SOME RECENT τ RESULTS FROM CLEO-II

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ABSTRACT

We report new results on the lifetime of the τ-lepton (τ_τ) and the magnitude of the helicity of the τ neutrino ($|h_\nu|$). The data were collected with the CLEO-II detector at CESR and consist of $\approx$2 fb^{-1} taken at energies near the $\Upsilon(4S)$. Using $\tau^+\tau^-$ pairs in which one (both) of the τ's decays to three charged particles we measure τ_τ=$(2.91 \pm 0.04 \pm 0.07) \times 10^{-13}$ ($(2.85 \pm 0.13 \pm 0.10) \times 10^{-13}$)s. We measure $|h_\nu| = 0.99 \pm 0.06 \pm 0.10$ using events where both τ's decay via $\tau \to \pi\nu$.

1. Introduction

In this paper we present new measurements of the τ lifetime based on a high statistics sample of 1 vs 3 and, for the first time, 3 vs 3 τ decays. We also present a new measurement of the magnitude of the helicity of ν_τ ($|h_\nu|$) using the reaction $e^+e^- \to \tau^+\tau^-$, $\tau^- \to \pi^-\nu_\tau$, $\tau^+ \to \pi^+\bar{\nu}_\tau$.

2. The Data Set

The data used in this analysis was taken with the CLEO detector at the Cornell Electron-Positron Storage Ring (CESR). It corresponds to a total integrated luminosity of 2 fb^{-1}, with $\approx$ 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 $\approx$1.8x10^6 τ-pairs. The CLEO-II detector emphasizes precision charged particle tracking and high resolution electromagnetic calorimetry. A detailed description of the detector can be found in Ref. [1].

3. τ Lifetime

The decay of the τ-lepton provides a useful testing ground for the Standard Model of electroweak interactions.[2] 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 mass and lifetime . To lowest order[3] and neglecting the electron and neutrino masses, the Standard Model predicts:

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

The calculated τ lifetime depends directly on experimental measurements of the μ mass and lifetime and the τ mass and electronic branching ratio. Using the world average values for these quantities[4] the predicted lifetime becomes:

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

*For the CLEO Collaboration.

3.1. *Event Selection*

The selection of 1 vs 3 tau events follows the procedure of Ref. [5]. Selection criteria include charge conservation, event topology, momentum and energy balance, and quality of charged track reconstruction. A total of 37471 events pass all of the 1 vs 3 event selection criteria.

The 3 vs 3 analysis is based on a sample of events in which both τ's decay into three charged hadrons and no π^{o}'s. The selection of double 3-prong events is discussed in detail in Ref. [6]. A total of 1447 events pass all selection criteria.

3.2. *Background Estimates*

The hadronic background in the 1 vs 3 (3 vs 3) sample is estimated using both data and Monte Carlo * calculations to be 1.0% (4.7%). From a Monte Carlo calculation we estimate the two photon background in both samples to be $< 0.2\%$, 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 to be $<0.5\%$ for the 1 vs 3 analysis and negligible for the 3 vs 3 analysis. We have also investigated possible contamination from beam gas interactions and $\Upsilon(4S) \rightarrow B\bar{B}$ decays and found these sources have a negligible effect on both analyses.

3.3. *Lifetime Determination Procedure*

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. 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.

Initial state radiation reduces the τ energy to less than the beam energy. Consequently, the τ's average flight path ($\approx 250\mu$m) 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.

3.4. *Vertex Reconstruction*

For the 1 vs 3 analysis the most probable decay length in the transverse plane, L_{xy}, is determined via the equations:

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

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*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^+.

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

In the above equations, 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. 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.† Beam positions in the xy plane, X_b and Y_b, are determined for each run. 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, 10 μm in y). Finally, t_x and t_y are direction cosines calculated from the momentum vector of the three charged tracks.

An event-by-event estimate of X_v and Y_v is obtained using a χ^2 minimization algorithm.[8] Events with a χ^2 per degree of freedom > 24 or reconstructed $|c\tau| > 0.42$ cm (≈ 50 τ lifetimes) are eliminated from further consideration.

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 τ's. This measurement is independent of the beam position. For the separation λ between two exponential decays the distribution is

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

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

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

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]

3.5. 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. 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. The lifetime of

†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.

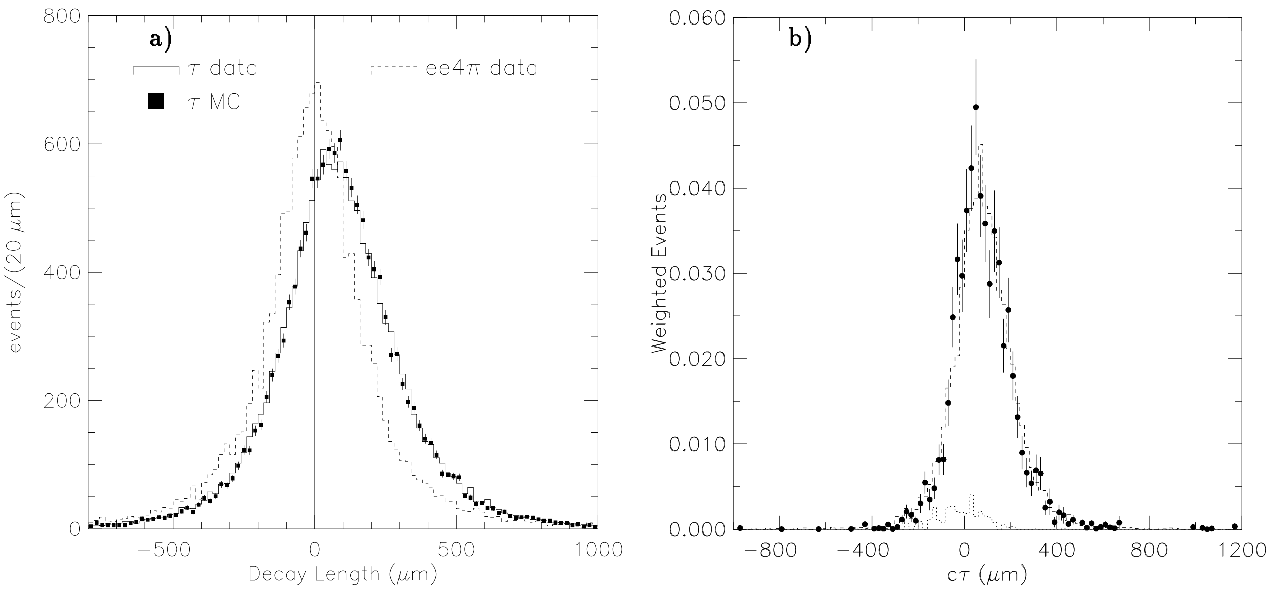

Fig. 1. Decay length distribution for Monte Carlo and Data for 1 vs 3 events (a) and for 3 vs 3 events (b). For 3 vs 3 sample data are indicated by points with error bars, simulation (signal plus background) by the dashed histogram, and background simulation by the dotted histogram.

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 $c\tau_{bg} = 7 \pm 22$ μm (-21 $\pm$ 13 μm).

The measured $c\tau$ distributions for 1 vs 3 and 3 vs 3 events are shown in Fig. 1a) and 1b) 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$\pm$1.1 μm for the 1 vs 3 sample and 79.8$\pm$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$\pm$1.2 μm for the 1 vs 3 sample and 85.3$\pm$3.8μm for the 3 vs 3 sample.

3.6. Systematic Errors

We have considered systematic errors 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.

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. Thus we conservatively assign a systematic error of $\pm 1.8 \mu$m to account for effects due to tracking, vertexing and the lifetime method.

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

3.7. Discussion

The results presented here are consistent with other measurements of τ_τ and the prediction of the Standard Model based on the world average of the τ electron branching ratio and m_τ.

4. Helicity of ν_τ

In the Standard Model neutrinos are left-handed leptons, tau decay is a V-A process, and the ν_τ helicity is $h_\nu = -1$.[10] In the rest frame of a $\tau^{-(+)}$ that decays to $\pi\nu$, the parent spin is maximally correlated (anticorrelated) to the daughter meson direction. Tau pairs have preferentially aligned spins when produced via the QED process $e^+e^- \rightarrow \gamma^* \rightarrow \tau^+\tau^-$. At center-of-mass energies above $\tau^+\tau^-$ threshold, each τ has a relativistic boost, and the meson directions in the center-of-mass systems are partially Lorentz-transformed into hadron energies. Thus for a left-handed ν_τ, the energies of the π^+ and the π^- are correlated. This correlation is also present if ν_τ was instead right handed with $h_\nu = +1$. However, if ν_τ has no preferred handedness there will be no correlations between the daughter energies.

For the decay of the τ to a pseudoscalar (*e.g.*, π) the neutrino helicity h_ν is related to to the parameters γ_{av} and ξ and the charged current couplings g_a and g_v by[11]

$$h_\nu = \xi_\pi = -\gamma_{av} = \frac{-2g_a g_v}{g_a^2 + g_v^2}. \tag{8}$$

The double differential cross section in terms of the scaled laboratory energies ($x = E/E_{beam}$) of the hadrons is given by

$$\frac{d^2\sigma}{dx_+ dx_-} = F_1(x_+, x_-) + h_\nu^2 \cdot F_2(x_+, x_-), \tag{9}$$

with F_1 and F_2 being known kinematic functions. For either $V-A$ or $V+A$ interactions the correlations will be maximal, whereas for pure V or pure A interactions the correlations will vanish.

4.1. Event Selection

Events consistent with $\tau^+\tau^- \rightarrow (\pi^+\overline{\nu})(\pi^-\nu)$ are extracted for this analysis. The event selection procedure is also designed to minimize backgrounds from non-τ QED processes such as $e^+e^-\gamma$, $\mu^+\mu^-\gamma$ and $\gamma\gamma$ interactions as well as τ backgrounds such as $\tau \rightarrow \rho\nu$, $\rho \rightarrow \pi^-\pi^o$. A total of 1972 events pass all selection criteria.

4.2. Determination of $|h_\nu|$

We use a maximum likelihood procedure to extract $|h_\nu|$. A large sample of $\tau^+\tau^-$ events were generated using KORALB[7] and GEANT[12] to assess which decay modes were significant sources of background for the analysis. It was found that 97% of all such events that passed the selection criteria came from $\pi\pi$, πK, $\pi\rho$, $\pi\mu$, and πK^* final states. Samples corresponding to several times the actual data are then generated for these five modes both with the $V-A$ and with the V hypotheses. The samples are scaled to the appropriate luminosity and binned as x_+ *vs.* x_-. For each bin (i,j) the predicted number of events, denoted n_{ij} for *any* value of h_ν is given by[13]

$$n_{ij}(h_\nu) = h_\nu^2 \cdot N_{ij}^{V-A} + (1-h_\nu^2) \cdot N_{ij}^{V}. \tag{10}$$

A binned Poisson likelihood is then taken as a function of h_ν as

$$\log \mathcal{L}(h_\nu) = \sum_{i,j} [d_{ij} \log n_{ij} - n_{ij} - \log(d_{ij}!)]. \tag{11}$$

The result of the maximum likelihood analysis is:

$$|h_\nu| = 0.99 \pm 0.06,$$

with the uncertainty being statistical.

4.3. Systematic Errors

We have made many systematic checks which can be divided into four broad categories: (i) dependence on the values of variables used in event selection, (ii) possible biases in the methodology, (iii) possible biases in the simulations, and (iv) our estimate of backgrounds. The systematic errors are summarized in the Table 2. Taking all the effects in quadrature we obtain an overall systematic uncertainty of $\delta|h_\nu| = \pm 0.10$.

4.4. Discussion

From a sample of $\approx$2000 events of the type $\tau^+\tau^- \rightarrow (\pi^+\overline{\nu})(\pi^-\nu)$ taken at $\sqrt{s} \sim$ 10.6 GeV CLEO has extracted the magnitude of the helicity of the tau neutrino. Given that this helicity is known to be negative,[14] the result is $h_\nu = -0.99 \pm 0.06 \pm 0.10$. This is consistent with the $V-A$ nature of the charged weak current mediating τ decay and with other measures of the ν_τ helicity.[15,16]

Table 2: Summary of systematic errors.

Parameter	$\Delta\xi$
Kinematic criteria	0.02
$\gamma\gamma$ veto	0.02
Isolated shower veto	0.03
Hadron identification	0.05
Trigger and LEVEL3	0.03
Simulation comparisons	0.04
Normalizations	0.01
$\log\mathcal{L}$ vs χ^2	0.04
Data-based corrections	0.03
Tau branching ratios	0.03
$\mu\mu\gamma$ backgrounds	0.01
Total syst uncertainty	0.10

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