Observation of new resonances decaying to $D\pi$ and $D^*\pi$ in inclusive $e^+e^-$
collisions near $\sqrt{s} = 10.58$ GeV

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We present a study of the $D^+/C_2^5/C_0$, $D_0^+/C_2^5$, and $D^+/C_3^+/C_2^5/C_0$ systems in inclusive $e^+e^-\rightarrow c\bar{c}$ interactions in a search for new excited $D$ meson states. We use a data set, consisting of $\sim 454$ fb$^{-1}$, collected at center-of-mass energies near 10.58 GeV by the BaBar detector at the SLAC PEP-II asymmetric-energy collider.
observe, for the first time, candidates for the radial excitations of the $D^0$, $D^{*0}$, and $D^{*+}$, as well as the $L = 2$ excited states of the $D^0$ and $D^+$, where $L$ is the orbital angular momentum of the quarks.

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The spectrum of mesons consisting of a charm and an up or a down quark is poorly known. The spectrum of quark-antiquark systems was predicted in 1985 using a relativistic chromodynamic potential model [1]. The low-mass spectrum of the $c\bar{u}$ or $c\bar{d}$ system is comprised of the ground states ($1S$), the orbital excitations with angular momentum $L = 1, 2$ ($1P$, $1D$), and the first radial excitations ($2S$). In this paper we label the states using the notation $D_j^{(2S+1)}(nL)$, where $J$ is the total angular momentum of the state, $n$ is the radial quantum number, and $L$ and $S$ are the orbital angular momentum and total spin of the quarks. Besides the ground states ($D, D^*$), only two $1P$ states, known as the $D_1(2420)$ and $D_2(2460)$ [2], are well-established experimentally since they have relatively narrow widths ($\sim 30$ MeV). In contrast, the other two $1P$ states, known as the $D_3(2400)$ and $D_4(2430)$, are very broad ($\sim 300$ MeV), making them difficult to detect [3–5].

To search for states not yet observed, we analyze the inclusive production of the $D^+\pi^-, D^{0}\pi^+$, and $D^{*+}\pi^-$ [6] final states in the reaction $e^+e^- \rightarrow c\bar{c} \rightarrow D^{(*)}\pi X$, where $X$ is any additional system. We use an event sample consisting of approximately $590 \times 10^6$ $e^+e^- \rightarrow c\bar{c}$ events (454 fb$^{-1}$) produced at $e^+e^-$ center-of-mass (CM) energies near 10.58 GeV and collected with the BABAR detector at the SLAC PEP-II asymmetric-energy collider. Our signal yield for the $L = 1$ resonances is more than 10 times larger than the best previous study [7], resulting in much greater sensitivity to higher resonances.

The BABAR detector is described in detail in Ref. [8]. Charged-particle momenta are measured with a five-layer, double-sided silicon vertex tracker (SVT) and a 40-layer drift chamber (DCH) inside a 1.5-T superconducting solenoidal magnet. A calorimeter consisting of 6580 CsI(Tl) crystals is used to measure electromagnetic energy. A ring-imaging Cherenkov radiation detector (DIRC), aided by measurements of ionization energy lost, $dE/dx$, in the SVT and DCH, is used for particle identification (PID) of charged hadrons.

The $D\pi$ system is reconstructed in the neutral $D^+\pi^-$ and charged $D^{0}\pi^+$ modes, where $D^+ \rightarrow K^-\pi^+\pi^+$ and $D^0 \rightarrow K^-\pi^+$. A PID algorithm is applied to all tracks. Charged kaon identification has an average efficiency of 90% within the acceptance of the detector and an average pion-to-kaon misidentification probability of 1.5%.

For all channels we perform a vertex fit for the $D^+$ and $D^0$ daughters. To improve the signal-to-background ratio for $D^+ \rightarrow K^-\pi^+\pi^+$, we require that the measured flight distance of the $D^+$ candidate from the $e^+e^-$ interaction region be greater than 5 times its uncertainty.

To improve the signal purity for $D^0 \rightarrow K^-\pi^+$ we require $\cos\theta_K > -0.9$, where $\theta_K$ is the angle formed by the $K^-$ in the $D^0$ candidate rest frame with respect to the prior direction of the $D^0$ candidate in the CM reference frame. The $D\pi$ candidates for both $D^+$ and $D^0$ are then reconstructed by performing a vertex fit with an additional charged primary pion, which originates from the $e^+e^-$ interaction region. For all vertex fits we require a $\chi^2$ probability $>0.1\%$.

In the $D^0\pi^+$ sample, we veto $D^0$ candidates from $D^+$ or $D^{*0}$ decays by forming $D^0\pi^+$ (where the $\pi^+$ is any additional pion in the event) and $D^0\pi^0$ combinations, and rejecting the event if the invariant-mass difference between this combination and the $D^0$ candidate is within $2\sigma$ of the nominal $D^*-D$ mass difference [2], where $\sigma$ is the detector resolution.

The $K^-\pi^+\pi^+$ and $K^-\pi^+\pi^-$ mass distributions are shown in Figs. 1(a) and 1(b). We fit these distributions to a linear background and a Gaussian signal; the signal widths obtained are $\sigma_{D^+} = 6.7$ MeV/c$^2$ and $\sigma_{D^0} = 7.6$ MeV/c$^2$. The signal region is defined to be within $\pm 2.5\sigma$ of the peak, while sideband regions are defined as the ranges $(\pm 5.0\sigma, \pm 7.5\sigma)$ and $(\pm 4.0\sigma, \pm 6.5\sigma)$ for the $D^+$ and $D^0$, respectively. The $D^+$ signal region has purity $N_S/(N_S + N_B) = 65\%$, where $N_S$ ($N_B$) is the number of signal (background) events, while the $D^0$ purity is $83\%$.

The $D^{*+}\pi^-$ system is reconstructed using the $D^0 \rightarrow K^-\pi^+\pi^-$ and $D^0 \rightarrow K^-\pi^+\pi^-\pi^+$ decay modes. A $D^0$ decay mass distribution for $(d)$ correspond to the $D^{*+}\pi^-$ sample and show the mass distribution for $D^0$ candidates and the $\Delta m$ distribution for $D^{*+}$ candidates. The vertical lines show the signal and, in (a) and (b), the sideband regions.
candidate is accepted if its invariant mass is within 30 MeV/c² of the mean value. A \( D^+ \) candidate is reconstructed by requiring an additional slow pion (\( \pi_s^0 \)) originating from the \( e^+ e^- \) interaction region. We select a \( D^+ \) candidate if the mass difference \( \Delta m = m(K^- \pi^+(\pi^-\pi^-)) - m(K^- \pi^+ \pi^-(\pi^+\pi^-)) \) is within 2.0 MeV/c² of the mean value. The \( D^0 \) candidate invariant-mass distribution and the \( \Delta m \) distribution are shown in Figs. 1(c) and 1(d). The \( D^+ \) signal purity is 89%. Finally, we reconstruct a \( D^{*+} \) candidate by combining a \( D^{*+} \) candidate with an additional charged track identified as a \( \pi^- \) and applying a vertex fit.

Background from \( e^+ e^- \rightarrow BB \) events, and much of the combinatorial background, are removed by requiring the CM momentum of the \( D^{(*)} \pi \) system to be greater than 3.0 GeV/c. In addition, we remove fake primary pion candidates originating mainly from the opposite side of the event by requiring \( \cos \theta_{\pi} > -0.8 \). The angle \( \theta_{\pi} \) is defined in the \( D^{(*)} \pi \) rest frame as the angle between the primary pion direction and the prior direction of the \( D^{(*)} \pi \) system in the CM frame.

To extract the resonance parameters we define the variables

\[
M(D^+ \pi^-) = m(K^- \pi^+ \pi^- \pi^-) - m(K^- \pi^+ \pi^-) + m_{D^+}, \quad \text{and} \quad M(D^0 \pi^+) = m(K^- \pi^+ \pi^-) - m(K^- \pi^+) + m_{D^0},
\]

where \( m_{D^+} \) and \( m_{D^0} \) are the values of the \( D^+ \) and \( D^0 \) mass [2]. The use of the mass difference improves the resolution on the reconstructed mass to about 3 MeV/c².

We remove the contribution due to fake \( D^+ \) and \( D^0 \) candidates by subtracting the \( M(D \pi) \) distributions obtained by selecting events in the \( D^+ \) or \( D^0 \) candidate mass sidebands.

The \( D^+ \pi^- \) and \( D^0 \pi^+ \) mass spectra are presented in Fig. 2 and show similar features.

(i) Prominent peaks for \( D_2^0(2460) \) and \( D_3^0(2460) \).

(ii) The \( D^+ \pi^- \) mass spectrum shows a peaking background (feeddown) at about 2.3 GeV/c² due to decays from the \( D_1(2420)^0 \) and \( D_2^0(2460) \) to \( D^+ \pi^- \). The \( D^+ \) in these events decays to \( D^+ \pi^0 \) and the \( \pi^0 \) is missing in the reconstruction. The missing \( \pi^0 \) has very low momentum because the \( D^+ \) decay is very close to threshold. Therefore, these decays have a mass resolution of only 5.8 MeV/c² and a bias of \(-143.2 \text{ MeV/c}^2\). Similarly, \( D^0 \pi^+ \) shows peaking backgrounds due to the decays of the \( D_1(2420)^+ \) and \( D_2^0(2460)^+ \) to \( D^{0\pi^+} \), where the \( D^{0\pi^+} \) decays to \( D^{0\pi^0} \).

(iii) Both \( D^+ \pi^- \) and \( D^0 \pi^+ \) mass distributions show new structures around 2.6 and 2.75 GeV/c². We call these enhancements \( D^*(2600) \) and \( D^*(2760) \).

We have compared these mass spectra with those obtained from generic \( e^+ e^- \rightarrow c\bar{c} \) Monte Carlo (MC) events. These events were generated using JETSET [9] with all the known particle resonances incorporated. The events are then reconstructed using a detailed GEANT4 [10] detector simulation and the event selection procedure used for the data. In addition, we study \( D \pi \) mass spectra from the \( D^+ \) and \( D^0 \) candidate mass sidebands, as well as mass spectra for wrong-sign \( D^+ \pi^+ \) and \( D^0 \pi^- \) samples. We find no backgrounds or reflections that can cause the structures at 2.6 and 2.76 GeV/c². In the study of the \( D^0 \pi^+ \) final state we find a peaking background due to events where the \( D^0 \) candidate is not a true \( D^0 \), but the \( K^- \) candidate and the \( \pi^+ \) candidate are from a true \( D^0 \rightarrow K^- \pi^+ \) decay. These combinations produce enhancements in \( M(D^0 \pi^+) \) both in the \( D^0 \) candidate mass signal region and sidebands. However, we find this background to be linear as a function of the \( D^0 \) candidate mass, and it is removed by the sideband subtraction.

The smooth background is modeled using the function

\[
B(x) = P(x) \times \begin{cases} \frac{e^{-c_1 x + c_2 x^2}}{e^{d_0 + d_1 x + d_2 x^2}} & \text{for } x \leq x_0, \\ e^{d_0 + d_1 x + d_2 x^2} & \text{for } x > x_0, \end{cases} \tag{1}
\]

where \( P(x) = \frac{1}{\pi \sqrt{2}} \sqrt{x^2 - (m_D + m_{\pi})^2} \text{[}x^2 - (m_{D} - m_{\pi})^2\text{]} \) is a two-body phase-space factor and \( x = M(D \pi) \). Only four parameters are free in the piecewise exponential: \( c_1, c_2, d_2, \) and \( x_0 \). The parameters \( d_0 \) and \( d_1 \) are fixed by

FIG. 2 (color online). Mass distribution for \( D^+ \pi^- \) (top) and \( D^0 \pi^+ \) (bottom) candidates. Points correspond to data, with the total fit overlaid as a solid curve. The dotted curves are the signal components. The lower solid curves correspond to the smooth combinatoric background and to the peaking backgrounds at 2.3 GeV/c². The inset plots show the distributions after subtraction of the combinatoric background.
The fit to the $D^0\pi^+$ mass spectrum is similar to that described for the $D^+\pi^-$ system. Because the feeddown is larger and the statistical precision of the resonances is not as good as for $D^+\pi^-$, we fix the width parameters of all resonances to the values determined from $D^+\pi^-$ assuming isospin symmetry. The fit to the $M(D^0\pi^+)$ mass distribution (fit B) is shown in Fig. 2 (bottom); this fit has $\chi^2$/NDF of 278/224. We find consistent mass values for both $D^*(2600)$ and $D^*(2760)$ in the fits of the $D^+\pi^-$ and $D^0\pi^+$ mass distributions.

We now search for these new states in the $D^{++}\pi^-$ decay mode. We define the variable $M(D^{++}\pi^-) = m(K^-\pi^+(\pi^+\pi^-)\pi^+\pi^-) - m(K^-\pi^+(\pi^+\pi^-)\pi^+\pi^-) + m_{D^{++}}$ where $m_{D^{++}}$ is the value of the $D^{++}$ mass [2]. The $D^{++}\pi^-$ mass distribution is shown in Fig. 3 and shows the following features:

(i) Prominent $D_s(2420)^0$ and $D_s^*(2460)^0$ peaks.

(ii) Two additional enhancements at $\sim 2.60$ GeV$/c^2$ and $\sim 2.75$ GeV$/c^2$, which we initially denote as $D^*(2600)^0$ and $D(2750)^0$.

Studies of the generic MC simulation as well as studies of the $D^+$ sidebands and the wrong-sign sample ($D^*^+\pi^+$) show no peaking backgrounds in this mass spectrum.

We fit $M(D^{++}\pi^-)$ by parametrizing the background with the function in Eq. (1). The $D_s(2420)^0$ and $D_s^*(2460)^0$ resonances are modeled using relativistic BW functions with appropriate Blatt-Weisskopf form factors. The $D^*(2600)^0$ and $D(2750)^0$ are modeled with relativistic BW functions. The broad resonance $D_s^*(2430)^0$ is known to decay to this final state, however, this fit is insensitive to it due to its large width ($\sim 380$ MeV) [4] and because the background parameters are free.

### Table I

Summary of the results. The first error is statistical and the second is systematic; “fixed” indicates the parameters were fixed to the values from fit A or C. The significance is defined as the yield divided by its total error.

<table>
<thead>
<tr>
<th>Resonance</th>
<th>Channel (fit)</th>
<th>Efficiency (%)</th>
<th>Yield ($\times 10^3$)</th>
<th>Mass (MeV$/c^2$)</th>
<th>Width (MeV)</th>
<th>Significance</th>
</tr>
</thead>
<tbody>
<tr>
<td>$D_s(2420)^0$</td>
<td>$D^+\pi^- (C)$</td>
<td>1.09 ± 0.03</td>
<td>120.2 ± 1.3 ± 2.3</td>
<td>2420.1 ± 0.1 ± 0.8</td>
<td>31.4 ± 0.5 ± 1.3</td>
<td>3.0σ</td>
</tr>
<tr>
<td>$D^*(2600)^0$</td>
<td>$D^+\pi^- (A)$</td>
<td>1.29 ± 0.03</td>
<td>242.8 ± 1.8 ± 3.4</td>
<td>2462.2 ± 0.1 ± 0.8</td>
<td>50.5 ± 0.6 ± 0.7</td>
<td>3.9σ</td>
</tr>
<tr>
<td>$D^*(2750)^0$</td>
<td>$D^+\pi^- (C)$</td>
<td>1.14 ± 0.04</td>
<td>34.3 ± 6.7 ± 9.2</td>
<td>2539.4 ± 4.5 ± 6.8</td>
<td>130 ± 12 ± 13</td>
<td>6.5σ</td>
</tr>
<tr>
<td>$D^*(2760)^0$</td>
<td>$D^+\pi^- (D)$</td>
<td>1.18 ± 0.05</td>
<td>71.4 ± 1.7 ± 7.3</td>
<td>2608.7 ± 2.4 ± 2.5</td>
<td>93 ± 6 ± 13</td>
<td>7.3σ</td>
</tr>
<tr>
<td>$D^*(2750)^0$</td>
<td>$D^+\pi^- (E)$</td>
<td>1.35 ± 0.05</td>
<td>26.0 ± 1.4 ± 6.6</td>
<td>2608.7 (fixed)</td>
<td>93 (fixed)</td>
<td>7.5σ</td>
</tr>
<tr>
<td>$D^*_s(2460)^0$</td>
<td>$D^+\pi^- (C)$</td>
<td>1.41 ± 0.09</td>
<td>11.3 ± 0.8 ± 1.0</td>
<td>2763.3 ± 2.3 ± 2.3</td>
<td>60.9 ± 5.1 ± 3.6</td>
<td>8.9σ</td>
</tr>
<tr>
<td>$D^*_s(2460)^0$</td>
<td>$D^0\pi^+ (B)$</td>
<td>110.8 ± 1.3 ± 7.5</td>
<td>2465.4 ± 0.2 ± 1.1</td>
<td>50.5 (fixed)</td>
<td>5.0σ</td>
<td></td>
</tr>
<tr>
<td>$D^*(2600)^0$</td>
<td>$D^0\pi^+ (B)$</td>
<td>13.0 ± 1.3 ± 4.5</td>
<td>2621.3 ± 3.7 ± 4.2</td>
<td>93 (fixed)</td>
<td>2.8σ</td>
<td></td>
</tr>
<tr>
<td>$D^*(2760)^0$</td>
<td>$D^0\pi^+ (B)$</td>
<td>5.7 ± 0.7 ± 1.5</td>
<td>2769.7 ± 3.8 ± 1.5</td>
<td>60.9 (fixed)</td>
<td>3.5σ</td>
<td></td>
</tr>
</tbody>
</table>
find that the mean value of the peak at \(j/C24\).

Because of the vector nature of the \(D^{*+}\), the \(D^{++}\) final state contains additional information about the spin-parity \((J^P)\) quantum numbers of the resonances. In the rest frame of the \(D^{*+}\), we define the helicity angle \(\theta_H\) as the angle between the primary pion \(\pi^-\) and the slow pion \(\pi^+\) from the \(D^{++}\) decay. The distributions in \(\cos \theta_H\) for the predicted resonances, assuming parity conservation, are given in Table II. Initially, we have attempted to fit the \(M(D^{*+}\pi^-)\) distribution incorporating only two new signals at \(\sim 2.6\text{ GeV}/c^2\) and at \(\sim 2.75\text{ GeV}/c^2\). However, when we extract the yields as a function of \(\cos \theta_H\) we find that the mean value of the peak at \(\sim 2.6\text{ GeV}/c^2\) increases by \(\sim 70\text{ MeV}/c^2\) between \(\cos \theta_H = -1\) and \(\cos \theta_H = 0\), and decreases again as \(\cos \theta_H \rightarrow +1\). This behavior suggests two resonances with different helicity-angle distributions are present in this mass region. To proceed we incorporate a new component, which we call \(D(2550)^0\), into our model at \(\sim 2.55\text{ GeV}/c^2\). We extract the parameters of this component by requiring \(|\cos \theta_H| > 0.75\) in order to suppress the other resonances. In this fit (C), shown in Fig. 3 (top), we fix the parameters of the \(D_1^*(2460)^0\) and \(D^*(2600)^0\) to those measured in \(D^+\pi^-\). We obtain a \(\chi^2/\text{NDF}\) of 214/205 for this fit. This fit also determines the parameters of the \(D_1(2420)^0\). We then perform a complementary fit (D), shown in Fig. 3 (middle), in which we require \(|\cos \theta_H| < 0.5\) to discriminate in favor of the \(D^*(2600)^0\). We obtain a \(\chi^2/\text{NDF}\) of 210/209 for this fit. To determine the final parameters of the \(D(2750)^0\) signal we fit the total \(D^{*+}\pi^-\) sample while fixing the parameters of all other BW components to the values determined in the previous fits. This final fit (E), shown in Fig. 3 (bottom), has a \(\chi^2/\text{NDF}\) of 244/207.

Table II. Properties of the predicted states [1]. The value of the parameter \(h\) depends on the state.

<table>
<thead>
<tr>
<th>State</th>
<th>Predicted mass</th>
<th>(J^P)</th>
<th>(\cos \theta_H) distribution</th>
</tr>
</thead>
<tbody>
<tr>
<td>(D_1^*(2S)^0)</td>
<td>(2.58\text{ GeV}/c^2)</td>
<td>0(^-)</td>
<td>(\propto \cos^2 \theta_H)</td>
</tr>
<tr>
<td>(D_1(2S)^0)</td>
<td>(2.64\text{ GeV}/c^2)</td>
<td>1(^-)</td>
<td>(\propto \sin^2 \theta_H)</td>
</tr>
<tr>
<td>(D_1(1P)^0)</td>
<td>(2.44\text{ GeV}/c^2)</td>
<td>1(^+)</td>
<td>(\propto 1 + h\cos^2 \theta_H)</td>
</tr>
<tr>
<td>(D_1^*(1P)^0)</td>
<td>(2.40\text{ GeV}/c^2)</td>
<td>0(^+)</td>
<td>Decay not allowed</td>
</tr>
<tr>
<td>(D_1(1P))</td>
<td>(2.49\text{ GeV}/c^2)</td>
<td>1(^+)</td>
<td>(\propto 1 + h\cos^2 \theta_H)</td>
</tr>
<tr>
<td>(D_1(1P))</td>
<td>(2.50\text{ GeV}/c^2)</td>
<td>2(^+)</td>
<td>(\propto \sin^2 \theta_H)</td>
</tr>
<tr>
<td>(D_1(1D))</td>
<td>(\sim 2.83\text{ GeV}/c^2)</td>
<td>2(^-)</td>
<td>(\propto 1 + h\cos^2 \theta_H)</td>
</tr>
<tr>
<td>(D_1(1D))</td>
<td>(2.82\text{ GeV}/c^2)</td>
<td>1(^-)</td>
<td>(\propto \sin^2 \theta_H)</td>
</tr>
<tr>
<td>(D_1(1D))</td>
<td>(\sim 2.83\text{ GeV}/c^2)</td>
<td>2(^-)</td>
<td>(\propto 1 + h\cos^2 \theta_H)</td>
</tr>
<tr>
<td>(D_1(1D))</td>
<td>(2.83\text{ GeV}/c^2)</td>
<td>3(^-)</td>
<td>(\propto \sin^2 \theta_H)</td>
</tr>
</tbody>
</table>

FIG. 3 (color online). Mass distributions for \(D^{*+}\pi^-\) candidates. Top: candidates with \(|\cos \theta_H| > 0.75\). Middle: candidates with \(|\cos \theta_H| < 0.5\). Bottom: all candidates. Points correspond to data, with the total fit overlaid as a solid curve. The lower solid curve is the combinatoric background, and the dotted curves are the signal components. The inset plots show the distributions after subtraction of the combinatoric background.
helicity parameter $h = 5.72 \pm 0.25$, where the error includes both statistical and systematic uncertainties. This value is consistent with the measurement by ZEUS [12]. The $\cos\theta_H$ distributions of the $D^*_2(2460)$ and $D^{*+}(2600)$ are consistent with the expectations for natural parity, defined by $P = (-1)^J$, and leading to a $\sin^2\theta_H$ distribution. This observation supports the assumption that the enhancement assigned to the $D^*(2600)$ in the $D^{*+}\pi^-$ and $D^{*+}\pi^+$ belong to the same state; only states with natural parity can decay to both $D^+\pi^-$ and $D^{*+}\pi^-$. The $\cos\theta_H$ distribution for the $D(2550)^0$ is consistent with pure $\cos^2\theta_H$ as expected for a $J^P = 0^-$ state.

The ratio of branching fractions $B(D^{*-}\to D^+\pi^-)/B(D^{*-}\to D^{*+}\pi^-)$ (where $D^{*-}$ labels any resonance) can be useful in the identification of the new signals with predicted states. We compute this ratio for the $D^*_2(2460)^0$, $D^*(2600)^0$, and $D(2750)^0$ using the yields obtained from the fits to the total samples and correcting for the reconstruction efficiency: $(N_{D^{*-}\pi^-}/e_{D^{*-}\pi^-})/(N_{D^{*+}\pi^-}/e_{D^{*+}\pi^-})$. The efficiencies and yields are shown in Table I. We find the following ratios:

\[
\begin{align*}
B(D^*_2(2460)^0 \to D^+\pi^-) & = 1.47 \pm 0.03 \pm 0.16, \\
B(D^*_2(2460)^0 \to D^{*+}\pi^-) & = 0.32 \pm 0.02 \pm 0.09, \\
B(D^*(2600)^0 \to D^+\pi^-) & = 0.42 \pm 0.05 \pm 0.11.
\end{align*}
\]

The first uncertainty is due to the statistical uncertainty on the yields. The second uncertainty includes the systematic uncertainty on the yields, the systematic uncertainty due to differences in PID and tracking efficiency, and the errors from the branching fractions for the decay chains [2]. Although in the last ratio the signal in the numerator may not be the same as the signal in the denominator, we determine the ratio, as it may help elucidate the nature of this structure.

In summary, we have analyzed the inclusive production of the $D^{*}\pi^-, D^0\pi^+$, and $D^{*+}\pi^-$ systems in search of new $D$-meson resonances using 454 fb$^{-1}$ of data collected by the BABAR experiment. We observe for the first time four signals, which we denote $D(2550)^0$, $D^*(2600)^0$, $D(2750)^0$, and $D^*(2760)^0$. We also observe the isospin partners $D^*(2600)^+$ and $D^+(2760)^+$. The $D(2550)^0$ and $D^*(2600)^0$ have mass values and $\cos\theta_H$ distributions that are consistent with the predicted radial excitations $D_{11}^0(2S)$ and $D_{12}^1(2S)$. The $D^*(2760)^0$ signal observed in $D^{*+}\pi^-$ is very close in mass to the $D(2750)^0$ signal observed in $D^{*+}\pi^-$; however, their mass and width values differ by 2.6$\sigma$ and 1.5$\sigma$, respectively. Four $L = 2$ states are predicted to lie in this region [1], but only two are expected to decay to $D^{*+}\pi^-$. This may explain the observed features.

We are grateful for the excellent luminosity and machine conditions provided by our PEP-II colleagues, and for the substantial dedicated effort from the computing organizations that support BABAR. The collaborating institutions wish to thank SLAC for its support and kind hospitality. This work is supported by DOE and NSF (USA), NSERC (Canada), CEA and CNRS-IN2P3 (France), BMBF and DFG (Germany), INFN (Italy), FOM (The Netherlands), NFR (Norway), MES (Russia), MICIIN (Spain), and STFC (United Kingdom). Individuals have received support from the Marie Curie EIF (European Union), the A. P. Sloan Foundation (USA), and the Binational Science Foundation (USA-Israel).

[6] Charge conjugates are implied throughout this paper.