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TEST OF CHARGE SYMMETRY OF  $K^+$  AND  $K^0$  MESONS IN THE ASSOCIATED PRODUCTION PROCESS

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### Publication Date

1962-06-05

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UNIVERSITY OF CALIFORNIA

Lawrence Radiation Laboratory  
Berkeley, California

Contract No. W-7405-eng-48

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IN THE ASSOCIATED PRODUCTION PROCESS

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M. Lynn Stevenson, Martin Block, Arnold Engler, Rosanna Gessaroli,  
Arthur Kovacs, Carl Meltzer, David Onley, Richard Kraemer,  
Mirko Nussbaum, Aihud Pevsner, and Peter Schlein

June 5, 1962

Paper for the 1962 International Conference on High Energy Physics at CERN

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June 5, 1962

(To be presented by Frank S. Crawford)

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.<sup>1</sup> The usual doublet structure is not manifestly demanded either by presently accepted theoretical or experimental results. If the  $K^+$  and  $K^0$  mesons do not form a doublet, it is possible that their relative parity

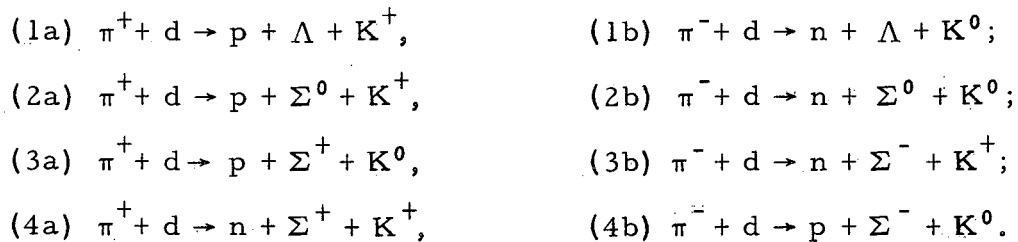
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\* This work was partly done under the auspices of the U. S. Atomic Energy Commission; the work done by the Northwestern University group was supported by the Office of Naval Research.

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is odd; some interesting conclusions could then be drawn.<sup>2</sup>

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

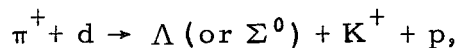


Violation of charge symmetry can be expected to cause appreciable differences between "symmetric" processes in total rates, angular distributions, momentum spectra, and lambda decay asymmetries.<sup>3</sup>

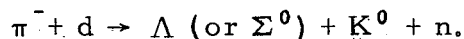
## II. EXPERIMENT

The 72-inch 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 focussing 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:



and



These could be much more readily identified than the reactions yielding charged sigma hyperons (as secondary scatters from neutrons often simulated sigma decay). Scanning was done on the  $\pi^+$  film for all single-vee decays associated with one or two charged prongs; scanning of the  $\pi^-$  film consisted of recording all single-vee and double-vee events associated with a "zero-prong" track, i. e., single- $K^0$  and single- $\Lambda$  as well as  $K^0$ - and  $-\Lambda$  observable

decays.<sup>4</sup> Caution had to be exercised not to discard events with the topology of reaction (3a), when in reality the " $\Sigma^+$  decay" was a scatter from a neutron of the  $K^+$  or proton of reactions (1a) or (2a).

Some 250 vee events were found in the 9 000  $\pi^+$  pictures taken, while about 700 vee events were obtained from the 22 000  $\pi^-$  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  $\Sigma^0$ -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, and for the  $\Sigma^0$ -K system it was 260 MeV/c. Incident momenta as measured from chamber tracks were

$$p_+ = 1240 \pm 30 \text{ MeV/c, and } p_- = 1250 \pm 30 \text{ MeV/c,}$$

in the first third of the run, and

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

in the remainder of the run.

Contamination of the  $\pi^+$  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.<sup>5</sup> Another technique used for finding contamination was to compare frequencies of obvious p-p scatters (heavy-ionizing) in pure proton film and in  $\pi^+$  film; from this a comparable but less reliable figure was obtained. A third method, the fitting of p-d and  $\pi^+$ -d scatters, and comparison 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.

Measurements of the lambda (or  $\Sigma^0$ ) events were made initially on the scanning table, with errors of 2 to 3 deg in angle and 5% in momentum. However, 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  $\Lambda$  decay hypotheses, and the production vertex was subsequently fitted, when possible, to 3-body production processes. The  $\chi^2$  distribution for fits of vee 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  $\chi^2$  value was less than 25. If  $\chi^2$  values for  $K^0$  and  $\Lambda$  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  $\pi^+$  film gave good fits at production; however, the lambda events in the  $\pi^-$  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.

### III. RESULTS

Total cross sections were calculated:

$$\sigma(\pi^+d \rightarrow p\Lambda K^+ \text{ and } p\Sigma^0 K^+) = 0.71 \pm 0.07 \text{ mb};$$

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

These figures resulted after correction for the attenuation of the beam by other interactions (14%), for contamination of the  $\pi^+$  beam by protons (6%), for scan efficiencies (after two scans, 99% on lambda events in the  $\pi^+$  film and 97% on those in the  $\pi^-$  film), and for decay branching ratios.



Thus the ratio of the total number of  $\Lambda$  (and  $\Sigma^0$ ) events from  $\pi^+$ -d interactions to the total number of  $\Lambda$  (and  $\Sigma^0$ ) events from  $\pi^-$ -d interactions has been determined to be

$$R \left( \frac{\Lambda K^+}{\Lambda K^0} \right) = 0.93 \pm 0.12$$

Figure 1 compares the distributions in laboratory momentum and angle of the lambdas produced in the charge-symmetric reactions. The dotted curves are the loci of equal values of  $\cos \Theta_{c.m.}$  in a system of reference that corresponds to the center-of-mass system of a pion of 1.23 GeV/c and a stationary target nucleon. The solid curve indicates 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 this solid curve indicates either that the target nucleon was not stationary or that the lambda was indirectly produced through  $\Sigma^0$  decay or hyperon interaction (with the spectator nucleon).

Figure 2 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  $d^2\sigma/dp d\Omega$  in laboratory momentum and angle, derived from Fig. 1, have been integrated between curves of constant c.m. angle in this fictitious frame to give  $d\sigma/d\Omega_{c.m.}$ . (Charge symmetry should, of course, hold in any arbitrary frame of reference).

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

$$\alpha_{\Lambda} \bar{P}_{\Lambda} = +0.55 \pm 0.10 \text{ for the } \Lambda K^+ \text{ final state;}$$

$$\alpha_{\Lambda} \bar{P}_{\Lambda} = +0.47 \pm 0.07 \text{ for the } \Lambda K^0 \text{ final state.}$$

Possible bias could be introduced in the determination of the  $\alpha_{\Lambda} \bar{P}_{\Lambda}$  for the lambdas of the  $\pi^-$  film through misinterpreting a  $K^0$  as a lambda; however, the likelihood of such an error was considered small (an ambiguous vee having

a much greater probability of being a lambda than a  $K^0$ ). The asymmetries and their errors were calculated from the expressions

$$a_{\Lambda \bar{\Lambda}} = (3 \sum \cos \theta_i) / N,$$

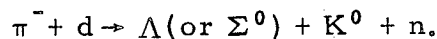
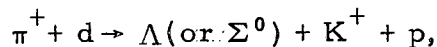
and

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

where  $\theta$  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. 2) and asymmetry of lambda decay, for the two reactions



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

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

which 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-inch 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.

REFERENCES AND FOOTNOTES

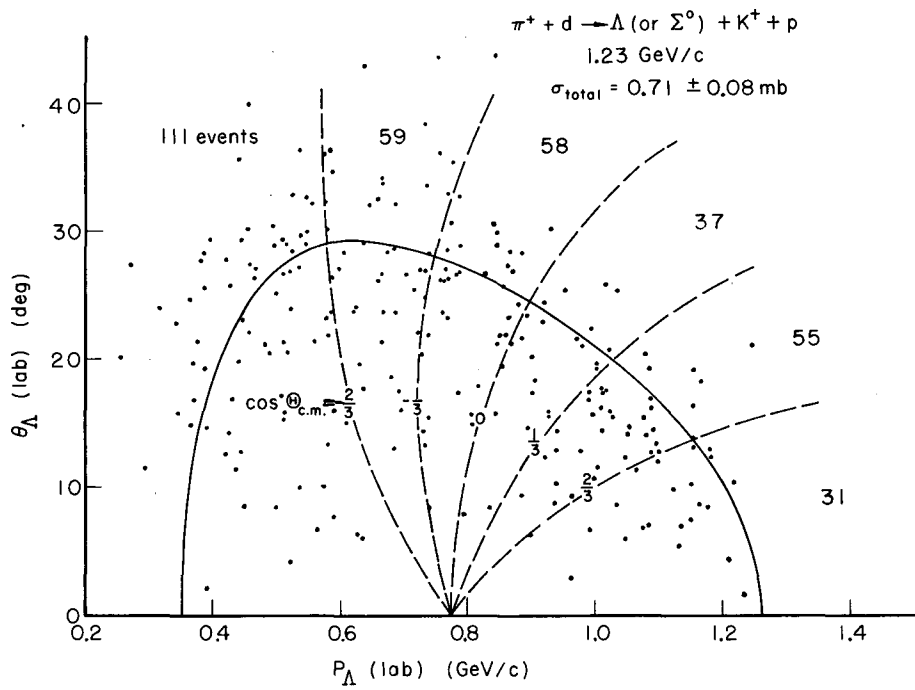
1. A. Pais, Phys. Rev., 110, 574 (1958).
2. A. Pais, Phys. Rev., 112, 624 (1958); A. Pais, UCRL-9460, p. 35.
3. We know of no reliable way to predict such differences; however, Born approximation estimates suggest up to 25% differences in angular distributions.
4. Events with the four-body final state  $\Lambda(K^0)\pi^-p$  appearing as vee-two-prongs in the  $\pi^-$  film were measured and fitted as the charge-symmetric counterparts of 4-body states accepted in the  $\pi^+$  film; they constituted less than 5% of all lambda events.
5. F. Crawford, Phys. Rev. 117, 1119 (1960).

FIGURE LEGENDS

Fig. 1A. Lambda distribution in  $\pi^+ + d$  reaction. The numbers of events are from the final experimental results and represent an increase of about 50% over the numbers reported in the text.

Fig. 1B. Lambda distribution in  $\pi^- + d$  reaction. The numbers of events are from the final experimental results and represent an increase of about 15% over the numbers reported in the text.

Fig. 2. Distributions in  $\Theta_{c.m.}$  obtained from those of Figs. 1A-1B. 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.



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Fig. 1a

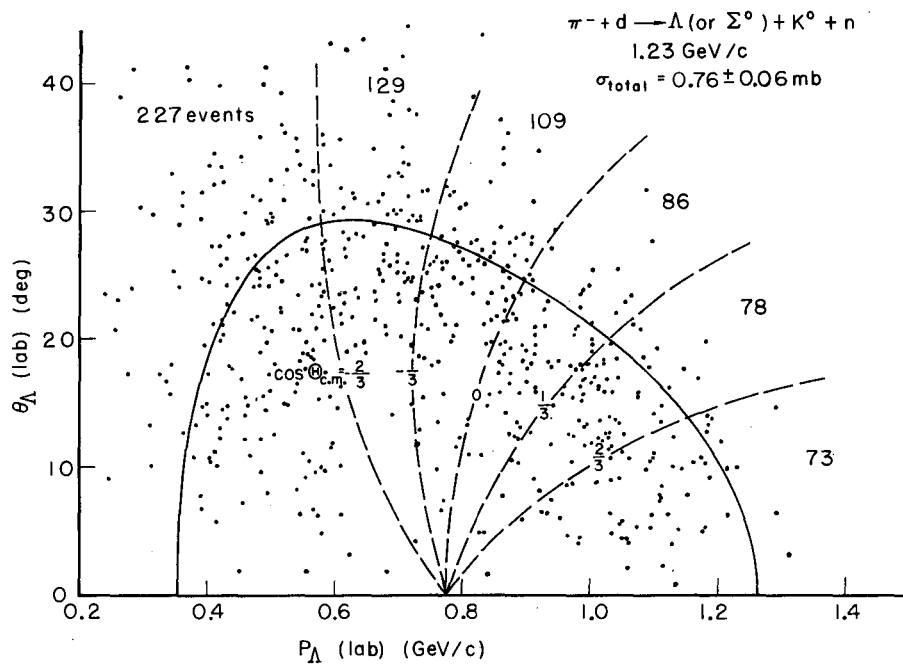
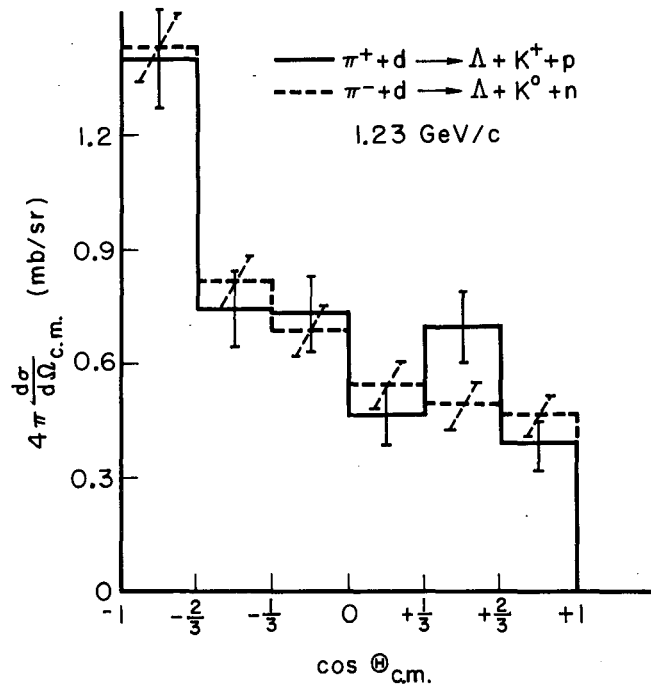


Fig. 1b



MU-27055

Fig. 2



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