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Searches for direct *CP* violation in charm hadrons at LHCb

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The amount of *CP* violation predicted by the Standard Model is too small by many orders of magnitude to explain our matter-dominated universe. New sources need therefore to be uncovered. LHCb is searching for new physics that might enhance *CP* violation. These proceedings present the latest results of searches for direct *CP* violation in the charm sector at LHCb.

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1 Introduction

The observed matter dominance of the universe cannot be explained by standard model (SM) sources of *CP* violation alone, which lead to a baryon asymmetry orders-of-magnitude smaller than observed [1, 2]. New sources of *CP* violation are therefore needed, and form the basis of a wide programme of searches at LHCb. No *CP* violation has been observed yet in the up-type sector. *CP* violation in the charm system is predicted to be very small by the SM [3, 4]. This therefore represents a low SM background environment for New Physics (NP) searches.

The LHCb detector has collected the largest sample of charm decays with very good momentum resolution and tracking efficiency, as well as excellent vertex resolution [5]. LHCb is currently the best place to perform precision measurements searching for *CP* violation in charm. These proceedings present the latest results on direct *CP* violation searches in the charm sector at LHCb.

2 A measurement of the *CP* asymmetry difference between $\Lambda_c^+ \to pK^+K^-$ and $\Lambda_c^+ \to p\pi^+\pi^-$

While many high-precision searches for *CP* violation have been performed in charm-meson decays, the corresponding experimental constraints in the charm baryon sector are much weaker, with only a handful of low-statistics measurements. Recently, *CP* violation was searched for in Λ_c^+ decays to ph^+h^-, through the difference in *CP* asymmetries of pK^+K^- and $p\pi^+\pi^-$ final states [6].

This analysis is based on a data sample corresponding to an integrated luminosity of 3.0 fb^{-1} collected in 2011 and 2012 (Run 1 data). The production mode is $\Lambda_b^0 \to \Lambda_c^+\mu^-X$ and the raw asymmetry is computed as

$$A_{\text{raw}}(f) = A_{\text{prod}}(\Lambda_b^0) + A_{\text{det}}(f)A_{\text{tag}}(\mu) + A_{CP}(f), \text{ with } f = pK^+K^-, p\pi^+\pi^- \,. \tag{1}$$

In order to cancel the experimental effects, the difference of the two raw asymmetries is taken to obtain ΔA_{CP}. The kinematics of the two final states are however not the same and cannot be cancelled out directly. Therefore, the $p\pi^+\pi^-$ final state is reweighted to match the pK^+K^- one. The reweighting is performed on the Λ_c^+ transverse momentum and pseudorapidity and on the proton transverse momentum using a decision tree with gradient boosting (GBDT). The weight function is also published in order to allow comparisons with theoretical predictions. A weighted ΔA_{CP} is therefore quoted

$$\Delta A_{CP}^{\text{wgt}} = A_{\text{raw}}(pK^+K^-) - A_{\text{raw}}^{\text{wgt}}(p\pi^+\pi^-) \,. \tag{2}$$

The mass distributions of the Λ_c^+ for the two final states are shown in Fig. 1. The signal yields are found to be 25190 ± 200 and 161390 ± 580 for the pK^+K^- and $p\pi^+\pi^-$ final states respectively. And the weighted ΔA_{CP} is measured to be

$$\Delta A_{CP}^{\text{wgt}} = (3.0 \pm 9.1 \pm 6.1) \times 10^{-3}, \tag{3}$$

which is compatible with no *CP* violation. This is the first measurement of *CP* parameters in three-body Λ_c^+ decays.

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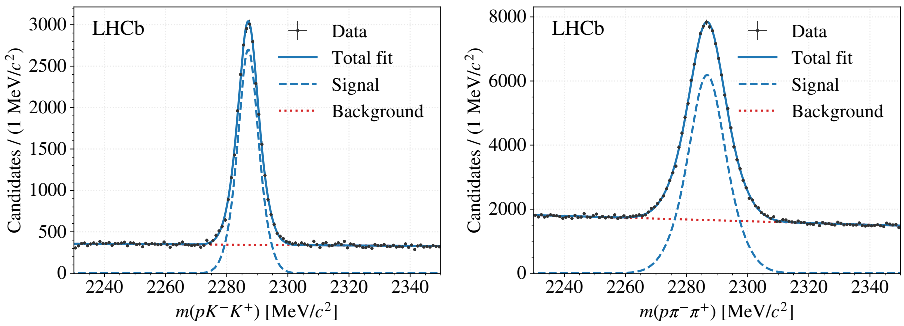

Figure 1: Invariant mass distribution of the pK^+K^- (left) and $p\pi^+\pi^-$ (right) final states.

3 Search for *CP* violation in the phase space of $D^0 \to \pi^+\pi^-\pi^+\pi^-$

Multibody charm decays have a rich resonant structure that might enhance the sensitivity to local *CP* asymmetries in the phase space. A recent analysis [7] applied for the first time the energy test [8] to a four-body decay, namely $D^0 \to \pi^+\pi^-\pi^+\pi^-$.

This analysis is also based on Run 1 data and is using the production mode $D^{*+} \to D^0\pi^+$. This results in a very pure sample of more than one million signal candidates. The energy test is a model independent unbinned method sensitive to local *CP* violation in the phase space. It uses a test statistic, T, to compare average distances between events split in two subsamples. It is defined as

$$T = \sum_{i,j>i}^{n} \frac{\psi_{ij}}{n(n-1)} + \sum_{i,j>i}^{\overline{n}} \frac{\psi_{ij}}{\overline{n}(\overline{n}-1)} - \sum_{i,j}^{n,\overline{n}} \frac{\psi_{ij}}{n\overline{n}}, \tag{4}$$

where ψ_{ij} is a Gaussian function

$$\psi_{ij} = \psi(d_{ij}) = e^{d_{ij}^2/2\delta^2} \tag{5}$$

of tunable width δ, where d_{ij} is a metric computing the distance between two space points in the five-dimensional phase space. The test statistic T therefore compares the average distances between the n events of the first sample, the average distances between the $\overline{n}$ events of the second sample and the average distances between all the events.

Two tests are performed, depending on how the dataset is split. The P-even test splits the dataset between the D^0 and $\overline{D}^0$ decays. The P-odd test makes use of the triple-product to split the dataset. The triple-product C_T is defined for D^0 decays as

$$C_T = \vec{p}_1 \cdot (\vec{p}_2 \wedge \vec{p}_3), \tag{6}$$

where $\vec{p}_i$ are the three-momenta of the daughter particles. For the $\overline{D}^0$ decays, the corresponding triple-product is obtained by applying the *CP* transformation $CP(C_T) = -C(C_T) = -\overline{C}_T$. The data is then split with respect to the sign of this triple-product.

The values of T, obtained with the two nominal splittings, are compared to a null-test. The dataset is split randomly many times in order to build a distribution of the "no *CP* violation" hypothesis. The p-value for the P-even test is $(4.6 \pm 0.5)\%$. The p-value for the P-odd test is $(0.6 \pm 0.2)\%$ corresponding to a significance of *CP* violation of 2.7σ. This is still compatible with no *CP* violation, but it might become significant when more statistics will be added.

4 Measurement of the time-integrated *CP* asymmetry in $D^0 \to K^0_S K^0_S$ decays

It has been shown that $D^0 \to K^0_S K^0_S$ decays are a fruitful place to look for *CP* violation in the charm sector (e.g. see Ref. [9]). This exact search has recently been performed at LHCb [10].

This analysis is based on a data sample corresponding to an integrated luminosity of 2.0 fb^{-1} collected in 2015 and 2016. The production mode is also $D^{*+} \to D^0\pi^+$ and the raw asymmetry is defined as

$$A_{\text{raw}}(K^0_S K^0_S) = A_{\text{prod}}(D^{*+}) + A_{\text{tag}}(\pi^+) + A_{CP}(K^0_S K^0_S), \tag{7}$$

where no detection asymmetries arise from the daughter particles of the D^0 since they are symmetric. The total number of signal candidates in this analysis is 1067 ± 41. The experimental effects are removed by using $D^0 \to K^+K^-$ as control channel [11]:

$$\Delta A_{CP} = A_{\text{raw}}(K^0_S K^0_S) - A_{\text{raw}}(K^+K^-)\,. \tag{8}$$

The *CP* asymmetry of $D^0 \to K^0_S K^0_S$ can therefore be retrieved using the measured value from $D^0 \to K^+K^-$: $A_{CP}(K^0_S K^0_S) = \Delta A_{CP} + A_{CP}(K^+K^-)$. The *CP* asymmetry is found to be $A_{CP} = (4.2 \pm 3.4 \pm 1.0)\%$, which is compatible with the results of the Run 1 analysis [12] ($A_{CP} = (-2.9 \pm 5.2 \pm 2.2)\%$). The average between the two analyses is $A_{CP} = (2.0 \pm 2.9 \pm 1.0)\%$.

5 Conclusion

These proceedings presented the highlight of three recent results on searches for direct *CP* violation in charm at LHCb. No *CP* violation has been observed in the charm sector yet. Nevertheless, the sensitivity achieved by these results is reaching the precision of the theory predictions of $10^{-3} - 10^{-4}$ [3,4]. Many more promising results with the entire Run 2 data sample will come soon.

References

[1] P. Huet and E. Sather, Phys. Rev. **D51** (1995) 379, arXiv:hep-ph/9404302.

[2] W. Bernreuther, Lect. Notes Phys. **591** (2002) 237, arXiv:hep-ph/0205279.

[3] F. Buccella *et al.*, Phys. Rev. **D51** (1995) 3478, arXiv:hep-ph/9411286.

[4] A. Khodjamirian and A. A. Petrov, Phys. Lett. **B774** (2017) 235, arXiv:1706.07780.

[5] LHCb collaboration, A. A. Alves Jr. *et al.*, JINST **3** (2008) S08005.

[6] LHCb collaboration, R. Aaij *et al.*, JHEP **03** (2018) 182, arXiv:1712.07051.

[7] LHCb collaboration, R. Aaij *et al.*, Phys. Lett. **B769** (2017) 345, arXiv:1612.03207.

[8] G. Zech and B. Aslan, ArXiv Mathematics e-prints (2003) arXiv:math/0309164.

[9] U. Nierste and S. Schacht, Phys. Rev. Lett. **119** (2017) 251801, arXiv:1708.03572.

[10] LHCb collaboration, R. Aaij *et al.*, arXiv:1806.01642, submitted to JHEP.

[11] LHCb collaboration, R. Aaij *et al.*, Phys. Lett. **B767** (2017) 177, arXiv:1610.09476.

[12] LHCb collaboration, R. Aaij *et al.*, JHEP **10** (2015) 055, arXiv:1508.06087.