Model-Independent Search for CP violation in $D^0 \to \pi^+\pi^+\pi^0$ in LHCb Run 2

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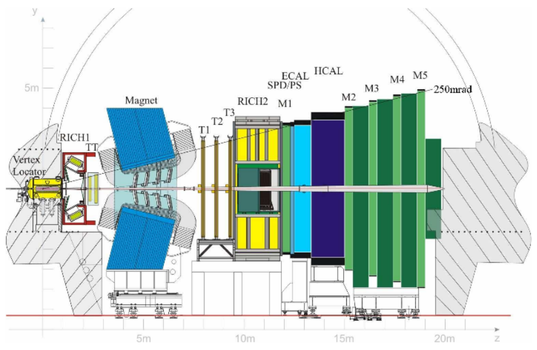
Introduction

CP violation (CPV) has only recently been observed in the charm sector. The Standard Model predicts CPV to be $O(10^{-3})$ This small level of CPV requires techniques which are sensitive to such levels. A model independent method known as the energy test was previously used in the analysis of this decay from Run 1 of LHCb and is subsequently used here. [1]

LHCb Detector

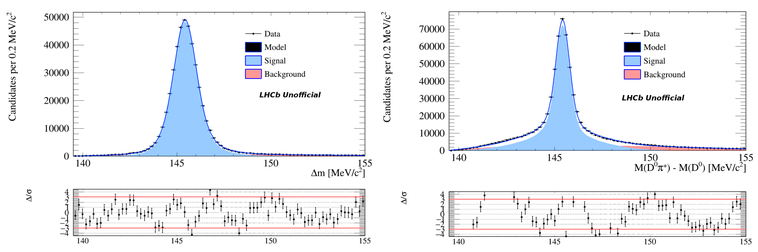
LHCb is a single-arm spectrometer designed to make precision measurements of CP violation and rare decays of B and D mesons.



It has many specialised sub systems for particle identification (muon, RICH1, RICH2) and vertex reconstruction (VELO,IT).[2]

Selection

- Selecting D^0 candidates from $pp \to D^{*\pm}X \to D^0\pi_s^\pm$.
- Distinguish between two types of candidate, **merged**, where photons are measured as a single cluster in the calorimeter and **resolved** where the photons are resolved as separate clusters
- Analysis method validated by topologically similar $D^0 \to K^-\pi^+\pi^0$ decays
- Trigger selection and offline selection applied to data. Final selection based on Multivariate Analysis (MVA)
- MVA based on sWeighted data. Examined the use of BDT variants and neural network models in the TMVA framework.



References

[1] Y. Grossman, A. L. Kagan, and Y. Nir, New Physics and CP Violation in singly Cabibbo suppressed D decays, Phys. Rev. D75 (2007) 036008, arXiv:0609178.

[2] LHCb collaboration, R. Aaij et al., LHCb detector performance, Int. J. Mod. Phys. A30 (2015) 1530022, arXiv:1412.6352.

[3] C. Parkes, S. Chen, J. Brodzicka et al., *On model-independent searches for direct CP violation in multi-body decays*, *J. Phys*,G44(8):085001, 2017. arXiv:1612.04705

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The Energy Test

- Statistical test for determining if two datasets come from the same underlying population [3]
- Test statistic T is calculated as

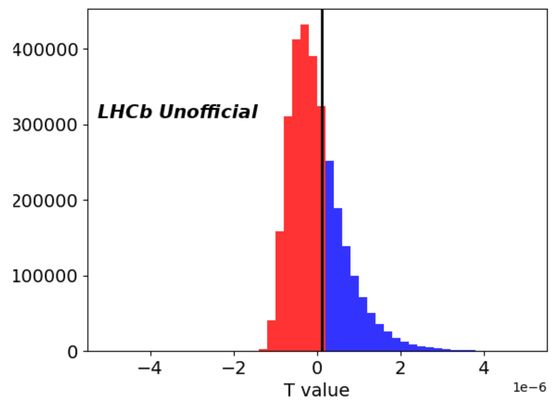
$$T = \sum_{i,j>i}^{n} \frac{\psi_{ij}}{n(n-1)} + \sum_{i,j>i}^{\bar{n}} \frac{\psi_{ij}}{\bar{n}(\bar{n}-1)} - \sum_{i,j}^{n,\bar{n}} \frac{\psi_{ij}}{n\bar{n}}$$

where ψ_{ij} is a function of the distance between two points in phase space, d_{ij} and has the form,

$$\psi_{ij} = e^{\frac{d_{ij}^2}{2\delta^2}}$$

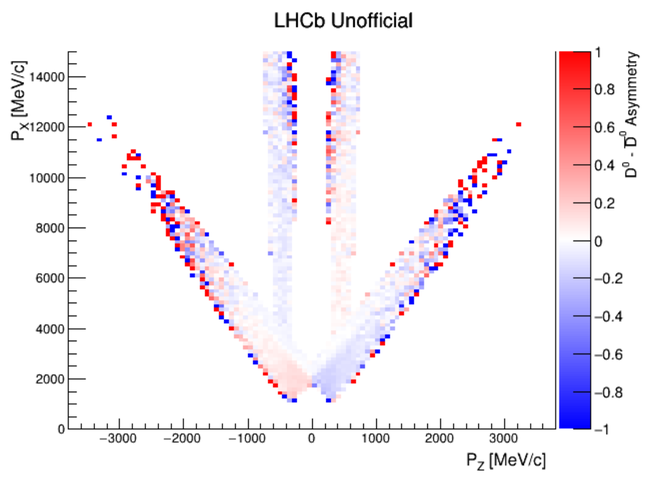
where $\delta = 0.3$ GeV^2/c^4 and selected based on previous sensitivity studies

- Distribution of T values produced by calculating the T value under random assignment of flavour (permutations).
- The fraction of permutation T-values (blue) greater than the nominal T value (black line) is the p-value.

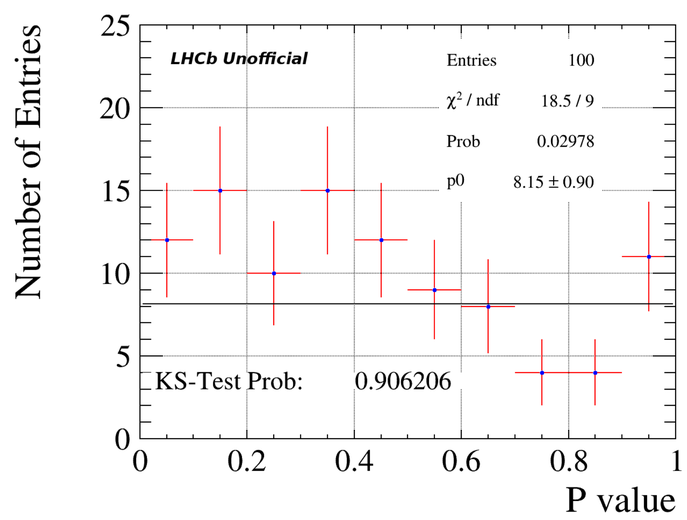


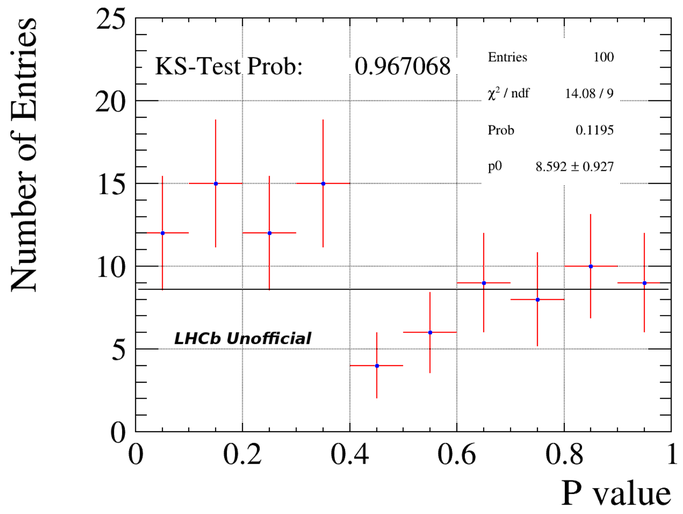
Energy Test - Control Channel

- Cabibbo favoured channel $D^0 \to K^-\pi^+\pi^0$ used to test method. No CPV expected.
- Looked at candidates in areas of detector asymmetries. Any asymmetries here could introduce a bias in final p-values. Split by polarity into 100 unique subsets and apply energy test to obtain a p-value



- Combined control channel yield: 7.5 million
- Control channel split into 8 groups by P_T and energy test applied under null hypothesis of CP symmetry





- Lowest p-value of 0.13, consistent with CP symmetry as expected

Summary and Next Steps

- Control channel selection finalised
- Control sample tested with the energy test
- Finalize selection of signal channel and assess systematic uncertainties
- Apply energy test to signal channel and unblind p-value after approval by collaboration