PhD/MSc Project in ALICE 2025 with the South African team

Title: e-μ Correlation studies in pp and Pb-Pb collisions in ALICE using LHC Run 3 data

ALICE Principal Investigators:

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Project Description

ALICE (A Large Ion Collider Experiment) [1] is one of the 4 major experiments at the Large Hadron Collider (LHC). It is a dedicated heavy-ion detector designed to study the physics of the strongly interacting primordial state of matter known as the quark-gluon plasma (QGP) at the highest energy densities reached in the laboratory so far. The QGP is studied using heavy-ion collisions (A-A) at ultra-relativistic energies provided by the LHC. ALICE studies the QGP by comprehensively studying particles (hadrons, leptons, photons, etc.) produced in these collisions. In Run 1 (2009-2013) and 2 (2015-2018), ALICE collected more than 10 petabytes of raw data and quickly expanded the knowledge gathered in previous experiments by identifying key physics measurements to further our understanding of the hot and dense QGP created in A-A collisions [2]. ALICE is the leading heavy-ion experiment in the world. This has been facilitated by the increased luminosity (interactions rates per unit cross-section) of the LHC to unprecedented peak luminosities of ~10^{27}cm^{-2}s^{-1}. One such key observable is the production of heavy-flavour hadrons i.e. hadrons containing heavy quarks produced in the collision via initial hard scattering processes. The characteristic flavour of heavy quarks is conserved throughout the evolution of the medium formed in A-A collisions. Their measurement illuminates in-medium energy loss mechanisms, propagation and hadronization, making heavy quarks (or heavy flavours) excellent probes of the QGP. Therefore, it is crucial to understand their interaction and their evolution in the underlying medium. More experimental data on heavy-flavour decay is necessary to improve the available theoretical models.

In ALICE, heavy-quark production has been studied by exploiting various experimental techniques utilizing the hadronic and leptonic (electron or muon) decay channels. This project entails looking into the production of these heavy quarks and their evolution in the QGP via electron-muon correlation measurements using the ALICE Run 3 detector which is recording pp and Pb-Pb collisions at 100 times the rates achieved in Runs 1 and 2. With these conditions, it is feasible to measure the correlations of electrons and muons in the ALICE central ($|\mu| < 1$) and forward ($-4.0 < \mu < -2.5$) pseudorapidity, respectively.

The semi-leptonic decay of heavy-flavour hadrons to a combination of lepton and hadron products will sometimes produce correlated electron-muon (e-μ) pairs. The pairs are oppositely charged (or “signed”) and, at sufficiently high transverse momenta, reflect the azimuthal direction of their parent particles. In this way e-μ pairs are a potential probe of heavy-flavour quark pairs, both for independent heavy-flavour research and eventually in studies of the quark-gluon plasma (QGP). The advantage of using this channel is that e-

μ would provide a cleaner and lower background signal than other currently utilised correlation probing methods. However, it has the disadvantage of being limited by statistics due to the ALICE detector's geometry. The expected increase in the statistics in Run 3 enabled by the ALICE Upgrades [2] and continuous readout opens a window to explore the feasibility of this differential study. Standalone Pythia 8 simulations have been used to predict the viability of undertaking such an analysis using this channel in pp data at 13.6 TeV in ALICE. The simulations were used to estimate the electron-muon signal pairs' statistics in a year to 3 years of Run 3 data-taking [3]. However, in that study, the realistic detector conditions were not considered since the reconstructed MC and experimental data were not yet ready for a comprehensive analysis when the study was being conducted. Therefore, this project will extend the study to include realistic simulation and experimental data.

Objectives

The objective is to analyze anchored (realistic) Monte Carlo simulation data to investigate the production of heavy-flavour via the electron-muon (e-μ) decay process in pp collisions at $\sqrt{s}$ = 13.6 and 5.36 TeV and the analysis of data collected in pp 2023-2024. A comprehensive pp study could potentially lead to an analysis of e-μ pairs in Run 3 Pb-Pb collisions at $\sqrt{s_{NN}}$ = 5.36 TeV. The study will involve analyzing anchored Monte Carlo (MC) data, i.e. MC including realistic detector configuration, and then extend the study to the analysis of dedicated pp/Pb-Pb data collected by ALICE in Run 3. The tools and data samples are available on the ALICE GRID as a requirement by the ALICE Collaboration. ALICE data analysis tutorials are presented 3 times a year by the ALICE O2 team.

The data analysis, presentation of results and regular updates would be done in line with the ALICE Physics Working Group Heavy Flavour (PWG-HF), the O2 project.

The candidate will learn to work in a modern high-energy physics data analysis framework, written in C++ and based on ROOT and ALICE Online-Offline (O2). The work will also include Monte-Carlo simulations within this framework and the usage of the worldwide LHC ALICE computing grid.

Requirements

The candidate will be expected to follow the tutorials to get familiar with the analysis techniques. The data analysis, presentation of results and regular updates would be done in line with the ALICE Physics Working Group Heavy Flavour (PWG-HF), the O² project.

The candidate will be expected to have a strong physics and/or computer/software background, know how to code in C++/ROOT, and Python, and be willing to learn the ALICE Online-Offline (O2) framework.

References:

[1] "*The ALICE experiment at the CERN LHC*", The ALICE Collaboration, et al, 2008 JINST 3 S08002, 10.1088/1748-0221/3/08/S08002.

[2] ALICE upgrades during the LHC Long Shutdown 2, ALICE Collaboration, JINST 19 (2024) P05062, https://iopscience.iop.org/article/10.1088/1748-0221/19/05/P05062

[3] A Feasibility Study for Electron-Muon Correlations at ALICE, Nina Nathanson, Thomas Dietel, Zinhle Buthelezi and Siegfried Förtsch, MSc Thesis, August 13, 2024, UCT. And *References therein*