PHYSICAL REVIEW VOLUME 130, NUMBER 5 1 JUNE 1963

Test of Charge Symmetry of K^+ and K^0 Mesons in the Associated Production Process*

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(Received 24 January 1963)

The charge symmetry of K^+ and K^0 mesons has been tested by comparing π^+ and π^- interactions at 1.23 BeV/c in the 72-in. deuterium bubble chamber. About 350 events of the type $\pi^++d\rightarrow K^++\Lambda(\text{or }\Sigma^0)+p$ and approximately 700 events of the type $\pi^-+d\rightarrow K^0+\Lambda(\text{or }\Sigma^0)+n$ have been compared. Total cross sections, angular distributions, momentum spectra, and lambda decay asymmetries show no deviations from charge symmetry. Details on angle-momentum distributions and decay asymmetries are given.

I. INTRODUCTION

IT has been remarked by Pais that it is important to verify directly whether the K^+ and K^0 mesons (or $\bar{K}^0$ and K^- mesons) are members of an isotopic doublet.[1] The usual doublet structure is not manifestly demanded by either presently accepted theoretical or experimental results. If the K^+ and K^0 mesons do not form a doublet, their relative parity may be odd; some interesting conclusions can then be drawn.[2]

A definite test of the symmetry of the K^+ and K^0 can be made by comparing π^+-d and π^--d interactions:

(1a) $\pi^++d\rightarrow p+\Lambda+K^+$, (1b) $\pi^-+d\rightarrow n+\Lambda+K^0$,

(2a) $\pi^++d\rightarrow p+\Sigma^0+K^+$, (2b) $\pi^-+d\rightarrow n+\Sigma^0+K^0$,

(3a) $\pi^++d\rightarrow p+\Sigma^++K^0$, (3b) $\pi^-+d\rightarrow n+\Sigma^-+K^+$,

(4a) $\pi^++d\rightarrow n+\Sigma^++K^+$, (4b) $\pi^-+d\rightarrow p+\Sigma^-+K^0$.

Violation of charge symmetry can be expected to cause appreciable differences between "symmetric" processes in total rates, angular distributions, momentum spectra, and lambda decay asymmetries.[3]

II. EXPERIMENT

The 72-in. bubble chamber was filled with liquid deuterium for the charge-symmetry experiment. A beam of positive pions at 1.23 GeV/c was selected from the bevatron and directed into the chamber by a system of bending and focusing magnets and one parallel-plate spectrometer. Subsequently, a beam of negative pions was selected at the same momentum and brought into the chamber.

The reactions chosen for study were (1) and (2) above:

$$\pi^++d\rightarrow\Lambda(\text{or }\Sigma^0)+K^++p,$$
$$\pi^-+d\rightarrow\Lambda(\text{or }\Sigma^0)+K^0+n.$$

These could be much more readily identified than the reactions yielding charged sigma hyperons (as secondary scatters from neutrons often simulated sigma decay). The π^+ film was scanned for all single-V decays associated with one or two charged prongs; scanning of the π^- film consisted of recording all single-V and double-V events associated with a "zero-prong" track, i.e., single-K^0 and single-Λ as well as associated $K^0-\Lambda$ observable decays.[4] Caution had to be exercised not to discard events with the topology of reaction (3a), when in reality the "Σ^+ decay" was a scatter from a neutron of the K^+ or the proton of reaction (1a) or (2a).

Some 350 V events were found in the 11 000 π^+ pictures taken, while about 700 V events were obtained from the 22 000 π^- pictures. The average number of incident pions was 12 to 14 tracks per frame.

The 1.23-GeV/c beam momentum was chosen to give $\Lambda-K$ or Σ^0-K production far enough above threshold for the K^+-K^0 mass difference to be negligible, but not so far above that many partial waves participated. With the final-state nucleon considered as a stationary spectator, the center-of-mass momentum for the $\Lambda-K$ system was 370 MeV/c; for the Σ^0-K system it was 260 MeV/c. Incident momenta as measured from chamber tracks were

$$p_+=1240\pm30\text{ MeV}/c\text{ and }p_-=1250\pm30\text{ MeV}/c$$

* This work was done partly under the auspices of the U. S. Atomic Energy Commission; the work done by the Northwestern University group was supported by the Office of Naval Research.

[1] Abraham Pais, Phys. Rev. **110**, 574 (1958).

[2] Abraham Pais, Phys. Rev. **112**, 624 (1958); Lawrence Radiation Laboratory Report UCRL-9460, 1960, p. 35. (unpublished).

[3] We know of no reliable way to predict such differences; however, Born approximation estimates suggest up to 25% differences in angular distributions.

[4] Events with the four-body final state $\Lambda(K^0)\ \pi^-p$ appearing as V-two prongs in the π^- film were measured and fitted as the charge-symmetric counterparts of 4-body states accepted in the π^+ film; they constituted less than 5% of all lambda events.

in the first third of the run, and

$$p_{+}=1215\pm 25\ \mathrm{MeV}/c \text{ and } p_{-}=1220\pm 20\ \mathrm{MeV}/c$$

in the remainder of the run.

Contamination of the π^+ beam by protons was found to be $(6\pm 3)\%$. This figure was obtained by examining the film with a microscope and counting all small delta rays below 4 MeV for a given length (45 cm) of track. The number of delta rays produced by protons is considerably higher than the number produced by pions and affords a clean separation of pion and proton tracks.[5] Another technique used for finding contamination was to compare frequencies of obvious p-p scatters (heavy-ionizing) in pure proton film and in π^+ film; from this a comparable but less reliable figure was obtained. A third method—fitting p-d and π^+-d scatters and comparing with known cross sections—did not yield a definitive result because of ambiguities in fitting the events to hypotheses of inelastic scatters.

A fiducial volume was defined for acceptance of events; requirements were unobstructed entry through the chamber window and good visibility.

All events reported in this paper have been measured on the Franckenstein measuring projector and the measurements passed through a kinematics fitting program. The decay vertex was fitted to K^0 and Λ decay hypotheses, and the production vertex was subsequently fitted, when possible, to 3-body production processes. The χ^2 distribution for fits of V decays had the expected form for three degrees of freedom, but had an average value two to three times that expected; hence, a fit was considered good if the χ^2 value was less than 25. If χ^2 values for K^0 and Λ decay were comparable, a decision could generally be made on the basis of ionization. (Ambiguous events were usually found to be lambda decays.) Most of the lambda events with acceptable decay fits in the π^+ film gave good fits at production; however, the lambda events in the π^- film could not be fitted unless the K^0 decay were observed. Since many events were impossible to fit at production, only the criterion for the decay fit was imposed for the acceptance of an event, both in the π^+ and π^- film.

III. RESULTS

Total cross sections were calculated to be:

$$\sigma(\pi^+d\rightarrow p\Lambda K^+ \text{ and } p\Sigma^0K^+)=0.71\pm 0.08 \text{ mb}$$

$$\sigma(\pi^-d\rightarrow n\Lambda K^0 \text{ and } n\Sigma^0K^0)=0.76\pm 0.06 \text{ mb.}$$

These figures were obtained after correction for the attenuation of the beam by other interactions (14%), for contamination of the π^+ beam by protons (6%), for scan efficiencies (after two scans, 99% on lambda events in the π^+ film and 97% on those in the π^- film), and for decay branching ratios. Errors are larger than statistical because of uncertainties in correction factors. (These cross sections may be compared with the cross section for $\pi^-+p\rightarrow\Lambda+K^0$ and Σ^0+K^0, which is $\sim$0.8 mb at 1.23 BeV/c.[6] With correction for the shadow effect in deuterium, this becomes $\sim$0.7 mb.) Thus, the ratio of the total number of Λ (and Σ^0) events from π^+-d interactions to the total number of Λ (and Σ^0) events from π^--d interactions has been determined to be

$$R(\Lambda K^+/\Lambda K^0)=0.93\pm 0.12.$$

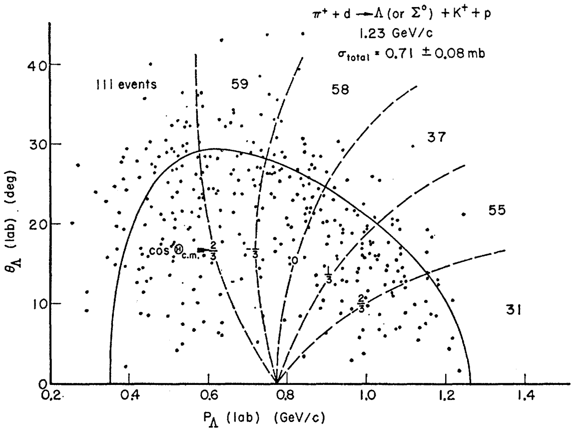

FIG. 1. Lambda distribution in the $\pi^+ + d$ reaction. (Thirteen large-angle events are not shown.)

Figures 1 and 2 show the distributions in laboratory momentum and angle of the lambdas produced in the charge-symmetric reactions. The dotted curves are the loci of constant values of $\cos\Theta_{\mathrm{c.m.}}$ in a system of reference that corresponds to the c.m. system of a pion of 1.23 GeV/c and a stationary target nucleon. The solid curves indicate the possible values of laboratory momentum and angle for the reaction $\pi+N\rightarrow\Lambda+K$ at 1.23 GeV/c. The fact that an event does not lie on the solid curve indicates either that the target nucleon was not stationary or that the lambda was indirectly produced through Σ^0 decay or hyperon interaction (with the spectator nucleon).

Figure 3 shows the "angular distributions" in the fictitious c.m. frame of a 1.23 GeV/c pion and a stationary nucleon. The differential cross sections $d^2\sigma/dpd\Omega$ in laboratory momentum and angle, derived from Figs. 1 and 2, have been integrated between curves of constant c.m. angle in this fictitious frame to give $d\sigma/d\Omega_{\mathrm{c.m.}}$. (Charge symmetry should, of course, hold in an arbitrary frame of reference.)

The asymmetry of lambda decay times average lambda polarization was evaluated for each of the charge-symmetric processes; it was found to be

$$\alpha_\Lambda\bar{P}_\Lambda=+0.55\pm 0.10$$

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[5] Frank S. Crawford, Phys. Rev. **117**, 1119 (1960).

[6] Data of F. S. Crawford, M. Cresti, M. L. Good, M. L. Stevenson, H. K. Ticho, and R. Douglass, in *Proceedings of the Ninth International Annual Conference on High Energy Physics, Kiev, 1951* (Academy of Sciences, Moscow, U.S.S.R., 1960), p. 443.

for the ΛK^+ final state and

$$\alpha_\Lambda \bar{P}_\Lambda = +0.47 \pm 0.07$$

for the ΛK^0 final state. Possible bias could be introduced in the determination of the $\alpha_\Lambda \bar{P}_\Lambda$ values for the lambdas of the π^- film through misinterpreting a K^0 as a lambda; however, the likelihood of such an error was considered small (an ambiguous V having a much greater probability of being a lambda than a K^0). The asymmetries and their errors were calculated from the expressions

$$\alpha_\Lambda \bar{P}_\Lambda = (3 \textstyle\sum_i \cos\theta_i)/N$$

and

$$\delta(\alpha\bar{P}) = [3/N - (\alpha\bar{P})^2/N]^{1/2},$$

where θ is the polar angle of the decay pion relative to the lambda production normal and N is the total number of events.

IV. CONCLUSIONS

Comparison has been made of results from seven measured quantities (x_i), i.e., differential cross section (the 6 regions of Fig. 3) and asymmetry of lambda decay, for the two reactions

$$\pi^+ + d \rightarrow \Lambda \text{ (or } \Sigma^0) + K^+ + p$$

and

$$\pi^- + d \rightarrow \Lambda \text{ (or } \Sigma^0) + K^0 + n.$$

The differential cross sections were normalized to the same total cross section for this study, since the total cross sections were found equal within the errors.

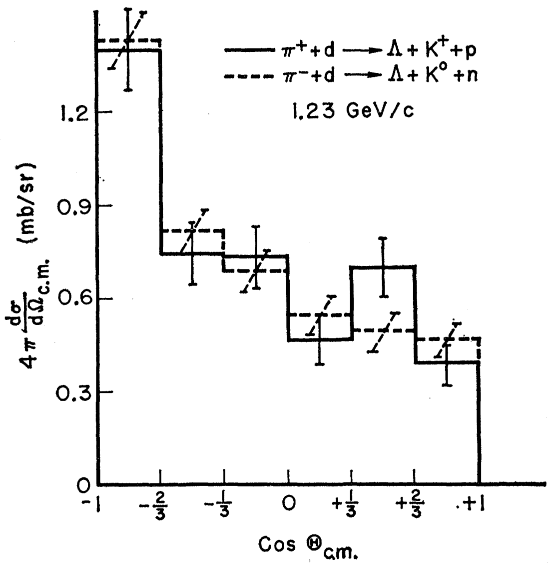

FIG. 3. Distributions in $\Theta_{c.m.}$ obtained from those of Figs. 1 and 2. Total cross sections for the two reactions have been normalized to the same value of 0.74 mb. The errors given are statistical only, based on the number of events found in each $\cos\Theta_{c.m.}$ interval.

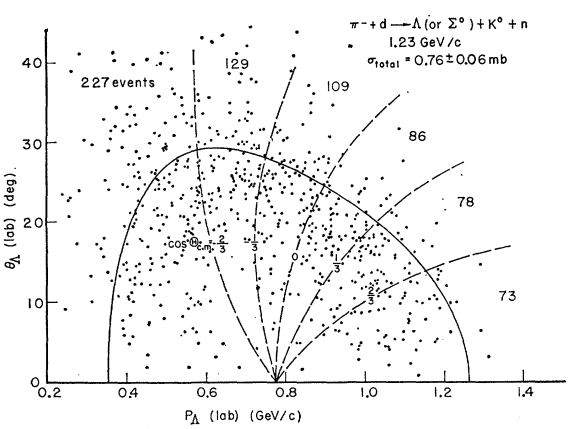

FIG. 2. Lambda distribution in the $\pi^- + d$ reaction. (Nineteen large-angle events are not shown.)

This comparison shows that the reactions, and hence the K mesons, are charge-symmetric. A quantitative statement can be made by calculating

$$\chi^2 = \textstyle\sum_i \sum_j (x_i^+ - x_i^-)(x_j^+ - x_j^-) G_{ij}^{-1},$$

with $G_{ij} = \delta x_i^+ \delta x_j^+ + \delta x_i^- \delta x_j^-$. Here χ^2 has an expected value of 6.0 (the seven degrees of freedom being reduced by one normalization condition). The value obtained from the experimental data is 5.9.

ACKNOWLEDGMENTS

It is a pleasure to thank the engineers of the 72-in. bubble chamber, under the direction of Bob Watt, for their assistance in preparing the deuterium-filled chamber and the taking of film. The work of the technicians under Dr. Frank Crawford in setting up the beam was very much appreciated. Finally, Dr. Luis Alvarez is to be thanked for his encouragement in the carrying out of this collaborative experiment.