Fermi National Accelerator Laboratory

Experimental Status of b Hadron Lifetimes

S. Donati

For the CDF Collaboration

I.N.F.N. Sezione di Pisa
Via Livornese, 1291, 56010, San Piero a Grado, Pisa, Italy

Fermi National Accelerator Laboratory
P.O. Box 500, Batavia, Illinois 60510

November 1999

Experimental Status of b Hadron Lifetimes

S. Donati, for the CDF Collaboration

INFN Sezione di Pisa, Via Livornese, 1291, 56010 San Piero a Grado, Pisa, Italy
mailto: donati@pi.infn.it

ABSTRACT: In this paper we review the most recent experimental results on the various b hadron species lifetimes obtained at electron - positron machines and at the Tevatron.

1. Introduction

The precise measurement of the specific B lifetimes is very important in the determination of elements of the Cabibbo - Kobayashi - Maskawa matrix. Furthermore measurements of the lifetimes of B hadrons probe decay mechanisms beyond the simple spectator quark decay model. In the spectator model the q quark within the B hadron acts as a spectator and the $\overline{b}$ quark decays as a free particle. In analogy to the muon lifetime and neglecting the $b \to u$ transitions, all the B hadrons would have the same lifetime, which would be given by following formula:

$$\Gamma = \frac{1}{\tau} = \frac{G_F^2 m_b^5}{192\pi^3} \cdot \mid V_{cb} \mid^2 \cdot \Phi \qquad (1.1)$$

where Φ is a phase space factor. Experimental results [1] show that this picture fails in the prediction of the charm hadron lifetimes, which are measured to be:

$$\tau(D^-) \sim 2.5\tau(D^0) \sim 2.5\tau(D_s^-) \sim 5.0\tau(\Lambda_c^-)$$

Due to the heavier quark mass, the lifetime differences are expected to be smaller among bottom hadrons. Differences are expected to arise from unequal amplitudes for the annihilation and W-exchange diagrams and from the final state Pauli interference effects. A lifetime difference between the B^+ and B^0 mesons of the order of 5 % and very similar B^0 and B_s^0 lifetimes are predicted on the basis of phenomenological models [2] (figure 1).

Several direct measurements of the single species of b hadrons have been performed by e^+e^- experiments and by CDF. The precision of these mea-
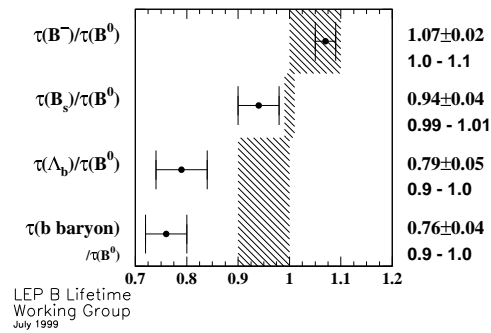
Figure 1: Comparison between the experimental results (points with error bars) and the theoretical prediction (shaded bands) for the ratios of the b hadrons lifetimes to the B^0 lifetime. See the text below for the discussion.

surements is now approaching the level where the small differences can be seen. Further improvements will provide a strong test of the B hadron decay mechanisms.

2. B^0 and B^+ lifetimes

Several techniques have been used to measure the B^0 and B^+ lifetimes by the LEP experiments, CDF and SLD. The cleanest method reconstructs exclusive B^0 and B^+ decays but suffers from small branching fractions (section 2.2). Most measurements use samples of semileptonic B decays with the $D^{(*)}$ exclusively reconstructed and intersected with the lepton to determine the B decay vertex (section 2.1). There are also more inclusive techniques used by e^+e^- experiments

which reconstruct secondary vertices from b hadron decays and distinguish B^+ and B^0 decays from the charge of the secondary vertex (section 2.3).

2.1 Measurements in $D^{(*)}l$ samples

This method has been used by CDF [3] and by ALEPH, DELPHI and OPAL at LEP.

CDF: For the CDF measurement data collected in run I (1992-1995) and corresponding to an integrated luminosity of 110 pb^{-1} have been used. In order to identify semileptonic decays of B mesons, events with a lepton (e^- or μ^-, denoted by l^-) associated with a D^0 or a D^{*+} are selected (in this paper charge conjugate modes are always implied). A single lepton trigger data set with a principal lepton p_t threshold of about 8 GeV/c is used. The D^0l^+ candidates consist mostly of charged B decays, while the $D^{*+}l^-$ consist mostly of neutral B decays. The D^0 mesons are reconstructed using the decay mode $D^0 \rightarrow K^-\pi^+$, while the D^{*+} decays are reconstructed using the decay mode $D^{*+} \rightarrow D^0\pi^+$, followed by the $D^0 \rightarrow K^-\pi^+$, $K^-\pi^+\pi^+\pi^-$ or $K^-\pi^+\pi^0$. From the D^0l sample events consistent with the decay chain $D^{*+} \rightarrow D^0\pi^+$ are removed. The total number of events in the signal region (defined to be in the mass range 1.84 to 1.88 GeV/c^2) is estimated to be 5198, with a background fraction of 0.53±0.02. For the D^{*+} modes, the D^{*+} meson is reconstructed by combining an additional track, assumed to have the pion mass, with the D^0 candidate and computing the mass difference (Δm) between the $D^0\pi^+$ and D^0 candidates. The estimated number of events in the signal regions are respectively 935, 1166 and 2858, with background fractions 0.09 ± 0.01, 0.18 ± 0.02 and 0.37 ± 0.02.

The decay vertex ($\vec{V}_B$) of the B meson is given by the intersection of the trajectory of the lepton with the flight path of the D^0 candidate. Using a common procedure for both D^0l^- and $D^{*+}l^-$ pairs, the B decay length L_B is defined as the displacement of $\vec{V}_B$ from the primary vertex, measured in the plane perpendicular to the beam axis, and projected onto the transverse momentum vector of the D^0l^- system:

$$L_B = \frac{(\vec{V}_B - \vec{V}_P) \cdot \vec{p}_t^{D^0l^-}}{\vec{p}_t^{D^0l^-}} \qquad (2.1)$$

The momentum of the B meson is necessary to measure the proper decay length of the decay. Due to the missing neutrino, this measurement cannot be performed precisely and $p_t^{D^0l^-}$ is used to estimate the B momentum for each event. This results in the so called "pseudo-proper decay length" ($x = L_B m_B/p_t^{D^0l^-}$). The correction for the difference between $p_t^{D^0l^-}$ and p_t^B is estimated from Monte Carlo and is introduced during the lifetime fit.

The lifetime measurement is obtained from a maximum likelihood fit to the observed pseudo-proper decay length distributions. The probability distribution of the signal consists of an exponential function, convoluted with the distribution of the correction factor and the resolution function. The combinatorial background is parameterized with three components: a Gaussian for the prompt component and two exponentials convoluted with a Gaussian for the left ($c\tau < 0$) and the right ($c\tau > 0$) tails. For each sample, the proper time distribution of the events in the signal mass region is fitted simultaneously with the one of the sideband mass regions and the wrong sign combinations, to model the combinatorial background. The results of the measurement are:

$$\tau(B^+) = 1.637 \pm 0.058^{+0.045}_{-0.043} \text{ ps}$$
$$\tau(B^0) = 1.474 \pm 0.039^{+0.052}_{-0.051} \text{ ps}$$
$$\tau(B^+)/\tau(B^0) = 1.110 \pm 0.056^{+0.033}_{-0.030}$$

ALEPH: The ALEPH Collaboration has measured the B^0 and B^+ lifetimes using a sample of four million hadronic Z decays collected in 1991-1995. The $D^{*+}l^-$ candidates are identified via the decay $D^{*+} \rightarrow D^0\pi^+$, followed by $D^0 \rightarrow K^-\pi^+$, $D^0 \rightarrow K^-\pi^+\pi^-\pi^+$, $D^0 \rightarrow K^-\pi^+\pi^0$ or $D^0 \rightarrow K_s^0\pi^+\pi^-$. The mass plots for the four decay channels are shown in figure 2. The D^0l^+ sample consists of events with a lepton and a D^0 candidate, where the D^0 is not the decay product of a D^{*+}. D^0 candidates are identified via the decay $D^0 \rightarrow K^-\pi^+$, $D^0 \rightarrow K^-\pi^+\pi^0$ and $D^0 \rightarrow K_s^0\pi^+\pi^-$. A fit to the proper time of 1915 $D^{*+}l^-$ (figure 3) and 2093 D^0l^+ candidates (figure 4) yields the following results [4]:
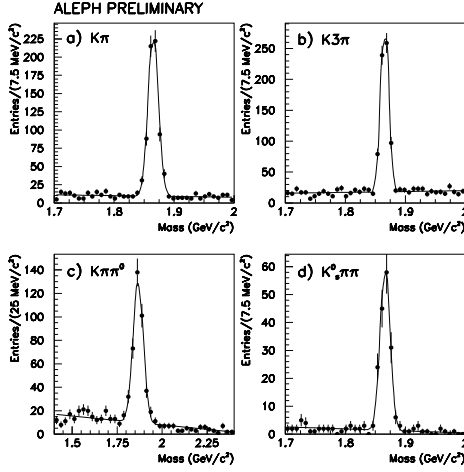
Figure 2: Invariant mass plots of the D^0 candidates for the four subsamples in the $D^{*-}l^+$ sample reconstructed by ALEPH.

Figure 3: Proper time distribution of the $D^- l^+$ ALEPH sample, with overlaid the result of the fit. Shaded are shown the background contribution and the B^0 and B^+ components.

$$\tau(B^+) = 1.646 \pm 0.056^{+0.036}_{-0.034} \text{ ps}$$
$$\tau(B^0) = 1.524 \pm 0.053^{+0.035}_{-0.034} \text{ ps}$$
$$\tau(B^+)/\tau(B^0) = 1.080 \pm 0.062 \pm 0.018$$

DELPHI: The DELPHI Collaboration has used the data collected from 1991-1993 to reconstruct a sample of 309 $D^{*+}l^-$ events in the channel $D^{*+}l^- \rightarrow D^0\pi^+$ followed by $D^0 \rightarrow K^-\pi^+$, $D^0 \rightarrow K^- \pi^+ \pi^- \pi^+$, $D^0 \rightarrow K^-\pi^+\pi^0$ and a sample of 377 $D^0 l^+$ events in the channels $D^0 \rightarrow K^-\pi^+$,
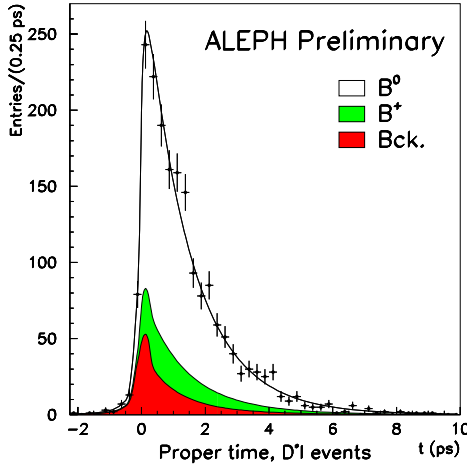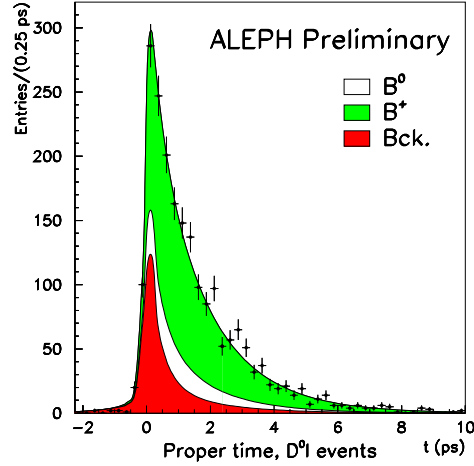

Figure 4: Proper time distribution of the $D^0 l^+$ ALEPH sample, with overlaid the result of the fit. Shaded are shown the background contribution and the B^+ and B^0 components.

$D^0 \rightarrow K^-\pi^+\pi^-\pi^+$. The lifetime measurement yields the following result [5]:

$$\tau(B^+) = 1.61^{+0.016}_{-0.16} \pm 0.12 \text{ ps}$$
$$\tau(B^0) = 1.524^{+0.14}_{-0.13} \pm 0.08 \text{ ps}$$
$$\tau(B^+)/\tau(B^0) = 1.00^{+0.17}_{-0.15} \pm 0.01$$

OPAL: The OPAL Collaboration has used 1.72 million hadronic Z^0 decays recorded during the period 1991-1993 and has reconstructed $D^{*+}l^-$ candidates in the channel $D^{*+}l^- \rightarrow D^0\pi^+$ followed by $D^0 \rightarrow K^-\pi^+$ and $D^0 \rightarrow K^-\pi^+\pi^-\pi^+$ decays. The B^0 mesons are reconstructed also through decays into $D^- l^+$ followed by the decay $D^- \rightarrow K^+\pi^-\pi^-$. The B^+ candidates are reconstructed through the decay $B^+ \rightarrow D^0 l^+$, with the D^0 reconstructed in the $D^0 \rightarrow K^-\pi^+$ channel. The resulting total sample consists of approximately 1000 events which allows the direct lifetime measurement [6]:

$$\tau(B^+) = 1.52 \pm 0.14 \pm 0.09 \text{ ps}$$
$$\tau(B^0) = 1.53 \pm 0.12 \pm 0.08 \text{ ps}$$
$$\tau(B^+)/\tau(B^0) = 0.99 \pm 0.14^{+0.05}_{-0.04}$$

2.2 Measurements in exclusive channels

The CDF Collaboration has measured the B^+ and B^0 meson lifetimes using fully reconstructed $B \rightarrow \Psi K$ decays ($\Psi = J/\psi$ or $\psi(2S)$ and $K =$

K^+, $K^*(892)^+$, K_s^0 or $K^0(892)^0$ [9]. The $\psi(2S)$ has been reconstructed in the decay $\psi(2S) \rightarrow J/\psi\ \pi^+\pi^-$ and the J/ψ in the $J/\psi \rightarrow \mu^+\mu^-$ decay. The kaons have been reconstructed using the decay channels $K_s^0 \rightarrow \pi^+\pi^-$, $K^*(892)^0 \rightarrow K^+\pi^-$ and $K^*(892)^+ \rightarrow K_s^0\pi^+$.

Starting from a data sample of 110 pb^{-1}, 824 fully reconstructed B^+ and 436 fully reconstructed B^0 are selected. The two-dimensional B meson decay length and the transverse momentum are used to obtain the proper time distribution for signal and background events (defined as the B sideband region). The lifetimes are extracted from a simultanesous fit to the signal and sideband events, with the sideband events used to determine the shape of the proper decay length distribution of the background in the signal region. The results of the fit are summarized below:

$$\tau(B^+) = 1.68 \pm 0.07 \pm 0.02 \text{ ps}$$
$$\tau(B^0) = 1.58 \pm 0.09 \pm 0.02 \text{ ps}$$
$$\tau(B^+)/\tau(B^0) = 1.06 \pm 0.07 \pm 0.02$$

2.3 Measurements from vertex charge reconstruction

A more inclusive approach used at e^+e^- machines is to reconstruct resolvable secondary vertices from b hadron decays, since their long lifetimes lead to significant decay lengths. The B^+ and B^0 decays are distinguished by reconstructing the charge of the secondary vertex. This technique results in much larger data samples and offers the possibility to improve the precision. This technique has been used by OPAL, DELPHI and L3 at LEP and by SLD at SLC.

OPAL: The analysis [10] exploits the topology of the $Z^0 \rightarrow b\bar{b}$ decay: two back-to-back jets aligned along the direction of the thrust axis. The event is divided into two hemispheres by the plane perpendicular to the thrust axis and containing the interaction region. One hemisphere is tagged as containing a b decay using a displaced vertex or a high momentum lepton. The production flavour of the b hadron in the tag hemisphere is determined using jet, vertex and lepton charge information.

The unbiased b decay in the other hemisphere is used to perform the measurement of the b hadron
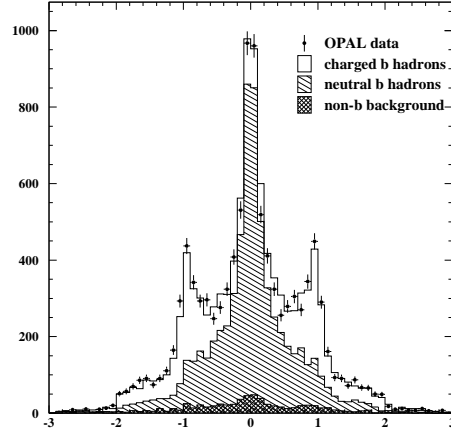

Figure 5: Distributions of the vertex charge Q in the OPAL data (points) and in Monte Carlo (histogram), normalised to the same number of entries. The expected contributions from charged b hadrons, neutral b hadrons and non-b background are indicated.

decay time. The decay time is determined by reconstructing the position and the energy of the decay vertex. To increase the purity of the sample the decay vertex is required to be separated from the primary vertex. Starting from a sample of 2.4 million hadronic Z^0 decays collected between 1993 and 1995, this leads to a sample of about 10,000 reconstructed vertices with well determined charge (figure 5). In figure 5 clear peaks at $Q = \pm 1$ and 0 are visible, corresponding to high purities of charged and neutral b hadrons. The actual sample composition is determined from Monte Carlo. The reconstructed decay times of the b hadrons are then used to determine the B^+ and B^0 lifetimes, employing the excess decay length technique to eliminate biases caused by the separated vertex requirement. The lifetimes are extracted by using a maximum likelihood fit to the mean excess proper time as a function of the modulus of the vertex charge Q. The measured values are:

$$\tau(B^+) = 1.643 \pm 0.037 \pm 0.025 \text{ ps}$$
$$\tau(B^0) = 1.523 \pm 0.057 \pm 0.053 \text{ ps}$$
$$\tau(B^+)/\tau(B^0) = 1.079 \pm 0.064 \pm 0.041$$

DELPHI: The DELPHI Collaboration has used 1.4 million of hadronic Z^0 decays from 1993 -

1996 data to reconstruct approximately 1800 B hadron candidates [11]. B hadrons are tagged as jets with a secondary vertex and the charge of the B candidate is taken to be the sum of the charges of the particles in the secondary vertex. The lifetime of charged and neutral B hadrons has been extracted by means of an unbinned maximum likelihood fit to the excess decay time. The measured lifetimes are:

$$\tau(B^+) = 1.72 \pm 0.08 \pm 0.06 \text{ ps}$$
$$\tau(B^0) = 1.63 \pm 0.14 \pm 0.13 \text{ ps}$$
$$\tau(B^+)/\tau(B^0) = 1.06^{+0.13}_{-0.11} \pm 0.10$$

L3: The L3 Collaboration has applied the method of measuring the charge of the secondary vertex to the 1994 - 1995 data [12] and has measured the following lifetimes:

$$\tau(B^+) = 1.66 \pm 0.06 \pm 0.03 \text{ ps}$$
$$\tau(B^0) = 1.52 \pm 0.06 \pm 0.04 \text{ ps}$$
$$\tau(B^+)/\tau(B^0) = 1.09 \pm 0.07 \pm 0.03$$

SLD: For this analysis the SLD Collaboration has used the entire sample of 550,000 hadronic Z^0 decays collected by the SLD experiment at SLC between 1993 and 1998 [13]. The excellent 3-D vertexing capabilities of SLD have been exploited with an inclusive topological vertexing technique to identify B hadron vertices with high efficiency. The decay length is measured using the reconstructed vertex location while the B hadron charge is determined from the total charge of the tracks associated with the vertex. The analysis of the 1997 - 1998 dataset of 350,000 Z^0 decays isolates 51,634 B hadron candidates (30,903 charged and 20,731 neutral) with good charge purity enhanced by the vertex mass, the beam polarization and opposite hemisphere jet charge information. The reconstructed vertex charge for the 1997 - 1998 dataset is shown in figure 6. The results from these data have been combined with the earlier 1993 - 1996 measurements to yield the following lifetime measurements:

$$\tau(B^+) = 1.623 \pm 0.020 \pm 0.034 \text{ ps}$$
$$\tau(B^0) = 1.585 \pm 0.021 \pm 0.043 \text{ ps}$$
$$\tau(B^+)/\tau(B^0) = 1.03^{+0.025}_{-0.024} \pm 0.024$$

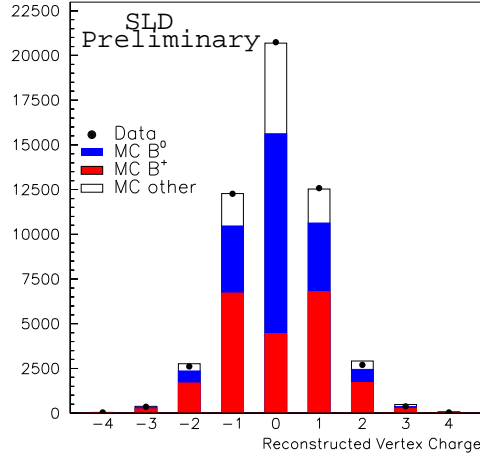The world averages resulting from all the available measurements are:

Figure 6: Reconstructed vertex charge for data (points) and Monte Carlo (histogram) for the 1997 - 1998 SLD dataset.

$$\tau(B^+) = 1.65 \pm 0.03 \text{ ps}$$
$$\tau(B^0) = 1.56 \pm 0.03 \text{ ps}$$
$$\tau(B^+)/\tau(B^0) = 1.07 \pm 0.02$$

Although with a limited statistical power, the world average for $\tau(B^+)/\tau(B^0)$ is beginning to show evidence for being different from unity, as expected from the theoretical prediction (figure 1).

3. B_s^0 lifetime

Several techniques have been used to measure the B_s^0 lifetime. In principle the best approach would be to use exclusive channels ($J/\psi\phi$), but at the moment it is statistically limited (section 3.3). The best measurements have been determined using the semileptonic channel $D_s^- l^+$, where the D_s^- can be fully or partially reconstructed. These measurements have been performed by LEP experiments as well as by CDF (section 3.1). There are more inclusive approaches, which use $D_s^- +$ hadrons, inclusive D_s^- and $\phi - l^-$ correlations (section 3.2). These approaches have been used only at LEP because they need a clean event topology and good particle identification.

3.1 Measurements from $D_s l$ correlations

CDF: The CDF Collaboration has used partially reconstructed semileptonic decays $B_s^0 \to D_s^- l^+ \nu$,

with the lepton being either an electron or a muon [14]. The D_s^- candidates are reconstructed in four modes:

- $D_s^- \to \phi\pi^-$, $\phi \to K^+K^-$

- $D_s^- \to K^{*0}K^-$, $K^{*0} \to K^+\pi^-$

- $D_s^- \to K_s^0 K^-$, $K_s^0 \to \pi^+\pi^-$

- $D_s^- \to \phi\mu^-\overline{\nu}$, $\phi \to K^+K^-$

For the first three decay modes the reconstruction is based on a single lepton trigger data set with a principal lepton p_t threshold of about 8 GeV/c, while the semileptonic D_s^- decay mode is based on a dimuon data sample selected with a muon p_t threshold of about 2 GeV/c and with the requirement $m(\mu\mu) < 2.8$ GeV/c^2.

Signal events are events with a $D_s^- l^+$ invariant mass between 3 and 5 GeV/c^2. About 600 signal events have been found, which is the largest sample of semileptonic B_s^0 from a single experiment. Mass plots for the four decay channels are shown in Fig 7. Control samples for the combinatorial background are obtained from the D_s^- mass sidebands and from wrong sign D_s^--lepton combinations. A source of background is due to $D_d^- \to K^{*0}\pi^-$ and $D_d^- \to K_s^0\pi^-$ events which can be reconstructed as D_s^- decays to $K^{*0}K^-$ and $K_s^0 K^-$. This is caused by the poor CDF particle identification. Due to low signal statistics, no attempt at reducing this background is performed. Instead, the estimated fraction of D_d^- events in the signal samples has been introduced as a parameter of the final lifetime fit. This fraction is estimated using the large mass difference between D_d^- and D_s^- and the shape of reflections in the mass distributions. Intersecting the D_s^- and the lepton trajectories in the transverse plane, the B_s^0 decay length is determined with a resolution of the about 100 μm. The correction for the missing transverse momentum of the neutrino is applied event by event to obtain the proper decay time. The combined result of the four modes is

$$\tau(B_s^0) = 1.36 \pm 0.09 \pm 0.05 \text{ ps}$$

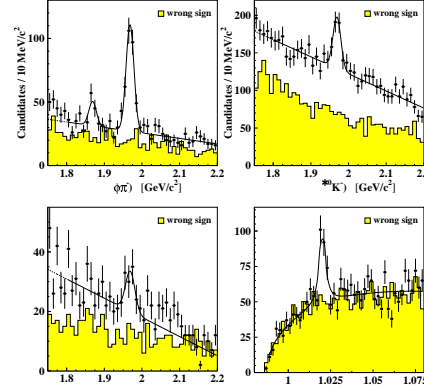which is the currently the most precise measurement from a single experiment.

Figure 7: D_s^- invariant mass for the $B_s^0 \to D_s^- l^+ \nu$ events reconstructed by CDF. Shaded histograms are the wrong sign $D_s^- l$ combinations which are used together with the D_s^- mass sidebands to determine the background shape in the lifetime fit. For the $D_s^- \to \phi\mu^-\nu$ channel the masses of the ϕ candidates are shown: in this case wrong sign combinations are $\mu^\pm\mu^\pm$ and $K^\pm K^\pm$ and the shaded histogram normalisation is rescaled to have the same number of signal and background events in the mass sidebands.

ALEPH: The ALEPH Collaboration has used the 1991-1995 data (four million Z^0 decays) to reconstruct $D_s^- l^+$ candidates (with the leptons being electrons as well as muons) in seven decay modes: $\phi\pi^-$, $K^{*0}K^-$, $K_s^0 K^-$, $\phi\pi^+\pi^-\pi^-$, $K^{*0}K^{*-}$, $\phi e^-\overline{\nu}$ and $\phi\mu^-\overline{\nu}$, where $\phi \to K^+K^-$, $K^{*0} \to K^+\phi^-$ and $K_s^0 \to \pi^+\pi^-$. 277 signal events have been found with a signal purity larger than 60 %. The measured B_s^0 lifetime is [15]:

$$\tau(B_s^0) = 1.54^{+0.14}_{-0.13} \pm 0.04 \text{ ps}$$

DELPHI: The DELPHI Collaboration has used the 1991 - 1995 data to perform this lifetime measurement. 230 $D_s^- l^+$ candidates have been reconstructed in eight decay modes: $\phi\pi^-$, $K^{*0}K^-$, $K_s^0 K^-$, $\phi\pi^+\pi^-\pi^-$, $\phi\pi^-\pi^0$, $K^{*0}K^{*-}$, $\phi e^-\overline{\nu}$ and $\phi\mu^-\overline{\nu}$. The measurement gives [16]:

$$\tau(B_s^0) = 1.42^{+0.14}_{-0.13} \pm 0.03 \text{ ps}$$

OPAL: The OPAL Collaboration has used the 1990 - 1995 for this analysis. $D_s^- l^+$ combinations are reconstructed in five decay modes: $\phi\pi^-$, $K^{*0}K^-$, $K_s^0 K^-$, $\phi e^-\overline{\nu}$ and $\phi\mu^-\overline{\nu}$. The total

number of signal events is estimated to be 172. The resulting B_s^0 lifetime measurement is [17]:

$$\tau(B_s^0) = 1.50^{+0.16}_{-0.15} \pm 0.04 \text{ ps}$$

3.2 Measurements from D_s-hadron(s) correlations

ALEPH: One or more tracks (excluding leptons) are combined with D_s^- candidates reconstructed in five channels: $\phi\pi^-$, $K^{*0}K^-$, $K_s^0K^-$, $\phi e^- \overline{\nu}$ and $\phi\mu^- \overline{\nu}$. This analysis uses also the semileptonic channel $D_s^- l^+$ with the D_s^- reconstructed in the mode $\phi\rho^-$, $\phi \to K^+K^-$, $\rho^- \to \pi^-\pi^0$, $\pi^0 \to \gamma\gamma$. The number of signal candidates (1620) is larger than in the $D_s^- l^+$ analysis, but the signal purity (22 %) is lower. The measured B_s^0 lifetime is [18]:

$$\tau(B_s^0) = 1.47 \pm 0.14 \pm 0.08 \text{ ps}$$

DELPHI: This analysis uses events with a fully reconstructed D_s^- accompanied by a charged hadron. The D_s^- are reconstructed in the two channels $D_s^- \to \phi\pi^-$ and $D_s^- \to K^{*0}K^-$. The measured B_s^0 lifetime is [16]:

$$\tau(B_s^0) = 1.49^{+0.16}_{-0.15} {}^{+0.07}_{-0.08} \text{ ps}$$

In this paper we do not have space to report on some less effective techniques which use inclusive D_s^- reconstruction (OPAL [7] and DELPHI [8]) and ϕl correlations (DELPHI [8]).

3.3 Measurement in exclusive channels

CDF has performed a B_s^0 lifetime measurement using 58 fully reconstructed $B_s^0 \to J/\psi\phi$ events [9]. Due to the limited statistics, the lifetime fit and the invariant mass fit are simultaneously performed in order to have the number of signal events better constrained. The measured value is:

$$\tau(B_s^0) = 1.34^{+0.23}_{-0.19} \pm 0.05 \text{ ps}$$

From all the available measurements the following world average is determined:

$$\tau(B_s^0) = 1.46 \pm 0.06 \text{ ps}$$

4. B_c discovery and lifetime

The CDF Collaboration has recently reported on the discovery of the B_c meson partially reconstructed in the $B_c \to J\psi l X$ ($l = e$ or μ) decay channel [19]. The measured lifetime is:

$$\tau(B_c) = 0.46^{+0.18}_{-0.16} \pm 0.03 \text{ ps}$$

5. Λ_b^0 lifetime

The Λ_b^0 baryon lifetime has been measured by CDF as well as by the ALEPH, DELPHI and OPAL experiments at LEP.

CDF: The Λ_b^0 is partially reconstructed using the semileptonic decay $\Lambda_b^0 \to \Lambda_c^+ l^- \overline{\nu}$, where the Λ_c^+ is reconstructed through its decay $\Lambda_c^+ \to p K^- \pi^+$ [20]. In figure 8 the mass plot for the Λ_b^0 candidates is shown. The estimated number of signal events is 197 ± 25. The fit to the pseudo-proper decay length (figure 9), where the background shape is estimated from the $\Lambda_c^+ \to pK^-\pi^+$ sidebands, gives the following results:

$$\tau(\Lambda_b^0) = 1.32 \pm 0.15 \pm 0.07 \text{ ps}$$

ALEPH: The ALEPH Collaboration has used the 1991 - 1995 data to reconstruct 193 $\Lambda_b^0 \to \Lambda_c^+ l^- \overline{\nu}$ events, with the Λ_c^+ reconstructed in four decay channels, $\Lambda_c^+ \to pK^-\pi^+$, $\Lambda_c^+ \to p\overline{K}^0$, $\Lambda_c^+ \to \Lambda\pi^+\pi^+\pi^-$ and $\Lambda_c^+ \to \Lambda\pi^+$ [21]. The measured Λ_b^0 lifetime is:

$$\tau(\Lambda_b^0) = 1.18^{+0.13}_{-0.12} \pm 0.03 \text{ ps}$$

Both CDF and ALEPH results agree on a Λ_b^0 lifetime smaller than the theoretical prediction (figure 1).

6. Conclusions

We have reviewed the current status of b hadrons lifetime measurements obtained at electron - positron machines and at the Tevatron. Although the current level of precision is insufficient to make definitive statements, the world average for $\tau(B^+)/\tau(B^0)$ is beginning to indicate a significant difference from unity, which is in agreement with the theory, while the Λ_b^0 lifetime is found to be smaller than predicted.
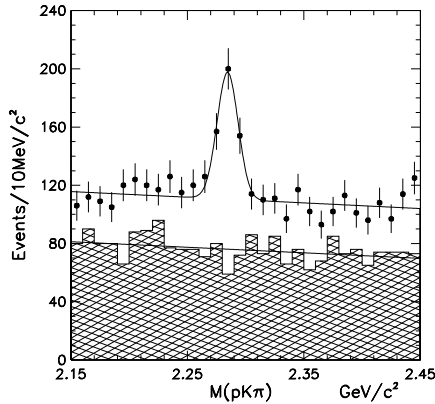
Figure 8: Invariant mass of Λ_c^+ candidates reconstructed by CDF for right (points with error bars) and wrong (shaded area) $\Lambda_c^+ l$ combinations. The fit yields 197 ± 25 right sign events. There is no evidence of a Λ_c^+ signal in wrong sign combinations. The signal region is defined to be 2.260 - 2.308 GeV/c^2 and the two sideband regions are 2.176 - 2.224 GeV/c^2 and 2.376 - 2.424 GeV/c^2.
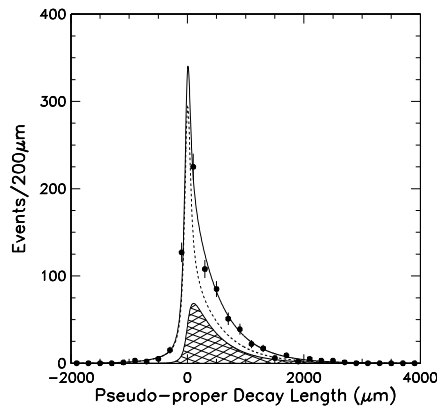

Figure 9: Pseudo-proper decay length distribution of the Λ_b^0 signal region events reconstructed by CDF. The points with error bars are data, the solid line is the fit result, the shaded area is the signal distribution and the shaded line is the background contribution.

References

[1] C. Caso et al. (Particle Data Group), *Eur. Phys. J.* **C3**, 1 (1998).

[2] M. B. Voloshin and M. A. Shifman, *Sov. Phys. JETP* **64** (1986) 698.

I. I. Bigi and N. G. Uraltsev, *Phys. Lett.* **B 280** (1992) 271.

I. I. Bigi, *Nuovo Cim.* **A109** (1996) 713.

[3] F. Abe et al., The CDF Collaboration, *Measurement of the B^- and $\overline{B}^0$ Meson Lifetimes using Semileptonic Decays Phys. Rev.* **D 58** (1998) 092002.

[4] G. Calderini, The ALEPH Collaboration *Measurement of the $\overline{B}^0$ and B^- Meson Lifetimes*, ALEPH 99-005, CONF 99-001.

[5] The DELPHI Collaboration, *A Measurement of the B^+ and B^0 Lifetimes using $\overline{D}l^+$ events*, Z. Physik **C 68** (1995) 13.

[6] The OPAL Collaboration, *A Measurement of the B^+ and B^0 lifetimes*, Z. Physik **C 67** (1995) 379.

[7] K. Ackerstaff, The OPAL Collaboration, CERN-PPE/97-095 (1997).

[8] P. Abreu et al. The DELPHI Collaboration, Z. Physik **C 71** (1996) 11.

[9] F. Abe et al., The CDF Collaboration, *Measurement of B Hadron Lifetimes Using J/ψ Final States at CDF*, Phys. Rev. **D 57** (1998) 5382.

[10] The OPAL Collaboration, *Measurement of the B^+ and B^0 Lifetimes and Search for CP(T) Violation using Reconstructed Secondary Vertices*, CERN-EP/98-195.

[11] The DELPHI Collaboration, *Lifetimes of Charged and Neutral B hadrons Using Event Topology*, Z. Physik **C 68** (1995) 363.

[12] M. Acciari et al., the L3 Collaboration, CERN-EP/98-127, Submitted to Phys. Lett. B.

[13] The SLD Collaboration, *Measurement of the B^+ and B^0 Lifetimes using Topological Vertexing at SLD*, SLAC-PUB-8206.

[14] F. Abe et al., The CDF Collaboration, *Measurement of the B_s^0 Meson Lifetime Using Semileptonic Decays*, Phys. Rev. **D 59** (1999) 032004.

[15] D. Buskulic et al., The ALEPH Collaboration, *Phys. Lett.* **B 377** (1996) 205.

[16] The DELPHI Collaboration, DELPHI 99-109 CONF 296.

[17] K. Ackerstaff et al., The OPAL Collaboration, CERN-PPE/97-159 (1997).

[18] D. Buskulic et al., The ALEPH Collaboration, CERN-PPE/97-157 (1997).

[19] F. Abe et al., The CDF Collaboration, *Observation of B_c Mesons in $p\bar{p}$ Collisions at $\sqrt{1.8}$ TeV*, *Phys. Rev.* **D 58** (1998) 112004.

[20] F. Abe et al., The CDF Collaboration, Λ_b^0 *Lifetime from $\Lambda_c^+ l^- \bar{\nu} X$ decays, Phys. Rev. Lett.* **77** (1996) 1439.

[21] The ALEPH Collaboration, *Measurement of the b baryon lifetime and branching fractions in Z decays*, CERN-PPE/97-111.