ABSTRACT

This thesis investigates the properties of hot and dense QCD matter produced in high-energy nuclear collisions at the CERN LHC, using data from the ALICE detector. At extreme temperatures and energy densities, nuclear matter transitions into a deconfined state of quarks and gluons—the quark–gluon plasma (QGP)—governed by Quantum Chromodynamics (QCD). Understanding its equation of state, transport properties, and phase structure requires precise event-by-event measurements of fluctuations, correlations, and collective flow.

The first part focuses on event-by-event mean transverse momentum ($\langle p_{\mathrm{T}} \rangle$) fluctuations in Pb–Pb and Xe–Xe collisions. Higher-order moments such as skewness and kurtosis reveal non-Gaussian features sensitive to initial-state fluctuations and collective dynamics. Results suggest the formation of a thermalized medium in most-central collisions, supported by hydrodynamic models. A baseline study in pp collisions at similar multiplicities, along with PYTHIA8 simulations with color reconnection, indicates a role for both initial- and final-state effects.

The second part introduces a new observable, $v_0(p_{\mathrm{T}})$, to study long-range p_{T} correlations and radial flow. This method enables p_{T}-differential measurements while suppressing short-range nonflow effects. The observed mass ordering at low p_{T} and quark-recombination-like behavior at high p_{T} reflect collective expansion and partonic dynamics. A blast-wave model with event-by-event fluctuations in freeze-out temperature and flow velocity, fitted via Bayesian analysis, provides new constraints on freeze-out dynamics. The extracted freeze-out temperatures are systematically higher than those from traditional p_{T} spectra, likely due to reduced resonance decay effects. Together, these findings establish $v_0(p_{\mathrm{T}})$ as a sensitive and complementary observable for investigating the collective

dynamics and hadronization mechanisms of the QGP.

The final part examines correlations among conserved charges—net-baryon, net-charge, and net-strangeness—via cumulants of net-proton, net-kaon, and net-charge distributions in Pb–Pb collisions. Significant deviations from Poisson expectations signal correlated particle production influenced by conservation laws and resonance decays. Comparisons of these measurements with hadron resonance gas models help constrain chemical freeze-out conditions.

Together, these studies offer new insights into the properties, correlations, and collective behavior of the QCD matter formed at the LHC.