

Measuring CP Violating Phase in Beauty Baryon Decays


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 (Received 1 October 2021; revised 20 December 2021; accepted 27 January 2022; published 23 February 2022)

One of the outstanding problems in physics is to explain the baryon–antibaryon asymmetry observed in nature. According to the well-known Sakharov criterion for explaining the observed asymmetry, it is essential that CP violation exist. Even though CP violation has been observed in meson decays and is an integral part of the standard model (SM), measurements in meson decays indicate that CP violation in the SM is insufficient to explain the observed baryon–antibaryon asymmetry. The SM predicts the existence of yet to be observed CP violation in baryon decays. A critical test of the SM requires that CP violation be measured in baryon decays as well, in order to verify that it agrees with the measurement using meson decays. In this Letter we propose a new method to measure the CP violating phase in b baryons, using interference arising implicitly due to Bose symmetry considerations of the decaying amplitudes.

DOI: [10.1103/PhysRevLett.128.081803](https://doi.org/10.1103/PhysRevLett.128.081803)

The proposal to observe CP violation in Σ -baryon decays [1] was first made by Okubo in 1957, much before the first observation of CP violation in 1964 by Fitch and Cronin using neutral K mesons. CP violation has since been observed in B mesons and D mesons as well. CP violating phases have been measured accurately in B -meson decays and the measurements are found consistent within the standard model (SM) and in agreement with the Kobayashi-Maskawa hypothesis.

One of the well-known Sakharov conditions [2,3] to explain baryon–antibaryon asymmetry in the Universe is the existence of CP violation. The observation of CP violation in baryon decays is expected within the SM and thus, of great interest. It would provide a direct probe of matter–antimatter asymmetry, arising from the CP violating sector of the SM. This is essential since measurements in meson decays indicate that CP violation in the SM is by itself insufficient to explain the observed baryon–antibaryon asymmetry [4]. However, CP violation has only been observed in meson decays and is yet to be convincingly demonstrated [5–14] in baryon decays. It is well known that the largest weak phases within the SM appear in $b \rightarrow u$ and $t \rightarrow d$ transitions. It is thus obvious that it would be easiest to observe CP violation in b baryons and one must explore the weak decays of the antitriplet ($\bar{3}$) beauty baryons.

While there is no reason to expect a disagreement between CP violating phases measured using baryons and that using mesons, within the SM, it nevertheless remains imperative that a clean measurement of the weak phase also be performed in baryons decays. A comparison of the measurements of CP violation in meson and baryon decays would provide a critical probe of physics beyond the SM. Unfortunately, measurement of CP violation in baryon decays is not straightforward. It is well known that for CP violation to be observed the amplitude must have two contributions with both having different strong phases and weak phases. However, in order to measure the CP violating phase using the decay(s) of any particle(s) one must satisfy certain further conditions. One of the critical requirements to measure any phase is that amplitudes interfere. The case of neutral B mesons mixing between particles and antiparticles allows for two distinct amplitudes to interfere, with one amplitude corresponding to direct decay and the other to decay via mixing. This results in the well-known time-dependent CP violation. However, baryon number conservation forbids oscillations between baryons and antibaryons disallowing such time-dependent mixing and consequent interference of two amplitudes. It is also essential that at least one of the decay amplitudes be reparametrization invariant [15,16] such that the CP violating phase to be measured can be uniquely defined [17]. Inability to satisfy this condition results in fewer independent observables than necessary to measure the weak phase. The methods to measure the phases β and α without approximations in B mesons satisfy all these conditions.

Interestingly, the phase γ can be measured, without the need for meson mixing. Interference of two decay

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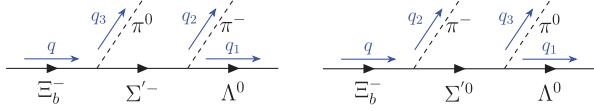


FIG. 1. Feynman diagrams contributing to the quasi two body decay $\Xi_b^-(q) \rightarrow \Lambda^0(q_1)\pi^-(q_2)\pi^0(q_3)$ via the $J^P = \frac{3}{2}^+$, $\Sigma'(1385)$ baryon resonance.

amplitudes arises from decay to the same final state via intermediate D^0 and \bar{D}^0 decays. The only proposal [18] to measure a weak phase using baryons is a straightforward extension of this method used in mesons, to achieve interference of two amplitudes. A proposal to measure a CP violating weak phase in baryon decays that is not a straightforward extension of the approach used in meson decays and one that relies on processes specific to baryons is still missing.

In this Letter we propose a new approach to measure the CP violating weak phase in baryon decays using interference arising due to Bose symmetry considerations of the decaying amplitudes. We start by exploring the weak decays of the antitriplet $\bar{3}$ beauty baryons which have been studied earlier in Refs. [19,20] and where large CP violation may be expected. As mentioned earlier for weak phases to be measurable, the additional criterion of reparametrization invariance must also hold. This reparametrization condition is severely restrictive for the weak decay of $\bar{3}b$ baryon and we find that even when the interference criterion due to Bose symmetry holds, measurement of the weak phase is not possible in most cases since reparametrization invariance of the amplitude does not hold. Considering all the weak decay modes of the $\bar{3}b$ baryons we find one mode, namely, $\Xi_b \rightarrow \Sigma'(1385)\pi$, where it is possible to measure the CP violating weak phase.

We show in detail how the weak phase can be measured using the decay $\Xi_b \rightarrow \Sigma'\pi$, where Σ' is the $J^P = \frac{3}{2}^+$ decuplet baryon resonance corresponding to $\Sigma'(1385)$. We consider the decays $\Xi_b^- \rightarrow \Sigma'^0(1385)\pi^-$ and $\Xi_b^- \rightarrow \Sigma'^-(1385)\pi^0$ depicted in Fig. 1. Note that Ξ_b^- is an isospin 1/2 state of bsd quarks. The subsequent strong decays of the $\Sigma'^0 \rightarrow \Lambda^0\pi^0$ and $\Sigma'^- \rightarrow \Lambda^0\pi^-$ result in the identical final state $\Xi_b^- \rightarrow \Lambda^0\pi^-\pi^0$ for both the decay modes. The $\Lambda^0\pi^-\pi^0$ Dalitz plot would depict both these decays and have special properties under exchange of the two pions, which are identical bosons under isospin symmetry. The interference between these two modes would arise implicitly from Bose symmetry correlations even though the two decay modes do not effectively interfere on the Dalitz plot. The $\pi^-\pi^0$ can either be in a $|1, -1\rangle$ or $|2, -1\rangle$ isospin state. Since, the two π bosons are identical under isospin their total wave function must be symmetric. This necessitates that the two pions in the odd isospin state $|1, -1\rangle$ must be antisymmetric under spatial exchange, whereas, the two pions of even isospin state $|2, -1\rangle$ must be symmetric under

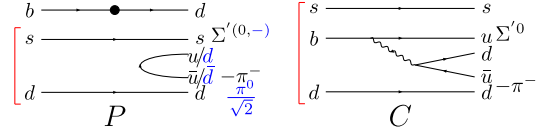


FIG. 2. Topological diagrams contributing to decay $\Xi_b^- \rightarrow \Sigma'\pi$ decays. The blob on the $b \rightarrow d$ transition in the diagram on the left corresponds to the $b \rightarrow d$ penguin. The red line straddling between the s and d quarks of the initial $\bar{3}$ state indicates anti-symmetry of quarks in the initial $\bar{3}$ state. The symmetric wavefunction of the $J^P = \frac{3}{2}^+$ nucleon Σ' allows only the above topologies.

spatial exchange. The Λ^0 is an isospin $|0, 0\rangle$ state, hence, the combined isospin of the final $\Lambda^0\pi^-\pi^0$ state must be identical to the isospin of the two pion state, which can either be a $|2, -1\rangle$ or $|1, -1\rangle$. Isolating the $\pi^-\pi^0$ symmetric state which has isospin $|2, -1\rangle$, would thus be equivalent to isolating the $\Delta I = 3/2$ changing contribution to the decay, which cannot arise from the penguin diagram and must have a pure $b \rightarrow u$ weak phase.

The topological diagram contributions to the decays $\Xi_b^- \rightarrow \Sigma'^0(1385)\pi^-$ and $\Xi_b^- \rightarrow \Sigma'^-(1385)\pi^0$ are depicted in Fig. 2. While the decay $\Xi_b^- \rightarrow \Sigma'^0(1385)\pi^-$ gets contributions from both the tree-level and penguin diagrams with the corresponding amplitudes denoted as C and P , respectively, only the P amplitude contributes to the decay $\Xi_b^- \rightarrow \Sigma'^-(1385)\pi^0$. This ensures that the weak phase cannot be reparametrized and plays a crucial role in the measurement of the CP violating weak phase. The CP violating weak phase measured using b baryons within our approach is free from any hadronic uncertainty and relies only on reliable theoretical inputs such as isospin and vanishingly small electroweak penguin contributions in $\Delta S = 0$, $b \rightarrow d$ decays.

We consider the decay in the Gottfried-Jackson frame with Ξ_b moving in the $+\hat{z}$ axis, with the two pions going back to back with the $\pi^-(q_2)$ at an angle θ to the $\Lambda^0(q_1)$. In this frame (see Fig. 3) $\vec{q}_2 + \vec{q}_3 = 0$. We define $s \equiv (q_2 + q_3)^2 = (q - q_1)^2$, $t \equiv (q_1 + q_3)^2 = (q - q_2)^2$, and $u \equiv (q_1 + q_2)^2 = (q - q_3)^2$. t and u can be written as

$$t = x + y \cos \theta, \quad (1)$$

$$u = x - y \cos \theta, \quad (2)$$

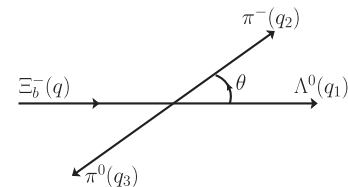


FIG. 3. Jackson frame in which $\Xi_b^-(q)$ decays to three bodies $\Lambda^0(q_1)$, $\pi^-(q_2)$, and $\pi^0(q_3)$.

where

$$x = \frac{M^2 + m_\Lambda^2 + 2m_\pi^2 - s}{2}, \quad (3)$$

$$y = \frac{\sqrt{s - 4m_\pi^2}}{2\sqrt{s}} \lambda^{1/2}(M^2, m_\Lambda^2, s), \quad (4)$$

and $\lambda(M^2, m_\Lambda^2, s) = (M^4 + m_\Lambda^4 + s^2 - 2M^2m_\Lambda^2 - 2M^2s - 2m_\Lambda^2s)$. M is the mass of the Ξ_b baryon, m_Λ is the mass of the Λ^0 , and m_π is the mass of the pions.

The matrix element for the weak decay $\Xi_b^- \rightarrow \Sigma'^{(-,0)} \pi^{(0,-)}$ is given by

$$\mathcal{M}(\Xi_b^- \rightarrow \Sigma' \pi) = -i q_\mu^\pi \bar{u}_{\Sigma'}^\mu (a + b \gamma_5) u_{\Xi_b}, \quad (5)$$

where, $u_{\Sigma'}^\mu$ is the Rarita-Schwinger spinor for the spin-3/2 decuplet and hence a Lorentz index, q_μ^π is the momentum of the π , and u_{Ξ_b} is the spinor of the Ξ_b . The two coefficients a and b depend on the CKM elements and flavor structure specific to the decay mode. It may be noted that a and b are related to the p - and d -wave decay amplitudes respectively. The Σ' baryon subsequently decays via strong interaction to a Λ^0 baryon and a pion with the matrix element for the decay being given by,

$$\mathcal{M}(\Sigma' \rightarrow \Lambda^0 \pi) = i g_{\Sigma' \Lambda \pi} q_\mu^\pi \bar{u}_\Lambda u_{\Sigma'}^\mu, \quad (6)$$

where, $g_{\Sigma' \Lambda \pi}$ is the invariant coupling for the decay. The decay for the conjugate modes $\bar{\Xi}_b^+ \rightarrow \bar{\Sigma}'^{(+,0)} \pi^{(0,+)}$ can be described analogously except that it would be described by new coefficients \bar{a} and \bar{b} that are related to a and b by reversing the respective weak phases. The propagator of the $\Sigma'(1385)$ baryon has the form [21]

$$\Pi^{\mu\nu}(k) = -\frac{(\not{k} + m)}{(k^2 - m^2 + im\Gamma)} \left(g^{\mu\nu} - \frac{2k^\mu k^\nu}{3m^2} - \frac{1}{3} \gamma^\mu \gamma^\nu + \frac{1}{3m} (k^\nu \gamma^\mu - k^\mu \gamma^\nu) \right), \quad (7)$$

corresponding to that of a spin-3/2 fermion with the four-momentum k , mass m , and width Γ .

The matrix element for the two-step decay $\Xi_b^-(q) \rightarrow \Sigma'^-[\rightarrow \Lambda^0(q_1) \pi^-(q_2)] \pi^0(q_3)$ is given by

$$\begin{aligned} \mathcal{M}_u &= \mathcal{M}(\Xi_b^-(q) \rightarrow \Sigma'^-[\rightarrow \Lambda^0(q_1) \pi^-(q_2)] \pi^0(q_3)) \\ &= g_{\Sigma' \Lambda \pi} \bar{u}(q_1) (a^- + b^- \gamma_5) \Pi^{\mu\nu}(q_{12}) u(q) q_3^\mu q_2^\nu, \end{aligned} \quad (8)$$

where $q_{ij} = q_i + q_j$ and m is the mass of $\Sigma'(1385)$ resonance. Similarly, the two-step decay $\Xi_b^-(q) \rightarrow \Sigma'^0[\rightarrow \Lambda^0(q_1) \pi^0(q_3)] \pi^-(q_2)$ is given by

$$\begin{aligned} \mathcal{M}_t &= \mathcal{M}[\Xi_b^-(q) \rightarrow \Sigma'^0[\rightarrow \Lambda^0(q_1) \pi^0(q_3)] \pi^-(q_2)] \\ &= g_{\Sigma' \Lambda \pi} \bar{u}(q_1) (a^0 + b^0 \gamma_5) \Pi^{\mu\nu}(q_{13}) u(q) q_2^\mu q_3^\nu. \end{aligned} \quad (9)$$

The matrix elements \mathcal{M}_u and \mathcal{M}_t are related by isospin. The sum of the matrix element of the two contributing modes must be completely Bose symmetric under the exchange of the two pions and may be written in an explicitly symmetric form as

$$\begin{aligned} \mathcal{M}(\Xi_b^- \rightarrow \Sigma'[\Lambda \pi] \pi) &= g_{\Sigma' \Lambda \pi} \bar{u}(q_1) \{ (A_e + B_e \gamma_5) \\ &\quad \times [\Pi^{\mu\nu}(q_{12}) + \Pi^{\mu\nu}(q_{13})] \\ &\quad + (A_o + B_o \gamma_5) [\Pi^{\mu\nu}(q_{12}) \\ &\quad - \Pi^{\mu\nu}(q_{13})] \} u(q) q_2^\mu q_3^\nu, \end{aligned} \quad (10)$$

where A_e, B_e and A_o, B_o are the even and odd parts of the amplitude under the exchange of the two pions and are given by

$$\begin{aligned} A_{e,o} &= (a^\pm \pm a^0)/2, \\ B_{e,o} &= (b^\pm \pm b^0)/2. \end{aligned} \quad (11)$$

The coefficients $a^0, a^-, b^0,$ and b^- are related (see Fig. 2) to the topological amplitudes [19,20], which after a phase rotation of $e^{i\gamma}$ may be written as follows:

$$\begin{aligned} a^0 &= -\frac{1}{2\sqrt{3}} (C_p - P_p e^{-i\alpha}), \\ a^- &= -\frac{1}{2\sqrt{3}} P_p e^{-i\alpha}, \\ b^0 &= -\frac{1}{2\sqrt{3}} (C_d - P_d e^{-i\alpha}), \\ b^- &= -\frac{1}{2\sqrt{3}} P_d e^{-i\alpha}, \end{aligned} \quad (12)$$

where C_p, P_p are related to the topological amplitudes contributing to the p wave with analogous definitions for the d wave. Here the p wave and d wave refer to waves in the intermediate $\Sigma' \pi$ state. Note that the phase rotation of $e^{i\gamma}$ does not alter any physical observable. Hence,

$$\begin{aligned} A_e &= -\frac{1}{4\sqrt{3}} C_p \equiv x_p, \\ A_o &= \frac{1}{4\sqrt{3}} C_p - \frac{1}{2\sqrt{3}} P_p e^{-i\alpha} \equiv -x_p + z_p e^{-i\alpha} e^{i\delta_p}, \\ B_e &= -\frac{1}{4\sqrt{3}} C_d \equiv x_d, \\ B_o &= \frac{1}{4\sqrt{3}} C_d - \frac{1}{2\sqrt{3}} P_d e^{-i\alpha} \equiv -x_d + z_d e^{-i\alpha} e^{i\delta_d}, \end{aligned} \quad (13)$$

where, $\delta_{(p,d)}$, is the strong phase difference between the penguin and the tree contribution for the p and d waves, respectively.

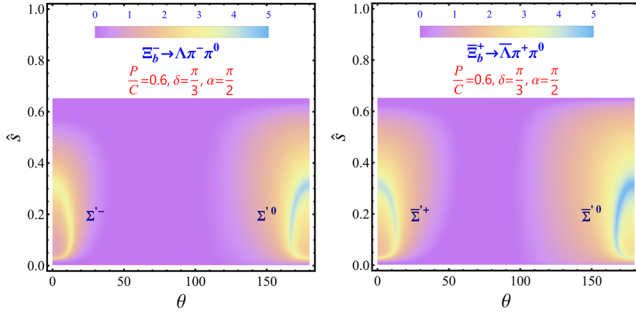


FIG. 4. Sample correlation-plots for the p -wave contributions for the specified choice of parameters. Plotted are the logarithmic value of the p -wave rates with an arbitrary scale that depends on C . Explicit dependence of some of the parameters on p -wave is suppressed for simplicity. The contributing intermediate Σ' resonances are depicted on the plots. The differences between the two plots arise only due to CP violation effects. Similar plots would arise from the d -wave contributions.

The decay rate for the three-body final state $\Lambda^0 \pi^- \pi^0$ will depend on the Mandelstam variables t and u . This can easily be cast in terms of s and $\cos \theta$ using Eqs. (1), (2), (3), and (4). It is obvious to conclude from Fig. 3 that under the exchange of the two pions, $\theta \leftrightarrow \pi - \theta$. The odd (even) part of the amplitude under the exchange of two pions must therefore be proportional to odd (even) powers of $\cos \theta$. Since Bose correlations are clearly depicted in plots involving $\hat{s} = s/M^2$ and θ , we refer to such plots as correlation plots. In Fig. 4, we show sample correlation plots for $P_p/C_p = 0.6$, $\delta_p = \pi/3$, and $\alpha = \pi/2$. Plotted are the logarithmic values of the p -wave rates with an arbitrary scale that depends on the choice of P_p/C_p and the p -wave rate for the decay $\Xi_b^- \rightarrow \Sigma' \pi^0$. In our calculations we have used $M = 5797$, $m = 1385$, $\Gamma = 38$, $m_\Lambda = 1115$, and $m_\pi = 135$ MeV. The effects of CP violation can be observed as differences between the two plots corresponding to mode and conjugate mode. The effects of Bose correlation are also obvious. The decay $\Xi_b^- \rightarrow \Sigma' \pi^0$ arises due to pure penguin [See Eqs. (8) and (12)]. If there are no Bose correlation effects contributing to the decays, the decays of $\Xi_b^- \rightarrow \Sigma' \pi^0$ and $\Xi_b^+ \rightarrow \bar{\Sigma}' \pi^0$ seen on the left of the two plots in Fig. 4 would look identical. However, the Dalitz plots show a marked difference between $\Xi_b^- \rightarrow \Sigma' \pi^0$ and $\Xi_b^+ \rightarrow \bar{\Sigma}' \pi^0$ on their respective Dalitz plot, providing a smoking gun evidence of large Bose correlation effects. This observation is fundamental to our new approach to measure CP violation. We will show next that the observed distributions along these narrow resonances provide enough information to extract all theoretical parameters from experimental data, including the p - and d -wave contributions, respectively.

The numerator of the decay rate N_Γ for both the mode and conjugate mode are worked out to have the complicated form

$$N_\Gamma = \sum_{n=0}^4 c_n(\hat{s}) \cos 2n\theta + \sum_{n=0}^3 d_n(\hat{s}) \cos(2n+1)\theta, \quad (14)$$

where all masses and momenta are normalized to M , the Ξ_b mass for simplicity, and

$$c_n(s) = [f_n^{(1)}(\hat{s})|A_e|^2 + f_n^{(2)}(\hat{s})|B_e|^2 + f_n^{(3)}(\hat{s})|A_o|^2 + f_n^{(4)}(\hat{s})|B_o|^2], \quad (15)$$

$$d_n(\hat{s}) = [g_n^{(1)}(\hat{s})\text{Re}(A_e A_o^*) + g_n^{(2)}(\hat{s})\text{Re}(B_e B_o^*) + g_n^{(3)}(\hat{s})\text{Im}(A_e A_o^*) + g_n^{(4)}(\hat{s})\text{Im}(B_e B_o^*)]. \quad (16)$$

The coefficients $f_n^{(i)}$ and $g_n^{(i)}$ are functions of \hat{s} and are easily computed in terms of kinematic factors. For a given choice of \hat{s} , $f_n^{(i)}$, and $g_n^{(i)}$ are just numbers. We henceforth drop explicit dependence on \hat{s} , since our solutions are valid for all \hat{s} . The numerator of the decay rate given in Eq. (14) can be fitted as a function of θ to obtain coefficients c_n and d_n . Having obtained c_0 , c_1 , c_2 , and c_3 it is obvious that $|A_e|^2$, $|A_o|^2$, $|B_e|^2$, and $|B_o|^2$ can easily be obtained. Similarly, $\text{Re}(A_e A_o^*)$, $\text{Re}(B_e B_o^*)$, $\text{Im}(A_e A_o^*)$, and $\text{Im}(B_e B_o^*)$ can be solved using d_0 , d_1 , d_2 , and d_3 . In order to solve for the amplitudes and their interference, one must have a minimum of eight bins in θ and \hat{s} involving both the resonances contributing to the process. Experimental procedure used in an actual analysis can be more refined. An identical analysis of the decay rate for the conjugate process would enable us to solve for $|\bar{A}_e|^2$, $|\bar{A}_o|^2$, $|\bar{B}_e|^2$, $|\bar{B}_o|^2$, and $\text{Re}(\bar{A}_e \bar{A}_o^*)$, $\text{Re}(\bar{B}_e \bar{B}_o^*)$, $\text{Im}(\bar{A}_e \bar{A}_o^*)$, and $\text{Im}(\bar{B}_e \bar{B}_o^*)$. Having solved the values of these amplitudes and their interference, our aim is to solve for the weak phase α and the amplitudes $x_{p,d}$ and $z_{p,d}$ defined in Eq. (13) and the strong phases $\delta_{p,d}$. In order to obtain the solutions for the p -wave parameters we define new intermediate observables r_i :

$$\begin{aligned} r_0 &= |A_e|^2 = |\bar{A}_e|^2 = x_p^2, \\ r_1 &= |A_o|^2 + |\bar{A}_o|^2 = 2x_p^2 + 2z_p^2 - 4x_p z_p \cos \delta_p \cos \alpha, \\ r_2 &= |A_o|^2 - |\bar{A}_o|^2 = -4x_p z_p \sin \delta_p \sin \alpha, \\ r_3 &= \text{Re}(A_e A_o^* - \bar{A}_e \bar{A}_o^*) = 2x_p z_p \sin \delta_p \sin \alpha, \\ r_4 &= \text{Im}(A_e A_o^* - \bar{A}_e \bar{A}_o^*) = 2x_p z_p \cos \delta_p \sin \alpha, \\ r_5 &= \text{Re}(A_e A_o^* + \bar{A}_e \bar{A}_o^*) = -2x_p^2 + 2x_p z_p \cos \delta_p \cos \alpha, \\ r_6 &= \text{Im}(A_e A_o^* + \bar{A}_e \bar{A}_o^*) = -2x_p z_p \sin \delta_p \cos \alpha. \end{aligned} \quad (17)$$

We find the solutions in terms of r_i to be

$$\begin{aligned} x_p^2 &= r_0, \\ \tan \delta_p &= r_3/r_4, \\ \tan \alpha &= -r_3/r_6 = r_2/(2r_6), \\ z_p^2 &= \frac{(r_3^2 + r_4^2)(r_3^2 + r_6^2)}{4r_0 r_3^2}. \end{aligned} \quad (18)$$

Since all the r_i are not independent, we find the relations

$$r_3^2 + r_4^2 + r_5^2 + r_6^2 = 2r_0r_1, \quad (19)$$

$$r_3r_5 + r_4r_6 = r_0r_2, \quad (19)$$

$$r_2 = -2r_3. \quad (20)$$

The solutions for the d -wave parameters can be obtained similarly. It is noted that both the p - and d -wave contributions must result in the measurement of the same weak phase α . We hence have two independent measurements of α corresponding to the two partial waves.

The observed Dalitz plot must have a more complicated structure with several resonances, and one may wonder if our approach to measure the weak phase would be possible. The contributions from heavier Σ' states have a similar decay dynamics with the same weak phase α , but the relevant amplitudes and strong phases would differ. While these resonances are not a cause for concern, suitable binning cuts would easily remove their contributions without losing relevant signal sample. Only the interference with the decay mode $\Xi_b^- \rightarrow \Lambda^0 \rho^- \rightarrow \Lambda^0 \pi^- \pi^0$, and modes involving heavier ρ -like resonances, instead of ρ , need a closer look. It is interesting to note that $\Xi_b^- \rightarrow \Lambda^0 \rho^-$ has a different \hat{s} dependence in the overlap region and contributes only to the odd part of the amplitude. Once data are available in several more \hat{s} bins; such interference effects can easily be isolated using the Dalitz distribution [22]. One does not need to impose cuts to remove the $\Xi_b^- \rightarrow \Lambda^0 \rho^-$ contributions.

We have demonstrated that Bose correlations arise from two intermediate decays $\Xi_b^- \rightarrow \Sigma'^0 \pi^-$ and $\Xi_b^- \rightarrow \Sigma'^- \pi^0$ contributing to the final state $\Xi_b^- \rightarrow \Lambda^0 \pi^- \pi^0$. Similar Bose correlations arise in the decay to conjugate final state $\Xi_b^+ \rightarrow \bar{\Lambda}^0 \pi^+ \pi^0$. We explicitly show that the weak phase α can be measured using both even and odd contributions to the amplitudes under pion exchange and comparing the mode and conjugate-mode correlation plots. Naively, one may be tempted to incorrectly assume that Bose correlation effects are too small to be observed. However, we have shown numerically and explicitly that such correlations are sizable, providing an unequivocal approach to measuring CP violation in baryon decays. The significant difference between the pure penguin decays of $\Xi_b^- \rightarrow \Sigma'^- \pi^0$ and $\Xi_b^+ \rightarrow \bar{\Sigma}'^+ \pi^0$ on their respective Dalitz plot is a smoking gun evidence of large Bose correlation effects. Our new approach to measure CP violation critically depends on such Bose correlations. Interestingly, inexplicably large CP violation effects are observed in the Dalitz plot of three body B -meson decays; we conjecture that these arise due to Bose correlations on the Dalitz plot.

We thank Sheldon Stone and Marcin Chrzęszcz for reading the manuscript and providing valuable suggestions. The work of S.R. is supported by the Grant No. CRG/2019/000362, Science and Engineering Research Board, Government of India.

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