Title
DECAY PROPERTIES OF THE E-HYPERON

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

Publication Date
1964-07-03

UCRL-11427

University of California

Ernest O. Lawrence Radiation Laboratory

DECAY PROPERTIES OF THE Ξ^- HYPERON

Berkeley, 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 Ξ^- HYPERON

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

July 3, 1964

DECAY PROPERTIES OF THE Ξ^- HYPERON †

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 Ξ^- has been investigated through analysis of $K^- + p \to \Xi^- + K^+$ 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 Ξ^- decays into a visible Λ in the bubble chamber. (These numbers correspond to cross sections of about 50 and 40 μb respectively at the lower and higher momenta.) The Ξ^- 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. [1])

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

$$\mathcal{I}(\hat{\Lambda}, \hat{p}) = I(\hat{\Lambda}) \left[1 + a_{\Lambda} \vec{P}(\hat{\Lambda}) \cdot \hat{p} \right] , \tag{1}$$

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

† Work done under the auspices of the U. S. Atomic Energy Commission.

parameter for the Λ decay as defined by Cronin and Overseth.[2] The number of parameters needed to describe the Ξ^- 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 Ξ^- decay parameters in the literature, we give the following definitions:

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

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 Ξ decay.

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

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

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

Our convention for α, β, and γ gives the experimental distribution as defined by Cronin and Overseth.[2] The quantity $\hat{n}$ is the normal to the plane of production $\hat{K}^-\times\hat{\Xi}^-/|\hat{K}\times\hat{\Xi}|$, and Π is the polarization of the Ξ^- along that axis. The distribution of the decay proton in the Λ rest frame not only yields the polarization vector $\vec{P}(\hat{\Lambda})$, but also permits measurement of the coefficient α.

The description of Ξ^- decay under the assumption of spin 3/2 is considerably more complex. Instead of the one parameter Π characterizing the initial state, seven parameters in addition to the decay parameters are necessary to describe the initial Ξ^- 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:

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

with each sum taken over all permitted L and M values up to $L_{max} = 3$. 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 $\mathcal{D}^{L}_{M1}(\hat{\Lambda}, 0)$ for $I\bar{P}\cdot\hat{x}$ and $I\bar{P}\cdot\hat{y}$ terms).

Two different methods of analysis were used for the Ξ^- spin determination; one of these was a maximum-likelihood treatment and the other was an averaging technique. For both analyses, events with an observed Λ 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."[3] Each moment ($\langle Y_{LM}\rangle$, $\langle PY_{LM}\rangle$, or $\langle P\mathcal{D}^{L}_{M1}\rangle$) was evaluated from one of the four Λ 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 α, β, or γ. The comparison of the overdetermined t_{LM} by a χ^2 test yielded best values of α, β, and γ.

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

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

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.[5] 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 α_Λ.

REFERENCES

1. J. P. Berge, P. E. Eberhard, J. R. Hubbard, G. R. Kalbfleisch, J. B. Shafer, F. T. Solmitz, 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
a_Λ	0.86±0.35
a_{Ξ^-}	-0.28±0.12
ϕ	0.64±0.3

Table II. Moment analysis of Ξ^-.

Results for 2J+1 (from L = 1, M = 0 moment)

and for decay parameters (with J = 1/2)

Experiment	Beam momentum (GeV/c)	$\hat{\Xi}\cdot\hat{K}^-$ limits	a_Λ [a]	2J+1	α	β	γ
Berkeley	2.45	-1.0, 1.0	0.62	1.6±1.4	-0.20	-0.23	0.95
	2.45	-1.0, 1.0	0.80	1.3±1.1	-0.26	-0.23	0.94
	2.6, 2.7	-1.0, 1.0	0.62	6.8±6.6	-0.25	-0.53	0.81
	2.6, 2.7	-1.0, 1.0	0.80	5.3±4.8	-0.23	-0.53	0.81
	2.6, 2.7	-1.0, 0	0.62	2.0±1.5	-0.14	0.02	0.99
	2.6, 2.7	-1.0, 0	0.80	1.6±1.1	-0.18	0.003	0.98
U. C. L. A. [b]	1.8, 1.95	-1.0, 1.0	0.62	1.53±0.88	-0.62	0.63	0.46

[a] The 0.80 value for a_Λ was utilized, in addition to the Cronin and Overseth 0.62 value, because recent Berkeley studies of Λ decays indicate that the higher value of a_Λ may be more nearly correct.

[b] See reference 5.