

# Fingerprinting CP-violating New Physics with Rare B Meson Decays



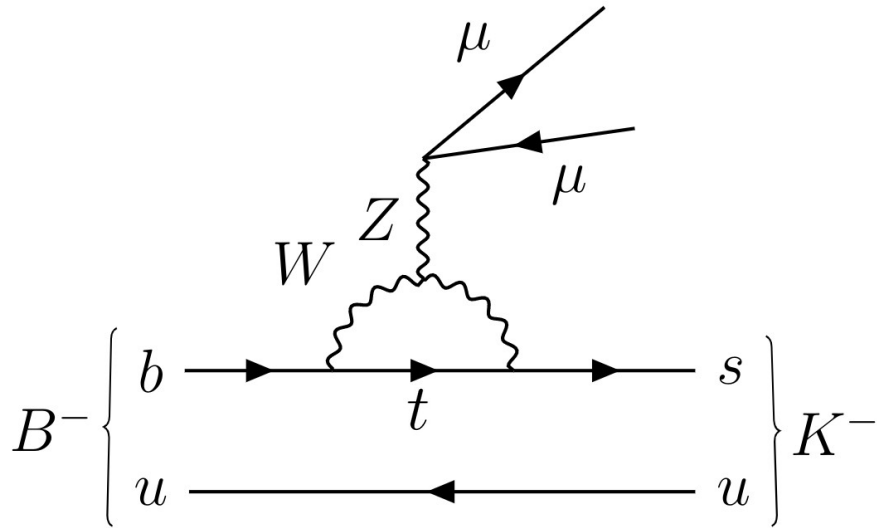
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with  
Robert Fleischer,  
Eleftheria Malami,  
Keri Vos

Lunteren 22-11-04

Nikhef

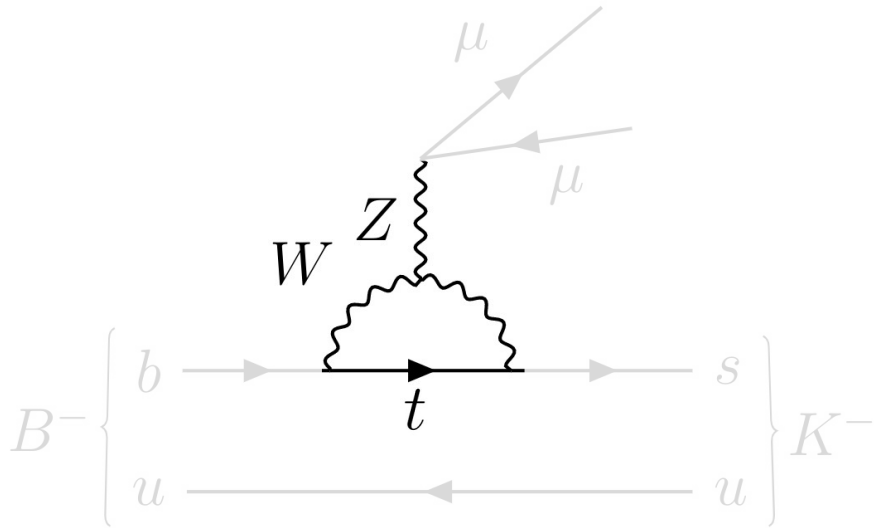
# Rare B meson decays

## Standard Model



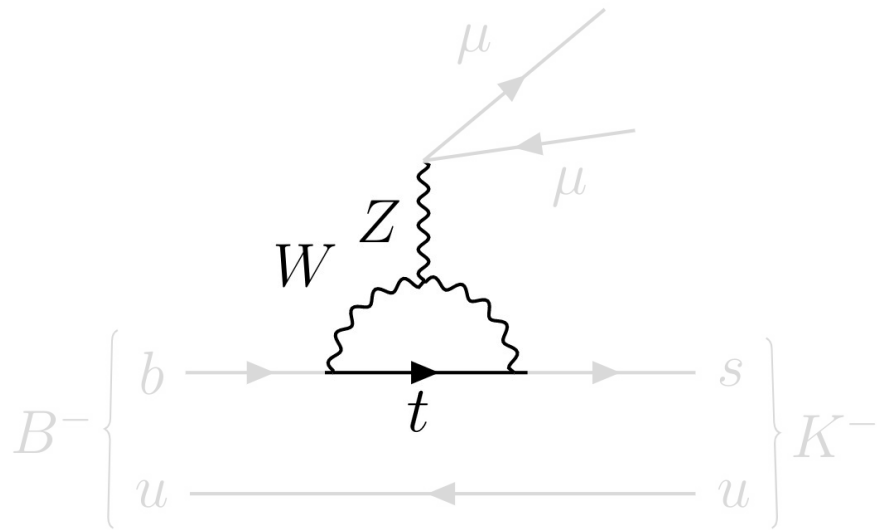
# Rare B meson decays

## Standard Model

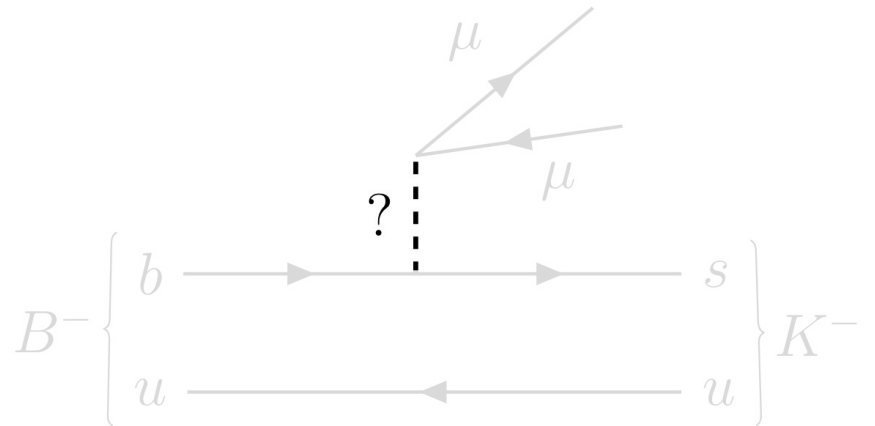


# Rare B meson decays

Standard Model



New physics?



# Anomalies in rare B meson decays

$$BR(B \rightarrow K \mu^+ \mu^-) \sim 4.7\sigma(!)$$

$$R_K \sim 3.1\sigma$$

and more...

$$R_{K^*}$$

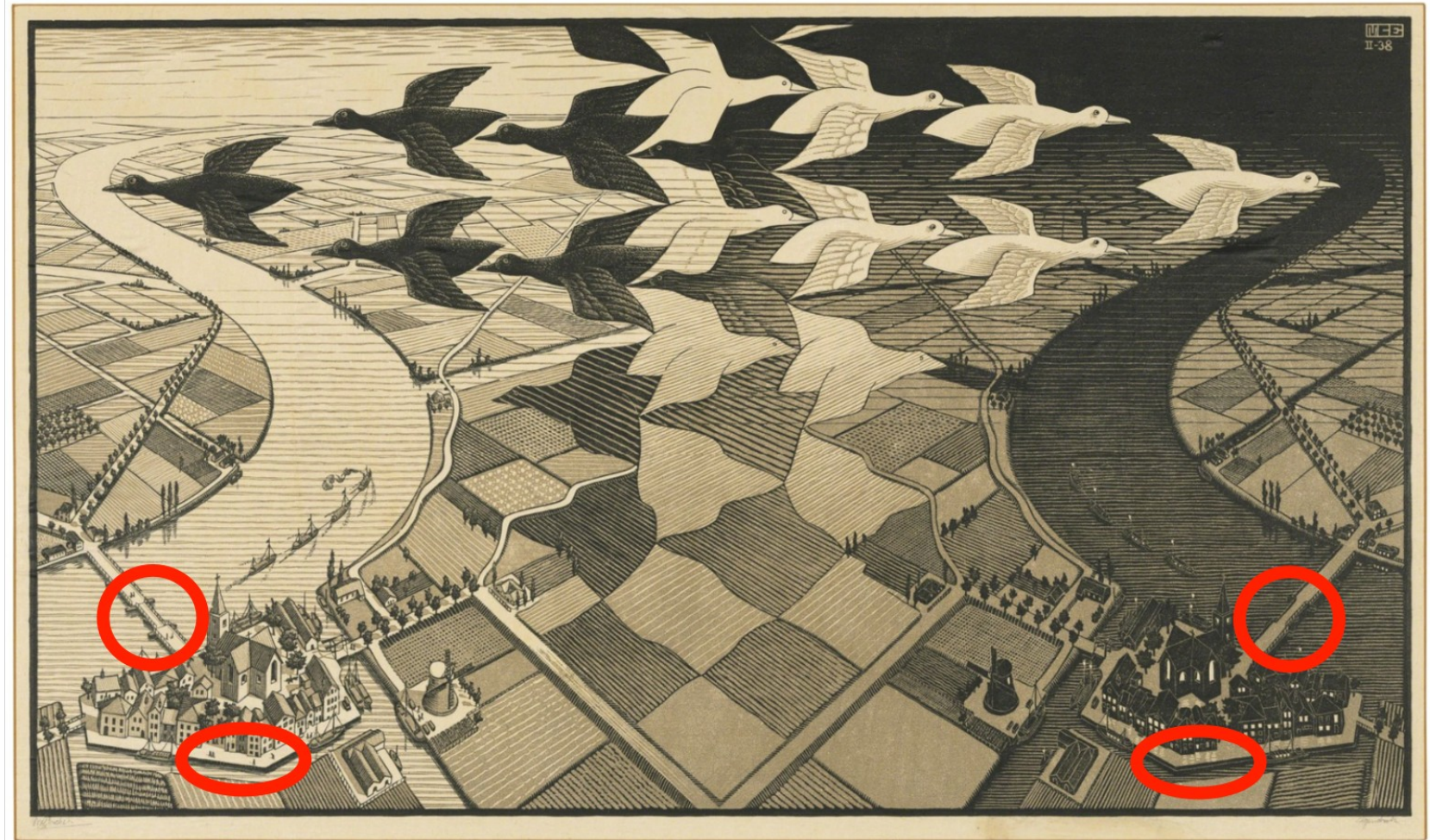
$$P'_5$$

$$BR(B \rightarrow K^* \mu^+ \mu^-)$$

$$BR(B_s \rightarrow \mu^+ \mu^-)$$

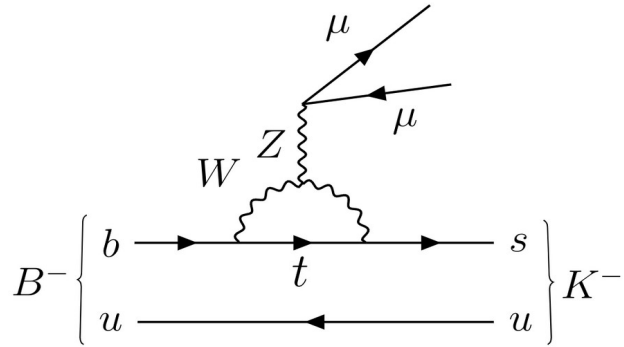
$$BR(\Lambda_b \rightarrow \phi \mu^+ \mu^-)$$

# CP violation

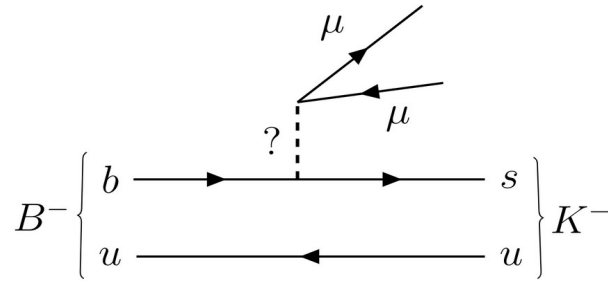


# Effective Field Theory

Standard Model

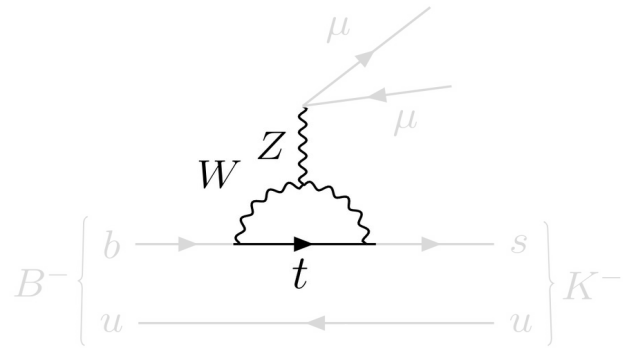


New physics?

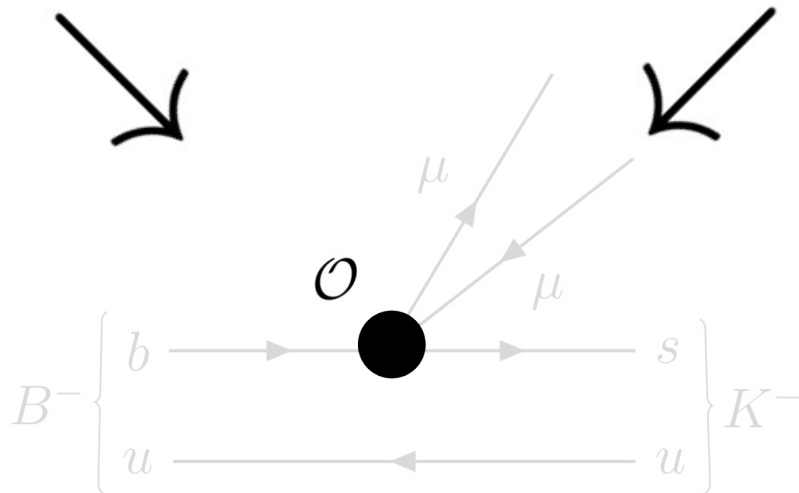
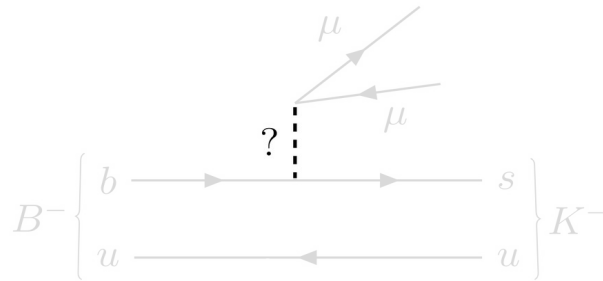


# Effective Field Theory

Standard Model



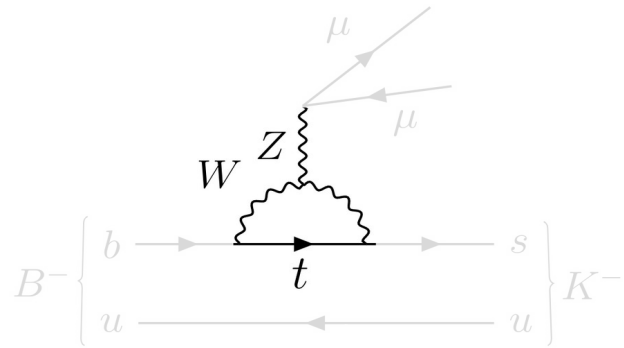
New physics?



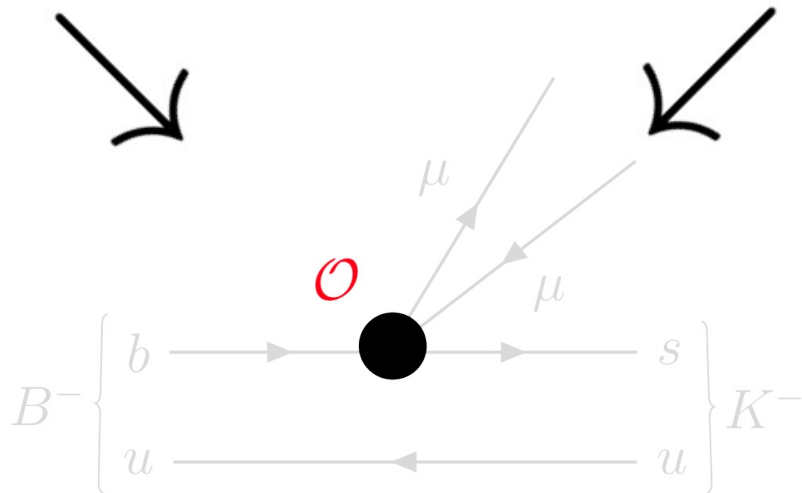
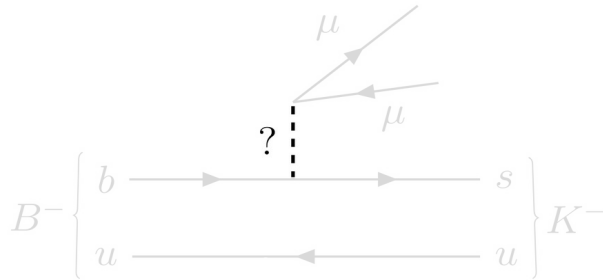


# Effective Field Theory

Standard Model



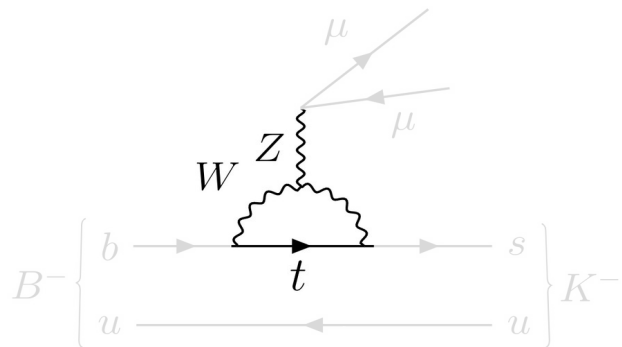
New physics?



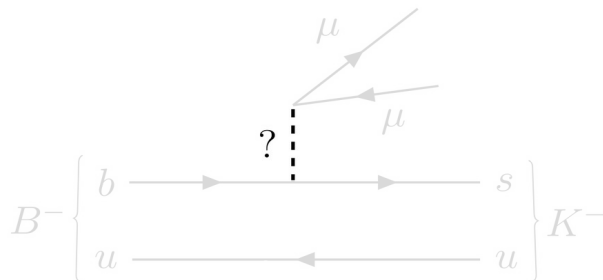
$$\mathcal{H}_{\text{eff}} = \sum_i C_i \mathcal{O}_i$$

# Effective Field Theory

Standard Model

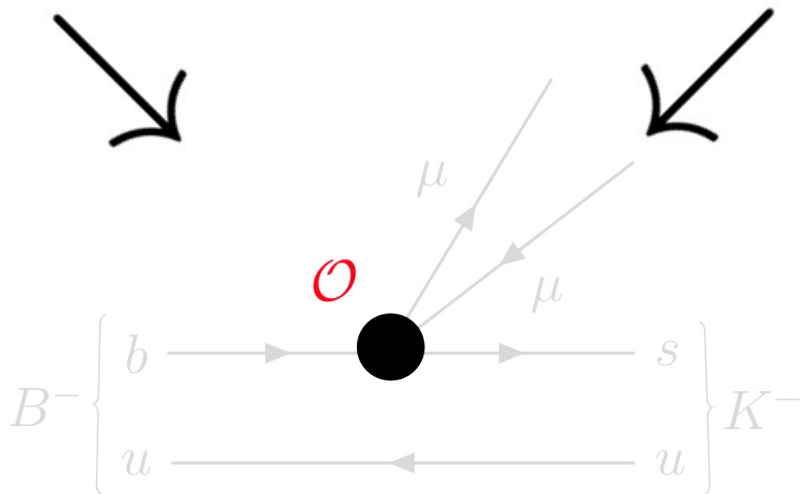


New physics?



$$\langle K^- | \mathcal{H}_{\text{eff}} | B^- \rangle$$

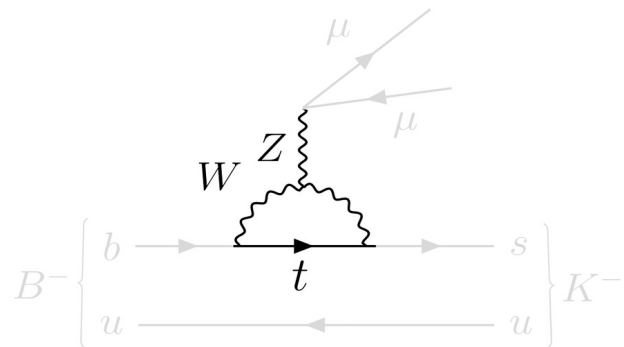
→ Theory predictions!



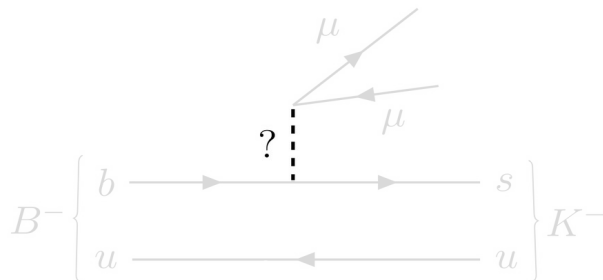
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# Effective Field Theory

Standard Model



New physics?

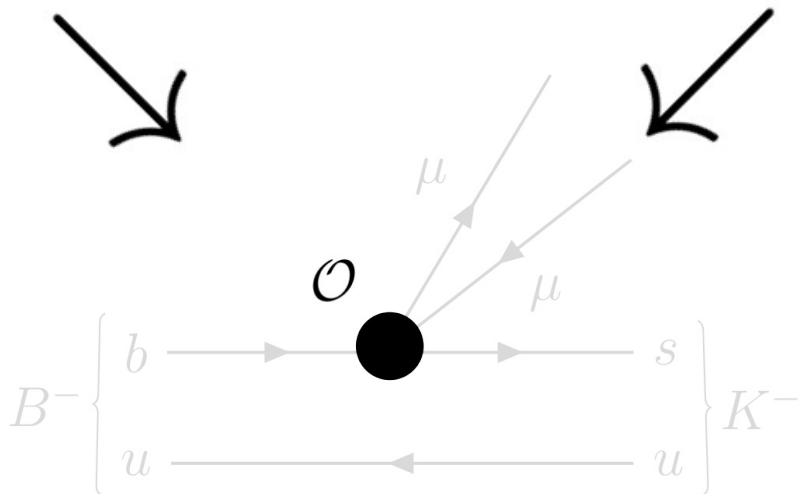


$$\langle K^- | \mathcal{H}_{\text{eff}} | B^- \rangle$$

→ Theory predictions!

Wilson coefficient

$$\mathcal{H}_{\text{eff}} = \sum_i C_i \mathcal{O}_i$$



$C_i \leftarrow \text{data}$

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Scenario 1:  $C_9^{\text{NP}} \neq 0$

Scenario 2:  $C_9^{\text{NP}} = -C_{10}^{\text{NP}} \neq 0$

Scenario 3:  $C_{10}^{\text{NP}} \neq 0$

Altmannshofer, Stangl (2021),  
Gubernari et al. (2022),  
Chundawat (2022),  
Geng et al. (2017),  
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...



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...

Direct CP  
asymmetry

$$A_{\text{CP}}^{\text{dir}} = \frac{\Gamma - \bar{\Gamma}}{\Gamma + \bar{\Gamma}}$$

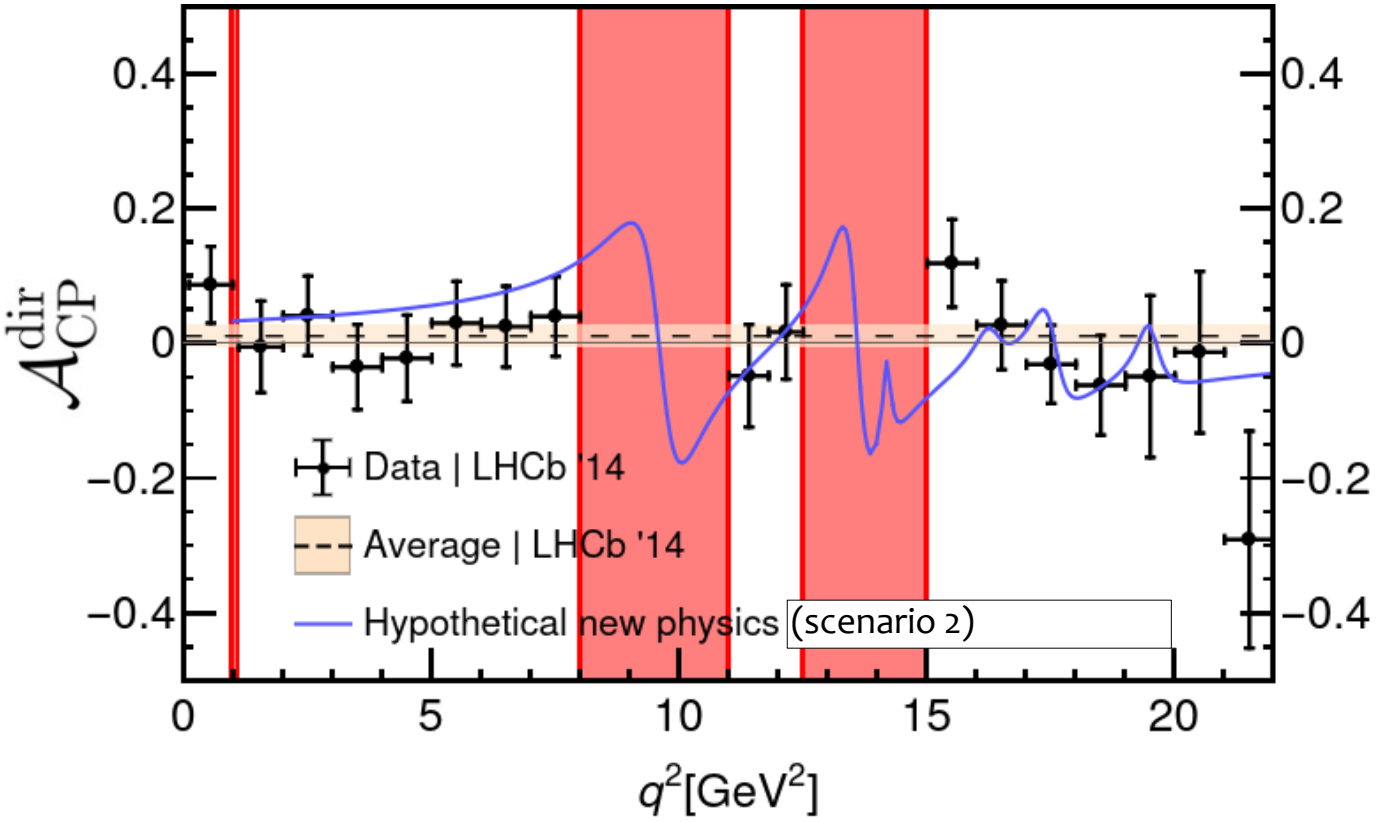


Direct CP  
asymmetry

$$\mathcal{A}_{\text{CP}}^{\text{dir}} = \frac{\Gamma - \bar{\Gamma}}{\Gamma + \bar{\Gamma}}, \quad \Gamma = \Gamma(B^+ \rightarrow K^+ \mu^+ \mu^-)$$
$$\bar{\Gamma} = \Gamma(B^- \rightarrow K^- \mu^- \mu^+)$$

# Direct CP asymmetry

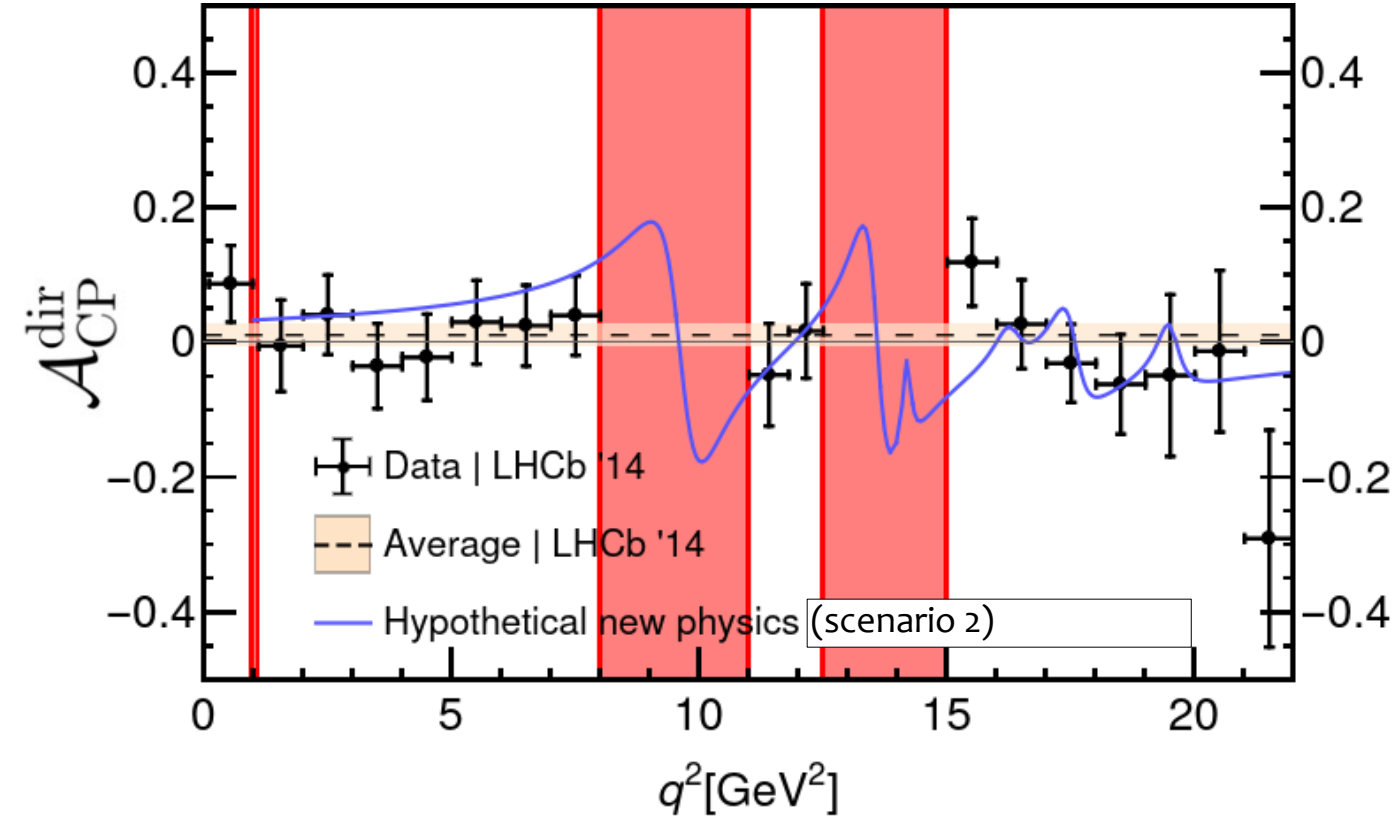
$$\mathcal{A}_{\text{CP}}^{\text{dir}} = \frac{\Gamma - \bar{\Gamma}}{\Gamma + \bar{\Gamma}}, \quad \Gamma = \Gamma(B^+ \rightarrow K^+ \mu^+ \mu^-) \\ \bar{\Gamma} = \Gamma(B^- \rightarrow K^- \mu^- \mu^+)$$



# Direct CP asymmetry

$$\mathcal{A}_{\text{CP}}^{\text{dir}} = \frac{\Gamma - \bar{\Gamma}}{\Gamma + \bar{\Gamma}}, \quad \Gamma = \Gamma(B^+ \rightarrow K^+ \mu^+ \mu^-)$$

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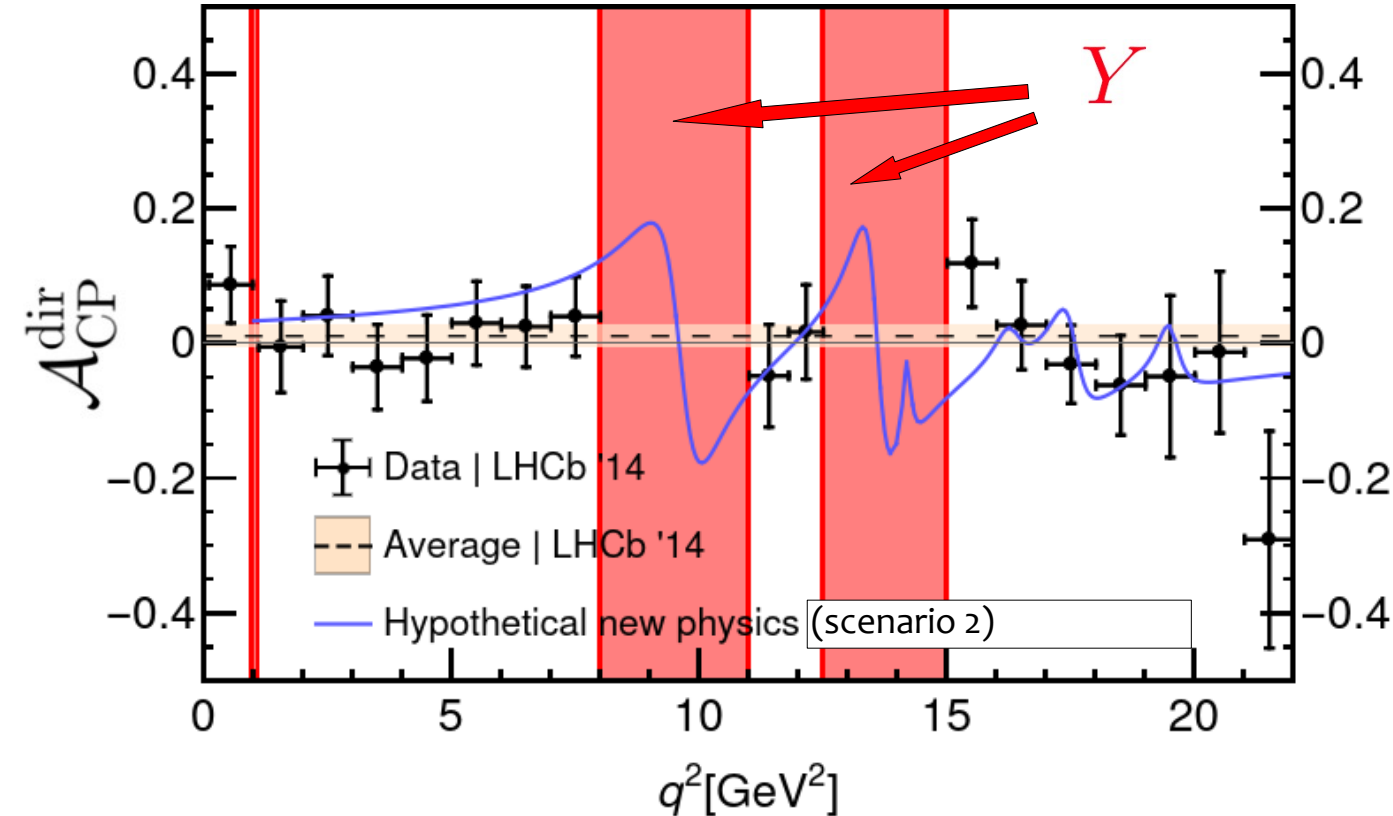
$$\mathcal{A}_{\text{CP}}^{\text{dir}} \propto \text{Im } C_9 \text{Im } Y$$

Bečirević, Fajfer, Košnik, Smolković  
(2020)

# Direct CP asymmetry

$$\mathcal{A}_{\text{CP}}^{\text{dir}} = \frac{\Gamma - \bar{\Gamma}}{\Gamma + \bar{\Gamma}}, \quad \Gamma = \Gamma(B^+ \rightarrow K^+ \mu^+ \mu^-)$$

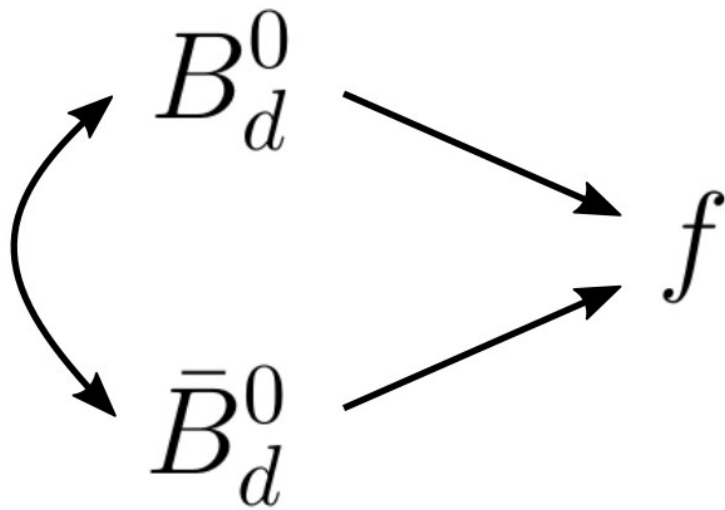
$$\bar{\Gamma} = \Gamma(B^- \rightarrow K^- \mu^- \mu^+)$$



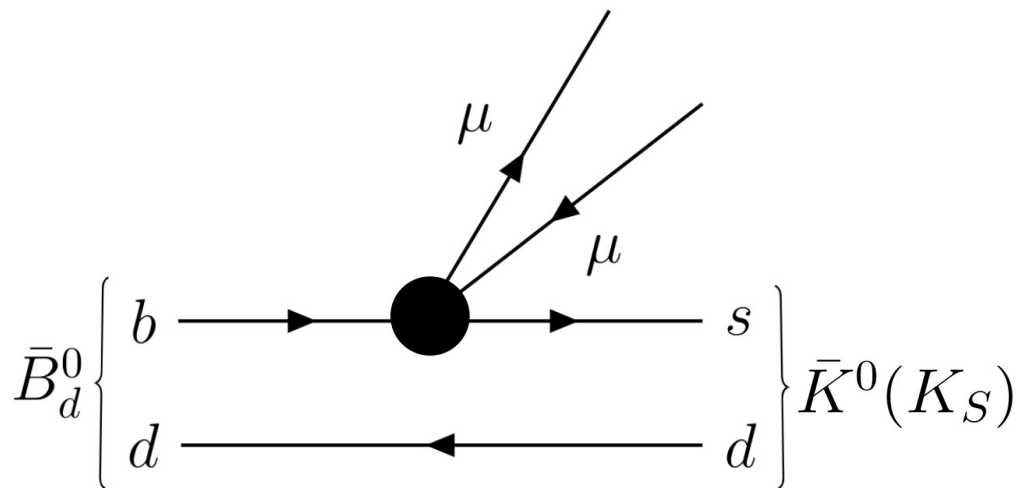
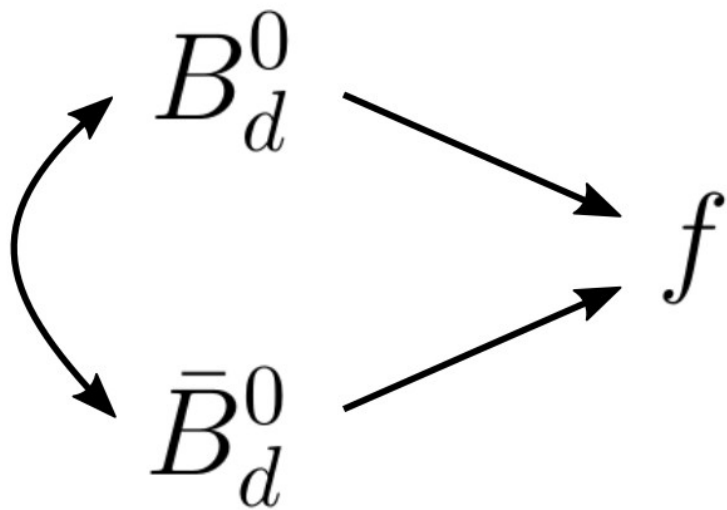
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Mixing-induced  
CP asymmetry  $A_{\text{CP}}^{\text{mix}}$



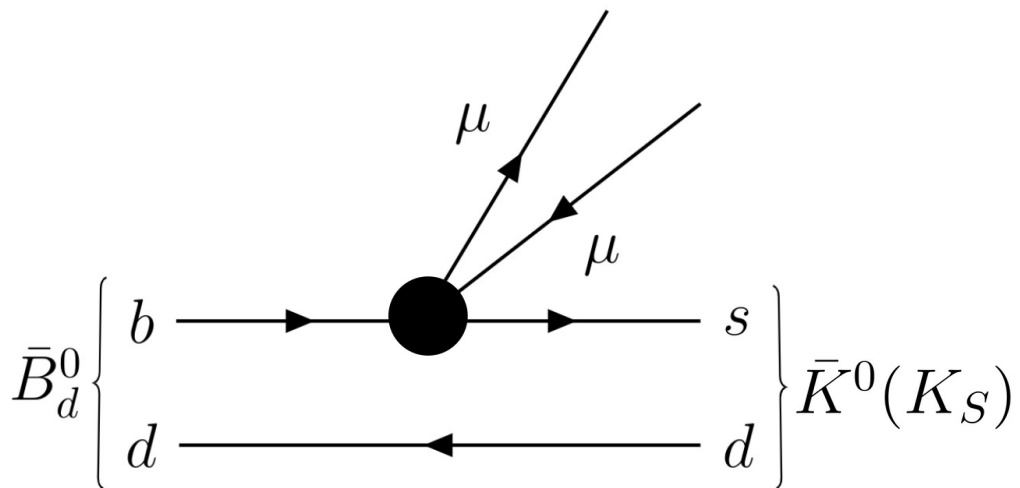
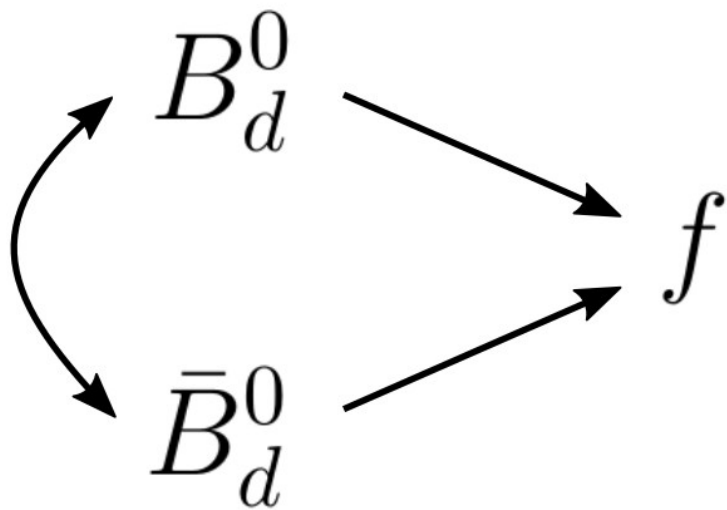
Mixing-induced  
CP asymmetry  $A_{\text{CP}}^{\text{mix}}$



$$\bar{B}_d^0 \rightarrow K_S \mu^+ \mu^-$$

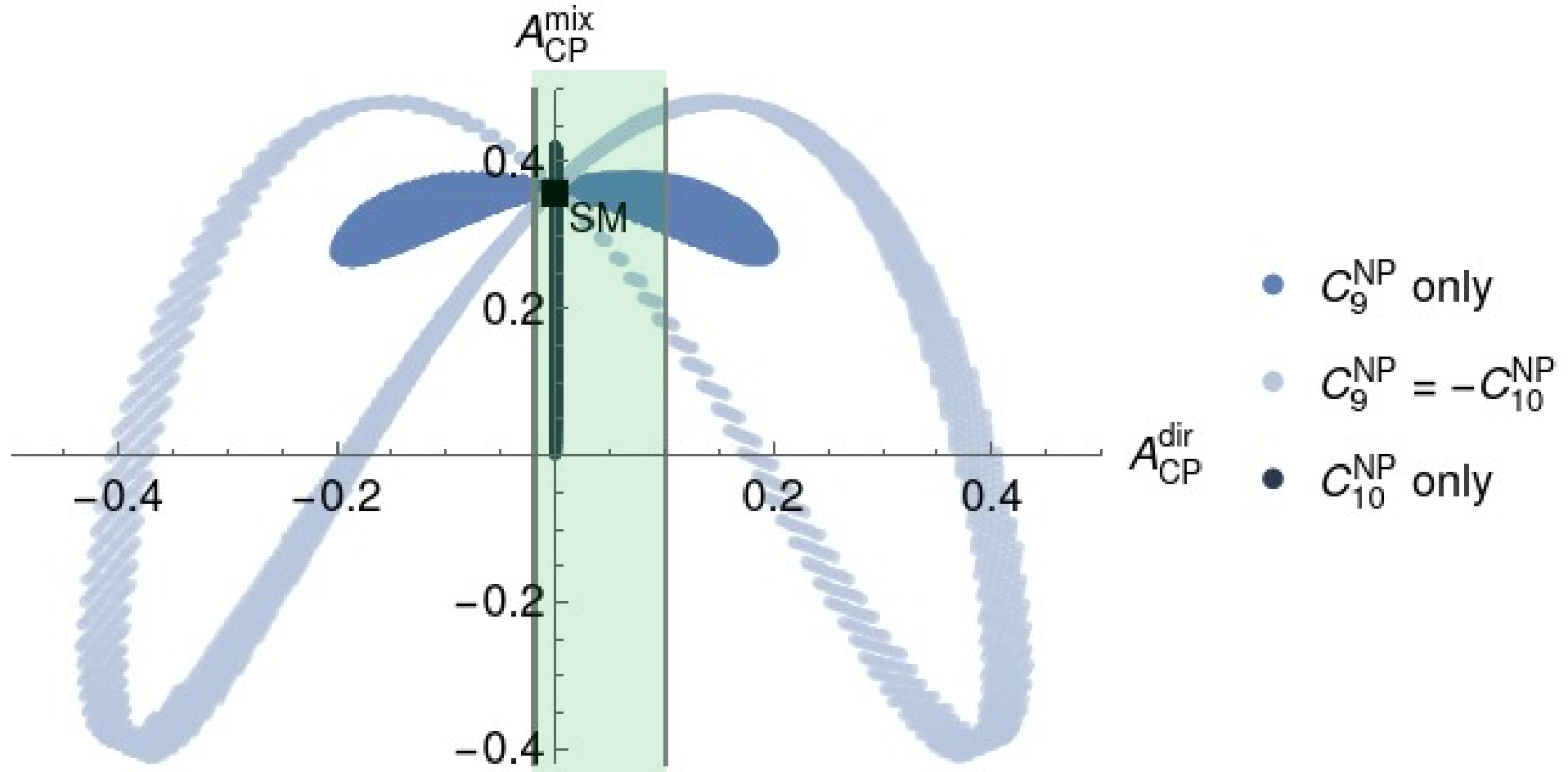
Mixing-induced  
CP asymmetry

$$A_{\text{CP}}^{\text{mix}}(\text{Im } C_9, \text{Im } C_{10}, \dots)$$



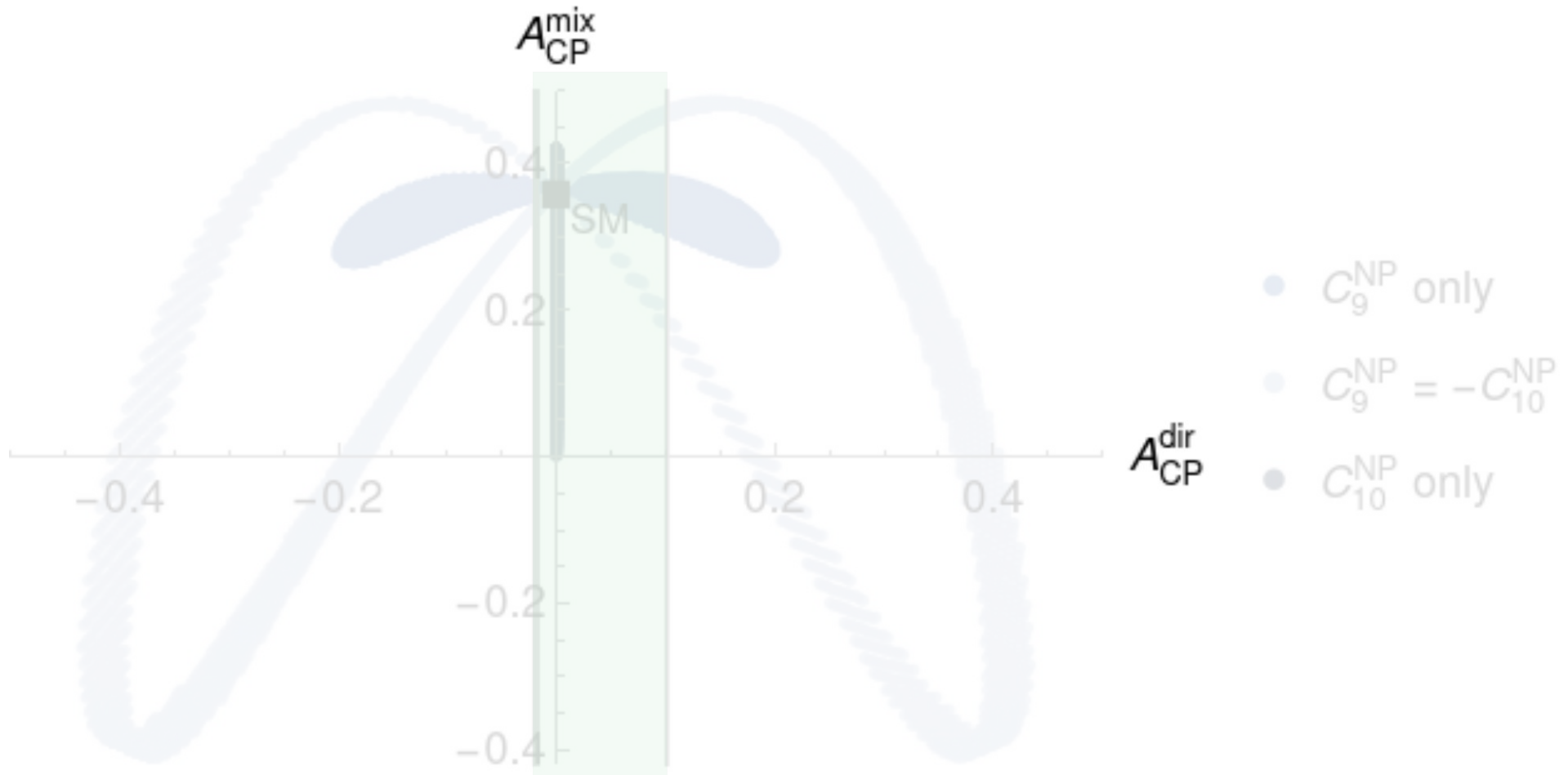
$$\bar{B}_d^0 \rightarrow K_S \mu^+ \mu^-$$

# Correlation between CP asymmetries

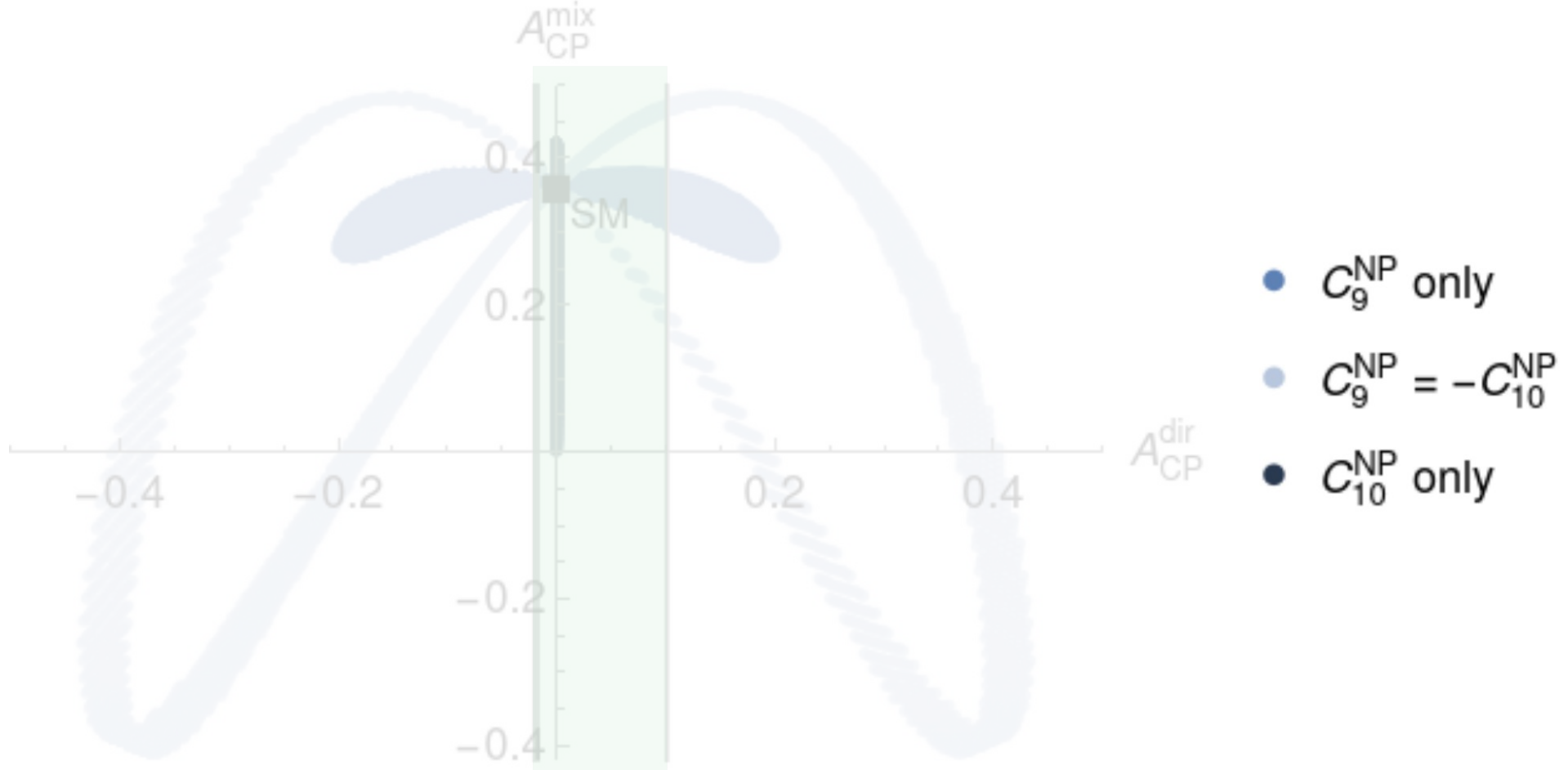




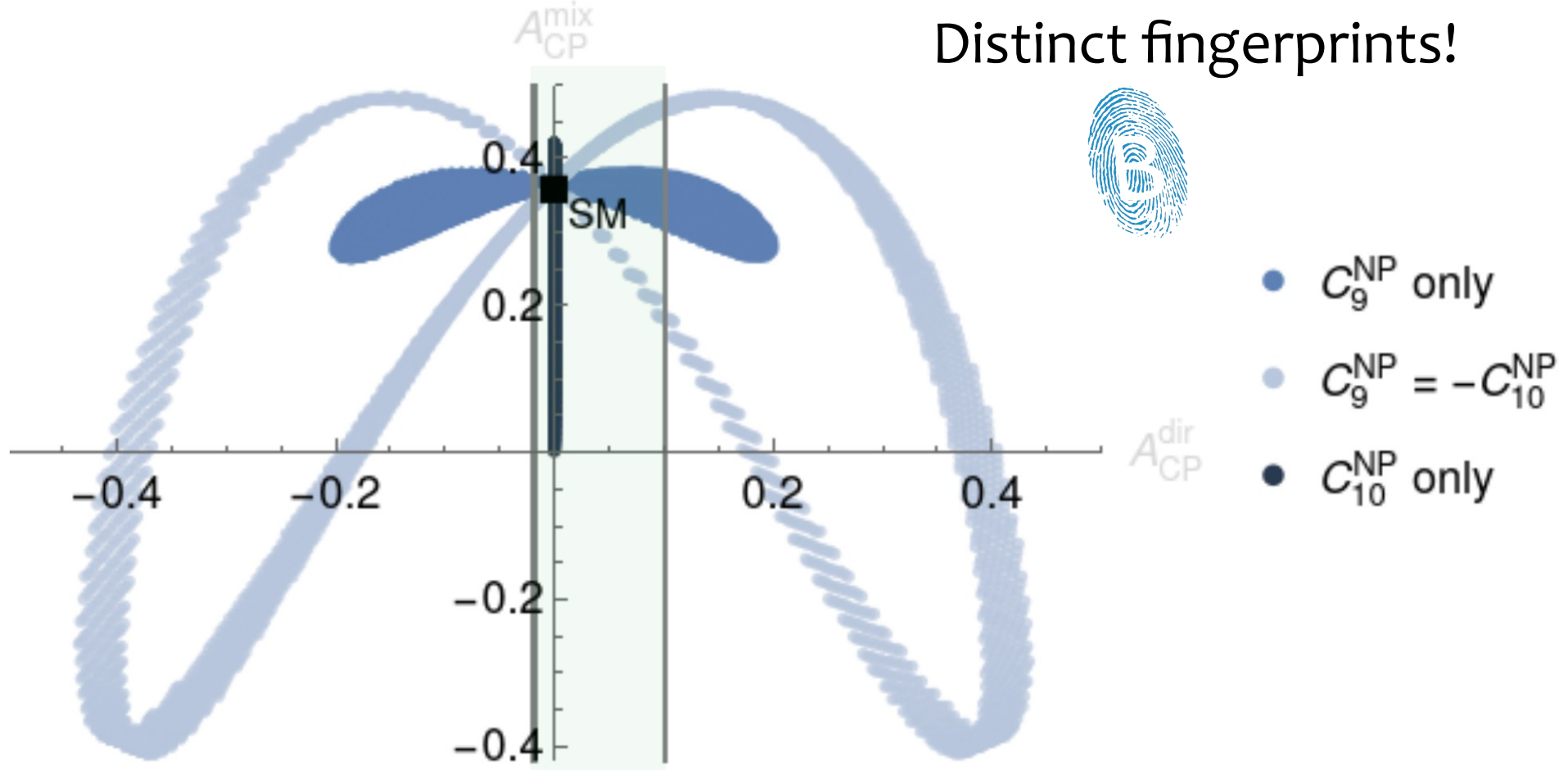
# Correlation between CP asymmetries



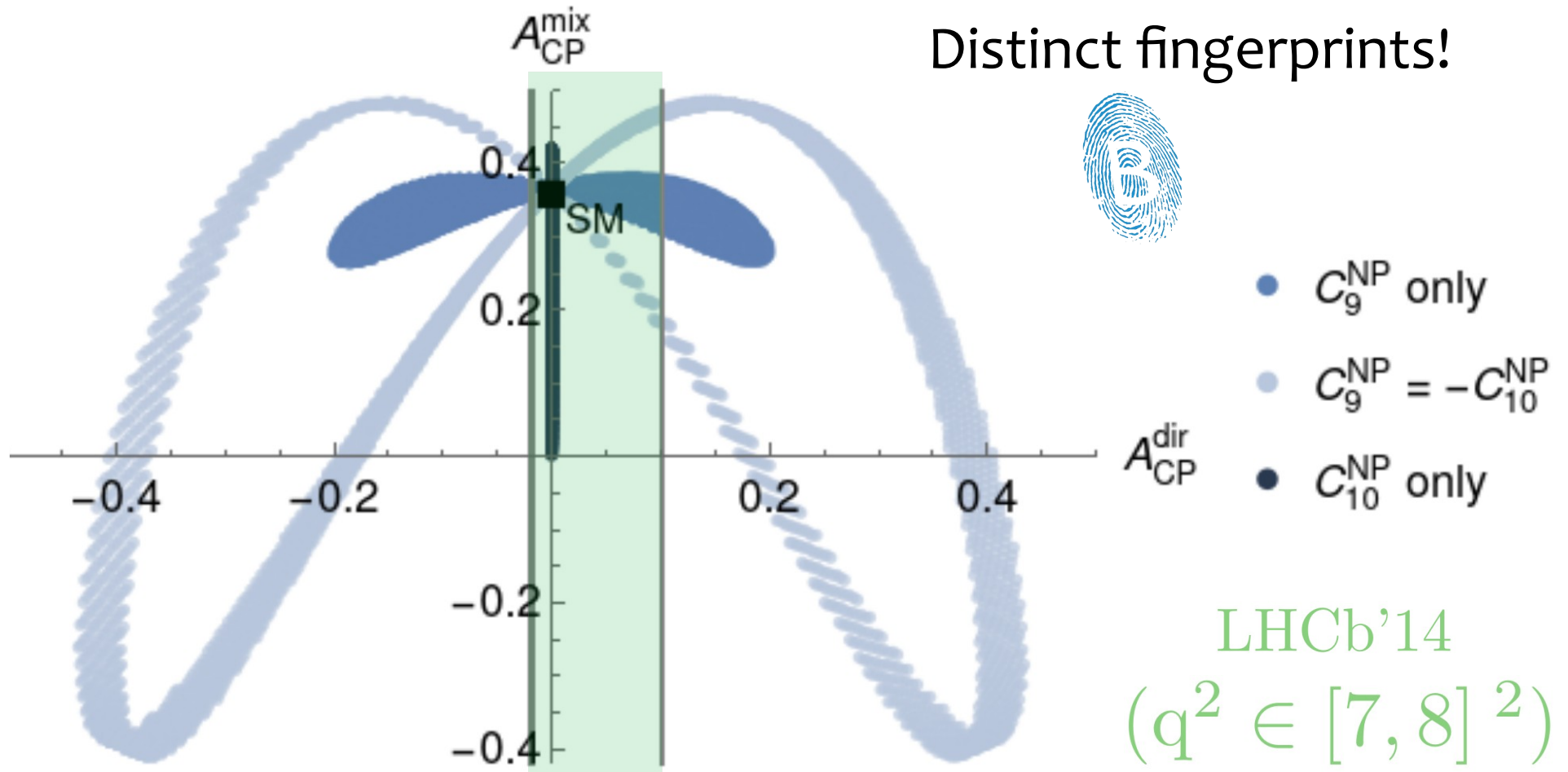
# Correlation between CP asymmetries



# Correlation between CP asymmetries



# Correlation between CP asymmetries



# Summary

- $C_i \in \mathbb{C} \rightarrow$



- $C_i \in \mathbb{C} \leftarrow$  data

difficult...

- **Solution:** exploit interplay between  $\mathcal{A}_{CP}^{\text{dir}}$  and  $\mathcal{A}_{CP}^{\text{mix}}$  !

- In progress, paper coming soon!

# Outlook

What could we do with CP violation in...?

- $R_K$
- $B_s^0 \rightarrow \mu^+ \mu^-$
- $B_d^0 \rightarrow K^{0*} \mu^+ \mu^-$
- $B^- \rightarrow K^- \tau^+ \tau^-$ ,  $B_s^0 \rightarrow \tau^+ \tau^-$