Investigation of the total charm-pair cross section in nonresonant e^+e^- annihilations at $\sqrt{s}=10.5$ GeV

T. Bowcock, K. Kinoshita, F. M. Pipkin, M. Procario, Richard Wilson, J. Wolinski, and D. Xiao
Harvard University, Cambridge, Massachusetts 02138

P. Haas, M. Hempstead, T. Jensen, D. R. Johnson, H. Kagan, R. Kass, and F. M. Morrow
Ohio State University, Columbus, Ohio 43210

P. Baringer, R. L. McIlwain, D. H. Miller, C. Ray Ng, and E. I. Shibata
Purdue University, West Lafayette, Indiana 47907

R. Poling
University of Minnesota, Minneapolis, Minnesota 55455

M. S. Alam, N. Katayama, I. J. Kim, W. C. Li, X. C. Lou, C. R. Sun, and V. Tanikella
State University of New York at Albany, Albany, New York 12222

D. Bortoletto, M. Goldberg, R. Holmes, N. Horwitz, A. Jawahery, G. C. Moneti, V. Sharma, and I. P. J. Shipsey
Syracuse University, Syracuse, New York 13210

S. E. Csorna and M. D. Mestayer
Vanderbilt University, Nashville, Tennessee 37235

I. C. Brock, T. Ferguson, and H. Vogel
Carnegie Mellon University, Pittsburgh, Pennsylvania 15213

C. Bebek, K. Berkelman, E. Blucher, J. Byrd, D. G. Cassel, D. M. Coffman, T. Copie, R. DeSalvo, J. W. DeWire, R. Ehrlich, R. S. Galik, B. Gittelman, S. W. Gray, A. M. Halling, D. L. Hartill, B. K. Heltsley, J. Kandaswamy, R. Kowalewski, D. L. Kreinick, Y. Kubota, J. D. Lewis, N. B. Mistry, J. Mueller, R. Namjoshi, S. Nandi, E. Nordberg, D. Perticone, D. Peterson, M. Pisharody, D. Riley, A. Silverman, S. Stone, and M. Worris
Cornell University, Ithaca, New York 14853

A. J. Sadoff
Ithaca College, Ithaca, New York 14850

P. Avery, D. Besson, and L. Garren
University of Florida, Gainesville, Florida 32611
(Received 26 February 1988; revised manuscript received 21 June 1988)

We report results from two new methods for measuring the total production of charmed particles in nonresonant e^+e^- annihilations at $\sqrt{s}=10.5$ GeV. The rate for detection of events containing two reconstructed charmed mesons relative to that for events containing one is used to extract information about total charm production independent of decay branching fractions. The value of $\Delta R_{c\bar{c}}$, the total charm-pair cross section normalized to the pointlike μ-pair cross section, is found to be $1.13^{+0.17}_{-0.13}\pm0.09$, under an assumption of limited particle correlations. In an independent analysis the inclusive cross section for $e^+e^-\to q\bar{q}\to e^{\pm}X$ is measured to be $0.293\pm0.017\pm0.017$ nb. Using measured relative production rates and semileptonic branching fractions of D^0 and D^+ mesons and estimates of these quantities for D_s and Λ_c, this is found to correspond to $\Delta R_{c\bar{c}}=2.07\pm0.12\pm0.26$. These two measurements are discussed in the context of measurements made by reconstruction of exclusive hadronic decay modes and of theoretical expectations.

I. INTRODUCTION

Among hadronic events produced in nonresonant e^+e^- annihilations, the fraction which contains charm is predicted by the parton model to be 0.40 at energies below the threshold for $B\bar{B}$ production. Any significant deviation from this value would represent a serious challenge to our understanding of e^+e^- annihilations. Experimentally, this fraction is usually derived from the reconstruction of charmed mesons and baryons in specific exclusive decay modes. The production cross section for each hadron is determined using the number observed in the specified decay mode, the decay branching fraction(s), and the detection efficiencies determined by Monte Carlo simulation. The determination of the total charm-pair cross section usually requires an extrapolation to momentum regions where detection efficiencies are low and the summation over all the deduced charm-hadron cross sections. This method depends heavily on the accuracy of the measured branching fractions for these decays.

In early 1986 measurements of the exclusive hadronic D branching fractions[1] yielded values nearly twice as large as the previously measured values[2] but were later revised downward.[3] Measurements of the total charm-pair cross section[4,5] using these different sets of branching fractions would yield opposite conclusions on whether all the expected charm had been accounted for. The importance of understanding the charm fraction is such that it is highly desirable to develop methods which are independent of these branching fractions.

The expected total charm-pair cross section $\sigma_{c\bar{c}}$ can be estimated from the measured total hadronic cross section multiplied by the charm fraction derived from theory. The measured[6] total hadronic cross section $\sigma_{\rm tot}$ at $\sqrt{s}=10.5$ GeV is $3.33\pm0.05\pm0.21$ nb, before applying radiative corrections. The corresponding value of R, the total hadronic cross section normalized to the pointlike μ-pair cross section, is $4.23\pm0.06\pm0.27$. In order to arrive at the experimentally observed total hadronic cross section from the naive prediction of the parton model, it is necessary to make corrections for radiative QED and QCD effects. The size of the QED corrections differs according to the mass of the primary quark and is smaller for charm events than for events containing lighter primary quarks. Using the calculation of Berends and Kleiss[7] to estimate these corrections for the different quark flavors, we find that the expected charm fraction at $\sqrt{s}=10.5$ GeV is 0.36 ± 0.03. The error in the charm fraction reflects largely the uncertainty in values of the primary quark masses used in the calculations. Effects due to hadronic resonances and of QCD on this fraction are expected to be small ($<1\%$). One can then obtain from this the expected contribution to R from charm, $\Delta R_{c\bar{c}} \equiv \sigma_{c\bar{c}}/\sigma_{\mu\mu} = 1.52\pm0.02\pm0.15$. We will compare our measurements to this value.

In this paper we describe two alternative methods of measuring the total charm-pair cross section. The first involves a comparison of the inclusive number of charmed particles observed in several nonleptonic decay modes with the number reconstructed in a *tagged* set of events in which a charmed particle has already been found. The method is independent of decay branching fractions and is relatively insensitive to charmed-meson reconstruction efficiencies. The second method extracts a total charm-pair cross section using the *semileptonic* decays of charmed particles. This method is dependent on the relative magnitude of the exclusive hadronic branching fractions and on the inclusive semileptonic branching fractions of charmed mesons.

II. DATA

The data consist of 77 pb^{-1} collected on the $\Upsilon(4S)$ resonance and 36 pb^{-1} collected at an energy below the $B\bar{B}$ threshold ($\langle\sqrt{s}\,\rangle=10.5$ GeV), taken with the CLEO detector at the Cornell Electron Storage Ring (CESR). Since the CLEO detector has been described in detail elsewhere,[8] we discuss briefly only those components that are used in the analyses presented here. Tracking of charged particles is accomplished by the 10-layer cylindrical vertex detector and the 17-layer main drift chamber. We achieve a momentum resolution of $(\Delta p/p)^2=(0.007p)^2+(0.006)^2$, where p is given in GeV/c. Charged particles may be identified by measurements of specific ionization in the main drift chamber and in the pressurized proportional wire chambers (dE/dx chambers), by the time of flight to the plastic scintillation counter array, and by their behavior in the 44-layer lead and proportional-tube shower detector.

III. CHARM-TAGGING METHOD

To illustrate this method we first consider a case of extreme simplicity, where the charm and anticharm quarks in an event fragment independently, with no correlations. Consider a charmed hadron X (the inclusion of antiparticle states is implied throughout this paper) which is observed in the decay mode i. The event containing this decay may contain in addition an identified anticharm particle $\bar{Y}$ observed in mode J. If the particle $\bar{Y}$ is identified in such a way that it has very little background, then the presence of $\bar{Y}$ in an event can simply be used to *tag* it as an event which contains charm. We call the hadron $\bar{Y}$ in such an event the *tag* and we call X the *recoil.*

Assume that N^Y tags are found in a given data sample containing $N_{c\bar{c}}=\sigma_{c\bar{c}}\int\mathcal{L}\,dt$ charmed hadronic events and of these events N_X^Y contain the charmed hadron X reconstructed in the decay mode $X\rightarrow i$. The fraction of the tagged events containing a hadron X is then $N_X^Y/(N^Y\epsilon_X^Y B_X)$, where ϵ_X^Y is the efficiency for reconstruction of the mode $X\rightarrow i$ in a tagged event and B_X is the branching fraction $B(X\rightarrow i)$. Under our simple assumption this fraction is the probability that a charmed-quark fragments into hadron X. Suppose that N_X hadrons X in the decay mode $X\rightarrow i$ are reconstructed in the total (untagged) data sample containing $N_{c\bar{c}}$ charmed events ($2N_{c\bar{c}}$ charmed quarks.) The probability of a quark fragmenting into a hadron X is $N_X/(2N_{c\bar{c}}\epsilon_X B_X)$, where ϵ_X is the efficiency for reconstruction of the mode $X\rightarrow i$ averaged over all events containing hadron X. These two measurements of the probability of a quark fragmenting into hadron X enable us to eliminate the "unknown" branching ratio B_X and determine independently of this quantity the total charm cross section $\sigma_{c\bar{c}}$ through $N_{c\bar{c}}$. If the reconstruction efficiency does not depend on the presence of an identified tag $\bar{Y}$ in an event, then $\epsilon_X/\epsilon_X^Y \sim 1$ and $\sigma_{c\bar{c}}$ can be determined independent of branching fractions and efficiencies:

$$\sigma_{c\bar{c}} \sim \frac{N_X}{2\int \mathcal{L}\,dt} \frac{N^Y}{N_X^Y} . \tag{1}$$

We emphasize that the above derivation is only valid under the assumption that there are no particle-type correlations between the c and $\bar{c}$ final states. In practice we are also sensitive to momentum correlations between the charmed and anticharmed particles. In general we reconstruct only high-momentum charmed particles. If there is such a momentum requirement for the tag and recoil, the effect of momentum correlations will be to make the probabilities for reconstruction of recoils in tagged and untagged events unequal.

Momentum correlations are most trivially manifested by the requirements of total energy and momentum conservation in each event. In the limit that the energy of one charmed particle is close to that of the beam energy, momentum-energy conservation requires the anticharmed particle to have similar, but opposite, momentum. This effect may be modeled and is taken into account in our analysis below. However, other sources of momentum correlations which may exist in the dynamics of the quark hadronization process, remain difficult to quantify and are not included.

To specify momentum correlations on a more quantitative basis, we define $D_X(x)$ and $D_X^Y(x)$ as functions of the scaled momentum variable $x \equiv p_X/p_X^{\max}[p_X^{\max} \equiv (E_{\text{beam}}^2 - M_X^2)^{1/2}]$. They are the respective probability densities for the fragmentation of a charmed quark to hadron X in untagged and tagged events. The numbers observed are related to the totals by

$$N_X = 2N^c B_X \int_{x_1}^{x_2} \epsilon_X(x) D_X(x)\,dx , \tag{2}$$

$$N_X^Y = N^Y B_X \int_{x_1}^{x_2} \epsilon_X^Y(x) D_X^Y(x)\,dx , \tag{3}$$

where we include explicitly the momentum dependence of the reconstruction efficiencies and X is observed in the interval $x_1 < x < x_2$. If there are no correlations, then $D_X(x) = D_X^Y(x)$. We can obtain an expression for $\sigma_{c\bar{c}}$ which is independent of B_X:

$$\sigma_{c\bar{c}} = \frac{1}{2\int \mathcal{L}\,dt} \frac{N_X N^Y}{N_X^Y} \frac{\int_{x_1}^{x_2} \epsilon_X^Y(x) D_X^Y(x)\,dx}{\int_{x_1}^{x_2} \epsilon_X(x) D_X(x)\,dx} . \tag{4}$$

If the efficiency changes slowly with x in the region $x_1 < x < x_2$, it can be separated from the integral:

$$\sigma_{c\bar{c}} = \frac{1}{2\int \mathcal{L}\,dt} \frac{N_X N^Y}{N_X^Y} \frac{\epsilon_X^Y d_X^Y}{\epsilon_X d_X} , \tag{5}$$

where $d_X^Y = \int_{x_1}^{x_2} D_X^Y(x)\,dx$ and $d_X = \int_{x_1}^{x_2} D_X(x)\,dx$, and ϵ_X and ϵ_X^Y are mean-efficiency values which are insensitive to correlations. However both d_X^Y and ϵ_X^Y will depend on the momentum region $x_1' < x < x_2'$ used to identify the tags Y. In our discussion below we have used the same momentum range for both the tagging and recoil particles.

The value of d_X/d_X^Y due to momentum correlations depends on the shape of the fragmentation function, the momentum range (x_1, x_2), and the degree of correlation. Positive momentum correlations result in values less than one. The Lund Monte Carlo model[9] has weak momentum correlations such that, with $x_1 = 0.5$ and $x_2 = 1$, $d_X/d_X^Y = 0.86 \pm 0.01$, for combinations of X and $\bar{Y}$ which are used here. We apply this value as a correction to the data.

Particle-type correlations result in different mixtures of particle types in tagged and untagged events and affect the measurement of $\sigma_{c\bar{c}}$. We have not corrected for this type of correlations. These can occur, for example, when particle multiplicity is low due to phase-space limitations. At a given center-of-mass energy, the production of a pair of charmed particles which do not contain charge conjugate light quarks requires production of extra particles. If the additional particles are necessarily very massive, then the production of certain combinations may be kinematically suppressed. For instance, to produce $D\bar{D}_s$ it is necessary to produce an extra kaon, and to produce $D\bar{\Lambda}_c$ requires an extra baryon. The Lund Monte Carlo program models these limited particle-type correlations. However, it is difficult to properly assess particle-type correlations without a knowledge of the relative abundances of all particle types and effective theoretical models of production mechanisms. There is a significant lack of this type of information for the case of baryons. For example, we have not allowed for the possibility of charmed diquark production being responsible for charmed-baryon production. The existence of charmed diquarks could lead to the pair production of charmed baryons and to large particle-type correlations.

Analysis

All 113 pb^{-1} of data taken on and off the $\Upsilon(4S)$ are used in this analysis. Hadronic events are required to have three or more charged tracks with total energy at least $0.3\sqrt{s}$ and more than 250 MeV of energy detected in the electromagnetic counters. We identify the charmed hadrons D^+, D^{*+}, and D^0 in the modes $D^+ \to K^-\pi^+\pi^+$, $D^{*+} \to D^0\pi^+$ $(D^0 \to K^-\pi^+, K^-\pi^+\pi^-\pi^+)$, $D^0 \to K^-\pi^+, K^-\pi^+\pi^-\pi^+$, and $D \to K^-\pi^+(\pi)$. For the kaon candidates in the reconstruction of the modes $D^0 \to K^-\pi^+\pi^-\pi^+$ and $D^+ \to K^-\pi^+\pi^+$ the accompanying information in the drift chamber, the dE/dx chamber, and the time-of-flight scintillators is required to satisfy loose identification criteria designed to maintain high acceptance of kaons while rejecting a large number of pions.

The last mode, $D \to K^-\pi^+(\pi)$, involves reconstruction using only one of the two pions in a cascade decay of the D, for example, in $D \to K^*\pi$, $K^* \to K\pi$ or $D \to K\rho$, $\rho \to \pi\pi$. A broad peak is produced by these decays in the

$K^-\pi^+$ invariant-mass distribution at ~ 1600 MeV/c^2 due to the spin properties of the K^* and ρ (Ref. 10).

To tag an event as containing charm, we look for D^{*-} mesons decaying to $\bar{D}^0\pi^-$, followed by $\bar{D}^0 \to K^+\pi^-$ and $K^+\pi^-\pi^+\pi^-$. These modes have a low background at high momenta,[11] and no particle identification is required in reconstruction. A D^{*-} momentum of at least 2.5 GeV/c is required. This ensures that the event comes from nonresonant e^+e^- annihilation; at energies above the threshold for $B\bar{B}$ production there is copious D production from decays of the B, but these have a maximum momentum of 2.57 GeV/c. The D^{*-} candidate is used to tag the event if the reconstructed mass of the daughter $\bar{D}^0$ candidate is within 30 MeV/c^2 of the nominal D^0 mass of 1.864 GeV/c^2 and the (D^{*-}-$\bar{D}^0$) mass difference is within 1.8 MeV/c^2 of 145.4 MeV/c^2.

The background in the sample of D^{*-} tags can be estimated by two methods. In the first, false tags are selected by requiring the same D^{*-}-$\bar{D}^0$ mass difference, but a $\bar{D}^0$ candidate mass in a "sideband" 30 MeV/c^2 wide and

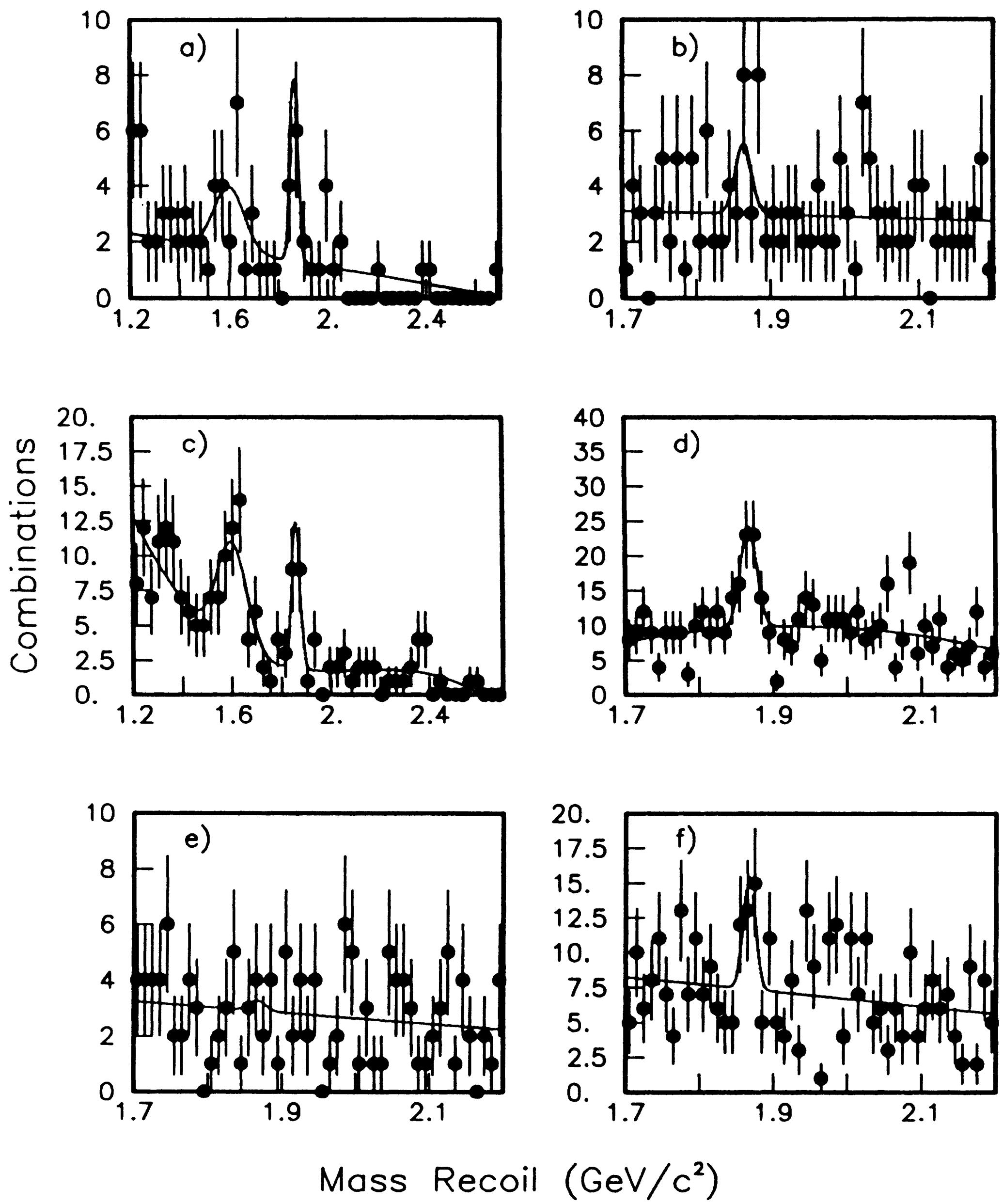

FIG. 1. Invariant-mass distributions of charmed-meson candidates in tagged events, together with fits to data. Charge-conjugate states are also included. The different tag-recoil combinations are (a) tag: $D^{*-} \to \bar{D}^0\pi^-, \bar{D}^0 \to K^+\pi^-$, recoil: $D^0 \to K^-\pi^+$; (b) tag: $D^{*-} \to \bar{D}^0\pi^-, \bar{D}^0 \to K^+\pi^-$, recoil: $D^0 \to K^-\pi^+\pi^-\pi^+$; (c) tag: $D^{*-} \to \bar{D}^0\pi^-, \bar{D}^0 \to K^+\pi^-\pi^+\pi^-$, recoil: $D^0 \to K^-\pi^+$; (d) tag: $D^{*-} \to \bar{D}^0\pi^-, \bar{D}^0 \to K^+\pi^-\pi^+\pi^-$, recoil: $D^0 \to K^-\pi^+\pi^-\pi^+$; (e) tag: $D^{*-} \to \bar{D}^0\pi^-, \bar{D}^0 \to K^+\pi^-$, recoil: $D^+ \to K^-\pi^+\pi^+$; (f) tag: $D^{*-} \to \bar{D}^0\pi^-, \bar{D}^0 \to K^+\pi^-\pi^+\pi^-$, recoil: $D^+ \to K^-\pi^+\pi^+$. In (a) and (c), the broad peak at 1600 MeV/c^2 from $D \to K^-\pi^+(\pi)$ is also fitted.

TABLE I. Numbers of charmed mesons reconstructed in the total data sample.

Particle	Decay mode	Number reconstructed ($p>2.5$ GeV/c)
D^0	$K^-\pi^+$	2145±182
	$K^-\pi^+\pi^-\pi^+$	3095±235
	$K^-\pi^+(\pi)$	3159±451
D^+	$K^-\pi^+\pi^+$	1078±158
D^{*+}	$\pi^+D^0, D^0\to K^-\pi^+$	533±28
	$\pi^+D^0, D^0\to K^-\pi^+\pi^-\pi^+$	770±50

centered 85 MeV/c^2 to either side of the D^0 mass. The second method involves counting the wrong-sign charm combinations, i.e., looking at the distribution of $D^{*-}\bar{D}^0$, $D^{*-}D^-$, $D^{*-}D^{*-}$ events. This method gives a slight overestimate of the background since permuted tracks for some correct-sign D^0's may satisfy the $\bar{D}^0$ mass cut. The results from both methods are consistent and yield backgrounds which are 0–10 % of the total signal, depending on the decay mode. For our final result we subtract background using the sideband method.

The invariant-mass distributions for D^0 and D^+ in tagged events are shown in Figs. 1(a)–1(f).

The numbers of particle candidates in each mode are obtained by fitting each invariant-mass distribution to a polynomial background and a Gaussian signal. The mean and width of the Gaussian are determined from the fit to the untagged distribution and fixed when fitting to the tagged distribution. The results of fits to the untagged distributions are summarized in Table I. Allowing for the different selection criteria used here, the numbers of D^0, D^+, and D^{*+} candidates are consistent with our most recent measurements of the D meson cross sections.[12] Note that the number of tags is the number of reconstructed charged D^*'s.

The charm reconstruction efficiences are determined by a detailed Monte Carlo simulation of the production and decay of charmed mesons in the CLEO detector. The numbers of recoils reconstructed and the mean ratios of efficiencies $\langle \epsilon_X^Y/\epsilon_X \rangle$ are shown in Table II. The ratios of efficiencies depend both on the type of the tagging particle and of the recoil particle. The mean ratio for each

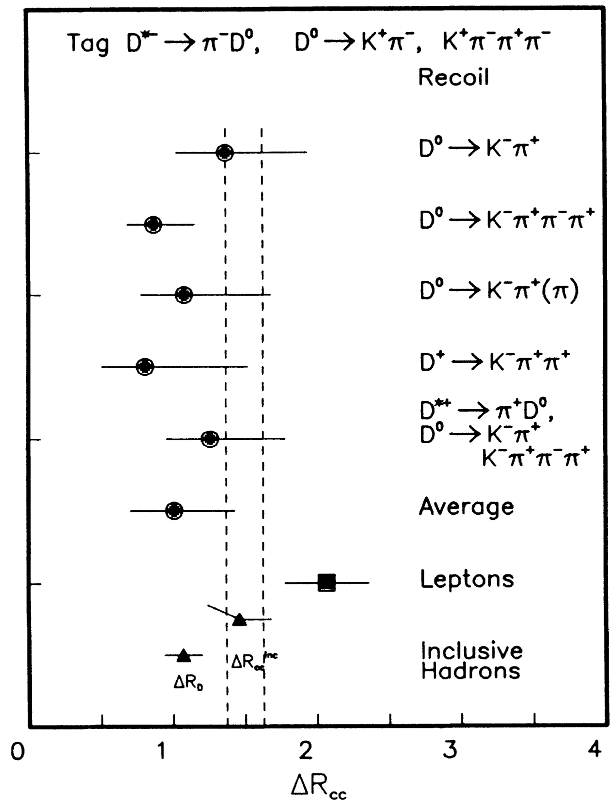

FIG. 2. The values of $\Delta R_{c\bar{c}}$ for the indicated decay modes, measured in CLEO data using the charm tagging method. The results for $\Delta R_{c\bar{c}}^{\rm lep}$ from the lepton measurement are also included for comparison. Superimposed are the values of ΔR_D and $\Delta R_{c\bar{c}}^{\rm inc}$ as determined from the inclusive charmed-meson rate and measured branching fractions. The theoretical expectation for $\Delta R_{c\bar{c}}$ is bounded by the dotted lines.

mode reflects a weighted average over the two separate modes of tags. The values for ϵ_X^Y/ϵ_X are significantly greater than one. This is partially due to the fact there is less loss from event-selection requirements in tagged events, and that a recoil traveling approximately opposite to an identified tag is in a region of good particle acceptance, due to the symmetry of the detector.

TABLE II. Numbers of charmed mesons reconstructed in tagged events. Background has been subtracted using the sideband method. The ratio of efficiencies $\langle \epsilon_X^Y/\epsilon_X \rangle$ and the derived values of $\sigma_{c\bar{c}}$ and $\Delta R_{c\bar{c}}$ are also shown.

Recoil	Number recoils	$\langle \epsilon_X^Y/\epsilon_X \rangle$	$\sigma_{c\bar{c}}$ (nb)	$\Delta R_{c\bar{c}}$
$D^0\to K^-\pi^+$	$18.7^{+6.3}_{-5.4}$	1.40	$1.08^{+0.44}_{-0.27}\pm0.10$	$1.37^{+0.56}_{-0.31}\pm0.13$
$D^0\to K^-\pi^+\pi^-\pi^+$	49.7 ± 11.9	1.65	$0.69^{+0.22}_{-0.13}\pm0.07$	$0.87^{+0.27}_{-0.16}\pm0.08$
$D\to K^-\pi^+(\pi)$	$36.2^{+12.7}_{-10.8}$	1.45	$0.85^{+0.47}_{-0.22}\pm0.09$	$1.08^{+0.59}_{-0.28}\pm0.11$
$D^+\to K^-\pi^+\pi^+$	16.1 ± 7.5	1.42	$0.64^{+0.56}_{-0.23}\pm0.06$	$0.81^{+0.71}_{-0.29}\pm0.08$
$D^{*+}\to\pi^+D^0$	$13.7^{+4.9}_{-3.9}$	1.55	$0.99^{+0.40}_{-0.23}\pm0.09$	$1.26^{+0.51}_{-0.28}\pm0.12$
Average			$0.90^{+0.13}_{-0.10}\pm0.08$	$1.13^{+0.17}_{-0.13}\pm0.09$

The computed values for $\sigma_{c\bar{c}}$ and $\Delta R_{c\bar{c}}$ for the different decay modes are summarized in Table II and the values of $\Delta R_{c\bar{c}}$ are displayed in Fig. 2. Although the data are statistically limited, examination of reconstructed events yields no evidence for strong momentum correlations between the two mesons, consistent with the Lund Monte Carlo model used to correct the data for these correlations. The weighted average of all of the measurements is $\sigma_{c\bar{c}}=0.90^{+0.13}_{-0.10}\pm0.08$ nb, which corresponds to $\Delta R_{c\bar{c}}\equiv\sigma_{c\bar{c}}/\sigma_{\mu\mu}=1.13^{+0.17}_{-0.13}\pm0.09$. The first error is statistical. The second error is systematic including the effects of uncertainties in the absolute value of the luminosity and in the signal-fitting procedures as well as the uncertainty in the reconstruction efficiencies and the degree of momentum correlation.

IV. INCLUSIVE LEPTON PRODUCTION

Below the threshold for production of B meson pairs, leptons in hadronic nonresonant e^+e^- events are produced almost exclusively from the decays of charmed hadrons. The charmed hadrons which decay semileptonically with significant branching fractions are the D^0, D^+, D_s, and Λ_c, with the D^0 and D^+ dominating the charm population.[4] Production of ψ in nonresonant e^+e^- annihilation is negligible,[13] and all other charm states are expected to eventually decay to one of these hadrons.

A. Analysis

Since the B mesons produced from the $\Upsilon(4S)$ contribute significant numbers of electrons via semileptonic decay, only the 36 pb^{-1} of data taken below the $B\bar{B}$ threshold are used in this analysis. Hadronic events are selected by requiring five or more charged tracks carrying a total energy (assuming all are pions) of at least $0.3\sqrt{s}$ and 250 MeV of shower energy. The more restrictive charged-multiplicity requirement is made to remove $\tau^+\tau^-$ events.

Identification of electrons with momenta above 0.4 GeV/c is accomplished by a maximum-likelihood technique, using measurements of ionization from the inner drift chamber and from the dE/dx chambers, time of flight from the scintillation counters, and energy deposition in the shower counters. The geometrical acceptance is limited to 48% of 4π steradians by the shower detector. The identification efficiency of electrons is determined from composite events constructed by combining a hadronic event with an electron identified in a radiative Bhabha event. The electron identification efficiency rises from 0.33 at 0.4 GeV/c to 0.90 at high momentum. The probability that a hadron will be misidentified as an electron is determined by examining the response of the detector to particles known to be hadrons, specifically from reconstruction of K^0_S and Λ decays. The misidentification probability ranges from $(0.6-1.4)\times10^{-2}$ over the electron momentum range. The geometrical acceptance and efficiency of event selection are determined by Monte Carlo simulation of events in the CLEO detector. Our measured electron momentum spectrum, corrected for misidentified hadrons and identification efficiencies, is shown in Fig. 3.

B. Determination of $\Delta R_{c\bar{c}}$

The continuum lepton spectrum can be modeled by the contribution from only the D^0 and D^+ mesons. It is reasonable to assume that the D_s will not alter this shape substantially, since its mass and fragmentation[14] are similar to those of the D mesons. The Λ_c also plays only a minor role, since both its semileptonic branching fraction and cross section are relatively small.[15] The relative contribution of D^0 and D^+ depends on the ratio of their abundances and on their semileptonic branching fractions. The abundance ratio of D^+/D^0 at $\sqrt{s}=10.5$ GeV has been measured[4] to be 0.48 ± 0.07. This result depends on the relative (but not absolute) magnitudes of the branching fractions for the decay modes used in the measurement. The semileptonic decay branching fractions have been investigated on the $\psi(3770)$ resonance,[2,16] and are well established. In our data sample the average semileptonic branching ratio for D's is computed to be $\langle B(D\to eX)\rangle=0.106\pm0.010$.

Starting with the measured relative abundances[4] and fragmentation functions fitted to the data[12] and allowing the D mesons to decay semileptonically with the measured branching fractions[17] and leptonic spectra,[18] we obtain a predicted continuum leptonic momentum spectrum. A fit of this spectrum to the measured distribution, allowing the normalization to vary, shows excellent agreement (Fig. 3). To obtain the total cross section, the model spectrum is used to extrapolate from 0.4 to 0 GeV/c, a 30% correction. The contribution of electrons from Dalitz decays of π^0's and from conversions of photons in the beam pipe is estimated from Monte Carlo studies to be 5%. After making these corrections we ob-

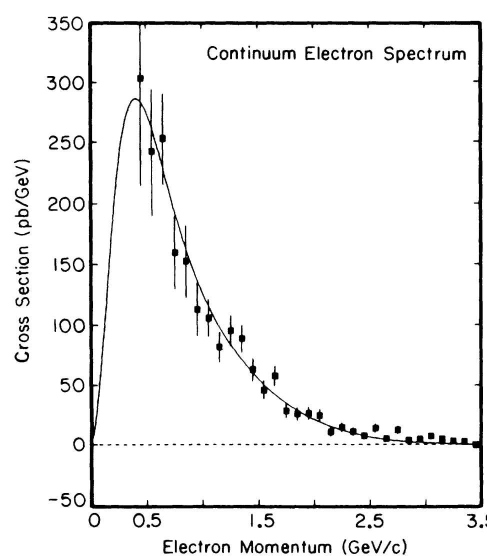

FIG. 3. Efficiency-corrected electron momentum distribution, shown with the fit to the expected distribution, calculated as described in the text.

tain a measurement of the inclusive cross section for electrons from charm in nonresonant hadronic events of $0.293\pm0.017\pm0.017$ nb, where the error includes the systematic uncertainties due to the fitting procedures and measured branching ratios.

To obtain from this measurement a value for the total charm-pair cross section, we need the abundances and semileptonic branching fractions of the D_s and Λ_c relative to those of the D^0 or D^+. Assuming that the semileptonic partial widths are the same for the D_s and Λ_c as for D^0/D^+ and taking their total widths from the measured lifetimes,[19] we estimate values for the semileptonic branching fractions of $(7.0\pm1.3)\%$ and $(3.3\pm0.7)\%$ for the D_s and Λ_c, respectively. If we assume that the D_s cross section[14] is 0.15 ± 0.04 nb and Λ_c comprises $(20\pm10)\%$ of the total charm-pair cross section,[15] we obtain a total charm-pair cross section of $\sigma_{c\bar{c}}=1.63\pm0.09\pm0.20$ nb, where the first error is statistical and the second is systematic, due to uncertainties in the branching fractions and cross sections. The corresponding value of $\Delta R_{c\bar{c}}$ is $\Delta R_{c\bar{c}}^{\text{lep}}=2.07\pm0.12\pm0.26$.

V. DISCUSSION

Each of the two methods described here yields a total charm-pair cross section which is independent of the absolute magnitudes of hadronic D-decay branching fractions. Each depends on different assumptions and can be considered as an independent measurement.

The charm tagging method is independent of all branching fractions but is dependent on assumptions about particle correlations, for which little information is available. It also presently suffers from large statistical errors. These charm tagging measurements can be compared with the most recent measurements at CLEO of the inclusive total cross section for D mesons,[12] $\sigma(D^0+D^+)=1.45\pm0.14\pm0.15$ nb, obtained using inclusive charmed mesons and the most recent Mark III hadronic branching fractions.[3] This can be translated into a contribution to R, $\Delta R_D\equiv\sigma(D^0+D^+)/2\sigma_{\mu\mu}=1.07\pm0.09\pm0.09$, and is displayed in Fig. 2. This contribution achieves a maximum value equal to $\Delta R_{c\bar{c}}$ if there is a complete $D\bar{D}$ correlation and the branching ratios used to determine ΔR_D are correct. If we assume that the D_s cross section[14] is 0.15 ± 0.04 nb and Λ_c comprises $(20\pm10)\%$ of the total charm-pair cross section,[15] we can derive from $\sigma(D^0+D^+)$ that $\Delta R_{c\bar{c}}^{\text{inc}}=1.46\pm0.11\pm0.19$, where the first error is the statistical error and the second is the systematic error including the uncertainty in the D_s and Λ_c cross sections. The two measurements ΔR_D and $\Delta R_{c\bar{c}}^{\text{inc}}$ are expected to bound our measurements of $\Delta R_{c\bar{c}}$, see Fig. 2, in the absence of anticorrelations.

The lepton spectrum method is a multistep construction. It relies on several previous measurements—the semileptonic and relative hadronic branching fractions of charmed mesons, their relative production rates, and their fragmentation distributions at $\sqrt{s}=10.5$ GeV. The measured lepton spectrum agrees very well with the form of a spectrum composed purely from decays of D^0 and D^+ with their measured fragmentation distributions and relative abundances. Although the contributions from D_s and Λ_c are not likely to be large, there is a large uncertainty in their production cross sections and semileptonic branching fractions. The accuracy of the final determination of $\sigma_{c\bar{c}}$ is limited by both of these factors.

We can compare the measured values of $\Delta R_{c\bar{c}}$ to the expected value of $1.52\pm0.02\pm0.15$ predicted by theory and to the values $\Delta R_D=1.07\pm0.09\pm0.09$ and $\Delta R_{c\bar{c}}^{\text{inc}}=1.46\pm0.11\pm0.19$ obtained from reconstruction of hadronic decay modes, discussed above.

The value $\Delta R_{c\bar{c}}=1.13^{+0.17}_{-0.13}\pm0.09$ obtained in the charm tagging method lies close to the measured ΔR_D and $\Delta R_{c\bar{c}}^{\text{inc}}$, in agreement with expectations. But with the present errors we are not able to specify the existence or the amount of $D\bar{D}$ correlations. An investigation of correlations between baryons and D mesons would shed some light on this question. However, in the present data samples these signals are statistically insignificant. We will continue to pursue this investigation in data currently being collected.

The value $\Delta R_{c\bar{c}}^{\text{lep}}=2.07\pm0.12\pm0.26$ obtained from the electron yield is higher than the measurement using exclusive hadronic decays. The two measurements are separated by 2.5σ. This measured value of $\Delta R_{c\bar{c}}^{\text{lep}}$ from the lepton spectrum is also higher than the expected theoretical contribution by 1.6 standard deviations.

VI. SUMMARY

We report results from two new methods of measuring the total charm cross section in nonresonant e^+e^- annihilations at $\sqrt{s}=10.5$ GeV. The measurements are broadly consistent with naive expectation. With larger data sample these techniques may enable us to obtain precise measurements of the charm fraction independent of measured branching ratios. We should also be able to study charm-particle correlations which will yield valuable information about the nature of charmed meson and baryon production.

ACKNOWLEDGMENTS

We are grateful to the CESR staff for their outstanding efforts which have made this work possible. Thanks are also extended to the Office of Junior Investigator Program of the DOE from H. Kagan and R. Kass and to the Bunting Institute from K. Kinoshita This research was conducted in part using the Cornell National Supercomputer Facility, which is funded by the National Science Foundation, New York State, and IBM. This work was supported by the National Science Foundation and the U.S. Department of Energy under Contracts Nos. DE-AC02-76ER01428, DE-AC02-76ER03066, DE-AC02-76ER03064, DE-AC02-76ER01545, DE-AC02-76ER05001, and FG05-86-ER40272.

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