Study of $B \to D^*h$ Decays and CP Violation

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DECLARATION

I herbey declare that the Summer Project Document titled **Study of $B \to D^*h$ Decays and CP Violation**, submitted to the Physics Department of IIT Madras, is a record of an original work undertaken by me under the supervision of Dr. James Frederick Libby.

The work has been conducted in the Physics Department of IIT Madras over 18th May 2022 to 14th July 2022.

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ABSTRACT

The document presented deals with a generalised simulation of the decay of a B meson into three bodies, one singular spinless meson and two other particles obtained from a resonance(chosen as D^*). The kinematics of the decay is based on the theoretical basis of the Standard Model and the obtained results can be used to verify data obtained at experiments like the Belle-II experiment which deals with B-Meson physics and CP-Violation in the Standard Model. The Dalitz Plot for the three-body decays as well as the ΔE parameter of the Partial Reconstruction in case of such decays signify the accuracy with regard to experimental values. The B-meson is generated through the annihilation of a positron and an electron, giving rise to the B^+B^- pair, which through their respective modes of Decay present a look into the CP-Violation in B-meson physics where it can be observed that the preference of decay in the two modes is not similar unlike what would be expected if the decays remained unchanged under CP transformation. A model for A_{CP} calculation which can be used to quantify the CP-violation in such a case.

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1 Introduction

Over the second half of the 20th Century, the Standard Model has developed into an extensive formulation which is used to describe almost the majority of particle interactions, explaining detector observations and outlining the structure of the universe at the high-energy scale. The Standard Model which also describes the dominance of matter over anti-matter in our universe deals with CP Violation in order to explain the occurrence. However, CP symmetry was initially thought to be conserved and the first instance of indirect CP Violation was observed in 1964 for Kaon Decays, the observed phenomenon was that these particles did not become their respective anti-particles and vice versa at the same rate as it should have been if CP Symmetry existed.

Direct CP Violation in B-mesons has been well documented after 2001 with the BaBar experiment at SLAC and the Belle Experiments consequently. The project deals with the kinematics of such B meson decays and develops a basic intuition for CP Violation ideas which one can encounter experimentally. The major decays that have been encountered during the project include $B^+ \to D^{*0}\pi^+ \to D^0\pi^0\pi^+$, $B^+ \to D^{*0}\pi^+ \to D^0\gamma\pi^+$, $B^\pm \to D^{*0}K^+ \to D^0\pi^{0\pm}$ and $B^\pm \to D^{*0}K^+ \to D^0\gamma^\pm$. The modelling of $D*$ resonance in this manner is also helpful to study the recreation of similar decays. The report outlines the theoretical basis of the SM Model, related Kinematics and a statistical approach towards CP Violation along with recreated results.

2 Kinematics of Two-Body Decay

The simplest approach to modelling the Three-Body decay through the resonance of $B \to D^*h$ is to start in the rest frame of the B particle. Considering the scenario as $0 \to 1 + 2$ we have the four-momentum of B as $P = (0, M)$. Then, following th5e equations $P = p_1 + p_2$ and $p = \sqrt{E^2 - m^2}$ we have the equations:

$$E_{1/2} = \frac{\sqrt{(M^2 \pm (m_1^2 - m_2^2))^2 - 4M^2 m_{1/2}^2}}{2M}$$

$$P_{1/2} = \frac{M^2 \pm (m_1^2 - m_2^2)}{2M}$$

We obtain the corresponding four-momenta of the 1 and 2 particles. Which for the inital simulation was $D*$ and π^+. However in order to obtain a proper simulation, the calculation must be performed considering the mass of the D^* particle through the Relativistic Breit-Wigner Resonance formulation.

3 Relativistic Breit-Wigner Resonance

In order to create a mass distribution to generate the two body decay through a resonance we must use a distribution for the $D*$ mass obtained from the initial decay. The commonly used method for which is the Relativistic Breit-Wigner Distribution. The mathematical formulation [6] for which is given by:

$$f(E; M, \Gamma) = \frac{M\Gamma}{\pi} \frac{1}{(E^2 - M^2)^2 + (M\Gamma)^2}$$

Here, E is the energy of the resonance, M is the mass of the unstable particle and Γ is the width of the resonance.

4 Formulation of Three-Body Decay

We start in the centre of mass frame where a projectile particle p collides with another particle at rest t. In our case, the annihilation of a positron and an electron gives rise to a B-meson pair which then decays further. Now considering the B-meson at rest, we get the formation of two particles say 1 and R where 1 is a stable particle and R is the unstable resonance. If the Z-axis is along the projectile direction, then we have:

$$\vec{p_R} = p_R(sin\theta_R\hat{x} + cos\theta_R\hat{z})$$

$$\vec{p_1} = -p_R(sin\theta_R\hat{x} + cos\theta_R\hat{z})$$

The next decay does not need to be restricted to the plane of the initial decay and can thus be characterised by their own set of polar angles.

Considering the helicity frame with respect to R, we set the Z-axis along the decay direction of R as seen from the centre of mass frame, and define helicity coordinates for particles 2 and 3 with θ_h and ϕ_h. Then:

$$\vec{p_2} = p_R(sin\theta_h cos\phi_h\hat{x} + sin\theta_h sin\phi_h\hat{y} + cos\theta_h\hat{z})$$

$$\vec{p_3} = -p_R(sin\theta_h cos\phi_h\hat{x} + sin\theta_h sin\phi_h\hat{y} + cos\theta_h\hat{z})$$

5 Dalitz Plots

Dalitz Plots are the most convenient tool used to analyze three body decay kinematics in their restricted phase space. The plot itself consists of a 2D histogram with one axis denoting the M^2 value for the particles $2, 3$ and another axis for the M^2 values of either 2 or 3 with 1. Thus giving the complete profile of the decay:

$$A \to 1 + R \to 1 + 2 + 3$$

5.1 Phase Space Distribution

For the three particles $1, 2$ and 3 we have the 9 Dimensional Phase Space given by [5]:

$$d^9R_3 = \frac{d^3\vec{p_1}}{2E_1}\frac{d^3\vec{p_2}}{2E_2}\frac{d^3\vec{p_3}}{2E_3}\delta^3(\vec{p_1} + \vec{p_2} + \vec{p_3})\delta(E_1 + E_2 + E_3 - E)$$

Utilising the fact that the sum of the momenta is within the delta function, we say $\vec{p_3} = -(\vec{p_1} + \vec{p_2})$. Then, integrating over the space, we have:

$$d^6 R_3 = \frac{d^3\vec{p_1}}{2E_1}\frac{d^3\vec{p_2}}{2E_2}\frac{1}{2E_3}\delta(E_1 + E_2 + E_3 - E)$$

Now, using $E^2 = p^2 + m^2$, we have:

$$E_3^2 = m_3^2 + p_3^2 = m_3^2 + (\vec{p_1} + \vec{p_2})\dot{(}\vec{p_1} + \vec{p_2})$$

$$E_3^2 = m_3^2 + p_1^2 + p_2^2 + 2p_1 p_2 \cos\theta_{12}$$

Now, to further simplify we can choose the Z-axis along the direction of $\vec{p_1}$ and integrate over the variable p_2.

$$d^3\vec{p_2} = p_2^2 dp_2 d(\cos\theta_{12}) d\phi_{12}$$

We can also write,

$$E^3 dE_3 = p_1 p_2 d(\cos\theta_{12})$$

Therefore,

$$d^4 R_3 = \frac{\pi}{4}\frac{d^3\vec{p_1}}{p_1 E_1}\frac{d^3\vec{p_2}}{p_2 E_2}\int_{E_{3_{min}}}^{E_{3_{max}}} dE_3 \delta(E_1 + E_2 + E_3 - E)$$

The limits of E_3 are given by $\sqrt{m_3^2 + (p_1 \pm p_2)^2}$. Thus, the phase space reduces to:

$$d^4 R_3 = \frac{\pi}{4}\frac{d^3\vec{p_1}}{p_1 E_1}\frac{d^3\vec{p_2}}{p_2 E_2}$$

Expanding $d^3\vec{p_1} = p_1^2 dp_1 d(\cos\theta_1 d\phi_1)$, we reduce it to a 2-D Phase Space :

$$d^2 R_3 = \pi^2 \frac{p_1 dp_1}{E_1}\frac{p_2 dp_2}{E_2}$$

Considering invariant masses, we can also write $E_i dE_i = p_i dp_i$. So,

$$d^2 R_3 = \pi^2 dE_1 dE_2$$

Where, $E_{3_{min}} \leq E - E_1 - E_2 \leq E_{3_{max}}$. Now we can obtain a function $F(E, E_1, E_2, m_1, m_2, m_3) = 0$ in order to obtain the kinematic boundary. The expression for F i s given by [5] :

$$\begin{aligned} F = (E^2 + m_1^2 + m_2^2 - m_3^2)^2 - 4m_1^2 m_2^2 - 8E(E_1^2 E_2 + E_1 E_2^2) + 4(E^2 + m_2^2)E_1^2 \\ +4(E^2 + m_1)^2 E_2^2 + 4(3E^2 + m_1^2 + m_2^2 - m_3)^2 E_1 E_2 \\ -4(E^2 + m_1^2 + m_2^2 - m_3^2)EE_1 - 4(E^2 + m_1^2 + m_2^2 - m_3^2)EE_2 \end{aligned}$$

5.2 Dalitz Plot Boundaries

In order to obtain the necessary information from a Dalitz Plot, we transform the equation for kinematic boundaries to be expressed in terms of invariant masses. The energies of the formed particles can be written as :

$$E_1 = \frac{E^2 + m_1^2 - m_{23}^2}{2E}$$

$$E_2 = \frac{E^2 + m_2^2 - m_{31}^2}{2E}$$

$$E_3 = \frac{E^2 + m_3^2 - m_{12}^2}{2E}$$

Then, we can rewrite the boundary as :

$$\begin{aligned} G(E, m_1, m_2, m_3, m_{12}^2, m_{23}^2) = m_{12}^4 m_{23}^2 + m_{12}^2 m_{23}^4 - m_{12}^2 m_{23}^2 (E^2 + m_1^2 + m_2^2 + m_3^2) \\ + m_{12}^2 (m_3^2 - m_2^2)(E^2 - m_1)^2 + m_{23}^2 (m_1^2 - m_2^2)(E^2 - m_3^2) \\ + (m_2^2 E^2 - m_1^2 m_3^2)(E^2 - m1^2 + m_2^2 - m3^2) \end{aligned}$$

The extreme conditions hold for

$$G = 0, \ \ \min(m_{ij}^2) = (m_i + m_j)^2, \ \ \max(m_{ij})^2 = (E - m_k)^2$$

.

6 Spin Consideration and Angular Distribution

If a particle with spin 0 decays into two particles both with 0 spin, then the angular distribution in such a case is uniform as there is no selective preference for the permitted values of angular momentum. However in our case we see the decay into spinless particles through a resonant state. The initial $B^\pm$ particle has spin and parity 0^-, the decay product $\pi^\pm$ or $K^\pm$ also has spin and parity 0^-. But the resonant unstable state $D^{*0}(2007)$ is of 1^- character which then further decays into two modes: $D^{*0} \to D^0\pi^0$ or $D^{*0} \to D^0\gamma$.

Of the two possible decay modes from the D^{*0}, the particles D^0 and π^0 are spinless, thus we have to factor in the angular distribution of the decay through the resonance in this case. However in the case of decay to a photon, there are two possible photon polarisation states and thus one of them will not be a part of the decay interaction based on the state of the D^{*0} and we can obtain a uniform distribution.

6.1 Angular Distribution

Following both the Helicity Formalism and Zemach Tensor Formalism we obtain a direct dependence of the angular distribution with the Legendre Polynomials [4]. For $L = 0$ it is uniform, $L = 1$ it is proportional to $\cos\theta$, for $L = 2$, it is $(3\cos^2\theta - 1)$ and so on.

If the Z-axis was aligned in the direction of $\vec{p_R}$ we boost along that direction into the rest frame of m_{23} and measure the angle between the particle 2 and the boost direction $\hat{\beta}$. This angle in question is the angle θ.

To calculate this angle, starting from the momentum of the particle 2, we have:

$$\vec{p_2} = \begin{pmatrix} p_2 \sin\theta_{2a} \\ 0 \\ p_2 \cos\theta_{2a} \end{pmatrix}$$

The Lorentz Boost factor here is $\vec{\beta} = \frac{\vec{p_a}}{E_a} = -\frac{p_1}{E-E1}\hat{z}$. Again, $\gamma = \frac{E-E_1}{m_{23}}$, so $\beta\gamma = \frac{p_1}{m_{23}}$. Thus in the Helicity Frame:

$$\begin{pmatrix} E_2^h \\ p_{2_x}^h \\ p_{2_z}^h \end{pmatrix} = \begin{pmatrix} \gamma & 0 & -\beta\gamma \\ 0 & 1 & 0 \\ -\beta\gamma & 0 & \gamma \end{pmatrix} \begin{pmatrix} E_2 \\ p_2 \sin\theta_{12} \\ p_2 \cos\theta_{12} \end{pmatrix}$$

Using the three obtained equations, we can write that

$$\cos\theta = \frac{\gamma p_2 \cos\theta_{2a} - \beta\gamma E_2}{p_2^h}$$

We already have the values for p_2^h and E_2^h from the two-body decay calculation and $\theta_{12} + \theta_{2a} = \pi$. The final value obtained is [4]:

$$\cos\theta = \frac{[-2m_{23}^2]m_{12}^2 + [m_{23}^2(m_2^2 + m_3^2 - m_{23}^2) + m_1^2(m_2^2 - m_3^2 + m_{23}^2) - E^2(m_2^2 - m_3^2 - m_{23}^2)]}{\sqrt{[E^4 + (m_1^2 - m_{23}^2 - 2E^2(m_1^2 + m_{23}^2)][m_2^4 + (m_{23}^2 - m_3^2)^2 - 2m_2^2(m_{23}^2 + m_3^2)]}}$$

7 Simulation of B^+ Decay

Using the theoretical background provided, the ROOT software was used to set up a generalised simulation of how such three body decays will work. The simulation starts with a positron and electron annihilation which can be treated as a projectile and target, coming to a total energy of 10.579 GeV. The mass of the formed B^+ and B^- are taken to be 5.27934 GeV [2].

The TGenPhaseSpace class in ROOT was used to simulate the particle decays and thus, the event is generated in the center-of-mass frame, but the decay products are finally boosted using the betas of the original particle which in this case is the combined four-vector at rest with 10.579 GeV energy. Then, the B^+ is isolated, and it is observed that it has a small momentum which is equivalent to if its consequent decays were considered to be from rest, boosted by the electron-positron pair dynamics.

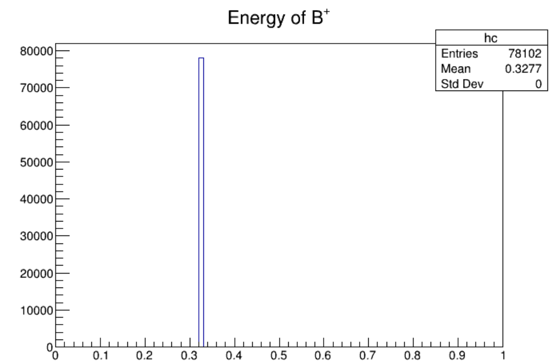

Figure 1: Momentum of B^+ Particle

We again use TGenPhaseSpace to create a new decay event in the centre of mass frame to obtain two products, one π^+ stable particle and the D^{*0} resonance.

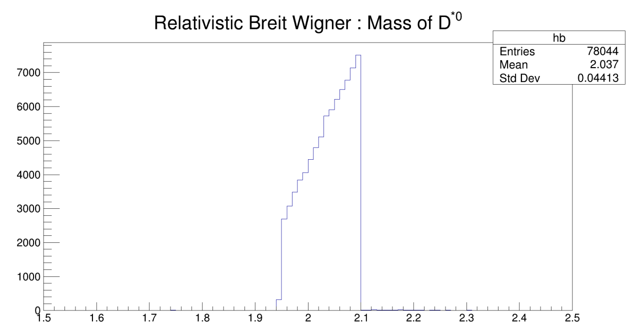

Figure 2: Resonance Mass Distribution

The energy and momentum distribution of the formed particles can confirm that the frame being used is consistent and thus we can set up the next decay from the resonance.

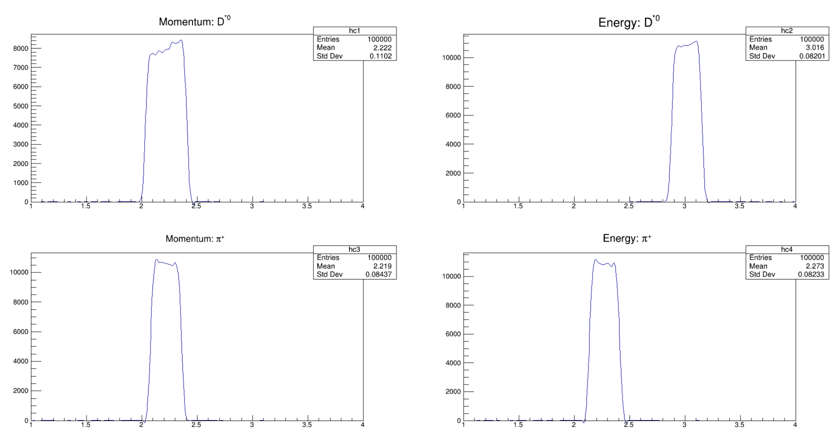

Figure 3: Energy-Momentum Distributions of π^+ and D^{*0}

Now we can separately consider the two cases where the D^{*0} unstable particle decays into either $D^0\pi^0$ or $D^0\gamma$. As described in the theoretical background, the former will be dependent on the angular distribution owing to the 1^- spin-parity character of the resonance particle and the latter will decay in only one mode, thus we can set up the Dalitz Plots for the complete three body decay of $B^+ \to D^0\pi^0\pi^+$ and $B^+ \to D^0\gamma\pi^+$. We have chosen the X-axis to denote the M^2 of the particles produced through the resonance :$D^0\pi^0$ or $D^0\gamma$ while the Y-axis is chosen as M^2 of $\pi^0\pi^+$ or $\gamma\pi^+$.

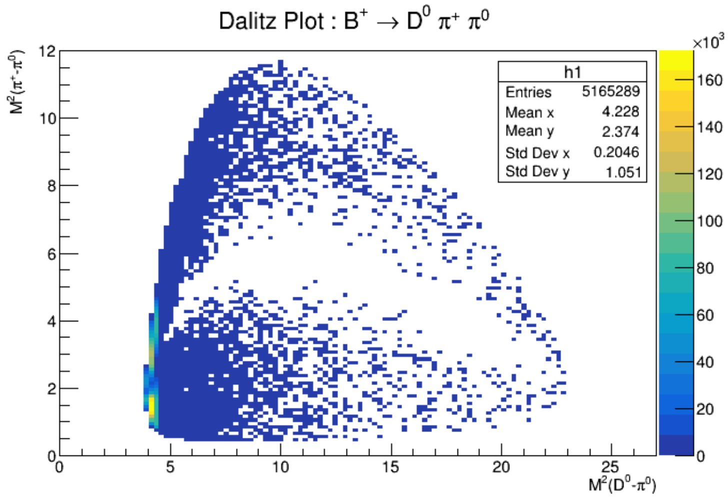

Figure 4: Dalitz Plot for $B^+ \to D^0\pi^0\pi^+$

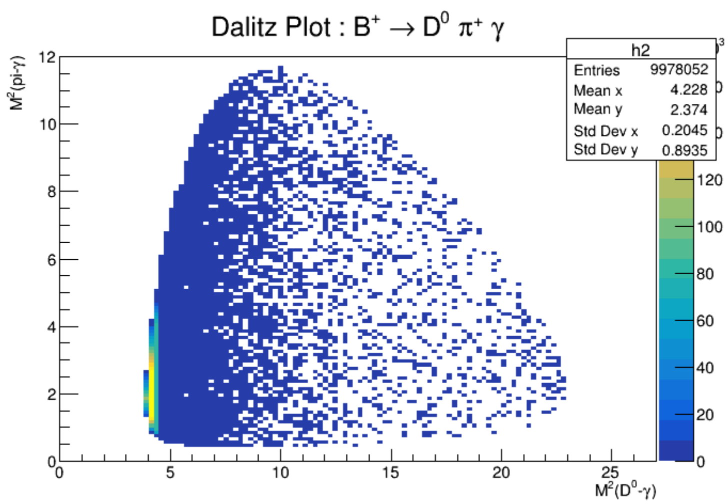

Figure 5: Dalitz Plot for $B^+ \to D^0\gamma\pi^+$

After obtaining the Dalitz Plots, one can proceed to calculate the ΔE parameter for partial reconstruction. Consider $\sqrt{s}$ to be the original energy of the annihilation. To proceed, we consider two cases, where in two of the decay modes we omit π^0 or γ and calculate the energy difference as

$$\Delta E = E_{D^0} + E_{\pi^+} - \frac{\sqrt{s}}{2}$$

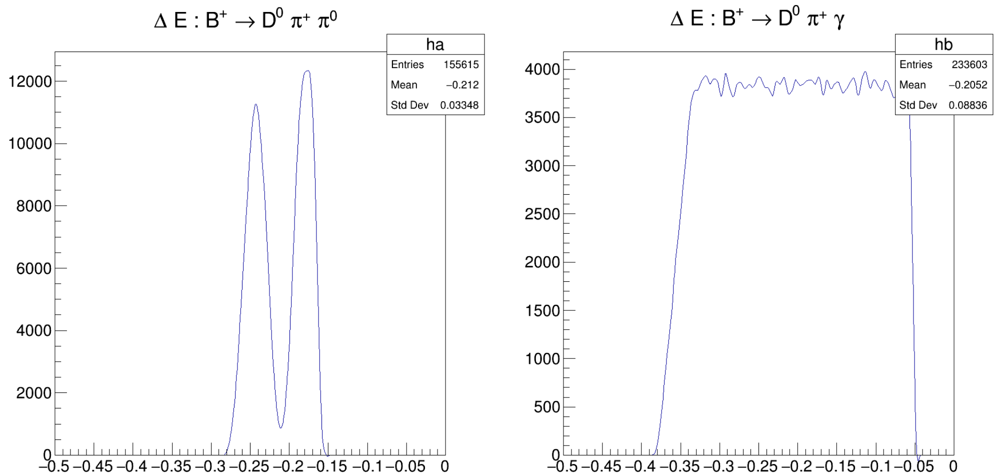

Figure 6: ΔE in Separate Decay Modes

The code used has been provided in Appendix A and all mass data is from [2].

8 CP Violation in B-Meson System

Within the confines of the Standard Model, the cause of CP Violation is described by the Cabbibo-Kobayashi-Masakawa(CKM) Matrix. Relating the weak eigenstates of quarks to the mass eigenstates, the CKM Matrix is given by the following:

$$\begin{pmatrix} d' \\ s' \\ b' \end{pmatrix} = \begin{pmatrix} V_{ud} & V_{us} & V_{ub} \\ V_{cd} & V_{cs} & V_{cb} \\ V_{td} & V_{ts} & V_{tb} \end{pmatrix} \begin{pmatrix} d \\ s \\ b \end{pmatrix}$$

The matrix can be re-written in terms of the Wolfenstein Parametrisation [3] as:

$$V_{CKM} = \begin{pmatrix} 1 - \frac{1}{2}\lambda^2 & \lambda & A\lambda^3(\rho - \iota\eta) \\ -\lambda & 1 - \frac{1}{2}\lambda^2 & A\lambda^2 \\ A\lambda^3(1 - \rho - \iota\eta) & -A\lambda^2 & 1 \end{pmatrix}$$

The existing complex phases in V_{td} and V_{ub} are the reasons behind the CP Violation as can be seen in the case of $B \to D^* h$ decays.

The unitary nature of the matrix gives rise to specific triangle relations, like:

$$V_{ud}V_{ub}^* + V_{cb}V_{cd}^* + V_{tb}V_{td}^* = 0$$

We have the angles $\gamma = Arg(V_{ub})^*$, $\beta = Arg(V_{td})*$ and $\alpha = \pi - \beta - \gamma$ which are used to directly measure the elements of the CKM Matrix.

Approaching B Meson systems, a common Decay Mode is $B^\pm \to D^0/\bar{D}^0\ K^\pm$. We can see the Feynman Diagram for two specific cases:

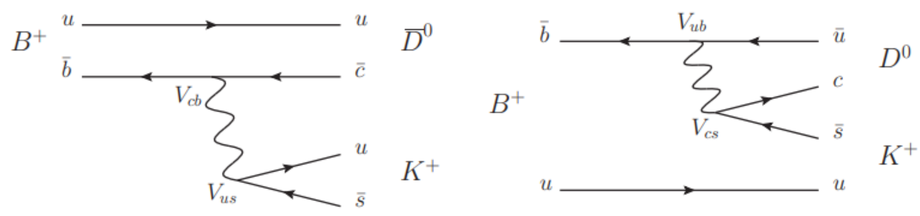

Figure 7: Feynman Diagrams for $B^+ \to \bar{D}^0 K^+$ and $B^+ \to D^0 K^+$ [7]

Now, in order to further understand how direct CP-Violation works, we must discern the decay rates of a certain decay. For example, we can construct the decay

$$B^\pm \to D^{*0} K^\pm$$

Where the D^{*0} can decay into CP even and odd final states. As done in the simulation, the $D^{*0} \to D^0\pi^0$ is the even final state, CP_+ and $D^{*0} \to D^0\gamma$ is the odd final state, CP_-.

The measure of direct CP Violation is obtained through GLW Analysis. Considering the case of D^{*0} as the CP eigenstate, there are two contributions in the decay $B^+ \to D^{*0}_{CP} K^+$. These are the $B^+ \to D^{*0} K^+$ and $B^+ \to \bar{D}^{*0} K^+$. If there had been no CP violation, we would have obtained the same decay amplitude for both products ideally. But, it is not seen and the difference can be denoted:

$$A(B^\pm \to D^{*0} K^\pm) = A_B$$

$$A(B^\pm \to \bar{D}^{*0} K^\pm) = A_B r_B e^{i(\delta_B \pm \gamma)}$$

Here, r_B is the ratio of the magnitudes of the two Decay Amplitudes and gives the most information regarding the degree to which CP Violation takes place in the decay. δ_B is the relative strong phase and γ is the relative weak phase which can be used to measure the unitary triangle parameters.

As there is not much CP Violation that can be observed in D decays, the decays to both eigenstates can be considered similar in nature and thus the Decay Rate for $B^\pm \to D^{*0}_{CP} K^\pm$ is given by:

$$\Gamma(B^\pm \to D^{*0}_{CP_+} K^\pm) = |A_B|^2 |A_D|^2 |1 + r_B e^{i(\delta_B \pm \gamma)}|^2$$

Now, we can associate the decay widths with the CP Assymetry variable:

$$\begin{aligned} A_{CP_\pm} &= \frac{\Gamma(B^- \to D^{*0}_{CP_\pm} K^-) - \Gamma(B^+ \to D^{*0}_{CP_\pm} K^+)}{\Gamma(B^- \to D^{*0}_{CP_\pm} K^-) + \Gamma(B^+ \to D^{*0}_{CP_\pm} K^+)} \\ &= \frac{\pm 2 r_B \sin(\delta_B) \sin(\gamma)}{1 + r_B^2 \pm 2 r_B \cos(\delta_B) \cos(\gamma)} \end{aligned}$$

9 Simulation of B Meson System with CP Violation

In order to model Direct CP Violation in a B Meson system, we choose the already established 3-Body decay and check for the cases with different probabilities of occurence. The 4 individual decay reactions are:

$$B^+ \to D^{*0} K^+,\ D^{*0} \to D^0 \pi^0\ [CP+]$$

$$B^+ \to D^{*0} K^+,\ D^{*0} \to D^0 \gamma\ [CP-]$$

$$B^- \to D^{*0} K^-,\ D^{*0} \to D^0 \pi^0\ [CP+]$$

$$B^- \to D^{*0} K^-,\ D^{*0} \to D^0 \gamma\ [CP-]$$

Considering an annihilation with equal production of B^+ and B^- we can choose to decay them solely into $CP+$ or $CP-$ mode to measure the $A_{CP_\pm}$. Then,

$$N_{B^-} + N_{B^+} = N$$

$$N_{B^-} - N_{B^+} = N A_{CP_\pm}$$

So $N_{B^-} = \frac{N}{2}(1 + A_{CP_\pm})$ and $N_{B^+} = \frac{N}{2}(1 - A_{CP_\pm})$ are the number of events that can be seen. For the simple case of decay into only one CP Final state, we can recreate the distribution of ΔE and A_{CP} as follows. We chose a Poisson Distribution to be the parameter for the of A_{CP}. Then, we take 1000 points around predicted values and run them through different number of decay particles. Thus we obtain the plots for A_{CP} as:

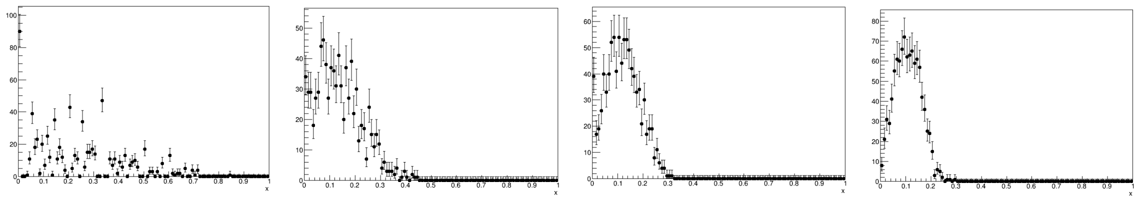

Figure 8: $-A_{CP_+}$ Values for Even CP Final State
a)1000 b)5000 c)10000 d)20000 decays [Left to Right]

No. of Decays	Mean: $-A_{CP_+}$	σ :$\mathbf{A}_{CP_+}$
1000	0.2293	0.1773
5000	0.1379	0.08896
10000	0.1205	0.06569
20000	0.1086	0.05095

The expected A_{CP_+} value is $-.1062$ taking the values $R_B = 0.196$, $\delta_B = 342°$ and $\gamma = 78°$ [1].

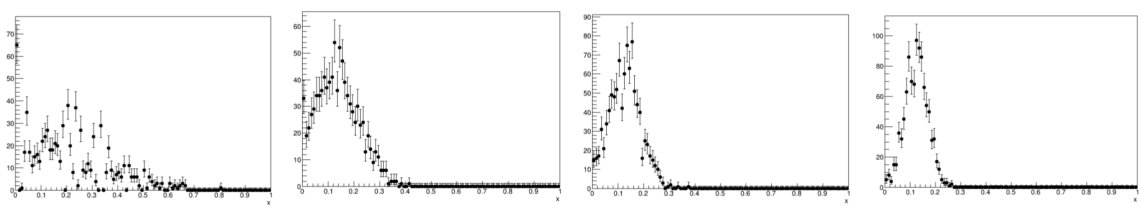

Figure 9: A_{CP_-} Values for Even CP Final State
a)1000 b)5000 c)10000 d)20000 decays [Left to Right]

No. of Decays	Mean: A_{CP_-}	σ :$\mathbf{A}_{CP_-}$
1000	0.2124	0.1535
5000	0.1390	0.07941
10000	0.1270	0.05973
20000	0.1241	0.04490

The expected A_{CP_-} value is 0.1233 taking the values $R_B = 0.196$, $\delta_B = 342°$ and $\gamma = 78°$ [1].

In order to model the distribution of ΔE that would be obtained through an experiment which considers all the four decay modes, we will need to add the pdfs of all the individual ΔEs.

Thus, each of the individual contribution terms would add as follows:

$$P(\Delta E) = \sum_i N_i B_f(D_i) P_i(\Delta E)$$

Where i denotes the cases and B_f is the Branching Fraction for Decay into CP_+ or CP_-. Thus, we have:

$$\begin{aligned} P(\Delta E) = &\frac{N_{B+}}{2}(1 - A_{CP_-})B_f(D^{*0} \to D^0\gamma)P_\gamma(\Delta E) \\ &+ \frac{N_{B-}}{2}(1 + A_{CP_-})B_f(D^{*0} \to D^0\gamma)P_\gamma(\Delta E) \\ &+ \frac{N_{B+}}{2}(1 - A_{CP_+})B_f(D^{*0} \to D^0\pi^0)P_{\pi^0}(\Delta E) \\ &+ \frac{N_{B-}}{2}(1 + A_{CP_+})B_f(D^{*0} \to D^0\pi^0)P_{\pi^0}(\Delta E) \end{aligned}$$

Using the Branching Fraction data from [2] considering the two types of decasy of D^{*0} add to a 100% contribution, we can obtain the following distributions for each individual case is as follows:

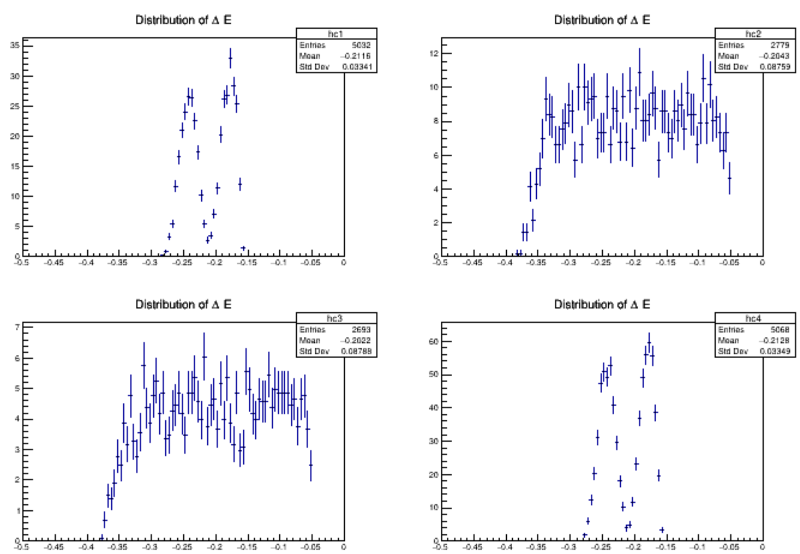

Figure 10: ΔE for each Decay Mode

And the final $P(\Delta E)$ including the CP Violation is given as:

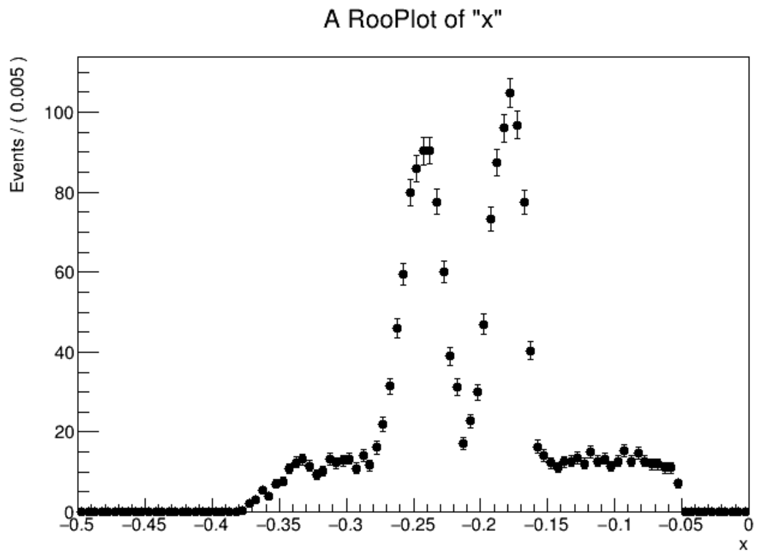

Figure 11: ΔE Distribution with Branching Fractions and CP Violation

The ΔE_π is cut off at the -0.14 GeV mark corresponding to the mass of the pions thus giving us a kinematic boundary for the decay parameter and the maximum stretch is nearly upto -0.3 GeV with two peaks corresponding to the angular distribution maxima we observed at -0.175GeV and near -0.25GeV.

In contrast the distribution for partial reconstruction omitting the γ starts at a much higher kinematic boundary of -0.05 GeV and stretches as an almost uniform plateau up to the -0.4 GeV mark.

10 Conclusion

Thus, throughout the document, it has been outlined how the decay of a B meson into three spinless particles can be recreated to get results identical to experimental data and statistical interpretations can be made for the same. A similar framework can be used for much more extensive formulation with separate signal and background channels, inclusion of noise, simulation of more decays from the source.

Summarising, we have noted down the necessary theoretical foundation within the confines of the Standard Model in order to simulate B meson to D meson decays and CP Violation and then used CERN-ROOT software to generate the corresponding Phase Spaces and Decays. The most important parameters that have been obtained are the Dalitz Plots and the distribution of $P(\Delta E)$ function for different decay products. For the recreation of $P(\Delta E)$ including CP-Violation considerations, we have utilised r_B, δ_B and γ parameters to obtain a degree of CP Violation through A_{CP} which produces a consistent framework when including ideal branching fractions for the decays taken.

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