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A MEASUREMENT OF R_{b} USING MULTIPLE TAGS

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A measurement of R_{b} using five mutually exclusive hemisphere tags is presented. The preliminary result is $R_b = 0.2158 \pm 0.0009(\text{stat.}) \pm 0.0011(\text{syst.})$.

1 Introduction

Among the measurements available at the Z^0 pole, R_{b}, the ratio of the Z^0 partial width into b quarks and its total hadronic partial width, is currently exciting particular interest. Most electroweak and QCD radiative corrections cancel in the ratio, leaving R_{b} sensitive to corrections that couple preferentially to b quarks, like the large CKM coupling to top quarks. As the parameters of the Standard Model become better constrained, a precise measurement of R_{b} tests the presence of novel vertex corrections.

This paper presents a new measurement of R_{b} using data recorded by ALEPH in 1992-95, consisting of nearly 4 million hadronic events. The measurement is performed using five hemisphere tags.[1] The most important of the tags is a lifetime-mass tag, offering high-purity b tagging.[2] Two additional b tags are used, together with tags designed to select charm and u, d and s flavors. The latter permit the experimental determination of the background efficiencies of the additional b tags. The five tags are mutually exclusive, so that a hemisphere is tagged at most by one tag.

2 The Method

Events are divided into hemispheres by the plane perpendicular to the thrust axis. The fraction of tagged hemispheres $f_{\mathrm{s},I}$ with tag I is

$$f_{\mathrm{s},I} = R_{\mathrm{b}}\epsilon_{\mathrm{b},I} + R_{\mathrm{c}}\epsilon_{\mathrm{c},I} + (1 - R_{\mathrm{b}} - R_{\mathrm{c}})\epsilon_{\mathrm{uds},I} \tag{1}$$

where $\epsilon_{a,I}$ are the hemisphere tagging efficiencies for flavor a using tag I.

The fraction of doubly tagged events $f_{\mathrm{d},IJ}$ with tags I and J is:

$$\begin{aligned} f_{\mathrm{d},IJ} = \quad & [R_{\mathrm{b}}\epsilon_{\mathrm{b},I}\epsilon_{\mathrm{b},J}(1+\rho_{\mathrm{b},IJ}) + R_{\mathrm{c}}\epsilon_{\mathrm{c},I}\epsilon_{\mathrm{c},J}(1+\rho_{\mathrm{c},IJ}) + \\ & (1 - R_{\mathrm{b}} - R_{\mathrm{c}})\epsilon_{\mathrm{uds},I}\epsilon_{\mathrm{uds},J}(1+\rho_{\mathrm{uds},IJ})]\ (2 - \delta_{IJ}) \end{aligned} \tag{2}$$

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where $\rho_{a,IJ}$ are the hemisphere-hemisphere efficiency correlations for flavor a and tags I and J.

Twenty quantities are measured: 5 single tag fractions and 15 double tag fractions. Of the 62 unknown parameters in the above two equations, R_{b} and 13 efficiencies are fitted to the data. The two remaining efficiencies, $\epsilon_{c,Q}$ and $\epsilon_{x,Q}$ (the Q tag is described below), and the 45 correlations are calculated using simulation. The systematic error reflects the uncertainties in these calculations. R_{c} is taken as 0.171 from electroweak theory.

3 Event selection

Using the data sample obtained on and near the Z^0 resonance with the ALEPH detector during the period 1992 to 1995, events must satisfy the following requirements: at least five reconstructed tracks; at least two jets clustered using the JADE algorithm[3] with energy greater than 10 GeV; $|\cos\theta_T| < 0.65$, where θ_T is the angle between the beam and the thrust axis; and $y_3 < 0.2$, where y_3 is the value of y_{cut} that sets the transition from 2 to 3 jets.[3] The remaining 2,059,066 events have a selection bias in favor of b quarks relative to the lighter quarks of $0.23 \pm 0.04\%$ and a contamination of tau events of $0.30 \pm 0.01\%$.

4 The Five Hemisphere Tags

In order to keep the hemisphere–hemisphere correlations small and their calculation transparent, the tag variables are constructed from quantities limited to the particular hemisphere only. A new primary vertex finder is employed, which reconstructs the Z^0 decay point seperately in each hemisphere.

The Q tag is a high purity b tag formed from the combination of two tagging algorithms. Both algorithms make use of 3-dimensional track impact parameters, defined as the distance of closest approach of the track to the primary vertex. The first algorithm provides the probability that all of the hemisphere tracks originate from the primary vertex.[4] The second algorithm exploits the b/c hadron mass difference. Tracks in a hemisphere are ordered inversely to their probability to originate from the primary vertex and are combined, in this order, until the invariant mass of the combination exceeds 1.8 GeV/c^2. The probability of the last track added to have originated from the primary vertex is used as a tagging variable.

The S tag uses the same lifetime-mass information as the Q tag but in a less pure b tagging range, together with a neural net variable that optimizes 25 event shape parameters for the selection of Z^0 decays to b quarks.[5]

The L tag requires an identified muon or electron, with momentum greater than 3 GeV/c, and transverse momentum with respect to its jet greater than 1.4 GeV/c.[6]

The X tag requires high probability that all tracks originate from the primary vertex, together with a requirement on the same neural net variable as the S tag, but in the opposite sense, in order to tag *uds* events.

The C tag, which is the most difficult to construct, makes use of lifetime and event shape properties. The tag uses a neural net variable that optimizes one lifetime and 19 event shape parameters for the selection of Z^0 decays to c quarks. In addition, tracks are divided into two groups with rapidity with respect to their jets greater or less than 5.1, chosen to get equal numbers of tracks for b hemispheres. The probabilities that the two groups of tracks originate from the hemisphere primary vertex are used for tagging.

The Monte Carlo expectations for the 3×5 efficiencies are shown in Table 1.

Tag	$\epsilon_{\rm uds}$ (%)	$\epsilon_{\rm c}$ (%)	$\epsilon_{\rm b}$ (%)
Q	0.029	0.20	19.55
S	0.200	1.40	17.57
L	0.156	0.69	4.25
X	11.70	3.96	0.23
C	7.93	16.20	2.59

Table 1: Tagging efficiencies as given by Monte Carlo simulation.

5 Result

The fit of R_b and 13 of the 15 efficiencies to the 20 measured tag fractions yields

$$R_{\rm b} = 0.21582 \pm 0.00087 \tag{3}$$

with a χ^2 of 8.1 for the 6 degrees of freedom, where the error is statistical. This result has been corrected for the event selection bias and tau contamination discussed in section 3.

6 Systematic uncertainties

The impact of a particular correlation on $R_{\rm b}$ is given by $\Delta R_{\rm b}/(R_{\rm b}\, \Delta\rho_{a,IJ})$, i.e. the relative uncertainty in $R_{\rm b}$ is the impact times the uncertainty in the correlation. The impacts vary a great deal, and uncertainties in only a dozen or so of the correlations contribute significantly to the uncertainty in R_b. The correlations with the biggest impacts are $\rho_{\mathrm{b},QQ}$, with impact 0.45, and $\rho_{\mathrm{b},QS}$, with impact 0.42. The impacts of the two Q tag background efficiencies are given by

$$\frac{\Delta R_\mathrm{b}}{R_\mathrm{b}} \frac{\epsilon_{\mathrm{b},Q}}{\Delta\epsilon_{\mathrm{c},Q}} = -1.5, \qquad \frac{\Delta R_\mathrm{b}}{R_\mathrm{b}} \frac{\epsilon_{\mathrm{b},Q}}{\Delta\epsilon_{\mathrm{uds},Q}} = -5.6$$

A brief description of the sources of systematic uncertainty is given below.

6.1 Detector simulation uncertainty

The Monte Carlo predictions for the Q tag background efficiencies depend on the impact parameter resolution and the efficiency for tracks to record a vertex detector hit. These quantites are measured in the data and remaining uncertainties produce corresponding errors in $\epsilon_{\mathrm{c},Q}$ and $\epsilon_{\mathrm{uds},Q}$.

6.2 Systematics from b and c physics uncertainties

Uncertainties in the physics charmed and light flavored hadrons propagate dominantly through the Q tag background efficiencies, whereas uncertainties in bottom physics propagate through the correlations. To assess these uncertainties the physics inputs to the Monte Carlo simulation are varied within their allowed experimental ranges.[7] The largest contribution found with this procedure is due to the rate of gluon splitting into heavy quarks.

6.3 Hemisphere-hemisphere correlation uncertainties

The correlations have three origins: detector inhomogeneities, the size and position of the interaction region, and the coupling of the B hadron momenta through gluon radiation and hadronization. The Monte Carlo simulation's ability to reliably calculate these sources of correlation is checked against data by studying the correlation due to variables linked to these correlating effects. Uncertainties are assigned that are in addition to those due to b and c physics that have been considered above.

The correlation contributions in the following four variables are compared between data and simulation: the cosine of the angle between the thrust and the beam axes, the component of the error in the reconstructed hemisphere primary vertex transverse to the thrust axis, the momenta of the two jets (because of their correlation with the B hadron momenta), and y_3 (to check the gluon radiation-induced correlations). The larger of either a measured difference between data and simulation or the precision of the comparison is assigned as an uncertainty in the correlation. The uncertainty in R_b is found by propagating and adding their contributions linearly, so as to take correlations between the correlations into account.

A summary of the systematic errors is given in Table 2.

source	ΔR_b
detector simulation	0.00050
Monte Carlo statistics	0.00047
event selection	0.00010
physics uncertainties	0.00083
hemisphere correlations	0.00033

Table 2: Systematic uncertainties.

7 Conclusions

The fraction of hadronic Z^0 decays to b quarks, R_b, has been measured using five mutually exclusive tags. The preliminary value is:

$$R_b = 0.2158 \pm 0.0009(\text{stat.}) \pm 0.0011(\text{syst.}) - 0.019 \times (R_\text{c} - 0.171) \qquad (4)$$

where the first error is statistical, the second is systematic, and the explicit dependence on R_c is given.

This measurement includes the 1992 data used in the earlier ALEPH R_b measurement with a lifetime tag[4] and therefore supercedes it.

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