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DECAY PROPERTIES OF THE Ξ^- HYPERON

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(Presented by George R. Kalbfleisch)

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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

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

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:

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

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

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

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

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 $\overline{P}(\hat{\Lambda})$, 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:

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

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 $I\overline{P}\cdot\hat{x}$ and $I\overline{P}\cdot\hat{y}$ 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 $\langle P\mathscr{D}^L_{M1} \rangle$) 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.

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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_{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.