I Know She Invented Fire, But What Has She Done Recently? -- On Charm's Second Renaissance

Ikaros Bigi (Notre Dame du Lac) Super-B Jan 2008

On Valencia's `genius loci'

El Cid -- most heroic figure of Valencia's past

chivalry's business practice throughout middle ages:
charge enemy at first sight with passion, yet no thinking

El Cid's innovation:

- brainstorming before the battle
- inviting feedback even from junior members of his staff

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➥ *El Cid -- Godfather of the `Workshop Concept'!*

Charm

- `Octobre Revolution' of 1974
  - validated quarks as physical entities
  - provided great leap forward for $SU(2)_L xU(1)$
- First Renaissance: Charm spectroscopy A. Polosa

  ("Muslim rulers of Spain expel Jews & Christians")
- Second Renaissance: D^0 Oscillations

  ("Fall of Constantinople 1453")

Study of
$\Delta S \neq 0$ instrumental in creation of SM
$\Delta C \neq 0$ central in its acceptance
$\Delta B \neq 0$ almost completed its validation

now race is on which one (+ $\Delta top \neq 0$) will show incompleteness of SM quark flavour dynamics

If evidence for D^0 oscillat. holds up with $x_D, y_D \sim 0.01$ --

$\Delta C \neq 0$ close behind $\Delta B \neq 0$ in this race!

Evidence for D^0 oscillat. a tactical draw

-- 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 $\not{C}P$ in B decays without much resonance - till B oscill. were observed by ARGUS in 1987!

☹ numerical size much smaller in D decays

☹ no definitive predictions for $\not{C}P$ from New Physics

☺ yet SM \`background' even tinier &

☺ experimentalists have become more experienced

will history repeat itself in a \`centi-ARGUS' scenario?

The Menu

Prologue: New Physics Scenarios & Uniqueness of Charm

I Inconclusiveness in Interpretation of D^0 Oscillations

II $\cancel{C}P$ with & without D^0 Oscillations -- the Decisive Stage

III Conclusions & Outlook

Disclaimer:
This is a realistic Menu for this WS, not a complete one!
Not included: $D \to l\nu,\ \tau\nu,\ l\nu h,\ \gamma h,\ l^+l^-h,\ e^+\mu^-h,\ \nu\nu h,\ h\text{+familon}$

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)

- SM `background' much smaller for FCNC of *Up*-type quarks
  - ➥ cleaner -- albeit smaller -- signal!

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

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

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

hadronization while hard to force under theor. control

enhances observability of $\cancel{CP}$

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

CP asymmetries in partial widths 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

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

2 general comments:

(A)

$x_D \ll y_D$ a possible, yet *not* a natural scenario!

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

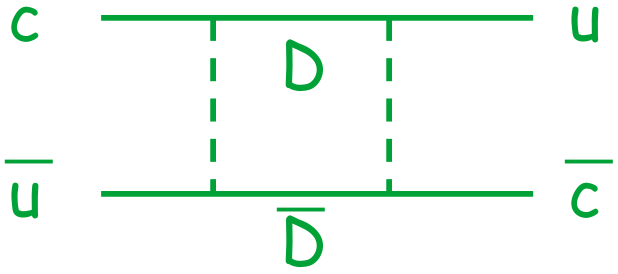
then $D^0 \to "f" \to \overline{D}^0$ via an *off*-shell final state

➾ 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



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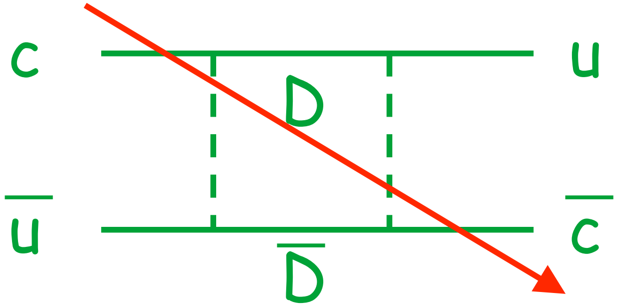


is misleading

- instead: those oscill. tell us about FCNC of *up-type* quarks

(1.2) Theoretical Predictions

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

\`inclusive' vs. \`semi-exclusive'

➻ \`inclusive':

quarks & gluons + nonperturb. contributions

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

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

☞ $\varepsilon_D\,|_{SM} \neq 0$!

✒ 'semi-exclusive':

hadrons

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

$$y_D\,(SM) \sim 0.01 \longrightarrow 0.001 \leq |x_D\,(SM)| \leq 0.01$$

dispersion relation

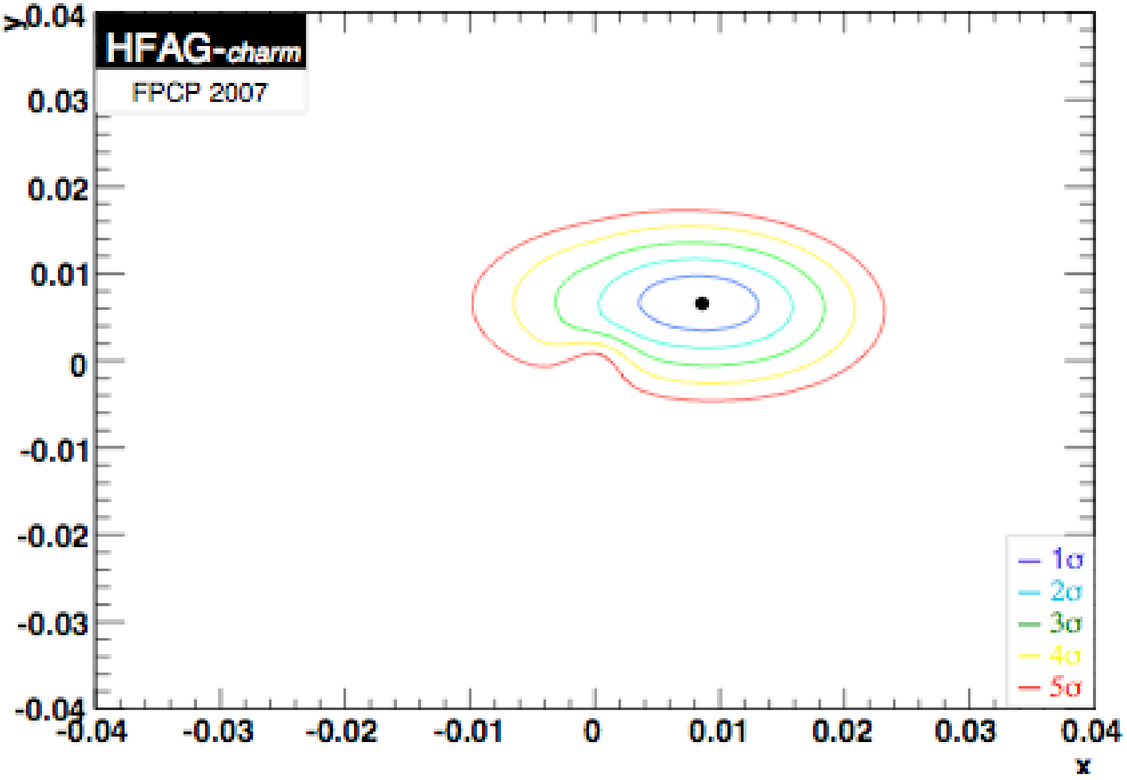
✍ cannot be extended to estimate ε_D

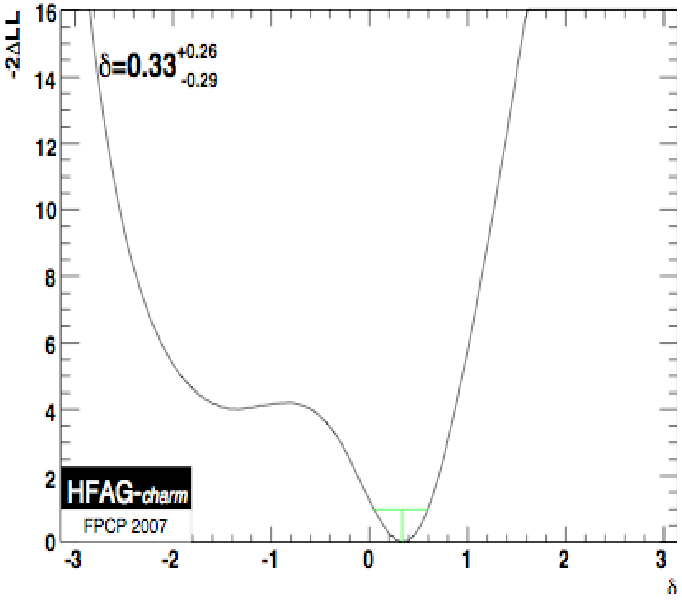
☞ my judgment: 2 questions

- ❑ 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

Late Spring 2007

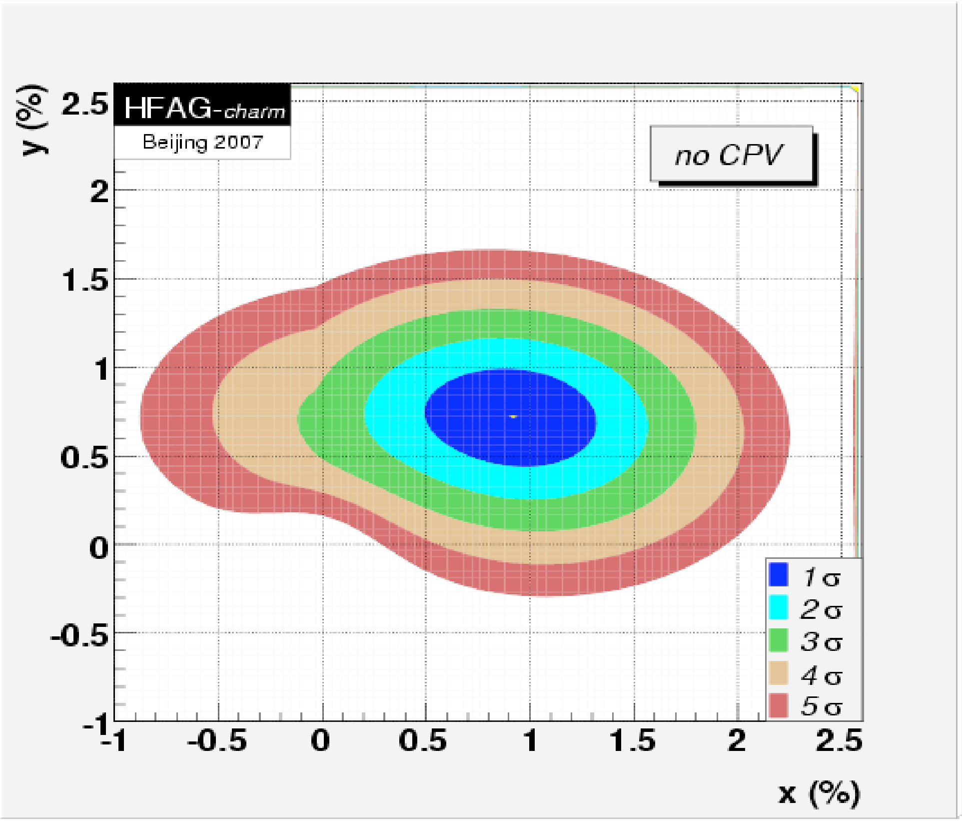


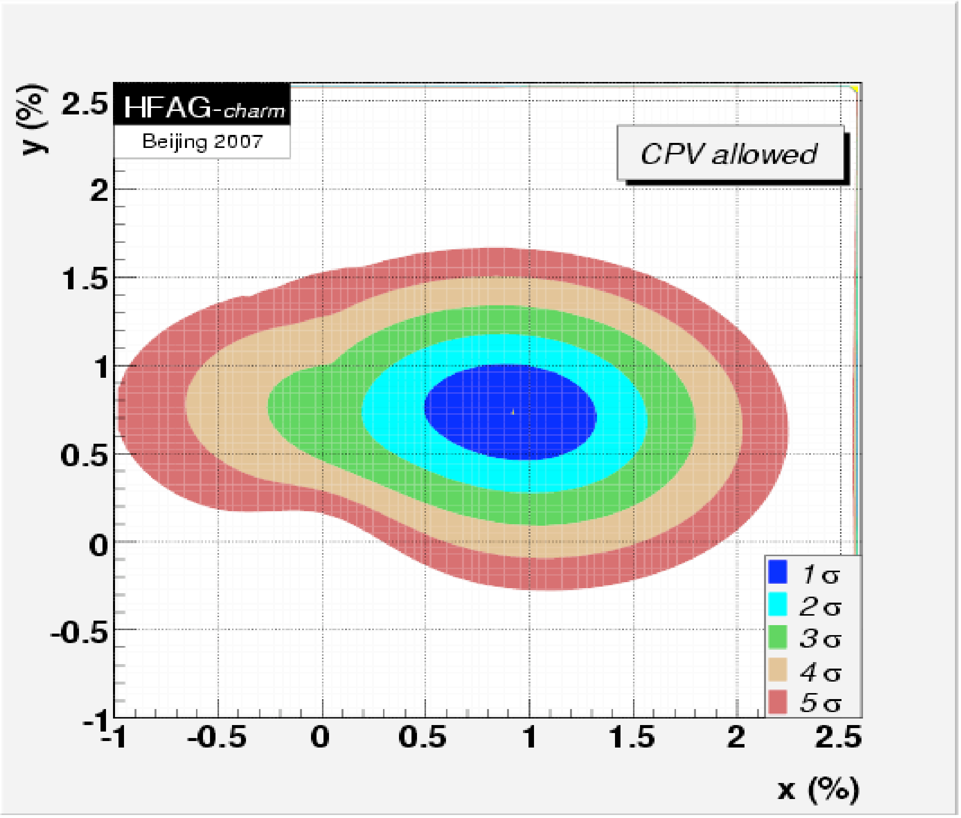


in this exercise $(x_D, y_D) \neq (0,0)$ emerges with 5 σ

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

End of 2007





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

$x_D = (0.97^{+0.27}_{-0.29})\%$, $y_D = (0.78^{+0.18}_{-0.19})\%$, $\delta = 0.38^{+0.20}_{-0.22}$

(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 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 ϵ'/ϵ_K!

✍ yet might also contain large contributions from NP!

How to resolve this conundrum?

- ○ theoretical breakthrough?
- ○ CP violation! Baryogenesis implies/requires NP in CP dynamics !

(1.5) First Task for WG: how to measure best x_D, y_D

Must measure x_D, y_D accurately

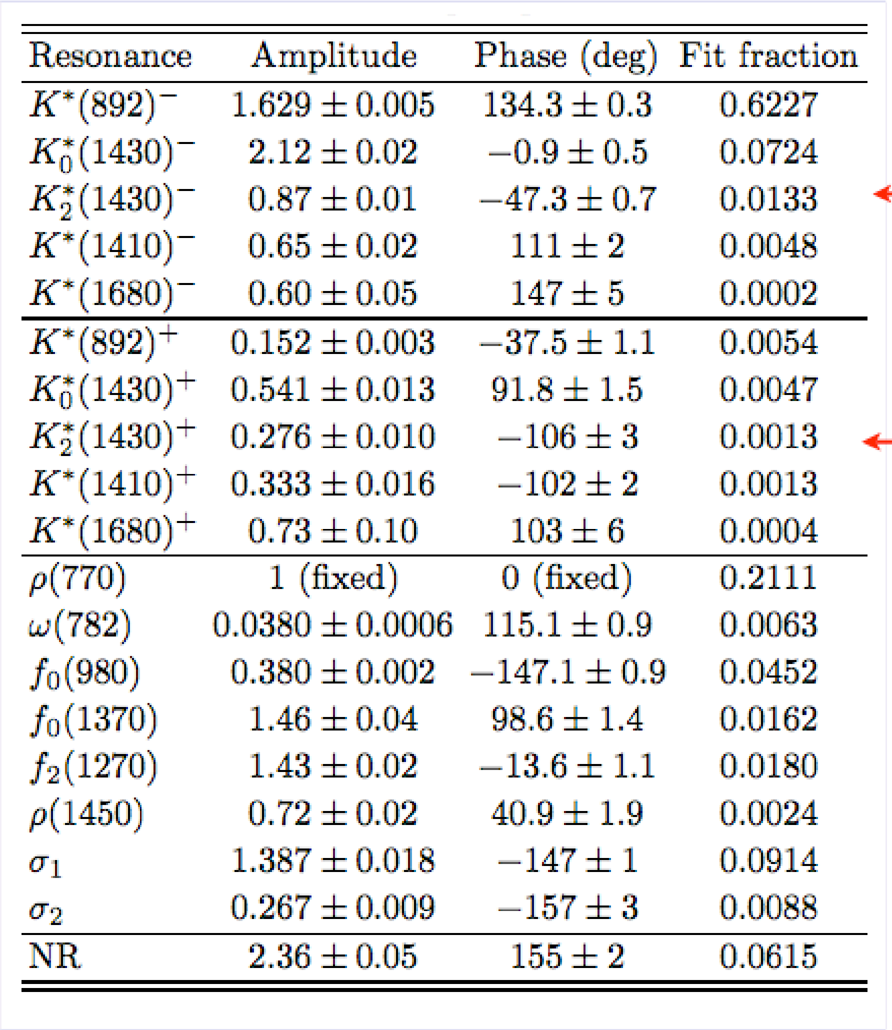
- serves as validation of Super-B charm analyses
- " " " " time dependent CP studies
- a breakthrough in theoret. technologies might occur

Questions for the WG

- How well can one do ?
- Running on the Υ(4S) vs. near charm threshold ?
- near charm threshold:
  - Can do time dependent measurements?
  - EPR correlations?
- time dependent Dalitz plots

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

BELLE



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 BELLE

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

seen by CLEO

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

makes no sense to me -- most likely incorrect

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

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

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

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

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 $D^\pm \rightarrow K_S h^\pm$)

☺ 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 $D^{\pm *} \rightarrow D\pi^\pm$

☺ many $H_c \rightarrow \geq 3$ P, VV… with sizeable BR's
  ➥ CP observables also in final state distributions

(2.1) The Program

Finding ~~CP~~ somewhere in $\Delta C \neq 0$ is a seminal discovery -- yet not a program, `merely' its first step!

Program (exp)

Study ~~CP~~ & ~~T~~ in

- $\Delta C = 1$ vs. $\Delta C = 2$; i.e., direct vs. indirect ~~CP~~ via t dependance
- CF vs. CS vs. DCS
- partial rates vs. Final State Distributions (FSD)
- down to 10^{-3} - 10^{-4} levels

using runs at ~ 10 GeV & ~ 4 GeV

Program (th)

- Develop phenomenology for ~~CP~~ & ~~T~~ in FSD
- Derive reliable SM predictions
- Analyze NP scenarios -- in particular Little Higgs Models

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

direct $\cancel{CP}$

(2.2.1) *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 *: $D^\pm \to K_{S[L]}\,\pi^\pm$

interference between $D^+ \xrightarrow[CF]{} \bar{K}^0\pi^+$ and $D^+ \xrightarrow[DCS]{} K^0\pi^+$

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: $D^\pm \to K^\pm\,\pi^+\pi^-$

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

if observe direct $\cancel{CP} \sim 1\%$ 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

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

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

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

A few general remarks on ~~CP~~ in *final state distributions*

$D \rightarrow PPP$

A Catholic Scenario:

single path to heaven: asymmetries in the Dalitz plot

$D \rightarrow PPPP$

A Calvinist Scenario

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

---

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!

Dalitz plots asymmetries

final state interact.
- 😐 will be there
- ☺ can*not* 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

An example for a T odd distribution

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

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

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

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

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

❶ Integrated (over 2 quadrants) T odd moment

$\langle A \rangle = 2\Gamma_3/\pi(\Gamma_1+\Gamma_2)$ vs. $\langle \bar{A} \rangle = 2\bar{\Gamma}_3/\pi(\bar{\Gamma}_1+\bar{\Gamma}_2)$

❷ Differential T odd moment

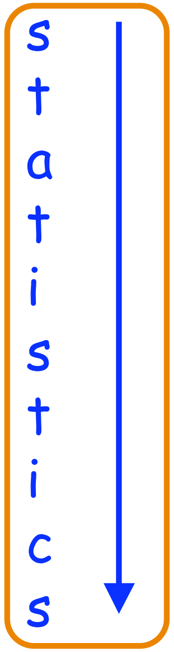
$d\Gamma/d\phi(D \rightarrow K\,K\,\pi^+\pi^-) = \Gamma_1\cos^2\phi+\Gamma_2\sin^2\phi + \Gamma_3\cos\phi\sin\phi$

same dynamical info, yet valuable experim. check

❸ Full amplitude analysis

☺ more dynamical info

☹ more model dependence (?)



statistics

For a different perspective see Antimo Palano's talk Thursday morning!

(2.3) ~~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 $K^0 \to$ “$\pi ,\eta,\eta',\pi\pi, \ldots$ “ $\to \overline{K^0}$ 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 (B)

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

➥ expect significant source for ~~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: $D^0 \to K_S\phi$ $\quad A_{CP}(t) = (x_D \sin\phi_{NP} - y_D \varepsilon_{NP} \cos\phi_{NP})(t/\tau_D)$

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

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

  $D^0 \to K^+K^-\pi^+\pi^-$ $\Gamma_3(t)$, $\overline{\Gamma}_3(t)$ 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. $D^0 \to l^+ \nu K^-$

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

➼ $a_{SL} \sim 0.1$ 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 $\Delta\Gamma/\Delta M \sim O(\text{few} \times 10^{-3})$
& $\sin\phi_{CKM,eff} \sim O(\text{few} \times 10^{-2})$

(2.4) $e^+ e^- \to D^0 \bar{D}^0$

Two special cases:

Case (A)

So far all observed $\cancel{CP}$ in partial widths -- except for one:

$K_L \to \pi^+\pi^-e^+e^-$

$$K_L \xrightarrow[\uparrow\ \text{suppressed}]{\cancel{CP}} \pi^+\pi^- \xrightarrow{E1} \pi^+\pi^-\gamma^* + K_L \xrightarrow[\uparrow\ \text{suppressed}]{CP,M1} \pi^+\pi^-\gamma^*$$

ϕ = angle between $\pi^+\pi^-$ & e^+e^- planes analyzes γ^* polarization

interference between CP E1 & CP M1 amplitude

➥ Forw-Backw asymmetry A in ϕ (Sehgal et al.)

$A = 14\ \%$ driven by $\varepsilon = 0.002$

price: BR ~ 3×10^{-7}

} trade BR for size of asymm.!

close analogy

$D_L \to K^+ K^- \mu^+ \mu^-$

BR ~ $O(10^{-6})$

$$D_L \xrightarrow{\cancel{CP}} K^+K^- \xrightarrow{E1} K^+K^- \gamma^* \; + \; D_L \xrightarrow{CP,M1} K^+K^- \gamma^*$$

↑ suppressed ↑ suppressed

ϕ = angle between K^+K^- & $\mu^+\mu^-$ planes analyzes γ^* polarization

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

➥ Forw-Backw asymmetry *A* in ϕ

preliminary studies:

factor ~ 10 - 50 enhancement of $\cancel{CP}$ in $D_L \to K^+K^-$

example for a unique capability of Super-Fl. Fact.:

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

↳ $K^+K^-\mu^+\mu^-$

Case (B)

$$e^+ e^- \rightarrow D^0 \bar{D}^0 \rightarrow f^{(1)}_{CP=\pm} f^{(2)}_{CP=\pm}$$

CP = +

CP = -

$$BR(D^0 D^0 \rightarrow f^{(1)}_{CP=\pm} f^{(2)}_{CP=\pm}) = BR(D^0 \rightarrow f^{(1)}_{CP=\pm})BR(D^0 \rightarrow f^{(2)}_{CP=\pm})x$$
$$\left[\boxed{2|\bar{\rho}(f^{(1)}_{CP=\pm}) - \bar{\rho}(f^{(2)}_{CP=\pm})|^2} + x_D{}^2(1-(q/p)^2 \rho\tilde{(}f^{(1)}_{CP=\pm})\rho\tilde{(}f^{(2)}_{CP=\pm}))\right]$$

$f_{CP=+}$ = KK, ππ, $K_L\phi$

$f_{CP=-}$ = $K_S\phi$, $K_S\pi$, $K_S\eta^{(')}$

(2.5) Benchmarks

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

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

  LHCb: $\geq 10^6$ $D^* \to D\pi \to [KK]_D\,\pi$ per 2 fb^{-1}

  ~ 58K $D^* \to D\pi \to [K^+\pi^-]_D\,\pi$
- 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 $\mathcal{O}(10^{-3})$

III 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 ~~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 10^{-3} (or even better) level !systematics!
  - ☞ 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
  - great opportunity for LHCb
    $D^0 \to K^+K^-$, $\pi^+\pi^-$, $K^+\pi^-$, $K^+K^-\mu^+\mu^-$ good channels for LHCb
  - yet need
    - more statistics &
    - more channels!

      ➥ need Super-Flavour Factory!