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Measurements of $B \to DK$ decays to constrain the CKM unitarity triangle angle γ at LHCb

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The angle γ of the CKM unitarity triangle remains the least precisely measured parameter of the CKM mixing matrix. The precision measurement of this parameter is one of the main goals of the LHCb experiment. We present a wide range of measurements of CP violation and partial rates in $B \to DK$ decays, as well as the latest LHCb measurement of γ combining all the individual inputs and including D^0 mixing.

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1. Introduction

As the angle γ is one of the least well constrained parameters of the Unitary Triangle (UT), its accurate determination remains one of the most important goals of the LHCb experiment [1]. The LHCb detector is a single-arm spectrometer at the LHC, optimised for beauty and charm flavour physics. It has been running successfully for more than 3 years, collecting about 3 fb^{-1} of data with different running conditions. These proceedings concentrate on the extraction of γ using only tree-level processes, which provide a theoretically clean environment without contributions from new physics processes. One of the most sensitive ways to measure γ is to use charged $B \to DK$ decays, exploiting the interference between $b \to c(\bar{u}s)$ and $b \to u(\bar{c}s)$ transitions. The two $B^- \to D^0 K^-$ and $B^- \to \bar{D}^0 K^-$ amplitudes involved can interfere when both the D^0 and $\bar{D}^0$ flavour eigenstates decay into the same final state f. The irreducible theoretical error on the procedure is due to electroweak penguin diagrams, with an estimated relative impact of order of 10^{-7} [2], which is well below any experimental sensitivity. The most obvious example is to choose the D final state f as an exact CP eigenstate, e.g. K^+K^- or $\pi^+\pi^-$: this is the so-called GLW method [3]. Another possible solution is to use non-CP eigenstates (ADS method [4, 5]) and to look for D decays which can proceed via either a Cabibbo-favoured decay (e.g. $\bar{D}^0 \to K^+\pi^-$) or a doubly-Cabibbo-suppressed decay ($D^0 \to K^+\pi^-$). If the favored B decay is followed by the suppressed D decay (and vice versa), this reverse suppression leads to amplitudes comparable in size and therefore to potentially large interference and sensitivity to γ. The use of non-CP eigenstates introduces extra parameters which depend on the particular D final state. Those parameters can be precisely measured and included in the combination as external constraints. Another complementary method (GGSZ [6]) uses self-conjugate three-body final states f, e.g. $D \to K_s^0\pi^+\pi^-, K_s^0K^+K^-$, where the interference on different regions of the Dalitz plot can be exploited. In principle, $B \to D\pi$ decays can be also used to gain sensitivity on γ, although they provide less sensitivity compared to their $B \to DK$ counterparts. The exact same formalism applies, with new observables and parameters entering the combination. This proceeding presents the first attempt to include such decays in a combination to extract γ.

2. Inputs to the combination and external constraints

Several published measurements have been used as inputs to the combination. They all use either the 1 fb^{-1} dataset collected in 2011 or the full 3 fb^{-1} dataset (2011+2012). All measurements involve the measurement of charge asymmetries or ratios of branching fractions. Ref [7] reports the first observation of CP violation in $B \to DK$ with $D \to K^+\pi^-, K^-\pi^+, K^+K^-, \pi^-\pi^+$. It includes measurements of the analogous $B \to D\pi$ modes, for a total of 13 observables. Ref [8] concentrates on the four-body final state $B \to D[K^\pm\pi^\mp\pi^+\pi^-]K$ and $B \to D[K^\pm\pi^\mp\pi^+\pi^-]\pi$, with the first observations of the suppressed ADS modes and a total of 7 observables measured. The last input is the Dalitz model-independent GGSZ analysis of $D \to K_S^0\pi^+\pi^-, K_S^0K^+K^-$ decays. Sect. 4 uses an updated version of the analysis using the the full 3 fb^{-1} dataset [9, 10] ($B \to DK$ modes only), while Sect. 5 uses only the 1 fb^{-1} published result [9] ($B \to DK$ and $B \to D\pi$ modes). The combination also includes external inputs, e.g. any information on the hadronic D^0 parameters (from CLEO [11]) and possible direct CP violation in the D^0 decays (from HFAG [12]). Sect. 5

takes into account the effects of $D^0 - \bar{D}^0$ mixing in the equations of the combination and includes the mixing parameters as inputs, taken from the recent LHCb publication [13].

3. Combining the inputs

The combination adopts a frequentist approach. The general idea is to measure as many quantities related to γ as possible and include them into a maximum likelihood fit. All measured variables are written in terms of the angle γ and some hadronic parameters to be fitted on data. The most important parameters in the combination are $r_B^{K,\pi}$, the ratios of the suppressed/favoured amplitudes, $\delta_B^{K,\pi}$, a CP-conserving strong phase, and the CP-violating angle γ. Most of the observables are assumed to follow a Gaussian behaviour and the experimental covariance matrix is included in the multidimensional Gaussian likelihood. If the number of equations is large enough compared to the number of the parameters to be extracted, the system is in principle solvable. As the equations are not linear, ambiguities are also possible. The combination uses the so-called plug-in method which is described in detail in [14]. Intervals for γ are calculated via toy experiments and errors are inflated accordingly to correct for any undercoverage of the procedure.

4. Combination using $B \to DK$ decays

This section presents the combination to extract γ using only the observables of $B \to DK$ decays [15]. They don't include $D^0 - \bar{D}^0$ mixing, but the effect is found to be small if only $B \to DK$ decays are considered (see Sect. 5). The combination uses the updated GGSZ analysis, using the full 3 fb^{-1} dataset [9, 10]. Results are shown in Fig. 1 and summarised in Tab. 1.

Parameter	$B \to DK$ combination
γ	67.2°
68% CL	$[55.1, 79.1]^\circ$
95% CL	$[43.9, 89.5]^\circ$

Table 1: Central value and CL intervals for the parameter γ.

5. Combination using $B \to DK$ and $B \to D\pi$ decays and including $D^0 - \bar{D}^0$ mixing

This section is based on the paper published in [14]. Here all inputs are based on the same 1 fb^{-1} dataset collected in 2011. This combination is the first to fully include the effects of $D^0 - \bar{D}^0$ mixing. $D^0 - \bar{D}^0$ mixing, despite being now a well established phenomenon, has been neglected so far in every previous result. Although this assumption is valid for $B \to DK$ decays within the current experimental precision, it can be shown that it must be taken into account properly if a degree-precision on γ is sought or if $B \to D\pi$ transitions are considered in the full combination [16]. $D^0 - \bar{D}^0$ mixing can easily be included by modifying slightly the equations used and including the D^0 mixing parameters x_D,y_D [13] as inputs: the formalism remains intact although with extra parameters to be considered. A nice review on how to include $D^0 - \bar{D}^0$ mixing can be found in Ref. [16], only the key points are summarised here:

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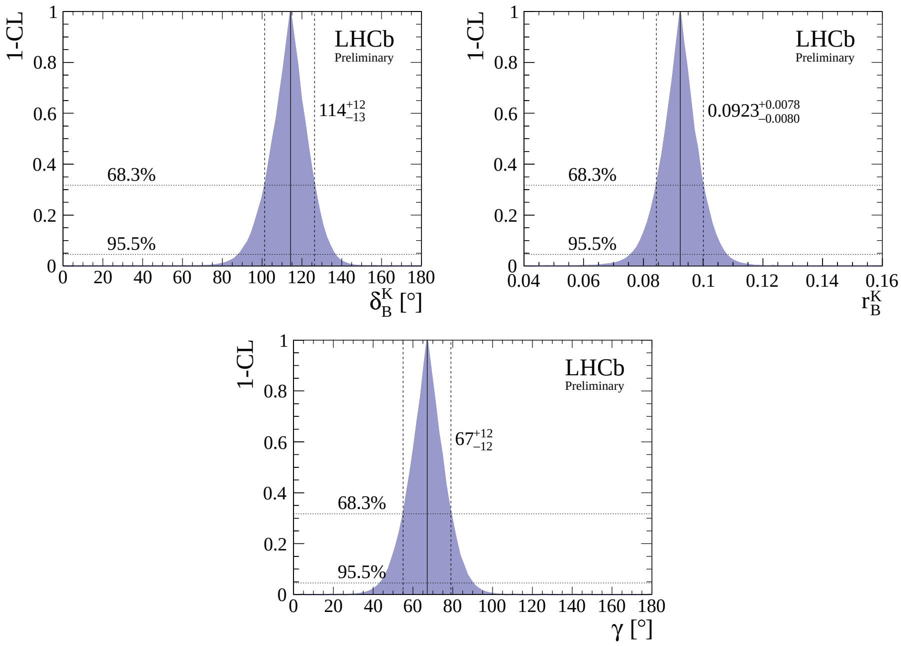

Figure 1: Plots showing the 1-CL for δ_B^K, r_B^K and γ from $B \to DK$ decays only [15] and including the 3 fb^{-1} GGSZ result [10]. The numbers quoted correspond to the central value and the 68.3% CL interval.

- It is negligible for the model-independent GGSZ method
- It is negligible for the GLW method (as corrections cancel in the double ratio used as input)
- It affects the ADS method using $B \to DK$ at the 10% level
- It affects the ADS method using $B \to D\pi$ at the 100% level

The combination is therefore corrected fully considering $D^0 - \bar{D}^0$ mixing. Furthermore, the D^0 decay time resolution and non-flat acceptance in the LHCb detector has been investigated and properly parameterised in the equations. The latest results for the $B \to DK$ and $B \to D\pi$ combinations are shown in Fig. 2 and summarised in Tab. 2.

Parameter	$B \to DK$ only	$B \to D\pi$ only	$B \to DK$ and $B \to D\pi$
γ	72.0°	18.9°	72.6°
68% CL	$[56.4, 86.7]^\circ$	$[7.4, 99.2]^\circ$ or $[167.9, 176.4]^\circ$	$[55.4, 82.3]^\circ$
95% CL	$[42.6, 99.6]^\circ$	no constraint	$[40.2, 92.7]^\circ$

Table 2: Central value and CL intervals for the parameter γ. The different contributions are shown separately when $B \to DK$ and $B \to D\pi$ decays are considered separately. Results are corrected for undercoverage and include systematic uncertainties.

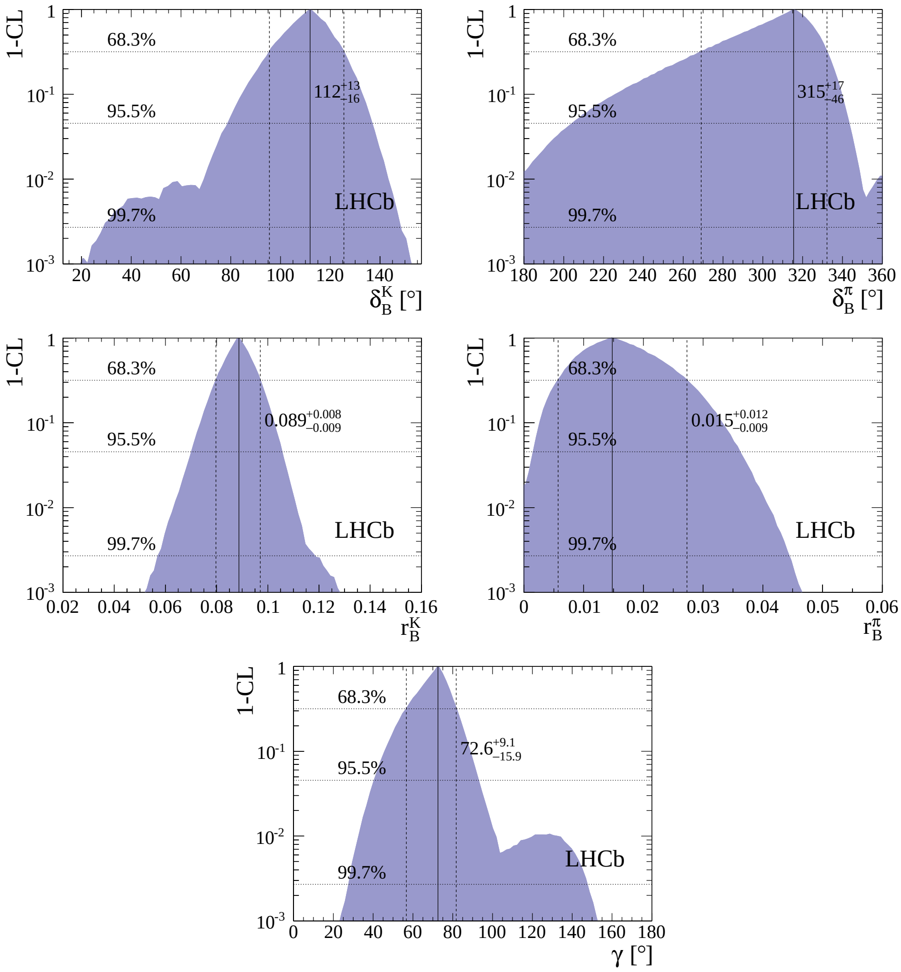

Figure 2: Plots showing the 1-CL for δ_B^K, δ_B^π, r_B^K, r_B^π and γ from the full combination of $B \to DK$ and $B \to D\pi$ modes [14]. The numbers quoted correspond to the central value and the 68.3% CL interval.

6. Summary

The CKM angle γ is extracted from a frequentist combination of measurements using $B^\pm \to DK^\pm$ and $B^\pm \to D\pi^\pm$ decays. The value extracted is $\gamma = (72.0^{+14.7}_{-15.6})^\circ$ when only $B^\pm \to DK^\pm$ are considered and $\gamma = (72.6^{+9.7}_{-17.2})^\circ$ once $B^\pm \to D\pi^\pm$ decays are included in the combination [14]. All angles are modulo 180°. Results are in excellent agreement with what found independently by the BELLE and BaBar collaborations, which quote a value of $\gamma = (69^{+17}_{-16})^\circ$ [17] and $\gamma = (68^{+15}_{-14})^\circ$ [18] respectively. All experiments have sensitivities comparable in size. At the moment, the extraction of γ at LHCb is still statistically limited, and its uncertainty will decrease once all analyses will be updated to the full 3 fb^{-1} available dataset. The combination will also benefit from the inclusion of other observables related to γ measured using other decay modes not considered so far.

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