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LIFETIME MEASUREMENT OF Λ_c

LEBC-EHS Collaboration

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ABSTRACT

We report on the Λ_c properties observed with the LEBC-EHS set up at CERN SPS with 360 GeV/c π^- and 400 GeV/c p beams. The lifetime is $(1.2^{+0.5}_{-0.3}) \times 10^{-13}$ s and the mass $(2284.7 \pm 2.3 \pm 0.5)$MeV/c^2.

More than ten years after the first observation of the Λ_c[(*)] charmed baryon [1] very little is known about its properties. Indeed, apart from its mass $M = (2281.2 \pm 3.0)\mathrm{MeV}/c^2$ [2], its lifetime, branching ratios and other properties are at best known to about a factor of 2.

We report in this letter on the measurements of the mass and lifetime of the Λ_c observed in a CERN SPS experiment performed with the LEBC-EHS experimental set-up. The production characteristics will be discussed in a forthcoming publication [3]. The key element of the experiment is the high resolution bubble chamber LEBC which provides not only a target of hydrogen where the initial interaction is visualized, but also a very good spatial resolution: the detection of tracks from charm decay vertices with an impact parameter precision of 2.5 µm [4] is possible. The trigger requires only an interaction in the target with more than two charged particles in the final state, yielding an estimated efficiency for charm events of $(98^{+2}_{-3})\%$. The two arms of the spectrometer provide a momentum resolution of $\Delta p/p = 0.8\%$ and an acceptance for three-prong decays of 95% for $x_F > 0$.

For the computation of the Λ_c properties we use the 3 Λ_c decays detected in the 360 GeV/c π^- beam exposure and published elsewhere [4] and the Λ_c observed in the 400 GeV/c proton run described here.

In the proton run the search for Λ_c is based on a sample of 143 three-prong decays found in two million LEBC pictures (two views per interaction). We consider only three-prong topologies since the one-prong decays have a non-negligible background of strange particles.

The sample of three prongs is a mixture of $D^\pm$, $D_s^\pm$ and Λ_c with a small contamination of strange particles (i.e., $K \to \pi\pi\pi$, $\Sigma \to pe^+e^-\gamma$). To reduce the charm particle ambiguities and to eliminate the background, we restrict the sample to three-prongs with three well reconstructed tracks. The EHS spectrometer acceptance is such that 67 three-prongs are kept with a contamination, at most, of 0.3 events, due to the strange particle background.

The reduction of charm particle ambiguities cannot be based only on kinematic separation since there is an overlap between different Λ_c, D and D_s channels. Particle identification of the decay tracks has then to be taken into account.

(*) We write Λ_c for Λ_c and $\bar{\Lambda}_c$ throughout this letter.

EHS [5] provides this information by using a large drift chamber ISIS where the ionization is measured for particles in the momentum range 5-40 GeV/c and a multicell threshold Forward Cerenkov (FC) which covers the momentum range 20-130 GeV/c; the lower and higher momenta are covered with a Silica Aerogel Cerenkov Detector SAD and the Transition Radiation Detector TRD respectively. The Hadron Calorimeters (HC) and Gamma Detectors (GD) provide the identification of hadronic and electromagnetic showers.

For a non-ambiguous Λ_c sample we require the presence of a uniquely identified proton (antiproton) among the decay products with same charge as the parent particle (like-sign) or three constraint (3C) kinematic fit without any other 3C fits to $D^{\pm}$, $D_s^{\pm}$.

A "unique" proton is defined by an ISIS mass assignment probability larger than 1% and at least 10 times the probability obtained for K or π mass assignment. For high momentum tracks the Forward Cerenkov information can also be used; in this case, we keep only mass assignments with probability greater than 5%. No incompatibility was found between the information provided by ISIS and FC.

Seven Λ_c were found and are presented in table 1(a). Events 1-2 have 3C Λ_c fit with a unique proton identified. The K^o and the π^o are detected by the Forward Hadron Calorimeter and Gamma Detector respectively. Event 3 has a proton uniquely identified and a zero constraint (0C) fit, requiring a π^o out of acceptance. The other events have no unique proton identified according to the criteria given above. Events 4-5 have only one 3C fit which is a Λ_c; it is confirmed by particle identification. For event 6, D and D_s fits are vetoed by the Forward Cerenkov. Event 7 has a possible D solution requiring an unseen π^o which has a very high probability (83%) to be detected by the electromagnetic calorimeters and is not found. We computed that the background from D, D_s is less than 0.3 event when a unique proton is not present in the final state. Table 1(b) gives the properties of the non-ambiguous Λ_c found in the π^- data [4].

Alternatively we treat the particle identification information of the same sample of 67 three-prong decays by a statistical method [6]. The particle composition is then determined by a Maximum Likelihood fit which takes into account the response of ISIS to the tracks from the 67 three-prong decays. This yields the results given in table 2 for the number of secondary tracks with the most likely mass assignment(*). The separation of like-sign and unlike sign tracks is given for e, π, K/p mass. As expected we find a few electrons in the like-sign column. These are related to semielectronic decays [6]. The K/p like-sign signal of 10 ± 3 tracks must come from $\Lambda_c \to pX$ or $D_s \to K^+X$ or from Cabibbo suppressed $D^+ \to K^+X$ decay modes.

To check the possibility of a correlation between the presence of 10 ± 3 K/p like-sign tracks and a short lived component we introduce a cut in the average impact parameter ⟨y⟩. A cut of ⟨y⟩ larger than 60 µm eliminates about 90% of the Λ_c signal if $\tau_{\Lambda c} = 1 \times 10^{-13}$ s. The results given in brackets in table 2 show that the like-sign K/p signal drops to zero and then is clearly related to a short living component that produces an excess of entries in the average impact parameter distribution for small values. This can be seen in the experimental distribution shown in fig. 1 where the charged D meson background, evaluated by Monte-Carlo and normalized above ⟨y⟩ = 100 µm, is superimposed. A cut on impact parameter to eliminate any possible topological contamination from D^o meson is applied to this sample (at least two tracks with impact parameter greater than 10 µm). A clear indication of an excess of entries in the region below 60 µm as discussed before is found. Its probability to be a D fluctuation is less than 1.5%. The dashed area represents the events of table 1(a) surviving the cuts defined for this figure.

Using the three-prong decays observed in the NA27 experiment (incident pion and proton data), we evaluate the mass of the Λ_c baryon. By using those decays with ⟨y⟩ less than 60 µm, we compute the Kπp invariant mass rejecting those combinations with mass hypothesis assignments having an ISIS probability less than 1%. Fig. 2 shows a clear peak around 2280 MeV. At the Λ_c bin mass value we have 6 entries, 5 of them having a unique 3C fit pKπ decay mode (table 1). The value of the Λ_c baryon mass using these five events is $(2284.7 \pm 2.3 \pm 0.5)\mathrm{MeV/c^2}$ where 2.3 is our statistical error and 0.5 a conservative estimation of the systematic errors. It is fairly consistent with the world average of $(2281.2 \pm 3.0)\mathrm{MeV/c^2}$ [2]. Note that the world data show a double peak structure for the mass of the Λ_c. If one takes the sharper and higher peak one finds a value of about 2284 $\mathrm{MeV/c^2}$ which is quite compatible with our results.

(*) If these values are used to compute branching ratios, ISIS losses must be taken into account.

The measurement of the lifetime was obtained by using all the unique Λ_c found in the NA27 experiment. This sample is based on the 7 events listed in table 1(a) and the 3 events in table 1(b).

To determine the lifetime we use the following likelihood function:

$$\pounds(\tau) = \Pi(1/\tau)\ \frac{e^{-t/\tau}}{e^{-t_{min}/\tau} - e^{-t_{max}/\tau}}$$

where t_{min} and t_{max} are the decay times corresponding to the lengths l_{min} and l_{max}. These two quantities, as defined in details as [4], are the minimum and maximum decay length necessary to observe the decay with high efficiency.

To determine t_{min} we first select the decays having a charm partner candidate (table 1) with at least one track with a maximum impact parameter greater than 50 µm. This selection guarantees a scanning efficiency larger than 95%. Events 4, 6 of table 1(a) and 1 from table 1(b) do not satisfy this criterium. All charm candidates were measured on a High Precision Device (HPD) which is very efficient in finding all tracks from secondary decay vertices with impact parameter larger than 10 µm (4 σ where σ is the HPD measurement error on impact parameters). Therefore for these Λ_c we simply require an impact parameter y larger than 10 µm to guarantee a correct topological interpretation of the decay. For the decays with no partner satisfying the previous requirement, t_{min} is computed requiring a maximum impact parameter greater than 50 µm for Λ_c [7].

Using this procedure 9 events remain with proper time greater than t_{min} yielding a lifetime value of

$$(1.2^{+0.5}_{-0.3}) \times 10^{-13}\ \mathrm{s}.$$

Fig. 3 shows the $t - t_{min}$ distribution and the curve corresponding to a lifetime of 1.2×10^{-13} s. Only statistical errors are given. Systematic errors due to length and momentum measurements are negligible (less than 2%). Moreover, we have checked that the results are stable versus the variation of t_{min}. We obtain a Λ_c lifetime which is significantly lower than the world average [2].

Taking into account that, to define this sample of decays, we have combined the clean geometrical information of the bubble chamber with the high precision EHS spectrometer and particle identification, the Λ_c used in this analysis contain a negligible contamination from other charged hadron decays.

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TABLE CAPTIONS

TABLE 1 (a,b) The tables give for each event an identification number (id), the number of degrees of freedom of the kinematic fits (ndf), the decay mode, the effective mass of the decay products with its error (m, Δm) for fully reconstructed decays, the proper time (t) and the minimum detectable time (t_{min}), the maximum impact parameter (y_{max}), the kinematic fit or the decay topology of the partner. Identified particles consistent with the kinematic interpretation are underlined once and those which are uniquely identified by ISIS or FC are underlined twice. No particle identification is available for particles not underlined. Tables 1(a,b) list the Λ_c candidates detected in pp and $\pi^- p$ interactions respectively. The X2 decay has not a clear topology.

TABLE 2 The table summarizes the number of tracks for different mass hypothesis (e, π, K/p) based on ISIS identification. The number of like-sign and unlike-sign tracks with respect to the parent particle are given. In brackets we give the same quantities for events having ⟨y⟩ larger than 60 µm.

TABLE 1(a)

id	ndf	Mode	m(Δm) MeV/c^2	t 10^{-13} s	t_{min} 10^{-13} s	y_{max} µm	Partner
1	3	$\underline{p}\pi^+\underline{\pi}^-K^0\pi^0$	2307 (35)	0.50	0.57	11	$\bar{D}^0$
2	3	$\underline{p}\pi^+\underline{K}^-\pi^0$	2255 (10)	2.96	0.64	83	D^-
3	0	$\underline{\bar{p}}K^+\underline{\underline{\pi}}^-(\pi^0)$		1.64	0.50	42	C3$^+$
4	3	$p\underline{K}^-\underline{\underline{\pi}}^+$	2293 (8)	0.82	0.66	62	C1$^-$
5	3	$\bar{p}\underline{\underline{K}}^+\underline{\underline{\pi}}^-$	2295 (5)	1.12	0.61	18	D^0
6	3	$\bar{p}\underline{K}^+\underline{\pi}^-$	2290 (6)	2.57	1.87	68	D^0
7	3	$pK^-\underline{\underline{\pi}}^-\pi^0$	2309 (14)	5.88	1.55	139	V2

TABLE 1(b)

id	ndf	Mode	m(Δm) MeV/c^2	t 10^{-13} s	t_{min} 10^{-13} s	y_{max} µm	Partner
1	3	$\underline{\underline{\pi}}^+\underline{\underline{\pi}}^-\underline{\pi}^-\bar{\Lambda}$	2291 (6)	1.25	1.12	55	-
2	3	$K^+\underline{\underline{\pi}}^-\underline{\underline{\bar{p}}}$	2275 (4)	1.93	1.30	32	D^+
3	3	$\underline{K}^-\underline{\underline{\pi}}^+p$	2284 (5)	2.87	1.99	67	X2

TABLE 2

	Like-sign		Unlike-sign	
e	1 ± 2	(< 1)	0	0
π	73 ± 6	(50 ± 6)	15 ± 4	(11 ± 4)
K/p	10 ± 3	(< 1)	14 ± 4	(9 ± 4)

FIGURE CAPTIONS

Fig. 1 Average impact parameter distribution based on a sample of 3-prong fully reconstructed decays from pp data. The solid line shows the charged D Monte-Carlo predictions normalized to the events with ⟨y⟩ larger than 100 µm. The dashed area corresponds to decays with a proton in the final state.

Fig. 2 pKπ invariant mass for the three-prong decays with an average impact parameter ⟨y⟩ smaller than 60 µm.

Fig. 3 $t-t_{min}$ distribution for the Λ_c sample.

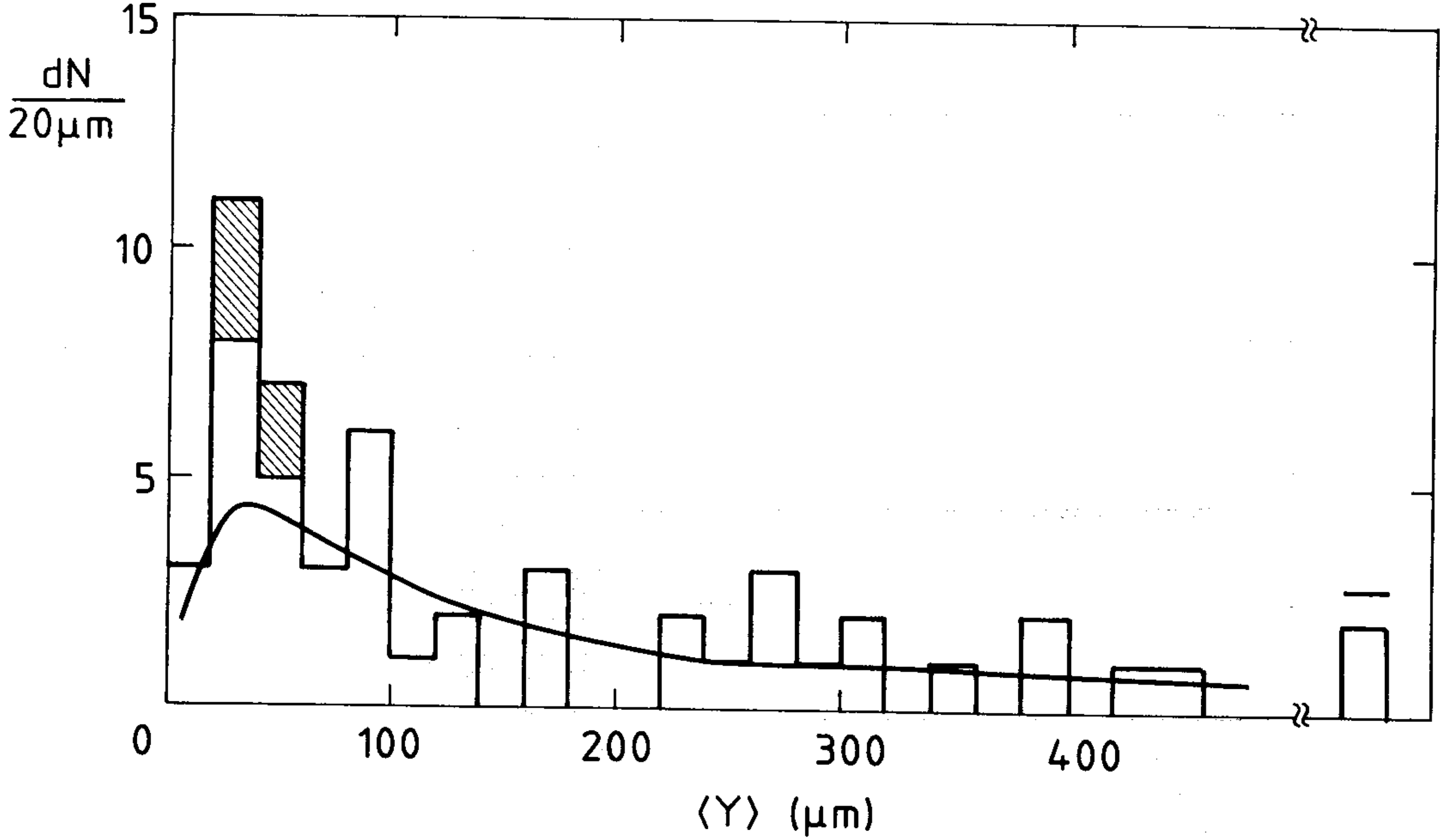

Fig. 1

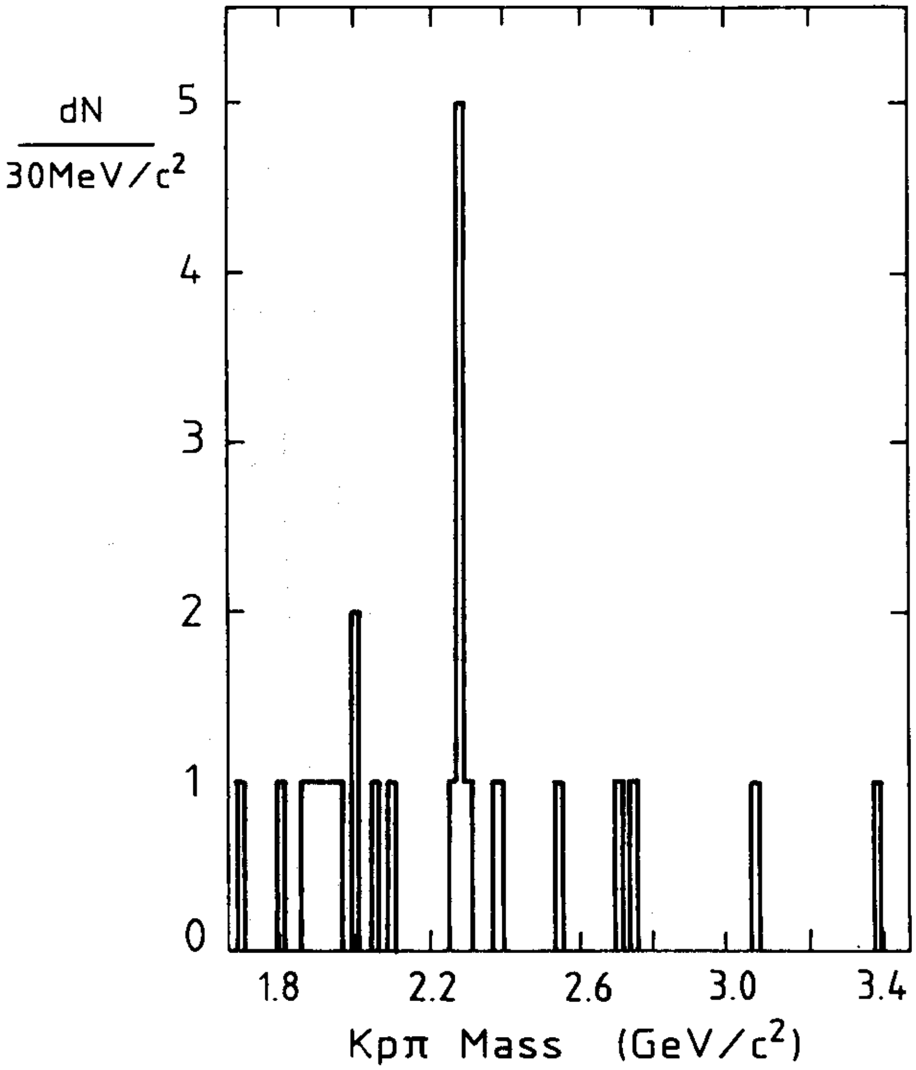

Fig. 2

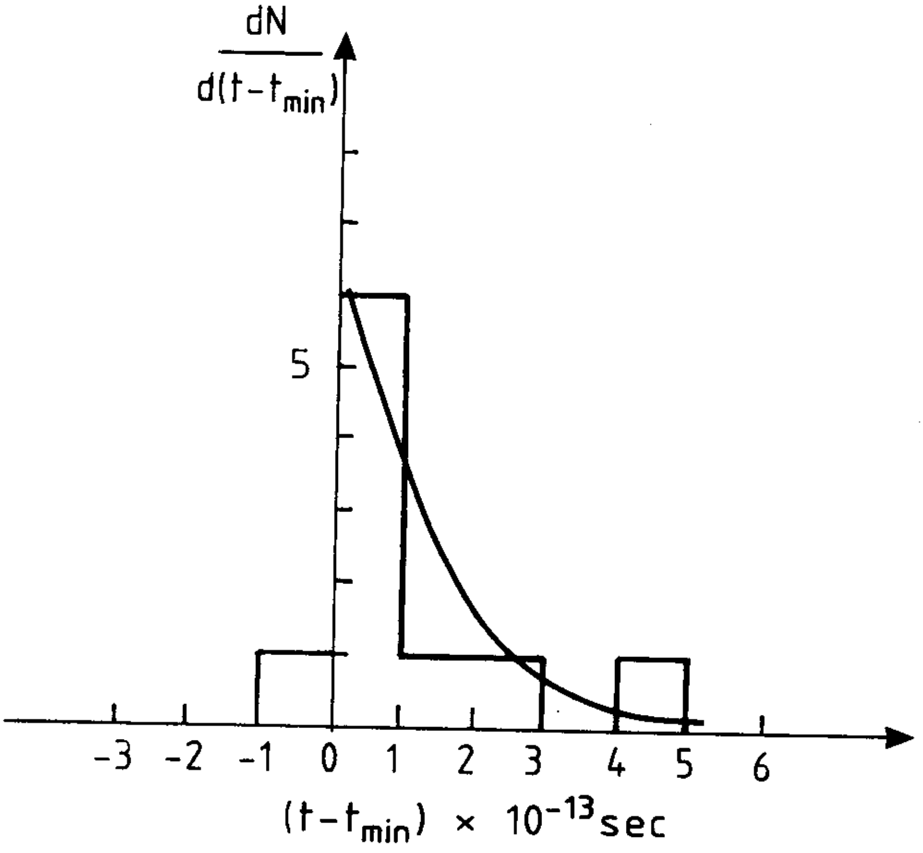

Fig. 3