Measuring Matter Antimatter Asymmetries at the Large Hadron Collider

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Abstract

Matter Antimatter asymmetry was investigated using pre-cut data from the 2011 run of the LHCb experiment. In particular the $B^{\pm} \to k^{\pm}\pi^{+}\pi^{-}$ decay channel was identified from the data and separated into B^{+} and B^{-} events using the software framework ROOT. The relative frequency of these events was used to calculate asymmetry across the entire phase-space (global CP asymmetry) and in localised regions of the phase-space (local CP asymmetry). We obtained a value of $-0.0144 \pm 0.0072_{stat} \pm 0.0019_{sys}$ for global CP asymmetry and $0.0590 \pm 0.0053_{stat} \pm 0.0319_{sys}$ for local CP asymmetry.

Introduction

The LHC collides protons with a centre-of-mass energy of $7TeV$ recreating the conditions of the early universe[1]. LHCb is one of four major experiments built around these collision points. The aim of LHCb is to explore what happened after the Big Bang that allowed matter to prevail over antimatter creating the Universe we live in today[2].

The process that brought about this imbalance is known as baryogenesis. One of the Sakharov conditions necessary for baryogenesis is CP Violation[3]. Although the detector will detect decays associated with charmed quarks, we were only interested in charmless decays. This is because as of yet CP Violation has not been observed in the charm sector[2].

Experimental method

The data we used already had pre-selection cuts applied and these cuts are summarised in Table 1. In addition to this we applied our own selection criteria. We ensured that the sum of particle charges had to equal ± 1 and any events containing a muon were filtered out. We also defined a 'tolerance' value such that all particles had to satisfy:

$$Prob(k) > tolerance \text{ OR } Prob(\pi) > tolerance$$

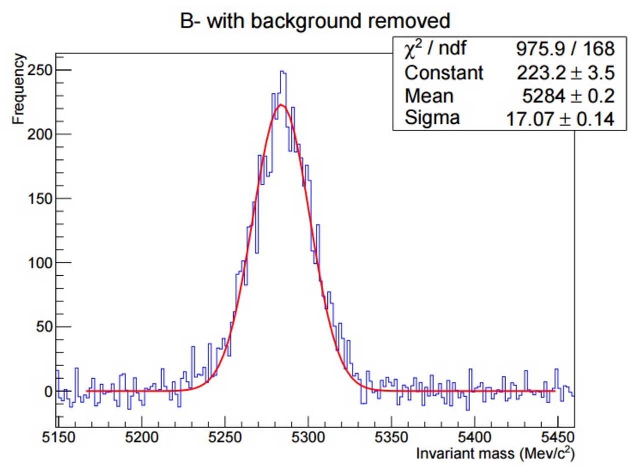
Variable	Selection cut
Track Transverse Momentum(p_T)	$> 0.1GeV/c$
Sum of p_T of Tracks	$> 4.5GeV/c$
Track Momentum(p)	$> 1.5GeV/c$
$B^{\pm}$ candidate mass	$5.05 < M_{KKK} < 6.30GeV/c^2$
Track Impact Parameter(IP) χ^2	> 1
Sum of IP χ^2 of Tracks	> 500
$B^{\pm}$ candidate vertex fit χ^2	< 12

Table 1: Table showing pre-selection cuts on the data.

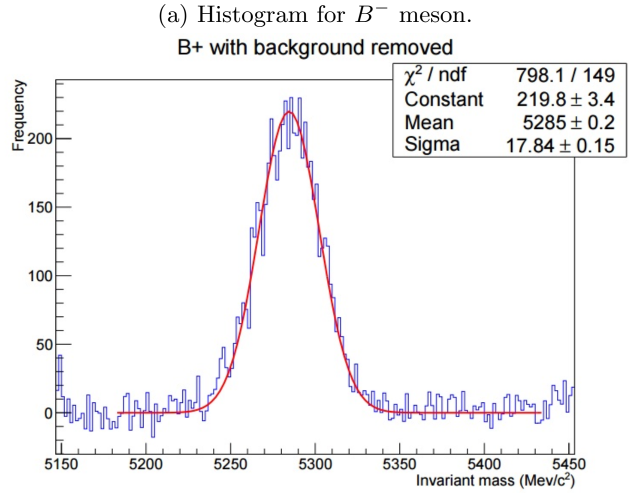
The momenta of each particle is known therefore we can calculate the invariant mass of the particles using energy and linear momentum conservation. We are only interested in $B^{\pm} \to k^{\pm}\pi^{+}\pi^{-}$ decays so we can substitute in the appropriate rest masses of kaons and pions to reconstruct the invariant mass of the parent B meson. B meson decays can also proceed via a 2 body resonance $B^{\pm} \to h^{\pm}R^{0}$ where h is a hadron and R_0 is a neutral particle resonance. Thus by selecting an appropriate pair of particles we can also reconstruct invariant masses for two-body resonances.

The D_0 charmed meson was removed by rejecting any events that contained a two-body invariant mass $M_{k\pi}$ within 3σ of its signal peak. No resonances due to the J/ψ meson were observed.

After removal of resonances there was still background data in our plots. In order to remove this background we used the root function ShowBackground() to create a histogram corresponding to the background and subtracted this from the original histogram[4][5]. The peaks corresponding to the isolated invariant mass of the B^{-} and B^{+} mesons were then be fitted with a gaussian and integrated to obtain the number of events as seen in Figure 1. Once the count of B^{-} and B^{+} events have been obtained we can then calculate the global CP asymmetry $A = \frac{N^{-}-N^{+}}{N^{-}+N^{+}}$. Systematic errors were quantified by considering the difference in asymmetry observed between the two magnet polarities.



(a) Histogram for B^{-} meson.



(b) Histogram for B^{+} meson.

Figure 1: Histograms for $B^{\pm}$ with background removed and Gaussian curves fitted.

In addition we can investigate to see whether more significant areas of asymmetry can be identified in localities of the phase-space. For a three-body decay we can specify the phase-space with a pair of two-body invariant masses squared. The two pairs of two-body invariant masses squared can then be plotted on a two-dimensional histogram. This is known as a Dalitz plot[6].

Large bin widths are used to make sure percentage errors in each bin are small. We can then divide the value in each bin by its associated statistical errors to create a significance plot such as that shown in Figure 2. We see that there is a band in the lower region of the plot which is statistically significant. This region which we call the 'lower region' is defined by

$$[3(GeV)^2 < M^2_{k\pi} < 15(GeV)^2, 0(GeV)^2 < M^2_{\pi\pi} < 3(GeV)^2]$$

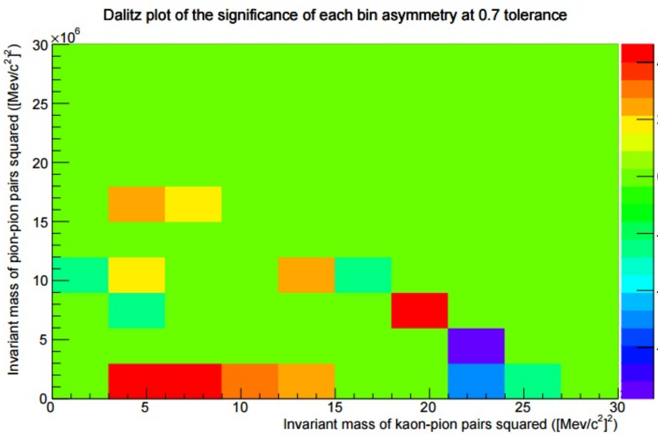


Figure 2: Dalitz plot showing significant values of asymmetry in localised regions of phase-space.

Results and Discussion

We obtained a value of $-0.0144 \pm 0.0072_{stat} \pm 0.0019_{sys}$ for the global cp asymmetry. Considering statistical errors alone this result is well below the 3σ to be considered evidence. The statistical errors are large due to our selection method. In order for the J/ψ meson's presence to be negligible we required high tolerance values of around 0.8. This gave us a high level of confidence that we had correctly identified the particles but it also gave us significantly less events and thus greater percentage errors.

In order to reduce the statistical errors in our global asymmetry I think more time should have been put into optimising the selection criteria. We defined a single tolerance value for the probability of a given particle being either a kaon or a pion; however in order to improve on this we should have separated these probabilities into two tolerance values: $tolerance_k$ and $tolerance_\pi$. The probability distribution of the kaon and pion in the data are quite different which can be seen in Figure 3.

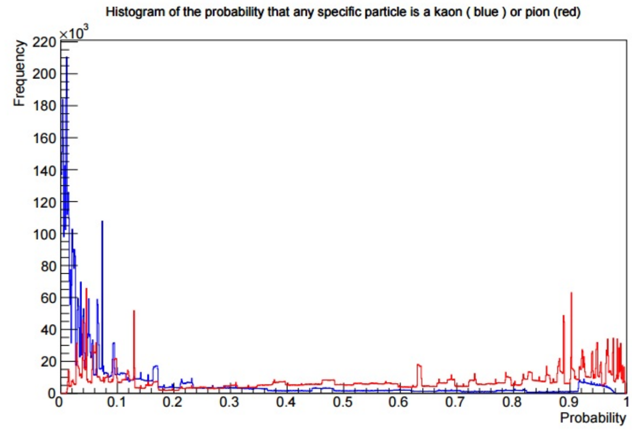


Figure 3: Probability distribution of kaons(blue) and pions(red).

For the local cp asymmetry in the 'lower region' of Figure 2 we obtained a value of $0.0590 \pm 0.0053_{stat} \pm 0.0319_{sys}$. Statistically this is very significant with over a 5σ significance which would be considered as a discovery. However when the systematic errors are taken into account this result is no longer significant and falls short of the 3σ to constitute as evidence for CP violation.

Conclusion

Overall we were unable to produce evidence for CP violation both globally and within a locality of the phase-space. I think this is largely due to our selection criteria and given further time, more investigation with varying tolerance levels should be carried out.

References

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