Improving the sensitivity to the Higgs boson self-coupling in the $HH \to bb\tau\tau$ channel

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The Standard Model of Particle Physics (SM) predicts Higgs bosons to couple to themselves in the form of a 3-point interaction. The strength of this self-coupling, generally referred to as λ, appears in the Higgs potential assumed in the SM and is thus a very important parameter to measure. In the SM, the value of λ can be computed at lowest order from the measured values of the Higgs boson mass and the Fermi constant, so that a measurement of λ provides a direct test of the SM. Instead of directly quoting the measured value of λ it is useful to refer to the self-coupling modifier κ_λ, which is given as the measured value of λ divided by the SM prediction, such that a value of $\kappa_\lambda = 1$ corresponds to the SM prediction.

The most sensitive probe of the self-coupling is the production of a pair of Higgs bosons. For collisions of protons at a centre-of-mass energy of 13 TeV, pairs of Higgs bosons are mainly produced through gluon-gluon fusion (ggF). Destructive interference between the two contributing leading-order Feynman diagrams leads to a very small cross section of $\sigma_{\mathrm{ggF}}(pp \to HH) = 31\,\mathrm{fb}$, such that Higgs boson pair production has not yet been observed experimentally. As only one of these two Feynman diagrams contains a Higgs boson self interaction, the interference of the two diagrams leads to the cross-section depending very strongly on the self-coupling parameter. This makes Higgs boson pair production a very sensitive probe of κ_λ, and the fact that di-Higgs production has not been observed yet already constrains the possible value range of κ_λ. A combination produced in 2023 of single- and di-Higgs production measurements performed by the ATLAS collaboration excluded values outside the interval $-0.4 < \kappa_\lambda < 6.3$ at 95% confidence level and was dominated by the results from di-Higgs measurements.

My work focuses on the $HH \to b\bar{b}\tau^+\tau^-$ channel. This channel combines a reasonably high branching fraction of 7.3% with a relatively clean final state, making it one of the three golden channels for observing di-Higgs production. The goal of my master thesis is to improve the sensitivity of the latest ATLAS analysis of this channel, reducing the width of the confidence interval obtained for κ_λ. The general approach is to make use of the fact that not only the total di-Higgs production cross-section depends on κ_λ, but that also the shapes of a number of kinematic distributions show a characteristic dependence on κ_λ as a result of the interference between contributing Feynman diagrams. While the expected number of events is too low to directly measure any distribution shapes, distributing events between kinematics based analysis categories can help to extract this additional information. I investigated multiple machine learning based approaches for defining such analysis categories which I will present in this talk.