2HDM Benchmarking

A fermiophobic heavy Higgs scenario

I. MOTIVATION & OVERVIEW

We propose a scenario based on the B5 benchmark studied in Ref. [1] in the context of Higgs–pair production. It describes a SM–like 125.03 GeV Higgs boson, along with a moderately heavier $\mathcal{CP}$–even companion H^0, which fully decouples from the fermionic sector. The latter condition can only be fulfilled in a **type–I** 2HDM with $\sin\alpha = 0$. The neutral $\mathcal{CP}$–odd and the charged Higgs scalars, in turn, have larger, almost degenerate masses in the $\mathcal{O}(500)$ GeV ballpark.

The parameter choice, as detailed below, is justified as follows. On the one hand, the measured LHC Higgs signal strengths enforces $\sin(\beta-\alpha) \lesssim 1$, which implies that the fermiophobic limit $\sin\alpha \simeq 0$ is only viable at large $\tan\beta$. The moderate Z_2 soft–breaking mass term m_{12}^2 allows to fulfill the vacuum stability and unitarity bounds, which become increasingly tight for large $\tan\beta$ values.

Compatibility with the available experimental constraints has been duly checked with a private interface of the public tools 2HDMC [2], HiggsBounds [3, 4], SuperIso [5, 6] and HiggsSignals [7, 8] along with complementary in–house routines. Experimental constraints include: i) mass bounds from direct searches; ii) LHC Higgs signal strength measurements; iii) Electroweak precision observables; iv) and flavor constraints from heavy flavor–meson physics. The suggested parameter choice satisfies as well the conditions of vacuum stability, perturbativity and unitarity.

Such a fermiophobic 2HDM setup is particularly challenging from the experimental viewpoint. On the one hand, the relatively low–mass heavy $\mathcal{CP}$–even Higgs, which is by construction completely unlinked from the fermion sector, cannot couple to gluons via the usual heavy–fermion loop exchange. For the same reason, the s–channel H^0 interchange does not contribute to the light di–Higgs production via $gg \to \mathrm{H}^0 \to \mathrm{h}^0\mathrm{h}^0$ [1]. On the other hand, owing to the fact that $\cos(\beta-\alpha) \ll 1$, the H^0 state hardly couples to the gauge bosons, while it interacts very weakly with a light Higgs pair through the trilinear coupling $\mathrm{H}^0\mathrm{h}^0\mathrm{h}^0$. Overall, this benchmark accounts for a quite genuine 2HDM possibility: namely, a relatively low–mass extended scalar, yet very elusive to direct collider searches. Opportunities to identify this class of scenarios would mostly rely on the ability to pin down the presence of heavier scalar fields, either through direct (viz. resonant) or indirect (off–shell or loop–induced) effects. These additional scalars can be produced in pairs or in association with weak gauge bosons via the couplings $\mathrm{ZH^+H^-}, \mathrm{ZA^0H^0}, \mathrm{W^\pm\,H^\mp\,H^0}, \mathrm{W^\pm\,H^\mp\,A^0}$ or through Higgs self–interactions.

A systematic exploration of fermiophobic 2HDM configurations was initiated in [9, 10] and continued with the characterization of its trademark collider signatures [11–13] and its interplay with the additional heavy Higgs phenomenology [14]. On the experimental side, dedicated fermiophobic scalar searches have been conducted using LEP [15], Tevatron [16] and LHC data [17].

Fermiophobic $\mathcal{CP}$–even scalars are also welcome from a model–building perspective. They can for instance appear in non–minimal supersymmetric extensions of the SM [18] or in GUT–based constructions [19]. Alternative proposals entertain as well fermiophobic neutral $\mathcal{CP}$–odd or charged Higgs bosons [20, 21].

II. PARAMETER SETUP

a. *Physical basis inputs* [in the notation and conventions of Ref. [2] and references therein.].

$\tan\beta$	α/π	m_{H^0} [GeV]	m_{A^0} [GeV]	$m_{\mathrm{H}^\pm}$ [GeV]	m_{12}^2 [GeV^2]
20.00	0.0000	200	500	500	2000

b. *Generic basis inputs* [in the notation and conventions of Ref. [2] and references therein.]

$\tan\beta$	m_{12}^2 [GeV^2]	λ_1	λ_2	λ_3	λ_4	λ_5
20.00	2000	0.000	2.568×10^{-1}	7.586×10^{0}	-3.462×10^{0}	-3.462×10^{0}

c. Hybrid basis inputs: [in the notation and conventions of Ref. [22]].

m_{h^0} [GeV]	m_{H^0} [GeV]	$\cos(\beta-\alpha)$	$\tan\beta$	Z_4	Z_5	Z_7
125.03	200	4.994×10^{-2}	20	-3.465×10^{0}	-3.465×10^{0}	3.286×10^{-2}

III. HIGGS BOSON PROPERTIES

d. Higgs boson couplings to fermions All couplings are normalized to the SM.

	g_{htt}	g_{hbb}	$g_{h\tau\tau}$	g_{hVV}	g_{hgg}	$g_{h\gamma\gamma}$
h^0	1.001	1.001	1.001	0.999	1.001	0.9509
H^0	0.000	0.000	0.000	0.005	0.000	-0.344
A^0	0.05	-0.05	-0.05	0.000	-	-

e. Higgs boson self–couplings All couplings are normalized to the SM, $g^{\rm SM}_{\rm HHH} = -3m^2_{\rm H}/v$

$$\begin{array}{llllll} h^0h^0h^0: & 0.9948 & H^0h^0h^0: & 0.0427 & H^0H^0h^0: & 0.8540 \\ H^0H^0H^0: & 0.0000 & h^0A^0A^0: & 9.7930 & H^0A^0A^0: & 0.4471 \end{array} \quad (1)$$

f. Higgs boson widths (obtained with 2HDMC [2] including leading QCD corrections).

	h^0	H^0	A^0	$H^\pm$
Γ [GeV]	4.387×10^{-3}	3.391×10^{-3}	2.057×10^{1}	2.139×10^{1}

[1] B. Hespel, D. López-Val, and E. Vryonidou, JHEP **1409**, 124 (2014), 1407.0281.
[2] D. Eriksson, J. Rathsman, and O. Stål, Comput.Phys.Commun. **181**, 189 (2010), 0902.0851.
[3] P. Bechtle, O. Brein, S. Heinemeyer, G. Weiglein, and K. E. Williams, Comput.Phys.Commun. **181**, 138 (2010), 0811.4169.
[4] P. Bechtle, O. Brein, S. Heinemeyer, G. Weiglein, and K. E. Williams, Comput.Phys.Commun. **182**, 2605 (2011), 1102.1898.
[5] F. Mahmoudi, Comput.Phys.Commun. **178**, 745 (2008), 0710.2067.
[6] F. Mahmoudi, Comput.Phys.Commun. **180**, 1579 (2009), 0808.3144.
[7] P. Bechtle, S. Heinemeyer, O. Stål, T. Stefaniak, and G. Weiglein, Eur.Phys.J. **C74**, 2711 (2014), 1305.1933.
[8] O. Stål and T. Stefaniak, PoS **EPS-HEP2013**, 314 (2013), 1310.4039.
[9] L. Brucher and R. Santos, Eur.Phys.J. **C12**, 87 (2000), hep-ph/9907434.
[10] A. Barroso, L. Brucher, and R. Santos, Phys.Rev. **D60**, 035005 (1999), hep-ph/9901293.
[11] A. G. Akeroyd and M. A. Diaz, Phys.Rev. **D67**, 095007 (2003), hep-ph/0301203.
[12] A. Akeroyd, M. A. Diaz, and F. J. Pacheco, Phys.Rev. **D70**, 075002 (2004), hep-ph/0312231.
[13] J. Kumar, A. Rajaraman, and D. Yaylali, Phys.Rev. **D86**, 115019 (2012), 1209.5432.
[14] A. Akeroyd, M. A. Diaz, and M. A. Rivera, Phys.Rev. **D76**, 115012 (2007), 0708.1939.
[15] DELPHI, J. Abdallah *et al.*, Eur.Phys.J. **C35**, 313 (2004), hep-ex/0406012.
[16] CDF, T. Aaltonen *et al.*, Phys.Rev.Lett. **108**, 011801 (2012), 1109.4427.
[17] ATLAS, G. Aad *et al.*, Eur.Phys.J. **C72**, 2157 (2012), 1205.0701.
[18] E. Gabrielli, K. Kannike, B. Mele, A. Racioppi, and M. Raidal, Phys.Rev. **D86**, 055014 (2012), 1204.0080.
[19] J. Hetzel and B. Stech, Phys.Rev. **D91**, 055026 (2015), 1502.00919.
[20] V. Ilisie and A. Pich, JHEP **1409**, 089 (2014), 1405.6639.
[21] R. Enberg, J. Rathsman, and G. Wouda, (2013), 1311.4367.
[22] H. E. Haber and O. Stål, to appear; see also slide presentations, e.g. https://indico.cern.ch/event/373558/ .