DETERMINATION OF THE BRANCHING RATIO FOR THE DECAY $B^0 \to D^{*-}\pi^+$

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Using the ARGUS detector at the e^+e^- storage ring DORIS II, the decay $B^0 \to D^{*-}\pi^+$ followed by $D^{*-} \to \bar{D}^0\pi^-$ has been studied. The data sample used in the analysis consists of 59.4 pb^{-1} taken on the $\Upsilon(4S)$and 20pb^{-1} taken in the nearby continuum at an energy just below that of the $\Upsilon(4S)$. These studies yield the result $Br(B^0 \to D^{*-}\pi^+) = (0.35 \pm 0.2 \pm 0.2)\%$.

One of the most difficult obstacles to obtaining a large sample of reconstructed B mesons was anticipated [1] to be the small branching ratio to any given hadronic channel. The initial finding [2–4], that branching ratios for some of the more accessible channels were at the few percent level, therefore came as something of a surprise. The discrepancy is further underscored by recent predictions [5], applying understanding gained from the study of D decays, which continue to lie well below the published experimental values. This letter reports a new measurement of the branching ratio for $B^0 \to D^{*-}\pi^+$, which is a factor of 5 smaller than that reported earlier by CLEO [3,4] and more in line with expectations.

The decay chain studied was

$$B^0 \to D^{*-}\pi_h^+ , \quad D^{*-} \to \bar{D}^0\pi_s^- , \qquad (1)$$

where the $\bar{D}^0$ is unobserved, and the subscripts h, s distinguish the two pions which are hard (high momentum) and soft (low momentum), respectively. (Throughout this paper, references to a specific charged state should be interpreted to include the charge conjugate state also). Although only the two pions are observed, much useful information concerning this proces may be obtained without complete kinematic reconstruction of the event. In particular, the branching ratio for $B^0 \to D^{*-}\pi^+$ can be measured with no dependence on the value of D^0 branching ratios.

The data presented here were taken with the ARGUS detector at the DORIS II e^+e^- storage ring at DESY, and consists of 59.4 pb^{-1} on the $\Upsilon(4S)$ resonance. For background studies we also include 20 pb^{-1} of data taken in the nearby continuum between the $\Upsilon(3S)$ and the $\Upsilon(4S)$. A brief description of the detector, trigger conditions, and multihadron selection criteria is given in ref. [6].

Based on Monte Carlo studies of the production and decay kinematics of B mesons in our experiment, we expect events representing (1) to consist of a pair of oppositely charged particles satisfying the following conditions:

$$p_s < 0.25\ \text{GeV}/c, \quad 2.0 < p_h < 2.5\ \text{GeV}/c,$$

$$\cos\alpha < -0.9 , \qquad (2)$$

where p_h and p_s are the momenta of the respective particles, and α is the angle between them, as shown in fig. 1. Thus, the characteristic signature for such events is the observation of a "slow" and a "fast" particle of opposite charge, travelling in nearly opposite directions.

In addition to satisfying the above selection criteria, each of the two particles had to have > 5% probability of being a pion. Particle identification was made on the basis of measurements of dE/dx in the drift chamber ano of time of flight [7]. To improve the signal-to-noise ratio we further required the Fox–Wolfram [8] second moment to be less than 0.5. This removes about 50% of the events (mostly jet-

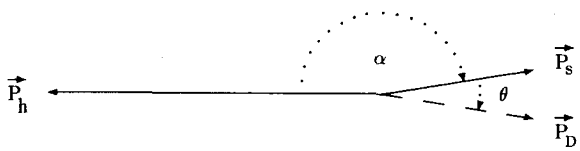

Fig. 1. Momentum vectors (not to scale) for particles of interest produced in the decay chain (1).

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like background) while retaining 82% of the signal.

For the decay chain (1), the invariant mass M of the three-body system consisting of D, π_s, and π_h, is given by

$$M^2 = (E_D + E_s + E_h)^2 - (\boldsymbol{p}_D + \boldsymbol{p}_s + \boldsymbol{p}_h)^2 , \quad (3)$$

where E and $\boldsymbol{p}$ are the energy and momentum of the particle designated in the subscript. The quantity E_D (and hence p_D) may be obtained from energy conservation using the fact that the energy of the B-meson (namely $E_D + E_s + E_h$) must be the beam energy. The only other unmeasured quantity in (3) is the direction of the D meson. Partial information on this may be derived from the requirement that the invariant mass of the D and π_s be that of the D*, leading to

$$M_{D^*}^2 = M_D^2 + M_\pi^2 + 2E_D E_s - 2p_D p_s \cos\theta . \quad (4)$$

This relation determines the angle θ between the D meson and the soft pion but not the azimuthal angle of $\boldsymbol{p}_D$ about $\boldsymbol{p}_s$. If we assume that $\boldsymbol{p}_D$, $\boldsymbol{p}_s$, and $\boldsymbol{p}_h$ all lie in the same plane, and have the relative orientation shown in fig. 1, then one has a configuration that maximizes the mass M, yielding a pseudomass [3] M^*. For this configuration eq. (3) yields the expression

$$(M^*)^2 = M_{D^*}^2 + M_\pi^2 + 2E_h(E_D + E_s)$$
$$- 2p_h p_s \cos\alpha - 2p_h p_D \cos(\alpha + \theta) , \quad (5)$$

from which M^* may be calculated.

The usefulness of the pseudomass parameter lies in the fact that the mass if the B meson, M_B, is already very close to the kinematic upper limit for M^* (namely, half the Υ(4S) mass). Thus, maximizing the mass M for each event, yields an M^* distribution in which events are herded into a fairly narrow mass interval between M_B and the kinematic limit. In order to be able to calculate M^* for a given event it is necessary that the (π_s, D) system be consistent with the production of a D*. Specifically this means that eq. (4) must yield physical solutions for cos θ, corresponding to real values for the angle θ between the D and π_s.

The unshaded histogram in fig. 2a shows the pseudomass distribution for B^0 candidates using data taken on the Υ(4S) resonance. This distribution includes genuine B^0 events as well as background events such as those arising from the random pairing of the tracks of fast and slow particles satisfying the selection criteria. To study this background we first inverted the track direction of the slow particle and then repeated the analysis, obtaining the shaded histogram shown in fig. 2a. Subtracting the shaded from the unshaded histogram, one obtains the distribution shown in fig. 2b. A clear excess of events arising from B decays is evident in the plot; there are a total of 100 ± 21.5 events with $M^* > 5.265$ GeV. In addition, the shape of the distribution is consistent with that of Monte Carlo events representing the decay chain (1) given by the smooth curve.

The above analysis was repeated using data taken in the continuum at energies just below that of the Υ(4S), where one expects to see no B signal. Before performing the analysis the magnitude of the momenta of all particles were scaled up by the ratio of the beam energies for the Υ(4S) and the continuum data (an increase of about 1%). The data sample was then analyzed as though it had been taken at the energy of the Υ(4S) resonance. The results are presented in fig. 2c; no signal is evident in the subtracted distribution shown. This is in striking contrast to the prominent signal seen in the Υ(4S) data, and gives added support to the conclusion that the observed signal is indeed due to B decays.

As an alternative to the "track-inverted" method of background determination used in fig. 2, one may use the energy-scaled continuum distribution, normalized to the statistical level of the Υ(4S) data. This method yields a signal of 120 ± 27 events with $M^* > 5.265$ GeV, consistent with the value found in fig. 2b. In our experiment the continuum data sample is only about 1/3 of that taken at the Υ(4S) energy and so must be scaled by roughly a factor of 3 in order to normalize the two data samples, before performing the background subtraction. As a result the statistical fluctuations of the smaller sample dominate. This effect becomes more serious as one performs the additional cut on p_h described below, and retains even fewer events. For this reason we use only the "track-inverted" events to perform the background subtraction but point out that, in all cases, the "continuum subtraction" method gives consistent results but with larger statistical errors.

Although the prominent signal in fig. 2b represents B meson decays into states with a D*, it is nevertheless not entirely due to the decay chain (1). The

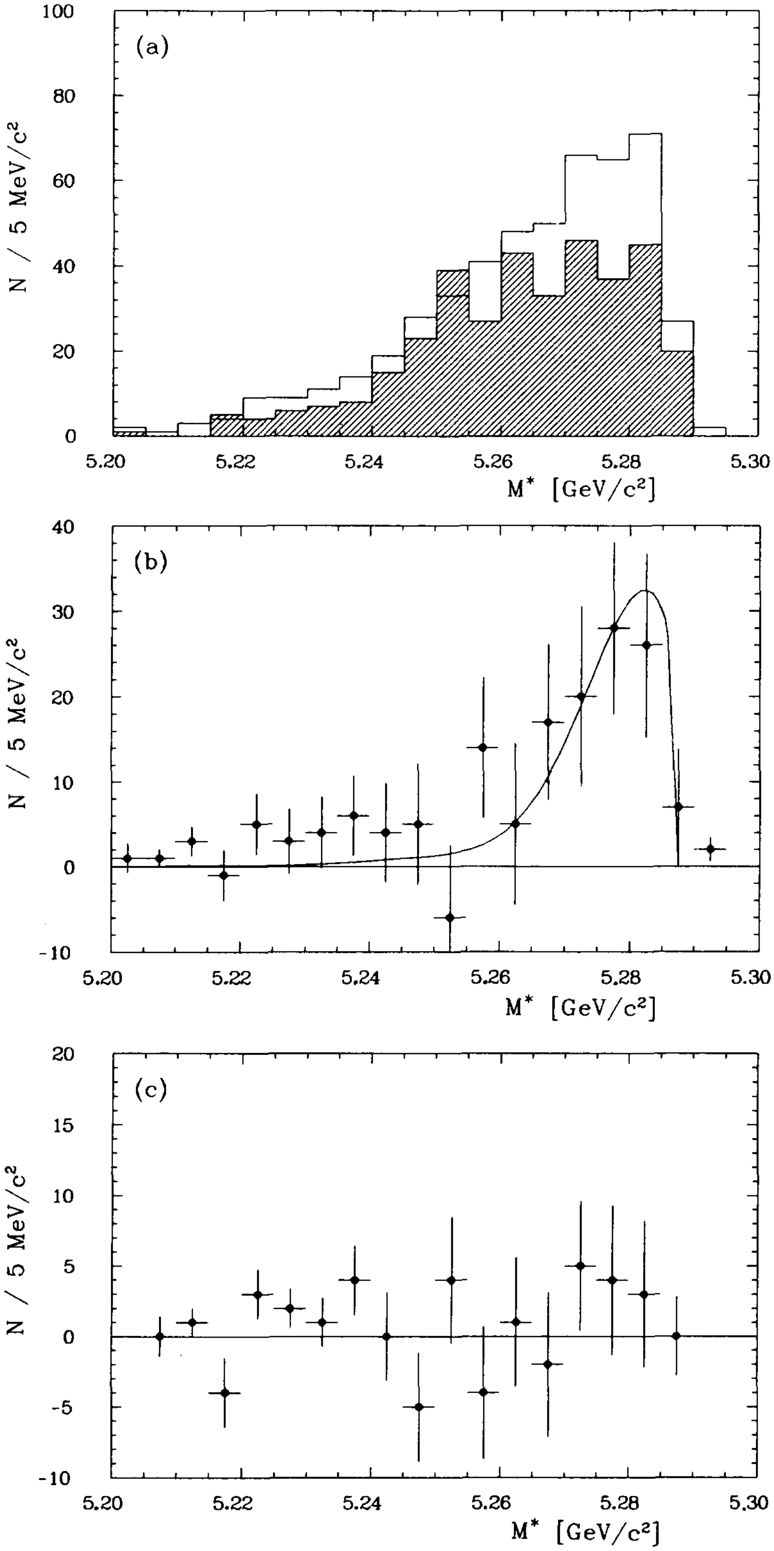

Fig. 2. (a) Pseudomass (M^*) distribution for data taken on the $\Upsilon(4S)$ resonance. The unshaded histogram represents B^0 candidates while the shaded one represents the background, obtained by inverting the direction of the soft pion before calculating M^*, as explained in the text. (b) Result of subtracting the shaded histogram from the unshaded one; the smooth curve shows the Monte Carlo distribution for events representing reaction (1), normalized to the current data. (c) Similar to (b) except that events come from data taken in the nearby continuum at energies just below the $\Upsilon(4S)$.

charged lepton spectrum from semileptonic B decays [9] has a tail which extends beyond 2 GeV/c so that decays $B^0 \to D^{*-} \ell^+ \nu$ can contribute to the observed signal when the charged lepton is fast and misidentified as a pion. In addition one also has contributions from processes such as the decay [4] $B^0 \to D^{*-} \rho^+$ and the decay [10] $B^+ \to \bar{D}(2420)^{*0} \pi^+$ followed by $\bar{D}(2420)^{*0} \to D^{*-} \pi^+$. We have investigated the contamination arising from these decay modes of the B and find that it is significant only for $p_h < 2.25$ GeV/c. The contamination is evident in the data where the number of events in the signal region is approximately 3 times larger for events with $2.0 < p_h < 2.25$ GeV/c than for those with $2.25 < p_h < 2.5$ GeV/c; in the absence of background one would expect a comparable number of events in the two momentum intervals.

Fig. 3 shows the distributions of figs. 2a and 2b with the additional requirement that the events satisfy $2.25 < p_h < 2.5$ GeV/c, thereby eliminating most of the background discussed above. There are a total of 24 ± 13.5 events with $M^* > 5.266$ GeV. This number needs to be corrected for residual contamination from background B-decays (12%) and for multiple counting arising from events with more than one B-candidate (8%). From a knowledge of our final overall acceptance (0.25) which includes the effects of all cuts, and the number of neutral B mesons expected in our data (45 000) [‡1], and the known branching ratio for the decay $D^{*-} \to \bar{D}^0 \pi^-$ (49%) [11] [‡2] we find

$$\mathrm{Br}(B^0 \to D^{*-} \pi^+) = (0.35 \pm 0.2 \pm 0.2)\%,$$

where the first error is statistical and the second is systematic. The systematic error arises primarily from uncertainty in the mass of the B and uncertainty in the relative branching ratio of B^0 decays into $D^* \rho$ and $D^* \pi$. Our measurement of the branching ratio is a factor of 5 smaller than the value $(1.7 \pm 0.5 \pm 0.5)\%$ reported earlier by the CLEO collaboration [4]; the two results are clearly in serious disagreement. A complementary study by us [12], based on the complete kinematic reconstruction of five events from the

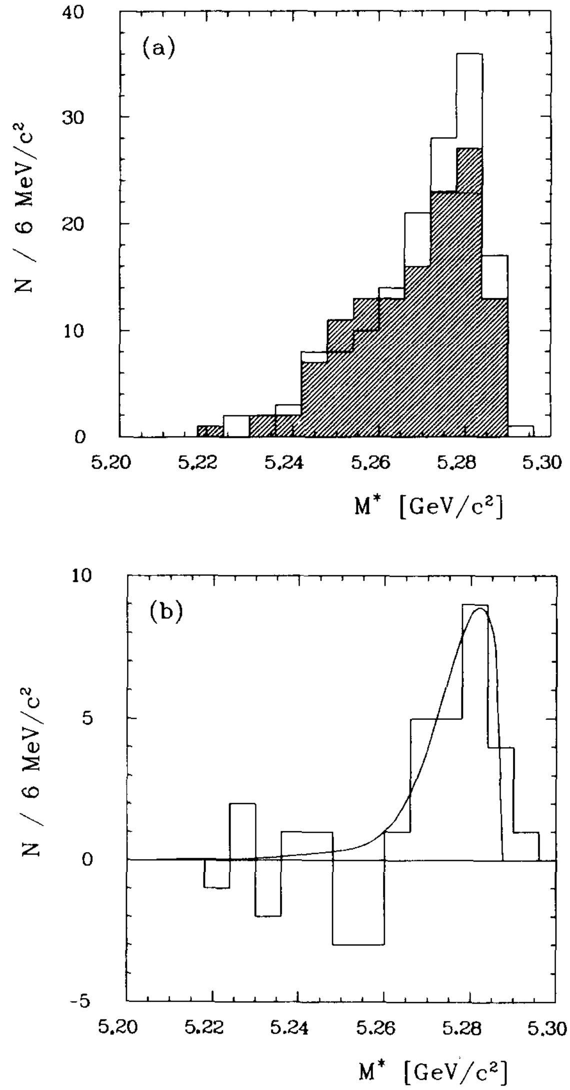

Fig. 3. Similar to figs. 2a and 2b except that the momentum of the hard pion is restricted to lie between 2.25 GeV/c and 2.5 GeV/c.

decay $B^0 \to D^{*-} \pi^+$, yields a branching ratio consistent with that reported here. Moreover, recent predictions [5] for this branching ratio have ranged from 0.33% to about 0.5%, also in good agreement with our result.

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[‡1] We have taken the number of neutral B mesons to be 45% of the total number of B mesons. Uncertainty in this number is one of the contributions included in the systematic error.

[‡2] In particular the branching ratio for the decay $D^{*-} \to \bar{D}^0 \pi^-$ is given as $(49 \pm 8)\%$ in the Errata to ref. [11].

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