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The SM-like Higgs Boson Mass in the CP-Violating High-Scale Next-to Minimal Supersymmetric Standard Model

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Abstract. In this report, we present a reliable prediction of the SM-like Higgs boson mass within the CP-violating next-to-minimal supersymmetric extension of the SM (NMSSM). We use an effective field theory framework together with two possible matching approaches: the matching of the quartic Higgs coupling and the matching of the pole mass of the Higgs boson. We compare results obtained by both methods and compare our results with the literature. We discuss the CP-violating effects arising from complex phases. Furthermore, we discuss different sources of the theoretical uncertainties entering our calculation.

1 Introduction

The content of this report is based on our presentation at the PIAS Workshop 2024: Physics at Different Scales. Supersymmetric (SUSY) theories, which incorporate the symmetry between bosons and fermions with the space-time symmetry, are still valid extensions of the SM — even after the discovery of the Higgs boson with a mass of 125 GeV at the Large Hadron Collider (LHC) in 2012 by the ATLAS [1] and CMS collaboration [2]. However, null results of supersymmetric particle searches at the LHC have pushed some of their masses to the TeV range. The two simplest supersymmetric models, the MSSM and the NMSSM, have been well studied in the literature and searched for in experiments. In these models the SM-like Higgs boson mass is bounded from above due to the Higgs quartic couplings being completely determined by gauge and Yukawa couplings. Furthermore, this mass can receive large quantum corrections: about 40% at one loop and 20% at two loops [3]. In particular, the most significant corrections arise from the top/stop sector, where their interaction with the Higgs boson is proportional to the large top Yukawa couplings. Therefore, a precise study of the SM-like Higgs boson is mandatory to scrutinize the Higgs properties in these models and to use experimental data to set constraints on the parameter space.

There have been a lot of efforts in the precise calculation of the Higgs boson masses in the NMSSM using fixed-order (FO) calculations, see e.g. [4] for a recent review. Our group has made significant contributions to this progress. The full one-loop corrections were presented in [5, 6]. We have used a mixed $\overline{\text{DR}}$-OS renormalization scheme together with full momentum dependence. We further provided the two-loop QCD corrections of $\mathcal{O}(\alpha_t\alpha_s)$ in [3], the two-loop EW corrections of $\mathcal{O}(\alpha_t^2)$ in [7], and of $\mathcal{O}((\alpha_t+\alpha_\lambda+\alpha_\kappa)^2)$ in [8]. Our results apply to both the CP-conserving and the CP-violating NMSSM. We have computed the two-loop contributions in the gaugeless limit. To simplify the calculation we applied the zero external momentum approximation. Regarding the renormalization of the top/stop sector, we applied both $\overline{\text{DR}}$ and OS conditions. Our one- and two-loop results of $\mathcal{O}(\alpha\alpha_s \to \alpha_t\alpha_s + (\alpha_t + \alpha_\lambda + \alpha_\kappa)^2)$ have been implemented in theprogram package `NMSSMCALC` [9]. It provides, besides the precise predictions of the NMSSM Higgs masses, the Higgs boson decay widths and branching ratios including the most relevant higher-order corrections. Furthermore, the code computes the trilinear Higgs self-couplings [10–12] at the full one-loop level and at the two-loop level of $\mathcal{O}(\alpha\alpha_s \to \alpha_t\alpha_s + (\alpha_t)^2)$. The loop-corrected W boson mass [13] at similar order can be also obtained, both for the CP-conserving and CP-violating cases.

In the fixed-order calculation, the loop corrections to the SM-like Higgs boson contain logarithmic terms such as $\ln \tilde{M}_x^2/M_x^2$ [14], where M_x and $\tilde{M}_x$ are the masses of a SM particle and its superparticle, respectively. In the case $\tilde{M}_x \gtrsim 1\,\text{TeV}$, the logarithmic terms can become large. This makes the FO results suffer from a large theory uncertainty due to missing, possible significant, higher-order (HO) corrections. To reduce the uncertainty and make the prediction reliable, these large logarithmic terms need to be resummed. The effective field theory (EFT) framework, where we assume the SM is a suitable EFT, can then be exploited to resum these terms using the SM renormalization group equation (RGE). At the matching scale, two possible matching conditions then can be applied: either the loop-corrected SM quartic Higgs coupling (QHC) at the matching scale can be identified with the corresponding loop-corrected NMSSM quartic Higgs coupling; or the pole mass of the SM-like Higgs boson in the NMSSM is matched to the SM Higgs pole mass. A discussion of EFT techniques in generic SUSY models, including the NMSSM, has been presented in [15] using the pole-mass matching condition, which was then implemented in `FlexibleEFTHiggs` and later in `SARAH/SPheno` [16]. In Ref. [17], the authors, however, have used the quartic-coupling matching condition at the full one-loop and the two-loop QCD level. In this work, we implement both matching conditions discussed in Refs. [15] and [17] in our computer code `NMSSMCALC` to allow for a consistent comparison of the two methods. We then evaluate the influence of the two matching approaches onthe Higgs mass prediction in a broad region of the parameter space where SUSY particle masses range from sub-TeV to hundreds of TeV. The EFT results are compared with the FO results, which are computed by `NMSSMCALC`. Furthermore, we discuss the effect of the CP-violating phases entering the SM-like Higgs mass prediction in the EFT approach. We identify several sources of theoretical uncertainties in our Higgs mass prediction, thereby distinguishing between SM and NMSSM uncertainties. Finally, a reliable estimate of the total uncertainty is provided.

2 Calculation framework

We consider the complex NMSSM, which contains two Higgs doublet superfields and one complex Higgs singlet superfield. We further impose a Z_3 symmetry to eliminate the linear and bilinear term in the superpotential. The remaining part of the superpotential is as in the MSSM. For further details on the particle content and the mass spectra, we refer to e.g. Refs. [7, 18]. In this report, we consider all the soft-SUSY-breaking mass parameters of the sfermions and gauginos, $m^2_{\tilde{Q}}$, $m^2_{\tilde{L}}$, $m^2_{\tilde{u}_R}$, $m^2_{\tilde{d}_R}$, $m^2_{\tilde{e}_R}$, and M_1, M_2, M_3, together with the tree-level masses of the singlet-like Higgs bosons m_{H_s}, m_{A_s} and the charged Higgs mass $m_{H^\pm}$ to be of the order of M_{SUSY}, where $M_{\text{SUSY}} \gg v$ with v being the SM vacuum expectation value. This is equivalent to $M_{\text{SUSY}} \gg m_{\text{SM}}$ with m_{SM} representing a mass of the heavy SM particles.

We want to extract an effective quartic Higgs self-coupling by matching quantities of the NMSSM to the corresponding ones of the SM. There are two possible matching condition schemes that relate the quartic Higgs coupling λ_h in the two theories.

- Quartic-coupling matching (QCM) scheme: the Higgs four-point vertex in the SM is required to be identical to the one of the SM-like Higgs boson in the NMSSM at the matching scale Q_{match},

$$\lambda_h^{\text{NMSSM},\overline{\text{MS}}}(Q_{\text{match}}) = \lambda_h^{\text{SM},\overline{\text{MS}}}(Q_{\text{match}}). \tag{1}$$

The coupling $\lambda_h^{\text{NMSSM},\overline{\text{MS}}}(Q_{\text{match}})$ can be written as the sum of the tree-level, one-loop, and MSSM two-loop parts,

$$\lambda_h^{\text{NMSSM},\overline{\text{MS}}}(Q_{\text{match}}) = \lambda_h^{\text{NMSSM,tree}} + \Delta\lambda_h^{\text{NMSSM,1l}} + \Delta\lambda_h^{\text{MSSM,2l}}\,. \tag{2}$$

SM contributions arising from SM fermions and gauge bosons are identical in both the NMSSM and the SM (assuming a proper tree-level matching was performed before, see discussion below).

Therefore, the SM contributions are canceled out in Eq. (1). We are left with the new physics contributions to λ_h^{NMSSM}. We simplify the identification of the new physics contribution by performing the calculation of the quartic Higgs coupling within the NMSSM in the limit $v \to 0$ but keep the singlet VEV non-zero. Then all SM particles, such as SM-like Higgs boson, gauge bosons, and SM fermions, become massless and do not contribute to the four-point vertex of the SM-like Higgs, while BSM particles are massive and contribute. We have performed two independent calculations for $\Delta\lambda_h^{\text{NMSSM,1l}}$, and checked that they are in full agreement. The two-loop QCD and mixed QCD-EW corrections as well as the $\mathcal{O}(\alpha_t^2)$ corrections in the limit of the CP-conserving MSSM contribution, $\Delta\lambda_h^{\text{MSSM,2l}}$, are taken from the literature [19, 20].

- Pole-mass matching (PMM) scheme: the pole mass of the Higgs boson in the SM is required to be equal to the one of the SM-like Higgs boson in the NMSSM at Q_{match},

$$(m_h^{\text{SM}})^2 - \text{Re}\hat{\Sigma}_h^{\text{SM}}\big((m_h^{\text{SM}})^2\big) \overset{!}{=} (m_h^{\text{NMSSM}})^2 - \text{Re}\hat{\Sigma}_h^{\text{NMSSM}}\big((m_h^{\text{NMSSM}})^2\big)\,, \tag{3}$$

where m_h denotes the tree-level mass and $\text{Re}\hat{\Sigma}_h$ refers to the real part of the renormalized self-energy of the $h \to h$ transition. In the NMSSM, we denote h to be the SM-like Higgs boson, and we ignore the contributions from all remaining renormalized self-energies of any $h \to h_i$ transitions with h_i being other Higgs bosons as they are of a higher order than considered in this report. Note that $\text{Re}\hat{\Sigma}_h^{\text{NMSSM}}\big((m_h^{\text{NMSSM}})^2\big)$ is taken from our previous one-loop fixed-order computation. From this matching relation, we evaluate the SM $\overline{\text{MS}}$ Higgs mass at the matching scale. The quartic coupling in the $\overline{\text{MS}}$ scheme is then computed from the tree-level relation

$$(m_h^{\text{SM}})^2 = 2(v^{\text{SM}})^2\,\lambda_h^{\text{SM,II}}\,. \tag{4}$$

To ensure that all large logarithms of $\ln\big(v^2/M_{\text{SUSY}}^2\big)$ on both sides on Eq. (3) are canceled, we apply a proper expansion around the tree-level solution. Thus, $\lambda_h^{\text{SM,II}}$ is free of these logarithms. Note, however, that we can not set $v{\equiv}0$ in the pole-mass matching scheme, since the VEV appears explictly in Eq. (4). In fact, we need to perform a double expansion in the loop order and in v^2/M_{SUSY}^2. Solving Eq. (3) and Eq. (4) for the Higgs quartic coupling, we obtain a similar expression as in the QCM:

$$\lambda_h^{\text{NMSSM},\overline{\text{MS}},\text{II}} = \lambda_h^{\text{NMSSM,tree,II}} + \Delta\lambda_h^{\text{NMSSM,1l,II}} + \Delta\lambda_h^{\text{MSSM,2l}}\,. \tag{5}$$

Apart from the Higgs quartic couplings, which are matched using the above-described matching conditions, there are three gauge couplings g_1, g_2, g_3, the top Yukawa coupling, and the VEV appearing in both the NMSSM and the SM, that need to be matched. First we match the top Yukawa coupling by using a tree-level relation,

$$Y_t^{\text{NMSSM},\overline{\text{DR}}} = Y_t^{\text{SM},\overline{\text{MS}}}/\sin\beta\,, \tag{6}$$

which is sufficient for a consistent computation of the effective QHC at the level considered in this report. For g_1, g_2, and g_3, we use the $\overline{\text{MS}} \to \overline{\text{DR}}$ one-loop conversion formulae,

$$g_i^{\text{NMSSM},\overline{\text{DR}}} = g_i^{\text{SM},\overline{\text{MS}}} + \delta g_i^{\text{reg}} + \delta g_i^{\text{thr}}\,, \tag{7}$$

where δg_i^{reg} are the $\overline{\text{MS}}$–$\overline{\text{DR}}$ shifts resulting from changing the regularization scheme when going from the SM to the NMSSM [21], and the δg_i^{thr} are the threshold corrections [22]. The matching of the VEV is only required in the pole-mass matching, but not in the QCM. The SM and the NMSSM VEV are related by

$$(v^{\text{SM}})^2 = (v^{\text{NMSSM}})^2 + \delta v^2 = (v^{\text{NMSSM}})^2\left(1 + \frac{\delta v^2}{v^2}\right)\,, \tag{8}$$

where δv is the threshold correction to the VEV. One can compute it from matching *e.g.* the Z-boson pole mass at the one-loop level. Alternatively, it also can be computed from the wave-function renormalization of the Higgs boson [23] due to Ward identities relating the two,

$$\frac{\delta v^2}{v^2} = \Big[\hat{\Sigma}_h^{\text{NMSSM}\prime}(0) - \hat{\Sigma}_h^{\text{SM}\prime}(0)\Big] + \mathcal{O}(v^2/M_{\text{SUSY}}^2)\,. \tag{9}$$

Here we denote $\hat{\Sigma}_h^{X\prime}$ as the first derivative of the renormalized self-energy with respect to the four-momentum squared.

We have implemented these conditions in the computation of the effective SM-like Higgs boson mass in our Fortran package `NMSSMCALC`, which is available at the following webpage:

https://www.itp.kit.edu/~maggie/NMSSMCALC/ .

For a detailed description of the incorporation of the effective quartic Higgs coupling into the Higgs mass prediction we refer to Ref. [24].

3 The SM-like Higgs boson mass prediction and comparisons between tools

Our procedure for the computation of the SM-like Higgs boson using the QCM condition is quite similar to the one employed in [17]. There are, however, differences in the treatment of the tadpoles. As already mentioned before, the BSM contributions to the QHC can be done in the "unbroken" phase. This means that the SM VEV can be set to zero while the singlet VEV is being kept non-zero. More specifically, we first keep v_u, v_d non-zero and use tadpole equations of t_{h_u}, t_{h_d}, t_{h_s} and t_{a_d}, t_{a_s} to eliminate the soft-SUSY breaking squared masses $m^2_{H_u}$, $m^2_{H_d}$, m^2_S, and the imaginary parts of the parameters A_λ, A_κ. Only after performing these replacements we take the limit $v \to 0$. As a result the counterterm of $\text{Im}(A_\lambda)$, which enters the renormalized quartic Higgs coupling, is calculated from the a_d-tadpole counterterm as

$$\delta^{(1)}\text{Im}(A_\lambda) = \frac{\sqrt{2}}{|\lambda| v_s \cos(\varphi_w - \varphi_y)\sin\beta}\frac{\delta^{(1)}t_{a_d}}{v}\,. \tag{10}$$

The one-loop tadpole $\delta^{(1)}t_{a_d}$ contains a term being proportional to v. Thus, $\frac{\delta^{(1)}t_{a_d}}{v}$ gives a finite contribution in the limit $v \to 0$. This procedure is different from [17] where tadpole equations for the doublets are not used at all. Moreover, no such contribution arises in the CP-conserving case, where $\text{Im}(A_\lambda) = 0$. Thus, one can expect that our final result is identical to the one obtained in [17] in the CP-conserving case. We have performed a comparison by running our code with the parameter point introduced in [17] which we denote by `BP1`. In the left plot of Fig. 1 we show the loop-corrected Higgs mass as a function of λ for the point `BP1`. The brown line is the result of Ref. [17], where they used `mr` [25] for SM RGE running and the $\text{OS} - \overline{\text{MS}}$ conversions. The result for M_h^{IV} and its uncertainty band obtained with `NMSSMCALC` is shown by the blue solid line. The orange dashed and green dotted lines are results where we combine `NMSSMCALC` with the codes `mr` and `SMDR`, respectively, to perform the SM OS-$\overline{\text{MS}}$ conversion and SM RGE-running in these codes. In the lower panel, we plot the differences of the brown line with the other three results. We find a difference of about $\sim 500 - 600\,\text{MeV}$ between `NMSSMCALC` and [17] in the whole range of λ. The difference shrinks down to the sub-MeV level when `NMSSMCALC` is combined with `mr`, which was used in [17]. Moreover, the four results are in agreement within the `NMSSMCALC` uncertainty band. We find that the missing HO corrections in the $\text{OS} - \overline{\text{MS}}$ conversion performed by `NMSSMCALC` is the main reason for the differences with `mr`, since the SM RGEs are of the same order in the two codes.

We now turn to the comparison of the results using the three methods that are now available in `NMSSMCALC` and shown in the right plot of Fig. 1 for a parameter point denoted by `BP2` taken from Ref. [4].This parameter point features the MSSM limit with the NMSSM-specific parameters λ and κ being set equal to a small value of 0.05. Masses of the SUSY particles are scaled with the mass parameter M_{SUSY}. We vary M_{SUSY} from 500 GeV to 100 TeV. The SM-like Higgs mass obtained by the FO method (black) using the $\overline{\text{DR}}$ scheme at $\mathcal{O}(\alpha_t(\alpha_t + \alpha_s))$ is compared with the results obtained from the QCM (blue) and PMM (red dashed) methods. We show the uncertainty estimated in the QCM method with the blue band. The lower panel shows the differences between the QCM the FO and the PMM results. We see a perfect agreement between the PMM and QCM for $M_{\text{SUSY}} > 2$ TeV, while for low M_{SUSY} the differences between them can be of several GeV. This demonstrates the significance of the v^2/M^2_{SUSY} contributions in the low M_{SUSY} regime. These contributions are present in the PMM but absent in the QCM. The FO and the PMM results are in better agreement for small M_{SUSY}. However, the FO line shows a different shape for larger M_{SUSY}.

4 CP-violating effects in the Higgs mass prediction

The NMSSM Higgs sector contains two parameters λ and κ, which can be complex, and two relative phases φ_s, φ_u between the three Higgs superfields. These phases may allow for the mixing of the CP-even and CP-odd Higgs states already at tree level. We want to examine the CP-violating effects from the complex phases of λ and κ in the Higgs mass computation. We find that they have a smaller impact on

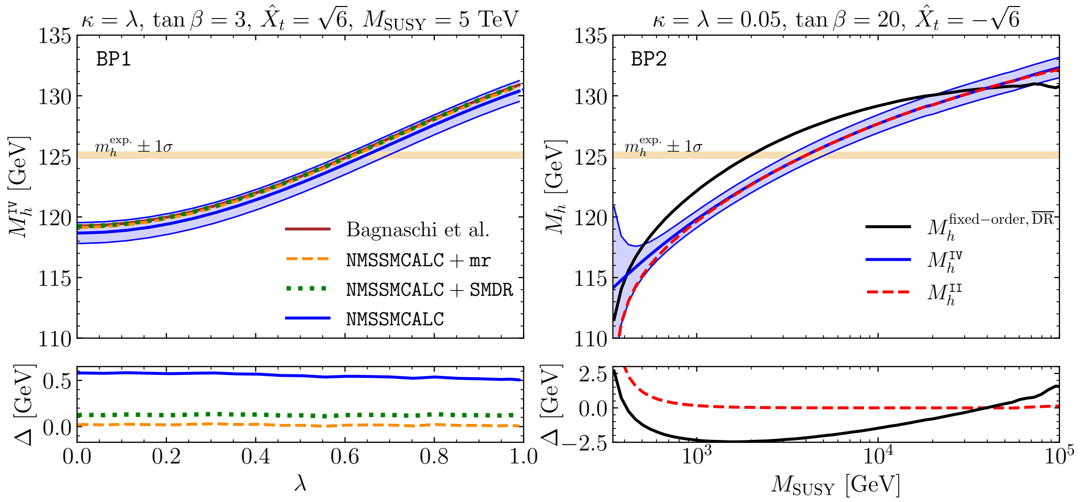

Figure 1: Left: Comparison of the loop-corrected Higgs mass of Ref. [17] and three NMSSMCALC results. **Right:** The FO, quartic coupling matching and pole-mass matching obtained with NMSSMCALC as functions of $M_{\rm SUSY}$ shown in black, blue and red-dashed lines, respectively. Figure taken from [24].

the EDM constraints compared to φ_s, φ_u. In Fig. 2, we present the Higgs mass results for BP1 (left) and BP3 (right) as functions of the complex phases of λ and κ. The benchmark point BP3 is obtained from a random scan (see [24] for more details). The solid lines show the PMM results while the QCM results are displayed by the dashed lines. Note that we have shifted the QCM results by $\Delta^{\rm SUSY}_{v^2/M^2_{\rm SUSY}}\Big|_{\varphi_i=0}$ which are found in Table 1. We find that the differences between the two results are very small for BP1 and larger for BP3, since BP3 features a large value of λ and larger mixing between the Higgs doublets and the singlet. In such a case, the SM may not be a good EFT anymore. In the lower panels, the normalized electric dipole moment of the electron (eEDM) computed from NMSSMCALC is displayed. We find that the eEDM excludes $|\varphi_\lambda| \gtrsim 0.05$ ($|\varphi_\kappa| \gtrsim 0.15$) for BP1 and $|\varphi_\lambda| \gtrsim 0.01$ ($|\varphi_\kappa| \gtrsim 0.03$) for BP3. For a more detailed discussion of CP-violating effects from complex phases of M_1, M_2, A_t, which enter the SM-like Higgs mass at the one-loop level, we refer the reader to [24].

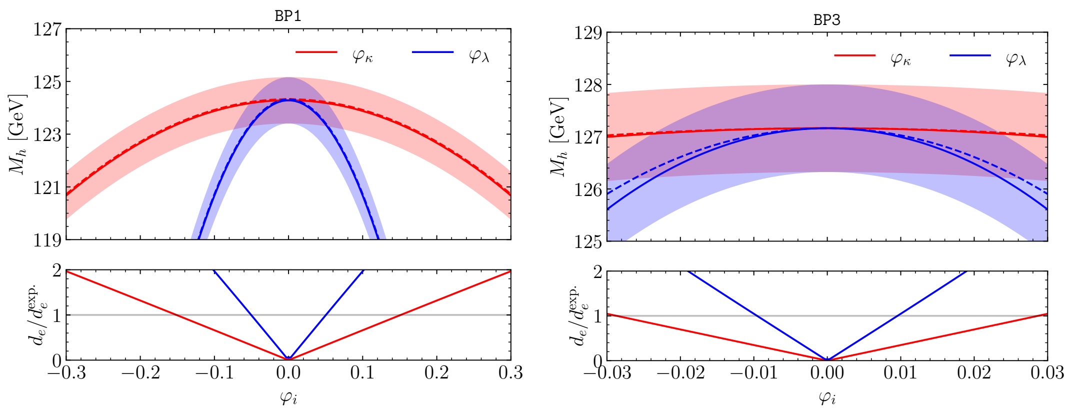

Figure 2: The prediction of the SM-like Higgs boson mass using the PMM (solid) and QCM (dashed) as functions of the phases of λ (blue) and κ (red) for the parameter point BP1 on the left panel and BP3 on the right panel. Figure taken from [24].

5 Uncertainties

The computation of the SM-like Higgs boson mass suffers from several sources of theoretical uncertainties. They can be classified into two categories: the SM uncertainty and the SUSY uncertainty. For the SM uncertainty, we define three types. The uncertainty due to the missing EW corrections in the SM $\overline{\text{MS}}$-OS parameter conversion is characterized by the difference between the two renormalization schemes as,

$$\Delta^{\text{SM}}_{G_F/\alpha_{M_Z}} = |M_h^{G_F} - M_h^{\alpha_{M_Z}}|. \tag{11}$$

The second type of uncertainty arises from the missing HO corrections in the relation between the Higgs quartic coupling and the Higgs pole mass. We estimate this uncertainty as

$$\Delta^{\text{SM}}_{Q_{\text{EW}}} = \max\{|M_h^{\text{OS}} - M_h^{\overline{\text{MS}},\text{pole}}(2M_t)|, |M_h^{\text{OS}} - M_h^{\overline{\text{MS}},\text{pole}}(M_t/2)|\}, \tag{12}$$

where $M_h^{\overline{\text{MS}},\text{pole}}(Q_{\text{EW}})$ is the $\overline{\text{MS}}$ Higgs pole mass at the scale $Q_{\text{EW}} = 2M_t$, or $Q_{\text{EW}} = M_t/2$. The third type comes from the missing HO corrections to the conversion of the Yukawa coupling of the top quark. We estimate it by adding/removing the three-loop corrections as

$$\Delta^{\text{SM}}_{Y_t} = M_h(Y_t^{\mathcal{O}(\alpha_s^2)}) - M_h(Y_t^{\mathcal{O}(\alpha_s^3)}). \tag{13}$$

The SUSY uncertainty originates from using a relation at the high-energy matching scale that misses higher-order contributions. We estimate them by changing the matching scale in the range of $[M_{\text{SUSY}}/2, 2M_{\text{SUSY}}]$. We then take the maximum of the two differences as

$$\Delta^{\text{SUSY}}_{Q_{\text{match}}} = \max\{|M_h^{M_{\text{SUSY}}/2} - M_h^{M_{\text{SUSY}}}|, |M_h^{2M_{\text{SUSY}}} - M_h^{M_{\text{SUSY}}}|\}. \tag{14}$$

We assume that the above-mentioned uncertainties areapproximately independent such that the combined uncertainty for the pole mass matching condition in NMSSMCALC is given by,

$$\Delta M_h^{\text{II}} = \left[\left(\Delta^{\text{SM}}_{G_F/\alpha_{M_Z}}\right)^2 + \left(\Delta^{\text{SM}}_{Q_{\text{EW}}}\right)^2 + \left(\Delta^{\text{SM}}_{Y_t}\right)^2 + \left(\Delta^{\text{SUSY}}_{Q_{\text{match}}}\right)^2\right]^{\frac{1}{2}}. \tag{15}$$

For the quartic coupling matching method, there is an additional source of the SUSY uncertainty. It arises from the missing v^2/M^2_{SUSY} - terms in the computation of the BSM quartic coupling. We therefore defined its total uncertainty as

$$\Delta M_h^{\text{IV}} = \left[(\Delta M_h^{\text{II}})^2 + (M_h^{\text{II}} - M_h^{\text{IV}})^2\right]^{\frac{1}{2}}, \tag{16}$$

where the term $(M_h^{\text{II}} - M_h^{\text{IV}})$ is the difference between the Higgs mass using the QCM method and the PMM one.

In Table 1, we show the individual and combined uncertainties when using the QCM and PMM methods for the three chosen benchmark points BP{1,2,3}. The SUSY scale uncertainty and the SM top-Yukawa uncertainty are the two dominant uncertainties. The SUSY scale uncertainty is rather large for point BP3 compared to BP1 and BP2. This is due to the BSM mass spectrum in BP3 which is rather light in comparison with the spectra of BP1 and BP2.

	$\Delta^{\text{SM}}_{Y_t}$	$\Delta^{\text{SM}}_{Q_{\text{EW}}}$	$\Delta^{\text{SM}}_{G_F/\alpha_{M_Z}}$	$\Delta^{\text{SUSY}}_{Q_{\text{match}}}$	$\Delta^{\text{SUSY}}_{v^2/M^2_{\text{SUSY}}}$	ΔM_h^{II}	ΔM_h^{IV}
BP1	-738	208	-19	376	-21	854	836
BP2	-685	208	-69	189	-5	743	743
BP3	-401	198	20	694	-2294	826	2415

Table 1: Five individual uncertainties and the total uncertainty estimate of the SM-like Higgs boson mass prediction using the quartic coupling matching and the pole-mass matching. All values are given in units of MeV. Table taken from [24].

6 Conclusions

We discussed a new prediction for the SM-like Higgs boson mass in the CP-violating NMSSM for large mass hierarchies using the EFT framework. We employed both the quartic coupling matching and the pole mass matching conditions to calculate the SM Higgs quartic coupling at the matching scale. Large logarithms are resummed by the use of SM RGEs from the matching to the electroweak scale where the SM-like Higgs mass is finally computed. We find good agreement between the two approaches at large SUSY scales. For low M_{SUSY}, the differences between the two results increase due to the importance of the v^2/M^2_{SUSY} terms which are present in the PMM, but missed in the QCM. We have also compared the EFT results with the FO result which show a rather different shape as the SUSY scale increases. Complex phases of NMSSM-specific parameters such as λ and κ may have a significant impact on the Higgs boson mass prediction. They are, however, constrained by the null-results of the eEDM experiments. Five different sources of uncertainties have been quantified. We find that the SUSY scale uncertainty and the SM uncertainty related to the top quark Yukawa coupling are the most dominant ones. We also find that if the mass of the singlet-like Higgs boson is lighter than 125 GeV, the SM effective low-energy theory is not an appropriate description. In the future, one may consider the singlet extension of the SM as a more appropriate EFT to cover NMSSM scenarios featuring a light singlet.

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