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Publication Date
1966-06-29

University of California

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Berkeley, California

Phys. Rev.

UCRL-16940 Rev.

UNIVERSITY OF CALIFORNIA

Lawrence Radiation Laboratory
Berkeley, California

AEC Contract No. W-7405-eng-48

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ABSTRACT

We show that the recent high-energy π^-p polarization data from CERN are explained in a natural way by the three-Regge pole model. The prediction of this model for π^+p polarization differs greatly from π^-p polarization in the region where $|t| < 0.6(\mathrm{GeV}/c)^2$. In particular in this region, the π^+p polarization has an opposite sign and comparable magnitude to that for π^-p.

This paper shows that recent high-energy $\pi^- p$ polarization data from CERN[1] are explained in a natural way by the three-Regge-pole model.[2] The prediction of the model for $\pi^+ p$ polarization has an opposite sign and comparable magnitude to that for $\pi^- p$.

Elastic πN scattering at small momentum transfer is dominated, in this model, by three Regge poles in the crossed channel. Thus it is a more complicated problem than the charge-exchange reactions, with only one or two poles, for which the Regge hypothesis has had great success.[2-7] However, this complication is largely compensated by the greater variety of data available.

The data we use are total cross sections,[8] differential cross sections for elastic[9,10] and charge-exchange[11,12] scattering, Coulomb interference measurements of the phase of the forward elastic amplitude,[13] and $\pi^- p$ elastic polarization.[1] These data are from 5.9 GeV/c upward, and with squared momentum transfer $|t| < 1\ (\text{GeV/c})^2$. For $d\sigma/dt$ data, we worked with a representative subset of 141 elastic points in the interval $-1 < t < -0.1$ and charge-exchange points in $-0.9 < t < 0$. There is also an indirect datum, i.e., from dispersion relations one can place a constraint on the zero intercept of P' trajectory.[14] The constraints on the amplitudes at the ρ by relating ρ-meson coupling constants to nucleon electromagnetic structure, as described in Ref. 2 and 6, are also included.

We set aside the recent charge-exchange polarization data.[15] In the present model, such polarization is necessarily zero, but it seems the observed nonzero values can be explained by small background effects--either the tails of s-channel resonances[16] or another low-lying trajectory[17]--which have negligible effect on other experimental quantities.

We assume scattering is dominated by the first and second vacuum Regge trajectories P and P' (presumably associated with the f and f' mesons) and the isovector ρ trajectory. Following Refs. 2 and 5, we parameterize these contributions of the trajectories to the invariant amplitudes A' and B of Singh:[18]

$$A' = \begin{cases} C_0 \exp(C_1 t)\, \alpha(\alpha + 1)\, \xi(E_L/E_0)^{\alpha} & \text{for P and P'} \\ C_0 \left[(1 + C_2) \exp(C_1 t) - C_2\right] (\alpha + 1)\, \xi(E_L/E_0)^{\alpha} & \text{for } \rho , \end{cases} \quad (1)$$

$$B = \begin{cases} D_0 \exp(D_1 t)\, \alpha^2 (\alpha + 1)\, \xi(E_L/E_0)^{\alpha-1} & \text{for P and P'} \\ D_0 \exp(D_1 t)\, \alpha(\alpha + 1)\, \xi(E_L/E_0)^{\alpha-1} & \text{for } \rho , \end{cases} \quad (2)$$

$$\xi(t) = - [\exp(- i\pi\alpha) \pm 1]/\sin \pi\alpha, \quad (3)$$

$$\alpha(t) = \alpha(0) + \alpha' t . \quad (4)$$

Here $\alpha(t)$ is the trajectory, $\xi(t)$ is the signature factor (with signature + for P and P', - for ρ), E_L is the total pion lab energy, and E_0 is a scale factor chosen to be 1 GeV. $C_0, C_1, C_2, D_0,$

D_1, $\alpha(0)$, and α' are adjustable parameters. The factor α^2 introduced here in contrast to that α used in Ref. 2 for the B_P and $B_{P'}$ amplitudes is at this stage purely ad hoc. It was made in formal analogy to the behavior of the ρ amplitudes at $\alpha_\rho = 0$ as discussed in Ref. 5.

For definiteness, let us fix C_0 and D_0 to mean the values for $\pi^- p$ elastic scattering. Then for $\pi^+ p$ scattering, P and P' stay the same while ρ changes sign; for charge exchange, P and P' terms vanish while ρ is multiplied by $-\sqrt{2}$.

Experimental quantities are given by

$$\sigma_T(s) = \text{Im}\, A'\,(s,t=0)/p, \tag{5}$$

$$\frac{d\sigma}{dt}(s,t) = \frac{1}{\pi s}\left(\frac{M_N}{4k}\right)^2 \left\{\left(1-\frac{t}{4M_N^2}\right)|A'|^2 - \frac{t}{4M_N^2}\left(\frac{4M_N^2 p^2 + st}{4M_N^2 - t}\right)|B|^2\right\}, \tag{6}$$

$$P(s,t) = -\frac{\sin\theta}{16\pi\sqrt{s}} \cdot \frac{\text{Im}\, A'B^*}{d\sigma/dt}, \tag{7}$$

where s is the square of total c.m. energy, p is the pion lab momentum, k is the c.m. momentum, θ is the c.m. angle, and P(s,t) is the polarization, defined relative to the direction $\underset{\sim}{p}_{in} \times \underset{\sim}{p}_{out}$ with $\underset{\sim}{p}_{in}$ and $\underset{\sim}{p}_{out}$ being the momenta of the pion.

We adjusted the Regge pole parameters for an optimum overall fit to the data. The results are shown in Tables I and II and Fig. 1. Table I gives the best-fit Regge parameters. Some parameters are not well determined, in particular D_0, D_1 and α' for both P and P', so ranges of solutions are possible. Table I shows two examples. Case (a) has moderate slopes for the P and P' trajectories, as in Ref. 2. Case (b) has a slightly smaller slope for P but a much bigger one for P', and has the interesting property[19] of allowing a secondary bump in $d\sigma/dt$ for elastic scattering, similar to that observed.[20] Table II lists the number of data of each kind that we used, with the corresponding contributions to χ^2 for both solutions. Notice the individual χ^2 values tabulated are comparable for both solutions. Figure 1 shows the fit to the new $\pi^- p$ polarization data for the solution (a). The corresponding fit for solution (b) is not illustrated here. It differs little from the one shown for $|t| < 0.6$, but beyond this region the fit of solution (b) rises more quickly. For instance, at $t = -0.8$, solution (b) gives 16% for 10 GeV/c. The rest of the data fitting is also not illustrated, but the quality of the fitting is essentially as good as in Refs. 2 and 5.

The $\pi^{\pm} p$ polarizations are proportional to the cross products of the A' amplitudes $(A'_P + A'_{P'} \mp A'_\rho)$ with the B amplitudes $(B_P + B_{P'} \mp B_\rho)$. The A'_ρ and B_ρ amplitudes are mainly determined by charge-exchange data, which require a small A'_ρ amplitude relative to A'_P and $A'_{P'}$ and a strong B_ρ amplitude. Since the A' and B amplitudes have the same phase for a given trajectory, ignoring the A'_ρ amplitude one is left with terms $(A'_P + A'_{P'}) \times B_\rho$, $(A'_P \times B_{P'})$ and $(A'_{P'} \times B_P)$ for the $\pi^- p$ polarization. The sign of B_ρ is plausibly determined by ρ-meson coupling constants,[2] and the sign of $(A'_P + A'_{P'})$ at $t = 0$ is fixed by σ_T. So the sign of $(A'_P + A'_{P'}) \times B_\rho$ is fixed. From $d\sigma\ (\pi^\pm p)/dt$ data, the magnitude of $(A'_P + A'_{P'}) \times B_\rho$ in the small $|t|$ region (say for $|t| < 0.6$) also is essentially determined. It then turns out that this term alone accounts for the most of the observed $\pi^- p$ polarization. The dominance of this term is also suggested by the vanishing of the observed polarization near $t = -0.6$, where the B_ρ amplitude vanishes. Although at this stage the individual terms $A'_P \times B_{P'}$ and $A'_{P'} \times B_P$ are not well determined (see Table I), in order to account for the observed polarization for $|t| < 0.6$, the sum of the contributions from these two terms has to be small. Now the $(A'_P + A'_{P'}) \times B_\rho$ term has opposite signs for $\pi^- p$ and $\pi^+ p$ polarizations. Since this term dominates, one is led to predict that $\pi^+ p$ polarizations for $|t| < 0.6$ should be comparable in magnitude and opposite in sign to that for $\pi^- p$. The prediction for solution (a) is illustrated in Fig. 2 at 6 and 10 GeV/c, where for $|t| < 0.6$ the $\pi^+ p$ polarization appears with opposite sign. Beyond this region, solution (a), as illustrated, predicts a small negative polarization. The corresponding prediction for solution (b), is not illustrated here. It is similar to the one shown for $|t| < 0.6$, but it remains positive near $t = -0.6$, and rises quickly beyond this region. For instance, this prediction gives 17% $\pi^+ p$ polarization at $t = -0.8$ for 10 GeV/c; this value is roughly the same as mentioned above for $\pi^- p$ polarization with the (b) fit. The relatively large polarization with the same sign for both π^+p and π^-p at $t = -0.8$ for solution (b) is due to the fact that here the contribution due to the sum of $(A'_P \times B_{P'})$ and $(A'_{P'} \times B_P)$ is large and dominates.

To conclude, our results show that the recent CERN π^-p polarization data are readily explained by the $P + P' + \rho$ Regge pole model. This model predicts that π^+p polarization will be comparable in magnitude and opposite in sign to π^-p results for $|t| < 0.6$.

We thank Professor Geoffrey F. Chew for his interest and encouragement in the course of this work. One of us (WR) thanks Professor Emilio G. Segre for the hospitality of the Physics Department, University of California, Berkeley.

FOOTNOTES AND REFERENCES

* This work supported in part by United States Atomic Energy Commission.

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Table I. Regge-pole parameters

Parameters and units		Solution (a)			Solution (b)		
		P	P'	ρ	P	P'	ρ
C_0	(mb GeV)	7.43	16.6	1.49	8.88	16.4	1.49
C_1	$(GeV)^{-2}$	1.68	6.17	2.01	2.49	2.42	1.98
C_2		-	-	1.79	-	-	1.80
D_0	(mb)	-27.4	-83.0	29.2	-3.55	-8.99	29.1
D_1	$(GeV)^{-2}$	4.94	7.96	0.12	0.41	-2.08	0.13
$\alpha(0)$		1.00	0.72	0.576	1.00	0.65	0.576
α'	$(GeV)^{-2}$	0.34	0.34	1.02	0.23	0.93	1.02

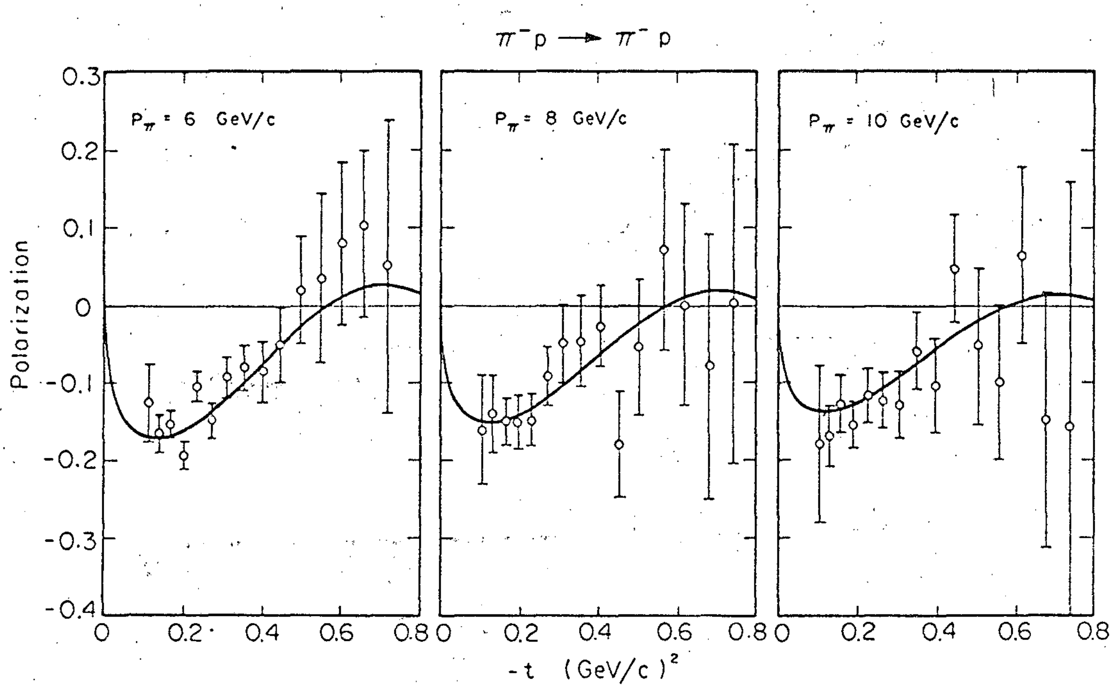
Table II. Data Fitted

Type	Number of data points	sol.(a) χ^2	sol.(b)
$P(\pi^- p)$	45	28	33
$\sigma_T(\pi^\pm p)$	16	10	7
$\frac{d\sigma}{dt}(\pi^\pm p)$	141	133	161
$\frac{d\sigma}{dt}(\pi^- p \to \pi^0 n)$	56	87	87
$\frac{\text{Re } A'(0)}{\text{Im } A'(0)}$	9	16	15
$\alpha_{P'}(0)$	1	0.1	0.3
ρ-coupling constraints	2	1	2
Total	270	275	305

FIGURE CAPTIONS

Fig. 1. $\pi^- p$ polarization data of Ref. 1 at 6,8, and 10 GeV/c compared with the Regge fit of solution (a).

Fig. 2. Predictions of $\pi^+ p$ polarization at 6 and 10 GeV/c from Regge model of solution (a).



π⁻p → π⁻p
Polarization
P_π = 6 GeV/c
P_π = 8 GeV/c
P_π = 10 GeV/c
-t (GeV/c)²
0.3
0.2
0.1
0
-0.1
-0.2
-0.3
-0.4
0
0.2
0.4
0.6
0.8

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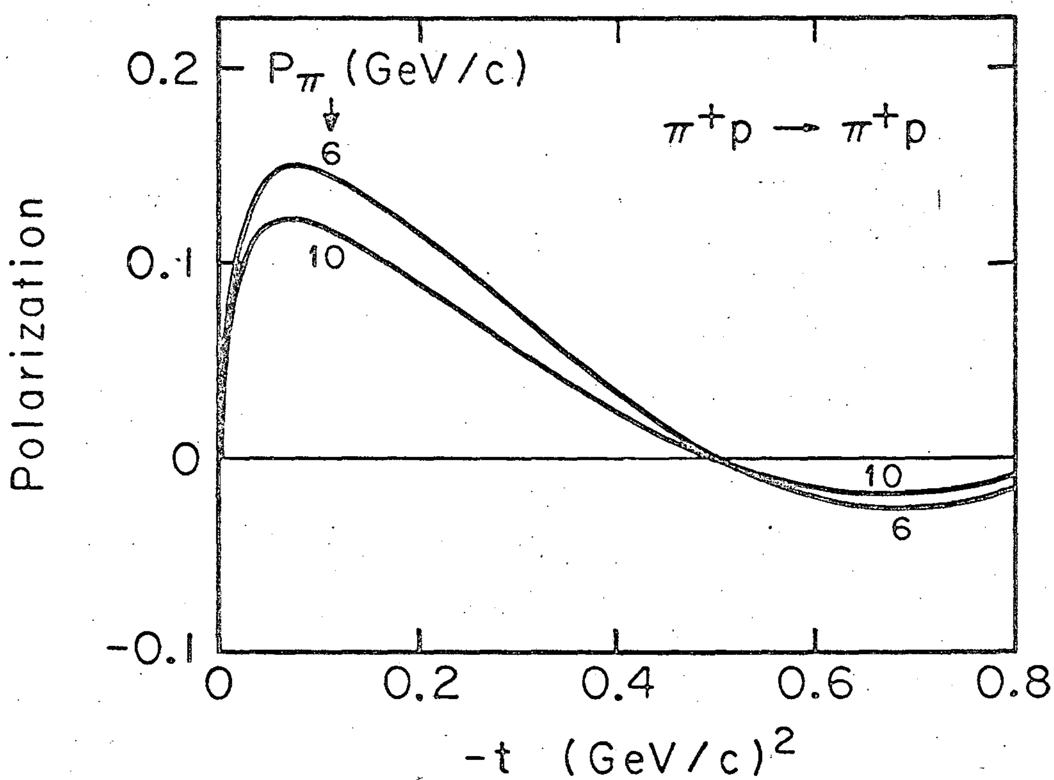

Polarization
P_π (GeV/c)
6
10
$\pi^+ p \to \pi^+ p$
0.2
0.1
0
-0.1
0
0.2
0.4
0.6
0.8
-t (GeV/c)^2

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