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Observation of CP violation in an amplitude analysis of $B^+ \to \pi^+\pi^+\pi^-$ decays

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Summary. — The violation of charge-parity (*CP*) symmetry in the Standard Model is driven by a single global phase, however manifestations of *CP*-violating quantities are non-trivial due to the essential role of the strong interaction in generating observable *CP* violation effects. Here we explore how the role of the strong phase in $B^+ \to \pi^+\pi^+\pi^-$ decays, described by the intermediate resonance structure and final-state rescattering effects, governs the manifestation of large *CP* violation.

Model-independent analyses of charmless three-body B^+ decays performed by the LHCb experiment [1] indicate large regions of phase-space where *CP* asymmetries are sizeable. Furthermore, a model-dependent study of the $B^+ \to \pi^+\pi^+\pi^-$ decay by the BaBar experiment [2] gave some evidence for *CP* violation in the $B^+ \to f_2(1270)\pi^+$ decay. Here we present the LHCb analysis of the $B^+ \to \pi^+\pi^+\pi^-$ phase-space [3, 4] on $3\,\text{fb}^{-1}$ of Run 1 LHCb data, where a model of the decay amplitude is explicitly constructed, on a dataset an order of magnitude larger than that of BaBar, with a significantly better signal to background ratio.

The amplitude model is constructed by first considering the resonant structure determined in the BaBar analysis, and adding components according to the increase in the likelihood ratio. These comprise the $\rho(770)^0$, $\omega(782)$, $f_2(1270)$, $\rho(1450)^0$, and $\rho_3(1690)^0$ resonances, along with a spin-0 "S-wave" contribution.

The $\pi\pi$ S-wave contains numerous overlapping resonances and decay channel openings, in addition to being the dominant contribution to the decay amplitude, and therefore is described using three separate approaches, which are then compared. The K-matrix model is a monolithic contribution that uses legacy scattering data to describe a five pole amplitude structure, with rescattering from $\pi\pi$, KK, $\eta\eta$, $\eta\eta'$, and multibody channels. The quasi–model-independent (QMI) approach divides the $\pi^+\pi^-$ mass spectrum into 17 roughly equi-populated bins, and fits directly for the complex amplitude in each bin. Finally, a conventional isobar model (a coherent sum of explicit amplitude contributions)

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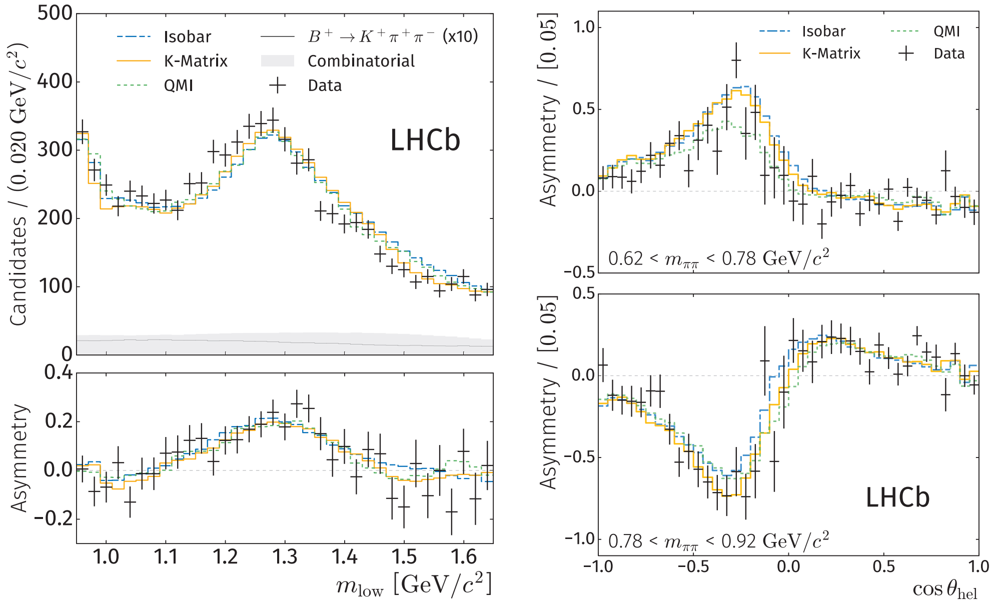

Fig. 1. – Projections of the *CP* asymmetry for data and fits as a function of $\cos\theta_{\rm hel}$ in the regions below (top left) and above (top right) the $\rho(770)^0$ resonance pole; and data and fits (top right) on the low combination of opposite-sign pion pair invariant mass in the $f_2(1270)$ mass region, with (bottom right) the corresponding *CP* asymmetry.

is also used, which incorporates the $f_0(500)$ resonance and a $KK \leftrightarrow \pi\pi$ rescattering component above the KK production threshold.

Models with all three S-wave approaches result in a good description of the data, except in the region around the $f_2(1270)$ resonance, potentially indicating interference with an additional unestablished spin-2 resonance in this region. Despite this, a measurement of the quasi–two-body *CP* asymmetry of the $f_2(1270)$ in each model is around with 40% with a significance in excess of 10 Gaussian standard deviations (σ), (fig. 1(right)).

Furthermore, *CP* violation characteristic of *CP* violation exclusively in the interference between the S-wave component and $\rho(770)^0$ resonance, which disappears when integrating through mass or cosine of the helicity angle, is observed at a level in excess of 25σ (fig. 1(left)). This is the first time such a manifestation of *CP* violation, in the interference between resonant components, has been observed. Additionally, *CP* violation in the S-wave component individually is observed at a level in excess of 10σ, and is the dominant source of *CP* asymmetry at low $m(\pi^+\pi^-)$.

These results are consistent with, and more precise than, previous measurements of this process, and give insight into how fundamental *CP*-violating phases generate observable matter-antimatter asymmetries in practice.

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