Snowmass2021 - Letter of Interest

Probing New Physics with Boosted Di-Higgs Signal using Fat Jet Signature

Thematic Areas:

■ (EF01) EW Physics: Higgs Boson properties and couplings
■ (EF02) EW Physics: Higgs Boson as a portal to new physics
■ (EF04) EW Physics: EW Precision Physics and constraining new physics
■ (EF08) BSM: Model specific explorations
■ (EF09) BSM: More general explorations

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In this proposal, we propose studying the prospect of resonant di-Higgs production at the future collider experiments utilising the jet substructure techniques, observing that the two b-jets coming out of the boosted Higgs boson may be interpreted as a single fat-jet (J_B). Hence, the distinguishing signal topology will be $pp \to J_B J_B$. Search strategies utilising boosted and collimated objects have proven to be spectacularly successful in searches at the LHC. The seminal ideas have burgeoned into many sophisticated methods that enable tagging jets arising from the decay of boosted heavy particles, improving searches for new topologies, investigating jet properties and mitigating underlying events and pile-up. Investigation of the di-Higgs signal utilising the fat jet signature will improve the sensitivity significantly and hence the future discovery potential of the di-Higgs signal also.

We are interested to systematically investigate the boosted and the semi-boosted regimes of the di-Higgs signal in the Beyond Standard Model (BSM) framework. As a UV complete scenario, we are considering the Two Higgs Doublet Model (2HDM) with specific Yukawa matrix ansatz[1], where $Y_{ij}^{(a)} = C_{ij}^{(a)} \cdot \min\{m_i,\, m_j\}/v$, with $C_{ij}^{(a)}$ being order one coefficients, m_i the mass of fermion i and v the electroweak vacuum expectation value. Such a pattern of couplings can explain the observed features of fermion masses and mixings and satisfies all flavor violation constraints arising from the exchange of neutral Higgs bosons. The rate for $\mu \to e\gamma$ decay and new contributions to CP violation in $B_s - \overline{B}_s$ mixing are predicted to be close to the experimental limits. In this framework, di-Higgs production rate will be enhanced and signal can be highly boosted with extra top Yukawa coupling. After being produced resonantly with the aid of extra large top Yukawa coupling, the heavy Higgs will further decay to two SM Higgs bosons which will be highly boosted for the heavy Higgs mass much above SM Higgs mass. It is quite important to mention that such enhancement in di-Higgs cross section for a $\mathcal{O}(TeV)$ mass resonance is not possible in scalar singlet extended scenario since the production rate will be highly suppressed due to severe limit on mixing from the recent searches for Higgs observable. Observation of such new resonant particles will provide many new insights about electro-weak scale.

Over the years, the phenomenology of 2HDM has been extensively studied[2]. However, most studies restrict the form of the Lagrangian by assuming additional discrete symmetries. The type-II 2HDM, for example, allows only one doublet to couple to up-type quarks, with the second doublet coupling to the down-type quarks and charged leptons. While this is natural in the supersymmetric extension, a discrete Z_2 symmetry has to be assumed to achieve this restriction in other cases. One motivation for such a discrete symmetry is to suppress Higgs-mediated flavor changing neutral currents (FCNC)[3]. However, it has been recognized that there is no need to completely suppress such FCNC[4], an appropriate hierarchy in the Yukawa couplings can achieve the necessary suppression. Recently, a modified ansatz for the Yukawa couplings of Higgs doublet Φ_a, where $Y_{ij}^{(a)} = \sqrt{2} C_{ij}^{(a)} \min\{m_i,\, m_j\}/v$ has been proposed[1] and which is valid for the couplings of each of the Higgs doublet. Here $C_{ij}^{(a)}$ are order one coefficients, m_i stands for the mass of fermion i and $v \simeq 246$ GeV is the electroweak vacuum expectation value (VEV). This modified ansatz can be realized in the context of unification[5] also. We refer to the 2HDM with no additional symmetry as simply the two Higgs doublet model (2HDM), with no qualifier, as opposed to type-I or type-II models, which require additional assumptions.

In short, the improved precision of the current and future experiments in measuring the di-Higgs signal is awaiting to discover potential new physics in the near future. For Snowmass 2021, we are interested in extending this study to explore new physics looking the prospect of resonant di-Higgs production at the future collider experiments (14 TeV, 27 TeV and 100 TeV) utilising the fat jet signatures.

References

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