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BACKWARD $\pi^p$ SCATTERING AS A FURTHER TEST FOR REGGE HIGH-ENERGY BEHAVIOR

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Although no experimental conflict with Regge behavior has been observed for reaction amplitudes at lab energies above 4 GeV, in most cases the theoretical predictions at currently available energies (below 30 GeV) are ambiguous because several trajectories simultaneously make significant contributions. Recently there have been studied two reactions, $\pi^- + p \rightarrow \pi^0 + n$ and $\pi^- + p \rightarrow \eta + n$, where only a single trajectory is important.\textsuperscript{1-4} The results provide strong support for the Regge pole hypothesis. We hope that this letter may encourage further measurements in the same class. Experimenters measuring reaction cross sections in the range above 4 GeV lab energy should be constantly aware that any reaction in which a single trajectory stands above its competitors by a full unit of $J$ (or more), if measured accurately with beams currently available at Brookhaven and CERN, is an especially significant test for Regge behavior.

We discuss here one new candidate for this category, backward $\pi^- p$ scattering, for which preliminary measurements already suggest an energy dependence of the Regge form.\textsuperscript{5,6} To our knowledge, however, the
necessary experimental precision for establishing Regge shrinkage here has not yet been achieved. It is possible to estimate what this rate of shrinkage will be. The predicted rate is substantial and should be accessible to current techniques.

Our argument has three elements: (a) Detailed study of the relevant crossed reaction, elastic $\pi^+ p$ scattering, has shown only one high-level communicating trajectory—that associated with the $\Delta$ (33 resonance). (b) The rough energy dependence already observed for backward $\pi^- p$ scattering is adequate to establish the $\Delta$ trajectory intercept at zero crossed energy. That is, we have

$$\frac{d}{d \ln s} \ln \left( \frac{d\sigma^{\pi^- p}}{du} \right) = \alpha_\Delta(\sqrt{u}) + \alpha_\Delta(\sqrt{u}) - 2,$$

where $s$ is the energy squared in the direct reaction $\pi^- p \to \pi^- p$, $u$ is the energy squared in the crossed reaction $\pi^+ p \to \pi^+ p$, and $\alpha_\Delta(\sqrt{u})$ is the $\Delta$ trajectory. Recent experiments near $u = 0$, at $P_{\text{lab}} = 4$ and $8 \text{ GeV/c}$, show a decrease by a factor $\approx 6$ between these two energies. Thus

$$2[\alpha_\Delta(0) - 1] \approx - \frac{\ln 6}{\ln 2},$$

or

$$\alpha_\Delta(0) \approx -0.3 \quad (2)$$
(c) We may then use this value together with the masses of the \( J = 3/2 \) (1236 MeV) and \( J = 7/2 \) (1924 MeV) particles on the trajectory to estimate at \( u = 0 \) the second derivative of \( \alpha_\Delta \) with respect to \( \sqrt{u} \), which determines the rate of peak shrinkage. Making a simple cubic fit to these three points in GeV units, we find

\[
\alpha_\Delta(\sqrt{u}) \approx 0.3 + 0.53 \sqrt{u} + 0.75 u \quad , \tag{3A}
\]

while the Pignotti form\(^9\) gives

\[
\alpha_\Delta(\sqrt{u}) \approx 4.0 + \frac{3.7}{1 - \sqrt{u}/3.8} \quad . \tag{3B}
\]

These two fits are shown in Fig. 7. In the first case \( \alpha_\Delta''(0) \) is 1.5 GeV\(^{-2}\) and in the second 0.5 GeV\(^{-2}\). Values in this range have been observed for several different meson trajectories,\(^4\) and have been obtained by Garcia from N/D calculations of the \( \Delta \) trajectory.\(^10\) They therefore seem entirely reasonable.

The width of the backward peak, \( \Gamma_b \), may be defined through

\[
\Gamma_b^{-1} = \left[ \frac{d}{du} \ln \frac{d\sigma_{\pi^+p}}{du} \right]_{u=0} \quad , \tag{4}
\]

so from Eq. (1) and Eq. (3),

\[
\frac{d}{d \ln s} (\Gamma_b^{-1}) = \left\{ \frac{d}{du} \left[ \alpha_\Delta(\sqrt{u}) + \alpha_\Delta(-\sqrt{u}) \right] \right\}_{u=0} = \alpha_\Delta''(0) \quad . \tag{5}
\]
The width (4), as measured roughly at 4 GeV lab momentum, is fairly broad:

$$\Gamma_b(p_{\text{lab}} = 4 \text{ GeV}) \approx 0.3 \text{ GeV}^2$$  \hspace{1cm} (6)

If $$\alpha''(0) = 1 \text{ GeV}^{-2}$$, formula (5) shows that such a width would be reduced by 50% in raising the lab energy by a factor $$\approx 5$$, that is, by going to 20-GeV/c incident pions.

Because a single (real) residue function is involved here, the shape of the backward peak is expected to be simple—not exhibiting the structure possible when spin-flip and non-spin-flip components are independent. Shrinkage of the peak thus should be on even more persuasive phenomenon than in the reaction $$\pi^- + p \rightarrow \pi^0 + n$$, where a strong spin-flip component leads to a complicated shape for the peak and confuses the definition of "width." 1,2

We do not want to convey the impression that the only significant test for Regge behavior lies in peak shrinkage. On the contrary, our opinion is that other aspects, such as energy behavior according to a power that is noninteger and the relation between this power and the phase, are equally important. 4,11 We also do not wish to suggest that in any absolute sense backward $$\pi^- p$$ scattering is more crucial than charge-exchange pion-nucleon scattering or other reactions dominated by a single trajectory. It is a fact of life, however, that most high-energy physicists think of peak shrinkage as the decisive criterion for Regge
behavior, and it is also a fact that the psychological impact of any particular experiment depends on whether its theoretical significance is spelled out in advance. Furthermore, the dedicated experimenters who measure precision reaction cross sections deserve a clean swipe now and then at an outstretched theoretical neck.
FOOTNOTES AND REFERENCES


7. Both the trajectory and residue functions for systems of odd baryon number are natural functions of energy, not energy squared, as first pointed out by V. N. Gribov, Soviet Physics-JETP 16, 1080 (1963). Gribov also showed that the power law in s for the unpolarized differential cross section corresponds to Eq. (1).

8. There has been uncertainty in some of the literature about whether Regge behavior should be expected for backward πN scattering near the point \( u = 0 \), because the cosine of the crossed-reaction angle...
may be small here even when $s$ is large. Maximal analyticity (e.g., the Mandelstam representation), however, assures us that, if the amplitude behaves as $s^f(u)$ (more generally, as a sum of powers) for a fixed value of $u$ not equal to zero, it must continue to so behave near $u = 0$. There is no singularity of $A(s,u)$ on the physical sheet in the neighborhood of $u = 0$.

10. Andres Garcia (Lawrence Radiation Laboratory), private communication, 1965.
The $\Delta$ trajectory as a function of $W = \sqrt{u}$. The two forms (A) and (B) are both constrained to pass through the particle masses at $J = 3/2$ and $J = 7/2$, as well as $J = -0.3$ at $W = 0$. The 2360-MeV $I = 3/2$ particle of conjectured spin $11/2$ is shown for reference.
Fig. 1

\( \alpha_\Delta(W) \)

\[ \begin{align*}
\text{(A)} & \quad \alpha_\Delta = -0.3 + 0.53W + 0.75W^2 \\
\text{(B)} & \quad \alpha_\Delta = -4.0 + \frac{3.7}{1 - W/3.8}
\end{align*} \]
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