# CHARMED LIVES

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Prelimary charm meson lifetimes using the new CLEO II.V silicon vertex detector are presented. These results are based on $1.6\,\mathrm{fb}^{-1}$ of data taken near the $\Upsilon(4\mathrm{s})$ resonance. The following results are consistent with previously measured lifetimes and the current world average:

$$\tau_{\mathrm{D}^0} = 0.403 \pm 0.009 \text{ (stat.) } {}^{+0.007}_{-0.011} \text{ (syst.) ps}$$

$$\tau_{\mathrm{D}^+} = 1.034 \pm 0.033 \text{ (stat.) } {}^{+0.033}_{-0.038} \text{ (syst.) ps}$$

$$\tau_{\mathrm{D}_\mathrm{s}^+} = 0.475 \pm 0.024 \text{ (stat.) } {}^{+0.025}_{-0.025} \text{ (syst.) ps}$$

## 1 Introduction

The $\Upsilon(4s)$ has been a physics rich environment for many years and is expected to yield exciting results in the years to come. With the advent of silicon detectors, the vertex physics at the $\Upsilon(4s)$ is expected to be scrutinized as never before but is not without challenge. Most tracks in a typical event are less than 1 GeV/c so the effect of multiple scattering must be minimized by building low $Z$ devices and placing them as close to the beams as possible. However, the beams at CESR are nearly 1/2 Amp (which is nearly 1/2 Amp more than any other silicon detector has seen) and so proximity is a compromise between vertex resolution and potential disaster. In the fall of 1995, a new precision silicon vertex detector[1] (SVX) was installed in the CLEO II[2] detector. The new detector configuration is referred to as CLEO II.V and is the prototype for similar detectors under construction for CLEO III[3], Belle[4] and BaBar[5]. The new SVX is a proof of principle that a silicon tracker can be successfully operated in such a challenging environment and has been an invaluable tool in the development and construction of the next generation devices. The preliminary charm lifetime measurements presented in this paper represent the first physics results from the new CLEO II.V SVX detector.

## 2 The New Silicon Vertex Detector

The CLEO II.V SVX is a three layer detector in a pinwheel configuration (see Figure 1). The

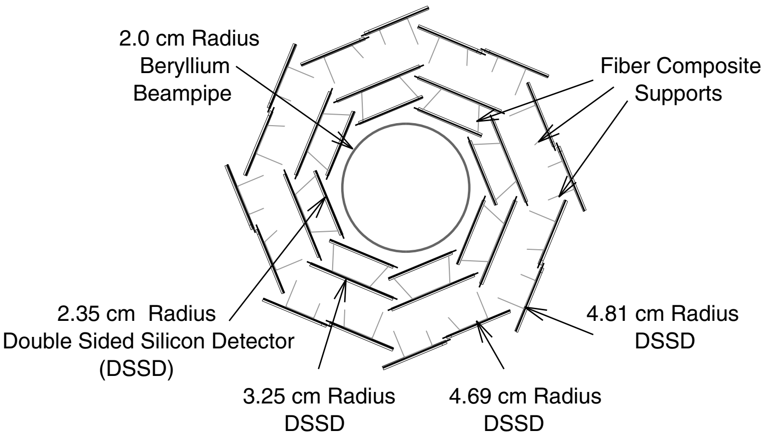


Figure 1: The CLEO II.V SVX is a compact device that registers both $r\phi$ and $z$ tracking information in 26,208 readout channels.

300 $\mu$m thick wafers are double-sided, producing both r$\phi$ and z hit information. The measured impact parameter resolutions for the SVX are

$$\sigma_{r\phi} = 24 \oplus \frac{42}{p \cdot sin^{3/2}\theta}\,\mu m \tag{1}$$

for the $r\phi$-side and

$$\sigma_z = 54 \oplus \frac{48}{p}\,\mu m\ ,\ (\theta = 90^\circ) \tag{2}$$

for the $z$-side. The multiple scattering coefficient is small due to the design of the device ($0.012{\cdot}X_0$ for SVX and $0.006{\cdot}X_0$ for the beampipe). The constant term is a function of the intrinsic resolution of the device and the short lever arm from the interaction region to the first SVX hit which is only 2.35 cm. The hit efficiencies in each layer of the device are high[1], resulting in an overall two-hit-per-view efficiency of 95% for each track in hadronic events.

## 3 Charm Sample Selection

The $\Upsilon(4s)$ energy scale is an excellent region for charm physics since there are two separable sources of charm mesons with large cross sections – $B$ decays (1 nb) and continuum production (1 nb). The

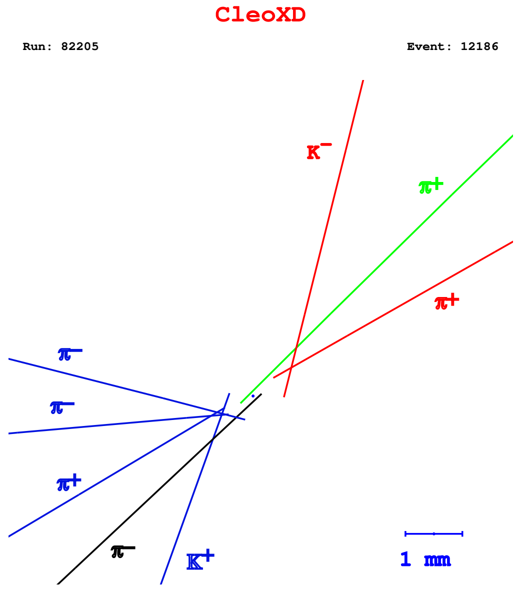


Figure 2: This event is interpreted as $e^+e^- \to D^{*+} + \bar{D}^0 + \pi^-$. There are three vertices - the lower left vertex is a $\bar{D}^0 \to K^+\pi^-\pi^+\pi^-$ decay, the center vertex is formed from a fragmentation pion (downgoing) and the soft $\pi$ from a $D^{*+} \to D^0\pi^+$ decay where the $D^0 \to K^-\pi^+$ vertex is the upper right vertex.

fragmentation function for continuum charm mesons is hard and it is quite distinct from the much softer spectrum from $B$ decays. Requiring a charm meson momentum greater than half the beam energy removes the charm from $B$ decays and is approximately 65% efficient for continuum events. The lifetime measurements presented in this paper were made using the continuum charm events.

A magnified CLEO II.V continuum charm event can be seen in Figure 2. The two jet tructure is evident and has been interpreted as $e^+e^- \to D^{*+} + \bar{D}^0 + \pi^-$. With the precision of the new SVX, three distinct vertices can be identified – the $\bar{D}^0 \to K^+\pi^-\pi^+\pi^-$ decay, the $D^{*+} \to D^0\pi^+$ decay and the primary interaction point where a fragmentation $\pi$ and the soft $\pi^+$ from the $D^{*+} \to D^0\pi^+$ form the third vertex. In the continuum charm events, the $D^0$ and $D_s^+$ will fly, on average, about 200 $\mu$m and the $D^+$ will fly about 480 $\mu$m.

This analysis was performed on 1.6 fb$^{-1}$ of the available 5 fb$^{-1}$ and was processed with a preliminary version of the reconstruction executable. Tracking cuts were employed to insure reasonable resonstruction on an event by event basis. Further, energy loss information, dE/dx, was required to be consistent with the expected energy loss. In order to optimize the impact parameter resolution, all tracks from the $D$ meson were required to have at least 2 hits in the SVX in each coordinate. To minimize the effects of multiple scattering, all tracks were required to have at least 200 MeV/c of momentum.

The lifetimes of the $D$ mesons are determined by measuring the distance they fly in the lab, $l_{dec}$, and their momenta for the proper time correction,

$$\tau = \frac{l_{dec}}{\gamma\beta} \quad . \tag{3}$$

The flight distance is derived from two space points – the decay vertex position and the production point. In this analysis, only fully reconstructed $D$ mesons are used which insures a decay vertex position[a] but well measured momentum as well. The production point is determined in two steps. First, the pseudo-track formed from the $D$ meson decay particles is vertexed with the run averaged beam spot, which at CESR is 7 $\mu$m high by 350 $\mu$m wide with a $z$ extent of 1 cm. The next step is to include fragmentation tracks and any tracks from higher order $D$ meson decays in the vertex fit. To minimize the lifetime bias from the opposite hemisphere, only tracks that contribute less than 5 to the vertex $\chi^2$ are used in the final interation point determination.

Each of the $D$ mesons in this analysis are reconstructed through a single decay channel. The $D^0$ is reconstructed through the

$$D^{*+} \to D^0\pi^+_{soft} \to K^-\pi^+\pi^+_{soft} \tag{4}$$

[a] Although there is SVX z information available, this preliminary analysis is done in two dimensions ($r\phi$).

decay chain. The $D^{*+} - D^0$ mass difference distribution is quite narrow, 440 KeV, demonstrating the precision with which CLEO II.V measures low momenta. This width can actually be reduced to less than 220 KeV in a three dimensional constrained fit to an event vertex but this is unnecessary in this analysis. A cut about the peak of the mass difference distribution of $\pm 0.8$ MeV is applied to arrive at the $D^0$ sample whose mass distribution can be seen in Figure 3. The $D^0$ mass distribution

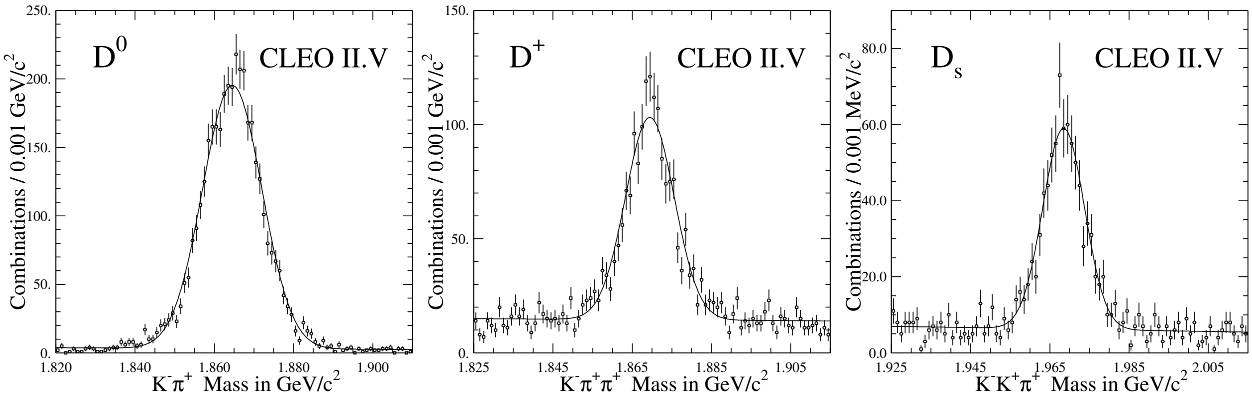


Figure 3: $K\pi$ mass distribution (left), $K\pi\pi$ mass distribution (center) and $KK\pi$ mass distribution (right).

is fit with a gaussian and a linear background. Due to the excellent overall momentum resolution,

$$\left[\frac{\sigma_p}{p}\right]^2 = (0.45\%)^2 + (0.16\% \cdot p)^2 \ , \tag{5}$$

fot the CLEO II.V data, the $D^0$ mass distribution is quite narrow ($7.5\,MeV$). There are 3610 signal events in the $D^0$ sample with 2.8% background in the $\pm 2\sigma$ $D^0$ mass region.

The $D^+$ is reconstructed through the

$$D^{*+} \rightarrow D^+\pi^0_{soft} \rightarrow K^-\pi^+\pi^+\pi^0_{soft} \tag{6}$$

decay chain. This channel relies on the excellent calorimetry in the detector since two low energy photons are required to reconstruct the $\pi^0$. The peak in the $D^{*+} - D^+$ mass difference distribution has a width of 1.01 MeV. This distribution is a measure of the calibration of the CsI crystals and the excellent resolution for low energy photons. A cut of $\pm 1.4$ MeV about the mass difference peak is applied to arrive at the $D^+$ sample. The resulting $D^+$ mass distribution has a width of 6.1 MeV (see Figure 3). The number of $D^+$ signal events is 1370 with 21.4% background in the $\pm 2\sigma$ region.

The $D_s^+$ is reconstructed via

$$D_s^+ \rightarrow \phi\pi^+ \rightarrow K^+K^-\pi^+. \tag{7}$$

Combinatorics in this channel are suppressed by requiring the intermediate $\phi$ mass to be within $\pm 6$ MeV of the nominal $\phi$ mass. Further background suppression occurs by requiring the $\phi$ helicity to be rather transverse, taking advantage of the vector to vector/pseudoscalar kinematics. Most of the combinatorics that are left are from random pion combinations in the backward direction of the decay so a cut is placed on the pion decay angle, $cos(\theta^{\pi^+}_{dec}) > -0.85$. The mass distribution for the $D_s^+$ sample can be seen in Figure 3 and has a width of 6.1 MeV. There are 697 $D_S^+$ candidates in the sample with 16.8% background in a $\pm 2\sigma$ window.

## 4 Unbinned Likelihood Lifetime Fits

The lifetime is determined in a six parameter unbinned log-likelihood fit. The fit parameters treat the signal and background and allow for tracking resolution adjustments. The fraction of signal and background is taken from the data itself. The mass distribution fits for each $D$ meson can be converted into a probability that the event is signal, $f_{sig}$, or background, $1 - f_{sig}$. The signal fraction is fit for a lifetime, $\tau_{sig}$, and the background is also allowed to have a component, $f_{\tau BG}$, that has a lifetime, $\tau_{BG}$. There is a global scaling factor, $S$, which scales the proper time uncertainties and an additional smearing term, $\sigma_{mis}$, applied to a fraction, $f_{mis}$, of the events where hard scattering or pattern recognition mistakes may have occurred.

Representations of the fits to the $D$ samples can be seen in Figure 4 where the fitted lifetime

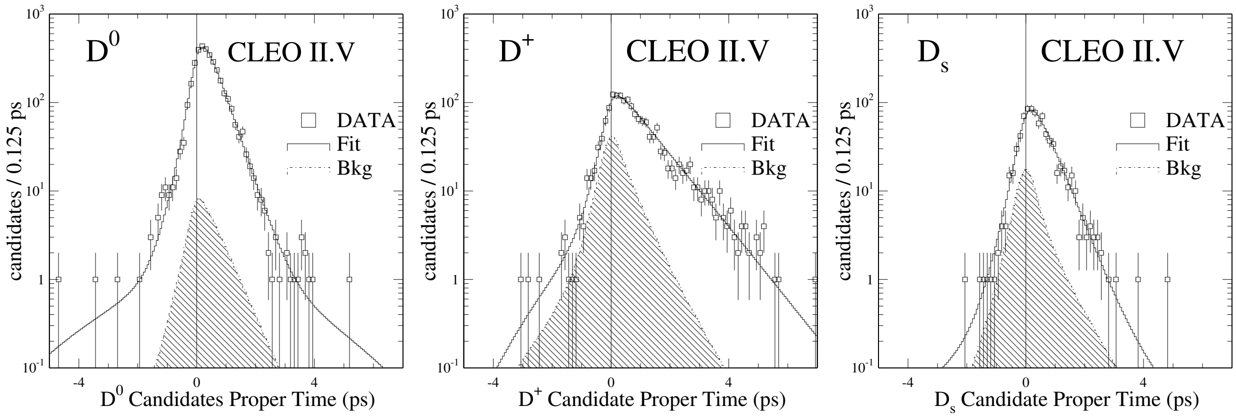


Figure 4: Proper time distribution for $D^0$ candidates (left), $D^+$ candidates (center) and $D_s^+$ candidates (right) around $\pm$ 2 $\sigma$ of the D mass peaks. The points are the binned proper time distributions and the solid line is the scaled fitting function. The estimated background fraction is indicated by the shaded area.

functions are superimposed on the binned proper time distributions. The fitted parameters for all three samples can be seen in Table 1. The fitted lifetimes are consistent with the world average lifetimes [6]. There is clearly a problem with the covariance matrices in this first pass over the data since the global scaling factor, $S$, inflates these errors by 50%. Optimized fitting weights and accurate Kalman input parameters will bring the scaling factor to unity for the final results.

Table 1: Results from the unbinned log-likelihood fit to the charm meson proper time distributions. The uncertainties are statistical only.

| Parameter | $D^0$ | $D^+$ | $D_s^+$ |
|---|---|---|---|
| $\tau_{\rm Sig}$ | 0.403 $\pm$ 0.009 ps | 1.034 $\pm$ 0.033 ps | 0.475 $\pm$ 0.024 ps |
| $\tau_{\rm BG}$ | 0.530 $\pm$ 0.081 ps | 0.529 $\pm$ 0.064 ps | 0.704 $\pm$ 0.116 ps |
| $f_{\tau_{\rm BG}}$ | 0.67 $\pm$ 0.10 | 0.38 $\pm$ 0.04 | 0.22 $\pm$ 0.05 |
| $S$ | 1.54 $\pm$ 0.04 | 1.47 $\pm$ 0.05 | 1.57 $\pm$ 0.06 |
| $f_{\rm mis}$ | 0.014 $\pm$ 0.003 | 0.052 $\pm$ 0.014 | 0.009 $\pm$ 0.006 |
| $\sigma_{\rm mis}$ | 2.8 ps $\pm$ 0.4 ps | 1.66 $\pm$ 0.20 ps | 2.7 $\pm$ 0.82 ps |

The CLEO II.V simulation has been used to test the lifetime fitting method. Figure 5 is a representation of the fit to the $D^0$ lifetime and looks very similar to the data. The lifetimes used in the simulation were varied over a wide range. The lifetime fit results, as a function of simulation input lifetimes, can also be seen in Figure 5. The fitting method tracks the input lifetimes quite well, demonstrating the robustness of the method.

## 5 Systematics

A study of the lifetime systematics was performed with the methods and results presented in table 2. The systematic errors were derived from data exclusively. Increasing the statistics of the samples by including all of the available luminosity and increasing the number of decay modes will not only decrease the statistical error but the systematic errors as well.

Global consistency checks were also performed. Lifetimes were measured as a function of dataset and global tracking parameters and were found to be consistent. The decay length uncertainty and vertex $\chi^2$ cuts were also changed and no significant dependence found. Due to the preliminary status of these measeuments, a very conservative approach was used to determine what is labeled as *consistency* in Table 2 from these sources. It is expected that these errors will be significantly reduced, if not entirely removed, in the final lifetime results.

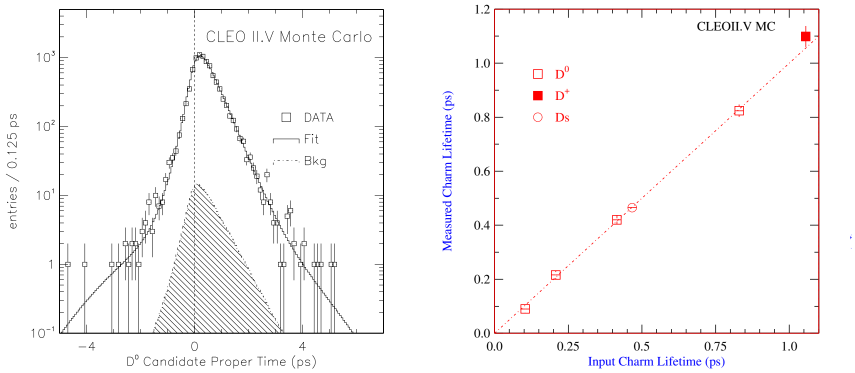


Figure 5: The CLEO simulation was used to test the robustness of the fitting method as a function of different $D$ meson lifetimes. The left plot is a representation of the fit against the binned proper lifetime distribution. The right plot shows the fitted lifetime as function of the simulation input lifetime.

Table 2: Systematic uncertainties for the charm meson lifetimes. The uncertainties marked with a star will decrease with more data and additional decay channels. The uncertainty *consistency* is due to the preliminary status of the results (see text).

| Uncertainty | $D^0$ | $D^+$ | $D_s^+$ | Method |
|---|---|---|---|---|
| decay vertex$^\star$ | $\pm$ 3.3 fs | $\pm$ 9.4 fs | $\pm$ 9.6 fs | $\gamma\gamma \rightarrow 4\pi$ events |
| decay length corr.$^\star$ | $^{+3.9}_{-3.8}$ fs | $^{+3.4}_{-3.2}$ fs | $^{+3.4}_{-3.3}$ fs | varied $\pm$ 1 $\sigma$ |
| $y$ beam position$^\star$ | $^{+0.4}_{-1.4}$ fs | $^{+0.0}_{-2.1}$ fs | $^{+0.0}_{-8.3}$ fs | varied $\pm$ 5 $\mu$m |
| $y$ beam size$^\star$ | $^{+0.5}_{-0.4}$ fs | $^{+0.0}_{-0.8}$ fs | $^{+1.0}_{-0.6}$ fs | varied $\pm$ 30 % |
| background$^\star$ | $^{+2.2}_{-0.1}$ fs | $^{+14.3}_{-2.0}$ fs | $^{+0.0}_{-10.1}$ fs | fit region varied |
| D mass | $\pm$0.1 fs | $\pm$0.3 fs | $\pm$0.1 fs | PDG D mass |
| D momentum | $\pm$0.1 fs | $\pm$0.3 fs | $\pm$0.1 fs | PDG D mass |
| consistency | $^{+4.2}_{-9.1}$ fs | $^{+27.7}_{-36.2}$ fs | $^{+23.3}_{-21.5}$ fs | cut variations |
| Total | $^{+6.9}_{-10.5}$ fs | $^{+32.8}_{-37.7}$ fs | $^{+25.4}_{-25.3}$ fs | |

## 6 Summary and Outlook

The preliminary CLEO II.V charmed meson lifetimes are presented in Figure 6 along with previous measurements and the world averages[6] in a graphical format. The final CLEO II.V charm lifetime analysis will include the entire CLEO II.V dataset ( possibly as large as 11 fb$^{-1}$ ), more decay modes, improvements in dE/dx and time-of-flight information and will utilize the precision SVX $z$ information. The final numbers from CLEO II.V are expected to be competitive with the world's best measurements.

The $D$ meson lifetimes are just the tip of the iceberg at CLEO II.V. There are charmed baryon lifetimes that can be measured in the same fashion as the mesons and are expected to be just as competitive. CLEO II.V could end up with over 20 million $\tau$ decays with precision vertex information (enough said). The dramatically improved $D^* - D$ mass difference resolution in CLEO II.V leads to a reduction of a factor of 3 in background (with respect to CLEO II) making a more precise measurement of $V_{cb}$ from $B \rightarrow D^* l\nu$ possible. Also, $D^0$ mixing becomes an interesting proposition with the new SVX. CLEO II was the first to observe the wrong sign $D^0$ decays and now, with precision vertexing, higher statistics and lower backgrounds, the prospects of a measuring the $D^0$ mixing parameters is within reach. At the very edge of our resolution is the $B$ lifetime. Before the SVX was installed the $B$ mesons produced at the $\Upsilon$(4s) could be considered effectively at rest. However, they do actually fly an average of 30 $\mu$m before decaying!

## 7 Acknowledgements

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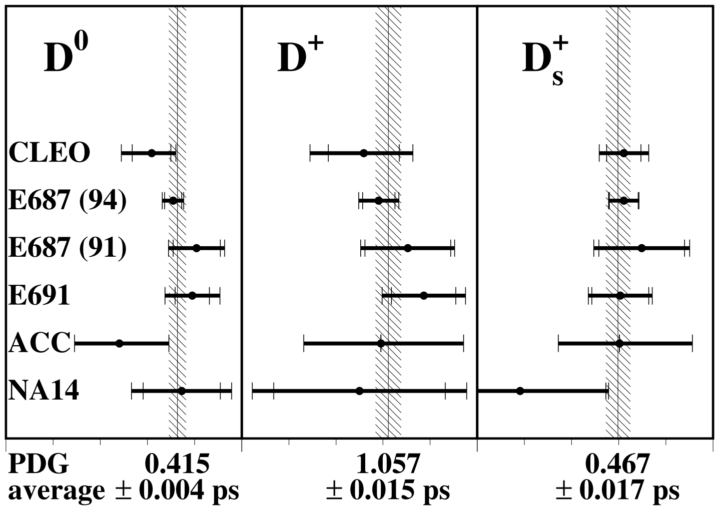


Figure 6: Preliminary CLEO II.V charm meson lifetimes compared to world averages and the measurements used to determine them.

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