with respect to the production normal $a_{\Xi}\text{-}\langle P_{\Xi}\rangle = +0.51\pm0.17$, 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 $a_{\Xi}\text{-}a_{\Lambda} = -0.52\pm0.13$ for our entire Ξ^- sample. If we combine this result with all the other results quoted in the Berkeley paper we get $a_{\Xi}\text{-}a_{\Lambda} = -0.38\pm0.6$ and using Cronin's $a_{\Lambda} = -0.61\pm0.5$, $a_{\Xi} = +0.62\pm0.11$. 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 $\beta_{\Xi} = -0.85\pm0.53$. 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:

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

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

$$K^- + p \rightarrow \Xi^- + K^0 + \pi^+ \tag{3}$$

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Kinematic fits were obtained using the TRED-KICK analysis system [3]. Data from all three reactions were combined for the mass, lifetime, and asymmetry parameter analyses, but only events due to reaction (1) were considered for the spin and time reversal parameter determinations since the latter depend upon the Ξ^- polarization.

The Ξ^- mass was determined from a sample of 70 events in which the decay Λ was observed, by using the direction cosines of the *unfitted* Ξ^- decay pion and the direction cosines and momentum of the *fitted* Λ. However, the Λ fit was made assuming only that it came from the Ξ^- decay vertex [4]. A typical mass determination from such a fit is accurate to $\pm$ 4 MeV. The results for the entire sample are shown in Fig. 1. The mean cascade mass is

$$M_{\Xi^-} = 1321.0 \pm 0.5 \text{ MeV}$$

where the error represents statistical accuracy only. This value is somewhat different from the presently accepted value [5] of 1318.4$\pm$1.2 MeV. In order to check for possible systematic effects we have measured the Λ mass using the Ξ^- decay Λ's. The measurement was carried out in a strictly analogous way to that used in the Ξ^- case, that is, the Λ mass was obtained from the *unfitted* kinematics of its decay products. The average error per determination was once again $\pm$4 MeV. The results for a sample of 64 Λ's are also shown in Fig. 1. The mean value is $M_\Lambda = 1115.9 \pm 1.0$ MeV which agrees very well with the accepted value of 1115.4$\pm$0.1 and thereby precludes the possibility of a significant systematic error.

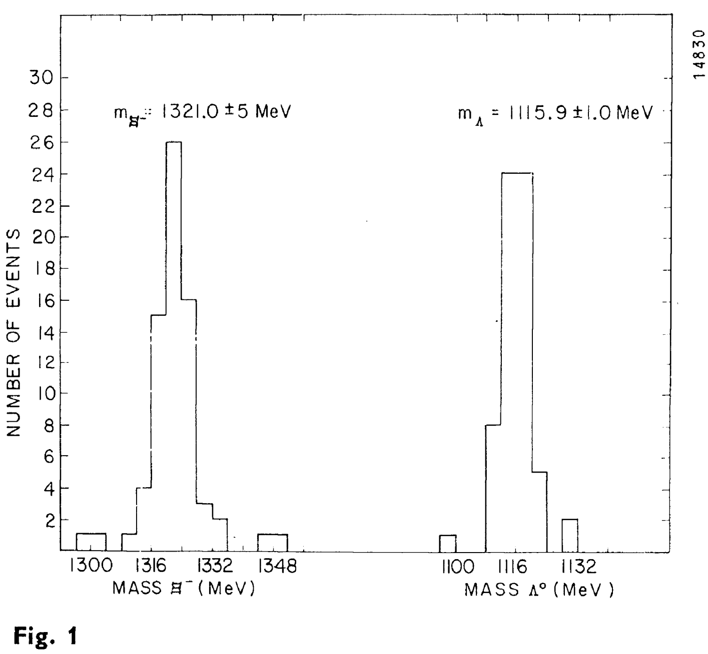

Fig. 1

The lifetime of the Ξ^- is calculated from a sample of 56 events in which the K^- and visible decay Λ vertex lay within a suitably chosen fiducial volume. The analysis is carried out using a modification of the Bartlett method [6] in which due consideration is given to the Λ decay detection probability. It is easy to show that the appropriate likelihood function describing our sample of $\Xi^- \to \Lambda + \pi^-$ decays is

$$L(1/\tau) = \prod_{i=1}^{n} N_i D_i(L_i, q_i, \tau) \exp\left[\frac{-l_i}{\tau q_i}\right]\frac{l_i}{q_i}$$

where

N_i = Normalization factor
D_i = Λ detection probability
l_i = Actual path length of the Ξ^-
q_i = Ξ^- lab momentum
L_i = Ξ^- potential path

From this one can form the Bartlett S function

$$S\left(\frac{1}{\tau}\right) = \frac{\partial L}{\partial T}\Big/\left[-\frac{\partial^2 L}{\partial \tau^2}\right]^{\frac{1}{2}}$$

which is convenient for analysis inasmuch as its average value is 0 and its variance is 1. Moreover it is asymptotically linear in $1/\tau$. A plot of $S(1/\tau)$ vs $1/\tau$ is shown in Fig. 2. The observed linearity allows the assignment of errors which truly have the meaning of a " standard deviation ". The mean cascade lifetime is

$$\tau_{\Xi^-} = (1.16^{+0.26}_{-0.17}) \times 10^{-10} \text{ sec.}$$

This value is in good agreement with that of Fowler *et al.* [7].

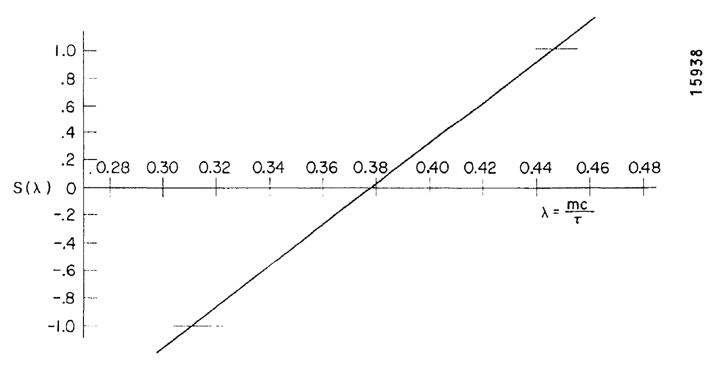

Fig. 2

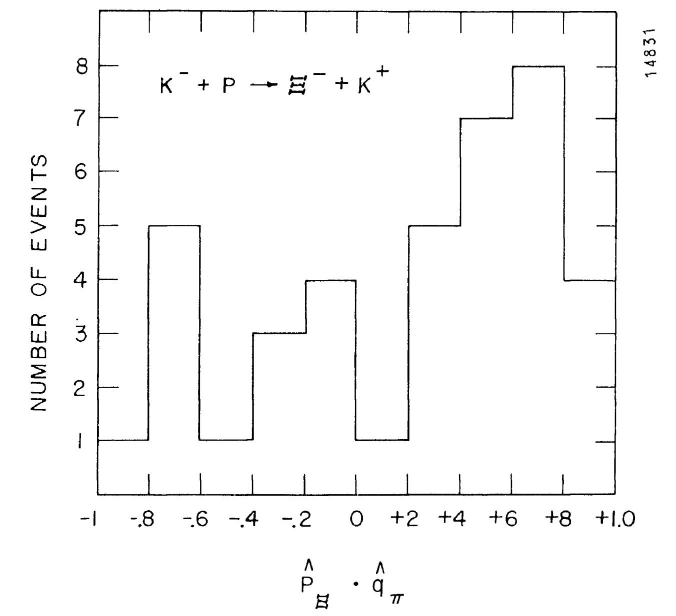

Fig. 3

The small size of the Ξ^- sample from reaction (1) does not allow a spin determination by means of the Adair analysis. However, a fortunate circumstance makes it possible to obtain a meaningful (although not conclusive) result using the method of Lee and Yang [8]. It can be shown that the test function inequalities,

$$\langle T_{JM}\rangle \leqq 1 \qquad -J \leqq M \leqq J$$

become harder to satisfy for any spin J (and z component M), the larger the value of the product $(\alpha_\Xi p_\Xi)$[9]. The latter can be obtained in the usual way from a measurement of the up-down asymmetry in the decay angular distribution

$$F(\hat{n}\cdot\hat{q}_\pi) = [1+\alpha_\Xi|\vec{p}_\Xi|(\hat{n}\cdot\hat{q}_\pi)] \quad \text{where } \hat{n} = \hat{q}_K \times \hat{q}_\Xi$$

The observed distribution is shown in Fig. 3. We find

$$\alpha_\Xi \bar{p}_\Xi = 0.52 \pm 0.26$$

and so the above inequalities become very sensitive tests for the spin. Using the test functions given in Ref. [8], we find

$$T_{1/2,\,1/2} = 0.52 \pm 0.26$$

$$T_{3/2,\,3/2} = 1.6 \ \pm 0.9$$

$$T_{5/2,\,5/2} = 3.7 \ \pm 1.7$$

Thus our data rules out spin 5/2 and favors $J = 1/2$, although it is clearly not conclusive.

Assuming that $J = 1/2$ and that there are no appreciable strong interactions in the $\Lambda-\pi$ final state, Ξ^- decay is described by the usual decay amplitudes s and p. In lieu of s and p, it is convenient to define the parameters,

$$\alpha_\Xi = 2\,\mathrm{Re}\,(s^*p)/(|s|^2+|p|^2) \text{ (asymmetry parameter)}$$

$$\beta_\Xi = 2\,\mathrm{Im}\,(s^*p)/(|s|^2+|p|^2) \text{ (time reversal parameter)}$$

The asymmetry parameter can be determined by a measurement of the distribution in the variable $\hat{q}_\Lambda\cdot\hat{q}_p$ where $\hat{q}_\Lambda$ is the Λ direction in the Ξ^- rest frame and $\hat{q}_p$ is the Λ decay proton direction in the Λ rest frame. Teutsch, Okubo, and Sudarshan [10] have shown that this distribution is given by

$$g(\hat{q}_\Lambda\cdot\hat{q}_p) = \tfrac{1}{2}[1+\alpha_\Lambda\alpha_\Xi(\hat{q}_\Lambda\cdot\hat{q}_p)]$$

Thus one directly measures the product $\alpha_\Lambda\alpha_\Xi$. Note that the distribution g is independent of the Ξ^- polarization and thus one can use the entire sample of 74 events with visible Λ decays. The experimental distribution is shown in Fig. 4; it is linear, as expected. The best value of $\alpha_\Lambda\alpha_\Xi = -0.63 \pm 0.20$. The α_Λ parameter is well known, however [11]. We use the value $\alpha_\Lambda = -0.61 \pm 0.05$ in this analysis. The likelihood function $L(\alpha_\Xi)$ is shown in Fig. 5. From Fig. 5, we find that the best value of the cascade asymmetry parameter is

$$\alpha_\Xi = +1.0^{+0.0}_{-0.35}$$

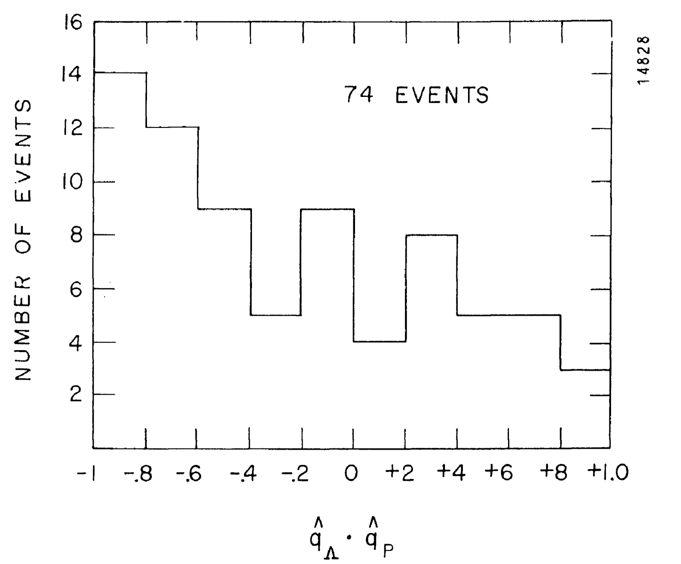

Fig. 4

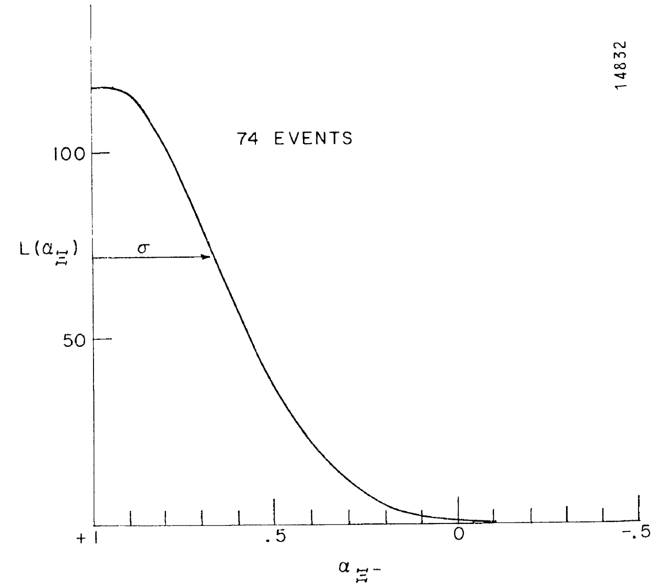

Fig. 5

This result corresponds to *complete longitudinal* polarization for the Λ from Ξ^- decay. In order to check the internal consistency of the data we have directly measured a *transverse* component of the Λ polarization $\langle\vec{\sigma}_{\Lambda\perp}\rangle$, by means of the correlation $(\hat{q}_\Xi \times \hat{q}_\Lambda)\cdot\hat{q}_\pi$ for 70 events. We find that $\langle\vec{\sigma}_{\Lambda\perp}\rangle = -0.02\pm0.05$ which confirms our determination of α_Ξ.

In similar fashion the time reversal parameter β_Ξ can be determined from the distribution in $(n\times\hat{q}_\Lambda\cdot\hat{q}_p)$ where $\hat{n}$ is the normal to the production plane. The expected distribution is

$$h(\hat{n}\times\hat{q}_\Lambda\cdot\hat{q}_p) = \frac{1}{2}\left[1+\frac{\pi}{4}\alpha_\Lambda\bar{P}_\Xi\beta_\Xi(\hat{n}\times\hat{q}_\Lambda\cdot\hat{q}_p)\right]$$

Note that this distribution is polarization dependent, and thus we use only the 30 events from reaction (1)

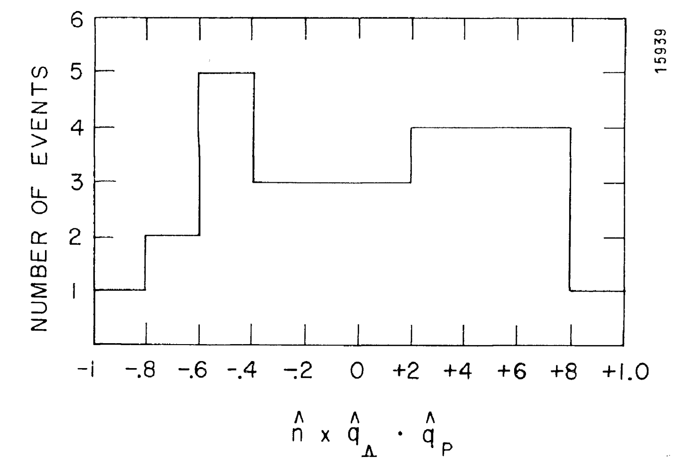

Fig. 6

with visible Λ's. The experimental distribution is shown in Fig. 6; the distribution is clearly consistent with isotropy.

Next we consider briefly the effect of final state interactions. As Lee and Yang have shown [12], such interactions have the effect of multiplying the s and p amplitudes by a phase factor which depends upon the $\Lambda-\pi$ phase shifts and the invariance properties of the interaction. In particular, the effect on α_Ξ is as follows:

If time reversal invariance holds, then

$$\alpha_\Xi \to \frac{2\ \mathrm{Re}\ (s^*p)}{|s|^2+|p|^2}\cos(\delta_p-\delta_s)$$

If charge conjugation invariance holds, then

$$\alpha_\Xi \to \frac{2\ \mathrm{Im}\ (s^*p)}{|s|^2+|p|^2}\sin(\delta_p-\delta_s)$$

Thus in order to infer the true cascade parameters, one must make some estimate of the $\Lambda-\pi$ phase shifts. Since the Ξ^- mass is close to the Y_1^* resonance energy, it seems reasonable to suppose that the $\Lambda-\pi$ system is dominated by a single resonating phase shift, δ. In the global symmetry model, since the resonant state has $J=3/2$ and the $\Lambda-\pi$ system must have $J=1/2$ (assuming spin 1/2 for the Ξ^-), the phase shifts involved are small; this model gives $\delta\approx10°$. Further, using the $\bar{K}N$ bound state model for the Y^*, Dalitz [13] has calculated the energy dependence of δ. At the energy appropriate to Ξ decay, this yields $\delta \approx 30°$.

Taking the above estimates for δ and our value of $\alpha_\Xi \approx 1$, the assumption of C invariance leads to values of $2\mathrm{Re}(s^*p)/(|s|^2+|p|^2)$ greater than unity, which clearly is forbidden. Of course, the estimates of δ must be considered only as a rough guide since the evidence for either model is not at all conclusive. However, since the $\Lambda-\pi$ resonance has a half-width of only 25 MeV and since the Ξ^- mass is more than 60 MeV below the resonance peak, one should expect small $\Lambda-\pi$ phase shifts from any sensible model. One can in fact turn the argument around and ask what value of δ would be required to allow C invariance in Ξ^- decay consistent to one standard deviation with the measured value of α_Ξ. This turns out to be $\approx75°$, which seems unreasonably large. Thus, although this evidence is not conclusive, it strongly suggests violation of charge conjugation invariance in Ξ^- decay.

In summary, the decay $\Xi^- \rightarrow \Lambda + \pi$ seems to be characterized by the same general features which characterize most of the hyperon-SIP weak interactions, namely, (a) strong parity violation, (b) lack of charge conjugation invariance, and (c) apparent time reversal invariance.

Finally we wish to point out that the weak interaction theories of d'Espagnat and Prentki [14], Treiman [15], and Pais [16], which make use of strong " global-type " symmetries to restrict the form of the weak interaction, predict $\frac{\alpha_\Lambda}{\alpha_\Xi} = +1$. Combining our result with those for α_Λ, we find that

$$\alpha_\Lambda/\alpha_\Xi = -0.6 \pm 0.3$$

which clearly disagree with the above predictions.

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DISCUSSION

YAMAGUCHI: I would like to ask either you or the previous speaker, what is the ratio of the lifetimes of Ξ^- and Ξ^0? Do you have any data?

LEITNER: We prefer not to give any numbers concerning Ξ^0 at this time.

d'ESPAGNAT: I would just like to ask if there is any information on the anomalous decay modes of the Ξ?

LEITNER: We do have some information,(*) of course. We will study this effect. It is a very difficult study, as you know, and it will take many years probably before we understand what the programmes are doing for us. But we have found one interesting event which is most likely to be the decay of a Ξ^- into an e^- and a Λ^0. Unfortunately the production mode is not a type which we can uniquely identify. That is, it may also be a Σ^- into the same decay mode, and on the basis of the measured values, as far as the usual way of identifying events is concerned, we are not able to distinguish between the Ξ^- and the Σ^-. The ionization is identical and so forth, so we have had to apply some indirect arguments. When we do that our best estimates of the probabilities for the event turn out to be Ξ^- to Σ^- probability for something like 70 to 1. But the uncertainty in this estimate is very large, so we prefer to say that we do not know what it is. It was an event of interest simply because the Λ^0 was there, and it was the first one that was seen.

ALVAREZ: This is really in the realm of strong interactions, but we have seen a reaction which we have looked for for a long time. This is, as far as I know, the first observed Ξ interaction. $\Xi^0 + p \rightarrow 2\Lambda^0 + \pi^+$.

(*) See Phis. Rev. Lett. *9*, p. 19 (1962).