Snowmass LOI: Directly Probing the CP-structure of the Higgs-Top Yukawa in $t\bar{t}h$ Production at HL-LHC and Future Colliders

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Thematic Areas: (check all that apply □/■)
■ (EF01) EW Physics: Higgs Boson properties and couplings
■ (EF02) EW Physics: Higgs Boson as a portal to new physics
■ (TF07) Collider phenomenology

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Abstract

Constraining the Higgs boson properties is a cornerstone of the LHC program and future colliders. This Letter of Interest discusses the *direct* measurement of the Higgs-Top Yukawa CP-structure in the $t\bar{t}h$ production. We plan to combine the most relevant decay channels, state-of-the-art of the kinematic methods, and machine learning techniques to further enhance the CP-sensitivity to the Higgs-top Yukawa.

The possible existence of a new CP-violating interaction can play a significant role in explaining the *matter-antimatter asymmetry* of the universe [1, 2]. Hence, the search for new sources of CP-violation is a clear target in the quest for new physics. A prominent path in this program is to improve our current understanding of the CP-structure of the Higgs coupling to fermions, particularly the top Yukawa coupling $y_t \sim 1$.

Whereas well-studied beyond the Standard Model (SM) CP-odd Higgs-vector boson interactions are one-loop suppressed, arising only via operators of dimension-6 or higher [3, 4], the CP-odd Higgs-fermion couplings could already manifest at tree level. Thus, the latter are naturally more sensitive to CP-violation than the former. Relevantly, this coupling structure can be *indirectly* probed by loop-induced interactions in Electric Dipole Moments (EDM). While this type of experiment can set very strong constraints on CP-mixed top Yukawa, the analyses critically assume the first generation fermions' Yukawas the same as in the SM and that CP-violation is limited to the third generation fermions [5]. Mild deviations on the poorly constrained strength or structure for the first generation fermions' Yukawas can appreciably deteriorate the limits. Thus, the *direct* (model independent) measurement of the Higgs-top CP-structure is required to disentangle potential new physics effects.

Analogously to the *direct* measurement of the top Yukawa strength, the *direct* measurement for its CP-phase also has the $pp \to t\bar{t}h$ channel as the most natural probe [6, 7, 8, 9]. Our *objective* will

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be to boost the prospects to *directly* access the Higgs-top CP-phase with the $pp \to t\bar{t}h$ process, using the most promising decay channels, the state-of-the-art kinematic reconstruction methods [10, 11], and *machine learning* techniques to maximally explore the complex multi-particle phase space.

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