Measurement of the Λ_c^+ Lifetime

J. C. Anjos,[3] J. A. Appel,[5] A. Bean,[1] S. B. Bracker,[8] T. E. Browder,[1] L. M. Cremaldi,[4] J. R. Elliott,[4],[a] C. O. Escobar,[7] P. Estabrooks,[2] M. C. Gibney,[4] G. F. Hartner,[8] P. E. Karchin,[1],[b] B. R. Kumar,[8] M. J. Losty,[6] G. J. Luste,[8] P. M. Mantsch,[5] J. F. Martin,[8] S. McHugh,[1] S. R. Menary,[8] R. J. Morrison,[1] T. Nash,[5] U. Nauenberg,[4] P. Ong,[8] J. Pinfold,[2] G. Punkar,[1] M. V. Purohit,[5] J. R. Raab,[1],[c] A. F. S. Santoro,[3] J. S. Sidhu,[2],[d] K. Sliwa,[5] M. D. Sokoloff,[5],[e] M. H. G. Souza,[3] W. J. Spalding,[5] M. E. Streetman,[5] A. B. Stundžia,[8] and M. S. Witherell[1]

(The Tagged Photon Spectrometer Collaboration)

[1]*University of California, Santa Barbara, Santa Barbara, California 93106*
[2]*Carleton University, Ottawa, Ontario, Canada K1S 5B6*
[3]*Centro Brasileiro de Pesquisas Fisicas, Rio de Janeiro, Brazil*
[4]*University of Colorado, Boulder, Colorado 80309*
[5]*Fermi National Accelerator Laboratory, Batavia, Illinois 60510*
[6]*National Research Council, Ottawa, Ontario, Canada K1A 0R6*
[7]*Universidade de São Paulo, 01000 São Paulo, Brazil*
[8]*University of Toronto, Toronto, Ontario, Canada M5S 1A7*
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We observe 97 decays of the charmed baryon, the Λ_c^+, into a $pK^-\pi^+$ final state in a Fermilab photoproduction experiment. The mass is measured to be $2286.2 \pm 1.7 \pm 0.7$ MeV/c^2. The positions of the production and decay vertices are reconstructed with the use of a silicon microstrip vertex detector. From these measurements, we determine the lifetime of the Λ_c to be $(0.22 \pm 0.03 \pm 0.02) \times 10^{-12}$ s.

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The properties of charmed baryons have not been well determined. Past measurements of the Λ_c lifetime[1,2] suggest a higher hadronic decay rate than for charmed meson states. A W-exchange mechanism allowing $cd \rightarrow su$ could account for this increased rate.[3] The usual helicity suppression inhibiting this mechanism in mesons can be relieved by the presence of the extra quark in this baryon state. This Letter presents a measurement of the Λ_c^+ lifetime from a photoproduction experiment using the Fermilab Tagged Photon Spectrometer. The analysis is similar to that used for our previously reported measurements of the D^0, D^+, and D_s^+ lifetimes.[4,5]

The Fermilab Tagged Photon Spectrometer is a large-acceptance two-magnet spectrometer equipped with silicon microstrip detectors, drift chambers, Čerenkov counters, and electromagnetic and hadronic calorimeters. The spectrometer has been described elsewhere.[5] A 90–260-GeV bremsstrahlung photon beam (the average photon energy is 145 GeV) is directed into a 5-cm-long beryllium target. The photoproduced charm states are detected and their decays reconstructed. The trigger requires a total transverse energy deposition in the calorimeters of at least 2.2 GeV and is highly efficient for charm. The present results are based on an analysis of our total data sample of 10^8 events.

To extract the lifetime of the Λ_c we use those decays identified as $\Lambda_c^+ \rightarrow pK^-\pi^+$ and its charge conjugate. Events are selected on the basis of Čerenkov identification probabilities and vertex information. Combinations of three particles satisfying a joint $pK^-\pi^+$ Čerenkov particle-identification probability of 50% or greater are selected. This requirement minimizes confusion from D^+ and D_s^+ decays in which one of the decay products is misidentified. We demand that the three charged tracks form a good vertex and that the line of flight of the reconstructed charm candidate pass within 80 μm of a reconstructed primary vertex candidate. The primary interaction vertex is required to lie within the beryllium target and the secondary decay vertex must be located before the first silicon microstrip detector plane. Charm candidates are selected from events in which the secondary decay vertex is located at least a distance $L_{\min}$ downstream of the primary vertex position. The distance $L_{\min}$ chosen for this analysis is 8σ, where σ is the error (typically 300 μm) on the distance between the primary and secondary vertices. About 20% of the events have multiple primary-vertex candidates. In those cases $L_{\min}$ is calculated from the most downstream candidate, to insure that it is downstream of any possible production point and does not modify the exponential decay distribution. An adjusted proper time, $t = T - T_{\min}$, is calculated from the point a distance $L_{\min}$ downstream of the selected primary vertex position to the observed decay vertex position, $t = (L_{\text{decay}} - L_{\min})/c\beta\gamma$.

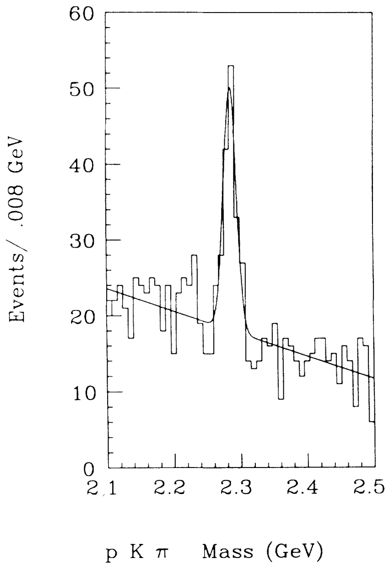

FIG. 1. $pK^-\pi^+$ mass distribution after analysis cuts. A Gaussian signal and linear background are superimposed.

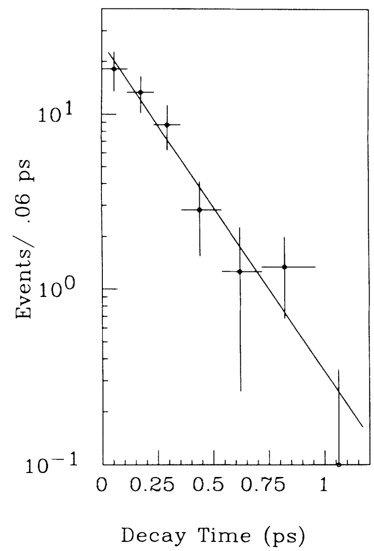

FIG. 2. Spectrum of decay time t for Λ_c events after background subtraction. The curve represents the best lifetime fit as described in the text.

The function

$$Nf(t)(1/\tau)\exp(-t/\tau)+B(t)$$

is used to fit the adjusted proper time distribution. In this expression $B(t)$ is the normalized time distribution for the background as determined from the regions of the mass plot excluding the Λ_c^+ mass region. We have chosen 2100–2255 and 2315–2500 MeV/c^2 for the background mass intervals below and above the Λ_c signal region. The signal region used is 2265–2305 MeV/c^2. The two parameters allowed to vary in the fit are N, the number of events in the charm signal, and τ, the charm lifetime. The function $f(t)$, the acceptance correction function, is obtained from a Monte Carlo simulation of charm production and the detector. It includes multiple scattering, energy loss, secondary interactions, and the full complement of detector components. The Monte Carlo program makes corrections for absorption, acceptance, resolution, and efficiency. These corrections produce about a 5% effect on the measured lifetime.

The $pK^-\pi^+$ invariant-mass distribution is shown in Fig. 1. A Gaussian fit to the signal and a linear fit to the background yields 97 ± 14 signal events over a background of 91 events. The signal width is consistent with a Monte Carlo signal width of 9.6 MeV/c^2. The uncorrected result for the mass is 2285.6 ± 1.7 MeV/c^2. We correct this mass for an observed shift of our measured D^+ mass of 1868.7 ± 0.3 MeV/c^2 with respect to the reported world average measurement of 1869.3 ± 0.6 MeV/c^2.[1] The corrected Λ_c mass measurement is $2286.2\pm1.7\pm0.7$ MeV/c^2. The quoted systematic error is dominated by the uncertainty in the world-average D^+ mass.[1]

The background-subtracted time distribution for events in the mass region 2265.0–2305.0 MeV/c^2 is shown in Fig. 2. The maximum-likelihood fit gives a lifetime of 0.22 ± 0.03 ps. The lifetime of background events within this region is about 0.16 ps. Contamination to the $pK^-\pi^+$ from misidentified D^+ and D_s^+ decays is determined to have a negligible effect on the observed lifetime ($+0.005\pm0.005$ ps). Positive Čerenkov identification of the proton and kaon candidates practically eliminates this source of contamination. The effect of including $f(t)$ in the fit is to shift the lifetime by -0.01 ps, with an associated systematic error of ±0.01 ps. The systematic error due to the background subtraction is estimated to be ±0.02 ps. In quadrature, these errors contribute ±0.02 ps to the systematic error. All other variations of the lifetime are consistent with statistical fluctuations. The final measurement of the Λ_c lifetime is $0.22\pm0.03\pm0.02$ ps, where the first error is statistical and the second systematic.

This measured lifetime agrees with the reported world average of $0.23^{+0.08}_{-0.05}$ ps[1] and with more recent measurements.[6] With this statistically improved measurement we determine the ratio of the Λ_c lifetime to the D^0 charmed-meson lifetime measured by this experiment[4] to be $\tau(\Lambda_c)/\tau(D^0)=0.52\pm0.07\pm0.05$. This short charm lifetime supports theoretical notions about the enhanced hadronic decay rate mentioned at the beginning of this Letter and contributes to the difficulty in experimental observation of this charmed state.

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[(a)]Now at Electromagnetic Applications, Inc., Denver, CO 80226.

[(b)]Now at Yale University, New Haven, CT 06520.

[(c)]Now at CERN, Division EP, CH-1211 Genève, Switzerland.

[(d)]Deceased.

[(e)]Now at University of Cincinnati, Cincinnati, OH 45221.

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