Extracting γ from three-body B-meson decays

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Three-body charmless hadronic B-meson decays are a great place to study the weak interactions of the Standard Model (SM), and in particular extract information about the weak-phase γ. Unlike two-body decays such as $B \to DK$ and $B \to D\pi$ where the decay amplitude only contains tree-level diagrams, amplitudes for three-body charmless B decays contain both trees and loops. γ extracted from three-body decays can thus be sensitive to new physics that can enter into loops at very high energies. In order to extract γ from three-body decays, however, one needs to use low energy symmetries such as U-spin and flavor SU(3). In this talk, we will show how U-spin and flavor-SU(3) symmetries can be used to develop methods for extracting γ from three-body B decays. We show a successful implementation of the flavor-SU(3) symmetry method applied to BaBar data. Future LHCb and Belle II data can be used to extract weak-phase information in three-body charmless hadronic B decays with greater precision than ever before.

The observed baryon-to-photon ratio of the universe [1] is several orders of magnitude larger than that predicted by the Standard Model. In order to explain this we need new sources of CP violation beyond the standard Cabibbo-Kobayashi-Maskawa (CKM) paradigm. Precision measurements of CKM unitarity triangle angle γ may reveal deviations from SM expectations and thus provide hints of new sources of CP violation. The standard methods for measuring the CKM angle γ, the so called GLW [2, 3], ADS [4], and GGSZ [5] methods, exploit interference between tree diagrams in B decays. Although new physics may affect tree diagrams [7], the above methods provide a theoretically clean way of measuring the SM value of γ [6]. As experiments become more and more precise [8–10], alternative methods for extracting γ, particularly ones involving decays that get contributions from loop diagrams, can help overconstrain the measurement of γ and help reveal discrepancies. Here we present two alternative methods for extracting γ using charmless three-body B decays.

The first method uses a pair of three-body decays related by U-spin symmetry. This method was proposed in Ref. [12] as an extension of a method involving two-body U-spin pairs [11]. Requiring a time-dependent Dalitz analyses of a U-spin related pair of three-body decays with flavor-neutral final states, it was shown that there are enough observables to extract γ from a fit. It was shown that in every Dalitz plot bin one can construct an equivalent of a CP-averaged branching ratio, a direct CP asymmetry and an indirect CP asymmetry. While there are six observables from the two decays, U-spin symmetry implies one relationship involving the branching ratios and CP asymmetries. Including the measurement of the $B-\bar{B}$ mixing phase as an external input, in addition to extracting three hadronic parameters (two magnitudes and one relative strong phase) one can also extract γ. In addition, this method also provides a way to test the amount of U-spin breaking using the U-spin relationship between branching ratios and CP asymmetries. One key advantage to this method is that utilizing the momentum dependence of Dalitz analyses one can find γ, as well as test U-spin breaking, in local regions and averaged over the entire Dalitz plot. The observables defined in this method become exact when the bins are pointlike. The effect of finite bin sizes is to introduce a systematic error that can be controlled by varying bin sizes until an optimum bin size is found for a given dataset.

The second method uses several three-body B decays that are related by flavor-SU(3) symmetry. An implementation of this method using BaBar data [15] was first presented in [14]. The method relies on diagrammatic analyses of three-body final states. Under SU(3) symmetry, since the final state has S3 symmetry (symmetry under interchange of the three identical particles in the final state), one can split the three-body decay amplitude into a fully-symmetric, a fully-antisymmetric and four mixed-symmetric states. In Ref. [13] it was shown that flavor-SU(3) diagrams are equivalent to flavor-SU(3) matrix elements for the fully-symmetric three-body final state. Further, in Ref. [14] it was shown that, in the flavor-SU(3) symmetry limit there are four effective diagrams that represent nine observables that can be constructed from four flavor-SU(3) related decays. Including seven hadronic parameters for the four diagrams (one magnitude and strong phase for each diagram, while ignoring one overall strong phase), there are enough observables to extract γ. In order to construct the observables from data an amplitude analysis using the isobar model was implemented for each of the four Dalitz plots. Once again, since both observables and parameters in three-body decays are momentum dependent, γ could be determined independently from different local regions of the Dalitz plots. The first implementation of this method found a fourfold discrete ambiguity in the determination of γ with one of the four values agreeing quite well with the SM expectation for γ from tree decays. In an extension of this method using five SU(3)-related three-body decays (instead of four decays) it was possible to extract an SU(3)-breaking parameter. Averaged over the kine-

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matically allowed Dalitz regions, this SU(3)-breaking parameter was found to be quite close to 1 indicating the absence of significant SU(3) breaking. Although the original analysis presented in Ref. [14] did not take into account systematic uncertainties in the data, a new analysis presented in this conference has now taken into several such sources of uncertainties [16].

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