PRODUCTION AND FRAGMENTATION OF THE D^{*0} MESON IN e^+e^- ANNIHILATIONS AT $\sqrt{s}=29$ GeV

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Neutral D^* meson production in e^+e^- annihilation at $\sqrt{s}=29$ GeV has been studied using the high resolution spectrometer. The decay of D^{*0} into $D^0\gamma$, where the D^0 decays into $K^-\pi^+$, has been observed. The production cross section in units of the point cross section is 0.63 ± 0.22 for fractional energy $Z\geqslant0.5$. The fragmentation function is compared with that of the D^{*-} meson measured in the same experiment.

Present understanding of the production and fragmentation of charmed mesons in e^+e^- annihilation derives mainly from the study of the D^{*+}, D^0 and D^+ mesons [1–8]. There is little information about the D^{*0} meson [9–11]. Near threshold the D^{*0} production cross section and decay branching ratios were obtained by performing fits to the recoil mass spectrum in tagged D events which included various D and D^* decay channels [9,10]. The only direct observation of the D^{*0} was made by the JADE collaboration [11]. The world average of the $D^{*0}\to D^0\gamma$ branching ratio is 0.485 ± 0.076 [12], which can be compared to the theoretical prediction of 0.29 [13]. In this paper, we report the observation of the D^{*0} in the decay channel $D^0\gamma$, with the D^0 decaying into $K^-\pi^+$. For simplicity, particle states here imply both the particle and its charge conjugate.

The data, corresponding to an integrated luminosity of 300 pb^{-1}, were collected using the high resolution spectrometer (HRS) at the PEP e^+e^- storage ring at a center of mass energy $\sqrt{s}=29$ GeV. The HRS is a general purpose detector, which is described in detail elsewhere [14]. The subsystems relevant to this analysis are the 17-layer drift chamber system and the barrel calorimeter system [15]. Both of these devices are located within the solenoidal magnetic field of 1.62 T. The momentum resolution for high momentum tracks is $\sigma_p/p\simeq2\times10^{-3}p$ (p in GeV/c). The barrel calorimeter is essential for this analysis; it consists of 40 identical modules, each covering a 9° wedge in azimuth (ϕ) and extending over the polar

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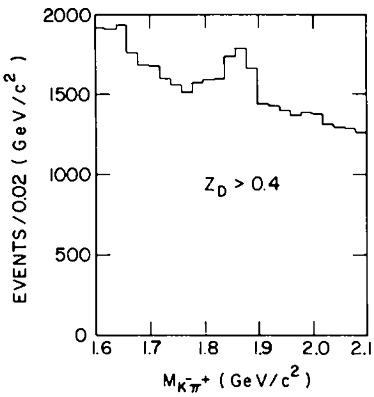

Fig. 1. $K^-\pi^+$ effective mass distribution for $Z_{K\pi} > 0.4$.

angle region $|\cos\theta| < 0.6$. Each module has two independent longitudinal segments consisting of lead-scintillator sandwiches (3 and 8 radiation lengths). Between the segments in each module is a single plane of 14 proportional wire tubes with current division readout, allowing shower location with a precision of 7.4 mrad azimuthally and 8 mrad in the dip angle. The energy resolution for electromagnetic showers is $\sigma_E/E \simeq 0.16/\sqrt{E}$ (E in GeV).

A clean sample of hadronic events was selected by requiring each event to have a minimum of five reconstructed charged tracks and to have a scalar sum of the total visible charged and neutral energy greater than 10 GeV.

No particle identification was used in reconstructing the D^0 meson from the D^{*0} decay and all charged particles originating from the interaction point were taken as both a pion and a kaon. The $K^-\pi^+$ effective mass distributions for $Z_{K\pi} > 0.4$, where $Z_{K\pi} = 2E_{K\pi}/\sqrt{s}$, is shown in fig. 1. A clear peak is seen around the D^0 mass of 1.865 GeV/c^2. In further analysis, all $K\pi$ combinations with $Z_{K\pi} > 0.4$ and with an effective mass between 1.82 and 1.90 GeV/c^2 were kinematically constrained to have the D^0 mass; only fits with a $\chi \leqslant 8$ were accepted. To further reduce the combinatorial background, a decay angle cut of $|\cos\theta^*_K| \leqslant 0.8$ was imposed, where θ^*_K is the angle between the K direction and the D^0 direction in the D^0 rest frame. Finally, all $K\pi$ combinations which, when combined with another pion from the event, were consistent with being from a $D^{*\pm}$ decay [2] were rejected. Since the detector has good mass resolution, the number of events with two $K^-\pi^+$ (π^-K^+) entries in the D^0 region is small.

A photon was defined as an isolated shower in the barrel calorimeter with no associated charged particle. The position of a shower was determined using information from the proportional wire tubes. Three categories of photon were used: a single isolated photon in a shower counter module; one photon sharing a shower counter module with a second photon (in this case the energy deposited in this module was divided equally between the two photons); and one photon and one charged particle sharing a shower counter module (in this case the average energy deposited by a minimum ionizing particle, which is 0.2 GeV, was subtracted from the total energy deposited in the module to determine the energy of the photon).

Since the angle between the D^0 direction and the photon in the lab frame, α, tends to be small, candidates corresponding to the $D^{*0} \to D^0\gamma$ decay were required to have $\cos\alpha \geqslant 0.9$ and further, the energy of the photon was required to be greater than 0.3 GeV. A photon was rejected if it was consistent with being from π^0 decay, defined as $M_{\gamma\gamma}$ between 0.10 and 0.17 GeV/c^2. All remaining candidates with $Z_{K\pi\gamma} \geqslant 0.5$ were accepted.

Because of the low Q value of the D^{*0} decay, the mass difference, $\Delta M = M(K^-\pi^+\gamma) - M(K^-\pi^+)$, was used to enhance the signal since the resolution in it is better than the resolution in mass. The ΔM distribution for $D^0\gamma$ decay is shown in fig. 2. A clear enhancement corresponding to the $D^0\gamma$ decay, is observed around 0.14 GeV/c^2. In order to estimate the background, the sidebands in the $K^-\pi^+$ combinations with $1.74 < M(K^-\pi^+) < 1.82$ GeV/c^2, and $1.90 < M(K^-\pi^+) < 1.98$ GeV/c^2 were combined with any photon candidate passing the previously described cuts. This background was parametrized with a smooth function,

$$f(\Delta M) = \alpha_1 (\Delta M)^{\alpha_2}$$

$$\times \exp\{-[\alpha_3 \Delta M + \alpha_4 (\Delta M)^2 + \alpha_5 (\Delta M)^3]\},$$

shown as the dashed curve in fig. 2. A Monte Carlo study [16][‡1] shows that a photon originating from a π^0 which was not removed by the selection cuts, when combined with a D^0, results in a peak at around 75

‡1 Version 5.3 of the Lund Monte Carlo has been used.

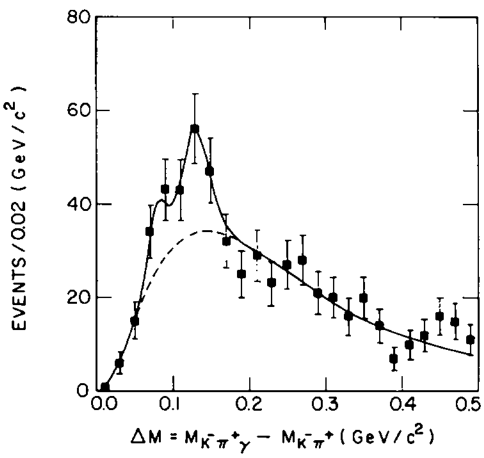

Fig. 2. The mass difference. $\Delta M = M(K^-\pi^+\gamma) - M(K^-\pi^+)$ distribution for $Z_{K\pi\gamma} \geqslant 0.5$. The solid curve is a fit to the data and the dashed curve is a fit to the background, both as described in the text.

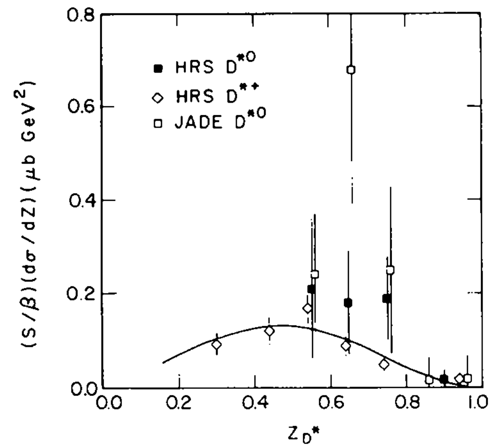

Fig. 3. The fragmentation function for the D^{*0} measured by this experiment and by the JADE collaboration (ref. [11]) for $Z_{D^{*0}} \geqslant 0.5$. The fragmentation function for the D^{*+} (ref. [18]), $Z_{D^*} > 0.2$, is shown for comparison. The curve is a fit of the Peterson fragmentation function (ref. [19]) to the D^{*+} data.

MeV/c^2; in fact, a hint of such a peak is observed in the data. The data in fig. 2 were fitted with the background parametrization plus a gaussian for the D^{*0} and a gaussian contribution for the photons originating from a π^0. The central values of the gaussians were fixed to those determined by the Monte Carlo simulation. The fitted widths are consistent with the detector resolution. The resulting signal for $D^{*0} \to D^0\gamma$ is 49 ± 14 events; the error includes the uncertainty in the background.

In determining the production cross section, corrections were made for acceptance and for initial-state radiation. Acceptance corrections, including all photon selections previously described, were calculated using a Monte Carlo simulation. A center of mass energy of 28.3 GeV was used for the point cross section to correct for initial-state radiation. The production cross sectionw as extracted from the measured number of $D^{*0} \to D^0\gamma$ decays using a branching ratio of 0.485 ± 0.076 [12]. The production cross section times the branching ratio is $\sigma(D^{*0})B(D^0 \to K^-\pi^+) = 3.79 \pm 1.30$ pb for $Z \geqslant 0.5$. Using the recent Mark III [17] result on the branching ratio for $D^0 \to K^-\pi^+$ of 0.056 ± 0.005, the cross section for D^{*0} at $Z \geqslant 0.5$ is 68 ± 24 pb, in agreement with the result of 42 ± 8 pb measured for D^{*+} in the same Z region by the HRS [18]. This D^{*+} cross section was calculated assuming a branching ratio for $D^{*+} \to D^0\pi^+ = 0.6 \pm 0.1$. The corresponding R value for D^{*0} is 0.63 ± 0.22, which can be compared with $R(D^{*0}) = 1.4 \pm 0.4$ at $Z \geqslant 0.5$ measured by the JADE collaboration. The result from JADE, which was recalculated using the new $D^0 \to K^-\pi^+$ decay branching ratio [17], differs by almost two standard deviations from our result.

Our measurement of the cross section for inclusive D^0 production [18] leads to an upper limit for the D^{*0} cross section at $Z \geqslant 0.5$ of 73 ± 9 pb, assuming that all D^0's result from D^* decay. Our measured value is in agreement with this limit. Adding the D^{*0} and D^{*+} cross sections, we obtain $R(D^*) = 1.01 \pm 0.23$ for $Z \geqslant 0.5$. Using the total D^{*+} cross section and the D^{*0} cross section obtained by extrapolating to low-Z regions, we find $R(D^*) = 1.92 \pm 0.46$ for all Z regions. The expected R value at 29 GeV for inclusive charm production for all Z regions is 3.5 using $\alpha_s = 0.17$; this includes 0.7 units from b decay. Our value of R for D^* production therefore accounts only partially for charm production.

In order to determine the D^{*0} fragmentation function, the above analysis was repeated for four Z regions. The fragmentation function is compared in fig. 3 with that for the D^{*+} and with the JADE D^{*0} data. The curve is a fit of the Peterson fragmentation function [19] to the D^{*+} data. The D^{*0} results are consistent with that for D^{*+} and is not inconsistent with the results from JADE.

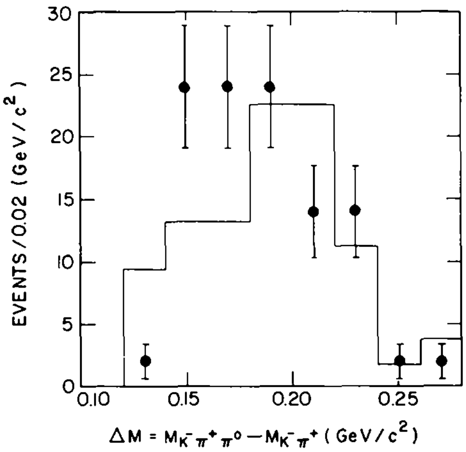

Fig. 4. The mass difference, $\Delta M = M(K^-\pi^+\pi^0) - M(K^-\pi^+)$ distribution for $Z_{K\pi\pi^0} \geqslant 0.5$. The histogram is the background as described in the text.

In order to search for the decay mode $D^{*0} \to D^0\pi^0$, the photon energy cut was reduced to 0.1 GeV to increase the detection efficiency. Combinations of two photons with a mass between 0.10 and 0.17 GeV/c^2 were taken as π^0 candidates. The energies of the two photons were then constrained to yield the π^0 mass, and combinations with $\chi^2 \leqslant 8$ for this mass constraint were accepted. The angle, λ, between the π^0 direction and the D^0 direction in the lab frame is small since the π^0 is produced with very low momentum in the D^{*0} rest frame. At 29 GeV, the energy of the π^0 in GeV is approximately numerically equal to $Z_{D^{*0}}$. Therefore, in order to reduce the combinatorial background, it was required that $\cos\lambda \geqslant 0.95$ and the energy of the two-photon system, $E_{\gamma\gamma}$, be between 0.4 and 1.2 GeV. Exploiting the fact that the energy of the π^0 is very small in the D^{*0} rest frame, one can calculate E_0 which is the energy of the π^0 in the lab frame, provided that the energy of the D^0 in the lab frame, E_D, is known. The energy difference, $|E_0 - E_{\gamma\gamma}|$, was required to be <0.2 GeV, where $E_0 = E_D x/(1-x)$, and $x = M(\pi^0)/M(D^{*0})$. This cut was applied to both the signal and the background region. All candidates with $Z_{K\pi(\gamma\gamma)} \geqslant 0.5$ were accepted.

Since the detection efficiency for the $D^0\pi^0$ decay is small, only a few candidates for this decay were found. The $\Delta M = M(K^-\pi^+\pi^0) - M(K^-\pi^+)$ distribution is shown in fig. 4. One possible background to the $D^0\pi^0$ decay comes from the decay $D^0 \to K^-\pi^+\pi^0$, which gives an enhancement in the $K^-\pi^-$ combinations known as the S^0 peak [20] at around 1.62 GeV. Such a $K^-\pi^-$ candidate, when combined with a π^0 candidate from the same D^0 decay would result in a ΔM distribution similar to the one for genuine $D^0\pi^0$ decay. In order to minimize this effect, sidebands away from the S^0 peak with $1.78 < M(K^-\pi^-) < 1.82$ GeV/c^2 and $1.90 < M(K^-\pi^+) < 1.94$ GeV/c^2 were used. The background histogram was normalized using four 80 MeV $K^-\pi^+$ sidebands centered at 1.70, 1.78, 1.94 and 2.02 GeV/c^2. The resulting background is shown as the histogram in fig. 4. The ΔM resolution for the D^{*0} signal is expected to be about 30 MeV from Monte Carlo studies; therefore, combinations with ΔM between 0.1 and 0.2 GeV/c^2 were considered as D^{*0} candidates. These selections yielded a signal of 16 ± 11 events after background subtraction.

Assuming that the only decay modes of the D^{*0} are $D^0\gamma$ and $D^0\pi^0$, the resulting branching ratio for $D^{*0} \to D^0\gamma$ is 0.47 ± 0.23, where the error includes the statistical error and uncertainties in acceptance calculations. This value is independent of the $D^0 \to K\pi$ branching ratio, since it is common to both $D^0\gamma$ and $D^0\pi^0$ decays.

In conclusion, we have observed the D^{*0} in the decay channel $D^0\gamma$. The cross section $\sigma(D^{*0})$ for $Z \geqslant 0.5$ is 68 ± 24 pb, and the corresponding R value is 0.63 ± 0.22, in good agreement with similar D^{*+} results from this experiment, and the D^{*0} results from JADE. The fragmentation function for the D^{*0} is consistent with that of the D^{*+} measured previously. Assuming $D^0\gamma$ and $D^0\pi^0$ are the only two decay modes, the branching ratio for $D^{*0} \to D^0\gamma$ is 0.47 ± 0.23, which is in agreement with previous measurement.

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