Submitted to EPS-HEP97, Jerusalem, 19-26 august, 1997
Parallel Session **1, 5** - Plenary Session **6, 23**

Paper n. 402

A new measurement of the mass and lifetime of the Ξ_c^+.

E687 Collaboration

P. L. Frabetti Dip. di Fisica dell'Università and INFN - Bologna, I-40126 Bologna, Italy

H. W. K. Cheung[a], J. P. Cumalat, C. Dallapiccola[b], J. F. Ginkel,
W. E. Johns[c], M. S. Nehring[d]
University of Colorado, Boulder, CO 80309, USA

J. N. Butler, S. Cihangir, I. Gaines, P. H. Garbincius, L. Garren,
S. A. Gourlay, D. J. Harding, P. Kasper, A. Kreymer, P. Lebrun,
S. Shukla, M. Vittone
Fermilab, Batavia, IL 60510, USA

S. Bianco, F. L. Fabbri, S. Sarwar, A. Zallo
Laboratori Nazionali di Frascati dell'INFN, I-00044 Frascati, Italy

R. Culbertson[e], R. W. Gardner[f], R. Greene[g], J. Wiss
University of Illinois at Urbana-Champaign, Urbana, IL 61801, USA

G. Alimonti, G. Bellini, M. Boschini, D. Brambilla, B. Caccianiga,
L. Cinquini[h], M. Di Corato, M. Giammarchi, M. Gullotta, P. Inzani,
F. Leveraro, S. Malvezzi, D. Menasce, E. Meroni, L. Moroni, D. Pedrini,
L. Perasso, F. Prelz, A. Sala, S. Sala, D. Torretta
Dip. di Fisica dell'Università and INFN - Milano, I-20133 Milan, Italy

D. Buchholz, D. Claes[i], B. Gobbi, B. O'Reilly[h]
Northwestern University, Evanston, IL 60208, USA

J. M. Bishop, N. M. Cason, C. J. Kennedy[j], G. N. Kim[k], T. F. Lin,
D. L. Puseljic[j], R. C. Ruchti, W. D. Shephard, J. A. Swiatek[l],
Z. Y. Wu[m]
University of Notre Dame, Notre Dame, IN 46556, USA

V. Arena, G. Boca, G. Bonomi, C. Castoldi, G. Gianini, M. Merlo,
S. P. Ratti, C. Riccardi, L. Viola, P. Vitulo
Dip. di Fisica Nucleare e Teorica dell'Università and INFN - Pavia, I-27100 Pavia, Italy

A. Lopez, University of Puerto Rico at Mayaguez, Puerto Rico

G. P. Grim, V. S. Paolone[n], P. M. Yager
University of California-Davis, Davis, CA 95616, USA

J. R. Wilson University of South Carolina, Columbia, SC 29208, USA

P. D. Sheldon Vanderbilt University, Nashville, TN 37235, USA

F. Davenport University of North Carolina-Asheville, Asheville, NC 28804, USA

K. Danyo[o], T. Handler University of Tennessee, Knoxville, TN 37996, USA

B. G. Cheon[p], J. S. Kang, K. Y. Kim
Korea University, Seoul 136-701, Korea

The measurement of the singly charmed baryon lifetimes with better accuracy may help to discriminate among different theoretical models [1].

We report in this paper a new measurement of both mass and lifetime of the charm-strange baryon Ξ_c^+. The data were collected in the Fermilab photoproduction experiment E687 during two run periods in 1990 and 1991. The total number of hadronic triggers recorded to tape was more than 500 millions.

Our collaboration already published a measurement of mass and lifetime of the Ξ_c^+ baryon decaying into $\Xi^-\pi^+\pi^+$ based on a sample of 29.7 ± 7.0 events [2]. We extend now our measurements to a new decay channel so that we may increase significantly our statistics. A new sample of about 50 events decaying into $\Sigma^+K^-\pi^+$ has been reconstructed and added to the previous sample of $\Xi^-\pi^+\pi^+$ decays to make a total of about 75 *candidate* events.

A detailed description of the E687 experimental setup can be found elsewhere [4]. The apparatus is a large aperture spectrometer capable of detecting charged hadrons produced in the interactions of a photon beam ($< E_\gamma > = 220$ GeV) on a beryllium target. Two electromagnetic calorimeters detect photons and electrons; two hadron calorimeters detect neutral hadrons and triggers on the total hadronic energy released in the interaction. High resolution tracking close to the target is provided by twelve planes of silicon microstrips in our microvertex detector (hereafter SSD). Particles coming out of the microvertex detector are deflected by two magnets of opposite polarity and traced by five multiwire proportional chambers (hereafter MWPC) to measure their momenta. Particle identification is provided by three multicell Cerenkov counters operating in threshold mode.

The selection of the $\Xi^-\pi^+\pi^+$ sample has already been described in a previous Ξ_c^+ publication [2]. We describe here the selection of the $\Xi_c^+ \rightarrow \Sigma^+K^-\pi^+$ 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 into $n\pi^+(48.31\%)$. Both channels have been studied separately and added to get our final $\Xi_c^+ \rightarrow \Sigma^+K^-\pi^+$ sample. A clear and detailed description of the Σ's reconstruction is included in previous publications [5].

Kaons and pions must be reconstructed in both the SSD and MWPC and the two sets of tracking parameters have to agree to within measurement errors. In addition, for kaons, we required a severe Cerenkov identification cut. 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 (hereafter CL) larger than 2%. The Ξ_c^+ candidate has to point to a primary vertex with $CL > 2\%$. The confidence level for any of the three tracks, Σ^+, K^- and π^+ to be forced into the primary vertex is required to be less than 95%, while the confidence level that any other track could be fitted into the secondary vertex is required to be less than 0.5%. The first cut (isolation cut I) is used to get rid of secondary tracks that were actually produced in the primary vertex, while the second cut (isolation cut II) is intended to reject higher multiplicity decays that could fake the secondary vertex we are searching for.

Being l the distance between the primary and secondary vertices and σ_l its error, we isolate our signal using also a *detachment parameter* defined as the inverse of the percent error, i.e.: l/σ_l. This turns out to be the principal cut parameter used to separate longer lived charm particle from non-charm background for most of our analysis. The two decay channels $\Xi^-\pi^+\pi^+$ and $\Sigma^+K^-\pi^+$ have been studied separately for a series of detachmnet cuts ranging from $l/\sigma_l > 3.4$ to $l/\sigma_l > 4.5$ [1]. This range has been choosen to maximize both the number of selected events in the signals and their signal to noise ratios.

Fig.s 1 show the invariant mass distributions for the three "channels": in fig.s 1a and 1b, the two Σ^+ sub-samples; in fig. 1c the combined Σ sample; in fig. 1d the $\Xi^-2\pi^+$ sample and finally, the whole sample in fig. 1e. Fig. 2a collects the mass values for the different $1/\sigma_l$.

We tested the possibility that other decays might contribute to the $\Xi^-\pi^+\pi^+$ invariant mass distribution. For instance, a $\Lambda_c^+ \rightarrow \Xi^-K^+\pi^+$ decay,

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[1] It is worth mentioning here that the 29.7 events in ref. [2] were obtained for $l/\sigma_l > 2.5$

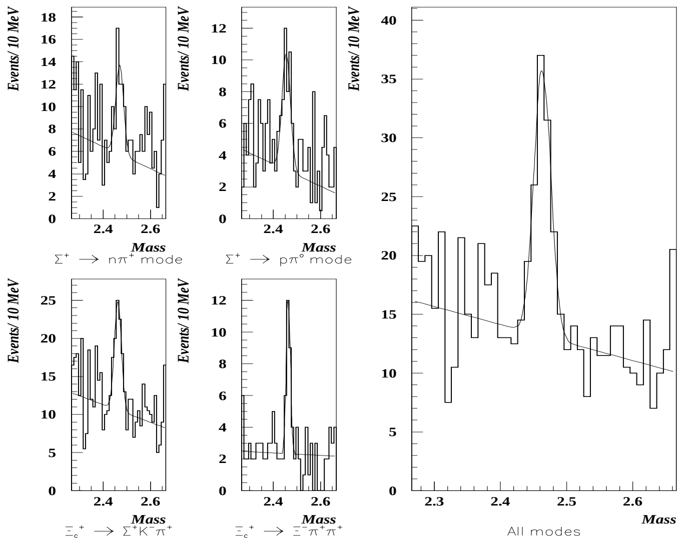

Figure 1: Mass for the 3 channels and for the total sample

with the kaon being misidentified as a π^+, can reflect into the $\Xi^-\pi^+\pi^+$ signal region. Another possibility is a missing π^o, as in the decay $\Xi_c^+ \to \Xi^-\pi^+\pi^+\pi^o$ or $\Xi_c^+ \to \Xi^-\rho^+\pi^+$ ($\rho^+ \to \pi^+\pi^o$). Montecarlo studies have shown these contributions to be negligible. We also performed some studies to check possible background contributions to the $\Xi_c^+ \to \Sigma^+K^-\pi^+$ mass plot. For instance a $\Xi_c^+ \to \Sigma^+\overline{K^{*o}}$ (with $\overline{K^{*o}} \to K^-\pi^+$) could contribute to the mass peak. A $\Lambda_c^+ \to \Sigma^+\pi^-\pi^+$ decay, with the negative pion being misidentified as a kaon, could fake the Ξ_c^+ decay we are studying. Both possibilities have been discharged.

Systematic errors have been also investigated. We separate first “fit variant” systematics from “selection” systematics and add the two contributions in quadrature. To estimate the “fit variant” uncertainty we considered ten different mass windows (each one shifted by 1 MeV) and three bin widths (10, 12 and 14 MeV) .

To estimate “selection” systematic errors we splitted our sample in the 3 *indipendent* decay channels, i.e.: $\Sigma^+(p\pi^o)K^-\pi^+$, $\Sigma^+(n\pi^+)K^-\pi^+$, $\Xi^-\pi^+\pi^+$. As a proof of mass stability also other 6 sub-samples are shown in Fig. 3, i.e:

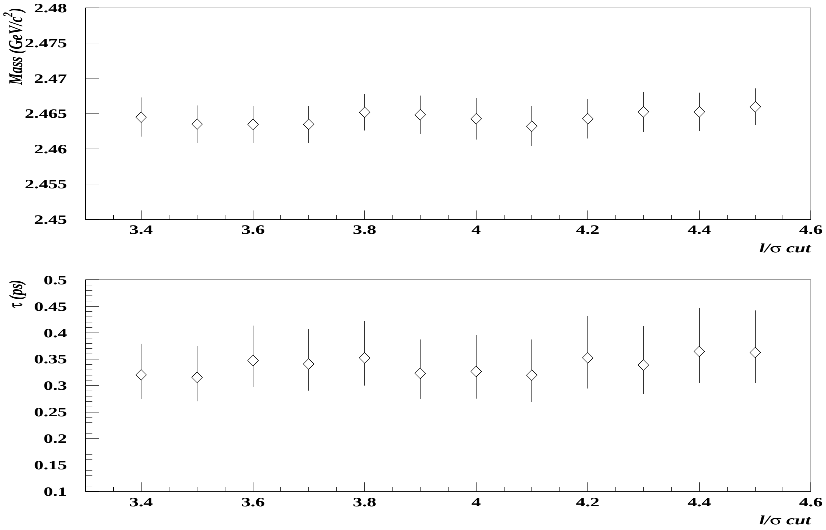

Figure 2: Mass (upper plot) and lifetime (lower plot) stability versus l/σ_l

channel, antichannel, 1990 data, 1991 data, low momentum ($p < 75\ GeV/c$), high momentum ($p \geq 75\ GeV/c$).

We quote a systematic error of $\pm 0.9(???) MeV/c^2$.

Selected at $l/\sigma_l > 3.6$, plotted with a bin width of 10 MeV/c^2 and fitted in the mass window shown in Fig. 1 we obtained a sample of 72.8 ± 11.3 events and a mass:

$$m(\Xi_c^+) = 2463.4 \pm 2.6(stat.) \pm 0.9(syst.) MeV/c^2 \qquad (1)$$

In Tab. 1 previous mass measurements are summarized and compared to our value. Although well comparable, our mass comes out somewhat lower than that of other experiments.

Using the same sample of events we also measured the Ξ_c^+ lifetime. For each candidate we calculated the *reduced proper time t'*:

$$t' = \frac{l - N\sigma_l}{\beta\gamma c} \qquad (2)$$

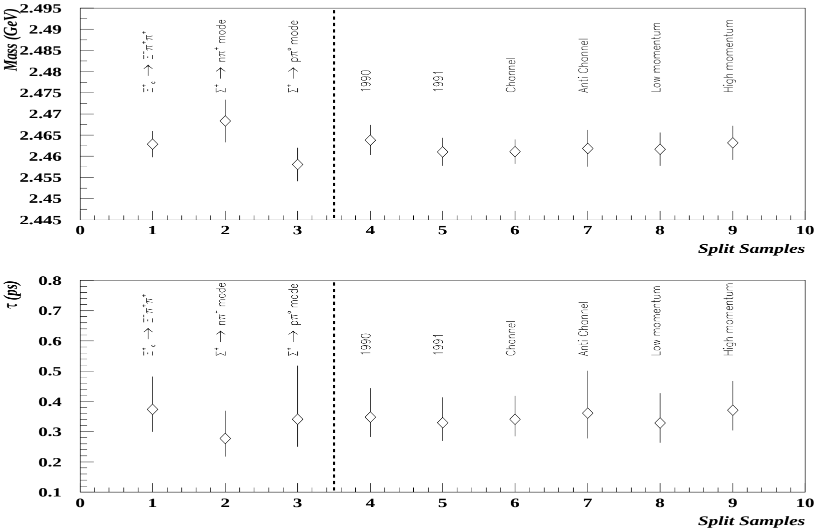

Figure 3: Mass(upper plot) and lifetime(lower plot) measurement for different sub-samples

where N is the vertex detachment cut assumed for the analysis ($N = 3.6$ for the events of Fig. 1) and $\beta\gamma$ is the Lorents boost factor. Montecarlo and data studies prove that σ_l is indipendent of l and consequently that the t' distribution for the Ξ_c^+'s is proportional to $e^{-t/\tau}$, τ being its lifetime. Assuming S as the total 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 a reduced proper time bin centered at t'_i is given by [3]:

$$n_i = S \frac{f(t'_i) e^{-t'_i/\tau}}{\sum_i f(t'_i) e^{-t'_i/\tau}} + B \frac{b_i}{\sum_i b_i} \tag{3}$$

where: b_i is the number of background events as measured from the mass sidebands and $f(t'_i)$ is the correction function estimated by a Montecarlo (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.

Experiment	Mass (MeV/c^2)	Events	Year of Pub.
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
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
PDG (average) [12]	2465.9 ± 1.4	-	1996
Our value (E687)	$2463.4 \pm 2.6 \pm 0.9$	73	1997

Table 1: Ξ_c^+ mass measurements

The background time evolution b_i is obtained from events in a *low* and a *high* mass sideband (10σ wide and 5σ away from the central mass value each). The function $f(t')$ corrects for effects due to spectrometer acceptance, analysis cut efficiencies and absorption of the daughter particles into the target, as a function of the reduced proper time. This function is parametrized as a first order polynomial and is needed to avoid an improper instrumental systematic increase of the measured lifetime. In Fig. 4 a typical correction function, obtained for $l/\sigma_l > 3.6$ and for the $\Xi_c^+ \to \Sigma^+(n\pi^+)K^-\pi^+$ decay channel, is shown. The correction functions for any l/σ_l or decay channel show the same behaviour.

To calculate the lifetime τ and to estimate the number of background events in the signal region, we used the maximum binned likelihood method by constructing, from a Poisson distrution, the probability of observing s_i events when n_i are predicted. We added a multiplicative factor to the likelihood function to take into account for the Poissonian probability of finding also the observed number of events in the background mass sidebands when the expected number is $5B$. The factor 5 accounts for the fact that the sideband region has been assumed to be 5 times wider than the signal region for a linear background.

The likelihood takes the form:

$$\mathcal{L} = \prod_i \frac{n_i^{s_i} e^{-n_i}}{s_i!} \cdot \frac{(5B)^{\sum_i b_i} e^{-5B}}{(\sum_i b_i)!} \tag{4}$$

This likelihood function has been constructed for all three decay modes of

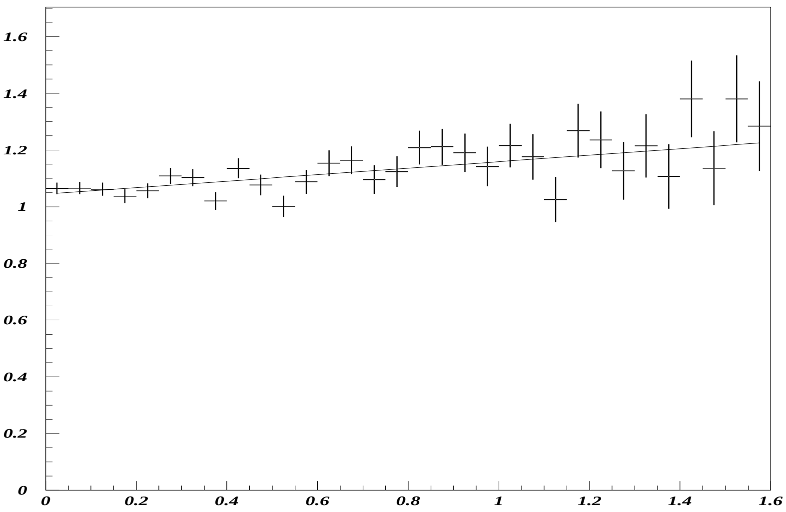

Figure 4: Correction function

the Ξ_c^+ so that the total likelihood is assumed to be the product of the three:

$$\mathcal{L} = \mathcal{L}_{\Xi^-\pi^+\pi^+} \cdot \mathcal{L}_{\Sigma^+K^-\pi^+}^{\Sigma^+\rightarrow p\pi^o} \cdot \mathcal{L}_{\Sigma^+K^-\pi^+}^{\Sigma^+\rightarrow n\pi^+} \tag{5}$$

The free parameters of the fit were 4: the lifetime τ and the number of background events for the 3 sub-decay channels. The fitting procedure has been repeated for several l/σ_l cuts (see Fig. 2b) and several sample selections, in order to investigate systematic errors.

We separated again fit variant systematics from "selection" systematics and added the two contributions in quadrature. For the fit variants we considered three different reduced proper time binning (0.04 ps, 0.05 ps and 0.07 ps), three different sideband widths and three different sideband positions. For "selection" systematics we splitted our sample into the same different sub-samples used for the mass measurement and we proceeded in the same way. In Fig. 3b the lifetime measurements for the sub-samples are shown.

Our new best estimate of the lifetime is quoted for $l/\sigma_l > 3.6$ for a bin

Experiment	Lifetime (ps)	Events	Year of Pub.
WA62 [10]	$0.48^{+0.21}_{-0.15}{}^{+0.20}_{-0.15}$	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
E687 [2]	$0.41^{+0.11}_{-0.08} \pm 0.02$	30	1993
PDG (average) [12]	$0.35^{+0.07}_{-0.04}$	-	1996
Our value (E687)	$0.35^{+0.06}_{-0.05} \pm 0.02$	73	1997

Table 2: Ξ_c^+ lifetime measurements

width of 0.05 ps. The value is:

$$\tau_{\Xi_c^+} = 0.35^{+0.06}_{-0.05} \pm 0.02 \tag{6}$$

In Tab. 2 previous lifetime measurements are summarized and comapared to our value. Our measurement of the Ξ_c^+ lifetime is in excellent agreement with all previous analyses and our statistical error is comparable to the one of the world average.

We wish to acknowledge the assistance of the staffs of Fermilab and the INFN of Italy, and the Physics Departments of the collaborating institutions. This research was supported in part by the National Science Foundation, the U.S. Department of Energy, the Italian Istituto Nazionale di Fisica Nucleare and Ministero dell'Università e della Ricerca Scientifica e Tecnologica, and by the Korean Science and Engineering Foundation.

References

[a] Present address: Fermilab, Batavia, IL 60510, USA.

[b] Present address: University of Maryland, College Park, MD 20742, USA.

[c] Present address: University of South Carolina, Columbia, SC 29208, USA.

[d] Present address: Vanderbilt University, Nashville, TN 37235, USA.

[e] Present address: Enrico Fermi Institute, University of Chicago, Chicago, IL 60637, USA.

[f] Present address: Syracuse University, Syracuse, NY 13244-1130, USA.

[g] Present address: University of Colorado, Boulder, CO 80309, USA.

[h] Present address: University of New York, Stony Brook, NY 11794, USA.

[i] Present address: Yale University, New Haven, CN 06511, USA.

[j] Present address: Pohang Accelerator Laboratory, Pohang, Korea.

[k] Present address: Lawrence Berkeley Laboratory, University of California, Berkeley, CA 94720, USA.

[l] Present address: Science Applications International Corporation, McLean, VA 22102, USA.

[m] Present address: Gamma Products Inc., Palos Hills, IL 60465, USA.

[n] Present address: Department of Physics and Astronomy, University of Pittsburgh, 3941 O'Hara St., Pittsburgh, PA 15260, USA.

[o] Present address: Brookhaven National Laboratory, Upton, NY 11793-5000, USA.

[p] Present address: KEK, National Laboratory for High Energy Physics, Tsukuba 305, Japan.

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