OBSERVATION OF INCLUSIVE D_s PRODUCTION IN B MESON DECAY

ARGUS Collaboration

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Using the ARGUS detector at the e^+e^- storage ring DORIS II, we have observed inclusive D_S production, using the channel $D_S^- \to \phi\pi^-$, in decays of B mesons produced on the $\Upsilon(4S)$ The product of branching ratios $BR(B \to D_S X)$ $BR(D_S^- \to \phi\pi^-)$ is $(4\ 2 \pm 0.9 \pm 0.6) \times 10^{-3}$. The D_S momentum spectrum suggests a substantial two-body component to the final states of $B \to D_S X$ decays.

Weak decays of B mesons provide a rich testing ground for models of heavy flavour decays [1]. In the spectator quark model one would expect these decays to be dominated by the transition $b \to W^- c$, with the W^- hadronic decay products evolving largely independent of the $c\bar{q}$ system. In particular, D_S mesons [‡1] can be produced by the two mechanisms shown in fig. 1. It would be of considerable interest to disentangle the contributions of these two processes, and thus determine the coupling of $W^- \to s\bar{c}$ in B decays. Because of the large mass of the c-quark, the process in fig. 1a is expected to be dominated by the fragmentation of the $c\bar{s}$ system to a D* or D. Since it is well known that the high multiplicities in B decays make it difficult to observe exclusive channels, we have studied inclusive D_S production via the $D_S^- \to \phi\pi^-$ mode [‡2]. First indications of the relative importance of the contributing diagrams have been obtained from the observed momentum spectrum.

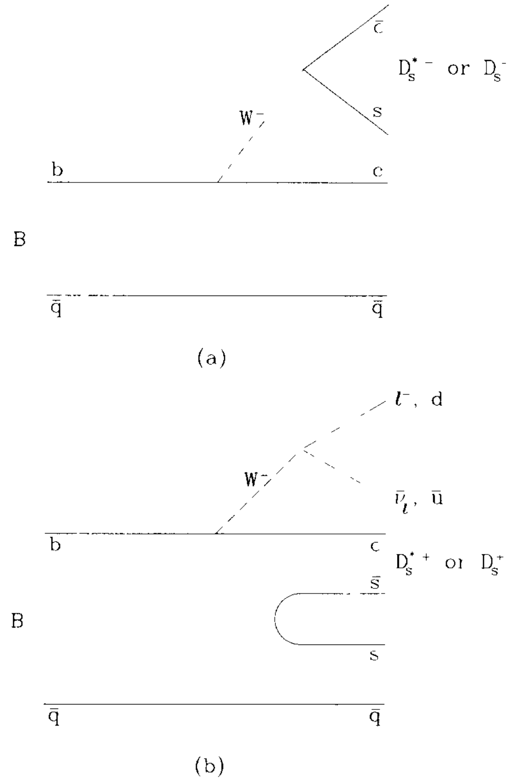

Fig 1 Diagram for D_S production from B decay: (a) $B \to D_S(c\bar{q})$, (b) $B \to W^- D_S(s\bar{q})$.

The data sample used for this analysis was collected using the ARGUS detector, operating in the e^+e^- storage ring DORIS II at DESY. It comprises an integrated luminosity of 145 pb^{-1}, of which 21.6 pb^{-1}, 36.6 pb^{-1}, 59.4 pb^{-1} and 27.4 pb^{-1} where taken on the $\Upsilon(1S)$, $\Upsilon(2S)$, $\Upsilon(4S)$ and in the continuum, respectively. The ARGUS detector is a 4π spectrometer, described in more detail elsewhere [3,4]. Charged-particle momenta and mean specific ionization loss were reconstructed using the ARGUS drift chamber. Particles were identified using both the measurements of specific ionization and of time-of-flight. Multihadron events were selected by requiring at least 3 tracks pointing to the interaction

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[‡1] We use the new naming scheme for hadrons in ref [2]. Specifically, D_S^- was called F^- and denotes the $\bar{c}s$ pseudoscalar meson state

[‡2] B is used to denote the mixture of neutral and charged B mesons produced in the $\Upsilon(4S)$ decay Since all D_S^* mesons are expected to decay electromagnetically to D_S, D_S here includes both the D_S^{*-} and D_S^-. References to a specific charge state also imply the charge conjugate state.

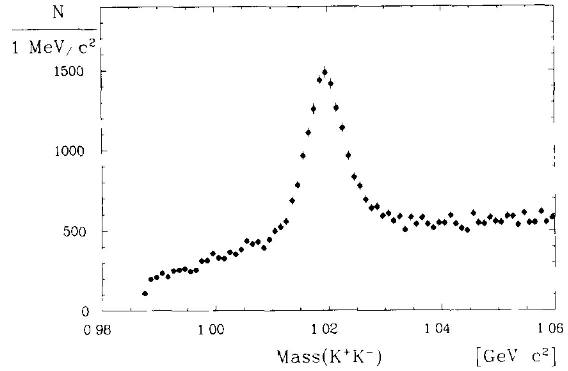


Fig. 2. K^+K^- invariant mass distribution in $e^+e^- \to K^+K^-X$

region, either originating from a common vertex or accompanied by an energy deposition of at least 1.7 GeV in the shower counters.

A prominent ϕ signal is observed in the invariant mass distribution of all K^+K^- pairs, shown in fig. 2. In the search for the decay $D_S^- \to \phi\pi^-$, those combinations of K^+K^- candidates with invariant mass within ± 15 MeV/c^2 of the nominal ϕ mass were taken as ϕ candidates and then combined with all π^- candidates in the event. Since the ϕ must have zero helicity in the D_S rest frame, the angular distribution of the K^- in the ϕ rest frame (with respect to the π) should be of the form $\cos^2\theta_K$, in contrast to the uniformly-distributed background. The angular distribution of the ϕ(with respect to the D_S boost direction) in the D_S rest frame is expected to be isotropic, i.e. constant in $\cos\theta_\phi$, since the D_S has spin zero, while the background from low-momentum points peaks along the boost direction. To reduce background, the following angle cuts were applied:

$$\cos\theta_\phi < 0.8 , \quad |\cos\theta_K| > 0.5 .$$

For D_S mesons produced from B decay, the momentum is kinematically limited to less than 2.5 GeV/c. This is equivalent to $x_p = p_{D_s}/p_{max} < 0.5$, where $p_{max} = (E^2_{beam} - M^2_{D_S})^{1/2}$.

The observed $\phi\pi^-$ mass spectra for $x_p < 0.5$ are shown in fig. 3a for the $\Upsilon(4S)$ and in fig. 3b for the combined $\Upsilon(1S)$, $\Upsilon(2S)$ and continuum data samples. Seen in fig. 3a is a clear enhancement near 1970 MeV/c^2. The sum of a gaussian plus third-order polynomial for the background was fitted to both distributions. The mass and RMS width of the gaussian

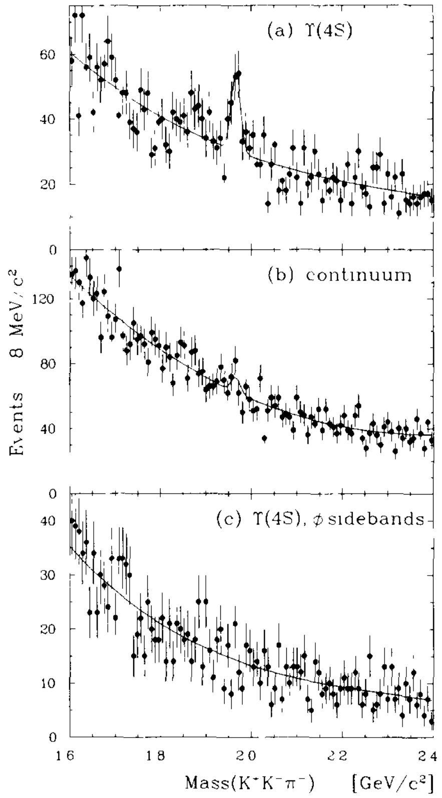


Fig. 3. $K^+K^-\pi^+$ invariant mass distribution with $m(K^+K^-)$ within ± 15 MeV/c^2 of the ϕ mass, $\cos\theta_\phi < 0.8$, $|\cos\theta_K| > 0.5$ and $x_p < 0.5$. The fitted curve is a gaussian plus third-order polynomial for the background. (a) For the $\Upsilon(4S)$ data, free mass and width. (b) For the $\Upsilon(1S)$, $\Upsilon(2S)$ and continuum data, mass and width fixed to that obtained in (a). (c) $K^+K^-\pi^+$ invariant mass distribution for the $\Upsilon(4S)$ data with $m(K^+K^-)$ outside the ϕ region The cuts employed were otherwise the same as for (a)

were determined from the $\Upsilon(4S)$ data sample to be $(1965.9 \pm 2.5 \pm 3.0)$ MeV/c^2 and (9.7 ± 2.4) MeV/c^2, respectively. These values were then used for the fit to the combined $\Upsilon(1S)$, $\Upsilon(2S)$ and continuum data sample. In the $\Upsilon(4S)$ sample we find 76.7 ± 17.4 events, while only 28.7 ± 17.9 events are observed in the combined $\Upsilon(1S)$, $\Upsilon(2S)$ and continuum data sample. The value of the width is consistent with Monte Carlo estimates.

The resolution and acceptance were studied using a Monte Carlo simulation. Events were passed through a full simulation of the ARGUS detector and reconstructed with the standard analysis programs. The acceptance was found to be constant, except for the region above x_p of 0.8. Various types of events were generated, depending on the application. For the purpose of understanding the momentum spectrum, the process $\Upsilon(4S)\to B^0\bar{B}^0$ or B^+B^- followed by the decay $B\to(D_S^*, D_S)c\bar{q}$ (fig. 1a) or $B\to W^-(D_S^*,D_S)s\bar{q}$ (fig. 1b) was simulated. Continuum charm events were simulated by fragmenting the charm quarks according to the Feynman–Field model [5].

In order to verify that the signal for the D_S is not contaminated by reflections from other charm states, a sideband check was made. If the K^+K^- invariant mass was required to lie not in the ϕ selection interval, but instead in two 16 MeV/c^2 bands on either side, no evidence for the D_S was found, as shown in fig. 3c. A fit to this distribution, using a gaussian with mass and width fixed to the values obtained from the signal for $D_S^-\to\phi\pi^-$, led to an upper limit of 12.7 events at the 90% confidence level.

An additional check was made that the angular distribution of $D_S^-\to\phi\pi^-$ events on the resonance was consistent with the $J^P=0^-$ assignment of the D_S meson. The amount of signal and the level of background at the D_S mass was obtained by fitting the invariant mass distribution in each of four bins in $\cos\theta_\phi$. The resulting angular distribution, after acceptance correction and renormalization, is shown in fig. 4a. The background is peaked at small angles, while the signal is consistent with the isotropic behavior expected for the decay of a 0^- particle. For the kaon helicity angle, the signal and background were similarly extracted in five bins of $\cos\theta_K$, as shown in fig. 4b. The distribution for the signal is consistent with the $\cos^2\theta_K$ expectation, while the background is flat.

In order to determine the rate of D_S production from direct $\Upsilon(4S)$ decays, it is necessary to subtract the contribution from the non-resonant $c\bar{c}$ annihilation events which form part of the raw $\Upsilon(4S)$ sample. This is done by scaling the observed rate in data taken in the nearby continuum, at centre-of-mass energies below the threshold for B meson production. The statistical error contributed by the continuum subtraction was reduced by augmenting the continuum data set with the $\Upsilon(1S)$ and $\Upsilon(2S)$ samples. This is justified by the expectation that charm production in the three-gluon or two-gluon-plus-photon decays of the $\Upsilon(1S)$ and $\Upsilon(2S)$ should be suppressed. The number of continuum D_S events in

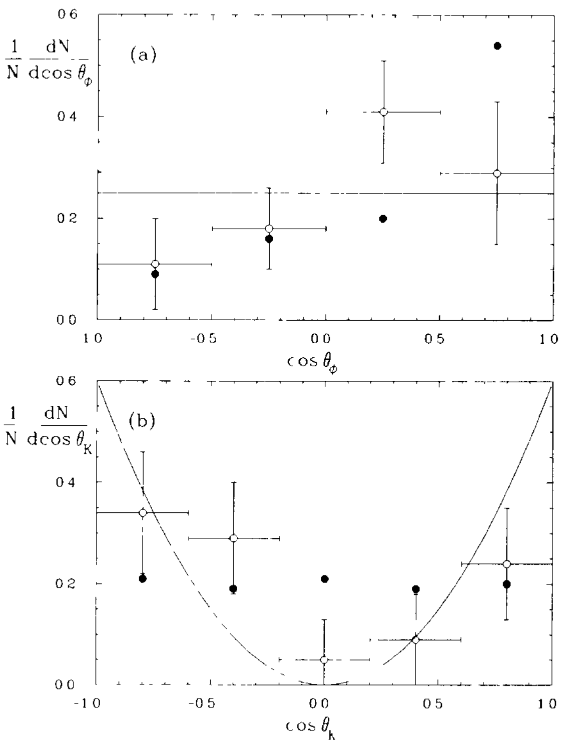
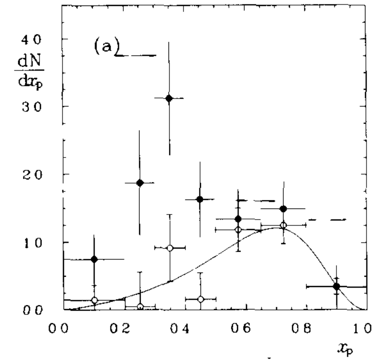


Fig. 4 (a) Angular distribution of the ϕ in the D_S rest frame (with respect to the D_S boost direction) for the $\Upsilon(4S)$ data (open points) The corresponding background distribution is also shown (solid points). The solid line is the expected isotropic distribution. (b) Angular distribution of the K^- in the ϕ rest frame (with respect to the π direction) for the $\Upsilon(4S)$ data (open points). The corresponding background distribution is also shown (solid points) The solid curve is the expected $\cos^2\theta_K$ distribution

the $\Upsilon(4S)$ sample was obtained by scaling the continuum signal by the ratio of the luminosity collected on the $\Upsilon(4S)$ to the energy-weighted sum of the luminosity for the various continuum data sets. For the $\Upsilon(1S)$ and $\Upsilon(2S)$ data, a correction was applied to account for the sizeable vacuum polarization contribution.

The momentum spectrum of the D_S was obtained by fitting the $\phi\pi^-$ invariant mass distribution in each of seven bins in x_p, using a gaussian of fixed mass and width plus a third-order polynomial for the background. The mass used was obtained from the fit to the mass spectra for the entire momentum range. The width from this fit was used to scale the x_p dependence of the width calculated by the detector Monte Carlo. Fig. 5a shows the D_S momentum



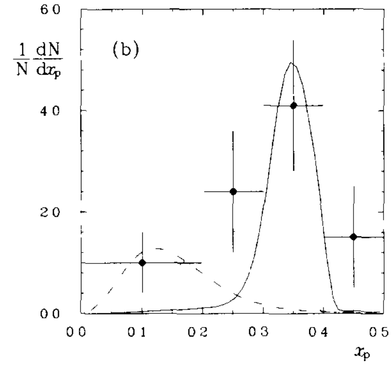


Fig 5 (a) Momentum distribution for D_S mesons from the $\Upsilon(4S)$ data (solid points) and from the continuum data (open points), where $x_p = p_{Ds}/p_{max}$ The continuum data has been scaled to the continuum under the $\Upsilon(4S)$ resonance. The solid curve is a fit of the Peterson fragmentation function to the continuum data The distributions have been normalized so that the integral of the Peterson fit is unity (b) Momentum distribution for D_S mesons from B meson decay. The curves are from a fit of Monte Carlo generated distributions for the decays $B \to D_S D$, $D_S D^*$, $D_S^* D$ and $\to D_S^* D^*$ (solid curve), $B \to D_S D \pi$ (dashed curve) and $B \to W^- D_S(s\bar{q})$ (dash-dotted curve)

spectrum, after acceptance correction, for events taken on the $\Upsilon(4S)$ resonance (solid points) and in the continuum (open points), scaled by the ratio of luminosities as described above. The Peterson form [6] of the fragmentation function was fit to the continuum data (solid curve), given an epsilon parameter of 0.13 ± 0.04, without correction for initial-state QED or QCD radiative effects. This fitted distribution was used to subtract the continuum contribution from the $\Upsilon(4S)$ data. The result is shown in fig. 5b. The normalization of the continuum subtraction is confirmed by the fact that, above x_p of 0.5, the observed number of events from direct $\Upsilon(4S)$ decays is consistent with zero. In contrast, there is an excess of events in the four bins below x_p of 0.5, representing clear evidence for inclusive D_S production in B decays.

The inclusive branching ratio for $B \to D_S X$ was determined by summing the corrected number of D_S mesons in the momentum interval below x_p of 0.5 and dividing the result by twice the number of $B\bar{B}$ events. The selection criteria for hadronic events used in this analysis were sufficiently unrestrictive that corrections for unobserved $B\bar{B}$ events were negligible. There were 460.6 ± 103.7 events, after acceptance correction, in a sample of $108\,000 \pm 13\,000$ B decays. The corresponding product of branching ratios $BR(B \to D_S X) \cdot BR(D_S^- \to \phi\pi^-)$ was found to be $(4.2 \pm 0.9 \pm 0.6) \times 10^{-3}$, where the systematic error is mainly due to the uncertainty in the number of B mesons in our data sample. This result is in good agreement with the value of $(3.8 \pm 1.0) \times 10^{-3}$ reported by CLEO [7].

To relate this result to D_S production in B decays, one requires the branching ratio for the decay $D_S^- \to \phi\pi^-$, which so far has only been measured in conjunction with the unknown cross section for $e^+e^- \to D_S X$ [8]. An estimate for the cross section for D_S production can be made based on the following assumptions: (1) the fraction of the hadronic cross section containing charmed quarks is 40%, and (2) the probability to produce an $s\bar{s}$ pair from the vacuum is 15%, based on the observed ratio of K to π production in continuum e^+e^- annihilation [9]. Using an average hadronic cross section of 3.5 nb, and allowing for the fact that there are two c quarks in each event, we estimate the cross section for D_S production to be 0.42 nb, where all D_S^* mesons are assumed to decay to D_S. From our previously reported value for the cross section times branching ratio [8], we calculate $BR(D_S^- \to \phi\pi^-) = (3.0 \pm 0.8)\%$, which leads to a branching ratio for $B \to D_S X$ of $(14 \pm 3)\%$. This estimate is consistent with the value $BR(B \to D_S X) = (9 \pm 2)\%$ predicted by Suzuki [10].

Two-body decays of B mesons, such as $B \to D_S D$, occur when the D_S is produced by the W decay (fig. 1a) and result in a narrow momentum range for the D_S. The width of the spectrum is defined by resolution, the small initial momentum of the B meson and the mixture in B decays of the possible two-body states. For this "two-body" component, shown as the solid curve in fig. 5b, we have assumed an equal admixture of $B \rightarrow D_S D$, $D_S D^*$, $D_S^* D$ and $D_S^* D^*$. The fragmentation of the W or the c quark may also produce an extra pion by pulling a quark pair from the vacuum, thus resulting in a "three-body" $B \rightarrow D_S D \pi$ component (dashed curve). On the other hand, if the D_S is produced by combining an $\bar{s}$ from the vacuum with the c quark from the b decay (fig. 1b), a much softer momentum spectrum results (dash-dotted curve)[‡3]. Fitting a linear combination of these three contributions to the observed momentum spectrum gives a "two-body" component for the decay $B \rightarrow D_S X$ of $(46 \pm 16)\%$. This is consistent with the CLEO [7] result and in agreement with theoretical predictions [12].

In summary, we have observed evidence for the production of D_S mesons in B meson decay and find the product of branching ratios $BR(B \rightarrow D_S X) \cdot BR(D_S^- \rightarrow \phi \pi^-)$ to be $(4.2 \pm 0.9 \pm 0.6) \times 10^{-3}$. The observed D_S momentum spectrum suggests that a large fraction of the D_S mesons produced in B decays are produced by the transition $W \rightarrow D_S$.

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‡3 We used a phase-space model for the $B \rightarrow D_S D \pi$ decay The LUND model [11] was used to generate the decay $B \rightarrow W^- (D_S^*, D_S) s\bar{q}$

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