Measurements of CPV and phases in charm decays at BESIII

Yang Gao

On behalf of the BESIII Collaboration

University of Science and Technology of China

Outline

- Recap analysis of CPV and phases in charm decays at BESIII
- BESIII experiment
- The quantum correlated(QC) data samples and double-tagging(DT) method
- CPV and strong phase measurement
- The future
- Summary

Recap analysis of CPV and phase in charm decay at BESIII

Conclusion and looking forward

Model-independent strong-phase parameters measured by BESIII essential for the improved determination of mixing and indirect CP violation parameters

Unique samples of threshold D, D_s and Λ decays can be searched for direct CP surprises, particularly in multibody modes with neutrals

Future Physics Programme at BESIII - Chin. Phys. C 44, 040001 (2020)

- 20 fb^{-1} at $\psi(3770)$ – run underway prior to BEPC upgrade in 2023

Improving c_i and s_i for charm mixing and indirect CP violation one of the primary motivators

- BESIII provides unique quantum correlated $D^0\bar{D}^0$ data to measure the strong-phase parameters in D decays as inputs to LHCb and Belle II for CKM angle γ measurement in the b sector
- Using 2.93 fb^{-1} e^+e^- collision data taken @ 3.773 GeV with BESIII detector, strong phase parameters of four D^0 decays are reported
  - $K_S^0\pi^+\pi^-, K_S^0K^+K^-, K^-\pi^+\pi^0, K^-\pi^+\pi^+\pi^-$

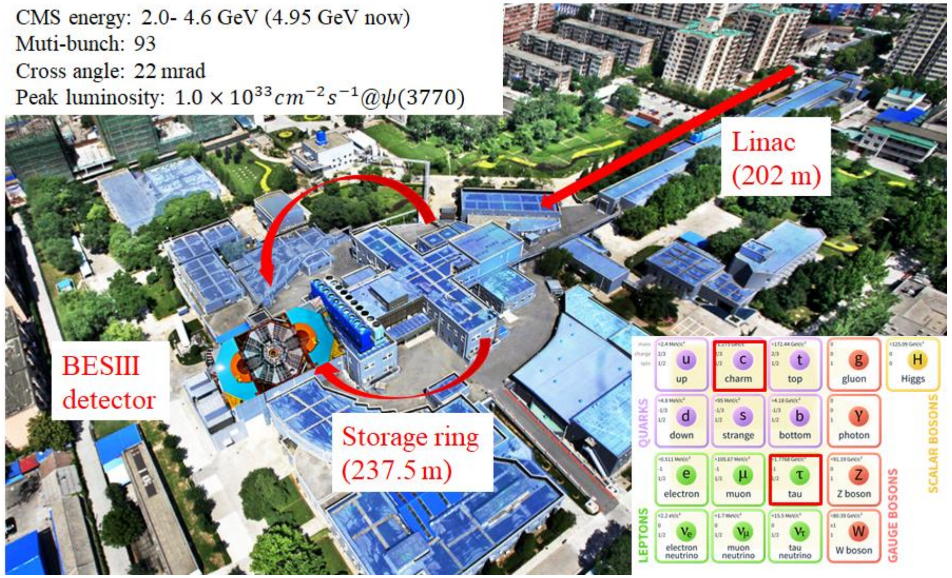
[CPC 44, 040001 (2020)]

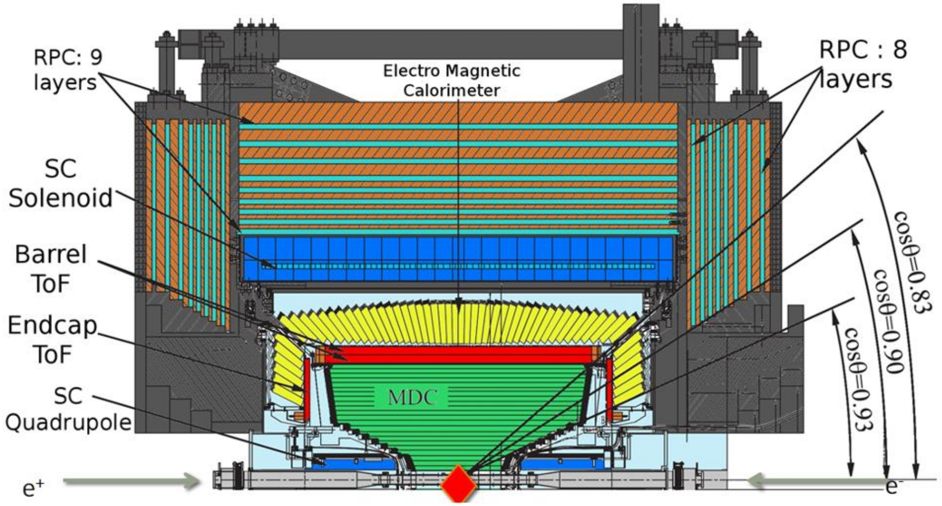
- 20 fb^{-1} $\psi(3770)$ data will be collected in the near future @ BESIII
  - More decays (e.g. $K_S^0\pi^+\pi^-\pi^0, \pi^+\pi^-\pi^+\pi^-, K^+K^-\pi^+\pi^-$ ...)
  - Higher precision (e.g. uncertainty on γ ~$1°$ → ~$0.4°$ for $K_S^0h^+h^-$)

Reference: CKM 2021: https://indico.cern.ch/event/891123/contributions/4601759/attachments/2350184/4008550/CKM%202021%20-%20charm%20CPV%20and%20mixing.pdf

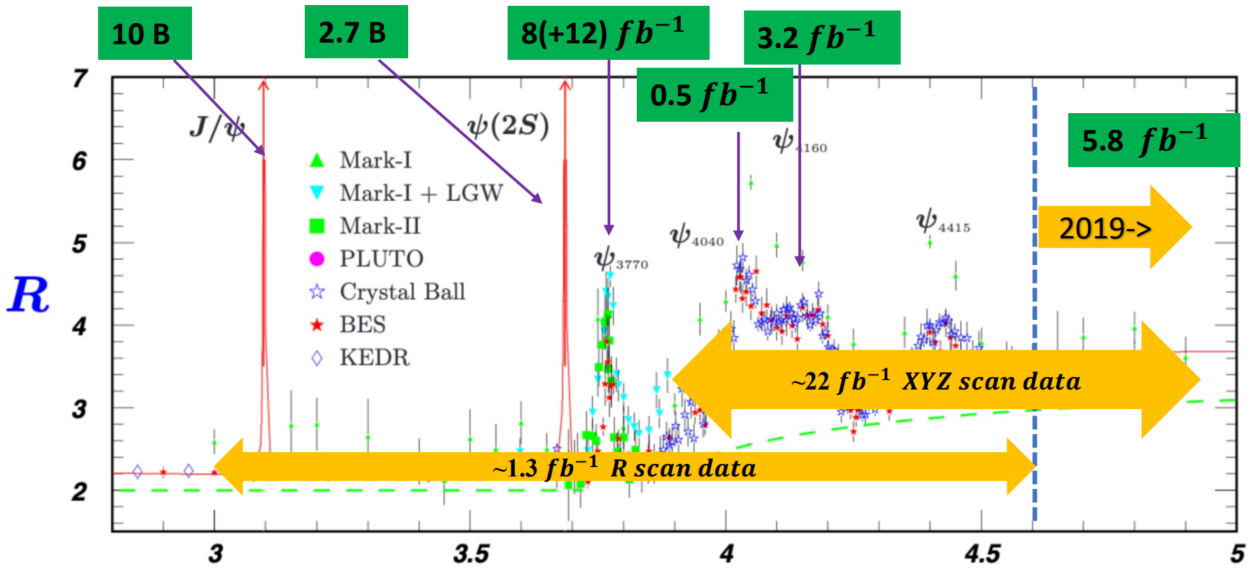
Reference: CKM 2021: https://indico.cern.ch/event/891123/contributions/4601746/attachments/2352942/4014577/CKM2021_strongphaseBESIII_shanxy.pdf

BESIII experiment





We are now here



Year	Integral Luminosity
2010&2011	2.93 fb^{-1} (This report)
2021-2022	~5 fb^{-1}
2022-2024	Plan to 12 fb^{-1}

Measurement of CPV in charm decay at BESIII

Experiment	Machine	Operation	C.M.	Luminosity	N_{prod}	Efficiency	Characters
BESIII	BEPC-II (e^+e^-)	2010-2011 (2021-) 2016-2019 2014+2020	3.77 GeV 4.18-4.23 GeV 4.6-4.7 GeV	2.9 $(8 \to 20)$ fb^{-1} 7.3 fb^{-1} 4.5 fb^{-1}	$D^{0,+}$: $10^7 (\to 10^8)$ D_s^+: 5×10^6 Λ_c^+: 0.8×10^6 ★☆	$\sim$ 10-30% ★★★	☺ extremely clean environment ☺ quantum coherence ☺ pure D-beam, almost no background ☹ no CM boost, no time-dept analyses
Belle II	SuperKEKB (e^+e^-)	2019-	10.58 GeV	0.4 $(\to 50)$ ab^{-1}	D^0: 6×10^8 $(\to 10^{11})$ $D^+_{(s)}$: 10^8 $(\to 10^{10})$ Λ_c^+: 10^7 $(\to 10^9)$	$\mathcal{O}$(1-10%) ★★	☺ clear event environment ☺ high trigger efficiency ☺ good-efficiency detection of neutrals ☺ time-dependent analysis ☹ smaller cross-section than LHCb
BELLE	KEKB (e^+e^-)	1999-2010	10.58 GeV	1 ab^{-1}	D: 10^9 Λ_c^+: 10^8 ★★☆		
LHCb	LHC (pp)	2011,2012 2015-2018 (2022-2025,2029-)	7+8 TeV 13 TeV	1+2 fb^{-1} 6 fb^{-1} $(\to 23 \to 50)$	5×10^{12} 10^{13} ★★★★	$\mathcal{O}(0.1\%)$ ★	☺ very large production cross-section ☺ large boost ☺ excellent time resolution ☹ dedicated trigger required

- From Long-Ke's reports: Overview of Charm Physics

➢ From LHCb, the direct CP violation observed at 10^{-3} level using $D^0 \to K^+K^-$ and $D^0 \to \pi^+\pi^-$.
  - PHYSICAL REVIEW LETTERS 122, 211803 (2019)

➢ The CP Asymmetry in BESIII is about 10^{-2}.
  - PRL 125 (2020) 14180
  - PRL 124 (2020) 241803

➢ No competitive to search for CP violation at BESIII since the achievable D^0 and $\bar{D}^0$ samples are smaller by more than 2-4 orders of magnitude than those at LHCb and BelleII.

CPV and strong phase measurement

What can BESIII do?

- BESIII can uniquely explore the quantum coherence of the initial $D^0\bar{D}^0$ state produced at $\psi(3770)$ to provide constraints on the mixing and CPV parameters.
- For decay to CP modes,

$$|D^0_+ >= p|D^0 > +q|\bar{D}^0 >$$
$$|D^0_- >= p|D^0 > -q|\bar{D}^0 >$$

$$\Gamma^{++}_{D^0\bar{D}^0} = [(x^2+y^2)(\cosh^2 a_m - \cos^2\phi)] \times [\frac{\Gamma^2(D^0 \to f_+)}{(1-y^2)(1+x^2)}]$$

$$\phi = \arg(p/q) \qquad R_m = |p/q| \qquad a_m = \log R_m$$

Decays of each D in the $D^0\bar{D}^0$ state into the same CP final states immediately indicate CPV in charm

- For Cabibbo-Favored and Double-Cabibbo-Suppressed final states, the decay width and asymmetry are shown,

$$\Gamma^{D^0_{K^-\pi^+},\bar{D}^0_{K^+\pi^-}}_{D^0\bar{D}^0} = [(x^2+y^2)(r^4 R_m^2 - 2r^2\cos 2(\delta+\phi) + R_m^2)] \times [\frac{\Gamma^2(D^0_{K^-\pi^+})}{2(1-y^2)(1+x^2)}]$$

The parameters of CPV are indicated immediately.

CPV and strong phase measurement

➢ For Cabibbo-Favored and Double-Cabibbo-Suppressed final states, the decay width and asymmetry are shown,

$$\mathcal{A}_{K\pi} = \frac{R(D^0_{\text{phys}} \to K^-\pi^+) - R(\bar{D}^0_{\text{phys}} \to K^+\pi^-)}{R(D^0_{\text{phys}} \to K^-\pi^+) + R(\bar{D}^0_{\text{phys}} \to K^+\pi^-)}$$

$$\approx (\frac{qr}{p})^2 h_{K\pi}[(\frac{|p|^2 - |q|^2}{|p|^2 + |q|^2})\cos(2\phi)(y\cos\delta_{K\pi} + x\sin\delta_{K\pi}) + \sin(2\phi)(y\sin\delta_{K\pi} - x\cos\delta_{K\pi})]$$

The strong phase differences are needed to extract parameters of CPV in some final states.

- **Excellent kinematical constrains might make BESIII competitive in studies of CP-asymmetries in some multi-body *D* decays which may provide information about strong phase difference in local phase space.**
    - Chinese Physics C Vol. 44, No. 4 (2020) 040001
    - JHEP, 03: 021 (2012)

CPV and strong phase measurement

- For binning CP Mixing of D^0,
- In LHCb, for example, $\bar{B} \to D^0(\to K_S^0\pi^+\pi^-)\mu^-\bar{\nu}_\mu X$

$$|D_+^0 >= p|D^0 > +q|\bar{D}^0 > \quad |D_-^0 >= p|D^0 > -q|\bar{D}^0 >$$

$$x = (m_1 - m_2)c^2/\Gamma \qquad x_{CP} = \frac{1}{2}\left[x\cos\phi\left(\left|\frac{q}{p}\right| + \left|\frac{p}{q}\right|\right) + y\sin\phi\left(\left|\frac{q}{p}\right| - \left|\frac{p}{q}\right|\right)\right]$$

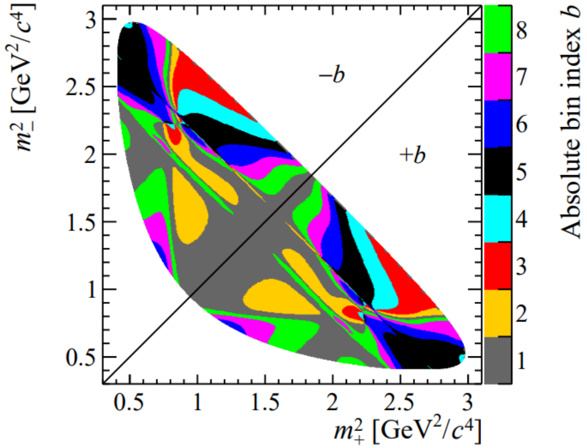
$$y = (\Gamma_1 - \Gamma_2)/(2\Gamma) \qquad y_{CP} = \frac{1}{2}\left[y\cos\phi\left(\left|\frac{q}{p}\right| + \left|\frac{p}{q}\right|\right) - x\sin\phi\left(\left|\frac{q}{p}\right| - \left|\frac{p}{q}\right|\right)\right]$$

$$2m = m_+ + m_-, \ 2\Gamma = \Gamma_+ + \Gamma_-, \ \Delta m = m_+ - m_-, \ \Delta\Gamma = \Gamma_+ - \Gamma_-$$

- CP-violation differences

$$\Delta x = \frac{1}{2}\left[x\cos\phi\left(\left|\frac{q}{p}\right| - \left|\frac{p}{q}\right|\right) + y\sin\phi\left(\left|\frac{q}{p}\right| + \left|\frac{p}{q}\right|\right)\right]$$

$$\Delta y = \frac{1}{2}\left[y\cos\phi\left(\left|\frac{q}{p}\right| - \left|\frac{p}{q}\right|\right) - x\sin\phi\left(\left|\frac{q}{p}\right| + \left|\frac{p}{q}\right|\right)\right]$$



- The ratio of yields between the Dalitz bin –b and Dalitz bin +b in the decay-time bin j

$$R_{bj}^{\pm} \approx \frac{r_b + \frac{1}{4} r_b \langle t^2 \rangle_j \, \mathrm{Re}\left(z_{CP}^2 - \Delta z^2\right) + \frac{1}{4}\langle t^2 \rangle_j \left|z_{CP} \pm \Delta z\right|^2 + \sqrt{r_b}\langle t \rangle_j \, \mathrm{Re}\left[X_b^*(z_{CP} \pm \Delta z)\right]}{1 + \frac{1}{4}\langle t^2 \rangle_j \, \mathrm{Re}\left(z_{CP}^2 - \Delta z^2\right) + r_b \frac{1}{4}\langle t^2 \rangle_j \left|z_{CP} \pm \Delta z\right|^2 + \sqrt{r_b}\langle t \rangle_j \, \mathrm{Re}\left[X_b(z_{CP} \pm \Delta z)\right]}$$

← **BESIII** $X_b \equiv c_b - i s_b$

$$F_i = \int_i a_f^2 d\Phi_f$$

$$F_{-i} = \int_i a_{-f}^2 d\Phi_f$$

$$c_i = \frac{1}{\sqrt{F_i F_{-i}}} \int_i a_f a_{-f} cos(\Delta\delta_D) d\Phi_f$$

$$s_i = \frac{1}{\sqrt{F_i F_{-i}}} \int_i a_f a_{-f} sin(\Delta\delta_D) d\Phi_f$$

$$z_{CP} \pm \Delta z \equiv -(q/p)^{\pm 1}(y + ix) \qquad x_{CP} = -\mathrm{Im}(z_{CP}), \quad \Delta x = -\mathrm{Im}(\Delta z)$$

$$y_{CP} = -\mathrm{Re}(z_{CP}), \quad \Delta y = -\mathrm{Re}(\Delta z)$$

(LHCb) arXiv:2208.06512

The QC data samples and DT

➢ **Quantum correlated $D^0\bar{D}^0$ decay at $\psi(3770)$**

$$e^+e^- \to \psi(3770) \to D^0\bar{D}^0 \to fg$$

$$|\psi(3770)> \to \frac{1}{\sqrt{2}}(|D^0>|\bar{D}^0> - |\bar{D}^0>|D^0>)$$

$$\Gamma(f,g) \propto (1+\frac{y^2-x^2}{2})[(r_f)^2+(r_g)^2-2r_fr_gR_fR_g\cos(\delta_f-\delta_g)]$$

$\propto$ Number of events

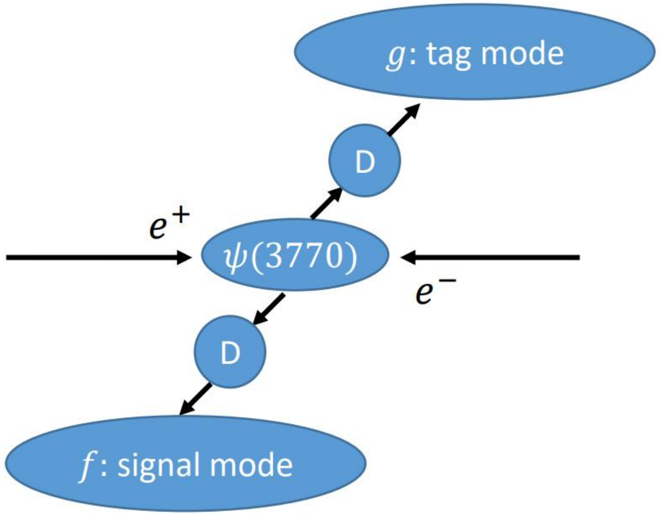
$$+\frac{x^2+y^2}{2}[1+(r_fr_g)^2-2r_fr_gR_fR_g\cos(\delta_f+\delta_g)]$$

Where

$$(r_f)^2 = \int|\bar{A}_f|^2d\Phi / \int|A_f|^2d\Phi$$

$$R_fe^{-i\delta_f} = \frac{\int A_f^*\bar{A}_fd\Phi}{\sqrt{\int|A_f|^2d\Phi\int|\bar{A}_f|^2d\Phi}}$$

Coherence factor   Strong phase difference



Advantages

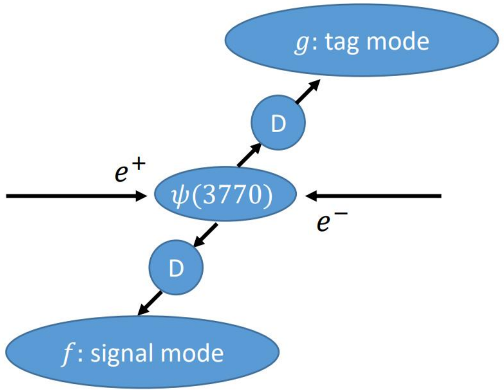
- ➢ Absolute branching fractions
- ➢ Quantum correlated $D^0\bar{D}^0$
- ➢ Clean background
- ➢ Full kinematic constraint reconstruct missing particle (ν, K_L^0)

Disadvantages

- ➢ Reduced reconstruction efficiency a little.
- ➢ Time-integrated measurements only

Strong phase measurements

- There are four results about strong phase at BESIII since CKM2021.



Process	Events (Million)	Cross Section (nb)
$e^+e^- \to \psi(3770) \to D^+D^-$	87	2.88
$e^+e^- \to \psi(3770) \to D^0\bar{D}^0$	111	3.66
$e^+e^- \to \psi(3770) \to$ non $D\bar{D}$	15	0.5
$e^+e^- \to q\bar{q}$	366	16.9
$e^+e^- \to \tau^+\tau^-$	90	3.0
$e^+e^- \to \gamma J/\psi$	33	1.1
$e^+e^- \to \gamma\psi(3686)$	102	3.4

- Inclusive MC

Table 1: The summaries of tag channels

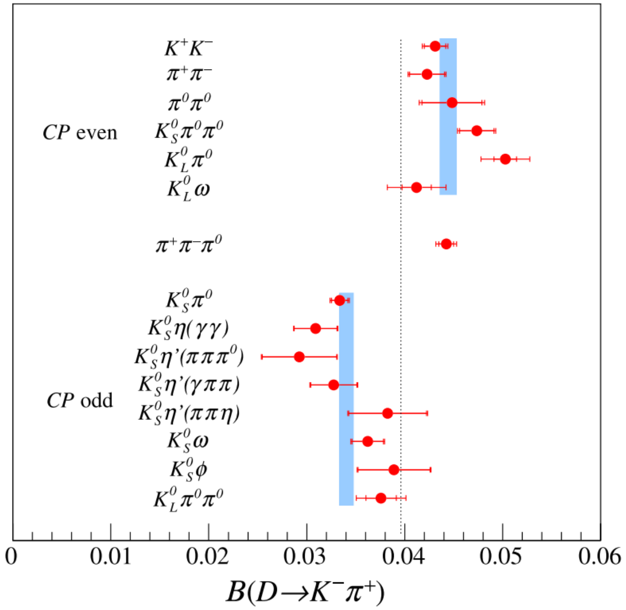
type	tag channel
CP even	K^+K^-, $\pi^+\pi^-$, $\pi^0\pi^0$, $K_S^0\pi^0\pi^0$, $K_L^0\omega_{\pi^+\pi^-\pi^0}$, $K_L^0\pi^0$
CP odd	$K_S^0\pi^0$, $K_S^0\eta_{\gamma\gamma}$, $K_S^0\eta_{\pi^+\pi^-\pi^0}$, $K_S^0\eta'_{\rho^0\gamma}$, $K_S^0\eta'_{\pi^+\pi^-\eta}$, $K_S^0\omega_{\pi^+\pi^-\pi^0}$, $K_S^0\phi$, $K_L^0\pi^0\pi^0$
CP Mixing	$K^+K^-\pi^0$, $\pi^+\pi^-\pi^0$, $\pi^+\pi^-\pi^+\pi^-$, $K_S^0\pi^+\pi^-\pi^0$, $K_S^0\pi^+\pi^-$, $K_L^0\pi^+\pi^-$

- Dataset: Quantum-correlated $D^0\bar{D}^0$ pairs corresponding to an integrated luminosity of 2.93 fb^{-1} collected at the $\psi(3770)$ resonance by the BESIII experiment

Strong phase measurements

Improved measurement of the strong-phase difference $\delta_D^{K\pi}$ in quantum-correlated $D^0\bar{D}^0$ decays.

Eur. Phys. J. C (2022) 82:1009



- Pure CP tag channels: $\mathcal{A}_{K\pi} \equiv \frac{\mathcal{B}(D_- \to K^-\pi^+) - \mathcal{B}(D_+ \to K^-\pi^+)}{\mathcal{B}(D_- \to K^-\pi^+) + \mathcal{B}(D_+ \to K^-\pi^+)}$

  Which to $\mathcal{O}(x, y, (r_D^{K\pi})^2)$ has the following relationship to the physics parameters:

$$\mathcal{A}_{K\pi} = \frac{-2r_D^{K\pi}\cos\delta_D^{K\pi} + y}{1 + (r_D^{K\pi})^2}.$$

- Similarly, CP Mixing tag channels:

$$\mathcal{A}_{K\pi}^{\pi\pi\pi^0} \equiv \frac{\mathcal{B}(D_X \to K^-\pi^+) - \mathcal{B}(D_+ \to K^-\pi^+)}{\mathcal{B}(D_X \to K^-\pi^+) + \mathcal{B}(D_+ \to K^-\pi^+)}, \Rightarrow \mathcal{A}_{K\pi}^{\pi\pi\pi^0} = \frac{(-2r_D^{K\pi}\cos\delta_D^{K\pi} + y)\, F_+^{\pi\pi\pi^0}}{1 + (r_D^{K\pi})^2 + (1 - F_+^{\pi\pi\pi^0})\,(2r_D^{K\pi}\cos\delta_D^{K\pi} + y)}.$$

- $K_{S,L}^0\pi^+\pi^-$:

$$Y(K^-\pi^+|K_S^0\pi^+\pi^-)_i = H(K_i + (r_D^{K\pi})^2 K_{-i} - 2r_D^{K\pi}\sqrt{K_i K_{-i}}[c_i\cos\delta_D^{K\pi} - s_i\sin\delta_D^{K\pi}])$$

$$Y(K^-\pi^+|K_L^0\pi^+\pi^-)_i = H'(K'_i + (r_D^{K\pi})^2 K'_{-i} - 2r_D^{K\pi}\sqrt{K'_i K'_{-i}}[c'_i\cos\delta_D^{K\pi} - s'_i\sin\delta_D^{K\pi}])$$

$$\mathcal{A}_{K\pi} = 0.132 \pm 0.011 \pm 0.007,\ \mathcal{A}_{K\pi}^{\pi\pi\pi^0} = 0.130 \pm 0.012 \pm 0.008$$

$$r_D^{K\pi}\cos\delta_D^{K\pi} = -0.0634 \pm 0.0048 \pm 0.0030 \pm 0.0004$$

$$r_D^{K\pi}\cos\delta_D^{K\pi} = -0.0562 \pm 0.0081 \pm 0.0050 \pm 0.0010$$

$$r_D^{K\pi}\sin\delta_D^{K\pi} = -0.011 \pm 0.012 \pm 0.007 \pm 0.003$$

$$\delta_D^{K\pi} = (187.6^{+8.9+5.4}_{-9.7-6.4})^\circ$$

More details: Inputs from BESIII for γ,XiaoKang Zhou,WG5,CKM2023.

Strong phase measurements

Measurement of the CP-even fraction of $D^0 \to \pi^+\pi^-\pi^+\pi^-$

Phys. Rev. D 106, 092004 (2022)

- Pure CP tag channels:

$$N(4\pi^\pm, g) = 2N_{D^0\bar{D}^0}(1+y^2)\mathcal{B}(4\pi^\pm)\mathcal{B}(g)[1-\eta^g_{CP}(2F_+^{4\pi^\pm}-1)],$$

$$N(g) = 2N_{D^0\bar{D}^0}(1+y^2)\mathcal{B}(g)[1-\eta^g_{CP}y],$$

$$N^\pm \equiv N(4\pi^\pm, g)[1-\eta^g_{CP}y]/N(g) = \mathcal{B}(4\pi^\pm)[1-\eta^g_{CP}(2F_+^{4\pi^\pm}-1)].$$

$$F_+ = \frac{N^+}{N^+ + N^-}$$

- Self-conjugate tag channels:

$$N^{\pi^+\pi^-\pi^0} \equiv N(4\pi^\pm, \pi^+\pi^-\pi^0)[1-(2F_+^{\pi^+\pi^-\pi^0}-1)y]/N(\pi^+\pi^-\pi^0)$$

$$= \mathcal{B}(4\pi^\pm)[1-(2F_+^{\pi^+\pi^-\pi^0}-1)(2F_+^{4\pi^\pm}-1)].$$

$$\frac{N^{\pi^+\pi^-\pi^0}}{N^+} = \frac{[1-(2F_+^{\pi^+\pi^-\pi^0}-1)(2F_+^{4\pi^\pm}-1)]}{2F_+^{4\pi^\pm}}$$

$$F_+ = \frac{N^+F_+^{\pi^+\pi^-\pi^0}}{N^{\pi^+\pi^-\pi^0} - N^+ + 2N^+F_+^{\pi^+\pi^-\pi^0}}$$

- $K^0_{S,L}\pi^+\pi^-$:

$$N(4\pi^\pm, |i|) = h[K_i + K_{-i} - 2\sqrt{K_iK_{-i}}c_i(2F_+^{4\pi^\pm}-1)]$$

$$N'(4\pi^\pm, |i|) = h'[K'_i + K'_{-i} + 2\sqrt{K'_iK'_{-i}}c'_i(2F_+^{4\pi^\pm}-1)]$$

$$F_+ = \frac{\Gamma_+}{\Gamma_+ + \Gamma_-} = \frac{\int |A_+|^2 d\Phi}{\int |A_+|^2 d\Phi + \int |A_-|^2 d\Phi}$$

Ignore CPV

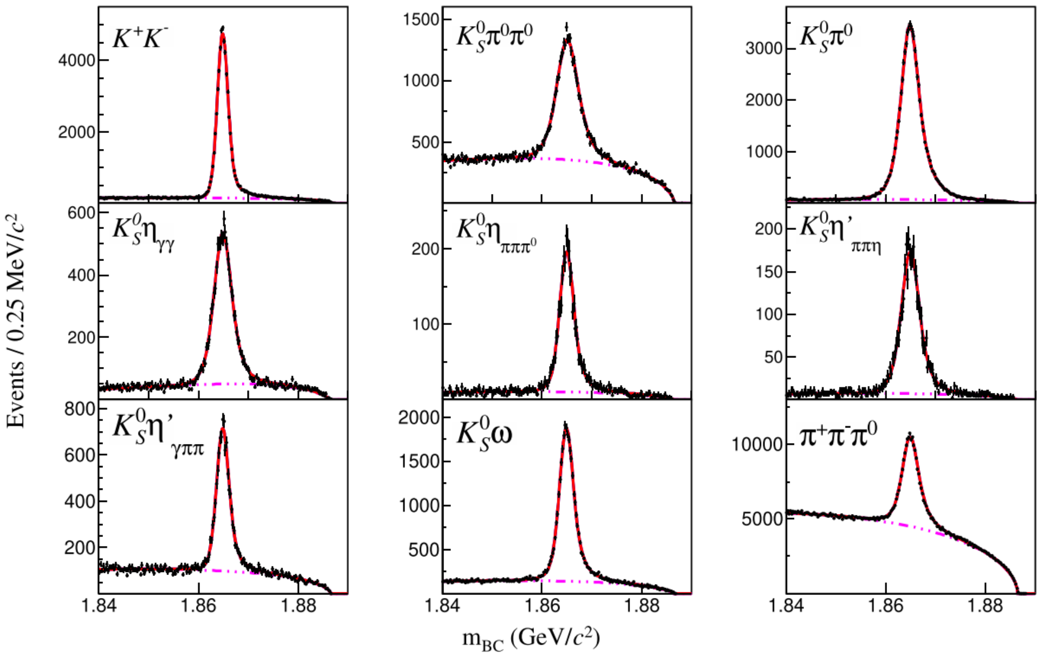
$$2F_+ - 1 = \frac{2}{\int |a_f|^2 + |a_{-f}|^2 d\Phi_f}\int |a_f||a_{-f}|cos(\Delta\delta_f)d\Phi_f$$

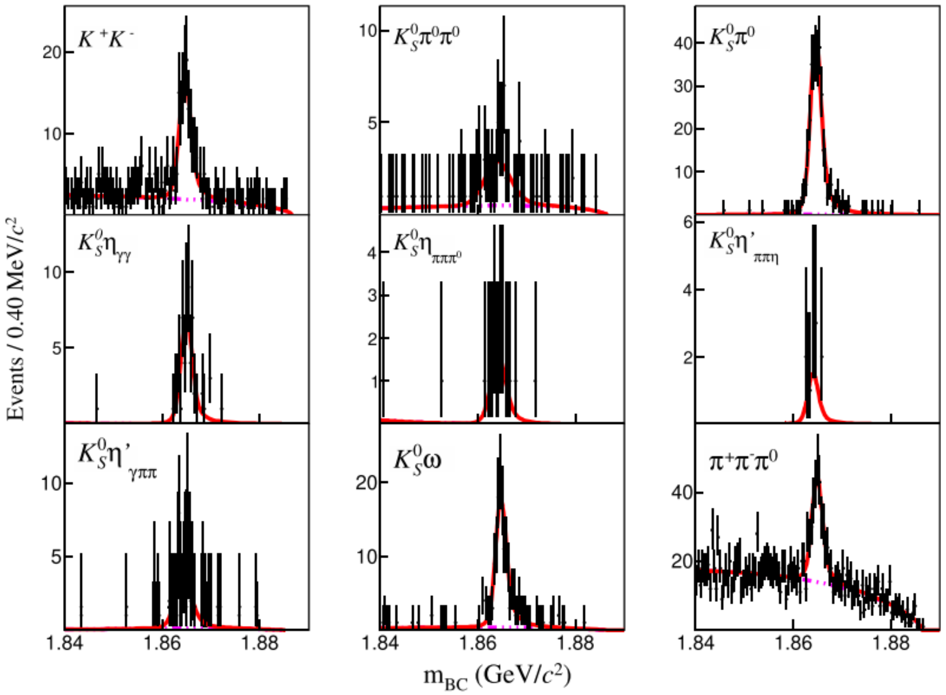
F_+ contains the information of strong phase difference in total phase space.

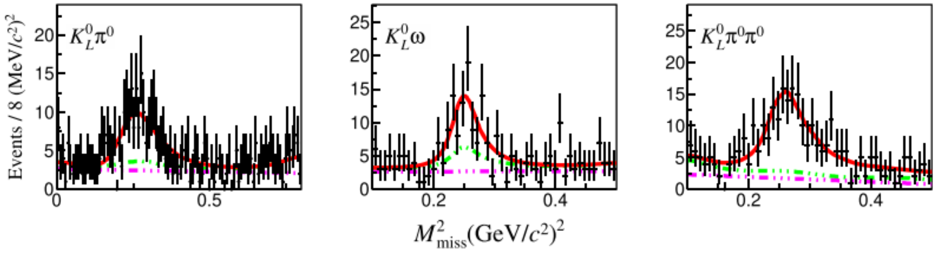
Strong phase measurements

Measurement of the CP-even fraction of $D^0 \to \pi^+\pi^-\pi^+\pi^-$

Phys. Rev. D 106, 092004 (2022)







- $N_{ST} = 369782$ with 9 ST channels.

$$m_{BC} = \sqrt{\left(E^2_{beam}\right)/c^4 - |\vec{p}_D|^2}$$

- E_{beam} is the beam energy.
- $\vec{p}_D$ is the momentum of the D candidates.

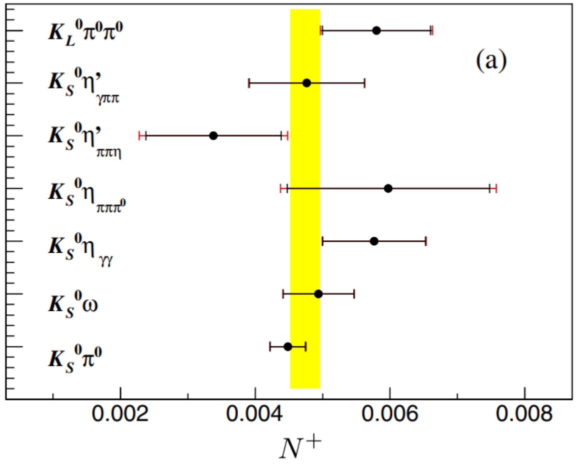
$$M^2_{miss} = (\sqrt{s}/2 - E_X)^2 - |\hat{\mathbf{p}}_{\mathbf{DT\ D}}\sqrt{s/4 - M_D^2} - \mathbf{p_X}|^2$$

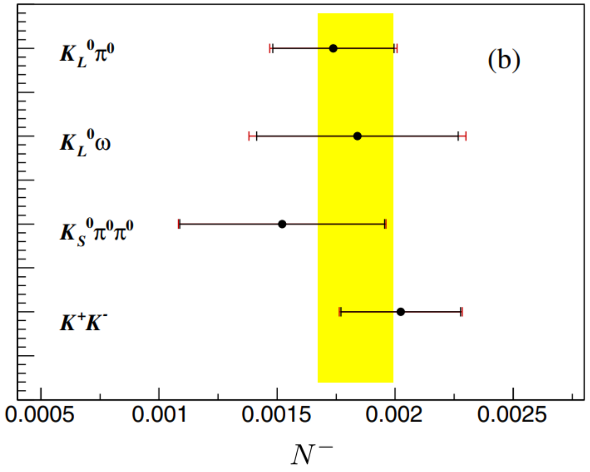
- E_X and $\mathbf{p_X}$ are the energy and momentum of the reconstructed particles in signal side.

Strong phase measurements

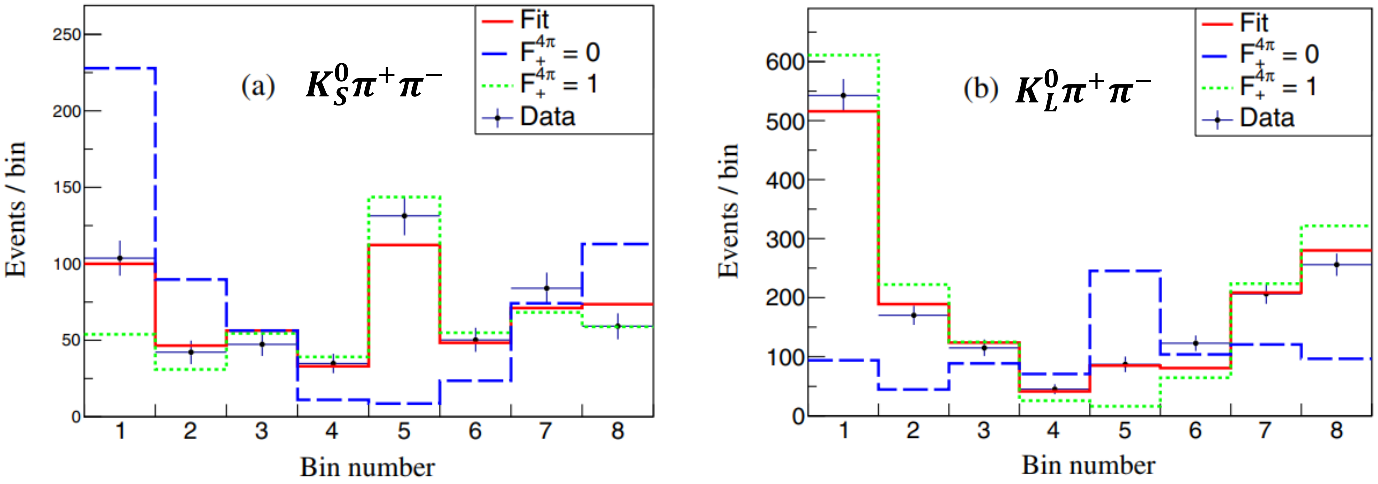
Measurement of the CP-even fraction of $D^0 \to \pi^+\pi^-\pi^+\pi^-$

Phys. Rev. D 106, 092004 (2022)





$$N^{\pi\pi\pi^0} = (1.64 \pm 0.21 \pm 0.06) \times 10^{-3},$$

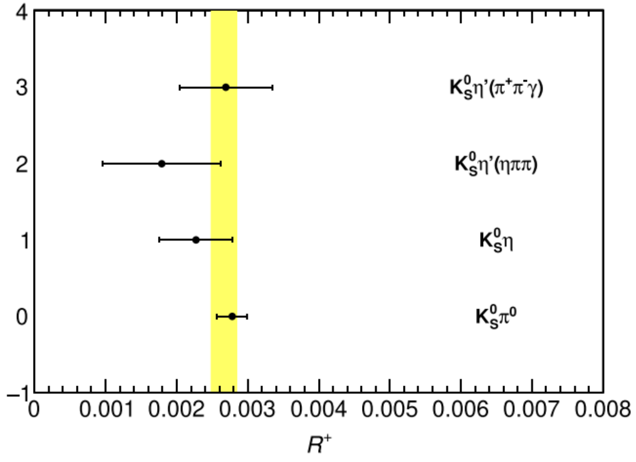


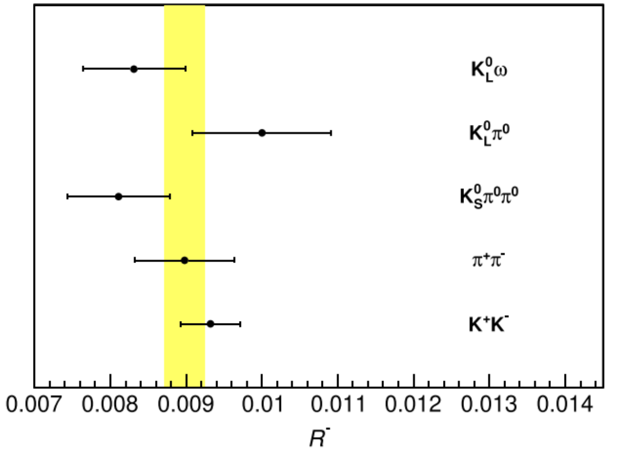
Measurement	F_+
BESIII	$\mathbf{0.735 \pm 0.015 \pm 0.005}$
CLEO-c	$0.769 \pm 0.021 \pm 0.010$

Strong phase measurements

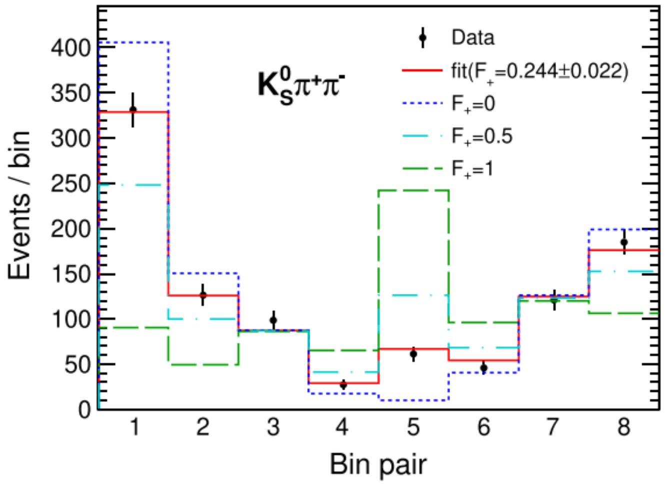
Determination of the CP-even fraction of $D^0 \to K_S^0\pi^+\pi^-\pi^0$

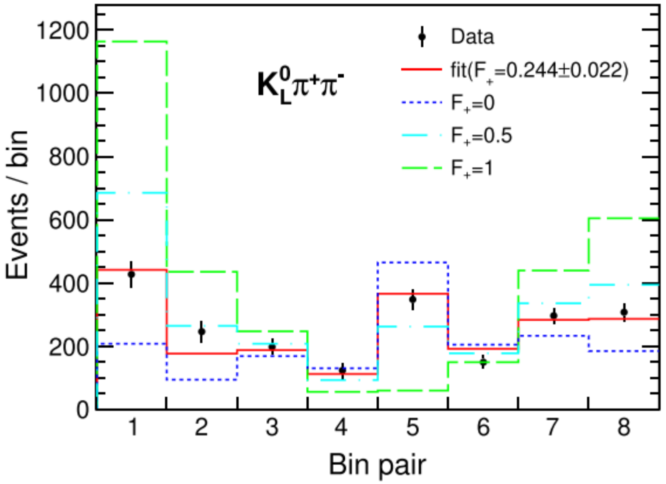
Phys. Rev. D 108, 032003 (2023)





$$F_+^{\pi^+\pi^-\pi^0} = 0.227 \pm 0.014 \pm 0.003$$
$$F_+^{\pi^+\pi^-\pi^+\pi^-} = 0.227 \pm 0.016 \pm 0.003$$



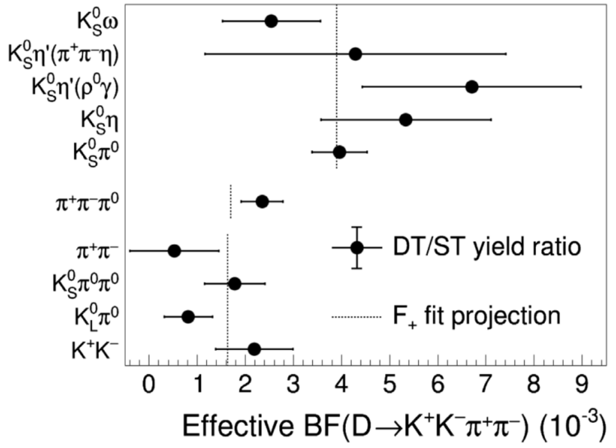


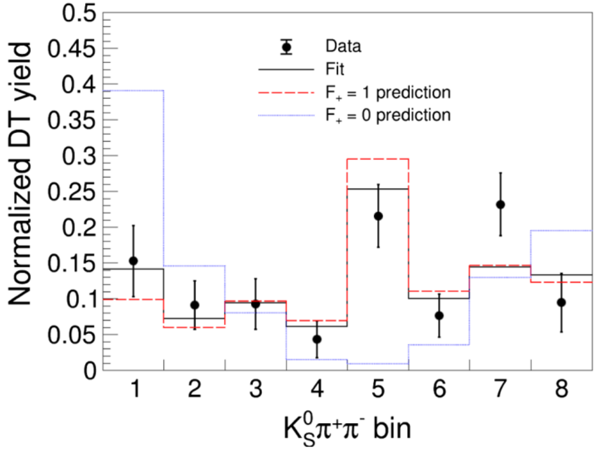
Measurement	F_+
BESIII	$\mathbf{0.235 \pm 0.010 \pm 0.002}$
CLEO-c	$0.238 \pm 0.012 \pm 0.012$

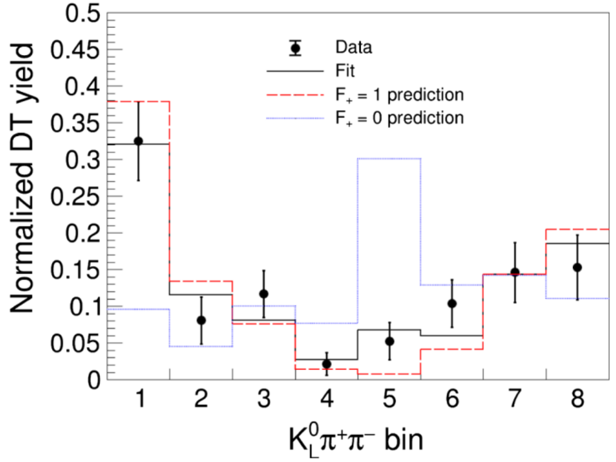
Other strong phase measurements

- **Measurement of the CP-even fraction of $D^0 \to K^+K^-\pi^+\pi^-$**

Phys. Rev. D 107, 032009 (2023)







$F_+ = 0.730 \pm 0.037 \pm 0.021$

More details: Inputs from BESIII for γ, XiaoKang Zhou, WG5, CKM2023.

- **Absolute Measurements of Branching Fractions of Cabibbo-Suppressed Hadronic $D^{0(+)}$ Decays Involving Multiple Pions**

Phys. Rev. D 106, 092005 (2022)

arXiv: 2206.13864v1

✓ **Some quick measurements of F_+**

Table 3. Summary of the ST yields of $CP\mp$ tags ($S^{\pm}_{\rm measured}$), the DT yields tagged by $CP\mp$ tags ($M^{\pm}_{\rm measured}$), the $CP+$ fraction (f_{CP+}), and the QC factor ($f_{\rm QC}$). The uncertainties are statistical only. A "/" denotes unmeasured quantites, occuring for one mode with a high-precision external result and for the two CP-eigenstates.

CP mode	$\bar{D}^0 \to K^+K^-$ ($CP+$)	$\bar{D}^0 \to K^0_S\pi^0$ ($CP-$)			
	$S^-_{\rm measured}$	$S^+_{\rm measured}$			
	57779±287	70512±311			
Decay mode	$M^-_{\rm measured}$	$M^+_{\rm measured}$	f_{CP+}	$f_{\rm QC}$ (%)	Uncertainty (%)
$D^0 \to \pi^+\pi^-\pi^0$	/	/	0.973 ± 0.017 [5]	93.5 ± 0.5	0.5
$D^0 \to \pi^+\pi^-2\pi^0$	65.7 ± 11.1	169.8 ± 13.9	0.682 ± 0.077	97.4 ± 0.7	0.7
$D^0 \to 4\pi^0$	/	/	1	93.1 ± 0.5	0.5
$D^0 \to 3\pi^0\eta$	/	/	1	93.1 ± 0.5	0.5
$D^0 \to 2\pi^+2\pi^-\pi^0$	37.8 ± 8.3	35.5 ± 6.6	0.438 ± 0.104	100.9 ± 0.9	0.9
$D^0 \to \pi^+\pi^-3\pi^0$	$5.2^{+3.5}_{-2.8}$	$6.8^{+3.4}_{-2.7}$	$0.520^{+0.338}_{-0.269}$	$99.7^{+3.0}_{-2.4}$	3.0
$D^0 \to 2\pi^+2\pi^-2\pi^0$	$3.5^{+2.8}_{-2.1}$	15.9 ± 3.7	$0.790^{+0.269}_{-0.255}$	$95.9^{+2.2}_{-2.1}$	2.2

Looking Forward

Decay mode	Quantity of interest	Comments
$D \to K_S^0 \pi^+ \pi^-$	c_i and s_i	Binning schemes as used in the CLEO-c analysis. With 20 fb^{-1} of data at 3.773 GeV, it might be worthwhile to explore alternative binning.
$D \to K_S^0 K^+ K^-$	c_i and s_i	Binning schemes as used in the CLEO-c analysis. With 20 fb^{-1} of data at 3.773 GeV, it might be worthwhile to explore alternative binning.
$D \to K^\pm \pi^\mp \pi^+ \pi^-$	R, δ	In bins guided by amplitude models, currently under development by LHCb.
$D \to K^+ K^- \pi^+ \pi^-$	c_i and s_i	Binning scheme guided by the CLEO-c model [68] or potentially an improved model in the future.
$D \to \pi^+ \pi^- \pi^+ \pi^-$	F_+ or c_i and s_i	Unbinned measurement of F_+. Measurements of F_+ in bins or c_i and s_i in bins could be explored.
$D \to K^\pm \pi^\mp \pi^0$	R, δ	Simple 2-3 bin scheme could be considered.
$D \to K_S^0 K^\pm \pi^\mp$	R, δ	Simple 2 bin scheme where one bin encloses the K^* resonance.
$D \to \pi^+ \pi^- \pi^0$	F_+	No binning required as $F_+ \sim 1$.
$D \to K_S^0 \pi^+ \pi^- \pi^0$	F_+ or c_i and s_i	Unbinned measurement of F_+ required. Additional measurements of F_+ or c_i and s_i in bins could be explored.
$D \to K^+ K^- \pi^0$	F_+	Unbinned measurement required. Extensions to binned measurements of either F_+ or c_i and s_i.
$D \to K^\pm \pi^\mp$	δ	Of low priority due to good precision available through charm-mixing analyses.

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Looking Forward

- For CPV, the decay of $D^0\overline{D}^0$ to the same CP final states has been studied based on blind analysis and will open data after finishing data taking plan.
- The CPV from polarization from Λ_c decay is in preparation.

- For some flavor decays, the strong phases would be updated using 20 fb^{-1}.

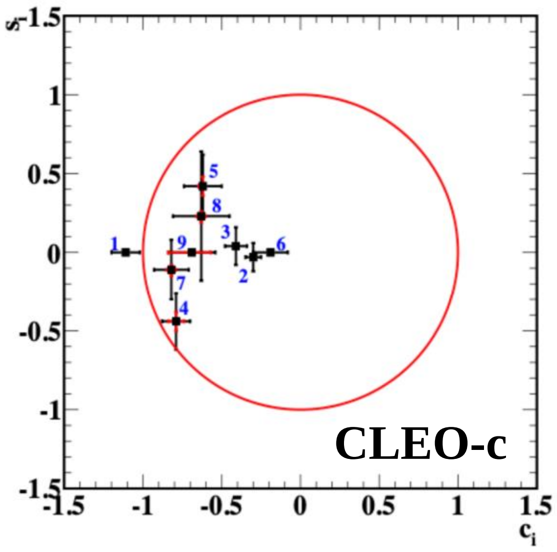
- For $\pi^+\pi^-\pi^0$ and $K^+K^-\pi^0$, the precision of F_+ would be improve with a factor more than 2 compared with CLEO-c's measurement. (~8 fb^{-1} in preparation)
- An optimized binning scheme and a precise c_i and s_i would be determined. (~8 fb^{-1}, ~20 fb^{-1})

- More precise c_i and s_i for $K_S^0\pi^+\pi^-$ and $K_L^0\pi^+\pi^-$, it is worthwhile to explore other binning. (~20 fb^{-1})

- A strong phase analysis of $K^+K^-\pi^+\pi^-$ is performed to measure the strong phase differences in bins of phase space. (~8 fb^{-1} in preparation) This would be the first binned analysis of this decay.
- The statistical uncertainty would be reduce significantly with 20 fb^{-1}.

Looking Forward

Bin	Bin region	m_L (GeV/c²)	m_U (GeV/c²)
1	$m_{\pi^+\pi^-\pi^0} \approx m_\omega$	0.762	0.802
2	$m_{K_S^0\pi^-} \approx m_{K^{*-}}$ &	0.790	0.994
	$m_{\pi^+\pi^0} \approx m_{\rho^+}$	0.610	0.960
3	$m_{K_S^0\pi^+} \approx m_{K^{*+}}$ &	0.790	0.994
	$m_{\pi^-\pi^0} \approx m_{\rho^-}$	0.610	0.960
4	$m_{K_S^0\pi^-} \approx m_{K^{*-}}$	0.790	0.994
5	$m_{K_S^0\pi^+} \approx m_{K^{*+}}$	0.790	0.994
6	$m_{K_S^0\pi^0} \approx m_{K^{*0}}$	0.790	0.994
7	$m_{\pi^+\pi^0} \approx m_{\rho^+}$	0.610	0.960
8	$m_{\pi^-\pi^0} \approx m_{\rho^-}$	0.610	0.960
9	Remainder	-	-



- $K_S^0\pi^+\pi^-\pi^0$
- Large branching fraction: 5.2%
- $F_+\sim 0.3$

- Only F_+ in BESIII based on 2.93 fb^{-1}.
- More precise F_+ is preparing.
- An optimized binning scheme and a precise c_i and s_i would be determined.

- Binned analysis of $\pi^+\pi^-\pi^+\pi^-$ is preparing (2.93 fb^{-1}).
- More precise of binned analysis $\pi^+\pi^-\pi^+\pi^-$ will be updated.

- More precise F_+ of $\pi^+\pi^-\pi^0\pi^0$ will be measured comparing with the BESIII's quick previous results.
- Binned analysis of $\pi^+\pi^-\pi^0\pi^0$ would be explored.

- ……

Summary

- BESIII provides unique quantum correlated $D^0\overline{D}^0$ data to measure the strong phase differences that are essential for the improved determination of mixing and indirect CP violation parameters.

- 20 fb^{-1} $\psi(3770)$ data will be collected in the near future (2024) @BESIII
  - More decays (e.g. $\pi^+\pi^-\pi^0$, $K^+K^-\pi^0$, $\pi^+\pi^-\pi^+\pi^-$, $K^+K^-\pi^+\pi^-$, $K_S^0\pi^+\pi^-\pi^0$ …)
  - Higher precision

Thank you!