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Dalitz Plot Analysis of Three Body D Meson Decays *

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Two years ago, at this workshop, we presented the results of Dalitz plot analysis for D^+ and D_s^+ decays to three pions [1]. In the D^+ meson decays, we found that the introduction of an additional scalar amplitude improved the fit quality and resulted in a goodness of fit measure that was very satisfactory. Since then, we have carried out a Dalitz plot analysis of the decay $D^+ \to K^-\pi^+\pi^+$ and also find that the introduction of a scalar amplitude substantially improves the goodness of fit. We present here the results of these Dalitz plot analyses and summarize the physics that has been produced.

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1. Introduction

The distributions of events across the Dalitz plot for three body D meson decays show remarkable structure, indicative of the nature of two body resonances that may be involved in the decay. As an example consider the simulation of the decay mode $D^+ \to K^-\pi^+\pi^+$ shown in Figure 1. If there are no resonance states involved, the distribution across the Dalitz plot is flat. A spin zero resonance will manifest a single node, spin one resonance shows two nodes, etc. Typically more than one resonance is involved, yielding complex structure across the Dalitz plot.

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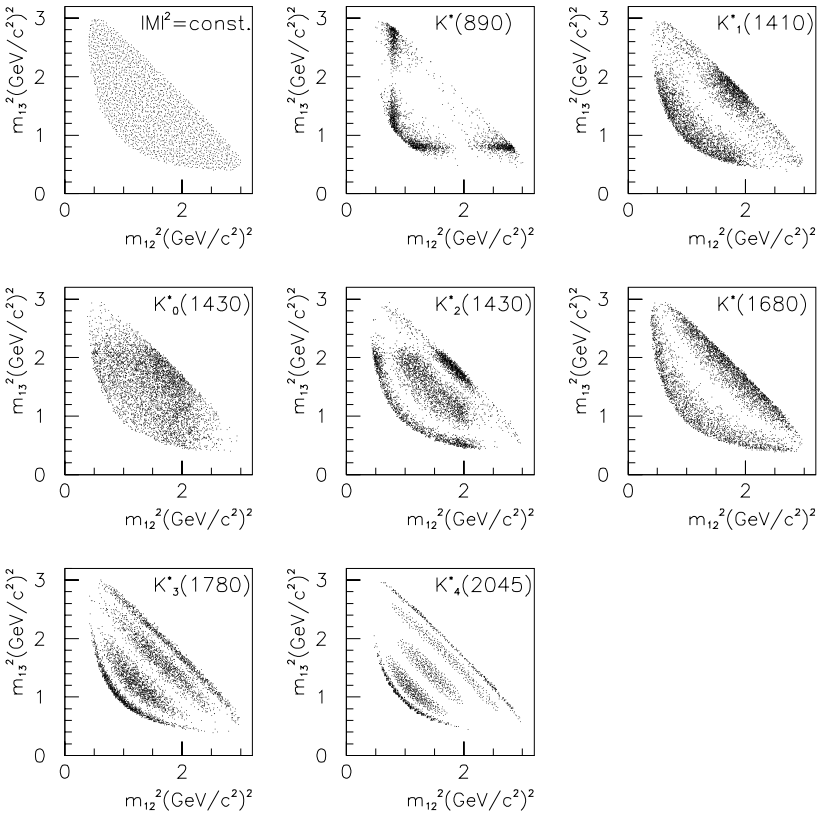

Fig. 1. Results of a simulation of the three body decays of $D^+ \to K^-\pi^+\pi^+$.

Data were taken from experiment E791 [2], a fixed-target experiment that ran in a negative 500 GeV/c pion beam in 1991/92 at Fermilab. The beam impinged on one platinum and four diamond targets. The spectrometer consisted of both wire chambers and silicon microstrip detectors upstream and downstream of the targets, two magnets, 35 drift chamber planes, two Čerenkov counters [3], electromagnetic and hadron calorimeters, and two planes of muon scintillation counters behind thick absorbers. The experiment accumulated 50 terabytes of data, 2×10^{10} events [4], and reconstructed [5] over 200,000 golden mode charm events.

A fitting routine was used to fit three body D decay distributions across the Dalitz plot using Breit-Wigner amplitudes modified by Blatt-Weisskopf

form factors and appropriate spin terms. In this "isobar model", the D-meson decays into the resonance state plus a pion, followed by the two body decay of the isobar. (See Figure 2.) The decay amplitude is given as a coherent sum of the individual modes.

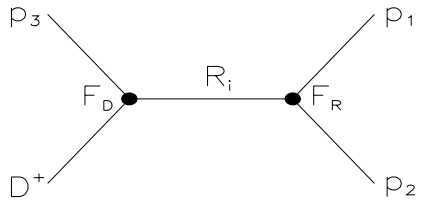

Fig. 2. A simple representation of the isobar model of D meson decays.

$$\mathcal{A} = a_0 e^{i\delta_0}\mathcal{A}_0 + \sum_{n=1}^{N} a_n e^{i\delta_n}\mathcal{A}_n(m_{12}^2, m_{13}^2) \tag{1}$$

$$\mathcal{A}_n = F_D^{(J)}\ F_n^{(J)}\ \mathcal{M}_n^{(J)}\ BW_n\ . \tag{2}$$

The quantities F_D and F_n are the Blatt-Weisskopf damping factors, and M_n describes the angular distribution due to the spin J of the resonance. The last term above is a relativistic Breit-Wigner function given by

$$BW_n = \frac{1}{m_0^2 - m^2 - im_0\Gamma(m)} \tag{3}$$

The magnitudes a_n measure the level of each contribution and the δ_n represent their relative phases.

The lowest order tree diagrams that might lead to three body D meson decays are given in Figure 3. There is little evidence in our data to support the existence of the annihilation diagram, and the W exchange is helicity suppressed [6]. The internal spectator process is color suppressed with respect to the external spectator. Destructive interference between the two provides the most likely explanation for the lifetime relationships $\tau_{D^0} \sim \tau_{D_S^+} \sim \tau_{D^+}/2.5$.

2. $D^+ \to \pi^-\pi^+\pi^+$

Fits to the Dalitz plot for $D^+ \to \pi^-\pi^+\pi^+$ decays show remarkable improvement if a scalar resonance is added to the list of particles used in the fit [7]. The distribution across the Dalitz plot is given in Figure 4.

An E791 sample of 1172 ± 61 $D^+ \to \pi^-\pi^+\pi^+$ events using a fit to an s-wave, is a significant improvement over one without. The NR component

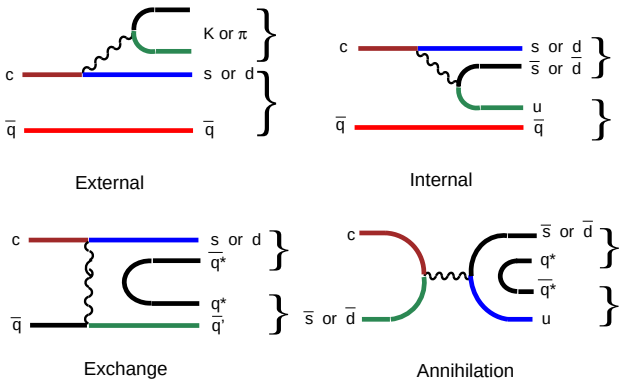

Fig. 3. Lowest order tree diagrams for decays of charmed mesons to two meson final states.

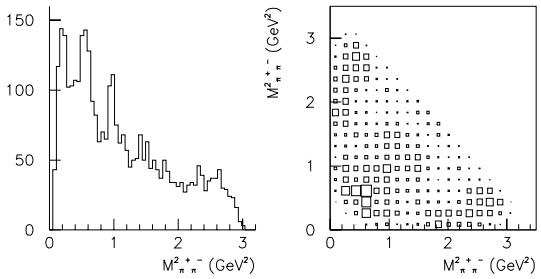

Fig. 4. The distribution across the Dalitz plot for $D^+ \to \pi^-\pi^+\pi^+$ decays.

is greatly reduced and the new s-wave "$\sigma \to \pi\pi$" amplitude dominates the fit. The parameters of the σ are: $m_\circ = (478^{+24}_{-23} \pm 17) MeV/c^2$ and $\Gamma_\circ = (324^{+24}_{-40} \pm 21) MeV/c^2$.

3. $D_s^+ \to \pi^-\pi^+\pi^+$

Improvement over previous [8] values for $f_\circ$ states were obtained from the analysis of $D_s^+ \to \pi^-\pi^+\pi^+$ decay [9]. The distribution across the Dalitz plot is given in Figure 5.

From a sample of 848 ± 44 $D_s^+ \to \pi^-\pi^+\pi^+$ decays we have results for the $f_\circ(980)$ using a coupled channel analysis: $g_\pi = 0.09 \pm 0.01 \pm 0.01$, $g_K = 0.02 \pm 0.04 \pm 0.03$, and $m_\circ = 977 \pm 3 \pm 2 MeV/c^2$. Using the same Breit-Wigner function for the $f_\circ(980)$ as for other resonances, we get $\Gamma_\circ =$

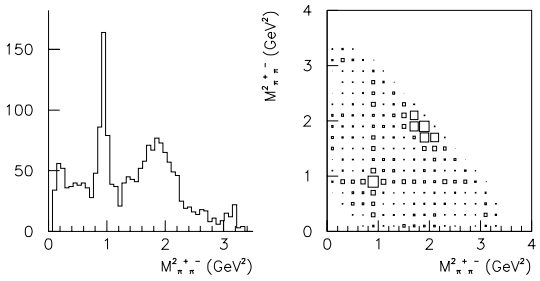

Fig. 5. The distribution across the Dalitz plot of $D_s^+ \to \pi^-\pi^+\pi^+$ decays.

$44 \pm 2 \pm 2 MeV/c^2$ and $m_\circ = 975 \pm 3 MeV/c^2$. For the $f_\circ(1370)$, we find $m_\circ = 1434 \pm 18 \pm 9 MeV/c^2$ and $\Gamma_\circ = 173 \pm 32 \pm 2 MeV/c^2$.

4. $D^+ \to K^-\pi^+\pi^+$

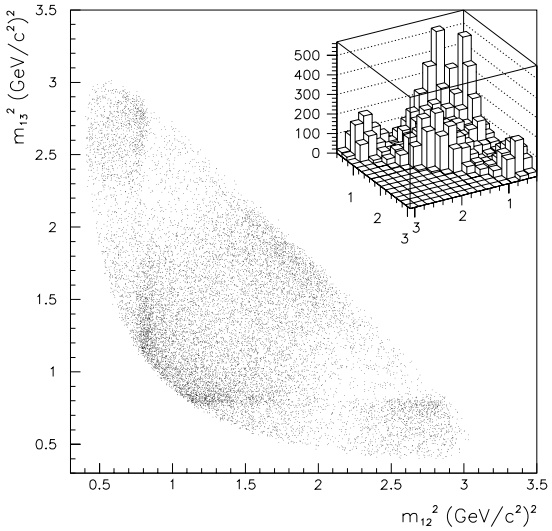

Fig. 6. The distribution across the Dalitz plot of $D^+ \to K^-\pi^+\pi^+$ decays.

For $D^+ \to K^-\pi^+\pi^+$ decay the distribution across the Dalitz plot is given in Figure 6. The inclusion of a scaler state greatly improves the fit. Improved values for $K^*_\circ(1430)$ parameters were also measured [10].

An E791 sample of about 15,090 events, the $D^+ \to K^-\pi^+\pi^+$ channel yields the result that an s-wave "$\kappa \to K\pi$" amplitude provides a significantly improved fit to the data. The parameters for the κ are: $m_\circ = (797 \pm 19 \pm$

$43) MeV/c^2$ and $\Gamma_\circ = (410 \pm 43 \pm 87) MeV/c^2$. The fit mass and width of the $K^*_\circ(1430)$ are $1459 \pm 7 \pm 5 MeV/c^2$ and $175 \pm 12 \pm 12 MeV/c^2$, respectively.

5. Summary

Analyses of three body D meson decays were presented based on results from the Fermilab experiment E-791. The results provide new evidence for the scalar states, the σ two π state, and the "κ" $K\pi$ state. Improvements in PDG values for $f_\circ$ and $K^*_\circ$ states were also measured.

6. Acknowledgments

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