Measurements of strong phase in $D^0 \rightarrow K\pi$ decay and $\gamma_{CP}$ via quantum-correlations at BESIII

Hajime Muramatsu, University of Minnesota
(for the BESIII collaboration)

- Strong phase in $D^0 \rightarrow K\pi$ decay
- $\gamma_{CP}$ measurement
Beijing Electron Positron Collider (BEPC-II)

- A symmetric $e^+e^-$ collider, operating at $E_{cm} \sim 2.0 \sim 4.6$ GeV (Charm factory!).
- It’s in Beijing: Easy access to the downtown area of Beijing with a nearby subway station!
BESIII detector

- A powerful general purpose detector.
- Excellent neutral and charged particle detection and identification with a large coverage.

**Magnet:** 1 T   Super conducting

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

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

**Muon ID:** 8~9 layer RPC
  \[ \sigma_{\Phi\Phi}=1.4 \text{ cm}~1.7 \text{ cm} \]

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

**Data Acquisition:**
  Event rate = 3 kHz
  Throughput ~ 50 MB/s

**Trigger:** Tracks & Showers
  Pipelined; Latency = 6.4 \(\mu\)s
Data samples we have

- @ J/ψ peak : 1.2 B J/ψ decays
  and some scan in the vicinity of the peak.
- @ ψ(3686) peak : 0.5 B ψ(3686) decays
  and some scan in the vicinity of the peak.
- Above D̅D threshold: 0.5/fb @ Ecm = 4.009 GeV,
  1.9/fb @ Ecm = 4.26 GeV,
  0.5/fb @ Ecm = 4.36 GeV,
  plus some scan samples as well.

The above samples have been producing very rich Physics results
such as hadron spectroscopy of Charmonia (e.g., h_c/η_c)
and of Charmonium-like states (X/Y/Z).

- Today, I report recent results from BESIII based on a sample that was
taken near D̅D threshold:
  2.92/fb @Ecm = 3.773 GeV
Sample at $E_{cm} = 3.773$ GeV

- The total integrated luminosity of 2.92 fb$^{-1}$ at this energy point is the largest in the world to date.

- In the selected hadronic events (multiple reconstructed charged/neutral hadrons or tracks), they are dominated by;

  \[ e^+e^- \rightarrow \gamma^* \rightarrow \psi(3770) \text{ and } e^+e^- \rightarrow \gamma^* \rightarrow (q\bar{q}) \text{ light hadrons} \]

  in which

  \[ \frac{\sigma(e^+e^- \rightarrow \psi(3770) \rightarrow \text{hadrons})}{\sigma(e^+e^- \rightarrow \text{NR} \rightarrow \text{hadrons})} \sim 1/2. \]

- Once $\psi(3770)$ is produced, it predominantly decays into a $D\bar{D}$ pair.
  For instance, we have $\sim 21$ M $D^0$ (or $\bar{D}^0$) decays in this sample.

  - Relatively clean event environment.

  - When the two $D$ mesons are reconstructed, the sample becomes almost background free.
Things can be done with the sample taken at or around $E_{cm} = 3.773$ GeV

- There are many interesting possible topics to study in D (weak) decays based on our sample, such as;
  
  - pure leptonic decays  
    (e.g., extraction of $|V_{cd}|$ and/or its decay constant, $f_D$).
  
  - Semi-leptonic decays  
    (e.g., extraction of their form factors, and then compare them vs B meson case).
  
  - With the largest sample of D mesons taken at the near threshold, one should look for rare/forbidden decays (e.g., FCNC, LNV, LFV).
  
  - or even $\psi(3770)$ itself such as $\psi(3770) \rightarrow \text{non-D}\bar{D}$ final states.

- But today, I report our attempt to measure some of the parameters of D$\bar{D}$ mixing using the unique characteristics of our $\psi(3770)$ data set taken at $E_{cm} = 3.773$ GeV.
Introduction

- D̅D̅ mixing is highly suppressed by the GIM mechanism and by the CKM matrix elements within the Standard Model.
- Observation of D̅D̅ mixing, first seen by the B factories (HFAG: arXiv 1207.1158) and now observed by LHCb: PRL110, 101802 (2013).
- Improving the constraints on the charm mixing parameter is important for testing the SM, such as long distance effects.
- D̅D̅ mixing is conventionally described by two parameters:
  \[ x = 2(M_1-M_2)/(\Gamma_1+\Gamma_2), \quad y = (\Gamma_1-\Gamma_2)/(\Gamma_1+\Gamma_2), \]
  where \( M_{1,2} \) and \( \Gamma_{1,2} \) are the masses and widths of the neutral D meson mass eigenstates. (Flavor eigenstates, \( D^0/D̅^0 \), are not the same as mass eigenstates, \( D_1/D_2 \))
  Or \( x' = x \cdot \cos \delta_{K\pi} + y \cdot \sin \delta_{K\pi}, \quad y' = y \cdot \cos \delta_{K\pi} - x \cdot \sin \delta_{K\pi}. \)
- \( \delta_{K\pi} \) is the strong phase difference between the doubly Cabibbo suppressed (DCS) decay, \( D^0 \to K^+\pi^+ \) and the Cabibbo favored (CF) decay, \( D^0 \to K^-\pi^- \) or \( \langle K^-\pi^+|D^0\rangle/\langle K^-\pi^+|D^0\rangle = -r \cdot e^{-i\delta}. \)
  So one can connect (\( x,y \)) with (\( x',y' \)) via \( \delta_{K\pi}. \)
- In this talk, I present preliminary results on \( \delta_{K\pi} \) and \( y \) using the quantum correlation between the produced \( D^0 \) and \( D̅^0 \) pair in data taken at BESIII.
The decay rate of a correlated state

- For physical process producing $D^0\bar{D}^0$ such as
  
  $e^+e^- \rightarrow \gamma^* \rightarrow \psi(3770) \rightarrow D^0\bar{D}^0$,
  
  the $D^0\bar{D}^0$ pair are in a quantum-correlated state.
  
  The quantum number of $\psi(3770)$ is $J^{PC} = 1^-$. 

  Thus, the $D^0\bar{D}^0$ pair in this process has $C = -$.

  For a correlated state with $C = -$, the two $D$ mesons are anti-symmetric
  in the limit of CP invariance:

  $\psi_- = \frac{1}{\sqrt{2}} \left( |D^0\rangle \langle \bar{D}^0| - |\bar{D}^0\rangle \langle D^0| \right)$

- The two produced neutral mesons must have opposite CP
  (i.e., see Goldhaber and Rosner, PRD15, 1254 (1977). That is;

  - Final states of (CP+, CP+) or (CP-, CP-) are forbidden.
  - Final states of (CP+, CP-) are maximally enhanced (doubled).
  - Final states of CP± against inclusive states (Single tag or ST) are not affected.
  - Final states of $(K^-\pi^+, CP\pm)$ are affected due to the interference between CF and DCS $(\delta_{K\pi})$. 

Extracting $\delta_{K\pi}$

- Neglecting higher orders in the mixing parameters (e.g., $y^2$), one can arrive at the following relation:
  \[ 2r \cos\delta_{K\pi} + y = (1 + R_{WS}) \cdot A_{CP \rightarrow K\pi}, \]
  where $R_{WS} \equiv \Gamma(D^0 \rightarrow K\pi^+)/\Gamma(D^0 \rightarrow K\pi^+)$ and
  $A_{CP \rightarrow K\pi} \equiv [B(D_2 \rightarrow K\pi^+) - B(D_1 \rightarrow K\pi^+)]/B(D_2 \rightarrow K\pi^+) + B(D_1 \rightarrow K\pi^+)].$

- We can extract $A_{CP \rightarrow K\pi}$ by tagging one D (tag side) with exclusive CP-eigenstates which then defines the eigenvalue of the other D ($A_{CP \pm} \equiv \langle K\pi^+ | D^{1,2} \rangle$).

- Then, with the knowledge of $r$, $y$, and $R_{WS}$ from the 3rd parties (HFAG2013 and PDG), we could derive $\cos\delta_{K\pi}$ in the end.

- The rest of the analysis becomes measurements of $B(D_{CP\pm} \rightarrow K\pi^+)$ while simultaneously reconstructing the $D_{CP\mp}$ on the tag side.
Measuring $B(D_{CP\pm \to K^-\pi^+})$

- **Double-Tag technique:**
  
  $B(D_{CP\pm \to K\pi}) = \frac{[B(D_{CP\pm \to CP^\mp \text{ states}) \times B(D_{CP\pm \to K\pi})]/B(D_{CP\pm \to CP^\mp \text{ states})}}{(n_{K\pi,CP^\mp}/n_{CP^\mp}) \cdot (\varepsilon_{CP^\mp}/\varepsilon_{K\pi,CP^\mp})}$

  where $n_{K\pi,CP^\mp}$ are yields of “$K\pi$” when CP states are simultaneously reconstructed on the tag side.

  $n_{CP^\mp}$ are yields of CP states (independent of how the other D decays).

  $\varepsilon_{CP^\mp}$ and $\varepsilon_{K\pi,CP^\mp}$ are the corresponding reconstruction efficiencies.

- **“Yields”** are extracted from $M_{bc}$ distributions: $M_{bc} = \sqrt{E_{beam}^2 - \vec{p}_D^2}$

- **CP states on Tag side (8 modes):**

  $CP^+$: $K^+K^-, \pi^+\pi^-, K_S^0\pi^0\pi^0, \pi^0\pi^0, \rho^0\rho^0$

  $CP^-$: $K_S^0\pi^0, K_S^0\eta, K_S^0\omega$

  where we reconstruct $K_S \to \pi^+\pi^-$, $\pi^0/\eta \to \gamma\gamma$, $\omega \to \pi^+\pi^0\pi^0$, $\rho \to \pi^+\pi^-\pi^0$.

- Notice that most of systematics on the tag side get canceled in $B(D_{CP\pm \to K\pi})$. The remaining systematics (reconstruction/simulation) of $K\pi$ are also canceled in the determination of $A_{CP \to K\pi}$.
Yields of CP states ($n_{CP\mp}$) (reconstruct only one of the two neutral D)

- Signal shape: MC shape, convoluted with a Gaussian (to compensate the difference in resolution between data and MC).
- Background: ARGUS background function.
Can also check “CP purity”

- When $D^0$ and $\bar{D}^0$ are reconstructed, final states with the same CP should yield zero events.

<table>
<thead>
<tr>
<th>Mode</th>
<th>Yield (tag $KK$)</th>
<th>Efficiency (%)</th>
<th>Yield (tag $K_S^0\pi^0$)</th>
<th>Efficiency (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>CP+ $K_S^0\pi^0\pi^0$</td>
<td>$8 \pm 3(*)$</td>
<td>$11.80 \pm 0.11$</td>
<td>$171 \pm 14$</td>
<td>$7.20 \pm 0.09$</td>
</tr>
<tr>
<td>CP+ $\rho\pi^0$</td>
<td>$13 \pm 8(*)$</td>
<td>$24.44 \pm 0.16$</td>
<td>$299 \pm 19$</td>
<td>$15.87 \pm 0.16$</td>
</tr>
<tr>
<td>CP- $K_S^0\omega$</td>
<td>$158 \pm 13$</td>
<td>$11.02 \pm 0.11$</td>
<td>$7 \pm 3(*)$</td>
<td>$6.77 \pm 0.08$</td>
</tr>
</tbody>
</table>

✴ Consistent with zero.
✴ Consider as one of the systematics.
Yields of $K\pi$ in double tags ($n_{K\pi,CP\mp}$) (reconstruct CP-final state from one D decay, with "$K\pi$" from the other D)

- Signal shape: MC shape, convoluted with a Gaussian (to compensate for the difference in resolution between data and MC).
- Background: ARGUS background function.
Preliminary fit results

<table>
<thead>
<tr>
<th>Mode(CP)</th>
<th>ST Yield</th>
<th>Efficiency(%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>$K^+K^-$</td>
<td>56156 ± 261 ± 61</td>
<td>62.99 ± 0.26</td>
</tr>
<tr>
<td>$\pi^+\pi^-$</td>
<td>20222 ± 187 ± 38</td>
<td>65.58 ± 0.26</td>
</tr>
<tr>
<td>$K^0_S\pi^0\pi^0$</td>
<td>25156 ± 235 ± 81</td>
<td>16.46 ± 0.07</td>
</tr>
<tr>
<td>$\pi^0\pi^0$</td>
<td>7610 ± 156 ± 56</td>
<td>42.77 ± 0.21</td>
</tr>
<tr>
<td>$\rho\pi^0$</td>
<td>41117 ± 354 ± 68</td>
<td>36.22 ± 0.21</td>
</tr>
<tr>
<td>$K^0_S\pi^0$</td>
<td>72710 ± 291 ± 34</td>
<td>41.95 ± 0.21</td>
</tr>
<tr>
<td>$K^0_S\eta$</td>
<td>10046 ± 118 ± 27</td>
<td>35.46 ± 0.20</td>
</tr>
<tr>
<td>$K^0_S\omega$</td>
<td>31422 ± 215 ± 49</td>
<td>17.88 ± 0.10</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Mode</th>
<th>DT Yield</th>
<th>Efficiency(%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>$K^0\pi^\pm, K^\pm K^-$</td>
<td>1669 ± 42 ± 4</td>
<td>42.65 ± 0.21</td>
</tr>
<tr>
<td>$K^0\pi^\pm, \pi^+\pi^-$</td>
<td>608 ± 25 ± 3</td>
<td>44.32 ± 0.21</td>
</tr>
<tr>
<td>$K^\pm\pi^0, K^0_S\pi^0\pi^0$</td>
<td>800 ± 30 ± 4</td>
<td>12.68 ± 0.13</td>
</tr>
<tr>
<td>$K^\pm\pi^0, \pi^0\pi^0$</td>
<td>212 ± 15 ± 0</td>
<td>29.75 ± 0.18</td>
</tr>
<tr>
<td>$K^\pm\pi^0, \rho\pi^0$</td>
<td>1240 ± 36 ± 1</td>
<td>25.44 ± 0.16</td>
</tr>
<tr>
<td>$K^\pm\pi^0, K^0_S\pi^0$</td>
<td>1688 ± 42 ± 4</td>
<td>29.06 ± 0.17</td>
</tr>
<tr>
<td>$K^\pm\pi^0, K^0_S\eta$</td>
<td>231 ± 16 ± 1</td>
<td>24.76 ± 0.16</td>
</tr>
<tr>
<td>$K^\pm\pi^0, K^0_S\omega$</td>
<td>725 ± 28 ± 1</td>
<td>12.47 ± 0.06</td>
</tr>
</tbody>
</table>

- These yields allow us to obtain $B(D_{CP\pm} \rightarrow K^-\pi^+)$ which then provides $A_{CP \rightarrow K\pi}$.
- $A_{CP \rightarrow K\pi} = (12.77\pm 1.31 \text{(stat.)})^{+0.33}_{-0.31} \text{(syst.)})\%$. 
Preliminary result on $\delta_{K\pi}$

- We have measured $A_{CP \to K\pi} = (12.77 \pm 1.31 \text{(stat.)} \pm 0.33 \text{-} 0.31 \text{(syst.)})\%$.

- Using the relation, $2 \cdot r \cdot \cos\delta_{K\pi} + y = (1 + R_{WS}) \cdot A_{CP \to K\pi}$, and with external inputs from HFAG2013 and PDG ($R_D = 3.47 \pm 0.06\%$, $y = 6.6 \pm 0.9\%$, $R_{WS} = 3.80 \pm 0.05\%$), we obtain

$$\cos\delta_{K\pi} = 1.03 \pm 0.12 \text{(stat.)} \pm 0.04 \text{(syst.)} \pm 0.01 \text{(external)}.$$ 

- Our result is consistent with and more precise than the recent CLEO result (PRD86, 112001 (2012)): $\cos\delta_{K\pi} = 1.15^{+0.19}_{-0.17} \text{(stat.)}^{+0.00}_{-0.08} \text{(syst.)}$. 
Determination of the mixing parameter, $y_{CP}$

- $y_{CP}$ is defined as;
  \[ 2 \cdot y_{CP} = (|q/p| + |p/q|) \cdot y \cdot \cos \phi - (|q/p| - |p/q|) \cdot x \cdot \sin \phi, \]

  where $p$ and $q$ are mixing parameters,
  and $\phi = \arg(q/p)$ is the weak phase difference of the mixing amplitudes.

  Notice: for no CPV case, $p = q = 1/\sqrt{2}$ and $y_{CP} \equiv y$.

- For $D$ decays into any CP-eigenstate, its decay rate can be described as;
  \[ |D_1\rangle = p|D^0\rangle + q|\bar{D}^0\rangle \]
  \[ |D_2\rangle = p|D^0\rangle - q|\bar{D}^0\rangle \]

- When one $D$ decays into a CP-eigenstate, while the other $D$ decays semi-leptonically,
  the decay rate can be given by;
  \[ R(D^0/\bar{D}^0 \to CP^\pm) \propto |A_{CP^\pm}|^2 \cdot (1 \mp y_{CP}). \]

- Semileptonic decay width does not depend on the CP of its parent $D$.

- Yet, the total width of its parent $D$ depends on CP.

- Result: semileptonic BF of $D_{1,2}$ gets modified by a factor of $1 \pm y_{CP}$.

- Combining the above two, and neglecting terms with $y^2$ (or higher), one can arrive at
  \[ y_{CP} = \frac{1}{4} \left( \frac{R_{t;CP^+_+}R_{CP^-_-}}{R_{t;CP^-_-}R_{CP^+_+}} - \frac{R_{t;CP^-_-}R_{CP^+_+}}{R_{t;CP^+_+}R_{CP^-_-}} \right) \]
Extracting $y_{CP}$ in our experiment

- The expression for $y_{CP}$ can be written as;
  
  $$y_{CP} = \frac{1}{4} \left[ \frac{\tilde{B}_+}{B_-} - \frac{\tilde{B}_-}{B_+} \right]$$

  where $\tilde{B}_{\pm}$ is the branching fraction, averaged over different CP tag modes, $\alpha$, that is obtained by minimizing

  $$\chi^2 = \sum_{\alpha} \frac{(\tilde{B}_{\pm} - B^\alpha_{\pm})^2}{(\sigma^\alpha_{\pm})^2}$$

- All branching fractions are obtained in a similar way, the double-tag method.

- When the semileptonic decays are reconstructed, however, we use $U_{miss}$ distributions to obtain their yields, instead of $M_{bc}$,

  $$U_{miss} \equiv E_{miss} - |\vec{p}_{miss}|$$

  which peaks $\sim 0$ if only missing particle is neutrino.

- Tag modes:

<table>
<thead>
<tr>
<th>Type</th>
<th>Modes</th>
</tr>
</thead>
<tbody>
<tr>
<td>$CP^+$</td>
<td>$K^+K^-$, $\pi^+\pi^-$, $K_S\pi^0\pi^0$</td>
</tr>
<tr>
<td>$CP^-$</td>
<td>$K_S^0\pi^0$, $K_S^0\omega$, $K_S^0\eta$</td>
</tr>
<tr>
<td>$l^\pm$</td>
<td>$Ke\nu$, $K\mu\nu$</td>
</tr>
</tbody>
</table>
Yields of CP states (n_{CP \mp})
(reconstruct only one of the two neutral D)

Figure 3: M_{BC} distributions and fits to data.

E_{\text{miss}} \equiv E_0 - E_K - E_l, \quad \vec{p}_{\text{miss}} \equiv - (\vec{p}_K + \vec{p}_l + \hat{p}_{ST}) \sqrt{E_0^2 - m^2 D}.

Here, E_K/l (\vec{p}_K/l) is energy/three-momentum of K^{\pm} or lepton l^{\mp}, \hat{p}_{ST} is the unit vector in the reconstructed direction of the CP-tagged D and m_D is the nominal D^0 mass. The U_{\text{miss}} distributions are plotted in Fig. 4 for D \to K \nu and D \to K \mu \nu modes.

In fits of the DT_{Ke \nu} modes, signal shape is modeled using MC shape convoluted with an asymmetric Gaussian and backgrounds are described with a 1st-order polynomial function. In fits of the DT_{K \mu \nu} modes, signal shape is modeled using MC shape convoluted with an asymmetric Gaussian. Backgrounds of Ke \nu are modeled using MC shape and their relative rate to the signals are fixed. Shape of K \pi \pi_0 backgrounds are taken from MC simulations with convolutio

Finally, we obtain the preliminary result as y_{CP} = -1.6 \pm 1.3\% (stat. \pm 0.6\% (syst.).

The result is compatible with the previous measurements \cite{12}. This is the most precise measurement of y_{CP} based on D^0 D^0 threshold productions. However, its precision is still statistically limited.

Preliminary
Yields of K_{ev} in double tags ($n_{K_{ev},CP\mp}$) (reconstruct CP-final states from one D decay, with “Kev” from the other D)

- Signal shape: MC shape, convoluted with an asymmetric Gaussian.
- Background: A 1st order polynomial.
Yields of $K\mu\nu$ in double tags ($n_{K\mu\nu, CP\pm})$
(reconstruct CP-final states from one D decay, with “$K\mu\nu$” from the other D)

- $K\pi\pi^0$ shapes and sizes are fixed based on control samples of actual data.
- The control samples are obtained by the same CP states and $K\pi\pi^0$, while ignoring the two photons from $\pi^0$ decays to calculate $U_{\text{miss}}$.
See the next slide for detail.

- Signal shape: MC shape, convoluted with an asymmetric Gaussian.
- Background: A 1st order polynomial. $K\pi\pi^0$ (dominant).
Fixing the $K\pi\pi^0$ shape

- Obtain $E_{\text{extra}} \equiv \text{Sum of the all un-used energies deposited in EM calorimeter.}$
- $E_{\text{extra}}$ tends to be larger if it is $K\pi\pi^0$ due to the ignored extra photons from $\pi^0$ decay and is small if it is $K\mu\nu$.
- We actually do require $E_{\text{extra}} < 0.2$ GeV to select $K\mu\nu$ signal candidates.

$\begin{align*}
E_{\text{extra}}(\text{GeV}) & \\
0 & \quad 0.2 \\
0.2 & \quad 0.4 \\
0.4 & \quad 0.6 \\
0.6 & \quad 0.8 \\
0.8 & \quad 1
\end{align*}$

$\begin{align*}
U_{\text{miss}}(\text{GeV}) & \\
0 & \quad 0.1
\end{align*}$

- Fix to $U_{\text{miss}}$ in $E_{\text{extra}} > 0.5$ GeV where $K\mu\nu$ peak is suppressed.
- The fitted shape $\equiv$ MC shape, convoluted with a Gaussian.

$\begin{align*}
(K\pi\pi^0 \text{ yields in data in } E_{\text{extra}} < 0.2 \text{ GeV}) &= R \times (K\pi\pi^0 \text{ yields in data in } E_{\text{extra}} > 0.5 \text{ GeV}),
\end{align*}$

where $R = (K\pi\pi^0 \text{ yields in MC in } E_{\text{extra}} < 0.2 \text{ GeV})/(K\pi\pi^0 \text{ yields in MC in } E_{\text{extra}} > 0.5 \text{ GeV}).$
Preliminary results

- Fitted yields for each mode:

<table>
<thead>
<tr>
<th>Modes</th>
<th>$N_{tag}$</th>
<th>$N_{tag,KeV}$</th>
<th>$N_{tag,K_{\mu\nu}}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>$K^+K^-$</td>
<td>54307 ± 252</td>
<td>1216 ± 40</td>
<td>1093 ± 37</td>
</tr>
<tr>
<td>$\pi^+\pi^-$</td>
<td>19996 ± 177</td>
<td>427 ± 23</td>
<td>400 ± 23</td>
</tr>
<tr>
<td>$K_S^0\pi^0\pi^0$</td>
<td>24369 ± 231</td>
<td>560 ± 28</td>
<td>558 ± 28</td>
</tr>
<tr>
<td>$K_S^0\pi^0$</td>
<td>71419 ± 286</td>
<td>1699 ± 47</td>
<td>1475 ± 43</td>
</tr>
<tr>
<td>$K_S^0\omega$</td>
<td>21249 ± 157</td>
<td>473 ± 25</td>
<td>501 ± 26</td>
</tr>
<tr>
<td>$K_S^0\eta$</td>
<td>9843 ± 117</td>
<td>242 ± 17</td>
<td>237 ± 18</td>
</tr>
</tbody>
</table>

- After correcting for efficiencies (branching fractions), we arrive at

$$y_{CP} = [-1.6\pm1.3(\text{stat.})\pm0.6(\text{syst.})]\%.$$  

- The result is statistically limited.

- The systematic uncertainty mainly comes from fitting procedures.
Comparison with other measurements

- Our result is consistent with the world average (HFAG2013; this preliminary result is not included in the average).

- Also consistent with the latest result from CLEO-c (PRD86, 112001 (2012));
  \[ y_{CP} = (4.2\pm2.0\pm1.0)\% \]
  (not listed in the figure).
Summary

- Quantum-correlated $D^0\bar{D}^0$ in $e^+e^-$ annihilations near threshold: Unique way to measure the Charm mixing parameters.

- Most precise measurement of strong phase difference in $D^0\rightarrow K\pi$. Will improve the determination of mixing parameters, x and y.

- Measurement of $y_{CP}$: Statistically limited, consistent with the world average.

- Will collect larger “open-charm” data samples in years to come: Expect many interesting results.