B MESON DECAYS TO Dπ AND Dρ

ARGUS Collaboration

H. ALBRECHT, P. BÖCKMANN, R. GLÄSER, G. HARDER, A. KRÜGER, A. NIPPE, M. REIDENBACH, M. SCHÄFER, W. SCHMIDT-PARZEFALL, H. SCHRÖDER, H.D. SCHULZ, F. SEFKOW, J. SPENGLER, R. WURTH, A. YAGIL
DESY, D-2000 Hamburg 52, Fed. Rep. Germany

R.D. APPUHN, A. DRESCHER, C. HAST, D. KAMP, H. KOLANOSKI, A. LINDNER, R. MANKEL, U. MATTHIESEN [1], H. SCHECK, G. SCHWEDA, B. SPAAN, A. WALTHER, D. WEGENER
Institut für Physik [2], Universität Dortmund, D-4600 Dortmund, Fed. Rep. Germany

W. FUNK, J.C. GABRIEL, J. STIEWE, S. WERNER
Institut für Hochenergiephysik [3], Universität Heidelberg, D-6900 Heidelberg, Fed. Rep. Germany

K.W. EDWARDS [4], W.R. FRISKEN [5], H. KAPITZA [4], R. KUTSCHKE [6], D.B. MACFARLANE [7], K.W. McLEAN [7], A.W. NILSSON [7], R.S. ORR [6], J.A. PARSONS [6], P.M. PATEL [7], J.D. PRENTICE [6], S.C. SEIDEL [6], J.D. SWAIN [6], G. TSIPOLITIS [7], T.-S. YOON [6]
Institute of Particle Physics [8], Canada

R. AMMAR, S. BALL, D. COPPAGE, R. DAVIS, S. KANEKAL, N. KWAK
University of Kansas [9], Lawrence, KS 66045, USA

T. RUF, S. SCHAEL, K.R. SCHUBERT, K. STRAHL, R. WALDI
Institut für Experimentelle Kernphysik [10], Universität Karlsruhe, D-7500 Karlsruhe 1, Fed. Rep. Germany

B. BOŠTJANČIČ, G. KERNEL, P. KRIŽAN, E. KRIŽNIČ, M. PLEŠKO
Institut J. Stefan and Oddelek za fiziko [11], Univerza v Ljubljani, YU-61111 Ljubljana, Yugoslavia

H.I. CRONSTRÖM, L. JÖNSSON
Institute of Physics [12], University of Lund, S-223 62 Lund, Sweden

A. BABAEV, M. DANILOV, B. FOMINYKH, A. GOLUTVIN, I. GORELOV, V. LUBIMOV, A. ROSTOVTSEV, A. SEMENOV, S. SEMENOV, V. SHEVCHENKO, V. SOLOSHENKO, V. TCHISTILIN, I. TICHOMIROV, Yu. ZAITSEV
Institute of Theoretical and Experimental Physics, 117 259, Moscow, USSR

R. CHILDERS, C.W. DARDEN and R.C. FERNHOLZ
University of South Carolina [13], Columbia, SC 29208, USA

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The decays $\bar{B}\to D\pi^-$ and $\bar{B}\to D\rho^-$ are observed in data taken by the ARGUS detector at DORIS II. The measured branching ratios of the decays $B^-\to D^0\rho^-$ and $\bar{B}^0\to D^+\rho^-$ are $(2.1\pm0.8\pm0.9)\%$ and $(2.2\pm1.2\pm0.9)\%$ respectively, while those of the decays $B^-\to D^0\pi^-$ and $\bar{B}^0\to D^+\pi^-$ are $(0.19\pm0.10\pm0.06)\%$ and $(0.31\pm0.13\pm0.10)\%$ respectively.

While D mesons are a dominant decay product of B meson decays, the soft D spectrum from B decays [1,2] and the high multiplicity of final state particles, $\bar{n}_{ch}=5.5$ and $\bar{n}_\gamma=5.0$ [2], indicate that B decay rates to resonant two-body low invariant mass states are rather small. This is in contrast to D meson decays which have low charged multiplicity, $\bar{n}_{D^0}=2.5$ and $\bar{n}_{D^+}=2.2$ [3], and resonant two-body decays account for most of the D decay width. Since large combinatorial backgrounds are encountered in the reconstruction of high multiplicity decays, only a small fraction of hadronic B decay modes have so far been reconstructed [4–7]. Fortunately, the modes most favorable for reconstruction are also of great importance in testing theoretical approaches to weak decays [8].

The data for this analysis were taken with the ARGUS detector at the e^+e^- storage ring DORIS II at DESY. The detector and its particle identification capabilities are described in ref. [9]. The 100 pb^{-1} sample used contains roughly 93 000 $\Upsilon(4S)$ decays yielding 186 000 B mesons; 45% of these are assumed to be neutral B's and 55% charged B's.

ARGUS results have already been presented on the reconstruction of B decays to D^{*+} and up to 3 π's [4]. In this report we present a study of the following decay modes [#1]:

$$B^-\to D^0\pi^- \qquad \bar{B}^0\to D^+\pi^-$$
$$\to D^0\pi^-\pi^0, \qquad \to D^+\pi^-\pi^0 .$$

The π^0's were reconstructed by detecting both photons from the decay $\pi^0\to\gamma\gamma$; each photon was required to have an energy $E>50$ MeV contained in two or more adjacent shower counters [10]. The D mesons were reconstructed from the following decays:

$$D^0\to K^-\pi^+ \qquad D^+\to K^0_s\pi^+$$
$$\to K^0_s\pi^+\pi^- \qquad \to K^-\pi^+\pi^+$$
$$\to K^-\pi^+\pi^-\pi^+, \qquad \to K^0_s\pi^+\pi^-\pi^+ .$$

According to the latest MARK III branching ratios [11], these modes account for 16.5% of D^0 decays and 14% of D^+ decays. To reduce combinatorial background, a cut is made on the angle ϑ_K between the K and the D direction in the D rest frame, namely $\cos\vartheta_K<0.8$. The K^0_s's are reconstructed from the decay $K^0_s\to\pi^+\pi^-$ in which a distinct secondary vertex is resolved. Mass constraint fits are performed on each intermediate state in the B decay chain in order to improve the B mass resolution.

The B-candidate selection criteria are

(1) The angle α between the thrust axes of the B-candidate and the remainder of the event must satisfy

$$|\cos\alpha|<0.8 \quad \text{for } D\pi ,$$
$$<0.7 \quad \text{for } D\pi\pi .$$

This cut removes an enormous amount of background from jet-like continuum events which peak sharply at $\cos\alpha=\pm1$. In contrast, B mesons from $\Upsilon(4S)$ decays are produced nearly at rest in the lab, are essentially uncorrelated, and yield an isotropic distribution.

(2) The energy E_{meas} of each $D\pi$ or $D\pi\pi$ combination must satisfy $|E_{meas}-E_{beam}|\leqslant2\sigma_E$, where σ_E is

[1] Present address: Stadtwerke St. Gallen, St. Gallen, Switzerland.
[2] Supported by the German Bundesministerium für Forschung und Technologie, under contract number 054DO51P.
[3] Supported by the German Bundesministerium für Forschung und Technologie, under contract number 054HD24P.
[4] Carleton University, Ottawa, Ontario, Canada K1S 5B6.
[5] York University, Downsview, Ontario, Canada M3J 1P3.
[6] University of Toronto, Toronto, Ontario, Canada M5S 1A7.
[7] McGill University, Montreal, Quebec, Canada H3A 2T8.
[8] Supported by the Natural Sciences and Engineering Research Council, Canada.
[9] Supported by the US National Science Foundation.
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[#1] References in this paper to a specific charged state are to be interpreted as implying the charge conjugate state also.

the energy measurement resolution #2. This cut utilizes the fact that the beam energy E_{beam} is also the energy of the B meson, which is half of the measured $\Upsilon(4S)$ mass of 10580 MeV [5]. Kinematically fitting E_{meas} to E_{beam} improves the mass resolution by nearly a factor of 10. The resulting B mass resolution, determined largely by the DORIS beam spread, is approximately 4 MeV.

(3) The total probability obtained from the sum of all χ^2 contributions from particle ID and kinematical fits must exceed 1%. Only one candidate per event per decay mode is selected on the basis of highest total probability. This requirement suppresses multiple counting in which particles exchange position in the decay chain, or in which very low momentum particles in the event are interchanged, both of which can artificially enhance the B signal.

The modes $D^0\pi^-$ and $D^+\pi^-$ are quite distinctive in that the D and the π are nearly back to back with lab momenta distributions sharply peaked at 2.3 GeV, and thus have low backgrounds. Fig. 1 shows the combined invariant mass distribution of both modes together with a fit to a gaussian of 4 MeV width and a background described below yielding 15 ± 5 events over a background of 8 ± 3 events.

The background of the modes $D^0\pi^-\pi^0$ and $D^+\pi^-\pi^0$ is much larger. The $\pi^-\pi^0$ subsystem was examined for evidence of two-body production. If one selects $D\pi^-\pi^0$ candidates in the B-mass signal region 5.27 GeV $< M <$ 5.29 GeV, the $\pi^-\pi^0$ invariant mass shows a clear ρ^- signal as is evident in fig. 2a. A fit with a Breit–Wigner of fixed mass and width and a smooth polynomial background yields 16 ± 6 signal events over a background of 11 ± 4 events in the ρ region (i.e., within $\pm 1.75\Gamma$ of the ρ mass). Conversely, selecting events with $\pi^-\pi^0$ invariant mass in this same ρ region yields a clear B signal, shown in fig. 2b with a fit yielding 16 ± 5 signal events over 11 ± 4 background.

Further evidence supporting the interpretation of these events as $\bar{B} \to D\rho^-$ may be found in the angular distribution of the π's from the ρ decay. Assuming that the B meson has spin 0, the ρ^- produced in the decay must have helicity 0; its subsequent decay to two pseudoscalar mesons should therefore have a characteristic $\cos^2\vartheta_\pi$ distribution, where ϑ_π is the angle between the ρ helicity axis and one of the π's, measured in the ρ rest frame. The acceptance-corrected distribution shown in fig. 3 is in good agree-

#2 For modes with only charged particles in the final state σ_E is typically 30 MeV and is required to be no greater than 60 MeV. For the π^0 modes with $P(\pi^0) < 900$ MeV σ_E is typically 45 MeV.

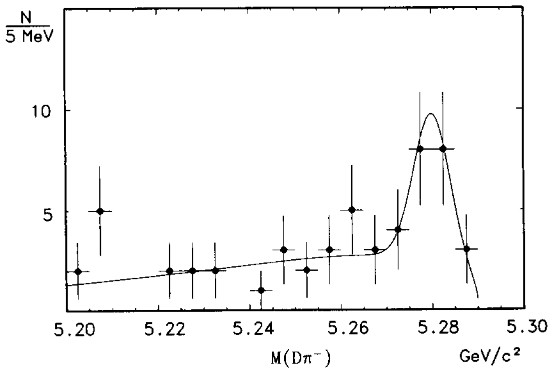

Fig. 1. Invariant mass of $D\pi^-$ candidates.

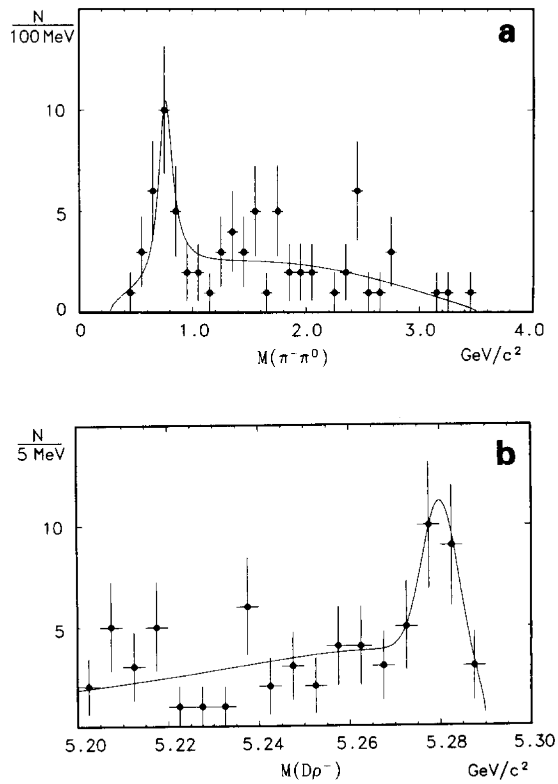

Fig. 2. Invariant mass distributions of (a) the $\pi^-\pi^0$ system from $D\pi^-\pi^0$ candidates in the B-signal region, (b) $D\pi^-\pi^0$ candidates after the ρ-cut on the $\pi^-\pi^0$ mass.

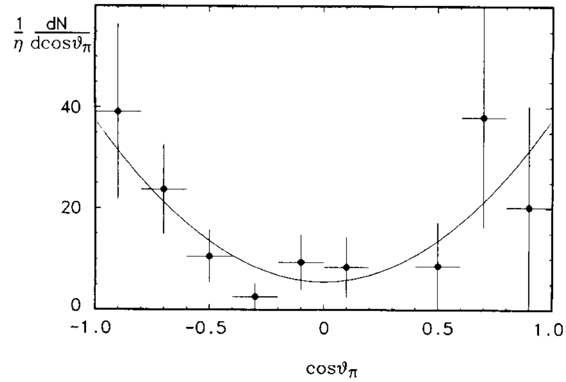

Fig. 3. Acceptance-corrected distribution of $\cos\vartheta_\pi$ for $\bar{B}\to D\rho^-$ events, where ϑ_π is the angle between the π^0 from $\rho^-\to\pi^-\pi^0$, and the ρ^- helicity axis in the ρ^- rest frame.

ment with a $\cos^2\vartheta_\pi$ component plus a flat component, as expected from the respective signal and background levels. The statistics for $\cos\vartheta_\pi>0$ are poor because in this region the π^0's have high lab momentum and the showers from the two photons tend to be spatially unresolved, resulting in a single shower cluster. A study using single-cluster π^0's yields a signal in good agreement with the rate obtained from two-cluster events, although the resolution is somewhat worse.

A search was also made for the "color-suppressed" decay $\bar{B}^0\to D^0\rho^0$. In contrast to the strong evidence for $\bar{B}\to D\rho^-$, no evidence for a B signal is found. An analysis similar to the previous one yields a 90% confidence level upper limit of four signal events.

The combined $D\pi^-$ and $D\rho^-$ candidates are shown in fig. 4. The measured masses of the charged and neutral B mesons are $5279.4\pm1.7\pm3.0$ MeV and

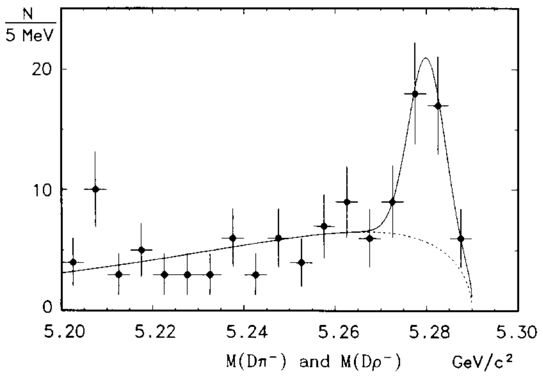

Fig. 4. Invariant mass of $D\pi^-$ and $D\rho^-$ candidates.

$5280.8\pm1.6\pm3.0$ MeV respectively, and are in good agreement with recently updated measurements [5,7]. The systematic uncertainty comes primarily from the scale dependence on the value taken for the mass of the $\Upsilon(4S)$.

The background shape was studied using four separate methods: continuum data, D-sideband combinations, Monte Carlo, and event mixing. Upon scaling the continuum data of 31 pb^{-1} to the $\Upsilon(4S)$ data, one finds that the background from continuum events accounts for (74 ± 20)% of the B candidate events in the B sideband region (5.20–5.27 GeV). But since the statistics are too limited to derive a background shape we resort to the D sideband to estimate this. Because the D signal rides on a background which is ~20 times larger than the signal, one expects fake D's to contribute the dominant part of the B-candidate background. The previous analysis of B decay to $D\pi^-$ and $D\rho^-$ was repeated using sideband D's (rather than those from the D-signal region) fit to the mass 1750 MeV. While the distribution from sideband D's is used to estimate the background shape from continuum events and fake D's from $\Upsilon(4S)$ events, Monte Carlo is used to estimate the background from correctly reconstructed D's in $\Upsilon(4S)$ events, which tend to populate the region near the B mass. The sum of both contributions is shown in fig. 5. The fitted curve is taken from a two-parameter function having a square root threshold at E_{beam}. Event mixing yields a distribution in good agreement with this shape. This shape is used to fit the B-candidate distributions and assigned a 25% systematic error.

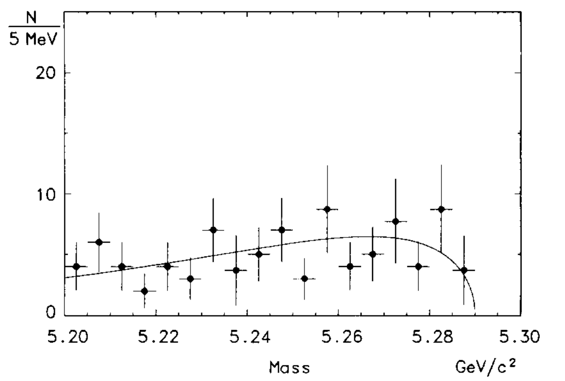

Fig. 5. Invariant mass distribution for $D\pi^-$ and $D\rho^-$ modes from the D-sideband analysis combined with Monte Carlo background from correctly reconstructed D's.

Table 1

Decay mode	Signal	Background	Efficiency	Branching ratio (%)
$B^- \to D^0\pi^-$	7	6 ± 3	0.036	$0.19\pm0.10\pm0.06$
$\to D^0\rho^-$	10	6 ± 3	0.0047	$2.1\pm0.8\pm0.9$
$\bar{B}^0 \to D^+\pi^-$	7	3 ± 2	0.027	$0.31\pm0.13\pm0.10$
$\to D^+\rho^-$	6	5 ± 3	0.0033	$2.2\pm1.2\pm0.9$
$\to D^0\rho^0$	<4	6 ± 3	0.022	<0.3 at 90% CL

A potentially dangerous background source referred to as "feed-down", which arises from actual B meson decays in which one or more particles in the decay chain have been missed, has been investigated in separate Monte Carlo studies. Among those sources considered were B decays to $D^*\pi^-$ and $D^*\rho^-$. For the $D\pi^-$ modes, which contain only charged particles in the final state, σ_E is typically 30 MeV, and from the requirement $|E_{meas}-E_{beam}| \leqslant 2\sigma_E$ only a small fraction of one event from the sources of feed-down considered is expected in the data. However, for the $D\rho^-$ modes, σ_E is highly correlated with the π^0 momentum due to a nearly linear rise in the shower energy resolution [10] at high energies. If we restrict the analysis to well-measured candidates in which the π^0 momentum is less than 900 MeV, we retain 75% of the $\bar{B}\to D\rho^-$ decays (reconstructed from two-cluster π^0 decays), while feed-down is reduced to a fraction amounting to less than one event in the data. Applying this cut to the data reduces the signal from 16 ± 5 $D\rho^-$ events to 12 ± 4 events; this is entirely consistent with the 75% retention expected if the initial sample were free of feed-down.

The fitted signals, background levels within $\pm2.5\sigma$ of the measured masses, the B-reconstruction efficiencies, and the resulting branching ratios with statistical and systematic errors are listed in table 1. While the results show rough agreement with the theoretical predictions of ref. [8], the measured decay rates of the vector modes $D\rho^-$ relative to the pseudoscalar modes $D\pi^-$ are large.

In summary, we have observed clear evidence for B decays to $D\pi^-$ and $D\rho^-$. The measured decay rate of $\bar{B}\to D\rho^-$ is substantially larger than the rate of $\bar{B}\to D\pi^-$.

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