INCLUSIVE B-HADRON SEMILEPTONIC DECAYS AT LEP AND EXTRACTION OF $|V_{\mathrm{cb}}|$

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Recent results on inclusive semileptonic branching fractions of B hadrons produced in Z decays at LEP are presented. New measurement techniques and approaches to b-decay modelling uncertainties are reported. The method of combination of the LEP results is described and a comparison with results obtained at the $\Upsilon(4S)$ is made. An extraction of the CKM matrix element $|V_{cb}|$ is presented.

1 Introduction

Measurements of the b-hadron semileptonic branching fraction BR($b \to \ell^- \bar{\nu}_\ell X$) provide important tests of the modelling of heavy hadron dynamics and lead to the most direct determination of $|V_{cb}|$. The cascade branching fraction BR($b \to c \to \ell^+ \nu_\ell X$) is important as cascade decays are the principal background to the direct decays and this ratio is a vital input to other measurements.

2 LEP measurements

Common features of the analyses of ALEPH[1], DELPHI[2], L3[3] and OPAL[4] are to divide the selected hadronic events into two hemispheres by a plane perpendicular to the thrust axis and to use lifetime information to construct hemisphere b-tags. These tags provide unbiased, high-purity samples of b-hadron hemispheres opposite to which prompt leptons can be selected. The tagging purities are determined from the data by double-tag methods. Direct and cascade branching ratios can then be obtained from fits to the measured lepton (p,p_t) spectra, using models for the expected fragmentation of b-quarks and for the expected spectra of the assumed components, as illustrated in Fig. 1. The poorly known lepton spectra of the components lead to the largest uncertainties in this method.

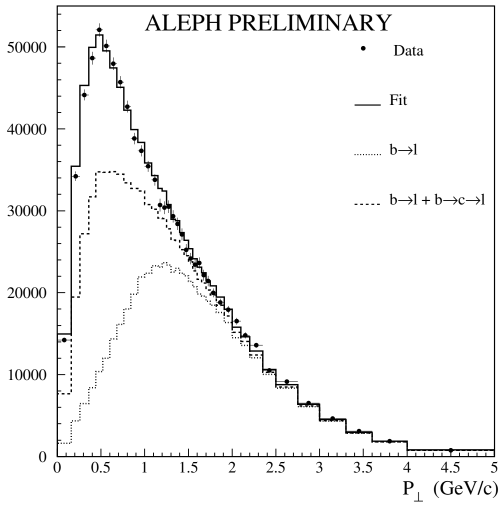

Figure 1. Comparison of measured and fitted p_t spectra together with corresponding expectations of contributions from $b \to \ell^- \bar{\nu} X$ and $b \to c \to \ell^+ \nu X$.

The principal approach adopted to reduce model dependencies is the use of charge correlation information in both di-lepton[1,2] and also single lepton events where weighted hemisphere charges[1,2,4] provide the second charge.

The preliminary ALEPH[1] charge correlation analysis simultaneously uses information from three independent samples. In two of them charge correlations between selected leptons and charge estimators from the opposite hemispheres are used and in the third only the number of leptons observed opposite to tightly $b-$tagged hemispheres is used, avoiding introduction of large spectra shape dependencies. The charge estimators are the lepton charge of a high p_t lepton and a hemisphere charge, constructed from momentum and impact parameter weighted charges.

DELPHI[2] have used four different analyses. One of them uses the charge correlation between the b quark and the lepton produced in its decay, where the quark charge is determined by reconstruction of the b-hadron decay vertex. Neural networks trained to separate b-hadron decay and fragmentation particles and to distinguish b and $\bar{b}$ jets were used.

L3[3] uses a double tag method with high p_t lepton and lifetime b-tags to determine tagging efficiencies, and hence BR($b \to \ell\bar{\nu}X$), together with R_b.

OPAL[4] combines the discriminating power of 8 input variables with two neural networks trained to distinguish direct and cascade decays from backgrounds, and performs a 2D fit to the outputs.

3 Lepton spectra modelling

Uncertainties arising from modelling the $b \to \ell$ spectra are estimated using a well defined prescription[5] of reweighting the lepton momentum in the b-hadron rest frame, obtained from the ACCMM model at which results are quoted, in order to use the other benchmark models ISGW($+1\sigma$) and ISGW**(-1σ).

ALEPH[1] also uses the spectra from exclusive predictions and branching ratio measurements of B mesons into D,D^* and D^{**}, to give the expected $b \to \ell$ lepton spectra and variations in it. This method causes a slight reduction in uncertainties compared to the above prescription for their p_t fit analysis.

4 Results and comparisons

The direct and cascade branching ratio results are combined in a LEPEWWG fit including the additional parameters R_b, BR($c \to \ell^+$) and the average mixing parameter $\bar{\chi}$; the BR($b \to \ell^-$) measurements and the combined results are shown in Fig. 2 and

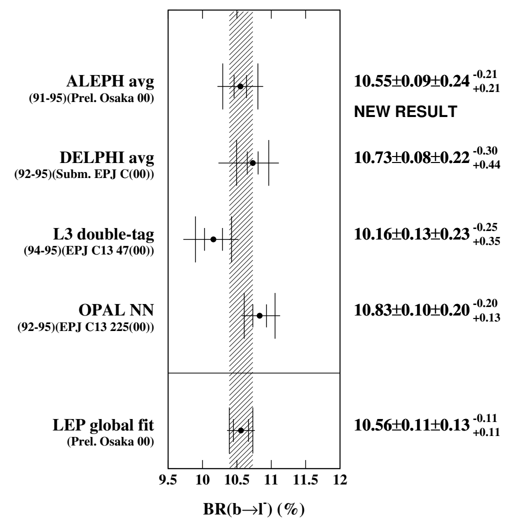

Figure 2. BR($b \to \ell^-$) results from the LEP experiments, together with the global fit result of the LEPHF EW working group. Uncertainties from statistical, systematic and modelling sources are given.

Table 1.

Table 1. Average BR results (%) with statistical, systematic and modelling uncertainties.

$b \to \ell^-$	$10.56 \pm 0.11 \pm 0.13 \pm 0.11$
$b \to c \to \ell^+$	$7.98 \pm 0.13 \pm 0.14 \pm 0.10$

Common input parameter values and systematic definitions are used for all measurements and the interdependencies and correlations between them are accounted for in the combination.

A comparison of the LEP results with results obtained at the $\Upsilon(4S)$ resonance[6] is shown in Fig. 3 together with HQET expectations[7]. The LEP BR($b \to \ell^-$) result has been corrected by the lifetime ratio $(\tau_{B^0} + \tau_{B^-})/2\tau_b = 1.021 \pm 0.013$[8], where τ_b is the average b-hadron lifetime measured at LEP. This correction accounts for the presence of B_s mesons and b-baryons in the LEP samples. Both the semileptonic branching ratio and charm multiplicity[9] results are in good agreement, but towards the lower end of expectations for m_c/m_b and μ/m_b.

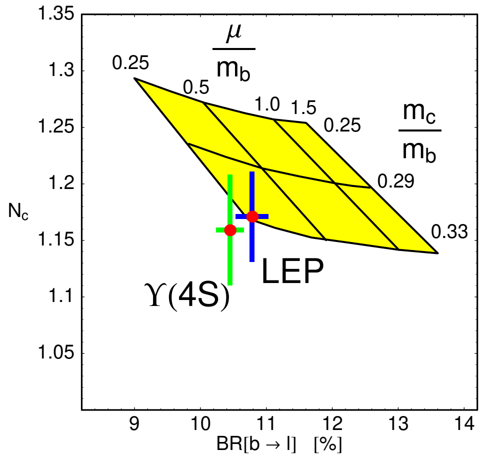

Figure 3. Charm multiplicity per b hadron decay N_c vs BR($b \to \ell$) from Z^0 and $\Upsilon(4S)$ results compared with HQET expectations for ranges of renormalisation scale μ/m_b and quark masses m_c/m_b.

5 Extraction of $|V_{cb}|$

HQET implemented through the operator product expansion[10] provides a relation between $\Gamma(b \to \ell^- \bar{\nu} X_c) = \mathrm{BR}(b \to \ell^- \bar{\nu} X_c)/\tau_b$ and $|V_{cb}|$, where X_c represents all states containing a charmed quark. Allowing $|V_{cb}|$ to be extracted from the inclusive semileptonic branching ratio, the charmless branching ratio $\mathrm{BR}(b \to \ell^- \bar{\nu} X_u) = (0.174 \pm 0.057)\%$[11] and the average b-hadron lifetime $\tau_b = 1.564 \pm 0.014$ ps[12].

$$|V_{cb}^{incl.}| = (40.70 \pm 0.45 \pm 2.03(th)) \times 10^{-3}$$

The 5% theory error[13] on this extraction[14] has been inflated by a factor of 2 compared to the original estimate[10].

6 Conclusion

Previously reported discrepancies between $\mathrm{BR}(b \to \ell^- \bar{\nu} X)$ measurements at the Z^0 and the $\Upsilon(4S)$ are now reduced to the 1.5σ level. The inclusive branching ratio provides our most precise determination of $|V_{cb}|$.

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