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Review of Charm and Beauty Lifetimes

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Abstract. A review of the latest experimental results on charm and beauty particle lifetimes is presented together with a brief summary of measurement methods used for beauty particle lifetime measurements. There have been significant updates to the D_s^+/D^0, B^+/B_d^0 and Λ_b^0/B_d^0 lifetime ratios which have some theoretical implications. However more precise measurements are still needed before one can make conclusive statements about the theory used to calculate the particle lifetimes.

INTRODUCTION

Motivation

The study of the charm and beauty particle lifetimes is broadly motivated by two main goals. The first is to convert relative branching fractions to partial decay rates and the second is to learn about the strong interaction.

Experimental data on decays are normally obtained by measuring decay fractions, *e.g.* $\Gamma(D^0 \to K^-\pi^+)/\Gamma(D^0 \to X)$, whereas theory calculates the partial decay rate, *e.g.* $\Gamma(D^0 \to K^-\pi^+)$. The lifetime of the particle, $\tau = \hbar/\Gamma(D^0 \to X)$, is needed in order to convert the experimentally measured decay fractions into decay rates. Not only does this allow tests of theoretical predictions but it also enables the extraction of Standard Model parameters if the theoretical calculations are reliable, *e.g.* a comparison of B semileptonic decay rates may allow the extraction of $|V_{cb}|$ and $|V_{ub}|$.

The second motivation for the study of lifetimes is that they are interesting in their own right. They allow us to learn more about the "Theoretically-Challenged" part of the Standard Model, *i.e.* non-perturbative QCD. This is one of the few areas of the Standard Model where experimental data and theoretical ideas closely interact. Although this has been touted as an area of the Standard Model not worth pursuing since a lot more theoretical understanding is needed before tests of the Standard Model can be made, it is also one area that is intellectually interesting.

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[1] Talk presented at the Heavy Quarks at Fixed Target Workshop, Fermi National Accelerator Laboratory, Batavia IL 60510, U.S.A., 10-12 Oct. 1998.

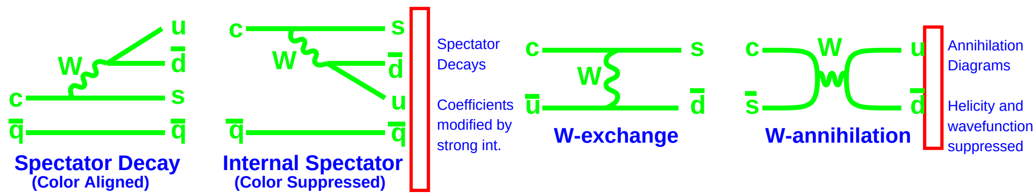

FIGURE 1. Hadronic decay diagrams for charm meson decays.

For example, even though we have some models, we have little idea about exactly *how* quarks turn into hadrons. In my view this *is* new physics since it is beyond what the Standard Model can do right now. Calculations using Lattice QCD are only just now being used to study the *dynamics* of decays and may start producing reliable results [1].

Decay Diagrams

The lifetime of a particle is given by the following expression:

$$\tau = \frac{\hbar}{\Gamma_{SL} + \Gamma_{NL} + \Gamma_{PL}} \tag{1}$$

where Γ_{SL} is the semileptonic decay rate, (*e.g.* $\Gamma(D^+ \to \ell^+ \nu_\ell X)$), Γ_{NL} is the non-leptonic or hadronic decay rate, (*e.g.* $\Gamma(D^+ \to \text{hadrons})$), and Γ_{PL} is the purely leptonic decay rate, (*e.g.* $\Gamma(D^+ \to \ell^+ \nu_\ell)$). Compared to the total rate, the purely leptonic decay rate is normally very small due to helicity suppression.[2] In addition current data for D meson decays indicates that the semileptonic rate for D^+ and D^0 are equal within at least about 10% if not better.[3] This means that the large difference between the observed D^+ and D^0 lifetimes ($\tau(D^+)/\tau(D^0) = 2.55 \pm 0.04$) is due to a large difference in the hadronic decay rates for the D^+ and the D^0. Thus in contrast to the spectator model [4] which has only the free charm quark decay diagram and predicts equal D^+ and D^0 lifetimes, we need to take into account spectator quark effects. This entails taking into account other decay diagrams like those in Figure 1 and any interferences between them.

The conventional wisdom used to explain the smaller hadronic width of the D^+ relative to the D^0 is that in the D^+ Cabibbo allowed decays ($c\bar{d} \to s(u\bar{d})\bar{d}$), there

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2) The B and D mesons both have spin 0 so that in the decay, the resulting lepton (anti-lepton) and anti-neutrino (neutrino) must *both* be either left-handed or *both* right-handed in order to conserve angular momentum. However the $V - A$ nature of the weak interaction requires left-handed particles and right-handed anti-particles [2].

3) The semileptonic decay rate is given by the ratio of the semileptonic branching ratio to the lifetime. Using the world average values for these compiled by the Particle Data Group [3], $\Gamma_{SL}(D^+) = (1.071 \pm 0.119) \times 10^{-13}$ GeV and $\Gamma_{SL}(D^0) = (1.067 \pm 0.041) \times 10^{-13}$ GeV.

exist identical quarks in the final state unlike for D^0, so there are additional (destructive) interference contributions for the D^+. Or, if we are talking about exclusive rather than inclusive decays, one can view the interference as that between the external spectator and internal spectator decay diagrams of Figure 1 which can lead to the same exclusive final state. It is relatively easy to show that the additional interference for inclusive hadronic decays for D^+ is destructive and can lead to a lifetime ratio of $\tau(D^+)/\tau(D^0) \sim 2.0$. However it is difficult to determine exactly how large a ratio of $\tau(D^+)/\tau(D^0)$ interference effects can accomodate and therefore how large is the additional contribution of Cabibbo allowed W-exchange decays in the D^0. Cabibbo allowed W-exchange decay is expected to contribute to lowering the D^0 lifetime but this contribution is wavefunction and helicity suppressed ($\sim \frac{|f_d|^2 m_s^2}{m_c^4}$) and is difficult to calculate reliably.

Clearly a better understanding of both charm and beauty inclusive decays is necessary. Experimental data on lifetimes from all the charm and beauty particles will allow us to learn more about how they decay and in turn use the data to extract standard model parameters like quark masses and the CKM matrix elements $|V_{cs}|$, $|V_{cd}|$, $|V_{cb}|$ and $|V_{ub}|$.

Theoretical Overview for Inclusive Decays

A systematic approach now exists for the treatment of inclusive decays that is based on QCD and consists of an Operator Product Expansion in the Heavy Quark Mass [5]. In this approach the decay rate is given by:

$$\Gamma_{H_Q} = \frac{G_F^2 m_Q^5}{192\pi^3} \Sigma f_i |V_{Qq_i}|^2 \left[A_1 + \frac{A_2}{\Delta^2} + \frac{A_3}{\Delta^3} + \frac{A_4}{\Delta^4} + ... \right] \tag{2}$$

where the expansion parameter Δ is often taken as the heavy quark mass and f_i is a phase space factor. $A_1 = 1$ gives the spectator model term and the A_2 term produces differences between the baryon and meson lifetimes. The A_3 term includes the non-spectator W-annhilation and Pauli interference effects. For mesons this term can be related to certain observables whereas for baryons particular quark models or QCD sum rules are needed to determine the parameters fully. Though scaling formally as $1/\Delta^3$, these non-spectator terms actually scale like f_Q^2/M_Q^2 and thus predict that the lifetime differences for the beauty particles should be about 10% of those seen in charm.

A theoretical review is outside the scope of this article and the reader is referred to other reviews [5].

REVIEW OF EXPERIMENTAL RESULTS

There have been new measurements of charm and beauty lifetimes since the 1998 review performed by the PDG [3]. Some are results published in journals while others were presented at conferences this year. Given the title of this Workshop, it is interesting to note that all the measurements of the B particle lifetimes come from collider experiments whereas all the ones for charm come essentially only from fixed target experiments.

In the past and even today, as well as lifetime measurements of the different species of B particles, measurements are often given for admixtures of B hadrons, either B^+/B^0_d, $B^+/B^0_d/B^0_s/b$-baryon or b-baryons. Given how well the lifetimes of the different species of B particles are now measured I think reviewing the measurements of the admixtures no longer makes sense from a physics standpoint. Even the measurement for b-baryons is not so much more precise than that for Λ^0_b, and the b-baryons sample contains a large contamination of Ξ_b with unknown lifetime. In the same vein I shall not include lifetime ratios derived from ratios of branching fractions as these involve additional assumptions and also because they do not significantly change the world average values.

Measurements of Beauty Particle Lifetimes

Methods used for the measurement of lifetimes of the B mesons can be broadly divided into three classes. The B meson can be completely reconstructed ("*Exclusive*"); the B meson decay vertex is reconstructed but its momentum is only partially reconstructed (*"Inclusive 1"*); and neither the B meson vertex not its momentum is completely reconstructed (*"Inclusive 2"*). It is interesting to separate the measurements into these three different classes as they have different systematic uncertainties and any differences may reflect effects which are not sufficiently understood.

Measurements of B^+ and B^0_d Lifetimes

Exclusive reconstruction is performed by the CDF and ALEPH collaborations. CDF uses B meson decays to $J/\psi K$, $J/\psi K^*$, $\psi' K$ and $\psi' K^*$ [6], whereas ALEPH looks for B decays to $J/\psi K$, $J/\psi K^*$ and D, D^* plus charged pions, (either direct pions or pions from the decay of the ρ or a_1) [7]. Measurements are still very much statistics limited since the B meson is completely reconstructed. The dominant systematics in the measurements are from non-Gaussian tails, possibly from misreconstruction, and uncertainties in the background lifetime distribution.

The *Inclusive 1* reconstruction involves reconstruction of semileptonic decays $B^0_d \to D^{*+}\ell^- X$, $B^0_d \to D^+\ell^- X$ and $B^+ \to D^0\ell^- X$, where the D^0 is explicitly tested to make sure it is not compatible with being from $D^{*+} \to D^0\pi^+$. However there is still contamination or dilution of the B^+ sample from B^0_d decays and vice-versa. For example, the $D^{(*)+}\ell^- X$ sample can contain 10–25% B^+ decays, due to $B^+ \to D^{**0}$, $D^{**0} \to D^{(*)+}\pi^-$. The B^+ and B^0_d lifetimes are obtained by a simultaneous fit to the $D^{(*)+}\ell^- X$ and $D^0\ell^- X$ samples. Since the lifetimes of the B^+ and B^0_d are so close together the B compositions of the samples are constrained

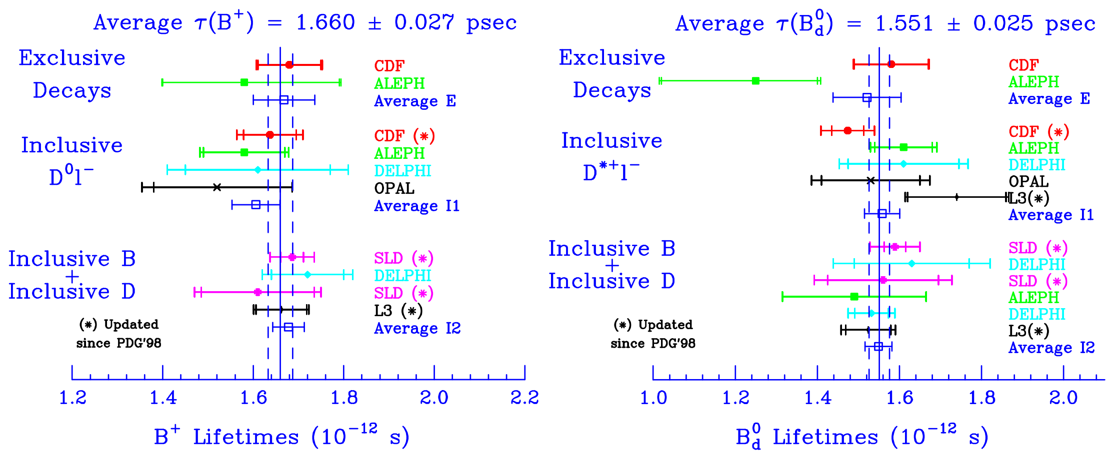

FIGURE 2. Lifetime measurements for B^+ and B_d^0 split into the three measurement method classes described in the text.

to be within the uncertainties of measurements for the various branching fractions needed in the calculation of the compositions. In additional, although the B vertex is obtained from the intersection of the D momentum vector and the lepton, the B momentum is not completely determined because of the unobserved neutrino in the B semileptonic decay. A Monte Carlo simulation is used to correct for this effect. The dominant systematic uncertainties for this type of measurement are the uncertainties in the composition and the corrections for the B momentum as well as uncertainties in the background. Measurements using this method have been done by the DELPHI [8] and OPAL [9] collaborations including using the $D^+\ell^-X$ sample, whereas the CDF [10] and ALEPH [7] collaborations use only the $D^{*+}\ell^-X$ and $D^0\ell^-X$ samples. L3 only uses their $D^{*+}\ell^-X$ sample in a (single) fit to obtain the B_d^0 lifetime [11].

In the *"Inclusive 2"* method the B meson decay vertex is not fully reconstructed. This includes a topological/vertex-charge method as well as methods based on the correlations of the B and subsequent charm decay products. The SLD [12], DELPHI [13] and L3 [14] collaborations use a topologocal method where a well separated (smeared B-C) secondary vertex is reconstructed from charged tracks to help select out a B particle decay and the vertex charge is used to tag whether the decay is from the B^+ or from the B_d^0. The SLD group also includes an event sample where a lepton is part of the secondary vertex to help further discriminate between B particle decays and background. Of the B particle decays the vertex charge selects out only about 55-77% of the correct B meson type. The fit for the B_d^0 and B^+ lifetimes are obtained by simultaneosuly fitting the charged and neutral vertex samples and with the help of Monte Carlo simulations. Since the composition has to be modeled as well as the smearing for both the B decay length and momentum, the measurement of the B lifetimes are already systematics limited for the measurements with the smallest statistical errors [12]. However the measurement of the B^+/B_d^0 lifetime ratio is not yet systematics limited. The other measurements

TABLE 1. Summary of B lifetime measurements split by experiment

Experiment	$\tau(B^+)$ **ps**	$\tau(B^0_d)$ **ps**	$\tau(B^+)/\tau(B^0_d)$
CDF[a]	1.661 ± 0.052	1.513 ± 0.053	1.091 ± 0.050
SLD[a]	1.678 ± 0.046	1.586 ± 0.057	1.059 ± 0.039
L3[a]	1.662 ± 0.061	1.571 ± 0.058	1.090 ± 0.076
ALEPH	1.580 ± 0.095	1.550 ± 0.067	1.030 ± 0.082
DELPHI	1.700 ± 0.090	1.548 ± 0.051	1.050 ± 0.100
OPAL	1.520 ± 0.166	1.530 ± 0.144	0.990 ± 0.147
World Average	1.660 ± 0.027	1.551 ± 0.025	1.065 ± 0.026

[a] Updated since PDG98

included in this class are from ALEPH [7] and DELPHI [13]. ALEPH used $\pi^-_B\pi^+_D$ correlations in $\overline{B^0_d} \to \pi^-_B D^{*+} X$ ($D^{*+} \to D^0\pi^+_D$), and DELPHI used $\pi^+_D\ell^-$ correlations in $\overline{B^0_d} \to D^{*+}\ell^- X$ ($D^{*+} \to D^0\pi^+_D$) to select out a signal and to fit for the B^0_d lifetime.

The measurements for $\tau(B^+)$, $\tau(B^0_d)$ and $\tau(B^+)/\tau(B^0_d)$ split into the three measurement method classes are shown in Figure 2. One can conclude that no systematic differences between the measurement methods exist to within the current uncertainties. The measurements split by collaboration are summarized in Table 1. Note that each collaboration already did an excellent job of calculating their own averages taking into account the correlations of their measurements using different methods. The LEP B Lifetime Working Group also calculates a world average as well as a LEP average. Using almost the same measurements as input they obtain the following world averages: $\tau(B^+) = 1.67 \pm 0.03$, $\tau(B^0_d) = 1.57 \pm 0.03$ ps and $\tau(B^+)/\tau(B^0_d) = 1.07 \pm 0.03$ [15].

The lifetime for the B^+ is now measured to be 2.6σ higher than for the B^0_d, which is becoming more significant.

Measurements of the B^0_s, Λ^0_b and B^+_c Lifetimes

Just as for the B^+ and B^0_d lifetime measurements, the methods for measuring the B^0_s lifetime can be split into the three measurement method classes described previously. Only CDF uses a fully reconstructed mode, $B^0_s \to J/\psi\phi^0$ [6]. For the *Inclusive 1* method, OPAL [16], ALEPH [17], CDF [18] and DELPHI [19] uses $\bar{B}^0_s \to D^+_s\ell^- X$ and ALEPH [20] and DELPHI [19] also use $\bar{B}^0_s \to D^+_s h^-$ where h is one (or more) hadrons. For the *Inclusive 2* where the B^0_s vertex is not reconstructed we have measurements from OPAL [21] and DELPHI [19] using $\bar{B}^0_s \to D^+_s X$ and DELPHI includes $\bar{B}^0_s \to \phi^0\ell^-$. These measurements are shown in Figure 3(a) and summarized in table 2.

The Λ^0_b lifetime has been measured using $\Lambda^0_b \to \Lambda^+_c\ell^- X$ where the Λ^+_c decay is fully reconstructed via various decay modes. The sample typically contains 70-90% Λ^0_b with a 1% contamination from Ξ_b. There has only been one minor update

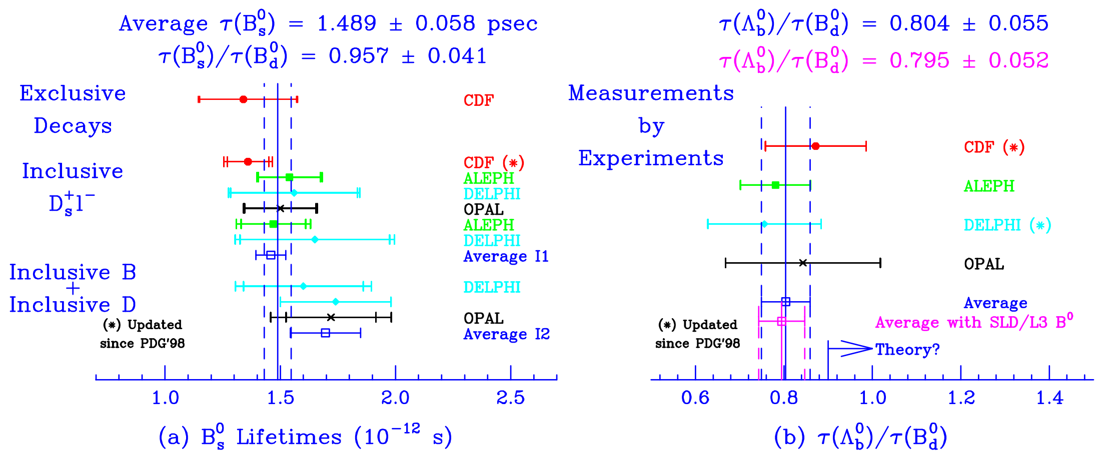

FIGURE 3. Lifetime measurements for (a) B_s^0 split by measurement methods as described in the text; and (b) $\tau(\Lambda_b^0)/\tau(B_d^0)$ split by experiment.

TABLE 2. Summary of B_s^0 and Λ_b^0 lifetime measurements split by experiment

Experiment	$\tau(B_s^0)$ ps	$\tau(\Lambda_b^0)$ ps	$\tau(\Lambda_b^0)/\tau(B_d^0)$
CDF[a]	1.356 ± 0.094	1.320 ± 0.166	0.872 ± 0.114
OPAL	1.570 ± 0.140	1.290 ± 0.238	0.843 ± 0.175
ALEPH	1.510 ± 0.110	1.210 ± 0.110	0.781 ± 0.079
DELPHI[b]	1.670 ± 0.140	1.170 ± 0.195	0.756 ± 0.128
World Average	1.489 ± 0.058	1.237 ± 0.078	0.804 ± 0.055[c]

[a] Updated since PDG98 for $\tau(B_s^0)$
[b] Updated since PDG98 for $\tau(\Lambda_b^0)$
[c] 0.795 ± 0.052 including other measurements for $\tau(B_d^0)$.

from DELPHI [22] since PDG98. The results are summarized in Table 2 and the results for $\tau(\Lambda_b^0)/\tau(B_d^0)$ are shown in Figure 3(b) compared to the theoretical limit. Although $\tau(\Lambda_b^0)/\tau(B_d^0)$ is small compared to theory it is still within 2σ of the theoretical limit.

CDF has observed the B_c^+ meson with a lifetime of $0.46^{+0.18}_{-0.16} \pm 0.03$ ps [23].

Measurements of Charm Particle Lifetimes

The World average lifetimes for the weakly decaying charm particles are dominated by measurements from Fermilab E687 published in 1993-1995. However there have been a few updates this year. The Fermilab E687 collaboration has published an new value for the lifetime of $\Xi_c^+ = 0.34^{+0.07}_{-0.05} \pm 0.02$ ps using an additional decay mode [24]. This supercedes their earlier published result. Direct measurements of charm particle lifetimes using the CLEO 2.5 experiment has been reported at conferences this year: $\tau(D^+) = 1.034 \pm 0.033^{+0.033}_{-0.038}$ ps [25], $\tau(D_s^+) =$

$0.475 \pm 0.024 \pm 0.025$ ps [25] and a more updated $\tau(D^0) = 0.410 \pm 0.006 \pm 0.005$ ps [26]. Although their new silicon tracker enables them to measure lifetimes to a precision rivaling the fixed target E687 results, the next generation fixed target experiment FOCUS will be overwhelming with a huge sample of fully reconstructed charm decays [27]. Results have also been presented by Fermilab E791 for $\tau(D^0) = 0.413 \pm 0.003(stat)$ ps [28] and $\tau(D_s^+) = 0.518 \pm 0.014 \pm 0.007$ ps [29].

The most significant consequence of these new measurements is that $\tau(D_s^+)$ is conclusively larger than $\tau(D^0)$, since the world average is now $\tau(D_s^+)/\tau(D^0) = 1.193 \pm 0.027$ compared to the earlier PDG98 value of 1.125 ± 0.042.

LIFETIMES AND THEORY

Λ_b^0, B^+ and B_d^0 Lifetimes

The smallness of the Λ_b^0 lifetime compared to the B_d^0 is often cited as a problem. In fact the measured ratio of $\tau(\Lambda_b^0)/\tau(B_d^0)$ is only 2σ from the theoretical limit of 0.9 given by Bigi [30]. Furthermore it was pointed out recently by Neubert and Sachrajda that if they use the same theoretical approach but without model dependent constraints on the parameters of the mass expansion, they can obtain ratios as low as 0.8 for $\tau(\Lambda_b^0)/\tau(B_d^0)$ and also the sign of $\tau(B^+) - \tau(B_d^0)$ is not determined [31]. Given that the measurements now indicate $\tau(B^+) > \tau(B_d^0)$ their results would point to a larger theoretical limit than 0.8. However more precise lifetime measurements are still needed.

In particular measurements to convincingly show that $\tau(B^+) > \tau(B_d^0)$ is interesting since studies of B^+ exclusive decay modes give the same sign for the external and internal spectator diagrams [32] which would suggest constructive interference in B^+ decays which could lead to a shorter lifetime than for the B_d^0.

Other theoretical approaches have been reported to explain the shortness of the Λ_b^0 lifetime. Datta, Lipkin and O'Donnell have shown that the Λ_b^0 lifetime can be shortened by phase space enhancement through isospin conservation [33]. Other authors have used the mass expansion approach but with the hadron mass instead of the heavy quark mass [34], or with the energy release instead of the quark mass as the expansion parameter [35].

D^0 and D_s^+ Lifetimes

The D_s^+ lifetime is now conclusively measured to be above the D^0 lifetime. However exactly how much larger is still not measured that precisely. A more accurate measurement is needed and may tell us much more about the nature and size of the W-annhilation contribution to the inclusive decay. Bigi and Uraltsev have used the mass expansion approach to analyze this lifetime difference and have concluded that a difference of $< 7\%$ is possible without WA contributions. Their estimation of the WA contribution puts an upper limit of $\tau(D_s^+)/\tau(D^0) < 1.20$ [36].

CONCLUSIONS

The most significant updates are that the D_s^+ lifetime is now conclusively measured to be above the D^0 lifetime, $\tau(D_s^+)/\tau(D^0) = 1.193 \pm 0.027$, however more precise measurements are needed to really study the size of weak annihilation effects. The B_c^+ meson has been observed with a lifetime of $0.46^{+0.18}_{-0.16} \pm 0.03$. The measured values of $\tau(B^+)/\tau(B_d^0) = 1.068 \pm 0.026$ and $\tau(\Lambda_b^0)/\tau(B_d^0) = 0.795 \pm 0.052$ are becoming more precise but still more accurate measurements are needed for both of these ratios. These ratios taken together, if more precisely measured, can indicate in a model independent fashion whether there is really a contradiction between theory and the measurements.

We can look forward to much more precise charm particle lifetimes from FOCUS [27] within a year and the future for new beauty particle lifetime measurements is also very bright with several new experiments ready soon or within a few years to take data (BELLE, BABAR, HERA-B, CDF and D0).

The study of charm and beauty lifetimes should continue to be an exciting field.

REFERENCES

1. Kronfeld, A., these proceedings.
2. Aitchison, I. J. R., and Hey, A. J. G., *Gauge Theories in Particle Physics*, 2nd ed., London: IOP Publishing Ltd., 1989, ch. 10, pp. 347-356.
3. Caso, C., *et al.*, PDG, *Eur. Phys. J.* **C 3**, 1-794 (1998).
4. Gaillard, M. K., Lee B. W., and Rosner, J. L., *Rev. Mod. Phys.* **47** 277-310 (1975); Altarelli, G., Cabibbo, N., and Maiani, L., *Phys. Rev. Lett.* **35**, 635-638 (1975); Cabibbo, N., and Maiani, L., *Phys. Lett.* **B 73**, 418-422 (1978) and references therein.
5. Bigi, I. I., *et al.*, "Non-leptonic Decays of Beauty Hadrons - From Phenomenology to Theory", in Stone, S. (ed.), *B Decays*, revised 2nd ed., Singapore: World Scientific, 1994, pp. 132-157, and references therein; Cheung, H. W. K., "The Physics of Charm Lifetimes", in *Proceedings of the 8th Meeting of the Division of Particles and Fields of the American Physical Society, Albuquerque, New Mexico*, Aug. 2-6, 1994, pp. 517-520, and references therein; Bellini, G., Bigi, I., and Dornan, P. J., *Phys. Rept.* **289**, 1-155 (1997).
6. Abe., F., *et al.*, CDF Collaboration, *Phys. Rev.* **D 57**, 5382-5401 (1998).
7. Buskulic, D., *et al.*, ALEPH Collaboration, *Z. Phys.* **C 71**, 31-44 (1998).
8. Abreu, P., *et al.*, DELPHI Collaboration, *Z. Phys.* **C 68**, 13-23 (1995).
9. Akers, R., *et al.*, OPAL Collaboration, *Z. Phys.* **C 67**, 379-388 (1995).
10. Abe, F., *et al.*, CDF Collaboration, *Phys. Rev.* **D 58**, 092002, 12 pages (1998).
11. L3 Collaboration, "Measurement of the B_d^0 Meson Lifetime using the decay $\bar{B}_d^0 \to D^{*+}\ell^-\bar{\nu}$", presented at the 29th Int. Conf. on High Energy Phys., Vancouver, Canada, July 23-29, 1998. L3 Note 2142.
12. Abe, K., *et al.*, SLD Collaboration, "Measurement of the B^+ and B_d^0 Lifetimes using Topological Vertexing at SLD", presented at the 29th Int. Conf. on High Energy Phys., Vancouver, Canada, July 23-29, 1998. SLAC Preprint SLAC-PUB-7868.

13. Adam, W., *et al.*, DELPHI Collaboration, *Z. Phys.* **C 68**, 363-374 (1995).
14. L3 Collaboration, "Upper Limit on the Lifetime Difference of Short- and Long-lived B_s^0 Mesons", presented at the 29th Int. Conf. on High Energy Phys., Vancouver, Canada, July 23-29, 1998. L3 Note 2281.
15. Alcaraz, J., *et al.*, LEP B lifetimes working group, See the latest writeup at the following URL http://home.cern.ch/~claires/lepblife.html.
16. Ackerstaff, K., *et al.*, OPAL Collaboration, *Phys. Lett.* **B 426** 161-179 (1998).
17. Buskulic, D., *et al.*, ALEPH Collaboration, *Phys. Lett.* **B 377** 205-221 (1996).
18. Abe, F., CDF Collaboration, "Measurement of the B_s^0 Meson Lifetime Using Semi-leptonic Decays", Fermilab preprint FERMILAB-Pub-98/172-E, August 1998.
19. Abreu, P., *et al.*, DELPHI Collaboration, *Z. Phys.* **C 71**, 11-30 (1996).
20. Barate, R., *et al.*, ALEPH Collaboration, *Eur. Phys. J.* **C 4** 367-385 (1998).
21. Ackerstaff, K., *et al.*, OPAL Collaboration, *Eur. Phys. J.* **C 2** 407-416 (1998).
22. Asman, B., *et al.*, DELPHI Collaboration, "Measurement of the lifetime of b-baryons", presented at the 29th Int. Conf. on High Energy Phys., Vancouver, Canada, July 23-29, 1998. DELPHI 98-72 CONF 140.
23. Abe, F. *et al.*, CDF Collaboration, *Phys. Rev.* **D 58**, 112004, 29 pages (1998); *Phys. Rev. Lett.* **81**, 2432-2437 (1998).
24. Frabetti, P. L., *et al.*, E687 Collaboration, *Phys. Lett.* **B 427**, 211-216 (1998).
25. Drell, S., *et al.*, CLEO Collaboration, "Precise Measurements of Charm Meson Lifetimes Using the New CLEOII Silicon Vertex Detector", presented at the 32nd Rencontres de Moriond, Les Arcs, France, Mar. 21-28, 1998.
26. Richichi, S. J. *et al.*, CLEO Collaboration, "Precise Measurements of the D^0 Meson Lifetime with the CLEOII.V Silicon Vertex Detector", presented at the 29th Int. Conf. on High Energy Phys., Vancouver, Canada, July 23-29, 1998.
27. FOCUS Collaboration results presented by Johns, W., Link, J. and Vaandering, E. in these proceedings.
28. Kwan, S. *et al.*, E791 Collaboration, "Measurement of a Limit on the $D^0\bar{D}^0$ Mixing Rates due to Lifetime Difference", presented at the 29th Int. Conf. on High Energy Phys., Vancouver, Canada, July 23-29, 1998.
29. E791 Collaboration results presented by Copty, N. in these proceedings.
30. Bigi, I. I., "Heavy Quark Expansions for Inclusive Heavy Flavor Decays and the Lifetimes of Charm and Beauty Hadrons," in *Proceedings of the 1996 Workshop on Heavy Quarks at Fixed Target, St. Goar, Germany*, Oct. 3-6, 1996, pp. 131-157.
31. Neubert, M., "Theory of Beauty Lifetimes", presented at the 2nd Int. Conf. on B Physics and CP Violation, Honolulu, Hawaii, Mar. 24-27, 1997. Neubert, M. and Sachrajda, C. T., *Nucl. Phys.* **B 483**, 339-370 (1997).
32. Honscheid, K., in Caso, C., *et al.*, PDG, *Eur. Phys. J.* **C 3**, pp. 522-533 (1998).
33. Datta, A., Lipkin, H. J. and O'Donnell, J. O., "Implications of Isospin Conservation in Λ_b^0 Decays and Lifetime", Univ. of Toronto prepint, UTPT-98-15, Sept. 1998.
34. Cheng, H. Y., *Phys. Rev.* **D 56**, 2783-2798 (1997). Cheng, H. Y., and Yang, K. C., "Nonspectator Effects and B Meson Lifetimes from a Field-theoretical Calculation", Taiwan Inst. Phys. preprint IP-ASTP-03-98, May 1998.
35. Ito, T., Matsuda, M. and Matsui, Y. *Prog. Theor. Phys.* **99**, 271-280 (1998).
36. Bigi, I. I., and Uraltsev, N. G., *Z. Phys.* **C 62**, 623-632 (1994).