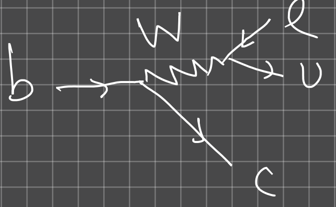
CP-Violating obs. in $B^0 \to D^* \mu \nu$

SL $b \to c \ell \nu$ in SM



$\ell = e, \mu, \tau$

$$H_{eff}^{SM} = \frac{G_F V_{cb}}{\sqrt{2}} O_L \quad ; \quad O_L = \bar{c}\gamma_\mu(1-\gamma_5)b\,\bar{\ell}\gamma^\mu(1-\gamma_5)\nu_\ell$$

B-anom. $R(D), R(D^*), R(J/\Psi) \Rightarrow$ NP in $b \to c \ell \nu$

- $$H_{eff} = H_{eff}^{SM} + \frac{G_F V_{cb}}{\sqrt{2}} \sum_i g_i O_i \, , \qquad O_R = \bar{c}\gamma_\mu(1+\gamma_5)b\,\bar{\ell}\gamma^\mu(1-\gamma_5)\nu_\ell$$
  $$i = S, P, L, R, T \qquad O_S = \bar{c}b\,\bar{\ell}(1-\gamma_5)\nu_\ell$$
  $\vdots$

CPV in $b \to c \mu \nu$

$$A_{dir}^{CP} = \Gamma(B^0 \to D^{*+}\mu\nu) - \Gamma(\bar{B}^0 \to D^{*}\mu^-\nu)$$
$$\Leftrightarrow \Delta\phi^{weak} \neq 0$$
$$\Delta\phi^{strong} \neq 0$$

in $b \to c \ell \nu$ $\Delta\phi^{strong} = 0 \Rightarrow A_{dir}^{CP} = 0$

if $\Delta\phi^{weak} \neq 0 \Rightarrow$ CPV eff. in the angular distrib.

$$A_{ang}^{CP} \neq 0.$$

$$\begin{cases} A_{ang}^{CP} = 0 \text{ in SM} \Rightarrow \text{Null test of SM} \\ A_{ang}^{CP} \neq 0 \text{ in 2 NP cases} \quad g_R \neq 0 \; ; \; g_P g_T^* \neq 0. \end{cases}$$

Angular distribution

Helicity formalism $B^0 \to D^* W^* \to (D^0 \pi)(\ell \nu_\ell)$

$$\Gamma^{SM} \sim |\mathcal{M}^{SM}|^2, \quad \mathcal{M}^{SM} \sim \sum_m A_m \mathcal{H}_{D^*}(m) \mathcal{L}_{W^*}(m)$$

$$\Gamma^{SM+NP} \sim |\underline{\mathcal{M}^{SM+NP}}|^2, \quad \mathcal{M}^{SM+NP} \sim \sum_m \underbrace{A_m^{NP}}_{g_{NP}} \underbrace{\mathcal{H}_{D^*}(m) \mathcal{L}_X^{NP}(m)}_{\text{kinematics}}$$

kinematics $q^2, \theta_\ell, \theta_D, \chi$

obtain $\dfrac{d^4\Gamma}{dq^2 d\theta_\ell \underline{d\theta_D} d\chi} = P_{tot} = P_{even} + P_{odd}$

$P_{odd} = 0$ in SM

$P_{odd} \neq 0$ in $g_R \neq 0 \Rightarrow P_{odd} \sim \sin\chi, \sin 2\chi$

$g_P g_T^* \neq 0 \Rightarrow P_{odd} \sim \sin\chi$

$P_{odd} \subset \mathrm{Im} \sin 2\theta_\ell \sin 2\theta_D \sin\chi$ where $\mathrm{Im} = \mathrm{Im}(q^2) \sim \mathrm{Im}(A_i A_j^*)$

$\sim \mathrm{Im}(g_R)$

$$P_{odd}^{(1)}(q^2, \theta_\ell, \theta_D) = \int_{-\pi}^{\pi} P_{tot}(q^2, \theta_\ell, \theta_D, \chi) \sin\chi \, d\chi \sim \mathrm{Im}(g_R), \ \mathrm{Im}(g_P g_T^*)$$

$$P_{odd}^{(2)}(q^2, \theta_\ell, \theta_D) = \int_{-\pi}^{\pi} P_{tot}(q^2, \theta_\ell, \theta_D, \chi) \sin 2\chi \, d\chi \sim \mathrm{Im}(g_R)$$

if $g_{NP} \ll 1$ i.e. $NP \ll SM$

$$P_{odd}^{(1)} = \mathrm{Im}(g_R) f_{RH}(q^2, \theta_\ell, \theta_D) + \mathrm{Im}(g_P g_T^*) f_{PT}(\ldots) \sim \sin\chi$$

$$P_{odd}^{(2)} = \mathrm{Im}(g_R) f_{RH}(q^2, \theta_\ell, \theta_D) \sim \sin 2\chi$$

BINNED ASYMMETRIES $A_i \sim P_{odd} \sim \mathrm{Im}(g_{NP})$

$$A_i^{(1)} = \frac{N_{bins}}{N_{evts}} \sum_{n=1}^{i} \sin \chi_n \quad ; \quad A_i^{(2)} = \sum \sin 2\chi$$

2D templates in $\cos\theta_e$ vs $\cos\theta_D$

Since $A_i \sim P_{odd} \sim \mathrm{Im}(g_{NP})$

$$\chi^2 = \sum_i \frac{(A_i^{data} - A_i^{model})^2}{\sigma^2}$$

$$A_i^{model} = \frac{\mathrm{Im}(g_R)_{fit}}{\mathrm{Im}(g_R)_0} A_{RH,i} + \frac{\mathrm{Im}(g_P g_T^*)_{fit}}{\mathrm{Im}(g_P g_T^*)_0} A_{PT,i}$$

$g_R, g_P g_T^* \ll 1 : (0.1i, 0.1i)$

$\sigma^{stat}_{g_R} \sim 0.01 \quad ; \quad \sigma^{stat}_{g_P g_T^*} \sim 0.001$

Systematic eff.

P-even : bkg comp ; FFs, reco efficiencies

P-odd : fake CPV

1. BKG $\quad \bar{B} \to D^* \mu \nu$

SL bkg : $B^0 \to D^* \tau \nu \to D^*(\mu\nu\nu)\nu$

$B^0 \to D^{**} \mu\nu \to (D^* \pi)\mu\nu$

All SL bkg : CPV = 0 in SM

$B \to D^{**}\mu\nu$: interf. $D^*(2420)$ and $D^*(2460)$ $\to \Delta\phi^{strong} \neq 0$

$\sigma_{Im(g_R)} \sim 0.01$; $\sigma_{Im(g_P g_T^*)} \sim 0.001 \propto \sigma_{stat}$

$\sigma^{mis}_{Im(g_R)} \sim 0.003$; $\sigma^{mis}_{Im(g_P g_T)} \sim 0.0002$