Physics with $B^0_{(s)} \to \bar{D}^0 K^+ K^-$ decay at LHCb

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17th workshop of the FCPPL/N

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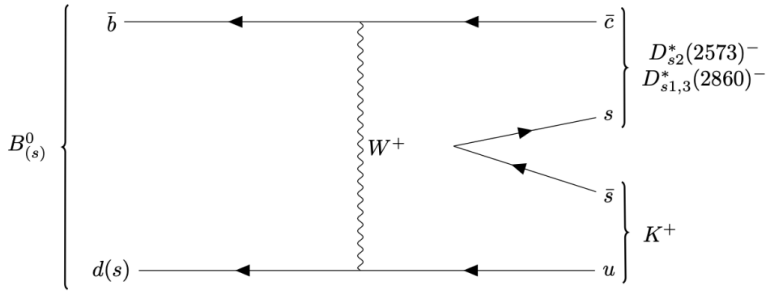
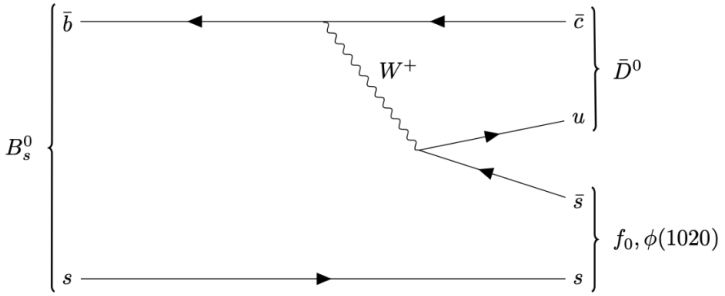
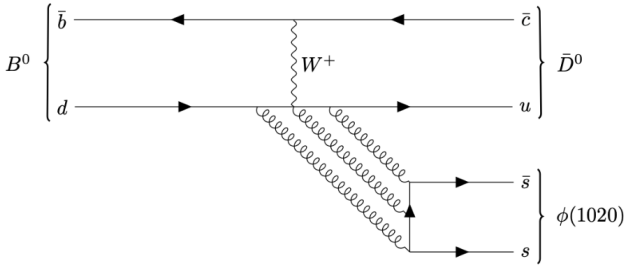
Physics motivation for $B^0_{(s)} \to \overline{D}^{(*)0} KK$

- Study neutral B-meson decays to the $\overline{D}^0 K^+ K^-$ final state: $B^0_{(s)} \to \overline{D}^0 K^+ K^-$, $B^0_{(s)} \to \overline{D}^0 \phi$







- Motivation:
  - γ measurement:
    - $B^0_s \to \overline{D}^{(*)0} \phi$ decay
    - Time-dependent Dalitz analyses of $B^0_s \to D K^+ K^-$
  - Hadron spectroscopy : study D^*_s spectrum, K^+K^- spectrum, indirectly search for glueball
  - Rare decay search: $B^0 \to \overline{D}^0 \phi$ is a W-exchange and OZI-suppressed process.
- Previous studies from our team :
  - Run 1 measurements established the experimental basis for these decays
    Phys. Rev. D 98 (2018) 072006, 071103
  - Run 1 + Run 2 studies further improved the sensitivity and motivated amplitude analyses
    Chin. Phys. C 45 (2021) 023003; JHEP 10 (2023) 123, 106

CKM matrix

- CKM matrix describes quark mixing in the SM
  - The complex phase is the only established source of CPV in the SM

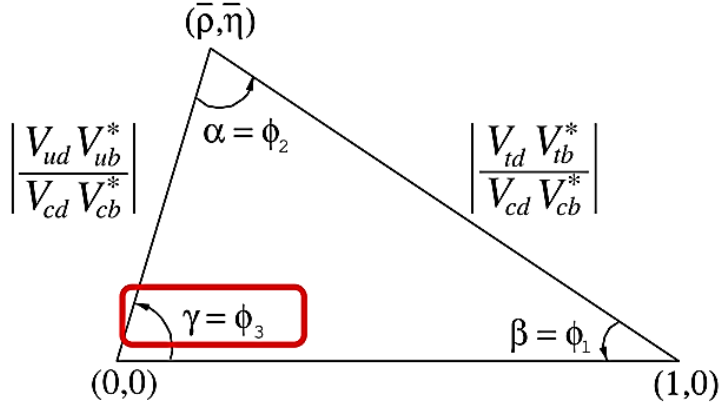
$$V_{CKM} = \begin{pmatrix} |V_{ud}| & |V_{us}| & |V_{ub}|e^{-i\gamma} \\ -|V_{cd}| & |V_{cs}| & |V_{cb}| \\ |V_{td}|e^{-i\beta} & -|V_{ts}|e^{i\beta_s} & |V_{tb}| \end{pmatrix} + O(10^{-3}) =$$

- Unitarity of the CKM matrix

  ⇒ the unitarity triangles (UTs)

  - Indirect search of BSM physics

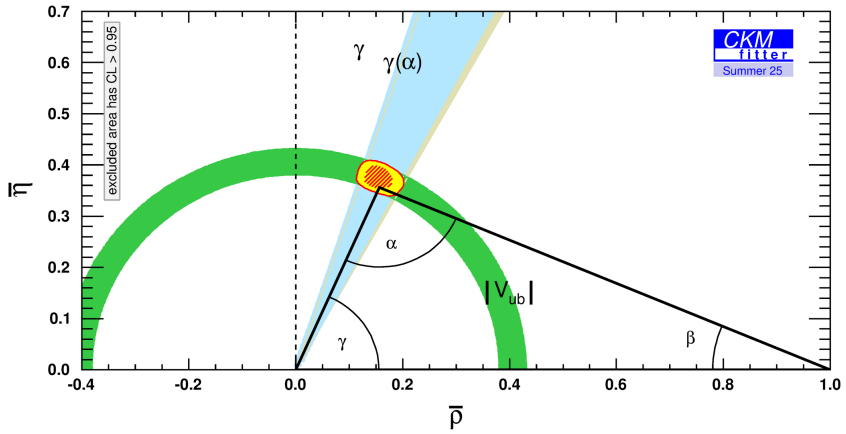
$$V_{ud}V_{ub}^* + V_{cd}V_{cb}^* + V_{td}V_{tb}^* = 0$$



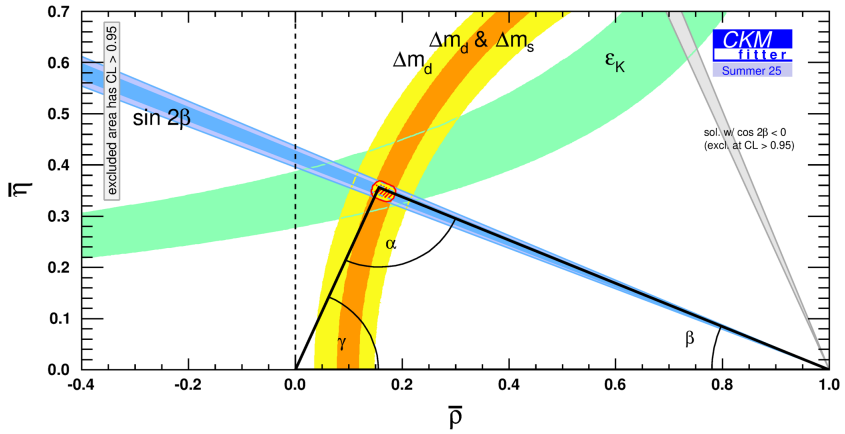
CKM angle γ

- Directly accessible through tree-level $B \to DX$ decays
- Tiny theoretical uncertainty ($\delta\gamma/\gamma < 10^{-7}$) (JHEP 1401(2014)05)
- HFLAV latest: $\gamma = (66.7^{+2.7}_{-2.8})°$
- LHCb combination: $\gamma = (62.8 \pm 2.6)°$(LHCb-CONF-2025-003)
- **Loop-level** (indirect measurement) is sensitive to New Physics
- CKM fitter latest: $\gamma = (66.2^{+2.7}_{-2.8})°$

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



Tree only



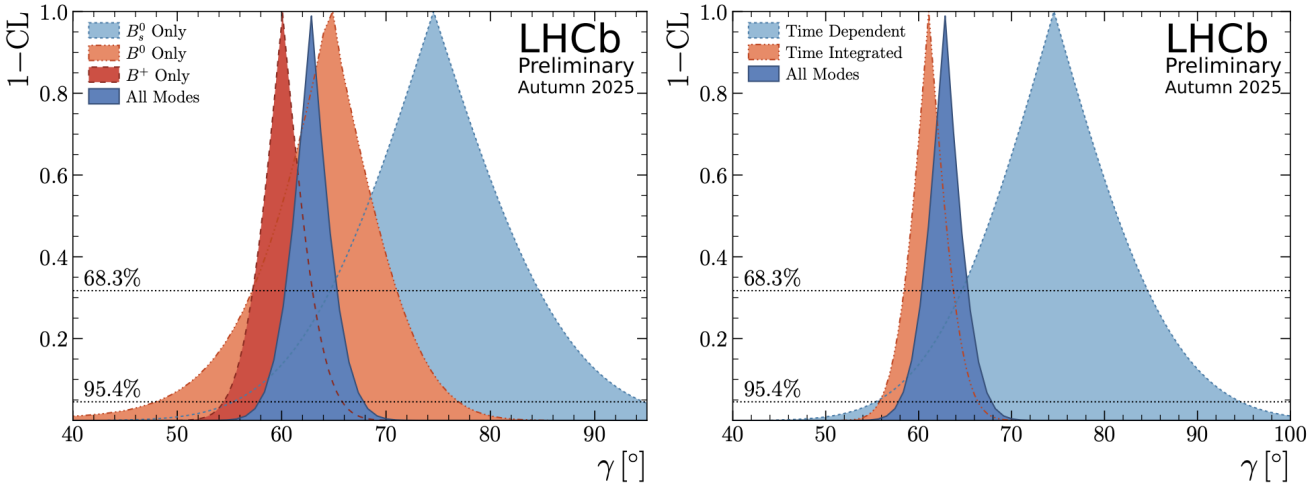
Loop only

CKM fitter 2025

γ measurement status at LHCb

- LHCb combines many $B \to DX$ decay modes to determine

$$\gamma = (62.8 \pm 2.6)^\circ$$



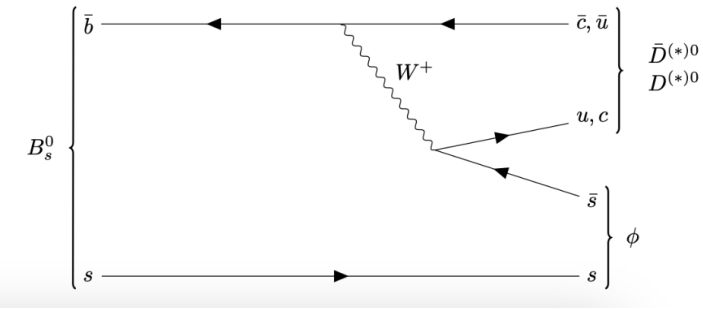
Species	γ value	68.3% CL interval
B^+	$63.4^{+3.2}_{-3.3}{}^\circ$	$[60.1, 66.6]^\circ$
B^0	$64.6^{+6.5}_{-7.5}{}^\circ$	$[57.1, 71.1]^\circ$
B_s^0	$75.0^{+10.0}_{-11.0}{}^\circ$	$[64.0, 85.0]^\circ$

LHCb-CONF-2025-003

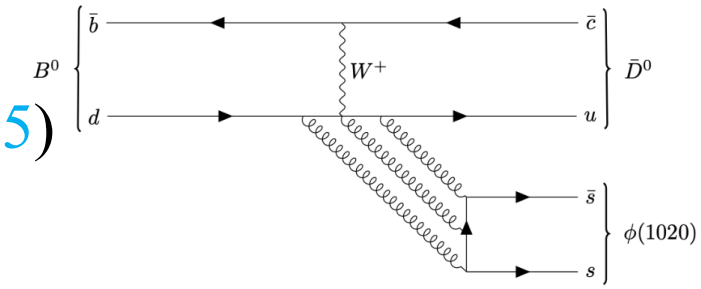
- Current precision is mainly driven by charged-B modes
- B_s^0 modes are less precise today, but provide complementary sensitivity through mixing and time-dependent CP violation
- Need more modes of B_s^0 constraining the γ errors in B_s^0 decay
  - γ sensitivity study in $B_s^0 \to \overline{D}^{(*)0}\phi$: 8°~19° (9fb^{-1}) (Chin. Phys. C45(2021) 023003)

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

- $B^0_{(s)} \to D^{(*)0}\phi$ can process by $b \to c$ or $b \to u$ transitions
  - Color suppressed and proportional to λ^3
  - Measuring longitudinal polarisation f_L is particular interesting
  - Can be used to determine γ



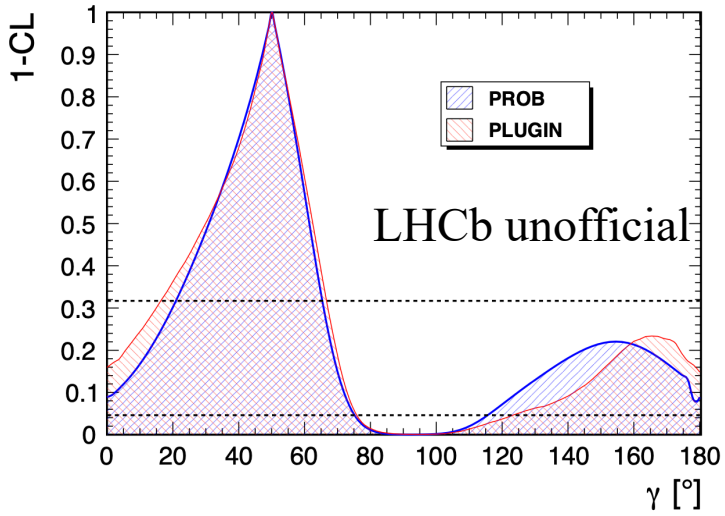
- $B^0 \to D^{(*)0}\phi$ can proceed by:
  - OZI suppress, W-exchange decay
  - Observed in charmonium decays (Phys. Rev. D 99 (2019) 012015) but not in b-hardon decays (Chin. Phys. C45(2021) 043001)
  - Help to extract $\omega - \phi$ mixing angle



- Previous studies from our team :
  - Observation of $B^0 \to D^{*0}\phi$ and search for $B^0 \to D^{(*)0}\phi$ decays (Phys. Rev. D98 (2018) 071103)
  - Evidence for the decays $B^0 \to D^{(*)0}\phi$ and updated measurements of the branching fractions of the $B^0_{(s)} \to D^{(*)0}\phi$ decays (JHEP 10 (2023) 123)

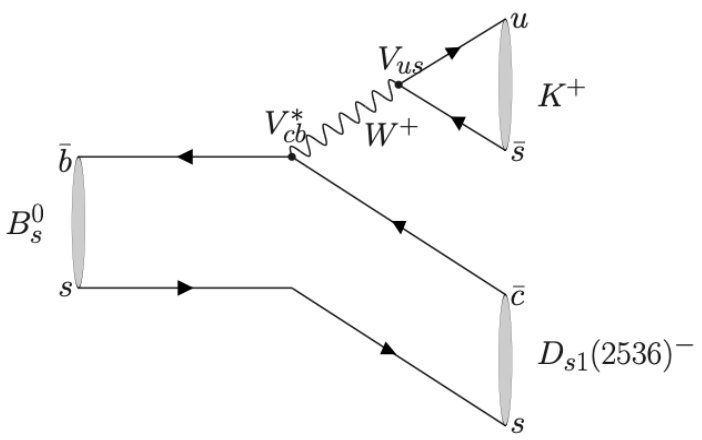
Measurement γ via $B_s^0 \to \bar{D}^{(*)0}\phi$ mode (ongoing)

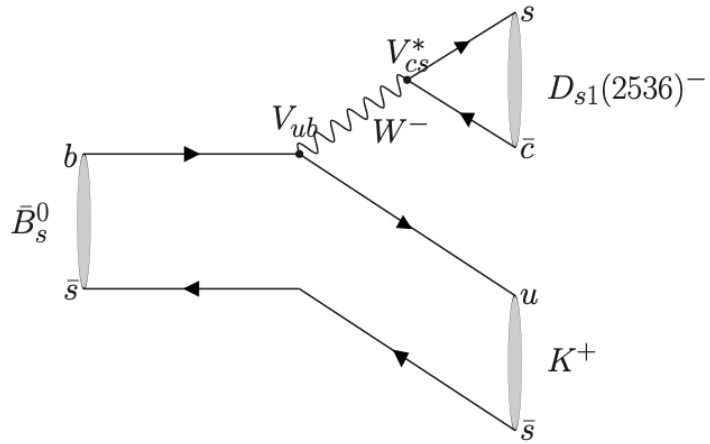
- First γ measurement using $B_s^0 \to D^{(*)0}\phi$ decays
  - New B_s^0-based channel, complementary to $B_s^0 \to D_s^{\mp}K^{\pm}$ and $B_s^0 \to D_s^{\mp}K^{\pm}\pi^+\pi^-$
- Time-integrated and flavour-untagged method
  - First implementation of a time-integrated method for extracting γ in the B_s^0 system
  - No need to resolve the fast $B_s^0 - \bar{B}_s^0$ oscillation
  - Sensitivity comes from interference between $B_s^0 - \bar{B}_s^0$ mixing and decay amplitudes
- Preliminary result: $\gamma = \left(50\ ^{+15}_{-30} \pm 9\right)^\circ$
- Status: Under LHCb collaboration review, aim to publish in 2026



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

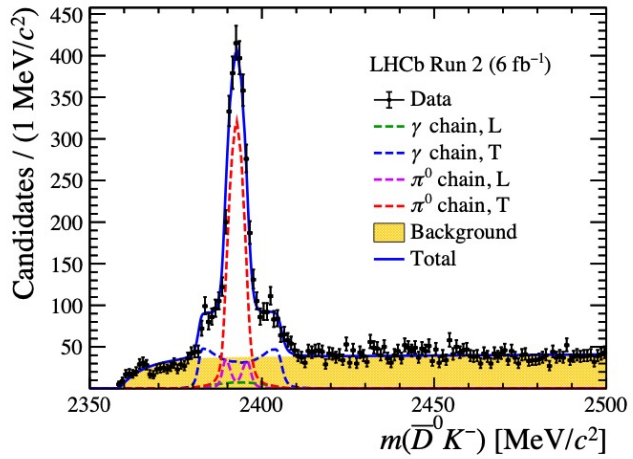
- The puzzle in the decay $B^0 \to D^{(*)-}K^+$ and $B^0_s \to D^{(*)-}\pi^+$
  - Their measured branching fractions smaller than those from calculation with QCD factorization (Phys. Rev. D 83 (2011) 014017, Eur. Phys. J. C 80 (2020) 951)
- The B^0_s mode can process via both $b \to c$ and $b \to u$ transition, which is sensitive to CKM angle γ
- γ can be probed by Time-dependent measurement to $B^0_s \to D_{s1}(2536)^{\mp}K^{\pm}$
- Searching for $B^0_s \to D_{s1}(2536)^{\mp}K^{\pm}$ decays and measuring the branch ratios is the first step

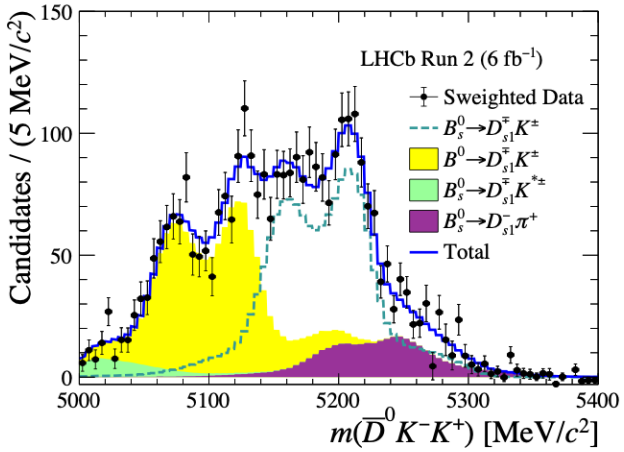




Observation of $B^0_{(s)} \to D_{s1}(2536)^{\mp}K^{\pm}$

- First observation of $B^0_{(s)} \to D_{s1}(2536)^{\mp}K^{\pm}$,
  - Observed with significance $> 10\sigma$ using LHCb Run 1+2 data.
- Measured product branching fractions
  - $\mathcal{B}\left(B^0_s \to D^{\mp}_{s1}(2536)K^{\pm}\right)\times\mathcal{B}(D^-_{s1}(2536) \to \overline{D}^{*0}(2007)K^-) = (2.49 \pm 0.11 \pm 0.12 \pm 0.25 \pm 0.06)\times10^{-5}$
  - $\mathcal{B}\left(B^0_s \to D^{\mp}_{s1}(2536)K^{\pm}\right)\times\mathcal{B}(D^-_{s1}(2536) \to \overline{D}^{*0}(2007)K^-) = (0.510 \pm 0.021 \pm 0.036 \pm 0.050)\times10^{-5}$.
- Status: Published (JHEP 10 (2023) 106), Preparation and early study on Run3 data for time-dependent study



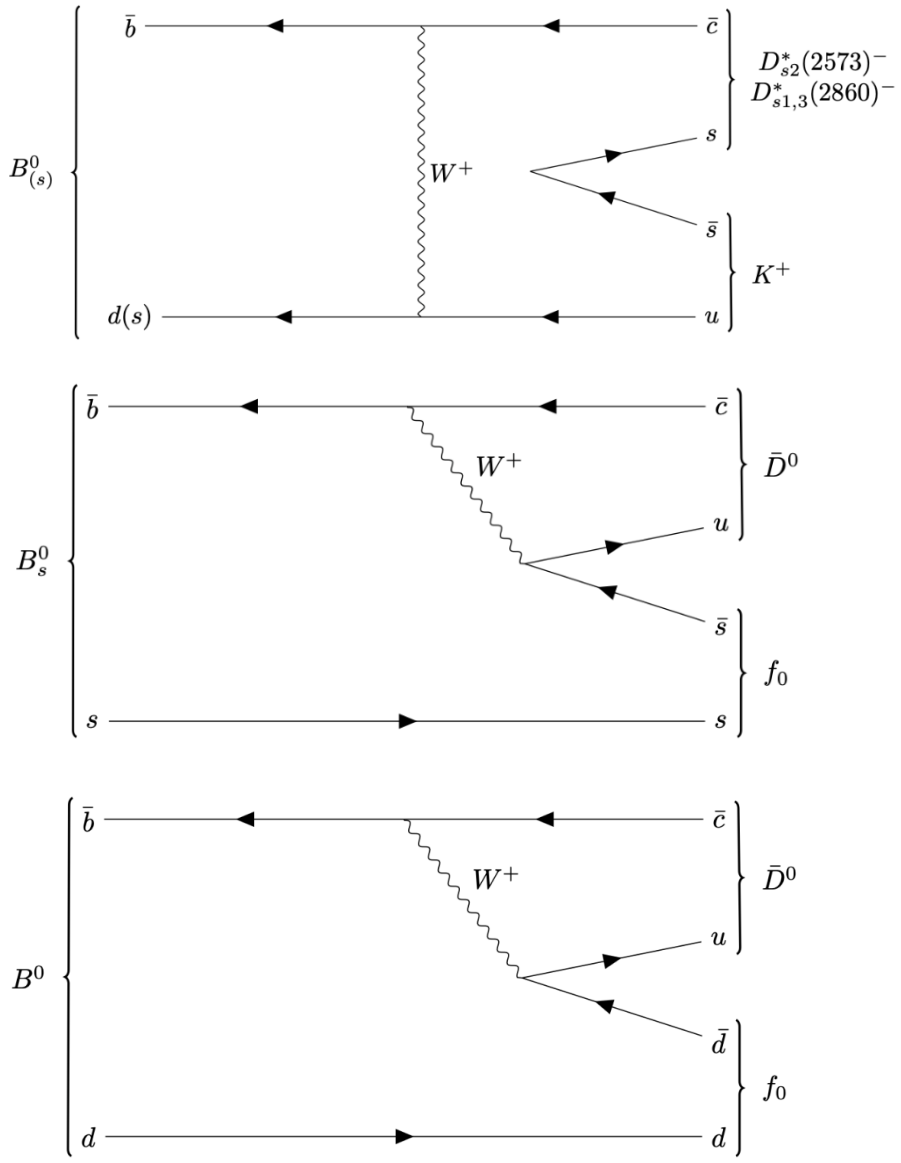


Introduction of $B^0 / B_s^0 \to \bar{D}^0 K^+ K^-$

- Dalitz plot analyses of $B^0 / B_s^0 \to \bar{D}^0 K^+ K^-$ can provide information on hadron spectroscopy
- D_s^* system (Phys. Rev. D 102, 056017 (2020)):
  - The $\bar{D}^0 K$ spectrum in $B^0 / B_s^0 \to \bar{D}^0 K^+ K^-$ probes excited charm-strange mesons, including $D_{s2}^*(2573)^-$, $D_{s1}^*(2760)$ and the 2.86 GeV region, where Dalitz-plot angular information helps separate overlapping spin states and test $2S$–$1D$ mixing scenarios
- $K^+ K^-$ system, scalar mesons, indirectly probe glueball content of the scalar mesons (arXiv:1301.0225):
  - Scalar mesons $f_0(1370), f_0(1500), f_0(1710)$ have potential glueball content:

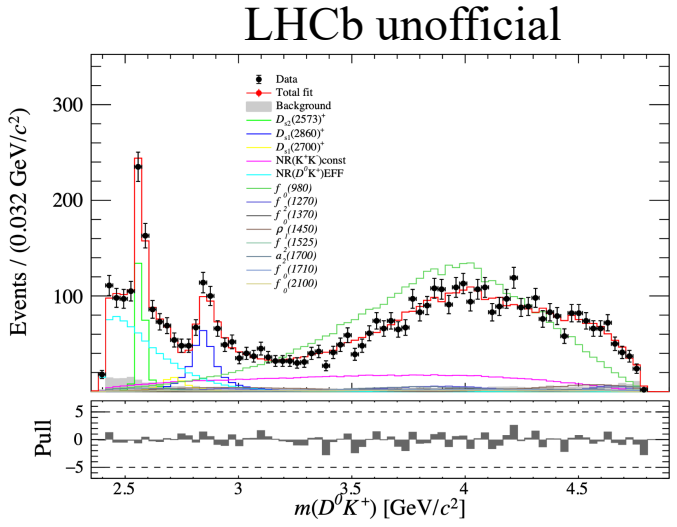
$$|f_0\rangle = \alpha_1 |G\rangle + \alpha_2 |\bar{s}s\rangle + \alpha_3 |\bar{n}n\rangle$$

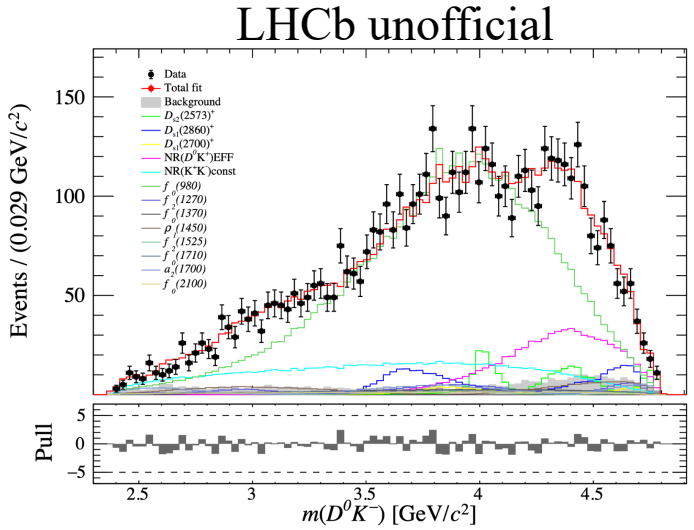
  - $B^0 \to \bar{D}^0 f_0$ and $B_s^0 \to \bar{D}^0 f_0$ can be $\bar{d}d$, $\bar{s}s$ flavor filter respectively
  - B_s^0 and B^0 fit results provide constraints on the scalar-meson composition

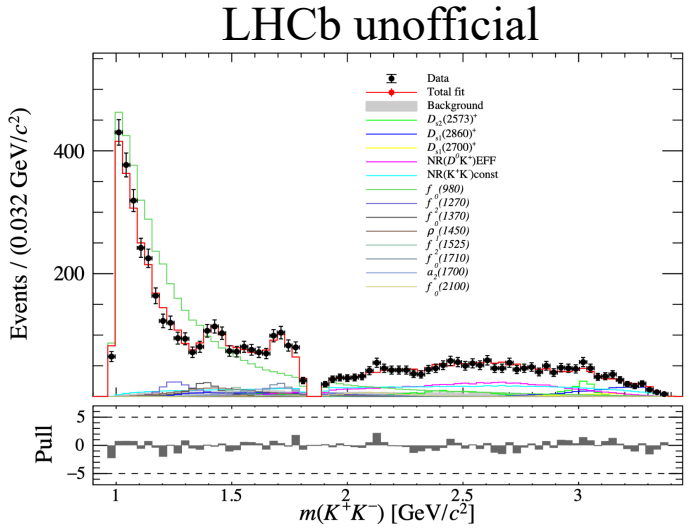


Dalitz plot analyses of $B^0 \to \bar{D}^0 K^+ K^-$ (ongoing)

- Dalitz plot analysis are performed for the $B^0 \to \bar{D}^0 K^+ K^-$ decays
- Baseline fit model is confirmed:
  - In $\bar{D}^0 K^-$ system: $D_{s2}^*(2573)^+, D_{s1}^*(2700)^+, D_{s1}^*(2860)^+, NR(D^0K^+)EFF$: EFF ($e^{-\alpha m^2}$) S-wave NR
  - In K^+K^-system: NR(K^+K^-): uniform S-wave NR,
    $f_0(980)$, $f_2(1270)$, $f_0(1370)$, $\rho(1450)$, $f_2(1525)$, $a_2(1700)$, $f_0(1710)$, $f_0(2100)$
- Fit fractions of all resonances involved in the fit model are measured
- Precise measurements of the masses and widths of $f_0(1370)$ and $D_{s1}^*(2860)^{\pm}$ are obtained
- Status: This analysis under LHCb collaboration review, aim to publish in 2026





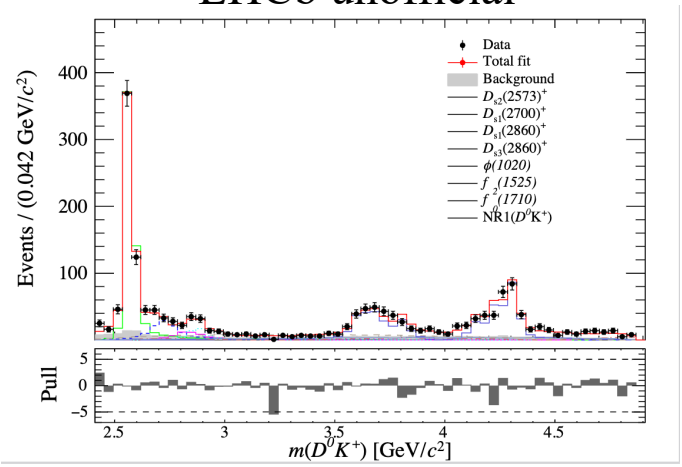


Distribution of data and fit

Dalitz plot analyses of $B_s^0 \to \bar{D}^0 K^+ K^-$ (ongoing)

- Dalitz plot analysis are performed for the $B_s^0 \to \bar{D}^0 K^+ K^-$ decays
- Baseline fit model is confirmed:
  - In $\bar{D}^0 K^-$ system: $D_{s2}^*(2573)^+, D_{s1}^*(2700)^+, D_{s1}^*(2860)^+, D_{s3}^*(2860)^+$, P-wave NR, NR1($D^0 K^+$)
  - In $K^+ K^-$system: NR($K^+ K^-$): $\phi(1020), f_2(1525), f_0(1710)$
- Fit fractions of all resonances involved in the fit model are measured
- Precise measurements of the masses and widths of $D_{s2}^*(2573)^{\pm}$ and $D_{s1}^*(2860)^{\pm}$ are obtained
- Status: This analysis under LHCb collaboration review, aim to publish in 2026

LHCb unofficial



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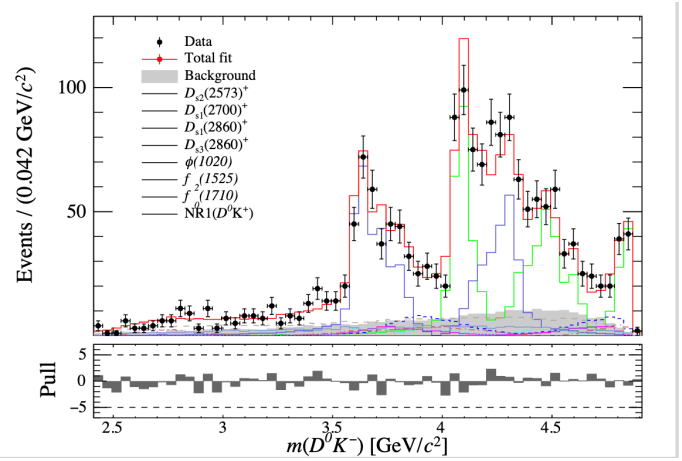

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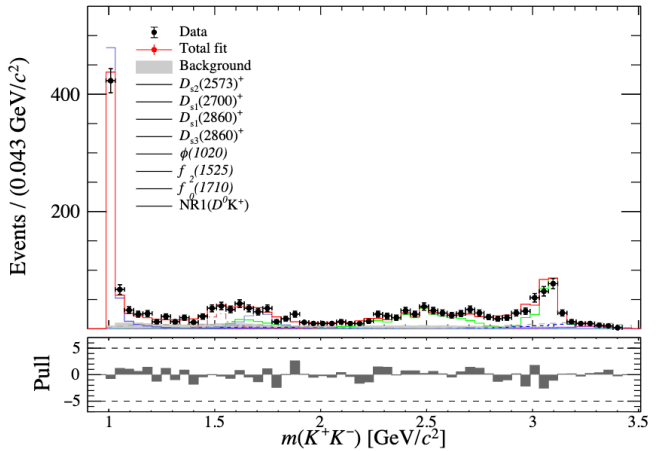
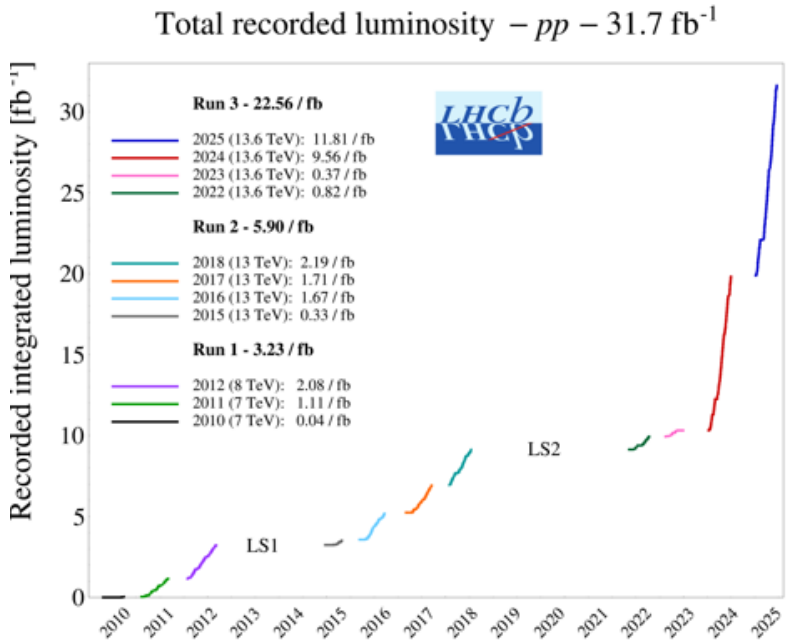


Distribution of data and fit

Prospects with LHCb Run 3 data

- With the increased luminosity and improved trigger performance in LHCb Run 3, larger samples of B_0 / $B_s^0 \to \bar{D}^0 K^+ K^-$, $B_{(s)}^0 \to \bar{D}^0 \phi$ are expected.
- Prospects on LHCb Run 3 data:
  - Time-dependent and flavour-tagged measurement of γ via $B_{(s)}^0 \to \bar{D}^0 \phi$
  - Time-dependent Dalitz plot analysis of $B_s^0 \to D K^+ K^-$
  - Time-dependent measurement of CP observables in $B_s^0 \to D_{s1}(2536)^{\mp} K^{\pm}$ as a potential new B_s^0-based input to γ
  - $B_0 \to \bar{D}^0 \phi$ decay is expected to be observed



Summary

- Three analyses are under LHCb collaboration review, aiming for publication in 2026
  - First measurement of the CKM angle γ in flavor-untagged $B_s^0 \to D^{(*)}\phi$ decays using a time-integrated method
  - Dalitz plot analysis of $B^0 \to \overline{D}^0 K^+ K^-$
  - Dalitz plot analysis of $B_s^0 \to \overline{D}^0 K^+ K^-$
- These studies improve LHCb γ precision and provide information on hadron spectroscopy
- Prospects with LHCb Run 3 data: larger samples will enable new time-dependent γ measurements, rare-decay searches, and more precise amplitude analyses

Thanks!