# $K^-p$ Elastic Scattering at 4.6 GeV/$c$*

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$K^-p$ elastic scattering at 4.6 GeV/$c$ is studied with a sample of approximately 2000 bubble chamber events. The elastic cross section is found to be $\sigma_{el}=4.2\pm0.3$ mb, and $\sigma_{el}/\sigma_{tot}=0.168\pm0.017$. The value of the forward differential cross section is consistent with zero real part of the scattering amplitude. No backward scattering events are observed. The Regge-pole model of Phillips and Rarita gives a reasonable fit to the data.

## I. INTRODUCTION

THE elastic scattering of negative kaons on protons has been studied at a number of incident momenta from 2 to 16 GeV/$c$ in counter and bubble-chamber experiments.[1–8] The data at 3 GeV/$c$ and higher momenta[1,3–8] are characterized by a slowly decreasing elastic cross section and a nearly constant width for the diffraction peak. Phillips and Rarita[9] have constructed a five-pole Regge model of this reaction, and earlier data were used to determine the parameters associated with this model. The more recent experiments[7,8] have compared their data with the predictions of this model with reasonably good agreement. We report here on a study of $K^-p$ elastic scattering at a beam momentum of 4.6 GeV/$c$. The data are based on over 11 000 measured two-prong events in a sample of approximately 45 000 pictures taken in the 80-in. hydrogen bubble chamber, using the separated negative kaon beam at the Brookhaven AGS.

## II. EXPERIMENTAL PROCEDURE

The two-prong topology in this film was scanned and measured in two parts. Approximately 75% of the events used in this analysis are from a portion of the film which was scanned twice and then rescanned to investigate differences between the first two scans. Only the data from the triply scanned film were used to estimate the total elastic cross section. The triply scanned section of film corresponded to $2.23\times10^7$ cm of $K^-$ path length. When corrected for fiducial-volume restrictions, unmeasured or failed events, this corresponded to $2.07\pm0.11$ $\mu$b/event. The remaining 25% of the events used in the analysis were from a portion of the film which was scanned only once. Since the scanning efficiency for this sample was not determined, this part of the data has not been used to estimate the elastic cross section. After carefully checking the angular distributions and loss of events as a function of $t$, the square of the four-momentum transfer, these events were used together with the first group for distributions in $t$ with the absolute scale determined by the events from the triply scanned portion of the film only. In the triple and single scans 7822 and 3326 two-prong events were found, respectively.

All the measured events were processed through standard reconstruction programs and successfully reconstructed events were then processed through a local version of the kinematic fitting program GUTS. The events were subjected to the six hypotheses: $K^-p\to K^-p$, $K^-p\to K^-p\pi^0$, $K^-p\to K^-\pi^+n$, $K^-p\to\pi^-p\bar{K}^0$, $K^-p\to\pi^-\pi^+\Lambda^0$, and $K^-p\to\pi^-\pi^+\Sigma^0$. Events selected as elastic fits were required to have ionization consistent with the elastic hypothesis and also to have $\chi^2<25$. On the basis of ionization consistency, most ambiguities could be removed except the ambiguity between elastic scatters and $K^-p\pi^0$. The background from all other ambiguities is estimated to be approximately 0.5%. An investigation of the ambiguous events between the final states $K^-p$ and $K^-p\pi^0$ showed that almost all of these belonged to the $K^-p$ final state. It was estimated that the maximum background introduced by assigning all such events as elastic scatters is ~2% of the data, and this was done. This gave 1468 and 501 elastic events from the triply and singly scanned film, respectively.

For low values of $t$, the recoil protons have a very short range. Such protons are not easily seen on the scanning table, so that the scanning efficiency is a strong function of $t$ for low $t$ values. For example, in the interval $|t|<0.05$ (GeV/$c$)$^2$, this effect is so large that the data in this region were not used in fitting the elastic angular

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distribution. For 0.05 $(\mathrm{GeV}/c)^2 < |t| < 0.10$ $(\mathrm{GeV}/c)^2$, this correction was found to be approximately 15% using a method discussed below, and for $|t| > 0.10$ $(\mathrm{GeV}/c)^2$ there was no discernible variation of the scanning efficiency with $t$. The correction for the lost events in the interval 0.05 $(\mathrm{GeV}/c)^2 < |t| < 0.10$ $(\mathrm{GeV}/c)^2$ was estimated by studying the distribution of the azimuthal angle in the c.m. This angle should be isotropically distributed about the beam direction. However, a scanning bias exists for protons moving toward or away from the cameras. For 0.05 $(\mathrm{GeV}/c)^2 < |t| < 0.10$ $(\mathrm{GeV}/c)^2$ there were 460 events, but from the azimuthal angle distribution it is estimated that there should have been 544 events. The corrected value for this interval was used in fitting the data. The restriction that $|t| > 0.05$ $(\mathrm{GeV}/c)^2$ guarantees that the events used for analysis are in a region where the maximum Coulomb interference is <1%, so that only nuclear scattering is observed and the lepton beam contamination can be disregarded.

To properly interpret the data, a knowledge of the $\pi$, $\mu$, and $e$ contaminants in the incident beam is necessary. Pion-proton elastic scattering will in almost every case give a satisfactory kinematic fit to an assumed kaon-proton elastic scattering and will be indistinguishable by ionization at this energy. The negative pion-proton elastic scattering cross section and the angular distribution have been measured at 4.13 and 4.95 GeV/$c$,[10] and by interpolating between these values, reasonable corrections for this background can be made once the pion contamination of the beam has been determined.

The beam contamination was measured in two ways. During the exposure a Čerenkov counter in the beam gave an upper limit of 20% for the $\pi$, $\mu$, and $e$ contamination. An analysis of the energy distribution of $\delta$ rays on beam tracks was carried out later to determine the $\pi$ and $\mu$ composition of the beam contaminants.

TABLE I. Number of observed events of elastic scattering of 4.6 GeV/$c$ $K^-p$ in different intervals of $|t|$, and corresponding values of the differential cross section $d\sigma/dt$ after correction.

| $\lvert t\rvert$ interval | No. of events observed | $d\sigma/dt$ [mb/(GeV/$c$)$^2$] | Statistical uncertainty | Total uncertainty |
|---|---|---|---|---|
| 0.0 -0.05 | 277 | not used | ··· | ··· |
| 0.05–0.10 | 460 | 18.05 | ±0.90 | ±1.52 |
| 0.10–0.15 | 362 | 12.02 | ±0.63 | ±1.03 |
| 0.15–0.20 | 235 | 7.81 | ±0.51 | ±0.73 |
| 0.20–0.25 | 170 | 5.65 | ±0.43 | ±0.58 |
| 0.25–0.30 | 140 | 4.65 | ±0.39 | ±0.50 |
| 0.30–0.35 | 76 | 2.52 | ±0.29 | ±0.34 |
| 0.35–0.40 | 54 | 1.79 | ±0.24 | ±0.28 |
| 0.40–0.45 | 40 | 1.33 | ±0.21 | ±0.23 |
| 0.45–0.50 | 29 | 0.96 | ±0.18 | ±0.19 |
| 0.50–0.55 | 21 | 0.70 | ±0.15 | ±0.16 |
| 0.55–0.60 | 18 | 0.60 | ±0.14 | ±0.15 |
| 0.60–0.65 | 12 | 0.40 | ±0.12 | ±0.12 |
| 0.65–0.70 | 8 | 0.27 | ±0.10 | ±0.10 |
| >0.70 | 60 | ··· | ··· | ··· |

From this analysis the background is estimated to be (18±6)% $\mu$'s and (1.2±1.0)% $\pi$'s.

## III. EXPERIMENTAL RESULTS

The data resulting from this study are given in Table I. The total errors shown for the $d\sigma/dt$ values include the systematic uncertainties and uncertainties associated with the corrections to the raw data.

The usual parametrizations of the dependence of $d\sigma/dt$ on $t$ that have been used in the literature[1,3,4,6–8] are

$$d\sigma/dt = \exp(A + B|t|) \tag{1}$$

and

$$d\sigma/dt = \exp(a + b|t| + ct^2)\,. \tag{2}$$

A standard least-squares analysis was carried out on the data to fit each of these distributions. The errors used in the least-squares analysis were the point-to-point errors only and do not reflect all of the systematic un-

TABLE II. Values of the constants $B$, $a$, $b$, and $c$ in Eqs. (1) and (2) for the $K^-p$ elastic differential cross section in several experiments at incoming kaon momenta ≥2 GeV/$c$.

| Incident momentum (GeV/$c$) | $\lvert t\rvert$ range (GeV/$c$)$^2$ | $B$ (GeV/$c$)$^{-2}$ | $a$ | $b$ (GeV/$c$)$^{-2}$ | $c$ (GeV/$c$)$^{-4}$ | Ref. |
|---|---|---|---|---|---|---|
| 2.0 | 0.035–1.20 | | 4.2 ±0.06 | −10.9 ±0.4 | 6.39±0.39 | 2 |
| 3.0 | 0.03 –1.10 | | 3.77±0.07 | − 8.87±0.56 | 2.34±0.75 | 3 |
| 3.46 | 0.05 –1.10 | −7.16 | 3.70±0.11 | − 8.69±0.27 | 1.98±0.44 | 6 |
| 4.1[a] | 0.05 –0.70 | −7.2 ±0.3 | 3.47±0.08 | − 8.2 ±0.3 | 1.60±0.50 | 7 |
| 4.6[a] | 0.05 –0.70 | −7.2 ±0.2 | 3.47±0.04[b] | − 8.2 ±0.7 | 1.7 ±1.2 | This expt. |
| 5.5[a] | 0.05 –0.70 | −7.3 ±0.3 | 3.48±0.07 | − 8.3 ±0.3 | 1.60±0.50 | 7 |
| 7.2 | 0.27 –1.19 | | 3.66±0.30 | −10.2 ±1.2 | 3.97±0.92 | 1 |
| 9.0 | 0.27 –1.18 | | 3.62±0.30 | −10.5 ±1.2 | 4.20±1.00 | 1 |
| 10.12 | 0.06 –0.42 | −7.70±0.22 | | − 9.18±0.99 | 3.56±2.32 | 8 |
| 10.12 | 0.06 –0.60 | −7.31±0.16 | 3.24±0.07 | − 9.12±0.61 | 3.46±1.13 | 8 |
| 10.12 | 0.06 –0.80 | −7.10±0.13 | | − 8.78±0.46 | 2.72±0.70 | 8 |
| 11.88 | 0.23 –1.03 | | 3.14±0.20 | − 7.67±1.06 | 1.24±1.27 | 4 |
| 15.91 | 0.22 –0.87 | | 2.96±0.26 | − 7.85±1.26 | 2.14±1.35 | 4 |

[a] See Ref. 11.
[b] The quoted error of ±0.04 on $a$ from the fit to Eq. (2) is statistical only. If we include all systematic effects this error becomes ±0.11.

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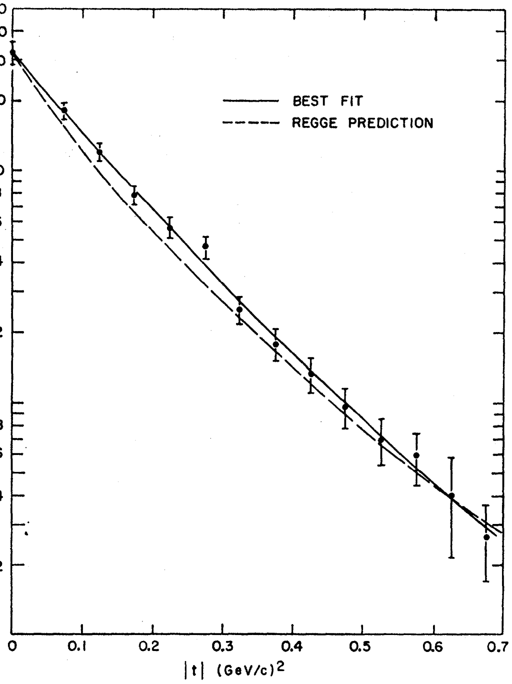


FIG. 1. The differential cross section for $K^-p$ elastic scattering at 4.6 GeV/$c$ as a function of the square of the four-momentum transfer $t$. The solid curve is the result of a fit of Eq. (2) to the data. The broken curve is the prediction of the Regge-pole model of Rarita and Phillips (Ref. 9).

certainties in the cross section. Because of the use of two different sets of data from the triply scanned and singly scanned parts of the film, fits were performed on each set individually. Only when the dependence on $|t|$ was seen to be consistent between the two sets was a fit carried out to the sum of the two data sets. As was mentioned earlier, the absolute scale is set from the triply scanned data only. The results of this fitting procedure are given in Table II,[11] along with the corresponding values of the parameters from previous experiments. The data, and the curve representing the fit to Eq. (2) using the parameters given for this experiment in Table II, are shown in Fig. 1. The errors shown are the statistical uncertainties only.

For evaluating $d\sigma/dt|_{t=0}$, and for making the necessary corrections for lost events at low $t$ values used in determining the elastic scattering cross section, use has been made only of the parameters resulting from the fit to Eq. (2). It should be emphasized, however, that the parameters determined by fitting Eq. (1) yield very satisfactory fits to the data.

Using the fitted parameters to estimate the number of events with $|t|<0.05$ (GeV/$c$)$^2$, and using the corrected number of events for $|t|>0.05$ (GeV/$c$)$^2$, and making appropriate corrections for $\pi^-$ beam contamination, for $K^-p\pi^0$ contamination in the "elastic" fits, and for events lost due to $\chi^2$ and missing mass restrictions, the $K^-p$ elastic scattering cross section at 4.6 GeV/$c$ was found to be 4.2±0.3 mb. From the fit to the data, with all similar corrections the forward scattering was evaluated as

$$d\sigma/dt|_{t=0}=32.1\pm3.5\text{ mb}/(\text{GeV}/c)^2. \quad (3)$$

In order to compare this value with the prediction of the optical theorem the total $K^-p$ cross section at this energy is needed. A counter experiment by Diddens *et al.*[12] measured $K^-p$ total cross sections at nearby energies and by an interpolation between their measured points we estimated the total cross section at 4.6 GeV/$c$ to be 25.1±0.7 mb. We also checked this value by an estimate of the cross section from our scan of the film. This estimate was consistent with the value quoted above, and so the value 25.1±0.7 mb was used. The optical theorem predicts a contribution of

$$d\sigma/dt|_{t=0}{}^{\text{opt}}=32.1\pm2.6\text{ mb}/(\text{GeV}/c)^2 \quad (4)$$

due to the imaginary part of the scattering amplitude. The ratio of the real part to the imaginary part of the scattering amplitude, $f$, at $t=0$, is then

$$\text{Re}f(0)/\text{Im}f(0)=0.0\pm0.2. \quad (5)$$

As in previous experiments on $K^-p$ elastic scattering above 2 GeV/$c$, there is no indication of a backward peak, corresponding to the fact that there are no presently known baryon exchange diagrams which could be expected to produce such a peak. In this experiment we observe no events for $\cos\theta_{\text{c.m.}}<0.0$, yielding $\sigma(\theta_{\text{c.m.}}>\pi/2)<2\pm1$ μb.

We have compared our elastic differential cross section shown in Fig. 1 with the predication of the Rarita and Phillips[9] parametrization of elastic scattering with a Regge-pole model. The dashed curve representing the Rarita-Phillips prediction is in agreement with our data, although most data points lie systematically higher over the $t$ interval shown.

## ACKNOWLEDGMENTS

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[11] We were bothered by the discrepancy between the quoted errors on the values of $b$ and $c$ in Mott *et al.* (Ref. 7), and those given here for this experiment, since the data are ~2000 events at each of 4.1, 4.6, and 5.5 GeV/$c$. Mott *et al.* (private communication) informed us that when the fit was carried out to the 4.1- and 5.5-GeV/$c$ data the errors were calculated by setting all off-diagonal elements of the correlation matrix to zero before inverting to obtain the error matrix. If a similar procedure is followed with our data, we obtain uncertainties on $b$ and $c$ approximately the same as those quoted from Mott *et al.*

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