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B Lifetimes at the Tevatron

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We review recent measurements of B meson and baryon lifetimes at D0 and CDF with emphasis on results for the Λ_b.

1. B Lifetimes

It has been 25 years since the first B meson lifetime measurements at MarkII and MAC [1] at PEP. At that time simple mass^5 scaling arguments had resulted in lifetime predictions of $\approx 5 \times 10^{-14}$ seconds, more than an order of magnitude shorter than the lifetimes observed. The relatively long lifetimes of b hadrons, along with precise vertex detector technology, have enabled an industry of B mixing, branching ratio, and lifetime measurements, providing the beautiful suite of measurements which now constrain the unitarity triangle.

Experimental progress has been mirrored by progress in theory, where the Heavy Quark Expansion (HQE) has had significant success in calculating b hadron lifetime ratios. Figure 1 shows B lifetime ratios as compiled by the Heavy Flavor Averaging group at the end of 2005 and 2006 [2] [3], as compared to a range of HQE predictions. The quality of these predictions are discussed in detail by Alexander Lenz in his contribution to this conference.

Overall the B^+ measurements agree well with theory while the B_s measurements are a bit lower than the prediction of a ratio of 1 for $\tau(B_s)/\tau(B_d)$. The B_s prediction is considered quite robust compared to that for the Λ_b. There have been changes in the theoretical calculations for Λ_b, which predicted a value of $\tau(\Lambda_b)/\tau(B_d) = 0.94$ in 2005. A more complete next-to-leading order calculation which includes $1/m_b^4$ corrections now predicts $\tau(\Lambda_b)/\tau(B_d) = 0.88 \pm .05$ [4]. New Λ_b lifetime data from CDF and D0 are now available. The CDF data, which was included in the 2006 HFAG compilation and which will be discussed in this note, is significantly higher than previous measurements and brings some uncertainty into the B-baryon lifetime picture.

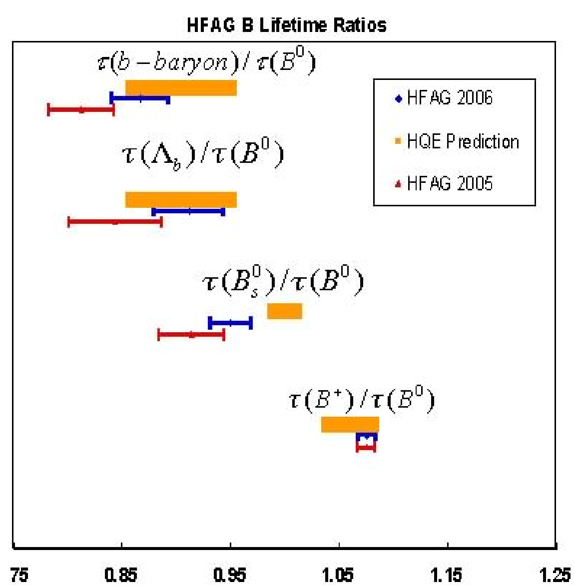

Figure 1. Summary of the 2005 and 2006 HFAG B lifetimes averages along with the range of theoretical predictions

2. Measurement Techniques

The two collider experiments have different strengths for lifetime measurements. D0 relies on an excellent, pure, muon trigger which has good single and dimuon acceptance. D0 also profits from a new inner layer tracking detector (Layer 0) and a somewhat lower track momentum cutoff. CDF has a larger tracker radius, providing better momentum resolution and signal/noise. CDF also can accommodate a high level 1 trigger rate which provides the ability to trigger in all-hadronic modes utilizing a displaced vertex trigger. Both experiments use similar analysis techniques, with unbinned maximum likelihood fits to the mass and lifetime distributions. Both have also improved their understanding of resolution functions and other systematic errors.

Most measurements are still dominated by statistical error, but systematics are becoming more of a concern. For fully reconstructed decays the dominant systematics include models of the background under the signal peak, alignment of the silicon vertex detectors, kinematic reflections, and resolution models. Partially reconstructed decays have significant additional systematics due to the calculation of the boost factor.

3. Λ_b Lifetimes

3.1. CDF $\Lambda_b \to J/\psi\Lambda$

There are three recent measurements of the Λ_b baryon from the Tevatron, two from D0 and one from CDF. The CDF result corresponds to $1fb^{-1}$ of integrated luminosity and utilizes the fully reconstructed decay $\Lambda_b \to J/\psi(\to \mu\mu)\Lambda(\to p\pi)$. Figure 2 shows the mass distribution and resulting lifetime fit with 538 ± 38 fitted signal events. The dominant systematics are detector alignment, V^0 pointing and the model of lifetime resolution. Results are [7]:

$$\begin{aligned} \tau(\Lambda_b) &= 1.593^{+0.083}_{-0.078} \pm 0.033\ ps \\ \tau(B_d) &= 1.524 \pm 0.030 \pm 0.016\ ps \\ \tau(\Lambda_b)/\tau(B_d) &= 1.041 \pm 0.057 \end{aligned}$$

Where the first of the two errors is statistical and the second systematic. This result is about 2.7σ higher than the central value of the 2005 HFAG average lifetime. The B_d result, which is very similar in topology to the Λ_b decay being studied is consistent with the world average.

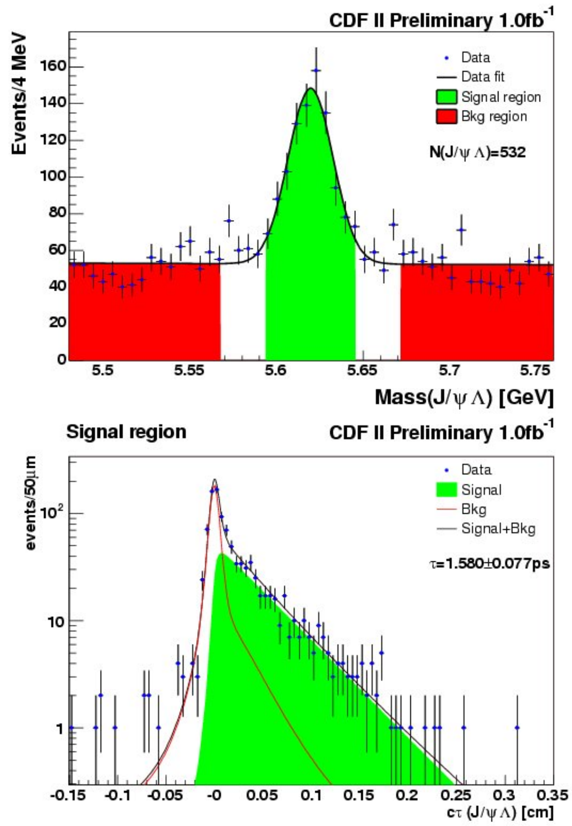

Figure 2. Mass (top) and lifetime (bottom) distributions for the CDF Λ_b sample.

3.2. D0 $\Lambda_b \to J/\psi\Lambda$

D0 has two new measurements. The first is in the same $\Lambda_b \to J/\psi\Lambda$ mode used by CDF and utilizes $1.2fb^{-1}$ of integrated luminosity. Mass and lifetime distributions are shown in Figure 3 The fitted yield of Λ_b is 174 ± 21 events. The results from the D0 fit are [6]:

$$\begin{aligned} \tau(\Lambda_b) &= 1.218^{+0.130}_{-0.115} \pm 0.042\ ps \\ \tau(B_d) &= 1.504^{+0.078}_{-0.074} \pm 0.050\ ps \end{aligned}$$

$$\tau(\Lambda_b)/\tau(B_d) \quad = \quad 0.811^{+0.096}_{-0.087} \pm 0.034$$

consistent with previous measurements. The systematics due to backgrounds are more significant for the D0 measurement due to the lower signal/noise ratio than CDF. Major systematics i nclude contamination from B_d, long lived components of the background, models of the mass and lifetime distributions, and alignment.

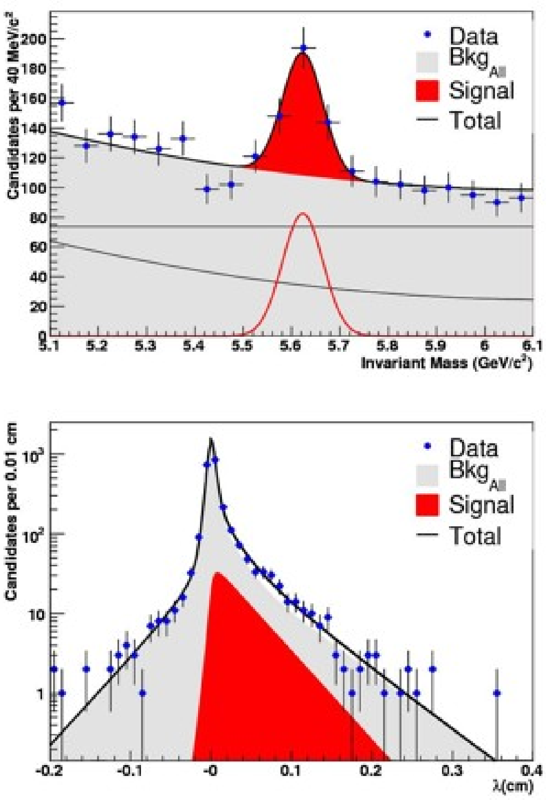

Figure 3. Mass (top) and lifetime (bottom) distributions for the fully reconstructed Λ_b sample from D0.

3.3. D0 Λ_b Lifetime in Semileptonic Decays

D0 has another measurement based on the Λ_b semileptonic decay, $\Lambda_b \rightarrow \mu\nu\Lambda_c X$. This sample has more Λ_b candidates than the fully reconstructed mode but suffers from smaller signal/background. It does provides an independent measurement of the lifetime with different systematic errors. The momentum of the Λ_b is modeled as a distribution of $p_T(\Lambda_c\mu)/p_T(\Lambda_b)$ based on Monte Carlo. A set of χ^2 fits to mass distributions in lifetime bins is used to extract a measured lifetime (Figure 4) of $\tau(\Lambda_b) = 1.28^{+0.12}_{-0.11} \pm 0.09$. Important contributions to the systematic error come from the mass fitting technique, determination of the missing momentum, and the resolution model.

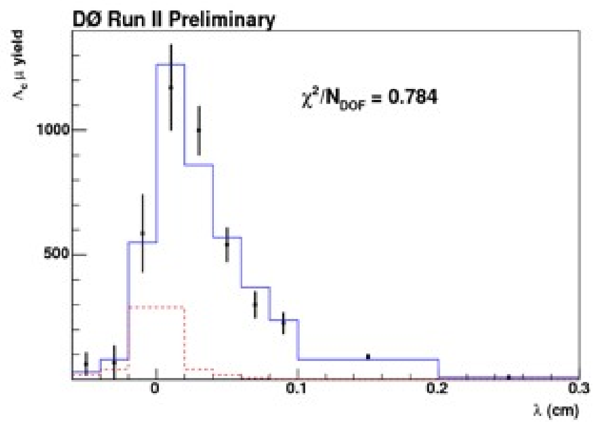

Figure 4. Lifetime distributions for the D0 semileptonic Λ_b lifetime measurement

3.4. Current Status

Figure 5 is a summary of the current status of Λ_b lifetimes. There is a 1.7σ discrepancy between the D0 and CDF measurements. The two experiments measure a consistent value for the $B_d \rightarrow J/\psi K_s$ lifetime, which has similar topology. CDF also has large samples of secondary vertex-trigger hadronic b decays and a measurement of the $\Lambda_c\pi$ mode is in progress. Hopefully, these, and other future measurements will provide a consistent picture.

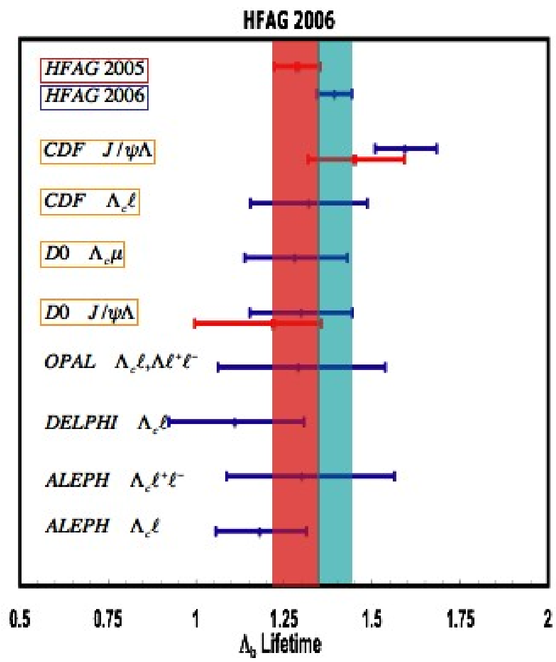

Figure 5. A summary of Λ_b lifetime measurements. The left shaded band corresponds to the 2005 HFAG average and the right shaded band to the 2006 average including the CDF $\Lambda_b \rightarrow J/\psi\Lambda$ result.

4. CDF Hadronic Lifetimes

CDF has a new set of measurements of B meson lifetimes based on decays into $J/\psi X$, based on analysis similar to the $J/\psi\Lambda$ analysis. These preliminary results are also based on $1fb^{-1}$ of data. The results are :

$$\begin{aligned} \tau(B^+ \rightarrow J\psi K^+) &= 1.630 \pm 0.016 \pm 0.011\ ps \\ \tau(B_s \rightarrow J/\psi\phi) &= 1.494 \pm 0.054 \pm 0.009\ ps \\ \tau(B^0 \rightarrow J/\psi K_s, K^*) &= 1.571 \pm 0.026 \pm\ 0.012\ ps \end{aligned}$$

5. B_s Semileptonic

Semileptonic decays of the B_s are "flavor specific", corresponding to an equal mixture of the heavy and light B_s eigenstates at $t = 0$. As such, these decays place a significant constraint on measurements of the B_s width difference, $\Delta\Gamma$. The CDF measurement corresponds to $360pb^{-1}$, and the D0 result to $400pb^{-1}$. CDF utilizes both electron and muon modes while the D0 result is confined to semi-muonic decays. Lifetime distributions are shown in Figure 6. The results are:

$$\begin{aligned} \tau_{fs}(B_s) &= 1.381 \pm 0.055^{+0.053}_{-0.046}\ ps(CDF)\ [8] \\ \tau_{fs}(B_s) &= 1.398 \pm 0.044^{+0.028}_{-0.025}\ ps(D0)\ [9] \end{aligned}$$

6. Conclusions

The wide range of heavy quark lifetime measurements have been a proving ground for precise calculations which mix perturbative and non-perturbative components. The work has provided confidence in our overall understanding of heavy quark systems. The tools and know-how developed over the last 25 years for lifetime calculations and measurements have become important components of continuing searches for new physics in mixing and CP violation. However the book is not yet closed, and we look forward to improved data to drive increasingly sophisticated theory.

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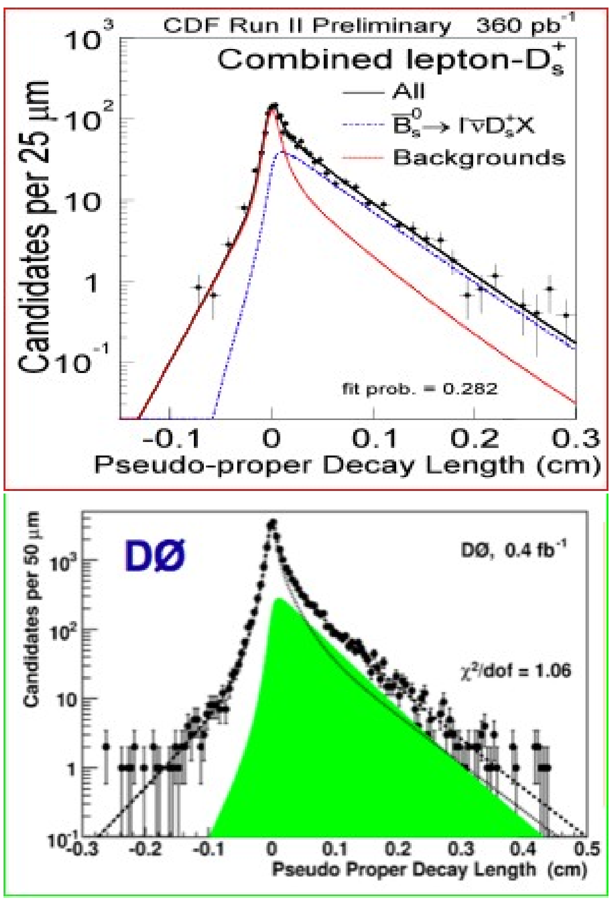

Figure 6. Lifetime distributions for the CDF (top) and D0(bottom) flavor-specific B_s lifetime measurements.