509: A Review of B Hadron Lifetimes

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Abstract. A review of B hadron lifetime measurements is presented. The new lifetime averages of B hadrons are:

$$\begin{aligned} \tau_{B^+} &= 1.67 \pm 0.04 \text{ ps}, & \tau_{B_d^0} &= 1.57 \pm 0.04 \text{ ps}, \\ \tau_{B_s^0} &= 1.53 \pm 0.06 \text{ ps}, & \tau_{b-baryon} &= 1.22 \pm 0.05 \text{ ps}, \\ \tau_b \text{ inclusive} &= 1.554 \pm 0.013 \text{ ps}, & \frac{\tau_{B^+}}{\tau_{B_d^0}} &= 1.07 \pm 0.04. \end{aligned}$$

1 Introduction and Methods

In the spectator model all heavy-quark hadrons have equal lifetimes. Non-spectator effects are due to Pauli Interference between internal and external spectator, weak annihilation, and W-exchange diagrams. These effects are calculated with Heavy Quark Expansion and scale like $1/m_Q^3$. In contrast to charmed hadrons, where $\tau_{D^+}/\tau_{D^0} = 2.55 \pm 0.04$, the lifetime differences for B hadrons are predicted to be small:

	Ref.[1]	Ref.[2]
$\tau_{B^+}/\tau_{B_d^0} \simeq$	$1 + 0.05(f_B/200\text{MeV})^2$	$1 + \mathcal{O}(1/m_b^3)$
$\tau_{B_s^0}/\tau_{B_d^0} \simeq$	$1 + \mathcal{O}(1\%)$	$(1.00 \pm 0.01) + \mathcal{O}(1/m_b^3)$
$\tau_{\Lambda_b}/\tau_{B_d^0} \simeq$	0.9	$(0.98 \pm 0.01) + \mathcal{O}(1/m_b^3)$

Thus one expects a hierarchy $\tau_{\Lambda_b} < \tau_{B_d^0} \approx \tau_{B_s^0} \leq \tau_{B^+}$. To test these predictions, precision measurements with errors on the percentage level are needed.

Measurements of the B hadron lifetimes are performed at LEP, SLD/SLC, and CDF/Fermilab. LEP experiments have collected up to 1.7 million B hadrons. SLD has 90k B hadrons, but has a smaller beam pipe and better beam spot constraints. CDF has a higher production rate (600 million B hadrons) but requires special B-hadron triggers. The mean decay length of a B hadron is 3 mm at LEP/SLD and 1.5 mm at CDF, respectively.

Two methods are being used to measure B hadron lifetimes. First, the impact parameter δ of lepton or hadron tracks stemming from B decays is positive on average ($\delta \sim c\tau_b \approx 300$ μm at LEP/SLC). The lepton impact parameter was employed when measuring τ_b first. It has the advantage that it depends only weakly on the Lorentz boost of the B hadron. Second, the reconstruction of secondary vertices for fully or partially reconstructed B decays allows to measure the decay length L of B hadrons, directly. Since L equals $\frac{p}{m_B}c\tau_b$, the momentum p of the B hadron needs also to be measured to extract its proper time. Fully reconstructed hadronic B decays have good momentum resolution but lack in statistics. In semileptonic decays, the neutrino is missing, and the charmed hadron often is only partially reconstructed. The momentum is then estimated by using missing energy measurements or scaling of the measured $D^{(*)}$-lepton momentum.

The decay length method is also used in a more inclusive approach, called topological vertexing. The total charge at the secondary vertex allows to obtain two separate data samples which are enhanced in charged and neutral B mesons, respectively. In order to extract the lifetimes τ_{B^+} and $\tau_{B_d^0}$, the respective purities of the charged and neutral samples for B^+ and B_d^0 as well as the contaminations from B_s^0 mesons and B baryons have to be estimated from Monte Carlo simulations. The advantage of this method are the larger samples obtainable.

2 Measurements of *B* Hadron Lifetimes

A new measurement of the inclusive b-hadron lifetime τ_b is presented by L3[3]. In hadronic events, the best combination of all tracks to give three vertices is searched for. Beam spot and kinematic constraints are imposed. The lifetime τ_b is then extracted from a binned χ^2 fit to a) the impact parameter distribution of 2007k secondary vertex tracks, and b) the decay length L of 584k secondary vertices. Fit a) as compared to b) reduces the dependence of τ_b on the B fragmentation, i.e. the mean energy of B hadron $< \mathrm{x_E} >_\mathrm{b}$, from 30 to 9 fs while having similar statistical power. The two results are combined taking into account their different dependence on $< \mathrm{x_E} >_\mathrm{b}$ and correlations and yield $\tau_b = 1.556 \pm 0.010 \pm 0.017$ ps (Fig. 1). They also measure $< \mathrm{x_E} >_\mathrm{b} = 0.709 \pm 0.004$. The current LEP average is $< \mathrm{x_E} >_\mathrm{b} = 0.702 \pm 0.008$. L3 has also updated their lepton impact parameter measurement and ALEPH presents a new measurement using secondary vertices.

When averaging these results with other measurements from LEP, SLD, and CDF (Fig. 1 and Ref.[4]) one should keep in mind that the sample compositions are slightly different. By using leptons we have to take into account the semileptonic branching ratios of the different B hadrons which are themselves proportional to the lifetime. We expect τ_b to be 10 fs larger than by using hadrons, whereas we measure it τ_b to be smaller by 35 ± 20 fs. In most decay length analyses the largest systematic error is due to the B fragmentation. Thus an increase in the average of all $< \mathrm{x_E} >_\mathrm{b}$ measurements would decrease these τ_b values by as much as 20 fs. The total error on the new world average is 13 fs.

Most of the existing measurements of the exclusive B meson lifetimes τ_{B^+} and $\tau_{B_d^0}$ made by ALEPH, DELPHI, OPAL and CDF are based on reconstructing $D^{(*)}$ mesons in semileptonic B decays[4]. Simultaneously they measure the ratio of lifetimes $\tau_{B^+}/\tau_{B_d^0}$ where some systematic errors cancel. The update from CDF on these analyses now includes the full Run 1 data set[5]. Improvements are made by using more inclusive methods. DELPHI has reconstructed 3523 ± 150 $\bar{B}^0_d \to D^{*+}X\ell^-\bar{\nu}$, $D^{*+} \to D^0\pi^+_s$ candidates using $\pi^+_s\ell^-$ correlations while only inclusively reconstructing the D^0 candidate[6]. This method is also employed by a similar L3 analysis[7]. SLD uses topological vertexing and has included their 1996 data, presented in a separate contribution[8]. The statistical error on these B^+ and B^0_d lifetime measurements is now ~40 fs, comparable to the systematic error (Fig. 2).

The best measurements of $\tau_{B^0_s}$, the lifetime of the B^0_s meson, use the decay $B^0_s \to D^-_s\ell^+\nu$ and reconstruct the D^-_s in many channels (ALEPH, DELPHI, OPAL and CDF, see Fig. 3 and Ref.[4]). OPAL has updated its $\tau_{B^0_s}$ measurement reconstructing 172 ± 28 $D^-_s\ell^+$ candidates in the following final states: $\phi\pi^-$, $K^{*0}K^-$, $K^0_sK^-$, and $\phi\ell^-\bar{\nu}$[9]. They also use 519 ± 136 hadronic D^-_sX candidates. The world average is now $\tau_{B^0_s} = 1.53 \pm 0.06$ ps.

B baryon lifetimes are discussed in detail in [10]. The new world average is $\tau_{b-baryon} = 1.22 \pm 0.05$ ps, definitely lower than the lifetime of B mesons.

3 Summary and Conclusion

The new world averages have been determined by the LEP B lifetimes working group[4]. Exclusive B^+, B^0_d, (B^0_s) meson lifetimes (Fig. 3) are now measured experimentally to 2.4% (4.0%). The lifetime hierarchy is predicted correctly: $\tau_{\Lambda_b} < \tau_{B^0_d} \approx \tau_{B^0_s} \leq \tau_{B^+}$. But the average B baryon lifetime is clearly lower ($\tau_{b-baryon}/\ \tau_{B^0_d} = 0.78 \pm 0.04$) than expected by theoretical predictions. The inclusive b-hadron lifetime is measured to 1% in agreement with the average of the exclusive lifetimes weighted by their fractions. Topological vertexing methods are improving measurements.

Acknowledgements

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References

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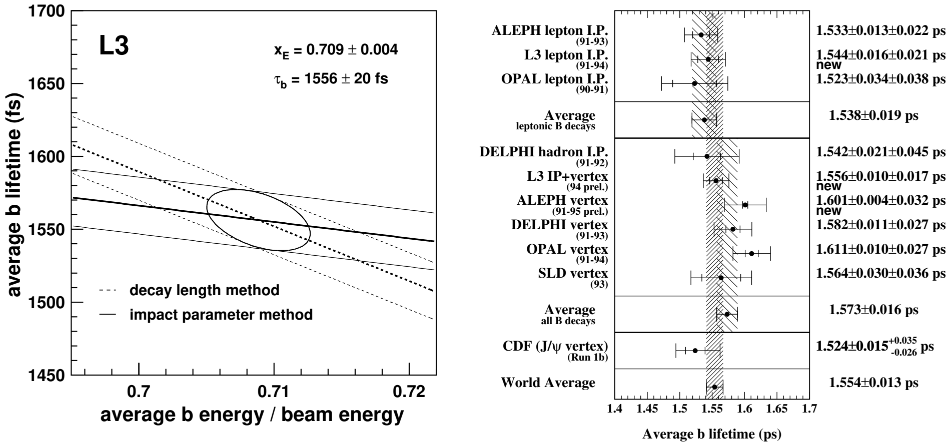

Fig. 1. L3 inclusive τ_b vs $< \mathrm{x_E} >_\mathrm{b}$; inclusive b-hadron lifetime measurements.

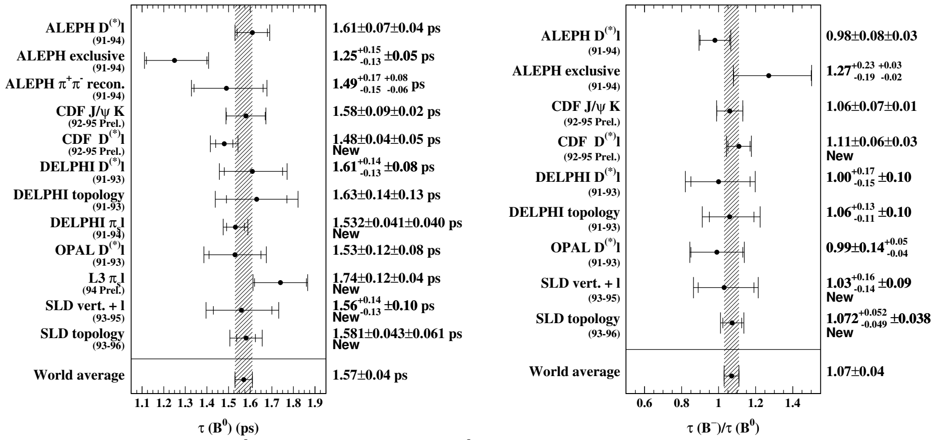

Fig. 2. B_d^0 lifetime and B^+/B_d^0 lifetime ratio measurements.

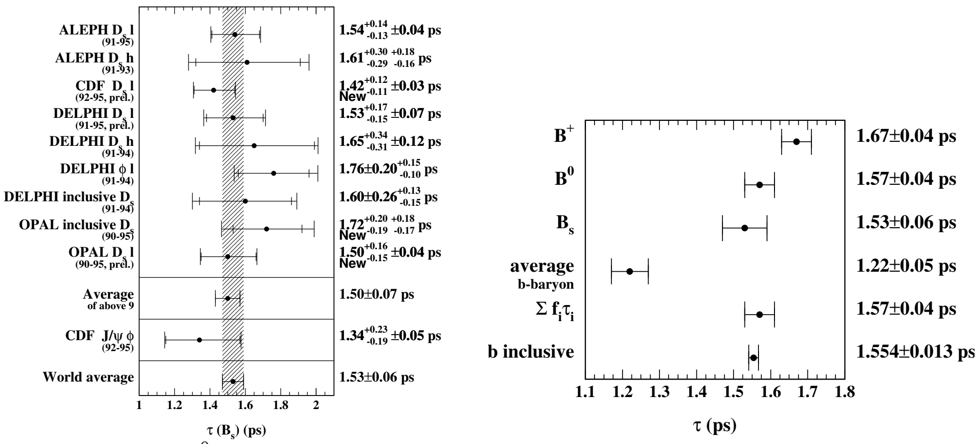

Fig. 3. B_s^0 lifetime and summary on B hadron lifetime measurements.