Laboratoire de Physique Corpusculaire de Clermont-Ferrand

b **Physics**

Pascal Perret

Laboratoire de Physique Corpusculaire de Clermont-Ferrand
Université Blaise Pascal, IN2P3-CNRS
F-63177 Aubière cedex, FRANCE.

e-mail: Pascal.Perret@in2p3.fr

Abstract

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I INTRODUCTION

The heavy mass of the b quark, around 5 GeV, so much greater than the strong interaction scale $\Lambda_{QCD} \sim 0.2$ GeV and the fact that it belongs to the same isospin doublet than the top quark, confere a special role to the b quark studies. Furthermore the top quark is too heavy to build hadrons and thus b hadrons are the heaviest. In that respect, b physics is a broad subject and one of the major areas of investigation of present experiments at CESR, LEP, SLC and Tevatron colliders. Experimentally b hadrons are easier to observe or to disentagle from other sources because tracks issued from their decays have higher transverse momentum and momentum due to the high mass and the hard fragmentation of the b hadrons. The lifetime of b hadrons (~ 1 ps) is relatively long and the subsequent presence of secondary vertices in detector can be used as a tag; for instance the mean decay length is 3 mm at LEP. They have also sizeable semileptonic branching ratios which allow to sign b events with the presence of leptons, cleanly identified, in decay products. Specific theoretical framework can be used for the description of the properties of b hadrons such as Heavy Quark Effective Theory (HQET) where a b hadron is considered like a hydrogen atom, Heavy Quark Symmetry (HQS) in the limit $m_b \to \infty$ or Heavy Quark Expansion (HQE) which allows expansions in $1/m_b$.

The main issues in b physics are to provide precision tests in the electroweak sector of the Standard Model (SM), to study the decay dynamics, especially the effect of strong interactions on the underlying quark decay, to understand the origin of CP violation and to measure the magnitude of the CKM matrix elements $|V_{cb}|$, $|V_{ub}|$, $|V_{td}|$ and $|V_{ts}|$, and to observe rare processes which can probe physics

beyond the SM. A selection of subjects is reviewed and, due to space limitations, only a short summary is given. More extensive recent summaries can be found in [1–4]. Production in Z decays, lifetimes, B^0-$\overline{B^0}$ oscillations and decays are mainly discussed in the following. Most of the given averages are provided by LEP working groups [5–7].

In the field of beauty hadron spectroscopy, the main result is the observation and measurement of the B_c meson, by CDF at Tevatron, with a mass of $6.40\pm0.39\pm0.13$ Gev/c^2 and a lifetime of $0.46^{+0.18}_{-0.16} \pm 0.05$ ps. More details can be found in the presentation of J. Troconiz, where recent results from Tevatron are covered.

II B PRODUCTION IN Z DECAYS

The relative ease with which b quarks can be separated from other quark flavours and the availability of large Z^0 event samples allow precision tests of the Standard Model to be carried out using Z $\rightarrow b\bar{b}$ decays at e^+e^- colliders. By the end of the LEP I phase (1989-1995), each of the four LEP experiments had recorded approximately 3.8 10^6 Z $\rightarrow q\bar{q}$, including nearly 0.8 10^6 Z $\rightarrow b\bar{b}$ decays, while by the end of 1997 SLD at SLC had recorded approximately 0.3 10^6 Z $\rightarrow q\bar{q}$ with polarized beams.

$\boldsymbol{R_b}$: Due to the large mass of the b quark and the fact that it belongs to the same isospin doublet than the top quark, the Z-$b\bar{b}$ coupling is one of the most interesting windows in the search for new physics. The partial width ratio $R_b = \frac{\Gamma(Z \rightarrow b\bar{b})}{\Gamma(Z \rightarrow q\bar{q})}$ is sensitive to m_{top} via vertex corrections, while the corrections in α_s and m_H are suppressed in a first approximation. A precision measurement of R_b would therefore represent a unique test of the Standard Model and would provide significant constraints on possible new physics such as additional Higgs bosons or supersymmetry.

The first R_b measurements were done using leptons [14–17]. In inclusive charged lepton analyses, the preferred approach is to fit a two-dimensional distribution (p,p$_\perp$) for single lepton and dilepton events together, and extract simulatneously R_b with other parameters as for instance R_c or $\mathcal{B}(b \rightarrow \ell)$. Relatively large systematic errors remain due mainly to uncertainties in the modelling of the semileptonic decay of the b quark; these measurements were not precise enough to perform a stringent test. Then the informations from silicon vertex detector were used and thanks to the large statistics available, "double tagging" techniques, were applied. The double tagging technique exploits the fact that the b and $\bar{b}$ quarks are typically produced back to back, in separate hemispheres as defined by the thrust axis. A b quark tag is applied separately to each hemisphere in a sample of hadronic events and the total number of single and double-tagged events are measured. Assuming backgrounds from charm and light quark events and the correlations between the hemispheres from Monte Carlo, as well as R_c from its SM value, both R_b and the b tagging efficiency can be extracted from data. In 1995 the world average R_b showed a discrepancy with more than 3σ (dominated by systematics) from the SM, and it

TABLE 1. Summary of R_b results.

ALEPH [8]	mult	1992-95	$0.2159 \pm 0.0009 \pm 0.0011$
DELPHI [9]	mult	1994-95	$0.2166 \pm 0.0008 \pm 0.0009$
L3 [10]	mult	1994-95	$0.2179 \pm 0.0015 \pm 0.0026$
L3 [11]	shape	1991	$0.2223 \pm 0.0030 \pm 0.0064$
OPAL [12]	mult	1992-94	$0.2178 \pm 0.0014 \pm 0.0017$
SLD [13]	vtx mass	1993-97	$0.2158 \pm 0.0017 \pm 0.0014$
LEP [14–17]	leptons		$0.2227 \pm 0.0020 \pm 0.0025$
LEP + SLC	corrected for γ exchange		0.21732 ± 0.00087

was shown that charm systematics were a worry (exponential charm lifetime tail (D^+) is difficult to cut away) and so a b purity of 94 % was not enough controlled, as well as the understanding of the correlations. A new round of analyses has been performed [8–10,13]. An increased purity is achieved by exploiting b/c hadrons masses and kinematical differences, by including for instance the invariant mass of the significant tracks. The primary vertex was initially measured with all tracks of the event, including a correlation between hemispheres. Primary vertices were then reconstructed, one per hemisphere. Finally lifetime tag was used in conjunction with other tags; variables are combined in multivariate analyses (neural network for instance). With this kind of analyses, a purity greater than 98 % with an efficiency greater than 30 % has been achieved by DELPHI [9]. Measurements are summarised in table 1. The combined result [5], $R_b^0 = 0.21732 \pm 0.00087$, corresponds to a precision $\frac{\Delta R_b}{R_b} = 0.4\%$. The statistical and systematic errors are comparable, the latter receiving contributions mainly from uncertainties in gluon splitting $g \to b\bar{b}$ and $g \to c\bar{c}$, from the tracking resolution of the detector, and from hemisphere correlations.

Gluon splitting: The gluon splitting $g \to b\bar{b}$ is an important ingredient in the R_b measurement, constituting the largest single systematic uncertainty. New methods have been developed to measure this parameter by searching for b-tagged jets in 4 jet events. The 2 b-tagged jets have to form a small angle and the initial quarks are required to be in opposite hemispheres. DELPHI has measured $g \to b\bar{b}$ = $(0.21 \pm 0.11 \pm 0.09)\%$ [18] and ALEPH $(0.26 \pm 0.04 \pm 0.09)\%$ [19], the average being $(0.24 \pm 0.09)\%$.

b Asymmetry: The other electroweak quantity of interest is the forward backward charge asymmetry A_{FB}^b, obtained from measurements of the angular distribution $\frac{d\sigma}{d\cos\theta} \propto 1 + \cos^2\theta + \frac{3}{8}A_{FB}^b \cos\theta$; where θ is the angle of the outgoing b quark with respect to the initial e^- direction. The asymmetry A_{FB}^b arises from differences in the coupling strengths of the Z to left- and right-handed fermions, and is one of the most sensitive quantities to the effective electroweak mixing angle $\sin^2\theta_{\text{eff}}^{\text{lept}} = 1/4(1 - g_{V\ell}/g_{A\ell})$ [5]. To measure A_{FB}^b, one needs to select a b sample, to define the b quark direction (usually approximated by the thrust axis), and to estimate the electric charge of the quark to assign the b quark to the forward or backward

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TABLE 2. Summary of A_{FB}^b results at $\sqrt{s} \approx m_Z$.

ALEPH [20]	leptons	1990-95	$0.0965 \pm 0.0044 \pm 0.0026$
DELPHI [21]	leptons	1991-94	$0.1075 \pm 0.0077 \pm 0.0031$
L3 [22]	leptons	1990-95	$0.0963 \pm 0.0065 \pm 0.0035$
OPAL [23]	leptons	1990-95	$0.0910 \pm 0.0044 \pm 0.0020$
ALEPH [24]	jet-charge	1991-95	$0.1017 \pm 0.0038 \pm 0.0032$
DELPHI [21]	jet-charge	1991-94	$0.0995 \pm 0.0072 \pm 0.0040$
L3 [25]	jet-charge	1994	$0.0855 \pm 0.0118 \pm 0.0056$
OPAL [26]	jet-charge	1991-95	$0.1004 \pm 0.0052 \pm 0.0046$
LEP + SLD	$A_{FB}^{0,b}$	winter 98	0.0998 ± 0.0022

direction. Leptons are good candidates, high p and $p_\perp$ leptons come mainly from b quarks and their electric charge allows to identify the b quark hemisphere [20–23]. Tag of $Z \to b\bar{b}$ using a lifetime/mass tag and using a momentum weighted track charge in each hemisphere to flag the b quark is also performed [24,21,25,26]. Both approaches are still statistically limited and achieve a similar overall precision. $D^{*\pm}$ or $K^\pm$ tag can also be used but are less performing [21,27]. For instance, at SLD, $b\bar{b}$ events are tagged using a mass tag, while kaons from $b \to c \to s \to K$ are used to sign the b quark direction with their charge and direction. The main measurements are summarized in table 2, and the average of the pole asymmetry is $A_{FB}^{0,b} = 0.0998$ $\pm$ 0.0022 [5]. $A_{FB}^{0,b}$ can be expressed as a measurement of the effective angle $\theta_{\text{eff}}^{\text{lept}}$: $\sin^2 \theta_{\text{eff}}^{\text{lept}} = 0.23213 \pm 0.00039$.

III LIFETIMES

In the quark spectator model, the heavy quark decays weakly without interacting with the other light quark(s). As a result, all the hadrons containing a b quark should have the same lifetime. As in the case of the charm hadrons, non-spectator effects, such as final state interference, W exchange, weak annihilation and helicity suppression lead to significant differences in the lifetimes of beauty hadrons. In heavy quark expansion (HQE) theory, a theoretical approach based on QCD and where the decay rates of a beauty hadron are expressed as an expansion in powers of $1/m_b$, the lifetime difference of baryons and mesons depends on terms of the order of $1/m_b^2$ and higher, while the lifetime of the different B mesons depend on terms $1/m_b^3$ [29]. The following hierarchy among the various species $\tau_{\Lambda_b} < \tau_{B_d^0} \simeq \tau_{B_s^0} < \tau_{B^+}$ is expected [28], but it seems that corrections in "$\mathcal{O}(1/m_b^3)$" could be large in the ratio $\tau(B^+)/\tau(B^0)$ without model assumptions [30,31]. The experimental determination of the magnitude of these differences is needed.

To measure the proper lifetime of a B hadron, it is necessary to determine its decay length and its momentum. Several different and complementary methods have been developed to perform such measurements. Fully reconstructed beauty hadron

final states are the cleanest way. These measurements [32] benefit from the precise determination of the secondary vertex, and since there are no missing particles, the momentum is well determined. Consequently these measurements have little dependence on simulation. However this technique is limited at LEP/SLC due to the available statistics. Larger samples are obtained by using the presence of a high momentum lepton to select semileptonic b decays, and by fully or partially reconstructing a charm hadron of the appropriate charge in the same jet [32–39]. The vertex resolution is still good due to the lepton, but the missing products degrade the momentum resolution. These methods suffer also from higher background due to fake contaminations and the "pollution" of B^+ and B^0 cross-contamination for instance. Another approach is based on pure topological vertexing. b decay vertices are reconstructed inclusively and the b hadron charge is determined from the total charge of the tracks associated with its vertex [40,41]. This method gives the highest statistics at the expense of a reduced purity and a greater sensitivity to the modelling simulation. Some measurements of the b lifetime over all hadron species are based on the impact parameters of tracks from b decays, generally leptons. The knowledge of the b fragmentation and of the semileptonic decay models systematically limits the accuracy of these measurements.

There are many lifetime measurements, their average [6] is given in table 3. Lifetime ratios are known experimentally close to 5% and the lifetime hierarchy among beauty hadrons is predicted correctly. No significant differences between the three B mesons lifetimes are observed and they are in good agreement with HQE predictions. However the ratio $\tau(b - \text{baryon})/\tau(B^0)$ is significantly different from unity [37,38,33,42] and smaller than usual predictions. This is correlated with a small semileptonic b-baryon semileptonic branching ratio (see below), and is the place of an intensive work.

TABLE 3. World average lifetime measurements and their ratio. Predictions are given in the last column.

$\tau(B^+)$	1.67 ± 0.04 ps	$\tau(B^+)/\tau(B^0)$	1.07 ± 0.04	1.0 - 1.1
$\tau(B^0)$	1.57 ± 0.04 ps			
$\tau(B_s)$	1.48 ± 0.06 ps	$\tau(B_s)/\tau(B^0)$	0.95 ± 0.05	0.99 - 1.01
$\tau(\Lambda_b)$	1.23 ± 0.08 ps	$\tau(\Lambda_b)/\tau(B^0)$	0.78 ± 0.06	0.9 - 1.0
$\tau(b - \text{baryon})$	1.22 ± 0.05 ps	$\tau(b - \text{baryon})/\tau(B^0)$	0.78 ± 0.04	0.9 - 1.0
$\tau(b)$	1.554 ± 0.013 ps			

IV B^0-$\overline{B^0}$ OSCILLATIONS

In the Standard Model, particle-anti-particle oscillations take place via a second order weak interaction process - box diagram - with a loop of W bosons and up-type quarks, which are dominated by top quark exchange in the case of neutral B

mesons. The oscillation frequency depends on the mass difference Δm_q between the mass eigenstates. Time integrated measurements are performed, they are typically based on counting same-sign and opposite-sign lepton pairs. At LEP both neutral B meson species are produced with a rate $f_{B_d^0}$ and $f_{B_s^0}$ (see below), and the LEP average is $\overline{\chi} = f_{B_d^0}\chi_d + f_{B_s^0}\chi_s = 0.1214 \pm 0.0043$ [5], while CLEO and ARGUS, at the $\Upsilon(4s)$ where only B_d^0 mesons are produced, measured $\chi_d^{\Upsilon(4s)} = 0.156 \pm 0.024$ [43].
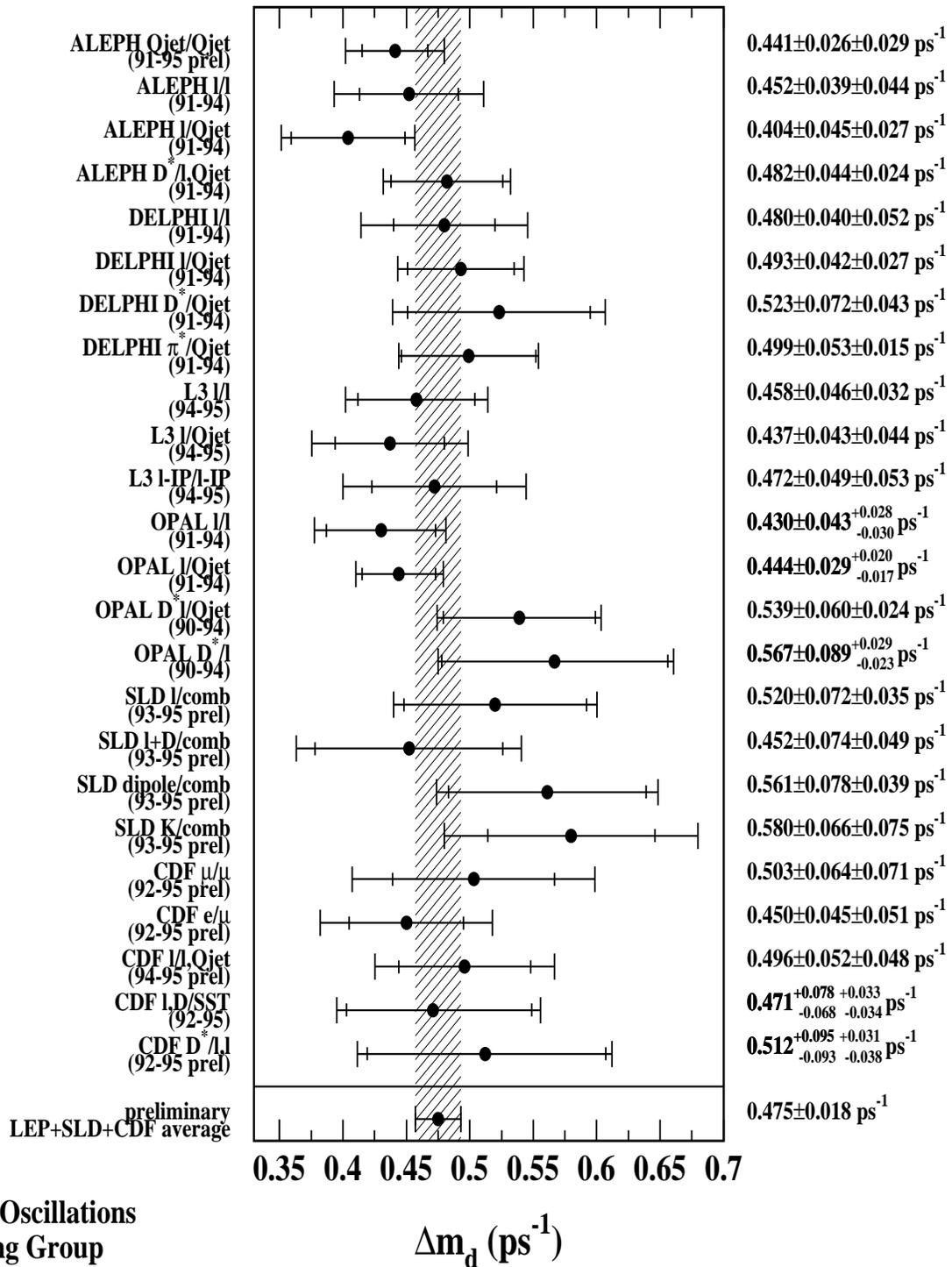
To measure the time dependence of the mixing, one needs to know the b flavour at production time and at decay time to define whether a mixing occured or not, as well as the B decay length and energy to reconstruct the proper decay time. Many different methods have been developed for this purpose. The final state tag is given by the charge of the decay products (lepton, $D^{*\pm}$, $D_s^\pm$ or $K^\pm$ [44]). For fully inclusive analyses based on topological vertexing, the final state tagging techniques include jet charge [45] and charge dipole methods [44]. For the initial flavour state, we can distinguish tags which exploit the B hadron decay in the opposite hemisphere using the charge of a lepton or a kaon, and those which exploit informations of the B candidate itself. These later one use the charge of a track from the primary vertex which is correlated with the production state of the B if that track is a decay product of a B^{**} state or if it is the first particle in the fragmentation chain [46,47]. The jet charge techniques work on both sides. At SLC, the beam polarization produces a sizeable forward-backward asymmetry in the $Z \to b\bar{b}$ decays and provides another very interesting and effective initial state tag, based on the polar angle of the B candidate [44].

A lot of different analyses have been performed to measure Δm_d [32,44–46,49–53]. An overview is shown in figure 1. Averaging all direct Δm_d measurements from LEP, SLD and CDF, yields $0.475 \pm 0.018 \text{ps}^{-1}$ [7]. The systematic uncertainties are not negligible; they are often dominated by the sample composition, mistag probability, or b hadron lifetime contributions. Including CLEO and ARGUS measurements of χ_d [43] give the world averages [7]: $\Delta m_d^{\text{world}} = 0.466 \pm 0.018 \text{ ps}^{-1}$ and $\chi_d^{\text{world}} = 0.174 \pm 0.011$.
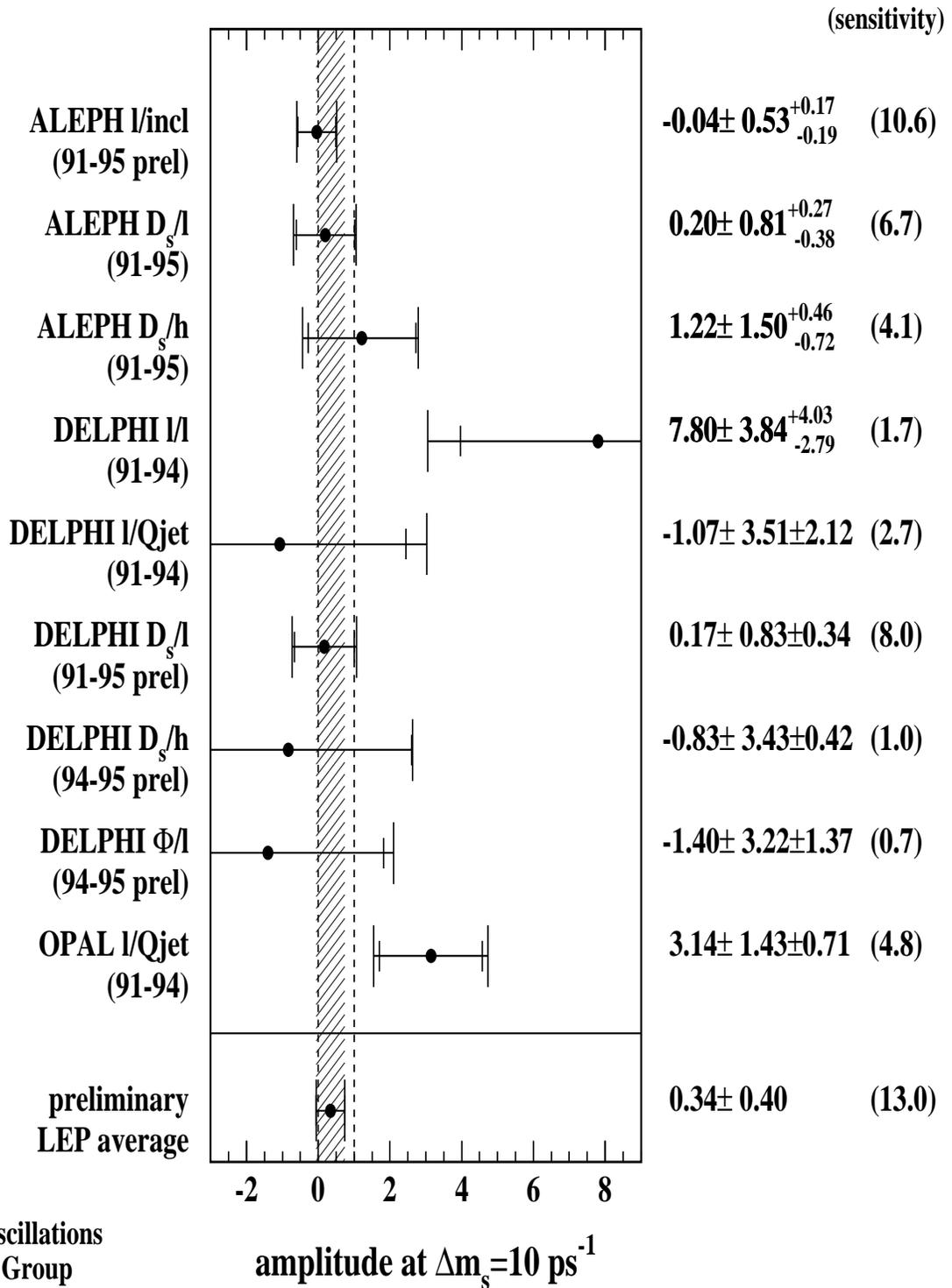
The B_s^0 oscillations have been the subject of many recent studies [47–49]. However, the B_s^0 mixing proceeds much faster than the B_d^0 mixing, and the time evolution has not been resolved. Only lower limits are derived, and an overview of the available sensitivities is given in figure 2. The combined 95% Confidence Level (C.L.) limit, derived from the amplitude method [54], is $\Delta m_s > 10.2 \text{ps}^{-1}$ [7].

The measurement of Δm_d and Δm_s are related, in the Standard Model, to the CKM matrix elements V_{td} and V_{ts} respectively. From Δm_d one gets $|V_{td}| = (8.8 \pm 0.2_{\Delta m_d} \mp 0.2_{m_t} \mp^{1.4}_{1.8th}) \times 10^{-3}$, with an uncertainty completely dominated by theoretical uncertainties. However, many uncertainties cancel in the frequency ratio, yelding $|V_{ts}|/|V_{td}| > 3.8$ at 95% C.L.

The B_s^0 and b baryon fractions can be extracted from branching ratio measurements. The LEP B oscillations working group estimates [7] $f_{\text{b-baryon}} = (10.6^{+3.7}_{-2.7})\%$ and $f_{B_s^0} = (10.8^{+3.3}_{-2.9})\%$. $\Delta m_d^{\text{world}}$ and χ_d^{world} can be used to improve our knowledge on

ALEPH Qjet/Qjet
(91-95 prel)
$0.441\pm0.026\pm0.029$ ps^{-1}

ALEPH l/l
(91-94)
$0.452\pm0.039\pm0.044$ ps^{-1}

ALEPH l/Qjet
(91-94)
$0.404\pm0.045\pm0.027$ ps^{-1}

ALEPH D*l,Qjet
(91-94)
$0.482\pm0.044\pm0.024$ ps^{-1}

DELPHI l/l
(91-94)
$0.480\pm0.040\pm0.052$ ps^{-1}

DELPHI l/Qjet
(91-94)
$0.493\pm0.042\pm0.027$ ps^{-1}

DELPHI D*/Qjet
(91-94)
$0.523\pm0.072\pm0.043$ ps^{-1}

DELPHI π^*/Qjet
(91-94)
$0.499\pm0.053\pm0.015$ ps^{-1}

L3 l/l
(94-95)
$0.458\pm0.046\pm0.032$ ps^{-1}

L3 l/Qjet
(94-95)
$0.437\pm0.043\pm0.044$ ps^{-1}

L3 l-IP/l-IP
(94-95)
$0.472\pm0.049\pm0.053$ ps^{-1}

OPAL l/l
(91-94)
$0.430\pm0.043^{+0.028}_{-0.030}$ ps^{-1}

OPAL l/Qjet
(91-94)
$0.444\pm0.029^{+0.020}_{-0.017}$ ps^{-1}

OPAL D*l/Qjet
(90-94)
$0.539\pm0.060\pm0.024$ ps^{-1}

OPAL D*/l
(90-94)
$0.567\pm0.089^{+0.029}_{-0.023}$ ps^{-1}

SLD l/comb
(93-95 prel)
$0.520\pm0.072\pm0.035$ ps^{-1}

SLD l+D/comb
(93-95 prel)
$0.452\pm0.074\pm0.049$ ps^{-1}

SLD dipole/comb
(93-95 prel)
$0.561\pm0.078\pm0.039$ ps^{-1}

SLD K/comb
(93-95 prel)
$0.580\pm0.066\pm0.075$ ps^{-1}

CDF μ/μ
(92-95 prel)
$0.503\pm0.064\pm0.071$ ps^{-1}

CDF e/μ
(92-95 prel)
$0.450\pm0.045\pm0.051$ ps^{-1}

CDF l/l,Qjet
(94-95 prel)
$0.496\pm0.052\pm0.048$ ps^{-1}

CDF l,D/SST
(92-95)
$0.471^{+0.078}_{-0.068}{}^{+0.033}_{-0.034}$ ps^{-1}

CDF D*/l,l
(92-95 prel)
$0.512^{+0.095}_{-0.093}{}^{+0.031}_{-0.038}$ ps^{-1}

preliminary
LEP+SLD+CDF average
0.475 ± 0.018 ps^{-1}

0.35 0.4 0.45 0.5 0.55 0.6 0.65 0.7

**LEP B Oscillations
Working Group**

Δm_d (ps^{-1})

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FIGURE 1. Measurements of Δm_d.

FIGURE 2. Sensitivities on Δm_s.

the fractions of weakly decaying bottom hadron in $Z \to b\bar{b}$ events. If one assumes also $\chi_s = 1/2$ and $f_{B^0} = f_{B^+} = (1 - f_{B^0_s} - f_{\text{b-baryon}})/2$, another estimate of $f_{B^0_s}$ can be extracted from χ_d^{world}, from the inclusive integrated mixing rate $\overline{\chi}$ measured at LEP, from the $f_{\text{b-baryon}}$ branching ratios estimate and from the b hadron lifetimes. Combining all the informations yields $f_{B^0_s} = (10.3^{+1.6}_{-1.5})\%$, $f_{\text{b-baryon}} = (10.6^{+3.7}_{-2.7})\%$ and $f_{B^0} = f_{B^+} = (39.5^{+1.6}_{-2.0})\%$. These results, including $\Delta m_d^{\text{world}}$, have been obtained by the LEP B oscillations working group in a consistent way. There are also new measurements of $f_{\text{b-baryon}} = (10.2 \pm 0.7 \pm 2.7)\%$ from ALEPH [55] and of $f_{B^0_s} = (10.8 \pm 1.3 \pm 2.2)\%$ from DELPHI [56] (from $f_{B^0_s + B^{**}_s} = (14.4 \pm 1.7 \pm 3.0)\%$ and assuming $f_{B^0_s}/(f_{B^0_s} + f_{B^{**}_s}) = 0.25 \pm 0.05$) . Including these measurements yields to $f_{B^0_s} = (10.4^{+1.4}_{-1.3})\%$, $f_{\text{b-baryon}} = (10.4^{+2.2}_{-1.9})\%$ and $f_{B^0} = f_{B^+} = (39.6^{+1.2}_{-1.4})\%$. DELPHI has also a preliminary measurement [56] of the rate of charged and neutral weak B hadrons: $\mathcal{B}(b \to X^0_B) = (57.8 \pm 0.5 \pm 1.0)\%$, $\mathcal{B}(b \to X^\pm_B) = (42.2 \pm 0.5 \pm 1.0)\%$.

V   DECAYS

A b decay multiplicity

There are two new measurements of the mean charged multiplicity in b-hadron decays at the Z, with much smaller systematic uncertainties than previous measurements. L3 has measured $< n_b > = 4.90 \pm 0.04 \pm 0.11$ [42]; while DELPHI found $< n_b > = 4.97 \pm 0.03 \pm 0.06$ [57].

B   semileptonic branching ratio

From the experimental point of vue, semileptonic branching ratios are accessible. They are relatively large and leptons have clean signatures. Furthermore all detectors have good lepton identification device. From the theoretical point of vue, despite strong interactions are quite important in these decays, they allow detailed theoretical predictions that can be tested experimentally. It is why they are among the most extensively studied decays.

At LEP, old analyses were done by performing a multi-parameter fit in the $(p, p_\perp)$ lepton spectrum [14,15,64]. The 4 electroweak heavy quark flavours parameters R_b, R_c, A^b_{FB}, A^c_{FB} can all be measured simultaneously, with the following parameters: χ, $\mathcal{B}(b \to \ell)$, $\mathcal{B}(b \to c \to \ell)$, $\mathcal{B}(c \to \ell)$, b, and c fragmentation parameters. Some collaborations have separate fits for smaller sets of parameters, and restrict to a $p_\perp$ region to enrich the sample in b. ALEPH has developed new techniques, first presented in 1995 [58], to measure more accurately $\mathcal{B}(b \to \ell)$ and $\mathcal{B}(b \to c \to \ell)$ using information from the silicon vertex detector. Events are split into 2 hemispheres, and a cut on the lifetime tag probability [59] is imposed on all hemispheres to prepare a very pure sample of $Z \to b\bar{b}$ events. Typically, a purity of 96 % in b events can be achieved with an efficiency of 25 %. Then the opposite

hemisphere a tagged hemisphere is used as an unbiased sample of b decays. A clear kinematic distinction allows to disentangle the $b \to \ell$ at high $p_\perp$ from $b \to c \to \ell$ at low $p_\perp$. While single leptons are sufficient to extract $\mathcal{B}(b \to \ell)$ and $\mathcal{B}(b \to c \to \ell)$, by performing a fit in the $p_\perp$ plane, the opposite-side dilepton sample , which is naturally enriched in b decays, is also used to measure at the same time the b fragmentation and the mixing parameter χ, taking advantage of the charge correlations. The charge correlations allow also to reduce the model dependence. Although the uncertainty from the semileptonic decay models is still dominant, it has been reduced nearly by a factor 2. This new analysis provides some significant improvements in systematic uncertainties thanks to the use of a very pure sample of b events, which suppresses the charm and light quark contributions, and to the fact that $\mathcal{B}(b \to \ell)$ is independent of R_b by construction.

DELPHI has performed the same kind of analysis, measuring $\mathcal{B}(b \to \ell)$, $\mathcal{B}(b \to c \to \ell)$ and χ [60]. And, OPAL has now, for this winter, an analysis of this type [64]. They use single muon sample only and a neural net to improve the discrimination between $b \to \ell$ and $b \to c \to \ell$. A measurement of $\mathcal{B}(b \to \ell)$ and $\mathcal{B}(b \to c \to \ell)$ is obtained. All LEP measurements of $\mathcal{B}(b \to \ell)$ and $\mathcal{B}(b \to c \to \ell)$ are summarized in table 4.

The new LEP average value [5] of $\mathcal{B}(b \to \ell)$ is 0.1104 ± 0.0019, while the $\Upsilon(4s)$ average is 0.1045 ± 0.0021 [2]. The discrepancy between these two numbers is 0.0059 ± 0.0028 corresponding to $2.1\ \sigma$. Furthermore, beauty baryons are produced at LEP and not at the $\Upsilon(4s)$ and their semileptonic branching ratio is smaller (this will be seen later). Consequently the LEP average is expected to be lower than the $\Upsilon(4s)$ result, contrary to the observed pattern. If we consider only the last measurements of $\mathcal{B}(b \to \ell)$, obtained with a new kind of method and corresponding to a second generation of $\mathcal{B}(b \to \ell)$ measurements [58,60,64] which are less model dependent, the Z average becomes $\mathcal{B}(b \to \ell)^Z = 0.1094 \pm 0.0030$, to be compared with $\Upsilon(4s)$ [65,66] average of $\mathcal{B}(b \to \ell)^{\Upsilon(4s)} = 0.1018 \pm 0.0040$ [2]. The discrepancy decrease to $1.5\ \sigma$.

TABLE 4. $\mathcal{B}(b \to \ell)$ and $\mathcal{B}(b \to c \to \ell)$ measurements (in %) at LEP.

	$\mathcal{B}(b \to \ell)$	$\mathcal{B}(b \to c \to \ell)$
ALEPH [14]	$11.2 \pm 0.3 \pm 0.4$	$8.8 \pm 0.3 \pm 0.8$
ALEPH [58]	$11.0 \pm 0.1 \pm 0.3$	$7.7 \pm 0.2 \pm 0.5$
DELPHI [15]	$11.3 \pm 0.5 \pm 0.7$	$7.9 \pm 0.5 \pm 1.2$
DELPHI [60]	$10.6 \pm 0.1 \pm 0.4$	$8.3 \pm 0.3 \pm 0.8$
L3 [61]	$11.4 \pm 0.5 \pm 0.4$	-
L3 [62]	$10.7 \pm 0.1 \pm 0.4$	-
OPAL [63]	$10.6 \pm 0.6 \pm 0.7$	$8.4 \pm 0.4 \pm 0.7$
OPAL(n) [64]	$10.9 \pm 0.1 \pm 0.5$	$9.9 \pm 0.3 \pm 1.3$
LEP Average	11.04 ± 0.19	8.07 ± 0.34

Historically, theoretical predictions of the semileptonic b branching ratio have been significantly larger than the measured values. Traditionally $\mathcal{B}(b \to \ell)^{\text{TH}} \geq 12.5\%$ [67], which disagrees with the experimental values. Various aspects of this problem have been scrutinized. The inclusive semileptonic b branching ratio is defined as:

$$\mathcal{B}(b \to \ell) = \frac{\Gamma_{\text{semi-leptonic}}}{\Gamma_{\text{semi-leptonic}} + \Gamma_{\text{hadronic}} + \Gamma_{\text{leptonic}}}$$

with $\Gamma_{\text{hadronic}} = \Gamma(b \to c\bar{u}d) + \Gamma(b \to c\bar{c}s) + \Gamma(b \to \text{no charm})$ and $\Gamma(b \to \text{no charm}) = \Gamma(b \to s(d)\gamma) + \Gamma(b \to s(d)g) + \Gamma(b \to u\bar{u}d)$.

Solutions of the problem consist to find a way to increase the theoretical hadronic rate. Theoretical possible solutions are that where there could be an enhancement of:

- $\Gamma(b \to c\bar{u}d)$ due to non perturbative effects. But, in the same time, these models predict $\tau_{B^+}/\tau_{B^0} \simeq 0.8$ [68] which is in desagreement with the experimental lifetime ratio of 1.07 ± 0.04 previously presented in table 3.

- $\Gamma(b \to c\bar{c}s)$ due to large higher order QCD corrections [69–71]. In the same time, these models affect the average number of charm quarks per b decay, n_c, which consequently has to be also measured experimentally (see later).

- $b \to$ no open charm, which could be a sizable fraction of $b \to c\bar{c}s$ transitions [72]. The hypothesis is that a large component of low mass $c\bar{c}$ pairs are seen as light hadrons and not as open charm. n_c would not be increased by this mechanism.

- $\Gamma(b \to \text{no charm})$ e.g. large $\mathcal{B}(b \to s\gamma)$ or $\mathcal{B}(b \to sg)$, from some sources of new physics.

charm counting : Classical charm counting experiments consist in measuring the rates of the weakly decaying charm hadrons in selected b events. The $\Upsilon(4s)$ branching ratio are from CLEO [73–75] giving $n_c^{\Upsilon(4s)} = 1.119 \pm 0.053$. LEP measurements are from ALEPH [76] $n_c = 1.230 \pm 0.036 \pm 0.038 \pm 0.053$ and from OPAL [77] $n_c = 1.061 \pm 0.045 \pm 0.060 \pm 0.037$, where the last error is due to D branching ratio, largely correlated between the experiments. A main difference between the experiments are assumptions made about the unmeasured Ξ_c contribution, which is set to 0 in the case of OPAL, whereas ALEPH estimates it to be 0.063 ± 0.021. Accepting this last estimate and including also DELPHI measurements of D^0 and D^+ rates [78], the average result is $n_c^Z = 1.202 \pm 0.067$ [2,4].

New methods have been developed to estimate n_c which can be written as: $n_c = 1 + \mathcal{B}(B \to D\bar{D}) + \mathcal{B}(B \to \text{"hidden"} c\bar{c}) - \mathcal{B}(B \to \text{no } c)$, where the "hidden" $c\bar{c}$ is the contribution of bound states (e.g. J/ψ). DELPHI has determined the fraction of b decays into 0,1 and 2 charmed hadrons thanks to an analysis of the hemisphere b tagging probability distribution in terms of Monte Carlo expectations of the three components [79]. They have measured: $\mathcal{B}(b \to 2\,c) = 0.136 \pm 0.042$ and

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$\mathcal{B}(b \to 0 \, c) = 0.033 \pm 0.021$. Substracting the hidden charm contribution of 0.026 ± 0.004 [73,80] yields a charmless B branching ratio without hidden charm of $\mathcal{B}(b \to$ no charm$) = 0.007 \pm 0.021$, to be compared with the Standard Model expectation of 0.016 ± 0.008 [81]. Imposing this SM value they have measured $n_c = 1.147 \pm 0.041 \pm 0.008$. An upper limit at 95% CL on new physics in charmless B decays is derived: $\mathcal{B}(b \to$ no charm$)^{\text{New}} < 0.037$. In another study, correlations of identified charged kaons with inclusively reconstructed D mesons were analysed [82]. A fit of the transverse momentum spectra of same and opposite sign K(extra)K(from D) samples has given $\mathcal{B}(b \to 2 \, c) = 0.170 \pm 0.035 \pm 0.032$ and $\mathcal{B}(b \to \bar{D}D_s X)/\mathcal{B}(b \to 2 \, c) = 0.84 \pm 0.16 \pm 0.09$.

CLEO has selected high momentum leptons, has studied D-lepton angular and charge correlations and has looked for wrong sign D [83]. They have measured the ratio of "upper vertex" charm to "lower vertex" charm : $\mathcal{B}(B \to DX)/\mathcal{B}(B \to \bar{D}X) = 0.100 \pm 0.026 \pm 0.016$. From that the number of D's produced at the upper vertex in B decays $\mathcal{B}(B \to DX) = 0.079 \pm 0.022$ is derived, as well as $\mathcal{B}(b \to c\bar{c}s) = 0.219 \pm 0.036$ and $n_c = 1.204 \pm 0.037$.

ALEPH has performed an inclusive analysis looking for doubly-charmed B decays, $B \to D\bar{D}(X)$, where D can be either a D^0, D^+, D^{*+} or a D_s, with both charmed mesons reconstructed [84]. The following branching ratios were measured:

$$
\begin{aligned}
\mathcal{B}(\text{b} \to \text{D}_s\text{D}^0, \text{D}_s\text{D}^\pm(X)) &= (13.1^{+2.6}_{-2.2}(\text{stat})^{+1.8}_{-1.6}(\text{syst})^{+4.4}_{-2.7}(\mathcal{B}_\text{D}))\% \\
\mathcal{B}(\text{b} \to \text{D}^0\bar{\text{D}}^0, \text{D}^0\text{D}^\pm(X)) &= (7.8^{+2.0}_{-1.8}(\text{stat})^{+1.7}_{-1.5}(\text{syst})^{+0.5}_{-0.4}(\mathcal{B}_\text{D}))\% \\
\mathcal{B}(\text{b} \to \text{D}^\pm\text{D}^\mp(X)) &< 0.9\% \text{ at } 90\% \text{ C.L.}
\end{aligned}
$$

providing the first evidence for doubly-charmed B decays involving no D_s production. The sum of the inclusive DD rates is:

$$(20.9^{+3.2}_{-2.8}(\text{stat})^{+2.5}_{-2.2}(\text{syst})^{+4.5}_{-2.8}(\mathcal{B}_\text{D}))\% \text{ leading to } n_c = 1.219 \, ^{+0.061}_{-0.045}.$$

An evidence for associated K^0_S and $\text{K}^\pm$ production in the decays $B \to \bar{\text{D}}\text{D}(X)$ was also found $\mathcal{B}(\text{B} \to \bar{\text{D}}^{(*)}\text{D}^{(*)}\text{K}) = (7.1^{+2.5}_{-1.5}(\text{stat})^{+0.9}_{-0.8}(\text{syst}) \pm 0.5(\mathcal{B}_\text{D}))\%$. which showed that $B \to \bar{\text{D}}^{(*)}\text{D}^{(*)}\text{K}$ is a large part of $B \to \bar{\text{D}}\text{D}(X)$ ($\approx 70\%$).

If previous n_c measurements could show some discrepancies between results obtained at LEP and at lower energy, the agreement is now better. Combining all these measurements leads to the world average $n_c = 1.178 \pm 0.021$.

$b \to s\gamma$: The flavour changig neutral current decay $b \to s\gamma$ has been seen in both exclusive and inclusive channels. The exclusive decay $B \to K^*\gamma$ has been measured by CLEO [85] $\mathcal{B}(B \to K^*\gamma) = (4.2 \pm 0.8 \pm 0.6) \, 10^{-5}$ and ALEPH has placed an upper limit on the $B_s \to \Phi\gamma$ penguin decays [86] $\mathcal{B}(B_s \to \Phi\gamma) < 29 \, 10^{-5}$ at 90% CL. CLEO has first observed the inclusive electromagnetic penguin decay [87] $\mathcal{B}(b \to s\gamma) = (2.32 \pm 0.57 \pm 0.35) \, 10^{-4}$ while ALEPH has published the first result at LEP. The signal was isolated in lifetime-tagged $b\bar{b}$ events by the presence of a hard photon associated with a system of a high momentum and rapidity hadrons [88]. $\mathcal{B}(b \to s\gamma) = (3.11 \pm 0.80 \pm 0.72) \, 10^{-4}$ was measured. The average of these two measurements is $(2.54 \pm 0.57) \, 10^{-4}$, consistent with the Standard Model expectation via penguin processes $(3.76 \pm 0.30)10^{-4}$ [89].

$b \to sg$: Large rates of $b \to sg$ [90] would show up an extra sources of charged kaons, especially visible at high momentum in the B rest frame. DELPHI has looked for a high $p_\perp$ kaon, identified with their RICH or dE/dX in the TPC in b tagged events [82], and derived an upper limit $\mathcal{B}(b \to sg) < 0.05$ at 95% C.L. In their wrong sign charm paper CLEO [83] has derived also $\mathcal{B}(b \to sg) < 0.068$ at 90% C.L.

To summarize, theoretical predictions on $\mathcal{B}(b \to \ell)$ can accommodate with lower value as predicted in the framework of $1/m_Q$ expansions with higher order perturbative QCD corrections. In these models the rate $b \to c\bar{c}s$ is increased while $\mathcal{B}(b \to \ell)$ is decreased. This is in agreement with the experimental situation. Other models, which predict new physics for instance, are disfavoured.

b-baryon semileptonic branching ratio : By determining the ratio $R_{\Lambda\ell} = \mathcal{B}(\Lambda_b \to \Lambda\ell^-X)/\mathcal{B}(\Lambda_b \to \Lambda X) = 0.070 \pm 0.012 \pm 0.007$ [91], using $\Lambda - \ell$ correlations, OPAL has a measurement of the Λ_b semileptonic branching ratio. ALEPH, on this side, has a measurement of the b-baryon semileptonic branching ratio, using $p - \ell$ correlations, by determining $R_{p\ell} = \mathcal{B}(b - \text{baryon} \to p\ell X)/\mathcal{B}(b - \text{baryon} \to pX) = 0.080 \pm 0.012 \pm 0.014$ [55]. Both can be assumed to be very similar to $\mathcal{B}(b - \text{baryon} \to \ell)$. They are significantly lower than the average $\mathcal{B}(b \to \ell)$. Combining them we get $\mathcal{B}(b - \text{baryon} \to \ell) = 0.074 \pm 0.011$. This confirms that light quarks play a significant role in the decay of b-baryons, as suggested by the short b-baryon lifetime measurements presented earlier. When correlated with this short lifetime, the agreement between the ratios $\tau_{b-\text{baryon}}/\tau_{B_d^0} = 0.78 \pm 0.04$ and $\mathcal{B}(b - \text{baryon} \to \ell)/\mathcal{B}(b \to \ell) = 0.67 \pm 0.10$ is consistent with the hypothesis of a constant semileptonic decay width for all b-hadrons.

$b \to \tau\nu_\tau(X)$: The study of this channel is interesting because the decay could proceed by a W or a Higgs boson. Thus a measurement of this decay channel could be sensitive to new physics, for example supersymmetry where two Higgs doublets are introduced. The SM prediction for $\mathcal{B}(b \to \tau\nu_\tau X)$ is $(2.30 \pm 0.25)\%$ [92], and its measurement limits the ratio $\tan\beta/m_{H^\pm}$, where $\tan\beta$ is the ratio of the vacuum expectation values for the Higgs fields and $m_{H^\pm}$ is the mass of the charged Higgs boson. DELPHI has performed a new measurement [93]. First b-tagging is used to obtain a sample of $Z \to b\bar{b}$ events. Then the events are required to have large missing energy and no electron or muon candidates. The result $\mathcal{B}(b \to \tau\nu_\tau X) = (2.52 \pm 0.23 \pm 0.49)\%$ is obtained, consistent with previous measurements from ALEPH: $(2.58 \pm 0.19 \pm 0.33)\%$ [94], L3: $(1.7 \pm 0.5 \pm 1.1)\%$ [95], and OPAL: $(2.58 \pm 0.11 \pm 0.51)\%$ [97]. The LEP average is $(2.52 \pm 0.26)\%$.

The fully leptonic $b \to \tau\nu_\tau$ decay is also very interesting. The expected branching ratio in the SM is $6\ 10^{-5}$, however with large uncertainty. Because of helicity conservation the rates are proportional to the square of the lepton mass. The purely leptonic decays to e and μ are expected to have the following branching ratios: $\mathcal{B}(b \to e\nu_e) = 5\ 10^{-12}$ and $\mathcal{B}(b \to \mu\nu_\mu) = 2\ 10^{-7}$. No signal of $B \to \tau\nu_\tau$ decays is observed and upper limits are given at 90% CL: $\mathcal{B}(b \to \tau\nu_\tau) < 1.6\ 10^{-3}$ from ALEPH [94], $1.1\ 10^{-3}$ from DELPHI [93] and $5.7\ 10^{-4}$ from L3 [96]. From

this last limit the best constraint $\tan\beta/m_{H^\pm} < 0.38$ at 90% CL is obtainbed.

C $\quad |V_{cb}|$ measurements

There are two main approaches to determine the magnitude of the CKM matrix element $|V_{cb}|$, either from inclusive semileptonic B decays or from exclusive channels such as $B \to D^{(*)}\ell\nu$.

The first one uses the measurement of the inclusive b semileptonic branching ratio and has the advantage of great statistical power. Treating the b quark as a free particle, its semileptonic partial width is

$$\Gamma(b \to c\ell\nu) = \frac{G_F^2\, m_b^5}{192\,\pi^3}\,\Phi\,|V_{cb}|^2 \equiv \alpha\,|V_{cb}|^2 = \frac{\mathcal{B}(b \to c\ell\nu)}{\tau_b}$$

where Φ is a phase space factor. The theoretical dominant uncertainties is dominated by the knowledge of the correction due to the binding of the b quark into a hadron, and the b quark mass dependence. Recent calculations [98], using HQET in combination with the technique of Operator Product Expansion, have rather small uncertainty and show that they are now under better control. $|V_{cb}|$ is then given by:

$$|V_{cb}| \;=\; 0.0419\sqrt{\frac{\mathcal{B}(B \to X_c\ell\bar{\nu})}{0.105}}\sqrt{\frac{1.55}{\tau_B}}(1 \pm 0.015 \pm 0.010 \pm 0.012)$$

The measured branching ratios need to be corrected for the $b \to u$ contribution: $\frac{\mathcal{B}(b \to u\ell\nu)}{\mathcal{B}(b \to c\ell\nu)} \simeq 2\left|\frac{V_{ub}}{V_{cb}}\right|^2 = (1.5 \pm 1.0)\%$. The value of $|V_{cb}|$ [2] is $(38.7 \pm 2.1)\,10^{-3}$ at the $\Upsilon(4s)$ and $(40.6 \pm 2.1)\,10^{-3}$ at the Z.

The second technique for measuring $|V_{cb}|$ is based on the study of exclusive channels such as $B \to D^{(*)}\ell\nu$. It has less theoretical limitations. The rate of this process is governed by $|V_{cb}|$ and Heavy Quark Symmetry provides model independent relations between the relevant weak decay form factors in the heavy quark limit. The corrections from the heavy quark symmetry breaking are calculable in the framework of HQET. The differential decay rate of $B \to D^{(*)}\ell\nu$, with respect to the boost w ($w = (m_B^2 + m_D^2 - q^2)/(2\,m_B\,m_D)$) of the $D^{(*)}$ in the B rest frame, is given by $d\Gamma(B \to D^{(*)}\ell\nu)/dw = G(w)\,|V_{cb}|^2\mathcal{F}^2(w)$ where $G(w)$ is a known phase space function and $\mathcal{F}(w)$ is a universal hadronic form factor. $\mathcal{F}(w)$ parametrizes the effects of the strong interaction on the decay, with an unknown shape. The product $|V_{cb}|\mathcal{F}(w)$ is then extrapolated to $w = 1$, which corresponds to the maximal value of q^2, by the expansion $\mathcal{F}(w) = \mathcal{F}(1)\,[1 - \rho^2(w - 1) + c(w - 1)^2 + ...]$. The intercept and slope are strongly correlated, and this needs to be accounted for when averaging results of different experiments. Furthermore, the expected value of $\mathcal{F}(1)$ is not exactly unity due to correction for the finite heavy quark mass: $\mathcal{F}(1)_{D^*\ell\nu} = 0.91 \pm 0.03$ for $B \to D^*\ell\nu$ decays [99], while $\mathcal{F}(1)_{D\ell\nu} = 0.98 \pm 0.07$

for $B \to D\ell\nu$ decays [100]. The decay $B \to D^*\ell\nu$ is favoured for the measurement, as the $1/m_Q$ correction is predicted to vanish, and experimentally it has a large branching ratio and clean signal. There is a new preliminary analysis from DELPHI, using a new parametrization [101] giving a more precise expansion versus the axial form factor, $\mathcal{A}(w) = \mathcal{A}(1) [1 + \rho_\mathcal{A}^2 \mathcal{G}(w) + ...]$. $(\mathcal{A}(1) \equiv \mathcal{F}(1))$. They got $\mathcal{A}(1)V_{cb} = (37.7 \pm 1.7(stat) \pm 1.7(syst)) 10^{-3}$, $\rho_\mathcal{A}^2 = 1.36 \pm 0.17 \pm 0.14$, $\mathcal{B}(B^0 \to \ell\nu D^*) = (5.18 \pm 0.16 \pm 0.49)\%$ and $|V_{cb}| = (41.4 \pm 3.0) 10^{-3}$. We can hope that in the future existing data will be re-analysed using this new parametrization. The previous published measurements are presented in table 5 and the average of the V_{cb} measurements from this channel, $B \to D^*\ell\nu$, is $|V_{cb}| = (38.7 \pm 3.1)$ 10^{-3} [107].

TABLE 5. Experimental values of $|V_{cb}|\mathcal{F}(1)$.

	$B \to D^*\ell\nu$	$B \to D\ell\nu$
ALEPH [102]	$(32.1 \pm 1.8 \pm 1.9) 10^{-3}$	$(28.2 \pm 6.8 \pm 6.5) 10^{-3}$
ARGUS [105]	$(39.2 \pm 3.9 \pm 2.8) 10^{-3}$	
CLEO [106]	$(35.2 \pm 1.9 \pm 1.8) 10^{-3}$	$(34.2 \pm 4.4 \pm 4.9) 10^{-3}$
DELPHI [103]	$(36.9 \pm 2.1 \pm 2.2) 10^{-3}$	
OPAL [104]	$(32.6 \pm 1.7 \pm 2.2) 10^{-3}$	

The decay $B \to D\ell\nu$ can also be used to measure $|V_{cb}|$ in a similar manner. Here there are fewer experimental results, as it is a more challenging mode, and only ALEPH [102] and CLEO [106] have used this channel (see table 5). Combining their results gives $|V_{cb}| = (39.4 \pm 5.0) 10^{-3}$ [107]. The experimental values for the intercept and the slope are combined with careful attention to the correlated errors.

The excellent agreement between a wide variety of methods for extracting V_{cb} is encouraging. The world average of all V_{cb} measurements leads to $|V_{cb}| = (39.5 \pm 1.7) 10^{-3}$. Improvements from theoretical and experimental sides are promising.

D $|V_{ub}|$ measurements

$|V_{ub}|$ can be extracted in a same way as $|V_{cb}|$ by looking to $b \to u$ transitions instead of $b \to c$ transitions. The inclusive and exclusive approaches can also be used. Due to the fact that a b decay is dominated by the process where the b quark turns into a c quark, the experimental determinations of $|V_{ub}|$ are very much difficult than those of $|V_{cb}|$. It is also more difficult from the theoretical point of vue because the u quark in the final state is no longer heavy.

The first observations for $b \to u$ transitions were done at the $\Upsilon(4s)$ were B mesons are produced at rest [108]. These analyses have looked at the endpoint of the single lepton spectrum for leptons from B decay that are kinematically incompatible with coming from the decay of a B meson to charm meson. From the lepton excess in this corner of phase space, theoretical models are used to

extrapolate the full lepton spectrum and $|V_{ub}| = (3.1 \pm 0.8)10^{-3}$ is extracted by CLEO [109]. Model uncertainties dominate the error.

ALEPH has published the first evidence for semileptonic $b \to u$ transitions in b hadrons produced at LEP [110]. ALEPH has inclusively reconstructed the hadronic system accompagning the lepton in the semileptonic B decays and has built a set of kinematic variables to discriminate between $X_u \ell \nu$ and $X_c \ell \nu$ transitions by taking advantage of the different shape properties of these final states. A neural network was used to extract the inclusive $\mathcal{B}(b \to X_u \ell \nu)$ branching ratio. They have measured $\mathcal{B}(b \to X_u \ell \nu) = (1.73 \pm 0.55 \pm 0.55) \, 10^{-3}$. An advantage of this analysis is that it integrates over the entire lepton and hadron spectrum for these decays, potentially reducing the model dependence of the result. A disadvantage is that it has to manage with the large background from $b \to c$ semileptonic decays which needs to be well understood.

The same kind of calculations than for $|V_{cb}|$ have been done to extract $|V_{ub}|$ from $\mathcal{B}(b \to X_u \ell \nu)$ [98]

$$|V_{ub}| = 0.0465 \sqrt{\frac{\mathcal{B}(B \to X_u \ell \bar{\nu})}{0.002}} \sqrt{\frac{1.55}{\tau_B}} (1 \pm 0.025_{\mathrm{pert}} \pm 0.03_{m_b})$$

The resulting value of $|V_{ub}|$ is $(4.16 \pm 1.02) \, 10^{-3}$.

$|V_{ub}|$ has also been extracted from the exclusive decays $B \to \pi \ell \nu$ and $B \to \rho \ell \nu$ at CLEO [111]. The value is $|V_{ub}| = (3.3 \pm 0.2 \pm 0.4 \pm 0.7) \, 10^{-3}$, where the errors are statistical, experimental systematic, and theoretical model dependence respectively.

All these $|V_{ub}|$ extractions are model dependent, however in different ways. The consistency of the results is thus comforting. The world average is then $|V_{ub}| = (3.4 \pm 0.5) \, 10^{-3}$

VI   SUMMARY AND PROSPECTS

b physics is a place of intensive work. The $e^+ e^-$ colliders and Tevatron have provided a large amount of data on the production and decay of beauty particles. In recent years the experiments at LEP, SLC and CESR have turned the studies on the b quark into precision physics. Numerous interesting new results have been provided and a lot of measurements have been performed. Among these results:

- In the electroweak sector, R_b has been measured, $R_b^0 = 0.2173 \pm 0.0009$, to an accuracy of $\sim 0.4\%$, the forward backward charge asymmetry $A_{FB}^{0,b} = 0.0998 \pm 0.0022$ leads to a measurement of $\sin^2 \theta_{\mathrm{eff}} = 0.23213 \pm 0.00039$ with an accuracy of $\sim 0.17\%$. One of the most precise determination of this quantity.

- In bottom spectroscopy, the B_c meson has been discovered by CDF at Tevatron.

- The B^+, B^0, B_s^0 and b-baryon lifetimes, and their ratio with the B_d^0 lifetime, have been measured with a good precision ($\sim 5\%$). The hierarchy among b hadron lifetimes agrees with theoretical predictions. But for the b baryon lifetime, predictions are higher than measurements by $\sim 3\sigma$. The semileptonic b baryon branching ratio confirms this puzzle ...

- The B_d^0-$\overline{B_d^0}$ oscillation frequency, $\Delta m_d = 0.466 \pm 0.018 \, ps^{-1}$, is also measured with similar accuracy ($\sim 4\%$); but the hadronic uncertainty limits the extracted value of $|V_{\mathrm{td}}| = (8.8 \pm 0.2_{\Delta m_{\mathrm{d}}} \mp 0.2_{m_{\mathrm{t}}} \mp^{1.4}_{1.8}{}_{F\sqrt{B}}) \times 10^{-3}$ to an accuracy of $\sim 20\%$.
  The B_s^0-$\overline{B_s^0}$ oscillation is still not seen and a limit $\Delta m_s > 10.2 \, ps^{-1}$ at 95% CL has been set. Nevertheless non negligible constraints on the CKM matrix with $\dfrac{|V_{\mathrm{ts}}|}{|V_{\mathrm{td}}|} > 3.8$ at 95% CL is provided.

- b semileptonic decays have been scrutinized intensively. If the situation between $\mathcal{B}(b \to \ell)$ measurements at $\Upsilon(4s)$ and Z energies is still to be clarified, the agreement being of the order of 2σ, these low $\mathcal{B}(b \to \ell)$ values agree with theoretical expectations which favour high values of the number of charm quark per b decay, as experimentally measured. A significant contribution of decays in $b \to c\bar{c}s$ transition, without D_s is observed. No hints for new physics is found in b decays.

- The CKM matrix element $|V_{cb}| = (39.5 \pm 1.7) \, 10^{-3}$ has been measured to an accuracy of $\sim 4\%$. Values of $|V_{cb}|$ show good agreement in results obtained from inclusive and exclusive studies. $|V_{ub}| = (3.4 \pm 0.5) \, 10^{-3}$ has also been measured but to an accuracy of $\sim 15\%$ as it is a lot more challenging. Limitations are due to models.

The accuracy of present data provides important tests of the SM and guides the developements of the understanding of the rich phenomenology of weak b decays.

No more substantial running at the Z pole is foreseen at LEP and the final analyses with optimised algorithms, or new analysis ideas, are being prepared. LEP has shown its capability for studying b physics. The large amount of data, highly efficient detectors, and good particle identification have allowed a wide range of b physics to be explored. The Z pole is very competitive to study b physics. SLC is still running and can benefics for the polarization and excellent resolution of their vertex detector to provide interesting results. CESR will continue to improve its luminosity and CLEO has upgraded the detector and will continue to play a significant role in B physics. The experiments at the e^+e^- colliders have also prepared important engineering data and developed analysis techniques that will be further exploited in the continuation of beauty physics at the next generation of b facilities.

HERA-B, at DESY, will start to collect data in 1998. Next year, in 1999, BABAR and BELLE will start to take data in the new b-factories. CDF and D0 get upgraded and will take data at much higher luminosity at the Tevatron, with perhaps B-TEV

in a few years. Then the LHC experiments will enter the scene in 2005, in particular LHCb, a specific detector to study b physics at pp collider, which will be able to do many analyses with large precision.

In conclusion there is a bright future for b physics in the next decade, with new dedicated or upgraded colliders and detectors, and with some challenges. The first observation of B_s^0-$\overline{B_s^0}$ oscillations and the measurement of Δm_s, the study of rare decays and of CP violation ...

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