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WEAK DECAYS AT PEP*

JOHN M. YELTON
Stanford Linear Accelerator Center
Stanford University, Stanford, California 94305

Abstract

Results are presented on four aspects of weak decays. The MARK II measurement of the τ lifetime, the MARK II measurement of the D^0 lifetime, the measurement from several experiments of the semi-leptonic branching fractions of hadrons constaining b and c quarks, and lastly the MAC measurement of the B lifetime.

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1. Introduction

All the measurements I shall present have been obtained at the PEP e^+e^- ring at SLAC operating with a centre-of-mass energy, $\sqrt{s}$, of 29 GeV. Experiments at PEP have typically analysed 150 $pb^{-1}$of data so far, and by the summer, this should have risen to over 200 pb^{-1}.

2. The MARK II Measurement of the τ Lifetime

This analysis is a high statistics update on that already published[1], and is preliminary. The MARK II detector at PEP is well known[2]. A recent addition, vital to the measurements of lifetimes, is a high resolution drift chamber known as the vertex chamber[3], positioned inside the inner shell of the main drift chamber. The vertex chamber is designed to constrain very well the trajectories of charged particles close to the origin of the events, and thus to measure decay lengths of weakly decaying particles. It has three features which make it particularly good for this purpose. Firstly the resolution on each measurement point is around 100 μ, secondly the first four measurement points are only $\sim$ 12 cm from the origin, and thirdly there is very little material between the event origin and the first measurement points. The error in the extrapolated position of a charged track near the origin of an event is around 100 μ.

Tau leptons are produced at PEP in pairs, each with the beam energy (14.5 GeV). They have a fairly distinctive signature energies and can be identified by topological cuts[1]. For lifetime measurements events are selected where one of the τ's decays to three charged particles and the other to either three charged particles or, more typically one charged particle. Figure 1 shows three views of such an event, as seen in the detector. For each event the path length is calculated from the production point of the taus, the decay point of the three-prong tau, and the direction of the tau. The production point of the taus is identified with the position at which the beams cross. The beam position is measured accurately every two-hour run by taking the mean position of a collection of well measured tracks. The error on the production point is dominated by the beam size, which is measured to be $\sim$ 500 μ in the horizontal direction and $\sim$ 80 μ in the vertical. The decay point of the tau is the position where its three tracks meet, its error is typically a few hundred microns. The direction of the tau is approximated by the direction of the three charged particles. The relationship used to find the most likely decay length from these measurements has been explained elsewhere[1].

So far, around 400 τ's have been identified in which all three tracks pass stringent quality requirements. The distribution of the errors on the individual measurements is shown in figure 2, only those with an uncertainty of less than 1.4 mm are retained. The distribution of path-lengths is shown in figure 3(a). It clearly offset from zero. The lifetime distribution is fit by the maximum liklihood method to a convolution of an exponential decay distribution and individual Gaussian errors. The mean path length is found to be 621 $\pm$ 52 μ. The line on figure 3(a) shows the expected shape of the distribution for this mean value. The mean path length is then corrected for the small hadronic background component to give a mean path length for τ's of 652 $\pm$ 55 μ. This is then converted to a mean lifetime using the known mean energy of the produced τ's (14.5 GeV with a small energy correction for initial state bremsstrahlung), to yield an answer of $(2.80 \pm 0.25) \times 10^{-13}$ s.

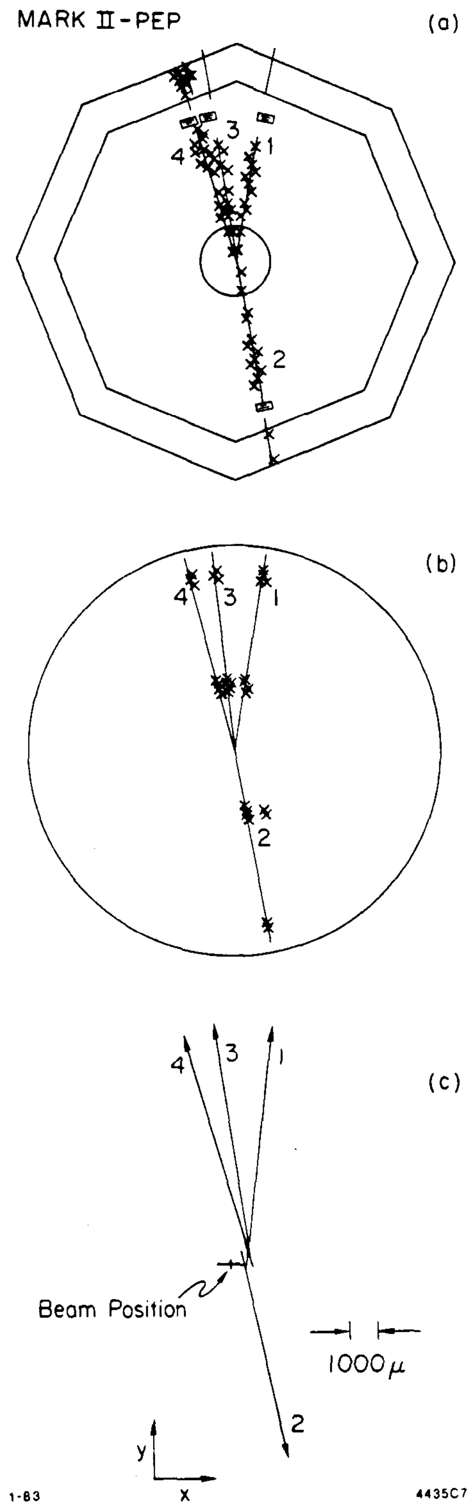

Fig. 1. Three views of a τ event from the lifetime sample. (a) showing drift chamber and vertex chamber, (b) just the vertex chamber and (c) just the vertex region.

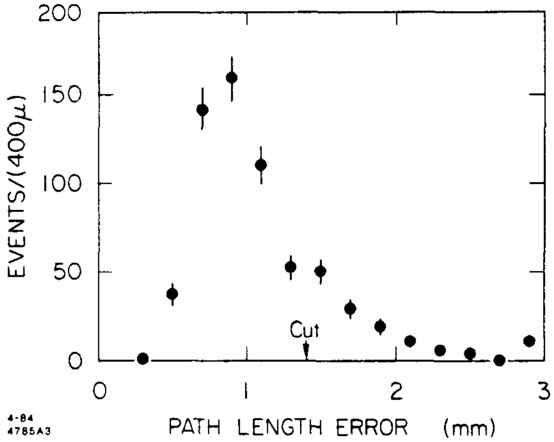

Fig. 2. The error distribution for the path length of the τ's that pass all track quality cuts.

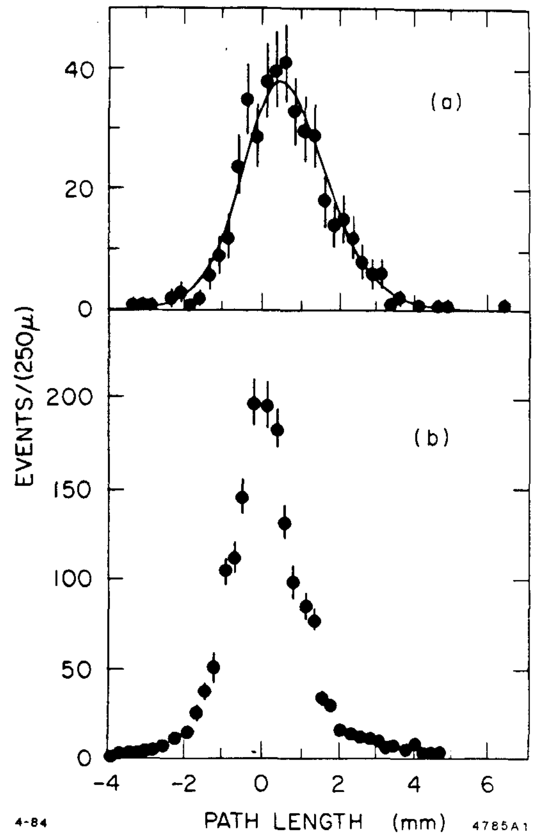

Fig. 3. The path length distribution for (a) the final τ sample and (b) the control sample. Preliminary data.

To check for possible biases in the data we have constructed a 'control' sample of 'pseudo-tau' decays in hadronic events. For this study we select three-track combinations in hadronic events which pass our tracking criteria and which have kinematic properties like the three-pion τ decays. Figure 3(b) shows the decay length distribution from these 'pseudo-tau' decays. The fitted mean decay length is 79 μ, roughly an order of magnitude less than real τ decays. A positive mean decay length of this order is expected because of the presence of tracks from charmed and bottom decays in the sample. We have investigated many more sources of potential systematic error, for example uncertainty in the error calculation and sensitivity to the track quality criteria. The total resultant systematic uncertainty is 0.3×10^{-13} s. Data is still being taken, by the summer both the statistical and systematic uncertainties should be smaller.

The τ lifetime is a measurement if fundamental importance in studying the lepton families. If the τ is truly sequential, theory predicts that its lifetime be 2.82 ± 0.18 s.[4] (the error comes mostly from the experimental uncertainty in the $\tau \rightarrow$ e branching fraction.) The experimental and theoretical numbers are thus very close, and the evidence is mounting that the τ is, indeed, a sequential lepton.

The preliminary number presented in this talk is compared with other measurements around the world in figure 4. Progress has been fast. Around 1980[6] it was demonstrated that the τ lifetime was not orders of magnitude away from the theoretical prediction. The MARK II[7] (before the vertex chamber was built), showed it to be non-zero, and now we can really demonstrate that the coupling of τ's is, at the very least, similar to the other leptons.

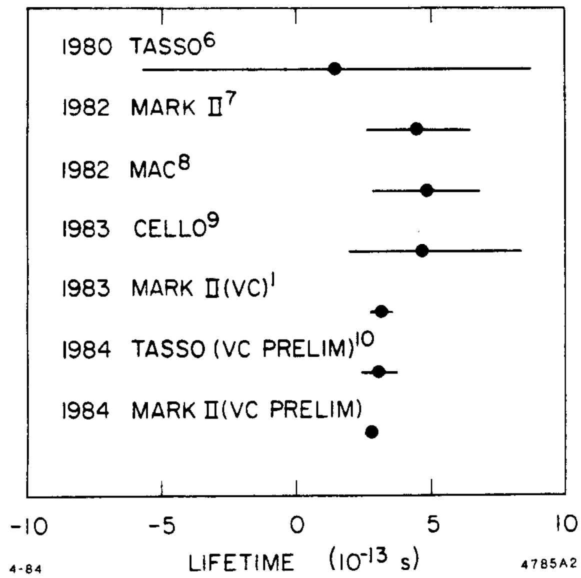

Fig. 4. The lifetime of the τ through the ages (statistical errors only are shown).

3. The MARK II Measurement of the D^0 Lifetime

This analysis is an update on those presented at previous conferences, and will soon be published in PRL[5]. After measuring the τ lifetime it is easy to see how one can measure the D^0 lifetime provided a clean sample of D^0 's can be isolated. Luckily, this is possible by observing the decay

$$D^{*+} \rightarrow D^0 \pi^+$$
$$\hookrightarrow K^- \pi^+$$

(Reference to a particle state will always imply the sum of that state and its charge conjugate state.) This decay mode has been shown to give good separation of signal and background at high D^{*+}energy[11]. No attempt to identify particles was made, but all tracks were tried as kaons and pions. All oppositely charged Kπ pairs with invariant mass between 1.72 GeV/c^2 and 2.00 GeV/c^2 were considered as D^0 candidates, and their momenta constrained using the D^0 mass. Each D^0 candidate was then combined with the additional pions of appropriate sign in the event. The mass difference, ($M_{D^0\pi}$ - M_{D^0}) is plotted in figure 5 for those combinations with z (=$E_{D^{*+}}/E_{BEAM}$) > 0.6. As in the case of τ, the tracks making up the D^{*+}were required to pass stringent track quality cuts. The mass difference plot shows a clear D^{*+}peak at around 145.5 MeV/c^2, containing 27 events.

For each D^0 the path length is found, as in the case of the τ, and the path length converted to a lifetime event by event using the D^0 momentum. The distribution of lifetimes is shown in figure 6, it is fit to a exponential distribution convoluted with individual gaussian errors. The fit allows for small contributions from combinatorial background (estimated at 2 events), and for D^{*+}'s arising from decays of B mesons (estimated at 0.7 events, with a large error). The resultant measurement for the D^0 lifetime is $\tau_{D^0} = 4.2^{+1.3}_{-1.0} \times 10^{-13}$ s (statistical error only). The systematic uncertainty is estimated to be 1.0×10^{-13} s, arising from the same uncertainties as in the τ measurement together with uncertainties in the contribution from background and B decays.

Historically the measurement of charm lifetimes has been a subject of disagreement between experiments. However, figure 7 shows recent measurements for the D^0 lifetime. The spread of results is consistent with that arising from statistical fluctuations, with a mean

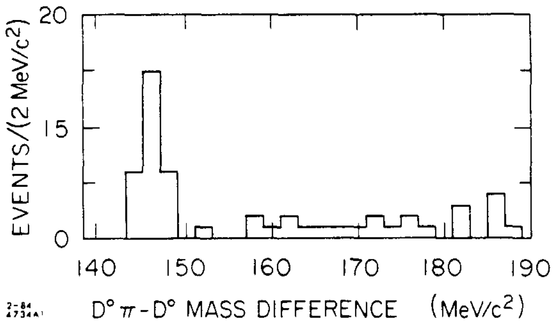

Fig. 5. The mass difference, $(M_{D^0\pi} - M_{D^0})$ for combinations with fractional energy, z, >0.6.

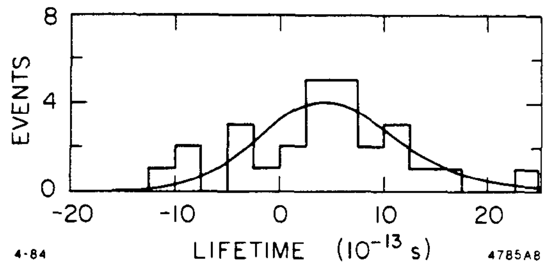

Fig. 6. The lifetime distribution for the 27 events passing all cuts (MARK II).

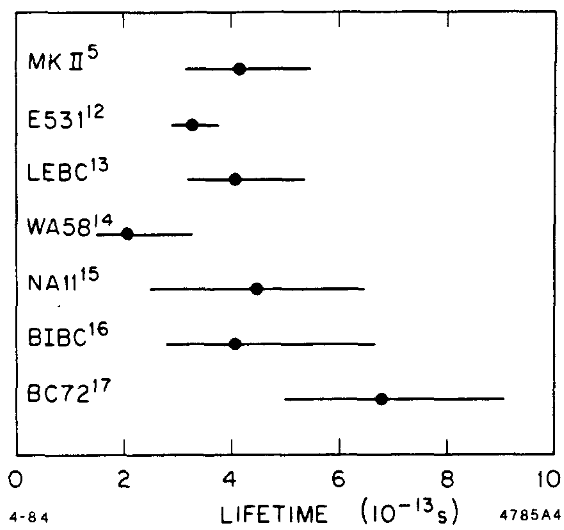

Fig. 7. The D^0 lifetime as measured by recent experiments around the world. Statistical errors only are shown.

measurement of around 4×10^{-13} s. This is considerably below that of the D^+ .[18] This difference in the lifetimes is taken as evidence of the importance of non-spectator diagrams in D decays.

4. Inclusive Lepton Production at PEP

Most experiments at PETRA and PEP now have results on direct lepton production, that is the study of leptons arising from charmed or bottom mesons. Bottom mesons have much greater mass than charmed mesons, so the leptons arising bottom decays are thrown out a long way from the event axis, and may be separated, on a statistical basis, from those arising from charmed decays. All experiments follow the same basic analysis method, though the methods used to identify leptons vary from experiment to experiment. I shall illustrate the analysis by showing some results on electrons from the PEP-4 (TPC) experiment as they are new (and preliminary)[19]. The PEP-4 experiment[2] has two methods for identifying electrons, by means of ionization loss in the TPC itself, and by detection of electromagnetic energy in the calorimeters outside the TPC. As the two detectors reject hadrons by essentially independent methods, the total hadron rejection is very good. The total misidentification probability for hadrons is as low as 0.003%, dependent on momentum. Unfortunately, because of the large amount of material before the lepton identification, there is a large background of electrons from conversions that have to be simulated by Monte-Carlo and subtracted. Figure 8 shows the electron momentum spectrum for electrons with (a) $P_T < 1$ GeV/c, and (b) $P_T > 1$ GeV/c, where P_T is the momentum perpendicular to the thrust axis of the event. The graph shows contributions due to conversions and the hadron misidentification (the latter is barely visible.)

The detected leptons are histogrammed in bins of P and P_T. This two-dimensional histogram is then fit for three variables. Firstly the branching fraction of B mesons into electrons, secondly the branching fraction of D mesons into electrons, and thirdly a measure of the fragmentation function of b quark decays. The charm fragmentation function is input from as it is known from many e^+e^- experiments. I shall not discuss the b fragmentation function, as it is outside the scope of this conference, sufficeth to say that it is hard. However the semi-leptonic branching fractions are displayed in table I for the TPC and other PEP and PETRA experiments. The unanimity is pleasing. Also included are the values of the semi-lepton branching fractions for B-mesons as measured at Cornell. It is clear that their ability to compare on and off resonance lepton production has a great advantage over PEP/PETRA energies. I shall not attempt to average between experiments as it not clear which of the systematic errors are in common. However it is clear that the branching fraction for bottom is around 13% into both muons and electrons, and for charm it is around 8%.

The fit in P,P_T space gives a probability for each lepton to be due to bottom decays, charm decays and due to the cascade bottom→charm→lepton. For instance the background subtracted electron momentum spectra for the TPC are shown in figure 9. The three different shadings show the number of leptons measured to be from the three processes. This statistical separation can then be used for many aspects of heavy meson studies, such as the measurement of lifetimes.

Table I

A compilation of results for the semi-leptonic branching fractions of bottom and charm. Many of these results are preliminary.

BRANCHING FRACTIONS (percentages)		
Bottom	Electrons	Muons
MARKII[20]	$13.5 \pm 2.6 \pm 2.0$	$12.6 \pm 5.2 \pm 3.0$
MAC [21]	$11.3 \pm 1.9 \pm 3.0$	$12.4 \pm 1.8 \pm 2.2$
DELCO [22]	14.6 ± 2.8	
TPC[19]	$11.0 \pm 1.8 \pm 1.0$	$13.2 \pm 1.8 \pm 1.0$
MARK-J[23]		$10.5 \pm 1.5 \pm 1.3$
CELLO[24]	$14.1 \pm 5.8 \pm 3.0$	$8.8 \pm 3.4 \pm 3.0$
TASSO[25]		$11.7 \pm 2.8 \pm 1.0$
CUSB[26]	$13.2 \pm 0.8 \pm 1.4$	
CLEO[27]	$11.9 \pm 0.7 \pm 0.4$	$10.1 \pm 0.5 \pm 1.0$
Charm	Electrons	Muons
MARKII[20]	$6.6 \pm 1.4 \pm 2.8$	$8.3 \pm 1.3 \pm 1.8$
MAC[21]	8.0 ± 3.0	9.0 ± 3.0
DELCO[22]	9.1 ± 1.3	
TPC[19]	$9.1 \pm 0.9 \pm 1.3$	$7.2 \pm 1.4 \pm 0.5$
MARK-J[23]		$11.5 \pm 1.0 \pm 1.7$
CELLO[24]		$12.3 \pm 2.9 \pm 3.9$
TASSO[25]		$8.2 \pm 1.2 \pm 2.0$

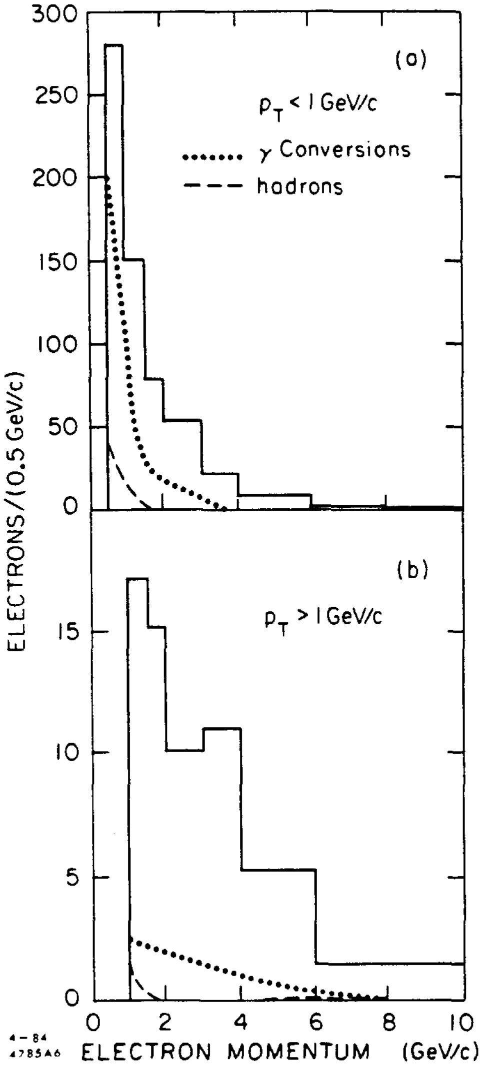

Fig. 8. The electron spectrum measured by the PEP-4 (TPC) experiment. Two bins of P_T are shown. Preliminary data.

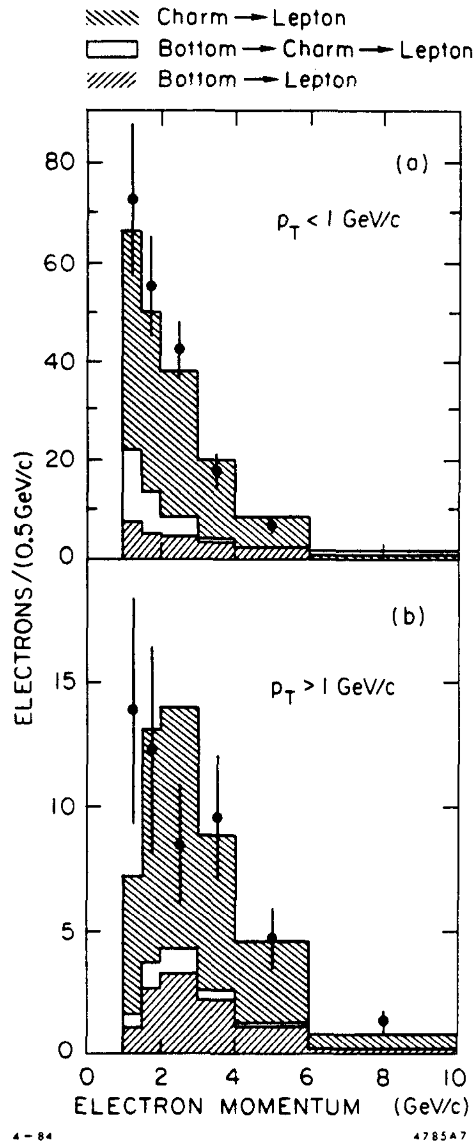

Fig. 9. The background subtracted electron spectrum measured by the PEP-4 (TPC) experiment. The contributions from the three processes leading to direct electrons are shown. Preliminary data.

5. The MAC Measurement if the B Lifetime

Last summer both MAC[28] and MARK II[29] published measurements of the B lifetime, referring to the mean lifetime of the mix of B hadron decays observed by semi-leptonic decays. Since that time MAC has updated their result[30], but MARK II is saving itself for this summer. Thus I shall only discuss the latest MAC results, and they should be considered preliminary. The analysis proceeds from their direct lepton studies. They define a region of P,P_T space, called the B-enhanced region, with $P > 2$ GeV and $P_T > 1.5$ GeV/c. Of these, ~ 30 %

are due to hadron background, ~18% due to charm and ~52% due to b decays. The B lifetime is then found from the impact parameter of these leptons. The impact parameter is the distance of closest approach of the particle trajectory to the production point, and is illustrated in figure 10. The position of the production point is taken to be the average beam position with its uncertainty. The MAC experiment[2] do not have a purpose built vertex chamber like the MARK II, but their drift chamber is of roughly the same dimensions, and is very effective for lifetime measurements. Their extrapolated track error is typically a few hundred microns, similar to the beam width. The impact parameter is defined to be a signed quantity, if the trajectory of the lepton crosses the thrust axis of the event after the beam position (thus signifying a positive decay path) the impact parameter is positive. The mean impact parameter, $<\delta>$, may be converted to the mean lifetime, τ, by the equation:

$$<\delta> = <\beta\gamma \sin\psi \; \sin\theta \, c\tau> = \alpha \, c\tau$$

Here ψ is a decay angle and α is a constant found by Monte-Carlo studies. For leptons arising from B decays α=0.45, and for those arising from charm decays, α=0.15. The value of α is rather insensitive to the exact shape of the fragmentation function. The impact parameter distribution for muons and electrons in the B-enhanced region of P,P_T space is shown in figure 11. Both show a positive offset indicating a finite decay length. (MAC now use the median impact parameter for $<\delta>$ rather than the mean, to reduce sensitivity to tails.) The impact parameter distributions are somewhat narrower than those already published by MAC, because of an improved track-fitting procedure used.

To check that biases in the chamber or analysis technique do not artificially create an apparent lifetime, a control sample is constructed from tracks from the same P,P_T bins as the B-enhanced region, but identified not as leptons but as hadrons. The median impact parameter found for this data set is $<\delta_{bg}>=23\pm7\mu$, much smaller than that of the leptons. The control sample is expected to have a positive average impact parameter, because of the heavy mesons contained in it. The Monte-Carlo prediction is:

$$<\delta_{bg}> = 8\,\mu + .03\, c\tau_B$$

and thus, if $\tau_B = 1.6 \times 10^{-12}$, $<\delta> = 22 \pm 6\,\mu$, very close to the expected value. The reason for choosing this value of τ_B will soon become apparent! Monte-Carlo studies can also tell what $<\delta>$ to expect due to charm events, it is $<\delta_c>\sim 20\,\mu$.

Now the B lifetime can be extracted for the muon and electron samples separately using the equation:

$$<\delta> = f_B\,\alpha\, c\tau_B + f_c <\delta_c> + f_{bg} <\delta_{bg}>$$

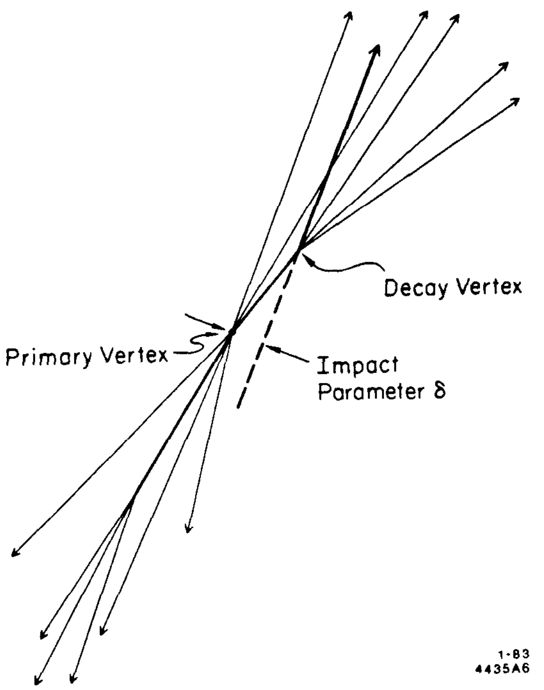

Fig. 10. The definition of the impact parameter, δ of a lepton.

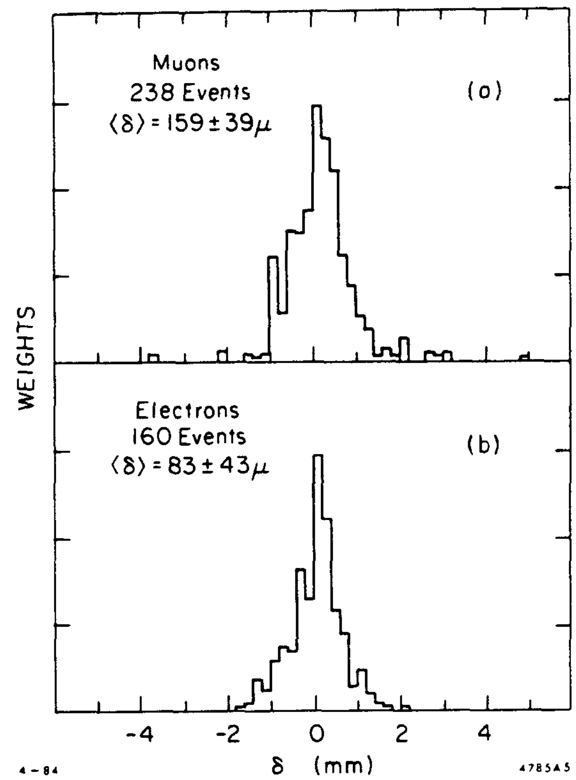

Fig. 11. The Impact parameter distributions for leptons as measured in the MAC detector. Preliminary data.

where the three term are due leptons coming from B decays, leptons coming from charm decays, and hadronic background respectively. Thus, as we know median values of δ_c ($\sim 20\mu$), and of δ_{bg} (as a function of τ_B), and we know the 'f' parameters (the fractions of the lepton sample arising from the three processes), we can solve for τ_B. Averaging over muon and electron samples, the answer is $\tau_B = (1.6 \pm 0.4 \pm 0.3) \times 10^{-12}$ s, where the errors are statistical and systematic respectively. The systematic error is mostly due to the uncertainty in calculating the contribution from bottom, charm and background that are in the sample. This preliminary result may be compared with the already published results from MAC of $\tau_B = (1.8 \pm 0.6 \pm 0.4) \times 10^{-12}$ s, and is in good agreement with the result from MARK II of $(1.20^{+.45}_{-.36} \pm .30) \times 10^{-12}$ s. The MAC experiment is still collecting data, so the statistical uncertainty should be reduced in the months to come. Furthermore, they intend to install a vertex detector, very close to the beam interaction region, which should increase their impact parameter resolution considerably. Not only the MARK II, but also other experiments at PEP and PETRA are planning to announce new results this summer, so by then I expect it to be proved beyond reasonable doubt that the B lifetime is, indeed, of the order of 10^{-12} s.

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