Determination of Strong & Weak Phases from $B \to D^{(*)\pm} D^{(*)\mp}$

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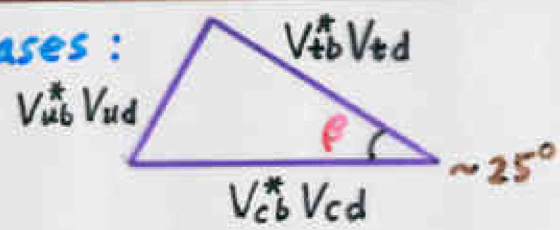
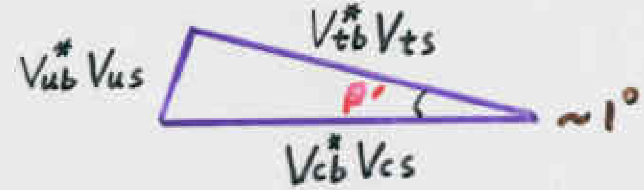
B-Factory: $B_d \to \begin{cases} D^+D^- & \leftarrow \text{Belle (hep-ex/0206014)} \\ D^{*+}D^- \oplus D^+D^{*-} \\ D^{*+}D^{*-} & \leftarrow \text{BaBar/Belle} \end{cases}$ LHC-B: $B_s \to \begin{cases} D_s^+ D_s^- \\ D_s^{*+}D_s^- \oplus D_s^+ D_s^{*-} \\ D_s^{*+} D_s^{*-} \end{cases}$

Note that "PV" and "VV" final states are NOT exact CP-even eigenstates!
[Aleksan, Le Yaouanc, Oliver, Pène, Raynal 93; Dunietz, Quinn, Snyder, Toki, Lipkin 91]

- Weak Phases :





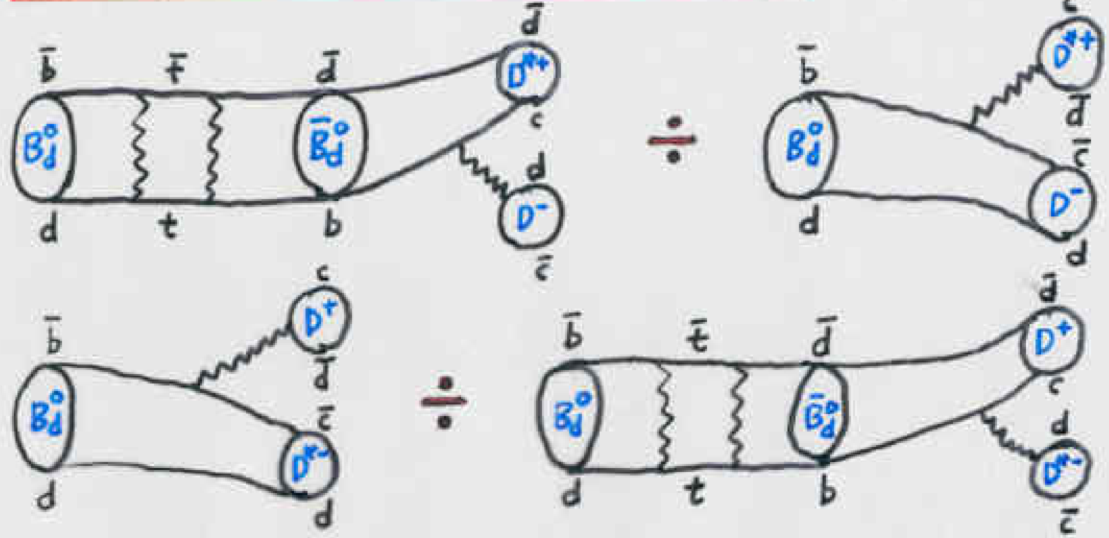
- Strong Phases: δ_d in $B_d \to D^{*+}D^-$ vs D^+D^{*-}, δ_s in $B_s \to D_s^{*+}D_s^-$ vs $D_s^+ D_s^{*-}$ CLEO, BaBar, Belle
- Factorization and Final-state Scattering : (in comparison with $B \to D^{(*)}\pi$) $\boxed{\text{big FSI}}$

I will talk about :

- A model-independent way to determine $\begin{cases} \beta \text{ and } \delta_d & \text{in } B_d \to D^{*+}D^- \oplus D^+ D^{*-} \\ \beta' \text{ and } \delta_s & \text{in } B_s \to D_s^{*+} D_s^- \oplus D_s^+ D_s^{*-} \end{cases}$
- Determination of $\begin{cases} \beta & \text{in } B_d \to D^{*+}D^{*-} \\ \beta' & \text{in } B_s \to D_s^{*+} D_s^{*-} \end{cases}$ withOUT the angular analysis
- Final-state Scattering effects in $B \to D^{(*)} \bar{D}^{(*)}$

②

1. $B_d \to D^{*\pm} D^{\mp}$ and $B_s \to D_s^{*\pm} D_s^{\mp}$ 【Z.Z.X., PLB443(98)365】



$$= \rho_d e^{i(\delta_d + 2\beta)}$$

$$= \rho_d e^{i(\delta_d - 2\beta)}$$

where $\rho_d = \dfrac{f_D}{f_{D^*}} \cdot \dfrac{A_0^{B_d D^*}(m_D^2)}{F_1^{B_d D}(m_{D^*}^2)}$ in the naive factorization approximation, and penguin-induced correction to the ratio is expected to be $\lesssim 4\%$.

- Time-dependent measurements:

$$\Gamma[B_d^0(t) \to D^{*+} D^-] \propto e^{-\Gamma_d t}\left[\frac{1+\rho_d^2}{2} + \frac{1-\rho_d^2}{2}\cos(\Delta m_d t) - \rho_d \sin(\delta_d + 2\beta)\sin(\Delta m_d t)\right]$$

$$\Gamma[B_d^0(t) \to D^{*-} D^+] \propto e^{-\Gamma_d t}\left[\frac{1+\rho_d^2}{2} - \frac{1-\rho_d^2}{2}\cos(\Delta m_d t) + \rho_d \sin(\delta_d - 2\beta)\sin(\Delta m_d t)\right]$$

- Determination of β and δ_d:

Define $S_\pm \equiv \sin(\delta_d \pm 2\beta)$, then
$$\begin{cases} \sin^2(2\beta) = \frac{1}{2}\left[(1 - S_+ S_-) \pm \sqrt{(1-S_+^2)(1-S_-^2)}\right] \\ \sin^2\delta_d = \frac{1}{2}\left[(1 + S_+ S_-) \pm \sqrt{(1-S_+^2)(1-S_-^2)}\right] \end{cases}$$

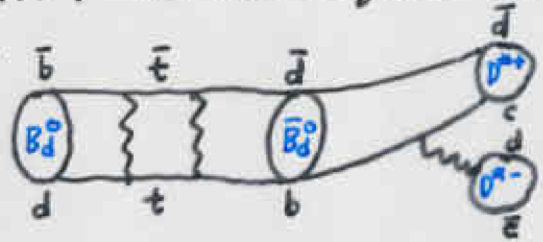
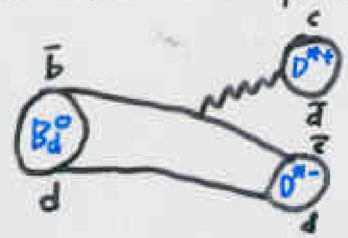
- Comparing the values of ρ_d (≈ 1.04) and ρ_s (≈ 1.03) from the NFA with the measurements will provide a clean test of the NFA.

③

2. $B_d \to D^{*+}D^{*-}$ and $B_s \to D_s^{*+}D_s^{*-}$ 【X.Y. Pham, Z.Z.X., PLB458(99)375】

$D^{*+}D^{*-}$: CP eigenstate $\begin{cases} \text{even} & \text{— S and D waves} \\ \text{odd} & \text{— P waves} \end{cases}$

- Do NOT do the angular analysis (sum over the polarizations of D^{*+} and D^{*-})

$\mathrm{Im}\Big[$  $\div$  $\Big] = R_{P\text{-wave}}(1 - R_{Penguin})\sin 2\beta$

- In the naive factorization approximation with heavy quark symmetry,

$$R_{P\text{-wave}} = \frac{m_B^3 - 3m_B m_{D^*}^2 + 10 m_{D^*}^3}{m_B^3 + m_B m_{D^*}^2 + 2 m_{D^*}^3} \approx 0.89$$

$R_{P\text{-wave}} = 1 - 2R$ ↑ 0.22 BaBar

$$R_{Penguin} = \frac{\bar{c}_3 + 3\bar{c}_4}{\bar{c}_1 + 3\bar{c}_2} \cdot \frac{\cos 2\beta}{\cos\beta} \cdot \left|\frac{V_{tb}V_{td}}{V_{cb}V_{cd}}\right| \approx -2.1\%$$

(Aleksan)

where $\bar{c}_i$ are effective Wilson coefficients 【Buchalla, Buras, Lautenbacher 96】

- As for $B_s \to D_s^{*+}D_s^{*-}$, we similarly obtain $R_{P\text{-wave}} \approx 0.90$ and $R_{Penguin} \approx -3.1\%$

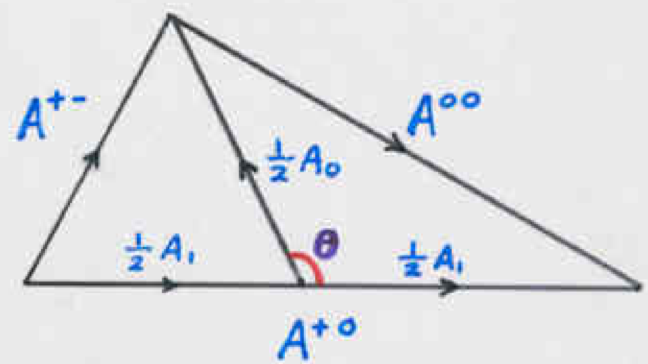
- The approach advocated here may be complementary to the angular analysis.

3. Final-state Scattering : $B \to D^{(*)}\bar{D}^{(*)}$

【A.I. Sanda, Z.Z.X. PRD56(97)341
Z.Z.X., PRD61(00)014010】

- Isospin triangle :

$$A^{+0} \equiv A(B_u^+ \to D^+\bar{D}^0) = A_1$$
$$A^{+-} \equiv A(B_d^0 \to D^+D^-) = \frac{1}{2}(A_1 + A_0)$$
$$A^{00} \equiv A(B_d^0 \to D^0\bar{D}^0) = \frac{1}{2}(A_1 - A_0)$$



Define $\frac{A_0}{A_1} \equiv z e^{i\theta}$, then $z = \sqrt{\frac{2(|A^{+-}|^2 + |A^{00}|^2)}{|A^{+0}|^2} - 1}$

$$\theta = \arccos\left(\frac{|A^{+-}|^2 - |A^{00}|^2}{z|A^{+0}|^2}\right)$$

$\cos\theta \leq 1$ leads to

- Constraint : $\mathcal{B}(B_d^0 \to D^0\bar{D}^0) \geq \left[\sqrt{\frac{\mathcal{B}(B_d^0 \to D^+D^-)}{\mathcal{B}(B_u^+ \to D^+\bar{D}^0)}} - 1\right]^2 \mathcal{B}(B_u^+ \to D^+\bar{D}^0)$

- Similar analysis is applicable for $B \to D^* D$ and $D^* D^*$ cases.

4. Concluding Remarks

① $B_d \to D^{*+}D^- \oplus D^+D^{*-}$ useful for β and δ_d ;

② $B_d \to D^{*+}D^{*-}$ without angular analysis for β ;

③ $B_s \to D_s^+D_s^-$, $D_s^{*+}D_s^-$, $D_s^+D_s^{*-}$, $D_s^{*+}D_s^{*-}$ useful for new physics.

④ Testing naive factorization hypothesis and probing final-state interactions.