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P.L. Frabetti et al.
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Fermi National Accelerator Laboratory
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P. L. Frabetti[a] H. W. K. Cheung[b,1], J. P. Cumalat[b], C. Dallapiccola[b,2], J. F. Ginkel[b], W. E. Johns[b,3], M. S. Nehring[b,4], E. W. Vaandering[b] J. N. Butler[c], S. Cihangir[c], I. Gaines[c], P. H. Garbincius[c], L. Garren[c], S. A. Gourlay[c], D. J. Harding[c], P. Kasper[c], A. Kreymer[c], P. Lebrun[c], S. Shukla[c], M. Vittone[c] S. Bianco[d], F. L. Fabbri[d], S. Sarwar[d], A. Zallo[d] C. Cawlfield[e], R. Culbertson[e,5], R. W. Gardner[e,6], E. Gottschalk[e], R. Greene[e,7], K. Park[e], A. Rahimi[e], J. Wiss[e] G. Alimonti[f], G. Bellini[f], M. Boschini[f], D. Brambilla[f], B. Caccianiga[f], L. Cinquini[f,8], M. Di Corato[f], P. Dini[f], M. Giammarchi[f], P. Inzani[f], F. Leveraro[f], S. Malvezzi[f], D. Menasce[f], E. Meroni[f], L. Milazzo[f], L. Moroni[f], D. Pedrini[f], L. Perasso[f], F. Prelz[f], A. Sala[f], S. Sala[f], D. Torretta[f] D. Buchholz[g], D. Claes[g,9], B. Gobbi[g], B. O'Reilly[g,8] J. M. Bishop[h], N. M. Cason[h], C. J. Kennedy[h,10], G. N. Kim[h,11], T. F. Lin[h], D. L. Puseljic[h,10], R. C. Ruchti[h], W. D. Shephard[h], J. A. Swiatek[h,12], Z. Y. Wu[h,13] V. Arena[i], G. Boca[i], G. Bonomi[i], C. Castoldi[i], G. Gianini[i], M. Merlo[i], S. P. Ratti[i], C. Riccardi[i], L. Viola[i], P. Vitulo[i] A. Lopez[j], L. Mendez[j], A. Mirles[j], E. Montiel[j], D. Olaya[j,8], E. Ramirez[j,8], C. Rivera[j], Y. Zhang[j,14] J. M. Link[k], V. S. Paolone[k,15], P. M. Yager[k] J. R. Wilson[l] J. Cao[m], M. Hosack[m], P. D. Sheldon[m] F. Davenport[n] K. Cho[o], K. Danyo[o,16], T. Handler[o] B. G. Cheon[p,17], Y. S. Chung[p], J. S. Kang[p], K. Y. Kim[p], K. B. Lee[p], S. S. Myung[p]

[a] *Dip. di Fisica dell'Università and INFN - Bologna, I-40126 Bologna, Italy*

[b] *University of Colorado, Boulder, CO 80309, USA*

[c] *Fermilab, Batavia, IL 60510, USA*

[d] *Laboratori Nazionali di Frascati dell'INFN, I-00044 Frascati, Italy*

[e] *University of Illinois at Urbana-Champaign, Urbana, IL 61801, USA*

[f] *Dip. di Fisica dell'Università and INFN - Milano, I-20133 Milan, Italy*

[g] *Northwestern University, Evanston, IL 60208, USA*

[h] *University of Notre Dame, Notre Dame, IN 46556, USA*

[i] *Dip. di Fisica Nucleare e Teorica dell'Università and INFN - Pavia, I-27100 Pavia, Italy*

[j] *University of Puerto Rico at Mayaguez, Puerto Rico*

[k] *University of California-Davis, Davis, CA 95616, USA*

[l] *University of South Carolina, Columbia, SC 29208, USA*

[m] *Vanderbilt University, Nashville, TN 37235, USA*

[n] *University of North Carolina-Asheville, Asheville, NC 28804, USA*

[o] *University of Tennessee, Knoxville, TN 37996, USA*

[p] *Korea University, Seoul 136-701, Korea*

Abstract

New measurements of the lifetime and mass of the Ξ_c^+ are presented. The Ξ_c^+ has been reconstructed through the two decay channels $\Xi^-\pi^+\pi^+$ and $\Sigma^+K^-\pi^+$. The data were accumulated by the Fermilab high energy photoproduction experiment E687. The lifetime is measured to be $0.34^{+0.07}_{-0.05}$ $(stat.) \pm 0.02$ $(syst.)$ ps while the mass is measured to be 2465.8 ± 1.9 $(stat.) \pm 2.5$ $(syst.)$ MeV/c^2.

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[1] Present address: Fermilab, Batavia, IL 60510, USA
[2] Present address: University of Maryland, College Park, MD 20742, USA
[3] Present address: University of South Carolina, Columbia, SC 29208, USA
[4] Present address: Vanderbilt University, Nashville, TN 37235, USA
[5] Present address: E. Fermi Inst., University of Chicago, Chicago, IL 60637, USA
[6] Present address: Indiana University, Bloomington, Indiana, IN 47405, USA
[7] Present address: Wayne State University, Detroit MI 48202, USA
[8] Present address: University of Colorado, Boulder, CO 80309, USA
[9] Present address: University of New York, Stony Brook, NY, 11794, USA
[10] Present address: AT&T, West Long Branch, NJ 07765, USA
[11] Present address: Pohang Accelerator Laboratory, Pohang, Korea
[12] Present address: Science Applications Inter. Corp., McLean, VA 22102, USA
[13] Present address: Gamma Products Inc., Palos Hills, IL 60465, USA
[14] Present address: Lucent Technologies, Lisle, IL 60532-3640, USA
[15] Present address: University of Pittsburg, Pittsburgh, PA 15260, USA
[16] Present address: Brookhaven National Laboratory, Upton, NY, 11793-5000, USA
[17] Present address: KEK, National Lab. for High Energy Physics, Tsukuba 305, Japan

We report a new measurement of both the lifetime and the mass of the charm-strange baryon Ξ_c^+. An improved measurement of the lifetime of the Ξ_c^+ may help to discriminate among theoretical models that incorporate strong interaction effects in charm decay [1]. The data were collected in the Fermilab photoproduction experiment E687 during two run periods in 1990 and 1991. Approximately 500 million hadronic triggers were recorded on tape.

The E687 collaboration has already published a measurement of the lifetime of the Ξ_c^+ baryon using decays into $\Xi^-\pi^+\pi^+$ based on a sample of 29.7 ± 7.0 events [2]. A new sample of events decaying into $\Sigma^+K^-\pi^+$ has been reconstructed and added to the previous sample of $\Xi^-\pi^+\pi^+$ decays. Invariant mass distributions for these samples are shown in fig. 1.

A detailed description of the E687 experimental set-up can be found elsewhere [3]. The apparatus is a large aperture spectrometer capable of detecting charged hadrons produced in the interactions of a photon beam ($< E_\gamma > = 220$ GeV) with a beryllium target. High resolution tracking close to the target is provided by twelve planes of silicon microstrips in our microvertex detector (SSD). Charged particles coming out of the microvertex detector are deflected by two magnets of opposite polarity and traced by five multiwire proportional chambers (MWPC) to measure their momenta. Particle identification is provided by three multicell Čerenkov counters operating in threshold mode. Two electromagnetic calorimeters detect photons and electrons; two hadron calorimeters detect neutral hadrons and trigger on the total hadronic energy released in the interaction.

The selection of the $\Xi^-\pi^+\pi^+$ sample has been described in a previous Ξ_c^+ publication [2]. We describe here the selection of the $\Xi_c^+ \to \Sigma^+K^-\pi^+$ decays (throughout this paper, the charge conjugate state is implied whenever a decay mode of a specific charge is stated). The Σ^+ baryons can decay either into $p\pi^o(51.57\%)$ or $n\pi^+(48.31\%)$. Both channels have been studied separately and are combined together to achieve our final $\Xi_c^+ \to \Sigma^+K^-\pi^+$ sample [18] . The Σ^+ decays are reconstructed using kinematic constraints. The direction of the Σ is given by the track left in the SSD, while the momentum of the daughter track is determined from the MWPC system. For the $\Sigma^+ \to n\pi^+$ decay, an energy over predicted momentum cut of $0.3 < E/p < 1.7$ is used to reduce background contamination for neutrons. A detailed description of the Σ reconstruction may be found in previous publications [4].

Kaons and pions are reconstructed in the SSD and MWPC and the two sets of tracking parameters must agree to within measurement errors. Kaons must be positively identified by the Čerenkov system. The three microstrip tracks identifying the three particles, i.e.: Σ^+, K^-, and π^+, are required to form a secondary vertex with a confidence level (CL) larger than 2%. The seed track, constructed from the sum of the momentum vectors of the three particles, has to point to a primary vertex with $CL > 2\%$. The confidence level that any

[18] This is the first observation of the decay $\Xi_c^+ \to \Sigma^+K^-\pi^+$ through the reconstruction of the decay $\Sigma^+ \to n\pi^+$.

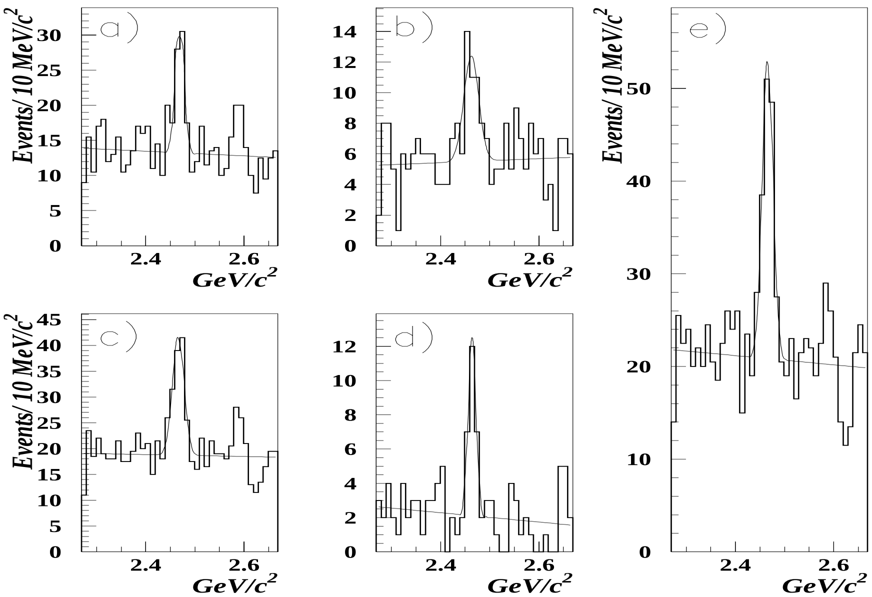

Fig. 1. Invariant mass distribution for: a) $\Sigma^+(p\pi^o)K^-\pi^+$; b) $\Sigma^+(n\pi^+)K^-\pi^+$; c) sum of the two; d) $\Xi^-\pi^+\pi^+$; e) sum of the three. These distribution were obtained with the cuts used for the mass measurement.

of the three daughter tracks, Σ^+, K^- and π^+ originates in the primary vertex is required to be less than 95%, while the confidence level that any other track could be fitted to the secondary vertex is required to be less than 0.5%. The primary isolation cut is used to remove secondary tracks that were produced in the primary vertex, while the secondary isolation cut is used to reject higher multiplicity decays. We further isolate our signal by using a *detachment parameter* l/σ_l where l is the distance between the primary and secondary vertices and σ_l is the error on this distance. The two decay channels $\Xi^-\pi^+\pi^+$ and $\Sigma^+K^-\pi^+$ have been studied separately for a series of detachment cuts ranging from $l/\sigma_l > 3.4$ to $l/\sigma_l > 4.5$ [19].

To determine the Ξ_c^+ lifetime we calculated for each candidate the *reduced proper time* t':

$$t' = \frac{l - N\sigma_l}{\beta\gamma c} \qquad (1)$$

where N is the vertex detachment cut and $\beta\gamma$ is the Lorentz boost factor. Taking S as the number of signal events in the signal mass region (defined as the region $\pm 2\sigma$ from the mass central value) and B as the total number of background events in the same region, the expected number of events n_i in

[19] The 29.7 events in ref. [2] were obtained for $l/\sigma_l > 2.5$

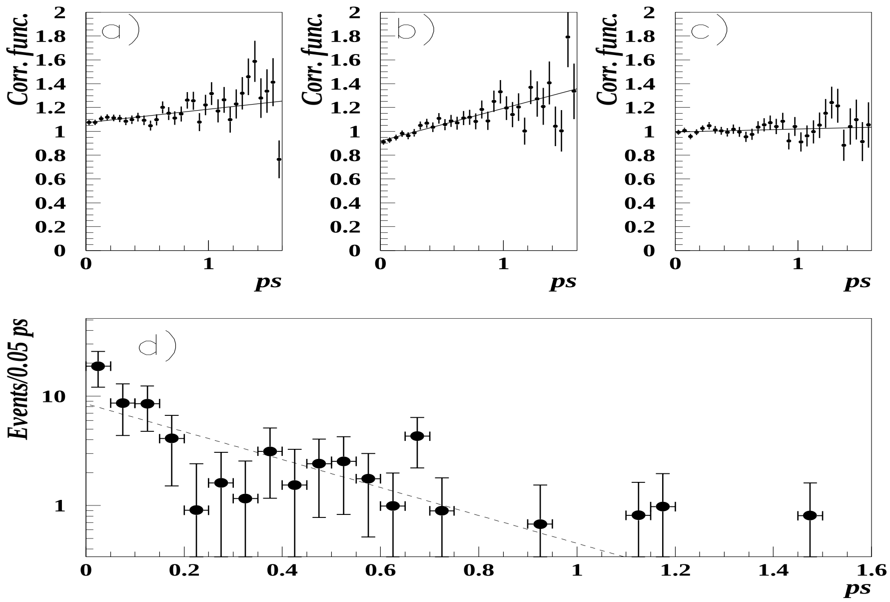

Fig. 2. Correction functions for: a) $\Sigma^+(n\pi^+)K^-\pi^+$; b) $\Sigma^+(p\pi^o)K^-\pi^+$; c) $\Xi^-\pi^+\pi^+$. d) Background subtracted, Montecarlo corrected reduced proper time distribution at $l/\sigma_l > 3.8$. The superimposed line represents the result of the fit.

the *i-th* reduced proper time bin centered at t'_i is given by [5]:

$$n_i = S\frac{f(t'_i)e^{-t'_i/\tau}}{\sum_i f(t'_i)e^{-t'_i/\tau}} + B\frac{b_i}{\sum_i b_i} \qquad (2)$$

where b_i is the number of events as measured from the mass sidebands and $f(t'_i)$ is the correction function estimated by a Monte Carlo (MC) simulation. To obtain this function the number of MC reconstructed events is divided by the value of the exponential function $e^{-t'/\tau_{MC}}$ (τ_{MC} being the MC input lifetime) for each reduced proper time bin considered. The background time evolution b_i is obtained from events in a *low* and a *high* mass sideband (10σ wide with one edge 5σ away from the central mass value and the other 15σ away) [20]. The function $f(t')$ corrects for effects due to spectrometer acceptance, cut efficiencies and absorption of the daughter particles, as a function of the reduced proper time. This function is parameterized as a first order polynomial and is used to avoid systematic effects. In Fig. 2 the correction functions for the three sub-samples obtained for $l/\sigma_l > 3.8$ are shown.

To calculate the lifetime τ and to estimate the number of background events in the signal region, we used the binned maximum likelihood method by constructing, from a Poisson distribution, the probability of observing s_i events

[20] The σ and the central values used to define the signal and sideband regions are those specific to each of the three decay channels.

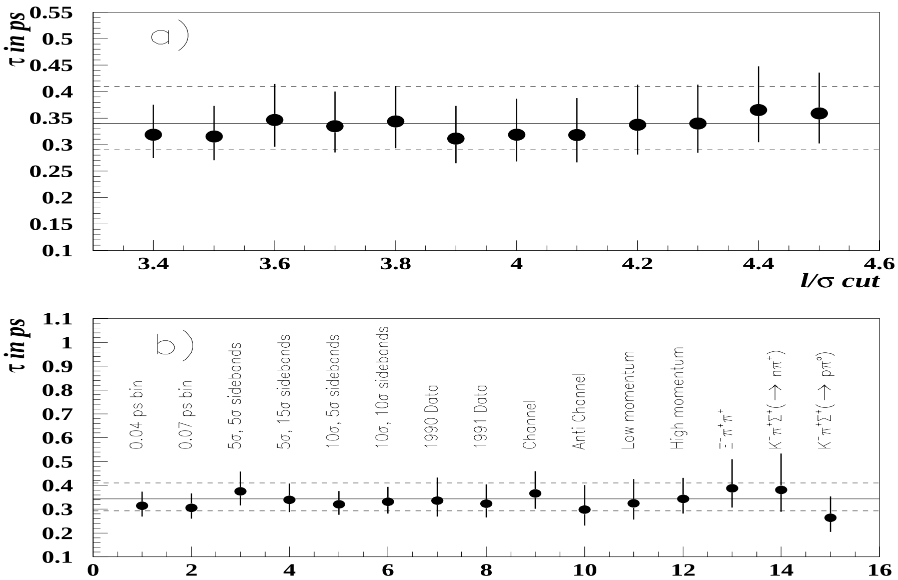

Fig. 3. a) Lifetime stability versus L/σ_l and b) lifetime measurements for systematic studies. The solid lines represent the central value and the dotted lines the statistical error at $l/\sigma_l > 3.8$.

when n_i are predicted. We added a multiplicative factor to the likelihood function to account for the Poisson probability of finding the number of observed events in the background mass sidebands when the expected number is $5B$. The factor 5 accounts for the fact that the sidebands region is 5 times wider than the signal region and the background is linear.
The likelihood takes the form:

$$\mathcal{L} = \prod_i \frac{n_i^{s_i} e^{-n_i}}{s_i!} \cdot \frac{(5B)^{\sum_i b_i} e^{-5B}}{(\sum_i b_i)!} \tag{3}$$

This likelihood function is constructed for each of the three decay modes of the Ξ_c^+. The total likelihood function is given by the product of the three likelihoods:

$$\mathcal{L} = \mathcal{L}_{\Xi^-\pi^+\pi^+} \cdot \mathcal{L}^{\Sigma^+ \to p\pi^o}_{\Sigma^+ K^-\pi^+} \cdot \mathcal{L}^{\Sigma^+ \to n\pi^+}_{\Sigma^+ K^-\pi^+} \tag{4}$$

There were four free parameters in the fit, the number of background events in each of the three decay channels and the lifetime τ. The fitting procedure was repeated for several l/σ_l cuts (see Fig. 3a). At $l/\sigma > 3.8$ we find the lifetime to be $0.34^{+0.07}_{-0.05}\,(stat.)$ ps.
Systematic effects were studied by looking at the variance in the fitted lifetime for different running conditions (1990 versus 1991), momentum regions

Table 1
Ξ_c^+ lifetime measurements

Experiment	Lifetime (ps)	Events	Year
WA62 [10]	$0.48^{+0.21\ +0.20}_{-0.15\ -0.15}$	53	1985
E400 [11]	$0.40^{+0.18}_{-0.12} \pm 0.10$	102	1987
Accmor [6]	$0.20^{+0.11}_{-0.06}$	6	1989
Previous E687 [2]	$0.41^{+0.11}_{-0.08} \pm 0.02$	30	1993
PDG (average) [12]	$0.35^{+0.07}_{-0.04}$	-	1996
This measurement (E687)	$0.34^{+0.07}_{-0.05} \pm 0.02$	56	1998

($p < 75$ GeV/c versus $p \geq 75$ GeV/c), charge states (particle versus anti-particle), decay modes ($\Xi^-\pi^+\pi^+$, $\Sigma^+(p\pi^o)K^-\pi^+$, $\Sigma^+(n\pi^+)K^-\pi^+$) and fitting methods (different bin sizes, sideband locations and widths). Adding together all the possible contributions we determine our systematic error for the lifetime measurement to be 0.02 ps. Lifetime measurements for systematic studies are shown in Fig. 3.
Our lifetime result is quoted at $l/\sigma_l > 3.8$ for a bin width of 0.05 ps using a sample of 56.0 ± 11.3 events. The value is: $\tau_{\Xi_c^+} = 0.34^{+0.07}_{-0.05}\,(stat.) \pm 0.02\,(syst.)$ ps. Fig.2d shows the background subtracted, Montecarlo corrected reduced proper time distribution for the Ξ_c^+ signal at $l/\sigma_l > 3.8$.
In Table 1 we present our value together with previously published measurements. The statistical error on our measurement is comparable to that of the previous world average.
To perform a mass measurement we chose different values for the l/σ_l, vertices confidence levels and momentum cuts for each decay mode, in order to maximize the ratio of signal to noise. We separately fitted the invariant mass distribution for the three decay modes ($\Xi^-\pi^+\pi^+$, $\Sigma^+(p\pi^o)K^-\pi^+$, $\Sigma^+(n\pi^+)K^-\pi^+$) with a Gaussian and a linear background (see Fig. 1). The width of the Gaussian was fixed to the Monte Carlo values. The results of the fits are summarized in Table 2. Combining the three independent measurements we obtained a total sample of 90.2 ± 14.0 events and a mass of $2465.8 \pm 1.9\,(stat.)$ MeV/c^2. The mass value was calculated by weighting each measurement by its statistical error. Possible systematic effects were studied by comparing the variance in the mass measurements for different running conditions (1990 versus 1991), momentum regions ($p < 75$ GeV/c versus $p \geq 75$ GeV/c), charge states (particle versus anti-particle) and fitting methods (different bin sizes and positions, log-likelihood versus χ^2 fit, background models). We determine our mass error due to systematic effects to be 2.5 MeV/c^2. The final mass measurement for the Ξ_c^+ is $2465.8 \pm 1.9(stat.) \pm 2.5(syst.)$ MeV/c^2.
In Table 3 our mass determination is compared to previous mass measurements. This latest E687 measurement supersedes the previous E687 determination.

Table 2
Ξ_c^+ mass fit results.

Mode	Mass (MeV/c^2)	Events
$\Xi^-\pi^+\pi^+$	2464.3 ± 2.8	21.2 ± 5.5
$\Sigma^+(p\pi^o)K^-\pi^+$	2468.3 ± 2.9	43.8 ± 10.2
$\Sigma^+(n\pi^+)K^-\pi^+$	2462.6 ± 5.5	25.2 ± 7.8

Table 3
Ξ_c^+ mass measurements

Experiment	Mass (MeV/c^2)	Events	Year
Accmor [6]	$2466.5 \pm 2.7 \pm 1.2$	5	1989
CLEO [7]	$2467 \pm 3 \pm 4$	23	1989
ARGUS [8]	$2465.1 \pm 3.6 \pm 1.9$	30	1990
Previous E687 [2]	$2464.4 \pm 2.0 \pm 1.4$	30	1993
CLEO [9]	$2467.0 \pm 1.6 \pm 2.0$	147	1996
PDG (fit) [12]	2465.6 ± 1.4	-	1996
This measurement (E687)	$2465.8 \pm 1.9 \pm 2.5$	90	1998

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