MEASUREMENT OF UPPER LIMITS FOR THE DECAY WIDTHS OF D^{*+} AND D^{*0}

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Upper limits for the decay widths of the D^{*+} and D^{*0} mesons have been measured using data from e^+e^- annihilations at $\sqrt{s}=29$ GeV obtained with the High Resolution Spectrometer at PEP. We find $\Gamma_{D^{*+}} < 1.1$ MeV/c^2 at 90% CL from an analysis of the mass difference distribution for the decay mode $D^{*+}\to D^0\pi^+$. The $D^{*+}-D^0$ mass difference is also measured to be $(145.40\pm0.05\pm0.10)$ MeV/c^2. We determine $\Gamma_{D^{*0}} < 2.1$ MeV/c^2 at 90% CL for a D^{*0} mass of 2007.2 MeV/c^2, from a search for the decay mode $D^{*0}\to D^+\pi^-$ which could occur if the width were sufficiently large.

The decay width is a fundamental property of all particles and contains important information on the underlying physics of the decay mechanism. Recognizing this, extensive effort has gone into determining the total and partial decay widths of particles. There are, however, several particles whose widths have not yet been well measured. Such examples are $D^{*+}(2010)$ and $D^{*0}(2007)$, where the present upper limits are $\Gamma_{D^{*+}} < 2.0$ MeV/c^2 and $\Gamma_{D^{*0}} < 5$ MeV/c^2 [1]. These values are very small compared to the widths of the other light mesons, despite the fact that the D^*'s decay strongly. Indeed, there are indications that the real widths may be less than 100 keV/c^2, as we discuss later. Therefore, the D^* is one of the narrowest particles among the strongly decaying particles.

In this paper we give improved upper limits for the decay widths of the D^{*+} and D^{*0} mesons using two different analysis techniques. The D^{*+} signal is reconstructed through the decay mode $D^{*+}\to D^0\pi^+$, with the D^0 decaying into the $K^-\pi^+$ channel. The analysis also includes the charge conjugate states. Since the Q-value of this decay is only 5.8 MeV, the mass difference ($\Delta\equiv M_{K^-\pi^+\pi^+}-M_{K^-\pi^+}$) can be determined extremely well. The width of the peak in the mass difference distribution is used to set an upper limit to the D^{*+} width, and the position of the peak gives the mass difference between the D^{*+} and D^0 mesons. The D^{*0} signal is searched for by looking for the decay mode $D^{*0}\to D^+\pi^-$, with D^+ decaying into the $K^-\pi^+\pi^+$ channel. Although this decay mode is kinematically forbidden for the central mass value, it can occur through the natural width of the D^{*0} [2]. Examples of particle decays where this is known to

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occur are $f_0(975)\to K\bar{K}$ and $a_0(980)\to K\bar{K}$. The $D^+\pi^-$ threshold is only 1.7 MeV/c^2 above the D^{*0} mass. Therefore, the threshold region in the mass difference distribution is used to put an upper limit on the D^{*0} width. The data sample used in the analysis corresponds to an integrated luminosity of 300 pb^{-1} at a center of mass energy of 29 GeV, obtained during the five years of operation of the High Resolution Spectrometer (HRS) at the PEP e^+e^- storage ring.

The HRS was a solenoidal spectrometer that measured charged and electromagnetic energy over 90% of the solid angle. The details of the detector are given elsewhere [3]. Substantial emphasis was placed on measurements of the charged particle momenta and all of the detector elements operated in a magnetic field of 1.62 T. The tracking system consisted of a vertex chamber, a central drift chamber, and an outer drift chamber. The central drift chamber had 15 cylindrical layers of drift cells. Eight of the layers had stereo wires (± 60 mrad) in order to measure the z position. The total material between the interaction point and the central drift chamber was less than 0.02 radiation length. The measured momentum resolution for high momentum tracks at large angles with respect to the beam was $\sigma_p/p \simeq 2\times 10^{-3}p$ (p in GeV/c). To select one-photon annihilation events and to reduce beam–gas and two-photon backgrounds, the events were required to have a minimum charged multiplicity of five and a scalar sum of charged track momenta and neutral particle energy greater than 10 GeV. No particle identification or shower counter information was used for this analysis.

In reconstructing the D^0 through the $K^-\pi^+$ decay mode, all of the tracks coming from the vertex were tried in turn as both K and π. Background reduction was achieved by requiring $z_D \geqslant 0.4$ and $|\cos\theta^*| < 0.7$, where $z_D \equiv 2E_D/\sqrt{s}$ and θ^* is the D^0 decay angle in the helicity frame. The $K\pi$ invariant mass spectrum in the D^0 region is shown in fig. 1, where the curve results from a fit using a polynomial form for the background and a gaussian form for the signal. The fitted mass of (1863 ± 3) MeV/c^2 is consistent with the currently accepted D^0 mass value of (1864.6 ± 0.6) MeV/c^2 [1]. The full width at half maximum (Γ) of (54 ± 4) MeV/c^2 is consistent with the apparatus resolution as determined by a Monte Carlo (MC) simulation. The enhancement around 1640 MeV/c^2 is due to the $D^0\to K^-\pi^+\pi^0$ decay mode and is not included in the fit.

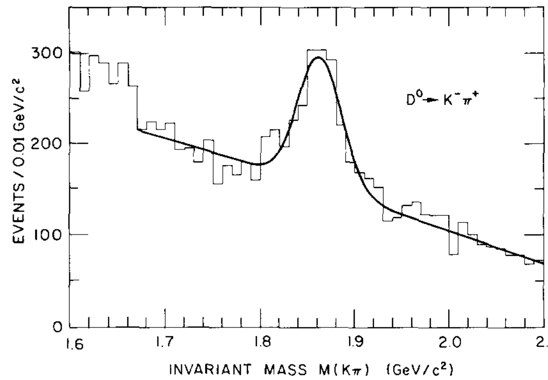

Fig. 1. The invariant $K\pi$ mass distribution with $z_D \geqslant 0.4$ and $|\cos\theta^*| < 0.7$, where z_D and θ^* are defined in the text.

Fig. 2 shows the distribution in the mass difference ($\Delta \equiv M_{K^-\pi^+\pi^+} - M_{K^-\pi^+}$) for $z_{D^*} \geqslant 0.4$ with the D^0 selections of 1810 MeV/$c^2 < M_{K^-\pi^+} < 1920$ MeV/c^2, which is the mass region for the D^0 determined above and $\chi^2 < 10$ for the mass constraint fit to the $D^0\to K^-\pi^+$ decay hypothesis. The peak in the distribution shows a clear signal for D^{*+} production over a small background. Four different parametrizations were tried in fitting the data of fig. 2, and the curve shows a fit to a linear background plus a gaussian signal with the overall normalization as a free parameter. The results are $\Delta = (145.40\pm0.05\pm0.10)$ MeV/c^2 for the peak value and $\Gamma = (1.17\pm0.09\pm0.06)$ MeV/c^2 for the width, where the first error is statistical and the second systematic. The systematic errors were estimated from the shift of the reconstructed mass of the

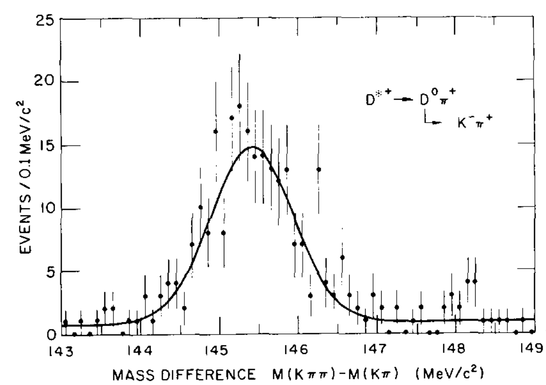

Fig. 2. The mass difference ($\Delta = M(K^-\pi^+\pi^+) - M(K^-\pi^+)$) distribution for $D^{*+}\to D^0\pi^+\to K^-\pi^+\pi^+$ with $z_{D^*} \geqslant 0.4$. The D^{*+} peak has a width of 1.17 MeV/c^2, consistent with the detector resolution.

D meson and the difference among the various parametrizations in the fit. The width remained the same, within the statistical errors, when the z_{D^*} cut was changed in the range from 0.4 up to 0.7, although the background became smaller as the cut was raised. According to the MC simulation of our detector, the apparatus resolution for Δ is $\Gamma_{\Delta}^{MC} = (0.94 \pm 0.11)$ MeV/c^2, where the error is statistical only. If we unfold the MC width quadratically from that measured, the remaining width is (0.70 ± 0.23) MeV/c^2, after adding the statistical error and the systematic error quadratically. Therefore, we put an upper limit on the D^{*+} decay width of $\Gamma_{D^{*+}} < 1.1$ MeV/c^2 at 90% CL, assuming that the error distribution is gaussian. This result is stable against the change of the MC width; the upper limit changes less than 0.06 if the MC width is varied within the error.

In reconstructing the D^+ through the $K^-\pi^+\pi^+$ decay mode, all of the tracks coming from the vertex were tried in turn as both K and π. The cuts of $z_D \geqslant 0.2$ and $|\cos\theta^*| > 0.15$ were applied, where θ^* is now defined by the axis perpendicular to the D^+ decay plane in the helicity frame. The invariant mass spectrum is shown in fig. 3, where the curve results from a fit using a polynomial form for the background and a gaussian form for the signal. The fitted mass is (1864 ± 3) MeV/c^2 and the width is (53 ± 4) MeV/c^2, consistent with that expected from the detector resolution.

The D^{*0} signal was searched for in the mass difference distribution $(\Delta \equiv M_{K^-\pi^+\pi^+\pi^-} - M_{K^-\pi^+\pi^+})$ for $z_{D^*} \geqslant 0.2$ with the D^+ selections of 1810 MeV/

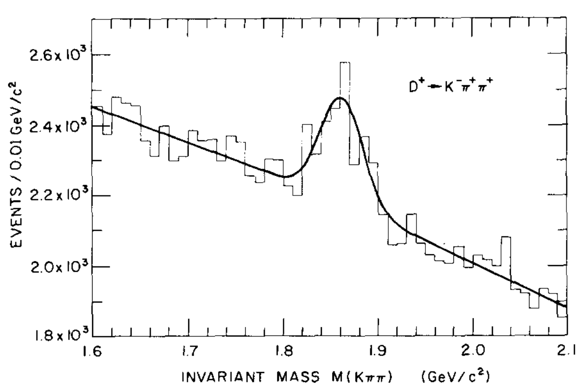

Fig. 3. The invariant $K\pi\pi$ mass distribution with $z_D \geqslant 0.2$ and $|\cos\theta^*| > 0.15$, where z_D and θ^* are redefined in the text.

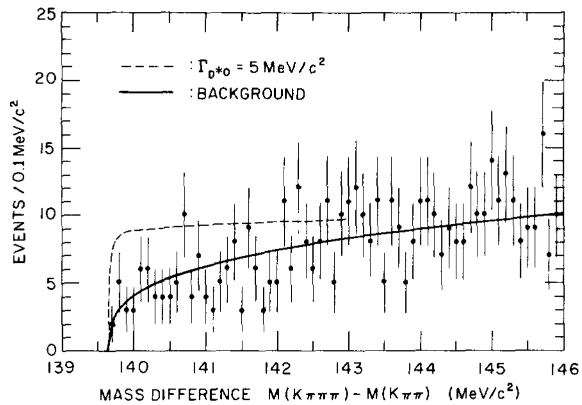

Fig. 4. The mass difference $(\Delta = M(K^-\pi^+\pi^+\pi^-) - M(K^-\pi^+\pi^+))$ distribution for D^{*0} with $z_{D^*} \geqslant 0.2$ and 1810 MeV/$c^2 <$ 1900 MeV/c^2. The solid curve shows the background estimated by the methods described in the text. The broken curve shows the expected signal with $\Gamma_{D^{*0}} = 5$ MeV/c^2.

$c^2 < M_{K^-\pi^+\pi^+} < 1900$ MeV/c^2 and $\chi^2 < 10$ for the D^+ mass constraint fit. Fig. 4 shows the mass difference distribution in the threshold region. The shape of the background, given by the solid curve in fig. 4, was estimated by three methods. Firstly, the D^+ candidates from the side bands of the peak in fig. 3 (1600 MeV/$c^2 < M_{K^-\pi^+\pi^+} < 1800$ MeV/c^2 and 1920 MeV/$c^2 < M_{K^-\pi^+\pi^+} < 2120$ MeV/c^2) were combined with the other π^-. Secondly, wrong sign combinations of $K^-\pi^+\pi^+\pi^+$ and $K^-\pi^+\pi^-\pi^+$ were studied. Thirdly, Monte Carlo events that do not include the $D^{*0} \to D^+\pi^-$ decay mode, were generated and passed through our detector simulation. All of these techniques gave a consistent shape within the statistical errors, and thus events resulting from the three methods were added together. The background was fitted to a form of $a(\Delta - \Delta_0)^b$, where a and b are free parameters and Δ_0 is a threshold value. The curve was normalized to the data in the region of 143 MeV/$c^2 < \Delta < 146$ MeV/c^2, away from the threshold.

After subtracting this background, the number of events in the threshold region of 139.7 MeV/$c^2 < \Delta < 143$ MeV/c^2 is -13 ± 17, consistent with no signal. The error is due to the statistics, as well as to the uncertainty in determining the background. The signal expected with $\Gamma_{D^{*0}} = 5$ MeV/c^2 (the current upper limit) is shown as the broken curve above the background in fig. 4, using experimental values [1] of $M_{D^{*0}} = 2007.2$ MeV/c^2 and $M_{D^+} = 1869.3$ MeV/

c^2. A p-wave Breit–Wigner form was used for the resonance shape of the D^{*0} and the mass difference distribution was smeared by the detector resolution. No threshold effect was used. The total number of D^{*0} produced was calculated from the D^{*+} data, assuming that the D^{*0} and D^{*+} production cross sections are equal. We used the most recent branching ratios for the reactions $D^0 \to K^-\pi^+$ and $D^+ \to K^-\pi^+\pi^+$ [4].

In order to set an upper limit, the width of the D^{*0} was varied with the masses of the D^{*0} and D^+ fixed at the above values and the expected signal was superimposed on the background curve. Then various χ^2 values were calculated between the curves for the signal plus background determined above and the data in the region of 139.7 MeV/$c^2 < \Delta <$ 143 MeV/c^2. The statistical error for the D^{*0} production and the normalization error for the background curve were included in the χ^2 calculation. In this way, we find the width to be $\Gamma_{D^{*0}} < 2.1$ MeV/c^2 at 90% CL. This result does not depend on the cuts applied previously. However, the current measurements of the D^{*0} mass have a large uncertainty of ± 2.1 MeV/c^2. Therefore, we repeated the above analysis for various D^{*0} mass values. The upper limit contour in the $M_{D^{*0}}$ versus $\Gamma_{D^{*0}}$ plane is shown in fig. 5.

These results may be compared to a calculation based on the measured branching fraction for the D^{*+} radiative decay. Since the radiative decay $D^{*+} \to D^+\gamma$ is an M1 transition, the electromagnetic width is given by the following formula:

$$\Gamma_{M1} = \tfrac{4}{3}\alpha(e_c/2m_c + e_d/2m_d)^2 k^3 ,$$

where $e_q/2m_q$ is the magnetic moment of the quark (charm quark and down quark) and k is the momentum of the photon. Therefore, the total decay width is given by $\Gamma_{D^{*+}} = \Gamma_{M1}/\mathrm{Br}(D^{*+} \to D^+\gamma)$. The estimated value of Γ_{M1} for $D^{*+} \to D^+\gamma$ is 2.4 keV/c^2, using the constituent quark masses of $m_c = 1.84$ GeV/c^2 and $m_d = 0.34$ GeV/c^2 [5]. The measured value of $\mathrm{Br}(D^{*+} \to D^+\gamma) = (17 \pm 5 \pm 5)\%$ [6] gives a total width of $\Gamma = 14^{+10}_{-4}$ keV/c^2, where the statistical and systematic errors are added quadratically. There are also calculations of the hadronic decay widths of $D^{*+} \to D^0\pi^+$ and $D^+\pi^0$ based on the SU(4)-invariant interaction [7]. Using these calculations and the measured branching ratios of these processes, the total width of the D^{*+} is (27 ± 5) keV/c^2, somewhat higher than that calculated from the radiative decay mode. Similar arguments apply for the D^{*0} decay. Our direct measurement is independent of such theoretical uncertainties.

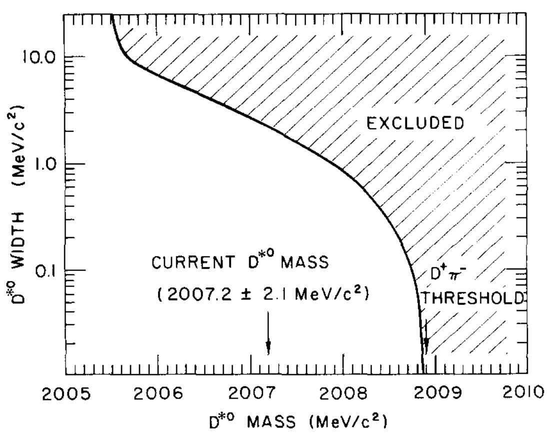

Fig. 5. The upper limit of the D^{*0} width as a function of the D^{*0} mass. The contour corresponds to the 90% confidence level.

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References

[1] Particle Data Group, M. Aguilar-Benitez et al., Review of particle properties, Phys. Lett. B 170 (1986) 1.
[2] K. Jagannathan, A. Jawahery, R. Namjoshi and C.G. Trahern, Phys. Rev. D 32 (1985) 1835.
[3] D. Bender et al., Phys. Rev. D 30 (1984) 515.
[4] J. Adler et al., Phys. Rev. Lett. 60 (1988) 89.
[5] E. Eichten, K. Gottfried, T. Kinoshita, K.D. Lane and T.M. Yan, Phys. Rev. D 21 (1980) 203.
[6] J. Adler et al., SLAC report SLAC-PUB-4518.
[7] H. Hallock, S. Oneda and M.D. Slaughter, Phys. Rev. D 15 (1977) 884;
R.L. Thews and A.N. Kamal, Phys. Rev. D 32 (1985) 810.