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MEASUREMENT OF THE τ LIFETIME

by

CELLO Collaboration

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Abstract :

Using the 3-prong decays of τ leptons observed at the CELLO detector at PETRA, the τ lifetime is determined to be

$$\left(4.7 \begin{array}{l} +3.9 \\ -2.9 \end{array}\right) \times 10^{-13} s.$$

A measurement of the τ lifetime provides a direct determination of the strength of the coupling of the τ weak-charged current. Data for the present experiment were collected with the CELLO detector at PETRA, DESY. The result of the τ lifetime measurement is presented in this paper.

The CELLO detector has been described elsewhere (1). The central detector features 5 proportional wire chambers (PWC) interspaced with 7 drift chambers in a solenoidal field of 1.3 T. The first drift chamber is at a radius of 25.5 cm. The spatial resolution obtained by the central detector is $\sim 350\ \mu$†. Between the interaction point and the first chamber (PWC), particles traverse .05 radiation length of beam pipe at a radius of 14 cm.

The data sample corresponds to an integrated luminosity of 11,300 nb^{-1} at an average beam energy of 17.1 GeV and 2,400 nb^{-1} at a beam energy of 11 GeV. The selection procedure for τ events at the higher energy is described in detail in Ref. 2. Events with four or more prongs were selected for the lifetime measurement ; τ's which decayed into at least 3 charged pions were used to reconstruct the decay vertex. The 17 GeV and the 11 GeV data contained $\sim$200 and $\sim$70 such decay candidates, respectively.

† This value takes into account all track configurations. Precisions have been measured for all chambers and have been included in the Monte-Carlo simulation.

A χ^2 minimization fitting procedure was applied to the multiprong vertices to determine the "most probable" vertex by varying the track parameters. Vertices with at least 3 prongs properly reconstructed were selected by visual scanning (by comparing the hits in the chambers with the reconstructed tracks). In addition, the distance of closest approach to the interaction point was required to be less than 1 cm in the plane transverse to the beam and less than 2.5 cm along the beam for at least three of the tracks. About a third of the decay candidates were thereby removed before fitting. As a result of the fit, the vertex coordinates, a complete error matrix and the probability of the vertex fit in terms of standard deviation (STDV)†† were obtained for each vertex. Vertices with STDV ≤ 1.0 were selected ; 143 out of the 176 vertices thus remained in the sample.

The τ decay length, ℓ_T , in the plane transverse to the beam was measured as the distance between the decay vertex and the mean beam crossing point along the τ line of flight determined by the sum of the momenta of the charged pions. For each event containing a decay vertex, the mean beam crossing point was determined using the Bhabha events from the corresponding machine filling. A typical error associated with each such measurement was estimated to be $\sim 200\,\mu$. The typical horizontal and vertical spread of the beam about the mean position were $\sigma_x < 1$ mm and $\sigma_y < 0.1$ mm respectively. Fig. 1 shows the distribution of the uncertainty, σ_ℓ, in the measurement of ℓ_T along the τ direction of flight. The error in the determination of the interaction point, being much smaller than that of the decay vertex does not play a significant role and was subsequently ignored. The ℓ_T's and the σ_ℓ's measured in the low energy data set were scaled by the ratio of the energy, and thereon added to the 17 GeV data set, a procedure identical to using the proper time distribution. Fig. 2 shows the distribution in ℓ_T with measurement uncertainties $\sigma_\ell \leq 8$ mm. The sample consisted of 78 events of which 21 came from the 11 GeV data.

†† $\text{STDV} = \sqrt{\chi^2/M}$ where M are the number of coordinate measurements.

To estimate the most probable mean flight distance, a maximum likelihood fit was performed to the decay length distribution. The probability, $P(\ell_{T_i})$, of measuring a decay length ℓ_{T_i} is given by the convolution of the exponential decay of the τ, a response function, R, and the τ angular distribution :

$$P(\ell_{T_i}) = C \int_0^\infty d\ell' \int_{\text{acceptance}} d\Omega_\tau (1+\cos^2\theta_\tau)\ \exp(-\ell'/\ell_o)\ R(\ell_{T_i} - \ell'\sin\theta_\tau)$$

This is equivalent (within the uncertainties and the range of the lifetime values) to considering a transverse decay length, ℓ_{T_o} , yielding :

$$P(\ell_{T_i}) = C' \int_0^\infty d\ell'_T\ \exp(-\ell'_T/\ell_{T_o})\ R(\ell_{T_i} - \ell'_T)$$

C and C' are normalization constants.

The response function was obtained from the three prong decays of Monte-Carlo τ events generated with zero lifetime which were passed through the same complete analysis chain as the real data with similar cuts. The simulation included decays, conversion of photons and Coulomb scattering as well as measurement uncertainties, thereby resulting in a slightly asymmetric shape for R. A response function was generated for each set of experimental conditions. As a result of the fit, the value of ℓ_{T_o} obtained was :

$$\ell_{T_o} = \left(.95 \begin{array}{l} +.80 \\ -.56 \end{array}\right) \text{ mm}$$

The dotted and the solid curves in Fig. 2 represent the smoothed and normalized response function, obtained from the convolution with $\ell_{T_o} = .95$ mm, respectively.

To check the fitting procedure, Monte-Carlo τ events were generated with two different lifetimes, (i) a "normal" τ lifetime, 3×10^{-13} s, and (ii) a lifetime $\simeq$ 3 times longer, 8.3×10^{-13} s. They were analyzed in the same way as the data. The solid curve in Fig. 1, showing the error distribution from the vertex fitting of the τ Monte-Carlo events normalized to the number of real events in the histogram, is in good agreement with the data. The two Monte-Carlo data sets were fitted with the corresponding response functions. Table 1 shows the results to be in agreement with the input data within the (statistical) uncertainties.

To check for additional systematic effects in the response function, R, which could be due to an incorrect simulation of the detector in the τ Monte-Carlo, the same procedure was applied to a control data sample where no significant lifetime effect was expected to be present. A sample of τ like events was constructed from multihadron events observed in the detector. Track triplets which simulated τ decays as nearly as possible were chosen and were subjected to the same fitting procedure as the real τ events. The resulting displacement in the transverse plane was found to be (.28 ± .33)mm, hence consistent with zero. Checks were also made by varying the shape of the response function slightly as obtained, for example, with different measurement errors. As a result of these tests, the systematic uncertainty in the ℓ_T measurement was estimated to be less than 0.2 mm.

Adding the statistical and the systematic errors in quadrature and transforming the result of ℓ_{T_0} to the 3 dimensional decay length, the τ lifetime was measured in this experiment to be :

$$\tau_\tau = \left(4.7 \begin{array}{l} +3.9 \\ -2.9 \end{array}\right) \times 10^{-13} \text{ s}$$

A preliminary result of $(4.9 \pm 2.9) \times 10^{-13}$ s was reported where the mean flight distance was calculated by using the weighted mean of ℓ_T :

$$\bar{\ell}_T = \frac{\sum_i \ell_{T_i}/\sigma_{\ell_i}^2}{\sum_i 1/\sigma_{\ell_i}^2}$$

With the present statistics, the same method yields $(4.0 \pm 2.2) \times 10^{-13}$s. The quoted error, however, is probably not realistic since this procedure implicitly assumes (i) Gaussian errors in ℓ_T measurements, and (ii) an exact knowledge of each σ_ℓ including all the effects, e.g. Coulomb and nuclear scattering.

Previous measurements of the τ lifetime are : $(-0.25 \pm 3.5)\times10^{-13}$ s by Tasso[4], $(4.6 \pm 1.9)\times10^{-13}$ s by Mark II (using a maximum likelihood fit method)[5], and $(4.9 \pm 2.0)\times10^{-13}$s by MAC[6,3] (using the weighted mean method).
Very recently, preliminary results updating these measurements have been available[7], and are as follows : $(0.8 \pm 2.2)\times10^{-13}$s by TASSO, $(3.31 \pm .57 \pm .7)\times10^{-13}$ s by MARK II (using a new vertex detector) and $(4.1 \pm 1.1 \pm 1.2)\times10^{-13}$s by MAC.

Assuming μ-τ universality and the branching fraction, B_e, for $\tau \to e\nu\bar{\nu}$ to be (0.176 ± 0.016)[8], the expected lifetime is :

$$\tau_\tau = \left(\frac{m_\mu}{m_\tau}\right)^5 \tau_\mu B_e = (2.8 \pm 0.25) \times 10^{-13}\text{s}.$$

All the above measurements are in agreement with the prediction within the quoted uncertainties.

We are indebted to the PETRA machine group and the DESY computer center for their excellent support during the experiments. We acknowledge the invaluable effort of all engineers and technicians of the collaborating institutions in the construction and maintenance of the apparatus, in particular the operation of the magnet system by G. Mayaux and Dr. Horlitz and their groups. The visiting groups wish to thank the DESY directorate for the support and kind hospitality extended to them. This work was partly supported by the Bundesministerium fur Forschung and Technologie.

FIGURES CAPTIONS

Fig. 1 : Distribution of the calculated uncertainty, σ_ℓ, along the tau direction of flight in the transverse plane. The solid curve represents the same distribution for the Monte-Carlo.

Fig. 2 : Distribution of the tau decay length, ℓ_T, in the transverse plane. The dotted curve represents the response function, whereas the solid curve corresponds to the maximum likelihood fit.

TABLE 1

	lifetime (s)	ℓ_{To} generated (mm)	ℓ_{To} fitted (mm)
MC data set 1	3×10^{-13}	.6	.6 ± .3
MC data set 2	8.3×10^{-13}	1.8	2.3 ± .3

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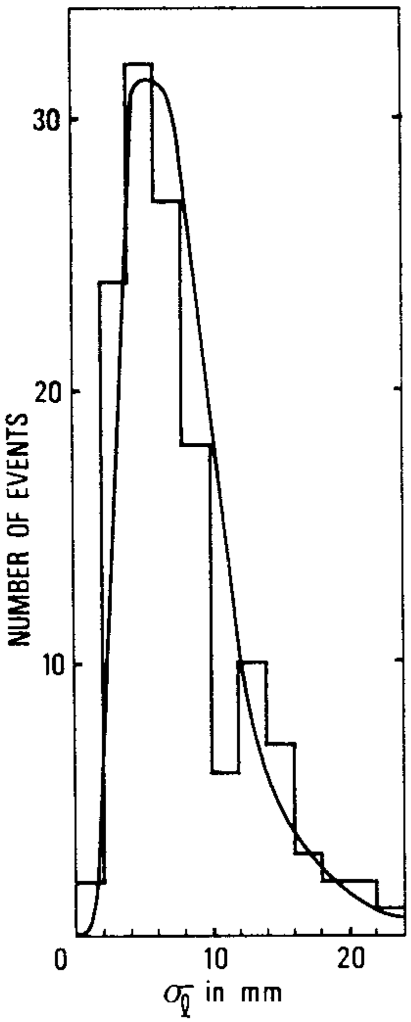
NUMBER OF EVENTS
30
20
10
0
10
20
σ_{ℓ} in mm

Fig. 1

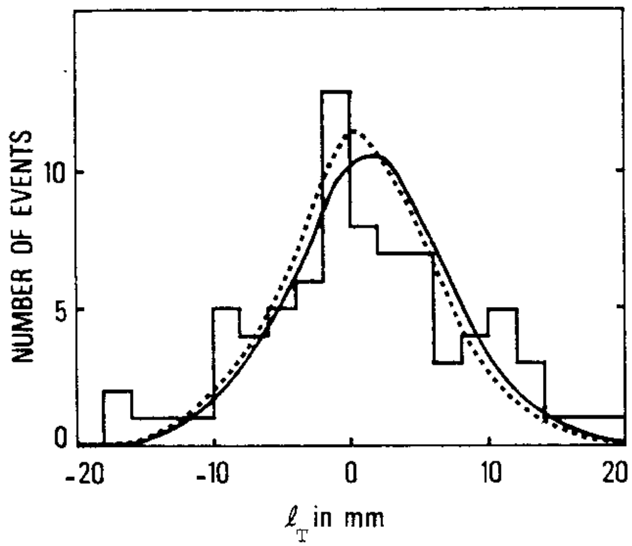
NUMBER OF EVENTS
10
5
0
-20
-10
0
10
20
ℓ_T in mm

Fig. 2