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PRECISE DETERMINATION OF THE LIFETIME OF THE CHARMED BARYON Λ_c
(ACCMOR Collaboration)

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ABSTRACT

We present the result on the measurement of the lifetime of the Λ_c from a sample of Λ_c decays obtained in the NA32 experiment in 1985 and 1986 using charge-coupled devices for vertex reconstruction and a trigger on $\Lambda_c \rightarrow pK^-\pi^+$ (and charge conjugate).

We observe a peak of 108 bias-free events at the Λ_c mass on a background of 7 events. The lifetime of the Λ_c is determined to be $1.96^{+0.23}_{-0.20} \cdot 10^{-13}$.

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1. INTRODUCTION

A search for $D_s^\pm \rightarrow K^+K^-\pi^\pm$, $\Lambda_c \rightarrow pK^-\pi^+$ and $\bar{\Lambda}_c \rightarrow \bar{p}K^+\pi^-$ was started with the ACCMOR spectrometer in 1985. It was a continuation of the NA32 experiment [1] with a modified target and vertex detector. For the first time charge-coupled devices, CCDs [2], were used as vertex detectors. They provided space points for secondary tracks close behind the target. Furthermore, the FAMP trigger [3] was reinstated in the experiment. This trigger had been used originally in the NA11 experiment in 1982 to collect 600,000 ϕ 's [4], but it had also proved to be a selective charm trigger yielding a sample of $D_s \rightarrow \phi\pi$ for mass determination and lifetime measurement [5].

We present the final sample of fully reconstructed Λ_c decays out of $16.7 \cdot 10^6$ triggers collected in 1985 and 1986. Earlier results on parts of this sample have been reported [6,7]. A recent summary on the Λ_c lifetime is found in Refs.[8] and [9]. Recent results have been published by NA27 [10], NA1 [11], E691 [12] and NA14 [13].

2. THE EXPERIMENT

The experiment was located in the H6 beam of the North Area at the CERN SPS. A negative beam with a momentum of 230 GeV was used. Two CEDAR Cerenkov counters served for tagging incident pions and kaons.

Hadronic charm decays into charged particles are fully reconstructed with the large acceptance forward spectrometer [4] and the set-up of the vertex detector, shown in Fig. 1. The spectrometer consisted of two magnets and 48 planes of drift chambers arranged in 4 groups. Three multicellular threshold Cerenkov counters were used to identify π, K, p in the momentum range 4-80 GeV.

A short 2.5 mm Cu target was used so that secondary vertices could be observed close to the primary vertex. Two CCDs were situated at 10 and 20 mm downstream from the target, CCD1 and CCD2, respectively. The decay region extended from the downstream end of the target to the front side of the CCD2. This allowed the observation of secondary decay vertices in air without background from secondary interactions. The CCDs [2] have pixels of $22 \mu\text{m} \times 22 \mu\text{m}$ and measure space coordinates with a precision of $\sigma_x \approx \sigma_y \approx 5 \mu\text{m}$ (x is the horizontal coordinate, y the vertical and z along the beam). Two tracks can be resolved if their separation in space exceeds $40 \mu\text{m}$. The readout procedure is described in Ref.[6]. With an incident beam rate of 10^6 particles per SPS burst of 2.5 s the detectors have a density of background hits of approximately 2 mm^{-2} in the readout area ($8.8 \text{ mm} \times 2.4 \text{ mm}$) from other beam particles and interaction products not related to the trigger event. This is very low when compared with the pixel density of 2100 mm^{-2} .

In addition to the CCDs, a vertex telescope of 8 silicon microstrip detectors V1-8 with capacitive charge division readout is used for high precision vertex reconstruction and a beam telescope of 7 silicon microstrip detectors B1-7 for precise reconstruction of the beam track. The main characteristics of the vertex detector are summarized in Table 1 of Ref.[6]. With this set-up the impact parameter of a track is measured with a precision of $\sigma_{dx} \approx \sigma_{dy} \approx (5^2 + (\frac{18}{p})^2)^{\frac{1}{2}} \mu\text{m}$ (dx, dy : minimal projected distance of a track from the primary vertex) where the momentum dependent term (p is measured in GeV) is the contribution from multiple scattering.

The trigger had two levels, a hardware trigger and the FAMP trigger, which have been described in Refs.[3] and [6]. The FAMP reconstruction takes on average 800 μs . Compared to an interaction trigger as in Ref.1, the trigger is expected to enrich the event sample by about a factor 12 in D_s and Λ_c events (defined as the enrichment factor due to the trigger), and to increase the sensitivity (defined as number of events per unit time) for D_s and Λ_c by about a factor 3.

In 1985, $6.3 \cdot 10^6$ FAMP-triggers were collected, of which about 4% is due to incident kaons and the remainder to incident pions. The same set-up was used again in 1986 when $10.8 \cdot 10^6$ FAMP-triggers were collected.

3. DATA ANALYSIS

The aim of the data analysis is the search for charm decay vertices with or without a K^0/Λ^0 . It is carried out in five steps.

First, for all events tracks are reconstructed in the drift chambers of the large acceptance forward spectrometer.

In the second step, the beam track and all other tracks are reconstructed in the beam and vertex telescope, respectively. The reconstruction of the tracks is made independently of the drift chamber track information. Then, the drift chamber tracks and the tracks in the vertex telescope are matched. Unassociated drift chamber tracks are used as a loose guidance in an attempt to recover tracks out of complex clusters of signals in the vertex telescope. Particle identification is made using the information of the Cerenkov hodoscopes. The reconstruction of the primary vertex is performed using all tracks found except tracks with a large impact parameter (the distance of closest approach in space of a track to the primary vertex), i.e. with a probability of less than 1% for belonging to the primary vertex. Figures 2a and 2b show the calculated error distributions in x , y and z of the fitted primary vertices (x/y is the horizontal/vertical coordinate, z is along the beam axis). Figure 3 shows the measured impact parameter distribution of all tracks. It has been checked that the error distributions correspond to properly normalized χ^2 distribution.

The third step selects events which have a primary vertex inside the Cu target and a candidate for a secondary vertex for reduction of the data sample, and amounts to a loose preselection of charm decays. Candidate events should have at least two tracks not originating from the primary vertex (as defined under step two) or contain one such a track and a V^0 candidate reconstructed with the drift chamber track elements. The data sample is reduced by about a factor seven.

The fourth step searches for secondary vertices and selects events containing at least one good secondary vertex which is constructed from the tracks not originating from the primary vertex (as defined under step two). Further, tracks which were originally used in the fit of the primary vertex are checked for compatibility with any of the secondary vertices. Frequently, this leads to multiple interpretations of the event which are all used in the final physics analysis. These vertices should have a probability of better than 99%, for which the data sample is reduced by about a factor four. The calculated precision of the distance between primary and secondary vertices is shown in Fig. 4, which corresponds again to a properly normalized χ^2 distribution.

In the last step, the secondary vertices are scanned for fully reconstructed charm decays by checking all combinations compatible with the particle identification. Also "wrong sign" combinations are formed for background studies. Decay channels with K^0 or Λ^0 are studied as well. Further, special channels involving missings π^0 's are investigated. This approach of the search for secondary vertices enables us to discover some rare decay modes which have not been observed before [14]. Secondary vertices inside the Cu target are excluded to remove possible secondary interactions. For the remaining events a final track recovery is attempted by using guidance from the available secondary vertices, and V^0 's are reconstructed in the drift chambers using the secondary vertices as production points. For each combination of particles in the secondary vertex the total momentum vector of the decay track is calculated which should originate with 99% probability from the primary vertex to be kept as a valid combination. For combinations with K^0 's and Λ^0 's, this condition is replaced by an impact parameter cut of less than 50 μm with respect to the primary vertex for this vector.

For the determination of the Λ_c lifetime we only retain the $pK^-\pi^+$ (and c.c) combinations.

4. RESULTS

The results presented are based on $16.7 \cdot 10^6$ FAMP triggers. Figure 5 shows the invariant mass distribution of the $pK^-\pi^+$ (and c.c) system as obtained from the analysis chain described above. We observe a signal of 166 events within 3σ of the Λ_c mass and a background of 230 events in the mass range from 2.1-2.5 GeV outside the signal. The

estimated background under the signal is 31 events, hence we have about 135 raw Λ_c events. For the analysis of a particular decay channel, the rather loose cuts of the general data analysis are further adjusted. In the present case, the purpose is to obtain a bias-free measurement of the lifetime of the Λ_c for which the removal of background is essential. A serious source of background are reflections from the decay channels $D_S^\pm \rightarrow K^+K^-\pi^\pm$ and $D^\pm \rightarrow K^+K^-\pi^\pm$ which occur due to ambiguities in the identification of p and K. These events are removed from the sample. Reflections due to $D^\pm \rightarrow K^\pm\pi^+\pi^\mp$ are not present due to the negligible ambiguity between proton and pion. The following cuts are further tightened to improve the signal/background ratio :

- We require a displacement for the impact parameter of more than 3σ with respect to the primary vertex (see Fig. 3) for at least two of the decay tracks, and 1σ for the third decay track,
- We require a minimum separation of $3\sigma_{\Delta z}$ between primary and secondary vertex (see Fig. 4).

For the extraction of the lifetime from the data, we have to correct for the acceptance of the selection criteria [15]. For each event we determine individually the minimum and maximum detectable lifetime, $t_{\min}$ and $t_{\max}$, respectively. This is done by "swimming" the decay configuration of the secondary vertex backwards and forwards, respectively, along the straight line connecting the primary and secondary vertex keeping all other parameters of the event fixed. The minimum and maximum positions, $l_{\min}$ and $l_{\max}$ respectively, along this line, where the event fails the imposed cuts, determine $t_{\min}$ and $t_{\max}$. In particular $t_{\max}$ is defined by the maximum position up to which events are accepted, i.e. the position of CCD2. As discussed in Ref.[15], we fit the distribution of corrected lifetimes, $t_{\text{cor}}/\tau = (t_{\text{meas}} - t_{\min})/\tau$, where τ is the mean lifetime. We have checked with a Monte Carlo program that the acceptance of the events over the decay volume between $l_{\min}$ and $l_{\max}$ does not affect the lifetime. We perform a combined maximum likelihood fit to the mass and corrected lifetime distributions for signal and background, where the lifetime distribution of the background is also taken to be exponential. For the mass spectrum we assume a gaussian signal on a linear background. where the width is obtained from the calculated mass resolution of each event. Figure 6 shows the invariant mass spectrum of the Λ_c sample which is used for the lifetime analysis. Figures 7 and 8 show the decay length and the corrected lifetime distributions for the Λ_c signal and the background, respectively. The fit yields for the Λ_c baryon

$$\tau = 1.96 \pm_{0.20}^{0.23} 10^{-13} \text{ s.}$$

whereas the background has a lifetime of $5.5 \pm_{0.7}^{0.8} 10^{-13} \text{ s}$. We have 108 events within 3σ of the Λ_c mass and a background of 75 events in the mass interval from 2.1 to 2.5 GeV. The es-

estimated background under the signal is 7 events. It should be noted that the background is mainly arising from charm decays with ambiguous particle identification and/or missing neutrals due to our topological search for secondary vertices. The fitted mass is 2285.6 ± 1.1 MeV, but we have not yet calibrated the absolute mass scale. However, Figs. 5 and 6 show the excellent mass resolution of the experiment due to the precision of the vertex telescope of CCDs and MSDs.

In order to study possible sources of systematic errors we have varied the cuts which determine our selection criteria. In particular, a wrong determination of $t_{\min}$ would introduce a serious bias in the lifetime measurement. Figure 9 shows the Λ_c lifetime as a function of a cut on the minimum distance $\Delta z_{\min}$ between the primary and secondary vertex. Our quoted lifetime is the value at $\Delta z_{\min} = 0$ mm. From $\Delta z_{\min} = 3$ mm onwards $t_{\min}$ is exclusively determined by the $\Delta z_{\min}$ cut and not by the $3 \sigma_{\Delta z}$ requirement. The variation of various other cuts is shown in Fig. 10 and explained in Table 1. Our quoted value is that at A. None of the various cuts yields a value for the lifetime which is different within our statistical errors from the quoted value. Figures 9 and 10 do not show evidence for a systematic error. We also check for effects of the distortion of tracks due to the use of a wrong hit in a CCD which may occur if the minimum distance between any two decay tracks is less than $50 \mu\text{m}$ in a CCD. Even the $50 \mu\text{m}$ cut in the CCDs has a negligible effect, whereas a Monte Carlo estimate yields an effect of at most a decrease of $0.04 \cdot 10^{-13}\text{s}$ in the lifetime.

We are still analysing the lifetime of $D_s^\pm$, $(\bar{D})^0$ and $D^\pm$. These require a careful study of the relative efficiency for reconstruction of events in the regions between target and CCD1, between CCD1 and CCD2, and CCD2 up to the first MSD. This is not important for the Λ_c lifetime. Figure 11 shows a calculation of the decay length distribution of Λ_c for three values of the Λ_c momentum. The data have a momentum distribution with an average value of 70 GeV. Only Λ_c particles with very high momenta in the tail of the distribution can reach beyond CCD1. Table 1 shows that only very few events (including background) are present in this region. We might lose at most a single event which for a momentum of 150 GeV would decrease the lifetime by at most $0.07/0.05 \cdot 10^{-13}\text{s}$, which is well within our statistical error. If we fix the lifetime of the background events artificially to zero, we obtain a Λ_c lifetime of $2.00 \pm_{0.20}^{0.23} \cdot 10^{-13}\text{s}$ which corresponds to a shift well within the statistical error. This shows that the presence of a few background events under our Λ_c signal does not affect our result. We conclude, that the systematic error on the Λ_c lifetime is negligible with respect to the statistical errors.

5. CONCLUSION

Our results agree well with previous results (Refs.[8]-[13]) within statistical error. We also have reanalysed our partial data samples used for our earlier publications (Refs.[6] and [7]) with our latest improved analysis program. The results are entirely compatible with the numbers given there for the Λ_c lifetime within statistical error. These numbers and our present result are in excellent statistical agreement.

The measured lifetime of the Λ_c baryon is $1.96^{+0.23}_{-0.20} \cdot 10^{-13} \text{s}$.

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Table 1.

The Λ_c lifetime for various values of the parameters of the cuts

Cut	impact parameter of decay tracks w.r.t. prim. vertex greater than $n\sigma$ n_1, n_2, n_3	probability that total momentum vector orig- inates from prim. vertex [%]	decay volume between target and	50 μm cut in CCD	τ_{Λ_c} [10^{-13}s]	# of Λ_c events	# of back- ground events
A	3,3,1	> 99	CCD2	no	$1.96 \pm_{0.20}^{0.23}$	108	75
B	3,3,1	> 99.9	CCD2	no	$2.06 \pm_{0.21}^{0.24}$	98	46
C	3,3,2	> 99	CCD2	no	$2.00 \pm_{0.22}^{0.25}$	90	57
D	3,3,3	> 99.9	CCD2	no	$1.89 \pm_{0.21}^{0.25}$	84	51
E	5,5,5	> 99.9	CCD2	no	$1.84 \pm_{0.22}^{0.26}$	72	38
F	3,3,1	> 99.9	CCD1	no	$2.04 \pm_{0.23}^{0.28}$	101	59
G	3,3,1	> 99.9	CCD1	no	$2.03 \pm_{0.23}^{0.28}$	97	39
H	3,3,1	> 99.9	CCD1	yes	$2.04 \pm_{0.28}^{0.37}$	84	31

Figure Captions

- Fig. 1 Side view of the vertex detector.
B1-B7 : silicon microstrip detectors for reconstruction of beam; T : 2.5 mm Cu-target; CCDs : charge-coupled devices; I : interaction counter; V1-V8 : silicon microstrip detectors (orientations shown are with respect to horizontal plane).
- Fig. 2 Error distributions of the fitted primary vertices (z-axis is beam direction).
- Fig. 3 Impact parameter distribution of all tracks with respect to primary vertex (non-pre-selected data).
- Fig. 4 Distribution of errors on decay lengths.
- Fig. 5 Raw invariant mass distribution of the $pK^-\pi^+$ and $\bar{p}K^+\pi^-$ system.
- Fig. 6 Invariant mass distribution of the $pK^-\pi^+$ and $\bar{p}K^+\pi^-$ system after all cuts for determination of the Λ_c lifetime.
- Fig. 7 Decay length (a) and corrected lifetime (b) distribution for the Λ_c signal.
- Fig. 8 Decay length (a) and corrected lifetime (b) distribution for the background.
- Fig. 9 The Λ_c lifetime and number of Λ_c events as function of the $\Delta z_{\min}$ cut.
- Fig. 10 The Λ_c lifetime and number of Λ_c events for the variation of various cuts listed in Table 1.
- Fig. 11 Decay length distribution of Λ_c for a Λ_c momentum of 50, 100 and 150 GeV.

Fig. 1

Fig. 2

Fig. 3

Fig. 4

Fig. 5

Fig. 6

Fig. 7a/b

Fig. 8a/b

Fig. 9

Fig. 10

Fig. 11