Search for local CP violation in the phase-space of $D^0 \to \pi^+\pi^-\pi^0$ decays with the LHCb experiment

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Charge-Parity (CP) violation is one of the Sakharov conditions, necessary to explain the difference between matter and antimatter observed in the universe. However, the standard model (SM) does not include enough CP violation to explain the large matter-antimatter asymmetry we observe, thus motivating searches for abundances in some processes not predicted by the SM.

We can observe CP violation in decays, also called direct CP violation, as the difference in decay rates for a given process with respect to its charge-conjugate process

$$A_{CP}(P \to f) = \frac{\Gamma(P \to f) - \Gamma(\bar{P} \to \bar{f})}{\Gamma(P \to f) + \Gamma(\bar{P} \to \bar{f})}, \tag{1}$$

where $\Gamma(P \to f) \propto |\mathcal{A}(P \to f)|^2$ is the decay rate that is proportional to the square of the amplitude $\mathcal{A}$.

In the charm sector, the predicted amount of CP asymmetry is of the order $\mathcal{O}(10^{-3} - 10^{-4})$. Due to the small size, only one observation has been made so far, as a difference $\Delta A_{CP} = A_{raw}(D^0 \to K^+K^-) - A_{raw}(D^0 \to \pi^+\pi^-)$. This study focuses on the $D^0 \to \pi^+\pi^-\pi^0$ process because it proceeds through the same electroweak decay as $D^0 \to \pi^+\pi^-$ and at the same time provides a non-trivial phase-space, where interferences of different intermediate states can lead to locally enhanced CP violation, even if at global level the amount is not significant.

The data has been collected by the LHCb detector in 2024 and corresponds to 7 fb^{-1} of integrated luminosity. After trigger and offline selections, including MVA training and application for combinatorial background suppression, data sample with a purity of at least 90 % is obtained.

This work uses a model-independent unbinned statistical test, known as the energy test, to test for the existence of local CP violation. In contrast to standard techniques that involve splitting the phase space into regions and measuring the CP asymmetry value for each one, this method does not require accurate modeling of the data or an arbitrary choice of regions that can introduce bias. However, one cannot measure the amount of CP violation or determine its location in the phase space with the energy test. It provides a single p-value, indicating how likely it is that the null hypothesis of CP conservation is true and in case asymmetries are detected, further studies will be required to determine its magnitude and location.