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MEASUREMENT OF THE LIFETIME OF THE CHARMED BARYON Λ_c

The ACCMOR Collaboration

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ABSTRACT

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

We observe a distinct peak at the Λ_c mass on zero background. The lifetime of the Λ_c is determined to be $(1.4 \pm_{-0.3}^{+0.5}) \cdot 10^{-13}$ s based on a sample of 14 events.

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1. INTRODUCTION

A search for $D_s^\pm \rightarrow K^+ K^- \pi^\pm$, $\Lambda_c \rightarrow p K^- \pi^+$ and $\bar{\Lambda}_c \rightarrow \bar{p} K^+ \pi^-$ was started with the ACCMOR spectrometer in 1985. It is a continuation of the NA32 experiment [1] with a modified target and vertex detector. For the first time charge-coupled devices, CCDs [2], are used as vertex detectors. They provide 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 a sample of fully reconstructed Λ_c decays out of part of the triggers collected in 1985. More data were taken in 1986.

2. EXPERIMENT

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

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

A short 2.5 mm Cu target is used so that secondary vertices can be observed close to the primary vertex. The decay region extends from the downstream end of the target to the front side of the first CCD, 10 mm behind the target. This allows the observation of secondary decay vertices in air without background from secondary interactions. A second CCD is positioned 10 mm downstream of the first CCD. The CCDs 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 illustrated in Fig. 2. The beam profile is made narrow vertically (FWHM $\approx 300 \mu\text{m}$) and wide horizontally (FWHM $\approx 8 \text{ mm}$), illuminating the region of the CCDs shown. During the beam burst, the charge transfer gates are clocked continuously at about 1.4 MHz. The charges deposited by the beam particles traversing the CCDs are shifted upwards in CCD1, downwards in CCD2, and are

eventually dumped at the output node. 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} . On acceptance of a trigger the fast shifting continues for about $200 \mu\text{s}$. The signals from the triggering event, shown as crosses in Fig. 2, are shifted into "parking areas" at which stage the fast shifting stops. The beam is turned off with a kicker magnet within $\sim 1 \text{ ms}$ until the readout is finished. The data of the pixels in the parking area (1/3 of the detector nearest to the output register) are now read out at a clock rate of 3 MHz under background-free conditions. The total readout time is about 15 ms. It has been reduced by two orders of magnitude compared with the earlier tests [2].

In addition to the CCDs, a telescope of 8 silicon microstrip detectors with capacitive charge division readout is used for high precision vertex reconstruction. The main characteristics of these detectors are summarized in Table 1. With this setup the impact parameter of a track (dx, dy : minimal projected distance of a track from the primary vertex) is measured with a precision of $\sigma_{dx} \approx \sigma_{dy} \approx (5^2 + (\frac{18}{p})^2)^{1/2} \mu\text{m}$ where the momentum dependent term (p is measured in GeV/c) is the contribution from multiple scattering. The primary vertex is determined with a precision of $\sigma_x \approx \sigma_y \approx 2 \mu\text{m}$ and $\sigma_z \approx 60 \mu\text{m}$. Figure 3 shows the measured primary vertex z -distribution for a sample of events. The smearing of the edge of the target is consistent with the quoted precision.

The trigger has two levels and uses various components of the spectrometer. The first level trigger uses a scintillator interaction counter together with the geometrical correlation between elements of two scintillation counter arrays, MA and MB, with cells of the Cerenkov hodoscopes C2 and C3, respectively. The coincidences $MA \bullet \overline{C2}$ and $MB \bullet \overline{C3}$ select events with at least two particles of opposite charge below the threshold of C2 and C3 (π -threshold 6.5 GeV/c and 12 GeV/c for C2 and C3, respectively). At the second trigger level the FAMP microprocessor system determines the momenta of all particles satisfying the hardware trigger. It uses the hit pattern of five proportional chamber planes which have wire orientations of $\pm 7^\circ$, $\pm 7^\circ$ and 0° with the vertical, respectively, and the field integrals of the spectrometer magnets, assuming that the particles originate from the target. It checks whether the selected particles have momenta in the range of the Cerenkov thresholds compatible with kaons and protons, thus rejecting first level triggers from pions below threshold.

The FAMP reconstruction takes on average 800 μ s. 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, $5.8 \cdot 10^6$ FAMP-triggers were collected, of which about 4% is due to incident kaons and the remainder to incident pions. The same setup was used again in 1986 when $10.5 \cdot 10^6$ FAMP-triggers were collected.

3. DATA ANALYSIS

For all events tracks are reconstructed in the drift chambers and particle identification is performed. These tracks are then used to guide the pattern recognition in the silicon telescope. The secondary vertex search is restricted to those track combinations of $pK^- \pi^+$ (or $\bar{p}K^+ \pi^-$) with an invariant mass between 2.1 and 2.42 GeV/c², where both kaon and proton are identified in the Cerenkov counters. Approximately one third of the events satisfies these two conditions.

The following criteria are applied for the selection of Λ_c candidates:

- the event must be incompatible with a single vertex hypothesis.
- a good fit is required to a secondary vertex separated from the primary vertex by more than 1 mm, and located downstream of the end of the target and upstream of the first CCD.
- the momentum sum of the Λ_c decay products should point back to the primary vertex.
- the decay tracks must not point back to the primary vertex. The impact parameters are required to be greater than 3σ for two of the tracks and greater than 2σ for the third, where the impact parameter is the distance of closest approach to the primary vertex and σ the error on this distance.
- all decay tracks should have at least one hit in the CCDs.
- events with additional tracks consistent with belonging to the decay vertex and not to the primary vertex are rejected.

Figure 4 shows an event containing a decay of $\Lambda_c \rightarrow pK^-\pi^+$. The primary interaction point and secondary decay vertex with associated tracks are clearly visible. The tracks are reconstructed from the hit pattern in drift chambers, vertex microstrip detectors and CCDs. In Fig. 4a the tracks are shown projected into the y-z plane together with the projected CCD hits (x). Even though the density of background hits in this projection appears to be rather high and a possible source of confusion, they are well separated in the x-y plane from the track hits (Fig. 4b). The decay tracks are an identified proton of 27.2 GeV/c, an identified K^- of 26.4 GeV/c, and an identified π^+ of 20.4 GeV/c. The mass of the $pK^-\pi^+$ system is $(2285 \pm 3) \text{ MeV}/c^2$. The decay distance is $(1.9 \pm 0.2) \text{ mm}$ corresponding to a lifetime of $2.0 \cdot 10^{-13} \text{ s}$. The decay has a Feynman $x_F = 0.31$. The impact parameters of the three decay tracks are $(33 \pm 6) \mu\text{m}$, $(47 \pm 6) \mu\text{m}$ and $(29 \pm 6) \mu\text{m}$ with respect to the primary vertex, and $(6 \pm 6) \mu\text{m}$, $(3 \pm 6) \mu\text{m}$ and $(8 \pm 6) \mu\text{m}$ with respect to the secondary vertex for K^- , p and π^+ , respectively.

4. RESULTS

The results presented here are based on $2.9 \cdot 10^6$ FAMP triggers. Figure 5a shows the invariant mass distribution of the $pK\pi$ system with the appropriate charge combination for Λ_c and $\bar{\Lambda}_c$. Three decays which have an ambiguous particle identification and are compatible with $D_s/D \rightarrow KK\pi$ are shown hatched, but removed for the lifetime determination of the Λ_c . We observe a distinct signal of 14 events around the Λ_c mass and 1 possible background event at a mass of $2215 \text{ MeV}/c^2$ with a very large mass error $\Delta m = 32 \text{ MeV}/c^2$. For all the other events the mass error is around $\Delta m = 4 \text{ MeV}/c^2$. Ten decays are $\Lambda_c \rightarrow pK^-\pi^+$ and four are $\bar{\Lambda}_c \rightarrow \bar{p}K^+\pi^-$. Figure 5b shows the distribution of decay lengths for the Λ_c decays. In order to extract the lifetime from the data, we have to correct for the acceptance of the selection criteria [6]. Figure 5c shows the distribution of the corrected lifetime for the Λ_c decays.

A maximum likelihood fit to these distributions yields the mass and lifetime of the Λ_c particle. We obtain a Λ_c mass of $(2285.6 \pm 1.1) \text{ MeV}/c^2$. The error in the mass is purely statistical. While we see no evidence for any systematic shifts in the mass scale, the systematic error is still under investigation. The lifetime of the Λ_c is $(1.4 \pm_{0.3}^{0.5}) \cdot 10^{-13} \text{ s}$. Varying the cuts we obtain an estimate of the systematic error of about $\pm 0.3 \cdot 10^{-13} \text{ s}$. Figure 5d shows the x_F distribution (not corrected for acceptance) of these events. All events originate from incident π^- beam particles.

5. SUMMARY

We have observed ten $\Lambda_c \rightarrow pK^- \pi^+$ and four $\bar{\Lambda}_c \rightarrow \bar{p}K^+ \pi^-$ decays. The measured lifetime of the Λ_c baryon is $(1.4 \pm_{0.3}^{0.5} \pm 0.3) \cdot 10^{-13} \text{ s}$. This is slightly shorter than previously measured by other experiments [7,8].

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Table 1 : The Vertex Microstrip Detectors

strip orientation (with horizontal)	14°	-14°	0°	90°
# planes	3	3	1	1
# strips/plane		1200		1200
strip pitch (μm)		20		20
# readout strips/plane		240		384
readout strip pitch inner (outer) region (μm)		60 (120)		60
precision for isolated tracks inner (outer) region (μm)		4.5 (7.8)		4.5
precision for close tracks inner (outer) region (μm)		17 (35)		17

Figure captions

Fig. 1 : Layout of target, beam and vertex detectors.

B1-B7	=	silicon microstrip detectors for reconstruction of beam tracks (orientations with respect to horizontal plane),
V1-V8	=	silicon microstrip detectors for reconstruction of primary interaction and decay vertices (orientations with respect to horizontal plane),
T	=	2.5 mm Cu target,
CCDS	=	charge-coupled devices (detail in insert, cooled to 180°K with nitrogen gas),
I	=	interaction counter.

Fig. 2 : Readout scheme of CCDs.

Fig. 3 : Z-distribution of the primary vertex for a sample of $\sim 120,000$ events. The dashed lines show the edges of the Cu target.

Fig. 4 : An event containing the decay of $\Lambda_c \rightarrow pK^- \pi^+$.

- The tracks and CCD hits (x) are projected into the y-z plane. The three decay tracks are labelled with their particle identity.
- The tracks and CCD hits (o CCD1, Δ CCD2) are projected into the x-y plane (front view). The solid symbols are the used CCD hits. Note that in this projection the ratio of the distances of the CCD hits from the vertex is constant and equal to the ratio of the z-separations of the two detectors from the vertex.

Fig. 5 : a) Invariant mass distribution of the $pK^- \pi^+$ and $\bar{p}K^+ \pi^-$ system. Hatched events are ambiguous with $D_s/D^\pm \rightarrow K^+ K^- \pi^\pm$ and are excluded for the lifetime determination.

- Distribution of decay lengths for the $\Lambda_c / \bar{\Lambda}_c$ decays.
- Distribution of corrected lifetime for the $\Lambda_c / \bar{\Lambda}_c$ decays.
- Feynman x_F distribution for the Λ_c decays (hatched) and $\bar{\Lambda}_c$ decays.

Fig.1

Fig. 2

Fig.3

Fig.5