CP Violation, Mixing and non-Leptonic Decays at BESIII

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(On behalf of the BESIII Collaboration)

Nankai University, Tianjin, China

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5 - 9 September 2016, Bologna, Italy
Beijing Electron Positron Collider II (BEPCII)

**Linac:** The injector, a 202M long electron position linear accelerator that can accelerate the electrons and positrons to 1.3 GeV.

**BESIII:** Beijing Spectrometer III, the main detector for BEPC II.

**The storage ring:** A sports track shaped accelerator with a circumference of 237.5M.
BEPCII: a double-ring machine

Compton back-scattering for high precision beam energy measurement

Beam energy: 1-2.3 GeV
Luminosity: \(1 \times 10^{33} \text{ cm}^{-2} \text{s}^{-1}\)
Optimum energy: 1.89 GeV
Energy spread: 5.16 \(\times 10^{-4}\)
No. of bunches: 93
Bunch length: 1.5 cm
Total current: 0.91 A
SR mode: 0.25A @ 2.5 GeV
BESIII Detector

Wire tracker (no Si); TOF + dE/dx for PID; CsI Ecal; RPC muon
BESIII Collaboration

~450 members
59 institutions from 13 countries

Europe (14)
- Germany: Univ. of Bochum, Univ. of Giessen, GSI, Univ. of Johannes Gutenberg, Helmholtz Ins. In Mainz
- Russia: JINR Dubna; BINP Novosibirsk
- Italy: Univ. of Torino, Univ. of Ferrara, Frascati Lab
- Netherland: KVI/Univ. of Groningen
- Sweden: Uppsala Univ.

Pakistan (2)
- Univ. of Punjab
- COMSAT CIIT

India (1)
- Indian Institute of Technology Madras

China (34)
- IHEP, CCAST, GUCAS, 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.
- Shanxi Univ., Sichuan Univ., Univ. of South China, Hunan Univ., Liaoning Univ.
- Nanjing Univ., Nanjing Normal Univ.
- Guangxi Normal Univ., Guangxi Univ.
- Suzhou Univ., Hangzhou Normal Univ.
- Lanzhou Univ., Henan Sci. and Tech. Univ.

Korea (1)
- Seoul Nat. Univ.

Japan (1)
- Tokyo Univ.
Charm data sample

- $\sim 2.9 \, fb^{-1} @ \psi(3770)$

- $\sim 0.5 \, fb^{-1} @ \psi(4040)$

- $\sim 3.0 \, fb^{-1} @ \psi(4170)$
$e^+ e^- \rightarrow c \bar{c} \rightarrow \bar{D}_{tag} D_{sig}$: Double-tag technique, Absolute measurement

- Tag $\bar{D}_{tag}$ in hadronic decay modes
  \[ \Delta E = E_{\bar{D}_{tag}} - E_{beam} \]
  \[ M_{BC} = \sqrt{E^2_{beam} - p^2_{\bar{D}_{tag}}} \]

- Reconstruct $D_{sig}$ using the remaining tracks not associated to $\bar{D}_{tag}$
  - $E_{D_{sig}} = E_{beam}$, $\vec{p}_{D_{sig}} = -\vec{p}_{\bar{D}_{tag}}$
  - no additional tracks/shower
  - (semi-)leptonic decay: missing neutrino, $U_{miss} \equiv E_{miss} - |\vec{p}_{miss}| \sim 0$

- High tagging efficiency
- Extremely clean
- Systematic uncertainties associated to tag side are mostly canceled out
Topics

• $D^+ \rightarrow K_S/K_L K^+ (\pi^0)$ and CP asymmetry
• $D^0 \rightarrow K_S/K_L \pi^0 (\pi^0)$ and mixing parameter $\gamma_{CP}$
• Analysis of $D^0 \rightarrow K_S \pi^+ \pi^-$
• Branching fraction of $D^0 \rightarrow K_S K^+ K^-$
• Amplitude analysis of $D^0 \rightarrow K^- \pi^+ \pi^+ \pi^-$
• Measurement of $D^{0, +} \rightarrow PP$
• Cabibbo suppressed decay $D^{0, +} \rightarrow \omega \pi^{0, +}$
• $D_S^+ \rightarrow \eta' X$ and $D_S^+ \rightarrow \eta' \rho$
D^+ \to K_S/ K_L K^+(\pi^0) and CP asymmetry

• In the Standard Model (SM), the singly Cabibbo suppressed (SCS) D meson hadronic decays are predicted to exhibit CP asymmetries at the order of 10^{-3}.
• Direct CP violation in SCS decays could arise from the interference between tree-level and penguin decay processes.
• DCS and CF decays are expected to be CP invariant in the SM because they are dominated by a single weak amplitude.
• So, measurements of CP asymmetries in SCS processes greater than O(10^{-3}) would be evidence of physics beyond the SM.
• CP asymmetry can be tested by using SCS decays D^+ \to K_S/ K_L K^+(\pi^0) based on a charge-dependent measurement.

\[ A_{CP} = \frac{\mathcal{B}(D^+ \to K_{S,L}^0 K^+(\pi^0)) - \mathcal{B}(D^- \to K_{S,L}^0 K^-(\pi^0))}{\mathcal{B}(D^+ \to K_{S,L}^0 K^+(\pi^0)) + \mathcal{B}(D^- \to K_{S,L}^0 K^-(\pi^0))} \]

• Absolute branching fraction

\[ \mathcal{B}_{\text{sig}} = \frac{N_{\text{DT}}/\epsilon_{\text{DT}}}{N_{\text{ST}}/\epsilon_{\text{ST}}} = \frac{N_{\text{DT}}/\epsilon}{N_{\text{ST}}} \]

where \( \epsilon = \epsilon_{\text{DT}}/\epsilon_{\text{ST}} \) is the efficiency of reconstructing the signal decay.
**D^+ → K_S/K_L K^+(π^0) and CP asymmetry**

[ Details can be found in Wenjing Zheng’s talk @ Sept.7 ]

\[ N_{ST} = 2N_{D^+D^-} - B_{tag} \epsilon_{ST} \]

\[ N_{DT} = 2N_{D^+D^-} - B_{tag} B_{sig} \epsilon_{DT} \]

The first and second uncertainties are statistical and systematic errors.

<table>
<thead>
<tr>
<th>Mode</th>
<th>( \mathcal{B}(D^+) \times 10^{-3} )</th>
<th>( \mathcal{B}(D^-) \times 10^{-3} )</th>
<th>( \overline{\mathcal{B}} \times 10^{-3} )</th>
<th>( A_{CP} )</th>
</tr>
</thead>
<tbody>
<tr>
<td>( K_S^0 K^\pm )</td>
<td>3.01 ± 0.12 ± 0.10</td>
<td>3.10 ± 0.12 ± 0.10</td>
<td>3.06 ± 0.09 ± 0.10</td>
<td>-1.5 ± 2.8 ± 1.6</td>
</tr>
<tr>
<td>( K_S^0 K^\pm \pi^0 )</td>
<td>5.23 ± 0.28 ± 0.24</td>
<td>5.09 ± 0.29 ± 0.22</td>
<td>5.16 ± 0.21 ± 0.23</td>
<td>1.4 ± 4.0 ± 2.4</td>
</tr>
<tr>
<td>( K_L^0 K^\pm )</td>
<td>3.13 ± 0.14 ± 0.13</td>
<td>3.32 ± 0.15 ± 0.13</td>
<td>3.23 ± 0.11 ± 0.13</td>
<td>-3.0 ± 3.2 ± 1.2</td>
</tr>
<tr>
<td>( K_L^0 K^\pm \pi^0 )</td>
<td>5.17 ± 0.30 ± 0.21</td>
<td>5.26 ± 0.30 ± 0.20</td>
<td>5.22 ± 0.22 ± 0.21</td>
<td>-0.9 ± 4.1 ± 1.6</td>
</tr>
</tbody>
</table>
The decay rates of $D \to K_S\pi'$s and $D \to K_L\pi'$s are not the same because of the interference between Cabibbo Favored component $D \to K^0\pi'$s and doubly Cabibbo suppressed $D \to K^0\bar{\pi}'s$ component [PLB 349(1995)363]. The sign of this interference of $K^0$ with $K^0\bar{\pi}'s$ is opposite for $K^0_L$ and $K^0_S$, so, $\text{Br}(D \to K_S\pi')$ and $\text{Br}(D^0 \to K_L\pi')$ should not in general be equal. The scale of the asymmetry is set by doubly Cabibbo suppression factor $\tan^2 \theta_C \approx 0.05$, where $\theta_C$ is the Cabibbo angle.

Previous CLEO-c result based on 281 pb$^{-1}$@$\psi(3770)$

$$R(D^0 \to K_{S,L}\pi^0) = 0.108 \pm 0.025 \pm 0.024$$

$$R(D^+ \to K_{S,L}\pi^+) = 0.022 \pm 0.016 \pm 0.018$$

Oscillations between meson and antimeson can occur when the flavor eigenstates differ from the physical mass eigenstates. These effects provide a mechanism whereby interference in the transition amplitudes of mesons and antimesons may occur. The oscillations are conventionally characterized by two dimensionless parameters $x=\Delta m/\Gamma$ and $y = \Delta \Gamma/\Gamma$. In the absence of CP violation, one has $y_{CP} = y$. 
D^0 \rightarrow K_S^0/K_L^0 \pi^0(\pi^0) \text{ and mixing parameter } y_{CP} 

- Branching fractions and asymmetries 

\[ R(D \rightarrow K_{S,L}^0 + \pi^0) = \frac{Br(D \rightarrow K_S^0\pi^0) - Br(D \rightarrow K_L^0\pi^0)}{Br(D \rightarrow K_S^0\pi^0) + Br(D \rightarrow K_L^0\pi^0)} \]

<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^0\pi^0}(%))</th>
<th>(R(D \rightarrow K_{S,L}^0\pi^0))</th>
</tr>
</thead>
<tbody>
<tr>
<td>(K\pi)</td>
<td>1.208±0.041</td>
<td>1.061±0.038</td>
<td>0.0646±0.0245</td>
</tr>
<tr>
<td>(K3\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><strong>All</strong></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^0\pi^0\pi^0}(%))</th>
<th>(R(D \rightarrow K_{S,L}^0\pi^0\pi^0))</th>
</tr>
</thead>
<tbody>
<tr>
<td>(K\pi)</td>
<td>1.024±0.049</td>
<td>1.299±0.080</td>
<td>-0.1183±0.0385</td>
</tr>
<tr>
<td>(K3\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><strong>All</strong></td>
<td>0.975±0.024</td>
<td>1.175±0.040</td>
<td>-0.0929±0.0209</td>
</tr>
</tbody>
</table>

[ Details can be found in Wenjing Zheng’s talk @ Sept.7 ]
$D^0 \rightarrow K_S/K_L\pi^0(\pi^0)$ and mixing parameter $y_{CP}$

- $y_{CP}$ measurement

$y_{CP}$ is obtained based on CP$^\pm$ + SL analysis: $D^0 \rightarrow K_S\pi^0$ and $D^0 \rightarrow K_L\pi^0$ versus $D^0 \rightarrow Ke^-\nu_e$

\[
N_{ST(CP^\pm)} = (1 \mp y_{CP}) \cdot 2 N_{D^0\bar{D}^0} B_{tag}\epsilon_{ST} \\
N_{DT(CP^\pm,Ke^-\nu_e)} = (1 + y_{CP}^2) \cdot 2 N_{D^0\bar{D}^0} B_{tag}\epsilon_{DT} \\
\alpha = \frac{N_{DT(CP^+,Ke^-\nu_e)}/\epsilon}{N_{ST(CP^+)}} \\
\beta = \frac{N_{DT(CP^-,Ke^-\nu_e)}/\epsilon}{N_{ST(CP^-)}}
\]

\[
y_{CP} = \frac{\alpha - \beta}{\alpha + \beta}
\]

statistical error only

<table>
<thead>
<tr>
<th>$\alpha (K^0_L\pi^0, Ke^-\nu_e)$</th>
<th>$\beta (K^0_S\pi^0, Ke^-\nu_e)$</th>
<th>$y_{CP} = \frac{\alpha - \beta}{\alpha + \beta}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>$3.603 \pm 0.142$</td>
<td>$3.533 \pm 0.100$</td>
<td>$(0.98 \pm 2.43%)$</td>
</tr>
</tbody>
</table>

[ Details can be found in Wenjing Zheng’s talk @ Sept.7 ]
Analysis of $D^0 \rightarrow K_S \pi^+ \pi^-$

Motivated by the quest to increase the precision of the angle $\gamma$ measurement in $B^- \rightarrow D K^-$ decay.

$$\gamma = \arg \left( -\frac{V_{ud} V_{ub}^*}{V_{cd} V_{cb}^*} \right)$$

Determine $\gamma$ through the interference between $b \rightarrow c$ and $b \rightarrow u$ transitions when $D^0$ and $\bar{D}^0$ both decay to the same final state $f(D)$.

BESIII can help reducing the systematics on this important measurement with providing more information on the $D^0 \rightarrow K^0 \pi^+ \pi^-$ decay.

With the amount of data LHCb collecting, $\gamma$ measurement soon will be systematically limited.

We will use the GGSZ* method to investigate the decay. Final states are three body, self-conjugate modes eg: $K_S KK, K_S \pi \pi$

- Binning regions of Dalitz plot where $\delta_D$ is similar
- Model independent, there is no incorrect binning.
- Optimization for binning for increased sensitivity.

*Giri, Grossman, Soffer, Zupan (GGSZ)
Analysis of $D^0 \rightarrow K_S \pi^+ \pi^-$

- $T_i$: measured in flavor decays
- $r_B$: color suppression $\sim 0.1$
- $\delta_B$: strong phase of $B$
- $c_i, s_i$: weighted average of $\cos(\Delta \delta_D)$ and $\sin(\Delta \delta_D)$, phase difference between $D$s given by $\Delta \delta_D$.
  
  *All but $c_i, s_i$ variables will be measured in $B$ factories.*

\[ \Gamma_i^{\pm} \equiv \int d\Gamma(B^{\pm} \rightarrow (K_S^{0} \pi^- \pi^+)_{D} K^{\pm}) \]
\[ = T_i + r_B^2 T_i \pm 2 r_B \sqrt{T_i T_i} [\cos(\delta_B + \gamma) c_i - \sin(\delta_B + \gamma) s_i] \]

$c_i, s_i$ can be measured using DT:
$D^0 \rightarrow K_S \pi^+ \pi^-$ versus $K_{S/L} \pi^+ \pi^-$ or CP tags
Analysis of $D^0 \rightarrow K_S \pi^+ \pi^-$

Measured using the world's largest $\psi(3770)$ data sample taken at the threshold.

Results consistent with the CLEO-c with superior statistical uncertainties.

Contribution to the uncertainty in gamma of $\pm 2.1^\circ$ using optimal binning, compared to Belle's current measurement of $\pm 4.3^\circ$ from CLEO-c's results.

<table>
<thead>
<tr>
<th>Bins</th>
<th>BES-III $c_i$</th>
<th>CLEO-c $c_i$</th>
<th>BES-III $s_i$</th>
<th>CLEO-c $s_i$</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0.066 ± 0.066</td>
<td>-0.009 ± 0.088</td>
<td>-0.843 ± 0.119</td>
<td>-0.438 ± 0.184</td>
</tr>
<tr>
<td>2</td>
<td>0.796 ± 0.061</td>
<td>0.900 ± 0.106</td>
<td>-0.357 ± 0.148</td>
<td>-0.490 ± 0.295</td>
</tr>
<tr>
<td>3</td>
<td>0.361 ± 0.125</td>
<td>0.292 ± 0.168</td>
<td>-0.962 ± 0.258</td>
<td>-1.243 ± 0.341</td>
</tr>
<tr>
<td>4</td>
<td>-0.085 ± 0.017</td>
<td>-0.890 ± 0.041</td>
<td>-0.090 ± 0.093</td>
<td>-0.119 ± 0.141</td>
</tr>
<tr>
<td>5</td>
<td>-0.278 ± 0.056</td>
<td>-0.208 ± 0.085</td>
<td>0.778 ± 0.092</td>
<td>0.853 ± 0.123</td>
</tr>
<tr>
<td>6</td>
<td>0.267 ± 0.119</td>
<td>0.258 ± 0.155</td>
<td>0.635 ± 0.293</td>
<td>0.984 ± 0.357</td>
</tr>
<tr>
<td>7</td>
<td>0.902 ± 0.017</td>
<td>0.869 ± 0.034</td>
<td>-0.018 ± 0.103</td>
<td>-0.041 ± 0.132</td>
</tr>
<tr>
<td>8</td>
<td>0.888 ± 0.036</td>
<td>0.798 ± 0.070</td>
<td>-0.301 ± 0.140</td>
<td>-0.107 ± 0.240</td>
</tr>
</tbody>
</table>

CLEO-c result: Phys. Rev. D 82, 112006
Branching fraction of $D^0 \rightarrow K^0_S K^+ K^-$

- Preliminary result on the branching fraction measurement via single tag
- Fit to “$m_{BC}$ vs. $m_{K^0_S}$”
- Dalitz analysis is ongoing

$$\mathcal{B}(D^0 \rightarrow K^0_S K^+ K^-) = (4.622 \pm 0.045 \pm 0.181) \times 10^{-3}$$

- Relative uncertainty: 4.0%
- Good agreement with PDG2015 value:

$$\mathcal{B}(D^0 \rightarrow K^0_S K^+ K^-) = (4.51 \pm 0.34)\%$$

$\leftrightarrow$ 7.5% relative uncertainty
Amplitude analysis of \( D^0 \rightarrow K^-\pi^+\pi^+\pi^- \)

- \( D^0 \rightarrow K^-\pi^+\pi^+\pi^- \) is one of the golden decay mode of \( D^0 \), its branching fraction is widely used to normalize other charm analysis, such as BF measurements, strong phase measurements, CKM unitary triangle measurement.
- Poor knowledge of intermediate processes will introduce large systematic uncertainty.
- Some intermediate process such as \( D^0 \rightarrow K^*_{0\text{bar}}\rho^0 \) can be used to check the calculation of LQCD or effective theories.

| Previous measurements (fit fractions) have performed by Mark III and E691, respectively |
|---------------------------------|----------------|----------------|
| Decay mode                     | Mark III       | E691           |
| \( D^0 \rightarrow K^-a_1^+(1260) \) | 0.492 ± 0.024 ± 0.08 | 0.47 ± 0.05 ± 0.10 |
| \( D^0 \rightarrow \bar{K}^*0\rho^0 \) | 0.142 ± 0.016 ± 0.05 | 0.13 ± 0.02 ± 0.02 |
| \( D^0 \rightarrow K_1^- (1270)\pi^+ \) | 0.066 ± 0.019 ± 0.03 |               |
| \( D^0 \rightarrow K^*0\pi^-\pi^+ \) | 0.140 ± 0.018 ± 0.04 | 0.11 ± 0.02 ± 0.03 |
| \( D^0 \rightarrow K^-\pi^+\rho^0 \) | 0.084 ± 0.022 ± 0.04 | 0.05 ± 0.03 ± 0.02 |
| \( D^0 \rightarrow 4\text{-body non-resonance} \) | 0.242 ± 0.025 ± 0.06 | 0.23 ± 0.02 ± 0.03 |
Amplitude analysis of $D^0 \rightarrow K^- \pi^+ \pi^+ \pi^-$

With the fit fractions and the BF of $D^0 \rightarrow K3\pi$, we get the BFs of the components

[ Details can be found in Yu Lu’s talk @ Sept.7 ]
Branching fraction of $D^{0,+} \to PP$

- Analysis of $D \to PP$ modes can provide information for SU(3) breaking effect study\(^{[PLB 712 (2012) 8186]}\) and CP violation searching.
- Absolute measurement of $D^0 \to K\pi$ is very important since it is commonly used as normalization mode in charm study.
- This measurement is completed with single tag technique

Only one $D$ meson is built in the analysis

\[
\Delta E = E_{D_{\text{tag}}} - E_{\text{beam}} \\
M_{BC} = \sqrt{E_{\text{beam}}^2 - p_{D_{\text{tag}}}^2}
\]
### Branching fraction of $D^{0,+} \rightarrow PP$

- **BESIII Preliminary**

<table>
<thead>
<tr>
<th>Mode</th>
<th>$N_{\text{signal}}^{\text{net}}$</th>
<th>$\varepsilon$ (%)</th>
<th>$\mathcal{B}^{\pm \text{(stat)}} \pm \text{(sys)}$</th>
<th>$\mathcal{B}_{\text{PDG}}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\pi^+ \pi^-$</td>
<td>21105 ± 249</td>
<td>66.03 ± 0.25</td>
<td>$(1.505 \pm 0.018 \pm 0.031) \times 10^{-3}$</td>
<td>$(1.421 \pm 0.025) \times 10^{-3}$</td>
</tr>
<tr>
<td>$K^+ K^-$</td>
<td>56438 ± 273</td>
<td>62.82 ± 0.32</td>
<td>$(4.229 \pm 0.020 \pm 0.087) \times 10^{-3}$</td>
<td>$(4.01 \pm 0.07) \times 10^{-3}$</td>
</tr>
<tr>
<td>$K^- \pi^+$</td>
<td>537745 ± 767</td>
<td>64.98 ± 0.09</td>
<td>$(3.896 \pm 0.006 \pm 0.073) %$</td>
<td>$(3.93 \pm 0.04) %$</td>
</tr>
<tr>
<td>$K_S^0 \pi^0$</td>
<td>66539 ± 302</td>
<td>38.06 ± 0.17</td>
<td>$(1.236 \pm 0.006 \pm 0.032) %$</td>
<td>$(1.20 \pm 0.04) %$</td>
</tr>
<tr>
<td>$K_S^0 \eta$</td>
<td>9532 ± 126</td>
<td>31.96 ± 0.14</td>
<td>$(5.149 \pm 0.068 \pm 0.134) \times 10^{-3}$</td>
<td>$(4.85 \pm 0.30) \times 10^{-3}$</td>
</tr>
<tr>
<td>$K_S^0 \eta'$</td>
<td>3007 ± 61</td>
<td>12.66 ± 0.08</td>
<td>$(9.562 \pm 0.197 \pm 0.379) \times 10^{-3}$</td>
<td>$(9.5 \pm 0.5) \times 10^{-3}$</td>
</tr>
</tbody>
</table>

| $\pi^0 \pi^+$ | 10108 ± 267                       | 48.98 ± 0.34      | $(1.259 \pm 0.033 \pm 0.025) \times 10^{-3}$ | $(1.24 \pm 0.06) \times 10^{-3}$ |
| $\pi^0 K^+$    | 1834 ± 168                        | 51.52 ± 0.42      | $(2.171 \pm 0.198 \pm 0.060) \times 10^{-4}$ | $(1.89 \pm 0.25) \times 10^{-4}$ |
| $\eta \pi^+$   | 11636 ± 215                       | 46.96 ± 0.25      | $(3.790 \pm 0.070 \pm 0.075) \times 10^{-3}$ | $(3.66 \pm 0.22) \times 10^{-3}$ |
| $\eta K^+$     | 439 ± 72                          | 48.21 ± 0.31      | $(1.393 \pm 0.228 \pm 0.124) \times 10^{-4}$ | $(1.12 \pm 0.18) \times 10^{-4}$ |
| $\eta' \pi^+$  | 3088 ± 83                         | 21.49 ± 0.18      | $(5.122 \pm 0.140 \pm 0.210) \times 10^{-3}$ | $(4.84 \pm 0.31) \times 10^{-3}$ |
| $\eta' K^+$    | 87 ± 25                           | 22.39 ± 0.22      | $(1.377 \pm 0.428 \pm 0.202) \times 10^{-4}$ | $(1.83 \pm 0.23) \times 10^{-4}$ |
| $K_S^0 \pi^+$  | 93884 ± 352                       | 51.38 ± 0.18      | $(1.591 \pm 0.006 \pm 0.033) \times 10^{-2}$ | $(1.53 \pm 0.06) \times 10^{-2}$ |
| $K_S^0 K^+$    | 17704 ± 151                       | 48.45 ± 0.14      | $(3.183 \pm 0.028 \pm 0.065) \times 10^{-3}$ | $(2.95 \pm 0.15) \times 10^{-3}$ |

[ Details can be found in Yu Lu’s talk @ Sept.7 ]
Cabibbo suppressed decay $D_{0,+}^{0} \rightarrow \omega \pi_{0,+}^{0}$

- The first observation of the singly Cabibbo-suppressed decay
- Double tag method to suppress backgrounds
- Also measure $D_{0,+}^{0} \rightarrow \eta \pi_{0,+}^{0}$

PRL116, 082001 (2016)

Improve understanding of U-spin and SU(3) flavor symmetry breaking effects in D decays and benefitting theoretical prediction of CP violation in D decays.
$D_s^+ \to \eta'X$ and $D_s^+ \to \eta'\rho$

- Old CLEO-c data gave $B(D_s^+ \to \eta'\rho^+) = (12.5 \pm 2.2)\%$
  - exceed the difference between $B(D_s^+ \to \eta'X)$ and known $B(D_s^+ \to \eta' + \text{exclusive})$
  - Theoretical calculation: $B(D_s^+ \to \eta'\rho^+) = (3.0 \pm 0.5)\%$

- BESIII results resolve the tension between inclusive and exclusive modes involving $\eta'$

0.482 pb$^{-1}$@4.009 GeV

**DT method for $B(D_s^+ \to \eta'X)$**

- 9 ST modes
- Fit to a 2D: $M(\pi\pi\eta)$ vs $M_{BC}(ST)$

$BF(D_s^+ \to \eta'X) = (8.8 \pm 1.8 \pm 0.5)\%$, consistent with PDG = $(11.7 \pm 1.7 \pm 0.7)\%$ within $\sim 1\sigma$.

**ST method for $B(D_s^+ \to \eta'\rho^+)$**

- Relative to $B(K^-K^+\pi^+)$
- 2D fit: $M_{BC}(ST)$ vs helicity angle ($\rho^+$ decays)

$BF(D_s^+ \to \eta'\rho^+) = (5.8 \pm 1.4 \pm 0.4)\%$
Summary

- $A_{\text{CP}}$ measurement in $D^+ \rightarrow K_S/K_L K^+(\pi^0)$, the BFs are consistent with PDG.
- $y_{\text{CP}}$ measurement in $D^0 \rightarrow K_S/K_L \pi^0(\pi^0)$, the BFs and its asymmetry are also obtained.
- Strong phase difference between $D^0$ and $D^{0\text{bar}} \rightarrow K_S \pi^+\pi^-$ are measured.
- Branching fractions for $D^0 \rightarrow K_S K^+ K^-$, $D \rightarrow \text{PP}$ (14 modes), $D \rightarrow \omega/\eta\pi$ and $D_S^+ \rightarrow \eta'\chi$ and $D_S^+ \rightarrow \eta'\rho$.
- Amplitude analysis of $D^0 \rightarrow K^- \pi^+ \pi^+ \pi^-$
Thank you!