# CP violation and $\gamma$ angle measurement in decay $B^{\pm} \to D^0(\to K_s^0\pi^+\pi^-\pi^0)h$ (Generalized BPGGSZ method)

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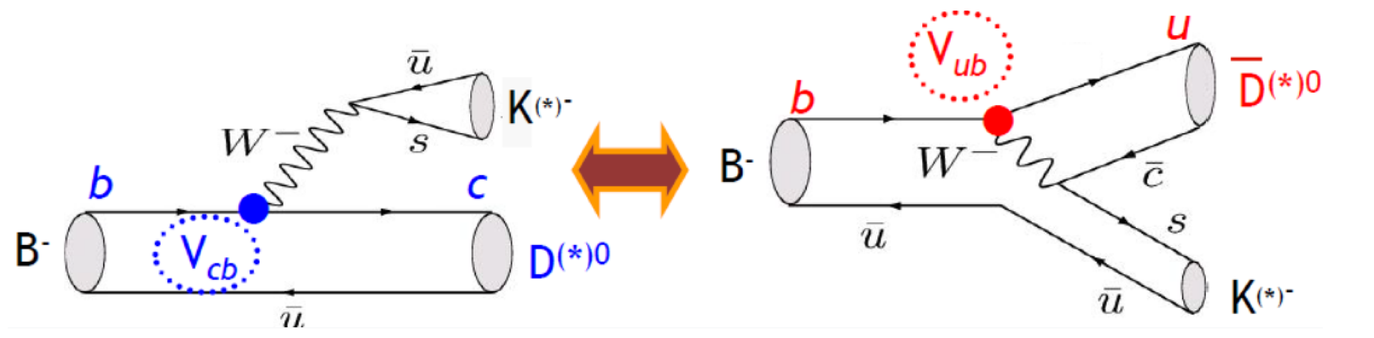
## Introduction

The $\gamma$ angle of the Cabibbo-Kobayashi-Maskawa (CKM) matrix sets a benchmark for CP violation, to be compared with the Standard Model (SM) predictions. In particular, direct measurements with tree-diagram decays sets a "standard candle" for the SM. One can then test discrepancy with loop-level measurements that could be sensible to new physics phenomenons. The CKMfitter group has notably proved that with a 1° precision on direct measurements, one may test the Standard Model up to at least 17 TeV [1].

Direct measurement current accurancy is around 4°. The accumulated statistics by the LHCb detector allows expecting an even more precise measurement of the $\gamma$ angle. As no analysis currently dominates the measurement, each mode helps to increase the precision on $\gamma$.

We can notably measure $\gamma$ by amplitude modulation in the interference between the processes $b \to c\bar{u}s$ and $b \to u\bar{c}s$. That is the case in the displayed Feynman diagrams where both decay have the same final state $D^0 \equiv [D^0/\bar{D}^0]$. The purpose of this study is to develop such a measurement with the tree-diagram decay $B^{\pm} \to D^0(\to K_s^0\pi^+\pi^-\pi^0)h$ decay, using LHCb data from Runs 1 and 2, thanks to a generalized BPGGSZ method.




The BPGGSZ method [2] with the three-body decay $D^0 \to K_s^0\pi^+\pi^-$ currently is the more precise studied mode in LHCb. That's why, in this analysis, we study the corresponding $D^0$ four-body decay with an additional $\pi^0$ which has been studied in Belle but still not in LHCb, where we have twice more statistics.

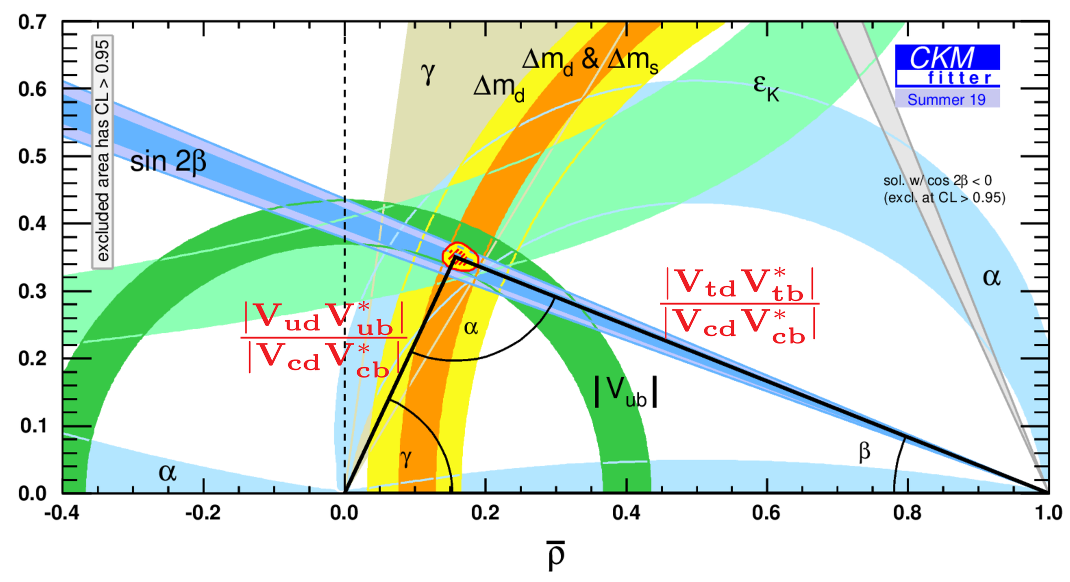
Direct measurement : $\gamma = (63.8^{+3.5}_{-3.7})°$ [3]

Indirect measurement : $\gamma = (65.7^{+0.9}_{-2.6})°$ [4]

## 1. The CKM matrix and $\gamma$ angle

$$\begin{pmatrix} d' \\ s' \\ b' \end{pmatrix} = \begin{pmatrix} V_{ud} & V_{us} & V_{ub} \\ V_{cd} & V_{cs} & V_{cb} \\ V_{td} & V_{ts} & V_{tb} \end{pmatrix} \begin{pmatrix} d \\ s \\ b \end{pmatrix} = \begin{pmatrix} 1-\frac{\lambda^2}{2} & \lambda & A\lambda^3(\rho - i\eta) \\ -\lambda & 1-\frac{\lambda^2}{2} & A\lambda^2 \\ A\lambda^3(1-\rho-i\eta) & -A\lambda^2 & 1 \end{pmatrix} \begin{pmatrix} d \\ s \\ b \end{pmatrix}$$

The $V_{CKM}$ matrix describes quarks transitions through the weak interaction. It can be defined by 4 independent parameters that can only be known by experiments. The Unitarity of $V_{CKM}$ gives 6 equations, each of them linked to a triangle in the complex plane, in particular the so-called "unitarity triangle" :

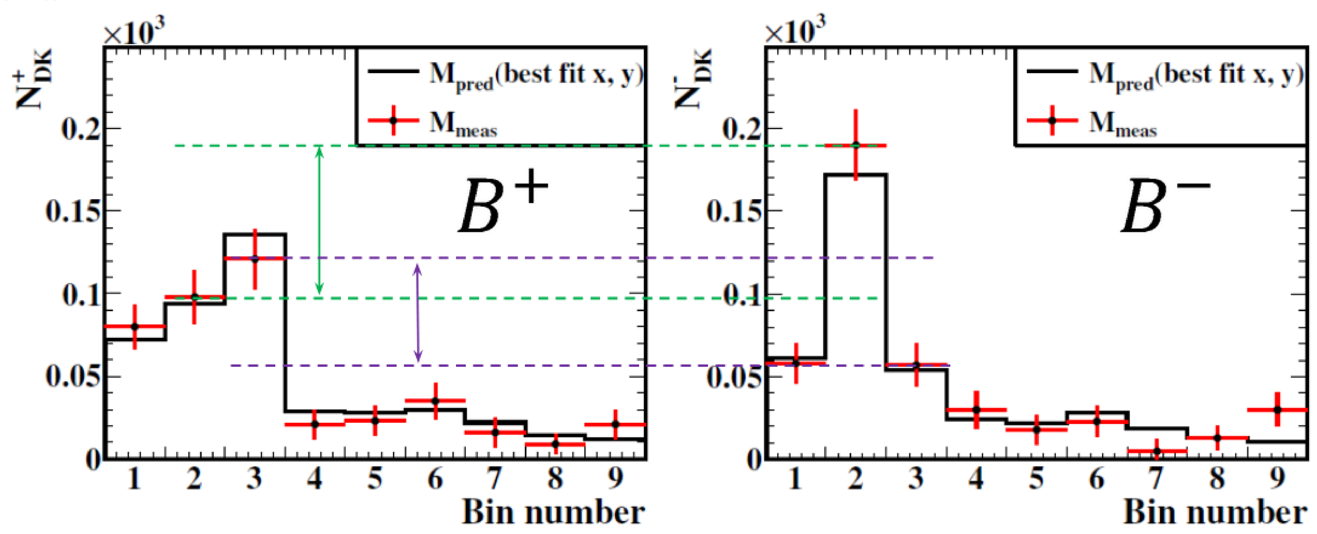



$$\sum_{i=1}^{3} V_{ij}V^*_{ki} = \sum_{i=1}^{3} V_{ij}V^*_{ik} = 0$$

## 2. The Strong phase $\delta_D$ mapping

The $\gamma$ measurement depends on the $\Delta\delta_D$ difference between the strong phases for $D^0 \to f(\delta_D)$ and $\bar{D}^0 \to f(\delta_D)$, which varies itself on the phase space of the four-body decay of $D^0$. One then needs a mapping of this strong phase.

In the Belle analysis [5], a binned map of the Phase Space has been used, using results from the Cleo-c experiment [6]. In a first approach, I will use the same binned scheme. The goal is to see some CP violation in those bins as we can see in the next figure from the Belle paper:




Next, we will perform an Amplitude Analysis with the LHCb 2011-2018 data, to obtain a continuous map of the strong phase, deducing a more precise result.

## 5. References


[1] Jerome Charles *et al.* Future sensitivity to new physics in $B_d$, $B_s$ and K mixings. *Phys. Rev. D*, 89, 2014. arXiv 1309.2293.

[2] A. Soffer A. Giri, Yu. Grossman and J. Zupan. Determining $\gamma$ using $B^{\pm} \to DK^{\pm}$ with multibody $d$ decays. *Phys. Rev. D*, 68, 2003. arxiv 0210433 [hep-ph].

[3] LHCb collaboration. Simultaneous determination of CKM angle $\gamma$ and parameters related to mixing and CP violation in the charm sector. 2022. https://gitlab.cern.ch/lhcb-datapkg/WG/B2OCConfig/-/jobs/26977334.

[4] CKMfitter group. CKMfitter global fit results as of Summer 19. http://ckmfitter.in2p3.fr/www/results/plots_summer19/num/ckmEval_results_summer19.html.

[5] J. Libby P.K Resmi and K. Trabelsi. First measurement of the CKM matrix angle $\phi_3$ with $B^{\pm} \to D(K_S^0\pi^+\pi^-\pi^0)K^{\pm}$ decays. *JHEP*, 2019. arXiv 1908.09499.

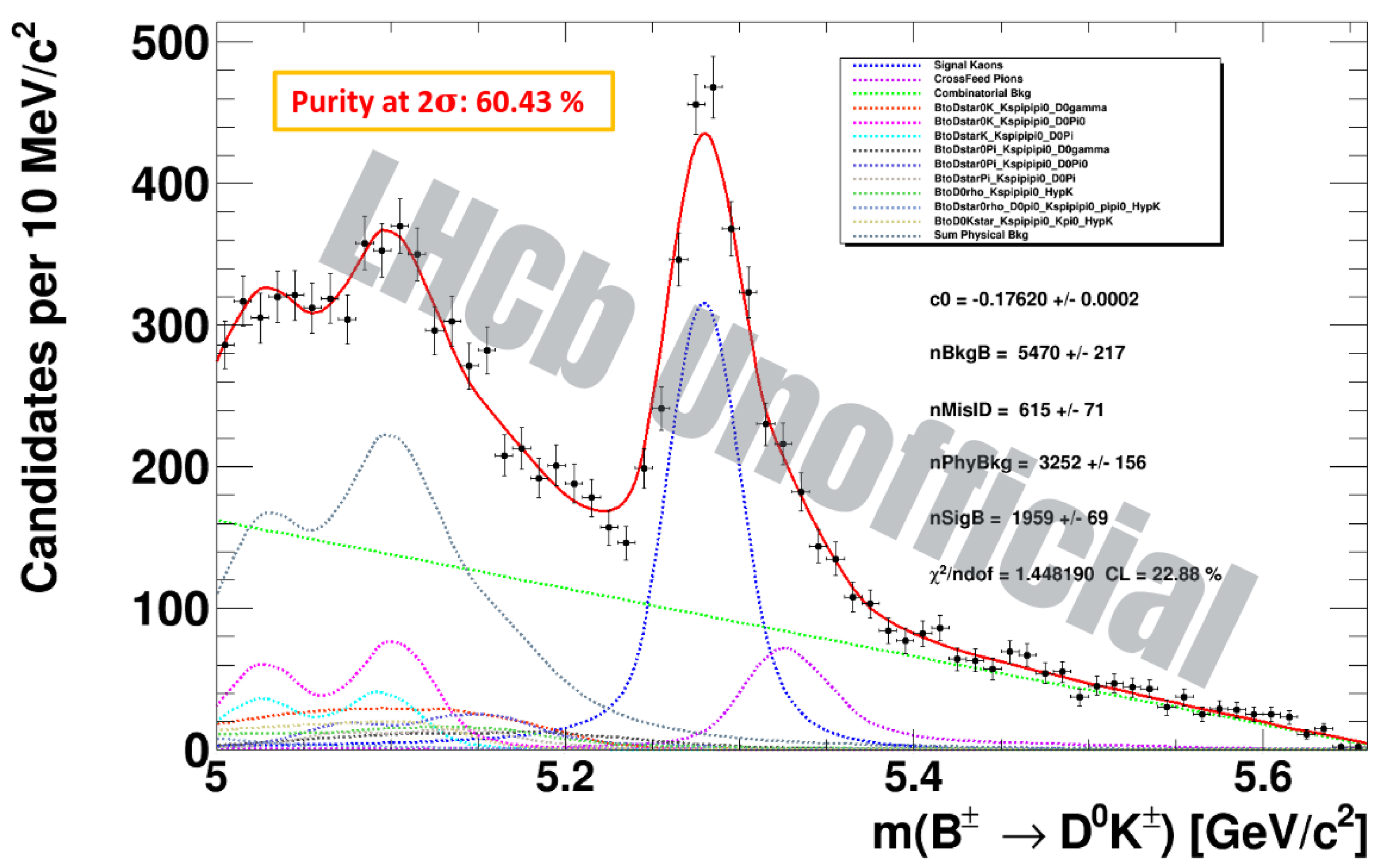
[6] S. Malde P.K Resmi, J. Libby and G. Wilkinson. Quantum-correlated measurements of $D^0 \to K_S^0\pi^+\pi^-\pi^0$ decays and consequences for the determination of the CKM angle $\gamma$. *JHEP*, 2018. arXiv 1710.10086.


## 3. Selection and background characterisation

- Signal selection performed with the reference channel $B^{\pm} \to D^0\pi^{\pm}$ (13 times larger than $B^{\pm} \to D^0K^{\pm}$).
- Selection based on :
  - One MVA on topological variables of $D^0$ decay
  - A second MVA on $B \to D^0h$ decay
  - One-dimensional cuts on the mass distributions of the $\pi^0$, $K_s^0$ and $D^0$ mesons

Once those selections are performed, we discriminate $K$ and $\pi$ using the DDL method based on a likelihood difference.

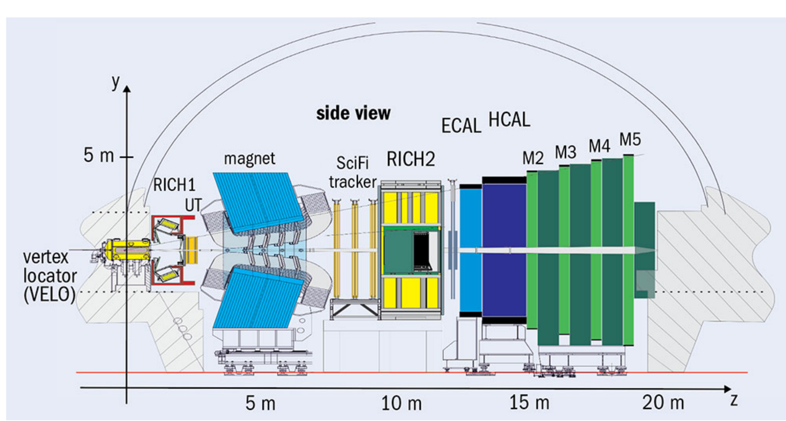
In addition to residual combinatorial background, different decay channel may interfere with the signal and we have simulated each of them to study this effect called "Physical Background". Another effect is the cross-feed when a $K$ or a $\pi$ is miss-identified. The following picture shows a fit of the mass distribution of the B meson, considering the signal, the crossfeed, physical and combinatorial backgrounds.




We finally obtain, in the mode, $1622 \pm 57$ signal events at $2\sigma$, which is twice the Belle experiment statistics which had $815 \pm 51$ events with a similar purity. Thus, it is clear that there is interest in re-doing this measurement with LHCb data.

## 4. Prospects

- Belle group obtained a measurement of $\gamma$ in the $2\sigma$ interval $(-29.7, 109.5)°$.
- With our statistics from Runs 1 and 2 (2011-2018 LHCb data $9fb^{-1}$), we then expect a $\approx 15-20°$ precision with the binning method.
- This mode will also be used to participate to an Amplitude Analysis of $D^0$ decay, additionally to the mode $B^{\pm} \to D^{*\pm}(\to D^0\pi)\mu\nu$. Thus, we will create a continuous map of $\Delta\delta_D$ to redo the study independently from Cleo-c bins.
- Measure of $D^0 \to K^{*\pm}\rho^{\mp}$ branching ratio will be made for the first time since Mark III... 30 years ago !
- This measure will be improved with Run 3 data ($23fb^{-1}$ in 2025). For this new data-taking period :
  - L0 trigger from 1 MHz to 40 MHz
  - A new Vertex Locator (VELO)
  - A new Tracker (SciFi)
  - ...




LHCb Collaboraion expects the combination of $\gamma$ measurements to give a $1-1.5°$ precision after Run3 and $0.3-0.4°$ in the late 2030's.