D^0-mixing and CPV in charm

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Flavor Physics and CP Violation
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Outline

D^0-mixing: **Calm before the storm**

- no new result since last year's FPCP
- but eagerly expecting final results (first observations?) from B-factories, updates from CDF and first results from LHCb

Search for CPV in charm: **all thunder but no lightning**

- Many new results since last year
  - A_{CP} in $D^0 \to \pi^+\pi^-$, K^+K^- from CDF
  - A_{CP} difference between $D^0 \to \pi^+\pi^-$ and $D^0 \to K^+K^-$ from LHCb
  - A_{CP} difference between $D^+ \to \phi\pi^+$ and $D_s^+ \to \phi\pi^+$ from Belle
- **See also M. Martinelli's talk on Thursday**

Phenomenology

- flavor eigenstate $\neq \mathcal{H}_{\rm eff}$ eigenstate (with defined mass $m_{1,2}$ and width $\Gamma_{1,2}$)

$$i\frac{\partial}{\partial t}\begin{pmatrix}|D^0\rangle\\|\overline{D}^0\rangle\end{pmatrix} = \mathcal{H}_{\rm eff}\begin{pmatrix}|D^0\rangle\\|\overline{D}^0\rangle\end{pmatrix} \qquad |D_{1,2}\rangle = p|D^0\rangle \pm q|\overline{D}^0\rangle \qquad (|p|^2+|q|^2=1)$$

- time evolution of flavor eigenstate

$$\boxed{|D^0(t)\rangle = \left[|D^0\rangle cosh\left(\frac{ix+y}{2}t\right) + \frac{q}{p}|\bar{D}^0\rangle sinh\left(\frac{ix+y}{2}t\right)\right] \times e^{-\frac{1}{2}(1+\frac{im}{\Gamma})t}}$$

Mixing parameters: $\mathbf{x} = \frac{\mathbf{m_1 - m_2}}{\mathbf{\Gamma}}$, $\quad \mathbf{y} = \frac{\mathbf{\Gamma_1 - \Gamma_2}}{\mathbf{2\Gamma}}$, $\quad \Gamma = \frac{1}{2}(\Gamma_1 + \Gamma_2)$

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- **Classification of CP-violating effects:**

$$\mathbf{A_{CP} = \frac{\Gamma(D\to f) - \Gamma(\overline{D}\to \bar{f})}{\Gamma(D\to f) + \Gamma(\overline{D}\to \bar{f})} = a_f^d + a_f^m + a_f^i}$$

1. $\mathbf{a_f^d}$: *CP* violation in decay

   $\hookrightarrow \left|\frac{\mathcal{A}_f}{\mathcal{A}_{\bar{f}}}\right| \equiv 1 + \frac{A_D}{2} \; (A_D \neq 0)$

2. $\mathbf{a_f^m}$: *CP* violation in mixing

   $\hookrightarrow \left|\frac{q}{p}\right| \equiv 1 + \frac{A_M}{2} \quad (A_M \neq 0)$

3. $\mathbf{a_f^i}$: *CP* violation in interference $(f = \bar{f}) \rightarrow \phi = arg\left(\frac{q}{p}\frac{\bar{A}_f}{A_f}\right) \; (\phi \neq 0)$

In SM both mixing ($x \sim y \sim 1\%$) and CPV ($\mathcal{O}(1)$) in charm system small.

Available Charm Samples

Diverse exp. conditions!

B-factories:

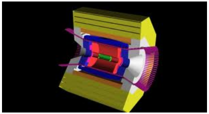
- continuum production @ $\Upsilon(4S)$: $\sigma(c\bar{c}) \approx 1.3$ nb
- Belle: $\sim 1.3 \cdot 10^9$ $c\bar{c}$ pairs
- Babar: $\sim 0.7 \cdot 10^9$ $c\bar{c}$ pairs

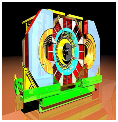
Tevatron:

- $p\bar{p}$ @ ~ 2 TeV
- CDF: $\sim 70 \cdot 10^9$ D^0's

Charm factories:

- $\psi(3770) \to D^0\overline{D^0}$, D^+D^-
- CLEO: $\sim 2.8 \cdot 10^6$ $D^0\overline{D}^0$ pairs
- BESIII: $\sim 12 \cdot 10^6$ $D^0\overline{D}^0$ pairs





LHC:

- pp @ 7 TeV
- LHCb: first results

D^0-mixing and t-dependent CPV measurements

Mixing measurements

Decay time distribution sensitive to mixing parameters x and y and depends on the final state:

$$\frac{dN(D^0 \to f)}{dt} \propto \left| \langle f | D^0 \rangle + \frac{q}{p} \left(\frac{ix+y}{2} \langle f | \overline{D}^0 \rangle \right) \right|^2$$

Final state	Belle	BaBar	CDF	Cleo	E791	Focus
$K^+\pi^-$	√	★	★	√	√	√
KK, $\pi\pi$	★	★		√	√	√
$K_S^0\pi\pi$	√	√		√		
$K_S^0 KK$	√	√				
$K^+\pi^-\pi^0$		★				
$K^+\pi^-\pi^-\pi^+$		√				
$K^+\ell^-\nu_\ell$	√	√		√	√	
quantum corr. in $\psi(3770) \to D^0\overline{D}^0$				√		

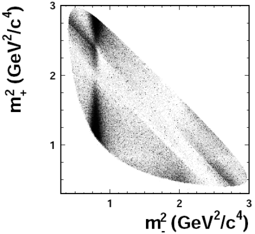
√ – measurement performed; ★ – evidence for mixing

Full list of all $D^0 - \overline{D}^0$ mixing measurements is available at: http://www.slac.stanford.edu/xorg/hfag/charm/index.html

Time dependent Dalitz analyses: $D^0 \to P^0 h^+ h^-$

- Many quasi 2-body intermediate states, e.g. in $D^0 \to K_S^0 \pi^+ \pi^-$ decays:
  $\hookrightarrow$ CF: $D^0 \to K^{*-}\pi^+$
  $\hookrightarrow$ DCS: $D^0 \to K^{*+}\pi^-$
  $\hookrightarrow$ CP: $D^0 \to \rho^0 K_S^0$

Dalitz plot for $D^0 \to K_S^0 \pi^+ \pi^-$



$$D^0 : \ \mathcal{A}(m_-^2, m_+^2) = \sum_r a_r e^{i\phi_r} \mathcal{A}_r(m_-^2, m_+^2) + a_{nr} e^{i\phi_{nr}}$$

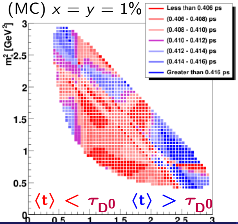
$$\overline{D}^0 : \ \bar{\mathcal{A}}(m_-^2, m_+^2) = \sum_r \bar{a}_r e^{i\bar{\phi}_r} \bar{\mathcal{A}}_r(m_-^2, m_+^2) + a_{nr} e^{i\phi_{nr}}$$

- Time dependent decay rate ($\mathcal{A}_{1,2} = \frac{1}{2}(\mathcal{A} \pm \bar{\mathcal{A}})$)

$$\Gamma(m_-^2, m_+^2, t) = e^{-\Gamma t}(|\mathcal{A}_1|^2 e^{-y\Gamma t} + |\mathcal{A}_2|^2 e^{y\Gamma t} + 2\mathcal{R}[\mathcal{A}_1\mathcal{A}_2^*]\cos(x\Gamma t) + 2\mathcal{I}[\mathcal{A}_1\mathcal{A}_2^*]\sin(x\Gamma t))$$

Simultaneous determination of x and y!

$\langle t \rangle$ across Dalitz plot



(Relative) Intrinsic sensitivities to mixing

Mode	$\mathcal{B} \cdot \varepsilon$	σ(x)	σ(y)	
$D^0 \to K_S^0 \pi^+ \pi^-$	100	10	9	★★★
$D^0 \to K_S^0 K^+ K^-$	15	33	23	★★
$D^0 \to \pi^0 \pi^+ \pi^-$	20	45	22	★

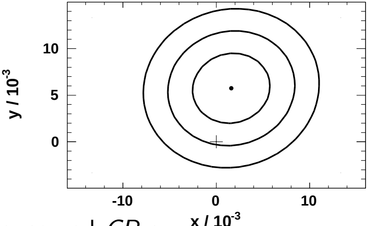
Taking into account $\mathcal{B}$'s and efficiencies (@ B-factories) but neglecting different purities

Mixing and CPV $D^0 \to K^0_S\pi^+\pi^-$, $D^0 \to K^0_S K^+ K^-$ decays

BaBar@469 fb^{-1} [PRL105,081803]

$D^0 \to K^0_S\pi^+\pi^-$ and $D^0 \to K^0_S K^+ K^-$

68%, 95% and 99.9% confidence level contours



Conserved CP symmetry ($|q/p| = 1$ & $\phi = 0$)

$$\mathbf{x = (0.16 \pm 0.23 \pm 0.14)\%}$$
$$\mathbf{y = (0.57 \pm 0.20 \pm 0.15)\%}$$

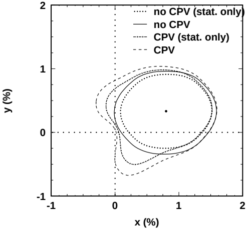
Most accurate determinations of x and y!

Expected statistical sensitivity using full Belle data sample $\sigma(x) = 0.18$ and $\sigma(y) = 0.15$

Belle@540 fb^{-1} [PRL99,131803]

$D^0 \to K^0_S\pi^+\pi^-$

95% confidence level contours



Conserved CP symmetry ($|q/p| = 1$ & $\phi = 0$)

$$\mathbf{x = (0.80 \pm 0.29^{+0.13}_{-0.16})\%}$$
$$\mathbf{y = (0.33 \pm 0.24^{+0.10}_{-0.14})\%}$$

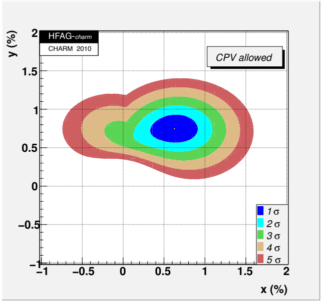
CPV allowed ($|q/p|$ & ϕ free parameters of the fit)

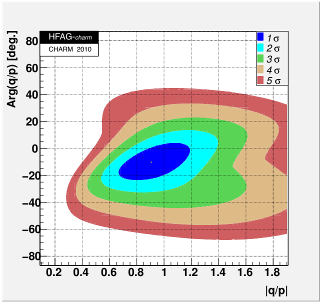
$$\mathbf{|q/p| = 0.86 \pm 0.30 \pm 0.09}$$
$$\mathbf{\phi = -0.24 \pm 0.30 \pm 0.09}$$

Consistent with no CPV!

World average of mixing parameters

Heavy Flavor Averaging Group (HFAG) perfromes an average of 8 underlying physics parameters from currently 30 observables. [www.slac.stanford.edu/xorg/hfag/]





$$\mathbf{x} = (0.63 \pm 0.20)\%$$
$$\mathbf{y} = (0.80 \pm 0.13)\%$$

$$|q/p| = 0.91^{+0.18}_{-0.16}$$
$$\phi(^\circ) = -10.0^{+9.4}_{-8.9}$$

No mixing point $(x, y) = (0, 0)$ is excluded at 10.2σ, while no *CP* violation point $(|q/p|, \phi) = (1, 0)$ is consistent within 1σ.

t-integrated CPV measurements

Reminder: looking for signals at $\sim 0.1\%$

Time-integrated searches of *CP* Violation

Key is to distinguish possible *CPV* asymmetry from detector effects and production asymmetry in reconstructed asymmetry

$$A^{\text{reco}} = \frac{N_D^{\text{reco}} - N_{\overline{D}}^{\text{reco}}}{N_D^{\text{reco}} + N_{\overline{D}}^{\text{reco}}}$$

$$N_D^{\text{reco}} = N_D^{\text{prod}} \cdot \mathcal{B}(D \to f) \cdot \varepsilon_f \Longrightarrow \text{if } A_i \ll 1 \Longrightarrow \boxed{\mathbf{A^{reco} = A_P^D + A_{CP}^f + A_\epsilon^f}}$$

$\mathbf{A_{CP}}$
CP asymmetry

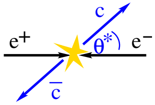
independent of any kinematic variable

LHCb:
$pp \neq CP$ symmetric
$\Downarrow$
Production asymmetry

CDF:
No production asymmetry ($p\overline{p}$)

$\mathbf{A_P}$
Production asymmetry

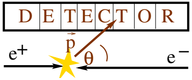
due to γ/Z interference in $e^+e^- \to c\overline{c}$



(anti-symmetric in $cos\theta_D^*$)

$\mathbf{A_\epsilon^f}$
Reconstruction asymmetry

$h^\pm$ reconstruction efficiency asymmetry



(p^{lab}, $cos\theta^{\text{lab}}$)

In order to control systematics $\mathbf{A_i}$'s are estimated on real data sample!

A_{CP} in $D^0 \to K^+K^-$ and $D^0 \to \pi^+\pi^-$ at CDF (5.94 fb^{-1})

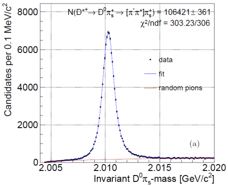
Use three different samples to correct for detector asymmetry and minimize systematics:

1. $D^{*+} \to D^0\pi_s^+ \to [h^+h^-]\pi_s^+ \implies A^{\text{reco}}(hh)^* = A_{CP}(hh) + A_\varepsilon(\pi_s)$
2. $D^{*+} \to D^0\pi_s^+ \to [K^-\pi^+]\pi_s^+ \implies A^{\text{reco}}(K\pi)^* = A_{CP}(K\pi) + A_\varepsilon(\pi_s) + A_\varepsilon(K\pi)$
3. $D^0 \to [K^-\pi^+] \implies A^{\text{reco}}(K\pi) = A_{CP}(K\pi) + A_\varepsilon(K\pi)$

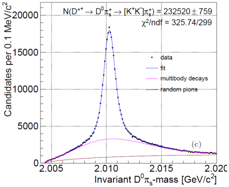
$$A_{CP}(hh)^* = A^{\text{reco}}(hh)^* - A^{\text{reco}}(K\pi)^* + A^{\text{reco}}(K\pi)$$

Assuming $A_P = 0$, $\varepsilon(D^*) = \varepsilon(D^0)\cdot\varepsilon(\pi_s)$, and kinematic distributions equal across samples

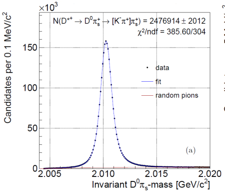
$[\pi^+\pi^-]^*$



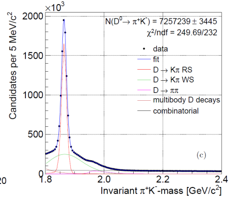
$[K^+K^-]^*$



$[K^-\pi^+]^*$



$[K^-\pi^+]$



A_{CP} in $D^0 \to K^+K^-$ and $D^0 \to \pi^+\pi^-$ at CDF ($5.94\ \text{fb}^{-1}$)

Preliminary results [CDF-NOTE-10296]:

1. $A^{\text{reco}}(\pi^+\pi^-)^* = (-1.86 \pm 0.23)\%$
2. $A^{\text{reco}}(K^+K^-)^* = (-2.32 \pm 0.21)\%$
3. $A^{\text{reco}}(K^-\pi^+)^* = (-2.91 \pm 0.05)\%$
4. $A^{\text{reco}}(K^-\pi^+) = (-0.83 \pm 0.03)\%$

Most precise measurements up to date

$$A_{CP}(\pi\pi)^* = (+0.22 \pm 0.24 \pm 0.11)\%$$

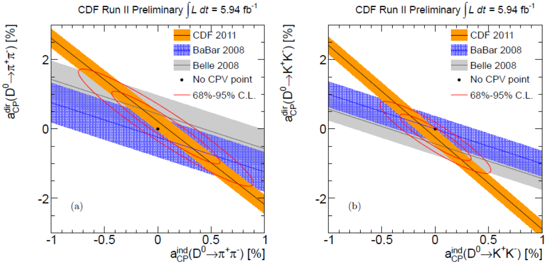
$$A_{CP}(KK)^* = (-0.24 \pm 0.22 \pm 0.10)\%$$

Systematics: largest contributions from charge dependent differences in mass shape and possible contamination of CPV from $B \to DX$ decays

NB: $A_{CP} = a^{\text{dir}}_{CP} + \frac{\langle t \rangle}{\tau} a^{\text{ind}}_{CP}$

Complementary to B-factories

$\langle t \rangle / \tau|_{\text{CDF}} > 1$ vs. $\langle t \rangle / \tau|_{\text{B-fact.}} = 1$



Averages:

- **Assuming $a^{\text{ind}}_{CP} = 0$**

  $a^{\text{dir}}_{CP}(\pi\pi) = (\ \ 0.19 \pm 0.22)\%$

  $a^{\text{dir}}_{CP}(KK) = (-0.24 \pm 0.17)\%$

- **Assuming $a^{\text{dir}}_{CP}(hh) = 0$**

  $a^{\text{ind}}_{CP} = (-0.01 \pm 0.08)\%$

Possible to include it in the global HFAG fit.

$A_{CP}(KK) - A_{CP}(\pi\pi)$ at LHCb (37 pb^{-1}; preliminary)

Search for direct CPV in SCS $D^0 \to K^+K^-$ and $D^0 \to \pi^+\pi^-$ produced in $D^{*+} \to D^0\pi_s^+$ decays

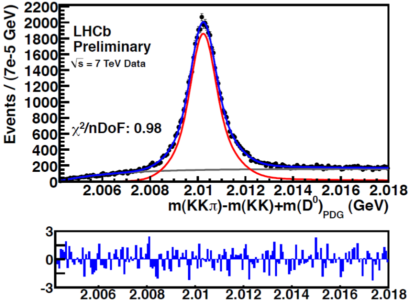
$$A^{\rm reco}(KK)^* = A_{CP}(KK)^* + A_\varepsilon(\pi_s) + A_P(D^*) \qquad A^{\rm reco}(\pi\pi)^* = A_{CP}(\pi\pi)^* + A_\varepsilon(\pi_s) + A_P(D^*)$$

$$\Downarrow$$

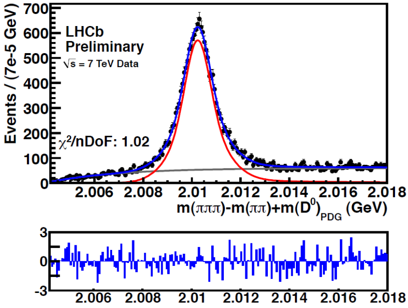
$$A_{CP}(KK)^* - A_{CP}(\pi\pi)^* = A^{\rm reco}(KK)^* - A^{\rm reco}(\pi\pi)^*$$

NB: $\mathbf{A_{CP} = a_{CP}^{dir} + \frac{\langle t \rangle}{\tau} a_{CP}^{ind}}$

$D^0 \to K^+K^-$



$D^0 \to \pi^+\pi^-$



Signal estracted in bins of p_T (3), η (4), split magnet polarity (2) and trigger conditions (2)

$A_{CP}(KK) - A_{CP}(\pi\pi)$ at LHCb (37 pb^{-1}; preliminary)

Search for direct CPV in SCS $D^0 \to K^+K^-$ and $D^0 \to \pi^+\pi^-$ produced in $D^{*+} \to D^0\pi_s^+$ decays

$$A^{\text{reco}}(KK)^* = A_{CP}(KK)^* + A_\varepsilon(\pi_s) + A_P(D^*) \qquad A^{\text{reco}}(\pi\pi)^* = A_{CP}(\pi\pi)^* + A_\varepsilon(\pi_s) + A_P(D^*)$$

$$\Downarrow$$

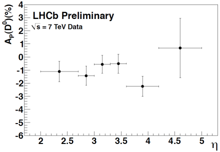
$$A_{CP}(KK)^* - A_{CP}(\pi\pi)^* = A^{\text{reco}}(KK)^* - A^{\text{reco}}(\pi\pi)^*$$

$$\mathbf{\Delta A_{CP} = (-0.28 \pm 0.70 \pm 0.25)\%}$$

Systematics:

- D^0 mass window: 0.20%
- Best cand. sel.: 0.13%
- Fit model: 0.06%
- Binning: 0.01%

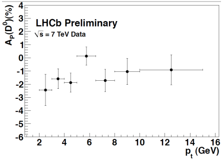
$A_P(D^0)$ over η



Using external measurements of $A_{CP}(hh)$ production asymmetry can be determined

$$\mathbf{A_P(D^0) = (-1.08 \pm 0.32 \pm 0.12)\%}$$

$A_P(D^0)$ over p_T



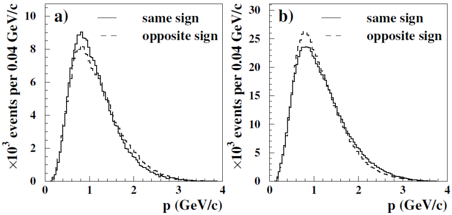
$A_{CP}(D^+ \to \phi\pi^+) - A_{CP}(D_s^+ \to \phi\pi^+)$ at Belle [955 fb^{-1}]

Measuring difference of A_{CP} in SCS $D^+ \to \phi\pi^+$ and CF $D_s^+ \to \phi\pi^+$ decays
in bins of $\cos\theta^*$, p_π and $cos(\theta_\pi)$:

$$D_{(s)}:\ A^{\rm rec} = A_{CP} + A_P(cos\theta^*) + A_\varepsilon^{KK} + A_\varepsilon^\pi(p_\pi, cos\theta_\pi)$$
$$\Downarrow$$
$$D - D_s:\ \Delta A^{\rm rec} = \Delta A_{CP} + \Delta A_P(cos\theta^*) + \Delta A_\varepsilon^{KK}$$

$A_\varepsilon^{KK} \neq 0!$

$D^\pm$ $D_S^\pm$



Due to interference of ϕ with
$K\pi$ S-wave ($f_0(980)$) in case of D (D_s)

Effect in opposite directions $\Rightarrow$ $\Delta A_\varepsilon^{KK} \neq 0!$

Determining A_ε^{KK}:

$$A_\varepsilon^{KK} = \int [P_{K^+}(x) - P_{K^-}(x)] A_\varepsilon^K(x) dx$$

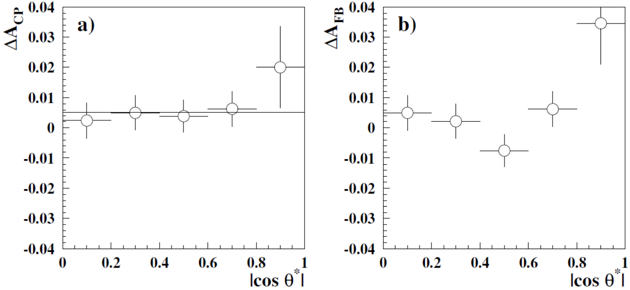
$P_K(x)$ - kaon phase space distr. in lab frame $x = (p, cos\theta)$

$A_\varepsilon^K(x)$ measured using $D_s \to \phi\pi$ and $D^0 \to K\pi$

$$\Delta A_\varepsilon^{KK} = (+0.111 \pm 0.025)\%$$

to be submitted soon to PRL

$\Delta A_{CP} = \frac{\Delta A^{reco}_{corr}(\cos\theta^*) + \Delta A^{reco}_{corr}(-\cos\theta^*)}{2}$ $\Delta A_P = \frac{\Delta A^{reco}_{corr}(\cos\theta^*) - \Delta A^{reco}_{corr}(-\cos\theta^*)}{2}$



Most precise measurements up to date

$$\Delta A_{CP} = (0.51 \pm 0.28 \pm 0.05)\%$$

ΔA_P consistent with 0 (C.L. 6%)

Results important for LHCb's measurement of flavor-specific asymmetry (a_{fs}) using the subtraction method (see R. Lambert's talk at Beauty'11):

- **need to take possible CPV in charm into account**
- **detector asymmetry, which does not cancel entirely when subtracting**

Conclusions

- Collective evidence for $D^0 - \overline{D}^0$ mixing are compelling
  - No single measurement exceeds 5σ
  - The no-mixing point is excluded at around 10σ
  - The WA of x and y seem consistent with SM expectations
  - Providing strong constraints for some New Physics models
- No evidence of CP violation (at the level of 0.2%)
  - Large CPV ($\mathcal{O}(1\%)$) already excluded in many modes from Belle, Babar and CDF
  - Possible signal of CPV at $\mathcal{O}(0.1\%)$ will be exciting but not evidence of New physics

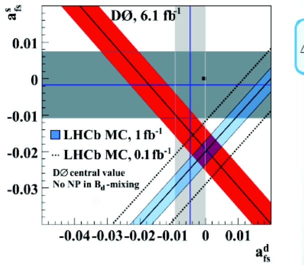
Backup slides

Flavor specific asymmetry at LHCb

taken from M. Calvi's talk on Monday

A_{sl}

Di-muon charge asymmetry measured by D0, giving hints of anomalous CPV in the mixing of neutral B mesons.



$$\Delta A_{fs} = \frac{a^s_{fs} - a^d_{fs}}{2} \rightarrow (2.1 \pm 0.3) \times 10^{-4} [S.M.]$$

- LHCb will measure $a^s_{sl} - a^d_{sl}$ from difference in asymmetry in $B_s \rightarrow D_s(KK\pi)\mu\nu$, $B^0 \rightarrow D^+(KK\pi)\mu\nu$.
- Orthogonal constraint to D0.

If there is NP in B_s mixing it will be seen by LHCb also in the ϕ_s measurement

M. Calvi - FPCP 2011 29

allowing for possible contribution of *CPV* in charm $\rightarrow$

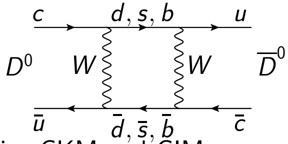
need external input to extract a_{fs} from b

$$\Delta A_{fs} = \frac{1}{2}(a^s_{fs} - a^d_{fs}) - \frac{1}{2}(A_{CP}(Ds) - A_{CP}(D))$$

Standard Model

Burdman, Shipsey, Ann.Rev.Nucl.Part.Sci.53,431; Falk et al., PRD65, 054034; Bigi, Uraltsev, Nucl. Phys. B592, 92;

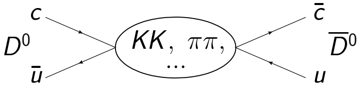
Short distance



Effective CKM and GIM suppression

$|x|, \ |y| \leq 10^{-3}$

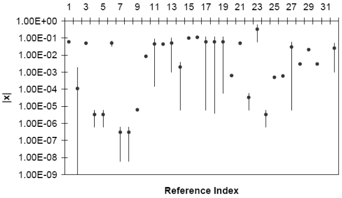
Long distance



Contribution from hadronic intermediate states

$x, \ y \sim$ up to 1%

New Physics predictions for |x|



A. Petrov, Int.J.Mod.Phys.A21, 5686;

- Large uncertainty in SM mixing rate
  $\hookrightarrow$ difficult to identify New Physics contributions
- however, measurements of x and y still provide usefull constraints on many New Physics models
- **See also A. Kagan's talk later today**

Mixing probability

- probability to observe an initial M^0 as M^0 or $\overline{M}^0$ after time t

$$\mathcal{P}_{\text{non-mix}}(t) = |\langle M^0(t)|M^0\rangle|^2 = \frac{1}{2}e^{-\Gamma t}\left[\cosh(y\Gamma t) + \cos(x\Gamma t)\right]$$

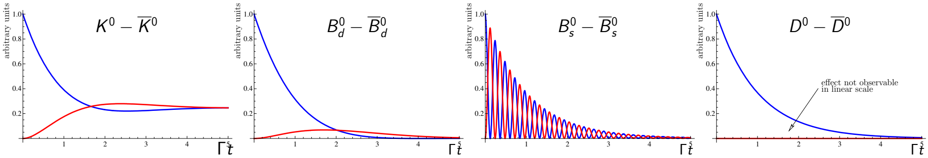
$$\mathcal{P}_{\text{mix}}(t) = |\langle M^0(t)|\overline{M}^0\rangle|^2 = \frac{1}{2}e^{-\Gamma t}\left[\cosh(y\Gamma t) - \cos(x\Gamma t)\right]$$

- time integrated mixing rate

$$R_M = \frac{\int_0^\infty \mathcal{P}_{\text{mix}}(t)dt}{\int_0^\infty \mathcal{P}_{\text{non-mix}}(t)dt} = \frac{x^2+y^2}{2+x^2-y^2}$$

M^0	x	y	R_M
K^0	0.946	0.997	0.994
B_d^0	0.776	< 0.01	0.23
B_s^0	26.1	0.15	0.997
D^0	0.01	0.01	**10^{-4}**

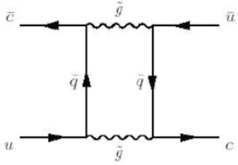
1 out of 10^4 D^0 mesons oscillates before it decays



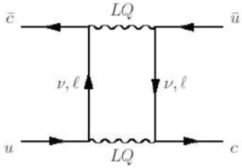
Large sample of D^0 mesons needed to observe $D^0 - \overline{D}^0$ mixing

New Physics in Charm Mixing

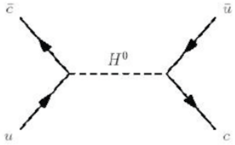
SUSY



Leptoquarks



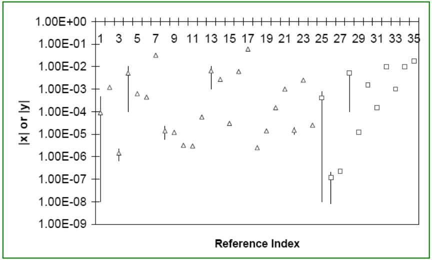
Extended Higgs

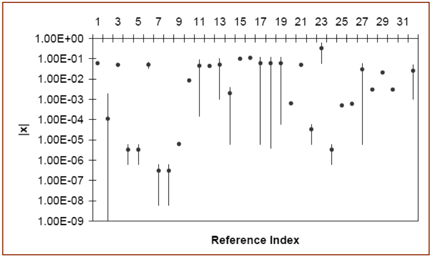


- Possible New Physics contributions can increase x, while y is mostly unaffected
  $\hookrightarrow$ $|x| \gg |y|$ would be a hint of New Physics

Compilation of predictions for x and y

Compilation of SM predictions for $|x|$ ($\triangle$) and $|y|$ ($\square$)
and New Physics predictions for $|x|$ ($\bullet$)





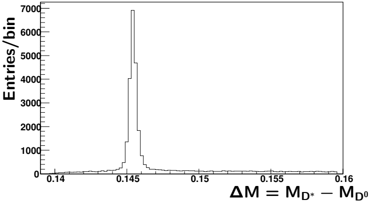
A. Petrov, Int.J.Mod.Phys.A21, 5686;

Common steps in $D^0 - \overline{D}^0$ mixing and CPV measurements

1. Tag the flavor of the produced neutral D meson
2. Measure proper decay time

Flavor tagging

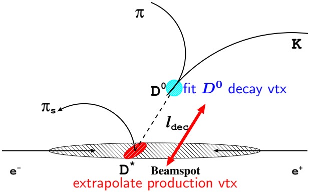
- require $\mathbf{D^{*+} \to D^0 \pi^+}$
  - $\hookrightarrow$ flavor tagging with π's charge
  - $\hookrightarrow$ background suppression with $\Delta M = M_{D^*} - M_{D^0}$



eliminate D^0s from $b \to c$ with $p_{\mathrm{CMS}}^{D^*} > 2.5$ GeV$/c^2$ (B-fact.) or use impact parameter (hadron col.)

Proper decay time

- Vertexing with beam point constraint



$$t = \frac{l_{dec}}{c\beta\gamma}\ , \quad \beta\gamma = \frac{p_{D^0}}{M_{D^0}}$$

σ_t uncertainty of the measurement typically between $1/6\tau_{D^0}$ and $1/2\tau_{D^0}$

Mixing and CPV in $D^0 \to K^+K^-,\ \pi^+\pi^-$ decays

- Measurement of lifetime difference between $D^0 \to K^-\pi^+$ (CP-mixed) and $D^0 \to K^+K^-,\ \pi^+\pi^-$ (CP-even) decays (tagged and untagged samples)

  $\hookrightarrow \Gamma(D^0, \overline{D}^0 \to K^{-,+}\pi^{+,-}) \propto e^{-t/\tau_{D^0}}$

  $\hookrightarrow \Gamma(D^0, \overline{D}^0 \to K^+K^-,\ \pi^+\pi^-) \propto e^{-(1+y_{CP})t/\tau_{D^0}}$

$$\mathbf{y_{CP}} \equiv \frac{\tau_{K\mp,\pi\pm}}{\tau_{K^+K^-,\pi^+\pi^-}} - 1 = \frac{1}{2}\left(\left|\frac{q}{p}\right| + \left|\frac{p}{q}\right|\right) y\cos\phi - \frac{1}{2}\left(\left|\frac{q}{p}\right| - \left|\frac{p}{q}\right|\right) x\sin\phi$$

In limit of no CPV $\mathbf{y_{CP} = y}$

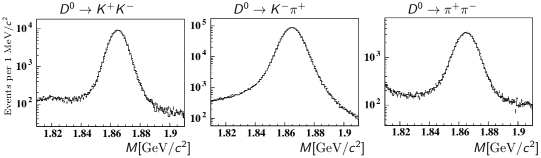
  - In untagged sample contribution of wrong sign (DCS $D^0 \to K^+\pi^-$) decays introduces negligible bias in y_{CP}

- CP Violation
  $\hookrightarrow \tau(D^0 \to f_{CP}) \neq \tau(\overline{D}^0 \to f_{CP})$

$$\mathbf{A_\Gamma} = \frac{\tau(\overline{D}^0 \to f_{CP}) - \tau(D^0 \to f_{CP})}{\tau(\overline{D}^0 \to f_{CP}) + \tau(D^0 \to f_{CP})} = \frac{1}{2}\left(\left|\frac{q}{p}\right| - \left|\frac{p}{q}\right|\right) y\cos\phi - \frac{1}{2}\left(\left|\frac{q}{p}\right| + \left|\frac{p}{q}\right|\right) x\sin\phi$$

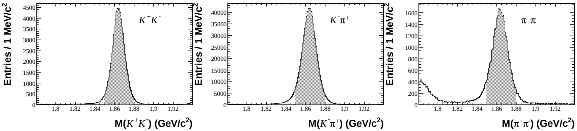
Mixing and CPV in $D^0 \to K^+K^-$, $\pi^+\pi^-$ decays

- Belle tagged analysis (540 fb^{-1}): PRL98, 211803 (2007)



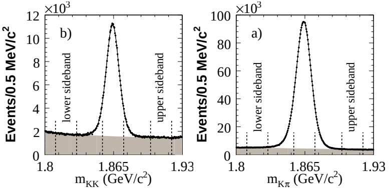
$D^0 \to$	Sig. yield	Purity
$K^-\pi^+$	1.22M	99%
K^+K^-	111k	98%
$\pi^+\pi^-$	49k	92%

- BaBar tagged analysis (384 fb^{-1}): PRD78, 011105 (2008)



$D^0 \to$	Sig. yield	Purity
$K^-\pi^+$	731k	99.9%
K^+K^-	70k	99.6%
$\pi^+\pi^-$	31k	98%

- BaBar untagged analysis (384 fb^{-1}): PRD80, 071103 (2009)



$D^0 \to$	Sig. yield	Purity
$K^-\pi^+$	2.71M	94.2%
K^+K^-	264k	80.9%

4× the size of the tagged sample and independent

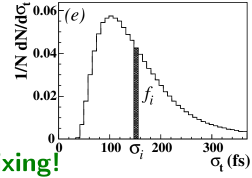
Mixing and CPV in $D^0 \to K^+K^-,\ \pi^+\pi^-$ decays (Belle)

- Fit to the proper decay time distribution

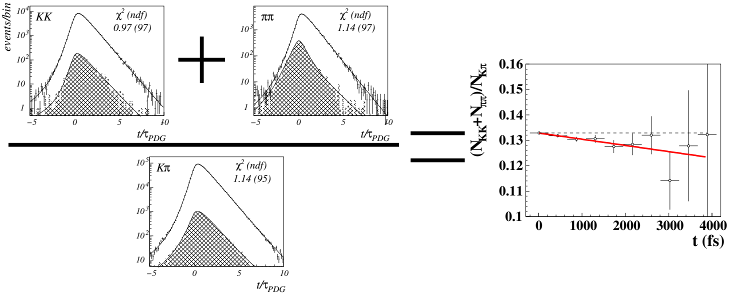
$$\boxed{\frac{dN}{dt} \propto \int e^{-t'/\tau} \cdot R(t-t')dt' + B(t)}$$

$$\Downarrow$$

$$R(t-t') = \sum_i^N f_i \sum_{k=1}^3 w_k G(t-t', \sigma_{ik}, t_0)$$



First evidence for $D^0 - \overline{D}^0$ mixing!



$$\boxed{y_{CP} = (1.31 \pm 0.32 \pm 0.25)\%}$$

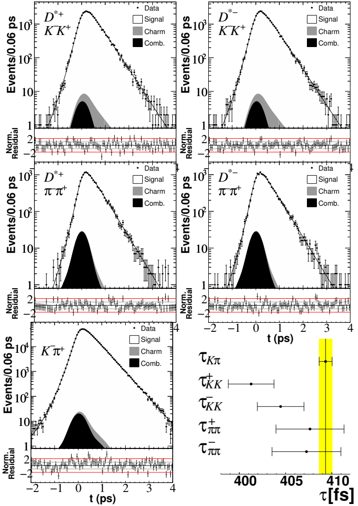
$$\boxed{A_\Gamma = (0.01 \pm 0.30 \pm 0.15)\%}$$

PRL98, 211803 (2007)

No evidence for CPV.

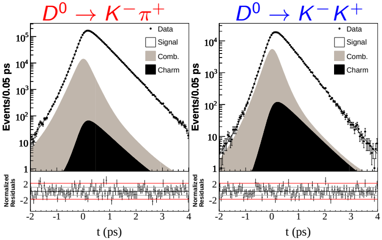
Mixing and CPV in $D^0 \to K^+K^-$, $\pi^+\pi^-$ decays (BaBar)

Tagged Sample PRD78, 011105 (2008)



$$\mathbf{y_{CP} = (1.24 \pm 0.39 \pm 0.13)\%}$$
$$\mathbf{\Delta Y = -(0.26 \pm 0.36 \pm 0.08)\%}$$

Untagged Sample PRD80, 071103 (2009)



$$\tau_{K\pi} = 410.39 \pm 0.38(\text{stat.})\ \text{fs}$$
$$\tau_{KK} = 405.85 \pm 1.00(\text{stat.})\ \text{fs}$$

$$\mathbf{y_{CP} = (1.12 \pm 0.26 \pm 0.22)\%}$$

Combined: tagged + untagged

$$\mathbf{y_{CP} = (1.16 \pm 0.22 \pm 0.18)\%}$$

4.1σ significance!

$$\Delta Y = (1 + y_{CP})A_\Gamma$$

Mixing and CPV in WS hadronic decays ($D^0 \to K^+\pi^-$)

- Right sign (RS) charge combination

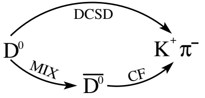
$$D^{*+} \to D^0(K^-\pi^+)\pi^+$$

$$\Gamma_{RS} \propto e^{-t/\tau_{D^0}}$$

- Wrong sign (WS) charge combination

$$D^{*+} \to D^0(K^+\pi^-)\pi^+$$

$\hookrightarrow$ DCS or mixing



$$\Gamma_{WS} \propto [R_D + y'\sqrt{R_D}(\Gamma t) + \frac{x'^2+y'^2}{4}(\Gamma t)^2]e^{-\Gamma t}$$

● DCS ● interference ● mixing

$\hookrightarrow$ $R_D = (0.331 \pm 0.008)\%$ DCS/CF rate

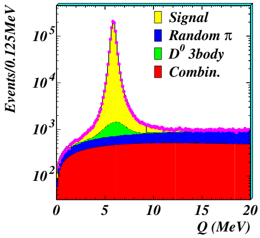
$\hookrightarrow$ $\mathbf{x' = x\cos\delta + y\sin\delta}$

$\hookrightarrow$ $\mathbf{y' = y\cos\delta - x\sin\delta}$

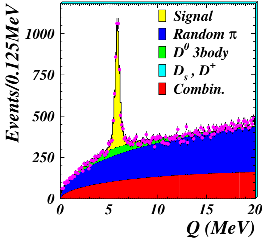
$\hookrightarrow$ δ strong phase between DCS and CF

(Accessible at charm factory)

RS events



WS events

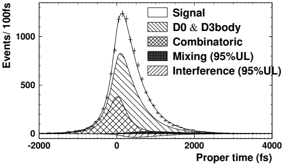


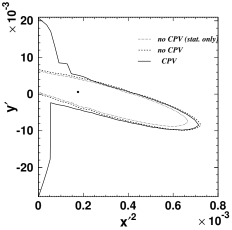
$$Q = M_{K\pi\pi} - M_{K\pi} - m_\pi$$

Mixing and CPV in WS hadronic decays $D^0 \to K^+\pi^-$

Belle $[400\ \mathrm{fb}^{-1}]$

PRL96, 151801 (2006).

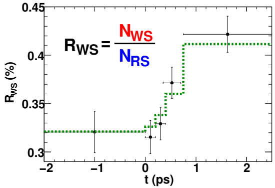


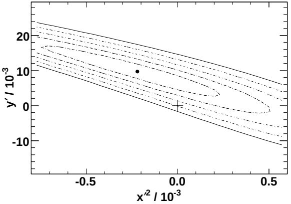


BaBar $[384\ \mathrm{fb}^{-1}]$

PRL98, 211802 (2007).

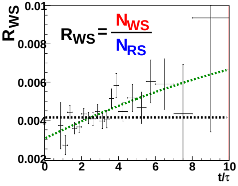
First Evidence!

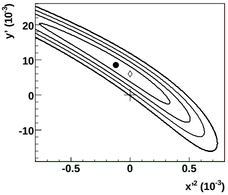




CDF $[1.5\ \mathrm{fb}^{-1}]$

PRL100, 121802 (2008).





Results assuming conservation of CP symmetry

Experiment	$R_D (10^{-3})$	$y' (10^{-3})$	$x'^2 (10^{-3})$	Signif.
CDF	3.04 ± 0.55	8.5 ± 7.6	-0.12 ± 0.35	3.8
BaBar	3.03 ± 0.19	9.7 ± 5.4	-0.22 ± 0.37	3.9
Belle	3.64 ± 0.17	$0.6\ ^{+4.0}_{-3.9}$	$0.18\ ^{+0.21}_{-0.23}$	2.0

No CPV found in DCS or mixing by Belle or Babar.

Mixing in WS $D^0 \to K^+\pi^-\pi^0$ decays (BaBar)

PRL103, 211801 (2009) [(384 fb^{-1})]

Analysis similar to the WS $D^0 \to K^+\pi^-$ analysis, however the strong phase δ varies across the Dalitz plot.

● DCS ● interference ● mixing

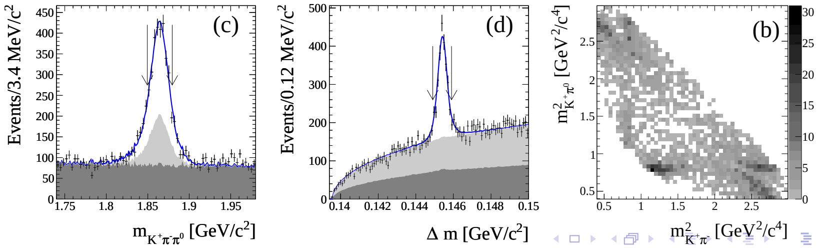
$$\frac{dN_{\bar{f}}(s_0,s_+,t)}{ds_0\,ds_+\,dt} = e^{-\Gamma t}\left\{|A_{\bar{f}}|^2 + |A_{\bar{f}}||\bar{A}_{\bar{f}}|\left[y''\cos\delta_{\bar{f}} - x''\sin\delta_{\bar{f}}\right](\Gamma t) + \frac{x''^2+y''^2}{4}|\bar{A}_{\bar{f}}|^2(\Gamma t)^2\right\}$$

$s_0 = m^2_{K^+\pi^-}$; $s_0 = m^2_{K^+\pi^0}$

- Mixing parameters

  $\hookrightarrow$

$$\mathbf{x'' = x\cos\delta_{K\pi\pi^0} + y\sin\delta_{K\pi\pi^0}} \quad \text{and} \quad \mathbf{y'' = y\cos\delta_{K\pi\pi^0} - x\sin\delta_{K\pi\pi^0}}$$



Mixing in WS $D^0 \to K^+\pi^-\pi^0$ decays (BaBar)

Assuming no CPV

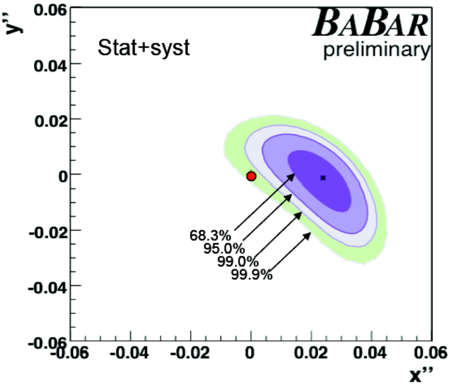
$$\begin{aligned} x'' &= (2.61^{+0.57}_{-0.68} \pm 0.39)\% \\ y'' &= -(0.05^{+0.55}_{-0.64} \pm 0.34)\% \\ R_M &= (2.9 \pm 1.6) \times 10^{-4} \end{aligned}$$

Allowing CPV

$$\begin{aligned} x''^{+} &= (2.53^{+0.54}_{-0.63} \pm 0.39)\% \\ y''^{+} &= -(0.05^{+0.63}_{-0.67} \pm 0.50)\% \end{aligned}$$

$$\begin{aligned} x''^{-} &= (3.55^{+0.73}_{-0.83} \pm 0.65)\% \\ y''^{-} &= -(0.54^{+0.40}_{-1.16} \pm 0.41)\% \end{aligned}$$

Results consistent with no CPV.



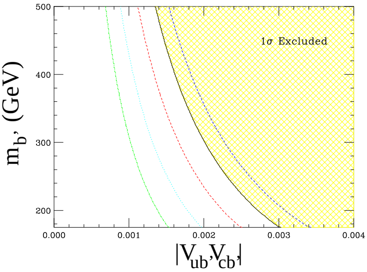
No mixing is excluded at 99% confidence level.

Impact – Constraints on new physics models from mixing

E. Golowich *et al.*, PRD76,095009

- Constraints on new physics models from $D^0 - \overline{D}^0$ complementary to those obtained in B and K sector
  $\hookrightarrow$ FCNC transitions with *down-like* quarks in charm sector (unique feature)
- 21 NP models considered $\rightarrow$ 17 with useful constraints

Example: quark b' from 4^{th} generation



E. Golowich *et al.*, PRD76,095009

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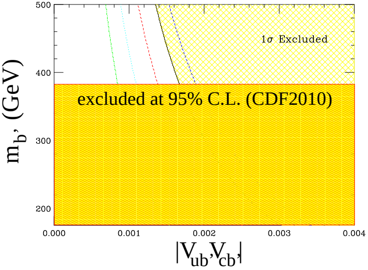
Example: quark b' from 4^{th} generation



$$|V_{ub'} V_{cb'}| < 0.002$$

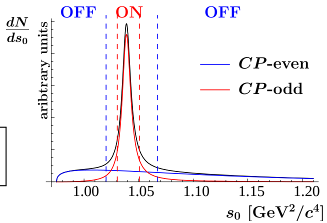
order of magnitude stronger constraint as from CKM unitarity

Providing complementary and improved constraints!

PRD80, 052006 (2009) [673 fb^{-1}]

Measurement of lifetime difference between CP-even and CP-odd eigenstates

- $\sqrt{s_0} = m_{K^+K^-}$ dependent CP mixture
  ↪ ON region: mainly CP-odd ($\phi(1020)K^0_S$)
  ↪ OFF region: mainly CP-even ($a_0(980)^0 K^0_S$)



$$\frac{d^2N(s_0,t)}{ds_0\,dt} \propto a_1(s_0)e^{-(1+y_{CP})t/\tau_{D^0}} + a_2(s_0)e^{-(1-y_{CP})t/\tau_{D^0}}$$

$a_{1,2}(s_0) = \int |\mathcal{A}_{1,2}(s_0,s_+)|^2 ds_+ ; \sqrt{s_+} = m_{K^0_S K^+} ; \mathcal{A}_{1,2} = \frac{1}{2}(\mathcal{A} \pm \overline{\mathcal{A}})$

- Effective lifetimes in ON and OFF regions

↪ $\tau_{\mathrm{ON,OFF}} = [1 + (1-2f_{\mathrm{ON,OFF}})y_{CP}]\tau_{D^0}$ $\Rightarrow$ $y_{CP} = \frac{1}{f_{\mathrm{ON}} - f_{\mathrm{OFF}}}\left(\frac{\tau_{\mathrm{OFF}} - \tau_{\mathrm{ON}}}{\tau_{\mathrm{OFF}} + \tau_{\mathrm{ON}}}\right)$

↪ $f_{\mathrm{ON}}, f_{\mathrm{OFF}}$ are CP-even fractions in ON and OFF regions, determined using 8-resonant Dalitz model (REF!!!)

$$y_{CP} = +(0.11 \pm 0.61(\mathrm{stat.}) \pm 0.52(\mathrm{syst.}))\%$$

Mixing parameters in $D^0 \to K_S^0 K^+ K^-$ and $D^0 \to K_S^0 \pi^+ \pi^-$

TABLE I: Results from the mixing fits. The first uncertainty is statistical, the second systematic and the third systematic from the amplitude model. For the nominal fit, the corresponding correlation coefficients between x and y are 3.5%, 16.0% and −2.7%, respectively.

Fit type	$x/10^{-3}$	$y/10^{-3}$
Nominal	$1.6 \pm 2.3 \pm 1.2 \pm 0.8$	$5.7 \pm 2.0 \pm 1.3 \pm 0.7$
$K_S^0 \pi^+ \pi^-$	2.6 ± 2.4	6.0 ± 2.1
$K_S^0 K^+ K^-$	-13.6 ± 9.2	4.4 ± 5.7
D^0	0.0 ± 3.3	5.5 ± 2.8
$\overline{D}^0$	3.3 ± 3.3	5.9 ± 2.8

Mixing in semileptonic decays $D^0 \to K^{(*)-}\ell^+\nu_\ell$

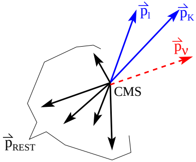
U. Bitenc *et al.* [Belle Collaboration], PRD77, 112003 (2008). [$\mathcal{L}$ =492 fb^{-1}]

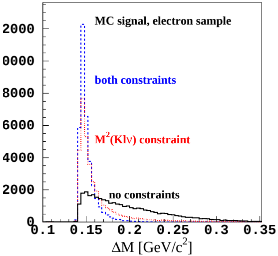
- Wrong sign (WS) charge combination accessible only via mixing

	Flavor at production		Flavor at decay	
without mixing	$D^{*+} \to D^0\pi^+$		$D^0 \to K^-\ell^+\nu_\ell$	**RS**
with mixing	$D^{*+} \to D^0\pi^+$	$D^0 - \overline{D}^0$	$\overline{D}^0 \to K^+\ell^-\nu_\ell$	**WS**

Neutrino reconstruction:

- $P_\nu = P_{\rm cms} - P_{K\ell} - P_{\rm rest}$
- $M^2_{K\ell\nu} = m^2_{D^0}$ & $(P^*_\nu)^2 = 0$



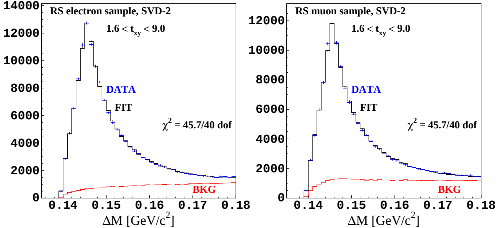


Time integrated mixing rate:

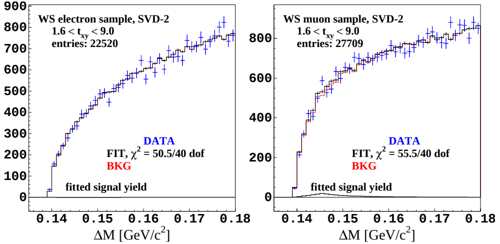
$$R_M \simeq \frac{x^2 + y^2}{2} = \frac{N_{\rm WS}}{N_{\rm RS}}$$

Mixing in semileptonic decays $D^0 \to K^{(*)-}\ell^+\nu_\ell$

RS events

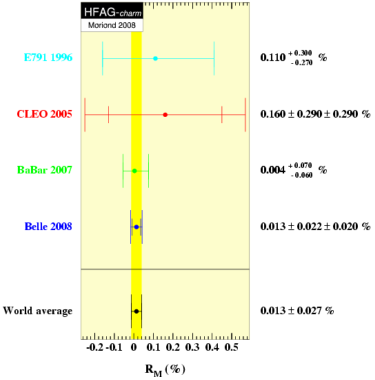


WS events



No WS charge combinations observed.

$$R_M = (1.3 \pm 2.2 \pm 2.0) \times 10^{-4}$$
$$R_M < 6.1 \times 10^{-4} \text{ @ 90\% C.L.}$$



http://www.slac.stanford.edu/xorg/hfag/

TABLE V: Expected precision (σ) on the measured quantities using methods described in the text for Super$B$ with an integrated luminosity of 75 ab^{-1} at Super$B$ at 10 GeV, 300 fb^{-1} ($\sim$ two months) running at charm threshold with Super$B$, and LHCb with 10 fb^{-1}[13].

Mode	Observable	$\Upsilon(4S)$ (75 ab^{-1})	$\psi(3770)$ (300 fb^{-1})	LHCb (10 fb^{-1})
$D^0 \to K^+\pi^-$	x'^2	3×10^{-5}		6×10^{-5}
	y'	7×10^{-4}		9×10^{-4}
$D^0 \to K^+K^-$	y_{CP}	5×10^{-4}		5×10^{-4}
$D^0 \to K_S^0\pi^+\pi^-$	x	4.9×10^{-4}		
	y	3.5×10^{-4}		
	$\|q/p\|$	3×10^{-2}		
	ϕ	2°		
$\psi(3770) \to D^0\overline{D}^0$	x^2		$(1-2) \times 10^{-5}$	
	y		$(1-2) \times 10^{-3}$	
	$\cos\delta$		$(0.01-0.02)$	

arXiv:0810.1312

FutureProspects

Table 5.23: Expected number of reconstructed $D^{*+} \to D^0\pi^+,\ D^0 \to K^-\pi^+$ decays at different facilities (projected using [292], [293], [294], [295]). †For charm factory the expected yield of $\Psi(3770) \to D^0\bar{D}^0,\ D^0 \to K^-\pi^+,\ \bar{D}^0 \to K^+\pi^-$ is quoted.

Facility	num. of $D^{*+} \to D^0\pi^+$, $D^0 \to K^-\pi^+$	int. luminosity [fb^{-1}]	Comment
existing B factories	2.5×10^6	1000	final data set
Super-KEKB	14×10^6	5000	purity $\sim 99\%$
Charm factory†	4×10^4	20	both D^0's reconstructed; $D^0\bar{D}^0$ in coherent state
Tevatron	0.5×10^6	0.35	
LHCb	15×10^6	2	

http://belle2.kek.jp/physics.html

FutureProspects

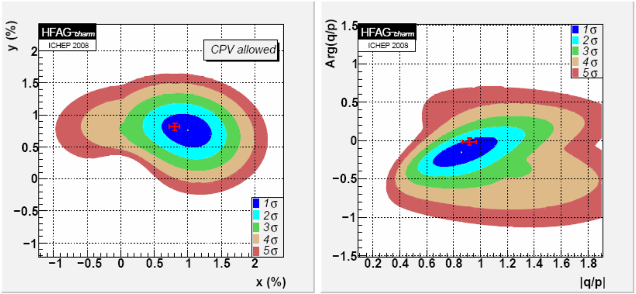


Figure 5.67: Left: The probability contours for the current world average values of the mixing parameters x and y [338]. The error bars denote the expected accuracy on the parameters with 50 ab^{-1} following from the extrapolation of results using K^+K^-, $\pi^+\pi^-$, $K^+\pi^-$ and $K_S\pi^+\pi^-$ final states. Right: The probability contours for the current world average values of the CPV parameters $|q/p|$ and ϕ [338]. The error bars denote the expected accuracy with the same assumptions as above.

http://belle2.kek.jp/physics.html

Time-integrated searches of *CP* Violation

- Searches for direct *CP* violation performed in total over 30 D^0, D^+ and D_s^+ decay modes in past 15 years
  $\hookrightarrow$ Belle, BaBar, Cleo, CDF, FOCUS, E796, E687
- No evidence for *CP* violation found so far
  $\hookrightarrow$ Sensitivity is in some cases reaching 0.2%
- Measurements statistical limited
  $\hookrightarrow$ All measurements can be significantly improved!

$D^0 \to$	A_{CP} [%]	$D^+ \to$	A_{CP} [%]	$D_s^+ \to$	A_{CP} [%]
K^+K^-	-0.16 ± 0.23	$K_S^0\pi^+$	-0.72 ± 0.26	$K_S^0K^+$	-0.28 ± 0.41
$\pi^+\pi^-$	$+0.22 \pm 0.37$	$K_S^0K^+$	-0.09 ± 0.63	$K_S^0\pi^+$	$+6.5 \pm 2.5$
$\pi^+\pi^-\pi^0$	-0.23 ± 0.42	$K^+K^-\pi^+$	$+0.39 \pm 0.61$	$K^+K^-\pi^+$	$+0.3 \pm 1.4$
$K^-\pi^+\pi^0$	$+0.16 \pm 0.89$	$K^-\pi^+\pi^+$	-0.5 ± 1.0	$\pi^+\pi^-\pi^+$	$+2.0 \pm 4.7$
$K_S^0\pi^0$	$+0.10 \pm 1.3$	$K^-\pi^+\pi^+$	-0.5 ± 1.0	$K^+\pi^-\pi^+$	$+11.2 \pm 7.1$
$K^+K^-\pi^0$	$+1.00 \pm 1.7$	$K_S^0\pi^+\pi^0$	$+0.3 \pm 0.9$	$\pi^+\eta$	-8.2 ± 5.3
$\pi^0\pi^0$	$+0.10 \pm 4.8$	$\pi^+\pi^-\pi^+$	-1.7 ± 4.2	$\pi^+\eta'$	-5.5 ± 3.9
$\vdots$	$\vdots$	$\vdots$	$\vdots$	$\vdots$	$\vdots$

Full list of all A_{CP} measurements is available at:
http://www.slac.stanford.edu/xorg/hfag/charm/index.html

Search for CP Violation with T-odd correlations

Assuming CPT invariance: T violation $\Rightarrow$ CP violation

- Possible only in $\geq$ 4-body decay
  $\hookrightarrow D^0 \to K^- K^+ \pi^- \pi^+$
- T-odd quantity:
  $$C_T \equiv \langle \vec{p}_{K^+} \cdot (\vec{p}_{\pi^+} \times \vec{p}_{\pi^-}) \rangle$$
- T violating asymmetry $\mathcal{A}_T$

$$D^0 : \; A_T = \frac{\Gamma(C_T>0) - \Gamma(C_T<0)}{\Gamma(C_T>0) + \Gamma(C_T<0)}$$

$$\overline{D}^0 : \; \overline{A}_T = \frac{\Gamma(-\overline{C}_T>0) - \Gamma(-\overline{C}_T<0)}{\Gamma(-\overline{C}_T>0) + \Gamma(-\overline{C}_T<0)}$$

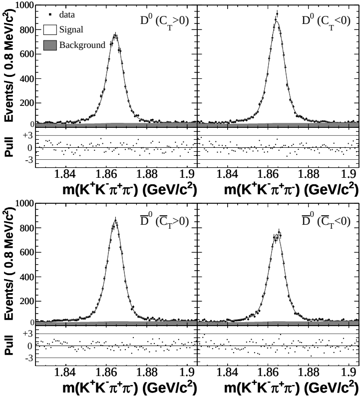
$$\mathcal{A}_T = \frac{1}{2}\left(A_T - \overline{A}_T\right)$$

Bigi, hep-ph/0107102 (2001)

Bensalem et al., PRD66, 094004 (2002)

A_T can be different from zero due to final state interactions, but $\mathcal{A}_T \neq 0$ represents CP violation.

BaBar PRD81, 111103 (2010)



$$A_T = (-68.5 \pm 7.3 \pm 4.5) \times 10^{-3}$$
$$\overline{A}_T = (-70.5 \pm 7.3 \pm 3.9) \times 10^{-3}$$

$$\mathcal{A}_T = (1.0 \pm 5.1 \pm 4.4) \times 10^{-3}$$

CPV backup

Number of reconstructed decays:

$$N^{reco} = N^{prod}_{D^{*+}} \cdot \mathcal{B}(D^{*+} \to D^0\pi^+) \cdot \mathcal{B}(D^0 \to h^+h^-) \cdot \epsilon_{hh} \cdot \epsilon_\pi$$

- Contributions to asymmetry in N^{reco}:
  - production (A_{FB})
  - branching fractions (A_{CP})
  - efficiencies (A_ϵ)
- If asymmetries are small ($A_{FB}, A_{CP}, A_\epsilon \ll 1$) it is easy to see, that the asymmetry in N^{reco} is:

$$A^{reco} = A^{D^{*+}}_{FB} + A^{D^0\pi}_{CP} + A^{hh}_{CP} + A^{hh}_{\epsilon} + A^{\pi}_{\epsilon}$$

- Some are zero: $A^{D^0\pi}_{CP} = 0$ (strong decay), $A^{hh}_\epsilon = 0$ (same final state)

CPV backup

- Production asymmetry (A_{FB}) is due to interference in $e^+e^- \to c\bar{c}$ (mediated by virtual γ or Z^0)
  - anti-symmetric function of $\cos\theta^*$ (follows from CP conservation)

$$A_{FB}(\cos\theta^*) = -A_{FB}(-\cos\theta^*)$$

- Measured asymmetry:

$$A^{reco} = A_{FB}^{D^{*+}}(\cos\theta^*) + A_{CP}^{hh} + A_\epsilon^\pi(\theta, p)$$

- Asymmetry in π_{slow} efficiency $A_\epsilon^\pi(\theta, p)$ can be measured in $D^0 \to K^-\pi^+$ by using tagged and untagged decays
- Corrected asymmetry

$$A_{corr}^{reco} = A^{reco} - A_\epsilon^\pi(\theta, p)$$

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

CPV backup

Number of reconstructed tagged and untagged $D^0 \to K^- \pi^+$ decays:

$$
\begin{aligned}
N^{\rm untag} &= N^{\rm prod}_{D^0} \cdot \mathcal{B}(D^0 \to K^-\pi^+) \cdot \epsilon_{K\pi} \\
N^{\rm tag} &= N^{\rm prod}_{D^{*+}} \cdot \mathcal{B}(D^{*+} \to D^0 \pi_S^+) \cdot \mathcal{B}(D^0 \to K^-\pi^+) \cdot \epsilon_{K\pi} \cdot \epsilon_\pi
\end{aligned}
$$

Measured asymmetry:

$$
\begin{aligned}
A^{\rm untag} &= A_{FB}^{D^0} + A_{CP}^{K\pi} + A_\epsilon^{K\pi} \\
A^{\rm tag} &= A_{FB}^{D^0} + A_{CP}^{K\pi} + A_\epsilon^{K\pi} + A_\epsilon^{\pi}
\end{aligned}
$$

Assuming $A_{FB}^{D^0} = A_{FB}^{D^{*+}}$:

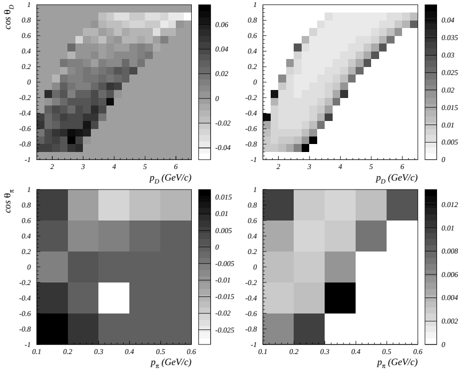
$$
A_\epsilon^\pi = A^{\rm tag} - A^{\rm untag}
$$

$A_\epsilon^{K\pi}$ and A_ϵ^π are functions of corresponding phase spaces.

CPV in $D^0 \to K^-K^+, \pi^-\pi^+$ decays backup (time-integrated)

Determination of soft pion π_s asymmetry:

- using tagged and untagged $D^0 \to K^-\pi^+$ decays



$\Longrightarrow$ asymmetry map of the untagged $K\pi$ sample (left) with uncertainty (right)

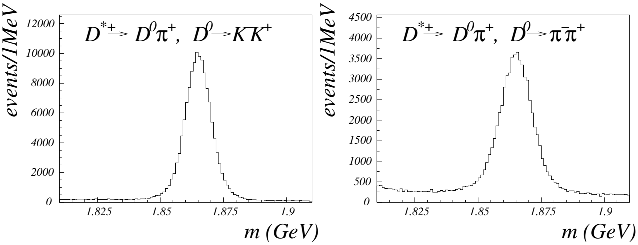
$\hookrightarrow$ weight D^0 candidates in the π_s tagged $K\pi$ sample

$\Longrightarrow$ asymmetry map of the slow pion efficiency (left) with uncertainty (right)

$\hookrightarrow$ weight D^0 yields to correct for tagging asymmetry

Averaging over the phase space the correction due to the π_S efficiency is found to be $(0.76 \pm 0.09\%)$.

CPV in $D^0 \to K^-K^+, \pi^-\pi^+$ decays backup (time-integrated)



The signal counting was performed by the mass-sideband subtraction.

Systematics:

Signal counting

	KK	$\pi\pi$
Signal shape diff.	0.02%	0.04%
Sideband position	0.01%	0.03%
Random π_{slow} bkg.	0.03%	0.03%
Total	0.04%	0.06%

π_S eff. correction

	KK	$\pi\pi$
Statistics of $K\pi$	0.09%	0.09%
Binning	0.03%	0.02%
Min. num. events/bin	0.04%	0.03%
Total	0.10%	0.10%

A_{CP} extraction

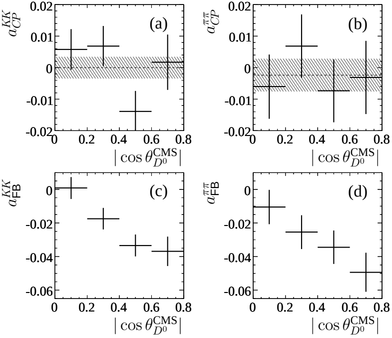
	KK	$\pi\pi$
Binning	0.03%	0.03%
SVD1/2	0.03%	0.00%
Total	0.04%	0.03%

Time integrated CPV in $D^0 \to K^+K^-, \pi^+\pi^-$ decays

$$A^{\rm reco}_{\rm corr}(cos\theta^*) = \frac{N(D^0) - N(\bar{D}^0)}{N(D^0) + N(\bar{D}^0)} = A^{D^{*+}}_{FB} + A^{hh}_{CP}$$

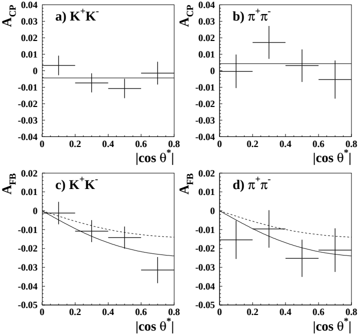
- $A_{CP} = \frac{A^{\rm reco}_{\rm corr}(cos\theta^*) + A^{\rm reco}_{\rm corr}(-cos\theta^*)}{2}$
- $A_{FB} = \frac{A^{\rm reco}_{\rm corr}(cos\theta^*) - A^{\rm reco}_{\rm corr}(-cos\theta^*)}{2}$

BaBar



PRL100, 061803

Belle



PLB670, 190

$$A^{KK}_{CP} = (0.00 \pm 0.34({\rm stat}) \pm 0.13({\rm syst}))\%$$
$$A^{\pi\pi}_{CP} = (-0.24 \pm 0.52({\rm stat}) \pm 0.22({\rm syst}))\%$$

$$A^{KK}_{CP} = (-0.41 \pm 0.30({\rm stat}) \pm 0.11({\rm syst}))\%$$
$$A^{\pi\pi}_{CP} = (+0.41 \pm 0.52({\rm stat}) \pm 0.12({\rm syst}))\%$$