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26 June 1984MEASUREMENT OF THE LIFETIME OF THE CHARMED STRANGE BARYON Λ^+ *)

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ABSTRACT

The lifetime of the charmed strange baryon Λ^+ has been determined in an experiment at the CERN SPS hyperon beam from the distribution of distances between production and decay of Λ^+ candidates of known momentum. The result is

$$\tau = (4.8_{-1.8}^{+2.9}) \times 10^{-13} \text{ s.}$$

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In a previous letter (1) we have reported the discovery of a narrow state at $2.46 \text{ GeV}/c^2$ in the $\Lambda K^- \pi^+ \pi^+$ channel, produced in Σ^- -Be interactions at the CERN SPS charged hyperon beam. The signal contained 82 events above a background of 147. From the charge and strangeness of this state, $Q = +1$ and $S = -2$, and its observed width which was compatible with the mass resolution of the apparatus, we concluded that the observed final state resulted from a Cabibbo-favoured decay of the charmed strange baryon Λ^+ (quark content csu).

We have now determined the Λ^+ lifetime from the distribution of distances between the Λ^+ production and decay vertices. These vertices were reconstructed from tracks observed in wire chambers.

The apparatus has been described in Ref. 1, and we discuss here only the features important for the lifetime measurement. The hyperon beam, which was tuned to a mean momentum of $135 \text{ GeV}/c$, was directed onto an 8 cm long beryllium target. The Σ^- in the beam were identified by a DISC Cherenkov counter. The momenta of charged secondary particles were measured in a two-stage magnetic spectrometer. Several sets of proportional chambers and drift chambers were used to measure the track of the incoming Σ^- and the tracks of secondary particles between the target and the first spectrometer magnet SMI (Fig. 1). The relevant chamber characteristics and the mean distance of each set from the target centre are listed in Table 1.

The material between the target and SMI amounted to 0.08 radiation lengths, which limited the accuracy of the backward extrapolation of low momentum tracks to the target. The mean momenta of the K^- and the π^+ from the Λ^+ decay were 25 and 10 GeV/c respectively, and for additional particles emerging from the target at large angles, even lower momenta were expected. We therefore used all chambers for pattern recognition, but only the chambers close to the target (B, C and D1) for extrapolation, to reduce the effects of multiple scattering.

We determined the A^+ lifetime by measuring the distance between the A^+ production and decay vertices. This distance is proportional to the A^+ momentum, which had a mean value of 90 GeV/c. The decay vertex was reconstructed from the K^- track and the two π^+ tracks. These tracks had to be separated from each other by an angle greater than 0.6 mrad in the horizontal plane or 0.2 mrad in the vertical plane to avoid spurious duplication of tracks. In addition, we required that the r.m.s. distance between the K^- and π^+ trajectories at the vertex be less than 700 μm , and that the vertex position was not, within errors, upstream of the target. Only events with a single $K^- \pi^+ \pi^+$ combination satisfying these criteria were used. The distribution of the effective ($A K^- \pi^+ \pi^+$) mass for this sample is shown in Fig. 2a, which contains 61 A^+ events above a background of 91.

In this experiment, it was not possible to determine the A^+ lifetime by measuring the transverse distance between the Σ^- track, seen in chambers A1 and A2, and the A^+ decay vertex. This method would have avoided the problems connected with the reconstruction of the production vertex, which will be discussed below. However, the mean P_T of the A^+ was only 0.65 GeV/c, which even with an A^+ lifetime as long as 10^{-12} s would result in a mean transverse distance of 80 μm , to be compared with the accuracy of 150 μm r.m.s. for chambers A1 and A2.

The production vertex was reconstructed from the tracks of the incoming Σ^- and of additional particles emerging from the target (Fig. 1). As large-angle tracks allowed a more precise determination of the vertex position, we rejected all additional tracks with an angle of less than 20 mrad with respect to the Σ^- track. Furthermore, we accepted tracks traversing chamber D1, even if they did not subsequently pass through the aperture of S1, thereby increasing the maximum accepted angle from about 40 to 140 mrad. The tracks had to pass within 1 mm of the Σ^- track

in the target region, and they had to be separated from any other track by at least 0.6 mrad in the horizontal plane and 0.2 mrad in the vertical plane. The vertex position had to be, within errors, inside the target, and the r.m.s. distance between all tracks used for its reconstruction had to be less than 700 μm .

These requirements reduced the number of A^+ candidates, the events with an effective mass $2445 \leq m(KK^-\pi^+\pi^+) < 2475 \text{ MeV}/c^2$, from 152 to 112. In this sample, the mean multiplicity of additional tracks fulfilling the production vertex conditions was 1.6. From the $m(KK^-\pi^+\pi^+)$ distribution of this sample (Fig.2b), it can be seen that the production vertex requirement enhances the signal to background ratio. The background under the peak was determined from the number of events in the five adjacent bins on each side, which we call the "near sample", assuming a linear effective mass distribution in this range. The signal to background ratio changed from 61/91 in Fig. 2a to 53/59 in Fig. 2b, thus the statistical significance of the A^+ signal was not affected. We have also determined the background from a second-order polynomial fit and obtained the same result.

The quality of the vertex reconstruction is demonstrated in Fig. 3, where we show the distribution of Δz , the distance along the beam between the reconstructed A^+ production and decay vertices (Fig. 1 inset). A positive value of Δz means that the A^+ decay vertex is downstream of the production vertex. The sample shown in Fig. 3a is the "far sample", comprising all events outside of the candidate and "near sample" intervals, i.e. events with $m(KK^-\pi^+\pi^+) < 2370 \text{ MeV}/c^2$ or $m(KK^-\pi^+\pi^+) > 2550 \text{ MeV}/c^2$. The mean of this distribution is at zero and its width is 6 mm r.m.s.

In Fig. 3b we show the Δz distribution for the A^+ candidates, which is shifted to positive Δz values, and in Fig. 3c the Δz distribution of the "near sample", which like that of the "far sample" is centred at zero.

Subtracting the Δz spectrum of the suitably normalized "near sample" from that of the candidate sample, we obtained the distribution of Fig. 3d for the A^+ signal. This distribution shows a clear shift to positive Δz values.

In order to determine the lifetime, we divided the candidate sample (Fig. 3b) into four subsamples with momenta 60-75, 75-90, 90-110 and > 110 GeV/c. For each subsample, we calculated for various A^+ lifetimes the Δz spectrum expected for A^+ having the mean momentum of that subsample. To describe the Δz resolution of the apparatus, we used the measured Δz distribution of the "near" background (Fig. 3c). We have checked that there is no Δz -momentum correlation in the background data and that the fraction of background in the candidate sample is momentum independent. Using a maximum likelihood method we then fitted the Δz distribution of the candidate subsample to the sum of the Δz distribution calculated for the A^+ and the one observed for the background. The results of the fits to each subsample are in agreement with each other and together yield an A^+ lifetime of

$$\tau = (4.8_{-1.5}^{+2.1}) \times 10^{-13} \text{ s} ,$$

where the error is the statistical error of the fit.

Uncertainties connected with the background have been studied by varying i) the boundaries of the momentum subsamples, ii) the amount of background in the sample and iii) the mass windows used for finding the Δz distribution of the background. We deduced a systematic error of $\pm 1.0 \times 10^{-13}$ s, which will be added in quadrature to the error quoted above.

The lifetime measurement could be affected by confusion between tracks originating from the Λ^+ production vertex and tracks from the decay of a charmed meson produced in association with the Λ^+ (see Fig. 1). From Monte Carlo calculations, we would expect this to result in an overall downstream shift of the "production" vertex and consequently in a reduction of the observed lifetime. We have seen no correlation between Λ^+ momentum and lifetime, which would have been evidence for such an effect, therefore we do not modify the measured lifetime value. However, we cannot exclude such an effect, therefore we add to the error on the positive side a systematic contribution calculated under the following assumptions: all additional tracks used for the production vertex are from D decays; the momentum of the D is on average 1/2 of the momentum difference between Σ^- and Λ^+ , i.e. 22.5 GeV/c; the D are an equal mixture of D^0 and D^- . The result of that calculation is 1.7×10^{-13} s and our final result then is

$$\tau_{\Lambda^+} = (4.8_{-1.8}^{+2.9}) \times 10^{-13} \text{ s} .$$

The only other lifetime measurements for charmed baryons are those for the Λ_c^+ , which result in

$$\tau_{\Lambda_c^+} = (2.2_{-0.4}^{+0.7}) \times 10^{-13} \text{ s} ,$$

based on 19 observed events (Ref. 2). This value is smaller than our measured Λ^+ lifetime, in agreement with theoretical estimates based on the absence of annihilation diagrams in Λ^+ decay (Refs. 3 and 4).

Clearly, the magnitude of the lifetime measured in this experiment strongly supports the identification of the observed $\Lambda K^- \pi^+ \pi^+$ state as a weak Cabibbo-favoured decay of the charmed strange baryon Λ^+ .

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Table 1

Chambers upstream of the first bending magnet. n: number of chambers, d: mean distance from target centre, p: wire pitch for MWPCs, maximum drift path for drift chambers. A coordinate axis angle of 0° (90°) signifies measurement of the horizontal (vertical) coordinate.

	n	d (cm)	p (mm)	Fiducial area (cm ²)	Coordinate axes
MWPC: A1,A2	2 x 4	-311,-21	0.5	3.2 x 3.2	$0^\circ, 90^\circ$
B	4 4	+17 +37	0.5	6.4 x 6.4	$0^\circ, 90^\circ$ $45^\circ, 135^\circ$
C	4 2	+69 +90	1	22.4 x 22.4	$0^\circ, 90^\circ$ $15^\circ, 75^\circ$
D1	4 2	+132 +152	1	41.5 x 41.5	$0^\circ, 90^\circ$ $15^\circ, 75^\circ$
D2	2 4	+187 +207	1	41.5 x 41.5	$15^\circ, 75^\circ$ $0^\circ, 90^\circ$
E1 E2	4 4	+262 +432	2	51.2 x 25.6 128.0 x 51.2	$0^\circ, 90^\circ$
Drift chambers: DC1-4	4 x 3	+312,+481 +521,+561	25 ($\sigma = 350 \mu\text{m}$)	78 x 78	$0^\circ, 120^\circ, 240^\circ$

Figure captions

- Fig. 1: Plan view of apparatus. A-E: MWPC sets. T: target. DC: drift chamber sets. H: scintillator hodoscopes. SMI: first spectrometer magnet. The inset shows a schematic view of charged tracks from associated A^+ , D^- production inside the target. V_p : production vertex; V_{A^+} : A^+ decay vertex with $K^- \pi^+ \pi^+$ tracks; V_D : D decay vertex.
- Fig. 2: Distributions of the effective $(\Lambda K^- \pi^+ \pi^+)$ mass.
- a) Events satisfying the A^+ decay vertex requirements.
 - b) Events satisfying the production vertex and A^+ decay vertex requirements.
- The curves show a second-order polynomial fit excluding the A^+ peak.
- Fig. 3: Distributions of Δz .
- a) "Far sample", 1329 events.
 - b) A^+ candidates, 112 events.
 - c) "Near sample", 295 events.
 - d) A^+ signal after background subtraction, 53 events.
- The solid curve is the Monte Carlo calculation for $\tau_{A^+} = 4.8 \times 10^{-13}$ s.

Fig. 1

Fig. 2

Fig. 3