Thesis abstract Arnaud Maury

« Neural Simulation-Based Inference study of the off-shell Higgs boson decaying into four leptons in the ATLAS experiment and commissioning of Gaussian-Sum Filtering for electron tracking »

The discovery of the Higgs boson was jointly announced by ATLAS and CMS on July 4th, 2012, confirming the Standard Model (SM) mechanism for mass generation. This 125 GeV resonance of the on-shell Higgs boson was discovered through several decay channels, including the $H \rightarrow ZZ \rightarrow 4\ell$ ($H^*4\ell$) channel. The study of the Higgs boson in its off-shell mass, above 180 GeV, gives us new insights into its properties, including its off-shell signal strength μ, total decay width Γ_H, and various couplings at large centre-of-mass energies. However, the off-shell Higgs boson is challenging to measure because of its non-resonant nature, large backgrounds, and especially large destructive quantum interference.

Neural Simulation-Based Inference (NSBI) is a set of Machine Learning (ML)--based statistical techniques which allow the measurement of fundamental parameters with Maximum Likelihood fit using Neural Networks' estimate of likelihood ratios on a per-event basis. NSBI enables the use of the full multi-dimensional final state information, unlike traditional HEP analyses where data is binned through low-dimensional summary statistics, thereby losing sensitivity. A new NSBI analysis of the off-shell Higgs boson production in the $H^*4\ell$ channel has been carried out using 139fb-1 of pp collision data at $\sqrt{s}=13$ TeV collected by the ATLAS experiment during Run 2 of the LHC. It is shown that NSBI is particularly well suited to handle quantum interference and is sensitive to subtle non-resonant signals.

Because of quantum interference, the statistical confidence intervals are not asymptotic and must be determined using Neyman construction. Due to NSBI being a per-event analysis while traditional HEP analyses are histogram-based, a new method for the Neyman Construction of confidence intervals using per-event pseudo-experiments has been developed. A series of diagnostic checks to demonstrate the robustness of the method are detailed. In particular, negative weight events from the considered datasets pose serious challenges.

The ATLAS detector is being upgraded for the upcoming High Luminosity (HL-LHC) phase, including the development of a novel all-silicon Inner Tracker (ITk). The intense environment of HL-LHC will demand greater computational requirements. ACTS is an open-source software developed for particle tracking, designed for multi-threading, high performance, and durable maintainability. It is scheduled to become the ATLAS reconstruction software for HL-LHC.

Due to bremsstrahlung, electron tracking with the standard Kalman Filter (KF) algorithm is not optimal. The Gaussian Sum Filtering (GSF) track fitting algorithm is better suited. The newly-developed ACTS GSF algorithm is first validated in ACTS standalone before being commissioned in Athena, the software framework of ATLAS, and validated on HL-LHC simulation.