OPAL Physics Note PN101
May 28, 1993

Update to Physics Note PN097: Combined OPAL Measurements of $\Gamma(Z^0 \to b\bar{b})/\Gamma(Z^0 \to \text{hadrons})$

The OPAL Collaboration

Abstract

A recently published measurement of $\Gamma_{b\bar{b}}/\Gamma_{had}$ has been combined with existing published and preliminary measurements by the OPAL Collaboration. The new combined result is:

$$\frac{\Gamma_{b\bar{b}}}{\Gamma_{had}} = 0.222 \pm 0.004 \pm 0.007,$$

where the first error is statistical and the second is systematic. The result assumes a value of $\Gamma_{c\bar{c}}/\Gamma_{had}$ of 0.171, with a 16% error. For the purpose of Standard Model fits, the $\Gamma_{c\bar{c}}$ error can be removed, and the dependence of the result on $\Gamma_{c\bar{c}}$ given explicitly. In this case, the combined result becomes:

$$\Gamma_{b\bar{b}}/\Gamma_{had} = 0.222 \pm 0.004 \pm 0.006.$$

The variation with $\Gamma_{c\bar{c}}/\Gamma_{had}$ is given by:

$$\frac{\Delta(\Gamma_{b\bar{b}}/\Gamma_{had})}{\Gamma_{b\bar{b}}/\Gamma_{had}} = -0.10\frac{\Delta(\Gamma_{c\bar{c}}/\Gamma_{had})}{\Gamma_{c\bar{c}}/\Gamma_{had}}.$$

These values are consistent with the result $\Gamma_{b\bar{b}}/\Gamma_{had} = 0.215 \pm 0.006 \pm 0.007 \pm 0.007$, obtained in an independent analysis using impact parameters and leptons simultaneously in the same data sample.

1 Introduction

In a previous OPAL physics note [1], four [2–4] of the five available measurements of $\Gamma_{b\bar{b}}/\Gamma_{had}$ were combined to give an average value. The fifth result, obtained using the "mixed-tag" technique [5], was not included in this average, because the statistical overlap between this measurement and the other measurements needs to be assessed. A sixth measurement of $\Gamma_{b\bar{b}}/\Gamma_{had}$ has recently been published by OPAL [6]. This measurement is based on an impact parameter tag, and unlike the measurement based on a vertex tag presented in [4] uses the data sample collected in 1990. The statistical overlap with the existing combined result is therefore very small, and the method used in [1] may be used to make a new combined measurement. A publication based on the mixed-tag method is in preparation, in which the statistical overlap of the mixed-tag result with other measurements will be assessed. Until this publication is available, we refrain from including it in the average, and continue to use it as a cross-check derived using an independent analysis technique on the same data sample.

2 Method

The measurements to be combined are:

(1)	$0.216 \pm 0.003 \pm 0.007 \pm 0.012$	Using electrons [2]
(2)	$0.224 \pm 0.003 \pm 0.010 \pm 0.011$	Using muons [2]
(3)	$0.223 \pm 0.012 \pm 0.007 \pm 0.009$	Using a double lepton tag [3]
(4)	$0.223 \pm 0.010 \pm 0.007 \pm 0.004$	Using a double vertex tag [4]
(5)	$0.222 \pm 0.007 \pm 0.006 \pm 0.005$	Using impact parameters [6]

In each case, the first error is statistical, the second reflects systematic uncertainties arising from detector modelling and the third systematic uncertainties arising from the modelling of b and c fragmentation and decay. The published results (1) and (2) include an error due to a 22% uncertainty in $\Gamma_{c\bar{c}}/\Gamma_{had}$ [9]. The preliminary results (3) and (4) include an error due to a 16% uncertainty in $\Gamma_{c\bar{c}}/\Gamma_{had}$, from the result presented in [10]. The quoted result (5) includes no error due to $\Gamma_{c\bar{c}}/\Gamma_{had}$. The dependence of this result on $\Gamma_{c\bar{c}}/\Gamma_{had}$ is given by: $\Delta\Gamma_{b\bar{b}}/\Gamma_{b\bar{b}} = -0.135 \times \Delta\Gamma_{c\bar{c}}/\Gamma_{c\bar{c}}$. In each case the central value assumes $\Gamma_{c\bar{c}}/\Gamma_{had} = 0.171$. The result (3) is consistent with, and has a large statistical overlap with, the result obtained in a multiparameter fit to samples of hadronic Z^0 decays with one or more identified leptons. This fit extracts values for $\Gamma_{b\bar{b}}/\Gamma_{had}$, semileptonic branching ratios and other b physics parameters [7].

These results are combined following the method in [1,8]. In Table 1, the errors for each measurement and the combined errors are quoted. The statistical error, Monte Carlo statistics error and the efficiency correlation error are treated as uncorrelated between measurements, as described in [1]. The other errors are taken to be fully correlated between the different measurement techniques. The following details should be noted:

- Although the track resolution error of the analysis presented in [4] is dominated by uncertainties in the resolution of the silicon microvertex detector, unlike the new result [6], the track resolution error has been conservatively assumed to be fully correlated between these two results.
- The b multiplicity error in method (5) and the b semileptonic decay model error in methods (1) and (2) are assumed to be uncorrelated.
- The error in each result due to an uncertainty in $\Gamma_{c\bar{c}}/\Gamma_{had}$ of 16% [10] is given in this table.

The covariance matrix for fractional errors in per cent (i.e. each entry in this covariance matrix is a

product of two fractional errors times 10^4) is:

$$\begin{pmatrix} 40.30 & 23.92 & 12.35 & 3.06 & 4.63 \\ 23.92 & 42.53 & 8.70 & 1.79 & 3.00 \\ 12.35 & 8.70 & 57.28 & 5.99 & 8.67 \\ 3.06 & 1.79 & 5.99 & 34.57 & 5.00 \\ 4.63 & 3.00 & 8.67 & 5.00 & 27.09 \end{pmatrix}$$

The resulting weights for each measurement are:

$$\begin{aligned} w_1 &= 0.121, \\ w_2 &= 0.173, \\ w_3 &= 0.085, \\ w_4 &= 0.278, \\ w_5 &= 0.343. \end{aligned}$$

3 Results

The new combined result is:

$$\Gamma_{b\bar{b}}/\Gamma_{had} = 0.222 \pm 0.004 \pm 0.007,$$

where the first error is statistical and the second systematic. This value is consistent with the result $\Gamma_{b\bar{b}}/\Gamma_{had} = 0.215 \pm 0.006 \pm 0.007 \pm 0.007$, obtained in an independent analysis using impact parameters and leptons simultaneously in the same data sample [5].

The results assume a value of $\Gamma_{c\bar{c}}/\Gamma_{had}$ of 0.171, with a 16% error. For the purpose of Standard Model fits, the $\Gamma_{c\bar{c}}$ error can be removed, and the dependence of the result on $\Gamma_{c\bar{c}}$ given explicitly. In this case, the combined result becomes:

$$\Gamma_{b\bar{b}}/\Gamma_{had} = 0.222 \pm 0.004 \pm 0.006.$$

The variation with $\Gamma_{c\bar{c}}/\Gamma_{had}$ is given by:

$$\frac{\Delta(\Gamma_{b\bar{b}}/\Gamma_{had})}{\Gamma_{b\bar{b}}/\Gamma_{had}} = -0.10 \frac{\Delta(\Gamma_{c\bar{c}}/\Gamma_{had})}{\Gamma_{c\bar{c}}/\Gamma_{had}}.$$

Sources of errors	Single-electron	Single-muon	Double-lepton	Double-vertex	Impact Param.	Combined
Statistical error	1.4%	1.4%	5.5%	4.5%	3.2%	1.8%
MC statistics	1.1%	1.2%	0.4%	0.8%	—	0.3%
Efficiency correlation	—	—	1.8%	2.8%	—	0.8%
Event selection efficiency	0.5%	0.5%	—	—	—	0.2%
Event selection bias	—	—	0.6%	0.3%	1.8%	0.8%
Conversions	0.9%	—	1.5%	—	—	0.2%
Fake electrons	0.2%	—	1.3%	—	—	0.1%
Fake muons	—	1.7%	1.4%	—	—	0.4%
Electron id. efficiency	2.9%	—	0.7%	—	—	0.4%
Muon id. efficiency	—	3.7%	0.3%	—	—	0.7%
Electron radiation loss	0.8%	—	—	—	—	0.1%
θ determination	—	0.4%	—	—	—	0.1%
Track resolution	—	—	—	1.7%	0.6%	0.7%
$Br(\mathrm{b} \to \ell^-)$	4.0%	4.2%	—	—	—	1.2%
$Br(\mathrm{b} \to \mathrm{c} \to \ell)$	1.9%	1.0%	—	—	—	0.4%
$Br(\mathrm{b} \to \mathrm{J}/\psi \to \ell)$	0.5%	0.4%	—	—	—	0.1%
$Br(\mathrm{b} \to \tau^- \to \ell^-)$	0.6%	0.4%	—	—	—	0.1%
b semilept. decay model	0.5%	0.3%	—	—	—	0.1%
b fragmentation	1.4%	1.2%	—	—	0.5%	0.6%
b lifetime	—	—	—	—	0.5%	0.2%
b decay multiplicity	—	—	—	—	1.8%	0.6%
$\Gamma_{\mathrm{c\bar{c}}}/\Gamma_{\mathrm{had}}$	1.4%	0.9%	2.7%	1.1%	2.2%	1.6%
c fragmentation	0.8%	0.3%	1.5%	0.6%	0.5%	0.6%
$Br(\mathrm{D}^\pm/\mathrm{D}^0 \to \mathrm{e})$	0.8%	0.5%	1.6%	—	—	0.3%
$f(\mathrm{D}^\pm)$:$f(\mathrm{D}^0)$:$f(\mathrm{D_s})$:$f(\Lambda_\mathrm{c}^\pm)$	0.5%	0.3%	1.0%	0.8%	0.9%	0.7%
c lifetime	—	—	—	0.4%	—	0.1%
c decay model	0.9%	0.5%	1.5%	0.6%	—	0.5%
b/c from fragmentation	0.5%	0.4%	1.2%	0.2%	—	0.3%
K^0 production rate	—	—	—	0.3%	—	0.1%
light flavour multiplicity	—	—	—	—	1.9%	0.7%
Total systematics	6.2%	6.4%	5.2%	3.8%	4.1%	3.1%
Total error	6.3%	6.5%	7.6%	5.9%	5.2%	3.5%

Table 1: Fractional errors on each and the combined result of the five measurements of $\Gamma_{\mathrm{b\bar{b}}}/\Gamma_{\mathrm{had}}$.

References

[1] OPAL Collaboration, Physics note PN097,
Combined OPAL measurements of $\Gamma(Z^0 \to b\bar{b})/\Gamma(Z^0 \to \text{hadrons})$.

[2] OPAL Collaboration, CERN-PPE/93-46,
Measurement of $\Gamma(Z^0 \to b\bar{b})/\Gamma(Z^0 \to \text{hadrons})$ using leptons. To be published in Z. Phys. C.

[3] OPAL Collaboration, Physics note PN091,
A measurement of $\Gamma(Z^0 \to b\bar{b})/\Gamma(Z^0 \to \text{hadrons})$ using single and double lepton events.

[4] OPAL Collaboration, Physics note PN095,
A measurement of $\Gamma(Z^0 \to b\bar{b})/\Gamma(Z^0 \to \text{hadrons})$ using double lifetime tagging.

[5] OPAL Collaboration, Physics note PN096,
A measurement of $\Gamma_{b\bar{b}}/\Gamma_{had}$ using impact parameters and leptons.

[6] OPAL Collaboration, CERN-PPE/93-79,
A measurement of $\Gamma(Z^0 \to b\bar{b})/\Gamma(Z^0 \to \text{hadrons})$ using an impact parameter technique.

[7] OPAL Collaboration, paper in preparation,
Measurements of $B^0\overline{B^0}$ mixing, $\Gamma(Z^0 \to b\bar{b})/\Gamma(Z^0 \to \text{hadrons})$ and semileptonic branching ratios for b-flavoured hadrons in hadronic Z^0 decays.

[8] The method is equivalent to that described in:
L.Lyons, D.Gibaut and P.Clifford, NIM A270(1988)110.

[9] OPAL Collaboration, Phys. Lett. B262(1991)341,
A Study of $D^\star$ Production in Z^0 Decays.

[10] OPAL Collaboration, Physics note PN064,
Update of a Study of $D^\star$ Production in Z^0 Decays.