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A Boosted Decision Tree for Signal and Background Discrimination in Boosted $HH \to b\bar{b}b\bar{b}$ Searches

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The production of Higgs boson pairs provides a direct probe of the Higgs sector and its self-interactions. However, searches in the $HH \to b\bar{b}b\bar{b}$ final state face substantial challenges due to the large multijet background. In the boosted regime, where each Higgs boson is reconstructed as a large radius jet, combining kinematic and jet substructure information offers an opportunity to improve signal and background discrimination.

This work presents the development and evaluation of a boosted decision tree (BDT) classifier for the boosted gluon-gluon fusion (ggF) $HH \to b\bar{b}b\bar{b}$ analysis. The classifier combines event-level kinematic observables with jet substructure variables to exploit correlations that are not fully captured by individual discriminating variables. Its performance and stability are assessed through four-fold cross-validation, yielding area under the receiver operating characteristic curve (AUC) values between 0.73 and 0.78. The model is further examined using SHapley Additive exPlanations (SHAP), which identify physically motivated observables, particularly the pseudorapidity separation between the Higgs boson candidates and their reconstructed masses, as important contributors to the classification.

Finally, the BDT score is incorporated into a binned statistical fit and compared with the invariant mass of the Higgs boson pair, m_{HH}. Under statistical-only assumptions, the expected upper limit on the signal strength improves from $\mu = 8.61$ to $\mu = 6.99$, corresponding to an improvement of approximately 20\%. These results demonstrate the potential of multivariate classification to enhance the sensitivity of boosted di-Higgs searches by exploiting the multidimensional structure of signal and background events.

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