Short - Measurement of CP violation in the $B^\pm \to K^\pm\pi^+\pi^-$ decay channel

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We present CP asymmetry measurements in the charmless $B^\pm \to K^\pm\pi^+\pi^-$ decay channel, using 2011 pp collision data from the LHCb. CP asymmetry across complete phase space was found to be $A_{CP}^{glo} = -0.004 \pm 0.013(\text{stat}) \pm 0.007(\text{syst}) \pm 0.007(J/\psi)$, which is consistent with zero. Evidence for CP violation in nature was found in a local region of phase space surrounding the $\rho(770)$ meson resonance state, where an asymmetry of $A_{CP}^{loc} = 0.729 \pm 0.051(\text{stat}) \pm 0.048(\text{syst}) \pm 0.007(J/\psi)$ was measured.

I. Introduction

Violation of the combined symmetry under charge conjugation (C) and parity transformation (P) is a crucial step to understanding the abundance of baryonic matter in the universe [1]. The specific decay of the charmless $B^\pm$ meson into one kaon and two pions sets a good basis for investigating CP violation. The CPT theorem requires symmetry under the product of C, P and T transformation, where T is time reversal. Weak decays of particles strongly violate C and P individually, but CP symmetry was long believed to hold [2]. In the standard model, a complex phase in the quark mixing matrix gives rise to CP violation [3]. The LHCb detector, a single-arm forward spectrometer, was built to study CP violation in the beauty and charm quark sector [1]. The former was investigated considering $B^\pm$ mesons, containing only the beauty quark.

II. Data and Selection

The studied $B^\pm$ mesons originated from proton-proton collisions in the Large Hadron Collider at a centre-of-mass energy of 7 TeV. The LHCb detector event selection occurs in two stages, a hardware stage and a software stage. Only events with high transverse energy and a two to four track secondary vertex with a large sum of transverse momenta pass the selection [4]. Additional selection criteria were applied to ensure a cleaner data sample for studying $B^\pm \to K^\pm\pi^+\pi^-$ decays. Furthermore, numerous two body resonance decays were identified, where $B^\pm \to h_1^\pm R^0$, $R^0 \to h_2^+ h_3^-$, h representing K or π and R^0 being a neutral meson. Important resonance states for this analysis include $\rho(770) \to \pi^+\pi^-$, $D^0 \to K^+\pi^-$ and $J/\psi \to \mu^+\mu^-$. The D^0 meson was not of interest due to its charm quark constituent, so was the J/ψ meson, decaying into muons, which are often misidentified as pions due to similar mass [2]. Therefore, two body mass regions $1.82 < M_{K^\pm\pi^\mp} < 1.90$ GeV/c^2 and $3.05 < M_{\pi^+\pi^-} < 3.15$ GeV/c^2 were excluded, where $M_{K^\pm\pi^\mp}$ and $M_{\pi^+\pi^-}$ are $K^\pm\pi^\mp$ and $\pi^+\pi^-$ invariant masses respectively, chosen so the overall charge of their decay products is zero.

III. Method and Results

A. Global Asymmetry

From the selected data, events were separated according to their $B^\pm$ meson charge and three body invariant mass was plotted on a histogram, as shown in Fig. 1. The events in the signal peak, around the $B^\pm$ meson mass, were isolated by fitting and then subtracting backgrounds. Two background contributions were identified, one due to four body decays with only three detected particles and a combinatorial background, due to random particle detections. These were modelled by a gaussian and an exponential function, respectively. Ignoring any systematic corrections, asymmetry is defined as

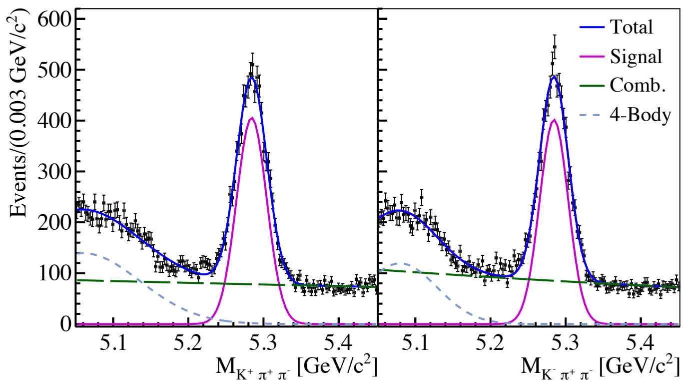

Fig. 1: Three body invariant mass histograms for B^+ decays (left) and B^- decays (right). The signal peak (solid magenta), the combinatorial background (dashed dark green) and the 4 body background (dashed light blue) combine to give a total fit (solid dark blue). Reduced χ^2 for the total fit of $\chi^2_{red} = 1.1$ and $\chi^2_{red} = 1.2$ were obtained for B^+ and B^-, respectively.

$$A_{CP} = \frac{N^- - N^+}{N^- + N^+}, \tag{1}$$

where N^+ and N^- are the number of B^+ and B^- decays respectively, obtained by summing all events under the background subtracted peaks. A global (over all phase space) asymmetry of $A_{CP}^{glo} = -0.004 \pm 0.013(\text{stat}) \pm 0.007(\text{syst}) \pm 0.007(J/\psi)$ was found, where the uncertainties are statistical, systematic and due to detection and production asymmetry, further discussed in Section IV. The statistical uncertainty was obtained by standard error propagation for uncorrelated events, where the uncertainties on $N^\pm$ were obtained from the signal fitting parameters.

B. Local Asymmetry

To localise phase space regions of large asymmetry, Dalitz plot analysis was used. To get a better estimate of bin asymmetry and reduce the number of background decays, only events in the three body invariant mass region $5.24 < M_{K^\pm\pi^+\pi^-} < 5.32$ GeV/c^2 were selected. The combinatorial background, present across the signal peak, see Fig 1, was approximated by a three body invariant mass region just above the signal peak, $5.35 < M_{K^\pm\pi^+\pi^-} < 5.43$ GeV/c^2, which was scaled accordingly and then subtracted. The background subtracted Dalitz plot of asymmetry over phase space is shown in Figure 2. Bin sizes were adjusted to roughly minimise the spread in the number of events per bin.

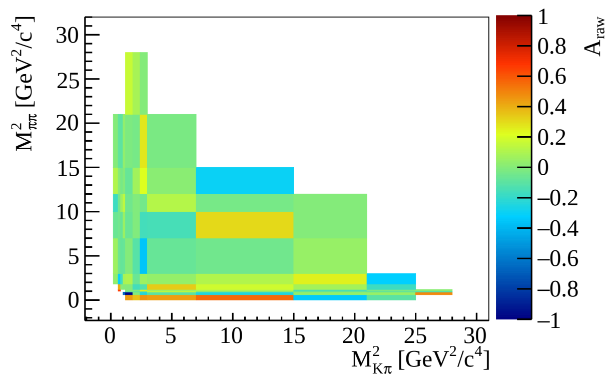

Fig. 2: A Dalitz plot of asymmetry across phase space, where A_{raw} represents the measured value of asymmetry.

We identified and further investigated the specific phase space region $0.0 < M^2_{K^{\pm}\pi^{\mp}} < 15.0$ GeV^2/c^4, $0.0 < M^2_{\pi^+\pi^-} < 0.6$ GeV^2/c^4, due to its large local asymmetry and significance on the Dalitz plot. The number of B^+ and B^- decays were determined from the background subtracted signal peaks, as shown in Fig. 3. A large positive local asymmetry of $A^{loc}_{CP} = 0.729 \pm 0.051$(stat) $\pm$ 0.048(syst) $\pm$ 0.007(J/ψ) was measured in this region of phase space.
Furthermore, the resonant state of the $\rho(770)$ meson was identified in the discussed local region and its impact on the asymmetry was investigated. The asymmetry in the $\rho(770)$ signal peak was found to be $A^{\rho(770)}_{CP} = 0.746 \ \pm 0.042$(stat) ± 0.048(syst) $\pm 0.007(J/\psi)$, which is a highly significant, 11.6 σ result. Excluding the resonance state from the local region, the asymmetry reduced to $A^{excl\ \rho(770)}_{CP} = 0.452 \pm 0.153$(stat) ± 0.048(syst) $\pm 0.007(J/\psi)$. Due to a lack of events, the width of $\rho(770)$ had to be approximated by 100 MeV/c^2 and the fitting resulted in larger statistical uncertainties [2].

IV. Discussion

CP violation is not fully understood, which makes measurements of CP asymmetry in the beauty quark sector a profound discovery. Furthermore, the $\rho(770)$ meson was found to play a significant role in CP violation, which is in agreement with experimental observations [5] and theoretical arguments [6].

A. Systematic uncertainties

Firstly, the effect of the magnet polarity of the LHCb detector, used to determine particle momenta, was investigated. The significance of the difference of asymmetry for different magnet polarities in each bin of the Dalitz plot was found to behave as expected of a purely statistical spread. Therefore, the global and local effect of magnet polarity was neglected.
The assigned systematic error originated from background fitting. In the global and each of the local cases, different models were fitted to combinatorial and 4 body backgrounds. Despite the fact that similar χ^2_{red} were obtained, the measured asymmetries differed slightly. The spread in the asymmetries was used to obtain systematic uncertainties on all measurements.

B. Detection and production asymmetry

The effect of a constant shift in asymmetry due to an inequality of detecting positively and negatively charged particles was investigated, using the $B^{\pm} \to K^{\pm} J/\psi \to K^{\pm}\mu^{+}\mu^{-}$

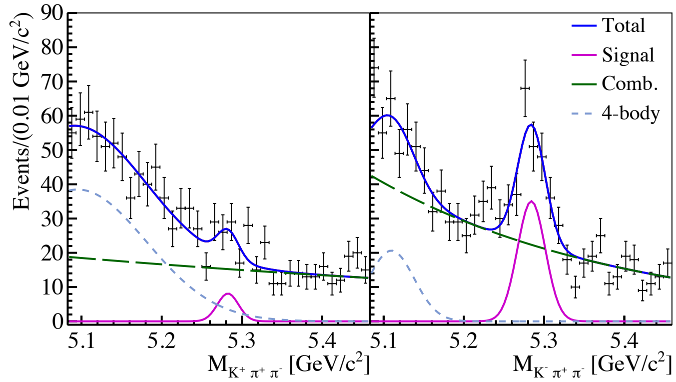

Fig. 3: Three body invariant mass for B^+ decays (left) and B^- decays (right) for the specified local region only. Reduced χ^2 for the total fit of $\chi^2_{red} = 0.8$ and $\chi^2_{red} = 1.5$ were obtained for B^+ and B^-, respectively.

decay as a control channel. This channel was chosen due to its very small and known value of asymmetry, $A_{CP} = 0.003 \pm 0.006$ [2]. The true value of asymmetry can be expressed as $A_{CP} = A_{raw} - A_{\Delta}$, where A_{Δ} is a correction term [4]. By asymmetry measurement in the control channel, the correction term was found to be $A_{\Delta} = -0.028 \pm 0.007$, which was applied to every measured value of asymmetry. The corresponding uncertainty on the correction term was assigned to each measurement, labelled J/ψ.
The different 4 body background shapes, strongly present in Fig. 3, but also in Fig. 1, are also likely caused by this effect. Although, detection and production asymmetry variation over phase space was not tested.

V. Conclusion

The found results indicate that there appears to be no violation of charge conjugation and parity transformation over combined phase space. Further investigation led to the observation of a large local asymmetry in the phase space region surrounding the $\rho(770)$ meson, with a significance of 10.4 σ. Both global and local asymmetries are consistent with previous measurements of the LHCb collaboration [4]. Furthermore, the $\rho(770)$ resonance state was evidently associated with CP violation, setting a good base for further research.

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