ASYMMETRY AND DIFFERENTIAL CROSS SECTION FOR ELASTIC SCATTERING OF K^+ MESONS BY POLARIZED PROTONS AT 1.54 AND 1.71 GeV/c *

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The asymmetry and differential cross section for elastic scattering of K^+ mesons from polarized protons have been measured at meson momenta of 1.54 and 1.71 GeV/c, and these new data have been included in an energy-independent phase-shift analysis. The $P_{3/2}$ wave obtained displays some resonancelike character.

Search for strangeness $S=+1$ baryon states has drawn attention to the study of the K^+-meson–proton interaction. Measurements of the total cross section with precision,[1] photoproduction of K^- mesons,[2] backward elastic scattering,[3] and elastic scattering below 1.5 GeV/c with subsequent phase-shift analyses[4] of these data initially suggested that such resonances might exist; however, measurements of the inelastic cross section and further analysis[5] cast doubt on their existence. Recent investigation of the elastic channel between 0.86 and 1.91 GeV/c using polarized targets[6,7] has indicated a resonancelike behavior for the $P_{3/2}$ partial wave, but has definitely precluded substantial resonance in other partial waves of this channel. We report[8] measurements of the asymmetry and differential cross section for elastic scattering of K^+ mesons from polarized protons for meson momenta of 1.54 and 1.71 GeV/c, and the results of an energy-independent phase-shift analysis which corroborate other recent studies of the elastic channel.

The experimental arrangement is shown in Fig. 1. K^+ mesons with a ±2% momentum interval from the partially separated beam No. 5 at the alternating-gradient synchrotron (AGS) at Brookhaven National Laboratory were identified by an ethylene-gas differential Cherenkov counter CB and were focused onto a 3-cm by 2-cm by 2.5-cm-thick lanthanum magnesium nitrate (LMN) target[9] containing protons with 0.60 polarization. Of the particles in the beam accepted by the Cherenkov counter, at most 0.5% could be particles other than K^+ mesons. The ten-by-ten hodoscope of scintillation counters HB located beam particles at its plane to 5 mm. The scat-

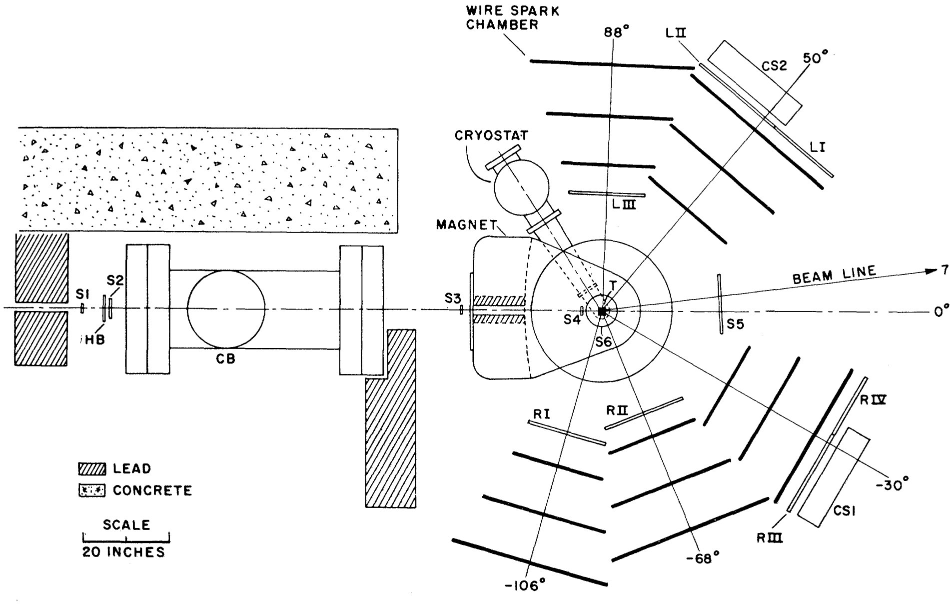

FIG. 1. Experimental arrangement: T, LMN target; $S1$, $S2$, $S3$, $S4$, $S5$, and $S6$, scintillation counters; HB, 10-by-10 scintillation beam hodoscope; CB, differential ethylene-gas Cherenkov counter; RI, RII, RIII, RIV, LI, LII, and LIII, scintillation trigger hodoscope, 10 counters per sector; $CS1$ and $CS2$, water Cherenkov counters. The cryostat, polarizing magnet, and wire spark chambers are indicated.

tered K^+ mesons and protons were detected by five banks of three wire spark chambers which had a spatial resolution of 1.3 mm vertically and 0.6 mm horizontally full width at half-maximum. Two 15-cm-thick water threshold Cherenkov counters, *CS*1 and *CS*2, were also used to distinguish scattered K^+ mesons from protons in the approximately 20° range of angles in the laboratory for which kinematic distinction alone was ambiguous.

A signal $S_1S_2S_3S_4\bar{S}_5$ from the telescope of scintillation counters opened the gates of a dc logic system[10] to an array of scintillation counters, as well as hodoscope *HB*. Signals from the array were formed into two logic tables, a sector table set to require one and only one particle on either side of the incident beam and a coplanarity table set to require the event to be coplanar within 15°. When these conditions were met, as well as *CB* and $\bar{S}_6$ which was derived from scintillation counters covering the poles of the polarizing magnet, then the spark chambers were triggered and their output, the state of the dc logic tables, the state of the dc logic observing *HB*, and the pulse heights in all Cherenkov counters *CB*, *CS*1, and *CS*2 were entered into a PDP-8 computer, which edited and transferred the data to magnetic tape and the Brookhaven National Laboratory "on-line" PDP-6 for analysis.

Two kinematic reconstructions were computed for each event. The first reconstruction assumed that a *K* meson had been elastically scattered to the left. From the coordinates established by the spark chambers, the trajectory of each scattered particle was traced through the field of the polarizing magnet to determine the point of interaction in the target to 6 mm. Using these trajectories and the point of interaction, the horizontal and vertical scattering angles of each scattered particle were established, the scattering angles expected for a recoil proton on the right were computed, and the differences between the actual angles for the particle on the right and these predicted angles, $\Delta\theta_H$ and $\Delta\theta_V$, were determined. The reconstruction was then repeated assuming that a *K* meson had been elastically scattered to the right, and both solutions were given equal weight in the analysis to follow.

For identification of the particles and separation of elastic events from background, reconstructed events were combined in each range of $\Delta(\cos\theta_K{}^{\text{c.m.}}) = 0.1$ to form a density of events as a function of $\Delta\theta_V$ and $\Delta\theta_H$. This density contained a sharp peak at the origin corresponding to correctly identified elastic events and a second broad peak displaced in $\Delta\theta_H$ corresponding to incorrectly identified elastic events. The average density was computed ignoring the region of the misidentification peak, except where the two peaks merged and the kinematic ambiguity was resolved by the water Cherenkov counters *CS*1 and *CS*2. Samples of the density are displayed in Fig. 2 for (a) forward, (b) middle, and (c) backward ranges of $\cos\theta_K{}^{\text{c.m.}}$. The angular

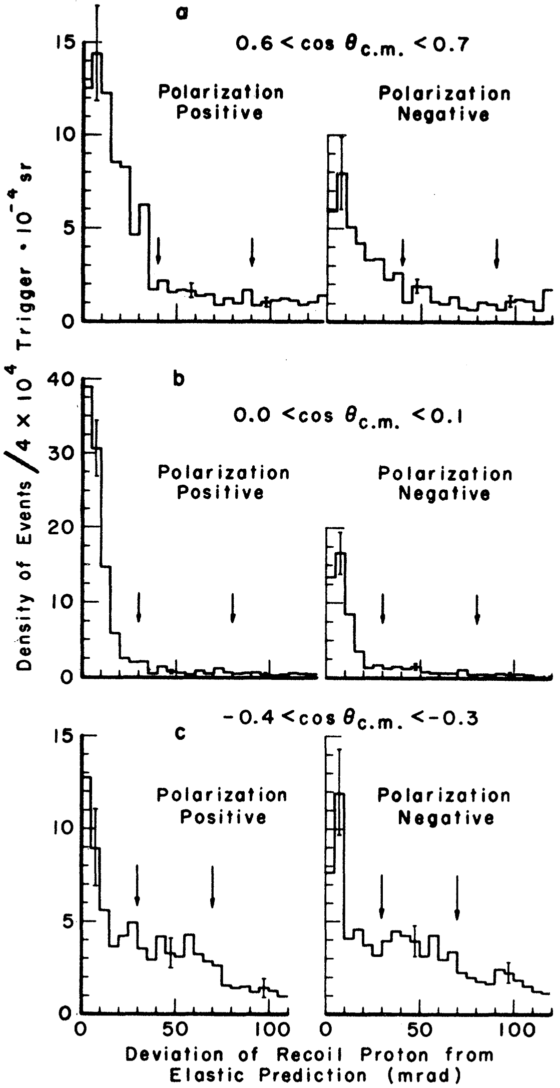

FIG. 2. Density of events versus deviation from elastic prediction showing the elastic peak and background for both signs of polarization in three ranges of $\cos\theta_K{}^{\text{c.m.}}$. The arrows indicate the region used to extrapolate background to the origin. The increased width of the peak in (a) resulted from small-angle scattering of the low-momentum, recoiling protons, while the increased background in (c) resulted from misidentified quasi-elastic and inelastic events.

width at half-maximum of the elastic peak, which resulted primarily from small-angle scattering in the target, is seen to be $\frac{1}{2}^\circ$ in the favorable middle range (b), but to broaden to $1\frac{1}{2}^\circ$ in the forward range (a) where the momentum of the recoil proton is small. The increased background observed in the backward region (c) was due primarily to the misidentified forward quasielastic scattering. The background was extrapolated to the origin using the region indicated between the arrows and subtracted, and introduced a systematic error less than ±0.02 in the asymmetry and ±4% in the differential cross section except for the most backward points.

From the 5500 elastic events gathered at 1.54 GeV/c and 6900 at 1.71 GeV/c, the left-right asymmetries have been determined for each range of $\Delta(\cos\theta_K{}^{\text{c.m.}}) = 0.1$ covered, and are displayed in Figs. 3(a) and 3(b). Since the polarization of the target protons, which averaged about 0.60 and was measured to an accuracy of ±0.03, was reversed at least three times at each momentum, the asymmetries were determined on each side of the apparatus independently without recourse to the acceptance and efficiencies. These two independent measurements were a convenient check on the consistency of the experiment. The errors shown are purely statistical and do not include possible systematic error in subtraction of background or error in polarization of the target.

The differential elastic cross sections displayed in Figs. 3(c) and 3(d) were determined from the fraction of events which occurred in the central portion of the spark chambers where the acceptance and efficiencies could be well established. Because of uncertainty in these factors and in the subtraction of background, the errors indicated in the figure include a ±7% error in the cross sections, in addition to the statistical error, but do not include a possible 5% error in normalization.

An energy-independent phase-shift analysis for the elastic channel of the K^+-meson–proton interaction has been made for ten incident meson momenta between 0.778 and 2.00 GeV/c. In addition to the new data presented above, all published data on asymmetry and differential cross

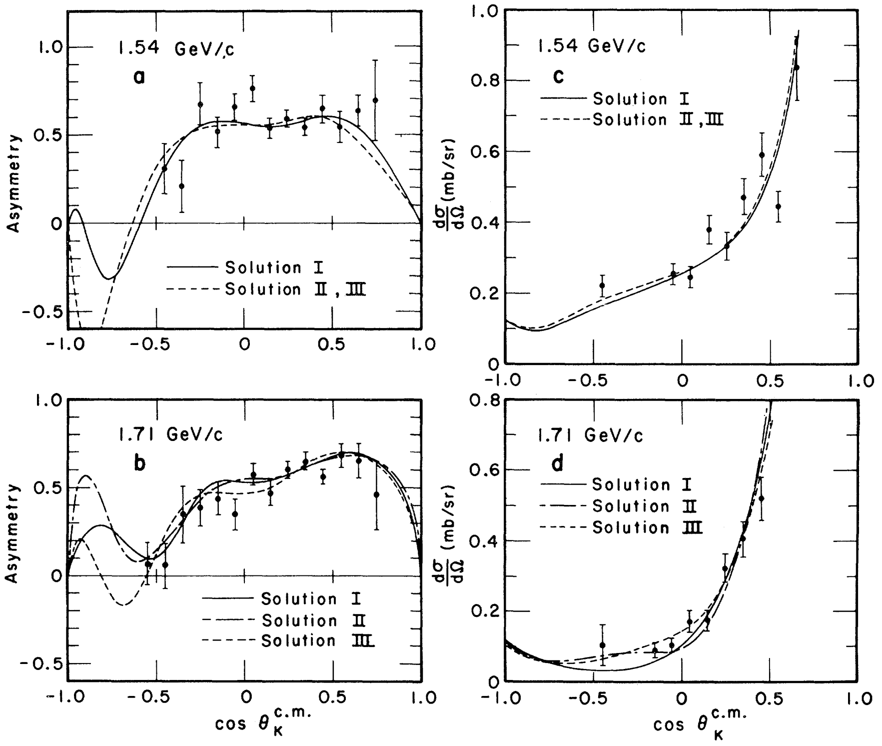

FIG. 3. Asymmetry and differential cross section for elastic scattering of K^+ mesons from polarized protons at meson momenta of 1.54 and 1.71 GeV/c in the laboratory. The errors shown for the asymmetry (a) and (b) are statistical only; however, the errors shown for the differential cross section (c) and (d) are statistical uncertainty plus 7% uncertainty in the estimate of acceptance and efficiency. An additional 5% error is estimated for the scale of the differential cross section. The several curves shown represent the predictions of solutions I, II, and III of our phase-shift analysis.

section in elastic scattering,[6,7,11] total cross sections,[1] inelastic cross sections,[5] and real parts of the forward elastic amplitude were used in the analysis. For each momentum except 0.778 GeV/c, at least one measurement of asymmetry was available. The analysis was restricted to S, P, and D waves below 1.4 GeV/c and S, P, D, and F waves above, for these were sufficient to fit the experimental data. Since the rate of angular variation was restricted by the number of partial waves, measurements of the asymmetry and differential cross section at two or three angles were statistically combined for most of the published data to make computations less cumbersome.

Sets of phase-shift parameters yielding minima in χ^2 were found by randomly searching a domain for a set with $\chi^2/P \leqslant 15$, where P is the number of pieces of data, and then by systematically minimizing χ^2 for such candidates. The domain of parameters for random search at each momentum was established by extrapolating from solutions at the momenta immediately lower; however, if any solutions appeared near the edge of this domain, it was expanded accordingly. This procedure, itself, constituted a loose condition for a smooth variation of parameters with momentum. The domain for the lowest momentum at 0.778 GeV/c was established from the results of Goldhaber et al.,[12] to which solutions were required to connect smoothly.

At each momentum 100 sets of phase-shift parameters which yielded $\chi^2/P \leqslant 2.5$ were obtained.[13] These were found to cluster in a limited region of the Argand diagram for each wave, and formed a density of solutions which appeared to peak. Overall momentum-dependent solutions were constructed from these by selecting sets which yielded the minimum path[14] in scattering-amplitude space weighted by χ^2. Three such solutions which are distinct have been obtained, and are compared with the present data by the curves in Fig. 3, where the agreement appears satisfactory. They also agree with the other individual items of data which have been used in the analysis, and yield $\chi^2/N < 1.5$, where N is the number of degrees of freedom, for the totality of original, uncombined data at each momentum except 1.37 and 1.89 GeV/c for which agreement appears considerably less satisfactory and systematic error in the data might be presumed.

The behavior of the scattering amplitudes for the three solutions is similar for momenta below 1.4 GeV/c, where, most strikingly, the $P_{3/2}$ amplitude describes a counter-clockwise half-circle in the Argand diagram as displayed by Fig. 4(a). Such behavior could be consistent with a $P_{3/2}$ resonance in the K^+p system. However, above 1.5 GeV/c, behavior of the solutions becomes qualitatively different and, for II and III, becomes rather uneven. As an example of the behavior of the three solutions, solution I is described in detail by the curves for δ and η in Figs. 4(b) and

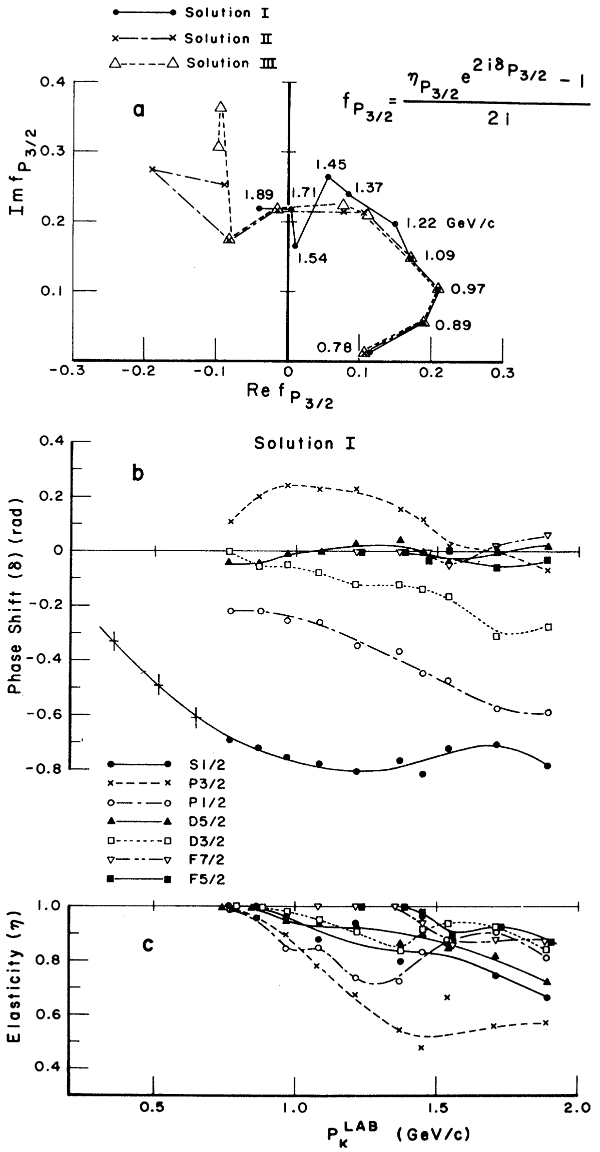

FIG. 4. Phase-shift analysis for the K^+p elastic channel. (a) Argand diagrams of the $P_{3/2}$ scattering amplitude for our solutions I, II, III which describe counter-clockwise half circles. The complete behavior of solution I is given by the phase-shifts and elasticities in (b) and (c) for the S, P, D, and F elastic amplitudes. Solutions II and III are similar. Points below 0.8 GeV/c are from Goldhaber et al., Ref. 12.

4(c).

The solutions in this analysis are compatible with one obtained by Bland et al.[11] (A_I^-) at 0.78, 0.86, and 0.96 GeV/c; with two obtained by the CERN group[6] (their solutions I and II) below 1.45 GeV/c; and with one obtained by the Argonne group[7] (their solution I). Resolution of the ambiguities which remain in all these analyses of the K^+p elastic channel and, particularly, verification of the tantalizing behavior of the $P_{3/2}$ amplitude must necessarily await more copious data on the asymmetry and differential cross section for elastic scattering of K^+ mesons from polarized protons with meson momenta above 1.5 GeV/c.

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[13] At 1.37 and 1.89 BeV/c, 100 solutions with $\chi^2/P \leq 4$ were obtained because of apparent systematic errors among differential cross section data.

[14] The paths in the scattering-amplitude space were defined by

$$D = \sum_{m,n} |f_m{}^{(n)} - f_m{}^{(n+1)}|^2 \left[\left(\frac{\chi^2}{P}\right)_{(n)} \left(\frac{\chi^2}{P}\right)_{(n+1)}\right]^Q \quad (Q = 0, 1, 2, 4).$$