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 K^-p AND $\bar{p}p$ ELASTIC SCATTERING AT 10.1 GeV/c

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ABSTRACT

The differential cross-sections for K^-p and $\bar{p}p$ elastic scattering have been measured over the four momentum transfer squared range $0.18 < -t < 3.3 \text{ (GeV/c)}^2$. The K^-p data decrease smoothly as a function of $-t$, whereas the $\bar{p}p$ data shows a break at $-t = 0.6 \text{ (GeV/c)}^2$ followed by a fast drop to $-t \approx 1.6 \text{ (GeV/c)}^2$ where the differential cross-section levels off and stays constant out to $-t = 3 \text{ (GeV/c)}^2$. Using data from other experiments the particle-antiparticle differential cross-section differences have been studied in order to isolate interference terms in the amplitudes. Very different behaviour is observed for Kp and pp .

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1. INTRODUCTION

In this paper we present the results of measurement of K^-p and $\bar{p}p$ elastic scattering at an incident momentum of 10.1 GeV/c. The data presented here were collected as parasitic triggers during an experiment to study the hypercharge exchange reactions $\pi^+p \rightarrow K^+\Sigma^+$ and $K^-p \rightarrow \pi^-\Sigma^+$ described in the previous paper [1]. The experiment covered a range in the four-momentum transfer squared of $0.2 < -t < 3.3$ (GeV/c)². Great care was taken to minimize the systematic errors which were kept less than 5%.

For the region $-t < 1$ (GeV/c)² extensive measurement already exist for incident momenta up to 200 GeV/c for both K^-p [2-10] and $\bar{p}p$ [4,5,7-10]. For larger absolute values of t , however, existing data is more limited. The near forward region, $-t \lesssim 3$ (GeV/c)², has been studied for momenta up to 14 GeV/c for K^-p [11-15] and up to 10 GeV/c for $\bar{p}p$ [12,13,16,17].

In section 2 of this paper we describe the experimental method and data analysis. The results are presented and discussed in section 3.

2. EXPERIMENTAL METHOD AND DATA ANALYSIS

The experimental equipment, a two arm spectrometer with momentum analysis in the forward arm, is that used in the geometry 2 of the hypercharge exchange experiment described in detail in the preceding paper [1]. Only a few details, relevant to the elastic channels, will be given here.

Trigger

The trigger for the elastic channels was an incident K^- or $\bar{p}$ defined in the beam Čerenkov counters [1] and one charged particle in each of the two arms of the spectrometer. The Čerenkovs C_1 and C_2 (see [1]) were not used in the trigger. The same veto counters were used as for the hypercharge exchange experiment : a beam veto and a target box veto [1]. The trigger rate for each of these channels was about 10^{-3} per incident K^- or $\bar{p}$. During the course of the experiment a total of 1 M triggers was accumulated.

Data analysis

The same method was employed for the elastic channels as for the hypercharge exchange reactions. The excellent resolution of the forward spectrometer permitted an analysis based almost solely on the missing mass technique. The requirement of a track in the recoil arm was essential for reducing the trigger rate but in the analysis merely ascertained the negligible level of the background. In Fig. 1 we show the missing mass distribution for the $\bar{p}p$ channel for all events requiring a track in the recoil arm. The background under the proton peak (standard deviation 64 MeV) is less than 0.1%. In Fig. 2 we show the effect of requiring a recoil track for events with $-t > 2 \text{ (GeV/c)}^2$. We conclude from these graphs that our final event samples contain a negligible amount of background. The same conclusion applies to the K^-p channel.

For details on correction of the data and acceptance calculations we refer to the hypercharge exchange paper [1].

3. RESULTS AND DISCUSSION

Our results for the differential cross-sections, based on 27620 K^-p and 11539 $\bar{p}p$ elastic events, are given in tables 1 and 2 respectively. The errors quoted are statistical, calculated from the number of events plus the uncertainty from the acceptance calculations. The overall normalization error is estimated to be $\pm 5\%$.

3.1 General features

The data obtained in this experiment are shown in Fig. 3. We compare our data to that at other energies [10-13, 15-16] in Figs 4 (K^-p) and 5 ($\bar{p}p$). We first discuss the general features of the angular distributions. The first diffraction minimum, around $-t = 1 \text{ (GeV/c)}^2$ for K^-p and $-t = 0.6 \text{ (GeV/c)}^2$ for $\bar{p}p$ disappears faster with increasing energy for K^-p than for $\bar{p}p$. At our momentum of 10 GeV/c there is a clear break followed by a shoulder for $\bar{p}p$ whereas the K^-p angular distribution drops smoothly.

A further striking difference between the K^-p and $\bar{p}p$ angular distributions shows up for the region $-t > 1.5 \text{ (GeV/c)}^2$. Here the K^- differential cross-section continues to drop smoothly whereas the $\bar{p}p$ differential cross-section

levels off and stays almost constant out to $-t \sim 3 \text{ (GeV/c)}^2$. At $-t = 2.7 \text{ (GeV/c)}^2$ the $\bar{p}p$ differential cross-section is an order of magnitude larger than that for K^-p at our energy 10 GeV. As can be seen in Fig. 5 this plateau for $\bar{p}p$ is already apparent at 3.7 GeV/c .

3.2 The forward slope

We have fitted the differential cross-section $d\sigma/dt$ to the forms

$$d\sigma/dt = A e^{Bt} \quad (1)$$

$$d\sigma/dt = A e^{Bt} + Ct^2 \quad (2)$$

The results of the fits are given in Table 3. The K^-p data follow form (1) over the range $0.24 < -t < 0.78 \text{ (GeV/c)}^2$.

Our value for the slope, $6.53 \pm 0.08 \text{ (GeV/c)}^{-2}$ in an excellent agreement with the value derived from a survey of elastic K^-p data [7], $6.50 \pm 0.28 \text{ (GeV/c)}^{-2}$. The K^-p data also give a good fit to the form (2) over a larger $-t$ range, $0.18 < -t < 1.5 \text{ (GeV/c)}^2$.

As already noted, the $\bar{p}p$ data show a more complex structure and give less good fits (Table 3). The value of the slope over the limited range $0.22 < -t < 0.60 \text{ (GeV/c)}^2$, $B = 12.6 \pm 0.2 \text{ (GeV/c)}^{-2}$, agrees well with the result from the survey [7], $B = 12.2 \pm 1.2 \text{ (GeV/c)}^{-2}$.

3.3 Antiparticle-particle cross-section difference

Differences between particle and antiparticle differential cross-sections isolate interference terms between even and odd C-parity amplitudes in the t-channel.

In a recent paper Carnegie et al. [26] have studied particle-antiparticle differential cross-section differences. They use

$$\Delta = \frac{d\sigma/dt (X^-p) - d\sigma/dt (X^+p)}{\sqrt{8 [d\sigma/dt (X^-p) + d\sigma/dt (X^+p)]}} \quad (3)$$

Assuming a peripheral amplitude in impact parameter space they argue that Δ is a good approximation for the $C = -1$ helicity non flip amplitude and fit Δ to a J_0 Bessel function :

$$\Delta = A e^{Bt} J_0 (R \sqrt{-t}) \quad (4)$$

In this model the amplitude is peaked at an impact = R . Their fit extends out to $-t = 0.8 \text{ (GeV/c)}^2$ at 10 GeV/c.

We have performed a similar analysis, extending the $-t$ range out to $-t = 3 \text{ (GeV/c)}^2$. We have compared our K^-p data with the K^+p data of Brandenburg et al. [4] and of Baglin et al. [19]*. Our $\bar{p}p$ data has been compared with published pp data where the systematic errors are small [2,22-25].

The differences Δ are plotted in Figs 6a) and b) for $K^\pm p$ and $p^\pm p$ respectively. When calculating the errors in Δ a 6% uncertainty for normalization was included. For $K^\pm p$ the form (4) gives an excellent fit out to $-t = 2.7 \text{ (GeV/c)}^2$. The full line in Fig. 6a) shows the fitted Bessel function. The parameters of the fit are given in Table 4. For the $p^\pm p$ data a fit to the form (4) gave an unacceptably large χ^2 . However, adding a J_1 Bessel function so that Δ has the form

$$\Delta = A e^{Bt} J_0 (R \sqrt{-t}) + A' e^{B't} J_1 (R' \sqrt{-t}) \quad (5)$$

* Brandenburg et al measures $K^\pm p$ and $p^\pm p$ at 10 GeV/c with small systematic errors. Their data is in excellent agreement with our K^-p and $\bar{p}p$ data in the region of $-t$ where they overlap. The 10 GeV/c K^+p data of Baglin et al [19] (systematic error $\pm 15\%$) overlaps with the data of Brandenburg in the region $0.45 < -t < 1.4 \text{ (GeV/c)}^2$. Fitting both data sets to an exponential in t gives the same slope but a 17% difference in normalization. We have therefore in our analysis renormalized the data of Baglin et al with a factor 1.17.

gave an excellent fit to the data, shown in Fig. 6b). The fit parameters are given in Table 4.

The parameters in (4) for the $K^\pm$ fit are in excellent agreement with those of Carnegie et al [26]. For the $p^\pm p$ data the comparison is not very meaningful, since the fit of Carnegie et al is limited to the region out to $-t = 0.6 \text{ (GeV/c)}^2$.

As an independent check we have calculated Δ ($t = 0$) using

$$\left(\frac{d\sigma}{dt} \right)_{t=0} = \frac{\sigma_{\text{tot}}^2}{16\hbar^2 c^2 \pi} (\alpha^2 + 1)$$

where σ_{tot} is the total cross-section and α is the ratio of real to imaginary part of the forward scattering amplitude.

For $K^\pm p$, using $\sigma_{\text{tot}} = 17.3 \text{ mb (K}^+ p) \text{ and } 22.5 \text{ mb (K}^- p) \text{ [27]}$ and $\alpha = -0.22 \pm 0.04$ and $-0.03 \pm 0.05 \text{ [20]}$ (K^+ and K^- respectively) we get $\Delta = 17.0 \sqrt{\mu\text{b}}/(\text{GeV/c})$, in excellent agreement with the results of our fit, 18.1 ± 1.5 . For $p^\pm p$, using $\sigma_{\text{tot}} = 40.2 \text{ mb (pp, [28,29])}$ and $52.6 \text{ mb (}\bar{p}p, [30])$ and $\alpha = -0.34 \pm 0.01$ and $-0.01 \pm 0.04 \text{ [31]}$ (pp and $\bar{p}p$ respectively) we get $\Delta = 36.8 \sqrt{\mu\text{b}}/(\text{GeV/c})$ in disagreement with the results of our fit, $88 \pm 2 \sqrt{\mu\text{b}}/(\text{GeV/c})$.

Apart from a small difference in interaction radius R (about 1 fm and 0.8 fm for Kp and pp respectively), the need for a J_1 Bessel function in the pp case suggests either a larger coupling of a spin flip part of the Pomeron to the nucleon or that a real part of the Pomeron shows up in pp .

3.4 Forward elastic scattering at 10 GeV/c

In Fig. 7 we display the general behaviour of $K^\pm p$ and $p^\pm p$ elastic scattering at the incident momentum of 10 GeV/c. The antiparticle angular distributions show more structures, in comparison with the $K^+ p$ and pp systems, which are exotic in the s -channel.

Table 1

Differential cross-sections for K^-p elastic scattering at 10.1 GeV/c.

The errors are statistical and represent one standard deviation.

The absolute normalization error is 5%.

$-t$ (GeV/c) ²	Δt	$d\sigma/dt$ $\mu b / (GeV/c)^2$	error
.19	.02	6309	280
.21	.02	5220	234
.23	.02	4423	200
.25	.02	3525	162
.27	.02	3120	144
.29	.02	2671	125
.31	.02	2272	109
.33	.02	2128	102
.35	.02	1801	88
.37	.02	1599	80
.39	.02	1425	72
.41	.02	1165	61
.43	.02	1016	55
.45	.02	895	50
.47	.02	829	47
.49	.02	684	40
.51	.02	603	37
.53	.02	545	34
.55	.02	478	31
.57	.02	434	29
.59	.02	411	28
.61	.02	314	23
.63	.02	308	23
.65	.02	249	20
.67	.02	237	19
.69	.02	195	17
.71	.02	184	16
.73	.02	138	15
.75	.02	126	14
.77	.02	128	13
.79	.02	131	13
.825	.05	111.1	8.4
.875	.05	88.5	7.2
.925	.05	71.4	6.3
.975	.05	48.5	5.0

$-t$ (GeV/c) ²	Δt	$d\sigma/dt$ $\mu b / (GeV/c)^2$	error
1.025	.05	51.1	5.1
1.075	.05	40.2	4.5
1.125	.05	32.0	3.9
1.175	.05	24.3	3.4
1.225	.05	21.4	3.2
1.275	.05	16.7	2.8
1.325	.05	19.0	3.0
1.375	.05	16.5	2.8
1.45	.10	11.3	1.7
1.55	.10	7.5	1.4
1.70	.20	4.5	0.8
1.90	.20	3.5	0.7
2.10	.20	1.3	0.4
2.30	.20	0.9	0.4
2.70	.60	<0.075	

Table 2

Differential cross-sections for $\bar{p}p$ elastic scattering at 10.1 GeV/c.
The errors are statistical and represent one standard deviation.
The absolute normalization error is 5%.

$-t$ (GeV/c) ²	Δt	$d\sigma/dt$ $\mu\text{b}/(\text{GeV}/c)^2$	error
.19	.02	19180	420
.21	.02	13120	320
.23	.02	9510	260
.25	.02	6960	210
.27	.02	5970	190
.29	.02	4630	170
.31	.02	3550	150
.33	.02	3128	140
.35	.02	2012	110
.37	.02	1491	88
.39	.02	1295	81
.41	.02	900	67
.43	.02	659	50
.45	.02	576	53
.47	.02	487	47
.49	.02	350	40
.525	.05	248	21
.575	.05	128	15
.625	.05	128	15
.675	.05	104	14
.725	.05	104	13
.775	.05	98	13
.825	.05	100	13
.875	.05	79	12
.925	.05	73	11
1.00	.10	54.3	6.4
1.10	.10	42.7	5.7
1.20	.10	29.9	4.7
1.30	.10	14.7	3.4
1.45	.20	4.8	1.4
1.70	.30	2.0	0.8
2.00	.30	1.2	0.6
2.30	.30	2.6	0.9
2.60	.30	2.0	0.9
3.00	.50	2.4	1.2

Table 3

Results of least squares fits to the forms $d\sigma/dt = A e^{Bt}$ (form 1) and $d\sigma/dt = A e^{Bt} + Ct^2$ (2).
NDF stands for the number of degrees of freedom in the fit.

Particle	-t range (GeV/c) ²	Fit form	A mb/(GeV/c) ²	B (GeV/c) ⁻²	C (GeV/c) ⁻⁴	χ^2 /NDF
K^-	0.24, 0.78	1	17.7 ± 0.7	6.53 ± 0.08	-	9.9/25
K^-	0.18, 1.5	2	29.1 ± 1.2	8.81 ± 0.15	-2.4 ± 0.1	29/41
$\bar{p}$	0.22, 0.60	1	173 ± 9	12.6 ± 0.2		27/14

Table 4

Results of the fit $\Delta = Ae^{Bt} J_0 (R \sqrt{-t}) (K^- p)$ and $\Delta = Ae^{Bt} J_0 (R \sqrt{-t}) + A'e^{B't} J_1 (R' \sqrt{-t}) (\bar{p} p^a)$. NDG stands for the number of degrees of freedom in the fit.

Quantity	$K^\pm p$	$p^\pm p$
$A, \sqrt{\mu b} / (\text{GeV}/c)$	18.1 ± 1.5	87.8 ± 1.5
$B, (\text{GeV}/c)^{-2}$	-1.46 ± 0.10	-1.68 ± 0.02
$R, (\text{GeV}/c)^{-1}$	4.96 ± 0.04	6.18 ± 0.02
$A', \sqrt{\mu b} / (\text{GeV}/c)$	-	27.3 ± 0.7
$B', (\text{GeV}/c)^{-2}$	-	-0.92 ± 0.03
$R', (\text{GeV}/c)^{-1}$	-	4.65 ± 0.02
χ^2/NDG	25/47	22/29

- a) It was not possible to obtain a reasonable fit of the $\bar{p} p$ data to the form with one Bessel function.

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Figure captions

- Fig. 1 : Missing mass distribution for a subsample of the $\bar{p}$ data, requiring a track in the recoil arm. The logarithmic scale should be noted. The proton peak has a standard deviation of $64 \text{ MeV}/c^2$ and is centred at $940 \text{ MeV}/c^2$.
- Fig. 2 : Missing mass distribution for the complete $\bar{p}$ sample for events with $-t > 2 (\text{GeV}/c)^2$. The hatched part represents the effect of requiring a track in the recoil arm. All events in the proton peak remain after the cut.
- Fig. 3 : The differential cross-sections as a function of $-t$ for $K^-\bar{p}$ and $\bar{p}p$ elastic scattering at $10.1 \text{ GeV}/c$ measured in this experiment.
- Fig. 4 : Forward differential cross-sections for $K^-\bar{p}$ elastic scattering measured in this experiment at $10.1 \text{ GeV}/c$ compared to data at 3.6 [11], 5 [12], 14 [15] and $100 \text{ GeV}/c$ [10]. The full lines are hand drawn through the data points to guide the eye.
- Fig. 5 : Forward differential cross-section for $\bar{p}p$ elastic scattering measured in this experiment at $10.1 \text{ GeV}/c$ compared to data at 3.7 [16], 5 [12], 9.7 [13] and $100 \text{ GeV}/c$ [10]. The full lines are hand drawn through the data points to guide the eye.
- Fig. 6 : The measured cross-section difference Δ as defined by equations (4) and (5) in the text as a function of $-t$ for $K^\pm p$ (a) and $p^\pm p$ (b). The lines represent the fits, equation (4) for $K^\pm p$ and (5) for $p^\pm p$.

Fig. 7 : Forward differential cross-sections for $K^{\pm}p$ and $p^{\pm}p$.
Filled circles represent $K^{\pm}p$, open $\bar{p}p$, both sets from this experiment except for $-t < 0.18 \text{ (GeV/c)}^2$, where the points come from ref. [4]. The full line represents $K^{\pm}p$ [19] and the broken line pp [3, 22-25], both at 10 GeV/c.

Fig. 1

Fig. 2

Fig. 3

Fig. 4

Fig. 5

Fig. 7