EUROPEAN ORGANIZATION FOR NUCLEAR RESEARCH

CERN-EP/81-05
21 January 1981

SMALL MOMENTUM TRANSFER K^-p CHARGE EXCHANGE SCATTERING AT 30 GeV/c

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Joint Experiment of IHEP, Serpukhov, USSR
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(Submitted to Nuovo Cimento)

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ABSTRACT

The $K^- p \rightarrow \bar{K}^0 n$ charge exchange differential cross-section has been measured at 30 GeV/c with high statistical accuracy and high angular resolution. The experiment was made at the IHEP 70 GeV accelerator, using a hodoscope hadron calorimeter to detect K_L^0 . The cross-section shows a dip at small $|t|$ which indicates a dominance of spin-flip amplitudes in ρ and A_2 exchanges in the t-channel.

The differential cross-section of the reaction

$$K^- + p \longrightarrow \bar{K}^0 + n \quad (1)$$

has been measured with 30 GeV/c K^- in the region of small momentum transfer where previous experiments had shown some evidence for a dip at $|t| \leq m_\pi^2$ (1-3).

The long lived component K_L^0 of $\bar{K}^0$ has been detected in a direct way through the use of a hodoscope hadron calorimeter which allows the simultaneous measurement of both the energy and the coordinates of hadrons⁴). This new technique gives a better resolution in t than the usual method of K_S^0 detection through their $\pi^+\pi^-$ decay.

The experiment has been performed at the IHEP 70 GeV accelerator. The lay-out is given on fig. 1. The 30 GeV/c negative particle beam is focused on a 40 cm long liquid hydrogen target. Kaons are identified in the beam with the help of gas Cerenkov counters. The kaon rate was $5 \cdot 10^4 K^-$ per burst.

The longitudinal coordinate of the interaction point is obtained with an accuracy of ± 3 cm from the amount of Cerenkov light emitted by the negative kaon until its disappearance in the liquid hydrogen of the target^{5,6}). Lateral coordinates are determined with hodoscopes H_1 and H_2 .

A guard counter system surrounding the target allows to reject charged and inelastic processes (a full description may be found in ref. 7). The ring of lead glass counters which detects photons efficiently is little sensitive to recoil neutrons, so that corrections to the measured cross-sections are less than $1.5 \cdot 10^{-2}$. Thus systematic errors are avoided at the smallest t , for which $\frac{d\sigma}{dt}$ in reaction (1) and neutron recoil emission are changing in a non monotonous way (in former experiments correction due to detected recoil neutrons amounted to $15 \cdot 10^{-2}$ (3,6)).

Forward neutral particles are detected in the hodoscope calorimeter⁴). A 3 meter magnet sweeps charged particles away from the calorimeter. The calorimeter is an iron-scintillator sandwich in which the scintillator planes are made of 14 hodoscope channels, 5 cm wide and 70 cm long, which are alternately horizontal and vertical. The light outputs from the 420 channels are added five by five through light guides giving a total of

84 separate counters (fig. 2). The division of the calorimeter in three identical blocks provides information on the longitudinal development of the showers which is useful to identify hadrons and to measure γ contamination.

The trigger is provided by the coincidence S_{1-5} , with vetoes from F_1 , F_2 , A and B. Electronics to measure signal amplitudes in the 84 calorimeter counters and the 96 guard system counters have been described earlier⁶⁾.

Guard system and calorimeter are calibrated at regular intervals during the runs in a wide muon beam⁶⁾. The calorimeter has also been calibrated with 30 GeV/c negative particles (K^- , π^- , $\bar{p}$, e^-)⁴⁾. Between calibrations, gain drifts are controlled to a 1% level in both set-ups with light pulses from LED (light emitting diodes)

Criteria for data analysis are:

- (a) signal amplitudes in guard system counters 0 are less than 35 MeV energy deposit equivalent;
- (b) in counters D and G, they are less than 45 MeV equivalent;
- (c) the energy released in the first calorimeter block E_1 is smaller than 0.9 of the total energy released E_k ⁴⁾: $\alpha_1 = A_1/A < 0.9$;
 A_i is the amplitude in the i^{th} block and $A = \sum A_i$ is the total amplitude in the calorimeter;
- (d) the total energy released in the calorimeter stays inside the range $20 \text{ GeV} < E_k < 40 \text{ GeV}$.

The first two criteria of the type

as well as events with higher π^0 multiplicities.

Criterion (c) suppresses events with γ rays in the calorimeter by more than an order of magnitude (for example γ -rays from π^0 in reaction (3) or from $K_S^0 \longrightarrow \pi^0 \pi^0$ decays). The efficiency of this rejection has been measured with π^0 from the charge exchange reaction $\pi^- p \longrightarrow \pi^0 n$ and with electron beams. Monte-Carlo simulations of background processes including (2) and (3) indicate a background contribution of less than 2% amongst selected events. A direct measurement of the background with a lead sandwich counter F_3 (two radiation lengths thick) placed behind the target and a search for clusters characteristic of electromagnetic showers in the first calorimeter block gave similar results.

The amplitude spectrum of selected events is identical to that obtained with monoenergetic kaons from the beam (fig. 3). The energy resolution of the calorimeter for 30 GeV kaons is $\sigma_E/E = 0.11$ ⁴⁾.

A total of 13.000 events remains after all cuts, i.e. an order of magnitude more than in previous experiments.

The identification of neutral hadrons detected in the calorimeter as kaons is confirmed by comparing the mean values of the energy released in the different blocks of the calorimeter by these events and by negative kaons (table I). Data from table I also show that K^- and K_L^0 have equal absorption cross-sections up to the accuracy of 3%. Nucleons showers develop more rapidly as nucleon absorption cross section is 1-5 times larger.

The position y_0 of the center of gravity of the amplitudes of the signals released by a hadron shower in the hodoscope channels is a biased estimate of the true hadron impact coordinate y_c . The difference between $\langle y_0 \rangle$ and y_c is non linear ⁴⁾. The use of y_0 instead of y_c distorts particle distributions in such a way as to concentrate events in the center and along the edges of the hodoscope cells ⁸⁾.

Corrections to y_0 have been made in order to minimise both the distortion of particle distributions and the systematic coordinate error (2 mm maximum). Kaon coordinates are determined with a precision of $\sigma = 1$ cm (fig. 4). A Monte-Carlo simulation shows that the procedure, which have been used for coordinate determination, distorts evaluated cross sections

for reaction (1) by less than 1%. The resolution in t , the squared four-momentum transfer, which depends mainly on the coordinate precision, is given for the 14 meters distance chosen between target and the calorimeter by

$$\delta t \text{ (FWHM)} = 0.002 + 0.08 \sqrt{|t|} \text{ (GeV/c)}^2$$

To evaluate cross-sections of reaction (1), corrections have been applied for the efficiency of the criteria on event selection, for the absorption of particles inside the target and downstream, for the loss of events due to accidental anticoincidences and for inelastic processes, as well as a small t -dependent correction due to neutrons detected in the guard system and corrections due to the finite t resolution of the set-up. The acceptance was evaluated through Monte-Carlo calculations. Differential cross-sections have been obtained in the interval $0 < |t| < 0.5 \text{ (GeV/c)}^2$ (fig. 5 and table II).

The 30 GeV total cross-section for reaction (1) is found to be

$$\sigma(K^- p \rightarrow \bar{K}^0 n) = (11 \pm 1) 10^{-30} \text{ cm}^2$$

in good agreement with previous measurements (the range above $t = 0.5 \text{ (GeV/c)}^2$ contributes about 6% to the total³⁾).

The presence of a dip in the differential cross-section at small $|t|$ shows the dominant contribution of the spin-flip amplitude. Behind the maximum, the cross-section decreases exponentially³⁾:

$$\frac{d\sigma}{dt} \sim e^{(6.3 \pm 0.2)t} \text{ for } |t| > 0.12 \text{ (GeV/c)}^2 \quad (4)$$

The $t = 0$ differential cross-section measured in the present experiment is shown on fig. 6 together with data existing for other K^- momenta. They follow a power law as a function of s , the square of the total energy in the center of mass:

$$\left. \frac{d\sigma}{dt} \right|_{t=0} = (240 \pm 30) \left(\frac{s}{s_0} \right)^{-1.08 \pm 0.09} 10^{-30} \text{ cm}^2 / (\text{GeV/c})^2, \quad (5)$$

where $s_0 = 10 \text{ GeV}^2$.

Charge exchange cross-sections for pion and kaons on nucleons at $t = 0$ are linked in a simple U (6) quark model by the relation^{9,10)}

$$\begin{aligned} & \frac{d\sigma}{dt} (\pi^- p \rightarrow \pi^0 n) + \frac{d\sigma}{dt} (\pi^- p \rightarrow \eta n) + \frac{d\sigma}{dt} (\pi^- p \rightarrow \eta' n) \\ & = \frac{d\sigma}{dt} (K^- p \rightarrow \bar{K}^0 n) + \frac{d\sigma}{dt} (K^+ n \rightarrow K^0 p). \end{aligned} \quad (6)$$

Data for the reaction $K^+ n \rightarrow K^0 p$ are missing at energies larger than 13 GeV. The relation

$$\frac{\sigma (K^+ n \rightarrow K^0 p)}{\sigma (K^- p \rightarrow \bar{K}^0 n)} \approx 1.3 \quad (7)$$

holds in the range from 3 GeV/c to 13 GeV/c¹¹⁾. The t dependences of the differential cross-sections of these reactions are practically the same.

At 13 GeV/c, relation (6) is satisfied within experimental errors ($\sim 25\%$)^{6, 11-13)}. Assuming that the ratio (7) does not change at higher energies, it is also satisfied at 30 GeV/c, the left hand side being^{6, 12, 13)} $(86 \pm 6) 10^{-30} \text{ cm}^2/(\text{GeV}/c)^2$ and the right hand side is $(90 \pm 9) 10^{-30} \text{ cm}^2$ according to the present data. This relation remains valid for $|t|$ values up to $0.12 (\text{GeV}/c)^2$. At larger $|t|$, discrepancies become significant (fig.5).

Reaction (1) may be described by the difference of two amplitudes corresponding to ρ and A exchange in the t -channel. Use has been made of a parametrisation similar to that which describes over large t intervals the reaction $\pi^- p \rightarrow \pi^0 n$ (ρ exchange) where the non spin-flip amplitude is given by $f_\rho(t) \sim \exp(c_+ t/2)$ and the spin-flip one is given by

$$g_\rho(t) \sim - (q c_- t)^{1/2} \exp(c_- t/2); c_+ \text{ and } c_- \text{ are equal to a few per cent}$$

accuracy over the whole energy range. The same is valid for the reaction $\pi^- p \rightarrow \eta n$ (A_2 exchange).

In this manner, the $|t|$ dependence of the differential cross-section of $K^- p$ charge exchange is described by the relation

$$\begin{aligned} \frac{d\sigma}{dt} (K^- p \rightarrow \bar{K}^0 n) & \sim \left(1 - G_\rho t\right) e^{c_\rho t} + R^2 \left(1 - G_A t\right) e^{c_A t} \\ & - 2R \left[\cos \phi_+ - \left(G_\rho G_A\right)^{1/2} t \cos \phi_- \right] e^{(c_\rho + c_A)t/2}. \end{aligned} \quad (8)$$

Here $G_\rho = q_\rho c_\rho$, $G_A = q_A c_A$, $R = |f_A(0)/f_\rho(0)|$. ϕ_+ is the phase between

ρ and A amplitudes without spin-flip and ϕ_- is the same with spin-flip. At 30 GeV/c, $G_\rho = (33.4 \pm 1.0) (\text{GeV}/c)^{-2}$ and $G_A = (33.6 \pm 1.5) (\text{GeV}/c)^{-2}$ are equal to a high precision^{6, 12)}. As a result formula (8) may be simplified to

$$\begin{aligned} \frac{d\sigma}{dt} (K^- p \rightarrow \bar{K}^0 n) \sim (1-Gt) \left(e^{c_\rho t} + R^2 e^{c_A t} \right) \\ - 2R \left[\cos \phi_+ - Gt \cos \phi_- \right] e^{(c_\rho + c_A)t/2} \end{aligned} \quad (9)$$

which has been used to fit the measured data of this experiment. Existing experimental values have been used for c and G ^{6, 12)} $c_\rho = (15.5 \pm 0.3) (\text{GeV}/c)^{-2}$, $c_A = (8.8 \pm 0.1) (\text{GeV}/c)^{-2}$ and $G = (33.5 \pm 1.3) (\text{GeV}/c)^{-2}$. R and $\phi_\pm$ were left as free parameters.

The resulting fit is shown on fig. 5. It is quite satisfactory in the whole range $0 < |t| < 0.5 (\text{GeV}/c)^2$. Best values for the free parameters are:

$$\begin{aligned} R &= 0.83 \pm 0.05, \\ \cos \phi_+ &= -0.08 \pm 0.07, \\ \cos \phi_- &= 0.23 \pm 0.02. \end{aligned} \quad (10)$$

The interference between ρ and A spin-flip amplitudes is thus destructive. It contributes significantly to the shape of the small $|t|$ differential cross section. On the other hand the interference of non spin-flip amplitudes is negligible in agreement with the prediction that these amplitudes are nearly pure imaginary^{14, 15)}. The value of the phase angle $\phi_+ = (95 \pm 4)^\circ$ is in good agreement with the phase shift between ρ and A_2 amplitude signatures deduced from the energy dependence of the differential cross-sections of $\pi^- p \rightarrow \pi^0 n$ and $\pi^- p \rightarrow \eta n$ reactions at $t = 0$. Intercepts are $\alpha_\rho(0) = 0.48 \pm 0.01$ and $\alpha_{A_2}(0) = 0.38 \pm 0.02$ ^{6, 12)}, giving $\phi_+ = (91 \pm 4)^\circ$.

If one puts $\cos \phi_+ = 0$ and if one takes the ratio (7) as a free parameter, an equally good fit may be obtained with $R = 0.80 \pm 0.03$, $\cos \phi_- = 0.27 \pm 0.03$ and $\sigma(K^+ n - K^0 p) / \sigma(K^- p - \bar{K}^0 n) = 1.4 \pm 0.2$.

The former analysis provides definite predictions about reaction $K^+ n \rightarrow K^0 n$, which is described by the sum of ρ and A_2 amplitudes. The study of this reaction would be of great interest at Serpukhov energies.

We would like to thank IHEP and CERN directorates for their support. We acknowledge C. Bricman and S.S. Gerstein for discussing the present results.

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Table I

Energy release of different 30 GeV/c particles
in the different sections of the calorimeter

Particle ^(*)	$\langle\alpha_1\rangle$	$\langle\alpha_2\rangle$	$\langle\alpha_3\rangle$	$\langle A \rangle$ rel. unit
K_L^0	0.376 ± 0.003	0.446 ± 0.002	0.181 ± 0.002	30
K^-	0.374 ± 0.003	0.447 ± 0.002	0.181 ± 0.002	30
$\bar{p}$	0.436 ± 0.002	0.422 ± 0.001	0.144 ± 0.001	31 ^(**)
π^-	0.387 ± 0.003	0.446 ± 0.002	0.168 ± 0.001	30
$\pi^0 \rightarrow 2\gamma$	0.930 ± 0.001	0.070 ± 0.002	0.010 ± 0.002	42 ^(***)
e^-	0.937 ± 0.001	0.062 ± 0.001	0.011 ± 0.002	42 ^(***)
μ^-	0.333	0.333	0.333	1.4

(*) For K^- , n^- and antiprotons, mean values $\langle\alpha_i\rangle$ are obtained with the same criterion as used for K_L^0 ($\alpha_1 < 0.9$).

(**) In the case of antinucleons the value of the total energy release is larger by 1 GeV due to their annihilation.

(***) Electromagnetic showers give a 40% larger light yield in the calorimeter than hadron showers of equal energy.

Table II

$\bar{K}^- p \rightarrow \bar{K}^0 n$ differential cross-sections at $p = 30$ GeV/c

$-t \left[(\text{GeV}/c)^2 \right]$	$\Delta t \left[(\text{GeV}/c)^2 \right]$	$d\sigma/dt \left[10^{-30} \text{cm}^2 / (\text{GeV}/c)^2 \right]^{(*)}$
0.005		39.1 ± 1.8
0.015	$\left. \begin{array}{c} \{ \\ \pm 0.005 \end{array} \right\}$	44.3 ± 1.9
0.025		47.4 ± 2.0
0.035		47.9 ± 2.0
0.045		45.9 ± 2.0
0.060		44.8 ± 1.5
0.080	$\left. \begin{array}{c} \{ \\ \pm 0.010 \end{array} \right\}$	40.3 ± 1.4
0.100		38.5 ± 1.3
0.120		35.4 ± 1.2
0.140		32.5 ± 1.1
0.165	$\left. \begin{array}{c} \{ \\ \pm 0.015 \end{array} \right\}$	28.5 ± 1.0
0.195		22.5 ± 0.9
0.230	$\left. \begin{array}{c} \{ \\ \pm 0.02 \end{array} \right\}$	18.4 ± 0.8
0.270		13.6 ± 0.7
0.310		10.3 ± 0.6
0.370	$\left. \begin{array}{c} \{ \\ \pm 0.04 \end{array} \right\}$	7.9 ± 0.6
0.450		5.2 ± 0.5
$\sigma = (11 \pm 1) 10^{-30} \text{cm}^2$		

(*) Relative point to point errors are given. Absolute systematic error is $\pm 7\%$.

FIGURE CAPTIONS

Fig. 1 : Experimental set-up. M_7 , M_{23} , M_{24} , L_{26} , L_{25} : magnets and quadrupole lenses at the end of the beam channel.

M: sweeping magnet with screen E

K: collimator

$S_1 - S_7$: scintillation counters

C_1 , C_2 : are gas threshold Cerenkov counters in a differential threshold mode¹⁶⁾

DC_2 , DC_3 : Cerenkov counters

$H_1 - H_2$: x-y coordinate hodoscopes

LH_2 : liquid hydrogen target, surrounded by the guard system made of:

F_1, F_2, A : scintillation counters

B: lead-scintillator sandwich

O: 72 lead-glass shower counters

D and G: 12 lead glass counters each

F_3 : is an auxiliary sandwich used in part of the measurements

HC: hodoscope hadron calorimeter.

Fig. 2 : Schematic view of the hadron calorimeter. 5 out of the 84 counters in both x and y directions are shown.

1: iron converter

2: scintillator

3: light guides

4: fiber glass light guide for the LED calibration system

5: photomultiplier.

Fig. 3 : Total spectrum of calorimeter events from the reaction $K^- p \rightarrow \bar{K}^0 n$, $\bar{K}^0 \rightarrow K_L^0$. Dotted line is a calibration spectrum obtained with monoenergetic 30 GeV/c K^- .

Fig. 4 : K^- coordinate measurement precision.

y_c : real coordinate

y_m : measured coordinate.

Figure Captions (Cont'd)

Fig. 5 : $K^- p \rightarrow \bar{K}^0 n$ differential cross-section at $p = 30$ GeV/c.

Horizontal bars at the bottom show the experimental t -resolution. Dotted curve is calculated according to a quark model^{9,10)} with equal $K^- p \rightarrow \bar{K}^0 n$ and $K^+ n \rightarrow K^0 p$ cross-sections and existing data^{6,12,13)}. Full curve is the fit with formula (9) of existing data on ρ and A_2 amplitudes^{6,12)}.

Fig. 6 : $t = 0$ differential cross-sections as a function of energy.

Open points: existing data¹⁻³⁾; black points: present experiment. Full curve: exponential law (4). Other curves are calculated in references 9 and 14.

Fig. 1

Fig. 2

Fig. 3

Fig. 4

Fig. 5

Fig. 6