CONSTRAINING TWO HIGGS DOUBLET MODELS WITH HEAVY LEPTON DECAYS*

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The one-loop contributions to the branching ratios for leptonic τ decays are calculated in two Higgs doublet models. The analysis focuses on the effect of charged Higgs and on the basic supersymmetric extension, the minimal supersymmetric Standard Model (MSSM).

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1. Introduction

The searches for new physical phenomena have been the subject of research over the last few decades. Searching for new phenomena in the domain of physics beyond the Standard Model can be performed in two ways. We can search for new particles directly, for instance at the LHC. Another way is to conduct indirect searches exploiting precision observables. We can find any deviations from what we know (the Standard Model) by investigating how some of its symmetries can be violated. Moreover, its effects can be sizable even if the mass scale of new physics is quite high.

One of such symmetries is the lepton flavor universality, which means that in the Standard Model, the gauge interactions are the same for all lepton flavors. This is only broken by the Yukawa couplings, which are quite small [1]. Therefore, at the Lagrangian level, we can assume the lepton flavor universality to be a symmetry where all charged leptons behave the same (before the electroweak symmetry breaking and neglecting their masses).

Recent years have provided us with interesting hints of effects violating the lepton flavor universality in various processes, see for *e.g.* [2]. These considerations have provided a motivation to investigate heavy lepton decays in one of the simplest extension of the Standard Model — the two Higgs doublet models.

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2. Lepton flavor universality in tau decays

The aim of this work is to constrain the SUSY parameters by considering the lepton flavor universality in tau decays. The sensitivity to the beyond the Standard Model processes is enhanced due to the high tau mass.

One of the hints of the Lepton Flavor Universality Violation can be studied in the rare decays of the B mesons, where we get different rates of decays into muons and electrons, and the tau lepton. The rates for D and D^* mesons are given by

$$\mathcal{R}_D = \frac{\mathrm{Br}(B \to D\tau\bar{\nu})}{\mathrm{Br}(B \to D\{e/\mu\}\bar{\nu})} \tag{1}$$

and

$$\mathcal{R}_{D^*} = \frac{\mathrm{Br}(B \to D^*\tau\bar{\nu})}{\mathrm{Br}(B \to D^*\{e/\mu\}\bar{\nu})}\,. \tag{2}$$

The measurement of these branching ratios (BR) deviates from the Standard Model prediction by 2.2σ and 3.9σ respectively [3].

3. τ leptonic decays in 2HDM

It has been shown that there is a strong correlation between the B-meson decays and the τ lepton flavor violating decays [4]. In light of this work, we calculate the full one-loop level corrections to the $\tau \to \mu$ process.

The tau leptonic decays in a 2HDM Type II are widely discussed in [5]. An extension of such a model with additional SUSY particles is the Minimal Supersymmetric Standard Model (MSSM).

The tree-level tau decays into a lighter lepton take place in the Standard Model with the $W^\pm$ exchange. In the MSSM, there is an additional tree contribution due to an exchange of the charged Higgs boson and the charged Goldstone boson. The charged Higgs contribution to the amplitude, compared with the $W^\pm$ contribution, is suppressed by a factor

$$\frac{2m_\tau m_l}{M_H^2}\tan^2\beta\frac{1}{v_1^2+v_2^2} \tag{3}$$

and the charged Goldstone boson contribution is smaller than the charged Higgs one (for $M_H \sim M_W$), because it does not contain the $\tan^2\beta$ term

$$\frac{2m_\tau m_l}{M_H^2}\frac{1}{v_1^2+v_2^2}\,. \tag{4}$$

The one-loop corrections include all the processes corrected for the self-energies, vertices, and boxes. The $W^{\pm} l \nu_l$ vertex corrections are proportional to the lepton mass, so we can only consider the radiative contributions to the $W^{\pm} \tau \nu_\tau$ vertex. If we take into account that $W^{\pm}$ and $H^{\pm}$ masses are large compared to the lepton masses and external momenta, we can neglect the masses of the muon and the electron in the calculations. The obtained one-loop corrections are universal, *i.e.* they do not depend on whether we consider a decay into an electron or a muon.

Working in the 't Hooft–Feynman gauge and using the conventions of [6], we calculated the non-universal contributions. They can arise either from a tree-level $H^{\pm}$ or different slepton masses in the loops. The first type is suppressed by a factor

$$\frac{m_\tau m_l}{m_{H^\pm}} \tan\beta \,. \tag{5}$$

4. Conclusion and outlook

All the processes have been calculated in the most general form. We have extracted the leading contributions involving sparticles shown in Fig. 1 and discussed their impact on the tau decay rate. The final part will involve calculating the ratio $\mathrm{Br}(\tau \to \mu\nu\bar{\nu})/\mathrm{Br}(\tau \to e\nu\bar{\nu})$ as a function of the selectron mass and discussing whether these effects can be detectable in future experiments.

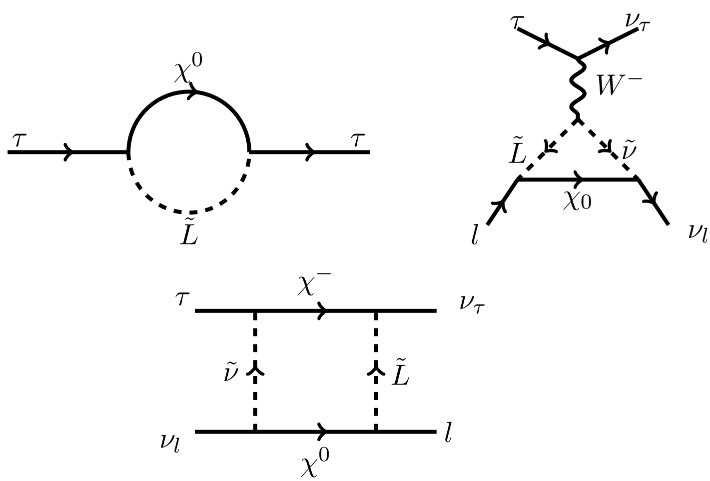

Fig. 1. The dominant one-loop contributions contributing to leptonic τ decays in the MSSM.

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