$\Gamma_{b\bar{b}}$ MEASUREMENTS USING PROMPT LEPTON OR EVENT SHAPE TAGGING

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ABSTRACT

I present the measurements of $\Gamma_{b\bar{b}}$ using prompt lepton or event shape tagging using the LEP detectors. The results from the individual experiments are averaged, taking into account common systematic errors as far as possible. From lepton tagging, $R_{b\bar{b}} = 0.221 \pm 0.003$ (stat.) ± 0.002 (sys.) ± 0.005 (common), while from event shape tagging, $R_{b\bar{b}} = 0.226 \pm 0.002$ (stat.) $\pm$ 0.003 (sys.) ± 0.004 (common). Combining these results with those from lifetime tagging we obtain $R_{b\bar{b}} = 0.2200 \pm 0.0027$.

Introduction

$\Gamma_{b\bar{b}}$, the partial decay width of the Z boson into $b\bar{b}$ quarks, is accurately predicted in the Standard Model. Because of an extra vertex correction involving the top quark it has a smaller dependence on the top mass than the other quark widths. In the ratio $R_{b\bar{b}} \equiv \Gamma_{b\bar{b}}/\Gamma_{had}$, where Γ_{had} is the hadronic decay width of the Z boson, many theoretical uncertainities cancel and so a limit on the top mass can be set. For example, with a top mass of 80 GeV $R_{b\bar{b}}$ is predicted to be 0.218, while for a mass of 260 GeV it is predicted to be 0.213. Therefore, in order to set a significant limit or test the Standard Model prediction for $\Gamma_{b\bar{b}}$, the error on the measurement should be $\approx 1\%$.

The results presented are a mixture of published and preliminary and also of the 1990, 1991 and 1992 data samples. All results that include the 1992 data are preliminary.

Lepton Tagging

The large mass of the b quark means that it can produce particles with high momentum transverse to its direction (p_t). In addition the leading b hadron typically carries 70% of the b quark energy. The semileptonic branching ratio of the b quark (Br(b $\rightarrow \ell$)) is about 10%, so that leptons (e,μ) with high p and p_t are a good tag for b quarks. Typical purities of events tagged by a single lepton are 80%.

The simplest method to measure $\Gamma_{b\bar{b}}$ is therefore to tag $Z \rightarrow b\bar{b}$ using leptons, count the number of observed leptons, subtract the background and divide by the semileptonic branching ratio (Br(b $\rightarrow \ell$)) and detection efficiency (ϵ). However, given that we want to measure $\Gamma_{b\bar{b}}$ to $\approx 1\%$, this means that the semileptonic branching ratio must also be known to this accuracy. As discussed in the talk of V. Choutko [1], the current accuracy on Br(b $\rightarrow \ell$) is closer to 5% and there are large uncertainties due to fragmentation and detection efficiency.

For example, OPAL [2] use their $1990 + 91$ data sample of electrons and muons and the CLEO branching ratios, Br(b $\rightarrow \ell$) and Br(b $\rightarrow$c $\rightarrow \ell$). They obtain $R_{b\bar{b}} = 0.220 \pm 0.002$ (stat.) ± 0.006 (exp.) ± 0.011 (model), where the systematic error is dominated by the lepton efficiency (0.005) and the semileptonic branching ratios (0.009). Another problem with this procedure is that the $\Upsilon(4S)$ only produces B_d^0 and B_u mesons, whereas there is a mixture of many more states at LEP.

The groups therefore use a combination of single leptons and dileptons to determine both $R_{b\bar{b}}$ and Br(b $\rightarrow \ell$) (or rather $\epsilon \times$ Br(b $\rightarrow \ell$)) separately:

$$\frac{\Gamma_{b\bar{b}}}{\Gamma_{had}} \approx \frac{N_\ell^2}{4N_{\ell\ell}N_{had}} \tag{1}$$

$$\langle \epsilon \times \mathrm{Br}(b \rightarrow \ell) \rangle \approx \frac{2N_{\ell\ell}}{N_\ell} \tag{2}$$

where N_ℓ is the number of tagged hemispheres and $N_{\ell\ell}$ is the number of events with 2 tagged hemispheres. One can either solve the above equations, or do a simultaneous fit to the lepton p and p_t spectra and extract $R_{b\bar{b}}$, Br(b $\rightarrow \ell$), Br(b $\rightarrow$c $\rightarrow \ell$) and fragmentation parameters. The disadvanatge of this approach is that it is limited by the double tag statistics.

Each experiment analyses its data differently. I will therefore briefly describe the differences between them before giving a combined result. A summary of the numbers is given in table 1.

1. **OPAL [3]:** $R_{b\bar{b}}$ is determined using equations (1) and (2). In order to minimize any correlations between the efficiencies in the 2 hemispheres they require that $\mid \cos(\theta_{thrust}) \mid < 0.6$ and $thrust > 0.7$. The main systematic error is from charm uncertainties (0.009) with additional errors from lepton background (0.005) and the effect of multijets (0.004).
2. **L3 [4]:** The ratio $N_{\ell\ell}/N_\ell$ is used to determine Br(b $\rightarrow \ell$) and then the p and p_t spectra are fit to determine $\Gamma_{b\bar{b}}$. The error is dominated by the statistical error on the branching ratio (0.0078), but those from efficiencies

Table 1: Measurements of $\mathrm{R_{b\bar{b}}}$ using lepton tagging. Three errors are quoted for the LEP average, the first is statistical, the second from uncorrelated systematic errors and the third from common systematic error.
$^{(a)}$ Combination of the published single tag [2] and preliminary double tag [3] results, taking into account the common errors.

$\Gamma_{\mathrm{b\bar{b}}}/\Gamma_{\mathrm{had}}$ from lepton tags				
	ALEPH 90–92 [5] prel.	DELPHI 91–92 [6] prel.	L3 90–91 [4] prel.	OPAL$^{(a)}$ 90–91 [2],[3] prel.
$\Gamma_{\mathrm{b\bar{b}}}/\Gamma_{\mathrm{had}}$	0.2223	0.222	0.2184	0.221
Stat. error	0.0042	0.009	0.0081	0.004
Uncorr. sys.	0.0033	0.002	0.0045	0.008
Common sys.	0.0046	0.004	0.0059	0.006
LEP average	$0.221 \pm 0.003 \pm 0.002 \pm 0.005$ $(\chi^2/(d.o.f.) = 0.1/3)$			

(0.0029 for e and 0.0016 for μ), background (0.0029) and fragmentation (0.0034) are also significant.

3. **ALEPH [5]:** A global fit is performed to a total of 8 variables: $\mathrm{R_{b\bar{b}}}$, $\mathrm{R_{c\bar{c}}}$, $\langle x_b \rangle$, $\langle x_c \rangle$, Br(b $\rightarrow \ell$), Br(b $\rightarrow$ c $\rightarrow \ell$), χ_B, $A_{\mathrm{b\bar{b}}}$ and $A_{\mathrm{c\bar{c}}}$. Within the fit $\mathrm{R_{b\bar{b}}}$ and Br(b $\rightarrow \ell$) are highly correlated (94%).
4. **DELPHI [6]:** A global fit is performed very similar to the ALEPH one, except that ϵ_{b} is the free fragmentation parameter and the charm fragmentation is fixed. $A_{\mathrm{b\bar{b}}}$, $A_{\mathrm{c\bar{c}}}$ and χ_B are not included in the fit, but this should have no effect on the $\mathrm{R_{b\bar{b}}}$ and Br(b $\rightarrow \ell$) results as the asymmetries and mixing depend on the charge and $\cos(\theta)$ of the leptons.

In order to average the results the common systematic errors are taken into account as far as possible. Errors from the semileptonic decay model, semileptonc branching ratios and contributions from $\mathrm{c\bar{c}}$ events are assumed to be completely correlated. All other errors, mainly due to detector efficiencies, are assumed to be uncorrelated. Each measurement is weighted by its total error.

Event Shape Tagging

The first attempt to use the event shape as a tag of a b quark events used the "Boosted Sphericity Product". However this suffers from large uncertainties, due to light quark fragmentation. More recent methods use a neural network or other multivariable analysis to combine many variables and also take into account the correlations between them.

The following features of b quark jets are used:

- b hadrons take $\approx 70\%$ of the beam energy and their decay products have similar energies;
- light quarks radiate away most of their energy in the form of gluons which leads to a broad spectrum of particle energies;
- the jet boost for b quark jets is somewhat smaller than for light quark jets.

The limits of such methods are the Monte Carlo modelling of both the light quark and the b quark jets. In order to reduce these errors further, attempts have been made to tag single jets rather than the whole events. This usually gives a lower purity, but the systematic errors can also be reduced.

Again, each experiment analyses its data differently using different variables and types of neural network. A brief description of the methods is below. The results are summarised in table 2.

Table 2: Measurements of $\mathrm{R_{b\bar{b}}}$ using event shape tagging. Three errors are quoted for the LEP average, the first is statistical, the second from uncorrelated systematic errors and the third from common systematic error.

$\Gamma_{\mathrm{b\bar{b}}}/\Gamma_{\mathrm{had}}$ from event shapes			
	ALEPH 90–91 [9]	DELPHI 90–91 [8]	L3 91 [7]
$\Gamma_{\mathrm{b\bar{b}}}/\Gamma_{\mathrm{had}}$	0.228	0.232	0.222
Stat. error	0.005	0.005	0.003
Uncorr. sys.	0.005	0.011	0.002
Common sys.	0.001	0.013	0.006
LEP average	$0.226 \pm 0.002 \pm 0.003 \pm 0.004$ $(\chi^2/(d.o.f.) = 1.1/2)$		

1. **L3 [7]:** The aim of the analysis is to separate b quark events from all others. Calorimetric measurements only are used to make the result as independent as posssible of the semileptonic branching ratio. A total of 11 variables is used, 5 for each jet and 1 global one. The variables are expanded using orthonormal transformations, with weights that are determined from a test sample. These are fed into a 1 layer neural network that has 1 non-linear transformation. In order to check that the Monte Carlo provides a good description of the data, events with a high p_t muon are used and the jet opposite the muon is plotted. As an example the energy gap between the 1st and 4th leading clusters is shown in figure 1. The dominant systematic errors are from varying the Monte Carlo parameters (0.005) and the b fragmentation parameters (0.003).
2. **DELPHI [8]:** The DELPHI group attempt to measure $\Gamma_{\mathrm{b\bar{b}}}$ and $\Gamma_{\mathrm{c\bar{c}}}$ simultaneously. In order to do this they have to include more information in their network. In addition to variables similar to those of L3 they use the

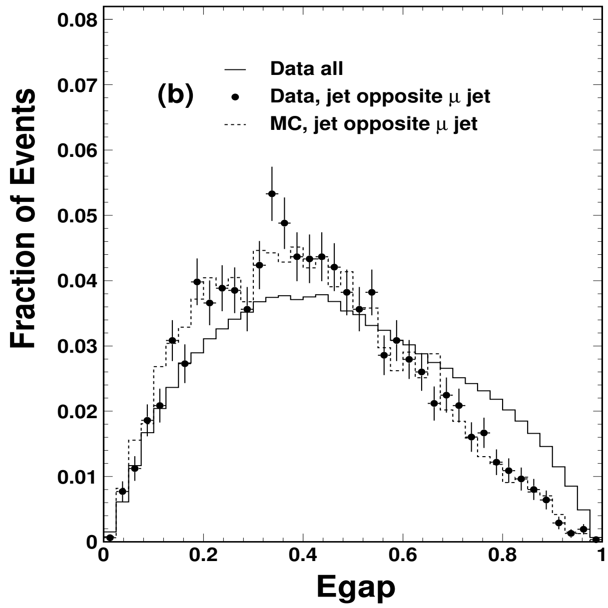

Figure 1: The energy gap between the 1st and 4th leading clusters

momentum of the slowest pion in each jet after boosting to a D^* energy equal to half the beam energy, in order to tag $D^* \rightarrow D$ decays; impact parameters to distinguish b quarks; and muon p and p_t to tag charm events. They use a more conventional feed forward network with 1 hidden layer. In total they have 19 input variables, 25 hidden nodes and 3 output variables. The systematic errors are from muon efficency and background (0.007), impact parameter (0.008), Monte Carlo parameters (0.010) and Monte Carlo model (0.008).

3. **ALEPH [9]:** ALEPH use 2 event shape methods. In the first they use a single jet neural network tag for events with and without a lepton tag. They construct 3 equations with 3 unknowns: f_b, ϵ_b, and ϵ_{udsc}, where f_b is the fraction of b quark events after the event selection cuts, and ϵ_b and ϵ_{udsc} are the efficiencies. The purity of the lepton sample is taken from the global fit described in the lepton tagging section and the correlation between its value and the extracted value of $R_{b\bar{b}}$ is taken into account.

   In the second method a combination of 2 variables is used: a "moment of inertia" and a "lateral mass". Both methods have very similar efficiency and purity so the results from them are averaged. The dominant systematic errors come from the knowledge of the lepton purity (0.004) and correlations (0.002).

The same procedure is used for averaging as in the lepton tag case. The systematic errors from varying the Monte Carlo parameters, including b fragmentation are treated as common.

Combined Result and Conclusions

The lepton tagging, event shape and lifetime tagging [10] results are combined assuming that the errors are uncorrelated:

$$R_{b\bar{b}} \quad = \quad 0.2200 \pm 0.0027$$

The accuracy on the measurement of $R_{b\bar{b}}$ is thus approaching the required 1% level. A first attempt has been made to take the correlations of the errors between the experiments into account. In future this treatment should be more rigorous. Double tag techniques are still statistically limited and so the results should improve further with more data.

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