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RECENT RESULTS OF THE CKM ANGLE γ MEASUREMENT AT THE LHCb AND PROSPECTS FOR RUN 3 AND RUN 4*

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The Standard Model (SM) description of the CP violation can be tested by over-constraining the angles of the Unitary Triangle. Discrepancies between precise measurements of the Cabibbo–Kobayashi–Maskawa (CKM) angle γ in the tree-level and loop-dominated processes might provide evidence of physics beyond the Standard Model. Recent results of the CKM angle γ with special attention to decays from the $B \to DK$ family and preliminary background studies for $B_s^0 \to D_s^* K^*$ decays are presented in this paper.

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1. Introduction

The CKM angle γ is defined as $\gamma \equiv \arg(-V_{ud}V_{ub}^*/V_{cd}V_{cb}^*)$. The CKM matrix elements V_{ij} specify the strength of weak transition between quarks i and j. It is the least precisely measured parameter of the Unitary Triangle and it can be determined experimentally by exploiting the interference between favored $b \to c$ and suppressed $b \to u$ transition amplitudes in tree-level decays such as $B \to DK$. Any significant discrepancies between direct measurement in tree-level decays (less affected by processes which could be related to the effects of physics beyond the SM) and loop-dominated processes would be a sign of physics beyond the SM.

The combined LHCb measurement of CKM angle γ yields: $\gamma = (74.0^{+5.0}_{-5.8})^\circ$ [1, 2], which is the most precise result from a single experiment. The very recent analysis of $B^0 \to DK^{*0}$ with D mesons decaying to two and four

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particles final state included data from the Run 1 and Run 2 periods collected at centre-of-mass energies $\sqrt{s}$ of 7, 8 and 13 TeV in the years 2011–2016 [3]. This result is in agreement with the previous LHCb measurements and shows the feasibility of the study of new decays with as much as six charged particles in the final state ($K^{*0} \to K\pi$ and $D \to K\pi, \pi K, KK$ or $D \to K\pi\pi\pi, \pi K\pi\pi, \pi\pi\pi\pi$) for the evaluation of the CKM angle γ.

Another complementary set of processes includes B_s^0 decays to vector mesons: $B_s^0 \to D_s^* K$, $B_s^0 \to D_s K^*$ and $B_s^0 \to D_s^* K^*$. The last two have not been observed yet and the searches for appropriate candidates in the whole data from Run 1 and Run 2 are ongoing. Due to the complicated topology, this analysis is preceded by the additional study of a simulated data sample to establish various sources of background that may influence the measurement.

2. Preliminary background studies in $B_s^0 \to D_s^* K^*$ decays

The $B_s^0 \to D_s^* K^*$ decay, where $D_s^* \to D_s\gamma$ and $K^* \to K^0\pi$ proceeds through two vector resonances D_s^* and K^*, which are reconstructed from six charged particles, K_{S}^0 and γ.

One can expect three types of background components: partially reconstructed decays, where one or more particles in a similar decay are not detected and it may lead to the same final state, enhancement in the signal caused by the wrong identification of one or more particles, and combinatorial background — random combination of the particles from the final states. The latter can be greatly removed by application of criteria and multivariate analysis. Analysis of the first two background contributions is done using data simulated with the Monte Carlo methods (MC).

The simulation that includes the full event reconstruction takes a lot of CPU time. Therefore, simplified simulations are used to identify potentially dangerous backgrounds as a first step.

The RapidSim package [4] uses simplified models to quickly produce large samples to study kinematics of potential background decays. It allows for the estimation of the possible physical contributions. However, it cannot be used in calculation of efficiencies due to lack of track reconstruction of the decay chain.

The $B_s^0 \to D_s^* K^*$ decay with $D_s^* \to D_s\gamma$ and $K^* \to K^0\pi$ is characterised by two resonance states: D_s^* and K^*. It is, therefore, difficult to find decays which would be partially reconstructed and result in such a complex final state. The fast simulation of decays with the π^0 meson and without one γ reconstructed like: $B^0 \to D^*(2010)K^*$, $D^*(2010) \to D\pi^0$ showed events well below the B_s^0 mass.

Besides the presence of two resonances, one can also expect the non-resonant contributions of the type $B_s^0 \to D_s\gamma K^0\pi$, which can pass through the selection criteria. Figure 1 shows the comparison of $K^0\pi$ and $D_s\gamma$ mass distributions for the resonant (grey/red lines) and non-resonant mode (black/blue lines). The relative number of events for the former decay was established assuming that B_s^0 decay proceeds equally often through the resonant state K^* and directly to the $K^0\pi$, while in the case of decays through D_s^*, the number of events was chosen arbitrarily. Albeit the requirement that one should select events from the region that has mass close to the nominal mass of K^* and D_s^* will remove most of this background, the non-resonant contribution must be included in the model which describes the reconstructed signal events.

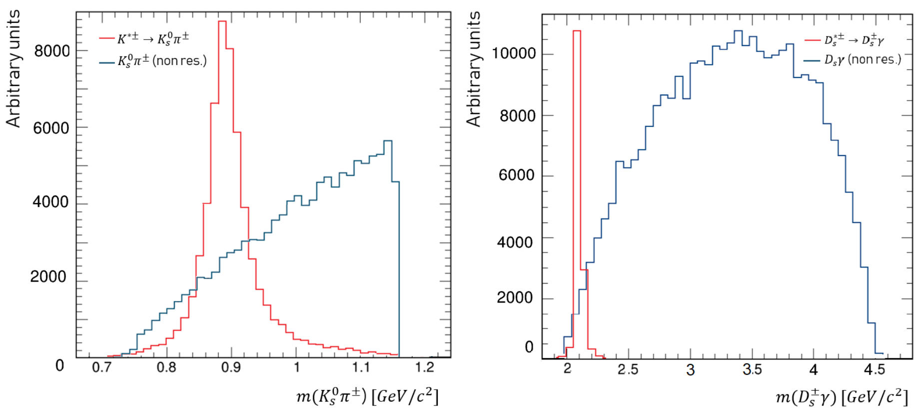

Fig. 1. Mass of $K^0\pi$ system (left) and $D_s\gamma$ (right). The grey/red line shows the decays with resonances K^* and D_s^*, respectively (pseudoexperiments produced with RapidSim [4]).

The other possible source of background is a misidentification of one pion as a kaon in the final state of the D meson decay. Such a D meson can be mistaken as a D_s meson which mainly decays to $KK\pi$ final state. In Fig. 2, left, the distribution of the mass of $D \to K\pi\pi$ and the mass in the case when 5% of pions are identified as kaons are shown. Therefore, one needs to exclude, in the selection of the real data, events that are compatible with D meson decay when the identification is changed from π to K.

Three decays: $B^0 \to D^*K^*$, $B^0 \to D_s^*K^*$ and the signal decay $B_s^0 \to D_s^*K^*$ are expected to appear in the mass distribution of the $D_{(s)}\gamma K^0\pi$ system. It is also possible that states: $D_sK^0\pi$, $DK^0\pi$, $D3\pi$, $D_s3\pi$ and $D^*(2010)K^0\pi$ with $D^*(2010) \to D^+\pi$, combined with a random, soft photon could mimic the signal decay $B_s^0 \to D_s^*K^*$. The size of possible contributions depends on the probability of the B^0 and B_s^0 production and branching fraction of the respective decays. A position of these background processes on the $D_s\gamma K^0\pi$ system mass is depicted in Fig. 2, right. It is assumed that the random γ is added to each event and distributions are normalized to $B^0 \to D^*K^*$ mode, which is $(3.3 \pm 0.7) \times 10^{-4}$ [5].

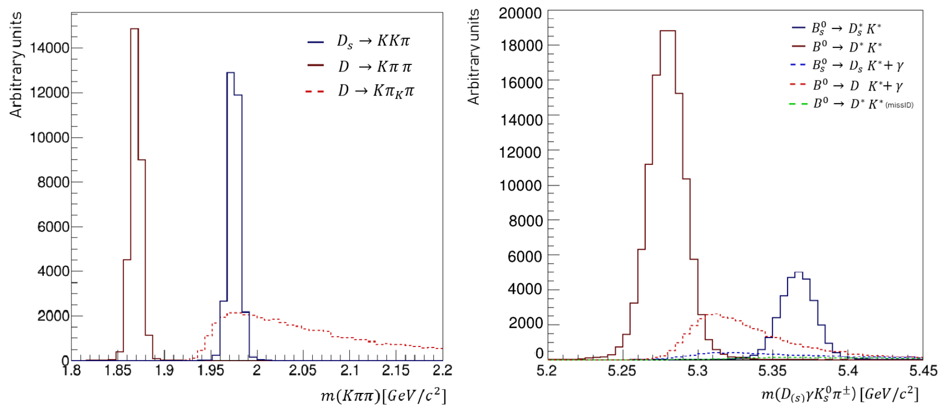

Fig. 2. Left plot: Mass of $D \to K\pi\pi$ candidates (grey/red line), $D_s \to KK\pi$ candidates (black/blue line) and $K\pi\pi$ system, where one pion is misidentified as kaon (dashed grey/red, line). Right plot: Mass of $D_s\gamma K^0\pi$ candidates for signal modes and potential background processes, the dashed histograms show decays combined with the low-energy, random photon (pseudoexperiments produced with RapidSim [4]).

Background studies showed that the mass of the combination of $B^0 \to DK^*$ decay with a random, low-energy photon lays within the region of the $B_s^0 \to D_s^*K^*$ mass. It means that such events can be misclassified as signal decay. Process of $B_s^0 \to D_sK^*$ decay with random photon is visible above the B_s^0 nominal mass. The expected contribution of the $B^0 \to D_sK^*$ decay is small, because its branching fraction: $(3.5 \pm 1.0) \times 10^{-5}$ [5] is significantly smaller in comparison with expected branching fraction of signal mode (10^{-4}). This analysis showed that the above processes should be simulated by a full simulation chain in the spectrometer to obtain a reliable parametrisation of the mass shapes that can be used in the fit model to real data collected at the LHCb experiment.

3. Prospect for Run 3 and Run 4

Upgrade of the LHCb spectrometer started immediately after the Run 2 (2018) and will be finished by the end of 2020. The main goal of this project is to replace the tracking and trigger systems completely. The main motivations that drive the modernisation process are the necessity of operating the detector at higher instantaneous luminosity $\mathcal{L} = 2 \times 10^{33}$ cm^{-2}s^{-1} and radiation damage that would render the previous system useless. The new tracking system comprises of new silicon pixel vertex detector (VELO), strip tracker (Upstream Tracker) and silicon fibre-based one (Fibre Tracker) [6]. The new event selection framework will feature innovative, flexible software trigger capable of processing events using full detector readout at 30 MHz. The upgraded LHCb is expected to collect approximately 50 fb^{-1} of data and match the theoretical uncertainties in a number of key measurements such as the CKM angle γ, angle β, B_s mixing phase β_s and more [7]. The anticipated precision of the CKM angle for Run 3 and 4 (years 2021–2023) is about 1.5° [7].

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REFERENCES

[1] R. Aaij *et al.* [LHCb Collaboration], LHCb-CONF-2018-002, 2018.

[2] R. Aaij *et al.* [LHCb Collaboration], *J. High Energy Phys.* **1612**, 087 (2016).

[3] R. Aaij *et al.* [LHCb Collaboration], *J. High Energy Phys.* **1908**, 041 (2019).

[4] G.A. Cowan, D.C. Craik, M.D. Needham, *Comput. Phys. Commun.* **214**, 239 (2017).

[5] M. Tanabashi *et al.* [Particle Data Group], *Phys. Rev. D* **98**, 030001 (2018).

[6] R. Aaij *et al.* [LHCb Collaboration], LHCB-TDR-015.

[7] R. Aaij *et al.* [LHCb Collaboration], CERN-LHCC-2011-001.