

hhh Coupling in SUSY Models after LHC Run I postprint

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Abstract

We examine the Higgs triple coupling in MSSM and NMSSM under current constraints, which include the LHC measurements, Higgs data, B physics, electroweak precision observables, relic density and so on. The ratio $\lambda_{hhh}^{\text{MSSM}}/\lambda_{hhh}^{\text{SM}}$ is above 0.97 due to the highly constrained parameter space, while the ratio $\lambda_{hhh}^{\text{NMSSM}}$ can reach 0.1 under current constraints. Precise

Full Text

Preamble

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Higgs Triple Coupling in SUSY Models after LHC Run I

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We examine the Higgs triple coupling in the MSSM and NMSSM under current constraints, which include LHC measurements, Higgs data, B physics observables, electroweak precision observables, relic density, and other constraints. The ratio $\lambda_{hhh}^{\text{MSSM}}/\lambda_{hhh}^{\text{SM}}$ is above 0.97 due to the highly constrained parameter space, while the ratio $\lambda_{hhh}^{\text{NMSSM}}$ can reach 0.1 under current constraints. Precise

measurements at future colliders will provide tighter constraints on the Higgs triple coupling in both MSSM and NMSSM.

Introduction

The discovery of a 125 GeV Higgs boson [?, ?] has completed the Standard Model (SM) particle spectrum. However, to fully describe the Higgs potential and confirm the SM, we still need to determine the Higgs self-couplings. In new physics models containing more than one Higgs boson, the Higgs self-coupling can change significantly, and such modifications are crucial for many theoretical and phenomenological problems, such as baryogenesis and vacuum stability. Therefore, it is important to calculate how large these changes can be under current experimental constraints.

An interesting feature of the MSSM Higgs sector has been shown in [?]. Even though the stop loop corrections to the Higgs self-coupling are significant, such large new physics contributions can always be absorbed by redefining the Higgs mass. Consequently, after carefully matching the Higgs mass and its self-coupling, the MSSM exhibits a decoupling property: when all non-SM particles are very heavy, the low-energy physics reduces to the SM. This matching between the Higgs mass and its coupling can be automatically obtained using the effective potential method [?, ?, ?, ?]. As suggested in [?], we employ the effective potential method for our calculations.

II. Higgs Sector in MSSM and NMSSM

The MSSM Higgs sector contains two doublets:

$$\begin{pmatrix} H_u^+ \\ H_u^0 \end{pmatrix}, \quad \begin{pmatrix} H_d^0 \\ H_d^- \end{pmatrix}$$

The tree-level Higgs potential can be expressed as:

$$V^{(0, \text{MSSM})} = m_1^2 |H_u|^2 + m_2^2 |H_d|^2 - B\mu \epsilon_{\alpha\beta} (H_u^\alpha H_d^\beta + \text{h.c.}) + \frac{g^2 + g'^2}{8} (|H_u|^2 - |H_d|^2)^2 + \frac{g^2}{2} |H_u^\dagger H_d|^2$$

Using the minimization conditions, the soft masses m_1^2 , m_2^2 , and $B\mu$ can be expressed in terms of M_A , $\tan\beta$, and other SM parameters. Thus, the tree-level MSSM Higgs sector is determined by M_A and $\tan\beta$. All couplings in the tree-level MSSM Higgs sector are gauge couplings, while the stop/top sector provides large quantum corrections to the tree-level potential.

In addition to the two Higgs doublets, the NMSSM Higgs sector is extended by a singlet $\langle S \rangle$, which introduces an effective μ term through spontaneous symmetry breaking. The tree-level Higgs potential in the NMSSM is:

$$V^{(0,\text{NMSSM})} = (|\lambda S|^2 + m_{H_u}^2) H_u^\dagger H_u + (|\lambda S|^2 + m_{H_d}^2) H_d^\dagger H_d + m_S^2 |S|^2 + \left[\lambda A_\lambda H_u H_d S + \frac{\kappa}{3} A_\kappa S^3 + \text{h.c.} \right] + \frac{g^2 + g'^2}{8} (H_u^\dagger H_u + H_d^\dagger H_d)$$

where λ and κ are dimensionless parameters, and A_λ and A_κ are dimensional trilinear terms. The most significant difference between the MSSM and NMSSM Higgs sectors lies in the Higgs couplings at tree-level. As mentioned previously, the Higgs couplings in the MSSM are all gauge couplings, whereas the Higgs couplings in the NMSSM can be very different, being subject only to theoretical constraints such as perturbativity at high energy scales, vacuum stability, and phenomenological constraints from Higgs data. Consequently, the Higgs triple coupling in the NMSSM can differ substantially from both the SM and MSSM predictions.

Next, we present the precise numerical values of the Higgs triple coupling in the MSSM and NMSSM under current experimental constraints.

III. Numerical Calculations and Results

The input SM parameters are taken from [?]: $m_t = 173.5$ GeV, $m_W = 80.385$ GeV, $m_Z = 91.1876$ GeV, $m_b^{\overline{\text{MS}}}(m_b) = 4.18$ GeV, $\alpha_s(M_Z) = 0.1184$, $\alpha(m_Z)^{-1} = 128.962$. The masses of sleptons, first and second generation squarks, and gauginos are all set to 2 TeV. We further require $M_{Q_3} = M_{U_3} = M_{D_3}$ and $A_t = A_b$. We then use NMSSMTools-4.4.1 [?] to perform random scans.

For the MSSM (which can be treated as a limiting scenario of the NMSSM, allowing NMSSMTools to be used for MSSM scans), the scan ranges are: $1 \leq \tan \beta \leq 60$, $0.2 \text{ TeV} \leq M_A \leq 1 \text{ TeV}$, $|\mu| \leq 1 \text{ TeV}$, $0.1 \text{ TeV} \leq M_{Q_3} \leq 2.5 \text{ TeV}$, and $|A_t| \leq 3M_{Q_3}$.

The scan ranges for the NMSSM are: $0 \leq \lambda \leq 0.7$, $|\kappa| \leq 0.7$, $0.2 \text{ TeV} \leq A_\lambda \leq 1 \text{ TeV}$, $|A_\kappa| \leq 1 \text{ TeV}$, $1 \leq \tan \beta \leq 20$, $0.1 \text{ TeV} \leq \mu \leq 1 \text{ TeV}$, $0.1 \text{ TeV} \leq M_{Q_3} \leq 1 \text{ TeV}$, and $|A_t| \leq 3M_{Q_3}$.

The constraints included in our analysis are: - Higgs data: HiggsBounds-4.2 [?] and HiggsSignals-1.3.0 [?] are used to exclude points outside the 2σ region. - B physics observables: $B \rightarrow X_s \gamma$, $B_s \rightarrow \mu^+ \mu^-$, $B_d \rightarrow X_s \mu^+ \mu^-$, and $B^+ \rightarrow \tau^+ \nu$ are required to be within the 2σ region. - Precision electroweak observables are required to be within the 2σ region. - Relic density is required to be below the 2σ upper bound from Planck [?]. The neutralino-proton scattering cross-section must satisfy the direct detection bound from LUX [?]. - The physical vacuum must be stable.

To quantify new physics effects, it is convenient to show the ratio $\lambda_{hhh}^{(N)\text{MSSM}} / \lambda_{hhh}^{\text{SM}}$. If this ratio deviates from one, it indicates SUSY effects, and the larger the deviation, the more significant the SUSY effects.

Fig. 1 and Fig. 2 show our main scan results. The deviation of the Higgs triple coupling in the MSSM is too small to be observed at future colliders, whereas

the deviation in the NMSSM is large enough to be detected. Moreover, large triple coupling deviations in the NMSSM always correspond to a scalar in the vicinity of the 125 GeV Higgs. Detailed discussions can be found in our longer paper [?].

IV. Constraint on HHH Coupling at Future Colliders

Large deviations in the Higgs triple coupling occur when the SM-like Higgs mixes substantially with other non-SM scalars. However, such significant mixing also causes deviations in the hVV and $h\bar{f}f$ couplings. Therefore, if we can measure the hVV and $h\bar{f}f$ couplings more precisely, the constraints on the Higgs triple coupling will become more stringent. Here we show only the NMSSM results in Fig. 3.

V. Conclusion

In this talk, we have shown the deviation of the Higgs triple coupling in the MSSM and NMSSM under current constraints. The ratio $\lambda_{hhh}^{\text{MSSM}}/\lambda_{hhh}^{\text{SM}}$ is above 0.97, while the ratio $\lambda_{hhh}^{\text{NMSSM}}/\lambda_{hhh}^{\text{SM}}$ can reach 0.1 under current constraints. Precise Higgs coupling measurements at future colliders can constrain deviations in the Higgs triple coupling more stringently.

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Figure Captions:

FIG. 1 [Figure 1: see original paper]: Scatter plots of the MSSM samples surviving all experimental constraints, projected on the planes of $\tan\beta$ versus m_A and $m_{\tilde{t}_1}$.

FIG. 2 [Figure 2: see original paper]: The dependence of $\lambda_{3h}^{\text{NMSSM}}$ versus λ and the singlet component $|O_{2s}|$ in h_2 , where $m_{h_2} < 2m_{h_1}$. The ILC (1 TeV, 1 ab^{-1}) and HL-LHC (14 TeV, 3 ab^{-1}) sensitivities are also plotted (the region below each horizontal line is detectable).

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