[1]See, for example, H. D. Politzer, Phys. Rep. 14C, 129 (1974).

[2]See, for example, A. Mueller, Phys. Rev. D 9, 963 (1974).

Comparison of $K^{\pm}N$ Charge-Exchange Reactions at 8.5 and 13 GeV/c

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The cross sections for the line-reversed reaction pairs $K^+n \to K^0p$ and $K^-p \to \overline{K}^0n$, and $K^+p \to K^0\Delta^{++}$ and $K^-n \to \overline{K}^0\Delta^-$ have been determined with high statistics and good relative normalization at 8.36 and 12.8 GeV/c in a spectrometer experiment at Stanford Linear Accelerator Center. The cross sections for the K^+-induced reactions are larger than for the K^-, contrary to the expectations of weakly-exchange-degenerate Regge-pole models. The ratio of the reaction cross sections is about the same as at lower energies and shows little change with momentum transfer.

The dominant t-channel exchanges for the reactions,

$$K^+n \to K^0p \,, \tag{1a}$$

$$K^-p \to \overline{K}^0n \,, \tag{1b}$$

are the ρ and A_2 trajectories. Simple weakly-exchange-degenerate Regge-pole models[1] predict that the cross sections for these two reactions should be equal. Previous detailed comparisons of (1a) and (1b) have determined that the ratio of the K^+ to K^- total cross section is essentially constant from 3 to 6 GeV/c at a value of about 1.3.[2,3]

The situation for the reactions,

$$K^+p \to K^0\Delta^{++}(1236) \,, \tag{2a}$$

$$K^-n \to \overline{K}^0\Delta^-(1236) \,, \tag{2b}$$

is similar; the cross-section ratio for this pair has been observed at 4 and 6 GeV/c and is greater than for Reactions (1).[3]

This Letter describes a comparison of the reactions pairs (1) and (2) at 8.36 and 12.8 GeV/c with high statistics and good relative normalization. The experiment was performed using the

downstream spectrometer of the large-aperture solenoid spectrometer (LASS) at Stanford Linear Accelerator Center.[4] An rf-separated kaon beam was incident upon a 90-cm-long liquid deuterium target. The production of a K^0 was detected via the $K_s^0 \to \pi^+\pi^-$ decay mode using the wire spark chambers and scintillation-counter hodoscopes in the spectrometer.

Reactions (1) and (2) were identified by means of the distribution in the square of the missing mass (M_X^2) recoiling against the K^0. The K^0 sample was defined by assuming the particles to be pions and then requiring the two-particle effective mass to be in the interval 0.478–0.518 GeV [Fig. 1(a)]. The M_X^2 calculated for these events is shown for the 8.36-GeV/c K^+ data in Fig. 1(b), the distributions for the other charge and energy being similar except for poorer resolution at the higher energy. Fermi motion did not significantly affect the M_X^2 resolution for the momentum-transfer region being studied.

The number of events for the reactions of interest was obtained by fitting a four-component function to the M_X^2 distribution for each $t'=t-t_{min}$ interval, where t is the four-momentum transfer
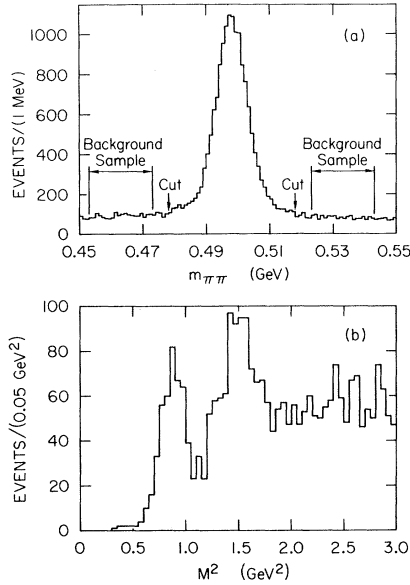
FIG. 1. (a) The two-pion effective mass distribution at 12.8 GeV/c showing the K^0 region. Events in the region labeled "background sample" were used to estimate the background under the K^0. (b) The distribution of the square of the missing mass (M_χ^2) for K^+ at 8.36-GeV/c K^+ showing the proton and Δ signals.

from the incident kaon to the final-state kaon. The four components represented (a) the nucleon-recoil signal, (b) the Δ-recoil signal, (c) the nonresonant background from the process $KN \to K^0 X$, and (d) the non-K^0 background resulting from the absence of particle identification in the experiment. Specifically, a Gaussian resolution function was used to describe the nucleon peak, and a p-wave Breit-Wigner shape broadened by the resolution function for the Δ line shape.[5] The contribution from multiparticle production and nonresonant background was parametrized by a smooth function for $1 < M_\chi^2 < 3$ GeV^2. The small background from non-K^0 events within the K^0 mass region was eliminated by subtracting events from control regions on either side of the K^0 mass cut [see Fig. 1(a)]. This four-component function provided a good description of the K^+ and K^- data at both energies, with only three variable parameters. The χ^2 per degree of freedom of these fits averaged 1.0 and in all cases was less than 1.8.

Isospin invariance was used to obtain the number of events for the Reactions (2) from the measured Δ signal, which included contributions from both target protons and neutrons. The number of nucleon and Δ events obtained in each t' interval was corrected for geometric acceptance, absorption by the material in the spectrometer, and pion decay losses as determined by a Monte Carlo simulation of the spectrometer characteris-

TABLE I. The differential and total cross sections in μb/GeV^2. The slope parameter B was determined by a fit to $Ae^{-B|t'|}$ for $0.12 < |t'| < 1.0$ GeV^2.

	8.36 GeV/c					12.8 GeV/c			
t'	K^+		K^-		t'	K^+		K^-	
GeV^2	$K^+n{\to}K^0p$	$K^+p{\to}K^0\Delta^{++}$	$K^-p{\to}\bar K^0 n$	$K^-n{\to}\bar K^0\Delta^-$	GeV^2	$K^+n{\to}K^0p$	$K^+p{\to}K^0\Delta^{++}$	$K^-p{\to}\bar K^0 n$	$K^-n{\to}\bar K^0\Delta^-$
0.0 –0.04	386±77	144±57	263±69	144±51	0.0 –0.02	191±42	63±30	107±41	31±26
0.04–0.08	380±40	329±52	250±35	340±40	0.02–0.04	192±23	82±21	152±22	75±19
0.08–0.12	326±39	367±44	215±36	355±59	0.04–0.08	212±14	156±14	169±13	110±11
0.12–0.16	205±36	372±54	188±37	271±42	0.08–0.12	160±11	169±12	108±10	122±11
0.16–0.22	261±35	257±42	135±29	202±41	0.12–0.16	135±11	179±12	109±10	103±10
0.22–0.30	124±25	177±31	118±27	146±33	0.16–0.22	113± 8	123± 8	83± 7	74± 7
0.30–0.50	72±19	75±20	84±20	98±24	0.22–0.30	73± 5	67± 6	49± 5	46± 5
0.50–1.0	13±13	17±17	14±14	18±18	0.30–0.50	34± 3	45± 3	28± 2	26± 3
					0.50–1.00	5.9±1.1	11± 1	2.6± 1	7± 1
σ_T (μb)	98±14	102±16	72±12	97±16	σ_T	50.2±5.8	50± 6	36.3±4.4	32± 4
Slope, B	4.6±0.8	5.9±1.1	4.4±1.1	4.3±1.0	Slope, B	5.3±0.3	4.6±0.2	5.7±0.3	4.7±0.4
Events	394±23	492±35	255±20	427±30	Events	1745±48	2492±77	1215±42	1517±62

tics. Corrections for track reconstruction effi-
ciency (12%), logic deadtime (1%), beam particle
decays (5%), and H_2 and HD contamination of the
liquid deuterium (3%) were also applied. The
losses due to the unseen decay modes of the K^0
were evaluated using 0.6867 for the $K_s^0 \to \pi^+\pi^-$
decay branching fraction.[6]

In the case of Reactions (1), the measured dif-
ferential cross sections were corrected for the
suppression of events at small t' ($|t'| < 0.1$ GeV^2)
caused by the Pauli exclusion principle. This
correction was computed assuming no spin-flip
contribution to the cross section and a deuteron
form factor calculated from the Hulthén wave
function.

The measured differential and total cross sec-
tions are presented in Table I. The total cross
sections were obtained by integrating the differ-
ential cross sections up to $|t'| = 1.0$ GeV^2. The
total-cross-section uncertainties include all

systematic effects which we estimate to be about
11%. The differential-cross-section uncertain-
ties in Table I do not include the systematic er-
rors. We estimate that the uncertainty in the
relative normalization between the reactions in
each pair (1) and (2), is 4% at each beam momen-
tum.

The observed differential cross sections show
a change of slope, or turnover, in the forward
direction which indicates substantial spin-flip
amplitudes. The forward dip for pair (2) is seen
to be significantly greater than for pair (1).

The ratio of the K^+ to K^- total cross sections
for Reactions (1) is 1.37 ± 0.22 at 8.36 GeV/c and
1.38 ± 0.09 at 12.8 GeV/c, where the errors in-
clude the relative systematic error. These re-
sults are plotted in Fig. 2(a) and indicate no en-
ergy dependence of the ratio from 3 to 13 GeV/c.
We discuss the s dependence of these reactions
in terms of this ratio because this experiment,
as well as the lower-energy Argonne National
Laboratory experiments,[2,3] was designed to mea-
sure both reactions in the same apparatus with
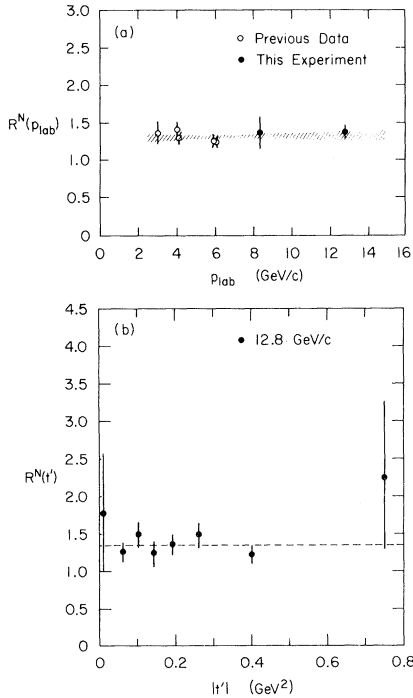the same analysis procedures, thus minimizing

FIG. 2. (a) The energy dependence of the ratio

$$R^N(p_{\text{lab}}) = \sigma_T(K^+ n \to K^0 p)/\sigma_T(K^- p \to \overline{K}^0 n).$$

The shaded area represents the one-standard-deviation
envelope for a fit of the form $A p_{\text{lab}}{}^n$. (b) The t' depen-
dence of the ratio

$$R^N(t') = [d\sigma(K^+ n \to K^0 p)/dt'] \, [d\sigma(K^- p \to \overline{K}^0 n)/dt']^{-1}$$
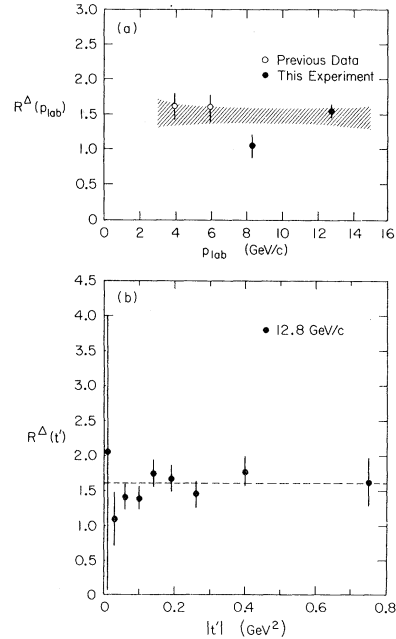
at 12.8 GeV/c.

FIG. 3. (a) The energy dependence of the ratio

$$R^\Delta(p_{\text{lab}}) = \sigma_T(K^+ p \to K^0 \Delta^{++})/\sigma_T(K^- n \to \overline{K}^0 \Delta^-).$$

The shaded area is as in Fig. 2(a). (b) The t' depen-
dence of the ratio

$$R^\Delta(t') = [d\sigma(K^+ p \to K^0 \Delta^{++})/dt'] \, [d\sigma(K^- n \to \overline{K}^0 \Delta^-)/dt']^{-1}$$

at 12.8 GeV/c.

the relative error in the cross-section measurements. A fit of the form $R^N(p_{lab}) = Ap_{lab}{}^n$ to the data in Fig. 2(a) yields the values $A = 1.28 \pm 0.13$ and $n = 0.014 \pm 0.060$. The shaded region in Fig. 2(a) shows the one-standard-deviation error band for this fit. The ratio for the differential cross sections for the high-statistics 12.8-GeV/c data is shown in Fig. 2(b) and reveals no substantial t' dependence.

The corresponding results for Reactions (2a) and (2b) are shown in Figs. 3(a) and 3(b). A fit of the form $A_{plab}{}^n$ to our data and the Argonne National Laboratory data of Ref. 3 gives the values $A = 1.55 \pm 0.38$ and $n = -0.02 \pm 0.11$, with the one-standard-deviation error band shown in Fig. 3(a). For this reaction pair we find no dependence of the cross-section ratio on s and a ratio consistent with no dependence on t'.

These results are in clear contradiction to the predictions of simple weakly-exchange-degenerate Regge-pole models. More importantly, they severely restrict any modifications to such models since most interpretations of the observed behavior, such as nondegenerate ρ-A_2 trajectories or lower-lying trajectories, predict a ratio that approaches unity as s increases—a behavior which we do not observe. The lack of t' dependence, if confirmed by better measurements in the forward direction, would suggest that the degeneracy-breaking mechanism is present in both the helicity flip and nonflip amplitudes.

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[1] V. Barger and D. Cline, *Phenomenological Theories of High Energy Scattering* (Benjamin, New York, 1969).

[2] R. Diebold *et al.*, Phys. Rev. Lett. **32**, 904 (1974).

[3] J. J. Phelan *et al.*, Phys. Lett. **61B**, 483 (1976).

[4] A detailed description of the spectrometer and data analysis may be found in M. G. D. Gilchriese, Ph.D. dissertation, Stanford University, 1977 (unpublished); M. G. D. Gilchriese *et al.*, to be published.

[5] J. D. Jackson, Nuovo Cimento **34**, 1644 (1964). The Breit-Wigner form used was

$$f_{BW}(M) = \frac{M}{P} \frac{\Gamma(M)}{(M_0{}^2 - M^2)^2 + M_0{}^2 \Gamma^2(M)}$$

with a mass-dependent width

$$\Gamma(M) = \Gamma_0 \left(\frac{P}{P_0}\right)^3 \frac{\rho(M)}{\rho(M_0)},$$

where P is the magnitude of the momentum of the decay products in the center-of-mass frame for a particle mass M; P_0 is the corresponding value for a particle of mass M_0, the central value of the resonance; and $\rho(M) = \{am_\pi{}^2 + P^2\}^{-1}$, with $a = 1.3$ as given by M. Gell-Mann and K. Watson [Annu. Rev. Nucl. Sci. **4**, 219 (1954)]. The Δ mass region was restricted to $M_X{}^2 \le 2.0$ GeV^2. If the upper limit were 3.0 GeV^2, the cross sections would increase by about 15%. The terms used in the fit were essentially of the same form as described in G. W. Brandenburg *et al.*, Phys. Rev. D **15**, 617 (1977).

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