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A MEASUREMENT OF THE TAU LIFETIME

ARGUS Collaboration

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Using the ARGUS detector at the electron-positron storage ring DORIS II at DESY, we have measured the lifetime of the τ lepton to be $(2.95 \pm 0.14 \pm 0.11) \times 10^{-13}$ s.

Measurements of the lifetimes of the fundamental fermions test the standard model of electroweak interactions. Quarks have only been found as constituents of hadrons and thus a direct measurement of a quark lifetime is not possible. This is not the case for τ leptons and a measurement of their lifetime is a direct test of the standard model. Assuming e–μ–τ universality, approximating the electron mass as zero, and assuming the neutrino masses to be zero, one can obtain

$$\tau_\tau = \tau_\mu \times \mathrm{Br}(\tau^- \to \nu_\tau e^- \bar{\nu}_e)(M_\mu/M_\tau)^5 \ .$$

Using the Particle Data Group values [1] of the $\tau^- \to \nu_\tau e^- \bar{\nu}_e$ branching ratio $(17.4 \pm 0.5\%)$, the μ lifetime $(2.197 \times 10^{-6}$ s) and particle masses ($M_\tau = 1784.2 \pm 3.2$ MeV/c^2, $M_\mu = 105.6$ MeV/c^2), one obtains the theoretical value for the τ lifetime $(2.79 \pm 0.08) \times 10^{-13}$ s. This lifetime was first measured by the MARK II collaboration [2]. Since then a number of measurements have been published [3] [#1] and the current world average is $(2.94 \pm 0.12) \times 10^{-13}$ s [5]. This new measurement represents a significant addition to the previous results.

The original components of the ARGUS detector, which have been described in detail elsewhere, consist of a drift chamber [6], a time of flight system [7], a shower counter system [8] and muon chambers [9]. The recent addition of a vertex chamber to the ARGUS detector [10] has made possible the measurement of the τ lifetime at ARGUS. By studying the distance of closest approach between Bhabha tracks, we measure the precision with which a single high energy electron track can be extrapolated to the vertex and find it on average to be (95 ± 4) μm.

The data used in this study were collected with the ARGUS detector in 1985 and 1986 in the energy range from 9.3 to 10.6 GeV at the DORIS II storage ring at DESY and corresponds to an integrated luminosity of 166 pb^{-1}. Events used in this analysis were of the type $e^+e^- \to \tau^+\tau^-$ in which one τ decays to a single charged particle (referred to as particle 1) plus neutrals and the other to three charged particles (referred to as 2, 3 and 4) plus neutrals, which corresponds to 23.2% of all τ pair events.

There were several potential sources of background to the τ sample: two-photon events, radiative Bhabha and μ pairs followed by photon conversion into an e^+e^- pair, continuum $q\bar{q}$ production and resonant decays to three gluons (ggg). Data selection cuts were chosen to optimize two conflicting objectives, namely, maximizing the acceptance, while keeping the background to a minimum. With these criteria in mind, it was required that

- there be exactly four charged tracks coming from the vicinity of the main vertex with a total charge of zero; in addition, there may be up to two further tracks not pointing to the interaction point, to allow for backscatters,
- particle 1 makes an angle of greater than 90° with each of the particles 2, 3 and 4,
- particle 1 makes an angle of greater than 120° with the momentum sum of particles 2, 3 and 4,
- $|\cos\theta|$ be less than 0.75, where θ is the angle between particle 1 and the beam direction,
- the mass of oppositely charged particle pairs be greater than 100 MeV/c^2 (assuming the particles are electrons), the total energy deposited in the shower counter system be less than 7 GeV and the momentum of each track must be less than 4 GeV/c, to reject radiative Bhabha and $\mu\mu\gamma$ events where the photon converts,

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[#1] For a review of recent results, including results only presented at conferences, see ref. [4].

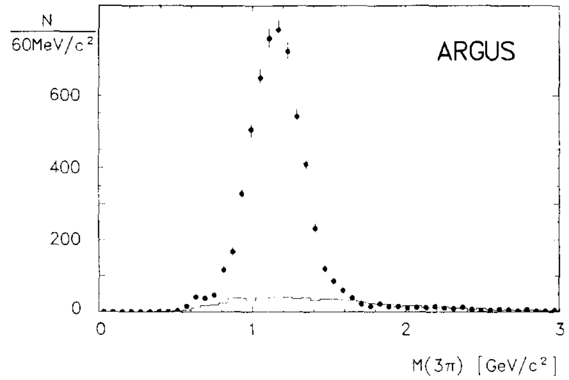

Fig. 1. Three-pion mass distribution for the data which survive all the τ selection and vertex quality cuts. The solid line is the Monte Carlo generated background distribution.

- there be no more than 3 γ candidates within 90° of the three-particle momentum sum, where a shower counter hit must have energy greater than 50 MeV and not be associated with a charged track, to be considered a photon,
- there be at most two photons within 90° of particle 1 and if there are two, their mass must be consistent with that of a π^0, by requiring $|M_{\gamma\gamma}-M_{\pi^0}|$ be less than 50 MeV/c^2,
- the mass of the particle 1, plus photons within 90° of it, if any, be less than 1.45 GeV/c^2, to ensure consistency with the ρ hypothesis,
- no event be accepted with a $\pi^+\pi^-$ mass within 50 MeV/c^2 of the K^0 mass,
- the χ^2 of the three-prong vertex fit be less than 15,
- the total energy of the charged particles in the event be greater than $0.3\times E_{\mathrm{cm}}$ and the total momentum component perpendicular to the beam be greater than 0.2 GeV/c in order to suppress beam–gas and two-photon events,
- σ_l be less than 0.06 cm (σ_l is the error in the proper decay length and is described below).

The three-pion mass distribution of the events thus selected is shown in fig. 1. There are 5696 events with a three-pion mass less than 1.8 GeV/c.

The cuts described above reduced contamination from two-photon and radiative lepton pair events to negligible amounts. The shape of the background from $q\bar{q}$ and ggg events was obtained using Monte Carlo events generated by the Lund programme [11], the parameters of which were adjusted so that the events had the same properties as those seen at ARGUS. The events were then passed through a simulation of the detector that smeared measurements using the measured resolutions of the detector components and the topological cuts described above were made. The spectrum obtained was normalized to the data in the mass region above 1.8 GeV/c^2 and in fig. 1 the Monte Carlo background is superimposed upon the measured three-pion mass spectrum. The background fraction in the region $M_{3\pi}<1.8$ GeV/c^2, thus obtained amounts to $(9.5\pm1.0)\%$.

The projection of the decay length of the tau, onto the plane perpendicular to the beam direction, was found using the average beam position, the decay vertex and associated errors. The beam positions were calculated, on a run-by-run basis, by minimizing the distance of closest approach to the beam center of tracks from all Bhabha events in the run. The beam widths were determined by studying the impact parameter distributions of Bhabha tracks and were found to have a σ of 480 μm in the horizontal direction and 85 μm in the vertical direction.

The τ decay vertex position was found using a parametric vertex fitting procedure which uses the 5 track parameters and their errors as input and outputs the vertex position, a new set of track parameters and the errors [12]. The most probable path length, projected onto the plane perpendicular to the beam direction, is given by

$$l_{xy}=\frac{x_v t_x B_{xx}+y_v t_y B_{yy}+B_{xy}(t_x y_v+t_y x_v)}{t_x^2 B_{xx}+t_y^2 B_{yy}+2t_x t_y B_{xy}}\ ,$$

where $(x_v,\ y_v)$ is the displacement from the beam centre of the fitted vertex, t_x and t_y are the direction cosines of the three-prong system and the matrix B is the inverse of the error matrix of x_v and y_v, which incorporates the beam spread, beam position and vertex position errors. The proper decay length is then

$$l\equiv c\tau_\tau=l_{xy}/\beta\gamma\sin\theta\ ,$$

where θ is the direction of the three-prong, which is approximately the τ direction, measured with respect to the beam axis. The error in l_{xy} is given by

$$\sigma_{l_{xy}}^2=(t_x^2 B_{xx}+t_y^2 B_{yy}+2t_x t_y B_{xy})^{-1}$$

and

$$\sigma_l=\sigma_{l_{xy}}/\beta\gamma\sin\theta\ .$$

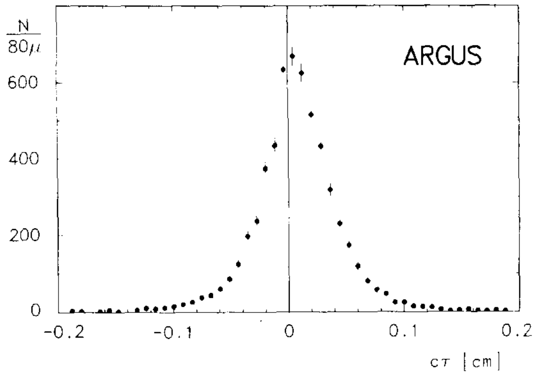

Fig. 2. The proper decay length distribution for the τ sample.

The errors on β, γ and $\sin\theta$ are negligible compared to $\sigma_{l_{xy}}$. The lifetime of the τ is found from the weighted mean decay length of the data ($\langle l\rangle$) using the relationship

$$\langle l\rangle=(1-b)\langle c\tau_\tau\rangle+b\langle l_{\mathrm{bg}}\rangle\ ,$$

where b is the fraction of the data which are background events, τ_τ is the lifetime of the tau lepton and l_{bg} is the apparent mean decay length of the background events. The average background decay length was found using events with a three-pion mass greater than 1.8 GeV/c^2 and was found to be (-18.6 ± 14.5) μm.

The distribution of the proper decay length is shown in fig. 2. Using the weighted mean of this distribution we obtained the result

$$\langle c\tau_\tau\rangle=(88.4\pm4.3)\ \mu\mathrm{m}$$

or

$$\tau_\tau=(2.95\pm0.14)\times10^{-13}\ \mathrm{s}\ .$$

The error is statistical only and was calculated from the mean variance. The lifetime has also been corrected for the average reduction in beam energy due to initial state radiation [13].

Varying the last three cuts discussed above by as much as 40%, caused the measured mean decay length to fluctuate by ±2.0 μm which we include in the systematic error. Shifting the beam position by one standard deviation in the analysis contributes a further ±2.0 μm to the systematic error. A one-standard-deviation change of the background fraction shifted the mean proper decay length ±1.0 μm. The uncertainty in the lifetime of the background events introduced an error of ±1.5 μm. These independent effects have been added in quadrature to define the systematic error.

We have checked our procedure for any bias towards longer or shorter lifetimes by studying Monte Carlo generated $e^+e^-\to\tau^+\tau^-$ events. The Monte Carlo simulated all known detector effects [14] and included initial state radiation [13]. Events were generated with 4 different lifetimes and in each case our lifetime procedure reproduced the input lifetime within errors. There was no evidence of a systematic bias.

Thus we obtain the result

$$\tau_\tau=(2.95\pm0.14\pm0.11)\times10^{-13}\ \mathrm{s}\ .$$

This result is slightly higher than, but in reasonable agreement with, the value obtained assuming e–μ–τ universality and is consistent with previous measurements. Adding the systematic and statistical errors of our result in quadrature and taking the weighted mean with the previously mentioned world average, one obtains a new world average of $(2.94\pm0.10)\times10^{-13}$ s. This value is one standard deviation larger than the theoretical prediction.

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