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Measurement of τ Lifetime and Branching Ratios*

E. Fernandez, W. T. Ford, N. Qi, A. L. Read, Jr., J. G. Smith
Department of Physics
University of Colorado, Boulder, Colorado 80309

T. Camporesi, R. De Sangro, A. Marini, I. Peruzzi,
M. Piccolo, F. Ronga
Laboratori Nazionali Frascati dell' I.N.F.N., Italy

H. T. Blume, R. B. Hurst, J. P. Venuti, H. B. Wald, Roy Weinstein
Department of Physics
University of Houston, Houston, Texas 77004

H. R. Band, M. W. Gettner, G. P. Goderre, O. A. Meyer,[a]
J. H. Moromisato, W. D. Shambroom, J. C. Sleeman, E. von Goeler
Department of Physics
Northeastern University, Boston, Massachussets 02115

W. W. Ash, G. B. Chadwick, S. H. Clearwater,[b]
R. W. Coombes, H. S. Kaye,[c] K. H. Lau, R. E. Leedy,
H. L. Lynch, R. L. Messner, L. J. Moss,
F. Muller,[d] H. N. Nelson, D. M. Ritson,
L. J. Rosenberg, D. E. Wiser, R. W. Zdarko
Department of Physics and Stanford Linear Accelerator Center
Stanford University, Stanford, California 94305

D. E. Groom, Hoyun Lee[e]
Department of Physics
University of Utah, Salt Lake City, Utah 84112

M. C. Delfino, B. K. Heltsley,[f] J. R. Johnson,
T. L. Lavine, T. Maruyama, R. Prepost
Department of Physics
University of Wisconsin, Madison, Wisconsin 53706

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[a] Present address: CERN, CH-1211, Geneva 23, Switzerland.
[b] Present address: Los Alamos National Lab., Los Alamos, NM 87545.
[c] Present address: Lawrence Berkeley Lab., Berkeley, CA 94720.
[d] Permanent address: CERN, CH-1211, Geneva 23, Switzerland.
[e] Present address: Department of Physics, Chungnam National University, Daejeon, Korea.
[f] Present address: Laboratory of Nuclear Studies, Cornell Univ., Ithaca, NY 14853.

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ABSTRACT

Precise results are reported for the τ lepton lifetime and several τ branching ratios obtained with the MAC detector operating at PEP at $\sqrt{s}$ = 29 GeV. We find $\tau_\tau=(3.15\pm0.36\pm0.4)\times10^{-13}$ sec. Results for the topological branching ratios B_1, B_3, B_5 (τ decaying into 1, 3, 5 charged particles) are $B_3\equiv1-B_1=0.133\pm0.003\pm0.006$ and $B_5<0.0017$ at the 95% confidence level. The fraction of all 3-prong decays unaccompanied by π^0's is found to be $0.61\pm0.03\pm0.05$.

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Insufficient precision in the measurements of the τ lepton lifetime and branching ratios has left open the possibility that not all major decay modes of the τ have been observed. Several authors[1,2] have conjectured that unobserved decay modes (possibly decays to previously unknown particles) might be responsible for the "missing" τ decays. In order to resolve this situation, it is necessary to measure, with a precision of better than 5%, the τ lifetime and branching ratios, especially for the leptonic modes and for the modes with three or more hadrons. We report here measurements of the τ lifetime, topological branching ratios B_1, B_3, B_5 (τ decaying into 1, 3 or 5 charged particles), and the first precise measurement of the branching ratios for tau decaying into three charged particles plus any number of π^0's. Combined with previous measurements these results suggest that either current measurements of the τ branching ratios are too low or there are indeed significant unobserved decay modes of the tau.

The MAC detector and event selection for the τ asymmetry sample have been described in the preceding letter.[3] All analyses except that for the 5-prong branching ratio use this sample with few additional requirements. In order to measure B_5, events with a topology of 1-4 or 1-5 are selected, i. e. events which, when divided by a plane perpendicular to the charged particle sphericity axis, have a single prong in one hemisphere and four or five in the other. Since the probability of missing at least one of five nearby charged tracks in the central drift chamber (CD) is about 50% (mainly due to overlap of nearby tracks), allowing the 1-4 topology increases the efficiency and reduces the systematic error due to the modeling of this inefficiency. Events for which the isolated track is identified as an electron are rejected to avoid background from the 2-photon process $ee \rightarrow ee$ + hadrons, in which one of the electrons is detected. The isolated track is required to have a momentum greater than 0.5 GeV/c, make an angle of less than 25° with respect to the sphericity axis, and be at least 120° from the nearest track. To reject hadronic and various soft backgrounds, the total calorimetric energy is required to be between 6 and 25 GeV, the sphericity of the event to be less than 0.035, and all calorimeter hit clusters with an energy greater than 1 GeV to be within 30° of the sphericity axis. The invariant mass, computed from the position and energy of calorimeter hits, must be less than 3 (4) GeV in the hemisphere with the smaller (larger) mass. The scalar sum of the charged track momenta is required to be at least 4 GeV/c. To reduce the background from events in which a τ decaying to three prongs is accompanied by an e^+e^- pair arising from π^0 Dalitz decay or photon conversion in the vacuum pipe or CD inner wall (total of 0.036 radiation lengths at normal incidence), events are rejected in which the topology is 1-4 and some track has a momentum less than 0.25 GeV/c, one or more tracks fail a loose vertex fit, or at least one pair of tracks gives a satisfactory χ^2 for a fit to the pair conversion hypothesis. The efficiency for 1-5 events passing these cuts is (10.5±1)%.

B_1, B_3, B_5 are determined from the 1-1, 1-3 and 1-5 topology samples as described above, where 1-2 and 1-4 topology events are included in the 1-3 and 1-5 samples respectively. Table I shows the total number of data events and the expected background in the various topologies. Since B_5 is much smaller than 1%, it is found separately. Approximately 45% of the background in the 1-5 sample is due to photon conversion pairs, 20% is from π^0 Dalitz decays, 25% is from 1-3 events with spurious extra tracks, and 10% is due to multi-hadron events. Since the background can account satisfactorily for the observed signal, we find $B_5<0.0017$ at the 95% confidence level, where systematic errors estimated to be ≃25% of the number of background events are included. This result is lower than previously published limits by the MKII collaboration[4] (.005), CELLO[5] (.009), and TPC[6] (.003 at 90% confidence level). It is also considerably lower than a theoretical prediction of 0.01.[7]

To measure B_1 and B_3, Monte Carlo methods[8,9] are used to calculate an efficiency matrix for the detection of 1-1 and 1-3 events given the various possible actual topologies. This matrix is shown in Table II; the efficiencies shown include the restriction that $|\cos\theta| < 0.7$, where θ is the polar angle of the thrust axis. The 1-5 and 3-3 topologies are neglected since their inclusion changes B_3 by only 0.0004. B_1 and B_3 are calculated by inverting this matrix. Secondary vertices (primarily $K_S \to \pi^+\pi^-$) are included in the assigned topology, but reconstructed e^+e^-

vertices are not; the answer is corrected for Dalitz decays and the ≈50% of events with e^+e^- pairs in which no vertex is found. The result is $B_3 \equiv 1-B_1 = 0.133 \pm 0.003 \pm 0.006$, where the first error is statistical and the second systematic. The primary contribution (0.004) to the systematic error arises from the Monte Carlo modeling of the response of the CD; the data and the Monte Carlo calculation do not agree well on the number of events with 1-2 topology. A scan of data and Monte Carlo generated 1-2 events indicates that ≈80% are actually 1-3 topology in which one track is missed. By varying the relevant cuts and Monte Carlo input, other contributions to the systematic error are estimated to be: tau branching ratios used in the Monte Carlo calculation (0.003); backgrounds (0.002); efficiency other than CD (0.002); acceptance cuts (0.0015); and e^+e^- and K_s uncertainties (0.001). The result for B_3 is somewhat smaller than the less precise results of MKII[4] (.14±.02±.01), CELLO[5] (.15±.02), and TPC[6] (.152±.009±.015).

The measurement of the branching ratio for $\tau \to 3$ prongs$+n\pi^0+\nu$ begins with events in the 1-3 topology sample just discussed. We use only the subsample in which there are exactly four CD tracks which all have a good χ^2 for a primary vertex fit, and 90% of the calorimetric energy is in the central calorimeters. This sample is divided according to the number of "neutrals" found in the 3-prong hemisphere. A neutral is defined to be a cluster of central shower chamber (SC) hits with energy greater than 2 GeV which is at least 4.75° from the nearest track in the CD, but within 25° of the sphericity axis. The former angular requirement reduces the number of false neutrals due to energy deposition from charged tracks in the SC and the latter reduces the background from radiative tau production events. A typical π^0 appears as a single neutral more than 90% of the time.

Assuming neutrals originate only from π^0 decays and radiative tau production, and using the efficiency matrix shown in Table III and the number of observed events (Table I), we find R_3, the fraction of all 3-prong events which have no π^0's, to be $0.61 \pm 0.03 \pm 0.05$. The second error is systematic and is estimated by varying the cuts described above. We assume that $B(\tau \to 3 \text{ prongs} + \geq 2\pi^0 + \nu)$ is small; the systematic error in R_3 due to the uncertainty in this assumption is negligible unless this branching ratio is ≥ 0.01 since the efficiency for detecting at least one shower is not very sensitive to the presence of a second π^0 in the event. This result combined with our value for B_3 gives $B(\tau \to 3 \text{ prongs} + \nu) = 0.081 \pm 0.008$ and $B(\tau \to 3 \text{ prongs} + \geq 1\pi^0 + \nu) = 0.052 \pm 0.008$. If kaons are neglected[10], this result is in agreement with the previously published measurements of $B(\tau \to 3\pi^\pm \nu)$ of MKII at SPEAR[10] (0.07 ± 0.05) and CELLO[5] ($.097 \pm .020 \pm .013$), but less so with the measurement by PLUTO at DORIS[11] ($B(\tau \to \rho^0 \pi^\pm \nu) = 0.054 \pm 0.017$). Our result also agrees with the prediction[1,13] $B(\tau \to 3\pi^\pm \pi^0 \nu) \simeq 5\%$ if the contribution of events with ≥ 2 π^0's is small as expected.

The measurement of the τ lifetime uses the full event sample discussed in ref. 2. The impact parameter technique is used, that is for each track we find the distance of closest approach to the interaction point (IP) in the plane transverse to the beam direction (δ). Since the resolution in δ is much larger than the expected mean due to the lifetime of the τ ($\simeq 40\mu m$), δ can be negative nearly as often as positive.

The sign is taken to be positive (negative) when the track appears to travel forward (backward) relative to the apparent τ direction. The latter is assumed to be along the thrust axis and pointing from the IP toward the place where the track intersects the thrust axis; of course negative δ's arise from displacement of the track due to resolution effects. All tracks are used for which there is a satisfactory χ^2 for a constrained fit to the primary vertex and an uncertainty in δ (σ_θ) less than 1 mm. The former requirement excludes secondary vertices (K_s decays and photon conversion pairs) and obviously spurious tracks, and the latter rejects poorly fit tracks. Fig. 1 shows the distribution of σ_θ for tracks satisfying all but the cut on this quantity and Fig. 2 gives the δ distribution, weighted by $1/\sigma_\theta^2$, for the final sample containing 23584 tracks. From the latter distribution we find the median, $\langle\delta\rangle = 43.6\pm5.0$ μm. The median rather than the mean is used in order to reduce sensitivity to background and K decays; the median is expected to be nearly equal to the mean for an exponential decay distribution with decay constant much smaller than the experimental resolution.

The median is related to the lifetime by

$$\langle\delta\rangle = \alpha c\tau.$$

where α=0.48±0.01±0.02 is obtained from the Monte Carlo simulation. Using this and the estimate of 3.9% background in the sample,[3] we find

$$\tau_\tau=(3.15\pm0.36\pm0.4)\times10^{-13}\ \text{sec},$$

where the first error is statistical and the second is systematic. The latter is dominated by the uncertainty in α, given above, and the possible presence of a bias in δ. A bias due to decays having large δ would result in a mean larger than the median, contrary to our observation that the mean is about 1σ smaller than the median. Analysis of a large sample of Monte Carlo generated events with full detector simulation and τ lifetime set to zero gives $\langle\delta\rangle=3.9\pm2.2\mu m$, indicating a bias of less than 6μm. To check for a systematic bias not simulated by the Monte Carlo calculation, we study the distribution of δ_0, the raw impact parameter from the track fit, which is uncorrelated with the tau's direction of travel. This bias is found to be less than 2μm. Other possible causes of systematic errors have been considered: uncertainties in α due to inaccurate Monte Carlo modeling including the momentum spectrum, mass distributions, input branching ratios, and angular dependence of the efficiency; the effect of π and K decay in flight; and uncertainty in the background fraction. All of these effects are negligible compared with the dominant systematic uncertainties discussed above. With the assumption of τ-μ universality, the τ lifetime is predicted to be

$$\tau_\tau=B_e(m_\mu/m_\tau)^5\tau_\mu=(2.8\pm0.2)\times10^{-13}\text{ sec},$$

where B_e (the branching ratio for $\tau\rightarrow e\nu\bar{\nu}$) is taken to be[14] 0.176±0.016. Thus this result is in good agreement with theoretical expectations, previous less precise measurements,[15] and a new precise measurement by the MKII collaboration,[16] $(2.86\pm0.16\pm0.25)\times10^{-13}$ sec.

In conclusion, the tau lifetime result is consistent with the predicted result given above. Our values for B_3 and R_3 are sufficiently small and of sufficient precision to make it unlikely that the 1-prong topology of the $\tau\rightarrow3\pi\nu$ and $\tau\rightarrow4\pi\nu$ modes could account for the missing ≈6% of the decays.[1] Either some τ branching ratio measurements are in error (including the leptonic ones), or there are significant unobserved decay modes.

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Table I. Number of observed events and predicted background in various topologies (systematic errors are included).

Topology	No. of events	Background
1-1	4693	105±15
1-2	489	20±10
1-3	2342	104±25
1-4	9	7±2
1-5	2	3±1
1-3+0 neutrals	1255	98±30
1-3+1,2 neutrals	255	24±7

Table II. Efficiency matrix for B_1, B_3 determination (errors are statistical only).

	Actual topology	
	1-1	1-3
1-1 sample	.219 ±.001	.0024±.0003
1-3 sample	.0092±.0003	.380 ±.003

Table III. Efficiency matrix for the 3-prong + $n\pi^0$ measurement (errors are statistical only).

No. of observed neutrals	n=0	n>0
0	0.229±0.002	0.145±0.002
1,2	0.011±0.001	0.083±0.002

References

1. F. J. Gilman and S. H. Rhie, SLAC-PUB-3444(1984).

2. T. N. Truong, Phys. Rev. D 30,1509(1984).

3. E. Fernandez, et al., Phys. Rev. Letters 54,nnn(1985). (this reference is to the preceding letter)

4. C. A. Blocker, et al., Phys. Rev. Letters 49,1369(1982).

5. H. J. Behrend, et al., Z. Phys. C 23,103(1984); H. J. Behrend, et al., Phys. Letters 114B,282(1982).

6. H. Aihara, et al., Phys. Rev. D 30,2436(1984).

7. T. N. Pham, C. Roiesnel, and Tran N. Truong, Phys. Letters 76B ,623(1978).

8. F. A. Berends, R. Kleiss, and S. Jadach, Nucl. Phys. B202,63(1982); R. L. Ford and W. R. Nelson, SLAC-PUB-210(1978); T. W. Armstrong in "Computer Techniques in Radiation Transport and Dosimetry", edited by W. R. Nelson and T. M. Jenkins (Plenum Press, New York, 1980).

9. The following τ decay modes are included in the Monte Carlo calculation (branching ratios in %): ρ (23.4), e (18.3), μ (17.8), π (11.1), A_1 (20.0), ρ' (6.8), K (0.5), K* (1.2), Q_1+Q_2 (0.7), 5-prong (0.2). The known Breit-Wigner mass distributions and decay modes are used where appropriate.

10. A limit B($K^{\pm}$ + 2 charged prongs + neutrals)<0.006 is given in ref. 6.

11. J. A. Jaros, et al., Phys. Rev. Letters 40,1120(1978).

12. W. Wagner, et al., Z. Phys. C 3,193(1980).

13. N. Kawamoto and A. I. Sanda, Phys. Letters 76B,446(1978).

14. C. A. Blocker, et al., Phys. Letters 109B,119(1982).

15. G. J. Feldman, et al., Phys. Rev. Letters 48,66(1982); W. T. Ford, et al., Phys. Rev. Letters 49,106(1982); H. J. Behrend, et al., Nucl. Phys. B211,369(1983); J. A. Jaros, et al., Phys. Rev. Letters 51,955(1983); M. A. Althoff, et al., Phys. Letters 141B,264(1984).

16. J. A. Jaros, "Proceedings of the 1984 SLAC Summer Institute" (to be published), and SLAC-PUB-3518(1984).

Figure Captions

Fig. 1. Distribution of the error in impact parameter (δ). Only events with $\sigma_\theta < 1$ mm are included in the final sample.

Fig. 2. Impact parameter distribution for the final sample of 23584 tracks.

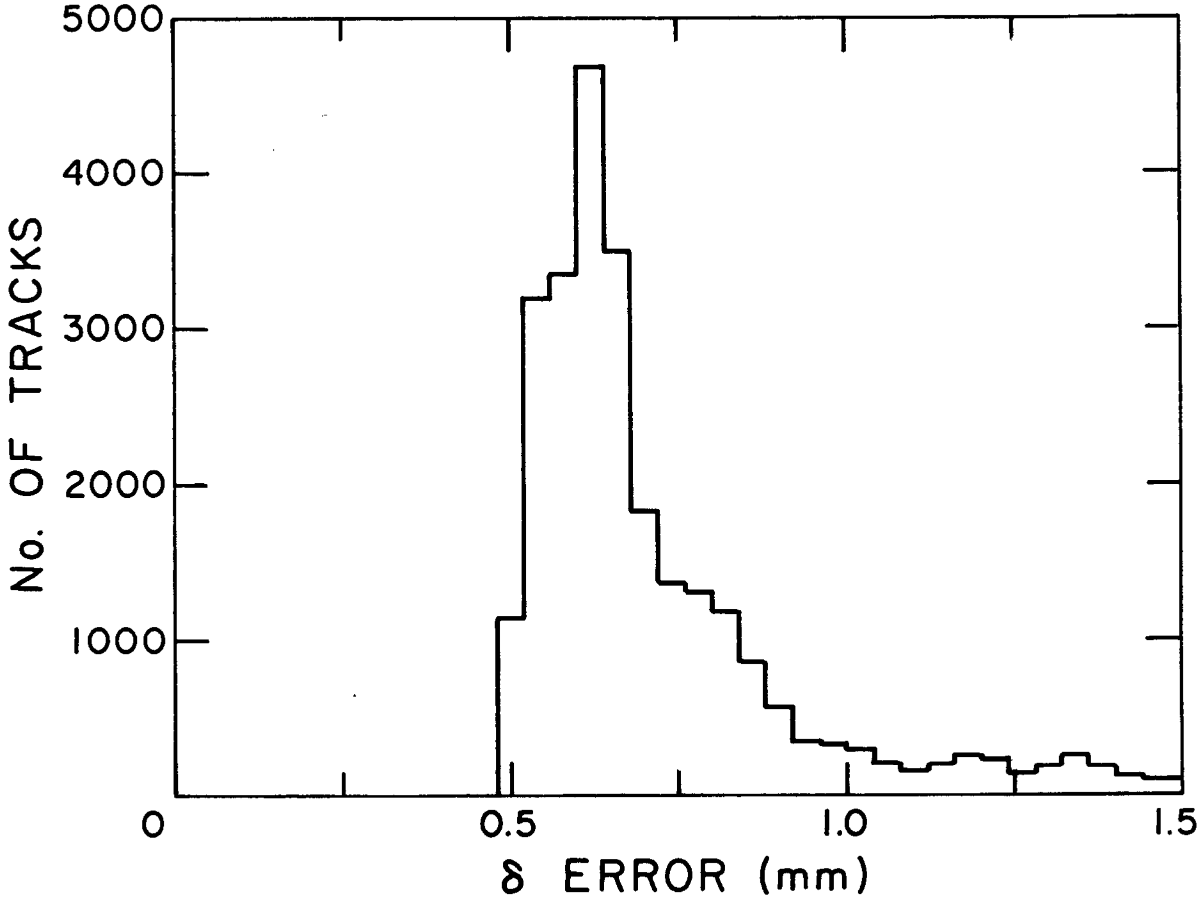

Fig. 1

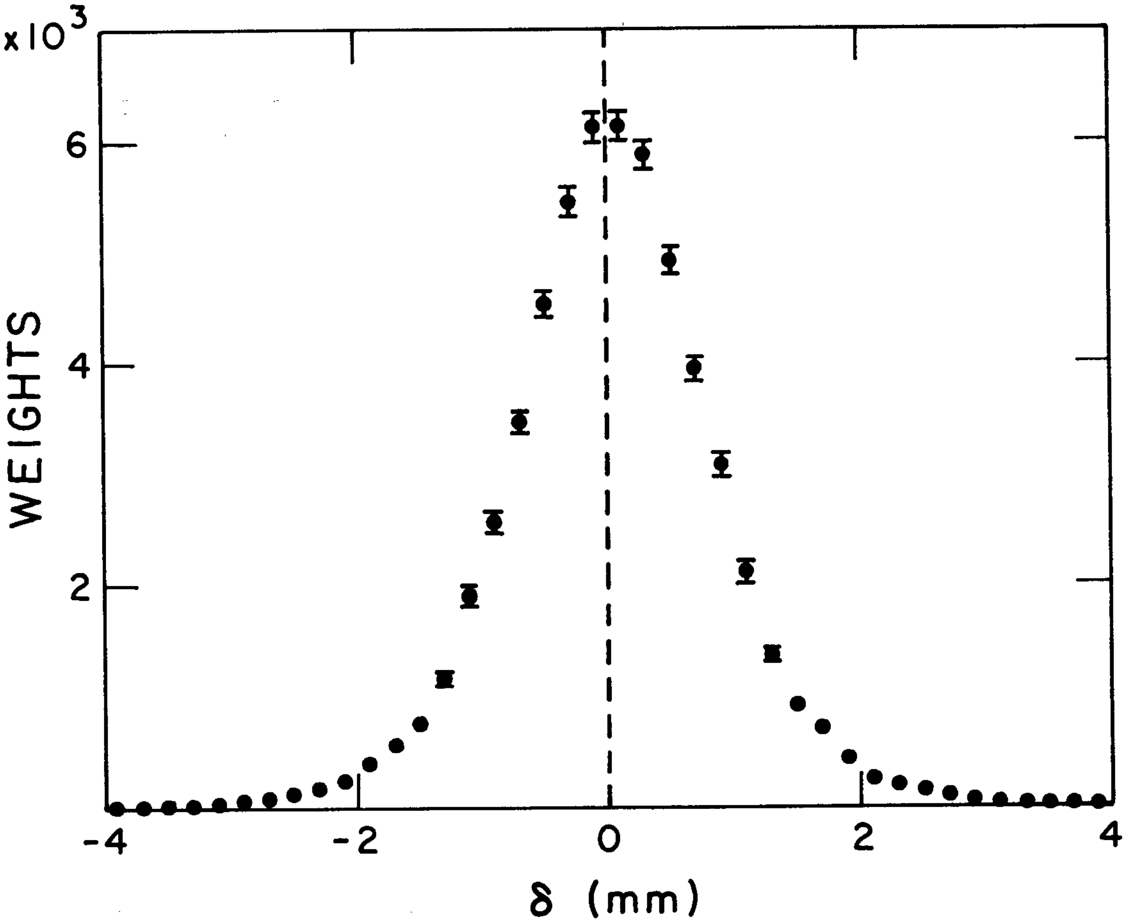

Fig. 2