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

The LHCb collaboration[†]

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 $3\,\text{fb}^{-1}$. 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, $\Delta\mathcal{A}_{CP} \equiv \mathcal{A}_{CP}(\Lambda_b^0 \to pK^-\mu^+\mu^-) - \mathcal{A}_{CP}(\Lambda_b^0 \to pK^- J/\psi)$ and $a_{CP}^{\widehat{T}\text{-odd}}$, where the latter is based on asymmetries in the angle between the $\mu^+\mu^-$ and pK^- decay planes. These are measured to be

$$\Delta\mathcal{A}_{CP} = (-3.5 \pm 5.0\,(\text{stat}) \pm 0.2\,(\text{syst})) \times 10^{-2},$$
$$a_{CP}^{\widehat{T}\text{-odd}} = (\ 1.2 \pm 5.0\,(\text{stat}) \pm 0.7\,(\text{syst})) \times 10^{-2},$$

and no evidence for *CP* violation is found.

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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 $\Lambda_b^0 \to p\pi^-\pi^+\pi^-$ 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 $B^0 : \Lambda_b^0 : B_s^0$ particles is approximately $4 : 2 : 1$ [9]. The LHCb collaboration has previously searched for CPV in $\Lambda_b^0 \to p\pi^- J/\psi$ and $\Lambda_b^0 \to pK^- J/\psi$ decays [10], as well as in charmless $\Lambda_b^0 \to pK_S^0\pi^-$, $\Lambda_b^0 \to \Lambda\phi$ and $\Lambda_b^0 \to \Lambda h^+h^-$ transitions [11–13].

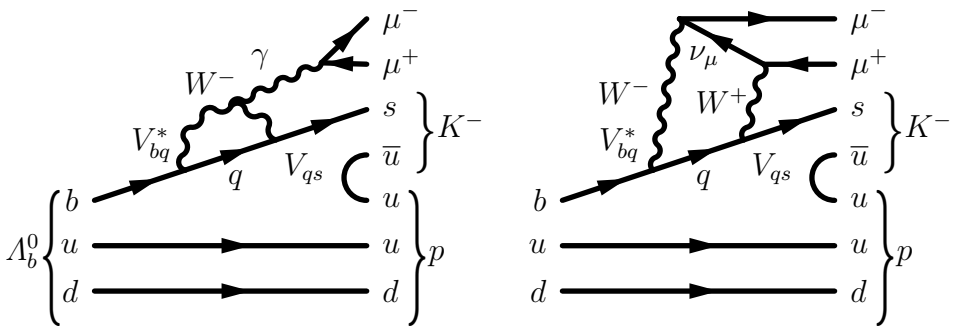

Figure 1: Diagrams for the decay $\Lambda_b^0 \to pK^-\mu^+\mu^-$, in which V_{bq} and V_{qs} are CKM matrix elements and q represents one of the three up-type quarks u, c or t, the t-quark contribution being dominant. The $u\overline{u}$ pairs originate from the hadronization process.

In this paper, a search for CPV in the hitherto unobserved decay $\Lambda_b^0 \to pK^-\mu^+\mu^-$ is reported.[1] 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 by the loop diagrams shown in Fig. 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 $\Lambda_b^0 \to pK^-\mu^+\mu^-$ in the SM [15,16], following from the CKM matrix elements shown in Fig. 1, makes this decay particularly sensitive to CPV effects from physics beyond the SM.

[1] The inclusion of charge-conjugate processes is implied throughout this paper, unless stated otherwise.

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 $\widehat{T}$ operators. Here, $\widehat{T}$ 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 $\widehat{T}$-even and *CP*-odd asymmetry, $\mathcal{A}_{CP}$, is related to the raw asymmetry $\mathcal{A}_{\rm raw}$ of the observed decay candidates

$$\mathcal{A}_{\rm raw} \equiv \frac{N(\Lambda_b^0 \to pK^-\mu^+\mu^-) - N(\overline{\Lambda}_b^0 \to \overline{p}K^+\mu^-\mu^+)}{N(\Lambda_b^0 \to pK^-\mu^+\mu^-) + N(\overline{\Lambda}_b^0 \to \overline{p}K^+\mu^-\mu^+)}, \tag{1}$$

via

$$\mathcal{A}_{\rm raw} \approx \mathcal{A}_{CP}(\Lambda_b^0 \to pK^-\mu^+\mu^-) + \mathcal{A}_{\rm prod}(\Lambda_b^0) - \mathcal{A}_{\rm reco}(K^+) + \mathcal{A}_{\rm reco}(p), \tag{2}$$

where $\mathcal{A}_{\rm prod}(\Lambda_b^0)$ is the Λ_b^0 production asymmetry, due to the pp initial state, and $\mathcal{A}_{\rm reco}(K^+)$ and $\mathcal{A}_{\rm reco}(p)$ 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 $\Lambda_b^0 \to pK^- J/\psi(\to \mu^+\mu^-)$, 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

$$\begin{aligned}\Delta\mathcal{A}_{CP} &\equiv \mathcal{A}_{CP}(\Lambda_b^0 \to pK^-\mu^+\mu^-) - \mathcal{A}_{CP}(\Lambda_b^0 \to pK^- J/\psi) \\ &\approx \mathcal{A}_{\rm raw}(\Lambda_b^0 \to pK^-\mu^+\mu^-) - \mathcal{A}_{\rm raw}(\Lambda_b^0 \to pK^- J/\psi).\end{aligned} \tag{3}$$

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 Sec. 5, is applied to correct for this, with residual effects considered as a source of systematic uncertainty in Sec. 6.

A pair of $\widehat{T}$-odd and P-odd observables, $A_{\widehat{T}}$ and $\overline{A}_{\widehat{T}}$, is obtained by defining the $\widehat{T}$-odd triple products of the final-state particle momenta in the Λ_b^0 rest frame

$$C_{\widehat{T}} \equiv \vec{p}_{\mu^+} \cdot (\vec{p}_p \times \vec{p}_{K^-}), \tag{4}$$

$$\overline{C}_{\widehat{T}} \equiv \vec{p}_{\mu^-} \cdot (\vec{p}_{\overline{p}} \times \vec{p}_{K^+}), \tag{5}$$

and taking the asymmetries

$$A_{\widehat{T}} \equiv \frac{N(C_{\widehat{T}} > 0) - N(C_{\widehat{T}} < 0)}{N(C_{\widehat{T}} > 0) + N(C_{\widehat{T}} < 0)}, \quad \overline{A}_{\widehat{T}} \equiv \frac{\overline{N}(-\overline{C}_{\widehat{T}} > 0) - \overline{N}(-\overline{C}_{\widehat{T}} < 0)}{\overline{N}(-\overline{C}_{\widehat{T}} > 0) + \overline{N}(-\overline{C}_{\widehat{T}} < 0)}, \tag{6}$$

where $N(\overline{N})$ is the number of Λ_b^0 ($\overline{\Lambda}_b^0$) signal candidates. These asymmetries are measured from the angular distributions of the decay products, with $C_{\widehat{T}}$ being proportional to $\sin\chi$ [18], where χ is the angle between the decay planes of the $\mu^+\mu^-$ and pK^- systems in the Λ_b^0 rest frame, as shown in Fig. 2.

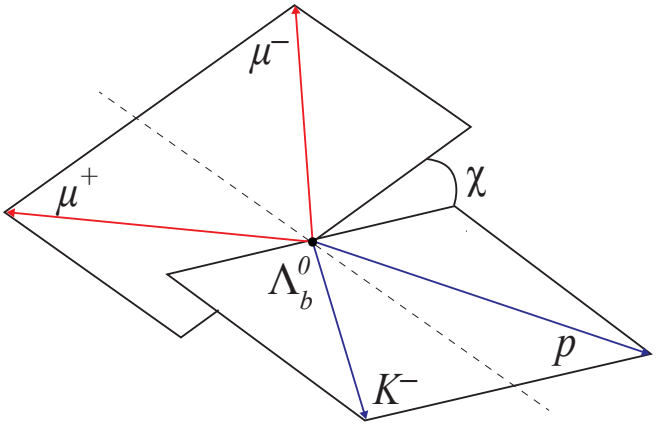

Figure 2: Definition of the angle χ for $\Lambda_b^0 \to pK^-\mu^+\mu^-$ decays, in the Λ_b^0 rest frame.

The observables $A_{\widehat{T}}$ and $\overline{A}_{\widehat{T}}$ are P- and $\widehat{T}$-odd but are not sensitive to CPV effects [17]. Following Ref. [18], CP-odd and P-odd observables are defined as

$$a_{CP}^{\widehat{T}\text{-odd}} \equiv \frac{1}{2}\left(A_{\widehat{T}} - \overline{A}_{\widehat{T}}\right), \qquad a_{P}^{\widehat{T}\text{-odd}} \equiv \frac{1}{2}\left(A_{\widehat{T}} + \overline{A}_{\widehat{T}}\right), \tag{7}$$

where a non-zero value of $a_{CP}^{\widehat{T}\text{-odd}}$ or $a_{P}^{\widehat{T}\text{-odd}}$ would signal CP or parity violation, respectively. These observables are by construction largely insensitive to the Λ_b^0 production asymmetry and detector-induced charge asymmetries.

The observables $\Delta\mathcal{A}_{CP}$ and $a_{CP}^{\widehat{T}\text{-odd}}$ are sensitive to different manifestations of CPV [17]. The CP asymmetry $\mathcal{A}_{CP}$ depends on the interference of $\widehat{T}$-even amplitudes, which can be written as $\mathcal{M}_i^e = a_i^e \exp\left[i(\delta_i^e + \phi_i^e)\right]$, where δ_i^e are CP-even strong phases, $CP(\delta_i^e) = \delta_i^e$, and ϕ_i^e are CP-odd weak phases, $CP(\phi_i^e) = -\phi_i^e$. This convention is such that all CPV effects are encoded in the CP-odd weak phases. The $\widehat{T}$-even and CP-odd part of the differential rate turns out to be

$$\left.\frac{\mathrm{d}\Gamma}{\mathrm{d}\Phi}\right|_{CP-\text{odd}}^{\widehat{T}-\text{even}} \propto a_1^e a_2^e \sin(\delta_1^e - \delta_2^e)\sin(\phi_1^e - \phi_2^e), \tag{8}$$

where only two $\widehat{T}$-even amplitudes are considered for simplicity. Therefore, $\mathcal{A}_{CP}$ is enhanced when the strong phase difference between the two amplitudes is large.
On the other hand, $a_{CP}^{\widehat{T}\text{-odd}}$ depends on the interference between $\widehat{T}$-even and $\widehat{T}$-odd amplitudes, the latter written as $\mathcal{M}_i^o = a_i^o \exp\left[i(\delta_i^o + \phi_i^o + \pi/2)\right]$, following the same convention used for $\widehat{T}$-even amplitudes. The $\widehat{T}$-odd and CP-odd part of the differential rate is therefore

$$\left.\frac{\mathrm{d}\Gamma}{\mathrm{d}\Phi}\right|_{CP-\text{odd}}^{\widehat{T}-\text{odd}} \propto a_1^e a_1^o \sin(\delta_1^e - \delta_1^o)\sin(\phi_1^e - \phi_1^o), \tag{9}$$

where one $\widehat{T}$-even and one $\widehat{T}$-odd amplitudes are considered for simplicity. As a consequence, $a_{CP}^{\widehat{T}\text{-odd}}$ is enhanced when the strong phase difference vanishes. Furthermore, the observables $\Delta\mathcal{A}_{CP}$ and $a_{CP}^{\widehat{T}\text{-odd}}$ 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 $(15 + 29/p_{\rm T})\,\mu$m, where $p_{\rm T}$ 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 $\Lambda_b^0 \to pK^- J/\psi$ 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 [24], in which final-state radiation is generated using Photos [25]. The interaction of the generated particles with the detector, and its response, are implemented using the Geant4 toolkit [26], as described in Ref. [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 $\Lambda_b^0 \to pK^-\mu^+\mu^-$ 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 Λ_b^0 flavour is determined from the charge of the kaon candidate, *i.e.* Λ_b^0 for negative and $\overline{\Lambda}_b^0$ 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/ψ, and $\psi(2S)$ mesons, respectively.

Several background contributions from exclusive decays are identified and rejected. These are $B_s^0 \to K^+K^-\mu^-\mu^+$ and $\overline{B}^0 \to K^-\pi^+\mu^+\mu^-$ decays, in which a kaon or a pion is misidentified as a proton, and $\Lambda_b^0 \to pK^-\mu^+\mu^-$ decays, in which proton and

kaon assignments are interchanged. Background also arises from $\Lambda_b^0 \to pK^- J/\psi$ and $\Lambda_b^0 \to pK^-\psi(2S)$ 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 $B_s^0 \to K^+K^-\mu^-\mu^+$ 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 [28, 29] with an adaptive boosting algorithm [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 [31, 32]. Simulated $\Lambda_b^0 \to pK^-\mu^+\mu^-$ 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, $m(pK^-\mu^+\mu^-) > 5800\,\text{MeV}/c^2$, 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 $m(pK^-\mu^+\mu^-) \in [5400, 5800]\,\text{MeV}/c^2$, the BDT classifier retains only 0.14% of the combinatorial background candidates, with a signal efficiency of 51%. Events in which more than one Λ_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 $\Lambda_b^0 \to pK^- J/\psi$, 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 $\Delta\mathcal{A}_{CP}$ measurement, the data are divided into two subsamples according to the Λ_b^0 flavour. For the measurements of the triple-product asymmetries, four subsamples are defined by the combination of the Λ_b^0 flavour and the sign of $C_{\widehat{T}}$ (or $\overline{C}_{\widehat{T}}$ for $\overline{\Lambda}_b^0$). The reconstruction efficiencies are studied with simulated events and are found to be equal for all subsamples.

The observable $\Delta\mathcal{A}_{CP}$ can be sensitive to kinematic differences between the signal and control-mode decays that affect the cancellation of the detection asymmetries in Eq. 3. This is taken into account by assigning a weight to each $\Lambda_b^0 \to pK^- J/\psi$ candidate such that the resulting proton and kaon momentum distributions match those of the signal $\Lambda_b^0 \to pK^-\mu^+\mu^-$ decays. These weights are determined from simulation samples for the signal and control modes. No such weighting is required for $a_{CP}^{\widehat{T}\text{-odd}}$ and $a_P^{\widehat{T}\text{-odd}}$, since these observables involve only one decay mode.

The asymmetry $\mathcal{A}_{\text{raw}}$ is determined from a simultaneous extended maximum likelihood unbinned fit to the Λ_b^0 and $\overline{\Lambda}_b^0$ invariant mass distributions. The $A_{\widehat{T}}$ and $\overline{A}_{\widehat{T}}$ 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 $\mathcal{A}_{\rm raw}$ is incorporated in the fit model as

$$N_{\overline{\Lambda}_b^0} = N_{\Lambda_b^0} \frac{1 - \mathcal{A}_{\rm raw}}{1 + \mathcal{A}_{\rm raw}}, \tag{10}$$

and $\Delta\mathcal{A}_{CP}$ is derived from the raw asymmetries measured in the signal and control modes according to Eq. 3. The asymmetries $A_{\widehat{T}}$ and $\overline{A}_{\widehat{T}}$ are included in the fit as

$$\begin{aligned} N_{\Lambda_b^0, C_{\widehat{T}}>0} &= \tfrac{1}{2} N_{\Lambda_b^0}(1 + A_{\widehat{T}}), \quad & N_{\Lambda_b^0, C_{\widehat{T}}<0} &= \tfrac{1}{2} N_{\Lambda_b^0}(1 - A_{\widehat{T}}), \\ N_{\overline{\Lambda}_b^0, -\overline{C}_{\widehat{T}}>0} &= \tfrac{1}{2} N_{\overline{\Lambda}_b^0}(1 + \overline{A}_{\widehat{T}}), \quad & N_{\overline{\Lambda}_b^0, -\overline{C}_{\widehat{T}}<0} &= \tfrac{1}{2} N_{\overline{\Lambda}_b^0}(1 - \overline{A}_{\widehat{T}}), \end{aligned} \tag{11}$$

and the observables $a_{CP}^{\widehat{T}\text{-odd}}$ and $a_{P}^{\widehat{T}\text{-odd}}$ are computed from $A_{\widehat{T}}$ and $\overline{A}_{\widehat{T}}$, 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 $\Lambda_b^0 \to pK^-\mu^+\mu^-$ and $\Lambda_b^0 \to pK^- J/\psi$ candidates, with fit results superimposed, are shown in Fig. 3. The $\mathcal{A}_{\rm raw}$ asymmetries are found to be $(-2.8 \pm 5.0) \times 10^{-2}$ for signal decays and $(2.0 \pm 0.7) \times 10^{-2}$ for the control mode, which yields efficiency-uncorrected $\Delta\mathcal{A}_{CP} = (-4.8 \pm 5.0) \times 10^{-2}$. The total signal yields from the fits to the data are 600 ± 44 candidates for $\Lambda_b^0 \to pK^-\mu^+\mu^-$, and $22\,911 \pm 230$ for $\Lambda_b^0 \to pK^- J/\psi$ decays. The uncertainties are statistical only. This represents the first observation of the $\Lambda_b^0 \to pK^-\mu^+\mu^-$ decay mode.

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

6 Systematic uncertainties

The analysis method depends upon the weighting procedure discussed in Sec. 5 to equalise the kinematic distributions of the protons and kaons between the signal and control modes. For $\Delta\mathcal{A}_{CP}$, 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 $a_{CP}^{\widehat{T}\text{-odd}}$ and $a_{P}^{\widehat{T}\text{-odd}}$, and therefore no systematic uncertainty is assigned. Instead, the effects of selection and detector acceptance on the triple-product asymmetries are estimated by measuring $a_{CP}^{\widehat{T}\text{-odd}}(pK^- J/\psi)$ on the control mode, $\Lambda_b^0 \to pK^- J/\psi$. 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 $a_{CP}^{\widehat{T}\text{-odd}}$ and $a_{P}^{\widehat{T}\text{-odd}}$. 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 $\Delta\mathcal{A}_{CP}$, of $+0.6 \times 10^{-2}$ on $a_{CP}^{\widehat{T}\text{-odd}}$ and of -1.4×10^{-2} on $a_{P}^{\widehat{T}\text{-odd}}$. A systematic uncertainty is assigned by varying the efficiencies

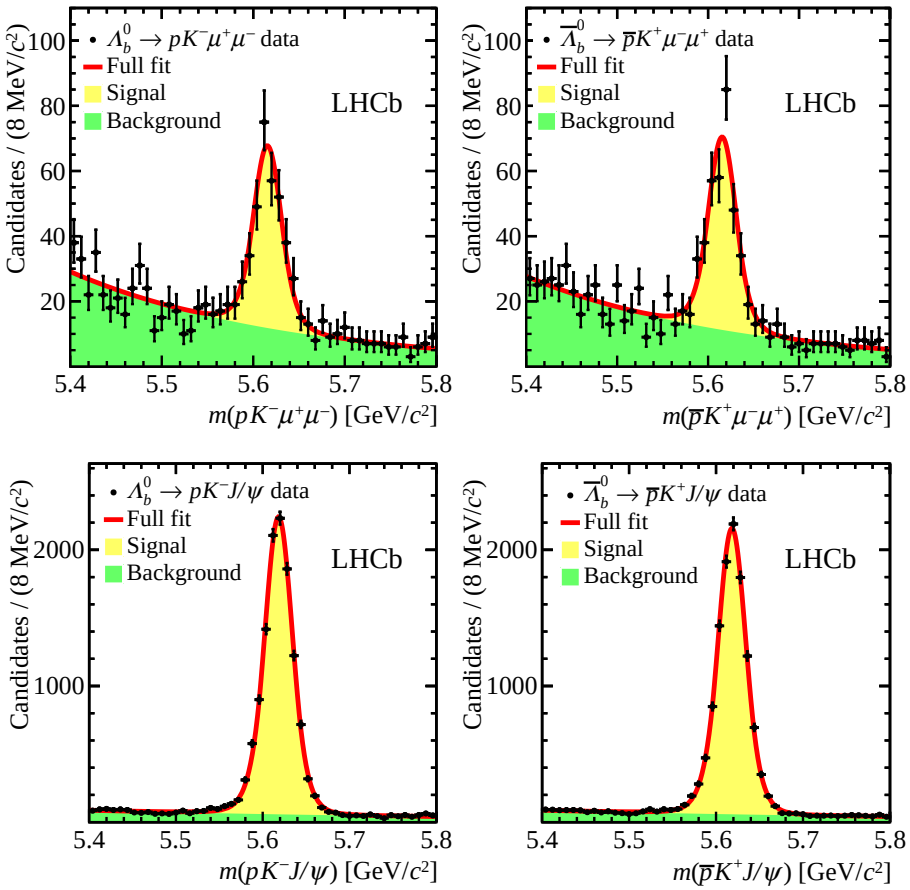

Figure 3: Invariant mass distributions of (top) $\Lambda_b^0 \to pK^-\mu^+\mu^-$ and (bottom) $\Lambda_b^0 \to pK^-J/\psi$ candidates, with fit results superimposed. Plots refer to the (left) Λ_b^0 and (right) $\overline{\Lambda}_b^0$ subsamples.

within their uncertainties. This amounts to $\pm\, 0.10 \times 10^{-2}$ for the $\Delta\mathcal{A}_{CP}$ observable and to $\pm\, 0.02 \times 10^{-2}$ for $a_{CP}^{\widehat{T}\text{-odd}}$ and $a_P^{\widehat{T}\text{-odd}}$.

The above effects are the dominant sources of systematic uncertainties. Other possible sources of systematic uncertainties are considered. The experimental resolution on $C_{\widehat{T}}$ 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 Λ_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 $\Lambda_b^0 \to pK^-\mu^+\mu^-$ is performed with a data sample containing 600 ± 44 signal decays, this representing the first observation of this Λ_b^0 decay mode. Two different CP-violating observables that are sensitive to different manifestations of CP violation, $\Delta\mathcal{A}_{CP}$ and $a_{CP}^{\widehat{T}\text{-odd}}$, are measured. The parity-violating

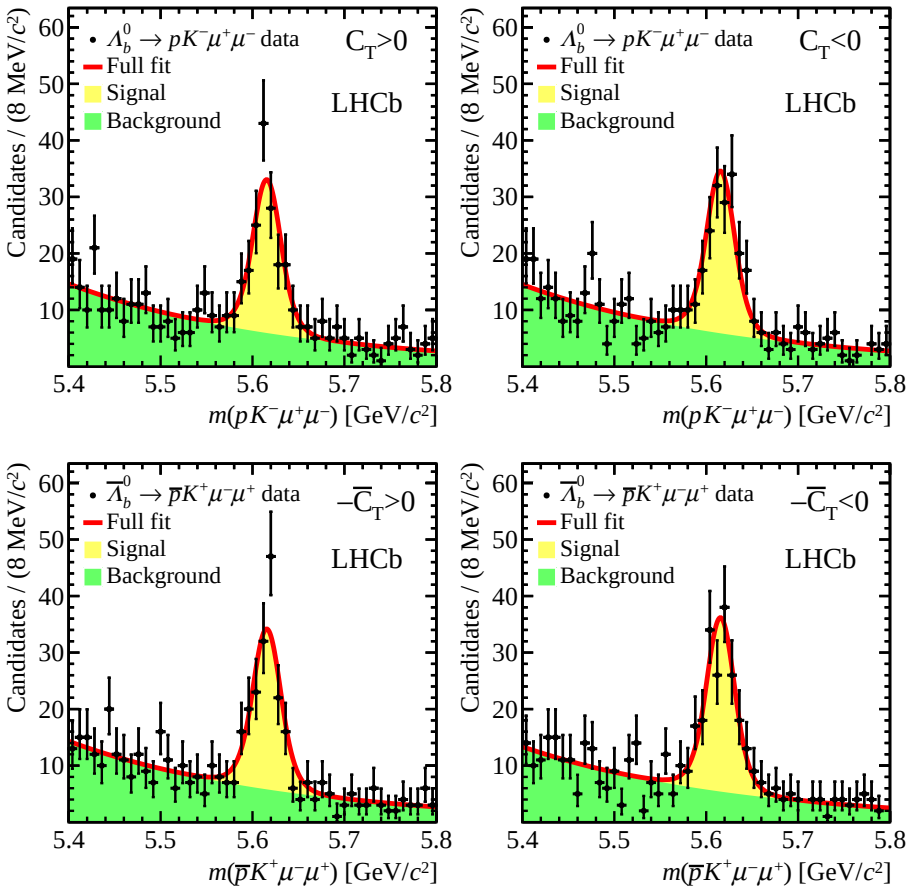

Figure 4: Invariant mass distributions of the $\Lambda_b^0 \to pK^-\mu^+\mu^-$ subsamples used for the $A_{\widehat{T}}$ and $\overline{A}_{\widehat{T}}$ measurements. Plots refer to (top) Λ_b^0 and (bottom) $\overline{\Lambda}_b^0$ decays divided into the subsamples (left) $C_{\widehat{T}} > 0, -\overline{C}_{\widehat{T}} > 0$ and (right) $C_{\widehat{T}} < 0, -\overline{C}_{\widehat{T}} < 0$.

observable $a_P^{\widehat{T}\text{-odd}}$ is also measured. The values obtained are

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

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

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

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 $b \to s\mu^+\mu^-$ transitions in B^0 and B^+ meson decays.

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