PROCEEDINGS OF SCIENCE

Strong Phase Measurements at BESIII

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The BESIII experiment has accumulated the world largest e^+e^- annihilation data sample at 3.773 GeV with an integrated lumonisity of 2.93 fb^{-1}. In this proceeding, we report the recent measurements of strong phase parameters in D^0 decay based on this data sample, which include $K^0_{S,L}\pi^+\pi^-$, $K^0_{S,L}K^+K^-$, $K^-\pi^+\pi^+\pi^-$ and $K^-\pi^+\pi^0$. The obtained parameters are important to reduce the systematic uncertainty of γ/ϕ^3 measurement at LHCb and Belle II experiments.

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1. Introduction

The study of quantum-correlated (QC) charm-meson pairs produced at threshold allows unique access to hadronic decay properties which have a wide range of physics applications. In particular, determination of the strong phase parameters provides important input to measurements of the Cabibbo-Kobayashi-Maskawa (CKM) [1] angle γ/ϕ_3. BESIII has accumulated the largest QC $D^0\bar{D}^0$ data sample at 3.773 GeV with integrated luminosity of 2.93 fb^{-1}, which can substantially improve the precision of strong phase parameters measurements in D^0 decays. In this proceeding, we summarized recent strong phase measurements of four decay modes $K^0_{S,L}\pi^+\pi^-$, $K^0_{S,L}K^+K^-$, $K^-\pi^+\pi^+\pi^-$ and $K^-\pi^+\pi^0$ at BESIII.

2. Strong phase measurement at BESIII

The CKM angle γ/ϕ_3 can be measured in tree-level decay $B^- \to DK^-$, where the D meason can be D^0 or $\bar{D}^0$. In such case, the decay rate of $B^- \to DK^-$ will contain the interference between amplitudes of D^0 and $\bar{D}^0$ decay to same final states. The decay rate of $B^- \to (f)_D K^-$ can be written as

$$\Gamma(B^- \to (f)_D K^-) \propto (r_D^f)^2 + r_B^2 + 2r_B r_D^f R_f \cos(\delta_{\rm B} \mp \gamma - \delta_{\rm D}^{\rm f}), \quad (1)$$

where r_D^f, R_f and δ_f are strong phase parameters. These strong phase paramters in D^0 meson decay can be measured model-independently with QC $D^0\bar{D}^0$ sample. For $D^0\bar{D}^0$ decayed from $\psi(3770)$, the amplitude of $D^0\bar{D}^0 \to fg$ can be described as (neglect D^0-$\bar{D}^0$ mixing)

$$A(D^0\bar{D}^0 \to fg) \propto |A_f\bar{A}_g - \bar{A}_f A_g|^2, \quad (2)$$

where the A_f and $\bar{A}_f$ represent the amplitudes of D^0 and $\bar{D}^0$ decay to f, respectively. The decay rate can be written as:

$$\Gamma(D^0\bar{D}^0 \to fg) \propto (r_D^f)^2 + (r_D^g)^2 - 2r_D^f r_D^g R_f R_g \cos(\delta_{\rm D}^{\rm f} - \delta_{\rm D}^{\rm g}), \quad (3)$$

where the definations of r_D^f, R_f and δ_f are showed below:

$$r_D^f = \frac{\int |\bar{A}_f|^2 {\rm d}\Phi}{\int |A_f|^2 {\rm d}\Phi}, \quad R_f e^{-i\delta_D^f} = \frac{\int A_f \bar{A}_f^* {\rm d}\Phi}{\sqrt{\int |A_f|^2 {\rm d}\Phi \int |\bar{\rm A}_{\rm f}|^2 {\rm d}\Phi}}. \quad (4)$$

The decay rate is sensitive to strong phase parameters, which makes quantum-correlated $D^0\bar{D}^0$ decays an ideal process to study strong phase parameters.

2.1 $K^0_{S,L}\pi^+\pi^-$ [2, 3] and $K^0_{S,L}K^+K^-$ [4]

The self-conjugate multi-body decay of $D^0 \to K^0_S h^+h^-$ can be used to measure γ/ϕ_3 angle with BPGGSZ method [5] by binning the phase space into 8 pairs of bins. The parameters of interest are amplitude-weighted average of cosines and sines of strong phase differences (c_i and s_i) in i-th phase space bin:

$$c_i = \frac{\int |A_f||\bar{A}_f| {\rm cos}\delta_{\rm D}^{\rm f} {\rm d}\Phi_{\rm i}}{\sqrt{\int |A_f|^2 {\rm d}\Phi_{\rm i} \int |\bar{\rm A}_{\rm f}|^2 {\rm d}\Phi_{\rm i}}}, \quad s_i = \frac{\int |A_f||\bar{A}_f| {\rm sin}\delta_{\rm D}^{\rm f} {\rm d}\Phi_{\rm i}}{\sqrt{\int |A_f|^2 {\rm d}\Phi_{\rm i} \int |\bar{\rm A}_{\rm f}|^2 {\rm d}\Phi_{\rm i}}}. \quad (5)$$

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According to Eq. 3, the expected number of events of $K_S^0 h^+ h^-$ final states with different tag modes, like CP tag modes, flavor tag modes and $K_{S,L}^0 h^+ h^-$ tag mode, can be described by the strong phase parameters of signal and tag modes. With a global fit to these double tag yields with different tag modes, c_i and s_i can be extracted. Fig. 1 shows the measurement results of c_i and s_i of $K_S^0\pi^+\pi^-$ and $K_S^0 K^+ K^-$ modes with equal $\Delta\delta_D$ binning. Our results is compatible with previous measurements with improved precision. The associated uncertainty on γ/ϕ_3 measurements with $K_S^0 h^+ h^-$ mode is $1°$ in latest measurement by LHCb [6] and BelleII [7].

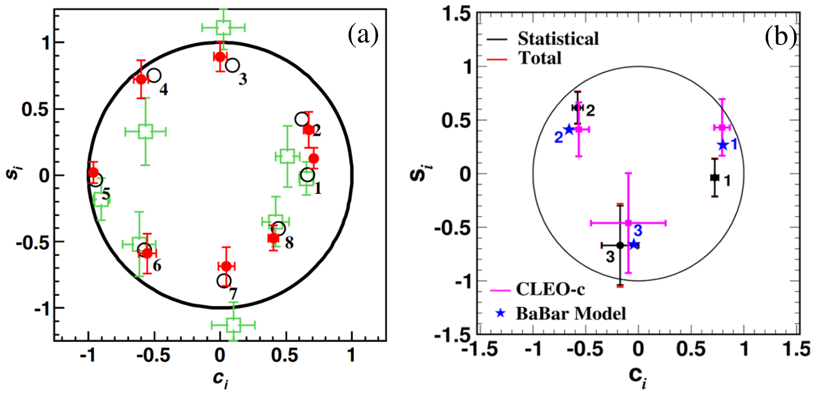

Figure 1: (a) The c_i and s_i of $K_S^0\pi^+\pi^-$ mode measured in this work (red dots with error bars), the prediction of amplitude model (black open circles) and the results of previous measurement (green open squares with error bars) with equal $\Delta\delta_D$ binning. (b) The c_i and s_i of $K_S^0 K^+ K^-$ mode measured in this work (black dots with error bars), the prediction of amplitude model (blue stars) and the results of previous measurement (pink dots with error bars) with equal $\Delta\delta_D$ binning when $N = 3$.

2.2 $K^-\pi^+\pi^0$ and $K^-\pi^+\pi^+\pi^-$ [8]

The Cabibbo favored (CF) and double Cabibbo suppressed (DCS) processes, like $K^-\pi^+\pi^0$ and $K^-\pi^+\pi^+\pi^-$, can be used to measure γ/ϕ_3 angle with ADS method [9]. The parameters of interest are R_f and δ_D^f. Similar with analysis of $K_S^0 h^+ h^-$ mode, the expected number of events of double tag yields with different tag modes can be described by the strong phase parameters of signal and tag modes. Here, a new observable ρ (the ratio between double yields with QC effect and without QC effect) is defined instead of double tag yields when the tag side decays to CP tag modes and like-sign(LS) tag modes. The like-sign tag mode means that the tag side has kaon of the same charge as that on the signal side. According to Eq. 3, ρ can be written as

$$\rho^f_{CP\pm} = 1 \mp \frac{2r_D^f R_f}{1+(r_D^f)^2}\cos(\delta_{\rm D}^{\rm f}), \quad \rho^{\rm f,g}_{\rm LS} = 1 - \frac{2{\rm r_D^f r_D^g}}{({\rm r_D^f})^2+({\rm r_D^g})^2}{\rm R_f R_g}\cos(\delta_{\rm D}^{\rm g}-\delta_{\rm D}^{\rm f}). \tag{6}$$

With a global fit to ρ and binned double tag yields with $K_S^0\pi^+\pi^-$ tag mode, R_f and δ_D^f can be extracted. Fig. 2 shows the the measurement results of R_f and δ_D^f by BESIII and CLEO. Our results is compatible with previous measurements with improved precision. Moreover, a binned analysis for $K^-\pi^+\pi^+\pi^-$ is also performed in this work. The results showed in Fig. 3. According to Monte Carlo study, the associated uncertainty on γ/ϕ_3 measurement with binned method for $K^-\pi^+\pi^+\pi^-$ is $\sim 6°$.

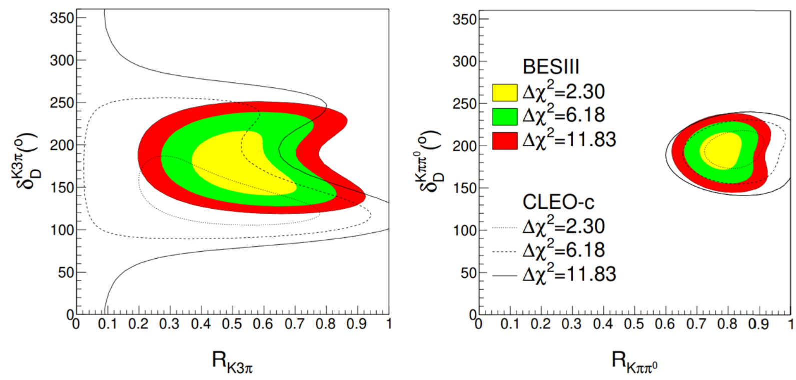

Figure 2: Scans of $\Delta\chi^2$ in the global $(R_{K3\pi}, \delta_D^{K3\pi})$ and $(R_{K\pi\pi^0}, \delta_D^{K\pi\pi^0})$ parameter space.Also shown are the equivalent contours determined from the CLEO-c data.

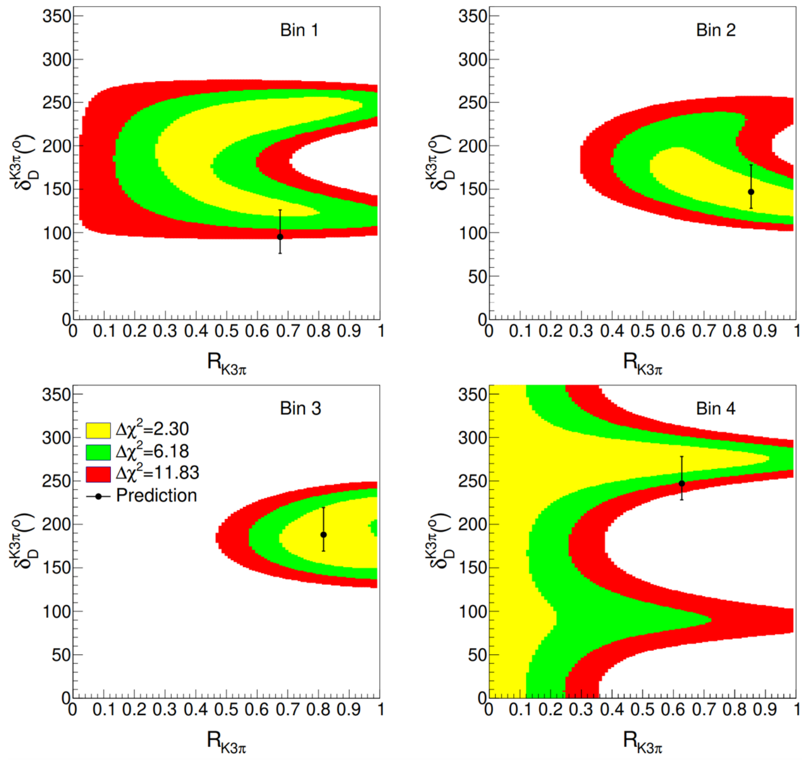

Figure 3: Scans of $\Delta\chi^2$ in the four bins of the $(R_{K3\pi}, \delta_D^{K3\pi})$ parameter space and the prediction from model.

3. Summary

Based on 2.93 fb^{-1} quantum-correlated $D^0\bar{D}^0$ data accumulated by BESIII, recent measurements on strong phase parameters for four decay modes $K^0_{S,L}\pi^+\pi^-$, $K^0_{S,L}K^+K^-$, $K^-\pi^+\pi^+\pi^-$ and $K^-\pi^+\pi^0$ are presented. BESIII plans to collect about 20 fb^{-1} data at 3.773 GeV in the next two years [10]. More measurements of strong phase parameters with higher precision will be coming in the future.

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