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Measurement of the Tau Lepton Lifetime

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Abstract

Using $\tau^+\tau^-$ pairs in which one or both of the τ's decays to three charged particles we measure the τ lepton lifetime. The data used in this analysis were collected with the CLEO-II detector at CESR and consist of an integrated luminosity of 2 fb^{-1} taken at energies near the $\Upsilon(4S)$. We use the vertex displacements of the three charged tracks to determine the τ lifetime. For a sample of events where one τ decays into three charged tracks and the other τ decays into one charged track we measure $\tau_\tau = (2.91 \pm 0.04 \pm 0.07) \times 10^{-13}$ s. For a sample of events where both τ's decay into three charged tracks we measure $\tau_\tau = (2.85 \pm 0.13 \pm 0.10) \times 10^{-13}$ s.

I. INTRODUCTION

The decay of the τ lepton provides a useful testing ground for the Standard Model of electroweak interactions [1]. Within the framework of this model the τ is a sequential lepton and therefore its properties such as mass, lifetime, and leptonic decay rate are related to

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each other. If the τ is a sequential lepton, then its coupling to the W is the same as that of the μ and its lifetime is directly related to the μ lifetime (τ_μ). To lowest order [2] and neglecting the electron and neutrino masses, the Standard Model predicts:

$$\tau_\tau = \tau_\mu (m_\mu / m_\tau)^5 B(\tau^- \to e^- \nu_\tau \bar{\nu}_e) \quad (1)$$

The calculated τ lifetime (τ_τ) depends directly on experimental measurements of the μ mass (m_μ) and lifetime and the τ mass (m_τ) and electronic branching ratio ($B(\tau^- \to e^- \nu_\tau \bar{\nu}_e)$). Using the world average values for these quantities [3] the predicted lifetime becomes:

$$\tau_\tau = (1.63 \pm 0.002) \times 10^{-12} B(\tau^- \to e^- \nu_\tau \bar{\nu}_e) = (2.92 \pm 0.03) \times 10^{-13}\ \mathrm{s}. \quad (2)$$

In this paper we present a new measurement of the τ lifetime based on a high statistics sample of 1 vs 3 and, for the first time, 3 vs 3 τ decays.

II. THE DATA SET

The data sample used in this analysis was accumulated at the Cornell Electron-Positron Storage Ring (CESR). It corresponds to a total integrated luminosity of 2 fb^{-1}, with approximately two thirds of the data collected at the $\Upsilon(4S)$ ($\sqrt{s}$ =10.58 GeV), and the rest at energies slightly below the $\Upsilon(4S)$. This luminosity corresponds to the production of some $1.8\mathrm{x}10^6$ τ-pairs, of which 25% [3] have one τ decaying into 1 charged track while the other decays into three charged tracks and 1% [3] have both τ's decaying into only three charged tracks.

III. DETECTOR

The CLEO-II detector emphasizes precision charged particle tracking and high resolution electromagnetic calorimetry. A brief description of the charged particle tracking system follows, while a detailed description of the detector can be found in Ref [4].

A. Charged Particle Tracking

The CLEO-II detector surrounds a 3.5 cm radius beryllium beampipe of thickness 0.5 mm. The inner wall of the pipe is coated with 25 μm of silver for synchrotron radiation shielding. The beampipe contributes 0.44% of a radiation length of material for a particle of normal incidence. Charged particle tracking is accomplished using information from three concentric chambers: a 6 layer straw tube chamber (PT), whose innermost layer is located 4.7 cm from the interaction point, a 10 layer high precision vertex wire chamber (VD), and a 51 layer (40 axial layers and 11 stereo layers) wire drift chamber (DR). The z position (coordinate along the beam axis) is determined using the stereo layers of the DR and cathode strips mounted on the inner and outer walls of both the VD and DR. Charged particles are momentum-analyzed using the 67 tracking layers inside a 1.5 Tesla superconducting coil. The typical spatial resolution of a reconstructed hadronic event vertex is ≈ 180 μm in the $r-\phi$ plane, perpendicular to the beam axis.

B. Event Selection

Our analysis is based on a sample of $e^+e^- \to \tau^+\tau^-$ events. We measure τ_τ using the vertex distribution of τ decays into three charged particles using both the 1 vs 3 and the 3 vs 3 topology. First we describe the selection criteria for the 1 vs 3 sample.

1. 1 vs 3 Event Selection

The selection of 1 vs 3 tau events follows the procedure of Ref. [5]. Selection begins by excluding all events which do not have exactly 4 charged tracks, with a net charge of 0. To ensure that the event is well measured, we demand the distance of closest approach of each track be within 1 cm of the IR in the xy-plane and 10 cm in z (the beam direction). The plane perpendicular to the highest momentum charged track is used to define two hemispheres. One hemisphere must have exactly one charged track, and the other must have 3 charged tracks. QED backgrounds such as radiative-Bhabha and two-photon interactions are suppressed by requiring that the total energy of the event be greater than $0.30E_{cm}$ and the total shower energy be less than $0.75E_{cm}$. The invariant mass of charged and neutral particles within each hemisphere must be less than 1.6 GeV (assuming all charged tracks are pions), and the missing mass must be between 0.5 and 7.0 GeV. To reduce 2 photon backgrounds, only one track is allowed to be identified as an electron. The total momentum vector of the particles in each hemisphere is required to be in the barrel region of the electromagnetic calorimeter, $|\cos\theta| < 0.80$, where the polar angle θ is defined with respect to the beam direction. The Monte Carlo selection efficiency for generic tau events is 10.2%. Continuum and 2 photon selection efficiencies are 0.14% and 0.19%, respectively ($B\bar{B}$ background is negligible).

Once an event has passed this basic event selection, additional cuts are applied based on tracking criteria. First, all of the three- prong charged tracks must have at least 2 PT hits, 4 VD hits, and 10 DR hits. Two of the three tracks must also satisfy the following cuts: have momentum in the range 0.3<p<4.0 GeV/c, > 39 drift chamber layers contributing to the track fit, distance of closest approach to the interaction region < 5 mm, and average track residual < 300 μm. Additional events are rejected if the 3-prong vertexing code cannot fit the tracks to a common vertex. This is discussed in detail below. Finally, all remaining events must have a measured value for $c\tau$ between -4100 and 4300 μm and a measured $c\tau$ error of less than 400 μm. The final data sample includes 37471 events.

2. 3 vs 3 Event Selection

The selection of double 3-prong events is discussed in detail in Ref. [6]. We require six charged tracks divided into hemispheres by the charged-particle thrust axis. The net charge in each hemisphere is required to be $\pm$ 1 and the total charge of the event must be zero. To ensure that the event is well-measured, we require the polar angle of all tracks to be in the central region of the detector, $|\cos\theta| < 0.81$, and the momenta to be greater than $0.05E_b$. Events with secondary vertices identified as being consistent with K_S or Λ decays or pair conversions are rejected. To reject hadronic background we veto events with energetic showers which are more than 30 cm from the nearest charged track, have a lateral profile consistent with that of photons, and have energy greater than 120 MeV. Hadronic background is further reduced with little loss of signal by requiring both 3-prong invariant masses to be less than 1.5 GeV/c^2. In order to reject two-photon background, we require that the polar angle of the missing momentum satisfy $\cos\theta < 0.98$. In addition we require the scalar sum of the charged particle momenta to be at least $0.45E_{cm}$. The sample at this level contains 3708 events.

Track and vertex quality requirements are as for the 1-3 analysis except that for the 3-3 sample only two of the three tracks have to satisfy the cuts on minimum numbers of hits, to avoid excessive loss of events. A total of 1447 events pass the selection criteria.

C. Background Estimates

The remaining hadronic background in the sample is modeled using a Monte Carlo simulation of continuum, two-photon and $B\bar{B}$ events in the CLEO-II tracking chambers and trigger system.[1]

1. 1 vs 3 Event Sample

The hadronic background in the 1 vs 3 sample is estimated using both data and Monte Carlo calculations to be 1.0%. From a Monte Carlo calculation we estimate the two photon background in the sample to be less than 0.2%, dominated by hadronic final states. By varying the selection criteria and studying the data and Monte Carlo we estimate the remaining background from Bhabha and mu-pair events with a photon conversion in the beam pipe to be less than 0.5%. We have also investigated possible contamination from beam gas interactions and $\Upsilon(4S) \to B\bar{B}$ decays and found these sources have a negligible effect on the analysis.

2. 3 vs 3 Event Sample

The measured backgrounds in the 3 vs 3 sample are [6] $4.7 \pm 0.9\%$ $q\bar{q}$, $<0.1\%$ $B\bar{B}$ and < 0.2 % two-photon events. These were determined from Monte Carlo calculations and data. In particular the scale of the $q\bar{q}$ background is set by the observed population of the mass sideband between 1.5 and 2.0 GeV/c^2.

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[1]Monte Carlo events have been generated using a $c\tau$ of 126 μm for the D^0 , 133 μm for the D_s, and 318 μm for D^+.

IV. LIFETIME DETERMINATION PROCEDURE

A. Measuring $c\tau$ for 1 vs 3 events

The tau proper flight distance, $c\tau$, is calculated using:

$$c\tau = \frac{1}{\gamma\beta}\frac{L_{xy}}{\sin\theta} = \frac{m_\tau}{p_\tau}\frac{L_{xy}}{\sin\theta} \tag{3}$$

where γ, β, and p_τ, the magnitude of the τ's momentum, are calculated using the beam energy. L_{xy} is the flight path in the plane transverse to the z axis. We measure L_{xy} rather than L because the tracking resolution in the xy ($= r\phi$) plane is an order of magnitude better than the resolution in the z direction. This decay distance is converted to the full decay distance (L) using $\sin\theta$, with θ the polar angle. The τ polar angle is approximated using the vector momentum of the 3 charged tracks. From a Monte Carlo calculation we find that the distribution of deviations between the true θ of the τ and θ calculated using the vector momentum of the three charged tracks has a mean of zero and an R.M.S. deviation of 5°.

Initial state radiation reduces the τ energy to less than the beam energy. Consequently, the τ's average flight path ($\approx$250μm) is less than that predicted by using the beam energy to calculate p_τ. Although on an event by event basis the true τ production energy is not known, the average correction to the τ energy can be determined from a Monte Carlo simulation [7]. We find the average decay distance of the selected τ sample is reduced by f_{rad}=3.1% from this effect.

1. Vertex Reconstruction

For each τ the most probable decay length in the transverse plane, L_{xy}, is determined via the equation:

$$L_{xy} = \frac{Xt_x\sigma_y^2 + Yt_y\sigma_x^2 - (Xt_y + Yt_x)\sigma_{xy}^2}{t_y^2\sigma_x^2 + t_x^2\sigma_y^2 - 2t_xt_y\sigma_{xy}^2} \tag{4}$$

with :

$$X = X_v - X_b \text{ and } Y = Y_v - Y_b \tag{5}$$

In the above equation, X_v and Y_v are the horizontal and vertical decay coordinates of the τ and X_b and Y_b are the horizontal and vertical production points of the τ. The determination of these quantities is discussed below. Here $\sigma_x^2(\sigma_y^2)$ is the variance of $X(Y)$ and σ_{xy}^2 is the correlation term for the X and Y vertex errors.[2] Finally, t_x and t_y are direction cosines calculated from the momentum vector of the three charged tracks. Negative decay distances

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[2]We expect the uncertainty in X to be larger than in Y since the error in X is dominated by the error in X_b which is dominated by the beam spread.

arise when the reconstructed vertex lies in the hemisphere opposite that of the 3-prong momentum vector.

An event-by-event estimate of X_v and Y_v is obtained using a χ^2 minimization algorithm [8]. In this procedure the three charged tracks opposite to the 1-prong are constrained to come from a common (X,Y) point. Events with a χ^2 per degree of freedom of greater than 24 or reconstructed $|c\tau|$ greater than 0.42 cm (approximately 50 τ lifetimes) are eliminated from further consideration.

2. Beam Positions

Beam positions in the xy plane, X_b and Y_b, are determined for each run using an average of 350 hadronic events. Events are required to have more than 4 charged tracks in order to eliminate τ events from the beam position calculation. Track quality cuts are imposed to eliminate poorly fit tracks and low momentum tracks which might have large multiple scattering effects. Tracks are fit to a common vertex with the same algorithm used for finding the τ decay point. With these event vertices we determine an average position and R.M.S. deviation every data run. After excluding events more than three standard deviations from the mean beam position, the process is repeated. The uncertainties in the beam position per run (σ) for x and y are typically 35 μm and 15 μm, respectively. The full error on the production point also includes a contribution from the finite extent of the beams (350 μm in x and 10 μm in y).

B. Measuring $c\tau$ for 3 vs 3 events

In the double vertex method we take 3 vs 3 τ-pairs, reconstruct both vertices, and compute the projection of the difference of these decay lengths along the estimated line of flight of the taus. The measurement is independent of the beam position. Hence systematic errors are limited to those associated with reconstruction of the vertices, which in turn depend on the track reconstruction and fitting.

For the separation λ between two exponential decays the distribution is

$$f(\lambda) = \frac{\lambda}{d^2} e^{-\lambda/d} \qquad (\lambda \geq 0) \tag{6}$$

(d$\equiv \langle\beta\gamma c\tau\rangle \simeq 250\mu$), which has mean $\langle\lambda\rangle = 2d$ and rms $\sigma_\lambda = \sqrt{2}d$. Note that $f(\lambda)$ vanishes at $\lambda = 0$, and $\langle\lambda\rangle/\sigma_\lambda = \sqrt{2}$, compared with unity for the exponential distribution.

Identifying the transverse projection λ_{xy} we have $L_{xy} = \frac{1}{2}\lambda_{xy}$ given by Eq. 4 with the replacements

$$X = 1/2(X_{v2} - X_{v1}),\ \ Y = 1/2(Y_{v2} - Y_{v1}),\ \ \sigma^{-1} = (\sigma_1^{-1} + \sigma_2^{-1}),$$

and $t_{x,y}$ = the direction cosines of the momentum-difference vector of the three-prong jets. The positions X_v and Y_v and their associated error matrices σ are obtained from χ^2 fits for each vertex [9].

The CLEO II detector emphasizes precision charged particle tracking and high resolution

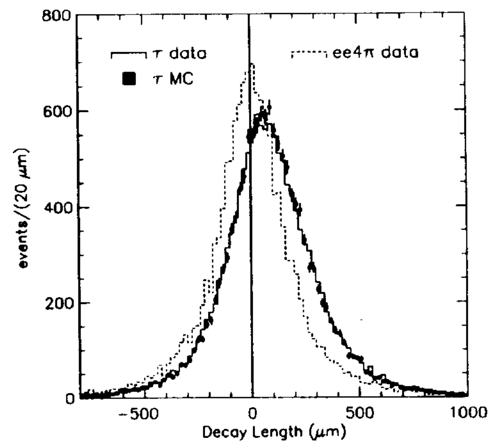

FIG. 1. Decay length distribution for Monte Carlo and Data for 1 vs 3 events.

C. The Lifetime

We determine the lifetime of our data sample using a weighted average of the proper flight distances calculated according to Eq. 3. The weight of each event is calculated using the error matrix from the vertex fit. We prefer to use this averaging procedure rather than a fitting technique (*e.g.* maximum likelihood) since the mean value of the distribution is independent of the scale of the decay length errors as long as they are symmetric. See [8] for more details.

The mean τ lifetime, τ_τ, and the mean lifetime of the event sample, τ_{meas}, are related by:

$$\tau_{meas} = (1 - f_{bg})(1 - f_{rad})\tau_\tau + f_{bg}\tau_{bg}, \tag{7}$$

where f_{bg} is the fraction of non-τ events in the sample, τ_{bg} is the mean lifetime of these events, and f_{rad} is the correction due to initial-state radiation discussed in Section IV A. The lifetime of the sample, τ_{meas}, is the average decay length found with the vertex-fitting process described above.

The lifetime of the background sample is computed using a Monte Carlo simulation and confirmed using data. For the hadronic background in the 1 vs 3 (3 vs 3) sample we find $c\tau_{bg}$ = 7 ± 22 μm (-21 ± 13 μm).

The measured $c\tau$ distributions for 1 vs 3 and 3 vs 3 events are shown in Fig. 1 and Fig. 2 respectively. Also displayed is a Monte Carlo calculation for this distribution (including contributions from the backgrounds) showing good agreement with the shape of the data distribution. We measure $c\tau_{meas}$ to be 83.7±1.1 μm for the 1 vs 3 sample and 79.8±3.6 μm for the 3 vs 3 sample. After correcting for backgrounds and initial state radiation we measure $c\tau_\tau$ to be 87.2±1.2 μm for the 1 vs 3 sample and 85.3±3.8μm for the 3 vs 3 sample.

($B\bar{B}$ background is negligible).

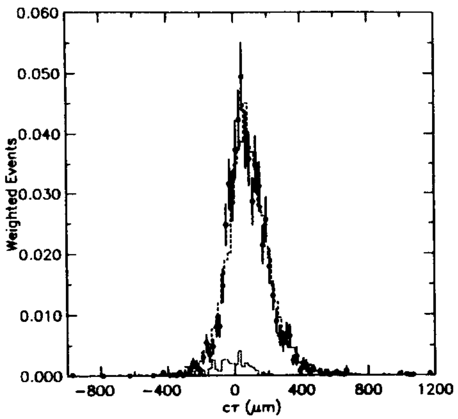

FIG. 2. Decay length distribution for Monte Carlo and Data for 3 vs 3 events. Data are indicated by points with error bars, simulation (signal plus background) by the dashed histogram, and background simulation by the dotted histogram.

V. CORRECTIONS, SYSTEMATIC ERRORS, AND CONSISTENCY CHECKS

A. Corrections and Systematic Errors

We have considered corrections and systematic errors for the measurement from several sources: charged particle tracking and subsequent vertex reconstruction, uncertainty in the beam position, uncertainty in the amount of background in the sample, and uncertainty in the lifetime of the background. We address these sources below.

We perform a detailed check of the methods of determining the τ vertex and decay length using Monte Carlo simulated data. To study possible bias from the vertex fitting method, we vary the τ lifetime in the Monte Carlo and compare the resulting $c\tau_\tau$ for the sample with the input. Monte Carlo samples of τ's with different lifetimes have been generated and processed through the analysis chain. We find no offset bias from this source.

For the 1 vs 3 analysis we used a large sample of two-photon events with 4 charged tracks in the final state as a systematic check of the vertexing code and method. Here we expect the event sample to have a mean decay length of 0 μm. After correcting for background events in this sample we measure an average decay length of -1.8 ± 1.8 μm, consistent with no bias. We conservatively assign a systematic error of ± 1.8 μm to account for effects due to tracking, vertexing and the lifetime method for the 1 vs 3 analysis.

For the 3 vs 3 analysis, systematic errors from uncertainty concerning the conversion of the true $c\tau$ to the reconstructed $c\tau$ have been considered. Because the beam position is in no way employed, the errors in the beam position estimation contribute no systematic uncertainty to the 3 vs 3 measurement. Among the effects we consider that do contribute are the finite statistics of the τ Monte Carlo sample, and biases in the vertex reconstruction algorithm, the track reconstruction, and the technique of central estimation. We estimate the combined systematic error from these sources to be 2.8 μm.

The sensitivity of the lifetime measurement to the beam position and beam size has been studied by independently shifting the beam position and beam width using data and Monte Carlo samples. Displacements of the central beam position by 100 μm does not shift the central lifetime value. Similarly, variation in the beam spot size up to 100 μm introduces no shift in the lifetime; therefore, we assign 0.3 μm, as the systematic error from these beam related sources.

The systematic error due to the uncertainty in the background fraction is calculated to be 1.0 μm, taking into account uncertainties in the modelling of the background composition and the sensitivity of the background fraction to the event selection criteria. This error also accounts for the change in f_{b_g} when we use two independent methods to estimate it. Finally, the systematic error due to the uncertainty in the lifetime of the background is calculated to be 0.2 (0.6)μm. for the 1 vs 3 (3 vs 3) analysis.

Systematic errors for the two analyses are summarized in Table 1. The total systematic error for each analysis is obtained by combining each term in quadrature. Thus for the 1 vs 3 sample we measure $c\tau_\tau = 87.2 \pm 1.2 \pm 2.1$ μm corresponding to $\tau_\tau = (2.91 \pm 0.04 \pm 0.07) \times 10^{-13}$ s, with the first error statistical and the second systematic. For the 3 vs 3 sample we measure $c\tau_\tau = 85.3 \pm 3.8 \pm 3.0$ μm corresponding to $\tau_\tau = (2.85 \pm 0.13 \pm 0.10) \times 10^{-13}$ s.

Table 1: Systematic errors for both analyses in μm.

Source	1 vs 3	3 vs 3
Tracking and Vertexing	1.8	2.8
Beam Position + Size	0.3	0.0
Background Fraction	1.0	1.0
Background Lifetime	0.2	0.6
Total	2.1	3.0

B. Consistency Checks

The vertex fitting procedure has been tested on data by examining the measured lifetime as a function of the χ^2/D.O.F., and as a function of the total number of PT hits included on the three-prong tracks. Both distributions are flat, indicating no bias. To check the sensitivity of $c\tau_{meas}$ to detector systematics the data have been divided into several sets of independent samples. We have studied these samples for biases due to: the charge of the decaying τ, the gas mixture (DME or argon/ethane) in the innermost tracking detector (PT), the tag of the recoiling τ, the χ^2/D.O.F. limit, and the ϕ and θ of the τ. In all cases there is good agreement between the samples.

VI. CONCLUSIONS

Using a large sample of 1 vs 3 τ events we measure $\tau_\tau = (2.91 \pm 0.04 \pm 0.07) \times 10^{-13}$ s, Using an independent sample of 3 vs 3 τ events we measure $\tau_\tau = (2.85 \pm 0.13 \pm 0.10) \times 10^{-13}$

s. In an earlier paper [10] we reported a measurement of τ_τ obtained with τ-pairs of the 1 vs 1 topology. In these events the lifetime is related to the dependence of the impact parameter difference on the acoplanarity angle. The result was $(2.94 \pm 0.07 \pm 0.12) \times 10^{-13}$ s. That sample is independent of those contributing to the present measurements. Taking account of the common systematic error of 0.06×10^{-13} s, associated mainly with the track reconstruction, we find the combined result from 1 vs 3, 3 vs 3, and 1 vs 1 events

$$\tau_\tau = (2.91 \pm 0.03 \pm 0.07) \times 10^{-13} \mathrm{s}.$$

This is consistent with other measurements of τ_τ and is consistent with the prediction of the Standard Model based on the world average of the τ electron branching ratio and m_τ.

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REFERENCES

[1] S. L. Glashow, A Salam, S. Weinberg, Rev. Mod. Phys, **52**, (1980) 515.

[2] A summary of the corrections to the τ lifetime can be found in: W. J. Marciano, The Vancouver Meeting, in: Proc. Particles and Fields '91 (Vancouver, August 1991), Vol. 1, ed. D. Axen, D. Bryman, and M. Comyn (World Scientific Publishing Co. Pte. Ltd., Singapore, 1992) p. 461. The radiative corrections to the lifetime calculation are of the order of α and increase the average decay length by less than 1%.

[3] (Particle Data Group) L. Montanet *et al.*, Phys. Rev. D **50**, 1173 (1994).

[4] Y. Kubota *et al.*, Nucl Inst. Meth. **320** (1992) 66;

[5] D. Bortoletto *et al.*, Phys. Rev. Lett. **71** (1993) 1791.

[6] B. Barish *et al.*, contribution to this conference, GLS0249.

[7] KORALB 2.1 S. Jadach and Z. Was, Comp. Phys. Commun. **64** (1991) 267, and TAUOLA1.5, S. Jadach, J. Kuhn, Z. Was, Comp. Phys. Commun. **64** (1991) 275. The size of the correction to the lifetime is insensitive to the photon energy cutoff used in the simulation.

[8] J. Whitmore, Ph.D. thesis, Ohio State University (1992) unpublished.

[9] W. T. Ford, CLEO Software Note CSN 94/329 (1994).

[10] Mourad Daoudi, Proceedings of the 5th International Symposium on Heavy Flavour Physics, Montréal, Canada, July 6-10, 1993.