Snowmass LOI: Higgs Properties at High Scales at the LHC

Dorival Gonçalves *[1], Tao Han †[2], Sze Ching Leung ‡[2], Satyanarayan Mukhopadhyay §[3], and Han Qin **(contact person)** ¶[2]

[1]Department of Physics, Oklahoma State University, Stillwater, OK, 74078, USA
[2]PITT PACC, Department of Physics and Astronomy, University of Pittsburgh, 3941 O'Hara St., Pittsburgh, PA 15260, USA
[3]Department of Theoretical Physics, Indian Association for the Cultivation of Science, Kolkata 700032, India

So far, measurements on the Higgs boson properties based on the signal strength are in full agreement with the Standard Model (SM) predictions [1, 2]. These measurements mostly focus on the on-shell Higgs boson production, exploring the Higgs properties at a low energy scale near the Higgs mass. A particularly important aspect would be to examine the Higgs sector across different energy scales, using the sizable off-shell Higgs boson rates at the LHC. The Higgs physics at high energy scales will be most sensitive to new physics beyond the Standard Model (BSM), and perhaps give us hints of solutions to the naturalness problem. As such, it is of special importance to study Higgs physics at high scales at the LHC and beyond.

Some initial explorations have been carried out for the off-shell production of the Higgs boson at the LHC to probe Higgs physics at higher energy scales by utilizing the process $gg \to h^* \to Z(\ell^+\ell^-)Z(\ell^+\ell^-)$ [3, 4]. We focus on the energy scale-dependence of the off-shell Higgs propagation, and of the top quark Yukawa coupling, $y_t(Q^2)$. The threshold effects in the Higgs propagator due to the existence of new states, such as a gauge singlet scalar portal and a possible continuum of states in a conformal limit, will lead to a measurable deviation in the differential distribution of the Z-pair invariant mass compared to SM prediction. We can also examine the modification of $y_t(Q^2)$ from its SM prediction in terms of the renormalization group running of the top Yukawa, which could be significant in the presence of large flat extra-dimensions. Furthermore, possible strongly coupled new physics in the top-Higgs sector is interesting to study. It can lead to the appearance of a non-local Q^2-dependent form factor in the effective top-Higgs vertex, which will also result in considerable deviations in the invariant mass distribution of the Z-boson pair.

With the rising popularity of machine learning in particle physics, we propose applying this technique to discriminate off-shell Higgs production from other processes, the final Higgs width sensitivity can be improved ranging from 5-10%. With this new technique, we also propose studying the form factor case mentioned above and the composite Higgs model where top partner is explicitly running in the loop by utilizing a different final state than before $gg \to h^* \to Z(\ell^+\ell^-)Z(\nu\bar{\nu})$. Benefiting from larger branching fraction of Z boson and the power of machine learning, we can probe BSM at higher energy scale than 4ℓ final state.

*dorival@okstate.edu
†than@pitt.edu
‡szl13@pitt.edu
§tpsnm@iacs.res.in
¶han.qin@pitt.edu

Beyond the off-shell Higgs measurements, we would like to explore Higgs production at a high transverse momentum, which also characterizes the high scale physics associated with Higgs properties.

References

[1] Georges Aad et al. Combined measurements of Higgs boson production and decay using up to 80 fb^{-1} of proton-proton collision data at $\sqrt{s} = 13$ TeV collected with the ATLAS experiment. *Phys. Rev. D*, 101(1):012002, 2020.

[2] Albert M Sirunyan et al. Combined measurements of Higgs boson couplings in proton–proton collisions at $\sqrt{s}$ =13 TeV . *Eur. Phys. J. C*, 79(5):421, 2019.

[3] Dorival Gonçalves, Tao Han, and Satyanarayan Mukhopadhyay. Off-shell higgs probe of naturalness. *Physical Review Letters*, 120(11), Mar 2018.

[4] Dorival Gonçalves, Tao Han, and Satyanarayan Mukhopadhyay. Higgs couplings at high scales. *Physical Review D*, 98(1), Jul 2018.