PROCEEDINGS OF SCIENCE

Impact of CPV phases on flavour violating H and Z decays

E. Pinsard,[a,*] A. Abada,[b] J. Kriewald,[c] S. Rosauro-Alcaraz[b] and A. M. Teixeira[a]

[a] *Laboratoire de Physique de Clermont (UMR 6533), CNRS/IN2P3, Univ. Clermont Auvergne, 4 Av. Blaise Pascal, 63178 Aubière Cedex, France*

[b] *Pôle Théorie, Laboratoire de Physique des 2 Infinis Irène Joliot Curie (UMR 9012), CNRS/IN2P3, 15 Rue Georges Clemenceau, 91400 Orsay, France*

[c] *Jožef Stefan Institut, Jamova Cesta 39, P. O. Box 3000, 1001 Ljubljana, Slovenia*

E-mail: emanuelle.pinsard@clermont.in2p3.fr

Standard Model extensions via heavy neutral leptons lead to modifications in the lepton mixing matrix, including new Dirac and Majorana CP violating phases. Here we consider the role of the Majorana fermions and of the new CP violating phases in Higgs and Z-boson lepton flavour violating decays, as well as in the corresponding CP-asymmetries. We confirm that these decays are sensitive to the presence of additional sterile states and show that the new CP violating phases may lead to both destructive and constructive interferences in the decay rates. Interestingly the $Z \to \mu^\pm \tau^\mp$ rates are within FCC-ee reach, with associated CP-asymmetries that can potentially reach up to 30%.

ArXiv ePrint: 2207.10109

1st International Conference on B-Physics at Frontier Machines (Beauty2023)
3-7 July, 2023
Clermont-Ferrand, France

[*] Speaker

https://pos.sissa.it/

PoS(BEAUTY2023)061

1. Introduction

It has been recently shown that the new leptonic CP violating (CPV) phases arising in Standard Model (SM) extensions with 2 heavy Majorana fermions can have a significant impact on charged lepton flavour violating (cLFV) observables and even alter the correlation between cLFV observables (that would be present in the CP conserving case) [1].

In [2] we carried out a comprehensive study of the role of the heavy neutral leptons (HNL), as well as their associated CPV phases, on cLFV neutral boson decays. We also discussed how the presence of the CP violating phases can be probed via the CP asymmetries in Z-boson decays. In the following, we highlight the most relevant results of this work.

2. Impact of leptonic CP phases on cLFV neutral boson decays

In order to study the effects of the CPV phases on cLFV neutral boson decays, we rely on a minimal SM extension via 2 Majorana sterile fermions. The presence of the new states will lead to an enlarged mixing matrix - instead of the 3×3 Pontecorvo-Maki-Nagakawa-Sakata (PMNS) matrix, the lepton mixings are now encoded in the 5×5 unitary matrix $\mathcal{U}$. The left-handed mixings correspond to the 3×3 upper left block of $\mathcal{U}$; this would-be PMNS, which is no longer unitary, leads to modified charged and neutral (lepton) currents.

The modified currents allow for tree-level flavour changing interactions and will also contribute to cLFV boson decays through one-loop vertex corrections and charged lepton self-energy diagrams. Both Higgs and Z decays share a common topology for the one-loop contributions, leading to analogous behaviours for these two observables. Their decay rates[1] are significantly impacted by the HNL masses - increasing with the heaviest HNL mass. In what follows we focus on TeV range HNL masses (with $m_4 = 5$ TeV and $m_5 - m_4 \in [10 \text{ MeV}, 1 \text{ TeV}]$), as this leads to cLFV Z decays within future FCC-ee sensitivity [5], while complying with all relevant experimental constraints. We will only discuss the $\mu - \tau$ sector[2] since the branching ratio for $Z \to \mu\tau$ is larger than for the other cLFV channels, thus offering more promising experimental prospects. Comparing $H \to \mu\tau$ and $Z \to \mu\tau$, both observables are strongly correlated in the CP conserving case. This behaviour is however affected by the presence of the new CPV phases that induce interference effects, both constructive and destructive. Notice that $H \to \mu\tau$ is far beyond future experimental reach, while $Z \to \mu\tau$ could be observable at a future FCC-ee (running at the Z-pole mass).

3. CP asymmetries in cLFV boson decays

In view of the capabilities of a future FCC-ee, we consider the potential contributions of this minimal model to CP-asymmetries in Z-boson decays, $\mathcal{A}_{CP}(Z \to \ell_\alpha \ell_\beta)$. The Dirac CPV phases have a significant impact on $\mathcal{A}_{CP}(Z \to \ell_\alpha \ell_\beta)$, while Majorana phases play a less significant role. However the latter lead to significant contributions provided that Dirac phases are also present.

Complying with all relevant experimental constraints, the CP-asymmetries in $Z \to \mu\tau$ can be very large (up to 100%), as it can be seen in the left panel of Fig. 1, where we present the

[1] We carried out the computation without any approximation and the form factors are given in [2]. Our predictions for the cLFV Z decay rate agree with previous results obtained in the limit of vanishing final state lepton masses [3, 4].

[2] The decays into $e\mu$ and $e\tau$ final states are discussed in [2].

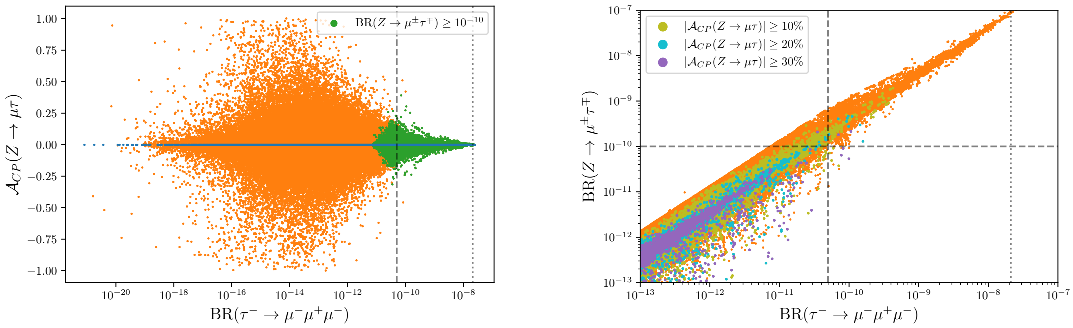

Figure 1: On the left, prospects for $\mathcal{A}_{CP}(Z \to \mu\tau)$ vs. $\mathrm{BR}(\tau \to \mu\mu\mu)$: orange (blue) points denote random (vanishing) values of all CPV phases; in green, points associated with $\mathrm{BR}(Z \to \mu^\pm\tau^\mp) \geq 10^{-10}$, within future reach of FCC-ee. On the right, $\mathrm{BR}(Z \to \mu^\pm\tau^\mp)$ vs. $\mathrm{BR}(\tau \to \mu\mu\mu)$. Colour code as before, with olive green, cyan and purple points respectively denoting $|\mathcal{A}_{CP}(Z \to \mu\tau)| \geq 10\%$, 20% and 30%. In both panels, dashed lines represent the future sensitivity.

prospects for $\mathcal{A}_{CP}(Z \to \mu\tau)$ vs. $\mathrm{BR}(\tau \to 3\mu)$. For both $\mathrm{BR}(\tau \to 3\mu)$ and $\mathrm{BR}(Z \to \mu\tau)$ within future FCC-ee sensitivity, the CP-asymmetries can still reach up to 20%. In the right panel of Fig. 1, we display a complementary view of these results, showing that in the $\mu - \tau$ sector one can simultaneously test the presence of HNL as well as their CPV phases via several observables. The joint observation of these three observables would be highly suggestive of such a SM extension via *at least* 2 heavy Majorana states.

Finally, in order to further emphasise the role of the CP-asymmetries, we have selected two benchmark points featuring the same heavy sterile masses and very different mixing angles. The CP conserving (P_1) point has vanishing CPV phases while the CP violating (P_2) one has non-zero Dirac and Majorana CPV phases. Both P_1 and P_2 lead to similar cLFV predictions both lying within future sensitivity[3], and thus rendering them indistinguishable if any cLFV signal would be observed in the future. It is worth noticing that P_2 features smaller mixing angles than P_1; the identical predictions for the cLFV observables is due to the role of CPV phases, which are at the source of constructive interferences. From an experimental point of view, these two regimes are indistinguishable, hence little can be learnt about the underlying flavour regimes or the presence of CPV phases. However, P_2 leads to non vanishing CP-asymmetries with $\mathcal{A}_{CP}(Z \to \mu\tau) = 30\,\%$, offering a clear distinction between CP conserving and CP violating scenarios.

4. Conclusions

Heavy neutral lepton extensions of the SM introduce new leptonic CPV phases that can have a significant impact on cLFV observables and their interpretation. We have illustrated these results within a minimal New Physics construction, in which 2 HNL are added to the SM content. In particular, the presence of the new TeV scale states (and their CPV phases) leads to $\mathrm{BR}(Z \to \mu\tau)$ within future FCC-ee sensitivity and the associated CP-asymmetries, that can reach up to 30%, is a key ingredient to disentangle between CP conserving and CP violating regimes.

[3]With $\mathrm{BR}(\mu \to 3e) = 2 \times 10^{-15}$, $\mathrm{CR}(\mu - e\,, \mathrm{Al}) = 5 \times 10^{-14}$, $\mathrm{BR}(\tau \to 3\mu) = 1 \times 10^{-10}$, $\mathrm{BR}(Z \to \mu\tau) = 2 \times 10^{-10}$.

Acknowledgments

This project has received support from the European Union's Horizon 2020 research and innovation programme under the Marie Skłodowska-Curie grant agreement No. 860881 (HIDDeν network) and from the IN2P3 (CNRS) Master Project, "Flavour probes: lepton sector and beyond" (16-PH-169).

References

[1] A. Abada, J. Kriewald and A. M. Teixeira, Eur. Phys. J. C **81** (2021) no.11, 1016 [arXiv:2107.06313 [hep-ph]].

[2] A. Abada, J. Kriewald, E. Pinsard, S. Rosauro-Alcaraz and A. M. Teixeira, "LFV Higgs and Z-boson decays: leptonic CPV phases and CP asymmetries," arXiv:2207.10109 [hep-ph].

[3] V. De Romeri, M. J. Herrero, X. Marcano and F. Scarcella, Phys. Rev. D **95** (2017) no.7, 075028 [arXiv:1607.05257 [hep-ph]].

[4] J. I. Illana and T. Riemann, Phys. Rev. D **63** (2001), 053004 [arXiv:hep-ph/0010193 [hep-ph]].

[5] A. Abada *et al.* [FCC], Eur. Phys. J. C **79** (2019) no.6, 474.