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Laboratoire de l'Accélérateur Linéaire

LIFETIME OF B HADRONS AT LEP

A. Stocchi

Laboratoire de l'Accélérateur Linéaire, IN2P3-CNRS
et Université de Paris-Sud, 91405 Orsay, France

Seminar given at the XXII ITEP International Winter School of Physics
Moscow, Russia, 22 February - 2 March 1994

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Abstract

A review of the experimental LEP results on B hadron lifetimes is presented. These results have been obtained from data registered up to 1992, which correspond to about 1M hadronic Z^0 decays for each of the four experiments.

1. INTRODUCTION

Physics motivations

In the spectator model approximation, the lifetime of B hadrons is given by the formula :

$$\tau_B = \frac{192\pi^3}{G_F^2 m_b^5} Br(B \to X\ell\nu) \frac{1}{F_c|V_{bc}|^2 + F_u|V_{bu}|^2} \tag{1}$$

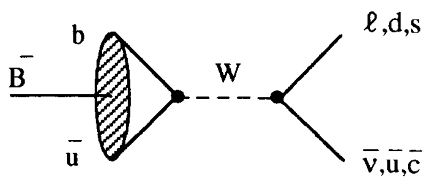
Due to the smallness of the ratio between the two C.K.M. couplings ($\frac{|V_{bu}|}{|V_{bc}|} = 0.08 \pm 0.02$) [1], the b → u transition can be neglected and the measurements of the B lifetime and of the semileptonic branching fraction, allow the determination of $|V_{bc}|$. Nevertheless both the constant F_c, which includes the effect of finite quark masses and QCD corrections, and the mass of the b quark m_b, are not well known and this limits the precision on the determination of $|V_{bc}|$.

An immediate consequence from the spectator model is that the lifetime of B hadrons is determined by the b quark independently of the other constituent quarks : all B hadrons have the same lifetime. For charm it has been observed experimentally that the lifetimes vary by large factors among the different hadrons [2].

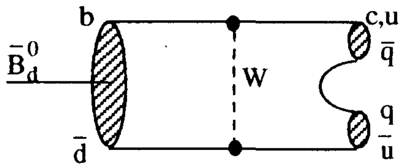
The charmed hadrons lifetimes, in unit of 10^{-13} s, are

D^+	D^0	D_s^+	Λ_c	Ξ_c^+	Ξ_c^0
10.66 ± 0.23	4.20 ± 0.08	$4.50^{+0.30}_{-0.26}$	$1.91^{+0.15}_{-0.12}$	$3.0^{+1.0}_{-0.6}$	$0.82^{+0.59}_{-0.30}$

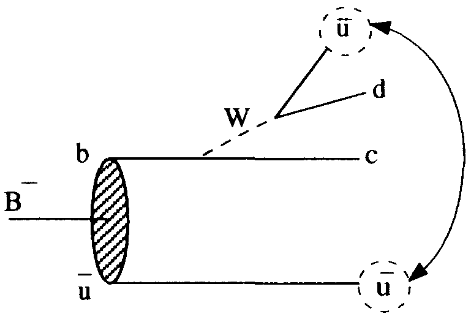
Non-spectator diagrams are invoked to explain such differences. For B hadron decays these diagrams are illustrated in the following :



Annihilation diagram : it concerns charged B hadrons. This diagram is suppressed both from helicity conservation and from the low value of the V_{bu} coupling. Its contribution is negligible.



Exchange diagram : it concerns neutral B hadrons, it is helicity suppressed for the B_d^0 but not for the Λ_b^0. Its principal effect is to shorten the Λ_b^0 lifetime.



Interference diagram : it concerns the charged B hadrons and the Λ_b. The destructive interference between the $\bar{u}$ quarks implies an increase of the B^- lifetime. A less important effect is also expected for Λ_b^0 due to the destructive interference between the d quarks.

Fig. 1 shows, in a qualitatively way, the effects of the different processes contributing to the differences between the B hadrons lifetimes.

	annih.	exch.	interf.
B^-	~0	0	↑↑
B_d^0	0	↓	0
B_s^0	0	↓	0
Λ_b^0	0	↓↓	↑

Fig. 1 : The qualitative effect of the different processes on the lifetime of the b hadrons. The arrows up or down indicate that the effect is to increase or to shorten the corresponding lifetime.

The following hierarchy is then expected :

$$\tau(B^+) > \tau(B^0) \gtrsim \tau(B_s^0) > \tau(\Lambda_b^0) \tag{2}$$

With respect to charmed mesons, the most important contributions to the lifetime differences are expected to be of the order of $(\frac{m_c}{m_b})^3$ [3].

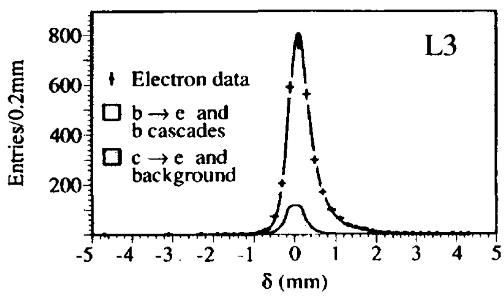
Detailed calculations give [3]c :

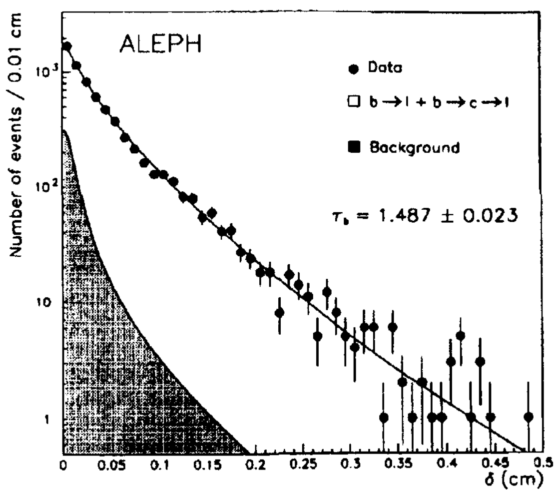
$$\begin{aligned} \frac{\tau(B^+)}{\tau(B^0)} &= 1 + 0.05(\frac{f_B}{200\ MeV})^2 \\ \frac{\tau(B_s^0)}{\tau(B_d^0)} &= 1 \pm 0.01 \\ \frac{\tau(\Lambda_b^0)}{\tau(B)} &\cong 0.9 \end{aligned} \tag{3}$$

2. INCLUSIVE B LIFETIME

Impact parameter method

The lifetime in this kind of analysis is measured from the impact parameter distribution of the leptons or more generally hadrons. The impact parameter of a track, defined as the distance of closest approach to the primary vertex of the event is insensitive, on average, to the momentum of the decaying particle and is related to the lifetime simply by $< \delta > \approx \alpha\ c\ \tau$, with $\alpha \sim 0.3$. Fig. 2 shows the impact parameter distributions obtained by ALEPH, L3 and OPAL Collaborations.





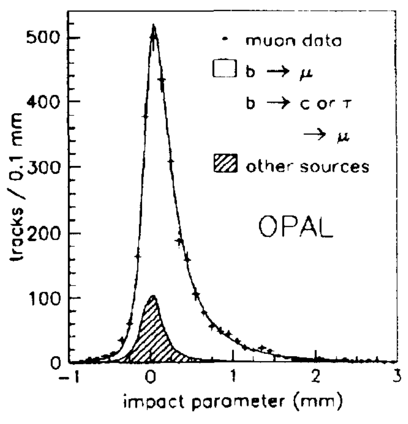


Fig. 2 : Lepton impact parameter distributions measured by ALEPH, L3 and OPAL experiments. In case of ALEPH, the result has been obtained using a 3D-Silicon Vertex Detector giving information both in $R\varphi$ and Z.

Inclusive vertex reconstruction

This analysis is based on the reconstruction of inclusive secondary vertices. An important enrichment in B hadrons (~ 90 %) of the analyzed event sample is obtained by asking a secondary vertex of good quality, a minimal flight distance (~ 1 mm) between the primary and secondary vertices and an invariant mass of the system of particles attached to the secondary vertex greater than a typical charmed meson mass. The decay length distribution obtained by the DELPHI Collaboration is shown in Fig. 4. The most important limitation on the precision on the lifetime from this analysis is the systematics error coming from the knowledge of the b fragmentation function.

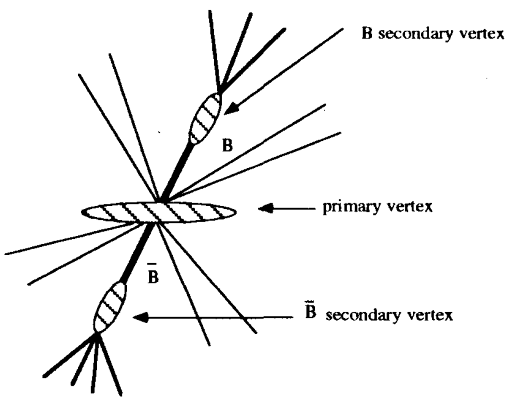


Fig. 3 : Schematic picture of a B event which is characterized by the presence of two secondary vertices.

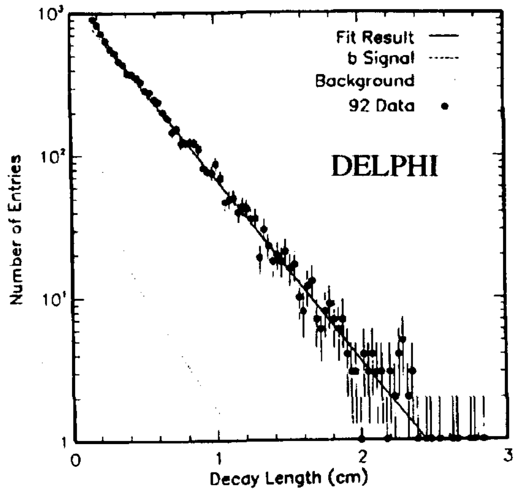


Fig. 4 : Decay length distribution of secondary vertices reconstructed in DELPHI.

$J/\psi \to \ell^+\ell^-$ reconstruction

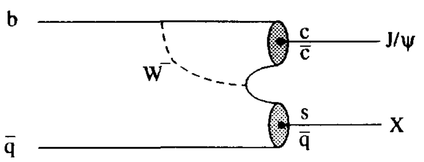


Fig. 5 : Production of a J/ψ in a B decay via an internal W emission diagram.

All B hadrons decays can contribute to the J/ψ production via the process illustrated in Fig. 5. All other sources of J/ψ production are found to be negligible.

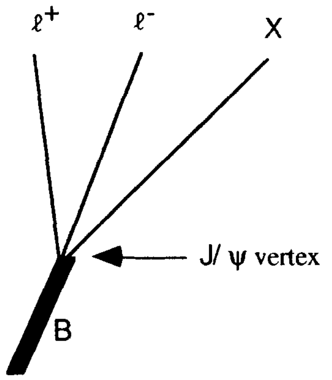


Fig. 6 : Schematic picture of J/ψ production from a B decay and of its decay into a lepton pair.

The J/ψ decay mode into a lepton pair is used. The main characteristics of this final state is the cleanness of the selected sample of events, as it can be noticed from the invariant dilepton mass spectrum of Fig. 7a and from the fact that the B vertex coincide with the $\ell^+\ell^-$ vertex (Fig. 6).

Nevertheless, there are almost two order of magnitude in statistics between this quasi-exclusive analysis and the previous ones. The precision that can be obtained on the lifetime is definitely limited by the statistics. Fig. 7b shows the proper time distribution of the J/Ψ candidate as obtained by ALEPH Collaboration.

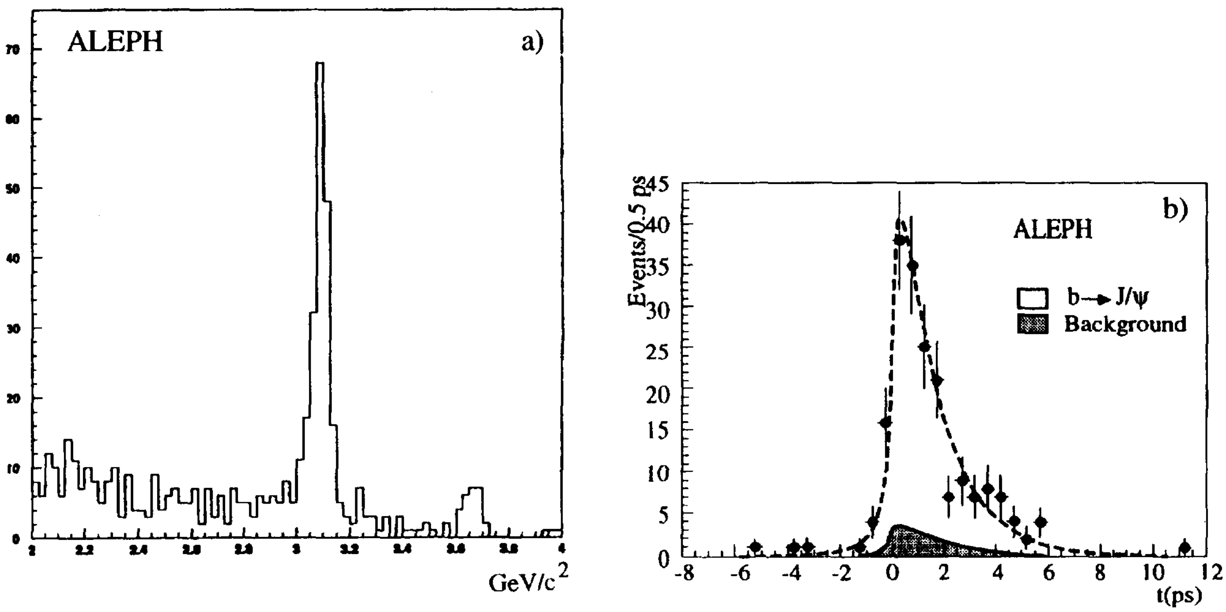


Fig. 7 : a) $\ell^+\ell^-$ invariant mass distribution (in GeV/c^2) b) proper time distribution (in ps) for the J/ψ candidates decaying into a pair of leptons from ALEPH.

Summary on inclusive B lifetime measurements

The results on the inclusive measurement of the B lifetime are summarized in Fig. 8. The global average is :

$$\tau(B) = 1.538 \pm 0.033 \text{ ps} \qquad \textit{LEP Average} \tag{4}$$

Experiment	Year	Method	Results in ps
PDG 92 [2]			1.29 ± 0.05
ALEPH[4]a	91	2D i.p. e + μ	1.49 ± 0.03 ± 0.06
ALEPH*[4]b	92	3D i.p. e + μ	1.487 ± 0.023 ± 0.038
DELPHI*[4]c	91	2D i.p. e + μ	1.37 ± 0.05 ± 0.05
L3[4]d	90/91	2D i.p. e + μ	1.535 ± 0.035 ± 0.028
OPAL[4]e	90/91	2D i.p. e + μ	1.523 ± 0.034 ± 0.038
DELPHI*[4]f	91/92	2D i.p. hadrons	1.542 ± 0.021 ± 0.045
ALEPH[4]g	91	dipole 2D	1.511 ± 0.022 ± 0.078
DELPHI*[4]h	91/92	2^{nd}vtxs + M > 1.7 GeV	1.599 ± 0.014 ± 0.035
DELPHI*[4]i	91/92	topol.2^{nd}vtxs	1.59 ± 0.06 ± 0.09
ALEPH*[4]l	90/92	192 $J/\Psi \to \ell^+\ell^-$	$1.41^{+0.13}_{-0.12} \pm 0.04$
DELPHI*[4]m	90/92	199 $J/\Psi \to \ell^+\ell^-$	$1.34^{+0.19}_{-0.15} \pm 0.08$
OPAL[4]n	90	36 $J/\Psi \to \ell^+\ell^-$	$1.32^{+0.31}_{-0.25} \pm 0.15$
LEP AVERAGE			1.538 ± 0.033
CDF[4]o		15 % of 5384 $J/\Psi \to \mu^+\mu^-$	1.46 ± 0.06 ± 0.06

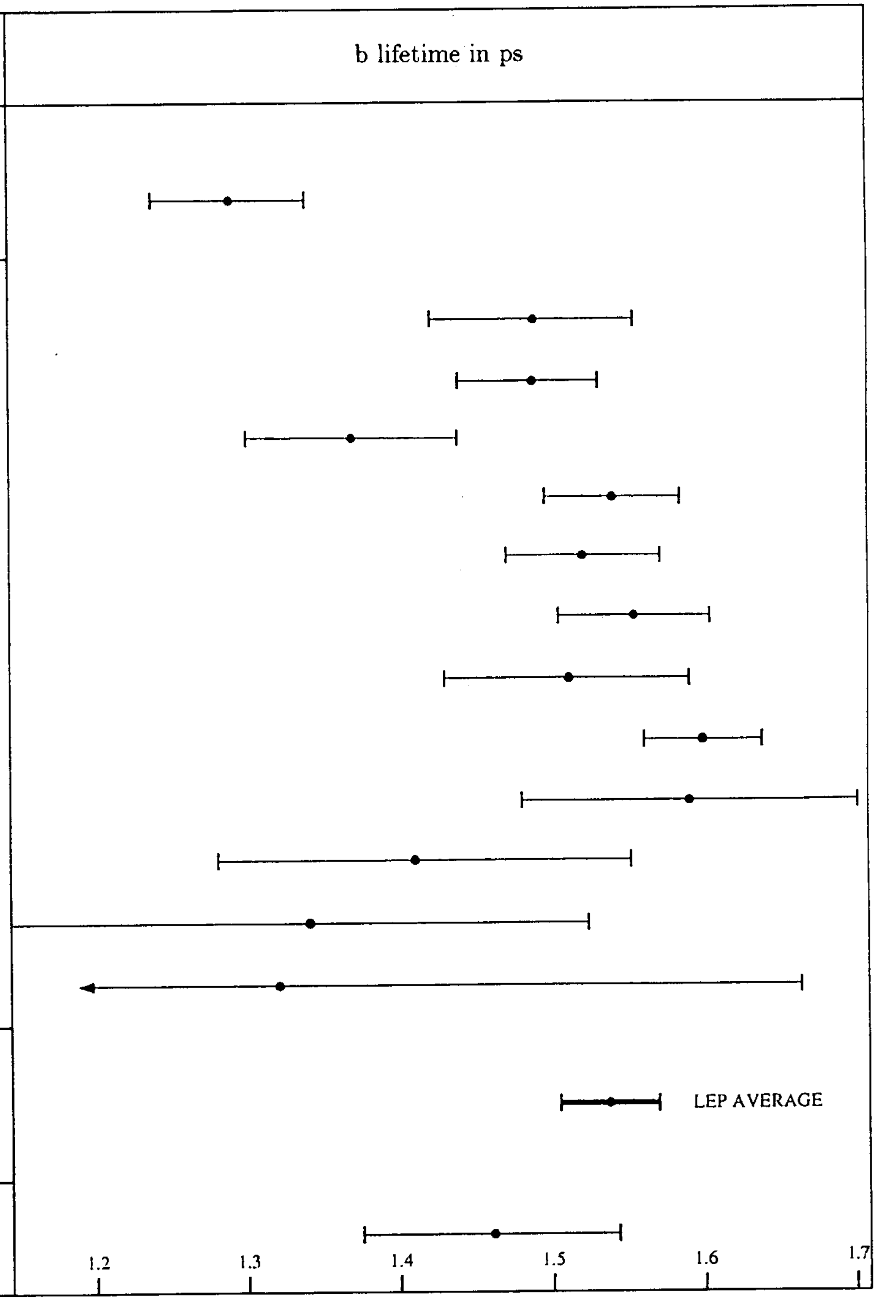


Fig. 8 : Summary of b lifetime measurements. Here and in the following, the start after the name of the experiment indicates that the result has not yet been published.

An attentive look of the results in Fig. 8 shows that this average is dominated by several measurements having a statistical precision around 2 % but a systematic error varying between 2 % and 5 %. On one hand a careful analysis of systematics errors is needed before averaging the results, on the other hand, it will be difficult to improve the actual precision on the inclusive B lifetime.

As it has been said in the introduction, $|V_{bc}|$ can be extracted using the relation (1). Using the overmentioned lifetime value and the semi-leptonic branching fraction of the B ($Br^b_{s\ell} \to \ell\nu X = 11.0 \pm 0.3 \pm 0.4$ %) [5] it follows :

$$|V_{bc}| = 0.040 \pm 0.001 \pm 0.007 \text{ (from } m_b, F_c) \quad (5)$$

Any further improvement on the precision on the B lifetime has no consequences on a better determination of $|V_{bc}|$ which is completely dominated by the poor knowledge on the constant F_c and on the masses of the b and c quarks.

3. $\bar{B}^0_d, B^-$ LIFETIMES

$B^-, \bar{B}^0_d$ lifetime measurement using $B \to D\ell\nu$ decays

The most classical approach to measure the B^- and $\bar{B}^0_d$ lifetimes is to use $D^0\ell^-$ and $D^{(*)+}\ell^-$ events. In these decays, the presence of a $D^{(*)+}$ with charge opposite to the lepton, tags the presence of a $\bar{B}^0_d$ at the initial state whereas the presence of a $\bar{D}^0$, not coming from a D^* decay, tags the presence of a charged B^- meson. This simple picture is complicated by the presence of D^{**} states coming from the $B \to D^{**}\ell\nu$ decay chain.

D^{**} hadrons :

The symbol D^{**} is generally used to indicate P-wave charmed states with positive parity. The interest here is to be able to evaluate for instance the importance of the diagram in Fig. 9b with respect to the one of Fig. 9a.

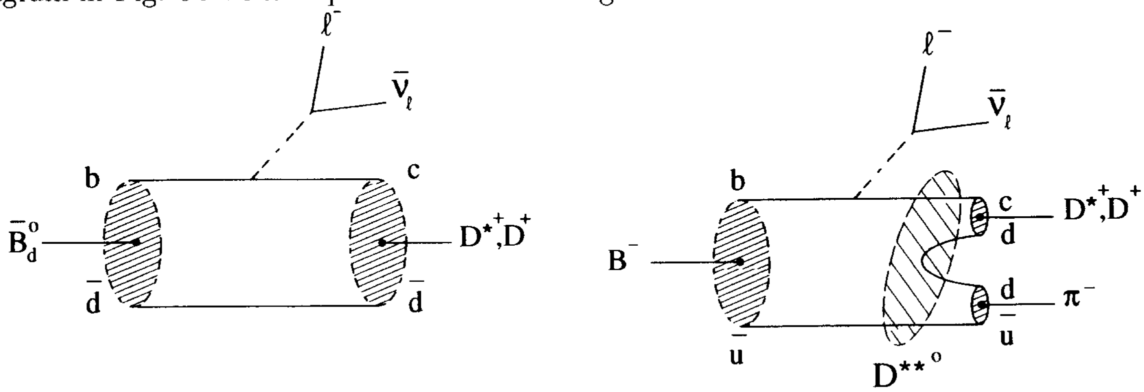


Fig. 9 : $D^{*+}\ell^-$ events from $\bar{B}^0_d$ and B^- meson decays. a) $D^{*-}\ell^-$ from $\bar{B}^0_d$ in the spectator model. b) $D^{*+}\ell^-$ from B^- via a D^{**} state.

The production of D^{**}, in semileptonic B decays, has been recently measured by ARGUS [6]

$$Br(B \to D^{**}\ell\nu) = 17 \pm 4\ \% \tag{6}$$

(it has to be noticed that this measurement differs from the previous from CLEO of 36 ± 12 %.)

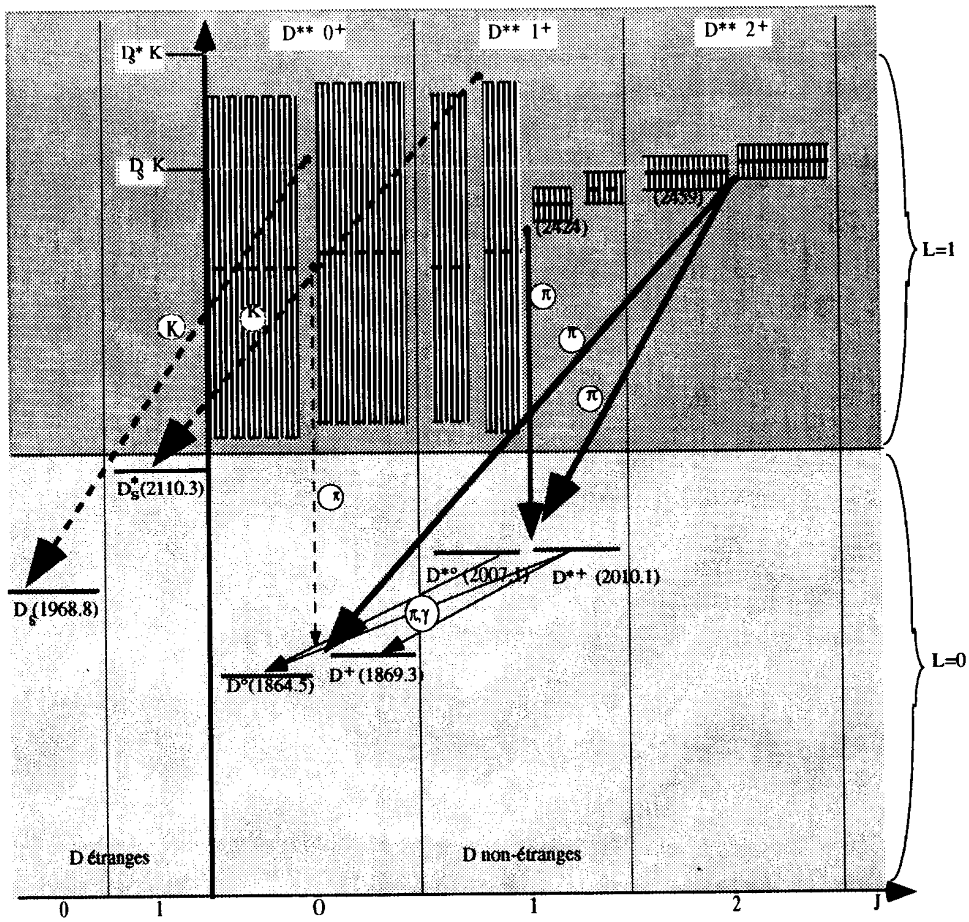
Nevertheless, large uncertainties are coming both from the lack of knowledge of the relative production rates of the different D^{**} states and of their decay channels. This situation is shown in a pictorial way in the Fig. 10. The absence of experimental informations can be condensed in the variable P_V^* giving the fraction of D^* final states in D^{**} decays :

$$P_V^* = \frac{Br(D^{**} \to D^*X)}{Br(D^{**} \to D^*X) + Br(D^{**} \to DX)} = 0.5 \pm 0.3 \tag{7}$$

The measurement of the B^- and $\bar{B}_d^0$ lifetimes via $B \to D\ell\nu$ requires the exclusive reconstruction of D meson final states. The following D meson decays have been used :

$$\begin{array}{lll} \underline{D^0\ell^-\ events} & \underline{D^+\ell^-\ events} & \underline{D^{*+}\ell^-\ events} \\ D^0 \to K^-\pi^+ & D^+ \to K^-\pi^+\pi^+ & D^{*+} \to D^0\pi^+ \\ & & \quad \hookrightarrow K^-\pi^+ \\ & & \qquad\ \ K^-\pi^+\pi^0 \\ & & \qquad\ \ K^-\pi^+\pi^+\pi^- \end{array} \tag{8}$$

Fig. 11 shows, the mass distribution of the $K^-\pi^+$ combinations for events containing an ℓ^- obtained by the OPAL Collaboration. The $D\ell$ vertex is used to estimate the B decay vertex ; the resolution is of the order of 300 μm for a typical flight distance of 3 mm. The energy of B mesons can be obtained by using the fact that the energy of the $D\ell$ system, $E(D\ell)$, scales approximately with its mass $m(D\ell)$. The measured decay length can be thus converted into decay time. This distribution, in case of OPAL, is shown in Fig. 11b. Tacking into account the presence of D^{**} states, the measurements of the lifetimes for the $D^0\ell^-$ and $D^{(*)+}\ell^-$ samples can be converted into B^- and $\bar{B}_d^0$ lifetimes. The results are summarized in Fig. 13 at the end of this paragraph. The accuracy of the individual measurements is still dominated by the statistical error, and the main part of systematic uncertainties is coming from the poor knowledge of the D^{**} sector and is common to all measurements.



D^{**} relative abondance	D^{**} state/width	decay
5 :	2^+ narrow	D^*, D
3 :	1^+ narrow	D^*
3 :	1^+ large	D^*
1 :	0^+ large	D

Fig. 10 : Masses, widths and decay modes of the non-strange D^* and D^{**} in the plan : mass vs total angular momentum. The states L=0 are in the bottom part (clear gray) while the D^{**} (L=1) are in the upper part (dark gray). The full lines indicate the states which have been measured while the dotted lines refer to the estimation of the mass and of the width given in [7]. Same conventions are used for the lines representing the decay modes. Since the D^{**} decay via strong interaction they have to obey spin and parity conservation rules. The relative abondance of D^{**} states is supposed to follow the spin counting rule $(2J + 1)$.

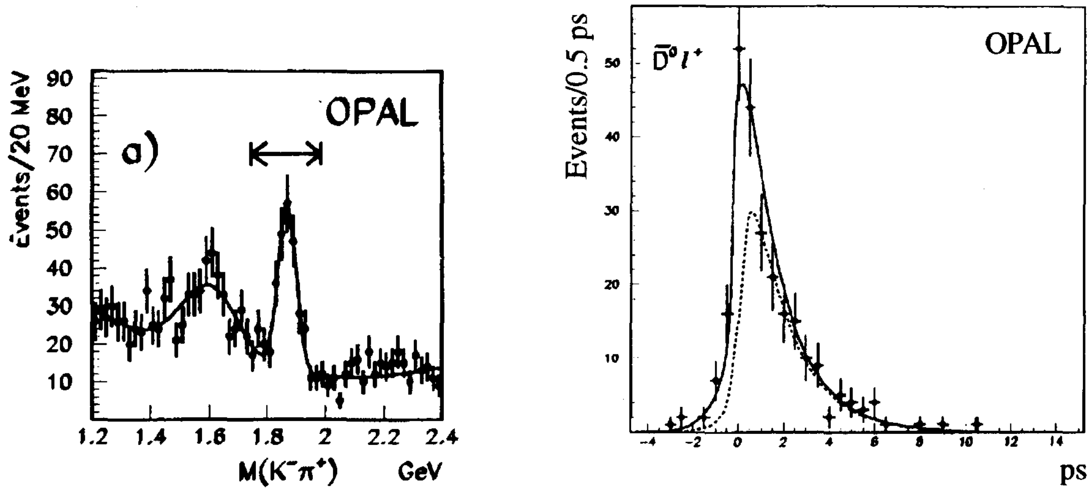


Fig. 11 : a) Mass distribution of $K^-\pi^+$ combinations (D^0 candidates) in correlation with an ℓ^-. b) Decay time distribution of the D^0 candidates in ps.

<u>**Reconstruction of B exclusive final states**</u>

This analysis is based on the exclusive reconstruction of hadronic final states by looking for instance at decays as $B \rightarrow D(n\pi)$ and $B \rightarrow J/\psi\ K$. The main interests of this analysis are the complete separation between B_d^0 and charged mesons and an accurate measurement of the B energy. However, the statistics is at least one order of magnitude less than in the previous analysis. Fig. 12 shows the J/ψ k invariant mass distribution obtained by the ALEPH Collaboration. The CDF Collaboration working at the $p\bar{p}$ Fermilab Tevatron Collider has done the same kind of analysis with a larger statistics.

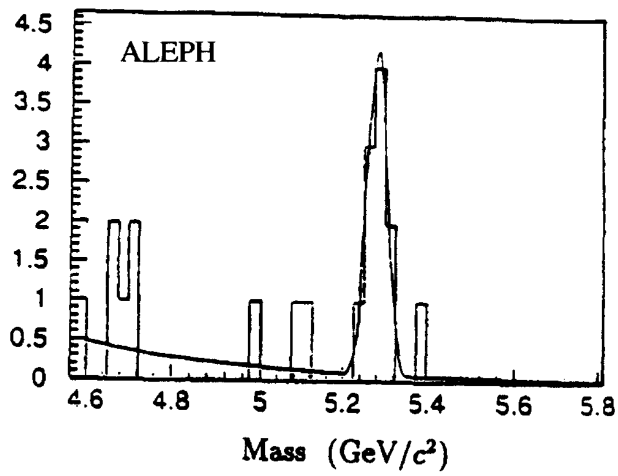


Fig. 12 : Exclusively reconstructed B meson : $B \rightarrow J/\Psi\ K$ from ALEPH Collaboration.

The results on B_d^0 and B^+ lifetimes measurements are summarized in Fig. 13. The analysis indicated as topological vertices is based on the inclusive reconstruction of secondary vertices and is analogous to those described in the previous section.

Experiment	Year	Method	$B^{\pm}$ lifetime / B^0 lifetime (ps)
ALEPH[8]a	91	69/77 $D^0\ell^+$	$1.47^{+0.22}_{-0.19}{}^{+0.15}_{-0.14}$
		66/77 $D^{*+}\ell^-$	$1.52^{+0.20}_{-0.18}{}^{+0.07}_{-0.13}$
DELPHI[8]b	91	92 ± 14 $D^0\ell^-$	$1.30^{+0.33}_{-0.29} \pm 0.16$
		96 ± 14 $D^{*+}(D^+)\ell^-$	$1.17^{+0.29}_{-0.23} \pm 0.16$
OPAL*[8]c	91/92	171 ± 21 $D^0\ell^-$	$1.66 \pm 0.20^{+0.11}_{-0.12}$
		354 ± 27 $D^{*+}(D^+)\ell^-$	$1.63 \pm 0.14^{+0.10}_{-0.11}$
ALEPH*[8]d	91/92	$27 \pm 7^{D(n\pi)}_{J/\psi,X}$	$1.77^{+0.45}_{-0.34} \pm 0.14$
		18 ± 7 $D(n\pi)$	$1.19^{+0.43}_{-0.29} \pm 0.14$
DELPHI*[8]e	91/92	topol.vertices	$1.81 \pm 0.12 \pm 0.19$
			$1.37 \pm 0.15 \pm 0.21$
LEP AVERAGE			1.68 ± 0.13 1.50 ± 0.12
CDF* [8]f		75 ± 10 $J/\psi X^+$	$1.63 \pm 0.21 \pm 0.16$
		61 ± 9 $J/\psi X^0$	$1.54 \pm 0.22 \pm 0.10$

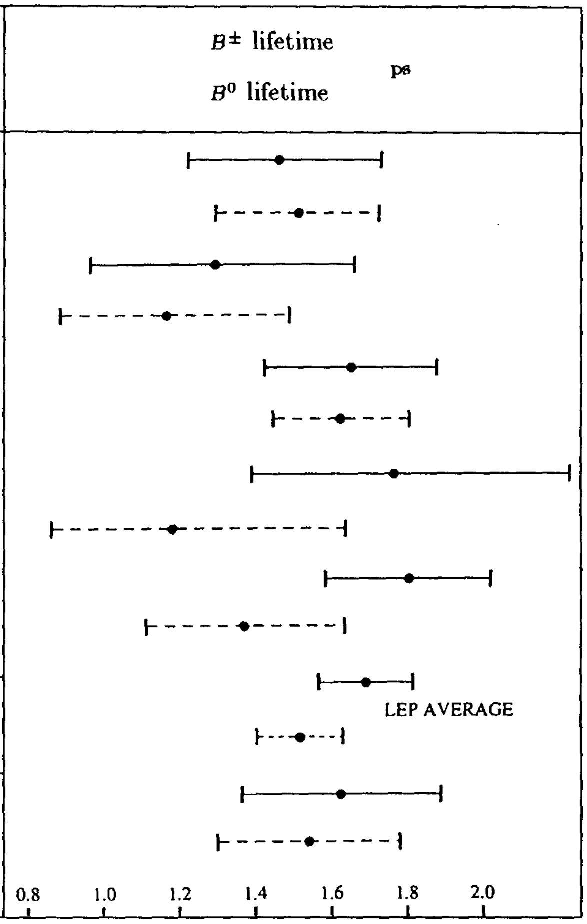


Fig. 13 : Summary of the results on B^- and $\bar{B}^0_d$ lifetimes measurements. Here and in the following the ratio quoted in front of some processes correspond to the signal over the total number of candidates.

The summary of the results on the $B^-/\bar{B}^0_d$ lifetime ratio is given in Fig. 14. For this measurement, the result obtained by the CLEO Collaboration, using the semileptonic branching fraction, is reported.

In conclusion a precision of about 10 % has been reached on the measurement of the $\bar{B}^0_d$ and B^- lifetimes. At LEP, this average is dominated by the $D\ell$ analyses. Nevertheless, in spite of the fact that the accuracy of each single measurement is still dominated by the statistical error, the precision on the average starts to be limited by the common systematic uncertainties coming from the poor knowledge of the D^{**} sector. It becomes of fundamental importance to be able to control the contribution from the D^{**} directly from data.

Experiment	Year	Method	Results
ALEPH[8]a	91	$D\ell$ evts	$0.96^{+0.19+0.18}_{-0.15-0.12}$
DELPHI[8]b	91	$D\ell$ evts	$1.11^{+0.51}_{-0.39}\pm0.11$
OPAL*[8]c	90/92	$D\ell$ evts	$1.02^{+0.19+0.08}_{-0.17-0.07}$
DELPHI*[8]d	91/92	topol. vertices	$1.32^{+0.22}_{-0.18}\pm0.22$
LEP AVERAGE			1.09 ± 0.15
CDF*[8]f		$J/\psi,X$ evts	$1.06 \pm 0.20 \pm 0.12$
CLEO*[8]g		$Br(B^+)/Br(B^0)$	$1.05 \pm 0.16 \pm 0.15$

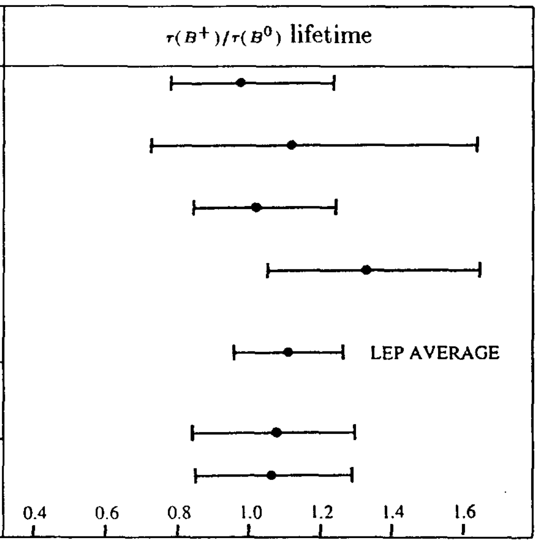


Fig. 14 : Summary of the results on the $B^-/\bar{B}^0_d$ lifetimes ratio

$$\begin{aligned} \tau(B^-) &= 1.68 \pm 0.12\ ps \\ \tau(\bar{B}^0_d) &= 1.50 \pm 0.12\ ps \qquad LEP\ Average \end{aligned} \tag{9}$$

$$\begin{aligned} \frac{\tau(B^+)}{\tau(B^0)} &= 1 + 0.05\,(\frac{f_B}{200\ MeV})^2 \quad theoretical\ expectations \\ &= 1.09 \pm 0.15 \qquad LEP Average \\ &= 1.07 \pm 0.11 \qquad LEP + CLEO + CDF \end{aligned} \tag{10}$$

4. B^0_s LIFETIME MEASUREMENT

$D^+_s\ \ell^-$ events

The measurement of the B^0_s lifetime has been performed up to now using its semileptonic decay $B^0_s \to D^-_s \ell^+ \nu$. This analysis was used also for the B^0_s discovery. The difficulties coming from D^{**} in $\bar{B}^0_d$ and B^- lifetime measurement are less important for the B^0_s. Figs. 15a and 15b show the production of $D_s\ell$ events from $\bar{B}^0_s$ and from non-strange B mesons respectively. The second process implies the production of a D^{**} state followed by the decay $D^{**} \to D_s K$. This decay is twicely suppressed both from the available phase space (as shown in figure 10) and from the fact that an extra strange-antistrange quark pair is requested.

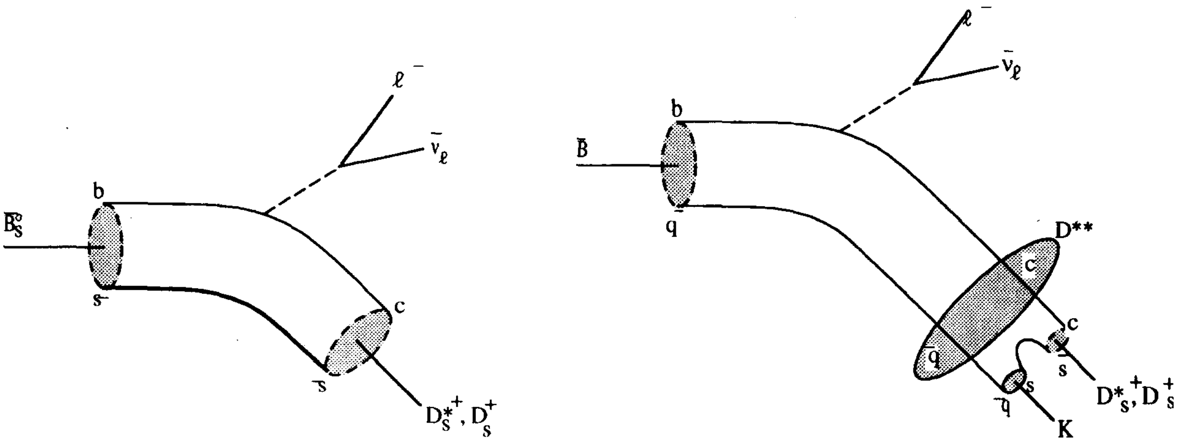


Fig. 15 : a) Semileptonic decay of $\bar{B}^0_s$. b) semileptonic decay of non-strange B hadrons into $D^{\pm}_s\ell^{\mp}$ pairs.

A detailed calculation which takes into account the D^{**} masses, widths and decay modes gives [7] :

$$\frac{P^{evt}(\bar{B} \to D^+_s K \ell^- \bar{\nu})}{P^{evt}(\bar{B}^0_s \to D^+_s K \ell^- \bar{\nu} X)} \lesssim 5\ \% \qquad (11)$$

(P^{evt} is the probability to obtain the quoted final state in a $b\bar{b}$ event)

An extra source of $D^+_s\ell^-$ events comes from the decay of non-strange B mesons into $D_s\bar{D}$ followed by the semileptonic decay of the $\bar{D}$. The order of magnitude of this process is the same as for the signal ; anyhow, in this case, the lepton is emitted from a charmed meson and the contribution from this process can be controlled and strongly reduced by requiring a lepton with high momentum and high transverse momentum with respect to the jet axis. As a conclusion, compared to the $(D^0\ell^-) - B^-$ and $(D^{*+}\ell^-) - \bar{B}^0_d$ analyses $D^+_s\ell^-$ events give a cleaner signature for the $\bar{B}^0_s$ mesons. Fig. 16 shows the D^+_s signal in two decay modes ($D^+_s \to \phi\pi^+$ and $D^+_s \to \bar{K}^{*0}K^+$) where in the same jet a lepton with $p_t > 1.2$ GeV/c opposite in charge is present as obtained by the DELPHI Collaboration.

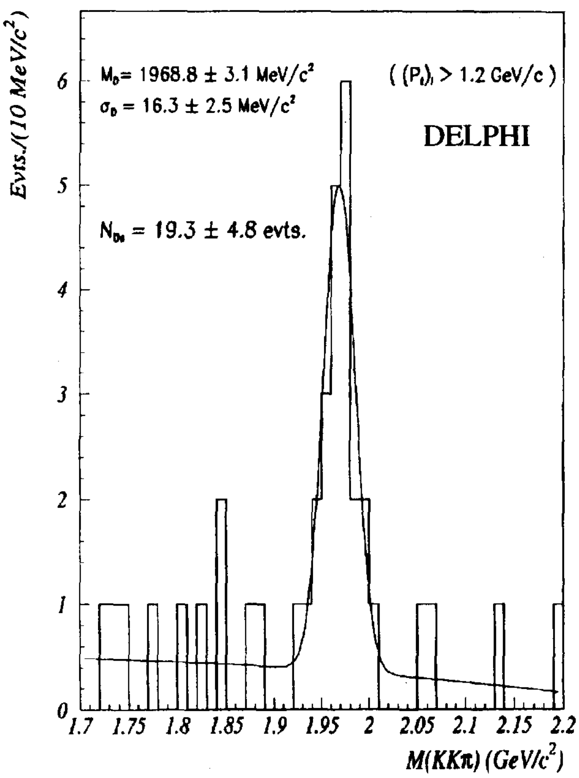


Fig. 16 : $KK\pi$ invariant mass distribution from DELPHI for D_s candidates accompanied by a lepton of opposite sign present in the same hemisphere and with $p^{\ell}_T > 1.2$ GeV/c.

The B_s^0 lifetime analysis is analogous to the one described for $\bar{B}_d^0$ and B^- mesons and is summarized in Fig. 17. DELPHI has also used $\phi\ell$ and inclusive D_s events, to access to a larger fraction of B_s^0 decays, but at the expense of a lower purity.

Experiment		Method	B_s^0 lifetime (ps)
ALEPH*[9]a	91/92	$31 \pm 7\ D_s^\pm \ell^\mp$	$1.90^{+0.46}_{-0.36} \pm 0.05$
DELPHI*[9]b	91/92	$19 \pm 5\ D_s^\pm \ell^\mp$	$1.29 \pm 0.42 \pm 0.20$
OPAL[9]c	91/92	$22/33\ D_s^\pm \ell^\mp$	$1.13^{+0.35}_{-0.26} \pm 0.09$
DELPHI[9]d	91	$31 \pm 11\ \phi\ell$	1.08 ± 0.73
		$17 \pm 5\ D_s \to \phi\pi$	$0.75^{+0.49}_{-0.33} \pm 0.22$
AVERAGE			1.49 ± 0.22

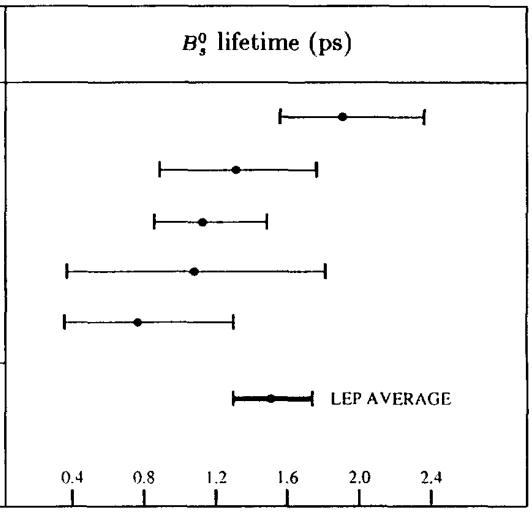


Fig. 17 : Summary of the results on B_s^0 lifetime measurement.

$$\begin{aligned} \tau(B_s^0) &= 1.49 \pm 0.22\ ps \quad LEP\ Average \\ \frac{\tau(\bar{B}_s^0)}{\tau(\bar{B}_d^0)} &= 1.00 \pm 0.01 \quad theoretical\ expectations \\ &= 1.00 \pm 0.17 \quad LEP Average \end{aligned} \tag{12}$$

In conclusion, it can be stressed that the B_s^0 lifetime is known with a precision of 15 %. It can be also noticed that the accuracy of measurement all the measurements is dominated by the statistical error. Furthermore, common systematic uncertainties coming from the D^{**} contribution are negligible in comparison with those induced by these particles in the $B^-/\bar{B}_d^0$ sector.

5. Λ_b^0 LIFETIME MEASUREMENT

$\Lambda^0\ell^-$ analysis

The privileged way to tag, up to now, the presence of Λ_b^0 baryons was to use $\Lambda^0\ell^-$ events (the diagram is illustrated in figure 18a).

The other processes which contribute to the $\Lambda^0\ell^-$ final state, in a jet, are :

- $\bar{B} \rightarrow \Lambda_c^+ \bar{N} \ell^- \bar{\nu} X$: the baryon production in semileptonic B meson decays. This contribution has different kinematical characteristics with respect to the signal because of the large mass of the produced hadronic system and thus can be reduced by asking for instance a high $\Lambda^0 \ell$ mass.

- Λ produced during the jet fragmentation and associated to a genuine or fake lepton.

  This process is expected to contribute in a similar way to the $\Lambda^0 \ell^-$ and to the wrong-sign $\Lambda^0 \ell^+$ samples. This equality is almost exact in the case of fake leptons whereas in the case of fake leptons is depending on the yield of baryon/antibaryon accompanying the B mesons and is experimentally verified at the 20 % level. In conclusion, the study of wrong-sign $\Lambda^0 \ell^+$ combinations directly on the data permits to control the rates and to study the time distributions of the most important backgrounds.

The characteristics of $\Lambda^0 \ell^-$ events are shown in Fig. 18b. There are two complications with respect to the previous measurements : the long decay length of the Λ^0 (several cm) and the fact that the Λ^0 is not directly coming from Λ_b^0.

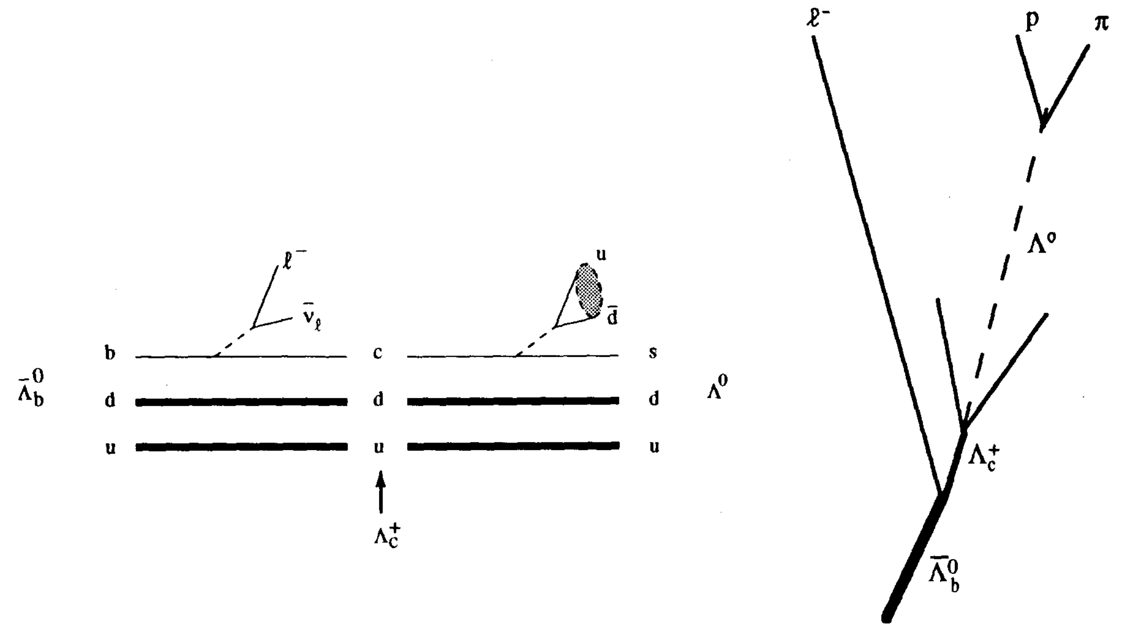


Fig. 18 : a) Diagram of the semiletonic $\bar{\Lambda}_b^0$ decay. b) Schematic picture of a $\Lambda^0 \ell^-$ event coming from a Λ_b^0 decay.

ALEPH and DELPHI Collaborations have also used events containing $\Lambda_c^+ \ell^-$ combinations. The advantage of this approach is the high purity in Λ_b^0 of these samples, but, at present it is limited by statistics. Fig. 19 shows the $p\pi$ invariant mass and the decay length distributions for $\Lambda - \ell$ candidates obtained by the OPAL Collaboration. Fig. 20

summarized the results on Λ_b^0 lifetime measurements.

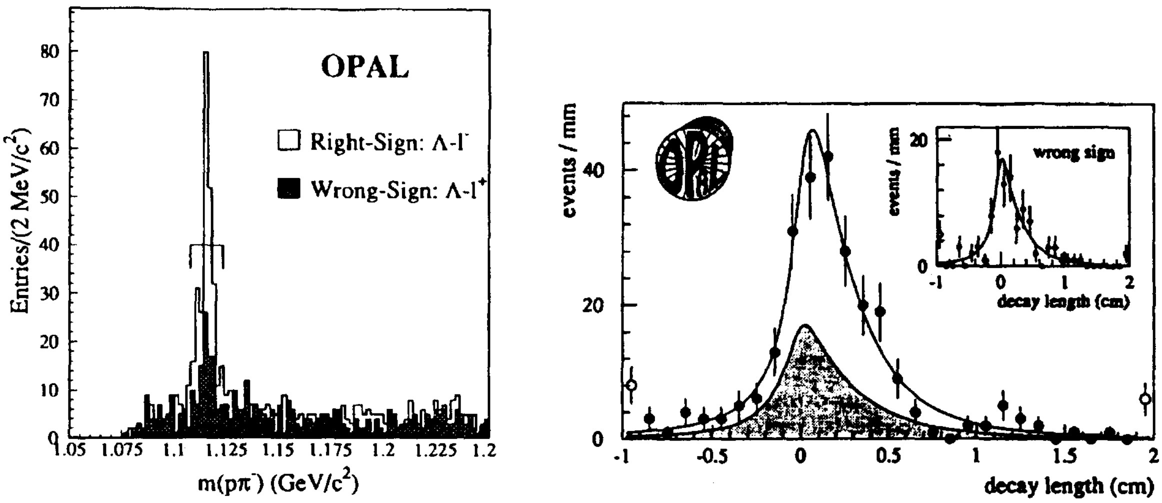


Fig. 19 : a) $\Lambda^0\ell^-$ events with $\Lambda^0 \to p\pi$. The hatched histogram corresponds to wrong-sign combinations ($\Lambda^0\ell^+$). b) decay length distribution of $\Lambda^0 - \ell$ candidates. The results are from the OPAL Collaboration.

Experiment	Year	Method	Λ_b lifetime (ps)
ALEPH[10]a	90/91	128 ± 28 $\Lambda\ell^-$	$1.12^{+0.32}_{-0.29} \pm 0.16$
DELPHI*[10]b	90/92	$20/40$ $(\Lambda\pi^+)\ell^-$	$0.68^{+0.36}_{-0.25} \pm 0.13$
OPAL[10]c	90/92	$157/261$ $\Lambda\ell^-$	$1.05^{+0.23}_{-0.20} \pm 0.08$
ALEPH*[10]d	91/92	$16/22$ $\Lambda_c^+\ell^-$	$1.16^{+0.42}_{-0.32} \pm 0.07$
DELPHI*[10]e	90/92	$12/18$ $\Lambda_c^+\ell^-$	$1.42^{+2.10}_{-0.60} \pm 0.30$
LEP AVERAGE			1.06 ± 0.15

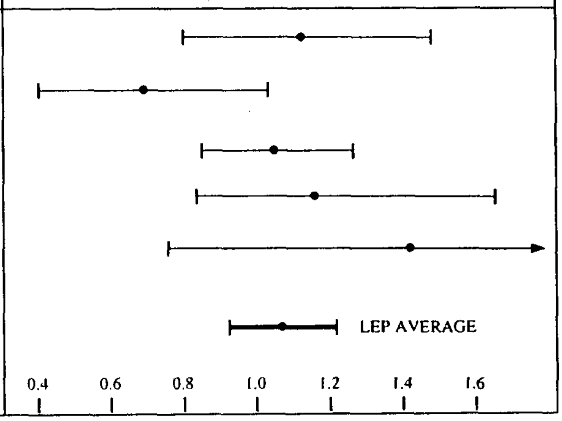


Fig. 20 : Summary of the measurement of the Λ_b^0 lifetime.

$$
\begin{aligned}
\tau(\Lambda_b^0) &= 1.06 \pm 0.15\ ps \quad \textit{LEP Average} \\
\frac{\tau(\Lambda_b^0)}{\bar{\tau}} &\simeq 0.9 \quad \textit{theoretical expectations} \\
&= 0.69 \pm 0.10 \quad \textit{LEP Average}
\end{aligned}
\qquad (13)
$$

The Λ_b^0 lifetime is known with a 15 % relative accuracy and all measurements are still dominated by statistical errors. The Λ_b^0 lifetime is expected to be lower than the average B hadron lifetime by about 10 %. The actual result is 2σ lower than this prediction.

6. CONCLUSIONS

Fig. 21 shows the summary of the B hadron lifetimes measured at LEP.

The B^+ and B_d^0 lifetimes are now known with a precision better than 10 %. Nevertheless, the error coming from the poor knowledge of the D^{**} sector which is common to all the measurements is starting to be dominating. A better knowledge of the D^{**} states is then needed both from experimental and theoretical points of view. A direct control of the D^{**} production in semileptonic B decay on the LEP data seems to be possible.

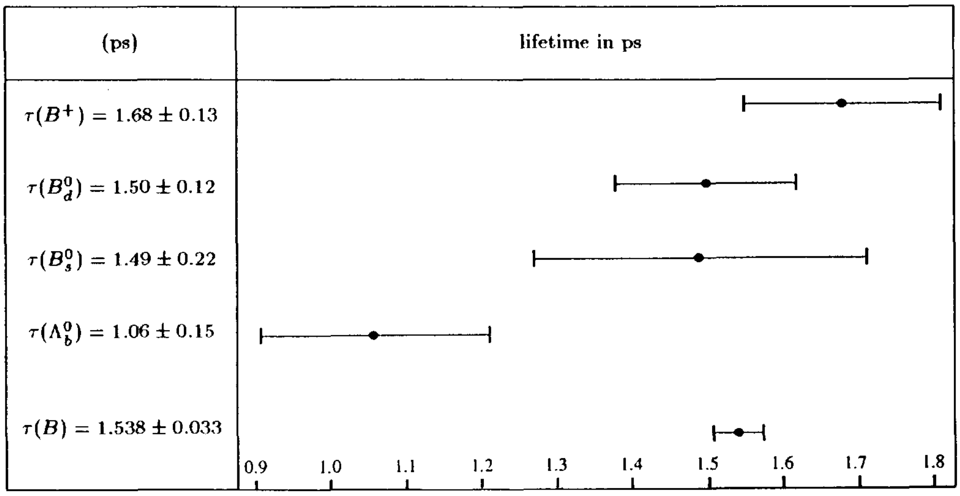


Fig. 21 : B hadrons lifetimes

A precision of 15 % has been reached both for B_s^0 and Λ_b^0 lifetimes ; the accuracy of these measurements is largely dominated by the statistical error.

No statistically significant difference has been measured among B meson lifetimes. On the contrary, the Λ_b^0 lifetime has been found to be 3σ lower than the average B lifetime.

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