Strong phase in $D^0 \to K\pi$ decay measurement at BESIII

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Abstract

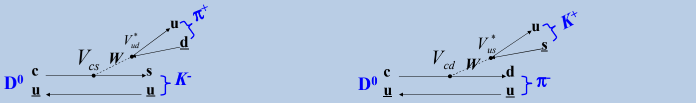
We study the process of $D^0\bar{D}^0$ pair productions based on 2.89 fb^{-1} of e^+e^- collision data collected with the BESIII detector at $\sqrt{s}$ = 3.773 GeV, and measure the asymmetry of the decay rates of $D^{CP\pm} \to K^-\pi^+$ ($D^{CP\pm}$ are the CP-odd and CP-even eigenstates) to be $(12.77 \pm 1.31^{+0.33}_{-0.31})$%. Using the quantum-correlated technique, the asymmetry, $A_{CP\to K\pi}$ can be used to extract the strong phase difference $\cos\delta_{K\pi}$ between the doubly Cabibbo-suppressed process $\bar{D}^0 \to K^-\pi^+$ and Cabibbo-favored $D^0 \to K^-\pi^+$. By taking inputs of other mixing parameters in world-average measurements, we obtain $\cos\delta_{K\pi} = 1.03 \pm 0.12 \pm 0.04 \pm 0.01$. Here, the first and second uncertainties are statistical and systematic, respectively. The third uncertainty corresponds to the uncertainties of the external inputs. This is the world-most accurate result of $\cos\delta_{K\pi}$, and can improve the world constrains on the mixing parameters and on the γ/ϕ_3 in the CKM matrix.

1. Introduction

$D\bar{D}$ mixing is highly suppressed by the GIM mechanism and by the CKM matrix elements within the Standard Model (Observation of $D\bar{D}$ mixing by LHCb [PRL 110 (2013)101802])

The relative phase $\delta_{K\pi}$ between DCS (Double-Cabibbo-Suppressed) amplitude and the corresponding CF (Cabibbo-Favored) amplitude:

- $\frac{\langle K^-\pi^+|\bar{D}^0\rangle}{\langle K^-\pi^+|D^0\rangle} = -re^{-i\delta_{K\pi}}$, $\delta_{K\pi} \propto$ the strong phase difference
- Improve the overall knowledge of charm mixing parameters
- An important ingredient for (over-)constraining the CKM unitary triangle γ/ϕ_3

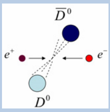


Cabibbo-Favored: Br ~ 3.88% *Double-Cabibbo-Suppressed: Br ~ 0.015%*

Left Figure: A example of CF decay. Right Figure: A example of DCS decay

Charm events at threshold:

- Quantum correlation of two D mesons: $e^+e^- \to \psi(3770) \to D^0\bar{D}^0$ → C=-1
- Very clean environment with little to no non-$D\bar{D}$ background
- Lots of systematic uncertainties cancel (double tag method)

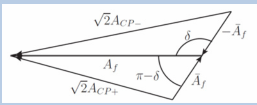


Formalism:

Omitting the higher orders of the mixing parameters, and assuming CP conservation:

$$2r\cos\delta_{K\pi} + y = (1 + R_{WS})A_{CP\to K\pi}$$

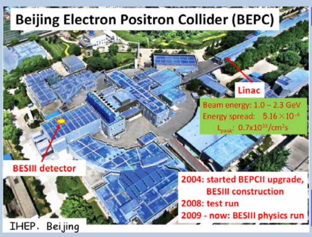
$$A_{CP\to K\pi} = \frac{Br_{D_2\to K\pi} - Br_{D_1\to K\pi}}{Br_{D_2\to K\pi} + Br_{D_1\to K\pi}}$$

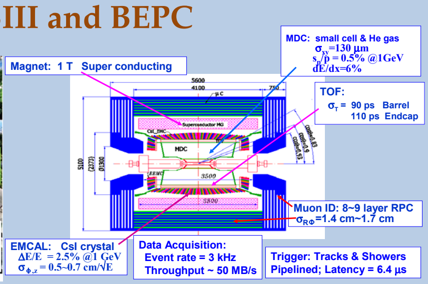


$$|D_1\rangle = \frac{|D^0\rangle + |\bar{D}^0\rangle}{2}, |D_2\rangle = \frac{|D^0\rangle - |\bar{D}^0\rangle}{2}$$

$$A_f = \langle K^-\pi^+|D^0\rangle, \bar{A}_f = \langle K^-\pi^+|\bar{D}^0\rangle,$$
$$A_{CP+} = \langle K^-\pi^+|D_1\rangle, A_{CP-} = \langle K^-\pi^+|D_2\rangle$$

2. BESIII and BEPC





Left Figure: the BEPC schematic. Right Figure: the BESIII schematic

Collected data samples at BESIII

	Previous data	BESIII now	Goal
J/ ψ	BESII: 58 M	1.2 B 20*BESII	10 B
ψ (3686)	CLEO: 28 M	0.5 B 20*CLEO	3 B
ψ (3770)	CLEO: 0.8 /fb	2.9 /fb 3.5*CLEO	20 /fb
Above open charm threshold	CLEO: 0.6/fb @4160MeV	2011: 0.5 /fb @ 4.009 GeV 2013: 1.9 /fb @ 4.26 GeV, 0.5 /fb @ 4.36 GeV and data for lineshape	5-10 /fb
R scan	BESII	2012: R @2.23,2.4,2.8,3.4 GeV 25 /pb tau mass	

world's largest samples of on-threshold $\psi(3770)$ data and keep increasing in the future

3. Determine $\delta_{K\pi}$ in experiment

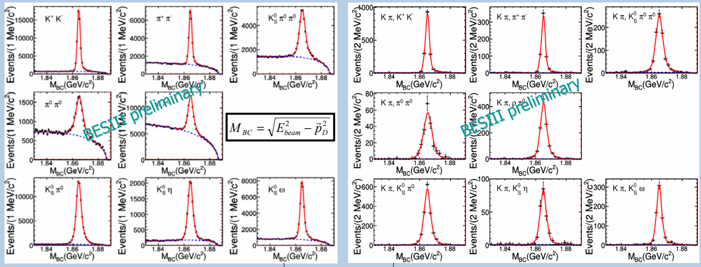
D tag method:

Type	Mode
Flavored	$K^-\pi^+$, $K^+\pi^-$
CP+	K^+K^-, $\pi^+\pi^-$, $K_S\pi^0\pi^0$, $\pi^0\pi^0$, $\rho^0\pi^0$
CP-	$K_S\pi^0$, $K_S\eta$, $K_S\omega$

- single tag (ST): $n_{CP\pm} = 2N_{D\bar{D}} \cdot B_{CP\pm} \cdot \varepsilon_{CP\pm}$
- double tag (DT): $n_{CP\pm,K\pi} = 2N_{D\bar{D}} \cdot B_{CP\pm} \cdot B_{D^{CP\mp}\to K\pi} \cdot \varepsilon_{CP\pm,K\pi}$

$$B_{D^{CP\pm}\to K\pi} = \frac{n_{CP\pm,K\pi}}{n_{CP\pm}} \cdot \frac{\varepsilon_{CP\pm}}{\varepsilon_{CP\pm,K\pi}}$$

$\varepsilon_{CP\pm} / \varepsilon_{CP\pm,K\pi}$ cancels most systematic effects within the $D \to CP\pm$ decay mode.

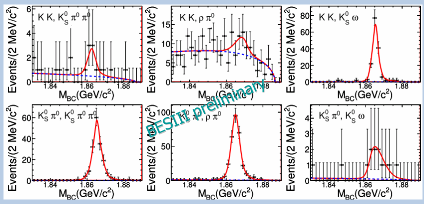


Left Figure: Single tags of CP modes. Right Figure: Double tags of (CP, $K\pi$) modes

$$A_{CP\to K\pi} = (12.77 \pm 1.31(stat.)^{+0.33}_{-0.31}(sys.))\%$$

CP purity check of CP-tag modes

The target CP modes are reconstructed by tagging CP+ (KK) and CP- ($K_S\pi^0$) decay.



Up Figure: Double tags of CP+,CP+ and CP+,CP- modes for CP purity check.

Mode	Yield(tag KK)	efficiency(%)	Yield(tag $K_S^0\pi^0$)	efficiency(%)
$K_S^0\pi^0\pi^0$	$8 \pm 3(*)$	11.80 ± 0.11	171 ± 14	7.20 ± 0.09
$\rho\pi^0$	$13 \pm 8(*)$	24.44 ± 0.16	299 ± 19	15.87 ± 0.16
$K_S^0\omega$	158 ± 13	11.02 ± 0.11	$7 \pm 3(*)$	6.77 ± 0.08

events with same-CP decays are consistent with 0

consider as systematic uncertainty

4. Systematic uncertainties

Correlated sys. uncertainties: cancelled in calculating $A_{CP\to K\pi}$

Un-correlated sys. Uncertainties are list below:

Source	K^+K^-	$\pi^+\pi^-$	$K_S^0\pi^0\pi^0$	$\pi^0\pi^0$	$\rho^0\pi^0$	$K_S^0\pi^0$	$K_S^0\eta$	$K_S^0\omega$
Lepton veto	0.2	0.2						
ΔE	0.6	0.5	0.9	0.7	1.8	0.7	0.5	1.5
Fitting	0.2	0.5	0.5	0.7	0.3	0.2	0.4	0.2
K_S^0 CP violation	–	–	0.2	–	–	0.2	0.2	0.2
CP purity	–	–	+1.3	–	+1.5	+0.2	–	+0.9
Quadratic sum	0.7	0.7	$^{+1.7}_{-1.0}$	1.0	$^{+2.4}_{-1.8}$	0.8	0.7	$^{+1.7}_{-1.5}$

BESIII preliminary

5. Summary

We measure: $A_{CP\to K\pi} = (12.77 \pm 1.31(stat.)^{+0.33}_{-0.31}(sys.))\%$

We have: $2r\cos\delta_{K\pi} + y = (1 + R_{WS})A_{CP\to K\pi}$

with external inputs of the parameters in HFAG2013 and PDG,

$$R_D = (3.47 \pm 0.06)\cdot 10^{-3}, y = (6.6 \pm 0.9)\cdot 10^{-3}, R_{WS} = (3.80 \pm 0.05)\cdot 10^{-3}$$

we obtain $\cos\delta_{K\pi} = 1.03 \pm 0.12 \pm 0.04 \pm 0.01$

CLEO measurements of strong phase differences and coherence factors done with 0.8 fb^{-1} at $\psi(3770)$. [CLEO, PRD 86 (2012) 112001]
without external inputs: $\cos\delta_{K\pi} = 0.81^{+0.22+0.07}_{-0.18-0.05}$,
with external inputs: $\cos\delta_{K\pi} = 1.15^{+0.19+0.00}_{-0.17-0.08}$.

BESIII result: the most precise measurement of $\delta_{K\pi}$ and compatible with the world average