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RECENT RESULTS ON WEAK DECAYS FROM THE MARK II EXPERIMENT

George H. Trilling

Lawrence Berkeley Laboratory and Department of Physics
University of California
Berkeley, California 94720

INTRODUCTION

In this paper I shall bring you up to date with respect to the MARK II Collaboration's work[1] on several aspects of weak decays. In particular, I shall be discussing our results on the ν_τ mass, and on τ, D^o and B lifetimes. I begin with a brief description of the MARK II detector.

The MARK II detector, operating at the electron-positron storage ring PEP at SLAC, consists principally of (1) a charged-particle tracking system immersed in a solenoidal magnetic field of 2.3 Kgauss, surrounded by (2) a lead-liquid argon electromagnetic calorimeter which in turn is surrounded by (3) a steel-proportional-tube muon identifier. The fractions of 4π solid angle covered by the various systems are 80% for the charged-particle tracker, 64% for the calorimeter and 45% for the full steel thickness (1 meter) of the muon identifier. The charged-particle tracking system consists of two separate parts both concentric with the beam line- (i) a conventional drift chamber with sixteen layers of sense wires between radii of 40 cm and 140 cm, and (ii) a high resolution cylindrical drift chamber (called the vertex detector) located between the beam pipe and the inner wall of the main drift chamber.

This vertex detector contains seven layers of sense wires, the inner four of which are closely spaced near a radius of 10 cm and the outer three of which are also closely spaced near a radius of 30 cm. The typical sense wire resolution is 100μ. The vacuum beam pipe is a thin beryllium tube which also serves as the inner wall of the vertex detector to minimize degradation of resolution by multiple scattering. The overall charged-particle momentum resolution is typically 1p(GeV/c)% with an additional 2% contribution from multiple scattering.

A NEW UPPER LIMIT ON THE ν_τ MASS

Present upper limits on the ν_τ mass have been set in two independent experiments. Bacino et al[2] have based their limit on the observed electron spectrum in τ decay, whereas Blocker et al[3], have determined a limit from the pion spectrum in the $\tau \to \pi + \nu_\tau$ decay mode. Both limits are 250 MeV/c^2 at the 95% confidence level.

We have used the following new approach to obtain an improved limit. We have identified the decay mode,

$$\tau^\pm \to \pi^\pm + \pi^+ + \pi^- + \pi^0 + \nu_\tau$$

and studied the 4π invariant mass spectrum. The upper limit of that spectrum will, in the absence of resolution effects, differ from the known τ mass by just the neutrino mass, and the high multiplicity involved will populate the mass spectrum near the upper end just where the information content is maximal.

The analysis is based on an integrated luminosity of 158 pb^{-1} corresponding, at our c.m. energy of 29 GeV, to about 16,000 produced τ pairs. Candidate events have four charged prongs of total charge zero and at least two detected photons of energy above 250 MeV. The plane perpendicular to the event thrust is used to divide space into two hemispheres and three of the tracks are required to lie in one hemisphere with a total momentum vector acollinear with the fourth track by less than 50°. Cuts are made to ensure good measurements of the tracks, and events in which track pairs are consistent with being Dalitz decays are rejected.

Special care is also exercised to ensure that the photons used in the analysis are well measured, and unconfused with the charged particles. The γ - γ mass spectrum, shown in Fig. 1, shows a clean π^0 peak, and only events in which there is one such pair with confidence level greater than 10%, and no additional pair with a χ^2 less than 10 (for one degree of freedom) are accepted. Finally, to minimize hadronic background the total energy of the $3\pi \pm \pi^0$ state

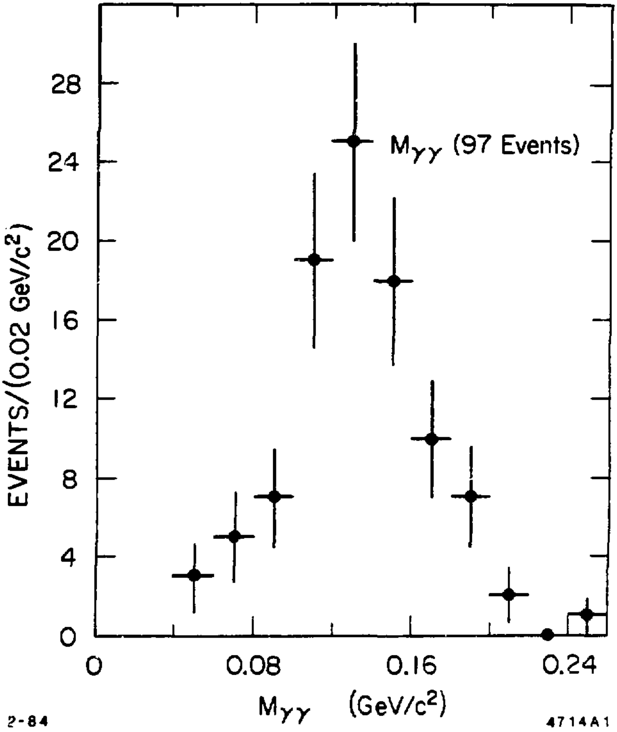

Fig. 1. γ - γ invarient mass distribution for $3\pi^{\pm}\pi^0$ candidates before requiring the confidence level for the fit to the π^0 hypothesis be greater than 10%.

is required to be greater than 8 GeV for $M_{4\pi} < 1.5$ GeV/c^2 and greater than 10 GeV for $M_{4\pi} > 1.5$ GeV/c^2. The residual hadronic background is estimated to be 3% for the full sample and (10 ± 10)% in the region $M_{4\pi} > 1.5$ GeV/c^2. The 4π invariant mass resolution has an average value of (53 ± 5) MeV/c^2 for $M_{4\pi} > 1.5$ GeV/c^2.

Fig. 2 shows the 4π mass spectrum for the 60 events which survive all the cuts. The curves shown are based on dominance of the 4π state by a ρ' of mass 1570 MeV/c^2 and width 510 MeV/c^2, with ν_τ masses of both zero (solid) and 250 MeV/c^2 (dashed). The fit for zero ν_τ mass is good, and we derive from the data above 1.5 GeV/c^2 a 95% C.L. upper limit of 155 MeV/c^2. If the decay is assumed to follow pure phase space rather than the ρ' shape, the ν_τ limit is unchanged, because the spectrum shape above 1.5 GeV/c^2 is almost completely phase-space dominated. After taking due account of uncertainties in resolution and hadronic background, we obtain as our final result a 95% confidence level upper limit for the ν_τ mass of 164 MeV/c^2.

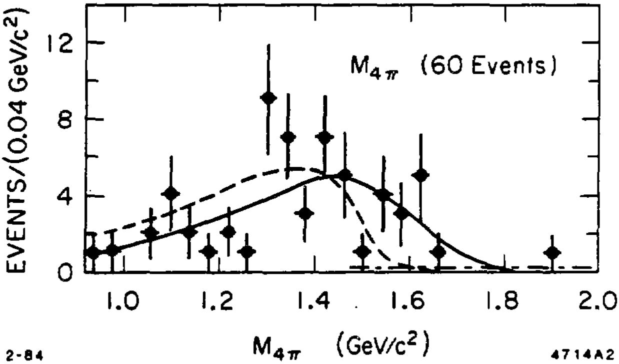

Fig. 2. $3\pi \pm \pi^0$ invariant mass distribution for the selected sample. The solid and dashed curves are explained in the text, and the dashed-dotted line represents the hadronic background.

LIFETIME MEASUREMENTS - GENERAL REMARKS

We now go to our lifetime measurements of τ, D^o and B. The first two of these are based on verticizing the decay tracks and measuring the distribution of decay proper times (for τ this is just proportional to the decay length since the τ is monoenergetic). The procedure is discussed in adequate detail in the paper of Jaros et al.[4] The B measurement is based on the observed distribution of impact parameters of high P_T leptons and has been discussed in the paper of Lockyer et al.[5] Here I just want to make a few general remarks:

(1) In all three cases the decays are identified through criteria which are <u>independent</u> of the decay times. We thus avoid the potential biases present in many of the techniques used for lifetime measurements, in which detection efficiency depends on time-of-flight.

(2) The measurement resolutions provided by the vertex detector are comparable to (τ, D^o) or broader than (B) the average time-of-flight signal. Our ability to get an accurate result is based on careful assurance that these resolution errors are random, and that their effect can be appropriately reduced with sufficient statistics.

(3) To obtain the best information from our data, we have used maximum likelihood fits of the experimental distributions to convolutions of theoretical distributions with expected resolutions. This procedure suffers from a potential bias - an underestimate of resolution will generally lead to an overestimate of lifetime. We have taken account of this potential problem in our analysis procedure and have included in our systematic errors estimates of any residual contributions from this source.

THE τ LIFETIME

The τ lifetime is easily predicted from the standard formulas,

$$\tau_\tau = \frac{1}{\Gamma_e} B_e$$

where

$$\Gamma_e = \frac{G^2 M_\tau^5}{192\pi^3} = 0.627 \times 10^{12}\ \mathrm{sec}^{-1}$$

and B_e is the electron branching ratio. Taking for B_e our measured value of 17.6 ± 1.1%, we find for the expected τ_τ the value $(2.81 \pm 0.2) \times 10^{-13}$ sec if the coupling constant G is the same as in muon decay. The dominating uncertainty in this prediction is the error in the branching ratio. This expected lifetime corresponds to a mean decay length of about 650μ at our energy of 14.5 GeV per beam.

We base our measurement on the reconstruction of vertices of three-prong τ decays, and the determination of decay lengths between the relevant beam interaction points and these vertices. The detailed procedure has been discussed in the paper of Jaros et al.[4] Great care is exercised in the selection of τ decays where all three prongs are well measured and have at least two hits in the inner four layers of the vertex detector and at least one hit in the outer three layers. In addition, cuts on (1) total event energy, (2) total energy, momentum and invariant mass of the 3π system, and (3) mass of the 3π plus neutrals in the same hemisphere are used to ensure freedom from hadronic contamination and removal of events with converted electron pairs. Because the vertex detector measures only x, y information (in the plane perpendicular to the beam) the vertex reconstruction is done only in that plane, the known total momentum vector of the three pions then being used to convert decay length to three dimensions. The vertex fit χ^2 distribution has the expected shape for one degree of freedom and a cut at $\chi^2 < 4$ is made. Only events for which the calculated decay length error is less than 1.4 mm (about 75% of the events)

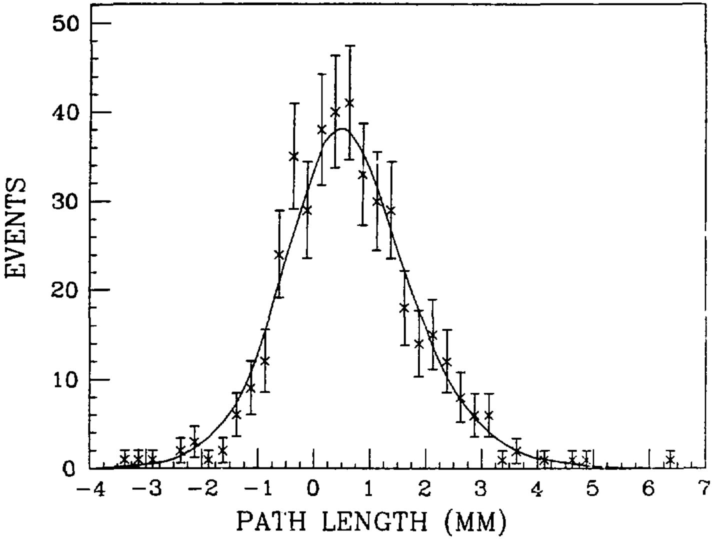

Fig. 3. τ decay length distribution. The solid curve is the fit to the data.

soon be able to reduce the systematic error. Our preliminary result is in excellent agreement with theory.

THE D^o LIFETIME

We identify D^o mesons through observation of the sequence

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

and choose events for which the D energy is at least 60% of the beam energy to minimize the background. No attempt is made to identify particles, and all tracks are tried as pions and kaons. Oppositely charged $K\pi$ pairs with invariant mass between 1.72 and 2.00 GeV/c^2 are considered as candidates and combined with additional pions of appropriate sign to study the distribution of $(M_{D\pi} - M_D)$. Furthermore events are retained only if each of the tracks which make up the D* candidate are well measured, have at least three vertex chamber hits, and can be fit to a vertex with reasonable χ^2. The π originating from the D* decay does not come from the real D^0 decay vertex, but because of the low Q value of the decay it passes very close to that vertex and the success of the three-particle fit provides a check that none of the tracks have been scattered or mismeasured. The distribution of $(M_{D\pi} - M_D)$ after these cuts is shown in Fig. 4. The sample is taken to be those 27 events which fall between 143 and 149 MeV/c^2. We estimate that this sample includes two events from hadron contamination and one event from D* originating in B decay.

Decay lengths are calculated in the same manner as for the τ sample, and converted to proper times from the measured momenta. The mean lifetime is obtained from a maximum likelihood fit of the 27 events with appropriate corrections due to hadron background, B decay contributions, and possible underestimates of decay length errors. A non-D^0 control sample is used to check possible systematic errors. Proper time distributions for the real data sample and for the control sample are shown in Fig. 5a and 5b respectively. Our final result for the D^0 lifetime is $(4.2\,^{+1.3}_{-1.0} \pm 1.0) \times 10^{-13}$sec.

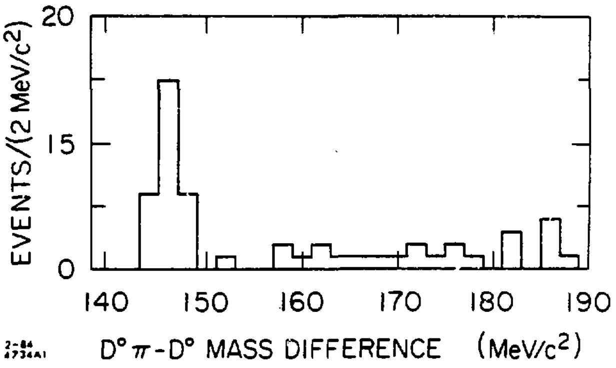

Fig. 4. The mass difference $M_{K\pi\pi} - M_{K\pi}$ for the selected sample.

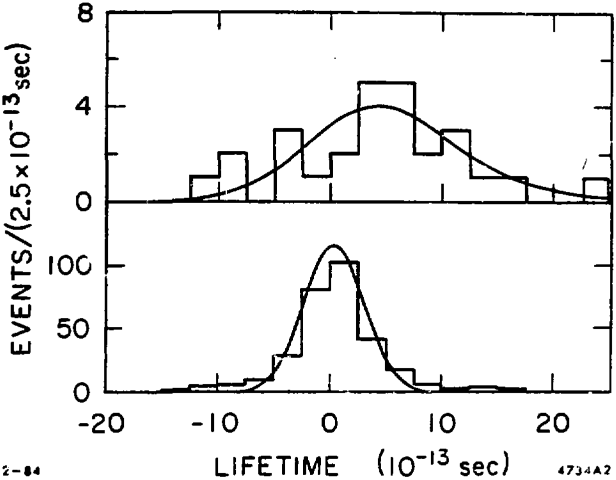

Fig. 5. The observed proper time distribution for (a) the 27 identified D^0 events; (b) the hadron control sample. The curves are (a) the result of the fit described in the text and (b) a Gaussian fit.

It is in good agreement with values from other experiments.

THE B LIFETIME

Our analysis of B lifetime has been published,[5] and we have no new results to report at this time. However, for completeness, I briefly recapitulate the main ingredients of that analysis. We identify heavy meson decays (bottom and charm) through detection of electrons and muons in hadronic interactions, and set up $c - \bar{c}$ and $b - \bar{b}$ enriched samples through appropriate cuts on lepton total momentum and transverse momentum relative to the event thrust axis. We define for each lepton in the x-y plane an impact parameter of its trajectory relative to the average beam position. We assume that each heavy meson originates at the average beam position and moves along the thrust axis in that direction which makes an acute angle with the lepton momentum vector. If, with that convention, its apparent decay length is positive (negative) we assign a positive (negative) sign to the corresponding impact parameter. It is then an excess of positive impact parameters which provides a signal for a finite mean decay length for the heavy meson. The interpretation of the impact parameter distribution in terms of actual lifetimes involves consideration of cuts used in the sample enrichments, position resolution, backgrounds and the momentum spectra of the bottom and charmed mesons. Impact parameter distributions for the b and c enriched regions are shown in Fig. 6a and 6b. Fig. 6c shows the corresponding distributions for hadrons with a non-leptonic track which satisfies the cuts (other than lepton identification) required for the lepton in the b-enriched sample. We particularly note the large preponderance of positive impact parameters in Fig. 6a. From maximum likelihood fits (shown in Fig. 6) coupled with external information on charm lifetimes, we obtain our best estimate of the mean lifetime of B hadrons, averaged over the species populations weighted by semileptonic decay probabilities. Our result is,

$$\tau_B = (12.0 {}^{+4.5}_{-3.6} \pm 3.0) \times 10^{-13} \text{ sec.}$$

Since the impact of this result on the quark weak mixing matrix will be described elsewhere in these Proceedings, I do not discuss it here.

I do however want to mention that we are trying to improve this important lifetime measurement through two separate analyses presently in progress: (i) an improved lepton impact parameter analysis with increased statistics and more optimal procedures and (ii) a study of reconstructed vertices of hadrons produced in the b and c enriched samples. This latter procedure uses information which is largely independent of the lepton measurements, but whose interpretation requires substantial and careful Monte Carlo modeling. We hope that results from these studies will be available in the not too distant future.

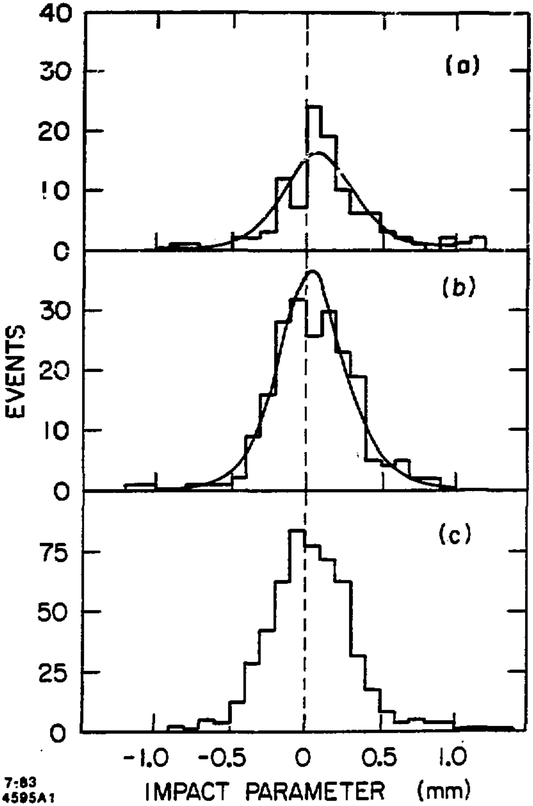

Fig. 6. Impact parameter distributions for (a) leptons in the $b - \bar{b}$ enriched sample, (b) leptons in the $c - \bar{c}$ enriched sample, (c) hadrons which satisfy all but the lepton cut of the $b - \bar{b}$ sample. The solid curves are results of maximum likelihood fits.

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