is observed, within 5% accuracy, down to a distance $\hbar/q = 1.2 \times 10^{-13}$ cm. For those who believe in cutoff theories, we may, of course, push this value further, and set, with 95% confidence, a limit of 2×10^{-14} cm for a cutoff in the virtual muon propagator.[7] Accordingly, we confirm the well-known result that a group[8] at CERN has recently obtained by means of a highly accurate measurement of the muon magnetic moment. Finally, the total energy of the two muons in their center of mass ranged from 240 to 290 MeV, and we exclude from this interval muon-muon interaction effects larger than 5%. Effects due to possible leptonic decays of the ω^0 and η^0 particles,[9] or to the σ^0 meson conjectured by Schwinger,[10] may be observed at higher energies. We are planning an experiment to explore these higher masses, and ranges of higher momentum transfers.

We would like to thank Professor C. Bernardini for his collaboration in the early stages of this work, and Mr. G. Ubaldini for having carried out much of the technical work with great skill and stamina.

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PROPERTIES OF THE Ξ^- HYPERON*

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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 decay.

The data for this experiment were obtained as part of a continuing study of the K^--p interaction in the 2- to 3-BeV/c range.[1] About 70 000 pictures at 2.3 BeV/c and ~30 000 at 2.5 BeV/c were obtained in a separated K^- beam[2] at the Brookhaven AGS. 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 ~5%. The sample chosen for analysis consists of all the cascades with a visible Λ decay, and a subsample of cascades without visible Λ decay selected in an unbiased way from a group of completely analyzed events.

The cascade hyperons were produced in the following reactions:

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

$$K^- + p \to \Xi^- + K^+ + \pi^0, \tag{2}$$

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

where $\Xi^- \rightarrow \Lambda + \pi^-$. 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 Λ decay 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 ±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 ± 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 way strictly analogous to that used in the Ξ^- case. 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 ± 0.1 and thereby precludes the possibility of a significant systematic error.

The lifetime of the Ξ^- is calculated from a sample of 56 events in which the production and visible Λ-decay vertices lie 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. A plot of the Bartlett function $S(mc/\tau)$ vs mc/τ is shown in Fig. 2. The observed linearity allows the assignment of errors which have the meaning of a "standard deviation." The mean cascade lifetime is

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

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

The small size of the Ξ^- sample from Reaction (1) does not allow a spin determination by means of the Adair analysis. However, the value of the product $(\alpha_{\Xi}\bar{P}_{\Xi})$ (see below) makes it possible to obtain some indication of the value of the spin by using the method of Lee and Yang.[8] It can be shown that the test-function inequalities,

$$\langle T_{JM}\rangle \leq 1, \quad -J \leq M \leq J,$$

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

$$f(\hat{n}\cdot\hat{q}_\pi) = \tfrac{1}{2}[1 + \alpha_{\Xi} P_{\Xi}(\hat{n}\cdot\hat{q}_\pi)],$$

where $\hat{n} = \hat{q}_K \times \hat{q}_{\Xi}$ and $\hat{q}_\pi$ is the direction of the Ξ^--decay pion in the Ξ^- rest frame. 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 sensitive tests for the spin. Using the test functions given in reference 3, we find

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

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

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

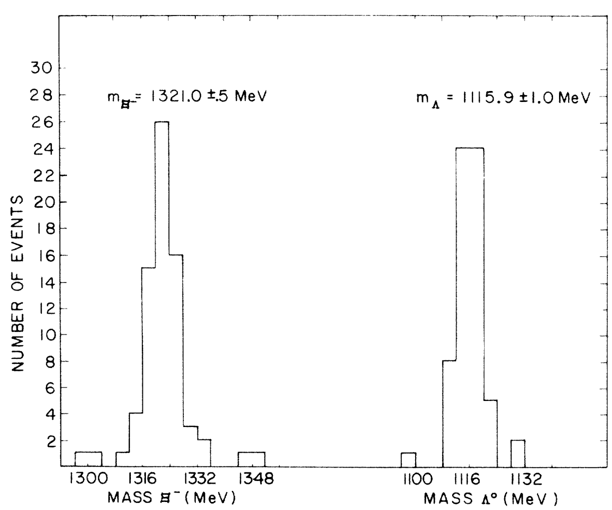

FIG. 1. Mass distribution for 74 Ξ^- and 64 Λ^0 events.

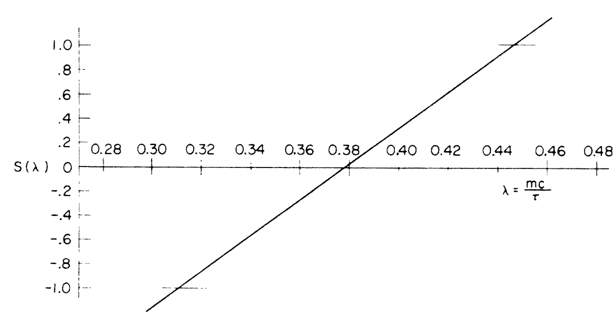

FIG. 2. Plot of Bartlett function $S(mc/\tau)$ versus mc/τ (in BeV/cm).

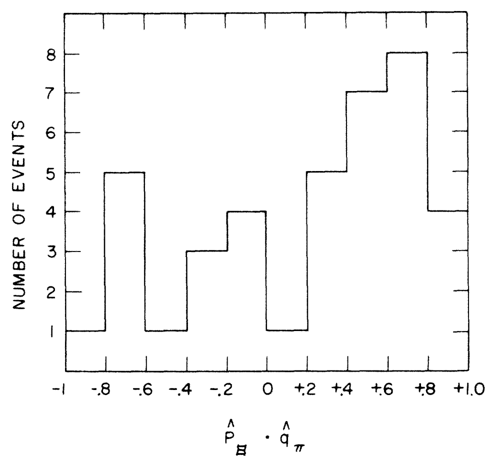

FIG. 3. Up-down distribution for 38 Ξ^- hyperons produced in the reaction $K^- + p \rightarrow \Xi^- + K^+$.

Thus our data favor $J = \frac{1}{2}$, although they are clearly not conclusive.

Assuming that $J = \frac{1}{2}$ and that there are no appreciable strong interactions in the Λ-π 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

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

(asymmetry parameter),

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

(time reversal parameter).

The asymmetry parameter can be determined by a measurement of the distribution (q) 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

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

Thus one directly measures the product $\alpha_{\Lambda}\alpha_{\Xi}$. Note that the distribution q 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 consistent with a linear distribution, as expected. The best value of $\alpha_{\Lambda}\alpha_{\Xi}$ is

$$\alpha_{\Lambda}\alpha_{\Xi} = -0.63 \pm 0.20.$$

The α_{Λ} parameter is well known[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

$$\alpha_{\Xi} = +1.0^{+0.0}_{-0.33}.$$

This result corresponds to complete longitudinal polarization for the Λ from Ξ^- decay.[12]

In similar fashion the time-reversal parameter β_{Ξ} can be determined from a distribution[13] in the variable $\hat{n} \times \hat{q}_{\Lambda} \cdot \hat{q}_p$, where $\hat{n}$ is the normal to the production plane. From the experimental distribution (based on a small sample of 30 events) it is found that $\beta_{\Xi} = 0.4 \pm 1.2$ which does not allow us to draw any conclusions regarding time-reversal invariance.

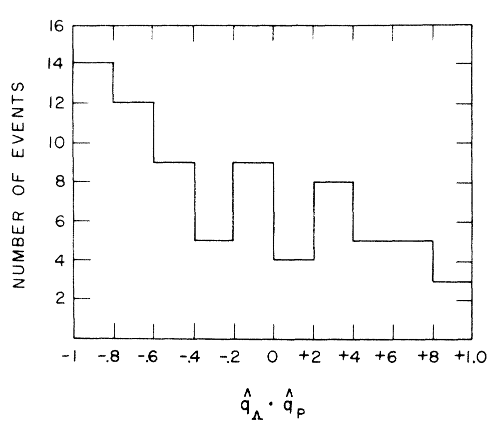

FIG. 4. Plot of $g(\hat{q}_{\Lambda} \cdot \hat{q}_p)$ for 74 Ξ^- decays in which the Λ^0 is seen.

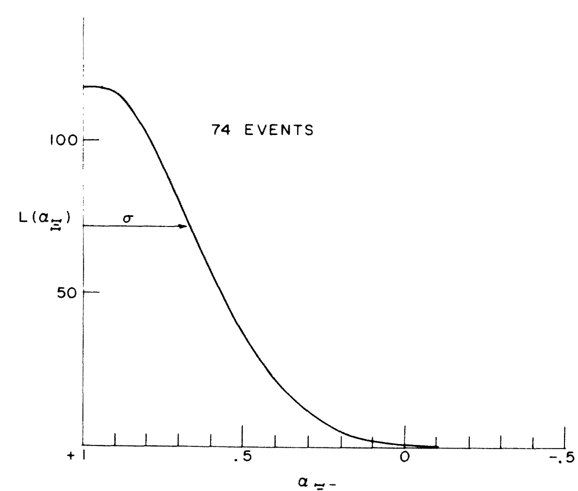

FIG. 5. Plot of the likelihood function $L(\alpha_{\Xi})$ versus α_{Ξ}.

Next we consider briefly the effect of final-state interactions. As Lee et al. have shown,[14] such interactions have the effect of multiplying the s and p amplitudes by a phase factor which depends upon the Λ-π 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

$$\alpha_{\Xi} = \pm \frac{2|s|\cdot|p|}{|s|^2+|p|^2}\cos(\delta_p - \delta_s);$$

if charge-conjugation invariance holds, then

$$\alpha_{\Xi} = \pm \frac{2|s|\cdot|p|}{|s|^2+|p|^2}\sin(\delta_p - \delta_s).$$

Thus in order to infer the true cascade parameters, one must make some estimate of the Λ-π phase shifts. Since the Ξ^- mass is close to the Y_1^* resonance energy, it seems reasonable to suppose that the Λ-π system is dominated by a single resonating phase shift. In the global symmetry model, since the resonant state has $J=\frac{3}{2}$ and the Λ-π system must have $J=\frac{1}{2}$ (assuming spin $\frac{1}{2}$ for the Ξ^-), the phase shifts involved are small; this model gives $\delta \approx 10°$. Further, using the $\bar{K}N$ bound-state model for the Y^*, Dalitz[15] has calculated the energy dependence of δ. At the energy appropriate to Ξ decay, one finds $\delta \approx 30$.

Taking the above estimates of δ, and our value of $\alpha_{\Xi} = 1.0 \pm 0.33$, the assumption of C invariance leads to the values $2(|s|\cdot|p|)/(|s|^2+|p|^2) = 5.75^{+0.0}_{-1.9}$ and $2.0^{+0.0}_{-0.66}$ for $\delta = 10°$ and 30 , respectively. Evidently no conclusion can be drawn regarding the violation of charge-conjugation invariance without knowledge of the phase shifts, although a δ of $10°$ would favor this violation.

Finally we wish to point out that our result $\alpha_{\Lambda}/\alpha_{\Xi} = -0.6 \pm 0.3$ is in agreement with the predictions of Pais[16] ($|\alpha_{\Lambda}| \approx |\alpha_{\Xi}|$) and Rosen[17] ($\alpha_{\Xi} \approx -\alpha_{\Lambda}$). Other[17] theories, which make use of strong "global-type" symmetries to restrict the form of the weak interaction, predict $\alpha_{\Lambda}/\alpha_{\Xi} \approx +1$ which clearly disagrees with our result.

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[12]In order to check the internal consistency of the data we have directly measured a transverse component of the Λ polarization $\vec{\sigma}_{\Lambda}$ by means of the correlation $(\hat{q}_{\Xi} \times \hat{q}_{\Lambda})\cdot\hat{q}_{\pi}$ for 70 events. We find that $\langle\vec{\sigma}_{\Lambda}\rangle = 0.02 \pm 0.05$ which confirms our determination of α_{Ξ}.

[12]The expected distribution is $h(\hat{n} \times \hat{q}_{\Lambda}\cdot\hat{q}_p) = \frac{1}{2}[1+\frac{1}{4}\pi\alpha_{\Lambda}P_{\Xi}\beta_{\Xi}(\hat{n} \times \hat{q}_{\Lambda}\cdot\hat{q}_p)]$. Note that this distribution is polarization dependent, and thus we use only the 30 events from Reaction (1) with visible Λ's.

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