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Measurement of the Ω_c^0 lifetime

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We report a precise measurement of the Ω_c^0 lifetime. The data were taken by the SELEX (E781) experiment using 600 GeV/c Σ^-, π^- and p beams. The measurement has been made using 83 ± 19 reconstructed Ω_c^0 in the $\Omega^-\pi^-\pi^+\pi^+$ and $\Omega^-\pi^+$ decay modes. The lifetime of the Ω_c^0 is measured to be $65 \pm\ 13\ (stat) \pm 9\ (sys)$ fs.

Several experiments [1–5] in the last years have detected the Ω_c^0 ground state. Recently at Fermilab the photoproduction experiment, FOCUS, reported an observation of a sample of 64 Ω_c^0 events and they measured its lifetime as $72 \pm 13 \pm 11$ fs [6]. The experiment WA89 published an Ω_c^0 lifetime measurement of $55^{+13}_{-11}\,^{+18}_{-23}$ fs from a sample of 86 events [7]. The present world average is 69 ± 12 fs as reported in Ref. [8]. Clearly additional measurements of lifetime as well as the branching ratios with more statistical accuracy are needed to test theoretical models [9].

In this letter we report the results of a new measurement of the lifetime based on data from the hadroproduction experiment SELEX (E781) at Fermilab. The measurement is based on a sample of 83 ± 19 fully reconstructed Ω_c^0 from 15.3×10^9 hadronic interactions.

The SELEX detector at Fermilab is a 3-stage magnetic spectrometer. The negatively charged 600 GeV/c beam contains nearly equal fractions of Σ and π. The positive beam contains 92% protons. Beam particles are identified as a baryon or a pion by a transition radiation detector. The spectrometer was designed to study charm production in the forward hemisphere with good mass and decay vertex resolution for charm momenta in the range 100-500 GeV/c. Five interaction targets (2 Cu and 3 C) have a total target thickness of 4.2% λ_{int} for protons. The targets are spaced by 1.5 cm. Downstream of the targets there are 20 Silicon Strip Detectors (SSD) with a strip pitch of 20-25 μm oriented in X, Y, U and V views. The first spectrometer level has three Multi-Wire Proportional Chambers (MWPC) with 3 mm wire spacing and 2x2 m^2 area downstream of bending magnet M1. The second spectrometer level has 7 MWPCs with 2 mm wire spacing downstream of the second bending magnet M2. Each chamber has two sensitive planes in two orthogonal projections. The scattered-particle spectrometers have momentum cutoffs of 2.5 GeV/c and 15 GeV/c respectively. Typical momentum resolution for a 100 GeV/c track is 0.5%. A Ring-Imaging Cerenkov detector (RICH) [10], filled with Neon at room temperature and pressure, provides single track ring radius resolution of 1.4% and 2σ K/π separation up to about 165 GeV/c. A layout of the spectrometer can be found elsewhere [11].

The Ω_c^0 decays studied here have a hyperon in the final state. Hyperons that decay upstream of or within the M1 magnet are called *Kink* tracks. They are characterized by one charged track that decays to another charged particle and a neutral particle undetected by the spectrometer. Such *Kink* tracks differ from the majority of spectrometer tracks in that the vertex silicon track segment does not link to straight line tracks segments measured in the spectrometers after M1 and/or M2. The *Kink* reconstruction algorithm examines all unlinked Vertex SSD track segments that point to the M1 magnet aperture and tries to match each unlinked segment with an unlinked downstream track measured in the M1/M2 spectrometer, using momentum-energy conservation with the hypothesis of a specific hyperon decay. The momentum of the parent hyperon ($\Omega^{\pm}$, $\Xi^{\pm}$ or $\Sigma^{\pm}$) is calculated using the assumed decay hypothesis. The daughter K^- in Ω^- decays must be RICH identified with the likelihood to be a K exceeding that of its being a π.

The charm trigger is very loose. It requires a valid beam track, at least 4 charged secondaries in the forward 150 mrad cone, and two hodoscope hits after the second bending magnet from tracks of charge opposite to that of the beam. We triggered on about 1/3 of all inelastic interactions. A computational filter linked MWPC tracks having momenta > 15 GeV/c to hits in the vertex silicon and made a full reconstruction of these tracks together with a beam track to form primary and secondary vertices in the event. Events consistent with only a primary vertex are not saved. About 1/8 of all triggers are written to tape, for a final sample of about 10^9 events.

In the full analysis the vertex reconstruction was repeated with tracks of all momenta. The RICH detector identified charged tracks above 25 GeV/c. Results reported here come from a second pass reconstruction through the data, using a production code optimized for hyperon reconstruction.

To separate the signal from the non-charm background we require that: (i) the spatial separation L between the reconstructed production and decay vertices exceeds 6 times the combined error σ_L, (ii) each decay track, extrapolated to the primary vertex z position, must miss by a transverse distance $s \geq 2.5$ times its error σ_s, (iii) each candidate hyperon track, extrapolated to the *Kink* vertex z position, must have a good vertex quality ($\chi^2/NDOF < 5$), (iv) the secondary vertex must lie outside any target material by at least 0.05 cm, and (v) decays must occur within a fiducial region.

The total transverse momentum of pions from the $\Omega^-\pi^+\pi^+\pi^-$ decay mode must be greater than 0.35 GeV/c with respect to the Ω_c^0 direction. This cut optimizes the signal to background ratio. We require a minimum π momentum of 8 GeV/c to reduce the number of fake invariant mass combinations. There are 107 ± 22 Ω_c^0 candidates in three decay channels: $\Omega^-\pi^+\pi^+\pi^-$, $\Omega^-\pi^+$, and $\Xi^-K^-\pi^+\pi^+$. Details of the Ω_c^0 mass measurement will be reported elsewhere [12]. In the $\Xi^-K^-\pi^+\pi^+$ mode the signal is small and the signal to noise ratio is poor. We've chosen not to include it in the lifetime measurement. The invariant mass distributions with tighter cuts for lifetime measurement are shown in Fig. 1 for the two decay modes used here.

The average combined error σ_L on the primary and secondary vertices and the average Ω_c^0 momentum give a proper time resolution of 16 fs, about 23% of $\tau_{\Omega_c^0}$. We used a binned maximum likelihood fitting technique with 5 fs width bins to determine the Ω_c^0 lifetime. The fit was applied to a reduced proper time distribution, $t^* = M(L - L_{min})/pc$ where M is the reconstructed charm mass, p the reconstructed momentum, L the measured vertex separation and L_{min} the minimum L for each event to pass all the imposed selection cuts. L_{min} is determined event-by-event, along with the acceptance, by the procedure described below. We fitted all events with $t^* < 600$ fs in the mass range $2.685 < M(\Omega_c^0) < 2.725$ GeV/c^2, $\pm\, 2.5\sigma$ from the Ω_c^0 central mass value.

The probability density function (1) is:

$$f(\tau_{\Omega_c^0},\ \tau_{B1},\ \tau_{B2},\ f_B,\ f_c;\ t^*) =$$

$$(1-f_B)N_S\frac{e^{-t^*/\tau_{\Omega_c^0}}}{\epsilon(t^*)\tau_{\Omega_c^0}} + f_B N_S B(t^*), \qquad (1)$$

where

$$B(t^*) = f_c\frac{e^{-t^*/\tau_{B1}}}{\tau_{B1}} + (1-f_c)\frac{e^{-t^*/\tau_{B2}}}{\tau_{B2}}. \qquad (2)$$

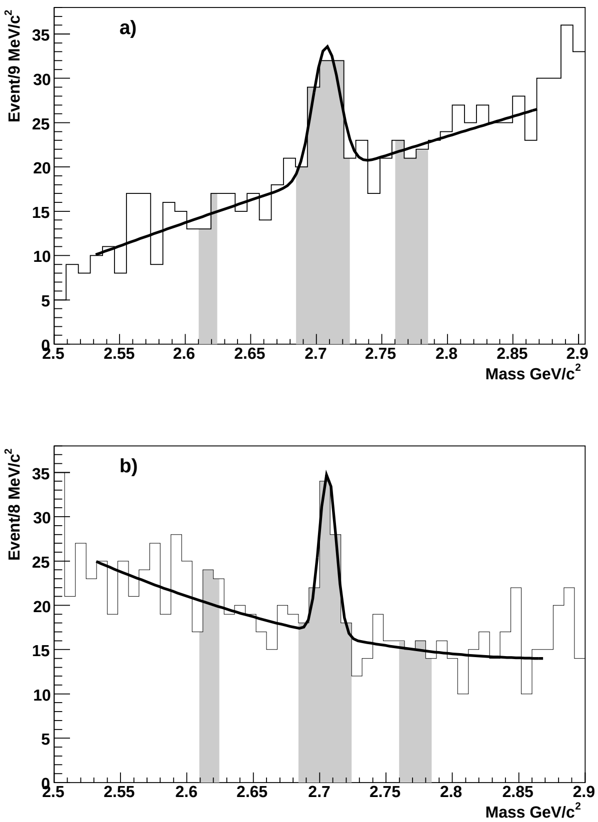

FIG. 1: Invariant mass distribution for (a) $\Omega_c^0 \to \Omega^-\pi^+\pi^-\pi^+$, (b) $\Omega_c^0 \to \Omega^-\pi^+$. The shaded regions show the Ω_c^0 signal and sideband regions.

The five parameters are: $\tau_{\Omega_c^0}$ (Ω_c^0 lifetime), τ_{B1}, τ_{B2} (background lifetimes), f_B (background fraction in the signal region) and f_c (background splitting function). N_S is the total number of events in the signal region.

The function is the sum of a term for the Ω_c^0 exponential decay corrected by the acceptance function $\epsilon(t^*)$ plus a background function $B(t^*)$ consisting of two exponentials to describe the strong decays and charm decays respectively. Its parameters were determined from the t^* distribution from the Ω_c^0 sidebands. Together the mass widths of the sideband background windows, $2.610 < M(\Omega_c^0) < 2.625$ GeV/c^2 and $2.760 < M(\Omega_c^0) < 2.785$ GeV/c^2 was equal to the signal mass window.

The proper-time-dependent acceptance $\epsilon(t^*)$ is independent of spectrometer features after the first magnet, e.g., RICH efficiency and tracking efficiency. These efficiencies affect only the overall number of events detected. The proper time distribution of these events depends crucially on vertex reconstruction. To evaluate $\epsilon(t^*)$ we generated Ω_c^0 events with a $(1-x_F)^3$ distribution and decayed them using the QQ package [13]. We embedded these generated decays into real data events and reconstructed the embedded decays with the offline package including multiple Coulomb scattering in the spectrometer and the measured detector performance. The correction function was evaluated as the fraction of the embedded events passing the selection cuts.

Fit results	$\Omega^-\pi^+\pi^+\pi^-$	$\Omega^-\pi^+$
$\tau_{\Omega_c^0}$	62.6 ± 22.0	65.8 ± 16.0
τ_{B1}	15.6 ± 6.2	10.1 ± 3.3
τ_{B2}	388.2 ± 27.0	281.4 ± 22.5
Signal	34 ± 12	23 ± 9
background	84 ± 13	81 ± 6
Signal yield	47 ± 16	36 ± 11

TABLE I: Lifetime fit results for the two Ω_c^0 decay modes analyzed. The errors are only statistical. The signal yield from the fits to the mass plots in Fig. 1 are also shown.

Source of uncertainty	$\Omega^-\pi^+\pi^-\pi^+$, $\Omega^-\pi^+$
Vertex reconstruction	<1
Acceptance function	1.75
Fit procedure	8.5
Total systematic error	8.6

TABLE II: Systematic error contributions in fs for the two Ω_c^0 decay modes analyzed.

Fig. 2 shows the overall fits to the data distributions as a function of reduced proper time for $\Omega^-\pi^+\pi^-\pi^+$ and $\Omega^-\pi^+$ decay modes. It also shows the acceptance function $\epsilon(t^*)$, which does not differ significantly from unity and is constant. This is due to the fact L_{min} is chosen 6 times the combined error, σ_L. With Selex's very high momentum and excellent resolution this cut removes only the first ~ 1.5 lifetimes from the sample.

Table I summarizes the lifetime fit results and the signal yields. We measure an average lifetime $65 \pm\ 13$ fs. The uncertainties are statistical only, evaluated where $-\ln\mathcal{L}$ increases by 0.5.

The systematic uncertainties for the Ω_c^0 lifetime analysis are listed in Table II and described below. Lifetime shifts due to reconstruction errors have been well studied in our D^0 and Λ_c work, with an order of magnitude higher statistics [14, 15]. Because of the high redundancy and good precision of the silicon vertex detector, vertex mismeasurement effects are small at all momenta. Proper time assignment depends on correct momentum determination. The SELEX momentum error is less than 0.5% in all cases. We assign a maximum systematic error from proper time mismeasurement of 1 fs. The acceptance function used in the fit was parameterized with a 1st and 2nd order polynomial. The difference in lifetime result is 1.75 fs. No significant difference in the lifetime correction function was found when we changed the n value of x_F distribution from 3 to 1. We varied the width of the

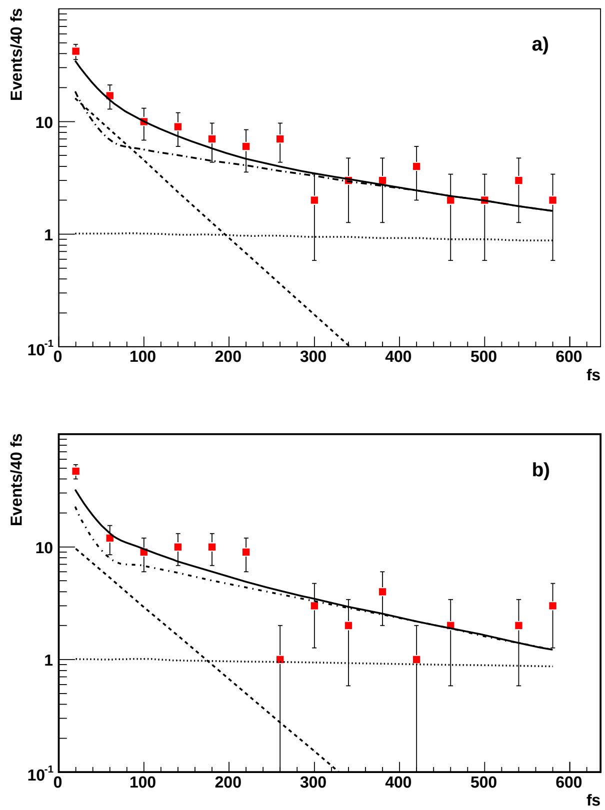

FIG. 2: Corrected reduced proper time distribution for events in the Ω_c^0 window 2706 ± 20 MeV/c^2 (full boxes) and the results from the maximum likelihood fit (solid curve) for a) $\Omega^-\pi^+\pi^+\pi^-$; b) $\Omega^-\pi^+$. The dashed curve shows the Ω_c^0 proper lifetime, the dashed-dot curve the fitted background and the dotted curve the acceptance.

sidebands and the bin size independently. The systematic error due to the fit procedure is 8.5 fs.

We have made a new measurement of the Ω_c^0 lifetime in two independent decay channels, $\Omega^-\pi^+\pi^+\pi^-$, $\Omega^-\pi^+$ using a maximum likelihood fit. SELEX measures the Ω_c^0 lifetime to be $\tau_{\Omega_c^0} = 65 \pm\ 13\ (stat) \pm 9\ (sys)$ fs. Our results are in excellent agreement with the world average [8] and with the recent results published by the FOCUS collaboration [6].

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