Measurement of matter antimatter asymmetries of the $B^{\pm} \to K^{\pm}K^{+}K^{-}$ decay

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We study the CP violation of the charmless $B^{\pm} \to K^{\pm}K^{+}K^{-}$ decay. The invariant mass spectra of the decay was reconstructed and a Gaussian fit was performed. The signal-to-noise ratio was found to be small. The global matter antimatter asymmetry was found to be $A_{\text{global}} = -0.047 \pm 0.007$. Two body resonances and their effects on CP violation were also studied. By excluding resonances in the two-body phase space of the decay, the CP violation was found to be $A_{\text{no resonance}} = -0.058 \pm 0.008$.

I. INTRODUCTION

In the era of high-energy particle colliders, the LHCb experiment at CERN provides an excellent environment for studying CP violations through the b quark and anti-b quark. Long term, these experiments can provide insights into the causes and origins of the matter antimatter asymmetries observed in the universe today. In this letter, we study the CP violation of the charmless $B^{\pm} \to K^{\pm}K^{+}K^{-}$ decay. We use the kaons in the decay to infer properties of the $B^{\pm}$ mesons and in particular we look for evidence of a significant difference in the decay rates between the B^{+} meson and the B^{-} meson. We also study two-body resonances and their effects on CP violation.

II. EXPERIMENTAL SETUP

In the LHCb experiment, the $B^{\pm}$ mesons are produced through pp collisions at $\sqrt{s} = 7$ TeV. The data was collected in 2011 and corresponds to an integrated luminosity of 1.0 fb^{-1} [1]. Possible decays of the $B^{\pm}$ mesons include both $B^{\pm} \to K^{\pm}K^{+}K^{-}$ and $B^{\pm} \to K^{\pm}\pi^{+}\pi^{-}$. A description of the LHCB instrumentation is given in [2]. The decay products travel through a silicon detector, which includes a high-precision detector for charged particles. A magnetic field is applied, which bends the tracks of the charged particles. As the charged particles travel through the detector, their tracks are reconstructed. By studying the decay vertices and momenta of the decay particles, specific particles in the detector can be identified.

III. ANALYSIS AND RESULTS

Initially, the data was pre-selected to require that exactly three charged tracks are present. Each track was required to have a likelihood of at least 50% of it corresponding to a kaon and each track was required to be inconsistent with that of a muon. The total number of events considered was 26959 after selection. The invariant mass of the $B^{\pm}$ mesons in each event was reconstructed by adding the vector momenta of the three decay kaons and combining them with the kaon mass $m_{K^{\pm}} = (493.677 \pm 0.016)$ MeV/c^2 [3]. This was done separately for the B^{+} and the B^{-} case. The results are plotted in Figure 1.

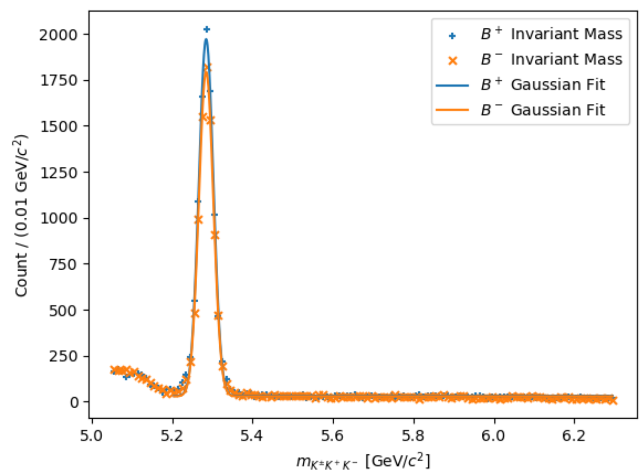

FIG. 1. Reconstructed invariant mass spectra of the $B^{\pm} \to K^{\pm}K^{+}K^{-}$ decays. In the region $m_{K^{\pm}K^{+}K^{-}} > 5.2$ GeV/c^2, a Gaussian fit was performed for the signal and the background was fitted to a constant.

There is a clear peak at around the $B^{\pm}$ mass $m_{B^{\pm}} = (5279.66 \pm 0.12)$ MeV/c^2 [3]. There is also an excess number of events in the $m_{K^{\pm}K^{+}K^{-}} < 5.2$ GeV/c^2 region. These events correspond to four-body decays and will not be studied in this letter. In order to estimate the background, the peak and background in the $m_{K^{\pm}K^{+}K^{-}} > 5.2$ GeV/c^2 region were fitted to the Gaussian relation

$$N = A \exp\left(-\frac{1}{2}\frac{(m_{K^{\pm}K^{+}K^{-}} - \mu)^2}{\sigma^2}\right) + B, \tag{1}$$

where N is the number of particles per 0.01 GeV/c^2, A is the height of the peak above the background, μ is the center of the peak, σ is the width of the peak and B is the background. The values of the optimal fits are shown in Table I.

There were 18782 candidate events with an invariant mass close to the invariant $B^{\pm}$ mass (within 2%). These

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TABLE I. Gaussian fit parameters of the three-body invariant mass spectra.

Decay	A [0.01 GeV/c^2]$^{-1}$	μ [GeV/c^2]	σ [GeV/c^2]	B [0.01 GeV/c^2]$^{-1}$
$B^+ \to K^+K^+K^-$	1940 ± 12	5.28461 ± 0.00013	0.01800 ± 0.00013	30.8 ± 1.74
$B^- \to K^-K^+K^-$	1765 ± 9	5.28456 ± 0.00011	0.01808 ± 0.00011	28.7 ± 1.3

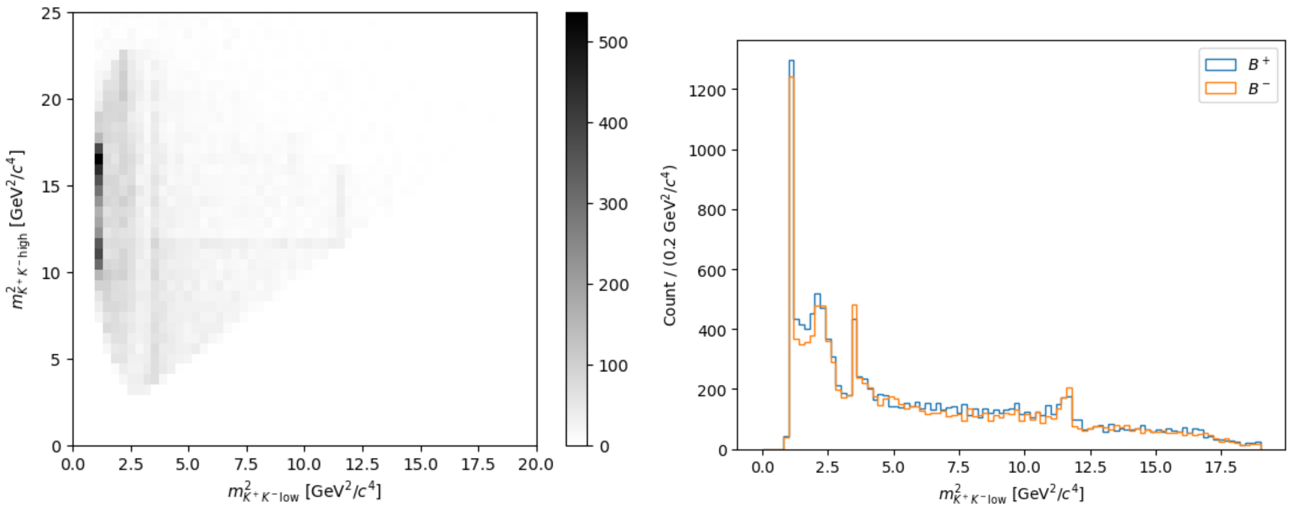

FIG. 2. Reconstructed squared invariant mass spectra of the two-body intermediate phase space in the $B^\pm \to K^\pm K^+K^-$ decays.

candidates were selected and the global matter antimatter asymmetry was calculated from

$$A_{\mathrm{global}} = \frac{N_- - N_+}{N_- + N_+}, \tag{2}$$

where N_- is the number of B^- candidates and N_+ is the number of B^+ candidates [1]. The corresponding standard deviation is given by

$$\sigma_A = \sqrt{\frac{1 - A^2_{\mathrm{global}}}{N_- + N_+}}. \tag{3}$$

The number of B^- candidates was found to be $N_- = 8947$. The number of background events from the B^- candidates in the region where $m_{K^\pm K^+K^-}$ is within 2% of the $B^\pm$ is 606. Similarly, the number of B^+ candidates was found to be $N_+ = 9835$ and the number of background events from the B^+ candidates is 650. Since the number of background events is small compared to the number of signal events, we do not remove the background in the analysis. The global asymmetry was found to be $A_{\mathrm{global}} = -0.047 \pm 0.007$. This is a 6.7σ deviation from 0 and is already significant evidence that the B^+ decay rate is higher than the B^- decay rate. We continue to investigate this data, however, to gain greater insight into the underlying decay process.

The decay $B^\pm \to K^\pm K^+K^-$ can happen either directly or via an intermediate particle. We consider the possible intermediate decay $B^\pm \to K^\pm R^0$, where R^0 in turn decays to K^+K^-. For convenience, we number the kaon decay products as follows: the kaon having charge opposite to the $B^\pm$ charge was given the index 1. The other two kaons having charge equal to the $B^\pm$ charge were randomly given indices 2 and 3, i.e. $B^\pm \to K_1^\mp K_2^\pm K_3^\pm$. The two possible intermediate decays are then $B^\pm \to R_2^0 K_3^\pm$ where $R_2^0 \to K_1^\mp K_2^\pm$ and $B^\pm \to K_2^\pm R_3^0$ where $R_3^0 \to K_1^\mp K_3^\pm$. The invariant masses of the intermediate mesons R_2^0 and R_3^0 were reconstructed using a similar process that was used for the $B^\pm$ invariant mass reconstruction. Since both R_2^0 and R_3^0 decay to the same particles K^+ and K^-, the ordering $m_{K^+K^-\mathrm{low}} < m_{K^+K^-\mathrm{high}}$ was imposed. The squared values of the two-body invariant masses are plotted in a Dalitz plot in Figure 2. The figure also contains a one dimensional histogram of $m^2_{K^+K^-\mathrm{low}}$.

In the Dalitz plot in Figure 2, there is a clear resonance band at $m^2_{K^+K^-\mathrm{low}} \approx 1.0$ GeV^2/c^4 and 10 GeV^2/c^4 $< \mathrm{m}^2_{\mathrm{K^+K^-high}} <$ 18 GeV^2/c^4. This resonance corresponds to a $\phi(1020)$ meson [4], which has mass $m_\phi = (1019.461 \pm 0.016)$ MeV/c^2 and decays to K^+K^- at (49.1 ± 0.5)% [3]. We therefore conclude that a significant percentage of the $B^\pm \to K^\pm K^+K^-$ decays happen via the intermediate decay $B^\pm \to K^\pm \phi(1020)$.

The one-dimensional histogram of $m^2_{K^+K^-\mathrm{low}}$ in Figure 2 shows another peak at $m^2_{K^+K^-\mathrm{low}} \approx 3.5$ GeV^2/c^4. This peak corresponds to decays that occur via the D^0 meson, in which a b quark decays to a c quark. CP violation in charm mesons are not yet known to occur. We reject

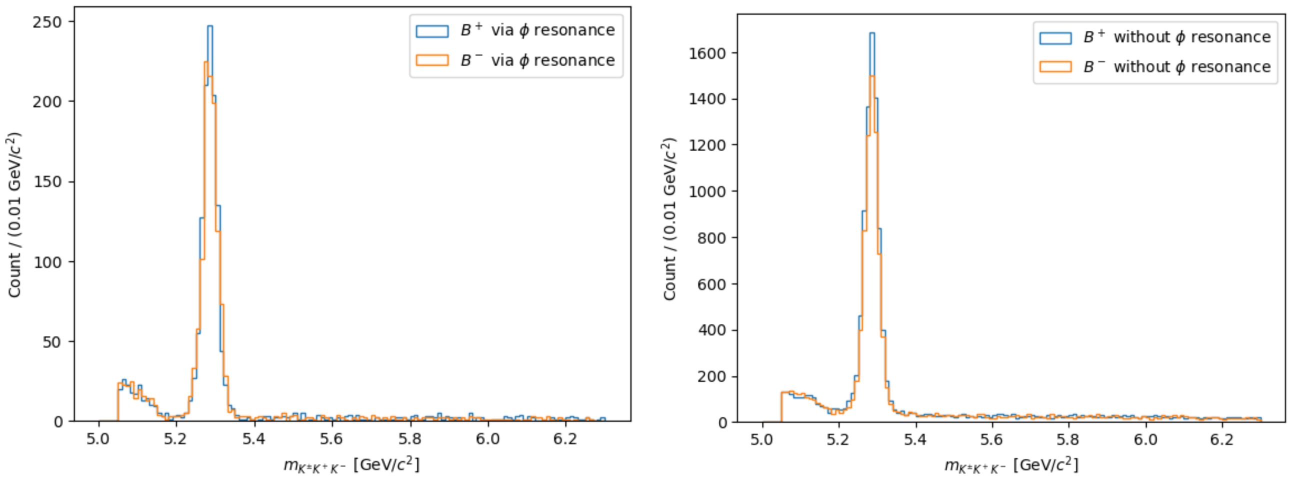

FIG. 3. Reconstructed invariant mass spectra of the $B^{\pm} \to K^{\pm}K^{+}K^{-}$ decays. The plot on the left shows the spectra where two of the kaons are decay products of a ϕ meson. The plot on the right shows the spectra where the $B^{\pm}$ meson directly decays to three kaons.

events with a two-body invariant mass within 2% of the mass of the D^0 meson, $m_{D^0} = (1864.84 \pm 0.05)$ MeV/c^2 [3], and restrict our calculation to evens with a three-body invariant mass within 2% of the $B^{\pm}$. There were 17728 events which fit these selection rules and the CP violation was calculated to be $A_{\text{charmless}} = -0.052 \pm 0.008$. This is a 6.5$\sigma$ deviation from 0 and is similar to the 6.7σ deviation observed earlier.

The CP violation of the decays that occur via the D^0 meson was also calculated to confirm that no charm CP violation was present. Events with a two-body invariant mass within 2% of the D^0 meson and a three-body invariant mass within 2% of the $B^{\pm}$ were selected. There were 1054 such events and the matter antimatter asymmetry was calculated to be $A_{\text{charm}} = 0.03 \pm 0.03$. Within the reported statistical uncertainty, this is not a significant deviation from 0 and hence we conclude that indeed no CP violation via the D^0 was observed in this experiment.

Finally, the CP violation for the case where $B^{\pm}$ decays to three kaons directly and for the case where $B^{\pm}$ first decays to ϕ was calculated separately. There were 2236 events with a two-body invariant mass within 2% of the the ϕ mass and with a three-body invariant mass within 2% of the $B^{\pm}$ mass. From these events, the CP violation for the ϕ resonance case was calculated to be $A_{\text{resonance}} = -0.01 \pm 0.02$. This is not a statistically significant deviation from 0 and hence we conclude that no CP violation is present when a ϕ resonance is present.

In the case where $B^{\pm}$ decays to three kaons directly, we found 15492 events with a two-body invariant mass at least 2% away from the ϕ mass and with a three-body invariant mass within 2% of the $B^{\pm}$ mass. Decays that occur via the D^0 meson were also excluded. The CP violation for the case without ϕ resonance was found to be $A_{\text{no resonance}} = -0.058 \pm 0.008$. This is a 7.25$\sigma$ deviation from 0 and is signifcant evidence that CP violation is present in the case where $B^{\pm}$ decays to three kaons directly.

IV. DISCUSSION

The CP violations reported above are in reasonable agreement with results from previous work [1]. The uncertainties reported in [1] are larger than those reported in this letter however. This is because in this analysis, only statistical uncertainties were considered. There are also systematic uncertainties present, which we did not account for. For example, it is unclear if in the experimental setup there is a difference in effectiveness of detecting positively and negatively charged particles. Due to the magnetic field applied, positively and negatively charged particles bend in opposite directions. If the detection effectiveness is higher in one region than in another, then this would induce an asymmetry in the observed B^- and B^+ decay rates. This effect was partly corrected for by reversing the polarity of the magnetic field. A calculation of the difference in observed CP violation for the cases where only one magnetic field direction is maintained is deferred to future research.

Another source of uncertainty is the background in the event considered in the analysis. Pre-selection rules were applied to the data requiring that each of the three tracks has a likelihood of at least 50% of it corresponding to a kaon and each track was required to be inconsistent with that of a muon. More pre-selection rules could be applied to for example limit the likelihood of a track corresponding to a pion.

Finally, we consider the uncertainties induced due to $B^{\pm}$ production asymmetry. The $B^{\pm}$ are produced from proton-proton collisions, which are not matter antimatter symmetric. This could also induce an asymmetry in the observed B^- and B^+ decay rates.

V. CONCLUSIONS

We investigated the $B^\pm \rightarrow K^\pm K^+ K^-$ decays and measured the matter antimatter asymmetry for various cases. We calculated the number of background events of the three-body invariant mass spectrum and found that the signal-to-noise ratio is small. The global CP violation was calculated to be $A_{\text{global}} = -0.047 \pm 0.007$. A resonance corresponding to a ϕ meson and a resonance corresponding to a D^0 meson were found in the two-body invariant mass distribution. No significant CP violation was detected in the cases where $B^\pm$ first decays to a ϕ or a D^0 meson. The charmless CP violation, where the D^0 resonance was ignored, was found to be $A_{\text{charmless}} = -0.052 \pm 0.008$. The CP violation for the case where no resonance was present, was found to be $A_{\text{no resonance}} = -0.058 \pm 0.008$.

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