dicate that at four-momentum transfers in the vicinity of 1.5 $(\mathrm{BeV}/c)^2$, the 1512-MeV resonance may be excited predominantly by scalar amplitudes. In addition, a comparison of the ratio of the 1512- to the 1238-resonance excitation as a function of electron scattering angle, using the data of Cone et al. and Brasse et al., suggests a significant scalar contribution to the excitation of the 1512 resonance.

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K^+p BACKWARD SCATTERING IN THE REGION FROM 1.0 TO 2.5 GeV/c*

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Elastic scattering of K^+ mesons from protons in the backward direction has been measured to high accuracy. The data indicate that baryon exchange is extremely important for $p_{\mathrm{lab}}(K) > 1.8$ GeV/c. A phase-shift analysis of the data suggests the existence of a $P_{1/2}$ resonance in the K^+p system at a mass of approximately 2 GeV/c^2.

We report on results of backward elastic scattering of K^+ mesons from protons[1] with high statistical accuracy in the momentum region from 1.0 to 2.5 GeV/c. The angular region covered was from $\cos\theta_{\mathrm{c.m.}} = -1.00$ to -0.70 on the average. The partially separated beam of the Brookhaven alternating-gradient synchrotron was used yielding of the order of 10^4 kaons[2] per pulse with a π/K ratio varying between 1 and 4; $\Delta p/p$ was ± 0.01 at the higher momenta and ± 0.02 at low momenta.

The experimental apparatus is shown in Fig. 1 and consists of three arrays of four wire spark chambers each with magnetostrictive read-out.[3] Both x and y coordinates were determined in each chamber, and were recorded on magnetic tape through a PDP-8 computer which was used for on-line control and some simple checks.[3] The first array of chambers was positioned at 45° to the beam line and detected both the incoming and scattered kaon track. After traversing this first array the beam was incident on a $7\frac{1}{2}$-in. long liquid-hydrogen target. The scattered proton traversed the second array of chambers which was positioned normally to the beam line. The directional information on the incoming and two scattered tracks as well as the incident kaon momentum suffice to determine elastic events, which were selected on the basis of (1) coplanarity (± 0.015 for normalized coplanarity), (2) kine-

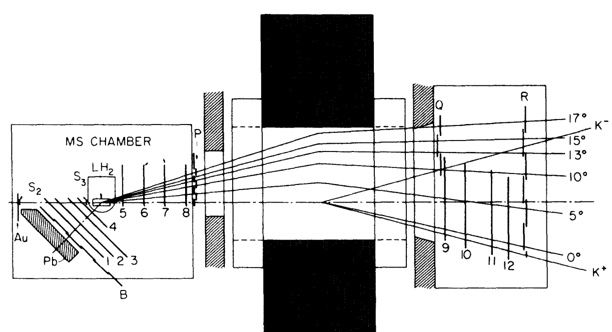

FIG. 1. The experimental apparatus drawn to scale. MS_{1-4}, MS_{5-8} and MS_{9-12} are digitized wire spark chambers. Arrays B, P, and R are the triggering counters. Typical trajectories through the system are shown.

matic angles (±20 mrad for the difference between observed and calculated proton angle), (3) the copunctuality of the three tracks (<0.6 cm), and finally (4) vertex within the hydrogen volume.[4]

For events where the proton laboratory angle was less than 10° the proton track was recorded in the third array of chambers after having traversed the $48\times48\times18$-in.[3] magnet. This overconstrains the event and provides a useful overall check of our event selection, etc., and also reduces the inelastic background to the order of 10^{-31} cm^2/sr even for $\cos\theta_{\mathrm{c.m.}}=0.998$.[5] This spectrometer arrangement was used to measure the incident beam momentum for each run, which is therefore known to ±20 MeV/c.

The spark chambers were triggered by appropriate scintillation counters at rates from 1 to 5 triggers per pulse. The spark chamber information stored on the magnetic tapes was processed off-line on the Brookhaven CDC-6600 computer within a few hours. A special program written by one of us (A.S.C.) performed geometrical reconstruction, filtering, application of rough selection criteria, final selection, etc. The overall efficiency of the spark chamber system for detection of an event was of the order of 98% and was continuously monitored.

The detection efficiency of the system was obtained by performing a Monte Carlo calculation. This included the solid angle covered by the spark chambers, the decay correction for the kaons, and multiple scattering and nuclear interactions in both the hydrogen target and other material in the beam path. The incident flux was counted directly. No other corrections were applied. However, we believe that a small uncertainty, not exceeding 7%, may still exist in the relative normalization between some sets of data taken at different momenta.[6] The same error applies to our knowledge of the absolute normalization of the overall data.

In Fig. 2 are shown 16 angular distributions obtained at approximately 100-MeV/c intervals. Each of these distributions contains on the average over 1000 events. One notices that the dis-

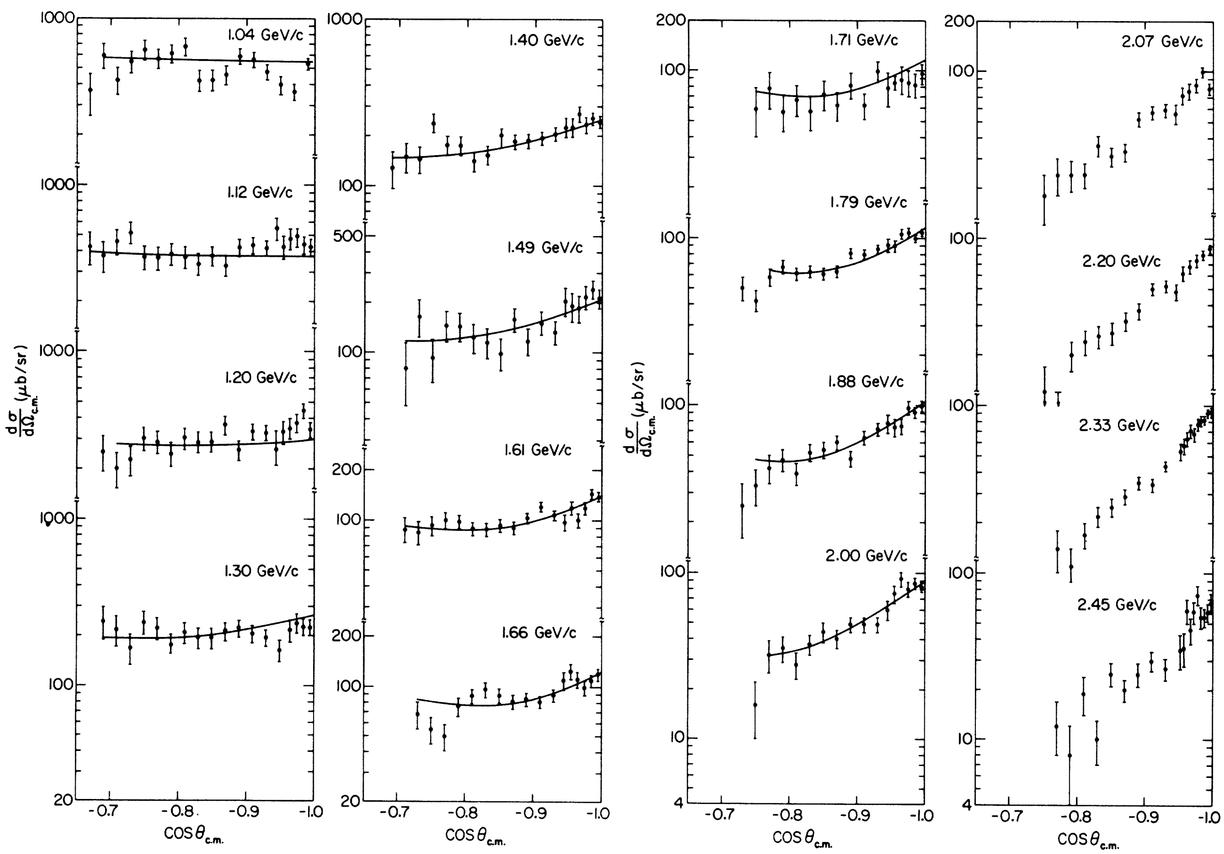

FIG. 2. Angular distributions $d\sigma/d\Omega$ for backward elastic scattering of K^+ mesons from protons. The solid lines are the fits obtained from a phase-shift analysis of all K^+p data up to 2.0 GeV/c (see text and following paper).

tributions are relatively flat until about 1.8 GeV/c, when a backward peak begins to develop and becomes more prominent at the higher momenta with slopes typically of e^{+8u}. Such behavior is indicative of baryon exchange[7] (in this case a Λ^0, Y^0, etc.); this view is further supported by the complete absence of peaks and a five to ten times lower backward cross section for K^-p scattering[8] where the exchange baryon would have to be a Z^{++} ($B=1, S=+1$ state).

If the detailed structure of the backward peaks (for example, at 2.32 GeV/c) is examined as a function of u, one finds evidence for a distinct break in the slope of the data at $u = -0.07$ (GeV/$c)^2$, with an indication of a small dip at this value of u.[9] If one then assumes that the exchange amplitude is correctly described by a Regge theory,[10] a zero of the contribution from the leading trajectory, assumed to be Λ_α, would occur when $a_{\Lambda\alpha} = -\frac{1}{2}$; a simple straight-line extrapolation of the $\Lambda\alpha$ trajectory places this zero at $u=0.2$, but a curvature in the trajectory could place it nearer the position of the observed break. We also remark that π^+p backward scattering[11] at the same total c.m. energy [$s=5.75$ (GeV/$c)^2$] shows the same slope, e^{+8u}, whereas the K^+p data[12] at 7 GeV/c [$s=14.3$ (GeV/$c)^2$] have a slope, $e^{+3.5u}$, consistent with our data in the region $u < -0.05$ (GeV/$c)^2$.

In Fig. 3 we show the behavior of the differential cross section $d\sigma/d\Omega$ at 180° as a function of incident kaon momentum.[13] The errors shown include a 7% contribution from systematic effects which may have affected the relative normalization at different momenta. Data from other experiments are also included.[14,15] While no prominent structure appears in the 180° cross section, nevertheless three broad shoulders emerge in the vicinity of 1.15, 1.45, and 2.0 GeV/c.[16] The backward peak develops on the last shoulder and therefore may be related to the observational onset of the hyperon-exchange mechanism. The shoulders may well be due to the interference of this exchange amplitude with direct-channel amplitudes which decrease with increasing energy.

The observed structure of the 180° cross section, to the accuracy measured, is too weak to permit definite statements about the existence of resonant states in the direct channel.[17] For this reason, but also in order to provide a systematic phenomenological analysis of these data, Martin[14] has extended the energy-dependent phase-shift analysis of all K^+p elastic scattering up to 2.0 GeV/c. The results of this analysis are re-

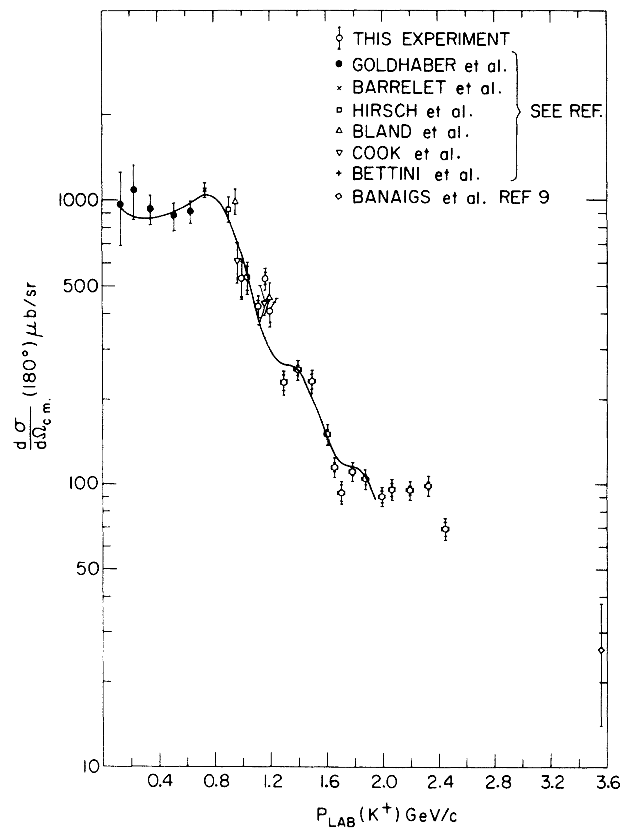

FIG. 3. The 180° differential cross section for K^+p elastic scattering as a function of incident K^+ momentum. The smaller error bars are only statistics, while the larger ones contain a 7% systematic uncertainty in relative normalization. The solid line is the cross section as obtained from a phase-shift analysis of all K^+p data up to 2.0 GeV/c (see text and following paper).

ported in the following Letter and indicate the possible existence of a $P_{1/2}$ resonance in the K^+p system with mass $m \simeq 2.0$ GeV/c^2 [$P_{\rm lab}(K) \simeq 1.46$ GeV/c], width $\Gamma \simeq 0.22$ GeV/c^2, and elasticity $\eta \simeq 0.1$.

The differential cross sections obtained from the phase-shift analysis are indicated by the solid lines in Fig. 2. One notes that the fits are quite satisfactory in general. Similarly the values of the 180° cross section obtained from the phase-shift analysis are indicated by the solid line in Fig. 3; again the agreement is quite satisfactory.

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‡During the performance of the above experiments the authors held guest appointments at Brookhaven National Laboratory, Upton, N.Y.

§Part of this work is the subject of a thesis to be submitted by S. Tewksbury in partial fulfillment of the requirements for the degree of Doctor of Philosophy at the University of Rochester, Rochester, N.Y.

[1]Using part of the same apparatus, we have previously measured π^+p and π^-p backward scattering. A. S. Carroll et al., Phys. Rev. Letters 20, 607 (1968).

[2]K mesons were selected by means of a liquid-radiator differential Čerenkov counter, with a pion contamination of ~0.003. We thank Dr. B. Leontić and collaborators for permission to use this counter.

[3]J. Fischer, in Proceedings of the International Conference On Electromagnetic Interactions, Dubna, U.S.S.R., February 1967 (Academy of Sciences, U.S.S.R., Moscow, 1967), Vol. 4, p. 179, and Brookhaven National Laboratory Report No. 11031 (unpublished).

[4]These criteria suffice to reduce the background from inelastic events to a few μb/sr.

[5]The presence of the magnet permits us to use a trigger which is sensitive to 0° protons and yet does not count the incident-beam K^+ mesons.

[6]We expect however that further analysis of the data will reduce the relative error between different momenta to the same level (~3%) as the statistical error.

[7]In particular, since the direct channel of the K^+p system is known not to have any strong resonances.

[8]These data were taken with the same apparatus and will be published later.

[9]A very pronounced dip occurs in π^+p backward scattering at higher energies for $u=-0.15$. See A. Ashmore et al., Phys. Rev. Letters 19, 460 (1967). See also V. Barger and D. Cline, ibid. 19 1504 (1967).

[10]An expansion of the scattering amplitude calculated from a Regge-pole theory for a single trajectory exchange is of the form

$$R(\sqrt{u}, s) = (\alpha+\tfrac{1}{2})(\alpha+\tfrac{3}{2})\gamma \frac{1+i\tau e^{-i\pi\alpha(u)}}{\cos(\pi\alpha)}\left(\frac{s}{s_0}\right)^{\alpha(u)-\frac{1}{2}},$$

which is zero for $\alpha=-\frac{1}{2}$ provided the signature τ is even and the residue function γ is finite. See, for example, C. B. Chiu and J. D. Stack, Phys. Rev. 153, 1575 (1967); V. Barger and D. Cline, Phys. Rev. 155, 1792 (1967).

[11]In the case of π^+p backward scattering, however, the contribution from direct-channel resonances must be important at this energy. (See Ref. 1.) Thus the agreement may be fortuitous.

[12]Preliminary results obtained from a recent run at CERN. A. Lundby, private communication.

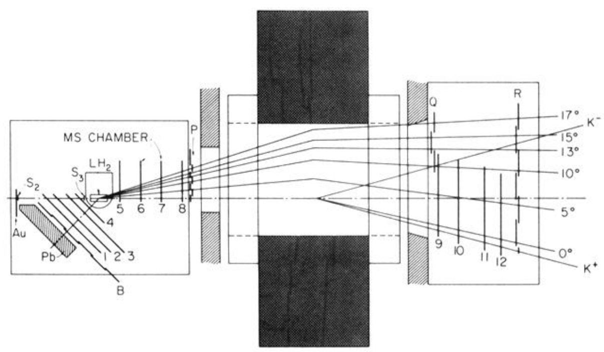
[13]The 180° cross sections were obtained by extrapolating the data between $\cos\theta_{\text{c.m.}}=-0.95$ and -0.99 according to the form $e^{-x\cos\theta}$.

[14]A. T. Lea, B. R. Martin, and G. C. Oades, Phys. Rev. 165, 1770 (1968). In this paper can be found a complete list of references on K^+p elastic scattering below 1.5 GeV/c.

[15]J. Banaigs et al., Phys. Letters 24B, 317 (1967).

[16]The backward elastic cross section must reflect the small variations observed in the recent precise measurements of the K^+p total cross section. R. L. Cool et al., Phys. Rev. Letters 17, 102 (1966); R. J. Abrams et al., ibid. 19, 259 (1967); W. M. Bugg et al., Phys. Rev. 168, 1466 (1968).

[17]Arguments have been frequently advanced that the 180° elastic cross section can be used to infer the existence of resonances in the direct channel. S. W. Kormanyos et al., Phys. Rev. Letters 16, 709 (1966); F. Ned Dikmen, ibid. 18, 798 (1966), V. Barger and D. Cline, Phys. Rev. 155, 1792 (1967). This, however, does not mean a direct correspondence of bumps and/or valleys of the 180° cross section with direct-channel resonances (see Ref. 1).



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