Orsay 7/'07

"This Year a New Era Has Commenced & You Can Say You Have Been Present" -- Goethe, the Cannonade of Valmy and Charm Dynamics

Ikaros Bigi (Notre Dame du Lac)

Cannonade of Valmy: 1792 battle in Northern France that saved `New' France from having (that era's) Standard Model of governance imposed by the `Old' powers.

Tactically a draw, strategically a French victory

Goethe's statement to the Prussian soldiers at camp fire:
'From this place and from this day forth commences a new era in the world's history, and you can all say that you were present at its birth.'

But written up much later; i.e. Goethe -- not unheard of for a theorist -- bragged about a *post*-diction.

in 2007: Strong evidence has surfaced for D oscillations,which
could become conclusive by the summer/fall.

A tactical draw in the struggle for gaps in the SM --
x_D & y_D while possibly generated by SM alone,
could contain large contributions from NP --

yet a strategic victory in sight:

CP studies in the future will decide the issue

possibly paving the way for a New SM to emerge!

A historical analogy:

We had been talking about $\cancel{CP}$ in B decays for years
without much resonance - till B oscill. were observed!

- ☹ numerical size much smaller in D decays,
- ☹ no definitive predictions for $\cancel{CP}$ from New Physics
- ☺ yet SM `background' even tinier &
- ☺ experimentalists have become more experienced

The Menu

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II $\cancel{CP}$ with & without D^0 Oscillations

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Prologue: New Physics Scenarios & Uniqueness of Charm

- New Physics in general induces FCNC
  - ✍ their couplings could be substantially stronger for Up-type than for Down-type quarks

(actually happens in some models which `brush the dirt of FCNC in the down-type sector under rug of the up-type sector')

- 2 conceivable scenarios
  - ❑ specific New Physics effects observable/ identifiable in charm decays only (much smaller SM `background')
  - ❑ New Physics effects observable in dynamics of down-type quarks -- B & K -- as well as up-type quarks
    - ☞ still essential complementary info on New Physics!

up-type quarks: u $\boxed{c}$ t

only up-type quark allowing full range of probes for New Phys.

- ☞ top quarks do not hadronize ⟶ no $T^0 - \overline{T}^0$ oscillations

  hadronization while hard to force under theor. control

  enhances observability of $\cancel{C}P$

- ☞ up quarks: no π^0-π^0 oscillations possible

  CP asymmetries basically ruled out by CPT

basic contention:
charm transitions are a unique portal for obtaining a novel access to flavour dynamics with the experimental situation being a priori favourable (apart from absence of Cabibbo suppression)!

I Inconclusiveness in Interpretation of D^0 Oscillations

(1.1) Basics

☺ fascinating quantum mechanical phenomenon

😐 ambiguous probe for New Physics (=NP)

☺ important ingredient for NP CP asymm. in D^0 decays

$$x_D = \frac{\Delta m_D}{\Gamma_D} \qquad y_D = \frac{\Delta\Gamma_D}{2\Gamma_D}$$

general expectations

- $\Delta\Gamma$: on-shell contributions
  - ➥ ~ insensitive to New Physics
- Δm: virtual intermediate states
  - ➥ sensitive to New Physics

$x_D \sim \mathcal{O}$(few %) conceivable in models

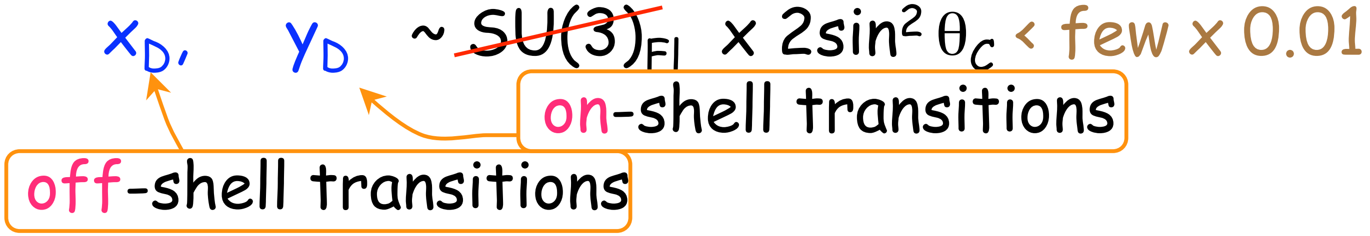
☛ central theoretical issue:

duality at the charm scale?

- ➻ more averaging in x_D than in y_D
- ➥ duality better in x_D than in y_D

D^0-$\overline{D}^0$ oscillations `slow' in the SM

How `slow' is `slow'?



$x_D, \quad y_D \sim \cancel{SU(3)}_{Fl} \times 2\sin^2\theta_C <$ few x 0.01

on-shell transitions

off-shell transitions

While the history of predicting x_D, y_D does not fill one of the glory pages of theoret. HEP, we are not completely off the mark either -- see for example:

hep-ph/9712475 (Lecture notes from 1997):
`CP Violation -- an Essential Mystery in Nature's Grand Design'
p.57f:"*It is often stated that the SM predicts … $x_D, y_D \leq 3\times10^{-4}$ I myself am somewhat flabbergasted by the boldness of such predictions… I cannot see how anyone can make such a claim with the required confidence…[my estimate] $x_D, y_D|_{SM} \leq 10^{-2}$.*"

2 general comments:

(A) $x_D << y_D$ *not* a natural scenario!

If $D^0 \rightarrow f \rightarrow \bar{D}^0$ via an *on*-shell final state

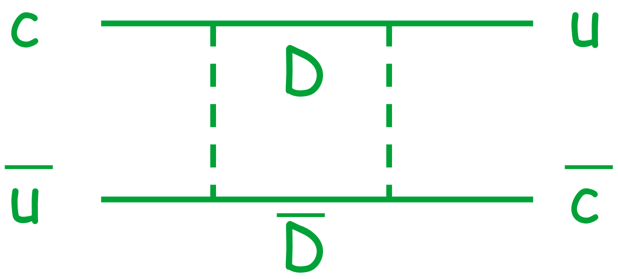
then $D^0 \rightarrow "f" \rightarrow \bar{D}^0$ via an *off*-shell final state

➥ dispersion relation connects Δm_D and $\Delta\Gamma_D$

(B)

GIM suppression $(m_s/m_c)^4$ of usual quark box diagram un-typically severe!

➥ statement oscillations of mesons built from up-type quarks teach us about down-type quark dynamics



2 general comments:

(A) $x_D < y_D$ natural in SM, yet $x_D \ll y_D$ *not*!

If $D^0 \rightarrow f \rightarrow \overline{D}^0$ via an *on*-shell final state

then $D^0 \rightarrow$ "f" $\rightarrow \overline{D}^0$ via an *off*-shell final state

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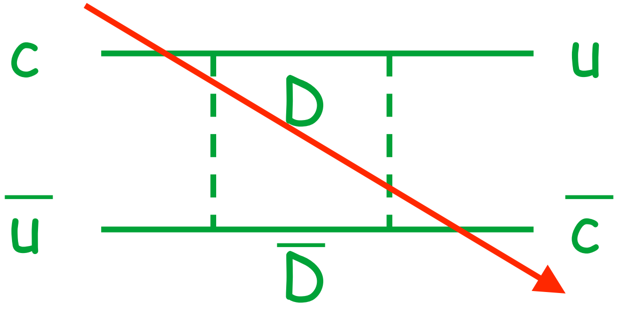


is misleading

(1.2) Theoretical Predictions

2 complement. approaches to evaluating Δm_D and $\Delta\Gamma_D$ in the SM:

`inclusive' vs. `exclusive'

➼ `inclusive':

quarks & gluons + nonperturb. contributions

OPE in powers of $1/m_c$, m_s, μ_{had} (quark condensates)

Uraltsev,IB,Nucl.Phys.B592('01)

$m_s^2 m_{had}^4/m_c^6$ (vs. m_s^4/m_c^4)

power counting in $1/m_c$ can be quite iffy

leading contrib. not given by partonic term

- $x_D\,(SM)|_{OPE}$, $y_D\,(SM)|_{OPE}$ ~ $\mathcal{O}(10^{-3})$ [$x_D\,(SM) < y_D\,(SM)$]
- unlikely uncertainties can be reduced
- violations of quark-hadron duality due to proximity of thresholds could enhance in particular y_D

- 'exclusive':

hadrons

$SU(3)_{Fl}$ breaking from phase space for 2-, 3-, 4-body modes

A. Falk et al., Phys. Rev. D65 (`02)

$$y_D\,(SM) \sim 0.01 \xrightarrow[\text{dispersion relation}]{} 0.001 \leq |x_D\,(SM)| \leq 0.01$$

☞ my judgment: 2 questions

- ❑ most likely value in SM? $x_D\,(SM),\ y_D\,(SM) \sim \mathcal{O}(10^{-3})$!
- ❑ can one rule out 0.01 ? No!

(1.3) Data

(1.3.1) Lifetimes of $D^0 \rightarrow K^+K^-, \pi^+\pi^-$ vs. $K^-\pi^+$

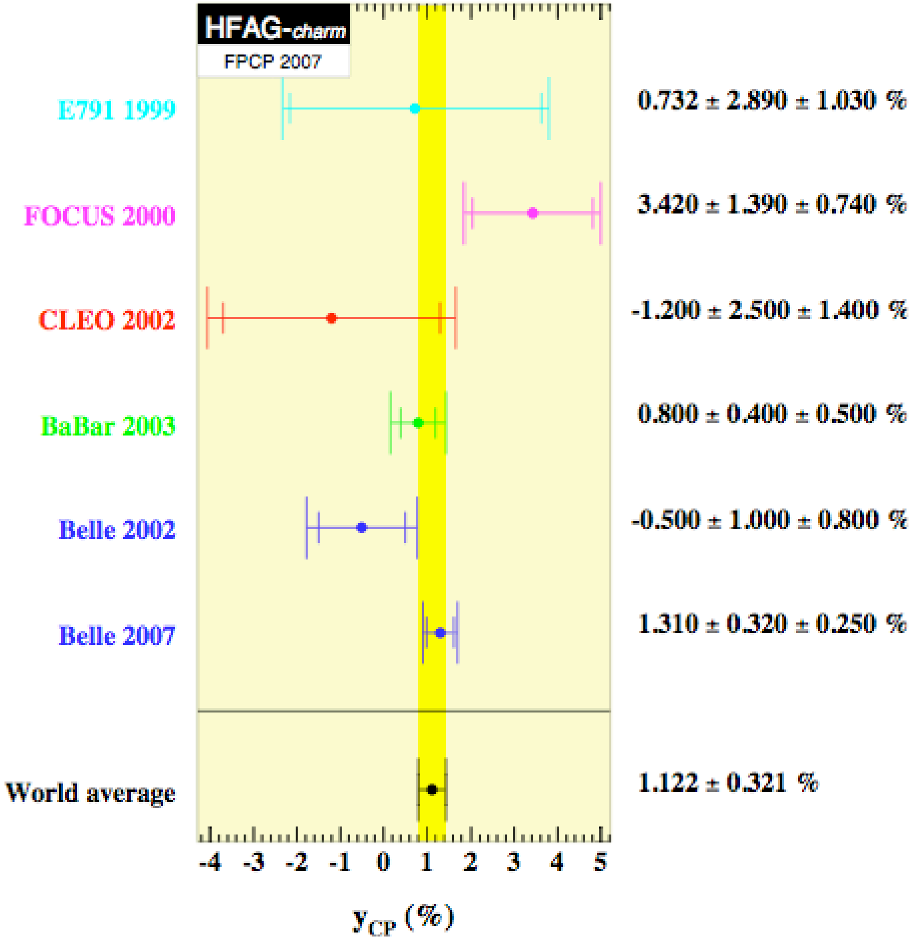
$y_{CP} = \bar{\tau}/\tau_{CP+} - 1$

with CP invariance $y_{CP} = y_D$

BELLE:

$y_{CP} = (1.31 \pm 0.30 \pm 0.15)\%$

[$\neq 0$ with 3.2 σ]



(1.3.2) $D^0(t) \rightarrow K^+\pi^-$

$$\text{Rate}(D^0(t) \rightarrow K^+\pi^-) \propto$$
$$[|T_{DCS}|^2 + y'_D\,(t\Gamma)T_{DCS}T_{osc} + R_M\,(t\Gamma)^2\,|T_{osc}|^2]$$

$y'_D = -\,x_D \sin\delta + y_D \cos\delta$, $x'_D = x_D \cos\delta + y_D \sin\delta$

$R_M = (x_D{}^2 + y_D{}^2)/2$

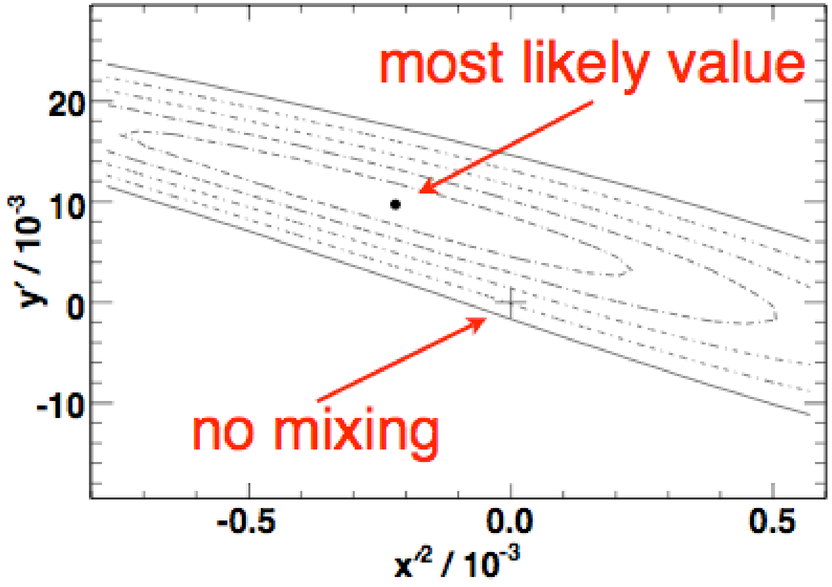
BABAR:

$y'_D = (0.97 \pm 0.44 \pm 0.31) \times 10^-$

$(x'_D)^2 = (-2.2 \pm 3.0 \pm 2.1) \times 10^{-4}$

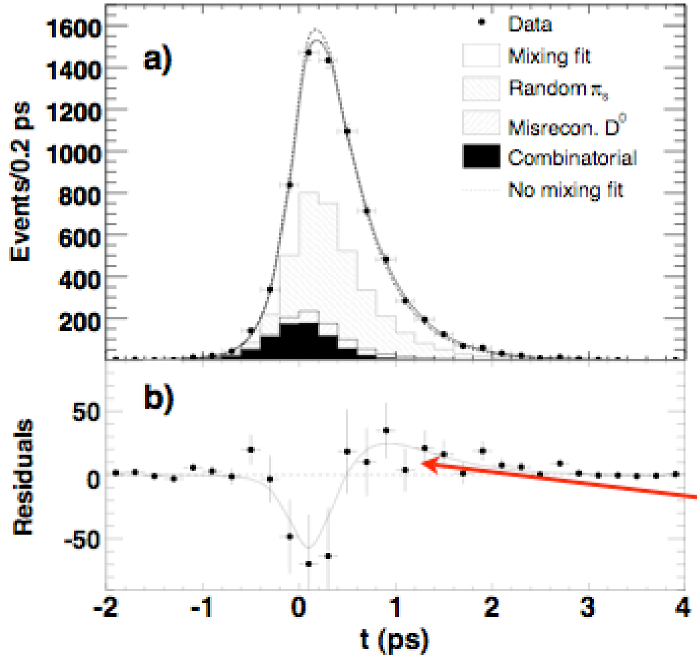
[3.9 σ]

$R_M = (-\,0.6 \pm 1.7) \times 10^{-4}$



Decay-time distribution deviates from a pure exponential

$$\frac{\Gamma_{\mathrm{WS}}(t)}{\Gamma_{\mathrm{RS}}(t)} = R_D + \underbrace{y'\sqrt{R_D}\,(\Gamma t)}_{\text{interference}} + \underbrace{\frac{x'^2 + y'^2}{4}(\Gamma t)^2}_{\text{oscillation}}$$

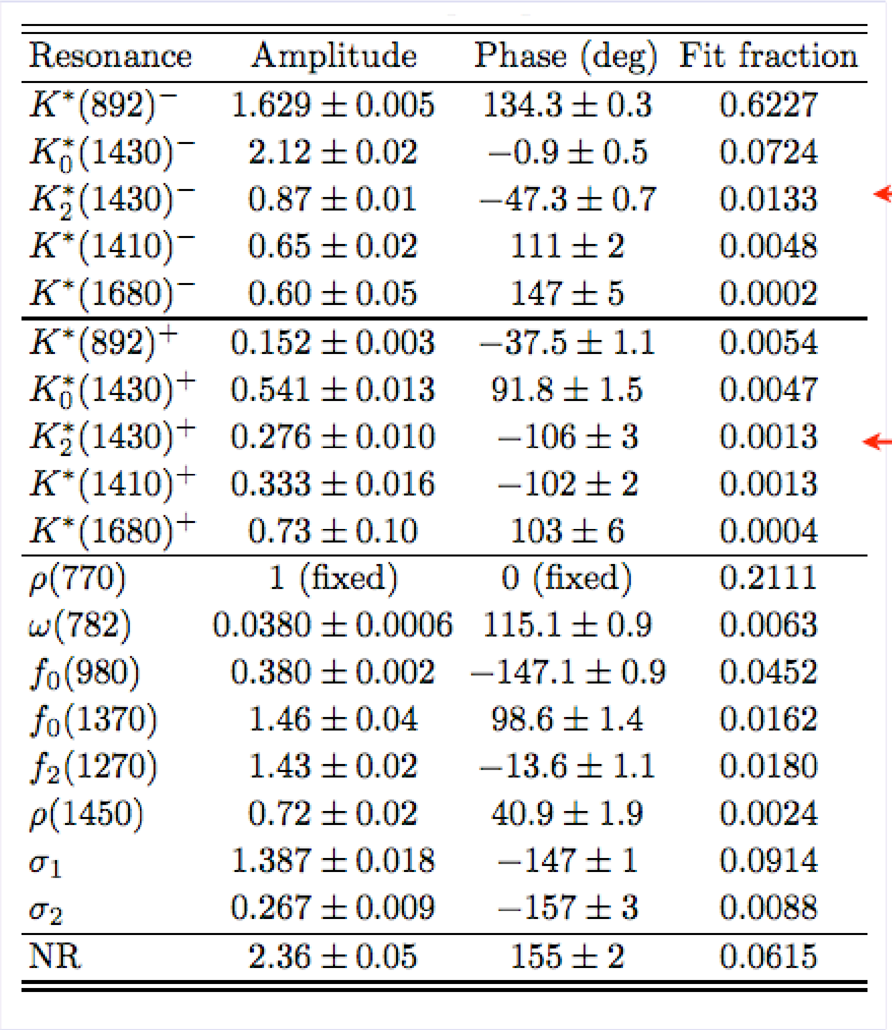


$$y' = y\cos\delta - x\sin\delta$$
$$x' = x\cos\delta + y\sin\delta$$

δ is an unknown strong-phase differenc

BABAR observes positive interference
$(y' > 0)$

(1.3.3) $D^0 (t) \rightarrow K_S \pi^+ \pi^-$



Resonance	Amplitude	Phase (deg)	Fit fraction
$K^*(892)^-$	1.629 ± 0.005	134.3 ± 0.3	0.6227
$K_0^*(1430)^-$	2.12 ± 0.02	-0.9 ± 0.5	0.0724
$K_2^*(1430)^-$	0.87 ± 0.01	-47.3 ± 0.7	0.0133
$K^*(1410)^-$	0.65 ± 0.02	111 ± 2	0.0048
$K^*(1680)^-$	0.60 ± 0.05	147 ± 5	0.0002
$K^*(892)^+$	0.152 ± 0.003	-37.5 ± 1.1	0.0054
$K_0^*(1430)^+$	0.541 ± 0.013	91.8 ± 1.5	0.0047
$K_2^*(1430)^+$	0.276 ± 0.010	-106 ± 3	0.0013
$K^*(1410)^+$	0.333 ± 0.016	-102 ± 2	0.0013
$K^*(1680)^+$	0.73 ± 0.10	103 ± 6	0.0004
$\rho(770)$	1 (fixed)	0 (fixed)	0.2111
$\omega(782)$	0.0380 ± 0.0006	115.1 ± 0.9	0.0063
$f_0(980)$	0.380 ± 0.002	-147.1 ± 0.9	0.0452
$f_0(1370)$	1.46 ± 0.04	98.6 ± 1.4	0.0162
$f_2(1270)$	1.43 ± 0.02	-13.6 ± 1.1	0.0180
$\rho(1450)$	0.72 ± 0.02	40.9 ± 1.9	0.0024
σ_1	1.387 ± 0.018	-147 ± 1	0.0914
σ_2	0.267 ± 0.009	-157 ± 3	0.0088
NR	2.36 ± 0.05	155 ± 2	0.0615

← Cabibbo favored

← doubly Cabibbo suppressed

Belle

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

Doubly Cabibbo suppressed contributions are *enhanced* at high masses

$$\frac{A_{K^*(892)^+}}{A_{K^*(892)^-}} \approx 0.1$$

seen by CLEO

$$\frac{A_{K_0^*(1430)^+}}{A_{K_0^*(1430)^-}} \approx 0.3$$

makes no sense to me -- Orsay group, check it!

$$\frac{A_{K_2^*(1430)^+}}{A_{K_2^*(1430)^-}} \approx 0.3$$

$$\frac{A_{K^*(1410)^+}}{A_{K^*(1410)^-}} \approx 0.5$$

each corresponds to ~700 events; comparable to BaBar's $D^0 \to K^+\rho^- \to K^+\pi^-\pi^0$ signal size

$$\frac{A_{K^*(1680)^+}}{A_{K^*(1680)^-}} \approx 1.2$$

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

Possible CP violation not investigated; assuming CP invariance

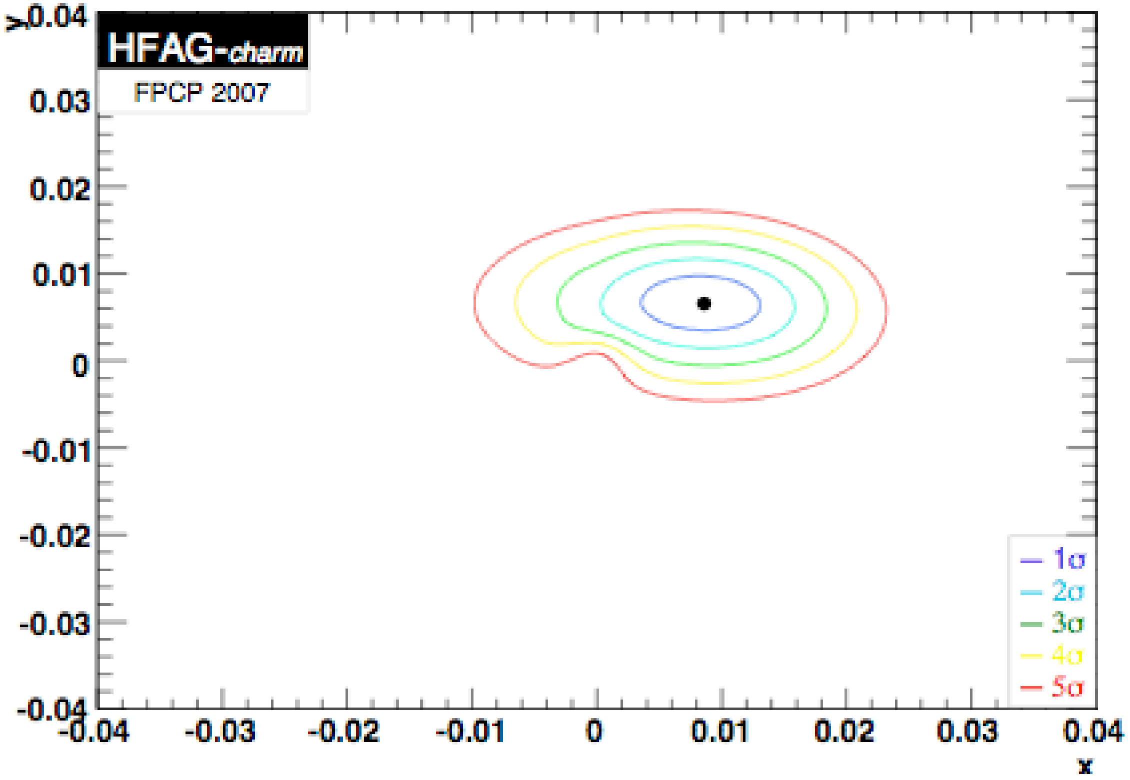
$$x = (0.80 \pm 0.29\,(\text{stat})\ ^{+0.09}_{-0.07}\,(\text{syst})\ ^{+0.15}_{-0.14}\,(\text{model}))\%$$

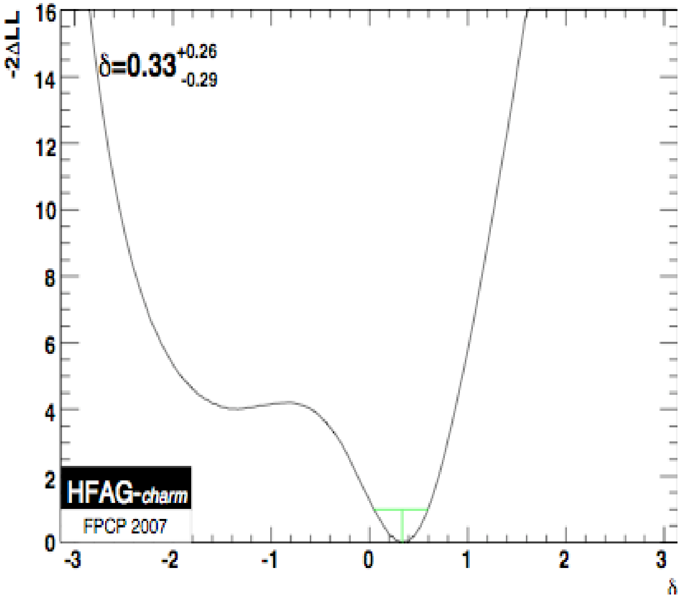
$$y = (0.33 \pm 0.24\,(\text{stat})\ ^{+0.07}_{-0.12}\,(\text{syst})\ ^{+0.08}_{-0.09}\,(\text{model}))\%$$

Reported systematics are much smaller than in other analyses.

(Belle KK,pipi) $y = (1.31 \pm 0.32\,(\text{stat}) \pm 0.25\,(\text{syst}))\%$

(BaBar Kpi) $y' = (0.97 \pm 0.44\,(\text{stat}) \pm 0.31\,(\text{syst}))\%$





in this exercise $(x_D,y_D) \neq (0,0)$ emerges with 5 σ

$x_D = (0.87^{+0.30}_{-0.34})\%$, $y_D = (0.66^{+0.21}_{-0.20})\%$, $\delta = 0.33^{+0.26}_{-0.29}$

(1.4) Interpretation?

☞ $x_D > 1\ \% \gg y_D$ could be interpreted as manifestation of New physics -- yet such a scenario has basically been ruled out

☞ data suggest: x_D, y_D can be in range ~ 0.5 - 1%

✍ could be due `merely' to SM dynamics --

- ➼ even then it would be a great discovery &
- ➼ it should be measured accurately --
  - ☞ must know (i) whether $(x_D,y_D) \neq 0$ & (ii) x_D=? vs. y_D = ? irrespective of theory -- like for $\varepsilon'/\varepsilon_K$!

✍ yet might also contain large contributions from NP!

How to resolve this conundrum?

❍ theoretical breakthrough?

❍ CP violation!

II $\not{C}P$ with & without D^0 Oscillations

☺ baryon # of Universe implies/requires NP in $\not{C}P$ dynamics

☺ existence of three-level Cabibbo hierarchy

SM rate CF : CS : DCS ~ 1 : 1/20 : 1/400

☺ within SM:
- ☞ tiny weak phase in 1x Cabibbo supp. modes: $V(cs) = 1 \ldots + i\lambda^4$
- ☞ no weak phase in Cab. favoured & 2 x Cab. supp. modes (except for $D^\pm \to K_S h^\pm$)

☺ CP asymmetry linear in NP amplitude

☺ D^0 oscillations at an observable rate!

☺ final state interactions large

☺ BR's for CP eigenstates large

☺ flavour tagging by $D^{\pm *} \to D\pi^\pm$

☺ many $H_c \to \geq 3$ P, VV… with sizeable BR's

➥ CP observables also in final state distributions

(2.1) $\cancel{CP}$ without D^0 Oscillations

direct $\cancel{CP}$

(2.1.1) *time integrated partial widths*

final state interact.
- 😐 necessary evil
- ☺ cannot fake signal
- ☺ ~ large in charm

☺ Cabibbo favour. (CF) modes: need New Physics (except *)

☺ 2x Cabibbo supp. modes (DCS):need New Physics (except *)

exception *: $D^\pm \longrightarrow K_{S[L]}\,\pi^\pm$

interference between $D^+ \underset{CF}{\longrightarrow} \bar{K}^0\pi^+$ and $D^+ \underset{DCS}{\longrightarrow} K^0\pi^+$

in KM only effect from $\cancel{CP}$ in K^0 - $\bar{K}^0$: $A_S=[+]_S-[-]_S= -3.3 \times 10^{-3}$

exists model by G. D'Ambrosio ('01), which creates observable effect in DCS while not affecting oscillations.

LHCb specific: $D^\pm \longrightarrow K^\pm\,\pi^+\pi^-$

😐 1x Cabibbo supp. modes (SCS)
possible with KM -- benchmark: $\mathcal{O}(\lambda^4) \sim \mathcal{O}(10^{-3})$
New Physics models: $\mathcal{O}(\%)$ conceivable
useful & detailed: Grossman, Kagan, Nir hep-ph/0609178

if observe direct ~~CP~~ ~ 1% in SCS decays --

- ❑ Is it New Physics for sure?
- ❑ Size of weak phase (and chirality) of its effective operator?

must analyze host of channels in an exercise in theor. engineering

~~CP~~ $\sim \sin\Delta\phi_{weak} \times \sin\Delta\alpha_{strong} \times M_1 \times M_2$

known from CKM

shaped by strong forces

- ○ choose set of reduced ME -- involves judgment of decay top.
- ○ fit to comprehensive data on D → PP, PV, VV
- ○ quality control provided by over-redundancy in fit
- ☞ Cleo-c & BESIII will provide data base

(2.1.2) Final state distributions: Dalitz plots,T-odd moments

Dalitz plots asymmetries

final state interact. {
😐 will be there
☺ cannot fake signal

considerable initial overhead -- yet will pay handsome dividends in the long run due to overconstraints

T-odd moments

final state interact. {
😐 not necessary
☹ a nuissance: can fake signal
☺ can be disentangled

very promising -- most effective theoretical tools not developed yet for small asymmetries (except Dalitz plot)

Pilot study by Focus (CLEO-c?)

☺ `local' asymmetry likely to be larger than integrated one

☺ angular asymmetry can provide info on chirality of underlying effective operator!

An example for a T odd distribution

$K_L \to \pi^+\pi^-e^+e^-$ BR ~ 3×10^{-7}

interference between $\cancel{CP}$ E1 & CP M1 amplitude

ϕ = angle between $\pi^+\pi^-$ & e^+e^- planes

forward-backward asymmetry in ϕ: A= 14 % driven by ε=0.002

-- i.e. trade BR for size of asymmetry!

$D \to K \bar{K} \pi^+\pi^-$

ϕ= angle between $\pi^+\pi^-$ & $K \bar{K}$ planes

$$d\Gamma/d\phi\ (D \to K \bar{K} \pi^+\pi^-) = \Gamma_1 \cos^2\phi + \Gamma_2 \sin^2\phi + \Gamma_3 \cos\phi \sin\phi$$

$$d\Gamma/d\phi\ (\bar{D} \to K \bar{K} \pi^+\pi^-) = \bar{\Gamma}_1 \cos^2\phi + \bar{\Gamma}_2 \sin^2\phi - \bar{\Gamma}_3 \cos\phi \sin\phi$$

- Γ_3 drops out after integrating over ϕ
  - Γ_1 vs. $\bar{\Gamma}_1$ & Γ_2 vs. $\bar{\Gamma}_2$: $\cancel{CP}$ in partial widths
- T odd moments $\Gamma_3, \bar{\Gamma}_3 \neq 0$ can be faked by FSI

  yet $\Gamma_3 \neq \bar{\Gamma}_3 \Longrightarrow \cancel{CP}$!

even closer analogy

$D \to K^+ K^- \mu^+ \mu^-$ BR ~ $O(10^{-6})$

A few general remarks on $\cancel{CP}$ in *final state distributions*

$D \to PPP$

A Catholic Scenario:

single path to heaven: asymmetries in the Dalitz plot

$D \to PPPP$

A Calvinist Scenario

many paths to heaven -- success reveals Heaven's blessing

$D \to K^+K^-\pi^+\pi^-$ ϕ = angle between $\pi^+\pi^-$ & K K planes

❶ Integrated (over 2 quadrants) T odd moment

$\langle A \rangle = 2\Gamma_3/\pi(\Gamma_1+\Gamma_2)$ vs. $\langle A \rangle = 2\Gamma_3/\pi(\Gamma_1+\Gamma_2)$

❷ Differential T odd moment

$d\Gamma/d\phi(D \to K\,K\,\pi^+\pi^-) = \Gamma_1\cos^2\phi + \Gamma_2\sin^2\phi + \Gamma_3\cos\phi\sin\phi$

same dynamical info, yet valuable experim. check

❸ Full amplitude analysis

☺ more dynamical info

☹ more model dependence (?)

statistics

(2.2) ~~CP~~ with D^0 Oscillations

All the previously given justifications for CP searches

plus

$L(\Delta C=2) \neq 0$

- provides a much wider stage for ~~CP~~ to surface
- allowing us to decide whether NP is involved.

Analogies with two other cases,
one from the past & one from the present:
K^0 & B_s oscillations

$\Delta S=2$:

Assume -- contrary to history -- that people had accepted the SM with 2 families when $\Delta M_K \neq 0$ was observed & knew about possibility of $\cancel{CP}$.

They would have reasoned that LD dynamics could produce ~ 1/3 of ΔM_K via $K^0 \to$ “π ,η,η',$\pi\pi$, … “ $\to \overline{K^0}$ and SD dynamics via the quark box diagram the rest.

This might have led to the proposal to search for $K_L \to \pi\pi$ to establish the presence of NP, namely the 3rd family (which is irrelevant for ΔM_K).

$\Delta B=2$ -- the topical example:

The observed value of $\Delta M(B_s)$ is fully consistent with SM expectations -- within sizable uncertainties. Yet a subdominant NP contribution to $\Delta M(B_s)$ could still provide the dominant source of time dependent $\cancel{CP}$ in $B_s \to \psi\phi$!

oscillations can generate time *dependent* CP asymmetries

- ❑ none seen so far down to the 1% (1%/$tg^2 \theta_C$) level --
- ☞ they are ~ (x_D or y_D) (t/τ_D)sin ϕ_{weak};
  - ➾ with x_D , $y_D \leq 0.01$ a signal would not have been credible
  - ➾ yet now it is getting interesting!

Scenario (A)

LD dynamics (involving barely 2 families) cannot generate ~~CP~~!

I.e., minimal scenario: *no* significant ~~CP~~ in $L(\Delta C=2)$,

direct ~~CP~~ only: (i) $|q|=|p|$,

whereas (ii) $|T(D \rightarrow f)| \neq |T(\overline{D} \rightarrow \overline{f})|$

(iii) $\mathrm{Im}\,(q/p)\overline{\rho}(f) \neq 0$

- CF: $K_S\pi^0$, $K_S\rho^0$, $\boxed{K_S\phi}$ $\mathrm{Im}V(cs)V(ud) = \eta|V(cb)|^2 \sim 0.6\times10^{-3}$
- DCS: $D^0 \longrightarrow K^+\pi^-$ -- $\mathrm{Im}V(cd)V(us) = 0$

  yet NP models a la D'Ambrosio
- CS: $D^0 \longrightarrow K^+K^-, \pi^+\pi^-$ -- time depend. & indep. CP

Scenario (B)

NP contributes significantly to $\mathcal{L}(\Delta C=2)$

➥ expect significant source for $\cancel{CP}$ in $\mathcal{L}(\Delta C=2)$:

(i) $|q| \neq |p|$, (ii) $|T(D \to f)| \neq |T(\overline{D} \to \overline{f})|$, (iii) $\mathrm{Im}\,(q/p)\overline{\rho}(f) \neq 0$

- CF: $D^0 \to K_S\phi$ $\quad A_{CP}(t) = (x_D \sin\phi_{NP} - y_D \epsilon_{NP} \cos\phi_{NP})(t/\tau_D)$

  $\mathcal{L}(\Delta C=2) \longrightarrow \phi_{NP}$ & $\epsilon_{NP} = 1 - |q/p|$

- CS: $D^0 \to K^+K^-, \pi^+\pi^-$ $\quad A_{CP}(t)=(x_D \sin\phi'_{NP} - y_D \epsilon_{NP} \cos\phi'_{NP})(t/\tau_D)$

  $D^0 \to K^+K^-\pi^+\pi^-$ $\Gamma_3(t)$, $\overline{\Gamma}_3(t)$ time dependence!

- DCS: $D^0 \to K^+\pi^-$ -- ditto (+NP models a la D'Ambrosio)

  the SM amplitude suppressed by $tg^2\theta_C$

The `Dark Horse'

SL: $D^0 \to l^- \nu K^+$ vs. $D^0 \to l^+ \nu K^-$

$R_M^{SL}=(1.7\pm3.9)\times10^{-4}$, $R_M^{WA}=(2.1\pm1.1)\times10^{-4}$

if $x_D = y_D = 7\times10^{-3}$, then $R_M = 5\times10^{-5}$

$a_{SL} \sim \mathrm{Min}[\Delta\Gamma/\Delta M, \Delta M/\Delta\Gamma] \sin\phi_{NP}$, $\Delta\Gamma/\Delta M \sim O(1)$

☞ $a_{SL} \sim 0.1$ conceivable (even few x 0.1)

-- i.e. relatively few wrong-sign leptons, yet with a large asymmetry!

vs.

✍ $a_{SL}(K_L) = 3.3 \times 10^{-3}$ with $\Delta\Gamma/\Delta M \sim O(1)$ & $\sin\phi_{CKM,eff} \ll 1$

✍ $a_{SL}(B_d) \sim 4 \times 10^{-4}$ with $\Delta\Gamma/\Delta M \sim O(\text{few} \times 10^{-3})$

✍ $a_{SL}(B_s) \sim 2 \times 10^{-5}$ with $\Delta\Gamma/\Delta M \sim O(\text{few} \times 10^{-3})$
& $\sin\phi_{CKM,eff} \sim O(\text{few} \times 10^{-2})$

(2.3) Benchmarks

☞ Allowed New Physics scenarios could produce $\cancel{CP}$ close to present experim. bounds, but hardly higher!

- time dependant CP asymmetries in
  - $D^0 \to K^+K^-, \pi^+\pi^-, K_S\phi$ down to $\mathcal{O}(10^{-4})$
  - $D^0 \to K^+\pi^-$ down to $\mathcal{O}(10^{-3})$

  LHCb: ~ 10^6 $D^* \to D\pi \to [KK]_D\,\pi$ in 10^7 sec

- direct $\cancel{CP}$ in partial widths of
  - $D^\pm \to K_{S[L]}\pi^\pm$ down to $\mathcal{O}(10^{-3})$
  - in a host of 1xCS channels down to $\mathcal{O}(10^{-3})$
  - in 2xCS channels down to $\mathcal{O}(10^{-2})$

- direct $\cancel{CP}$ in the final state distributions:

  Dalitz plots, T-odd correlations etc. down to $\mathcal{O}(10^{-3})$

IV Conclusions & Outlook

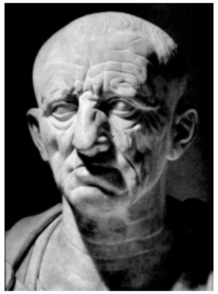
- a lot of work of great importance to be done
  - establish $(x_D, y_D) \neq 0$
  - determine $x_D = ?$ vs. $y_D = ?$
  - go after $\cancel{CP}$ ← main message
    - in all of its possible manifestations
      - time dependent & independent,
      - partial widths, Dalitz plots, T odd moments …
    - and on all Cabibbo levels
      - (i) $D^0 \to K_S \pi^+\pi^- / K_S K^+K^-$
      - (ii) $D^0 \to \pi^+\pi^- / K^+K^-$
      - (iii) $D^0 \to K^+ \pi^-$
    - down to the 0.001 (or even better) level
    - present no-signal not telling!
- can expect a positive learning curve for theorists -- yet do not count on miracles

The Big Picture

- detailed study of charm decays provides a novel & possibly unique window onto flavour dynamics
  - need the statistical muscle of the LHCb

    interesting and worthy challenge for LHCb

    $D^0 \rightarrow K^+K^-, \pi^+\pi^-, K^+\pi^-, K^+K^-\mu^+\mu^-$ good channels for LHCb
  - ☞ yet need more statistics & channels!



“Ceterum Censeo Fabricam Super Saporis Esse Faciendam”

“Moreover I Advise a Super-Flavour Factory has to be Built”

example for a unique capability:

$e^+ e^- \rightarrow \psi''(3770) \rightarrow D\bar{D} \rightarrow (K^+K^-)_D D_L$

$\quad\quad\quad\quad\quad\quad\quad\quad\quad\quad\quad\quad\quad\quad\quad\quad\quad\quad \hookrightarrow K^+K^-\mu^+\mu^-$

It is the task of the physicist to make the greatest use of a special gift from Nature

D^0 oscillations are such a gift

➥ it is your duty -- & there is fame within your grasp!