New CP violation effect in charm decays

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CP violation in D decay into neutral K

- Belle measurement with 3.2 sigma from zero

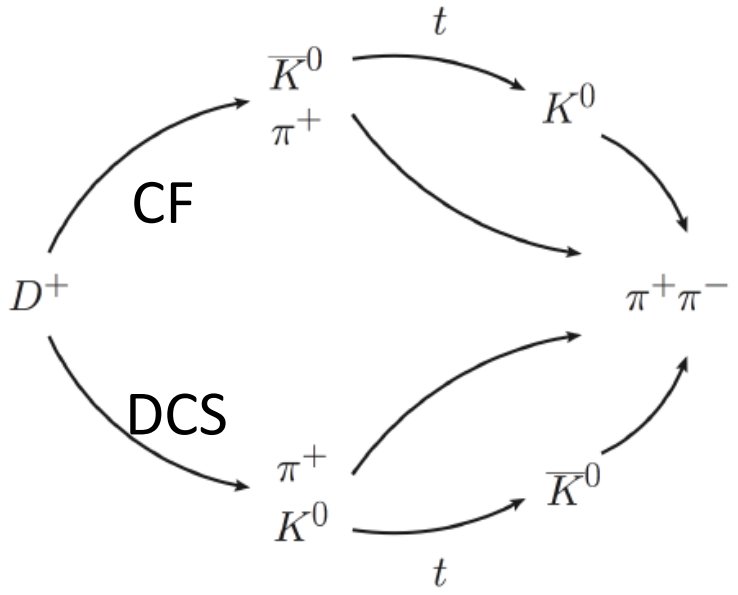
$$A_{CP}(D^+ \to \pi^+ K_S^0) = (-3.63 \pm 0.94 \pm 0.67) \times 10^{-3}$$

- Ks is reconstructed via decay into two charged pions
- K_L also decays into two pions
- Data mainly due to kaon mixing of order 10^{-3}
- Postulated in literature: deducting kaon mixing, data reveal direct CP asymmetry in charm decays

Lipkin, Xing 1999
D'Ambrosio, Gao 2001
Bianco, Fabbri, Benson, Bigi 2003
Grossman, Nir 2012

Our observation

- This is not correct!
- Kaon mixing induces a new CP observable
- More complicated than ordinary mixing-induced CP asymmetry in, say, $B^0(t) \to \pi^+\pi^-$: both oscillation and decay occur in mother particle
- The new observable arises from interference between mother decay and daughter mixing



New CP observable

- Neglect direct CP asymmetry in $K \to \pi\pi$

$$A_{CP}(t) \simeq \left[A_{CP}^{\overline{K}^0}(t) + A_{CP}^{\rm dir}(t) + A_{CP}^{\rm int}(t) \right] / D(t)$$

- Known kaon mixing

$$D(t) = e^{-\Gamma s t}(1 - 2 r_f \cos\delta_f \cos\phi)$$

$$A_{CP}^{\overline{K}^0}(t) = 2e^{-\Gamma s t}\mathcal{R}e(\epsilon) - 2e^{-\Gamma t}\left[\mathcal{R}e(\epsilon)\cos(\Delta m t) + \mathcal{I}m(\epsilon)\sin(\Delta m t)\right]$$

- Direct CP

$$\mathcal{A}(D \to f K^0)/\mathcal{A}(D \to f \overline{K}^0) = r_f\, e^{i(\phi+\delta_f)}$$

$$A_{CP}^{\rm dir}(t) = e^{-\Gamma s t}\, 2 r_f \sin\delta_f \sin\phi$$

strong phase

$$|V_{cd}^* V_{us}/V_{cs}^* V_{ud}| \sim \mathcal{O}(10^{-2})$$

$$\phi \equiv Arg\left[-V_{cd}^* V_{us}/V_{cs}^* V_{ud}\right] = (-6.2 \pm 0.4) \times 10^{-4}$$

- New observable

$$A_{CP}^{\rm int}(t) = -4 r_f \cos\phi \sin\delta_f \left[e^{-\Gamma s t}\mathcal{I}m(\epsilon) - e^{-\Gamma t}\Big(\mathcal{I}m(\epsilon)\cos(\Delta m t) - \mathcal{R}e(\epsilon)\sin(\Delta m t)\Big)\right]$$

Numerical results

- Direct CP asymmetry always negligible
- New observable becomes comparable to kaon mixing as t ~ few times of K short lifetime

global fit to branching-ratio data to fix

$$r_{\pi^+} = -0.073 \pm 0.004,$$

$$\delta_{\pi^+} = -1.39 \pm 0.05$$