Elastic K^--Proton Interaction at 1.45 GeV/c and Comparison with Absorption Models

A. Fridman
Département de Physique Corpusculaire, Centre de Recherches Nucléaires de Strasbourg, France
and
Institut für Hochenergiephysik der Universität Heidelberg, Heidelberg, Germany

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O. Benary,* A. Michalon, B. Schiby, R. Strub, and G. Zech
Département de Physique Corpusculaire, Centre de Recherches Nucléaires de Strasbourg, France
(Received 12 January 1966)

The K^--p scattering at 1.45 GeV/c was studied. A comparison with absorption models for low scattering angle has been made. The presence of a backward bump in the elastic differential cross section seems to indicate a spin-flip part in the scattering amplitude. The comparison with other data suggests a possible trend for a shrinking of the diffraction peak in the K^--p scattering.

1. INTRODUCTION

The differential cross section for elastic K^--p scattering has been studied at 1.45 GeV/c using the 32-cm CERN hydrogen bubble chamber. The results are presented here and compared with theoretical models based on strong absorption. An interesting aspect of our data is the appearance of a backward bump which cannot be explained by the usual baryon exchange because the exchange particle must have both baryonic number and strangeness equal to $+1$.

A comparison of our results with those of other experiments in the same energy region seems to suggest some shrinkage of the diffraction peak with increasing energy.

2. SELECTION OF EVENTS

All of the two-prong events scanned were measured on the Som-Enetra machine and passed through the CERN chain programs, THRESH-GRIND-BAKE. The identification of the events was based on the kinematic results calculated by GRIND and the observation of bubble density.

The value of the incident-beam momentum was estimated by means of 488 fitted τ decays to be 1.45 $\pm$0.036 GeV/c.

Because of the small size of our chamber, we have for the identification always considered the production $K^-+p\to\Sigma^\pm+\pi^+$ without observation of $\Sigma^\pm$ decays. The $\Sigma^\pm$ hypothesis was rejected when the $\Sigma^\pm$ path length was greater than 4 mean free decay paths. Because the center-of-mass (c.m.) energy available is relatively small (2 GeV), the classification of the events as elastic was easy. Less than 1% of the classified events were ambiguous in the sense that the bubble-density observation did not permit us to reject completely the inelastic-fit hypothesis. The χ^2 distribution for the elastic events is in satisfactory agreement with the theoretical expression for four constraints.

In order to overcome the difficulty of low scanning efficiency for events with low momentum transfer, we have introduced a cutoff of 7 mm on the proton recoil. This corresponds to a c.m. scattering angle of about 7°. A correction for this loss has been made, using the additional assumption that the differential cross section at low momentum transfer is proportional to e^{-bt}. Thirty-two events were added to our sample of 1629 elastic-fit events.

In Fig. 1 we have presented a part of our data in a Peyrou plot in which longitudinal center-of-mass momentum is plotted against transverse momentum. The dispersion of the points in this plot reflects the influence of the incident-beam momentum distribution and the fitting procedure of GRIND.

3. EXPERIMENTAL RESULTS

The differential cross section is represented in Figs. 2 and 3 and the data are tabulated in Table I. The straight line of Fig. 3 corresponds to the e^{-bt} law for the differential cross section, where b is estimated to be $b=7.2_{-0.1}^{+0.2}$ (GeV/c)$^{-2}$. This value can be compared with those obtained in other experiments in the same

Table I. K^-p elastic differential scattering cross section at 1.45 GeV/c. The elastic cross section (12 mb) was taken from other experiments.[a]

Barycentral cosΘ	Number of events	$d\sigma/d\Omega$ (mb/sr)	Barycentral −cosΘ	Number of events	$d\sigma/d\Omega$ (mb/sr)
1.0–0.9	535	6.46	0.0–0.1	31	0.36
0.9–0.8	362	4.16	0.1–0.2	26	0.30
0.8–0.7	207	2.38	0.2–0.3	15	0.17
0.7–0.6	110	1.27	0.3–0.4	16	0.18
0.6–0.5	55	0.63	0.4–0.5	16	0.18
0.5–0.4	29	0.33	0.5–0.6	18	0.21
0.4–0.3	22	0.25	0.6–0.7	15	0.17
0.3–0.2	14	0.16	0.7–0.8	49	0.56
0.2–0.1	8	0.09	0.8–0.9	48	0.55
0.1–0.0	24	0.28	0.9–1.0	29	0.33

[a] See, for instance, M. L. Stevenson, University of California Radiation Laboratory report UCRL 11493, 1964 (unpublished).

* On leave from Weizmann Institute, Rehovot, Israel.

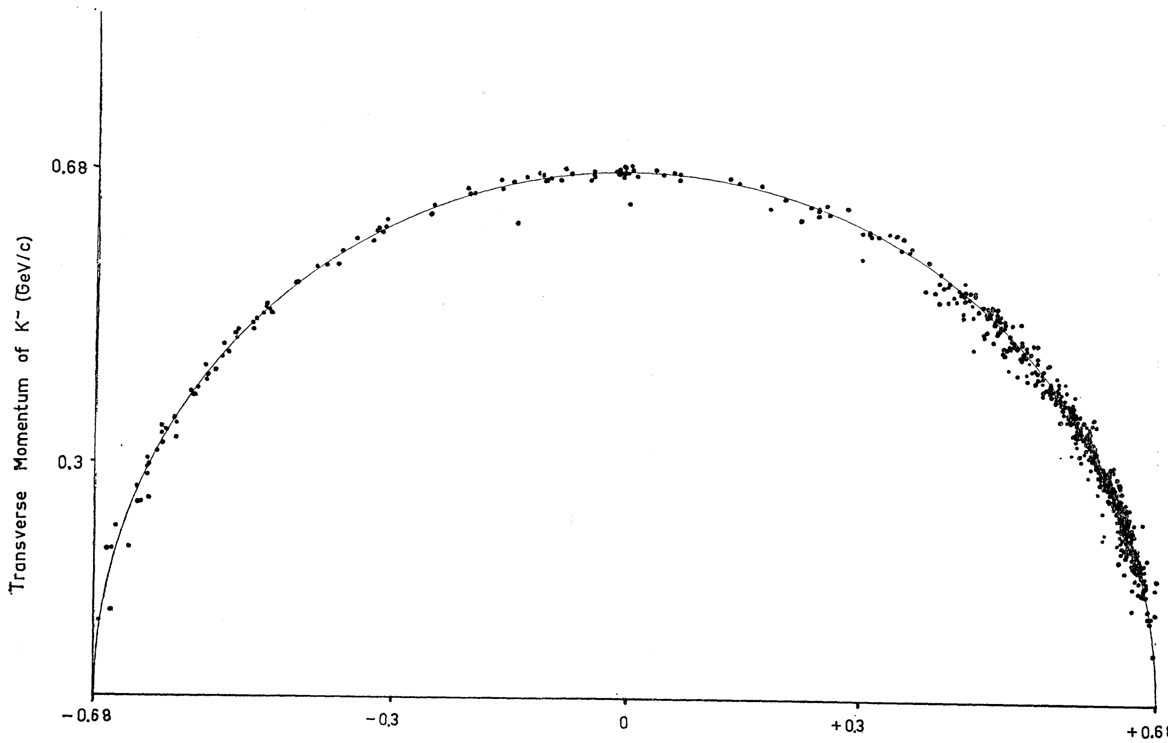

FIG. 1. Peyrou plot of transverse momentum versus c.m. longitudinal momentum for K^- produced in the reaction $K^-+p \rightarrow K^-+p$ for 500 events.

energy region (Table II). From Table II it seems that there exists a trend for a shrinking of the diffraction peak in the narrow energy range involved.

An important feature of Figs. 2 and 3 is the backward bump which occurs at the c.m. scattering angle corresponding to $\cos\Theta \leq -0.7$. From our data a rough estimate of $|\alpha|$, the absolute value of the ratio of the real part to imaginary part of the scattering amplitude at zero momentum transfer, can be made:

$$|\alpha| = \left|\frac{\mathrm{Re}f(0)}{\mathrm{Im}f(0)}\right| = 0.57_{-0.33}^{+0.31}.$$

The errors are obtained from the statistical errors

TABLE II. Elastic diffraction peaks for various K^- incident momenta.

P (lab) (GeV/c)	Interval fitted $t \leq$ (GeV/c)^2	b (GeV/c)$^{-2}$	Reference
1.22	~0, 33	~5.8	a
1.45	0.5	$7.2^{+0.2}_{-0.1}$	this experiment
1.95	0.6	7.9±0.6	b
2	0.4	9.1	c

[a] J. H. Munson, University of California Radiation Laboratory report No. UCRL 11155, 1963 (unpublished).
[b] V. Cook *et al.*, Phys. Rev. 123, 320 (1961).
[c] R. Crittenden *et al.*, Phys. Rev. Letters 12, 429 (1964).

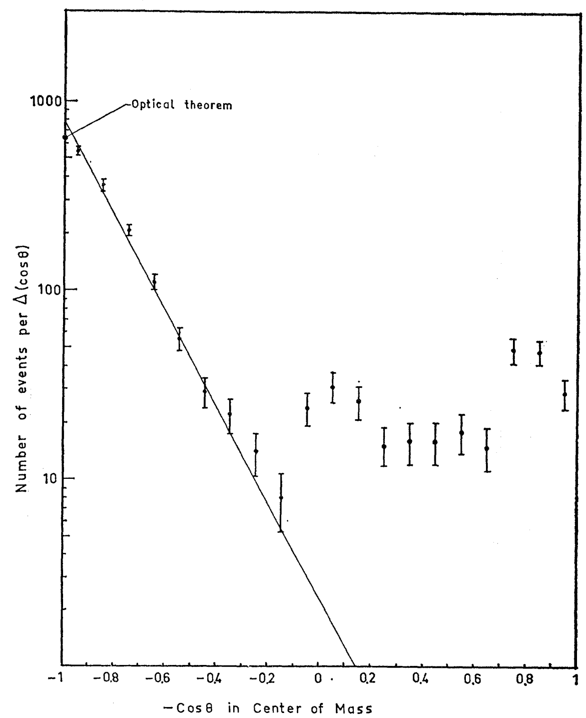

FIG. 2. Logarithmic distribution of 1629 K^-p elastic scattering events versus momentum transfer squared. The straight line shows $d\sigma/d\Omega = \sigma_0 e^{-bt}$ with $b = 7.2$ (GeV/c)$^{-2}$.

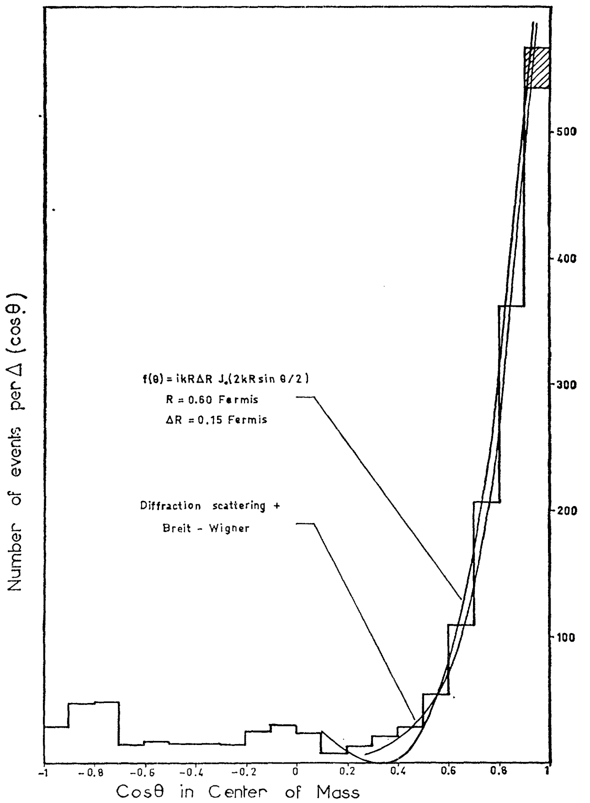

FIG. 3. Differential cross section for 1629 K^-p elastic differential scattering events. The shaded area represents the added events due to losses at small scattering angles. $P_{K^-}=1.45$ GeV/c.

on the elastic and total cross sections and from the uncertainty on b. The backward bump and the $|\alpha|$ value, although not known with a high accuracy, indicate that a purely imaginary, exponential diffraction scattering amplitude will not explain our data.

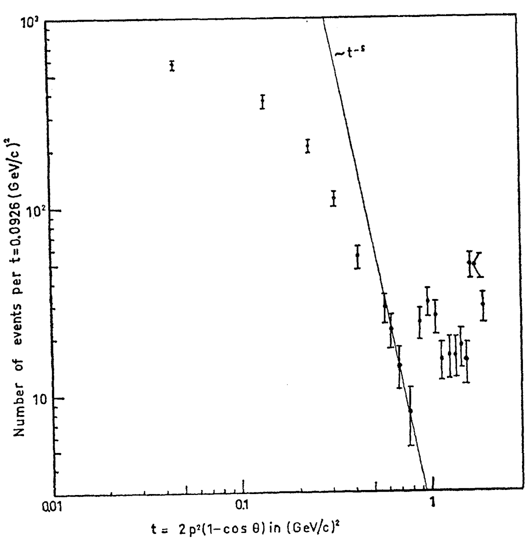

FIG. 4. Plot of the differential cross section in the manner of Serber.

Another way to represent the data has been suggested by Serber[1] (Fig. 4). Serber attributes the t^{-5} law for the proton-proton differential cross section for large momentum transfer to a purely absorptive Yukawa potential. The same dependence is found for K^--p scattering at 2 GeV/c.[2] It can be seen that our data follow the t^{-5} law (Fig. 4) for events with large momentum transfer but only in the forward hemisphere. This may indicate that other mechanisms contribute to the scattering in the backward hemisphere.

4. DISCUSSION OF EXPERIMENTAL DATA

A. Optical Model

Many publications[1-3] on elastic scattering have attempted to explain the data in terms of the optical model. This approximation satisfactorily describes the elastic cross section at small angles but not for large momentum transfers. The model is based on the well-known expression for the scattering amplitude[4]

$$f(\Theta) = -ik\int_0^\infty J_0(2kc\sin(\Theta/2))(e^{i\chi(c)}-1)c\,dc,$$

where Θ is the center-of-mass scattering angle, c the impact parameter, and $\chi(c)$ is a phase calculated by the WKB method. Two simple cases for the scattering amplitudes are the Fraunhofer diffraction model and the bright-annulus model which yield, respectively, the following expressions for the scattering amplitude[4]:

$$f(\Theta) = ikR^2(1+\alpha'\cos\Theta)\frac{J_1(2kR\sin(\Theta/2))}{2kR\sin(\Theta/2)}, \quad \text{case I};$$

$$f(\Theta) = ikJ_0(2kR\sin(\Theta/2))R\Delta R, \quad \text{case II}.$$

In the first case R is the range of the potential and in II R is the radius of the annulus.

Our experimental differential cross section at low momentum transfers cannot be fitted with a scattering amplitude of type I. A satisfactory fit is obtained with an annulus $R=0.60$ F and $\Delta R=0.15$ F (Fig. 3). According to this model the K^- is scattered from the outer edges of the proton. The data are not very sensitive to the exact shape of the absorptive potential.[5]

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[1] R. Serber, Phys. Rev. Letters **10**, 357 (1963).
[2] R. Crittenden, H. Martin, W. Kernan, L. Leipuner, A. C. Li, F. Ayer, L. Marshall, and M. L. Stevenson, Phys. Rev. Letters **12**, 429 (1964).
[3] W. Chinowsky, G. Goldhaber, S. Goldhaber, T. O'Halloran, and B. Schwarzschild, Phys. Rev. **139**, B1411 (1965).
[4] R. J. Glauber, Lectures Delivered at the Summer Institute for Theoretical Physics, University of Colorado, 1958–1959 (unpublished); N. Austern, International Summer School on Selected Topics in Nuclear Theory, Low Tatra Mountains, 1962 (unpublished).
[5] L. Marshall and T. Oliphant, Phys. Letters **18**, 83 (1965).

B. Influence of the Resonance $Y^*(1820)$ on the Scattering Amplitude

Because the mass of the $Y^*(1820)$ resonance is not very far from the c.m. energy 2 GeV, this resonance can contribute to the elastic scattering amplitude.

In the partial-wave expansion of the scattering amplitude,

$$f(\Theta)=(1/2ik)\sum_{l=0}^{\infty}(2l+1)(1-e^{2i\delta_l})P_l(\cos\Theta),$$

the phases δ_l can be calculated with the assumption of pure diffraction scattering with the presence of a resonance amplitude.

For the diffraction scattering at low momentum transfer[6] we have

$$1-e^{2i\delta_l}=1-e^{-2|\delta_l|}=\sigma_T\frac{e^{-l^2/2p^2b}}{4\pi b},$$

where p is the c.m. momentum and b the slope calculated previously. The total cross section in the high-energy limit, σ_T, is here adjusted in order to give the correct experimental cross section at zero momentum transfer. The additional phase is calculated from a Breit-Wigner formula for the resonant scattering amplitude with elasticity $x=0.7$.[7] In Fig. 3 we have plotted the theoretical differential cross section obtained in this manner. The constant b is now adjusted in such a way that the differential cross section gives a good description of our experimental data. The value b is found to be $b\simeq 5$ $(\mathrm{GeV}/c)^{-2}$.

For large momentum transfers, where the optical model is no longer valid, a pure resonant scattering amplitude cannot explain our data.

C. Backward Scattering

In order to explain the backward peaking in πp scattering Minami[8] has suggested a purely imaginary scattering amplitude of the form

$$f(\Theta)=i\{\exp[\tfrac{1}{2}(A_0+A_1t)] +C\pm\exp[\tfrac{1}{2}(B_0+B_1(u-u_0))]\}.$$

The fact that Fig. 2 does not show a backward peak but merely a bump suggests that such a scattering amplitude will not be applicable to our data. The bump, statistically significant, can be due to the presence of a spin-flip $g(\Theta)$ in the scattering amplitude which gives in the differential cross section a term proportional to $|g(\Theta)|^2\sin^2\Theta$ (Θ is the c.m. scattering angle). Such a spin-flip amplitude can be predicted in principle by a Regge-pole model where a (K^+p) system is the pole responsible for the spin-flip amplitude. As a (K^+p) system has never been seen, this system, if it exists, must lie on a curved Regge trajectory in such a way that the (K^+p) has no physical angular momentum.[9]

5. CONCLUSION

If we take into account the contribution of the resonant scattering amplitude we obtain a lower estimate of b [$\simeq 5(\mathrm{GeV}/c)^{-2}$] than the previous calculated value. If we compare with the value 9.1 $(\mathrm{GeV}/c)^{-2}$ of Crittenden *et al.*, this will favor greater shrinkage of the diffraction peak.

Using the unitarity of the S matrix Minami[10] has derived a lower limit of b which is 5.07 $(\mathrm{GeV}/c)^{-2}$. Our value [7.2 $(\mathrm{GeV}/c)^{-2}$ or $\simeq 5$ $(\mathrm{GeV}/c)^{-2}$] is compatible with this limit. Based on the optical model it is predicted in the same reference that the width Γ of the diffraction peak is smaller for K^-p than for K^+p ($\Gamma_{K^-p}<\Gamma_{K^+p}$).[11] There exist K^+p elastic-scattering data at the same energy[12]; we find that $1.5\Gamma_{K^-p}\cong\Gamma_{K^+p}$. It would be very useful to know the ratio $|\alpha|$ with better accuracy in order to compare with the prediction based on the Regge-pole model made by Phillips and Rarita.[13] Another way to know whether a spin-flip amplitude really contributes to the scattering at 1.45 GeV/c would be a polarization measurement of the recoil proton.

ACKNOWLEDGMENTS

We are grateful to Professor P. Cüer and Professor H. Filthuth for encouraging and supporting this work. We want to thank Professor R. Omnes for a useful and fruitful discussion. We thank also Dr. J. L. Basdevant and Dr. Dosch and the staff of the Institut für Hochenergiephysik der Universität Heidelberg for many discussions and computer facilities. We wish to thank Dr. A. Shapira for an interesting discussion about this work.

[6] See, for instance, L. Van Hove, Theoretical Problems in Strong Interactions at High Energies, Lectures given at CERN, 1964 (unpublished).

[7] R. Armenteros, M. Ferro-Luzzi, D. W. G. Leith, R. Levi-Setti, A. Minten, R. D. Tripp, H. Filthuth, V. Hepp, E. Kluge, H. Schneider, R. Barloutaud, P. Granet, J. Meyer, and J.-M. Porte (unpublished).

[8] S. Minami, Phys. Rev. **133**, B1581 (1964).

[9] R. Omnes (private communication).

[10] S. Minami, Phys. Rev. **135**, B1263 (1964).

[11] This conclusion is also valid if there is a contribution of a resonant scattering amplitude in the K^-p channel.

[12] A. Bettini, N. Cresti, S. Limentani, M. Peruzzo, and R. Santagello, Phys. Letters **16**, 83 (1965).

[13] R. J. N. Phillips and W. Rarita, Phys. Rev. **139**, B1336 (1965).