Snowmass 2021, Letters of Interest

2HDM under the Higgs and Electroweak Precision Measurements

Ning Chen[a], Tao Han[b], Shuailong Li (**contact person**)[c], Shufang Su[c], Wei Su[d], and Yongcheng Wu[e]

[a]School of Physics, Nankai University, Tianjin 300071, China
[b]Department of Physics and Astronomy, University of Pittsburgh, Pittsburgh, PA 15260, USA
[c]Department of Physics, University of Arizona, Tucson, Arizona 85721, USA
[d]ARC Centre of Excellence for Particle Physics at the Terascale, Department of Physics,University of Adelaide, South Australia 5005, Australia
[e]Ottawa-Carleton Institute for Physics, Carleton University, 1125 Colonel By Drive, Ottawa, Ontario K1S 5B6, Canada

August 29, 2020

Thematic Areas:

■ (EF02) EW Physics: Higgs Boson as a portal to new physics
■ (EF01) EW Physics: Higgs Boson properties and couplings
■ (EF04) EW Precision Physics and constraining new physics
■ (EF08) BSM: Model specific explorations
■ (TF07) Collider phenomenology

The discovery of the SM-like Higgs boson is a milestone for the particle physics. All the indications from the experimental measurements seem to confirm the validity of the Standard Model (SM). However, there are compelling arguments in favor of new physics beyond the SM (BSM). Thus, searching for signal beyond SM will be of high priority either directly or indirectly. There have been many Higgs factory proposals, including the CEPC in China [1, 2], the FCC-ee at CERN [3–6] and the ILC in Japan [7–10], which can reach sub-percentage precision determination of the Higgs properties, and thus is sensitive to BSM associated with the Higgs boson. In addition, these machines will have corresponding Z-pole programs, providing improved measurements of SM electroweak precision observables. Such unprecedented precisions would lead to hints of new physics associated with the EW sector, and is thus worth of intensive studies on BSM models.

*email address: chenning_symmetry@nankai.edu.cn (Ning Chen), than@pitt.edu (Tao Han), shuailongli@email.arizona.edu (Shuailong Li), shufang@email.arizona.edu (Shufang Su), wei.su@adelaide.edu.au (Wei Su), ycwu@physics.carleton.ca (Yongcheng Wu).

We study the impacts of the precision measurement using two Higgs doublet models (2HDMs) [11] as benchmark models [12–15]. To illustrate the extent to which the parameter space can be probed, a multi-variable global fit is performed. The loop effects for the Higgs couplings, which can be probed with such high precision, are included in the analysis. The loop correction highly depends on the masses of the heavy particles running in the loop. Such indirect constraints from precision measurements can cover parameter space that cannot be probed by direct searches. The indirect Higgs studies up to one-loop level also shift the wrong-sign Yukawa regime relative to the tree level region. For mass-degenerate case, upper limit on $|\cos(\beta-\alpha)|$, which indicates the deviation from the alignment limit, can be set as a function of $\tan\beta$. We also extend the study to non-degenerate Higgs masses case. The mass difference between the non-SM Higgses are constrained by the Higgs precision measurements, similar to the constraints from Z-pole measurements estimated through oblique-parameters.

Further, with high precisions achieved with the proposed Higgs factories, it is possible to distinguish models with different Higgs Yukawa coupling structure [16]. The different types of the 2HDMs are good benchmarks for such studies. Such analysis contains mainly two parts. First, the discovery potential of different types is established, and the differences in the correlations of various Higgs coupling are characterized. Then, assuming a particular type of 2HDM as a underlying model, we demonstrate the extend to which that other types can be distinguishable. With the illustration of certain benchmark points, it is found that, although the loop corrections weaken the correlations among couplings in each types of model, large part of the parameter space of different types of 2HDMs can be distinguished from the benchmark point in the underlying model.

These analyses demonstrate the great physics potential for the future Higgs precision measurements at the Higgs factories. It could either put strong constraints on the BSM model parameter space if no deviation from the SM predictions is detected, or could help to discover the BSM Higgs sector and to discriminate among different incarnations of the 2HDMs, if a deviation is observed. Although our study mainly focuses on 2HDM, this endeavor should be continued in extending to other Higgs extension models such as Composite Higgs Model. More importantly, with new proposals for future colliders, such as a high-energy muon collider, we would like to consider the potential improvements for exploring their physics in the new environment. It will be of great interests to pursue along this direction and to be prepared for hint that future colliders may provide us.

References

[1] CEPC-SPPC Study Group, "CEPC-SPPC Preliminary Conceptual Design Report. 1. Physics and Detector." `http://cepc.ihep.ac.cn/preCDR/volume.html`, 2015.

[2] **CEPC Study Group** Collaboration, *CEPC Conceptual Design Report: Volume 2 - Physics & Detector*, `arXiv:1811.10545`.

[3] **FCC** Collaboration, A. Abada et al., *FCC Physics Opportunities*, *Eur. Phys. J.* **C79** (2019), no. 6 474.

[4] **FCC** Collaboration, A. Abada et al., *FCC-ee: The Lepton Collider*, *Eur. Phys. J. ST* **228** (2019), no. 2 261–623.

[5] **TLEP Design Study Working Group** Collaboration, M. Bicer et al., *First Look at the Physics Case of TLEP*, *JHEP* **01** (2014) 164, [arXiv:1308.6176].

[6] N. Alipour Tehrani et al., *FCC-ee: Your Questions Answered*, in *CERN Council Open Symposium on the Update of European Strategy for Particle Physics* (A. Blondel and P. Janot, eds.), 6, 2019. arXiv:1906.02693.

[7] H. Baer, T. Barklow, K. Fujii, Y. Gao, A. Hoang, S. Kanemura, J. List, H. E. Logan, A. Nomerotski, M. Perelstein, et al., *The International Linear Collider Technical Design Report - Volume 2: Physics*, arXiv:1306.6352.

[8] P. Bambade et al., *The International Linear Collider: A Global Project*, arXiv:1903.01629.

[9] **LCC Physics Working Group** Collaboration, K. Fujii et al., *Tests of the Standard Model at the International Linear Collider*, arXiv:1908.11299.

[10] K. Fujii et al., *ILC Study Questions for Snowmass 2021*, arXiv:2007.03650.

[11] G. C. Branco, P. M. Ferreira, L. Lavoura, M. N. Rebelo, M. Sher, and J. P. Silva, *Theory and phenomenology of two-Higgs-doublet models*, *Phys. Rept.* **516** (2012) 1–102, [arXiv:1106.0034].

[12] J. Gu, H. Li, Z. Liu, S. Su, and W. Su, *Learning from Higgs Physics at Future Higgs Factories*, *JHEP* **12** (2017) 153, [arXiv:1709.06103].

[13] N. Chen, T. Han, S. Su, W. Su, and Y. Wu, *Type-II 2HDM under the Precision Measurements at the Z-pole and a Higgs Factory*, *JHEP* **03** (2019) 023, [arXiv:1808.02037].

[14] N. Chen, T. Han, S. Li, S. Su, W. Su, and Y. Wu, *Type-I 2HDM under the Higgs and Electroweak Precision Measurements*, arXiv:1912.01431.

[15] W. Su, *Probing loop effects in wrong-sign Yukawa region of 2HDM*, arXiv:1910.06269.

[16] T. Han, S. Li, S. Su, W. Su, and Y. Wu, *Comparative Studies of 2HDMs under the Higgs Boson Precision Measurements*, arXiv:2008.05492.