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LIFETIMES OF HEAVY FLAVORS*

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ABSTRACT

This paper reviews recent experimental results on the lifetimes of the tau lepton and charmed and b–flavored hadrons, and discusses the physical significance of these measurements.

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INTRODUCTION

Experimental studies of the lifetimes of heavy quarks and leptons are providing new and fundamental information about the weak interactions, including some surprises. By now the unexpected difference between the charged and neutral D lifetimes is experimentally established, and during this past year a surprise from a year ago, that the B lifetime is unexpectedly long, has been confirmed by several experiments.

This paper will review our knowledge of the heavy flavor lifetimes. It treats, in turn, new and more precise measurements of the tau lifetime, an update on charm lifetime results, and the wealth of new information on the B lifetime.

1. TAU LIFETIME

In the standard model, tau semileptonic decay proceeds in perfect analogy to muon decay. This leads to a simple relationship between the τ and μ lifetimes:

$$\tau_\tau = \left(\frac{m_\mu}{m_\tau}\right)^5 \tau_\mu \, \mathrm{B}\,(\tau \to e\nu_\tau\bar{\nu}_e) \quad .$$

That is, if the tau couples to the charged weak bosons with the same strength as the muon, and if the interaction is V–A, and if the tau neutrino is massless, the tau lifetime is predicted to be $\tau_\tau = (2.82 \pm 0.18) \times 10^{-13}$ s. The theoretical uncertainty arises because of the present experimental uncertainty[1] in the tau semileptonic branching ratio, B.

These assumptions are few enough, and fundamental enough, that the failure of this prediction would have important consequences. For example, if the measured lifetime were greater than this prediction, a massive tau neutrino, or mixing to a heavier lepton generation, or even the failure of universality could be indicated.

Two experiments have improved significantly on the early tau lifetime measurements[2] by employing high precision drift chambers close to the interaction point. Both experiments[3] study pair-produced taus from e^+e^- annihilations, the MARK II at PEP and TASSO at PETRA. They use the now familiar technique of measuring the decay length by determining the distance between the known collision point and the three particle vertex resulting from $\tau \to \nu 3\pi$ decays. Figure 1 shows the decay length distribution measured by the MARK II detector. The full PEP data set, an integrated luminosity of 209 pb^{-1} at $\sqrt{s} = 29$ GeV, has been used in the measurement, giving 807 decays including the 156 previously published. The average decay length resolution is 1000 μ, comparable to the mean decay length $\bar{l} = 635 \pm 36$ μ. The lifetime is determined by a maximum likelihood fit to two parameters, the average decay length, and a factor which scales the estimated resolution. The result is $\tau_\tau = (2.86 \pm 0.16 \pm 0.25) \times 10^{-13}$ s, where the first error is statistical and the second is systematic. The TASSO collaboration at PETRA has performed a similar measurement with their vertex detector. From an integrated luminosity of 10.2 pb^{-1} at an average $E_{c.m.} = 42.5$ GeV, they have found a mean decay length of 1051 ± 270 μ for 48 decays. Their value for the tau lifetime is $(3.18^{+0.59}_{-0.75} \pm 0.56) \times 10^{-13}$ s, consistent with the MARK II value and the theoretical prediction.

The MAC collaboration at PEP has determined the tau lifetime by measuring the mean impact parameter of tracks from tau decays. Although the impact parameter resolution is modest ($\bar{\sigma}_\delta \approx 900$ μ) and the expected effect small ($\bar{\sigma}_\delta \approx 50$ μ), the huge statistic available

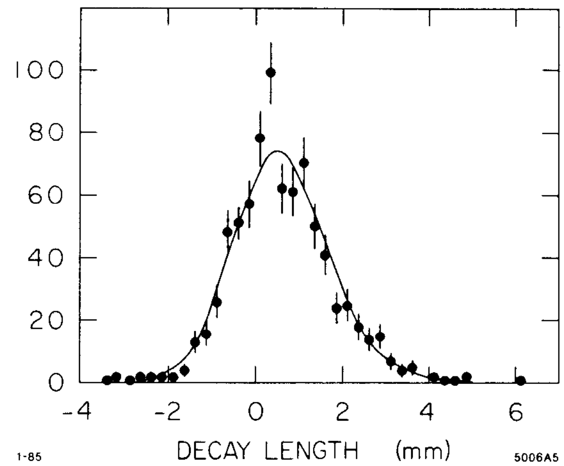

Fig. 1. Tau decay lengths measured by the MARK II collaboration at $\sqrt{s} = 29$ GeV at PEP.

(23,000 tracks!) gives considerable precision. They find the mean impact parameter to be $46.7 \pm 5.1\ \mu$. The corresponding tau lifetime is $(3.3 \pm 0.4 \pm 0.4) \times 10^{-13}$ s, where a Monte Carlo simulation is used to relate impact parameter and lifetime. This result agrees with those quoted above. That the systematic uncertainty is of order 1% of the typical measurement accuracy is a remarkable testament to the cancellation of systematic effects in impact parameter measurements.

A summary of the tau lifetime measurements is shown in Fig. 2. The experiments are in good agreement with each other and in excellent agreement with the theoretical prediction. The most recent result from MARK II confirms μ–τ universality to the level of 5%, to be compared to μ–e universality which is known from studies[4] of pion decay to the 0.8% level.

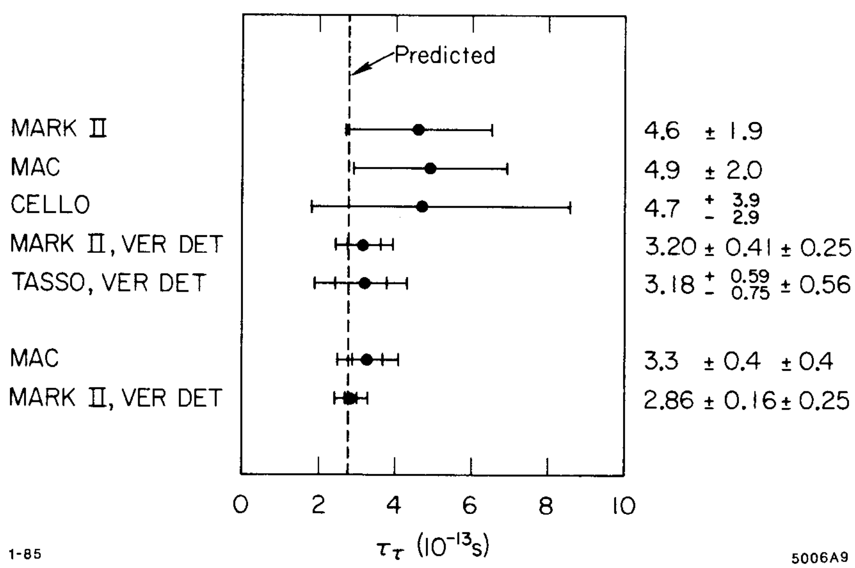

Fig. 2. Tau lifetime measurements. Data from Refs. 2 and 3.

The data can be used to place limits on the tau neutrino mass and mixing effects in the lepton sector if we assume universality is valid. The tau neutrino mass is constrained to be less than 322 MeV/c^2 at 95% C.L., which is not competitive with limits derived from other measurements.[5] If the tau neutrino mixed with a neutrino heavier than the tau, the decay rate would be suppressed by a factor $\cos^2\theta$, where θ is the mixing angle. The present data cannot exclude the possibility of rather large mixing effects: at 95% C.L., $\sin\theta < 0.46$.

High precision tests of μ–τ universality will require not only increasingly accurate measurements of the τ lifetime, but similar improvements in measurements of the tau semileptonic branching ratio and the tau neutrino mass. Uncertainties in the predicted lifetime coming from these factors are at the 5% level at present, comparable to the statistical error of the MARK II measurement.

2. CHARM LIFETIME MEASUREMENTS

The experimental situation is qualitatively unchanged from Reay's review[6] at the Como Conference one year ago. Several new results have been reported, however. Especially interesting are the new measurements of the semileptonic branching ratios of D° and D^+ mesons and the sighting and lifetime determination of the charmed strange baryon, A^+. The pattern of charm lifetimes is still largely unknown with only the D° and D^+ lifetimes measured to the 10% level.

A. MEASUREMENTS OF D° AND D^+ LIFETIMES

Figure 3 summarizes our knowledge of the D° lifetime. It includes new data from BC72/75 and NA27, and a refined analysis from NA11. Although the measurements are not in perfect agreement, they are certainly not inconsistent with each other. The weighted average for the D° lifetime, $3.8 \pm 0.3 \times 10^{-13}$ s, is within one standard deviation of all but two of the measurements. A curiosity worth noting is the sighting of a very long-lived D° candidate by the BC72/75 collaboration. It is a cleanly identified $D^\circ \to K\pi\pi\pi$ decay with a proper lifetime of 5.2×10^{-12} s, nearly fourteen times the average lifetime.

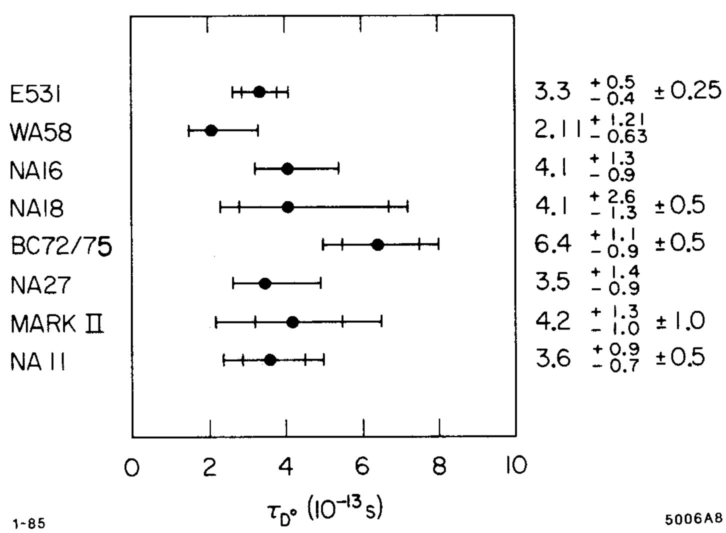

Fig. 3. D° lifetime measurements. The data are given in Ref. 7.

Figure 4 shows all the measurements of the D^+ lifetime to date and includes new points from BC72/75, NA27, NA11 and WA58. There is good agreement among the experiments, with the exception of WA58 which has too short a fiducial length to measure a picosecond

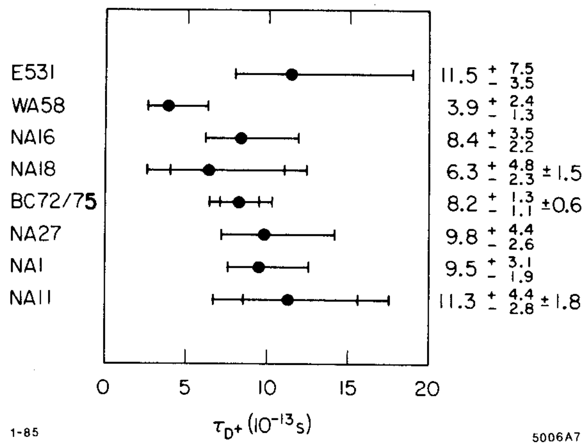

Fig. 4. D^+ lifetime measurements. See Ref. 9 for the data.

lifetime reliably with small statistics. The weighted average, excluding that WA58 point, is $8.9 \pm 0.9 \times 10^{-13}$ s.

The ratio of the lifetimes is $\tau(D^+)/\tau(D^\circ) = 2.33 \pm 0.30$, which is significantly different from one, the value expected if the decays were described by the spectator model, *i.e.*, free charmed quark decay. Only spectator diagrams contribute to the Cabibbo–allowed semileptonic decays, so we expect $\Gamma(D^\circ \to e^+\nu X) = \Gamma(D^+ \to e^+\nu X)$. Consequently, the ratio of the charged to neutral semileptonic branching ratios is expected to be equal to the ratio of the lifetimes. The MARK III collaboration[10] at SPEAR has reported new determinations of the semileptonic branching ratios, and finds $B(D^+ \to e^+\nu X)/B(D^\circ \to e^+\nu X) = 2.3^{+0.5}_{-0.4} \pm 0.1$, which is in excellent agreement with the lifetime ratio given above.

B. MEASUREMENTS OF Λ_c, F AND A^+ LIFETIMES

Figure 5 summarizes the world's knowledge of the Λ_c baryon and F meson lifetimes. The Λ_c baryon appears shorter lived than the D^+, and the F lifetime is still quite uncertain, although probably in the 4×10^{-13} s range. A CERN hyperon experiment[12] WA62 has presented evidence for the charmed, strange baryon A^+, and on the basis of about 60 decays finds its lifetime to be $4.8^{+2.8}_{-1.8} \times 10^{-13}$ s.

3. B LIFETIME MEASUREMENTS

The B lifetime is an interesting physical quantity because it is a direct measure of the strength of the weak transitions between quark generations. In principle it depends on two of the K–M matrix elements describing quark mixing, V_{bc} and V_{bu}. In practice the b quark couples predominantly to charm, so the B lifetime measures the magnitude of V_{bc}. This quantity is a fundamental parameter in the standard model and is of interest in its own right. It takes on special importance since it is the last piece of experimental information needed to deduce the magnitudes of the remaining matrix elements in the K–M model.

Two experiments reported[13] last year that the B lifetime is in the 1 ps range, substantially longer than was anticipated. This result has been confirmed this past year by three additional experiments. These new measurements together with new data from the original experiments are discussed below. All of the work comes from studies of the reaction

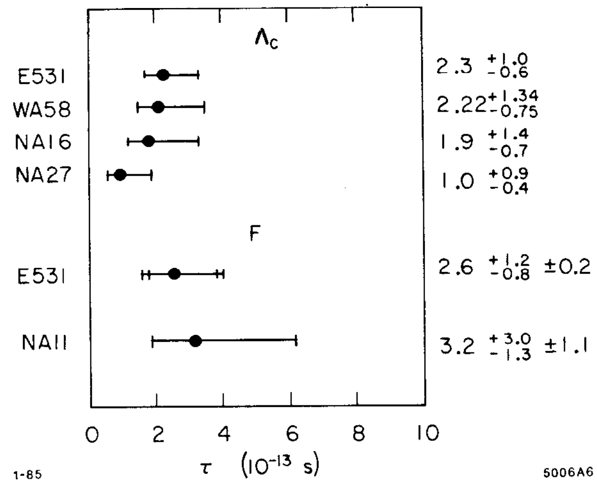

Fig. 5. Λ_c and F lifetime measurements. See Ref. 11 for the data.

$e^+e^- \to b\bar{b}$ in the PEP/PETRA energy regime. Three separate techniques have been used, and will be discussed in turn: lepton impact parameter measurements, hadron impact parameter measurements and jet vertex measurements.

A. LEPTON IMPACT PARAMETER MEASUREMENTS

The DELCO and JADE experiments have reported new measurements of the B lifetime during this past year, and both the MAC and MARK II groups have updated their published results with refined analyses and more data. All four experiments use roughly the same strategy in the measurement. The reaction $e^+e^- \to b\bar{b}$ is tagged by selecting hadronic events with a high momentum lepton, which has in addition a high transverse momentum with respect to the thrust direction of the event. Studies of inclusive lepton production in e^+e^- interactions have led to a quantitative understanding of this lepton signal and its backgrounds and show that these leptons come principally from B decays. Given that the lepton is from B decay, a measurement of its impact parameter then measures the B lifetime. Specifically, one measures the distance of closest approach between the lepton and the center of the beam ellipse, projected in the plane perpendicular to the beams. In experiments to date, the resolution in this measurement is several times the average impact parameter, so the measurement of the sign of the impact parameter is all-important. It is determined by assuming the B was produced at beam center and travelled in the thrust direction. The intersection of this "B trajectory" with the lepton trajectory gives rise to an apparently positive or negative decay length. The impact parameter is signed accordingly.

The impact parameter distribution is calculated by Monte Carlo methods. The calculations depend on well-known input parameters (the electron sprectrum from B decay and the b quark fragmentation function) and the particulars of the jet axis determination and event selection cuts. A typical distribution is shown in Fig. 6(a) for 1 ps B lifetime. Such distributions scale with the parent lifetime, of course, and have only a weak dependence on the details of fragmentation. In the limit where the B is highly relativistic, the distribution is independent of the energy of the B.

Note that the distribution is very sharply peaked and has a long exponential tail. Negative impact parameters arise from occasional errors in assigning the B direction; these make the apparent decay length negative. Fig. 6(b) shows how the distribution appears

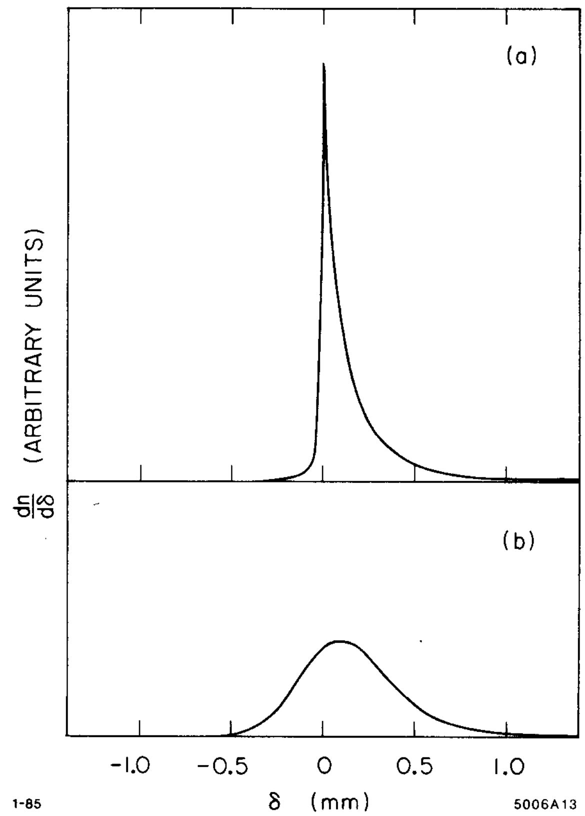

Fig. 6. Calculated lepton impact parameters for τ_b = 1 ps: (a) before resolution smearing; (b) after resolution smearing.

after it has been convoluted with the experimental resolution, which has been put at 200 μ in this example. Clearly, present experiments, which have resolutions $\geq$ 200 μ, are only sensitive to the mean of the impact parameter distribution.

Some of the distinguishing features of the four experiments are shown in Table I. Different experimental techniques are used for identifying leptons, and slightly different kinematic ranges are used to select $b\bar{b}$ candidates. Note in particular that the very clean lepton identification of the DELCO experiment results in a very clean $b\bar{b}$ sample, and permits event selection without reference to longitudinal lepton momentum. The JADE experiment, which uses lead-glass in addition to dE/dx information also has very clean, if inefficient, electron identification, and has enhanced the cleanliness of both lepton samples by requiring the events not be "three-jet-like." Much of the high p_t charm contamination comes from three-jet events where the thrust direction estimate is poor. The MAC experiment has the largest lepton sample, with nearly 400 events analyzed. The MARK II with its vertex detector has the best impact parameter resolution and consequently the best statistical precision of the experiments to date.

The impact parameter distributions from the four experiments are shown in Figs. 7–10. All of the experiments see mean impact parameters which are significantly positive. The MARK II, DELCO and JADE experiments determine the average B lifetime using maximum likelihood fits to the data; the MAC experiment derives its answer from the median of the impact parameter distribution.

Table I

	MAC	MARK II	DELCO	JADE
Lepton ID e	Pb/Gas Calorimeter	L Argon calorimeter	Čerenkov + Pb/Scintillator	Pb Glass + dE/dx
μ	Magnetized Fe Absorber	Fe Absorber		Fe Absorber
B Enriched Region (GeV/c)	$P > 2$ $P_T > 1.5$	$P > 2$ $P_T > 1$	$P_T > 1$	$P > 1.5$ $P_T > .9$
Fraction of Lepton Candidates from B Decays	0.53	0.64	0.77	.88 e .71 μ
$\int \mathcal{L}\, dt\, (pb^{-1})$	160	220	118	63
No. Leptons	398	270	60	99
Average Resolution (μ)	600	200	400	480
Average Impact Parameter (μ)	$159 \pm 39\, \mu$ $83 \pm 42\, e$	80 ± 17	215 ± 81	$282 \pm 66\, \mu$ $457 \pm 107\, e$

The results are tabulated in Fig. 11 They range from the MARK II value of $.85 \pm .17 \pm .20$ ps to the JADE value of $1.8^{+.5}_{-.3} \pm .3$ ps. Given the complexity of the analyses and the large systematic errors, the agreement is satisfactory.

Several checks have been performed in each of the experiments. The MAC, MARK II and JADE experiments find agreement between their muon and electron samples. The MARK II and DELCO experiments measure the impact parameter distribution of low transverse momentum leptons and extract average charm particle lifetimes consistent with expectation. All the experiments have measured the average impact parameter for high transverse momentum hadron tracks and find results consistent with expectations of the Monte Carlo. Finally, all the experiments have measured the tau lepton lifetime using impact parameter techniques and find good agreement with published results.

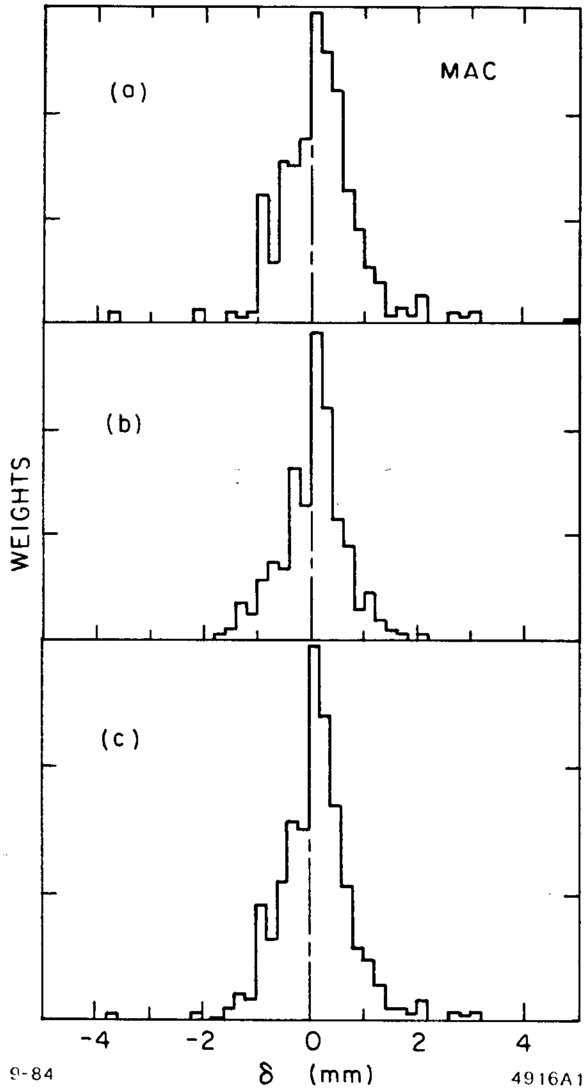

Fig. 7. Weighted impact parameter distributions from MAC. (a) muons; (b) electrons; (c) combined electrons and muons.

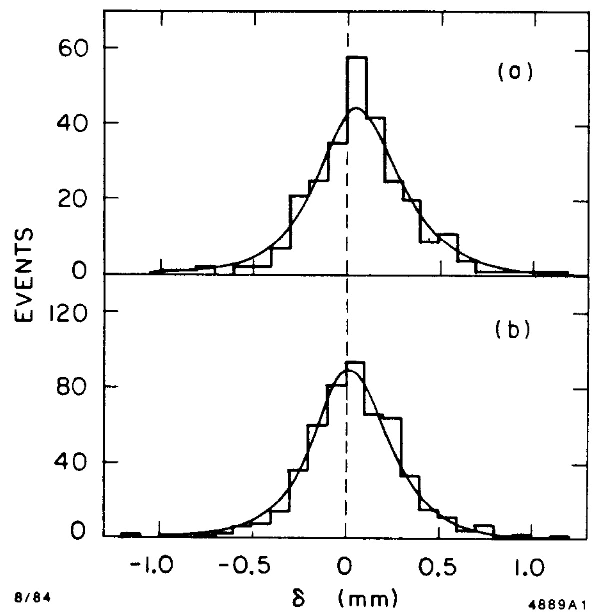

Fig. 8. Lepton impact parameter distributions from MARK II. (a) *b*-region; (b) *c*-region.

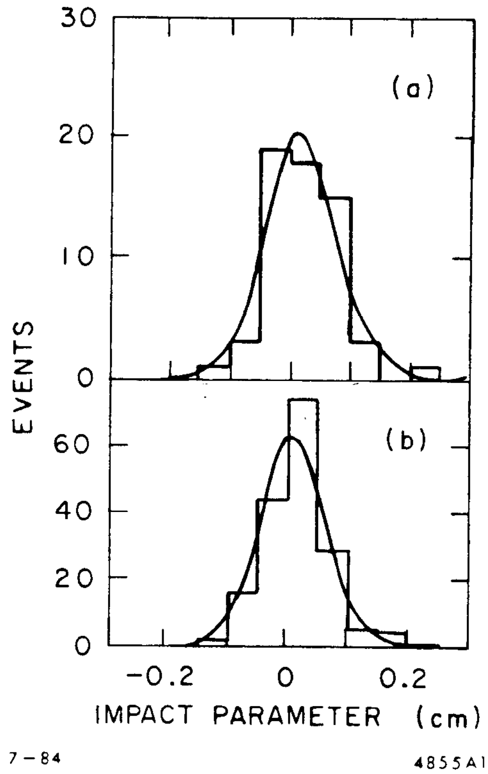

Fig. 9. Electron impact parameter distributions from DELCO. (a) b-region; (b) c-region. Data from Ref. 14.

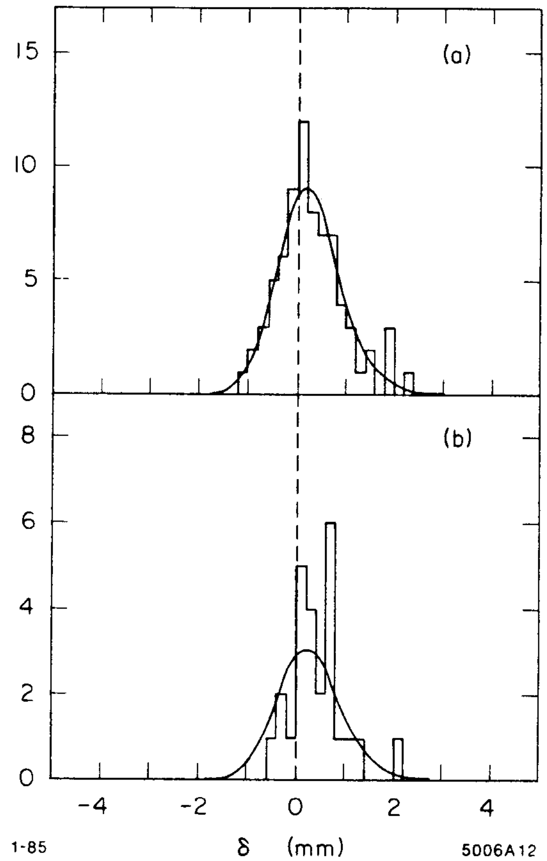

Fig. 10. Lepton impact parameter distributions from JADE. (a) muons; (b) electrons.

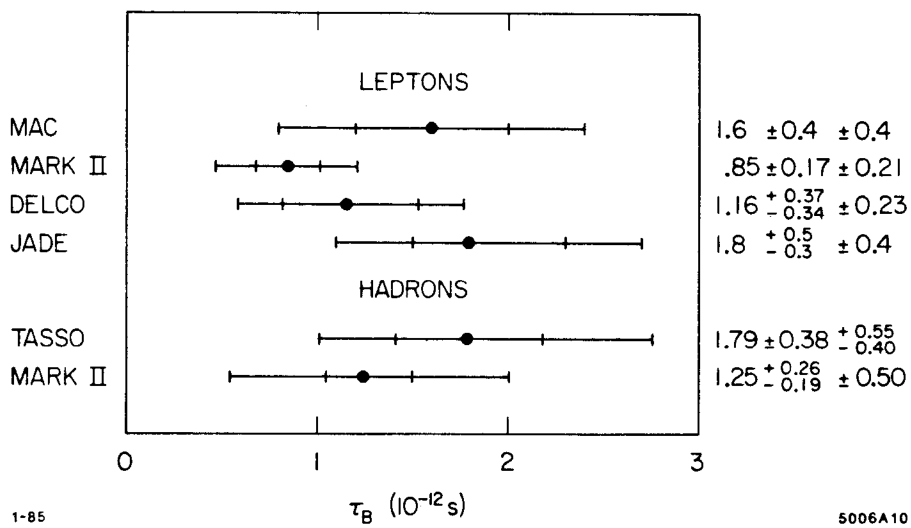

Fig. 11. Measured lifetimes of B hadrons.

B. HADRON IMPACT PARAMETER AND JET VERTEX MEASUREMENTS

The TASSO, JADE and MARK II experiments have made B lifetime measurements using hadron tracks. The advantage is clear: most of the B decay debris is hadronic, so the statistical power of the measurements is greatly enhanced. There is a compensating disadvantage: the analysis becomes dependent on all the particulars of $b\bar{b}$ production, fragmentation, and decay. These particulars are all known (if not well-known), however, so detailed analyses are possible. Since roughly two-thirds of the charged particle multiplicity in a $b\bar{b}$ event at PEP or PETRA energies is due directly to B decay, effects of a finite B lifetime appear prominently in the data. Specifically, the average B decay length at PEP energies is about 600 $\mu \times \tau_b\,(ps)$. Charm secondaries produced in these decays travel on average only $\sim$ 250 μ more, so it is the B lifetime which dominates the vertex topology of these events.

The TASSO experiment[15] has determined the B lifetime by measuring the average impact parameter of hadronic tracks in a b–enriched data set. Enrichment is accomplished without the benefit of lepton identification. Instead events are selected on the basis of "jet sphericity." In rough terms, the sphericity of each jet is measured in a frame of reference which approximates that of the produced B hadrons. In this frame $b\bar{b}$ events tend to be more spherical than events from other quark parentage, allowing some discrimination on the basis of event shape alone. The b enriched sample has the product of the two jet sphericities greater than .1; Monte Carlo calculation shows it to be 32% $b\bar{b}$, 35% $c\bar{c}$ and 33% $u\bar{u}$, $d\bar{d}$ and $s\bar{s}$ in composition. Most of the data (79 pb^{-1}) was collected at $\sqrt{s} \approx 34$ GeV with modest impact parameter resolution, $\sigma_\delta = 1100\ \mu$. The more recent data (14 pb^{-1}) was collected after the addition of a vertex detector at $\sqrt{s} = 43.3$ GeV and has $\sigma_\delta \approx 380\ \mu$. The average impact parameters of well-measured tracks with momentum exceeding 1 GeV/c in the b enriched sample were $105 \pm 13\ \mu$ and $109 \pm 23\ \mu$ in the respective data sets. Figure 12 shows the higher resolution data. The lifetimes of the two data sets are determined by comparing these measured values with Monte Carlo predictions for various B lifetimes. The two data sets give consistent answers; the combined measurements give $\tau_b = 1.83^{+.38}_{-.35}{}^{+.37}_{-.34}$ ps. The group also measured average impact parameters in all events and in b depleted events, and found values consistent with Monte Carlo predictions for $\tau_b = 1.8$ ps.

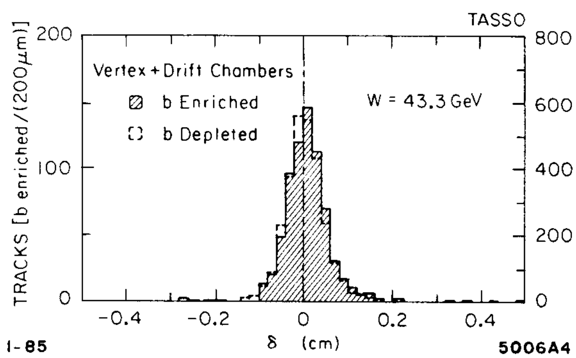

Fig. 12. Hadron impact parameters in b–enriched and b–depleted data sets from TASSO.

The JADE experiment followed a slightly different strategy: B enriched events were selected with the high transverse momentum lepton tag. They measured the impact parameter of hadronic tracks in 63 pb^{-1} of data and found an average impact parameter of $195 \pm 62\ \mu$, which converts to a B lifetime $\tau_b = 1.7 \pm 0.5$ ps. This result is consistent with their lifetime determination from lepton tracks, and is presented as a check on the other measurement.

The MARK II experiment has used yet another technique. First, a B–enriched sample is tagged with the high P_T lepton requirement. Then each event is divided in half by the plane perpendicular to the thrust axis and a separate vertex is formed from the tracks in each jet. Care is exercised to exclude tracks which may come from Λ's or K_s^o's, tracks with momentum less than 600 MeV/c (whose association to one jet or the other is problematic), and tracks which have not been fitted reliably. At least three tracks are required for a good vertex. Finally, the distance between the vertex and the known interaction point is measured, assuming the decay particles travelled in the thrust direction. The resultant distribution of decay lengths is shown in Fig. 13 for the entire MARK II data set (209 pb^{-1}). The average vertex resolution is 400 μ, to be compared to an expected decay length of $\sim$ 600 μ, so this is the most sensitive of the techniques used to date to measure τ_b. The decay length distribution is strikingly asymmetric and shows clear evidence for an exponential tail on the high side. Its mean is 413 ± 43 μ.

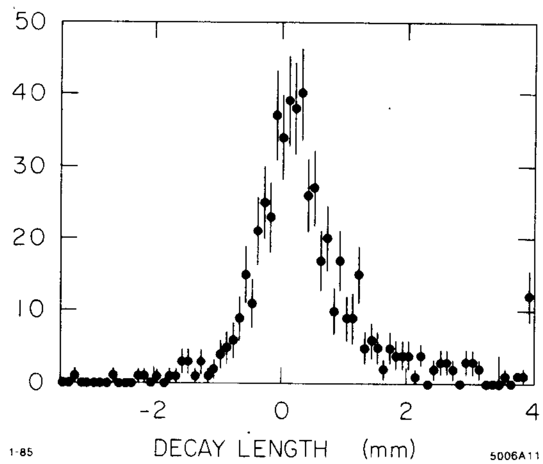

Fig. 13. "Jet decay lengths" in b–enriched events from MARK II.

The lifetime is found with a maximum likelihood technique which fits the observed distribution to the sum of three distributions: $b\bar{b}$, $c\bar{c}$, and background. Monte Carlo techniques are used to determine the $b\bar{b}$ and $c\bar{c}$ components as a function of the particle lifetimes; the background distribution is measured directly from hadronic events. The B lifetime is found to be $1.25^{+.26}_{-.19} \pm .50$ ps.

C. RESULTS AND CONCLUSIONS

Figure 11 summarizes the results of B lifetime measurements reported this past year. The experiments are in reasonable agreement, considering their large systematic errors, and confirm that the B lifetime is in the 1 ps regime. The weighted average of the results is 1.22 ± 0.17 ps.

Strictly speaking, all the experiments have not measured the same physical quantity. The lepton impact parameter measurements determine the B lifetime, averaged over bottom hadron species, weighted by the product of their respective semileptonic branching ratios and production cross sections. The hadron impact parameter measurements measure the B lifetime averaged over bottom hadron species weighted by their production cross sections alone. The differences between these measurements are expected to be small, however, as a simple model calculation will illustrate. Let us assume that the production is dominated by equal charged and neutral B meson production , and call the ratio of the charged to neutral lifetime ρ. Then the average "leptonic" lifetime is $\tau_l = \tau_o(\rho^2+1)/(\rho+1)$ and the average "hadronic" lifetime is $\tau_h = \tau_o(\rho+1)/2$ where τ_0 is the neutral B lifetime. An immediate consequence is that $\tau_l \geq \tau_h$. For practical purposes, however, $\tau_l \approx \tau_h$; even when ρ varies from 0.5 to 2, τ_l and τ_h remain equal to within about 10%.

Lee-Franzini[16] has proposed the following expression relating the B lifetime to the K–M matrix element $|V_{bc}|$:

$$|V_{bc}|^2 = \frac{(2.777 \pm 0.179) \times 10^{-15}\ \mathrm{s}}{(1+R_b)\tau_B} \quad .$$

Here R_B is the ratio of the B semileptonic branching ratios to final states without and with charmed particles. The expression removes some of the model uncertainties of the spectator model with experimental constraints coming from the measured B semileptonic branching ratio and the observed electron spectrum. Putting $R_b = 0.03$, one finds $|V_{bc}| = 0.047$. With this added input, and the row and column unitarity constraints, the magnitudes of all the K–M matrix elements are determined or severely constrained. The smallness of $|V_{bc}|$ imposes interesting constraints on the top quark mass,[17] the ratio of ϵ'/ϵ in K decay,[18] and mixing and CP violation in the B system.[19]

The long B lifetime has interesting experimental consequences, too. At PEP energies the average B decay length is nearly 1 mm, so even devices with modest impact parameter resolution ($\sim$ 100 μ) can tag long-lived B decays with practical efficiencies (few %) and little background.

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REFERENCES

1. C. A. Blocker *et al.*, Phys. Lett. 109B, 119 (1982).
2. G. J. Feldman *et al.*, Phys. Rev. Lett. 48, 66 (1982); W. T. Ford *et al.*, Phys. Rev. Lett. 49, 106 (1982); H. J. Behrend *et al.*, Nucl. Phys. B211, 369 (1983).
3. J. A. Jaros *et al.*, Phys. Rev. Lett. 51, 955 (1983); M. Althoff *et al.*, Phys. Lett. 141B, 264 (1984).
4. D. Bryman *et al.*, Phys. Rev. Lett. 50, 7 (1983).
5. The best limit to data is $m_{\nu_\tau} < 136$ MeV/c^2 at 95% C.L. from the MARK II collaboration. See C. Matteruzzi *et al.*, Phys. Rev. Lett. 52, 1869 (1964).
6. N. Reay in *"Proceedings of Physics in Collision III,"* ed. G. Bellini *et al.*, Editions Frontieres, Gif Sur Yvette, France, 1983.
7. D° lifetime measurements by experiment: E531, Ref. 6; WA58, Adamovich *et al.*, submitted to Phys. Lett.; NA16, M. Aguilar-Benitez *et al.*, Phys. Lett. 122B, 312 (1982); NA18, A. Badertscher *et al.*, Phys. Lett. 123B, 471 (1983); BC72/75, SLAC Hybrid Facility Photon Collaboration, Ref. 8; NA27, Ref. 8; Mark II, J. M. Yelton *et al.*, Phys. Rev. Lett. 52, 2019 (1984); NA11, Ref. 8.

8. R. Klanner in *"Proceedings of the International Conference on High Energy Physics,"* 22nd, Leipzig, DDR, July 19-25, 1984, Zeuth, DDR, Akademie der Wissenschaften der DDR.

9. D^+ lifetime measurements by experiment: E531, N. Ushida *et al.*, Phys. Rev. Lett. 51, 2362 (1983); WA58, Adamovich *et al.*, submitted to Phys. Lett.; NA16, M. Aguilar–Benitez *et al.*, Phys. Lertt. 122B, 312 (1983); NA18, A. Badertscher *et al.*, Phys. Lett. 123B, 471 (1983); BC72/75, SLAC Hybrid Facility Photon Collaboration, Ref. 8; NA27, Ref. 8; NA1, E. Albini *et al.*, Phys. Lett. 110B, 339 (1982); NA11, Ref. 8.

10. R. M.Baltrusaitis *et al.*, SLAC–PUB–3532, submitted to Phys. Rev. Lett.

11. Λ_c and F lifetime measurements by experiment: E531, N. Ushida *et al.*, Phys. Rev. Lett. 51, 2362 (1983); WA58, Adomovich *et al.*, submitted to Phys. Lett.; NA16, M. Aguilar–Benitez *et al.*, Phys. Lett. 122B, 312 (1983); NA11, Ref. 8; NA27, Ref. 8.

12. M. Bourquin, talk at the SLAC Summer Institute on Particle Physics, July 23–August 3, 1984, Stanford, California.

13. E. Fernandez *et al.*, Phys. Rev. Lett. 51, 1022 (1983); N. S. Lockyer *et al.*, Phys. Rev. Lett. 51, 1316 (1983).

14. D. E.Klem *et al.*, Phys. Rev. Lett. 53, 1873 (1984).

15. M. Althoff *et al.*, DESY 84/094, submitted to Phys. Lett.

16. J. Lee–Franzini, Stonybrook preprint 84–0537.

17. P. Ginsparg, S. Glashow and M. Wise, Phys. Rev. Lett. 50, 1415 (1983).

18. F. Gilman and J. Hagelin, Phys. Lett. 126B, 111 (1983)

19. See for example L. L. Chau and W. Y. Keung, Phys. Rev. D29, 592 (1984).