

Abstract

The goal of high-energy nuclear physics is to characterise the phase diagram of QCD. From calculations on the lattice, it is predicted that a crossover phase transition takes place for baryon-number symmetric matter at a temperature $T_c \approx 155$ MeV. This process determines the transition from conventional nuclear matter to a more exotic deconfined partonic phase, known as quark-gluon plasma (QGP). This phase, present in the early universe about $1 \mu\text{s}$ after the Big Bang, can be recreated in the laboratory via high-energy heavy-ion collisions at the CERN Large Hadron Collider (LHC), where energy densities as high as $O(10 \text{ GeV}/\text{fm}^{-3})$ are achieved. The ALICE detector at the LHC is designed to investigate the deconfined QCD phase produced in such collisions.

As quarks and gluons cannot be directly observed, the ALICE detector is used to measure hadronic probes carrying information on the QGP evolution. Consequently, for these studies it is crucial to understand the hadronisation mechanism, by which the fundamental QCD degrees of freedom recombine into hadrons. From a theoretical perspective, different models are available to describe the hadronisation process, most notably, the statistical hadronisation model (SHM) and the string fragmentation model.

The particle-antiparticle balance in the production of hadrons at the LHC is affected by the initial conditions of the collisions through the baryon number stopping, consisting of the transport of a baryon number excess from the colliding ions to the midrapidity regions where hadron production is measured. In addition, the different underlying hadronisation mechanisms provide a different implementation of quantum number conservation in the hadronisation process, implying a different rapidity correlation range among the conserved quantum numbers. This Thesis addresses both of these topics through the extraction of chemical potentials in Pb–Pb collisions at $\sqrt{s_{\text{NN}}} = 5.02$ TeV and via measurements of event-

by-event hadron-multiplicity fluctuations in pp, p-Pb, and Pb-Pb collisions at $\sqrt{s_{\text{NN}}} = 5.02$ TeV. These measurements rely on the selection of pure samples of a wide array of light-flavour hadrons: this is achieved with the excellent tracking and particle identification capabilities of the ALICE detector.

The chemical potentials, regulating the conservation of quantum numbers in the grand canonical version of the SHM, are extracted from measurements of antiparticle-to-particle yield ratios of hadrons and light nuclei. The latter, along with protons, are sensitive probes of the baryon asymmetry of the hadron system formed in the collisions. This measurement includes also charged pions and omega baryons, which probe the balancing of electric charge and strangeness, respectively. The results obtained for the baryon number and electric charge chemical potentials are compatible with zero independently of the collision centrality, showing with unprecedented uncertainty that a baryon-number free and electrically neutral system is formed in Pb-Pb collisions at the LHC. These findings, which provide precise constraint for quantum-number transport models in the TeV energy scale, are published in Physical Review Letters [1].

Event-by-event hadron multiplicity fluctuations give insights into the hadronisation mechanisms. In this Thesis, the measurements of normalised second order cumulant of the net- $\Xi^\pm$ number and the Pearson correlation coefficient between the net- $\Xi^\pm$ and net- $K^\pm$ numbers are presented. This study, relying on the selection of pure kaon and Ξ samples also using machine learning techniques, is carried out in Pb-Pb collisions and, for the first time ever, also in pp and p-Pb collisions. The results indicate that the strange-antistrange correlation observed in data is weaker than predicted by string fragmentation, regulated by a conservation volume for strangeness extending over about 3 units of rapidity. Additionally, the data suggest the existence of a significant same-sign strangeness correlation, as predicted by the SHM in the canonical ensemble approach. The obtained results are published in Physical Review Letters [2]. Finally, the Pearson correlation between the antideuteron and the net- Λ numbers is determined in Pb-Pb collisions at $\sqrt{s_{\text{NN}}} = 5.02$ TeV. The results of this analysis, approved as an official public result of the ALICE Collaboration, indicate that a large conservation volume determines the conservation of quantum numbers also in the processes underlying nuclear formation.