Search for b-hadron decays with CP asymmetry and its measurement at the LHCb detector

Kerim Guseynov

Based on analyses by the LHCb Collaboration:
Observation of the suppressed $\Lambda_b^0 \to DpK^-$ decay with $D \to K^+\pi^-$ and measurement of its CP asymmetry,
Phys.Rev. D104 (2021) 112008
Model-independent measurement of the CKM angle γ using $B^0 \to DK^{*0}$ decays with $D \to K_S^0\pi^+\pi^-$ and $K_S^0K^+K^-$,
JHEP 06 (2016) 131
Updated search for B_c decays to two charm mesons, JHEP 12 (2021) 117

Faculty of Physics
Moscow State University

April 19, 2023

Introduction

- The CP asymmetry is responsible for the matter/antimatter imbalance in the Universe.
- While the Standard Model has sources of CP violation, they are not large enough to account for the observed matter dominance.
  Nonetheless, their measurement is still important.
- The main source is the CKM quark mixing matrix.
  Its least precise measurement is the γ angle.
- $B^- \to DK^-$ and some others are thoroughly investigated, but there are decays with better interfering amplitudes.
- Measurements of CP violation in specific decays also test theoretical calculation.
- Search for new complex decays with interference may reveal new physics.

Cabibbo Kobayashi Maskawa matrix. Quark mixing. Meson mixing

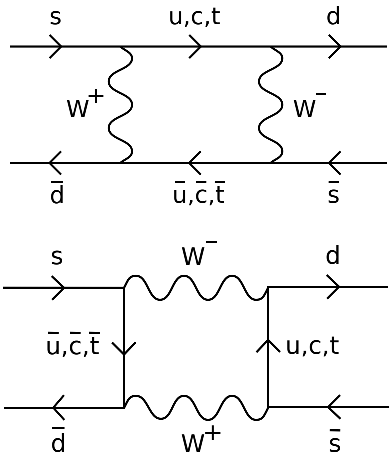
$$\begin{bmatrix} d' \\ s' \\ b' \end{bmatrix} = \begin{bmatrix} V_{\mathrm{ud}} & V_{\mathrm{us}} & V_{\mathrm{ub}} \\ V_{\mathrm{cd}} & V_{\mathrm{cs}} & V_{\mathrm{cb}} \\ V_{\mathrm{td}} & V_{\mathrm{ts}} & V_{\mathrm{tb}} \end{bmatrix} \begin{bmatrix} d \\ s \\ b \end{bmatrix}$$

Quarks are not the same for the strong and weak interactions

Unnoticed in normal decays like $n \to pe^- \bar{\nu}_e$

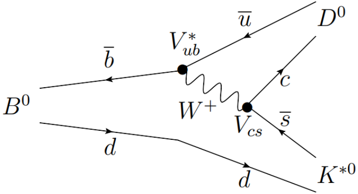
Kaon mixing: K^0, $\bar{K}^0$, $\to K^0_S$, K^0_L

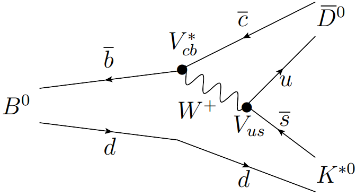
Same for other neutral mesons: D^0, B^0, B^0_s

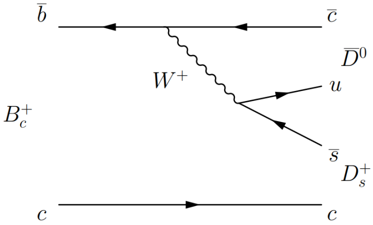


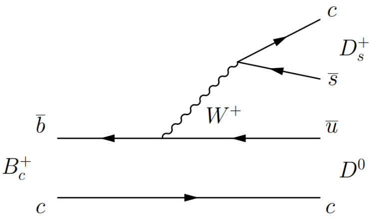
Neutral kaon mixing

Decays with possible CP asymmetry. Interference

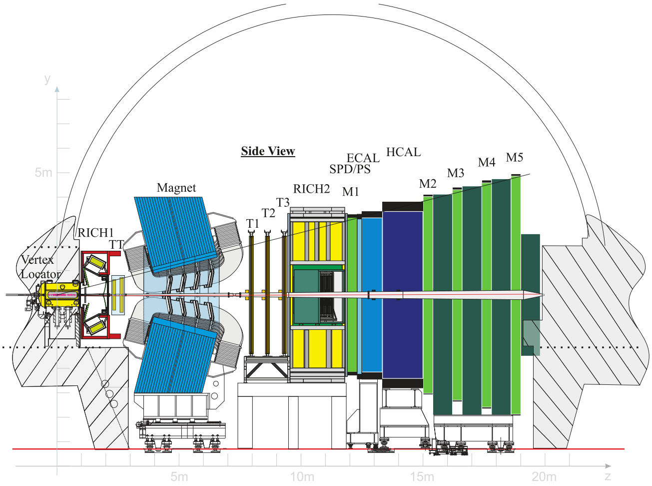


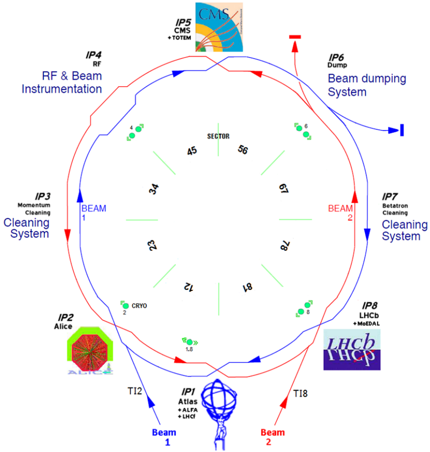






The LHCb detector at the LHC





Measurements

- Ratio of decays and the asym. of the less probable one: $\Lambda_b^0 \to D(\to K^\mp\pi^\pm)pK^-$

$$R = \frac{\mathcal{B}(\Lambda_b^0 \to [K^-\pi^+]_D pK^-)}{\mathcal{B}(\Lambda_b^0 \to [K^+\pi^-]_D pK^-)},$$

$$A = \frac{\mathcal{B}(\Lambda_b^0 \to [K^+\pi^-]_D pK^-) - \mathcal{B}(\overline{\Lambda}_b^0 \to [K^-\pi^+]_D \overline{p}K^+)}{\mathcal{B}(\Lambda_b^0 \to [K^+\pi^-]_D pK^-) + \mathcal{B}(\overline{\Lambda}_b^0 \to [K^-\pi^+]_D \overline{p}K^+)}.$$

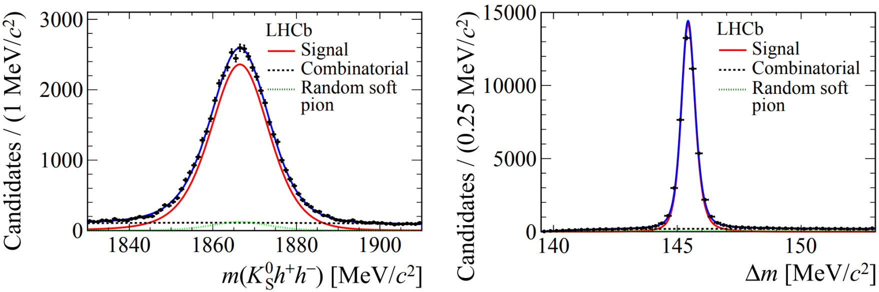
- Event distribution by momenta and measurements of interference parameters:

$$B^0 \to DK^{*0}, \qquad D \to K_S^0\pi^+\pi^- \text{ or } K_S^0K^+K^-$$

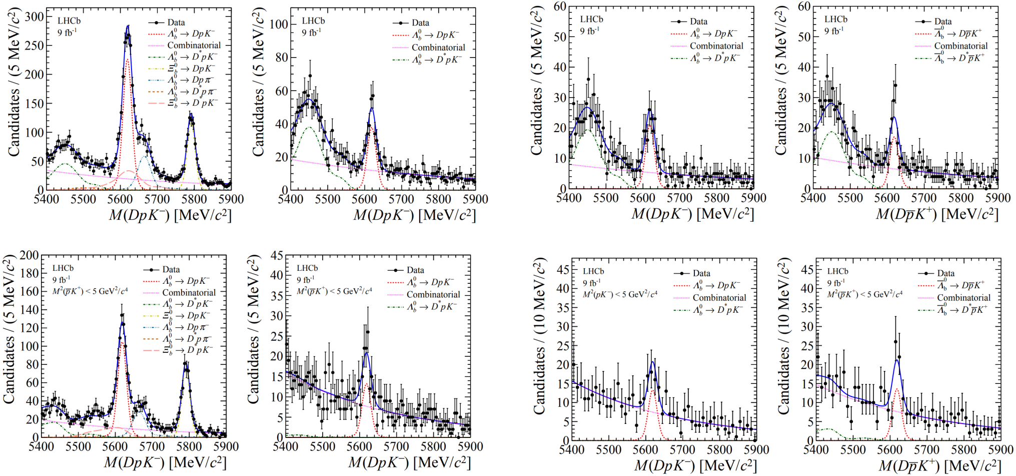
- Search for decays of B_c^+ into $D_s^+\bar{D}^0$, $D_s^+D^0$, $D^+\bar{D}^0$, D^+D^0, $D_s^{*+}D^0$, $D_s^+D^{*0}$, etc.

Event selection

- Cuts on kinematic variables: p_T, η, distance from the pp interaction, . . . ,
- Cuts on particle identification parameters and event reconstruction variables,
- Exclusion of specific troublesome cases by cutting out kinematic regions,
- Usage of neural networks for further improvement of signal purity and quality.

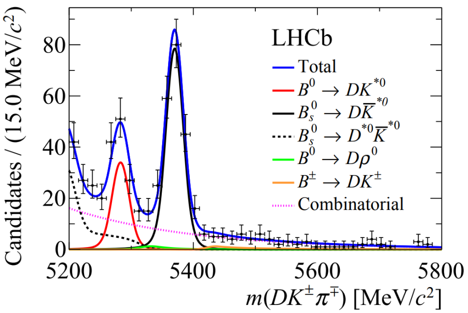


Invariant mass spectrum model and fit: $\Lambda_b^0 \to DpK^-$

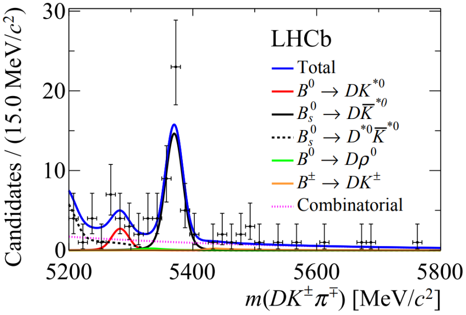


$D \to K^-\pi^+$ $\quad$ $D \to K^+\pi^-$ $\quad$ Λ_b^0 $\quad$ $\overline{\Lambda}_b^0$

Invariant mass spectrum model and fit: $B^0 \to DK^{*0}$

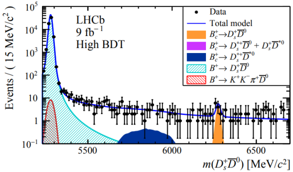


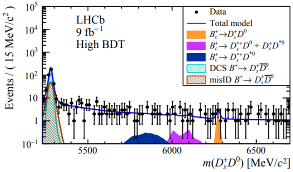
$D \to K_S^0\pi^+\pi^-$

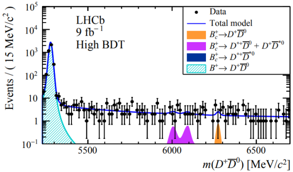


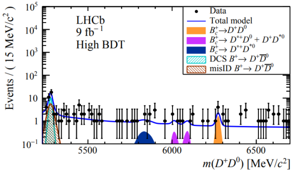
$D \to K_S^0K^+K^-$

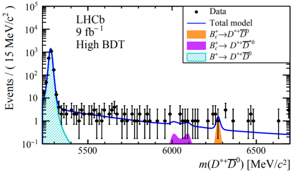
Invariant mass spectrum model and fit: $B_c^+ \to DD$

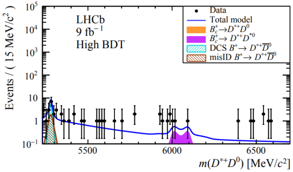


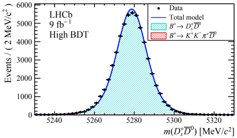


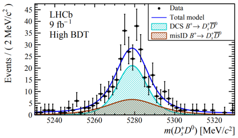






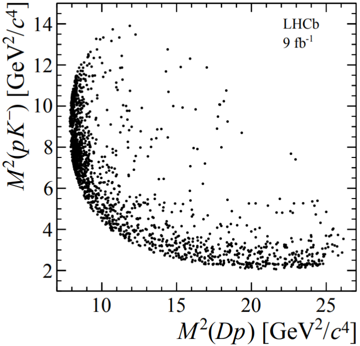


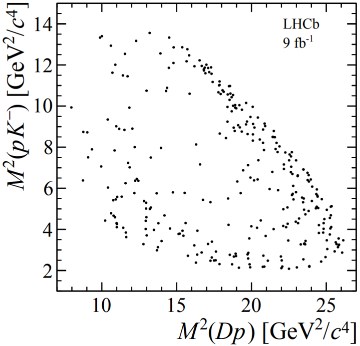


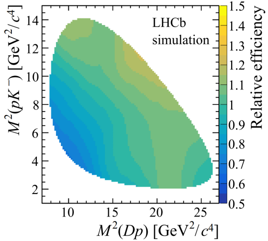


$$
\begin{aligned}
\mathcal{B}(B_c^+ \to D_s^+ \overline{D}^0) &< 7.2\,(8.4) \times 10^{-4};\\
\mathcal{B}(B_c^+ \to D_s^+ D^0) &< 3.0\,(3.7) \times 10^{-4};\\
\mathcal{B}(B_c^+ \to D^+ \overline{D}^0) &< 1.9\,(2.5) \times 10^{-4};\\
\mathcal{B}(B_c^+ \to D^+ D^0) &< 1.4\,(1.8) \times 10^{-4};\\
\mathcal{B}(B_c^+ \to D_s^{*+} \overline{D}^0) &< 5.3\,(5.7) \times 10^{-4};\\
\mathcal{B}(B_c^+ \to D_s^+ \overline{D}^{*0}) &< 4.6\,(5.6) \times 10^{-4};\\
\mathcal{B}(B_c^+ \to D_s^{*+} D^0) &< 0.9\,(1.0) \times 10^{-3};\\
\mathcal{B}(B_c^+ \to D_s^+ D^{*0}) &< 6.6\,(8.4) \times 10^{-4};\\
\mathcal{B}(B_c^+ \to D^{*+} \overline{D}^0) &< 3.8\,(4.8) \times 10^{-4};\\
\mathcal{B}(B_c^+ \to D^{*+} D^0) &< 2.0\,(2.4) \times 10^{-4};\\
\mathcal{B}(B_c^+ \to D^+ \overline{D}^{*0}) &< 6.5\,(8.2) \times 10^{-4};\\
\mathcal{B}(B_c^+ \to D^+ D^{*0}) &< 3.7\,(4.6) \times 10^{-4};\\
\mathcal{B}(B_c^+ \to D_s^{*+} \overline{D}^{*0}) &< 1.3\,(1.5) \times 10^{-3};\\
\mathcal{B}(B_c^+ \to D_s^{*+} D^{*0}) &< 1.3\,(1.6) \times 10^{-3};\\
\mathcal{B}(B_c^+ \to D^{*+} \overline{D}^{*0}) &< 1.0\,(1.3) \times 10^{-3};\\
\mathcal{B}(B_c^+ \to D^{*+} D^{*0}) &< 7.7\,(8.9) \times 10^{-4}.
\end{aligned}
$$

Dalitz plot for $\Lambda_b^0 \to DpK^-$: resonances, efficiency, measurements







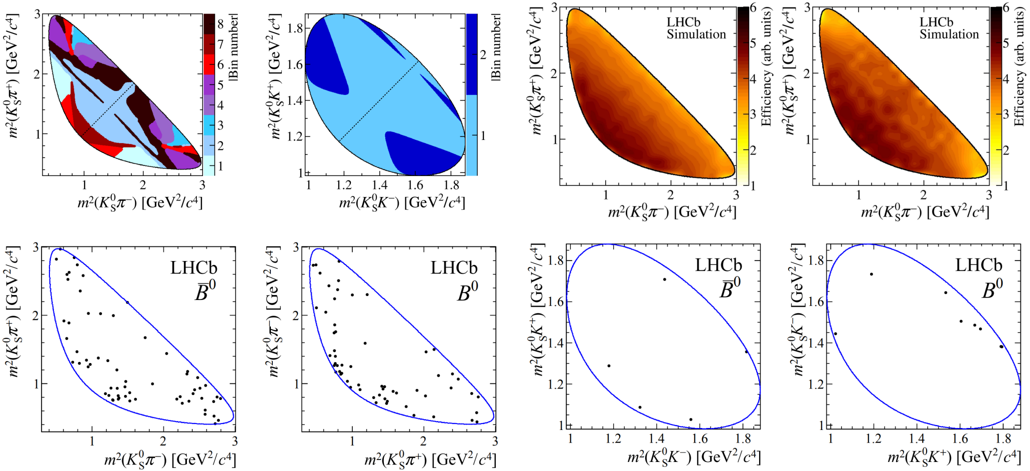
$D \to K^-\pi^+$

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

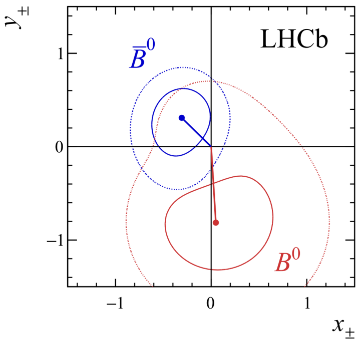
Full:
$$R = 7.1 \pm 0.8\,(\text{stat.})^{+0.4}_{-0.3}\,(\text{syst.}),$$
$$A = 0.12 \pm 0.09\,(\text{stat.})^{+0.02}_{-0.03}\,(\text{syst.}),$$

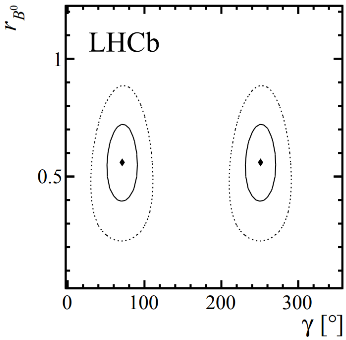
Restricted:
$$R = 8.6 \pm 1.5\,(\text{stat.})^{+0.4}_{-0.3}\,(\text{syst.}),$$
$$A = 0.01 \pm 0.16\,(\text{stat.})^{+0.03}_{-0.02}\,(\text{syst.}).$$

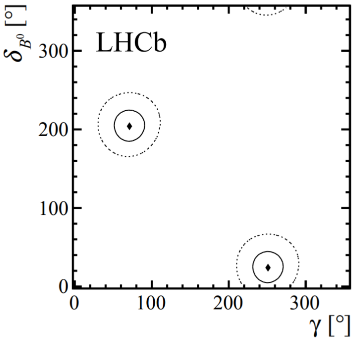
Dalitz plot for $B^0 \to DK^{*0}$: binning, points, efficiency



$B^0 \to DK^{*0}$ amplitude interference parameters







$$
\begin{aligned}
x_+ &= 0.05 \pm 0.35 \pm 0.02,\\
x_- &= -0.31 \pm 0.20 \pm 0.04,\\
y_+ &= -0.81 \pm 0.28 \pm 0.06,\\
y_- &= 0.31 \pm 0.21 \pm 0.05,
\end{aligned}
$$

$$
\begin{aligned}
r_{B^0} &= 0.56 \pm 0.17,\\
\delta_{B^0} &= (204\,^{+21}_{-20})^\circ,\\
\gamma &= (71 \pm 20)^\circ.
\end{aligned}
$$

$$\gamma = (65.9 \pm 3.4)^\circ$$

World average

Conclusion

- First observation of $\Lambda_b^0 \to D\,(\to K^+\pi^-)\,pK^-$;
  measurement of its probability relative to $\Lambda_b^0 \to D\,(\to K^-\pi^+)\,pK^-$ (same as expected);
  measurement of its CP asymmetry (consistent with zero).
- $B^0 \to DK^{*0}$ with $D \to K_S^0\pi^+\pi^-$, $K_S^0K^+K^-$ amplitude interference is measured using a purely data-driven approach.
  The results are independent of other ones and will still contribute to the γ measurements despite the worse accuracy.
- Upper limit on the probabilities of 16 $B_c^+ \to DD$ are improved.
  Evidence of a single one, $B_c^+ \to D_s^+\bar{D}^0$, is reported.
- Larger data samples are already on the way.

Conclusion

- First observation of $\Lambda_b^0 \to D\,(\to K^+\pi^-)\,pK^-$;
  measurement of its probability relative to $\Lambda_b^0 \to D\,(\to K^-\pi^+)\,pK^-$ (same as expected);
  measurement of its CP asymmetry (consistent with zero).
- $B^0 \to DK^{*0}$ with $D \to K_S^0\pi^+\pi^-$, $K_S^0K^+K^-$ amplitude interference is measured using a purely data-driven approach.
  The results are independent of other ones and will still contribute to the γ measurements despite the worse accuracy.
- Upper limit on the probabilities of 16 $B_c^+ \to DD$ are improved.
  Evidence of a single one, $B_c^+ \to D_s^+\bar{D}^0$, is reported.
- Larger data samples are already on the way.

Thank you!