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DALITZ PLOT ANALYSIS IN FOCUS

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ABSTRACT

Proper tools of analysis are by now required to fully exploit the high statistics in the charm sector; Dalitz plot analysis has revealed to be one of the most powerful investigation methods to study charm phenomenology. FOCUS has performed a pioneering Dalitz plot analysis through the first application of the *K-matrix* formalism to the D^+ and $D_s^+ \to \pi^+\pi^-\pi^+$ final states, with a statistics of about 1500 events for each decay. The first Dalitz plot analysis of $D_s^+ \to K^+\pi^-\pi^+$ is also presented ($\sim$ 500 events) along with the $D^+ \to K^+\pi^-\pi^+$ one ($\sim$ 200 events).

1 Introduction

The analysis of the three-body final state by fitting Dalitz plots has proved to be a unique tool for investigating effects of resonant substructure, inter-

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ference patterns, and final-state-interactions in the charm sector. The isobar formalism, which has been traditionally applied to charm amplitude analyses, provides an effective description valid for many decay channels. Nevertheless many amplitude analyses require detailed knowledge of the light-meson sector; in particular, the need to model intermediate scalar particles contributing to the charm meson in their decays has caused us to question the validity of the Breit-Wigner approximation for the description of the relevant scalar resonances. A formalism for studying overlapping and many channel resonances has been proposed long ago and is based on the *K-matrix* 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, 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. The *K-matrix* approach allows us to incorporate directly the results from spectroscopy experiments. In addition, the *K-matrix* formalism provides a direct way of respecting the two-body unitarity constraint which is not explicitly guaranteed in the simple isobar model. FOCUS has performed a pioneering analysis through the first application of the *K-matrix* formalism to the D_s^+ and $D^+ \to \pi^+\pi^-\pi^+$ final states [1].

The excellent quality of FOCUS data allows also for investigation of suppressed modes, such as D^+ and $D_s^+ \to K^+\pi^-\pi^+$, which are, respectively, doubly and singly Cabibbo suppressed decays. The simultaneous presence of both $\pi^+\pi^-$ and $K^+\pi^-$ resonances, along with the limited statistics of these samples, makes a *K-matrix* analysis for these decays not viable; thus we applied the traditional isobar model to fit these channels [2].

2 Amplitude parametrization

2.1 Isobar model

A resonant amplitude for a quasi-two-body channel, of the type

$$\begin{array}{ll} D \to & r + c \\ & \hookrightarrow a + b\,, \end{array} \tag{1}$$

is described, in the contest of the traditional isobar model, as:

$$A = F_D F_r \times |\bar{c}|^J |\bar{a}|^J P_J(\cos\Theta^r_{ac}) \times BW(m_{ab}) \tag{2}$$

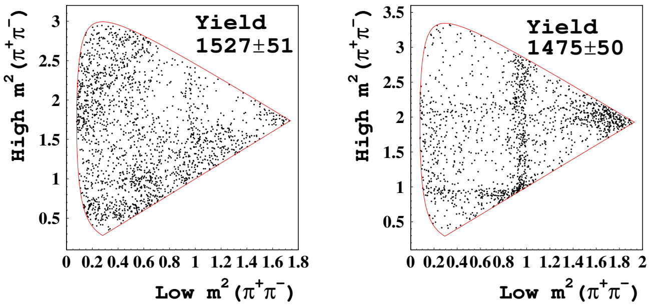
i.e. as the product of two vertex form factors (Blatt–Weisskopf momentum-dependent factors), a Legendre polynomial of order J representing the angular decay wave function, and a relativistic Breit–Wigner (BW) representing the propagator. In this approach the total amplitude is assumed to consist of a constant term describing the direct non-resonant three-body decay and a coherent sum of functions (Eq. 2) representing intermediate two-body resonances.

2.2 *K-matrix* model

For a well-defined wave of specific isospin and spin IJ, characterized by narrow and isolated resonances the propagator is of the simple BW form. In contrast, when the specific wave IJ is characterized by large and heavily overlapping resonances, just as the scalars, the propagation is no longer dominated by a single resonance, but is the result of complicated interplay among the various resonances. In this case, it can be demonstrated on very general grounds that the propagator may be written in the context of the *K-matrix* approach as $(I - iK \cdot \rho)^{-1}$ where K is the matrix for the scattering of particle a and b of Eq.1 and ρ is the phase-space matrix. For a more detailed formalism description we refer to [1]. In the *K-matrix* approach, the production process is viewed as consisting of an initial preparation of several states, which then propagate via the term $(I - iK\rho)^{-1}$ into the final state. In order to write down the propagator, we need the scattering matrix and to perform a meaningful fit to D mesons to three-pion data, we need a full description of the scalar resonances in the relevant energy range. At the present time the only self-consistent description of S-wave isoscalar scattering is that given in the *K-matrix* representation by Anisovich and Sarantsev through a global fit of the available scattering data from the $\pi\pi$ threshold up to 1900 MeV. In the fit to our FOCUS data, the *K-matrix* parameters are fixed to the values of [3]; the free parameters are only those peculiar to the D decay process.

3 Dalitz plot analysis of D^+ and $D_s^+ \to \pi^+\pi^-\pi^+$ with the *K-matrix* formalism

The Dalitz plots of D^+ and D_s^+ in $\pi^+\pi^-\pi^+$ are represented in Fig. 1(a) and 1(b), respectively. The results of the fits of these decays, using the *K-matrix* formalism, are reported in table 1. The confidence levels of the fits are 7.7% for D^+ and 3% for D_s^+. It is interesting to point out that, in the $D^+ \to \pi^+\pi^-\pi^+$



(a) $D^+ \to \pi^+\pi^-\pi^+$ (b) $D_s^+ \to \pi^+\pi^-\pi^+$

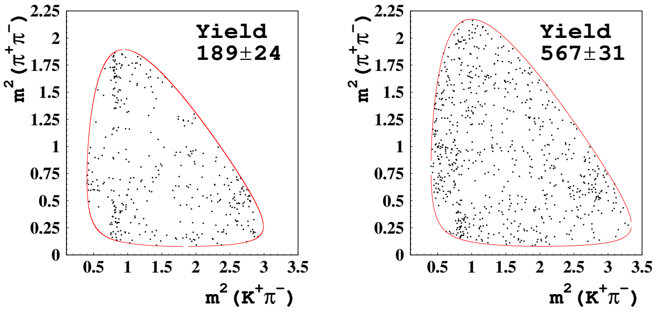
Figure 1: *Dalitz plots of D^+ and $D_s^+ \to \pi^+\pi^-\pi^+$.*

Decay channel	Fit fraction (%)	Phase ϕ_j (degrees)	Amplitude coefficient
	$D^+ \to \pi^+\pi^-\pi^+$		
$(S-wave)\,\pi^+$	$56.00 \pm 3.24 \pm 2.08$	0 (fixed)	1 (fixed)
$f_2(1270)\,\pi^+$	$11.74 \pm 1.90 \pm 0.23$	$-47.5 \pm 18.7 \pm 11.7$	$1.147 \pm 0.291 \pm 0.047$
$\rho(770)\,\pi^+$	$30.82 \pm 3.14 \pm 2.29$	$-139.4 \pm 16.5 \pm 9.9$	$1.858 \pm 0.505 \pm 0.033$
	$D_s^+ \to \pi^+\pi^-\pi^+$		
$(S-wave)\,\pi^+$	$87.04 \pm 5.60 \pm 4.17$	0(fixed)	1(fixed)
$f_2(1270)\,\pi^+$	$9.74 \pm 4.49 \pm 2.63$	$168.0 \pm 18.7 \pm 2.5$	$0.165 \pm 0.033 \pm 0.032$
$\rho(1450)\,\pi^+$	$6.56 \pm 3.43 \pm 3.31$	$234.9 \pm 19.5 \pm 13.3$	$0.136 \pm 0.030 \pm 0.035$

Table 1: *Fit results for D^+ and $D_s^+ \to \pi^+\pi^-\pi^+$ with the K-matrix formalism.*

analysis, no new resonance is necessary not present in the scattering to describe the decay dynamics. In contrast, the simple isobar model would require the presence of an "ad hoc" scalar resonance ($\sigma(600)$) to fit the data with a decent confidence level [4].

The $D_s^+ \to \pi^+\pi^-\pi^+$ decay is one of the best candidate for quantifying the role of the annihilation process in the charm hadronic decays through the evaluation of the non-resonant and $\rho(770)\pi^+$ components. It is interesting to



(a) $D^+ \to K^+\pi^-\pi^+$ (b) $D_s^+ \to K^+\pi^-\pi^+$

Figure 2: *Dalitz plots of D^+ and $D_s^+ \to K^+\pi^-\pi^+$.*

note that our *K-matrix* results (table 1(b)) require neither of them. A high non-resonant component, about 25%, is otherwise necessary to get a decent fit to the data [5)] through the isobar model. This flat contribution across the Dalitz plot seems to compensate for the model inadequateness to describe broad and overlapping resonances, thus weaking the potentiality of the Dalitz plot analysis to gauge the level of the annihilation contribution in the charm hadronic decays.

4 Dalitz plot analysis of D^+ and $D_s^+ \to K^+\pi^-\pi^+$ with the isobar model

The D^+ and $D_s^+ \to K^+\pi^-\pi^+$ Dalitz plots are fitted with the traditional isobar model. As already stated the simultaneous presence of both $\pi^+\pi^-$ and $K^+\pi^-$ resonances and the low statistics of these decays make not conceivable a *K-matrix* analysis. The Dalitz plots and the results of the fits are shown in Fig. 2 and in table 2, respectively. The confidence levels of the fits are 9.2% for D^+ and 5.5% for D_s^+. In both the decays the dominant contributions are $\rho(770)$ and $K^*(892)$ with a phase configuration almost real, suggesting a marginal role of final state interactions in these channels.

Decay channel	Fit fraction (%)	Phase ϕ_j (degrees)	Amplitude coefficient
	$D^+ \to K^+\pi^+\pi^-$		
$\rho(770)K^+$	$39.43 \pm 7.87 \pm 8.15$	0 (fixed)	1 (fixed)
$K^*(892)\pi^+$	$52.20 \pm 6.84 \pm 6.38$	$-167.1 \pm 14.4 \pm 23.0$	$1.151 \pm 0.173 \pm 0.161$
$f_0(980)K^+$	$8.92 \pm 3.33 \pm 4.12$	$-134.5 \pm 31.4 \pm 41.9$	$0.476 \pm 0.111 \pm 0.143$
$K_2^*(1430)\pi^+$	$8.03 \pm 3.72 \pm 3.91$	$54.4 \pm 38.3 \pm 20.9$	$0.451 \pm 0.125 \pm 0.129$
	$D_s^+ \to K^+\pi^+\pi^-$		
$\rho(770)K^+$	$38.83 \pm 5.31 \pm 2.61$	0 (fixed)	1 (fixed)
$K^*(892)\pi^+$	$21.64 \pm 3.21 \pm 1.14$	$161.7 \pm 8.6 \pm 2.2$	$0.747 \pm 0.080 \pm 0.031$
NR	$15.88 \pm 4.92 \pm 1.53$	$43.1 \pm 10.4 \pm 4.4$	$0.640 \pm 0.118 \pm 0.026$
$K^*(1410)\pi^+$	$18.82 \pm 4.03 \pm 1.22$	$-34.8 \pm 12.1 \pm 4.3$	$0.696 \pm 0.097 \pm 0.025$
$K_0^*(1430)\pi^+$	$7.65 \pm 5.0 \pm 1.70$	$59.3 \pm 19.5 \pm 13.2$	$0.444 \pm 0.141 \pm 0.060$
$\rho(1450)K^+$	$10.62 \pm 3.51 \pm 1.04$	$-151.7 \pm 11.1 \pm 4.4$	$0.523 \pm 0.091 \pm 0.020$

Table 2: *Fit results for D^+ and $D_s^+ \to K^+\pi^-\pi^+$ with the isobar formalism.*

5 Conclusions

Dalitz plot analysis is giving interesting and promising results. FOCUS has carried out a pioneering work through the first application of the *K-matrix* approach to charm sector in the D^+ and $D_s^+ \to \pi^+\pi^-\pi^+$ decays. The results are extremely encouraging since the same parametrization of both two-body $\pi\pi$ resonances, coming from light-quark experiments, works for charm decay too. The Dalitz plot analysis of the doubly and singly Cabibbo suppressed decays D^+ and $D_s^+ \to K^+\pi^-\pi^+$ has been performed as well; the $D_s^+ \to K^+\pi^-\pi^+$ represents the first amplitude analysis for this channel.

References

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