$B_s \to D_s^{\pm} K^{\mp}$ decays
Can they reveal New Physics?

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Introduction

CP Violation and flavour physics

- Within the SM, CP violation is described by the Cabibbo-Kobayashi-Maskawa (CKM) matrix
- **Goal**: test the SM
  precisely determine CKM parameters in SM
  search for possible indirect signals of New Physics (NP)
- B meson decays are significant for these studies
- A key parameter is the extraction of the CKM angle γ
  - for precision measurements of γ
    $\Rightarrow$ we can use $B_s \to D_s^{\pm} K^{\mp}$ decays

Motivation

- **Intriguing value of the angle γ by LHCb[3]**

$$\gamma = (128^{+17}_{-22})^o$$

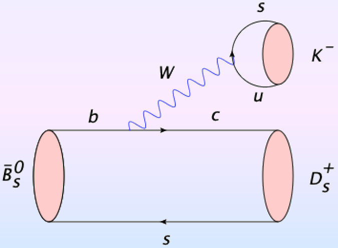
- **Shed more light on the $B \to DK$ decay**

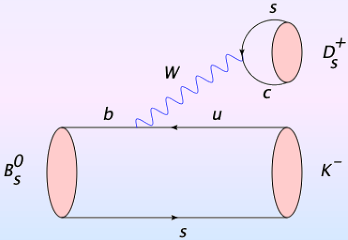
Based on:

1. arXiv:hep-ph/0304027
2. arXiv:1208.6463 [hep-ph]
3. arXiv:1712.07428

$B_s \to D_s^{\pm} K^{\mp}$

- non-leptonic decay $\Rightarrow$ not clean decays (hadronic matrix elements)
- only tree diagram contributions
- both B_s^0 and $\bar{B}_s^0$ may decay into the same final state





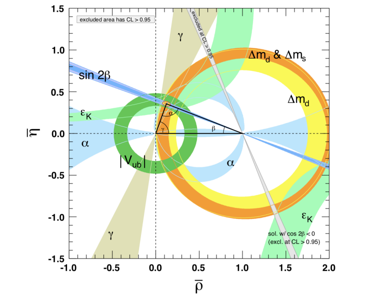
- important feature: neutral B meson oscillations
- interference effects between $B^0 - \overline{B}^0$ mixing and decay processes arise
- **clean determination of $\gamma + \phi_s$** (ϕ_s: determined with $B_s^0 \to J/\psi\phi$)

Angle γ and the Unitarity Triangle

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

Unitarity Triangle

$$V_{ud}V_{ub}^* + V_{cd}V_{cb}^* + V_{td}V_{tb}^* = 0$$



- The important question is whether:
  - the curves (from different decays and transitions- using SM formulae) intersect in a single point and
  - the triangle angles agree with the angles from CP asymmetries in B systems and CP conserving B decays
- Any inconsistency will give hints about physics beyond the SM
- Parametrized by three angles and one complex phase:
  the complex phase $\Rightarrow$ source of CP violation in SM

Theoretical Background

Amplitudes

We can write the amplitude in the general form:

$$A(\overline{B_s^0} \to D^+K^-) =< K^-D^+|H_{eff}(\overline{B}_s^0 \to D^+K^-)|\overline{B_s^0} >$$

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Introducing the:

- υ_s,$\overline{\upsilon}_s$,υ_s*: CKM factors and
- M_s, $\overline{M}_s$: matrix elements

we can rewrite the amplitudes in the form:

$$A(\overline{B_s^0} \to D^+K^-) = \frac{G_F}{\sqrt{2}}\bar{\upsilon}_s\bar{M}_s$$

$$A(B_s^0 \to D^+K^-) = (-1)^L e^{i\phi_{CP}}\frac{G_F}{\sqrt{2}}\upsilon_s*M_s$$

$$A(\overline{B}_s^0 \to D^-K^+) = \frac{G_F}{\sqrt{2}}\bar{\upsilon}_s\bar{M}_s$$

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Parameter ξ_s

We define the parameter ξ as:

$$\xi_s = -e^{-i\phi_s}\left[e^{i\phi_{CP}}\frac{A(\overline{B}_s^0 \to D^+K^-)}{A(B_s^0 \to D^+K^-)}\right]$$

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- Inserting the amplitude formulas in the previous relation, the convention dependent phase ϕ_{CP} gets cancelled:

$$\xi_s = -(-1)^L e^{-i(\phi_s+\gamma)}\left[\frac{1}{x_s e^{i\delta_s}}\right]$$

- where the term x_s is defined as: $x_s = R_b\alpha_s$ and

$$\alpha_s e^{i\delta_s} = e^{-i[\phi_{CP}(D)-\phi_{CP}(K)]}\frac{M_s}{\overline{M}_s}$$

- with $\alpha_s e^{i\delta_s}$ being a physical observable (ϕ_{CP} phases are cancelled in the ratio of hadronic matrix elements)

Parameter $\overline{\xi}_s$

Similarly, for the CP conjugate case, we get:

$$\overline{\xi}_s = -e^{-i\phi_s}\left[e^{i\phi_{CP}}\frac{A(\overline{B}_s^0 \to D^- K^+)}{A(B_s^0 \to D^- K^+)}\right]$$

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- Otherwise: factorization $\Rightarrow$ to handle hadronic matrix elements
- Plugging form factor F_0 and decay constants f_K into the factorised matrix element, the decay amplitude takes the form:

$$< D^{\pm} K^{\mp} | H_{eff} | \bar{B}^0_s >= i \frac{G_f}{\sqrt{2}} V_{CKM} \alpha(\mu) f_K F_{0\,\bar{B}^0_s \to D}(M_K^2)(M_{B_s}^2 - M_D^2)$$

Branching Ratios

- Experimental branching ratio:

$$BR(B_s \to f)_{exp} = \frac{1}{2}\int < \Gamma(B_s(t) \to f) > dt$$

- Theoretical branching ratio:

$$BR(B_s \to f)_{theo} = \frac{\tau_{B_s}}{2} < \Gamma(B_s^0(t) \to f) > |t = 0$$

- Connecting the experimental to the theoretical branching ratio

$$BR(B_s \to f)_{theo} = \frac{1 - y_s^2}{1 + \mathcal{A}_{\Delta\Gamma} y_s} BR(B_s \to f)_{exp}$$

- Importance of $\Delta\Gamma_s$

$$y_s = \frac{\Delta\Gamma_s}{2\Gamma_s} \approx 0.1$$

Observables

- Time-dependent CP Asymmetry

$$\frac{\Gamma(B_s^0(t) \to f) - \Gamma(\overline{B}_s^0(t) \to \bar{f})}{\Gamma(B_s^0(t) \to f) + \Gamma(\overline{B}_s^0(t) \to \bar{f})} = \left[\frac{C\ \cos(\Delta M_s\ t) + S\ \sin(\Delta M_s\ t)}{\cosh(\Delta\Gamma_s\ t/2) + \mathcal{A}_{\Delta\Gamma}\sinh(\Delta\Gamma_s\ t/2)}\right]$$

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- where we have the asymmetries:

$$C = \frac{1 - |\xi_s|^2}{1 + |\xi_s|^2} = \frac{|A(B_s^0 \to f)|^2 - |A(\bar{B}_s^0 \to \bar{f})|^2}{|A(B_s^0 \to f)|^2 + |A(\bar{B}_s^0 \to \bar{f})|^2}$$

$$S = \frac{2\ \mathrm{Im}\xi_s}{1 + |\xi_s|^2}$$

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- and the observable $\mathcal{A}_{\Delta\Gamma}$ which depends on C and S

$$\mathcal{A}_{\Delta\Gamma} = \frac{2\ \mathrm{Re}\xi_s}{1 + |\xi_s|^2}$$

Analysis

Rewriting the Observables

$$C = -\left[\frac{1 - x_s^2}{1 + x_s^2}\right], \qquad \overline{C} = +\left[\frac{1 - x_s^2}{1 + x_s^2}\right]$$

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$$\mathcal{A}_{\Delta\Gamma} = -\frac{2\ x_s \cos(\phi_s + \gamma + \delta_s)}{1 + x_s^2}, \qquad \overline{\mathcal{A}}_{\Delta\Gamma} = -\frac{2\ x_s \cos(\phi_s + \gamma - \delta_s)}{1 + x_s^2}$$

LHCb Collaboration Measurements

$$\bar{C}_s = 0.73 \pm 0.15$$

$$S_s = 0.49 \pm 0.21 \qquad \overline{S}_s = 0.62 \pm 0.21$$

$$\mathcal{A}_{\Delta\Gamma s} = 0.31 \pm 0.32 \qquad \overline{\mathcal{A}}_{\Delta\Gamma s} = 0.62 \pm 0.21$$

We use ϕ_s, taking the average determined by HFLAV:

$$\phi_s = (-1.2 \pm 1.8)^o$$

Measurements of the $B \to DK$ branching ratios from LHCb:

$$\frac{BR(B_s^0 \to D_s^{\pm} K^{\mp})_{exp}}{BR(B_s^0 \to D_s^{\pm} \pi^{\mp})_{exp}} = 0.0646 \pm 0.0043 \pm 0.0025$$

Using data from $B \to D\pi$ decay

- We can combine information from the two systems linked by U-spin symmetry
- With U-spin flavour symmetry of strong interactions:
  - hadronic parameters x_s and δ_s of $B \to DK$ are related to x_d and δ_d of the $B \to D\pi$

$$x_s = -\frac{x_d}{\epsilon} = 0.31^{+0.046}_{-0.053}\big|_{input} \pm 0.06\big|_{SU(3)}$$

$$\delta_s = \delta_d = \left[-35^{+69}_{-40}\big|_{input} \pm 20\big|_{SU(3)}\right]^{o}$$

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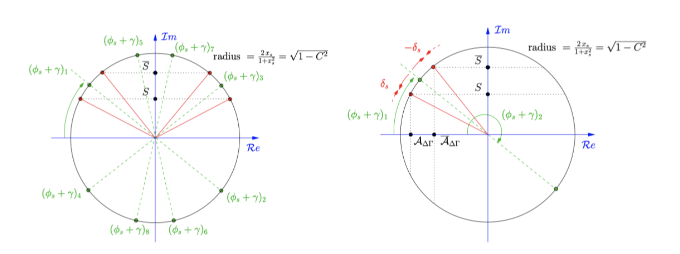
- With hadronic parameters, we may calculate $B \to DK$ observables

However, we have enough info to analyse both systems separately [and to avoid the hadronic parameters]
$\Rightarrow$ we don't have to make any U-spin assumptions and
$\Rightarrow$ we may use these decays to test the U-spin symmetry.

Illustrating the Discrete Ambiguities

$$C^2 + S^2 + \mathcal{A}_{\Delta\Gamma}^2 = 1 = \bar{C}^2 + \bar{S}^2 + \bar{\mathcal{A}}_{\Delta\Gamma}^2$$

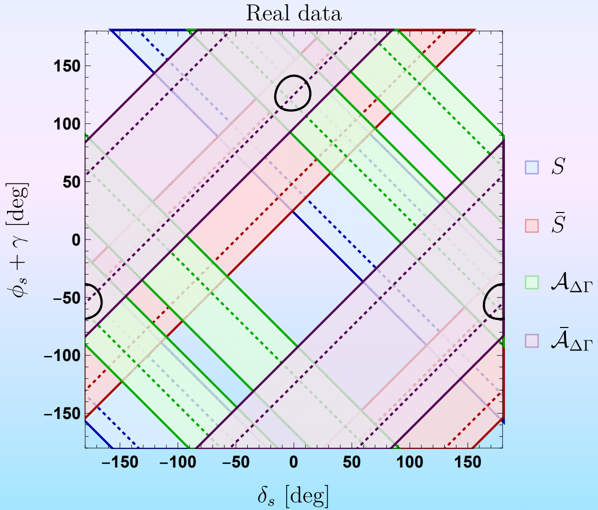
$$\mathcal{A}_{\Delta\Gamma} + iS = -(-1)^L \sqrt{1 - C^2} e^{-i(\phi_s + \gamma + \delta_s)}$$
$$\bar{\mathcal{A}}_{\Delta\Gamma} + i\bar{S} = -(-1)^L \sqrt{1 - \bar{C}^2} e^{-i(\phi_s + \gamma - \delta_s)}$$



Assumption: $C = -\bar{C}$

The picture we get for the Current data

From $\overline{C}_s$ we may determine x_s yielding: $x_s = \sqrt{\frac{1-\overline{C}_s}{1+\overline{C}_s}} = 0.4 \pm 0.13$ and plug that into S, $\overline{S}$, $\overline{\mathcal{A}}_{\Delta\Gamma}$, $\mathcal{A}_{\Delta\Gamma}$ to obtain contours in $(\delta_s, (\phi_s + \gamma))$



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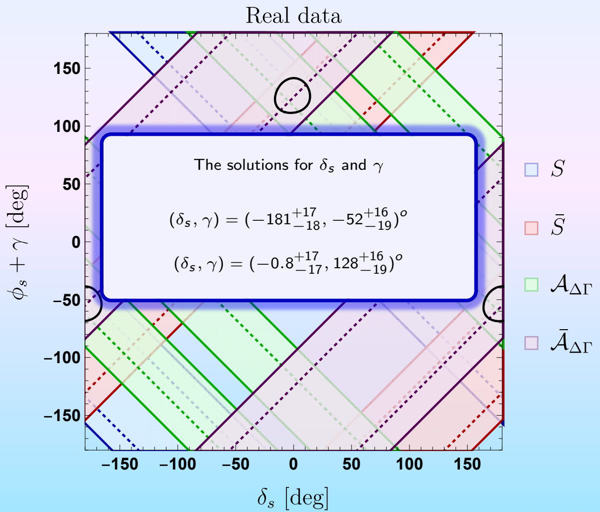

The solutions for δ_s and γ

$$(\delta_s, \gamma) = (-181^{+17}_{-18}, -52^{+16}_{-19})^o$$

$$(\delta_s, \gamma) = (-0.8^{+17}_{-17}, 128^{+16}_{-19})^o$$

Moving to New Physics...

- Could it be New Physics?
- How would it enter?
  - Might NP appear at the amplitude level?
- How would it affect the observables?
- Interplay with other New Physics constraints?

This is still work in progress
Stay tuned!

Conclusions

Final Remarks

- Our Strategy:
  $\xi \times \bar{\xi}$ can be calculated from the corresponding observables and leads to the determination of $\phi_s + \gamma$
- Even though $B \to DK$ is not a clean decay (non-leptonic), it allows a clean extraction of $\phi_s + \gamma$ (ϕ_s is determined)
- The value of $(\gamma = 128^{+17}_{-22})^o$ by LHCb is intriguing
- The observable $\mathcal{A}_{\Delta\Gamma}$ is crucial to resolve ambiguities
- Room to explore NP [work in progress]

Thank you!