CP violation and mixing in charm

A. Carbone,
University and INFN-Bologna

9th Franco-Italian meeting on B physics

Annecy, 18 Feb. 2013

Why search for CP violation in charm ?

CP-violating asymmetries in the charm sector provide a unique probe for physics beyond the Standard Model (SM)

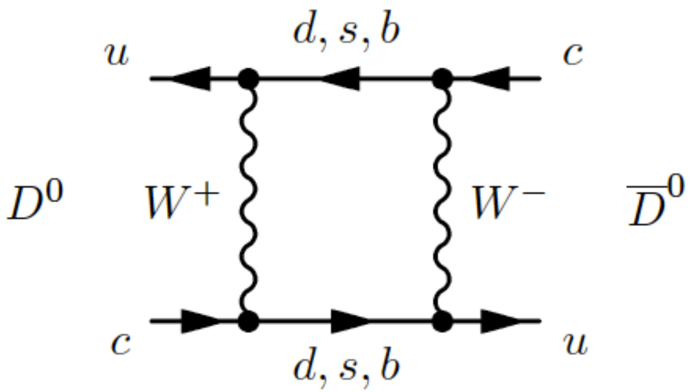
Interest increased in the past few years since evidence for D^0 mixing was first seen

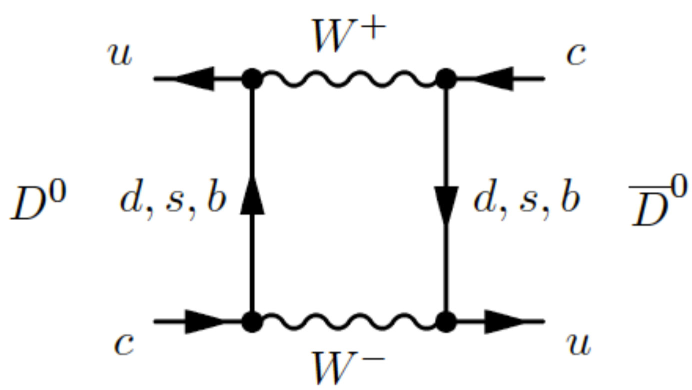
BaBar: [PRL 98, 211802 (2007)]

Belle : [PRL 98, 211803 (2007)]

CDF : [PRL 100, 121802 (2008)]

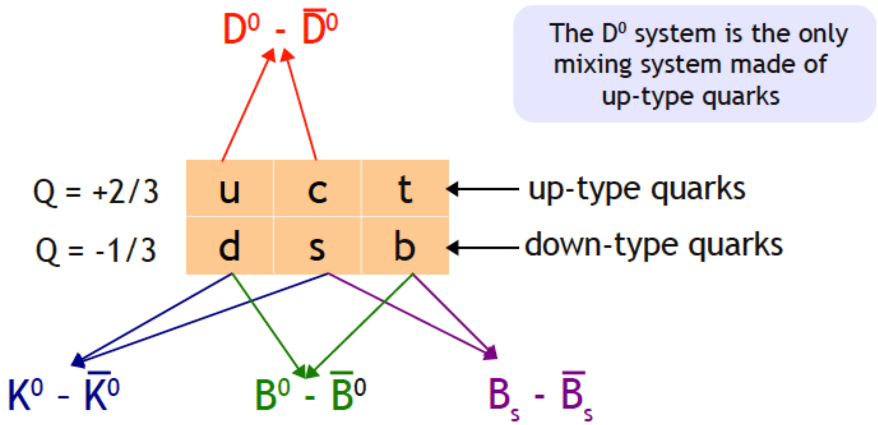
LHCb : [PRL acepted (2013)]





Why search for CP violation in charm ?

- In the Standard Model (SM) we have 4 systems of meson-antimeson that can mix:
- Mixing has been experimentally established in all of them.



2011, evidence of CPV reported by LHCb and CDF Collaborations:

in the difference of integrated asymmetries:

$$A_{CP}(D \rightarrow KK) - A_{CP}(D \rightarrow \pi\pi)$$

Interpretation is not straightforward, maybe accommodated in the Standard Model but may also be a hint of New Physics!

Why search for CP violation in charm ?

SM charm physics is CP conserving to first approximation (dominance of 2 generation)

New Physics (NP) can enhance CP-violating observables

interaction eigenstates (u, c, t) mass eigenstates

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

Wolfeinstein parametrization up to λ^4

Unitary triangle for charm

$$V_{ud}V_{cd}^* + V_{us}V_{cs}^* + V_{ub}V_{cb}^* = 0$$

$$\sim\lambda \qquad \sim\lambda \qquad \sim\lambda^5$$

With b-quark contribution neglected: only **2** generations contribute → **real 2x2 Cabibbo matrix**

Mixing of neutral meson: formalism

- Time-evolution described by Schrödinger's equation

$$i\frac{\partial}{\partial t}\begin{pmatrix}|P^0(t)\rangle \\ |\overline{P}^0(t)\rangle\end{pmatrix} = \left[\begin{pmatrix}M_{11} & M_{12} \\ M_{12}^* & M_{22}\end{pmatrix} - \frac{i}{2}\begin{pmatrix}\Gamma_{11} & \Gamma_{12} \\ \Gamma_{12}^* & \Gamma_{22}\end{pmatrix}\right]\begin{pmatrix}|P^0(t)\rangle \\ |\overline{P}^0(t)\rangle\end{pmatrix}$$

- Eigenstates can have different masses and decay width

$$|P_{L,H}\rangle = p|P^0\rangle \pm q|\overline{P}^0\rangle \quad \text{where} \quad \frac{q}{p} = \sqrt{\frac{M_{12}^* - \frac{i}{2}\Gamma_{12}^*}{M_{12} - \frac{i}{2}\Gamma_{12}}}$$

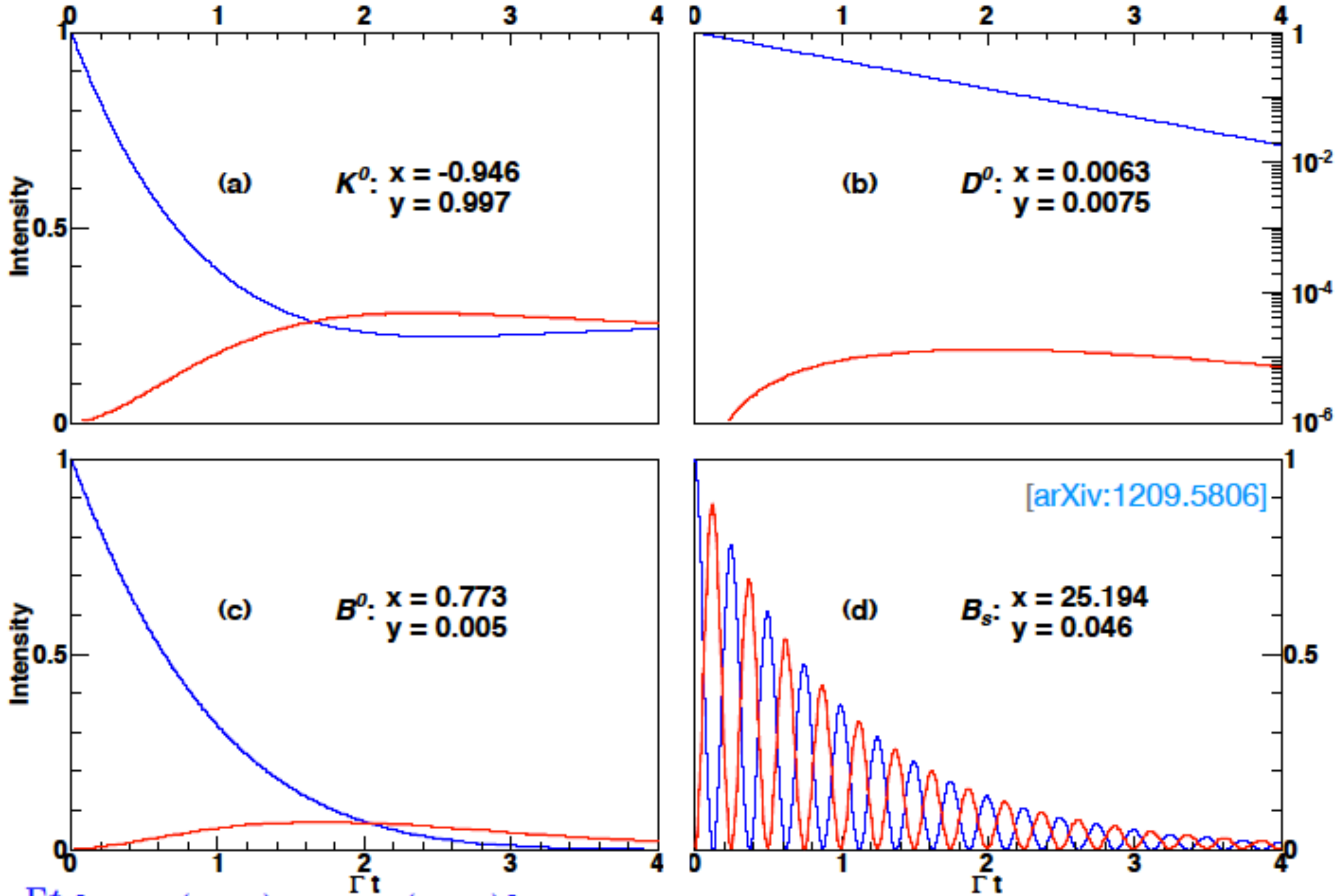
$$x = \frac{\Delta m}{\Gamma} = \frac{m_H - m_L}{(\Gamma_H + \Gamma_L)/2}, \quad y = \frac{\Delta\Gamma}{2\Gamma} = \frac{\Gamma_H - \Gamma_L}{\Gamma_H + \Gamma_L}$$

- If CP is conserved, q and p are real, i.e. |q/p| = 1 and φ = arg(q/p) = 0

Mixing of neutral mesons: phenomenology

Blue line:
given a P^0, at t=0, the probability of finding a P^0 at t

Red Line:
given a P^0, at t=0, the probability of finding a $\bar{P}^0$ at t



$$|\langle P^0(0)|P^0(t)\rangle|^2 \propto e^{-\Gamma t}\left[\cosh(y\Gamma t) + \cos(x\Gamma t)\right]$$

$$|\langle P^0(0)|\overline{P}^0(t)\rangle|^2 \propto e^{-\Gamma t}\left[\cosh(y\Gamma t) - \cos(x\Gamma t)\right]$$

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CP violation in charm

- 3 modes of observing CP violation:
  - in decay: amplitudes for a process and its conjugate differ
  - in mixing: rates of $D^0 \to \bar{D}^0$ and $\bar{D}^0 \to D^0$ differ
  - in interference between mixing and decay diagrams
- the SM indirect CP violation expected to be very small and universal for CP eigenstates → $O(10^{-3})$
- Direct CP violation expected small as well
  - Negligible in Cabibbo-favoured modes (SM tree dominates everything)
  - In singly-Cabibbo-suppressed modes: up to $O(10^{-4} - 10^{-3})$ plausible
- Both can be enhanced by NP, in principle up to O(%)

Definitions:
$$A_f = \langle D^0|\mathcal{H}|f\rangle \quad A_{\bar{f}} = \langle D^0|\mathcal{H}|\bar{f}\rangle$$
$$\bar{A}_{\bar{f}} = \langle \bar{D}^0|\mathcal{H}|f\rangle \quad \bar{A}_{\bar{f}} = \langle \bar{D}^0|\mathcal{H}|\bar{f}\rangle$$

CPV in the interference, $\varphi f \neq 0$

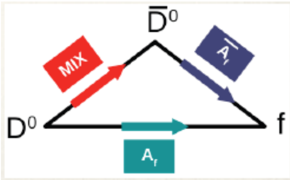
$$\lambda_f = \frac{q}{p}\frac{\bar{A}_f}{A_f} = \left|\frac{q}{p}\frac{\bar{A}_f}{A_f}\right| \exp[i(\delta_f + \phi_f)]$$
strong +weak phase

direct CPV, AfD≠0

$$A_D^f = \frac{|A_f/\bar{A}_f|^2 - |\bar{A}_{\bar{f}}/A_{\bar{f}}|^2}{|A_f/\bar{A}_f|^2 + |\bar{A}_{\bar{f}}/A_{\bar{f}}|^2}$$

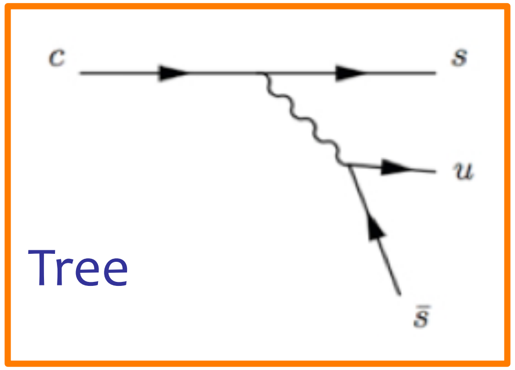
CPV in mixing, AM≠0

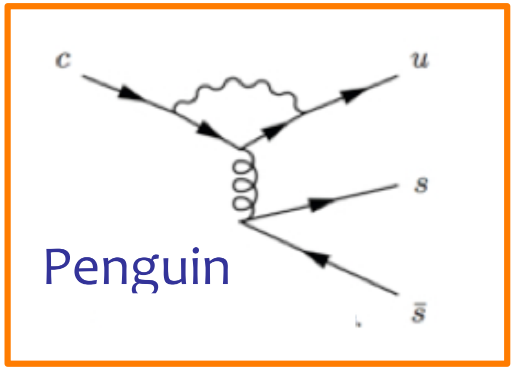
$$A_M = \frac{R_M^2 - R_M^{-2}}{R_M^2 + R_M^{-2}}, \quad R_M = \frac{q}{p}$$



Where to look for CP violation?

- Singly Cabibbo Suppressed (SCS) decays are an interesting sector for direct CPV searches
- Interference between Tree and Penguin can generate direct CP asymmetries
  - Several classes of NP can contribute
  - … but also non-negligible SM contribution

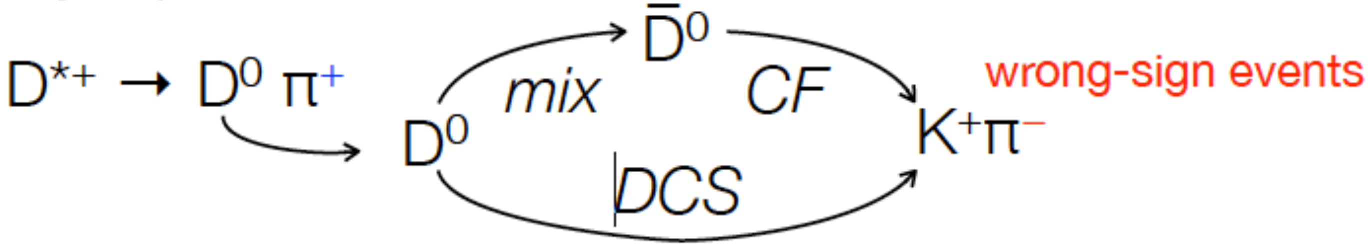




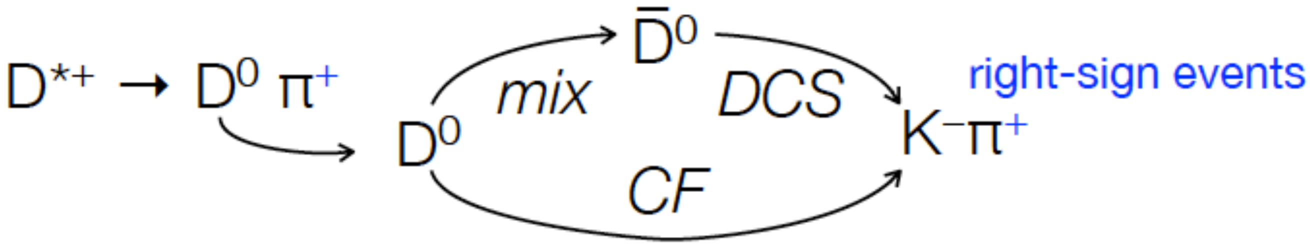
Mixing

Charm mixing with $D^0 \rightarrow K^+\pi^-$

- Exploit interference between mixing and doubly-Cabibbo-suppressed decay amplitudes



- Compare to RS events which are dominated by Cabibbo-favored amplitude

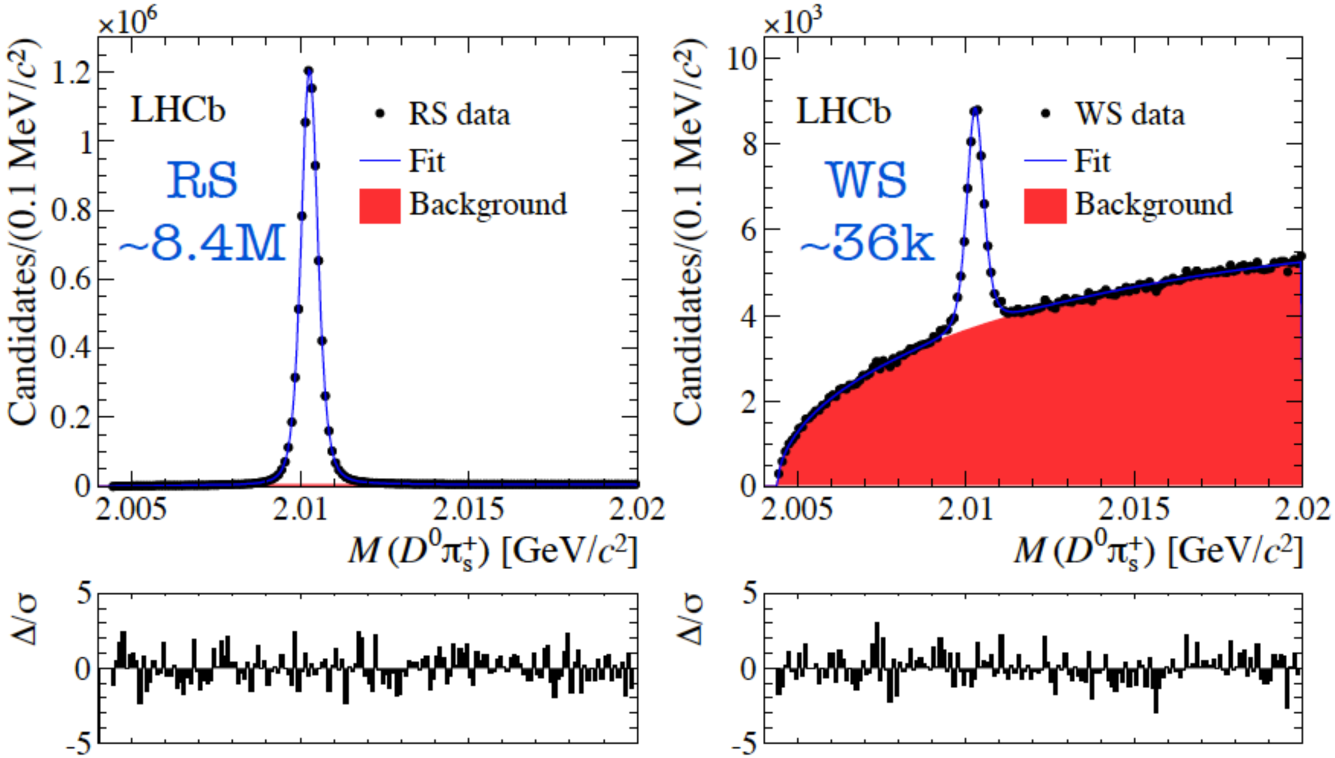


- Assuming |x|,|y|<<1 and no CPV

$$R(t) = \frac{N_{WS}(t)}{N_{RS}(t)} = R_D + \sqrt{R_D}y't + \frac{x'^2 + y'^2}{4}t^2 \qquad \begin{array}{l} x' = x\cos\delta + y\sin\delta \\ y' = y\cos\delta - x\sin\delta \end{array}$$

- Would be consistent with R_D for all t in the zero mixing case.

Recent mixing measurements from LHCb



Measured by LHCb on 1fb-1 to be (accepted PRL LHCb-PAPER-2012-038):

$$R_D = (3.52 \pm 0.15) \times 10^{-3},$$
$$y' = (7.2 \pm 2.4) \times 10^{-3},$$
$$x'^2 = (-0.09 \pm 0.13) \times 10^{-3}.$$

Correlation coefficient		
R_D	y'	x'^2
1	−0.954	+0.882
	1	−0.973
		1

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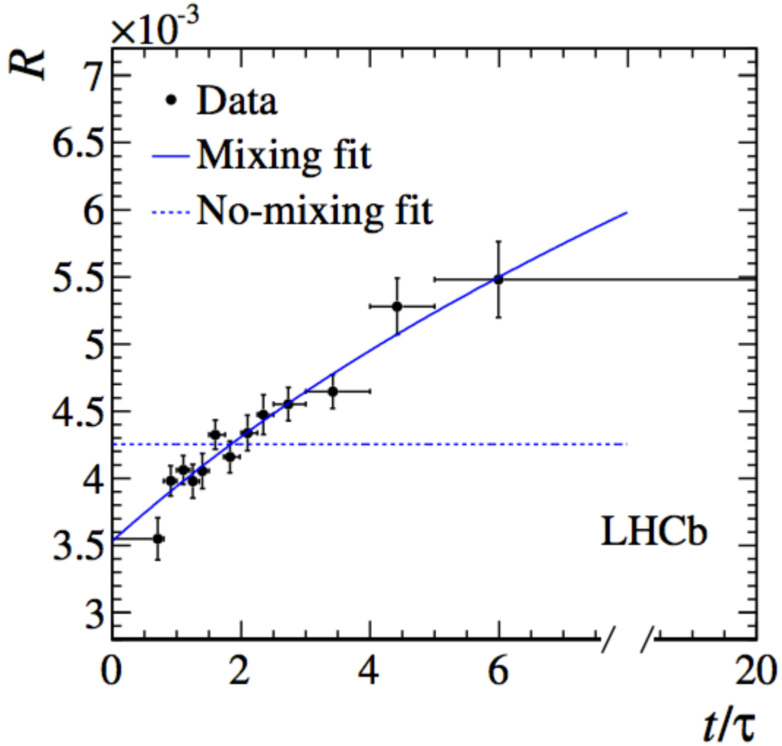

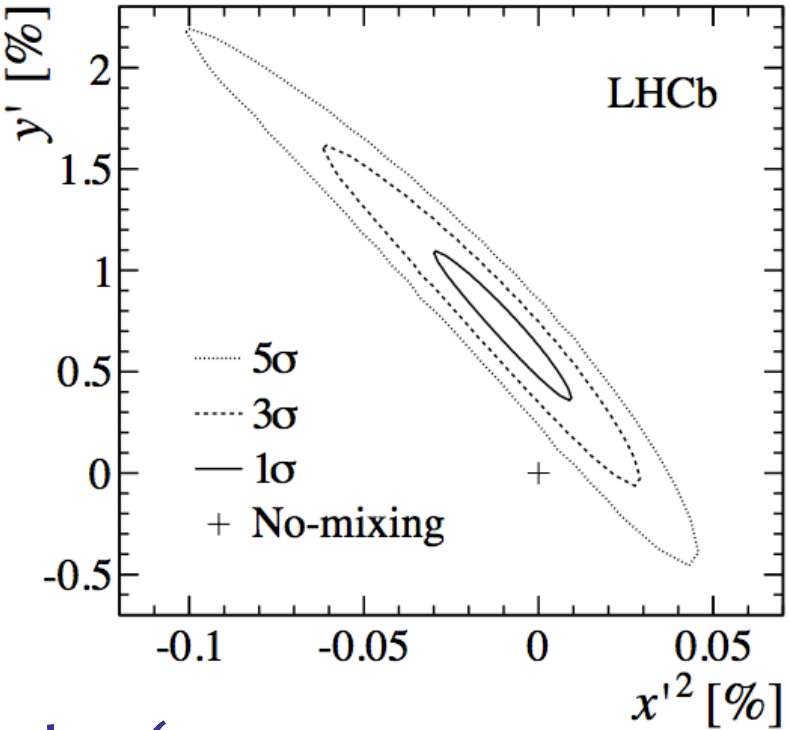

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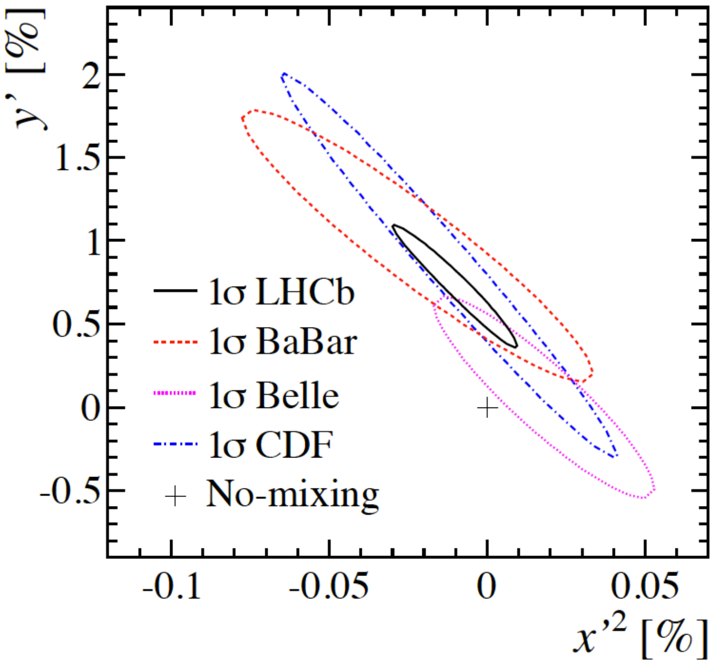
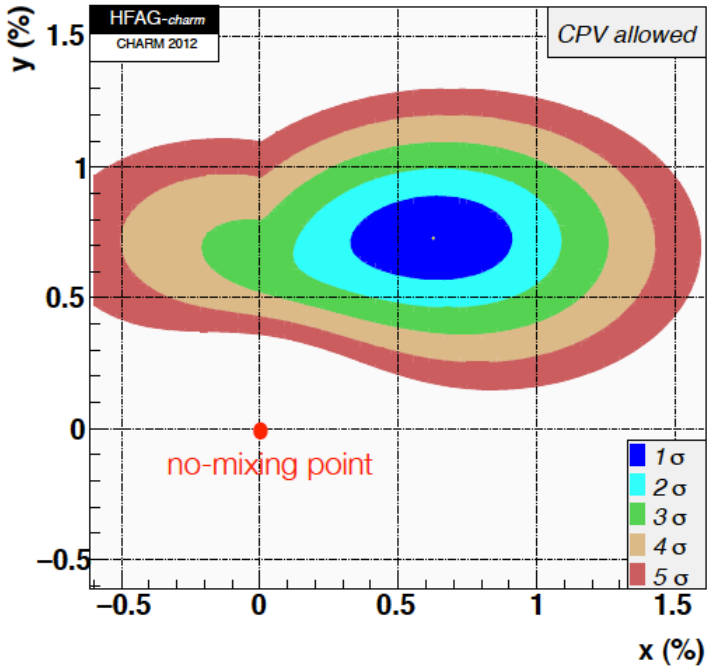
Experimental status



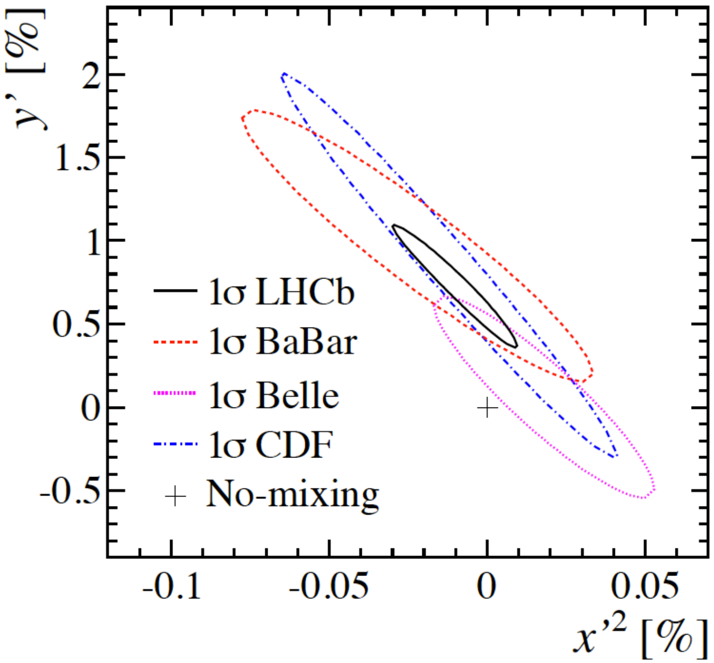


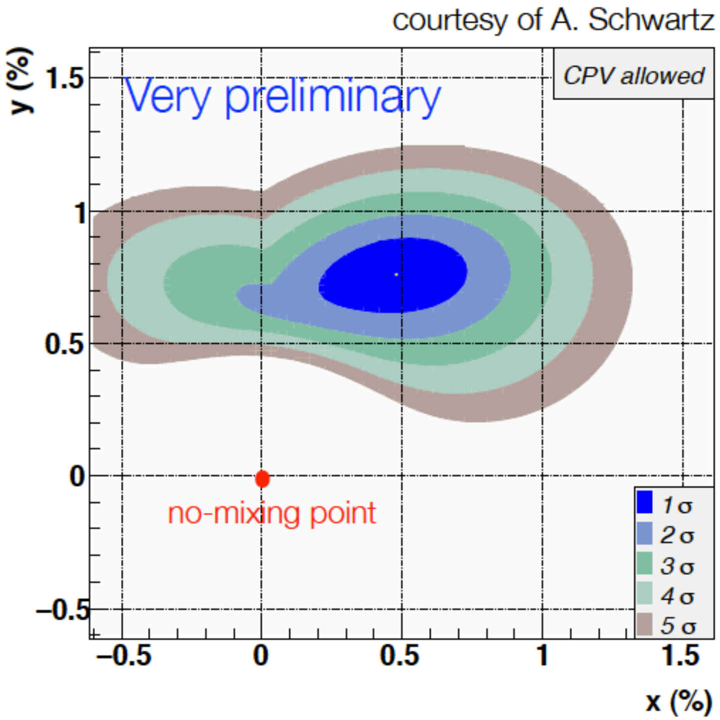
x = (0.63 ± 0.19)%
y = (0.73 ± 0.11)%

Experiment	R_D (10^{-3})	y' (10^{-3})	x'^2 (10^{-4})
LHCb	3.52 ± 0.15	7.2 ± 2.4	-0.9 ± 1.3
BaBar	3.03 ± 0.19	9.7 ± 5.4	-2.2 ± 3.7
Belle	3.64 ± 0.17	$0.6^{+4.0}_{-3.9}$	$1.8^{+2.1}_{-2.3}$
CDF	3.04 ± 0.55	8.5 ± 7.6	-1.2 ± 3.5

BaBar: Phys. Rev. Lett. 98 (2007) 211802
Belle: Phys. Rev. Lett. 96 (2006) 151801
CDF: Phys. Rev. Lett. 100 (2008) 121802

Experimental status





x = (0.63 ± 0.19)%
y = (0.73 ± 0.11)%

x = (0.48 ± 0.14)%
y = (0.76 ± 0.10)%

Experiment	R_D (10^{-3})	y' (10^{-3})	x'^2 (10^{-4})
LHCb	3.52 ± 0.15	7.2 ± 2.4	-0.9 ± 1.3
BaBar	3.03 ± 0.19	9.7 ± 5.4	-2.2 ± 3.7
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y_{CP} and A_{Γ}

Effective lifetime

- The effective lifetime of the D^0 or $\overline{D}^0$ is the average proper decay time of an initial state of D^0 or $\overline{D}^0$.
- In decay to a CP undefined final state, eg $K^{\mp}\pi^{\pm}$, effective lifetime is average of heavy and light mass eigenstate lifetimes, τ_{D^0}.
- For CP eigenstate, eg K^+K^-, effective lifetime is modified by mixing and interference between mixing and decay → sensitive to CPV.

y_{CP}

- Compares effective lifetime of CP undefined final state to that of CP eigenstate final state:

$$y_{CP} = \frac{\tau_{\text{eff}}(\mathrm{D}^0 \to \mathrm{K}^-\pi^+) + \tau_{\text{eff}}(\overline{\mathrm{D}}^0 \to \mathrm{K}^+\pi^-)}{\tau_{\text{eff}}(\mathrm{D}^0 \to \mathrm{K}^+\mathrm{K}^-) + \tau_{\text{eff}}(\overline{\mathrm{D}}^0 \to \mathrm{K}^+\mathrm{K}^-)} - 1,$$

$$\simeq \eta_{CP}\left[\left(1 + \frac{1}{8}A_m^2\right) y\cos\phi - \frac{1}{2}A_m x \sin\phi\right]$$

also ππ

where

$$\left|\frac{q}{p}\right|^{\pm 2} \equiv 1 \pm A_m$$

- Don't need D⁰ flavour tag.
- Equal to mixing parameter y in no CPV case.

A_Γ

- CP asymmetry of effective lifetime in decay to CP eigenstate final state:

$$A_\Gamma = \frac{\tau_{\text{eff}}(\overline{\text{D}}^0 \to \text{K}^+\text{K}^-) - \tau_{\text{eff}}(\text{D}^0 \to \text{K}^+\text{K}^-)}{\tau_{\text{eff}}(\overline{\text{D}}^0 \to \text{K}^+\text{K}^-) + \tau_{\text{eff}}(\text{D}^0 \to \text{K}^+\text{K}^-)}$$
$$\simeq \left[\frac{1}{2}(A_m + A_d)y\cos\phi - x\sin\phi\right]$$

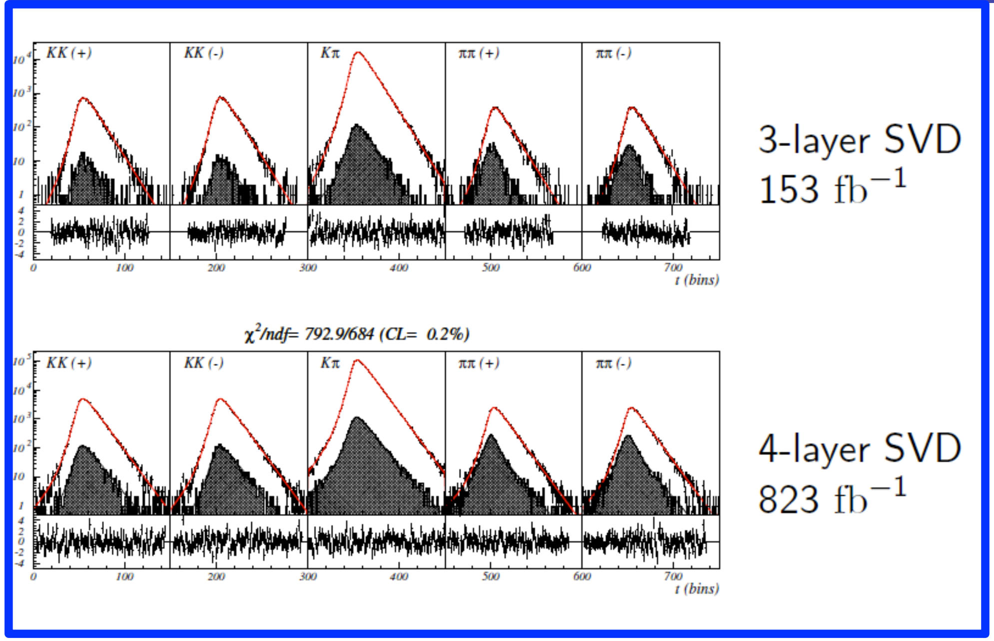
also $\pi\pi$

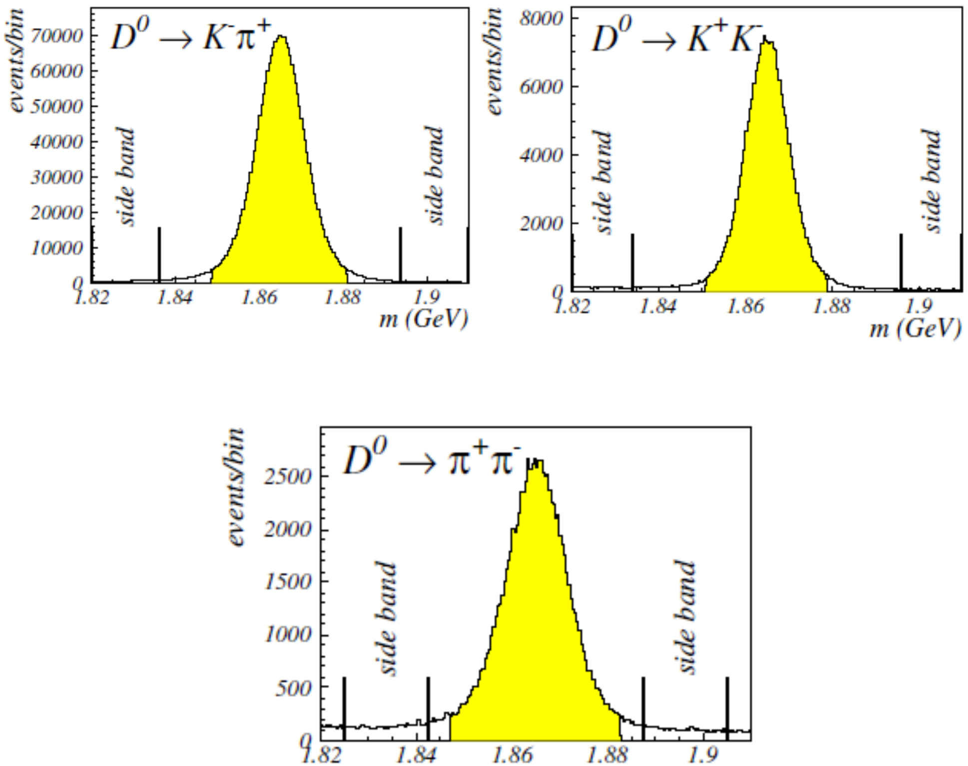
where

$$\left|\frac{\bar{A}_f}{A_f}\right|^{\pm 2} \equiv 1 \pm A_d$$

- D^0 flavour tag required – use $D^{*\pm} \rightarrow D^0\pi_s^{\pm}$
- Consistent with zero in no CPV case.

Recently measurements: Belle using 976 fb-1

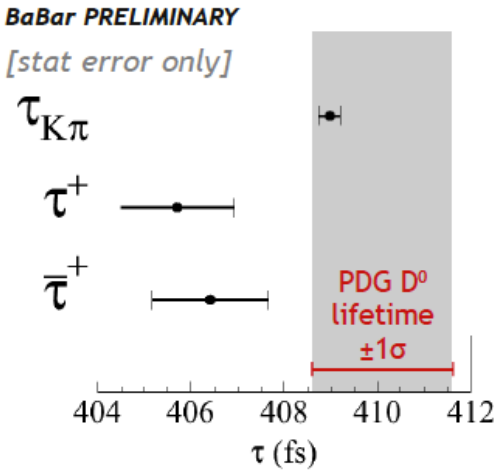


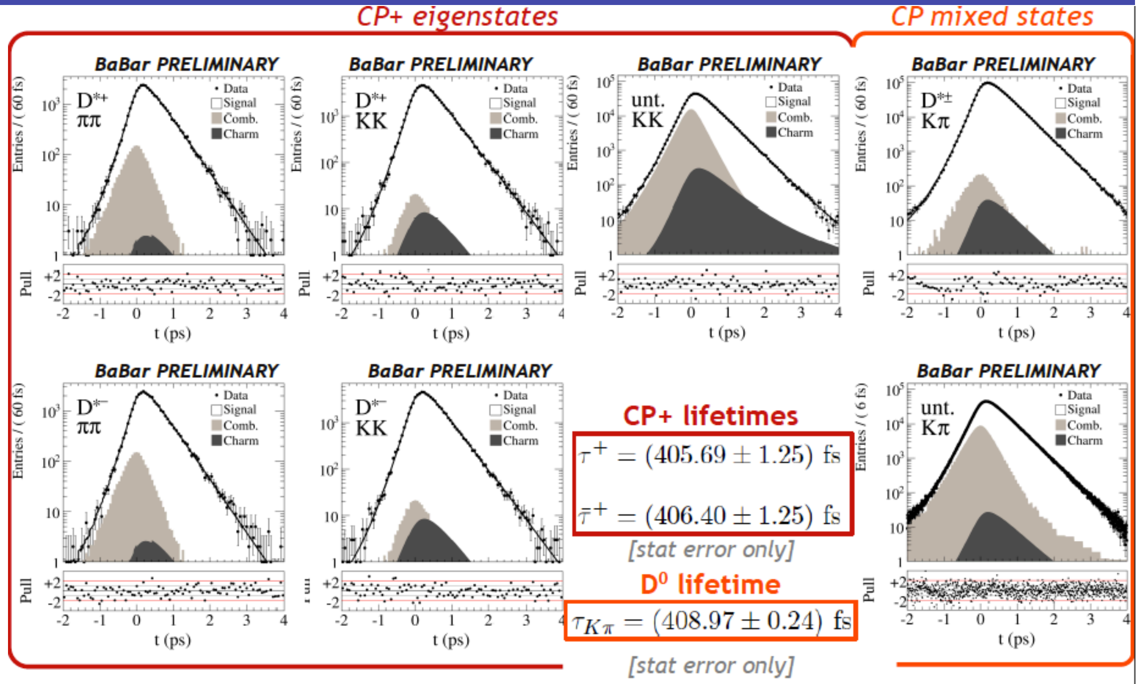


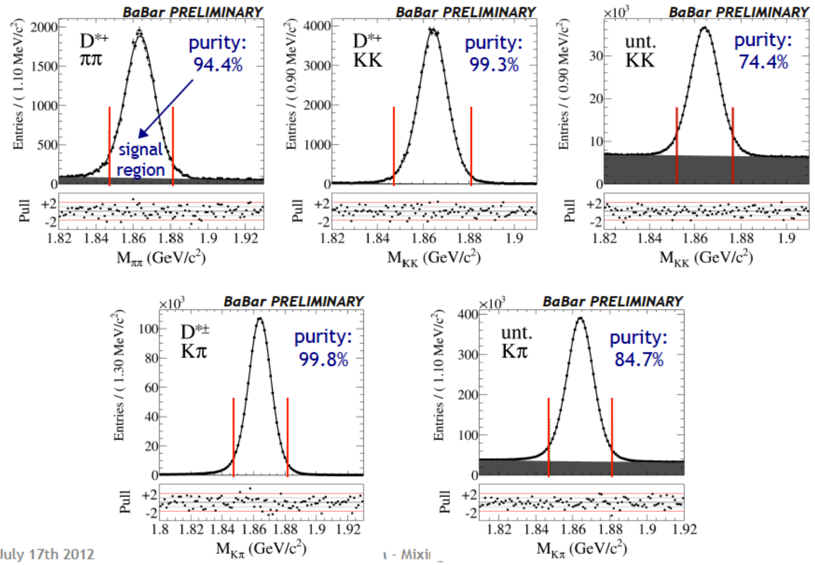
channel	KK	$K\pi$	$\pi\pi$
yield	242k	2.61M	114k
purity	98.0%	99.7%	92.9%

- y_{CP} =(+1.11±0.22±0.11)% : 4.5σ away from no mixing
- A_Γ =(-0.03±0.20±0.08)% : No indirect CPV
- $\tau(D^0 \to K^-\pi^+)$=(408.56±0.54) fs : consistent with PDG

Recently measurements: BaBar using 976 fb-1







July 17th 2012

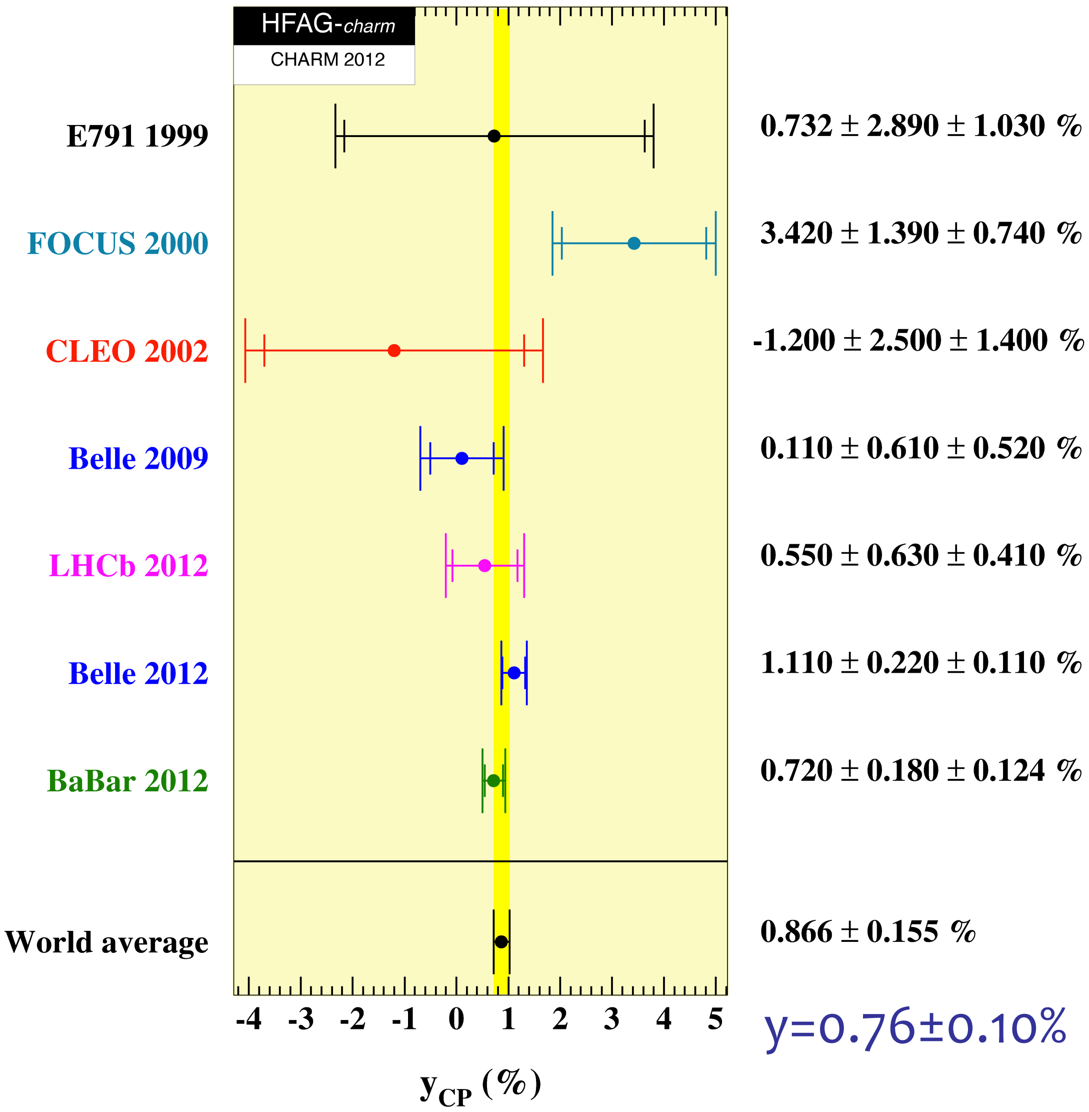
BaBar PRELIMINARY

$$y_{CP} = [0.720 \pm 0.180(\text{stat}) \pm 0.124(\text{syst})]\%$$

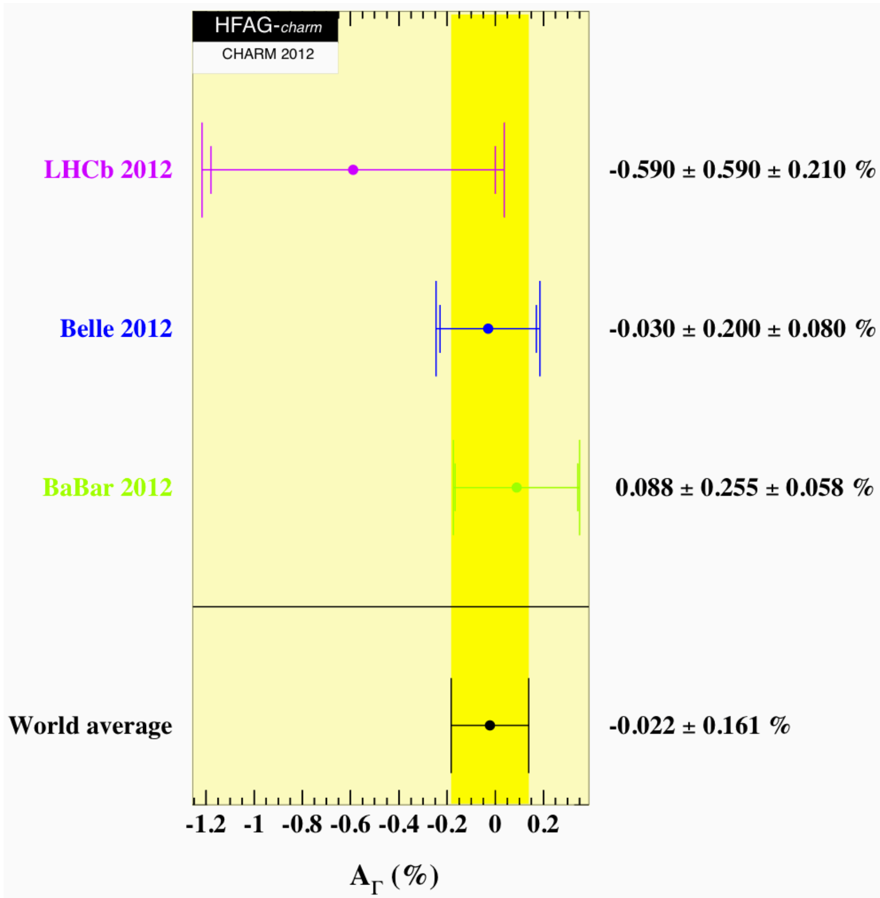
$$A_\Gamma = [0.088 \pm 0.255(\text{stat}) \pm 0.058(\text{syst})]\%$$

➔ exclude no-mixing hypothesis @ 3.3σ
➔ no CP Violation observed

HFAG y_{CP} and A_Γ



y=0.76±0.10%



time-integrated CP asymmetry → ΔA_{CP}

Observable in time-integrated CP asymmetry

- We are looking for CP asymmetry defined as

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

with f=KK and f=ππ and

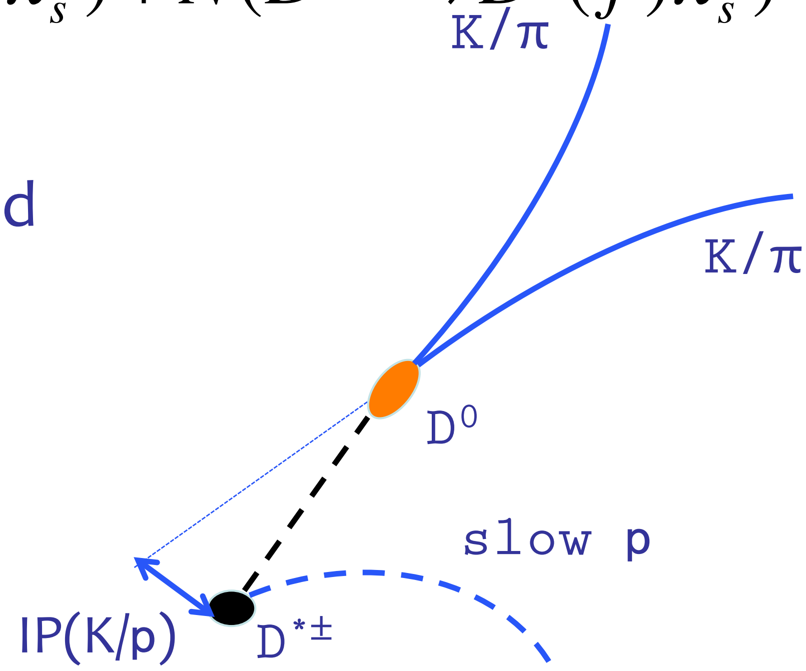
- The flavor of the initial state (D^0 or $\overline{D^0}$) is tagged by requiring a $D^{*+} \to D^0\pi^+_s$ decay, with the flavour determined by the charge of the slow pion (π^+_s)
- "slow" because of its lower average momentum (~5 GeV/c) with respect to the D^0 daughters (~30 GeV/c)

Observable in time-integrated CP asymmetry

- The raw asymmetry for tagged D⁰ decays to a final state f is given by

$$A_{raw}(f) = \frac{N(D^{*+} \to D^0(f)\pi_s^+) - N(D^{*-} \to \overline{D}^0(\overline{f})\pi_s^-)}{N(D^{*+} \to D^0(f)\pi_s^+) + N(D^{*-} \to \overline{D}^0(\overline{f})\pi_s^-)}$$

- where N(X) refers to the number of reconstructed events of decay X after background subtraction



Observable in time-integrated CP asymmetry

- What we measure is the physical asymmetry plus asymmetries due both to production and detector effects

$$A_{\rm raw}(f) = A_{CP}(f) + A_{\rm D}(f) + A_{\rm D}(\pi_{\rm s}) + A_{\rm P}(D^{*+})$$

Observable in time-integrated CP asymmetry

- What we measure is the physical asymmetry plus asymmetries due both to production and detector effects

$$A_{\mathrm{raw}}(f) = A_{CP}(f) + A_{\mathrm{D}}(f) + A_{\mathrm{D}}(\pi_{\mathrm{s}}) + A_{\mathrm{P}}(D^{*+})$$

  - … which is true: O(%)

Observable in time-integrated CP asymmetry

- What we measure is the physical asymmetry plus asymmetries due both to production and detector effects

$$A_{\rm raw}(f) = \boxed{A_{CP}(f)} + A_{\rm D}(f) + A_{\rm D}(\pi_{\rm s}) + A_{\rm P}(D^{*+})$$

Physics CP asymmetry

Observable in time-integrated CP asymmetry

- What we measure is the physical asymmetry plus asymmetries due both to production and detector effects

$$A_{\mathrm{raw}}(f) = A_{CP}(f) + A_{\mathrm{D}}(f) + A_{\mathrm{D}}(\pi_{\mathrm{s}}) + A_{\mathrm{P}}(D^{*+})$$

Physics CP asymmetry

Detection asymmetry of D^0

Time-integrated CP asymmetry

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Physics CP asymmetry

Detection asymmetry of D^0

Detection asymmetry of “slow” pions

Observable in time-integrated CP asymmetry

- What we measure is the physical asymmetry plus asymmetries due both to production and detector effects

$$A_{\mathrm{raw}}(f) = A_{CP}(f) + A_{\mathrm{D}}(f) + A_{\mathrm{D}}(\pi_{\mathrm{s}}) + A_{\mathrm{P}}(D^{*+})$$

Physics CP asymmetry

Detection asymmetry of D^0

Production asymmetry

Detection asymmetry of "slow" pions

- $D/\overline{D}$ (as well as $B/\overline{B}$) production asymmetries need to be taken into account in proton-proton interactions at LHC

Observable in time-integrated CP asymmetry

- What we measure is the physical asymmetry plus asymmetries due both to production and detector effects

$$A_{\mathrm{raw}}(f) = A_{CP}(f) + A_{D}(f) + A_{\mathrm{D}}(\pi_{\mathrm{s}}) + A_{\mathrm{P}}(D^{*+})$$

Physics CP asymmetry

Detection asymmetry of D^0

Production asymmetry

Detection asymmetry of "slow" pions

- No detection asymmetry for D^0 decays to K^-K^+ or $\pi^-\pi^+$

Observable in time-integrated CP asymmetry

- What we measure is the physical asymmetry plus asymmetries due both to production and detector effects

$$A_{\mathrm{raw}}(f) = A_{CP}(f) + A_{\mathrm{D}}(f) + A_{\mathrm{D}}(\pi_{\mathrm{s}}) + A_{\mathrm{P}}(D^{*+})$$

Physics CP asymmetry

Detection asymmetry of D^0

Production asymmetry

Detection asymmetry of "slow" pions

- No production asymmetry in e^+e^- and $p\bar{p}$ interaction

Observable in time-integrated CP asymmetry

- … if we take the raw asymmetry difference

$$\Delta A_{CP} \equiv A_{raw}(KK) - A_{raw}(\pi\pi) = A_{CP}(KK) - A_{CP}(\pi\pi)$$

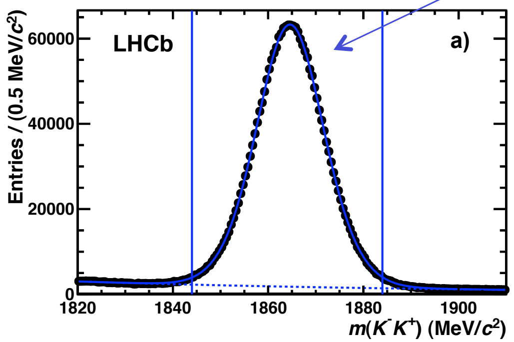
- the production and the “slow” pion detection asymmetries will cancel

Recently measurements: LHCb with 0.6/fb

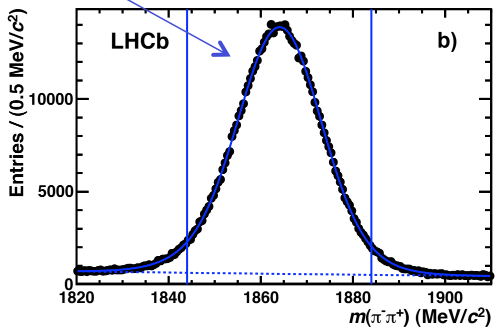
Invariant mass of K^-K^+ and $\pi^-\pi^+$

This is NOT a Monte Carlo

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



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



D^0 decays come from $D^{*+} \to D^0\pi^+$ decays in region:

$0 < \delta m < 15$ MeV

$\delta m = m(D^0\pi^+) - m(D^0) - m(\pi^+)$

For window mass:

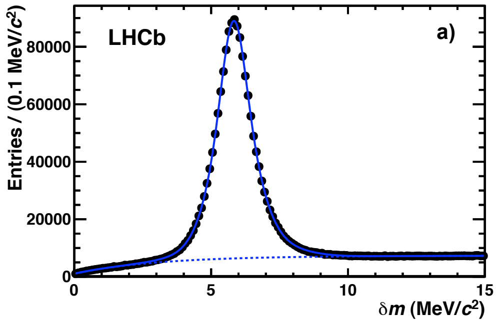
$1844 < m(D^0) < 1884$ MeV

K^-K^+: 1.4million events

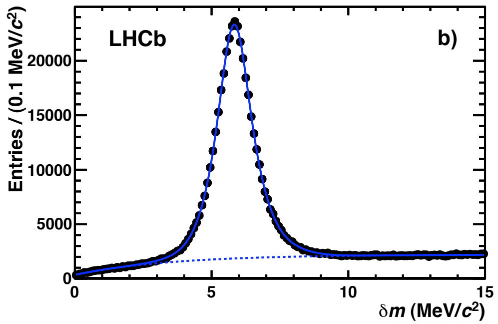
$\pi^-\pi^+$: 381k events

L = 0.62/fb (2011)

$1844 < m(D^0 \to K^-K^+) < 1884$MeV



$1844 < m(D^0 \to \pi^-\pi^+) < 1884$MeV



From simultaneous fits for both distributions (D^0 and anti-D^0) to δm we measure:

$$\Delta A_{CP} \equiv A_{CP}(K^+K^-) - A_{CP}(\pi^+\pi^-)$$

$$\Delta A_{CP} = [-0.82 \pm 0.21^{stat} \pm 0.11^{syst}]\%$$

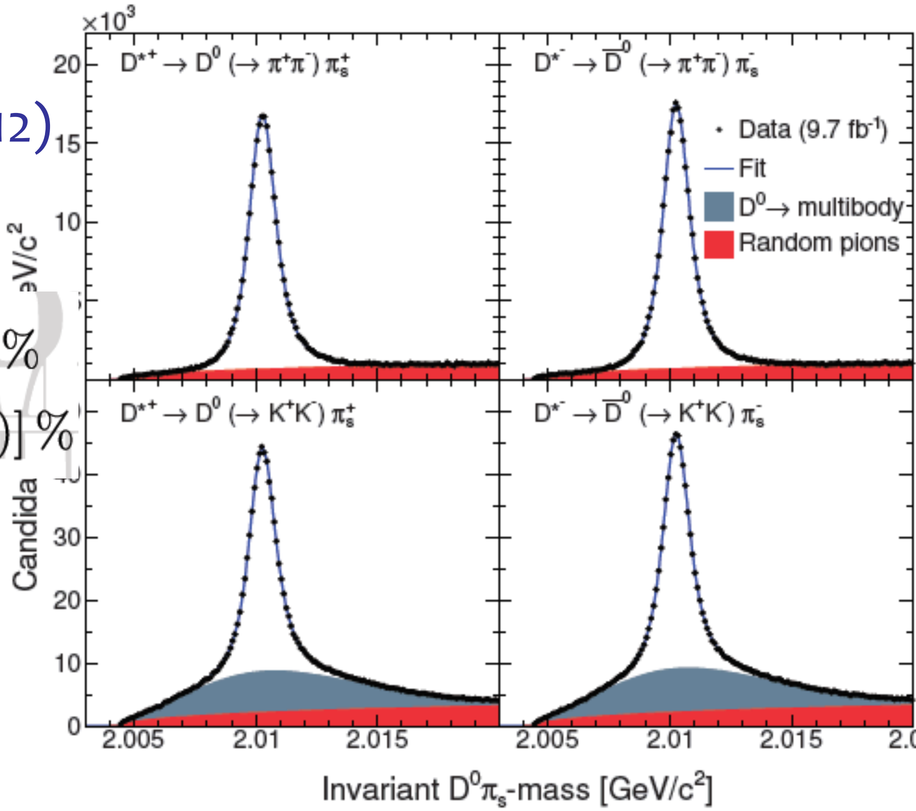
significance: **3.5 σ**

Phys.Rev.Lett 108(2012)111602

Recently measurements: CDF with 9.7/fb

$$\Delta A_{CP} = (-0.62 \pm 0.21 \pm 0.10)\%$$

Phys. Rev. Lett. 109, 111801 (2012)

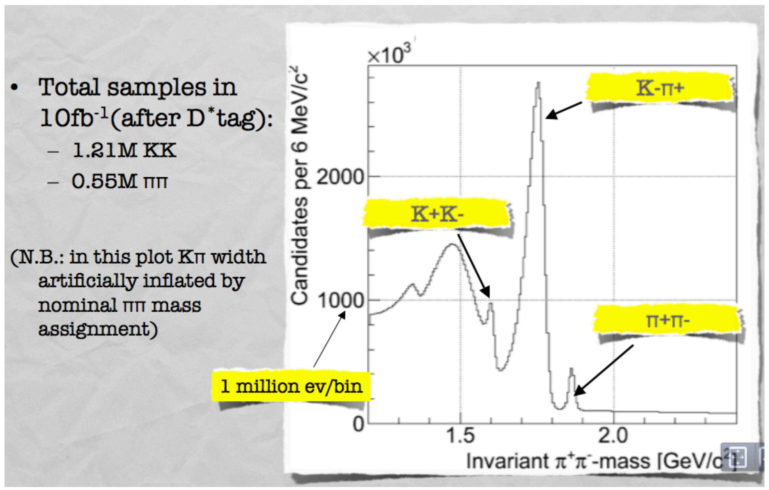


Individual Mode Asymmetries

$$A_{CP}(\pi^+\pi^-) = [0.22 \pm 0.24(\text{stat}) \pm 0.11(\text{sys})]\,\%$$

$$A_{CP}(K^+K^-) = [-0.24 \pm 0.22(\text{stat}) \pm 0.09(\text{sys})]\,\%$$

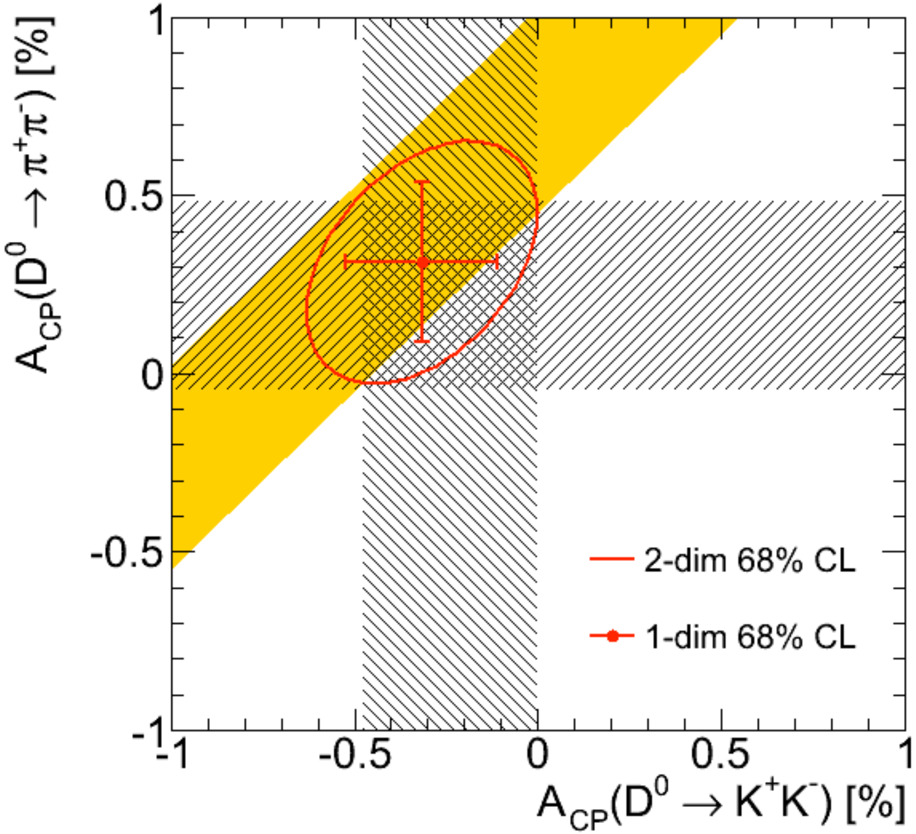
PRD 85, 012009 (2012)



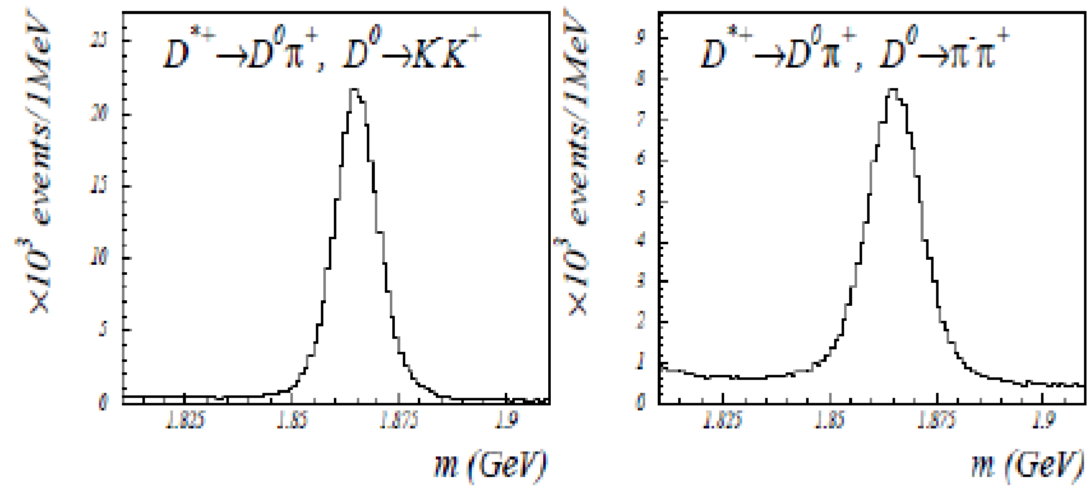
Combined measurement

$A_{CP}(D^0 \to \pi^+\pi^-) = (+0.31 \pm 0.22)\%$
$A_{CP}(D^0 \to K^+K^-) = (-0.32 \pm 0.21)\%$

- Can combine the ΔA_{CP} result with the $A_{CP}(\pi\pi)$ and $A_{CP}(KK)$ result
  - remove events from the ΔA_{CP} analysis that were used in the other analysis, to create a statistically independent sample
  - roughly 15% improvement on uncertainty from the earlier $A_{CP}(\pi\pi)$ and $A_{CP}(KK)$ result

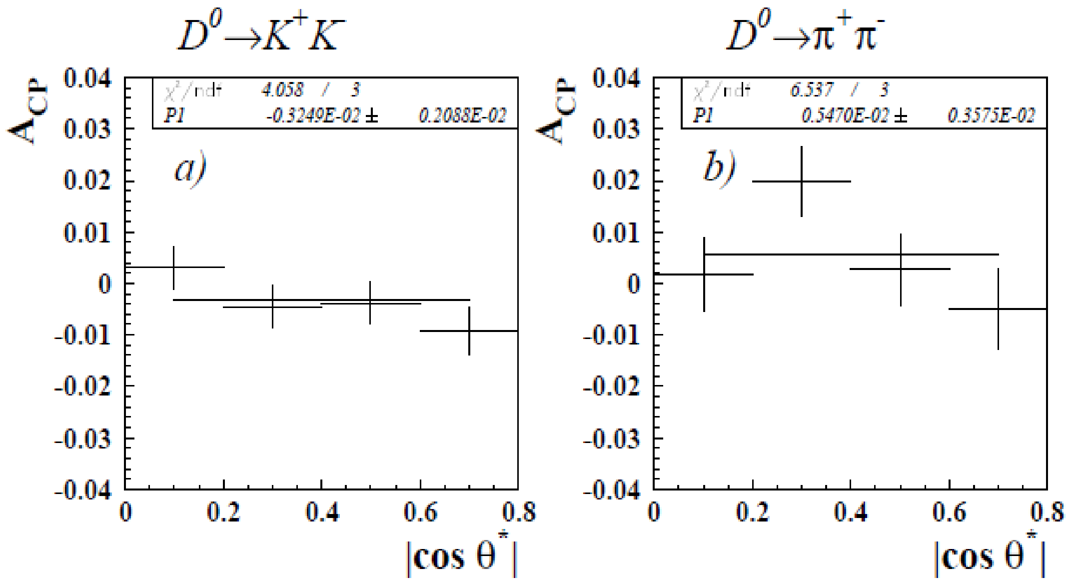


Recently measurements: Belle with 976/fb



Belle preliminary using 976 fb^{-1}

yield
$D^0 \rightarrow K^+K^-$ ~282k
$D^0 \rightarrow \pi^+\pi^-$ ~123k



$A_{CP}^{D^0\to K^+K^-}$	(-0.32±0.21±0.09)%
$A_{CP}^{D^0\to \pi^+\pi^-}$	(+0.55±0.36±0.09)%
ΔA_{CP}	(-0.87±0.41±0.06)%

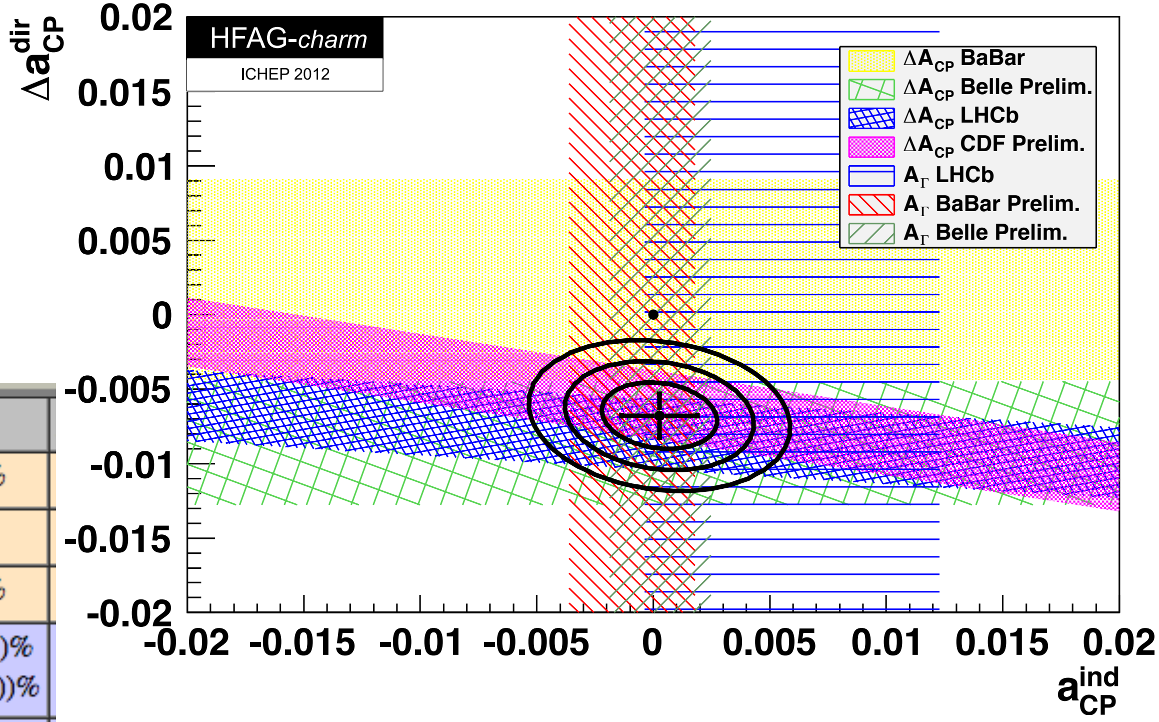
- $A_{CP}^{D^0\to K^+K^-}$: best sensitivity
- ΔA_{CP} : 2.1σ away from zero

Summary of ΔA_{CP}

$$a_{CP}^{ind} = (0.027 \pm 0.163)\%$$

$$\Delta a_{CP}^{dir} = (-0.678 \pm 0.147)\%$$

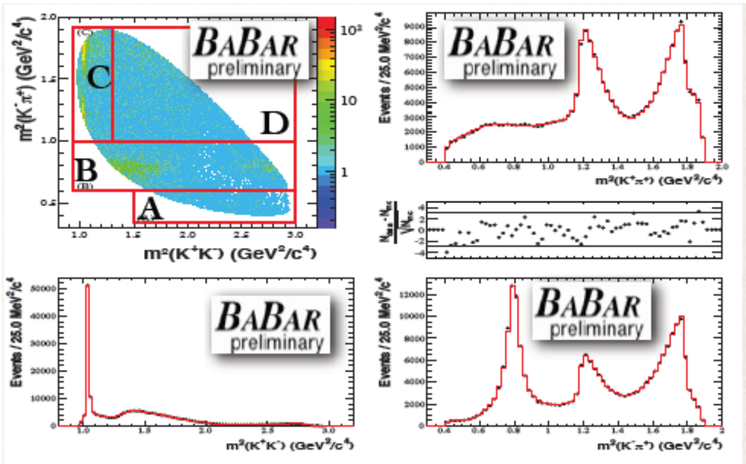
Year	Experiment	Results
2012	Belle Prelim.	$A_\Gamma = (-0.03 \pm 0.20\ (\text{stat.}) \pm 0.08\ (\text{syst.}))\%$
2012	BaBar Prelim.	$A_\Gamma = (0.09 \pm 0.26\ (\text{stat.}) \pm 0.06\ (\text{syst.}))\%$
2011	LHCb	$A_\Gamma = (-0.59 \pm 0.59\ (\text{stat.}) \pm 0.21\ (\text{syst.}))\%$
2008	BaBar	$A_{CP}(KK) = (0.00 \pm 0.34\ (\text{stat.}) \pm 0.13\ (\text{syst.}))\%$ $A_{CP}(\pi\pi) = (-0.24 \pm 0.52\ (\text{stat.}) \pm 0.22\ (\text{syst.}))\%$
2012	Belle Prelim.	$\Delta A_{CP} = (-0.87 \pm 0.41\ (\text{stat.}) \pm 0.06\ (\text{syst.}))\%$
2011	LHCb	$\Delta A_{CP} = (-0.82 \pm 0.21\ (\text{stat.}) \pm 0.11\ (\text{syst.}))\%$
2012	CDF Prelim.	$\Delta A_{CP} = (-0.62 \pm 0.21\ (\text{stat.}) \pm 0.10\ (\text{syst.}))\%$
	Fit Result	**Agreement with no CP violation** **CL = 2.0x10^{-5}**

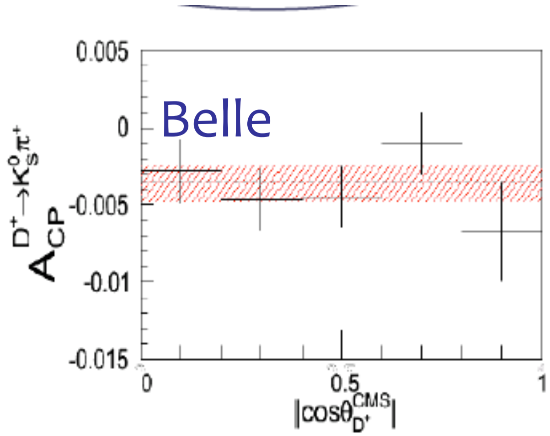


$$A_{CP}(h^+h^-) = A_{CP}^{\rm dir}(h^+h^-) + \frac{\langle t \rangle}{\tau} A_{CP}^{\rm ind}(h^+h^-)$$

Search for time integrated CP violation D→3 body and D→4 body

- Need at least 2 amplitudes with different weak and strong phases:
  - Singly Cabibbo Suppressed (SCS): tree + penguin
  - Cabibbo Favoured (CF) + Doubly Cabibbo Suppressed (DCS)
- Several decays explored so far by, BaBar, Belle, CDF and LHCb
  - $D^{\pm} \to KK\pi$, $Ds \to K_s^0 K(\pi)$, $D^{\pm} \to K_s^0 K$
- No CPV observed!

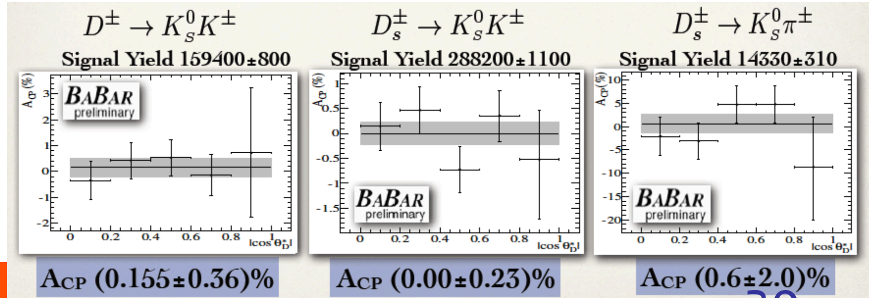




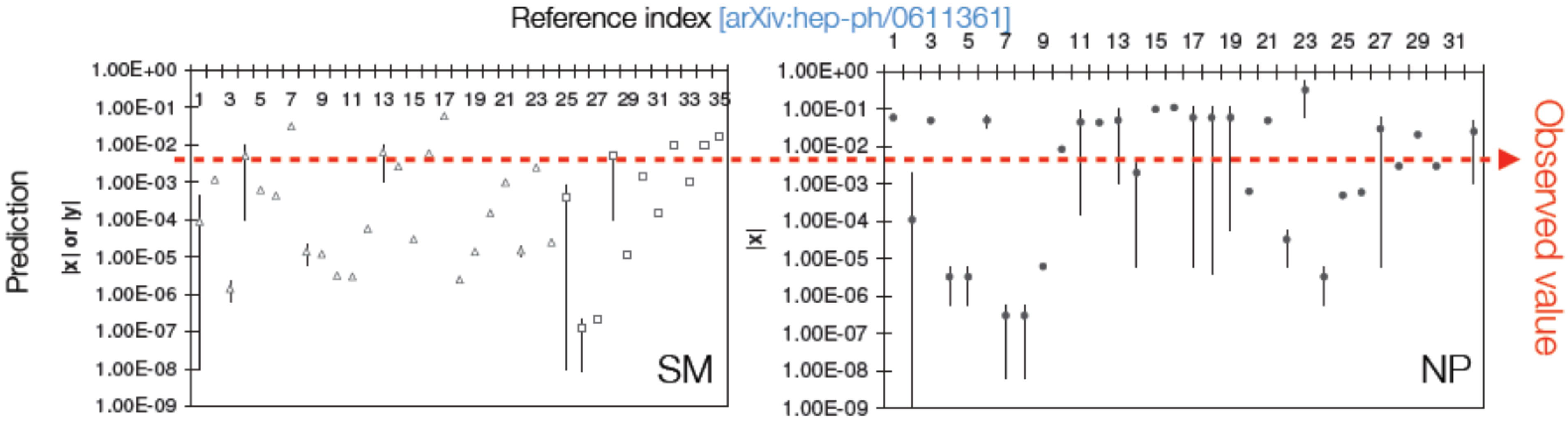
- $A_{CP}^{D^+ \to K_S^0 \pi^+}$ = (-0.363±0.094±0.067)%

  consistent with CPV in K_s^0 system

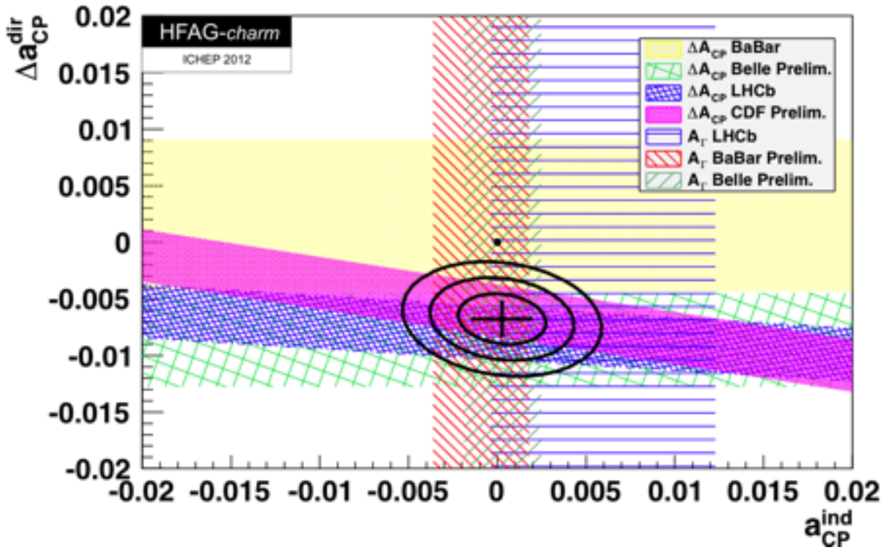
Dalitz plot region	$N(D^+)$	$\epsilon(D^+)$[%]	$N(D^-)$	$\epsilon(D^-)$[%]	A_{CP}[%]
(A) Below $\bar{K}^*(892)^0$	1882 ± 70	7.00	1859 ± 90	6.97	-0.65 ± 1.64 ± 1.73
(B) $\bar{K}^*(892)^0$	36770 ± 251	7.53	36262 ± 257	7.53	-0.28 ± 0.37 ± 0.21
(C) $\phi(1020)$	48856 ± 289	8.57	48009 ± 289	8.54	-0.26 ± 0.32 ± 0.45
(D) Above $\bar{K}^*(892)^0$ and $\phi(1020)$	25616 ± 244	8.01	24560 ± 242	8.00	1.05 ± 0.45 ± 0.31



"Charming puzzle"



- Observed mixing rate (as well as direct CPV) is on the upper end of most standard model predictions
- Could be interpreted as a hint for the presence of new physics
- More precise measurements are needed to clear the picture



Conclusions

- The evidence of CPV reported by LHCb and CDF has renewed the interest of the physics community into charm, as a place where to look for NP
- No CPV observed with the latest 2012 result with several decay modes
- All experiments extracted the maximum information from their data, except LHCb which will play a fundamental rule in the next feature (3/fb on tape!)
    - Expected ΔA_{CP} update from D→hh and semi-leptonic with 1/fb for Moriond QCD 2013
    - Expected soon result A_Γ and y_{CP} and many others results from D→3-4 bodies
- In the near future (next run) LHCb will collect a huge amount of data, the challenge for discovering CPV will be to have systematic uncertainties under control

Backup

Search for direct CPV

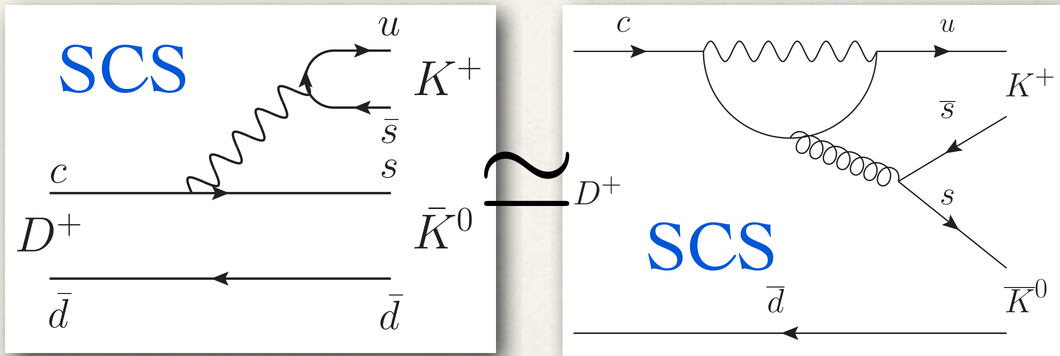
- Need at least 2 amplitudes with different weak and strong phases:
  - Singly Cabibbo Suppressed (SCS): tree + penguin
  - Cabibbo Favoured (CF) + Doubly Cabibbo Suppressed (DCS)
- Time integrated CP asymmetries:

$$A_{CP} = \frac{\mathcal{B}\left(D_{(s)} \to f\right) - \mathcal{B}\left(\overline{D}_{(s)} \to \overline{f}\right)}{\mathcal{B}\left(D_{(s)} \to f\right) + \mathcal{B}\left(\overline{D}_{(s)} \to \overline{f}\right)}$$

- Contribution from $K^0 - \overline{K}^0$ mixing: **+(-)0.332±0.006%** when a K^0 ($\overline{K}^0$) is in the final state
- Three-body decays CPV effects can be enhanced in certain Dalitz Plot (DP) regions
- DP model-dependent and model-independent searches

$D^\pm \to K^+K^-\pi^\pm$	SCS tree+penguin
$D_s^\pm \to K_S^0 K^\pm$	CF + DCS
$D^\pm \to K_S^0 K^\pm$	SCS tree+penguin
$D_s^\pm \to K_S^0 \pi^\pm$	SCS tree+penguin

$$D^\pm \to K_S^0 K^\pm$$



$$CPV \sim 0.1\%$$