Thesis abstract Marko Mihovilovic

« Search for Higgs boson pair production and development of the High Granularity Timing Detector with the ATLAS experiment at the LHC»

This thesis presents contributions to both detector instrumentation and Higgs boson physics within the ATLAS experiment at the Large Hadron Collider (LHC). It combines the development of detector technologies for the High-Luminosity LHC (HL-LHC) with studies of Higgs boson pair production, one of the most important processes for exploring the Higgs sector and testing the Standard Model of particle physics. The first part of the thesis focuses on the High Granularity Timing Detector (HGTD), a new ATLAS detector subsystem that will provide precision timing measurements in the forward region during HL-LHC operation. The HGTD is designed to mitigate the effects of up to 200 simultaneous proton--proton interactions per bunch crossing by providing timing resolutions of a few tens of picoseconds. The detector is based on Low Gain Avalanche Detectors (LGADs) coupled to dedicated ALTIROC front-end ASICs. This thesis presents the detector concept and performance requirements, followed by detailed studies related to module production and qualification. Contributions include the development and optimization of module assembly procedures, precision metrology measurements, electrical characterization, thermal cycling campaigns, and production testing. The results demonstrate the robustness of the detector modules and contribute to their qualification for integration into the HGTD demonstrator and, ultimately, the ATLAS upgrade programme. The second part of the thesis is dedicated to the study of Higgs boson pair (HH) production. Since the discovery of the Higgs boson in 2012, understanding the properties of this particle has become a central objective of the LHC physics programme. In particular, Higgs boson pair production provides direct sensitivity to the Higgs boson self-coupling, allowing the structure of the Higgs potential to be probed experimentally for the first time. Furthermore, the vector boson fusion (VBF) production mode offers a unique opportunity to study the interactions between Higgs bosons and electroweak gauge bosons, making it especially sensitive to possible deviations from Standard Model predictions. The thesis first presents contributions to the combined Run~2 ATLAS and CMS search for Higgs boson pair production, which establishes the most stringent constraints to date on non-resonant HH production and anomalous Higgs boson couplings. This work involved studies of the statistical combination methodology and the extraction of constraints on the Higgs boson self-coupling. Building upon these results, the thesis develops a search for non-resonant Higgs boson pair production in the boosted $HH\rightarrow b\bar{b}\tau^+\tau^-$ final state using the Run~2 and partial Run~3 ATLAS datasets. The analysis targets events in which the Higgs bosons are produced with large transverse momentum, resulting in highly collimated decay products. Dedicated trigger studies, event selection strategies, boosted object reconstruction techniques, and data-driven background estimation methods are developed. Machine-learning techniques are employed to improve signal--background discrimination and to enhance the separation of gluon-fusion and vector-boson-fusion Higgs boson pair production mechanisms. The analysis extends the ATLAS HH programme to a new boosted topology and improves the sensitivity to Higgs boson pair production and its underlying interactions.

Together, the detector and physics studies presented in this thesis contribute both to the preparation of ATLAS for HL-LHC operation and to the ongoing effort to understand the mechanism of electroweak symmetry breaking through precision studies of the Higgs sector.