Measurement of the Ω_c^0 Lifetime

J. M. Link, M. Reyes, and P. M. Yager
University of California, Davis, CA 95616

J. C. Anjos, I. Bediaga, C. Göbel, J. Magnin, A. Massafferri,
J. M. de Miranda, I. M. Pepe, and A. C. dos Reis
Centro Brasileiro de Pesquisas Físicas, Rio de Janeiro, RJ, Brasil

S. Carrillo, E. Casimiro, E. Cuautle, A. Sánchez-Hernández, C. Uribe, and F. Vázquez
CINVESTAV, 07000 México City, DF, Mexico

L. Agostino, L. Cinquini, J. P. Cumalat, B. O'Reilly, J. E. Ramirez, I. Segoni, and M. Wahl
University of Colorado, Boulder, CO 80309

J. N. Butler, H. W. K. Cheung, G. Chiodini, I. Gaines, P. H. Garbincius,
L. A. Garren, E. Gottschalk, P. H. Kasper, A. E. Kreymer, and R. Kutschke
Fermi National Accelerator Laboratory, Batavia, IL 60510

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

C. Cawlfield, D. Y. Kim, A. Rahimi, and J. Wiss
University of Illinois, Urbana-Champaign, IL 61801

R. Gardner and A. Kryemadhi
Indiana University, Bloomington, IN 47405

C. H. Chang, Y. S. Chung, J. S. Kang, B. R. Ko, J. W. Kwak, and K. B. Lee
Korea University, Seoul, Korea 136-701

K. Cho and H. Park
Kyungpook National University, Taegu, Korea 702-701

G. Alimonti, S. Barberis, M. Boschini, A. Cerutti, P. D'Angelo, M. DiCorato, P. Dini,

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L. Edera, S. Erba, M. Giammarchi, P. Inzani, F. Leveraro, S. Malvezzi, D. Menasce,
M. Mezzadri, L. Moroni, D. Pedrini, C. Pontoglio, F. Prelz, M. Rovere, and S. Sala
INFN and University of Milano, Milano, Italy

T. F. Davenport III
University of North Carolina, Asheville, NC 28804

V. Arena, G. Boca, G. Bonomi, G. Gianini, G. Liguori, M. M. Merlo,
D. Pantea, D. Lopes Pegna, S. P. Ratti, C. Riccardi, and P. Vitulo
Dipartimento di Fisica Nucleare e Teorica and INFN, Pavia, Italy

H. Hernandez, A. M. Lopez, E. Luiggi, H. Mendez,
A. Paris, J. Quinones, W. Xiong, and Y. Zhang
University of Puerto Rico, Mayaguez, PR 00681

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

T. Handler and R. Mitchell
University of Tennessee, Knoxville, TN 37996

D. Engh, M. Hosack, W. E. Johns, M. Nehring, P. D. Sheldon,
K. Stenson, E. W. Vaandering, and M. Webster
Vanderbilt University, Nashville, TN 37235

M. Sheaff
University of Wisconsin, Madison, WI 53706

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Abstract

The FOCUS experiment(FNAL-E831) has used two channels, $\Omega^-\pi^+$ and $\Xi^-K^-\pi^+\pi^+$, to measure the lifetime of the Ω_c^0 charmed baryon. From a sample of 64 ± 14 signal events at a mass of 2.698 GeV/c^2, we measure an Ω_c^0 lifetime of $72 \pm 11\,(\text{stat.}) \pm 11\,(\text{sys.})$ fs, substantially improving upon the current world average.

I. INTRODUCTION

Several experiments have searched for the Ω_c^0, $J^P = 1/2^+\{css\}$ ground state. The first claim of an observation of the Ω_c^0 was made by CERN experiment WA62 with a cluster of 3 events in the decay channel of $\Omega_c^0 \to \Xi^- K^- \pi^+ \pi^+$ (throughout this Letter, charge conjugate states are assumed) at a mass of 2740 ± 20 MeV/c^2 [1]. The ARGUS collaboration followed with signals for the Ω_c^0 in $\Omega^- \pi^+ \pi^+ \pi^-$ and $\Xi^- K^- \pi^+ \pi^+$ based on 0.380 fb^{-1} of data [2], but these signals were not confirmed by the CLEO experiment which had a much higher sensitivity. Fermilab photoproduction experiment E687 reported an observation of the Ω_c^0 decaying to $\Sigma^+ K^- K^- \pi^+$ with a mass of $2699.9 \pm 1.5 \pm 2.5$ MeV/c^2 [3] and a lifetime of $86\ ^{+27}_{-20} \pm 28$ fs [4]. E687 published an earlier observation in the $\Omega^- \pi^+$ channel with a mass of $2705.9 \pm 3.3 \pm 2.3$ MeV/c^2 [5]. In 1995, CERN experiment WA89 reported 200 Ω_c^0 events in seven modes, although the published lifetime result of $55\ ^{+13}_{-11}\ ^{+18}_{-23}$ fs comes from only two of the decay modes [6]. In 2000, CLEO presented an Ω_c^0 mass of $2694.6 \pm 2.6 \pm 1.9$ MeV/c^2 with the combined signal from four decay modes [7].

Clearly, the lifetime measurement of the Ω_c^0 is still not well measured. Additional measurements with improved statistical accuracy are needed to test theoretical models. The lifetime measurement is particularly important (when combined with other charm baryon lifetime measurements) in estimating the interference effects from different contributing diagrams [8]. The current uncertainty on the Ω_c^0 lifetime is more than 30% [9] of the lifetime value and is too large to extract meaningful information on the interfering amplitudes. In this Letter we report a new lifetime value of the Ω_c^0 baryon from the FOCUS experiment.

The FOCUS spectrometer is well-suited to reconstruct short-lived charm decays. Two silicon microvertex systems provide excellent separation between the production and charm decay vertices. The target silicon system (TS) consists of two pairs of silicon planes, each immediately downstream of a pair of BeO target segments. The second silicon strip detector (SSD) consists of 12 silicon planes, downstream of the target region. Charged particles are tracked and momentum analyzed with five stations of multiwire proportional chambers in a two magnet forward spectrometer. Three multicell threshold Čerenkov detectors are used to identify electrons, pions, kaons, and protons and are described in detail in a previous FOCUS publication [10].

II. RECONSTRUCTION OF HYPERONS, Ξ^- AND Ω^-

A detailed description of Ξ^- and Ω^- reconstruction in the FOCUS spectrometer can be found elsewhere [11]. Using the "cascade" reconstruction algorithm, we are able to reconstruct the decays $\Xi^- \to \Lambda^0\pi^-$ and $\Omega^- \to \Lambda^0 K^-$, which have branching fractions of 99.9% and 67.8%, respectively. In this analysis, we only use Ξ^-'s and Ω^-'s which decay downstream of the SSD. This allows us to track the Ξ^- or Ω^- in the SSD before it decays. A vertex is found between a Λ^0 and a π^- or a K^- and the $\Lambda^0\pi^-$ or $\Lambda^0 K^-$ combined momentum vector must match the slopes and positions of a track in the SSD. For Ω^- candidates, we require mass differences of $|M(\Xi^-) - M(\Lambda^0\pi^-)| > 30$ MeV/c^2 and $|M(\Omega^-) - M(\Lambda^0 K^-)| < 20$ MeV/c^2, ensuring that most of the more copiously produced Ξ^-'s are removed from the Ω^- sample.

III. RECONSTRUCTION OF Ω_c^0 CANDIDATES

The Ω_c^0 candidates are formed by making a vertex hypothesis for the daughter particles. We use a Ξ^- and three charged tracks of the right charge combination for the $\Xi^- K^-\pi^+\pi^+$ mode, and an Ω^- and an oppositely charged track for the $\Omega^-\pi^+$ mode. The confidence level of the decay vertex of the Ω_c^0 candidate is required to be greater than 10%. The combined momentum vector located at the decay vertex forms the Ω_c^0 track. A candidate driven vertexing algorithm [12] uses the Ω_c^0 track as a seed track to find a production vertex with a confidence level greater than 1%. The primary multiplicity, including the seed track, must be at least 3 tracks and the production vertex must be inside a target. The significance of separation between the production and the decay vertices (L/σ_L) must be greater than 2 for the $\Xi^- K^-\pi^+\pi^+$ mode and greater than 0 for the $\Omega^-\pi^+$ mode. Different values are chosen for the L/σ_L cut due to a difference in the secondary vertex resolution. Čerenkov particle identification (PID) is performed by constructing a log likelihood value $\mathcal{W}_i$ for the particle hypotheses ($i = e, \pi, K, p$). The π consistency of a track is defined by $\Delta\mathcal{W}_\pi = \mathcal{W}_{\rm min} - \mathcal{W}_\pi$, where $\mathcal{W}_{\rm min}$ is the minimum $\mathcal{W}$ value of the other three hypotheses. Similarly, we define $\Delta\mathcal{W}_{K,\pi} = \mathcal{W}_\pi - \mathcal{W}_K$ for kaon identification. We require $\Delta\mathcal{W}_{K,\pi} > 3$ for kaons and $\Delta\mathcal{W}_\pi > -6$ for pions. In the $\Xi^- K^-\pi^+\pi^+$ mode, we add additional combination PID cuts based on Monte Carlo simulation studies. We define $\sum \Delta\mathcal{W}_\pi$ to be the positive sum over pion candidates and the negative sum over other particle candidates. Also $\Delta\mathcal{W}_{K,\pi}+\Delta\mathcal{W}_{K,p}$ is used for separation between the protons and the kaons. $\sum\Delta\mathcal{W}_{\pi}$ and $\Delta\mathcal{W}_{K,\pi}+\Delta\mathcal{W}_{K,p}$ are required to be greater than 7. In the $\Omega^-\pi^+$ mode the momentum asymmetry, $(P_{\Omega^-}-P_{\pi^+})/(P_{\Omega^-}+P_{\pi^+})$, is required to be greater than -0.2 and less than 0.7. Also the π^+ transverse momentum must be larger than 0.2 GeV/c and the the momentum of Ω_c^0 must be greater than 50 GeV/c. The resulting mass spectra are shown in Fig. 1. The mass spectra are fit with a Gaussian function for the signal distribution and a first order polynomial function for the background. From the combined sample, we find a fitted mass of 2697.5 ± 2.2 MeV/c^2 (systematic uncertainty not evaluated), consistent with the results of other experiments.

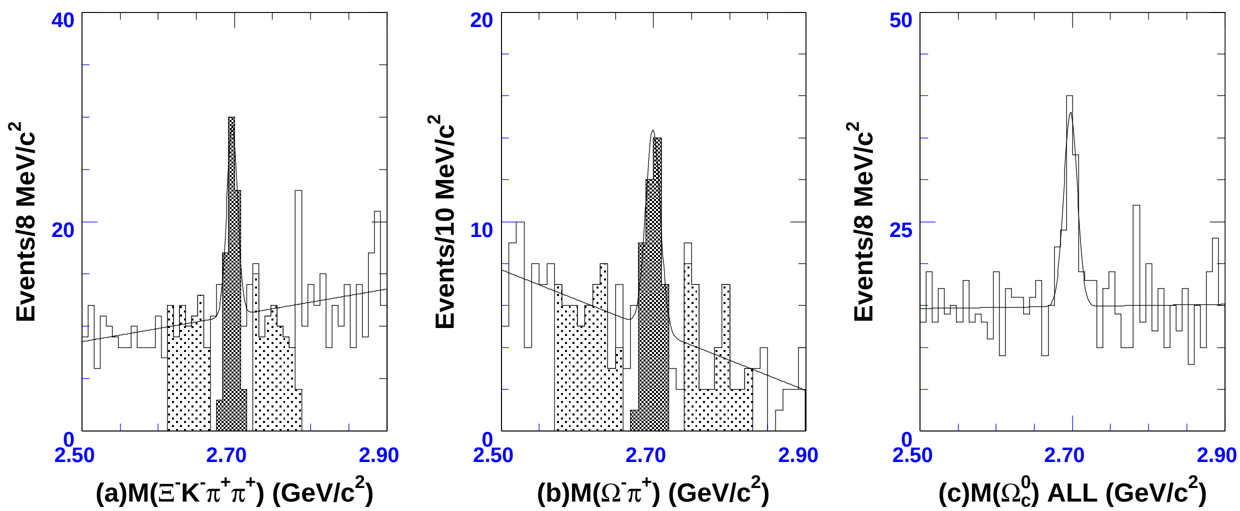

FIG. 1: Invariant mass distributions for Ω_c^0 candidates: (a) Reconstructed mass of $\Xi^-K^-\pi^+\pi^+$. There are 38 ± 9 events at a mass of 2696.5 ± 1.9 MeV/c^2. (b) Reconstructed mass of $\Omega^-\pi^+$. There are 23 ± 7 events at a mass of 2699.4 ± 3.4 MeV/c^2. (c) Combined invariant mass distribution. There are 64 ± 14 events at a mass of 2697.5 ± 2.2 MeV/c^2. We define the signal region (hatched area) to be within 2σ of the fitted mass value and the two sideband regions (dotted area) are 4–12σ from the fitted mass value.

IV. LIFETIME MEASUREMENT

To measure a lifetime in fixed target experiments, we use a binned maximum likelihood technique [13]. We fit the reduced proper time distribution, defined as $t' = (L - N\sigma_L)/\beta\gamma c =$

$t - N\sigma_t$, where N is the separation cut value between the production and the decay vertex, βc is the particle velocity, and γ is the Lorentz boost factor to the Ω_c^0 center of mass frame.

The signal region is defined to lie within $2\,\sigma$ of the fitted Ω_c^0 mass. The background is assumed to have the same lifetime behavior in the signal region as in the sidebands, 4–12 σ away from the peak. Taking S as the number of signal events in the signal region and B as the total number of background events in the same region, the expected number of events n_i in the i^{th} reduced proper time bin centered at t'_i is given by:

$$n_i = S \frac{f(t'_i)e^{-t'_i/\tau}}{\sum_i f(t'_i)e^{-t'_i/\tau}} + B \frac{b_i}{\sum_i b_i} \tag{1}$$

where b_i describes the background reduced proper time as estimated from sidebands and $f(t'_i)$ is a correction function which takes into account the effects of spectrometer acceptance and efficiency, analysis cut efficiencies, and particle absorption. The $f(t')$ distribution are shown in Fig. 2 for each decay mode.

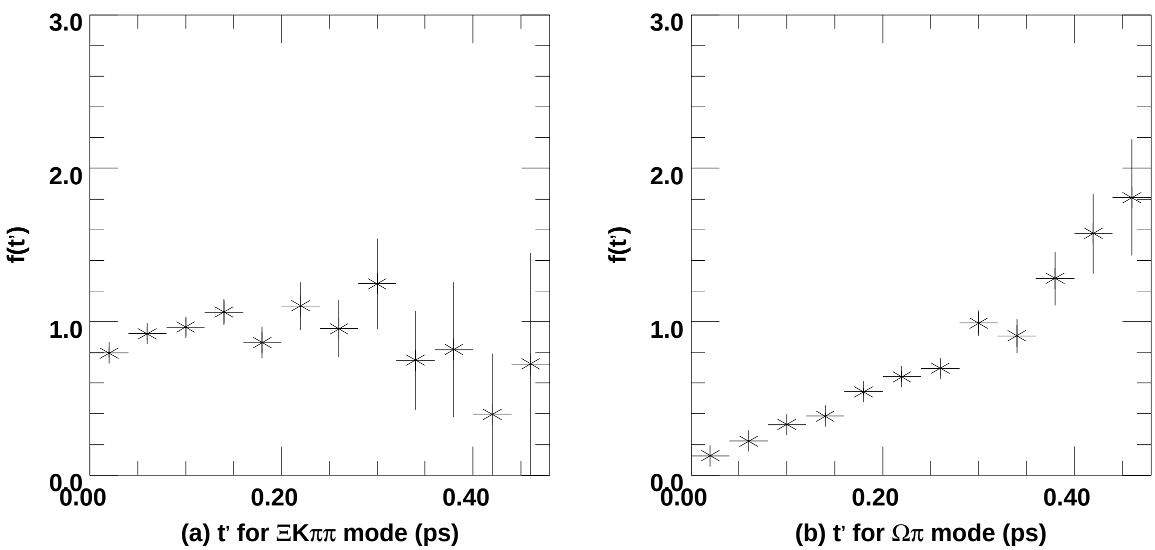

FIG. 2: The $f(t')$ correction function is displayed for each mode.

The likelihood is constructed from the product of the Poisson probability of observing s_i events when n_i are expected with the Poisson probability of observing $N_b = \sum b_i$ events in the sidebands when $4B$ background events are expected. The factor of 4 accounts for the fact that the sideband region is four times wider than the signal region. The likelihood takes the form:

$$\mathcal{L} = \left(\prod_i \frac{n_i^{s_i} e^{-n_i}}{s_i!}\right) \times \left(\frac{(4B)^{N_b} e^{-4B}}{N_b!}\right) \tag{2}$$

The combined likelihood function is given by the product of the likelihoods:

$$\mathcal{L}_{\Omega_c^0} = \mathcal{L}_{\Xi^- K^- \pi^+ \pi^+} \times \mathcal{L}_{\Omega^- \pi^+} \tag{3}$$

There are 3 fit parameters; one parameter for the lifetime τ and two parameters, $B_{\Xi^- K^- \pi^+ \pi^+}$ and $B_{\Omega^- \pi^+}$, for the backgrounds from each mode. Our measurement of the Ω_c^0 lifetime is 72 ± 11 fs as shown in Fig. 3. In Fig. 4, the t' distributions from the data and from the fit are compared with each other.

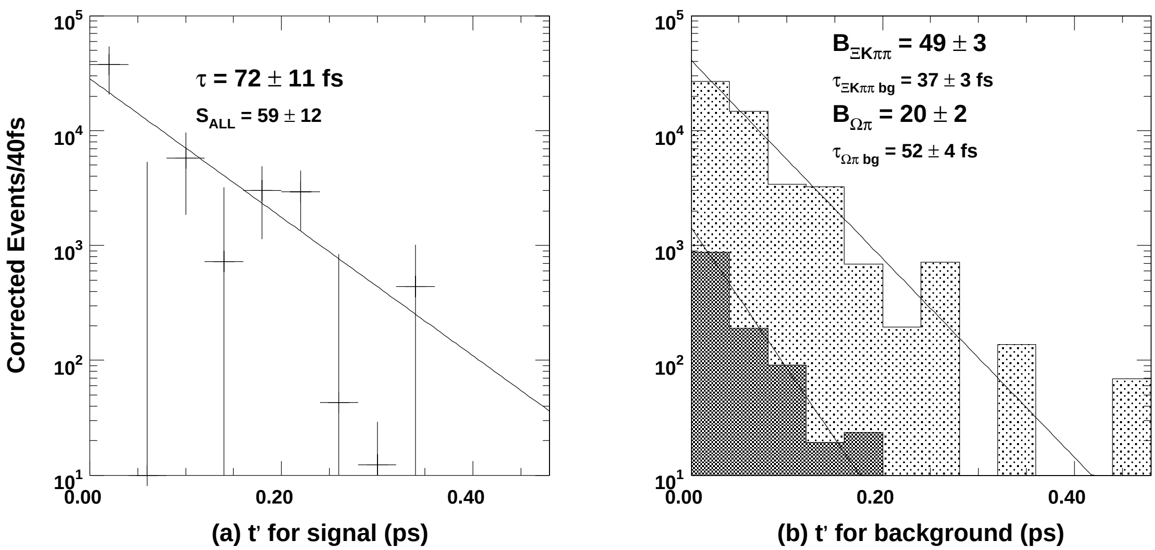

FIG. 3: (a) The corrected t' distribution with the lifetime fit function for the combined signal. (b) The t' distributions of expected backgrounds in the signal band for each mode; the dark region is for $\Xi^- K^- \pi^+ \pi^+$ and the light one is for $\Omega^- \pi^+$. Lines show the lifetime fitting functions for signal and background distributions. The lifetime fit finds 59 ± 12 signal events rather than 64 ± 14 due to the 2σ mass window used.

V. STUDIES OF SYSTEMATIC ERRORS

We have studied various systematic uncertainties associated with the Monte Carlo modeling by computing the lifetimes of independent data samples split by particle/antiparticle,

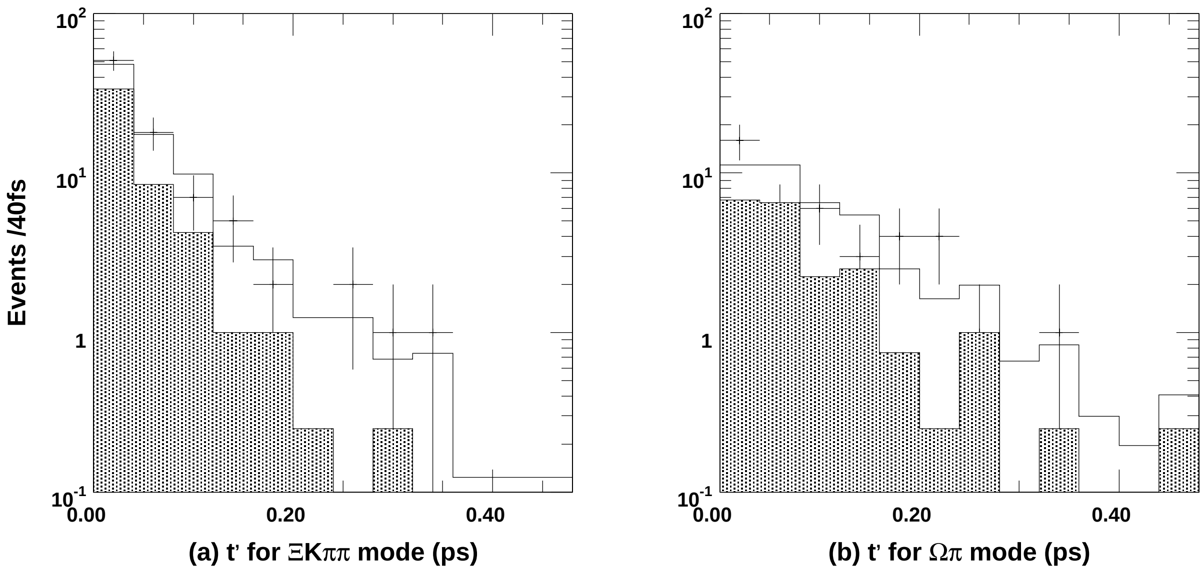

FIG. 4: The predicted events (histogram) are superimposed on the observed events (points) while the shaded distribution displays the t' distribution of the background for (a) the $\Xi^- K^- \pi^+ \pi^+$ mode and (b) the $\Omega^- \pi^+$ mode.

primary vertex position (upstream and downstream target region), Ω_c^0 momentum (greater than 70 GeV/c / less than 70 GeV/c) and production vertex multiplicity (>5 / $\leq$ 5). All lifetimes from these samples are consistent within the statistical error as shown in Fig. 5 points 1–8, indicating a negligible systematic error due to the Monte Carlo simulation.

Since the binned likelihood method has been used to measure the lifetime, we have investigated the uncertainty from the fit range and binning effects by examining the variance in lifetime for different t' bin sizes (Fig. 5 points 10–11) and for different fitting ranges (Fig. 5 point 9).

The proper time resolution of our fully simulated Monte Carlo for the Ω_c^0 data is about 40–50 fs. We have tested the accuracy of the fitting procedure when the lifetime is comparable to the proper time resolution. We used a toy Monte Carlo study to test the fitting procedure using the proper time from which we extracted a systematic uncertainty of 4 fs. The toy Monte Carlo test was also used to validate the statistical error determination.

The systematic uncertainty due to the background contamination is examined by investigating the reflections from other charm baryon decays and by varying the sideband and

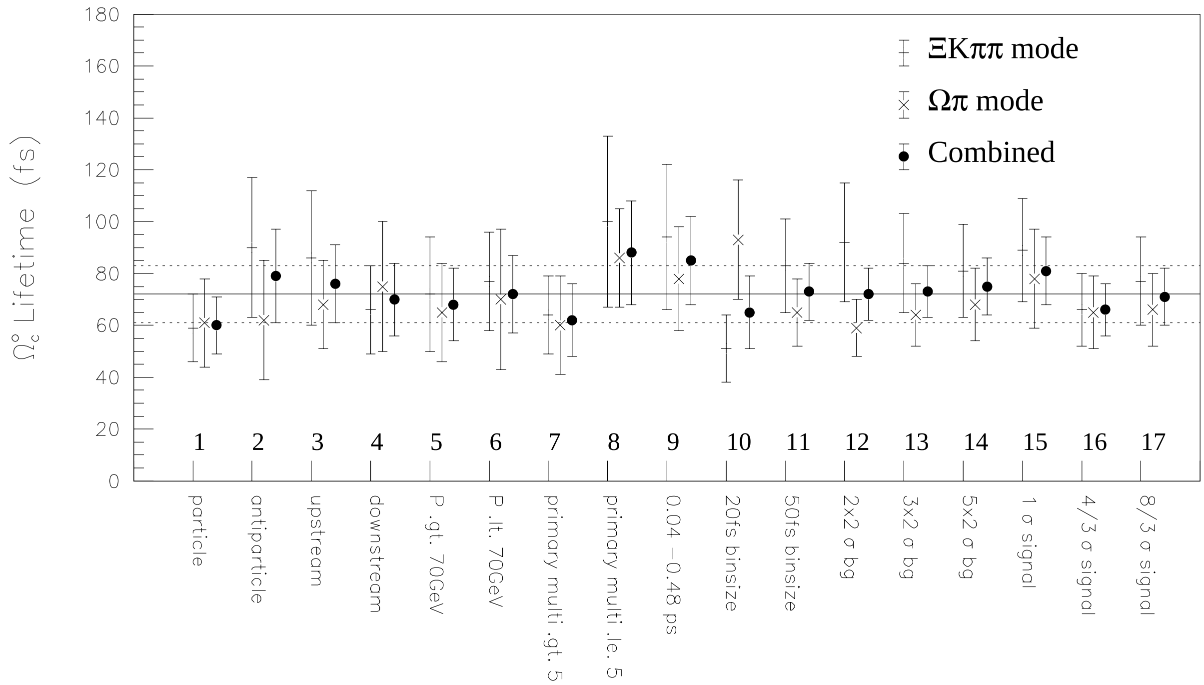

FIG. 5: Lifetime measurements for systematic studies. The solid line represents the best determined value for the Ω_c^0 lifetime and the two dotted lines show the extent of the statistical error.

signal regions (Fig. 5 points 12–17).

The studies of the systematic uncertainties are summarized in Table I. The total systematic uncertainty of the Ω_c^0 lifetime measurement is determined to be 11 fs by adding all of the systematic uncertainties in quadrature.

VI. CONCLUSION

We measure an Ω_c^0 lifetime of $72 \pm 11 \pm 11$ fs using 64 ± 14 events in the two decay modes, $\Omega^-\pi^+$ and $\Xi^-K^-\pi^+\pi^+$. We compare our result with previous measurements in Table II. Our lifetime result is consistent with previous Ω_c^0 lifetime results. This 20% measurement of the lifetime substantially improves upon the current (30%) world average.

TABLE I: The itemized list of the systematic uncertainties. The numbers in the Items column refer to the entry numbers in Fig. 5.

Systematic Source	Items	Uncertainty (fs)
Split Sample Method	Particle and antiparticle (1,2)	~ 0
	Upstream and downstream target (3,4)	~ 0
	High and low momentum (5,6)	~ 0
	Primary vertex multiplicity (7,8)	~ 0
Fit variant	Bin size (10,11) and fitting region (9)	± 9
t' Resolution	Toy Monte Carlo studies	± 4
Background	Sideband (12,13,14) and signal band (15,16,17)	± 5
Total		± 11

TABLE II: The Ω_c^0 lifetime measurements

Experiment	Lifetime	Decay Modes
E687	$86\ ^{+27}_{-20} \pm 28$ fs	$\Sigma^+ K^- K^- \pi^+$
WA89	$55\ ^{+13}_{-11}\ ^{+18}_{-23}$ fs	$\Xi^- K^- \pi^+ \pi^+$, $\Omega^- \pi^+ \pi^+ \pi^-$
PDG2002	64 ± 20 fs	
FOCUS	$72 \pm 11 \pm 11$ fs	$\Xi^- K^- \pi^+ \pi^+$, $\Omega^- \pi^+$

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