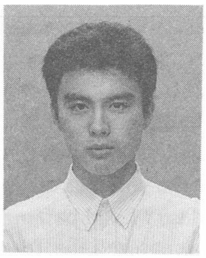
# NEW MEASUREMENTS OF $\Gamma(Z^0 \rightarrow b\bar{b})/\Gamma(Z^0 \rightarrow \text{hadrons})$ FROM OPAL

Masahiro Morii
ICEPP, Dept. of Physics, Univ. of Tokyo, Tokyo, Japan



## ABSTRACT

New measurements of the fractional decay width of the $Z^0$ into $b\bar{b}$ quarks performed by the OPAL Collaboration are reported. Two new methods, called the 'double lepton tagging' and 'double lifetime tagging' techniques, are introduced for better control of systematic uncertainties. Combining the new results with updated results of the previous OPAL measurements, a value of $\Gamma_{b\bar{b}}/\Gamma_{had} = 0.222 \pm 0.005(\text{stat.}) \pm 0.008(\text{sys.})$ was obtained from the data collected during 1990 and 1991. Using the latest OPAL measurement of the $Z^0$ hadronic decay width, $\Gamma_{had} = 1739 \pm 11$ MeV, the partial width of the decay $Z^0 \rightarrow b\bar{b}$ was determined to be $\Gamma(Z^0 \rightarrow b\bar{b}) = 386 \pm 16$ MeV.

## 1 INTRODUCTION

The partial decay widths of the $Z^0$ into different quark and lepton final states are well predicted by the Standard Model. Among them, the width for $b\overline{b}$ final states, $\Gamma(Z^0 \rightarrow b\overline{b})$, is of special interest because of its different dependence on the top quark mass from those for other quark flavours. The difference arises from the electroweak correction to the $Z^0 b\overline{b}$ vertex involving top quarks, which can potentially offer important infonnation for constraining the Standard Model. To take advantage of this infonnation, the width must be measured to a precision smaller than the amount of the $Z^0 b\overline{b}$ vertex correction, which is 2–3% for a top quark mass around 150 GeV/$c^2$. While the total hadronic decay width of the $Z^0$ has been measured to a precision below 1%, the precision of the previous measurements of the fractional width $\Gamma_{b\bar{b}}/\Gamma_{had} = \Gamma(Z^0 \rightarrow b\overline{b})/\Gamma(Z^0 \rightarrow \text{hadrons})$ are no better than 5%.

The principal difficulty common to most measurements of $\Gamma_{b\bar{b}}/\Gamma_{had}$ is the estimation of the efficiency of the $b\overline{b}$ event selection. For example, measurements using high-momentum leptons to select $b\overline{b}$ events require precise knowledge of the b-quark fragmentation, the semileptonic branching fractions of the bottom hadrons, and the lepton detection efficiency of the detector. The systematic uncertainties of these parameters dominate the errors of the previous measurements, limiting usefulness of $\Gamma_{b\bar{b}}/\Gamma_{had}$ in detennining the Standard Model parameters.

The OPAL Collaboration has measured the fractional decay width $\Gamma_{b\bar{b}}/\Gamma_{had} \equiv \Gamma(Z^0 \rightarrow b\overline{b})/\Gamma(Z^0 \rightarrow \text{hadrons})$ using several different techniques. To achieve better control of the systematic error, two new techniques called 'double lepton tagging' and 'double lifetime tagging' have been introduced. Both techniques are designed to be insensitive to the efficiencies of the $b\overline{b}$ event selections, thus have lower systematic errors than the previous measurements.

In this report, the two new techniques are explained. Preliminary results obtained from the data collected during 1990 and 1991 are presented. These results are also combined with those obtained using other measurement techniques.

## 2 DOUBLE LEPTON TAGGING TECHNIQUE

In a decay of a $Z^0$, the produced b and $\overline{b}$ quarks are observed as back-to-back jets. It is therefore likely that each hemisphere of the event defined by the plane perpendicular to the thrust axis has one jet containing a bottom hadron. In the *double lepton tagging* measurement, each hemisphere is tagged as b-hemisphere, independently from the opposite one, if it contains at least one lepton with large momentum and large transverse momentum relative to the direction of the jet. The selection efficiency is expected to be the same for, and uncorrelated between, the two hemispheres of an event. Suppose $N_\ell$ hemispheres are tagged in a sample of $N_{had}$ hadronic $Z^0$ decays, and $N_{\ell\ell}$ events have their both hemispheres tagged, then the observed numbers can be expressed as

$$N_\ell = 2N_{\rm had}\frac{\Gamma_{\rm b\bar{b}}}{\Gamma_{\rm had}}\,\varepsilon_\ell + N_\ell^{\rm bg}, \quad (1)$$

$$N_{\ell\ell} = N_{\rm had}\frac{\Gamma_{\rm b\bar{b}}}{\Gamma_{\rm had}}\,\varepsilon_\ell^{\,2} + N_{\ell\ell}^{\rm bg}, \quad (2)$$

where $\varepsilon_\ell$ is the tagging efficiency for a hemisphere of a $\rm b\bar{b}$ event and $N_\ell^{\rm bg}$ and $N_{\ell\ell}^{\rm bg}$ denote contributions from non-$\rm b\bar{b}$ events which must be estimated separately. Once the background terms are estimated, the fractional width $\Gamma_{\rm b\bar{b}}/\Gamma_{\rm had}$ can be extracted simply by

$$\frac{\Gamma_{\rm b\bar{b}}}{\Gamma_{\rm had}} = \frac{(N_\ell - N_\ell^{\rm bg})^2}{4(N_{\ell\ell} - N_{\ell\ell}^{\rm bg})N_{\rm had}}, \quad (3)$$

without knowing the efficiency $\varepsilon_\ell$.

This technique has a clear advantage over conventional measurement techniques, i.e., it requires no precise knowledge of the selection efficiency $\varepsilon_\ell$ which was the primary source of the systematic uncertainty in the previous measurements. The technique still requires estimation of the background, but the amount of the background can be kept low enough by choosing appropriate selection criteria for leptons.

There is, however, a drawback in the double lepton tagging technique: the statistical error of the measurement is limited by the number of double-tagged events $N_{\ell\ell}$, which is less than 1% of the available $\rm b\bar{b}$ events. High statistics, e.g. $10^6$ $\rm b\bar{b}$ events which will be available in the near future, is required to make full use of the new technique.

The double lepton tagging technique was applied to the data collected by the OPAL detector during 1990 and 1991. The momentum $p$ and the transverse momentum $p_{\rm t}$ of leptons were required to be

$$\begin{cases} p > 2\,{\rm GeV}/c \quad \text{and} \quad p_{\rm t} > 0.8\,{\rm GeV}/c \quad \text{for e,} \\ p > 3\,{\rm GeV}/c \quad \text{and} \quad p_{\rm t} > 0.9\,{\rm GeV}/c \quad \text{for } \mu. \end{cases}$$

In a sample of $N_{\rm had} = 2.4 \times 10^5$ hadronic $\rm Z^0$ decays, $N_\ell = 11612$ tagged hemispheres and $N_{\ell\ell} = 414$ double-tagged events were found. From these numbers and the estimated numbers of background, a value of

$$\frac{\Gamma_{\rm b\bar{b}}}{\Gamma_{\rm had}} = 0.233 \pm 0.012(\text{stat.}) \pm 0.012(\text{sys.})$$

was obtained.

The systematic error of the measurement is dominated by the uncertainty of the amount of background coming from semileptonic decays of charmed hadrons. The contribution from charmed hadrons can be reduced by requiring higher transverse momentum for the leptons, but this is not advantageous at the moment because of the limited statistics. It is therefore expected that both statistical and systematic errors will improve with increasing statistics.

## 3 DOUBLE LIFETIME TAGGING TECHNIQUE

Bottom hadrons produced in the decay of $Z^0$'s travel typically 2–3mm before decaying. The OPAL detector can, with its silicon micro-vertex detector installed in 1991, efficiently separate this distance between the primary and the secondary vertex, giving another source of information for $b\overline{b}$ event selection. Bottom selection using lifetime information generally has higher efficiency than that using lepton detection, but the efficiency is less well-known because of its strong dependence on the detector resolution, the lifetimes of the bottom hadrons and the b-quark fragmentation. This higher but less well-known efficiency means that the lifetime tagging is even more suitable for applying a double tagging technique.

In each hemisphere of the hadronic $Z^0$ decay events, possible secondary vertices are searched for. The decay length $L$ is defined for each secondary vertex as the distance from the primary vertex. If the secondary vertex is found upstream of the primary vertex, the decay length $L$ is given a negative sign. The hemisphere is tagged as a b-hemisphere if the significance of the decay length, $L$ divided by its measurement error $\sigma_L$, is greater than a cutoff, typically 10.

Though the efficiency of the b-selection method is not necessarily known in the double tagging technique, the amount of background still has to be estimated using Monte Carlo simulation. Since the resolution of the detector is not perfectly known, the resolution in the Monte Carlo sample must be varied to account for our understanding of the detector, leading to a considerable systematic error in the result. In order to overcome this difficulty, a further sophistication of the double tagging technique called *'folded double tagging technique'* was introduced.

As well as the *forward-tag* defined by $L/\sigma_L > 10$, a *backward-tag* was defined by requiring a secondary vertex with $L/\sigma_L < -10$. The number of backward-tagged hemispheres, $N_{\overline{v}}$, is expected to behave in the same way as the number of forward-tagged hemispheres, $N_v$, with varying detector resolution. The difference $N_v - N_{\overline{v}}$ is therefore less sensitive to the detector resolution while retaining most of the physics information. The numbers of tagged hemispheres and double-tagged events are then expressed as

$$N_v - N_{\overline{v}} = 2N_{\mathrm{had}} \frac{\Gamma_{b\overline{b}}}{\Gamma_{\mathrm{had}}} (\epsilon_v - \epsilon_{\overline{v}}) + (\text{background}), \quad (4)$$

$$N_{vv} - N_{v\overline{v}} + N_{\overline{v}\overline{v}} = N_{\mathrm{had}} \frac{\Gamma_{b\overline{b}}}{\Gamma_{\mathrm{had}}} (\epsilon_v - \epsilon_{\overline{v}})^2 + (\text{background}), \quad (5)$$

where $N_{vv}$, $N_{v\overline{v}}$ and $N_{\overline{v}\overline{v}}$ are defined as

$N_{vv}$: the number of events with both hemispheres selected by forward-tag,

$N_{v\bar{v}}$: the number of events with one hemisphere selected by forward-tag and the other selected by backward-tag,

$N_{\bar{v}\bar{v}}$: the number of events with both hemispheres selected by backward-tag,

and $\epsilon_v$ and $\epsilon_{\bar{v}}$ are the selection efficiencies for forward-tag and backward-tag respectively. Equations (4) and (5) can be solved for $\Gamma_{b\bar{b}}/\Gamma_{had}$ analogously to equations (1)–(3). This folded double tagging technique has the advantage of a smaller effect due to the detector resolution uncertainty in addition to all the advantages of the double tagging technique.

In a sample of $N_{had} = 1.1 \times 10^5$ hadronic $Z^0$ decays recorded in 1991 with silicon micro-vertex detector information, $N_v = 7840$ forward-tagged hemispheres and $N_{\bar{v}} = 517$ backward-tagged hemispheres were found. The numbers of double-tagged events were $N_{vv} = 462$, $N_{v\bar{v}} = 29$ and $N_{\bar{v}\bar{v}} = 0$. From these numbers, a value of

$$\frac{\Gamma_{b\bar{b}}}{\Gamma_{had}} = 0.233 \pm 0.010(\text{stat.}) \pm 0.008(\text{sys.})$$

was obtained. The result is limited by statistics, but is more precise than that of the double lepton tagging measurement thanks to the higher efficiency of the lifetime tag.

## 4 OTHER MEASUREMENTS AND COMBINED RESULT

The two published OPAL measurements of $\Gamma_{b\bar{b}}/\Gamma_{had}$, using the number of inclusive electrons[1] and muons[2], have been updated including the data collected during 1990 and 1991 which corresponds to $4.8 \times 10^5$ hadronic $Z^0$ decays[3]. The new results are

$$\frac{\Gamma_{b\bar{b}}}{\Gamma_{had}} = \begin{cases} 0.216 \pm 0.003(\text{stat.}) \pm 0.014(\text{sys.}) & \text{using electrons,} \\ 0.224 \pm 0.003(\text{stat.}) \pm 0.015(\text{sys.}) & \text{using muons.} \end{cases}$$

Combining these results with the double lepton tagging and the double lifetime tagging results,

$$\frac{\Gamma_{b\bar{b}}}{\Gamma_{had}} = 0.222 \pm 0.005(\text{stat.}) \pm 0.008(\text{sys.})$$

is obtained. Using the recently updated OPAL measurement of the total hadronic decay width of the $Z^0$, $\Gamma_{had} = 1739 \pm 11$ MeV[4], the above result corresponds to

$$\Gamma(Z^0 \to b\bar{b}) = 386 \pm 16 \text{ MeV},$$

which is in good agreement with the Standard Model prediction. The overall uncertainty of the result is $\pm 4.1\%$.

The 'mixed tag' measurement, which has been reported previously[5], has also been updated. The measurement makes use of the information of *mixed-tag* events, which have one hemisphere tagged by a lepton and the other hemisphere tagged by lifetime, as well as double-lepton and double-lifetime events. The new result is

$$\frac{\Gamma_{b\bar{b}}}{\Gamma_{had}} = 0.215 \pm 0.006(\text{stat.}) \pm 0.010(\text{sys.}),$$

which is consistent with the combined result of the other four measurements.

## 5 SUMMARY

The OPAL Collaboration has measured the fractional decay width $\Gamma_{b\bar{b}}/\Gamma_{had} \equiv \Gamma(Z^0 \to b\bar{b})/\Gamma(Z^0 \to \text{hadrons})$ using several different techniques. To achieve better control of the systematic error, two new techniques called 'double lepton tagging' and 'double lifetime tagging' have been introduced. Applied to the data recorded by the OPAL detector during 1990 and 1991, both techniques have proved to be effective in reducing systematic errors, whereas the results are statistically limited. Combining the new results with updated results of the previous OPAL measurements, a value of $\Gamma_{b\bar{b}}/\Gamma_{had} = 0.222 \pm 0.005(\text{stat.}) \pm 0.008(\text{sys.})$ was obtained from the data collected during 1990 and 1991. Using the latest OPAL measurement of the $Z^0$ hadronic width, $\Gamma_{had} = 1739 \pm 11$ MeV, the partial width of the decay $Z^0 \to b\bar{b}$ was determined to be $\Gamma(Z^0 \to b\bar{b}) = 386 \pm 16$ MeV.

## References

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