Light Scalar Mesons in Charm Meson Decays

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Abstract

We present recent results on scalar light mesons based on Dalitz plot analyses of charm decays from Fermilab experiment E791. Low mass scalar mesons are found to have large contributions to the decays studied, $D^+ \to K^-\pi^+\pi^+$ and $D^+, D_s^+ \to \pi^-\pi^+\pi^+$. These results demonstrate the importance of charm decays as a new environment for the study of light meson physics.

1 Introduction

Here we present an overview of the results we obtained analysing the decays $D_s^+ \to \pi^-\pi^+\pi^+$ [1], $D^+ \to \pi^-\pi^+\pi^+$ [2] and $D^+ \to K^-\pi^+\pi^+$ [3], using data collected in 1991/92 by Fermilab experiment E791 from $500 GeV/c\pi - -nucleon$ interactions. For details see [ref791].

To obtain these results, we had to introduce a new approach in Dalitz plot analysis in order to extract the mass and width of the scalar resonances by allowing them as floating parameters in the fit. We begin this paper presenting the general method, applied in the $D^+ \to K^-\pi^+\pi^+$ Dalitz-plot analysis, then we discuss the $D_s^+ \to \pi^-\pi^+\pi^+$ and $D^+ \to \pi^-\pi^+\pi^+$ studies using the same procedure.

2 The $D^+ \to K^-\pi^+\pi^+$ Dalitz-plot Analysis

From the original 2×10^{10} events collected by E791, and after reconstruction and selection criteria, we obtained the $k^-\pi^+\pi^+$ sample shown in Figure 1(a). The cross-hatched region contains the events selected for the Dalitz-plot analysis. There are 15090 events in this sample, of which 6% are background.

Figure 1(b) shows the Dalitz-plot for these events. The plot presents a rich structure, where we can observe the clear bands from $\overline{K}^*(890)\pi^+$, and an accumulation of events at the upper edge of the diagonal, due to heavier resonances. To study the resonant substructure, we perform an unbinned maximun-likelihood fit to the data, with

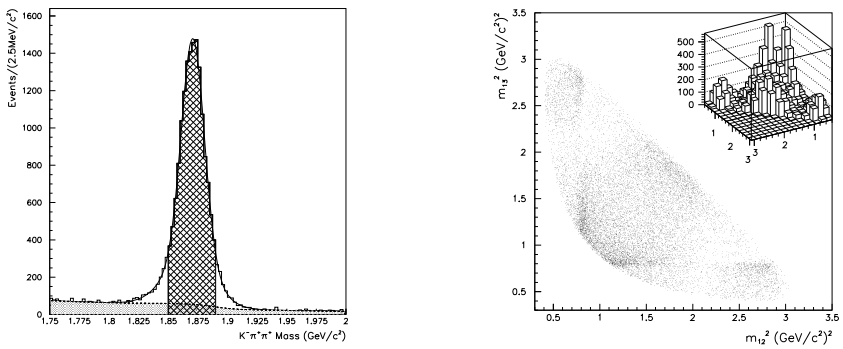

Figure 1: (a) The $K^-\pi^+\pi^+$ invariant mass spectrum. The filled area is background; (b) Dalitz plot corresponding to the events in the dashed area of (a).

probability distribution functions (PDF's) for both signal and background sources. In particular, for each candidate event, the signal PDF is written as the square of the total physical amplitude $\mathcal{A}$ and it is weighted for the acceptance across the Dalitz plot (obtained by Monte Carlo (MC)) and by the level of signal to background for each event, as given by the line shape of Figure 1(a). The background PDF's (levels and shapes) are fixed for the Dalitz-plot fit, according to MC and data studies.

We begin describing our first approach to fit the data, which represents the conventional Dalitz-plot analysis including the known $K\pi$ resonant amplitudes ($\mathcal{A}_n,\ n \geq 1$), plus a constant non-resonant contribution. The resonance amplitudes used to describe the signal, Breit-Wigner parametrizations with Blatt-Weisskopf damping factors are described in reference [3].

Using this model with well-known resonances, we find contributions from the following channels: the non-resonant, responsible for more than 90% of the decay rate, followed by $\overline{K}^*_0(1430)\pi^+$, $\overline{K}^*(892)\pi^+$, $\overline{K}^*(1680)\pi^+$ and $\overline{K}^*_2(1430)\pi^+$. The decay fractions and relative phases are available in reference [3].

To evaluate the fit quality, we compute a χ^2 from binned, two-dimensional distributions of data and decay model events. The χ^2 comes from the differences in the binned numbers of events between the data and the model (from a fast MC simulation). We obtain $\chi^2/\nu = 2.7$ (ν being the number of degrees of freedom), with a corresponding confidence level (CL) of 10^{-11}. We thus conclude that a model with the known $K\pi$ resonances, plus a non-resonant amplitude, is not able to describe the $D^+ \to K^-\pi^+\pi^+$ Dalitz plot satisfactorily. Thus, we are led to try an extra scalar resonance in our fit model. This second fit model, is constructed by the inclusion of an extra scalar state with unconstrained mass and width. For consistency, the mass and width of the other scalar state, the $K^*_0(1430)$, are also free parameters of the fit. We adopt a better description for these scalar states by introducing gaussian-type form-factors [5] to take into account the finite size of the decaying mesons.

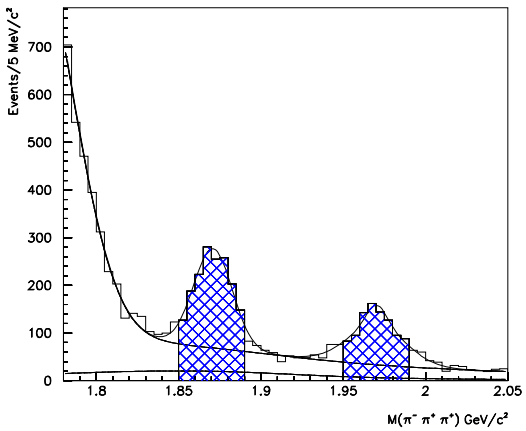

Figure 2: The $\pi^-\pi^+\pi^+$ invariant mass spectrum. The dashed line represent the total background. Events used for the Dalitz analyses are in the hatched areas.

Using this model, we obtain the values of $797 \pm 19 \pm 42$ MeV/c^2 for the mass and $410 \pm 43 \pm 85$ MeV/c^2 for the width of the new scalar state (first error statistical, second error systematic), referred to here as the κ. The values of mass and width obtained for the $K_0^*(1430)$ are respectively $1459 \pm 7 \pm 6$ MeV/c^2 and $175 \pm 12 \pm 12$ MeV/c^2, appearing heavier and narrower than presented by the PDG [6]. The decay fractions and relative phases with systematic errors, are given in reference [3]. The $\kappa\pi^+$ state is now the dominant channel with decay fraction about 50%.

3 The $D_s^+ \to \pi^-\pi^+\pi^+$ Results

In Figure 2 we show the $\pi^-\pi^+\pi^+$ invariant mass distribution for the sample collected by E791 after reconstruction and selection criteria [1, 2]. Besides combinatorial background, reflections from the decays $D^+ \to K^-\pi^+\pi^+$, $D^0 \to K^-\pi^+$ (plus one extra π^+ track) and $D_s^+ \to \eta'\pi^+$, $\eta' \to \rho^0(770)\gamma$ are all taken into account. The hatched regions in Figure 2 show the samples used for the Dalitz-plot analyses. There are 1686 and 937 candidate events for D^+ and D_s^+ respectively, with a signal to background ratio of about 2:1. The Dalitz plots for these events are shown in Figure 3, the axes corresponding to the two $\pi^-\pi^+$ invariant-masses squared.

For the $D_s^+ \to \pi^-\pi^+\pi^+$ events in Figure 3(a), the signal amplitude includes all channels with well known dipion resonances [6]: $\rho^0(770)\pi^+$, $f_0(980)\pi^+$, $f_2(1270)\pi^+$, $f_0(1370)\pi^+$, $\rho^0(1450)\pi^+$ and the non-resonant, assumed constant across the Dalitz plot.

The measured $f_0(980)$ standard Breit-Wigner parameters are $m_0 = 975 \pm 3$

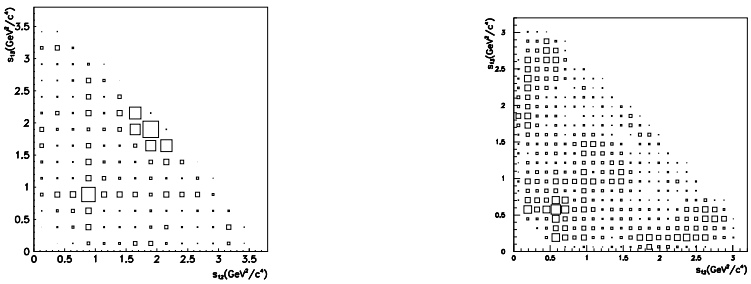

Figure 3: (a) The $D_s^+ \to \pi^-\pi^+\pi^+$ Dalitz plot and (b) the $D^+ \to \pi^-\pi^+\pi^+$ Dalitz plot. Since there are two identical pions, the plots are symmetrized.

MeV/c^2 and $\Gamma_0 = 44 \pm 2 \pm 2$ MeV/c^2. The confidence level of the fit for $D_s^+ \to \pi^-\pi^+\pi^+$ is 35%.The decay fractions and relative phases, with systematic errors, are given in reference [1]. The $f_0(980)\pi^+$ state is the dominant channel with decay fraction about 50%.

In Figure 4 we show the $\pi^-\pi^+$ mass-squared projections for data (points) and model (solid lines, from fast-MC).

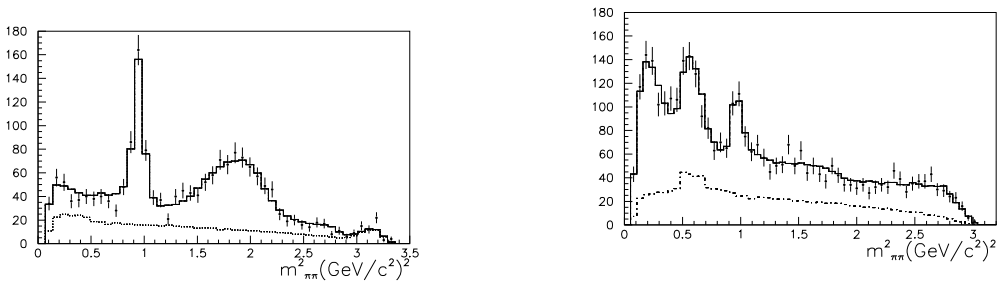

Figure 4: (a) s_{12} and s_{13} ($m^2_{\pi\pi}$) projections for $D_s^+ \to \pi^-\pi^+\pi^+$ data (dots) and our best fit (solid). (b) s_{12} and s_{13} projections for $D^+ \to \pi^-\pi^+\pi^+$ data (dots) and our best fit (solid) for models with $\sigma(500)\pi^+$ amplitude. In both figures the dashed distribution corresponds to the expected background level.

4 The $D^+ \to \pi^-\pi^+\pi^+$ Results

In a first approach, we try to fit the $D^+ \to \pi^-\pi^+\pi^+$ Dalitz plot of Figure 3(b) with the same amplitudes used for the $D_s^+ \to \pi^-\pi^+\pi^+$ analysis. Using this model, the non-resonant, the $\rho^0(1450)\pi^+$, and the $\rho^0(770)\pi^+$ amplitudes are found to dominate [2]. However, this model does not describe the data satisfactorily, especially at low

$\pi^-\pi^+$ mass squared [2]. The χ^2/ν obtained from the binned Dalitz plot for this model is 1.6, with a CL less than 10^{-5}.

To investigate the possibility that another $\pi^-\pi^+$ resonance contributes to the $D^+ \to \pi^-\pi^+\pi^+$ decay, we add an extra scalar resonance amplitude to the signal PDF, with mass and width as floating parameters in the fit.

We find that this model improves our fit substantially. The mass and the width of the extra scalar state are found to be $478^{+24}_{-23} \pm 17$ MeV/c^2 and $324^{+42}_{-40} \pm 21$ MeV/c^2, respectively. Refering to this state as the $\sigma(500)$, we observe that the $\sigma(500)\pi^+$ channel produces the largest decay fraction [2]; the non-resonant amplitude, which is dominant in the model without $\sigma(500)\pi^+$, drops substantially. The model with the sigma describes the data very well, as can be seen by the $\pi\pi$ mass squared projection in Fig. 4(b). The χ^2/ν is now 0.9, with a corresponding confidence level of 91%.

5 Conclusion

From the data of the Fermilab E791 experiment, we studied the Dalitz plots of the decays $D^+ \to K^-\pi^+\pi^+$, $D_s^+ \to \pi^-\pi^+\pi^+$, and $D^+ \to \pi^-\pi^+\pi^+$. In these three final states, the scalar intermediate resonances were found to give the largest contributions to the decay rates. We obtained strong evidence for the existence of the $\sigma(500)$ and κ scalar mesons, measuring their masses and widths. We also obtained new measurements for masses and widths of the other scalars studied, $f_0(980)$, $f_0(1430)$ and $K_0^*(1430)$.

The results presented here show the potential of D meson decays for the study of light meson spectroscopy, in particular in the scalar sector [7].

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