CP-violation and mixing in charmed mesons at Belle

Karina Arinstein

Budker Institute of Nuclear Physics
Novosibirsk, Russia

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Rencontres du Vietnam
Beyond The Standard Model of Particle Physics

Outline:

- Introduction
- Belle detector
- CPV mechanisms in D-mesons
- Direct CPV
  - $A_{CP}(D^0 \to K^+K^-, \pi^+\pi^-)$
  - $A_{CP}(D^\pm \to K_S^0\pi^\pm)$
- Mixing
  - x, y in $D^0 \to K_S^0\pi^+\pi^-$
  - y_{CP}, A_Γ in $D^0 \to K^+K^-, \pi^+\pi^-$
- Summary

Mechanisms of CPV:

Direct CPV ($\Delta C = 1$):

decay amplitudes for D^0-, D^+-decays and their flavor conjugated processes differ ($|A_f| \neq |\bar{A}_{\bar{f}}|$)

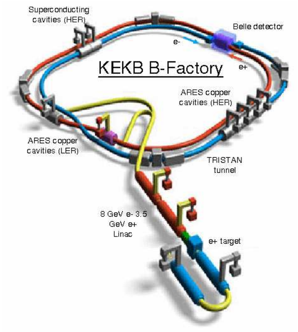
SM predictions:
$O(10^{-3})$ in singly Cabibbo suppressed decays (SCS)
smaller in Cabibbo favored and doubly Cabibbo suppressed (DCS)
(A. Petrov, arXiv:1101.3822v1; F. Buccella *et al.*,PLB 302, 319 (1993))

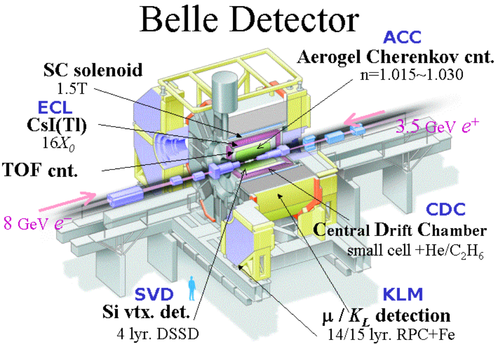
Indirect CPV:

- in mixing ($\Delta C = 2$): rates $D^0 \to \bar{D}^0$ and $\bar{D}^0 \to D^0$ differ
- in interference between mixing and direct decay amplitudes.

SM predictions:
$O(10^{-4} - 10^{-5})$ (I. Bigi *et al.*, JHEP 1106, 089 (2011))

Direct CPV depends on the final state,
indirect CPV is universal for all D-mixing processes.





The Belle detector (KEKB collider), KEK, Tsukuba, Japan:

- World luminosity record: $L \simeq 2.1 \times 10^{34}$ cm^{-2}s^{-1}
- Data taking finished in 2010 $\Rightarrow$ Upgrade to Belle II
- Total integrated luminosity: over 1 ab^{-1}
  - 711 fb^{-1} $\Upsilon(4S)$ (772×10^6 $B\overline{B}$-pairs)
  - 121 fb^{-1} $\Upsilon(5S)$
  - $\Upsilon(1S)$, $\Upsilon(2S)$, $\Upsilon(3S)$ scan

$A_{CP}(D^0 \to K^+K^-, \pi^+\pi^-)$ with 977 fb^{-1}

Time-integrated CP-asymmetry for final CP-eigenstate f:

$$a^f_{CP} = \frac{\Gamma(D^0 \to f) - \Gamma(\overline{D}^0 \to f)}{\Gamma(D^0 \to f) + \Gamma(\overline{D}^0 \to f)}$$

Recent ΔA_{CP} measurements

$$\Delta A_{CP} = A^{KK}_{CP} - A^{\pi\pi}_{CP}$$

$(-0.82 \pm 0.21 \pm 0.11)\%$ (LHCb 0.62 fb^{-1}, PRL 108, 111602 (2012)) 3.5σ

$(-0.62 \pm 0.21 \pm 0.10)\%$ (CDF 9.7 fb^{-1}, arXiv:1207.2158v1) 2.7σ

SM or NP?

Theoretical predictions for SM contributions to this value can reach up to a few per mille. On the other hand, New Physics can also contribute to ΔA_{CP}.

$\Rightarrow$ **Important to measure $A(KK)$ and $A(\pi\pi)$ with high precision!**

$$A_{CP}^{KK} = \frac{\Gamma(D^0 \to KK) - \Gamma(\overline{D}^0 \to KK)}{\Gamma(D^0 \to KK) + \Gamma(\overline{D}^0 \to KK)}$$, similarly for $A_{CP}^{\pi\pi}$

$$N^{rec} = N_{prodD^*} \cdot \mathcal{B}(D^* \to D^0 \pi_S) \cdot \mathcal{B}(D^0 \to KK) \cdot \varepsilon_{KK} \cdot \varepsilon_{\pi_S}$$

For small asymmetries: $A^{rec} = A_{CP}^{KK} + A_{FB}^{D^*} + A_{CP}^{D^0 \pi_S} + A_{\varepsilon}^{KK} + A_{\varepsilon}^{\pi_S}$

- $A_{CP}^{D^0 \pi_S} = 0$ (strong decay)
- $A_{\varepsilon}^{KK} = 0$ (CP symmetric final state)
- $A_{\varepsilon}^{\pi_S}$: detector-induced asymmetry accounted for using control data samples ($D^0 \to K\pi$). **Important in other $A(D^0 \to f)$ measurements!**
- $A_{FB}^{D^*}$: due to interference of virtual γ and Z_0 in $e^+e^- \to c\bar{c}$ and is a function of $cos(\theta^*)$, $A_{FB}^{D^*}(cos(\theta^*)) = -A_{FB}^{D^*}(-cos(\theta^*))$ ($\theta^* = D^*$ polar angle in CMS).

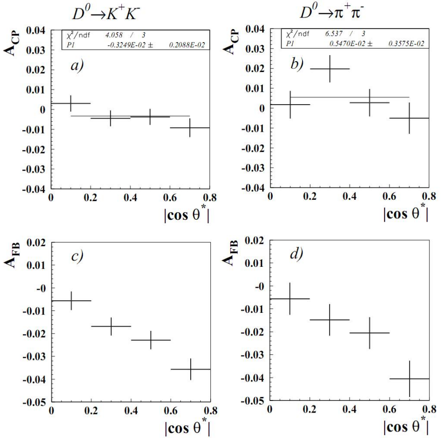
$$\Rightarrow A_{corr}^{rec} = A^{rec} - A_{\varepsilon}^{\pi_S},$$

$$A_{corr}^{rec}(cos(\theta^*)) = A_{CP}^{KK} + A_{FB}^{D^*}(cos(\theta^*))$$

$$A_{CP} = \frac{A_{corr}^{rec}(cos(\theta^*)) + A_{corr}^{rec}(-cos(\theta^*))}{2}$$

$$A_{FB} = \frac{A_{corr}^{rec}(cos(\theta^*)) - A_{corr}^{rec}(-cos(\theta^*))}{2}$$

- $D^{*+} \to D^0\pi_S^+$, $D^{*-} \to \overline{D}^0\pi_S^-$
- $p(D^*) > 2.5(3.1)$ GeV/c for $\Upsilon(4S)/(5S)$ data
- $1.81 < M(D^0_{cand}) < 1.91$ GeV/c^2
- $Q = M(\pi_S D^0_{cand}) - M(D^0_{cand}) - m(\pi_S) < 20$ MeV/c^2
- $D^0 \to$ charged tracks, K/π separation: $\mathcal{L}(K) \Leftarrow$ CDC, ACC, TOF
- D^0 vertex fit
- D^* IP constrained fit



976 fb^{-1} Belle data

	KK	$\pi\pi$
N_{ev}	282×10^3	123×10^3

Belle (976 fb^{-1})

$$A_{CP}^{KK} = (-0.32 \pm 0.21 \pm 0.09)\%$$
$$A_{CP}^{\pi\pi} = (+0.55 \pm 0.36 \pm 0.09)\%$$

Experiment	$\Delta A_{CP}(\%)$	σ from zero	Reference
Belle, 540 fb^{-1}	$-0.86 \pm 0.60 \pm 0.07$	1.4	PLB 670, 190 (2008)
LHCb, 0.62 fb^{-1}	$-0.82 \pm 0.21 \pm 0.11$	**3.5**	PRL 108, 111602 (2012)
CDF, 9.7 fb^{-1}	$-0.62 \pm 0.21 \pm 0.10$	2.7	arXiv:1207.2158v1
Belle, 976 fb^{-1}	$-0.87 \pm 0.41 \pm 0.06$	2.1	

The results are in agreement with our previous measurement and with recent measurements from LHCb and CDF.

Source of syst.	$A_{CP}^{KK}(\%)$	$A_{CP}^{\pi\pi}(\%)$	$\Delta A_{CP}(\%)$
Signal counting	0.055	0.023	0.037
Slow π eff. corr.	0.065	0.067	0.014
A_{CP} extraction	0.006	0.050	0.051
Quadrature sum	0.085	0.087	0.064

$$A_{CP}(D \to K_S^0\pi) = \frac{\Gamma(D^+ \to K_S^0\pi^+) - \Gamma(D^- \to K_S^0\pi^-)}{\Gamma(D^+ \to K_S^0\pi^+) + \Gamma(D^- \to K_S^0\pi^-)} = A_{CP}^{D^+} + A_{CP}^{\overline{K}_0}$$

- $A_{CP}^{D^+}$: CPV from D^+ decay
- $A_{CP}^{\overline{K}_0}$: CPV in K^0 system, $(-0.332 \pm 0.006)\%$ (J. Phys. G **37** 075021 (2010)).

  If measured $A_{CP}(D \to K_S^0\pi)$ is significantly inconsistent with $A_{CP}^{\overline{K}_0}$, this could be an indication of NP.

$$A_{rec}(D^+ \to K_S^0\pi^+) = A_{CP}(D \to K_S^0\pi) + A_{FB}^{D^+} + A_{\varepsilon}^{\pi^+} + A_D$$

- $A_{FB}^{D^+}$: D^+ production asymmetry, odd function of $cos(\theta_{D^+}^{CMS})$
- $A_{\varepsilon}^{\pi^+}$: $\pi^{\pm}$ detection asymmetry, depends on $p_{T\pi^+}^{lab}, cos(\theta_{\pi^+}^{lab})$,

  corrected for using control data samples ($D^+ \to K^-\pi^+\pi^+$, $D^0 \to K^-\pi^+\pi^0$)
- A_D: asymmetry due to difference in interaction of K^0 and $\bar{K}^0$ with detector material, depends on $p_{K_S^0}^{lab}$. Calculated according to PRD **84**, 111501 (2011).

$$\Rightarrow A_{rec}^{corr} = A_{CP}^{D^+ \to K_S^0\pi^+} + A_{FB}^{D^+}$$

$$A_{CP}^{D^+ \to K_S^0\pi^+} = \frac{A_{rec}^{corr}(cos\theta_D) + A_{rec}^{corr}(-cos\theta_D)}{2}$$

$$A_{FB}^{D^+} = \frac{A_{rec}^{corr}(cos\theta_D) - A_{rec}^{corr}(-cos\theta_D)}{2}$$

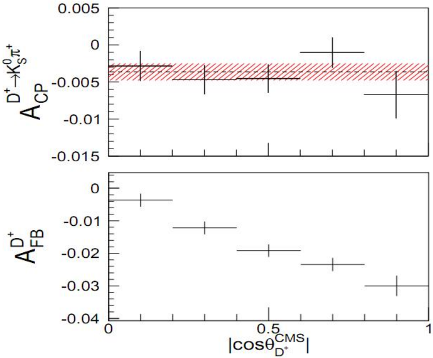
$N_{sign}(D^+ + D^-) = (1738 \pm 2) \times 10^3$

$A_{CP}(D^+ \to K_S^0\pi^+) = (-0.363 \pm 0.094 \pm 0.067)\%$

consistent with $A_{CP}^{K_S^0}$, **PRL 109, 021601 (2012)**

$A_{CP}^{D^+} = (-0.018 \pm 0.094 \pm 0.068)\%$ consistent with zero.

Most precise measurement of $A_{CP}(D^+ \to K_S^0\pi^+)$ to date.



Experiment	$A_{CP}(D^+ \to K_S^0\pi^+)$, %	Reference
FOCUS	$-1.6 \pm 1.5 \pm 0.9$	PRL 88, 041602 (2002)
CLEO	$-1.3 \pm 0.7 \pm 0.3$	PR D 81, 052013 (2010)
BaBar	$-0.44 \pm 0.13 \pm 0.10$	PR D 83, 071103 (2011)
New world ave.	-0.41 ± 0.09	

Mixing formalism:

Hamiltonian eigenstates of D^0-$\overline{D}^0$ system:

$$|D_{1,2}\rangle \ = \ p|D^0\rangle \ \pm \ q|\overline{D}^0\rangle, \ p^2 + q^2 = 1$$

(can be CP-eigenstate if $\frac{q}{p} = 1$, i.e. no CPV)

Time evolution:

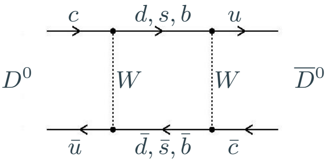
$$|D_{1,2}(t)\rangle \ = \ e_{1,2}(t)|D_{1,2}(0)\rangle,$$

$$e_{1,2}(t) \ = \ e^{-i(m_{1,2} - \frac{i}{2}\Gamma_{1,2})t}$$

$$\Rightarrow \frac{dN(D^0 \to f)}{dt} \ = \ |A(D^0(t) \to f)|^2 \ =$$

$$= \ e^{-\Gamma t}|A_f \ - \ \frac{q}{p}\frac{y+ix}{2} \ \Gamma t \ \bar{A}_f|^2$$

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



SM predictions for x, y:

quark box diagrams $\sim O(10^{-7} - 10^{-6})$, long distance effects $\sim O(10^{-3} - 10^{-2})$.

New Physics can provide additional box diagrams.

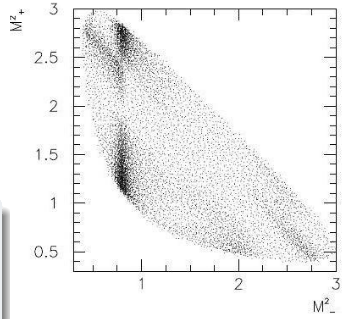
3-body charge self conjugated modes: x, y can be extracted using t-dependent Dalitz analysis. $D^0 \to K_S^0\pi^+\pi^-$: $A_f = A(m_-^2, m_+^2)$, $m_-^2 = m^2(K_S^0\pi^-)$, $m_+^2 = m^2(K_S^0\pi^+)$

Assuming no CPV ($\bar{A}(m_-^2, m_+^2) = A(m_+^2, m_-^2)$, $q/p = 1$), decay rate(time):

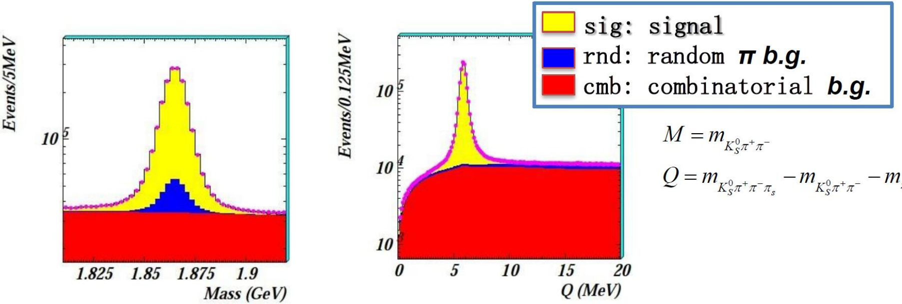
$$|M(m_+^2, m_-^2, t)|^2 =$$
$$(|A_1|^2 e^{-y\Gamma t} + |A_2|^2 e^{y\Gamma t} +$$
$$2Re(A_1 A_2^*) cos(x\Gamma t) + 2Im(A_1 A_2^*) sin(x\Gamma t))e^{-\Gamma t}$$

$$A_{1,2} = \frac{1}{\sqrt{2}}(A_f + \bar{A}_f)$$

Similarly for $|\overline{M}(m_+^2, m_-^2, t)|^2$...



t-integrated Dalitz plot (DP) $D^0 \to K_S^0\pi^+\pi^-$ distribution.



$M = m_{K_S^0\pi^+\pi^-}$

$Q = m_{K_S^0\pi^+\pi^-\pi_s} - m_{K_S^0\pi^+\pi^-} - m_\pi$

- $D^{*+} \to D^0\pi^+$, $D^{*-} \to \overline{D}^0\pi^-$, $D^0(\overline{D}^0) \to K_S^0\pi^+\pi^-$
- K_S^0: $|M_{\pi^+\pi^-} - M_{K_S}| < 10$ MeV$/c^2$
- D^0 proper decay time measurement: $t = \frac{l_{dec}}{c\beta\gamma}$, $\beta\gamma = \frac{p_{D^0}}{M_{D^0}}$
- $\sigma_t < 1000$ fs

$\Upsilon(4S)$, $\Upsilon(5S)$ **full data set** (920 fb^{-1}):

Signal	1.23×10^6
Rand. π_s bckgr.	0.01×10^6
Comb. bckgr.	0.05×10^6

(Signal purity = 95.6%)

Unbinned likelihood function:

$$2ln\mathcal{L} = 2\sum_{i=1}^{n} ln(f_{sig}p_{sig}(m^2_{-i}, m^2_{+i}, t_i) + f_{rnd}p_{rnd}(m^2_{-i}, m^2_{+i}, t_i) + f_{cmb}p_{cmb}(m^2_{-i}, m^2_{+i}, t_i))$$

$$p_{sig}(m^2_{-i}, m^2_{+i}, t_i) = \frac{\int_0^\infty dt' R_{sig}(t_i - t')|M(m^2_{-i}, m^2_{+i}, t')|^2 \varepsilon(m^2_{-i}, m^2_{+i})}{\int_0^\infty dt \int_D dm^2_- dm^2_+ |M(m^2_-, m^2_+, t)|^2 \varepsilon(m^2_-, m^2_+)}, \; f_{cm} = (1 - f_{si} - f_{rn})$$

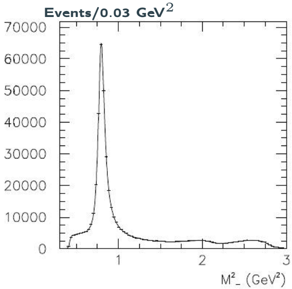
- f_x determined by 2D $M - Q$ fit,
- DP efficiency functions $\varepsilon(m^2_-, m^2_+)$ estimated from MC sim., parameterized by 3rd order polynomial,
- background shape estimated from $M - Q$ sidebands,
- signal DP distribution convolved with resolution function R_{sig}

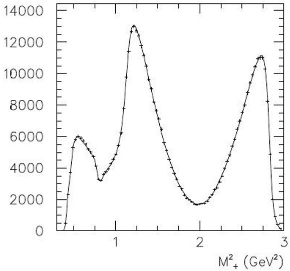
Dalitz model (best fit description)

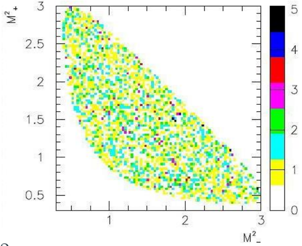
$$A(m^2_-, m^2_+) \;=\; B_{r \neq S} + K_{\pi\pi,S} + L_{K\pi,S}$$

- P-, D-wave:
  Breit-Wigner, 12 resonances
- $\pi^+\pi^-$ S-wave: **K-matrix model**
- $K\pi$ S-wave: **LASS model**

Resonances: $K^*(892)$, $K^*_0(1430)^-$, $K^*_2(1430)^-$, $K^*(1410)^-$, $K^*(1680)^-$, $K^*(892)^+$, $K^*_0(1430)^+$, $K^*_2(1430)^+$, $K^*(1410)^+$, $K^*(1680)^+$, $\rho(770)$ (fixed), $\omega(782)$, $f_2(1270)$, $\rho(1450)$, $K_s\pi$ and $\pi\pi$ S-waves.





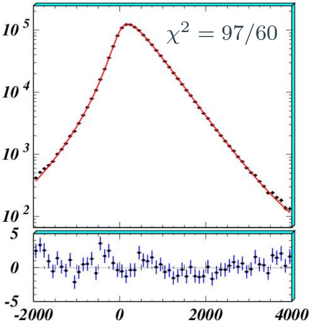


$\chi^2 = 1.246$ for $N_{df} = 3653 - 49$

	fit results			95% C.L. int. (stat. only)
x(%)	0.56 ± 0.19	$^{+0.03}_{-0.09}$	$^{+0.06}_{-0.09}$	(0.09,1.03)
y(%)	0.30 ± 0.15	$^{+0.04}_{-0.05}$	$^{+0.03}_{-0.06}$	(-0.08,0.68)

Uncertainties: stat., experimental and model syst.

$$\tau = 410.3 \pm 0.45 \text{ fs, consistent with}$$
$$\tau_{PDG} = 410.1 \pm 1.5 \text{ fs}$$



	$x(\%)$	$y(\%)$
Belle 540 fb^{-1} PRL 99, 131803 (2007)	$0.80 \pm 0.29 \,^{+0.09}_{-0.07} \,^{+0.10}_{-0.14}$	$0.33 \pm 0.24 \,^{+0.08}_{-0.12} \,^{+0.06}_{-0.08}$
BaBar 469 fb^{-1} PRL 105, 081803 (2010)	$0.16 \pm 0.23 \pm 0.12 \pm 0.08$	$0.57 \pm 0.20 \pm 0.13 \pm 0.07$
Belle 920 fb^{-1}	$0.56 \pm 0.19 \,^{+0.03}_{-0.09} \,^{+0.06}_{-0.09}$	$0.30 \pm 0.15 \,^{+0.04}_{-0.05} \,^{+0.03}_{-0.06}$

Most precise determination of x, y to date!

Mixing parameter y_{CP}

$y_{CP} = \frac{\tau_{K\pi}}{\tau_{CP}} - 1$, $CP : KK, \pi\pi$

- CP conservation: $y_{CP} = y$
- CP violation: $y_{CP} = ycos\phi - \frac{1}{2}A_M xsin\phi$, $|\frac{q}{p}|^2 = 1 + A_M$, $\phi = arg(\frac{q}{p})$

CP asymmetry in lifetimes

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

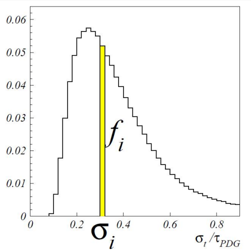
- CP conservation: $A_\Gamma = 0$
- CP violation: $A_\Gamma = \frac{1}{2}A_M ycos\phi - xsin\phi$

Belle 2007 measurement (540 fb^{-1}):

- $y_{CP} = (1.31 \pm 0.32 \pm 0.25)\%$ $\Rightarrow$ **first evidence for mixing (3.2 σ)**
- $A_\Gamma = (0.01 \pm 0.30 \pm 0.15)\%$

$$f(t) = \frac{N}{\tau} \int e^{-t'/\tau} R(t-t')dt' + B(t)$$

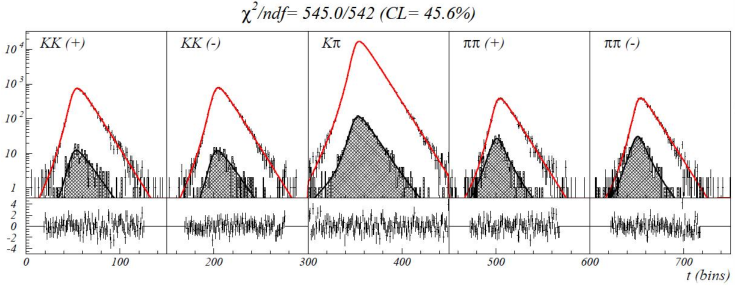
- N: normalization (free fit parameter)
- τ: lifetime (free fit parameter)
- $R(t-t')$: signal resolution function
- $B(t)$: signal-window background estimated from $M-Q$ sidebands
- Large disagreement between data and MC: up to 5% of lifetime ⇒ Measurement must be performed in bins of $cos(\theta^*)$ to reduce systematics + add cut $|cos(\theta^*) < 0.9|$ (1% signal lost). θ^* – polar angle of D^0 in CMS.



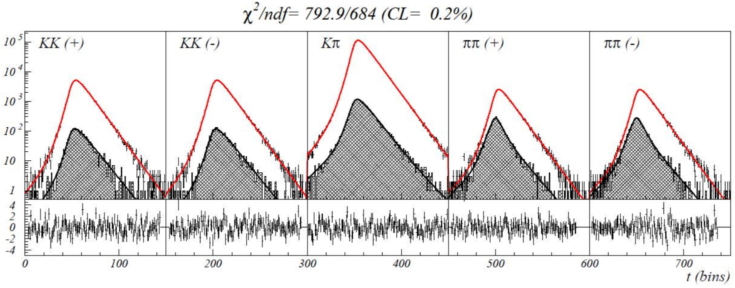
Resolution function constructed for each $cos(\theta^*)$ bin by fitting $(t - t_{gen})/\sigma_t$.

Lifetime fit performed simultaneously for all decay modes:

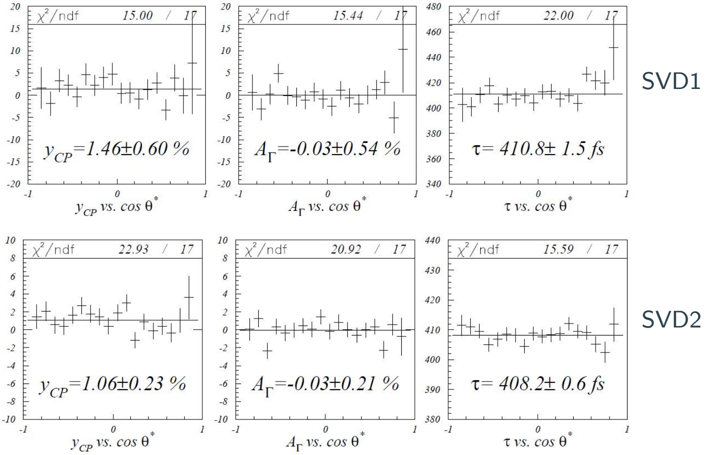
$D^0 \to KK$, $\overline{D}^0 \to KK$, $D^0 \to K^-\pi^+$, $D^0 \to \pi\pi$, $\overline{D}^0 \to \pi\pi$:



SVD1



SVD2



$y_{CP}(\%)$	$A_\Gamma(\%)$
1.11 ± 0.22	-0.03 ± 0.20

$\tau_{K\pi} = 408.56 \pm 0.54$ fs
(consistent with $\tau_{PDG} = 410.1 \pm 1.5$ fs)

source	Δy_{CP} (%)	ΔA_{Γ} (%)
acceptance	0.050	0.044
SVD misalignments	0.060	0.041
mass window position	0.007	0.009
background	0.059	0.050
resolution function	0.030	0.002
binning	0.021	0.010
sum in quadrature	0.11	0.08

$$y_{CP} = (1.11 \pm 0.22 \pm 0.11)\%$$
$$A_{\Gamma} = (-0.03 \pm 0.20 \pm 0.08)\%$$

- y_{CP}: 4.5σ away from zero, stat. + syst. error combined (4.5σ, stat. error only)
- A_{Γ}: consistent with zero

Big data sample and good detector performance allow us to measure A_{CP} and mixing in different decay modes using different techniques.

- $A_{CP}^{KK} = (-0.32 \pm 0.21 \pm 0.09)\%$
  $A_{CP}^{\pi\pi} = (+0.55 \pm 0.36 \pm 0.09)\%$
  $\Delta A_{CP} = (-0.87 \pm 0.41 \pm 0.06)\%$ (agreement with LHCb and CDF)
- $A_{CP}(D^+ \to K_S^0\pi^+) = (-0.363 \pm 0.094 \pm 0.067)\%$ is consistent with $A_{CP}^{K_S^0}$
  $A_{CP}^{D^+} = (-0.018 \pm 0.094 \pm 0.068)\%$ consistent with zero.
  Most precise measurement to date.
- Mixing in $D^0 \to K_S^0\pi^+\pi^-$:
  $x = (0.56 \pm 0.19 \; {}^{+0.03}_{-0.09} \; {}^{+0.06}_{-0.09})\% \quad y = (0.30 \pm 0.15 \; {}^{+0.04}_{-0.05} \; {}^{+0.03}_{-0.06})\%$
  Most precise measurement to date.
- Mixing in $D^0 \to KK, \pi\pi$:
  $y_{CP} = (1.11 \pm 0.22 \pm 0.11)\% \to$ confirmed evidence for mixing in D decays
  $A_\Gamma = (-0.03 \pm 0.20 \pm 0.08) \to$ consistent with zero

We hope for more experimental opportunities with the upgraded Belle II detector.

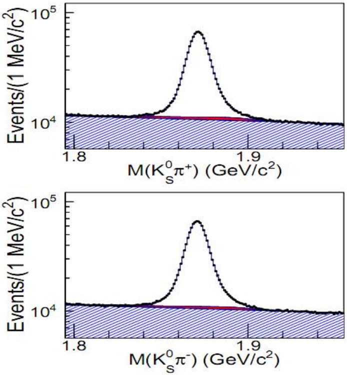
Thank you.

BACKUP

Event selection, $D^+ \to K_S^0\pi^+$

- $D^+ \to K_S^0\pi^+$, $K_S^0 \to \pi^+\pi^-$
- $p(D^+) > 2.5(3.0)$ GeV/c for $\Upsilon(4S/5S)$ data
- $1.795 < M(K_S^0\pi^+) < 1.955$ GeV/c^2
- $1.855 < M(\pi^+\pi^-) < 1.885$ GeV/c^2
- K_S^0 vertex fit
- D^+ IP constrained fit

$$N_{sign}(D^+ + D^-) \; = \; (1738 \pm 2) \times 10^3$$



$D^0 \to K_S^0\pi^+\pi^-$ decay model parameters

Resonance	Amplitude	Phase (deg)
$K^*(892)^-$	1.593 ± 0.005	131.6 ± 0.2
$K_0^*(1430)^-$	2.071 ± 0.025	-196.1 ± 2.2
$K_2^*(1430)^-$	1.136 ± 0.011	-41.2 ± 0.6
$K^*(1410)^-$	0.503 ± 0.022	83.5 ± 2.3
$K^*(1680)^-$	1.676 ± 0.157	-85.5 ± 3.5
$K^*(892)^+$	0.140 ± 0.002	-41.5 ± 0.7
$K_0^*(1430)^+$	0.174 ± 0.011	-104.8 ± 3.8
$K_2^*(1430)^+$	0.082 ± 0.009	-34.8 ± 6.8
$K^*(1410)^+$	0.252 ± 0.017	-141.5 ± 4.0
$K^*(1680)^+$	1.409 ± 0.117	89.9 ± 5.0
$\rho(770)$	1 (fixed)	0 (fixed)
$\omega(782)$	0.0369 ± 0.0005	115.2 ± 0.7
$f_2(1270)$	1.284 ± 0.019	-31.4 ± 0.9
$\rho(1450)$	0.556 ± 0.052	84.8 ± 5.0
$\pi\pi$ S-wave		
β_1	4.26 ± 0.03	163.0 ± 0.5
β_2	10.82 ± 0.04	15.8 ± 0.4
β_3	38.2 ± 0.5	1.8 ± 1.0
β_4	14.4 ± 0.2	-10.1 ± 0.8
f_{11}^{prod}	12.60 ± 0.07	-161.7 ± 0.5
f_{12}^{prod}	14.0 ± 0.2	-175.9 ± 0.7
f_{13}^{prod}	9.6 ± 0.5	-120.9 ± 2.5

$K\pi$ S-wave parameters	
$\mathrm{M}(MeV/c^2)$	1462.5 ± 2.4
$\Gamma(MeV/c^2)$	266.1 ± 4.6
F	0.4270 ± 0.0309
$\phi_F(rad)$	0.261 ± 0.022
R	1(fixed)
$\phi_R(rad)$	2.528 ± 0.056
$a(GeV/c^{-1})$	0.177 ± 0.006
$r(GeV/c^{-1})$	-19.9 ± 0.8
$K^*(892)$ parameters	
$M_{K^*(892)} MeV/c^2$	893.69 ± 0.05
$\Gamma_{K^*(892)} MeV/c^2$	47.63 ± 0.10