Recent results on mixing and CPV in charm decays at B factories

Daniel Greenwald
For the Belle Collaboration

Technische Universität München, Physik Department
Institute for Hadronic Structure & Fundamental Symmetries

10th International Workshop on the CKM Unitarity Triangle
Heidelberg, September 18, 2018
B Factories

Analysis Methods

Recent Mixing Measurements
- $D^0 \rightarrow \pi^+ \pi^- \pi^0$
- $D^0 \rightarrow K^+ K^- \text{ and } \pi^+ \pi^-$

Recent CP-Violation Measurements
- $D^+ \rightarrow \pi^+ \pi^0$
- $D^0 \rightarrow K_S^0 K_S^0$
- $D^0 \rightarrow \rho^0 \gamma, \phi \gamma, \text{ and } \bar{K}^{*0} \gamma$
Experiments at asymmetric-energy $e^+e^-$ colliders

BaBar @ PEP-II $\rightarrow \sim 550 \text{ fb}^{-1}$
Belle @ KEKB $\rightarrow \sim 1 \text{ ab}^{-1}$

running mostly at $\sqrt{s} \approx \Upsilon(4S)$ mass $\rightarrow$ for B physics

Cross section for $c\bar{c}$ (1.3 nb) larger than for $b\bar{b}$ (1.1 nb)

BaBar

Belle

1.5 T Superconducting Solenoid
144 quartz bars
11000 PMs

EMC
6580 CsI(Tl) crystals

$\Upsilon(4S)$

$e^+$ (3.1 GeV)

$e^-$ (9 GeV)

Drift Chamber
40 layers

Instrumented Flux Return
LSTs/RPCs (muons / neutral hadrons)

Si vtx. det.
3/4 lyr. DSSD

Aerogel Cherenkov cnt.
n=1.015-1.030

Csl(Tl)
$16X_0$

TOF counter

Central Drift Chamber
small cell +He/C$_2$H$_6$

$\mu / K_L$ detection
14/15 lyr. RPC+Fe
I will present some recent analyses of decays

\[ D^\pm \text{ or } D^0 \rightarrow K^\pm, \pi^\pm, K_S^0, \pi^0, \gamma \]

How do we reconstruct such events?

- **K^\pm, \pi^\pm:**
  - tracks in the detector → selected by track quality → “good” tracks
  - identified by PID information from detectors → “good” pions and kaons
- **K_S^0**
  - via decay to \( \pi^+\pi^- \)
  - identified by displacement, vertexing, ... → “good” \( K_S^0 \)’s
- **\( \pi^0 \)**
  - via decay to \( \gamma\gamma \)
  - identified by diphoton invariant mass → “good” \( \pi^0 \)’s
- **\( \gamma \)**
  - seen as cluster in electromagnetic calorimeter
  - selected by quality and disociation with tracks & \( \pi^0 \)’s → “good” photons
Now we have our final-state particles

- **Reconstruct D**
  - by invariant mass, by vertexing
  - veto uds and non-D B decays

- **Require minimum momentum of D (or D*)**
  - veto $b\bar{b}$ events with decay to charm
  - veto combinatorically constructed D
Methods: Flavor Tagging

Now we have our D meson, we tag flavor (and veto background)

- From D* decay:
  \[
  D^{*+} \rightarrow \pi^+ D^0 \\
  D^{*-} \rightarrow \pi^- \bar{D}^0
  \]

  (rest of the event ignored)

- Full charm event reconstruction

  \[e^+ e^- \rightarrow c\bar{c} \rightarrow X_{\text{frag}} + X_{\bar{c}} + D^{(*)}\]

  (see A. Schwartz’s talk on Belle II)

Both help reduce backgrounds, too.
Mixing measurements require lifetime:

\[ t_{\text{meas}} = \frac{l_{\text{dec}}}{c \beta \gamma} \quad \text{with} \quad \beta \gamma = \left| \hat{p}_{D^0} \right| / m_{D^0} \]

(with a projection of \( \vec{l}_{\text{dec}} \) onto \( \hat{p}_{D^0} \) often used)

uncertainty on \( t \) from uncertainties on production vertex, decay vertex, and momentum used to create resolution function:

\[ \mathcal{R}(t_{\text{true}}|t_{\text{meas}}, \sigma_t^2) \]

D. Greenwald — Recent results on mixing and CPV in charm decays at B factories
Measurement of $D^0/\bar{D}^0$ mixing parameters from time-dependent Dalitz analysis

$$x = \frac{m_1 - m_2}{\frac{1}{2}(\Gamma_1 + \Gamma_2)} \quad \text{and} \quad y = \frac{\Gamma_1 - \Gamma_2}{\Gamma_1 + \Gamma_2}$$

the normalized mass-eigenstate mass & width differences, where

$$\left| D^0(t) \right> = \frac{1}{2p} \left( \left| D^0_1(t) \right> + \left| D^0_2(t) \right> \right) \quad \text{and} \quad \left| \bar{D}^0(t) \right> = \frac{1}{2q} \left( \left| D^0_1(t) \right> - \left| D^0_2(t) \right> \right)$$

with flavor eigenstates $D^0$ and $\bar{D}^0$; and mass eigenstates $D^0_1$ and $D^0_2$
From a data sample of $468 \text{ fb}^{-1}$ at and below $\sqrt{s} \approx \Upsilon(4S)$ mass

\[ D^*+ \rightarrow \pi_s^+ D^0, \quad D^*- \rightarrow \pi_s^- \overline{D}^0 \quad \text{and} \quad D^0/\overline{D}^0 \rightarrow \pi^+ \pi^- \pi^0 \]

Extra care is taken to veto spurious “soft” pions ($\pi_s^+$)

A fit is performed to the whole decay chain to contrain
- the D decay vertex
- the D production vertex ($D^*$ decay vertex)
- the D mass
- the $\pi^0$ mass

Require:
- D momentum above minimum $\rightarrow$ remove BG and B decay
- $\Delta m \equiv m(D^*) - m(D)$ within narrow band of nominal value
- $t \in [-2, 3] \text{ps}$ and $\sigma_t < 0.8 \text{ ps}$
- veto against $D^0 \rightarrow K_S^0 \pi^0, \ K^- \pi^+ \pi^0, \ K_S^0 \pi^+ \pi^-$ events
\( D^0 \rightarrow \pi^+ \pi^- \pi^0 \): BaBar; PRD93, 112014 (2016)

\[ \Rightarrow 138 \times 10^3 \text{ decays with } 91\% \text{ purity} \]

includes small fraction (< 1\%) of wrongly-reconstructed \( D^* \)

\[ \rightarrow \text{ flavor tagging assumed random} \]
D* decays to flavor eigenstate, which decays to $\pi^+ \pi^- \pi^0$ according to

$$|A|^2 \propto e^{-t/\tau_D} |\bar{A}|^2 \left[ \cosh \left( y \frac{t}{\tau_D} \right) + \cos \left( x \frac{t}{\tau_D} \right) \right] + e^{-t/\tau_D} \left| \frac{q}{p} \bar{A} \right|^2 \left[ \cosh \left( y \frac{t}{\tau_D} \right) - \cos \left( x \frac{t}{\tau_D} \right) \right]$$

$$- 2e^{-t/\tau_D} \left[ \text{Re} \left( \frac{q}{p} A^* \bar{A} \right) \sinh \left( y \frac{t}{\tau_D} \right) - \text{Im} \left( \frac{q}{p} A^* \bar{A} \right) \sin \left( x \frac{t}{\tau_D} \right) \right]$$

holding at all points in the Dalitz space:

$$A \equiv A(s_+, s_-), \quad \bar{A} \equiv \bar{A}(s_+, s_-) \quad \text{with} \quad s_+ \equiv m^2(\pi^+ \pi^0), \quad s_- \equiv m^2(\pi^- \pi^0)$$

time-dependent unbinned Dalitz-plot analysis to fit

- amplitudes for decay to intermediate states
- $x$, $y$, and $\tau_D$

including convolution with time resolution function

analysis assumes CP: $q/p = 1$ and $\bar{A}(s_+, s_-) = A(s_-, s_+)$
The Dalitz model contains

- $\rho(770)$, $\rho(1450)$, $\rho(1700)$ in positive, negative, and neutral charges
- $f_0(980)$, $f_0(1370)$, $f_0(1500)$, $f_0(1710)$, $f_2(1270)$, and $f_0(500)$
- and a flat nonresonant component
The Dalitz model contains

- $\rho(770)$, $\rho(1450)$, $\rho(1700)$ in positive, negative, and neutral charges
- $f_0(980)$, $f_0(1370)$, $f_0(1500)$, $f_0(1710)$, $f_2(1270)$, and $f_0(500)$
- and a flat nonresonant component

data, fit, signal function, background function (from sidebands)
The fit results in

\[ x = (15 \pm 12 \pm 6)\% \quad y = (2 \pm 9 \pm 5)\% \quad \tau_D = (410.2 \pm 3.8) \text{ fs} \]

From \( D^0 \to K_S^0 \pi^+ \pi^- \)

<table>
<thead>
<tr>
<th>Year</th>
<th>Experiment</th>
<th>( x )</th>
<th>( y )</th>
</tr>
</thead>
<tbody>
<tr>
<td>2016</td>
<td>LHCb</td>
<td>(-8.6 \pm 5.3 \pm 1.7)%</td>
<td>(-0.3 \pm 4.6 \pm 1.3)%</td>
</tr>
<tr>
<td>2016</td>
<td>Belle</td>
<td>(5.6 \pm 1.9^{+0.7}_{-1.3})%</td>
<td>(3.0 \pm 1.5^{+0.5}_{-0.8})%</td>
</tr>
<tr>
<td>2014</td>
<td>BaBar</td>
<td>(1.6 \pm 2.3 \pm 1.4)%</td>
<td>(5.7 \pm 2.0 \pm 1.5)%</td>
</tr>
<tr>
<td>2005</td>
<td>CLEO</td>
<td>(19^{+32}_{-33} \pm 6)%</td>
<td>(-14 \pm 24 \pm 9)%</td>
</tr>
</tbody>
</table>

(incl. \( K_S^0 K^+ K^- \))
updated measurement of $y_{\text{CP}}$ and $A_\Gamma$ using the full Belle data set in decays

$$D^0 \rightarrow K^+K^- \quad \text{and} \quad D^0 \rightarrow \pi^+\pi^-$$

$$y_{\text{CP}} \equiv \frac{\tau(D^0 \rightarrow K^-\pi^+)}{\tau(D^0 \rightarrow h^+h^-)} - 1$$

and

$$A_\Gamma \equiv \frac{\tau(\bar{D}^0 \rightarrow h^+h^-) - \tau(D^0 \rightarrow h^+h^-)}{\tau(\bar{D}^0 \rightarrow h^+h^-) + \tau(D^0 \rightarrow h^+h^-)}$$

These relate to $x$ and $y$: ($\phi \equiv \arg(q/p)$)

$$y_{\text{CP}} = \frac{1}{2} \left( |q/p| + |p/q| \right) y \cos \phi - \frac{1}{2} \left( |q/p| - |p/q| \right) x \sin \phi \xrightarrow{\text{CP}} y$$

$$A_\Gamma = \frac{1}{2} \left( |q/p| - |p/q| \right) y \cos \phi - \frac{1}{2} \left( |q/p| + |p/q| \right) x \sin \phi \xrightarrow{\text{CP}} 0$$

So $y_{\text{CP}} \neq y \rightarrow \text{CP violation.}$
From a data sample of $976 \text{ fb}^{-1}$

\[
\begin{align*}
\text{D}^{*+} & \rightarrow \pi_s^+ \text{D}^0, \\
\text{D}^{*-} & \rightarrow \pi_s^- \overline{\text{D}}^0 \\
\text{and } \quad \text{D}^0/\overline{\text{D}}^0 & \rightarrow \text{K}^+\text{K}^-, \pi^+\pi^-, \text{K}^-\pi^+
\end{align*}
\]

requiring “good” pions and kaons

- fit for D decay vertex
- fit for D production vertex (D* decay vertex)

Require

- D* momentum above minimum $\rightarrow$ remove BG and B decay
- D mass within $2.25\sigma$ window around nominal mass
- $\Delta m$ within narrow window of nominal value
- $\sigma_t < 370$ fs
$D^0 \rightarrow K^+K^-, \pi^+\pi^- : \text{Belle; PLB753 412 (2016)}$

\[ \Rightarrow \]

- $242 \times 10^3 K^+K^- \text{ events; 98\% pure}$
- $114 \times 10^3 \pi^+\pi^- \text{ events; 93\% pure}$
- $2.61 \times 10^6 K^-\pi^+ \text{ events; 99.7\% pure}$
measured lifetimes fit to with distributions

\[ F(t) \propto \frac{1}{\tau} \int_0^\infty e^{-t/\tau} R(t|t_{\text{meas}}, \sigma_t^2) \, dt + \text{Background}(t) \]

resolution function accounts for dependence on polar angle of \( D^0 \) in CM frame. It is determined from MC.

The background contains a prompt component and an exponentially decaying component. It is fixed from fits to the sidebands and MC.

simultaneous fit for \( y_{CP} \) and \( A_\Gamma \) (and \( \tau_D \)) to

- \( D^0 \to K^+K^- \)
- \( \bar{D}^0 \to K^+K^- \)
- \( D^0 \to \pi^+\pi^- \)
- \( \bar{D}^0 \to \pi^+\pi^- \)
- \( D^0 \to K^-\pi^+ + \bar{D}^0 \to K^+\pi^- \)
$D^0 \to K^+ K^-$, $\pi^+ \pi^-$: Belle; PLB753 412 (2016)

(a) $D^0 \to K^+ K^-$

(b) $\bar{D}^0 \to K^+ K^-$

(c) $D^0 \to \pi^+ \pi^-$

(d) $\bar{D}^0 \to \pi^+ \pi^-$

(e) $D^0 \to K^- \pi^+ + cc$
The fit results in

\[ \begin{align*}
    y_{CP} &= (11.1 \pm 2.2 \pm 0.9)\% \\
    A_\Gamma &= (-0.3 \pm 2.0 \pm 0.7)\% \\
    \tau_D &= (408.46 \pm 0.54) \text{ fs}
\end{align*} \]

Also from \( K^+ K^-, \pi^+ \pi^- \):

<table>
<thead>
<tr>
<th>Year</th>
<th>Experiment</th>
<th>( y_{CP} )</th>
<th>( A_\Gamma )</th>
</tr>
</thead>
<tbody>
<tr>
<td>2016</td>
<td>LHCb (D(^*))</td>
<td>((7.2 \pm 1.8 \pm 1.2)%)</td>
<td>((-0.12 \pm 0.28 \pm 0.10)%)</td>
</tr>
<tr>
<td>2016</td>
<td>LHCb (leptonic)</td>
<td>((13.1 \pm 3.2 \pm 2.5)%)</td>
<td>((0.1 \pm 3.0 \pm 1.5)%)</td>
</tr>
<tr>
<td>2012</td>
<td>BaBar</td>
<td>((7.2 \pm 1.8 \pm 1.2)%)</td>
<td>((0.9 \pm 2.6 \pm 0.6)%)</td>
</tr>
<tr>
<td>2007</td>
<td>Belle</td>
<td>((13.1 \pm 3.2 \pm 2.5)%)</td>
<td>((0.1 \pm 3.0 \pm 1.5)%)</td>
</tr>
</tbody>
</table>

Previous systematic uncertainty reduced; in large part from robust resolution function:
- \(1.4\% \rightarrow 0.3\% \) in \( y_{CP} \);
- \(0.8\% \rightarrow 0.02\% \) in \( A_\Gamma \)
For $D \rightarrow \pi \pi$, the standard model expectation is

$$A_{CP}^{D}(\Delta I = 3/2) \approx 0 = A_{CP}^{D^{+} \rightarrow \pi^{+}\pi^{0}} < \mathcal{O}(10^{-3})$$


So measuring a sizeable CP asymmetry is a sign of new physics.
We can also use the measurement to inform $A^{CP}(\Delta I = 1/2)$:

$$\left| A(D^0 \to \pi^+\pi^-) \right|^2 + \left| A(D^0 \to \pi^0\pi^0) \right|^2 - \frac{2}{3} \left| A(D^+ \to \pi^+\pi^0) \right|^2 = 3\left| A_{\Delta I=1/2} \right|^2$$

Current measurements:

$$A^{CP}_{+-} = (+0.13 \pm 0.14)\% \quad \text{(world average)}$$

$$A^{CP}_{00} = (-0.03 \pm 0.65)\% \quad \text{(Belle)}$$

$$A^{CP}_{+0} = (+2.9 \pm 2.9)\% \quad \text{(CLEO)}$$
We measure

\[
\frac{N(D^+ \to \pi^+\pi^0) - N(D^- \to \pi^-\pi^0)}{N(D^+ \to \pi^+\pi^0) + N(D^- \to \pi^-\pi^0)} \equiv A_{\pi\pi}^{\text{raw}} \approx A_{\pi\pi}^{\text{CP}} + A_{\pi\pi}^{\text{FB}} + A_{\pi\pi}^{\text{det}}
\]

and

\[
\frac{N(D^+ \to \pi^+K_S^0) - N(D^- \to \pi^-K_S^0)}{N(D^+ \to \pi^+K_S^0) + N(D^- \to \pi^-K_S^0)} \equiv A_{\pi K}^{\text{raw}} \approx A_{\pi K}^{\text{CP}} + A_{\pi K}^{\text{FB}} + A_{\pi K}^{\text{det}}
\]

So

\[
A_{\pi\pi}^{\text{CP}} (D^+ \to \pi^+\pi^0) = A_{\pi\pi}^{\text{CP}} (D^+ \to \pi^+K_S^0) + A_{\pi\pi}^{\text{raw}} - A_{\pi K}^{\text{raw}}
\]

\[
(-0.363 \pm 0.115) \% \text{ (Belle)}
\]
From a data sample of 921 fb\(^{-1}\) reconstruct

\[ D^\pm \rightarrow \pi^\pm \pi^0 \quad \text{and} \quad D^\pm \rightarrow \pi^\pm K_S^0 \]

requiring “good” pions, \( \pi^0 \)’s, and \( K_S^0 \)’s
both via \( D^{*\pm} \rightarrow \pi_s^0 D^\pm \) (“tagged”) and without (“untagged”)

Require

- \( D^{(*)} \) momentum above minimum \( \rightarrow \) veto BG and B decays

Categorize:

- If \( \pi_s^0 \) found such that \( \Delta m \) is within \( 1.5\sigma \) of nominal value \( \rightarrow \) “tagged” sample
- Else \( \rightarrow \) “untagged” sample

Fit for \( A^{\text{raw}} \) separately in the “tagged” and “untagged” samples \( \rightarrow \) combine
D$^+ \rightarrow \pi^+ \pi^0$ : Belle; PRD97, 011101 (2018)

tagged

\[ \chi^2/\text{DoF} = 0.91 \]

\[ \chi^2/\text{DoF} = 0.82 \]

D$^+$

untagged

\[ \chi^2/\text{DoF} = 1.69 \]

\[ \chi^2/\text{DoF} = 1.24 \]

D$^-$

D. Greenwald — Recent results on mixing and CPV in charm decays at B factories
Yields from fit results:

- Tagged: \( \approx 7 \times 10^3 \pi^\pm \pi^0 \) events; \( \approx 70 \times 10^3 \pi^\pm K_S^0 \) events.
- Untagged: \( \approx 100 \times 10^3 \pi^\pm \pi^0 \) events; \( \approx 1 \times 10^6 \pi^\pm K_S^0 \) events.

And the combined result from all fits:

\[
A^{\text{CP}}(D^+ \rightarrow \pi^+ \pi^0) = (+2.31 \pm 1.24 \pm 0.23) \%
\]

previously \((2.9 \pm 2.9)\%\) (CLEO) @ Belle II \(\rightarrow\) \((\pm 0.18 \pm 0.20)\%\)

And an update to

\[
A^{\text{CP}}(\Delta I = 1/2) = (-2.2 \pm 2.7) \%
\]

previously \((-2.7 \pm 4.2)\%\) @ Belle II: uncertainty \(\lesssim 0.05\%\)
possible decay to find CP violation in D decay, as we heard yesterday:

\[ |A^{CP}(D^0 \rightarrow K^0_SK^0_S)| \leq \mathcal{O}(1\%) \]

[Hiller, Jung, Schacht PRD87.014024 (2013); Nierste, Schacht PRD92.054036 (2015)]

From a data sample of 921 fb\(^{-1}\)

\[ D^{*+} \rightarrow \pi^+_s D^0, \quad D^{*-} \rightarrow \pi^-_s D^0 \quad \text{and} \quad D^0 \rightarrow K^0_SK^0_S \]

from "good" \(K^0_S\)'s identified by a neural network.

Again, we measure \(A^{CP}\) relative to another channel:

\[ A^{CP}(D^0 \rightarrow K^0_SK^0_S) = A^{raw}_{K^0_SK^0_S} - A^{raw}_{K^0_S\pi^0} + A^{CP}(D^0 \rightarrow K^0_S\pi^0) + A^K \]

\((-0.20 \pm 0.17)\% \text{ (PDG)}\)

\(-0.11\%\)

Require

- \(D^*\) momentum above minimum \(\rightarrow\) veto BG and B decays
- \(\pi^\pm_s\) originates from \(e^+e^-\) interaction point
- \(m(K^0_S)\) and \(m(\pi^0)\) within 4\(\sigma\) of nominal value
- \(m(D)\) within 3\(\sigma\) of nominal value
unbinned fit to $\Delta m$ distributions to get raw asymmetries

\[ D^0 \rightarrow K^0_S K^0_S \]    \[ \bar{D}^0 \rightarrow K^0_S K^0_S \]
The fit results in

$$A^{CP}(D^0 \rightarrow K^0_S K^0_S) = (-0.02 \pm 1.53 \pm 0.02 \pm 0.17) \%$$

$$\mathcal{B}(D^0 \rightarrow K^0_S K^0_S) = (1.321 \pm 0.023 \pm 0.036 \pm 0.044) \times 10^{-4}$$

Previous measurements

<table>
<thead>
<tr>
<th>Year</th>
<th>Experiment</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>2015</td>
<td>LHCb</td>
<td>$(-2.9 \pm 5.2 \pm 2.2)%$</td>
</tr>
<tr>
<td>2000</td>
<td>CLEO</td>
<td>$(-23 \pm 19)%$</td>
</tr>
</tbody>
</table>

@ Belle-II: $\rightarrow (\pm 0.21 \pm 0.04)\%$
\[ A_{\text{CP}}(D^0 \to V\gamma) \geq \mathcal{O}(\%) \to \text{new physics} \]

From a data sample of 943 fb\(^{-1}\)

\[ D^*^+ \to \pi_s^+ D^0 \quad \text{and} \quad D^0 \to \pi^+\pi^- \gamma, \ K^+K^- \gamma, \ \pi^+K^- \gamma \]

using “good” pions, kaons, and photons; and veto against \(\gamma\) from \(\pi^0\)

require

- “good” D and D\(^*\) vertices
- \(m(h^+h^-)\) within wide window around \(V\) mass
- \(\Delta m\) within narrow window of nominal value

\[ A_{\text{CP}}(D^0 \to [h^+h^-]_V\gamma) \] measured relative to \(A_{\text{CP}}(D^0 \to h^+h'^-)\)

\[ A_{V\gamma}^\text{CP} = A_{V\gamma}^{\text{raw}} - A_{h^+h'^-}^{\text{raw}} + A_{h^+h'^-}^{\text{CP}} \quad \text{with} \quad V \to h^+h'^- \]

\(\Rightarrow\) cancels forward-backward and detection asymmetries
2D unbinned fits to $m(D^0)$ and $V \rightarrow h^+ h'^-$ helicity angle for $A_V^{\text{raw}}$

$$D^0 \rightarrow \rho^0 \gamma$$

$$D^0 \rightarrow \phi \gamma$$

$$D^0 \rightarrow \bar{K}^* \gamma$$

$$A_{\rho \gamma}^{\text{CP}} = (5.6 \pm 15.2 \pm 0.6)\% \quad A_{\phi \gamma}^{\text{CP}} = (-9.4 \pm 6.6 \pm 0.1)\% \quad A_{K^* \gamma}^{\text{CP}} = (-0.3 \pm 2.0 \pm 0.04)\%$$

statistical uncertainty @ Belle-II →

2.1%  0.9%  0.3%
• BaBar & Belle have an impressive record of measurements

• Analyses are still published nearly a decade after the end of running

  (2016) \( x \) and \( y \) in \( D^0 \rightarrow \pi^+\pi^-\pi^0 \)

  (2016) \( y_{\text{CP}} \) and \( A_{\Gamma} \) in \( D^0 \rightarrow K^+K^- \) and \( \pi^+\pi^- \)

  (2017) \( A_{\text{CP}} \) in \( D^0 \rightarrow K_S^0K_S^0 \)

  (2017) \( A_{\text{CP}} \) in \( D^0 \rightarrow \rho^0\gamma, \phi\gamma, \) and \( \bar{K}^{*0}\gamma \)

  (2018) \( A_{\text{CP}} \) in \( D^+ \rightarrow \pi^+\pi^0 \)

• See also S. Bahinipati’s talk on Thursday on triple-product asymmetries in

  • \( D^+ \rightarrow K_S^0K^+\pi^-\pi^- \)
  • \( D^0 \rightarrow K_S^0\pi^+\pi^-\pi^0 \)
  • \( D^0 \rightarrow K^+K^-\pi^+\pi^- \)

• Many results dominated by statistical uncertainties
  \( \rightarrow \) Belle II will greatly reduce these (see talks today by J. Kumar; G. Casarosa)