$D^0 - \bar{D}^0$ mixing and CPV measurements at the B-factories

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BELLE

BABAR

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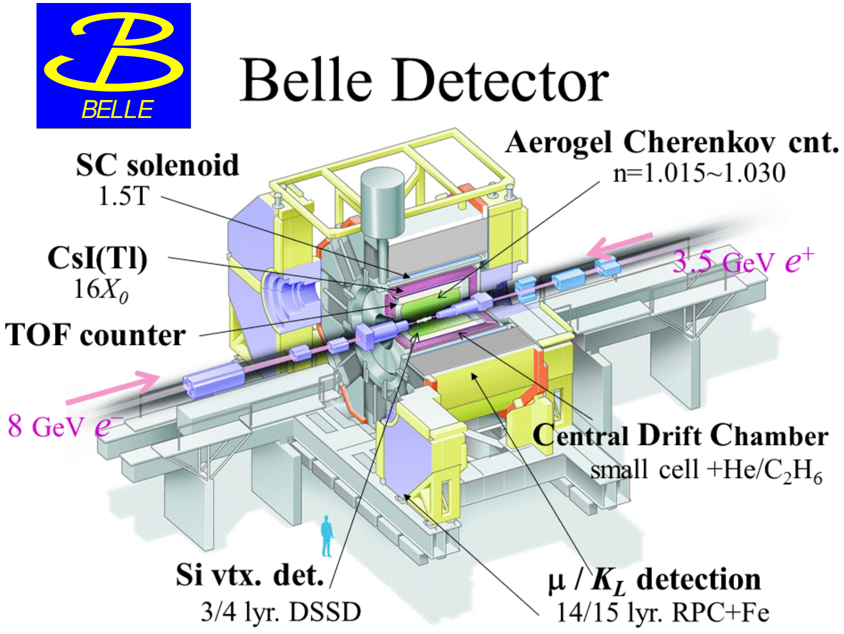
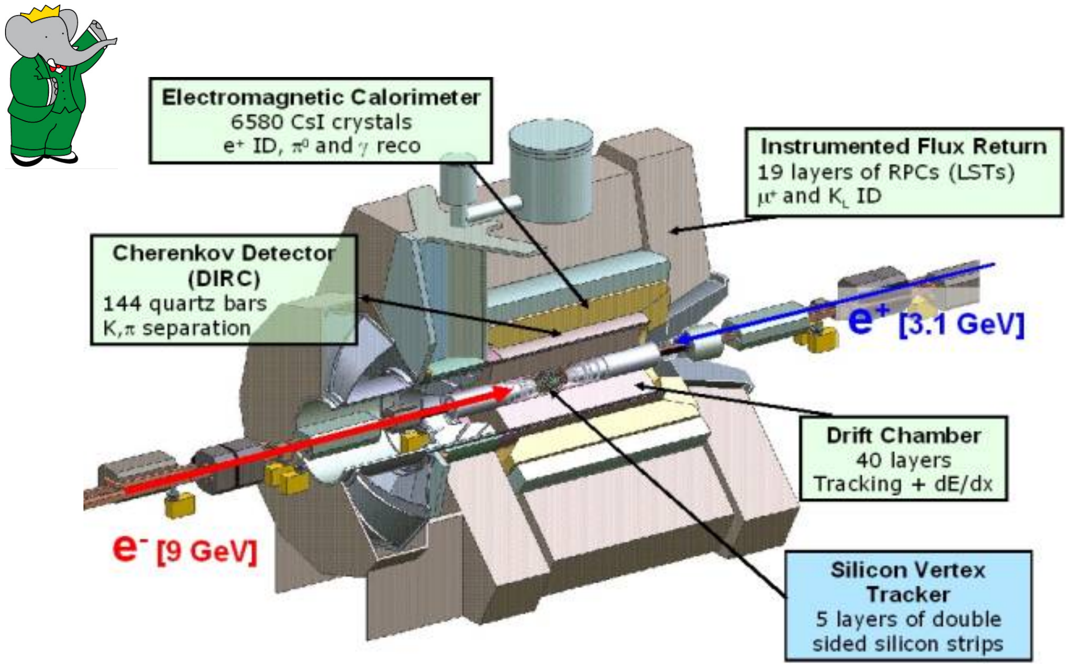
Outline

- Belle & BaBar at the B-factories
- Formalism and Status of $D^0-\bar{D}^0$ mixing and *CP* violation
- Several $D^0-\bar{D}^0$ mixing and *CP* asymmetry measurements
  - Mixing in $D^0\to\pi^+\pi^-\pi^0$ via TDDA at BaBar [PRD **93**, 112014, (2016)]
  - T-odd asymmetry in $D^0\to K_S^0\pi^+\pi^-\pi^0$ at Belle [PRD **95**, 091101(R), (2017)]
  - *CP* asymmetry in $D^0\to K_S^0K_S^0$ at Belle [PRL **119**, 171801, (2017)]
  - *CP* asymmetry in $D^+\to\pi^+\pi^0$ at Belle [PRD **97**, 011101(R), (2018)]
- Summary

Belle @KEKB and BaBar @PEP-II





- ✓ KEKB and PEP-II: asymmetric e^+e^- colliders, operate near $\Upsilon(4S)$ resonance, with high peak luminosity $2.1(1.2)\times10^{34}$ $cm^{-2}s^{-1}$
- ✓ Comparable cross section for $c\bar{c}$ @$\sqrt{s}$ = 10.58 GeV $\Longrightarrow$ also charm factories
- ✓ Excellent vertex info. & PID with SVD, Cherenkov detector, etc. for precise flight time of D mesons
- ✓ Good reconstructed capacity for $\gamma/\pi^0/K_S^0$ final states

Process	cross section σ(nb)
$b\bar{b}$	1.1
$c\bar{c}$	1.3
$q\bar{q}$(q=u,d,s)	2.1
$\tau^+\tau^-$	0.93
$\gamma\gamma$	11.1

Regular method at B-factories

- D^{*+} tagging method (needed for $D^0 - \bar{D}^0$ mixing):
  D^0 flavor is tagged by charge of $\pi_s^{\pm}$ from $D^{*\pm}$

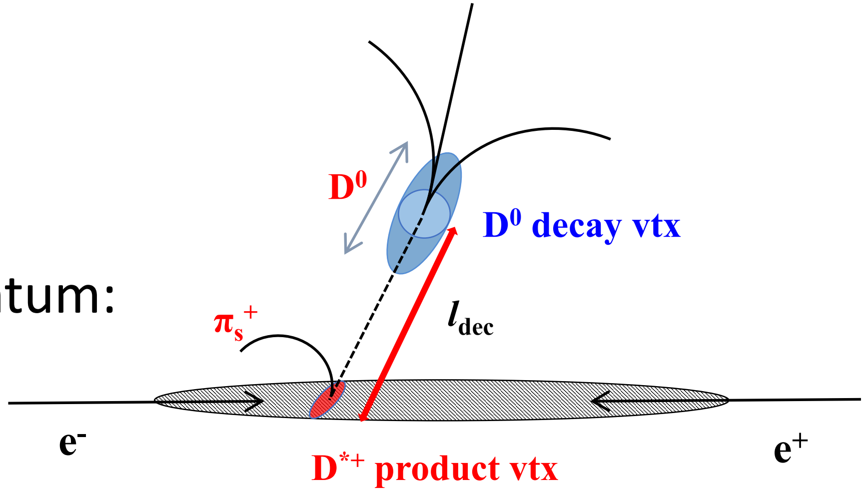
$$D^{*+}(c\bar{d}) \to D^0(c\bar{u})\pi_s^+;\ D^{*-}(\bar{c}d) \to \bar{D}^0(\bar{c}u)\pi_s^-$$

- Veto signals from B decays by a limit on $p^*(D^*)$ or $p^*(D^0)$
- Determine D^0 lifetime t and its error σ_t with vertices and momentum:

$$t = \frac{m_{D^0}}{cp}\left(\overrightarrow{r_{dec}} - \overrightarrow{r_{prod}}\right) \cdot \frac{\vec{p}}{p}$$

$$\sigma_t^2 = \left(\frac{\partial t}{\partial \eta}\right)^T V_\eta \left(\frac{\partial t}{\partial \eta}\right),\ V_\eta = \begin{pmatrix} V_{dec} & cov(dec, IP) & cov(dec, p) \\ cov(IP, dec) & V_{IP} & cov(IP, p) \\ cov(p, dec) & cov(p, IP) & V_p \end{pmatrix}$$

D^{*+} tagging



Introduction to $D^0 - \bar{D}^0$ mixing

- Mixing: neutral particle changes to its anti-particle and vice versa

$$K^0 \Leftrightarrow \bar{K}^0,\ B_d^0 \Leftrightarrow \bar{B}_d^0,\ B_s^0 \Leftrightarrow \bar{B}_s^0,\ D^0 \Leftrightarrow \bar{D}^0$$

- $D^0 - \bar{D}^0$ mixing: only up-type quark meson system
- Flavor eigenstates ($D^0, \bar{D}^0$) ≠ mass eigenstates

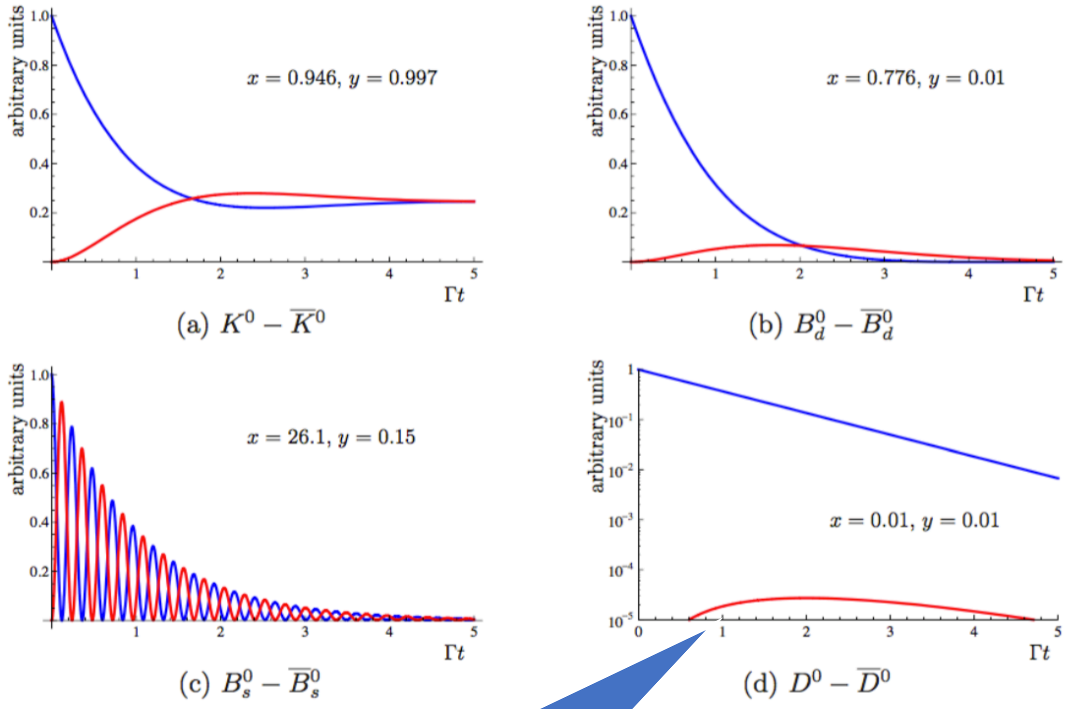
  ($D_{1,2}$ with $m_{1,2}$ and $\Gamma_{1,2}$)

$$|D_{1,2}\rangle \equiv p|D^0\rangle \pm q|\bar{D}^0\rangle \quad (\mathrm{CPT: p^2} + q^2 = 1)$$

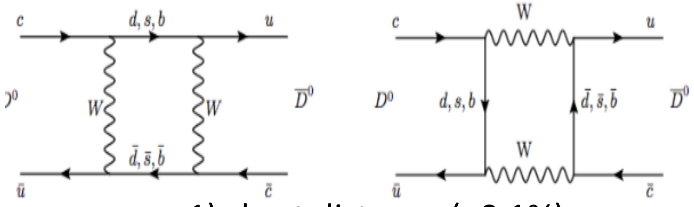
- Mixing parameters:

$$x \equiv 2\frac{m_1 - m_2}{\Gamma_1 + \Gamma_2}, y \equiv \frac{\Gamma_1 - \Gamma_2}{\Gamma_1 + \Gamma_2}$$

- Standard model (SM) predicts: |x|, |y|~$\mathcal{O}$(1%)
- Precisely measure x and y
  - test SM
  - search for New physics (NP), such as |x|>>|y|



difficult to measure



1) short distance (<0.1%)

2) long distance (~1%)

Introduction to *CP* violation

$$A_{CP}^{f} = \frac{N(D \to f) - N(\bar{D} \to \bar{f})}{N(D \to f) + N(\bar{D} \to \bar{f})} = A_d^f + A_m^f + A_i^f$$

- ***CP*** **introduction:**
  - C: charge-conjugated transform ($P \to \bar{P}$)
  - P: parity transform ($\vec{x} \to -\vec{x}$)
  - *CP*: C-P- combined transform
- **CKM parameterization by Wolfenstein in SM**

$$V = \begin{pmatrix} 1-\lambda^2/2 & \lambda & A\lambda^3(\rho - i\eta) \\ -\lambda & 1-\lambda^2/2 & A\lambda^2 \\ A\lambda^3(1-\rho-i\eta) & -A\lambda^2 & 1 \end{pmatrix}$$

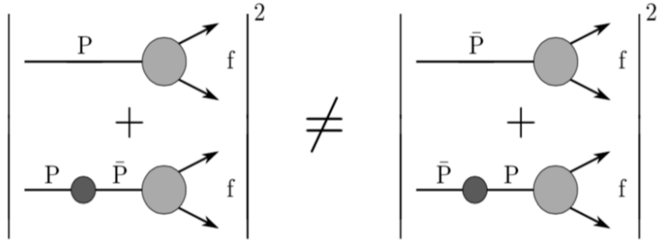
only by the complex phase in CKM matrix

- **SM predicts in charm sector: ~$\mathcal{O}$(0.1%)**
  - Significant enhancement w.r.t. SM ⟹ NP

- In the decay (direct): $|A_f/\bar{A}_{\bar{f}}| \neq 1$

- In the mixing (indirect): $|\frac{q}{p}| \neq 1$

- In the interference: $\arg(q/p) \neq 0$



Status of $D^0 - \bar{D}^0$ mixing and *CP* violation

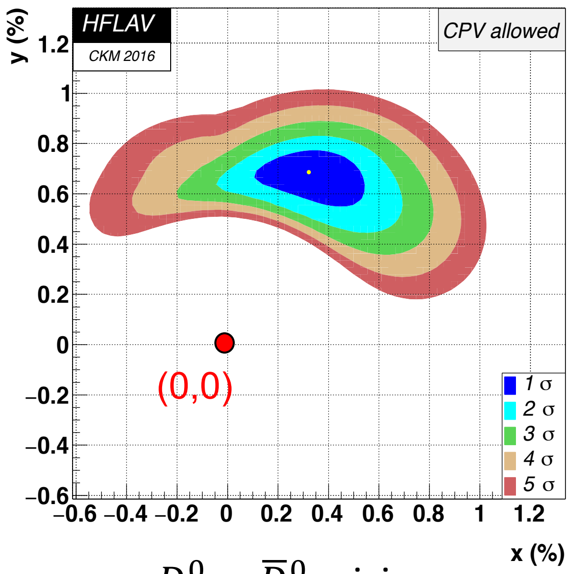
L.K. Li *Beauty 2018*

Decay Type	Final State	BELLE		LHCb	CDF	CLEO	BESIII
DCS 2-body(WS)	$K^+\pi^-$	★	☆	★ (a)	★	√	√ $\delta_{K\pi}$
DCS 3-body(WS)	$K^+\pi^-\pi^0$	o (c)	☆			√ A_{CP}	o δ
CP-eigenstate	(even) h^+h^-	☆	☆	☆ (b) A_{CP}	√ A_{CP}	√	
	(odd) $K_S^0\phi$	√					
Self-conj. 3-body decay	$K_S^0\pi^+\pi^-$	√	√	√	√ A_{CP}	√	o δ
	$K_S^0K^+K^-$	o	√	o			o δ
	$K_S^0\pi^0\pi^0$					√ Dalitz	o y_{CP}
Self-conj. SCS 3-body decay	$\pi^+\pi^-\pi^0$	√ A_{CP}	√ mixing A_{CP}	√ A_{CP}			o δ
	$K^+K^-\pi^0$		√ A_{CP}				o δ
SCS 3-body	$K_S^0K^\pm\pi^\mp$			√ A_{CP}		√ δ	o δ
Semileptonic decay	$K^+\ell^-\nu_\ell$	√	√			√	
Multi-body(n≥4)	$K^+\pi^-\pi^+\pi^-$	√ R_{WS}	√	★			o δ_{RS}
	$\pi^+\pi^-\pi^+\pi^-$	o A_{CP}		√ (d) A_{CP}			
	$K^+K^-\pi^+\pi^-$	o A_T	√ A_T	√ (e) A_{CP}		√ A_{CP}	o
	$K_S^0\pi^+\pi^-\pi^0$	√ A_T					
$\psi(3770) \to D^0\bar{D}^0$ via correlations						√ $\delta_{K\pi}$	√ y_{CP}

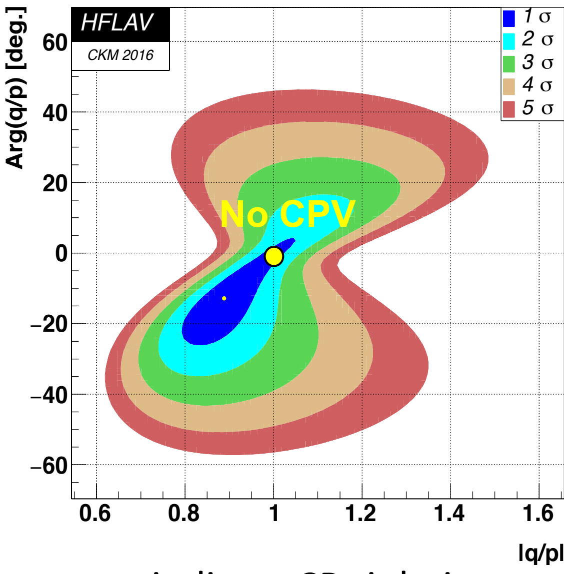
In $D^0 - \bar{D}^0$ mixing measurements: ★for observation (>5σ); ☆for evidence (>3σ); √for measurement published; o for analysis on going. A_T stands for measuring *CP* asymmetry using T-odd correlations.

Status of $D^0 - \bar{D}^0$ mixing and *CP* violation

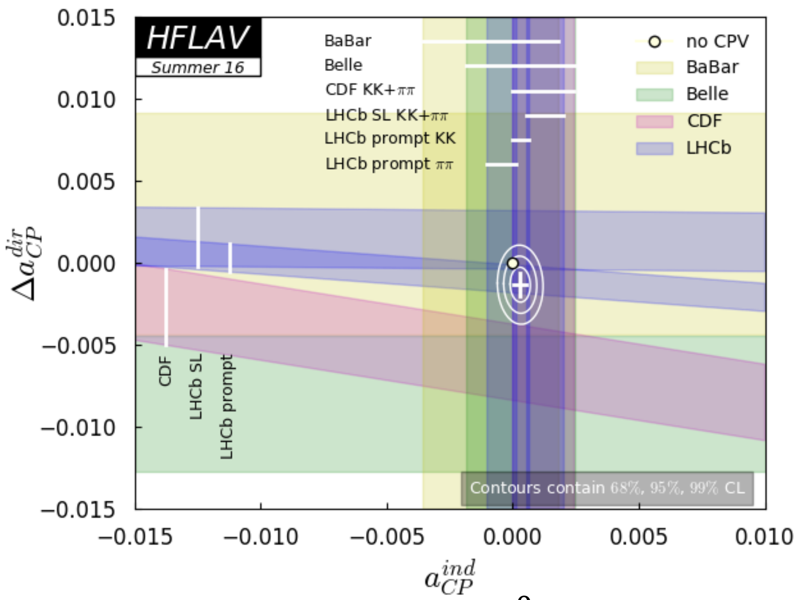
- From HFLAV 2016



$D^0 - \bar{D}^0$ mixing



indirect *CP* violation



CP violation in $D^0 \to KK/\pi\pi$

- >> 11.5σ to exclude no mixing (x,y)=(0,0) with CPV-allowed
- No hint for indirect CPV: no CPV point at C.L. = 40%
- No clear evidence of direct CPV: no CPV at C.L. = 9.3%

Mixing in $D^0 \to \pi^+\pi^-\pi^0$ via TDDA at BaBar

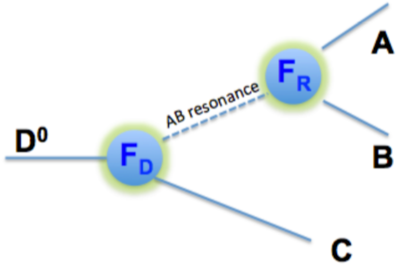
[PRD **93**, 112014 (2016)]

- Time-dependent Dalitz analysis (TDDA) technique used in $D^0 \to K_S^0\pi^+\pi^-$ contributes a lot to HFLAV
- Self-conjugate final state $D^0 \to \pi^+\pi^-\pi^0$ provides direct measurements of *x* and *y*
- Decay rate for D^0 by D^{*+} tagging method:

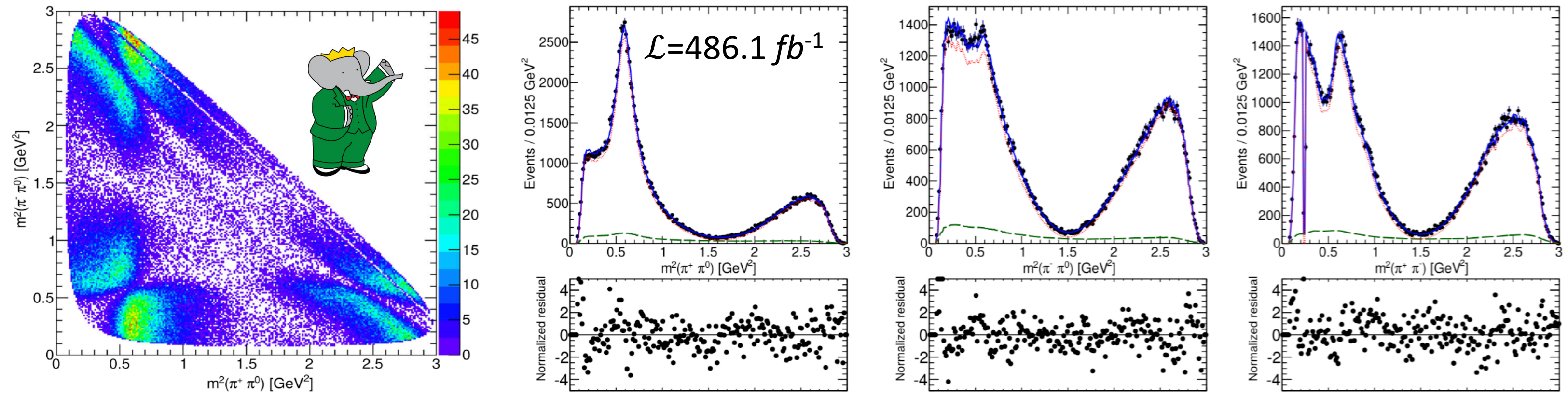
$$|M(f,t)|^2 \propto \frac{e^{-\Gamma t}}{2}[\left(\left|A_f\right|^2 + \left|\frac{q}{p}\right|^2 \left|\bar{A}_f\right|^2\right)\cosh(y\Gamma t) + \left(\left|A_f\right|^2 - \left|\frac{q}{p}\right|^2 \left|\bar{A}_f\right|^2\right)\cos(x\Gamma t) + 2\Re\left[\frac{q}{p}\bar{A}_f A_f^*\right]\sinh(\Gamma t) + 2\Im[\frac{q}{p}\bar{A}_f A_f^*]\sin(x\Gamma t)]$$

- Dalitz plot is parameterized by an Isobar model

$$\bar{A}_f(s_-,s_+) = A_f(s_+,s_-) = \sum_k c_k w_k(s_+,s_-)$$



- BaBar performs first TDDA in $D^0 \to \pi^+\pi^-\pi^0$:



$x = (1.5 \pm 1.2 \pm 0.6)\%$
$y = (0.2 \pm 0.9 \pm 0.5)\%$

- Statistics dominated
- Systematic uncertainty reduced by increased samples

T-odd asymmetry in $D^0 \to K_S^0\pi^+\pi^-\pi^0$ at Belle

[PRD **95**, 091101(R) (2017)]

- Large *Br* of 5.2%, sample of $\mathcal{O}(10^6)$ $\Longrightarrow$ a test at precision of $\mathcal{O}(10^{-3})$ for *CP* asymmetry
- First T-asymmetry measurement for D mesons with two neutral particles

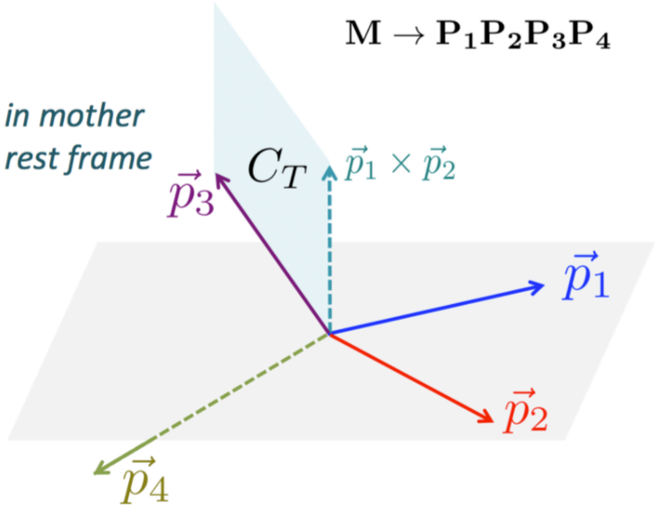
Method:

- Parity-odd observable $C_T = \vec{p}_1 \cdot (\vec{p}_2 \times \vec{p}_3)$ for D^0 and its *CP*-conjugated observable $-\bar{C}_T$ for $\bar{D}^0$
- Define two asymmetry parameters:

$$A_T = \frac{\Gamma(C_T>0)-\Gamma(C_T<0)}{\Gamma(C_T>0)+\Gamma(C_T<0)},\ \bar{A}_T = \frac{\Gamma(-\bar{C}_T>0)-\Gamma(-\bar{C}_T<0)}{\Gamma(-\bar{C}_T>0)+\Gamma(-\bar{C}_T<0)}$$

  - A_T, $\bar{A}_T$ nonzero due to FSI effects

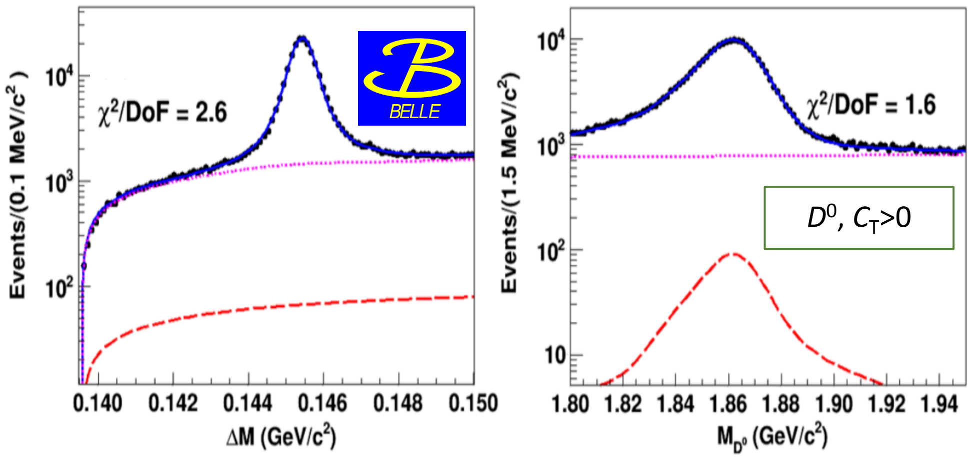
- *CP* violation sensitive parameter: $a_{CP}^{T-odd} = \frac{1}{2}(A_T - \bar{A}_T)$
  - nonzero $\Longrightarrow$ clear signature of T violation [Mat.-fys.Medd. **28**, 005 (1954)]
- Via CPT theorem, the T-asymmetry is equivalent to *CP* violation



T-odd asymmetry in $D^0 \to K_S^0\pi^+\pi^-\pi^0$ at Belle

[PRD **95**, 091101(R) (2017)]

- Signal decay channel: $e^+e^- \to c\bar{c} \to XD^{*+}$, $D^{*+} \to \pi_s^+ D^0$, $D^0 \to K_S^0\pi^+\pi^-\pi^0$
  - Data set with $\mathcal{L}$= 966 fb^{-1}
  - 2D ($M_{D^0}, \Delta M(= M(D^*) - M(D^0))$) correlated fit performed for signal extract and a_{CP}^{T-odd} calculation
  - Simultaneously fit to four samples: D^0 with C_T>0, C_T<0 and $\bar{D}^0$ with -$\bar{C}_T$>0, -$\bar{C}_T$<0



a_{CP}^{T-odd} measurements in nine regions

Bin	Resonance	Invariant mass requirement (MeV/c^2)	$A_T(\times10^{-2})$	$a_{CP}^{T\text{-odd}}(\times10^{-3})$
1	$K_S^0\omega$	$762 < M_{\pi^+\pi^-\pi^0} < 802$	$3.6 \pm 0.5 \pm 0.5$	$-1.7 \pm 3.2 \pm 0.7$
2	$K_S^0\eta$	$M_{\pi^+\pi^-\pi^0} < 590$	$0.2 \pm 1.3 \pm 0.4$	$4.6 \pm 9.5 \pm 0.2$
3	$K^{*-}\rho^+$	$790 < M_{K_S^0\pi^-} < 994$ $610 < M_{\pi^+\pi^0} < 960$	$6.9 \pm 0.3^{+0.6}_{-0.5}$	$0.0 \pm 2.0^{+1.6}_{-1.4}$
4	$K^{*+}\rho^-$	$790 < M_{K_S^0\pi^+} < 994$ $610 < M_{\pi^-\pi^0} < 960$	$22.0 \pm 0.6 \pm 0.6$	$1.2 \pm 4.4^{+0.3}_{-0.4}$
5	$K^{*-}\pi^+\pi^0$	$790 < M_{K_S^0\pi^-} < 994$	$25.5 \pm 0.7 \pm 0.5$	$-7.1 \pm 5.2^{+1.2}_{-1.3}$
6	$K^{*+}\pi^-\pi^0$	$790 < M_{K_S^0\pi^+} < 994$	$24.5 \pm 1.0^{+0.7}_{-0.6}$	$-3.9 \pm 7.3^{+2.4}_{-1.2}$
7	$K^{*0}\pi^+\pi^-$	$790 < M_{K_S^0\pi^0} < 994$	$19.7 \pm 0.8^{+0.4}_{-0.5}$	$0.0 \pm 5.6^{+1.1}_{-0.9}$
8	$K_S^0\rho^+\pi^-$	$610 < M_{\pi^+\pi^0} < 960$	$13.2 \pm 0.9 \pm 0.4$	$7.6 \pm 6.1^{+0.2}_{-0.0}$
9	Remainder	…	$20.5 \pm 1.0^{+0.5}_{-0.6}$	$1.8 \pm 7.4^{+2.1}_{-5.3}$

$$a_{CP}^{T-odd} = (-0.28 \pm 1.38^{+0.23}_{-0.76})\times10^{-3}$$

- Consistent with no *CP* violation
- Statistically dominated, sensitivity can be improved by Belle II

No evidence for *CP* violation in various bins of $K_S^0\pi^+\pi^-\pi^0$ phase space

CP asymmetry in $D^0 \to K_S^0 K_S^0$ at Belle

[PRL **119**, 171801 (2017)]

- SM-based calculation upper limit 1.1% for direct CPV at 95% C.L. [PRD 92, 054036 (2015)]
- Singly Cabibbo-suppressed (SCS) decay, special interest: possible interference with NP amplitudes $\Longrightarrow$ large nonzero CPV

Method:

- Signal mode ($D^0 \to K_S^0 K_S^0$):

$$\mathrm{A}_{raw} = \frac{N(D^0)-N(\bar{D}^0)}{N(D^0)+N(\bar{D}^0)} = A_{CP} + A_\epsilon^K + A_{FB} + A_\epsilon^\pm$$

  - A_{CP}: true *CP* asymmetry
  - A_ϵ^K: from different strong interaction of $K^0/\bar{K}^0$ mesons with nucleons of the detector material
    $A_\epsilon^{K^0/\bar{K}^0}$ = (-0.11±0.11)% [PRD 84, 111501 (2011)]
  - A_{FB}: forward- backward production asymmetry of D^0 mesons
  - $A_\epsilon^\pm$: from different detection efficiencies for $\pi^\pm$

  } eliminated by normalization mode (A_{FB}, $A_\epsilon^\pm$)

- Normalization mode ($D^0 \to K_S^0 \pi^0$): $A_{CP}^{D^0 \to K_S^0 \pi^0}$ = (-0.20 ± 0.17)% [PDG 2016]

Measure $A_{CP}^{D^0 \to K_S^0 K_S^0} = \left(A_{raw}^{D^0 \to K_S^0 K_S^0} - A_{raw}^{D^0 \to K_S^0 \pi^0}\right) + \left(A_{CP}^{D^0 \to K_S^0 \pi^0}\right) + A_\epsilon^{K^0/\bar{K}^0}$

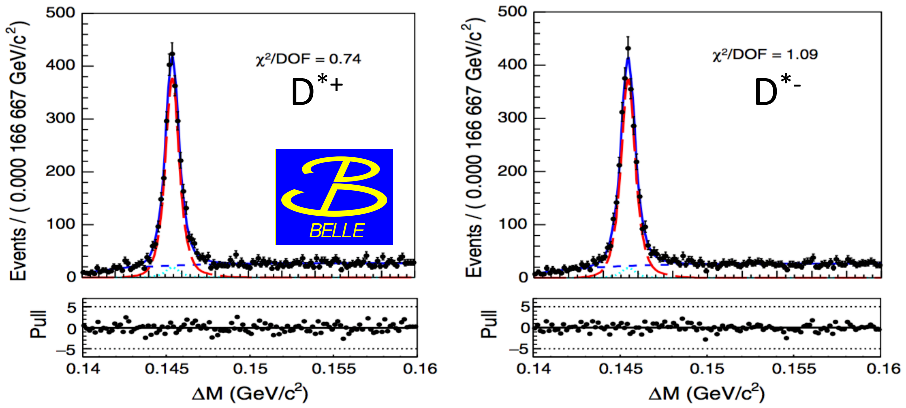
CP asymmetry in $D^0 \to K_S^0 K_S^0$ at Belle

[PRL **119**, 171801 (2017)]

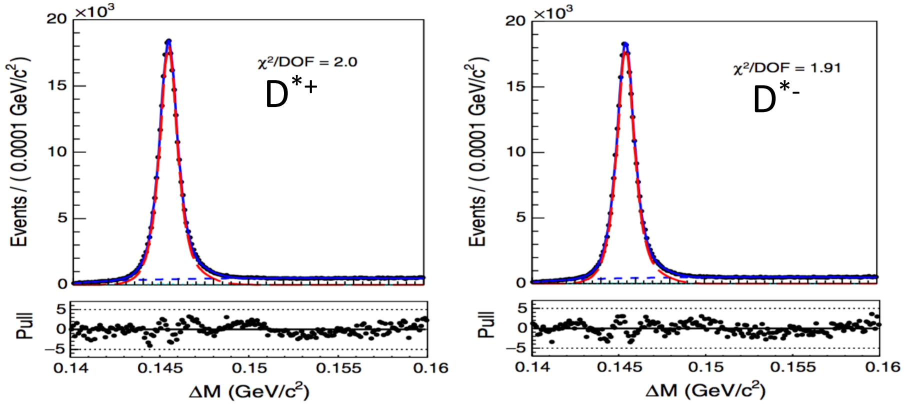
- A_{raw}: simultaneous fit on the ΔM

  Data set with $\mathcal{L}$= 921 fb^{-1}

$D^0 \to K_S^0 K_S^0$: signal mode



$D^0 \to K_S^0 \pi^0$: normalization mode



- Comparison of A_{CP} & B_r measurement results

Exp.	Results	$\mathcal{L}$ (fb^{-1})
CLEO A_{CP}	(-23±19)%	13.7
LHCb A_{CP}	(2.0±2.9±1.0)% (Beauty 2018)	5
Belle A_{CP}	(-0.02±1.53±0.02±0.17)%	921
BESIII Br	$(1.67\pm0.11\pm0.11)\times10^{-4}$	2.93
Belle Br	$(1.32\pm0.02\pm0.04\pm0.04)\times10^{-4}$	921

  - A_{CP} consistent with no CPV, precision comparable to theory prediction (1.1%), improved precision
  - B_r consistent with the world average (PDG), 2.3σ away from a recent BESIII measurement

- Both measurements are the most precise ones available for $D^0 \to K_S^0 K_S^0$ mode

CP violation in $D^+ \to \pi^+\pi^0$ at Belle

[PRD **97**, 011101(R) (2018)]

- SCS decays (like $D^+ \to \pi^+\pi^0$): excellent candidates to probe CPV
- Any CP asymmetry found in these SCS channels points to NP [PRD 85,114036 (2012)]

Method:

- Signal mode ($D^+ \to \pi^+\pi^0$):

$$A_{raw}^{\pi\pi} = \frac{N(D^+\to\pi^+\pi^0)-N(D^-\to\pi^-\pi^0)}{N(D^+\to\pi^+\pi^0)+N(D^-\to\pi^-\pi^0)} = A_{CP}^{\pi^+\pi^0} + \boxed{A_{FB} + A_\epsilon^{\pi^\pm}}$$

→ eliminated by normalization mode

  - A_{CP}: true CP asymmetry
  - A_{FB}: forward- backward production asymmetry of D mesons
  - $A_\epsilon^{\pi^\pm}$: from different detection efficiencies for $\pi^\pm$

- Normalization mode ($D^+ \to \pi^+ K_S^0$):

$$A_{CP}^{K\pi} = (-0.363 \pm 0.094 \pm 0.067)\%$$

[PRL 109, 021601 (2012)]

Measure $A_{CP}^{\pi\pi} = \left(A_{raw}^{D^+\to\pi^+\pi^0} - A_{raw}^{D^+\to\pi^+K_S^0}\right) + A_{CP}^{K\pi}$

CP violation in $D^+ \to \pi^+\pi^0$ at Belle

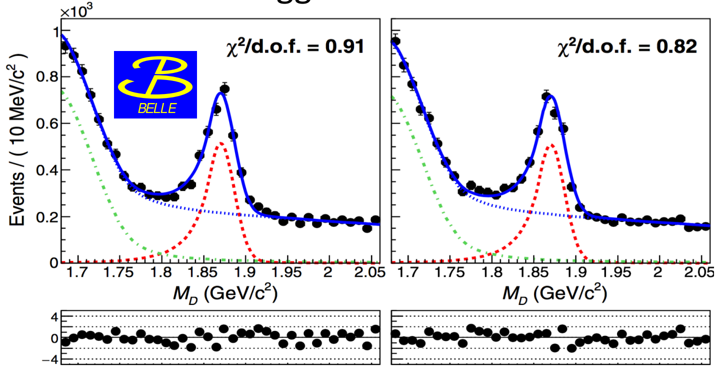
[PRD **97**, 011101(R) (2018)]

Method:

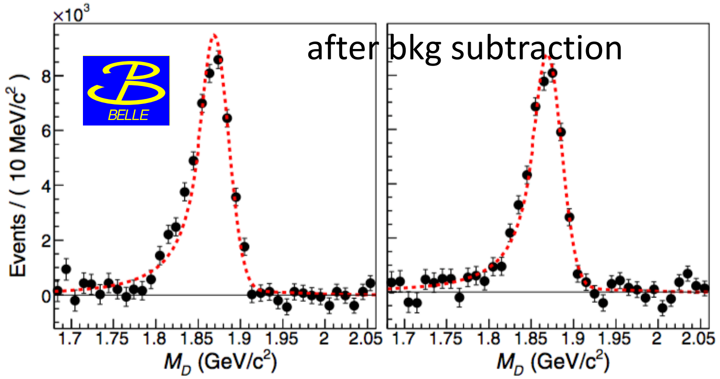
$$A_{CP}^{\pi\pi} = \left(A_{raw}^{D^+\to\pi^+\pi^0} - A_{raw}^{D^+\to\pi^+K_S^0}\right) + A_{CP}^{K\pi}$$

➢ Simultaneous fit to M_D for raw asymmetries

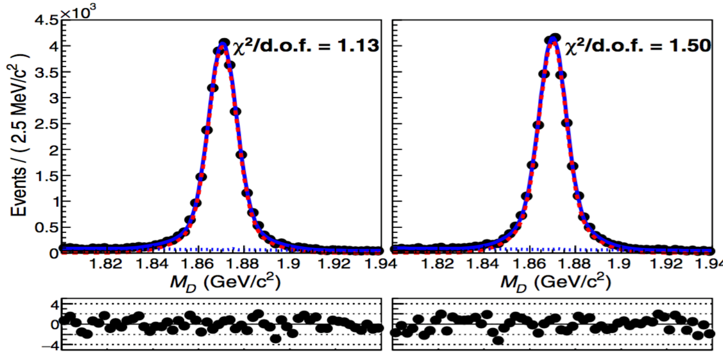
tagged: $D^+ \to \pi^+\pi^0$



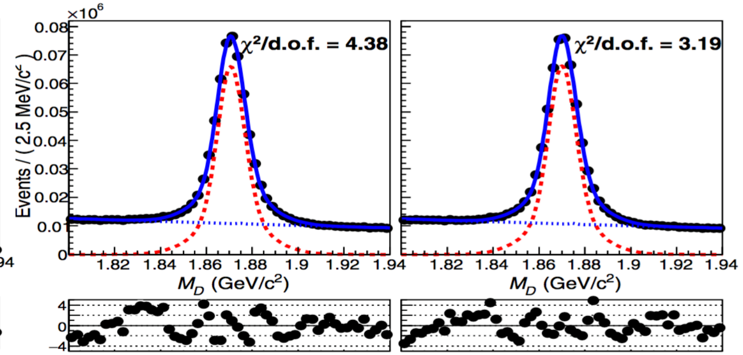
untagged: $D^+ \to \pi^+\pi^0$



tagged: $D^+ \to \pi^+K_S^0$



untagged: $D^+ \to \pi^+K_S^0$



- Signal mode: $D^+ \to \pi^+\pi^0$
- Normalization mode: $D^+ \to \pi^+K_S^0$
- $A_{raw}^{\pi\pi}/A_{raw}^{K\pi}$ for tagged and untagged samples

  tagged $\Delta A_{raw} = (+0.81 \pm 1.97 \pm 0.19)\%$

  untagged $\Delta A_{raw} = (+4.02 \pm 1.61 \pm 0.32)\%$
- Combination:

$$\Delta A_{raw} = (+2.67 \pm 1.24 \pm 0.23)\%$$

$$A_{CP}^{D^+\to\pi^+\pi^0} = (+2.31\pm1.24\pm0.23)\%$$

- consistent with SM expectation
- improved precision by more than a factor of 2

Summary

- Belle and BaBar have achieved fruitful production on charm physics at the B-factories, based on an integrated luminosity of ~1.0 ab^{-1} and ~0.5 ab^{-1} data sets.
- Several $D^0 - \overline{D}^0$ mixing and *CP* asymmetry measurements.
  - ✓ First measurement of mixing parameters in $D^0 \to \pi^+\pi^-\pi^0$ at BaBar
    - x = (1.5±1.2±0.6)%, y = (0.2±0.9±0.5)%
  - ✓ First measurement of *CP* asymmetry via T-odd in $D^0 \to K_S^0\pi^+\pi^-\pi^0$ at Belle:
    - $A_{CP}^{D^0\to K_S^0\pi^+\pi^-\pi^0}$ = $(-0.28\pm1.38^{+0.23}_{-0.76})\times10^{-3}$ ⟹ consistent with no *CP* violation
  - ✓ *CP* asymmetry in $D^0 \to K_S^0 K_S^0$ at Belle
    - $A_{CP}^{D^0\to K_S^0 K_S^0}$ = (-0.02±1.53±0.02±0.17)% ⟹ consistent with SM, significantly improved precision
    - Br = $(1.32\pm0.02\pm0.04\pm0.04)\times10^{-4}$ ⟹ consistent with the world average
  - ✓ *CP* violation in $D^+ \to \pi^+\pi^0$ at Belle
    - $A_{CP}^{D^+\to\pi^+\pi^0}$ = (+2.31±1.24±0.23)% ⟹ consistent with SM expectation, improved precision
- Statistically limited, more precise results and improved sensitivity are expected at Belle II due to the increased dataset.

Thank you!

Backup

- Belle II sensitivity estimation based on ToyMC
  - Smear decay time with Gauss (σ =140 fs) for 1000 experiments

Table 1. Belle measurements and Belle II estimations of expected sensitivities of mixing parameters x', y' and CP-violating parameters $|q/p|$, ϕ of flavor tagged $D^0 \to K^+\pi^- + c.c.$ decays, under situation of CPV and CPV-allowed.

	Parameter	Belle 976 fb^{-1}	Belle II 5 ab^{-1}	Belle II 20 ab^{-1}	Belle II 50 ab^{-1}
no CPV	$\delta(x'^2)$ (10^{-5})	22	7.5	3.7	2.3
	$\delta(y')$ (%)	0.34	0.11	0.056	0.035
CPV-allowed	$\delta(x')$ (%)		0.37	0.23	0.15
	$\delta(y')$ (%)		0.26	0.17	0.10
	$\delta(\|q/p\|)$		0.197	0.089	0.051
	$\delta(\phi)$ (°)		15.5	9.2	5.7

➢ Time-integrated *CP* asymmetries measurements

$$A_{CP}^{f} = \frac{\Gamma(D^0 \to f) - \Gamma(\bar{D}^0 \to \bar{f})}{\Gamma(D^0 \to f) + \Gamma(\bar{D}^0 \to \bar{f})}$$

Expected A_{CP} uncertainty @ Belle II of 50 ab^{-1} (D^{*+} tagging)

$$\sigma_{\mathrm{BelleII}} = \sqrt{(\sigma_{\mathrm{stat}}^2 + \sigma_{\mathrm{syst}}^2) \cdot (\mathcal{L}_{\mathrm{Belle}}/50\ \mathrm{ab}^{-1}) + \sigma_{\mathrm{irred}}^2}$$

Table 2. Time-integrated *CP* asymmetries measurements from Belle, and the precision expected for Belle II in 50 ab^{-1} of data.

Channel	Current measurement			Scaled
	$\mathcal{L}(\mathrm{fb}^{-1})$	value(%)	References	50 ab^{-1}
$D^0 \to K^+K^-$	976	$-0.32 \pm 0.21 \pm 0.09$	PoS ICHEP2012 (2013) 353	± 0.03
$D^0 \to \pi^+\pi^-$	976	$+0.55 \pm 0.36 \pm 0.09$	PoS ICHEP2012 (2013) 353	± 0.05
$D^0 \to \pi^0\pi^0$	966	$-0.03 \pm 0.64 \pm 0.10$	PRL **112**, 211601 (2014)	± 0.09
$D^0 \to K_S^0\pi^0$	966	$-0.21 \pm 0.16 \pm 0.07$	PRL **112**, 211601 (2014)	± 0.03
$D^0 \to K_S^0\eta$	791	$+0.54 \pm 0.51 \pm 0.16$	PRL **106**, 211801 (2011)	± 0.07
$D^0 \to K_S^0\eta'$	791	$+0.98 \pm 0.67 \pm 0.14$	PRL **106**, 211801 (2011)	± 0.09
$D^0 \to K_S^0K_S^0$	921	$-0.02 \pm 1.53 \pm 0.17$	PRL **119**, 171801 (2017)	± 0.20
$D^0 \to \pi^+\pi^-\pi^0$	532	$+0.43 \pm 1.30$	PLB **662**, 102 (2008)	± 0.13
$D^0 \to K^+\pi^-\pi^0$	281	-0.60 ± 5.30	PRL **95**, 231801 (2005)	± 0.40
$D^0 \to K^+\pi^-\pi^+\pi^-$	281	-1.80 ± 4.40	PRL **95**, 231801 (2005)	± 0.33
$D^+ \to \pi^0\pi^+$	921	$+0.89 \pm 1.98 \pm 0.22$	PRD **97**, 011101(R) (2018)	± 0.40
$D^+ \to \phi\pi^+$	955	$+0.51 \pm 0.28 \pm 0.05$	PRL **108**, 071801 (2012)	± 0.04
$D^+ \to \eta\pi^+$	791	$+1.74 \pm 1.13 \pm 0.19$	PRL **107**, 221801 (2011)	± 0.14
$D^+ \to \eta'\pi^+$	791	$-0.12 \pm 1.12 \pm 0.17$	PRL **107**, 221801 (2011)	± 0.14
$D^+ \to K_S^0\pi^+$	977	$-0.36 \pm 0.09 \pm 0.07$	PRL **109**, 021601 (2012)	± 0.03
$D^+ \to K_S^0K^+$	977	$-0.25 \pm 0.28 \pm 0.14$	JHEP **02** (2013) 098	± 0.05
$D_s^+ \to K_S^0\pi^+$	673	$+5.45 \pm 2.50 \pm 0.33$	PRL **104**, 181602 (2010)	± 0.29
$D_s^+ \to K_S^0K^+$	673	$+0.12 \pm 0.36 \pm 0.22$	PRL **104**, 181602 (2010)	± 0.05

➢Measurements of mixing parameters in Self-conjugate final state decays

	x (%)	y (%)	Luminosity (fb^{-1})
$D^0 \to K_S^0\pi^+\pi^-$ (no CPV) (CPV-allowed)	$0.56\pm0.19^{+0.067}_{-0.127}$ $0.58\pm0.19^{+0.0734}_{-0.1177}$	$0.30\pm0.15^{+0.050}_{-0.078}$ $0.27\pm0.16^{+0.0546}_{-0.0854}$	921 (Belle)
$D^0 \to K_S^0\pi^+\pi^-$(no CPV)	-0.86±0.53±0.17	0.03±0.46±0.13	1.0 (LHCb)
$D^0 \to K_S^0h^+h^-$(h=K/π) (no CPV)	0.16±0.23±0.12±0.08	0.57±0.20±0.13±0.07	468.5 (BaBar)
$D^0 \to \pi^+\pi^-\pi^0$ (no CPV)	1.5±1.2±0.6	0.2±0.9±0.5	468.1(BaBar)

➢T-odd measurements Vs. other measurements in D meson decays

$D^0 \to K_S^0\pi^+\pi^-\pi^0$	$a_{CP}^{\text{T-odd}} = (-0.28 \pm 1.38^{+0.23}_{-0.76}) \times 10^{-3}$	Belle[1]
$D^0 \to K^+K^-\pi^+\pi^-$	$a_{CP}^{\text{T-odd}} = (+1.7 \pm 2.7) \times 10^{-3}$	LHCb[2], BaBar[3], Focus[4]
$D^+ \to K_S^0K^+\pi^+\pi^-$	$a_{CP}^{\text{T-odd}} = (-1.10 \pm 1.09) \times 10^{-2}$	BaBar[5], Focus[4]
$D_s^+ \to K_S^0K^+\pi^+\pi^-$	$a_{CP}^{\text{T-odd}} = (-1.39 \pm 0.84) \times 10^{-2}$	BaBar[5], Focus[4]

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