

New Measurements of Polarization and Differential Cross Sections in K^+p Elastic Scattering in the 1.7–3-GeV/ c Range*

R. Patton, W. A. Barletta,[†] R. D. Ehrlich, A. Etkin,[‡] P. A. Souder, and M. E. Zeller
J. W. Gibbs Laboratory, Yale University, New Haven, Connecticut 06520

and

M. Mishina

J. W. Gibbs Laboratory, Yale University, New Haven, Connecticut 06520, and University of Tokyo, Tokyo, Japan

and

D. M. Lazarus

Brookhaven National Laboratory, Upton, New York 11973

(Received 30 December 1974)

We have measured the polarization parameter and differential cross sections in K^+p elastic scattering from a polarized target from small $|t|$ and small $|u|$ at five momentum points: 1.7, 2.1, 2.4, 2.7, and 3.0 GeV/ c . The polarized-proton target was butanol cooled at 0.5° by a ^3He – ^4He refrigerator; a combination of multiwire proportional chambers and scintillation counters detected the scattered particles. The results for small $|u|$ are discussed in the context of pure Regge-pole models with exchange-degenerate Λ trajectories.

Amplitudes for K^+p elastic scattering constructed from pure pole exchange in the u channel, with degenerate Λ and Σ trajectories, yield predictions of zero polarization in the backward direction (small $|u|$) and a monotonic energy dependence of the 180° differential cross sections.¹ While published measurements indicate small backward polarizations, they are of limited statistical accuracy and do not extend above 2.1 GeV/ c in incident beam momentum.² Previous measurements of the 180° cross sections,³ as a function of beam momentum, have shown a deviation from the monotonic behavior predicted by such models.⁴ This anomaly, occurring between 2 and 3 GeV/ c laboratory momenta, might be due to unexplained structure in the amplitudes, possible systematic errors in previous experiments,⁵ or a combination of the two. Our measurements were thus made in order to resolve these questions and to test the hypotheses of a pure pole-exchange Regge model.

Since the forward-to-backward ratio of differential cross sections is large in K^+p elastic scattering, we have also measured polarizations and angular distributions in the forward direction with significantly higher statistical accuracy than previously obtained.²

The apparatus is shown in Fig. 1. The partially separated beam, derived from the G10 internal target at the Brookhaven National Laboratory (BNL) alternating-gradient synchrotron, con-

tained from 8×10^3 K^+ /pulse at 1.7 GeV/ c to 5×10^4 K^+ /pulse at 3.0 GeV/ c . This beam was incident on the polarized target after passing through trigger counters S1–S3, a gas differential Čerenkov counter (\check{C}_B), a scintillation counter hodoscope (BH), and two multiwire proportional chambers (PWC's). Lack of a count in scintillation counter S4 indicated that the particle had

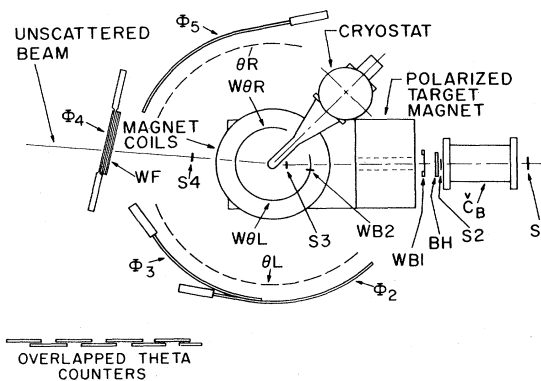


FIG. 1. Plan view of the experimental apparatus. W0L, W0R, and WF are proportional wire chambers; θ_R and θ_L are vertical scintillation counters overlapped as shown in the lower left-hand corner. Φ_2 , Φ_3 , Φ_4 , and Φ_5 are scintillation counters measuring distance perpendicular to the plane. Φ_2 and Φ_5 are orange-peel shaped to keep an approximately constant acceptance in Φ . The polarized-target magnetic field is perpendicular to the plane of the drawing.

interacted in the target. The horizontal angles of the trajectories of the scattered particles were determined to $\pm 1^\circ$ by a set of cylindrically shaped PWC's, $W_{\theta L}$ and $W_{\theta R}$, nested in the magnet coils and by scintillation counters, θL and θR . In addition, the forward-going particle was detected by a flat PWC, WF , with $\pm 0.3^\circ$ resolution. The vertical angles of the trajectories were determined by curved scintillation counters, Φ , located directly behind θL , θR , and WF .

The target, similar to one built at CERN,⁶ was maintained in a 25-kG magnetic field at a temperature of $\sim 0.55^\circ\text{K}$ by a ^3He - ^4He refrigerator. The unbound protons in the butanol target, $\frac{1}{4}$ of the total number of protons, had an average polarization of 60%. Dimensions of the target were 1.27 cm vertically, 2.03 cm horizontally, and 2.29 cm along the beam. Polarization directions were reversed approximately eight times per momentum point.

A PDP-15 computer collected the data through a CAMAC interface. For each event the computer recorded on magnetic tape the scintillation counters and wire chamber channels participating in the event along with the pulse height of the beam Čerenkov counter. Condensation of the primary data, i.e., removal of obviously unconstructable events, was performed on the PDP-10 at the BNL on-line data facility; final event reconstruction and analysis was completed at the BNL computing facility on the CDC 6600's.

Kinematic reconstruction was done by minimizing a linearized χ^2 where the actual wire and counter coordinates were fitted to those expected from an elastic-scattering hypothesis. The num-

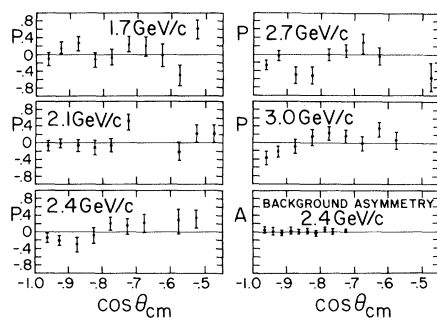


FIG. 2. Polarization parameter, P , at each momentum point plotted against the cosine of the center-of-mass scattering angle in the backward direction, and the asymmetry of the background at 2.4 GeV/c plotted against the cosine of the center-of-mass scattering angle.

ber of elastic events in each bin of $\cos\theta_{c.m.}$ (cosine of the center-of-mass scattering angle) was determined from two dimensional histograms of χ^2 versus coplanarity, $\Delta\phi$. These χ^2 - $\Delta\phi$ histograms were divided into signal and background regions; the background region was then fitted by a polynomial in χ^2 and $\Delta\phi$ which was used to extrapolate the background underneath the elastic peak.

As is the usual situation in polarized-target experiments, the largest single source of background is due to quasi-elastic scattering of kaons from bound protons in the complex target nuclei. This background has only a small probability of kinematically simulating elastic scattering in our apparatus; the signal-to-background ratios in the forward directions were $\sim 5.5:1$. Because the forward cross sections can be as much as 200 times greater than those in the back, the signal-to-noise ratios were worse for backward scattering, ranging from 3:1 in the -0.96 region of $\cos\theta_{c.m.}$ to 1.5:1 in the -0.7 region.

Measured polarizations are shown in Figs. 2 and 3; the sign is determined by the Basel convention.⁷ Also shown in Fig. 2 are typical asymmetries of events in the background regions. The errors shown are statistical only and do not include possible systematic errors on target polarization, $< 7\%$, or background hypothesis, $< 7\%$, both of which would appear as scale errors on the absolute value of the polarization. Systematic uncertainty in beam normalization, which would cause additive effects in the measured asymmetries, were $< 2\%$ as can be seen in Fig. 2.

In the backward direction, for our three higher momentum points, the data suggest a systematically negative polarization. That the background

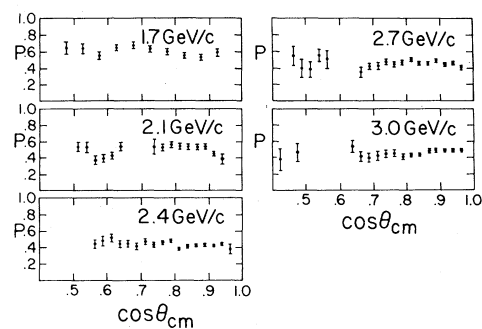


FIG. 3. Polarization parameter, P , at each momentum point plotted against the cosine of the center-of-mass scattering angle in the forward direction.

shows no such asymmetry supports this conclusion. Such a phenomenon contradicts the predictions of pure Regge-pole exchanges with degenerate trajectories. New results⁸ of observation of nonzero polarization in $K^+p \rightarrow K^0n$ have

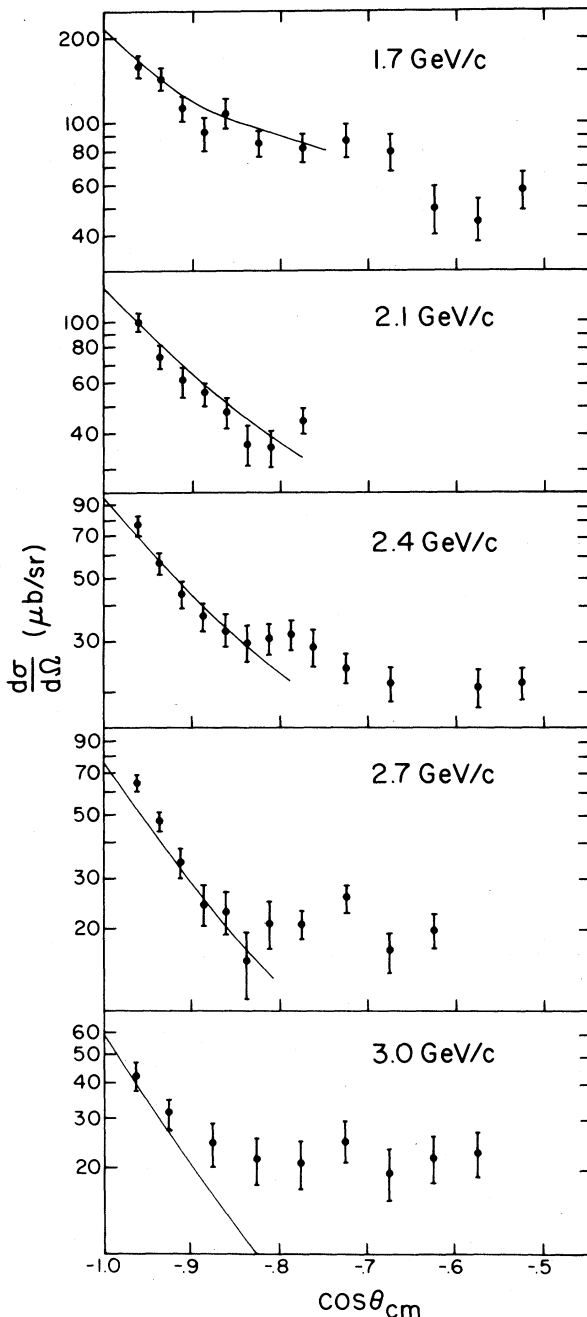


FIG. 4. Differential cross sections at each momentum point plotted against the cosine of the center-of-mass scattering angle in the backward direction. The curves through the data are the results of a Regge-pole model described in the text.

also indicated the necessity of a more complex description of KN scattering.⁹

The forward-direction polarization is remarkably constant as a function of both scattering angle and beam momentum. This constancy persists to very low values of $|t|$; most notably at 3.0 GeV/c, where the most forward point is $t = -0.086$ GeV/c.³ This effect has been observed in the past at lower energies,² albeit not with as high a statistical accuracy as here shown.

The backward differential cross sections are displayed in Fig. 4. Absolute normalization of these data was determined by the normalization of our forward differential cross section data to the optical points of published data.^{3,10} The scale factor needed to obtain agreement between our data and published data was approximately 1.15, independent of momentum. The uncertainty in this normalization is approximately 8%, due mainly to uncertainties in the published data. Slopes of the forward differential cross sections as a function of angle are in agreement with published data. Normalization of the backward cross sections is made using the same scale factor as that employed for the forward data in addition to knowledge of the acceptance of the apparatus as calculated by Monte Carlo techniques.

The smooth lines through the data of Fig. 4 are the results of a fit made in the backward direction with a pure Regge-pole model employing exchange degenerate Λ_α and Λ_γ trajectories. While the fit is qualitatively correct, we cannot adequately reproduce the slope variations in the backward peaks or the behavior of the cross section at 180° as determined by straight-line extrapolation of the data.

Extrapolations of the backward differential cross sections to 180° by means of a fit of the form $d\sigma/d\Omega = A \exp[B(1 - \cos\theta_{c.m.})]$ are shown in Fig. 5. Also shown in this figure are equivalent extrapolations of published data. As can be seen, our data are higher than the previous results of Carroll *et al.* at 1.7 and 2.1 GeV/c, and are in good agreement with Whitmore *et al.* at higher momentum points.³ Our data indicate that the anomalous behavior of the cross section is not as pronounced as previously measured; however, we find that the backward cross sections for momenta above 1.7 GeV/c show a deviation, both in slope and in value at 180° , from any smooth fit connecting the published data at lower and higher momenta.

We gratefully acknowledge the help given us by the administration, operators, and support

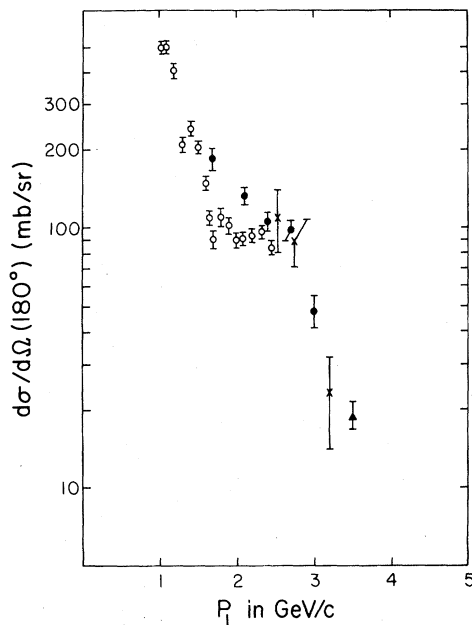


FIG. 5. Extrapolated differential cross sections to $\theta_{c.m.} = 180^\circ$. Closed circles are results of this experiment; open circles, Carroll *et al.*; X's, Whitmore *et al.*; triangle, Banaigs *et al.* (Ref. 3).

personnel at BNL. We also are indebted to Dr. J. Vermeulen and Dr. P. Roubeau for their help and advice in constructing the polarized target.

*Research supported by the U. S. Atomic Energy Commission under Contract No. AT(11-1) 3075 and by the

Japan Society for the Promotion of Science.

†Present address: Lawrence Livermore Laboratory, Livermore, Calif. 94550.

‡Present address: City College of New York, New York, N. Y. 10031.

¹V. Barger, Phys. Rev. **179**, 1371 (1969); E. L. Berger and G. C. Fox, Phys. Rev. **188**, 2120 (1969); E. J. Sacharidis, Nucl. Phys. **B69**, 157 (1974). We assume that the trajectory functions, α , are functions of u rather than of \sqrt{u} .

²M. G. Albrow *et al.*, Nucl. Phys. **B30**, 273 (1971); J. G. Asbury *et al.*, Phys. Rev. Lett. **23**, 194 (1969); B. A. Barnett *et al.*, Phys. Lett. **34B**, 655 (1971); R. D. Ehrlich *et al.*, Phys. Rev. Lett. **26**, 925 (1971).

³A. S. Carroll *et al.*, Phys. Rev. Lett. **21**, 1282 (1969); J. Banaigs *et al.*, Nucl. Phys. **B9**, 640 (1969); D. Cline, C. Moore, and D. Reeder, Phys. Rev. Lett. **19**, 675 (1967); J. Whitmore *et al.*, Phys. Rev. D **3**, 1092 (1970).

⁴G. S. Abrams *et al.*, in *Hyperon Resonances—70*, edited by E. C. Fowler (Moore Publishing Co., Durham, N. C., 1970), p. 53.

⁵C. Lovelace and F. Wagner, Nucl. Phys. **B24**, 141 (1970). This possibility was suggested as a result of inconsistencies between data of different experiments.

⁶P. Roubeau and J. Vermeulen, Cryogenics **11**, 478 (1971).

⁷For definition of Basel convention, see Helv. Phys. Acta, Suppl. No. 6, Fourth Cover (1961).

⁸W. Beusch *et al.*, Phys. Lett. **46B**, 477 (1973).

⁹C. Meyers and Ph. Salin, Nucl. Phys. **B19**, 237 (1970). These authors generated polarization in $K^+p \rightarrow K^0n$ by absorptive corrections involving Pomeron-Regge-pole interference.

¹⁰K. Abe *et al.*, University of Maryland Technical Report No. 74-023, 1973 (unpublished); P. C. Barber *et al.*, Nucl. Phys. **B61**, 125 (1973).

Dependence of Transverse-Momentum Distributions of π^- 's on P_\perp of a Proton in pp Interactions at 28.5 GeV/c*

T. S. Clifford, E. Lazarus,† G. P. Larson,‡ W. N. Schreiner, P. Schübelin, F. Turkot,§ and L. von Lindern||

Brookhaven National Laboratory, Upton, New York 11973

(Received 4 February 1975)

We present transverse-momentum distributions of π^- 's produced in the reaction $p_1 p_2 \rightarrow p_3 X$ at 28.5 GeV/c observed by the Multiparticle Argo Spectrometer System. As the transverse momentum of the trigger proton p_3 is raised from 0.4 to 1.6 GeV/c we find that the shape of the π^- momentum distribution *normal* to the (p_1, p_3) plane remains unchanged. The shape of the distribution *in* the plane is also relatively constant but the distribution shifts to balance transverse momentum.

In inelastic high-energy particle collisions there is considerable interest¹ in the details of how the transverse momentum of a high- P_\perp particle is balanced by the other particles. Furthermore, changes in the shape of the momentum dis-

tribution of the produced pions normal to the plane defined by the incident and high- P_\perp particle as a function of the high- P_\perp particle's transverse momentum may provide insight into hadronic structure. Specifically, one expects quite