CP asymmetries of $\bar{B} \to X_s/X_d\gamma$ in models with three Higgs doublets

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Motivation of 3HDM

- Not as much literature attention as the 2HDM.
- Rich scalar structure.
- Dark Matter(Inert doublet).
- Extra sources of CP-violation in charged scalar sector.

Charged Higgs in 3HDM

- Three active Higgs doublet, each with a vev.
- Mixing matrix U rotates the gauge eigenstate to mass eigenstates.
- Yukawa coupling X_i, Y_i, Z_i are functions of four mixing parameters.
- $\tan\beta(=v_2/v_1)$, $\tan\gamma(=(v_1^2+v_2^2)/v_3)$, θ (mixing angle), δ (CP-violation phase).

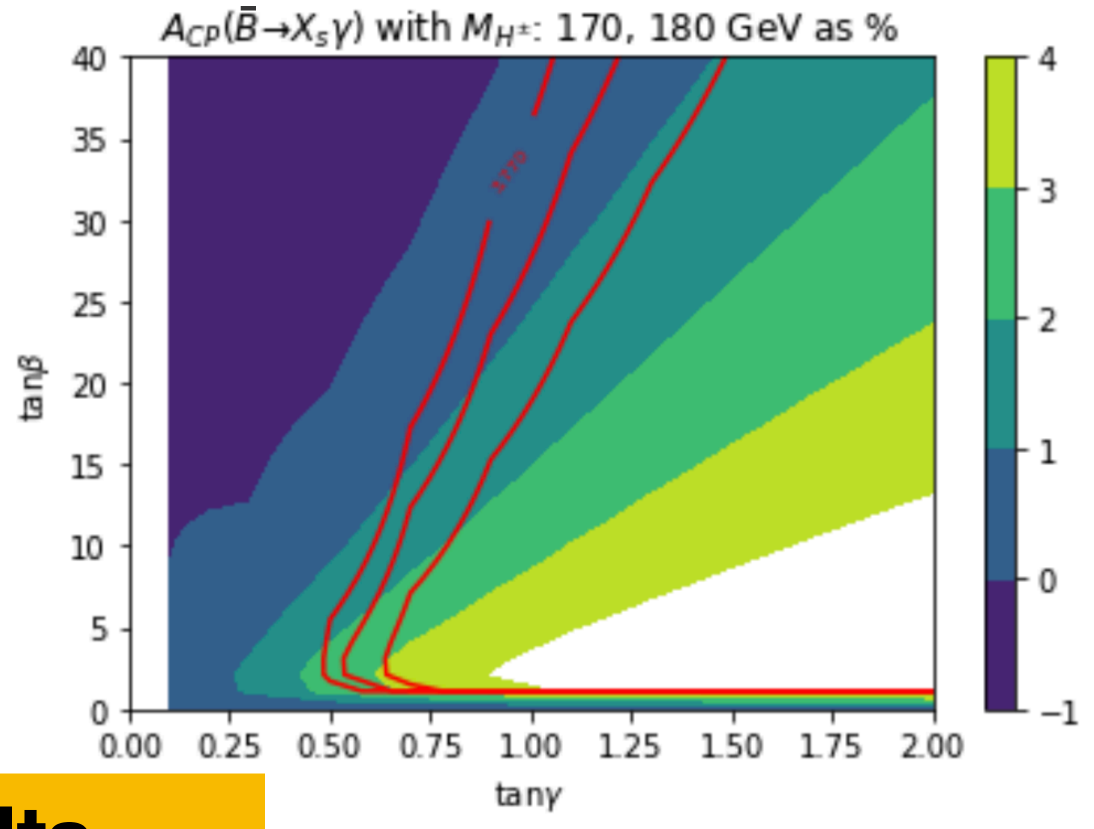
$$\Phi_i = \begin{pmatrix} \phi_i^+ \\ (\phi_i^{0,real} + i\phi_i^{0,imag})/\sqrt{2} \end{pmatrix}, \sum_i v_i^2 = v_{sm}^2 = (246GeV)^2, i = 1,2,3$$

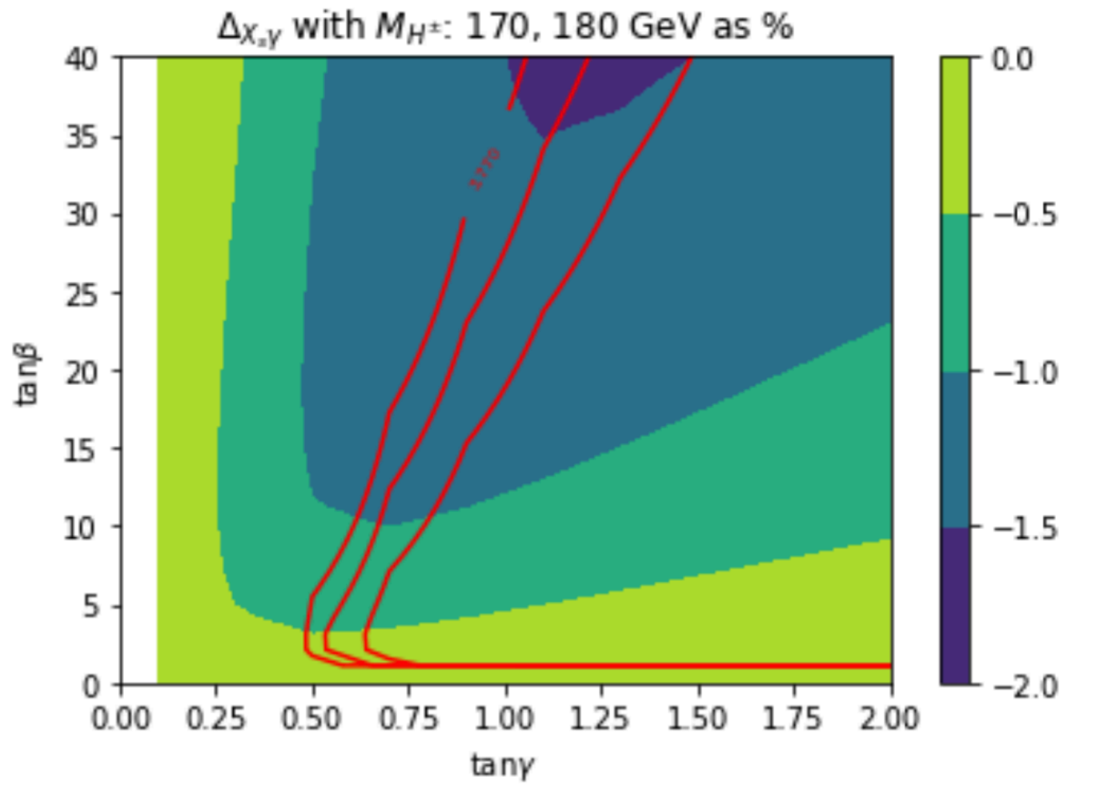
$$\mathscr{L}_{H_i^\pm} = -\sum_{i=2}^{3} H_i^+\{\frac{\sqrt{2}V_{ud}}{v_{sm}}\bar{u}(m_d X_i P_R + m_u Y_i P_L)d + \frac{\sqrt{2}m_l}{v_{sm}} Z_i \bar{\nu}_L l_R\} + H.c$$

$$\begin{pmatrix} G^+ \\ H_2^+ \\ H_3^+ \end{pmatrix} = U \begin{pmatrix} \phi_1^+ \\ \phi_2^+ \\ \phi_3^+ \end{pmatrix} \qquad X_i = \frac{U_{d2}^\dagger}{U_{d1}^\dagger}, \qquad Y_i = -\frac{U_{u2}^\dagger}{U_{u1}^\dagger}, \qquad Z_i = \frac{U_{\ell 2}^\dagger}{U_{\ell 1}^\dagger}$$

BR($\bar{B} \to X_s\gamma$) and Direct CP-asymmetry

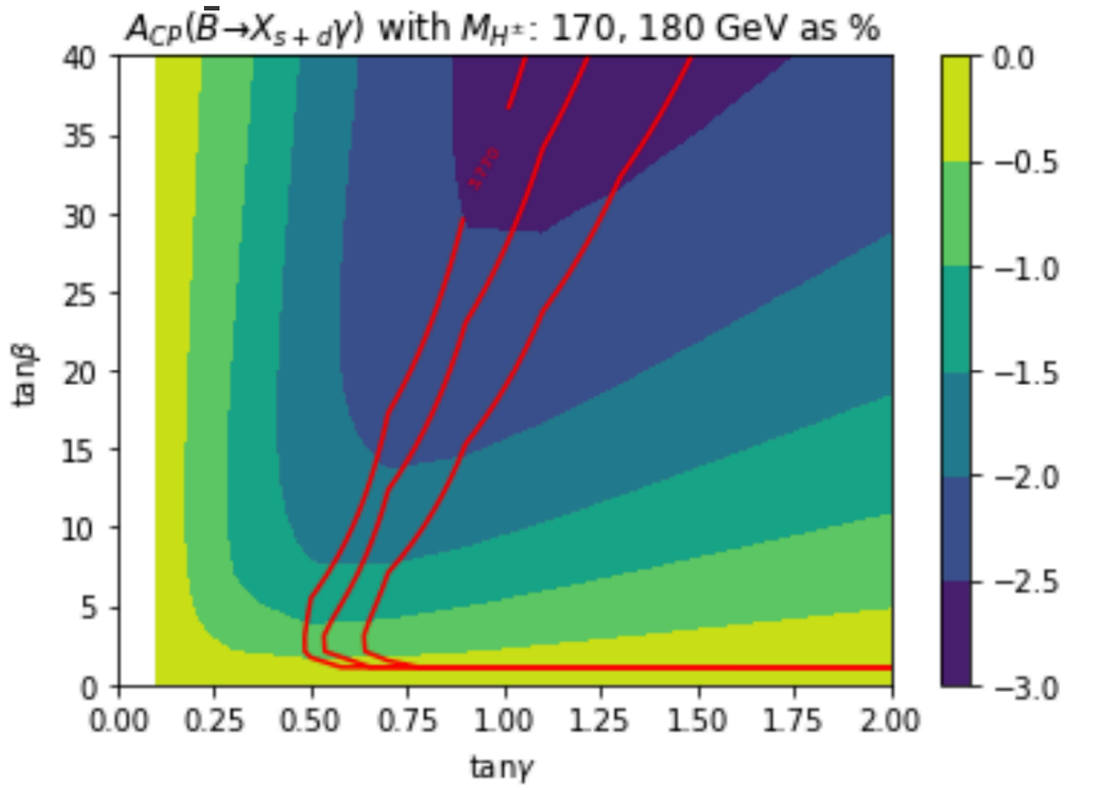
- BR($\bar{B} \to X_s\gamma$) is a constraint on new physics.
- Direct CP-asymmetry($\mathscr{A}_{CP}(\bar{B} \to X_s\gamma)$),
- CP-asymmetry difference($\Delta\mathscr{A}_{X_s\gamma}$) and Untagged-asymmetry($\mathscr{A}_{CP}(\bar{B} \to X_{s+d}\gamma)$)
- CP-asymmetry observables might provide a signal for new physics.





Results

- $\Delta\mathscr{A}_{X_s\gamma}$ and $\mathscr{A}_{CP}(\bar{B} \to X_{s+d}\gamma)$ have a SM prediction essentially zero with small theoretical error.
- A measurement of 2.5 ± 0.5 % for $\mathscr{A}_{CP}(\bar{B} \to X_{s+d}\gamma)$ would provide 5 sigma evidence for physics beyond SM.
- Feasible to observe at BELLE-II.
- GIM-like mechanism between H_2^+ and H_3^+ in imaginary contribution of $X_iY_i^*$



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Scalar Potential for 3HDM

$$V = m_{11}^2\Phi_1^\dagger\Phi_1 + m_{22}^2\Phi_2^\dagger\Phi_2 + m_{33}^2\Phi_3^\dagger\Phi_3 - [m_{12}^2\Phi_1^\dagger\Phi_2 + m_{13}^2\Phi_1^\dagger\Phi_3 + m_{23}^2\Phi_2^\dagger\Phi_3 + \textbf{h.c.}]$$

$$+\frac{1}{2}\lambda_1(\Phi_1^\dagger\Phi_1)^2 + \frac{1}{2}\lambda_2(\Phi_2^\dagger\Phi_2)^2 + \frac{1}{2}\lambda_3(\Phi_3^\dagger\Phi_3)^2 + \lambda_{12}(\Phi_1^\dagger\Phi_1)(\Phi_2^\dagger\Phi_2) + \lambda_{13}(\Phi_1^\dagger\Phi_1)(\Phi_3^\dagger\Phi_3) + \lambda_{23}(\Phi_2^\dagger\Phi_2)(\Phi_3^\dagger\Phi_3)$$

$$+\lambda'_{12}(\Phi_1^\dagger\Phi_2)(\Phi_2^\dagger\Phi_1) + \lambda'_{13}(\Phi_1^\dagger\Phi_3)(\Phi_3^\dagger\Phi_1) + \lambda'_{23}(\Phi_2^\dagger\Phi_3)(\Phi_3^\dagger\Phi_2) + \frac{1}{2}[\lambda''_{12}(\Phi_1^\dagger\Phi_2)^2 + \lambda''_{13}(\Phi_1^\dagger\Phi_3)^2 + \lambda''_{23}(\Phi_2^\dagger\Phi_3)^2 + \textbf{h.c.}],$$

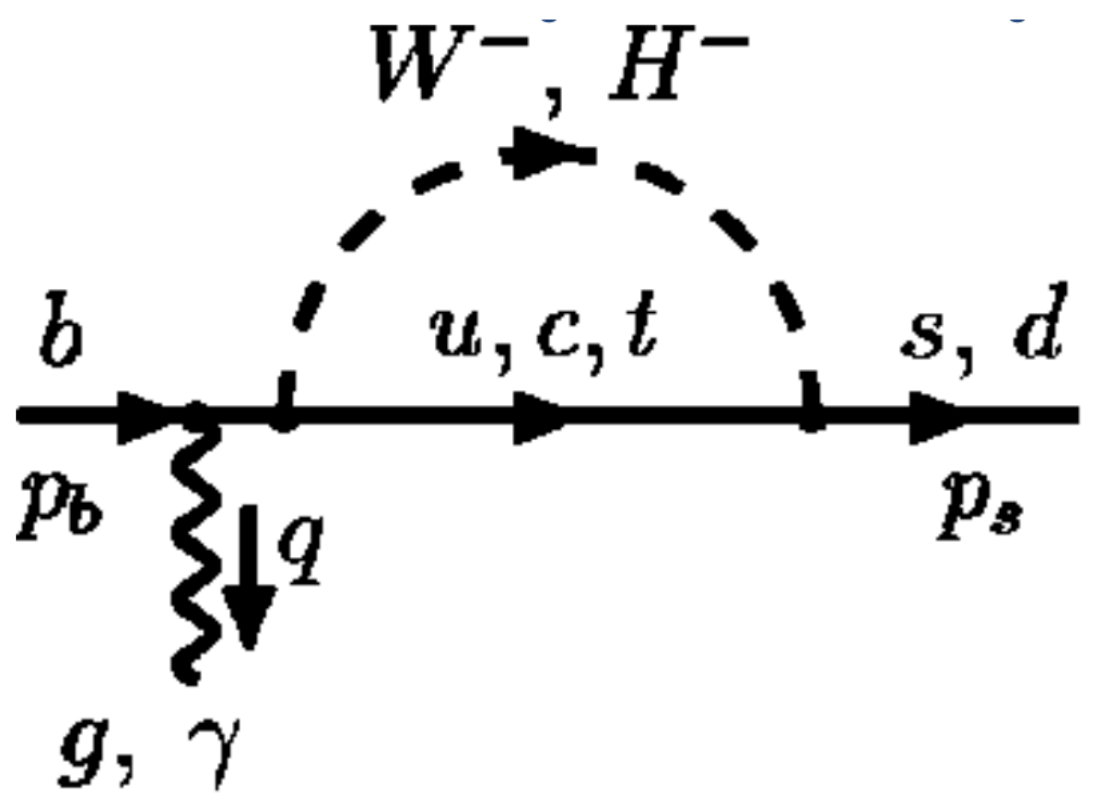
3HDM	U	D	L
Type-I	2	2	2
Type-II	2	1	1
Flipped	2	2	1
Lepton specific	2	1	2
Democratic	2	1	3

$$X_i = \frac{U_{d2}^\dagger}{U_{d1}^\dagger}, \qquad Y_i = -\frac{U_{u2}^\dagger}{U_{u1}^\dagger}, \qquad Z_i = \frac{U_{\ell 2}^\dagger}{U_{\ell 1}^\dagger}$$

6 complex parameters and only one will be the remaining CP-violation parameter and appear in charged Higgs mass matrix.

$$m_{12}^2, m_{13}^2, m_{23}^2, \lambda''_{12}, \lambda''_{13}, \lambda''_{23}. \qquad \textbf{Im}(\lambda''_{12}) = \delta$$

$\bar{B} \to X_s\gamma$



$$H_{\textbf{eff}} = -\frac{4G_f}{\sqrt{2}}V_{ts}^*V_{tb}\sum_i^8 C_i(\mu_b)O_i(\mu_b)$$

Three Wilson coefficients are dominant:

$$C_2, C_7, C_8 \propto [Y_i^2 \textbf{ and } (X_iY_i^*)]$$

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CP-asymmetry observables

- Direct CP-asymmetry($\mathscr{A}^{CP}_{X_{s(d)}\gamma}$)
- CP-asymmetry difference($\Delta\mathscr{A}_{X_s\gamma}$)
- Untag-asymmetry($\mathscr{A}_{CP}(\bar{B} \to X_{s+d}\gamma)$)

$$\mathscr{A}^{CP}_{X_{s(d)}\gamma} = \frac{\Gamma(\bar{B} \to X_{s(d)}\gamma) - \Gamma(B \to X_{s(d)}\gamma)}{\Gamma(\bar{B} \to X_{s(d)}\gamma) + \Gamma(B \to X_{s(d)}\gamma)}$$

$$\Delta\mathscr{A}_{X_s\gamma} = \mathscr{A}^{\pm}_{X_s\gamma} - \mathscr{A}^{0}_{X_s\gamma}$$

$$\mathscr{A}_{CP}(\bar{B} \to X_{s+d}\gamma) = \frac{\mathscr{A}_{X_s\gamma} + R_{ds}\mathscr{A}_{X_d\gamma}}{1 + R_{ds}}\,.\, R_{ds} \approx |V_{td}/V_{ts}|^2$$

B^0 for neutral B mesons: $\mathscr{A}^{0}_{X_{s(d)}\gamma}$.

$B, \bar{B}$ for charged B mesons(B^+, B^-): $\mathscr{A}^{\pm}_{X_{s(d)}\gamma}$

GIM-like mechanism for CP-asymmetry

$$X_iY_i^* = -\frac{U^\dagger_{1i}U_{i2}}{U^\dagger_{11}U_{12}},$$

$$\sum_{i=2}^{3} \mathrm{Im}(X_iY_i^*)f(M_{H_i^+}) = -\frac{1}{U^\dagger_{11}U_{12}}[\mathrm{Im}(U^\dagger_{12}U_{22})f(M_{H_2^+}) + \mathrm{Im}(U^\dagger_{13}U_{32})f(M_{H_3^+})]$$

In the case of $M_{H_2^+} = M_{H_3^+}$, such result will be $= -\frac{1}{U^\dagger_{11}U_{12}}\mathrm{Im}(\delta_{12})f(m) = 0$

because $\mathrm{Im}(X_2Y_2^*) = -\mathrm{Im}(X_3Y_3^*)$.

BELLE-II	SM prediction	Hadronic tag	Leptonic tag	Sum of exclusives
$\mathscr{A}^{CP}_{X_s\gamma}$	$-1.9\,\% < \mathscr{A}^{CP}_{X_s\gamma} < 3.3\,\%$	X	X	0.19%
$\Delta\mathscr{A}_{X_s\gamma}$	0	0.70%	0.48%	X
$\mathscr{A}_{CP}(\bar{B} \to X_{s+d}\gamma)$	0	1.3%	X	0.3%