

HIGH-ENERGY  $\pi^-p$ ,  $K^-p$ , AND  $\bar{p}p$  ELASTIC SCATTERING\*A. Ashmore,† C. J. S. Damerell,‡ W. R. Frisken,§ and R. Rubinstein  
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Differential cross sections for elastic scattering of 6-GeV/c  $\pi^-$ ,  $K^-$ , and  $\bar{p}$  from protons have been measured in the angular range 25°-105° (c.m. system) and for 8-GeV/c  $\pi^-$  in the angular range 75°-115° (c.m. system). Structure in the angular distributions has been observed.

We report here results from a recent Brookhaven National Laboratory alternating-gradient synchrotron experiment on the study of high-energy elastic scattering of  $\pi^-$ ,  $K^-$ , and  $\bar{p}$  from protons; some data for  $\pi^\pm p$  scattering near 180° c.m. have already been reported.<sup>1</sup> In the present work, elastic scattering of  $\pi^-$ ,  $K^-$ , and  $\bar{p}$  from protons at 6 GeV/c has been measured for center-of-mass angles 25°-105°; measurements for 8 GeV/c  $\pi^-$  at center-of-mass angles 75°-115° have also been made. (Actual beam momenta were 5.8, 5.9, and 7.9 GeV/c.)

The experimental arrangement is shown in Fig. 1. A beam defined by scintillation counters was incident on a 2-ft long liquid-hydrogen target; the type of particle was determined by one

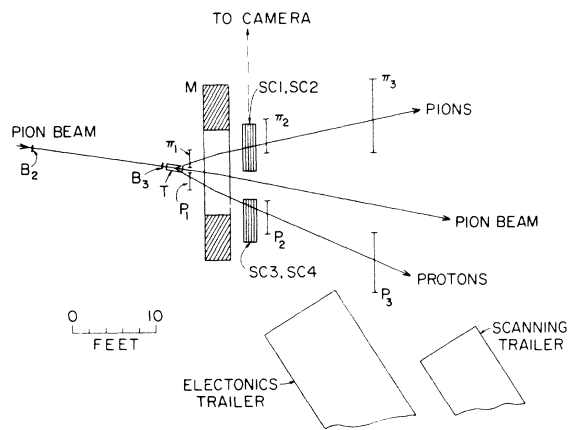


FIG. 1. Experimental layout.  $SC_1$ ,  $SC_2$ ,  $SC_3$ , and  $SC_4$  are optical spark chambers;  $\pi_1$ ,  $\pi_2$ ,  $\pi_3$ ,  $P_1$ ,  $P_2$ , and  $P_3$  represent banks of scintillation counters;  $M$  is the large-aperture magnet;  $B_2$  and  $B_3$  are beam scintillation counters;  $T$  is the liquid-hydrogen target. Not shown are a counter  $B_1$  and one threshold and two differential gas Cherenkov counters in the incident beam. Also not shown are several anticoincidence counters placed in the vicinity of the hydrogen target.

threshold and two differential gas Cherenkov counters. Scattered and recoil particles were momentum analyzed by magnet  $M$ , with an aperture 10 ft wide  $\times$  2 ft high  $\times$  3 ft long, and detected by a number of scintillation-counter telescopes shown as  $\pi_1$ ,  $\pi_2$ ,  $\pi_3$ ,  $P_1$ ,  $P_2$ ,  $P_3$ ; there were typically six such telescopes for each particle. A coincidence between a beam particle, a pion telescope, and a proton telescope caused the optical spark chambers  $SC_1$ - $SC_4$  to be pulsed. With a beam of  $\sim 5 \times 10^5$  particles (mostly  $\pi^-$ ) per pulse, the trigger rate was  $\sim 1$  per 3 pulses.

In the analysis of the photographs, the pion (or kaon or antiproton) track was assumed to come from an elastic event and its trajectory extrapolated back through the magnet to the target and required to pass through a fiducial volume. For tracks satisfying this criterion, the corresponding elastic-scattering proton trajectory was calculated; the differences between the position and angles of this track and the track observed in the proton spark chamber were then determined. In this way it was possible to separate elastic from inelastic events; inelastic background under the elastic peak was always less than 10%. Elastic events were between 2 and 70% of the total number of triggers, depending on angle and energy.

Corrections were applied to the data for target-empty rate, for muon and electron contamination of the pion beam, for decay of the scattered pion or kaon, and for absorption of particles in scintillators, target, and other material. Solid angle acceptance was determined by a Monte Carlo calculation. All results presented are given with statistical errors only; additional systematic uncertainties of  $\pm 15\%$  are not included.

Results obtained for 6- and 8-GeV/c  $\pi^-$  are shown in Fig. 2, together with some earlier data at 8 GeV/c.<sup>2</sup> The 6-GeV/c data were taken with two slightly different experimental arrangements,

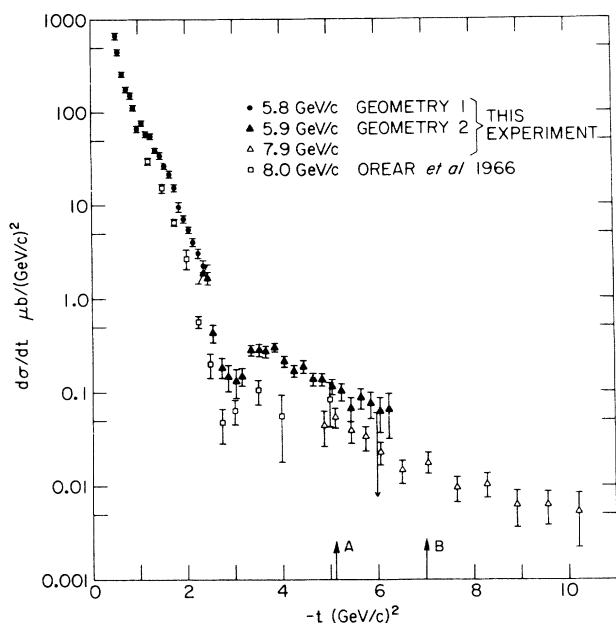


FIG. 2. Angular distributions for  $\pi^-p$  elastic scattering. The data at small  $|t|$  for 8.0 GeV/c are from Ref. 2. The arrows on the abscissa marked A and B indicate  $90^\circ$  (c.m. system) for 5.9 and 7.9 GeV/c, respectively.

designated Geometry 1 and Geometry 2. The structure seen in the differential cross section at  $-t \approx 1.0$  (GeV/c) $^2$  has been observed previously $^{2-4}$  and is much more pronounced at lower energies. In addition, a prominent dip is seen at  $-t \approx 3.0$  (GeV/c) $^2$  at both 6 and 8 GeV/c. At the largest momentum transfers measured, the differential cross sections at these two momenta continue to decrease and are a factor of 2 to 3 apart.

In Fig. 3(a), we show the 6-GeV/c  $\bar{p}-p$  data. At the smallest momentum transfers measured, we see a decrease in cross section. This is consistent with previous measurements at lower energy $^5$  which show a dip at  $-t \approx 0.5$  (GeV/c) $^2$ . There is also evidence for a second dip at  $-t \approx 1.8$  (GeV/c) $^2$ .

$K^-p$  results at 6 GeV/c are shown in Fig. 3(b) and possibly give evidence for some structure at  $-t \approx 0.9$  (GeV/c) $^2$ , as in the  $\pi^-p$  case; the statistical accuracy is not sufficient to see if there is any structure at larger angles.

In all the cross sections measured, data at our smallest  $|t|$  values are in agreement with other measurements made closer to the forward direction. $^{3,6-8}$

A comparison of the cross sections for  $\pi^-$ ,  $K^-$ , and  $\bar{p}$  at 6 GeV/c shows that they all have

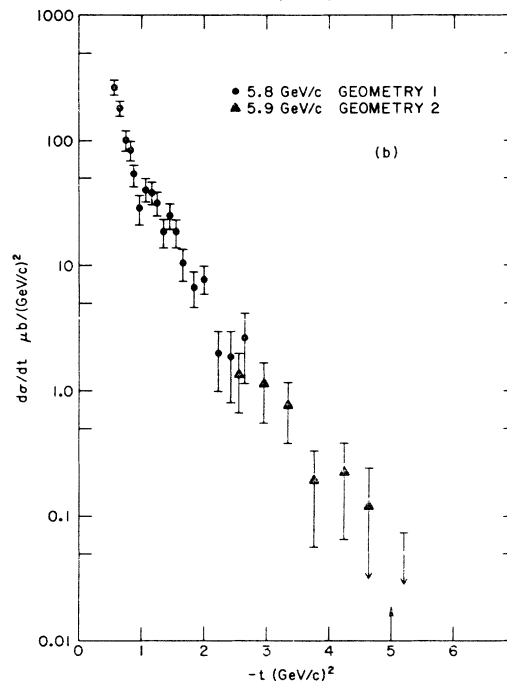
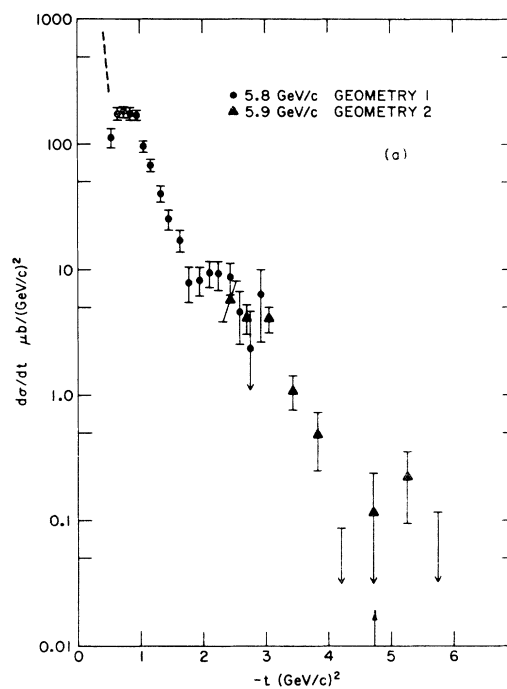


FIG. 3. Angular distributions for (a)  $\bar{p}-p$  elastic scattering, and (b)  $K^-p$  elastic scattering. The dashed line in (a) indicates the trend of the angular distribution at smaller angles from Refs. 6 and 7. Arrows on the abscissas indicate  $90^\circ$  (c.m. system). When no events were observed in a bin, an upper limit is shown corresponding to one event.

roughly the same order of magnitude, while all falling by three decades in the region measured, and the  $\pi^-$  and  $\bar{p}$  at least show considerable

structure. This is in contrast to results for  $p$ - $p$ <sup>9</sup> and  $n$ - $p$ <sup>10</sup> 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 (GeV/c)<sup>2</sup>, as found for the  $\bar{p}$ - $p$  scattering, and that a radius of 0.9 F gives minima in reasonable agreement with the  $\pi^-$ - $p$  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  $\pi^+$ - $p$  scattering has been measured over the angular range  $135^\circ < \theta_{c.m.} < 180^\circ$  for pion laboratory momenta of 5.9, 9.9, and 13.7 GeV/c and also for  $\pi^-$ - $p$  at 5.9 and 9.9 GeV/c. More limited angular distributions are presented for  $\pi^-$ - $p$  at 13.7 and 16.3 GeV/c and  $\pi^+$ - $p$  at 17.1 GeV/c. In both the  $\pi^-$ - $p$  and  $\pi^+$ - $p$  scattering the cross section rises by over 2 orders of magnitude in the backward direction; for  $\pi^+$ - $p$  only, there is a sharp dip at  $u = -0.15$  (GeV/c)<sup>2</sup>.

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  $165^\circ < \theta_{c.m.} < 180^\circ$ .<sup>1</sup> In the present work a different experimental arrangement shown in Fig. 1 extended the angular range to  $\theta_{c.m.} \approx 135^\circ$ . Both the scattered protons and pions were observed in thin-plate spark chambers after magnetic analysis as shown in Fig. 1. The spark-