The babar physics book

7.6 Partial Reconstruction of $B_d \to D^{(*)\pm}\pi^{\mp}$ Decays to Extract $\sin(2\beta+\gamma)$

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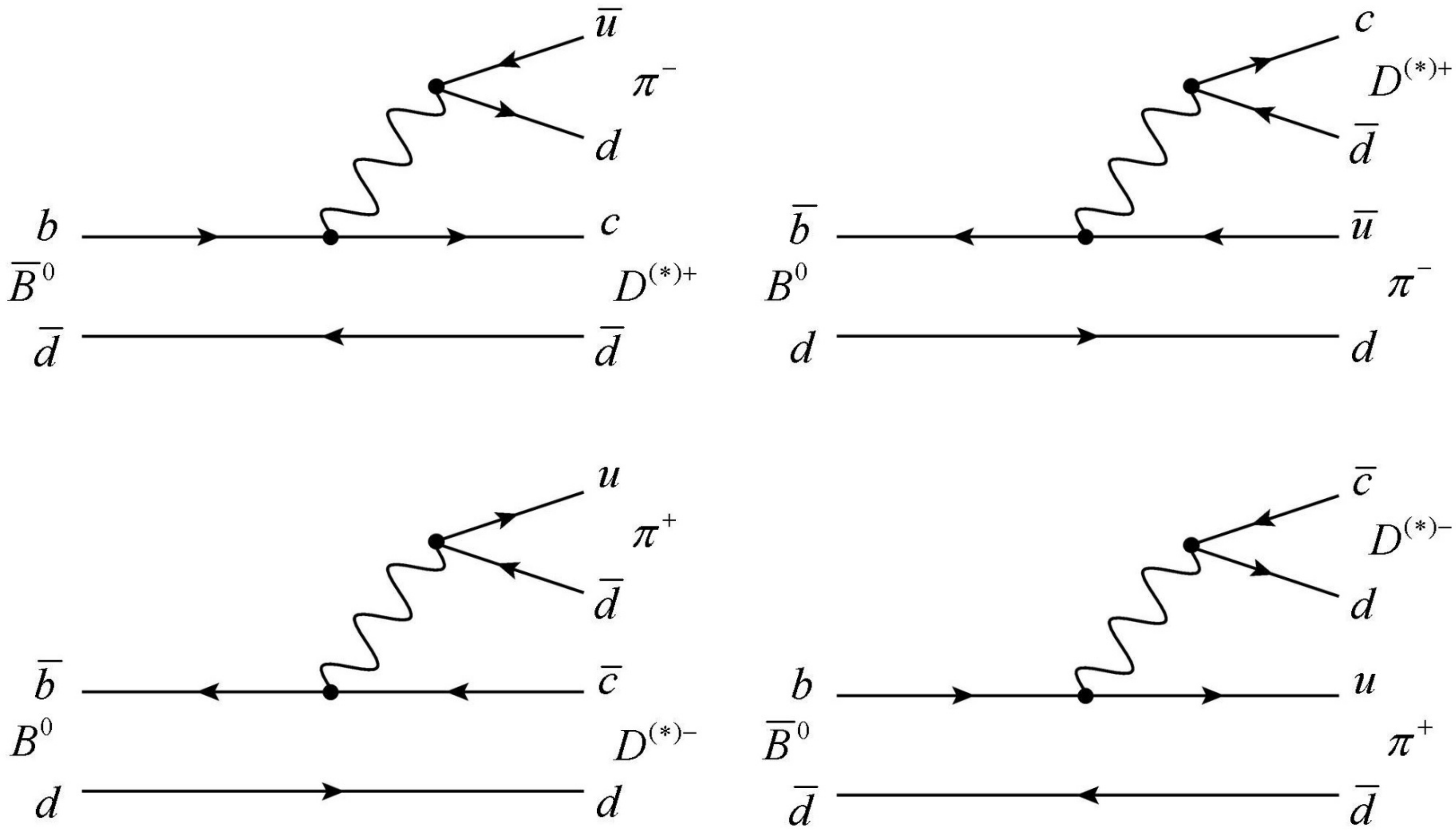
Introduction

- Extraction of $\sin(2\beta+\gamma)$
  - $B_d \to D^{(*)\pm}\pi^{\mp}$ の部分再構成
  - This method : $\sin(\beta-\alpha)$ の測定と同一視可能

- $B_d \to D^{(*)\pm}\pi^{\mp}$
  - CP asymmetries are small.
  - The decay rate are large.
  - 終状態の再構成
    - inclusively
    - 比較的低バックグラウンドで

Theoretical Framework

- $B_d \to D^{(*)\pm}\pi^{\mp}$: Pure tree decays

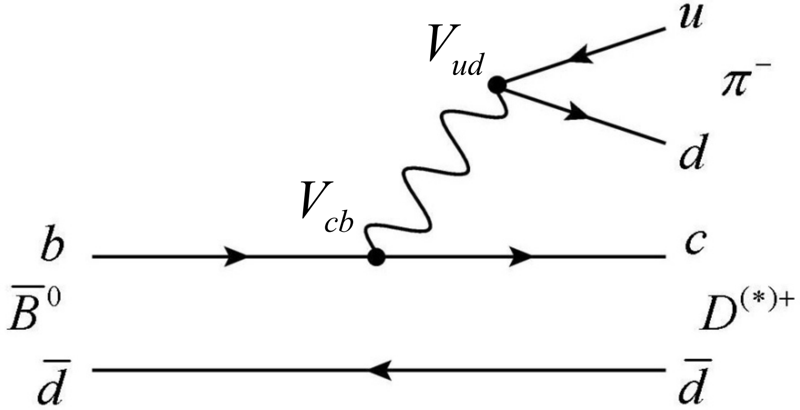


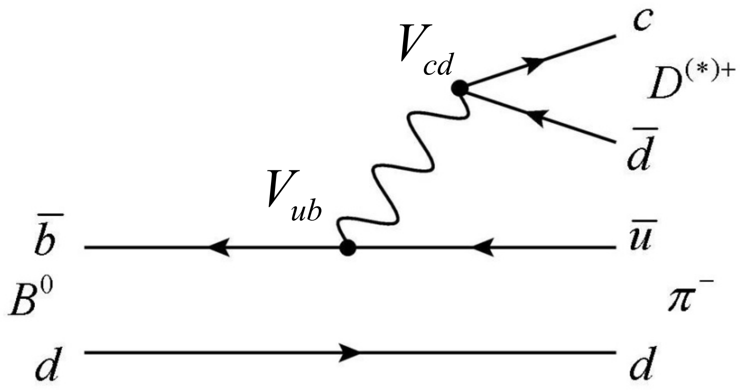
Hamiltonian

$$\mathcal{H}_{eff}\left(\overline{B}^0 \to f\right) = \frac{G_F}{\sqrt{2}}\,\overline{v}\left[\overline{\mathcal{O}}_1\mathcal{C}_1(\mu) + \overline{\mathcal{O}}_2\mathcal{C}_2(\mu)\right]$$

$$\mathcal{H}_{eff}\left(B^0 \to f\right) = \frac{G_F}{\sqrt{2}}\,v^*\left[\mathcal{O}_1^\dagger\mathcal{C}_1(\mu) + \mathcal{O}_2^\dagger\mathcal{C}_2(\mu)\right]$$

- f : 終状態
- v : CKM factor
  - $D^{*+}\pi^-$: $f = c\overline{d}\, d\overline{u}, \; \overline{v} \equiv V_{ud}^* V_{cb} = \left(1 - \frac{\lambda^2}{2}\right) A\lambda^2, \; v \equiv V_{cd}^* V_{ub} = -A\lambda^4 R_b e^{-i\gamma}$





$$\bar{v} \equiv V_{ud}^* V_{cb}$$

$$\bar{v} \equiv V_{ud}^* V_{cb} = \left(1 - \frac{\lambda^2}{2}\right) A\lambda^2$$

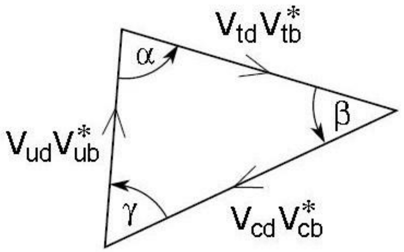
- The Wolfenstein parametrization

$$V_{CKM} \approx \begin{pmatrix} 1-\frac{\lambda^2}{2} & \lambda & A\lambda^3(\rho - i\eta) \\ -\lambda & 1-\frac{\lambda}{2} & A\lambda^2 \\ A\lambda^3(1-\rho-i\eta) & -A\lambda^2 & 1 \end{pmatrix} + \mathrm{O}(\lambda^4)$$

$v \equiv V_{cd}^{*} V_{ub}$

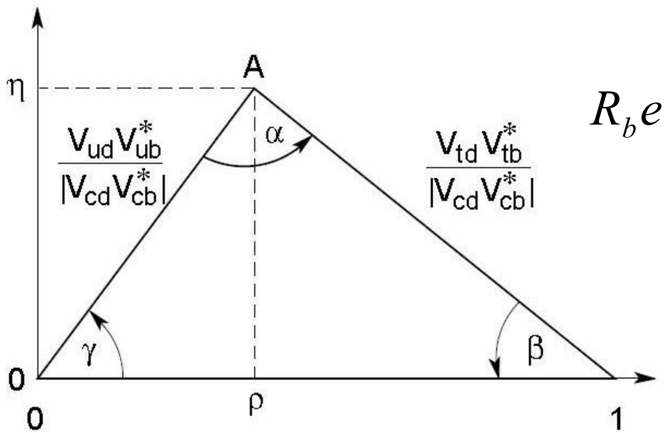
$$v \equiv V_{cd}^{*} V_{ub} = (-\lambda) A \lambda^3 (\rho - i\eta) = -A\lambda^4 (\rho - i\eta) = -A\lambda^4 R_b e^{-i\gamma}$$

$$R_b \equiv \frac{\left|V_{ud} V_{ub}^{*}\right|}{\left|V_{cd} V_{cb}^{*}\right|} = \sqrt{\bar{\rho}^2 + \bar{\eta}^2} = \frac{1 - \frac{\lambda^2}{2}}{\lambda} \left|\frac{V_{ub}}{V_{cb}}\right|$$



$$\bar{\rho} = \rho\left(1 - \frac{\lambda^2}{2}\right), \bar{\eta} = \eta\left(1 - \frac{\lambda^2}{2}\right)$$

$$e^{-i\gamma} = \cos\gamma - i\sin\gamma = \left|\frac{V_{cd} V_{cb}^{*}}{V_{ud} V_{ub}^{*}}\right| (\rho - i\eta)$$



$$R_b e^{-i\gamma} = \frac{1 - \frac{\lambda^2}{2}}{\lambda} \left|\frac{V_{cd}}{V_{ud}}\right| (\rho - i\eta) = \frac{1 - \frac{\lambda^2}{2}}{\lambda} \frac{\lambda}{1 - \frac{\lambda^2}{2}} (\rho - i\eta) = \rho - i\eta$$

遷移振幅

- current-current operator

$$\overline{\mathcal{O}}_1 = \left(\bar{d}_\alpha u_\beta\right)_{V-A}\left(\bar{c}_\beta b_\alpha\right)_{V\text{-}A},\ \overline{\mathcal{O}}_2 = \left(\bar{d}_\alpha u_\alpha\right)_{V-A}\left(\bar{c}_\beta b_\beta\right)_{V\text{-}A}$$

$$\mathcal{O}_1 = \left(\bar{d}_\alpha c_\beta\right)_{V-A}\left(\bar{u}_\beta b_\alpha\right)_{V\text{-}A},\ \mathcal{O}_2 = \left(\bar{d}_\alpha c_\alpha\right)_{V-A}\left(\bar{u}_\beta b_\beta\right)_{V\text{-}A}$$

- The Wilson coefficient function $\mathcal{C}_1, \mathcal{C}_2$
- 遷移振幅

$$A\left(\overline{B}^0 \to f\right) \equiv \left\langle f \middle| \mathcal{H}_{eff}\left(\overline{B}^0 \to f\right) \middle| \overline{B}^0 \right\rangle = \frac{G_F}{\sqrt{2}} \bar{v} \overline{M}_f$$

$$A\left(B^0 \to f\right) \equiv \left\langle f \middle| \mathcal{H}_{eff}\left(B^0 \to f\right) \middle| B^0 \right\rangle = e^{i\phi CP(B_d)} \frac{G_F}{\sqrt{2}} v^* M_{\bar{f}}$$

$$\overline{M}_f \equiv \left\langle f \middle| \overline{\mathcal{O}}_1(\mu)\mathcal{C}_1(\mu) + \overline{\mathcal{O}}_2(\mu)\mathcal{C}_2(\mu) \middle| \overline{B}^0 \right\rangle$$

$$M_{\bar{f}} \equiv \left\langle \bar{f} \middle| \mathcal{O}_1(\mu)\mathcal{C}_1(\mu) + \mathcal{O}_2(\mu)\mathcal{C}_2(\mu) \middle| \overline{B}^0 \right\rangle$$

遷移振幅

$$A\left(\overline{B}^0 \to f\right) \equiv \left\langle f \middle| \mathcal{H}_{eff}\left(\overline{B}^0 \to f\right) \middle| \overline{B}^0 \right\rangle$$

$$= \frac{G_F}{\sqrt{2}} \overline{v} \left\langle f \middle| \overline{\mathcal{O}}_1(\mu)\mathcal{C}_1(\mu) + \overline{\mathcal{O}}_2(\mu)\mathcal{C}_2(\mu) \middle| \overline{B}^0 \right\rangle$$

$$= \frac{G_F}{\sqrt{2}} \overline{v}\, \overline{M}_f$$

$$\overline{M}_f \equiv \left\langle f \middle| \overline{\mathcal{O}}_1(\mu)\mathcal{C}_1(\mu) + \overline{\mathcal{O}}_2(\mu)\mathcal{C}_2(\mu) \middle| \overline{B}^0 \right\rangle$$

遷移振幅

$$A\left(B^0 \to f\right) \equiv \left\langle f \middle| \mathcal{H}_{eff}\left(B^0 \to f\right) \middle| B^0 \right\rangle$$

$$= \frac{G_F}{\sqrt{2}} v^* \left\langle f \middle| \mathcal{O}_1^\dagger(\mu)\mathcal{C}_1(\mu) + \mathcal{O}_2^\dagger(\mu)\mathcal{C}_2(\mu) \middle| B^0 \right\rangle$$

$$= e^{i\phi CP(B_d)} \frac{G_F}{\sqrt{2}} v^* \left\langle \bar{f} \middle| \mathcal{O}_1(\mu)\mathcal{C}_1(\mu) + \mathcal{O}_2(\mu)\mathcal{C}_2(\mu) \middle| \overline{B}^0 \right\rangle$$

$$= e^{i\phi CP(B_d)} \frac{G_F}{\sqrt{2}} v^* M_{\bar{f}}$$

$$(CP)\left|B^0\right\rangle = e^{i\phi CP(B_d)}\left|\overline{B}^0\right\rangle$$

$$\overline{M}_f \equiv \left\langle f \middle| \overline{\mathcal{O}}_1(\mu)\mathcal{C}_1(\mu) + \overline{\mathcal{O}}_2(\mu)\mathcal{C}_2(\mu) \middle| \overline{B}^0 \right\rangle$$

$$M_{\bar{f}} \equiv \left\langle \bar{f} \middle| \mathcal{O}_1(\mu)\mathcal{C}_1(\mu) + \mathcal{O}_2(\mu)\mathcal{C}_2(\mu) \middle| \overline{B}^0 \right\rangle$$

$$(CP)\mathcal{O}_k^\dagger (CP)^\dagger = \mathcal{O}_k$$

$$\left\langle f \middle| \mathcal{O}_1^\dagger(\mu)\mathcal{C}_1(\mu) + \mathcal{O}_2^\dagger(\mu)\mathcal{C}_2(\mu) \middle| B^0 \right\rangle$$

$$= \left\langle f \middle| (\mathcal{CP})^\dagger (\mathcal{CP})\left[\mathcal{O}_1^\dagger(\mu)\mathcal{C}_1(\mu) + \mathcal{O}_2^\dagger(\mu)\mathcal{C}_2(\mu)\right](\mathcal{CP})^\dagger (\mathcal{CP}) \middle| B^0 \right\rangle$$

$$= e^{i\phi CP(B_d)} \left\langle \bar{f} \middle| \mathcal{O}_1(\mu)\mathcal{C}_1(\mu) + \mathcal{O}_2(\mu)\mathcal{C}_2(\mu) \middle| \overline{B}^0 \right\rangle$$

λ

- CP対称性の破れを評価する全ての情報を含む

$$\lambda = \frac{q}{p}\frac{\overline{A}_f}{A_f}, \frac{q}{p} = \frac{V_{tb}^* V_{td}}{V_{tb} V_{td}^*} e^{2i\xi_B}$$

$$\lambda(B_d \to f) = \frac{q}{p}\frac{A(\overline{B}^0 \to f)}{A(B^0 \to f)} = -e^{-i\phi_M^{(d)}} \frac{\bar{v}}{v^*}\frac{\overline{M}_f}{M_{\bar{f}}} = -e^{-i(2\beta+\gamma)} \frac{1}{\lambda^2 R_b}\frac{\overline{M}_f}{M_{\bar{f}}}$$

  - $\phi_{CP}(B_d)$はキャンセルされる

- analogous

$$\lambda(B_d \to \bar{f}) = \frac{q}{p}\frac{A(\overline{B}^0 \to \bar{f})}{A(B^0 \to \bar{f})} = -e^{-i\phi_M^{(d)}} \frac{v}{\bar{v}^*}\frac{M_{\bar{f}}}{\overline{M}_f} = -e^{-i(2\beta+\gamma)} \lambda^2 R_b \frac{M_{\bar{f}}}{\overline{M}_f}$$

2β+γ

$$\lambda(B_d \to f)\lambda(B_d \to \bar{f}) = e^{-2i(2\beta+\gamma)}$$

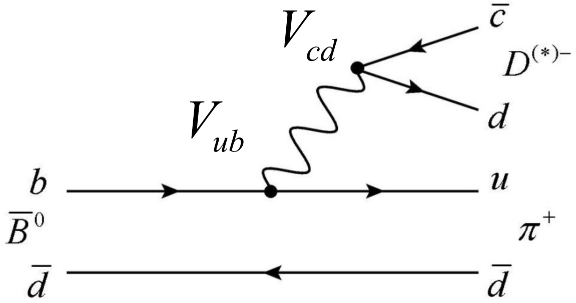
- $2\beta : B^0 - \overline{B}^0$ *mixing phase* → 他の崩壊から求められる

→γを求められる

The experimental approach

$\overline{B}^0 \to D^{*+}\pi^-$

- Possible CP violation mode
  - even in the absence of $B^0 - \overline{B}^0$ *mixing* : $\overline{B}^0 \to D^{*+}\pi^-, \overline{B}^0 \to D^{*-}\pi^+$
  - $\overline{B}^0 \to D^{*-}\pi^+$: doubly-Cabbibo suppressed (DCS) decay



- 独立にsin(2β+γ)を測定可能
  - 組み合わせることでhadronic part をキャンセル可能

- 7.6.1 終了

Backup

CP transformation

$$(CP)\left|B^0\right\rangle = e^{i\phi_{CP}(B_d)}\left|\overline{B}^0\right\rangle$$

$$(CP)\mathcal{O}_k^\dagger (CP)^\dagger = \mathcal{O}_k$$

$$\left\langle f\left|\mathcal{O}_1^\dagger(\mu)\mathcal{C}_1(\mu) + \mathcal{O}_2^\dagger(\mu)\mathcal{C}_2(\mu)\right|B^0\right\rangle$$
$$= \left\langle f\left|(\mathcal{CP})^\dagger(\mathcal{CP})\left[\mathcal{O}_1^\dagger(\mu)\mathcal{C}_1(\mu) + \mathcal{O}_2^\dagger(\mu)\mathcal{C}_2(\mu)\right](\mathcal{CP})^\dagger(\mathcal{CP})\right|B^0\right\rangle$$
$$= e^{i\phi_{CP}(B_d)}\left\langle \bar{f}\left|\mathcal{O}_1(\mu)\mathcal{C}_1(\mu) + \mathcal{O}_2(\mu)\mathcal{C}_2(\mu)\right|\overline{B}^0\right\rangle$$

$$\overline{M}_f \equiv \left\langle f\left|\overline{\mathcal{O}}_1(\mu)\mathcal{C}_1(\mu) + \overline{\mathcal{O}}_2(\mu)\mathcal{C}_2(\mu)\right|\overline{B}^0\right\rangle$$
$$M_{\bar{f}} \equiv \left\langle \bar{f}\left|\mathcal{O}_1(\mu)\mathcal{C}_1(\mu) + \mathcal{O}_2(\mu)\mathcal{C}_2(\mu)\right|\overline{B}^0\right\rangle$$

mixing