Annual Report on PhD Activity (2nd year)

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September 22, 2025

The work and research I conducted during the 2024/2025 academic year as a PhD student at the University of Genoa and a researcher in the ATLAS experiment can be summarized as follows:

- Development of GN3 the new ATLAS Flavour Tagging Algorithm
- ATLAS VH(bb/cc) Run2 + partial Run3 Analysis
- Research stay at the *Max Planck Institute*
- Workshops and Conferences

1 Development of GN3, the new ATLAS Flavour Tagging Algorithm

During the second year of my PhD, I worked in the development of a new flavour-tagging algorithm, GN3, which will be employed in upcoming ATLAS analyses using data collected during Run 2 and Run 3 of the LHC. GN3 is the successor of GN2, a transformer-based model designed to infer the probability that a reconstructed jet in ATLAS originates from a b-quark or a c-quark produced during the proton-proton collision at LHC.

Like GN2, GN3 relies on a transformer architecture, but its set of input features has been significantly extended. In addition to reconstructed tracks produced by charged particles traversing the ATLAS detector, GN3 also incorporates calorimeter clusters from neutral particles as well as leptonic tracks (electrons and muons), which were not included in the GN2 training.

GN3 has demonstrated substantially improved performance compared to its predecessor. These advancements are illustrated in the plots available at this link, and will be further documented in an upcoming ATLAS PUB Note, for which I am the main editor. The note is expected to be released in the coming months.

In addition, this year I was responsible for releasing to the collaboration the fully calibrated GN2 tagger, tuned to Run 2 and partial Run 3 data. This tagger has since been successfully employed in numerous ATLAS analyses, delivering significant results across several areas of high-energy physics, particularly in Higgs measurements and di-Higgs searches.

2 ATLAS VH(bb/cc) Run2 + partial Run3 Analysis

A large part of my work during this year of my PhD has been dedicated to the ATLAS ongoing analysis aimed at measuring the decay of the Higgs boson into pairs of charm and bottom quarks in the associated production channel with a vector boson, $V(Z|W)H$. This process, which has proven to be the most sensitive to probing the interaction of the Higgs boson with bottom and charm quarks, is studied using the full Run2 dataset of the LHC together with a portion of the dataset collected during the ongoing Run3 phase (2022–2024)[1].

The importance of this analysis is considerable within the high-energy physics community, as it will significantly improve our understanding of the Higgs boson and, in particular, strengthen the current constraints on the charm Yukawa coupling in the decay $H \to c\bar{c}$.

[1] Total expected integrated luminosity of $\sim 300 fb^{-1}$ ($140 fb^{-1}$ from Run2 and $\sim 160 fb^{-1}$ from Run3)

My contribution to this analysis includes the production of Monte Carlo datasets through the dedicated analysis framework and the continuous updates of this package, which must evolve in line with the latest recommendations for reconstructed objects (particles, jets, etc.) provided by the ATLAS experiment and directly used in the analysis. In addition, I am directly responsible for the fitting of data to Monte Carlo simulations, which is essential to obtain the final measurement of the $VH(bb|cc)$ process.

3 Research stay at the *Max Planck Institute*

From January to the end of September 2025, I was a PhD student in the ATLAS group at the Max Planck Institute in Munich, Germany, under the supervision of Prof. Marumi M. Kado. This institute co-funds my PNRR PhD fellowship together with the University of Genoa. During this period, I had the opportunity to work directly with the Particle Flow subgroup of ATLAS at the institute.

Particle Flow in ATLAS refers to the reconstruction of objects such as electrons, photons, and jets by combining information from reconstructed tracks in the tracking detectors (for charged particles) and from calorimetric measurements obtained from the electromagnetic and hadronic calorimeters of the experiment.

Within this context, my work focused on initiating the design of a new Particle Flow algrithm using machine learning architectures such as transformers. The ultimate goal is to develop a single, global reconstruction algorithm[2], capable of reconstructing the key objects used in analyses, including electrons, photons, and jets, as well as hadrons (both charged and neutral) that leave direct signatures in the detector.

This project, which is still in the R&D phase and will only be deployed in the next HL-LHC stage (Run 4), has the potential to revolutionize the current approach to particle reconstruction in ATLAS and to improve it significantly, thereby impacting the future ATLAS analyses during Run 4.

4 Workshops and Conferences

- **ICNFP, Crete (Greece), 16-31/07/2025. Plenary talk: Machine Learning in ATLAS**:
- **QCD@LHC2025, Stony Brook (US), 8-12/09/2025. Plenary talk: Recent Higgs Measurements at LHC**

[2]Currently, object reconstruction and calibration is handled by separate ATLAS groups such as *e/gamma*, *muon*, etc.