Charm physics

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Cornell (permanent) and Weizmann (this year)

Where are we in charm? (personal view)

- CPV in decay
  - SU(3) and all that
- Getting control over SU(3) breaking
  - Can we argue that SU(3) breaking between charged conjugate states are suppressed?
- Mixing
  - How large can CPV in mixing be?

CPV in SCS D decays

CPV 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:

$$\Delta\mathcal{A}_{CP} \equiv \mathcal{A}_{CP}(D \to K^+K^-) - \mathcal{A}_{CP}(D \to \pi^+\pi^-) \sim 0$$

- It used to be $(-0.656 \pm 0.154)\%$, and we argued that it is due to a $\Delta U = 0$ rule
- What is going on?

Why a $\Delta U = 0$ rule

We need to recall some "old" problems

- The KK vs $\pi\pi$ ratio

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

- 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

U spin analysis

- U spin ($\varepsilon = 0.2$, $\xi = |V_{cb}V_{ub}/V_{cs}V_{us}| \sim 6 \times 10^{-4}$)

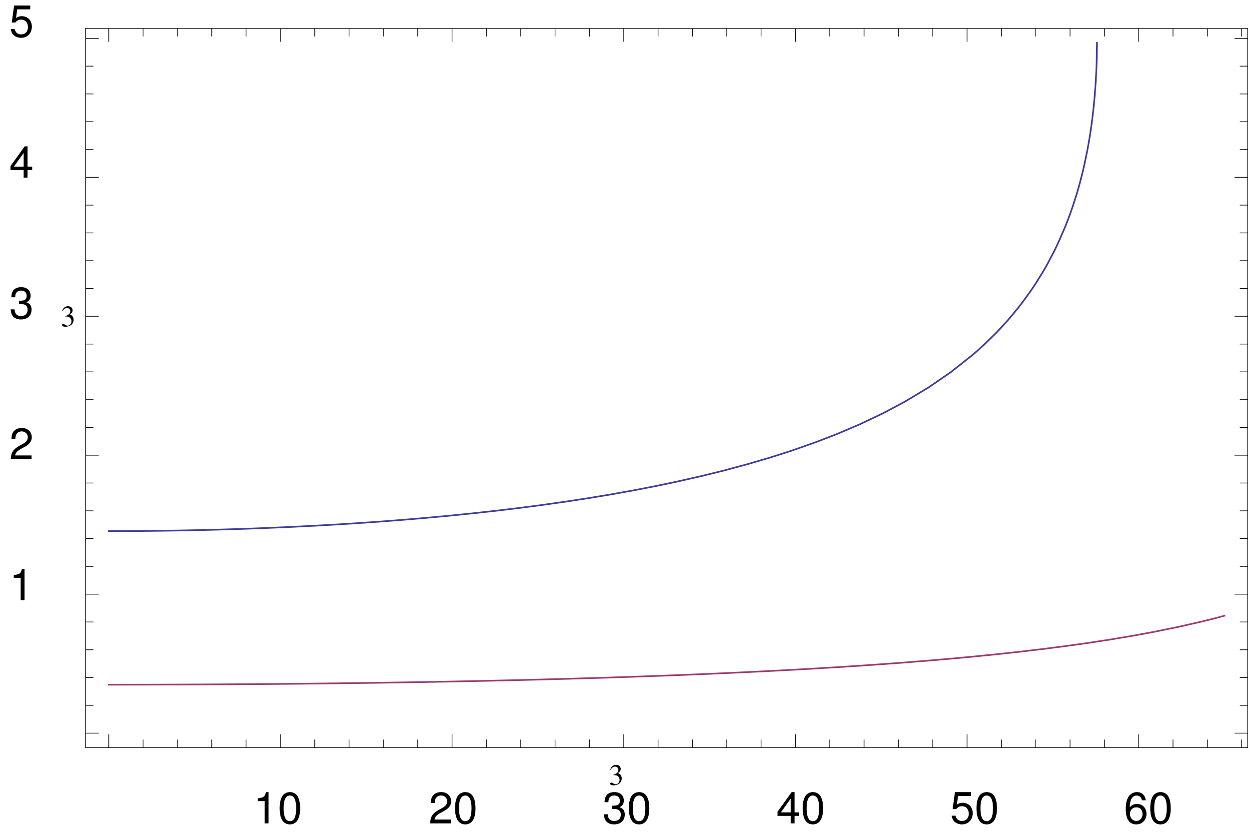
$$A(\bar{D}^0 \to \pi^+ K^-) = (t_0 + \varepsilon t_1)$$
$$A(\bar{D}^0 \to K^+ \pi^-) = (t_0 - \varepsilon t_1)$$
$$A(\bar{D}^0 \to \pi^+ \pi^-) = (t_0 + \varepsilon p_1 + \xi p_0)$$
$$A(\bar{D}^0 \to K^+ K^-) = (t_0 - \varepsilon p_1 - \xi p_0)$$

- $A_{CP} \sim p_0\, t_0\, \sin\delta$
- BR data implies $p_1 \gg t_1$
- We expect $p_1 \sim p_0$
- Old data $\Rightarrow$ large δ and large p/t
- Current data $\Rightarrow$ smaller δ and/or smaller p/t

More on SU(3) breaking

Plots

Assuming same strong phase, to explain the BR data



- blue:p_1/t_0 red:t_1/t_0 $\varepsilon = 0.2$

Again the data

We saw

$$\frac{p_1}{t_0} \gg \frac{t_1}{t_0}$$

Why is that?

- If we assume "universal" SU(3) breaking, that is, $p_1/p_0 \sim t_1/t_0$ we need $\Delta U = 0$ rule with $p_0 \gg t_0$
- Another option: SU(3) breaking in p is larger, that is $p_1/p_0 \gg t_1/t_0$ with $p_0 \sim t_0$
- We might have both

Similar question in B decays (see Dean's talk)

Charge conjugation states

- When we have charge conjugated (CC) final states, their FSIs are the same

$$A(u\bar{d}s\bar{u} \to \pi^+ K^-) = A(\bar{u}d\bar{s}u \to \pi^- K^+)$$
$$A(u\bar{d}d\bar{u} \to \pi^+ \pi^-) \neq A(u\bar{s}s\bar{u} \to K^+ K^-)$$

- There are also phase space effects
- Still, CC does not imply no breaking in $K\pi$
- In term of U spin, small breaking in CC-states manifest itself as larger SU(3) breaking on penguins

Can we formally argue that SU(3) breaking in penguins are larger?

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

CPV in the mixing

Work in progress with Kagan, Ligeti, Perez, Petrov

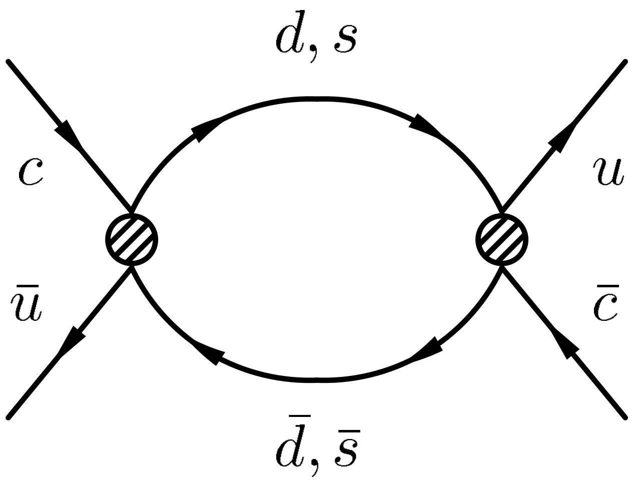
see also, M. Bobrowski, A. Lenz, J. Riedl, J. Rohrwild, 1002.4794

What is the upper value possible in the SM?

- How large can the physical phase be?
- How large can a CPV observable be?

Not easy to deal with long distance

Fish diagram



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

$$\phi_{12} \sim \xi \times \frac{\sin\theta_C}{\sqrt{x,y}} \sim 3 \times 10^{-3}$$

- We think that we can show that it is at most 10^{-2}

Definitions

My first time ever with such a slide, sorry

$$\phi_{12} = \arg(m_{12}\Gamma_{12}^*)$$

$$\lambda_i = V_{ci}V_{ui}^* \Rightarrow \lambda_d = -(\lambda_b + \lambda_s)$$

$$\Gamma_{12} = -\sum_{i,j=s,b} \lambda_i\,\lambda_j\;\Gamma_{ij} \qquad M_{12} = -\sum_{i,j=s,b} \lambda_i\,\lambda_j\;M_{ij}$$

$$\Gamma_{12} = \Gamma_{12}^0 + \delta\Gamma_{12} \qquad M_{12} = M_{12}^0 + \delta M_{12}^0$$

$$\Gamma_{12}^0 = -\lambda_s^2\;(\Gamma_{ss} - 2\Gamma_{sd} + \Gamma_{dd}) \qquad \delta\Gamma_{12} = 2\lambda_s\,\lambda_b\;(\Gamma_{ss} - \Gamma_{dd}) + O(\lambda_b^2)$$

- $\phi_{12} \neq 0$ due to λ_b in $\delta\Gamma_{12}$ and δM_{12}

More refine question

- CPV arises from the misalignment between V_{us} and V_{RD}
- How large $\delta\Gamma_{12}/\Gamma_{12}^0$ and $\delta M_{12}/M_{12}^0$ can be?
- We only try to get a rough upper bound

$$\frac{\delta\Gamma_{12}}{\Gamma_{12}^0} = \frac{\lambda_b}{\lambda_s} \times \frac{\Gamma_{ss} - \Gamma_{dd}}{\Gamma_{ss} - 2\Gamma_{sd} + \Gamma_{dd}} \sim 6 \times 10^{-4} \times \frac{\epsilon}{\epsilon^2}$$

- Can we estimate the SU(3) breaking in the relvant terms?

How large a CPV observable can be?

$$\phi_{12} \sim 6 \times 10^{-4} \times \frac{\Gamma_{ss} - \Gamma_{dd}}{\Gamma_{ss} - 2\Gamma_{sd} + \Gamma_{dd}}$$

- What can we say about

$$\frac{\Gamma_{ss} - \Gamma_{dd}}{\Gamma_{ss} - 2\Gamma_{sd} + \Gamma_{dd}}$$

- Naively it is of order $1/\epsilon \sim 5$
- Yet, maybe we have that “enhanced” SU(3) breaking and it is much larger
- We argue that

$$\Gamma_{ss} - \Gamma_{dd} < \Gamma$$

- Under this assumption we conclude $\phi_{12} < 0.01$

How large a CPV observable can be?

Getting the phase, ϕ_{12} is not the end of the story

- 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

Conclusions

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- CPV in SDS decays: It cannot tell us much about $\Delta U = 0$ rule
- Can we say anything about the pattern of SU(3) beaking?
- How rigorously can we bound the phase of the mixing?