Measurement of the inclusive charmless and double-charm B branching ratios

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DELPHI Collaboration

Abstract

The DELPHI experiment at LEP has measured the inclusive charmless B hadron decay branching ratio, the B branching ratio into two charmed particles, and the total number of charmed particles per B decay, using the hadronic Z data taken between 1992 and 1995. The results are extracted from a fit to the b-tagging probability distribution based on the precise impact parameter measurements made using the microvertex detector. The inclusive charmless B branching ratio, including B decays into hidden charm ($c\bar{c}$), is measured to be 0.033 ± 0.021. The B branching ratio into two open charmed particles is 0.136 ± 0.042. The mean number of charmed particles per B decay (including hidden charm) is 1.147 ± 0.041. After subtracting the B decay branching ratio into hidden charm, the charmless B branching ratio is found to be 0.007 ± 0.021, compatible with the Standard Model expectation. Models that predict an additional contribution to the charmless B branching ratio of 0.037 or higher are excluded with at least 95% confidence.

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1 Introduction

At present no measurements exist of the inclusive branching ratio of B particles[1] 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 the ratio of the CKM matrix elements V_{ub}/V_{cb} is small. It is measured in semi-leptonic B decays. The last two processes can occur only 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 0.016 ± 0.008 [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 for $b \to c\bar{c}s$ followed by $c\bar{c}$ annihilation [8], which would be included in the measured charmless B branching ratio.

A third possible solution, that also does not require new physics and in addition 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. However, this increases the mean 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 about 1.30 ± 0.05 [8] or 1.20 ± 0.06 [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 into D^0, D^+, D_s, Λ_c, and Ξ_c [10–12]. 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 mean number of charmed particles in B decays is 1.10 ± 0.05 [10]. The average of the LEP results is 1.17 ± 0.07 if the same assumptions on branching ratios are made.

This paper presents measurements of the B decay branching ratios into no open charm, $Br_{0\mathrm{C}}$, and into double open charm, $Br_{2\mathrm{C}}$, and the mean number of charmed particles per B decay, N_c. The measured B decay branching ratio $Br_{0\mathrm{C}}$ includes charmless B decays and 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 [10,13], is subtracted from the observed $Br_{0\mathrm{C}}$ to obtain the truly charmless B branching ratio. The decays to hidden charm are counted as contributing two charmed particles per decay to N_C. The measured branching ratio $Br_{2\mathrm{C}}$ includes only B decays into two open charmed particles.

[1] In the text, the notation B refers to both 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.

2 Method

The measurement is based on a new application of the b-tagging technique [14] using the precise track extrapolation provided by the microvertex detector. The b-tagging probability is calculated in the following way [14]. 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 in P_H^+ between a hemisphere with a charmless B decay and one with a B decay giving 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 of the b-tagging probability per hemisphere P_H^+ have different shapes for simulated charmless (including hidden charm), single charm and double (open) 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 (including hidden charm), single charm and double (open) charm B decays can be extracted.

It is clear that this technique allows a measurement of the B branching ratios $Br_{0\mathrm{C}}$ and $Br_{2\mathrm{C}}$ and of the mean number of charmed particles N_C that is largely independent of previous measurements and has different systematic errors.

In the following, the event selection and analysis are described, the results for the branching ratios are presented, the results are discussed and compared with those of other experiments, and an upper limit is given for possible new physics contributing to the branching ratio of the b-quark into charmless particles.

3 Analysis

The DELPHI detector and its performance are described in [15,16]. The data taken around the Z pole from 1992 to 1995 were analyzed. In 1992 and 1993 the silicon vertex detector measured only the $R\phi$ coordinate, while in 1994 and 1995 the z 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 [17].

The selection of hadronic events is based on the standard hadronic tag [18]. A total of 674K, 711K, 1,359K and 636K hadronic events were selected for the 1992, 1993, 1994 and 1995 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 by requiring the polar angle of the thrust axis to lie between 57° and 123° for the 1992 and 1993 data; in 1994 and 1995 the vertex detector was longer so polar angles between 50° and 130° were accepted. The measured particles were clustered into jets with the LUCLUS 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 first two jets contained at least 70 % of the total energy.

Samples of $Z \to q\bar{q}$ events generated by JETSET7.3 [19] with DELPHI tuning [20], including the modified description of B decays and in particular of their branching fractions on the basis of recent data, were passed through the detector simulation program DELSIM [16] and processed with the same analysis chain as the real data. The simulated data set corresponds to 5,826K 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. To reduce the effects of far tails, very low b-tagging probabilities per track of 10^{-3} or lower in $R\phi$ (2.5×10^{-3} in Rz) were transformed [2] to values ranging from 10^{-3} to 2×10^{-4}.

A sample enriched in B events was selected by requiring that in one hemisphere, used to tag the event, the hemisphere 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 b-quarks. In the 1994 and 1995 data the cut value could be lower, because of the measurement of the impact parameter in the Rz plane.

In the opposite hemisphere, where the measurement was performed, it was required only that at least two tracks had vertex detector hits and a positive lifetime sign.

One event can give at most two measurement hemispheres. Thus 41K, 54K, 202K and 92K measurement hemispheres were selected for the 1992, 1993, 1994 and 1995 data respectively. About 84% of the sample consisted of Z decays to $b\bar{b}$ quark pairs.

The b-tagging probability distribution for the measurement hemispheres was used to extract the charmless (including hidden charm), single charm and double (open) 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 ($udsc$) quark background:

(i) No open 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 open 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 contained the charmless decays and also the decays into hidden charm ($c\bar{c}$), like the J/ψ and its excited states, because these states decay promptly. Category (ii) contained the b quark decays into two open charmed particles (D^0, D^+, D_s, Λ_c, Ξ_c, or Ω_c). Class (iii) contained only decays into one charmed particle. Events from up, down, strange or charm quarks were put in category (iv). For each of the classes, the corresponding b-tagging probability distribution $\mathcal{F}^{\rm class}(P)$ was extracted from the simulation.

A constrained binned χ^2 fit was then performed using the following fitting function:

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

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

The background scaling factor $R_{\rm BKG}$ was constrained to be around 1 and the slope α around 0 by including in the fit an additional χ^2 contribution for $R_{\rm BKG}$ with an error of

[2] Using the formula $P' = P_{min}\log(P_{min})/\log(P)$ for track probabilities P less than $P_{min} = 1(2.5) \times 10^{-3}$.

0.1 and another for the slope α with an error of 3×10^{-3}. The errors assigned to $R_{\rm BKG}$ and α correspond to their systematic uncertainties (see below).

4 Results

The constrained binned χ^2 fit to the data was performed for P values ranging from 0 to 15.5 for the 1992 and 1993, and from 0 to 40 for the 1994 and 1995 data[3]. Events with P values above 15.5 or 40 were put in the last bin and used in the fit. The fitting range was chosen to have more than about 100 entries per bin. The statistical error on the simulation was included in the error per bin.

Figures 2 and 3 show the data and the result of the fit for each data set. The background, charmless (0C), double charm (2C) and single charm (1C) contributions are indicated with different shadings.

The result of the fit for the branching ratio $Br_{\rm 0C}$ is given in Table 1, and for the branching ratio of B hadrons into two charmed particles $Br_{\rm 2C}$ in Table 2. The total error corresponds to the statistical, correlated and uncorrelated year-to-year 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 68.7/57 for the 1992 data, 70.9/57 for 1993, 70.5/75 for 1994 and 85.6/75 for 1995. The background scale factors $R_{\rm BKG}$ were 0.93, 0.87, 0.96 and 1.00, and the slope parameters α were -6×10^{-3}, -2×10^{-3}, 1×10^{-3} and 2×10^{-3}, for the 1992, 1993, 1994 and 1995 data respectively. This is consistent with the expectation that $R_{\rm BKG}$ should equal one and α should equal zero within the assigned errors of 0.1 and 3×10^{-3} respectively. The results were stable if the error on the slope parameter in the constrained fit was varied by a factor 1.5.

data set	$Br_{\rm 0C}$	stat. error	uncorr. syst. error	corr. syst. error	total error
1995	0.001	0.033	0.012	0.009	0.037
1994	0.036	0.029	0.012	0.009	0.033
1993	0.061	0.038	0.022	0.014	0.046
1992	0.057	0.046	0.022	0.014	0.053
combined	0.033				0.021

Table 1: Results for the charmless B branching ratio $Br_{\rm 0C}$ including B decays into hidden charm and the statistical and uncorrelated and correlated systematic errors.

A detailed breakdown of the systematic errors is given in Table 3. The contributions in the first group were determined by varying the following parameters assumed in the analysis according to the recommendations of the heavy flavour working group [21]: the fractions of B_s mesons (f_{B_s}) and Λ_b baryons (f_{Λ_b}) in b jets, the average lifetime of the b quark (τ_b), the lifetimes of the B_s and Λ_b, the average fractions of the energy taken by the B hadron $< x_b >$ and by the charmed particle in the B decay $< x_c >$, where ϵ in Table 3 refers to the Peterson fragmentation function, the average B hadron decay charged multiplicity N_b (excluding tracks from K^0_s and Λ particles), the charged multiplicity N_C in charm decays, the branching ratio $Br(D \to K^0\, X)$, and the probability of a gluon giving a c-quark or a b-quark pair in an event.

[3] The ranges differ because the z coordinate was measured only in 1994 and 1995.

data set	Br_{2C}	stat. error	uncorr. syst. error	corr. syst. error	total error
1995	0.084	0.044	0.035	0.033	0.065
1994	0.143	0.043	0.035	0.033	0.065
1993	0.125	0.056	0.035	0.028	0.072
1992	0.198	0.053	0.035	0.028	0.070
combined	0.136				0.042

Table 2: Results for the branching ratio of B hadrons into two open charmed particles Br_{2C} and the statistical and uncorrelated and correlated systematic errors.

The measurement can also be sensitive to the relative numbers of charmed particles with very different lifetimes, in particular of the D^+ and Λ_c particles. Therefore the fractions of D^+ mesons ($f(D^+)$) in single and double charm B decays and the fraction of Λ_c baryons in single charm B decays were varied within the indicated ranges. The mean values and variations used for these branching ratios are extrapolations from the measurements made at the $\Upsilon(4S)$ [10]. Finally, the efficiencies for wrongly tagging light quark and charm quark pairs as b-quark pairs were varied by 5% and 10% respectively, as in [14].

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

Tables 1 and 3 show that the total correlated systematic error on the branching ratio Br_{0C} is rather small, namely 0.014 (0.009) for the 1992 and 1993 (1994 and 1995) data, with the largest contributions coming from f_{Λ_b}, τ_b, $< x_b >$, $< x_c >$, and N_b. The total correlated systematic error on Br_{2C} is larger (see Tables 2 and 3) and amounts to 0.028 (0.033) for the 1992 and 1993 (1994 and 1995) 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 is described in detail in [22]. This tuning was also used for the DELPHI measurement of the fraction of b-quark events in hadronic Z decays [14][4]. The quality of both the track reconstruction and the tuning were better for the 1994 and 1995 data than for previous years [23].

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 branching ratio Br_{0C} was 0.022 in 1992 and 1993, and 0.012 in 1994 and 1995. The uncorrelated systematic error on the branching ratio Br_{2C} was 0.035 for all years.

[4]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 also on the simulation for the distributions for the various categories of B decays (i.e. no, single, and double charm production).

source	value and variation	$\delta Br_{0\mathrm{C}}$ 1992/1993	$\delta Br_{0\mathrm{C}}$ 1994/1995	$\delta Br_{2\mathrm{C}}$ 1992/1993	$\delta Br_{2\mathrm{C}}$ 1994/1995
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
$< x_c >$ B decays	ϵ=0.42 ± 0.07	0.003	0.004	0.012	0.016
N_b	5.25 ± 0.35	0.004	0.004	0.012	0.006
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 event	0.0238 ± 0.0048	0.001	0.001	0.001	0.001
$g \to bb$ per event	$(0.13 \pm 0.04) \times (g \to c\bar{c})$	0.001	0.001	0.001	0.001
$f(D^+)$ $1C$	0.23 ± 0.03	0.001	0.001	0.002	0.004
$f(D^+)$ $2C$	0.16 ± 0.03	0.001	0.001	0.001	0.001
$f(\Lambda_c)$ $1C$	0.10 ± 0.03	0.002	0.001	0.006	0.002
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 3: Breakdown of the systematic error on the branching ratio $Br_{0\mathrm{C}}$ and $Br_{2\mathrm{C}}$. See text for the definition of the symbols.

Including the background scaling factor R_{BKG} and the slope parameter α in the fit increased the statistical errors but reduced the systematic errors, thus reducing the total errors significantly. For example, varying the average lifetime of the b quark τ_b over the range indicated in Table 3 with α fixed induced large changes in the branching ratios $Br_{2\mathrm{C}}$ and $Br_{0\mathrm{C}}$ of about 0.035 and 0.048 respectively and large increases in the χ^2 of the fit of order 25, corresponding to effects of order 5 standard deviations. Allowing α to vary in the fit improved the agreement with the data and reduced the changes in the branching ratios to below 0.01 (see Table 3). The effects due to the uncertainty in $< x_b >$ were similar. The error assigned to α in the fit corresponded to the variations in α induced by the systematic errors on τ_b and $< x_b >$, so the χ^2 changes were reduced and became of order unity.

In this way, therefore, the impact parameter information related directly to τ_b was largely absorbed into the determination of the parameter α instead of affecting the branching ratios of interest here. Indeed, including α in the fit is almost equivalent to fitting τ_b itself, but simpler to implement. This also avoided a possible circularity problem arising from the fact that such impact parameter information has been used previously to determine τ_b assuming Standard Model values for these branching ratios.

The error assigned to R_{BKG} in the fit reflected the 10% uncertainty in the efficiency for charm (see Table 3).

5 Interpretation of Results

The results for the branching ratios for the different years are shown in Figure 4. The χ^2/dof for combining the four results for the charmless B branching ratio (including hidden charm) is 2.1/3, and that for the double (open) charm branching ratio is 2.7/3.

Taking into account the correlated and uncorrelated errors (see Table 2), the branching ratio of B hadrons into two open charmed particles is measured to be:

$$Br_{2\mathrm{C}} = 0.136 \pm 0.042.$$

The result for the charmless B branching ratio including B decays into hidden charm is:

$$Br_{0\mathrm{C}} = 0.033 \pm 0.021.$$

Subtracting the hidden charm contribution of 0.026 ± 0.004 [10,13] yields a charmless B branching ratio without hidden charm of :

$$Br(b \to no\ charm) = 0.007 \pm 0.021,$$

to be compared with the Standard Model expectation of 0.016 ± 0.008 [3].

The measurement of the charmless B branching ratio is compatible with the Standard Model prediction. Imposing the Standard Model value, the mean number of charmed particles per B decay, N_C, was extracted from the fit to the b-tagging probability distributions. The branching ratio for decays into hidden charm, $Br_{c\bar{c}}$, 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 fit used the formula $N_C = 1 + Br_{2\mathrm{C}} + Br_{c\bar{c}} - Br_{0C}^{SM}$, where Br_{0C}^{SM} is the charmless B branching ratio in the Standard Model and $Br_{0C}^{SM} + Br_{c\bar{c}} = Br_{0C}$ in equation 1 was kept fixed. The result is summarized in Table 4 [5].

The combined result is:

$$N_C = 1.147 \pm 0.041 \pm 0.008,$$

where the last error comes from the uncertainty on the charmless B branching ratio in the Standard Model. The χ^2/dof for combining the results for the four years is 2.5/3.

data set	N_C	stat. error	uncorr. sys. error	corr. sys. error	total
1995	1.097	0.043	0.035	0.033	0.065
1994	1.154	0.042	0.035	0.033	0.063
1993	1.136	0.054	0.035	0.028	0.070
1992	1.203	0.050	0.035	0.028	0.067
combined	1.147				0.041

Table 4: Results for the mean number of charmed particles per B decay and the statistical and uncorrelated and correlated systematic errors.

[5] Alternatively, one can extract N_C using the measured value $Br_{0C} = 0.033 \pm 0.021$ assuming that this branching ratio contains contributions from charmless and hidden charm B decays and no contribution from charm annihilation, as in the Standard Model. This gives $N_C = 1 + Br_{2\mathrm{C}} + 2\,Br_{c\bar{c}} - Br_{0C}$, and hence $N_C = 1.155 \pm 0.041 \pm 0.021$, where the last error comes from the experimental uncertainty on the measured branching ratio Br_{0C}.

An upper limit on new physics in charmless B decays can be derived from the measured charmless B branching ratio. Subtracting the Standard Model contribution, the branching ratio for new physics is

$$Br(b \to no\ charm)^{NEW} = -0.009 \pm 0.021 \pm 0.008.$$

Taking into account that this branching ratio cannot be negative, the upper limit at 95% confidence level is $Br(b \to no\ charm)^{NEW} < 0.037$. Using a dedicated simulation program for $b \to sg$ decays [6], the probability distribution for these decays was compared to the no open charm distribution $\mathcal{F}^{0C}(P)$. The distributions were found to be identical within statistical errors. 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 $Br_{2C} = 0.136 \pm 0.042$ can be compared to the recent preliminary results from the CLEO and ALEPH experiments. 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 [24], while ALEPH presented in 1996 a preliminary measurement of the branching ratio for the last process of $0.128 \pm 0.027 \pm 0.026$ [25]. 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, $N_C = 1.147 \pm 0.041$, is compatible with the recent CLEO result for B^+ and B^0 mesons, $N_C = 1.10 \pm 0.05$ [10] and the previous LEP average of $N_C = 1.17 \pm 0.07$. All three values lie somewhat below the theoretical expectation of N_C=1.2 to 1.3.

6 Conclusion

Using a new application of the b-tagging technique, the inclusive charmless B branching ratio, the inclusive B branching ratio into two open charmed particles, and the mean number of charmed particles per B decay have been measured.

The measured charmless B branching ratio, including B decays into hidden charm, was found to be $Br_{0C} = 0.033 \pm 0.021$. Subtracting the hidden charm contribution of 0.026 ± 0.004 [10,13] yields a truly charmless B branching ratio of 0.007 ± 0.021. This result agrees with the Standard Model expectation of 0.016 ± 0.008 [3]. The corresponding upper limit at 95% CL on charmless B decays due to new physics is $Br(b \to no\ charm)^{NEW} < 0.037$. This result puts severe constraints on models that predict a large charmless B branching ratio.

The branching ratio of the b-quark into two open charmed particles Br_{2C} was found to be 0.136 ± 0.042, compatible with recent preliminary measurements [24,25].

The mean number of charmed particles per B decay is $N_C = 1.147 \pm 0.041$, compatible with the recent CLEO [10] and LEP results. This new measurement, like the previous measurements, is slightly lower than the theoretical expectation of N_C=1.2 to 1.3.

7 Acknowledgements

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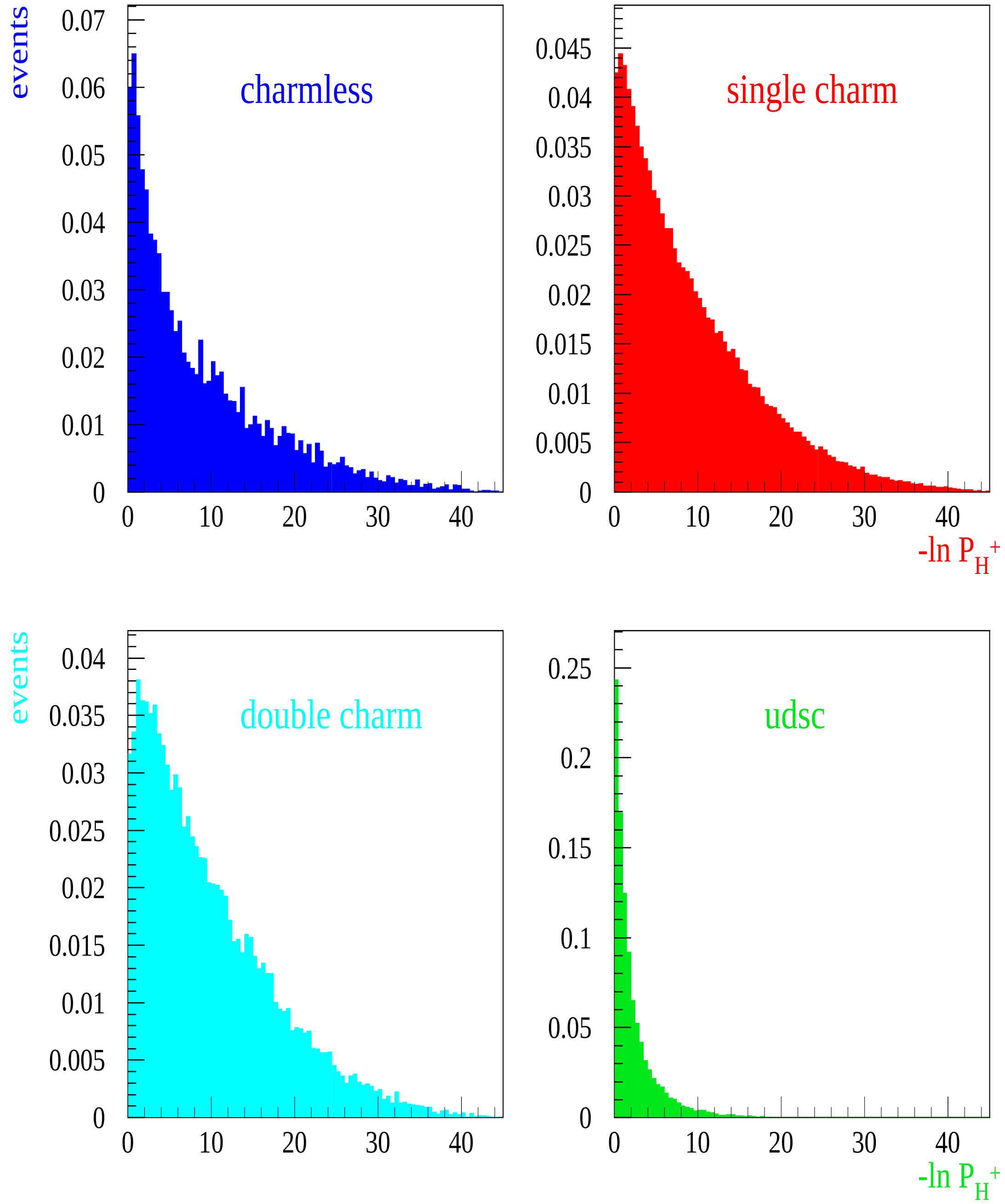

Figure 1: The b-tagging probability distribution per hemisphere, P_H^+, from the 1994 simulation for charmless and hidden charm B hadron decays, B decays into one charm particle, B decays into two open charm particles, and the $udsc$ background.

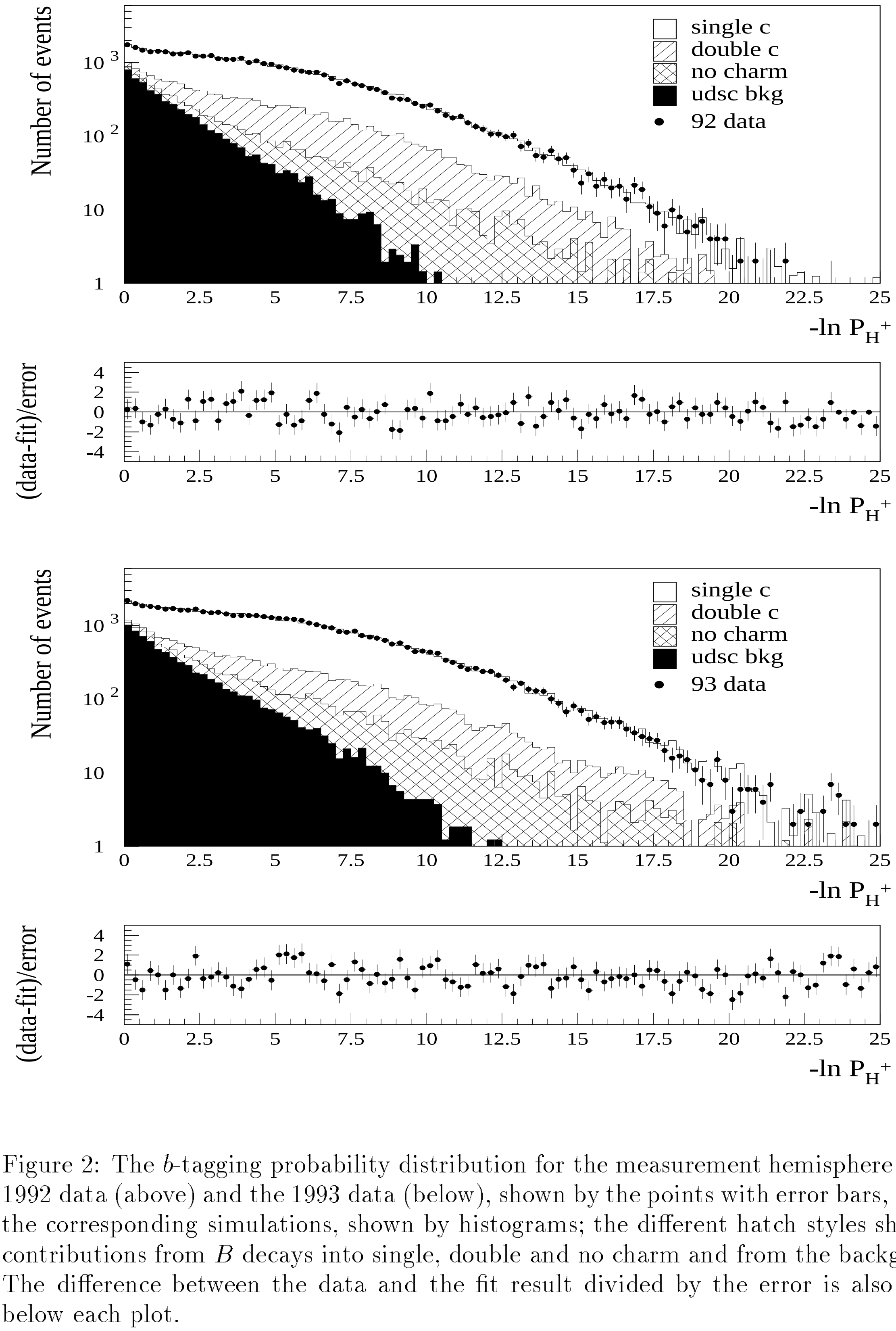

Figure 2: The b-tagging probability distribution for the measurement hemisphere for the 1992 data (above) and the 1993 data (below), shown by the points with error bars, and for the corresponding simulations, shown by histograms; the different hatch styles show the contributions from B decays into single, 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.

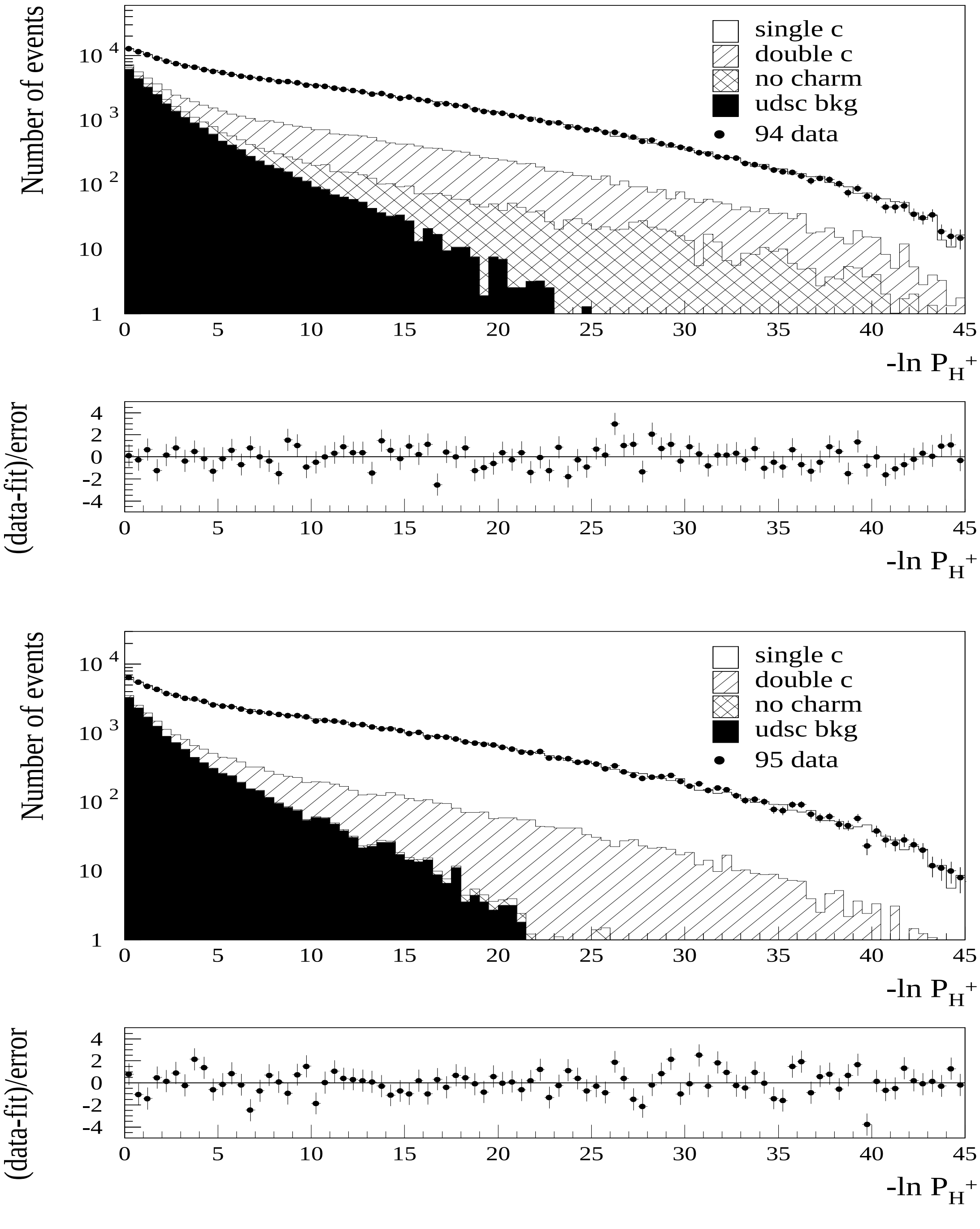

Figure 3: Same as Figure 2 for the 1994 data (above) and the 1995 data (below).

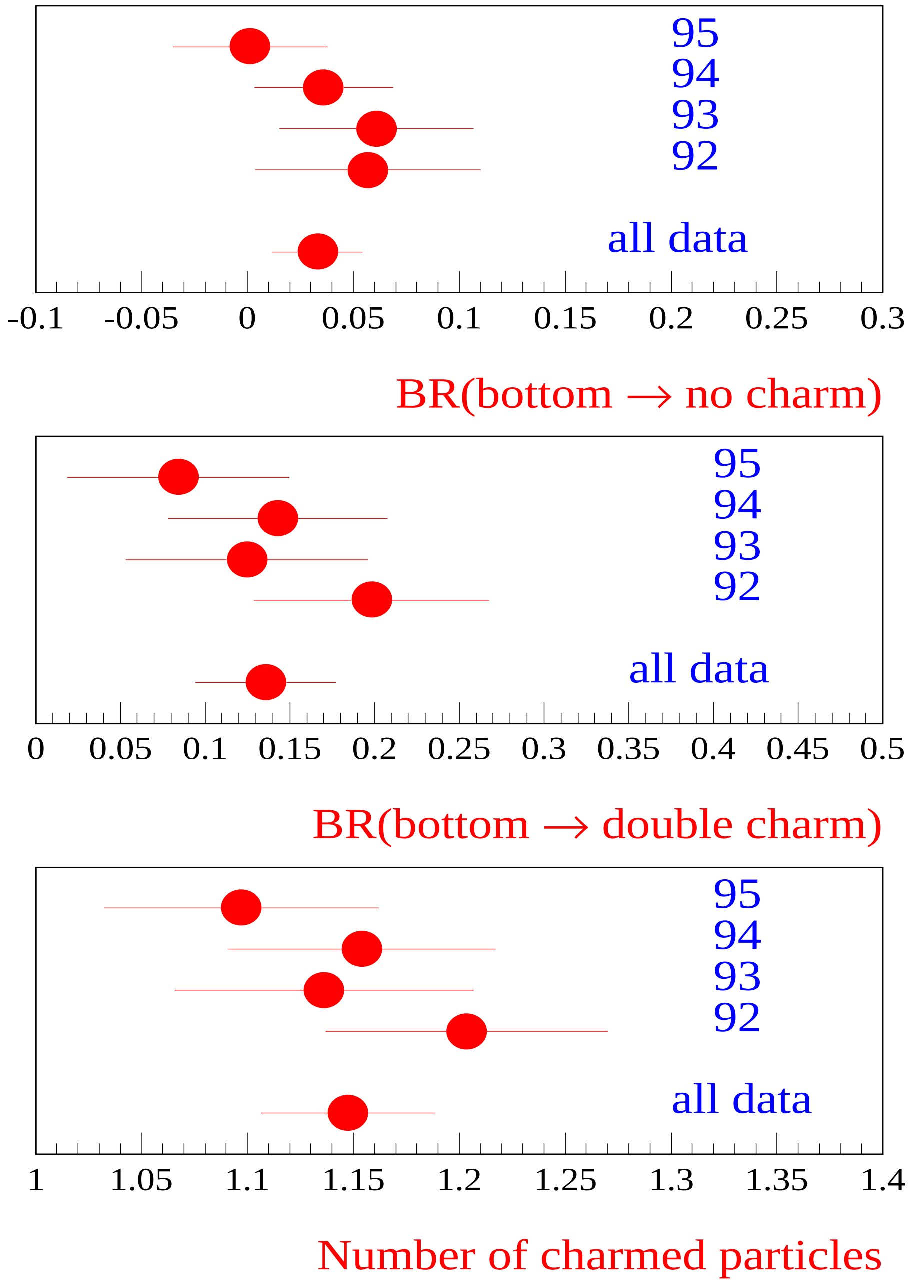

Figure 4: Summary of the results for the branching ratio of a b-quark into charmless final states including hidden charm (upper plot), the branching ratio into double charm final states (middle), and the number of charmed particles per B decay (lower). The error bars correspond to the total (stat+syst) error.

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