CHARMED HADRON SPECTROSCOPY FROM FOCUS

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We report charmed hadron spectroscopy results from the photoproduction experiment FOCUS (FNAL-E831). We report new, precise measurements of the masses and widths of the D_2^{*+} and D_2^{*0} mesons, evidence for the D_0^{*+} and D_0^{*0} broad states (the first such evidence in $D^0\pi^+$), and confirmation of the recently observed $D_s^+(2317)$ charmed-strange state.

1 Introduction

With very accurate measurements of the parameters of the ground state charmed mesons, interest has shifted to the array of excited charm meson states, especially with the interesting discoveries of the last year in the D_s sector.

In the limit of infinite quark masses, D mesons may be treated as a "hydrogen atom" type object where the heavy quark does not contribute to the orbital degrees of freedom. In this treatment the quantum numbers of the heavy and light quarks decouple. The heavy quark is described by its spin, s_Q, and the light quark degrees of freedom are described by $\boldsymbol{j_q} = \boldsymbol{s_q} + \boldsymbol{L}$ where $\boldsymbol{s_q}$ is the spin of the light quark and $\boldsymbol{L}$ is its angular momentum. For $L = 1$ we have $j_q = 1/2, 3/2$. Combined with $s_Q = 1/2$, we obtain four states, one with $J = 0$, one with $J = 2$, and two with $J = 1$ (one each with $j_q = 1/2$ and $3/2$). In the Heavy Quark Symmetry limit, conservation of parity and j_q requires that the strong decays $D_J^{(*)}(j_q = 3/2) \to D^{(*)}\pi$ proceed via D-wave decays while $D_J^{(*)}(j_q = 1/2) \to D^{(*)}\pi$ proceed via S-wave decays. States decaying via S-wave decays are expected to be broad while those decaying via D-wave are expected to be narrow.

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[a] For the FOCUS Collaboration (`http://www-focus.fnal.gov/`)

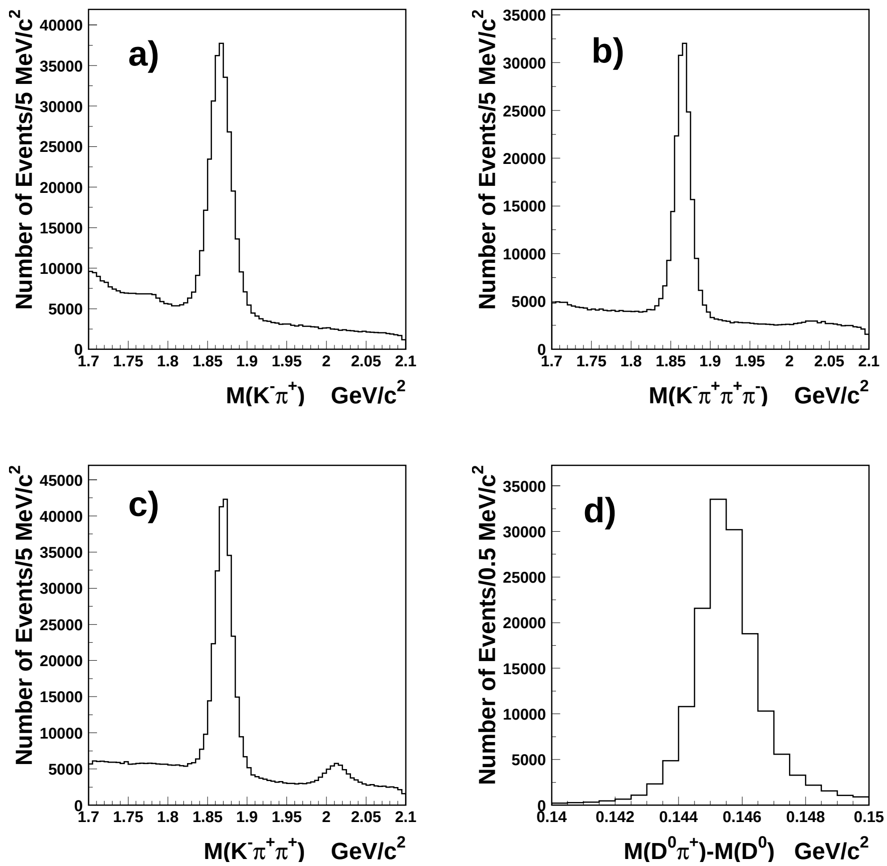

Figure 1: D^0 and D^+ samples used in the analysis. The top left plot shows $D^0 \to K^-\pi^+$, the top right shows $D^0 \to K^-\pi^+\pi^+\pi^-$, and the bottom left shows the $D^+ \to K^-\pi^+\pi^+$ sample. Also shown is the $D^{*+} - D^0$ mass difference which is used as a veto on D^0 candidates. (The additional bump in the $D^+ \to K^-\pi^+\pi^+$ plot is from $D^{*+} \to D^0\pi^+$; $D^0 \to K^-\pi^+$.)

2 Measurements of $L = 1$ D mesons decaying to $D\pi$

Photoproduction of charm is a good compromise between the excellent purity of e^-e^+ collisions and the large numbers of higher multiplicity events available in hadron-nucleon collisions. The lower multiplicity of the photoproduction vertex is especially important for spectroscopy of excited charm states since discriminating between pions produced in the interaction and those originating from decays is difficult.

For its studies of $D^0\pi^+$ and $D^+\pi^-$ final states, FOCUS begins with over 500,000 D mesons decaying into their "golden" modes: $D^0 \to K^-\pi^+$, $D^+ \to K^-\pi^+\pi^+$, and $D^0 \to K^-\pi^+\pi^+\pi^-$. These samples are shown in Figure 1. Typical cuts are placed on these samples requiring the production and decay vertices to be well separated and that the daughter particle species are identified by the Čerenkov system. Combinations within 2σ of the nominal D mass are combined with additional pions to form excited D meson candidates. Also shown in Figure 1 is the invariant mass of $D^{*+} \to D^0\pi^+$ candidates; D^0s from candidates within 3σ of the D^{*+} mass are excluded from further consideration.

In Figure 2 we show the results of fitting the $D\pi$ invariant mass distributions without including contributions from broad S-wave decays. The left-most "peak" in both plots is due to feed-downs from the D_1 and D_2^* states which decay to $D^*\pi$ and the D^* subsequently decays to either a D^0 or D^+ and an undetected γ or π^0. The shape of this feed-down contribution is

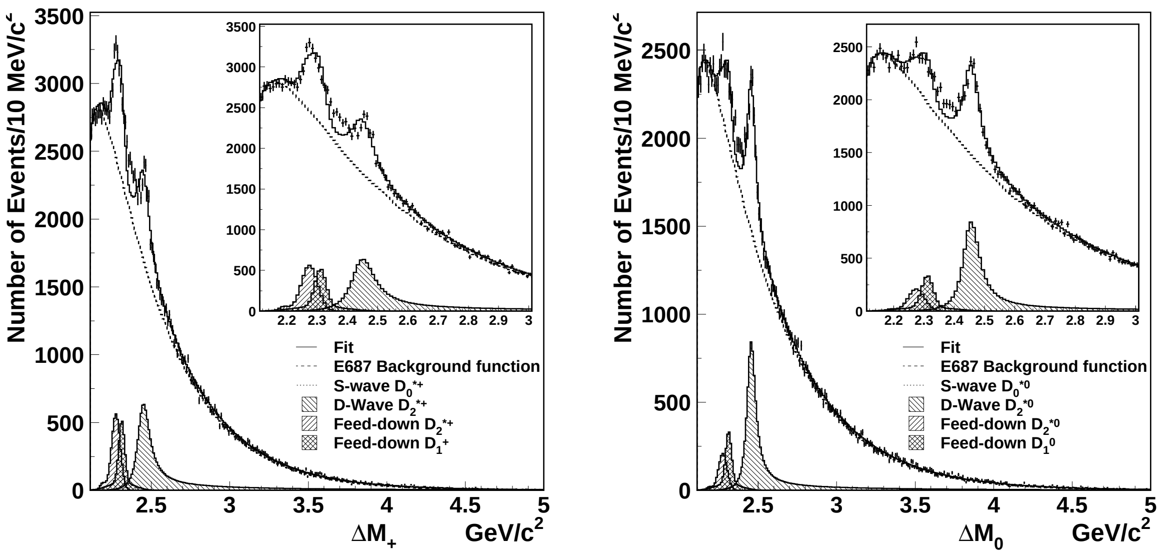

Figure 2: Fitting $D\pi$ invariant masses without an S-wave contribution. The $D^0\pi^+$ invariant mass is shown on the left, the $D^+\pi^-$ on the right. Also shown in the insert of each plot is the invariant mass below 3.0 GeV/c^2.

determined by Monte Carlo simulations using the PDG values for the D_1 and D_2^* masses and widths. The second, right-most peaks, are the previously observed D_2^* states. Inspecting the fits in Figure 2, it is apparent that the fit quality is very poor between the feed-down and D_2^* peaks for both charge combinations even though the D_2^* fit parameters obtained in this fit are very far from the accepted values. It is this disagreement that leads us to introduce an S-wave contribution.

In Figure 3 we show the results obtained by fitting with the contributions outlined above plus an additional contribution attributed to $D_0^* \to D\pi$ decays. Not, however, that we cannot distinguish between $D_0^* \to D\pi$ and other decays, such as a $j_q = 1/2$ (broad) $D_1 \to D^*\pi$ where the D^* decays with undetected neutrals. However, the measured yields of excess in neutral and charged final states suggest the contamination from feed-downs is small. In our measurement, shown in Figure 3, we have also included our values for the D_2^* parameters in the simulated feed-down shapes rather than PDG values as in Figure 2. (This is a small effect.)

We have tried several different background parameterizations and other systematic tests to assess the errors on our measurements and to test the assumption of a broad component. In all cases, a broad component is needed to adequately fit the data. To minimize systematic errors on the mass scaling of the experiment, we actually measure mass differences with respect to the D^0 or D^+ and add the PDG D masses to obtain our final numbers. As no one source of systematic error dominates, the reader is referred to the publication [1] for a detailed discussion of the systematic studies.

In Table 1 we compare our results for the narrow D_2^* states and our results for the broad state, which are interpreted as D_0^* states, with the PDG [2] averages and with recent results from Belle. [3] In addition to the values in Table 1, we also measure the mass splitting between D_2^{*+} and D_2^{*0} to be $3.1 \pm 1.9 \pm 0.9$ compared to the PDG value of 0.0 ± 3.3. The D_0^* results from Belle only consider the neutral final state, so our evidence for D_0^{*+} is the first such observation. For both the D_2^* and D_0^* the statistical accuracy of our results compare favorably with both the world averages (if any) and the Belle results. The FOCUS results have recently been published [1], and the published paper should be consulted for additional details.

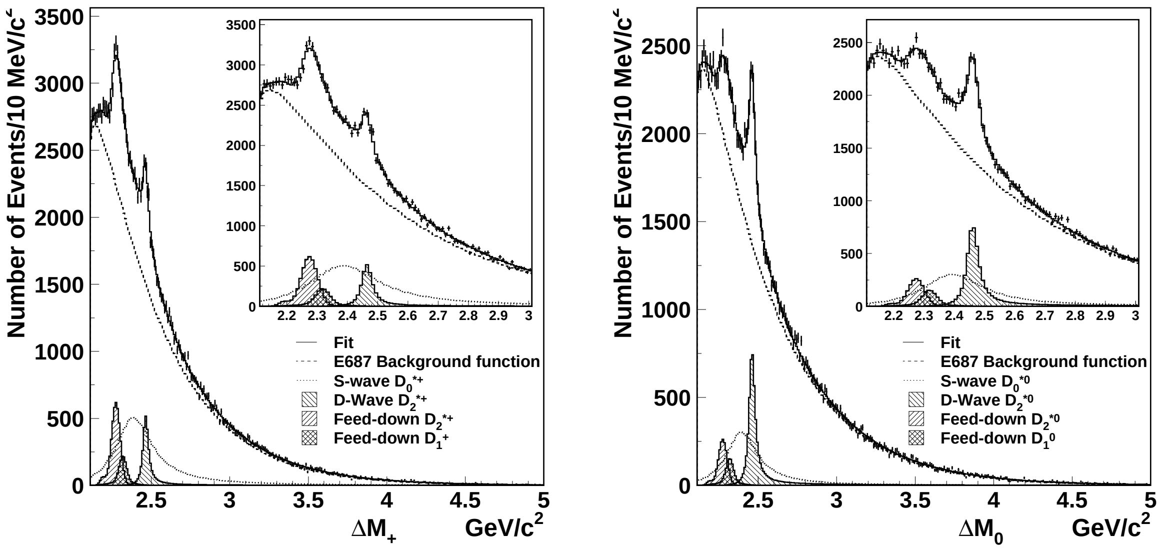

Figure 3: Fitting $D\pi$ invariant masses with an S-wave contribution. The $D^0\pi^+$ invariant mass is shown on the left, the $D^+\pi^-$ on the right. Also shown in the insert of each plot is the invariant mass below 3.0 GeV/c^2. As evident in the regions between the feed-down peaks and the D_2^* signals, the fit quality is much improved by the addition of S-wave contributions for D_0^*.

Table 1: Summary of results for D_2^{*0} and D_2^{*+}. This table compares the results from this measurement with those from the Particle Data Group and Belle (not included in the PDG).

	D_2^{*0}	D_2^{*+}	"$D_0^{*0}(j_\ell = \frac{1}{2})$"	"$D_0^{*+}(j_\ell = \frac{1}{2})$"
Yield	$5776 \pm 869 \pm 696$	$3474 \pm 670 \pm 656$	9810 ± 2657	18754 ± 2189
Mass	$2464.5 \pm 1.1 \pm 1.9$	$2467.6 \pm 1.5 \pm 0.8$	$2407 \pm 21 \pm 35$	$2403 \pm 14 \pm 35$
PDG03	2458.9 ± 2.0	2459 ± 4		
Belle03	2461.6 ± 3.9		2308 ± 36	
Width	$38.7 \pm 5.3 \pm 2.9$	$34.1 \pm 6.5 \pm 4.2$	$240 \pm 55 \pm 59$	$283 \pm 24 \pm 34$
PDG03	23 ± 5	25^{+8}_{-7}		
Belle03	45.6 ± 8.0		276 ± 66	

3 Observation of $D_s^+(2317) \to D_s^+\pi^0$

Recent observations by BaBar,[4] CLEO,[5] and Belle [6] of two unexpected, narrow, excited D_s states have proved exciting. A likely explanation for these states appears to be that they are $L = 1$ mesons which lie below the $D^{(*)}K$ thresholds, the preferred decay modes. Instead, they are constrained to decay via $D_s^{(*)+}\pi^0$. Why these D_s states should be less massive than earlier predicted is an open question. FOCUS confirms the first of these states, the $D_s^+(2317)$ which decays to $D_s^+\pi^0$. The D_s^+ is reconstructed in $D_s^+ \to \phi\pi^+$; $\phi \to K^+K^-$ which is then combined with a π^0 reconstructed from two photons in the inner calorimeter. The energy of this π^0 is corrected based on studies of the decays $D_s^{*+} \to D_s\pi^0$ and $D^0 \to K^-\pi^+\pi^0$. A plot of the $D_s\pi^0$ mass is shown in Figure 4. We find 58 events and preliminarily measure the mass to be 2323 ± 2 MeV/c^2. We do not quote a systematic error at this time.

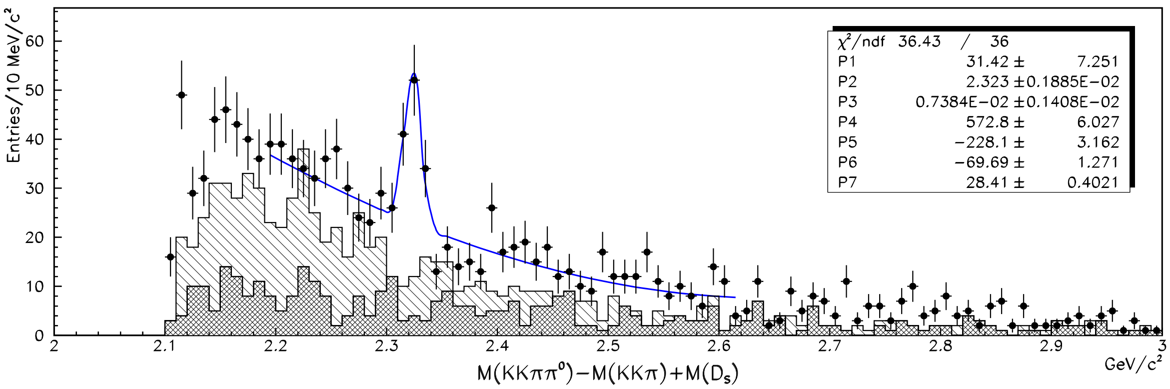

Figure 4: Preliminary invariant mass plot showing $D_s^+(2317) \to D_s^+\pi^0$. We observe 58 events in this decay mode with a mass of 2323 ± 2 MeV/c^2.

4 Conclusion

Interest in charmed meson spectroscopy has increased recently because of surprising discoveries in the D_s sector. FOCUS is adding to the body of knowledge for $L = 1$ mesons with the measurements presented in this contribution. These include precise measurements of the D_2^* parameters with comparable statistical precision to the previous world averages and the first evidence for the expected broad D_0^* states. Additionally we are able to confirm the observation of the $D_s^+(2317)$ state observed by other experiments. Not presented in this contribution are studies of $D_s^+(2536)$ and $D_s^+(2573)$ in $D^{(*)}K$ final states or studies of $L = 1$ D mesons decaying to $D^{*+}\pi^{\pm}$.

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