Simulation-Based Inference for the study of Higgs Self-Coupling in the $HH \rightarrow bb\tau\tau$ Decay Channel with the ATLAS Experiment and Machine Learning Benchmarks for Uncertainty Quantification

The 2012 Higgs discovery and the subsequent mass measurement are important milestones for the BEH mechanism, which gives mass to fundamental particles. However, the Higgs mass is only one of the 2 free parameters in the Higgs potential; the other is the Higgs self-coupling constant, lambda. A study of the di-Higgs process could give us a direct measurement of the lambda parameter, thus giving us a more precise measurement of the higgs potential.

Simulation-Based Inference (SBI) has emerged as a robust machine learning framework for high-dimensional parameter estimation, circumventing the information loss associated with traditional histogram-based methods. SBI is particularly relevant for Di-Higgs (HH) production, where we expect substantial destructive interference in the cross section. Following the recent successful application of SBI in the ATLAS off-shell Higgs analysis, we present an ongoing study applying these techniques to the $HH \rightarrow bb\tau\tau$ channel. This work aims to quantify the gains in sensitivity in $\kappa\lambda$ estimation relative to standard summary statistics, using the GNN classifier score. Preliminary results and the validation of the neural estimator via calibration tests will be discussed, highlighting the potential for NSBI to enhance the physics reach of future LHC datasets.

High-dimensional parameter estimation is also necessary to reduce systematic uncertainties. Various other methods have been proposed over the last decade to estimate systematic uncertainty accurately. A fair benchmark is required to compare such methods in the context of uncertainty quantification properly. To address this, the Fair Universe project organised the Fair Universe HiggsML Uncertainty Challenge (https://arxiv.org/abs/2410.02867), which ran from Sep 2024 to 14th March 2025 and was accepted as an official NeurIPS2024 competition. The goal of the challenge was to measure the Higgs to tau+ tau- cross-section, using a dataset of particle 4-momenta. Participants were evaluated on both their ability to precisely determine the correct cross-section and their ability to report correct, well-calibrated uncertainty intervals.