Exploring an avenue of New Physics in $B \to D\overline{D}$ decays

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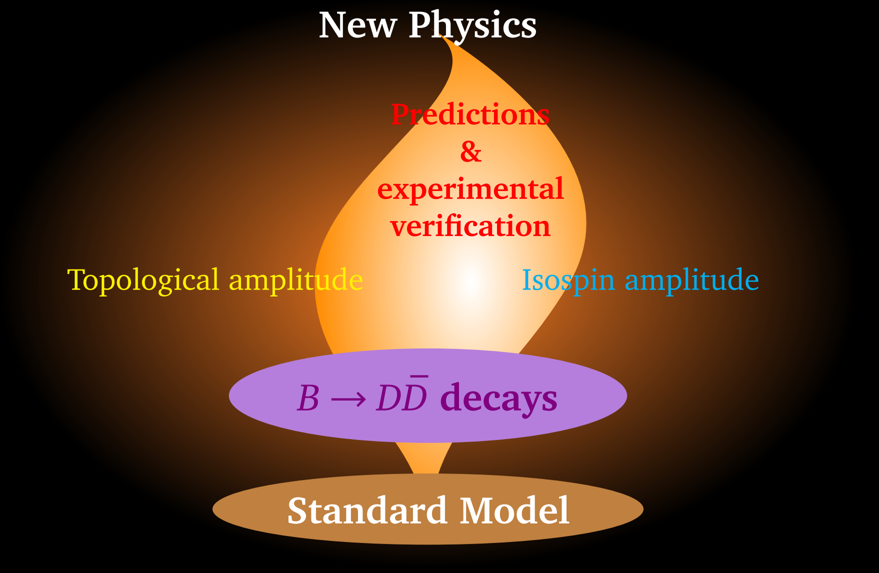
A bird's eye view of the story



Players in our game

- We shall study the $B \to D\overline{D}$ decays here.
  - $B^+ \to D^+\bar{D}^0$, $\quad B^- \to D^-D^0$,
  - $B^0 \to D^+D^-$, $\quad \bar{B}^0 \to D^+D^-$,
  - $B^0 \to D^0\bar{D}^0$, $\quad \bar{B}^0 \to D^0\bar{D}^0$.

- These are all **weak decays**, i.e. decays facilitated by exchange of weak gauge bosons $W^\pm$, but the initial and final states are all mesons which are strongly bound states of a quark and an anti-quark.

- **The players:** B and D mesons.

$$B^+ \equiv \left(\overline{b}\, u\right), \quad B^0 \equiv \left(\overline{b}\, d\right), \qquad B^- \equiv (\overline{u}\, b), \quad \overline{B}^0 \equiv \left(\overline{d}\, b\right),$$

$$D^+ \equiv \left(\overline{d}\, c\right), \quad D^0 \equiv (\overline{u}\, c), \qquad D^- \equiv (\overline{c}\, d), \quad \overline{D}^0 \equiv (\overline{c}\, u).$$

We can only analyse the game (the decays and their various aspects) by knowing the rules and tools of the game.

Fundamentals of the game

- *Concept:* Similar to spin, quantum mechanically analogous to angular momentum, first proposed by WERNER HEISENBERG (1932).
  - proton = 'isospin up' nucleon $\left|\frac{1}{2},+\frac{1}{2}\right\rangle$
  - neutron = 'isospin down' nucleon $\left|\frac{1}{2},-\frac{1}{2}\right\rangle$
- *Basis:* Quarks u and d form an isospin doublet.
- *Usefulness:* Strong interaction respects isospin symmetry, electroweak interaction does not. Its a simple concept that has many beautiful applications in particle physics.
- *Breaking:* Its a very good symmetry, broken only at about 1% level.

$$\frac{m_n - m_p}{m_n} \approx 10^{-3}.$$

  Reasons for isospin breaking,
  - slight mass difference between u and d quarks,
  - electroweak contributions.
- *Caution:* Should not be confused with WEAK ISOSPIN which is associated with the symmetry $SU(2)_L$.

Fundamentals of the game

Isospin amplitude

- Isospin amplitude $\equiv$ Transition amplitude that is defined on the basis of isospin consideration alone.

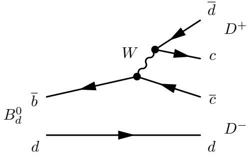
- *Methodology:*
  - Write down both initial and final states in terms of isospin state, $|I, I_3\rangle$.
  - Find out how isospin changes in the currents constituting the underlying effective Hamiltonian $\mathscr{H}$.
  - Define the isospin amplitudes, $A_k = \left\langle I_{\text{out}}, I_{3,\text{out}} \right| \mathscr{H}_{\Delta I=k} \left| I_{\text{in}}, I_{3,\text{in}} \right\rangle$.
  - Decompose the complete transition amplitude in terms of the various appropriate isospin amplitudes following the Wigner-Eckart theorem.

- *Note:* Since isospin is broken by electroweak interaction, though slightly, it is possible to incorporate isospin breaking by considering extra isospin changing currents in the Hamiltonian.

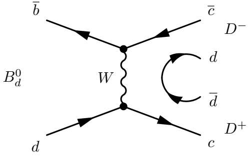
- There exists a nice way to classify various quark-level diagrams contributing to most of the hadronic meson decays in a systematic manner. Each diagram is generically called a *topology*.
- The amplitudes associated with these distinct diagrams are usually called *topological amplitudes*.
- We shall come across the following diagrams in our analysis.
  - *No loop topologies:*
    1. Color-allowed Tree diagram T,
    2. W-Exchange diagram E, and
    3. W-Annihilation diagram A.
  - *One loop topologies:*
    1. QCD-Penguin diagram P_q,
    2. Color-suppressed EW-Penguin diagram $P^C_{EW,q}$,
    3. QCD-Penguin exchange diagram PE_q,
    4. EW-Penguin exchange diagram $PE_{EW,q}$,
    5. QCD-Penguin annihilation diagram PA_q, and
    6. EW-Penguin annihilation diagram $PA_{EW,q}$.

  Here q denotes the quark in the loop.

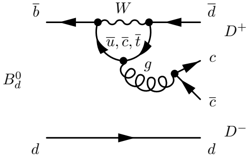
The various quark diagrams for $B^0 \to D^+ D^-$ decay



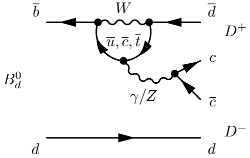
Color-allowed Tree Diagram T



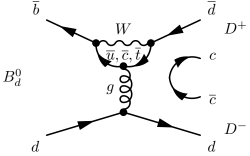
W-exchange Diagram E



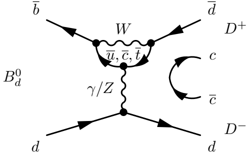
QCD-Penguin Diagram P



Color-suppressed EW-Penguin Diagram P_{EW}^C

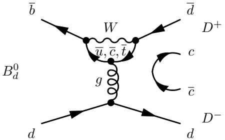


QCD-Penguin Exchange Diagram PE

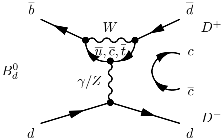


EW-Penguin Exchange Diagram PE_{EW}

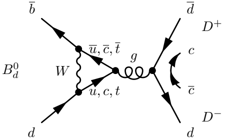
The various quark diagrams for $B^0 \to D^+D^-$ decay



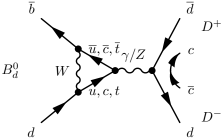
QCD-Penguin Exchange Diagram PE



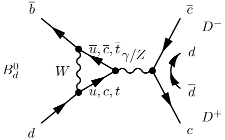
EW-Penguin Exchange Diagram PE_{EW}



QCD-Penguin Annihilation Diagram PA

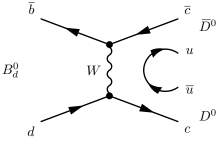


EW-Penguin Annihilation Diagram PA_{EW}

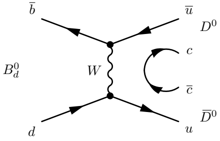


EW-Penguin Annihilation Diagram PA_{EW}

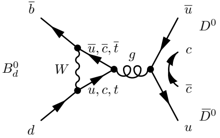
The various quark diagrams for $B^0 \to D^0\overline{D}^0$ decay



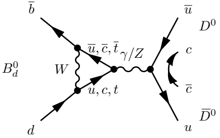
W-Exchange diagram E



W-Exchange diagram E

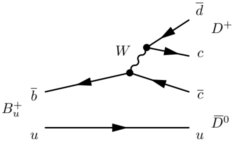


QCD-Penguin Annihilation Diagram PA

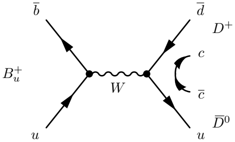


EW-Penguin Annihilation Diagram PA_{EW}

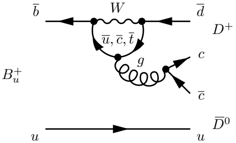
The various quark diagrams for $B^+ \to D^+ \bar{D}^0$ decay



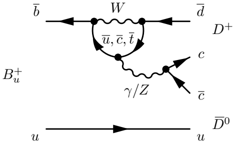
Color-allowed Tree Diagram T



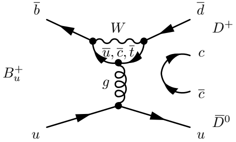
W-annihilation Diagram A



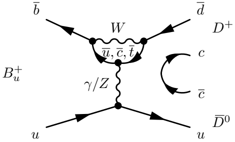
QCD-Penguin Diagram P



Color-suppressed EW-Penguin Diagram P_{EW}^C



QCD-Penguin Exchange Diagram PE



EW-Penguin Exchange Diagram PE_{EW}

Fundamentals of the game

Two-body decay rate

The partial decay rate for a two particle mode is:

$$\Gamma(1 \to 2+3) = S\frac{\sqrt{\lambda(m_1^2, m_2^2, m_3^2)}}{16\pi m_1^3}\,|\mathscr{M}|^2\,,$$

where

- m_1, m_2, m_3 are the masses of particles 1, 2 and 3 respectively,
- *statistical factor* $\equiv S = \begin{cases} 1 & \text{if particles 2 and 3 are distinct} \\ \frac{1}{2} & \text{if particles 2 and 3 are identical} \end{cases}$,
- $\mathscr{M} \equiv \langle 2+3|\,\mathscr{H}\,|1\rangle$ is the decay amplitude for the process,
- λ is the Källén function

$$\lambda(m_1^2, m_2^2, m_3^2) = m_1^4 + m_2^4 + m_3^4 - 2m_1^2m_2^2 - 2m_1^2m_3^2 - 2m_2^2m_3^2.$$

Note: Decay amplitude for any two-body decay has mass dimension 1.

Therefore, the branching ratio for this decay mode is

$$\mathrm{Br}(1 \to 2+3) = \frac{1}{\Gamma_T}\,\Gamma(1 \to 2+3) = \frac{1}{\Gamma_T}\,S\,\frac{\sqrt{\lambda(m_1^2, m_2^2, m_3^2)}}{16\pi m_1^3}\,|\mathscr{M}|^2\,,$$

where Γ_T = total decay rate of particle 1.

Since the mean lifetime of particle 1 is defined as

$$\tau = \frac{1}{\Gamma_T},$$

we have

$$\mathrm{Br}(1 \to 2+3) = \tau\,S\,\frac{\sqrt{\lambda(m_1^2, m_2^2, m_3^2)}}{16\pi m_1^3}\,|\mathscr{M}|^2\,.$$

Score board of the game

The experimental observables

- **Branching ratios**

$$\mathcal{B}_{+-} = \frac{1}{2}\tau_0 \frac{\sqrt{\lambda\left(m_{B^0}^2, m_{D^+}^2, m_{D^+}^2\right)}}{16\pi\, m_{B^0}^3}\left(|A_{+-}|^2 + |\bar{A}_{+-}|^2\right),$$

$$\mathcal{B}_{00} = \frac{1}{2}\tau_0 \frac{\sqrt{\lambda\left(m_{B^0}^2, m_{D^0}^2, m_{D^0}^2\right)}}{16\pi\, m_{B^0}^3}\left(|A_{00}|^2 + |\bar{A}_{00}|^2\right),$$

$$\mathcal{B}_{\rm ch} = \frac{1}{2}\tau_+ \frac{\sqrt{\lambda\left(m_{B^+}^2, m_{D^+}^2, m_{D^0}^2\right)}}{16\pi\, m_{B^+}^3}\left(|A_{0-}|^2 + |\bar{A}_{+0}|^2\right),$$

- **CP asymmetries**

$$C_{+-} = \frac{|A_{+-}|^2 - |\bar{A}_{+-}|^2}{|A_{+-}|^2 + |\bar{A}_{+-}|^2}, \quad C_{00} = \frac{|A_{00}|^2 - |\bar{A}_{00}|^2}{|A_{00}|^2 + |\bar{A}_{00}|^2}, \quad A_{\rm CP} = \frac{|A_{0-}|^2 - |\bar{A}_{+0}|^2}{|A_{0-}|^2 + |\bar{A}_{+0}|^2},$$

where $A_{+-} = \mathrm{Amp}\left(\bar{B}^0 \to D^+D^-\right)$, $A_{00} = \mathrm{Amp}\left(\bar{B}^0 \to D^0\bar{D}^0\right)$, $A_{0-} = \mathrm{Amp}\left(B^- \to D^0D^-\right)$, and the amplitudes with 'over-bar' correspond to the CP conjugate modes.

The known and unknown in the Score board

The Experimental Data

PDG 2016	LHCb 2016	HFAG 2016
$B_{+-} = (2.11 \pm 0.18) \times 10^{-4}$,		
$C_{+-} = -0.46 \pm 0.21$	$0.26^{+0.18}_{-0.17}(\text{stat}) \pm 0.02(\text{syst})$	-0.13 ± 0.10,
$B_{00} = (1.4 \pm 0.7) \times 10^{-5}$,		
$C_{00} = ?????$		
$B_{\text{ch}} = (3.8 \pm 0.4) \times 10^{-4}$,		
$A_{\text{CP}} = -0.03 \pm 0.07$.		

Our goal here is to predict the unknown C_{00} from the other known observables.

If experiments observe a value of C_{00} which deviates significantly from our predicted value, it would beg some form of New Physics as an explanation.

Play begins... 1st strategy

Isospin decomposition of the decay amplitudes

- Isospin of $B = \frac{1}{2}$. Total isospin of $D\bar{D} = 0, 1$.
  Two currents in the Hamiltonian that change isospin by $\Delta I = \frac{1}{2}, \frac{3}{2}$.
- Isospin decomposition,

$$A_{+-} \equiv \text{Amp}(\bar{B}^0 \to D^+ D^-) = \frac{1}{\sqrt{2}} (A_1 + B_1 + A_0)\,,$$

$$A_{00} \equiv \text{Amp}(\bar{B}^0 \to D^0 \bar{D}^0) = \frac{1}{\sqrt{2}} (A_1 + B_1 - A_0)\,,$$

$$A_{0-} \equiv \text{Amp}(B^- \to D^0 D^-) = \frac{1}{\sqrt{2}} (2A_1 - B_1)\,,$$

  where A_0 and A_1 are isospin amplitudes facilitated by the $\Delta I = \frac{1}{2}$ current to the isospin $I = 0, 1$ final states respectively and B_1 denotes the isospin amplitude with $\Delta I = \frac{3}{2}$ current to $I = 1$ final state.
  The conjugate amplitudes are decomposed analogously.
- $A_0 = \frac{1}{\sqrt{2}} (A_{+-} - A_{00})$, $A_1 = \frac{1}{3\sqrt{2}} (A_{+-} + A_{00} + 2A_{0-})$, and

  $B_1 = \frac{\sqrt{2}}{3} (A_{+-} + A_{00} - A_{0-})$.

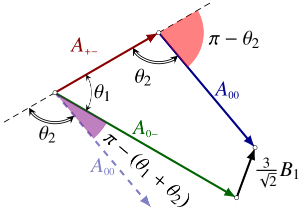
Play begins… 1st strategy

Isospin decomposition of the decay amplitudes

- In the literature, the $\Delta I = \frac{3}{2}$ current is assumed to be small as it is associated with the suppressed W-exchange and W-annihilation diagrams.
- If the Hamiltonian had only $\Delta I = \frac{1}{2}$ current, then

$$B_1 = 0 \implies A_{+-} + A_{00} = A_{0-}.$$

- We are first interested in finding how big can B_1 be.
  So we shall keep $B_1 \neq 0$.
- The amplitudes form a quadrilateral in the complex plane.



Depanding on values of θ_1 and θ_2 we can have either a *simple* or a *self-intersecting* quadrilateral.

Play inturrupted… some reshuffling

Defining convenient variables

For convenience of handling algebra, we get rid of the pesky phase-space factors from the branching ratios by defining new variables,

$$\mathscr{B}_{+-} = \frac{16\pi m_{B^0}^3}{\tau_0 \sqrt{\lambda\left(m_{B^0}^2, m_{D^+}^2, m_{D^+}^2\right)}} B_{+-} = \frac{1}{2}\left(|A_{+-}|^2 + \left|\overline{A}_{+-}\right|^2\right),$$

$$\mathscr{B}_{00} = \frac{16\pi m_{B^0}^3}{\tau_0 \sqrt{\lambda\left(m_{B^0}^2, m_{D^0}^2, m_{D^0}^2\right)}} B_{00} = \frac{1}{2}\left(|A_{00}|^2 + \left|\overline{A}_{00}\right|^2\right),$$

$$\mathscr{B}_{\mathrm{ch}} = \frac{16\pi m_{B^0}^3}{\tau_+ \sqrt{\lambda\left(m_{B^+}^2, m_{D^+}^2, m_{D^0}^2\right)}} B_{\mathrm{ch}} = \frac{1}{2}\left(|A_{0-}|^2 + \left|\overline{A}_{+0}\right|^2\right),$$

and in terms of these we have

$$C_{+-} = \frac{1}{2\mathscr{B}_{+-}}\left(|A_{+-}|^2 - \left|\overline{A}_{+-}\right|^2\right),$$

$$C_{00} = \frac{1}{2\mathscr{B}_{00}}\left(|A_{00}|^2 - \left|\overline{A}_{00}\right|^2\right),$$

$$A_{\mathrm{CP}} = \frac{1}{2\mathscr{B}_{\mathrm{ch}}}\left(|A_{0-}|^2 - \left|\overline{A}_{+0}\right|^2\right).$$

Play inturrupted… some reshuffling

Amplitude modulus squares in terms of new variables

$$|A_{+-}| = \sqrt{\mathscr{B}_{+-}\left(1 + C_{+-}\right)}\,, \qquad \left|\bar{A}_{+-}\right| = \sqrt{\mathscr{B}_{+-}\left(1 - C_{+-}\right)}\,,$$
$$|A_{00}| = \sqrt{\mathscr{B}_{00}\left(1 + C_{00}\right)}\,, \qquad \left|\bar{A}_{00}\right| = \sqrt{\mathscr{B}_{00}\left(1 - C_{00}\right)}\,,$$
$$|A_{0-}| = \sqrt{\mathscr{B}_{\text{ch}}\left(1 + A_{\text{CP}}\right)}\,, \qquad \left|\bar{A}_{+0}\right| = \sqrt{\mathscr{B}_{\text{ch}}\left(1 - A_{\text{CP}}\right)}\,.$$

Since the *CP* asymmetries must always lie between −1 and 1, i.e.

$$-1 \leqslant C_{00}, C_{+-}, A_{\text{CP}} \leqslant 1,$$
$$\Longrightarrow 0 \leqslant 1 \pm C_{00}, 1 \pm C_{+-}, 1 \pm A_{\text{CP}} \leqslant 2,$$

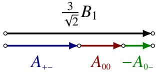
the moduli of the amplitudes are ensured to be positive and real by definition.

Play resumes… finding limits on $|B_1|$ and $\left|\overline{B}_1\right|$

Playing with the quadrilateral

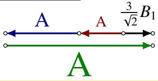
• The Maximum Scenario

$$|B_1|^2_{\max} = \tfrac{2}{9}\Big(|A_{+-}| + |A_{00}| + |A_{0-}|\Big)^2$$



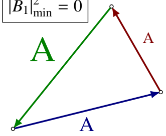
• 1st Minimum Scenario

$$|B_1|^2_{\min} > 0$$



• 2nd Minimum Scenario

$$|B_1|^2_{\min} = 0$$



$$A_{+-} + A_{00} - A_{0-} = \frac{3}{\sqrt{2}}B_1$$

↓

Given: $|A_{+-}|, |A_{00}|, |A_{0-}|$ → Find **maximum** of $|B_1|$

→ $$|B_1|_{\max} = \frac{\sqrt{2}}{3}\Big(|A_{+-}| + |A_{00}| + |A_{0-}|\Big)$$

→ $$|B_1|^2_{\max} = \frac{2}{9}\Big(|A_{+-}| + |A_{00}| + |A_{0-}|\Big)^2$$

Given → Find **minimum** of $|B_1|$

↓

Arrange $|A_{+-}|, |A_{00}|$ and $|A_{0-}|$ in decreasing order

↓

Let $\left|\text{\Large A}\right| > |\text{A}| > |\text{\small A}|$, where $\text{\Large A}, \text{A}, \text{\small A} = A_{+-}, A_{00}, -A_{0-}$.

↓

Is $\left|\text{\Large A}\right| > |\text{A}| + |\text{\small A}|$?

Yes → $$|B_1|_{\min} = \frac{\sqrt{2}}{3}\Big(\left|\text{\Large A}\right| - |\text{A}| - |\text{\small A}|\Big) > 0$$

→ $$|B_1|^2_{\min} = \frac{2}{9}\Big(-\left|\text{\Large A}\right| + |\text{A}| + |\text{\small A}|\Big)^2 > 0$$

No → $$|B_1|_{\min} = 0$$

→ $$|B_1|^2_{\min} = 0$$

Play intensifies... 2nd strategy

Decomposition of decay amplitude in terms of topological amplitudes

- **Setting up the notation:**
  - No loop topologies: $N \in \{T, E, A\}$
  - One loop topologies: $L \in \{P, P^C_{EW}, PE, PA_{EW}, PA, PA_{EW}\}$

$$N_x = N \left| V^*_{xb} V_{xd} \right|,$$
$$L_{qx} = L_q \left| V^*_{xb} V_{xd} \right|,$$

where $x = u, c, t$.

- We shall use the unitarity of the CKM matrix, especially the condition that

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

to eliminate the CKM factor $V^*_{ub} V_{ud}$.

- We shall also use the weak phase β which is defined as

$$\beta = \arg\left(-\frac{V^*_{cb} V_{cd}}{V^*_{tb} V_{td}} \right),$$

to help us write the topological amplitudes after including the CKM factors.

Play intensifies… 2nd strategy

Decomposition of decay amplitude in terms of topological amplitudes

- Isospin amplitudes:

$$A_1 = A_1' + A_1'' e^{i\beta}, \qquad \bar{A}_1 = A_1' + A_1'' e^{-i\beta},$$
$$A_0 = A_0' + A_0'' e^{i\beta}, \qquad \bar{A}_0 = A_0' + A_0'' e^{-i\beta},$$
$$B_1 = B_1' + B_1'' e^{i\beta}, \qquad \bar{B}_1 = B_1' + B_1'' e^{-i\beta},$$

- Neglecting up and charm quark contributions in comparison with top quark contribution (just for simpler look) we get,

$$A_1' = \frac{1}{3\sqrt{2}}\left(-3T_c + E_c + 2A_c\right),$$
$$A_1'' = \frac{1}{3\sqrt{2}}\Big(-E_t - 2A_t + 3P_{tt} + 2P^C_{EW,tt} + 3PE_{tt} + PE_{EW,tt} + PA_{EW,tt}\Big),$$
$$A_0' = \frac{1}{\sqrt{2}}\left(-T_c + E_c\right),$$
$$A_0'' = \frac{1}{3\sqrt{2}}\Big(3E_t + 3P_{tt} + 2P^C_{EW,tt} + 3PE_{tt} - PE_{EW,tt} - 12PA_{tt} - 5PA_{EW,tt}\Big),$$
$$B_1' = \frac{\sqrt{2}}{3}\left(E_c - A_c\right),$$
$$B_1'' = \frac{\sqrt{2}}{3}\left(-E_t + A_t + PA_{EW,tt} - PE_{EW,tt}\right).$$

Play intensifies. . . 2nd strategy

Decomposition of decay amplitude in terms of topological amplitudes

- Isospin amplitudes:

$$A_1 = \left(\left|A_1'\right| + \left|A_1''\right| e^{i\beta}\right) e^{i\delta_1}, \qquad \overline{A}_1 = \left(\left|A_1'\right| + \left|A_1''\right| e^{-i\beta}\right) e^{i\delta_1},$$
$$A_0 = \left(\left|A_0'\right| + \left|A_0''\right| e^{i\beta}\right) e^{i\delta_0}, \qquad \overline{A}_0 = \left(\left|A_0'\right| + \left|A_0''\right| e^{-i\beta}\right) e^{i\delta_0},$$
$$B_1 = \left|B_1'\right| + \left|B_1''\right| e^{i\beta}, \qquad \overline{B}_1 = \left|B_1'\right| + \left|B_1''\right| e^{-i\beta},$$

  where $\delta_{1,0}$ are the strong phases.

- Thus $|A_0| = \left|\overline{A}_0\right|$, $|A_1| = \left|\overline{A}_1\right|$ and $|B_1| = \left|\overline{B}_1\right|$.

- We choose to put B_1 along the real axis. This is just a choice and there is nothing sacro-sanct about this.

Play intensifies. . . 2nd strategy

Decomposition of decay amplitude in terms of topological amplitudes

$$\begin{aligned} A_{+-} &= A'_{+-} + A''_{+-} e^{i\beta}, \\ A_{00} &= A'_{00} + A''_{00} e^{i\beta}, \\ A_{0-} &= A'_{0-} + A''_{0-} e^{i\beta}, \end{aligned}$$

where

$$\begin{aligned} A'_{+-} &= \frac{1}{\sqrt{2}} \left(|A'_1| e^{i\delta_1} + |A'_0| e^{i\delta_0} + |B'_1| \right), \\ A''_{+-} &= \frac{1}{\sqrt{2}} \left(|A''_1| e^{i\delta_1} + |A''_0| e^{i\delta_0} + |B''_1| \right), \\ A'_{00} &= \frac{1}{\sqrt{2}} \left(|A'_1| e^{i\delta_1} - |A'_0| e^{i\delta_0} + |B'_1| \right), \\ A''_{00} &= \frac{1}{\sqrt{2}} \left(|A''_1| e^{i\delta_1} - |A''_0| e^{i\delta_0} + |B''_1| \right), \\ A'_{0-} &= \frac{1}{\sqrt{2}} \left(2 |A'_1| e^{i\delta_1} - |B'_1| \right), \\ A''_{0-} &= \frac{1}{\sqrt{2}} \left(2 |A''_1| e^{i\delta_1} - |B''_1| \right). \end{aligned}$$

Play in final stage… 3rd strategy

Finding the goal post: Expressing C_{00} in terms of other known observables

By explicitly expanding it is easy to show that

$$\mathscr{B}_{+-}C_{+-} + \mathscr{B}_{00}C_{00} + \mathscr{B}_{\rm ch}A_{\rm CP} = 0,$$

$$\Longrightarrow \frac{B_{+-}C_{+-}}{\sqrt{\lambda\left(m^2_{B^0}, m^2_{D^+}, m^2_{D^+}\right)}} + \frac{B_{00}C_{00}}{\sqrt{\lambda\left(m^2_{B^0}, m^2_{D^0}, m^2_{D^0}\right)}} + \frac{B_{\rm ch}A_{\rm CP}}{\sqrt{\lambda\left(m^2_{B^+}, m^2_{D^+}, m^2_{D^0}\right)}}\left(\frac{m^3_{B^+}}{m^3_{B^0}}\frac{\tau_0}{\tau_+}\right) = 0.$$

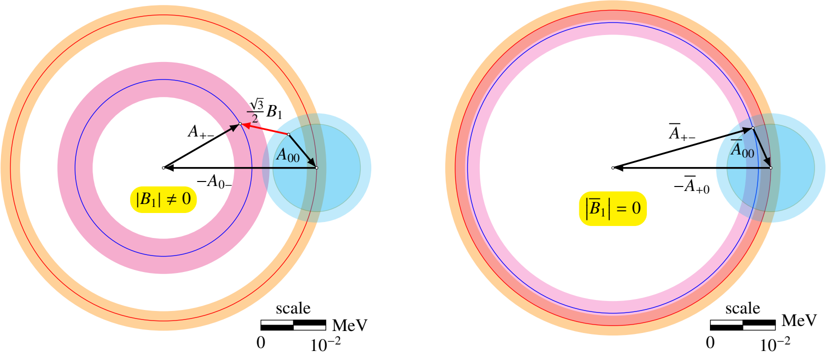
Thus we can now predict for C_{00} in terms of other observables,

$$C_{00} = -\frac{\sqrt{\lambda\left(m^2_{B^0}, m^2_{D^0}, m^2_{D^0}\right)}}{B_{00}}\left(\frac{B_{+-}C_{+-}}{\sqrt{\lambda\left(m^2_{B^0}, m^2_{D^+}, m^2_{D^+}\right)}} + \frac{B_{\rm ch}A_{\rm CP}}{\sqrt{\lambda\left(m^2_{B^+}, m^2_{D^+}, m^2_{D^0}\right)}}\left(\frac{m^3_{B^+}}{m^3_{B^0}}\frac{\tau_0}{\tau_+}\right)\right).$$

Play is going to end… looking up the score board

Predicting C_{00} and limiting $|B_1|$, $|\overline{B}_1|$

PDG Data



$|A_{0-}| = (2.358 \pm 0.150) \times 10^{-10}$ MeV

$|A_{+-}| = (1.362 \pm 0.271) \times 10^{-10}$ MeV

$0 < |A_{00}| < (0.674 \pm 0.168) \times 10^{-10}$ MeV

$|\overline{A}_{+0}| = (2.430 \pm 0.152) \times 10^{-10}$ MeV

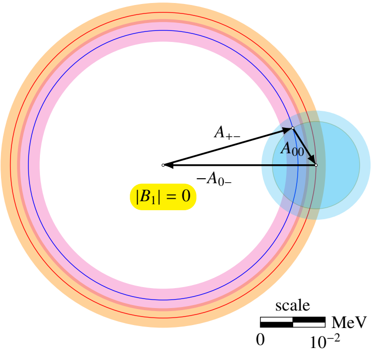
$|\overline{A}_{+-}| = (2.239 \pm 0.187) \times 10^{-10}$ MeV

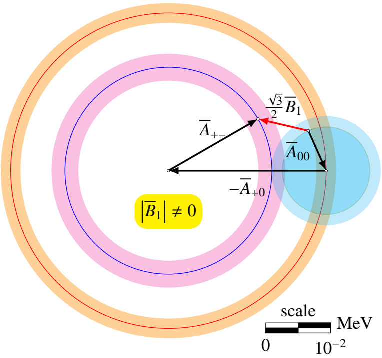
$0 < |\overline{A}_{00}| < (0.674 \pm 0.168) \times 10^{-10}$ MeV

Play is going to end… looking up the score board

Predicting C_{00} and limiting $|B_1|$, $|\overline{B}_1|$

LHCb Data





$|A_{0-}| = (2.358 \pm 0.150) \times 10^{-10}$ MeV

$|A_{+-}| = (2.080 \pm 0.174) \times 10^{-10}$ MeV

$0 < |A_{00}| < (0.674 \pm 0.168) \times 10^{-10}$ MeV

$|\overline{A}_{+0}| = (2.430 \pm 0.152) \times 10^{-10}$ MeV

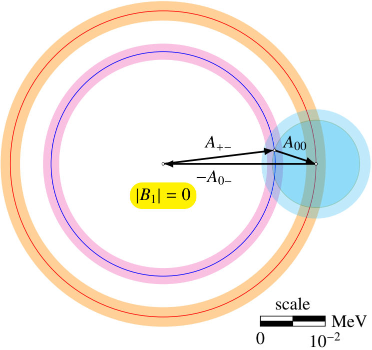
$|\overline{A}_{+-}| = (1.594 \pm 0.207) \times 10^{-10}$ MeV

$0 < |\overline{A}_{00}| < (0.674 \pm 0.168) \times 10^{-10}$ MeV

Play is going to end… looking up the score board

Predicting C_{00} and limiting $|B_1|$, $|\overline{B}_1|$

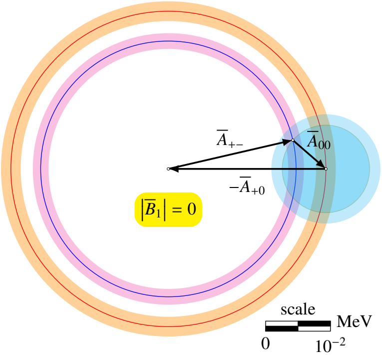
HFAG Data



$|A_{0-}| = (2.358 \pm 0.150) \times 10^{-10}$ MeV

$|A_{+-}| = (1.729 \pm 0.124) \times 10^{-10}$ MeV

$0 < |A_{00}| < (0.674 \pm 0.168) \times 10^{-10}$ MeV



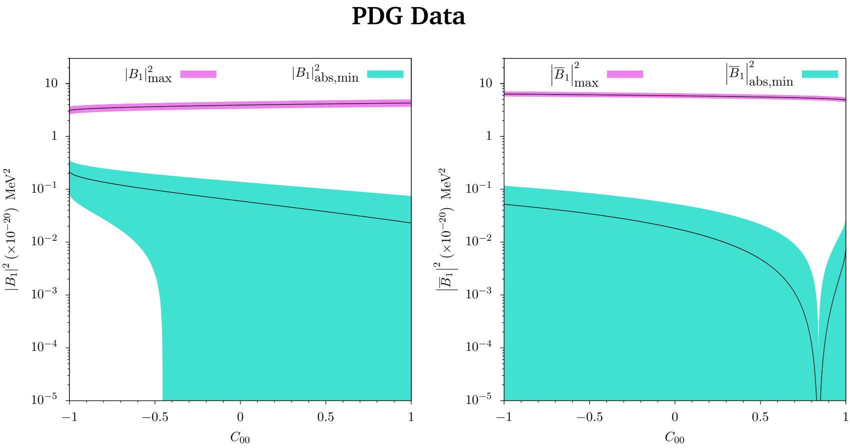
$|\overline{A}_{+0}| = (2.430 \pm 0.152) \times 10^{-10}$ MeV

$|\overline{A}_{+-}| = (1.970 \pm 0.121) \times 10^{-10}$ MeV

$0 < |\overline{A}_{00}| < (0.674 \pm 0.168) \times 10^{-10}$ MeV

Play is going to end... looking up the score board

Predicting C_{00} and limiting $|B_1|$, $|\overline{B}_1|$

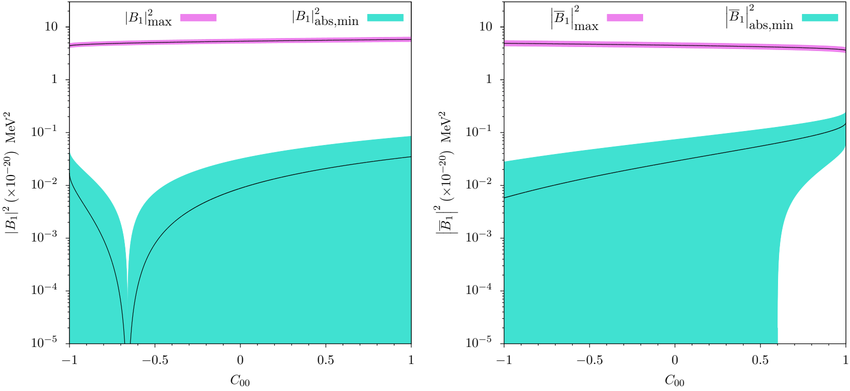


$$C_{00} = 7.708 \pm 5.329.$$

Play is going to end… looking up the score board

Predicting C_{00} and limiting $|B_1|$, $|\overline{B}_1|$

LHCb Data

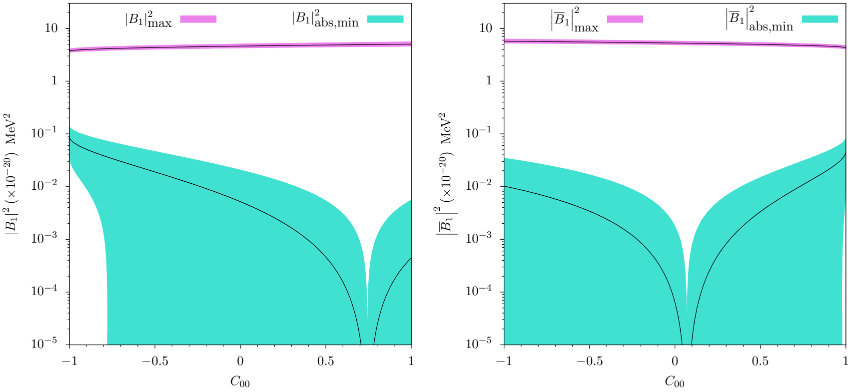


$$C_{00} = -3.173 \pm 3.639.$$

Play is going to end... looking up the score board

Predicting C_{00} and limiting $|B_1|$, $|\overline{B}_1|$

HFAG Data



$$C_{00} = -0.13 \pm 0.10.$$

Outcome of the game

Inferences from the numerical analysis

- We can predict C_{00} and put limits on the $\Delta I = \frac{3}{2}$ contribution in the amlitude, in terms of other known observables.
- Current prediction in C_{00} has large error, predominantly because B_{00} has a large error, B_{00} is consistent with 0 at 2σ standard deviation.
- We urge experimentalists for a preliminary measurement of C_{00} and a more precise measurement of B_{00}.
- If experimentally measured C_{00} differs substantially from the theoretically predicted value, it would cry for a New Physics exlanation.
- Our primary aim here has been just to predict C_{00}, and not to speculate about New Physics possibilities in the current experimental scenario.

Thank You