The Value of Charm in the Era of Beauty

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The SM painting of Charm Dynamics is

~~dull~~ unexciting

☞ anything exciting Þ New Physics

☞ calibrate our SM tools in charm transit.

Outline

I D^0-$\bar{D}^0$ oscillations in the SM

II Lifetimes of C = 1&2 hadrons

III Charm meson resonances

Concede: no killer application (yet)

I D^0-$\bar{D}^0$ oscillations in the SM

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

D^0-D^0 oscillations `slow' in the SM

How `slow' is `slow'?

x_D, y_D ~ ~~SU(3)~~$_{Fl}$ • $2\sin^2 q_C$ < few • 0.01

on-shell transitions

off-shell transitions

Experimental status

x_D < 3 %

y'_D = - 2.5 $^{+1.4}_{-1.6}$ – 0.3 %	CLEO, DfiKp
y_D = 0.8 – 2.9 1.0 %	E 791, DfilnK
y_D = 1.16 $^{+1.67}_{-1.65}$ %	BELLE
y_D = 3.42 – 1.39 0.74 %	FOCUS, DfiKK vs. DfiKp
y_D = -1.1 – 2.5 1.4 %	CLEO, DfiKK, pp vs. DfiKp

data consistent with zero -- on the % level

➥ the game has just begun!

considerable previous literature -- yet with several ad-hoc elements mainly with respect to nonperturbative dynamics

conventional wisdom *used to be*

x_D, $y_D|_{SM} \sim 10^{-4} - 10^{-3}$ “Þ” N\$P if $x_D > 10^{-3}$!

\$ 2 related, though not identical questions:

❶ What are the most likely SM values for x_D, y_D?

❷ How large could $x_D|_{SM}$ conceivably be?

systematic analysis based on $O_{perator}$ P_{roduct} $E_{xpansion}$

expansion in powers of $1/m_c$, m_s, KM

for
$x_D|_{SM}$, y_D $<\sim$ 0.01 to hold,
need some mechanism to enforce cancellations
maybe “precocious” duality?

an ancient theorem/observation:

$$T(D^0 \to \bar{D}^0) \propto (m_s - m_d)^2$$

U spin (s,d)

interaction eigenstates

$s' = s \cos\theta_C - d \sin\theta_C$, $d' = d \cos\theta_C + s \sin\theta_C$

corresponding QN **S'**, **D'**

S'$[D^0]$= **D'**$[D^0]=0$

$$(\bar{u}c)(\bar{s}'d'): \Delta C = -\Delta S' = \Delta D' = 1$$

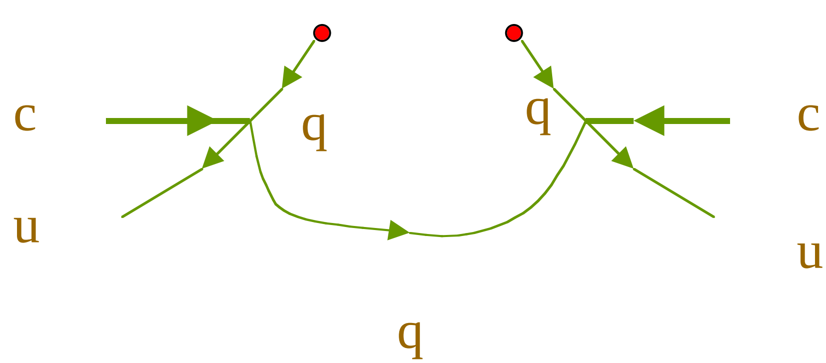
$D^0 \to \bar{D}^0$: $\Delta S' = 2$, yet $\Delta S' = 0$ in QCD for $m_s = m_d$

$\delta H(\Delta S' \neq 0) = \sin\theta_C \cos\theta_C (m_s - m_d)(\bar{s}'d')$

➥ $T(D^0 \to \bar{D}^0) \propto O((\delta H)^2)$ q.e.d.

purely U spin argument irrespective of m_u

contributions from higher-dimensional operators with a very gentle GIM factor ~ $m_s^2 \mu_{had}^4/m_c^6$ due to condensates in the OPE



- since $x_D(SM)|_{OPE}$, $y_D(SM)|_{OPE}$ µ $m_s^2 m_{had}^4/m_c^6$

  ➥ numerical prediction ~ $O(10^{-3})$ quite uncertain

  & unlikely uncertainties can be reduced

- central theoretical issue:

  does quark-hadron duality hold at the charm scale?

  ☛ more averaging in x_D than in y_D

  ➥ duality better in x_D than in y_D

general expectations

❑ DG: on-shell contributions

➥ insensitive to New Physics

❑ mD: virtual intermediate states

➥ sensitive to New Physics

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

y_D = 3.42 – 1.39 – 0.74% FOCUS ?!

if $y_D \sim 0.01$ {

for x_D £ few x 10^{-3}: $1/m_c$ expan. okay!

for $x_D \sim 0.01$: theor. conundrum

sobering lesson:

case for New Physics based on x_D uncertain!

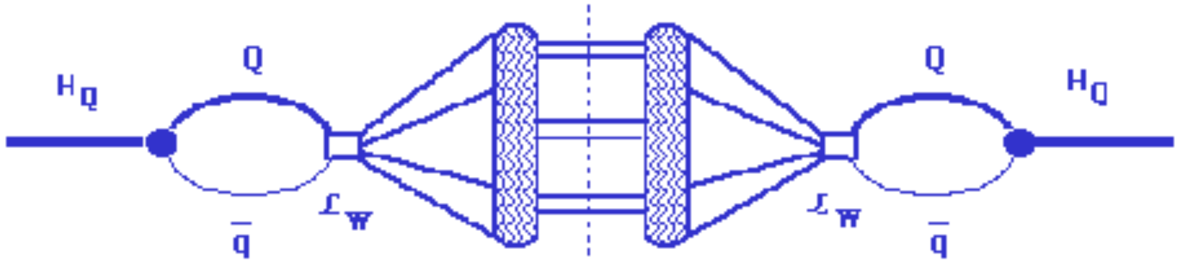
➥ search for $\not{C}P$ in D^0-$\bar{D}^0$ oscillations

Caveat en passant:

❑ DG(B_s) vulnerable to violations of local duality!

remember when extracting |V(td)| from Dm(B_d)/DG(B_s)

II Lifetimes of C = 1&2 hadrons



use Wilsonian OPE

$$\Gamma(H_Q \to f_{incl}) = \frac{G_F^2 \left|KM\right|^2 m_Q^5}{192\,\pi^3} \times$$

$$\times \left\{ c_3(f) \left\langle H_Q \right| \bar{Q}\,Q \left| H_Q \right\rangle + c_5(f) \frac{\left\langle H_Q \right| \bar{Q} i\sigma \cdot G\, Q \left| H_Q \right\rangle}{m_Q^2} + c_6(f) \frac{\left\langle H_Q \right| \left(\bar{Q}\Gamma q\right) \cdot \left(\bar{q}\Gamma Q\right) \left| H_Q \right\rangle}{m_Q^3} + \ldots \right\}$$

J interesting in its own right

J positive feedback with lattice QCD

J close to onset of duality

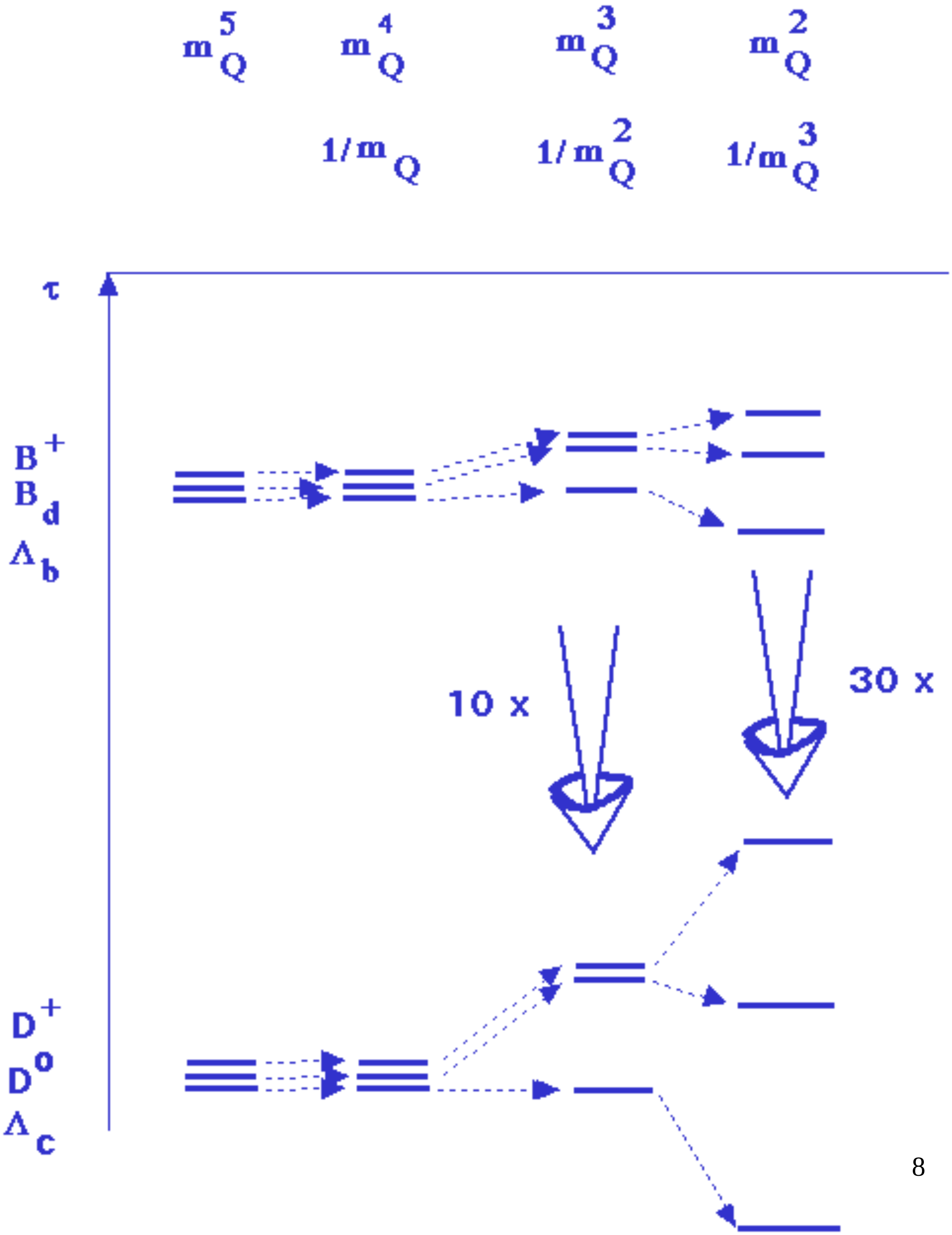
J B fi D*/D l n controlled by m_c, not m_b scale

J predictive power for lifetimes of C=2 hadrons

L "plausible deniability" due to sizeable uncertainty in

- perturb.
- higher order nonpert. & ~~duality~~ contributions

Pattern



m_Q^5
m_Q^4
m_Q^3
m_Q^2
$1/m_Q$
$1/m_Q^2$
$1/m_Q^3$
τ
B^+
B_d
Λ_b
10 x
30 x
D^+
D^0
Λ_c

II.1 C=1 Hadrons

Guberina et al. '84

➥ $\tau(D^+) > \tau(D^0) \sim \tau(D_s^+) \geq \tau(\Xi_c^+) > \tau(\Lambda_c^+) > \tau(\Xi_c^0) > \tau(\Omega_c^+)$

	$1/m_c$ expect.	comments on expect.	data
$\tau(D^+)/\tau(D^0)$	~ 2.4	PI in $\tau(D^+)$ consistent treatment of momenta in `wavefunction'	2.54 ± 0.01
$\tau(D_s)/\tau(D^0)$	1.0 – 1.07 0.9 – 1.3 1.08 ± 0.04	without WA with WA QCD SR	1.125 ± 0.042 PDG '98 1.22 ± 0.02
$\tau(\Lambda_c^+)/\tau(D^0)$	~ 0.5	Quark model matrix elem.	0.49 ± 0.01
$\tau(\Lambda_c)/\tau(\Xi_c^0)$	~ 1.6 – 2.2	"	2.0 ± 0.4
$\tau(\Xi_c^0)/\tau(\Omega_c)$	~ 1.4	"	1.42 ± 0.14
$\tau(\Xi_c^+)/\tau(\Lambda_c)$	~ 1.3 – 1.6 $\times 1.5 \to 2.25$	"	2.2 ± 0.1
$\tau(\Xi_c^+)/\tau(\Xi_c^0)$	~ 2.8 $\times 1.5 \to 4.2$	"	4.5 ± 0.9
$\tau(\Xi_c^+)/\tau(\Omega_c)$	~ 4 $\times 1.5 \to 6$	"	5.8 ± 0.9

- yes, apply expansion in $1/m_c$ at your own risk, but ...
  - observed pattern reproduced/predicted semiquantitatively -- with $\tau(D^+)/\tau(W_c^0) \sim 20$!
  - destructive PI main engine driving lifetime differences among mesons (first suggested by Rueckl et al. '74):
    - proper treatment of PI always yields $\tau(D^+) > \tau(D^0)$
  - primary impact of HQE: WA is non-leading
    - $\tau(D_s) » \tau(D^0)$

WA -- while not leading -- still significant in D decays

- impact of WA on exclusive meson decays: constructive in D^0 and/or destructive in D_s?
- recent claim: $\tau(D_s)/\tau(D^0) » 1.2$ "explained" b SU(3)$_{Fl}$ relation between hadronic phase space
  - still a model -- phase space not unique
  - no need for WA??

the challenge for theory:

dual descript. in terms of quarks and gluon d.o.f.?

quark PS + quark nonpert. dynamics

dual to

had. PS + boundstate dynamics

- second impact of HQE: explains absolute size of $BR_{SL}(D)$

- baryons present complex challenge:

  several contributions (WS, +PI,-PI) of different signs
  `help' from sizeable experimental uncertainties

  - pattern & numbers quite different from strange baryons:

    - $\tau(W_c^0) < \tau(X_c^0) < \tau(L_c^+) < \tau(X_c^+)$

      vs.

      $\tau(S^+)$ » $\tau(W^-) < \tau(S^-)$ » $\tau(X^-) < \tau(L^0) < \tau(X^0)$

    - $\tau(X_c^+)/\tau(W_c^0) \sim 6.2$ vs. $\tau(X^0)/\tau(W^-) \sim 3.6$

  - sign for significant discrepancy in $\tau(X_c^+)$ only: lives longer by ~ 50 % than predicted (accidental presence of near-by resonance drives ~~duality~~?)

II.2 C=2 Baryons

SELEX '02 finds:

"Ξ_{cc}^{+}" $\to \Lambda_c^{+} K^{-} \pi^{+}$ with $M = 3519 \pm 1$ MeV & $\tau < 0.033$ ps

"Ξ_{cc}^{++}" $\to \Lambda_c^{+} K^{-} \pi^{+} \pi^{+}$ with $M = 3460$ MeV

& "comparable" τ

$\Rightarrow$ 2 major headaches for theorists

- ☞ isospin mass splitting:

  SELEX: ~ 60 MeV vs. B.E. ~ few · 100 MeV

- ☞ lifetimes

  HQE predicts substantially different lifetimes!
  e.g.:

  $\tau(\Xi_{cc}^{++}) / \tau(\Xi_{cc}^{+}) \sim 2.9 - 5.2$

  ❶ $\tau(\Xi_{cc}^{++}) = 0.46 \pm 0.05$ ps, $\tau(\Xi_{cc}^{+}) = 0.16 \pm 0.05$ ps

  Kiselev et al.

  ❷ $\tau(\Xi_{cc}^{++}) \sim 1.05$ ps, $\tau(\Xi_{cc}^{+}) \sim 0.2$ ps

  Guberina et al.

`Yours truly' conclusion:

Whatever the two SELEX states are -- they are not

X_{cc}^{++} & X_{cc}^{+} -- or HQE got it all wrong for charm!

III Charm meson resonances

☞ surprise!

BABAR '03 sees unexpected narrow state X

D_s^* „ Xfi D_s p^0

~~fi~~ D_s D_s g, gg

☞ masses & QN of D** … states and the saturation of SV & spin sum rules for B transitions

IV Summary

"Charm in the presence of Beauty --
like Botticelli in the Sistine Chapel"

One travels to la Sistina to see Michelangelo --
yet once there, have a quality look at Botticelli et al.
Likewise: one builds a B factory to study B physics,
yet do not ignore the charm you can collect there.

- finding New Physics not guaranteed -- yet conceivable
  - very hard (at best) to make conclusive case through observing D^0-D^0 oscillations per se
  - much cleaner case through CP asymmetries
    - involving D^0-D^0 oscillations
    - in Cabibbo allow. & doubly supp. modes
- lots of calibration & appreciation work for better understanding of beauty (and QCD) dynamics
  - engineering inputs
  - study transition to the `duality regime'
    - HQE prediction work amazingly well for lifetimes of charm hadrons
      exception: $\tau(X_c^+)$ exceeds expect. by ~ 50%
    - if SELEX is correct on C=2 baryons: major headache for theory!
  - charm scale -- `bridge' between light & heavy flavours & a meeting/market place between different theor. technologies:
    HQE, chiral models, quark models,
    lattice QCD from below and from above
  - charm spectroscopy
    - relevant for understanding B dynamics
    - appears to show surprises