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

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The charmless decay $B^\pm \to K^\pm\pi^+\pi^-$ is reconstructed using data collected by LHCb. The global CP violation for this decay mode was measured to be $A_{CP} = 0.004 \pm 0.003$ (stat.) ± 0.008 (sys.) $\pm$ 0.007 ($J/\psi K^\pm$), where the third uncertainty is due to the $B^\pm \to J/\psi K^\pm$ decay mode. Analysis of Dalitz plots shows further localised regions of CP asymmetry.

The phenomenon of CP violation in the weak decay is included in the standard model through the CKM matrix [1]. The $B^\pm \to K^\pm\pi^+\pi^-$ decay channel is reconstructed and the number of decay events corresponding to $B^\pm$ mesons is measured. The objectives of this experiment are to measure the global CP violation A_{CP} and to utilise Dalitz plots to further examine regions of local CP violation.

Experiments into the possible violation of CP symmetry have been carried out, e.g. Belle collaboration found observed CP violation in the $B^\pm \to f_2(1270)K^\pm$ decay [2]. The LHCb collaboration has investigated the $B^\pm \to K^\pm\pi^+\pi^-$ decay channel [3] and found an inclusive CP asymmetry of 2.8σ. Local measurements of positive CP asymmetry observed around the $\rho(770)^0$ resonance agree with observations from Belle and BaBar [4].

The LHCb detector is a single-arm spectrometer [5]. The analysis detailed in this report is based on pp collision data collected in 2011, with a centre-of-mass energy of 7 TeV.

Events corresponding to the decay channel of interest are selected by a trigger consisting of a hardware and a software stage. A hardware trigger selects only particles with a large energy transverse to the beam direction. The software stage requires the candidate events to have a minimum transverse momentum of $p_{\mathrm{T}} > 0.1$ GeV/c. The sum of transverse momenta must be $>$ 4.5 GeV/c, with each track momentum $>$ 1.5 GeV/c. Assuming all final state particles are kaons, the software stage reconstructs the $B^\pm$ candidate and requires $5.05 < M_{KKK} < 6.30 GeV/c^2$. Selection cuts based on the particle identification information from the ring-imaging Cherenkov (RICH) detectors are made. Electrically charged particles passing through the RICH detector, that contains a medium with refractive index n, emit Cherenkov radiation [6]. By measuring the angle of emitted light, the θ_c the particle velocity v can be estimated by

$$\cos\theta_c = \frac{c}{nv}. \tag{1}$$

The velocity v can also be estimated for each candidate particle using momentum data and a theoretical angle θ_c can be produced. Comparing the theoretical and measured angles yields a probability for each candidate particle identity, this probability data is then used to select events for analysis. For example, a candidate kaon is selected if the probability that it is a kaon multiplied by the complement probability of it being a pion is > 0.6, and vice-versa for pion selection.

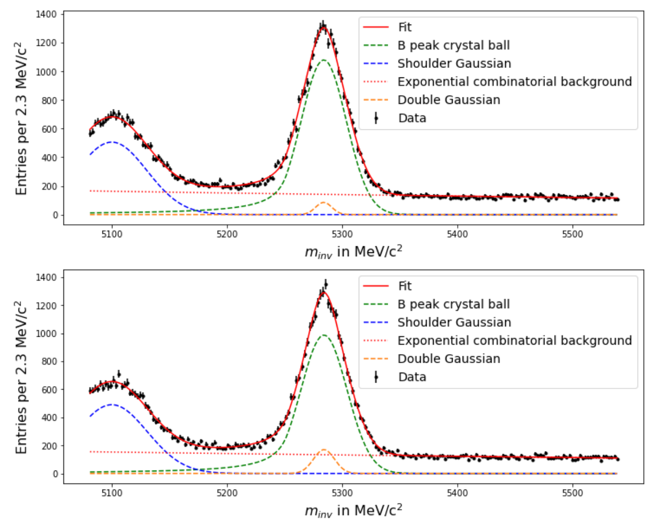

FIG. 1. Invariant mass spectra of B^+ (upper) and B^- (lower). The goodness-of-fit values are $\chi^2_{\mathrm{red}} = 1.21$ (upper) and $\chi^2_{\mathrm{red}} = 1.10$ (lower).

The collision events occur at highly relativistic energies. For this reason, the invariant mass of the candidate particles is the quantity of choice for reconstructing the decay channels of interest to this experiment.

The signal events corresponding to the $B^\pm \to K^\pm\pi^+\pi^-$ decay channel are parametrised using the sum of a Gaussian and a Crystal Ball function [7]. The fits are shown in figure 1. An exponential function models the combinatorial background. The combinatorial background is due to misidentified particles being reconstructed with incorrect masses. A Gaussian models the left hand peaking background, which is due to partially reconstructed four-body decays.

The number of counts, $N^\pm$, corresponding to reconstructed $B^\pm$ decay is calculated by integrating the area underneath the fitting function, from which the integral of the area under the exponential function (within the same limits) is subtracted. The raw global CP violation is calculated using

$$A_{\text{raw}} = \frac{N^- - N^+}{N^- + N^+}. \tag{2}$$

To account for detector asymmetries, either due to localised malfunctions or asymmetries by design, two values of A_{raw} are measured for opposite magnet polarities. From these two values, a systematic uncertainty is derived by

$$\sigma_{sys.} = \frac{\mid A_{up} - A_{down} \mid}{2}. \tag{3}$$

A central value for A_{raw} is obtained by taking the arithmetic mean of the two values for CP asymmetry. Global CP asymmetry is obtained using

$$A_{CP} = A_{\text{raw}} - A_{\Delta}, \tag{4}$$

where A_{Δ} is a correction term due to kaon detector asymmetries $A_D(K^{\pm})$ and $B^{\pm}$ production asymmetries $A_P(B^{\pm})$. By measuring the raw $J/\psi K$ asymmetry and subtracting the intrinsic CP asymmetry of $J/\psi K$ this uncertainty can be estimated:

$$A_{\Delta} = A_{\text{raw}}(J/\psi K) - A_{CP}(J/\psi K). \tag{5}$$

This works because the muons from the decay $B^{\pm} \to J/\psi(\mu^+\mu^-)K^{\pm}$ can be misidentified as pions due to their similar kinematics and event topology. The kaons involved in this decay also have similar kinematics to those from $B^{\pm} \to K^{\pm}\pi^+\pi^-$. $A_{\text{raw}}(J/\psi K)$ is obtained by restricting the selection criteria to only allow three-body decays that have a $\pi^+\pi^-$ two-body decay resonance in the region of the $J/\psi K$ invariant mass [8]. The global CP asymmetry of the decay channel $B^{\pm} \to K^{\pm}\pi^+\pi^-$ was measured to be

$$A_{CP} = 0.004 \pm 0.003 \text{ (stat.)} \pm 0.008 \text{ (sys.)} \pm 0.007 \ (J/\psi K^{\pm}) \tag{6}$$

with an uncertainty used to checking the consistency of the result found by taking the sum in quadrature of the statistical and systematic uncertainty. The significance of the global CP asymmetry of the $B^{\pm} \to K^{\pm}\pi^+\pi^-$ decay channel is 0.5σ (consistent with 0).

The $B^{\pm} \to K^{\pm}\pi^+\pi^-$ decay channel can have many intermediate decay particles before decaying to the final state particles. Plotting the invariant mass spectra of the two possible neutral two-body resonances, $R^0 \to K^{\pm}\pi^{\mp}$ and $R^0 \to \pi^+\pi^-$, allows the identification of possible intermediate resonances. Since this experiment is concerned only with the charmless decay of the $B^{\pm}$ meson, the charmed D^0 meson is removed by excluding the region ± 40 MeV/c^2 around the invariant mass of D^0. The decay $J/\psi \to \mu^+\mu^-$ can be misidentified in the detector as a decay to a pair of pions, peaking on the $\pi^+\pi^-$ plot. The region around the mass of J/ψ is removed due to this misidentification and, for the same reasons as D^0, the fact that J/ψ is also a charmed meson.

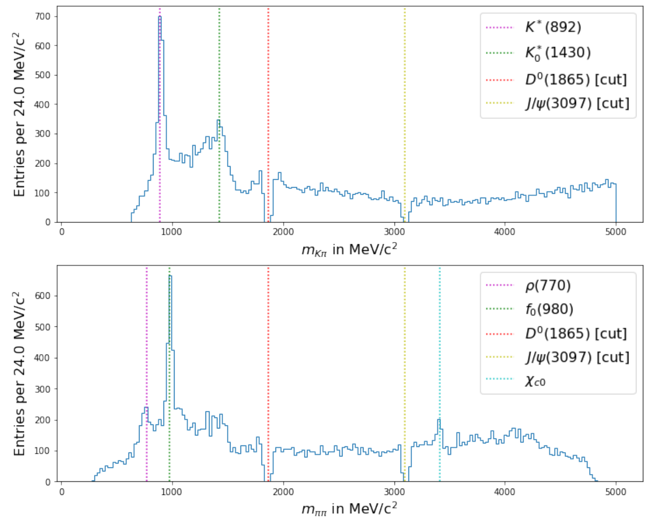

FIG. 2. Reconstructed two-body invariant mass plots, showing the intermediate decay channels $R^0 \to K^{\pm}\pi^{\mp}$ (upper) and $R^0 \to \pi^+\pi^-$ (lower). Possible intermediate candidates for each two-body resonance are listed in the legends of the respective plots.

By plotting the square of the two neutral two-body resonances, a Dalitz plot can be produced such as the one shown in 3. Dalitz plots show regions of localised CP asymmetry and can be used to identify specific decays that exhibit CP violation. Dalitz plots describe the full kinematics of three-body decays. Bands appearing on the Dalitz plot indicate resonances, where the number of minima indicates the spin of each resonance.

By producing a Dalitz plot of both $B^{\pm}$ phase spaces and taking the bin-by-bin difference yields a plot of the local CP asymmetries. Application of the Miranda method [9] (considering the significance of each bin rather than the CP asymmetry) quantifies the significance of CP asymmetry in each localised region on the Dalitz plot in figure 3. In particle physics, "evidence" is defined as >3 standard deviations (σ) and "observation" as $>5\sigma$. No areas of evidence are observed in figure 3.

In conclusion, the $B^{\pm} \to K^{\pm}\pi^+\pi^-$ decay was found to be CP symmetric, with a significance of only 0.5σ. The Dalitz plot of this decay channel shows no regions of CP asymmetry. These two results are inconsistent with those measured by LHCb, Belle and BaBar, most likely due to errors in the analytical techniques used in this lab. This is highly likely, especially considering that this experiment uses the same data as the LHCb collaboration.

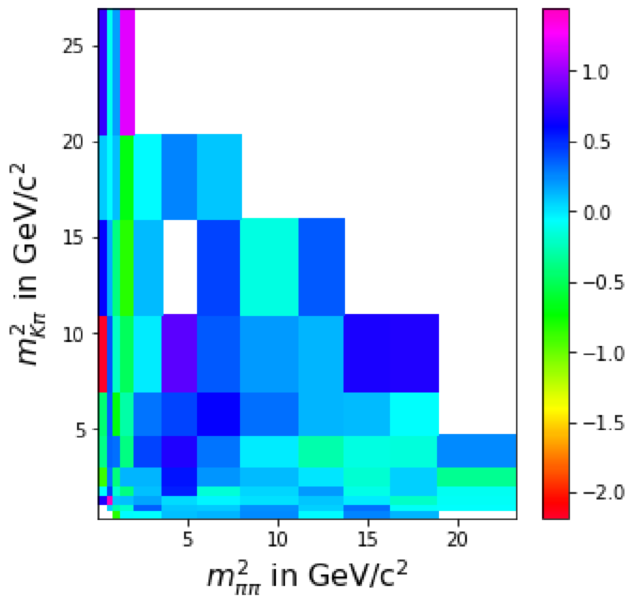

FIG. 3. Applying the Miranda method to the Dalitz plot shows regions of significance. No such regions of "evidence" ($>3\sigma$) or "observation" ($>5\sigma$) are observed on the Dalitz plot in this experiment.

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