The CP-violating 2HDM

In the C2HDM the three neutral Higgs states of the 2HDM mix as

$$\begin{pmatrix} H_1 \\ H_2 \\ H_3 \end{pmatrix} = R^{3\times 3}_{\alpha_1,\alpha_2,\alpha_3} \begin{pmatrix} \rho_1 \\ \rho_2 \\ A \end{pmatrix} .$$

Each of the H_i obtains couplings to gauge bosons and both CP-even ($c^e_{ff}(H_i)$) and CP-odd ($c^o_{ff}(H_i)$) couplings to fermions.

We[1] propose benchmark points based on [1506.06755] and [1711.09419] featuring CP-violating phenomenology of h_{125} and the additional Higgs bosons.

[1] Philipp Basler, Duarte Fontes, Maggie Mühlleitner, Jorge C. Romao, Rui Santos, Joao P. Silva, Jonas Wittbrodt

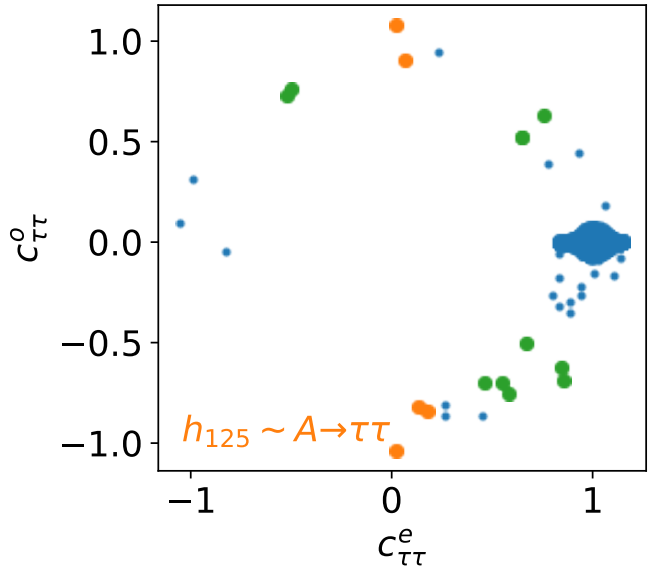
Benchmark Points in the C2HDM

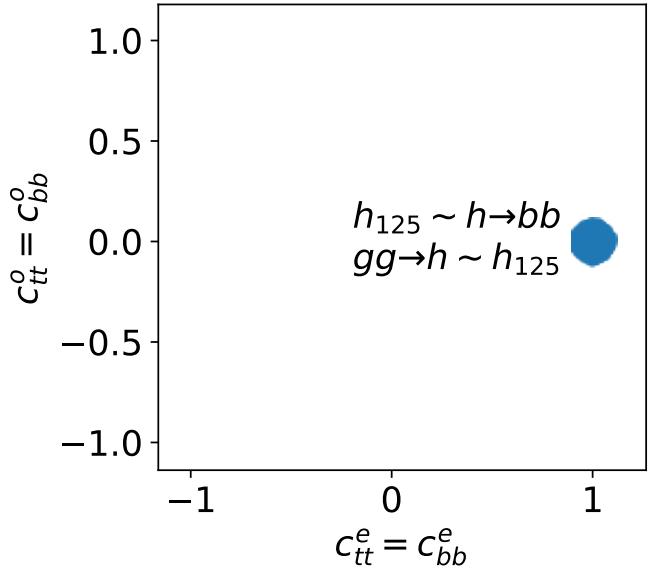
Our parameter points are based on [1711.09419] including constraints from:

- unitarity, boundedness from below, vacuum stability,
- EW-precision (S, T, U) and B-physics,
- Higgs measurements and searches (`C2HDM_HDECAY` + `HiggsBounds5`/`HiggsSignals2`),
- electron EDM

in the `ScannerS` framework.

CP-violation in $h_{125} \to \tau^+\tau^-$





Lepton-specific Yukawa couplings

	$\max(c^e_{\tau\tau})$	$c^e_{\tau\tau} \sim c^o_{\tau\tau}$
m_{H_1} [GeV]	86	125.09
m_{H_2} [GeV]	125.09	140
m_{H_3} [GeV]	251.12	156.73
$m_{H^\pm}$ [GeV]	245	220
α_1	-0.0952	1.52
α_2	0.65	-0.045
α_3	0.152	1.18
$\tan\beta$	8.55	14.5
$\Re(m^2_{12})$ [GeV^2]	2500	1600
$c^e_{\tau\tau}$	0.024	0.737
$c^o_{\tau\tau}$	-1.031	0.652
$\mu^{h_{125}}_{\tau\tau}$	1.075	0.983

Undoubtable Signs of CP-violation

Establish CP-violation from the simultaneous observation of three Higgs boson decay modes [1506.06755].

$h_{125} \to ZZ$ ✓

$\Rightarrow \mathrm{CP}(h_{125}) = 1$

- C2: $\begin{cases} H_2 \to h_{125} Z & \Rightarrow \mathrm{CP}(H_2) = -1 \\ H_2 \to ZZ & \Rightarrow \mathrm{CP}(H_2) = 1 \end{cases}$
- C3: $\begin{cases} H_3 \to h_{125} Z & \Rightarrow \mathrm{CP}(H_3) = -1 \\ H_3 \to ZZ & \Rightarrow \mathrm{CP}(H_3) = 1 \end{cases}$
- C6: $\begin{cases} H_3 \to H_2 Z & \Rightarrow \mathrm{CP}(H_2) \neq \mathrm{CP}(H_3) \\ H_3 \to h_{125} H_2 & \Rightarrow \mathrm{CP}(H_2) = \mathrm{CP}(H_3) \end{cases}$
- C7: $\begin{cases} H_2 \to h_{125} Z & \Rightarrow \mathrm{CP}(H_2) = -1 \\ H_2 \to h_{125} h_{125} & \Rightarrow \mathrm{CP}(H_2) = 1 \end{cases}$

CP-violation in Higgs decay combinations I

C2: $\begin{cases} H_2 \to h_{125} Z \\ H_2 \to ZZ \end{cases}$ C3: $\begin{cases} H_3 \to h_{125} Z \\ H_3 \to ZZ \end{cases}$ C7: $\begin{cases} H_2 \to h_{125} Z \\ H_2 \to h_{125} h_{125} \end{cases}$

Type I Yukawa couplings

	C2 ($i = 2$)	C3 ($i = 3$)	C7 ($i = 2$)
	$XX = ZZ$		$XX = h_{125} h_{125}$
m_{H_1} [GeV]	125.09	125.09	125.09
m_{H_2} [GeV]	255.0	220.0	260.0
m_{H_3} [GeV]	265.046	264.556	379.775
$m_{H^\pm}$ [GeV]	185.0	285.0	375.0
α_1	1.39	1.43	1.38
α_2	0.025	0.036	-0.032
α_3	-1.07	-0.24	1.53
$\tan\beta$	2.82	4.36	3.24
$\Re(m_{12}^2)$ [GeV^2]	14500	11000	31000
$\sigma_{H_i} \times \mathrm{Br}_{H_i \to h_{125} Z}$ [fb]	1596	404	1452
$\sigma_{H_i} \times \mathrm{Br}_{H_i \to XX}$ [fb]	335	295	1193

CP-violation in Higgs decay combinations II

$$\text{C6:} \begin{cases} H_3 & \to H_1 H_2 \\ H_3 & \to Z H_2 \\ H_1 & \to ZZ \end{cases}$$

- Higgs-to-Higgs decay close to threshold $\to$ large $\text{Br}_{H_3 \to H_1 H_2}$
- H_2 decays mainly to $b\bar{b}$ so $b\bar{b}\gamma\gamma$ final state $\sim 0.2\,\text{fb}$.

Type I Yukawa couplings

	C6
m_{H_1} [GeV]	125.09
m_{H_2} [GeV]	134
m_{H_3} [GeV]	268.097
$m_{H^\pm}$ [GeV]	252
α_1	1.295
α_2	0.188
α_3	-1.56
$\tan\beta$	2.63
$\Re(m_1 2^2)$ [GeV^2]	3800
$\sigma_{H_3} \times \text{Br}_{H_3 \to H_2 H_1}$ [fb]	137
$\sigma_{H_3} \times \text{Br}_{H_3 \to H_2 Z}$ [fb]	572
$\text{Br}_{H_2 \to b\bar{b}}$	0.58