OBSERVATION OF THE CHARGED ISOSPIN PARTNER OF THE $D^*(2459)^0$

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Using the ARGUS detector at the DORIS II e^+e^- storage ring at DESY, we have observed a new charmed meson of mass $(2469 \pm 4 \pm 6)$ MeV/c^2, decaying to $D^0\pi^+$. This state is a strong candidate for the charged isospin partner of the $D^*(2459)^0$. The isospin mass splitting is measured to be $(14 \pm 5 \pm 8)$ MeV/c^2.

The spectroscopy and decay properties of excited charmed mesons have been calculated within several different models [1]; the predictions are sensitive to the spin-structure of the quark–antiquark potential at relatively large distances. The mass splitting between charged and neutral isospin partners is of interest as it yields valuable constraints on constituent-quark masses [2].

The Tagged Photon Collaboration (E691) recently reported [3] the observation of a state of mass 2459 MeV/c^2, henceforth referred to as the $D^*(2459)^0$, decaying to $D^+\pi^-$ [#1]. This observation has since been confirmed by ARGUS [4] and by CLEO [5]. The observed mass is in the range of values expected for $L=1$ D mesons. Given this interpretation, spin–parity conservation in strong decays implies the identification of the $D^*(2459)^0$ as an $L=1$ D meson with spin–parity of either 0^+ or 2^+. The large mass and narrow width observed for this meson favour its interpretation as the 2^+ state. This view is further supported by a decay angular analysis [4] performed by ARGUS which suggests that the $D^*(2459)^0$ is produced with non-zero polarization, impossible for the 0^+ state.

Here we report on the first observation of a new charmed meson, decaying to $D^0\pi^+$, which is a candidate for the charged isospin partner of the $D^*(2459)^0$. In the following, we refer to this new state as the $D^*(2469)^+$.

The analysis presented here [6,7] is based on a data sample of 251 pb^{-1} collected on the $\Upsilon(4S)$ resonance and in the nearby continuum with the ARGUS detector at the DORIS II e^+e^- storage ring at DESY. The ARGUS detector is a 4π spectrometer described in detail elsewhere [8]. Charged tracks were required to have momenta transverse to the beam direction greater than 60 MeV/c. Charged particle identification was made on the basis of specific ionization and time-of-flight measurements, with the information being combined into an overall likelihood ratio for each of the mass hypotheses, e, μ, π, K, and p. All particle hypotheses with likelihood ratio in excess of 5% were accepted.

We have searched for excited charmed mesons in the decay channel

$$D^{*+} \to D^0\pi^+$$
$$\quad\quad \hookrightarrow K^-\pi^+\,, \quad K^-\pi^+\pi^+\pi^-\,.$$

$K\pi$ ($K3\pi$) combinations with an invariant mass within 40 (30) MeV/c^2 of the D^0 mass [9], and which agree with the D^0 mass hypothesis with a χ^2 of less than 4, were accepted as D^0 candidates. These were then combined with all remaining π^+ candidates.

In order to reduce the very large background, especially in the $K3\pi$ decay mode, arising from random combinations of kaons with a large number of slow pion candidates in each event, it was required that $\cos\theta^*_K$ be less than 0.7 (0.0) in the $K\pi$ ($K3\pi$) case. Here θ^*_K is defined as the angle between the kaon and the D^0 boost direction, as measured in the D^0 rest frame. Since the D^0 has spin zero, one would expect the $\cos\theta^*_K$ distribution arising from signal events to

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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.

be isotropic, whereas the background peaks strongly towards $\cos\theta^*_K = 1$.

As in the $D^+\pi^-$ analysis [4], two further requirements were made of the $D\pi$ combinations. First, since the fragmentation process leads to a hard momentum spectrum for particles containing a primary charmed quark, we required $x_p(D\pi) > 0.55$, where the scaled momentum of the $D\pi$ combination, $x_p(D\pi)$, is defined by $x_p(D\pi) = p(D\pi)/p_{max}$, and p_{max} is given by $p_{max} = \sqrt{E^2_{beam} - m^2(D\pi)}$. The second requirement was that $\cos\theta^*_\pi > -0.9$, where θ^*_π is defined as the angle between the pion flight direction and the $D\pi$ boost direction, as measured in the $D\pi$ rest frame. This second cut serves to remove some of the large combinatorial background arising from the abundantly produced slow pions, which are concentrated towards $\cos\theta^*_\pi = -1$.

The spectrum of the mass difference, $m(D^0\pi^+) - m(D^0)$, for the D^0 decay mode $K\pi(K3\pi)$, for all $D\pi$ combinations surviving the cuts outlined above is shown in figs. 1a, 1b. In each plot, a clear signal at a mass difference of about 600 MeV/c^2 is observed.

No signal was observed in the corresponding mass difference plots of $K\pi$ ($K3\pi$) combinations from the 40 (30) MeV/c^2 wide sidebands immediately above and below the selected D^0 signal region.

The enhancement observed at a mass difference of about 450 MeV/c^2 results from feed-down from possible decays $D^{*+}_J \to D^*(2010)^0\pi^+$, with the subsequent decay $D^*(2010)^0 \to D^0\pi^0$ or $D^0\gamma$, where the neutrals are not included in the selected decay chain. This feed-down enhancement was first seen by E691 [3], who had insufficient statistics to directly observe the $D^*(2469)^+$. The feed-down enhancement peak, arising as it does from a $D^*(2010)\pi$ final state, is very difficult to interpret in terms of single $L=1$ state and is most probably, as in the case of the $D^*(2420)^0$ [6,7], a superposition of two states.

Assuming the observed signal to be the isospin partner of the $D^*(2459)^0$, the signal-to-background ratio can be improved by utilizing the anisotropic $\cos\theta^*_\pi$ distribution observed in the $D^+\pi^-$ analysis [4]. Thus, one expects the signal to be enhanced at large values of $|\cos\theta^*_\pi|$. Indeed, as shown by the shaded histograms in fig. 1, there is no appreciable signal in evidence for $|\cos\theta^*_\pi| < 0.4$. Introducing, therefore, the further requirement that $|\cos\theta^*_\pi| > 0.4$ yields the mass difference plots shown in fig. 2.

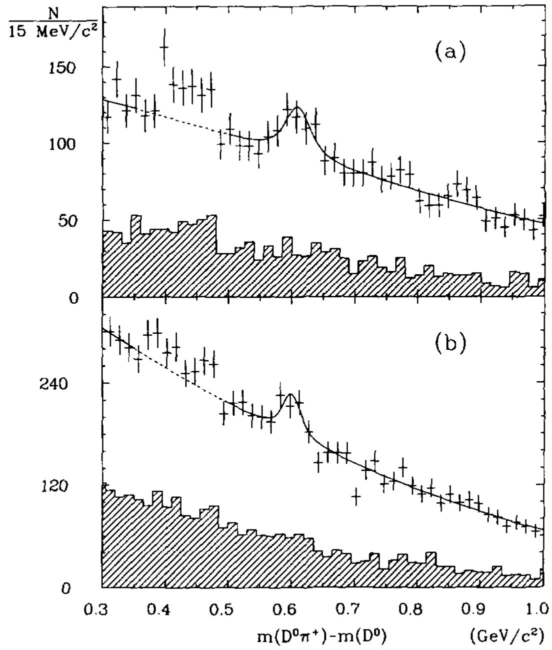

Fig. 1. $m(D^0\pi^+) - m(D^0)$ mass difference spectra for all accepted $D^0\pi^+$ combinations in the D^0 decay modes (a) $K\pi$ and (b) $K3\pi$. The data points represent all data with $\cos\theta^*_\pi > -0.9$, while the hatched histograms are those data satisfying $|\cos\theta^*_\pi| < 0.4$. The curves correspond to the fits described in the text.

The mass difference spectra in fig. 2 were fitted with a function which is a sum of a simple, non-relativistic Breit–Wigner convoluted with a gaussian to parameterize the signal plus a third-order polynomial to describe the combinatorial background. Mass differences in the range 0.35–0.50 GeV/c^2 were excluded from the fit in order to avoid effects from the feed-down structure. The mass resolution for the signal was fixed to values of 9.0 (8.4) MeV/c^2 for the $K\pi$ ($K3\pi$) channel, as determined from Monte Carlo studies. The results of the fits are summarized in table 1. The $K\pi$ and $K3\pi$ results are consistent with each other, and a weighted average mass difference and width have been calculated and are included in the table.

The average mass difference corresponds to a mass measurement of (2469 ± 4) MeV/c^2, and the combined statistical significance of the signal is approximately 4.4 standard deviations. By varying the cuts,

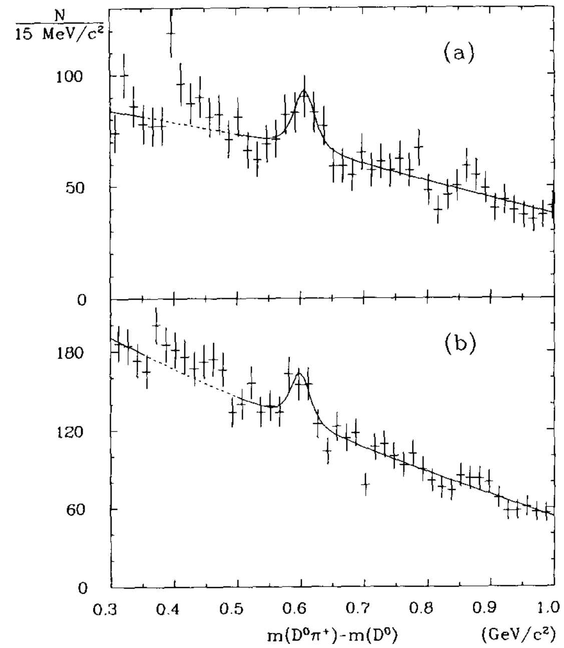

Fig. 2. $m(D^0\pi^+)-m(D^0)$ mass difference spectra for all accepted $D^0\pi^+$ combinations in the D^0 decay modes (a) $K\pi$ and (b) $K3\pi$, with the further requirement that $|\cos\theta_\pi^*|>0.4$. The curves correspond to the fits described in the text.

the background shape, and the mass resolution, the sstematic error in the average mass and width are estimated to be 6 and 10 MeV/c^2 respectively. The natural width is consistent with the result of $(15^{+13}_{-10}\,{}^{+5}_{-10})$ MeV/c^2 [4] measured for the $D^*(2459)^0$.

To compare the production cross section with that measured for the $D^*(2459)^0$, the mass difference spectrum of fig. 1a was fitted with the function described previously, in order to determine the number of events with $x_p>0.55$ and $\cos\theta_\pi^*>-0.9$. This procedure has the advantage that large systematic errors arising from extrapolating the x_p and $\cos\theta_\pi^*$ spectra can be avoided by utilizing the same cuts for both the $D^0\pi^+$ and the $D^+\pi^-$ analyses. Here the very small difference in the x_p spectra expected due to the isospin mass splitting has been neglected. Only the $K\pi$ data was used here since, without the $|\cos\theta_\pi^*|>0.4$ requirement, the $K3\pi$ data does not appreciably increase the statistical significance of the result. The fit, shown superimposed in fig. 1a, yielded 122 ± 46 events, with a mass difference and width consistent with the results of table 1.

After correcting for the differences in detection efficiencies, as determined by Monte Carlo, and for the relevant D meson branching ratios [9], the following result was obtained:

$$\frac{\sigma(D^*(2469)^+)\times Br(D^*(2469)^+\to D^0\pi^+)}{\sigma(D^*(2459)^0)\times Br(D^*(2459)^0\to D^+\pi^-)}=0.8\pm0.4\pm0.3\,.$$

The systematic error is dominated by the uncertainty in the background shape underneath the $D^*(2469)^+$.

Neglecting the small difference in the branching ratios to the $D\pi$ final state which might result from the isospin mass splitting, the production cross sections for the $D^*(2459)^0$ and for the $D^*(2469)^+$ are consistent with each other.

Finally, comparing with the result from our $D^*(2459)^0$ observation [4], the isospin mass splitting has been measured to be

$$m[D^*(2469)^+]-m[D^*(2459)^0]=+(14\pm5\pm8)\ \mathrm{MeV}/c^2\,.$$

Table 1
Results for the fits described in the text to the $m(D^0\pi^+)-m(D^0)$ mass difference spectra shown in fig. 2.

D^0 decay mode	Fitted mass differences (MeV/c^2)	Fitted width (MeV/c^2)	Fitted number of events
$K^-\pi^+$	607.2 ± 4.9	28.3 ± 17.8	112 ± 35
$K^-\pi^+\pi^+\pi^-$	600.0 ± 5.7	26.2 ± 15.7	150 ± 49
average	604.1 ± 3.7	27.1 ± 11.8	

This result is consistent with, but tends to be higher than, the prediction [2] of +4.4 MeV/c^2 made assuming the identification of the two mesons as the $L=1$ D mesons of spin–parity 2^+.

In summary, we have observed a new charmed meson of mass (2469±4±6) MeV/c^2 decaying to $D^0\pi^+$. The natural width and production cross section are consistent with that measured for the $D^*(2459)^0$. The isospin mass splitting, $m[D^*(2469)^+]-m[D^*(2459)^0]$, is measured to be +(14±5±8) MeV/c^2.

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