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First Measurement of the Inclusive Charmless B Decay Branching Ratio and Determination of the $b \to c\bar{c}s$ Rate

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Abstract

A measurement of the inclusive B decay branching ratios into charmless and double charmed final states has been performed, using the data collected by the DELPHI experiment at LEP from 1992 to 1995, by mean of two different techniques that are presented in two different notes.

In the first analysis, the results are extracted from a fit to the b-tagging probability distribution based on the precise impact parameter measured by the Micro Vertex detector. The inclusive charmless B branching ratio, including B decays into hidden charm as $c\bar{c}$ states, is measured to be 0.044 ± 0.025, the B branching ratio into two charmed particles is 0.163 ± 0.046 and the number of charmed particles per B decay is 1.163 ± 0.045.

A second method is based on identified kaons in the RICH. Using partially reconstructed charm particles in combination with a kaon, the B decay branching ratio into two charmed particles BR($B \to D\bar{D}X$) has been determined to be 0.170 $\pm$ 0.047. In addition an upper limit is obtained for the yield of the $b \to sg$ process by a fit to the transverse momentum distribution of identified secondary kaons.

The combination of these results, discussed at the end of the paper, gives an accurate determination of the $B \to D\bar{D}X$ decay rate and constrains models predicting enhanced contribution to the charmless B decay branching ratio from new physics.

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Measurement of the Inclusive Charmless and Double Charm B Decay Branching Ratios with the b-tagging Probability Technique

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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.

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 $Z \to q\bar{q}$ 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:

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

where $P = -\log(P_H^+)$, the $\mathcal{F}^{0\mathrm{C},2\mathrm{C},1\mathrm{C},\mathrm{BKG}}(P)$ 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 $Br_{0\mathrm{C}}$, $Br_{2\mathrm{C}}$, and $Br_{1\mathrm{C}}$ 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: $Br_{0\mathrm{C}}$, $Br_{2\mathrm{C}}$, ($Br_{1\mathrm{C}}$ 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^0_s 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_{0C} 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_{2C}, 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_{0C} was 0.02 in 1992 and 1993, and 0.01 in 1994. The uncorrelated systematic error on the double charm branching ratio Br_{2C} 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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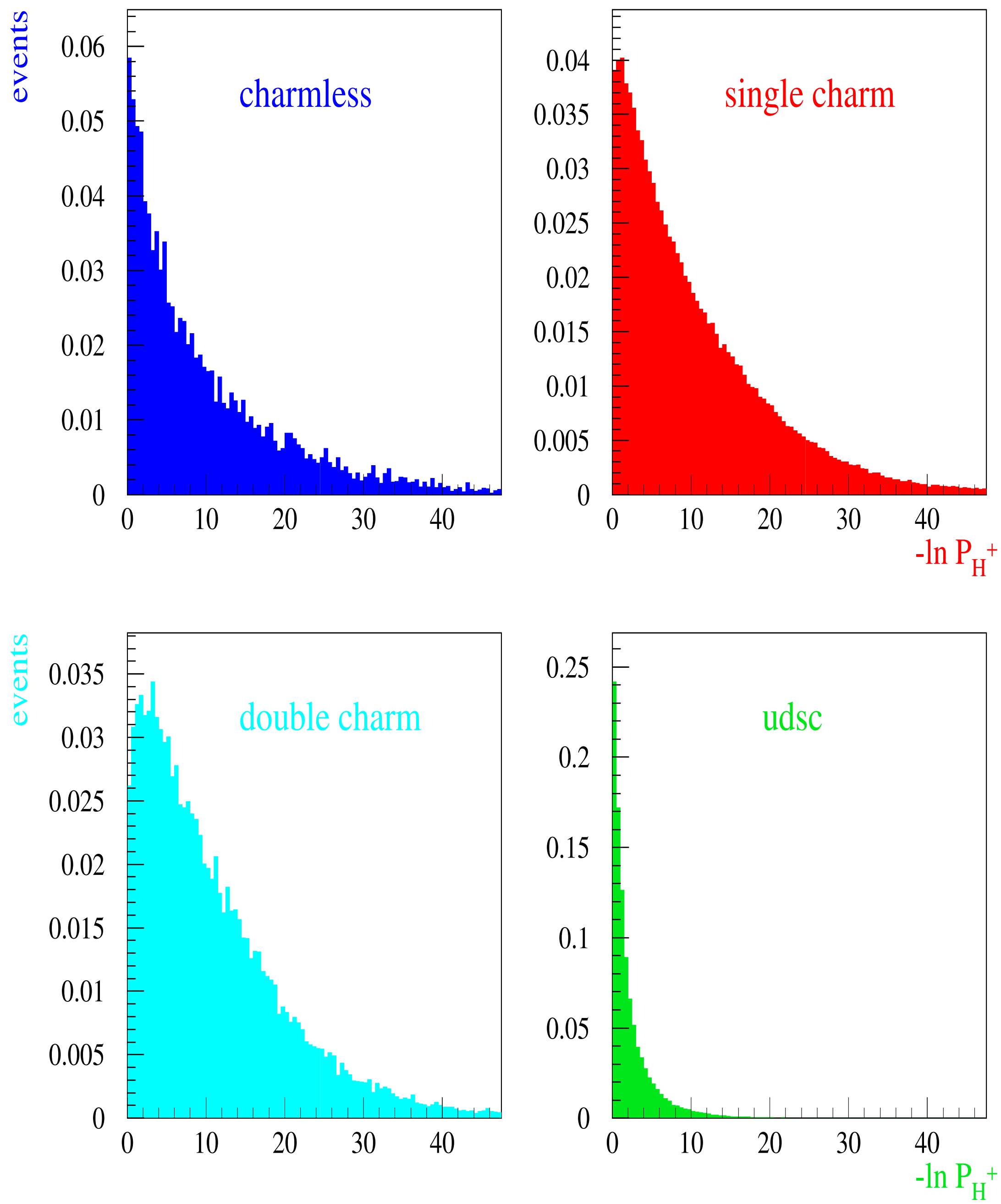

Figure 1: The b-probability distribution per hemisphere, P_H^+, from the 1994 simulation for charmless and hidden charm B hadron decays, B decays into one charm particle, B decays into two (open) charm particles, and the udsc background.

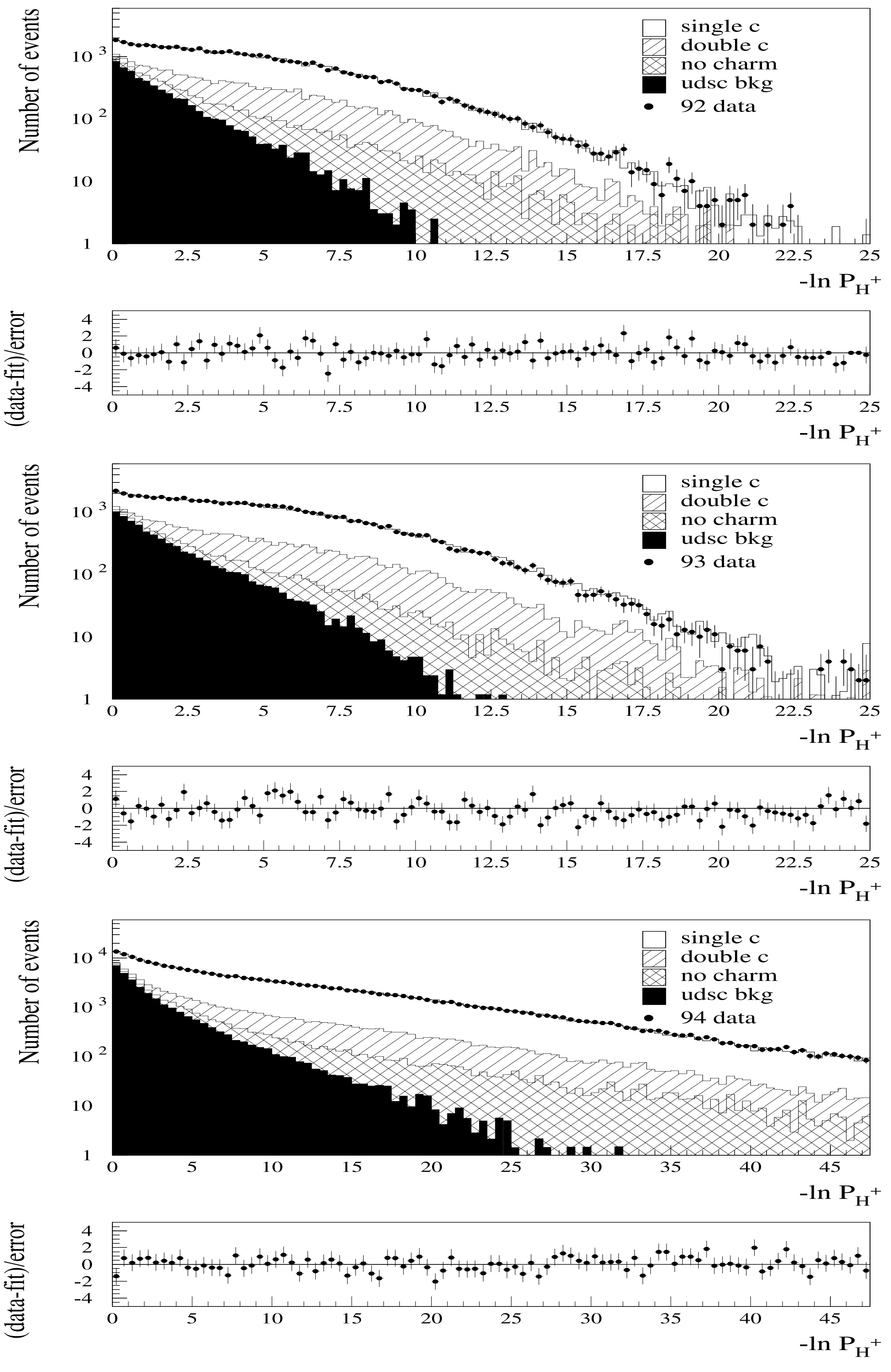

Figure 2: The b-probability distribution for the measurement hemisphere for the 1992-1994 data (points with error bars) and simulation (histograms), showing with different hatch styles the contributions from B decays into single, double and no charm and from the background. The difference between the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

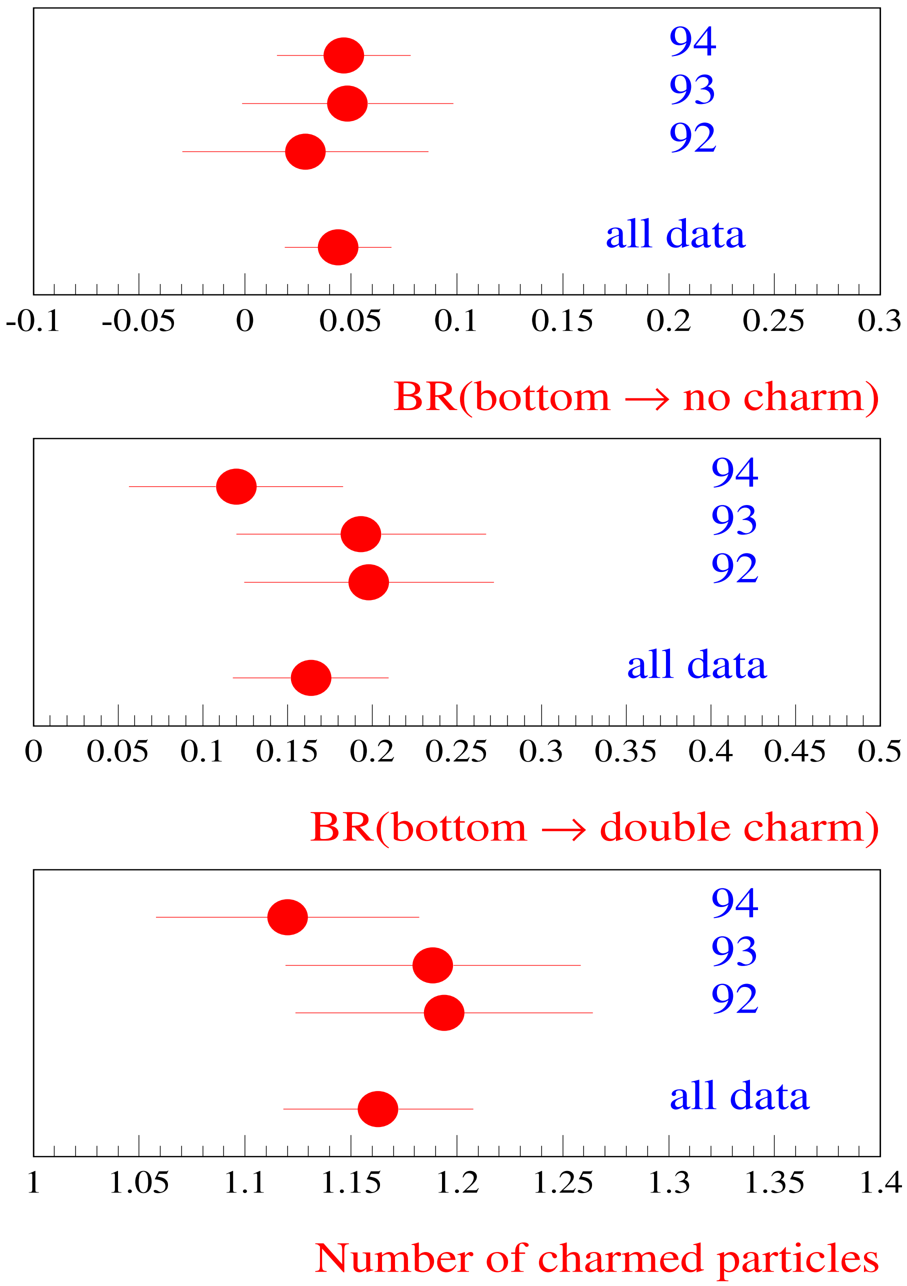

Figure 3: Summary of the results for the branching ratio of a bottom quark into charmless final states including hidden charm (upper plot), the branching ratio into double charm final states (middle), and the number of charmed particles per B decay (lower). The error bars correspond to the total (stat+syst)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

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Measurement of the Inclusive $b \to c\bar{c}s$ Decay and Study of $b \to sg$ Transitions with Identified Charged Kaons

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Abstract

The inclusive $b \to c\bar{c}s$ and $b \to sg$ transitions have been studied using the shape of the transverse momentum distribution of identified charged kaons. Preliminary results obtained in the analysis of 2 M Z^0 hadronic decays recorded in 1994 and 1995 are presented. The fraction of open double charm $B \to D\bar{D}X$ decays has been measured to be 0.170 ± 0.035 (stat) $\pm$ 0.032 (syst) using secondary kaons correlated with inclusively reconstructed D mesons. From a fit to the p_t distribution of kaons in b tagged events an upper limit to the $b \to sg$ transition has been derived: BR$(b \to sg) < 0.05$ (95% C.L.).

1 Introduction

The studies of heavy flavour physics at LEP have brought a significant amount of data on the dynamics of the weak decays of the b quark. With a sensitivity to decay branching ratios of few times 10^{-5}, many rare b decay channels have been investigated and charmless b decays have been observed in hadronic final states. More recently, possible inconsistencies found in the re-analyses of the data on the inclusive $b \to c\ell\nu$ and the $b \to c\bar{c}s$ rates and on the kaon yield in B decays have prompted the developement of models with either an enhanced $b \to c\bar{c}s$ through the contribution of $B \to D\bar{D}KX$ [1] or a large $b \to sg$ rate [2]. The rates for $b \to s$ transitions have been estimated in Standard Model. QCD corrections have been computed at the leading order and have been found to enhance the $b \to sq\bar{q}$ rate and suppress the $b \to sg$ one. As a results the Standard Model expectation for $b \to sg$ is $(2.3 \pm 0.6) \times 10^{-3}$ [3]. The $b \to sg$ rate is poorly constrained by present data

Table 1: *Exclusive branching ratios for $B \to Kn\pi$ decays (in units of the inclusive $b \to sg$ rate), estimated by a $b \to sg$ generator, compared with the published* DELPHI *results for the same channels.*

Channel	BR/BR($b \to sg$)	DELPHI
$K\pi$	5.2×10^{-5}	$2.4\ ^{+1.7}_{-1.1} \times 10^{-5}$
$K\pi\pi$	3.4×10^{-4}	$<3.3 \times 10^{-4}$
$K\pi\pi\pi$	9.4×10^{-4}	$<2.3 \times 10^{-4}$

on $b \to s\gamma$ and by the measurements of the exclusive rates of $B \to Kn\pi$. In fact it has been shown [3] that the $b \to sg$ rate is not bound by the CLEO measurement [4] and the DELPHI limits [5] on the radiative decay $b \to s\gamma$. Further there is a substantial theoretical uncertainty on the relative branching ratios of exclusive modes that receive contributions from $b \to sg$ transitions and that are constrained by present data from CLEO and LEP. As an example, the branching ratios for $B \to Kn\pi$ with ($n = 1, 2, 3$) final states have been estimated by means of a $b \to sg$ generator as dicussed in section 2.2. The results are given in Table 1, in units of the inclusive $b \to sg$ rate and they are compared with the DELPHI limits on these modes [5]. This comparison shows that a significant enhancement of the inclusive $b \to sg$ rate cannot be ruled out by the present data.

Recent preliminary measurements of $B \to D\bar{D}KX$ support the predictions of a $b \to c\bar{c}s$ rate larger than the spectator model prediction and await further confirmations.

The number of $K^{\pm}$ mesons produced in b decays and the distribution of their transverse momenta reflects the phase space and flavour dynamics in the B hadron decay and are therefore sensitive to the decay mechanisms. In fact most of the $b \to c\bar{c}s$ decays are characterised by three strange hadrons in the final state and soft p_t spectra. An enhanced rate of loop mediated $b \to s$ transitions increases the yield of kaons at large values of p_t. The hadron identification capabilities of the DELPHI detector have been exploited in this study to determine the fraction of double charm decays and to constrain models with large $b \to sg$ decay rates. This analysis is based on the study of identified charged kaons in b-tagged events and complements the one based on the shape of the b-tagging probabilities [6] since the resulting systematics are largely uncorrelated.

2 Data Analysis

The preliminary results reported in this note are based on the analysis of the data collected by the DELPHI experiment during the LEP runs in 1994 and 1995. These data sets have recently been reprocessed using improved pattern recognition and track fit procedures. Hadronic events were selected using the standard DELPHI criteria giving a total of 2.08 M events for the real data. In addition 4.5 M $Z^0 \to q\bar{q}$ and 0.8 M $Z^0 \to b\bar{b}$ Monte Carlo events including full detector simulation were used. The sample of hadronic events was enriched in $Z^0 \to b\bar{b}$ decays by applying a b-tagging selection based on the probability for the hypothesis that all the reconstructed charged particles in the event originated at the primary vertex. The tagging was applied to the global event in order to reduce biases due to the B decay topology, Only events with a b-tagging probability below 0.002 were considered.

In order to discriminate efficiently between $b \to c$, $b \to c\bar{c}s$ and $b \to s$ decays it is necessary to achieve both a high kaon tagging efficiency and a large pion rejection. Kaon candidates were selected among charged particle tracks having momentum 3.5 GeV/c $< p <$ 20 GeV/c and with at least one hit associated in the vertex detector (VD). A hadron identification algorithm based on the combined response of the RICH detector and on the dE/dx measurements in the TPC was used [7]. Two levels of kaon tagging were defined. The standard tagging provided a response which is uniform in efficiency and corresponds to 45 % over the full momentum interval with a purity ranging from 67 % to 80 %. A tighter selection giving a constant purity of 80 % was also used for consistency checks of the results obtained with the standard tagging criteria. Jets were reconstructed using the LUCLUS clustering algorithm, events with four or more reconstructed jets were rejected. The transverse momentum of tagged kaons was computed with respect of the estimated B hadron direction. For each jet in a b-tagged event, a inclusive secondary vertex search was performed. Candidate B decay tracks were selected and a common vertex was fitted. Secondary vertices having associated particles with a total energy in excess of 18 GeV and an invariant mass above 2.5 GeV/c^2 were used to define the B hadron direction as the vector joining the primary vertex to the secondary vertex. For those cases failing these criteria, the B hadron direction was approximated by the jet thrust axis computed including the kaon candidate. Only jets with at least three particles, of which two or more were charged, and a total energy of more than 20 GeV were considered. Jets with $|cos\ \theta| > 0.87$, where θ is the polar angle of the jet thrust axis, were also rejected.

2.1 Determination of BR($B \to D\bar{D}X$)

The measurement of the number and transverse momentum distribution of kaons in jets containing a $D^{0,\pm}$ meson provides an inclusive method to determine the double charm rate in B decays. This analysis started from a sample of jets in b-tagged events containing at least one tagged $K^\pm$ meson. The kaon track was required to have an impact probability of originating from the primary vertex lower than 0.10 and an impact parameter distance smaller than 2.0 cm. An inclusive algorithm was then used to increase the fraction of kaons from cascade $B \to D \to K$ decays: the kaon track was iteratively tested with other charged particle tracks belonging to the same jet for forming a secondary detached vertex. Vertices made from two or three tracks and having decay distance w.r.t the primary vertex larger than four times the associated error, total energy of more than 7 GeV and fit probability larger than 0.001 were selected. For each jet, the combination giving the $K^-\pi^+$ or the $K^-\pi^+\pi^+$ invariant mass M closest to the nominal D^0 and D^+ masses was chosen. A jet was accepted if the chosen combination fulfilled the condition 1.65 GeV/c^2 $<$ $M_{K\pi,K\pi\pi} < 1.95$ GeV/c^2 or if the mass difference $M(K^-\pi^+\pi^+) - M(K^-\pi^+)$ was smaller than 0.16 GeV/c^2. Kaons compatible with originating from a $D_s \to K\bar{K}\pi$ decay were discarded by rejecting cases for which a $K\bar{K}\pi$ combination had mass compatible with the D_s mass. This inclusive D reconstruction procedure selected 7950 kaons in real data and 8064 in simulation.

From simulation it was estimated that in 42 % of the D candidates the kaon candidates originated from a D^0, in 15 % from a $D^\pm$ and in 15 % from either a D_s or a Λ_c decay. The remaining 28% was due to either to genuine kaons from other sources or to misidentified pions or protons.

Additional tagged kaons were then searched for in the jet containing a candidate D meson. The tagged kaons were required to have a probability of coming from the primary vertex lower than 0.02 on the basis of their measured impact parameter and to contribute 3.5 or more to the vertex fit χ^2 when added to the reconstructed D vertex. These cuts were intended to select kaons from the B decay chain but not originating from the same vertex as the kaon from the reconstructed D meson.

The fractions of events with zero, one, or more than one additional tagged kaons were studied in data and simulation and found to be in good agreement. In the combined 1994+1995 data set, 719 jets with at least one additional tagged kaon associated to a partially reconstructed D decay were selected, with 749 expected from simulation. The efficiency of the selection of such jets was obtained from simulation and found to be 0.12 for $B \to D\bar{D}X$ and 0.07 for $B \to DX$ decays. The amount of background from non-B decays was estimated to be 0.071 ± 0.006.

The number of kaons in b-tagged jets and their p_t distribution are sensitive to the fraction of double charm b decays. This sensitivity was enhanced by studying separately kaons of same and opposite sign compared to the one from the D decay.

Kaons of the same sign are due to the processes $B \to \bar{D}D_sX$ and $B \to D\bar{D}KX$

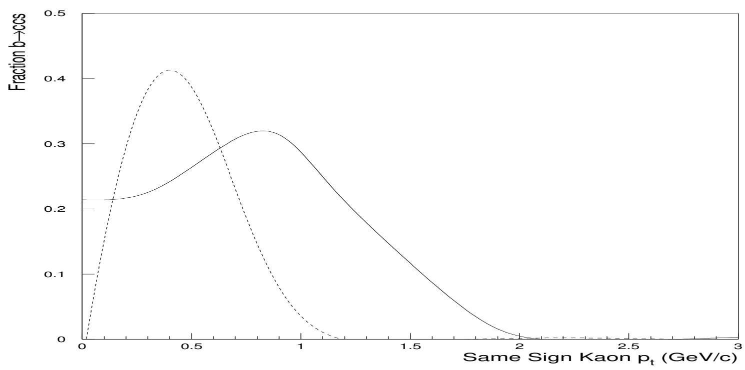

Figure 1: *Fraction of same sign kaons from $b \to c\bar{c}s$ decays as a function of the their transverse momentum assuming BR($B \to D\bar{D}X$)=0.15. The continuous line represents $B \to \bar{D}D_sX$ and the broken line $B \to D\bar{D}KX$ decays.*

or to $B \to cud$ with a $s\bar{s}$ pair produced by fragmentation. The first two sources are characterised by a smaller phase space and the resulting p_t spectrum is concentrated at lower values. The same is valid when comparing genuine kaons from double charm decays to misidentified pions from $B \to Dn\pi$ decays. The relative contribution from $B \to \bar{D}D_sX$ and $B \to D\bar{D}KX$ to the double charm decay rate also influences the shape of the kaon p_t spectrum and there is presently only little experimental data available. The fraction of kaons from $b \to c\bar{c}s$ decays from both these processes in the sample of genuine kaons from B decays selected from the analysis is shown in Figure 1 as a function of the kaon p_t value. In order to reduce the uncertainty due to the relative contribution of $\bar{D}D_sX$ and $D\bar{D}KX$ final states, the fraction of $\bar{D}D_sX$ decays in the double charm $D\bar{D}X$ sample was extracted from the measured p_t spectra. Kaons of opposite sign in double charm B decays originate from either a D or a D_s decay and their p_t distribution is similar to that expected for $b \to c$ transitions.

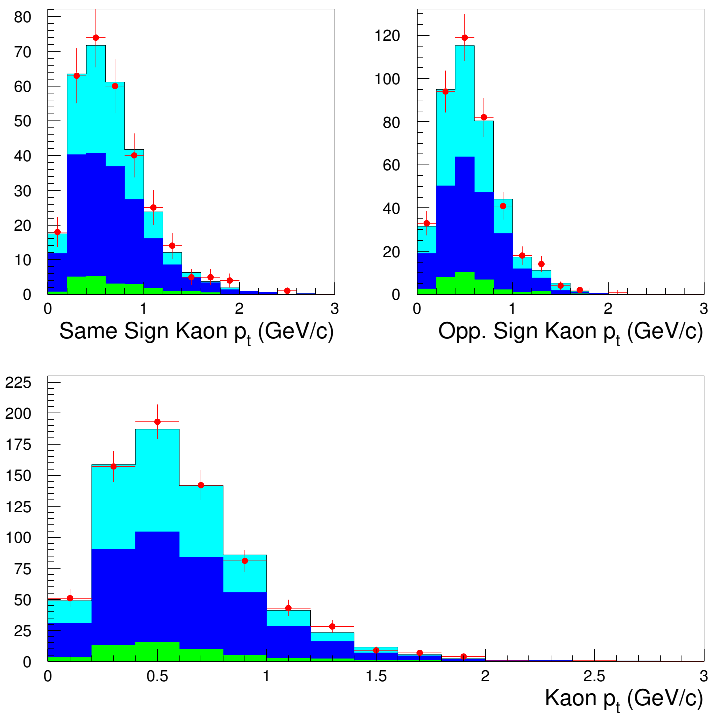

Figure 2: *Transverse momentum distribution of charged kaons associated to an inclusively reconstructed $D \to K$ meson. The upper plots show the distribution for same sign (left) and opposite sign kaons (right) and the lower plot their sum. The dark grey histogram represents the contribution from $b \to c$ decays, the upper light grey histogram that of $b \to c\bar{c}s$ decays and the lower one the background. Their fractions correspond to the result of the fit.*

The fraction of $B \to D\bar{D}X$ was extracted by a χ^2 fit to the p_t distribution of tagged kaons associated with an identified D decay. This fit was performed separately for the two correlations of charge with the kaon originating at the reconstructed D vertex (see Figure 2). In the fit, the fraction of double charm decays and the fraction $\frac{BR(B\to\bar{D}D_sX)}{BR(B\to D\bar{D}X)}$ of these in the $B \to \bar{D}D_sX$ modes were left free; the background was kept fixed at the value obtained from the simulation and its uncertainty was then propagated as a systematic error. The results of the fit are given in Table 2.

Table 2: *Result of the fit to the p_t distribution of kaons associated to a reconstructed D meson.*

Selection	BR($B \to D\bar{D}X$)	$\frac{BR(B\to\bar{D}D_sX)}{BR(B\to D\bar{D}X)}$	Fit Prob.
Same sign kaons	0.160 ± 0.056	$0.80\ ^{+0.20}_{-0.23}$	0.99
Opp. sign kaons	0.176 ± 0.045	$0.86\ ^{+0.14}_{-0.20}$	0.97
Combined	$\mathbf{0.170 \pm 0.035}$	$\mathbf{0.84 \pm 0.16}$	

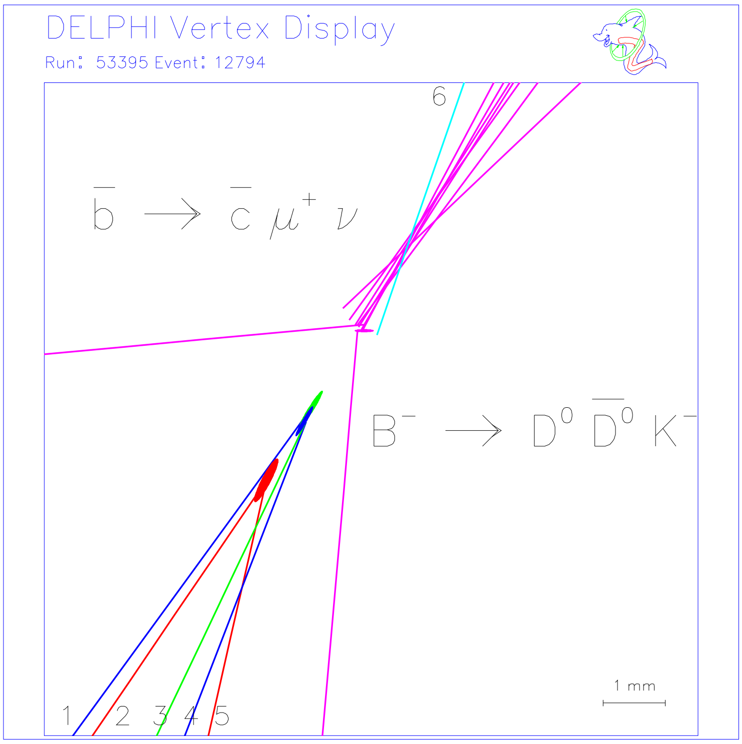

Figure 3: *Display of the vertex region of a candidate double charm $B^- \to D^0\bar{D}^0K_3^-X$; $D^0 \to K_2^-\pi_5^+$, $\bar{D}^0 \to K_1^+\pi_4^-(\pi^0)$ decay. There are three identified kaons in the lower jet and one identified μ_6^+ in the upper jet, defining the b charges. The B^- decay is not compatible with either containing a D_s^- or a $D_{s1,J}^- \to \bar{D}^0K^-$ on the basis of the invariant mass of the $K^+K^-\pi^-$ system.*

As consistency checks, the analysis was repeated using different kaon and D selections. Tighter kaon tagging criteria were applied to improve the pion rejection: the combined result became 0.174 ± 0.054 and the fraction of $\bar{D}D_sX$ decays $0.63\ ^{+0.37}_{-0.42}$. Then the analysis was repeated for jets with a fully reconstructed $D^0 \to K\pi$ or $D^+ \to K\pi\pi$ meson:

the result was 0.213 ± 0.062 and the fraction of $\bar{D}D_sX$ decay $0.92\ ^{+0.08}_{-0.18}$. These results are in good agreement within their statistical errors. A candidate decay $B^- \to D^0\bar{D}^0K^-$ is shown in Figure 3.

Several sources of systematic errors have been taken into account. In particular the agreement of the multiplicities and momentum distributions of charm and strange particles in the B rest frame in the DELPHI simulation and in published data have been considered.

Table 3: *Sources of systematic error for the B double charm decay rate.*

Parameter	Value	Range	$\mathrm{BR}(B \to D\bar{D}X)$ Syst. Err.	$\frac{BR(B\to \bar{D}D_sX)}{BR(B\to D\bar{D}X)}$ Syst. Err.
$< n_{ch}^B >$	5.40	± 0.15	0.009	0.01
$D/ < n_{ch}^B >$	0.38	± 0.03	0.007	0.03
K Energy Spectrum	-	$\pm$ 4%	0.005	0.07
Nb. $K^\pm$ in B dec.	0.79	± 0.06	0.003	0.01
Nb. D^0, D^- in B dec.	0.87	± 0.035	0.005	0.01
Nb. D_s in B dec.	0.118	± 0.031	0.010	0.02
Nb. Λ_c in B dec.	0.04	± 0.02	0.003	0.01
$\mathrm{BR}(D_s \to K^\pm)$	0.48	± 0.10	0.025	0.03
$f(B_s)$	0.103	± 0.015	0.010	0.01
$f(\Lambda_b)$	0.106	± 0.035	0.007	0.01
K tag efficiency	-	$\pm 0.5\%$	0.004	0.01
Background	0.071	± 0.006	0.006	0.01
Total			**0.032**	**0.09**

First the B charged decay multiplicity was studied. Simulated events were re-weighted such that the distribution of the $B\bar{B}$ charged decay multiplicity agreed with that recently measured by the CLEO experiment at the $\Upsilon(4S)$ resonance [8]. Then the average value was changed within the experimantal errors and the width of the distribution was also varied within the constrain of the measured multiplicity distribution (see Figure 4).

Then the momentum spectrum of K from B decays was checked by comparing the distribution for K_s^0 from the DELPHI simulation with ARGUS data [9] and they were found to agree well as shown in Figure 4. A residual uncertainty of 4% on the absolute momentum scale was used for the systematic error contribution.

The number of K in B decays is also a source of uncertainty and the value in the simulation was changed by the uncertainty of the present world average [10]. Similarly the effect of the uncertainty on the numbers of D^0, D^+ and D_s mesons and of charmed baryons in B decays [14] was studied by changing the production rate of the different charm species within their uncertainties while keeping the total charm yield fixed. Additional sources of systematic uncertainty are the the K production in D_s decays and the B_s and Λ_b production rates. The inclusive $K^\pm$ yield in D_s decays was measured by the MARK III experiment to be $0.33^{+0.22}_{-0.19}$ [11] with large statistical uncertainty. Therefore $\mathrm{BR}(D_s \to K^\pm X)$ was estimated for this analysis from the published measurements of the D_s exclusive decay modes [10]. These branching ratios were then changed within their errors and these uncertainties were propagated to that of the kaon yield. The missing part of the decays was modelled using either estimates of multibody final states and the JETSET [13] treatment of weak decays of heavy hadrons. The difference between the two estimates was also included in the error. The result was 0.48 $\pm$ 0.10 and it was used for evaluating the systematic error contribution. The fractions of B_s and Λ_b hadrons and their uncertainties were taken from [12]. Finally the uncertainties from kaon tagging efficiency and the background subtraction were propagated.

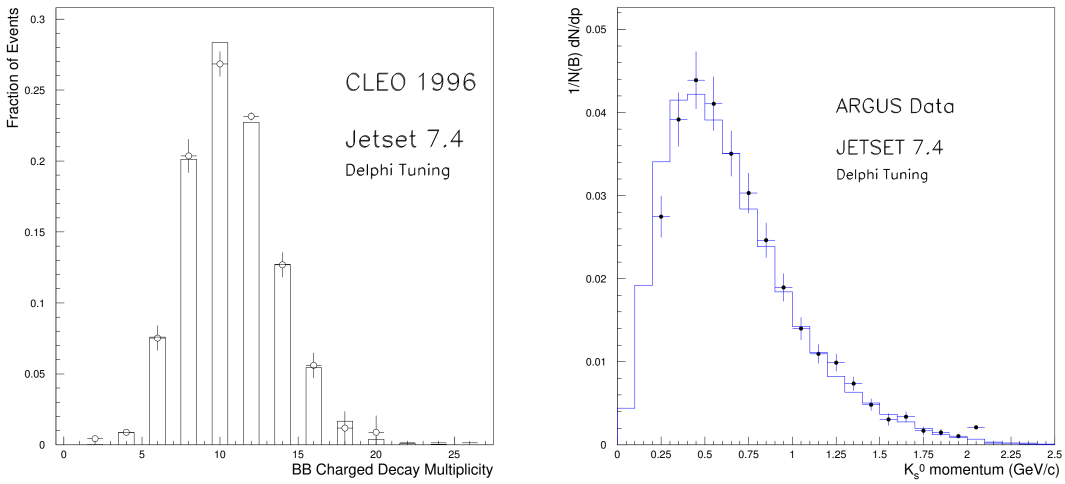

Figure 4: Comparison the simulation with published data for the charged BB decay multiplicity (left) and the momentum spectrum of K^0_s from B decays (right).

The range of variation for the parameters and the resulting systematic errors are summarized in Table 3. Summing these contributions in quadrature a total systematic error of 0.032 was estimated. In conclusion, the result is:

$$\mathrm{BR}(B \to D\bar{D}X) = 0.170 \pm 0.035\ (\mathrm{stat}) \pm 0.032\ (\mathrm{syst.})$$

$$\frac{B \to \bar{D}D_s X}{B \to D\bar{D}X} = 0.84 \pm 0.16\ (\mathrm{stat.}) \pm 0.09\ (\mathrm{syst.}).$$

This result is compared with other determinations of the double charm rate in B decays in Table 4.

Table 4: *Recent results on double charm production in B decays.*

Experiment	$\mathrm{BR}(B \to D\bar{D}X)$	$\frac{BR(B \to \bar{D}D_s X)}{BR(B \to D\bar{D}X)}$
CLEO [15]	0.181 $\pm$ 0.037	0.56 $\pm$ 0.19
ALEPH [16]	0.253 $\pm$ 0.054	0.49 $\pm$ 0.20
This Analysis	**0.170 $\pm$ 0.047**	**0.84 $\pm$ 0.18**

2.2 Search for inclusive $b \to sg$ decays

A large rate of $b \to sg$ transitions can be detected, at LEP, by the distortion of the p_t spectrum of kaons from B decays. Due to the large phase space available in the $b \to sg$ transition, the momentum of the K in the B rest frame from these decays is typically larger than if the kaon originates in $b \to c \to s$ decays. An enhancement of the yield of kaons at large (p, p_t) values can therefore signal a large rate for the $b \to sg$ process [2].

The p and p_t distributions of kaons from B mesons decaying by the $b \to sg$ transition were studied on simulated B decays. The $b \to sg$ generator modelled these decays as follows [17]. In the B rest frame, a string was attached from the s to the g and from the g to the spectator quark, so that the gluon was a kink in the string. In the decay, the s quark and the gluon were emitted back to back with energies $m_b/2$, while the spectator quark momentum was determined by the Fermi momentum p_F. The system was then boosted and allowed to fragment using the JETSET model [13]. Results are presented assuming the kinematics of the kaons produced in $b \to sg$ decays as described by this model.

A search for an excess of kaons from B decays at values of p_t above 1 GeV/c was performed in the DELPHI data. The analysis relied on *a)* the characteristics kinematics of B decays and *b)* the accurate extrapolation of charged particle tracks to their production vertices to separate B decay products from primary particles.

Jets containing at least one tagged kaon with $p > 4.5$ GeV/c were selected in b-tagged events. Since the kaon produced in the hadronisation of the s quark from the b decay chain is the leading particle in 70% of cases, different selection criteria were applied for leading tagged kaons: the kaon was required to have a probability of belonging to the primary vertex of less than 0.15 if it was the leading particle in the jet or below 0.02 otherwise. The impact parameter of the kaon was signed according to the position of crossing with the estimated B flight direction using the lifetime sign convention. Kaons with negative impact parameter were rejected.

Background from misidentified pions as well as from kaons from double charm and B_s decays was partially suppressed by requiring the sign of the kaon charge to be equal to that of the b quark. This was estimated by the jet charge Q_{Jet}, defined as the momentum-weighted sum of the charges of the particles belonging to the jet. For those cases for which $|Q_{Jet}| > 0.10$, the kaon p_t was signed by the product of the kaon charge and the jet charge. If the jet charge was below the cut value of 0.10, therefore not providing useful discrimination on the b quark charge, the kaon p_t was signed positive. A total of 44500 tagged kaons fulfilling these selection criteria were selected in real data.

The ratio of selected particles in real data and simulation was 0.998 ± 0.007. From the simulation, the background of misidentified pions and of kaons not coming from B decays corresponds to 18% of the selected sample. The momentum distribution was checked to be in good agreement with the simulation.

The fraction of $b \to sg$ decays was extracted by a χ^2 fit to the shape of the p_t distribution. The shape of the $b \to sg$ signal was obtained as the distribution for kaons from the decays produced with the generator described above and passed through the full DELPHI detector simulation. In the fit the fractions of $b \to sg$, $b \to c$ and $b \to c\bar{c}s$ and the background were left free. The relative ratio of double charm to single charm decays was fixed to the result of the previous analysis. The amount of charmless $b \to u, d$ transitions was fixed to 0.015.

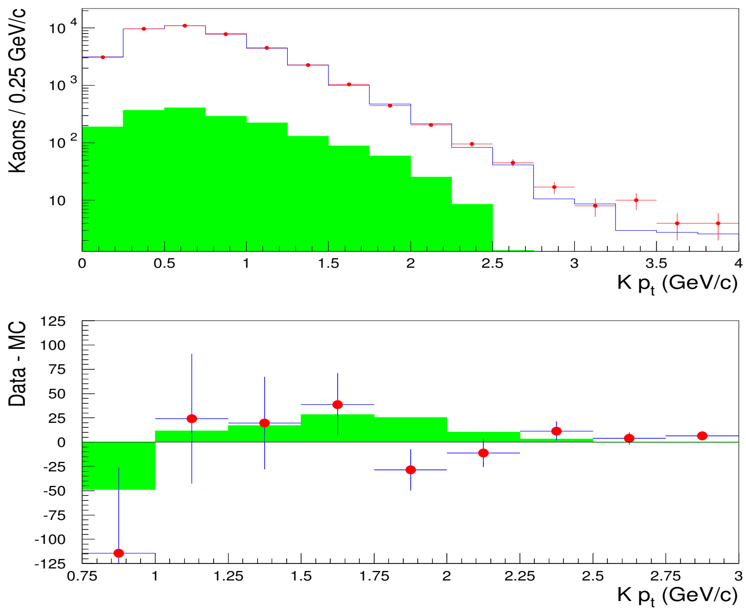

Figure 5: *The p_t distribution of selected kaons (upper plot). The points with error bars represent the real data and the histogram the simulation normalised to the same number of Z^0 hadronic decays. The lower plot shows the real data subtracted by the Monte Carlo prediction of $b \to c$ decays and background. The grey histograms are the expected contribution of $b \to sg$ corresponding to the fitted fraction.*

The result of the fit is BR($b \to sg$) = 0.005 $^{+0.017}_{-0.005}$. The fit probability was 0.20. The amount of background from the fit was 0.16 ± 0.02, in agreement with the simulation prediction of 0.18. The p_t distribution for kaons with charge sign equal to that of the jet is shown in Figure 5 for real data and simulation, together with the simulation-subtracted distribution in the region sensitive to the presence of $b \to sg$ decays.

Several sources of systematic uncertainty have been taken into account. Firstly, it is important to verify that the simulation reproduces accurately the transverse momentum distribution of particles from B decays other than $b \to sg$ and from the background. The analysis was therefore repeated for K's in jets containing an inclusively reconstructed D decays as described in the previous section. The p_t spectra of real data and simulation agreed well over the full range used in the analysis and the result of the fit was BR($b \to sg$) = 0.000 $^{+0.026}_{-0.000}$. This shows that the modelling of the kinematics in $b \to c$ transition does not introduce any significant biases.

The B decay multiplicity also modifies the p_t spectrum of the decay products. The charged B decay multiplicity and the width of the multiplicity distribution were changed within the constraints of the experimental measurements as discussed in the previous section.

The transverse momentum distribution of kaons from background, as $s\bar{s}$ pairs produced by fragmentation, was studied by selecting kaon candidates with negative signed impact parameter. While the p_t spectra agreed well up to about 2.0 GeV/c, the real data is enhanced at larger p_t values. This effect has already been noted in inclusive particle spectra. Therefore primary kaons in simulations were rescaled in order to reproduce the distribution observed on the real data. Since this discrepancy does not effect the region were the $b \to sg$ signal is enhanced, this correction did not change the result of the fit significantly. Finally, possible discrepancies in the p_t spectrum of B decay products were studied on a high statistics sample of tagged pions fulfilling the kaon selection criteria used in the analysis except for hadron identification. The distributions of transverse momenta for real data and simulation agreed well in the region 0.5 GeV/c $< p_t <$ 2.5 GeV/c. In the region p_t $<$ 0.5 GeV/c the simulation overestimated the data. A correction function was derived from this comparison and applied to the selected kaons in simulation. The fit was repeated and the result again agreed.

The second source of systematic uncertainty is due to the modelling of the $b \to sg$ decays. The effect of the uncertainty on the value of the Fermi momentum p_F measured at the $\Upsilon(4S)$ resonance in semileptonic and radiative decays [18, 19] was taken into account. Its variation modifies the broadening of the distribution of the K momentum in the B rest frame and therefore of the kaon p_t.

As a result of these studies a systematic error was estimated. This error takes into account both the change in the central value for the fitted $b \to sg$ fraction and that of the statistical error from the fit, reflecting a change in the experimental sensitivity. The resulting preliminary upper limit is:

$$\mathrm{BR}(b \to sg) < 0.05 \ (95\ \%\ \mathrm{C.L.})$$

3 Conclusions

The inclusive $b \to c\bar{c}s$ and $b \to sg$ were studied using the statistics collected by the DELPHI experiments during 1994 and 1995. The analyses are based on the study of the p_t distribution of identified charged kaons in b-tagged events. Preliminary results were obtained. The inclusive branching ratio for B decays into open double charm final states $B \to D\bar{D}X$ was measured to be 0.170 $\pm$ 0.035 (stat) $\pm$ 0.032 (syst) using a $D - K$ correlation technique. The fraction of $\bar{D}D_sX$ decays contributing to the double charm rate was also estimated to be 0.84 $\pm$ 0.16 (stat) $\pm$ 0.09 (stat). An enhanced rate for $b \to sg$ transition can be detected by as a distortion of the p_t spectrum of kaons from B decays. The analysis of almost 45000 candidate secondary kaons did not show any significant enhancements. Using a dedicated $b \to sg$ generator this was used to set the upper limit BR$(b \to sg) < 0.05$ at 95% C.L.

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References

[1] G. Buchalla *et al.*, *Hadronization of $b \to c\bar{c}s$*, FERMILAB-PUB-95/167-T and I. Dunietz *et al.*, *Large Charmless Yeld in B decays and Inclusive B Decay Puzzles*, FERMILAB-PUB-96/421-T.

[2] A.L. Kagan, *Phys. Rev.* **D 51** (1995), 6169 and
A.L. Kagan and J. Rathsman, *Hints on Enhanced $b \to sg$ from Charm and Kaon Counting*, hep-ph 9701300 (1997).

[3] M. Ciuchini *et al.*, *Phys. Rev.* **B 388** (1996), 353 and
Erratum, **B 393** (1997), 489.

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

[5] W. Adam *et al.* (DELPHI Collaboration), *Z. Phys.* **C 72** (1996), 207.

[6] P.M. Kluit, *First measurement of the inclusive charmless B branching ratio*, DELPHI Note 97-80 CONF 66/1.

[7] M. Battaglia and P.M. Kluit, *Particle Identification using the RICH detector based on the RIBMEAN package*, DELPHI Note 96-133.

[8] P. Avery *et al.* (CLEO Collaboration), *Charged Particle Multiplicity in B Meson Decay*, CLEO-CONF 96-28.

[9] H. Albrecht *et al.* (ARGUS Collaboration), *Z. Phys* **C62** (1994), 371.

[10] Review of Particle Properties, *Phys. Rev.* **D 54** (1996).

[11] D. Coffman *et al.* (MARK III Collaboration), *Phys. Lett.* **B 263** (1991), 135.

[12] The LEP B Oscillation Working Group, LEPBOSC Note 97/1.

[13] T. Sjostrand, *Comp. Phys. Comm.* **82** (1994), 74.

[14] L. Gibbons *et al.* (CLEO Collaboration), *The Inclusive Decays $B \to DX$ and $B \to D^*X$*, CLEO 96-23.

[15] R. Wang, *Semileptonic Branching Fraction and Hadronic Width of the B Mesons in the Light of the new CLEO Observation of $b \to \bar{D}X$*, SLAC-PUB-7312 (1996).

[16] The ALEPH Collaboration, *Study of double charmed B decays at LEP*, ICHEP96 PA05-060.

[17] A.L. Kagan and T. Sjostrand, private communications.

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

[19] A. Ali, C. Greub, *Photon Energy Spectrum in $B \to X_s + \gamma$ and Comparison with Data*, SLAC-PUB-95-6940.

Combination of the Two Analyses

The analyses of B decays into two charm particles and into charmless final states using the b-tagging probability and the charged kaon p_t spectra have been presented in the two attached notes. In summary the branching ratio for production of two charmed particles in B decays was measured to be:

$$\mathrm{BR}(B \to D\bar{D}X) = 0.163 \pm 0.046$$

in the b-tagging probability analysis and

$$\mathrm{BR}(B \to D\bar{D}X) = 0.170 \pm 0.047$$

in the kaon p_t analysis.

The two analyses performed adopted significantly different techniques for the measurement. As a consequence the systematic error are largely uncorrelated and it is interesting to improve the accuracy of this measurement by averaging the two results. This average was computed taking into account common systematics. These are due to the fractions of B_s and Λ_b hadrons produced, the number of D^+ and Λ_c hadrons in B decays and the charged B decay multiplicity. The total correlated systematic error is ± 0.010 for b-tagging probability analysis and ± 0.016 for the kaon p_t analysis. The statistical error and the other components of the systematic error were assumed to be uncorrelated. The final result was:

$$\mathrm{BR}(B \to D\bar{D}X) = 0.166 \pm 0.036$$

The inclusive branching ratio for charmless B decays was estimated to be:

$$\mathrm{BR}(B \to no\ charm) = 0.022 \pm 0.025$$

from the b-tagging probability analysis after subtraction of the hidden charm contribution. This result can be used to set an upper limit on possible contributions to the b charmless decay rate beyond Standard Model. Removing the predicted Standard Model charmless rate, the $\mathrm{BR}(b \to no\ charm)^{NEW}$ branching ratio from possible new physics is constrained to be:

$$\mathrm{BR}(b \to no\ charm)^{NEW} < 0.045 \text{ (95\% C.L.)}$$

The shape of the p_t spectrum of candidate secondary charged kaons in b-tagged events was also used to search for an anomalously large $b \to sg$ decay rate. No excess of events was observed at large p_t values. By using a dedicated $b \to sg$ generator, this was used to set the upper limit:

$$\mathrm{BR}(b \to sg) < 0.050 \text{ (95\% C.L.)}$$