Combined signatures of heavy Higgses and vectorlike fermions

Radovan Dermisek,[1,*] Enrico Lunghi,[1,†] Navin McGinnis,[1,2,‡] and Seodong Shin[3,§]

[1] *Physics Department, Indiana University, Bloomington, IN 47405, USA*
[2] *High Energy Physics Division, Argonne National Laboratory, Lemont, IL 60439, USA*
[3] *Department of Physics, Jeonbuk National University, Jeonju, Jeonbuk 54896, Korea*

EF Topical Groups:

■ (EF02) EW Physics: Higgs Boson as a portal to new physics
■ (EF08) BSM: Model specific explorations

TF Topical Groups:

■ (TF07) Collider phenomenology
■ (TF08) BSM model building

In extensions of two Higgs doublet models with vectorlike quarks and leptons, the decays of vectorlike fermions may easily be dominated by cascade decays through charged/neutral Higgs bosons or the new fermions might appear in the decays of heavy Higgses (depending on the mass hierarchy).

The first possibility leads to two heavy Higgs bosons in association to various SM quarks, resulting in final states with, for example, six top or bottom quarks [1, 2], see figure 1. The heavy Higgs bosons are effectively pair produced with QCD size cross sections and lead to final states with very small irreducible SM background (the dominant background happens to originate from QCD multi-jet final states). Thus searching for them in top- and bottom-rich events presents a unique opportunity for the LHC and future colliders. For instance, a search strategy focusing on the $6b$ final state allows to explore a wide range of vectorlike quarks and Higgs bosons masses at the LHC. The sensitivity to the charged and neutral Higgs bosons, extending to about 2 TeV, stands out when compared to models without vectorlike matter.

The second possibility leads to the final states presented in figure 2. In particular, signatures involving leptons are extremely clean: the reach of the HL-LHC is $m_H \lesssim 3.3$ TeV and $m_{e_4} \lesssim 2.2$ TeV where H is a heavy neutral Higgs

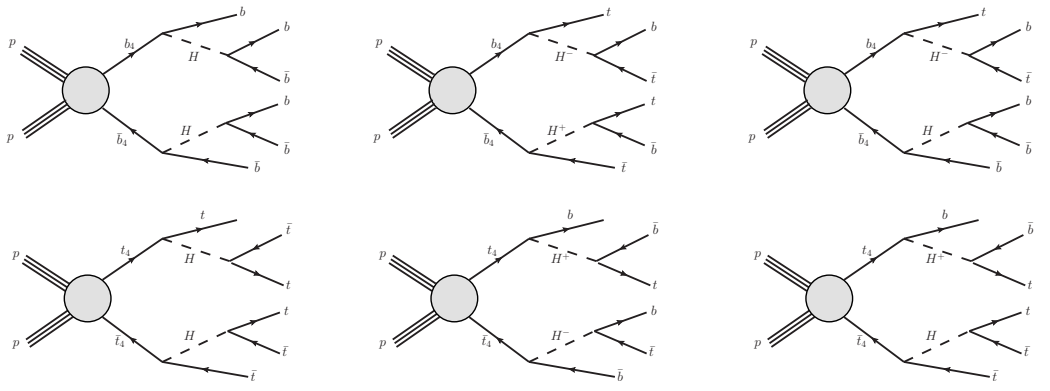

FIG. 1. Representative cascade decays of pair produced vectorlike top and bottom quarks through neutral Higgs bosons (left), charged Higgs bosons (middle), and mixed cases of one decaying through a neutral and the other through a charged Higgs boson (right).

* dermisek@indiana.edu
† elunghi@indiana.edu
‡ nmmcginn@indianax.edu
§ sshin@jbnu.ac.kr

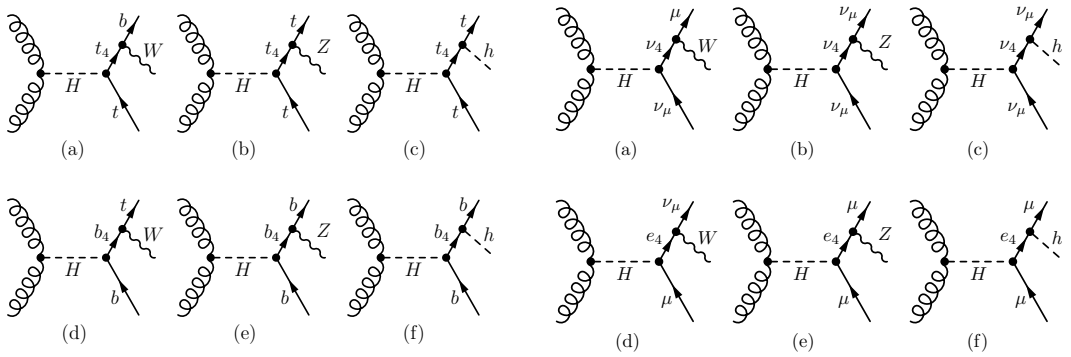

FIG. 2. Examples of new decay topologies of a heavy neutral Higgs boson through vectorlike quarks (left) and leptons (right). Similar decays are possible for the heavy CP-odd Higgs boson.

and e_4 is a charged vectorlike lepton (mixing with the SM muon) [3]. In the case of vectorlike quarks, the reach still extends to heavy Higgs masses up to $\lesssim 2.5$ TeV and vectorlike quark masses $\lesssim 2$ TeV at the HL-LHC [4].

We plan to summarize existing studies, extend them further and study the reach at future colliders. The benchmark model we consider is a type-II two Higgs doublet model augmented with vectorlike fermions whose quantum numbers are identical to the SM fermions [1, 5]. The same or very similar signatures can also be found in composite Higgs models or models with various top partners. In addition, these signatures can arise in models with Z' or W' with the neural (charged) Higgs boson in figures 1 and 2 replaced by Z' (W'). However, the rates for the final states in other models might not reach the rates that are possible in the 2HDM. Our results can be easily re-interpreted in these models, thus fostering possible collaboration with other groups.

[1] R. Dermisek, E. Lunghi, and S. Shin, JHEP **04**, 019 (2019), arXiv:1901.03709 [hep-ph].
[2] R. Dermisek, E. Lunghi, N. McGinnis, and S. Shin, JHEP **07**, 241 (2020), arXiv:2005.07222 [hep-ph].
[3] X. Cid Vidal *et al.*, "Report from Working Group 3: Beyond the Standard Model physics at the HL-LHC and HE-LHC," in *Report on the Physics at the HL-LHC,and Perspectives for the HE-LHC*, Vol. 7, edited by A. Dainese, M. Mangano, A. B. Meyer, A. Nisati, G. Salam, and M. A. Vesterinen (2019) pp. 585–865, arXiv:1812.07831 [hep-ph].
[4] R. Dermisek, E. Lunghi, and S. Shin, JHEP **03**, 029 (2020), arXiv:1907.07188 [hep-ph].
[5] R. Dermisek, E. Lunghi, and S. Shin, JHEP **02**, 119 (2016), arXiv:1509.04292 [hep-ph].