Measuring γ Cleanly with CP-Tagged B_s Decays

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A.F. Falk and A.A. Petrov, *Phys. Rev. Lett.* **85**, 252 (2000)

The Challenge:

Measure γ with negligible theoretical uncertainty!

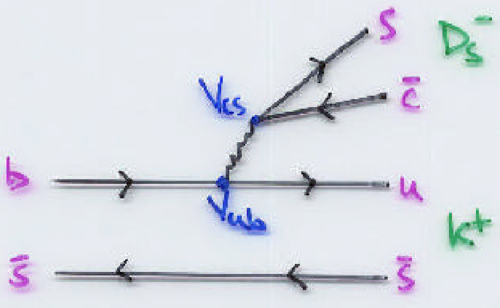
$$\gamma = \arg\left[-\frac{V_{ud}V_{ub}^*}{V_{cd}V_{cb}^*}\right] \approx \arg\left[-\frac{V_{cs}V_{ub}^*}{V_{us}V_{cb}^*}\right] \approx \phi_3$$

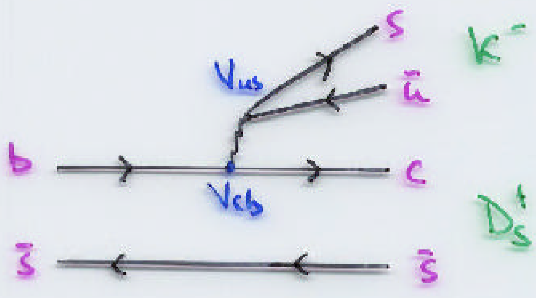
$$= \text{phase of } b \to u \text{ transition (Wolfenstein param.)}$$

- Cleanliness requires decays mediated by a single weak amplitude – no penguins!

- Compare phases of $b \to u\bar{c}s$ and $b \to c\bar{u}s$:

$\overline{B}_s \to D_s^- K^+$ $\qquad\qquad$ $\overline{B}_s \to D_s^+ K^-$





- Even though $s\bar{s}$ rescattering topologies do contribute, the signs of the D_s and K fix the weak phase of the decay amplitude.

The Strategy

- Fix final state $D_s^- K^+$. Define flavor-tagged amplitudes

$$A_1 = A(B_s \to D_s^- K^+) = a_1 e^{i\delta_1}$$

$$A_2 = A(\overline{B}_s \to D_s^- K^+) = a_2 e^{-i\gamma} e^{i\delta_2}$$

δ_i are unknown strong phases

- CP eigenstate combination: $B_s^{\rm CP} = B_s + \overline{B}_s$

(This assumes a phase convention, which is fixed for this talk.)

- Define CP-tagged amplitude

$$A_{\rm CP} = A(B_s^{\rm CP} \to D_s^- K^+) = (A_1 + A_2)/\sqrt{2}$$

- Compare to $D_s^+ K^-$ final state

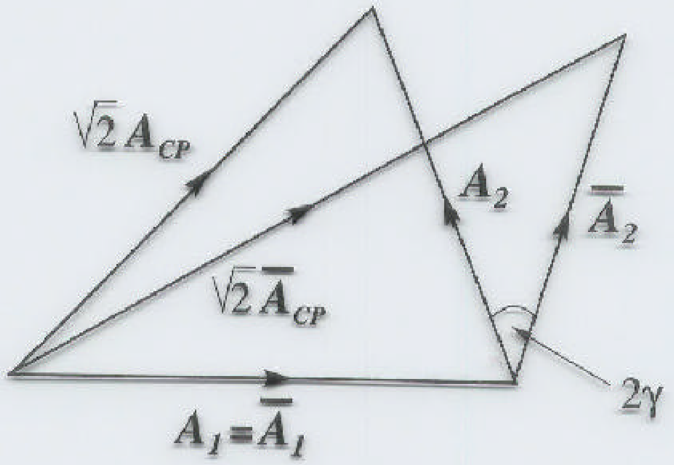
$$\overline{A}_1 = A(\overline{B}_s \to D_s^+ K^-) = a_1 e^{i\delta_1}, \qquad |A_1| = |\overline{A}_1|$$

$$\overline{A}_2 = A(B_s \to D_s^+ K^-) = a_2 e^{i\gamma} e^{i\delta_2}, \qquad |A_2| = |\overline{A}_2|$$

$$\overline{A}_{\rm CP} = A(B_s^{\rm CP} \to D_s^+ K^-) = (\overline{A}_1 + \overline{A}_2)/\sqrt{2}$$

- Although $|A_{\rm CP}| \neq |\overline{A}_{\rm CP}|$ only if $\delta = \delta_2 - \delta_1 \neq 0$, the extraction of γ does not depend on large δ.

• Extract 2γ from triangle relation. The triangles are not "squashed":



• Analytic expression:

$$
\begin{aligned}
\alpha &= \frac{2|A_{\rm CP}|^2 - |A_1|^2 - |A_2|^2}{2|A_1||A_2|} \\
\overline{\alpha} &= \frac{2|\overline{A}_{\rm CP}|^2 - |\overline{A}_1|^2 - |\overline{A}_2|^2}{2|\overline{A}_1||\overline{A}_2|} \\
2\gamma &= \arccos\alpha - \arccos\overline{\alpha} \qquad (**)
\end{aligned}
$$

[(**) expression is incorrect in published paper]

• γ has an eightfold ambiguity in the region $0 \leq \gamma < 2\pi$

CP tagging

- Need CP tagging to measure $\Gamma(B_s^{\rm CP} \to D_s^- K^+)$

- Use $\Upsilon(5S) \to B_s \overline{B}_s$:

$\Upsilon(5S)$ is CP-even, decay products in a p-wave

$$\Downarrow$$

$B_s/\overline{B}_s$ combinations have anticorrelated CP

- Tagging mode should conserve CP in decay:

$$B_s^{\rm CP} \to D_s^+ D_s^-$$

- The CP value of tagging mode does not enter the analysis

- The B_s and $\overline{B}_s$ mix before decaying. In the Standard Model, CP violation in B_s is small, of order $\beta_s \sim \lambda^2$. But β_s ought to be constrained independently.

- CP tagging is not possible in a hadronic environment

This analysis is unique to a B Factory at the $\Upsilon(5S)$!!

Is this feasible? Crude estimate only

- Goal is ~ 100 CP-tagged and reconstructed events
- Assume a luminosity-upgraded B Factory, with

$$\mathcal{L} \approx 10^{35}\,\mathrm{cm}^{-2}\,\mathrm{sec}^{-1}$$

$$\sigma(B_s\overline{B}_s)/\sigma(\Upsilon(4S)) \approx 10^{-2} \quad ?$$

$$B(B_s^{\mathrm{CP}} \to D_s^+ D_s^-) \approx 10^{-2}$$

$$B(B_s^{\mathrm{CP}} \to DK) \approx 2 \times 10^{-4}$$

$$\Downarrow$$

100 events in ~ 1 year

- Assume flavor-tagged decays measured by BTeV or LHCb

This is much too optimistic!

- You need to reconstruct the D_s's. Three of them, two of which are in the tagging mode.

- If efficiency is 10%, this is not good enough

- Combine many D_s decay modes? Help!

This is too pessimistic!

- Use $B_s \overline{B}_s^*$ and $\overline{B}_s B_s^*$ combinations from $\Upsilon(5S)$:

$$B_s^* \to B_s + \gamma\,, \text{ magnetic } \gamma \text{ with CP} = -1$$

$$\Downarrow$$

$$B_s \text{ and } \overline{B}_s \text{ have correlated CP}$$

- Similarly, $B_s^* \overline{B}_s^* \;\Rightarrow\; B_s$ and $\overline{B}_s$ with anticorrelated CP (**)

Gain ~~at least~~ an order of magnitude!

- Use additional final states:

$$D_s K^*\,, \qquad D_s^* K\,, \qquad D_s^* K^*$$

- Use more CP tagging modes, some of which might require an angular analysis:

$$\psi\eta\,, \qquad D_s^* \overline{D}_s^*\,, \qquad \psi\phi$$

CP tagging in the B_d system

• In the Standard Model, CP is violated in B_d mixing, so the CP correlation depends on the decay time t.

• A complicated analysis is possible, *if* you

1. know β precisely
2. measure t for each decay

The amplitude analysis must then be performed at fixed t.

Extract a value of γ for each t bin, compare for consistency.

• In principle, B Factories at the $\Upsilon(4S)$ could do this.

But could it be feasible?!

Summary

- The method is theoretically clean.

Good...

- The method is unique to the $\Upsilon(5S)$.

Intriguing!

- The method might even be feasible.

Experimental details?