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Exotic Higgs Decays in Type-II 2HDMs at Future 100 TeV Hadron Colliders

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Thematic Areas:
■ (EF02) EW Physics: Higgs Boson as a portal to new physics
■ (EF08) BSM: Model specific explorations
■ (TF07) Collider Phenomenology

Abstract: The exotic decay modes of non-Standard Model (SM) Higgses in models with extended Higgs sectors can serve as powerful search channels to explore the space of Two-Higgs Doublet Models (2HDMs). A 100 TeV collider would be an ideal machine to search for those heavier Higgses. We study the three prominent exotic decay channels, $A \to HZ$, $A \to H^{\pm}W^{\mp}$ and $H^{\pm} \to HW^{\pm}$, and find that a 100-TeV *pp* collider can probe almost the entire region of the Type-II 2HDM parameter space that survives current theoretical and experimental constraints.

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Introduction - After the discovery of a light Standard Model (SM)-like Higgs boson at the LHC [1, 2], the search for Higgs 'siblings' has become even more pressing. Two-Higgs-Doublet Models (2HDMs) comprise a well-motivated class of extensions to the SM Higgs sector. In addition to the SM-like Higgs, these models contain one CP-even Higgs H, one CP-odd Higgs A, and a pair of charged Higgses $H^{\pm}$.

Conventional searches for non-SM Higgses mainly focus on modes where they decay into pairs of SM particles. While these modes have been proven to be effective in the discovery of the SM-like Higgs, they suffer from certain limitations when it comes to searches for non-SM heavy Higgses. (1) the couplings of A and H to the SM gauge bosons are suppressed since the current data constrain the parameter region of 2HDMs to the alignment limit, and (2) the decay channels to pair of quarks have limited sensitivity due to large QCD backgrounds or non-trivial interference effects while the decay channels to pair of leptons are usually suppressed except in certain limited regions of parameter space.

Exotic Higgs Decays - While degenerate Higgs spectra in supersymmetry-inspired 2HDMs are well-studied, a hierarchical spectrum in the most general 2HDM is still possible under both experimental and theoretical constraints. Additional exotic decay channels open up in this case, for example, the decay of a heavy Higgs to a lighter Higgs and an SM gauge boson. Once these modes open up, they typically become dominant in large regions of parameter space, thus reducing the branching fractions of the conventional decay modes and relaxing the experimental limits based on them.

A future hadron collider, like the Future Circular Collider (FCC) at CERN [3, 4] or the Super proton-proton Collider (SppC) in China [5], with a center of mass energy around 100 TeV[1], would be an ideal machine to study heavy non-SM Higgses. At such a machine, top quarks produced in heavy particle decays will be highly boosted, resulting in fat jets that can be effectively identified using top-tagging techniques and distinguished from the large SM backgrounds that typically pose a challenge at the LHC.

In this contribution, we will summarize previous results on the potential of a future 100 TeV hadron collider for the discovery of heavy non-SM Higgses in hierarchical Type-II 2HDMs [7, 8]. Taking into account theoretical considerations and experimental constraints, we propose two benchmark planes: **BP-A** ($m_A > m_H = m_{H^{\pm}}$) with $A \to HZ/H^{\pm}W^{\mp}$ and **BP-B** ($m_A = m_{H^{\pm}} > m_H$) with $A \to HZ$, $H^{\pm} \to HW^{\pm}$. Using machine learning and top-tagging techniques, we systematically study several different kinds of final state signatures.

BP-A ($m_A > m_H = m_{H^{\pm}}$)	**BP-B** ($m_A = m_{H^{\pm}} > m_H$)
$A \to HZ \to (bb/\tau\tau/tt)\ell\ell$	
$A \to H^{\pm}W^{\mp} \to tb\ell\nu$	$H^{\pm} \to HW^{\pm} \to (\tau\tau/tt)W^{\pm}$

The decay channels to third generation quarks are quite effective for heavy scalars in the small $\tan\beta$ region and complementary to the traditional $bb/\tau\tau$ search states.

Summary - Combining all these search channels, almost the entire parameter space in hierarchical Type-II 2HDMs, with mass splittings $m_A - m_H \gtrsim 150$ GeV, can be explored at a future Hadron collider, as shown in figure 1. We will also discuss several possible improvements and some other interesting signatures that should help cover the whole parameter region.

[1] We do not consider the High-Energy Large Hadron Collider (HE-LHC) which is designed to operate at a center of mass energy $\sqrt{s} = 27$ TeV [6].

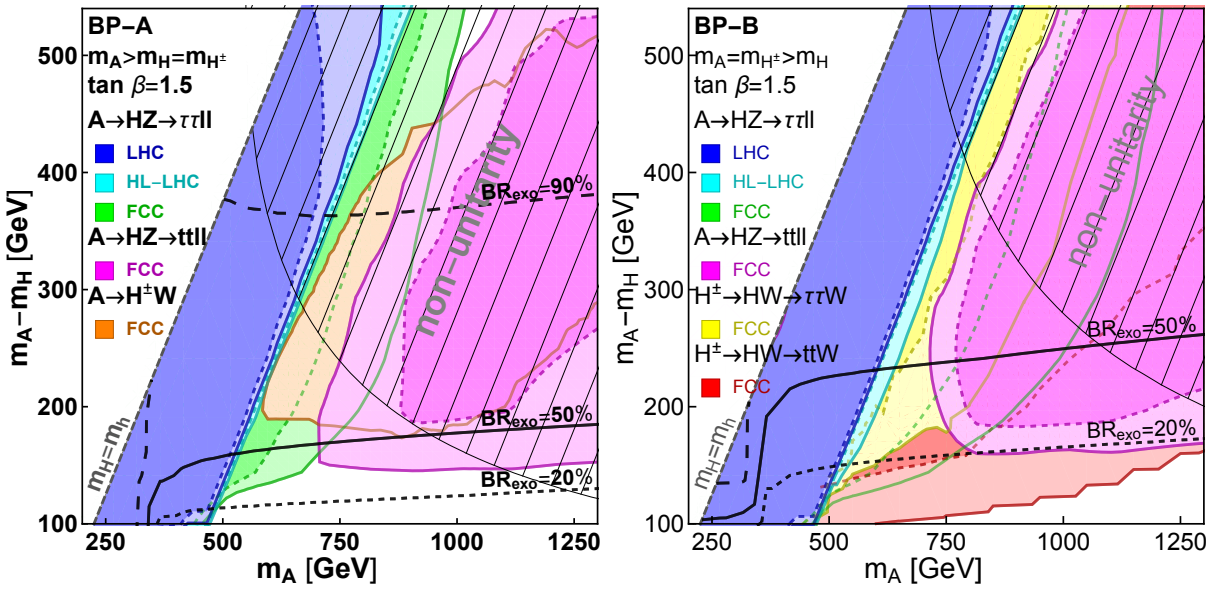

Figure 1: Reach for the exotic Higgs decay channels at the LHC, HL-LHC and 100 TeV pp collider for **BP-A** (left) with the mass hierarchy $m_H = m_{H^\pm} < m_A$ and **BP-B** (right) with the mass hierarchy $m_H < m_{H^\pm} = m_A$ [7, 8]. The dashed and solid curves indicate the 5σ discovery and 95% C.L. exclusion region, respectively.

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