structure. This is in contrast to results for p-p [9] and n-p [10] elastic scattering at the same incident momentum where the cross sections show smooth behavior and have a magnitude at large angles considerably greater than observed here.

It is interesting to note that a simple black-disk diffraction pattern for a radius of 1.1 F gives minima at $-t \approx 0.5$ and 1.9 $(\text{GeV}/c)^2$, as found for the $\bar{p}$-p scattering, and that a radius of 0.9 F gives minima in reasonable agreement with the π^--p results.

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STRUCTURE IN BACKWARD PION-PROTON ELASTIC SCATTERING FROM 6 TO 17 GeV/c *

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The angular distribution for elastic π^+-p scattering has been measured over the angular range $135° < \theta_{\text{c.m.}} < 180°$ for pion laboratory momenta of 5.9, 9.9, and 13.7 GeV/c and also for π^-p at 5.9 and 9.9 GeV/c. More limited angular distributions are presented for π^--p at 13.7 and 16.3 GeV/c and π^+-p at 17.1 GeV/c. In both the π^--p and π^+-p scattering the cross section rises by over 2 orders of magnitude in the backward direction; for π^+-p only, there is a sharp dip at $u = -0.15$ $(\text{GeV}/c)^2$.

This paper presents results from a Brookhaven National Laboratory alternating-gradient synchrotron experiment on the scattering of high-energy pions by protons in the backward direction. Some preliminary results have already been presented using an experimental arrangement which covered $165° < \theta_{\text{c.m.}} < 180°$.[1] In the present work a different experimental arrangement shown in Fig. 1 extended the angular range to $\theta_{\text{c.m.}} \approx 135°$. Both the scattered protons and pions were observed in thin-plate spark chambers after magnetic analysis as shown in Fig. 1. The spark-
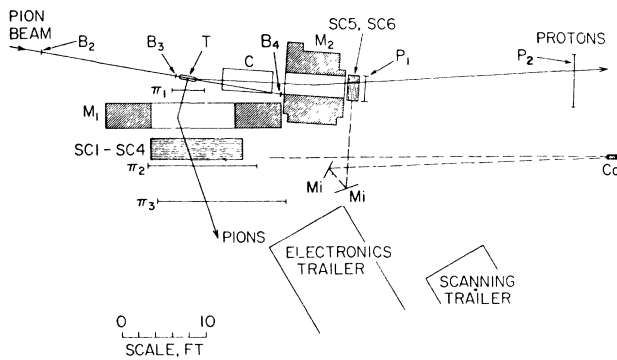
FIG. 1. Experimental layout. Scattered pions pass through magnet M_1 and spark chambers SC1 to SC4. Forward recoil protons pass through threshold gas Cherenkov counter C, magnet M_2, and spark chambers SC5 and SC6. The symbols π_1, π_2, π_3, P_1, and P_2 stand for banks of scintillation counters. The liquid-hydrogen target is T, Mi are mirrors, and Ca is the camera. B_3 and B_4 are beam counters. Not shown are counters B_1 and a threshold Cherenkov counter in the beam.

chamber trigger required a coincidence between the incoming beam telescope $B_1B_2B_3\overline{B}_4$, one of the five proton telescopes P_1P_2, and one of the ten pion telescopes $\pi_1\pi_2\pi_3$. Forward-scattered pions and beam halo were vetoed by the threshold gas Cherenkov counter C. Each pion track was extrapolated back to the target assuming the kinematically correct momentum for elastic scattering. Extrapolated tracks missing the target were rejected. The horizontal and vertical positions and angles of the corresponding proton were calculated and compared with the measured

values at the spark chamber. These plots were used to determine the inelastic background under the elastic peaks. At 9.9 GeV/c the inelastic correction was typically ~15%. Only for cross sections ~0.01 μb/(GeV/c)^2 did this correction get as large as 50%. Other corrections were made for the target-empty rate, for muon and electron contamination in the beam, and for decay of the scattered pions. Solid-angle acceptance and the absorption of pions and protons in the scintillators, target, and other material were determined by Monte Carlo calculations. The errors shown are statistical combined with the errors in the inelastic and empty-target subtractions. For each geometry there is an additional normalization error of ~±10%.

The results are plotted in Figs. 2 and 3. The cross sections for $u > -0.15$ (GeV/c)^2 were obtained using a different geometry and have been published in preliminary form.[1] Analysis of these earlier results has now been completed and the final cross sections which supersede those of Ref. 1 are shown in Figs. 2 and 3. It should be pointed out that the earlier results indicated a possible small dip or flattening out of the π^--p backward peak at 180°. However, the final results no longer give such a strong indication and are consistent with no such structure. At 5.9 and 9.9 GeV/c the results of the two geometries overlap with reasonable agreement. The π^--p results show a smoothly decreasing cross section out to a u value of -2.5 (GeV/c)^2. As seen in Fig. 2, least-squares fits to the π^--p points for $u > -0.7$ (GeV/c)^2 show that in this region the
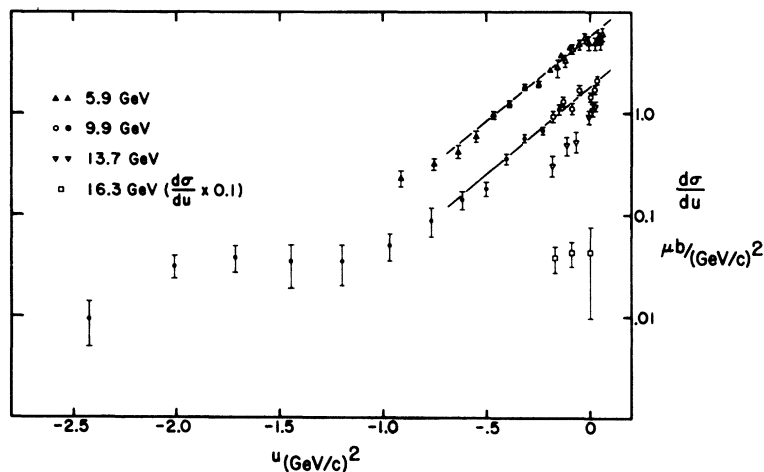

FIG. 2. Angular distributions of the backward π^--p elastic scattering. The open symbols are revisions of the results from Ref. 1. "u" is the square of the crossed four-momentum transfer and varies as $\cos\theta_{c.m.}$. The straight lines represent the least-squares fits described in the text. The 16.3-GeV/c results are plotted one decade lower.
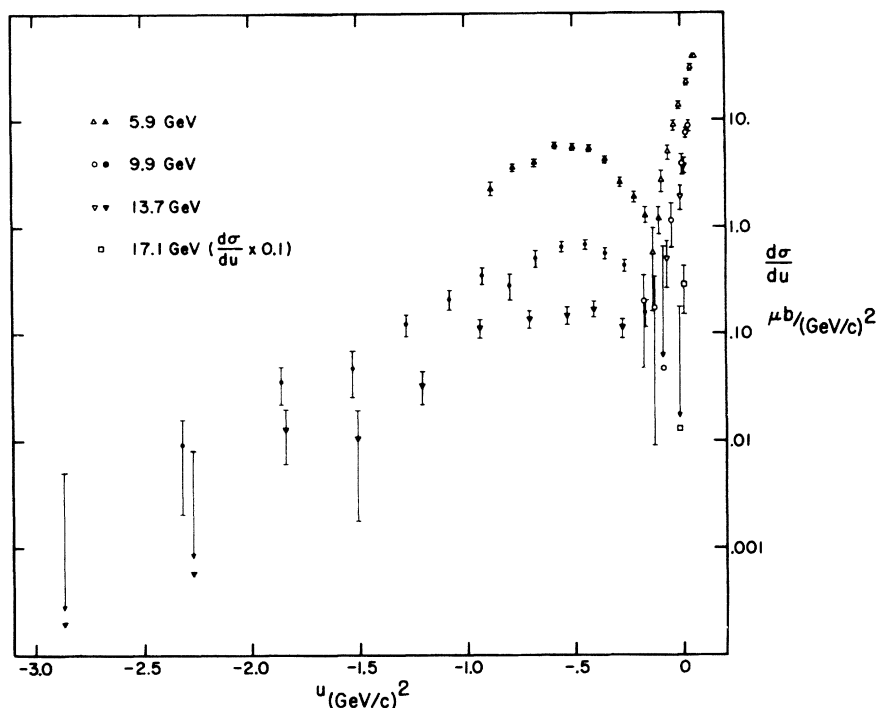
FIG. 3. Angular distribution of the backward π^+-p elastic scattering. The open symbols are revisions of the results from Ref. 1. The four "points" which represent upper limits are set at two standard deviations. The 17.1-GeV/c results are plotted one decade lower.

π^--p backward peaks are consistent with the shape $d\sigma/du \propto e^{Au}$, where $A = 3.81 \pm 0.13$ (GeV/c)$^{-2}$ for 5.9 GeV/c and $A = 3.96 \pm 0.19$ (GeV/c)$^{-2}$ for 9.9 GeV/c. These π^--p backward peaks are about twice as wide as most forward peaks.

The π^+-p backward peak has a sharp dip with a minimum at $u = -0.15$ (GeV/c)^2 at all energies. This dip has previously been observed at momenta up to 8 GeV/c.[2,3] Although our 5.9-GeV/c results are in quantitative disagreement with those of Ref. 2, the qualitative features remain. Our results are also in quantitative agreement with 8- and 16-GeV/c π^--p results of the BNL-Carnegie Tech group.[4] We note that the π^+-p dip at $u = -0.15$ (GeV/c)^2 may be so sharp as to be comparable with the bin widths of our points plotted in Fig. 3; hence our measured cross sections at the center of the dip may be significantly larger than the actual cross sections. At 9.9 GeV/c the ratio of the measured π^+-p to π^--p cross section at $u = -0.15$ (GeV/c)^2 is $\sim\frac{1}{7}$, so that the ratio of the actual cross sections could easily be $\frac{1}{9}$ or less. The ratio $\frac{1}{9}$ is of special interest since it is implied whenever the isospin-$\frac{1}{2}$ exchange amplitude is zero. A sharp dip in the π^+-p backward peak at $u \approx -0.15$ (GeV/c)^2 along with no dip

in the π^--p is readily understood by the Regge theory of baryon exchange,[5] with the $T = \frac{1}{2}$ exchange amplitude going through zero or through a pronounced minimum near $u = -0.15$ (GeV/c)^2. The Regge theory also predicts a general energy dependence of the approximate form $d\sigma/du \propto s^{2\alpha(u)-2}$. Our results show such an energy dependence and are consistent with $\alpha_N(u)$ and $\alpha_\Delta(u)$ corresponding to the usual Chew-Frautschi nucleon and Δ trajectories.[5,6] The π^+-p backward peaks close to 180° have about one-half the width of most forward peaks. This anomaly can be explained as a consequence of the zero predicted by Reggeized baryon exchange.

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EVIDENCE FOR LINEAR EXTRAPOLATIONS OF BARYON-EXCHANGE TRAJECTORIES THROUGH PARTICLE MASS SPECTRA*

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The N_α and Δ_δ Regge-trajectory functions in the scattering region are obtained from analysis of new data on backward $\pi^\pm p$ elastic scattering. At small $|u|$, the intercepts and slopes of both trajectories agree with straight-line extrapolations $\alpha = a + bu$ through the baryon masses. In the large $|u|$ region, the trajectories appear to be leveling off.

The appealing feature of the Regge-pole theory of hadron interactions is the conjectured connection between particle mass spectra and particle exchange amplitudes as expressed by the trajectory functions. This connection has not been entirely established up to the present either because of lack of adequate scattering data (for baryon-exchange reactions) or lack of established strings of particles (for meson-trajectory states). Fortunately, new data on $\pi^\pm p$ backward elastic scattering obtained by a Cornell-Brookhaven National Laboratory collaboration[1] now allows a check of the interrelationship of baryon exchange trajectories and the N^* resonance states.

In this Letter we present the essential results of a detailed analysis of the new Cornell-Brookhaven National Laboratory data[1] along with all other available high-energy data[2] (above 4 BeV/c) on backward $\pi^\pm p$ elastic scattering. Our findings are summarized in the following statements[3]:

(1) Both intercepts and slopes of the N_α and Δ_δ trajectories are in excellent agreement with straight-line extrapolations $\alpha = a + bu$ through the known resonance spectra.

(2) The N_α and Δ_δ trajectories at large $|u|$ appear to deviate from linear forms and may in fact be approaching constant limiting values at large $|u|$. If verified by more accurate data, this observation may indicate indirect evidence

for elementary-particle constituents (e.g., quarks) of the baryons.[4]

(3) The ratio of $\pi^- p$ to $\pi^+ p$ differential cross sections[1] in the $\pi^+ p$ dip region ($u \simeq 0.2$) appears to be roughly 9. Therefore, only N_α and Δ_δ trajectories are required to explain the data. Furthermore, in order to maintain this observed $\approx 9/1$ ratio the N_α trajectory can be allowed no appreciable $\sqrt{u}$ term. Possible contributions from an N_γ amplitude necessarily must be small.

In Figs. 1 and 2 the solid curves show our fits to the new data obtained with a Regge model with linear N_α and Δ_δ trajectories of the form

$$\alpha(\sqrt{u}) \simeq a + bu.$$

The trajectories were essentially determined by the data with $|u| < 1$ (BeV/c)^2. The fitted trajectory parameters are[5]

$$\alpha = -0.38 + 0.88u \text{ for } N_\alpha,$$

$$\alpha = +0.19 + 0.87u \text{ for } \Delta_\delta.$$

We estimate errors $\sim 20\%$ for the Δ_δ trajectory parameters and $<10\%$ for the N_α trajectory parameters. These should be compared with the Chew-Frautschi plot values[6]:

$$\text{Re}\alpha = -0.39 + 1.0u \text{ for } N_\alpha,$$

$$\text{Re}\alpha = 0.15 + 0.9u \text{ for } \Delta_\delta.$$