$B_{(s)} \to D^{(*)}\phi$ study

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On behalf of LHCb collaboration

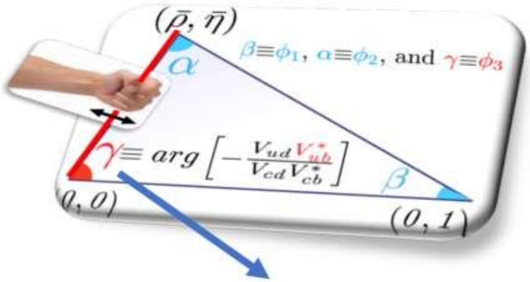
CLHCP 2023

Outline

- Motivation
- Improved measurement on $B^0_{(s)} \to \overline{D}^{(*)0}\phi$
- Measurement of γ via $B^0_s \to \overline{D}^{(*)0}\phi$
- Summary

Precise measurement of the CKM angle γ

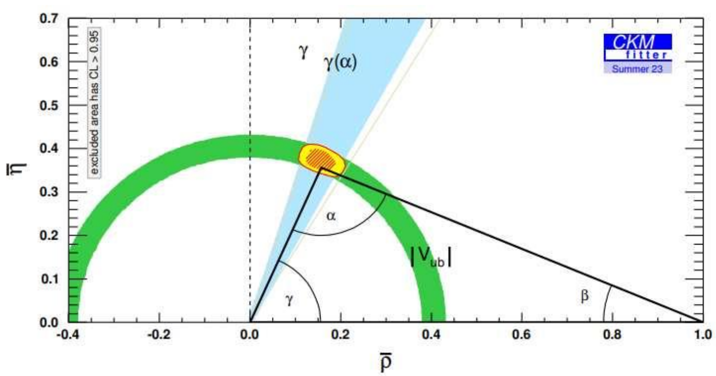
- Measure γ directly using tree-level decays
- Theoretically clean ($\frac{\delta\gamma}{\gamma} < 10^{-7}$) (JHEP 1401(2014)051)
- HFLAV latest: $\gamma = (65.9^{+3.3}_{-3.5})^\circ$
- LHCb dominated: $\gamma = (63.8^{+3.5}_{-3.7})^\circ$ (LHCb-CONF-2022-003)



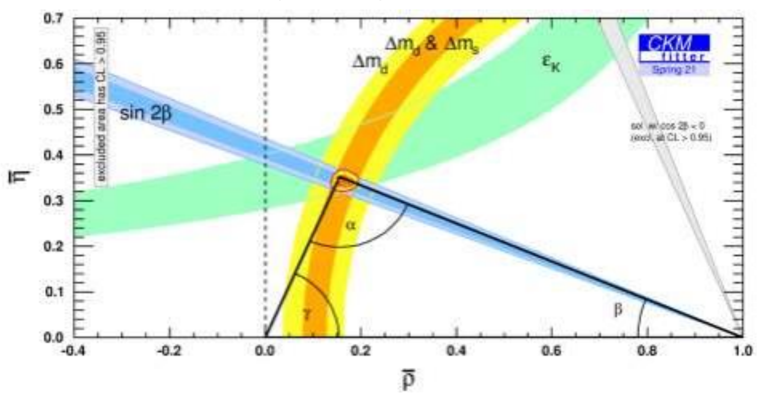
$$\gamma = \arg\left(-\frac{V_{ud}V_{ub}^*}{V_{cd}V_{cb}^*}\right)$$

- Loop-level(indirect measurement) is sensitive to New Physics
- CKMFitter latest: $\gamma = (66.3^{+0.7}_{-1.9})^\circ$

Tree only



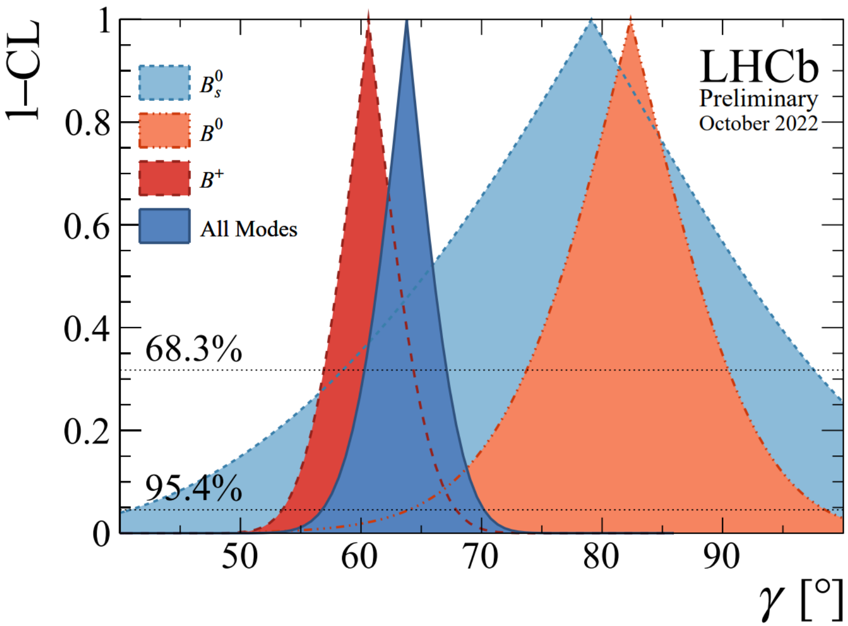
Loop only



LHCb γ combination (LHCb-CONF-2022-003)

- Best knowledge of γ comes from combination of many measurements
- Largest uncertainty for γ in B_s^0 mode:
- $\gamma = (79^{+21}_{-24})°$
  - $B_s^0 \to D_s^{\mp} K^{\pm}$: $\gamma = (128^{+17}_{-22})°$(JHEP 03(2018)059)
  - $B_s^0 \to D_s^{\mp} K^{\pm} \pi^+ \pi^-$: $\gamma = (44 \pm 12)°$ (JHEP 03(2021)137)
- Need more modes of B_s^0constraint the γ uncertainty in B_s^0 decay
  - γ sensitivity study in $B_s^0 \to \overline{D}^{(*)0}\phi$: 8°~ 19° (9/fb)

Chin. Phys. C45(2021) 023003



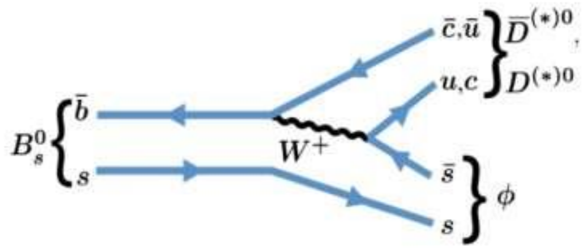
Improved measurement on $B^0_{(s)} \to \overline{D}^{(*)0}\phi$

arXiv:2306.02768

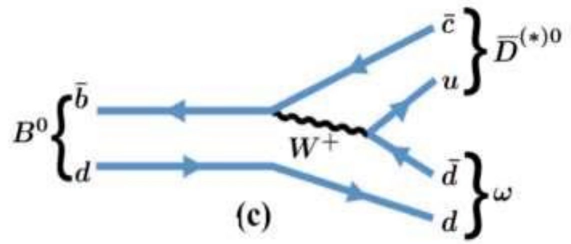
Accepted by JHEP

Introduction of $B^0_{(s)} \to \overline{D}^{(*)0}\phi$

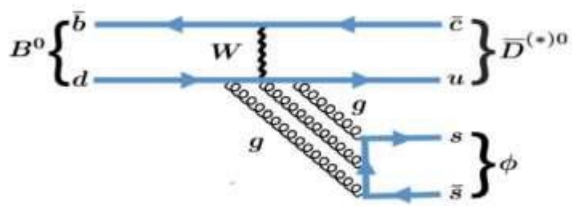
- $B_s^0 \to \overline{D}^{(*)0}\phi$ measured by LHCb with Run-1 data
  (Phys. Rev. D 98 (2018) no.7, 071103)



- $B_s^0 \to \overline{D}^{(*)0}\phi$:
  - Can be proceed by $b \to c$ or $b \to u$ process:
  - Color suppressed and proportional to λ^3
  - Measuring longitudinal polarization (f_L) is particular interest
  - Can be used to determine γ

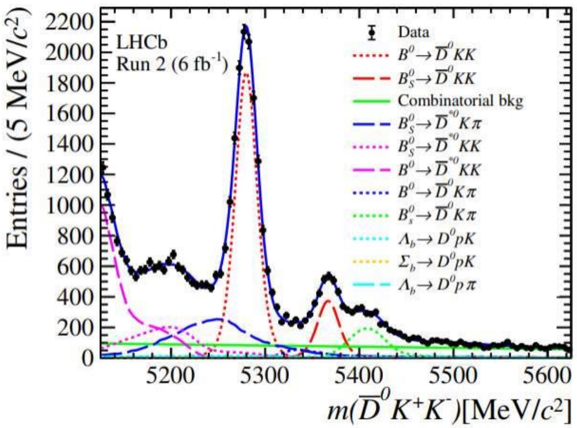


- $B^0 \to \overline{D}^{(*)0}\phi$:
  - Can be proceed by OZI suppress, W-exchange decay
  - Observed in charmonium decays (Phys. Rev. D 99 (2019) 012015) but not in b-hardon decays(Chin. Phys. C45(2021) 043001)
  - Theoretical predict $B(B^0 \to \overline{D}^0\phi) \sim 2 \times 10^{-6}$ (Phys. Lett. B 666(2008) 185)
  - Help to extract $\omega - \phi$ mixing angle



Branching fraction measurements of $B^0_{(s)} \to \overline{D}^{(*)0}\phi$

- All Run1+Run2 data (~9/fb) used
- $B^0 \to \overline{D}^0 KK$: normalization mode



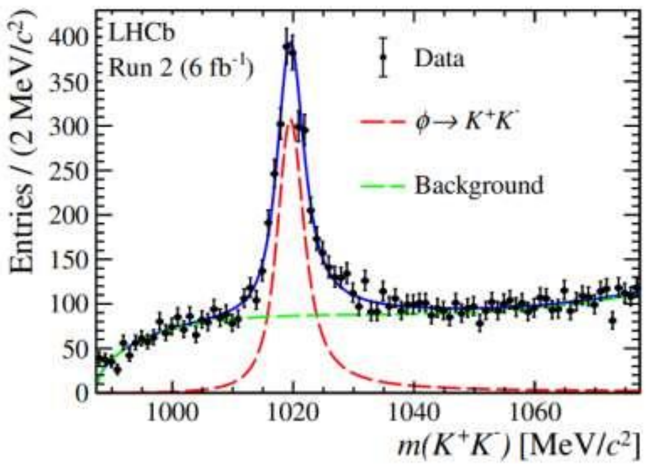
- Similar study strategy to the previous Run1 work

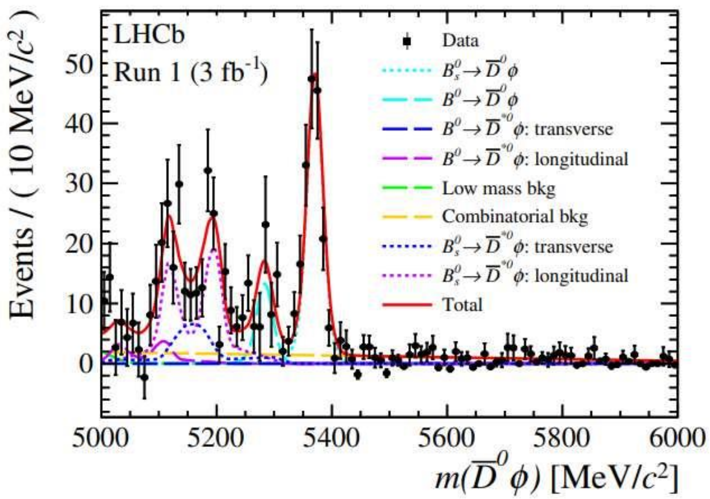
(Phys. Rev. D98(2018)072006, 071103)

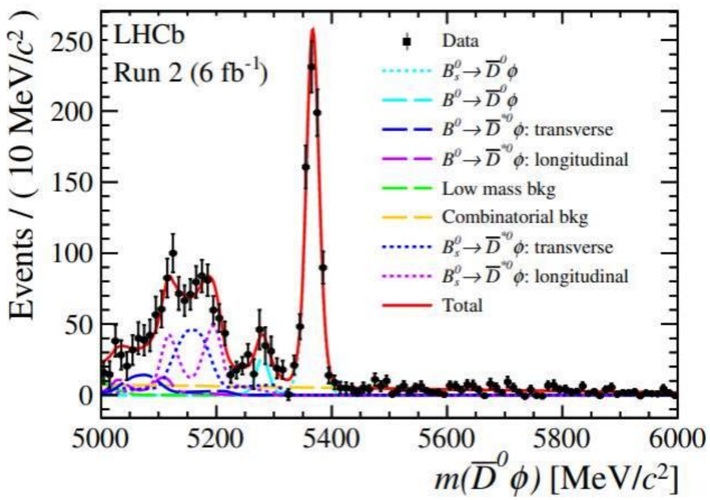
- Optimized the selection criteria → Efficiencies and yields improved ~30% with almost similar background level

Study strategy

- Use s-Plot technique to extract ϕ signal
- Partial reconstruction for D^{*0}
  - Shapes of transverse/longitudinal polarized $D^{*0} \to D^0\, \gamma/\pi^0$ from MC simulation







Result

- The evidence of $B^0 \to \overline{D}^{(*)0}\phi$ is reported

$$\mathcal{B}(B^0 \to \overline{D}^0\phi) = (7.7 \pm 2.1 \pm 0.7 \pm 0.7) \times 10^{-7}, \quad 3.6\sigma$$
$$\mathcal{B}(B^0 \to \overline{D}^{*0}\phi) = (2.2 \pm 0.5 \pm 0.2 \pm 0.2) \times 10^{-6}. \quad 4.3\sigma$$
$$\mathcal{B}(B_s^0 \to \overline{D}^0\phi) = (2.30 \pm 0.10 \pm 0.11 \pm 0.20) \times 10^{-5},$$
$$\mathcal{B}(B_s^0 \to \overline{D}^{*0}\phi) = (3.17 \pm 0.16 \pm 0.17 \pm 0.27) \times 10^{-5}.$$

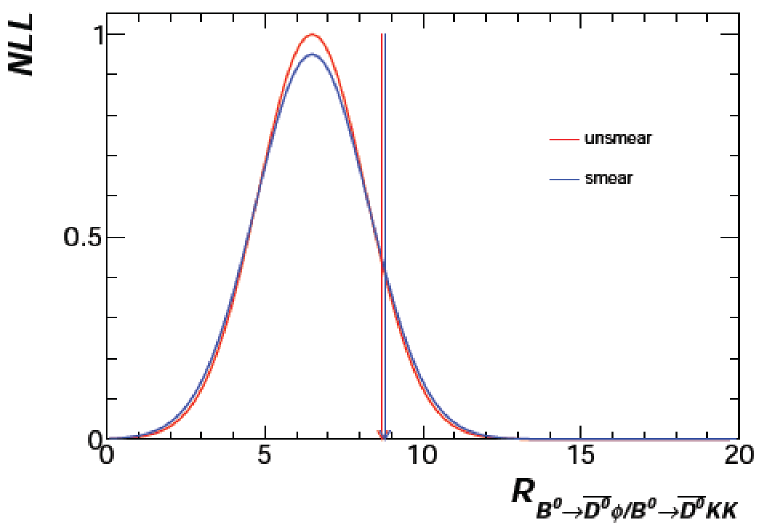
- The fraction of longitudinal polarization
  - $f_L(B_s^0 \to \overline{D}^{*0}\phi) = (53.1 \pm 6.0 \pm 1.9)\%$
  - $f_L(B^0 \to \overline{D}^{*0}\phi) = (65.7 \pm 21.6 \pm 2.9)\%$

- Consistent with previous analysis, with precision improved

$B^0 \to \overline{D}^0\phi$ upper limit

- Consider systematic, up-limit for $B^0 \to \overline{D}^0\phi$ is

$$\mathcal{B}(B^0 \to \overline{D}^0\phi) < 10.55 \times 10^{-7} \text{ at } 90\% \text{ of CL.}$$
$$\mathcal{B}(B^0 \to \overline{D}^0\phi) < 11.47 \times 10^{-7} \text{ at } 95.45\% \text{ of CL } (2\ \sigma).$$



- Theoretical prediction: $(21 \pm 3) \times 10^{-7}$ based on $\omega - \phi$ mixing angle $\delta = -4.64°$

$\omega - \phi$ mixing angle

- $\omega - \phi$ mixing ($\omega^I = \frac{u\bar{u}+d\bar{d}}{\sqrt{2}}, \phi^I = s\bar{s}$)

$$\begin{pmatrix} \omega \\ \phi \end{pmatrix} = \begin{pmatrix} \cos\delta & \sin\delta \\ -\sin\delta & \cos\delta \end{pmatrix} \begin{pmatrix} \omega^I \\ \phi^I \end{pmatrix}$$

- Then $\tan^2\delta = \frac{B(B^0 \to \bar{D}^0\phi)}{B(B^0 \to \bar{D}^0\omega)} \times \frac{\Phi(\omega)}{\Phi(\phi)}$, with $\frac{\Phi(\omega)}{\Phi(\phi)} = 1.05 \pm 0.01$

- $\tan^2\delta = (3.6 \pm 0.7 \pm 0.4) \times 10^{-3}$

  Consistent with the theoretical prediction

(Phys. Lett. B 666(2008) 185)

Measurement of γ via $B_s^0 \to \overline{D}^{(*)0}\phi$

Strategy to determinate angle γ

- Time-integrated yields of different D^0 sub decay modes:

$$N(\boldsymbol{K^+\pi^-}) = C_{K\pi}\,[A(1 + r_B^2 + 4r_B r_D^{K\pi}\cos\delta_B\cos(\delta_D^{K\pi} + \gamma)) - 2Byr_B\cos(\delta_B + 2\beta_s - \gamma)]$$
$$N(\boldsymbol{K^-\pi^+}) = C_{K\pi}\,[A(1 + r_B^2 + 4r_B r_D^{K\pi}\cos\delta_B\cos(\delta_D^{K\pi} - \gamma)) - 2Byr_B\cos(\delta_B - 2\beta_s + \gamma)]$$
$$N\left(\boldsymbol{K^+\pi^-\pi^0}\right) = C_{K\pi}\,F_{K\pi\pi^0}\left[A\left(1 + r_B^2 + 4r_B r_D^{K\pi\pi^0} R_D^{K\pi\pi^0}\cos\delta_B\cos\left(\delta_D^{K\pi\pi^0} + \gamma\right)\right) - 2Byr_B\cos(\delta_B + 2\beta_s - \gamma)\right]$$
$$N\left(\boldsymbol{K^-\pi^+\pi^0}\right) = C_{K\pi}\,F_{K\pi\pi^0}\left[A\left(1 + r_B^2 + 4r_B r_D^{K\pi\pi^0} R_D^{K\pi\pi^0}\cos\delta_B\cos\left(\delta_D^{K\pi\pi^0} - \gamma\right)\right) - 2Byr_B\cos(\delta_B - 2\beta_s + \gamma)\right]$$
$$\ldots$$
$$N(\boldsymbol{K^+K^-}) = 2C_{K\pi}\,F_{KK}[\mathrm{A}(1 + r_B^2 + 2r_B\cos\delta_B\cos\gamma\,) - By(\cos 2\beta_s + r_B^2\cos 2(\beta_s - \gamma) + 2r_B\cos(2\beta_s - \gamma)\cos\delta_B]$$

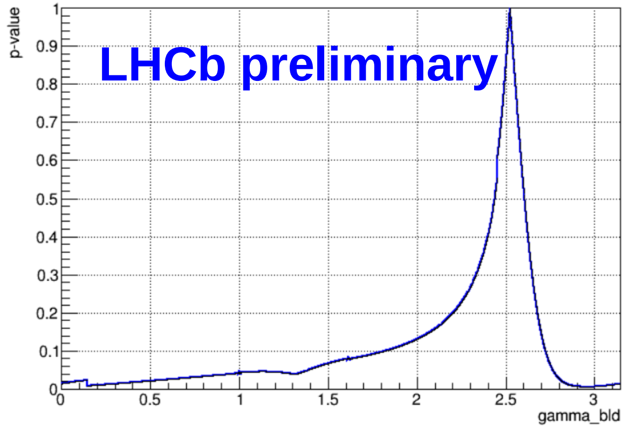
  - $N(mode)$: yields determined from data
  - $r_D^{K\pi}, \delta_D^{K\pi}, r_D^{K\pi\pi^0}, \delta_D^{K\pi\pi^0}, R_D^{K\pi\pi^0}$: parameters in D^0 decay (external input)
  - γ, β_s: parameters in B_s decay (external input)
  - $F_{KK} = \frac{\varepsilon_{KK}}{\varepsilon_{K\pi}} \times \frac{Br\left(D^0 \to KK\right)}{Br(D^0 \to K^-\pi^+)}$
  - A and B are parameters determined from decaytime acceptance
  - γ, r_B, δ_B will be determined from fit

[Chinese Phys. C 45 023003 (2021)]

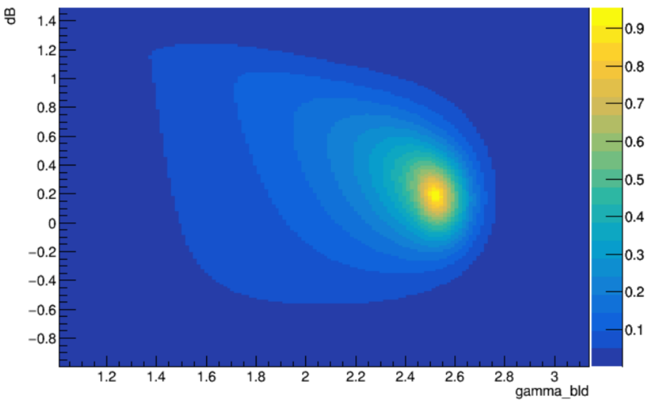
Measurement of γ via $B_s^0 \to \bar{D}^{(*)0}\phi$

- Flavour mode: $D^0 \to K^-\pi^+/K^-\pi^+\pi^-\pi^+/\,K^-\pi^+\pi^0$
  - π^0 reconstruction is challenging in LHCb
- CP-even mode: $D^0 \to K^-K^+/\,\pi^+\pi^-$
  - $D^0 \to K_s^0 hh$ modes do not included due to lack of statistic
- More yields than expected in sensitivity study
- Bad uncertainty of $B_s^0 \to \bar{D}^{*0}\phi$, but dominated modes is $B_s^0 \to \bar{D}^0\phi$
- Blind analysis ongoing, preliminary result gives

$$\gamma = (XXX^{+8}_{-16})^\circ$$



LHCb preliminary



Summary

- Improved measurement on $B_{(s)}^0 \rightarrow \overline{D}^{(*)0}\phi$
  - New branch ratio results consistent with previous
  - Evidence of $B^0 \rightarrow \overline{D}^{(*)0}\phi$
- Ongoing study of γ measurement via $B_s^0 \rightarrow \overline{D}^{(*)0}\phi$

Backups