Review of Charm Lifetimes

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ABSTRACT: A review of the latest experimental results on charm particle lifetimes is presented. The most significant update is that the D_s^+ lifetime is conclusively larger than the D^0 lifetime and signifies that W-exchange/W-annihilation contributions are large. Using new high statistics data on $D^+ \to K^+\pi^+\pi^-$ together with the D_s^+ lifetime and some assumptions, one can phenomenologically extract the strength of the W-exchange contribution in D^0 decays and of W-annihilation in D_s^+ decays. These are larger than or at the limit of theoretical expectations using QCD-based operator production expansion techniques.

1. Introduction

1.1 Motivation

The study of charm particle lifetimes is broadly motivated by two main goals. The first is to enable the conversion of relative branching fractions to partial decay rates and the second is to learn more about the strong interaction.

Experimental data on charm decays are normally obtained by measuring decay fractions, *e.g.* $\Gamma(D^0 \to K^-\pi^+)/\Gamma_{tot}(D^0)$, whereas theory calculates the partial decay rate, $\Gamma(D^0 \to K^-\pi^+)$. The lifetime of the particle, $\tau = \hbar/\Gamma_{tot}(D^0)$, is needed in order to convert the experimentally measured decay fractions into decay rates. Not only does this allow tests of theoretical predictions but it also enables the extraction of Standard Model parameters if the theoretical calculations are reliable, *e.g.* a comparison of D semileptonic decay rates may allow a direct extraction of $|V_{cs}|$ and $|V_{cd}|$ allowing a test of the unitarity of the CKM matrix.

The second motivation for the study of lifetimes is that they are interesting in their own right. They allow us to learn more about the "Theoretically-Challenged" part of the Standard Model, *i.e.* non-perturbative QCD. This is one of the few areas of the Standard Model where experimental data and theoretical ideas closely interact and is thus intellectually interesting. For example, even though we have some models, we have little idea about exactly *how* quarks turn into hadrons and we are still learning about the importance of different contributions to quark decays. Calculations using Lattice QCD are only just now being used to study the *dynamics* of decays and reliable results are still being eagerly awaited [1].

1.2 Decay Diagrams

The lifetime of a particle is given by the following expression:

$$\tau = \frac{\hbar}{\Gamma_{SL} + \Gamma_{NL} + \Gamma_{PL}} \tag{1.1}$$

where Γ_{SL} is the semileptonic decay rate, (*e.g.* $\Gamma(D^+ \to \ell^+\nu_\ell X)$), Γ_{NL} is the non-leptonic or hadronic decay rate, (*e.g.* $\Gamma(D^+ \to \text{hadrons})$), and Γ_{PL} is the purely leptonic decay rate, (*e.g.* $\Gamma(D^+ \to \ell^+\nu_\ell)$). Compared to the total rate, the purely leptonic decay rate is normally very small due to helicity suppression.[1] In addition

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[1]The D meson has spin 0 so that in the decay, the resulting lepton (anti-lepton) and anti-neutrino (neutrino) must *both* be either left-handed or *both* right-handed in order to conserve angular momentum. However the $V-A$

current data for D meson decays indicate that the semileptonic rates for D^+ and D^0 are equal to within at least about 10% if not better.[2] This means that the large difference between the observed D^+ and D^0 lifetimes ($\tau(D^+)/\tau(D^0) = 2.55 \pm 0.04$) is due to a large difference in the hadronic decay rates for the D^+ and the D^0. Thus in contrast to the spectator model [4] which only has the free charm quark decay diagram and predicts equal D^+ and D^0 lifetimes, we need to take into account spectator quark effects. This entails taking into account other decay diagrams like those in figure 1 and any interferences between them.

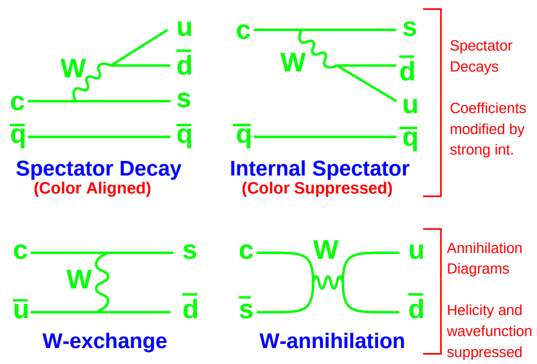

Figure 1: Hadronic decay diagrams for charm meson decays.

The conventional wisdom used to explain the smaller hadronic width of the D^+ relative to the D^0 is that in the D^+ Cabibbo-allowed decays ($c\bar{d} \to s(u\bar{d})\bar{d}$), there exist identical quarks in the final state unlike for D^0, so there are additional (destructive) interference contributions for the D^+. Or, we can talk about a model where one views the interference as that occurring between the external spectator and internal spectator decay diagrams of figure 1 which can lead to the same exclusive final state. Ignoring the more complicated soft gluonic exchanges, it is relatively easy in this model to roughly show that the additional interference for inclusive hadronic decays for D^+ is destructive and can lead to a lifetime ratio of $\tau(D^+)/\tau(D^0) \sim 2.0$. However it is difficult to determine exactly how large a ratio of $\tau(D^+)/\tau(D^0)$ interference effects can accommodate and therefore how large is the additional contribution of Cabibbo-allowed W-exchange decays needed for the D^0. One has to take care in calculating the size of the Pauli interference since naive calculations can produce too large a value resulting in a negative total decay rate for the D^+ [5]. Cabibbo-allowed W-exchange decay is expected to contribute to lowering the D^0 lifetime but this contribution is wavefunction and helicity suppressed ($\sim |f_d|^2 m_s^2/m_c^4 \sim 10^{-3}$ without gluon exchange) and is difficult to calculate reliably.

Clearly a better understanding of charm inclusive decays is necessary. Experimental data on lifetimes from all the charm particles will allow us to learn more about how they decay and in turn use the data to extract Standard Model parameters like quark masses and the CKM matrix elements $|V_{cs}|$ and $|V_{cd}|$.

1.3 Theoretical Overview

A systematic approach now exists for the treatment of inclusive decays that is based on QCD and consists of an operator product expansion in the Heavy Quark Mass [6]. In this approach the decay rate is given by:

$$\Gamma_{H_Q} = \frac{G_F^2 m_Q^5}{192\pi^3} \Sigma f_i |V_{Qq_i}|^2 \left[A_1 + \frac{A_2}{\Delta^2} + \frac{A_3}{\Delta^3} + ... \right] \tag{1.2}$$

where the expansion parameter Δ is often taken as the heavy quark mass and f_i is a phase space factor. $A_1 = 1$ gives the spectator model term and the A_2 term produces differences between the baryon and meson lifetimes. The A_3 term includes the non-spectator W-annihilation and Pauli interference effects. For meson decays, parts of these terms can be related to certain observables whereas for baryons one relies solely on particular quark models or QCD sum rules to determine the parameters fully. The importance of higher order terms is not really known though some studies have pointed to possibly large higher order contributions [5, 7].

nature of the weak interaction requires left-handed particles and right-handed anti-particles[2].

[2]The semileptonic decay rate is given by the ratio of the semileptonic branching ratio to the lifetime. Using the world average values for these compiled by the Particle Data Group [3], $\Gamma_{SL}(D^+) = (1.071 \pm 0.119) \times 10^{-13}$ GeV and $\Gamma_{SL}(D^0) = (1.067 \pm 0.041) \times 10^{-13}$ GeV.

A theoretical review is outside the scope of this article and the reader is referred to other reviews [6].

2. Review of Experimental Results

There have been new measurements of charm lifetimes since the 1998 review performed by the PDG [3]. Some are results published in journals while others were presented at conferences this year. Table 1 shows the experiments that have shown new lifetime measurements.

Experiment	Beam Type
E791	500 GeV π^-
CLEO	e^+e^- collider at $\Upsilon(4S)$
FOCUS	190 GeV photon
SELEX	600 GeV Σ^- and π^-

Table 1: Charm experiments

2.1 Experimental Method

Unlike the lifetime measurements for the b particles, the methods used for measurements of the charm particle lifetimes are more straight forward. Firstly, the number of reconstructed charm decays are large enough that only exclusive decays are used – inclusive methods are not needed. This means that the charm particle momentum is fully measured.

For the fixed target experiments, the resolutions of the production and decay vertices are about 10 μm in each of the two directions transverse to the beam direction and about 400–600μm along the beam direction. The resolution varies with the multiplicity of charged tracks in the vertices as well as on the momenta of the charged tracks. Since the boost is typically large ($\langle\beta\gamma\rangle \sim$ 40–100) the full 3-dimensional decay length (ℓ) is used to measure the proper time for the decay, $t = \ell/\gamma\beta c = (\ell/c) \times (m_D/p_D)$, where p_D and m_D are the momentum and rest mass of the charm particle respectively. The typical proper time resolution is about 40–60 fs for E791 and FOCUS and is smaller, ~20 fs, for SELEX due to their much larger average D momentum. To eliminate background, charm candidates are selected that have a large separation between the production and decay vertices, typically by many σ_ℓ, *i.e.* $\ell > N\sigma_\ell$. This selection drastically reduces the acceptance of candidates with short lifetimes and the acceptance as a function of proper time is rapidly varying at short proper times. In order to reduce the systematic uncertainty that would be associated with having to know this acceptance function accurately, one uses the reduced proper time, $t' = t - (N\sigma_\ell/c) \times (m_D/p_D)$. The acceptance as a function of t' is quite flat and therefore only small acceptance corrections are necessary. The effect of using the reduced proper time is to start the clock at a different point for each charm candidate event, determined by σ_ℓ. One assumes, and can check that there is no drastic bias in σ_ℓ that could affect the t' distribution from following a pure exponential decay. Any bias would have to be correctly simulated in the Monte Carlo.

Even with the relatively small boost ($\langle\beta\gamma\rangle \sim$ 1.7) for charm mesons produced in a e^+e^- collider running at the $\Upsilon(4S)$, data from CLEO-II.5 can be used to measure lifetimes. This is possible due to a newly installed silicon vertex detector, which enabled CLEO to obtain a resolution on the decay vertex of 80–100 μm in the D flight direction in the xy plane. This corresponds to relatively poor proper time resolutions of about 140–200 fs, but is however sufficient to competitively measure the lifetimes of the charm mesons as these are longer lived than the charm baryons. Due to the detector and magnetic field arrangement of CLEO, the decay length and momentum of the charm meson is measured in the xy plane, (which is transverse to the beam direction). The inherently smaller backgrounds in e^+e^- collisions allow selection of charm signals without any vertex detachment selection criteria. This means that the the absolute proper time $t = (\ell^{xy}/c) \times (m_D/p_D^{xy})$ can be used, thus eliminating one contribution to the acceptance uncertainty. However, the relatively large proper time resolution requires good knowledge of this resolution including non-Gaussian tails which could bias the fitted lifetime. Although the new silicon tracker in CLEO-II.5 has enabled them to measure lifetimes to a precision rivaling the fixed target-dominated world averages, the next generation fixed target experiment FOCUS will be overwhelming with a huge sample of fully recon-

Experiment	$\tau(D^+)$ fs	$\tau(D^0)$ fs	$\tau(D_s^+)$ fs	$\tau(\Lambda_c^+)$ fs
PDG98	1057 ± 15	415 ± 4	467 ± 17	206 ± 12
E791[a]	1065 ± 48	$413 \pm 3 \pm 4$	$518 \pm 14 \pm 7$	
CLEO	$1033.6 \pm 22.1^{+9.9}_{-12.7}$	$408.5 \pm 4.1^{+3.5}_{-3.4}$	$486.3 \pm 15.0^{+4.9}_{-5.1}$	
FOCUS[b]			506 ± 8	204.5 ± 3.4
SELEX[b]				177 ± 10
World Average	1052 ± 12	412.8 ± 2.7	499.9 ± 6.1	201.9 ± 3.1

a $\tau(D^+)$ using only the $\phi\pi^+$ mode, no systematic uncertainty quoted

b Preliminary result with no systematic uncertainty quoted

Table 2: Summary of new charm lifetime measurements split by experiment

structed charm decays.

The lifetimes are usually extracted using a maximum likelihood fit. Either a binned (proper time) likelihood or an unbinned (candidate-by-candidate) likelihood is used. For the binned likelihood, events are taken from the mass peak region with events from mass sidebands giving an estimate of the background lifetime distribution. For the unbinned likelihood, the mass as well as the proper time for each charm candidate is used where candidates from a wide mass region are selected. As well as fitting for the lifetime, the fraction of background is also usually varied in the fits. The details of each fit are different for each lifetime measurement.

2.2 Measurements of Charm Lifetimes

The world average lifetimes for the weakly decaying charm particles are dominated by measurements from Fermilab E687 published in 1993-1995. These are beginning to be superseded by updates this year to the D meson lifetimes as well as to the Λ_c^+ lifetime.

The CLEO collaboration has published their measurements for the lifetimes of the D^+, D^0 and D_s^+ [8]. The modes used were $D^0 \to K^-\pi^+$, $K^-\pi^+\pi^0$, $K^-\pi^+\pi^-\pi^+$, $D^+ \to K^-\pi^+\pi^+$, and $D_s^+ \to \phi\pi^+$ with $\phi \to K^+K^-$. Besides the usual vertexing requirements, to additionally suppress backgrounds they required that the D^0 and D^+ come from D^{*+} decays to $D^0\pi^+$ and $D^+\pi^0$ respectively. The momentum of the π^0 in the decay $D^0 \to K^-\pi^+\pi^0$ is required to be > 100 MeV/c and the D^{*+} and D_s^+ mesons are required to have momenta larger than 2.5 GeV/c. A seven parameter fit is used to extract the lifetime for each mode before any averaging is done. Three proper time resolutions are used in the fit, two of them to model underestimates of the mismeasurement errors. Two backgrounds are fitted, one with zero lifetime and another component with a finite lifetime. An unbinned likelihood is used but with the probability associated with the candidate mass determined in a separate (mass) fit. The CLEO measurements are shown in table 2, and the figures are available in their publication [8].

E791 is a hadroproduction experiment that took data in 1990–1991 at Fermilab and new measurements using these data have recently been published for the lifetimes of the D_s^+ [9] and the D^0 [10]. Figures of the signals and lifetime fits are available in these publications. For the $D_s^+ \to \phi\pi^+$ measurement, due to the requirement of a resonance $\phi \to K^+K^-$, only a loose Čerenkov particle ID requirement is made on the kaon with the same sign as the pion. However any possible background from $D^+ \to K^-\pi^+\pi^+$ where one of the pions is misidentified as a kaon is eliminated by removing candidates that have a $K^-\pi^+\pi^+$ mass within ± 30 MeV/c^2 of the D^+ mass. This selection requires that the background mass distribution be modeled with a piecewise linear function with a discontinuity fixed at 1.95 GeV/c^2. An unbinned likelihood fit is performed over the whole mass range that extracts the D^+ lifetime as well as the D_s^+ lifetime for this mode. In order to reduce any uncertainty in the acceptance, the acceptance is not obtained using only a Monte Carlo simulation, instead $D^+ \to K^-\pi^+\pi^+$ data are used together with the ratio of Monte Carlo $\phi\pi$ and $K\pi\pi$ acceptances. The acceptance for $K\pi\pi$ is obtained by dividing the data distribution by a pure exponential with the world average D^+ lifetime, $\epsilon_{data}(K\pi\pi)$. The acceptance for $\phi\pi$ is then given by $\epsilon_{data}(K\pi\pi) \times (\epsilon_{MC}(\phi\pi)/\epsilon_{MC}(K\pi\pi))$ for each t' bin. The lifetime results are shown in table 2. Results are also shown in the table for the D^0 lifetime measured using the $K^-\pi^+$ decay mode. This measurement was performed together with a lifetime measurement in the K^+K^- decay mode [10]. Here, a different technique was used to extract the lifetime since the K^+K^- sidebands do not accurately reflect the background under the D^0 mass peak. Events were split into reduced proper time bins and the number of D^0 signal events was found from a mass fit using a Gaussian with mean and sigma fixed to that obtained in a fit to all events. A fit to these signal events as a function of t' using a single exponential after particle identification weighting and acceptance corrections gives the extracted lifetime.

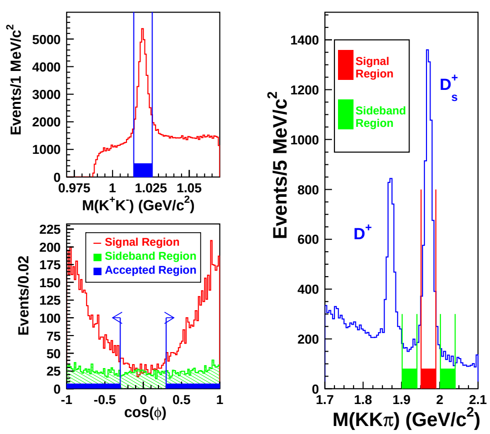

Figure 2: FOCUS signal for $D_s^+ \to \phi\pi^+$.

The Fermilab FOCUS photoproduction experiment took data in 1996–1997 and is the follow-on experiment to E687 with significant improvements to the data quality as well as having collected charm samples 15–20 times larger than the E687 sample [11]. A preliminary measurement of the D_s^+ lifetime has been made using 50% of the data sample in the decay mode $D_s^+ \to \phi\pi^+$ [12]. The signal and selection regions are shown in figure 2. As well as a cut on the K^+K^- mass to select a ϕ, a cut is also made on the helicity angle of the decay. Since the D_s^+ and π^+ each have spin 0 and the ϕ has spin 1, to conserve angular

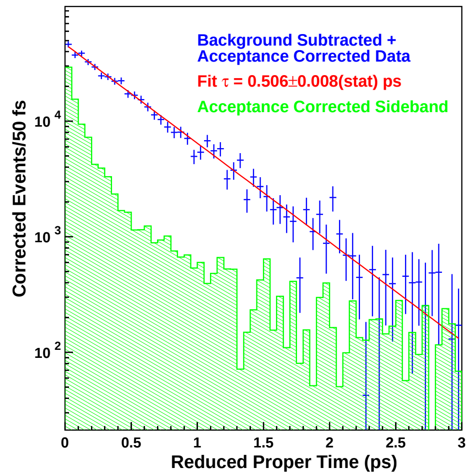

Figure 3: Preliminary FOCUS lifetime result for $D_s^+ \to \phi\pi^+$.

momentum the ϕ and π^+ must be in an orbital angular momentum $L = 1$ state. Hence the distribution of the angle between the π^+ and one of the kaons in the ϕ centre-of-mass should vary as $(Y_{L=1}^{m=0})^2 \propto cos^2\varphi$ for signal candidates whereas the yield of background candidates are expected to be independent of φ. This allows a selection for candidates with $|\varphi| > 0.3$ to increase signal-to-noise. The result of the lifetime fit is shown in figure 3. The preliminary result on the measured lifetime using 50% of the FOCUS data is given in table 2. Also shown in table 2 is the preliminary measurement of the lifetime of the Λ_c^+ using 80% of the FOCUS data. The Λ_c^+ is reconstructed using the $pK^-\pi^+$ decay mode and the signal and results of the lifetime fit are shown in figure 4. For both measurements a binned likelihood is used, taking events from the sidebands as the model for the lifetime distribution for background events under the charm mass peak. The acceptance is taken from Monte Carlo simulations. The acceptance correction is small, being larger for D_s^+ than for Λ_c^+.

SELEX is another Fermilab experiment that collected data in 1996-1997. The data were taken using a 600 GeV Σ^- beam and a π^- beam. The experiment was designed for good acceptance in the forward region and to produce larger fractions of charm-strange baryons. Shown in ta-

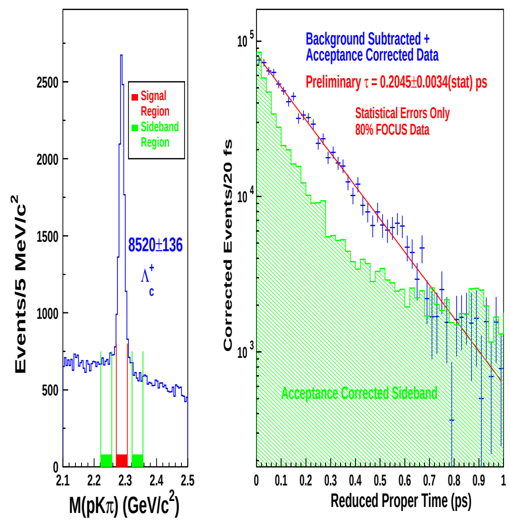

Figure 4: Preliminary signal and lifetime results for FOCUS $\Lambda_c^+ \to pK^-\pi^+$.

ble 2 is a preliminary measurement of the Λ_c^+ lifetime using 100% of the SELEX data in the $\Lambda_c^+ \to pK^-\pi^+$ mode [13]. The acceptance correction was obtained using D^0 data and checked with K_s^0 decays which occur near the interaction region. The signal and fit are published elsewhere [13].

The measurements and new world averages are shown in figure 5. The most significant result of these new measurements is that $\tau(D_s^+)$ is conclusively larger than $\tau(D^0)$. The world average is now $\tau(D_s^+)/\tau(D^0) = 1.211 \pm 0.017$ using the FOCUS measurement with statistical error only, this can be compared to the earlier PDG98 value of 1.125 ± 0.042.

3. Lifetimes and Theory

3.1 D^0 and D_s^+ Lifetimes

The D_s^+ lifetime is now conclusively measured to be above the D^0 lifetime, $\tau(D_s^+)/\tau(D^0) = 1.211 \pm 0.017$. Bigi and Uraltsev have used the QCD-based operator product expansion method to analyze this lifetime difference and have concluded that $\tau(D_s^+)/\tau(D^0) = 1.00$–$1.07$ is possible without W-annihilation or W-exchange contributions [14]. The D_s^+ lifetime is reduced by $\sim 3\%$ due to $D_s^+ \to \ell^+\nu_\ell$; Pauli interference in Cabibbo-suppressed D_s^+ decays increase the D_s^+ lifetime by $\sim 4\%$; and $SU(3)_f$ breaking in the "Fermi motion" of the c quark is expected to increase the D_s^+ lifetime by $\sim 4\%$, (one can view the quarks in the D_s^+ as more confined since f_{D_s} and hence the wavefunction at the original is larger for D_s^+ than for D^0.) Any difference in the measured D_s^+ and D^0 lifetimes larger than 7% must be attributed to sizable W-annihilation or W-exchange (WA/WX) effects.

With their estimation of the WA/WX contribution, Bigi and Uraltsev conclude that the ratio $\tau(D_s^+)/\tau(D^0) = 1.00$–$1.27$, though 0.8–1.27 is possible since the sign could change when one allows for interference between the WA/WX and the spectator contributions [14].

In a recent paper Cheng and Yang have also examined the D_s^+ and D^0 lifetime difference using the QCD-based operator product expansion technique together with the QCD sum rule approach to estimate the hadronic matrix elements [5]. They obtained $\tau(D_s^+)/\tau(D^0) \approx 1.08 \pm 0.04$ including their estimation of WX/WA contributions to both D^0 and D_s^+ decays. For the size of the WX/WA they calculate $\Gamma_{WX}(D^0)/\Gamma_{NL}^{Spect} = 0.10 \pm 0.06$ and $\Gamma_{WA}(D_s^+)/\Gamma_{NL}^{Spect} = 0.04 \pm 0.03$, where Γ_{NL}^{Spect} is the spectator decay contribution to the non-leptonic width.

3.2 Phenomenological Extraction of the W-exchange/W-annihilation in Inclusive D^0 and D_s^+ Decays

With the currently available large charm samples and more precise measurements of rare branching fractions, one may be able to do more phenomenological extractions from the data. As an illustration, a phenomenological extraction of the strength of the W-exchange/W-annihilation contribution to inclusive D^0 and D_s^+ decays can be done using some simple assumptions. The extraction is made possible by a now fairly precise measured value for

$$r_{DCSD} = \frac{\Gamma(D^+ \to K^+\pi^-\pi^+)}{\Gamma(D^+ \to K^-\pi^+\pi^+)} = (6.8 \pm 0.9) \times 10^{-3} \qquad (3.1)$$

This is an average of the value obtained by the PDG [3] and a preliminary FOCUS measurement of $r_{DCSD} = (6.5 \pm 1.1) \times 10^{-3}$ which includes statistical errors only [15].

I make the following assumptions:

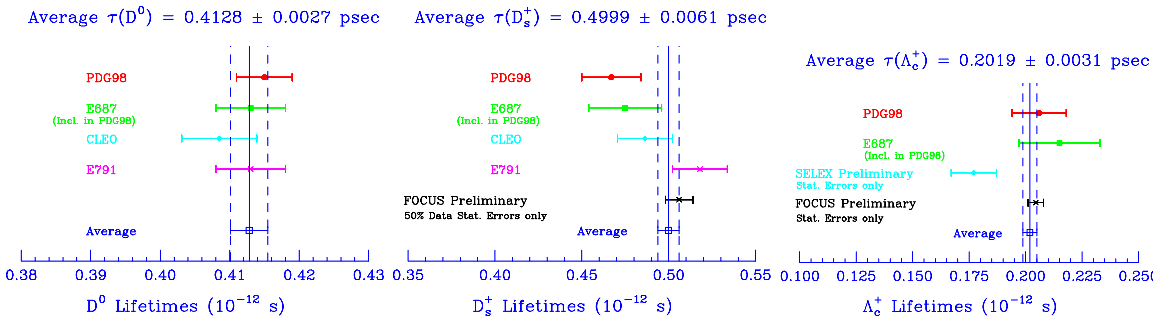

Figure 5: Summary of new charm lifetime measurements.

1. $\Gamma(D^+ \to K^+\pi^-\pi^+) \propto tan^4\theta_c \cdot \Gamma_{NL}^{Spect} + \Gamma_{WA}^{D^+}$;
2. $\Gamma(D^+ \to K^-\pi^+\pi^+) \propto \Gamma_{NL}^{PI}$;
3. $\Gamma_{WA}^{D^+} << tan^4\theta_c \cdot \Gamma_{NL}^{Spect}$; and
4. No interference between the WA/WX contribution and the spectator contribution.

Assumptions 1 and 2 make a possibly dubious relationship between an exclusive decay rate and a part of the inclusive rate. This could be approximately accurate if the effects of resonances and final state interactions in these decays are small enough to allow this assumption. With assumption 3, one can set $\Gamma_{WA}^{D^+} = 0$ in assumption 1. Finally assumption 4 gives $\Gamma_{tot}(D^0) = \Gamma_{NL}^{Spect} + \Gamma_{SL} + \Gamma_{WX}$ and $\Gamma_{tot}(D^+) = \Gamma_{PI} + \Gamma_{SL}$.

Using $r_{DCSD} = (6.8 \pm 0.9) \times 10^{-3}$ together with $\tau(D^+)/\tau(D^0) = 2.55 \pm 0.04$ and $\Gamma_{SL}/\Gamma_{tot} = 0.135 \pm 0.006$ obtained from the measured value of $BR_{SL}(D^0 \to X\ell\nu_\ell)$, the value for the strength of the W-exchange contribution can be extracted:

$$\frac{\Gamma_{WX}}{\Gamma_{NL}^{Spect}} = 0.29 \pm 0.17 \qquad (3.2)$$

where the error is just from the measured quantities and does not of course include uncertainties implicit in the assumptions of this model. The error is dominated by the error in r_{DCSD}.

In addition, using $\tau(D_s^+)/\tau(D^0) = 1.211 \pm 0.017$, $\Gamma_{NL}^{Spect}(D_s^+) = \alpha\Gamma_{NL}^{Spect}$ and together with $\Gamma_{WA}(D_s^+) = \beta\Gamma_{WX}$, the relative strength of the W-annihilation in D_s^+ decays to W-exchange in D^0 decays can be extracted to be $\beta = 0.33$ and thus:

$$\frac{\Gamma_{WA}(D_s^+)}{\Gamma_{NL}^{Spect}} = 0.10 \qquad (3.3)$$

The value of α has been taken to be $1/1.07$ to account for the differences between the D_s^+ and D^0 non-spectator decay contributions mentioned in the previous section.

This illustration only serves to give a somewhat more quantitative measure of the unexpectedly large size of the W-exchange/W-annihilation contributions. The phenomenologically extracted values of these are 2–3 times larger than those calculated by Cheng and Yang [5]. A more detailed model treatment is limited by the large uncertainties on some of the measured quantities used.[3] Note that we expect $\Gamma_{WX}^{D^0}$ to be different from $\Gamma_{WA}^{D_s^+}$ since the former is colour-suppressed whereas the latter is colour-allowed, but also since this in itself would predict the wrong sign for this difference, there must be more complicated processes, for example in the gluon exchanges in the two cases.

4. Conclusions

A number of new charm particle lifetime measurements have been published or were shown at conferences this year. The most significant update is that the D_s^+ lifetime is now conclusively measured to be above the D^0 lifetime. The ratio $\tau(D_s^+)/\tau(D^0) = 1.191 \pm 0.024$ using published measurements. Using the FOCUS preliminary measurement gives $\tau(D_s^+)/\tau(D^0) = 1.211 \pm$

[3] If one sets $\Gamma_{WA}^{D^+} = tan^4\theta_c \times \Gamma_{WX}^{D^0}$ we would get a non-sensible result of $\Gamma_{WA}^{D^+} = -\Gamma_{NL}^{Spect}$. A more reasonable assumption may be to set $\Gamma_{WA}^{D^+} = tan^4\theta_c \times \Gamma_{WA}^{D_s^+}$. However other problems arise here too, either because the assumptions are too simplistic or the measured quantities are still not yet measured precisely enough for a more sophisticated model.

0.017. This lifetime ratio is now large enough for one to conclude that the W-exchange contribution in D^0 decays is large, estimated to be about 30% of the non-leptonic spectator contribution using a simple phenomenological model. The W-exchange contribution appears to be at the limit of or larger than the values calculated using the QCD-based operator production expansion techniques. More precise charm data, for example in semileptonic decays, is needed to extract the size of the matrix elements used in these techniques to control the weight of WA/WX in D decays [5]. Note that this is in contrast to studies of W-exchange contributions in exclusive D^0 decays which is always complicated by final-state interactions, e.g. $D^0 \to \phi K_s^0$. If the W-exchange contribution is as large as the lifetime measurements suggest, then it must appear somewhere in the exclusive decays. However, conclusive evidence of W-exchange contributions in exclusive D^0 decays is still missing. Where are they?

We can look forward to more precise charm particle lifetimes from the Fermilab FOCUS and SELEX experiments, for both charm baryons and mesons. This should ensure continued theoretical interest in the physics of charm lifetimes.

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