Machine Learning Techniques to explore scalar-fermion couplings

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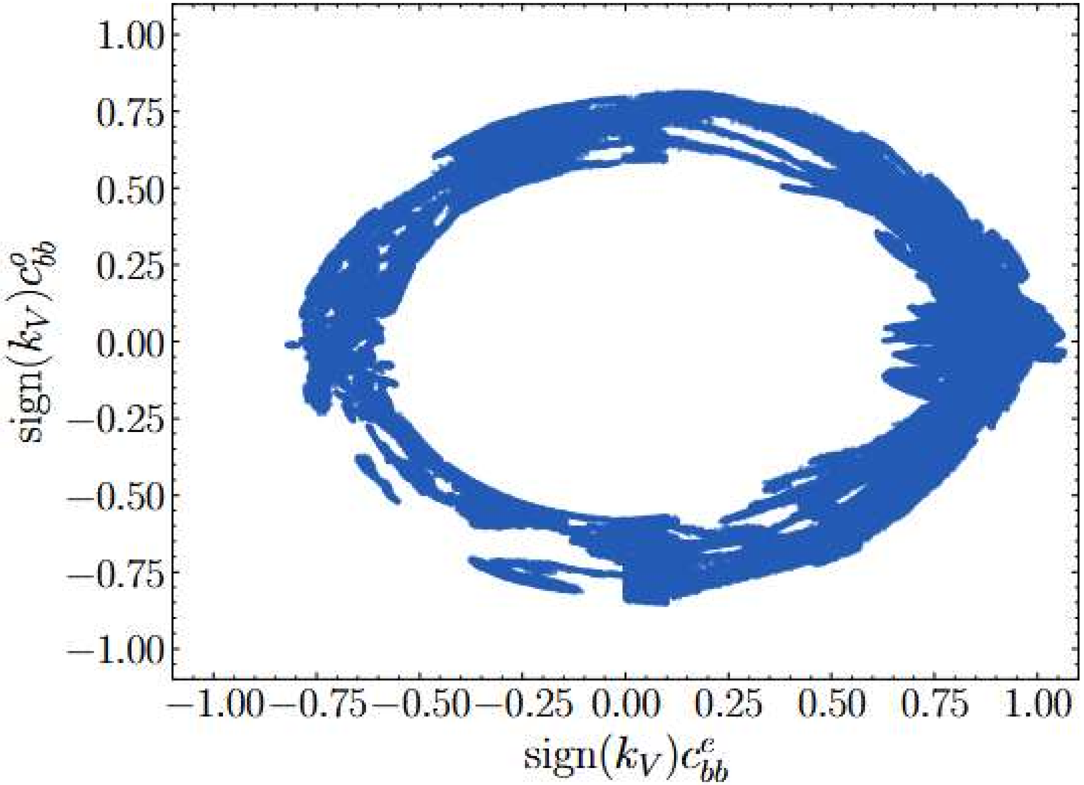
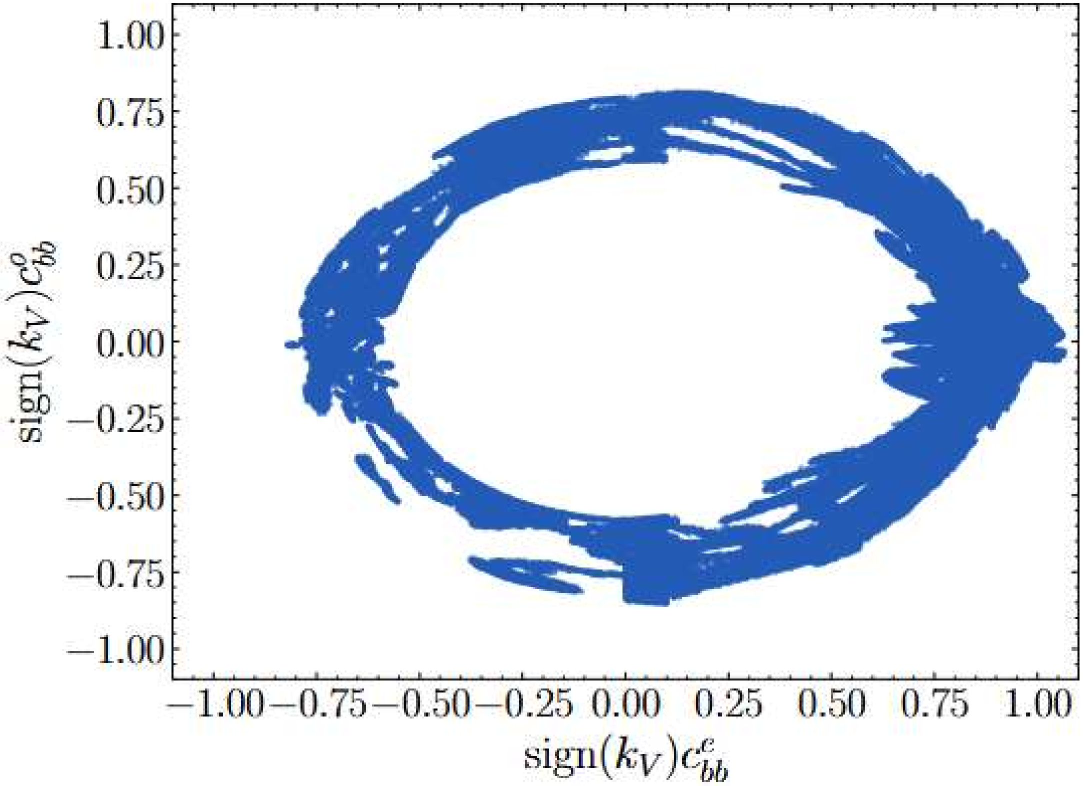
h_{125} couplings



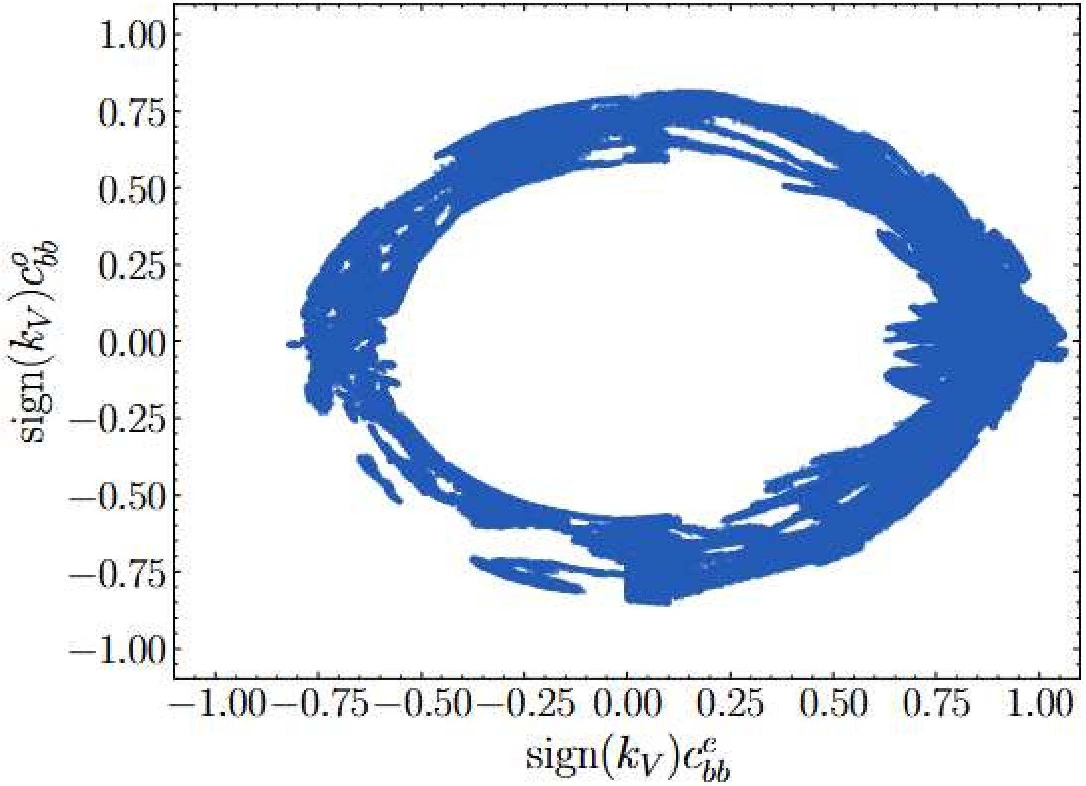
h_{125} couplings



Standard Model

$$-\mathcal{L}_{h_{125}ff} = \frac{m_f}{v}\bar{f}fh_{125}$$

h_{125} couplings



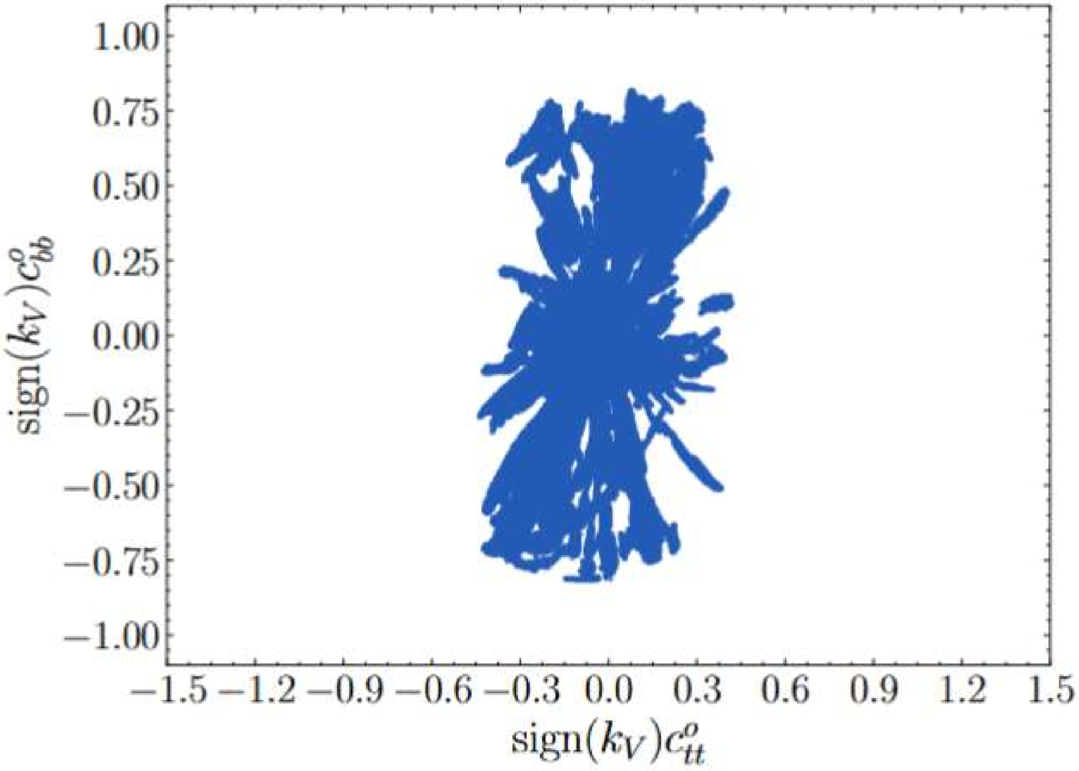
Standard Model

$$-\mathcal{L}_{h_{125}ff} = \frac{m_f}{v}\bar{f}fh_{125}$$

C3HDM

$$-\mathcal{L}_{h_{125}ff} = \frac{m_f}{v}\bar{f}(c^e_{h_{125}ff} + i\gamma_5 c^o_{h_{125}ff})fh_{125}$$

Is h_{125} Scalar (S) or PseudoScalar (PS)?



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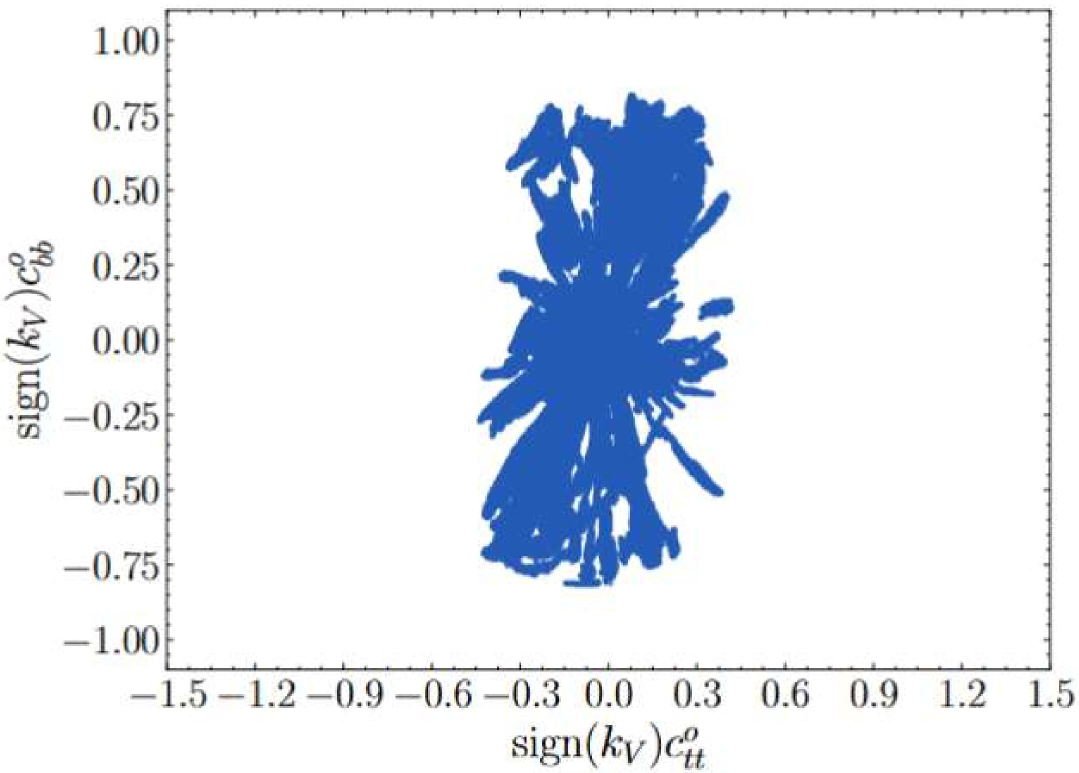


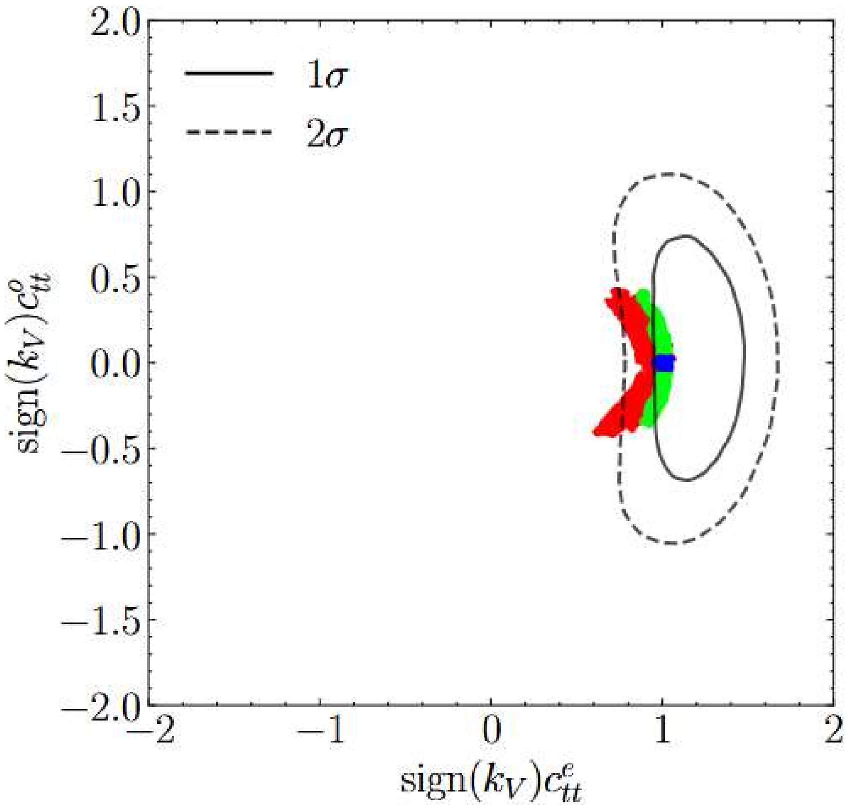
Pure S $h_{125}tt$ & Pure PS $h_{125}bb$

OR

Pure S $h_{125}bb$ & Maximally PS $h_{125}tt$

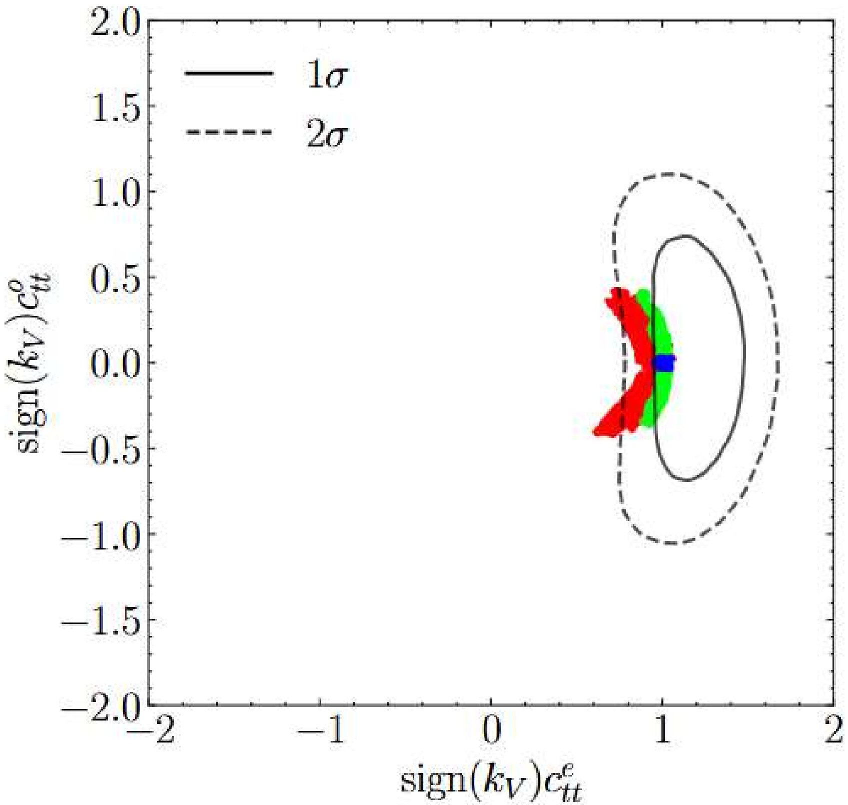
Or (almost) anything in between!

Machine Learning Capabilities



[R. Boto et. al., 2505.10625]

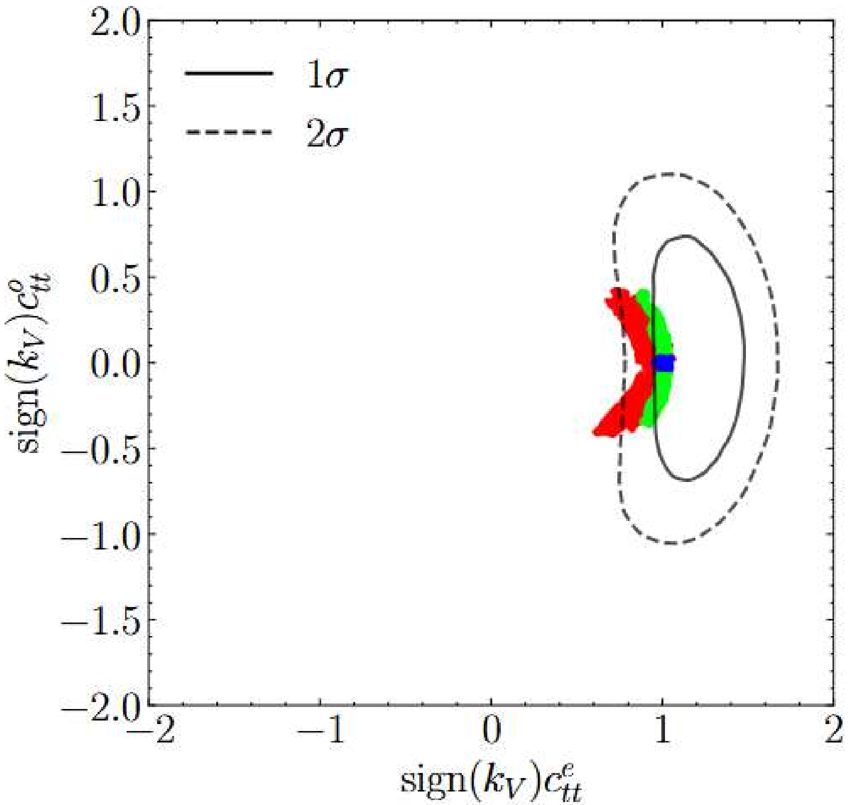
Machine Learning Capabilities



[R. Boto et. al., 2505.10625]

$c^o_{tt} \approx 0$

Machine Learning Capabilities

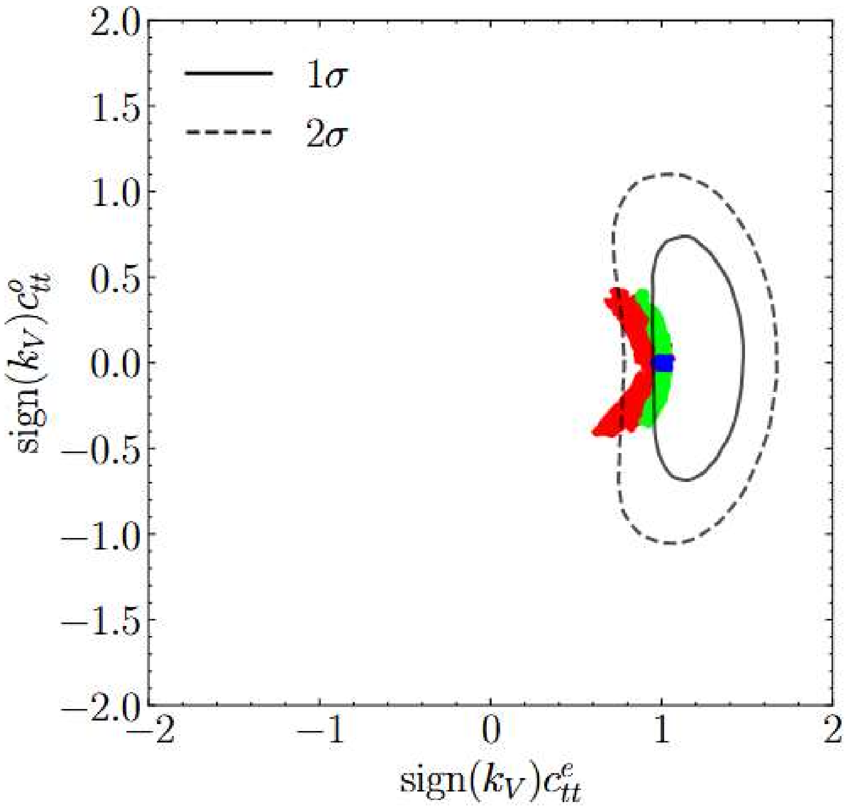


[R. Boto et. al., 2505.10625]

Informed traditional scanning methods → $c^o_{tt} \approx 0$

Machine Learning Techniques → $|c^o_{tt}| \lesssim 0.5$

Machine Learning Capabilities



[R. Boto et. al., 2505.10625]

Informed traditional scanning methods → $c^o_{tt} \approx 0$

In 3 Months

Machine Learning Techniques → $|c^o_{tt}| \lesssim 0.5$

In 3 Days

Monitoring Machine Learning

Type	I	II	X	Y	Z
$h_1 = h_{125}$	t, τ	τ	t	✓	✓
$h_2 = h_{125}$	t, τ	τ	t	✓	✓
$h_3 = h_{125}$	t, τ	τ	t	✓	✓
$h_4 = h_{125}$	t, τ	τ	t	✓	✓
$h_5 = h_{125}$	t, τ	$\underline{\times}$	t	$\underline{\times}$	$\underline{\times}$

Monitoring Machine Learning

Type	I	II	X	Y	Z
$h_1 = h_{125}$	t, τ	τ	t	✓	✓
$h_2 = h_{125}$	t, τ	τ	t	✓	✓
$h_3 = h_{125}$	t, τ	τ	t	✓	✓
$h_4 = h_{125}$	t, τ	τ	t	✓	✓
$h_5 = h_{125}$	t, τ	$\underline{\times}$	t	$\underline{\times}$	$\underline{\times}$

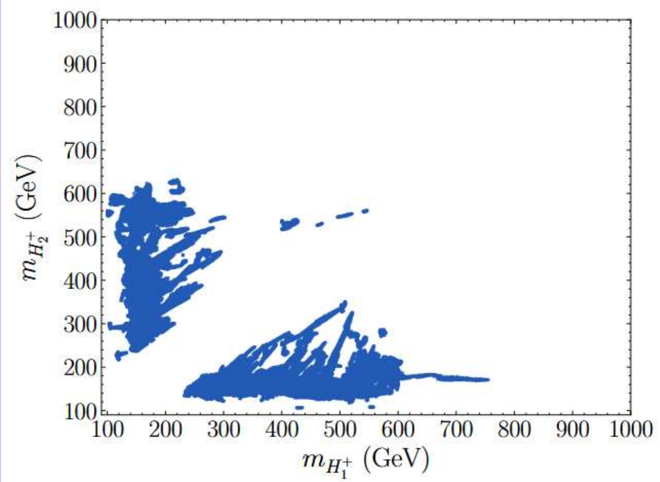
ML $\Gamma(B \to X_s\gamma)$ $vs.$ STU

Monitoring Machine Learning

Type	I	II	X	Y	Z
$h_1 = h_{125}$	t, τ	τ	t	✓	✓
$h_2 = h_{125}$	t, τ	τ	t	✓	✓
$h_3 = h_{125}$	t, τ	τ	t	✓	✓
$h_4 = h_{125}$	t, τ	τ	t	✓	✓
$h_5 = h_{125}$	t, τ	×	t	×	×

ML $\Gamma(B \to X_s\gamma)\ vs.\ STU$

Physics



$\Gamma(B \to X_s\gamma) + STU \Rightarrow m_{h_i} > 125\ GeV$

Ruled out by ordering: $m_{h_i} \leq 125\ GeV$

Conclusions

- Fully explored all 25 models within the C3HDM with Machine Learning Techniques
- Expanded the $|c^{o}_{bb}| > |c^{e}_{bb}|$ for Type Y and Type Z (excluding h_5 ordering)
- There can be 4 undetected scalar particles lighter than the h_{125}
- Monitored ML enabled us to understand h_5 failure in Types II,Y and Z
- Found the interesting possibilities:

Pure S $h_{125}tt$ & Pure PS $h_{125}bb$

Pure S $h_{125}bb$ & Maximally PS $h_{125}tt$

- **Help motivate precise experimental probes into the CP nature of h_{125}**
- **An article with these results has been sent for publication:** [Boto, Matos, Romão, Silva, 2510.02445]