Snowmass Letter of Interest:

Using Lorentz boosted jets to constrain the inclusive production of Higgs bosons

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ABSTRACT

Despite the discovery of the Higgs boson decay in five separate decay channels many parameters of the Higgs boson remain largely unconstrained. This is because of the inaccessibility to all Higgs decay modes. In this contribution, we present an approach that is sensitive to all decays of the Standard Model Higgs boson, and potentially decays that go beyond the standard model. Our approach consists of performing an inclusive measurement of Higgs boson decays at a hadron collider by requiring the Higgs boson to be resolved as a single high p_T jet. With new approaches from machine learning and a modified jet reconstruction, we capture all decays in a minimally biased way. This should provide a model-dependent limit of the branching ratio of Higgs to jets, that can be translated to a limit on the total width, complementary to other Higgs width measurements.

Contents

1 Motivation

The detailed study of the Higgs mechanism is one of the primary goals in particle physics and a consideration of P5. In particular, the measurement of the parameters of the Higgs boson discovered at the Large Hadron Collider (LHC) will help decide if it is consistent with the Standard Model (SM) Higgs boson. For the next 15 years, the highly intense and energetic proton collisions of the LHC and HL-LHC will make this accelerator the only facility capable of producing Higgs bosons and tackling this task.In this contribution, we explore the possibility of constraining all the Higgs boson decay modes through the measurement of boosted Higgs boson jets at the LHC.

The measurement of inclusive Higgs boson production is only considered possible at a lepton collider through ZH and WWH fusion associated production [1; 2]. The recoil mass information obtained from the conservation of energy in the collision and the measurement of the Z boson decay allow for a full Higgs boson reconstruction. Instead, a hadron collider lacks the ability to reconstruct the full momentum of the collision. In this contribution, however, we explore the reconstruction of all the Higgs boson decays, whether visible or semi-visible, in a jet cone. To identify this jet we explore an event topology when the Higgs boson is produced with large transverse momentum and is recoiling against another jet.

This catch-all decays method, first proposed in [3], is sensitive to challenging decay modes with large background contributions such as $h \to gg$ or $h \to cc$. It should provide a constraint on the branching ratio of Higgs into jets which, together with other constraints on the cross section times branching ratio of specific Higgs decays, both visible and invisible, may be translated into an uncertainty on the Higgs boson total width. In future studies, we aim to reduce the model-dependence of this constraint, which can yield similar and complimentary sensitivity to direct LHC measurements of the Higgs boson width obtained through the measurement of off-shell $h \to ZZ$ production [4; 5].

2 Measurement Strategy

This analysis aims to extract the inclusive Higgs boson signal from the mass distribution of the reconstructed Higgs jet. It faces two major challenges.

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- The first is the inclusion of all the Higgs boson decay products, whether visible, semi-visible or invisible, in the reconstruction of the Higgs jet. For a high p_T Higgs boson ($p_T > 200$ GeV) Lorentz invariance enforces that the decay components be found within a jet cone with a distance parameter of 0.8[1]. For invisible objects, such as neutrinos or potentially dark matter, the angular resolution of longitudinal direction is limited to within the cone of the decay components of the resonant object.

  In [3], we explored a modified jet selection and reconstruction to include semi-visible decays, such as $h \to \tau\tau$ and $h \to WW^*$ decays. Instead of selecting the leading jet in the event, we selected a composite object, defined as the leading $p_T^{\text{jet+MET}}$ jet in the event. Then, we modified the mass reconstruction by adding regressed missing energy to the jet, before computing the mass. This improved the mass resolution for $h \to \tau\tau$ and $h \to WW^*$ decays and can naturally be extended broadly to all semi-visible decays.

- The second challenge is the extraction of the Higgs boson signal from background in an approach that is not sensitive to the decays of the Higgs boson. This implies a jet selection that aims to reduce the dominant multijet background while isolating the Higgs boson signal for all decays.

  In [3], we explored a deep neural network selection trained on particle-level information which showed improved sensitivity to commonly explored decays such as $h \to bb/\tau\tau$ and even some sensitivity to background-like decays such as $h \to gg$. However, by using the particles of the jet as input we introduce a bias on the Higgs decay structure. To avoid this, we studied a selection on collinear-drop-like variables [6], as a tool to isolate the color singlet Higgs jet, without added assumptions of its decay.

3 Outlook & Plans

In [3] we showed that this approach can be sensitive to a SM Higgs boson inclusive signal to a level of $0.14 \times \sigma_{\text{SM}}$ [2] with the data increase expected at the HL-LHC. This translates to a model-dependent bound on the total width with an uncertainty of $\delta\Gamma_h < 1.4$ MeV, comparable to off-shell measurements of the Higgs boson total width with an uncertainty of 1 MeV [5]. For a Snowmass white paper we plan to summarize the main points presented in [3] and expand on its strategy. In particular, we aim to demonstrate the feasibility of measuring not so well studied decays of the Higgs boson, such as $h \to gg$ and decays beyond the Standard Model. To this end, we plan to study the expected sensitivity both with new color singlet identification techniques such as [7] and with an anomaly-detection approach that leverages on a prior knowledge of well known decay modes of the Higgs boson.

References

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[1] In [3] the low p_T threshold of the Higgs jet is at least 400 GeV because it is driven by the data rate of the high-level trigger.

[2] $0.41 \times \sigma_{\text{SM}}$ for $h \to gg$ decays)