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DECAY PROPERTIES OF THE Ξ^- HYPERON

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July 3, 1964

DECAY PROPERTIES OF THE Ξ^- HYPERON[†]

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(Presented by George R. Kalbfleisch)

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July 3, 1964

The spin of the Ξ^- 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 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, $\mathcal{J}(\hat{\Lambda}, \hat{p})$ 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

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

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

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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:

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

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 Ξ decay.

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

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

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

Our convention for 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 $P(\hat{\Lambda})$, 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:

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

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 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 $\beta = \sin \phi \sqrt{1-a^2}$ and where $\gamma = \cos \phi \sqrt{1-a^2}$.

The averaging technique was an application of the Byers-Fenster "moment analysis."³ 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 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 Fenster³ and Ademollo and Gatto⁴) 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.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} .

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

Parameter	Value
α_{Λ}	0.86 ± 0.35
α_{Σ^+}	-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)	$\hat{z} \cdot \hat{k}^-$ 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

^aThe 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.

^bSee reference 5.

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