Measurement of the CKM angle γ in $B^{\pm} \to DK^{*\pm}$ decays

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Motivation

- Cabibbo-Kobayashi-Maskawa (CKM) matrix describes the quark mixing

$$\begin{pmatrix} d' \\ s' \\ b' \end{pmatrix} = \underbrace{\begin{pmatrix} V_{ud} & V_{us} & V_{ub} \\ V_{cd} & V_{cs} & V_{cb} \\ V_{td} & V_{ts} & V_{tb} \end{pmatrix}}_{V_{CKM}} \begin{pmatrix} d \\ s \\ b \end{pmatrix}$$

- Unitarity of V_{CKM} represented by a **triangle in the complex plane**

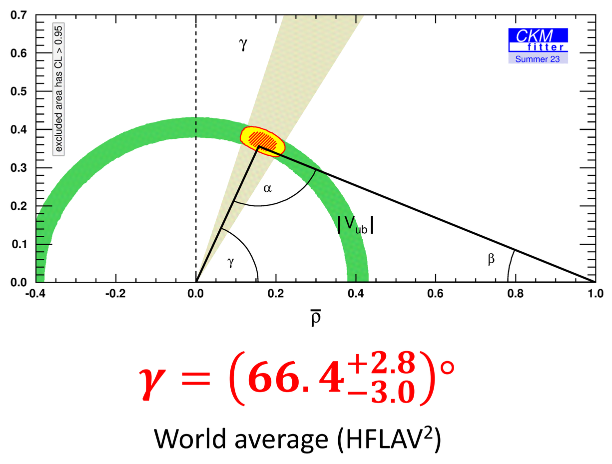
$$V_{ud}\,V_{ub}^* + V_{cd}\,V_{cb}^* + V_{td}\,V_{tb}^* = 0$$

- Weak phase $\boldsymbol{\gamma}$ is the only angle **easily accessible at tree level**

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

- Hadronic parameters can be determined from data => **theoretical uncertainty** on γ is **negligible**

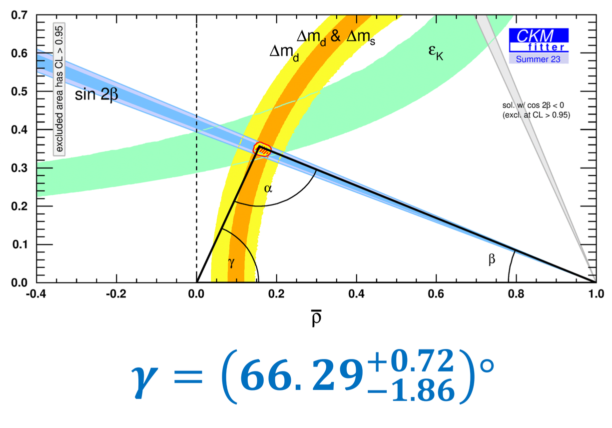
Tree-level (direct measurement)[1]



$\gamma = (66.4^{+2.8}_{-3.0})^{\circ}$

World average (HFLAV[2])

Loop-level (indirect measurement)[1]

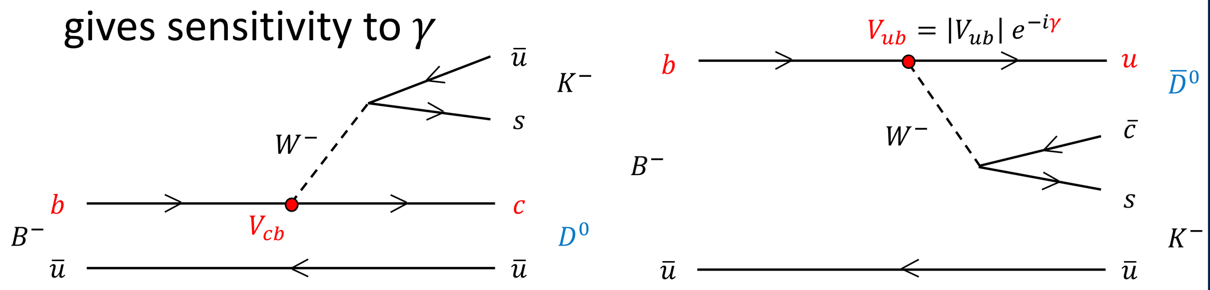


$\gamma = (66.29^{+0.72}_{-1.86})^{\circ}$

- Direct measurements of γ at tree level are expected to be benchmarks of the Standard Model
- Indirect measurements: global fits to the unitary triangle. Inputs include loop processes, where New Physics effects are expected to contribute

A discrepancy between direct and indirect measurements would be a clear sign of New Physics

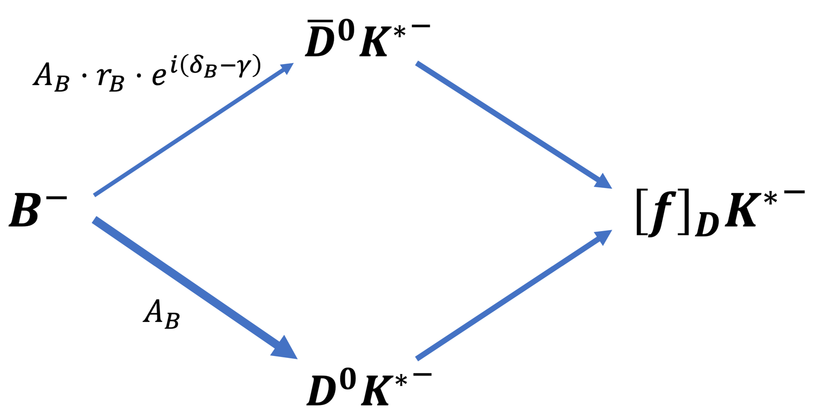
- **Direct measurements of γ** in $B \to DK$ like decays. The D meson is a superposition of D^0 and $\bar{D}^0$ states, which are reconstructed in **common final states**. Both D^0 and $\bar{D}^0$ need to be able to decay to the same final state
- **Interference** between $b \to cW$ and $b \to uW$ transitions gives sensitivity to γ



- Strategy to cover all **B and D decay combinations** to improve overall sensitivity to γ
- Measurement of γ in $B^{\pm} \to DK^*(892)^{\pm}$ decays. **Comprehensive study** of a range of **D decay modes** profiting from information between the different modes

GLW modes[3,4]: (quasi-)CP eigenstates

$$D \to K^+K^-,\ D \to \pi^+\pi^-(\pi^+\pi^-)$$



- Measure **rate ratios** to the favoured mode
- Measure **rate asymmetries** between B^- and B^+
- Relatively smaller observable CP violation due to amplitudes of different sizes

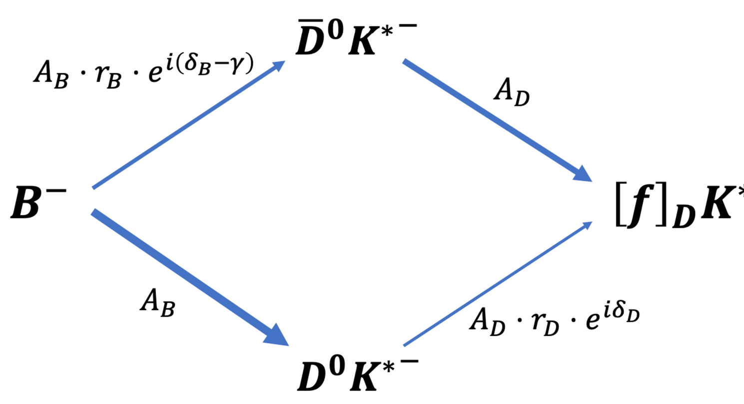
$$R_{CP} = \frac{\Gamma(B^- \to [h^+h^-]_D K^{*-}) + \Gamma(B^+ \to [h^+h^-]_D K^{*+})}{\Gamma(B^- \to [K^-\pi^+]_D K^{*-}) + \Gamma(B^+ \to [K^+\pi^-]_D K^{*+})} \frac{\mathcal{B}(D^0 \to K^-\pi^+)}{\mathcal{B}(D^0 \to h^+h^-)}$$
$$= 1 + r_B^2 + 2\,\kappa\, r_B \cos(\delta_B)\cos(\gamma)$$

$$A_{CP} = \frac{\Gamma(B^- \to [h^+h^-]_D K^{*-}) - \Gamma(B^+ \to [h^+h^-]_D K^{*+})}{\Gamma(B^- \to [h^+h^-]_D K^{*-}) + \Gamma(B^+ \to [h^+h^-]_D K^{*+})} = \frac{2\,\kappa\, r_B \sin(\delta_B)\sin(\gamma)}{R_{CP}}$$

ADS modes[5]: non-CP eigenstates

Cabibbo-favoured (CF) $D \to K^-\pi^+(\pi^-\pi^+)$

Doubly Cabibbo-suppressed (DCS) $D \to \pi^-K^+(\pi^-\pi^+)$



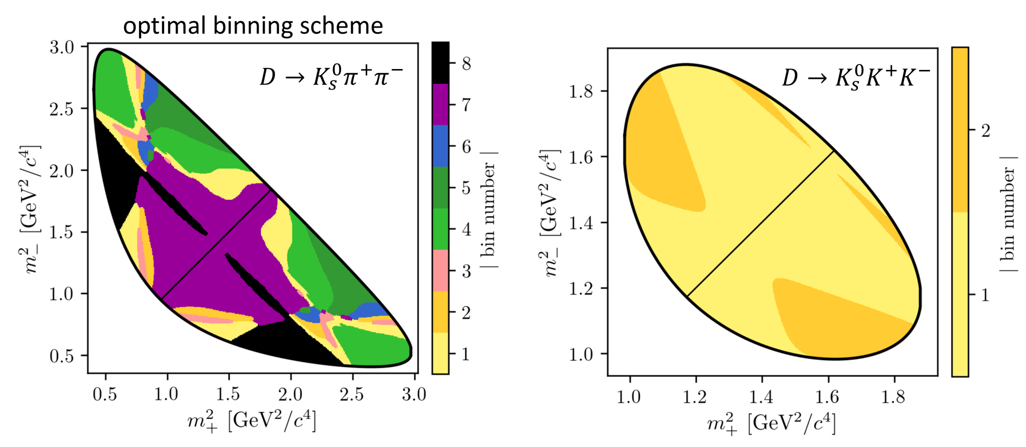
- External inputs: **D decay parameters** r_D, δ_D
- **Maximal interference** due to similar sized amplitudes

$$R_{ADS} = \frac{\Gamma(B^- \to [\pi^-K^+]_D K^{*-}) + \Gamma(B^+ \to [\pi^+K^-]_D K^{*+})}{\Gamma(B^- \to [K^-\pi^+]_D K^{*-}) + \Gamma(B^+ \to [K^+\pi^-]_D K^{*+})}$$
$$= r_B^2 + r_D^2 + 2\,\kappa\, r_B\, r_D \cos(\delta_B + \delta_D)\cos(\gamma)$$

$$A_{ADS} = \frac{\Gamma(B^- \to [\pi^-K^+]_D K^{*-}) - \Gamma(B^+ \to [\pi^+K^-]_D K^{*+})}{\Gamma(B^- \to [\pi^-K^+]_D K^{*-}) + \Gamma(B^+ \to [\pi^+K^-]_D K^{*+})} = \frac{2\,\kappa\, r_B\, r_D \sin(\delta_B + \delta_D)\sin(\gamma)}{R_{ADS}}$$

BPGGSZ modes[6,7]: three-body self-conjugate states

$$D \to K_S^0\pi^+\pi^-,\ D \to K_S^0K^+K^-$$



- Complex system of resonances
- Interference appears as different distributions of the **D meson Dalitz plot** for B^- and B^+
- First measurement at LHCb in this channel

$$x_{\pm} = r_B \cdot \cos(\delta_B \pm \gamma)$$
$$y_{\pm} = r_B \cdot \sin(\delta_B \pm \gamma)$$

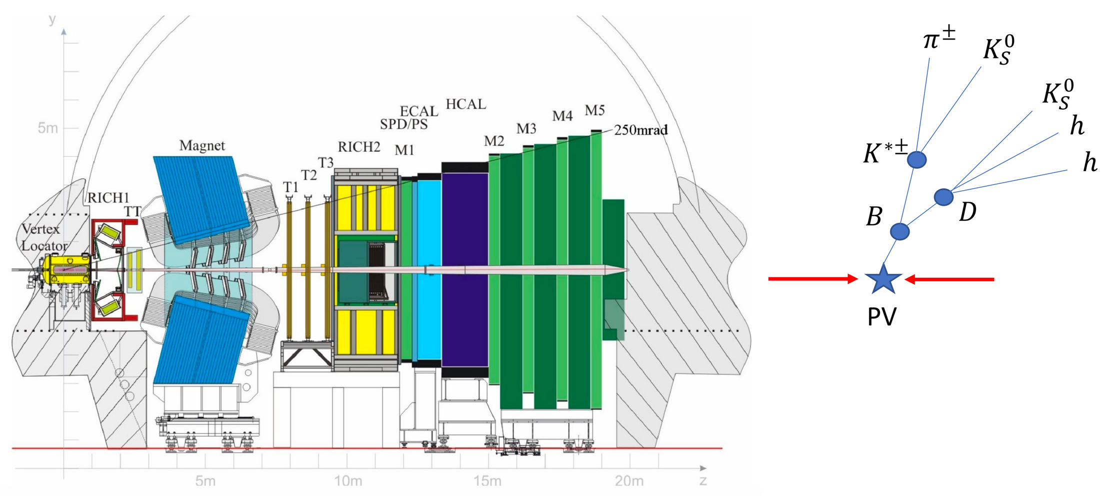
Yields in each Dalitz bin

$$N_{\pm i}^- \propto F_{\pm i} + (x_-^2 + y_-^2)F_{\mp i} + 2\kappa\sqrt{F_i F_{-i}}\,(x_-\, c_{\pm i} + y_-\, s_{\pm i})$$

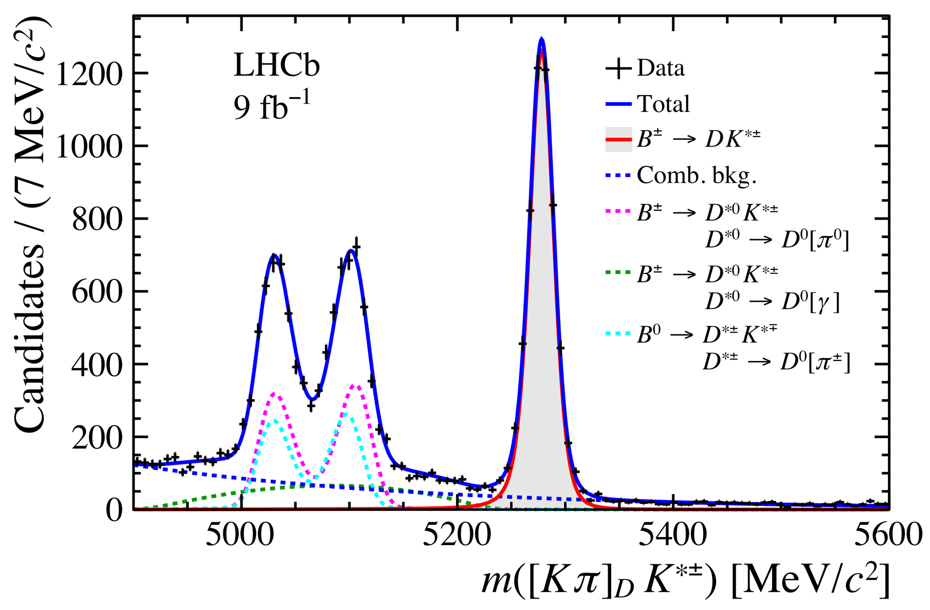
Fractional yield of flavour-tagged D^0 — Coherence factor (for non-resonant contribution) — Strong-phase differences (input from CLEO[8]+BESIII[9,10,11])

Candidate selection and background determination

- LHCb detector[12]:
  - **Vertex Locator** (VELO): secondary vertices measured with good resolution
  - **Tracking system**: good momentum resolution
  - **Particle Identification** (PID): distinguish pions from kaons



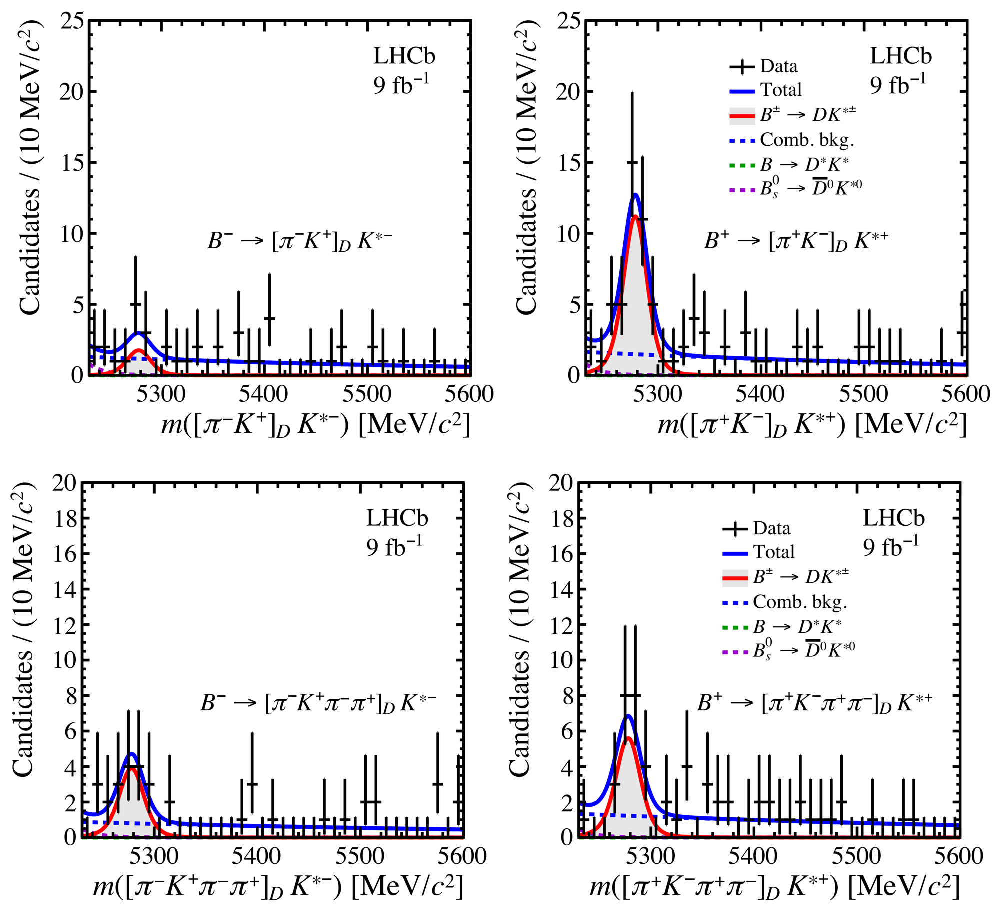
- Boosted Decision Tree (BDT) efficiently reduces combinatorial background
- Peaking backgrounds removed by flight distance cuts



- Mass parametrisation benefits from the high statistics favoured mode
- **Advantages** of this channel:
  - **Clean signal peak**, well separated from partially reconstructed backgrounds
  - Large **purity**
  - No counterpart of misidentified background from $B^{\pm} \to D\pi^{\pm}$ in $B^{\pm} \to DK^{\pm}$

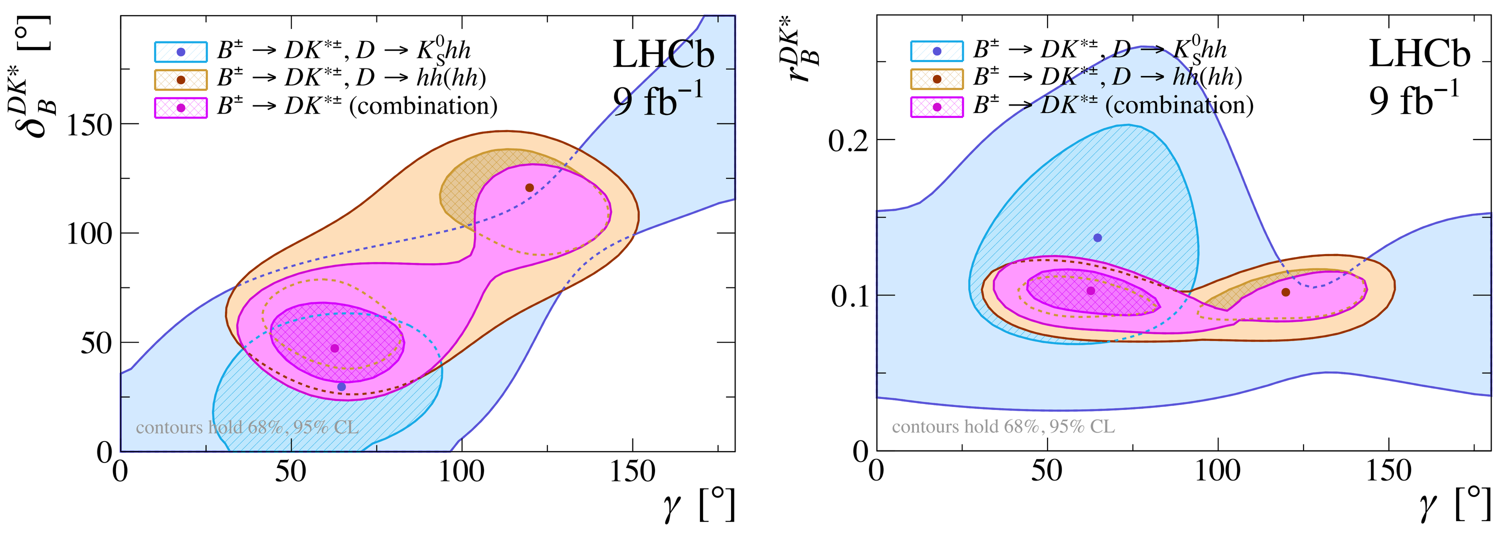
Determination of CP-violating observables

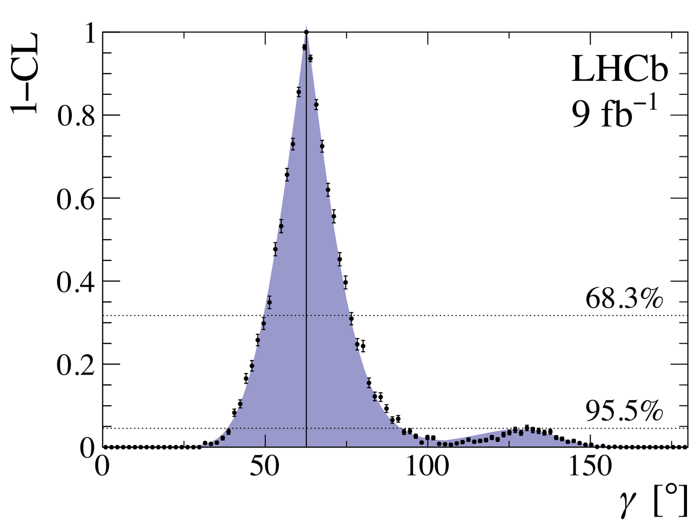
- **Simultaneous fit** for the different categories defined by B charge and D decay mode to measure the CP observables
- Small asymmetries within the favoured modes
- Larger **asymmetries** observed for the suppressed modes and CP-eigenstates modes
- CP observables measured **for all three types of D decay modes** considered in this analysis
- **First observation** of the suppressed $B^{\pm} \to [\pi^{\pm}K^{\mp}]_D K^{*\pm}$ and $B^{\pm} \to [\pi^{\pm}K^{\mp}\pi^{\pm}\pi^{\mp}]_D K^{*\pm}$ decays



Results and interpretation

- Determination of the physics parameters of interest from the measured CP observables
- **Multiple solutions** obtained from **two- and four-body** decay modes, due to trigonometric equations relating CP observables to physics parameters
- **Three-body** decay modes lead to a **single solution**





- Combination yields $\gamma = (63 \pm 13)^{\circ}$
- Result for γ consistent with world average. Model-independent results, using external strong-phase inputs
- Valuable addition to γ measurements, included in the latest LHCb combination[13]

References

[1] Phys. Rev. **D91** (2015) 073007, http://ckmfitter.in2p3.fr/
[2] Phys. Rev. **D107** (2023) 052008 (arXiv:2206.07501)
[3] Phys. Lett. B **253** (1991) 483
[4] Phys. Lett. B **265** (1991) 172
[5] Phys. Rev. Lett. **78** (1997) 3257
[6] Phys. Rev. D **68** (2003) 054018
[7] Phys. Rev. D **70** (2004) 072003
[8] Phys. Rev. D **82** (2010) 112006
[9] Phys. Rev. D **101** (2020) 112002
[10] Phys. Rev. D **102** (2020) 052008
[11] Phys. Rev. Lett. **124** (2020) 241802
[12] Int. J. Mod. Phys. **A30** (2015) 1530022
[13] LHCb-CONF-2024-004

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