EXPERIMENTAL ASPECTS OF INCLUSIVE $|V_{\rm cb}|$ MEASUREMENTS

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We report on the experimental status of inclusive measurements of the B-hadron lifetime and the semileptonic branching ratio $\mathrm{Br}(\mathrm{b} \to \ell\nu \mathrm{X})$. Lifetime analyses are based on the information provided by accurate silicon microvertex detectors. Semileptonic decay measurements require good lepton identification and rejection power for non-prompt decays. Potential weak points and discrepancies among experiments are discussed. Both experimental analyses can be combined to provide a precise determination of the $|V_{\rm cb}|$ component of the Kobayashi-Maskawa matrix.

1 Introduction

The $|V_{\rm cb}|$ element of the Kobayashi-Maskawa matrix can be determined from the following expression in the context of HQET (Heavy Quark Effective Theory) [a]:

$$\Gamma(B \to X_c l\nu) \quad = \quad \frac{G_F^2 m_b^5}{192\ \pi^3}\ |V_{\rm cb}|^2\ F_{\rm theo} \qquad (1)$$

where G_F is the Fermi coupling constant, m_b is the b-quark mass and $F_{\rm theo}$ is a factor that differs from 1 due to perturbative QCD, phase space and non-perturbative corrections. The experimental input is provided by the semileptonic partial width $\Gamma(B \to X_c l\nu) = \mathrm{Br}(\mathrm{b} \to \ell\nu\mathrm{X})/\tau_b$, where τ_b is the average B-hadron lifetime and $\mathrm{Br}(\mathrm{b} \to \ell\nu\mathrm{X})$ is the inclusive semileptonic branching ratio of the b-quark. We will assume the contribution from $b \to ul\nu$ decays to be negligible [2]. A simpler expression to use is:

$$\frac{|V_{\rm cb}|}{0.0398} \quad = \quad \left(\frac{\mathrm{Br}(\mathrm{b} \to \ell\nu\mathrm{X})}{10.77\%}\ \frac{1.6\ \mathrm{ps}}{\tau_b} \right)^{\frac{1}{2}} \qquad (2)$$

The size of the theoretical uncertainties in the previous formula is controversial. We will assign a conservative theoretical error of $\Delta|V_{\rm cb}|(\mathrm{theo}) = \pm 0.0040$, as suggested in Reference 1.

2 Measurements of τ_b

Measurements of the average B lifetime are based on the study of charged tracks coming from B weak decays. Lifetime analyses profit from the high accuracy of current silicon microvertex detectors. Impact parameters (δ) and decay lengths (L) are measured with very small uncertainties ($\sigma(\delta) < 30\ \mu$m, $\sigma(L) < 500\ \mu$m), to be compared to the typical values for weakly decaying B-hadrons ($\delta \sim 200\ \mu$m, $L \sim 3$ mm at LEP).

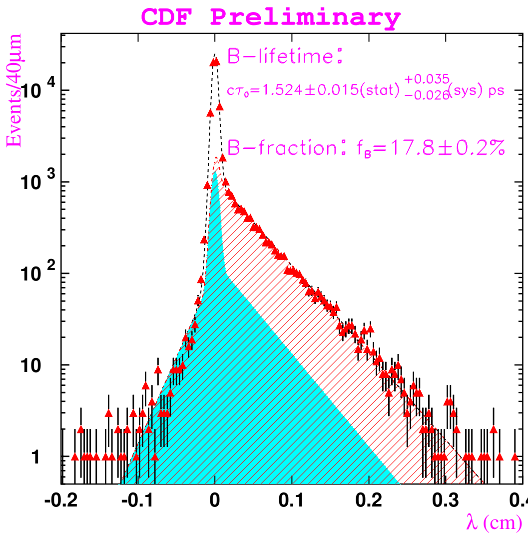

Figure 1: Average B-hadron lifetime from CDF using J/ψ decays. The fraction of J/ψ decays coming from B quarks is also a free parameter in the fit.

Using the impact parameter distribution [3,4] leads to small b-fragmentation uncertainties since, in the relativistic limit, δ does not depend on the hadron boost, p_B/m_B. In most analyses of this kind a high-purity sample of tracks from weakly decaying B-hadrons is obtained by selecting high p, p_t leptons [3]. The relevant systematic errors come from the limited knowledge of the semileptonic decay process.

[a] For a more complete theoretical discussion on inclusive $|V_{\rm cb}|$ measurements, see Reference 1 and references therein.

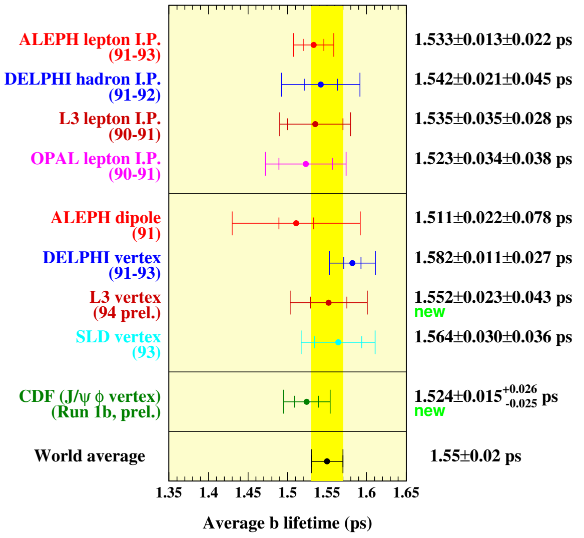

Figure 2: Combination of LEP, SLD and CDF average B-hadron lifetimes by the LEP B Lifetime Working Group.

Measuring the decay length [5,6,7] has the main advantage of being more direct ($L = p_B/m_B\ \tau_b$) and more sensitive (p_B is large). More or less sophisticated vertex algorithms have been developed by the different collaborations in order to optimize the resolution and the reliability. The distance between the primary and the secondary vertex is assigned to be the decay length, L. The main systematic error comes from the B-fragmentation assumptions entering the boost determination.

Figure 1 shows the distribution obtained by the CDF Collaboration from a collection of 62500 J/ψ decays, which is a preliminary value reported at this Conference [5]. After few hundred microns, the b-component is dominant and presents a slope proportional to the value of τ_B. Let us note that these clean decays offer a competitive way for hadron colliders when compared to the hadronic samples at LEP and SLC. Another new preliminary measurement at the Conference has been presented by L3 [6], using their new microvertex detector. Both new values are quoted in Figure 2.

The combination from all available inclusive B lifetime measurements has been performed by the LEP B Lifetime Working Group [8] (Figure 2). Uncertainties on fragmentation, decay modelling, branching fractions, lifetimes and charged multiplicities are considered as fully correlated among the different experiments. The current updated average is $\tau_B = 1.55 \pm 0.02$ ps. The final uncertainty is dominated by fragmentation and decay model effects.

3 Measurements of $\mathrm{Br}(b \to \ell\nu X)$

Measurements of the semileptonic branching fraction of B hadrons have been performed at the $\Upsilon(4S)$ [9,10] and at LEP [11,12,13]. These two centre-of-mass regions provide two different physics environments:

- At the $\Upsilon(4S)$, B mesons are produced in pairs and almost at rest, leading to uncorrelated decay directions and to back-to-back particles coming from the same decay. A major feature is that production of B_s^0 and Λ_b hadrons is not allowed kinematically. The background from the continuum is not negligible, but can be controlled.

- At the Z mass, $\mathrm{B}^\pm$, B_d^0, B_s^0 and Λ_b decays are all accessible. They are produced also in pairs, but with a back-to-back configuration, due to the large boost. The missing energy can be large due to the presence of energetic neutrinos. Lifetime tags can also be applied to reduce the non-$b\bar{b}$ background. The understanding of the jet properties could be relevant, since lepton parameters are referred to it.

New measurements at the $\Upsilon(4S)$ rely on the integration of the leptonic spectrum over essentially the full momentum range. The recent CLEO measurement [10] follows an original analysis performed at ARGUS [9]. The $B\overline{B}$ event is tagged by requiring the presence of a very energetic lepton. A second lepton in the event is used to analyse the momentum spectrum of the decay. Kinematic and charge correlations are used to disentangle the different contributions: non-back-to-back leptons use to come from different B decays and same-charge leptons use to come from cases in which one of the decays proceeds via $b \to c \to l$. Systematic uncertainties due to the modelling of the leptonic decay are extremely small (0.5% in the missing fraction for the CLEO measurement). Averaging ARGUS and CLEO analyses leads to $\mathrm{Br}(b \to \ell\nu X) = (10.40 \pm 0.16(\mathrm{stat}) \pm 0.30(\mathrm{syst}))\%$,

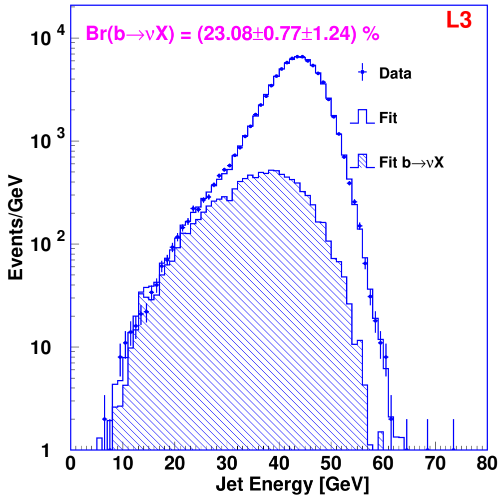

Figure 3: Fit to the total semileptonic branching fraction Br(b $\to \nu$X) performed by the L3 Collaboration. The relative proportion $e : \mu : \tau$ is assumed to be $1 : 1 : 0.25$.

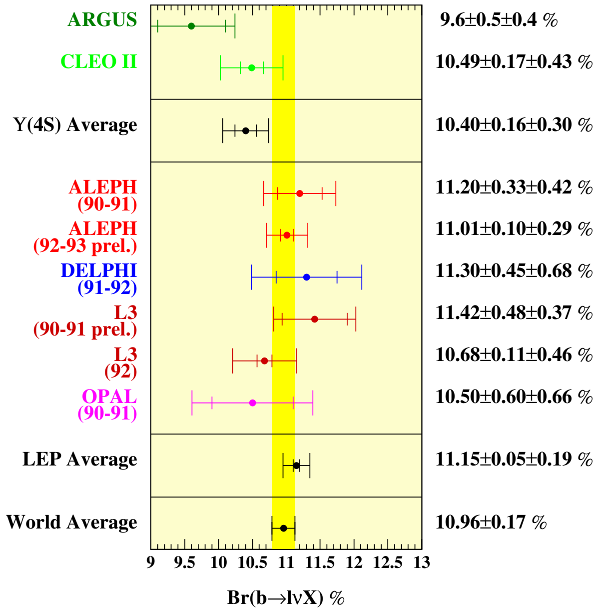

Figure 4: Br(b $\to \ell\nu$X) measurements at the $\Upsilon(4S)$ and at LEP. The average of LEP results takes into account the correlation with R_b measurements and the latest inputs agreed by the LEP HF Working Group.

where an absolute correlated systematic error of 0.10% has been assumed.

LEP measurements are based on studies of the momentum and transverse momentum distributions of leptons with respect to the closest jet. Events with two leptons are also used to decrease systematic uncertainties. Selected events are normalised in most analyses to the total number of hadronic decays, that is, there is an unavoidable interference with $R_\mathrm{b} \equiv \Gamma_\mathrm{b}/\Gamma_\mathrm{had}$ assumptions. Typical parameters in the fit are R_b, Br(b $\to \ell\nu$X), $< x_E >$ (the average energy fraction carried by the B-hadron), χ (the average B^0-$\bar{\mathrm{B}}^0$ mixing parameter) and Br(b $\to$ c $\to \ell$). A common systematic uncertainty between LEP analyses is the modelling of the b-semileptonic decay, the lepton spectra at rest being simulated using CLEO measurements. Typical difficulties are the background processes (punch-through, decays, $c \to l, \ldots$). A potential weak point is the absence of deep studies on QCD effects and jet properties of $b\bar{b}$ events at the Z. The understanding of the semileptonic decay process at LEP is not satisfactory yet, and some new approaches have been developed recently.

The ALEPH collaboration has a set of preliminary studies (up to three) [11] in which the b-component is enhanced by applying lifetime tags. The big uncertainty on the assumed R_b value is no longer present. The study that they choose to be combined with other LEP results uses single and opposite-side double-lepton fits. The single-lepton fit is most sensitive to the fragmentation parameter $< x_E >$ and to Br(b $\to \ell\nu$X) itself. Opposite-side leptons enter in the double-lepton fit to disentangle the mixing parameter χ (using charge correlations) and the b $\to$ c $\to \ell$ component.

The L3 collaboration has published a new analysis [12] on a 2-jet hadronic sample. A consistent treatment of electrons, muons and neutrinos is performed. Neutrinos are taking into account by the missing energy measured in each hemisphere. Control subsamples are built using lifetime tags, high-p_t tags and light-quark tags (events containing particles with a very large momentum fraction of the beam energy). A measurement of the total semileptonic branching ratio Br(b $\to \nu$X) $= (23.08 \pm 0.77(\mathrm{stat}) \pm 1.24(\mathrm{syst}))\%$ has been obtained for the first time (Figure 3). Some conclusions of the study are interesting. A rather hard fragmentation ($< x_E >= 0.72 \pm 0.02$) was required in the simulation in order to get simultaneous agreement in the momentum distributions of muons, electrons and neutrinos. More-

Table 1: Average of inclusive $|V_{\rm cb}|$ measurements.

	$\lvert V_{\rm cb}\rvert$
$\Upsilon(4S)$	$0.0391 \pm 0.0007(\mathrm{exp}) \pm 0.0040(\mathrm{theo})$
LEP	$0.0408 \pm 0.0004(\mathrm{exp}) \pm 0.0040(\mathrm{theo})$
Average	$0.0404 \pm 0.0003(\mathrm{exp}) \pm 0.0040(\mathrm{theo})$

over, differences in the measured value were observed when three-jet events were added to the initial two-jet sample, reflecting possible problems in the understanding of the jet properties.

Figure 4 shows all $\mathrm{Br}(\mathrm{b} \to \ell\nu\mathrm{X})$ measurements that have been included in the average. The average has been performed with the standard procedure described in Reference 14[b]. A 2σ inconsistency between $\Upsilon(4S)$ and LEP is observed. The difference can be hardly attributed to a different hadron composition.

A first remark is that the average value does not follow directly from the $\mathrm{Br}(\mathrm{b} \to \ell\nu\mathrm{X})$ numbers, since all Heavy Flavour measurements [14] are used in the fit. For instance, the correlation with the $R_{\rm b}$ value is -12%, for a fitted value of $R_{\rm b} = 0.2175 \pm 0.0011$. A second remark is that no consistency is required among the fitted $< x_E >$ values of the different experiments. A higher $< x_E >$ parameter would result in a lower $\mathrm{Br}(\mathrm{b} \to \ell\nu\mathrm{X})$ number.

4 $|V_{\rm cb}|$ from inclusive measurements

We can summarise the present status in Table 1. Formula 2 has been applied and a value of $\tau_b = 1.60 \pm 0.03$ has been assumed to be the average lifetime of B^0_d and $\mathrm{B}^\pm$ mesons [8] at the $\Upsilon(4S)$. There exist positive correlations between τ_b and $\mathrm{Br}(\mathrm{b} \to \ell\nu\mathrm{X})$ measurements (due to fragmentation effects) that decrease the experimental uncertainty. In order to be conservative, such effect will be neglected.

Measurements at the $\Upsilon(4S)$ and at LEP are found to be consistent within the theoretical uncertainty but experimentally inconsistent at the 2σ level. More experimental input is needed to understand the origin of the discrepancies. The final average is in agreement with $|V_{\rm cb}|$ values from exclusive measurements reported at this Conference [15].

[b] The official LEP Electroweak Group average for this Conference does not include the new L3 result, due to technical reasons. The average presented here takes it into account.

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