Utilising $B \to \pi K$ Decays at the High-Precision Frontier

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Introduction

$B \to \pi K$ decays have a rich phenomenology:

- Dominant contribution from QCD penguins.
- Colour-allowed tree & electroweak penguin (EWP) at the same level.
- $B_d^0 \to \pi^0 K_S$: only channel with mixing-induced CP asymmetry.

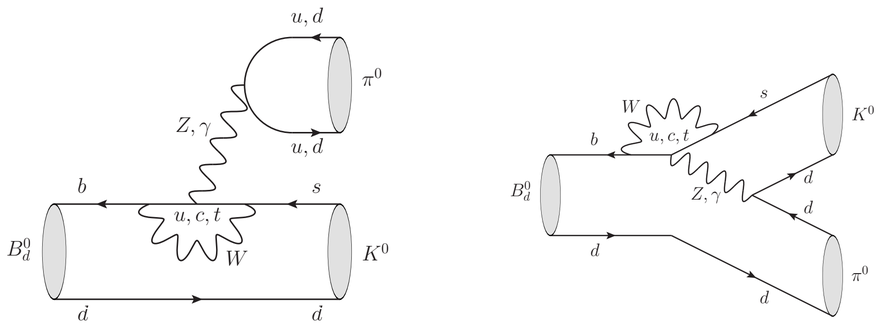

Figure 1: Colour-allowed ($\hat{P}_{EW}$) and colour-suppressed ($\hat{P}^{C}_{EW}$) EWP contributions to $B_d^0 \to \pi^0 K^0$.

- Puzzling data in the past → current status?
  [R. Fleischer, S. Jäger, D. Pirjol, J. Zupan (2008)]
- Can be explained by a modified EWP sector.

EWP effects characterized by

$$q e^{i\phi} e^{i\omega} \equiv -\left(\frac{\hat{P}_{EW} + \hat{P}^{C}_{EW}}{\hat{T} + \hat{C}}\right) \overset{\text{SM}}{=} \frac{-3}{2\lambda^2 R_b}\left(\frac{C_9 + C_{10}}{C_1 + C_2}\right) R_q = (0.68 \pm 0.05) R_q,$$

where $R_q = 1.0 \pm 0.3$ parametrizes $SU(3)$-breaking corrections.

Mixing-induced CP asymmetry and isospin relation

The mixing-induced CP asymmetry in $B_d^0 \to \pi^0 K_S$ is given by

$$S_{CP}^{\pi^0 K_S} = \sin(\phi_d - \phi_{00})\sqrt{1 - (A_{CP}^{\pi^0 K_S})^2},$$

where $A_{CP}^{\pi^0 K_S}$ is the direct CP asymmetry, ϕ_d is the B_d^0–$\bar{B}_d^0$ mixing phase and

$$\phi_{00} \equiv \arg(\bar{A}_{00} A_{00}^*).$$

→ Correlation between the CP asymmetries.

What is the cleanest way to determine ϕ_{00}?

Use isospin relation between the $B \to \pi K$ amplitudes:

$$\begin{aligned} 3A_{3/2} &\equiv \sqrt{2}A(B_d^0 \to \pi^0 K^0) + A(B_d^0 \to \pi^- K^+) \\ &= \sqrt{2}A(B^+ \to \pi^0 K^+) + A(B^+ \to \pi^+ K^0) = -(\hat{T} + \hat{C})\left(e^{i\gamma} - q e^{i\phi} e^{i\omega}\right). \end{aligned}$$

Then ϕ_{00} follows from amplitude triangles. Very clean relation: if q and ϕ are known, only $SU(3)$ input to determine $|\hat{T} + \hat{C}|$ from $B^+ \to \pi^+ \pi^0$.

Correlation between CP asymmetries

Employ ϕ_{00} to obtain a correlation between the CP asymmetries of $B_d^0 \to \pi^0 K_S$.

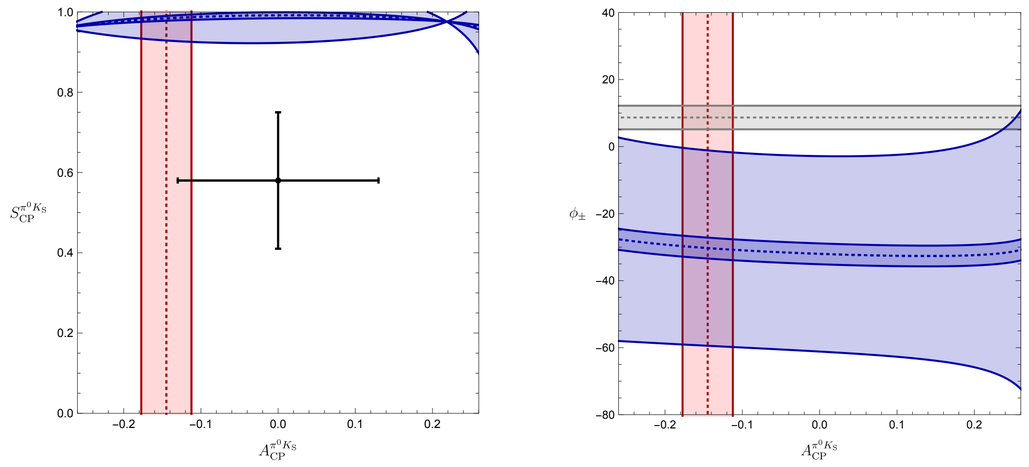

Figure 2: Left panel: Correlation between the CP asymmetries of $B_d^0 \to \pi^0 K_S$ from the amplitude triangles (blue) compared with current data (black cross). Right panel: Angle $\phi_\pm$ from the amplitude triangles (blue) compared with theory (grey).

- Due to sharper inputs (γ) the discrepancy is stronger then in 2008.
- New aspect: compare $\phi_\pm = \arg(\bar{A}_\pm A_\pm^*)$ from amplitude triangles with theory.
- Solve discrepancy by change in data → move $\mathcal{B}r(B_d \to \pi^0 K^0)$ by 2.5σ or New Physics (NP) → modified EWP sector?

Determination of q and ϕ

- Use amplitude triangles in a different way → determine q and ϕ.
- Can apply for charged and neutral decays separately
  → for now use charged data as current uncertainty $S_{CP}^{\pi^0 K_S}$ still large
- Minimal $SU(3)$ input → only to fix normalization $|\hat{T} + \hat{C}|$.
- No topologies have to be neglected.

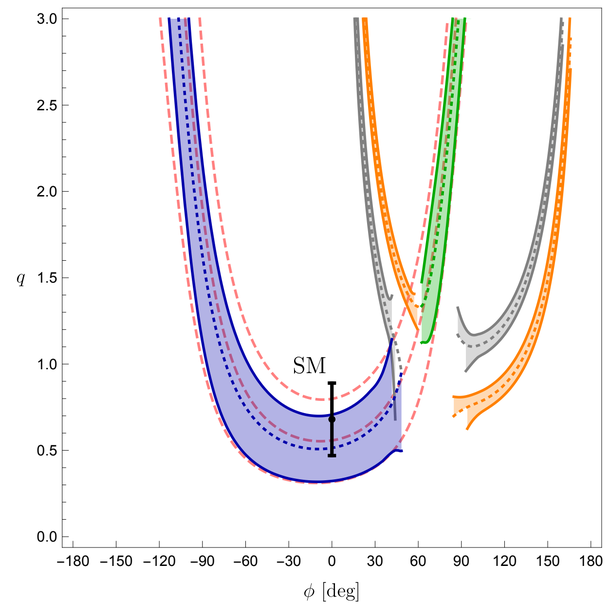

Figure 3: Contours in ϕ–q plane from charged amplitude relations and comparison with R_c (dashed).

We find agreement with SM but also room for NP. Compare also with contour from

$$R_c \equiv 2\left[\frac{\mathcal{B}r(\pi^0 K^+)}{\mathcal{B}r(\pi^+ K^0)}\right] = 1 - 2\,r_c \cos\delta_c(\cos\gamma - q\cos\phi) + \mathcal{O}(r_c^2)$$

→ excellent agreement!

How can we pin down the value of q and ϕ?

Additional contour from $S_{CP}^{\pi^0 K_S}$

Convert measurement of $S_{CP}^{\pi^0 K_S}$ into value of ϕ_{00}. Additional contour from

$$\tan\phi_{00} = 2\,(r\cos\delta - r_c\cos\delta_c)\sin\gamma + 2\,r_c\,(\cos\delta_c - 2\,\tilde{a}_C/3)\,q\sin\phi + \mathcal{O}(r_{(c)}^2).$$

- $r_{(c)}, \delta_{(c)}$ are hadronic parameters determined from $B \to \pi\pi$ decays.
- $\tilde{a}_C$ describes colour-suppressed EWPs → fix through data.

We study 3 scenarios for measurements of $S_{CP}^{\pi^0 K_S}$ at Belle II.

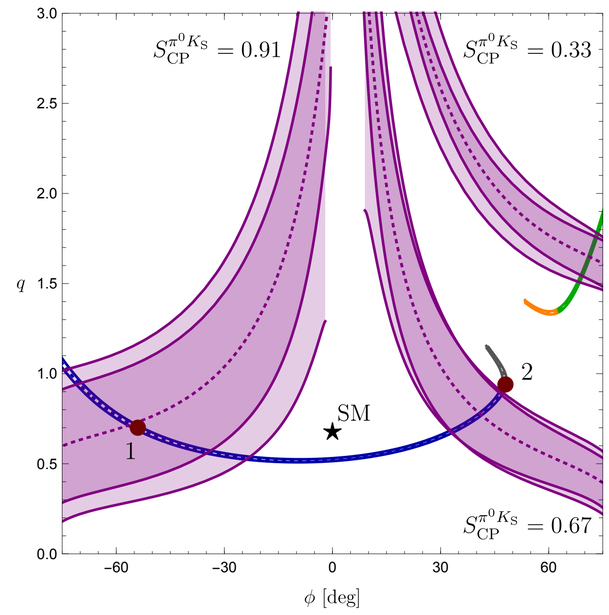

Figure 4: Contours from $S_{CP}^{\pi^0 K_S}$ (purple) compared with those from the triangle relations.

- Exp. uncertainty (small bands): ± 0.04 for the CP asymmetries of $B_d^0 \to \pi^0 K_S$.
- Th. uncertainty (wide bands): 20% non-factorizable $SU(3)$-breaking corrections.

→ We can match experimental precision with theory.

Exciting potential for discovery of NP!

Conclusions

- Data from $B_d^0 \to \pi^0 K_S$ have shown *puzzling patterns* in the past.
- We have performed a *state-of-the-art analysis*.
- *Discrepancy* in correlation between CP asymmetries became *stronger*.
- Will data move to *confirm SM* or *is it NP?*
- We have presented a strategy to pin down the EWP parameters q and ϕ.
- We look forward to data from *Belle II* and *LHCb*.