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CHARM AND BEAUTY LIFETIME MEASUREMENTS WITH THE MARK II VERTEX DETECTOR*

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Abstract

We have measured the lifetime of the D^o meson and the average lifetime of b-flavored hadrons with the MARK II vertex detector at PEP. We find $\tau_{D^o} = \left(4.0 {}^{+1.4}_{-1.1} \pm 1.0\right) \times 10^{-13}$ sec and $\tau_b = \left(12.0 {}^{+4.5}_{-3.6} \pm 3.0\right) \times 10^{-13}$ sec.

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1. Introduction

Techniques for isolating charm[1] and beauty[2] signals in e^+e^- annihilations in the PEP/PETRA energy range have been developed during the past two years. These techniques and the fact that heavy mesons are moving relativistically in this energy range have made lifetime studies possible. This paper reviews measurements of the lifetimes of the D^o meson and b-flavored hadrons (B) done with the MARK II vertex detector at PEP. The data sample reported here corresponds to an integrated luminosity of 80 pb^{-1}, all taken at center-of-mass energy 29 GeV.

2. MARK II Vertex Detector

The MARK II detector[3] is a familiar charged and neutral particle spectrometer using a large, solenoidal coil. It provides charged particle tracking and electron identification over 65%, and muon identification over about 45% of the solid angle. A high precision drift chamber,[4] called the vertex detector, is located just outside the beam pipe. In conjunction with the main tracking chamber, it measures trajectories near the interaction point with 100μ accuracy in the plane perpendicular to the beams.

3. D° Lifetime Measurement

Method. We measure the D^o lifetime by finding the displacement of the D^o decay vertex from the average beam position for a sample of D^o mesons coming from D^* decay. Knowing the D^o direction and momentum, we can thus calculate the proper time for each decay.

Event Selection. We first impose tight tracking quality cuts ($\chi^2/df < 5$) to ensure accurate track extrapolations. D^o and $\bar{D}^o$'s are selected by choosing pairs of these tracks whose invariant mass is between 1.72 and 2.00 GeV/c^2 when one track is assigned a pion mass and the other a kaon mass. We combine these D^o candidates with a third track of the appropriate charge and study the mass difference $m_{K^\mp\pi^\pm\pi^\pm} - m_{K^\mp\pi^\pm}$. This mass difference is shown in Fig. 1 for events where the $K^\mp\pi^\pm\pi^\pm$ energy exceeds 60% of the beam energy. The obvious cluster of events in the vicinity of $m_{D^*} - m_D = 145.4$ MeV/c^2 comprises our sample. We estimate that there are 1.5 background events.

Projected Decay Length. The projected decay length is determined[5] from the $K\pi$ vertex position, the average beam position, the respective vertex and beam error matrices, and the D^o direction. The beam position is a crucial ingredient in this procedure. We measure it fill-by-fill by finding the point which minimizes the distance of closest approach for an ensemble of well-measured tracks. The average beam position is known to $\pm 20\mu$ vertically and horizontally; the beam size is 480μ horizontally and 65μ vertically, and the beam position is stable.

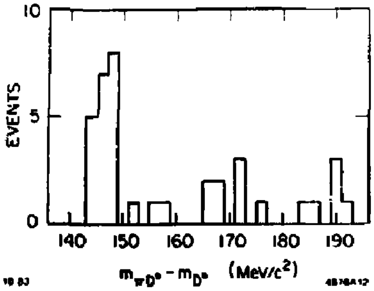

Fig. 1. Mass difference $m_{K^\mp\pi^\pm\pi^\pm} - m_{K^\mp\pi^\pm}$ for $K^\mp\pi^\pm$ combinations near the D^0 mass and $E_{K\pi\pi}/E_{beam} > .6$.

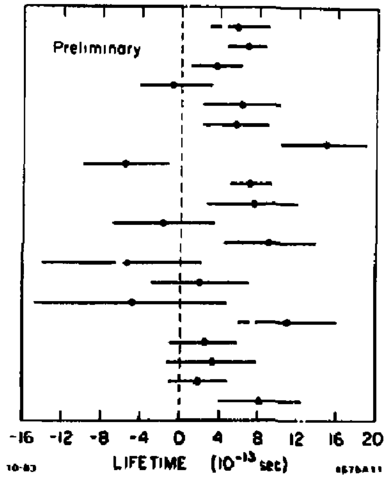

Fig. 2. Measured D^0 Lifetimes.

Results. The proper times and their errors are shown in Fig. 2. We fit these data with a maximum likelihood technique using the convolution of a Gaussian resolution function and an exponential distribution as a fitting function. We find $\tau_{D^0} = \left(4.0 {}^{+1.4}_{-1.1}\right) \times 10^{-13}$ s. The lifetime is practically unchanged when we exclude any 2 of the 20 events from the fit, so the background has little influence on our result. It is very unlikely that a B meson would decay to a D^* with energy above 60% of the beam energy. Including these and other uncertainties in the analysis, we assign a systematic error of $\pm 1.0 \times 10^{-13}$ s to our result.

Checks and Conclusions. We have checked that our method works on Monte Carlo simulated data and reproduces the input lifetimes within statistical errors. We have also measured the lifetime of a control sample where we eliminated very hard particles and K^0_S's. We found it to be $(1.0 \pm 0.2) \times 10^{-13}$ sec, but expect it to be slightly positive because of charm and beauty secondaries in the sample.

Our result, $\tau_{D^0} = \left(4.0 {}^{+1.4}_{-1.1} \pm 1.0\right) \times 10^{-13}$ sec, is in good agreement with the current world average,[6] and is significantly lower than the world average D^+ lifetime.

4. B Lifetime Measurement

The lifetime of hadrons containing the b quark measures the weak coupling between the bottom quark and the charm and up quarks. In the context of the Kobayoshi-Maskawa[7] parameterization of quark mixing, the lifetime is related to the magnitudes of the matrix elements U_{bu} and U_{bc}.

Method. We have determined the average B lifetime[8] by measuring the impact parameter of leptons coming from B decays. Specifically, we measure the distance of closest approach between the lepton trajectory and the average beam position, projected in the plane perpendicular to the beams. Although the impact parameter is positive-definite in principle, the tracking and beam position errors give rise to both positive and negative impact parameters. To sign the impact parameter, we assume the parent decays forward, approximate the parent's direction with the thrust direction and the primary vertex with the average beam position. The impact parameter is positive if the intersection of this approximate B trajectory with that of the lepton corresponds to a positive decay length, and negative otherwise. The resolution in the impact parameter is the sum in quadrature of the track error ($\sim 100\mu$) and the effective beam size, which is a function of the azimuth. It ranges from about 100μ to 500μ. We exclude (vertical) trajectories, where the error exceeds 350μ.

B – Enriched Region. Inclusive lepton production has been studied by several experiments[2] at PEP and PETRA by measuring the momentum and transverse-momentum (with respect to the jet axis) of leptons in hadronic events. The average b and c semileptonic branching ratios determined from these measurements are in good agreement with each other and with measurements at lower energy.[9] The fitted transverse momentum spectrum for electrons with momentum above 2 GeV/c from the MARK II experiment is shown in Fig. 3. Above 1 GeV/c transverse momentum, $80 \pm 8\%$ of the prompt leptons come from B decays and $20 \pm 8\%$ from charm decays. This constitutes the b-enriched region. $20 \pm 7\%$ of the lepton candidates in this sample are misidentified hadrons. The c-enriched region, with transverse momentum less than 1 GeV/c, is $34 \pm 9\%$ background. Its prompt lepton signal is $68 \pm 8\%$ charm and $32 \pm 8\%$ beauty.

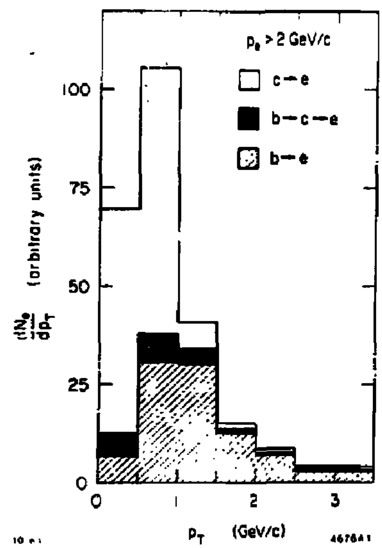

Fig. 3. Transverse momentum spectrum of prompt electrons produced in e^+e^- annihilations at 29 GeV. The highest bin includes all leptons with transverse momenta above 3 GeV/c.

Measured Impact Parameters. We measure the projected impact parameter for both electrons and muons in events with at least 5 charged particles and charged energy in excess of 25% of the center-of-mass energy. After tight track quality cuts ($\chi^2/df < 5$), we are left with 307 leptons in the two regions. Their impact parameter distributions are shown in Figs. 4(a) and 4(b). Excluding impact parameters beyond ±1 mm, the mean impact parameter in the b-enriched region is 106 ± 29μ, and in the c-region, 63 ± 18μ. The means of these distributions are significantly positive, and the distribution of b-enriched leptons is visibly asymmetric. Some of the lepton candidates are in fact misidentified hadrons. The mean impact parameter of hadrons in the b-region (c-region) is 36 ± 12μ (12 ± 7μ). See Fig. 4(c).

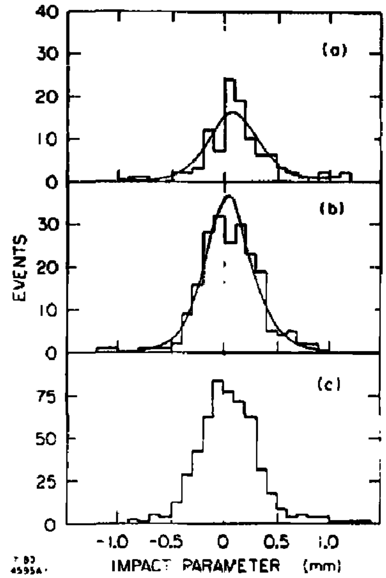

Fig. 4. Measured impact parameter distributions. (a) Leptons in the b-enriched region; (b) leptons in the c-enriched region; (c) hadrons in the b-enriched region.

Fits to the Impact Parameter Distributions. We fit each of the lepton distributions to the sum of three terms: background, the contribution from B decays, and the contribution from charm decays. The normalizations for the three terms come from the inclusive lepton analysis described above. The contributions from B and charm decays are evaluated in a two-step process. Using Monte Carlo methods, we first calculate the expected impact parameter distributions, including the effects of our event selection and momentum cuts. There are four such distributions, one each for charm and beauty in each of the regions. The contribution to the fitting function is then determined by folding the impact parameter distribution with a Gaussian resolution function. We find the average charm and bottom lifetimes with a simultaneous fit to the two impact parameter distributions using a maximum likelihood technique, and find $\tau_b = \left(10.3 {}^{+\,5.2}_{-\,4.2}\right) \times 10^{-13}$ s and $\tau_c = \left(8.3 {}^{+\,5.1}_{-\,4.8}\right) \times 10^{-13}$ s. Using world average data on the charm lifetimes, semileptonic branching ratios, and production cross-sections, we calculate $\tau_c = (6.0 \pm 1.5) \times 10^{-13}$ s. If we fix τ_c to this value in the fit, the statistical significance of the b lifetime improves, and we find $\tau_B = \left(12.0 {}^{+\,4.5}_{-\,3.6}\right) \times 10^{-13}$ s. The systematic error is 25%.

Checks. We checked our method on Monte Carlo generated data and found it to be accurate. The measured charm lifetime is consistent with expectation. The electron and muon samples show comparable B lifetimes. Finally, the hadron distributions provide a consistency check. If we use our measured b lifetime as input for a Monte Carlo simulation, we calculate the means of the background distributions to be 14± 12μ in the c-enriched region and 37 ±24μ in the b-enriched region, in good agreement with the measured values.

Conclusion. We have measured the B lifetime to be $\tau_b = \left(12.0^{+\,4.5}_{-\,3.6} \pm 3.0\right) \times 10^{-13}$ s, in agreement with the value recently reported by the MAC collaboration.[10] As expected in the standard model, the decay is suppressed. The fact that the effective $b \to c$ coupling strength is far below the universal Fermi strength together with the assumption that the sum of the b's charged weak couplings is of universal strength, implies that the b couples to at least one other, heavier quark, e.g. the t quark. Gaillard and Maiani[11] have related τ_B to the K-M matrix elements, U_{bc} and U_{bu}. Assuming the U_{bu} contribution to be negligible and setting the b quark mass to 5 GeV, we find $|U_{bc}| = \left(0.053^{+\,0.010}_{-\,0.009}\right)$, where the error is statistical only. This is significantly smaller than the analogous element governing strange particle decay $|U_{su}| = .22$, the sine of the Cabibbo angle.

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