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Search for CP violation in $\Lambda_b^0 \to pK^-$ and $\Lambda_b^0 \to p\pi^-$ decays at LHCb

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Summary. — The LHCb experiment at the Large Hadron Collider has been designed to perform high-precision flavour-physics measurements. In particular, CP-violation measurements are of great importance to shed light on some open issues related to the baryon asymmetry in the Universe and to find evidence for physics beyond the Standard Model. A search for CP violation in $\Lambda_b^0 \to pK^-$ and $\Lambda_b^0 \to p\pi^-$ decays using an integrated luminosity of 3.0 fb^{-1} collected by the LHCb experiment during Run 1 is presented. The CP asymmetries are found to be $A_{CP}(pK^-) = -0.020 \pm 0.013 \pm 0.019$ and $A_{CP}(p\pi^-) = -0.035 \pm 0.017 \pm 0.020$, where the first uncertainties are statistical and the second systematic. No evidence for CP violation is found.

The violation of the CP symmetry in charmless two-body b-meson decays is well established [1] and it is interesting to search for it also in b-baryon decays proceeding through the same quark-level transitions. The decays of Λ_b^0 baryons to two-body charmless final states pK^- and $p\pi^-$ are expected to exhibit CP asymmetries at the level of 6% in the generalised factorisation approach [2] and as large as 30%, although with sizeable uncertainties, in the perturbative quantum-chromodynamics formalism [3]. The only available measurement of such quantities has been performed by the CDF Collaboration and the CP asymmetries have been found to be compatible with zero within uncertainties of about 9% [4].

The CP asymmetries can be expressed as the sum of various components,

$$A_{CP}^{pK^-} = A_{\rm raw}^{pK^-} - A_{\rm D}^{p} - A_{\rm D}^{K^-} - A_{\rm P}^{\Lambda_b^0} - A_{\rm PID}^{pK^-} - A_{\rm trigger}^{pK^-}, \quad (1)$$

$$A_{CP}^{p\pi^-} = A_{\rm raw}^{p\pi^-} - A_{\rm D}^{p} - A_{\rm D}^{\pi^-} - A_{\rm P}^{\Lambda_b^0} - A_{\rm PID}^{p\pi^-} - A_{\rm trigger}^{p\pi^-}, \quad (2)$$

where $A_{\rm raw}^{f}$ is the raw asymmetry of the final states $f = pK^-,\ p\pi^-$, $A_{\rm D}^{h}$ (with $h = p,\ K^-$ and π^-) are the proton, kaon and pion detection asymmetries, $A_{\rm P}^{\Lambda_b^0}$ is the

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Λ_b^0 production asymmetry, $A^f_{\rm PID}$ are the asymmetries in the particle-identification (PID) efficiencies of the two final states and $A^f_{\rm trigger}$ are the asymmetries in the trigger efficiencies of the final-state particles. The inclusion of charge-conjugate processes is implied throughout.

The raw asymmetry of the final state f is defined as

$$A^f_{\rm raw} = \frac{N_{\rm sig}(\Lambda_b^0 \to f) - N_{\rm sig}(\overline{\Lambda}{}_b^0 \to \overline{f})}{N_{\rm sig}(\Lambda_b^0 \to f) + N_{\rm sig}(\overline{\Lambda}{}_b^0 \to \overline{f})}, \tag{3}$$

where $N_{\rm sig}$ denotes the observed signal yield, with $f = pK^-$ ($p\pi^-$) and $\overline{f}$ its charge conjugate.

Particle-identification criteria are applied to the final-state particles to divide the total sample into mutually exclusive subsamples corresponding to the final-state hypotheses pK^-, $\overline{p}K^+$, $p\pi^-$ and $\overline{p}\pi^+$. The final states $K^+\pi^-$, π^+K^-, K^+K^- and $\pi^-\pi^-$ are also selected to study the background due to other B-hadron decays. A multivariate classifier is employed to reduce the level of combinatorial background.

The raw asymmetries are measured by means of simultaneous binned extended maximum-likelihood fits to the invariant-mass distributions of pK^-, $\overline{p}K^+$, $p\pi^-$ and $\overline{p}\pi^+$, $K^+\pi^-$, π^+K^-, K^+K^- and $\pi^-\pi^-$ final states. The signal components are modelled by means of power-law functions, accounting for the emission of photons in the final state, convolved with the sum of two Gaussian functions. The combinatorial background is parameterised with an exponential function, whereas the partially reconstructed background due to decays where one or more particles are missed, is described by ARGUS [5] functions. Finally, the backgrounds due to the misidentification of one or both final-state particles are modelled with shapes obtained from simulated events.

The pK^-, $\overline{p}K^+$, $p\pi^-$ and $\overline{p}\pi^+$ invariant-mass distributions are shown in fig. 1, with the result of the fits overlaid to the data points. The raw asymmetries of $\Lambda_b^0 \to pK^-$ and $\Lambda_b^0 \to p\pi^-$ decays are found to be $A^{pK^-}_{\rm raw} = 0.010 \pm 0.013$ and $A^{p\pi^-}_{\rm raw} = 0.005 \pm 0.017$.

The determination of the instrumental asymmetries is a crucial ingredient in order to obtain the CP asymmetries. The kaon detection asymmetry is obtained by subtracting the raw asymmetries of $D^+ \to K^0_S\pi^+$ and $D^+ \to K^-\pi^+\pi^+$ control samples and correcting for the K^0 [6] and pion detection asymmetries. The latter is obtained using $D^{*+} \to D^0(\to K^-\pi^+\pi^-\pi^+)\pi^+$ decays and taking the ratio of partially to fully reconstructed candidates to obtain efficiencies from which an asymmetry is computed. The proton detection asymmetry is estimated employing simulated events, since no measurements of this quantity are available yet. Particle identification asymmetries are calculated from the PID efficiencies obtained from large calibration samples of $D^{*+} \to D^0(\to K^-\pi^+)\pi^+$, $\Lambda^0 \to p\pi^-$ and $\Lambda_c^+ \to pK^-\pi^+$ decays and with the aid of simulated events in the phase-space region not covered by calibration data. The Λ_b^0 production asymmetry is taken from a previous LHCb measurement [7] and the trigger asymmetries are estimated with data-driven techniques. Systematic uncertainties related to the choice of the fit model and the determination of the PID efficiencies are assessed using pseudoexperiments.

The following CP asymmetries are obtained:

$$A^{pK^-}_{CP} = -0.020 \pm 0.013 \pm 0.019,$$
$$A^{p\pi^-}_{CP} = -0.035 \pm 0.017 \pm 0.020,$$

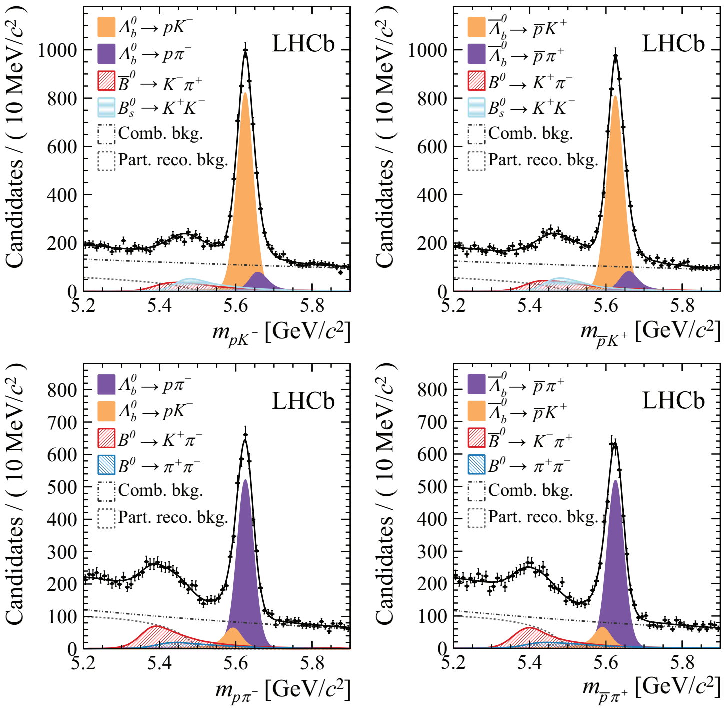

Fig. 1. – Invariant-mass distributions of (top left) pK^-, (top right) $\overline{p}K^+$, (bottom left) $p\pi^-$ and (bottom right) $\overline{p}\pi^+$ candidates. The result of the fits is overlaid to the data points.

where the first uncertainties are statistical and the second systematic. No evidence for CP violation is found. These are the world's best measurements to date, with better precision with respect to previous CDF determinations [4].

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