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Averaging Lifetimes for B Hadron Species at LEP

LEP B Lifetimes Working Group

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Abstract

The measurement of the lifetimes of the individual B species are currently among the most interesting physics results. Many of these measurements are approaching the 5–10% level of precision. However, in order to reach the precision necessary to test the current theoretical predictions, the results from different experiments need to be averaged together. Therefore, the relevant systematic uncertainties of each measurement need to be well defined in order to understand the correlations between the results from different experiments.

In this paper we summarize the activity of a LEP working group on B lifetimes which has been organized in order to coordinate the effort among the different experiments and obtain more reliable lifetime averages. Furthermore, we discuss the dominant sources of systematic errors which lead to correlations between the different measurements and we propose a common method for presenting the results. Finally, we present the current results from this group concerning the averaging of the measurements from LEP.

1 Introduction

LEP offers excellent opportunities to measure individual B hadron lifetimes. These measurements are currently among the most interesting physics results since, after the success of the spectator model in explaining the order of magnitude of the average lifetime of B hadrons, they should allow us to test corrections to this model provided by the Heavy Quark Effective Theory.

The LEP experiments have measured the average B hadron lifetime to a precision of $\approx 2\%$. They have also provided the first measurements of B_s^0 and Λ_b lifetime.

The precision on individual B hadron lifetimes continues to improve with the increasing size of the available data samples and the improved understanding of the systematic uncertainties. Nevertheless the precision required on individual B hadron lifetimes ($< 5\%$) to test the theory can only be reached by combining the results of different experiments. The task of averaging these measurements plays an important role since the resulting averages can differ from each other by an amount comparable to the required precision, depending on the way the statistical error is treated and on the assumptions made concerning the correlated systematic uncertainties. Moreover, the task of averaging these results is complicated by the fact that different experiments use different assumptions concerning these systematics.

In this paper, we propose a way to simplify this task. One of the main problems in trying to determine correlations among the different measurements concerns how different experiments treat identical systematics. Therefore in the sections that follow we propose procedures for handling several of the important sources of common systematic error amongst experiments.

2 Backgrounds

An important source of correlated uncertainties between measurements arises from the imprecise knowledge of the amount and of the lifetime of background particles in the data sample. For instance in the measurement of the average B hadron lifetime the main source of background is due to charmed particles which have lifetimes of the same order of magnitude of B hadrons [1]. The average B lifetime is computed assuming measured branching ratios and charmed hadron lifetimes; systematic uncertainties are evaluated by varying these quantities within the experimental errors. This procedure introduces a correlation among the results from different measurements.

In other analyses the amount and/or the lifetime of the background particles is either extracted at the same time as the lifetime of the signal or measured directly in an independent way. In this case the related systematic uncertainty is due to the limited statistics of the data sample used and is not correlated between experiments.

B hadrons of a different species from the one being measured constitute another source of background. An example of this case is represented by the measurements of B^0 and $B^\pm$ lifetimes based on semileptonic B decays [2, 3, 4]. In this case, the B^0 is a background for the $B^\pm$ and the $B^\pm$ a background for the B^0.

In the following subsections we discuss the sources of backgrounds, their lifetimes and branching ratios in B hadron lifetime measurements.

2.1 Backgrounds in B^0 and $B^\pm$ lifetime measurements

In measurements of the B^+ and B^0 lifetimes based on semileptonic decays, events containing D^0 or $D^{(*)+}$ mesons with an associated lepton of high p_t [2, 3, 4] are selected. The relative contributions of charged and neutral B mesons to the $D^{(*)}l$ samples must be evaluated in order to extract their lifetimes separately. These contributions depend on the following physics parameters :

- D^{**}, D^*, D^0 relative production rates in B semileptonic decays, [1]
- branching ratios $D^{**} \to D^{(*)}\pi$,

All the analyses assume equal production rates of B^0 and B^+ mesons in Z decays and use isospin rules to determine the relative fraction of the decays yielding charged and neutral $D^{(*)}$. Nevertheless different sets of input parameters are used for the B and D branching ratios.

In the ALEPH [2] and DELPHI [3] analyses the same procedure to estimate the D^{**} production rate in B semileptonic decays is followed. This quantity is computed as the difference between the inclusive branching ratio $B^0 \to l\nu X$ and the sum of the exclusive branching ratios $(B^0 \to D^* l\nu) + (B^0 \to D l\nu)$ (all measured at $\Upsilon(4S)$) but different values are used for the input quantities. In the OPAL analysis [4] the CLEO measurement [5] of the fraction of B semileptonic decays producing D^{**} (f^{**}=0.36 $\pm$ 0.12) is used.

Another possible choice could be to take the branching ratio $B \to D^{**} l\nu$ reported by the Particle Data Group [1] which is based on a single measurement made by ARGUS. This result corresponds to D^{**} resonant states and has not been updated to the most recent values of the branching ratios $D^0 \to K\pi$ and $D^0 \to K3\pi$.

We suggest that the ALEPH and DELPHI procedure be followed taking the relevant B^0 branching ratio from the most recent *Review of Particles Properties* [1] (see Table 1) since this procedure also takes into account decays with non resonant π production and has the advantage of being based on the average of

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[1] We use the symbol D^{**} to represent, in addition to the P-wave states, possible non-resonant decays of the type $B \to \bar{D}(n\pi)l^+X$ and higher spin states

several measurements. The resulting D^{**} production rate in B^0 semileptonic decay is 3.2±1.7 % which corresponds to $f^{**} = 0.34 \pm 0.13$. The corresponding B^- branching ratio can be obtained from

$$BR(B^- \to l^- X) = \frac{\tau_-}{\tau_0}\, BR(B^0 \to l^- X')$$

which is derived from the expectation that the partial semileptonic decay widths of charged and neutral B hadrons are equal.

Another effect which contributes to the systematic uncertainty comes from the fact that the decays of D^{**} states may result in both pseudoscalar and vector charmed mesons. The relative importance of these decays determines the composition of $D^{(*)}l$ samples. These uncertainties are often parameterized in terms of

$$p_v = \frac{BR(D^{**} \to D^* X)}{BR(D^{**} \to D^* X) + BR(D^{**} \to DX)}$$

This quantity is poorly known and has often been estimated using theoretical assumptions.

We suggest using the recent measurement of the branching ratio $B^- \to D^{*+}\pi^- l^- \nu$ [6] to get an estimate based on experimental quantities. The fraction of D^{**} decaying into D^* can be therefore expressed in the following way:

$$p_v = \frac{BR(B^- \to D^{**0} l\nu)(BR(D^{**0} \to D^{*+}\pi^-) + BR(D^{**0} \to D^{*0}\pi^0))}{BR(B^- \to D^{**0} l\nu) BR(D^{**0} \to D or D^{(*)} X)}$$

The first term in the numerator is the measured branching ratio $B^- \to D^{*+}\pi^- l^- \nu$, the second term is obtained assuming that $D^{(*)}\pi$ states are produced with a fixed value of isospin and using isospin conservation. The denominator is the D^{**} production rate in B^0 semileptonic decays described previously. Assuming that the lifetimes of B^0 and of B^+ particles are equal this procedure gives $p_v = 0.45 \pm 0.28$.

Background contamination in the $D^{(*)}l$ sample is mainly of combinatorial nature. Decays like $B \to D_s^{(*)+} D^{(*)}$ $(D_s^{(*)+} \to l^+ X)$ or $D^{(*)}\tau\nu X$ $(\tau \to l\nu\nu)$ give smaller contributions which are estimated according to measured branching ratios. The proposed set of input parameters is shown in Table 1.

2.2 Backgrounds in B_s^0 lifetime measurements

All LEP experiments have measured the lifetime of B_s^0 mesons, $\tau_{B_s^0}$, using samples of events in which a $D_s^{\pm}$ meson is accompanied by a high p_t lepton [7, 8, 9]. The background consists of a combinatorial part and a "physics" part due to decays of non strange B hadrons that lead to final states containing $KK\pi l$. The main source of such physics background are the decays $B_{u,d} \to D_s^+ \bar{D} X$ $(\bar{D} \to l^- \nu X)$ and $B_{u,d} \to D_s^- K l^+ \nu X$. The branching ratios of the first process can be estimated from measured quantities (see Table 1), while the second decay has not been observed. A theoretical analysis yields [18] the limit $B_{u,d} \to$

$D_s^- K l^+ \nu X < 0.025 \times BR(B_d \rightarrow X l \nu)$ which we suggest taking as a conservative estimate.

More inclusive methods have been also used to measure $\tau_{B_s^0}$. In the ALEPH analysis [10], $D_s^\pm$ particles are correlated with a high p_t hadron of opposite sign. In the DELPHI analysis [8], events with $D_s^\pm$ particles are used. These methods select samples of events with larger physics backgrounds since $D_s^\pm$ particles can be produced not only in the decays of non-strange B hadrons, but also in $c\bar{c}$ fragmentation.

To account for the first kind of background, the fraction of $D_s^\pm$ from B_s^0 decays ($f_b^s \times BR(B_s^0 \rightarrow D_s X)$) is given in Table 1. This is estimated by combining the ALEPH [10], DELPHI [11], and OPAL [12] measurements. The ALEPH result [10] refers only to decays not going via W^-, therefore before combining with the other measurements we added the contribution of the decays proceeding via W^- with the assumption that they are similar to the corresponding B^+ and B^0 contributions measured at $\Upsilon(4S)$. The DELPHI [11] and OPAL [12] results have been obtained by measuring the branching ratio $b \rightarrow D_s X$ and comparing it with the same quantity measured at $\Upsilon(4S)$ where no B_s^0 mesons are produced (they interpret the excess of D_s as being entirely due to B_s^0) . Therefore their measurements have been updated to the most recent result obtained at $\Upsilon(4S)$ [13].

The background from $c\bar{c}$ events can be estimated using the measured probability that a c quark fragments into a $D_s^\pm$ (f_c^s, see Table 1) and the Z partial width into c quarks, $\Gamma_{c\bar{c}}$.

The lifetimes of the background particles can be taken as the average B hadron lifetime for particles from $b\bar{b}$ decays and as the $D_s^\pm$ lifetimes for particles from $c\bar{c}$ decays.

In computing the average of different measurements a difficulty can arise when experiments measure simultaneously the lifetime of a given B species and a correlated parameter. In this case the B lifetimes measured by the experiments correspond to different values of the correlated parameter and should be scaled to the same parameter value before combining. If the measurements of the correlated parameter obtained by the different experiments are consistent, the combined lifetime results with and without scaling should agree. Nevertheless we suggest for the purpose of getting a consistent combined average to specify the dependence of the measured lifetime on the parameter such that the measured lifetime can be easily scaled to a different parameter value.

2.3 Backgrounds in B baryon lifetime measurements

B baryon decays can be isolated by selecting events containing Λ_c particles and a lepton of opposite sign emitted at large transverse momentum in the same jet [14, 16].

A more inclusive approach consists of using samples of baryons, Λ or protons, accompanied by a "right sign" lepton in the same jet [15, 16, 17].

Physics background processes, such as B meson decay ($\bar{B} \to \Lambda_c^+ l^- \nu X$) are suppressed by requiring a high lepton transverse momentum with respect to jet axis. The main background results from accidental combinations of real or fake Λ (Λ_c) associated with real or fake leptons.

In all the cases (except in the method based on $p\mu$ correlations) the fraction of signal relative to the background is determined from the data as the ratio between right and wrong sign events. The background events have two components: one consisting of events with fake vertices (which therefore have a lifetime distribution corresponding to the detector resolution) and another consisting of events with secondary vertices originating from charm and B meson decays which have a lifetime distribution. In the analyses based on decay length, the amount and/or the lifetime of the background combinations (with or without lifetime) are extracted at the same time as the lifetime of the signal. Therefore the related systematic uncertainties are not correlated among measurements.

3 B momentum estimation

Almost all exclusive B lifetime measurements are based on the reconstruction of B decay lengths. In some analyses these decay lengths are converted into proper times event by event, while in other analyses a statistical approach is used. In both cases the relativistic boost of the B hadron needs to be estimated.

In most of the analyses the B particles are only partially reconstructed and their energies are estimated from the energies of the detected decay products. The estimator often includes scale factors or corrections obtained from Monte Carlo simulations. No matter what estimator is used, however, systematic errors must be evaluated for the following effects (and perhaps others as well):

- Uncertainties in the b fragmentation function
- Uncertainties in P-wave D production in B decays
- Uncertainties in branching ratios of B and C hadrons
- Uncertainties in B hadron masses
- Uncertainties in B baryon polarization
- Uncertainties in modelling neutral hadronic energy
- Uncertainties in detector momentum and energy resolution

Not all of the items are relevant to each analysis; however, all are potential sources of correlation between different measurements, and the extent of the correlation can only be determined if each experiment quotes a systematic error for each of these effects. A set of suggested input values and ranges of uncertainty for these parameters are given in Table 1, 2 and 3.

3.1 b fragmentation function

The mean energy fraction of B and C hadrons in Z decays has been measured and used in numerous heavy flavor analyses [19]. The values used in lifetime analyses should be the same as those used in electroweak heavy flavor analyses. Care should be taken that the fragmentation function might be different for different B species (especially Λ_b and B_s^0).

3.2 P-wave D mesons in semileptonic B decay

This item has been discussed in subsection 2.1.

3.3 Uncertainties in branching ratios of B and C hadrons

The branching ratio uncertainties of importance in the B energy estimate tend to be those describing the production of additional particles in partially reconstructed modes, e.g., additional pions produced in decays of the type $B \to D^{(*)}\ell\nu X$. Where specific final states have been measured and are quoted in the latest review of particle properties one should use the PDG numbers [1] directly.

3.4 B baryon polarization

The b quark polarization in $Z \to b\bar{b}$ decays is expected to survive (at least partially) the hadronization phase. The momentum spectrum of the leptons from B baryon decays depends on the amount of polarization of the decaying particle.

All current LEP measurements of the lifetimes of B baryons are based on semileptonic decays and the B baryon momentum is estimated from the observed decay products. Therefore a systematic uncertainty in the estimated momentum arises from imprecise knowledge of the B baryon polarization. The sensitivity to polarization will be different for different momentum estimators. The averaging of results can still be done, however, if each experiment quotes the uncertainty due to the same range of variation of the polarization and quotes the lifetime result for the same value of polarization, or alternatively gives the functional dependence of the lifetime on the polarization.

In absence of an experimental result (which would be the preferred value to use) we suggest that the B baryon polarization be taken as -0.47 ± 0.47, which is the central value of the allowed range.

3.5 *B* baryon mass

The uncertainties on the B hadron masses also affect the B momentum estimation. This effect is important mainly for B baryons since the Λ_b mass has the largest (±50 MeV) uncertainty among the observed B hadron states and since some of the selected events may come from other B baryons, e. g. Ξ_b, which are expected to have masses about 0.2-0.3 Gev/c^2 greater.

Considering that $\sim$ 0.7 of the signal in the data sample used for lifetime determination is expected to be Λ_b, we suggest a variation of the B baryon mass of ± 100 MeV for the evaluation of the systematic error.

3.6 Detector resolution and neutral hadronic energy

The uncertainties in charged momentum resolution are almost certainly independent between experiments. However, uncertainties due to neutral energy modelling (in, e.g., GEANT) and uncertainties due to decay topologies with overlapping particles which cannot be measured separately may be correlated. It would be helpful if variations in the models used in evaluating the uncertainty in detector response to hadronic showers could be standardized.

4 Experimental Correlated Uncertainties

There may be several measurements of the same quantity done by the same experiment using different techniques. DELPHI is an ideal example of this, usually exploiting several techniques in order to obtain their best possible result. In this case, systematic uncertainties normally treated as being uncorrelated with measurements from other experiments will be correlated among the measurements of the same experiment. Sources of uncertainties of this kind are due to primary and secondary vertex reconstruction procedures, detector resolution, tracking errors, B flight direction reconstruction, detector alignment uncertainties and will be discussed in the following subsections.

To make the task of averaging easier and more reliable experiments should quote the amount of statistical correlation between their measurements of the same quantities performed using different techniques. They should also quote which systematics are correlated and the size of these correlations.

4.1 Primary vertex reconstruction

Some information on the primary vertex is already given by the known size of the beam overlap region. However the position of the interaction region may change during a fill (because of orbit corrections), which makes it necessary to monitor it. The precision with which this can be done depends of course on the performance of the tracking detectors.

Because of the rather complex algorithms used to reconstruct the primary vertex the errors can be regarded as uncorrelated amongst the LEP experiments. However they should be completely correlated for different measurements done at the same experiment.

4.2 Secondary vertex reconstruction and tracking resolution

The secondary vertex reconstruction error depends on the resolution of the tracking device. Furthermore there are contributions due to multiple scattering, pattern recognition errors, and alignment. In complex topological vertex searches (e.g. looking inclusively for displaced vertices), systematic errors of the algorithm used have to be added.

A good measure of the tracking performance is the impact parameter resolution, which can be measured using *uds* events or the tails with "negative" lifetime of the impact parameter distribution (which then also includes errors of the primary vertex reconstruction). For impact parameter analyses this is sufficient. Sometimes Monte Carlo corrections or scale factors are applied to the measured "resolution function".

For secondary vertex reconstruction the resolution is often obtained using simulated events. Corrections which take into account deficiencies of the Monte Carlo are applied.

The resolution can be treated as uncorrelated for different experiments and as fully correlated for measurements at the same detector, except if the resolution is dominated by errors due to the reconstruction algorithm specific to a certain analysis.

4.3 Flight direction

The reconstruction of the flight direction is important for most of the vertexing algorithms. It is crucial for the sign of the impact parameter and for all projective vertex measurements using $r - \phi$ information only. In addition some methods for calculating the total decay length combining primary and secondary vertices (most likely decay length) and certain topological vertex algorithms depend on the knowledge of the B flight direction.

As the B hadron is normally only partially reconstructed, the B flight direction must be approximated. Most of the analyses use the jet axis, while some use the direction of reconstructed secondaries as the estimate of the B direction. This implies systematic uncertainties, which are deduced from Monte Carlo. Jet axis reconstruction depends also on the algorithm and what information is used (charged tracks with/without calorimeter information). Systematic effects can arise from uncertainties in b fragmentation and B decay.

It is very difficult to estimate how much these errors are correlated between different experiments. Correlations are probably small as the algorithms used are often different. In any case it would be very useful if papers explained:

- which quantity has been used for the B-direction measurement
- how the errors propagate to the lifetime
- which jet algorithm was used (if any)
- which decay model was used in case where the B-direction is estimated from secondaries.

5 The averaging procedure

A variety of methods have previously been used to average lifetime measurements from different experiments. The naive approach is simply to weight the measurements according to their error, thus for a measurement $\tau_i \pm \sigma_i$ the weight is taken as $1/\sigma_i^2$. Lifetime measurements however have an underlying exponential distribution, so $\sigma_i \propto \tau_i$. Therefore if a measurement fluctuates low then its weight in the average will increase, leading to a bias towards low values. An alternative method, to avoid this bias, is to calculate the weight using the *relative* error σ_i/τ_i [21]. That this is not just an academic question can be illustrated using the world averages quoted for the B_s^0 at the Winter Conferences 1994:

$$\begin{aligned} \tau(B_s^0) &= (1.38 \pm 0.17)\,\mathrm{ps} \quad \text{(la Thuile [22])}\ , \\ \tau(B_s^0) &= (1.66 \pm 0.22)\,\mathrm{ps} \quad \text{(Moriond [23])}\ , \end{aligned} \tag{1}$$

even though both averages were performed using essentially the same data! In the first case the absolute error was used in the weight, whilst in the second case the relative error was used.

This issue can be clarified using a simple Monte Carlo. A sample of N events is generated according to an exponential distribution (with $\tau = 1$), smeared by a Gaussian resolution function (with r.m.s width w). The mean τ_i and variance σ_i^2 of the events is then calculated, simulating a single lifetime measurement. This is then repeated for many samples, and their weighted mean calculated (see Figure 1). Weighting with the absolute error, as shown in Figure 1 (a), a bias to low values is seen, as expected. For perfect resolution ($w = 0$) the bias is about 10 % when the sample size is 20 events, decreasing for higher sample sizes; the effect of finite resolution is to reduce the bias. If instead the samples are weighted according to their relative error, as shown in Figure 1 (b), then for perfect resolution there is no bias. However, as the resolution is degraded a bias appears towards *higher* values. For a resolution typical of the experiments

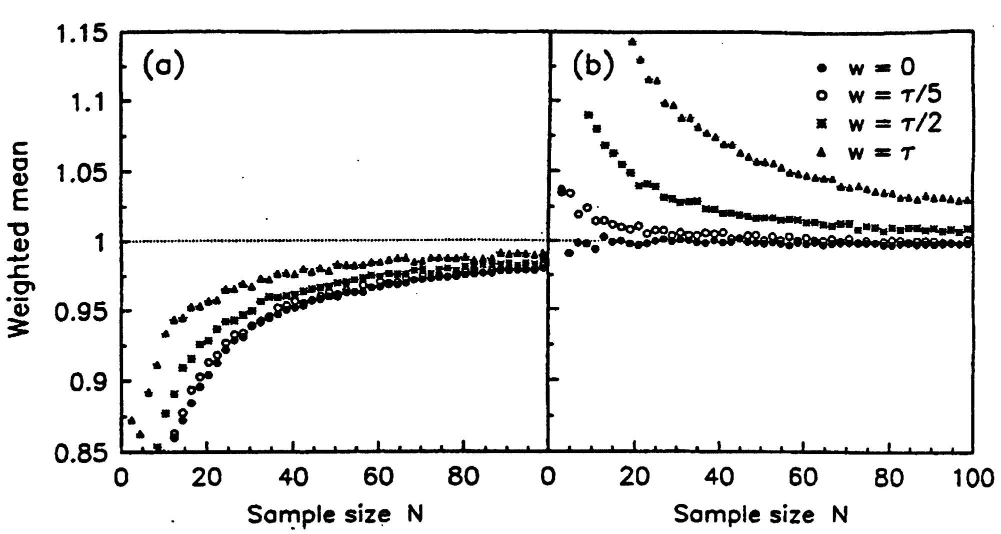

Figure 1: Weighted mean of many samples, each of N events: (a) weighting with the absolute error σ_i, (b) weighting with the relative error σ_i/τ_i.

measuring heavy flavour lifetimes with microvertex detectors, $w \lesssim \tau/10$, the bias is a few percent or less; nevertheless it seems worthwhile to try to avoid it.

In an ideal world each experiment would provide the log-likelihood function they calculated for their events, and these would be summed and then fitted for the combined lifetime. In practice this would be difficult to organize, and there is the additional question of how to include systematic errors. Instead, one could attempt to reconstruct the likelihood function of each experiment from the quoted asymmetric errors [24]. For an experiment with perfect resolution, with an underlying exponential distribution, the form of the likelihood function is maximally asymmetric and can be calculated:

$$\ln \mathcal{L}_{\mathrm{E}}(\tau) = -N\left(\frac{\tau_i}{\tau} + \ln \tau\right) . \tag{2}$$

In the limit of poor resolution the likelihood function is symmetric:

$$\ln \mathcal{L}_{\mathrm{G}}(\tau) = -\frac{1}{2}\left(\frac{\tau_i - \tau}{\sigma}\right)^2 . \tag{3}$$

The approximation is made that the likelihood function for a given experiment is a linear combination of these two forms:

$$\ln \mathcal{L} = a \ln \mathcal{L}_{\mathrm{E}} + b \ln \mathcal{L}_{\mathrm{G}} , \tag{4}$$

and the coefficients a and b are determined from the quoted errors, using (for a value $\tau\,{}^{+\sigma_1}_{-\sigma_2}$) $\ln \mathcal{L}(\tau + \sigma_1) = \ln \mathcal{L}(\tau - \sigma_2) = \ln \mathcal{L}(\tau) - \frac{1}{2}$. The functions $-\ln \mathcal{L}$ are then summed for all of the experiments, and a fit is made for the minimum of their sum, which gives the average.

The final complexity is the treatment of correlated systematic errors: a second parameter can then be added to the fit, to allow a common movement of the mean, with a Gaussian constraint applied according to the correlated error. The above technique has been implemented in the averaging program COMBY [25] and has been shown to work well on uncorrelated Monte Carlo data samples. One possible drawback of the present available version of the COMBY program is its ability to handle several different measurements which have different sets of correlated uncertainties between the various results. In this case, the best way to handle the correlations is to construct a covariance matrix and then to minimize the $\chi^2 = \Sigma_i \Sigma_j (\bar{\tau} - \tau_i)(\bar{\tau} - \tau_j) E^{-1}$, where E^{-1} is the inverse of the error matrix constructed assuming that the error on the measured lifetime is fractional, $\bar{\tau}$ is our best estimate and τ_i are the separate estimates derived from the data. This alternative technique is used by the averaging program COMBINE [26] and correctly treats correlations among the different measurements, however the uncertainties become symmetrized and do not allow for asymmetric errors on the final result. Also, this second technique does not properly handle the bias introduced due to detector resolution (as mentioned above).

For a situation close to the actual measurements which need to be combined (N > 30), Monte Carlo studies have shown that the results from two averaging methods developed in our group differ from the true input value of lifetime by about 1% (in the case of no correlated uncertainties). This difference should be attributed as a systematic uncertainty on the average arising from our knowledge of how to combine the results, but will typically be negligible compared with the overall error.

As example we report in Tables 4, 6 and 8 the combined results for the exclusive B hadron lifetimes obtained with the two methods described above. Most of the measurements presented are taken from the contributions to the ICHEP94 Conference. The list of the systematic errors assumed as correlated between the experiments and the amount of correlation used in the computation with the program COMBINE are given in Tables 5, 7 and 9.

6 Conclusions

In this note we have discussed the relevant sources of correlation among the B lifetime measurements and made some specific suggestions about the input quantities that should be used so that the task of making LEP average is more straightforward.

For this purpose we encourage that the determination of all systematic errors be explained fully in the description of the analyses, ensuring that all input parameters used are documented and that all individual contributions to the final error are separately specified.

Some of the values reported for the input quantities in Tables 1, 2 and 3 will change and hopefully improve with time. Therefore work will continue in order to keep these Tables updated.

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Table 1: Summary of quantities which contribute to the systematic uncertainties in the measurement of the lifetimes for the various B hadrons. Also listed are the “best ”currently available values for these quanties and their uncertainties. (Note: All values are taken from Phys.Rev.D50, Review of Particle Properties, 1 August 1994, unless otherwise stated.)

Source of Systematic Uncertainty	Mean Value ± Variation
BR$(B \to lX)_{LEP}$	11.0 ± 0.5 %
BR$(B \to lX)_{\Upsilon(4S)}$	10.43 ± 0.24 %
BR$(B^0 \to l\nu X)$	9.5 ± 1.6 %
BR$(B \to D^- l^+ \nu X)$	2.7 ± 0.8 %
BR$(B \to \bar{D}^0 l^+ \nu X)$	7.0 ± 1.4 %
BR$(B^0 \to D^- l^+ \nu)$	1.9 ± 0.5 %
BR$(B^+ \to \bar{D}^0 l^+ \nu)$	1.6 ± 0.7 %
BR$(B \to D^* l \nu X)$	7.0 ± 2.3 %
BR$(\bar{B}^0 \to D^{*+} l^- \nu)$	4.4 ± 0.4 %
BR$(B \to D^{**} l^+ \nu)$	2.7 ± 0.7 %
BR$(B^- \to D^{*+} \pi^- l^- \nu)$	0.97 ± 0.33 % [6]
BR$(B_{u,d} \to D^{(*)} D_s^{(*)})$	5.0 ± 0.9 %
BR$(B \to D_s^{\pm} l^{\mp} X_{(s)\nu})$	$< 0.025 * BR(B_d \to X l \nu)$[18]
BR$(b \to D_s^{\pm}(\phi\pi)X)_{(LEP)}$	0.84 ± 0.15 %[11, 12]
BR$(b \to D_s^{\pm}(\phi\pi)_{\Upsilon(4S)}$	$(10.46 \pm 0.71)\% \times (3.5 \pm 0.4)\%$ [13]
$f^b_{B^0_s} \times BR(B^0_s \to D_s^{\pm}(\phi\pi)X)$	$(4.6 \pm 1.0) \times 10^{-3}$ [11, 10, 12]
$f^b_{B^+}$	0.40 ± 0.04 [33]
$f^b_{B^0}$	0.40 ± 0.04 [33]
$f^b_{B^0_s}$	0.12 ± 0.04 [33]
$f^b_{Bbaryons}$	0.08 ± 0.04 [33]
f^c_s	0.125 ± 0.036[10]

Table 2: Summary of quantities which contribute to the systematic uncertainties in the measurement of the lifetimes for the various B hadrons. Also listed are the "best "currently available values for these quanties and their uncertainties. (Note: All values are taken from Phys.Rev.D50, Review of Particle Properties, 1 August 1994, unless otherwise stated.)

Source of Systematic Uncertainty	Mean Value ± Variation
BR($b \to c \to l^+$)	7.9 ± 1.6 % [19]
BR($b \to \bar{c} \to l^-$)	1.3 ± 0.5 % [19]
BR($B \to D^- X)_{\Upsilon(4S)}$	26 ± 4 %
BR($B \to \bar{D}^0 X)_{\Upsilon(4S)}$	54 ± 6 %
BR($B \to D^{*-} X)_{\Upsilon(4S)}$	23 ± 4 %
BR($b \to \Lambda_c(pk^-\pi^+)X)_{LEP}$	48 ± 13 % [31]
BR($c \to lX$)	9.8 ± 0.5 % [19]
BR($D^\pm \to e^+X$)	17.2 ± 1.9 %
BR($D^0 \to e^+X$)	7.7 ± 1.2 %
BR($D^0 \to \mu^+X$)	10.0 ± 2.6 %
BR($D_s \to lX$)	$\frac{BR(D^0 \to l^+X)\tau_{D_s}}{\tau_{D^0}}$
BR($b \to \tau \to l$)	0.7 ± 0.2 % [19]
BR($B \to \tau X$)	4.1 ± 1.0 %
BR($\tau \to eX$)	17.90 ± 0.17 %
BR($\tau \to \mu X$)	17.44 ± 0.23 %
BR($B \to J/\psi X$)	1.30 ± 0.17 %
BR($J/\psi \to e^+e^-$)	5.99 ± 0.25 %
BR($J/\psi \to \mu^+\mu^-$)	5.97 ± 0.25 %
BR($D^{*+} \to D^0\pi^+$)	68.1 ± 1.3 %
BR($D_s^\pm \to \phi\pi^\pm$)	3.5 ± 0.4 %
BR($D_s^\pm \to \overline{K}^{*0}K^\pm$)	3.3 ± 0.5 %
BR($D_s^\pm \to K^{*\pm}\overline{K}^0$)	4.2 ± 1.0 %
BR($\Lambda_c \to pk\pi$)	4.4 ± 0.6 %

Table 3: Summary of quantities which contribute to the systematic uncertainties in the measurement of the lifetimes for the various B hadrons. Also listed are the "best "currently available values for these quanties and their uncertainties. (Note: All values are taken from Phys.Rev.D50, Review of Particle Properties, 1 August 1994, unless otherwise stated.)

Source of Systematic Uncertainty	Mean Value ± Variation
M_{Λ_B}	5641 ± 50 MeV/c^2
Overall B baryon mass	5.7 ± 0.1 MeV/c^2
B baryon polarization	-0.47 ± 0.47
BR($\Lambda_c \to \Lambda X$)	$35 \pm 11\%$
BR($\Lambda_b \to \Lambda_c l \nu \pi$)/$\Lambda_b \to \Lambda_c l \nu$)	0.3 ± 0.3
Average τ_B	1.537 ± 0.021 ps
$\tau_{D^\pm}$	1.057 ± 0.015 ps
τ_{D^0}	0.415 ± 0.004 ps
$\tau_{D_s^\pm}$	0.467 ± 0.017 ps
τ_{Λ_c}	$0.200 + 0.0.011 - 0.010$ ps
τ_τ	0.2966 ± 0.0031 ps
$\Gamma(b\bar{b})/\Gamma(hadrons)$	0.2202 ± 0.0020 [20]
$\Gamma(c\bar{c})/\Gamma(hadrons)$	0.1583 ± 0.0098 [20]
Mean B energy fraction (x_b)	0.70 ± 0.02 [19]
Mean C hadron energy fraction (x_c)	0.51 ± 0.02 [19]
B decay multiplicity	5.72 ± 0.31 [32]
D decay multiplicity	2.39 ± 0.14 [19]

Table 4: Summary of B^0, $B^\pm$ lifetime measurements and of the ratio $\tau_{B^\pm}/\tau_{B^0}$. The fitted amount of correlation by the program COMBY (CORR) is also presented.

Experiment	Method	τ (ps)	Ref
B^0			
ALEPH	*Dl*	$1.71^{+0.12}_{-0.11} \pm 0.08$	[2]
ALEPH	excl.	$1.17^{+0.24}_{-0.19} \pm 0.05$	[29]
DELPHI	*Dl*	$1.17^{+0.29}_{-0.23} \pm 0.16$	[3]
DELPHI	top.	$1.68 \pm 0.15^{+0.11}_{-0.16}$	[30]
OPAL	*Dl*	$1.62^{+0.10}_{-0.10} \pm 0.10$	[4]
COMBINE RESULT		$1.630^{+0.087}_{-0.087}$	
COMBY RESULT		$1.616^{+0.096}_{-0.094}$ CORR=0.178	
$B^\pm$			
ALEPH	*Dl*	$1.71^{+0.15}_{-0.15} \pm 0.08$	[2]
ALEPH	excl.	$1.30^{+0.25}_{-0.20} \pm 0.06$	[29]
DELPHI	*Dl*	$1.30^{+0.33}_{-0.29} \pm 0.16$	[3]
DELPHI	top.	$1.72^{+0.08}_{-0.08} \pm 0.06$	[30]
OPAL	*Dl*	$1.53^{+0.14}_{-0.14} \pm 0.11$	[4]
COMBINE RESULT		$1.661^{+0.075}_{-0.075}$	
COMBY RESULT		$1.654^{+0.080}_{-0.080}$ CORR=0.394	
$\tau_{B^\pm}/\tau_{B^0}$			
ALEPH		$1.00^{+0.14}_{-0.13} \pm 0.08$	[2]
DELPHI	*Dl*	$1.11^{+0.51}_{-0.39} \pm 0.05 \pm 0.010$	[3]
DELPHI	top	$1.02^{+0.13}_{-0.10}$	[30]
OPAL	*Dl*	$0.94^{+0.12}_{-0.12} \pm 0.07$	[4]
COMBINE RESULT		$0.990^{+0.089}_{-0.089}$	
COMBY RESULT		$0.990^{+0.093}_{-0.087}$ CORR=0.026	

Table 5: Correlated systematic uncertainties and amount of correlation(ps) assumed in computing the average with the program COMBINE between B^0, $B^\pm$ lifetime measurements and the ratio of $\tau_{B^\pm}/\tau_{B^0}$.

Experiment	D^{**} Syst.	Background Size Sys	B Energy/Mom. Est. Sys
B^0			
ALEPH(Dl)	0.050 0.050	0.023 0.023	0.030 0.030
ALEPH(excl.)	—	0.036 0.034	—
DELPHI(Dl)	0.050 0.050	0.012 0.012	0.074 0.074
DELPHI(top.)	—	—	—
OPAL(Dl)	0.020 0.014	0.060 0.060	0.010 0.010
$B^\pm$			
ALEPH(Dl)	0.070 0.070	0.021 0.021	0.030 0.030
ALEPH(excl.)	—	0.044 0.030	—
DELPHI(Dl)	0.050 0.050	0.013 0.013	0.082 0.082
DELPHI(top.)	—	—	—
OPAL(Dl)	0.030 0.030	0.060 0.060	0.010 0.010
$\tau_{B^\pm}/\tau_{B^0}$			
ALEPH(Dl)	0.075 0.075	0.010 0.010	0.010 0.010
DELPHI(Dl)	0.100 0.100	0.011 0.011	—
DELPHI(top.)	—	—	—
OPAL(Dl)	0.032 0.022	0.040 0.040	—

Table 6: Summary of B_s^0 lifetime measurements. The fitted amount of correlation by the program COMBY (CORR) is also presented [27].

Experiment	Method	$\tau_{B_s^0}$ (ps)	Ref.
ALEPH	$D_s l$	$1.92^{+0.45}_{-0.35} \pm 0.04$	[7]
ALEPH	$D_s(h)$	$1.75^{+0.30+0.18}_{-0.28-0.23}$	[10]
DELPHI	$D_s l$	$1.32^{+0.41}_{-0.32} \pm 0.18$	[8]
DELPHI	D_s	$1.56^{+0.38}_{-0.32} \pm 0.23$	[8]
OPAL	$D_s l$	$1.33^{+0.26}_{-0.21} \pm 0.06$	[9]
Average COMBINE		1.55 ± 0.14	
Average COMBY		$1.53^{+0.14}_{-0.13}$ CORR=0.061	

Table 7: Correlated systematic uncertainties and amount of correlation (ps) assumed in computing the average with the program COMBINE between $\tau_{B^0_s}$ measurements.

Experiment	Background lifetime	Background fraction	Position resolution
ALEPH($D_s l$)	$^{+.03}_{-.04}$	0.02	0.02
ALEPH($D_s(h)$)	-	0.13	0.03
DELPHI($D_s l$)	-	-	-
DELPHI(D_s)	-	0.08	-
OPAL ($D_s l$)	0.02	0.01	-

Table 8: Summary of B baryon lifetime measurements [28].

Experiment	Method	τ_{Λ_b} (ps)	Ref.
ALEPH	Λl	$1.07^{+0.13}_{-0.12} \pm 0.10$	[15]
ALEPH	$\Lambda_c l$	$1.06^{+0.40}_{-0.27} \pm 0.07$	[14]
DELPHI	$\Lambda\mu\pi$	$1.09^{+0.29}_{-0.22} \pm 0.06$	[16]
DELPHI	$\Lambda_c l$	$1.31^{+0.70}_{-0.41} \pm 0.09$	[16]
DELPHI	$p\mu$	$1.27^{+0.35}_{-0.29} \pm 0.09$	[16]
OPAL	Λl	$1.26^{+0.16}_{-0.15} \pm 0.07$	[17]
Average COMBINE		1.17 ± 0.11	
Average COMBY		$1.17^{+0.11}_{-0.10}$	

Table 9: Correlated systematic uncertainties and amount of correlation (ps) assumed in computing the average with the program COMBINE between B baryon lifetime measurements.

Experiment	Resol.	Fragm.	Polariz.	B baryon mass	Decay model	Background	B baryon purity
ALEPH(Λl)	0.02	0.03	0.05	-	-	0.049	0.05
ALEPH($\Lambda_c l$)	0.013	0.01	0.004	0.02	0.032	0.051	-
DELPHI($\Lambda\mu\pi$)	-	0.01	0.01	0.02	0.03	-	0.045
DELPHI($\Lambda_c l$)	-	-	-	0.020	0.020	0.080	-
DELPHI($p\mu$)	-	-	0.015	-	-	-	-
OPAL(Λl)	-	0.001	0.047	0.013	0.024	0.034	-

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