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Imprint of quark flavor violating SUSY in h(125) decay width ratios at future lepton colliders

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We study the lighter CP-even neutral Higgs boson decays $h \to c\bar{c}, b\bar{b}, \gamma\gamma, gg$ in the Minimal Supersymmetric Standard Model (MSSM) with general quark flavor violation (QFV), identifying the h as the Higgs boson with a mass of 125 GeV. We compute the widths of these h decays and the width ratios at NLO level focusing on their deviations from the standard model (SM) predictions. From a systematic MSSM parameter scan respecting all the relevant theoretical and experimental constraints, such as those from K- and B-meson data and the Supersymmetric (SUSY) particle mass limits from the LHC experiments, we find that the deviations of these MSSM decay width ratios from their SM values can be quite sizable in strong contrast to the usual studies in the MSSM with Minimal Flavor Violation (MFV). We point out that the experimental measurement uncertainties as well as the MSSM prediction uncertainties tend to cancel out significantly in the width ratios, making the measurement of these width ratios a very sensitive probe of virtual SUSY loop effects in these h decays at future lepton colliders such as ILC, CLIC, CEPC, FCC-ee and muon-collider (MuC). We show that the deviations of the width ratios can be significantly enhanced compared with that of a single width; e.g. the deviation of the decay width ratio $\Gamma(h \to b\bar{b})/\Gamma(h \to c\bar{c})$ from the SM value can exceed +100% and that of $\Gamma(h \to \gamma\gamma)/\Gamma(h \to gg)$ from the SM value can be as large as about +8%. Moreover, we find that future lepton colliders such as ILC, CLIC, CEPC, FCC-ee and MuC can observe such sizable deviations of the width ratios from the SM at high signal significance *even after* the failure of SUSY particle discovery at the HL-LHC. In case the deviation pattern shown here is really observed at the lepton colliders, then it would strongly suggest the discovery of QFV SUSY (the MSSM with general QFV).

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1. Introduction

What is the SM-like Higgs boson discovered at LHC? It can be the SM Higgs boson. It can be a Higgs boson of New Physics. Here we study a possibility that it is the lightest Higgs boson h of the Minimal Supersymmetric Standard Model (MSSM), focusing on the widths and the width ratios of the decays $h \to c\bar{c}, b\bar{b}, \gamma\gamma, gg$ with special emphasis on Supersymmetric Quark Flavor Violation (SUSY QFV). We focus on the $\tilde{c}_{L/R} - \tilde{t}_{L/R}$ and $\tilde{s}_{L/R} - \tilde{b}_{L/R}$ mixing which are described by the QFV parameters M^2_{Q23}, M^2_{U23}, T_{U23}, T_{U32} and M^2_{Q23}, M^2_{D23}, T_{D23}, T_{D32}, respectively. We also refer to the quark-flavor conserving (QFC) parameters T_{U33} and T_{D33} which induce the $\tilde{t}_L - \tilde{t}_R$ and $\tilde{b}_L - \tilde{b}_R$ mixing, respectively. We assume that R-parity is conserved and that the lightest neutralino $\tilde{\chi}^0_1$ is the lightest SUSY particle (LSP).

2. Parameter scan

We compute the decay widths $\Gamma(h^0 \to c\bar{c})$, $\Gamma(h^0 \to b\bar{b})$ at full 1-loop level and the loop-induced decay widths $\Gamma(h^0 \to \gamma\gamma)$, $\Gamma(h^0 \to gg)$ at NLO QCD level in the MSSM with QFV [1–3]. *For the first time*, we perform a systematic MSSM-parameter scan for these decay widths, respecting all the relevant theoretical and experimental constraints described in [4]. We generate the MSSM-parameter points by using random numbers in the ranges shown in Table 1 of Ref. [4]. All input parameters are $\overline{\text{DR}}$ parameters defined at scale Q = 1 TeV, except m_A(pole) which is the pole mass of the CP odd Higgs boson A^0. We don't assume a GUT relation for the gaugino masses M_1, M_2, M_3. From 377180 input points generated in the scan, 3208 points survived all the constraints. We show these survival points in the scatter plot in this article.

3. Deviation of width ratios from SM prediction

We define the relative deviation of the MSSM width ratios from their SM values as follows: $DEV(X/Y) = [\Gamma(X)/\Gamma(Y)]_{MSSM}/[\Gamma(X)/\Gamma(Y)]_{SM} - 1$, where $\Gamma(X) = \Gamma(h \to X\bar{X})$. We remark that the experimental measurement uncertainties as well as the MSSM prediction uncertainties tend to cancel out significantly in the width ratios $\Gamma(X)/\Gamma(Y)$.
In Fig. 1 we show the scatter plot in the DEV(b/c)-T_{U32} plane obtained from our parameter scan, where T_{U32} is the $\tilde{c}_L - \tilde{t}_R$ mixing parameter. We see the followings:
(i) There is a strong correlation between DEV(b/c) and T_{U32}.
(ii) DEV(b/c) can exceed +100% for large $|T_{U32}|$.
(iii) According to Ref. [5], the expected absolute 1σ error of DEV(b/c) measured at ILC is given by $\Delta DEV(b/c)$ = (3.1%, 2.1%, 1.3%) at (ILC250, ILC250+500, ILC250+500+1000). Similar results are obtained for the future lepton colliders other than ILC in Ref. [5].
(iv) Future lepton colliders, such as ILC, can observe such large deviation from the SM at very high significance.

In Fig. 2(a) we show the contour plot of DEV(b/c) in the T_{U32}-M^2_{U23} plane around the benchmark scenario P1 described in [6], which satisfies all the relevant theoretical and experimental constraints including all the expected SUSY-particle (sparticle) mass limits (including (m_{A/H^+}, $\tan\beta$) limits)

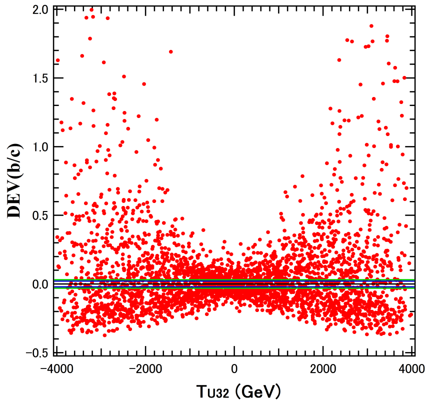

Figure 1: The scatter plot in the DEV(b/c)-T_{U32} plane obtained from the MSSM parameter scan described in Section 2. The black horizontal line marks the SM prediction. The green and blue horizontal lines indicate the expected absolute 1σ error of DEV(b/c) measured at ILC250 and ILC250+500, respectively [5].

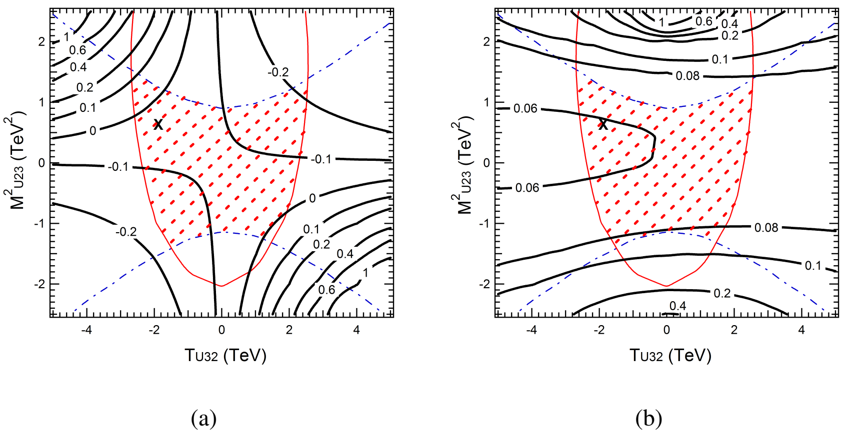

Figure 2: The contour plots of (a) DEV(b/c) and (b) DEV(γ/g) in the T_{U32}-M^2_{U23} plane around the benchmark point P1 marked by "X". The red hatched region is allowed by all the constraints including the expected sparticle mass limits from HL-LHC [7, 8].

from negative sparticle-search in the HL-LHC experiment [7, 8]. Here, M^2_{U23} is the $\tilde{c}_R - \tilde{t}_R$ mixing parameter. We see that DEV(b/c) can be very large (about -20% to +15%) in the sizable region allowed by all the constraints including the expected sparticle mass limits from the future HL-LHC experiment [7, 8]. Such large deviation can be observed at ILC with very high significance (see the item (iii) in the discussion of Fig. 1).

In Fig. 2(b) we show the contour plot of DEV(γ/g) around the benchmark point P1 in the T_{U32}-M^2_{U23} plane. We find that DEV(γ/g) can be sizable (about +6% to +9%) in the large region allowed by all the constraints including the expected sparticle mass limits from the future HL-LHC experiment [7, 8]. According to Ref. [5], the expected absolute 1σ error of DEV(γ/g) measured at ILC is given by $\Delta DEV(\gamma/g)$ = (3.3%, 2.8%, 2.3%) at (ILC250, ILC250+500, ILC250+500+1000). Similar results are obtained for the future lepton colliders other than ILC in Ref. [5]. Hence, such sizable deviation DEV(γ/g) can also be observed at future lepton colliders like ILC with high significance.

4. Conclusion

We have studied the decays $h \to c\bar{c}, b\bar{b}, \gamma\gamma, gg$ in the MSSM with general QFV due to squark generation mixings. *In strong contrast to* the usual studies in the MSSM with MFV, we have found that the deviations of the ratios of these MSSM decay widths from the SM values can be quite sizable. *For the first time*, we have performed the systematic MSSM parameter scan for these decay widths respecting all of the relevant theoretical and experimental constraints. From the parameter scan and the contour plot analysis, we have found the following:

- DEV(b/c) can exceed ~ +100%.
- DEV(γ/g) can be as large as ~ +9%.
- These sizable deviations in the h decays are due to (i) large scharm-stop mixing and large scharm/stop involved trilinear couplings $T_{U23}, T_{U32}, T_{U33}$, (ii) large sstrange-sbottom mixing and large sstrange/sbottom involved trilinear couplings $T_{D23}, T_{D32}, T_{D33}$ and (iii) large bottom Yukawa coupling Y_b for large $\tan\beta$ and large top Yukawa coupling Y_t.

Such sizable deviations from the SM can be observed at high signal significance in future lepton colliders such as ILC, CLIC, CEPC, FCC-ee and MuC *even after* the failure of SUSY particle discovery at the HL-LHC. In case the deviation pattern shown here is really observed at the lepton colliders, then it would strongly suggest the discovery of QFV SUSY (the MSSM with general QFV).

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PoS(EPS-HEP2023)487