

Boccardo Lucrezia

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DOTTORATO IN FISICA E NANOSCIENZE - CICLO XXXIX - SECOND YEAR REPORT

TUTORS

Andrea Coccaro: Researcher at *Istituto Nazionale Fisica Nucleare* division of Genova

Federico Sforza: Professor at *University of Genova* - Physics Department

RESEARCH ACTIVITY

I carry out my research activity in the ATLAS experiment at the Large Hadron Collider at CERN. The ATLAS experiment is at the forefront of particle physics and its efforts focus on the understanding of the fundamental building blocks of our Universe through high-energy collisions of protons and heavy ions. My work focuses on three main areas of research: Higgs physics, Standard Model precise measurements, and flavor tagging. They will be described in more detail in the following sections. From September 2024 to September 2025, I conducted my research at the University of Geneva and at CERN, as a Swiss Excellence Fellow under the local supervision of professor Tobias Golling, and I participated in the 2025 data taking operations for the ATLAS experiment as a shifter in the Control Room for the Inner Detector desk.

FLAVOUR TAGGING

Many analyses in the ATLAS experiment rely on flavor tagging, which is the identification of the quark that originated a particular jet that is reconstructed in the detector. In recent years, flavor tagging has undergone a transformative shift due to the introduction of Graph Neural Networks and transformers: the new algorithm, GN2, shows improvements in c -jet efficiency (the probability of mistakenly tagging a c -jet as a b -jet) of almost a factor 4 with respect to the algorithm that was used in Run 2. However, this algorithm has been trained on Monte Carlo samples, and its behavior on real, actual data is not guaranteed to be the same: for this reason, it is calibrated through special analyses that are carried out to extract scale factors to re-weight the probability of tagging a c -jet as a b -jet in simulation and take into account this possible mismatch. During my second year, I continued my work on the calibration and the evaluation of the c -jet efficiency using a sample of c -jets produced in association with a W boson. This task was my qualification project to become an official ATLAS author, and I achieved this role in February 2025. I am currently working on a generalisation of the calibration to an inclusive sample of c -jets. During my tenure as a Swiss Excellence Fellow, I worked with the University of Geneva team on Optimal Transport, a novel calibration technique that provides a continuous calibration of GN2 using transport maps instead of weights. In January 2025, I became one of the people responsible for the production of samples which are used in the training and the calibration of flavour tagging algorithms.

HIGGS PHYSICS

One of the main goals of the Large Hadron Collider was the discovery of the much sought after Higgs boson. This extraordinary feat was achieved in 2012, but much is still to be known about this boson that is responsible for the mass of the other Standard Model particles. Among the many analyses carried out in ATLAS, the $VH, H \rightarrow b\bar{b}, c\bar{c}$ analysis, which is the associated production of a vector boson W or Z with a Higgs boson decaying to b - or c -quarks, has the task of precisely measuring the coupling of the Higgs boson to the two quarks. I am currently involved in this analysis, which will include data from both Run 2 and Run 3 of the LHC. The analysis is divided into two topologies, based on the p_T of the Higgs boson: the resolved topology, in which the Higgs boson decays into quarks that originate two jets of radius $R = 0.4$, or, at higher p_T , the boosted topology, in which there is only one large R jet of $R = 1$. In both cases, I contribute as one of the main maintainers of the analysis framework, and I also work on studies of flavour-tagging performance and modelling, as well as the preparation and management of the datasets. At the beginning of 2025, I was also involved in a study that was included in ATLAS and CMS's inputs to the European Strategy for Particle Physics. The study aimed to perform a projection of $VH, H \rightarrow b\bar{b}, c\bar{c}$ sensitivity for High-Lumi LHC, the new phase of the Large Hadron Collider that is expected to reach luminosities as high as 3 ab^{-1} . In this study, existing Run-2 results were extrapolated to the High-Lumi LHC

conditions. The projections indicate about 7% precision on $H \rightarrow b\bar{b}$ and an expected upper limit of 2.2 times the Standard Model prediction for $H \rightarrow c\bar{c}$. My contribution focused on studying the impact of improved c -jet rejection on the overall significance of the measurement.

STANDARD MODEL ANALYSIS

The ATLAS experiment also performs extremely precise measurements of already-known quantities from the Standard Model, in order to test the consistency of the theory with data and reduce uncertainties, increasing the sensitivity to new physics. I am currently involved in a precision measurement of the production cross-section of a Z in association with one or two c -jets. This analysis uses a similar framework as the one used for the VH analysis mentioned above, and I am mostly involved in framework maintenance and flavour tagging studies.

PHD COURSES

Machine Learning for Particle Physics (course from the Master's degree in Physics): *A. Cocco, F.A. Di Bello, R. Torre*

QCD and Collider Physics: *S. Marzani*

Advanced Statistics for Data Analysis: *F. Badaracco, F.A. Di Bello, F. Parodi*

2025 European School of High Energy Physics to be attended in October 2025

PUBLICATIONS

The ATLAS collaboration, **Measurements of the production cross-section for a Z boson in association with b - or c -jets in proton-proton collisions at $\sqrt{s} = 13$ TeV with the ATLAS detector**, [Eur. Phys. J. C 84 \(2024\) 984](#)

The ATLAS Collaboration, **Expected sensitivity of the ATLAS experiment to $H \rightarrow b\bar{b}$ and $H \rightarrow c\bar{c}$ decays in the VH production mode at the High Luminosity LHC**, [ATL-PHYS-PUB-2025-012](#)

The ATLAS & CMS Collaborations, **Highlights of the HL-LHC physics projections by ATLAS and CMS**, [ATL-PHYS-PUB-2025-018](#)

CONFERENCES AND WORKSHOPS

HIGHLIGHTED CONFERENCES ARE LINKS TO THE PUBLIC PAGE OF MY CONTRIBUTIONS, NON-HIGHLIGHTED CONFERENCES ARE ATLAS INTERNAL

ATLAS Collaboration Week, CERN, 14 - 18 October 2024. Poster: *Run 2+3 prospects for the $VHbb/cc$ analysis with the GN2 flavour tagger*

Villa Boninchi ML Workshop, Geneva, 21-25 October 2024. Talk: *FTAG in ATLAS: an overview of Run 2*

LHCC, Large Hadron Collider Committee Conference, CERN, 18 November 2024. Poster: *Measurements of the production cross section for a Z boson in association with b - and c -jets in proton-proton collisions at $\sqrt{s} = 13$ TeV with the ATLAS detector*

ATLAS Collaboration Week, CERN, 17 - 21 February 2025. Poster: *GN2 calibration and c -jet efficiency evaluation using $W + c$ events*

CIPANP, Conference on the Intersections of Nuclear and Particle Physics, Madison, Wisconsin, USA, 09 - 13 June 2025. Talk: *Focus talk on recent Higgs measurements*

XVIII ATLAS Italia Workshop, Udine, 01 - 03 July 2025. Talk: *$VH(bb,cc)$ Resolved/Boosted analyses Run2 + partial Run 3*

QCD@LHC 2025, Stonybrook University, NY, USA, 08 - 12 September 2025. Talk: *Non-resonant HH searches and $H+HH$ combinations by ATLAS and CMS*

ATLAS Higgs and diHiggs Workshop, the University of Warwick, UK, 15 - 19 September 2025. Talk: *Object ID and Calibration with ML*

FELLOWSHIPS AND AWARDS

Swiss Excellence Fellowship: one-year fellowship awarded by the Swiss Confederation to conduct research at the University of Geneva, under professor Tobias Golling. The project focuses on the application of innovative machine learning techniques to particle physics, with a focus on flavour tagging.