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RESULTS ON CHARMED MESON SPECTROSCOPY FROM FOCUS

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Abstract

We report the preliminary measurement by the FOCUS Collaboration (E831 at Fermilab) of masses and widths of the $L=1$ charm mesons: a D_2^{*0} state of mass (width) $2463.5 \pm 1.5 \pm 1.5(30.5 \pm 1.9 \pm 3.8)$ MeV/ c^2 decaying to $D^+\pi^-$, and a D_2^{*+} state of mass (width) $2468.2 \pm 1.5 \pm 1.4(28.6 \pm 1.3 \pm 3.8)$ MeV/ c^2 decaying to $D^0\pi^+$. The fit of the invariant mass distribution requires an additional term to account for a broad structure over background.

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In this paper we present preliminary results from the FOCUS experiment (E831 at Fermilab) on the spectroscopy of bound states of a charm quark and a lighter quark with orbital angular momentum $L = 1$, called $D_2^*(c\bar{u}, c\bar{d})$. With the high-statistics, high-mass resolution experiments attaining maturity, emphasis has been shifted from the ground state (0^- and 1^-) $c\bar{q}$ mesons and ($1/2^+$ and $3/2^+$) cqq baryons to the orbitally- and, only very recently, radially-excited states¹. A consistent theoretical framework for the spectrum of heavy-light mesons is given by the ideas of Heavy Quark Symmetry (HQS), later generalized by Heavy Quark Effective Theory in the QCD framework. The basic idea (mediated from the JJ coupling in atomic physics) is that in the limit of infinite heavy quark mass: a) the much heavier quark does not contribute to the orbital degrees of freedom, which are completely defined by the light quark(s) only; and b) properties are independent of heavy quark flavor. Heavy Quark Symmetry provides explicit predictions on the spectrum of excited charmed states[1].

In the limit of infinite heavy quark mass, the spin of the heavy quark \mathbf{S}_Q decouples from the light quark degrees of freedom (spin \mathbf{s}_q and orbital \mathbf{L}), with \mathbf{S}_Q and $\mathbf{j}_q \equiv \mathbf{s}_q + \mathbf{L}$ the conserved quantum numbers. Predicted excited states are formed by combining \mathbf{S}_Q and \mathbf{j}_q . For $L = 1$ we have $j_q = 1/2$ and $j_q = 3/2$ which, combined with S_Q , provide prediction for two $j_q = 1/2$ ($J=0,1$) states, and two $j_q = 3/2$ ($J=1,2$) states. These four

¹In the past, these excited states were called generically and improperly D^{**} .

states are named respectively D_0^* , $D_1(j_q = 1/2)$, $D_1(j_q = 3/2)$ and D_2^* . Finally, parity and angular momentum conservation favor the ($j_q = 1/2$) states to decay to the ground states mainly via S-wave transitions (broad width), while ($j_q = 3/2$) states would decay via D-wave (narrow width). While the narrow states are well established, the evidence for the broad states (both in the c -quark and in the b -quark sector) is much less stringent [2].

The data for this paper were collected in the Wideband photoproduction experiment FOCUS during the Fermilab 1996–1997 fixed-target run. FOCUS is a considerably upgraded version of a previous experiment, E687 [3]. In FOCUS, a forward multi-particle spectrometer is used to measure the interactions of high energy photons on a segmented BeO target. We obtained a sample of over 1 million fully reconstructed charm particles in the three major decay modes: $D^0 \rightarrow K^- \pi^+$, $K^- \pi^+ \pi^- \pi^+$ and $D^+ \rightarrow K^- \pi^+ \pi^+$.

The FOCUS detector is a large aperture, fixed-target spectrometer with excellent vertexing, particle identification, and reconstruction capabilities for photons and π^0 's. A photon beam is derived from the bremsstrahlung of secondary electrons and positrons with an ≈ 300 GeV endpoint energy produced from the 800 GeV/ c Tevatron proton beam. The charged particles which emerge from the target are tracked by two systems of silicon microvertex detectors. The upstream system, consisting of 4 planes (two views in 2 stations), is interleaved with the experimental target, while the other system lies downstream of the target and consists of twelve planes of microstrips arranged in three views. These detectors provide high resolution separation of primary (production) and secondary (decay) vertices with an average proper time resolution of ≈ 30 fs for 2-track vertices. The momentum of a charged particle is determined by measuring its deflections in two analysis magnets of opposite polarity with five stations of multiwire proportional chambers. Three multicell threshold Čerenkov counters are used to discriminate between pions, kaons, and protons.

1 Analysis Procedure and Results

The decays $D^0 \rightarrow K^- \pi^+$, $D^+ \rightarrow K^- \pi^+ \pi^+$, $D^0 \rightarrow K^- \pi^+ \pi^- \pi^+$, $D^{*+} \rightarrow D^0 \pi^+$ were selected (Fig.1). To ensure clean charm samples, candidate events were selected with a large ℓ/σ_ℓ , being ℓ the separation of the primary and weak decay vertices, and σ_ℓ its uncertainty; the primary multiplicity was required to be greater than 1, and the primary to be located within one of the interaction targets; the kaon and pion candidates to be consistent with the kaon and pion hypothesis, based on the Čerenkov identification system; the weak decay vertex to be outside of the interaction targets ($\sigma_{OoM} > 0$) for the $D^0 \rightarrow K^- \pi^+ \pi^- \pi^+$ mode only; and $|\cos \theta_K| < 0.7$ for the $D^0 \rightarrow K^- \pi^+$ mode only, where the decay angle θ_K is defined as the angle which, in the D rest frame, the kaon momentum

forms with the D momentum in the lab. The results in this paper have been shown to be insensitive to the detailed choice of selection parameters.

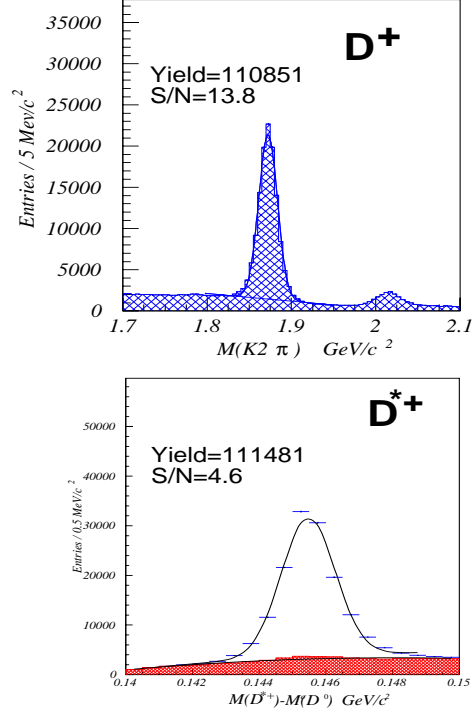


Figure 1: Mass plots for $D^+ \rightarrow K^-\pi^+\pi^+$ (top); and $D^{*+} \rightarrow D^0\pi^+$ (bottom).

The principal preliminary result in this paper relates to a study of the $D^+\pi^-$ and $D^0\pi^+$ mass spectra. The D^+ or D^0 candidates were combined with the pion tracks in the primary vertex to form L=1 D -meson candidates. Events with charm candidates coming from D^* decays were rejected by applying a $\pm 3\sigma$ cut around the $D^* - D$ mass difference. Figure 2 shows the distribution in the invariant mass difference

$$\Delta M_0 \equiv M(D^+\pi^-) - M(D^+) + M_{PDG}(D^+).$$

The plot shows a pronounced peak, consistent with being due to a D_2^{*0} of mass $M \approx 2460 \text{ MeV}/c^2$. Because of the narrow width, this state has traditionally been identified as the $J = 2^+$ state. The additional enhancement at $M \approx 2300 \text{ MeV}/c^2$ is consistent, as verified from Monte Carlo simulations, with arising from the feed-down of the states D_1^0 and D_2^{*0} decaying to $D^{*+}\pi^-$, with the D^{*+} subsequently decaying to D^+ and undetected neutral pion. The D_2^{*0} signal was fitted with a relativistic D -wave Breit-Wigner function, convoluted with a gaussian resolution function ($\sigma = 7\text{MeV}$). The

Table 1: Preliminary measurements of masses and widths for narrow structures in $D^+\pi^-$ and $D^0\pi^+$ invariant mass spectra.

	Mass MeV/ c^2	Width MeV/ c^2
D_2^{*0}	$2463.5 \pm 1.5 \pm 1.5$	$30.5 \pm 1.9 \pm 3.8$
PDG2000	2458.9 ± 2.0	23 ± 5
D_2^{*+}	$2468.2 \pm 1.5 \pm 1.4$	$28.6 \pm 1.3 \pm 3.8$
PDG2000	2459 ± 4	25_{-7}^{+8}

background was fitted with the sum of an exponential, and two gaussians for the feed-downs described above, whose peaks and widths were fixed at the Monte Carlo values. The slope of the exponential was fixed to the value determined by a fit to the wrong-side events mass distribution, which is very well described by a single-slope exponential in the entire fitting interval $2250 - 3000 \text{ MeV}/c^2$. For this fit we get a $\chi^2/\text{dof} = 2$, and a $\Gamma = 55 \pm 3 \text{ MeV}/c^2$ D_2^{*0} width statistically non compatible with the PDG2000 world average of $\Gamma = 23 \pm 5 \text{ MeV}/c^2$. We then add an S -wave relativistic Breit-Wigner function to the fit, which improves the fit quality $\chi^2/\text{dof} = 0.9$, and provides a width $\Gamma = 30 \pm 2 \text{ MeV}/c^2$ compatible to the PDG2000 value.

The mass difference

$$\Delta M_+ \equiv M(D^0\pi^+) - M(D^0) + M_{PDG}(D^0)$$

spectrum (Fig. 2 shows structures similar to those in the ΔM_0 spectrum. The prominent peak is consistent with being due to a D_2^{*+} of mass $M \approx 2460 \text{ MeV}/c^2$. The additional enhancement at $M \approx 2300 \text{ MeV}/c^2$ is consistent, as verified from Monte Carlo simulations, with arising from the feed-down of the states D_1^0 and D_2^{*0} decaying to $D^{*0}\pi^+$, with the D^{*0} subsequently decaying to D^0 and undetected neutral pion. The fitting procedure for the ΔM_+ spectrum follows the same guidelines as the ΔM_0 . Several systematics checks have been performed to verify the stability of our measurements of masses and widths, such as fit variants varying the selection cuts over an extended range, and the stability of our mass measurements when performed on statistically independent subsamples (ℓ/σ_ℓ greater and less than 30, particle vs. antiparticle, momentum of the pion from the D_2^* decay greater and less than $18\text{GeV}/c$, momentum of the D meson greater and less than $70\text{GeV}/c$). Table 1 summarizes the preliminary results on the measurements of masses and widths from the study of $D^0\pi^+$ and $D^+\pi^-$ final states.

In conclusion, FOCUS has collected a large sample of D_2^{*0} and D_2^{*+} L=1 mesons out of the total sample of about 10^6 D meson states, and $0.5 \cdot 10^4$ D^* meson states. The study of the $D\pi$ mass spectrum provides new preliminary values of the masses and widths

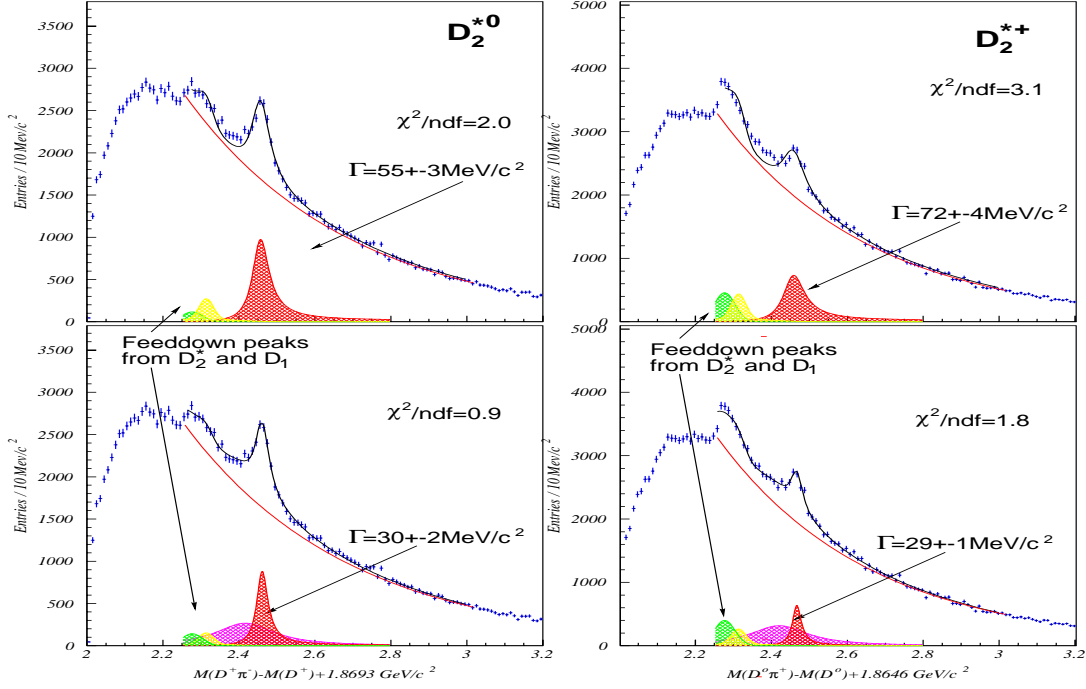


Figure 2: The $D^+\pi^-$ ($D^0\pi^+$) mass spectra is shown on the left (right). The invariant mass variable is defined as $\Delta M_0 \equiv M(D^+\pi^-) - M(D^+) + M_{PDG}(D^+)$ and $\Delta M_+ \equiv M(D^0\pi^+) - M(D^0) + M_{PDG}(D^0)$, respectively. In each of the top plots, the mass spectrum was fitted with a relativistic D -wave Breit-Wigner function, convoluted with a gaussian resolution function, and the sum of an exponential and two gaussians for the background. For each final state, the bottom histogram shows the fit results when a S -wave relativistic Breit-Wigner function is added to the above fit functions.

for the D_2^* meson (Tab. 1). The $D\pi$ mass spectrum (once subtracted the background, the D_2^* signal, and the expected feed-downs) shows an excess of events centered around $2420 \text{ MeV}/c^2$ and about $185 \text{ MeV}/c^2$ wide. A broad ($\sim 100\text{--}200 \text{ MeV}/c^2$) state (the D_0^*) is predicted by HQS at about $2350 \text{ MeV}/c^2$. The observed excess could be reminiscent of this state, or of a feed-down from another broad state such as the $D_1(j_q = 1/2)$, possibly interfering. Work is in progress to verify such hypothesis.

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References

- [1] S. Godfrey and N. Isgur, Phys. Rev. **D32**, 189 (1985); S. Godfrey and R. Kokoski, Phys. Rev. **D43**, 1679 (1991); N. Isgur and M.B. Wise, Phys. Rev. Lett. **66**, 1130 (1991); E.J. Eichten, C.T. Hill and C. Quigg, Phys. Rev. Lett. **71**, 4116 (1993); J. Bartelt and S. Shukla, Annu. Rev. Nucl. Part. Sci 1995 **45** 133-61.
- [2] F. L. Fabbri, In **Frascati 1999, Hadron spectroscopy** 627-639; S. Bianco, hep-ex/9911034.
- [3] P. L. Frabetti *et al.* (E687 Coll.), Nucl. Instrum. Meth. **A320**, 519 (1992).