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First measurement of the inclusive charmless B branching ratio

Preliminary

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Abstract

A measurement of the inclusive charmless B decay branching ratio, the B branching ratio into two charmed particles, and the total number of charmed particles in B decays has been performed by the DELPHI experiment at LEP, using the hadronic Z data taken between 1992 and 1994. The results are extracted from a fit to the b-tagging probability distribution based on the precise impact parameter measurements by the microvertex detector. The inclusive charmless B branching ratio, including B decays into hidden charm ($c\bar{c}$), is measured to be 0.044 ± 0.025. The B branching ratio into two open charmed particles is 0.163 ± 0.046. The mean number of charmed particles per B decay (including hidden charm) is 1.163 ± 0.045. The charmless B branching ratio is compatible with the Standard Model expectation. Models that predict an additional contribution to the charmless B branching ratio of 0.045 or higher are excluded at 95% CL.

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1 Introduction

At present no measurements exist of the inclusive branching ratio of B particles into final states without a charmed particle.

In the Standard Model, charmless b decays are based on the rare processes: $b \to u$, $b \to s(d)\gamma$ and $b \to s(d)g$. The first process occurs at tree level but is suppressed because of the small value of the ratio of the CKM matrix elements V_{ub}/V_{cb}. It is measured in semi-leptonic B decays. The last two processes can only occur through penguin loop diagrams. The inclusive branching ratio $b \to s\gamma$ is measured to be $(1.9 \pm 0.5) \times 10^{-4}$ [1]. For the inclusive $b \to s(d)g$, no measurements exist; only some branching ratios into exclusive final states are known [2]. In the Standard Model, the total charmless b decay rate is expected to be 0.026 ± 0.01 [3].

An outstanding puzzle in B physics is that the theoretical prediction [4] for the semi-leptonic B branching ratio is higher than the measured values. This can be solved if, for example, the non-leptonic contribution to B decays is larger than expected.

New physics beyond the Standard Model can enhance the predicted inclusive charmless b branching ratio, through the contributions of new particles or flavour changing neutral currents in loop diagrams. As a possible solution to the puzzle, it has therefore been suggested that the charmless b branching ratio may be as large as 0.10 to 0.15, due to new physics [5]. A large branching ratio for the process $b \to s(d)g$ is consistent with present measurements of the kaon content in B decays [6], and is not excluded by limits that can be derived from the measurement of the branching ratio $b \to s\gamma$ [7].

Since the $b \to c\bar{c}s$ decay rate is hard to calculate reliably due to the small energy release, an alternative possible solution to the puzzle that does not require new physics is to assume a large branching ratio of 0.15 ± 0.05 [8] for $b \to c\bar{c}s$ followed by $c\bar{c}$ annihilation, thus leading to a large additional branching ratio into so-called 'hidden charm' that would be included in the measured charmless b branching ratio.

A third possible solution, that does not require new physics and does not affect the measured charmless b branching ratio, is to assume a larger branching ratio for $b \to c\bar{c}s$ where the $c\bar{c}$ quarks do not annihilate. This increases the number of charmed particles per B decay. Explaining the measured semi-leptonic B branching ratio in this way would imply a number of charmed particles per B decay of 1.3 ± 0.05 [8], or 1.2 ± 0.05 [9]. The present measurements of the number of charmed particles in B decays at the $\Upsilon(4S)$ and LEP are based on branching ratio measurements of B hadrons[1] into D^0, D^+, D_s, Λ_c, and Ξ_c [10, 11, 12]. They have rather large common systematic uncertainties because of uncertainties in the branching ratios of charmed particles into exclusive final states. The recent CLEO result for the number of charmed particles in B decays is 1.10 ± 0.05 [10]. The LEP results are compatible with this value if the same assumptions on branching ratios are made. The measured number of charmed particles per B decay is rather low compared with theoretical expectations.

This paper presents measurements of the charmless and double charmed B decay branching ratios $Br_{0\mathrm{C}}$ and $Br_{2\mathrm{C}}$, and thus of the number of charmed particles per B decay.

The results are based on a new application of the b-tagging technique [13] using the precise track extrapolations provided by the microvertex detector. The b-tagging

[1]In the text, the notation B refers to B mesons (including the B_s^0 meson) and B baryons, except for $\Upsilon(4S)$ measurements where it refers only to B_d^0 and B^+ mesons.

probability is calculated in the following way [13]. First a primary vertex is fitted, then each track measured in the microvertex detector is extrapolated to the primary vertex and the lifetime signed impact parameter is determined. The lifetime sign is positive if the track crosses the axis of the jet to which it belongs in front of the primary vertex, negative if it crosses behind. From the impact parameter of each track and its error, the probability that the track is compatible with the primary vertex is evaluated. Finally, the combined probability, denoted by P_H^+, is calculated; this is the probability for the hypothesis that all the tracks with positive lifetime signs in a given hemisphere come from the primary vertex. For hemispheres with one or more secondary vertices, P_H^+ tends to be small.

The difference between a charmless B decay and a B decay with one or two charmed particles is due to the lifetime of the charmed particles; these different classes of events have one, two or three secondary vertices respectively. As shown in Figure 1, the distributions for the simulated b-tagging probability per hemisphere P_H^+ have different shapes for charmless, single charm and double charm B decays; in general, additional secondary vertices in a hemisphere result in a lower average probability. By fitting the P_H^+ distribution, the branching ratios for charmless, single charm and double charm B decays can be extracted.

The measured charmless B decay branching ratio $Br_{0\mathrm{C}}$ will include the B decays into 'hidden charm' (i.e. $b \to c\bar{c}s$ decays that do not give open charm states). A hidden charm contribution estimated from the measured $B \to J/\psi(\psi\prime)X$ branching ratios to amount to 0.026 ± 0.004 [3, 10] is subtracted from the observed $Br_{0\mathrm{C}}$ and added to $Br_{2\mathrm{C}}$.

The results are then used to determine the number of charmed particles per B decay. It is clear that this technique allows a measurement of the B branching ratios and the number of charmed particles that is largely independent of previous measurements and has different systematic errors.

The plan of the paper is the following. Firstly, the event selection and analysis are described. Secondly, the results for the branching ratios are presented. Finally, the results are discussed and compared with those of other experiments. An upper limit is given for possible new physics in the branching ratio of the bottom quark into charmless particles.

2 Analysis

The DELPHI detector and its performance are described in [14]. The data taken around the Z pole from 1992 to 1994 were analyzed. In 1992 and 1993 the silicon vertex detector measured only the $R\phi$ coordinate, while in 1994 the Rz coordinate was also measured; here R is the radius orthogonal to the beam axis, z is the coordinate parallel to it, and ϕ denotes the azimuthal angle. Details of the performance of the vertex detector are given in [15].

The selection of hadronic events is based on the standard hadronic tag [18]. A total of 674K, 711K and 1,359K hadronic events were selected for the 1992, 1993 and 1994 data.

The thrust axis of the event was calculated using charged and neutral particles. Events that were fully contained in the vertex detector were selected: the polar angle of the thrust axis had to lie between 57° and 123° for the 1992 and 1993 data, in 1994 the vertex detector was longer so polar angles between 50° and 130° were accepted. The measured particles were clustered with the LUCLUS jet algorithm with an invariant mass cut of 5 GeV/c^2.

The jets were ordered in energy. Events with hard gluons were suppressed by requiring that the sum of the energies in the third, fourth, etc. jets was less than 30 % of the total energy.

Samples of $Z \to q\overline{q}$ events generated by JETSET7.3 [19] with DELPHI tuning [20] were passed through the detector simulation program DELSIM [21] and processed with the same analysis chain as the real data. The simulated data set corresponds to 4,137K selected hadronic events.

Events were divided into two hemispheres according to the direction of the thrust axis. The b-tagging probability P_H^+ defined above was calculated for both hemispheres.

A sample enriched in B events was selected by requiring that in one hemisphere, used to tag the event, this probability P_H^+ was less than 0.005 (0.01 for the 1992 and 1993 data). The value of the cut was chosen to optimize the efficiency and purity for bottom quarks. In the 1994 data the cut value could be lowered, because of the measurement of the impact parameter in the Rz plane.

In the opposite hemisphere, where the measurement was performed, it was only required that at least two tracks have vertex detector hits and a positive lifetime sign. One event can give at most two measurement hemispheres. Thus 41K, 54K and 202K measurement hemispheres were selected for the 1992, 1993 and 1994 data respectively. About 84% of the sample consists of Z decays to $b\bar{b}$ quark pairs.

The b-tagging probability distribution for the measurement hemispheres was used to extract the charmless, single charm and double charm B branching ratios. The following procedure was adopted. The simulated events were divided into four classes, three for b quark decays and one for the light quark background:

(i) No charm (0C): $b \to u\bar{u}d$, $b \to ul\nu$, $b \to s\gamma$, $b \to d\gamma$, $b \to sg$, $b \to dg$ and $b \to (c\bar{c})s$, where $(c\bar{c})$ is a hidden charm state.

(ii) Double charm (2C): $b \to c\bar{c}s$

(iii) Single charm (1C): $b \to c\bar{u}d$, $b \to cl\nu$, $b \to u\bar{c}s$

(iv) Light quark background (BKG): u, d, s, and c quark events

The first category contains the charmless decays. The decays into hidden charm $(c\bar{c})$, like J/ψ and excited states, also fall in class (i), because these states promptly decay. In category (ii), the b quark decays into two open charmed particles ($D^0, D^+, D_s, \Lambda_c, \Xi_c$, or Ω_c). Class (iii) contains only decays into one charmed particle. Events from light or charm quarks were put in category (iv). For each of the classes, the b-tagging probability distribution $\mathcal{F}(P)$ was extracted from the simulation. The following fitting function was used:

$$\mathcal{F}(P) = R_N(1+\alpha P)[Br_{0C}\mathcal{F}^{0C}(P) + Br_{2C}\mathcal{F}^{2C}(P) + Br_{1C}\mathcal{F}^{1C}(P) + R_{BGK}\mathcal{F}^{BKG}(P)] \quad (1)$$

where $P = -\log(P_H^+)$, the $\mathcal{F}^{\mathrm{0C,2C,1C,BKG}}(P)$ are the distributions for the classes (i) to (iv), R_N is an overall normalization factor, R_{BKG} is the background scaling factor, and α is the slope parameter (see next paragraph). The parameters Br_{0C}, Br_{2C}, and Br_{1C} are defined as the branching ratios for no charm, double charm, and single charm; they add up to 1. R_N is the ratio of the number of hemispheres in data and simulation and R_{BKG} is a background scaling factor, which is equal to 1 if data and simulation agree. The following parameters were left free in the fit: Br_{0C}, Br_{2C}, (Br_{1C} is eliminated), R_{BKG}, R_N, and α.

The slope parameter α was introduced into the fit because it substantially reduces the systematic error on the branching ratio $Br_{2\mathrm{C}}$. Using simulated data, it was observed that varying the average lifetime of the b quark τ_b or the mean energy fraction taken by the B hadron $< x_b >$ over the appropriate range (see Table 1) gave large systematic errors on the branching ratio $Br_{2\mathrm{C}}$ of 0.035 and 0.02 respectively. The change in the shape of the $\mathcal{F}(P)$ distributions caused by these systematic errors can be parametrized by a function which is approximately linear in P. When the slope parameter α was introduced as a free parameter in the fit, changing τ_b ($< x_b >$) over the relevant range changed the slope from 2-4 (1-2) $\times 10^{-3}$ but reduced the systematic error on the branching ratio $Br_{2\mathrm{C}}$ from these sources to below 0.01 (see Table 1).

source	value and variation	$\delta Br_{0\mathrm{C}}$ 1992/1993	$\delta Br_{0\mathrm{C}}$ 1994	$\delta Br_{2\mathrm{C}}$ 1992/1993	$\delta Br_{2\mathrm{C}}$ 1994
f_{B_s}	0.12 ± 0.02	0.001	0.001	0.001	0.002
f_{Λ_b}	0.09 ± 0.03	0.005	0.004	0.003	0.007
τ_b	1.55 ± 0.05 ps	0.005	0.003	0.007	0.006
τ_{B_s}	1.6 ± 0.15 ps	0.001	0.001	0.002	0.002
τ_{Λ_b}	1.3 ± 0.15 ps	0.002	0.002	0.005	0.004
$< x_b >$	0.702 ± 0.008	0.008	0.003	0.007	0.012
$< x_c >$	ϵ_c=0.42 ± 0.07	0.003	0.004	0.012	0.016
N_c	2.53 ± 0.06	0.001	0.001	0.002	0.001
$Br(D \to K^0\, X)$	0.46 ± 0.06	0.004	0.001	0.008	0.011
$g \to c\bar{c}$ per hadron	0.0238 ± 0.0048	-	-	0.001	0.001
$f(D^+)\ 1C$	0.23 ± 0.03	0.001	0.001	0.002	0.004
$f(\Lambda_c)\ 1C$	0.10 ± 0.03	0.002	0.001	0.006	0.002
$f(D^+)\ 2C$	0.16 ± 0.03	0.001	0.001	0.001	0.001
N_b	5.25 ± 0.35	0.004	0.004	0.012	0.006
uds efficiency	$\pm$ 5%	0.003	0.002	0.009	0.003
c efficiency	$\pm$ 10%	0.003	0.002	0.013	0.019
total corr. syst.		0.014	0.009	0.028	0.033
resolution function		0.022	0.012	0.035	0.035
total uncorr. syst.		0.022	0.012	0.035	0.035

Table 1: Breakdown of the systematic error on the charmless B branching ratio $Br_{0\mathrm{C}}$ and the B branching ratio into two open charmed particles $Br_{2\mathrm{C}}$. See text for the definition of the symbols.

The background scaling factor R_{BKG} can also be left free in the fit, because the shape of the b-probability distribution for the udsc background is very different from the distributions for b quarks (see Figure 1). Leaving it free reduces the systematic errors on the branching ratios $Br_{2\mathrm{C}}$ and $Br_{0\mathrm{C}}$.

It is clear that the background scaling factor R_{BKG} should be around 1 and the slope α around 0. Therefore a constrained fit was performed with an additional χ^2 contribution for R_{BKG} with an error of 0.1 and for the slope α with an error of 3×10^{-3}. The error on the background reflects the 10% uncertainty in the efficiency for charm (see Table 1). The error on the slope corresponds to the variations induced by the systematic errors on τ_b and x_b. Applying these constraints with these errors was found to minimise the total errors on the fitted Br values.

3 Results

A binned χ^2 fit to the data was performed for P values ranging from 0 to 15 for the 1992 and 1993, and from 0 to 45 for the 1994 data. The statistical error on the simulation is included in the error per bin. The fitting range was chosen to exclude the tails of the distributions where there are less than 100 events per bin. Figure 2 shows the result of the fit for the different data sets. The background, charmless, double charm and single charm contributions are indicated with different shadings.

The result of the fit for the charmless B branching ratio $Br_{0\mathrm{C}}$ is given in Table 2, and for the branching ratio of B hadrons into two charmed particles $Br_{2\mathrm{C}}$ in Table 3. The total error corresponds to the statistical, correlated and uncorrelated systematic errors. The correlation in the fit between the two branching ratios is very small and can be neglected. The χ^2 per degree of freedom of the fit is 62.7/55 for the 1992 data, 69.4/55 for 1993, and 62.7/85 for 1994. The background scale factors R_{BKG} were 0.93, 0.91 and 0.98 and the slope parameters α were -6×10^{-3}, -3×10^{-3} and 4×10^{-3} for the 1992, 1993 and 1994 data respectively. This is consistent with the expectation that R_{BKG} should equal one and α should equal zero within the associated errors. The results were stable if the error on the slope parameter in the constrained fit was varied by a factor 1.5.

data set	$Br_{0\mathrm{C}}$	stat. error	uncorr. syst. error	total error
1994	0.047	0.028	0.012	0.032
1993	0.048	0.043	0.022	0.050
1992	0.029	0.052	0.022	0.058
combined	0.044			0.025

Table 2: Results for the charmless B branching ratio $Br_{0\mathrm{C}}$ and errors.

data set	$Br_{2\mathrm{C}}$	stat. error	uncorr. syst. error	total error
1994	0.119	0.041	0.035	0.063
1993	0.193	0.058	0.035	0.073
1992	0.198	0.059	0.035	0.073
combined	0.163			0.046

Table 3: Results for the branching ratio of B hadrons into two open charmed particles $Br_{2\mathrm{C}}$ and errors.

A study has been performed to estimate the systematic errors that affect the measurement. A detailed breakdown can be found in Table 1.

The fraction of B_s mesons (f_{B_s}) and Λ_b baryons (f_{Λ_b}) in b decays, the average lifetime of the b quark (τ_b), and the lifetimes of the B_s and Λ_b were varied. The average fractions of the energy taken by the B hadron $< x_b >$ and by the charmed particle $< x_c >$ in the B decay were changed. The observed average B hadron decay multiplicity (N_b, excluding tracks from K_s^0 and Λ particles) was varied. The charged multiplicity in charm decays, the branching ratio $Br(D \to K^0 X)$ and the fraction of gluons giving a charm quark pair were changed. The above variations correspond to the recommendations of the heavy flavour working group [22].

The measurement can also be sensitive to the relative amount of charmed particles with very different lifetimes, in particular the D^+ and Λ_c particles. Therefore the fraction of D^+ mesons ($f(D^+)$) and Λ_c baryons in single and double charm B decays were varied within the indicated ranges. The mean values and variations for these branching ratios are extrapolations from the measurements made at the $\Upsilon(4S)$ [10]. The efficiencies for light quarks and charm quarks were varied by 5% and 10% respectively, as in [13].

The above systematic errors are considered to be fully correlated for the different years. Other correlated systematic errors are considered to be negligible.

From Table 1 it is concluded that the total correlated systematic error on the branching ratio for charmless B decays $Br_{0\mathrm{C}}$ is rather small, 0.014 (0.009) for the 1992 and 1993 (1994) data, the largest contributions coming from $< x_b >$, $< x_c >$, τ_b, N_b and f_{Λ_b}. For the systematic error on the branching ratio for B hadron decays into two charmed particles $Br_{2\mathrm{C}}$, the correlated systematic error is larger and amounts to 0.028 (0.033) for the 1992 and 1993 (1994) data. The largest contributions come from $< x_b >$, $< x_c >$, N_b, $Br(D \to K^0 X)$ and the charm and light quark efficiencies.

The dominant source of uncorrelated systematic error is the tuning of the resolution of the microvertex detector. The procedure for tuning the track impact parameter resolutions and b-tagging probabilities for 1992 and 1993 data are described in detail in [16]. This tuning was also used for the DELPHI measurement of the fraction of b-quark events in hadronic Z decays [13][2]. The quality of the track reconstruction and the tuning for the 1994 data was better than for previous years [17].

The resolution function was determined in the following way. The b-tagging probability per track was studied in light quark events with negative impact parameters, and tuned to be flat. The same procedure was followed for real data and simulation, and two resolution functions were extracted. The systematic error from the resolution function, due to remaining discrepancies between data and simulation, was obtained by applying to the simulation the resolution function of the data. The full analysis was then repeated. The systematic error on the branching ratios is not correlated between the different data sets, because the tuning was done separately for each year. The uncorrelated systematic error on the charmless B branching ratio $Br_{0\mathrm{C}}$ was 0.02 in 1992 and 1993, and 0.01 in 1994. The uncorrelated systematic error on the double charm branching ratio $Br_{2\mathrm{C}}$ was 0.035 for all years (see Table 1).

The results for the branching ratios for the different years are shown in Figure 3. The χ^2/dof for combining the three results for the charmless B branching ratio is 0.09/2, and

[2]The R_b measurement made use of the simulated distributions of P only for the small light and charm quark contaminations. In contrast, here it is necessary to rely on the simulation for the distributions for the various categories of B decays (i.e. no, single, and double charm production).

that for the double charm branching ratio is 1.1/2.

Taking into account the correlated and uncorrelated errors (see Table 2), the result for the charmless B branching ratio is:

$$Br_{0\mathrm{C}} = 0.044 \pm 0.025.$$

Subtracting the hidden charm contribution of 0.026 ± 0.004 [3, 10] yields a charmless B branching ratio of 0.022 ± 0.025, to be compared with the Standard Model expectation of 0.026 ± 0.01 [3].

The branching ratio of B hadrons into two open charmed particles is measured to be (see Table 2):

$$Br_{2\mathrm{C}} = 0.163 \pm 0.046.$$

The measurement of the charmless B branching ratio is compatible with the Standard Model prediction. Imposing the Standard Model value, the number of charmed particles per B decay N_C is extracted. The branching ratio for decays into hidden charm was assumed to be 0.026 ± 0.004. These decays were counted as contributing two charmed particles per B decay, the rest of the charmless branching ratio as giving no contribution. The result is summarized in Table 4.

The combined result is:

$$N_C = 1.163 \pm 0.045 \pm 0.01,$$

where the last error comes from the uncertainty on the charmless B branching ratio in the Standard Model. The χ^2/dof of the fit combining the results for the three years is 1.0/2.

data set	N_C	stat. error	uncorr. sys. error	total
1994	1.120	0.040	0.035	0.062
1993	1.189	0.054	0.035	0.068
1992	1.193	0.054	0.035	0.069
combined	1.163			0.045

Table 4: Results for the number of charmed particles per B decay and errors.

From the measured charmless B branching ratio, one can derive an upper limit on new physics in charmless B decays. Subtracting the Standard Model contribution, the branching ratio for new physics is

$$Br(b \to no\ charm)^{NEW} = -0.008 \pm 0.025 \pm 0.012.$$

Taking into account that this branching ratio cannot be negative, the upper limit at 95 % confidence level is $Br(b \to no\ charm)^{NEW} < 0.045$. Models that predict a large charmless B branching ratio in the range 0.10 – 0.20 [5, 8] are therefore excluded.

The measurement of B decays to two open charmed particles of $Br_{2\mathrm{C}} = 0.163 \pm 0.046$ can be compared to the recent results from CLEO and ALEPH. CLEO measured the branching ratio for $\bar{B} \to D_s^- X$ to be 0.10 ± 0.027 and that for $\bar{B} \to \bar{D} X$ to be 0.081 ± 0.026 [23], while ALEPH measured the branching ratio for the last process to be $0.128 \pm 0.027 \pm 0.026$ [24]. The two branching ratios should be added to obtain the B branching ratio into double charm. The results are compatible within the errors and confirm the rather high B branching ratio into two open charmed particles.

The measured number of charmed particles per B decay, $N_C = 1.163 \pm 0.045$, is compatible with the recent CLEO result for B^+ and B^0 mesons, $N_C = 1.10 \pm 0.05$ [10]. This new measurement is closer to the theoretical expectation of N_C=1.2 to 1.3. The combined experimental value is still low compared with the theoretical expectation.

4 Conclusion

Using a new application of the b-tagging technique, measurements have been performed of the inclusive charmless B branching ratio, the B branching ratio into two open charmed particles and the total number of charmed particles in B decays.

The charmless B branching ratio, including B decays into hidden charm, has been measured to be $Br_{0\mathrm{C}} = 0.044 \pm 0.025$. This is compatible with the Standard Model prediction of 0.052 ± 0.012. An upper limit at 95 % CL on new physics in charmless B decays is derived of $Br(b \to no\ charm)^{NEW} < 0.045$. This result puts severe constraints on models that predict a large charmless B branching ratio.

The branching ratio of the bottom quark into two open charmed particles $Br_{2\mathrm{C}}$ is measured to be 0.163 ± 0.046. The result is compatible with recent measurements.

The number of charmed particles per B decay is determined to be $N_C = 1.163 \pm 0.045$, compatible with the recent CLEO result. This new measurement is slightly lower than the theoretical expectation of N_C=1.2 to 1.3.

5 Acknowledgements

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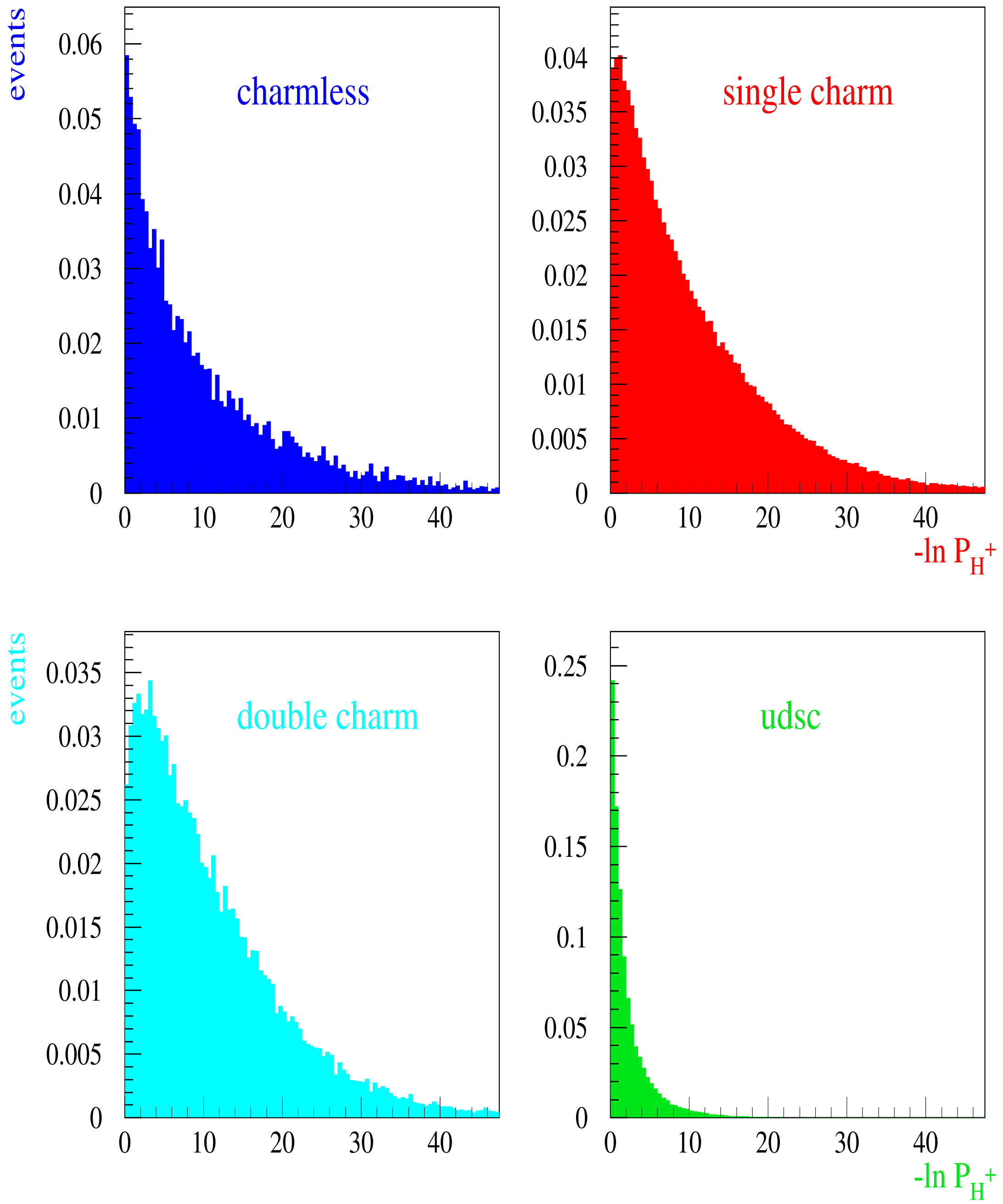

Figure 1: The b-probability distribution per hemisphere, P_H^+, from the 1994 simulation for charmless and hidden charm B hadron decays, B decays into one charm particle, B decays into two (open) charm particles, and the udsc background.

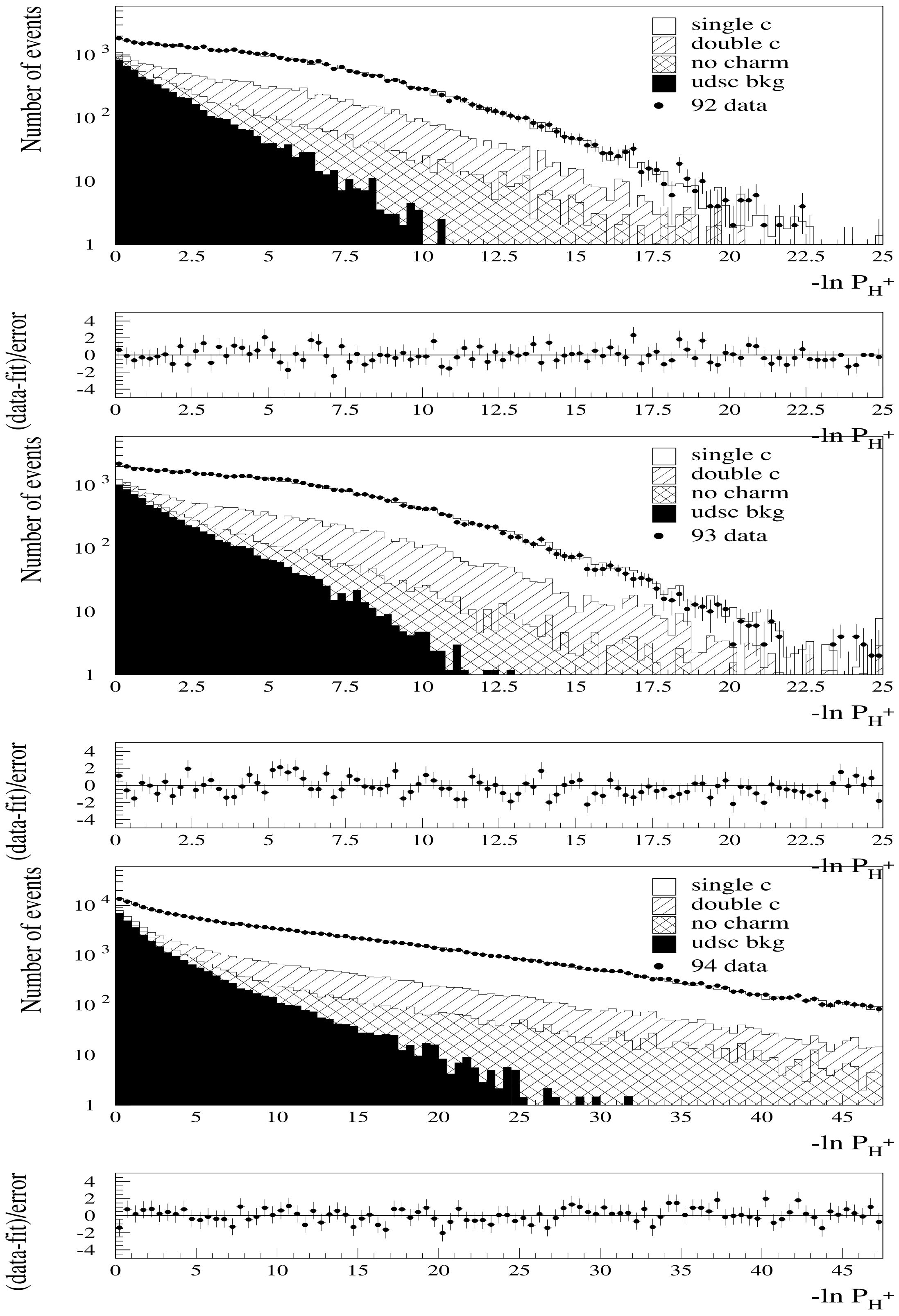

Figure 2: The b-probability distribution for the measurement hemisphere for the 1992-1994 data (points with error bars) and simulation (histograms), showing with different hatch styles the contributions from B decays into single, double and no charm and from the background. The difference between the data and the fit result divided by the error is also shown below each plot.

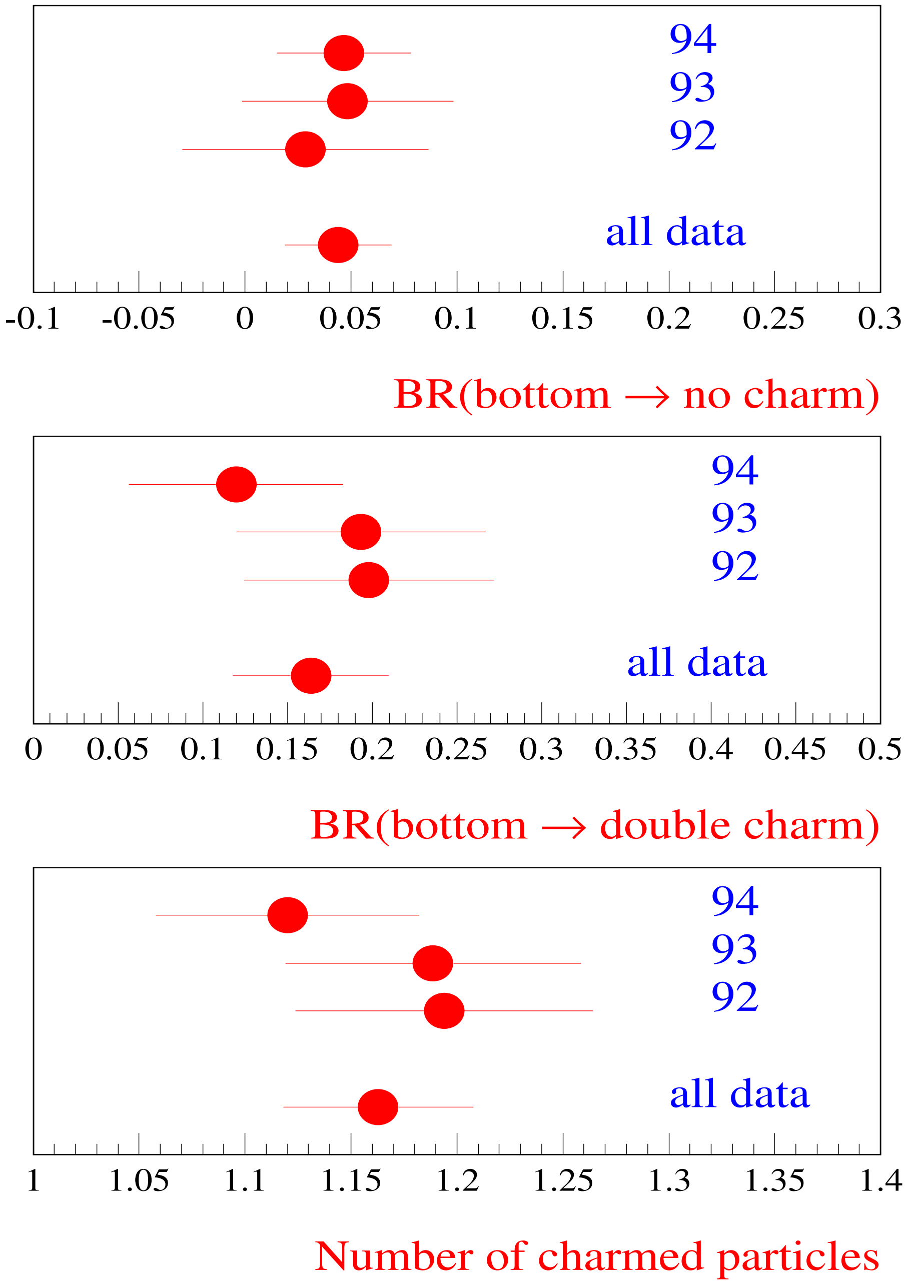

Figure 3: Summary of the results for the branching ratio of a bottom quark into charmless final states including hidden charm (upper plot), the branching ratio into double charm final states (middle), and the number of charmed particles per B decay (lower). The error bars correspond to the total (stat+syst) error.

References

[1] M.S. Alam et al. (CLEO Collaboration), Phys. Rev. Lett. **74** (1995) 2885.

[2] M. Battle et al. (CLEO Collaboration), Phys. Rev. Lett. **71** (1993) 3992;
W. Adam et al. (DELPHI Collaboration), Z. Phys. **C72** (1996) 207;
D. Busculic et al. (ALEPH Collaboration), Phys. Lett. **B384** (1996) 471.

[3] G. Buchalla et al., Phys. Lett. **B364** (1995) 188.

[4] G. Altarelli and S. Petrarca, Phys. Lett. **B261** (1991) 303;
I. Bigi et al., Phys. Lett. **B261** (1994) 408;
M. Neubert, hep-ph/9702375;
M. Neubert and B. Stech, hep-ph/9705292.

[5] B. Grzadkowski and W.-S. Hou, Phys. Lett. **B272** (1991) 383;
A.L. Kagan, Phys. Rev **D51** (1995) 6196;
L. Roszkowski and M. Shifman, Phys. Rev. **D53** (1996) 404.

[6] A.L. Kagan and J. Rathsman, hep-ph/9701300.

[7] M. Ciuchini et al., Phys. Lett. **B388** (1996) 353, erratum **B393** (1997) 489.

[8] I. Dunietz et al., FERMILAB-PUB-96/421-T, hep-ph/9612421.

[9] M. Neubert and C.T. Sachrajda, Nucl. Phys. **B482** (1997) 339.

[10] L. Gibbons et al. (CLEO Collaboration), CLNS 96/1454, hep-ex/9703006.

[11] D. Busculic et al. (ALEPH Collaboration), Phys. Lett. **B388** (1996) 648.

[12] G. Alexander et al. (OPAL Collaboration), Z. Phys. **C72** (1996) 1.

[13] P. Abreu et al. (DELPHI Collaboration), Z. Phys. **C65** (1995) 555;
P. Abreu et al. (DELPHI Collaboration), Z. Phys. **C70** (1996) 531.

[14] P. Aarnio et al. (DELPHI Collaboration), Nucl. Instr. Meth. **A 303** (1991) 233;
P. Abreu et al., Nucl. Instr. Meth. **A378** (1996) 57.

[15] R. Bingefors et al., Nucl. Instr. Meth. **A328** (1993) 447;
V. Chabaud et al., Nucl. Instr. Meth. **A368** (1996) 314.

[16] G. Borisov and C. Mariotti, Nucl. Instr. Meth. **A372** (1996) 181.

[17] G. Borisov and C. Mariotti, 'Tuning of the b-tagging for 1994 data', DELPHI 97-16 PHYS 672.

[18] P. Abreu et al. (DELPHI Collaboration), Phys. Lett. **B312** (1993) 253.

[19] T. Sjöstrand, Comp. Phys. Comm. **39** (1986) 347;
M.Bengtsson and T. Sjöstrand, Comp. Phys. Comm. **43** (1987) 367.

[20] P. Abreu et al. (DELPHI Collaboration), Z. Phys. **C73** (1996) 11.

[21] DELPHI Collaboration, DELPHI event generation and detector simulation - User Guide, DELPHI Note 86-67 (1998), unpublished.

[22] D. Abbaneo et al. (The LEP electroweak working group), CERN LEPHF/96-01.

[23] R. Wang et al. (CLEO Collaboration), Nucl. Phys. B Proc. Supp. **54A** (1997) 261.

[24] R. Barate et al. (ALEPH Collaboration), submitted to ICHEP 96, PA05-060.