Fermi National Accelerator Laboratory

B^+ and B^0 Mean Lifetime Measurements

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Abstract

We review B^+ and B^0 mean lifetime measurements, including direct measurements and determination of the lifetime ratio via measurements of the ratio of branching ratios. We present world averages.

1. Introduction

The most precise determination of the CKM matrix element V_{cb} is obtained by comparing measurements of branching ratios of exclusive $b \to cl\nu$ decays at a particular kinematic point with theoretical predictions of the width of the transition [1]. The mean lifetime of the particular B hadron for the exclusive decay is needed to make this comparison.

The mean lifetime of the D^+ is 2.5 times that of the D^0. The difference in the B system is expected to be smaller, with the mean B^+ lifetime perhaps 7% larger than that of the B^0[2].

We present herein results on direct measurements, as well as results from measurements of ratios of branching ratios. The numerical value of all results, and the world averages, are presented in Fig. 1. References to a specific charge state imply the charge-conjugate state as well. For the direct measurements, the decay length L of the B meson is measured with a silicon vertex detector, and the boost $\beta\gamma$ is measured with tracking in a magnetic field, and calorimetry. The proper lifetime $c\tau$ is simply the ratio $L/\beta\gamma$. We present results from CDF, from the reaction $p\bar{p}(\sqrt{s} = 1.8 \text{ TeV}) \to b\bar{b} + X$, and results from ALEPH, DELPHI, and OPAL, from the reaction $e^+e^- \to Z \to b\bar{b}$.

If a B^+ decay mode is related to a B^0 decay mode by a single isospin amplitude, the ratio of branching

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ratios is equivalent to the ratio of mean lifetimes. We present such results using inclusive semileptonic decays from CLEO, and $J/\psi K$ decays from CDF.

2. Fully reconstructed decays

In the case where the B hadron is fully reconstructed, the B hadron type, $\beta\gamma$, and L are all unambiguously measured, and the systematic uncertainties are minimal. CDF has reconstructed [3]:

- $B^+ \to J/\psi K^+, J/\psi K^{*+}, \psi(2S)K^+, \psi(2S)K^{*+}$
- $B^0 \to J/\psi K_S, J/\psi K^{*0}, \psi(2S)K_S, \psi(2S)K^{*0}$

The decay $J/\psi \to \mu^+\mu^-$ triggers the event. Without the trigger restriction, ALEPH has reconstructed [4]:

- $B^+ \to J/\psi K^+, \bar{D}^0\pi^+, \bar{D}^0\rho^+, \bar{D}^0a_1^+$
- $B^0 \to D^-\pi^+, D^{*-}\pi^+$

3. Partial reconstruction of $B \to \bar{D}^{(*)}l\nu X$

In this method, one reconstructs the charmed meson and the lepton from a semileptonic decay. Events with $D^{*-} \to \bar{D}^0\pi^-$ are dominantly B^0, events with $\bar{D}^0$, excluding D^{*-} candidates, are dominantly B^+, and events with D^- are dominantly B^0 since $\bar{D}^{*0}$ does not decay to D^-.

Some complications are that the decay is not fully reconstructed, so it is necessary to estimate the boost of the B based on the boost of the lepton and charm.

This can be done with about 15% resolution. Systematic uncertainties in the average boost lead to systematic uncertainties in the mean lifetime. Also, approximately 30% of semileptonic decays are through the chain $B \to \bar{D}^{**} l \nu, \bar{D}^{**} \to \bar{D}^* \pi$ or $\bar{D}\pi$. This, along with an imperfect efficiency for reconstructing the soft pion from the D^{**} decay chain, mixes the composition of the samples. This mix needs to be understood in order to obtain individual B lifetimes.

There are results from ALEPH [5], DELPHI [6], OPAL [7], and CDF [8]. For the purposes of the world average, we assume that systematic uncertainties in background shape and sample composition are correlated among all experiments. The boost estimate depends on the B production and decay spectra, and so we assume that systematic uncertainties from this source are correlated among the LEP experiments only.

4. Topological Reconstruction

The DELPHI collaboration has selected 1816 secondary vertex candidates [9] for which all tracks are unambiguously assigned to either the primary or secondary vertex. The charge of the B hadron candidate is simply the sum of the charges of the tracks assigned to the secondary vertex. The B purity is 99%, and the charged/neutral assignment is 80% correct for the charged sample, and 57% correct for the neutral sample. The proper lifetime for an event is taken relative to the minimum value for which the event would have passed the cuts.

The B^+ and B^0 lifetimes are extracted using independent measurements of the Λ_b and B_s fractions and lifetimes, which lead to the dominant systematic uncertainty.

5. Ratios of Branching Ratios

CLEO produces B mesons in the reaction $e^- e^- \to \Upsilon(4S) \to B^+ B^-, B^0 \bar{B}^0$. Therefore, tagging the charge of one B determines the charge of the other B, and by counting leptons opposite the tag sample, one determines the semileptonic branching ratios of the charge and neutral B mesons. This method of using tags has the advantage over previous methods of being independent of the branching ratio of the $\Upsilon(4S)$ to charged and neutral B mesons. CLEO has used 3 tagging techniques [10]:

- Fully reconstruct $B \to \bar{D}^{(*)}\pi/\rho/a_1, \psi K, \psi K^*$.
- Observe only the lepton and "slow" pion in the decay chain $B^0 \to D^{*-} l \nu, D^{*-} \to \bar{D}^0 \pi^-_{slow}$. Contributions from $\bar{D}^{**}$ are suppressed with lepton momentum cuts. This provides most of the tags for the neutral sample.

- Reconstruct only the "fast" and "slow" pions in the decay chain $B^0 \to D^{*-}\pi^+_{fast}, D^{*-} \to \bar{D}^0\pi^-_{slow}$.

The major systematic uncertainties are from the uncertainty in the lepton spectrum, and from a dependence of the efficiency of the tag selection on the multiplicity of the untagged B.

CDF has reconstructed $B^+ \to \psi K^+$ and $B^0 \to \psi K_s$ [11]. Assuming the production cross-section for B^+ and B^0 are equal, CDF derives the ratio of branching ratios.

6. Conclusions

The world average is calculated [12] grouping systematic uncertainties into correlated sets as stated above. The results are shown in Fig. 1. We conclude that the B^+ lifetime is consistent with being the same as the B^0 lifetime. The uncertainty on the world average is similar to the largest theoretically expected difference. Many experiments can add additional channels, and all experiments cited herein continue to take data, so we can expect continued improvements in precision in the near future.

References

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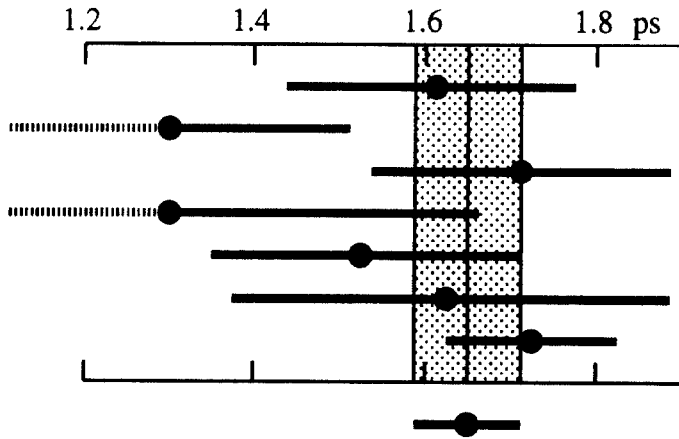
B⁺ Measurements

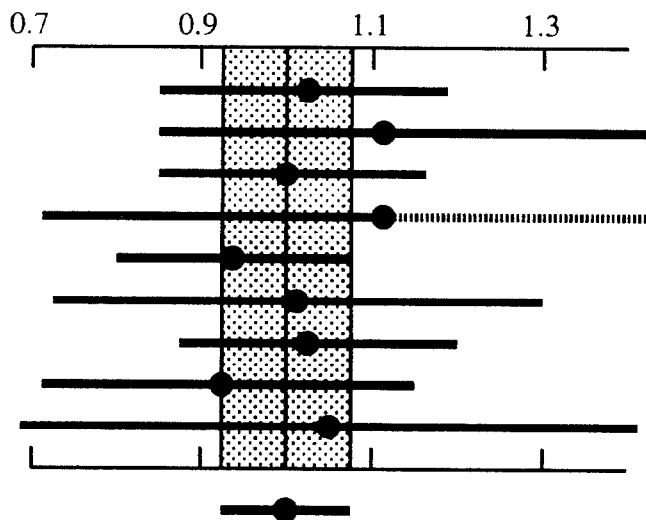|	
$1.61\pm0.16\pm0.05$	CDF Full Reconstruction
$1.30^{+0.25}_{-0.20}\pm0.06$	ALEPH Full Reconstruction
$1.71\pm0.15\pm0.08$	ALEPH Lepton + Charm
$1.30^{+0.33}_{-0.29}\pm0.15\pm0.05$	DELPHI Lepton + Charm
$1.53\pm0.14\pm0.11$	OPAL Lepton + Charm
$1.63\pm0.20\pm0.16$	CDF Lepton + Charm
$1.72\pm0.08\pm0.06$	DELPHI Topological

1.652 ± 0.065 B^+ World Average Mean Lifetime
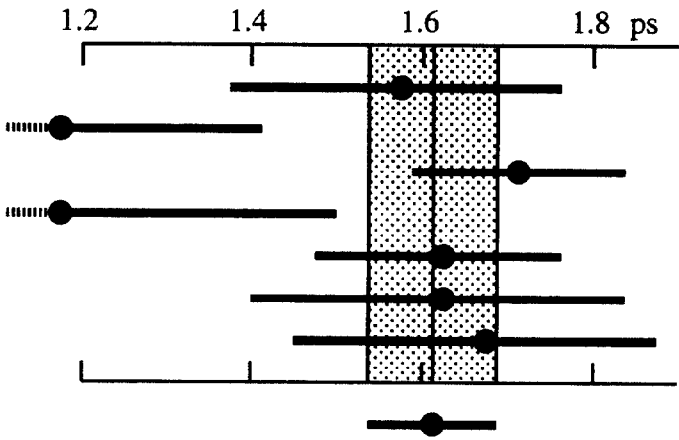
B⁰ Measurements

$1.57\pm0.18\pm0.08$	CDF Full Reconstruction
$1.17^{+0.24}_{-0.19}\pm0.06$	ALEPH Full Reconstruction
$1.71^{+0.12}_{-0.11}\pm0.06$	ALEPH Lepton + Charm
$1.17^{+0.29}_{-0.23}\pm0.15\pm0.05$	DELPHI Lepton + Charm
$1.62\pm0.10\pm0.10$	OPAL Lepton + Charm
$1.62\pm0.16\pm0.15$	CDF Lepton + Charm
$1.68\pm0.15^{+0.13}_{-0.17}$	DELPHI Topological

1.614 ± 0.078 B^0 World Average Mean Lifetime

B⁺/B⁰ Ratio Measurements

$1.02\pm0.16\pm0.05$	CDF Full Reconstruction
$1.11^{+0.31}_{-0.25}\pm0.03$	ALEPH Full Reconstruction
$1.00^{+0.14}_{-0.13}\pm0.08$	ALEPH Lepton + Charm
$1.11^{+0.51}_{-0.39}\pm0.05\pm0.10$	DELPHI Lepton + Charm
$0.94\pm0.12\pm0.07$	OPAL Lepton + Charm
$1.01\pm0.23\pm0.17$	CDF Lepton + Charm
$1.02^{+0.13+0.13}_{-0.10-0.10}$	DELPHI Topological
$0.93\pm0.18\pm0.12$	CLEO Semileptonic Ratio
$1.05\pm0.3\pm0.2$	CDF J/Ψ K Ratio

1.003 ± 0.069 B^+/B^0 World Average Ratio