Measurements of CPV and mixing in $B \to DX$ decays at LHCb

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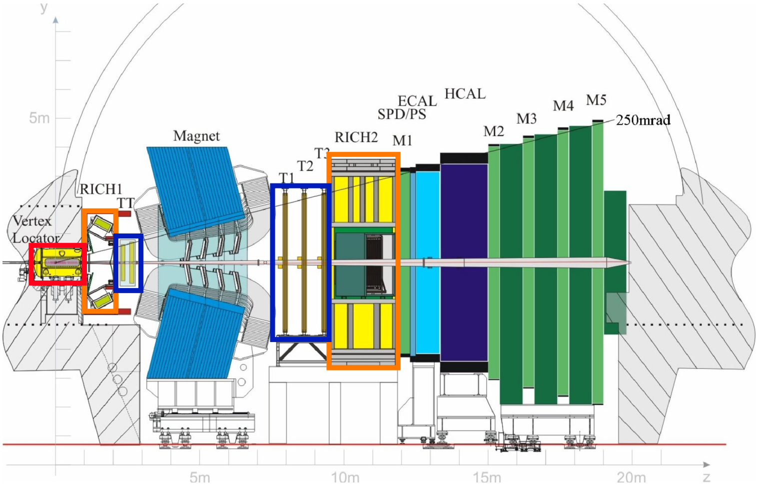
on behalf of the LHCb collaboration

Implications Workshop

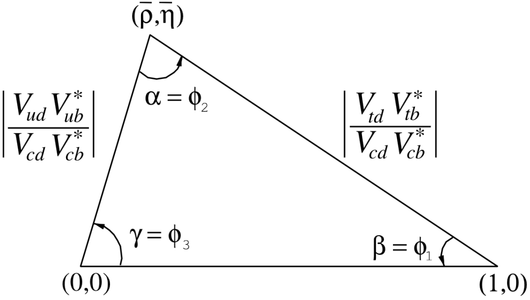
23rd October 2024



$B \to DX$ decays: select signal using displaced B and D vertices and PID

Using VELO, tracking system, and RICH detectors

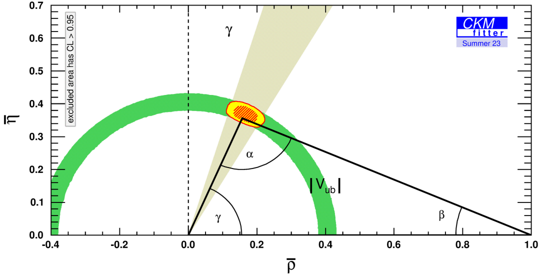
CPV and Mixing



$$\gamma \equiv \arg\left[-\frac{V_{ub}^* V_{ud}}{V_{cb}^* V_{cd}}\right] \qquad \beta \equiv \arg\left[-\frac{V_{cb}^* V_{cd}}{V_{tb}^* V_{td}}\right] \qquad \beta_s \equiv \arg\left[-\frac{V_{ts}^* V_{tb}}{V_{cs}^* V_{cb}}\right]$$

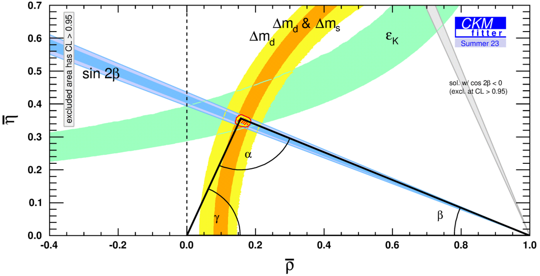
CKM Angle γ

Tree-Level Direct Measurement



$$\gamma = (65.9^{+3.3}_{-3.5})^{\circ}$$

Loop-Level Indirect Measurement



$$\gamma = (65.29^{+0.72}_{-1.86})^{\circ}$$

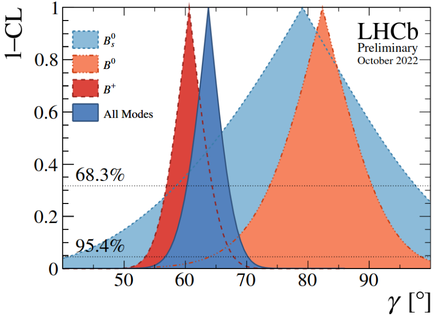
CKMFitter Summer 2023

- γ measurements have negligible theoretical uncertainty[1]

[1] JHEP 2014 (2014)

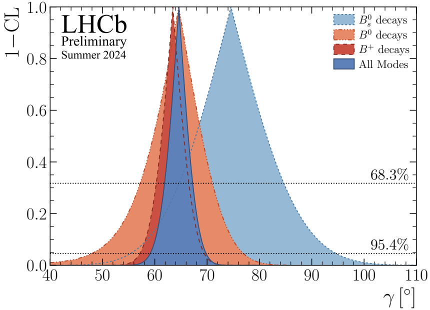
LHCb γ Combination

LHCb-CONF-2022-003



$$\gamma = (63.8^{+3.5}_{-3.7})^\circ$$

LHCb-CONF-2024-004



$$\gamma = (64.6 \pm 2.8)^\circ$$

Very nice result, exceeding Run 1 + 2 target precision of 4°

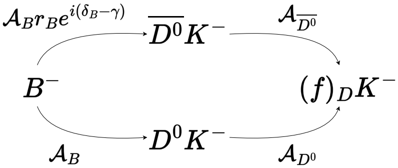
Run 3 + 4 target[2]: 1°

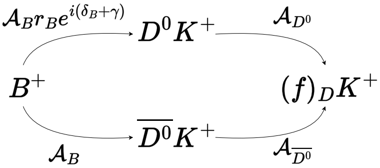
Today will discuss some new results (incl. in latest combination) and how we intend to reach 1° precision

[2] LHCb-PUB-2018-009

Measuring CKM angle γ at LHCb

Interference of $b \to u\bar{c}s$ and $b \to c\bar{u}s$

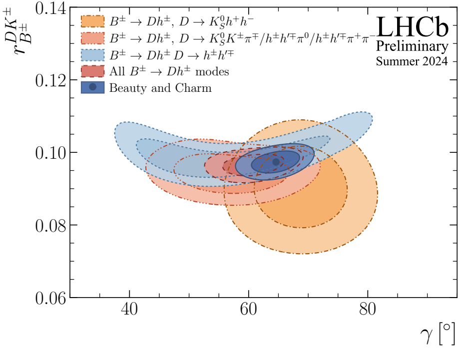




Compare B^+ and B^- yields to measure γ

Measuring CKM angle γ at LHCb

Combining results from different D final states is important for improving sensitivity



LHCb-CONF-2024-004

For the first time, one analysis includes 2-, 3-, and 4-body D decay modes: LHCb-PAPER-2024-023

$B^\pm \to DK^{*\pm}$: LHCb-PAPER-2024-023 (In preparation)

Measurement of γ using $B^\pm \to DK^{*\pm}$ with $K^{*\pm} \to K^0_S\pi^\pm$

Supersedes LHCb measurement using Run 1 and 2015-2016 data, and includes 3-body modes

CP eigenstates/significant CP content

- $D \to K^\pm K^\mp$
- $D \to \pi^\pm\pi^\mp$
- $D \to \pi^\pm\pi^\mp\pi^\pm\pi^\mp$

Suppressed decays

- $D \to \pi^\pm K^\mp$
- $D \to \pi^\pm K^\mp\pi^\pm\pi^\mp$

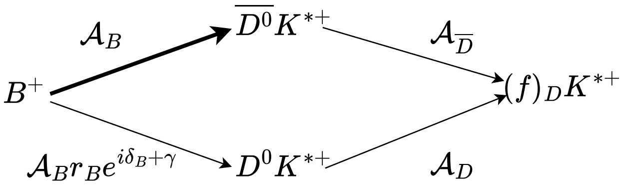
Self-conjugate decays

- $D \to K^0_S\pi^+\pi^-$
- $D \to K^0_S K^+ K^-$

Favoured decays used as control modes

CP eigenstates/significant CP content

- $D \to K^+K^-$, $D \to \pi^+\pi^-$, $D \to \pi^+\pi^-\pi^+\pi^-$
- $\mathcal{A}_D \approx \mathcal{A}_{\overline{D}}$
- Interference and therefore sensitivity to $\gamma \propto r_B$, for $B^\pm \to DK^{*\pm}$: $r_B \approx 0.1$
- External inputs: F_+, CP-even fraction[3] of $D \to \pi^+\pi^-\pi^+\pi^-$

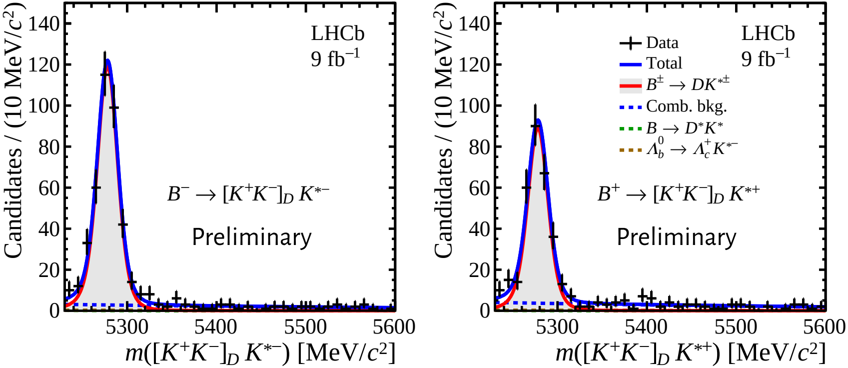


Measure ratios and asymmetries

[3] Phys. Rev. D106 (2022) 092004, Phys. Lett. B747 (2015) 9

Results: $D \to KK$

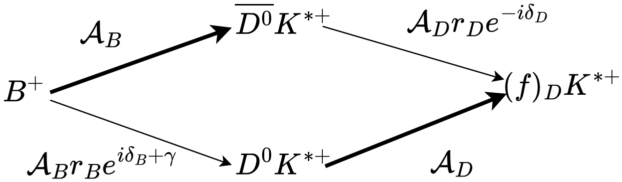
Fitting charge-separated $m(DK^*)$



$$A_{KK} = 0.14 \pm 0.04 \pm 0.001$$

Suppressed decays

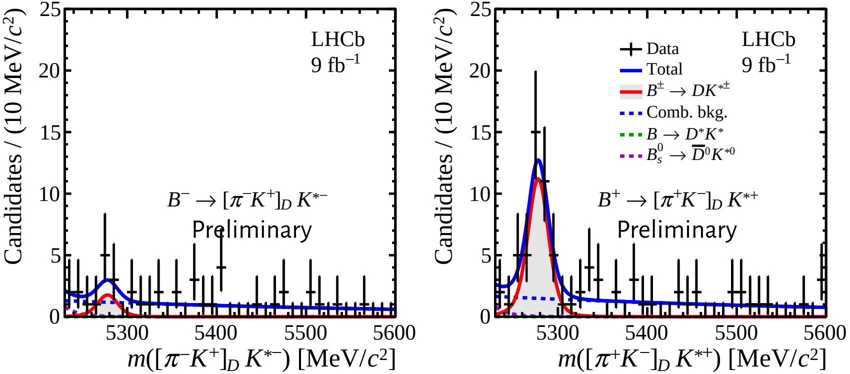
- E.g. $D \to K^-\pi^+$, $D \to \pi^+K^-\pi^+\pi^+$
- $r_{D(B)}$ and $\delta_{D(B)}$ are ratio of $D(B)$ amplitudes and strong phase difference between them
- Maximal interference due to similarly sized amplitudes
- External inputs: $R_{K3\pi}$, coherence factor for $D \to \pi^+K^-\pi^+\pi^+$



Measure ratios and asymmetries

Results: $D \to \pi K$

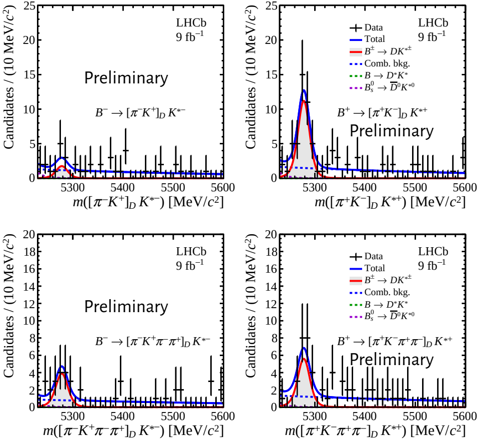
Fitting charge-separated $m(DK^*)$



$$A_{\pi K} = -0.73 \pm 0.16 \pm 0.03$$

Results: $D \to \pi K(\pi\pi)$

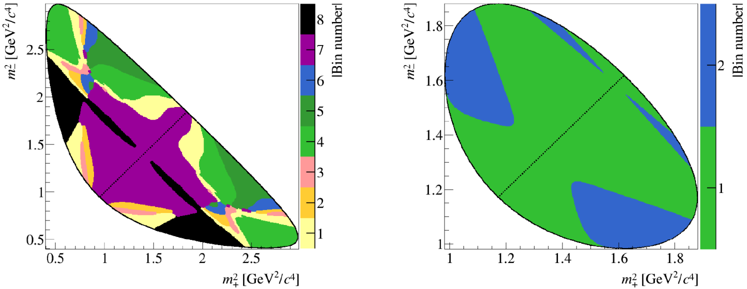
BONUS: First observations of $B^\pm \to DK^{*\pm}$, $D \to \pi^\pm K^\mp(\pi^\pm\pi^\mp)$



With Run 3, potential to include currently unobserved decays $\to$ further improve precision on γ

Self-conjugate Multi-body Decays

- $D \to K_S^0 \pi^+ \pi^-$ and $D \to K_S^0 K^+ K^-$
- r_D and δ_D vary over the D decay phase space $\to$ bin Dalitz plot[4]
- External inputs[5]: c_i and s_i - amplitude-weighted average of $\cos(\delta_D)$ and $\sin(\delta_D)$ over bin i



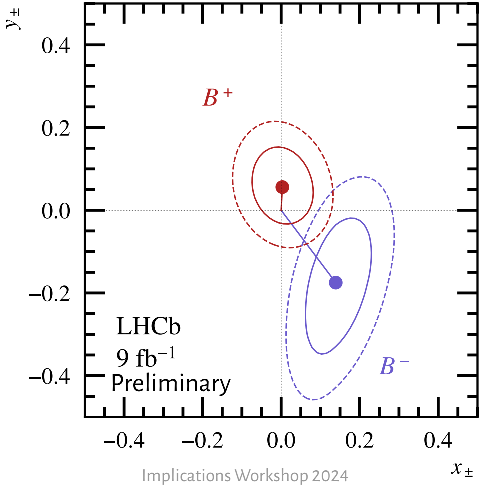
Use binned B^+ and B^- yields to measure cartesian CP observables

[4] Phys. Rev. D82 (2010) 112006

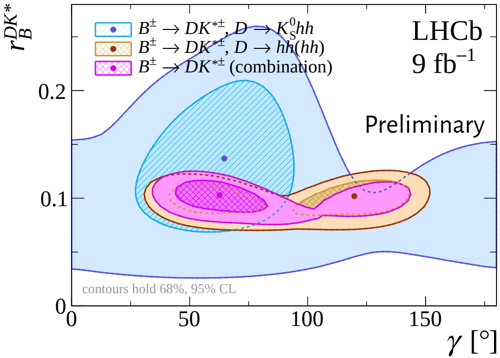
[5] Phys. Rev. D82 (2010), Phys. Rev. D 102 (2020), Phys. Rev. D 101 (2020)

Results: $D \to K_S^0\pi^+\pi^-$ and $D \to K_S^0K^+K^-$

Dalitz-plot binned fits to charge-separated $m(DK^*)$



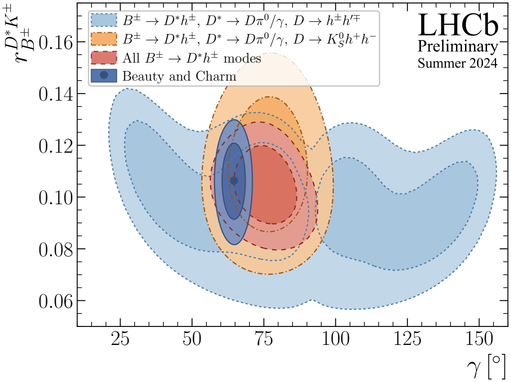
Combined Results



$$\gamma = (63 \pm 13)^\circ$$

- Statistically limited
- $\sigma(\text{syst.})/\sigma(\text{stat.}) \approx 1/3$: systematics would become limiting with Run 3 + 4
- One of the dominant syst. from c_i and s_i in 3-body modes: updates expected from BESIII

$B^{\pm} \to D^{*}h^{\pm}$

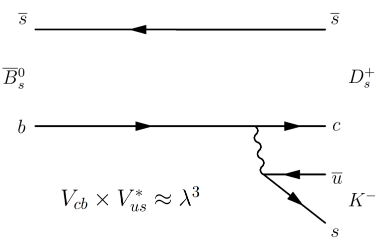


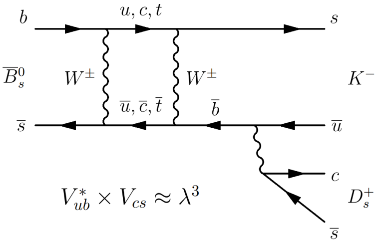
- $B^{\pm} \to D^{*}h^{\pm}$, $D \to hh'$: JHEP 04 (2021) 081
- $B^{\pm} \to D^{*}h^{\pm}$, $D \to K_{S}^{0}hh$ with fully reco. $D^{*} \to D\pi^{0}/\gamma$: JHEP 12 (2023) 013
- $B^{\pm} \to D^{*}h^{\pm}$, $D \to K_{S}^{0}hh$ with part. reco. $D^{*} \to D\pi^{0}/\gamma$: JHEP 12 (2024) 118

$B_s \to D_s^{\mp} K^{\pm}$: LHCb-PAPER-2024-020 (In preparation)

Time-dependent CPV

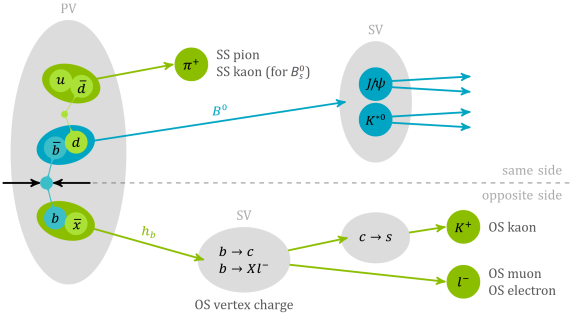
Interference between mixing and decay $\to$ relative phase difference of $\gamma - 2\beta_s$





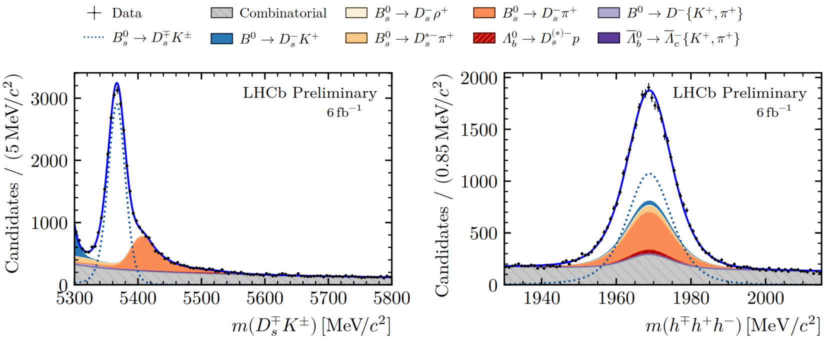
$B_s \to D_s^{\mp} K^{\pm}$: LHCb-PAPER-2024-020 (In preparation)

Flavour-tagging: SS Kaon and OS combination taggers



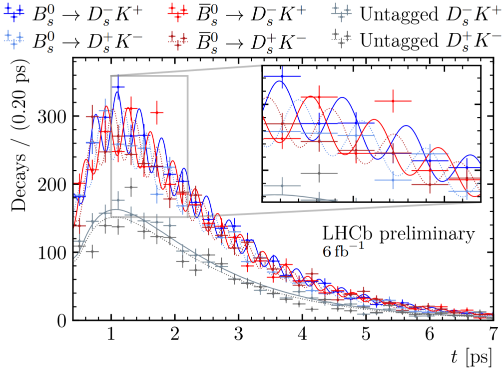
$B_s \to D_s^{\mp} K^{\pm}$: LHCb-PAPER-2024-020

Mass fits to extract $s\,Weights$



Results

Fit to decay time distribution to extract CP observables



$$\gamma = (74 \pm 11)^\circ$$

Improving precision on γ using $B_s \to D_s K$ decays

Particularly important given sensitivity to NP due to mixing and CPV in decay contributions[6]

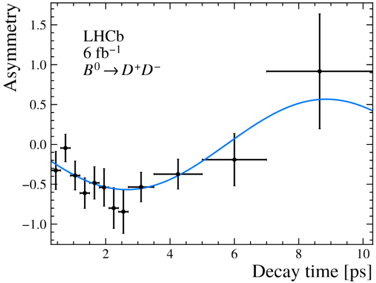
[6] arXiv:2110.04240

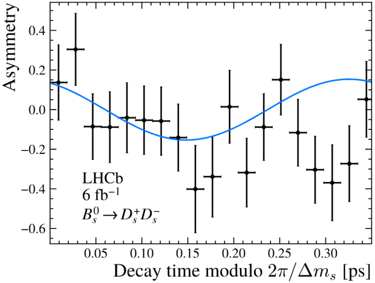
$B^0_{(s)} \to D^+_{(s)} D^-_{(s)}$: LHCb-PAPER-2024-027 (Submitted to JHEP)

arXiv:2409.03009

Measure CPV in mixing using similar method to $B_s \to D_s^{\mp} K^{\pm}$

Non-negligible penguin contributions $\to$ help control theo. uncert.[7] in e.g. β in $B^0 \to J/\psi K^0_S$





$$S_{D^+D^-} = -0.552 \pm 0.100(\text{stat.}) \pm 0.010(\text{syst.})$$
$$C_{D^+D^-} = 0.128 \pm 0.103(\text{stat.}) \pm 0.010(\text{syst.})$$

Rejection of CP symmetry at 6σ

$$\phi_s = -0.086 \pm 0.106(\text{stat.}) \pm 0.028(\text{syst.})$$
$$|\lambda_{D_s^+ D_s^-}| = 1.145 \pm 0.126(\text{stat.}) \pm 0.031(\text{syst.})$$

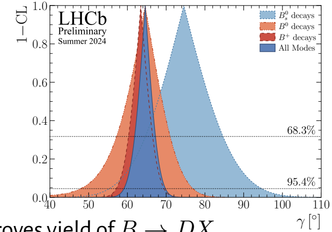
Consistent with CP symmetry

Run 3: promising given high stat. and low syst. uncertainties

[7] arXiv:2311.16952

Conclusion

- Current LHCb precision on γ is $2.8°$, surpassing target of $4°$
- Few remaining Run 1 + 2 analyses in review
- Run 3 analyses have started
  - Upgraded detector $\rightarrow$ improved PID and tracking
  - Upgraded trigger (no hardware trigger) $\rightarrow$ particularly improves yield of $B \rightarrow DX$
- Expecting updates to external inputs (e.g. c_i and s_i by BESIII)
- In good stead to reach Run 3 + 4 target precision on γ of $1°$



Thank You!