SLAC-PUB-7941
October 10, 1998

Charmless and Double-Charm B Decays at SLD*

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Abstract

We present new results from the study of B decays at SLD: a measurement of the inclusive double-charm branching fraction in B-hadron decays and a search for the rare exclusive charmless decays $B^+ \rightarrow \rho^0\pi^+(K^+)$ and $B^+ \rightarrow K^{*0}\pi^+(K^+)$. Using a novel technique which consists of counting charged kaons produced at the secondary (B) vertex and the tertiary (D) vertex, we measure $\mathcal{B}(B \rightarrow D\bar{D}X) = 0.188 \pm 0.025(stat) \pm 0.059(syst)$. Another technique, based on the comparison of the charge of the D vertex to the flavor of the B hadron at production, yields a consistent result. In the search for rare exclusive B^+ decays, no candidates were found and competitive branching ratio upper limits are derived.

Talk given at the XXIX International Conference on High Energy Physics
Vancouver, BC, Canada, July 23–29, 1998

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*Work supported by U.S. Department of Energy contract DE-AC03-76SF00515.

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1 Introduction

The motivation for the analyses presented here lies in trying to shed some light into a long-standing B decay puzzle. For some time, the B semileptonic branching ratio (B_{SL}) and the charm yield in B decays (n_C) appeared to be too low compared to the theoretical expectation. While this is no longer the case at LEP, this discrepancy seems to persist at the Υ(4S), as illustrated in Fig 1 [1,2].

One way of reconciling a small B_{SL} is by having a large B hadronic width Γ_{Had}, which in turn can be due to a large $b \to c\bar{c}s$ partial width. By the same token, a large $B \to D\bar{D}X$ branching ratio can result in a large charm yield. This is shown in the following equations:

$$\begin{aligned} B_{SL} &= \frac{\Gamma_{SL}}{\Gamma_{SL} + \Gamma_{Had}} \\ \Gamma_{Had} &= \Gamma(b \to c\bar{u}d) + \Gamma(b \to c\bar{c}s) \\ &\qquad + \Gamma(b \to sg) + \Gamma(b \to u) \\ n_C &= 1 + f_{D\bar{D}} - f_{NOC}. \end{aligned}$$

Here, $f_{D\bar{D}}$ and f_{NOC} represent the B double-charm and no-open-charm branching fractions, respectively.

Another possible scenario is to have a large contribution from the $b \to sg$ and $b \to u$ transitions. For example, A. Kagan and J. Rathsman suggest that the $b \to sg$ decay could possibly be enhanced to a branching ratio as large as 10% [3]. An inclusive search for $b \to sg$ is currently underway at SLD [4]. Preliminary results from that analysis were covered in A. Litke's talk [5] at this conference.

In the present paper, results are given on the measurement of the inclusive branching fraction $\mathcal{B}(B \to D\bar{D}X)$ and a search for the rare exclusive decays $B^+ \to \rho^0\pi^+(K^+)$ and $B^+ \to K^{*0}\pi^+(K^+)$. These analyses benefit from the very good tracking and vertexing efficiency and resolution of SLD provided by a precision 3-D CCD pixel vertex detector. In addition, the high polarization of the SLC electron beam permits an excellent $b/\bar{b}$ separation, while the Cherenkov Ring Imaging Detector (CRID) provides good particle identification. The total SLD data sample of $\sim 550k$ hadronic Z^0's, collected between 1993 and 1998, was used in the rare B^+ decay search, whereas $\sim 250k$ hadronic Z^0's were analyzed in the B double-charm fraction measurement.

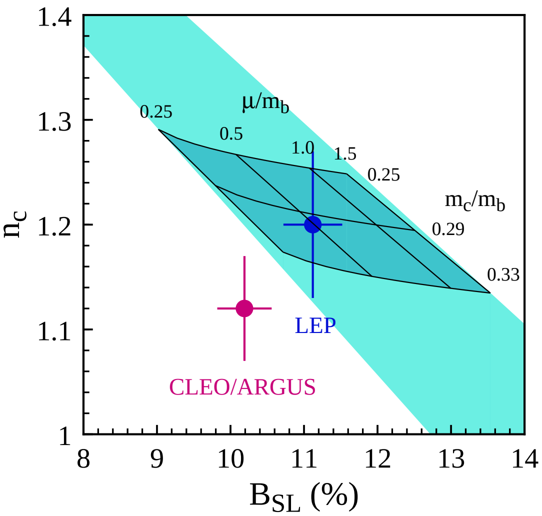

Figure 1: Charm yield vs. semileptonic branching ratio, from Ref. 1. Theoretical bounds are defined by the quark mass ratio m_c/m_b and the renormalization scale μ.

2 Measurement of $\mathcal{B}(B \to D\bar{D}X)$

The $B \to D\bar{D}X$ decay channel is governed mainly by the $b \to c\bar{c}s$ quark transition illustrated by the spectator diagram of Fig. 2, where in addition to the D meson from the $b \to c$ transition, a second so-called "wrong-sign" D is produced in the $W^- \to \bar{c}s$ decay. Previous measurements [6,7,8] of the branching ratio for this decay yielded a value of $\sim$ 20% with an uncertainty $\simeq \pm$4%.

At SLD, the measurement is performed using an inclusive approach based on selecting B decays with two well separated vertices. This is achieved, in part, by requiring that the χ^2 probability that all tracks in the B

Table 1: Number of charged kaons in B- and D-vertex and their ratio.

	$N_{K^-,B}$	$N_{K^+,B}$	$N_{K^-,D}$	$N_{K^+,D}$	$N_{K,B}/N_{K,D}$
Data	758	559	1168	746	0.688 ± 0.025
M.C. $D\bar{D}$	3115	2339	2380	1880	1.280 ± 0.026
M.C. "Not-$D\bar{D}$"	5386	3974	11489	6549	0.519 ± 0.007

decay chain originate from a single vertex be $< 5\%$. We refer to the vertex closest to the interaction point as the "B-vertex" and the one furthest as the "D-vertex", as in the standard $b \to c$ decays. Note that for $B \to D\bar{D}X$ decays, the so-called "B-vertex" is rather likely to be one of the two D mesons. The two unique techniques we make use of to extract the double-charm fraction $f_{D\bar{D}}$ rely essentially on this fact. They are described below.

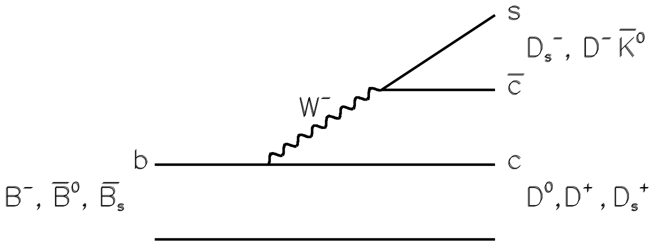

Figure 2: Tree-level diagram for $b \to c\bar{c}s$.

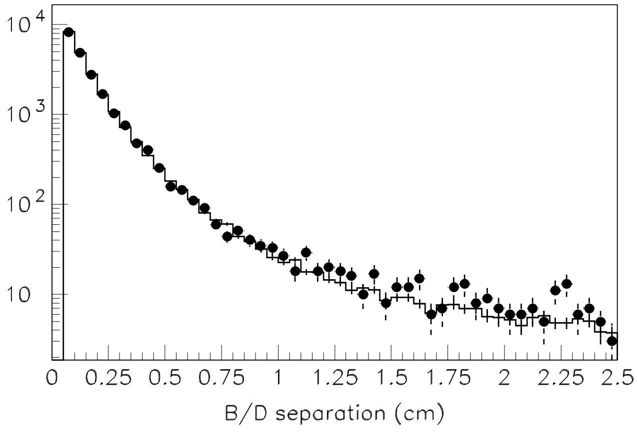

Figure 3: Reconstructed distance between B and D vertices. The dots represent the data and the histogram the Monte Carlo.

Fig. 3 shows the reconstructed distance between the B and D vertices. Good agreement between the data and the Monte Carlo is seen. The Monte Carlo simulation of the production and decay of B mesons at the Z^0 resonance is based on the JETSET 7.4 generator [9] and the CLEO B decay model [10].

2.1 The Kaon Counting Method

In this analysis we count the number of charged kaons identified by the CRID that are attached to the B-vertex and the D-vertex. We then compare the ratio of these two numbers in the data to that from two Monte Carlo samples: one containing exclusively double-charm B decays, and one made up of all other B decay channels. Since kaons are copiously produced in the $c \to s$ transition, one expects to find substantially more kaons in the D-vertex for single-charm B decays. This is not the case for double-charm B decays where one of the D mesons may be reconstructed as the B-vertex. The ratio of the number of $K^{\pm}$'s in the B-vertex to that in the D-vertex is shown in the last column of Table 1. It can be seen clearly that this ratio in the data has a double charm component, whose fraction we deduce to be

$$f_{D\bar{D}} = 0.188 \pm 0.025(stat).$$

This is after having applied a correction for the difference in efficiency for selecting single-charm (ϵ_D) and double-charm ($\epsilon_{D\bar{D}}$) decays of the B. We estimate the ratio of these efficiencies to be $\epsilon_{D\bar{D}}/\epsilon_D = 1.34 \pm 0.03$.

An interesting cross check is provided by the K^+/K^- asymmetry at the D-vertex (see Table 1). For a single-charm B decay, the sign of the kaon there is – (+) if it originated from the $b \to c \to s$ ($\bar{b} \to \bar{c} \to \bar{s}$) decay chain. For double-charm decays, the D-vertex may correspond to the wrong-sign D meson which produces a kaon with opposite sign. Thus the kaon charge asymmetry in this case is different. The $B \to D\bar{D}X$ fraction we extract from this asymmetry is $f_{D\bar{D}} = 0.29 \pm 0.11(stat)$.

Note that, in this discussion, the $K^{\pm}$ sign is given by the kaon charge multiplied by the sign of the b-quark charge, as determined by tagging the b or $\bar{b}$ flavor of the B meson at production. The initial state b flavor tagging at SLD relies mainly on the large polarized forward-backward asymmetry for $Z^0 \to b\bar{b}$ decays. It is complemented by other tags using information from the opposite hemisphere to the selected B vertex. These tags include the momentum-weighted track charge sum (jet charge), the dipole charge for a topologically reconstructed vertex and the charge of an identified kaon or

Table 2: Systematic errors in the measurement of $f_{D\bar{D}}$ for the kaon counting method.

	σ_{syst}
Detector Systematics	
Tracking Efficiency	± 0.003
Tracking Resolution	± 0.007
$K^{\pm}$ Id. Efficiency	< 0.001
$\pi^{\pm}$ Fake Rate	± 0.007
Track Misassignment	± 0.042
Physics Systematics	
$udsc$ Background	± 0.004
B Multiplicity	± 0.015
B_s Fraction	± 0.011
Λ_b Fraction	± 0.007
$\mathcal{B}(B_{u,d} \to D^0 X)$	± 0.002
$\mathcal{B}(B_{u,d} \to D^+ X)$	± 0.002
$\mathcal{B}(B_{u,d} \to D_s^+ X)$	± 0.004
$B \to D\bar{D}$ Model	± 0.015
Charm Multiplicity	± 0.032
TOTAL	± 0.059

a high transverse-momentum lepton. Further details can be found in Ref. 11.

The analyzing power of the kaon counting technique is somewhat reduced experimentally due to the misassignment of tracks between the B and D vertices. In order not to rely entirely on the Monte Carlo simulation, the track misassignment rate is calibrated in the data using semileptonic $b \to l$ and $b \to c \to l$ decays. This is done by comparing the lepton sign in these decays to the initial-state b-quark flavor (sign). Wrong combinations of the two are the result of an initial-state flavor mistag (whose rate is well determined) and/or a misassignment of the lepton to the B- or D-vertex. We measure the track assignment efficiency to be $\epsilon_{T.A.} = 0.70 \pm 0.03$. The same analysis performed on the Monte Carlo gives a consistent result. The statistical error in this efficiency translates into a systematic uncertainty of ±0.042 in $f_{D\bar{D}}$.

Another important source of systematic error in this measurement is the uncertainty in the charm decay multiplicity, which is not very well determined experimentally [12]. Other systematic errors are listed in Table 2. Combining all the components in quadrature we get a total systematic error of ±0.059. Thus, our preliminary measurement of the B double-charm branching fraction using the kaon counting method is

$$f_{D\bar{D}} = 0.188 \pm 0.025(stat) \pm 0.059(syst).$$

2.2 D Charge Method

In this analysis, we compare the sign of the reconstructed D-vertex to the initial-state flavor of the B meson. For example, when a B^- decays to a single charmed meson, we expect the D-vertex to be positively charged (see Fig. 2). Whereas, for a double-charm decay of the same B^-, the reconstructed D-vertex can be either positively or negatively charged, since it may correspond to either a right- or wrong-sign D meson. This is, of course, without taking into account decays of the B^- into a neutral D meson, for simplicity. The distribution of the D-vertex charge multiplied by the b-quark charge sign of the B meson at production is shown in Fig. 4. There is good agreement between the data, represented by the dots, and the Monte Carlo, by the solid histogram. The Monte Carlo is a sum of a pure single-charm (shaded histogram) component and double-charm component. Note that the latter is asymmetric.

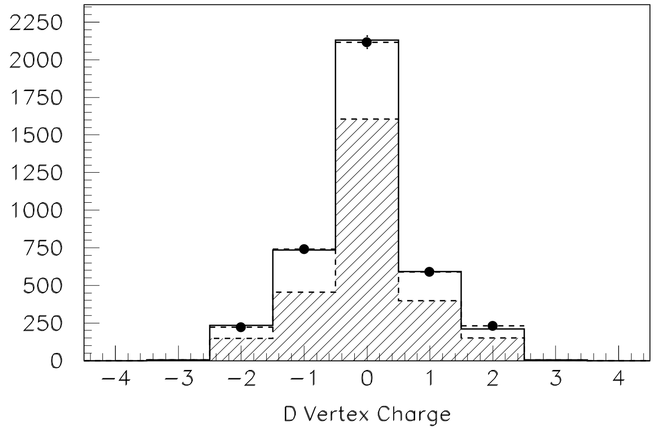

Figure 4: D-vertex charge (multiplied by sign of b-quark charge). The various components are explained in the text.

Similarly to the kaon counting method, this technique is also sensitive to the misassignment of tracks between the B and D vertices. Furthermore, the large D^0 production rate degrades its analyzing power.

We extract the B double-charm branching fraction by fitting the data distribution in Fig. 4 to the two Monte Carlo distributions corresponding to the D-charge for single- and double-charm decays. The result of the χ^2 fit is

$$f_{D\bar{D}} = 0.195 \pm 0.045(stat),$$

which is consistent with the above value obtained with the kaon counting method. The systematic error for this measurement is currently being evaluated.

3 Search for Charmless B^+ Decays

We have searched for the exclusive three-prong decays $B^+ \to \rho^0 \pi^+ (K^+)$, $\rho^0 \to \pi^+\pi^-$; and $B^+ \to K^{*0}\pi^+(K^+)$,

$K^{*0} \to K^+\pi^-$. These are mediated by the tree-level $b \to u$ and the one-loop penguin $b \to d(s)$ transitions. Theoretical predictions for the corresponding branching ratios are in the 10^{-6} – 10^{-5} range [13,14,15]. The best experimental limits come from CLEO [16] and are about a factor 5 – 10 larger. These are based on the observation of a small number of events (e.g. 8 observed decays for an expected background of 3 in the $\rho\pi$ channel). For the decays $B^+ \to \rho^0\pi^+$, $K^{*0}\pi^+$, the DELPHI [17] experiment observes a total of 3 decays, with a background estimated at 0.15. The resulting branching ratio is $\mathcal{B}(B \to \rho(K^*)\pi) = (1.7^{+1.2}_{-0.8} \pm 0.2) \times 10^{-4}$.

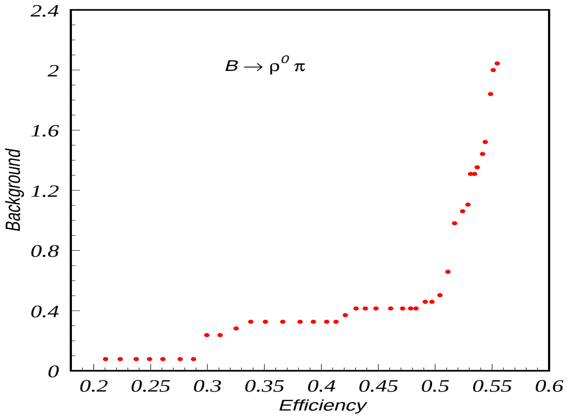

Figure 5: Background vs. efficiency evolution as the cut on the discriminator function output is varied.

While CLEO and DELPHI have used relatively large samples of B^+'s, their efficiency is small ($\approx 6.0\%$). At SLD, with our high resolution vertexing capability, we achieve an efficiency as high as 50% within our acceptance. With a sample of $\sim 100k$ B^+'s, we can set comparable limits to CLEO and DELPHI.

Table 3: Efficiency and background estimate for each of the four final states in the $B^+ \to$ 3-prong search (not including the branching ratio for $\rho^0 \to \pi^+\pi^-$ and $K^{*0} \to K^+\pi^-$).

	Efficiency	Estimated Background
$\rho^0\pi^+$	0.50	0.61
$\rho^0 K^+$	0.45	0.61
$K^{*0}\pi^+$	0.52	0.37
$K^{*0}K^+$	0.46	0.37

The analysis consists of three steps. First, we form a three-prong vertex with charge $= \pm 1$. We apply track quality, background suppression, and decay kinematics requirements. The latter include B mass and energy cuts, and ρ^0 and K^{*0} mass and center-of-mass helicity angle cuts. No kaon identification is required. In the second stage of the analysis, we construct a discriminator function using eight kinematic and vertexing variables, each with a parametrization for signal and background. Finally, we determine the optimal cut on the output variable of this discriminator function. This is done, relying on Poisson statistics, by minimizing the expected branching ratio upper limit as a function of efficiency, for each of the decay channels, under the assumption that the true branching fraction is 0. The variation of the expected background vs. efficiency for the $\rho\pi$ channel is shown in Fig. 5. The optimal discriminator function output cut for this channel can be inferred from the figure, corresponding to an efficiency of $\approx 50\%$. It is important to note that this study is performed using only a Monte Carlo sample for the background, independently of the data.

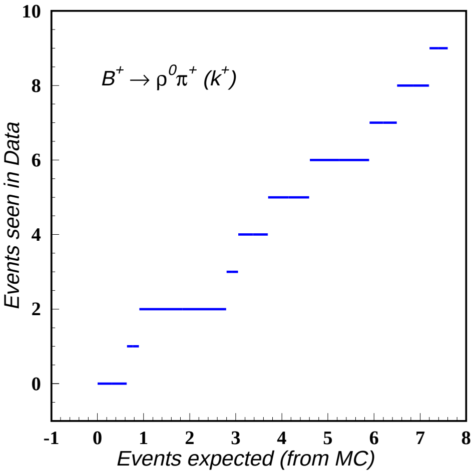

Figure 6: Number of observed decays in the data vs. expected background from the Monte Carlo, as the cut of the discriminator function is relaxed.

Table 4: Systematic uncertainty in the efficiency for each of the $B^+ \to$ 3-prong final states.

	$\rho^0\pi^+$	$\rho^0 K^+$	$K^{*0}\pi^+$	$K^{*0}K^+$
Mass Resolution	-0.3%	-0.9%	-0.4%	+0.1%
Tracking Effic.	-0.6	-0.5	-0.4	-0.2
Vertex Resolution	-2.5	-1.7	-1.0	-0.9
b Fragmentation	±0.4	±0.0	±0.3	±0.4
Total Uncertainty	±3.8%	±3.1%	±2.1%	±1.4%

No events are observed in any of the four decays we searched for in the data. The amount of background we estimate for each channel is listed in Table 3, together with the individual efficiencies. The number of observed decays in the data is compared to the expected background as the cut on the discriminator function is relaxed. We find that the two track one another very well, providing a nice cross check of the analysis. This is illustrated in Fig. 6.

Table 4 contains the systematic uncertainty in the efficiency for each of the decay channels. The first three components in the table correspond to the shift in absolute efficiency observed in the Monte Carlo when it is smeared according to transverse momentum resolution, tracking efficiency, and impact parameter resolution, respectively. The last component corresponds to the uncertainty associated with the measurement of the average B-hadron energy at the Z^0. Taking into account these systematic errors and the uncertainty in the estimate of the number of B^+'s contained in the data ($\pm 1.1\%$), we set 90% C.L. upper limits. These are given in Table 5. They are consistent with the CLEO limits. For the combined $\rho^0\pi^+$ and $K^{*0}\pi^+$ final states, the agreement between our result and DELPHI's branching ratio measurement, given above, is only at the $\leq 10\%$ confidence level.

Table 5: Preliminary 90% CL upper limits (B.R.$\times 10^5$) for the four exclusive final states in the $B^+ \to$ 3-prong search. Corresponding CLEO and DELPHI limits are also given.

	CLEO	DELPHI	SLD Preliminary
$B^+ \to \rho^0\pi^+$	5.8	16	8.2
$B^+ \to \rho^0 K^+$	1.4	12	9.2
$B^+ \to K^{*0}\pi^+$	3.9	39	11.9
$B^+ \to K^{*0}K^+$			13.5

4 Conclusions

We have presented a measurement of the $B \to D\bar{D}X$ branching ratio using two novel techniques. These rely on the high efficiency inclusive topological vertex reconstruction of the SLD detector, as well as its excellent initial-state b / $\bar{b}$ flavor tagging, and its very good particle identification capability. The first method, called the kaon counting technique, gives the following preliminary result:

$$\mathcal{B}(B \to D\bar{D}X) = 0.188 \pm 0.025(stat) \pm 0.059(syst).$$

This is comparable in precision and in good agreement with recent measurements by other experiments. The systematic error, which is conservatively estimated at this stage of the analysis, is dominated by the track mis-assignment rate between secondary and tertiary vertices, and by the charm decay multiplicity. It is expected to be improved significantly.

The second method, dubbed the D-charge technique, gives a consistent result. This analysis is not as mature yet, but it provides a good cross check for the kaon counting technique. The two measurements will be combined, taking into account common systematics, and the overall error in the double-charm branching ratio will be significantly decreased. An additional improvement in the statistical error is expected with the inclusion of a data sample not yet analyzed.

We have also shown the results of a search for rare exclusive charmless $B^+ \to$ 3-prong decays. Here also, the high resolution tracking and vertexing of SLD greatly enhances the experimental sensitivity to these modes. An overall efficiency of 50% is achieved. No candidates were observed in the data for the $\rho^0\pi^+(K^+)$ and $K^{*0}\pi^+(K^+)$ final states, and competitive upper limits are derived.

Other interesting analyses in B decays are underway at SLD, in particular a measurement of the B semileptonic branching fraction and a search for the $b \to sg$ transition. Together with the measurements presented here, a significant contribution toward a better understanding of the semileptonic branching ratio vs. charm yield puzzle will be made.

Acknowledgements

I would like to thank my colleagues Glen Crawford, Per Reinertsen, and Bruce Schumm for their contribution.

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