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Dalitz Plot Analysis of $D^+ \to K_S^0\pi^+\pi^0$ at BESIII

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We perform an analysis of the $D^+ \to K_S^0\pi^+\pi^0$ Dalitz plot using a data set of 2.92 fb^{-1} of e^+e^- collisions at the $\psi(3770)$ accumulated by the BESIII Experiment, in which 166694 candidate events are selected with a background of 15.1%. The Dalitz plot is found to be well-represented by a combination of six quasi-two-body decay channels ($K_S^0\rho^+$, $K_S^0\rho(1450)^+$, $\overline{K}^{*0}\pi^+$, $\overline{K}_0(1430)^0\pi^+$, $\overline{K}(1680)^0\pi^+$, $\overline{\kappa}^0\pi^+$) plus a small non-resonant component. Using the fit fractions from this analysis, partial branching ratios are updated with higher precision than previous measurements.

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1. Introduction

A clear understanding of final-state interactions in exclusive weak decays is an important ingredient in our ability to predict decay rates and to model the dynamics of two-body decays of charmed mesons. Final-state interactions can cause significant changes in decay rates, and can cause shifts in the phases of decay amplitudes. Clear experimental data can help refine theoretical models of these phenomena.

Three-body decays provide a rich laboratory in which to study the interferences between intermediate-state resonances. They also provide a direct probe of final-state interactions in certain decays. When a particle decays into three pseudo-scalar particles, intermediate resonances which dominate the decay rate and amplitudes are typically obtained with a Dalitz plot analysis technique [1]. This provides both the amplitudes and phases of the intermediate decay channels, which in turn allows us to deduce their relative branching fractions. These phase differences can even allow details about very broad resonances to be extracted by observing their interference with other intermediate states.

A large contribution from a $K\pi$ S-wave intermediate state has been observed in earlier experiments. Both the E791 [2] and CLEO-c [3] collaborations interpreted their data with a Model-Independent Partial Wave Analysis (MIPWA) and found a phase shift at low $K\pi$ mass to confirm the $\kappa\pi$ component in the $D^+ \to K^-\pi^+\pi^+$ decay. Complementary to this channel, the $D^+ \to K_S^0\pi^+\pi^0$ decay is also a golden channel to study the $K\pi$ S-wave in D decays.

The previous Dalitz plot analysis of $D^+ \to K_S^0\pi^+\pi^0$ by the MARKIII [4] collaboration included only two intermediate decay channels, $K_S^0\rho$ and $\overline{K}^{*0}\pi^+$, and was based on a small data set. A much larger data sample of e$^+$e$^-$ collisions at $\sqrt{s} \approx 3.773$ GeV has been accumulated with the BESIII detector [5] running at the Beijing Electron-Positron Collider (BEPCII) [6]. With much larger statistics, it is possible to measure relative branching fractions more precisely and to find more intermediate resonances.

2. Dalitz Fit at BESIII

The BESIII collaboration has established the Dalitz plot analysis based on the technology of maximum likelihood fitting. The likelihood function is defined as $\mathscr{L} = \prod_{i=1}^{N} \mathscr{P}(x_i, y_i)$, where N is the event number and $\mathscr{P}(x,y)$ is the probability density function (p.d.f.) on Dalitz plot. For signal with background in data, it is described as

$$\mathscr{P}(x,y) = f_S \frac{|\mathscr{M}(x,y)|^2 \varepsilon(x,y)}{\int\limits_{DP} |\mathscr{M}(x,y)|^2 \varepsilon(x,y) dxdy} + f_B \frac{B(x,y)}{\int\limits_{DP} B(x,y) dxdy}, \tag{2.1}$$

where $\mathscr{M}(x,y)$ is the decay matrix element, $\varepsilon(x,y)$ is the efficiency shape, $B(x,y)$ is the background shape, f_S and f_B are the fractions of signal and background, respectively. The DP denotes the kinematic region on the Dalitz plot. The decay matrix element is contributed by isobar model. The efficiency is parameterized by a Monte-Carlo sample [7]. The background includes two parts: peaking and non-peaking background. The peaking background is estimated by a Monte-Carlo simulation, and the non-peaking background is parameterized by the low and high sidebands of the distribution of the recoiling mass of selected D meson m_{rec} of data.

3. Results of the D to Ks pi pi0 Decay

Decay Mode	Parameters	Favored	w/o $\overline{\kappa}$	w/o NR	Final
Non-resonant	FF(%)	4.5±0.7	18.3±0.6		4.6±0.7
	$\phi(^\circ)$	269±6	232.7±1.3		279±6
$K_S^0\rho(770)^+$	FF(%)	84.6±1.8	82.0±1.3	86.7±1.1	83.4±2.2
	$\phi(^\circ)$	0(fixed)	0(fixed)	0(fixed)	0(fixed)
$K_S^0\rho(1450)^+$	FF(%)	1.80±0.20	6.03±0.29	0.63±0.12	2.13±0.22
	$\phi(^\circ)$	198±4	167.1±2.1	186±8	187.0±2.6
$\overline{K}^*(892)^0\pi^+$	FF(%)	3.22±0.14	2.99±0.10	3.30±0.10	3.58±0.17
	$\phi(^\circ)$	294.7±1.3	279.3±1.2	292.3±1.5	293.2±1.3
$\overline{K}^*(1410)^0\pi^+$	FF(%)	0.12±0.05	0.18±0.05	0.12±0.05	
	$\phi(^\circ)$	228±9	301±10	243±12	
$\overline{K}_0^*(1430)^0\pi^+$	FF(%)	4.5±0.6	10.5±1.3	3.6±0.5	3.7±0.6
	$\phi(^\circ)$	319±5	306.2±2.0	317±4	334±5
$\overline{K}_2^*(1430)^0\pi^+$	FF(%)	0.118±0.018	0.086±0.014	0.111±0.015	
	$\phi(^\circ)$	273±7	265±9	267±7	
$\overline{K}^*(1680)^0\pi^+$	FF(%)	0.21±0.06	0.58±0.08	0.43±0.10	1.27±0.11
	$\phi(^\circ)$	243±6	284±4	234±5	251.8±1.9
$\overline{K}_3^*(1780)^0\pi^+$	FF(%)	0.034±0.008	0.055±0.008	0.037±0.008	
	$\phi(^\circ)$	130±12	113±9	131±11	
$\overline{\kappa}^0\pi^+$	FF(%)	6.8±0.7		18.8±0.5	7.7±1.2
	$\phi(^\circ)$	92±6		11.6±1.9	93±7
NR+$\overline{\kappa}^0\pi^+$	FF(%)	18.1±1.4	18.3±0.6	18.8±0.5	19.2±1.8
$K_S^0\pi^0$ S wave	FF(%)	18.9±1.0	15.8±1.0	21.2±1.0	17.1±1.4
χ^2/n		1672/1209	2497/1209	1777/1209	2068/1209

Table 1: The preliminary results of the fits to the $D^+ \to K_S^0\pi^+\pi^0$ Dalitz plot with statistical errors only for different resonance choices, fit fraction (FF) and phase (ϕ). The "Final"are momoentum-dependent corrected.

Based on 166,694 selected candidate events with a background of 15.1%, a decay matrix element is constructed by possible intermediate resonance decay modes. After more possible intermediate resonance decay modes were considered in different isobar models, three models are compared principally, the Cabbibo favored model, the model without the $\overline{\kappa}$ and the model without the non-resonant. The results are listed in the column "Favored", "w/o $\overline{\kappa}$"and "w/o NR"of Table 1, respectively. It is found that the goodness of fit in the "w/o $\overline{\kappa}$"model is much worse than in the favored model, which indicates the $\overline{\kappa}$ has a large confidence level in our data. If a non-resonant component is removed, the goodness of fit also becomes worse, indicating the non-resonant is indeed present in our data.

In the above three models, the contributions of the three channels $\overline{K}^*(1410)^0\pi^+$, $\overline{K}_2^*(1430)^0\pi^+$ and $\overline{K}_3^*(1780)^0\pi^+$ are not significant, and their fit fractions are less than 0.2%. Therefore, we remove them from the final model. The final model (F) is composed of a non-resonant component and intermediate resonances modes, including $K_S^0\rho(770)^+$, $K_S^0\rho(1450)^+$, $\overline{K}^*(892)^0\pi^+$, $\overline{K}_0^*(1430)^0\pi^+$, $\overline{K}^*(1680)^0\pi^+$ and $\overline{\kappa}^0\pi^+$. The projections of the fit and the Dalitz plot can be found in Fig. 1.

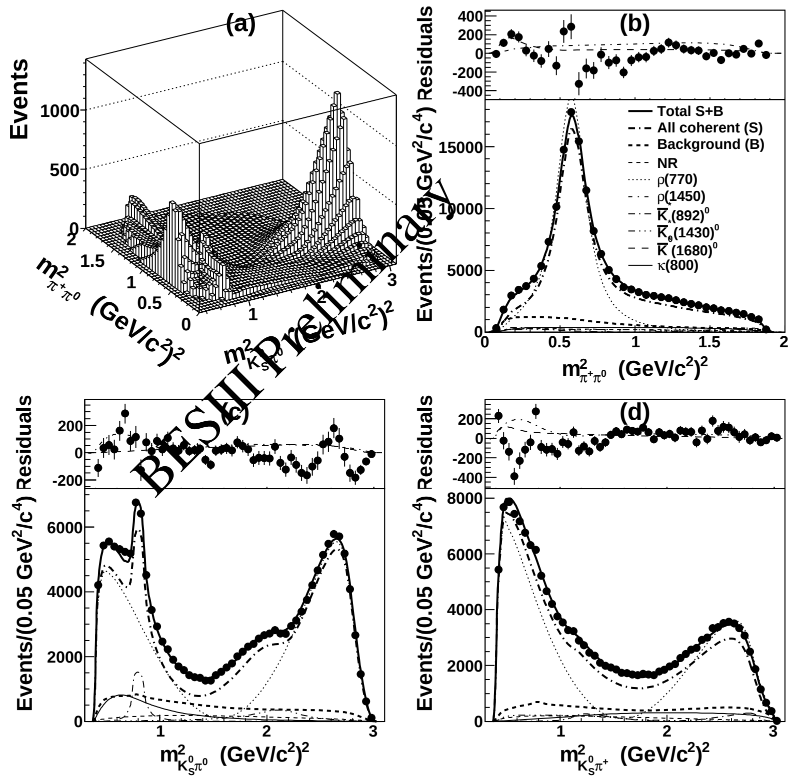

Figure 1: The results of fitting the $D^+ \to K_S^0\pi^+\pi^0$ data with final chosen resonances. (a) Distribution of fitted p.d.f. and projections on (b) $m^2_{\pi^+\pi^0}$, (c) $m^2_{K_S^0\pi^0}$ and (d) $m^2_{K_S^0\pi^+}$. Residuals between data and the total p.d.f. are shown by dots with statistical error bars on the top insets.

A deviation of efficiency between data and MC simulation will cause a deviation of the fit results. Therefore, a momentum-dependent correction is applied to the final results. The results are listed in the column "Final"of Table 1.

In fits with these models, the formalism of the κ is taken as the complex pole form, and the position of the pole κ is allowed to float as a free complex parameter. The mass and width of the $K_0^*(1430)^0$, taken as a Breit-Wigner function, are also floated, since the measured values from E791 [8] and CLEO-c [3] in the $D^+ \to K^-\pi^+\pi^+$ decay are not consistent wuthg the PDG ones. Finally, the pole of the κ obtained is at $(752 \pm 15 \pm 69^{+55}_{-73}, -229 \pm 21 \pm 44^{+40}_{-55})$ MeV, which is consistent with the model C result of CLEO-c. And the mass and width of the $K_0^*(1430)^0$ are $1464 \pm 6 \pm 9^{+9}_{-28}$ MeV and $190 \pm 7 \pm 11^{+6}_{-26}$ MeV, respectively, and are consistent with CLEO-c's results, while they are not consistent with the PDG. In the model without the $\overline{\kappa}$, the results are 1444 ± 4 MeV and 283 ± 11 MeV with statistical errors only, which are consistent with the PDG values.

4. Summary and Discussion

BESIII has established the technology of Dalitz plot analysis. Based on it, the $D^+ \to K_S^0\pi^+\pi^0$

Mode	Partial Branching Fraction (%)
$D^+ \to K_S^0\pi^+\pi^0$ Non Resonant	$0.32\pm0.05\pm0.25^{+0.28}_{-0.25}$
$D^+ \to \rho^+ K_S^0, \rho^+ \to \pi^+\pi^0$	$5.83\pm0.16\pm0.30^{+0.45}_{-0.15}$
$D^+ \to \rho(1450)^+ K_S^0, \rho(1450)^+ \to \pi^+\pi^0$	$0.15\pm0.02\pm0.09^{+0.07}_{-0.11}$
$D^+ \to \overline{K}^*(892)^0\pi^+, \overline{K}^*(892)^0 \to K_S^0\pi^0$	$0.250\pm0.012\pm0.015^{+0.025}_{-0.024}$
$D^+ \to \overline{K}_0^*(1430)^0\pi^+, \overline{K}_0^*(1430)^0 \to K_S^0\pi^0$	$0.26\pm0.04\pm0.05\pm0.06$
$D^+ \to \overline{K}^*(1680)^0\pi^+, \overline{K}^*(1680)^0 \to K_S^0\pi^0$	$0.09\pm0.01\pm0.05^{+0.04}_{-0.08}$
$D^+ \to \overline{\kappa}^0\pi^+, \overline{\kappa}^0 \to K_S^0\pi^0$	$0.54\pm0.09\pm0.28^{+0.36}_{-0.19}$
$NR+\overline{\kappa}^0\pi^+$	$1.30\pm0.12\pm0.12^{+0.12}_{-0.30}$
$K_S^0\pi^0$ S-wave	$1.21\pm0.10\pm0.16^{+0.19}_{-0.27}$

Table 2: The preliminary results of partial branching fractions calculated by combining our fit fractions with the PDG's $D^+ \to K_S^0\pi^+\pi^0$ branching ratio. The errors shown are statistical, experimental systematic and modeling systematic ones, respectively.

Dalitz plot is well-represented by a combination of a non-resonant component plus six quasi-two-body decays, $\overline{\kappa}$ included. The preliminary results are consistent with the results of the E791 and CLEO-c collaboration for the $D^+ \to K^-\pi^+\pi^+$ decay.

The final fit fraction and phase for each component, multiplied by the world average $D^+ \to K_S^0\pi^+\pi^0$ branching ratio of (6.99±0.27)% [9], which yield the partial branching fractions shown in Table 2. The error on the world average branching ratio is incorporated by adding it in quadrature with the experimental systematic errors on the fit fractions to give the experimental systematic error on the partial branching fractions.

In this result, the $K_S^0\pi^0$ waves could be compared with the $K^-\pi^+$ waves in the $D^+ \to K^-\pi^+\pi^+$ decay. For example, according to our measured branching ratio of $D^+ \to \overline{K}^{*0}\pi^+ \to K_S^0\pi^+\pi^0$ and the PDG value of branching ratio of $D^+ \to \overline{K}^{*0}\pi^+ \to K^-\pi^+\pi^+$ of (1.01±0.11)%, the ratio of branching fraction of $D^+ \to \overline{K}^{*0}\pi^+ \to K^-\pi^+\pi^+$ and $D^+ \to \overline{K}^{*0}\pi^+ \to \overline{K}^0\pi^+\pi^0$ is calculated to 2.02 ± 0.34, which is consistent with what is expected.

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