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MEASUREMENT OF THE B HADRON LIFETIME FROM MARK II AT PEP*

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Abstract

Using data taken by the Mark II detector at PEP, the decays of B hadrons are tagged by identifying leptons at high transverse momentum. By means of a precision inner drift chamber, the impact parameters of these leptons are measured with respect to the B production point. From this impact parameter distribution, the B hadron lifetime is found to be 0.98 ± 0.12 ± 0.13 ps. This measurement can be used to place constraints models of quark mixing.

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1. Introduction

The B hadron lifetime is important because it is a measure of the strength of the weak transitions between quarks. Within the six quark mixing scheme proposed by Kobayashi and Maskawa,[2] the B lifetime measures the matrix elements $|V_{ub}|$ and $|V_{cb}|$ describing $(b \rightarrow u)$ and $(b \rightarrow c)$ transitions, respectively. There are numerous calculations of the expected B decay rate within the Standard Model. These calculations have used the free quark model for B hadron decay[3] and models describing transitions between exclusive hadronic states.[4]

There are a number of experimental complications that arise in the determination of the B lifetime. At PEP/PETRA energies, $b\bar{b}$ events constitute only $\sim 10\,\%$ of the total hadronic event sample. The low fraction of $b\bar{b}$ events, the relatively high multiplicity of B decays, and the propensity of B hadrons to produce neutral particles have made full reconstruction of exclusive decays difficult. It is therefore valuable to enrich the hadronic sample in $b\bar{b}$ events in order to maximize sensitivity to the B lifetime. In the Mark II analysis presented here, this enrichment is done by tagging high transverse momentum leptons from B decay. The impact parameters of these lepton tracks measured relative to the B production point are then used to determine the B lifetime.

Previous measurements of the B lifetime have been made by numerous experiments at PEP and PETRA. The most recent results are given in Ref. 5. These measurements find B lifetime values in the 1.0 to 1.5 ps range and employ diverse techniques to extract the lifetime from a hadronic event sample.

In this talk, the final B lifetime measurement from the Mark II detector at PEP is reported.[6] The detector is briefly described, along with studies made to understand the experimental resolution. An analysis of inclusive leptons produced at 29 GeV is discussed. The method of impact parameter measurement is presented and the lifetime is extracted by means of a maximum likelihood fit to the lepton impact parameter distribution. The systematic errors associated with the lifetime determination are summarized at the end of the talk.

2. Mark II Detector

The Mark II detector has been described in detail elsewhere.[7] Electrons are identified by requiring consistency between the momentum of a track as measured in the central drift chamber and the corresponding track energy measured in a Pb-Liquid Argon calorimeter.[8] Muons are identified in a system of hadron absorber and proportional tubes.

Of primary importance for this analysis is a high precision inner drift chamber or Vertex Chamber (VC).[9] The VC has seven layers of axial wires strung between 11 and 32 cm from the interaction point. From Bhabha separation distances, the impact parameter resolution of the VC for high momentum tracks is found to be 85 μm . The resolution function for tracks in hadronic events (similar to those used in the lifetime analysis) is determined from the impact parameter/error distribution of tracks having a small fraction of their transverse momentum in the xy plane.* This resolution function is found to have a larger width and more tail than the function describing Bhabha tracks.

3. Inclusive Lepton Analysis

The Mark II detector at PEP accumulated an integrated luminosity of 204 pb^{-1} at $E_{cm} = 29$ GeV. Using this data, 2631 electron and 1230 muon candidates with momentum greater than 2 GeV/c are isolated. The lepton (p, p_t) spectrum is fit in terms of its various contributions from charm decays, bottom decays, and background sources. From the fit, the semi-leptonic charm and bottom hadron branching ratios are determined, along with the average hadron energy ($< z >$ of fragmentation).† Since B decays are not fully reconstructed, knowledge of the fragmentation $< z >$ is crucial in order to convert an estimator such as impact parameter to lifetime. The results of the inclusive lepton analysis are

* This criterion selects a sample of tracks with little lifetime information in the xy plane, which is the VC measurement plane.

† Only $< z_b >$ is determined from the fit; the value of $< z_c >= 0.68$, determined from exclusive charm decays, is fixed.

given in Table 1. They are in good agreement with those obtained by other experiments.[10]

Table 1. Results from the MARK II inclusive lepton analysis.

Quantity	Electron	Muon
$BR(c \rightarrow l)$	$9.6 \pm 0.7 \pm 1.5$ (%)	$7.8 \pm 0.9 \pm 1.2$ (%)
$BR(b \rightarrow l)$	$11.2 \pm 0.9 \pm 1.1$ (%)	$11.8 \pm 1.2 \pm 1.0$ (%)
$< z_b >$	$0.85 \pm 0.03 \pm 0.05$	$0.82 \pm 0.04 \pm 0.05$

The lepton p_t spectra are illustrated in Figure 1. From this figure, it can be seen that the majority of leptons at high transverse momentum come from B decays. A B enhanced sample is defined by requiring leptons to have p_t greater than 1 GeV/c. In this sample, $65 \pm 5\,\%$ of the leptons come from primary or secondary B hadron decays; the remaining leptons come approximately equally from C hadron decays or background.

4. Lifetime Determination

We have seen that tagging leptons at high p_t serves to enrich a hadronic event sample in B hadron decays. These leptons are used to estimate the B lifetime by the calculation of a signed impact parameter. The impact parameter is measured in the xy plane with respect to the presumed B production point. The thrust axis of the event serves to estimate the B flight direction and to determine the impact parameter sign. The impact parameter is signed positive if the intersection point of lepton trajectory and the assumed B trajectory corresponds to a positive decay length and is signed negative otherwise.

The beam position (determined from Bhabha tracks over many events) can be used as an estimate for the B production point. We improve upon this estimate by the use of a vertex method. Each event is divided into two hemispheres by a plane perpendicular to the thrust axis. A vertex is made of the quality tracks in each jet. Using this vertex, the thrust direction, and the beam position as inputs to the decay length method,[11] an estimate is made of the B production point. A variety of checks in the data and Monte Carlo show that this procedure produces an unbiased estimate of the B production point. The lepton impact parameter is measured with respect to the production point. A factor of two gain in impact parameter precision is obtained by using the estimated production point over the beam centroid. This gain results from the reduction in the error due to the horizontal beam size.

The impact parameter distribution for the 617 leptons in the B enhanced sample is shown in Figure 2. With the aid of the Monte Carlo, a maximum likelihood fit to this distribution yields:

$$\tau_b = 0.98 \pm 0.12 \pm 0.13 \text{ psec} ,$$

where the first error is statistical and the second is systematic. In the fit, the resolution function discussed in Section 2 is used. This function accounts for non-Gaussian tails in the resolution.

A summary of the systematic errors affecting the lifetime measurement are presented in Table 2. The overall systematic error is largely determined by uncertainties in the resolution, fragmentation, and lepton fractions.

Table 2. Systematic errors for the MARK II lifetime measurement.

Quantity	Error on Lifetime
Resolution uncertainty	± 0.07 psec
B fragmentation, $<z>= 0.83 \pm 0.07$	± 0.05 psec
Lepton (B) fractions	± 0.08 psec
Other	± 0.04 psec
Total	± 0.13 psec

5. Conclusions

The B lifetime measurement presented in this talk is consistent with those from other experiments. Using the calculation of Ref. [3], the results of this measurement imply a value of $|V_{cb}| = 0.0.54 \pm 0.003 \pm 0.004$.* The smallness of $|V_{cb}|$ in relation to the Cabibbo angle indicates that the mixing between the third generation of quarks and the lighter generations is much weaker than that between the first two generations.

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* The value of $|V_{cb}|$ is obtained assuming $|V_{ub}|/|V_{cb}| = 0.15$, consistent with the results presented by CLEO and ARGUS at this Symposium.

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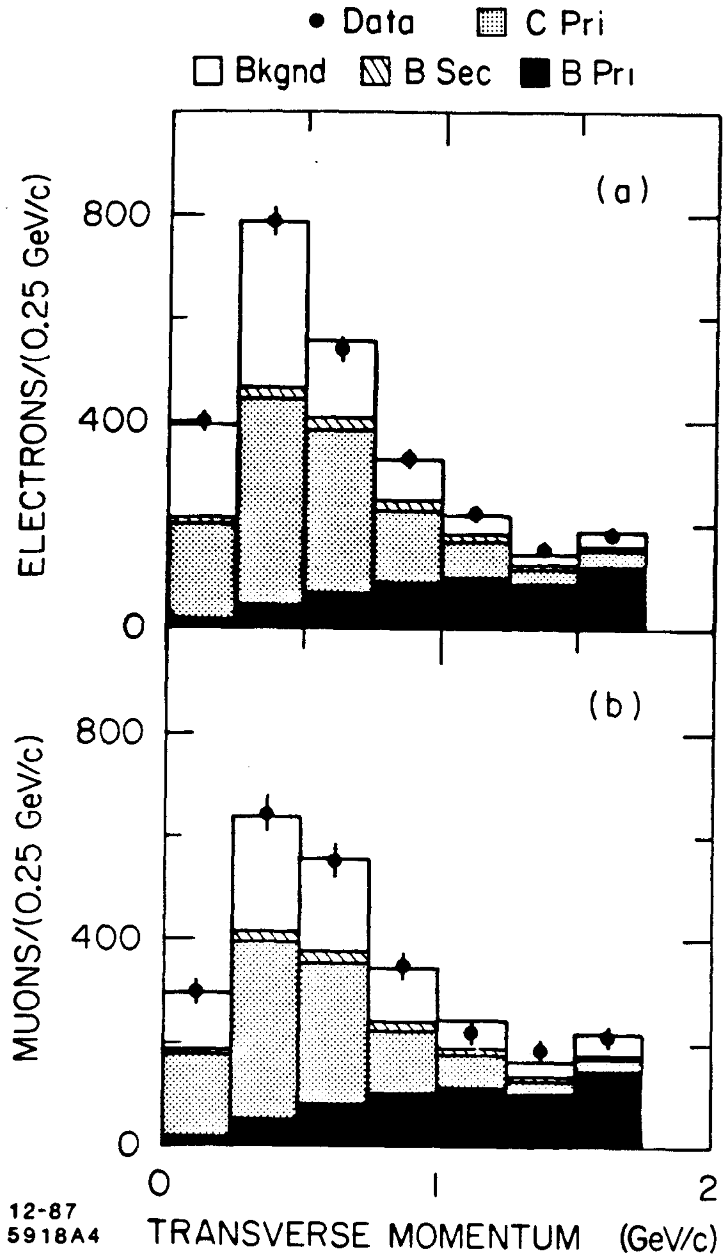

Figure 1: Results from the inclusive lepton analysis. Transverse momentum spectra for a) electrons and b) muons. The data is represented by points with error bars; the various components of the fit are represented by bargraphs.

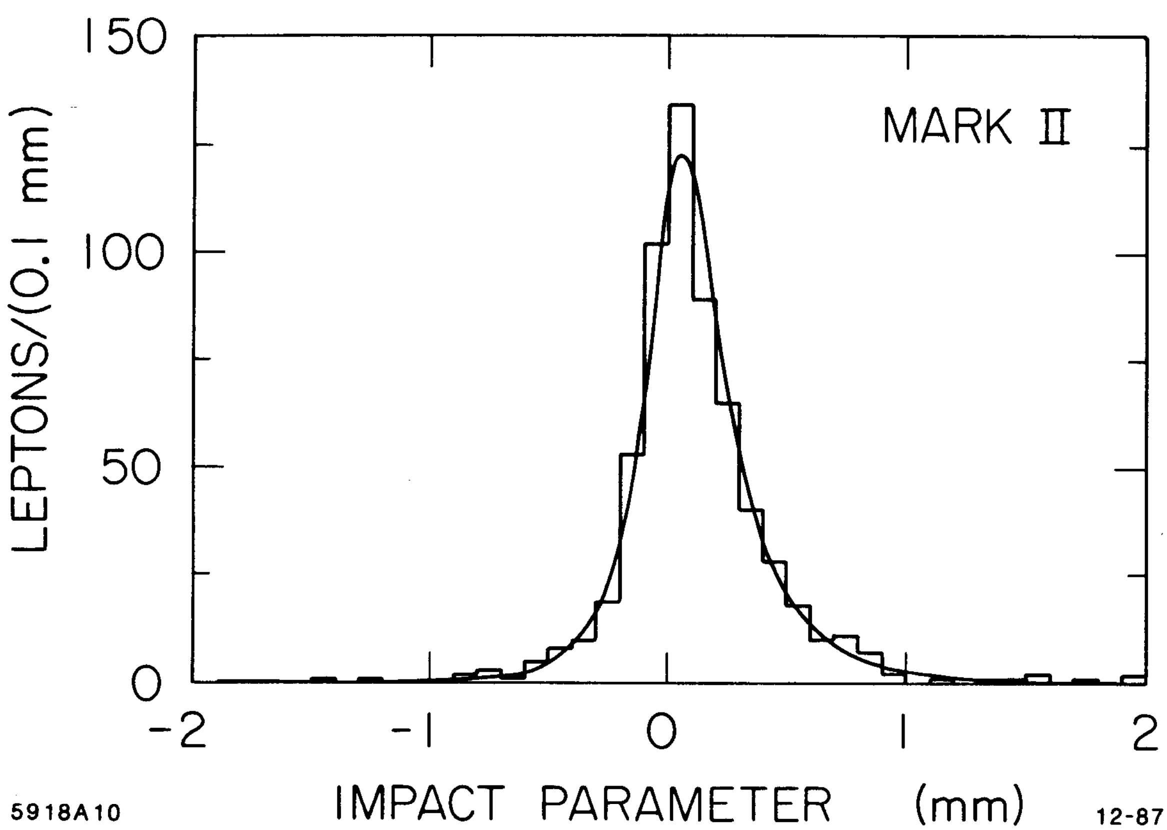

Figure 2: Impact parameter distribution for the sample of high p_t leptons. The curve corresponds to the maximum likelihood fit for the measured lifetime.