Measurements of the CP violation phase $\phi_s$ at LHCb

1. Mixing-induced CP violation in $B_s^0 \rightarrow J/\psi K^+ K^-$

$$\phi_M = 2\arg(V_{cb}V_{cs}^*)$$

Decay: $\phi_D = \arg(V_{cb}V_{cs}^*)$

$\phi_s = \arg\left(\frac{A_B^0(1+\Gamma/\Gamma^*)}{A_B^0(1-\Gamma/\Gamma^*)}\right) = \phi_M - 2\phi_D$

SM prediction (if ignoring subleading process):$^{[11]}$

$\phi_s = -2\arg\left(\frac{V_{cb}V_{cs}^*}{V_{ub}V_{us}^*}\right) = -37.6^{+0.8}_{-0.7}$ mrad (Very Precise!)

$\phi_s$ can probe New Physics, if new particles contribute to the box diagrams

$B_s^0 \rightarrow J/\psi K^+ K^-$ is one of the golden channels to search for New Physics!

Here are the results based on LHCb Run-I 3fb$^{-1}$ data sample

2. Previous LHCb Run-I results of $\phi_s$ measurement

$\phi_s$ is experimentally accessed via the following time-dependent asymmetry, where both $B_s^0$ and $\bar{B}_s^0$ decay to final state $f$

$$\mathcal{A}_{CP} = \frac{\Gamma_{BG} - \Gamma_{GB}}{\Gamma_{BG} + \Gamma_{GB}} = \frac{S_f \sin(\Delta m t) - C_f \cos(\Delta m t)}{\cosh(\Delta m t) + \mathcal{A} \sinh(\Delta m t)}$$

$S_f = \eta_f \sin \phi_s$

Angular analysis to separate different CP eigenstates

Time-dependent angular analysis to get the CP parameters

<table>
<thead>
<tr>
<th>Decay Mode</th>
<th>$\phi_s$</th>
<th>$\Delta\Gamma_s$ (ps$^{-1}$)</th>
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<tbody>
<tr>
<td>$J/\psi \phi$</td>
<td>$-0.058 \pm 0.049 \pm 0.006$</td>
<td>$+0.0805 \pm 0.0091 \pm 0.0033$</td>
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<tr>
<td>$J/\psi \pi^+ \pi^-$</td>
<td>$+0.070 \pm 0.068 \pm 0.008$</td>
<td>$-$</td>
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<tr>
<td>$\psi(2S) \phi$</td>
<td>$+0.23^{+0.29}_{-0.26} \pm 0.02$</td>
<td>$+0.066^{+0.41}_{-0.44} \pm 0.007$</td>
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<tr>
<td>$D_s^+ D_s^-$</td>
<td>$+0.02 \pm 0.17 \pm 0.02$</td>
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3. Measurement above $\phi(1020)$ in $m_{K^+ K^-}$

- Time-dependent amplitude analysis determines $\phi_s$: $^{[3]}$
  
  - $\phi_s = 119 \pm 107 \pm 24$ mrad
  - $\Gamma_s = 0.650 \pm 0.006 \pm 0.004$ ps$^{-1}$
  - $\Delta\Gamma_s = 0.066 \pm 0.018 \pm 0.010$ ps$^{-1}$

- Fit fraction of resonances in the decay are also determined.

- $f_2^+(1525)$ parameters measured:
  - $M_{f_2^+} = 1522.2 \pm 1.3 \pm 1.1$ MeV
  - $\Gamma_{f_2^+} = 78.0 \pm 3.0 \pm 3.7$ MeV

4. Conclusions and prospects

Compatible with SM estimations! Stay tuned with Run-II results!

5. Reference