Status and prospects of $D$ mixing and CPV at BESIII

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University of Chinese Academy of Sciences
(On behalf of the BESIII collaboration)
Outline

• Introduction and BESIII
• Recent results on D mixing and CPV
• Future plan & physics prospects
• Summary
Quantum correlated (QC) neutral $D$ state near threshold

Quantum Correlations (QC) and CP-tagging are unique

Taking advantage the quantum coherence of $DD$ pairs, BESIII can study the charm physics in an unique way

- strong phase in $D$ decays
- $D$ mixing parameters
- direct CP violation
- ...

If $D^0$ in CP eigenstate, $\overline{D^0}$ must be in opposite CP eigenstate
QC inputs for Charm Physics

Precision CKM test

Charm Mixing & CP violation

- inputs from Quantum Correlated (QC)
  $\psi(3770) \rightarrow D\bar{D}$ decays
  - (Averaged)Strong phase difference: $\delta_D$
  - Coherent factors: $R_D$
  - (Averaged)Strong phase in Dalitz bins: $c_i, s_i$
- $B$ factories, LHCb, Super $B$ factories are the customers
δ and γ/φ₃ input

- *D* hadronic parameters for a final state

\[
A(D^0 \to f) = \frac{\mathcal{A}(D^0 \to f)}{\mathcal{A}(D^0 \to f)} \equiv -r_D e^{-i\delta_D}
\]

- Charm mixing parameters: \(x = \frac{\Delta M}{\Gamma}, y = \frac{\Delta \Gamma}{2\Gamma}\)
  - Time-dependent WS \(D^0 \to K^+\pi^-\) rate \(\Rightarrow\)
    \(y' = y \cos \delta_{K\pi} - x \sin \delta_{K\pi}\) (LHCb)
  - \(\delta_{K\pi}\): QC measurements from Charm factory

- \(\gamma/\phi_3\) measurements from \(B \to D^0 K\)
  - \(b \to u\): \(\gamma/\phi_3 = \text{arg} V'^\ast_{ub}\)
    - most sensitive method to constrain \(\gamma/\phi_3\) at present
  - GLW, ADS method
  - \(r_D, \delta_D\): QC measurements from Charm factory

- GGSZ method
  - \(c_i, s_i\): QC measurements from Charm factory
Time-integrated decay rates

- No time dependent information at Charm threshold
- Anti-symmetric wavefuction:
  \[ \Gamma_{ij}^2 = |\langle i|D^0\rangle\langle j|\bar{D}^0\rangle - \langle j|D^0\rangle\langle i|\bar{D}^0\rangle|^2 \]
- Double tag rates:
  \[ A_i^2A_j^2[1 + r_i^2r_j^2 - 2r_i r_j \cos(\delta_i + \delta_j)] \]
- CP tag: \( r=1, \delta=0 \) or \( \pi; \ l^\pm \) tag: \( r=0 \)
- Single and Double tag rates
  \[ z_f \equiv 2 \cos \delta_f, \ r_f \equiv \frac{A_{DCS}}{ACF}, \ R_M \approx \frac{x^2+y^2}{2} \]

<table>
<thead>
<tr>
<th>C-odd</th>
<th>( f )</th>
<th>( \bar{f} )</th>
<th>( l^+ )</th>
<th>( l )</th>
<th>( CP+ )</th>
<th>( CP- )</th>
</tr>
</thead>
<tbody>
<tr>
<td>( f )</td>
<td>( R_M[1 + r_f^2(2 - z_f^2) + r_f^4] )</td>
<td></td>
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<tr>
<td>( \bar{f} )</td>
<td>( 1 + r_f^2(2 - z_f^2) + r_f^4 )</td>
<td>( R_M[1 + r_f^2(2 - z_f^2) + r_f^4] )</td>
<td>( r_f^2 )</td>
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<td>( R_M )</td>
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<td>( l^+ )</td>
<td>( r_f^2 )</td>
<td>( l )</td>
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<td>( R_M )</td>
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<tr>
<td>( l^- )</td>
<td>( l )</td>
<td>( r_f^2 )</td>
<td></td>
<td>( R_M )</td>
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<tr>
<td>( CP+ )</td>
<td>( 1 + r_f(r_f + z_f) )</td>
<td>( 1 + r_f(r_f + z_f) )</td>
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<tr>
<td>( CP- )</td>
<td>( 1 + r_f(r_f - z_f) )</td>
<td>( 1 + r_f(r_f - z_f) )</td>
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<tr>
<td>Single Tag</td>
<td>( 1 + r_f^2 - r_fz_f(A - y) )</td>
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</table>

\[ \psi(3770) \to [D^0 \bar{D}^0 - \bar{D}^0 D^0]/\sqrt{2} \]
\[ = -[D_{CP+}D_{CP-} - D_{CP-}D_{CP+}]/\sqrt{2} \]
\[ D_{CP\pm} = [D^0 \pm \bar{D}^0]/\sqrt{2} \]
Beijing Electron Positron Collider (BEPC)

beam energy: 1.0 – 2.3 GeV

2004: started BEPCII upgrade, BESIII construction
2008: test run
2009 - now: BESIII physics run

- 1989-2004 (BEPC):
  \[ L_{\text{peak}} = 1.0 \times 10^{31} / \text{cm}^2 \text{s} \]
- 2009-now (BEPCII):
  \[ L_{\text{peak}} = 1.0 \times 10^{33} / \text{cm}^2 (4/5/2016) \]
BESIII data samples

- 4100~4400 MeV: 0.5/fb coarse scan
- 3850~4590 MeV: 0.5/fb fine scan
- In 2015, we finished energy scan at 2000~3000 MeV
- In 2016, we took 3/fb Ds data about 4180 MeV for Ds physics
  (about 5 times of CLEO-c data)
The BESIII Detector

Magnet: 1 T Super conducting

MDC: small cell & He gas
\sigma_{xy} = 130 \mu m
\delta p/p = 0.5\% @1 GeV
dE/dx = 6\%

TOF:
\sigma_T = 90 \text{ ps Barrel}
110 \text{ ps Endcap}

Muon ID: 8~9 layer RPC
\sigma_{R\Phi} = 1.4 \text{ cm} \sim 1.7 \text{ cm}

EMCAL: CsI crystal
\Delta E/E = 2.5\% @1 \text{ GeV}
\sigma_{\phi,z} = 0.5\sim 0.7 \text{ cm/}\sqrt{E}

Data Acquisition:
Event rate = 3 kHz
Throughput \sim 50 \text{ MB/s}

Trigger: Tracks & Showers
Pipelined; Latency = 6.4 \mu s

The new BESIII detector is hermetic for neutral and charged particle with excellent resolution, PID, and large coverage.
BESIII Collaboration

~ 450 members from 57 institutions in 13 countries

US (5)
Univ. of Hawaii
Carnegie Mellon Univ.
Univ. of Minnesota
Univ. of Rochester
Univ. of Indiana

Mongolia (1)
Institute of Physics and Technology

Pakistan (2)
Univ. of Punjab
COMSAT CIIT

India (1)
Indian Institute of Technology

Europe (14)
Germany: Univ. of Bochum,
Univ. of Giessen, GSI
Univ. of Johannes Gutenberg
Helmholtz Ins. In Mainz, Univ. of Munster
Russia: JINR Dubna; BINF Novosibirsk
Italy: Univ. of Torino, Frascati Lab, Ferrara Univ.
Netherlands: KVI/Univ. of Groningen
Sweden: Uppsala Univ.
Turkey: Turkey Accelerator Center

China (32)
IHEP, CCAST, UCAS, Shandong Univ.,
Univ. of Sci. and Tech. of China
Zhejiang Univ., Huangshan Coll.
Huazhong Normal Univ., Wuhan Univ.
Zhengzhou Univ., Henan Normal Univ.
Peking Univ., Tsinghua Univ.,
Zhongshan Univ., Nankai Univ., Beihang Univ.
Shanxi Univ., Sichuan Univ., Univ. of South China
Hunan Univ., Liaoning Univ., Univ. of Sci. and Tech. Liaoning
Nanjing Univ., Nanjing Normal Univ., Southeast Univ.
Guangxi Normal Univ., Guangxi Univ.
Suzhou Univ., Hangzhou Normal Univ.
Lanzhou Univ., Henan Sci. and Tech. Univ.
Jinan Univ.

Korea (1)
Seoul Nat. Univ.

Japan (1)
Tokyo Univ.

Pakistan (2)
Univ. of Punjab
COMSAT CIIT

India (1)
Indian Institute of Technology

Political Map of the World, June 1999

CKM 2016, Mumbai
Charm facilities

• Hadron colliders (huge cross-section, energy boost)
  – Tevatron (CDF, D0)
  – LHC (LHCb, CMS, ATLAS)
• e⁺e⁻ Colliders (more kinematic constrains, clean environment, ~100% trigger efficiency)
  – B-factories (Belle(-II), BaBar)
  – Threshold production (CLEOc, BESIII)
    • Can not compete in statistics with Hadron colliders & B-factories!!!
    • Quantum Correlations (QC) and CP-tagging are unique
    • Only D meson pairs, no extra CM Energy for pions
    • Systematic uncertainties cancellations while applying double tag technique
Strong Phase $\delta_{K\pi}$

Quantum correlation $\rightarrow$ Interference $\rightarrow$ access strong phase!

$$\langle K\pi | D_{CP\pm} \rangle = (\langle K\pi | D^0 \rangle \pm \langle K\pi | \bar{D}^0 \rangle) / \sqrt{2} \Rightarrow \sqrt{2} A_{CP\pm} = A_{K\pi} \pm A_{\bar{K}\pi}$$

$\pi - \delta_{K\pi}$

2.93 fb$^{-1}$ @ 3.773 GeV

**BESIII results:**

- The third error is due to the input parameters
- World best precision
- In 10 fb$^{-1}$ BESIII data, precision of $\cos \delta_{K\pi}$ will reach $\sim$0.07

**Flavor tags:** $K\pi^+, K^+\pi$

**CP+ tags (5 modes):** $K^-K^+, \pi^+\pi^-, K_S^0\pi^0\pi^0, \pi^0\pi^0, \rho^0\pi^0$

**CP- tags (3 modes):** $K_S^0\pi^0, K_S^0\eta, K_S^0\omega$

PLB 734, 227 (2014)
\[(c_i, s_i)\) in \(D^0 \to K_{s,L} \pi^+ \pi^-\) Dalitz analysis

GGSZ (Dalitz) method

\[N_i^\pm = h_B \left[ K_{\pm i}^2 + r_b^2 K_{+i}^2 + 2 \sqrt{K_i K_{-i}} \left( x_c c_i \pm y_s s_i \right) \right]\]

\(B^\pm \to DK^\pm\) yields

from flav.-tagged 
\(D \to K_{s,L} \pi \pi\)

extracted from fit 
to the \(B^\pm\) yields

measured by CLEO 
[PRD82, 112006 (2010)]

We can calculate \(c_i\) and \(s_i\) from double tags of 
\(D^0 \to K_{s} \pi^+ \pi^-\) vs \(D^0 \to (K_{s,L} \pi^+ \pi^-\) or CP eigenstates)

A relationship can be shown between 
Dalitz bin yields and 
\(c_i\) and \(s_i\) 
(in backup slides)

Only \(c_i, s_i\) from \(K_s \pi^+ \pi^-\) is used to calculate \(\gamma\).
However adding in \(D^0 \to K_L \pi^+ \pi^-\) we can calculate \(c'_i, s'_i\) and use how they relate to \(c_i, s_i\) to further constrain our results in a Global fit.
Still statistical limited.

- Only statistical errors for BESIII
- Consistent agreement with CLEO-c measurements, but superior in statistical errors

- Based on the BESIII results, we expect a reduction in the \((c_i, s_i)\) contribution to the uncertainty in \(\gamma/\phi_3\) of \(\sim 40\%\).

- Crucial inputs for the future analysis carried out in the LHCb and BelleII experiment.
We measure the $y_{CP}$ using CP-tagged semi-leptonic D decays, which allows to access CP asymmetry in mixing and decays.

**Reconstructed modes:**

- **Flavor tags:** $K_{e
\nu}$, $K_{\mu
\nu}$
- **CP+ tags (3 modes):** $K^-K^+$, $\pi^+\pi^-$, $K^0_S\pi^0\pi^0$,
- **CP- tags (3 modes):** $K^0_S\pi^0$, $K^0_S\eta$, $K^0_S\omega$

**Single Tags**

**Double Tags**

**BESIII result:**

$$y_{CP} = (-2.0 \pm 1.3 \pm 0.7)\%$$

- Most precise measurement with QC charm mesons
- In the limit of no CP violation: $y_{CP} = y$
interference of the CF component \( D \to K^0\pi^0 \)'s with the DCS \( D \to K^0\pi^0 \)'s component. \( |K^0_L| \approx 1/\sqrt{2} \) (\( |K^0| - |K^0>| \) and \( |K^0_S| \approx 1/\sqrt{2} \) (\( |K^0| + |K^0>| \)). The sign of this interference of \( K^0 \) with \( K^0 \) is opposite for \( K^0_L \) and \( K^0_S \).

Single tag:
- \( \text{CP}^+ \): KK, \( \pi\pi \);
- \( \text{CP}^- \): \( K_S\pi^0 \);
- Cabibbo Favored (CF): \( K\pi \), \( K\pi\pi\pi \), \( K\pi\pi^0 \);

Double tag:
- \( \text{CP}^+ \) (KK, \( \pi\pi \), \( K_L\pi^0 \), \( K_S\pi^0\pi^0 \)) VS CF (\( K\pi \), \( K\pi\pi\pi \), \( K\pi\pi^0 \));
- \( \text{CP}^- \) (\( K_S\pi^0 \), \( K_L\pi^0\pi^0 \)) VS CF (\( K\pi \), \( K\pi\pi\pi \), \( K\pi\pi^0 \));

We can have
**K_L reconstruction and DT yields**

- \( \kappa_L \) interact with EMC and deposit part of energy, thus giving position information.
- After reconstructing all other particles, \( K_L \) can be inferred from its position information and the constraint \( \Delta E = 0 \).

![Graph of \( K^- \pi^+ \) vs \( K_L \pi^0 \)]

**Statistical only**

<table>
<thead>
<tr>
<th>( D \rightarrow K_{S,L}^0 \pi^0 )</th>
<th>( Br_{K_S^0 \pi^0}(%) )</th>
<th>( Br_{K_L \pi^0}(%) )</th>
<th>( R(D \rightarrow K_{S,L}^0 \pi^0) )</th>
</tr>
</thead>
<tbody>
<tr>
<td>( K_L )</td>
<td>1.208±0.041</td>
<td>1.061±0.038</td>
<td>0.0646±0.0245</td>
</tr>
<tr>
<td>( K \pi )</td>
<td>1.212±0.037</td>
<td>0.985±0.036</td>
<td>0.1035±0.0237</td>
</tr>
<tr>
<td>( K \pi \pi^0 )</td>
<td>1.251±0.028</td>
<td>0.953±0.029</td>
<td>0.1351±0.0186</td>
</tr>
<tr>
<td>All</td>
<td>1.230±0.020</td>
<td>0.991±0.019</td>
<td>0.1077±0.0125</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>( D \rightarrow K_{S,L}^0 \pi^0 \pi^0 )</th>
<th>( Br_{K_S^0 \pi^0 \pi^0}(%) )</th>
<th>( Br_{K_L \pi^0 \pi^0}(%) )</th>
<th>( R(D \rightarrow K_{S,L}^0 \pi^0 \pi^0) )</th>
</tr>
</thead>
<tbody>
<tr>
<td>( K_L )</td>
<td>1.024±0.049</td>
<td>1.299±0.080</td>
<td>-0.1183±0.0385</td>
</tr>
<tr>
<td>( K \pi )</td>
<td>0.887±0.043</td>
<td>1.097±0.073</td>
<td>-0.1060±0.0409</td>
</tr>
<tr>
<td>( K \pi \pi^0 )</td>
<td>1.010±0.036</td>
<td>1.158±0.060</td>
<td>-0.0681±0.0313</td>
</tr>
<tr>
<td>All</td>
<td>0.975±0.024</td>
<td>1.175±0.040</td>
<td>-0.0929±0.0209</td>
</tr>
</tbody>
</table>

CLEO: \( R(K_{S,L} \pi^0) = (10.8 \pm 2.5 \pm 2.4)\% \)

- Consistent with PDG values
- \( K_{S,L} \pi^0 \) agrees with U-spin symmetry
- \( K_L 2\pi^0 \) is the first measurement
Single-tag yields can be got from $K_S \pi^0$, $K_L \pi^0$ branching fraction measurement results. Double-Tag yields are from $U_{\text{miss}}$ fit.

This work gives: $y_{CP} = (0.980 \pm 2.429)\%$ (preliminary) \textit{Statistical only}

Consistent with the published BESIII result: $y_{CP} = (-2.0 \pm 1.3 \pm 0.7)\%$
CPV in charm factory

**CP asymmetry:** \[ A_{CP}(f) = \frac{\Gamma(f) - \Gamma(\bar{f})}{\Gamma(f) + \Gamma(\bar{f})} \]

- ★ CPV in charm:
  - ✤ SM: \(\leq\) a few \%
  - ✤ NP: >\~ 1\%
- ★ World precision: \~ 0.1\%
- ★ CLEO-c measured \(A_{CP}\) based on single tag events
  - ✤ at the order 1\% for all modes
  - ✤ no evidence of CPV
  - ✤ systematics dominant

**BESIII preliminary**

<table>
<thead>
<tr>
<th>(B) (stat)(\pm) (sys)</th>
<th>(B_{PDG})</th>
</tr>
</thead>
<tbody>
<tr>
<td>(\pi^+\pi^-)</td>
<td>((1.505 \pm 0.018 \pm 0.031) \times 10^{-3})</td>
</tr>
<tr>
<td>(K^+K^-)</td>
<td>((4.229 \pm 0.020 \pm 0.087) \times 10^{-3})</td>
</tr>
<tr>
<td>(K^-\pi^+)</td>
<td>((3.96 \pm 0.06 \pm 0.073)%)</td>
</tr>
<tr>
<td>(K_S^0\pi^0)</td>
<td>((1.236 \pm 0.006 \pm 0.032)%)</td>
</tr>
<tr>
<td>(K_S^0\eta)</td>
<td>((5.149 \pm 0.068 \pm 0.134) \times 10^{-3})</td>
</tr>
<tr>
<td>(K_S^0\eta')</td>
<td>((9.562 \pm 0.197 \pm 0.379) \times 10^{-3})</td>
</tr>
<tr>
<td>(\pi^0\pi^+)</td>
<td>((1.259 \pm 0.033 \pm 0.025) \times 10^{-3})</td>
</tr>
<tr>
<td>(\pi^0K^+)</td>
<td>((2.171 \pm 0.198 \pm 0.060) \times 10^{-4})</td>
</tr>
<tr>
<td>(\eta\pi^+)</td>
<td>((3.790 \pm 0.070 \pm 0.075) \times 10^{-3})</td>
</tr>
<tr>
<td>(\eta K^+)</td>
<td>((1.393 \pm 0.228 \pm 0.124) \times 10^{-4})</td>
</tr>
<tr>
<td>(\eta'\pi^+)</td>
<td>((5.122 \pm 0.140 \pm 0.210) \times 10^{-3})</td>
</tr>
<tr>
<td>(\eta'K^+)</td>
<td>((1.377 \pm 0.428 \pm 0.202) \times 10^{-4})</td>
</tr>
<tr>
<td>(K_S^0\pi^+)</td>
<td>((1.591 \pm 0.006 \pm 0.033) \times 10^{-2})</td>
</tr>
<tr>
<td>(K_S^0K^+)</td>
<td>((3.183 \pm 0.028 \pm 0.065) \times 10^{-3})</td>
</tr>
</tbody>
</table>

Data: \(2.93\) fb\(^{-1}\) taken at \(3.773\) GeV;
Decays of interests:
\(D^0 \rightarrow \pi^+\pi^- , K^+K^- , K^-\pi^+ , K_S^0\pi^0 , K_S^0\eta , K_S^0\eta'\)
\(D^+ \rightarrow \pi^0\pi^+ , \pi^0K^+ , \eta\pi^+ , \eta K^+ , \eta'\pi^+ , \eta'K^+ , K_S^0\pi^+ , K_S^0K^+\)

In future charm factory, it is important to reduce the systematic uncertainty by using a large \(D\) threshold sample

- BESIII has good potential to explore CPV
- Many channels have best precisions
BFs and CPV in SCS decays
$D^+ \rightarrow K_S K^+ , K_S K^+ \pi^0 , K_L K^+$ and $K_L K^+ \pi^0$

- The singly Cabibbo-suppressed (SCS) decay mode $D^+ \rightarrow K^0 K^+$ is useful for the estimation of SU(3) violating effects in the $D$ meson system.
- Direct CP violation in SCS $D^+$ decays could arise from the interference between tree-level and penguin decay processes.

- 6 CF ST modes v.s. DT signal modes; KL is inferred by EMC shower and the constraint $\Delta E = 0$
- Two dimensional fits to $M_{BC}(\text{tag})$ versus $M_{BC}(\text{signal})$

<table>
<thead>
<tr>
<th>Mode</th>
<th>$\bar{B} \times 10^{-3}$</th>
<th>$A_{CP}$ (%)</th>
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</thead>
<tbody>
<tr>
<td>$K_S^0 K^\pm$</td>
<td>$3.06 \pm 0.09 \pm 0.10$</td>
<td>$-1.5 \pm 2.8 \pm 1.6$</td>
</tr>
<tr>
<td>$K_S^0 K^\pm \pi^0$</td>
<td>$5.16 \pm 0.21 \pm 0.23$</td>
<td>$1.4 \pm 4.0 \pm 2.4$</td>
</tr>
<tr>
<td>$K_L^0 K^\pm$</td>
<td>$3.23 \pm 0.11 \pm 0.13$</td>
<td>$-3.0 \pm 3.2 \pm 1.2$</td>
</tr>
<tr>
<td>$K_L^0 K^\pm \pi^0$</td>
<td>$5.22 \pm 0.22 \pm 0.21$</td>
<td>$-0.9 \pm 4.1 \pm 1.6$</td>
</tr>
</tbody>
</table>

- $B(D^+ \rightarrow K_S K^+)$ agrees with the CLEO's
- BFs of $D^+ \rightarrow K_S K^+ \pi^0$, $K_L K^+$ and $K_L K^+ \pi^0$ are measured for the first time
- No evidence for CPV
Prospects of data taking at BESIII

- BESIII collected world’s largest samples of $J/\psi$, $\psi(2S)$, $\psi(3770)$, $Y(4260)$, … from $e^+e^-$ production.
- It will continue to run a few years.

<table>
<thead>
<tr>
<th></th>
<th>BESIII</th>
<th>Goal</th>
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</thead>
<tbody>
<tr>
<td>$J/\psi$</td>
<td>$1.3*10^9$</td>
<td>21x BESII</td>
</tr>
<tr>
<td>$\psi'$</td>
<td>$0.6*10^9$</td>
<td>24x CLEO-c</td>
</tr>
<tr>
<td>$\psi(3770)$</td>
<td>$2.93 \text{ fb}^{-1}$</td>
<td>21x CLEO-c</td>
</tr>
<tr>
<td>Above open charm threshold</td>
<td>$0.5 \text{ fb}^{-1} @\psi(4040)$, $1.9 \text{ fb}^{-1} @\sim4260$, $0.5 \text{ fb}^{-1} @4360$, $1.0 \text{ fb}^{-1} @4420$, $0.5 \text{ fb}^{-1} @4600$, scan data @4.19$\sim4.30\text{GeV in 2017.}$</td>
<td>$&gt;15 \text{ fb}^{-1}$</td>
</tr>
<tr>
<td>$R$ scan and tau</td>
<td>$3.8-4.6 \text{ GeV at 105 energy points}$, $2.0-3.1 \text{ GeV at 20 energy points}$</td>
<td></td>
</tr>
<tr>
<td>$Y(2175)$</td>
<td>$100 \text{ pb}^{-1} (2015)$</td>
<td></td>
</tr>
<tr>
<td>$\psi(4170)$</td>
<td>$3 \text{ fb}^{-1} (2016)$</td>
<td></td>
</tr>
</tbody>
</table>

Opportunities for precise determination of strong phase and $D$ mixing

CKM 2016, Mumbai
Prospects of charmed hadron decays

Data at 3.773, 4.18 GeV and 4.63 GeV

<table>
<thead>
<tr>
<th></th>
<th>Systematic</th>
<th>Statistical</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\Delta f_{D^+}/f_{D^+}$</td>
<td>$\sim0.9%_{\text{BESIII}}$</td>
<td>2.6% 1.3%</td>
</tr>
<tr>
<td>$\Delta f_{D^s+/f_{D^s+}(\mu+\tau)}$</td>
<td>$\sim1.4%_{\text{CLEO-c}}$</td>
<td>$\sim1.5%$ $\sim0.7%$</td>
</tr>
<tr>
<td>$\Delta f_{D\to K}/f_{D\to K}$</td>
<td>$\sim0.5%_{\text{BESIII}}$</td>
<td>0.4% 0.2%</td>
</tr>
<tr>
<td>$\Delta f_{D\to \pi}/f_{D\to \pi}$</td>
<td>$\sim0.7%_{\text{BESIII}}$</td>
<td>1.3% 0.6%</td>
</tr>
<tr>
<td>$</td>
<td>V_{cs}</td>
<td>_{D^s\to l^+\nu(\mu+\tau)}$</td>
</tr>
<tr>
<td>$</td>
<td>V_{cs}</td>
<td>_{D^0\to K^-e^+\nu}$</td>
</tr>
<tr>
<td>$</td>
<td>V_{cd}</td>
<td>_{D^+\to \mu^+\nu}$</td>
</tr>
<tr>
<td>$</td>
<td>V_{cd}</td>
<td>_{D^0\to \pi^-e^+\nu}$</td>
</tr>
<tr>
<td>$(c_i,s_i)$ in $D^0\rightarrow K^0\pi^+\pi^-$</td>
<td>Uncertainty for $\gamma/\phi_3$</td>
<td>1% 0.5%</td>
</tr>
<tr>
<td>$\Lambda_{c^+}\rightarrow pK^-\pi^+$</td>
<td>$4.8%$ (0.6 fb$^{-1}@4.6$)</td>
<td>$\sim2%$ (3 fb$^{-1}@4.6X$)</td>
</tr>
</tbody>
</table>
Strong phases in $D$ hadronic decays

<table>
<thead>
<tr>
<th>Decay mode</th>
<th>Quantity of interest</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>$D \rightarrow K^0 \pi^+ \pi^-$</td>
<td>$c_i$ and $s_i$</td>
<td>Binning schemes as those used in the CLEO-c analysis. With future, very large $\psi(3770)$ data sets, it might be worthwhile to explore alternative binning.</td>
</tr>
<tr>
<td>$D \rightarrow K^0 K^+ K^-$</td>
<td>$c_i$ and $s_i$</td>
<td>Binning schemes as those used in the CLEO-c analysis. With future, very large $\psi(3770)$ data sets, it might be worthwhile to explore alternative binning.</td>
</tr>
<tr>
<td>$D \rightarrow K^\pm \pi^+ \pi^- \pi^-$</td>
<td>$R$, $\delta$</td>
<td>In bins guided by amplitude models, currently under development by LHCb.</td>
</tr>
<tr>
<td>$D \rightarrow K^+ K^- \pi^+ \pi^-$</td>
<td>$c_i$ and $s_i$</td>
<td>Binning scheme can be guided by the CLEO model [18] or potentially an improved model from LHCb in the future.</td>
</tr>
<tr>
<td>$D \rightarrow \pi^+ \pi^- \pi^+ \pi^-$</td>
<td>$F_+$ or $c_i$ and $s_i$</td>
<td>Unbinned measurement of $F_+$. Measurements of $F_+$ in bins or $c_i$ and $s_i$ in bins could be explored.</td>
</tr>
<tr>
<td>$D \rightarrow K^+ \pi^- \pi^0$</td>
<td>$R$, $\delta$</td>
<td>Simple 2-3 bin scheme could be considered.</td>
</tr>
<tr>
<td>$D \rightarrow K^0 \pi^+ \pi^- \pi^0$</td>
<td>$R$, $\delta$</td>
<td>Simple 2 bin scheme where one bin encloses the $K^*$ resonance.</td>
</tr>
<tr>
<td>$D \rightarrow \pi^+ \pi^- \pi^0$</td>
<td>$F_+$</td>
<td>No binning required as $F_+ \sim 1$.</td>
</tr>
<tr>
<td>$D \rightarrow K^0 \pi^+ \pi^- \pi^0$</td>
<td>$F_+$ and $c_i$ and $s_i$</td>
<td>Unbinned measurement of $F_+$ required. Additional measurements of $F_+$ or $c_i$ and $s_i$ in bins could be explored.</td>
</tr>
<tr>
<td>$D \rightarrow K^+ K^- \pi^0$</td>
<td>$F_+$</td>
<td>Unbinned measurement required. Extensions to binned measurements of either $F_+$ or $c_i$ and $s_i$ possible.</td>
</tr>
<tr>
<td>$D \rightarrow K^\pm \pi^\mp$</td>
<td>$\delta$</td>
<td>Of low priority due to good precision available through charm-mixing analyses.</td>
</tr>
</tbody>
</table>

LHCb-PUB-2016-025

Status at BESIII
- ➤ published
- ➢ under study
- ➣ in plan

CKM 2016, Mumbai
Summary

• Unique access to strong phases & ability to extract model-independent results with charm at threshold
• BESIII is successfully operating since 2008  
  – Collected large data samples in the $\tau$-charm mass region
• BESIII will continue to run 6 – 8 years.
• BESIII team has learned and developed technology for charm mixing and CPV at threshold.  
  – 2nd generation of QC analyses, while CLEO-c activity is declining.  
  – more precision, new modes, new variables  
  – some challenges on the systematics
• Future goals  
  >15 /fb $\psi(3770)$ data, and roughly 50M $D^0$, 50M $D^+$, 1M $\Lambda_c$, 15M $D_s$, produced near threshold

Many works are ongoing; Stay tuned!
Thank you!

谢谢！
Connections of $c_i, s_i$ and $c'_i, s'_i$

From the CP tag modes, we are able to find $c_i$ and $c'_i$

$$M_i = \frac{S_{\pm}}{2S_f} (K_i \pm 2c_i \sqrt{K_i K_{i'}} + K_{i'})$$

$$(CP, K_S^0 \pi^+ \pi^-)$$

$$M'_i = \frac{S_{\pm}}{2S_f} (K'_i \pm 2c'_i \sqrt{K'_i K'_{i'}} + K'_{i'})$$

$$(CP, K_L^0 \pi^+ \pi^-)$$

$'$ indicates numbers from $K_i \pi^\pi$ decays.

$M_i$ yields in each bin of Dalitz plot for CP even(odd) modes.

$S_{\pm}(S_-)$, number of single tags for CP even(odd) modes.

$K_i(K_{i'})$, yields in each bin of Dalitz plot in flavor modes.

From the Double Dalitz modes, we are able to find $c_i, c'_i, s_i, s'_i$

$$M_{i,j} = \frac{N_{D_i D_j}}{2S_f^2} (K_i K_j + K_{i'} K_{j'} - 2\sqrt{K_i K_{j'} K_{i'} K_j} (c_i c_j + s_i s_j))$$

$$(K_S^0 \pi^+ \pi^-, K_S^0 \pi^+ \pi^-)$$

$$M'_{i,j} = \frac{N_{D_i D_j}}{2S_f^2} (K_i K'_j + K_{i'} K'_{j'} + 2\sqrt{K_i K'_{j'} K_{i'} K'_j} (c_i c'_j + s_i s'_j))$$

$$(K_S^0 \pi^+ \pi^-, K_L^0 \pi^+ \pi^-)$$

$M_{i,j}$ yields in each $i^{th}$ bin of the first Dalitz plot and the $j^{th}$ bin for the second Dalitz plot.

$S_f$, number of single tags for flavor modes.

$K_i(K_{i'})$, yields in each bin of Dalitz plot in flavor modes.
Impacts in LHCb $\gamma/\phi_3$ measurement

<table>
<thead>
<tr>
<th>Run Period $[E_{CM}]$</th>
<th>Collected / Projected luminosity per run</th>
<th>Cumulative yield factor compared to Run 1</th>
<th>Year attained</th>
</tr>
</thead>
<tbody>
<tr>
<td>Run 1 [7,8 TeV]</td>
<td>3 fb$^{-1}$</td>
<td>1</td>
<td>2012</td>
</tr>
<tr>
<td>Run 2 [13 TeV]</td>
<td>5 fb$^{-1}$</td>
<td>4</td>
<td>2018</td>
</tr>
<tr>
<td>LHCb phase-1 upgrade [14 TeV]</td>
<td>50 fb$^{-1}$</td>
<td>60</td>
<td>2030</td>
</tr>
<tr>
<td>LHCb phase-2 upgrade [14 TeV]</td>
<td>300 fb$^{-1}$</td>
<td>$\sim 400$</td>
<td>2035(?)</td>
</tr>
</tbody>
</table>

- By considering the evolution of the LHCb measurements, which may differing among modes, this strong phase uncertainty is
  - 1.7 to 2.2$^\circ$ at the end of Run 2
  - 1.8 to 2.5$^\circ$ at the end of the phase 1 upgrade

- So now compared to the total precision an $\gamma$ from LHCb expected
  - Run I $- \sigma(\gamma) = 7^\circ$ - limited impact of strong phase measurements
  - Run II $- \sigma(\gamma) = 3.5^\circ$ - becomes significant
  - Upgrade phase I $\sigma(\gamma) \sim$ strong phase uncertainty
Amplitude analysis of $D^0 \rightarrow K^- \pi^+ \pi^+ \pi^-$

- This decay is one of three golden decay mode of $D^0$
- The knowledge of intermediate process can be widely used in many measurements, such as to study branching fraction and strong phase used in CKM unitary triangle $\gamma$ measurement
- Construct coherent sum of 23 amplitudes and fit to data (double-tag (DT) 15912 events with purity of 99.4%)

$$\chi^2 / ndf = 1.1$$

- Improvements over the existing results!
- Strong phase extraction is under studies
With the fit fractions (FF) of every components and the branching ratio of $D^0 \to K^-\pi^+\pi^+\pi^-$, we calculate the branching ratios of the components with

$$Br(\text{Component}) = FF(\text{Component}) Br(D^0 \to K^-\pi^+\pi^+\pi^-).$$

The results are listed in the table below:

<table>
<thead>
<tr>
<th>Component</th>
<th>Branching fraction (%)</th>
<th>PDG value (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>$D^0 \to K^*^0\rho^0$</td>
<td>0.99 ± 0.04 ± 0.04 ± 0.03</td>
<td>1.05 ± 0.23</td>
</tr>
<tr>
<td>$D^0 \to K^-a_1^+(1260)(\rho^0\pi^+)$</td>
<td>4.41 ± 0.22 ± 0.30 ± 0.13</td>
<td>3.6 ± 0.6</td>
</tr>
<tr>
<td>$D^0 \to K_1^- (1270)(K^*^0\pi^-)\pi^+$</td>
<td>0.07 ± 0.01 ± 0.02 ± 0.00</td>
<td>0.29 ± 0.03</td>
</tr>
<tr>
<td>$D^0 \to K_1^- (1270)(K^-\rho^0)\pi^+$</td>
<td>0.27 ± 0.02 ± 0.02 ± 0.01</td>
<td></td>
</tr>
<tr>
<td>$D^0 \to K^-\pi^+\rho^0$</td>
<td>0.68 ± 0.09 ± 0.18 ± 0.02</td>
<td>0.51 ± 0.23</td>
</tr>
<tr>
<td>$D^0 \to \bar{K}^*^0\pi^-\pi^+$</td>
<td>0.57 ± 0.03 ± 0.03 ± 0.02</td>
<td>0.99 ± 0.23</td>
</tr>
<tr>
<td>$D^0 \to K^-\pi^+\pi^+\pi^-$</td>
<td>1.77 ± 0.05 ± 0.04 ± 0.05</td>
<td>1.88 ± 0.26</td>
</tr>
</tbody>
</table>

In the table, the first and second uncertainties of the branching ratios are statistical and systematic uncertainties from the fit fractions, the third errors is the uncertainties related to $Br(D^0 \to K^-\pi^+\pi^+\pi^-)$ in PDG.