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Low-lying Regge trajectory and polarizations in $\pi^{\pm}p$ elastic reaction at intermediate energy

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In this note we examine how a low-lying Regge trajectory provides a natural explanation of the departure from mirror symmetry in the πN elastic-scattering polarization at intermediate energy. This result confirms the conjecture of Dash and Navelet, who invoke the same mechanism in NN scattering.

In a recent paper, Dash and Navelet[1] proposed an elegant explanation of the anomalous energy dependence of the polarization parameter in pp and pn reactions for an incident momentum between 2 and 6 GeV/c. They have shown that such a behavior might be explained by the occurrence of the exchange of a low-lying vacuum trajectory with negative intercept, referred to as the σ trajectory. A "σ" component in the flip amplitude is adequate to reconcile the "good old" Regge theory with the experimental data for p_{lab} above 2 GeV/c. This σ has been identified as a Reggeized continuation of the strong attractive scalar potential needed to describe the low-energy NN phase shifts.[2] Since this scalar exchange is naturally associated with the $I=0$ $\pi\pi$ s-wave resonance ϵ at $m_\epsilon \sim 700$ MeV, it is appealing to examine the effect of this trajectory in πN elastic scattering above the resonance region. Here again the most sizable effect occurs in the polarizations. In conventional Regge models one predicts that the polarizations in $\pi^+ p$ and $\pi^- p$ are just opposite; this is referred to as the "mirror symmetry." This is indeed the case at high energy. However, the data in the intermediate region (2 GeV/$c \leq p_{\text{lab}} \leq 6$ GeV/c) strongly violate this symmetry. Experimentally the sum of the two polarizations $\pi^+ p$ and $\pi^- p$, i.e. the positive-signature part, decreases with energy faster than their difference, the negative-signature part, by roughly two powers of energy. Therefore the departure from the mirror symmetry cannot be accounted for by a strong flip component of the f_0 exchange, since the sum and the difference of the polarizations do not have the same energy behavior. The purpose of this paper is to show that this unexpected behavior is a manifestation of the same low-lying σ trajectory as in NN scattering.

We turn now to the analysis of the data. We denote by P the effective vacuum-exchange amplitude, whose trajectory intercept is around 1; this includes the naive Pomeron with $\alpha(0)=1$, and the f_0 component with $\alpha(0) \simeq 0.5$. In the differential cross sections, all contributions are screened by that of the Pomeron, which gives by far the leading term. Thus, for the polarizations we have the approximate expression

$$\text{Pol}(\pi^{\mp} p) \simeq -\frac{2\,\text{Im}[(P+\sigma\pm\rho)_{++}(P+\sigma\pm\rho)^*_{+-}]}{|P_{++}|^2}. \quad (1)$$

Let S (D) be the sum (difference) of the two polarizations; S (D) is the interference term of the effective vacuum nonflip amplitude with the t-channel isospin 0 (1) flip amplitude, namely,

$$S \equiv \text{Pol}(\pi^+ p) + \text{Pol}(\pi^- p) \approx -4\frac{\text{Im}(P_{++}\sigma^*_{+-})}{|P_{++}|^2}, \quad (2)$$

$$D \equiv \text{Pol}(\pi^+ p) - \text{Pol}(\pi^- p) \approx 4\frac{\text{Im}(P_{++}\rho^*_{+-})}{|P_{++}|^2}. \quad (3)$$

In the expression for S we have neglected two terms:

(i) the $P_{++}P^*_{+-}$ term, which is negligible as stated by amplitude analyses[3] (furthermore, this term will not decrease fast enough with energy);

(ii) the $(\rho_{++}\rho^*_{+-})$ term, which has a fast $1/s$ energy dependence but gives a very small contribu-

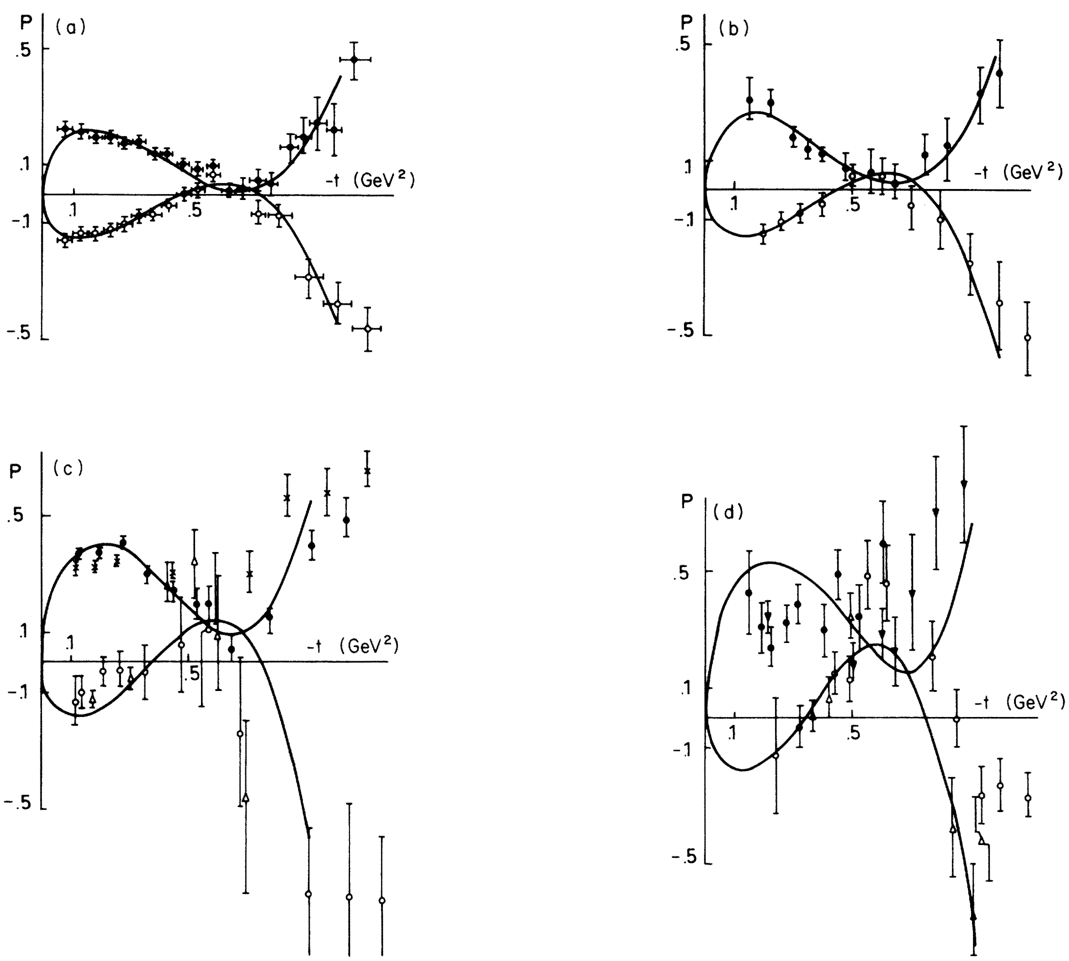

FIG. 1. π^+p and π^-p elastic polarizations: (a) ● π^+p, ○ π^-p $P_{\text{lab}}=6$ GeV/c (Ref. 4), (b) ● π^+p, ○ π^-p $P_{\text{lab}}=5.15$ GeV/c (Ref. 5), (c) ● π^+p $P_{\text{lab}}=2.39$ GeV/c (Ref. 5), × π^+p $P_{\text{lab}}=2.74$ GeV/c (Ref. 5), ○ π^-p $P_{\text{lab}}=2.74$ GeV/c (Ref. 5), △ π^-p $P_{\text{lab}}=2.5$ GeV/c (Ref. 6), (d) ● π^+p $P_{\text{lab}}=1.87$ GeV/c (Ref. 6), ▼π^+p $P_{\text{lab}}=1.988$ GeV/c (Ref.6), ○ π^-p $P_{\text{lab}}=1.988$ GeV/c (Ref. 6), △ π^-p $P_{\text{lab}}=2.07$ GeV/c (Ref. 6).

tion, namely,

$$-\frac{2\,\mathrm{Im}(\rho_{++}\rho_{+-}^{*})}{|P_{++}|^{2}}\sim\mathrm{Pol}(\pi^-p\to\pi^0n)\,\frac{d\sigma/dt(\pi^-p\to\pi^0n)}{d\sigma/dt(\pi^+p)+d\sigma/dt(\pi^-p)}\le 10^{-2}\,. \quad (4)$$

As far as D is concerned, its energy dependence is quite compatible with that given by the $P\rho$ interference. The parametrization we choose for S and D is similar to the one given in Ref. 1:

$$S\approx A\sqrt{-t}\,\sin\frac{\pi}{2}[\alpha_P(t)-\alpha_\sigma(t)]\left(\frac{\nu}{\nu_0}\right)^{\alpha_\sigma(t)-\alpha_P(t)}, \quad (5)$$

and

$$D\approx B\sqrt{-t}\,\sin\frac{\pi}{2}\alpha_\rho(t)\cos\frac{\pi}{2}[\alpha_P(t)\ \ \alpha_\rho(t)]\left(\frac{\nu}{\nu_0}\right)^{\alpha_\rho(t)-\alpha_P(t)}, \quad (6)$$

with $\nu=2m_NE_{\text{lab}}$, $\nu_0=1$ GeV^2, and the $\sin(\pi/2)\alpha_\rho(t)$ accounts for the wrong-signature nonsense zero (WSNZ) of the ρ-flip amplitude at $\alpha_\rho(t)=0$. (This parametrization obviously has a shortcoming: As one goes down in energy the polarization parameter may become larger than 1 at some t value.) Such a parametrization yields a very good fit to the polarizations of π^+p and π^-p at $p_L=6$ GeV/c with the following parameters.

$\alpha_P(t)=1.0+0.2t$, $\alpha_\rho(t)=0.56+t$,

$\alpha_\sigma(t)=-0.32+t$, $A_0=4.9$ GeV^{-1}, $B_0=1.13$ GeV^{-1},

$A=A_0e^{-2.44t}$, $B=B_0e^{-2.44t}$.

The trajectories of P and ρ have been chosen *a priori*; that of the σ has been determined by studying the energy dependence of S as one goes to low energies. The experimental accuracy on the polarizations in the 2–3 GeV/c domain is poor; nevertheless the effect of the σ is sizable, and the resulting $\alpha_\sigma(t)$ is similar to the one used in NN scattering by Dash and Navelet.[1] We have determined A and B by using the data at $P_{\text{lab}} = 6$ GeV/c because of the great accuracy of the measurements.

By studying the total cross section, we notice that at 2 GeV/c we are still in the resonance domain for π^+p but not for π^-p; thus there is a better agreement for the polarization of π^-p than for π^+p at 2 GeV/c. The agreement of this crude model with the experimental data[4-6] is shown in Figs. 1(a)–1(d).

Some final remarks are in order.

(i) As shown in Figs. 1(c) and 1(d), the experimental accuracy at low energy is poor. The P'' trajectory of Barger and Phillips[7] of intercept 0 or the low vacuum trajectory of Bali and Dash[8] $\alpha(0) = -0.03$ might as well reproduce the data. However, we want to emphasize that in NN scattering[1] the trajectory is well determined with an intercept ~ -0.4, and this intercept is compatible with the experimental data in the 2–3 GeV/c domain. Furthermore, a shift in the intercept leads to a shift in the position of the zero of S.

(ii) Since the sum S decreases faster than the difference D, the mirror symmetry for the two polarizations is predicted to develop at high energy, but the lower the energy (above the resonance domain) the bigger the violation of this symmetry.

(iii) Most amplitude analyses at 6 GeV/c have shown that M^0_{+-} amplitude corresponding to the exchange of $I = 0$ in the t channel has both its real and imaginary parts negative. This suggests that the component $\sigma_{+-} = -\gamma_\sigma \exp(-\frac{1}{2}i\pi\alpha_\sigma)$ $(\gamma_\sigma > 0)$, which has these features, is still present at 6 GeV/c.

(iv) As stated in Ref. 1, it appears that the σ is more strongly coupled to NN than to $\pi\pi$. Indeed one can evaluate the ratio of the nonflip couplings $(\gamma\sigma\pi\pi/\gamma\sigma NN)_{++}$ by looking at the quantity A defined in Eq. (5);

$$\sigma_{\text{tot}}(\pi N)A_{\pi N} \simeq (\gamma\sigma\pi\pi)(\gamma\sigma NN)_{+-},$$

$$\sigma_{\text{tot}}(NN)A_{NN} \simeq (\gamma\sigma NN)_{++}(\gamma\sigma NN)_{+-},$$

which yield, using the value of A_{NN} determined in Ref. 1,

$$(\gamma\sigma\pi\pi/\gamma\sigma NN)_{++} \sim \tfrac{1}{5}.$$

All the above remarks support the existence of the σ exchange in πN scattering, which provides a natural explanation for the departure from the normal Regge behavior.

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