

University of California  
Ernest O. Lawrence  
Radiation Laboratory

TWO-WEEK LOAN COPY

*This is a Library Circulating Copy  
which may be borrowed for two weeks.  
For a personal retention copy, call  
Tech. Info. Division, Ext. 5545*

DECAY PROPERTIES OF THE  $\Xi^-$  HYPERON

Berkeley, California

## **DISCLAIMER**

This document was prepared as an account of work sponsored by the United States Government. While this document is believed to contain correct information, neither the United States Government nor any agency thereof, nor the Regents of the University of California, nor any of their employees, makes any warranty, express or implied, or assumes any legal responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by its trade name, trademark, manufacturer, or otherwise, does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or any agency thereof, or the Regents of the University of California. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or any agency thereof or the Regents of the University of California.

FOR DUBNA CONF. Aug. 5-15, 1964

UCRL-11427

~~UNIVERSITY OF CALIFORNIA~~

Lawrence Radiation Laboratory  
Berkeley, California

AEC Contract No. W-7405-eng-48

DECAY PROPERTIES OF THE  $\Xi^-$  HYPERON

Philippe Eberhard, Janice Button-Shafer, and Deane W. Merrill

July 3, 1964

DECAY PROPERTIES OF THE  $\Xi^-$  HYPERON<sup>†</sup>

Philippe Eberhard, Janice Button-Shafer, and Deane W. Merrill

(Presented by George R. Kalbfleisch)

Lawrence Radiation Laboratory  
University of California  
Berkeley, California

July 3, 1964

The spin of the  $\Xi^-$  has been investigated through analysis of  $K^- + p \rightarrow \Xi^- + K^+$  events obtained in the 2.5 GeV/c run with the 72-inch bubble chamber at the Bevatron. The analyzed samples consisted of approximately 65 events at 2.45 GeV/c and 165 events at 2.6 to 2.7 GeV/c, counting only the events where the  $\Xi^-$  decays into a visible  $\Lambda$  in the bubble chamber. (These numbers correspond to cross sections of about 50 and 40  $\mu\text{b}$  respectively at the lower and higher momenta.) The  $\Xi^-$  polarization, averaged over all production angles, was found to be rather large (70 and 50%) in each of the two samples. (Comparison with data at lower momenta showed that the cross section decreased markedly from a peak value at 1.5 GeV/c, but that the average polarization over all production angles increased.<sup>1)</sup>)

If we define  $\hat{\Lambda}$  as a unit vector along the  $\Lambda$  direction in the  $\Xi$  rest frame and  $\hat{p}$  as a unit vector along the proton direction in the  $\Lambda$  rest frame,  $\mathcal{J}(\hat{\Lambda}, \hat{p})$  represents the probability of a given configuration of the decay of the  $\Xi$  and of the decay of the  $\Lambda$ , per unit solid angle  $d\Omega_{\hat{\Lambda}}$  and  $d\Omega_{\hat{p}}$ . Regardless of the  $\Xi^-$  spin we have

$$\mathcal{J}(\hat{\Lambda}, \hat{p}) = I(\hat{\Lambda}) [1 + a_{\Lambda} \overline{P}(\hat{\Lambda}) \cdot \hat{p}], \quad (1)$$

where  $I(\hat{\Lambda})$  characterizes the distribution of the  $\hat{\Lambda}$  in the  $\Xi$  rest frame,  $\overline{P}(\hat{\Lambda})$  is the polarization vector of the  $\Lambda$  at a given angle, and  $a_{\Lambda}$  is the asymmetry

---

<sup>†</sup> Work done under the auspices of the U. S. Atomic Energy Commission.

parameter for the  $\Lambda$  decay as defined by Cronin and Overseth.<sup>2</sup> The number of parameters needed to describe the  $\Xi^-$  initial spin state for an assumed half-integer spin  $J$  is  $[(2J+1)^2/2] - 1$ ; these parameters are overdetermined by the four distributions  $I(\hat{\Lambda})$ ,  $IP_x(\hat{\Lambda})$ ,  $IP_y(\hat{\Lambda})$ , and  $IP_z(\hat{\Lambda})$ , which contain a total of  $3/2(2J+1)^2 - 2$  measurable coefficients.

Because of the lack of consistency of  $\Xi^-$  decay parameters in the literature, we give the following definitions:

$$\begin{aligned} \alpha &= 2 \operatorname{Re} a^* b / (|a|^2 + |b|^2) \\ \beta &= 2 \operatorname{Im} a^* b / (|a|^2 + |b|^2) \\ \gamma &= (|a|^2 - |b|^2) / (|a|^2 + |b|^2), \end{aligned} \quad (2)$$

where  $a$  is the amplitude for the  $\ell = J-1/2$  decay amplitude, and  $b$  is the amplitude for the  $\ell = J+1/2$  decay amplitude in the transition matrix describing  $\Xi$  decay.

If the  $\Xi^-$  has spin  $1/2$ , the distributions defined in Eq. (1) are

$$I(\hat{\Lambda}) = 1 + \alpha \Pi \hat{\Lambda} \cdot \hat{n} \quad (3a)$$

$$I(\hat{\Lambda})P(\hat{\Lambda}) = (\alpha + \Pi \hat{\Lambda} \cdot \hat{n}) \hat{\Lambda} + \beta \Pi \hat{n} \times \hat{\Lambda} + \gamma \Pi \hat{\Lambda} \times (\hat{n} \times \hat{\Lambda}). \quad (3b)$$

Our convention for  $\alpha$ ,  $\beta$ , and  $\gamma$  gives the experimental distribution as defined by Cronin and Overseth.<sup>2</sup> The quantity  $\hat{n}$  is the normal to the plane of production  $\hat{K}^- \times \hat{\Xi}^- / |\hat{K}^- \times \hat{\Xi}^-|$ , and  $\Pi$  is the polarization of the  $\Xi^-$  along that axis. The distribution of the decay proton in the  $\Lambda$  rest frame not only yields the polarization vector  $P(\hat{\Lambda})$ , but also permits measurement of the coefficient  $\alpha$ .

The description of  $\Xi^-$  decay under the assumption of spin  $3/2$  is considerably more complex. Instead of the one parameter  $\Pi$  characterizing the initial state, seven parameters in addition to the decay parameters are

necessary to describe the initial  $\Xi^-$  spin state. The distribution given by Eq. (1) above, expressible in terms of the spherical harmonic  $Y_{10}$  for spin 1/2, must include higher orders of spherical harmonics up to  $Y_{3M}$  for spin 3/2. The decay distributions for  $J = 3/2$  analogous to Eqs. (3a) and (3b) may be written:

$$\begin{aligned}
 I(\hat{\Lambda}) &= \Sigma \text{ even-L terms} + a \Sigma \text{ odd-L terms} \\
 I(\hat{\Lambda})\bar{P}(\hat{\Lambda}) \cdot \hat{\Lambda} &= \Sigma \text{ odd-L terms} + a \Sigma \text{ even-L terms} \\
 I(\hat{\Lambda})\bar{P}(\hat{\Lambda}) \cdot \hat{x} &= \text{Re}[(\gamma+i\beta) \Sigma \text{ odd-L terms}] \\
 I(\hat{\Lambda})\bar{P}(\hat{\Lambda}) \cdot \hat{y} &= \text{Im}[(\gamma+i\beta) \Sigma \text{ odd-L terms}] ,
 \end{aligned}
 \tag{4}$$

with each sum taken over all permitted  $L$  and  $M$  values up to  $L_{\text{max}} = 3$ . Each term is composed of a Clebsch-Gordan coefficient times the expectation value of a spin operator  $t_{LM} \equiv \langle T_{LM} \rangle$  times the spherical harmonic  $Y_{LM}(\Lambda)$  (or the function  $\mathcal{D}_{M1}^L(\hat{\Lambda}, 0)$  for  $I\bar{P} \cdot \hat{x}$  and  $I\bar{P} \cdot \hat{y}$  terms).

Two different methods of analysis were used for the  $\Xi^-$  spin determination; one of these was a maximum-likelihood treatment and the other was an averaging technique. For both analyses, events with an observed  $\Lambda$  length of less than 1 cm as projected onto a plane perpendicular to the optical axis were excluded; the remaining sample was corrected appropriately.

Difficulties in comparing different hypotheses described by a greatly varying number of parameters were avoided by using only the distributions integrated over the azimuth around the normal  $\hat{n}$  in the likelihood method to fit the data. This technique leaves unchanged the distributions for spin 1/2, but reduces from seven to three the number of "polarization coefficients" for spin 3/2.

The likelihood method gives betting odds of eight to one in favor of spin 1/2 against 3/2. Under the hypothesis of spin 1/2, our determinations of the decay parameters are given in Table I, where  $\beta = \sin \phi \sqrt{1-\alpha^2}$  and where  $\gamma = \cos \phi \sqrt{1-\alpha^2}$ .

The averaging technique was an application of the Byers-Fenster "moment analysis."<sup>3</sup> Each moment ( $\langle Y_{LM} \rangle$ ,  $\langle P Y_{LM} \rangle$ , or  $\langle P \otimes_{M1}^L \rangle$ ) was evaluated from one of the four  $\Lambda$  direction and polarization distributions; the contribution of each event was weighted with the particular function of interest and summed over all events. Each moment contained the expectation value of a tensor spin operator, multiplied in some cases by  $\alpha$ ,  $\beta$ , or  $\gamma$ . The comparison of the overdetermined  $t_{LM}$  by a  $\chi^2$  test yielded best values of  $\alpha$ ,  $\beta$ , and  $\gamma$ .

In addition to the  $\beta$  or  $\gamma$  factor, the transverse polarization components contain an additional  $2J+1$  factor. This quantity was evaluated (in a manner suggested by Byers and Fenster<sup>3</sup> and Ademollo and Gatto<sup>4</sup>) from the expression (for each odd-L, M combination)

$$(2J+1)^2 = \frac{|IP_x \text{ moment}|^2 + |IP_y \text{ moment}|^2}{|IP \cdot \hat{\Lambda} \text{ moment}|^2 - |I \text{ moment}|^2} \quad (5)$$

The values obtained from the events at 2.45 and 2.6 to 2.7 GeV/c for  $2J+1$  are given in Table II. Only the  $L=1, M=0$  moments yield definitive values for  $2J+1$ . Also presented is the evaluation made by Ticho et al.<sup>5</sup> with U. C. L. A. data at 1.8 and 1.95 GeV/c. Because the  $2J+1$  quantity is not Gaussian, central values are of greater significance than the indicated errors. The most likely value is closer to 2 (spin 1/2) than to 4 (spin 3/2). Results do not appear to be sensitive to the value of  $\alpha_{\Lambda}$ .

REFERENCES

1. J. P. Berge, P. E. Eberhard, J. R. Hubbard, G. R. Kalbfleisch, J. B. Shafer, F. T. Solnitz, M. L. Stevenson, S. G. Wojcicki, and P. G. Wohlmut, UCRL-11529.
2. J. W. Cronin and O. E. Overseth, Phys. Rev. 129, 1795 (1963).
3. N. Byers and S. Fenster, Phys. Rev. Letters 11, 52 (1963).
4. M. Ademollo and R. Gatto, Phys. Rev. 133, B531 (1964).
5. D. D. Carmony, G. M. Pjerrou, P. E. Schlein, W. E. Slater, D. H. Stork, and H. K. Ticho, Phys. Rev. Letters, 12, 482 (1964).

Table I. Decay parameters for  $J = 1/2$  from 230 events from 2.45-, 2.6-, and 2.7-GeV/c runs

Parameter	Value
$\alpha_{\Lambda}$	$0.86 \pm 0.35$
$\alpha_{\Xi}$	$-0.28 \pm 0.12$
$\phi$	$0.64 \pm 0.3$

Table II. Moment analysis of  $\Xi^-$ .Results for  $2J=1$  (from  $L=1, M=0$  moment)and for decay parameters (with  $J=1/2$ )

Experiment	Beam momentum (GeV/c)	$\hat{z} \cdot \hat{k}^-$ limits	$a_\Lambda^a$	$2J=1$	$\alpha$	$\beta$	$\gamma$
Berkeley	2.45	-1.0, 1.0	0.62	$1.6 \pm 1.4$	-0.20	-0.23	0.95
	2.45	-1.0, 1.0	0.80	$1.3 \pm 1.1$	-0.26	-0.23	0.94
	2.6, 2.7	-1.0, 1.0	0.62	$6.8 \pm 6.6$	-0.25	-0.53	0.81
	2.6, 2.7	-1.0, 1.0	0.80	$5.3 \pm 4.8$	-0.23	-0.53	0.81
	2.6, 2.7	-1.0, 0	0.62	$2.0 \pm 1.5$	-0.14	0.02	0.99
	2.6, 2.7	-1.0, 0	0.80	$1.6 \pm 1.1$	-0.18	0.003	0.98
U. C. L. A. <sup>b</sup>	1.8, 1.95	-1.0, 1.0	0.62	$1.53 \pm 0.88$	-0.62	0.63	0.46

<sup>a</sup>The 0.80 value for  $a_\Lambda$  was utilized, in addition to the Cronin and Overseth 0.62 value, because recent Berkeley studies of  $\Lambda$  decays indicate that the higher value of  $a_\Lambda$  may be more nearly correct.

<sup>b</sup>See reference 5.

This report was prepared as an account of Government sponsored work. Neither the United States, nor the Commission, nor any person acting on behalf of the Commission:

- A. Makes any warranty or representation, expressed or implied, with respect to the accuracy, completeness, or usefulness of the information contained in this report, or that the use of any information, apparatus, method, or process disclosed in this report may not infringe privately owned rights; or
- B. Assumes any liabilities with respect to the use of, or for damages resulting from the use of any information, apparatus, method, or process disclosed in this report.

As used in the above, "person acting on behalf of the Commission" includes any employee or contractor of the Commission, or employee of such contractor, to the extent that such employee or contractor of the Commission, or employee of such contractor prepares, disseminates, or provides access to, any information pursuant to his employment or contract with the Commission, or his employment with such contractor.



*[The text in this section is extremely faint and illegible due to low contrast and noise.]*

