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Liftetimes and masses of b-hadrons at LEP[1]

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Lifetimes and masses of b-hadrons at LEP [1]

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Abstract

Latest LEP results concerning hadrons containing b-quarks are reviewed. The average lifetime of the b-hadrons together with the lifetimes of the B_u^+, B_d^0, B_s and Λ_b and first mass measurements of the B_s and Λ_b are presented.

1 Introduction

According to the spectator model the lifetimes of b-hadrons should be equal. However, after taking into account non-spectator effects like the quark interference which causes the lifetime's difference between the B_u and B_d and the W-exchange pushing down the lifetime of the Λ_b, the following pattern of lifetime's ratios emerges [1]:

$\tau_{B_u^-}/\tau_{B_d^0} \cong 1.05 \qquad \tau_{B_s^0}/\tau_{B_d^0} \cong 1.00 \qquad \tau_{\Lambda_b^0}/\tau_{B_d^0} \cong 0.90.$

The masses of the B_s and Λ_b hadrons are predicted by the Heavy Quark Effective Theory [2] to be of $(5345 \div 5388)$ MeV/c^2 and $(5600 \div 5630)$ MeV/c^2, respectively.

From the experimental point of view testing this pattern of lifetime's ratios together with mass measurements is really a challenge. As the differences between lifetimes are so small it is necessary to measure them with the precision of a few percent. The measurement of masses requires the ability of the full reconstruction of at least some decays of the B_s and Λ_b. These goals may be achieved only while being provided with a substantial sample of b-hadrons and appropriate detectors offering a high-precision tracking together with discrimination between protons, kaons, pions and leptons.

The statistics of hadronic events collected by each LEP experiment is shown in the Table 1 together with the yields of individual b-hadrons and the expectation of total sample by the end of 1995 which mark the beginning of the LEP-II programme [3]. The results presented below have been obtained mainly with the data recorded between 1990 and 1992.

The typical decay length of the b-hadron at LEP is about 3 mm while the position of the interaction point is measured with the accuracy of about 30 μm (in the plane perpendicular to the beam axis). Therefore the reconstruction of b-hadron vertices is possible only with the help of the silicon vertex detectors providing very precise position's measurement close to the interaction region.

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Table 1: Statistics of hadronic events recorded by each LEP experiment together with estimation of the sample available by the end of the LEP programme in 1995.

Year	1990 – 92	1993	1995
total statistics	1 000 000	700 000	5 000 000
sample of B_u, B_d	352 000	246 000	1 760 000
sample of B_s	53 000	37 000	265 000
sample of Λ_b	35 000	25 000	175 000

2 Momentum estimation of the b-hadrons

The lifetime defined as $\tau_b = l_b/(\beta_b\gamma_b) = (m_b l_b)/p_b$ is extracted with the fit using the maximum likelihood technique. The decay length l_b is usually measured for partially or fully reconstructed vertices of b-hadrons. To recover the momentum p_b or boost $\beta_b\gamma_b$ of the b-hadron from the momenta of its know decay products (p_{rec}) several methods common to most measurements described below have been developed. First the momentum of the b-hadron is estimated by convoluting the measured momentum p_{rec} with the probability distribution of p_b/p_{rec} taken from Monte Carlo simulation ([4], [5]). Alternatively a linear (quadratic) relation is assumed between these two momenta with the coefficients estimated from Monte Carlo studies ([6]–[11]). For some semileptonic partially reconstructed decays like e.g. $B \to D^{(*)}lX$ it is reliable to assume that the only missing particle is the neutrino. Then the energy of the b-hadron is estimated by subtracting the energy of all hadronization particles accompanying the B from the beam energy ([12], [13]). It is also possible to estimate the boost of the b-hadron from the boost of particles belonging to its jet ([14]–[16]). The resolution of momentum's estimation for all these methods varies from 14 % to 25 %. It is included as the main source of systematic error together with the uncertainties due to the size and shape of the background(s).

3 Lifetime of the generic b-hadron

The generic b-hadron is any particle containing the beauty quark. Therefore its lifetime is equivalent to the average lifetime of the b-hadrons. Below the basic methods of performing this measurement are briefly commented together with the results obtained so far.

3.1 Impact parameter method

The impact parameter of the track is usually defined in the plane perpendicular to the beam axis (2D) as the closest distance between the track (typically an energetic lepton of a high transverse momentum) itself and the production point. It is signed with respect to the position of crossing between the track and jet axis. One exploits the fact that tracks from b-hadrons should predominantly populate the positive tail of the distribution and extract their lifetime using the maximum likelihood technique. All four LEP collaborations ([17]–[21]) contributed in this measurement (see Fig. 1). The recent result of ALEPH [18] profits from the precise measurement of track's position in three dimensions (3D) with the help of the new double-sided vertex detector. The last measurement of DELPHI uses sample of 'good' i.e. precise

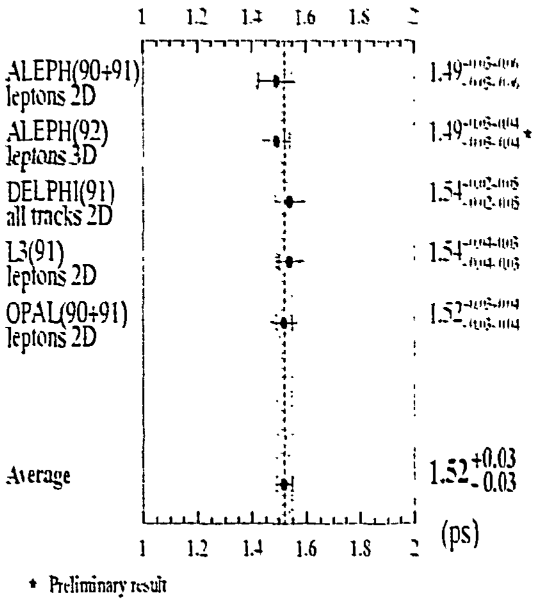

Figure 1: Lifetime of generic b-hadron measured with the impact parameter method.

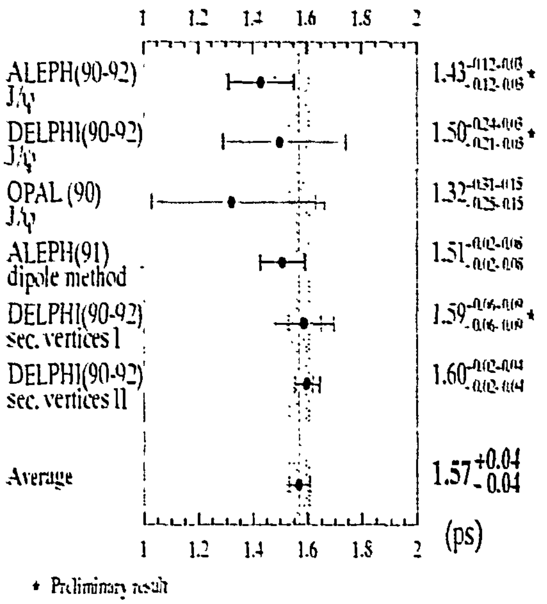

Figure 2: Lifetime of generic b-hadron measured from partially reconstructed b-vertices.

measured hadronic tracks together with a new technique of rejecting non-$b\bar{b}$ events [19]. The measurements are dominated by systematic uncertainties due to the treatment of the b-quark fragmentation and decays in the simulation.

3.2 Decay length of the vertices $b \to J/\psi(\to l^+l^-)X$

At LEP more than 98 % of J/ψ particles has been created from beauty quarks. As the lifetime of the J/ψ is negligible in comparison with the one of the b-hadron, the reconstruction of the the decay vertex $J/\psi \to l^+l^-$ allows directly for the measurement of the b-hadron's decay length ([4], [6], [14]). The results reported so far are collected in Fig. 2. At present they are limited by statistics but by the end of 1995 the quality of measurements by these method should be comparable to the impact parameter ones.

3.3 Inclusive reconstruction of generic secondary vertices

ALEPH [22] extracts the secondary vertices with the dipole method. The event is divided into two hemispheres with respect to the thrust axis. In each of them the weighted average of the intersections track-jet axis is found. The dipole is defined as the distance between these two points. As the $b\bar{b}$ events contain secondary vertices which are well separated from the production point, the dipole should be on average bigger for them.

DELPHI ([19], [23]) look for for generic secondary vertices defined (according to the Monte Carlo tuned algorithm) as groups of well-measured tracks intersecting close to each other. The reduction of vertices not coming from beauty hadrons is obtained by taking into account only the ones with at least four particles, being well separated from the production point (minimum distance 1mm) and having a high invariant mass (typically bigger than 1.7 GeV/c^2) [19]. The average lifetime of b-hadrons is extracted from the slope of the decay length's distribution of such vertices. Present accuracy is at the same level in comparison with impact parameter measurements. The systematic error origins mainly from the possible bias of the vertex-finding

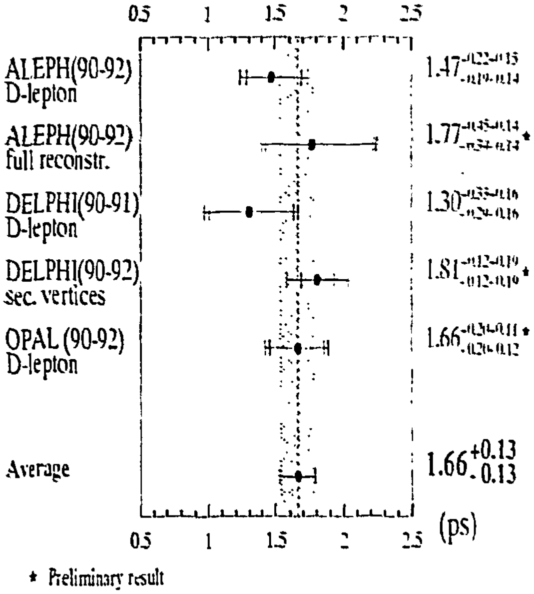

Figure 3: Lifetime of the B_u^+ meson.

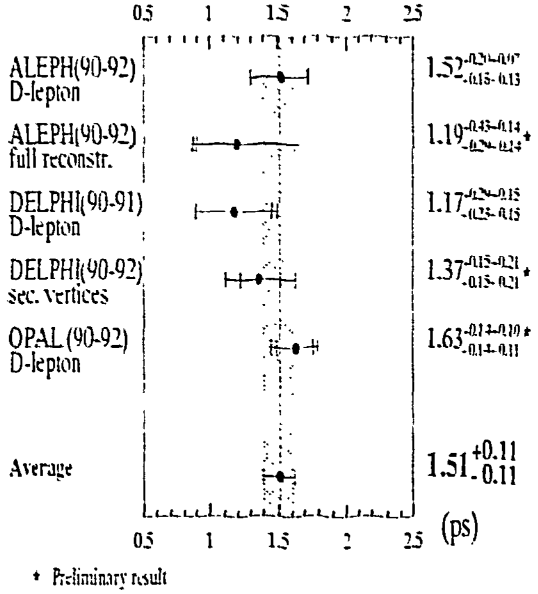

Figure 4: Lifetime of the B_d^0 meson.

algorithm, from the momentum estimation and from the uncertainties in the b-quark fragmentation. Two DELPHI results are included in Fig. 2. The second one [23] is a by-product of slightly different measurement exploiting the same technique and aimed for the measurement of lifetimes of B_u^- and B_d^0 mesons. It was proved that appropriate algorithm of vertex's finding can reliable measure the charge of the b-hadron. In the case of neutral b-hadron it is necessary to subtract the contributions from the B_s and Λ_b to get the lifetime of the B_d^0 which also contributes to systematic uncertainties.

The overall average of the results presented so far (Fig. 1 and 2) is 1.54 ± 0.02. [3]

4 Lifetimes of the B_u^+ and B_d^0 mesons

4.1 Partially reconstructed semileptonic decays $B \to D^{(*)}X$

Charged and neutral non-strange mesons can be tagged separately using the partially reconstructed semileptonic decays $B \to D^{(*)}X$. There exists the clear pattern in which the presence of charged D or D^* meson together with the lepton of opposite sign is the signature of the neutral B meson while the D^0 not coming from charged D^* together with the lepton marks the presence of charged B. This charged symmetry is, however, 'mixed' by the presence of D^{**} mesons which are P and higher waves D meson states together with non-resonant decays $Dn\pi$, (n=1,2,3...). The maximum likelihood fit to the lifetime distributions is performed in the samples D^-l^+, $D^{*-}l^+$ and $\bar{D}^0l^+$. The main sources of systematic uncertainties are due to the estimation of the B-meson momentum, of the size of the backgrounds and of the yield of D^{**} mesons. The results obtained by ALEPH [15], DELPHI [7] and OPAL [8] are collected in Fig. 3 and 4.

[3] each time when averaging the statistical errors were assumed to be uncorrelated; the common systematic uncertainties has been taken into account when necessary; fractional errors has been used.

4.2 Fully reconstructed decays of the B_u^+ and B_d^0

The full reconstruction of the non-strange B-meson decays has been achieved at LEP ([24], [25]) via the chains $B \to D^{(*)}n\pi$ (n=1,2,3...) and $B \to K^{(*)}J/\psi$ (see Fig 3 and 4). So far only ALEPH [24] has reported the lifetime's measurement for charged and neutral B-mesons using their sample of fully reconstructed decays. Apart from the estimation of the background's shape this measurement is the most direct and clean one. It suffers, however, from the small statistics of the decays in question.

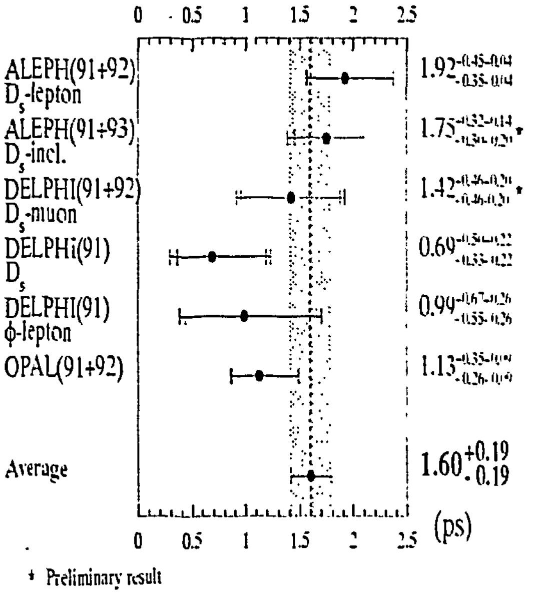

Figure 5: Lifetime of the B_s^0 meson.

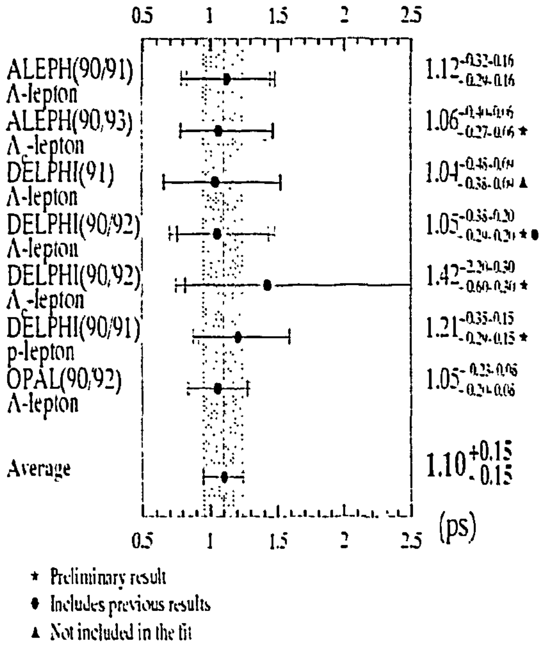

Figure 6: Lifetime of the b-baryon.

5 The lifetime of the B_s meson

LEP collaborations pioneered and still play a leading role as far as measurements of the lifetime and mass of the B_s are concerned. The lifetime (see Fig. 5) is extracted from partially reconstructed vertices of the B_s decay like $D_s^+l^-$ (ALEPH [12], DELPHI[9], OPAL[11]), and $D_s^+h^-$ (ALEPH[16], DELPHI[10]), where h marks an energetic and charged hadron and ϕl (DELPHI)[10]. The reconstruction of the D_s meson is performed in the channels KK^{*0} and $\phi\pi$.

6 The average lifetime of the b-baryons

The basic tag of the presence of the b-baryons is the observation of one of its baryonic remnants like the Λ_c, Λ^0 or proton correlated to the an energetic and a high-p_T lepton in the same hemisphere. In this method the sample of b-baryons is populated mainly by the lightest among them i.e. the Λ_b. One cannot, however, neglect the contributions from heavier states like the Ξ_b, Ω_b etc. Therefore what is measured is the average lifetime of the b-baryons.

To extract the lifetime OPAL [5] takes the intersection Λ^0–lepton. DELPHI demands additional charged pion (intended to come from the $\Lambda_b(\rightarrow \Lambda_c)$) in the vertex fit to improve the resolution and also profits from the Ring Imaging Čerenkov identification to obtain the measurement for the vertex p–lepton [13]. The correlation Λ_c–lepton (ALEPH [26], DELPHI [13]) gives a cleaner sample but at the prize of reduced statistics. ALEPH [27] presented also the lifetime measurement with the help of impact parameter method using leptons correlated to the Λ^0. All results available so far are collected in Fig. 6.

Last year first DELPHI [28] and then ALEPH [29] has presented the possible evidence for the Ξ_b beauty baryon carrying an open strangeness. An excess of the same-sign pairs Ξ_s – lepton (ALEPH 11.3 ± 10 and DELPHI 7.6 ± 3.7 events; 1 and 2 standard deviations effect, respectively) is being naturally interpreted as the signature of the Ξ_b. The possible confirmation of this observation together with first estimates of the lifetime are expected soon after analyzing the data collected in 1993.

7 Masses of the B_s and Λ_b

First candidates of fully reconstructed decay modes of the B_s (ALEPH [30], DELPHI [31] and OPAL [25]) and Λ_b (DELPHI [32] and OPAL [33]) have been recently reported. The decay channels involved together with the available statistics are collected in tables 2 and 3, respectively. The common features of their decay products making the detection possible are: low multiplicity together with the presence of only charged particles and intermediate resonances. The mass of each candidate is obtained from a global mass constrained fit imposing the masses of the intermediate state particles and recomputing the secondary and primary vertices. The systematic error to the mass measurement come from the uncertainty in the absolute mass scale and from possible errors in the detector's alignement. The LEP combined masses of the B_s and Λ_b fit very well with the theoretical predictions.

8 Summary

The sample of data analyzed per each LEP experiment allows for giving precise (with the error of 1.3 %) measurement of the average lifetime of the b-hadron (see Fig. 7). The present accuracy of lifetime's ratios for individual hadronic states containing the b-quark collected in the Table 4 is on the edge of possibility to test theoretical predictions. There is an indication of the presence of non-spectator effects as the Λ_b's lifetime is lower than the one in the meson sector. The observation of lifetime's differences between b-mesons needs, however, better accuracy of measurements. This may be achieved by the end of LEP data taking in 1995 when the error of lifetime's differences is to be reduced by the factor of two.

To illustrate the progress which has been made at LEP during the last two years it is sufficient to quote the ratio of lifetimes of non-strange B-mesons presented at the same Meeting in 1992 [34]: $\tau_{B^\pm}/\tau_{B^0} = 1.16^{+0.67}_{-0.46} \pm 0.11$.

The average lifetime obtained by weighting the measured lifetimes of b-hadron states with their expected yields $B^+{:}B^0{:}B_s{:}\Lambda_b = 0.4{:}0.4{:}0.12{:}0.08$ is in reasonable agreement with the direct measurement (see Fig 7).

Table 2: Fully reconstructed decay modes of the B_s meson together with measurements of its mass.

Expt.	B_s's decay mode	B_s's mass (MeV/c^2)	# of events
ALEPH	$D_s^-(\phi\pi^-)\pi^+$	5401 ± 77	1
	$\psi'\phi$	5368.4 ± 4.3	1
ALEPH	average	$5368.6 \pm 5.6 \pm 1.5$	
DELPHI	$D_s^-(\phi\pi^-)\pi^+$	5325 ± 32	1
	$D_s^-(\phi\pi^-)a_1$	5345 ± 32	1
	$J/\psi\phi$	5389 ± 16	1
DELPHI	average	$5374 \pm 16 \pm 2$	
OPAL	$J/\psi\phi$	5359 ± 17	1
	$D_s^-\pi$	5370 ± 40	6
OPAL	average	$5361 \pm 16 \pm 7$	
LEP	average	5368.5 ± 5.2	
Theory	prediction	$5345 \div 5388$	

The present LEP combined values of masses for the B_s and Λ_b agree very well with the theoretical predictions (see tables 2 and 3) and in the future more precise measurements are certainly awaited.

Even after this enormous and fruitful effort there is still the need to invest new techniques and explore additional decay channels. Apart from further measurements of lifetimes and masses of known states and expected confirmation of the strange b-baryons, the extensive work is going on in search for higher spin $B^{*}_{u,d}$ and B^{*}_s mesons and for the B_c meson with open charm.

Table 3: Fully reconstructed decay modes of the Λ_b baryon together with measurements of its mass.

Expt.	Λ_b's decay mode	Λ_b's mass (MeV/c^2)	# of events
DELPHI	$\Lambda_b \to D^0 p\pi^-$	5614 ± 31	1
	$\Lambda_b \to \Lambda_c\pi$	5662 ± 43	1
DELPHI	average	$5635^{+38}_{-29} \pm 4$	
OPAL	$\Lambda_b \to \Lambda_c\pi$	5620 ± 30	6
LEP	average	5627 ± 22	
Theory	prediction	$5600 \div 5630$	

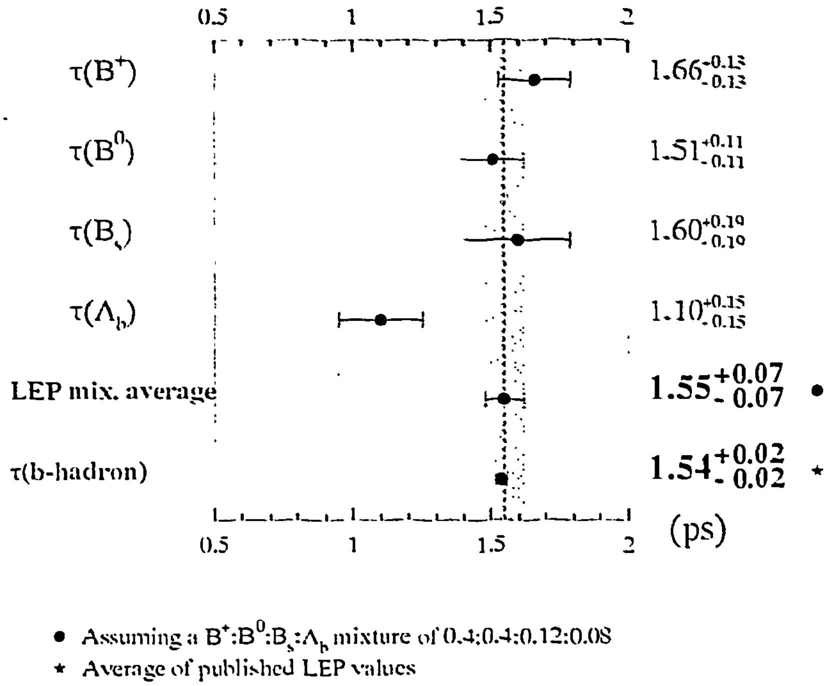

Figure 7: Summary of measurements of b-hadrons lifetimes.

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Table 4: Measured and predicted ratios of lifetimes for b-hadrons.

	Theory	Experiment	error 1992 (%)	error 1995 (%)
$\tau_{B^\pm}/\tau_{B^0}$	$\simeq 1.05$	1.10 ± 0.12	13	6
$\tau_{B^0_s}/\tau_{B^0}$	$\simeq 1.00$	1.06 ± 0.15	19	8
$\tau_{\Lambda_b}/\tau_{B^0}$	$\simeq 0.90$	0.73 ± 0.11	15	7

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