Observation of the decay $\Lambda_b^0 \to pK^-\mu^+\mu^-$ and a search for $CP$ violation

The LHCb collaboration

E-mail: nicola.neri@mi.infn.it

Abstract: A search for $CP$ violation in the decay $\Lambda_b^0 \to pK^-\mu^+\mu^-$ is presented. This decay is mediated by flavour-changing neutral-current transitions in the Standard Model and is potentially sensitive to new sources of $CP$ violation. The study is based on a data sample of proton-proton collisions recorded with the LHCb experiment, corresponding to an integrated luminosity of 3 fb$^{-1}$. The $\Lambda_b^0 \to pK^-\mu^+\mu^-$ decay is observed for the first time, and two observables that are sensitive to different manifestations of $CP$ violation are measured, $\Delta A_{CP} \equiv A_{CP}(\Lambda_b^0 \to pK^-\mu^+\mu^-) - A_{CP}(\Lambda_b^0 \to pK^-J/\psi)$ and $a_{CP}^{\text{odd}}$, where the latter is based on asymmetries in the angle between the $\mu^+\mu^-$ and $pK^-$ decay planes. These are measured to be

$$\Delta A_{CP} = (-3.5 \pm 5.0 \text{ (stat)} \pm 0.2 \text{ (syst)}) \times 10^{-2},$$

$$a_{CP}^{\text{odd}} = (1.2 \pm 5.0 \text{ (stat)} \pm 0.7 \text{ (syst)}) \times 10^{-2},$$

and no evidence for $CP$ violation is found.

Keywords: B physics, CP violation, FCNC Interaction, Hadron-Hadron scattering (experiments)

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1 Introduction

The phenomenon of CP violation (CPV), related to the difference in behaviour between matter and antimatter, remains an intriguing topic more than fifty years after its discovery in the neutral kaon system [1]. Within the Standard Model of particle physics (SM), CPV is incorporated by a single, irreducible weak phase in the Cabibbo-Kobayashi-Maskawa (CKM) quark mixing matrix [2, 3]. However, the amount of CPV in the SM is insufficient to explain the observed level of matter-antimatter asymmetry in the Universe [4–6]. Therefore, new sources of CPV beyond the SM are expected to exist. Experimental observations of CPV remain confined to the $B$- and $K$-meson systems. Recently, the first evidence for CPV in $B^0 \to p\pi^-\pi^+\pi^-$ was found at the level of 3.3 standard deviations [7] and a systematic study of CPV in beauty baryon decays has now begun.

Among dedicated heavy-flavour physics experiments, the LHCb detector [8] is unique in having access to a wide range of decay modes of numerous $b$-hadron species. Beauty baryons are produced copiously at the LHC, and within the LHCb detector acceptance the production ratio of $B^0 : A^0_s : B^0_s$ particles is approximately 4 : 2 : 1 [9]. The LHCb collaboration has previously searched for CPV in $A^0_b \to p\pi^-J/\psi$ and $A^0_b \to pK^-J/\psi$ decays [10], as well as in charmless $A^0_b \to pK^0_s\pi^-$, $A^0_b \to A\phi$ and $A^0_b \to Ah^+h^-$ transitions [11–13].

In this paper, a search for CPV in the hitherto unobserved decay $A^0_b \to pK^-\mu^+\mu^-$ is reported. It is a flavour-changing neutral-current process with the underlying quark-level transition $b \to s\mu^+\mu^-$. The leading-order transition amplitudes in the SM are described

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1 The inclusion of charge-conjugate processes is implied throughout this paper, unless stated otherwise.
by the loop diagrams shown in figure 1. In extensions to the SM, new heavy particles could contribute to the amplitudes with additional weak phases, providing new sources of CPV [14, 15]. The limited amount of CPV predicted for the decay $B^0 \to pK^+\mu^+\mu^-$ in the SM [15, 16], following from the CKM matrix elements shown in figure 1, makes this decay particularly sensitive to CPV effects from physics beyond the SM.

2 CP-odd observables

Two types of CP-odd observables are studied in this paper. Following refs. [7, 17], the differential rate of any pair of CP-conjugate processes can be decomposed into four parts with definite even and odd transformation properties under the CP and motion-reversal $\hat{T}$ operators. Here, $\hat{T}$ is the unitary operator that reverses both momentum and spin three-vectors, to be distinguished from the antiunitary time-reversal operator $T$ which reverses initial and final states.

A $\hat{T}$-even and CP-odd asymmetry, $A_{CP}$, is related to the raw asymmetry $A_{raw}$ of the observed decay candidates

$$A_{raw} \equiv \frac{N(A_b^0 \to pK^-\mu^+\mu^-) - N(\bar{A}_b^0 \to \bar{p}K^+\mu^-\mu^-)}{N(A_b^0 \to pK^-\mu^+\mu^-) + N(\bar{A}_b^0 \to \bar{p}K^+\mu^-\mu^-)},$$

via

$$A_{raw} \approx A_{CP}(A_b^0 \to pK^-\mu^+\mu^-) + A_{prod}(A_b^0) - A_{reco}(K^+) + A_{reco}(p),$$

where $A_{prod}(A_b^0)$ is the $A_b^0$ production asymmetry, due to the $pp$ initial state, and $A_{reco}(K^+)$ and $A_{reco}(p)$ are the reconstruction asymmetries for kaons and protons, mainly due to the different interaction cross-sections of particles and antiparticles with the detector material. By measuring the difference of raw asymmetries between the signal and the Cabibbo-favoured control mode $A_b^0 \to pK^-J/\psi(\to \mu^+\mu^-)$, the production and reconstruction asymmetries cancel to a good approximation. No significant CPV is expected in the latter decay, since its amplitude is dominated by tree-level CP-conserving diagrams, which leads to

$$\Delta A_{CP} \equiv A_{CP}(A_b^0 \to pK^-\mu^+\mu^-) - A_{CP}(A_b^0 \to pK^-J/\psi)$$

$$\approx A_{raw}(A_b^0 \to pK^-\mu^+\mu^-) - A_{raw}(A_b^0 \to pK^-J/\psi).$$

Figure 1. Diagrams for the decay $B^0 \to pK^+\mu^+\mu^-$, in which $V_{tbq}$ and $V_{tsq}$ are CKM matrix elements and $q$ represents one of the three up-type quarks $u$, $c$ or $t$, the $t$-quark contribution being dominant. The $u\pi$ pairs originate from the hadronization process.
Imperfect cancellation in the production and reconstruction asymmetries can arise from differences in the kinematic distributions of the signal and control modes. A weighting procedure, discussed in section 5, is applied to correct for this, with residual effects considered as a source of systematic uncertainty in section 6.

A pair of \( T \)-odd and \( P \)-odd observables, \( A_{\bar{T}} \) and \( A_{\bar{P}} \), is obtained by defining the \( T \)-odd triple products of the final-state particle momenta in the \( \Lambda_0^b \) rest frame

\[
C_{\bar{T}} = \tilde{p}_{\mu^+} \cdot (\tilde{p}_p \times \tilde{p}_{K^-}),
\]

\[
\bar{C}_{\bar{T}} = \tilde{p}_{\mu^-} \cdot (\tilde{p}_p \times \tilde{p}_{K^+}),
\]

and taking the asymmetries

\[
A_{\bar{T}} = \frac{N(C_{\bar{T}} > 0) - N(C_{\bar{T}} < 0)}{N(C_{\bar{T}} > 0) + N(C_{\bar{T}} < 0)}, \quad \bar{A}_{\bar{T}} = \frac{\overline{N}(-\bar{C}_{\bar{T}} > 0) - \overline{N}(-\bar{C}_{\bar{T}} < 0)}{\overline{N}(-\bar{C}_{\bar{T}} > 0) + \overline{N}(-\bar{C}_{\bar{T}} < 0)},
\]

where \( N(\overline{N}) \) is the number of \( \Lambda_0^b \) (\( \overline{\Lambda}_0^b \)) signal candidates. These asymmetries are measured from the angular distributions of the decay products, with \( C_{\bar{T}} \) being proportional to \( \sin \chi \), where \( \chi \) is the angle between the decay planes of the \( \mu^+\mu^- \) and \( pK^- \) systems in the \( \Lambda_0^b \) rest frame, as shown in figure 2.

The observables \( A_{\bar{T}} \) and \( \bar{A}_{\bar{T}} \) are \( P \)- and \( \bar{T} \)-odd but are not sensitive to CPV effects [17]. Following ref. [18], CP-odd and \( P \)-odd observables are defined as

\[
a_{\Lambda CP}^{T,\text{odd}} = \frac{1}{2} (A_{\bar{T}} - \bar{A}_{\bar{T}}), \quad a_{\Lambda P}^{T,\text{odd}} = \frac{1}{2} (A_{\bar{T}} + \bar{A}_{\bar{T}}),
\]

where a non-zero value of \( a_{\Lambda CP}^{T,\text{odd}} \) or \( a_{\Lambda P}^{T,\text{odd}} \) would signal CP or parity violation, respectively. These observables are by construction largely insensitive to the \( \Lambda_0^b \) production asymmetry and detector-induced charge asymmetries.

The observables \( \Delta A_{\Lambda CP} \) and \( a_{\Lambda CP}^{T,\text{odd}} \) are sensitive to different manifestations of CPV [17]. The CP asymmetry \( A_{\Lambda CP} \) depends on the interference of \( \bar{T} \)-even amplitudes, defined as
\[ \mathcal{A}_{CP} \propto a_1^e a_2^e \sin(\delta_1^e - \delta_2^e) \sin(\phi_1^e - \phi_2^e). \] (2.8)

The convention used to define strong and weak phases is such that all CPV effects are encoded in the CP-odd weak phases. Therefore, \( \mathcal{A}_{CP} \) is enhanced when the strong phase difference between the two amplitudes is large. On the other hand, \( a_{CP}^{T, odd} \) depends on the interference between \( T \)-even and \( T \)-odd amplitudes, the latter defined as \( a_T^e \exp \left[ i(\delta_T^e + \phi_T^e + \pi/2) \right] \), which have a relative CP-even strong phase \( \delta_1^e - \delta_2^e \) and a relative CP-odd weak phase \( \phi_1^e - \phi_2^e \).

\[ a_{CP}^{T, odd} \propto a_1^e a_0^0 \cos(\delta_1^e - \delta_0^e) \sin(\phi_1^e - \phi_0^e). \] (2.9)

As a consequence, \( a_{CP}^{T, odd} \) is enhanced when the strong phase difference vanishes. It is worth noting that the asymmetries reported in eqs. (2.8), (2.9) are CP-odd, being proportional to an odd function of the weak phase difference. Furthermore, the observables \( \Delta \mathcal{A}_{CP} \) and \( a_{CP}^{T, odd} \) are sensitive to different types of CPV effects from physics beyond the SM [16].

3 Detector and simulation

The LHCb detector [8, 19] is a single-arm forward spectrometer covering the pseudorapidity range \( 2 < \eta < 5 \), designed for the study of particles containing \( b \) or \( c \) quarks. The detector includes a high-precision tracking system consisting of a silicon-strip vertex detector surrounding the \( pp \) interaction region, a large-area silicon-strip detector located upstream of a dipole magnet with a bending power of about 4 Tm, and three stations of silicon-strip detectors and straw drift tubes placed downstream of the magnet. The tracking system provides a measurement of momentum, \( p \), of charged particles with a relative uncertainty that varies from 0.5% at low momentum to 1.0% at 200 GeV/c. The minimum distance of a track to a primary vertex (PV), the impact parameter (IP), is measured with a resolution of \( (15 + 29/p_T) \) \( \mu \)m, where \( p_T \) is the component of the momentum transverse to the beam, in GeV/c. Different types of charged hadrons are distinguished using information from two ring-imaging Cherenkov detectors. Photons, electrons and hadrons are identified by a calorimeter system consisting of scintillating-pad and preshower detectors, an electromagnetic calorimeter and a hadronic calorimeter. Muons are identified by a system composed of alternating layers of iron and multiwire proportional chambers. The online event selection is performed by a trigger [20], which consists of a hardware stage, based on information from the calorimeter and muon systems, followed by a software stage, which applies a full event reconstruction.

Simulated signal events are used to determine the effect of the detector geometry, trigger, reconstruction and selection on the angular distributions of the signal and \( \Lambda_b^0 \rightarrow pK^- J/\psi \) control sample. Additional simulated samples are used to estimate the contribution from specific background processes. In the simulation, \( pp \) collisions are generated using PYTHIA [21, 22] with a specific LHCb configuration [23]. Decays of hadronic particles are
described by EvtGen \cite{24}, in which final-state radiation is generated using PHOTOS \cite{25}. The interaction of the generated particles with the detector, and its response, are implemented using the Geant4 toolkit \cite{26}, as described in ref. \cite{27}.

4 Selection of signal candidates

The present analysis is performed using proton-proton collision data corresponding to 1 and 2 fb$^{-1}$ of integrated luminosity, collected with the LHCb detector in 2011 and 2012, at centre-of-mass energies of 7 and 8 TeV, respectively. The $\Lambda_b^0 \rightarrow pK^-\mu^+\mu^-$ candidates are reconstructed from a proton, a kaon and two muon candidates originating from a common vertex, and are selected using information from the particle identification system. The $\Lambda_b^0$ flavour is determined from the charge of the kaon candidate, i.e. $\Lambda_b^0$ for negative and $\Lambda_b^0$ for positive kaons. Only candidates with reconstructed invariant mass, $m(pK^-\mu^+\mu^-)$, in the range [5350, 6000] MeV/c$^2$ and a $pK^-$ invariant mass, $m(pK^-)$, below 2350 MeV/c$^2$ are retained, with the latter requirement being applied to reduce the combinatorial background contribution. The spectrum in the dimuon mass squared, $q^2$, is considered, excluding the resonance regions $q^2 \in [0.98, 1.10]$, [8.0, 11.0] and [12.5, 15.0] GeV$^2$/c$^4$ that correspond to the masses of the $\phi(1020)$, $J/\psi$, and $\psi(2S)$ mesons, respectively.

Several background contributions from exclusive decays are identified and rejected. These are $B_s^0 \rightarrow K^+K^-\mu^+\mu^-$ and $\bar{B}^0 \rightarrow K^-\pi^+\mu^+\mu^-$ decays, in which a kaon or a pion is misidentified as a proton, and $\Lambda_b^0 \rightarrow pK^-\mu^+\mu^-$ decays, in which proton and kaon assignments are interchanged. Background also arises from $\Lambda_b^0 \rightarrow pK^-J/\psi$ and $\Lambda_b^0 \rightarrow pK^-\psi(2S)$ decays in which a muon is misidentified as a kaon and the kaon as a muon. These components are effectively eliminated by tightened particle identification requirements combined with selection criteria on invariant masses calculated under the appropriate mass hypothesis (e.g. assigning the kaon mass to the candidate proton to identify possible $B_s^0 \rightarrow K^+K^-\mu^+\mu^-$ background decays). After these requirements the background contribution from the above decays is negligible. No indication of other specific background decays is observed. The remaining combinatorial background is suppressed by means of a boosted decision tree (BDT) classifier \cite{28, 29} with an adaptive boosting algorithm \cite{30}. The BDT is constructed from variables that discriminate between signal and background, based on their kinematic, topological and particle identification properties, as well as the isolation of the final-state tracks \cite{31, 32}. Simulated $\Lambda_b^0 \rightarrow pK^-\mu^+\mu^-$ events in which the decay products are uniformly distributed in phase space are used as the signal training sample and a correction for known differences between data and simulation is applied. Candidates from data in the high mass region, $m(pK^-\mu^+\mu^-) > 5800$ MeV/c$^2$, are used as the background training sample and then removed from the window of the mass fit described below. After optimisation of the significance, $S/\sqrt{S+B}$, where $S$ and $B$ are the number of signal and background candidates in the region $m(pK^-\mu^+\mu^-) \in [5400, 5800]$ MeV/c$^2$, the BDT classifier retains only 0.14% of the combinatorial background candidates, with a signal efficiency of 51%. Events in which more than one $\Lambda_b^0$ candidate survives the selection constitute less than 1% of the sample and all candidates are retained; the systematic uncertainty associated with this is negligible. The identical selection is applied to the
control-mode $A_{b}^{0} \rightarrow pK^{-} J/\psi$, except that the dimuon squared mass is required to be in the range $[9.0, 10.5] \text{GeV}^{2}/c^{4}$.

5 Asymmetry measurements

For the $\Delta A_{CP}$ measurement, the data are divided into two subsamples according to the $A_{b}^{0}$ flavour. For the measurements of the triple-product asymmetries, four subsamples are defined by the combination of the $A_{b}^{0}$ flavour and the sign of $C_{b}^{T}$ (or $\bar{C}_{b}^{T}$ for $\bar{A}_{b}^{0}$). The reconstruction efficiencies are studied with simulated events and are found to be equal for all subsamples.

The observable $\Delta A_{CP}$ can be sensitive to kinematic differences between the signal and control-mode decays that affect the cancellation of the detection asymmetries in eq. (2.3). This is taken into account by assigning a weight to each $A_{b}^{0} \rightarrow pK^{-} J/\psi$ candidate such that the resulting proton and kaon momentum distributions match those of the signal $A_{b}^{0} \rightarrow pK^{-}\mu^{+}\mu^{-}$ decays. These weights are determined from simulation samples for the signal and control modes. No such weighting is required for $a_{b}^{T,\text{odd}}$ and $a_{P}^{T,\text{odd}}$, since these observables involve only one decay mode.

The asymmetry $A_{raw}$ is determined from a simultaneous extended maximum likelihood unbinned fit to the $A_{b}^{0}$ and $\bar{A}_{b}^{0}$ invariant mass distributions. The $A_{\bar{F}}$ and $\bar{A}_{F}$ asymmetries are determined by means of a simultaneous extended maximum likelihood unbinned fit to the four subsamples defined above. The signal model for all fits is the sum of two Crystal Ball functions [33], one with a low-mass power-law tail and one with a high-mass tail, and a Gaussian function, all sharing the same peak position. Only the peak position, the total width of the composite function and the overall normalization are free to vary, with all other shape parameters fixed from a fit to simulated decays. The background is modelled by an exponential function. The raw asymmetry $A_{raw}$ is incorporated in the fit model as

$$N_{A_{b}} = N^{0}_{A_{b}} \frac{1 - A_{raw}}{1 + A_{raw}}, \quad \text{(5.1)}$$

and $\Delta A_{CP}$ is derived from the raw asymmetries measured in the signal and control modes according to eq. (2.3). The asymmetries $A_{\bar{F}}$ and $\bar{A}_{F}$ are included in the fit as

$$N_{A_{b}, C_{b}>0} = \frac{1}{2} N_{A_{b}} (1 + A_{\bar{F}}), \quad N_{A_{b}, C_{b}<0} = \frac{1}{2} N_{A_{b}} (1 - A_{\bar{F}}),$$

$$N_{\bar{A}_{b}, \bar{C}_{b}>0} = \frac{1}{2} N_{\bar{A}_{b}} (1 + \bar{A}_{\bar{F}}), \quad N_{\bar{A}_{b}, \bar{C}_{b}<0} = \frac{1}{2} N_{\bar{A}_{b}} (1 - \bar{A}_{\bar{F}}), \quad \text{(5.2)}$$

and the observables $a_{CP}^{T,\text{odd}}$ and $a_{P}^{T,\text{odd}}$ are computed from $A_{\bar{F}}$ and $\bar{A}_{F}$, which are found to be uncorrelated. Background yields are fitted independently for each subsample, while all the signal shape parameters are shared among the subsamples.

The invariant mass distributions of $A_{b}^{0} \rightarrow pK^{-} \mu^{+}\mu^{-}$ and $A_{b}^{0} \rightarrow pK^{-} J/\psi$ candidates, with fit results superimposed, are shown in figure 3. The $A_{raw}$ asymmetries are found to be $(-2.8 \pm 5.0) \times 10^{-2}$ for signal decays and $(1.7 \pm 0.7) \times 10^{-2}$ for the control mode. After applying the weighting procedure to account for kinematic differences between signal and
Figure 3. Invariant mass distributions of (top) $A_0^0 \rightarrow pK^-\mu^+\mu^-$ and (bottom) $A_0^0 \rightarrow pK^-J/\psi$ candidates, with fit results superimposed. Plots refer to the (left) $A_0^0$ and (right) $\bar{A}_0^0$ subsamples.

control-mode decays, a value of $(2.0 \pm 0.7) \times 10^{-2}$ is obtained for the control-mode asymmetry, which yields efficiency-uncorrected $\Delta A_{CP} = (-4.8 \pm 5.0) \times 10^{-2}$. The total signal yields from the fits to the data are $600 \pm 33$ candidates for $A_0^0 \rightarrow pK^-\mu^+\mu^-$, and $22,911 \pm 162$ for $A_0^0 \rightarrow pK^-J/\psi$ decays. The uncertainties are statistical only. This represents the first observation of the $A_0^0 \rightarrow pK^-\mu^+\mu^-$ decay mode.

The invariant mass distributions of the $A_0^0 \rightarrow pK^-\mu^+\mu^-$ subsamples used for the $A_T$ and $\bar{A}_T$ measurements, with fit results superimposed, are shown in figure 4. From the signal yields, the triple-product asymmetries are found to be $A_T = (-2.8 \pm 7.2) \times 10^{-2}$ and $\bar{A}_T = (4.0 \pm 6.9) \times 10^{-2}$, and the resulting efficiency-uncorrected parity- and $CP$-violating observables are $a_T^{\text{odd}} = (-3.4 \pm 5.0) \times 10^{-2}$ and $a_{CP}^{\text{odd}} = (0.6 \pm 5.0) \times 10^{-2}$, where again the uncertainties are statistical only.

6 Systematic uncertainties

The analysis method depends upon the weighting procedure discussed in section 5 to equalise the kinematic distributions of the protons and kaons between the signal and control
modes. For $\Delta A_{CP}$, the associated systematic uncertainty is estimated by varying the weights within their uncertainties and taking the largest deviation, $\pm 0.15 \times 10^{-2}$, as a systematic uncertainty. No weighting is needed for $a_{CP}^{\text{odd}}$ and $a_{P}^{\text{odd}}$, and therefore no systematic uncertainty is assigned. Instead, the effects of selection and detector acceptance on the triple-product asymmetries are estimated by measuring $a_{CP}^{\text{odd}}(pK^-J/\psi)$ on the control mode, $A_{b}^{C} \rightarrow pK^-J/\psi$. A value of $(0.5 \pm 0.7) \times 10^{-2}$ is obtained. For this mode negligible CPV is expected, and the statistical uncertainty of the measured asymmetry is assigned as the corresponding systematic uncertainty on the observables $a_{CP}^{\text{odd}}$ and $a_{P}^{\text{odd}}$. The effects of the reconstruction efficiency on the measured observables are considered by weighting each event by the inverse of the efficiency extracted from simulated events. This leads to a change in the central values of $+1.3 \times 10^{-2}$ on $\Delta A_{CP}$, of $+0.6 \times 10^{-2}$ on $a_{CP}^{\text{odd}}$ and of $-1.4 \times 10^{-2}$ on $a_{P}^{\text{odd}}$. A systematic uncertainty is assigned by varying the efficiencies within their uncertainties. This amounts to $\pm 0.10 \times 10^{-2}$ for the $\Delta A_{CP}$ observable and to $\pm 0.02 \times 10^{-2}$ for $a_{CP}^{\text{odd}}$ and $a_{P}^{\text{odd}}$.
The above effects are the dominant sources of systematic uncertainties. Other possible sources of systematic uncertainties are considered. The experimental resolution on $C_B$ is studied with simulated signal events. The effect of the fit model choice is studied by fitting simulated pseudoexperiments with an alternative fit model, in which the Crystal Ball functions are replaced with bifurcated Gaussian functions and the exponential background shape is replaced with a polynomial. Systematic effects from $A_b^0$ polarisation [34], multiple candidates, and residual physical backgrounds are also studied. These contributions have negligible impact on the measured asymmetries.

7 Conclusions

The first search for $CP$ violation in the process $A_b^0 \rightarrow pK^-\mu^+\mu^-$ is performed with a data sample containing 600 $\pm$ 33 signal decays, this representing the first observation of this $A_b^0$ decay mode. Two different $CP$-violating observables that are sensitive to different manifestations of $CP$ violation, $\Delta A_{CP}$ and $a_{CP}^{T\text{-odd}}$, are measured. The parity-violating observable $a_{CP}^{T\text{-odd}}$ is also measured. The values obtained are

$$\Delta A_{CP} = (-3.5 \pm 5.0 \text{ (stat)} \pm 0.2 \text{ (syst)}) \times 10^{-2},$$

$$a_{CP}^{T\text{-odd}} = (1.2 \pm 5.0 \text{ (stat)} \pm 0.7 \text{ (syst)}) \times 10^{-2},$$

$$a_{CP}^{T\text{-odd}} = (-4.8 \pm 5.0 \text{ (stat)} \pm 0.7 \text{ (syst)}) \times 10^{-2}.$$

The results are compatible with $CP$ and parity conservation and agree with SM predictions for CPV [15, 16], and with experimental results [35, 36] for decays mediated by $b \rightarrow s\mu^+\mu^-$ transitions in $B^0$ and $B^+$ meson decays.

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19 Laboratori Nazionali dell’INFN di Frascati, Frascati, Italy
20 Sezione INFN di Genova, Genova, Italy
21 Sezione INFN di Milano Bicocca, Milano, Italy
22 Sezione INFN di Milano, Milano, Italy
23 Sezione INFN di Padova, Padova, Italy
24 Sezione INFN di Pisa, Pisa, Italy
25 Sezione INFN di Roma Tor Vergata, Roma, Italy
26 Sezione INFN di Roma La Sapienza, Roma, Italy
27 Henryk Niewodniczanski Institute of Nuclear Physics Polish Academy of Sciences, Kraków, Poland
28 AGH - University of Science and Technology, Faculty of Physics and Applied Computer Science, Kraków, Poland
29 National Center for Nuclear Research (NCBJ), Warsaw, Poland
30 Horia Hulubei National Institute of Physics and Nuclear Engineering, Bucharest-Magurele, Romania
31 Petersburg Nuclear Physics Institute (PNPI), Gatchina, Russia
32 Institute of Theoretical and Experimental Physics (ITEP), Moscow, Russia
33 Institute of Nuclear Physics, Moscow State University (SINP MSU), Moscow, Russia
34 Institute for Nuclear Research of the Russian Academy of Sciences (INR RAN), Moscow, Russia
35 Yandex School of Data Analysis, Moscow, Russia
36 Budker Institute of Nuclear Physics (SB RAS), Novosibirsk, Russia
37 Institute for High Energy Physics (IHEP), Protvino, Russia
38 ICCUB, Universitat de Barcelona, Barcelona, Spain
39 Universidade de Santiago de Compostela, Santiago de Compostela, Spain
40 European Organization for Nuclear Research (CERN), Geneva, Switzerland
41 Institute of Physics, Ecole Polytechnique Fédérale de Lausanne (EPFL), Lausanne, Switzerland
42 Physik-Institut, Universität Zürich, Zürich, Switzerland
43 Nikhef National Institute for Subatomic Physics, Amsterdam, The Netherlands
44 Nikhef National Institute for Subatomic Physics and VU University Amsterdam, Amsterdam, The Netherlands
45 NSC Kharkiv Institute of Physics and Technology (NSC KIPT), Kharkiv, Ukraine
46 Institute for Nuclear Research of the National Academy of Sciences (KINR), Kyiv, Ukraine
47 University of Birmingham, Birmingham, United Kingdom
48 H.H. Wills Physics Laboratory, University of Bristol, Bristol, United Kingdom
49 Cavendish Laboratory, University of Cambridge, Cambridge, United Kingdom
50 Department of Physics, University of Warwick, Coventry, United Kingdom
51 STFC Rutherford Appleton Laboratory, Didcot, United Kingdom
52 School of Physics and Astronomy, University of Edinburgh, Edinburgh, United Kingdom
53 School of Physics and Astronomy, University of Glasgow, Glasgow, United Kingdom
54 Oliver Lodge Laboratory, University of Liverpool, Liverpool, United Kingdom
55 Imperial College London, London, United Kingdom
56 School of Physics and Astronomy, University of Manchester, Manchester, United Kingdom
57 Department of Physics, University of Oxford, Oxford, United Kingdom
58 Massachusetts Institute of Technology, Cambridge, MA, United States
59 University of Cincinnati, Cincinnati, OH, United States
60 University of Maryland, College Park, MD, United States
61 Syracuse University, Syracuse, NY, United States
62 Pontifícia Universidade Católica do Rio de Janeiro (PUC-Rio), Rio de Janeiro, Brazil, associated to
63 University of Chinese Academy of Sciences, Beijing, China, associated to
64 School of Physics and Technology, Wuhan University, Wuhan, China, associated to
65 Institute of Particle Physics, Central China Normal University, Wuhan, Hubei, China, associated to

– 15 –
Departamento de Fisica, Universidad Nacional de Colombia, Bogota, Colombia, associated to 8

Institut für Physik, Universität Rostock, Rostock, Germany, associated to 12

National Research Centre Kurchatov Institute, Moscow, Russia, associated to 32

Instituto de Fisica Corpuscular, Centro Mixto Universidad de Valencia - CSIC, Valencia, Spain, associated to 38

Van Swinderen Institute, University of Groningen, Groningen, The Netherlands, associated to 43

\footnote{Universidade Federal do Triângulo Mineiro (UFTM), Uberaba-MG, Brazil}

\footnote{Laboratoire Leprince-Ringuet, Palaiseau, France}

\footnote{P.N. Lebedev Physical Institute, Russian Academy of Science (LPI RAS), Moscow, Russia}

\footnote{Università di Bari, Bari, Italy}

\footnote{Università di Bologna, Bologna, Italy}

\footnote{Università di Cagliari, Cagliari, Italy}

\footnote{Università di Ferrara, Ferrara, Italy}

\footnote{Università di Genova, Genova, Italy}

\footnote{Università di Milano Bicocca, Milano, Italy}

\footnote{Università di Roma Tor Vergata, Roma, Italy}

\footnote{Università di Roma La Sapienza, Roma, Italy}

\footnote{AGH - University of Science and Technology, Faculty of Computer Science, Electronics and Telecommunications, Kraków, Poland}

\footnote{LIFAELS, La Salle, Universitat Ramon Llull, Barcelona, Spain}

\footnote{Hanoi University of Science, Hanoi, Viet Nam}

\footnote{Università di Padova, Padova, Italy}

\footnote{Università di Pisa, Pisa, Italy}

\footnote{Università degli Studi di Milano, Milano, Italy}

\footnote{Università di Urbino, Urbino, Italy}

\footnote{Università della Basilicata, Potenza, Italy}

\footnote{Scuola Normale Superiore, Pisa, Italy}

\footnote{Università di Modena e Reggio Emilia, Modena, Italy}

\footnote{Iligan Institute of Technology (IIT), Iligan, Philippines}

\footnote{Novosibirsk State University, Novosibirsk, Russia}

\footnote{Deceased}