a small background (< 15%). See M. Alston-Garnjost *et al.*, Phys. Lett. 33B, 607 (1970). Furthermore we observe no detectable differences in shapes of $d\sigma/dt$ at the incident momenta 4.5, 6, and 7.1 GeV/c at the present level of statistics; thus, we assume the shape of $d\sigma/dt$ for A_2^+ at 6 GeV/c by using 7.1 GeV/c data.

[7]$\Lambda(1520)$ is defined from 1.5 to 1.54 GeV and does not overlap with the A_2^- region at our incident momenta.

[8]Ref. 3 and K. J. Foley *et al.*, Phys. Rev. D 6, 747 (1972).

[9]See G. C. Fox and A. J. G. Hey, Nucl. Phys. B56, 366 (1973), for details.

[10]D. J. Crennell *et al.*, Phys. Rev. Lett. 27, 1674 (1971); H. A. Gordon *et al.*, Phys. Rev. D 8, 779 (1973).

Exotic Interactions of Charged Leptons*

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We consider the information available about nonelectromagnetic lepton interactions in experiments which are relatively insensitive to the loop structure of the underlying theory. Further experiments which would clarify the role of exotic interactions are proposed and discussed.

Recent theoretical and experimental developments have once again focused attention on the question: What is the precise nature of the interaction between electrons, muons, and hadrons? Almost all gauge theories[1] augment the conventional electromagnetic interaction between these particles with additional interactions. Furthermore, recent experimental results indicating (a) a nearly constant cross section in e^+e^- annihilation into hadrons[2] and (b) deviations from Bjorken scaling in deep inelastic muon-hadron scattering[3] have invited the speculation[4] that exotic (i.e., nonelectromagnetic) interactions may be coming into play at newly available energies.

In this note we report on a systematic study of the information available about exotic lepton interactions in "tree experiments." (By "tree experiments" we mean experiments which are insensitive to the loop structure of the underlying theory.) We restrict ourselves to energies well below the masses of all intermediate vector bosons; this permits us to encompass a variety of theoretical proposals in a compact phenomenological interaction. We determine the consequences of this interaction for (a) atomic spectroscopy, (b) e^+e^- annihilation, and (c) deep inelastic lepton-hadron scattering. While our analysis leads us to tilt towards the view that exotic lepton interactions are unlikely to play a significant