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# Search for Rare $B$ Meson Decays into $D_S^+$ Mesons

*The ARGUS Collaboration*

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**Abstract**

A search has been performed for rare $B$ meson decays into $D_S^+$ mesons arising from $b \to u$ transitions, $W$ exchange modes, $B^+$ annihilation processes, and decays where the $D_S^+$ is not produced via a $W \to c\bar{s}$ quark pair coupling, using the ARGUS detector operating on the $\Upsilon(4S)$ resonance at the $e^+e^-$ storage ring DORIS II. Upper limits for individual decay modes are obtained. In addition, from a study of $D_S^+\ell^-$ correlations an upper limit of $BR(B \to D_S^+\ell^- X) < 1.2\,\%$ (90% CL) is determined.

## 1 Introduction

Following the discovery of $B^0\overline{B}^0$ oscillations [1] and the measurement of a finite coupling for the third to first generation $b \to u$ transition via the weak interaction, large CP violation asymmetries are expected in neutral $B$ meson decays due to the physical phase of the Cabibbo-Kobayashi-Maskawa (CKM) matrix [2]. The finite value for $V_{ub}$ has been inferred from the observation of an excess of leptons in the inclusive spectrum beyond the kinematic limit for $b \to c$ transitions [3]. However, no evidence for $b \to u$ quark couplings has yet been seen in hadronic $B$ decays. Clearly, it is important to establish additional evidence in other channels.

Recently, detailed studies of Cabibbo-allowed double-charm decays $B \to D_S^{(*)}D^{(*)}$ have been performed [4], leading to a determination of the weak decay constant $f_{D_S}$ of the $D_S^+$ meson[1]. If the $b \to c$ transition in these modes were replaced by a $b \to u$ quark coupling, then the $D_S^+$ meson would be accompanied by a light meson, such as a $\pi$, $\rho$ or $\omega$, instead of the $D^{(*)}$ (see Fig. 1a). These kinds of two-body $B \to D_S^+ X_u$ decays ($X_u = \pi, \rho, \omega$) are well suited for observing $b \to u$ transitions in hadronic $B$ decays, since the $D_S^+$ meson can only occur via a $W \to c\bar{s}$ quark pair coupling in the decay chain $b \to u\,W$ (Fig. 1a). Thus, it is not possible, for example, to produce $D_S^+$ mesons in two-body decays through a so-called colour-suppressed internal $W$ emission in a $b \to c$ transition (see Fig. 1b).

Searches for other rare $B$ decays into $D_S^+$ mesons occuring via $W$ exchange and $B^+$ annihilation processes, shown in Fig. 2a) and 2b), are also of interest. While these are the dominant production mechanisms for the final states in this case, there could be diagrams beyond tree-level which are also able to contribute[2]. Tests of the strength of $W$ exchange processes in $B$ decays are important, particularly in the light of the ARGUS discovery of a large branching fraction for $D^0 \to \overline{K}^0\phi$ [5], a candidate for $W$ exchange contributions in charm decays. $B^+$ annihilation processes could be used to extract the weak decay constant $f_B$, required to obtain the CKM matrix element $|V_{td}|$ from $B^0\overline{B}^0$ mixing.

[1] Unless otherwise stated references in this paper to a specific charged state are to be interpreted as implying the charge conjugate state as well.

[2] Note that throughout this paper we refer to these channels which are supposedly dominated by the processes indicated in Fig. 2a) and 2b) as '$W$ exchange channels' and '$B^+$ annihilation channels', respectively.

A rare $B$ meson decay of special interest arises when the $D_s^+$ is not produced from the $W \to c\bar{s}$ vertex and the $W$ boson decays into a lepton or quark pair as shown in Fig. 2c). In the recent noteworthy LEP publications on the analysis of $B_s^0$ meson production using $D_s^+\ell^-$ correlations in hadronic $Z$ decays [6], such decay modes were reported to be a serious background source. The same is valid in the search for $B_s^0\overline{B}_s^0$ mixing which can be inferred using $D_s^+$ lepton correlations. Therefore, the investigation of $D_s^+\ell^-$ correlations in $B$ decays[3] is of vital complement to the LEP analyses.

The outline of the paper is as follows: After a short description of the data selection in Section 2 the analysis of exclusive rare $B$ decays into $D_s^+$ mesons from $b \to u$-, $W$ exchange-, and $B^+$ annihilation processes is detailed in Section 3 together with a search for exclusive decays where the $D_s^+$ is not produced from the $W \to c\bar{s}$ vertex. The study of $D_s^+\ell^-$ correlations in $B$ decays is the topic of Section 4 while our conclusions are presented in Section 5.

## 2 Data Samples and Event Selection Procedure

The data sample used for these studies was obtained with the ARGUS detector operating at the $e^+e^-$ storage ring DORIS II at centre-of-mass energies on the $\Upsilon(4S)$ resonance and in the nearby continuum. An integrated luminosity of 246 pb$^{-1}$ was collected on the $\Upsilon(4S)$ resonance, which corresponds to about 209 000 decays $\Upsilon(4S) \to B\overline{B}$ assuming that the $\Upsilon(4S)$ resonance decays only to $B\overline{B}$ pairs. The $q\bar{q}$ continuum sample comprises an integrated luminosity of 109 pb$^{-1}$. The ARGUS detector, its trigger and particle identification capabilities are described in detail elsewhere [7].

Multihadron events are selected by requiring at least three tracks with either a common main vertex or a total energy deposition in the shower counters of more than 1.7 GeV. The identification of charged hadrons is based on momentum and energy loss ($dE/dx$) measurements in the main drift chamber and on time-of-flight (ToF) measurement. A relative likelihood for the possible mass hypotheses $e$, $\mu$, $\pi$, $K$, $p$ is calculated for each charged particle on the basis of this information [7]. For a given particle, all hypotheses with a likelihood ratio greater than 1% are accepted. Lepton identification combines additional information from the electromagnetic calorimeter and the muon chambers in computing the likelihood ratio and is described in more detail in section 4.

Good particle identification and geometric acceptance are ensured by requiring that all particles have a polar angle $\theta$ with respect to the beam axis within the interval $|\cos\theta| < 0.92$. In addition, only photons with an energy deposition in the calorimeter of at least 60 MeV are considered. All combinations of two photons with an invariant mass between 100 MeV/c$^2$ and 170 MeV/c$^2$ are accepted as $\pi^0$ candidates. Energetic $\pi^0$ mesons, whose decay photons often merge into a single cluster in the electromagnetic calorimeter, are included in the analysis by

[3]If not otherwise stated in this paper the expression '$B$' meson always implies a '$B^0$' or '$B^+$' meson.



considering all shower clusters with an energy greater than 800 MeV as $\pi^0$ candidates. $K_S^0$ mesons are reconstructed from their $\pi^+\pi^-$ decay forming a secondary vertex. The invariant $\pi^+\pi^-$ mass is required to lie within $\pm 30$ MeV/c$^2$ of the nominal $K_S^0$ mass [8].

## 3 Search for Exclusive Rare $B$ Decays into $D_S^+$ Mesons

Our search for exclusive rare $B$ decays into $D_s^+$ mesons concentrates on modes associated with (a) $b \to u$ transitions, (b) $W$ exchange processes, (c) $B^+$ annihilation modes, and (d) decays where the $D_s^+$ meson is not produced from the $W \to c\bar{s}$ vertex:

| | (a) | | (b) | | (c) | | (d) |
|---|---|---|---|---|---|---|---|
| $B^0$ | $\to D_s^+\pi^-$ | $B^0$ | $\to D_s^-K^+$ | $B^+$ | $\to D_s^+\phi$ | $B^0$ | $\to D_s^-\pi^+K_S^0$ |
| | $\to D_s^+\rho^-$ | | $\to D_s^-K^{*+}$ | | $\to D_s^+K_S^0$ | | $\to D_s^-\pi^+K^{*0}$ |
| | $\to D_s^+a_1^-$ | | | | $\to D_s^+\overline{K}^{*0}$ | $B^+$ | $\to D_s^-\pi^+K^+$ |
| $B^+$ | $\to D_s^+\pi^0$ | | | | | | $\to D_s^-\pi^+K^{*+}$ |
| | $\to D_s^+\rho^0$ | | | | | | |
| | $\to D_s^+\omega$ | | | | | | |
| | $\to D_s^+a_1^0$ | | | | | | |

and on all corresponding channels where the $D_s^+$ is replaced by a $D_s^{*+}$. Small branching ratios and reconstruction efficiencies require the $D_s^+$ meson to be reconstructed in as many clean decay channels as possible: $D_s^+ \to \phi\pi^+$, $D_s^+ \to \phi\pi^+\pi^+\pi^-$, $D_s^+ \to K_S^0K^+$, $D_s^+ \to K_S^0K^{*+}$, $D_s^+ \to \overline{K}^{*0}K^+$, $D_s^+ \to \overline{K}^{*0}K^{*+}$, with the subsequent decays $\phi \to K^+K^-$ ($\pm 12$ MeV/c$^2$), $\overline{K}^{*0} \to K^-\pi^+$ ($\pm 70$ MeV/c$^2$), and $K^{*+} \to K_S^0\pi^+$ ($\pm 70$ MeV/c$^2$), where the invariant mass of the final particle combination agrees with the nominal particle mass [8] within the precision specified in brackets. The remaining particles from the $B$ decays listed above are reconstructed through $\rho^0 \to \pi^+\pi^-$ ($\pm 140$ MeV/c$^2$), $\rho^+ \to \pi^+\pi^0$ ($\pm 140$ MeV/c$^2$), $a_1 \to \rho\pi$ ($\pm 140$ MeV/c$^2$), and $\omega \to \pi^+\pi^-\pi^0$ ($\pm 35$ MeV/c$^2$). To improve momentum resolution a mass constraint fit is applied to all intermediate states having a natural width much smaller than the mass resolution of the detector ($K_S^0$, $\pi^0$, $\omega$, $D_s^+$, and $D_s^{*+}$).

The reconstruction of $D_s^+$ candidates and the subsequent selection of $B$ meson candidates is performed in a manner similar to the study of $B \to D_s^{(*)}D^{(*)}$ decays described in [4]. Thus $D_s^+$ candidates are required to have an invariant mass within $\pm 20$ MeV/c$^2$ for the $\phi\pi^+\pi^+\pi^-$ channel, while all other $D_s^+$ decay modes are required to lie within $\pm 30$ MeV/c$^2$ of their nominal mass value [8]. A serious source of background in the search of rare $B \to D_s^+X$ decays is the misidentification of $D_s^+ \to K_S^0K^+$ and $D_s^+ \to \overline{K}^{*0}K^+$ candidates through reflections from $D^+ \to K_S^0\pi^+$ and $D^+ \to \overline{K}^{*0}\pi^+$. Misidentifying the $\pi^+$ from a $D^+$ decay as a $K^+$ shifts the invariant mass of the particle combination into the $D_s^+$ mass region, where Monte Carlo studies of $B \to D^+\pi$ decays show that about 30% – 40% of these $D^+$ decays fake a $D_s^+$. To reduce this fake rate to a level of less than $10^{-3}$, only clearly identified $K^+$ with momenta less than 0.8 GeV/c are used for these two $D_s^+$ decay modes. Furthermore, the decay $D^+ \to K_S^0\pi^+\pi^-\pi^+$ can give rise to a reflection in the decay $D_s^+ \to K^{*+}\overline{K}^{*0}$, followed by $K^{*+} \to K_S^0\pi^+$ and $\overline{K}^{*0} \to K^-\pi^+$. A similar $D^+$ fake rate of less than $10^{-3}$ is obtained by restricting the $K^-$ in the $\overline{K}^{*0} \to K^-\pi^+$ decay to momenta below 1.0 GeV/c. Monte Carlo studies show that $D^+$ reflections are negligible in the other three $D_s^+$ channels. Finally, selected $D_s^{*+}$ candidates are required to have a mass difference, $m(D_s^+\gamma) - m(D_s^+)$, lying in the interval from 100 MeV/$c^2$ to 180 MeV/$c^2$.

In the search for $B$ candidates, the following additional criteria are required. The energy $E$ of candidates for rare $B \to D_s^+X$ decays must lie within $\pm 2\sigma_E$ of the beam energy, where $\sigma_E$ is the experimentally determined energy resolution. Mass resolution is improved for all $B$ meson candidates through use of a kinematic fit which constrains their energy to the beam energy. Background from continuum events is suppressed by using the angle $\delta$ between the thrust axis of the $B$ candidate and the thrust axis of all remaining particles in the event. For $B$ decays originating from the $\Upsilon(4S)$ resonance this distribution should be isotropic, whereas continuum events are peaked at $|\cos\delta| = 1$. Events are selected with $|\cos\delta| < 0.8$. If any photon is involved in the reconstruction of the $B$ candidate, the more restrictive requirement of $|\cos\delta| < 0.6$ is made, since the combinatorial background is larger in these channels due to the large number of soft photons. In addition, the momenta of the decay products of the two-body $B$ decays are restricted to lie below the appropriate kinematic limit for $B$ decays. The momentum cuts for the individual decay modes can be found in Table 1. In the three-body decays (displayed in Fig. 2 c) no momentum cuts are applied.

Finally, all combinations with a mass greater than 5.15 GeV/$c^2$ are considered as $B$ candidates. Particularly in channels with neutral particles, where a large combinatorial background can occur, events may contain more than one $B$ candidate in a given decay mode. Multiple counting is avoided by accepting only the one $B$ candidate per decay channel per event which has the largest total probability calculated from the sum of all $\chi^2$ contributions from particle identification and kinematic fits.

In the two-body decay $B^0 \to D_s^+\pi^-$ the $\pi^-$ has a momentum around 2.3 GeV/c and cannot be adequately distinguished from a $K^-$ in the decay $\overline{B}^0 \to D_s^+K^-$ by the particle identification capabilities of the ARGUS detector. Although the energy of the $B$ candidate is already restricted to lie within $\pm 2\sigma_E$ of the beam energy to facilitate the separation of corresponding $D_s^+$ and $D_s^{*+}$ modes, Monte Carlo studies reveal a cross talk between the $D_s^+\pi^-$ and $D_s^+K^-$ modes of more than 50% even for a cut within $\pm 1\sigma_E$. Under these conditions, it is not possible to distinguish between the $b \to u$ decay $B^0 \to D_s^+\pi^-$ and the $\overline{B}^0 \to D_s^+K^-$ mode arising from a $W$ exchange process. Therefore, only the one $B$ decay per event which has the largest total probability for both of these decay channels is selected. The decay modes $B^+ \to D_s^+\rho^0$ and $B^+ \to D_s^+\overline{K}^{*0}$ are also indistinguishable, since the $K^-$ from the $\overline{K}^{*0}$ is usually fast and not clearly separable by means of particle identification from a $\pi^-$ of the



$\rho^0$ decay. Similar cross talk problems arise in the corresponding $D_s^{*+}\pi^-$ versus $D_s^{*+}K^-$ and $D_s^{*+}\rho^0$ versus $D_s^{*+}\overline{K}^{*0}$ modes. Further studies show that no other cross talk problems arise among the remaining $B$ decay channels, including those involving corresponding $D_s^{*+}$ and $D_s^+$ modes, using the selection criteria described.

After application of all selection criteria, the invariant mass distributions for the analyzed decay channels shown in Fig. 3 are obtained. Here, (a)-(d) are channels with cross talk, (e) and (f) represent $W$ exchange processes, (g)-(o) $b \to u$ transitions, and (p)-(s) $B^+$ annihilation modes, while (t)-(A) are the decays where the $D_s^+$ meson is not produced from the $W \to c\bar{s}$ vertex. No significant signals are found for any single decay modes investigated. Studies of $D_s^+$ candidates from the $D_s^+$ sideband above the selected $D_s^+$ mass region, $B\overline{B}$ Monte Carlo events containing no rare $B \to D_s^+X$ decays, as well as our continuum data sample are performed. These show a constant background level in the observed mass spectra. To obtain the number of events in the $B$ signal region, a fit is performed to each mass distribution using a constant to parametrize the background plus a Gaussian with width and mass fixed by Monte Carlo studies. Upper limits on signals in the $B$ mass region are obtained by integrating the likelihood distribution obtained in the fits over positive values of the number of events. In order to obtain upper limits on branching ratios reconstruction efficiencies are calculated using simulated $\Upsilon(4S) \to B\overline{B}$ decays where one $B$ meson decays to the appropriate channels while the second $B$ decays in any allowed mode. The events are passed through a detailed detector simulation and the ARGUS reconstruction program. The branching ratios of all subsequent decays are taken from [8]. Since $D_s^+$ branching ratios are only reliably known relative to $BR(D_s^+ \to \phi\pi^+)$, a fixed value of 2.7% is assumed for $BR(D_s^+ \to \phi\pi^+)$ as taken from [8]. The extracted upper limits (90% confidence level) on the branching ratios for rare $B$ decays into $D_s^+$ mesons arising from $b \to u$ transitions, $W$ exchange modes, $B^+$ annihilation processes and decays where the $D_s^+$ is not produced from the $W \to c\bar{s}$ vertex, are listed in Table 2. High momentum $\pi^0$ candidates in the two-body decay $B^+ \to D_s^{(*)+}\pi^0$ are identified from single cluster showers in the electromagnetic calorimeter where the two photons of the $\pi^0$ decay have merged. Using the requirement that the energy of the $B$ candidate lies within $\pm 2\sigma_E$ of the beam energy, the energy resolution of these merged $\pi^0$'s is too poor to allow a distinction between the decays $B^+ \to D_s^+\pi^0$ and $B^+ \to D_s^{*+}\pi^0$, which differ only by the soft photon from the decay $D_s^{*+} \to D_s^+\gamma$. Therefore a single upper limit is given in Table 2 for both channels.

## 4 Study of $D_S^+\ell^-$ Correlations

One way to search for $B_s^0$ mesons and $B_s^0\overline{B}_s^0$ mixing at LEP is to take advantage of the semileptonic decay $\overline{B}_s^0 \to D_s^+\ell^-\overline{\nu}$. Since the $D_s^+\ell^-$ pair could also originate from $B^0$ or $B^+$ decays as shown in Fig. 2c) it is of great interest to search for $D_s^+\ell^-$ correlations in our $\Upsilon(4S)$

data sample, where only $B^0$ and $B^+$ mesons are produced.

Lepton identification for this study combines available information from several detector components into a global likelihood ratio [7]. For electrons, this likelihood ratio ($L_e$) is constructed from measurements of $dE/dx$ in the main drift chamber, time-of-flight, and the energy, size and lateral spread of the associated cluster in the electromagnetic calorimeter. A particle with $L_e > 0.7$ is considered to be an electron. Contamination from photon conversions is significantly reduced by eliminating electron candidates which, when combined with an oppositely charged particle in the event consistent with the electron hypothesis, have either an invariant mass of less than 100 MeV/c$^2$, or form a secondary decay vertex. For muons, the quality of the match between the projected particle track and the associated hit in the muon chambers is also used in forming a likelihood ratio ($L_\mu$). A particle with at least one hit in the outer two layers of the muon chambers and $L_\mu$ greater than 0.7 is considered to be a muon.

$D_s^+$ mesons are reconstructed through their decay modes into $\phi\pi^+$, $K_S^0K^+$, $K_S^0K^{*+}$, and $\overline{K}^{*0}K^{*+}$ with the same selection criteria as described in section 3. The decay channel $D_s^+ \to \phi\pi^+\pi^+\pi^-$ is not used for this study due to large combinatorial background. Likewise, the decay chain $D_s^+ \to \overline{K}^{*0}K^+$, $\overline{K}^{*0} \to K^-\pi^+$ is not used, since the exchange of the $K^+$ of the $D_s^+$ with the $\pi^+$ of the $\overline{K}^{*0}$ often leads to an additional $D_s^+$ candidate.

In order to suppress known background sources which give rise to $D_s^+\ell^-$ correlations, the following selection criteria are applied. Leptons from semileptonic charm decays produced in cascade decays $b \to c \to \ell$ are relatively soft [9] and are suppressed by requiring the lepton momentum $p_\ell$ to be greater than 1.4 GeV/c. The requirement of a high momentum lepton also leads to low hadron misidentification rates of 0.5% and 2% for $e$ and $\mu$, respectively, and suppresses background from $e^+e^- \to c\bar{c}$ continuum events, where the $c$ quark fragments to a $D_s^+$, and the $\bar{c}$ decays in a semileptonic mode. The continuum contribution is further suppressed by requiring the second Fox-Wolfram moment [10] of the event $H_2 < 0.4$ and by demanding the scaled momentum $x_p$ of the $D_s^+$ candidate to be less than 0.5, where $x_p = p_{D_s^+}/p_{max}$ and $p_{max} = \sqrt{E_{beam}^2 - m_{D_s^+}^2}$. Since all decay products of $B$ mesons are restricted to $x_p < 0.5$ the scaled momentum of the lepton also has to be less than 0.5. The level of the remaining $q\bar{q}$ background can be directly checked by performing the same analysis on the $q\bar{q}$ continuum data sample.

The main source of $D_s^+\ell^-$ background comes from uncorrelated $D_s^+\ell^-$ production in $\Upsilon(4S) \to B\overline{B}$ decays where one $B$ produces the $D_s^+$ while the $\overline{B}$ decays semileptonically producing a $\ell^-$. However the analysis can be restricted to $D_s^+\ell^-$ pairs from the semileptonic decay of one $B$ meson by using the recoil mass technique developed for the study of $\overline{B}^0 \to D^{*+}\ell^-\overline{\nu}$ decays [11]. This method relies on the fact that $B$ mesons produced in decays of the $\Upsilon(4S)$ resonance are nearly at rest, so that the $B$ momentum is approximately zero. The missing neutrino can be inferred if the mass squared of the system recoiling against the



$D_s^+$ and $\ell^-$ is consistent with zero:

$$M_{rec}^2 = [E_{beam} - (E_{D_s^+} + E_{\ell^-})]^2 - [\vec{p}_{D_s^+} + \vec{p}_{\ell^-}]^2 .$$

Since the semileptonic $B$ decay (Fig. 2c) produces other particles besides the $D_s^+$, resulting in positive values for $M_{rec}^2$, a requirement of $M_{rec}^2 > -2.0$ GeV$^2$/c$^4$ is applied to reduce the background of uncorrelated $D_s^+\ell^-$ combinations which are expected at negative $M_{rec}^2$ values. Monte Carlo studies however show that the $M_{rec}^2$ distribution of uncorrelated $D_s^+\ell^-$ combinations peaks towards $M_{rec}^2 \cong 0$ GeV$^2$/c$^4$, so that this cut suppresses only about 40% of this background.

The $D_s^+$ candidates found in events with a $\ell^-$ after application of all selection criteria are shown in Fig. 4a). A fit finds $(19.9 \pm 8.8)$ events, where the background shape, as well as the $D_s^+$ mass and width, are fixed to the values found for events obtained with relaxed lepton selection criteria. The mass distribution for the latter is shown in Fig. 4b), where a fit gives a $D_s^+$ mass of $(1966.4 \pm 1.6)$ MeV/c$^2$ and width $\sigma = (9.7 \pm 1.7)$ MeV/c$^2$, consistent with our previous measurement [4]. An enhancement from Cabibbo-suppressed $D^+$ decays is also visible. In all subsequent fits of the $D_s^+$ mass spectrum the $D^+$ mass region is omitted. After subtracting an estimated contribution of $(12.4 \pm 3.1)$ uncorrelated $D_s^+\ell^-$ events, as derived from our inclusive measurement $B \to D_s^+X$ [4] and the semileptonic $B$ decay rate [9], only $(7.5 \pm 9.3)$ events remain. Unfortunately the large errors of this result do not allow a useful limit to be derived.

A more restrictive upper limit on the production of $D_s^+\ell^-$ pairs in $B$ decays is obtained by considering $D_s^+\ell^-K^-$ and $D_s^+\ell^-K_S^0$ correlations, since an extra kaon is expected from the decay mechanism in Fig. 2c). For this purpose, only clearly identified $K^-$ with momenta less than 0.8 GeV/c are selected. However, since the $K_S^0$ is almost background free, all momenta up to the kinematic limit for $B$ decays, $x_p < 0.5$, are allowed. The $D_s^+$ mass distributions from $D_s^+\ell^-K^-$ and $D_s^+\ell^-K_S^0$ combinations are shown in Fig. 5 for the $\Upsilon(4S)$ and continuum data. A fit to the former gives $(2.8 \pm 3.4)$ events for $D_s^+\ell^-K^-$ and $(-0.4 \pm 2.0)$ for $D_s^+\ell^-K_S^0$, while the continuum data contain no entries in the $D_s^+$ signal region as seen in Fig. 5b) and d). Integrating the likelihood distribution obtained in the fits over positive values of the number of events, upper limits at the 90% confidence level of 8.6 events for $D_s^+\ell^-K^-$ and 4.9 events for $D_s^+\ell^-K_S^0$ are obtained. Correcting for acceptance obtained by Monte Carlo study, upper limits (90% CL) for the corresponding branching ratios $BR(B \to D_s^+\ell^-K^-X) < 0.8\,\%$ and $BR(B \to D_s^+\ell^-\overline{K}^0X) < 1.2\,\%$ are determined. Since no reliable model for this type of semileptonic decay (see Fig. 2c) exists, the efficiency of the lepton cut $p_\ell < 1.4$ GeV/c is estimated by studying the semileptonic decays $B \to D\,\ell\,\nu$ and $B \to D^*\,\ell\,\nu$ using the model of Bauer, Stech, and Wirbel [12]. Here, the leptonic parts of the $B \to D^{(*)}\,\ell\,\nu$ modes are comparable when the mass of the '$D$' or '$D^*$' meson is replaced by the mass of the $D_s^+K^{(*)}$ combination.

Since an upper limit on the $BR(B \to D_s^+ \ell^- X)$ is the more relevant number, an estimate of the relative fraction of $K^-$ and $\overline{K}^0$ in semileptonic $B$ decays with an additional $D_s^+$ meson (Fig. 2c) is required. The decays of $K^*(892)$ mesons give equal numbers of $K^-$ and $\overline{K}^0$ in the final state, as do higher excited kaon resonances. Therefore, assuming the ratio of $K^-$ and $\overline{K}^0$ to be approximately one, the distributions for $D_s^+ \ell^- K^-$ and $D_s^+ \ell^- K_S^0$ may be summed as shown in Fig. 5e) and f). The number of fitted events is now $(2.5 \pm 4.0)$ and an upper limit (90% CL) of 9.3 is obtained, leading to the bound (90% CL):

$$BR(B \to D_s^+ \ell^- X) < 1.2\,\%.$$

This limit implies that a $D_s^+$ meson is produced in less than about 10% of all semileptonic $B$ decays. As mentioned before this number is of specific relevance to the background determination of the recently reported LEP results on $B_s^0$ meson production [6]. Rather than relying on Monte Carlo studies or calculations using theoretical assumptions to estimate this serious background, a measured upper limit is now provided.

## 5 Conclusion

In summary, rare decays of $B$ mesons into $D_s^+$ mesons have been investigated. In particular we have searched for $B \to D_s^+ X$ decays from $b \to u$ transitions, $W$ exchange modes, $B^+$ annihilation processes as well as for $B$ decays where the $D_s^+$ is not produced from a $W \to c\bar{s}$ vertex. Upper limits for individual decay modes were given. The upper limits on the branching ratios of particular decay channels lie in the region of $10^{-3}$. A comparison to theoretical expectations, for example, of the model of Bauer, Stech, and Wirbel [12], which predicts branching ratios for $b \to u$ transitions involving $D_s^+$ mesons of the order of $10^{-4}$ by using $|V_{ub}/V_{cb}| = 0.1$, seems to indicate that the investigated decay modes are not too far from being observed. In addition, from a study of $D_s^+ \ell^-$ correlations in $B$ decays we obtained an upper limit of $BR(B \to D_s^+ \ell^- X) < 1.2\,\%$ (90% CL) which is of interest for treating the background in the search for $B_s^0$ meson production or $B_s^0 \overline{B}_s^0$ mixing at LEP using $D_s^+$ lepton correlations.

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# Figure Captions

**Figure 1** Spectator diagram for a $B$ meson decay showing (a) a $b \to u$ transition and (b) for internal $W$ emission.

**Figure 2** Diagrams for rare $B$ decays into $D_s^+$ mesons via (a) $W$ exchange, (b) $B^+$ annihilation, and (c) a process where the $D_s^+$ is not produced from the $W \to c\bar{s}$ vertex.

**Figure 3** Invariant mass distributions of the investigated rare $B$ decays into $D_s^+$ mesons:
(a) $D_s^+\pi^-/D_s^+K^-$ (b) $D_s^{*+}\pi^-/D_s^{*+}K^-$ (c) $D_s^+\rho^0/D_s^+\overline{K}^{*0}$ (d) $D_s^{*+}\rho^0/D_s^{*+}\overline{K}^{*0}$
(e) $D_s^+K^{*-}$ (f) $D_s^{*+}K^{*-}$ (g) $D_s^{(*)+}\pi^0$
(h) $D_s^+\rho^-$ (i) $D_s^{*+}\rho^-$ (j) $D_s^+\omega$ (k) $D_s^{*+}\omega$
(l) $D_s^+a_1^-$ (m) $D_s^{*+}a_1^-$ (n) $D_s^+a_1^0$ (o) $D_s^{*+}a_1^0$
(p) $D_s^+\phi$ (q) $D_s^{*+}\phi$ (r) $D_s^+K_S^0$ (s) $D_s^{*+}K_S^0$
(t) $D_s^-\pi^+K_S^0$ (u) $D_s^{*-}\pi^+K_S^0$ (v) $D_s^-\pi^+K^{*0}$ (w) $D_s^{*-}\pi^+K^{*0}$
(x) $D_s^-\pi^+K^+$ (y) $D_s^{*-}\pi^+K^+$ (z) $D_s^-\pi^+K^{*+}$ (A) $D_s^{*-}\pi^+K^{*+}$.
Here, (a)-(d) are channels with cross talk, (e) and (f) represent $W$ exchange processes, (g)-(o) $b \to u$ transitions, and (p)-(s) $B^+$ annihilation modes, while (t)-(A) are the decays where the $D_s^+$ meson is not produced from the $W \to c\bar{s}$ vertex.

**Figure 4** Invariant mass distribution for $D_s^+$ candidates in events with (a) $D_s^+\ell^-$ combinations, and (b) loose lepton requirements. The solid curves result from a fit described in the text.

**Figure 5** The invariant mass spectrum of $D_s^+$ candidates from $\Upsilon(4S)$ events containing (a) $D_s^+\ell^-K^-$, (c) $D_s^+\ell^-K_S^0$, and (e) $D_s^+\ell^-K^-/K_S^0$ combinations, with corresponding distributions for continuum data in (b), (d), and (f), respectively.



Table 1: List of momentum cuts on each of the two decay products used for the reconstruction of the specified two-body $B$ decays.

| Momentum cut | $B$ decay channel |
|---|---|
| $< 2.5$ GeV/c | $D_s^{(*)+}\pi, D_s^{(*)+}K$ |
| $< 2.4$ GeV/c | $D_s^{(*)+}\rho, D_s^{(*)+}K^*, D_s^{(*)+}\phi, D_s^{(*)+}\omega$ |
| $< 2.3$ GeV/c | $D_s^{(*)+}a_1$ |

Table 2: Summary of upper limits (90% confidence level) on the number of events and corresponding branching ratios for rare $B$ decays into $D_s^+$ mesons. Note that a fixed value of 2.7% for $BR(D_s^+ \to \phi\pi^+)$ is assumed.

| Decay mode | Upper limits (90% CL) events | $BR$ |
|---|---|---|
| **channels with cross talk** | | |
| $D_s^+\pi^-/D_s^+K^-$ | 6.3 | $1.7\cdot10^{-3}$ |
| $D_s^{*+}\pi^-/D_s^{*+}K^-$ | 3.8 | $1.2\cdot10^{-3}$ |
| $D_s^+\rho^0/D_s^+\overline{K}^{*0}$ | 7.9 | $3.4\cdot10^{-3}$ |
| $D_s^{*+}\rho^0/D_s^{*+}\overline{K}^{*0}$ | 3.7 | $2.0\cdot10^{-3}$ |
| **$b \to u$ transitions** | | |
| $D_s^{(*)+}\pi^0$ | 3.0 | $0.9\cdot10^{-3}$ |
| $D_s^+\rho^-$ | 4.2 | $2.2\cdot10^{-3}$ |
| $D_s^{*+}\rho^-$ | 3.8 | $2.5\cdot10^{-3}$ |
| $D_s^+\omega$ | 5.3 | $3.4\cdot10^{-3}$ |
| $D_s^{*+}\omega$ | 2.4 | $1.9\cdot10^{-3}$ |
| $D_s^+a_1^-$ | 5.2 | $3.5\cdot10^{-3}$ |
| $D_s^{*+}a_1^-$ | 3.4 | $2.9\cdot10^{-3}$ |
| $D_s^+a_1^0$ | 4.1 | $3.0\cdot10^{-3}$ |
| $D_s^{*+}a_1^0$ | 2.4 | $2.2\cdot10^{-3}$ |
| **$W$ exchange processes** | | |
| $D_s^+K^{*-}$ | 2.3 | $4.6\cdot10^{-3}$ |
| $D_s^{*+}K^{*-}$ | 2.3 | $5.8\cdot10^{-3}$ |

| Decay mode | Upper limits (90% CL) events | $BR$ |
|---|---|---|
| **$B^+$ annihilation processes** | | |
| $D_s^+\phi$ | 2.3 | $1.7\cdot10^{-3}$ |
| $D_s^{*+}\phi$ | 2.3 | $2.1\cdot10^{-3}$ |
| $D_s^+\overline{K}^0$ | 2.3 | $2.5\cdot10^{-3}$ |
| $D_s^{*+}\overline{K}^0$ | 2.3 | $3.1\cdot10^{-3}$ |
| **$D_s^+$ not from $W \to c\bar{s}$ vertex** | | |
| $D_s^+\pi^-K^0$ | 5.1 | $7.3\cdot10^{-3}$ |
| $D_s^{*+}\pi^-K^0$ | 2.3 | $4.2\cdot10^{-3}$ |
| $D_s^+\pi^-K^{*0}$ | 7.9 | $5.0\cdot10^{-3}$ |
| $D_s^{*+}\pi^-K^{*0}$ | 3.4 | $2.7\cdot10^{-3}$ |
| $D_s^+\pi^-K^+$ | 3.3 | $1.1\cdot10^{-3}$ |
| $D_s^{*+}\pi^-K^+$ | 3.7 | $1.6\cdot10^{-3}$ |
| $D_s^+\pi^-K^{*+}$ | 3.8 | $8.6\cdot10^{-3}$ |
| $D_s^{*+}\pi^-K^{*+}$ | 3.7 | $1.1\cdot10^{-2}$ |

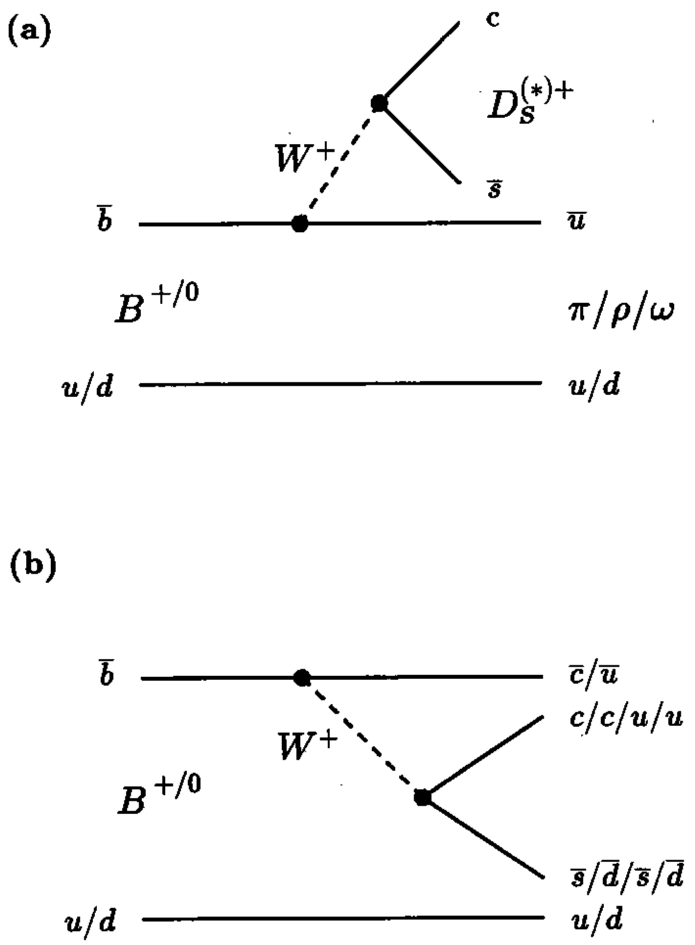



Figure 1



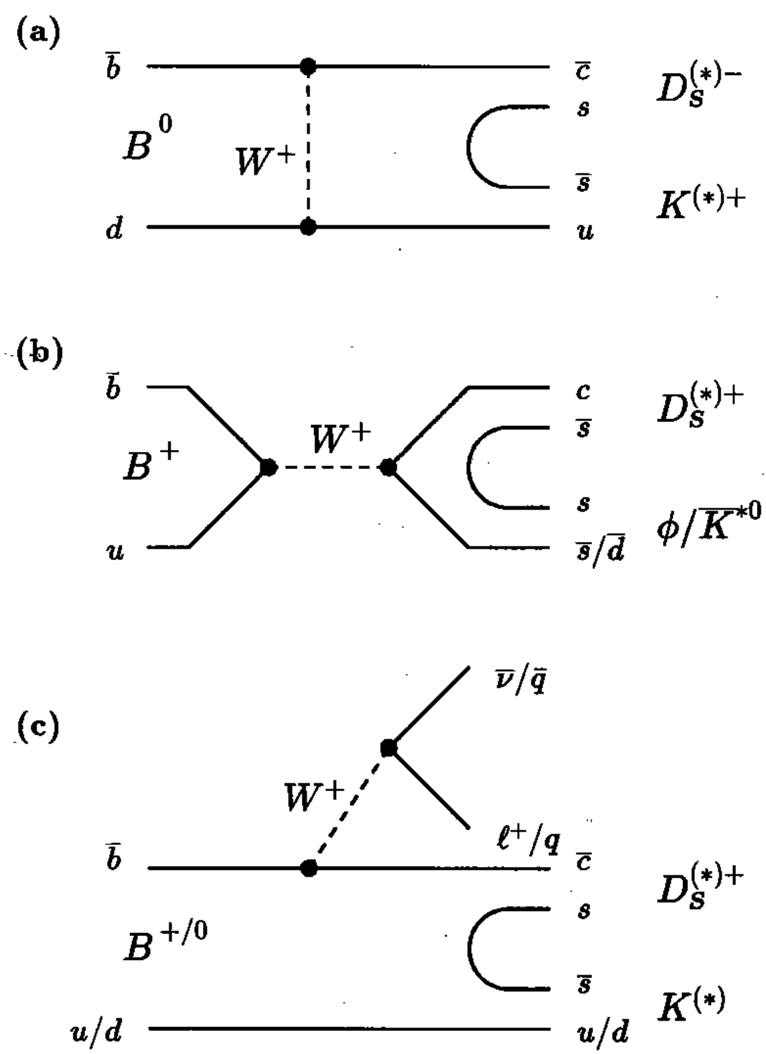



Figure 2

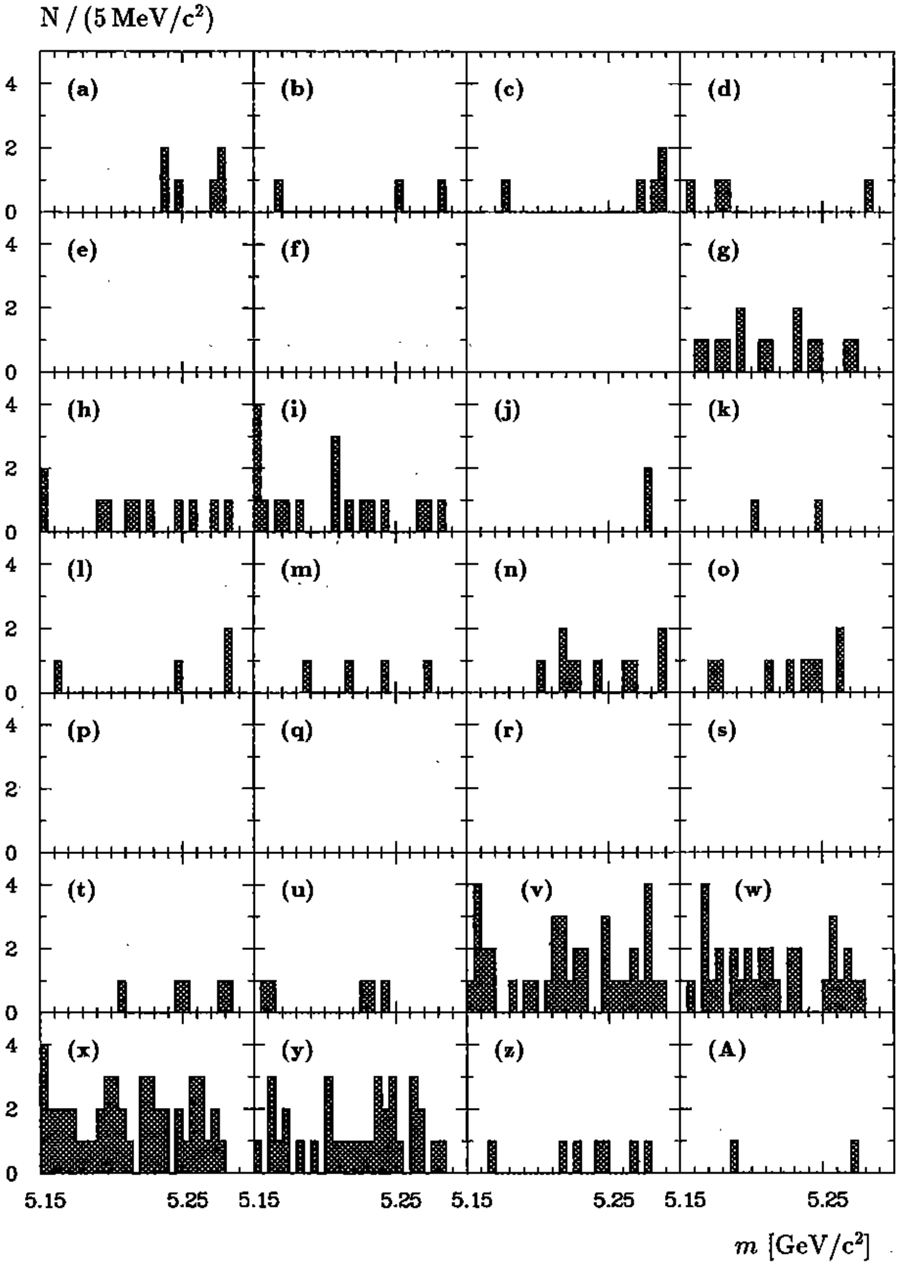



**Figure 3**



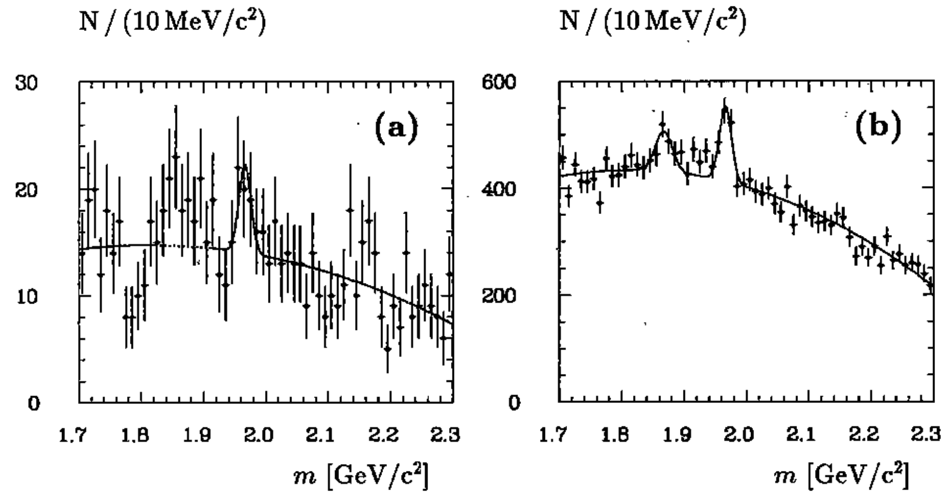
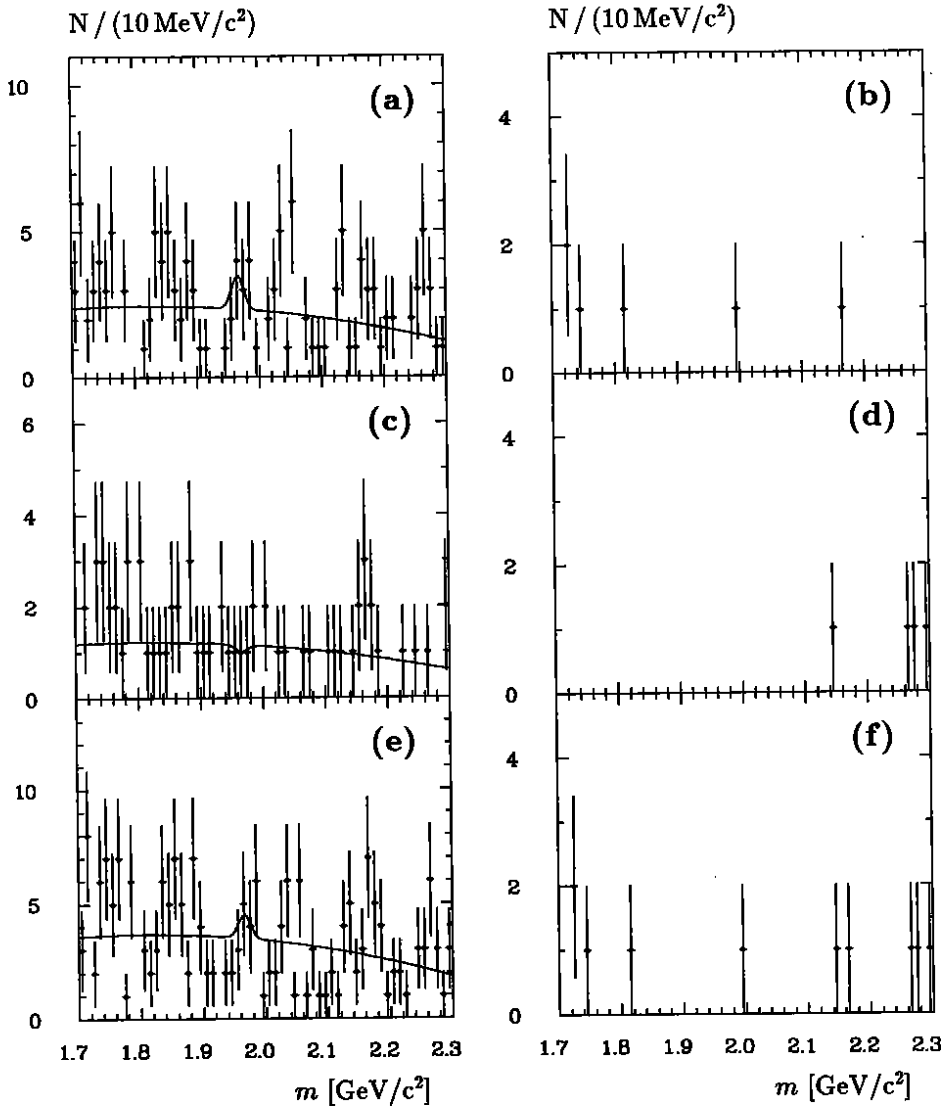



**Figure 4**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N / (10 MeV/c²)
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1.7 1.8 1.9 2.0 2.1 2.2 2.3
m [GeV/c²]
m [GeV/c²]

**Figure 5**