Search for *CP* violation in $\Lambda_b^0 \to pK^-\mu^+\mu^-$ decays at LHCb

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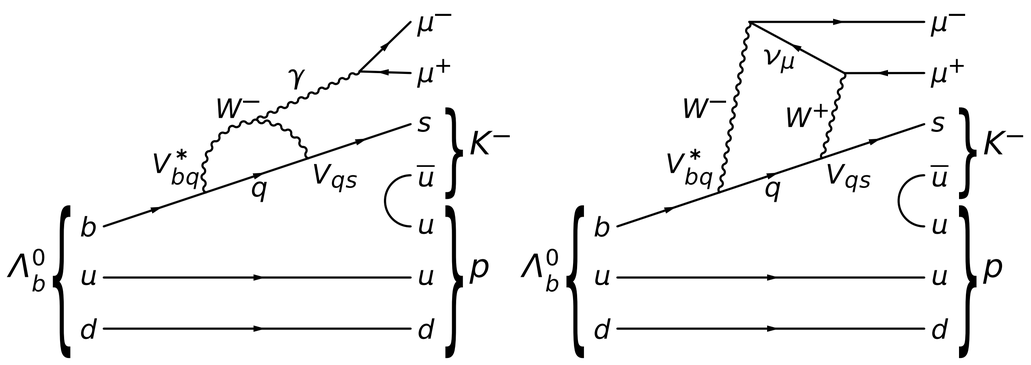
Motivation

- ***CP*** symmetry **violation** (CPV) in particle decays successfully described by the **Cabibbo-Kobayashi-Maskawa** (CKM) **mechanism**, but too small to explain the universe **matter-antimatter asymmetry**; new sources of CPV expected to arise from **new physics** beyond the SM.
- First CPV evidence in a **baryon decay** reported by the LHCb experiment in $\Lambda_b^0 \to p\pi^-\pi^+\pi^-$ [1], paving the way for a **systematic study** of CPV in **beauty baryons**.
- The rare, flavour-changing neutral current process $\Lambda_b^0 \to pK^-\mu^+\mu^-$ is described by loop diagrams in the Standard Model (SM), in which **new particles** may provide **additional CPV** sources.



Feynman diagrams for the decay $\Lambda_b^0 \to pK^-\mu^+\mu^-$, in which $q = u, c, t$, where the dominant contribution comes from the top quark.

- CPV in $\Lambda_b^0 \to pK^-\mu^+\mu^-$ **suppressed** by the hierarchical structure of the CKM mechanism, making it particularly sensitive to CPV from **physics beyond the SM**.

CP-violating observables

- Two *CP*-violating observables are measured, the first extracted from the asymmetry between Λ_b^0 and $\overline{\Lambda}_b^0$ decays

$$\mathcal{A}_{\text{raw}} \equiv \frac{N(\Lambda_b^0) - N(\overline{\Lambda}_b^0)}{N(\Lambda_b^0) + N(\overline{\Lambda}_b^0)} = \mathcal{A}_{CP} + \mathcal{A}_{\text{prod}}(\Lambda_b^0) + \mathcal{A}_{\text{det}}(K^-) + \mathcal{A}_{\text{det}}(p).$$

Non-CPV terms cancelled exploiting **Cabibbo-favoured** decays $\Lambda_b^0 \to pK^-J/\psi(\to \mu^+\mu^-)$, defining

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

- The second built from **triple products** of particle **momenta**, sensitive to the **angular distribution** of the decay

$$C_{\hat{T}} \equiv \vec{p}_{\mu^+} \cdot (\vec{p}_p \times \vec{p}_{K^-}), \qquad \overline{C}_{\hat{T}} \equiv \vec{p}_{\mu^-} \cdot (\vec{p}_{\bar{p}} \times \vec{p}_{K^+}),$$

and taking the asymmetries

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

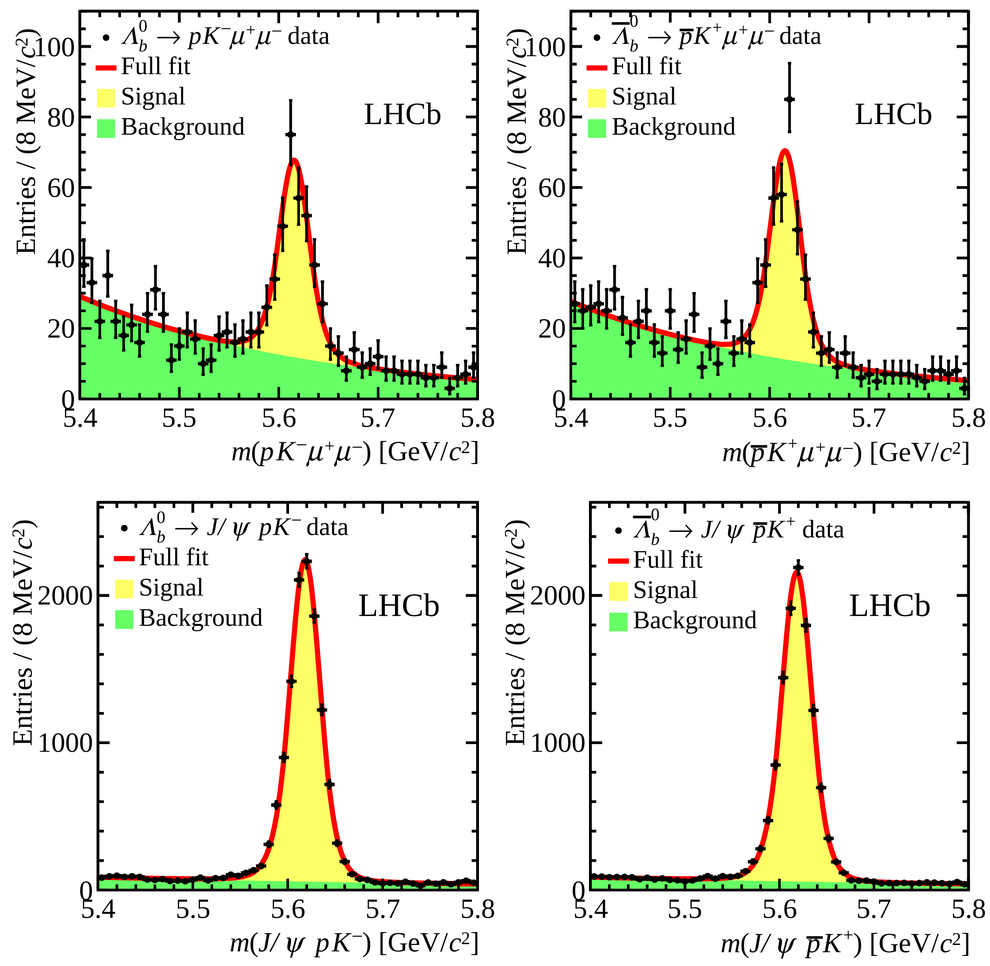
- Their difference is ***CP*-odd**, the sum is **parity-odd**

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

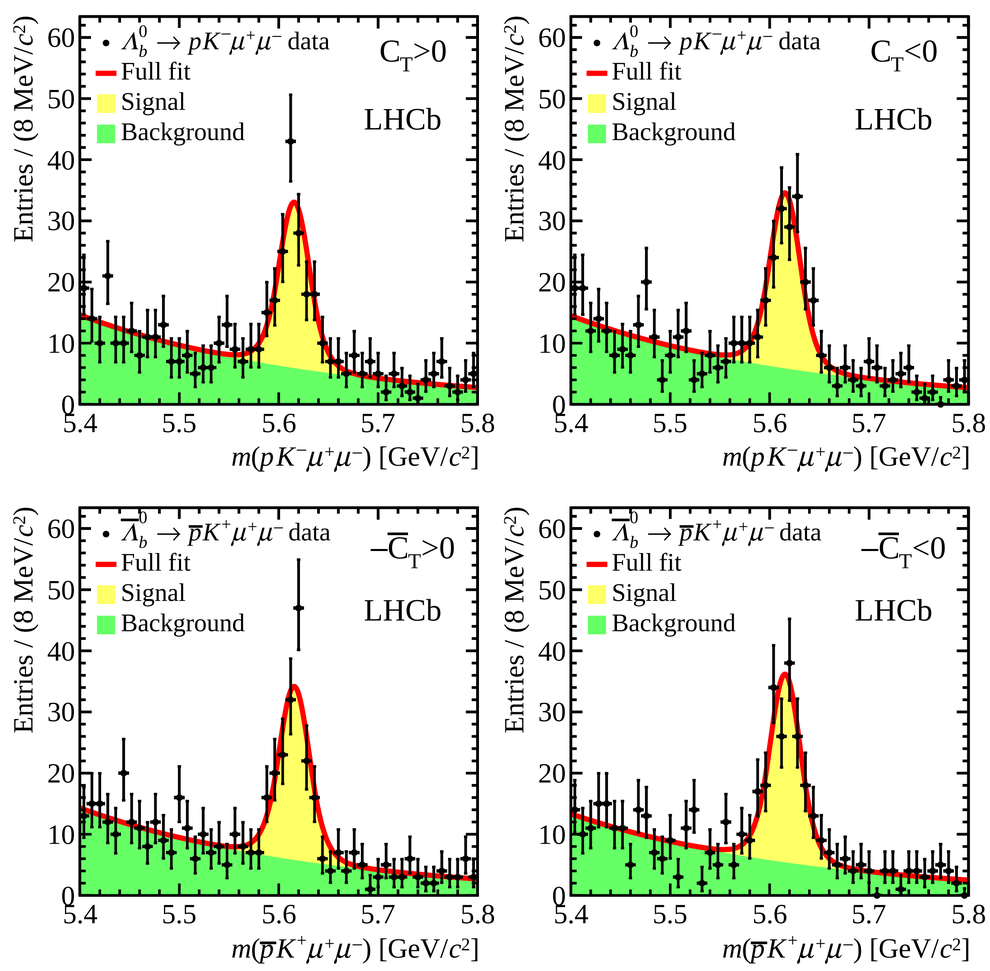
- $\Delta\mathcal{A}_{CP}$ and $a_{CP}^{\hat{T}\text{-odd}}$ transform differently under parity and motion-reversal operations, resulting in **different sensitivities to CPV**.

Data analysis

- Analysis performed using *pp* collisions recorded by the **LHCb** experiment during **LHC Run I** (2011-12, $3\,\text{fb}^{-1}$).
- Signal selection exploiting the unique **hadron** and **muon identification** capabilities of the LHCb experiment and a refined **multivariate classification** retaining only 0.14% of combinatorial background and 51% of signal candidates.
- Yields from maximum likelihood fits: $\Lambda_b^0 \to pK^-\mu^+\mu^-$: 600 ± 44, $\Lambda_b^0 \to pK^-J/\psi$: $22\,900 \pm 230$.
- Applied corrections for kinematic differences between signal and Cabibbo-favoured decays and detector efficiency; Corresponding systematic uncertainties are the sole important contributions.



Fits used in the $\mathcal{A}_{raw}$ extraction from (top) $\Lambda_b^0 \to pK^-\mu^+\mu^-$ and (bottom) $\Lambda_b^0 \to pK^-J/\psi$ decay modes.



Fits used in the $A_{\hat{T}}$ and $\overline{A}_{\hat{T}}$ extraction

Conclusions

- Measured values **compatible** with ***CP*** and **parity conservation**, in agreement with SM expectations [2, 3]

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

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

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

- **Statistical precision** envisaged to be $\sim 2 \times 10^{-2}$ after **LHC Run II**, pushing forward the search for **new sources of *CP* violation**.

References

[1] LHCb collaboration, R. Aaij *et al.*, *Probing matter-antimatter asymmetries in beauty baryon decays*, Nature Physics (2017) doi:10.1038/nphys4021.

[2] A. K. Alok *et al.*, *New physics in $b \to s\mu^+\mu^-$: CP-violating observables*, JHEP **11** (2011) 122, arXiv:1103.5344.

[3] M. A. Paracha *et al.*, *Imprints of CP violation asymmetries in rare $\Lambda_b \to \Lambda\ell^+\ell^-$ decay in family non-universal Z' model*, PTEP (2015) , arXiv:1408.4318.