PHYSICAL REVIEW

LETTERS

Backward Elastic $\pi^+ p$ Scattering at 3.7 and 7.1 GeV/c*

W. Michael, G. S. Abrams, M. Alston-Garnjost, A. Barbaro-Galtieri, B. Y. Daugeras,†
G. Gidal, A. D. Johnson, G. R. Lynch, F. T. Solmitz, and F. C. Winkelmann
Lawrence Berkeley Laboratory, University of California, Berkeley, California 94720
(Received 14 April 1975)

The differential cross section of $\pi^+ p$ elastic scattering has been measured in two high-statistics bubble-chamber exposures at laboratory beam momenta of 3.7 and 7.1 GeV/c. A new feature suggested by these data is a dip in $d\sigma/du$ at $-u \simeq 3$ GeV^2. This dip corresponds well to the third zero of $J_0(b\sqrt{-u'})$, where $\hbar c/b = 1$ fm. The effective u-channel Regge trajectory computed for these two energies has a slope of 0.22 ± 0.26.

Some 189 000 events of $\pi^+ p$ elastic scattering have been observed in the Stanford Linear Accelerator Center 82-in. hydrogen bubble chamber exposed to π^+ beams of momenta 3.7 and 7.1 GeV/c. At 3.7 GeV/c, 50 000 events have been obtained from 550 000 pictures having a sensitivity of 14 events/μb, while at 7.1 GeV/c, 139 000 events have been obtained from 700 000 pictures having a sensitivity of 43 events/μb.[1] The overall statistical level of this experiment thus approaches that typically attained with use of counter apparatus. Furthermore, the acceptance of the bubble chamber is essentially flat for values of the square of the momentum transfer greater than about 0.07,[2] while background is negligible in the four-constraint–fit category of elastic scattering (both relevant considerations in observing structure in the differential cross section). A further important feature of this experiment is the significant spread in beam momentum about the two nominal values. The full width at half maximum of the beam distribution is about 110 and 260 MeV/c, respectively, at 3.7 and 7.1 GeV/c, while the momentum of an individual beam track is known to about 0.5%; i.e., about 18 and 35 MeV/c, respectively.[3]

The kinematics of the experiment is displayed in Fig. 1 in terms of the conventional Mandelstam variables s, t, and u sloping at 45°. It is apparent from this figure that because of the spread in s, a structure (dip) at constant u will be less well defined in a projection on t, and conversely for a structure at constant t. Figure 2 shows the differential cross section in terms of t and u for the full range of each variable. Note that the effect of the spread in s is to cause the cross section to appear to turn over at the upper
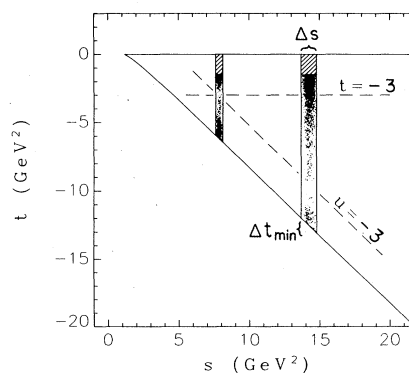

FIG. 1. Mandelstam plot showing the kinematic regions covered by this experiment. Note the effect of the spread in s. A portion of the data is also displayed here.
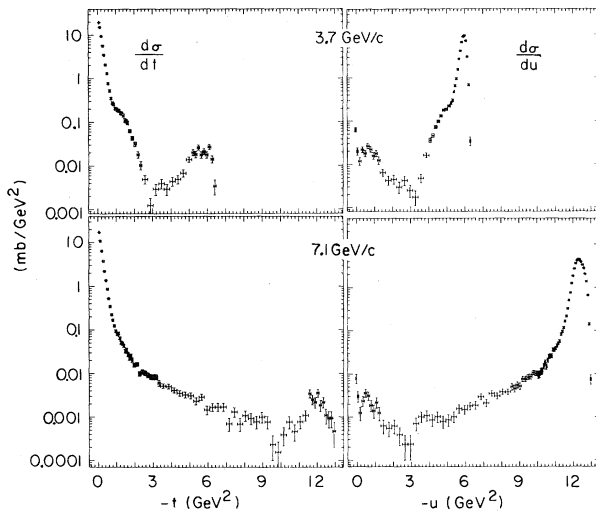
FIG. 2. Differential cross section with respect to t and u. The spread in s causes the apparent turnover at the upper limit in either variable (see Fig. 1).

FIG. 3. $d\sigma/du$ for $-u < 6$.

limit in both projections, and, in particular, the backward peak and dip (at $-u \simeq 0.15$) are not visible in the t projection. This effect should be kept in mind when examining previous data, as discussed further below.

Figure 2 shows a dip in the 3.7-GeV/c data at $-t \simeq -u \simeq 3$. In the 7.1-GeV/c data, a similar dip occurs at $-u \simeq 3$, which corresponds to $-t \simeq 10$. Furthermore, there is no significant dip near $-t = 3$. Inspection of Fig. 1 suggests that the simplest interpretation of these observations is in terms of a fixed-u feature (zero) of the amplitude (or a fixed-u' feature[4]). For greater clarity, the region $-u < 6$ is shown in Fig. 3. The shapes of the two distributions are quite similar for $-u < 3$. The backward peak and well-known dip at $-u \simeq 0.15$ are evident at both energies. The dip at $-u \simeq 3$ is the absolute minimum of the cross section in both cases. The position of this dip is shifted downward by about 0.3 from the lower to the higher energy.

A determination of πN scattering amplitudes is, of course, not possible with a measurement of only $d\sigma(\pi^+ p \to \pi^+ p)/du$. However, some qualitative observations can be made.

(a) The observed dip at $-u \simeq -u' \simeq 3$ corresponds well to the third zero of $J_0(b\sqrt{-u'})$ with $\hbar c b \simeq 1$ fm. The well-known dip at $-u' \simeq 0.2$ ($-u \simeq 0.15$) falls at the first zero of J_0. Thus the major structures in the data at both energies can be associated with zeros of J_0 (which corresponds asymptotically to the s-channel helicity-flip am-
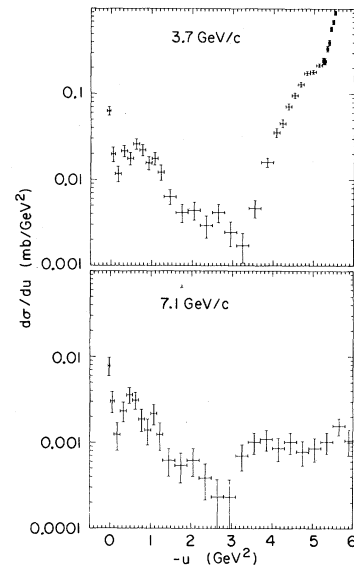
plitude). These structures are also qualitatively in accord with the model of Chu and Hendry[5] in which dips are associated with the zeros of the rotation functions (d functions). Furthermore, their model shows a zero not only in the helicity-flip amplitude at $-u \simeq 3$, but also in the nonflip amplitude at $-t \simeq 3$, and since these two points coincide at 3.7 GeV/c (see Fig. 1), the dip at that energy is predicted to be quite pronounced. Zeros of the helicity-flip amplitude, calculated by Buttimore and Spearman from a phase-shift analysis, have been found to correspond to the first two zeros of J_0 in an energy region in which the third zero is inaccessible.[6] Also, over a range of lower energies, a dip at $-u \simeq 1.3$ (near the second zero of J_0) has been reported by Abe et al.[7] The observed structures thus suggest models in which absorptive effects dominate, that is, those in which zeros of the amplitudes correspond to zeros of the Bessel functions.

(b) The conventional N_α Regge trajectory has its second wrong-signature nonsense zero at $-u \simeq 2.3$,[8] and so does not correlate well with the dip at $-u \simeq 3$. However, more complex Regge models, such as that of Donnachie and Thomas[9] incorporating quark rearrangement processes, appear to be capable of reproducing a broad minimum near $-u = 3$. As a further test of simple Regge ideas, an effective Regge trajectory has been computed for the two energies of this experiment by use of the standard dependence

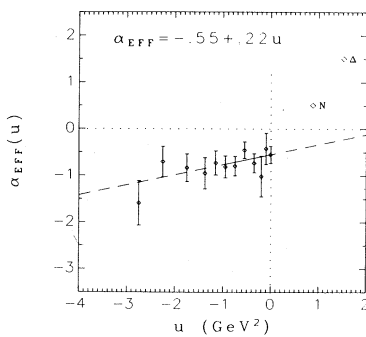$$d\sigma/du \propto (s - t)^{2\alpha_{\rm eff}(u) - 2}.$$

FIG. 4. Chew-Frautschi plot showing the effective u-channel Regge trajectory for the two energies of this experiment. The straight line has been fitted to the points in the range $-1 < u < 0$.

The resulting values of $\alpha_{\rm eff}(u)$ are shown in Fig. 4. This effective trajectory represents a mixture of isospin $\frac{1}{2}$ and $\frac{3}{2}$ in the u channel, but isospin $\frac{1}{2}$ is presumed to dominate.[10] A straight-line fit to the points in the range $-1 < u < 0$ yields the result

$$\alpha_{\rm eff}(u) = (-0.55 \pm 0.14) + (0.22 \pm 0.26)u.$$

The slope obtained is consistent with zero. This slope is quite insensitive to the relative normalization of the two energies, having the same value for relative normalizations differing by ± 30%. The data points obtained by Barger et al.[11] for the isospin-$\frac{1}{2}$ trajectory are also consistent with this slope.

In examining results from past experiments at neighboring energies, it was found that experimenters either have not displayed $d\sigma/du$ beyond $-u = 3$, or have aggregated the data in bins of such width that no dip is discernible near $-u = 3$.[12] Furthermore, in this region of u, previous experiments appear to be inconsistent among themselves with regard to both dips and the absolute value of the cross section.[13] However, keeping in mind the kinematic effect illustrated in Fig. 1, plots of $d\sigma/dt$ can be read approximately in terms of u. The data of Brabson et al.[14] at 3.5 GeV/c and those of Eide et al.[15] at 5 GeV/c indicate a dip at the t value corresponding to $-u \simeq 3$, and so offer corroboration of the dip observed here, while the data of Rust et al.[16] at 5 GeV/c show no significant effect in this region.

We would like to thank the scanning and support

staffs of Group A and the Trilling-Goldhaber group for their effort in processing these data.

[1]The data at 3.7 GeV/c were measured with the flying spot digitizer; those at 7.1 GeV/c with the spiral reader. Reconstruction and kinematic fitting were done with TVGP-SQUAW. Elastic events are taken as those having a χ^2 confidence level greater than 1% for the four-constraint fit.

[2]Square of momentum transfer is given in GeV^2 throughout this Letter.

[3]The momentum is correlated by the beam optics with the transverse position of the beam track in the bubble chamber.

[4]The variable u' is $u - u_0$, where u_0 is the u value of the lower boundary curve in Fig. 1. The value of u_0 is about 0.09 and 0.05, respectively, at 3.7 and 7.1 GeV/c.

[5]S. Chu and A. W. Hendry, Phys. Rev. Lett. 25, 313 (1970).

[6]N. H. Buttimore and T. D. Spearman, Nucl. Phys. B84, 531 (1975). They also find that zeros of the non-flip amplitude correspond to the second and third zeros of J_1. M. G. Albrow et al., Nucl. Phys. B25, 9 (1971), have reported a fixed-u minimum of the polarization at $-u \simeq 0.65$, which is near the second zero of J_1.

[7]K. Abe et al., Phys. Rev. D 10, 3556 (1974).

[8]The N_α trajectory is taken as $\alpha(u) = -0.4 + 0.9u$ [see A. Donnachie and P. R. Thomas, Nuovo Cimento 19A, 279 (1974)].

[9]Donnachie and Thomas, Ref. 8.

[10]See, for example, V. Barger et al. Nucl. Phys. B49, 206 (1972).

[11]Barger et al., Ref. 10.

[12]See, for example, A. Eide et al., Nucl. Phys. B60, 173 (1973); C. Baglin et al., Phys. Lett. 47B, 85 (1973).

[13]C. Lovelace et al., Lawrence Berkeley Laboratory Report No. LBL-63, 1973 (unpublished), p. 34. For a numerical discussion of apparent inconsistencies see J. K. Storrow and G. A. Winbow, Nucl. Phys. B53, 62 (1973).

[14]B. B. Brabson et al., Phys. Rev. Lett. 25, 553 (1970).

[15]Eide et al., Ref. 12, Fig. 13. Note that one π^+ point is nearly obscured by the π^- data plotted on the same graph. The acceptance function for that experiment is given by F. H. Schmidt et al., Phys. Lett. 45B, 157 (1973), Fig. 3, and it also has a pronounced dip at $-t \simeq 6$, so that systematic errors could possibly contribute to the observed shape.

[16]D. R. Rust et al., Phys. Rev. Lett. 24, 1361 (1970).