Study of D_2^{*0} and D_1^0 Mesons

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Abstract

Using data from the CLEO II and CLEO II.V detectors at the Cornell Electron Storage Ring, we have studied the properties of two $L = 1$ charmed mesons, $D_1(2420)^0$ and $D_2(2460)^{*0}$. We reconstruct the $D_2(2460)^{*0}$ in the two decay modes $D_2^{*0} \to D^+\pi^-$ and $D_2^{*0} \to D^{*+}\pi^-$, and we reconstruct the $D_1(2420)^0$ in the mode $D_1^0 \to D^{*+}\pi^-$. For the $D_1(2420)^0$, we find a mass and width of $\Gamma = 2421.4 \pm 2.5$ MeV/c^2 and 36.7 ± 10 MeV/c^2, respectively. For the $D_2(2460)^{*0}$, we find a mass of 2462.5 ± 1.8 MeV/c^2 and a width of $\Gamma = 56.2 \pm 10.0$ MeV/c^2. This width is significantly larger than values obtained in previous studies.

Introduction

The mesons composed of one charmed quark (Q) and one light quark ($\bar{q}$), with relative orbital angular momentum $L = 1$, are known as the D** mesons. There are four states, with spin-parity $J^P = 0^+,\ 1^+,\ 1^+,$ and 2^+. Three of these states, with spin-parity $J^P = 0^+,\ 1^+,$ and 2^+, carry total quark spin $S = 1$, while the remaining $J^P = 1^+$ state carries quark spin $S = 0$. In the notation introduced by the Particle Data Group [1], these states are labeled D_1, D_0^*, D_1^*, and D_2^*, where the subscript is the spin J of the state.

Parity and angular momentum conservation allow the decays $D_2^{*0} \to D^{*+}\pi^-$ and $D_2^{*0} \to D^+\pi^-$ through D-wave decays, and $D_1^0 \to D^{*+}\pi^-$ through both S-wave and D-wave decays. Heavy Quark Effective Theory (HQET) [2, 3], predicts the mixing of the two D_1^0 states such that one mixed state, with a very large width (hundreds of MeV/c^2), decays primarily via S waves, while the other mixed state is relatively narrow (tens of MeV/c^2) and decays through D-waves.

This goal of this analysis was to determine the mass and width of the D_2^{*0} and of the narrow D_1^0 state, using all of the available data from CLEO II and CLEO II.V. Additionally, we hoped to obtain values for the branching fractions of the two D_2^{*0} decay modes.

Data Sample and Event Selection

The data used in this analysis were selected from hadronic events produced in e^+e^- annihilations at CESR and collected with the CLEO II and CLEO II.V detectors. A detailed description of the detector can be found elsewhere [4]. The center-of-mass energies used were at the mass of the $\Upsilon(4S)$, $E_{CM} = 10.580$ GeV, and in the nearby continuum. The CLEO II data used in the $D_2^{*0} \to D^+\pi^-$ analysis correspond to an integrated luminosity of 3593 pb^{-1}, while the CLEO II.V data have an integrated luminosity of 4547 pb^{-1}. For the $D_2^{*0} \to D^*+\pi^-$ and $D_1^0 \to D^* + \pi^-$ analysis, the CLEO II.V data correspond to an integrated luminosity of 5259 pb^{-1}. Events selected were required to have a primary vertex within ± 2 cm in the $r - \phi$ plane (perpendicular to the beam) and ± 5 cm in the z-direction (the direction of the beam) of the normal interaction point, to have a minimum of 3 tracks,and to have a total visible energy greater than 15% of the center-of-mass energy (to reduce contamination from two-photon events).

Additionally, a 3 standard deviation dE/dx cut was placed on all charged tracks and a 3 standard deviation time-of-flight cut was made when the information was available.

When reconstructing π^0 candidates, we used pairs of photons from the barrel region, $|\cos\theta| < 0.707$, where the energy resolution is best. The photons selected had a minimum energy of 50 MeV/c^2 and were isolated from charged tracks. The π^0 candidates were required to have an invariant mass within 20 MeV/c^2 of the known π^0 mass and, when kinematically fit to the known π^0 mass, have a χ^2 less than or equal to 12.

$D_2^{*0} \to D^+\pi^-$

We first reconstructed the D^+ in the decay mode $D^+ \to K^-\pi^+\pi^+$. To reduce the background, we required that candidates satisfy the condition $\cos\theta_K < 0.8$, where θ_K is the angle between the direction of the D^+ momentum and the direction of the K^- momentum in the D^+ rest frame. The signal distribution of $\cos\theta_K$ is expected to be flat, while Monte Carlo studies showed that the background peaks near 1. Selected candidates were further required to satisfy $|M(K^-\pi^+\pi^+) - 1869.3\,\mathrm{MeV/c^2}| \leq 15$ MeV/c^2, about a 3σ cut.

Each D^+ candidate was then combined with each remaining π^- in the event. We required $\cos\theta_\pi > -0.84$, where θ_π is the angle between the direction of the D_2^{*0} momentum and the direction of the π^- momentum, which reduced contamination from combinations of the D^+ with the many slow π^- tracks in an event. To reduce combinatorial background, selected events were required to satisfy $x_p(D_2^{*0}) > 0.65$, where

$$x_p(D_2^{*0}) = p(D_2^{*0})/p_{max} \tag{1}$$

and

$$p_{max} = \sqrt{E_{beam}^2 - M(D_2^{*0})^2}. \tag{2}$$

To further purify the sample, we calculated the total probability, P_{tot}, of the candidate using the particle identification (dE/dx, and time-of-flight when available) of the π and K particles. $P_{tot}(\chi^2_{tot}, N_{dof})$ is defined as the probability to observe $\chi^2 > \chi^2_{tot}$ for N_{dof} degrees of freedom. For signal the distribution of P_{tot} is expected to be flat; however, Monte Carlo studies showed a large peak at P_{tot}=0 due to background contamination. We accordingly imposed the requirement $P_{tot} > 0.2$.

The $M(D^+\pi^-) - M(D^+) + 1869.3$ MeV/c^2 mass distribution for all CLEO II and CLEO II.V candidates surviving the above cuts is shown in Figure 1. The spectrum was fitted using a Breight-Wigner resonance shape convoluted with a double Gaussian resolution function for the signal, and a fourth-order Chebyshev polynomial for the background. Since we did not reconstruct neutrals in the decay chain, the region from 2250 MeV/c^2 to 2450 MeV/c^2 is populated by feed-down from the decay $D_J^0 \to D^{*+}\pi^-$, with $D^{*+} \to D^+\pi^0$ or $D^+\gamma$. This region was accordingly excluded from the fit.

The parameters for the double Gaussian were constrained to values determined from Monte Carlo studies of signals with zero intrinsic width. The fitted spectrum for CLEO II Monte Carlo data is shown in Figure 2. The data in Figure 1 were fitted using the resolutions (σ's) determined from CLEO II Monte Carlo data; the results of a fit using parameters determined from CLEO II.V Monte Carlo data and the results of the CLEO II and CLEO II.V data when plotted separately can be found in Table 1.

TABLE 1. CLEO measurement of the $D_2(2460)^{*0}$ mass and width.

Experiment	Mass(MeV)	Width(MeV)
CLEO II	2463.3±2.7	55.7±9.2
CLEO II.V	2461.1±2.6	52.6±5.4
CLEO II & II.V, σ's from CLEO II Monte Carlo	2462.5±2.0	56.3±10.0
CLEO II & II.V, σ's from CLEO II.5 Monte Carlo	2462.5±2.2	56.1±6.9

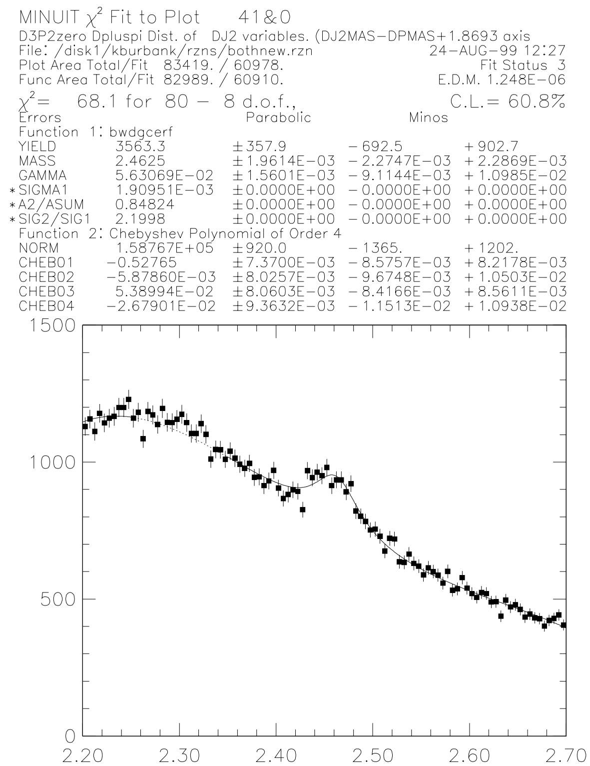

FIGURE 1. The $M(D^+\pi^-) - M(D^+) + 1869.3 MeV/c^2$ mass distribution for CLEO II and CLEO II.V candidates, fitted with parameters from CLEO II Monte Carlo studies.

We find a D_2^{*0} width of 56 ±10 MeV/c^2, which is larger than values found in previous studies [1]. The results of these studies are shown in Figure 3.

Prompted by this discrepancy, we investigated the resolution of the D^+. Monte Carlo data, showed a resolution of 4.6±0.54 MeV/c^2 for CLEO II.V. Fluctuations in the small amount of available CLEO II Monte Carlo data precluded a good fit, but the parameters from the CLEO II.V fit the data nearly as well as the best fit.

The D^+ mass spectra for CLEO II and CLEO II.V data were then fit to a double Gaussian function with a first-order Chebyshev polynomial for the background. Figure 4 shows this distribution for the CLEO II.V data; we obtain a resolution of 5.3±0.49 MeV/c^2. For both CLEO II and CLEO II.V data, the resolutions found were comparable to those found in

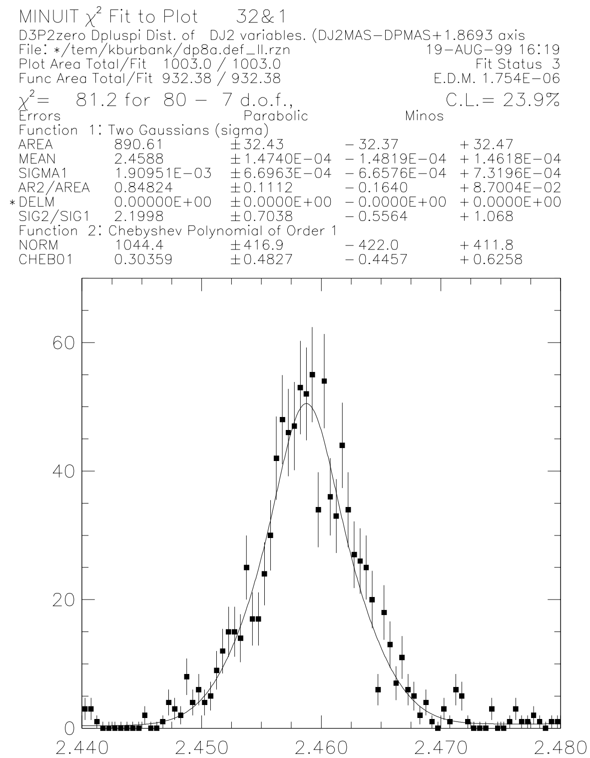

FIGURE 2. The $M(D^+\pi^-) - M(D^+) + 1869.3MeV/c^2$ mass distribution for CLEO II Monte Carlo data with zero-width signal.

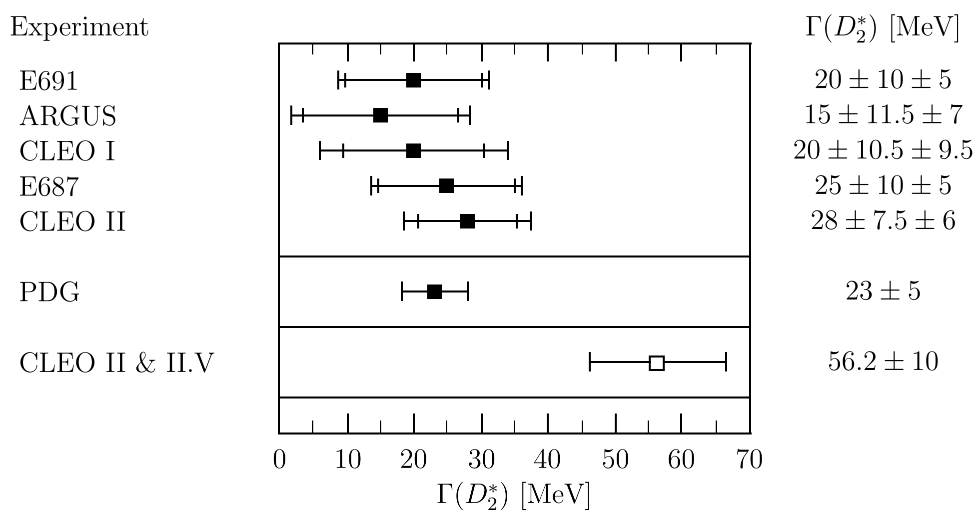

FIGURE 3. Measurements of the D_2^{*0} total width.

the Monte Carlo studies, as was expected since the intrinsic width of the D^+ is very small. Since the width of the D^+ was much smaller than that of the D_2^{*0}, it cannot account for the unexpectedly high width of the D_2^{*0}.

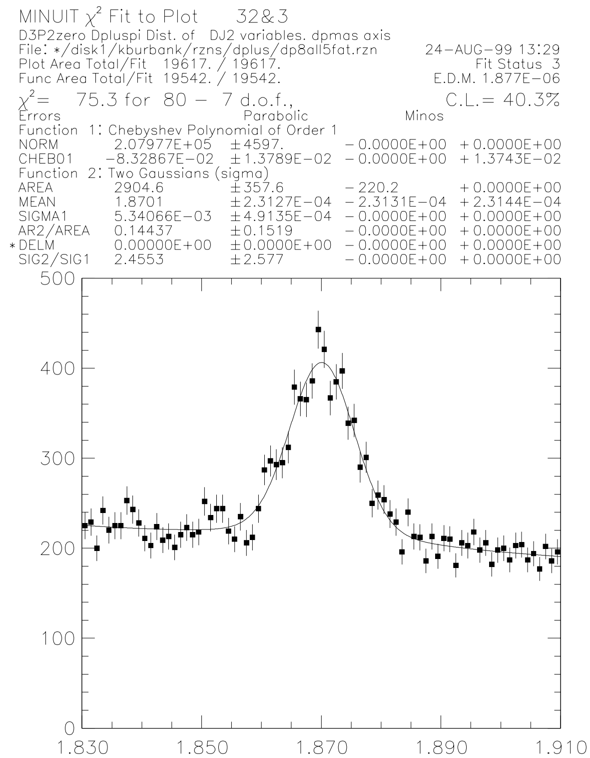

FIGURE 4. The mass distribution of D^+ candidates.

$$D_J \to D^{*+}\pi^-$$

We began by reconstructing D^0 in the three decay modes

$$\begin{aligned} D^0 &\to K^-\pi^+ \\ &\to K^-\pi^+\pi^+\pi^- \\ &\to K^-\pi^+\pi^0 \end{aligned} \tag{3}$$

Each D^0 candidate was required to satisfy $|M(D^0) - 1864.6\ \text{MeV}/c^2| \leq 50\ \text{MeV}/c^2$. The D^0 candidates were then combined with each remaining π^- in the event to form D^{*+} candidates.

To reduce combinatorial background, we require that $p_{\pi^-} < 300\ \text{MeV}/c^2$, and to ensure that the slow π^- is oppositely aligned with the K^-, we require that their momenta be of opposite sign. To purify the sample, we impose the cut $|M(D^{*+}) - M(D^0) - 145.42\ \text{MeV}/c^2\ | \leq 2\ \text{MeV}/c^2$. Finally, we combined the D^{*+} candidates with π^- particles to form D_J candidates.

The $M(D^{*+}\pi^-) - M(D^0) + 2010\ \text{MeV}/c^2$ mass distribution for all selected CLEO II.V D_J candidates is shown in Figure 5. Computer problems made it difficult to fit this spectrum with a Breit-Wigner resonance convoluted with a double Gaussian, as we did in the D^+ analysis. Instead, since the resolution was small compared to the width, we fit using two Breight-Wigner resonance shapes for the signal and a fourth-order Chebyshev polynomial for the background.

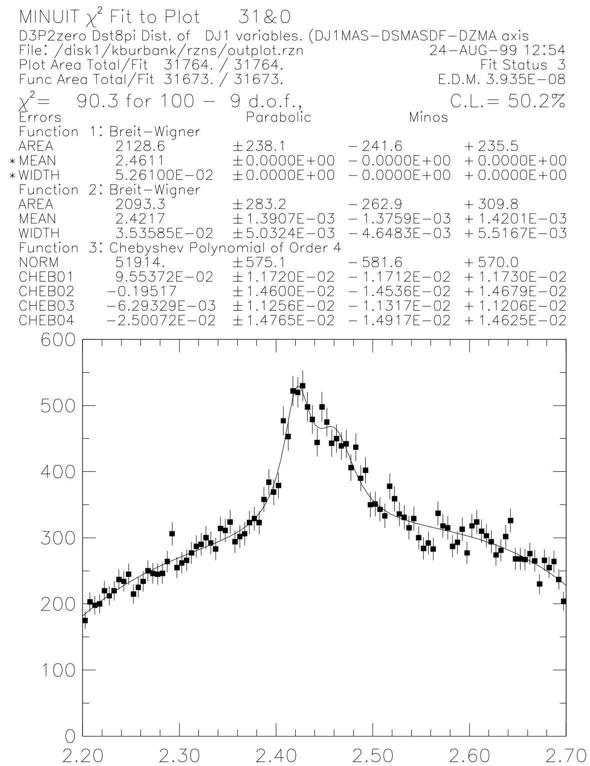

FIGURE 5. The $M(D^{*+}\pi^-) - M(D^0) + 2010$ MeV/c^2 mass distribution for all selected CLEO II.V D_J candidates.

When the mass and width of the Breight-Wigner resonance corresponding to the D_2^{*0} are constrained to the values obtained from the above analysis of the $D_2^{*0} \to D^+\pi^-$ decay mode, we obtain a mass of 2421.7±1.4 MeV/c^2 for the D_1^0 and a width of Γ=35.4±5.0 MeV/c^2.

Results and Conclusions

We obtain a mass of 2421.4±2.5 MeV/c^2 and a width of Γ = 36.7±10.0 MeV for the $D_1(2420)^0$. For the $D_2(2460)^{*0}$, we find a mass of 2462.5±1.8 MeV/c^2 and a width of Γ = 56.2±10.0 MeV/c^2. The masses agree well with previous results [1]; however, we find $\Gamma(D_2^{*0})$ to be two to three standard deviations higher than previous measurements.

The cause of the unexpectedly high D_2^{*0} width remains unknown and this issue must be investigated further. One direction for further work should be an investigation of possible effects caused by binning when fitting the data. Additionally, for purposes of comparison, the data used in the previous CLEO study [5] should be reanalyzed with the techniques used in this analysis.

Acknowledgments

I would like to thank Prof. David Cassel of Cornell University for proposing this Research Experience for Undergraduates project and for his support and guidance throughout the process. I would also like to thank Dr. Naresh Menon of Purdue University for his help and his enthusiasm in answering my innumerable questions along the way.

This work was supported by the National Science Foundation REU grant PHY-9731882 and research grant PHY-9809799.

Footnotes and References

1. Particle Data Group, C. Casso *et al.*, The European Physical Journal **C3**, 1 (1998)
2. J. Bartelt and S. Shukla, Ann. Rev. Nucl. Part. Sci. **45**, 133 (1995).
3. R. Kutschke, Proceedings of the NATO Advanced Study Institute on Hadron Spectroscopy and the Confinement Problem, London and Swansea, July 1995.
4. CLEO Collaboration, Y. Kubota *et al.* Nuclear Instruments and Methods A **320**, 66 (1992)
5. CLEO Collaboration, P. Avery *et al.*, Physics Letters B **331**, 236 (1994)