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K^+N Charge-Exchange Scattering at 1.94 GeV/c*

D. W. Davies, R. Poster, P. E. Schlein, and W. Slater
Department of Physics, University of California, Los Angeles, California 90024

and

B. Barish, R. Gomez, and S. C. Loken
Department of Physics, California Institute of Technology, Pasadena, California 91109

and

R. Juhala and E. Malamud
National Accelerator Laboratory, Batavia, Illinois 60510
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Experimental results are presented on the reaction $K^+n \to K^0p$ at 2 GeV/c. As required by strong ρ-A_2 exchange degeneracy, the $d\sigma/dt$ distribution shows no structure at $t \simeq -0.6$ (GeV/c)^2. The $d\sigma/du$ distribution for backward charge-exchange scattering does not agree with proposed $I=0$ baryon-exchange models.

We have studied the reaction

$$K^+n \to pK^0 \tag{1}$$

in a 500 000 picture exposure of the 25-in. deuterium-filled bubble chamber at the Lawrence Radiation Laboratory. The deuterium provided the target neutron, and the reaction actually studied was

$$K^+d \to ppK^0, \tag{2}$$

with the K^0 decaying visibly in the chamber. This reaction has a two-prong-plus-vee topology if both protons have lab momentum greater than 100 MeV/c, or a one-prong-plus-vee topology if the momentum of one of the protons is less than 100 MeV/c. (The range is then too short to be visible in the chamber.) Events of both topologies were fitted to reaction (2), as well as all other possible reactions leading to those topologies. Reaction (2) is a highly constrained fit and it was found that taking all events that had a good fit to this reaction led to a very clean sample of 2000 events, with less than 2% contamination. We find that the cross section for $K^+d \to ppK^0$ at 1.94 GeV/c is 1.94 ± 0.14 mb; this number agrees well with previous measurements[1-4] above 1 GeV/c and a $P_{\text{lab}}^{-(2.10\pm0.05)}$ dependence as noted in Ref. 4.

If we assume that the K^+ interacted only with the neutron in the deuteron, we have the impulse model. In this model one of the protons in the final state is considered a "spectator" to the reaction, and, except for Pauli-exclusion-principle effects, can be effectively ignored. The model predicts that the laboratory momentum spectrum of this "spectator" proton (assumed to be the proton with the lower momentum) should be the same as the momentum spectrum of a nucleon in the deuteron. Comparing our data to the Hulthén[5] momentum spectrum we find very good agreement below 300 MeV/c; above 300 MeV/c we find 15% of our data, whereas from the Hulthén distribution we would expect 1–3%. These events exhibit a similar dif-

TABLE I. Coefficients of Legendre-series expansion of the c.m. angular distribution.

	a_1	a_2	a_3	a_4	a_5
No correction	0.96 ± 0.02	0.61 ± 0.03	0.11 ± 0.03	-0.21 ± 0.03	-0.21 ± 0.03
Corrected	0.99 ± 0.03	0.66 ± 0.05	0.17 ± 0.05	-0.15 ± 0.05	-0.16 ± 0.05
	a_6	a_7	a_8	a_9	a_{10}
No correction	-0.23 ± 0.03	-0.08 ± 0.03	-0.12 ± 0.03	-0.06 ± 0.03	-0.01 ± 0.03
Corrected	-0.18 ± 0.05	-0.06 ± 0.04	-0.11 ± 0.04	-0.05 ± 0.04	-0.01 ± 0.03

ferential cross section to the rest of the data and have been included in what follows, except as noted in Table I.

Figure 1 shows $d\sigma/dt$ for our data, where

$$t = (P_{K^+} - P_{K^0})^2 .$$

In the very-low-$|t|$ region we see a sharp drop in $d\sigma/dt$. This arises from two effects: The spin-flip part of the K^+n scattering vanishing as $\theta \to 0°$, and the Pauli principle suppressing the spin-nonflip amplitude as $t \to 0$. These two effects make the differential cross section vanish at $t=0$ in the impulse model. At finite values of t we can correct for the effects of the Pauli principle if we know how much spin-flip and -nonflip amplitude is present.

The data have been corrected assuming both all spin-flip and all spin-nonflip, and the changes to the first two t bins have been indicated in Fig. 1. The upper end of the arrow is the cross section if the amplitude is all spin-nonflip; the lower end corresponds to all spin-flip. It is evident that even if the amplitude is all spin-nonflip, the differential cross section for $K^+n \to K^0p$ flattens out and perhaps even turns over in going from $t = -0.2$ $(\mathrm{GeV}/c)^2$ to $t=0$. This is in contrast to the K^+p elastic scattering data at 1.97 GeV/c,[6] which shows a small increase in slope at very low $|t|$.

We can use the optical theorem and isospin invariance to relate the K^+p and K^+n total cross sections[7] to the square of the imaginary part of the charge-exchange (CEX) amplitude at $t=0$. A comparison of this to our $d\sigma/dt$ at $t=0$ results in an estimate of the ratio of the imaginary to real parts at $t=0$:

$$\left|\frac{A_I}{A_R}\right|^2_{t=0} = \left(\frac{d\sigma}{dt}\bigg|^{\mathrm{CEX}}_{t=0} \frac{16\pi(\hbar c)^2}{(\sigma_{K^+p} - \sigma_{K^+n})^2}\right)^{-1}$$
$$= (1.5 \pm 0.8) \times 10^{-2} ,$$

where we have assumed that $d\sigma/dt$ at $t=0$ is equal to 2.5 ± 0.5 mb/$(\mathrm{GeV}/c)^2$. (The large error in $d\sigma/dt$ reflects the uncertainty in the amount of spin-flip amplitude present.) Thus we see that there is little, if any, imaginary part to the charge-exchange amplitude at $t=0$.

From $t = -0.2$ $(\mathrm{GeV}/c)^2$ to $t = -1.4$ $(\mathrm{GeV}/c)^2$, $d\sigma/dt$ falls exponentially with $|t|$. We have fitted $d\sigma/dt$ in the region $t = -0.2$ $(\mathrm{GeV}/c)^2$ to $t = -1.2$

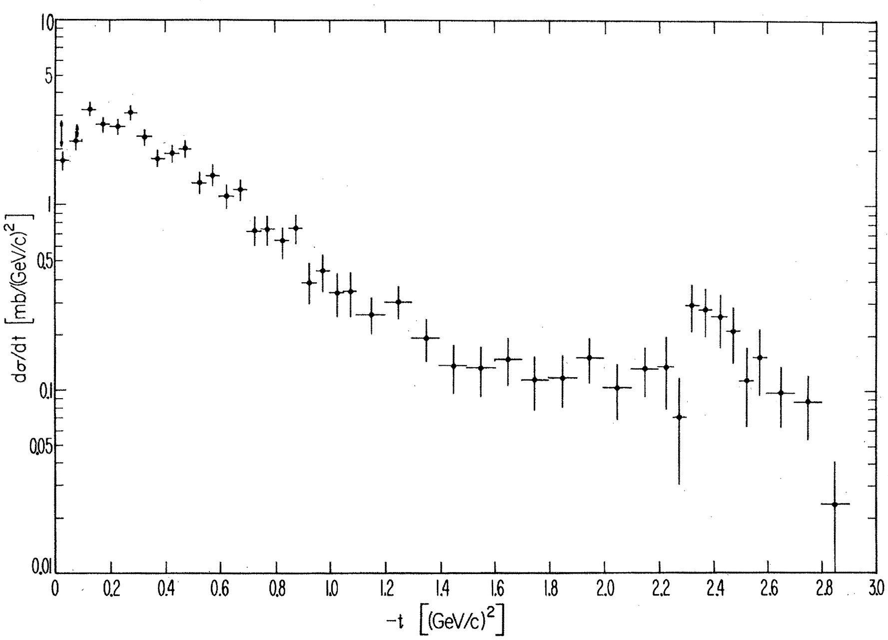

FIG. 1. $d\sigma/dt$. The first two bins have been corrected for the Pauli principle (arrows) as noted in text.

$(\mathrm{GeV}/c)^2$ to the form e^{at}. We obtain $a = 2.67 \pm 0.13$ $(\mathrm{GeV}/c)^{-2}$. We have also fitted the published data at 2.3 (Ref.2) and 3.0 GeV/c (Ref.3), and find in all three cases the slope so obtained is the same as the slope found in K^+p elastic scattering at the corresponding momentum.[8] The charge-exchange slope at 12 GeV/c is slightly smaller than, but probably also consistent with the elastic data at that energy.

If one attributes the forward peak to an exchange mechanism (e.g., ρ and A_2 exchange) then the absence of any structure at $t \simeq -0.6$ $(\mathrm{GeV}/c)^2$ is a strong argument in favor of ρ-A_2 exchange degeneracy. We can see from our data, with good statistics, that there are no dips or breaks in $d\sigma/dt$ anywhere in this region.

As noted by Cline, Matos, and Reeder,[9] the equality of $d\sigma/dt$ for K^-p charge-exchange scattering and K^+n charge-exchange scattering at $t=0$ is another test of ρ-A_2 strong exchange degeneracy. At 1.95 GeV/c, Dauber[10] obtains $d\sigma/dt = 2.3 \pm 0.4$ $\mathrm{mb}/(\mathrm{GeV}/c)^2$ for K^-p charge-exchange scattering, to be compared with our value at 1.94 GeV/c of 2.5 ± 0.5 $\mathrm{mb}/(\mathrm{GeV}/c)^2$ for K^+n charge-exchange scattering.

There are several models based on ρ and A_2 exchange that attempt a simultaneous fit to $\pi^-p \to \pi^0 n$, $\pi^-p \to \eta n$, and $K^-p \to \bar{K}^0 n$; however, in order to fit these data the models require nondegenerate ρ and A_2 trajectories,[11,12] and so predict the wrong shape for $K^+n \to K^0p$. Also without the introduction, *ad hoc*, of lower-lying trajectories they are unable to reproduce the magnitude of the cross section at our energy.

The peak in Fig. 1 at $t \simeq -2.4$ $(\mathrm{GeV}/c)^2$ corresponds to backward charge-exchange scattering. Note that since the neutron is moving when struck by the beam, the invariant mass of the K^+n (and consequently the K^0p) system is different from one event to another and therefore there is not a simple one-to-one correspondence between $d\sigma/du$ and $d\sigma/dt$. Figure 2 shows the data replotted as $d\sigma/du$, where

$$u = (P_{K^+} - P_p)^2 .$$

Exchange of $I=0$ or $I=1$ hyperons could give a peak near the backward direction. The same amplitudes that contribute to backward K^+n charge-exchange scattering also contribute (some with an opposite sign) to backward K^+p elastic scattering. Recent analyses of backward K^+p elastic scattering have led some people to conclude that the reaction was dominated by $I=0$ baryon exchange.[13] This implies that the backward K^+n CEX and K^+p elastic differential cross section should be the same. The straight line on Fig. 2 is the backward elastic scattering data.[12] The two are clearly inconsistent. We have made extensive checks of our

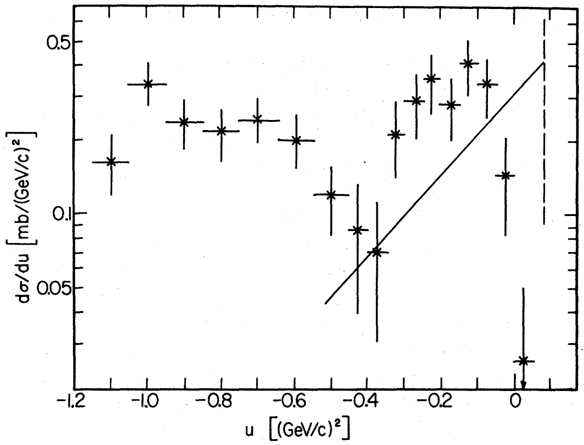

FIG. 2. $d\sigma/du$, where u is the momentum transfer from the beam to the nonspectator proton.

data and believe that we have neither lost events near $u = u_{\max}$ nor gained events near $u = -0.2$ $(\mathrm{GeV}/c)^2$. We are forced to conclude that if the baryon-exchange model is correct there is a large amount of $I=1$ exchange.

An independent check of the $I=0$ baryon-exchange model could be made with backward K^+n elastic scattering data. If $I=0$ exchange is dominant, then backward K^+n elastic scattering should be *much smaller than* backward K^+p elastic scattering. However, isotopic-spin invariance implies that where our K^+n charge-exchange cross section is very small ($u > 0$), the K^+n elastic scattering should be *equal to* the K^+p elastic scattering. Until the present there has been no K^+n elastic scattering data available. We have preliminary results on backward K^+n elastic scattering from our exposure which give a cross section $d\sigma/du = 0.40^{+0.14}_{-0.12}$ $\mathrm{mb}/(\mathrm{GeV}/c)^2$ for $0 < u < u_{\max}$. This is entirely consistent with the K^+p data, and inconsistent with dominant $I=0$ baryon exchange.

Since our data should also prove useful in KN phase-shift analyses, we have included in Table I the coefficients of a Legendre-series expansion of the angular distribution. In order to restrict the range of K^0p c.m. energies, we have used only events with spectator momentum less than 250 MeV/c. This results in a reasonably Gaussian-like c.m. energy distribution centered at 2.205 GeV with a full width at half height of 0.080 GeV. The expansion used was

$$\frac{d\sigma}{d(\cos\theta_{\mathrm{c.m.}})} = a_0\left(1 + \sum_{l=1}^{10} a_l (2l+1)^{1/2} P_l(\cos\theta_{\mathrm{c.m.}})\right).$$

Values of a_l are given in Table I for the data with and without corrections due to the Pauli principle. The larger errors on the corrected values reflect the uncertainty in the amount of spin-flip and spin-nonflip present.

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New Data on the Reaction $K^+p \to \pi^+ pK^0$ and a Detailed Comparison with the Veneziano Model

Victor Waluch, Stanley Flatté, Jerome H. Friedman, and Dennis Sivers*
Lawrence Radiation Laboratory, University of California, Berkeley, California 94720†

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We have made detailed fits to new data on the reaction $K^+p \to \pi^+ pK^0$ at 12 GeV/c using the generalized Veneziano model with several different sets of assumptions. We find that the quality of the fits depends to a large degree on the choice of kinematic factors, and we also find that a good fit can be obtained only by using five adjustable parameters, multiple trajectories, and several kinematic factors.

I. INTRODUCTION

The Bardakci-Ruegg generalization of the Veneziano model has many properties thought to be essential for the description of production processes.[1,2] It has duality, single- and double-Regge limits, crossing symmetry, and pole factorization.[3] The model's only glaring shortcoming, absence of unitarity,[4] has not deterred phenomenologists from comparing it directly with data in a variety of interactions.

Petersson and Törnqvist[5] used a five-point model to study the reaction $K^-p \to \pi^+\pi^-\Lambda$, and Törnqvist[6] the reaction $\pi^+p \to K^+\pi^+\Lambda$. They reported good overall fits with only one free parameter, albeit many assumptions. Chan, Raitio, Thomas, and Törnqvist[7] (hereinafter referred to as CRTT) undertook the study of the reactions

(i) $K^+p \to \pi^+pK^0$,

(ii) $K^-p \to p\pi^-\overline{K}^0$,

(iii) $\pi^-p \to pK^-K^0$,

which are related by crossing symmetry, and Bartsch *et al.*[8] made a study of reaction (ii). Raitio[9] subsequently studied the reactions

(iv) $K^+n \to K^0\pi^+n$,

(v) $K^-n \to \overline{K}^0\pi^-n$,

related to (i) – (iii) by isospin invariance. These studies reported that an adequate fit to the data in the various channels could be obtained from a simple model with the over-all normalization as the only free parameter. Cross sections, as well as the various experimental distributions available in the three-particle final state, were fitted with no new parameters.

In view of the simplifying assumptions used to eliminate arbitrary constants, this global success appears impressive. Since the predictions depend on the form assumed for the input trajectory functions[10], it may be misleading to claim that CRTT used a one-parameter model, but they certainly described a vast amount of data with less inherent freedom than previous phenomenological models.