Study of the b-hadron decays at LHCb

Dong Ao

On behalf of collaborators:

D. Decamp, O. Deschamps, L. Guerry, Y. Hou, C. Huang,J. Wang, S. Monteil, H. Sazak, W. Qian, Y. Shang, Y. Song, S. Ricciardi, V. Tisserand, S. T'Jampens, X. Wu, Z. Wu, Z. Wang, Z. Yang, S. Zhang, Y. Zhang, X. Zhou

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- Improved measurements on $B^0_{(s)} \to \overline{D}^{(*)0}\phi$
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- Dalitz analysis of $B^0 \to \overline{D}^0 KK$
- $B^0_{(s)}/\Lambda^0_b \to \pi^0 hh'$ study
- Summary

Overview of the project

- Study in $\overline{D}^0 KK$ system
  - Improved measurements on $B^0_{(s)} \to \overline{D}^{(*)0}\phi$ (JHEP10(2023)123)
  - CKM angle γ measurement via $B^0_s \to \overline{D}^{(*)0}\phi$ Ongoing Sensitivity studies(*Chin. Phys. C45(2021) 023003*)
  - Observation of $B^0_{(s)} \to D_{s1}(2536)^{\mp}K^{\pm}$ (JHEP10(2023)106)
  - Dalitz analysis of $B^0 \to \overline{D}^0 KK$ Ongoing
  - Dalitz analysis of $B^0_s \to \overline{D}^0 KK$ Ongoing

- Study in $\pi^0 hh'$ system Ongoing
  - CPV measurement
  - CKM angel α measurement

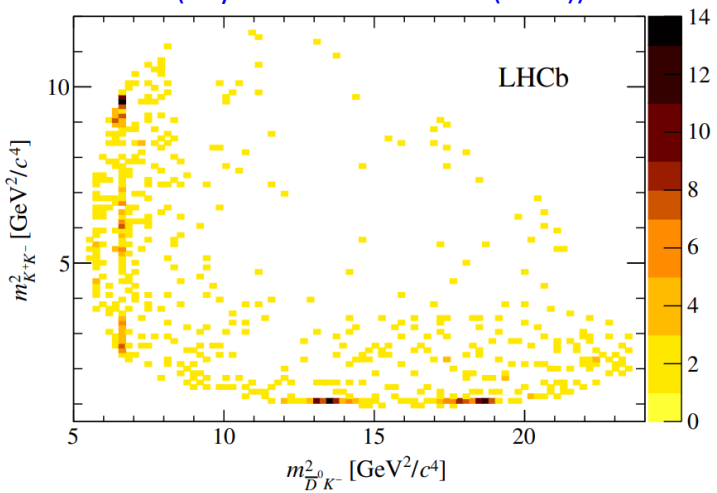
Physic motivation (spectroscopy studies)

- Rich resonant structures

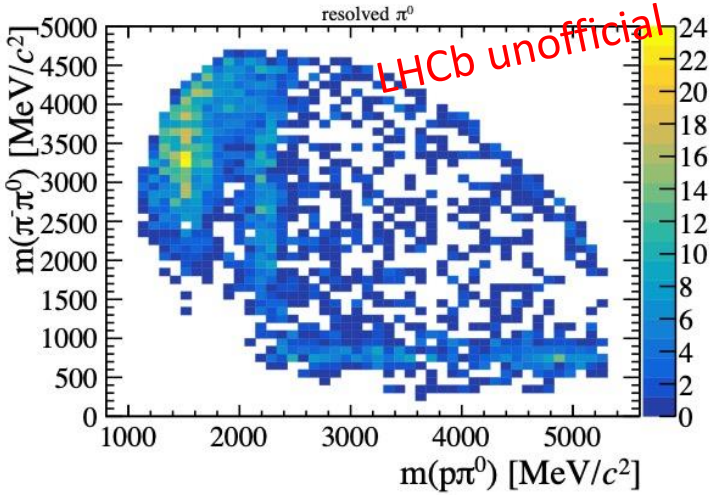
- ϕ, ρ, exited D_s^* …

$B_s^0 \to \bar{D}^0 KK$

(Phys. Rev. D.98 072006 (2018))



$\Lambda_b^0 \to p\pi^-\pi^0$

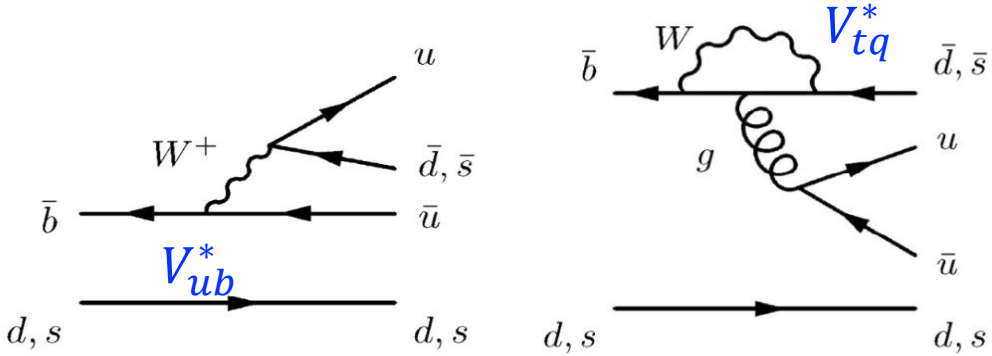


Physic motivation (CPV measurement)

$B^0_{(s)}/\Lambda^0_b \to hh\pi^0$ system

- Beauty charmless decays: $b \to q\bar{q}s, q\bar{q}d$

  Interference between tree and loop diagrams gives rise to direct CP violation

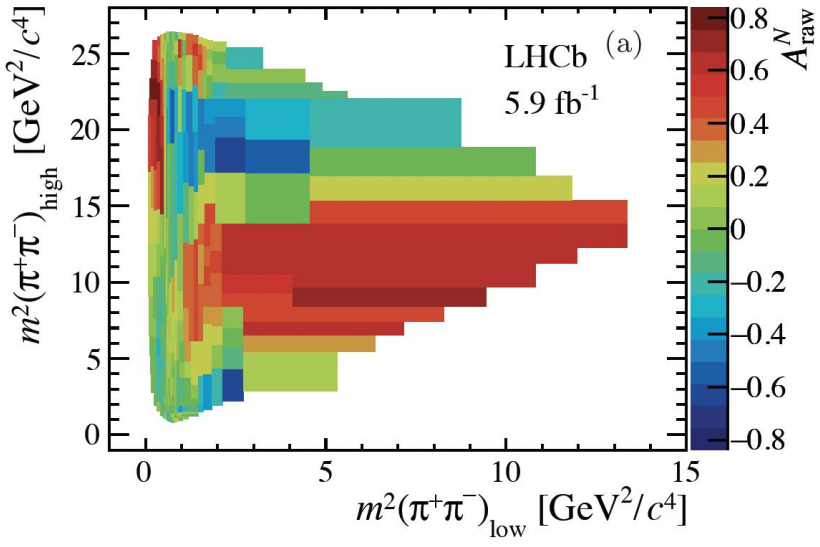


Tree Penguin

- K-π puzzle : CP asymmetries in 2-body B meson decays inconsistent with simple isospin relation (Phys.Rev.D 71 (2005) 057502)

- Large and variation of CP violation in localized phase space of B^+ 3-body decays (LHCb: Phys. Rev. D108 (2023) 012008)

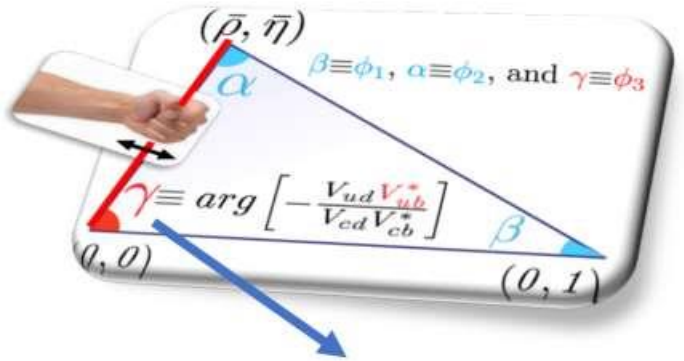
- Neutral $B^0_{(s)}$ decays yet to be explored
  - Phase-space dependent CP violation expected
  - To test isospin/SU(3) relations for quasi-two-body CP violation and branching fraction



Physic motivation (CPV measurement)

$B \to DKK$ system

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



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

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

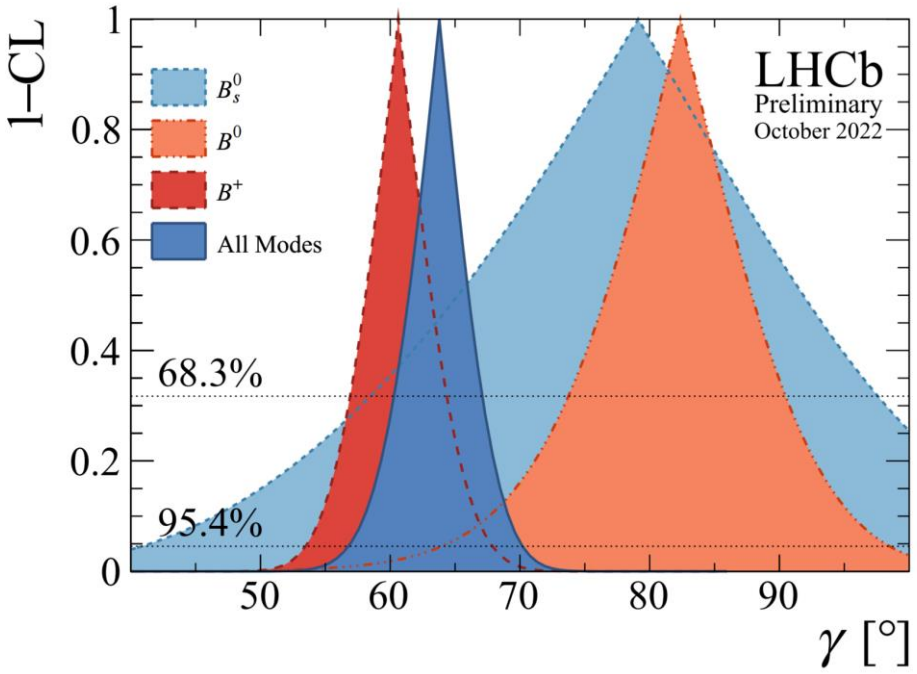
LHCb γ combination (LHCb-CONF-2022-003)

- 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^0 to constrain the γ uncertainty
  - γ sensitivity study via $B_s^0 \to \overline{D}^{(*)0}\phi$: $8° - 19°$ $(9\ \mathrm{fb}^{-1})$

(*Chin. Phys. C45(2021) 023003*)

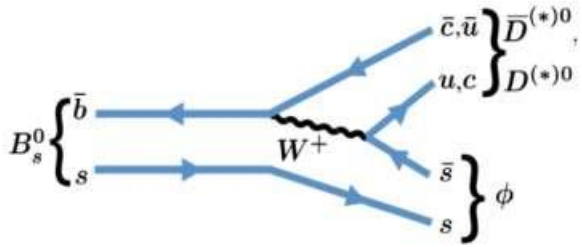
Improved branching ratio measurements on $B^0_{(s)} \to \overline{D}^{(*)0}\phi$

arXiv: 2306.02768

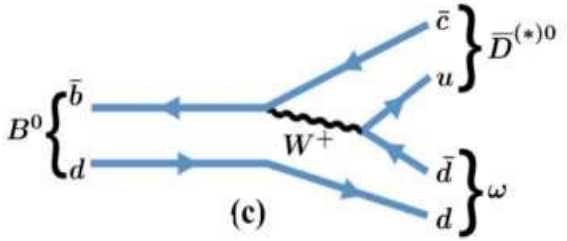
JHEP10(2023)123

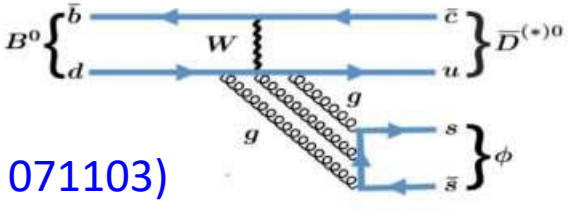
Introduction of $B^0_{(s)} \to \overline{D}^{(*)0}\phi$

- $B^0_s \to \overline{D}^{(*)0}\phi$ can proceed by $b \to c$ or $b \to u$ process:
  - Measuring longitudinal polarization (f_L) is particularly interesting
  - Can be used to determine γ



- $B^0 \to \overline{D}^{(*)0}\phi$ can be proceeded by:
  - OZI suppressed decay
  - $B^0 \to \overline{D}^{(*)0}\omega$ with $\omega - \phi$ mixing
  - Theoretical prediction $B^0 \to \overline{D}^0\phi \sim 1.6 \times 10^{-6}$ (Phys. Lett. B 666(2008) 185)
  - $B(B^0 \to \overline{D}^0\phi) < 2.0(2.3) \times 10^{-6}$ at 90%(95%) CL
  - Help to extract $\omega - \phi$ mixing angle





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

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

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

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

- Fraction of longitudinal polarization

$$f_L(B_s^0 \to \overline{D}^{*0}\phi) = (53.1 \pm 6.0 \pm 1.9)\%$$

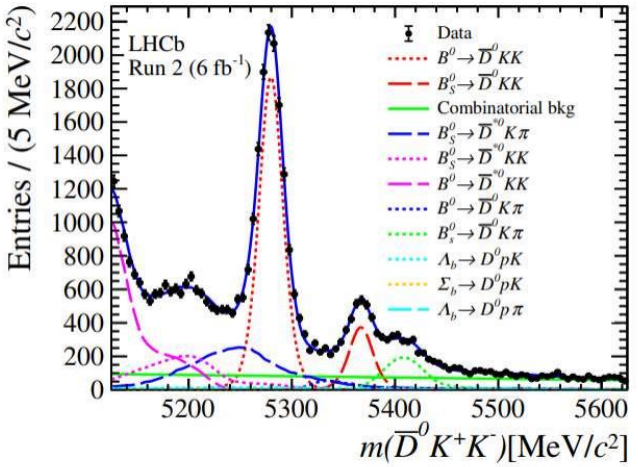
- Combining the branching fractions of $B^0 \to \overline{D}^{(*)0}\omega$, $\omega - \phi$ mixing angle determined:

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

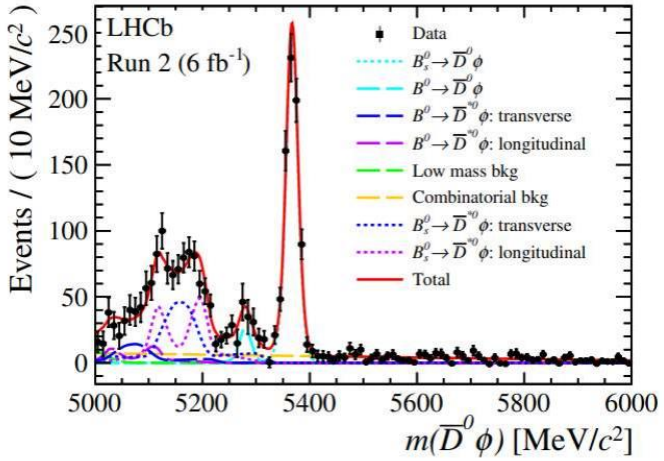
Consistent with the theoretical prediction

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

Control channel $B^0 \to \overline{D}^0 KK$



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



CKM angle γ measurement via $B_s^0 \to \overline{D}^{(*)0}\phi$

Ongoing

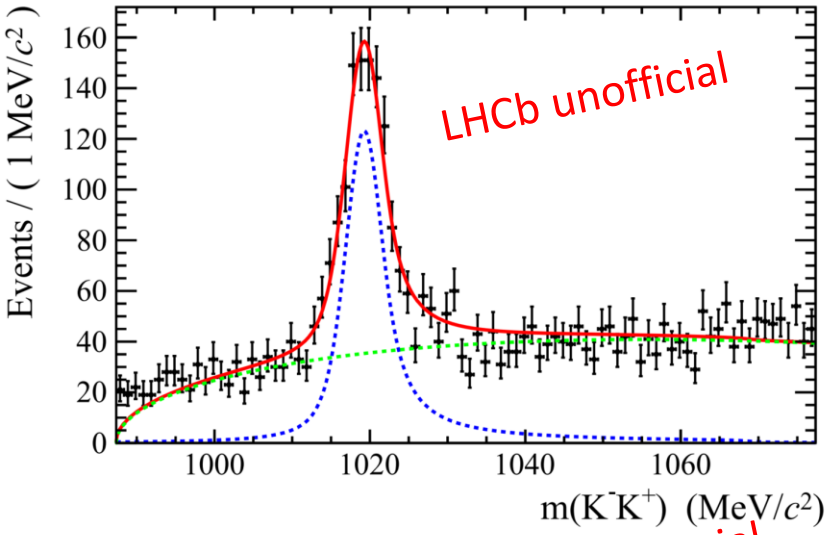
CKM angle γ measurement via $B_s^0 \to \overline{D}^{(*)0}\phi$

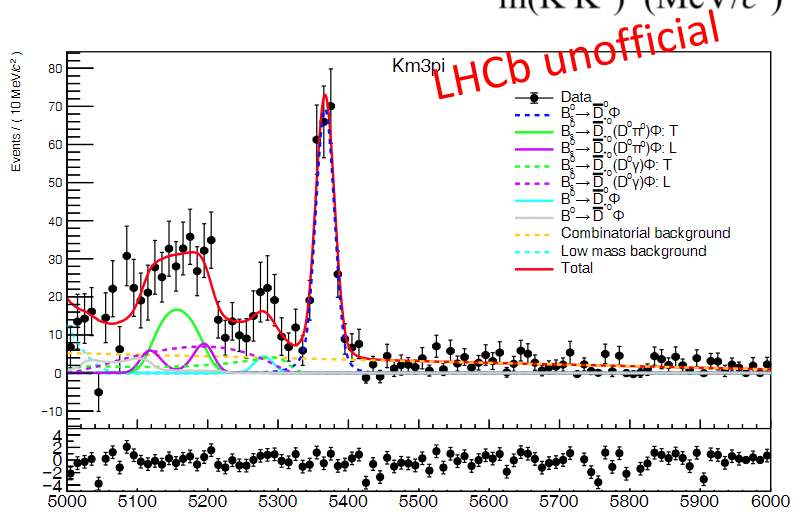
- Time-integrated and flavour-untagged method

  (Phys.Rev.D.69.113003-2004)
  (Phys. Lett. B 649 (2007) 61)
  (LHCb-PUB-2010-005)

- Using various neutral D meson sub-decays
  - Flavour specific modes: $K\pi, K\pi\pi\pi, K\pi\pi^0$
  - CP eigenstates modes: $KK, \pi\pi$ ($K_S^0 hh$ not include due to lack of statistics)

- Use sPlot technique to extract pure ϕ signal





CKM angle γ measurement via $B_s^0 \to \overline{D}^{(*)0}\phi$

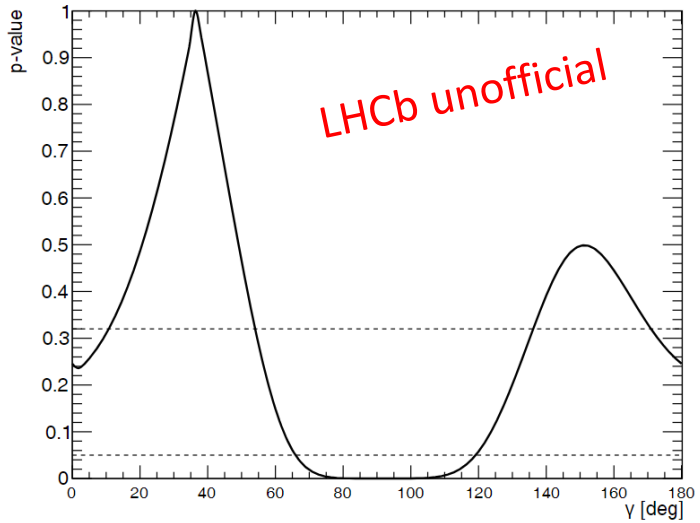
- Analysis ongoing, preliminary result gives:

$$\gamma = (37^{+17}_{-26})°$$

- Compatible with sensitivity study ($8° - 19°$)

(*Chin. Phys. C45(2021) 023003*)

- Worse $B_s^0 \to \overline{D}^{*0}\phi$ uncertainty than prediction (large background contamination), dominated by $B_s^0 \to \overline{D}^0\phi$



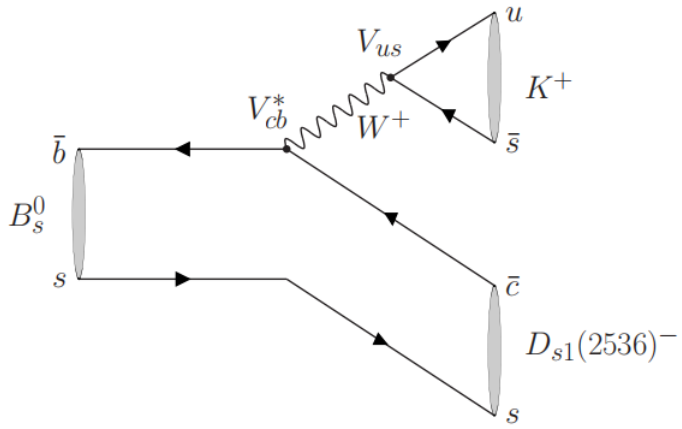
Observation of $B^0_{(s)} \rightarrow D_{s1}(2536)^{\mp} K^{\pm}$

arXiv: 2308.00587

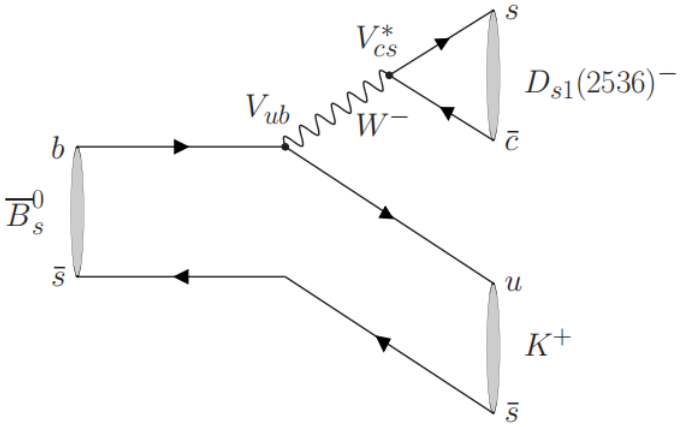
JHEP10(2023)106

Search for of $B^0_{(s)} \rightarrow D_{s1}(2536)^{\mp}K^{\pm}$

- Can proceed by $b \rightarrow c$ or $b \rightarrow u$ process
  - Sensitive to CKM angle γ

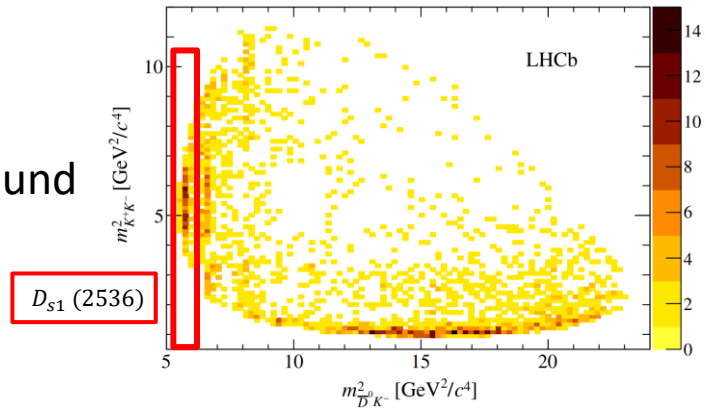


- An extension of previous $B^0_{(s)} \rightarrow \overline{D}^0 KK$ work
  - A significant peak corresponding to D_{s1} (2536) (Phys. Rev. D.98 072006 (2018))
  - $D_{s1}(2536)^{\mp}K^{\pm}$ not observed in $B^0_{(s)}$ in previous study



$B^0 \rightarrow \overline{D}^0 KK$

background



Observation of the decay $B^0_{(s)} \to D_{s1}(2536)^{\mp}K^{\pm}$

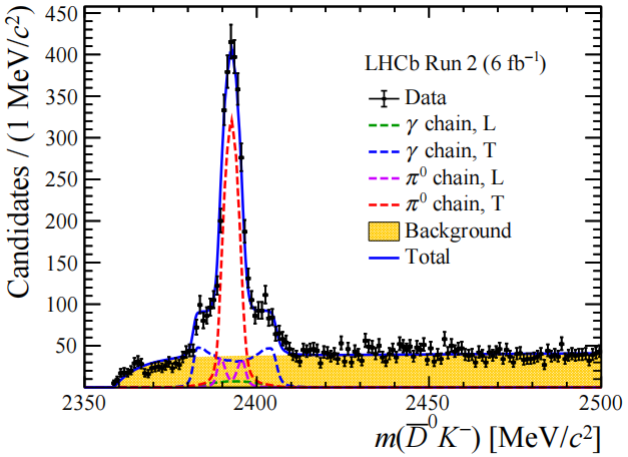
- sPlot technique is used to extract $D_{s1}(2536)^{\mp}$ signal

- Observation of $B^0_{(s)} \to D_{s1}(2536)^{\mp}K^{\pm}$

$$B\left(B^0_s \to D_{s1}(2536)^{\mp}K^{\pm}\right) \times B(D_{s1}(2536)^{-} \to \overline{D}^{*}(2007)^0K^{-}) = (2.49 \pm 0.11 \pm 0.12 \pm 0.25 \pm 0.06) \times 10^{-5}$$

$$B\left(B^0 \to D_{s1}(2536)^{\mp}K^{\pm}\right) \times B(D_{s1}(2536)^{-} \to \overline{D}^{*}(2007)^0K^{-}) = (0.510 \pm 0.021 \pm 0.036 \pm 0.050) \times 10^{-5}$$

$> 10\sigma$



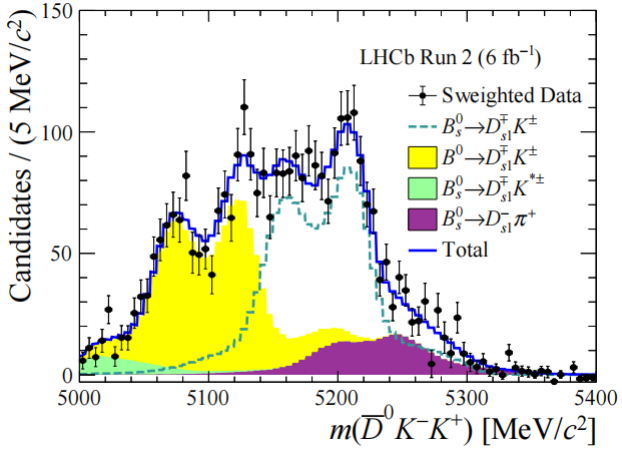
- Helicity-related parameters also determined

Amplitudes ratio of S- and D-wave:

$$k = 1.11 \pm 0.15 \pm 0.06$$

Amplitudes phase difference of S- and D-wave:

$$|\psi| = 0.70 \pm 0.09 \pm 0.04$$



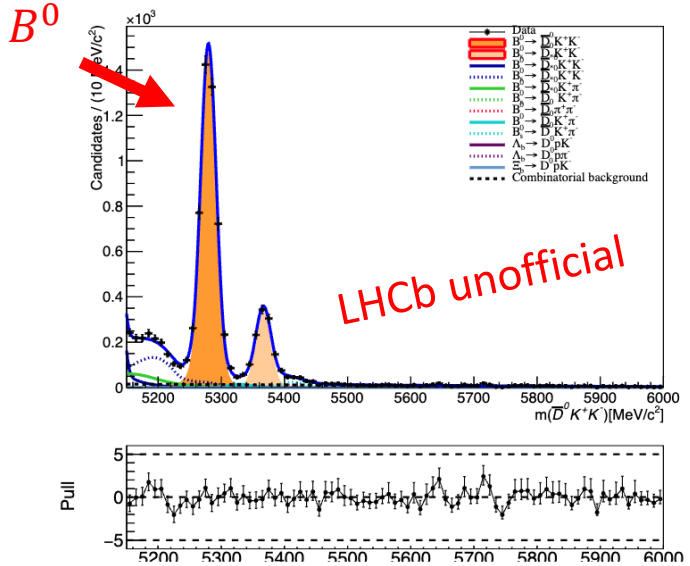
Dalitz analysis of $B^0_{(s)} \to \overline{D}^0 KK$

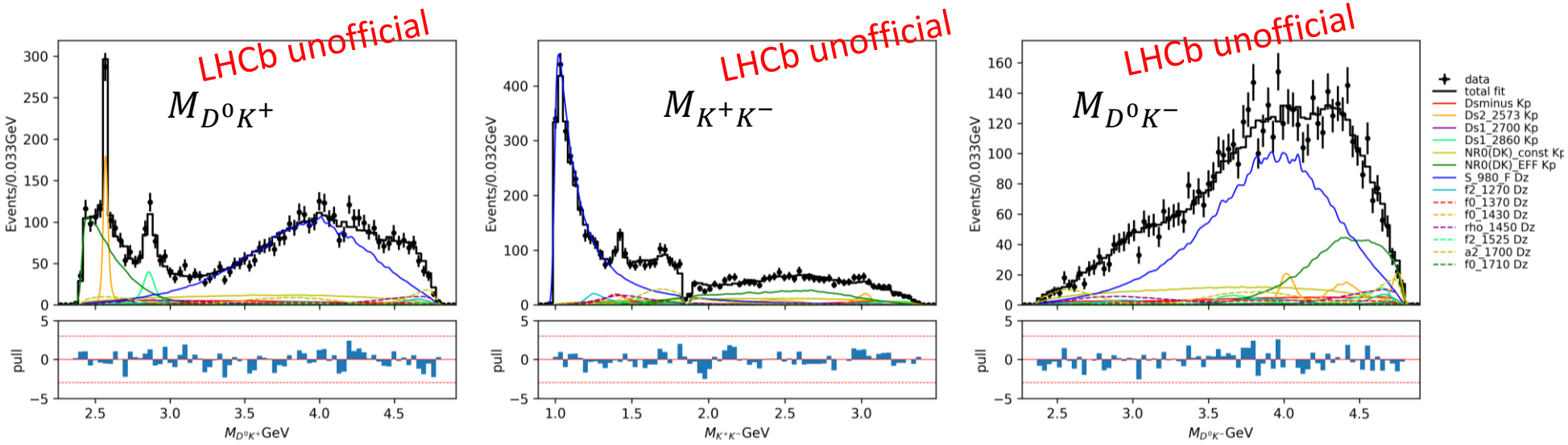
Ongoing

Dalitz analysis of $B^0 \to \bar{D}^0 KK$

- High purity after selection:
  - ~5000 signals with purity 93% for $B^0 \to \bar{D}^0 KK$

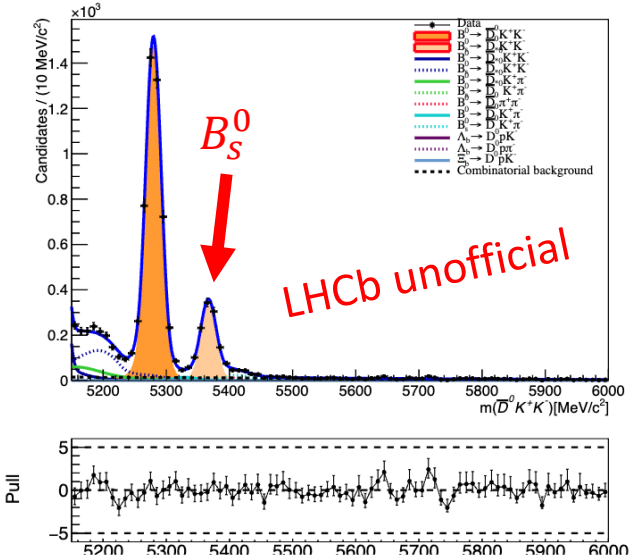
- Dalitz analysis ongoing
  - $D_{s2}^*(2573)^-, D_{s1}^*(2700)^-, f_0(980), f_2(1270)$ peaks observed in projection plots

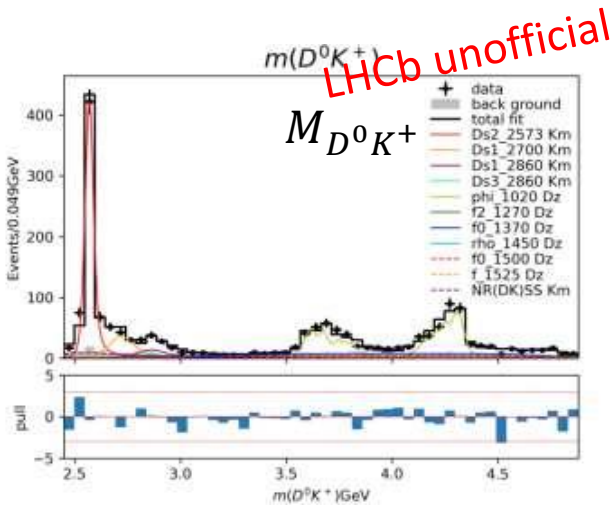


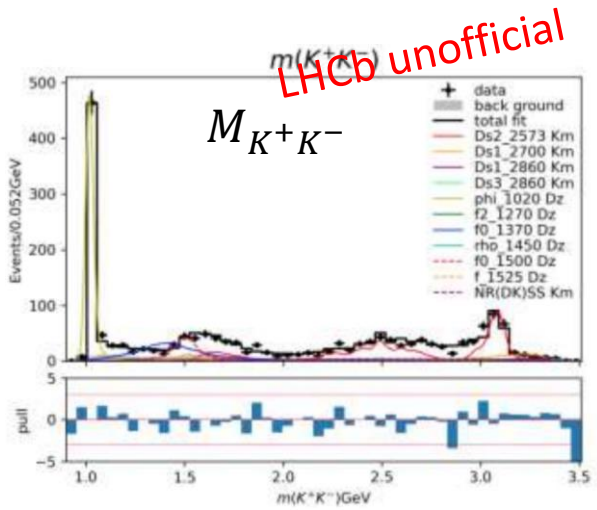


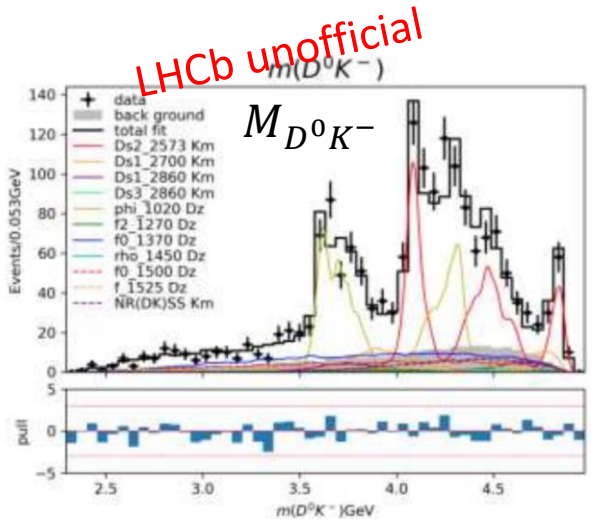
Dalitz analysis of $B_s^0 \to \bar{D}^0 KK$

- High purity after selection:
  - ~1200 signals with purity 83% for $B_s^0 \to \bar{D}^0 KK$
- Dalitz analysis ongoing
  - $D_{s2}^*(2573)^-, D_{s1}^*(2700)^-, \phi(1020), f_2(1270)$ peaks observed in projection plots









$B^0_{(s)}/\Lambda^0_b \to \pi^0 h^+ h'^-$ studies

Ongoing

$B^0_{(s)}/\Lambda^0_b \to \pi^0 h^+ h'^-$ decays

- No data available at hadron colliders
  - $B^0 \to \pi^0 h^+ h'^-$ only measured by B-factories, much more statistics at LHCb
  - $B^0 \to \pi^0 \pi^+ \pi^-$ via ρ resonances golden channel for CKM angle α measurement
  - $\Lambda^0_b \to \pi^0 p h^-$ only accessible by LHCb

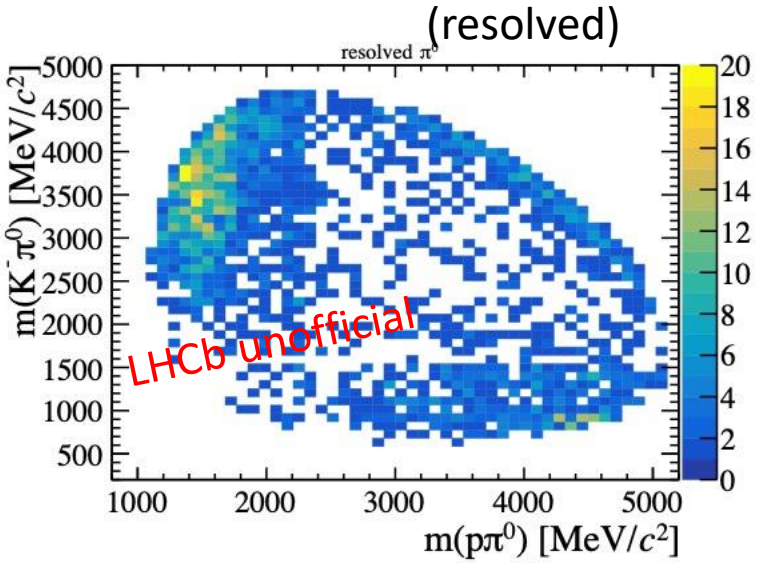
- Included decays: $B^0_{(s)} \to \pi^+\pi^-\pi^0$, $B^0_{(s)} \to K^+\pi^-\pi^0$, $B^0_{(s)} \to K^+K^-\pi^0$, $\Lambda^0_b \to pK^-\pi^0$, $\Lambda^0_b \to p\pi^-\pi^0$
  - Similar decay topology, permitting simultaneous event selection
  - Relative branching fraction measurements cancel systematic uncertainties
  - Self flavor-tagged decays make possible direct CP violation measurement

- Key analysis
  - π^0 reconstruction/calibration: merged $\pi^0(\to \gamma\gamma)$, resolved π^0 (two γ forming a single big cluster)
  - Huge combinatorial background: due to lack of verting information for π^0
  - π^0- γ separation for resolved π^0

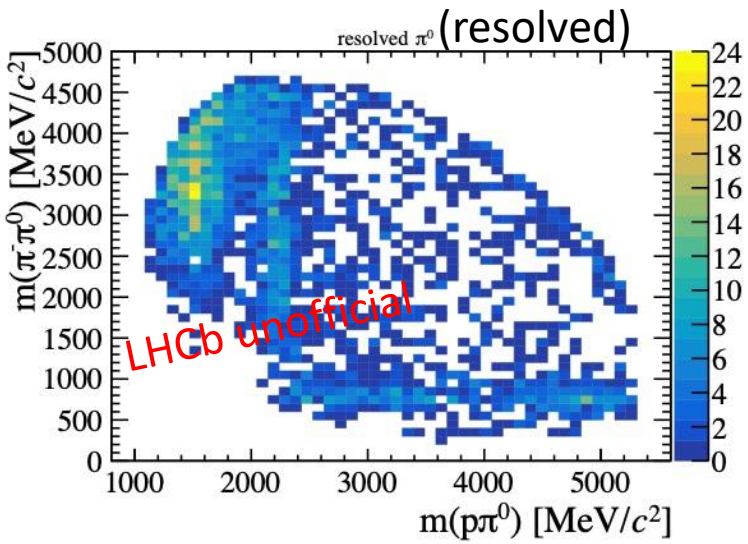
Promising measurements

- Huge statistics already with LHCb Run1+Run2 data
- Rich Dalitz/resonance structures
- Reasonable purity achieved in localized resonance regions

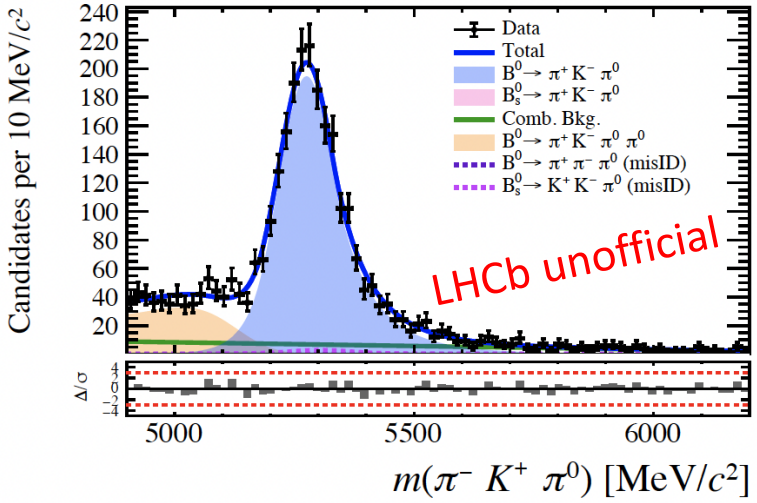
$\Lambda_b^0 \to pK^-\pi^0$ (resolved)
Total yield ~ 4000



$\Lambda_b^0 \to p\pi^-\pi^0$
Total yield ~ 4000



$B^0 \to K^+\pi^-\pi^0$
Total yield $\sim 100\,000$



K^{*+} region with $\cos\theta < 0$

Summary

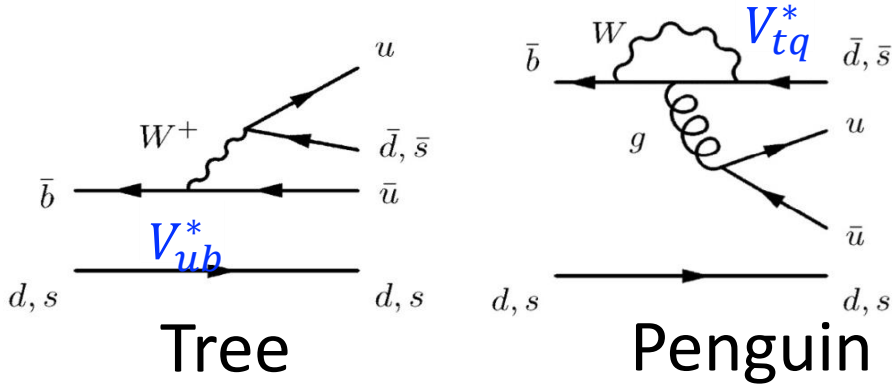
- Papers published
  - Study of the CKM angle γ sensitivity using flavor untagged $B_s^0 \to \widetilde{D}^{(*)0}\phi$ decays (Chin. Phys. C45(2021) 023003)
  - Evidence for the decays $B^0 \to \overline{D}^{(*)0}\phi$ and updated measurement of the branching fractions of the $B_s^0 \to \overline{D}^{(*)0}\phi$ decays (JHEP10(2023)123)
  - Observation of the decay $B^0_{(s)} \to D_{s1}(2536)^{\mp}K^{\pm}$ (JHEP10(2023)106)
- Work ongoing
  - CKM angle γ measurement via $B_s^0 \to \overline{D}^{(*)0}\phi$
  - Dalitz analysis of $B^0_{(s)} \to \overline{D}^0 KK$
  - Studies with $B^0_{(s)}/\Lambda_b^0 \to \pi^0 h^+ h'^-$

Thank you for your attention

Backups

$b \to hh\pi^0$ system

- Interference between tree/penguin diagrams
  - Direct CPV



- $\Lambda_b^0 \to ph\pi^0$: yet no baryon CPV observed

(Phys. Lett. B, 2018, 787 : 124 – 133)

- $B^0 \to \pi^0\pi^+\pi^-$ via ρ resonances: CKM angle α measurement

$$\alpha = \arg\left(-\frac{V_{td}V_{tb}^*}{V_{ud}V_{ub}^*}\right)$$