PHYSICAL REVIEW D
PARTICLES AND FIELDS

THIRD SERIES, VOL. 7, NO. 9 1 May 1973

Measurement of Neutral Cascade Production from Negative-Kaon–Hydrogen at 1.8 GeV/c, $K^-p \to K^0 \Xi^0$ *

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(Received 10 August 1972)

The reaction $K^-p \to K^0\Xi^0$ was investigated in a counter–spark-chamber experiment carried out at the Bevatron. The c.m. angular distribution was obtained from a sample of 59 events for an incident meson momentum of 1.8 GeV/c. A Legendre-polynomial fit to the data yielded the coefficients $B_0 = 1.00 \pm 0.27$, $B_1 = 0.45 \pm 0.42$, $B_2 = 1.08 \pm 0.47$, $B_3 = -1.20 \pm 0.62$ for an expression of the form $d\sigma/d\Omega = (\sigma/4\pi)\sum_{l=1}^{l=4} B_l P_l(\theta)$, where σ = total cross section, and θ = c.m. production angle of the K^0, $P_l(\theta)$ = lth Legendre polynomial. The χ^2 for this three-degree-of-freedom fit was 3.00.

I. INTRODUCTION

A spark-chamber experiment has been carried out to measure the production properties of the neutral cascade hyperon. The hyperons were produced by exposing a liquid-hydrogen target to a K^- enriched 1.8-GeV/c meson beam derived from the Bevatron. In a triggering mode designed to select $K^-p \to K^0\Xi^0$ events ~200 000 pictures were taken within a four-month period. After scanning and measuring, data analysis yielded 59 events from which the production differential cross section $d\sigma/d\Omega(K^-p \to K^0\Xi^0)$ was derived.

Other groups[1,2] measured this production angular cross section, but their results were based on fewer events. A comparison of Legendre coefficients shows that the results of the present experiment agree with those of (2) at 1.7 GeV/c to within experimental errors. The apparent small Ξ^0 polarization in $K^-p \to K^0\Xi^0$ at 1.8 GeV/c limits the conclusions concerning the possible exchanges responsible for the shape of the angular distribution.

II. EXPERIMENT

The 1.8-GeV/c K^- enriched beam was also used for an earlier experiment,[3] where it is fully described. Figure 1 shows the beam transport system and the experimental area. Meson discrimination was such that the physical ratio K^-/π^- on the target was ~1/10. The ethylene Čerenkov counter, however, provided an electronic K^- trigger that made the electronic ratio K^-/π^- effectively ~100/1. The rms beam momentum spread was ±5 percent.

The counter–spark-chamber layout inside the experimental house is given in Fig. 2. Beam-defining counters ensured triggers only for mesons incident on the liquid-hydrogen flask. Counter $T3$ performed the essential function of providing a neutral

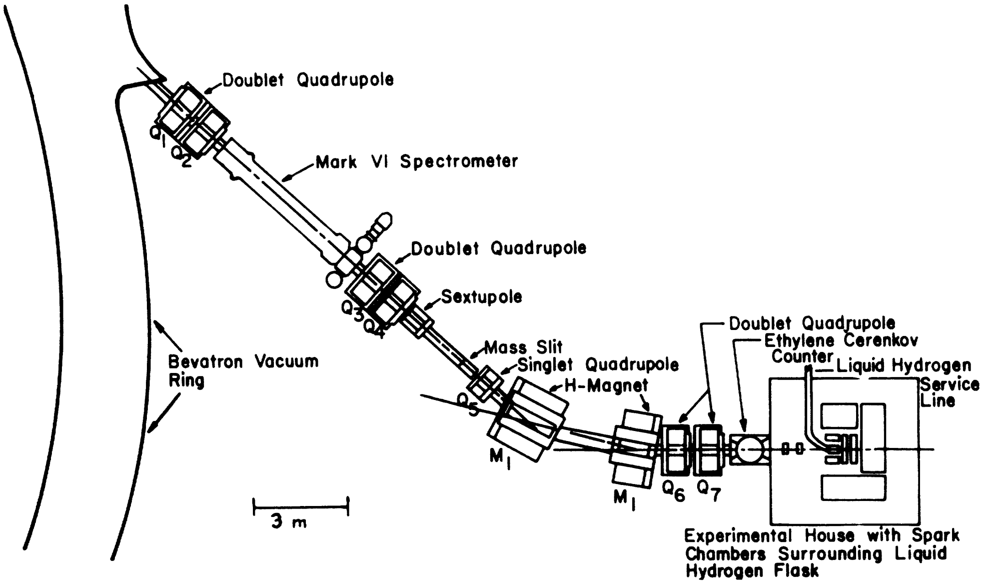

FIG. 1. Separated negative 1.8-GeV/c meson beam and the principal experimental detector configuration.

trigger. Placed in anticoincidence with the beam signal, this disk-shaped counter vetoed the many charged-particle production events. As measured during the experiment the efficiency of counter $T3$ varied between 99.5% and 99.8%.

Having discriminated against charged-particle production, it was necessary to have additional counters to identify the signature of desired events. For this purpose a counter hodoscope was used to detect the decay modes $K^0 \to \pi^+\pi^-$ and $\Xi^0 \to \Lambda^0\pi^0 \to p\pi^-\pi^0$. As shown in Fig. 2 the hodoscope consisted of an array of 60 narrow picket counters immediately in front of 9 wider paddle counters. The "paddles" were for coincidence purposes and the "pickets" were used to count the number of charged particles in the final state. The nanosecond-electronic logic signature required four different (picket-paddle) triggers during a short gate generated by a neutral trigger for the spark chambers to be pulsed.

Events were recorded by photographing ~90° stereo views of six optical spark chambers. The chambers surrounding the target were designed to subtend ~2π sr of the solid angle for particles orig-

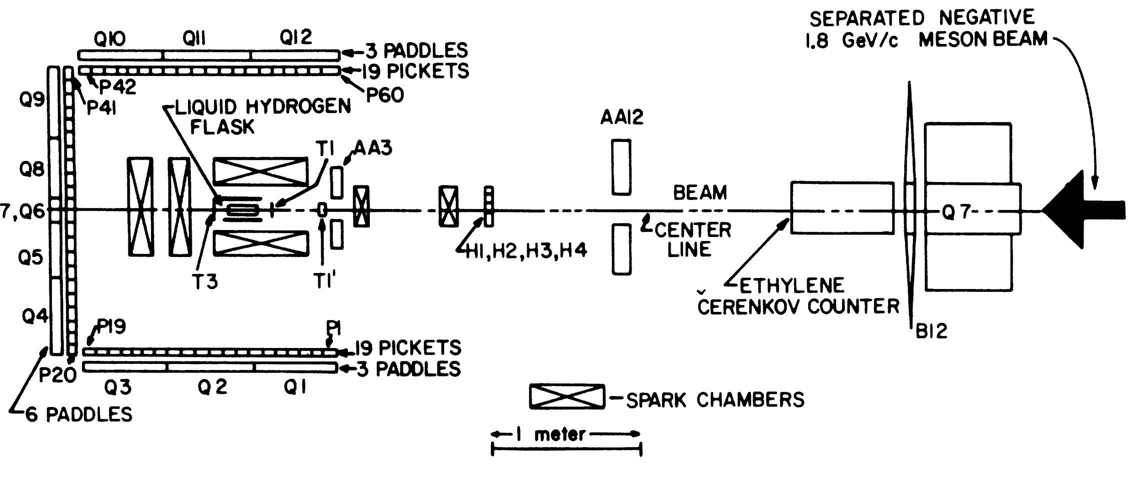

FIG. 2. The details of the experimental detector configuration: (a) Meson beam. Čerenkov detector, beam defining hodoscope and annular ring veto detectors and the basic neutral trigger ($K^-p \to$ neutrals) detector elements surrounding the liquid hydrogen flask; (b) secondary particle picket counters and paddle counters used to detect four-track events $[K^-p \to K^0\Xi^0 \to (K^0 \to \pi^+\pi^-)\ (\Lambda \to p\pi^-)]$.

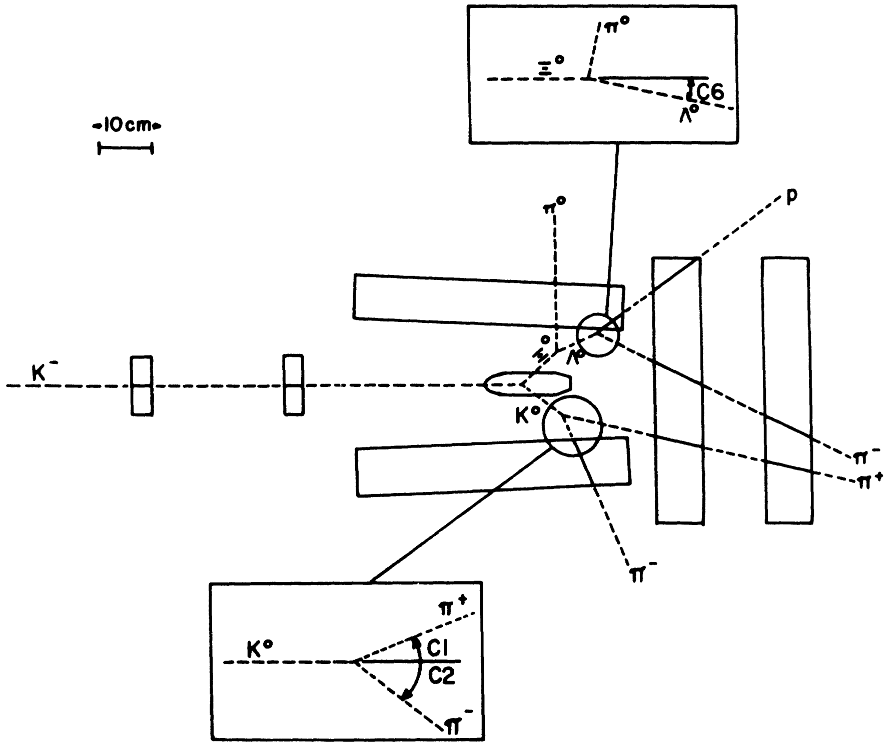

FIG. 3. Schematic diagram of typical four-track event in the optical spark chambers.

inating from near the target. The cameras, located 6.1 m above the experiment, recorded tracks, fiducial marks, and event numbers on 70-mm film.

III. DATA REDUCTION

During the experiment 200 000 pictures were taken. These were examined by scanners trained to identify an incoming track and four outgoing tracks whose topology was consistent with $K^-p \rightarrow K^0\Xi^0$ four-track events. A typical event for which scanners looked is shown in Fig. 3. The result of the scan was 4500 candidates. These events were then measured on the LRL SCAMP. This film-plane digitized machine produced output on magnetic tape according to a fixed format. Computer analysis next yielded the equations of five particle tracks referenced to a surveyed coordinate system defined by the fiducial marks.

Kinematical relationships were applied in the next stage of reduction, which was an iterative fitting of the events to a hypothesized neutral cascade production event. For those events which converged the program calculated χ^2 values for the fits and the fitted values. Finally, certain cuts were made to reduce the effects of the most important contaminating events. Constraints were placed on the χ^2 values, hyperon missing mass, production point location, and K^0 lifetime. Table I gives the number of candidates surviving certain of the cuts. The missing-mass restriction was the most severe and the magnitudes of the other cuts

TABLE I. Effect of cuts on number of events.

Restrictions on the data	Number of events pairing
χ^2 for over-all fit ≤ 100	260
χ^2 for K^0 and Λ^0 vertex fits <6	235
$1.2 <$ hyperon missing mass < 1.4 GeV/c^2	120
$-66.0 <$ production point location along beam axis < -50.8 cm	213
production point location perpendicular to beam axis < 2.54 cm	253
K^0 lifetime > 0.508 cm	200
K^0 lifetime < 10.2 cm	266

were determined by the effect on the shape and size of this peak. An earlier experiment[4] using the same apparatus obtained an excellent missing-mass distribution for the K^-p charge exchange reaction. This demonstrated the validity of an approach based on reconstruction of the missing mass. The net result of this sorting process was a sample of 59 events which, taken with the known flux and target dimensions, gave a total cross section $\sigma(K^-p \to K^0\Xi^0) \sim 125\ \mu b$, consistent with the results of previous experiments.

The geometrical constraints and the various "cuts" (e.g., minimum neutral length gap) on the data were factored through a Monte Carlo program modeling the experiment. In the usual way the experimental setup was modeled and events were generated according to known distributions. The Monte Carlo events were traced through the experiment from spark locations to film images and through reduction in exactly the same way as the real data were processed. Thus the consequences of the experimental geometrical and reconstruction constraints were unfolded from the data by comparing the reconstructed data distributions with those Monte Carlo generated events.

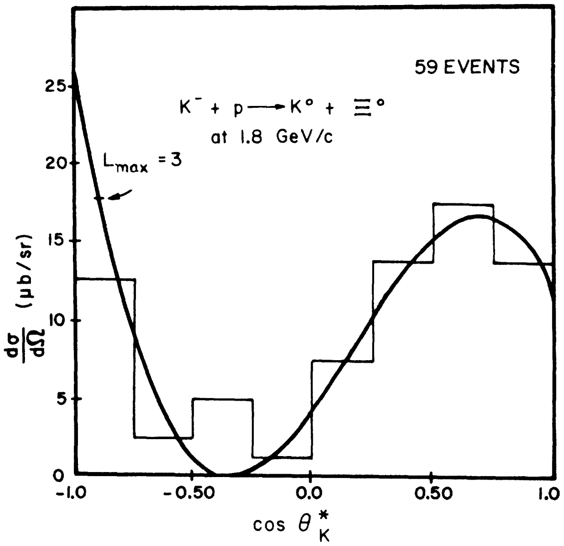

FIG. 4. The differential cross section $d\sigma/d\Omega\,(K^-p \to K^0\Xi^0)$ in cm for K^- angle. The smooth curve is the fit to the data using up to order $l=3$ Legendre polynomials. We have $\cos\theta_K^* = -\vec{K}^- \cdot \vec{K}^0$. The relatively sharp peak is partly a consequence of the smaller relative detection efficiency, and thus a large uncertainty in the final data, in this region.

IV. RESULTS AND CONCLUSIONS

The corrected differential cross section is shown in Fig. 4. The fit was made to the form

$$d\sigma/d\Omega = (\sigma/4\pi)[B_0P_0(\theta) + B_1P_1(\theta) + B_2P_2(\theta) + B_3P_3(\theta)],$$

where

$P_l(\theta) = l$th Legendre polynomial,
θ = center-of-mass production angle of the K^0,
σ = total cross section from (2).

The expansion coefficients for our data are

$B_0 = 1.00 \pm 0.27$,
$B_1 = 0.45 \pm 0.42$,
$B_2 = 1.08 \pm 0.47$,
$B_3 = -1.20 \pm 0.62$.

From the shape of the distribution one may deduce that baryon exchange is the dominant production mechanism. This large backward peak may be ascribed to Σ^+ exchange while the absence of a forward peak is due to the lack of a meson candidate possessing the required quantum numbers. These results have been noted previously. Concerning direct channel resonances, the coefficients are consistent with $\Lambda(2100)$ formation but do not rule out others. A partial wave analysis would be very desirable, but the experimental errors were too large for polarization data to be obtained. It is hoped that the data presented here when combined with that of other experiments will make a contribution toward settling the matter of neutral cascade production. Further details concerning the experiment may be found in Ref. 5.

ACKNOWLEDGMENTS

We would like to thank Dr. Lofgren and the staff of the Bevatron at the Lawrence Radiation Laboratory for the help during all stages of this experiment. We want to thank Weldon Purcell and other machinists in the physics shop at the University of Washington for building much of the equipment. We thank J. Jaske and E. Dunn for assistance during many phases of the experiment. The interest of Dr. R. W. Williams in the work is appreciated.

*Work supported in part by the National Science Foundation, and also by the Oregon State University Research Council and Computer Center.

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[1] G. Burgun, J. Meyers, E. Pauli, B. Tallini, J. Vrana, A. DeBellefon, A. Berthon, K. L. Rangan, J. Beaney, S. M. Deen, C. M. Fisher, and J. R. Smith, Nucl. Phys. B8, 447 (1968).

[2] P. M. Dauber, J. P. Berge, J. R. Hubbard, D. W. Merrill, and Richard A. Muller, Phys. Rev. 179, 1262 (1969).

[3] G. M. Bingham, V. Cook, J. W. Humphrey, O. R. Sander, R. W. Williams, G. E. Masek, T. Maung, and H. Ruderman, Phys. Rev. D 1, 3010 (1970).

[4] N. D. Sossong, R. Ellsworth, J. R. Carlson, H. F. Davis, and D. E. Jauch, Phys. Rev. D 5, 2711 (1972).

[5] J. R. Carlson, Ph.D. thesis, Oregon State University, 1970 (unpublished).

PHYSICAL REVIEW D VOLUME 7, NUMBER 9 1 MAY 1973

Reactions $K^-d \to \bar{K}^0\pi^-d$ and $K^-d \to \bar{K}^0\pi^-np_s$ at 5.5 GeV/c†

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(Received 11 August 1972)

New data are presented on cross sections and angular distributions of resonances produced in the reactions $K^-d \to \bar{K}^0\pi^-d$ and $K^-d \to \bar{K}^0\pi^-np_s$ at 5.5 GeV/c. The production mechanisms and decay angular distributions are analyzed for the $\bar{K}^*(890)$, $\bar{K}^*(1420)$, and $\Delta(1236)$ resonances. The $\bar{K}^0\pi^-np_s$ final state is discussed in terms of the Veneziano B_5 model and also using the Van Hove longitudinal-phase-space technique. In addition, a Regge model with absorption is used to describe $\Delta(1236)$ production in the reaction $\bar{K}N \to \bar{K}\Delta(1236)$. The spherical harmonic moments of the $\bar{K}^0\pi^-$ system as a function of $K\pi$ mass are discussed for the reaction $K^-d \to \bar{K}^0\pi^-p$ + MM.

I. INTRODUCTION

We present here a study of resonance production in the reactions

$$K^-d \to \bar{K}^0\pi^-np, \tag{1.1}$$

$$K^-d \to \bar{K}^0\pi^-d, \tag{1.2}$$

$$K^-d \to \bar{K}^0\pi^-p + \text{MM}, \tag{1.3}$$

where the $\bar{K}^0$ meson decays into charged pions. These results come from an analysis of 370 000 pictures taken with the 30-in. deuterium bubble chamber. The chamber was exposed to an electrostatically separated, high-purity[1] beam of 5.5-GeV/c K^- mesons produced at the Zero Gradient Synchrotron. Some results from this exposure have already been published.[2]

Previous studies of K^--deuterium interactions over a wide range of momenta have shown that coherent production of the $\bar{K}^{*-}(890)$ and $\bar{K}^{*-}(1420)$ are dominant features of reaction (1.2). The deuteron form factor ensures that $\bar{K}^*$ production occurs for only very small momentum transfers, and the $\bar{K}^*$ production is expected to be mediated through $I=0$ (ω^0) t-channel exchange. The interest in studying reaction (1.1) lies in the possibility of observing K^-n interactions. It is generally observed that the fractions of $\bar{K}^*(890)$ and $\Delta(1236)$ production contributing to the $K\pi N$ final state as well as the production and decay properties of the $\bar{K}^{*-}(890)$ are roughly independent of the bombarding K^- energy in the range 3–5 GeV/c. This is also true of the reaction $K^+p \to K^0\pi^+p$ up to 10 GeV/c.[3] We present data on the production and decay processes for these resonances at 5.5 GeV/c and compare our results to the predictions of some models.