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New physics implication of Higgs precision measurements

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Studying the properties of the Higgs boson can be an important window to explore the physics beyond the Standard Model (SM). In this work, we present studies on the implications of the Higgs precision measurements at future Higgs Factories. We perform a global fit to various Higgs search channels to obtain the 95 % C.L. constraints on the model parameter spaces of Two Higgs Double Model (2HDM) and Minimal Supersymmetric Standard Model (MSSM). In the 2HDM, we analyze tree level effects as well as one-loop contributions from the heavy Higgs bosons. The strong constraints on $\cos(\beta-\alpha)$, heavy Higgs masses and their mass splitting are complementary to direct search of the LHC as well as possible future Z pole precision measurements. For the MSSM, we study both the Higgs couplings and mass precisions. The constraints on the CP-odd Higgs mass m_A and stop mass scale m_{SUSY} can be complementary to the direct search of HL-LHC. We also compare the sensitivity of various future Higgs factories, namely Circular Electron Positron Collider (CEPC), Future Circular Collider (FCC)-ee and International Linear Collider (ILC).

Keywords: Higgs Factories; 2HDM; MSSM

1. Introduction

While all the indications from the current particle physics measurements seem to confirm the validity of the Standard Model (SM) up to the electroweak scale of a few hundreds GeV, and the observed Higgs boson is SM-like, there are compelling arguments, both from theoretical and observational points of view, in favor of the existence of new physics beyond the SM (BSM). As such, searching for new Higgs bosons would be of high priority since they are present in many extensions of theories beyond the SM. One of the most straightforward, but well-motivated extensions is the two Higgs doublet model (2HDM),[1] as well as Minimal Supersymmetric Standard Model (MSSM). There are five massive spin-zero states in the spectrum $(h, H^0, A^0, H^\pm)$ after the electroweak symmetry breaking.

Complementary to the direct searches, precision measurements of SM parameters and the Higgs properties could lead to relevant insights on new physics. High precision achieved at future Higgs factories with about 10^6 Higgs bosons, and possible Z pole measurements with $10^{10}-10^{12}$ Z bosons[3–6] would hopefully shed light

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on the new physics associated with the electroweak sector. To take advantage of these precisions,[7,8] we make a global fit to explore their abilities of detecting new particles and constraining model parameter space.

2. Study methods and Global fit results

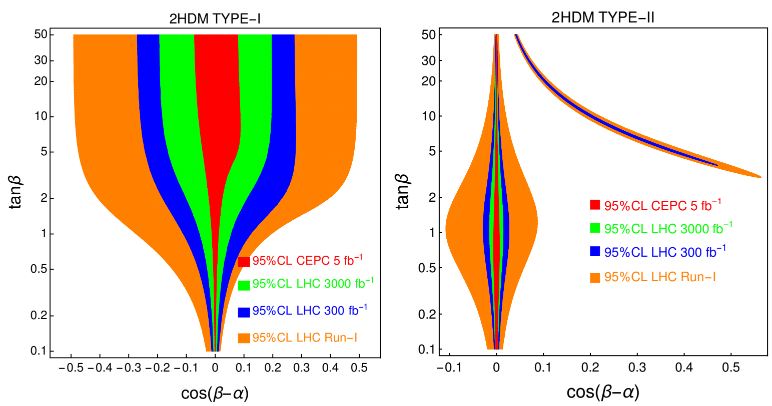

Fig. 1. The allowed region in the plane of $\cos(\beta-\alpha)$-$\tan\beta$ at 95% C.L. for the Type-I and Type-II of 2HDM, given LHC and CEPC Higgs precision measurements. The other two types are similar to Type-II. The special "arm" regions for the Type-II is the wrong-sign Yukawa region. More details are shown in Ref.[7]

There is a plethora of articles in the literature to study the effects of the heavy Higgs states on the Higgs couplings in Models with extended Higgs sector.[1,7,8] In 2HDM, identifying the light CP-even Higgs h to be the experimentally observed 125 GeV Higgs, the couplings of h to the SM fermions and gauge bosons receive two contributions: tree-level values, which are controlled by the mixing angles α of the CP-even Higgses and $\tan\beta$, ratios of the vacuum expectation values of two Higgses: $\tan\beta = v_2/v_1$, and loop contributions with heavy Higgses running in the loop.

With a global fit to the Higgs rate measurements at the LHC as well as the CEPC, assuming that no deviation to the SM values is observed at future measurements, the 95% C.L. region in the $\cos(\beta-\alpha)$ vs. $\tan\beta$ plane for various types of 2HDM (depending on how the two Higgs doublets are coupled to the quark and lepton sectors) are shown in Fig. 1 for tree-level only effects. $\cos(\beta-\alpha)$ in all four types are tightly constrained at both small and large values of $\tan\beta$, except for Type-I, in which constraints are relaxed at large $\tan\beta$ due to suppressed Yukawa couplings.

To fully explore the Higgs factory potential in search for new physics beyond the SM, both the tree-level deviation and loop corrections need to be considered. Fig. 2 shows the 95% C.L. global fit results to all CEPC Higgs rate measurements in the Type-II 2HDM parameter space, including both tree level and loop corrections.

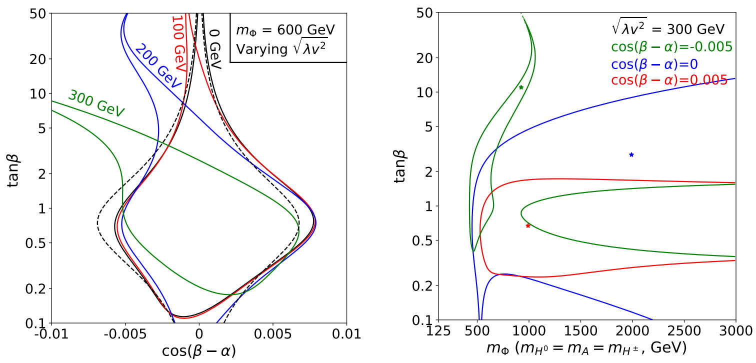

Fig. 2. Three-parameter fitting results at 95% C.L. with CEPC precision for Type-II 2HDM. The left panel shows the parameter space $\cos(\beta-\alpha)$ vs. $\tan\beta$, varying the value $\sqrt{\lambda v^2}$ with $m_A = m_H = m_{H\pm} = m_\Phi = 600$ GeV. The tree-level only global fit results are shown by the dashed black lines for comparison. The right panel shows the m_Φ vs. $\tan\beta$ plane, varying the value of $\cos(\beta-\alpha)$ with $\sqrt{\lambda v^2} = 300$ GeV. The colored stars show the corresponding best fit point. More details are shown in Ref.[8]

Degenerate Heavy Higgs masses $m_A = m_H = m_{H^\pm} = m_\Phi$ are assumed such that Z-pole precision measurements are automatically satisfied. The left panel shows $\cos(\beta-\alpha)$ - $\tan\beta$ parameter space with regions enclosed by curves are allowed if no deviation from the SM prediction is observed. Black, red, blue and green curves are for model parameter $\sqrt{\lambda v^2} = \sqrt{m_\Phi^2 - m_{12}^2/s_\beta c_\beta} = 0$, 100, 200, and 300 GeV, respectively. The tree-level only global fit results are shown by the dashed black lines for comparison. $|\cos(\beta-\alpha)|$ is typically constrained to be less than about 0.008 for $\tan\beta \sim 1$. For smaller and larger values of $\tan\beta$, the allowed range of $\cos(\beta-\alpha)$ is greatly reduced. Loop effects from heavy Higgses tilt the value of $\cos(\beta-\alpha)$ towards negative, especially in the large $\tan\beta$ region.

The right panel of Fig. 2 shows the 95% C.L. allowed region in m_Φ - $\tan\beta$ plane, with $\cos(\beta-\alpha) = -0.005$ (green), 0 (blue) and 0.005 (red). In the alignment limit of $\cos(\beta-\alpha) = 0$, the heavy Higgs mass $m_\Phi > 500$ GeV are still allowed for $\tan\beta \lesssim 10$. Once deviating away from the alignment limit, the constraints on the heavy Higgs mass get tighter. Comparing to the direct searches of the heavy Higgs bosons at hadron colliders,[9] The reach in the heavy Higgs mass and couplings at future Higgs factories can be complementary to the direct search limits at the LHC, especially for intermediate values of $\tan\beta$.

Going beyond the degenerate mass case, both the Higgs and Z-pole precision variables are sensitive to the mass splittings between the charged Higgs and the neutral ones. Fig. 3 shows the 95% C.L. range of $\Delta m_A = m_A - m_H$ vs. $\Delta m_C = m_{H^\pm} - m_H$ plane, for Higgs and Z-pole precision constraints individually in (left panel), and combined constraints (right panel), with $m_H = 600$ GeV and $\sqrt{\lambda v^2} = 300$ GeV. For the Higgs precision fit, the alignment limit (blue curve) leads to

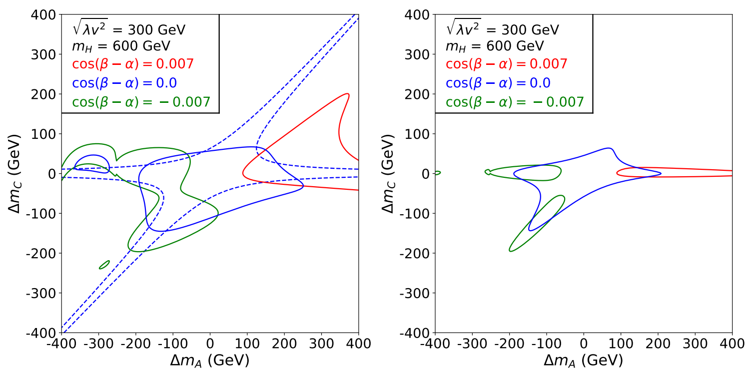

Fig. 3. Three-parameter fitting 95% C.L. range of Δm_A - Δm_C plane, focusing on the $\cos(\beta-\alpha)$ dependence (given by different colored lines), for Higgs and Z-pole precision constraints individually (left panel), and combined constraints (right panel) in the Type-II 2HDM. More details are shown in Ref.[8]

both Δm_A and Δm_C around 0 within a few hundred GeV range. Even for small deviation away from the alignment limit, Δm_A is constrained to be positive for $\cos(\beta-\alpha) = 0.007$, and negative for $\cos(\beta-\alpha) = -0.007$. The Z pole precision measurements (shown in region enclosed by blue dashed curves) constrain either $\Delta m_C \sim 0$ or $\Delta m_C \sim \Delta m_A$, equivalent to $m_{H^\pm} \sim m_{H,A}$. Combining both the Higgs and Z pole precisions (right panel), the range of $\Delta m_{A,C}$ are further constrained to a narrower range. The expected accuracies at the Z-pole and at a Higgs factory are quite complementary in constraining heavy Higgs mass splittings.

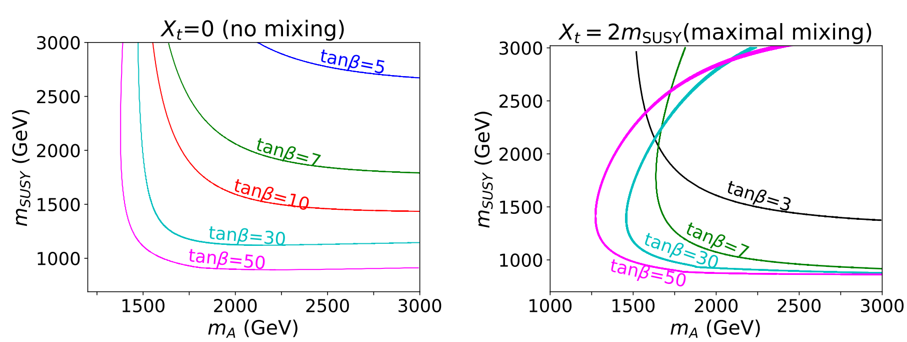

Fig. 4. The three dimension global fitting with varying m_A, m_{SUSY} and $\tan\beta$ for setting $X_t = 0$ (the left one) and $X_t = 2m_{SUSY}$ (the right one) separately. μ is set to be 500 GeV.

As a specific model of Type-II 2HDM, MSSM can also be strongly constrained by future Higgs precisions. As in Fig. 4, we show the global fit result in plane $m_A - m_{SUSY}$. Here we choose serval $\tan\beta$ values to show results, 50, 30,10,7,5,3 for the magenta, cyan, red, green, blue and black respectively. The left(right) is for no(maximal) left-right stop mixing sector, and we can see $\tan\beta$ less than 5(3) is totally excluded by CEPC Higgs precisions. Generally we can have $m_A \geq 1.2$ TeV, $m_{SUSY} \geq 800$ GeV, which can be complementary to future HL-LHC.

3. Conclusion

In this paper, we presented the results for the impactsof the precision measurements of the SM parameters at the proposed Z-factories and Higgs factories on the extended Higgs sector, including 2HDM and MSSM. For the tree-level 2HDM, $|\cos(\beta-\alpha)|$ can be restricted 0.008. When including the loop effects, CEPC precision can give lower bound on non-SM Higgs masses, as well as their splitting. Combining the Higgs and Z-pole precisions, the typical heavy Higgs mass splitting is constrained to be less than about 200 GeV. For the MSSM, the constraint on mA is 1.2 TeV, which is complementary to that from the direct searches at future hadron colliders.

Acknowledgments

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