Measurement of R_b with the L3 detector

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We present a new measurement of $R_b = \Gamma(Z \to b\bar{b})/\Gamma(Z \to \text{hadrons})$ with the L3 detector using a double tag method. The analysis uses 540 k hadronic events collected in 1994 and exploits the capabilities of the Silicon Microvertex Detector. The lifetime tagging of b-events is performed by using tracks with large impact parameter with respect to the interaction point. We obtain a value of $R_b = 0.2185 \pm 0.0028 \pm 0.0033 - 0.146(R_c - 0.171)$ where the first error comes from statistics, the second is the total systematic uncertainty and the fourth term gives the dependence of the measurement on the fraction of c-events in the hadronic Z decays.

1. INTRODUCTION

The partial decay width of the Z boson into $b\bar{b}$ quark pairs, $\Gamma(Z \to b\bar{b})$, is a particularly interesting quantity as a test of the Standard Model because, as opposed to the other lighter quarks, the top mass couples in the vertices with full strength. Experimentally it is more convenient to measure its relative contribution to the total hadronic width, $R_b = \Gamma(Z \to b\bar{b})/\Gamma(Z \to \text{hadrons})$, since most of the experimental uncertainties cancel in the ratio and the theoretical uncertainties from the strong coupling constant α_s and the unknown Higgs mass are negligible. Several measurements of R_b have been performed [1] and their average [2] is not fully consistent with the Standard Model. Therefore it is interesting to have additional measurements of R_b.

In this note we present recent preliminary results on R_b obtained with the L3 detector at LEP. The measurement is performed on a high purity sample of $Z \to b\bar{b}$ events. The b tagging method is based on the long life-time of hadrons containing b quarks and relies on data from the L3 Silicon Microvertex Detector (SMD) [3] which has been fully operational since 1994. The results presented here are limited to 1994 data.

2. THE L3 DETECTOR

The L3 detector and its performance is described in detail in [4]. The main components of the detector are: a Silicon Microvertex Detector; a central tracking chamber; a high resolution electromagnetic calorimeter composed of BGO crystals; a ring of scintillator counters; a hadron calorimeter with uranium absorber and proportional wire chamber readout and a high precision muon spectrometer. On either side of the detector there is an array of BGO crystals at low polar angles to measure the luminosity by detecting small-angle Bhabha scattering. All these sub-detectors are located in a 12 m diameter magnet which provides a uniform field of 0.5 T along the beam direction.

The sub-detectors relevant for this analysis are the Silicon Microvertex Detector (SMD) and the central tracking chamber (TEC). The SMD is made of two concentric layers of silicon detectors placed at 6 and 8 cm from the interaction region. Each layer provides a two-dimensional position measurement and the resolution, for normal incident tracks, is 12 μm along the beam direction and 8 μm along the direction perpendicular to the beam. The TEC consists in two coaxial cylindrical drift chambers with 12 inner and 24 outer sectors. The sensitive region is between 10 and 45 cm in the radial direction, with 62 layers of wires giving a spatial resolution of approximately 50 μm.

3. EVENT SELECTION AND RECONSTRUCTION

In order to have a clean sample of hadronic events selection cuts are applied on the collected events. They are described in detail in [5]

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and select 99.15% of all the hadronic Z decays with a small contamination from other processes (0.15%). To ensure that the selected events are amenable to an analysis based on life-time information, the event is required to have at least four reconstructed tracks and $|\cos\theta_T| < 0.7$, being θ_T the polar angle of the thrust. After applying all these selection criteria we obtained a sample of 540 k hadronic events from the data taken in 1994 which correspond to a total integrated luminosity of 34 pb^{-1}.

From the hits on the SMD and the TEC we reconstruct the trajectories of the charged particles in the $r - \phi$ plane for hadronic events. The position of the beam-spot is determined from the reconstructed tracks and averaged every 200 events to closely follow the drifts of the beam position. The beam size is determined to be 110 μm in the horizontal direction and 20 μm in the vertical one. Afterwards, the primary vertex is determined for each event with an iterative procedure which starts from the beam-spot as initial estimate. At each step of the iteration the primary vertex is calculated, using the beam-spot as a constraint, with the tracks selected for that step. If the χ^2 probability of the vertex is less than 0.05 the track with the largest contribution is removed and the procedure repeated until the χ^2 probability is at least 0.05 or there are three tracks left. The efficiency for the reconstruction of the primary vertex is 99.5% and is found to be independent of the quark flavour within one per mill. The resolution obtained with this method depends on the azimuthal angle of the event thrust and on the number of tracks used for its determination. In the horizontal direction it is $\sim$45μm for light quark events and $\sim$77μm for b-events. The worse resolution for b-events is due to the unavoidable inclusion of b-decay tracks in the vertex determination. In the vertical direction the uncertainty is dominated by the width of the beam spot ($< 20\mu$m).

Once the primary vertex of the event is reconstructed we divide the event into two hemispheres defined by a plane normal to the thrust axis. For each track we calculate the impact parameter, IP, as the minimum distance between the primary vertex and the track, with a positive (negative) sign if the track intersects the jet axis it is associated to in front of (behind) the primary vertex. Finally we calculate the total error on the impact parameter, σ_{IP}, as a combination of the error from the track fit, the multiple scattering contribution and the contribution of primary vertex error and determine the significance of the track, s, as the impact parameter divided by its error.

4. HEAVY QUARK TAGGING

The procedure to tag heavy quarks is based on the resolution function $R(x)$ which is obtained from a fit to the significances of all reconstructed tracks with negative impact parameters (thus, mainly events with light primary quarks contribute). The tracks selected for each hemisphere are classified according to the number of associated clusters in the SMD and for each class different parameters for the resolution function are used. From the normalised resolution function $R(x)$ we can obtain the probability that a track originated at the primary vertex has a significance greater than s as:

$$P(s) = \int_s^\infty R(x)dx \qquad (1)$$

For all the n tracks in the same hemisphere we have the set of significances $\{s_1, ..., s_n\}$. Being all independent, we associate to this configuration the product of the probabilities for each individual track denoted by $\pi_n = P(s_1)\cdot...\cdot P(s_n)$. Finally, from the distribution of π_n we obtain the probability that they all come from the primary vertex as:

$$L(n) = \pi_n \sum_{k=0}^{n-1} (-\ln\pi_n)^k/k! \qquad (2)$$

The variable used to tag the b quarks is defined as $D = -\log_{10}L(n)$ and is determined separately on both hemispheres of the event. The distribution of the discriminant variable D is shown in Figure 1 together with the Monte Carlo expectation and its components in terms of the different primary quark flavours.

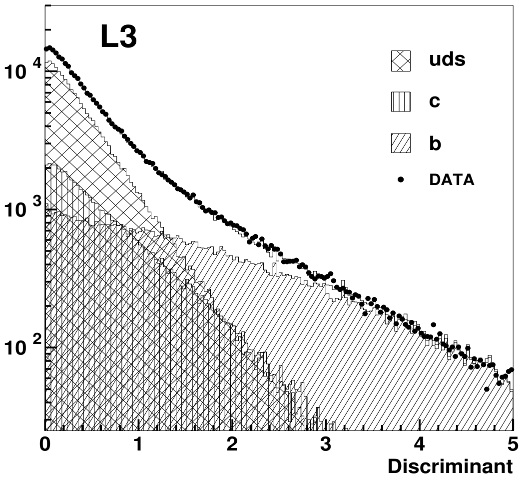

Figure 1. Distribution of the tagging variable D for data and Monte Carlo with the flavour composition of the Monte Carlo sample.

5. DETERMINATION OF R_b

A hemisphere is tagged if the discriminant variable D is larger than a certain value D_{cut}. The number of tagged hemispheres, N_t, can be expressed as:

$$\frac{N_t}{2N_h} = R_b(\epsilon_b - \epsilon_{uds}) + R_c(\epsilon_c - \epsilon_{uds}) + \epsilon_{uds} \quad (3)$$

with N_h the number of selected hadronic events, ϵ_i the probability to tag one hemisphere for a primary quark of flavour i and R_b and R_c the relative contribution of b and c quarks to the Z boson hadronic width. Similarly, the number of events with two tagged hemispheres can be expressed as:

$$\frac{N_{tt}}{N_h} = R_b(c_b\epsilon_b^2 - \epsilon_{uds}^2) + R_c(\epsilon_c^2 - \epsilon_{uds}^2) + \epsilon_{uds}^2 \quad (4)$$

where the factor c_b, hemisphere correlation, takes into account the fact that the tagging in one hemisphere is not independent of the tagging on the other hemisphere.

From this two equations we can determine two unknown parameters; we choose them to be ϵ_b and R_b. From data we measure N_h, N_t, and N_{tt}, from the Monte Carlo simulation [2] we get $\epsilon_c, \epsilon_{uds}$, and c_b, and from the Standard Model R_c. The efficiency for b-tagging and the purity of the selected sample depend on the value of D_{cut} as shown in Figure 2. The value of the discriminant cut D_{cut} used to determine R_b is taken as the one which minimises the total error on R_b.

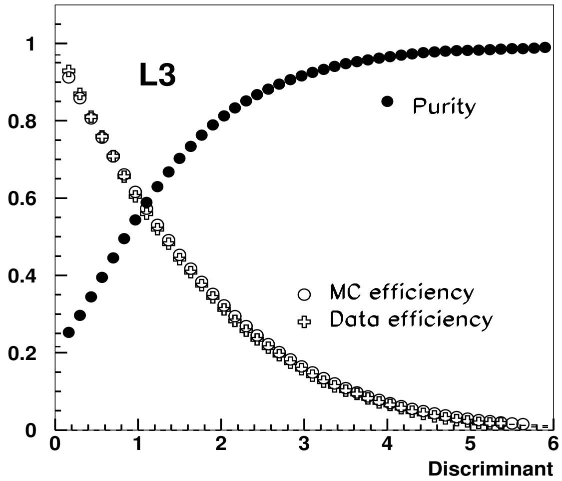

Figure 2. Efficiency and purity of the $b\bar{b}$ sample as a function of the discriminant cut.

6. ERRORS ON R_b

As well as the statistical error on R_b and that coming from the limited Monte Carlo statistics we consider several sources of systematic errors. The systematic uncertainties considered here are detector effects, such as the tracking resolution and

[2] Hadronic events are generated with JETSET [6] and passed through the L3 simulation [7] and reconstruction programs.

inefficiencies in the detector, and physics effects which enter through the modelling of the signal and the background. This uncertainties influence the calculation of the background efficiencies, ϵ_c and ϵ_{uds} and the hemisphere correlation, c_b.

The Monte Carlo estimated parameters $\epsilon_c, \epsilon_{uds}$ and c_b are affected, to some extent, by the resolution function of the simulated sample of events. In order to determine the error from the tracking resolution, two resolution functions $R(x)$ are determined from Monte Carlo, one with the final adjustment applied to the Monte Carlo and the other one without. Half of the difference in $\epsilon_c, \epsilon_{uds}$ and c_b calculated using these two functions is taken conservatively as the contribution to the possible systematic error and propagated to give the error contribution to R_b.

The uncertainty on ϵ_c is estimated by varying the different parameters which affect the production of charmed hadrons (fragmentation, production rates, life-times and charge multiplicity). For the light quark efficiency we have considered residual effects from the production of light hadrons with long-life times (K°_S and Λ's) and from the fraction of gluon splitting into $b\bar{b}$ and $c\bar{c}$. The above parameters are varied following the suggestions of reference [2].

Table 1
Systematic error contributions to R_b

Error source	ΔR_b internal	ΔR_b external
Charm syst.	0.11%	0.14%
uds syst.	0.14%	0.12%
hem. corr.	0.19%	0.09%

The correlation between the b-tagging efficiencies in the two hemispheres of an event, c_b, can be affected by detector inefficiencies, the primary vertex determination (both hemispheres share a common vertex) and physics effects (modelling of the b parameters and hard gluon emission). To quantify possible systematic effects we have studied different variables, q, for each hemisphere which could be influenced by tagging in the opposite hemisphere. For a particular value of D_{cut} we define three normalised distributions: the distribution of q for all hemispheres, $N(q)$, the distribution for tagged hemispheres, $T(q)$, and for co-tagged hemispheres, $C(q)$, where a co-tagged hemisphere is the hemisphere opposite to a tagged one, regardless of whether it is itself tagged or not.

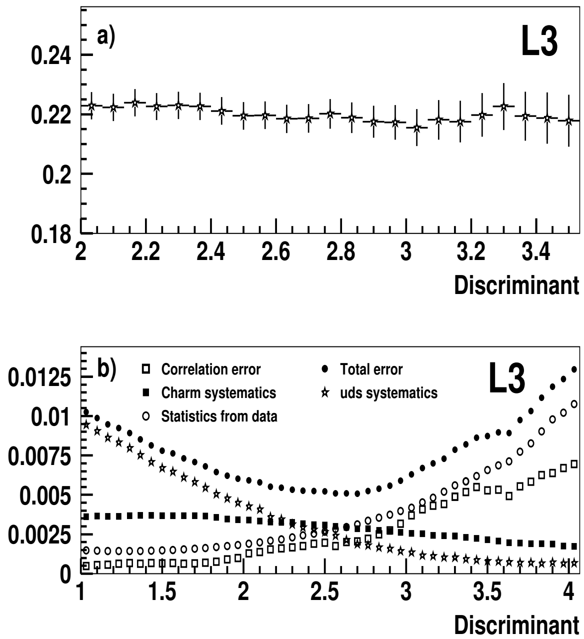

Figure 3. a) Value of R_b as a function of the discriminant cut. b) Statistical, systematic and total error on R_b as function of the discriminant cut.

The effect on the hemisphere correlation of the variable q can be expressed as:

$$c_b^q = \frac{\int T(q)C(q)dq}{\int N(q)T(q)dq} \qquad (5)$$

This coefficient allows one to study the difference in c_b^q between data and Monte Carlo, quantify the influence of the different sources and check if the main contributing sources are understood. The uncertainty on the possible systematic effects is propagated to give the systematic error contribution to R_b from the hemisphere correlations.

The summary of all the systematic uncertainties for a value of $D_{cut} = 2.7$, including the error from the Monte Carlo statistics, is shown in Table 1 where "internal" refers to sources inherent to this experiment and "external" to sources in common with other experiments.

7. RESULTS

The values of R_b obtained for different values of D_{cut} are shown in Figure 3 together with the statistical and systematic errors. For values of the discriminant cut between 2 and 3.5 the value of R_b is stable and the purity of the sample increases from 80% to 95%.

The value of the discriminant cut which minimises the error on on R_b is $D_{cut} = 2.7$ (Figure 3). For this value we obtain the following efficiencies for the backgrounds:

$$\begin{aligned} \epsilon_c &= 1.76\pm0.02(\mathrm{stat})\pm0.11(\mathrm{syst})\% \\ \epsilon_{uds} &= 0.356\pm0.004(\mathrm{stat})\pm0.028(\mathrm{syst})\% \end{aligned}$$

and a hemisphere correlation of:

$$c_b = 0.960\pm0.005(\mathrm{stat})\pm0.007(\mathrm{syst})$$

The final measurement of R_b then gives:

$$\begin{aligned} R_b &= 0.2185 \pm 0.0028(\mathrm{stat}) \\ &\pm\ 0.0033(\mathrm{syst}) - 0.146(R_c - 0.171) \end{aligned}$$

together with a b efficiency of $\epsilon_b = 19.31\pm0.01\%$. This measurement significantly improves our previous result [8]. It is in agreement with the expectation of the Standard Model ($R_b^{SM} = 0.2156$) and compatible with previous determinations [1].

REFERENCES

1 ALEPH Collab., D. Buskulic et al., Phys. Lett. B313 (1993) 535;
OPAL Collab., D. Akers et al., Z. Phys. C65 (1994) 17;
DELPHY Collab., P. Abreu et al., Z. Phys. C65 (1995) 555;
SLD Collab., K. Abe et al., Phys. Rev. D53 (1996) 1023.

2 The LEP Experiments: ALEPH, DELPHI, L3, OPAL, Combining Heavy Flavour Electroweak Measurements at LEP, CERN-PPE/96-017.

3 M. Acciarri et al., Nucl. Inst. and Meth. A351 (1994) 300.

4 L3 Collab., O. Adriani et al., Phys. Rep. 236 (1993) 1.

5 L3 Collab., B. Adeva et al., Z. Phys. C51 (1991) 179.

6 T. Sjostrand, Comp. Phys. Comm. 39 (1986) 347;
T. Sjostrand and M. Bengtsson, Comp. Phys. Comm. 43 (1987) 367.

7 R. Brun et al., GEANT3, CERN DD/EE/84-1 (revised in September 1987);
H. Fesefeld, GHEISHA, RWTH Aachen Report PITHA 85/02 (1987).

8 L3 Collab., 0. Adriani et al., Phys. Lett. B317 (1993) 474.