Flavour Physics and CP Violation: Expecting the LHC

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Content

- Standard-Model description of CP violation
- Weak decays of B-meson
- The neutral B-meson system
- New Physics

Standard-Model description of CP violation

标准模型:

粒子物理标准模型将除引力以外在其他三种相互作用(强相互作用.电磁相互作用,弱相互作用)有机在统一再在了一起

CKM矩阵:

在标准模型中,夸克的质量通过Yukawa作用项产生的,CKM矩阵将夸克的电弱本征态和质量本征态相联系:

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

CKM矩阵:

$$\hat{V}_{\rm CKM} = \begin{pmatrix} c_{12}c_{13} & s_{12}c_{13} & s_{13}e^{-i\delta_{13}} \\ -s_{12}c_{23} - c_{12}s_{23}s_{13}e^{i\delta_{13}} & c_{12}c_{23} - s_{12}s_{23}s_{13}e^{i\delta_{13}} & s_{23}c_{13} \\ s_{12}s_{23} - c_{12}c_{23}s_{13}e^{i\delta_{13}} & -c_{12}s_{23} - s_{12}c_{23}s_{13}e^{i\delta_{13}} & c_{23}c_{13} \end{pmatrix}$$

CKM矩阵的相结构:二代CKM矩阵,三代CKM矩阵

CKM的实验信息

Nuclear beta decays, neutron decays $\Rightarrow |V_{ud}|$.

$K \to \pi\ell\bar{\nu}$ decays $\Rightarrow |V_{us}|$.

ν production of charm off valence d quarks $\Rightarrow |V_{cd}|$.

Charm-tagged W decays (as well as ν production and semileptonic D decays) $\Rightarrow |V_{cs}|$.

Exclusive and inclusive $b \to c\ell\bar{\nu}$ decays $\Rightarrow |V_{cb}|$.

Exclusive and inclusive $b \to u\ell\bar{\nu}$ decays $\Rightarrow |V_{ub}|$.

$\bar{t} \to \bar{b}\ell\bar{\nu}$ processes $\Rightarrow$ (crude direct determination of) $|V_{tb}|$.

$$|\hat{V}_{\rm CKM}| = \begin{pmatrix} 0.9739\text{–}0.9751 & 0.221\text{–}0.227 & 0.0029\text{–}0.0045 \\ 0.221\text{–}0.227 & 0.9730\text{–}0.9744 & 0.039\text{–}0.044 \\ 0.0048\text{–}0.014 & 0.037\text{–}0.043 & 0.9990\text{–}0.9992 \end{pmatrix}$$

CKM矩阵:

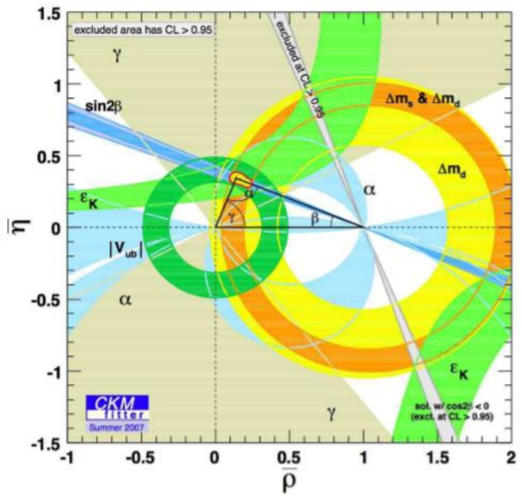
CKM矩阵的参数化:

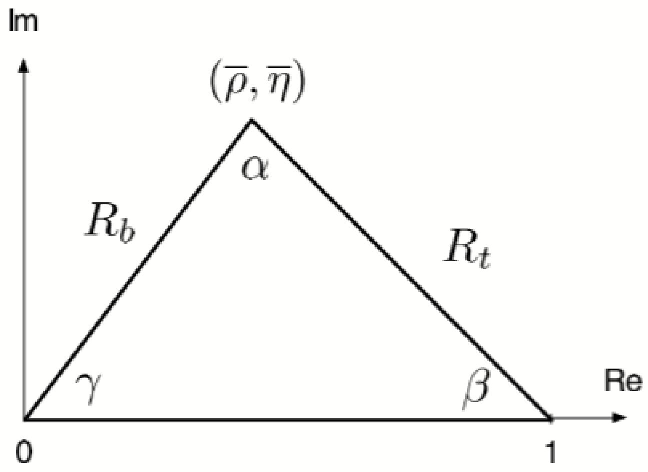
唯象上比较直观和实用的Wolfenstein参数化方案

$$\lambda,\ A,\ \rho \text{ and } \eta,$$

CKM矩阵的幺正三角形:

根据CKM矩阵的幺正性可以得到六个正交性关系,在复平面内表达为六个面积一样的三角形





Weak decays of B-meson

Leptonic Decays:

$$B^- \to \ell \bar{\nu}_\ell$$

跃迁振幅

$$\Gamma(B^- \to \ell\bar{\nu}_\ell) = \frac{G_F^2}{8\pi} M_B m_\ell^2 \left(1 - \frac{m_\ell^2}{M_B^2}\right)^2 f_B^2 |V_{ub}|^2$$

衰减率

Semileptonic Decays :

$$b \to c$$

跃迁振幅

$$T_{fi} = \frac{G_F}{\sqrt{2}} V_{cb} \left[\bar{u}_\ell \gamma^\alpha (1-\gamma_5) v_\nu\right] \langle D^+ | \bar{c}\gamma_\alpha (1-\gamma_5) b | \bar{B}_d^0 \rangle$$

Non-Leptonic Decays:

$b \to q_1 \, \bar{q}_2 \, d \, (s)$ 最复杂的B介子衰变

$q_1 \neq q_2 \in \{u, c\}$: *only* tree diagrams contribute.

$q_1 = q_2 \in \{u, c\}$: tree *and* penguin diagrams contribute.

$q_1 = q_2 \in \{d, s\}$: *only* penguin diagrams contribute.

Weak decays of B-meson

Non-Leptonic Decays:

利用算子积展开计算低能有效哈密顿量

$$\mathcal{H}_{\text{eff}} = \frac{G_F}{\sqrt{2}} \left[\sum_{j=u,c} V_{jr}^* V_{jb} \left\{ \sum_{k=1}^{2} C_k(\mu)\, Q_k^{jr} + \sum_{k=3}^{10} C_k(\mu)\, Q_k^r \right\} \right]$$

Current–current operators:

$$\begin{aligned} Q_1^{jr} &= (\bar{r}_\alpha j_\beta)_{V-A} (\bar{j}_\beta b_\alpha)_{V-A} \\ Q_2^{jr} &= (\bar{r}_\alpha j_\alpha)_{V-A} (\bar{j}_\beta b_\beta)_{V-A}. \end{aligned}$$

QCD penguin operators:

$$\begin{aligned} Q_3^r &= (\bar{r}_\alpha b_\alpha)_{V-A} \textstyle\sum_{q'} (\bar{q}'_\beta q'_\beta)_{V-A} \\ Q_4^r &= (\bar{r}_\alpha b_\beta)_{V-A} \textstyle\sum_{q'} (\bar{q}'_\beta q'_\alpha)_{V-A} \\ Q_5^r &= (\bar{r}_\alpha b_\alpha)_{V-A} \textstyle\sum_{q'} (\bar{q}'_\beta q'_\beta)_{V+A} \\ Q_6^r &= (\bar{r}_\alpha b_\beta)_{V-A} \textstyle\sum_{q'} (\bar{q}'_\beta q'_\alpha)_{V+A}. \end{aligned}$$

EW penguin operators (the $e_{q'}$ denote the electrical quark charges)

$$\begin{aligned} Q_7^r &= \tfrac{3}{2} (\bar{r}_\alpha b_\alpha)_{V-A} \textstyle\sum_{q'} e_{q'} (\bar{q}'_\beta q'_\beta)_{V+A} \\ Q_8^r &= \tfrac{3}{2} (\bar{r}_\alpha b_\beta)_{V-A} \textstyle\sum_{q'} e_{q'} (\bar{q}'_\beta q'_\alpha)_{V+A} \\ Q_9^r &= \tfrac{3}{2} (\bar{r}_\alpha b_\alpha)_{V-A} \textstyle\sum_{q'} e_{q'} (\bar{q}'_\beta q'_\beta)_{V-A} \\ Q_{10}^r &= \tfrac{3}{2} (\bar{r}_\alpha b_\beta)_{V-A} \textstyle\sum_{q'} e_{q'} (\bar{q}'_\beta q'_\alpha)_{V-A}. \end{aligned}$$

B-meson decays

$B_q^0 - \bar{B}_q^0$混合的薛定谔方程

$$|B_q(t)\rangle = a(t)|B_q^0\rangle + b(t)|\bar{B}_q^0\rangle,$$

混合参数

$$x_q \equiv \frac{\Delta M_q}{\Gamma_q} = \begin{cases} 0.776 \pm 0.008 & (q = d) \\ \mathcal{O}(20) & (q = s) \end{cases}$$

B-meson decays

CP破坏:

直接CP破坏(衰变中的CP破坏)

$$\mathcal{A}_{CP}^{dir} \equiv \frac{\Gamma(\bar{B} \to \bar{f}) - \Gamma(B \to f)}{\Gamma(\bar{B} \to \bar{f}) + \Gamma(B \to f)} = \frac{|\bar{A}|^2 - |A|^2}{|\bar{A}|^2 + |A|^2},$$

非直接CP破坏(中性B介子混合引起的CP破坏)

$$\mathcal{A}_{\rm SL} \equiv \frac{\Gamma(\bar{B}^0(t) \to l^+\nu_l X) - \Gamma(B^0(t) \to l^-\bar{\nu}_l X)}{\Gamma(\bar{B}^0(t) \to l^+\nu_l X) + \Gamma(B^0(t) \to l^-\bar{\nu}_l X)} = \frac{1 - |q/p|^4}{1 + |q/p|^4}.$$

混合型CP破坏(混合和衰变引起的CP破坏)

$$-C_f \cos \Delta m_B t + S_f \sin \Delta m_B t$$

Highlights of B-physics at the LHC

- LHC实验的目标，具有高统计性和互补性

由于目前的e+ e−B工厂 在γ（4S）共振下运行，该共振衰变为$B_{u,\ d}$，没有衰变为Bs介子，因此BaBar和Belle实验无法探索Bs系统。然而，强子对撞机产生了大量Bs介子。Bs介子系统的物理潜力可以得到充分利用，它为更好的研究CP破坏提供了可能。

Conclusions and outlook

LHC精确的实验结果可以给我们检验标准模型和寻找超出标准模型的新物理提供了优良的研究环境

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