MEASUREMENT OF THE DECAY $B^0 \to D^{*-}\ell^+\nu$

ARGUS Collaboration

H. ALBRECHT, A.A. ANDAM [1], U. BINDER, P. BÖCKMANN, R. GLÄSER, G. HARDER, A. NIPPE, M. SCHÄFER, W. SCHMIDT-PARZEFALL, H. SCHRÖDER, H.D. SCHULZ, R. WURTH, A. YAGIL [2,3]
DESY, D-2000 Hamburg, Fed. Rep. Germany

J.P. DONKER, A. DRESCHER, D. KAMP, H. KOLANOSKI, U. MATTHIESEN, H. SCHECK, B. SPAAN, J. SPENGLER, D. WEGENER
Institut für Physik [4], Universität Dortmund, D-4600 Dortmund, Fed. Rep. Germany

J.C. GABRIEL, T. RUF, K.R. SCHUBERT, J. STIEWE, K. STRAHL, R. WALDI
Institut für Hochenergiephysik [5], Universität Heidelberg, D-6900 Heidelberg, Fed. Rep. Germany

K.W. EDWARDS [6], W.R. FRISKEN [7], D.J. GILKINSON [8], D.M. GINGRICH [8], H. KAPITZA [6], P.C.H. KIM [8], R. KUTSCHKE [8], D.B. MACFARLANE [9], J.A. McKENNA [8], K.W. McLEAN [9], A.W. NILSSON [9], R.S. ORR [8], P. PADLEY [8], J.A. PARSONS [8], P.M. PATEL [9], J.D. PRENTICE [8], H.C.J. SEYWERD [8], J.D. SWAIN [8], G. TSIPOLITIS [9], T.-S. YOON [8], J.C. YUN [6]
Institute of Particle Physics [10], Canada

R. AMMAR, D. COPPAGE, R. DAVIS, S. KANEKAL, N. KWAK
University of Kansas [11], Lawrence, KS 66045, USA

B. BOŠTJANČIČ, G. KERNEL, M. PLEŠKO
Institut J. Stefan and Oddelek za fiziko [12], Univerza v Ljubljani, 61111 Ljubljana, Yugoslavia

L. JÖNSSON
Institute of Physics [13], University of Lund, S-22362 Lund, Sweden

A. BABAEV, M. DANILOV, B. FOMINYKH, A. GOLUTVIN, I. GORELOV, V. LUBIMOV, V. MATVEEV, V. NAGOVITSIN, V. RYLTSOV, A. SEMENOV, V. SHEVCHENKO, V. SOLOSHENKO, V. TCHISTILIN, I. TICHOMIROV, Yu. ZAITSEV
Institute of Theoretical and Experimental Physics, 117259 Moscow, USSR

R. CHILDERS, C.W. DARDEN and Y. OKU
University of South Carolina [14], Columbia, SC 29208, USA

Received 20 July 1987

Using the ARGUS detector at the e^+e^- storage ring DORIS II at DESY we have investigated the decays $B^0 \to D^{*-}e^+\nu$ and $B^0 \to D^{*-}\mu^+\nu$. The B^0 mesons were produced in 39600 $\Upsilon(4S) \to B^0\bar{B}^0$ decays. Assuming electron–muon universality we obtain a branching ratio $BR(B^0 \to D^{*-}e^+\nu) = BR(B^0 \to D^{*-}\mu^+\nu) = (7.0 \pm 1.2 \pm 1.9)\%$.

Inclusive leptonic branching ratios for the decay of B particles are known quite accurately. Groups at CESR [1] and DORIS II [2] have studied leptons from the decays of B mesons which are produced in $\Upsilon(4S)$ decays. The branching ratio for the decay $B \to X\ell^+\nu$ [#1], where B represents a mixture of B^0 and B^+ mesons and ℓ^+ is either an e^+ or a μ^+, is measured to be $(11.8 \pm 0.3 \pm 0.6)\%$ [3]. Groups at PETRA [4] and PEP [5] obtain a similar value: $BR(B \to X\ell^+\nu) = (12.0 \pm 0.6 \pm 1.5)\%$ [3]. In this case, however, B represents a mixture of b-flavored mesons and baryons produced in the continuum above $B\bar{B}$ threshold. The near equality of the two values leads one to conclude that this is either a coincidence due to a fortuitous mixture of B hadrons on the $\Upsilon(4S)$ and in the continuum or that all B particles have about the same lifetime. It is therefore highly desirable to obtain exclusive semileptonic branching ratios for all species of B hadrons.

We report the first measurement of the exclusive semileptonic decay $B^0 \to D^{*-}\ell^+\nu$. This decay is studied with B^0 mesons produced in 88 000 $\Upsilon(4S)$ decays. The event sample corresponds to an integrated luminosity of 101 pb^{-1} on the $\Upsilon(4S)$ and 45 pb^{-1} in the continuum below the $\Upsilon(4S)$. A short description of the ARGUS detector and its trigger conditions as well as its particle identification capabilities can be found in ref. [6].

[1] On leave from University of Science and Technology, Kumasi, Ghana.
[2] Weizmann Institute of Science, 76100 Rehovot, Israel.
[3] Supported by the Minerva Stiftung.
[4] Supported by the German Bundesministerium für Forschung und Technologie, under the contract number 054DO51P.
[5] Supported by the German Bundesministerium für Forschung und Technologie, under the contract number 054HD24P.
[6] Carleton University, Ottawa, Ontario, Canada K1S 5B6.
[7] York University, Downsview, Ontario, Canada M3J 1P3.
[8] University of Toronto, Toronto, Ontario, Canada M5S 1A7.
[9] McGill University, Montreal, Quebec, Canada H3A 2T8.
[10] Supported by the Natural Sciences and Engineering Research Council, Canada.
[11] Supported by the US National Science Foundation.
[12] Supported by Raziskovalna skupnost Slovenije and the Internationales Büro KfA, Jülich.
[13] Supported by the Swedish Research Council.
[14] Supported by the US Department of Energy, under contract DE-AS09-80ER10690.
[#1] References in this paper to a specific charged state are to be interpreted as implying the charge-conjugate state also.

The identification electrons and muons, as well as the reconstruction of D^{*-} mesons, is performed in the ARGUS detector with high efficiency and low misidentification probability [7]. For lepton identification, information from all detector components is used coherently by combining the measurements into an overall likelihood [2]. The available information consists of dE/dx and time-of-flight measurements, and the magnitude and topology of energy deposition in the shower counters. In addition, for muons, a hit in an outer muon chamber is required and information on the distance between the hit and expected impact point is included in the likelihood. The e^+ or μ^+ hypothesis is accepted if the likelihood exceeds 80%. D^{*-} mesons are reconstructed in the decay chain $D^{*-} \to \bar{D}^0\pi^-$, followed by $\bar{D}^0 \to K^+\pi^-$ where the $K^+\pi^-$ mass is kinematically constrained to the $\bar{D}^0$ mass. Fig. 1a shows the $\bar{D}^0\pi^-$ mass spectrum for events which contain a positive lepton with momentum larger than 1.0 GeV/c and requiring $x_p(\bar{D}^0\pi^-) < 0.5$ ($x_p = p/p_{max}$) which is necessarily satisfied by particles originating from decays of B mesons produced at the $\Upsilon(4S)$. One observes a prominent D^{*-} signal on a low background. These D^{*-} mesons originate predominantly from $\Upsilon(4S)$ decays as can be demonstrated by examining the x_p distribution, shown in fig. 1b, for events containing a D^{*-} and at least one positive lepton with momentum larger than 1.0 GeV/c. The D^{*-} candidates are selected by requiring that the probability calculated from the sum of χ^2's from the $\bar{D}^0$ and D^{*-} mass hypotheses and the particle identification information exceeds 5%. Above $x_p > 0.5$ only a small number of D^{*-} mesons is observed, originating from the e^+e^- continuum. The dashed histogram shows the corresponding distribution in the continuum below the $\Upsilon(4S)$ scaled by the luminosity ratio.

The partial reconstruction of the decay $B^0 \to D^{*-}\ell^+\nu$ is possible because B^0 mesons produced in $\Upsilon(4S)$ decays are nearly at rest. The neutrino is unobserved, but can be inferred if the recoil mass squared against the $D^{*-}\ell^+$ system, M^2_{Recoil}, is consistent with zero. M^2_{Recoil} is defined by

$$M^2_{Recoil} = [E_{beam} - (E_{D^{*-}} + E_{\ell^+})]^2 - (\boldsymbol{p}_{D^{*-}} + \boldsymbol{p}_{\ell^+})^2 .$$

By requiring the D^{*-} candidates to have $x_p < 0.5$ and the ℓ^+ to have momentum larger than 1.0 GeV/c, we

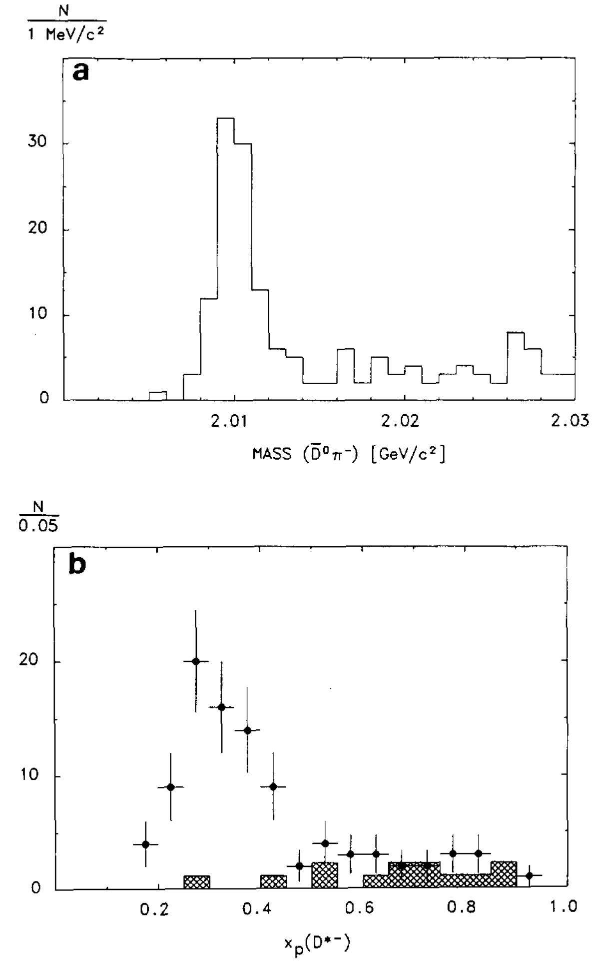

Fig. 1. (a) Mass ($\bar{D}^0\pi^-$) for $x_p(\bar{D}^0\pi^-)<0.5$ ($x_p=p/p_{max}$) in events containing at least one positive lepton (μ^+, e^+) with momentum $p>1.0$ GeV/c. (b) x_p spectrum of D^{*-} mesons in events containing at least one positive lepton (μ^+, e^+) with momentum $p>1.0$ GeV/c. The continuum contribution is shown as a dashed histogram.

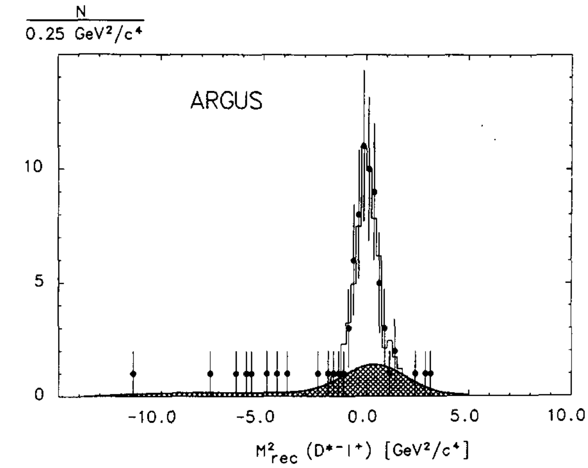

Fig. 2. Recoil mass squared $M^2_{Recoil}=[E_{beam}-(E_{D^{*-}}+E_{\ell^+})]^2-(p_{D^{*-}}+p_{\ell^+})^2$ with $D^{*-}\to\bar{D}^0\pi^-$ and one lepton (μ^+, e^+) with momentum $p>1.0$ GeV/c. The dashed curve shows the background, the histogram the Monte Carlo prediction for the decay $B^0\to D^{*-}\ell^+\nu$.

obtain the recoil mass squared spectrum shown in fig. 2. The prominent peak at $M^2_{Recoil}=0$ corresponds to a B^0 signal on a low background. The position and shape of the signal is well described by the Monte Carlo prediction for $\Upsilon(4S)\to B^0\bar{B}^0$ followed by the semileptonic decay $B^0\to D^{*-}\ell^+\nu$ (histogram in fig. 2).

Background contributions to the observed signal can come from the following sources:

(1) continuum under the $\Upsilon(4S)$ resonance,

(2) uncorrelated D^{*-} mesons and leptons where the D^{*-} originates from one B meson and the lepton from the other one,

(3) faked $D^{*-}\ell^+$ combinations due to particle misidentification,

(4) possible decays of $B\to[D^{*-}\ell^+\nu X]$ such as $B\to D^*(2420)\ell\nu$, followed by $D^*(2420)\to D^{*-}\pi$, or $B^0\to D^{*-}\tau^+\nu$, followed by $\tau^+\to\ell^+\nu\nu$.

These background sources have been carefully studied. The continuum contribution is determined from data taken at energies below the $\Upsilon(4S)$ mass. The background from uncorrelated or faked $D^{*-}\ell^+$ combinations is estimated from wrong charge combinations ($D^{*-}\ell^-$) and from $D^{*-}\pi^+$ combinations respectively. The background from (4) is studied by means of Monte Carlo simulations and contributes mainly in the region $M^2_{Recoil}>0$. The shape of the entire background (1)–(4) is reasonably well described by the one derived from the $D^{*-}\pi^+$ combination in (3) which is parametrized by a gaussian plus a third-order polynomial (shaded curve in fig. 2).

The M^2_{Recoil} spectrum is fit with a gaussian for the signal and a background parameterization as described above. From this analysis we find a signal of (47 ± 8) events divided equally between the decays $B^0\to D^{*-}e^+\nu$ and $B^0\to D^{*-}\mu^+\nu$. The acceptance for the decay chain $D^{*-} \to \bar{D}^0 \pi^-$, followed by $\bar{D}^0 \to K^+ \pi^-$, has been determined by a Monte Carlo simulation. Taking into account the branching ratios, $BR(D^{*-} \to \bar{D}^0 \pi^-) = (49 \pm 8)\%$ [8] and $BR(\bar{D}^0 \to K^+ \pi^-) = (4.2 \pm 0.4 \pm 0.4)\%$ [9], we obtain a reconstruction efficiency for D^{*-} mesons of $\eta(D^{*-}) = (0.80 \pm 0.18)\%$ where the error mainly reflects the uncertainty in the branching ratios for the D^{*-} and D^0 decays [#2]. The efficiency for a lepton with a momentum of $p > 1.0$ GeV/c is determined to be $\eta(e^+) = 0.75 \pm 0.05$ and $\eta(\mu^+) = 0.69 \pm 0.07$. The momentum cut at $p > 1.0$ GeV/c reduces the lepton acceptance by a factor of 0.75 ± 0.08 as determined by Monte Carlo calculations. For the number of neutral B mesons we obtain $N(B^0) = 79200 \pm 8000$, assuming the fraction of the neutral B mesons in $\Upsilon(4S)$ decays is 45%.

The branching ratios determined separately for the decays $B^0 \to D^{*-} e^+ \nu$ and $B^0 \to D^{*-} \mu^+ \nu$ are the same within errors as expected from electron–muon universality. We therefore assume this equality and use the combined data to obtain

$$BR(B^0 \to D^{*-} e^+ \nu) = BR(B^0 \to D^{*-} \mu^+ \nu)$$
$$= (7.0 \pm 1.2 \pm 1.9)\%,$$

where the first error is statistical and the second systematic.

The decay $B^0 \to D^{*-} \ell^+ \nu$ has been studied theoretically by several authors [10–14]. The observed value of the branching ratio is in agreement with theoretical predictions of about (6–8)% [12,13] for this process. Furthermore, the momentum spectrum of the charged leptons from the decay $B^0 \to D^{*-} \ell^+ \nu$ (fig. 3a) has a similar shape to the inclusive spectrum of primary leptons in $\Upsilon(4S)$ decays (solid curve in fig. 3a) [2] and to theoretical predictions in refs. [12,14] (dashed and dotted curve respectively in fig. 3a). The $x_E(D^{*-})$ distribution ($x_E = E/E_{beam}$) for the events in the signal region (fig. 3b) is reasonably well fit by the theoretical prediction in ref. [12] (solid curve in fig. 3b). As expected from the fact that the D^{*-} meson is a spin-one object, the decay rate rises steeply from the lower kinematical limit at $x_E = 0.38$ and vanishes slowly at large values of x_E.

[#2] The D^{*-} reconstruction efficiency scales with the values for the D^{*-} and D^0 branching ratios.

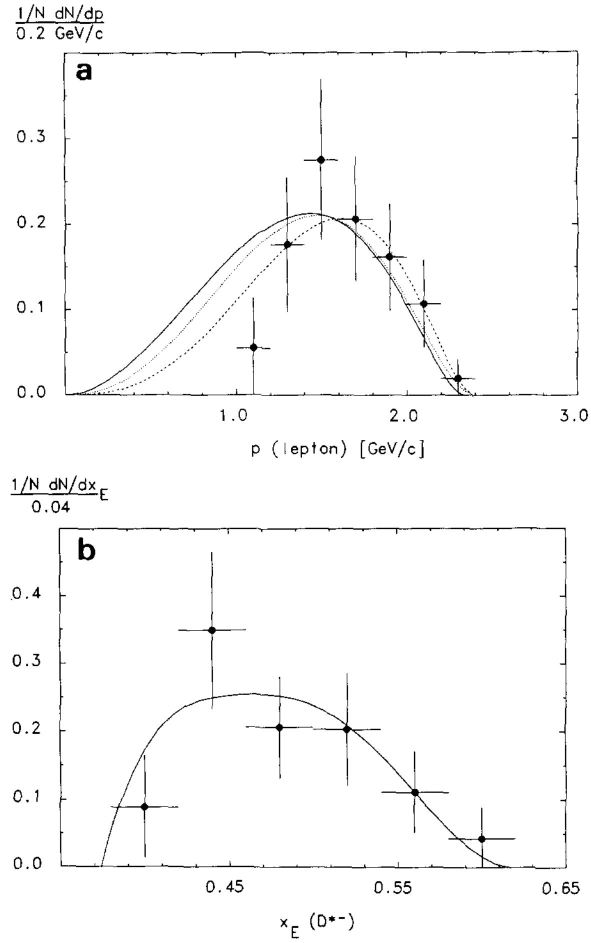

Fig. 3. (a) Momentum spectrum of leptons (μ^+, e^+) from the decay $B^0 \to D^{*-} \ell^+ \nu$ after acceptance correction. The curves are taken from refs. [2,12,14] (solid, dashed and dotted curve, respectively). (b) x_E distribution for D^{*-} mesons ($x_E = E/E_{beam}$) form the decay $B^0 \to D^{*-} \ell^+ \nu$ after acceptance correction. The solid curve is the prediction from ref. [12].

Theory also predicts that the total rate for $B^0 \to X_{\bar{c}} \ell^+ \nu$, where $X_{\bar{c}}$ is a charmed meson, is nearly saturated by the lowest lying states, namely the D^- and D^{*-} [14], consistent with the absence of a pronounced tail for $M^2_{Recoil} > 0$ in fig. 2. These two together should contribute about 90% of the total rate, with the D^{*-} and D^- produced in a ratio of 3:1. Taking the theoretical prediction for the fraction of D^{*-} mesons in semi-leptonic decays to be $(70 \pm 10)\%$, we find $BR(B^0 \to X_{\bar{c}} \ell^+ \nu) = (10.0 \pm 1.7 \pm 3.1)\%$. Within the errors this branching ratio alone saturates the measured inclusive leptonic branching ratio of the decay $B \to X\ell^+\nu$ [1,2], once again showing the dominance of $b \to c$ transitions over $b \to u$ transitions. However, this statement holds only if the lifetime difference between charged and neutral B mesons is not too large.

In summary, we have observed the decay $B^0 \to D^{*-}\ell^+\nu$. It is, so far, the strongest exclusive decay channel for B mesons [15]. The decay rate and momentum spectra are nicely described by the theory of weak decays of B mesons.

It is a pleasure to thank U. Djuanda, E. Konrad, E. Michel, and W. Reinsch for their competent techical help in running the experiment and processing the data. We thank Dr. H. Nesemann, B. Sarau, and the DORIS group for the excellent operation of the storage ring. The visiting groups wish to thank the DESY directorate for the support and kind hospitality extended to them.

References

[1] CLEO Collab., A. Chen et al., Phys. Rev. Lett. 52 (1984) 1084;
CUSB Collab., C. Klopfenstein et al., Phys. Lett. B 130 (1983) 444;
CUSB Collab., C. Levman et al., Phys. Lett. B 141 (1984) 271.

[2] ARGUS Collab., S. Weseler, Ph.D. Thesis, University of Heidelberg (April 1986), report IHEPHD/86-2.

[3] S. Weseler, Proc. Intern. Symp. on Production and decay of heavy hadrons (Heidelberg, 1986) p. 119.

[4] MARK J Collab., B. Adeva et al., Phys. Rev. Lett. 51 (1983) 443;
CELLO Collab., H. Behrend et al., Z. Phys. C 19 (1983) 291;
TASSO Collab., M. Althoff et al., Z. Phys. C 22 (1984) 219; Phys. Lett. B 146 (1984) 443;
JADE Collab., W. Bartel et al., Z. Phys. C 33 (1987) 339.

[5] MARK II Collab., M.E. Nelson et al., Phys. Rev. Lett. 50 (1983) 1542;
MAC Collab., B. Fernandez et al., Phys. Rev. Lett. 50 (1983) 2054;
DELCO Collab., D.E. Koop et al., Phys. Rev. Lett. 52 (1984) 970;
DELCO Collab., T. Pal et al., Phys. Rev. D 33 (1986) 2708;
TPC Collab., H. Aihara et al., Phys. Rev. D 31 (1985) 2719; Z. Phys. C 27 (1985) 39.

[6] ARGUS Collab., H. Albrecht et al., Phys. Lett. B 134 (1984) 137; B 150 (1985) 235.

[7] ARGUS Collab., H. Albrecht et al., Phys. Lett. B 196 (1987) 101.

[8] Particle Data Group, Review of Particle Properties, Phys. Lett. B 170 (1986) 1.

[9] MARK III Collab., R. Schindler, Intern. Europhysics Conf. on High energy physics (Uppsala, 1987).

[10] F.E. Close, G.J. Gounaris and J.E. Paschalis, Phys. Lett. B 149 (1984) 209.

[11] M. Suzuki, Phys. Lett. B 155 (1985) 112.

[12] M. Wirbel, B. Stech and M. Bauer, Z. Phys. C 29 (1985) 637.

[13] M. Shifman and M. Voloshin, preprint ITEP-64 (1987).

[14] B. Grinstein, M.B. Wise and N. Isgur, preprint CALT-68-1311 (January 1986).

[15] ARGUS Collab., H. Albrecht et al., Phys. Lett. B 185 (1987) 218.