NEW CHARM RESULTS FROM FOCUS

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ABSTRACT

New results from the photoproduction experiment FOCUS are reported: Dalitz plot analysis, semileptonic form factor ratios and excited meson spectroscopy.

I report[1] on three new results from the photoproduction experiment FOCUS: the first Dalitz plot analysis of charm meson decays using the K-matrix approach [1], new measurements of the $D_s^+ \to \phi(1020)\ \mu^+\nu$ form factor ratios [2], and new measurements on L=1 excited meson spectroscopy [3], i.e., precise measurements of the masses and widths of the D_2^{*+} and D_2^{*0} mesons, and evidence for broad states decaying to $D^+\pi^-, D^0\pi^+$ (the first such evidence in $D^0\pi^+$). The data for this paper were collected in the Wideband photoproduction experiment FOCUS during the Fermilab 1996–1997 fixed-target run.

1 Dalitz plot analysis of D_s^+ and D^+ decay to $\pi^+\pi^-\pi^+$ using the K-matrix formalism

Charm-meson decay dynamics has been extensively studied in the last decade. The analysis of the three-body final state by fitting Dalitz plots has proved to be a powerful tool for investigating effects of resonant substructure, interference patterns, and final state interactions in the charm sector [4, 5]. The isobar formalism, which has traditionally been applied to charm amplitude analyses, represents the decay amplitude as a sum of relativistic Breit-Wigner propagators multiplied by form factors plus a term describing the angular distribution of the two body decay of each intermediate state of a given spin. Many amplitude analyses require detailed knowledge of the light-meson sector. In the case of a narrow, isolated resonance, there is a close connection between the

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position of the pole on the unphysical sheet and the peak we observe in experiments at real values of the energy. However, when a resonance is broad and overlaps with other resonances, this connection is lost. The Breit-Wigner parameters measured on the real axis (mass and width) can be connected to the pole-positions in the complex energy plane only through models of analytic continuation.

A formalism for studying overlapping and many channel resonances has been proposed long ago and is based on the *K-matrix* [6, 7] parametrization. This formalism, originating in the context of two-body scattering, can be generalized to cover the case of production of resonances in more complex reactions [8], with the assumption that the two-body system in the final state is an isolated one and that the two particles do not simultaneously interact with the rest of the final state in the production process [7]. The *K-matrix* approach allows us to include the positions of the poles in the complex plane directly in our analysis, thus directly incorporating the results from spectroscopy experiments.

Full details on event selection and analysis cuts are reported in [1]. The Dalitz plot analyses are performed on events within $2\,\sigma$ the nominal D_s^+ or D^+ mass (Fig. 1). The decay amplitude of the D meson into the three-pion

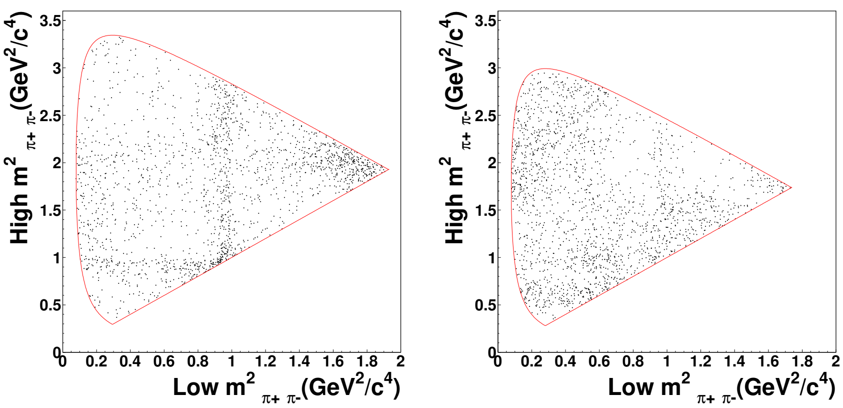

Figure 1: D_s^+ *(left) and* D^+ *(right) Dalitz plots.*

final state is written as $A(D) = a_0 e^{i\delta_0} + F_1 + \sum_i a_i e^{i\delta_i} B(abc|r_i)$ where the first term represents the direct non-resonant three-body amplitude contribution, F_1

is the contribution of S-wave states and the sum is over the contributions from the intermediate two-body non-scalar resonances. $B(abc|r_i)$ are Breit-Wigner terms. The amplitude for the particular channel $(00)_l^{++}\pi$ can be written in the context of the *K-matrix* formalism as $F_l = (I - iK\rho)^{-1}_{lj} P_j$ where I is the identity matrix, K is the *K-matrix* describing the isoscalar S-wave scattering process, ρ is the phase-space matrix for the five channels, and P is the "initial" production vector into the five channels. In this picture, the production process can be viewed (Figure 2) as consisting of an initial preparation of several states, which are then propagated by the $(I - iK\rho)^{-1}$ term into the final one. Only the F_1 amplitude is present in the isosinglet S-wave term since we are describing the dipion channel.

We use the *K-matrix* parametrization of $(00)^{++}$-wave scattering following obtained through a global fit of the available scattering data from $\pi\pi$ threshold up to 1900 MeV, see [9]. The results are presented in Table 1.

Table 1: *Results on D_s^+ and $D^+ \to \pi^+\pi^-\pi^+$ fit fractions and phases. Beside the first reported error, which is statistical, two systematic errors are quoted. The first one is from the measurement systematics and the second one is due to the particular solution chosen for the* K-matrix *poles and backgrounds.*

	D_s^+	
decay channel	fit fraction (%)	phase (deg)
(S-wave) π^+	$87.04 \pm 5.60 \pm 4.17 \pm 1.34$	0 (fixed)
$f_2(1270)\,\pi^+$	$9.74 \pm 4.49 \pm 2.63 \pm 1.32$	$168.0 \pm 18.7 \pm 2.5 \pm 21.7$
$\rho^0(1450)\pi^+$	$6.56 \pm 3.43 \pm 3.31 \pm 2.90$	$234.9 \pm 19.5 \pm 13.3 \pm 24.9$
	D^+	
decay channel	fit fraction (%)	phase (deg)
(S-wave) π^+	$56.00 \pm 3.24 \pm 2.08 \pm 0.50$	0 (fixed)
$f_2(1270)\,\pi^+$	$11.74 \pm 1.90 \pm 0.23 \pm 0.18$	$-47.5 \pm 18.7 \pm 11.7 \pm 5.3$
$\rho^0(770)\pi^+$	$30.82 \pm 3.14 \pm 2.29 \pm 0.17$	$-139.4 \pm 16.5 \pm 9.9 \pm 5.0$

In conclusion, the *K-matrix* formalism has been applied for the first time to the charm sector in our Dalitz plot analyses of the D_s^+ and $D^+ \to \pi^+\pi^-\pi^+$ final states. Furthermore, the same model is able to reproduce features of the $D^+ \to \pi^+\pi^-\pi^+$ Dalitz plot that otherwise would require an *ad hoc* σ resonance. In addition, the non-resonant component of each decay seems to be described by known two-body S-wave dynamics without the need to include constant amplitude contributions.

The *K-matrix* treatment of the S-wave component of the decay amplitude

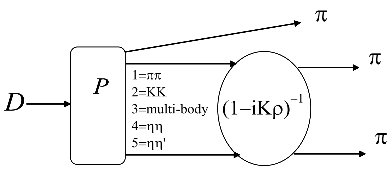

Figure 2: K-matrix *picture of a D meson decay to three pions, with a dipion in a isosinglet S-wave.*

allows for a direct interpretation of the decay mechanism in terms of the five virtual channels considered: $\pi\pi$, $K\bar{K}$, $\eta\eta$, $\eta\eta'$ and $4\,\pi$. The resulting picture, for both D_s^+ and D^+ decay, is that the S-wave decay is dominated by an initial production of $\eta\eta$, $\eta\eta'$ and $K\bar{K}$ states. Dipion production is always much smaller. This suggests that in both cases the S-wave decay amplitude primarily arises from a $s\bar{s}$ contribution such as that produced by the Cabibbo favoured weak diagram for the D_s^+ and one of the two possible singly Cabibbo suppressed diagrams for the D^+. For the D^+, the $s\bar{s}$ contribution competes with a $d\bar{d}$ contribution. That the $f_0(980)$ appears as a peak in the $\pi\pi$ mass distribution in D^+ decay, as it does in D_s^+ decay, shows that for the S-wave component the $s\bar{s}$ contribution dominates. Comparing the relative S-wave fit fractions that we observe for D_s^+ and D^+ reinforces this picture. The S-wave decay fraction for the D_s^+ (87 %) is larger than that for the D^+ (56 %). Rather than coupling to an S-wave dipion, the $d\bar{d}$ piece prefers to couple to a vector state like $\rho^0(770)$ which accounts for $\sim$ 30% of the D^+ decay. This interpretation also bears on the role of the annihilation diagram in the $D_s^+ \to \pi^+\pi^-\pi^+$ decay. Our data suggest that the S-wave annihilation contribution is negligible over much of the dipion mass spectrum. It might be interesting to search for annihilation contributions in higher spin channels, such as $\rho^0(1450)\pi$ and $f_2(1270)\pi$.

2 New measurements of the $D_s^+ \to \phi(1020)\,\mu^+\nu$ form factor ratios

The $D_s^+ \to \phi(1020)\,\mu^+\nu$ decay amplitude is described by four form factors with an assumed (pole form) q^2 dependence. The $D_s^+ \to \phi(1020)\,\mu^+\nu$ amplitude is then described by ratios of form factors taken at $q^2 = 0$. The traditional set is: r_2, r_3, and r_v. According to flavor SU(3) symmetry, one expects that

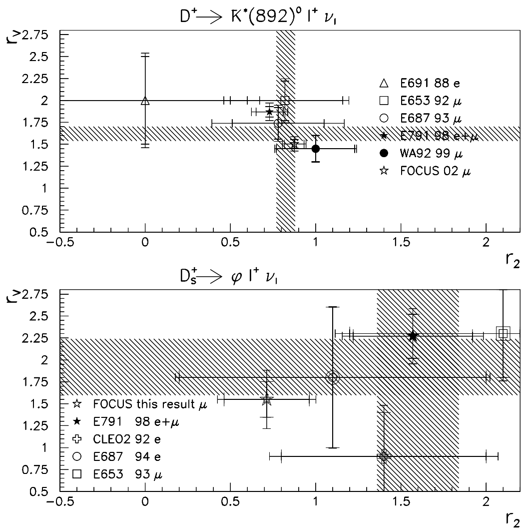

Figure 3: *Form-factor ratios comparison in previous data, and the new FOCUS result. World averages (not including this result) are also shown (shaded bands).*

the form factor ratios describing $D_s^+ \to \phi(1020)\ \mu^+\nu$ should be similar to those describing $D^+ \to \overline{K}^*(892)^0\mu^+\nu$ since the only difference is an $\bar{s}$ spectator quark instead of a $\bar{d}$ spectator quark. The existing lattice gauge calculations [10] predict that the form factor ratios describing $D_s^+ \to \phi(1020)\ \ell^+\nu_\ell$ should lie within 10% of those describing $D^+ \to \overline{K}^*(892)^0\ell^+\nu_\ell$. Although the measured r_v form factors are quite consistent between $D_s^+ \to \phi(1020)\ \ell^+\nu_\ell$ and $D^+ \to \overline{K}^*(892)^0\ell^+\nu_\ell$, there is presently a 3.3 σ discrepancy between the r_2 values measured for these two processes with the previously measured $D_s^+ \to \phi(1020)\ \ell^+\nu_\ell$ value being a factor of about 1.8 times larger than the r_2 value measured for $D^+ \to \overline{K}^*(892)^0\ell^+\nu_\ell$ (Figure 3). For a review and references see [4], while full details on event selection are found in [2]. The $m_{K^+K^-}$ distribution for the $D_s^+ \to K^+K^-\mu^+\nu$ candidates is shown in Figure 4.

The r_v and r_2 form factors were fit to the probability density function described by four kinematic variables (q^2, $\cos\theta_{\rm V}$, $\cos\theta_\ell$, and χ) for decays in

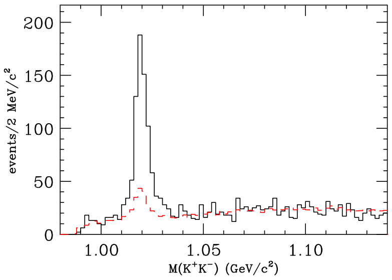

Figure 4: *The data is the solid histogram and $c\bar{c}$ background Monte Carlo is the dashed histogram. The $c\bar{c}$ background Monte Carlo is normalized to the same number of events in the sideband region 1.04 GeV/c^2 $< m_{K^+K^-} <$ 1.14 GeV/c^2.*

the mass range $1.010 < m_{K^+K^-} < 1.030$. We find r_v=1.549 $\pm$ 0.250 $\pm$ 0.145, r_2=0.713$\pm$0.202$\pm$0.266. Our measured r_v and r_2 values for $D_s^+ \to \phi(1020)\ \mu^+\nu$ are very consistent with our measured r_v and r_2 values for $D^+ \to \overline{K}^*(892)^0\mu^+\nu$ [11]. The measurements reported here call into question the apparent inconsistency between r_2 values the $D^+ \to \overline{K}^*(892)^0\ell^+\nu_\ell$ and $D_s^+ \to \phi(1020)\ \ell^+\nu_\ell$ form factors present in previously published data and are consistent with the theoretical expectation that the form factors for the two processes should be very similar.

3 L=1 excited charm meson spectroscopy

High-statistics datasets from fixed-target and e^+e^- colliders have recently provided the physics community with a wealth of data on excited charm meson spectroscopy. I report in this paper on new results [3] on L=1 $c\bar{u}, c\bar{d}, c\bar{s}$ states, pointing the reader to detailed reviews for an account of the experimental scenario [12, 4]. In the limit of infinitely heavy quark mass, the heavy-light meson behaves analogously to the hydrogen atom, *i.e.,* the heavier quark does not contribute to the orbital degrees of freedom (which are completely defined by the light quark). The angular momentum of the heavy quark is described by its spin S_Q, and that of the light degrees of freedom are described by $\mathbf{j_q} = \mathbf{s_q} + \mathbf{L}$, where $\mathbf{s_q}$ is the light quark spin and $\mathbf{L}$ is the orbital angular momentum of the light quark. The quantum numbers $\mathbf{S_Q}$ and $\mathbf{j_q}$ are individually conserved. The quantum numbers of the excited $L = 1$ states are formed by combining $\mathbf{S_Q}$ and $\mathbf{j_q}$. For $L = 1$ we have $j_q = 1/2$ and $j_q = 3/2$. When combined with $\mathbf{S_Q}$ they provide two $j_q = 1/2$ (J=0,1 where J is the total angular momentum of the excited charm meson) states, and two $j_q = 3/2$ (J=1,2) states. In this paper these four states will be denoted by D_0^*, $D_1(j_q = 1/2)$, $D_1(j_q = 3/2)$ and D_2^*.

Analysis procedures are explained in detail in [3]. The $L = 1$ charm mesons were reconstructed via $D^+\pi^-$ and $D^0\pi^+$ combinations. The D^0 decays were reconstructed in the channels $D^0 \rightarrow K^-\pi^+$ and $D^0 \rightarrow K^-\pi^+\pi^+\pi^-$. The D^+ decays were reconstructed in the channel $D^+ \rightarrow K^-\pi^+\pi^+$. Our starting samples for these decay modes are 210,000, 125,000 and 200,000 events, respectively. Figure 5c) shows the distribution of the invariant mass difference

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

where $M_{\mathrm{PDG}}(D^+)$ is the world average D^+ mass [13]. Figure 5c) shows a pronounced, narrow peak near a mass $M \approx 2460\,\mathrm{MeV}/c^2$, which is consistent with the D_2^{*0} mass. The additional enhancement at $M \approx 2300\,\mathrm{MeV}/c^2$ is consistent with feed-downs from the states D_1^0 and D_2^{*0} decaying to $D^{*+}\pi^-$ when the D^{*+} subsequently decays to a D^+ and undetected neutrals.

The mass difference

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

spectrum (Figure 5d) shows similar structures to the ΔM_0 spectrum. The prominent peak is consistent with a D_2^{*+} of mass $M \approx 2460\,\mathrm{MeV}/c^2$. The additional enhancement at $M \approx 2300\,\mathrm{MeV}/c^2$ is again consistent with feed-downs.

We fit the invariant mass difference histograms with terms for the D_2^{*0}, D_2^{*+} peaks, D_1 and D_2^* feed-downs, combinatoric background and the possibility of a broad resonance. The broad resonance is necessary to obtain a fit to the data of acceptable quality (Fig.5 c-d). Our final results are shown in Table 2. Our mass measurement of the broad state is higher than a recent measurement by BELLE [14]. Our result on the broad state have stimulated a series of theory studies, which try to reconcile the experimental picture of excited non-strange, and strange charmed mesons.

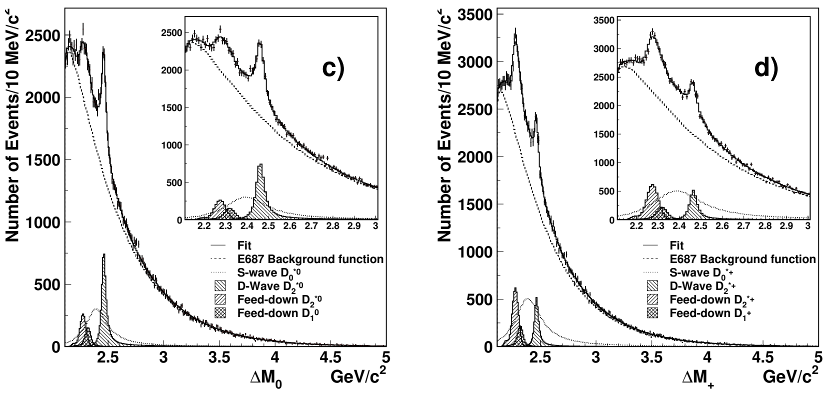

Figure 5: *The fit to the $D^+\pi^-$ (left) and $D^0\pi^+$ (right) mass spectra including a term for an S-wave resonance.*

Table 2: *Measured masses and widths for narrow and broad structures in $D^+\pi^-$ and $D^0\pi^+$ invariant mass spectra. The first error listed is statistical and the second is systematic. Units for the masses and widths are* MeV/c^2.

	D_2^{*0}	D_2^{*+}	$D^0_{1/2}$	$D^+_{1/2}$
Yield	$5776 \pm 869 \pm 696$	$3474 \pm 670 \pm 656$	9810 ± 2657	18754 ± 2189
Mass	$2464.5 \pm 1.1 \pm 1.9$	$2467.6 \pm 1.5 \pm 0.76$	$2407 \pm 21 \pm 35$	$2403 \pm 14 \pm 35$
PDG03	2458.9 ± 2.0	2459 ± 4		
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}		

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