Charming CPV

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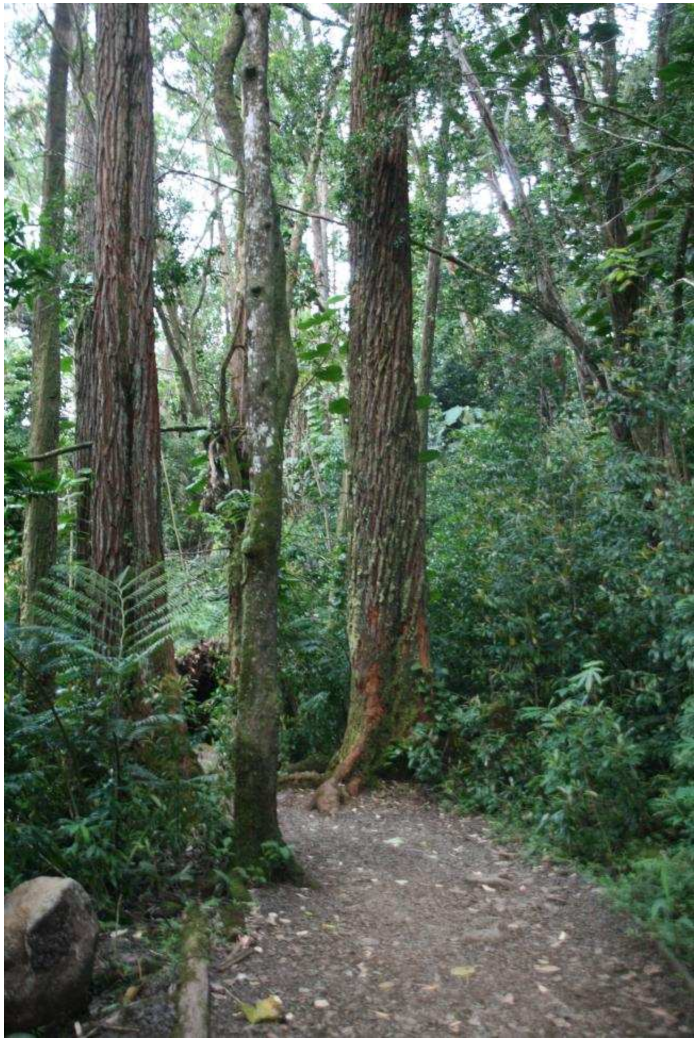
Outline

- Instead of introduction: Field trip to Manoa falls
- CPV in SCS decays
- CPV in mixing
- Conclusion

Educational field trip to Manoa falls

Manoa Falls

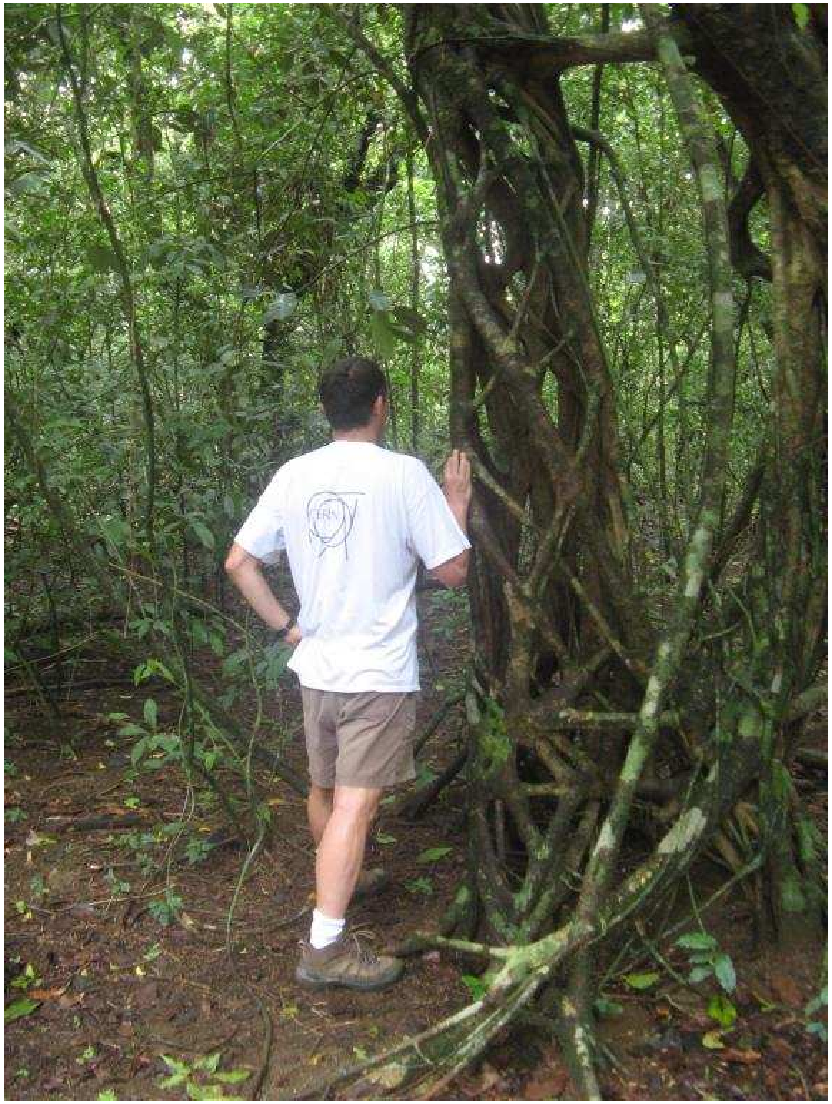
M. Bobrowski, YG, Z. Ligeti, May 15, 2012



Tree loop duality

UV picture

Is it a rare phenomena?



What about the penguins?

All you need to know for charm physics

CPV in SCS D decays

What is new in charm?

We will discuss "one" number

$$\mathcal{A}_{CP}(D \to f) \equiv \frac{\Gamma(D \to f) - \Gamma(\bar{D} \to \bar{f})}{\Gamma(D \to f) + \Gamma(\bar{D} \to \bar{f})}$$

The data:

$$\Delta\mathcal{A}_{CP} \equiv \mathcal{A}_{CP}(D \to K^+K^-) - \mathcal{A}_{CP}(D \to \pi^+\pi^-)$$

$$= (-0.656 \pm 0.154)\%$$ World average

$\sim 4\sigma$ from zero

Systematic? Statistics? NP? SM?

What is old in charm?

We need to recall some “old” problems

- The KK vs $\pi\pi$ ratio

$$\left|\frac{\mathcal{A}(D^0 \to K^+K^-)}{\mathcal{A}(D^0 \to \pi^+\pi^-)}\right| - 1 = 0.82 \pm 0.02\%$$

- When we put the four PP rates together we have

$$\frac{|\mathcal{A}(D^0 \to K^+K^-)| + |\mathcal{A}(D^0 \to \pi^+\pi^-)|}{|\mathcal{A}(D^0 \to K^+\pi^-)| + |\mathcal{A}(D^0 \to K^-\pi^+)|} - 1 = (4.0 \pm 1.6) \times 10^{-2}$$

- Both relations above vanish in the SU(3) limit

$D \to f$ amplitudes

We talk only about SCS decay into a CP eignestate

- We can write the decay amplitude as

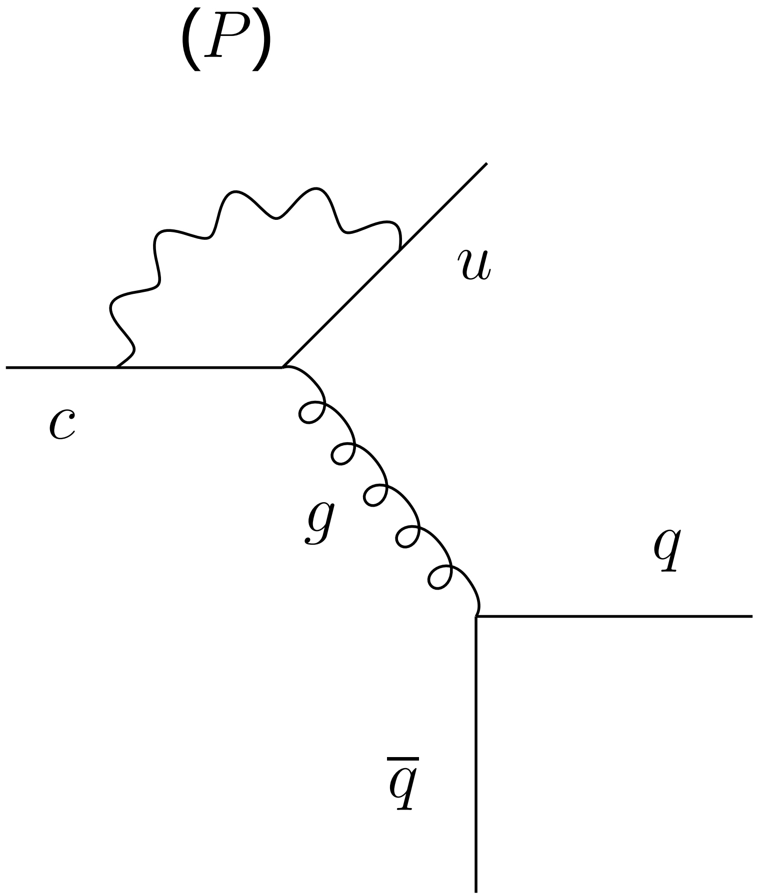
$$\mathcal{A}(D \to f) = A_f \left[1 + r_f e^{i(\delta_f + \phi_f)}\right]$$

$$\mathcal{A}(\bar{D} \to \bar{f}) = A_f \left[1 + r_f e^{i(\delta_f - \phi_f)}\right]$$

- δ_f is a strong phase. ϕ_f is a weak phase
- The whole point is to calculate $r_f \sim P/T$
- The direct CP asymmetry is

$$a_{CP} = 2r_f \sin\delta \sin\phi$$

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



What do we refer to as SM amplitudes?

What is the probability of $c \to u\bar{d}d$ to give $D \to K^+K^-$?

$$O_d \equiv \langle K^+K^-|\bar{c}u\bar{d}d|D^0\rangle$$

- Not zero! We can have $s\bar{s}$ from the vacuum to generate K^+K^-
- $d\bar{d}$ can scatter into $s\bar{s}$
- Is this a tree or penguin?
- Perturbative picture is not justified here
- Remember Manoa falls!

SM amplitudes

How to relate the diagrams to the decay amplitudes?

$$\mathcal{A}(D \to K^+K^-) = \lambda_d O_d + \lambda_s O_s + \lambda_b O_b$$

- O_q are the $\bar{c}uq\bar{q}$ matrix elements. O_b can be neglected

$$\lambda_q = V_{cq}^* V_{uq} \qquad \lambda_d \approx -\lambda_s \gg \lambda_b$$

- Unitarity $\Rightarrow$ $\lambda_d = -\lambda_s - \lambda_b$ $\Rightarrow$

$$\mathcal{A}(D \to K^+K^-) \propto (O_s - O_d) + \xi(O_s + O_d) = C\left[1 + r_f e^{i(\delta+\gamma)}\right]$$

where

$$\xi = \frac{V_{cb}V_{ub}}{V_{cs}V_{us}} \sim 6\times 10^{-4} \qquad r_f = |\xi| \times X_H \qquad X_H = \left|\frac{O_s + O_d}{O_s - O_d}\right|$$

How large can X_H be?

The asymmetry is $a_{CP} \approx 2 \times 10^{-3} \times X_H \sin\delta \sin\gamma$

- To explain the data we need $X_H \gtrsim 3$
- Naively

$$X_H \sim \frac{P}{T} \sim \frac{\alpha_S(m_c)}{\pi} \sim 0.1$$

- We obtain this ratio from $B \to K\pi$ and $B \to \pi\pi$

$$X_H \sim 0.15$$

- In the heavy quark limit

$$\frac{X_H(D)}{X_H(B)} \sim \frac{\alpha_S(m_c)}{\alpha_S(m_b)} \sim 2 \;\Rightarrow\; X_H \sim 0.3$$

What can we say about X_H?

Is the above estimate of $X_H \sim 0.3$ reliable?

- Golden and Grinstein (89); Brod, Kagan, Zupan (11): X_H can be large.
- Remember "the $\Delta I = 1/2$ rule"
  - Unexplained enhancement of factor of about 22 of "penguin" over "tree"
  - Very low energy
- The "penguin" vs "tree" is a perturbative picture. At low energy it is all messed up
- Maybe charm is more like kaon and what we see is a similar $\Delta I = 1/2$ rule for charm

The $\Delta I = 1/2$ rule

- In the isospin limit, two matrix elements. The data gives $A_0/A_2 \approx 22$
- Only A_0 include the “penguins”
- Very rough idea: $u\bar{u}$ in, almost 50$\%$ $d\bar{d}$ out
- Isospin breaking can be enhanced by A_0
- The $\Delta I = 1/2$ rule is a non perturbative enhancement
- The data is very accurate

$$K: 22.45 \pm 0.05 \quad D: 2.50 \pm 0.08 \quad B: 0.96 \pm 0.09$$

- B is heavy, no enhancement. D seems between B and K. Enhancement of the “penguins”

The $\Delta U = 0$ rule

- We can write the reduced amplitudes in term of U spin reduced matrix elements, including first order breaking

$$A(\bar{D}^0 \to \pi^+ K^-) = (t_0 + t_1 \epsilon)$$
$$A(\bar{D}^0 \to K^+ \pi^-) = (t_0 - t_1 \epsilon)$$
$$A(\bar{D}^0 \to \pi^+ \pi^-) = (t_0 + p_1 \epsilon + \xi p_0)$$
$$A(\bar{D}^0 \to K^+ K^-) = (t_0 - p_1 \epsilon - \xi p_0)$$

- p_1 is a “broken penguin”
- Dynamical assumption $p_1 \sim p_0$ (we saw it in kaons)
- Fit the BR data and the asymmetry

$$p_1/t_0 \sim 3$$

What should we do next?

What else can be done?

- Zoltan: “While the central value of Δa_{CP} is much larger than what was expected in the SM, we cannot yet exclude that it may be due to a huge hadronic enhancement in the SM”
- Yuval: “While the central value of Δa_{CP} fits nicely in the SM, we cannot yet exclude that it may be due to NP”

  - Topologically the above two statements are equivalent
  - Just like a bagel and a mug are
  - Yet, to emphasize, whether Zoltan, me, or anyone else is the bagel is not the issue
  - The issue is how can we keep on checking

Checks

How can we check if it is SM or NP?

- “Easy” for NP to generate a gluonic penguin at the right size
- One check is for CPV in $D \to V\gamma$
- Other modes, like PV, VV and multibody
- Measure the separate asymmetries. The U spin argument predict that they scale like the inverse square root of the rates
- Several isospin relations

The big question: How to determine: SM or NP

CPV in $D - \bar{D}$ Mixing

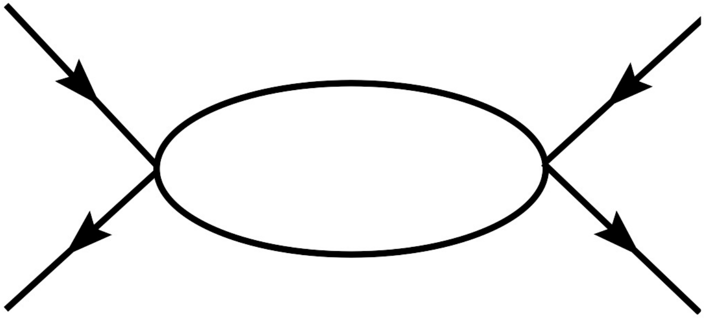
CPV in the mixing

What is the upper value possible in the SM?

- How large the phase can be?
- How it is related to the fundamental phase?
- How large a CPV observable can be?

Not easy to deal with long distance

Fish



How large the phase can be?

- Roughly speaking, we are looking for the phase of the mixing
- The short distance phase is $O(1)$
- Long distance dominates, and it is almost real

$$\phi \sim 6 \times 10^{-4} \times \frac{\sin\theta_C}{\sqrt{x, y}}$$

- At most 10^{-2}

How large a CPV observable can be?

- The phase that appears in the mixing is suppressed by $x/\sqrt{x^2+y^2}$
- Any observable is suppressed by x or y
- Any CPV observable from mixing is suppressed by at least 10^{-4}
- Seeing it in the near future, will be a signal of NP (I do take risks!)

Conclusions

Conclusions

- CPV in charm decays: Is it SM or NP?
- CPV in mixing is still expected to be much below current sensitivity
- Go and hike Manoa falls