Measurement of CP Violation in $B^{\pm} \to \pi^{\pm}\pi^{+}\pi^{-}$ Decay Channal at Large Hadron Collider

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Abstract: A set of selected pp collision data samples which were collected by LHCb[1] in 2011 are studied. Contained $B^{\pm} \to \pi^{\pm}\pi^{+}\pi^{-}$ decays in magnet "up" and "down" polarities are constructed. Global CP asymmetry in this channel is measured to be $A_{CP} = 0.126 \pm 0.023 \pm 0.026$, in which the first and second uncertainties are statistical and systematic respectively. Larger asymmetry in local area of phase space is also observed.

1 Introduction

The Standard Model (SM)[2] of particle physics, which developed in early 1970s, has been successfully explaining almost all experiment results and made precise predictions. Although the SM has been considered as the best theory describing fundamental particles and their interaction, phenomena such as large scale of matter antimatter asymmetry in the universe are not fully explained. Matter antimatter asymmetry is described by Charge Parity (CP) invariance violation in the SM, but the effect is too small to explain observed magnitude. Therefore, additional sources of CP violation above SM may contributes to the exceeding magnitude of asymmetry. Charmless B meson to 3 hadrons decay is observed to have the largest CP violation. Measuring CP violation provides evidence of physics beyond The SM.

2 Candidates Selection

The LHCb[1] detector is designed for studying particles containing b and c quark. Analysed data was preselected by hardware and software trigger from approximately 10^{14} pp collision events with centre-of-mass energy of 7 TeV. Most important pre-selection cuts are listed in the labscript[3]. Information from the particle identification system[4] are used to separate $B^{\pm} \to \pi^{\pm}\pi^{+}\pi^{-}$ events. Apart from rejecting muon, the probability of each particle to be a pion is required to be larger than 0.794 to make sure 50 per cent B candidates have final states of 3 pion. CP Asymmetry introduced by charmed decay of B mesons are removed by rejecting D^{0} resonance by excluding $\pm 50 MeV$ region of D^{0} meson mass in two body invariant mass $M_{\pi^{+}\pi^{-}}$ spectrum.

3 Global Asymmetry

Raw asymmetry of $B^{\pm} \to \pi^{\pm}\pi^{+}\pi^{-}$ mode is defined as $A_{raw} = \epsilon^{-} - \epsilon^{+}$, where $\epsilon^{\pm} = \frac{N_{B^{\pm}}}{N_{B^{+}}+N_{B^{-}}}$ is efficiency. $N_{B^{\pm}}$ is estimated by fitting B meson invariant mass spectra and integrating contribution of signal models. Cruijff function with zero right radiative tail was chosen to be signal model, the mean, width and left tail parameters were left free. We described the combinatorial background by an exponential function, all of its parameters were left to be fitted. Backgrounds caused by four-body-decay were parametrized by gaussian, whose peak positions were fixed to 5134 MeV for B^{+} and 5040 MeV for B^{-} by optimizing deduced χ^{2} of fitting, We also tried to introduce a small peak centred in 5215 MeV to describe $B^{\pm} \to K^{\pm}\pi^{+}\pi^{-}$ in which one Kaon was misidentified, however, contribution of it is negligible with rather strict selection criteria we implemented. The invariant mass contribution and fitting results are shown in figure 1. In-
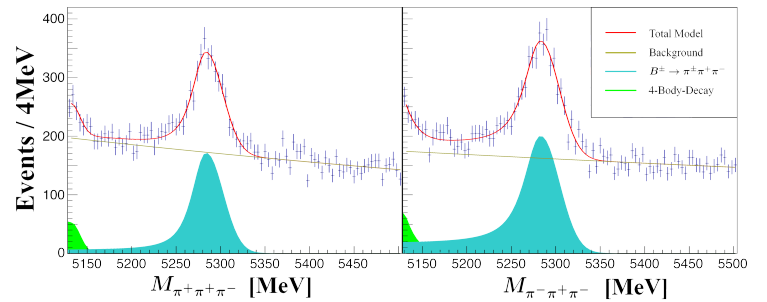

Figure 1: Invariant mass spectra and fitting results. Left panel is B^{+} and Right panel is B^{-}

tegration of signal model gives $N_{B^{+}} = 2251 \pm 81$ and $N_{B^{-}} = 2789 \pm 82$. Raw CP asymmetry yields $A_{raw} = 0.107 \pm 0.023(statistical)$. Since detector efficiencies for B^{+} and B^{-} are not equal in different magnet polarities, a detector polarity correction is made based on $\epsilon^{\pm}_{up}$ and $\epsilon^{\pm}_{down}$ in two subsets of data, defined as $A_{cor} = \epsilon^{-}_{cor} - \epsilon^{+}_{cor}$, where $\epsilon^{\pm}_{cor} = (\epsilon^{\pm}_{up} + \epsilon^{\pm}_{down})/2$. A_{CP} is calculated by excluding B-meson production asymmetry $A_{P} = -0.004 \pm 0.004$[5] from A_{cor}, which yields $A_{CP} = A_{cor} - A_{P} = 0.126 \pm 0.023$, Uncertainty above is statistical only, estimated by integrating fitting-error within 3-sigma width around signal mean. 4 aspects of sources of systematic uncertainties were studied. Uncertainty introduced by polarity correction is significantly larger than other sources, estimated by $\pm(A_{raw} - A_{cor})$. Method used in calculating error of chosen signal model is comparing A_{raw} given by "similar-good-fit" Cruijff function and double gaussian signal model, defined as $\pm(A_{raw}^{Cruijff} - A_{raw}^{Gaussian})$. This two function give deduced $\chi^{2}_{+} = 1.109$, $\chi^{2}_{-} = 1.065$ and $\chi^{2}_{+} = 1.162$, $\chi^{2}_{-} = 1.118$ respectively. Lorentz function was not included since it gives relatively higher deduced χ^{2}. By shifting the position of 4-body gaussian function, we estimated uncertainty of partially reconstructed 4-body-decay. However, its magnitude is around 10^{-5}, which is negligible. B meson production uncertainty was considered as systematic error. Total

systematic uncertainty is calculated by sum in quadrature of each contribution, main systemetic uncertainties are listed in Table 1.

Table 1: Main systematic Uncertainties

Source	Uncertainty
Polarity Correction	0.023
Signal Function	0.011
4-body Backgrounds	0.000
B Meson Production	0.004
Total	0.026

In summary, inclusive CP asymmetry is measured to be $A_{CP} = 0.126 \pm 0.023(statistical) \pm 0.026(systematical)$ total uncertainty is calculated by $\pm\sqrt{0.023^2 + 0.026^2} = \pm0.035$, significance yeilds 3.63σ.

4   Local Asymmetry

In order to investigate the distribution of CP violation, we studied local asymmetries in 2-body mass $M^2_{high\ \pi^+\pi^-}$ and $M^2_{low\ \pi^+\pi^-}$ phase space. Candidates whose mass are within 2σ width of signal model on 3-body mass spectrum are selected to be combined signal. Background are defined as the average candidates in a 7 times wider region on the higher-mass side adjoin the signal region. The background distribution was rescaled linearly to match the distribution of signal in Dalitz plot. We set different bin size across the phase space to make sure every bins have approximately equal number of events. Asymmetries in i^{th} bin was calculated by $A_i = \frac{N_i^- - N_i^+}{N_i^+ - N_i^+}$, corresponding error is statistical only. Asymmetry and significance are shown in Figure 2. Area 1, $[M^2_{low} \in (0, 0.5),\ M^2_{high} \in (17, 24)]$ and Area 2, $[M^2_{low} \in (1, 3),\ M^2_{high} \in (5, 15)]$ have relatively high asymmetries and significances, while
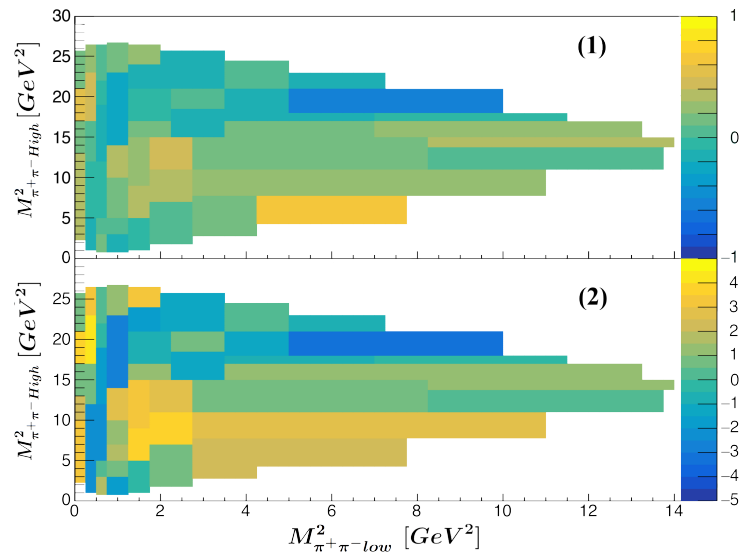

Figure 2: (1) Asymmetries distributed in phase space. (2) Significance in local phase space area.

Area 3, $[M^2_{low} \in (5, 10),\ M^2_{high} \in (18, 21)]$ has high significance but negative asymmetry. Same methods used in measuring global CP asymmetry were used in these areas to evaluate the original results. Results in local areas are shown in Figure 3. Aera 1 and 2 have
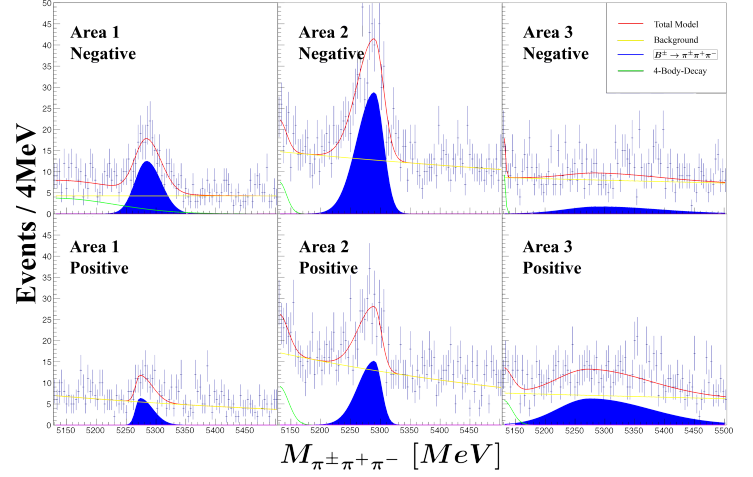

Figure 3: Invariant mass spectrum and fitting results in local areas

significant peak at signal region, but asymmetry observed in Area 3 is faked by noise. Binned χ^2 test[6] was performed to check local asymmetries we observed, which yeilds deduced $\chi^2 = 7.47$, indicating almost certain local asymmetry.

5   Conclusions

Global CP asymmetry in $B^\pm \to \pi^\pm\pi^+\pi^-$ channal was measured to be 0.126 ± 0.035, with significance 3.63σ. Larger asymmetry distributed in phase space is observed. This results are consistant with measurements of LHCb Collaboration. [5]

References

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