Exclusive b Hadron Lifetime Measurements at LEP

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Abstract

The quantity of data collected at LEP is now sufficient to make statistically meaningful measurements and comparisons of the lifetimes of individual b hadrons. Observations of variations in lifetimes among the different species would provide important information for models of b hadron decay. Results are presented of recent LEP measurements for the lifetimes of B^0, B^+ and B_s^0 mesons, and b baryons.

1 Introduction

The lifetimes of b hadrons are dependent not only on the strength of the b quark coupling to c and u quarks, but also on "non-spectator" effects and final-state interactions within the decaying particle. The spectator model assumes that the b quark decays independently of the other quarks, implying that all b hadrons decay with the same lifetime. The prediction of this model is violated in the charm system, where it is observed that the D^+ lifetime is approximately 2.5 times the D^0 lifetime [1]. More sophisticated decay models predict b hadron lifetime differences of at 10–20% at most [2]; observations of a deviation of much greater magnitude would be hard for these models to accommodate. The non-spectator effects expected to have the largest influence on the b hadron lifetimes are interference, which affects significantly only the B^- and Λ_b^0, and W exchange, which affects the $\overline{B}^0$, B_s^0 and Λ_b^0. Diagrams illustrating these effects are shown in Figure 1. The interference effects are predicted to be destructive, leading to an increase in lifetime, while the W exchange leads to a decrease. After including the effects of

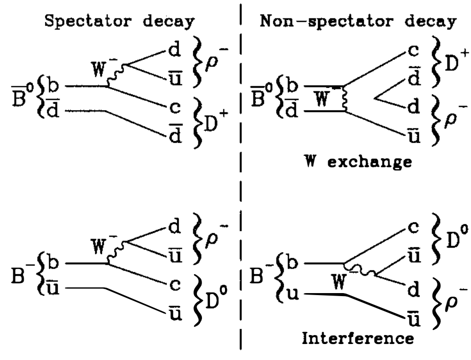

Figure 1: Spectator and non-spectator decays of B mesons.

Cabibbo suppression, helicity conservation, phase space, and gluonic interactions, the following lifetime hierarchy is predicted:

$$\tau(B^-) > \tau(\overline{B}_s^0) \geq \tau(\overline{B}^0) > \tau(\Lambda_b^0)$$

In this note I present a summary of measurements of exclusive b hadron lifetimes at the LEP e^+e^- collider at CERN. A brief discussion of the measurement techniques will be followed by a summary of the results and an assessment of future prospects.

2 Measurement Techniques

Briefly, measurements of b hadron lifetimes to date have all used either the *impact parameter* or the *decay length* method. With the former technique, the impact parameter (i.e. the distance of closest approach to the event origin) distribution of tracks is asssumed to be a convolution of a "physics" function (derived from Monte Carlo), which as the name suggests, descibes the "pure" physics properties (momentum spectrum, lifetime), with a "resolution function" which describes the detector effects. These two functions are folded in a fit where the b hadron lifetime in the physics function is a free parameter. This method has the advantage that it is efficient, in that, generally, only one track/event (usually a high-momentum lepton) is required. Its disadvantages are that it does not have much statistical power per event, it depends heavily on the modeling of b decay physics, and requires a high degree of understanding of the detector resolution.

The decay length technique measures directly the distance of the secondary b decay vertex from the primary vertex. The decay length is converted to a time after estimating the momentum of the parent b hadron, as it is only partially reconstructed. A fit is made on the decay time distribution, which usually has a non-trivial background. Usually, it is not strongly dependent on Monte Carlo input, and because two or more tracks/event are used, it is statistically more powerful/event than impact parameters, although it is not very efficient, for the same reason.

3 Exclusive Lifetime Results from LEP

3.1 $\overline{B}^0$ and B^- Lifetimes

These two mesons make up about 80 % of the b hadrons produced at LEP. The most common approach [3] is to make use of the fact that the charged B meson decays into a neutral D meson, and vice versa. The events are tagged by demanding a fully reconstructed D/D^* (from any of several hadronic decay channels), along with a high-momentum electron of the appropriate charge. This is complicated by the decays of neutral B's into charged D^*'s, which then decay into neutral D's, leading to contamination of the two samples. Further contamination results from "doubly excited" D^{**} mesons, whose production and decay properties are almost entirely unmeasured. Nonetheless, with some reasonable assumptions, such as that $\overline{B}^0$ and B^- mesons are produced in equal numbers, and that the branching ratios for D^{**} decays are related by isospin Clebsch-Gordon coefficients, these uncertainties can be brought down to manageable levels.

The energy of the parent B meson is usually estimated from Monte Carlo predictions which relate the measured kinematic properties of the partially reconstructed event to the true initial B meson energy. Simultaneous decay length fits are done to the two samples. Another technique [4] is to tag samples of charged and neutral b hadrons. This requires a reliable Monte Carlo estimate of the probability of measuring the wrong charge, in order to assess the conatmination of the two samples. By assuming the compositions of the two samples, the $\overline{B}^0$ and B^- lifetimes are extracted. The results of the measurements are given in Table 1.

Measurement	Tagging Method	Result ±stat. ± sys.	Largest Systematic Error
ALEPH $\tau_{\overline{B}^0}$		$1.52^{+0.20+0.07}_{-0.18-0.13}$	
τ_{B^-}	$D^{(*)}/\ell$	$1.47^{+0.22+0.15}_{-0.19-0.14}$	$Br(\overline{B}^0 \to D)/Br(\overline{B}^0 \to D^*)$
$\tau_{B^-}/\tau_{\overline{B}^0}$		$0.96^{+0.19+0.18}_{-0.15-0.12}$	
DELPHI τ_{B^0}		$1.17^{+0.29+0.16}_{-0.23-0.16}$	decay length reconstruction
τ_{B^+}	$D^{(*)}/\ell$	$1.30^{+0.33+0.16}_{-0.29-0.16}$	decay length reconstruction
τ_{B^+}/τ_{B^0}		$1.11^{+0.51+0.11}_{-0.39-0.11}$	D^{**} branching fractions
OPAL τ_{B^0}		$1.51^{+0.24+0.12}_{-0.23-0.14}$	detector calibration
τ_{B^+}	$D^{(*)}/\ell$	$1.51^{+0.30+0.12}_{-0.28-0.14}$	detector calibration
τ_{B^+}/τ_{B^0}		$1.00^{+0.33+0.08}_{-0.25-0.08}$	background level/shape
DELPHI τ_{B^0}		$1.55^{+0.25+0.19}_{-0.25-0.18}$	possible analysis bias
τ_{B^+}	jet charge& mass	$1.56^{+0.20+0.14}_{-0.20-0.14}$	possible analysis bias
τ_{B^+}/τ_{B^0}		$1.01^{+0.29+0.14}_{-0.22-0.14}$	B charge unfolding
LEP Averages	τ_{B^0}	1.48 ± 0.14	
	τ_{B^+}	$1.49^{+0.15}_{-0.14}$	
	τ_{B^+}/τ_{B^0}	$1.00^{+0.17}_{-0.14}$	

Table 1: LEP lifetime results for $\overline{B}^0$ and B^- mesons. Lifetimes are given in picoseconds.

3.2 B^0_s Lifetimes

To date, most measurements of τ_{B_s} [5] have used decay lengths obtained from a combination of a high-momentum lepton, and either a fully or partially reconstructed (using the ϕ from the $\phi\pi$ decay channel) D_s meson; it is also possible to use an inclusive D_s sample. These measurements are (in principle) more straightforward than than those of the B^0/B^+; the largest systematic error is typically due the parameterization and level of the background, which in turn is mainly due to low statisics; however, in the cases of the ϕ/ℓ and the inclusive D_s samples, it is also necessary to make some assumptions regarding the sample composition. The inclusive D_s signal is also subject to relatively high combinatoric backgrounds. The results of the measurements are given in Table 2.

3.3 b baryon Lifetimes

Although not precisely determined, within the mixture of b baryons produced at LEP, the Λ_b^0 is expected to comprise about 70 %. The b baryons are tagged by identifying either a

Measurement	Tagging Method	Result $\pm$stat. $\pm$ sys.	Largest Systematic Error
ALEPH	D_s/ℓ	$2.26^{+0.66}_{-0.48} \pm 0.12$	background level/shape
DELPHI	See table caption	1.0 ± 0.30	background level/shape; signal composition
OPAL	D_s/ℓ	$1.13^{+0.37}_{-0.17} \pm 0.17$	background level/shape
LEP Average		$1.57^{+0.27}_{-0.24}$	

Table 2: LEP lifetime results for the B_s^0 meson. Lifetimes are given in picoseconds. The DELPHI result is combination of Ds/ℓ, ϕ/ℓ and inclusive D_s measurements.

Λ^0/ℓ combination, or a Λ_c^+/ℓ combination, where the Λ_c^+ has been fully reconstructed from the $pK^-\pi^+$ decay channel [6]. The Λ_c^+/ℓ tag gives a more pure signal, but is inefficient, while the Λ^0/ℓ tag is subject to contamination from accidental combinations of real leptons with Λ^0's from fragmentation. Decay lengths measured for events tagged with a Λ^0/ℓ combination have large errors due to the long Λ^0 lifetime, and because the Λ^0 is not a direct decay product of the b baryon. Also, if the measurement relies heavily on Monte Carlo input to describe the momentum spectrum of the decay products, $\tau_{\Lambda_b^0}$ is subject to an additional uncertainty due to the possibility that it is produced with a significant degree of polarization. The results of the measurements are given in Table 3.

Measurement	Tagging Method	Result $\pm$stat. $\pm$ sys.	Largest Systematic Error
ALEPH	Λ^0/ℓ (ℓ impact parameter)	$1.12^{+0.32}_{-0.29} \pm 0.16$	ℓ "physics function"
ALEPH	Λ_c^+/ℓ (decay length)	$1.16^{+0.42}_{-0.32} \pm 0.07$	background lifetime
DELPHI	Λ^0/ℓ (decay length)	$1.04^{+0.48}_{-0.38} \pm 0.09$	track selection
OPAL	Λ^0/ℓ (decay length)	$1.01^{+0.20}_{-0.18} \pm 0.08$	decay length bias
LEP Average		$1.07^{+0.17}_{-0.15}$	

Table 3: LEP lifetime results for b baryons. Lifetimes are given in picoseconds.

4 Summary

Measurements of exclusive b hadron lifetimes at LEP are approaching the precision necessary to be able to make statistically significant comparisons. So far, the lifetimes of all of the b hadrons except the b baryon are less than one standard deviation from each other and from the average b hadron lifetime of 1.40 ± 0.04 ps [7]. Meaningful tests of the detailed predictions of b hadron decay models will require more data. Measurement errors are all statistics-limited at present. Based on current statistics, and assuming that the 1993 data sample is twice as large as for 1992, a projection of the precision of the various measurements can be made:

- B^0/B^+ $\Delta\tau/\tau \sim 5\%$
- B_s^0 $\Delta\tau/\tau \sim 8$–10%
- Λ_b^0 $\Delta\tau/\tau \sim 6$–8%

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