Ξ^- HYPERONS IN THE REACTION $K^- + p \to \Xi^- + K^+$ (*)

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(presented by H. K. Ticho)

I. INTRODUCTION

We have been studying the reaction

$$K^- + p \to \Xi^- + K^+ \tag{1}$$

in the Berkeley 72-inch hydrogen bubble chamber; to date, we have analyzed about 450 events in which the Ξ^- decays into $\Lambda + \pi^-$ and the Λ subsequently decays into $p + \pi^-$. In the momentum range thus far investigated, 1.2 to 1.6 GeV/c incident K^- momentum, the cross section for reaction (1) rises from ≈ 60 to $\approx 200 \mu$b. The angular distributions are characterized by marked forward peaking of the Ξ^- (see Fig. 1).

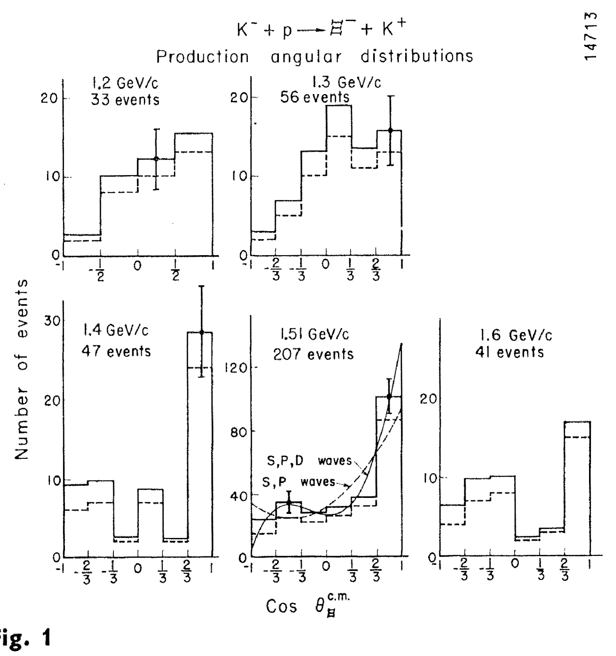

Fig. 1

The decay distributions show a substantial amount of parity violation, indicating the presence of both s- and p-wave amplitudes in the Ξ^- decay; the s-wave seems to dominate over the p-wave. The rest of this paper is devoted to a discussion of the decay distributions.

II. Ξ^- DECAY DISTRIBUTION

In what follows we shall assume, for simplicity, that the Ξ has spin 1/2; our data are consistent with that assumption, but we are at present not able to rule out the possibility of higher spin.

If the decay amplitude is written in the form $(S_\Xi - P_\Xi \boldsymbol{\sigma} \cdot \hat{\Lambda})$, then the Λ angular distribution is given by

$$I = (1 - \alpha_\Xi \mathscr{P}_\Xi \hat{n} \cdot \hat{\Lambda}), \tag{2}$$

and the Λ polarization by

$$\vec{\mathscr{P}}_\Lambda = \frac{1}{I}\{-\alpha_\Xi \hat{\Lambda} + \mathscr{P}_\Xi[(\hat{n} \cdot \hat{\Lambda})\hat{\Lambda} - \beta_\Xi \hat{n} \times \hat{\Lambda} + \gamma_\Xi \hat{\Lambda} \times (\hat{n} \times \hat{\Lambda})]\} \tag{3}$$

Here $\hat{\Lambda}$ is a unit vector directed along the line of flight of the Λ in the Ξ rest frame; $\mathscr{P}_\Xi \hat{n}$ is the polarization vector of the Ξ, ($|\hat{n}| = 1$); and α_Ξ, β_Ξ, γ_Ξ are given by

$$\alpha_\Xi = 2\,\mathrm{Re}\,(S_\Xi^* P_\Xi)/(|S_\Xi|^2 + |P_\Xi|^2),$$

$$\beta_\Xi = 2\,\mathrm{Im}\,(S_\Xi^* P_\Xi)/(|S_\Xi|^2 + |P_\Xi|^2),$$

(*) Work done under the auspices of the U.S. Atomic Energy Commission.

and

$$\gamma_\Xi = (|S_\Xi|^2 - |P_\Xi|^2)/(|S_\Xi|^2 + |P_\Xi|^2) . \tag{4}$$

Note that

$$\alpha_\Xi^2 + \beta_\Xi^2 + \gamma_\Xi^2 = 1 . \tag{5}$$

III. DETERMINATION OF α_Ξ

The longitudinal polarization of the Λ from an unpolarized sample of Ξ's is equal to $-\alpha_\Xi$ (see Eqs. (2) and (3)) [1]. This polarization can be determined by a measurement of the asymmetry of the Λ decay; the distribution for the proton direction $\hat{p}$, ($|\hat{p}| = 1$) is given by

$$(1 - \alpha_\Lambda \vec{\mathscr{P}}_\Lambda \cdot \hat{p}) = (1 + \alpha_\Lambda \alpha_\Xi \hat{\Lambda} \cdot \hat{p}) .$$

This distribution, for our entire sample of Ξ's, is shown in Fig. 2. (Such a complete sample of Ξ's including all production angles must necessarily be unpolarized.) We obtain the value

$$\alpha_\Lambda \alpha_\Xi = -0.30 \pm 0.08 .$$

This is to be compared with the previously reported values, -0.65 ± 0.35 by Fowler *et al.* [2], -0.07 ± 0.30 by Alvarez *et al.* [3], and -0.64 ± 0.25 by Bertanza *et al.* [4].

Using the recently reported value

$$\alpha_\Lambda = -0.61 \pm 0.05 \ ^{5)},$$

we obtain

$$\alpha_\Xi = 0.50 \pm 0.13 .$$

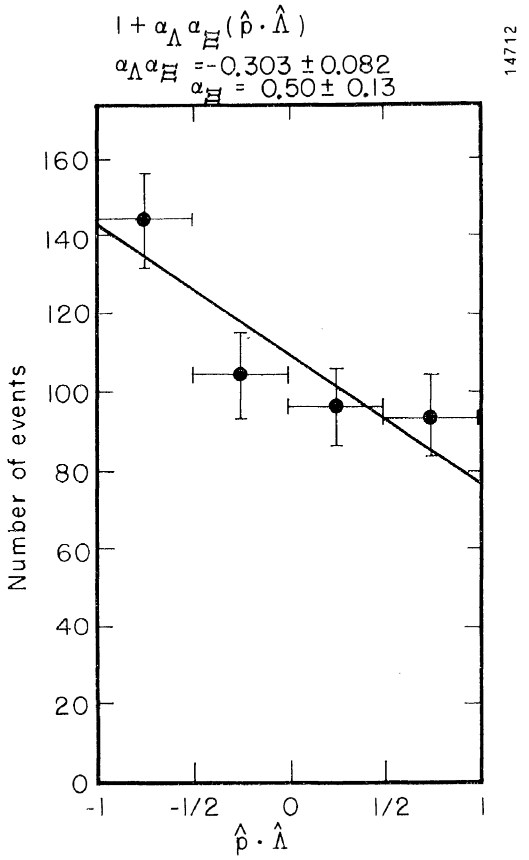

Fig. 2

IV. SIMULTANEOUS DETERMINATION OF α_Ξ, β_Ξ AND γ_Ξ

Once α_Ξ has been determined, one can in principle measure the polarization $\mathscr{P}_\Xi$ for a given production angle by observing the " up-down " asymmetry (see Eq. (2)). Then one could determine β_Ξ and γ_Ξ by a measurement of the transverse components of the Λ polarization (Eq. (3)).

We represent $\mathscr{P}_\Xi(\theta)$ in terms of the amplitudes of a partial wave analysis, in order to combine the data from all production angles. The probability function for the c.m. production angle $\theta_\Xi^{c.m.}$ and the decay Λ and the proton directions $\hat{\Lambda}$ and $\hat{p}$ is then

$$f = \frac{1}{D}\frac{d\sigma}{d\Omega}(\theta_\Xi^{c.m.})(1 - \alpha_\Lambda \vec{\mathscr{P}}_\Lambda \cdot \hat{p})(1 - \alpha_\Xi \mathscr{P}_\Xi(\theta_\Xi^{c.m.})\hat{n} \cdot \hat{\Lambda})$$

$$= \frac{1}{D}\frac{d\sigma}{d\Omega}(\theta_\Xi^{c.m.})\{1 + \alpha_\Xi \alpha_\Lambda \hat{p} \cdot \hat{\Lambda} + \mathscr{P}_\Xi(\theta_\Xi^{c.m.})[-\alpha_\Xi \hat{n} \cdot \hat{\Lambda}$$

$$- \alpha_\Lambda \hat{p} \cdot ((\hat{n} \cdot \hat{\Lambda})\hat{\Lambda} + \beta_\Xi \hat{\Lambda} \times \hat{n} + \gamma_\Xi (\hat{\Lambda} \times \hat{n}) \times \hat{\Lambda})]\} .$$

Here $\hat{n}$ is a unit vector in the direction $\hat{K}_{inc} \times \hat{\Xi}$. ($D$ is chosen so that the integral of f over all the relevant angles is unity.) We can now write a likelihood function for all the events at a given c.m. energy:

$$\mathscr{L} = \prod_{i=1}^{N} f_i ,$$

where $f_i \equiv f(\theta_{\Xi i}^{c.m.}, \hat{n}_i, \hat{\Lambda}_i, \hat{p}_i)$ is a function of the partial-wave amplitudes, and α_Ξ and β_Ξ ; γ_Ξ is determined from α_Ξ and β_Ξ to within a sign.

The bulk of our data is concentrated at 1.51 GeV/c incident K^- momentum. The angular distributions (Fig. 1) suggest that *s*- and *p*-waves alone are no longer adequate to describe the reaction in this energy region. We have therefore used *s*-, *p*- and *d*-waves in the analysis. We have not yet made a detailed study of whether partial waves higher than *d* are necessary, and how they might affect our conclusions. At momenta other than 1.51 GeV/c there were insufficient data to warrant a partial-wave analysis; on the other hand, these data did contribute significantly to the determination of α_Ξ through the Λ longitudinal polarization. We therefore wrote the likelihood function in the form

$$\mathscr{L}' = \prod_{i=1}^{N} f_i \prod_{j=1}^{M} (1+\alpha_\Lambda \alpha_\Xi \hat{\Lambda}_j \cdot \hat{p}_j)\,,$$

where the sum over i extends over all events at 1.51 GeV/c ($N = 207$), and the sum over j over all other events ($M = 199$). We used a search program for the IBM 7090 to determine the values of the parameters which lead to a maximum of $\mathscr{L}'$. Two maxima were found, one corresponding to $\gamma_\Xi = [1-(\alpha_\Xi^2+\beta_\Xi^2)]^{\frac{1}{2}}$, and the other to $\gamma_\Xi = -[(1-(\alpha_\Xi^2+\beta_\Xi^2)]^{\frac{1}{2}}$, with these results.

γ_Ξ positive solution:

$$\alpha_\Xi = 0.45 \pm 0.11$$
$$\beta_\Xi = -0.63 \pm 0.31$$
$$\gamma_\Xi = 0.63 \pm 0.31$$

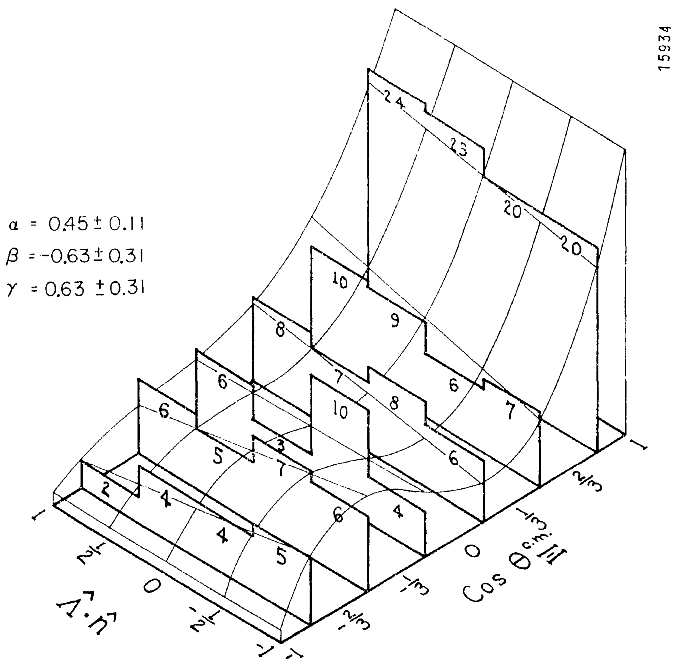

Fig. 3a

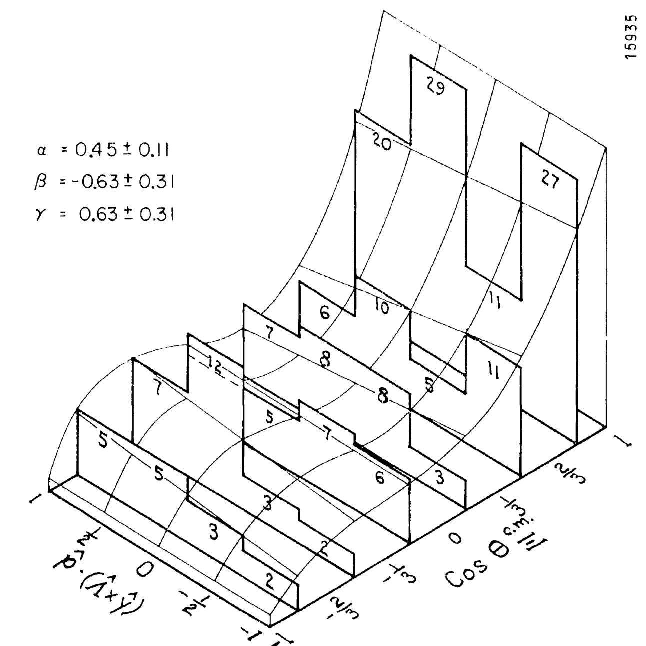

Fig. 3b

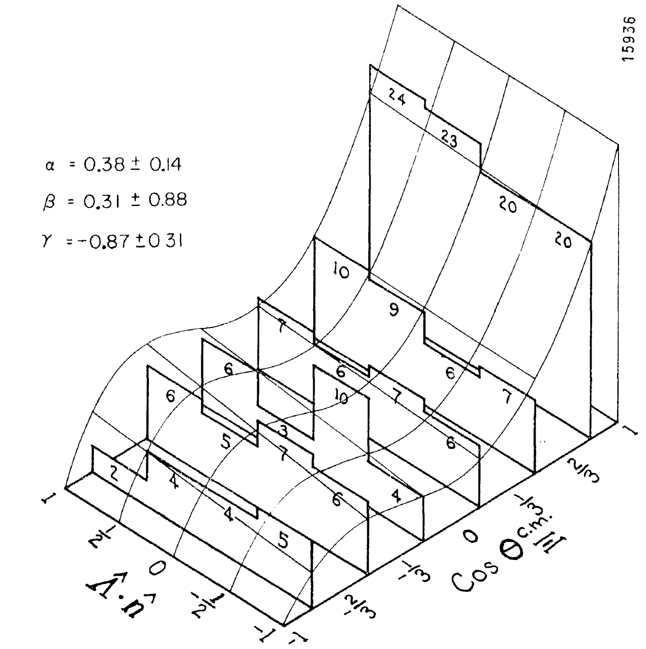

Fig. 4a

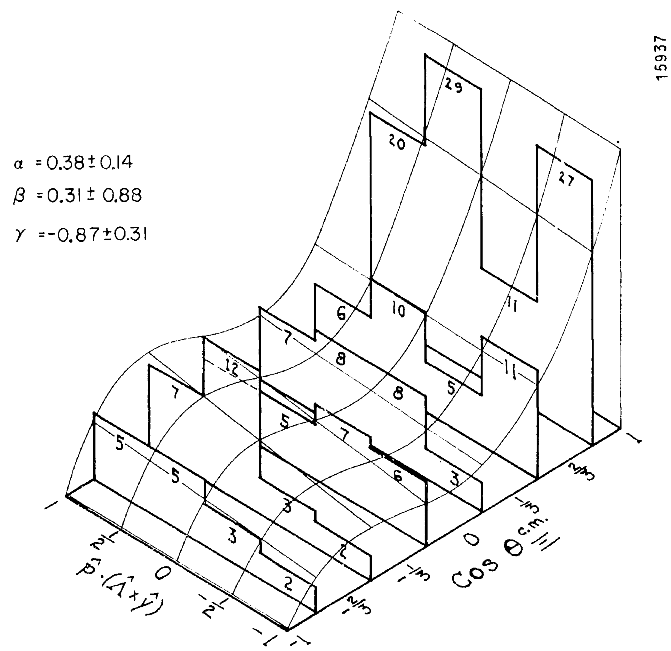

Fig. 4b

γ_Ξ negative solution:

$$\alpha_\Xi = 0.38 \pm 0.14$$
$$\beta_\Xi = 0.31 \pm 0.88$$
$$\gamma_\Xi = -0.87 \pm 0.31$$

The γ_Ξ positive solution gives a larger value of $\mathscr{L}'$ hence a better fit to the data: $\mathscr{L}'(\gamma_\Xi > 0)/\mathscr{L}'(\gamma_\Xi < 0) = 40$.

We do not know yet whether these data allow us to rule out the γ_Ξ negative solution.

It is difficult to present the fit to the data graphically, since f is a function of four independent angles. Figures 3a, b and 4a, b present two 2-dimensional distributions for the γ_Ξ positive and γ_Ξ negative solutions; these may help the reader visualize the data and the quality of the fits.

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6. We are indebted to Dr. Fernand Grard for the use of his Malik program; for a description see, A General Program for Statistical Analysis Using the Maximum—Likelihood—Method Malik Program, Lawrence Radiation Laboratory Report 10153, March 30 (1962), (unpublished).

DISCUSSION

TICHO: I would like to add to these results of the Berkeley K72 Group those of the UCLA group. We have studied the $\Xi^- K^+$ reaction at 1.80 GeV/c. At this momentum the Ξ's appear highly polarized. In fact, from the up-down asymmetry

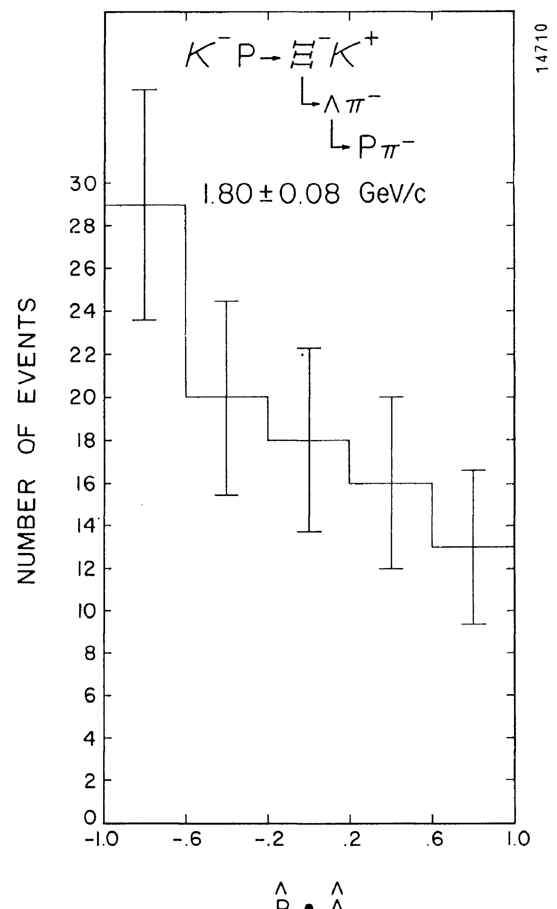

Fig. 5

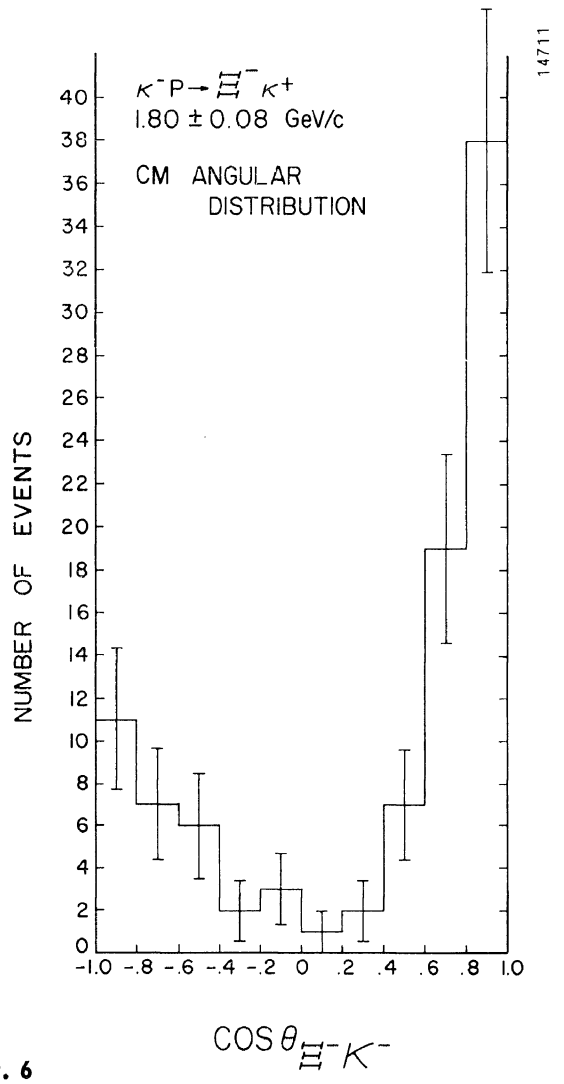

Fig. 6

with respect to the production normal a_{Ξ} - $\langle P_{\Xi} \rangle = +0.51 \pm 0.17$, where $\langle P_{\Xi} \rangle$ is an average over all production angles. To complement the results of the Alvarez group I should like to show the angular distribution at production, Fig. 5, and a plot of the *longitudinal* polarization of the Λ's from Ξ^- decay, Fig. 6. Combining these data with our $\Xi^- K\pi$ events we find a_{Ξ}-$a_{\Lambda} = -0.52 \pm 0.13$ for our entire Ξ^- sample. If we combine this result with all the other results quoted in the Berkeley paper we get a_{Ξ}-$a_{\Lambda} = -0.38 \pm 0.6$ and using Cronin's $a_{\Lambda} = -0.61 \pm 0.5$, $a_{\Xi} = +0.62 \pm 0.11$. Finally, let me remark, with a strong warning that this result is preliminary, that we have looked at the asymmetry of Λ decay with respect to the $\hat{n} \times \hat{\Lambda}$ direction — $\hat{n}$ is the normal to the production plane, $\hat{\Lambda}$ the direction of Λ emission — and find $\beta_{\Xi} = -0.85 \pm 0.53$. This tends to support the " positive γ_{Ξ} " solution of the Berkeley group.

YAMAGUCHI: I would like to know whether you have tried to determine the spin of the Ξ hyperon by any method?

TICHO: On the basis of the data at the present time we cannot rule out spin 3/2.

PROPERTIES OF THE Ξ^- HYPERON (*)

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(presented by J. Leitner)

The purpose of this note is to report a determination of the properties of the Ξ^- hyperon. In particular, we discuss the mass, lifetime, spin, space and decay parameters based on a sample of 85 cascades, 74 of which have a visible Λ.

The data for this experiment were obtained as part of a continuing study of the $K^- - p$ interaction in the 2 to 3 GeV/c range [1]. About 70 000 pictures at 2.3 GeV/c and 30 000 at 2.5 GeV/c were obtained in a separated K^- beam [2] at the Brookhaven Alternating Gradient Synchrotron. Both counter and chamber studies indicate that the beam is composed of K's, μ's, and π's in the ratio 7.5 : 2.0 : 0.5 to an accuracy of $\sim 5\%$. The sample chosen for analysis consists of all the cascades with a visible decay Λ and a subsample of cascades without visible decay Λ selected in an unbiased way from a group of completely analyzed events.

The cascade hyperons were produced in the following reactions:

$$K^- + p \rightarrow \Xi^- + K^+ \quad (1)$$

$$K^- + p \rightarrow \Xi^- + K^+ + \pi^0 \quad \text{where } \Xi^- \rightarrow \Lambda + \pi^- \quad (2)$$

$$K^- + p \rightarrow \Xi^- + K^0 + \pi^+ \quad (3)$$

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