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DELPHI RESULTS ON THE $Z^0 \to b\bar{b}$ PARTIAL WIDTH AND ON THE AVERAGE B HADRONS SEMILEPTONIC BRANCHING RATIO

Philip Bambade
For the DELPHI collaboration

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U.E.R
de
l'Université Paris-Sud

Institut National
de Physique Nucléaire
et
de Physique des Particules

Bâtiment 200 - 91405 ORSAY Cedex

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DELPHI results on the $Z^0 \rightarrow b\bar{b}$ partial width and on the average B hadrons semileptonic branching ratio

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presented by :

Philip Bambade
Laboratoire de l'Accélérateur Linéaire, IN2P3 - CNRS
et Université de Paris-Sud, F-91405 ORSAY Cedex, FRANCE

Abstract :

Results from DELPHI on the $Z^0 \rightarrow b\bar{b}$ partial width ($\Gamma_{b\bar{b}}$) and on the average B hadron semileptonic branching ratio ($B_{s.l.}$) are reviewed. Prospects are given for improving these measurements, using different complementary techniques.

INTRODUCTION

At LEP, $b\bar{b}$ events are produced through e^+e^- annihilation at the Z^0 pole with a branching ratio of about 15%. The statistics recorded by DELPHI in 1990 and in 1991 correspond respectively to about 26000 and 66000 $b\bar{b}$ pairs.

The first step in studying these events consists in isolating them experimentally to measure basic inclusive production and decay rates. Because of the characteristically large mass and long lifetime of the b quark, the decay products of the B hadrons formed through hadronization have larger transverse momenta with respect to the jet axis (P_t) and larger impact parameters than other tracks. These properties can be used to design different global tagging or enrichment schemes based on the full event. It is also possible to restrict oneself to leptons emitted in semileptonic decays. In this case, only about a two fifth of the $b\bar{b}$ sample is used - corresponding to the combined semileptonic branching ratio - but one benefits from the fact that leptons can be clearly signed experimentally.

The global methods provide direct measurements of the ratio R_b of $\Gamma_{b\bar{b}}$ to the hadronic width. This ratio has been shown to be sensitive to the top mass at the 1% level through electroweak radiative corrections, almost independently of the standard Higgs mass[1] . Although experimentally challenging, precise measurements of R_b are interesting to constrain the top mass within LEP data, and to exhibit anything unexpected at the $Zb\bar{b}$ vertex.

The methods based on leptons measure the products $\Gamma_{b\bar{b}} \times B_{s.l.}$ and $\Gamma_{b\bar{b}} \times B^2_{s.l.}$, from the single and dilepton rates N_l and N_{ll}, and allow $B_{s.l.}$ to be extracted. Predictions of $B_{s.l.}$ are mainly based on the spectator model[2] , where a decaying B hadron is entirely assimilated to its contained b quark, assumed to decay weakly as if it were free. The measurement of $B_{s.l.}$ in LEP conditions is important because of the experimentally significant discrepancy existing between measurements performed at lower energies[3] and predictions of the spectator model. After introducing QCD corrections for hard gluon exchange and after allowing variations in the assumed quark masses, this discrepancy amounts to about 20%[4] . Resolving it may help refine our understanding of bound states containing heavy quarks: are non spectator diagrams important as they are in the charm sector[2] , or does the free quark model not provide an adequately precise picture of B hadrons, whose decays are known to occur mainly through the formation of resonances such as D, D^* and D^{**}[4] ?

Both R_b and $B_{s.l.}$ can be determined combining single and dilepton measurements[5] However, as can be easily shown, precise results require not only very large lepton samples, but also very good control of backgrounds from fake leptons and from leptons which do not originate from B mesons[6] . An approach which is more tolerant with the accuracy of the lepton identification algorithm, and perhaps more promising for the future, has been applied in DELPHI. It consists of measuring R_b from global methods based on the full event, and $B_{s.l.}$ from the single lepton rate N_l and from the measured R_b. After a brief description of the main components of the DELPHI detector, results are first presented on $\Gamma_{b\bar{b}} \times B_{s.l.}$, using muons in the 1991 data, and both electrons and muons in the 1990 data. Results on R_b are then presented, using two complementary global methods, applied so far only on the 1990 data: one based on the shape of the events, measured by the boosted sphericity product of their jets, and one based on the precise measurement of track impact parameters. In the final section, the results obtained are discussed and some prospects for improvements are given. A new and potentially powerful method for extracting R_b with minimal errors is suggested, based on using the redundancy provided by two independent discriminators for $b\bar{b}$ events such as the ones described in this report.

THE DELPHI APPARATUS

DELPHI is a 4π detector, operated at the LEP e^+e^- collider at CERN. A complete description exists in the litterature[7]. We outline solely components used in the measurements reported here, along with their performance obtained from 1991 data.

Only charged tracks are used. They are measured in a 1.2 Tesla magnetic field with three central tracking detectors:

- the Inner Detector (ID), a drift chamber with $12\ cm < r < 28\ cm$ and $29^0 < \vartheta < 151^0$
- the Time Projection Chamber (TPC), with $28\ cm < r < 122\ cm$ and $21^0 < \vartheta < 159^0$
- the Outer Detector (OD), with five layers of drift tubes at $r \simeq 2\ m$ and $50^0 < \vartheta < 130^0$

The average momentum resolution is $\Delta P/P \simeq (0.001 - 0.01)P$ [P in GeV]. The dE/dx of tracks is measured in the TPC with 6% resolution.

Precise impact parameter information is provided in $R\phi$ by the Vertex Detector (VD), consisting of three concentric shells of silicon with strips along Z at $25\mu m$ separation, situated at $6.5cm$ ($27^0 < \vartheta < 153^0$), $9cm$ ($37^0 < \vartheta < 143^0$), and $11cm$ ($42^0 < \vartheta < 138^0$). Measured resolutions for single hits and for track impact parameters are respectively $8\mu m$ and $\sigma^2_{i.p.} \simeq (25\mu m)^2 + (60\mu m/P)^2$ [P in GeV].

The High density Projection Chamber (HPC), a gas sampling detector, performs electromagnetic calorimetry with 17.5 radiation lengths of lead starting at $r = 208cm$, in the barrel region ($42^0 < \vartheta < 138^0$). Its energy resolution is $(\sigma_E/E)^2 \simeq (26\%/\sqrt{E})^2 + (7\%)^2$ and its spatial resolution is better than $1mm$ in Z. Further out, the Hadron Calorimeter (HCAL), also a gas sampling device, gives an energy resolution $\sigma_E/E \simeq 120\%/\sqrt{E}$. Behind it are the muon chambers, covering the regions $53^0 < \vartheta < 127^0$ for the barrel (MUB) and $12^0 < \vartheta < 48^0$ and $132^0 < \vartheta < 168^0$ for the endcaps (MUF).

MEASUREMENT OF $\Gamma_{b\bar{b}} \times B_{s.l.}$ USING SINGLE LEPTONS

Muons, characterized by their low radiation and interaction probabilities, are identified by the presence of hits in the MUB or MUF compatible with a track. The longitudinal shape of the energy deposits in the HCAL is also used to help monitor misidentified hadrons. Electrons are identified by the presence of an electromagnetic shower compatible with a track. The dE/dx measured in the TPC is used to monitor and to help reject misidentified hadrons. The efficiencies of the muon and electron algorithms, measured in jets, are respectively 78% and 58%, with probabilities of hadron misidentification around 1% in both cases.

Leptons from B hadrons are distinguished from other leptons through their harder P and P_t spectra. To extract $\Gamma_{b\bar{b}} \times B_{s.l.}$, the prediction of the Monte-Carlo simulation is adjusted to the two-dimensional (P, P_t) measured distribution. This is illustrated in Fig. 1, where the inclusive muon distributions from the 1991 analysis in the MUB and MUF are shown, with different shades for each of the contributing components: $b \rightarrow \mu$, $b \rightarrow c \rightarrow \mu$, $c \rightarrow \mu$, and misidentified hadron. The results obtained in 1990, with the barrel only, are[8] :

$$\Gamma_{b\bar{b}} \times B_{s.l.} = 0.0229 \pm 0.0017(stat) \pm 0.0011(syst)$$

using muons with $P > 4$ GeV, and:

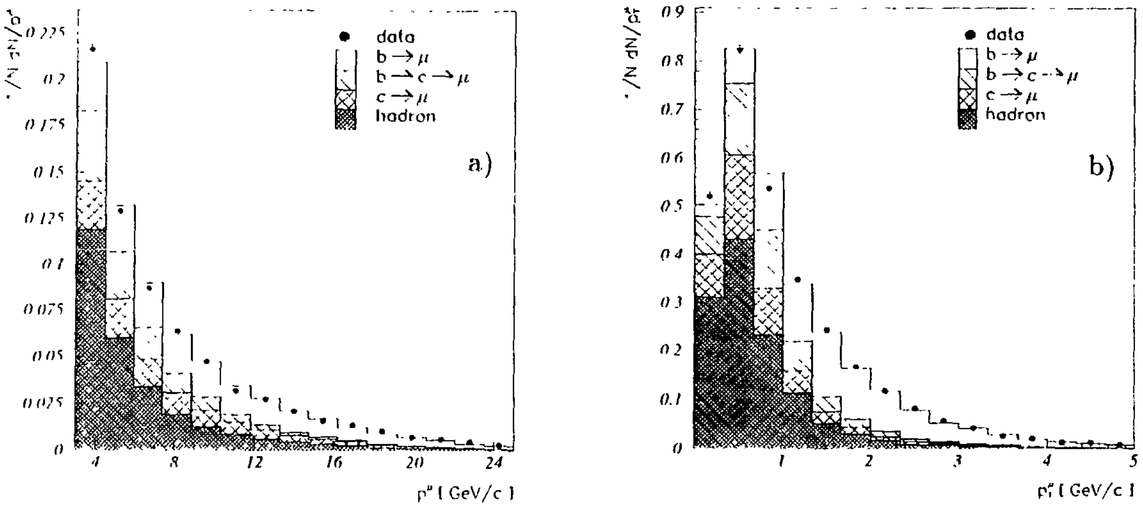
$$\Gamma_{b\bar{b}} \times B_{s.l.} = 0.0211 \pm 0.0019(stat) \pm 0.0013(syst)$$

using electrons with $P > 3$ GeV. The preliminary result obtained in 1991, using muons with $P > 3$ GeV in both the barrel and forward regions, is:

$$\Gamma_{b\bar{b}} \times B_{s.l.} = 0.0231 \pm 0.0006(stat) \pm 0.0011(syst)$$

In this last analysis, only some of the systematic errors have yet been checked. The systematic error from the 1990 analysis has therefore been quoted. It can be noted that the statistical error is much smaller than in 1990. This results not only from the larger statistics recorded in 1991, but also from using both the forward and barrel regions, from extending the muon identification down to $P > 3$ GeV, and from the availability of a larger Monte-Carlo sample in 1991.

The main components of the systematic errors in these results are the uncertainties on the efficiencies of the lepton identification algorithms, resulting from remaining discrepancies between its behaviour in the data and its description by the Monte-Carlo simulation. It is expected that with the increased 1991 statistics, such mismatches will be reduced to allow smaller final errors. The results also depend on the assumed fraction of semileptonic decays occuring through D^{**} states, because of the softening of the P spectrum. The results reported here were obtained using 20 % for this fraction. If it is 36 %, as indicated by recent measurements at the Υ_{4S}[9] , they should be increased by 0.0009.



a) P distribution

b) P_t distribution

Fig. 1 : Projections of the P versus P_t fitted bidimensional distributions showing the amplitude of the various components in the sample of muon candidates.

GLOBAL MEASUREMENTS OF R_b

Measurement with the Boosted Sphericity Product[10]

The presence in $b\bar{b}$ events of numerous tracks emitted at large P_t results in jets with larger sphericity than for other flavours. This is illustrated in Fig. 2, where is shown the product of the sphericities of each jet, separately boosted with $\beta = 0.96$, computed from the Monte-Carlo simulation for $b\bar{b}$, and non-$b\bar{b}$ events. The particular value of β is chosen to maximize sensitivity. The points represent the data, and the dotted line the result of the adjustment of the Monte-Carlo prediction to these data, used to determine R_b. Although the discriminating power is not outstanding, satisfactory results can be obtained with moderate statistics. Application on the 1990 data gives:

$$R_b = 0.219 \pm 0.014(stat) \pm 0.019(syst)$$

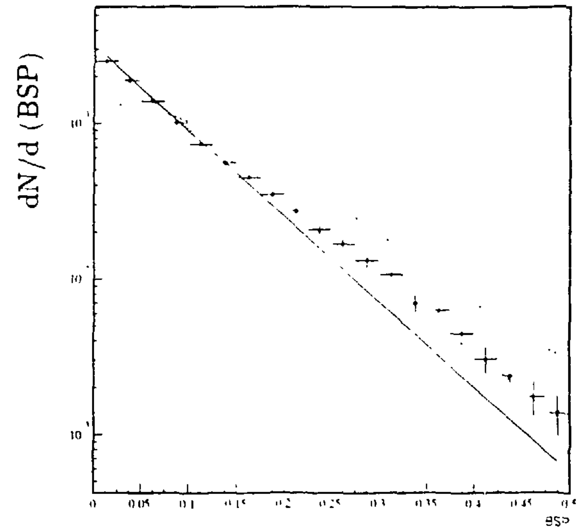


Fig. 2 : Differential distribution of the boosted sphericity product. The points represent the data. The lines superimposed correspond to the predictions of the Monte-Carlo simulation (JETSET PS) for $b\bar{b}$ events (dashed line), non-$b\bar{b}$ events (solid line), and for the result of the fit to the data (dotted line)

The systematic error is dominated by the understanding of the hadronization process. In particular the modelling of the P_t of tracks is important. A procedure has been developped to correct for discrepancies between simulation and data, without biasing the result on R_b. The result is also sentitive to the b quark fragmentation function. The factor of three larger statistics available in 1991 is expected to allow a reduction of these systematic errors by up to a factor two.

Measurement with Impact Parameters[11]

The long lifetime of B hadrons and the large P_t of its decay products result in events where typically several tracks pass near the interaction point with an offset - or impact parameter - which can be resolved using the VD. This is illustrated in Fig. 3, where the impact parameter of all tracks with $P_t > 1$ GeV is shown. The sign is chosen according to the compatibility between its intersection with the reconstructed jet axis, and the occurence of a particle decay with long lifetime in the same hemisphere. The impact parameters are calculated with respect to the mean beam position, calculated for each LEP fill from the hadronic events, rather than from a reconstructed primary vertex. Although the mean beam position has errors which are larger than those usually obtained on the reconstructed vertex, it is expected to yield smaller biases, since the primary vertex reconstructed in a $b\bar{b}$ event includes some offset tracks. An event is tagged as $b\bar{b}$ if:

$$N_{i.p.>0} - N_{i.p.<0} \geq 3$$

where $N_{i.p.>0}$ and $N_{i.p.<0}$ are the number of positive and negative lifetime signed tracks in the event. Taking a difference as above largely eliminates, on an event by event basis, events which would be wrongly tagged as $b\bar{b}$ because of the uncertainty in the interaction point. Using the Monte Carlo simulation to compute the efficiency of this cut for $b\bar{b}$ and non-$b\bar{b}$ events, it is possible to extract R_b. In the analysis performed with the *1990* data, keeping only tracks with $P > 1$ GeV, with at least one associated position measurement in the VD, and having an impact parameter larger than twice its computed error and smaller than $2mm$, the result obtained is:

$$R_b = 0.21 \pm 0.01(stat) \pm 0.03(syst)$$

The efficiency of the $b\bar{b}$ event selection is 9% and its purity 65%.

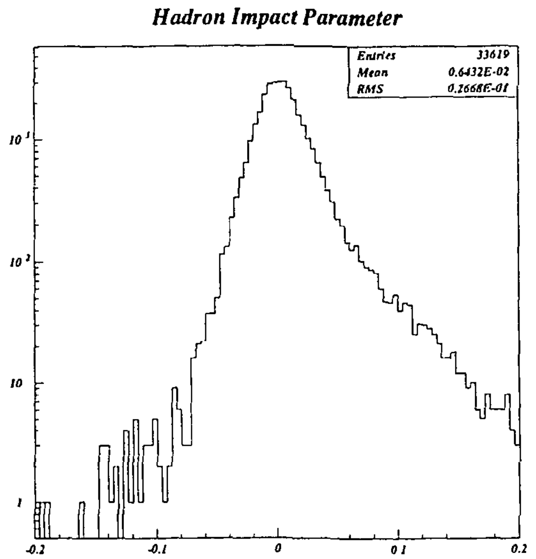


Fig. 3 : Impact parameter distribution for high P_t hadrons, with respect to the mean beam position, computed for each LEP fill

The systematic uncertainty is dominated by the understanding of the inefficiencies of the tracking. These were carefully studied and the simulation was tuned to reproduce the data as well as possible. Particularly critical is the efficiency for matching tracks to hits in the VD. The systematic error quoted reflects mismatches which are not yet fully understood in the data, and which can thus not be reproduced by the simulation. In 1990, only the two outermost layers of the VD, at *9* and *11cm*, were installed.

Using the improved precision of the present setup and the factor of three larger statistics available in 1991 to understand track errors better, it is expected that the precision of this measurement will be improved.

SUMMARY

In this report, measurements by DELPHI of R_b and $\Gamma_{b\bar{b}} \times B_{s.l.}$ available at the time of the conference have been presented. The 1990 results for R_b are:

$$R_b = 0.219 \pm 0.014(stat) \pm 0.019(syst)$$

from the boosted sphericity product, and

$$R_b = 0.21 \pm 0.01(stat) \pm 0.03(syst)$$

from the impact parameter method. The 1990 results for $\Gamma_{b\bar{b}} \times B_{s.l.}$ are:

$$\Gamma_{b\bar{b}} \times B_{s.l.} = 0.0229 \pm 0.0017(stat) \pm 0.0011(syst)$$

using muons, and:

$$\Gamma_{b\bar{b}} \times B_{s.l.} = 0.0211 \pm 0.0019(stat) \pm 0.0013(syst)$$

using electrons. The preliminary 1991 result, with muons in both the barrel and forward regions, is:

$$\Gamma_{b\bar{b}} \times B_{s.l.} = 0.0231 \pm 0.0006(stat) \pm 0.0011(syst)$$

A complete update with 1991 data is in progress.

Since the two results for R_b have quite independent systematics, and since the result based on the impact parameter method is obtained using only 9% of the $b\bar{b}$ statistics (compared with more than 50% for the boosted sphericity method), they can essentially be averaged to give:

$$R_b = 0.215 \pm 0.019$$

This result for R_b can be combined with the average of the 1990 electron and 1991 muon results on $\Gamma_{b\bar{b}} \times B_{s.l.}$ to obtain:

$$B_{s.l.} = (10.3 \pm 1.0)\%$$

DISCUSSION AND FUTURE PROSPECTS

The result obtained on R_b is compatible with the Standard Model prediction but its precision is not nearly good enough to sense effects from the top quark. Although less precise, the result for $B_{s.l.}$ is compatible with measurements performed at the Υ_{4S}. It confirms the discrepancy found with theory.

Certainly the understanding of the systematic uncertainties of the measurements reported will improve with more statistics, but it is not clear if 1% levels can be reached, as is needed particularly for precise determinations of R_b.

A new method developed to reduce the dependence on accurate Monte-Carlo descriptions, may allow significant reduction in systematics[12]. It consists of exploiting the redundancy of at least two independent discriminating variables to allow efficiency measurements to be performed within data. One (for example a variable based on impact parameters) is used to produce several samples with different degrees of enrichment in $b\bar{b}$ events. Distributions of the other (for example a variable based on event shapes such as the boosted sphericity product) are then decomposed formally in terms of their $b\bar{b}$ and non-$b\bar{b}$ content, for each of the enriched samples:

$$BSP_i \;=\; \alpha_i \; BSP_b \;+\; (1-\alpha_i) \; BSP_{nonb}$$

where $i = 1, 2, \ldots$ correspond to the enriched samples and α_i is the fraction of $b\bar{b}$ events in the ith sample. BSP_b and BSP_{nonb} are the specific distributions for only $b\bar{b}$ and non-$b\bar{b}$ events, which can be assumed to remain unchanged in the different samples if the two discriminating variables are truly independent. With at least three samples, the above equations can be solved simultaneously for the α_i fractions and for these specific distributions. The accuracy of the result depends on the degree to which the latter remain unchanged in the different samples. The Monte-Carlo simulation can be used to quantify this.

A first test of such a method, using 1990 data, has been made using, as the two independent discriminators, a combination of ten event shape variables (including the boosted sphericity product), and several impact parameter variables similar to the one described in this report[12]. The preliminary result obtained is $R_b = 0.223 \pm 0.004(stat)$. The statistical error is small because of the efficiency and purity provided by the discriminators used. Although an estimation of systematic errors is still being worked on, an indication is given from the spread of 0.013 in the results obtained with the different impact parameter variables used. More work is in progress to confirm these results with 1991 data, to ascertain the error calculation through Monte-Carlo studies, and to study the feasibility of further reducing it. It will be very interesting to find out the limit of such a method.

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References

1. J. Barnebeu, A. Pich and A. Santamaria, CERN-TH/90-5931
2. G. Altarelli and S. Petrarca, CERN-TH/91-6017
3. A. Golutvin, Contribution to the 4th Int. Symp. on Heavy Flavour Physics (Orsay, France, June 1991)
4. A. Dobrovolskaya, Contribution to the 4th Int. Symp. on Heavy Flavour Physics (Orsay, France, June 1991), LPTHE Orsay/91-48
5. W. Venus, Contribution to "Les Rencontres de Physique de la Vallée d'Aoste" (La Thuile, Italy, March 1992)
6. P. Roudeau, LAL Orsay/91-69
7. P. Aarnio et al. (DELPHI Collaboration), The DELPHI Detector at LEP, Nucl. Instr. and Meth. A303 (1991) 233-276
8. P. Abreu et al. (DELPHI Collaboration),CERN-PPE/92-79
9. K. Reim (Argus Collaboration), Contribution to this Conference
10. P. Abreu et al. (DELPHI Collaboration),CERN-PPE/92-7
11. P. Dauncey, Contribution to the 4th International Symposium on Heavy Flavour Physics (Orsay, France, June 1991)
12. E. Cortina et al., DELPHI/92-27/PHYS-163 (Internal Note)